

**Total and Differential Cross-Section
Measurement and Interpretation of $W^\pm W^\pm$
Scattering in Effective Field Theories with the
Run 2 Data of the ATLAS Experiment**

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Abstract

Vector boson scattering (VBS) is an essential process to probe the details of electroweak symmetry breaking in the Standard Model of Particle Physics. It is sensitive to the for now last extension of this very successful model: the Higgs boson and its underlying mechanism which plays a crucial role in the quartic gauge boson scattering. For this purpose, the $W^\pm W^\pm jj$ final state is analysed with full Run 2 data of 139 fb^{-1} from the ATLAS experiment at a centre-of-mass energy $\sqrt{s} = 13 \text{ TeV}$ at the LHC. Two different signal definitions are investigated: electroweak (EW) $W^\pm W^\pm jj$ with the focus on VBS and the inclusive $W^\pm W^\pm jj$ signal definition which is gauge invariant separable from other processes also at NLO. After the observation of the EW $W^\pm W^\pm jj$ process by both the ATLAS and CMS experiments the details of electroweak symmetry breaking are studied now in more detail. It is the first detailed study of the $W^\pm W^\pm jj$ final state with the ATLAS experiment.

The cross-section for EW $W^\pm W^\pm jj$ is measured to be $2.88 \pm_{0.21}^{0.22} \text{ (stat.)} \pm_{0.18}^{0.20} \text{ (syst.) fb}$ and for inclusive $W^\pm W^\pm jj$ a cross-section of $3.35 \pm_{0.22}^{0.22} \text{ (stat.)} \pm_{0.19}^{0.21} \text{ (syst.) fb}$ is found. They are both compatible with the Standard Model prediction.

Differential cross-sections in variables sensitive to the characteristics of VBS and effective field theories (EFT) are derived with the likelihood-based unfolding approach for the number of gap jets $N_{gapJets}$, the Zeppenfeld variable of the third jet ξ_{j_3} , the invariant mass of the tagging jets m_{jj} , the invariant mass of the two charged leptons $m_{\ell\ell}$ and the transverse mass m_T . In general, good agreement with the theory predictions is found. The largest discrepancy is found for $310 \leq m_T < 410 \text{ GeV}$ for inclusive $W^\pm W^\pm jj$ where more events are observed than expected with a local (global) significance of 3.1σ (2.5σ).

Limits on EFT parameters, modelling anomalous quartic gauge boson couplings with dimension-eight operators, are set for unclipped and clipped EFT predictions also near the unitarization bound. Overall, the limited number of collision events is the dominant source of uncertainty, followed by modelling uncertainties of the signal and the $W^\pm Z jj$ background.

Kurzdarstellung

Vektorbosonstreuung (VBS) ist ein essenzieller Prozess um die Details der elektroschwachen Symmetriebrechung zu untersuchen. Er ist sensitiv auf die vorerst letzte Erweiterung des Standardmodells der Teilchenphysik: das Higgs Boson und der zugrundeliegende Mechanismus, der bei der Vierer-Eichbosonstreuung eine entscheidende Rolle spielt. Aus diesem Grund wird der $W^\pm W^\pm jj$ -Endzustand mit den gesamten Daten des Run 2 des ATLAS Experiments bei einer Schwerpunktsenergie von $\sqrt{s} = 13$ TeV am LHC analysiert. Zwei verschiedene Signaldefinitionen werden untersucht: die elektroschwache (EW) $W^\pm W^\pm jj$, mit dem Fokus auf VBS und die inklusive $W^\pm W^\pm jj$ -Signaldefinition, welche von anderen Prozessen auch auf NLO eichinvariant separierbar ist. Nach der Beobachtung des EW- $W^\pm W^\pm jj$ -Prozesses bei beiden, dem ATLAS und CMS, Experimenten wird die elektroschwache Symmetriebrechung nun detaillierter untersucht. Dies ist die erste detaillierte Studie des $W^\pm W^\pm jj$ -Endzustands mit dem ATLAS Experiment.

Der Wirkungsquerschnitt von EW $W^\pm W^\pm jj$ wurde zu $2.88 \pm_{0.21}^{0.22}$ (stat.) $\pm_{0.18}^{0.20}$ (syst.) fb bestimmt und der vom inklusiven $W^\pm W^\pm jj$ zu $3.35 \pm_{0.22}^{0.22}$ (stat.) $\pm_{0.19}^{0.21}$ (syst.) fb. Beide sind mit der Standardmodellvorhersage kompatibel.

Differenzielle Wirkungsquerschnitte von Variablen, die sensitiv auf die Merkmale der VBS und effektiven Feldtheorien (EFT) sind, werden mit einem auf die Likelihood-Funktion basierenden Entfaltungsverfahren für die folgenden Variablen berechnet: die Anzahl der Jets zwischen den zwei hochenergetischsten Jets $N_{gapJets}$, die Zeppenfeldvariable für den dritten Jet ξ_{j3} , die invariante Masse der hochenergetischsten Jets m_{jj} , die invariante Masse der zwei geladenen Leptonen $m_{\ell\ell}$ und die transversale Masse m_T . Im Allgemeinen wurde eine gute Übereinstimmung mit den Theorievorhersagen gefunden. Die größte Abweichung gibt es für $310 \leq m_T < 410$ GeV für den inklusiven $W^\pm W^\pm jj$ -Prozess, wobei mehr Ereignisse als erwartet gemessen werden, mit einer lokalen (globalen) Signifikanz von 3.1σ (2.5σ).

Grenzen auf EFT Parameter, welche anormale quadratische Eichbosonkopplungen mit acht-dimensionalen Operatoren modellieren, werden auf gekappte und ungekappte EFT-Vorhersagen, auch nahe der Unitaritätsverletzungsgrenze, gesetzt. Insgesamt ist die begrenzte Anzahl an gemessenen Teilchenkollisionen die dominante Unsicherheit, gefolgt von der Modellierungsunsicherheit des Signalprozesses und des $W^\pm Zjj$ -Untergrunds.

Contents

1	Introduction	1
2	Theoretical Framework	3
2.1	Quantum Field Theory	3
2.2	Standard Model of Particle Physics	4
2.2.1	Quantum Chromodynamics: $SU(3)$	5
2.2.2	The Electroweak Sector: $SU(2) \times U(1)$	5
2.2.3	Vector Boson Scattering in $W^\pm W^\pm jj$ Final State	8
2.3	Physics Beyond the Standard Model	11
2.4	Calculation of Theory Predictions in Proton-Proton Collisions	12
2.4.1	Calculation of the Matrix Element	14
2.4.2	PDF Modelling	14
3	Experimental Setup	17
3.1	The Large Hadron Collider	17
3.1.1	The Accelerator Chain	17
3.1.2	Parts of the LHC	18
3.2	The ATLAS Detector	19
3.2.1	Coordinates	20
3.2.2	Layout	20
3.2.2.1	Inner Detector	21
3.2.2.2	Electromagnetic Calorimeter	21
3.2.2.3	Hadronic Calorimeter	21
3.2.2.4	Muon System	22
3.2.2.5	Luminosity Measurement	22
3.2.3	Trigger System	22
3.2.4	Object Reconstruction	23
3.2.4.1	Electron Reconstruction	23
3.2.4.2	Muon Reconstruction	24
3.2.4.3	Jet and MET Reconstruction	24
4	Contributing Processes	27
4.1	Simulation of the Processes	27
4.2	Signal Process	28
4.3	Background Processes	28
4.3.1	$W^\pm Zjj$ Background	29
4.3.1.1	Systematic Uncertainties	29
4.3.2	Non-prompt Lepton Background	29
4.3.2.1	Systematic Uncertainties	31
4.3.3	Conversions Background from Electron Charge Misidentification	32
4.3.3.1	Lost Transverse Momentum during Charge Flip	32
4.3.3.2	Systematic Uncertainties	33
4.3.4	Other Prompt, $V\gamma$ and Zjets Background	33
5	Object and Event Selection	35
5.1	Object Selection	35

5.1.1	Overlap Removal and MET Definition	36
5.1.2	Analysis Lepton and Jet Selection	37
5.2	Event Selection	37
5.2.1	Event Selection of Signal Region	39
5.2.2	Event Selection of low- m_{jj} Control Region	39
5.2.3	Event Selection of WZ Control Region	39
5.3	Truth Level Object Selection	39
5.4	Fiducial Phase Space	40
5.5	WZ Control Region on Truth Level	42
6	Uncertainties	43
6.1	Experimental Uncertainties	43
6.2	Theory Uncertainties	43
6.2.1	Scale Uncertainty	43
6.2.2	Parton Distribution Function (PDF) Uncertainty	44
6.2.3	Strong Coupling α_S Uncertainty	44
6.2.4	Parton Shower Uncertainty	44
6.2.5	NLO EW Corrections	44
6.2.6	NLO QCD Corrections	45
6.3	No Application of Smoothing	45
6.4	Normalisation of Theory Uncertainties in the Fiducial Phase Space	45
6.5	All Uncertainties	46
6.5.1	Uncertainties Included in all Fits	46
6.5.2	Theory Uncertainties in Cross-Section Measurements	46
6.5.3	Theory Uncertainties in EFT Limit Setting	57
6.6	Overview over Size of Uncertainties in Cross-Section Measurement	59
7	Statistical Analysis	65
7.1	Frequentist Statistic	65
7.2	Signal Definition and Inputs of Statistical Analysis	66
7.3	The Statistical Model	66
7.3.1	The Constraint Term	67
7.3.2	The Expected Yield	68
7.3.2.1	Splitting Systematics into Shape and Normalisation Effect	69
7.4	Maximum Likelihood Estimate	69
7.4.1	Likelihood Scan	70
7.4.2	Uncertainty and Correlation Estimation	71
7.4.3	Uncertainty of the Signal Strength	71
7.4.3.1	Systematic Break Down of Uncertainties	72
7.4.4	Pre- and Post-Fit Plots and Tables	73
7.4.5	Pull Plot	74
7.4.6	Impact and Ranking Plot	74
7.5	Cross Section Measurement	75
7.6	Looking for Signal with Test Statistic	76
7.6.1	Test Statistic for Observation	77
7.6.2	Test Statistic for Limit Setting	77
7.6.3	The p -Value of the Test Statistic Value	78
7.6.3.1	Toys for p -Value Calculation	78
7.6.3.2	Asymptotic Formula for p -Value Calculation	79
7.7	Handling of Observed Data	81
7.7.1	Blinding Observed Data	81
7.7.2	Uncertainty of Observed Data	81
7.8	Significance Estimation in Binning Optimisation	81
7.8.1	Significance Estimate in One Bin	82
7.8.2	Significance Estimate over Multiple Bins	83
7.8.3	Equation Used for Binning Optimisation	84
7.9	Unfolding	85

7.9.1	Likelihood-Based Unfolding	87
7.9.2	Uncertainties on the Unfolded Distribution	88
7.9.3	Alternative Unfolding Approaches	88
7.9.3.1	Regularized Unfolding	88
7.9.3.2	Disentangle Fit from Unfolding	89
7.9.3.3	Different Handling of Out-of-Fiducial Region Events	90
7.9.3.4	Unbinned Approaches	92
7.9.4	Using Unfolded Data in Reinterpretation	92
7.10	Uncertainties after Normalisation	93
8	Total Cross-Section Measurement	97
8.1	Fitting Setup	97
8.2	Binning Optimisation	98
8.3	Handling of Uncertainties	98
8.4	Pre-Fit Distributions	98
8.5	Results of the Asimov Fit	103
8.5.1	Cross-Section Extraction for EW $W^\pm W^\pm jj$	107
8.5.2	Cross-Section Extraction for Inclusive $W^\pm W^\pm jj$	111
8.6	Results of the Fit to Observed Data	112
8.6.1	Cross-Section Extraction for EW $W^\pm W^\pm jj$	122
8.6.2	Cross-Section Extraction for Inclusive $W^\pm W^\pm jj$	122
9	Differential Cross-Section Measurement	125
9.1	Fitting Setup	126
9.2	Binning Optimisation and Resulting Migration Matrices	126
9.3	Handling of Uncertainties	127
9.4	Pre-fit Distributions for $m_{\ell\ell}$ for the Derived Binning	136
9.5	Results of the Asimov Fit for $m_{\ell\ell}$ with EW Signal	136
9.6	Results of the Fit to Observed Data for $m_{\ell\ell}$ with EW Signal	139
9.7	Unfolded Distributions	151
9.7.1	Local and Global Significance of Deviations between Prediction and Observed Data	151
9.7.2	Comparison of Summed Differential Cross-Sections and Total Cross-Section Measurements	156
10	Limit Setting on Dimension-Eight EFT Parameters	167
10.1	EFT Formalism	167
10.1.1	Studied Operators	168
10.1.2	Used MC Simulation	169
10.2	Unitarity Bounds	169
10.2.1	Clipping	170
10.3	Fitting Setup	170
10.4	Binning Optimisation	171
10.5	Handling of Uncertainties	174
10.6	Expected Limits	174
10.6.1	Detailed Information for Operator M0 without Clipping	175
10.6.2	Two-Dimensional Limits	177
10.7	Observed Limits	177
10.7.1	Detailed Information for Operator T1 Clipped at 1.5 TeV	183
10.7.2	Detailed Information for Operator M0 Clipped at 700 GeV	183
10.7.3	Two-Dimensional Limits	183
10.8	Comparison with Other Analyses	183
10.8.1	Reinterpretation of Partial Run 2 ATLAS Data	183
10.8.2	Interpretation of Full Run 2 CMS Data	184
10.8.3	Combined Limits of ATLAS and CMS	184
11	Summary	195

A	Monte Carlo Samples Used in the Analysis	197
B	Additional Information about Total Cross-Section Measurement	205
B.1	Results of the Asimov Fit with EW $W^\pm W^\pm jj$ Signal	205
B.2	Results of the Asimov Fit with Inclusive $W^\pm W^\pm jj$ Signal	217
B.3	Results of the Fit to Observed Data with EW $W^\pm W^\pm jj$ Signal	232
B.4	Results of the Fit to Observed Data with Inclusive $W^\pm W^\pm jj$ Signal	244
C	Additional information about unfolded distributions	261
C.1	Additional Results for $m_{\ell\ell}$	261
C.1.1	Results of the Asimov Fit for $m_{\ell\ell}$ with EW+Int+QCD Signal	261
C.1.2	Results of the Fit to Observed Data for $m_{\ell\ell}$ with EW+Int+QCD Signal	267
C.2	Results for m_{jj}	268
C.2.1	Pre-Fit Distributions for m_{jj}	268
C.2.2	Results of the Asimov Fit for m_{jj} with EW Signal	276
C.2.3	Results of the Asimov Fit for m_{jj} with EW+Int+QCD Signal	279
C.2.4	Results of the Fit to Observed Data for m_{jj} with EW Signal	281
C.2.5	Results of the fit to Observed Data for m_{jj} with EW+Int+QCD Signal	293
C.3	Results for m_T	294
C.3.1	Pre-Fit Distributions for m_T	294
C.3.2	Results of the Asimov Fit for m_T with EW Signal	302
C.3.3	Results of the Asimov Fit for m_T with EW+Int+QCD Signal	305
C.3.4	Results of the Fit to Observed Data for m_T with EW Signal	308
C.3.5	Results of the Fit to Observed Data for m_T with EW+Int+QCD Signal	319
C.4	Results for $N_{gapJets}$	320
C.4.1	Pre-Fit Distributions for $N_{gapJets}$	320
C.4.2	Results of the Asimov Fit for $N_{gapJets}$ with EW Signal	328
C.4.3	Results of the Asimov Fit for $N_{gapJets}$ with EW+Int+QCD Signal	333
C.4.4	Results of the fit to Observed Data for $N_{gapJets}$ with EW Signal	338
C.4.5	Results of the Fit to Observed Data for $N_{gapJets}$ with EW+Int+QCD Signal	344
C.5	Results for ξ_{j_3}	348
C.5.1	Pre-Fit Distributions for ξ_{j_3}	348
C.5.2	Results of the Asimov Fit for ξ_{j_3} with EW Signal	348
C.5.3	Results of the Asimov Fit for ξ_{j_3} with EW+Int+QCD Signal	352
C.5.4	Results of the Fit to Observed Data for ξ_{j_3} with EW Signal	356
C.5.5	Results of the Fit to Observed Data for ξ_{j_3} with EW+Int+QCD Signal	367
D	Additional EFT Studies	377
D.1	Expected Limits Calculated with Toys	377
D.2	Free Floating Normalisation EW $W^\pm W^\pm jj$ in EFT Limit Setting	377
D.3	Additional Information for Expected Limits	380
D.4	Additional Information for Observed Limits	384

Chapter 1

Introduction

The purpose of this thesis is to produce a detailed study of the vector boson scattering (VBS) process in the $W^\pm W^\pm jj$ final state using the full Run 2 data of ATLAS at the Large Hadron Collider (LHC). It is an extremely rare process which allows to newly probe relevant parts of our current best understanding of the fundamental principles of our universe.

The Standard Model of Particle Physics (SM) describes the interaction of fundamental particles. It is very well tested including the Higgs boson, discovered in 2012, and the related mechanism of electroweak symmetry breaking. This Higgs boson is essential in vector boson scattering as discussed in the Theory Chapter 2 which is thus of great interest to probe the details of the Standard Model. The Standard Model is still incomplete and does not include phenomena like gravity, dark matter or neutrino masses [1]. Therefore it is tested at high energies in high detail to understand where it breaks and to shed light on potential new physics phenomena including new particles.

The ATLAS detector at the LHC, described in Chapter 3, is designed to study these open questions. It is a multi-purpose detector which was already used to detect the Higgs boson in parallel to the CMS detector [2, 3]. In this work, ATLAS data is analysed to study VBS in more detail in the $W^\pm W^\pm jj$ final state. This final state is especially suited to study VBS because the EW contribution, containing VBS, is in general larger than in other final states. Data recorded between 2015 and 2018 in Run 2 is analysed corresponding to an integrated luminosity of 139 fb^{-1} . The recorded events are studied using the leptonic decay of the $W^\pm$ bosons, thus defining the signature of the signal: two charged leptons being electrons or muons, two neutrinos and two jets. The neutrinos are not detected and are only indirectly visible due to momentum conservation as missing transverse energy.

Also other processes, called background processes, have the same or a similar signature in the detector. These backgrounds are discussed in Chapter 4. The main backgrounds are estimated with data-driven approaches. For example, the leptonic decay of $W^\pm Z jj$, when one lepton from Z decay is not detected, can have the same signature. In order to minimize these contributions and to estimate them, special event selection criteria are applied as shown in Chapter 5.

Uncertainties, listed in Chapter 6, need to be incorporated during the statistical analysis, detailed in Chapter 7. Experimental uncertainties of object identification and reconstruction are considered as well as the uncertainty of the luminosity determination. There are also dedicated uncertainties of backgrounds estimated with data-driven approaches. Additionally, the theory predictions are only known to a certain order in perturbative theory and any interpretation of the data with their help thus needs to be covered with appropriate uncertainties.

The total cross-section of EW and inclusive $W^\pm W^\pm jj$ production is determined in Chapter 8. These cross-sections represent the probability that the signal process occurs in proton-proton collisions at a centre of mass energy of 13 TeV.

The $W^\pm W^\pm jj$ final state, sensitive to VBS and the underlying electroweak symmetry breaking, is studied in detail with the differential cross-section measurement and EFT limit setting. The measurement of differential cross-sections is described in Chapter 9. Five variables are chosen which are sensitive to VBS, EFT effects or both: the number of gap jets $N_{gapJets}$, the Zeppenfeld variable of the third jet ξ_{j_3} , the invariant mass of the tagging jets m_{jj} , the invariant mass of the two charged leptons $m_{\ell\ell}$ and the transverse mass m_T . A novel unfolding method is implemented which maximises the amount of information extracted from the data for later interpretation.

With the aim of looking for signs of new physics in a model-independent way, limits are set on effective field theory (EFT) extensions of the Standard Model in Chapter 10. EFT describes low-energy effects of new physics phenomena at high energies which are out of the energy reach of current accelerators.

The main results are finally summarized in Chapter 11 completed by an outlook towards Run 3.

Chapter 2

Theoretical Framework

In this chapter the physical theories are defined which are probed in the main part of this thesis against the experimental results. A theory of the smallest particles usually consists of:

1. the particle content and the states they could be in,
2. a description of how the particles/states propagate in time and space,
3. including interactions with other objects.

A good theory has (among other things) the following properties:

- it has few free parameters,
- a broad range of validity and
- is able to make predictions.

The best-tested theory in existence today of this is the Standard Model of Particle Physics, defined in Section 2.2, which is a quantum field theory, defined in Section 2.1. It is defined by the local gauge symmetry $SU(3) \times SU(2) \times U(1)$. It describes all the known forces, except gravity and was proven to be correct to a high accuracy. But there are still some open questions which are discussed in Section 2.3.

2.1 Quantum Field Theory

In 1924 the duality of wave and particle properties of not only photons (1905, Albert Einstein [4]), but also electrons (1924, Louis de Broglie [5]) was observed. A Nobel prize was awarded to both of them for their respective observations [6, 7]. In the following years, it was manifested, that all elementary particles follow this duality. A quantum theory can explain this duality and the extension to a quantum field theory was done to also explain the observed annihilation and creation of particles during interactions.

An essential part of a quantum field theory is that all quantum objects take all possible paths from A to B at once because of their wave properties and can interfere with themselves or other quantum objects on their path. Only when the state is measured it takes on a specific value - otherwise, it only follows a probability distribution propagating in time. The state ψ describes the existing particles and their 4-momentum and space-time position distribution. Only the probability $|\psi|^2$ is measurable, not ψ itself. Because of this the "structure of the theory" should be invariant under $\psi \rightarrow \psi' = e^{-i\chi(x,t)}\psi$ which is later seen in gauge theories. Via weighted integrals it is possible to calculate observables like momentum or energy.

The probability to measure the final state $|o\rangle$ starting from an initial state $\langle i|$ is: $\sum_i |\langle i|S|o\rangle|^2$ where S describes all possible transformations from initial to final state with their probability defined by the lagrangian of the quantum field theory, called S-matrix. The S-matrix needs to be a unitary operator to ensure that the probability of any process is not larger than one. Because of the square, different ways of coming from i to o are entangled, visible in interferences.

Table 2.1: Overview of fermions in the Standard Model of particle physics. All fermions have spin of $\frac{1}{2}$ within in Standard Model. The particles' electric charge Q , weak charge Y_W and third component of the weak isospin T_3 (L), where only left-handed particles and right-handed antiparticles have non-zero isospin, are shown. For participation in the strong force, only 1 or 0 is shown in the column 'QCD'. Quarks can have three different colour charges. Masses are taken from Ref. [8]. "The u-, d-, and s-quark masses are the $\bar{M}\bar{S}$ masses at the scale $\mu = 2 \text{ GeV}$. The c- and b-quark masses are the $\bar{M}\bar{S}$ masses renormalized at the MS mass, i.e. $\bar{m} = \bar{m}(\mu = m)$. The t-quark mass is extracted from event kinematics." [8] The digits in parenthesis are the uncertainties. For neutrinos only an upper bound is known.

Name	Symbol	Mass [GeV]	Charges			
			Q	$T_3(L)$	Y_W	QCD
Electron	e	0.000 510 998 950 00(15)	-1	$-\frac{1}{2}$	-1	0
Muon	μ	0.105 658 375 5(23)	-1	$-\frac{1}{2}$	-1	0
Tau	τ	1.776 86(12)	-1	$-\frac{1}{2}$	-1	0
Electron-neutrino	ν_e	0.000 000 000(1)	0	$\frac{1}{2}$	-1	0
Muon-neutrino	ν_μ	0.000 000 000(1)	0	$\frac{1}{2}$	-1	0
Tau-neutrino	ν_τ	0.000 000 000(1)	0	$\frac{1}{2}$	-1	0
Up-quark	u	0.0022(5)	$+\frac{2}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	1
Down-quark	d	0.0047(5)	$-\frac{1}{3}$	$-\frac{1}{2}$	$\frac{1}{3}$	1
Charm-quark	c	1.27(2)	$+\frac{2}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	1
Strange quark	s	0.093(9)	$-\frac{1}{3}$	$-\frac{1}{2}$	$\frac{1}{3}$	1
Top-quark	t	172.7(3)	$+\frac{2}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	1
Bottom-quark	b	4.18(3)	$-\frac{1}{3}$	$-\frac{1}{2}$	$\frac{1}{3}$	1

In order to incorporate observed special relativity into the theory a Lorentz invariant Lagrange function is usually constructed.

2.2 Standard Model of Particle Physics

The Standard Model of particle physics is the best probed model before the Planck scale. After the Planck scale gravity can not be neglected and the SM is known to be incomplete. The Planck scale is reached for energies above 10^{19} GeV which corresponds to distances below 10^{-35} m , times below 10^{-44} s or masses above 10^{-8} kg . The large hadron collider, from which data is analysed in this thesis, runs at $1.3 \cdot 10^4 \text{ GeV}$ and is thus well below the Planck scale. Natural units and Heavyside-Lorentz-System are used in this thesis where $\hbar = c = 1$ and $k_B = \epsilon_0 = \mu_0 = 1$ is assumed. With this, all units can be presented in GeV. To convert e.g. masses into SI units the following factors can be used:

$$1.97 \cdot 10^{-16} \text{ m} = 1 \text{ GeV}^{-1}$$

$$6.6 \cdot 10^{-25} \text{ s} = 1 \text{ GeV}^{-1}$$

$$1.78 \cdot 10^{-27} \text{ kg} = 1 \text{ GeV}$$

More information can be found e.g. in Ref. [1].

The Standard Model includes elementary particles which are particles without permanent substructure and whose properties are defined by quantum numbers. There are particles with a half-odd-integer spin, called fermions, shown in Table 2.1, and particles with integer spin, called bosons, shown in Table 2.2. There is an antiparticle for each particle with the same mass, but inverse charges. Chargeless particles are their own antiparticle. There are three generations of particles, where the first includes the electron, electron-neutrino, up-quark and down-quark. The quarks and neutrinos are shown in their mass eigenstates. The Cabibbo-Kobayashi-Maskawa (CKM) matrix needs to be applied to change to the weak eigenstates (d' , s' , b') of quarks starting from the mass eigenstates (d , s , b) important for the interaction with W bosons [1]. The fermions are grouped into doublets of left-handed fermions for each

Table 2.2: Overview of bosons in the Standard Model of particle physics. The particles' electric charge Q , weak charge Y_W and third component of the weak isospin T_3 (L), where only left-handed particles and right-handed antiparticles have non-zero isospin, are shown. For participation in the strong force, only 1 or 0 is shown in the column 'QCD'. Gluons can have a linear combination of products of colour and anticolour charge. Masses are taken from Ref. [8]. The digits in parenthesis are the uncertainties. For photons an upper bound of 10^{-27} GeV is known.

Name	Symbol	Mass [GeV]	Charges				Spin
			Q	$T_3(L)$	Y_W	QCD	
Gluon	g	0	0	0	0	1	1
Photon	γ	0	0	0	0	0	1
W Boson	W	80.377(12)	± 1	± 1	0	0	1
Z Boson	Z	91.1876(21)	0	0	0	0	1
Higgs Boson	H	125.25(17)	0	$-\frac{1}{2}$	1	0	0

generation for leptons L , with $L_1 = \begin{pmatrix} \nu_{e,L} \\ e_L \end{pmatrix}$ and quarks Q , with $Q_1 = \begin{pmatrix} u_L \\ d'_L \end{pmatrix}$.

There are three out of four fundamental forces included in the Standard Model: electromagnetic, weak and strong force. The strong force is important for binding quarks within neutrons and protons in the core of atoms. Gluons are the transmitter of the force and it is described by quantum chromodynamics (QCD). The coupling strength is denoted by α_S . The electromagnetic force can be described by quantum electrodynamics (QED) and explains e.g. the interaction of electrons. The mediator is the photon. The coupling strength is denoted by $\alpha_{em} \approx \frac{\alpha_S}{137}$. The weak force is described together with QED in the electroweak sector of the Standard Model. It is mediated by W and Z bosons which occur in nature e.g. in beta decays of neutrons.

There is no known direct interaction/force between fermions in the Standard Model. They can only be mitigated via gauge bosons.

The whole lagrangian of the SM can be summarized as:

$$\mathcal{L}_{\text{SM}} = \mathcal{L}_{\text{bosonic}} + \mathcal{L}_{\text{fermionic}} + \mathcal{L}_\phi + \mathcal{L}_{\text{Yukawa}} \quad (2.1)$$

In the following sections, each part of the SM lagrangian will be explained in more detail and which physics they define/include.

The terms $\mathcal{L}_\phi + \mathcal{L}_{\text{Yukawa}}$ are explained in Section 2.2.2 about Electroweak symmetry breaking. The other terms can be split into an electroweak part and a QCD part and are explained in the respective sections.

$$\mathcal{L}_{\text{fermionic}} + \mathcal{L}_{\text{bosonic}} = \mathcal{L}_{\text{fermionic, QCD}} + \mathcal{L}_{\text{bosonic, QCD}} + \mathcal{L}_{\text{fermionic, EW}} + \mathcal{L}_{\text{bosonic, EW}} \quad (2.2)$$

The mathematical derivation is only depicted in more detail for the electroweak part of interest in the context of this thesis. For the other terms, only the final Feynman diagrams and their couplings are shown.

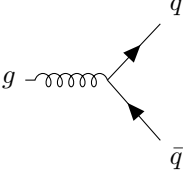
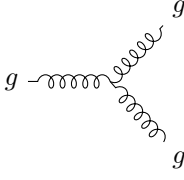
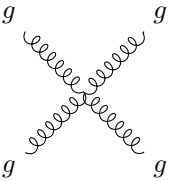
2.2.1 Quantum Chromodynamics: $SU(3)$

Quantum Chromodynamics (QCD) follows the local $SU(3)$ symmetry which is a non-abelian theory [1]. The vertices of quarks and gluons are shown in Table 2.3. Because of the non-abelian structure of QCD, there is self-coupling of gluons. These self-couplings result in confinement, meaning that quarks form quark-antiquark pairs via gluon emission when pulled apart such that they can not get isolated. This plays later an important role when single quarks or gluons are emitted in the final state. Because of confinement, they form immediately hadrons in a shower of hadronic particles, called jets.

2.2.2 The Electroweak Sector: $SU(2) \times U(1)$

The electroweak sector follows the local $SU_L(2) \times U_Y(1)$ gauge symmetry. The weak interaction $SU_L(2)$ only interacts with left-handed particles and right-handed anti-particles. This

Table 2.3: Vertices and their coupling strength involving gluons, i.e. strong coupling $g_S = \sqrt{4\pi\alpha_S}$.

Vertex	Coupling strength	Vertex	Coupling strength
	$\sim g_S$		$\sim g_S$
	$\sim g_S^2$		

property is axiomatically implemented in the lagrangian. The generators of the groups are Pauli matrices τ_{1-3} and $Y = \frac{1}{2}$. With the gauge fields W_μ^a of $SU_L(2)$ and B_μ of $U_Y(1)$.

The lagrangian of electroweak theory is:

$$\mathcal{L}_{\text{EW}} = \mathcal{L}_{\text{fermionic, EW}} + \mathcal{L}_{\text{bosonic, EW}} + \mathcal{L}_\phi + \mathcal{L}_{\text{Yukawa}} \quad (2.3)$$

with

$$\mathcal{L}_{\text{fermionic, EW}} = \bar{L}_1 D_\mu \gamma^\mu L_1 + \bar{e}_R D_\mu \gamma^\mu e_R + \bar{Q}_1 D_\mu \gamma^\mu Q_1 + \bar{d}_R D_\mu \gamma^\mu d_R + \bar{u}_R D_\mu \gamma^\mu u_R \quad (2.4)$$

$$\mathcal{L}_{\text{bosonic, EW}} = -\frac{1}{4} W_{\mu\nu}^a W^{a\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} \quad (2.5)$$

$$\mathcal{L}_\phi = (D_\mu \phi)^\dagger (D^\mu \phi) - V(\phi) \text{ where } V(\phi) = \mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2 \quad (2.6)$$

$$\mathcal{L}_{\text{Yukawa}} = -\lambda_e \bar{L}_1 \phi e_R - \lambda_d \bar{Q}_1 \phi d_R - \lambda_u \bar{Q}_1 (i\tau_2 \phi^*) u_R + h.c. \quad (2.7)$$

with the complex field Higgs doublet $\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$ and the gamma matrix γ^μ . The Yukawa coupling and the fermionic term is only shown for the first of the three generations. For more generations the CKM-matrix would need to be included [9]. The Higgs potential $V(\phi)$ contains two parameters: a real μ^2 and a real λ parameter. For low energies, i.e. after symmetry breaking, μ^2 is negative while for high energies μ^2 is positive.

This lagrangian is invariant under gauge transformations:

$$SU(2)_L : \phi \rightarrow \phi' = e^{-i\theta^a(x)T^a} \phi \text{ with } T^a = \frac{\tau}{2} \text{ and} \quad (2.8)$$

$$U(1)_Y : \phi \rightarrow \phi' = e^{-i\theta(x)Y} \phi \text{ with } Y = \frac{1}{2}. \quad (2.9)$$

This means that the lagrangian and the whole resulting physics follow the $SU(2)_L \times U(1)_Y$ symmetry. Each symmetry group has generators, fields and couplings. The generator of $SU(2)_L$ is T^a , the gauge field $W_\mu^a(x)$ and the gauge coupling g_W . The generator of $U(1)_Y$ is $Y = \frac{1}{2}$, the gauge field $B_\mu(x)$ and the gauge coupling g_Y . The covariant derivative is defined as:

$$D_\mu = \partial_\mu - ig_W T^a W_\mu^a - ig_Y B_\mu \quad (2.10)$$

For low energies, ϕ picks the minima of the potential $\mathcal{L}_\phi$. The minimum of the potential is not unique - because of the gauge invariance a certain value can be picked. It is chosen to be:

$$\phi^+ = 0 \text{ and } \phi^0 = \frac{v}{\sqrt{2}} \quad (2.11)$$

where v is the vacuum expectation value.

This ground state is invariant under

$$U(1)_{\text{QED}} : \phi \rightarrow \phi' = e^{-i\theta(x)(T_3+Y)}\phi \text{ with } Y = \frac{1}{2} \quad (2.12)$$

representing the $U(1)$ symmetry of quantum electrodynamic (QED). In summary $SU(2)_L \times U(1)_Y$ gets broken into $U(1)_{\text{QED}}$. The vacuum expectation value can be expanded for small excitations $H(x)$ to:

$$\phi = \begin{pmatrix} 0 \\ v + H(x) \end{pmatrix}. \quad (2.13)$$

In the end, the gauge bosons realized in nature are of interest being linear combinations of the gauge fields:

$$Z_\mu := \frac{g_W W_\mu^3 - g_Y B_\mu}{\sqrt{g_W^2 + g_Y^2}} \quad (2.14)$$

$$W_\mu^\pm := \frac{1}{\sqrt{2}}(W_\mu^1 \mp iW_\mu^2) \quad (2.15)$$

$$A_\mu := \frac{g_Y W_\mu^3 + g_W B_\mu}{\sqrt{g_W^2 + g_Y^2}}. \quad (2.16)$$

The part $\mathcal{L}_\phi$ simplifies with the chosen form of the ground state and the bosons realized in nature to:

$$\mathcal{L}_\phi = \frac{1}{2}(\partial_\mu H)^2 + \left[\frac{g_W^2 + g_Y^2}{8} Z_\mu Z^\mu + \frac{g_W^2}{4} W_\mu^+ W^{-,\mu} - \frac{1}{2}v^2\lambda \right] (v + H)^2 + \frac{\lambda}{4}(v + H)^4 \quad (2.17)$$

This can be split into kinetic terms, mass terms, self-interaction terms and a constant which does not affect physics predictions:

$$\mathcal{L}_\phi = \mathcal{L}_{\phi, \text{ kin.}} + \mathcal{L}_{\phi, \text{ mass}} + \mathcal{L}_{\phi, \text{ int.}} - \frac{1}{4}v^4\lambda \quad (2.18)$$

with

$$\mathcal{L}_{\phi, \text{ kin.}} = \frac{1}{2}(\partial_\mu H)^2 \quad (2.19)$$

$$\mathcal{L}_{\phi, \text{ mass}} = \frac{1}{2} \underbrace{\frac{g_W^2 + g_Y^2}{4} v^2}_{=:m_Z^2} Z_\mu Z^\mu + \frac{1}{2} \underbrace{\frac{g_W^2 v^2}{4}}_{=:m_W^2} W_\mu^+ W^{-,\mu} + \frac{1}{2} \underbrace{2\lambda v^2}_{=:m_H^2} H^2 \quad (2.20)$$

$$\begin{aligned} \mathcal{L}_{\phi, \text{ int.}} = & \frac{m_Z^2}{v} Z_\mu Z^\mu H + \frac{m_W^2}{v} W_\mu^+ W^{-,\mu} H + \frac{m_Z^2}{2v^2} Z_\mu Z^\mu H^2 \\ & + \frac{m_W^2}{2v^2} W_\mu^+ W^{-,\mu} H^2 + \frac{m_H^2}{2v} H^3 + \frac{m_H^2}{8v^2} H^4 \end{aligned} \quad (2.21)$$

In Table 2.4 the resulting Feynman vertices and their coupling strength are shown. The coupling strength increases with mass.

The Yukawa coupling terms for the first generation without neutrino masses simplify to:

$$\mathcal{L}_{\text{Yukawa}} = -\lambda_e \bar{L}_1 \phi e_R - \lambda_d \bar{Q}_1 \phi d_R - \lambda_u \bar{Q}_1 (i\tau_2 \phi^*) u_R + h.c. \quad (2.22)$$

$$= -\underbrace{\frac{\lambda_e v}{\sqrt{2}}}_{m_e} (\bar{e}_L e_R + \bar{e}_R e_L) - \underbrace{\frac{\lambda_d v}{\sqrt{2}}}_{m_d} (\bar{d}_L d_R + \bar{d}_R d_L) - \underbrace{\frac{\lambda_u v}{\sqrt{2}}}_{m_u} (\bar{u}_L u_R + \bar{u}_R u_L) \quad (2.23)$$

$$= -\underbrace{\frac{\lambda_e v}{\sqrt{2}}}_{m_e} \bar{e}e - \underbrace{\frac{\lambda_d v}{\sqrt{2}}}_{m_d} \bar{d}d - \underbrace{\frac{\lambda_u v}{\sqrt{2}}}_{m_u} \bar{u}u \quad (2.24)$$

The bosonic electroweak term $\mathcal{L}_{\text{bosonic, EW}}$ can be simplified with the in nature realized bosons (see Equation 2.14 to 2.16) to:

$$\mathcal{L}_{\text{bosonic, EW}} = \underbrace{-\frac{1}{4}W_{\mu\nu}^a W^{a\mu\nu}}_{\mathcal{L}_{\text{bosonic, EW, W}}} - \underbrace{\frac{1}{4}B_{\mu\nu}B^{\mu\nu}}_{\mathcal{L}_{\text{bosonic, EW, B}}} \quad (2.25)$$

with field strength tensors:

$$W_{\mu\nu}^a := \partial_\mu W_\nu^a - \partial_\nu W_\mu^a + g_W \epsilon^{abc} W_\mu^b W_\nu^c \quad (2.26)$$

$$B_{\mu\nu} := \partial_\mu B_\nu - \partial_\nu B_\mu \quad (2.27)$$

where:

$$\mathcal{L}_{\text{bosonic, EW, B}} = -\frac{1}{4}(\partial_\mu B_\nu \partial^\mu B^\nu - \partial_\nu B_\mu \partial^\mu B^\nu - \partial_\mu B_\nu \partial^\nu B^\mu + \partial_\nu B_\mu \partial^\nu B^\mu) \quad (2.28)$$

$$= -\frac{1}{2}(B_\nu(\partial^\nu \partial^\mu - g^{\nu\mu} \partial_\alpha \partial^\alpha)B_\mu) \quad (2.29)$$

$$\mathcal{L}_{\text{bosonic, EW, W}} = -\frac{1}{4}W_{\mu\nu}^a W^{a\mu\nu} \quad (2.30)$$

$$\begin{aligned} &= -\frac{1}{4}[2(W_\nu^a(\partial^\nu \partial^\mu - g^{\nu\mu} \partial_\alpha \partial^\alpha)W_\mu^a) \\ &\quad + (g_W \epsilon^{abc} W_\mu^b W_\nu^c)(\partial^\mu W^{a,\nu} - \partial^\nu W^{a,\mu}) \\ &\quad + (\partial_\mu W_\nu^a - \partial_\nu W_\mu^a)g_W \epsilon^{abc} W^{b,\mu} W^{c,\nu} \\ &\quad + g_W^2(W_\mu^b W_\nu^c W^{b,\mu} W^{c,\nu} - W_\mu^b W_\nu^c W^{c,\mu} W^{b,\nu})] \end{aligned} \quad (2.31)$$

resulting in:

$$\begin{aligned} \mathcal{L}_{\text{bosonic, EW}} &= -\frac{g_W^2}{2}[W_\mu^+ W^{-,\mu} W_\nu^+ W^{-,\nu} - W_\mu^+ W^{-,\nu} W_\mu^+ W^{-,\nu}] \\ &\quad + g_W^2 \cos^2 \theta_W [Z^\mu Z^\nu W_\mu^+ W_\nu^- - Z^\mu Z_\mu W^{+,\nu} W_\nu^-] \\ &\quad + g_W e \cos \theta_W [A^\mu Z^\nu W_\mu^+ W_\nu^- + A^\mu Z^\nu W_\nu^+ W_\mu^- - 2A_\mu Z^\mu W^{+,\nu} W_\nu^-] \\ &\quad + e^2 [A^\mu A^\nu W_\mu^+ W_\nu^- - A^\mu A_\mu W^{+,\nu} W_\nu^-] \\ &\quad - ie[\partial^\mu A^\nu (W_\mu^+ W_\nu^- - W_\nu^+ W_\mu^-) \\ &\quad \quad + A^\nu (-W^{+,\mu} \partial_\nu W_\mu^- + W^{-,\mu} \partial_\nu W_\mu^+ + W_\mu^+ \partial^\mu W_\nu^- - W_\mu^- \partial_\mu W_\nu^+)] \\ &\quad - ig_W \cos \theta_W [\partial^\mu Z^\nu (W_\mu^+ W_\nu^- - W_\nu^+ W_\mu^-) \\ &\quad \quad + Z^\nu (-W^{+,\mu} \partial_\nu W_\mu^- + W^{-,\mu} \partial_\nu W_\mu^+ + W_\mu^+ \partial^\mu W_\nu^- - W_\mu^- \partial_\mu W_\nu^+)] + \dots \end{aligned} \quad (2.32)$$

The resulting Feynman diagrams are shown in Table 2.5. The Feynman diagrams involving fermions have their origin in the fermionic lagrangian $\mathcal{L}_{\text{fermionic}}$ which is not explained here in detail. More details about the deduction of Feynman rules can be found e.g. in Ref. [10]. The term $+g_W \epsilon^{abc} W_\mu^b W_\nu^c$ only occurs for non-abelian, i.e. $[T^a, T^b] \neq 0$, theories. U(1) is abelian, because of which photons do not interact directly with itself.

2.2.3 Vector Boson Scattering in $W^\pm W^\pm jj$ Final State

In this thesis we are interested in quartic vector boson scattering (VBS) which includes the following diagrams on leading order with WZ final state shown in Figure 2.1 and with WW shown in Figure 2.2.

$W^\pm Z$ is a main background discussed in Section 4.3.1.

The $W^\pm W^\pm$ has always $W^\pm W^\pm$ also in the initial state as shown in Figure 2.2.

This process is studied at a proton collider where quarks and gluons are in in initial state.

Two groups of Feynman diagrams involved on leading order are summarized in Figure 2.3. Subfigure (a) and (b) show Feynman diagrams with couplings of order $\alpha_{ew}^6 \alpha_S^0$ after squaring the matrix element. This process is denoted EW $W^\pm W^\pm jj$ in the rest of this thesis. Subfigure (a) involves the actual VBS we are interested in where VBS can be any subdiagram shown in Figure 2.1 and 2.2. Subfigure (c) and (d) represent diagrams with the same final state, but

Table 2.4: Vertices and their coupling strength involving a Higgs boson. The coupling to other particles is proportional to their mass.

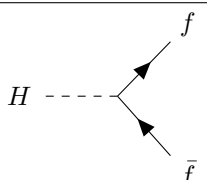
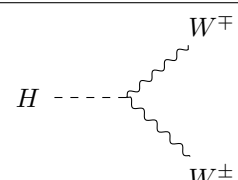
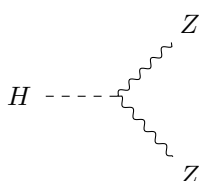
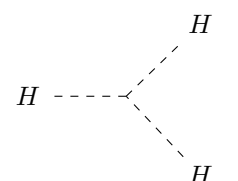
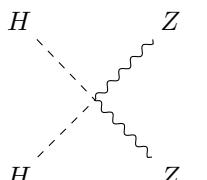
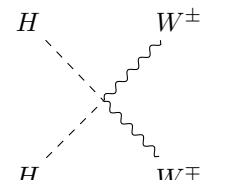
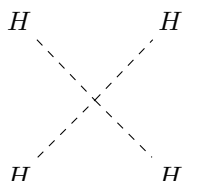
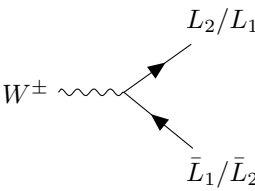
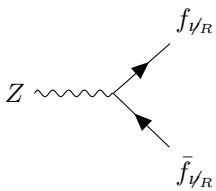
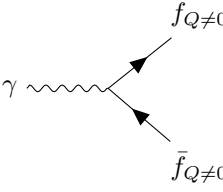
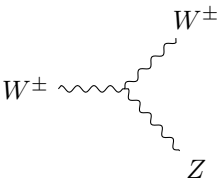
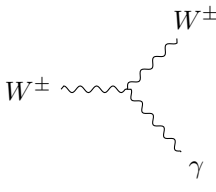
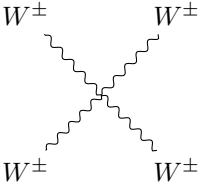
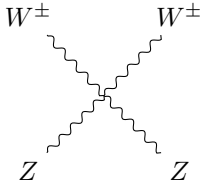
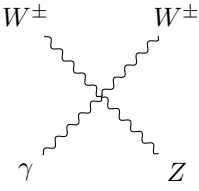
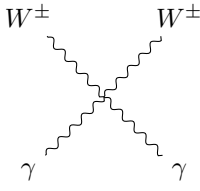
Vertex	Coupling strength	Vertex	Coupling strength
	$\sim \frac{m_f}{v}$		$\sim \frac{m_W^2}{v}$
	$\sim \frac{m_Z^2}{v}$		$\sim \frac{m_H^2}{v}$
	$\sim \frac{m_Z^2}{v^2}$		$\sim \frac{m_W^2}{v^2}$
	$\sim \frac{m_H^2}{v^2}$		

Table 2.5: Vertices and their coupling strength involving electroweak fields. The couplings can be transformed according to $g_W = \frac{e}{\sin \theta_W}$ and $g_Y = \frac{e}{\cos \theta_W}$. When $W^\pm$ is written, all combinations are possible which are allowed within charge conservation. It is: $e = \sqrt{4\pi\alpha_{em}} = 0.3$ and $\sin^2 \theta_W = 0.23$ in the context of couplings. Due to quadratic matrix element this becomes a normal α_{em} for each tri-vertex

Vertex	Coupling strength	Vertex	Coupling strength
	$\sim g_W$		$\sim \frac{g_W}{\cos \theta_W}$
	$\sim e$		
	$\sim e \frac{\cos \theta_W}{\sin \theta_W}$		$\sim e$
	$\sim \frac{e^2}{\sin^2 \theta_W} = g_W^2$		$\sim e^2 \frac{\cos^2 \theta_W}{\sin^2 \theta_W}$
	$\sim e^2 \frac{\cos \theta_W}{\sin \theta_W}$		$\sim e^2$

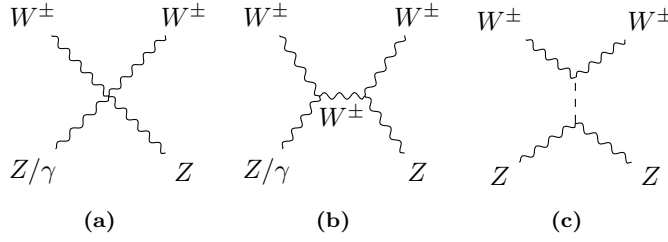


Figure 2.1: VBS diagrams with WZ in final state

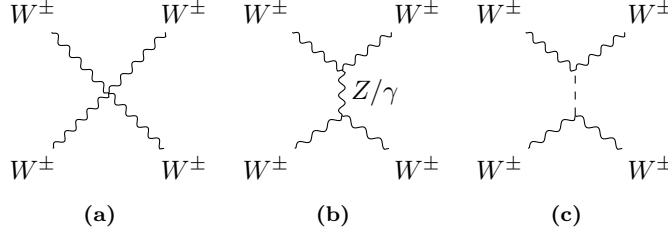


Figure 2.2: VBS diagrams with W[±]W[±] in final state

two strong couplings resulting in order $\alpha_{ew}^4 \alpha_S^2$ of the squared matrix element. This process is denoted QCD $W^\pm W^\pm jj$ in the rest of this thesis. For QCD $W^\pm W^\pm jj$ diagrams are not allowed with one or two gluons in the initial state because of electric charge conservation in each vertex. This leads to a higher EW to QCD $W^\pm W^\pm jj$ ratio compared to the EW to QCD $W^\pm Zjj$ ratio. Since the matrix element gets squared also the combination of subfigures (a,b) and (c,d) are possible, denoted Interference $W^\pm W^\pm jj$ of order $\alpha_{ew}^5 \alpha_S^1$.

The chosen gauge, e.g. in equation 2.8 and 2.9, should not affect the measured cross-sections. The gauge can change the contribution from different diagrams and thus only gauge invariant separable processes should be measured. On leading order these are EW, Int and QCD $W^\pm W^\pm jj$. On next-to-leading order, they are not gauge invariant separable [11]. Because of this both the cross-section of only EW $W^\pm W^\pm jj$ and the combined EW+Int+QCD $W^\pm W^\pm jj$ cross-section are measured in this work.

To have a high EW contribution dedicated selection criteria are chosen defined in Chapter 5. In the VBS diagrams the two quarks are not connected and thus there is also no colour connection between these jets during hadronisation. Because of this, the two resulting jets are radiated in the forward direction with a large m_{jj} and separation along the beam axis ΔY_{jj} . Because of the missing colour connection very few jets are expected between the two tagging jets measured with the variable $N_{gap, Jets}$.

The Higgs contributions Figure 2.1 and 2.2 are needed for not violating unitarity of longitudinal polarised W boson scattering [1]. One of the next interesting steps would be to look into the polarisation of the bosons to study this non-violation in more detail.

2.3 Physics Beyond the Standard Model

The SM is known to be incomplete and there are signs that there could be a more fundamental theory.

Completely missing in the Standard Model are gravity, including gravitational waves [12], and the masses of neutrinos, known from neutrino oscillation [13]. Cosmological observations also hint at the existence of dark energy [14] and dark matter [15] which are also not part of the SM, but make up 95% of the energy content of the universe.

There are 19 parameters in the Standard Model which are measured experimentally and are not predicted by it [1]:

- the 9 masses of quarks and charged leptons encoded in the Yukawa coupling constants

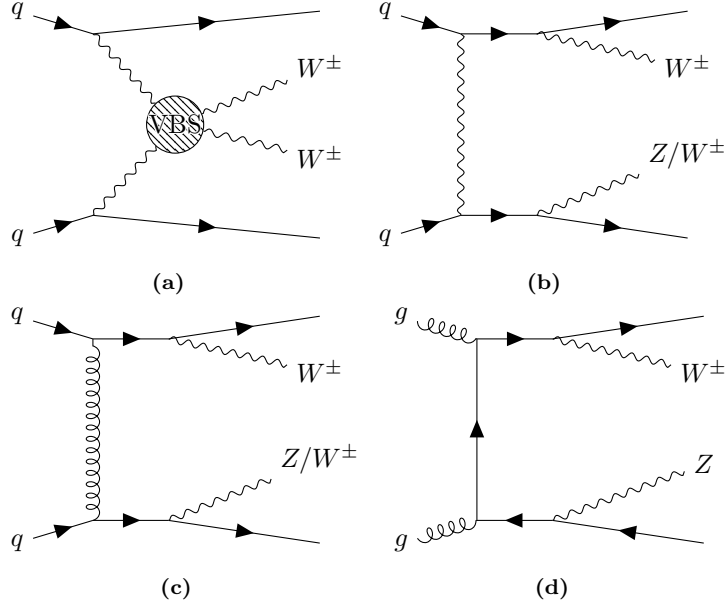


Figure 2.3: Different example Feynman diagrams for two incoming quarks or gluons and two outgoing jet together with $W^\pm Z$ or $W^\pm W^\pm$. Diagrams of type (d) with gluons in the initial state are not possible for $W^\pm W^\pm$ in the final state because of charge conservation.

- 3 mixing angles and 1 charge-parity violating phase in the quark mixing CKM matrix
- 3 gauge couplings: g_Y , g_W and g_S
- 2 parameters connected to the Higgs mechanism: the vacuum expectation value v and the Higgs boson mass m_H
- 1 parameter for the charge-parity-symmetry violations in QCD via the QCD vacuum angle

Additionally, the speed of light and the Plank constant are used by the Standard Model, but their value is not explained. The SM includes the observed fermions and boson and forces axiomatically and no reason is provided why there are (only) these particles and forces. This leaves room for a potential more general theory which also predicts some or all of those parameters, particles and forces.

An effective field theory (EFT) approach is studied in Chapter 10 where it is assumed, that the Standard Model is a low-energy description of a more general theory. The EFT introduces lower energy effects originating from effects at high energies which are not observed yet.

2.4 Calculation of Theory Predictions in Proton-Proton Collisions

The number of expected events N in a given phase space of a process X is:

$$N = \sigma_X \cdot L \quad (2.33)$$

where

σ_X is the cross-section and a measure of the probability that this process X occurs and L is the integrated luminosity representing the amount of data taken during collisions.

More information about the luminosity can be found in Section 3.2.2.5. Cross sections are measured in barn where $1 \text{ barn} = 10^{-28} \text{ m}^2$.

For proton-proton collisions the parton distribution function $f(x)$, defined in Section 2.4.2, with the energy fraction x of a proton at the renormalisation scale μ depending on the parton type a and b needs to be considered. The cross-section is:

$$\sigma_X = \sum_{a,b} \int dx_1 f_a(x_1, \mu^2) \int dx_2 f_b(x_2, \mu^2) \tilde{\sigma}_X. \quad (2.34)$$

The cross-section of a process $\tilde{\sigma}_X$ with two incoming and $n - 2$ outgoing particles can be calculated via Fermi's golden rule [16].

$$\tilde{\sigma}_X = \frac{S\hbar^2}{4\sqrt{(p_1 p_2)^2 - (m_1 m_2 c^2)^2}} \int |\mathcal{M}|^2 (2\pi)^4 \delta^4(p_1 + p_2 - \dots - p_n) \prod_{j=3}^n 2\pi \delta(p_j^2 - m_j^2 c^2) \theta(p_j^0) \frac{d^4 p_j}{(2\pi)^4} \quad (2.35)$$

with the δ function for total 4-momentum conservation and masses of outgoing particles, the θ function to ensure, that outgoing particles do not have negative energy. It is integrated over all possible combinations of outgoing four-momenta.

The statistical factor S takes care of potential double counting. If outgoing particles are the same, then S is 1 divided by the combinations with indistinguishable final states.

The factor 2π stems from the Fourier transformation of delta functions from position space to momentum space [1].

The factor $\frac{\hbar^2}{4\sqrt{(p_1 p_2)^2 - (m_1 m_2 c^2)^2}}$ is a residual of making the matrix element Lorentz invariant [1].

These integrals are of high dimension in the final state studied in this thesis. There are two ingoing particles and six outgoing ones. It needs to be integrated over the four-momentum of all these particles which is not feasible analytically. Because of this, it is solved numerically by generating Monte Carlo (MC) events according to the probability distribution. This introduces statistical modelling uncertainties discussed in Section 6.2.

To generate events for a p-p collider multiple issues need to be addressed shown in Figure 2.4:

1. Calculate the matrix element $\mathcal{M}$, explained in Section 2.4.1, with highest precision possible, starting from leading order.
2. The initial state is protons which consist of multiple particles - only one parton of each proton will interact in the matrix element. For this the parton distribution function (PDF) needs to be considered, explained in Section 2.4.2.
3. Some final state objects are not stable and decay into others before reaching the detector, called showering. This includes hadronisation and photon emission.
4. Simulation of the detector and the detector response is performed, explained in Section 4.1.

The MC generators, incorporating these first three steps used in this work, are [18]:

Sherpa : Sherpa [17, 19] is a multi-purpose event generator using COMIX [20] and OpenLoops [21] and merged with Sherpa parton shower based on Catani-Seymour dipole factorisation [22] according to MEPS@NLO prescription [23–26]. In this work events are generated for up to one additional parton at NLO and up to three additional partons at LO.

Madgraph : Madgraph [27] interfaced with both Herwig [28, 29] and Pythia [30] for showering depending on the sample.

Powheg : Powheg [31] interfaced with Pythia8 for showering is used in this work.

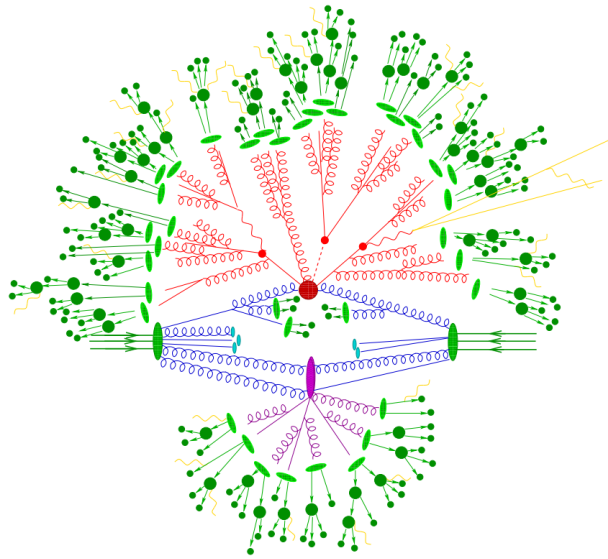


Figure 2.4: “Pictorial representation of a $t\bar{t}h$ event as produced by an event generator. The hard interaction (big red blob) is followed by the decay of both top quarks and the Higgs boson (small red blobs). Additional hard QCD radiation is produced (red) and a secondary interaction takes place (purple blob) before the final-state partons hadronise (light green blobs) and hadrons decay (dark green blobs). Photon radiation occurs at any stage (yellow).” [17]

2.4.1 Calculation of the Matrix Element

The lagrangian defines which vertices exist and how probably certain propagations and vertices are in combination. These combinations, which can be represented with Feynman diagrams, are calculated in the matrix element. The Feynman diagrams which connect the ingoing and outgoing particles with the fewest vertices are called leading order (LO). If more vertices are added, then more accurate next-to-leading order (NLO) diagrams can be calculated. In principle all possible combinations of vertices would need to be included. But since this is not possible uncertainties due to the missing combinations are estimated.

During the matrix element calculation, regularisation, renormalisation and factorisation is needed to handle divergences. Divergences appear for momentum $\rightarrow 0$ radiations, called infrared (IR) divergences, collinear radiations and large momentum in loops, called ultra-violet (UV) divergences. One form of regularisation is dimensional regularisation where a regularisation parameter ϵ is introduced to model the deviating dimension. The original theory can be retrieved in the limit $\epsilon \rightarrow 0$. In the renormalisation step the resulting Lagrangian $\mathcal{L}^\epsilon$ is chosen such, that observables exist in the limit $\epsilon \rightarrow 0$. This cures the UV divergences but also introduces the renormalisation scale which also depends on α_S . The choice of renormalisation scale would have no effect if all orders were included in the calculation, but since this is not possible there is a residual effect. To cure all IR divergences the factorisation scale is introduced which has also some effect on observables with a limited number of perturbative orders considered. More details can be found in e.g. [9].

With the variation of the renormalisation, factorisation scale and α_S the uncertainty due to the considered limited order is estimated.

2.4.2 PDF Modelling

The PDF defines the probability distribution of partons inside the proton and their respective fraction of the total momentum of the proton.

NNPDF [32] is used for all samples as nominal PDF set, shown in Figure 2.5. For the calculation of PDF uncertainties two additional PDFs are used as described in Section 6.2.2.

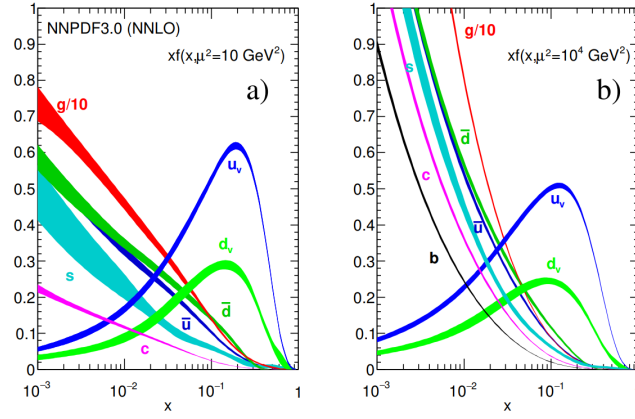


Figure 2.5: “The bands are x times the unpolarized (a,b) parton distribution $f(x)$ (where $f = u_v, d_v, \bar{u}, \bar{d}, s \approx \bar{s}, c \approx \bar{c}, b \approx \bar{b}, g$) obtained in NNLO NNPDF3.0 global analysis at scales $\mu^2 = 10 \text{ GeV}^2$ (left) and $\mu^2 = 10^4 \text{ GeV}^2$ (right), with $\alpha_S(M_Z^2) = 0.118$. ” [33]

Chapter 3

Experimental Setup

A chain of accelerators is used to accelerate protons. In the last accelerator, the Large Hadron Collider (LHC), a beam energy of 6.5 TeV is reached, described in Section 3.1. In the centre of the ATLAS detector, described in Section 3.2, the beams collide and decay products are measured with nearly full spatial coverage. The number of recorded decay products is a consideration between financial costs, e.g. due to CPU processing time, and interesting physics to measure.

3.1 The Large Hadron Collider

A short overview of the main characteristics of the accelerator is given here. More information can be found in [34] and [35].

The LHC is designed to accelerate and collide protons or heavy ions (Hi). It is built in the tunnel of the former Large Electron-Positron Collider and is used for proton-proton and Hi-Hi collisions since 2010. The LHC is designed for proton-proton collisions with a centre-of-mass energy of up to 14 TeV and heavy (Pb) ions with a centre-of-mass energy of 2.8 TeV. For the data analysed in this thesis, LHC was operated at a centre-of-mass energy of 13 TeV. The LHC has a circumference of 26.7 km and lies between 47 and 170 m below the surface.

3.1.1 The Accelerator Chain

There is a sequence of smaller accelerators, which are also used for other experiments, pre-accelerating the protons. A schematic overview is given in Figure 3.1 for both proton and

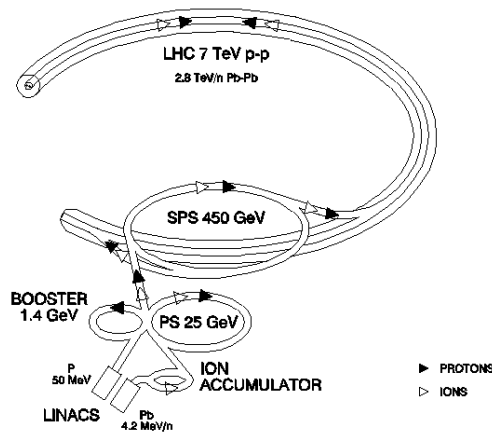


Figure 3.1: "The LHC injector complex" from Ref. [34]

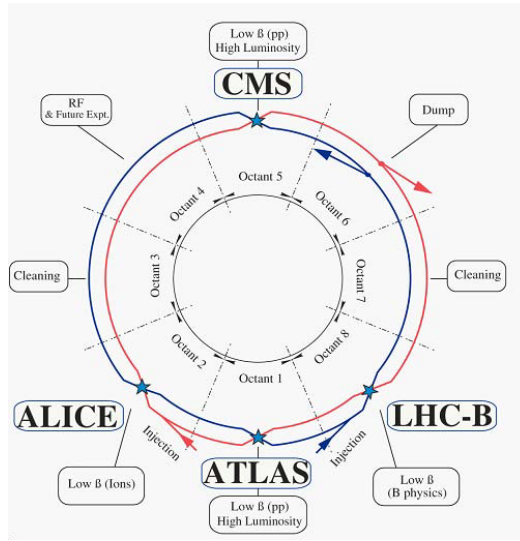


Figure 3.2: "Schematic layout of the LHC (Beam 1- clockwise, Beam 2 — anticlockwise)." from Ref. [34]

heavy ion injection.

For the proton-proton collisions examined in this thesis, the following accelerators are used:

1. **Linear accelerator 2 (Linac2):** linear accelerator which extracts protons and accelerates them to 50 MeV
2. **Proton Synchrotron Booster (PS Booster):** circular accelerator which accelerates protons from 50 MeV to 1.4 GeV,
3. **Proton Synchrotron (PS):** circular accelerator which accelerates protons from 1.4 GeV to 25 GeV,
4. **Super Proton Synchrotron (SPS):** circular accelerator which accelerates protons from 25 GeV to 450 GeV,
5. **LHC:** circular accelerator which accelerates protons from 450 GeV to 6.5 TeV.

The circular accelerators get filled at their lower energy and once filled the proton energy gets ramped up.

More details of a typical run can be found in Ref. [36].

3.1.2 Parts of the LHC

Figure 3.2 shows the parts of the LHC. There are eight arcs and eight straight sections. Straight sections are 528 m long and used for experiments and beam handling.

There are four large experiments: ATLAS at point 1, CMS at point 5, ALICE at point 2, and LHC-B at point 8. ATLAS and CMS are both multi purpose detectors which try to have nearly full spatial coverage to detect nearly all particles from the collision point. They act as two independent experiments to perform high precision measurements of the Standard Model and to search for new physics beyond the Standard Model. The biggest success so far was the observation of the Higgs Boson, which was discovered in both the detectors in 2012 [2] [3].

For beam handling there are:

- vertical injection from below at point 2 and 8,
- each two collimation systems at point 3 and 7, a momentum cleaning system at point 3 and a betatron cleaning system at point 7,

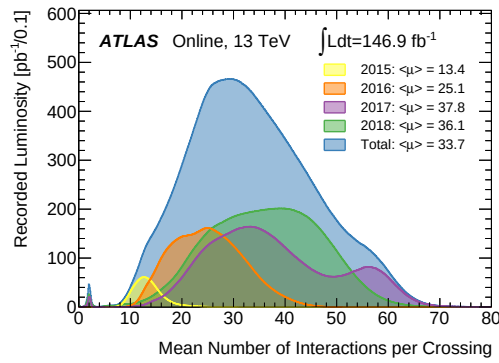


Figure 3.3: "Number of Interactions per Crossing Shown is the luminosity-weighted distribution of the mean number of interactions per crossing for the 2015 – 2018 pp collision data at 13 TeV centre-of-mass energy. All data recorded by ATLAS during stable beams is shown, and the integrated luminosity and the mean μ value are given in the figure. The mean number of interactions per crossing corresponds to the mean of the Poisson distribution of the number of interactions per crossing calculated for each bunch. It is calculated from the instantaneous per bunch luminosity as $\mu = L_{\text{bunch}} \times \sigma_{\text{inel}}/f_r$ where L_{bunch} is the per bunch instantaneous luminosity, σ_{inel} is the inelastic cross-section which we take to be 80 mb for 13 TeV collisions, and f_r is the LHC revolution frequency." from [39]

- for each beam a radiofrequency system [37] to accelerate the particles at point 4,
- beam dump in point 6 for vertical extraction of beams,
- approximately 10 quadrupoles to match the beams from the arcs dispersion suppressors to the apparatuses in the straight section

Each of the eight arcs consists of 23 regular arc cells. Where each arc cell consists of six 14.3 m actual bending distances. This means that the effective circumference relevant to the bending magnet strength is 15.8 km. There is in each arc area one dispersion suppressor at both ends to mainly cancel horizontal dispersion.

The bending magnets are cooled below 2 K with superfluid helium to achieve superconductivity and can reach magnetic fields above 8 T.

Details about the beam configuration during Run 2 and the reasons for their choices can be found in Ref. [38]. A short overview is given here. Run 2 lasted from April 2015 to 10th December 2018. The beam energy was 6.5 TeV, resulting in a center of mass energy at the colliding points of 13 TeV. The year 2015 was mainly used for commissioning with in total 455 hours of stable beams, to be used for physics collisions. The time from 2016 to 2018 was mainly used for data-taking with in total 1840h + 1634h + 1932h = 5406 hours of stable beams. This means there were 5861 hours of stable beams provided by LHC during Run 2.

Data taking was started in 2015 with a bunch spacing of 50 ns. In July 2015 it was switched to 25 ns bunch spacing which was kept until the end of Run 2. There are between 1868 and 2556 bunches per ring. Each of the bunches consists of $(1.1 \text{ to } 1.25) \cdot 10^{11}$ protons.

For technical reasons fewer bunches, but higher luminosity were set up in 2017 which resulted in more interactions per bunch crossing $\langle \mu \rangle$ which is shown in Figure 3.3.

An integrated luminosity of 139 fb^{-1} with an uncertainty of 1.7% was measured in Run 2 in ATLAS [40], see Figure 3.4.

3.2 The ATLAS Detector

The ATLAS Detector [34] is a general purpose detector to measure the decay products from the collision point with nearly full spatial coverage with the exception of the very difficult to detect neutrinos. It needs to have high interaction rates, resist the radiation doses and handle the particle multiplicities. There is also the CMS detector with an independent

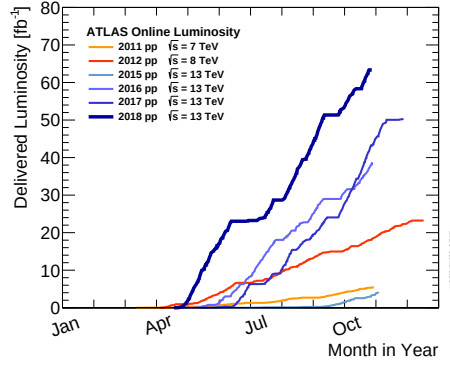


Figure 3.4: "Delivered Luminosity versus time for 2011-2018 (p-p data only) Cumulative luminosity versus day delivered to ATLAS during stable beams and for high energy p-p collisions. " from [39]

collaboration with the same aim to validate each other's results. The principle layout of the ATLAS detector did not change compared to the description in Ref. [41] written by the author of this thesis.

3.2.1 Coordinates

A right-handed cartesian coordinate system is used with the nominal interaction point as the origin of the coordinate system. The anticlockwise beam direction defines the z -axis where side-A of the ATLAS detector is defined to be in positive z and side-C of the detector in negative z . The coordinates x, y are transverse to the beam direction. The x -axis points from the interaction point to the center of the LHC ring while the positive y -axis points upwards.

Spherical coordinates are used to denote direction in space starting from the collision point with the polar angle ϕ and the azimuthal angle θ . The polar angle ϕ is the angle with respect to the x -direction in the plane orthogonal to the beam direction. The azimuthal angle θ is the angle with respect to the beam direction. As measure of the angle θ the pseudorapidity η is defined as

$$\eta := -\ln(\tan(\theta/2)). \quad (3.1)$$

The pseudorapidity is defined such that $\Delta\eta$ is independent of boosts along the beam direction for massless particles.

This is used to define the distance in pseudorapidity-azimuthal angle space:

$$\Delta R := \sqrt{\Delta\eta^2 + \Delta\phi^2}. \quad (3.2)$$

3.2.2 Layout

Only particles with a long enough lifetime reach the detector. They have to travel from the beam centre to the border of the beam tube, which is approximately 35 mm. Particles expected to reach the detector are photons, electrons, muons, neutrinos, and light hadrons like pions, protons and neutrons. To distinguish them four subdetectors are present: the inner detector, the electromagnetic calorimeter, the hadronic calorimeter and the muon system. A schematic view of the forward-backward symmetric ATLAS detector is shown in Figure 3.5. The structure is defined by the magnets used to determine the charge and momentum of particles.

There is a thin superconducting solenoid magnet surrounding the inner-detector cavity with a field strength in the beam direction of 2 Tesla. Three large superconducting toroids are placed around the calorimeters in the barrel and the two end-caps. They have an eightfold azimuthal symmetry around the calorimeters with an air-core.

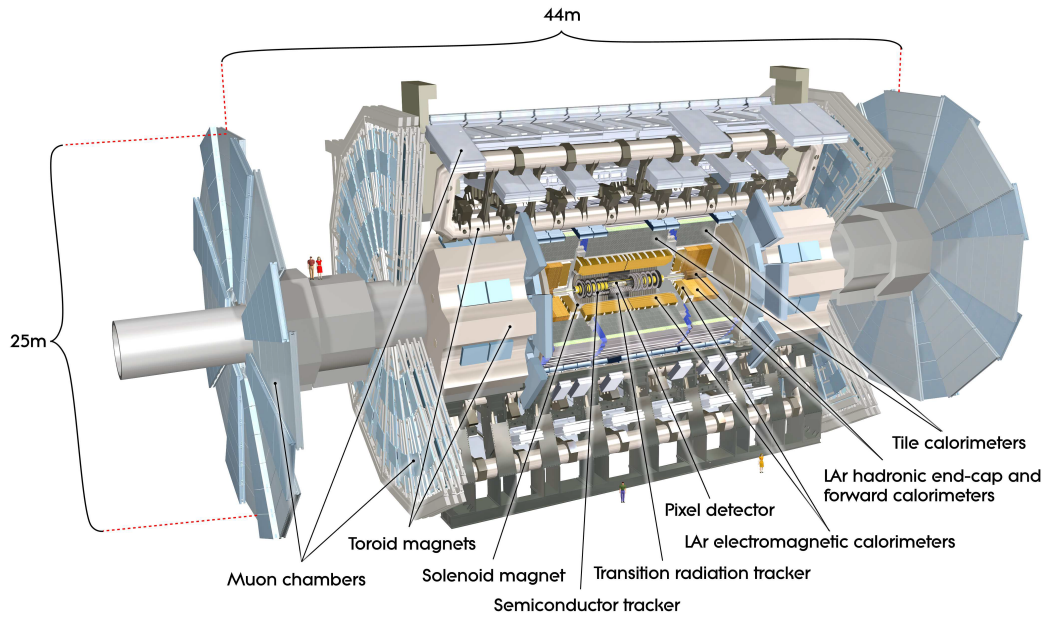


Figure 3.5: "Cut-away view of the ATLAS detector. The dimensions of the detector are 25 m in height and 44 m in length. The overall weight of the detector is approximately 7000 tonnes." from: [42]

3.2.2.1 Inner Detector

The subdetector nearest to the beam pipe is the inner detector, surrounded by a solenoid magnet producing a magnetic field of 2 Tesla. It covers the central region, defined as $|\eta| < 2.5$, and detects charged particles with silicon stripes, pixels and drift tubes filled with xenon and argon. Due to the magnetic field, charged particles describe a curved path from which their transverse momentum can be calculated.

The charge of particles can be determined from the curved path, too. For charged particles with high momentum or more in the forward direction, the momentum and charge resolution get worse because the path is bent less under these circumstances.

3.2.2.2 Electromagnetic Calorimeter

The electromagnetic calorimeter surrounds the inner detector. It consists of a barrel covering the area till $|\eta| < 1.475$. At the end of the barrel there are two end-caps, covering the space till $|\eta| = 3.2$. The electromagnetic calorimeter is built to measure the energy of light electromagnetically interacting particles, like photons, electrons or positrons. There are alternating layers of lead and liquid argon. Lead acts as an absorber and lets the electromagnetically interacting particles decay into showers. The number of particles is measured in the liquid argon layers. From the measured properties of the shower, the energy of the initial particle is recalculated.

This detector has a high granularity to reach good spatial and energy resolution.

3.2.2.3 Hadronic Calorimeter

The electromagnetic calorimeter is surrounded by the hadronic calorimeter, designed to measure the energy of hadrons. It also consists of layers of absorbers and active medium. Here, steel is used as absorber. It consists of a tile barrel, two end-caps (HEC) and a liquid argon forward calorimeter (FCal). The barrel covers $|\eta| < 1.7$, HEC covers $1.5 < |\eta| < 3.2$ and FCal covers $3.1 < |\eta| < 4.9$. The barrel uses scintillating tiles as active material, whereas HEC and FCal uses liquid argon. The hadronic calorimeter works similar to the electromagnetic by producing showers in the absorbers which are measured by the active material.

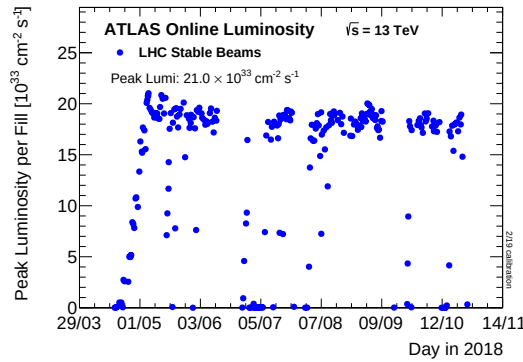


Figure 3.6: "The peak instantaneous luminosity delivered to ATLAS during stable beams for pp collisions at 13 TeV centre-of-mass energy is shown for each LHC fill as a function of time in 2018. The luminosity is determined using counting rates measured by the luminosity detectors, and is based on an initial estimate from van-der-Meer beam-separation scans during 2017. " from [43]

3.2.2.4 Muon System

The outermost subdetector is the muon system. It measures muons which are the only detectable particles which are expected to escape the hadronic calorimeter. The muon system is embedded in a magnetic field coming from a toroid magnet. Through this field the muons are redirected and, similar to the inner detector, the momentum can be calculated from this. The muon trajectories are measured with drift tubes and Cathode Strip Chambers.

3.2.2.5 Luminosity Measurement

Cross sections are a measure of the probability that a process occurs in a given phase space and is measured in femto barn fb where $1 \text{ fb} = 10^{-43} \text{ m}^2$. The instantaneous luminosity is given in per cross-section and per second shown in Figure 3.6.

The integrated luminosity is the relevant number for physics analysis, shown in Figure 3.7. For example, a process with a cross-section of 3 fb is expected to occur $3 \cdot 139 = 417$ times in the Run 2 data set of an integrated luminosity of 139 fb^{-1} .

The absolute luminosity measurement is calibrated at low luminosities with the van der Meer method [44, 45] and is extrapolated from there to the high luminosity condition used for data taking for physical analysis.

The uncertainty in the combined 2015–2018 integrated luminosity is 1.7 % [40], obtained using the LUCID-2 detector [46] for the primary luminosity measurements.

3.2.3 Trigger System

The measurements of the detector are clustered into events containing all information associated with one inelastic p-p scattering process. Due to technical and financial constraints, not all events can be stored. There is a three level trigger system which selects only the interesting events. The information read out from the subdetectors is kept in a pipeline in order to minimize the dead time of the detector.

The hardware based level-one trigger (L1) uses only a little information from the detector to decide within $2.5 \mu\text{s}$ whether to keep an event. If it is kept, L1 defines regions of interest (RoI) where something interesting happened.

The level-two trigger (L2) uses the RoIs and all measurements within these regions to decide within 40 ms if the event should be discarded.

The last trigger is the event filter which uses all detector information to make a decision within 4 s and reduces the event rate to 200 Hz. L2 and event filter together form the High-

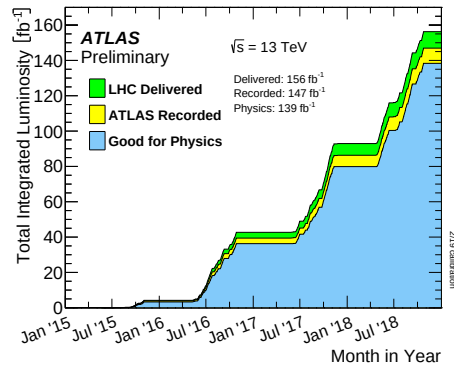


Figure 3.7: "Total Integrated Luminosity and Data Quality in 2015-2018 Cumulative luminosity versus time delivered to ATLAS (green), recorded by ATLAS (yellow), and certified to be good quality data (blue) during stable beams for pp collisions at 13 TeV centre-of-mass energy in 2015-2018. The complete pp data sample in 2018 is shown. The delivered luminosity accounts for the luminosity delivered from the start of stable beams until the LHC requests ATLAS to put the detector in a safe standby mode to allow a beam dump or beam studies. The recorded luminosity reflects the DAQ inefficiency, as well as the inefficiency of the so-called "warm start": when the stable beam flag is raised, the tracking detectors undergo a ramp of the high-voltage and, for the pixel system, turning on the preamplifiers. The data quality assessment shown corresponds to the All Good efficiency shown in the 2015-2018 Full Dataset DQ tables here. The All Good Data Quality criteria require all reconstructed physics objects to be of good data quality. " from [43]

Level Trigger whose accepted events are permanently stored.

3.2.4 Object Reconstruction

To make sense of detector signals, reconstruction algorithms were developed to built objects that later on could be identified as particles.

3.2.4.1 Electron Reconstruction

A detailed description of the used electron reconstruction and identification can be found in Ref. [47] and with more details about the working points in Ref. [48]. Also the included uncertainties for electrons shown in Table 6.1 are explained in more detail in these references. The reconstruction algorithm is calibrated as stated in Ref. [47].

The reconstruction algorithm starts with combining EM and hadronic calorimeters into topological clusters. Those topological clusters which have an EM energy above 400 MeV and a higher entry in EM compared to the hadronic calorimeter are considered as **EM topo clusters**.

Tracks are reconstructed in the inner detector and matched to clusters.

Initial electron candidates are EM topo clusters with at least one associated track which fulfils some quality requirements defined in Ref. [49]. Initial photon candidates are EM topo clusters with no associated tracks or converted photons visible in the track pattern.

For final electron candidates, nearby bremsstrahlung radiations are merged back to get the initial four-momentum.

Since there are several background processes which could mimic an electron, identification criteria are needed. Backgrounds are, for example, energy deposits from hadronic jets, converted photons or electrons from heavy-flavour hadron decays. The interesting electrons are the ones from the hard scattering vertex or from heavy resonances such as Higgs, W and Z boson. A minimum number of hits in the parts of the inner detector are required and other discriminating variables are used with different strictnesses depending on the working point. There are two identification working points used in this thesis:

- **LooseLH**: with an efficiency of approximately 93%,
- **TightLH**: with an efficiency of approximately 80% but a higher background rejection rate.

The efficiencies gradually improve from low to high energies. Another criterion is isolation, quantifying how strongly it should be separated from neighbouring tracks and energy deposits in the calorimeter. The **Gradient** working point is used, designed to have an efficiency of 90% at $p_T=25$ GeV and 99% at $p_T=60$ GeV while having a uniform efficiency in η .

The electron charge ID selector (ECIDS) is used to veto charge misidentification in signal electrons [48]. It uses a boosted decision tree to categorize each electron whether it might be affected by a charge misidentification.

Efficiencies are calculated for electrons with $E_T > 4.5$ GeV and $|\eta| < 2.47$ in Ref. [47]. These minimum requirements are also set in the object selection of baseline electrons in this thesis.

3.2.4.2 Muon Reconstruction

A detailed description of the used muon reconstruction and identification can be found in Ref. [50]. Also the included uncertainties for muons shown in Table 6.1 are explained in more detail in this reference. The reconstruction algorithm is calibrated as stated in Ref. [50].

Informations of hits in the muon system, inner detector and also the calorimeters are used for the reconstruction. Out of them, muon candidates are constructed according to the chosen identification working point. There are two identification working points used in this thesis:

- **Medium** with an average efficiency of 97% and 0.17% light-hadron misidentification rate and
- **Loose**: which is a superset of **Medium** with an average efficiency of 99% and approx. 0.25% light-hadron misidentification rate

for simulated $t\bar{t}$ events with muons $20 < p_T < 100$ GeV and $|\eta| < 2.5$ [50]. The efficiency is worse for $|\eta| < 0.1$ due to the limited coverage of the muon system. It improves with larger p_T and $|\eta|$.

The **FixedCutPflowTight** working point is used for the isolation which has an efficiency of 87% and 0.9% bottom- and charm-hadron misidentification rate for simulated $t\bar{t}$ events with muons $20 < p_T < 100$ GeV and $|\eta| < 2.5$ [50].

The muon reconstruction, identification, vertex association and isolation efficiencies are measured for tracks with $p_T > 3$ GeV and $|\eta| < 2.7$ in Ref. [50] and are used in this work. These minimum requirements are also set in the object selection of baseline muons in this thesis.

3.2.4.3 Jet and MET Reconstruction

Details about the Jet reconstruction and identification can be found in Ref. [51] with details on the b-jet identification in Ref. [52]. Details about MET can be found in Ref. [53]. Also the included uncertainties for jets and MET shown in Table 6.1 and 6.2 are explained in more detail in these references. For the identification of jets, the anti-kt algorithm [54] with a radius parameter $R=0.4$ is used. The probability of radiations of partons with very low momentum or colinear to the radiating parton are divergent. The jet reconstruction algorithm has to cope with this and the result should be independent of these radiations. The anti-kt algorithm fulfils this requirement. It starts from four-momentum objects p_i defined with the particle flow **PFlow** [55] algorithm: energy deposits in the calorimeter are updated by the more precise four-momentum estimate from tracks from charged particles in the inner detector.

The following terms are determined:

- $d_i := p_{T,i}^{-2}$: the transverse momentum of the deposited energies to the power of -2 and

- $d_{i,j} := \min(p_{T,i}^{-2}, p_{T,j}^{-2}) \frac{\Delta R_{i,j}}{R}$: the combined energetic and spatial distance of all deposited energies,

where $\Delta R_{i,j}$ is the spatial distance between the deposited energies i and j . The values d_i and $d_{i,j}$ are ordered in a list in increasing order. If the smallest value is a $d_{i,j}$, then the four-momenta of i and j are added, they are treated as one object in the following and the list is updated accordingly. If the smallest value is a d_i , then it is marked as jet and all occurrences of i are deleted in the list.

Jet vertex tagging (JVT) [56] is used to suppress jets from neighbouring p-p collisions during the same bunch crossing.

The relative jet energy resolution is measured in Ref. [51] and ranges from $(24 \pm 1.5)\%$ at 20 GeV to $(6 \pm 0.5)\%$ at 300 GeV. This minimum energy requirement is also used in the object selection of baseline jets in this thesis.

To identify jets originated from a b-quark the output of a deep-forward neural network **DL1r tagger** is used with the working point **fixed-cut 85%** with an efficiency of 85% [52].

MET is defined in Section 5.1.1.

Chapter 4

Contributing Processes

The main goal of this thesis is to study the scattering of two same-charged W bosons. The W bosons are unstable with a lifetime of $3.16 \cdot 10^{-25}$ s in which they would travel on average less than 10^{-10} m.¹ Since the beam pipe is much larger ($\approx 2.5 \cdot 10^{-2}$ m) than this only the decay products can be measured. W bosons decay, according to the PMG data book [57], in 32.59(27)% into lepton-pairs and to 67.41(27)% into hadrons. The hadrons will form jets, which are frequent in p-p colliders and thus hard to trace back to W bosons.

The lepton pairs consist of a neutrino and a charged lepton. From the charged leptons taus have a very short lifetime and mainly only the decay products will be measurable.² Thus, only muons and electrons are considered in this analysis in the final state to reach high WW-scattering purity. There are also semi-leptonic [58, 59] final states examined, but not in this thesis.

Because of electromagnetic charge conservation two same-sign W bosons cproduced together with two jets, the so-called tagging jets.

This defines the final state studied: it consists of two leptons, electron and/or muon, missing transverse momentum (from two neutrinos) and two tagging jets.

Unfortunately, also other processes can have this final state. Additionally, the detector is not perfect, and the charge of the leptons could get misidentified or jets could get misinterpreted as leptons in the reconstruction process. Thus, also processes with three jets and one charged lepton before reconstruction could contribute to the background of signal like looking events. The signal process is defined in Section 4.2 and the background processes in Section 4.3.

4.1 Simulation of the Processes

There is a processing chain within ATLAS of generated samples. They are only be first generated by the MC generators on truth level in EVNT format. They include already on-the-fly weights (OTF weights) which are used to reweight the events to get the scale, PDF and α_S variations. They are used to calculate the corresponding uncertainties in Chapter 6. Afterwards, the detector simulation, implemented in Geant4 [60], is applied resulting in the intermediate HITS file. Physical objects get reconstructed in the AOD file. Finally, an analysis specific derivation is created with already some selection criteria of the fiducial region applied. In this thesis STDM3 [61] is used.

Table 4.1 lists the samples used in this thesis and the used generators, orders and PDF set.

¹The W decay width from PMG is $\Gamma_W = 2.08(4)$ GeV and the resulting lifetime is $\tau_W = 1/\Gamma_W = 3.16 \cdot 10^{-25}$ s. Assuming a maximal energy $E_{\max} = 13$ TeV and the mass $m_W = 80.38$ GeV the average maximum distance $s_{\max, av}$ can be calculated: $\gamma_{\max} = \frac{\sqrt{E_{\max} - m_W}}{m_W} = 162$, $v_{\max} = \sqrt{1 - \frac{1}{\gamma_{\max}^2}} c$, $s_{\max, av} =$

$v_{\max} \cdot \gamma_{\max} \cdot \tau_W = 1.54 \cdot 10^{-11}$ m.

²With $E_{\tau, \text{mean}} \approx 100$ GeV, $m_\tau = 1776.86$ MeV, $\tau_\tau = 290.3 \cdot 10^{-15}$ s [57] the average mean distance $s_{\text{mean}, av}$ can be calculated: $\gamma_{\text{mean}} = \frac{\sqrt{E_{\text{mean}} - m_\tau}}{m_\tau} = 55$, $s_{\text{mean}, av} = v_{\text{mean}} \cdot \gamma_{\text{mean}} \cdot \tau_\tau = 4.8 \cdot 10^{-3}$ m.

³Combined with *WWW* and *WH* samples as described in the text.

Table 4.1: "A summary of MC samples used to simulate signal and major background processes in the signal region. The notation V is used to represent either W or Z/γ ." [18]

Process, short description	ME Generator + parton shower	Order	Tune	PDF set in ME
EW, Int, QCD $W^\pm W^\pm jj$, nominal signal	MADGRAPH5_AMC@NLO2.6.7 + HERWIG7.2	LO	HERWIG	NNPDF3.0NLO
EW, Int, QCD $W^\pm W^\pm jj$, alternative shower	MADGRAPH5_AMC@NLO2.6.7 + PYTHIA8.244	LO	A14	NNPDF3.0NLO
EW $W^\pm W^\pm jj$, NLO pQCD approx.	SHERPA2.2.11 ³	+0,1j@LO	SHERPA	NNPDF3.0NNLO
EW $W^\pm W^\pm jj$, NLO pQCD approx.	POWHEG Boxv2 + PYTHIA8.230	NLO (VBS approx.)	AZNLO	NNPDF3.0NLO
QCD $W^\pm W^\pm jj$, NLO pQCD approx.	SHERPA2.2.2	+0,1j@LO	SHERPA	NNPDF3.0NNLO
QCD $VVjj$	SHERPA2.2.2	+0,1j@NLO; +2,3j@LO	SHERPA	NNPDF3.0NNLO
EW $W^\pm Z/\gamma^* jj$	MADGRAPH5_AMC@NLO2.6.2+PYTHIA8.235	LO	A14	NNPDF3.0NLO
EW $Z/\gamma^* Z/\gamma^* jj$	SHERPA2.2.2	LO	SHERPA	NNPDF3.0NNLO
QCD $V\gamma jj$	SHERPA2.2.11	+0,1j@NLO; +2,3j@LO	A14	NNPDF3.0NNLO
EW $V\gamma jj$	MADGRAPH5_AMC@NLO2.6.5+PYTHIA8.240	LO	A14	NNPDF3.0NLO
VVV	SHERPA2.2.1 (leptonic) & SHERPA2.2.2 (one $V \rightarrow jj$)	+0,1j@LO	SHERPA	NNPDF3.0NNLO
$t\bar{t}V$	MADGRAPH5_AMC@NLO2.3.3.p0 + PYTHIA8.210	NLO	A14	NNPDF3.0NLO
tZq	MADGRAPH5_AMC@NLO2.3.3.p1 + PYTHIA8.212	LO	A14	NNPDF2.3LO
$W^\pm W^\pm jj$ EFT	MADGRAPH5_AMC@NLO2.6.5 + PYTHIA8.235	LO	A14	NNPDF3.0NLO
$H_5^{\pm\pm}$	MADGRAPH5_AMC@NLO2.9.5 + PYTHIA8.245	LO	A14	NNPDF3.0NLO

4.2 Signal Process

The used signal processes are listed in Table 4.1. A LO sample is used. For a complete NLO sample EW and QCD NLO effects need to be added to the three EW, interference and QCD sample - so in total six corrections. Only three of them were available at the time this thesis was written.

For the nominal LO $W^\pm W^\pm jj$ Madgraph sample the shower Herwig7 is used because NLO QCD is only available in Herwig7 and the nominal sample should be close to a possible better signal sample. In the timescale of the analysis presented here, the NLO QCD Madgraph sample was not ready. There is also a recent paper publishing the NLO EW Powheg calculation for EW $W^\pm W^\pm jj$ [62]. Also this sample was not ready in time for inclusion in this analysis. More details about the status of NLO predictions including showers can be found in Ref. [63].

EW $W^\pm W^\pm jj$ Powheg uses the VBS approximation [64] and the factorisation and renormalisation scale are fixed to W boson mass for this sample. These have known deviations due to the approximations as discussed in Ref. [63] and is used only as a comparison.

The nominal signal sample is listed in Table A.1. The uncertainties are estimated with the help of the samples listed in Table A.2 according to the procedure described in Section 6.2.

Dedicated selection requirements are applied to select events in a region enriched in signal events as described in Chapter 5.

4.3 Background Processes

Contributing background processes, sorted in decreasing order of the yield, are:

- $W^\pm Zjj \rightarrow \ell\ell\nu jj$,
- Non-prompt, mainly from $W(\rightarrow \ell\nu) + jets$ and $t\bar{t}$ (semileptonic decays)
- Conversions, consisting of photon conversions from $V\gamma$ processes and electron charge misidentification,
- Other prompt, consisting of top, triboson and ZZ contributions.

The list of all used MC samples for other prompt and $V\gamma$ backgrounds can be found in Table A.3.

The non-prompt lepton and electron charge misidentification background sources are estimated using data-driven methods, while other background sources are modelled using MC. The backgrounds with the largest contribution and hardest to model in this process are $W^\pm Zjj$ background, non-prompt lepton, and conversion background. Their derivation is described in more detail in this chapter. Please note that this work was not done by the author of this thesis. It is needed in the following to understand the different background contributions and their associated uncertainties.

The background estimations are validated in eight dedicated validation regions ('Inclusive VR', 'Z(ee) Peak VR', 'Low ΔY_{jj} VR', 'Low m_{jj} ', 'Low N_{jet} VR', 'Top-Fakes VR', 'Top-EWK VR' and 'Trilepton Inclusive VR'). Good agreement between data and MC was found in all regions [65].

4.3.1 $W^\pm Zjj$ Background

If one lepton from Z of $W^\pm Zjj \rightarrow \ell\ell\ell\nu jj$ is not reconstructed, then the same configuration as for the signal process is possible: 2 leptons + 2 jets + E_T^{miss} . Because of this a WZ control region (WZ CR) is introduced in the main fit to determine QCD $W^\pm Zjj$ normalisation data-driven. The WZ CR is chosen close to the signal region to have similar kinematics, but modified to be dominated by QCD $W^\pm Zjj$. It is defined in Section 5.2.3.

The WZ CR contains only one bin in the final fits and no splitting by flavour nor m_{jj} is performed. A m_{jj} bin wise QCD $W^\pm Zjj$ normalisation factor in the main fit could be considered in future analysis of this process.

Mismodelling of m_{jj} is known and seen by other analyses, e.g. in Ref. [66]. Because of this the m_{jj} shape is reweighted according to data before the main fit. An exponential falling reweighting function is used in a four bin fit in the WZ CR with EW suppression requirement in the range $200 < m_{jj} < 2500$ GeV to be sensitive to the QCD $W^\pm Zjj$ process. The EW-suppression requirement was optimised to be: a WZ centrality above 0.5, to increase the $W^\pm Zjj$ QCD to EW ratio while keeping many QCD $W^\pm Zjj$ events. Data and MC are normalised to one to keep the normalisation information for the main fit. To not use data twice the m_{jj} shape is determined from m_{jj} in WZ CR only in this first step. Only one bin in WZ CR is used in the main fit with free floating QCD $W^\pm Zjj$ normalisation to not use the shape information from data in WZ CR twice.

4.3.1.1 Systematic Uncertainties

Uncertainties from reweighting are:

- **MjjRewPDF**: envelope in exponent taken around PDF and α_S variations,
- **MjjRewScale**: missing higher order effects in the QCD $W^\pm Zjj$ simulation, estimated as envelope in exponent from renormalisation and factorization scale variations,
- **MjjRewStat**: due to limited MC and data events by variation of the reweighting function resulting in an up and down variation.

Several other reweighting functions and limited bin information are tested to confirm, that the statistical uncertainty covers these cases.

4.3.2 Non-prompt Lepton Background

Non-prompt leptons are additional leptons passing signal lepton selection from heavy-flavour hadron decay or jets misidentified as leptons. Non-prompt muons stem mostly from heavy-flavour hadron decays, while electrons stem mostly from light-flavour hadron decays. It turned out, that non-prompt muons are a bit more frequent than non-prompt electrons in the signal region. Events which contain a non-prompt signal lepton are called non-prompt background. This background is estimated using a data-driven method with the so-called "fake factor method". Details can be found in [67].

The fake factor method is based on a looser lepton selection 'Anti-ID', defined below. The ratio of leptons passing the signal selection $N_{\text{ID}}^{\text{non-prompt}}$ divided by the number of leptons passing the looser lepton selection $N_{\text{Anti-ID}}^{\text{non-prompt}}$ is called fake factor F .

$$F = \frac{N_{\text{ID}}^{\text{non-prompt}}}{N_{\text{Anti-ID}}^{\text{non-prompt}}} . \quad (4.1)$$

The fake factor is estimated in a dedicated dijet region shown in Table 4.2. Fake factors are calculated for two different triggers: HLT_e12_lhvloose_nod0_L1EM10VH and HLT_mu14

and the stricter trigger used in the analysis. The first trigger was used to have more events to calculate the fake factor from, but these fake factors can not get applied to events in the SR which get triggered only by its Anti-ID lepton. Dedicated fake factors with the SR triggers in the dijet region are used in this case. The nominal trigger is split into 2015 and 2016-18 data taking periods.

Table 4.2: Dijet event selection used in the fake factor estimation as described in Ref. [67].

Dijet event selection
GRL
Trigger
Trigger matching
$N_l = 1$ and $p_T^l > 27 \text{ GeV}$
$N_{\text{jet}} > 0$
$p_T^{\text{tagging jet}} > 25(30) \text{ GeV}$
$ \Delta\phi(l, j) > 2.8$
$E_{T, \text{track}}^{\text{miss}} + m_T < 50 \text{ GeV}$
b-jetveto
ID or Anti-ID lepton

The low- m_{jj} control region is used as control region in the main fit for further determining their contribution close to SR with a looser m_{jj} requirement: $200 < m_{\text{jj}} < 500 \text{ GeV}$.

In the end this fake factor is applied to a region close to the SR with the looser lepton selection 'Anti-ID' applied. This results in the non-prompt background estimate in the signal region and low- m_{jj} CR region.

The looser selection is designed to be close to the signal lepton selection, but without overlap. The quality requirements are chosen looser than for the signal selection to have more non-prompt leptons and thus more data to infer from.

The nominal signal lepton selection can be found in Table 5.4. The 'Anti-ID' selection applies the same requirements, but for electrons:

- LHMedium instead of LHTight ID,
- no Gradient Isolation required,
- fail either LHTight ID or Gradient Isolation to have no overlap with the signal electron selection,

and for muons:

- $|d_0/\sigma_{d_0}| < 10$ instead of $|d_0/\sigma_{d_0}| < 3$,
- FixedCutPflowLoose isolation instead of FixedCutPflowTight isolation and
- fail either $|d_0/\sigma_{d_0}| < 3$ or FixedCutPflowTight isolation to have no overlap with the signal muon selection.

There are different origins of non-prompt leptons, like light mesons, c mesons or b mesons. It is important that the leptons in the signal region (both ID and Anti-ID) have the same origin as in the dijet region where the fake factors get estimated to have the same relative probabilities. By applying the b-veto or requiring at least one b-jet the origins can get varied to two extremes. The mean is used in the analysis to be close to the SR and the two extremes are used as jet composition systematic uncertainty. All other systematic uncertainties are calculated around b-jet veto to be close to SR.

Fake factors are extracted from single-lepton data dominated by non-prompt leptons in the dijet region. There, prompt contributions, estimated by MC, need to be subtracted from data:

$$F = \frac{N_{\text{ID}} - N_{\text{ID}}^{\text{prompt}}}{N_{\text{Anti-ID}} - N_{\text{Anti-ID}}^{\text{prompt}}} . \quad (4.2)$$

Fake factors are calculated separately for electrons and muons, separated in three bins of lepton transverse momentum p_T with bin edges: [27, 35, 55, 200] GeV. For electrons it is further split into three bins of $|\eta|$ with bin edges: [0, 1.37, 1.52, 2.47]. The crack region is also excluded in the SR, but has a small neglectable effect because a different η definition is used. The track-based η is used for the fake factor while the cluster based η is used in the SR.

In the signal process, there are two leptons. Since the contribution from two non-prompt leptons is negligible [68] only one non-prompt lepton is considered. The predicted background yield is:

$$N_{\text{ID+ID}}^{\text{non-prompt}} = F(f_{\ell_1}, p_{T,\ell_1}, |\eta_{\ell_1}|) \cdot \left(N_{\text{ID}(f_{\ell_2})+\text{Anti-ID}(f_{\ell_1})} - N_{\text{ID}(f_{\ell_2})+\text{Anti-ID}(f_{\ell_1})}^{\text{prompt, charge flip}} \right) + F(f_{\ell_2}, p_{T,\ell_2}, |\eta_{\ell_2}|) \cdot \left(N_{\text{ID}(f_{\ell_1})+\text{Anti-ID}(f_{\ell_2})} - N_{\text{ID}(f_{\ell_1})+\text{Anti-ID}(f_{\ell_2})}^{\text{prompt, charge flip}} \right), \quad (4.3)$$

where f_{ℓ_i} is the flavour, either e or μ , of the i -th lepton. In addition to the prompt background, data-driven estimated background due to charge-flip, defined in Section 4.3.3, is subtracted.

The method was cross-checked with a second approach where the fake factor was determined from events with two reconstructed leptons [68]. Sufficient agreement was found.

4.3.2.1 Systematic Uncertainties

There are different sources of systematic uncertainties. In the final fit they are there for each trigger configuration, split into 2015, 2016-18 data taking periods for the nominal SR trigger and commonly 2015-16 for the nominal dijet region trigger

They are grouped into:

- **gamma__[bins SR, low- m_{jj} CR]** includes statistical uncertainties of data in ID+Anti-ID SR,
- **mu_FF_STAT_2015_2018__[1-3]__1** statistical uncertainties of muon fake factor in p_T bin 1-3 for nominal dijet region trigger,
- **mu_FF_STAT__[2015,2016_2018]__[1-3]__1** statistical uncertainties of muon fake factor in p_T bin 1-3 for SR trigger,
- **el_FF_STAT_2015_2018__[1-3]__[1-3]** statistical uncertainties of electron fake factor in p_T bin 1-3 in $|\eta_\ell| < 1.37$, crack or $|\eta_\ell| > 1.52$ for nominal dijet region trigger,
- **el_FF_STAT__[2015,2016_2018]__[1-3]__[1-3]** statistical uncertainties of electron fake factor in p_T bin 1-3 in $|\eta_\ell| < 1.37$, crack or $|\eta_\ell| > 1.52$ for SR trigger,
- **FF_Prompt** Prompt lepton subtraction in the fake factor estimate: modelling of dominant prompt contamination W+jets in dedicated control region shows up to 5% difference which is included as unc. on the total prompt contamination. The 5% variation is applied to the prompt background in the fake factor calculation in the dijet region,
- **el_FF_AntiIDSF, mu_FF_AntiIDSF** variations of prompt electron and muon contributions in the ID+AntiID region, related to the identification and isolation efficiency for AntiID leptons,
- **el_FF_BTagged and mu_FF_BTagged** Jet flavour composition: taking b-veto and inverse as systematic variations where the true composition is somewhere in between,
- **FF_MET** $E_{T,track}^{miss} + m_T$ variation: The energy requirement is varied 5 GeV up and down - the resulting difference of the non-prompt prediction is taken as uncertainty.

4.3.3 Conversions Background from Electron Charge Misidentification

The background prediction of charge-flipped leptons is estimated using a data-driven method [69]. In principle, muons and electrons could be affected, but the contribution from muon charge flip is small and can be neglected [70]. The contribution from electron charge flip is estimated from opposite-sign data events with a weight w applied, according to the charge flip rate estimated from data. Opposite-sign data is taken from the signal region (SR) with only the same-sign charge requirement changed to opposite-sign charge. These events are weighted according to $|\eta|$ and p_T of the leptons.

The weight applied on opposite sign events on reco level is:

$$w = \frac{\varepsilon_{\ell 0}(1 - \varepsilon_{\ell 1}) + \varepsilon_{\ell 1}(1 - \varepsilon_{\ell 0})}{(1 - \varepsilon_{\ell 0})(1 - \varepsilon_{\ell 1}) + \varepsilon_{\ell 0}\varepsilon_{\ell 1}}. \quad (4.4)$$

It is the ratio of the probability that exactly one lepton changes the charge to the probability that both or neither lepton flips the charge. In the modified opposite sign SR we measure the absolute number in the denominator and can infer the number in the numerator by multiplying with w .

The charge flip probabilities $\varepsilon_\ell(|\eta_\ell|, p_{T,\ell})$ are calculated from MC, corrected with data-to-MC scale factors (SF) [71] in an extra region defined in Table 4.3. The probabilities are defined in discrete steps of $|\eta_\ell|$ (i-th bin) and $p_{T,\ell}$ (j-th bin). The probability $\varepsilon_{\text{misID},ij}$ is the ratio between the number of events with misID $N_{\text{misID},ij}$ and the total number of events $N_{\text{all},ij}$:

$$\varepsilon_{\text{misID},ij} = \frac{N_{\text{misID},ij}}{N_{\text{all},ij}}. \quad (4.5)$$

In this region, $Z \rightarrow ee$ decays are examined with reconstructed same-sign electrons. The sideband subtraction method, involving a Z window requirement, is used to estimate the background of non-Z processes [72].

The MC events are corrected by applying data-to-MC SFs for each of the electrons depending on whether there is a charge-flip in MC (SF_{wrong}) or not ($\text{SF}_{\text{correct}}$):

$$\text{SF}_{\text{wrong}} = \frac{\varepsilon_{\text{data}}}{\varepsilon_{\text{MC}}}, \quad \text{SF}_{\text{correct}} = \frac{1 - \varepsilon_{\text{data}}}{1 - \varepsilon_{\text{MC}}}, \quad (4.6)$$

where $\varepsilon_{\text{data}}$ is the charge flip probability in data estimated with the sideband subtraction method from $Z \rightarrow ee$ events. The charge flip probability in MC is ε_{MC} .

Requirements
$m_{\ell\ell} > 20$ GeV (remove contributions from soft-QCD processes)
Electrons passing the ECIDS condition
$ \eta < 2.5$, excluding crack region ($1.37 < \eta < 1.52$)
$p_T > 20$ GeV
Electrons fulfilling TightLH and Gradient
Single-lepton trigger and matching
Remove FSR-induced electrons at truth level

Table 4.3: Region where charge flip probabilities are calculated from $Z \rightarrow ee$ process. Probabilities depend on η and p_T . All requirements are also applied in the signal region defined in Section 5.2.1 with the exception of the FSR requirement on truth level. FSR-induced electrons are removed at truth level to avoid the influence in charge misidentification from their contributions following Ref. [73].

4.3.3.1 Lost Transverse Momentum during Charge Flip

The reconstructed energy of a charge-flipped electron can be considerably smaller than its actual energy. Charge flips occur mostly when an electron from Bremsstrahlung of opposite

charge is followed in the reconstruction instead of the original electron. The remains of the original electron are then missing in the standard calculation. This needs to be corrected. The data events in the OS SR get corrected before applying any requirement. Only one of the leptons performs charge flip to end up in the SR and thus only one lepton gets corrected. In the ee channel, the corrected electron gets picked randomly according to the probability $\varepsilon_{\text{misID},ij}$ that a lepton performed the charge flip.

The correction involves two things:

1. Mimicking the underestimated energy with a 'residual energy scale correction factor' α and
2. smearing the distribution with dE to get the energy resolution of charge-flipped electrons of its p_T and η .

The corrected momentum $p_T^{\text{corrected}}$ is:

$$p_T^{\text{corrected}} = \frac{p_T^{\text{old}}}{\alpha} + dE, \quad (4.7)$$

The energy scaling factor α depends on η , because Bremsstrahlung depends on the detector material on the path of the electron. It is the quotient of the averaged reco to truth p_T ratios $P_{p_T,i}^{\text{right/wrong}} = \left\langle \frac{p_T^{\text{Reco}}}{p_T^{\text{truth}}} \right\rangle_i^{\text{right/wrong}}$ for the i -th η bin:

$$\alpha_i = \frac{P_{p_T,i}^{\text{right}}}{P_{p_T,i}^{\text{wrong}}}. \quad (4.8)$$

The smearing factor dE is applied via adding a random number resulting in the expected total resolution.

4.3.3.2 Systematic Uncertainties

Systematic uncertainties of the charge flip cover effects of systematically varying the scale factors. The variations of scaling factors are provided by Egamma Combined Performance group [72] together with the scaling factors themselves. The variations include:

- variation of the width of the sideband in the sideband subtraction in $Z \rightarrow ee$ decays for estimating charge flip probabilities
- different removals of FSR-induced electrons
- 2D vs. uncorrelated 1Dx1D η , p_T parametrization for $p_T > 95$ GeV as systematic variation motivated by low statistics in that region

The uncertainties are finally summarized into:

- **chFlipSF**: symmetrized envelope over scale factor variations,
- **gamma__[bins SR, low- m_{jj} CR]** includes statistical uncertainties of data in opposite-sign SR.

4.3.4 Other Prompt, $V\gamma$ and Zjets Background

Zjets in the WZ control region, other prompt backgrounds and $V\gamma$ are estimated by the MC samples listed in Table A.3. Zjets is only directly added in the WZ control region. In other regions it is part of non-prompt background and conversions background.

Chapter 5

Object and Event Selection

The object and event selection criteria are mainly kept from Ref. [74]. Only some minor adjustments are made to incorporate updated recommendations and to improve the significance of the signal for the cross-section measurements. As a potential improvement e.g. quark-gluon tagging is studied in Ref. [75], but no significant improvement is found. Quark-gluon tagging is considered because in the $W^\pm W^\pm jj$ final state there are mainly quark-initiated jets while other processes can have a higher fraction of gluon-initiated jets. Vetoing gluon initiated jets could thus improve the signal significance.

First, the relevant objects, like electrons, muons and jets, are selected in Section 5.1 in each event. Afterwards, event selection criteria are applied to create regions of phase-space where the background and signal composition vary, enabling to constrain the former and measure the latter when compared to data. There are in total three regions on reconstruction level:

- the signal region, defined in Section 5.2.1,
- the low- m_{jj} control region, defined in Section 5.2.2,
- the WZ control region, defined in Section 5.2.3,

and two regions on truth-level:

- the fiducial phase space, defined in Section 5.4 and
- the truth-phase space of the WZ control region, defined in Section 5.5.

The regions on reconstruction level are needed to constrain signal and backgrounds. The measured cross-sections are defined in the fiducial phase space. For a meaningful definition of the normalisation strength of QCD $W^\pm Zjj$ background μ_{WZ} the truth-phase space of the WZ control region is also defined.

Table 5.1 summarizes the predicted yields of all processes in the three regions on reco-level. The predicted cross-section in the fiducial phase space of the signal samples are shown in Section 5.4 in Table 5.8.

5.1 Object Selection

The object selection includes three steps:

- the preselection of electrons, muons and jets, shown in Table 5.2 and 5.3,
- the overlap removal between these objects and the missing transverse momentum definition, described in Section 5.1.1 and
- the selection of signal electrons, muons and jets, shown in Table 5.4 and 5.5.

Table 5.1: Overview of samples and their predicted contribution in each region. $W^\pm W^\pm jj$ is grouped as a signal in the signal region and as a non-prompt background in the WZ control region.

NP name	Signal Region	low- m_{jj} CR	WZ CR
EW $W^\pm W^\pm jj$	234.90	36.61	–
Int $W^\pm W^\pm jj$	7.59	2.16	–
QCD $W^\pm W^\pm jj$	24.04	24.30	–
QCD $W^\pm Zjj$	82.81	131.07	799.73
EW $W^\pm Zjj$	14.94	4.36	141.32
Non-prompt			
e fakes	22.99	44.15	–
μ fakes	32.64	43.11	–
Z+jets	–	–	27.67
EW $W^\pm W^\pm jj$	–	–	0.03
Int $W^\pm W^\pm jj$	–	–	0.00
QCD $W^\pm W^\pm jj$	–	–	0.01
Conversions			
Charge Flip	10.11	11.12	–
$W\gamma$	10.37	13.84	0.14
$Z\gamma$	0.55	0.96	7.96
Other prompt			
Top	3.99	5.46	41.14
Triboson	0.65	0.61	15.40
ZZ	2.44	3.73	58.37

Since there are multiple interactions in each LHC bunch crossing, there are multiple vertices possible. The primary vertex is chosen to be the one with the largest sum of squared transverse momenta of the associated tracks. The distance to the primary vertex is described with the longitudinal impact parameter $|z_0 \times \sin \theta|$ and with the transverse impact parameter $|\frac{d_0}{\sigma_{d_0}}|$.

Table 5.2: Baseline selection criteria of electrons and muons. Details about identification working points, the minimal kinematic and geometrical requirements can be found in Section 3.2.4.

	Electron	Muon
Identification	LooseLH	Loose
Kinematic Acceptance	$p_T > 4.5 \text{ GeV}$	$p_T > 3 \text{ GeV}$
Geometrical Acceptance	$ \eta < 2.47$	$ \eta < 2.7$
Impact Parameter Requirement	$ z_0 \times \sin \theta < 0.5 \text{ mm}$ $ \frac{d_0}{\sigma_{d_0}} < 5$	$ z_0 \times \sin \theta < 1.5 \text{ mm}$ $ \frac{d_0}{\sigma_{d_0}} < 15$
Isolation Requirement	none	none

5.1.1 Overlap Removal and MET Definition

Missing transverse momentum (MET) is calculated applying transverse momenta conservation to the reconstructed particles ("hard term") and the unassociated soft detector signals ("soft term"). Particle flow jets are used for the hadronic hard term. Tracks of charged

¹The Pflow algorithm combines information from tracker and calorimeter during object reconstruction.

Table 5.3: Baseline selection criteria of jets.

	Jet
Algorithm	PFlow ¹ , anti- k_T with resolution parameter $R = 0.4$ corrected for pileup effects and smeared to data resolution
Kinematic Acceptance	$p_T > 20 \text{ GeV}$
Geometrical Acceptance	$ \eta < 4.5$

particles are used for the soft-term. The baseline selected electrons, muons and jets are fed to MET. An internal MET overlap removal is performed.

During overlap removal baseline-selected objects are removed when the same physical object seems to be reconstructed and categorized as multiple different objects. The jet algorithm classifies nearly all electrons and muons as jets because of the deposit in the calorimeter. On the other side, jets could also consist of electrons and muons. Muons and Electrons have a similar footprint in the inner detector and the electromagnetic calorimeter. The procedure defined in Ref. [76] with updates presented in [77] is used. Jets identified as originating from the hadronization of a b quark are never removed during this overlap removal.

Their order of removal is:

1. ℓ vs. ℓ removal:

- e - e : if two electrons have overlapping EM calorimeter entries or share one inner detector track, then remove the electron with lower p_T ,
- e - μ : if an electron and a muon share one inner detector track and if muon is tagged in muon chambers, then remove the electron (probably bremsstrahlung created a photon which was detected in EM leading to an electron candidate); if muon is not tagged in muon chamber, then remove the muon.

2. e vs. j removal:

- if $\Delta R_{e,j} < 0.2$, then remove the jet,
- if $0.2 \leq \Delta R_{e,j} < \min\left(0.4, 0.04 + \frac{10 \text{ GeV}}{p_T^e}\right)$, then remove the electron.

3. μ vs. j removal:

- remove the jet,
 - if $\Delta R_{\mu,j} < 0.2$,
 - if the jet has less than three associated tracks with $p_T > 500 \text{ MeV}$ or
 - if the p_T ratio of the muon and jet is larger than 0.5, $p_T^\mu/p_T^j > 0.5$ and the ratio of the muon p_T to the p_T sum of tracks with $p_T > 500 \text{ MeV}$ associated to the jet is larger than 0.7.
- if jet j is not removed by other criteria and $\Delta R_{\mu,j} < \min\left(0.4, 0.04 + \frac{10 \text{ GeV}}{p_T^\mu}\right)$, then the muon is removed.

5.1.2 Analysis Lepton and Jet Selection

The electron, muon, jet and b-jet selection is applied to those particles which pass the baseline selection and the overlap removal. The criteria are summarized in Table 5.4 and 5.5.

5.2 Event Selection

Listed here are the requirements that events have to fulfil - otherwise they get vetoed. Also weights get applied to MC events to compensate for data mismodelling. The trigger requirement depends on the data taking period [78–80].

For 2015 the triggers are:

Table 5.4: Signal electron and muon selection criteria. Details about the identification and isolation working points can be found in Section 3.2.4. Those working points are chosen which maximise the expected significance.

	Electron	Muon
Identification	TightLH	Medium
Kinematic Acceptance	$p_T > 27 \text{ GeV}$	$p_T > 27 \text{ GeV}$
Geometrical Acceptance	$ \eta < 2.47$, excluding $1.37 \leq \eta \leq 1.52$	
Impact parameter requirements	as for preselection	$ z_0 \times \sin \theta < 0.5 \text{ mm}$ $\frac{d_0}{\sigma_{d_0}} < 3$
Isolation Requirement	Gradient	FixedCutPflowTight
Additional	Pass ECIDS	

Table 5.5: Signal jet and b-jet selection criteria. Details about the b-tagging working point can be found in Section 3.2.4.3.

	Jet	b-Jet
Kinematic Acceptance	$p_T > 25 \text{ GeV}$	$p_T > 20 \text{ GeV}$
Geometrical Acceptance	$ \eta < 4.5$	$ \eta < 2.5$
Additional	JVT for $p_T < 60 \text{ GeV}$ and $ \eta < 2.5$ –	JVT for $p_T < 60 \text{ GeV}$ fixed-cut 85% of DL1r tagger [52]

- for electrons:
 - HLT_e24_lhmedium_L1EM20VH: $E_{T,e} > 24 \text{ GeV}$, **MediumLH** identification and $E_{T,e,L1} > 20 \text{ GeV}$,
 - HLT_e60_lhmedium: $E_{T,e} > 60 \text{ GeV}$ and **MediumLH** identification or
 - HLT_e120_lhloose: $E_{T,e} > 120 \text{ GeV}$ and **LooseLH** identification,
- for muons:
 - HLT_mu20_iloose_L1MU15: $p_{T,\mu} > 20 \text{ GeV}$, **Loose** identification and $p_{T,\mu,L1} > 15 \text{ GeV}$ or
 - HLT_mu50: $p_{T,\mu} > 50 \text{ GeV}$.

For 2016 to 2018 the triggers are:

- for electrons (no requirement on d_0 for identification):
 - HLT_e26_lhtight_nod0_ivarloose: $E_{T,e} > 26 \text{ GeV}$ and combination of **TightLH** and **LooseLH** identification,
 - HLT_e60_lhmedium_nod0: $E_{T,e} > 60 \text{ GeV}$ and **MediumLH** identification or
 - HLT_e140_lhloose_nod0: $E_{T,e} > 140 \text{ GeV}$ and **LooseLH** identification,
- for muons:
 - HLT_mu26_ivarmedium: $p_{T,\mu} > 26 \text{ GeV}$ and **Medium** identification or
 - HLT_mu50: $p_{T,\mu} > 50 \text{ GeV}$.

At least one trigger needs to be triggered by one of the signal leptons.

At least three tracks associated to the primary vertex are required. Contributions from additional proton-proton collisions are simulated by overlaying minimum bias events from PYTHIA 8.

After passing trigger requirements, three non overlapping analysis regions are build: the signal region, the low- m_{jj} control region and the WZ control region.

5.2.1 Event Selection of Signal Region

The signal region is designed to measure the signal process.

Exactly two signal leptons with the same electric charge need to be present.

To suppress conversion backgrounds from $Z/\gamma^* \rightarrow ee$ two ee -channel specific requirements are made: $|m_{ee} - m_Z| > 15$ GeV and $|\eta^e| < 1.37$. The dilepton invariant mass $m_{\ell\ell'}$ is required to be above 20 GeV.

To suppress prompt backgrounds, events with a third baseline lepton after overlap removal are vetoed. Additionally, events are vetoed if a third baseline lepton forms a Z boson lepton candidate with one of the signal leptons with $|m_{\ell\ell} - m_Z| < 15$ GeV.

Because of the two neutrinos in the leptonic decay of the same-charged W bosons a missing transverse momentum of at least 30 GeV is required.

At least two signal jets need to be present in the event: one jet with transverse momentum above 65 GeV and the second above 35 GeV. The two jets with the highest transverse momentum are called tagging jets and an invariant mass m_{jj} above 500 GeV and a separation along the beam axis of $|\Delta Y_{jj}| > 2$ is required to suppress QCD induced background and increase the relative VBS contribution.

As additional jets in the signal region only jets with $p_T > 25$ GeV are considered.

Background contributions from tops are suppressed by vetoing events with a selected b-jet.

5.2.2 Event Selection of low- m_{jj} Control Region

The same requirements as in Section 5.2.1 need to be fulfilled with the exception of the m_{jj} requirement which is required to be between 200 and 500 GeV. It serves to constrain non-prompt and conversions induced backgrounds.

5.2.3 Event Selection of WZ Control Region

The WZ control region is chosen close to the signal region to have similar kinematics, but is modified to be dominated by QCD $W^\pm Zjj$ to determine its normalisation close to the signal region.

There are:

- at least two signal leptons required with $m_{\ell\ell} \geq 20$ GeV,
- a third lepton with $p_T > 15$ GeV and among the three leptons one same flavour opposite charge pair as Z candidate,
- $m_{\ell\ell\ell} \geq 106$ GeV to reduce contribution from Z+jets and $Z\gamma$,
- $MET > 30$ GeV,
- at least two jets with $p_{T,jet1} \geq 65$ GeV and $p_{T,jet2} \geq 35$ GeV,
- b-jet veto,
- $|\Delta Y_{jj}| \geq 2$ and $m_{jj} > 200$ GeV to be close to signal region and low- m_{jj} control region.

5.3 Truth Level Object Selection

The MCTruthClassifier [81] is used to identify electrons via values 1 for ‘unknown electron’ and 2 for ‘isolated electron’. Muons are identified with value 5 for ‘unknown muon’ and 6 for ‘isolated muon’. To both leptons photons which are emitted in showering are added back to get the original momentum. For the tau-veto ‘isolated taus’ are selected via the

MCTruthClassifier. For all three lepton candidates, particles from detector simulation are not included.

To mimic the overlap removal on reconstruction level jets are first deleted and secondly electrons:

1. first, all jets are deleted for which there is an electron within $\Delta R_{e,j} < 0.4$ and the electron has more than 50% of the p_T of the jet.
2. Afterwards, electrons are deleted if there is a jet with $\Delta R_{e,j} < 0.4$ and the electron has less than 50% of the p_T of the jet.

The following kinematic and geometrical requirements are summarized in Table 5.6 for different lepton classes used later in the truth-level event selection.

Table 5.6: Veto, third and signal electron and muon truth-level selection.

	Electron	Muon
Veto lepton		
Kinematic Acceptance	$p_T > 4.5 \text{ GeV}$	$p_T > 3 \text{ GeV}$
Geometrical Acceptance	$ \eta < 2.5$	$ \eta < 2.5$
Third lepton		
Kinematic Acceptance	$p_T > 15 \text{ GeV}$	$p_T > 15 \text{ GeV}$
Geometrical Acceptance	$ \eta < 2.5$	$ \eta < 2.5$
Signal lepton		
Kinematic Acceptance	$p_T > 27 \text{ GeV}$	$p_T > 27 \text{ GeV}$
Geometrical Acceptance	$ \eta < 2.5$	$ \eta < 2.5$

The same kinematic and geometrical requirements are applied on truth-level as on reco-level summarized in Table 5.7 for truth jets.

MET is the sum of all non-interacting particles on truth-level.

Table 5.7: Signal jet and b-jet truth level object selection.

	Jet	b-Jet
Kinematic Acceptance	$p_T > 25 \text{ GeV}$	$p_T > 20 \text{ GeV}$
Geometrical Acceptance	$ \eta < 4.5$	$ \eta < 2.5$
Additional	–	an associated b-hadron with $p_T > 5 \text{ GeV}$

5.4 Fiducial Phase Space

The total and differential cross-section is measured in the fiducial region on "truth level". It is designed to have an easy definition to be applicable by theorists who would like to compare their results with the measured results. But at the same time, it should be an optimised phase space where the signal-to-background ratio is high close to the signal region on reconstruction level. The following selection criteria are chosen:

- exactly two same-sign signal leptons
- no veto lepton
- $\Delta R_{\ell\ell} > 0.2$
- $m_{\ell\ell} > 20 \text{ GeV}$
- ee channel: $|\eta| < 1.37$ and $|m_{ee} - m_Z| > 15 \text{ GeV}$

Table 5.8: Overview of signal samples and their predicted cross-section in the fiducial phase space. [18]

Description	$\sigma_{\text{fid}}^{\text{EW}}$ [fb]	$\sigma_{\text{fid}}^{\text{EW+Int+QCD}}$ [fb]
MG5_AMC+HERWIG7	$2.53 \pm 0.04 (\text{PDF}+\alpha_S) \pm_{0.19}^{0.22} (\text{scale})$	$2.92 \pm 0.05 (\text{PDF}+\alpha_S) \pm_{0.27}^{0.34} (\text{scale})$
MG5_AMC+PYTHIA8	$2.53 \pm 0.04 (\text{PDF}+\alpha_S) \pm_{0.19}^{0.22} (\text{scale})$	$2.90 \pm 0.05 (\text{PDF}+\alpha_S) \pm_{0.26}^{0.33} (\text{scale})$
SHERPA	$2.48 \pm 0.04 (\text{PDF}+\alpha_S) \pm_{0.27}^{0.40} (\text{scale})$	$2.92 \pm 0.04 (\text{PDF}+\alpha_S) \pm_{0.37}^{0.56} (\text{scale})$
SHERPA $\otimes$ NLO EW	$2.10 \pm 0.03 (\text{PDF}+\alpha_S) \pm_{0.23}^{0.34} (\text{scale})$	$2.54 \pm 0.03 (\text{PDF}+\alpha_S) \pm_{0.33}^{0.49} (\text{scale})$
POWHEG BOX +PYTHIA	2.64	–

- $p_{T,\text{jet1}} > 65 \text{ GeV}$, $p_{T,\text{jet2}} > 35 \text{ GeV}$
- $\text{MET} > 30 \text{ GeV}$
- tau veto
- b veto
- $\Delta Y_{jj} \geq 2.0$, $m_{jj} > 500 \text{ GeV}$

The predicted cross-sections in this phase space are summarized in Table 5.8 for the signal samples defined in Section 4.1 and the theory uncertainties defined in Section 6.2.

The predicted fiducial cross-section is taken from the Monte Carlo simulation and is computed as:

$$\sigma_{\text{pred}}^{\text{fid}} = \sigma_{\text{pred}}^{\text{tot}} \cdot \mathcal{A}, \quad (5.1)$$

where

$\sigma_{\text{pred}}^{\text{tot}}$ is the total cross-section provided by the Monte Carlo generator in the total phase space where the events are generated which includes the fiducial phase space and

$\mathcal{A}$ is the acceptance being $\frac{\text{sum of weights in fiducial phase space}}{\text{sum of weights in total phase space}}$.

The total phase space depends on the sample such that only the fiducial cross-sections can be compared between the samples in a meaningful way.

For EW $W^\pm W^\pm jj$ the acceptance is 0.085 and the efficiency is 0.57.

The following theory uncertainties are considered for the theory prediction: scale, PDF, α_S , shower and NLO corrections. For the prediction itself, only the first three are provided because the other two can be estimated by comparing samples generated on LO with higher order samples. The PDF and α_S uncertainties are combined. The different precisions and showers used for predictions are summarized in Table 4.1.

So-called on-the-fly (OTF) weight variations are used to propagate the scale, PDF and α_S variations. They affect both, the total cross-section $\sigma_{\text{pred}}^{\text{tot}}$ as well as the acceptance $\mathcal{A}$. For a variation, the varied total cross-section is multiplied by: $\frac{\text{sum of weights of variation in total phase space}}{\text{sum of nominal weight in total phase space}}$. The acceptance of the variation is $\frac{\text{sum of weights of variation in fiducial phase space}}{\text{sum of weights of variation in total phase space}}$. To calculate the fiducial cross-section of a variation $\sigma_{\text{pred,variation}}^{\text{fid}}$ only a modified acceptance needs to be used: $\mathcal{A}_{\text{variation}} = \frac{\text{sum of weights of variation in fiducial phase space}}{\text{sum of nominal weights in total phase space}}$

$$\sigma_{\text{pred,variation}}^{\text{fid}} = \sigma_{\text{pred}}^{\text{tot}} \cdot \mathcal{A}_{\text{variation}}, \quad (5.2)$$

The same definitions are also used for the i -th bin of an unfolded observable O :

$$\sigma_{\text{pred}}^{\text{fid},O_i} = \sigma_{\text{pred}}^{\text{tot}} \cdot \mathcal{A}^{O_i}, \sigma_{\text{pred,variation}}^{\text{fid},O_i} = \sigma_{\text{pred}}^{\text{tot}} \cdot \mathcal{A}_{\text{variation}}^{O_i}, \quad (5.3)$$

The resulting theory predictions are included in the unfolded distributions in Section 9.7.

5.5 WZ Control Region on Truth Level

The same requirements as on reconstruction level are applied with the small difference of additional overlap removal during event selection and no b-jet veto in the truth-level selection:

- at least two signal leptons with $\Delta R_{\ell\ell} > 0.3$ and $m_{\ell\ell} \geq 20$ GeV
- a third lepton and among the three leptons with highest p_{T} one same flavour opposite charge pair
- $m_{\ell\ell\ell} \geq 106$ GeV
- $\text{MET} > 30$ GeV
- at least two jets with $p_{T_{jet1}} \geq 65$ GeV and $p_{T_{jet2}} \geq 35$ GeV
- $\Delta R_{j\ell} > 0.3$
- $|\Delta Y_{jj}| \geq 2$
- $m_{jj} > 200$ GeV

Chapter 6

Uncertainties

For the total and differential cross-section measurement and following interpretation it is essential to consider all uncertainties of the reconstruction of objects in the detector and the uncertainties of the theory prediction of signal and background. This chapter summarises the uncertainties included in this thesis. The first Sections 6.1 and 6.2 summarise how the uncertainties are calculated. Afterwards, smoothing and normalisation are discussed in Section 6.3 and 6.4. The following Section 6.5 shows which uncertainty is included in which part of the analysis. Finally, in Section 6.6 numerical values of the uncertainties are shown for an example.

6.1 Experimental Uncertainties

The reconstruction and identification of objects in the ATLAS detector, which is associated with experimental uncertainties, are defined in Section 3.2.4. Uncertainties of data-driven estimated backgrounds, i.e. non-prompt background and conversions, are described in Section 4.3.

6.2 Theory Uncertainties

Different sources of modelling uncertainties are shown in Section 2.4. The estimation of these uncertainties is explained in this section. The limited number of generated MC events is included as MC statistical uncertainty in the fits.

6.2.1 Scale Uncertainty

The scale uncertainty results from missing higher order correction of the perturbative expansion of the partonic cross-section. It consists of the variation of the renormalisation μ_r and factorization scale μ_f . The scale uncertainty is calculated as envelope from seven points $(\tilde{\mu}_r, \tilde{\mu}_f)$:

$$\begin{aligned} & (1.0\mu_r, 2.0\mu_f), \quad (2.0\mu_r, 2.0\mu_f), \\ & (0.5\mu_r, 1.0\mu_f), \quad (1.0\mu_r, 1.0\mu_f), \quad (2.0\mu_r, 1.0\mu_f), \\ & (0.5\mu_r, 0.5\mu_f), \quad (1.0\mu_r, 0.5\mu_f) \end{aligned}$$

as recommended in Ref. [82].

The scale uncertainty on the number of expected events N_i in the i -th bin is

$$\delta^{\text{scale}} N_i = \max_j |(N_i(\tilde{\mu}_{r_j}, \tilde{\mu}_{f_j}) - N_i(\mu_r, \mu_f))|. \quad (6.1)$$

The renormalisation scale variation μ_f is not available in LO EW $W^\pm W^\pm \text{j j}$ and EW $W^\pm Z \text{j j}$ because there is no strong coupling involved.

The nominal scale choice is:

$$\mu_r = \mu_f = \sqrt{p_T^{\text{jet1}} p_T^{\text{jet2}}}. \quad (6.2)$$

For the Standard Model prediction of EFT limit setting a different nominal scale is used:

$$\mu_r = \mu_f = \frac{1}{2} \sum_j p_T^{\text{object } j}. \quad (6.3)$$

The difference between these two nominal scales is added to the scale uncertainty in EFT limit setting.

6.2.2 Parton Distribution Function (PDF) Uncertainty

It is calculated as the envelope of three different nominal PDF (NNPDF [32], MMHT [83] and CT14 [84]) and the uncertainty from 100 NNPDF3.0 variations.

NNPDF3.0 is used for all processes as nominal PDF $N_i = N_{i,\text{NNPDF}}$ with different precision during the calculation of PDF uncertainties. The uncertainty on the number of events N_i is:

$$\delta^{\text{PDF, up}} N_i = \max \left(N_{i,\text{MMHT}}, N_{i,\text{CT14}}, N_i + \frac{1}{10} \sqrt{\sum_j (N_{i,\text{NNPDF}}^{\text{variation } j} - N_i)^2} \right), \quad (6.4)$$

$$\delta^{\text{PDF, down}} N_i = \min \left(N_{i,\text{MMHT}}, N_{i,\text{CT14}}, N_i - \frac{1}{10} \sqrt{\sum_j (N_{i,\text{NNPDF}}^{\text{variation } j} - N_i)^2} \right). \quad (6.5)$$

6.2.3 Strong Coupling α_S Uncertainty

This uncertainty stems from experimental uncertainties in the determination of α_S and the variation of its value at m_Z scale from $\alpha_S(m_Z) = 0.118$ to 0.117 and 0.119 . According to recommendation [85] the uncertainty of α_S in the i -th bin is:

$$\delta^{\text{shower}} N_i = \left| \frac{N_i(\alpha_{\text{down}}) - N_i(\alpha_{\text{up}})}{2} \right|. \quad (6.6)$$

It can be added in quadrature to the PDF uncertainty to get the total combined uncertainty.

6.2.4 Parton Shower Uncertainty

For the nominal shower Herwig 7 is used. The uncertainty is calculated by comparing this to the alternative shower from Pythia 8. The uncertainty on the predicted number of events N_i is:

$$\delta_{\text{syst}} N_i = |N_i(\text{Herwig 7}) - N_i(\text{Pythia 8})|. \quad (6.7)$$

There is no 100% correlation between the bins expected from the theory side. However approximately 200 extra nuisance parameters would need to be introduced in unfolding to represent this in unfolding fits. Because of this, it is combined into one nuisance parameter. If the shower uncertainty gets constrained within the fit it needs to be split between the bins.

6.2.5 NLO EW Corrections

NLO EW corrections are derived for the $W^\pm W^\pm \text{j j}$ measurement with partial Run 2 data [74] depending on $m_{\text{j j}}$ from Ref. [11].

This dependence is fitted with:

$$f(m_{\text{j j}}) = 0.511135 + 0.175910 \cdot \log \left(\frac{m_{\text{j j}}}{\text{GeV}} \right) - 0.0180658 \cdot \log \left(\frac{m_{\text{j j}}}{\text{GeV}} \right)^2 \quad (6.8)$$

For $m_{\text{j j}}$ below 200 GeV the value: $f(m_{\text{j j}} < 200 \text{ GeV}) = f(200 \text{ GeV})$ is used.

This dependence is applied to each event to also get uncertainties for other observables.

6.2.6 NLO QCD Corrections

A sample with a third jet simulated in matrix element is used to model a dominant effect towards NLO calculation: For QCD $W^\pm W^\pm jj$, Sherpa 2.2.2 with 2,3jets@LO is used. For EW $W^\pm W^\pm jj$, Sherpa 2.2.11 with 2,3jets@LO, with additional samples for triboson and Higgs contribution, listed in Table A.2, are used. There is one NLO QCD correction uncertainty for EW $W^\pm W^\pm jj$ and another one for QCD $W^\pm W^\pm jj$ to separate the two effects since it is not a complete NLO calculation. The 1σ down uncertainty is defined by the alternative Sherpa sample, while the Madgraph Herwig 7 sample is used as the nominal sample. It was tested that unfolding Pseudodata according to Sherpa prediction with this setup yields the same results as unfolding it with Sherpa as signal sample within uncertainties.

6.3 No Application of Smoothing

Because of MC statistical uncertainties, there can be unexpected fluctuations in systematic variations. One way of solving it is to make these variations smooth by smoothing algorithms. In this thesis smoothing is not used.

The advances of using smoothing are:

- avoids artificial/strange pulls and constraints, but this should only occur when MC statistical uncertainty is comparable with data statistical uncertainty. There are 1-3 orders of magnitude in between, so this is not a problem.
- reduce double counting of MC statistical uncertainties
- makes fit more stable

On the other side, there are also disadvantages:

- smoothing is not recommended for weight variations,
- no smoothing is more conservative,
- smoothing is Bayesian motivated: difficult to interpret frequentistic after smoothing,
- different reasonable smoothing approaches give different results. A particular choice could artificially reduce systematic uncertainty.

6.4 Normalisation of Theory Uncertainties in the Fiducial Phase Space

The reason for normalisation is that in cross-section measurements one is interested in the number of observed events in truth phase space. If a nuisance parameter of a modelling uncertainty of the signal process is pulled, then it should not affect the total number of truth-level events - only the shape should be affected. Otherwise, it would need to be corrected for in the cross-section calculation. This is explained in more detail in Section 7.5. Because of this all theory uncertainties related to the measured cross-section are normalised on truth level.

The same reasoning is applied for QCD $W^\pm Zjj$ with the free floating QCD $W^\pm Zjj$ normalisation strength parameter μ_{WZ} . For μ_{WZ} it does not matter if and whether on reco- or truth-level normalised in WZ CR because it is only one bin in WZ CR. All related modelling uncertainties are normalised on truth level to be able to interpret the normalisation strength parameter as relative QCD $W^\pm Zjj$ cross-section strength.

In the EW $W^\pm W^\pm jj$ cross-section measurements the interference term should not be normalised, because the normalisation effect only cancels for the calculation of the observed cross-section of EW $W^\pm W^\pm jj$.

For shower, NLO correction and α_S the variations get normalised to nominal on truth level with the help of a normalisation factor which gets multiplied to the reco level distribution.

For the scale uncertainties, where an envelope is calculated, the dominant contributions in each bin are used for the normalisation on truth-level. For the PDF uncertainty, where 102 variations get combined, the same combination is performed on truth-level. The result on truth-level is used to calculate the normalisation factor.

6.5 All Uncertainties

Systematic uncertainties are separated into experimental and modelling uncertainties. Backgrounds estimated with data-driven methods have both types of uncertainties. They are grouped into one of the two groups without a strong reason. $W^\pm Zjj$ background uncertainties are grouped as modelling uncertainties. Non-prompt and charge misidentification background uncertainties are grouped as experimental uncertainties because they get introduced due to an imperfect detector. But also modelling uncertainties are part of the estimate of these uncertainties. For these backgrounds detailed impact information split by nuisance parameter in the ranking plots and tables are needed to get an insight which source of uncertainty dominates.

Nearly all uncertainties are two-sided, meaning, that they have a predicted up and down variation in the expected yields. Exceptions are the NLO correction uncertainties:

- EW $W^\pm W^\pm jj$ NLO EW correction,
- EW $W^\pm W^\pm jj$ NLO QCD correction and
- QCD $W^\pm W^\pm jj$ NLO QCD correction,

which are only one-sided. By definition the one-sided uncertainty is implemented as down uncertainty. The up-variation corresponds to the nominal prediction. Due to the 6-th order polynomial, it is possible that there is a slight residual effect in the yield for up-pulls. This is needed to make the expected yield smooth and the fits stable to converge to the maxima.

6.5.1 Uncertainties Included in all Fits

A list of all included experimental uncertainties is shown in Table 6.1 and 6.2. A relative luminosity uncertainty of 1.7% is used in the fit, as explained in Section 3.2.2.5.

The uncertainties of other prompt background, $V\gamma$ and Zjets in WZ control region is also included in all fits.

The total cross-section uncertainties for other backgrounds are shown in Table 6.3. They are conservatively estimated in similar phase spaces in the cited sources. $V\gamma$ is modelled with Sherpa 2.2.11 with a conservative uncertainty of 40% which was estimated in Ref. [74]. With the new ECIDs requirement there are too few MC events to estimate it again with a data-driven method. Top contributions are shown in Table 6.4. 13% would be overall conservative, but the top background is scaled with the same nuisance parameter in WZ control region and signal region where different processes are dominant. Because of this, a conservative uncertainty of 40% is assumed in agreement with the previous analysis [74]. Zjets is only explicitly included in WZ control region, in the signal region it is part of the non-prompt background estimate.

6.5.2 Theory Uncertainties in Cross-Section Measurements

The included theory uncertainties for total cross-section measurements are shown in Table 6.5 and further for EW $W^\pm W^\pm jj$ in Table 6.6 and for inclusive $W^\pm W^\pm jj$ in Table 6.7. The information about normalisation is summarised for EW $W^\pm W^\pm jj$ in Table 6.8 and for inclusive $W^\pm W^\pm jj$ in Table 6.9.

There are more than 1,000 histograms in which the theory uncertainties are calculated for this thesis. Because of the large number only some are shown here in Figure 6.1 to 6.6. The scale and PDF uncertainty are normalised after the envelope calculation as described above. The theory uncertainty histogram in Figure 6.3 and 6.4 is from between the two stages. WZ

Table 6.1: Experimental uncertainties included in the statistical analysis part one.

NP name	Description
Electron calibration	
EG_RESOLUTION_ALL	Electron and photon energy resolution unc.
EG_SCALE_ALL	Electron and photon energy scale unc
EL_EFF_ID_CorrUncertaintyNP[0-15]	Electron ID correlated efficiency unc. NP 0-15
EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP[0-17]	Electron ID uncorrelated efficiency unc. NP 0-17
EL_EFF_Iso_TOTAL_INPCOR_PLUS_UNCOR	Electron isolation eff. unc.
EL_EFF_Reco_TOTAL_INPCOR_PLUS_UNCOR	Electron reconstruction eff. unc.
EL_EFF_TriggerEff_TOTAL_INPCOR_PLUS_UNCOR	Electron trigger eff. unc.
EL_EFF_Trigger_TOTAL_INPCOR_PLUS_UNCOR	Electron trigger scale factor unc.
Muon calibration	
MUON_EFF_ISO_STAT	Muon stat. isolation eff. unc.
MUON_EFF_ISO_SYS	Muon syst. isolation eff. unc.
MUON_EFF_RECO_STAT	Muon reconstruction and ID eff. stat. unc. for $p_T > 15$ GeV
MUON_EFF_RECO_SYS	Muon reconstruction and ID eff. syst. unc. for $p_T > 15$ GeV
MUON_EFF_TTVA_STAT	Muon stat. track-to-vertex association eff. unc.
MUON_EFF_TTVA_SYS	Muon syst. track-to-vertex association eff. unc.
MUON_EFF_TrigStatUncertainty	Muon stat. trigger eff. unc.
MUON_EFF_TrigSystUncertainty	Muon syst. trigger eff. unc.
MUON_ID	Muon momentum resolution unc. from inner detector
MUON_MS	Muon momentum resolution unc. from muon system
MUON_SAGITTA_RESBIAS	Muon charge dependent momentum scale unc. based on residual bias
MUON_SAGITTA_RHO	Muon charge dependent momentum scale unc. based on combination of corrections
MUON_SCALE	Muon momentum scale uncertainty
Jet energy scale and resolution	
JET_BJES_Response	Jet energy scale unc. on b-jets
JET_EffectiveNP_Detector[1-2]	Jet in-situ detector: NP 1-2
JET_EffectiveNP_Mixed[1-3]	Jet in-situ mixed: NP 1-3
JET_EffectiveNP_Modelling[1-4]	Jet in-situ modelling: NP 1-4
JET_EffectiveNP_Statistical[1-6]	Jet in-situ stat.: NP 1-6
JET_EtaIntercalibration_Modelling	Jet η intercalibration modelling
JET_EtaIntercalibration_NonClosure_highE	Jet η intercalibration non-closure high energy
JET_EtaIntercalibration_NonClosure_negEta	Jet η intercalibration non-closure negative η
JET_EtaIntercalibration_NonClosure_posEta	Jet η intercalibration non-closure positive η
JET_EtaIntercalibration_TotalStat	Jet η intercalibration statistical
JET_Flavor_Composition	Jet flavour composition
JET_Flavor_Response	Jet flavour response
JET_JER_DataVsMC_MC16_MCsmear	Jet energy resolution smearing MC
JET_JER_DataVsMC_MC16_PDsmear	Jet energy resolution smearing pseudo data
JET_JER_EffectiveNP_[1-12]	Jet energy resolution: NP 1-12
JET_JvtEfficiency	Jet Jet-Vertex-Tagging (JVT) eff. unc.
JET_Pileup_OffsetMu	Jet pile-up offset μ
JET_Pileup_OffsetNPV	Jet pile-up offset N_{PV}
JET_Pileup_PtTerm	Jet pile-up p_T term
JET_Pileup_RhoTopology	Jet pile-up ρ topology
JET_PunchThrough_MC16	Jet energy scale unc. for punch-through jets
JET_SingleParticle_HighPt	Jet energy scale unc. from behaviour of high p_T jets
E_T^{miss} scale and resolution	
MET_JetTrk_Scale	MET scale unc. due to tracks in jets
MET_SoftTrk_ResoPara	MET track-based soft term longitudinal resolution unc.
MET_SoftTrk_ResoPerp	MET track-based soft term transverse resolution unc.
MET_SoftTrk_Scale	MET track-based soft term longitudinal scale unc.

Table 6.2: Experimental uncertainties included in the statistical analysis part two.

NP name	Description
<i>b</i> -tagging inefficiency	
FT_EFF_Eigen_B_[0-2]	b-tagging: efficiency (b jets), NP 0-2
FT_EFF_Eigen_C_[0-2]	b-tagging: efficiency (c jets), NP 0-2
FT_EFF_Eigen_Light_[0-3]	b-tagging: efficiency (light), NP 0-3
FT_EFF_extrapolation	b-tagging: efficiency b-tag extrapolation unc. to high- p_T
FT_EFF_extrapolation_from_charm	b-tagging: efficiency c-mistag extrapolation unc. to high p_T
Background, misid. leptons	
FF_MET	Lepton misid.: MET+ p_T cut variation
FF_Prompt	Lepton misid.: prompt subtr. variation
el_FF_AntiIDSF	$e^\pm$ misid.: prompt subtr. calibration
el_FF_BTagged	$e^\pm$ misid.: light/heavy hadr. origin
el_FF_STAT_2015_1_1	$e^\pm$ misid.: trigger stat. 2015 $p_{T,\ell} < 35$ GeV, $ \eta_\ell < 1.37$
el_FF_STAT_2015_1_2	$e^\pm$ misid.: trigger stat. 2015 $p_{T,\ell} < 35$ GeV, crack
el_FF_STAT_2015_1_3	$e^\pm$ misid.: trigger stat. 2015 $p_{T,\ell} < 35$ GeV, $ \eta_\ell > 1.52$
el_FF_STAT_2015_2018_1_1	$e^\pm$ misid.: stat. $p_{T,\ell} < 35$ GeV, $ \eta_\ell < 1.37$
el_FF_STAT_2015_2018_1_2	$e^\pm$ misid.: stat. $p_{T,\ell} < 35$ GeV, crack
el_FF_STAT_2015_2018_1_3	$e^\pm$ misid.: stat. $p_{T,\ell} < 35$ GeV, $ \eta_\ell > 1.52$
el_FF_STAT_2015_2018_2_1	$e^\pm$ misid.: stat. $35 < p_{T,\ell} < 55$ GeV, $ \eta_\ell < 1.37$
el_FF_STAT_2015_2018_2_2	$e^\pm$ misid.: stat. $35 < p_{T,\ell} < 55$ GeV, crack
el_FF_STAT_2015_2018_2_3	$e^\pm$ misid.: stat. $35 < p_{T,\ell} < 55$ GeV, $ \eta_\ell > 1.52$
el_FF_STAT_2015_2018_3_1	$e^\pm$ misid.: stat. $p_{T,\ell} > 55$ GeV, $ \eta_\ell < 1.37$
el_FF_STAT_2015_2018_3_2	$e^\pm$ misid.: stat. $p_{T,\ell} > 55$ GeV, crack
el_FF_STAT_2015_2018_3_3	$e^\pm$ misid.: stat. $p_{T,\ell} > 55$ GeV, $ \eta_\ell > 1.52$
el_FF_STAT_2015_2_1	$e^\pm$ misid.: trigger stat. 2015 $35 < p_{T,\ell} < 55$ GeV, $ \eta_\ell < 1.37$
el_FF_STAT_2015_2_2	$e^\pm$ misid.: trigger stat. 2015 $35 < p_{T,\ell} < 55$ GeV, crack
el_FF_STAT_2015_2_3	$e^\pm$ misid.: trigger stat. 2015 $35 < p_{T,\ell} < 55$ GeV, $ \eta_\ell > 1.52$
el_FF_STAT_2015_3_1	$e^\pm$ misid.: trigger stat. 2015 $p_{T,\ell} > 55$ GeV, $ \eta_\ell < 1.37$
el_FF_STAT_2015_3_2	$e^\pm$ misid.: trigger stat. 2015 $p_{T,\ell} > 55$ GeV, crack
el_FF_STAT_2015_3_3	$e^\pm$ misid.: trigger stat. 2015 $p_{T,\ell} > 55$ GeV, $ \eta_\ell > 1.52$
el_FF_STAT_2016_2018_1_1	$e^\pm$ misid.: trigger stat. 2016-18 $p_{T,\ell} < 35$ GeV, $ \eta_\ell < 1.37$
el_FF_STAT_2016_2018_1_2	$e^\pm$ misid.: trigger stat. 2016-18 $p_{T,\ell} < 35$ GeV, crack
el_FF_STAT_2016_2018_1_3	$e^\pm$ misid.: trigger stat. 2016-18 $p_{T,\ell} < 35$ GeV, $ \eta_\ell > 1.52$
el_FF_STAT_2016_2018_2_1	$e^\pm$ misid.: trigger stat. 2016-18 $35 < p_{T,\ell} < 55$ GeV, $ \eta_\ell < 1.37$
el_FF_STAT_2016_2018_2_2	$e^\pm$ misid.: trigger stat. 2016-18 $35 < p_{T,\ell} < 55$ GeV, crack
el_FF_STAT_2016_2018_2_3	$e^\pm$ misid.: trigger stat. 2016-18 $35 < p_{T,\ell} < 55$ GeV, $ \eta_\ell > 1.52$
el_FF_STAT_2016_2018_3_1	$e^\pm$ misid.: trigger stat. 2016-18 $p_{T,\ell} > 55$ GeV, $ \eta_\ell < 1.37$
el_FF_STAT_2016_2018_3_2	$e^\pm$ misid.: trigger stat. 2016-18 $p_{T,\ell} > 55$ GeV, crack
el_FF_STAT_2016_2018_3_3	$e^\pm$ misid.: trigger stat. 2016-18 $p_{T,\ell} > 55$ GeV, $ \eta_\ell > 1.52$
mu_FF_AntiIDSF	$\mu^\pm$ misid.: prompt subtr. calibration
mu_FF_BTagged	$\mu^\pm$ misid.: light/heavy hadr. origin
mu_FF_STAT_2015_1_1	$\mu^\pm$ misid.: trigger stat. 2015 $p_{T,\ell} < 35$ GeV
mu_FF_STAT_2015_2018_1_1	$\mu^\pm$ misid.: stat. $p_{T,\ell} < 35$ GeV
mu_FF_STAT_2015_2018_2_1	$\mu^\pm$ misid.: stat. $35 < p_{T,\ell} < 55$ GeV
mu_FF_STAT_2015_2018_3_1	$\mu^\pm$ misid.: stat. $p_{T,\ell} > 55$ GeV
mu_FF_STAT_2015_2_1	$\mu^\pm$ misid.: trigger stat. 2015 $35 < p_{T,\ell} < 55$ GeV
mu_FF_STAT_2015_3_1	$\mu^\pm$ misid.: trigger stat. 2015 $p_{T,\ell} > 55$ GeV
mu_FF_STAT_2016_2018_1_1	$\mu^\pm$ misid.: trigger stat. 2016-18 $p_{T,\ell} < 35$ GeV
mu_FF_STAT_2016_2018_2_1	$\mu^\pm$ misid.: trigger stat. 2016-18 $35 < p_{T,\ell} < 55$ GeV
mu_FF_STAT_2016_2018_3_1	$\mu^\pm$ misid.: trigger stat. 2016-18 $p_{T,\ell} > 55$ GeV
Background, charge misrec.	
chFlipSF	Charge flip unc.
Pileup modelling	
PRW_DATASF	Uncertainty on pileup reweighting
Luminosity	
Lumi	Luminosity

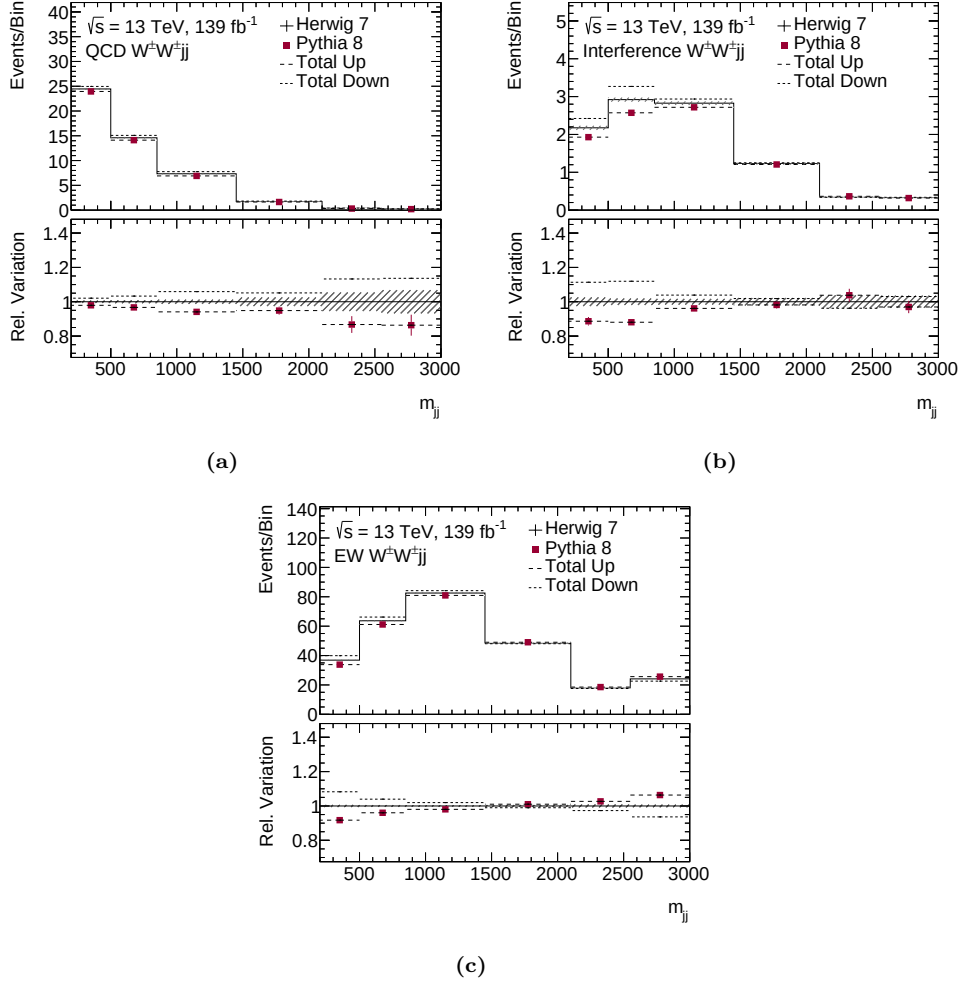


Figure 6.1: Parton shower uncertainties calculated for QCD $W^\pm W^\pm jj$ (a), Interference $W^\pm W^\pm jj$ (b) and EW $W^\pm W^\pm jj$ (c) summed over all channels in the signal region and low- m_{jj} control region. The EW $W^\pm W^\pm jj$ parton shower uncertainty is normalised on truth level in the fiducial region to nominal as done in the total cross-section measurement of EW $W^\pm W^\pm jj$. The hatched black area represents the MC statistical uncertainty of the nominal parton shower Herwig 7. The total uncertainty is the symmetrized envelope taking into account Pythia 8 around the nominal prediction from Herwig 7.

Table 6.3: Theory uncertainties of smaller prompt backgrounds as used in the fit

Process	Uncertainty	Source
Vgamma	40 %	estimated in Ref. [74]
ZZ	20 %	estimation from Ref. [86]
top	30 %	< 13%, see Table 6.4
Zjets	30 %	only in WZ control region - order of magnitude of non-prompt estimate in signal region
triboson	30 %	estimation from Ref. [86]

Table 6.4: Contributions to top background in different regions. Relative theory uncertainties are taken from Ref. [87, 88].

	Wt	ttW	ttZ	ttbar dilepton decay
signal region	0 ± 0	0.63 ± 0.06	0.18 ± 0.04	0.10 ± 0.06
WZ control region	0 ± 0	0.39 ± 0.05	3.34 ± 0.13	5.7 ± 0.5
low- m_{jj} control region	0 ± 0	0.83 ± 0.08	0.29 ± 0.04	0.15 ± 0.08
relative theory unc.	6%	13%	12%	6%

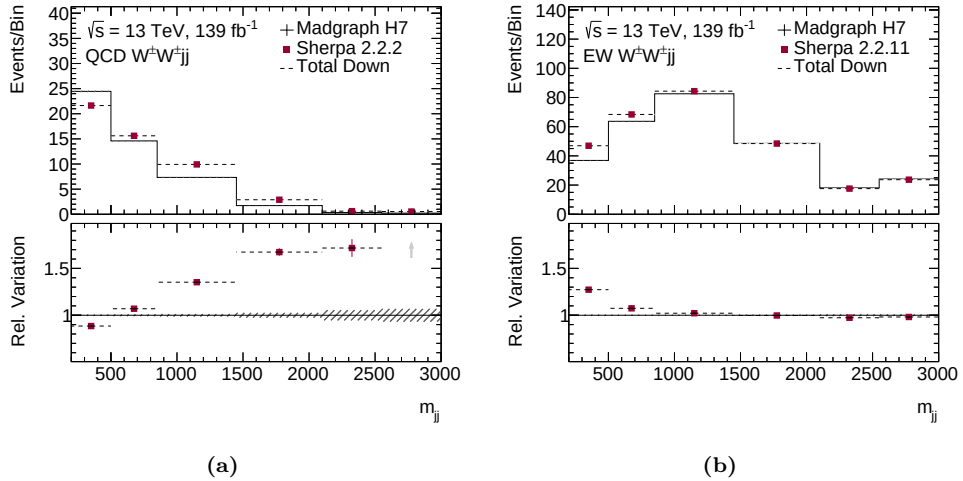
**Figure 6.2:** NLO QCD correction uncertainties calculated for QCD $W^\pm W^\pm jj$ (a) and EW $W^\pm W^\pm jj$ (b) summed over all channels in the signal region and low- m_{jj} control region. The EW $W^\pm W^\pm jj$ NLO QCD correction uncertainty is normalised on truth level in the fiducial region to nominal as done in the total cross-section measurement of EW $W^\pm W^\pm jj$. The hatched black area represents the MC statistical uncertainty of the nominal LO prediction from Madgraph Herwig 7. The total uncertainty is defined as down variation in the fit and is defined by the Sherpa sample including a third jet in the matrix element.

Table 6.5: Background modelling and model statistical uncertainties of total cross-section measurement

NP name	Description
Background, WZ scale, PDF & α_s	
WZ_EW4_TheoAlphas	QCD WZjj α_s uncertainty
WZ_EW4_TheoPdf	QCD WZjj PDF uncertainty
WZ_EW4_TheoScale	QCD WZjj scale uncertainty
WZ_EW6_TheoAlphas	EW WZjj α_s uncertainty
WZ_EW6_TheoPdf	EW WZjj PDF uncertainty
WZ_EW6_TheoScale	EW WZjj scale uncertainty
Background, WZ reweighting	
MjjRewPDF	WZ m_{jj} reweighting PDF variation
MjjRewScale	WZ m_{jj} reweighting scale variation
MjjRewStat	WZ m_{jj} reweighting statistics
Background, other	
Wgamma_XS	$W\gamma$ cross-section
ZZ_XS	ZZ cross-section
Zgamma_XS	$Z\gamma$ cross-section
Zjets_XS	Z+jets cross-section
top_XS	top cross-section
triboson_XS	triboson cross-section
Model statistical	
gamma_stat_CutCRWZ3Lep_all_bin_0	Statistics WZ CR
gamma_stat_CutLowMjj_ee_bin_0_0	Statistics low- m_{jj} CR ee channel
gamma_stat_CutLowMjj_em_bin_0_0	Statistics low- m_{jj} CR $e\mu$ channel
gamma_stat_CutLowMjj_me_bin_0_0	Statistics low- m_{jj} CR μe channel
gamma_stat_CutLowMjj_mm_bin_0_0	Statistics low- m_{jj} CR $\mu\mu$ channel
gamma_stat_CutSR_ee_bin_[0-4]_0	Statistics ee channel, bin 1-5
gamma_stat_CutSR_em_bin_[0-4]_0	Statistics $e\mu$ channel, bin 1-5
gamma_stat_CutSR_me_bin_[0-4]_0	Statistics μe channel, bin 1-5
gamma_stat_CutSR_mm_bin_[0-4]_0	Statistics $\mu\mu$ channel, bin 1-5

Table 6.6: Signal modelling uncertainties of total cross-section measurement of EW $W^\pm W^\pm jj$

NP name	Description
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	
signal_EW6_TheoAlphas	EW $W^\pm W^\pm jj$ α_s uncertainty
signal_EW6_TheoPdf	EW $W^\pm W^\pm jj$ PDF uncertainty
signal_EW6_TheoScale	EW $W^\pm W^\pm jj$ scale uncertainty
signal_EW6_TheoShower	EW $W^\pm W^\pm jj$ shower uncertainty
EW $W^\pm W^\pm jj$, QCD corrections	
signal_EW6_TheoQCDCorr	EW $W^\pm W^\pm jj$ NLO QCD correction
EW $W^\pm W^\pm jj$, EW corrections	
signal_EW6_TheoEwcorr	EW $W^\pm W^\pm jj$ NLO EW correction
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	
signal_EW5_TheoAlphas	Int $W^\pm W^\pm jj$ α_s uncertainty
signal_EW5_TheoPdf	Int $W^\pm W^\pm jj$ PDF uncertainty
signal_EW5_TheoScale	Int $W^\pm W^\pm jj$ scale uncertainty
signal_EW5_TheoShower	Int $W^\pm W^\pm jj$ shower uncertainty
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	
signal_EW4_TheoAlphas	QCD $W^\pm W^\pm jj$ α_s uncertainty
signal_EW4_TheoPdf	QCD $W^\pm W^\pm jj$ PDF uncertainty
signal_EW4_TheoScale	QCD $W^\pm W^\pm jj$ scale uncertainty
signal_EW4_TheoShower	QCD $W^\pm W^\pm jj$ shower uncertainty
QCD $W^\pm W^\pm jj$, QCD corrections	
signal_EW4_TheoQCDCorr	QCD $W^\pm W^\pm jj$ NLO QCD correction

Table 6.7: Signal modelling uncertainties of total cross-section measurement of EW $W^\pm W^\pm jj$

NP name	Description
$W^\pm W^\pm jj$ shower, scale, PDF & α_s	
signal_AllEW_TheoAlphas	Inclusive $W^\pm W^\pm jj$ α_s uncertainty
signal_AllEW_TheoPdf	Inclusive $W^\pm W^\pm jj$ PDF uncertainty
signal_AllEW_TheoScale	Inclusive $W^\pm W^\pm jj$ scale uncertainty
signal_AllEW_TheoShower	Inclusive $W^\pm W^\pm jj$ shower uncertainty
EW $W^\pm W^\pm jj$, QCD corrections	
signal_EW6_TheoQCDCorr	EW $W^\pm W^\pm jj$ NLO QCD correction
EW $W^\pm W^\pm jj$, EW corrections	
signal_EW6_TheoEwcorr	EW $W^\pm W^\pm jj$ NLO EW correction
QCD $W^\pm W^\pm jj$, QCD corrections	
signal_EW4_TheoQCDCorr	QCD $W^\pm W^\pm jj$ NLO QCD correction

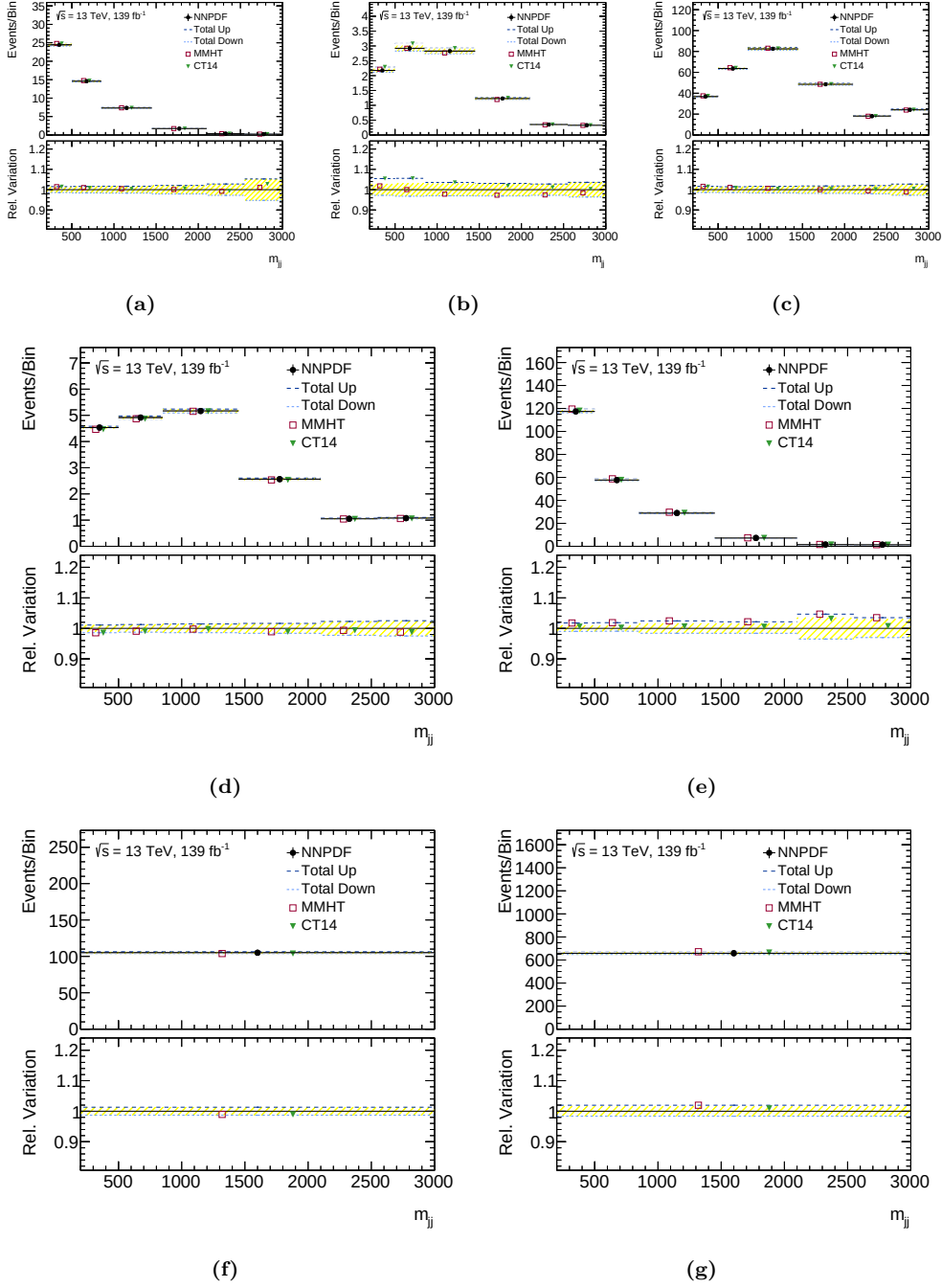


Figure 6.3: PDF uncertainties calculated for QCD $W^\pm W^\pm jj$ (a), Interference $W^\pm W^\pm jj$ (b), EW $W^\pm W^\pm jj$ (c), WZ EW (d) and QCD $W^\pm Zjj$ (e) summed over all channels in the signal region and low- m_{jj} control region and WZ EW (f) and QCD $W^\pm Zjj$ (g) in the WZ control region. The hatched yellow area represents the PDF uncertainty calculated from 100 variations within the nominal NNPDF. Two alternative shower predictions from MMHT and CT14 are shown in red and green. The total PDF uncertainty is the envelope around the yellow band and the two different PDF predictions.

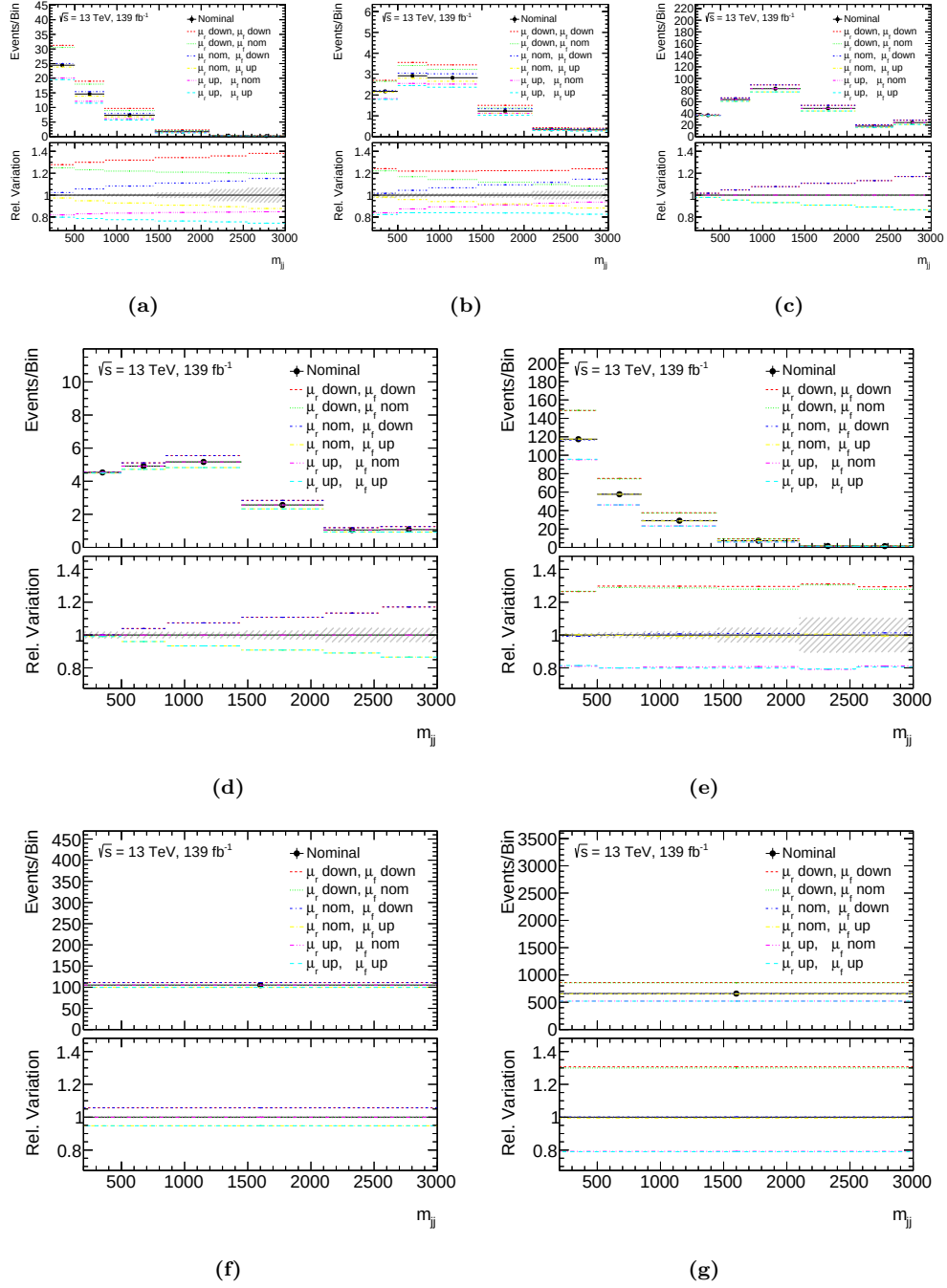


Figure 6.4: Scale uncertainties calculated for QCD $W^\pm W^\pm jj$ (a), Interference $W^\pm W^\pm jj$ (b), EW $W^\pm W^\pm jj$ (c), WZ EW (d) and QCD $W^\pm Z jj$ (e) summed over all channels in the signal region and low- m_{jj} control region and WZ EW (f) and QCD $W^\pm Z jj$ (g) in the WZ control region. The hatched grey area represents the MC statistical uncertainty. Seven combinations of up (multiplied by 2) and down (multiplied by 0.5) variations of the renormalisation and factorisation scale are shown. The total scale uncertainty is the envelope around all variations.

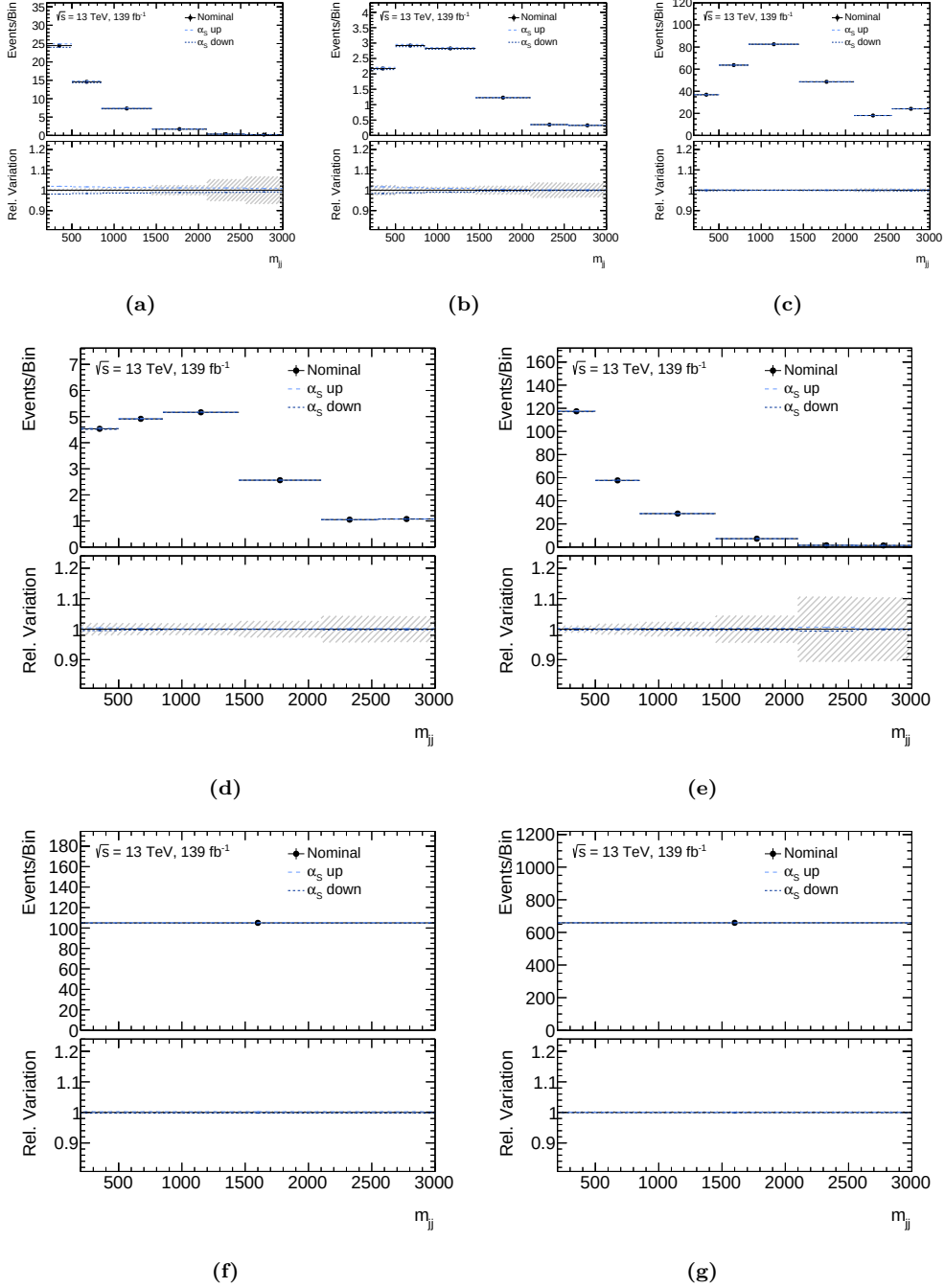


Figure 6.5: α_S uncertainties calculated for QCD $W^\pm W^\pm jj$ (a), Interference $W^\pm W^\pm jj$ (b), EW $W^\pm W^\pm jj$ (c) summed over all channels in the signal region and low- m_{jj} control region and WZ EW (d) and QCD $W^\pm Z jj$ (e) summed over all channels in the signal region and low- m_{jj} control region and WZ EW (f) and QCD $W^\pm Z jj$ (g) in the WZ control region. The EW $W^\pm W^\pm jj$ α_S uncertainty is normalised on truth level in the fiducial region to nominal as done in the total cross-section measurement of EW $W^\pm W^\pm jj$ and QCD $W^\pm Z jj$ α_S uncertainty is normalised on truth level to nominal in the WZ CR. The hatched black area represents the MC statistical uncertainty of the nominal prediction.

Table 6.8: Theory uncertainties used in total and differential cross-section measurement of EW $W^\pm W^\pm jj$ and their normalisation: '-' not included, 's' included normalised, 'sn' included with shape and normalisation. Only WZ EW4 is normalised to nominal in the truth WZ control region. All other normalised variables are normalised in the fiducial signal region.

Theory uncertainty	QCD $W^\pm Z jj$	WZ EW	QCD $W^\pm W^\pm jj$	Interference $W^\pm W^\pm jj$	EW $W^\pm W^\pm jj$
α_S , PDF, Scale	s (WZ CR)	sn	sn	sn	s
Shower	-	-	sn	sn	s
NLO QCD	-	-	sn	-	s
NLO EW	-	-	-	-	s

Table 6.9: Theory uncertainties used in total and differential cross-section measurement of inclusive $W^\pm W^\pm jj$ and their normalisation: '-' not included, 's' included normalised, 'sn' included with shape and normalisation

Theory uncertainty	QCD $W^\pm Z jj$	WZ EW	QCD $W^\pm W^\pm jj$	EW $W^\pm W^\pm jj$	Inclusive $W^\pm W^\pm jj$
α_S , PDF, Scale	s (WZ CR)	sn	-	-	s
Shower	-	-	-	-	s
NLO QCD	-	-	s	s	-
NLO EW	-	-	-	s	-

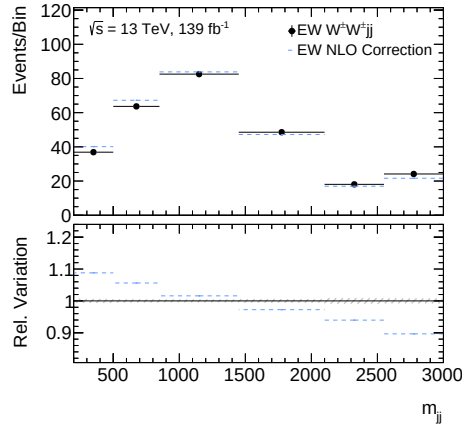


Figure 6.6: NLO EW correction uncertainties calculated for EW $W^\pm W^\pm jj$ summed over all channels in the signal region and low- m_{jj} control region. The EW $W^\pm W^\pm jj$ NLO EW correction uncertainty is normalised on truth level in the fiducial region to nominal as done in the total cross-section measurement of EW $W^\pm W^\pm jj$. The hatched black area represents the MC statistical uncertainty of the nominal LO prediction from Madgraph Herwig 7. The NLO EW uncertainty is defined as down variation in the fit and is calculated as described in Ref. [11].

Table 6.10: Background modelling and model statistical uncertainties for differential cross-section measurement

NP name	Description
Background, WZ scale, PDF & α_s	
WZ_EW4_TheoAlphas	QCD WZjj α_s uncertainty
WZ_EW4_TheoPdf	QCD WZjj PDF uncertainty
WZ_EW4_TheoScale	QCD WZjj scale uncertainty
WZ_EW6_TheoAlphas	EW WZjj α_s uncertainty
WZ_EW6_TheoPdf	EW WZjj PDF uncertainty
WZ_EW6_TheoScale	EW WZjj scale uncertainty
Background, WZ reweighting	
MjjRewPDF	m_{jj} reweighting PDF variation
MjjRewScale	m_{jj} reweighting scale variation
MjjRewStat	m_{jj} reweighting statistics
Background, other	
Wgamma_XS	$W\gamma$ cross-section
ZZ_XS	ZZ cross-section
Zgamma_XS	$Z\gamma$ cross-section
Zjets_XS	Z+jets cross-section
top_XS	top cross-section
triboson_XS	triboson cross-section
Model statistical	
gamma_stat_CutCRWZ3Lep_all_bin_0	Statistics WZ CR
gamma_stat_CutSR_all_bin_[0-5]_[0-5]	Statistics SR, m_{jj} bin 1-6, $m_{\ell\ell}$ bin 1-6
gamma_stat_CutLowMjj_all_bin_0_[0-5]	Statistics low- m_{jj} CR, $m_{\ell\ell}$ bin 1-6

shower uncertainty is not explicitly added here, because it is already considered in the m_{jj} reweighting in Section 4.3.1.

For inclusive $W^\pm W^\pm jj$ the uncertainties α_s , PDF, Scale and Shower are included as one combined nuisance parameter affecting the total signal strength, because the decomposition into EW, Int and QCD is not needed. Only the explicit NLO EW and QCD corrections are applied to the respective signal contribution.

For differential cross-section measurements the same theory uncertainties as for total cross-section measurement are used, but $W^\pm W^\pm jj$ is split into truth bins of the unfolded variable. They get normalised on truth level for each truth slice separately.

The included theory uncertainties for differential cross-section measurements are shown in Table 6.10 and further for EW $W^\pm W^\pm jj$ in Table 6.11 and for inclusive $W^\pm W^\pm jj$ in Table 6.12. The uncertainty names are variable-specific and are shown for $m_{\ell\ell}$.

6.5.3 Theory Uncertainties in EFT Limit Setting

The EFT limit setting requires to include the theory uncertainties arising from the EFT simulation. For the EFT simulation the decomposition technique is used as described in Section 10.1.2. The EFT effect is split into SM interference and quadratic term per EFT operator and the interference between two operators. In Section D.3 it is shown, that the SM interference is very small compared to the quadratic term. Since the interference between two operators is not very small compared to the quadratic term, theory nuisance parameters affecting all EFT contributions in 2D limit setting are treated correlated to not break the decomposition. Only for 2D limit setting two Wilson coefficients are allowed to be non-zero at the same time.

Table 6.11: Signal Modelling uncertainties for differential $m_{\ell\ell}$ cross-section measurement of EW $W^\pm W^\pm jj$

NP name	Description
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	
signal_EW6_truthBin[20-320]to[80-inf]_TheoAlphas	EW $W^\pm W^\pm jj$ α_s unc. truth bin 1-6
signal_EW6_truthBin[20-320]to[80-inf]_TheoPdf	EW $W^\pm W^\pm jj$ PDF unc. truth bin 1-6
signal_EW6_truthBin[20-320]to[80-inf]_TheoScale	EW $W^\pm W^\pm jj$ scale unc. truth bin 1-6
signal_EW6_truthBin[20-320]to[80-inf]_TheoShower	EW $W^\pm W^\pm jj$ shower unc. truth bin 1-6
EW $W^\pm W^\pm jj$, QCD corrections	
signal_EW6_truthBin[20-320]to[80-inf]_TheoQCDCorr	EW $W^\pm W^\pm jj$ NLO QCD correction truth bin 1-6
EW $W^\pm W^\pm jj$, EW corrections	
signal_EW6_truthBin[20-320]to[80-inf]_TheoEwcorr	EW $W^\pm W^\pm jj$ NLO EW correction truth bin 1-6
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	
signal_EW5_truthBin[20-320]to[80-inf]_TheoAlphas	Int $W^\pm W^\pm jj$ α_s unc. truth bin 1-6
signal_EW5_truthBin[20-320]to[80-inf]_TheoPdf	Int $W^\pm W^\pm jj$ PDF unc. truth bin 1-6
signal_EW5_truthBin[20-320]to[80-inf]_TheoScale	Int $W^\pm W^\pm jj$ scale unc. truth bin 1-6
signal_EW5_truthBin[20-320]to[80-inf]_TheoShower	Int $W^\pm W^\pm jj$ shower unc. truth bin 1-6
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	
signal_EW4_TheoAlphas	QCD $W^\pm W^\pm jj$ α_s uncertainty
signal_EW4_TheoPdf	QCD $W^\pm W^\pm jj$ PDF uncertainty
signal_EW4_TheoScale	QCD $W^\pm W^\pm jj$ scale uncertainty
signal_EW4_TheoShower	QCD $W^\pm W^\pm jj$ shower uncertainty
QCD $W^\pm W^\pm jj$, QCD corrections	
signal_EW4_TheoQCDCorr	QCD $W^\pm W^\pm jj$ NLO QCD correction

Table 6.12: Signal Modelling uncertainties for differential $m_{\ell\ell}$ cross-section measurement of inclusive $W^\pm W^\pm jj$

NP name	Description
$W^\pm W^\pm jj$ shower, scale, PDF & α_s	
signal_AllEW_truthBin[20-320]to[80-inf]_TheoAlphas	Inclusive $W^\pm W^\pm jj$ α_s unc. truth bin 1-6
signal_AllEW_truthBin[20-320]to[80-inf]_TheoPdf	Inclusive $W^\pm W^\pm jj$ PDF unc. truth bin 1-6
signal_AllEW_truthBin[20-320]to[80-inf]_TheoScale	Inclusive $W^\pm W^\pm jj$ scale unc. truth bin 1-6
signal_AllEW_truthBin[20-320]to[80-inf]_TheoShower	Inclusive $W^\pm W^\pm jj$ shower unc. truth bin 1-6
EW $W^\pm W^\pm jj$, QCD corrections	
signal_EW6_truthBin[20-320]to[80-inf]_TheoQCDCorr	EW $W^\pm W^\pm jj$ NLO QCD correction truth bin 1-6
EW $W^\pm W^\pm jj$, EW corrections	
signal_EW6_truthBin[20-320]to[80-inf]_TheoEwcorr	EW $W^\pm W^\pm jj$ NLO EW correction truth bin 1-6
QCD $W^\pm W^\pm jj$, QCD corrections	
signal_EW4_TheoQCDCorr	QCD $W^\pm W^\pm jj$ NLO QCD correction

The nuisance parameters included for one and two-dimensional limits are listed in Table 6.13. The uncertainties which are specific to the dimension are listed for 1D in Table 6.14 and for 2D in Table 6.15. The information about normalisation is summarised in Table 6.16.

6.6 Overview over Size of Uncertainties in Cross-Section Measurement

The included uncertainties and their impact on the different processes are shown in this section for the m_T -differential EW $W^\pm W^\pm jj$ cross-section measurement.

They are shown for the signal region in Table 6.17, for the low- m_{jj} control region in Table 6.18 and for the WZ control region in Table 6.19.

The largest absolute modelling statistical uncertainties in the signal region and low- m_{jj} control region have the non-prompt background, followed by Wgamma and QCD $W^\pm Zjj$. These modelling statistical uncertainties get merged into one nuisance parameter for each bin as shown in the above tables. They can not be separated by process in the final analysis. The other uncertainties and their impact are discussed in the respective section about total cross-section measurement in Chapter 8 and differential cross-section measurement in Chapter 9.

Table 6.13: WZjj and $W^\pm W^\pm$ jj Modelling and Model statistical uncertainties for 1D and 2D EFT limit setting.

NP name	Description
EW $W^\pm W^\pm$ jj, shower, scale, PDF & α_s	
EFT_sm_sm_TheoAlphas	EW $W^\pm W^\pm$ jj α_s unc.
EFT_sm_sm_TheoPdf	EW $W^\pm W^\pm$ jj PDF unc.
EFT_sm_sm_TheoScale	EW $W^\pm W^\pm$ jj scale unc.
EFT_sm_sm_TheoShower	EW $W^\pm W^\pm$ jj shower unc.
EW $W^\pm W^\pm$ jj, QCD corrections	
EFT_sm_sm_TheoQCDCorr	EW $W^\pm W^\pm$ jj NLO QCD correction
EW $W^\pm W^\pm$ jj, EW corrections	
EFT_sm_sm_TheoEwcorr	EW $W^\pm W^\pm$ jj NLO EW correction
Int $W^\pm W^\pm$ jj, shower, scale, PDF & α_s	
signal_EW5_TheoAlphas	Int $W^\pm W^\pm$ jj α_s uncertainty
signal_EW5_TheoPdf	Int $W^\pm W^\pm$ jj PDF uncertainty
signal_EW5_TheoScale	Int $W^\pm W^\pm$ jj scale uncertainty
signal_EW5_TheoShower	Int $W^\pm W^\pm$ jj shower uncertainty
QCD $W^\pm W^\pm$ jj, shower, scale, PDF & α_s	
signal_EW4_TheoAlphas	QCD $W^\pm W^\pm$ jj α_s uncertainty
signal_EW4_TheoPdf	QCD $W^\pm W^\pm$ jj PDF uncertainty
signal_EW4_TheoScale	QCD $W^\pm W^\pm$ jj scale uncertainty
signal_EW4_TheoShower	QCD $W^\pm W^\pm$ jj shower uncertainty
QCD $W^\pm W^\pm$ jj, QCD corrections	
signal_EW4_TheoQCDCorr	QCD $W^\pm W^\pm$ jj NLO QCD correction
Background, WZ scale, PDF & α_s	
WZ_EW4_TheoAlphas	QCD WZjj α_s uncertainty
WZ_EW4_TheoPdf	QCD WZjj PDF uncertainty
WZ_EW4_TheoScale	QCD WZjj scale uncertainty
EFTWZ_sm_sm_TheoAlphas	EW WZjj α_s uncertainty
EFTWZ_sm_sm_TheoPdf	EW WZjj PDF uncertainty
EFTWZ_sm_sm_TheoScale	EW WZjj scale uncertainty
Background, WZ reweighting	
MjjRewPDF	m_{jj} reweighting PDF variation
MjjRewScale	m_{jj} reweighting scale variation
MjjRewStat	m_{jj} reweighting statistics
Background, other	
Wgamma_XS	$W\gamma$ cross-section
ZZ_XS	ZZ cross-section
Zgamma_XS	$Z\gamma$ cross-section
Zjets_XS	Z+jets cross-section
top_XS	top cross-section
triboson_XS	triboson cross-section
Model statistical	
gamma_stat_CutCRWZ3Lep_all_bin_0	Statistics WZ CR
gamma_stat_CutLowMjj_all_bin_0_0	Statistics low- m_{jj} CR
gamma_stat_CutSR_all_bin_0_[0-4]	Statistics SR, bin 1-5

Table 6.14: EFT uncertainties for 1D EFT limit setting of M0.

NP name	Description
EFT WZ Int M0 & M1 scale, PDF & α_s	
EFTWZ_M0_27_int_TheoAlphas	Int EFT WZ M0 α_s unc.
EFTWZ_M0_27_int_TheoPdf	Int EFT WZ M0 PDF unc.
EFTWZ_M0_27_int_TheoScale	Int EFT WZ M0 scale unc.
EFT Int $W^\pm W^\pm jj$ M0 & M1 scale, PDF & α_s	
EFT_M0_6_int_TheoAlphas	Int EFT M0 α_s unc.
EFT_M0_6_int_TheoPdf	Int EFT M0 PDF unc.
EFT_M0_6_int_TheoScale	Int EFT M0 scale unc.
EFT WZ Quad M0 & M1 scale, PDF & α_s	
EFTWZ_M0_27_quad_TheoAlphas	Quad EFT WZ M0 α_s unc.
EFTWZ_M0_27_quad_TheoPdf	Quad EFT WZ M0 PDF unc.
EFTWZ_M0_27_quad_TheoScale	Quad EFT WZ M0 scale unc.
EFT Quad $W^\pm W^\pm jj$ M0 & M1 scale, PDF & α_s	
EFT_M0_6_quad_TheoAlphas	Quad EFT M0 α_s unc.
EFT_M0_6_quad_TheoPdf	Quad EFT M0 PDF unc.
EFT_M0_6_quad_TheoScale	Quad EFT M0 scale unc.

Table 6.15: EFT uncertainties for 2D EFT limit setting of M0-M1.

NP name	Description
EFT WZ M0 & M1 scale, PDF & α_s	
EFTWZ_common_TheoAlphas	EFT WZ M0, M1 α_s unc.
EFTWZ_common_TheoPdf	EFT WZ M0, M1 PDF unc.
EFTWZ_common_TheoScale	EFT WZ M0, M1 scale unc.
EFT $W^\pm W^\pm jj$ M0 & M1 scale, PDF & α_s	
EFT_common_TheoAlphas	EFT M0, M1 α_s unc.
EFT_common_TheoPdf	EFT M0, M1 PDF unc.
EFT_common_TheoScale	EFT M0, M1 scale unc.

Table 6.16: Theory uncertainties used in limit setting and their normalisation: '-' not included, 's' included normalised, 'sn' included with shape and normalisation

Theory uncertainty	QCD $W^\pm Z jj$	WZ EW	QCD $W^\pm W^\pm jj$	Interference $W^\pm W^\pm jj$	EW $W^\pm W^\pm jj$	EFT cross+quad+int
α_s , PDF, Scale	s (WZ CR)	sn	sn	sn	sn	sn
Shower	-	-	sn	sn	sn	-
NLO QCD	-	-	sn	-	sn	-
NLO EW	-	-	-	-	sn	-

Table 6.17: Uncertainties split by sample and uncertainty category in the signal region.

Uncertainty	$W^\pm W^\pm jj$ EW		$W^\pm W^\pm jj$ Int		$W^\pm W^\pm jj$ QCD		$W^\pm W^\pm jj$ QCD		$W^\pm W^\pm jj$ EW		Non-prompt		chFlip	Conversions		Other prompt		
	signal_EW6	EW	signal_EW5	Int	signal_EW4	QCD_EW4	WZ_EW4	QCD_W^\pm Zjj	WZ_EW6	WZ_EW6	efakes	mfakes		Wgamma	Zgamma	top	triboson	ZZ
Nominal	234.9	$\pm 0.4\%$ $\pm 0.5\%$ $\pm 1.1\%$ $\pm 0.1\%$ $\pm 0.2\%$ $\pm 0.6\%$ $\pm 0.6\%$	7.6	$\pm 0.3\%$ $\pm 0.3\%$ $\pm 0.5\%$ $\pm 1.4\%$ $\pm 0.3\%$ $\pm 1.1\%$	24.0	$\pm 0.4\%$ $\pm 0.5\%$ $\pm 0.5\%$ $\pm 2.3\%$ $\pm 0.2\%$ $\pm 1.1\%$	82.8	$\pm 0.4\%$ $\pm 0.5\%$ $\pm 0.4\%$ $\pm 0.4\%$ $\pm 0.5\%$ $\pm 1.1\%$	14.9	$\pm 0.4\%$ $\pm 0.5\%$ $\pm 0.5\%$ $\pm 2.3\%$ $\pm 0.4\%$ $\pm 1.2\%$	23.0	32.6	10.1	10.4	0.5	4.0	0.6	2.4
Electron calibration															$\pm 1.0\%$ $\pm 1.3\%$ $\pm 0.9\%$ $\pm 2.2\%$ $\pm 0.9\%$ $\pm 1.0\%$ $\pm 1.0\%$	$\pm 0.8\%$ $\pm 1.3\%$ $\pm 0.9\%$ $\pm 1.2\%$ $\pm 0.9\%$ $\pm 1.0\%$ $\pm 1.0\%$	$\pm 1.1\%$ $\pm 0.9\%$ $\pm 2.0\%$ $\pm 0.3\%$ $\pm 21.1\%$ $\pm 0.3\%$ $\pm 1.1\%$	$\pm 0.5\%$ $\pm 0.9\%$ $\pm 0.4\%$ $\pm 20.6\%$ $\pm 1.8\%$ $\pm 0.9\%$ $\pm 1.3\%$
Muon calibration																		
Jet energy scale and resolution																		
E_T^{miss} scale and resolution																		
b -tagging inefficiency																		
Background, misid. leptons											$\pm 16.6\%$ $\pm 28.7\%$							
Background, charge misrec.													$\pm 37.7\%$ $\pm 35.0\%$					
Pileup modelling																		
Luminosity		$\pm 0.3\%$ $\pm 0.3\%$ $\pm 1.5\%$ $\pm 0.8\%$ $\pm 4.3\%$ $\pm 0.0\%$ $\pm 0.0\%$	$\pm 0.3\%$ $\pm 0.2\%$ $\pm 1.7\%$		$\pm 0.1\%$ $\pm 0.3\%$ $\pm 1.7\%$		$\pm 0.1\%$ $\pm 0.0\%$ $\pm 0.0\%$		$\pm 0.2\%$ $\pm 0.0\%$ $\pm 1.7\%$					$\pm 1.5\%$ $\pm 0.6\%$ $\pm 1.7\%$	$\pm 18.3\%$ $\pm 7.0\%$ $\pm 1.7\%$	$\pm 10.6\%$ $\pm 7.8\%$ $\pm 1.7\%$	$\pm 0.0\%$ $\pm 0.4\%$ $\pm 1.7\%$	$\pm 0.2\%$ $\pm 0.3\%$ $\pm 1.7\%$
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s																		
EW $W^\pm W^\pm jj$, QCD corrections																		
EW $W^\pm W^\pm jj$, EW corrections																		
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s																		
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s																		
QCD $W^\pm W^\pm jj$, QCD corrections																		
Background, WZ scale, PDF & α_s																		
Background, WZ reweighting																		
Background, other																		
Model statistical		$\pm 0.2\%$									$\pm 17.6\%$ $\pm 10.9\%$	$\pm 3.1\%$ $\pm 3.1\%$		$\pm 40.0\%$ $\pm 40.0\%$ $\pm 11.9\%$	$\pm 40.0\%$ $\pm 40.0\%$ $\pm 50.4\%$	$\pm 30.0\%$ $\pm 30.0\%$ $\pm 5.8\%$	$\pm 30.0\%$ $\pm 20.9\%$ $\pm 0.4\%$	$\pm 20.0\%$ $\pm 20.9\%$ $\pm 3.7\%$

Table 6.18: Uncertainties split by sample and uncertainty category in the low- m_{ij} control region.

Uncertainty	$W^\pm W^\pm jj$ EW signal_EW6	$W^\pm W^\pm jj$ Int signal_EW5	$W^\pm W^\pm jj$ QCD signal_EW4	$W^\pm W^\pm jj$ QCD WZ_EW4	WZ EW WZ_EW6	Non-prompt efakes	chFlip	Conversions Wgamma	Zgamma	Other prompt top	ZZ
Nominal	36.6	2.2	24.3	131.1	4.4	44.1	11.1	13.8	1.0	5.5	3.7
Electron calibration	$\pm 0.3\%$	$\pm 0.2\%$	$\pm 0.3\%$	$\pm 0.4\%$	$\pm 0.4\%$	—	—	$\pm 1.3\%$	$\pm 1.1\%$	$\pm 0.6\%$	$\pm 0.5\%$
Muon calibration	$\pm 0.3\%$	$\pm 0.3\%$	$\pm 0.5\%$	$\pm 0.4\%$	$\pm 0.4\%$	—	—	$\pm 0.8\%$	$\pm 0.8\%$	$\pm 0.5\%$	$\pm 0.4\%$
Jet energy scale and resolution	$\pm 0.5\%$	$\pm 0.5\%$	$\pm 0.5\%$	$\pm 0.5\%$	$\pm 0.7\%$	—	—	$\pm 1.1\%$	$\pm 0.8\%$	$\pm 0.7\%$	$\pm 0.4\%$
E_T^{miss} scale and resolution	$\pm 1.0\%$	$\pm 0.7\%$	$\pm 2.8\%$	$\pm 5.8\%$	$\pm 3.2\%$	—	—	$\pm 2.1\%$	$\pm 2.1\%$	$\pm 0.3\%$	$\pm 0.9\%$
b -tagging inefficiency	$\pm 0.1\%$	$\pm 0.1\%$	$\pm 0.5\%$	$\pm 0.3\%$	$\pm 0.5\%$	—	—	$\pm 23.4\%$	$\pm 88.6\%$	$\pm 7.4\%$	$\pm 6.1\%$
b -tagging inefficiency	$\pm 0.1\%$	$\pm 0.1\%$	$\pm 0.5\%$	$\pm 0.3\%$	$\pm 0.5\%$	—	—	$\pm 23.4\%$	$\pm 88.6\%$	$\pm 7.4\%$	$\pm 6.1\%$
b -tagging inefficiency	$\pm 0.2\%$	$\pm 0.3\%$	$\pm 0.3\%$	$\pm 0.8\%$	$\pm 0.7\%$	—	—	$\pm 0.8\%$	—	$\pm 0.6\%$	$\pm 0.9\%$
b -tagging inefficiency	$\pm 0.7\%$	$\pm 0.8\%$	$\pm 0.9\%$	$\pm 1.0\%$	$\pm 2.4\%$	—	—	$\pm 0.8\%$	$\pm 1.0\%$	$\pm 1.1\%$	$\pm 1.0\%$
Background, misid. leptons	—	—	—	—	—	$\pm 11.5\%$	—	$\pm 0.8\%$	—	$\pm 5.7\%$	—
Background, charge misrec.	—	—	—	—	—	$\pm 11.4\%$	$\pm 42.1\%$	—	—	—	—
Pileup modelling	$\pm 0.2\%$	$\pm 0.4\%$	$\pm 0.2\%$	$\pm 0.4\%$	$\pm 0.3\%$	—	$\pm 38.1\%$	$\pm 3.5\%$	$\pm 3.6\%$	$\pm 0.9\%$	$\pm 0.2\%$
Luminosity	$\pm 0.3\%$	$\pm 0.5\%$	$\pm 0.4\%$	$\pm 0.4\%$	$\pm 0.9\%$	—	—	$\pm 1.6\%$	$\pm 1.6\%$	$\pm 1.4\%$	$\pm 0.3\%$
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	$\pm 1.7\%$	$\pm 1.7\%$	$\pm 1.7\%$	—	$\pm 1.7\%$	—	—	$\pm 1.7\%$	$\pm 1.7\%$	$\pm 1.7\%$	$\pm 1.7\%$
EW $W^\pm W^\pm jj$, QCD corrections	$\pm 10.5\%$	—	—	—	—	—	—	—	—	—	—
EW $W^\pm W^\pm jj$, EW corrections	$\pm 29.5\%$	—	—	—	—	—	—	—	—	—	—
EW $W^\pm W^\pm jj$, EW corrections	$\pm 8.9\%$	—	—	—	—	—	—	—	—	—	—
EW $W^\pm W^\pm jj$, EW corrections	$\pm 0.0\%$	—	—	—	—	—	—	—	—	—	—
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	—	$\pm 11.6\%$	—	—	—	—	—	—	—	—	—
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	—	—	$\pm 27.9\%$	—	—	—	—	—	—	—	—
QCD $W^\pm W^\pm jj$, QCD corrections	—	—	$\pm 27.9\%$	—	—	—	—	—	—	—	—
QCD $W^\pm W^\pm jj$, QCD corrections	—	—	$\pm 11.9\%$	—	—	—	—	—	—	—	—
Background, WZ scale, PDF & α_s	—	—	—	$\pm 4.2\%$	$\pm 1.1\%$	—	—	—	—	—	—
Background, WZ scale, PDF & α_s	—	—	—	$\pm 4.5\%$	$\pm 1.6\%$	—	—	—	—	—	—
Background, WZ reweighting	—	—	—	$\pm 6.5\%$	—	—	—	—	—	—	—
Background, other	—	—	—	—	—	—	—	—	—	—	—
Model statistical	$\pm 0.6\%$	$\pm 2.5\%$	$\pm 0.7\%$	$\pm 1.2\%$	$\pm 2.0\%$	$\pm 11.3\%$	$\pm 2.5\%$	$\pm 40.0\%$	$\pm 40.0\%$	$\pm 30.0\%$	$\pm 20.0\%$
			$\pm 0.7\%$	$\pm 1.2\%$	$\pm 2.0\%$	$\pm 11.3\%$	$\pm 2.5\%$	$\pm 13.8\%$	$\pm 44.7\%$	$\pm 30.0\%$	$\pm 20.0\%$
			$\pm 0.7\%$	$\pm 1.2\%$	$\pm 2.0\%$	$\pm 11.3\%$	$\pm 2.5\%$	$\pm 13.8\%$	$\pm 44.7\%$	$\pm 30.0\%$	$\pm 20.0\%$
			$\pm 0.7\%$	$\pm 1.2\%$	$\pm 2.0\%$	$\pm 11.3\%$	$\pm 2.5\%$	$\pm 13.8\%$	$\pm 44.7\%$	$\pm 30.0\%$	$\pm 20.0\%$

Table 6.19: Uncertainties split by sample and uncertainty category in the WZ control region. The experimental uncertainties of Wgamma are covered by the 100% MC statistical uncertainty of this sample in the WZ control region.

Uncertainty	QCD $W^\pm Z_{jj}$		WZ EW		Zjets	Non-prompt		signal_EW4	Conversions		Other prompt	
	WZ_EW4	Zjj	WZ_EW6			signal_EW6	signal_EW5		Wgamma	Zgamma	top	ZZ
Nominal	799.7	141.3	27.7	0.0	0.0	0.0	0.0	0.0	0.1	8.0	41.1	58.4
Electron calibration	$\pm 0.3\%$	$\pm 0.4\%$	$\pm 0.4\%$	$\pm 0.8\%$	$\pm 0.8\%$	$\pm 0.8\%$	$\pm 4.8\%$	$\pm 1.6\%$	—	$\pm 0.9\%$	$\pm 0.6\%$	$\pm 0.3\%$
Muon calibration	$\pm 0.5\%$	$\pm 0.6\%$	$\pm 1.8\%$	$\pm 5.2\%$	$\pm 5.2\%$	$\pm 5.2\%$	$\pm 0.1\%$	$\pm 1.6\%$	—	$\pm 1.2\%$	$\pm 0.6\%$	$\pm 0.4\%$
Jet energy scale and resolution	$\pm 3.4\%$	$\pm 2.2\%$	$\pm 2.6\%$	$\pm 43.7\%$	$\pm 43.7\%$	$\pm 43.7\%$	$\pm 0.1\%$	$\pm 0.2\%$	—	$\pm 3.5\%$	$\pm 0.9\%$	$\pm 0.6\%$
E_T^{miss} scale and resolution	$\pm 0.4\%$	$\pm 0.3\%$	$\pm 1.1\%$	$\pm 32.6\%$	$\pm 32.6\%$	$\pm 32.6\%$	$\pm 0.0\%$	$\pm 0.3\%$	—	$\pm 1.0\%$	$\pm 0.5\%$	$\pm 0.3\%$
b -tagging inefficiency	$\pm 0.7\%$	$\pm 0.5\%$	$\pm 7.2\%$	$\pm 0.0\%$	$\pm 0.0\%$	$\pm 0.0\%$	$\pm 18.4\%$	—	—	$\pm 6.5\%$	$\pm 0.9\%$	$\pm 0.2\%$
E_T^{miss} scale and resolution	$\pm 0.9\%$	$\pm 1.0\%$	$\pm 1.2\%$	$\pm 1.6\%$	$\pm 1.6\%$	$\pm 1.6\%$	$\pm 2.0\%$	$\pm 0.9\%$	—	$\pm 0.7\%$	$\pm 0.6\%$	$\pm 1.1\%$
Pileup modelling	$\pm 0.9\%$	$\pm 0.0\%$	$\pm 0.3\%$	$\pm 1.6\%$	$\pm 1.6\%$	$\pm 1.6\%$	$\pm 2.0\%$	$\pm 0.9\%$	—	$\pm 0.7\%$	$\pm 0.6\%$	$\pm 1.1\%$
Luminosity	$\pm 0.0\%$	$\pm 0.4\%$	$\pm 1.7\%$	$\pm 1.7\%$	$\pm 1.7\%$	$\pm 1.7\%$	$\pm 1.7\%$	$\pm 1.7\%$	$\pm 1.7\%$	$\pm 1.7\%$	$\pm 1.7\%$	$\pm 1.7\%$
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	—	—	—	$\pm 3.4\%$	$\pm 3.4\%$	$\pm 3.4\%$	—	—	—	—	—	—
EW $W^\pm W^\pm jj$, QCD corrections	—	—	—	$\pm 0.3\%$	$\pm 0.3\%$	$\pm 0.3\%$	—	—	—	—	—	—
EW $W^\pm W^\pm jj$, EW corrections	—	—	—	$\pm 73.4\%$	$\pm 73.4\%$	$\pm 73.4\%$	—	—	—	—	—	—
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	—	—	—	$\pm 0.0\%$	$\pm 0.0\%$	$\pm 0.0\%$	$\pm 66.8\%$	—	—	—	—	—
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	—	—	—	—	—	—	$\pm 66.8\%$	$\pm 91.2\%$	—	—	—	—
QCD $W^\pm W^\pm jj$, QCD corrections	—	—	—	—	—	—	—	$\pm 88.4\%$	—	—	—	—
Background, WZ scale, PDF & α_s	$\pm 1.7\%$	$\pm 6.1\%$	—	—	—	—	—	$\pm 20.7\%$	—	—	—	—
Background, WZ reweighting	$\pm 0.3\%$	$\pm 5.6\%$	—	—	—	—	—	—	—	—	—	—
Background, other	—	—	—	—	—	—	—	—	—	—	—	—
Model statistical	$\pm 0.3\%$	$\pm 0.4\%$	—	—	—	—	$\pm 69.0\%$	$\pm 41.0\%$	$\pm 40.0\%$	$\pm 40.0\%$	$\pm 30.0\%$	$\pm 20.0\%$
	$\pm 0.3\%$	$\pm 0.4\%$	$\pm 12.8\%$	$\pm 20.5\%$	$\pm 20.5\%$	$\pm 20.5\%$	$\pm 69.0\%$	$\pm 41.0\%$	$\pm 100.0\%$	$\pm 15.3\%$	$\pm 2.0\%$	$\pm 1.8\%$

Chapter 7

Statistical Analysis

The statistical analysis is the heart of the physics analysis and required to get the most information and sense out of the data recorded at the ATLAS experiment. This chapter explores the indispensable role of statistics in our quest to unravel the mysteries of the subatomic universe, shedding light on the methodologies and tools that underpin our ability to interpret the data.

It starts with the definition of frequentist statistic in Section 7.1 and the signal definition in Section 7.2. The used likelihood function is shown in Section 7.3 and the maximum likelihood estimate and its properties including uncertainties are discussed in Section 7.4. Afterwards, the concepts for calculating p -values are presented in Section 7.6, followed by comments about the handling of observed data in Section 7.7. The equation used for binning optimisation is shown in Section 7.8. Section 7.9 motivates and explains the used unfolding method. The last Section 7.10 summarises the equation used for uncertainty propagation in normalised distributions.

7.1 Frequentist Statistic

In nature, there is only one fixed true theory of particle physics implemented. Because of this frequentist statistic is used as much as possible in this thesis, which does not assign probabilities to a certain theoretical model.¹ Random variables are distributed around one fixed theory which one assumes to be true. So, if one looks at different theoretical models there is only the conditional probability to measure the data given the theory parameter. There is no probability that a certain theory parameter is implemented in nature given the data.

The following notation for probability density functions (pdfs) is used: $f(n|\mu, \Theta)$. In this notation, the parameters μ and Θ are fixed theory parameters. They define the distribution of the observable. The observable n is the random variable distributed according to f for the fixed theory. For example, the Poisson distribution is:

$$Pois(n|\nu) = \frac{\nu^n}{n!} e^{-\nu}, \quad (7.1)$$

with the expected number of events ν defined by theory and the observed number of events n .

It is not possible to show that a theory is true, but only that observed data is very unlikely to originate from a specific theory prediction. The task of the statistical analysis is to calculate the probability of measuring the data given a certain theory and then to try to rule out as many theories as possible. To summarise the agreement with a hypothesis, the significance is used. Significance expresses how many standard deviations the measured value is apart from the mean if mapped to a standard normal distribution.

¹In contrast to this there is Bayesian statistic which associates a degree of belief to a certain theory model.

7.2 Signal Definition and Inputs of Statistical Analysis

The signal is the measurable manifestation of the physical process we are interested in. Directly associated with it is the signal strength μ which quantifies with which factor the nominal signal prediction is multiplied.

It can be tested whether the signal is present at all in nature. For this, it is tested how well-observed data is described by the signal hypothesis, e.g. $\mu > 0$, compared to an alternative hypothesis, e.g. $\mu = 0$. Via this procedure, one of the two hypotheses can be classified as less likely to cause the observed data distribution. Once a process is observed or at least evidence is found for it, total and differential cross-sections can be measured. For processes whose signals are not observed yet, exclusion limits on their parameters can be set.

There are different signal processes defined in this thesis:

- $W^\pm W^\pm jj$ EW, for the total and differential cross-section measurement,
- $W^\pm W^\pm jj$ EW+Int+QCD, for the total and differential cross-section measurement and
- the contribution of one or two EFT operators, for 1D and 2D limit setting.

A binned maximum likelihood fit is performed to measure the properties of the signal. One or more discriminating variables are used to distinguish signal from other processes, called backgrounds. A binned approach is chosen to deal with the theory prediction via discrete MC events. For a continuous fit one would need to extrapolate the pdf between the MC events. For a binned fit one can directly use the theory prediction with a Poisson uncertainty around the number of MC events.

The nominal inputs including experimental uncertainties and uncertainties from backgrounds estimated with data-driven methods are provided by the Freiburg ATLAS group [89, 90]. Other modelling uncertainties are calculated by the Dresden ATLAS group [91, 92]. The nominal predictions are provided in the discriminating variable(s) along with their 1σ up and down variation of each systematic uncertainty covering 68% of the expected systematic fluctuations. These are called three point variations from which any other variation is inter- and extrapolated during the fit. Five or more point variations would make the statistical analysis more robust, but are not available yet. Therefore the extrapolation should not go too far, since no good modelling is expected above e.g. $2\text{--}3\sigma$ variation. This is one motivation to thoroughly check the pulls, i.e. observed variations, in the analysis.

The development of the statistical software used in this thesis was taken over during the creation of the observation paper [74, 93]. Starting there the software was finalized for that paper. It has been extended by 2D fitting, 1D+2D limit setting and LH-based unfolding during the analysis of the full Run 2 data.

7.3 The Statistical Model

A binned maximum likelihood fit is performed using a Python wrapper around HistFactory [94]. HistFactory is part of Root [95] and a wrapper around RooStats [96] and RooFit [97]. The function "MakeModelAndMeasurementsFast" from HistFactory is used to construct $\mathcal{L}(n|\mu, \Theta)$. The bins b are grouped into histograms which are defined in fit regions r . "Fit regions" are characterized by their selection criteria, the phase space. They are later the combination of "region" and "channel". Whether there is a contribution of a sample s , which can be signal or a background, depends on the fit region r . The likelihood function is defined as:

$$\mathcal{L}(n|\mu, \Theta) = C(\gamma, \lambda, \alpha) \cdot \prod_{r \in \text{fit regions}} \prod_{b_r \in \text{bins in } r} \text{Pois}(n_{b_r} | \nu_{b_r}(\gamma_{b_r}, \lambda, \alpha, \phi)), \quad (7.2)$$

where:

- Θ is the set $\{\lambda\} \cup \alpha \cup \gamma \cup \phi \setminus \mu$ of all nuisance parameters and normalisation factors without signal strength μ ,
- n_{b_r} number of observed events in bin b of fit region r ,
- ν_{b_r} number of expected events in bin b of fit region r ,
- γ set of nuisance parameters encoding Monte Carlo statistical uncertainties,
- α set of nuisance parameters encoding experimental and theoretical uncertainties,
- ϕ set of parameters encoding unconstrained normalisation factors (like the signal strength μ),
- λ nuisance parameter of relative luminosity, i.e. $\frac{\text{fitted luminosity}}{\text{nominal luminosity}}$.

The likelihood function is the product of the constraint term $C(\gamma, \lambda, \alpha)$, defined in Section 7.3.1 and Poisson distributions around the expectations of each bin $\nu_{b_r}(\gamma_{b_r}, \lambda, \alpha, \phi)$, defined in Section 7.3.2. For the inclusive cross-section measurement it is for example $\nu_{b_r}(\gamma_{b_r}, \lambda, \alpha, \phi) = \nu_{\text{Bkg}, b_r}(\Theta) + \sqrt{\mu} \cdot \nu_{\text{Int}, b_r}(\Theta) + \mu \cdot \nu_{\text{Signal}, b_r}(\Theta)$.

7.3.1 The Constraint Term

The constraint term is:

$$C(\gamma, \lambda, \alpha) = C_\gamma(\gamma) \cdot C_\lambda(\lambda) \cdot C_\alpha(\alpha), \quad (7.3)$$

with:

$$C_\gamma(\gamma) = \prod_{r \in \text{fit regions}} \prod_{b_r \in \text{bins in } r} \text{Pois}(m_{b_r} | \gamma_{b_r} \cdot \tau_{b_r}), \quad (7.4)$$

$$C_\lambda(\lambda) = \text{Gaussian}(\lambda_0 = 1 | \lambda, \Delta\lambda_{\text{nom}}), \quad (7.5)$$

$$C_\alpha(\alpha) = \prod_{\alpha_i \in \alpha} \text{Gaussian}(\alpha_{i,0} = 0 | \alpha_i, 1), \quad (7.6)$$

where:

- m_{b_r} weighted summed number of observed MC events in bin b of fit region r ,
- τ_{b_r} weighted summed number of expected events in bin b of fit region r before scaling by γ ,
- $\Delta\lambda_{\text{nom}}$ relative uncertainty of luminosity,
- λ_0 observed value of λ in external luminosity measurement,
- $\alpha_{i,0}$ observed value of α_i in external systematic uncertainty measurement.

The luminosity and systematic uncertainties are implemented such that the observed values in external measurements are $\lambda_0 = 1$ and $\alpha_{i,0} = 0$. The MC statistical uncertainty $\Delta_{\text{MC stat}} \nu_{\text{nom}, b_r}$ of ν_{nom, b_r} is encoded in τ_{b_r} defined as $\tau_{b_r} := \left(\frac{\nu_{\text{nom}, b_r}}{\Delta_{\text{MC stat}} \nu_{\text{nom}, b_r}} \right)^2$, derived from the Poisson uncertainty of τ_{b_r} : $\Delta_{\text{MC stat}} \tau_{b_r} = \sqrt{\tau_{b_r}}$ and $\frac{\Delta_{\text{MC stat}} \tau_{b_r}}{\tau_{b_r}} \stackrel{!}{=} \frac{\Delta_{\text{MC stat}} \nu_{\text{nom}, b_r}}{\nu_{\text{nom}, b_r}}$. In the case with equal weights, this corresponds to the number of expected simulated events in that bin summed over all samples.

The constraint term $C(\gamma, \lambda, \alpha)$ is maximal if there are no deviations, i.e. when $\gamma_{b_r} = \frac{m_{b_r}}{\tau_{b_r}} = 1$, $\lambda = 1$ and $\alpha_i = 0$.

The MC statistical uncertainty of the signal process is included in the total MC statistical uncertainty. Only for significance calculations of the background-only hypothesis it is excluded.

The number of observed and nominal expected MC events are equal, $m_{b_r} = \tau_{b_r}$. Only for MC toy generation, they can differ where only the observed number of MC events m_{b_r} is varied.

	θ_0	$\Delta\theta_0$
λ	1	0.017
α_i	0	1
γ_{b_r}	1	$\frac{1}{\sqrt{\tau_{b_r}}}$

Table 7.1: Pre-fit nuisance parameter value θ_0 and its pre-fit uncertainty $\Delta\theta_0$ for the nuisance parameters of luminosity λ , systematics α_i and MC statistical uncertainty γ_i . The uncertainty of luminosity is explained in Section 3.2.2.5.

Some of the systematic variations of experimental uncertainties are derived from combined performance groups within ATLAS. They use optimised data selections to minimize the uncertainties. Hence no further reduction of these experimental uncertainties is expected.

The types of uncertainties used in the model construction are summarised in Table 7.1.

7.3.2 The Expected Yield

Each experimental and theoretical systematic uncertainty α_i is split into normalisation $\eta_{r,\text{norm}}^s(\alpha_i)$ and shape $\sigma_{b_r,\text{shape}}^s(\alpha_i)$ effect for the extrapolation. This is done to avoid negative expectations for down pulls of systematic uncertainties which could arise if the total effect would be linearly extrapolated like the shape effects. The expected number of events is:

$$\nu_{b_r}(\gamma_{b_r}, \lambda, \alpha, \phi) = \nu_{b_r}(\mu, \Theta) = \sum_{s \in \text{samples}} \nu_{b_r}^s(\gamma_{b_r}, \lambda, \alpha, \phi), \quad (7.7)$$

with

$$\begin{aligned} \nu_{b_r}^s(\gamma_{b_r}, \lambda, \alpha, \phi) \\ = \lambda \cdot \gamma_{b_r} \left(\nu_{b_r}^{s,\text{nom}} + \sum_{\alpha_i \in \alpha \text{ in } r,s} \sigma_{b_r,\text{shape}}^s(\alpha_i) \right) \prod_{\phi_j \in \phi \text{ in } s} \phi_j \prod_{\alpha_i \in \alpha \text{ in } r,s} \eta_{r,\text{norm}}^s(\alpha_i), \end{aligned} \quad (7.8)$$

with

$$\eta_{r,\text{norm}}^s(\alpha_i) = \begin{cases} \left(\frac{\nu_{r,\text{tot}}^{s,\text{up}_i}}{\nu_{r,\text{tot}}^{s,\text{nom}_i}} \right)^{\alpha_i} & \text{if } \alpha_i \geq 1, \\ 1 + a\alpha_i + b\alpha_i^2 + c\alpha_i^3 + d\alpha_i^4 + e\alpha_i^5 + f\alpha_i^6 & \text{if } |\alpha_i| < 1, \\ \left(\frac{\nu_{r,\text{tot}}^{s,\text{down}_i}}{\nu_{r,\text{tot}}^{s,\text{nom}_i}} \right)^{-\alpha_i} & \text{if } \alpha_i \leq -1, \end{cases} \quad (7.9)$$

$$\sigma_{b_r,\text{shape}}^s(\alpha_i) = \begin{cases} \alpha_i(\nu_{b_r,\text{shape}}^{s,\text{up}_i} - \nu_{b_r}^{s,\text{nom}}) & \text{if } \alpha_i > 1, \\ g\alpha_i + h\alpha_i^2 + y\alpha_i^4 + z\alpha_i^6 & \text{if } |\alpha_i| \leq 1, \\ \alpha_i(\nu_{b_r}^{s,\text{nom}} - \nu_{b_r,\text{shape}}^{s,\text{down}_i}) & \text{if } \alpha_i < -1. \end{cases} \quad (7.10)$$

The expected yield in absence of deviations, i.e. if all variation factors are 1 in the nominal case, is $\nu_{b_r}^{s,\text{nom}}$. The parameters $a, b, c, d, e, f, g, h, y, z$ are fully determined by requiring a smooth transition up to the second derivation at $\alpha_i = -1$ and $\alpha_i = 1$.

The factors γ_{b_r} and λ are not always applied to all samples. Data-driven modelled backgrounds, i.e. non-prompt and conversions backgrounds, are not scaled by the luminosity uncertainty factor λ , because they are derived with a data-driven method for the actual observed integrated luminosity. In fits for observations, the signal sample is not scaled by γ_{b_r} and its MC statistical uncertainty is also not part of γ_{b_r} .

For each systematic uncertainty in each bin the -1σ variation $\nu_{b_r}^{s,\text{down}_i}$ and $+1\sigma$ variation $\nu_{b_r}^{s,\text{up}_i}$ is known as well as the nominal point $\nu_{b_r}^{s,\text{nom}}$. They are split into shape $\nu_{b_r,\text{shape}}^{s,\text{up}_i}$,

$\nu_{b_r, \text{shape}}^{s, \text{down}_i}$ and normalisation effects $\nu_{r, \text{tot}}^{s, \text{up}_i}$, $\nu_{r, \text{tot}}^{s, \text{down}_i}$ according to Equations 7.11 to 7.15. Between $\alpha_i = -1$ and $\alpha_i = 1$ the bin prediction is interpolated. Below $\alpha_i = -1$ and above $\alpha_i = 1$ it is extrapolated. The normalisation effect is 6th-order polynomially interpolated and exponentially extrapolated, the shape effect is 6th-order polynomially interpolated and linearly extrapolated in the fit. The 6-th order polynomial interpolation is chosen such that there is a smooth transition of all derivatives up to the second between the interpolation and extrapolation².

Samples are scaled linearly by unconstrained normalisation factors ϕ_j , if not stated otherwise.

7.3.2.1 Splitting Systematics into Shape and Normalisation Effect

Splitting is applied to avoid unphysical negative predicted yields when a systematic uncertainty is extrapolated to very low values. An exception are interference terms which can be negative already for the nominal prediction. The same procedure is also applied for them to be consistent which ensures, that the sign of the overall effect does not change for varied predictions. During this splitting the normalisation is summed over bins because a consistent shape effect within one fit region is desired. It is not summed over regions, channels or samples because systematics have different effects in e.g. the WZ control region than in the signal region, they are also different for channels, e.g. conversions background is channel dependent, and they are also different for different samples.

The normalisation and shape effect is:

$$\nu_{r, \text{tot}}^{s, \text{nom}_i} = \sum_{b_r \in \text{bins in } r \text{ with systematic } i} \nu_{b_r}^{s, \text{nom}}, \quad (7.11)$$

$$\nu_{r, \text{tot}}^{s, \text{up}_i} = \sum_{b_r \in \text{bins in } r \text{ with systematic } i} \nu_{b_r}^{s, \text{up}_i}, \quad (7.12)$$

$$\nu_{r, \text{tot}}^{s, \text{down}_i} = \sum_{b_r \in \text{bins in } r \text{ with systematic } i} \nu_{b_r}^{s, \text{down}_i}, \quad (7.13)$$

$$\nu_{b_r, \text{shape}}^{s, \text{up}_i} = \nu_{b_r}^{s, \text{up}_i} \cdot \frac{\nu_{r, \text{tot}}^{s, \text{nom}_i}}{\nu_{r, \text{tot}}^{s, \text{up}_i}}, \quad (7.14)$$

$$\nu_{b_r, \text{shape}}^{s, \text{down}_i} = \nu_{b_r}^{s, \text{down}_i} \cdot \frac{\nu_{r, \text{tot}}^{s, \text{nom}_i}}{\nu_{r, \text{tot}}^{s, \text{down}_i}}, \quad (7.15)$$

where

$\nu_{r, \text{tot}}^{s, \text{up}_i}$ is the total integral of up-variation of systematic α_i in fit region r for sample s and

$\nu_{b_r, \text{shape}}^{s, \text{up}_i}$ is the shape only up-variation of α_i in the b -th bin of fit region r for sample s .

7.4 Maximum Likelihood Estimate

The maximum likelihood estimates of μ and Θ are denoted $\hat{\mu}$ and $\hat{\Theta}$. They are derived by choosing them such that the likelihood function $\mathcal{L}(n|\mu, \Theta)$ is maximized:

$$\mathcal{L}(n|\hat{\mu}, \hat{\Theta}) = \max_{\mu, \Theta} \mathcal{L}(n|\mu, \Theta). \quad (7.16)$$

This is called the "signal+background fit" or "unconditional fit" where all nuisance parameters and signal strengths are varied in order to maximize the likelihood function. It is used to derive the measured signal strength $\hat{\mu}$. The optimisation is done numerically via Minuit2 [98, 99] from Root [95].

The estimates $\hat{\Theta}$ and $\hat{\mu}$ are asymptotically consistent and asymptotically unbiased [100]. They also reach the minimum variance bound asymptotically. Asymptotic means for a large

²These are the defaults in the used ROOT 6 version[95], see function `setInterpCode()` in `HistFactory::PiecewiseInterpolation`.

number of events. The maximum likelihood estimators are invariant under parameter transformation: If $\phi = g(\Theta)$, then $\hat{\phi} = g(\hat{\Theta})$. This is used for example for Wilson coefficients in EFT limit setting, which are needed to be estimated in linear and quadratic form.

For unfolding and two-dimensional limit setting there are multiple signal parameters which are later denoted as $\mu \in M$.

For further statistical analysis "conditional fits" are needed, where μ or $\theta \in \Theta$ are fixed to a specific value in the fit. If $\theta \in \Theta$ is fixed, then the set of all remaining nuisance and normalisation parameters is defined as $\Theta_\theta := \Theta \setminus \theta$. All remaining parameters $\hat{\Theta}_\theta(\theta)$ and $\hat{\mu}(\theta)$ are estimated during the maximum likelihood fit. By convention, $\hat{\Theta}(\theta)$ or $\hat{\mu}(\theta)$ are used if only the parameter in parenthesis is set constant and all others are reoptimised. If no parenthesis is added for $\hat{\Theta}$, then the parameters without a hat in the likelihood function $\mathcal{L}$ or yield function ν are fixed during the maximum likelihood fit.

There are several things to take care of during the maximum likelihood optimisation. There can be local extrema or extended extrema as discussed in Ref. [101]. To check for this likelihood scans are performed, see Section 7.4.1. Each of the likelihood scans is checked for a better global extrema than the found extrema. None are found for the results presented in this thesis. To further investigate the maximum likelihood estimates there are several properties which are looked at and summarised in the following subsections.

7.4.1 Likelihood Scan

The likelihood scan shows the ratio of likelihood functions with one parameter fixed. For the signal strength μ it is defined as:

$$-\Delta \ln \mathcal{L} := -\ln \frac{\mathcal{L}(n|\mu, \hat{\Theta})}{\mathcal{L}(n|\hat{\mu}, \hat{\Theta})} = -\ln \mathcal{L}(n|\mu, \hat{\Theta}(\mu)) + \ln \mathcal{L}(n|\hat{\mu}, \hat{\Theta}). \quad (7.17)$$

For other nuisance parameters or normalisation factors $\theta \in \Theta$ it is:

$$-\Delta \ln \mathcal{L} := -\ln \frac{\mathcal{L}(n|\hat{\mu}, \theta, \hat{\Theta}_\theta)}{\mathcal{L}(n|\hat{\mu}, \hat{\Theta})} = -\ln \mathcal{L}(n|\hat{\mu}, \theta, \hat{\Theta}_\theta) + \ln \mathcal{L}(n|\hat{\mu}, \hat{\Theta}). \quad (7.18)$$

The likelihood scan can be interpreted in different ways:

- It can be interpreted as the negative log-likelihood of the conditional fit, with the y-axis adjusted. The y-axis is adjusted such that the minima is at 0 by subtracting the negative log-likelihood of the unconstrained fit. It shows a projection of the maximized multidimensional likelihood function.
- It can be used to read off the asymmetric frequentist constructed standard deviation. In the end, this is how Minos calculates the uncertainty by numerically calculating the intersection with $-\Delta \ln \mathcal{L} = 0.5$.
- It can also be used as likelihood ratio for finding the 5% quantile in limit setting. The diagonal method is used in a wrapper around HistFactory to calculate the crossing with $-\Delta \ln \mathcal{L} = 1.921$ numerically to a precision of 0.2%, see Section 7.6.3.2.
- It can also be used to read off the significance of a process, which is multiplied by the normalisation strength μ , by calculating the value at $\mu = 0$. It is shown in Section 7.6.3.2 that the corresponding significance is $Z = \sqrt{2 \cdot (-\Delta \ln \mathcal{L})}$. The convention in high energy physics is: If it is at least a 3σ deviation, then it is called "evidence" for the process. If it is at least a 5σ deviation, then it is an "observation" of the process.
- The curve is calculated with limited precision to save computational time. From a theoretical point smooth functions are expected. To not hide the limited precision

the calculated points are linearly connected. Only when pulled parameters reach the maximum of 5σ or the bounds of normalisation parameters are reached non-smoothness can occur. These bounds are only reached for significances above 5σ and need to be checked explicitly. For this thesis and the observation paper [74] this was explicitly checked and no 5σ pull was expected nor observed.

- It is also used to check for local minima. If negative $-\Delta \ln \mathcal{L}$ values are observed it indicates, that the found maxima is not the global one.

7.4.2 Uncertainty and Correlation Estimation

It is possible to estimate the standard deviation of a parameter via the likelihood ratio: $-\Delta \ln \mathcal{L} = 0.5$. For the signal strength parameter μ the post-fit uncertainty $\Delta \hat{\mu}^{\text{up/down}}$ is implicitly defined from:

$$-\ln \frac{\mathcal{L}(n|\mu^{\text{up/down}}, \hat{\Theta})}{\mathcal{L}(n|\hat{\mu}, \hat{\Theta})} = 0.5, \quad (7.19)$$

where $\Delta \hat{\mu}^{\text{up}} := \mu^{\text{up}} - \hat{\mu}$ and $\Delta \hat{\mu}^{\text{down}} := \mu^{\text{down}} - \hat{\mu}$.

For all other nuisance parameters the post-fit uncertainty $\Delta \hat{\theta}_i$ is implicitly defined from:

$$-\ln \frac{\mathcal{L}(n|\hat{\mu}, \theta_i^{\text{up/down}}, \hat{\Theta}_{\theta})}{\mathcal{L}(n|\hat{\mu}, \hat{\Theta})} = 0.5, \quad (7.20)$$

where $\Delta \hat{\theta}_i^{\text{up}} := \theta_i^{\text{up}} - \hat{\theta}_i$ and $\Delta \hat{\theta}_i^{\text{down}} := \theta_i^{\text{down}} - \hat{\theta}_i$. For the "unconditional fit" $\hat{\mu}$ is used. For "conditional fits" it can also be set constant to a specific value, e.g. for limit setting, where different μ values are probed.

This asymmetric uncertainty is provided by Minos from Minuit2 within Root. Also a rough symmetric estimate is possible via the inverse of the matrix of second derivatives according to the equation: covariance $V = (\langle \mathcal{I}(\hat{\Theta} \cup \{\hat{\mu}\}) \rangle)^{-1} \approx (\mathcal{I}(\hat{\Theta} \cup \{\hat{\mu}\}))^{-1}$, with the Fisher information $\mathcal{I}(\Theta \cup \{\mu\}) = -\frac{\partial^2 \ln \mathcal{L}(n|\hat{\mu}, \hat{\Theta})}{\partial(\Theta \cup \{\mu\})^2}$. This assumes the large sample limit, that the Fisher information can be estimated from data[100]. The correlation is:

$$C_{ij} = V_{ij} / \sqrt{V_{ii} \cdot V_{jj}}. \quad (7.21)$$

The resulting correlations are provided by Hesse from Minuit2 within Root and later presented in the correlation plots and tables.

Only the more correct estimate from Minos is used as uncertainty in this work. If a symmetric uncertainty is needed, then the uncertainty from Minos is symmetrized. For correlations the result provided by Hesse is used.

7.4.3 Uncertainty of the Signal Strength

The asymmetric uncertainty calculated by Minos is used also for splitting the uncertainty by contribution.

Firstly, the fit is performed with all nuisance parameters not fixed. The resulting uncertainty of the signal strength $\hat{\mu}$ of this fit corresponds to the total uncertainty $(\Delta \hat{\mu}^{\text{down, total}}, \Delta \hat{\mu}^{\text{up, total}})$. In the following steps, nuisance parameters are set to the resulting values from this initial fit, if they are set constant. The calculation is only shown for the up uncertainty. The equation for down is the same after replacing "up" with "down". The systematic uncertainties are split into the groups modelling, experimental and luminosity uncertainty: $\Theta_{\text{mod.}} \cup \Theta_{\text{exp.}} \cup \{\lambda\} = \Theta$.

Secondly, the fit is repeated with the luminosity parameter λ set constant. The uncertainty contribution of the luminosity can be calculated as:

$$\Delta\hat{\mu}^{\text{up, lumi}} := \sqrt{(\Delta\hat{\mu}^{\text{up, total}})^2 - (\Delta\hat{\mu}^{\text{up}}(\hat{\lambda}))^2}, \quad (7.22)$$

where $\Delta\hat{\mu}^{\text{up}}(\hat{\lambda}) := \mu^{\text{up, lumi}}(\hat{\lambda}) - \hat{\mu}$, with:

$$-\ln \frac{\mathcal{L}(n|\mu^{\text{up, lumi}}, \lambda = \hat{\lambda}, \hat{\Theta}_{\text{mod.}}, \hat{\Theta}_{\text{exp.}})}{\mathcal{L}(n|\hat{\mu}, \hat{\Theta})} = 0.5. \quad (7.23)$$

Then, the fit is performed with additionally all modelling uncertainties $\Theta_{\text{mod.}} \subset \Theta$ according to Table 6.5 and e.g. 6.6 set to constant:

$$\Delta\hat{\mu}^{\text{up, mod}} := \sqrt{(\Delta\hat{\mu}^{\text{up}}(\hat{\lambda}))^2 - (\Delta\hat{\mu}^{\text{up}}(\hat{\lambda}, \hat{\Theta}_{\text{mod.}}))^2}, \quad (7.24)$$

where $\Delta\hat{\mu}^{\text{up}}(\hat{\lambda}, \hat{\Theta}_{\text{mod.}}) := \mu^{\text{up, lumi, mod}}(\hat{\lambda}, \hat{\Theta}_{\text{mod.}}) - \hat{\mu}$, with $\mu^{\text{up, lumi, mod}}$ chosen such that:

$$-\ln \frac{\mathcal{L}(n|\mu^{\text{up, lumi, mod}}, \lambda = \hat{\lambda}, \Theta_{\text{mod.}} = \hat{\Theta}_{\text{mod.}}, \hat{\Theta}_{\text{exp.}})}{\mathcal{L}(n|\hat{\mu}, \hat{\Theta})} = 0.5. \quad (7.25)$$

Afterwards, it is performed with additionally all experimental modelling uncertainties according to Table 6.1 and 6.2 set to constant:

$$\Delta\hat{\mu}^{\text{up, exp}} := \sqrt{(\Delta\hat{\mu}^{\text{up}}(\hat{\lambda}, \hat{\Theta}_{\text{mod.}}))^2 - (\Delta\hat{\mu}^{\text{up}}(\hat{\lambda}, \hat{\Theta}_{\text{mod.}}, \hat{\Theta}_{\text{exp.}}))^2}, \quad (7.26)$$

where $\Delta\hat{\mu}^{\text{up}}(\hat{\lambda}, \hat{\Theta}_{\text{mod.}}, \hat{\Theta}_{\text{exp.}}) := \mu^{\text{up, lumi, mod, exp}}(\hat{\lambda}, \hat{\Theta}_{\text{mod.}}, \hat{\Theta}_{\text{exp.}}) - \hat{\mu}$, with $\mu^{\text{up, lumi, mod, exp}}$ chosen such that:

$$-\ln \frac{\mathcal{L}(n|\mu^{\text{up, lumi, mod, exp}}, \lambda = \hat{\lambda}, \Theta_{\text{mod.}} = \hat{\Theta}_{\text{mod.}}, \Theta_{\text{exp.}} = \hat{\Theta}_{\text{exp.}})}{\mathcal{L}(n|\hat{\mu}, \hat{\Theta})} = 0.5. \quad (7.27)$$

The uncertainty of the last fit corresponds to the stat only uncertainty and is

$$\Delta\hat{\mu}^{\text{up, stat}} := \Delta\hat{\mu}^{\text{up}}(\hat{\lambda}, \hat{\Theta}_{\text{mod.}}, \hat{\Theta}_{\text{exp.}}). \quad (7.28)$$

By construction it is:

$$\Delta\hat{\mu}^{\text{up, total}} = \sqrt{(\Delta\hat{\mu}^{\text{up, stat}})^2 + (\Delta\hat{\mu}^{\text{up, mod}})^2 + (\Delta\hat{\mu}^{\text{up, exp}})^2 + (\Delta\hat{\mu}^{\text{up, lumi}})^2}. \quad (7.29)$$

7.4.3.1 Systematic Break Down of Uncertainties

For a more detailed break down of uncertainties the nuisance parameters are split into smaller groups. The contribution of a group is calculated as above by calculating the quadratic difference between the two fits, where the group was set constant in the second fit. The content of each group is shown in Table 6.1, 6.2, 6.5 and e.g. 6.6. The nuisance parameters are set constant in the following order:

1. Luminosity
2. Electron calibration
3. Muon calibration
4. Jet energy scale and resolution

5. E_T^{miss} scale and resolution
6. b -tagging inefficiency
7. Pileup modelling
8. Background, misid. leptons
9. Background, charge misrec.
10. Background, WZ reweighting
11. Model statistical
12. Background, other
13. $W^\pm W^\pm \text{jj}$ shower, scale, PDF & α_s
14. QCD $W^\pm W^\pm \text{jj}$, shower, scale, PDF & α_s
15. QCD $W^\pm W^\pm \text{jj}$, QCD corrections
16. Int $W^\pm W^\pm \text{jj}$, shower, scale, PDF & α_s
17. EW $W^\pm W^\pm \text{jj}$, shower, scale, PDF & α_s
18. EW $W^\pm W^\pm \text{jj}$, QCD corrections
19. EW $W^\pm W^\pm \text{jj}$, EW corrections
20. Background, WZ scale, PDF & α_s

7.4.4 Pre- and Post-Fit Plots and Tables

The pre-fit (post-fit) plots and tables show the yields in each bin including uncertainties before (after) the fit. The pre- and post-fit yields can be shown summed over any fit regions r' , bins $b'_{r'}$ and samples s' . It is described here for a "bin u " which is a partial or total sum over these dimensions.

The tables and plots show the nominal yield ν_u^{nom} and its uncertainty $\Delta\nu_u^{\text{nom}}$.

The pre-fit yields $\nu_{u,\text{pre}}^{\text{nom}}$ and up/down-variation in bin u for each nuisance parameter i , excluding normalisation factors ϕ , are:

$$\nu_{u,\text{pre}}^{\text{nom}} := \sum_{r',s',b'_{r'}} \nu_{b'_{r'}}^{s'}(\mu_0, \Theta_0), \quad (7.30)$$

$$\nu_{u,\text{pre}}^{\text{up/down}_i} := \sum_{r',s',b'_{r'}} \nu_{b'_{r'}}^{s'}(\mu_0, \theta_{i,0} \pm \Delta\theta_{i,0}, \Theta_{\theta,0}), \quad (7.31)$$

where the pre-fit nuisance parameter values and uncertainties are shown in Table 7.1. The pre-fit values of the normalisation factors ϕ_0 depend on the sample. For SM processes they are set to 1 and for BSM processes to 0 if not stated otherwise. The post-fit values and uncertainties for systematic i are:

$$\nu_{u,\text{post}}^{\text{nom}} := \sum_{r',s',b'_{r'}} \nu_{b'_{r'}}^{s'}(\hat{\mu}, \hat{\Theta}), \quad (7.32)$$

$$\nu_{u,\text{post}}^{\text{up/down}_i} := \sum_{r',s',b'_{r'}} \nu_{b'_{r'}}^{s'}(\hat{\mu}, \theta_i^{\text{up/down}}, \hat{\Theta}_\theta), \quad (7.33)$$

where the post-fit nuisance parameter values are used. In the "unconditional fit" $\hat{\mu}$ is used, for "conditional fits" μ can be set constant to a specific value. The value of $\theta_i^{\text{up/down}}$ is determined according to Equation 7.20.

In Equation 7.33 one could also use the conditional best-fit values $\hat{\mu}$ and $\hat{\Theta}_\theta$. But this would

require more computational time to include in the statistical analysis. The above equation is on average more conservative than this, but only impacts the yield tables and plots and not the main results like the measured cross-section including uncertainties or limits.

The uncertainty of each nuisance parameter gets symmetrized:

$$\nu_{u,pre/post}^{unc_i} = \frac{|\nu_{u,pre/post}^{up_i} - \nu_{u,pre/post}^{nom}| + |\nu_{u,pre/post}^{down_i} - \nu_{u,pre/post}^{nom}|}{2}. \quad (7.34)$$

The pre-fit uncertainty is the quadratic sum over $\nu_{u,pre/post}^{unc_i}$ of the nuisance parameters i in the considered category c :

$$\Delta_c \nu_{u,pre}^{nom} = \sqrt{\sum_{\theta_i \in \text{category } c} (\nu_{u,pre}^{unc_i})^2} \quad (7.35)$$

For post-fit uncertainties the correlation matrix C from Equation 7.21 is included in the combination:

$$\Delta_c \nu_{u,post}^{nom} = \sqrt{\sum_{\theta_i, \theta_j \in \text{category } c} \nu_{u,post}^{unc_i} C_{ij} \nu_{u,post}^{unc_j}} \quad (7.36)$$

In this equation it is assumed, that an up variation of nuisance parameter θ_i results in an up variation of the expected yield of the sum of all samples and bins, i.e. $\nu_{total,post}^{up_i} > \nu_{total,post}^{down_i}$. If this is not the case, then the correlation needs to be multiplied by -1. This is implemented by multiplying $\nu_{u,post}^{unc_i}$ or $\nu_{u,post}^{unc_j}$ with -1 when the systematic i or j are defined with inverse total predicted up- and down-yields.

The uncertainty is split into the three categories for pre-and post-fit tables: statistical, modelling and systematic uncertainty. In pre-fit tables the statistical part contains the MC statistical uncertainty. For post-fit tables only the effect of signal strength μ is grouped into the statistical component and is taken from a fit with only statistical uncertainties. The splitting into modelling and experimental uncertainty is done according to Section 6.5.

The uncertainty shows how much the bin yield varies within the uncertainty of all included nuisance parameters.

7.4.5 Pull Plot

The pull plot shows for each parameter $\theta_i \in \Theta$ the post-fit value $\hat{\theta}_i$ and uncertainty $\Delta\hat{\theta}_i$ relative to the pre-fit value $\theta_{i,0}$ and its pre-fit uncertainty $\Delta\theta_{i,0}$. The pre-fit nominal value $\phi_{i,0}$ and uncertainty $\Delta\phi_{i,0}$ for normalisation parameters is not well defined because there is no external constraint. By definition $\phi_{i,0} = 0$ and $\Delta\phi_{i,0} = 1$ are chosen in the pull plot, such that the absolute post-fit value and uncertainty correspond to the shown y-axis-values.

It serves as a diagnostic plot to quickly see which parameters are pulled the most and which are constrained the most. Pulled means that the best-fit value deviates in terms of standard deviations from the pre-fit value. These pulled parameters help the most to bring the prediction closer to the observation. A nuisance parameter is constrained when the uncertainty is smaller post-fit than pre-fit. It means that the observed data helps to reduce the uncertainty on this parameter. This should only affect modelling uncertainties, because experimental uncertainties are already constrained pre-fit in dedicated phase space regions during the calibration.

7.4.6 Impact and Ranking Plot

For four variations of each nuisance parameter θ_i the resulting $\hat{\mu}(\theta_i)$ is compared to the nominal signal strength $\hat{\mu}$. The difference $\Delta\mu_i(\theta_i)$ is plotted in the ranking plot, defined as:

$$\Delta\mu_i(\theta_i) := \hat{\mu}(\theta_i) - \hat{\mu}. \quad (7.37)$$

For the pre-fit uncertainty impact the two values $\theta_i = \theta_{i,0} \pm \Delta\theta_{i,0}$ are tested. For the post-fit impact, the values $\theta_i = \hat{\theta}_i + \Delta\hat{\theta}_i^{up}$ and $\theta_i = \hat{\theta}_i - \Delta\hat{\theta}_i^{down}$ are tested.

In the ranking plots, nuisance parameters are sorted/ranked by the absolute post-fit impact:

$$\max_{\theta_i = \hat{\theta}_i \pm \Delta \hat{\theta}_i^{\text{up/down}}} |\Delta \mu_i(\theta_i)|. \quad (7.38)$$

The ranking plot includes also the pull information, which is explained in Section 7.4.5.

This diagnostic plot helps to identify the nuisance parameters which influence the parameter of interest the most within their uncertainties, i.e. which are ranked highest. The highest ranked nuisance parameters are thus the dominant sources of uncertainties. It is important to understand them in more detail to make sure that they are correctly modelled. To get more precise results in future analysis these are also the first candidates to determine with lower uncertainties pre-fit, e.g. by using a higher order signal sample, if higher order correction uncertainties are ranked high.

7.5 Cross Section Measurement

The expected, measured and predicted cross-sections are compared in the fiducial region. The fiducial region is defined in Section 5.4 and the calculation of theory predictions are described in Section 4.1.

The predicted (from fit to Asimov data) and measured (from fit to data) fiducial cross-sections are derived from:

$$\sigma_{\text{meas}}^{\text{fid}} = \sigma_{\text{pred}}^{\text{fid}} \cdot \hat{\mu}, \quad (7.39)$$

$$\Delta \sigma_{\text{meas}}^{\text{fid}} = \sigma_{\text{pred}}^{\text{fid}} \cdot \Delta \hat{\mu}, \quad (7.40)$$

where $\Delta \hat{\mu}$ is the uncertainty on the signal strength $\hat{\mu}$.

In principle, both $\sigma_{\text{pred}}^{\text{fid}}$ and $\hat{\mu}$ are affected by pulls of modelling nuisance parameters $\hat{\theta}_i$ of the signal in the calculation of the measured cross-section.

The nominal fiducial prediction $\sigma_{\text{pred}}^{\text{fid}}(\theta_i = 0)$ is multiplied by the scaling factor

$$F_{\text{fid.PS}}^{\hat{\theta}_i} := \frac{\text{sum of weights of variation } \hat{\theta}_i \text{ in fiducial phase space}}{\text{sum of nominal weights in fiducial phase space}}, \quad (7.41)$$

to get the fiducial cross-section prediction $\sigma_{\text{pred}}^{\text{fid}}(\hat{\theta}_i) = \sigma_{\text{pred}}^{\text{fid}}(\theta_i = 0) \cdot F_{\text{fid.PS}}^{\hat{\theta}_i}$. The factor $F_{\text{fid.PS}}^{\hat{\theta}_i}$ is only precisely calculated for $\hat{\theta}_i = \pm 1$, for other points some interpolation and extrapolation needs to be assumed as later derived in Equation 7.48. The measured signal strength $\hat{\mu}$ also depends on $\hat{\theta}_i$ via the expected yield $\nu_{b_r}^{\text{signal, up}_i/\text{down}_i}$ of the signal.

To simplify the calculation and correctly consider the correlation between these two terms in equation 7.39, the scaling factor of $\sigma_{\text{pred}}^{\text{fid}}$ is moved into the determination of $\hat{\mu}$, such that only the effect on $\hat{\mu}$ needs to be considered as shown in equation 7.40. The measured cross-section is for the best-fit result ($\hat{\mu} = \hat{\mu}$) and any variation ($\hat{\mu}$ according to Equation 7.19):

$$\sigma_{\text{meas, (varied)}}^{\text{fid}} = \sigma_{\text{pred}}^{\text{fid}}(\hat{\theta}_i) \cdot \hat{\mu}(\hat{\theta}_i, \nu_{b_r}^{\text{signal, up}_i/\text{down}_i}) \quad (7.42)$$

$$= \sigma_{\text{pred}}^{\text{fid}}(\theta_i = 0) \cdot F_{\text{fid.PS}}^{\hat{\theta}_i} \cdot \hat{\mu}(\hat{\theta}_i, \nu_{b_r}^{\text{signal, up}_i/\text{down}_i}) \quad (7.43)$$

$$= \sigma_{\text{pred}}^{\text{fid}}(\theta_i = 0) \cdot \hat{\mu}(\hat{\theta}_i, \nu_{b_r, \text{scaled}}^{\text{signal, up}_i/\text{down}_i}), \quad (7.44)$$

where $\nu_{b_r, \text{scaled}}^{\text{signal, up}_i/\text{down}_i}$ is implicitly defined by:

$$\hat{\mu}(\hat{\theta}_i, \nu_{b_r, \text{scaled}}^{\text{signal, up}_i/\text{down}_i}) = F_{\text{fid.PS}}^{\hat{\theta}_i} \cdot \hat{\mu}(\hat{\theta}_i, \nu_{b_r}^{\text{signal, up}_i/\text{down}_i}). \quad (7.45)$$

In the following, it will be shown that:

$$\nu_{b_r, \text{scaled}}^{\text{signal, up}_i/\text{down}_i} = \nu_{b_r}^{\text{signal, up}_i/\text{down}_i} \cdot \frac{1}{F_{\text{fid.PS}}^{\text{up}_i/\text{down}_i}} \quad (7.46)$$

fulfils this implicit equation, with the scaling factor:

$$F_{\text{fid.PS}}^{\text{up}_i/\text{down}_i} := \frac{\text{sum of weights of up}_i/\text{down}_i\text{-variation in fiducial phase space}}{\text{sum of nominal weights in fiducial phase space}}. \quad (7.47)$$

Scaling the expected yield $\nu_{b_r}^{\text{signal, up}_i/\text{down}_i}$ only affects the normalisation factors $\nu_{r,\text{tot}}^{\text{signal, up}_i/\text{down}_i}$ and not the shape factors $\nu_{r,\text{shape}}^{\text{signal, up}_i/\text{down}_i}$ according to Equation 7.11 to 7.15. According to Equation 7.8, the factor $\frac{1}{F_{\text{fid.PS}}^{\text{up}_i/\text{down}_i}}$ gets propagated to the expected yield as multiplicative factor next to the signal strength $\hat{\mu}$ with some assumed inter- and extrapolation according to Equation 7.9. To cancel the fiducial cross-section factor $F_{\text{fid.PS}}^{\hat{\theta}_i}$, the inverse needs to be applied when scaling the up and down variation of the uncertainty, as done in Equation 7.46.

The resulting interpolation and extrapolation which is assumed for scaling the predicted fiducial cross-section is:

$$F_{\text{fid.PS}}^{\hat{\theta}_i} = \begin{cases} (F_{\text{fid.PS}}^{\text{up}_i})^{\hat{\theta}_i} & \hat{\theta}_i > 1, \\ \text{smooth interpolation} & \hat{\theta}_i \leq |1|, \\ (F_{\text{fid.PS}}^{\text{down}_i})^{-\hat{\theta}_i} & \hat{\theta}_i < -1. \end{cases} \quad (7.48)$$

The interpolation corresponds to the ratio of the interpolation with and without normalised yields, where both numerator and denominator are 6-th order polynomials. The extra- and interpolation is chosen such that the normalisation in Equation 7.46 cancels it. But it is also well-motivated on its own. It is a normalisation effect with its typical extrapolation to avoid negative predictions for down-pulls. The interpolation has a smooth connection to extrapolation until second order and equals 1 for $\hat{\theta}_i = 0$.

This means that the uncertainty of the signal strength $\Delta\hat{\mu}$ does not include the normalisation effect of the modelling uncertainties.

Theory uncertainties affect all: the expected, measured and predicted cross-section.

In the expected and measured fiducial cross-section the normalisation is determined from the fit to data. Only the shape effect needs to be considered. To achieve this, all theory variations are normalised to nominal in the fiducial region as motivated in Equation 7.46 and implemented in Section 6.4.

Experimental uncertainties only have an effect on the expected and measured cross-section and are included in the fit ending up in the uncertainty $\Delta\hat{\mu}$.

The equations presented here are also true for differential cross-section measurements. They can be interpreted as a fiducial cross-section measurement, where the fiducial phase space includes only one unfolded bin at a time.

7.6 Looking for Signal with Test Statistic

It is not possible to prove that a theory is correct. But a valid statement for example is that the null hypothesis H_0 is very unlikely compared to an alternative hypothesis H_1 . To do so a test statistic t is defined which quantifies with which hypothesis data agrees better. In this work the likelihood ratio, which is proven to have maximal power[100], is used as test statistic for differentiating two hypotheses: $t = -2 \ln \frac{\mathcal{L}(n|H_0)}{\mathcal{L}(n|H_1)}$.

The different hypotheses used for observation and limit setting are summarised in Table 7.2.

A fixed μ is used in the likelihood of the null hypothesis H_0 . The nuisance parameters Θ are estimated to be $\hat{\Theta}$ which maximizes $\mathcal{L}(n|\mu, \hat{\Theta})$ for the fixed μ , called maximum likelihood estimate:

$$\mathcal{L}(n|\mu, \hat{\Theta}) = \max_{\Theta} \mathcal{L}(n|\mu, \Theta). \quad (7.49)$$

	H0 signal strength	H1 signal strength	raw test statistic
observation	$\mu = 0$	any $\hat{\mu}$	$t_0 = -2 \ln \frac{\mathcal{L}(n \mu=0, \hat{\Theta})}{\mathcal{L}(n \hat{\mu}, \hat{\Theta})}$
limit setting	fixed μ	any $\hat{\mu}$	$t_\mu = -2 \ln \frac{\mathcal{L}(n \mu, \hat{\Theta})}{\mathcal{L}(n \hat{\mu}, \hat{\Theta})}$

Table 7.2: Hypotheses and raw test statistics used for observations and limit setting.

The likelihood function $\mathcal{L}(n|\mu=0, \hat{\Theta})$ is not used directly as test statistic, because this would describe how well our understanding of the detector and all other physics processes are. It is not sensitive to the question: Does the data agree better with a model with a certain signal strength or not? A deviation could also just be caused by completely different effects. A deviation would just indicate that there is a deviation, but not whether there is a model that can cover that deviation. Hence the likelihood ratio is used.

7.6.1 Test Statistic for Observation

The raw test statistic for observations is $t_0 = -2 \ln \frac{\mathcal{L}(n|\mu=0, \hat{\Theta})}{\mathcal{L}(n|\hat{\mu}, \hat{\Theta})}$. But there is typically a physical boundary: The signal strength should not be negative. It should not be called an observation if we see fewer events than background-only expected, while the alternate model does not allow a negative number of signal events. Therefore a modified test statistic q_0 is used:

$$q_0 := \begin{cases} -2 \ln \frac{\mathcal{L}(n|\mu=0, \hat{\Theta})}{\mathcal{L}(n|\hat{\mu}, \hat{\Theta})} & \hat{\mu} \geq 0 \\ 0 & \hat{\mu} < 0 \end{cases} \quad (7.50)$$

The test statistic q_0 sets half of the test statistic values distributed around the background-only hypothesis to 0. The raw test statistic t_0 is only 0 for the best fit value $\mu = \hat{\mu}$. The larger the test statistic value the more H_1 agrees with data compared to H_0

7.6.2 Test Statistic for Limit Setting

The raw test statistic for limit setting is:

$$t_\mu = -2 \ln \frac{\mathcal{L}(n|\mu, \hat{\Theta})}{\mathcal{L}(n|\hat{\mu}, \hat{\Theta})}. \quad (7.51)$$

This is the test statistic which is used to set limits on EFT parameters. An exclusion of the SM can happen for this test statistic. Several different test statistics and methods are considered which can not exclude the SM, but are explicitly not chosen.

There are two different choices motivated by a physical boundary which avoid SM exclusion [102, 103]:

1. different test statistic for $\hat{\mu} < 0$ and $\hat{\mu} > \mu$, called $\tilde{q}_\mu$, defined in Ref. [103] and
2. other H_1 hypothesis: $\mu = 0$ handled with conservative CLs method.

For the combination between CMS and ATLAS in 2011 for the Higgs boson search, see Ref. [104], the test statistic $\tilde{q}_\mu$ together with the CLs method was used. The main reasons to use t_μ in this thesis are:

- there is no physical boundary for EFT limits,

- a correct 95% coverage, i.e. no conservative approach which loses information, is desired, and
- the 95% interval should include the theory predictions which describe observed data best.

7.6.3 The p -Value of the Test Statistic Value

The final decision to reject a hypothesis is done via the p -value $P(q_{0,obs}|\mu = 0)$. It quantifies how probable it is to measure something like the observed test statistic value or something more extreme. For observations it is defined as:

$$P(q_{0,obs}|\mu = 0) := \int_{q_{0,obs}}^{\inf} f(q_0|\mathcal{L}(n|\mu = 0, \Theta)) dq_0, \quad (7.52)$$

where $f(q_0|\mathcal{L}(n|\mu = 0, \Theta))$ is the probability distribution to measure q_0 given data n distributed according to probability $\mathcal{L}(n|\mu = 0, \Theta)$ ³.

The test statistic q_0 from Equation 7.50 was used for the observation of the EW $W^\pm W^\pm jj$ process with the partial Run 2 data [74]. The binning was optimised, including the discriminating variable choice, such that the background-only fit to signal+background Asimov data is unlikely.

To calculate the p -value, the expected distribution of $f(q_{\mu'}|\mathcal{L}(n|\mu, \Theta))$ is needed. It can be calculated numerically with (Monte Carlo) toys or calculated asymptotically analytically. In the toy-driven approach possible observed data are generated according to the pdf. For each of these pseudo data, called toy, the test statistic is calculated - resulting in the expected distribution of test statistic values. In the large sample limit, the distribution can be calculated with the asymptotic formula [103] which is mainly used in this thesis.

7.6.3.1 Toys for p -Value Calculation

With toys test statistic values are generated according to the assumed underlying probability density functions. The distribution of test statistic values can then be used to calculate the quantile of the observed data which is the observed p -values.

An unconditional ensemble [105] is used where all observed values are varied during toy generation. The varied observed values are the observed data in each bin n_{b_r} which are Poisson distributed around mean ν_{b_r} and the observed values in auxiliary measurements:

- the observed luminosity λ_0 which is Gaussian distributed around mean 1 with standard deviation $\Delta\lambda_{\text{nom}}$,
- the observed weighted summed number of MC events in each bin m_{b_r} which are Poisson distributed around mean τ_{b_r} and
- the observed systematic value if the i -th systematic $\alpha_{i,0}$ which is Gaussian distributed around mean 0 with standard deviation 1.

This approach is computationally expensive:

- for observation: $\approx 10^8$ toys⁴ are needed, where for each of the toys, a S+B fit and a Bkg-only fit needs to be performed to calculate the test statistic value,
- for limit setting: 2000 - 5000 toys are needed, see Section 7.10, with each a S+B fit and a fit for each parameter point ($\approx 10^2$) is needed

The function "ToyMCSampler" implemented in the software RooStats[96] is used to generate the toys and calculate the test statistic value for each toy.

³Here, $\mathcal{L}$ is normalised to 1 over all possible observations n such that it can be interpreted as a probability density function.

⁴The significance of 5σ corresponds to 1 in $3 \cdot 10^7$ cases.

7.6.3.2 Asymptotic Formula for p -Value Calculation

The underlying test statistic of q_0 is t_0 which is a special case of t_μ . In this section t_μ is studied whose results can thus also be applied to q_0 .

A generalized test statistic t_M of t_μ is studied with r parameters of interest for 2D limit setting ($r = 2; M = (\mu_1, \mu_2)$), 1D limit setting ($r = 1; M = \mu_1$) and observation ($r = 1; M = \mu = 0$):

$$M := (\mu_1, \dots, \mu_r), \quad (7.53)$$

$$t_M := -2 \ln \frac{\mathcal{L}(n|M, \hat{\Theta})}{\mathcal{L}(n|\hat{M}, \hat{\Theta})}. \quad (7.54)$$

For expected limit intervals the expected probability density function of t_M for assumed true value M' is needed. This is proven by Wald [106] to be non-central χ^2 distributed in the asymptotic case for a large number of expected events ν [107]:

$$f(t_M|\Lambda, r) = \frac{1}{2} e^{-(t_M + \Lambda)/2} \left(\frac{t_M}{\Lambda} \right)^{(r/4 - 1/2)} I_{r/2-1}(\sqrt{\Lambda t_M}), \quad (7.55)$$

with the non-centrality parameter Λ and the modified Bessel function $I_\nu(y)$

$$\Lambda(M, M') := \sum_{i,j=1}^r (\mu_i - \mu'_i) \tilde{V}_{ij}^{-1} (\mu_j - \mu'_j), \quad (7.56)$$

$$I_\nu(y) := (y/2)^\nu \sum_{j=0}^{\infty} \frac{(y^2/4)^j}{j! \Gamma(\nu + j + 1)}, \quad (7.57)$$

where Γ is the Gamma function⁵ and $\tilde{V}^{-1}$ the inverse of the covariance matrix of the signal parameters.

For $r = 1$ degree of freedom this becomes [103]:

$$f(t_M|\Lambda) = \frac{1}{2\sqrt{t_M}} \frac{1}{\sqrt{2\pi}} \left[\exp\left(-\frac{1}{2}(\sqrt{t_M} + \sqrt{\Lambda})^2\right) + \exp\left(-\frac{1}{2}(\sqrt{t_M} - \sqrt{\Lambda})^2\right) \right]. \quad (7.58)$$

For p -value calculation the cumulative distribution function (cdf) $F_r(t_M|M')$ is needed. For two dimensional, i.e. $r = 2$, cdf $F_r(t_M|M')$ is calculated numerically⁶ by summing over the pdf $f(t_M|\Lambda, r)$ starting with the lowest t_M value. They result in the median, which is the 50% quantile of $F_r(t_M|M')$. The 1σ band which is expected to include the observed limits in 68.3% of the cases is defined by the 15.87%- and 84.13%-quantile. The 2σ band which is expected to include the observed limits in 95.4% of the cases is defined by the 2.28%- and 97.72%-quantile of $F_r(t_M|M')$. The 2D limit plots are created by scanning a 41 x 41 grid and calculating for each point $F_r(t_M|M')$ numerically. The median and 1, 2 σ bands are drawn as contours along the corresponding quantiles of $F_r(t_M|M')$.

There is a difference between median expected limits and Asimov expected limits in 1D and 2D limits [108, 109]. In 1D limits the Asimov expected limits are shown. In 2D the median expected limits are shown to be placed in the middle of the 1 and 2 σ expected bands.

In the case $M = M'$ the cdf F_r is central chi-squared distributed [110]. It is [111]:

$$F_r(t_M|M) = \frac{\gamma(\frac{r}{2}, \frac{t_M}{2})}{\Gamma(\frac{r}{2})}, \quad (7.59)$$

with the lower incomplete gamma function $\gamma(s, t)$:

$$\gamma(s, t) = \int_0^t t^{s-1} e^{-t} dt. \quad (7.60)$$

⁵The Gamma function is recursively defined: $\forall n \in \mathcal{N} : \Gamma(n) = (n-1)!$ and $\forall z \in \mathcal{C}$ with $\Re(z) > 0 : \Gamma(z) = \int_0^\infty x^{z-1} e^{-x} dx$.

⁶The cdf is calculated with the class <https://root.cern/doc/master/classRooNonCentralChiSquare.html>.

Necessary conditions for Wilks' theorem
ASYMPTOTIC: Sufficient data is observed.
INTERIOR: Only values of μ and θ which are far from the boundaries of their parameter space are admitted.
IDENTIFIABLE: Different values of the parameters specify distinct models.
NESTED: H_0 is a limiting case of H_1 , e.g. with some parameter fixed to a sub-range of the entire parameter space.
CORRECT: The true model is specified either under H_0 or under H_1 .

Figure 7.1: Conditions under which t_μ is χ^2 distributed from Ref. [112].

For $r = 2$ degrees of freedom this becomes:

$$F_2(t_M|M) = 1 - e^{-\frac{t_M}{2}}, \quad (7.61)$$

since $\Gamma(1) = 1$ and $\gamma(1, x) = 1 - e^{-x}$.

Equation 7.61 is used to calculate the observed 2D limits by drawing the contour at $F_2(t_M|M) = 0.05$. The resulting area includes the one true theory with 95% if the true theory can be parametrized as assumed in the EFT ansatz.

For $r = 1$ degree of freedom $F_1(t_M|M)$ is [103]:

$$F_1(t_M|M) = 2\Phi(\sqrt{t_M}) - 1, \quad (7.62)$$

where Φ is the cumulative distribution function of the standard Gaussian with mean zero and standard deviation one.

It can be shown that [103, 106]:

$$t_M = -2 \ln \lambda(M) = \sum_{i,j=1}^r (\mu_i - \hat{\mu}_i) \tilde{V}_{ij}^{-1} (\mu_j - \hat{\mu}_j) + \sum_{binsb} \mathcal{O} \frac{1}{\sqrt{\nu_b}}. \quad (7.63)$$

With a large dataset, it is shown, in Ref. [103] that an Asimov dataset can be used to estimate M' . Because the Asimov dataset corresponds to M' , it is $\hat{M} = M'$. With this, the estimate for Λ is:

$$t_M(M') = -2 \ln \lambda_A(M) \approx \sum_{i,j=1}^r (\mu_i - \mu'_i) \tilde{V}_{ij}^{-1} (\mu_j - \mu'_j) = \Lambda. \quad (7.64)$$

The non-centrality parameter Λ could be calculated from the to be estimated covariance V with Equation 7.56. But as shown in Ref. [103] it turns out to be more accurate to use Equation 7.64.

At the end, the p -value is calculated as:

$$p(t_M|M') = 1 - F_r(t_M|M'). \quad (7.65)$$

The significance Z is:

$$Z_\mu = \Phi^{-1}(1 - p). \quad (7.66)$$

For the special case $M = M'$ and $r = 1$ it is shown in Ref. [103], that:

$$Z_0 = \sqrt{q_0}. \quad (7.67)$$

These asymptotic results rely on the assumption, that t_μ is χ^2 distributed. To verify this the five criteria from [112], summarised in Figure 7.1, are checked to be fulfilled. Monte Carlo methods are used to check whether the "asymptotic" assumption is also valid. In Section D.1 toys and asymptotic formula are compared for EFT limit setting and good agreement is found.

7.7 Handling of Observed Data

Some special treatment is used for observed data. It is blinded in the analysis and is presented with frequentist uncertainty bars in pre- and post-fit plots.

7.7.1 Blinding Observed Data

The analysis strategy, including event selection and binning, is optimised without looking into observed data in the signal region. Only simulated and data-driven estimated data, derived from the sum of expected theory predictions and of data driven estimated backgrounds in other regions, called the Asimov data set, is used. The aim of this is to not optimise into statistical fluctuations. There are always statistical fluctuations due to the Poisson distribution of data around the true underlying theory. If one chooses to include only those bins in the fit where there is a up fluctuation observed in data, one could increase the "observed significance" artificially. Therefore the event selection and binning are optimised without knowing the observed data in the signal region. In principle also MC events are affected by statistical fluctuations, and it would be best to only use fully analytical predictions for the event selection optimisation. Unfortunately, this is not available for the studied $W^\pm W^\pm jj$ process. Because of this it is important that there are enough MC events in each bin to not optimise into MC statistical fluctuations. At least one MC events for each background process and at least 10 MC events in each bin are required. Since there are at least 10 times more MC events generated than expected in data these requirements are sufficient because the local significance is still dominated by the statistical uncertainty of data.

7.7.2 Uncertainty of Observed Data

There are different ways to quantify the uncertainty of observed data [113]. The frequentist approach is used in this thesis for observed data. The error bars are drawn such that the theories covered by the uncertainty bars would expect the observed data deviation in at least 68% of the most likely cases. The 68% interval around each predicted Poisson distribution is chosen such that 16% are excluded in each of the two tails. In contrast to this plain Poisson uncertainties, i.e. the square root of the predicted number of data events, are used for expected data.

7.8 Significance Estimation in Binning Optimisation

This calculation is inspired by and similar to the one in [114]. The following calculation is meant to be more general, more extensive and closer to the formalism in the rest of the thesis. More general means, that it should not only apply for observation and not only for one bin, but also for limit setting and multiple bins. As shown above, the quantity to measure and optimise is the significance calculated with the Wald approximation:

$$Z_{\text{gen}}(\mu) = \sqrt{-2 \ln \frac{\mathcal{L}(n|\mu, \hat{\hat{\theta}})}{\mathcal{L}(n|\hat{\mu}, \hat{\theta})}} \quad (7.68)$$

In the binning and signal region optimisation a simplified form is needed to save computation time. It is shown later in Section 7.8.2 that with this simplified approach the significance can be calculated in each bin separately and quadratically added for expected significances. First, the significance calculation for one bin is shown in Section 7.8.1. Afterwards, it is generalized to multiple bins in Section 7.8.2. Finally, the equations used for the binning optimisation are summarised in Section 7.8.3.

7.8.1 Significance Estimate in One Bin

For each bin, all uncertainty sources are combined into one uncertainty σ . There is for each bin the expected number of signal events S , the expected background events B , the signal strength μ and only one nuisance parameter γ for systematic uncertainties encoding the uncertainty σ .

$$Z_{\text{bin}}(\mu) = \sqrt{-2 \ln \frac{\tilde{\mathcal{L}}(n|\mu, \hat{\gamma})}{\tilde{\mathcal{L}}(n|\hat{\mu}, \hat{\gamma})}}, \quad (7.69)$$

where a simplified likelihood function is used:

$$\tilde{\mathcal{L}}(n|\mu, \gamma) := \text{Pois}(n|\gamma(\mu S + B)) \cdot \text{Pois}(m|\gamma\tau), \quad (7.70)$$

where m represents the auxiliary measurement with which nuisance parameters γ got restricted, $m = \tau = \frac{(\tilde{\mu}S+B)^2}{\sigma^2}$ with the absolute uncertainty σ on $\tilde{\mu}S + B$. $\tilde{\mu}$ is the signal strength assumed when defining the uncertainty.

Equation 7.70 is the correct equation for MC statistical uncertainties, where $\tau = m =$ number of raw expected number of MC events, if all MC events have the same weight of 1. Gaussian uncertainties are modelled as Poisson in order to implicitly avoid negative yields. Splitting into normalisation part and shape part has to some extent similar effects like using Poisson instead of Gaussian constraint. The quadratic sum of all systematic uncertainties is σ^2 .

The γ parameter, which maximizes $\tilde{\mathcal{L}}(n|\mu, \gamma)$ for a given μ is denoted $\hat{\gamma}(\mu)$.

The maximum likelihood estimate of γ for any μ is derived from $\frac{\partial \tilde{\mathcal{L}}(n|\mu, \gamma)}{\partial \gamma} = 0$:

$$\hat{\gamma} = \frac{n + m}{B + \mu S + \tau}. \quad (7.71)$$

For the denominator in Z_{bin} also $\hat{\mu}$ and $\hat{\gamma}$ are needed, where $\hat{\gamma} := \hat{\gamma}(\hat{\mu})$. After deriving $\mathcal{L}(n|\hat{\mu}, \hat{\gamma}(\mu))$ with respect to μ and setting to zero, it is found:

$$\hat{\mu} = \frac{\frac{n}{\hat{\gamma}} - B}{S}. \quad (7.72)$$

This gives:

$$\hat{\gamma} = \hat{\gamma}(\hat{\mu}) = \frac{m}{\tau} = 1. \quad (7.73)$$

Putting Equation 7.71, 7.72 and 7.73 into Equation 7.69 gives, using Equation 7.1:

$$\begin{aligned} Z_{\text{bin}}(\mu, \sigma) &= \sqrt{-2 \ln \left[\frac{\text{Pois}(n|\hat{\gamma}(\mu S + B)) \text{Pois}(m|\hat{\gamma}\tau)}{\text{Pois}(n|n) \text{Pois}(m|\tau)} \right]} \\ &= \sqrt{-2 \ln \left[\frac{\frac{1}{n!} (\hat{\gamma}(\mu S + B))^n e^{-\hat{\gamma}(\mu S + B)} \frac{1}{m!} (\hat{\gamma}\tau)^m e^{-\hat{\gamma}\tau}}{\frac{1}{n!} n^n e^{-n} \frac{1}{m!} \tau^m e^{-\tau}} \right]} \\ &= \sqrt{2n \ln \left[\frac{n((B + \mu S)\sigma^2 + (\tilde{\mu}S + B)^2)}{(\mu S + B)(n\sigma^2 + (\tilde{\mu}S + B)^2)} \right] - 2 \frac{(\tilde{\mu}S + B)^2}{\sigma^2} \ln \left[1 + \frac{(n - B - \mu S)\sigma^2}{(B + \mu S)\sigma^2 + (\tilde{\mu}S + B)^2} \right]}. \end{aligned} \quad (7.74)$$

The case $\sigma = 0$ can be calculated in the limit $\sigma \rightarrow 0$ using Equation 7.76:

$$Z_{\text{bin}}(\mu, 0) = \sqrt{2 \left(n \ln \left[1 + \frac{n - \mu S - B}{\mu S + B} \right] - (n - B - \mu S) \right)} \quad (7.75)$$

As further simplification, $\ln[1+x]$ with $x = \frac{n-\mu S-B}{\mu S+B}$ can be tailored around $x=0$, assuming that n is relatively close to $\mu S+B$:

$$\ln(1+x) = x - \frac{x^2}{2} + \frac{x^3}{3} - \frac{x^4}{4} + \dots \quad (7.76)$$

This is in the first terms similar to:

$$\frac{1}{2}\left(1+x - \frac{1}{1+x}\right) = x - \frac{x^2}{2} + \frac{x^3}{2} - \frac{x^4}{2} + \dots \quad (7.77)$$

Approximating $\ln(1+x)$ with $\frac{1}{2}\left(1+x - \frac{1}{1+x}\right)$ gives:

$$\begin{aligned} Z_{\text{bin, approx}}(\mu, 0) &= \sqrt{n \left[1 + \frac{n-\mu S-B}{\mu S+B}\right] - n \left[\frac{1}{1 + \frac{n-\mu S-B}{\mu S+B}}\right] - 2(n-B-\mu S)} \\ &= \frac{|n - (\mu S + B)|}{\sqrt{(\mu S + B)}}. \end{aligned} \quad (7.78)$$

The validity of this approximation is tested via toys in Figure 3a in Ref. [103]. Also for low expectations of only two background events the approximation works well for significances $Z < 3$.

Continuing from Equation 7.74, the approximation can also be applied in the general case including an uncertainty σ . The following short notation was used during the calculation: $t := (B + \mu S)$ and $\tilde{t} := (\tilde{\mu} S + B)$.

$$\begin{aligned} Z_{\text{bin}}(\mu, \sigma) &= \sqrt{2n \ln \left[\frac{n(t\sigma^2 + \tilde{t}^2)}{t(n\sigma^2 + \tilde{t}^2)} \right] - 2 \frac{\tilde{t}^2}{\sigma^2} \ln \left[\frac{n\sigma^2 + \tilde{t}^2}{t\sigma^2 + \tilde{t}^2} \right]} \\ &= \sqrt{2n \ln \left[1 + \frac{(n-t)\tilde{t}^2}{t(n\sigma^2 + \tilde{t}^2)} \right] - 2 \frac{\tilde{t}^2}{\sigma^2} \ln \left[1 + \frac{(n-t)\sigma^2}{t\sigma^2 + \tilde{t}^2} \right]}, \end{aligned} \quad (7.79)$$

$$(7.80)$$

$$\begin{aligned} Z_{\text{bin, approx}}(\mu, \sigma) &\approx \sqrt{n \left[\frac{n(t\sigma^2 + \tilde{t}^2)}{t(n\sigma^2 + \tilde{t}^2)} \right] - n \left[\frac{t(n\sigma^2 + \tilde{t}^2)}{n(t\sigma^2 + \tilde{t}^2)} \right] - \frac{\tilde{t}^2}{\sigma^2} \left[\frac{n\sigma^2 + \tilde{t}^2}{t\sigma^2 + \tilde{t}^2} \right] + \frac{\tilde{t}^2}{\sigma^2} \left[\frac{t\sigma^2 + \tilde{t}^2}{n\sigma^2 + \tilde{t}^2} \right]} \\ &= \sqrt{\frac{(n-t)^2}{\frac{tn}{\tilde{t}^2}\sigma^2 + t}} \\ &= \frac{|n - (\mu S + B)|}{\sqrt{\frac{n(\mu S + B)}{(\tilde{\mu} S + B)^2}\sigma^2 + (\mu S + B)}}. \end{aligned} \quad (7.81)$$

7.8.2 Significance Estimate over Multiple Bins

The total significance over multiple bins is:

$$Z(\mu) = \sqrt{-2 \ln \prod_i \frac{\tilde{\mathcal{L}}(n_i | \mu, \hat{\gamma}_i)}{\tilde{\mathcal{L}}(n_i | \hat{\mu}, \hat{\gamma}_i)}}. \quad (7.82)$$

The total significance can nearly be separated into independent factors for each bin which could be optimised separately. Only the parameter $\hat{\mu}$ is jointly used over all bins and needs to be optimised in a correlated way over the bins a priori. For only one bin this is obviously no problem. For k bins this results in a polynomial of k -th order when calculating $\hat{\mu}$ analytically.

Table 7.3: Estimated Significance in a Bin for Different Use Cases.

Purpose	Asimov data	Theory	$Z_{\text{bin, approx}}(\mu, \sigma)$	Equation 7.74
Observation	$\mu_A = 1$	$\mu = \tilde{\mu} = 0$	$\frac{S}{\sqrt{\frac{\sigma^2(S+B)}{B} + B}}$	$Z_{\text{bin}}(0, \sigma)$
Limit setting	$\mu_A = 0$	$\mu = \tilde{\mu} = 1$	$\frac{S}{\sqrt{\frac{\sigma^2 B}{S+B} + S+B}}$	$Z_{\text{bin}}(1, \sigma)$
Measurement of upper uncertainty around 1.2	$\mu_A = 1$	$\mu = \tilde{\mu} = 1.2$	$\frac{0.2S}{\sqrt{\frac{\sigma^2(S+B)}{1.2S+B} + 1.2S+B}}$	$Z_{\text{bin}}(1.2, \sigma)$

For observed data this is needed and done numerically with Minos in the full fit. For expected significances the data distribution is assumed to be:

$$n_i = \mu_A S_i + B_i, \quad (7.83)$$

with the Asimov signal strength μ_A . The globally optimised $\hat{\mu}$ would be the same as an individual $\hat{\mu}_i$ for the special case where all individually optimised $\hat{\mu}_i$ are equal. In this case using separate $\hat{\mu}_i$ in each bin would be equivalent to having one global $\hat{\mu}$. Since Equation 7.72 simplifies to $\hat{\mu}_i = \mu_A$ for the Asimov data set it is valid to use individual $\hat{\mu}_i$ within the calculation.

With this simplification for Asimov data, the total significance can be rewritten to:

$$\begin{aligned}
 Z_{\text{simple}}(\mu) &= \sqrt{-2 \ln \prod_i \frac{\tilde{\mathcal{L}}(n_i | \mu, \hat{\gamma}_i)}{\tilde{\mathcal{L}}(n_i | \hat{\mu}, \hat{\gamma}_i)}} = \sqrt{-2 \ln \prod_i \frac{\tilde{\mathcal{L}}(n_i | \mu, \hat{\gamma}_i)}{\tilde{\mathcal{L}}(n_i | \hat{\mu}_i, \hat{\gamma}_i)}} = \sqrt{\sum_i -2 \ln \frac{\tilde{\mathcal{L}}(n_i | \mu, \hat{\gamma}_i)}{\tilde{\mathcal{L}}(n_i | \hat{\mu}_i, \hat{\gamma}_i)}} \\
 &= \sqrt{\sum_i Z_{\text{bin}, i}(\mu, \sigma)^2}. \quad (7.84)
 \end{aligned}$$

Equation 7.84 is only valid if data is distributed according to Equation 7.83. The usage of Equation 7.84 for observed data would only be valid if the model allows different signal strength in each bin which is typically not physically allowed or motivated⁷.

Table 7.3 shows the different Asimov data and theories to test for the different use cases: observations, limit setting and measurements. The factor next to σ^2 in $Z_{\text{bin, approx}}(\mu, \sigma)$ can be cancelled by calculating the uncertainty σ for $\tilde{\mu}S + B = \sqrt{(\mu S + B)(\mu_A S + B)}$.

7.8.3 Equation Used for Binning Optimisation

For the actual binning optimisation simplification introduced with Equation 7.77 is not used. Instead, Equation 7.74 with $\mu = \tilde{\mu}$ is used since σ should be the uncertainty of the tested hypothesis:

$$Z_{\text{bin}}(\mu, \sigma) = \sqrt{2n \ln \left[\frac{n(\sigma^2 + (\mu S + B))}{(n\sigma^2 + (\mu S + B)^2)} \right] - 2 \frac{(\mu S + B)^2}{\sigma^2} \ln \left[1 + \frac{(n - B - \mu S)\sigma^2}{(B + \mu S)\sigma^2 + (\mu S + B)^2} \right]}. \quad (7.85)$$

The above Equation 7.85 is only valid for $\mu S + B \neq 0$, $n \neq 0$ and $\sigma \neq 0$.

The case $\mu S + B = 0$ does not occur in binning optimisation, because a minimum number of MC events is required in each bin. Also the other two cases do not occur for the same reason for the used Asimov data.

⁷Separate signal strengths would be motivated for LH-based unfolding without migrations. But one is typically not interested in the total significance in this case.

7.9 Unfolding

The aim of fundamental research is to perform experiments to compare data with theory predictions and find a predictive theory which describes our nature best. At a later stage, these theories can be used in future applications. In the case of the current ATLAS and CMS measurements, one does not know yet all potential theories with which one wants to compare the data with in the future. As experimentalist we try to publish our data as usable for current and future theorists as possible.

If the raw data from the total cross-section measurement were published, then the theorists would need to apply a full detector simulation on their prediction to compare with the data. To simplify this procedure the data gets transformed to undo the detector effects, called unfolding, with which the data can be easily compared without knowing the detector. The detector effects include e.g. limited spatial resolution, limited spacial coverage or misidentification.

Distributions after detector simulation in the reconstructed phase space, defined in 5.2.1, are called 'on reco-level'. Distributions before detector simulation in the fiducial phase space, defined in 5.4, are called 'on truth-level'. Unfolding starts with data on reco-level which gets unfolded to truth-level. MC events of the signal sample have both, reco and truth, information. This information is used to unfold data from reco-level to truth-level.

Each simulated event has in the unfolded variable a value on reco-level ν and the on truth-level μ .

The aim is to measure the distribution μ of events which passed the truth-level selection T starting from the distribution ν of events which passed the reco-level selection R .

The signal sample, used to unfold the data, is generated on truth level with two charged leptons and two jets. Thus, all variables derived from truth-objects are defined in both R and T . Just the reco-level variable ν might only be defined in R and is thus not used in $T \setminus R$. For example there is no reconstructed $m_{\ell\ell}$ defined in $T \setminus R$ if no second lepton got reconstructed.

During the reconstruction and identification of objects, not the identical four-momenta are reconstructed from the truth-level objects. The migration matrix $M(\nu|\mu, R)$ contains this conditional probability to measure a reco value ν for a given truth value μ after reco-level selection in a signal sample event. The migration matrix could in principle be defined in $R \vee T$ or in full R , while full R is used in this work.

Not all events pass both reco- and truth-level selection which is encoded in the efficiency factor $\epsilon(T; R, \mu)$. This efficiency can be split into two parts

$$\epsilon(R; T, \mu) = \frac{\epsilon_{\text{fid}}(T|R, \mu)}{\epsilon_{\text{eff}}(R|T, \mu)}. \quad (7.86)$$

They are:

fiducial correction $\epsilon_{\text{fid}}(T|R, \mu)$: the conditional probability that a signal sample event with truth-level value μ which passes reco-level selection also passes truth-level selection.

efficiency correction $\epsilon_{\text{eff}}(R|T, \mu)$: the conditional probability that a signal sample event with truth-level value μ which passes truth-level selection also passes reco-level selection.

The fiducial correction can be both applied depending on truth value μ , as done here and also depending on reco-value ν , as discussed in Section 7.9.3.3. How the fiducial and efficiency correction needs to be applied to get from truth-level phase space to reco-level phase space is shown in Figure 7.2.

The effect of the detector can be expressed as a mathematical folding process [103]: The number of expected events $N(\nu)$ with value ν after reco-level selection are:

$$N(\nu, R) = \int_{-\infty}^{\infty} M(\nu|\mu, R) \epsilon(R; T, \mu) N(\mu, T) d\mu + \beta(\nu). \quad (7.87)$$

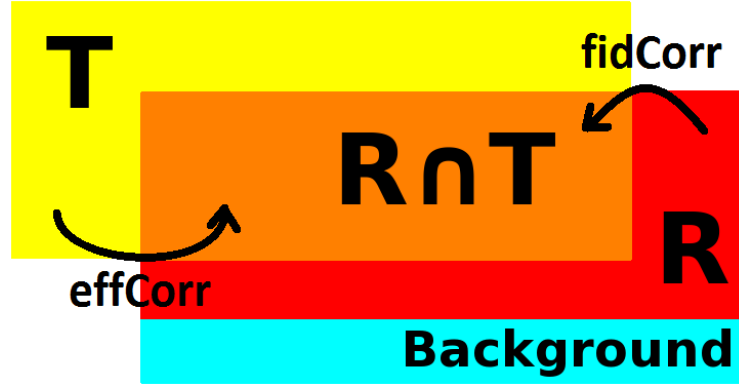


Figure 7.2: Different selection levels of events. $\mathbf{R}$ contains all events passing the selection on reco-level (reco-selection), $\mathbf{T}$ contains all events passing the selection on truth-level (truth-selection). If an event passes both selection criteria it is part of the joint phase space $\mathbf{R} \cap \mathbf{T}$. The background includes events which pass the selection on reco-level, but come from another process than the signal.

where $N(\mu)$ is the expected number of events with truth-level value μ .

The efficiency and the migration matrix can be summarized into the response matrix:

$$R(R, \nu; T, \mu) := M(\nu|\mu, R)\epsilon(R; T, \mu) \quad (7.88)$$

Conditional probabilities are defined within the set of events of the signal sample. These can be used to express the migration matrix and corrections. With this it can be shown, that the equation for folding is statistically correct:

$$\begin{aligned} & \sum_{\mu} M(\nu|R, \mu) \cdot \frac{\epsilon_{\text{eff}}(R|\mu \cap T)P(\mu \cap T)}{\epsilon_{\text{fid}}(T|R \cap \mu)} \\ &= \sum_{\mu} P(\nu|R \cap \mu) \cdot \frac{P(R|\mu \cap T)P(\mu \cap T)}{P(T|R \cap \mu)} \\ &= \sum_{\mu} \frac{P(\nu \cap R \cap \mu)P(R \cap \mu \cap T)P(\mu \cap T)P(R \cap \mu)}{P(R \cap \mu)P(\mu \cap T)P(T \cap R \cap \mu)} \\ &= P(\nu \cap R) \end{aligned} \quad (7.89)$$

This is still frequentistic for the signal sample because there is only one true value of μ, ν, T, R for each event. Only when making the assumption, that these conditional probabilities are also true for the unfolded data additional assumptions are made. These result in additional unfolding related uncertainties which are discussed in Section 7.9.2.

Binned distributions are used because information about migrations are needed which are only available with limited precision. Unbinned approaches are discussed in Section 7.9.3.4.

The count in a bin i is defined as

$$\mu_i := \int_{\text{bin } i} N(\mu) d\mu. \quad (7.90)$$

The index i represents the range of values included in this bin. The values ν_i, M_{ij} and ϵ_{fid} are always defined and summed in reco phase space R , while ϵ_{eff} and μ_i are defined and summed in truth phase space T .

For binned distributions Equation 7.87 is:

$$\nu_i = \sum_{j=1}^M R_{ij} \mu_j + \beta_i. \quad (7.91)$$

The inverse of it is the equation used for unfolding:

$$\mu_j = \sum_{i=1}^M R_{ij}^{-1} (\nu_i - \beta_i). \quad (7.92)$$

Equation 7.92 is the equation of unfolding with Matrix Inversion. It has the smallest possible variance [103] and it is the best option for comparison with future theories. Other unfolding methods are discussed in Section 7.9.3.1. It can happen, that there are large anti-correlations between unfolded bins because there is not enough information about from which neighbouring bin a reco-event came. This will result in large error bars in the unfolded distribution and also the nominal unfolded points can have large alternating up and down fluctuations. To make a more intuitive result neighbouring bins can be merged as described in Section 7.9.4. This way results having the smallest possible variance can be published and it is possible to make intuitive histograms from them without adding additional information.

Migrations in the migration matrix M result in negative entries on the next-to-diagonal in the inverted matrix, because events on reco-level could migrate from either of the neighbouring bins.

This is why tests are performed before unblinding to ensure, that the negative yield case is very unlikely to reach. This is done with the fit to Asimov data where it is checked, that a negative yield is very unlikely within uncertainties. A requirement on the least expected significance in each bin and a maximum migration is used to ensure this already during binning optimisation.

It is often stated as a problem of unfolding, that the inversion does not need to be possible [115]. For more bins on truth-level, than a reco-level this is indeed a problem. But in this thesis the opposite is the case with more events on reco-level than on truth-level, due to a second discriminating variable used in the fit. But when integrating over the second variable, then it results in a square matrix. For square matrices inversion is always and only possible if the determinant is non-zero. As shown in the binning optimisation Section 9.2 a stability above 65% is reached in each bin. The stability is the fraction of events in the migration matrix which stay in the same reco-level bin for a fixed truth-level bin. If the stability is above 50% in each bin, then the matrix is invertible [116]. Because of this non-invertibility is not a problem for the nominal unfolding. But they do also need to be invertible for all statistical and systematic fluctuations.

For statistical fluctuations near the not invertible case, it is very unlikely to actually hit a non-invertible case. But it has several drawbacks for the propagated uncertainty if it is near the non invertible case. The uncertainties are not any more gaussian distributed.

This is why it is ensured, that the non-invertible case is very unlikely to reach. Again, the required stability of at least 65% makes a down fluctuation below 50% very unlikely.

7.9.1 Likelihood-Based Unfolding

In this thesis the unfolding is performed in one step with the maximum likelihood fit, called Likelihood-based unfolding, the same Ansatz as used e.g. in [117].

The observed signal strength is extracted from:

$$\mathcal{L}(n|\hat{\boldsymbol{\mu}}, \hat{\Theta}) = \max_{\boldsymbol{\mu}, \Theta} \mathcal{L}(n|\boldsymbol{\mu}, \Theta), \quad (7.93)$$

where $\boldsymbol{\mu}$ is the vector of all signal strengths on truth-level.

The LH-based unfolding is advantageous because:

- the unfolding is performed implicitly and conveniently within the fit and
- it allows obtaining well-defined signal strengths with statistical uncertainty, including correlations, directly from the maximum likelihood fit.

The fit is performed on reco-level over the bins which get unfolded and also split in a second variable to increase the sensitivity. They are mapped to a 1D unfolded distribution on truth-level. So, in total it is a 3D migration matrix, which maps from 2D on reco-level to 1D on truth-level. This 3D matrix makes the migration matrix even more stable with respect to the non-invertible case.

The fiducial region and the reco-level selection should be close to each other to not extrapolate too much with the efficiency and fiducial correction. The low- m_{jj} control region is included in the reco-level selection to further constrain data-driven estimated backgrounds.

This region is not part of the fiducial region. The migration matrix defined with and without low- m_{jj} control region is discussed in Section 7.9.3.3. The split signal strengths are used in the signal region and the low- m_{jj} control region. The average signal strength is used in the WZ control region, where the signal is a very small non-prompt background contribution because three leptons are required there.

7.9.2 Uncertainties on the Unfolded Distribution

There are several sources of uncertainties which the unfolded result has. Related to the unfolding inputs there are the statistical uncertainties of the data. For the background and signal prediction there are the MC statistical uncertainty, the experimental systematic uncertainty and the theory uncertainty. The unfolding itself also adds an uncertainty due to hidden variables.

All statistical, experimental and modelling uncertainties are propagated by the maximum likelihood fit. They are directly estimated from maximum likelihood with Minos as described in Section 7.4.2.

The observed data is Poisson distributed around the theory prediction. During unfolding the Standard Model prediction is assumed. Frequentistic 1σ uncertainties are calculated, but these are only estimates if they need to be extrapolated to other deviations correlated across the bins. There is a reweighting approach proposed in Ref. [41] to compensate for some differences. The frequentistic defined uncertainties are better than the uncertainties estimated around the data prediction. But there are still some differences. If there are more than 20 signal events in each bin, then these differences are expected to be small as is studied in Ref. [41].

The conditional probabilities, in e.g. the migration matrix, might look different for other samples or future models. Different shower and NLO predictions are included with the respective uncertainties. So, this effect is partially covered. For more extreme models it might be worth recalculating the migration matrix and corrections to correct for this mismodelling during reinterpretation.

7.9.3 Alternative Unfolding Approaches

Some alternative unfolding approaches are discussed in this section. Sometimes regularization is used, explained in Section 7.9.3.1. Also unfolding can be done in a separate step, separated from the fit as described in Section 7.9.3.2. Out-of-fiducial region events can be scaled according to the reco value and not the truth value. For example in Ref. [67] the same data as in this thesis is unfolded with other choices made. Finally, there are also approaches for unbinned unfolding. Different unfolding approaches are already discussed by the author of this thesis in Ref. [41].

7.9.3.1 Regularized Unfolding

The mathematically correct way of undoing the folding is to invert the migration matrix. But the inversion of the matrix is not always possible and also the anti-correlation might result in unphysical, negative events in an unfolded bin.

One solution is to rebin the unfolded solution before or after unfolding. In the non-invertible case rebinning is needed before unfolding. A large stability and small enough uncertainties after binning optimisation, as done in this thesis, circumvent these additional steps.

Another solution is to use explicit regularization. It is motivated from image reconstruction [118], where one is interested in the best prediction and correctly estimated uncertainties are not needed. It is motivated as a Bayesian method where a degree of belief is added to the unfolded distribution, making unfolded distributions smoother [103]. This results in smoother distributions, but the uncertainties are either very large or too small to cover only the information in the data if the matrix-inversion unfolded distribution without regularisation is not smooth. The matrix inversion has the smallest possible variance.

In these explicit regularization unfolding methods the information deficit is compensated by putting in extra information, that the unfolded distribution should be flat or similar to a predefined prior. Some of these methods are:

- Bayesian iterative unfolding [115],
- Singular Value Decomposition (SVD) [119] or
- Matrix Inversion with Tikhonov regularization term as implemented in TUnfold [120].

Regularization can also be interpreted as a frequentist biased estimator. In this case it is very hard to compare this biased estimator with a new theory in reinterpretation. The correct uncertainty calculation would need by definition at least as large uncertainties as the matrix inversion result, which degrades the power of a future comparison compared to unfolding with matrix inversion. Therefore no regularization is used in this thesis.

7.9.3.2 Disentangle Fit from Unfolding

Unfolding can also be performed disentangled from the maximum likelihood fit. This makes it easier to optimise unfolding separately, enables unfolding methods like Bayesian Iterative unfolding but also causes more work in propagating uncertainties.

In principle nearly the same nominal results can be derived if matrix inversion is used as unfolding method. But the uncertainty propagation is much more complicated and e.g. frequentist Poisson uncertainties on the unfolded data are not possible to get with the same precision. For this one would need to rebuild the likelihood function during unfolding to mimic the one-step procedure.

While signal and its scaling factors $\mu_{\text{bin } i}$ are split on truth level in LH-based unfolding, it is split on reco level for the fit for the two-step procedure. Nearly perfect agreement is reached in the two-step procedure on reco-level after the first step. Only if a second variable is used with a different signal-to-background ratio across the bins slight differences could occur like for the LH-based unfolding.

The same nominal result is expected because the matrix is always invertible: The prediction on reco level is both times very flexible. Only migrations cause slightly different predictions on reco level for the maximum likelihood fit if a second variable is used. This effect is expected to be even smaller than the differences on reco-level due to the second variable between data and fit within LH-unfolding.

For LH-based unfolded the stat unc. is directly there: estimated asymmetrical with maximum LH: already after Neyman construction: 68% interval with correct frequentist coverage. In the two-step procedure this is much more complicated: the uncertainties need to get propagated through unfolding, often with toy-driven approaches. In principle one could also start with the Neyman constructed post-fit uncertainties. But it is only possible to propagate it to truth-level approximately. The full statistical model would be needed to propagate them correctly to truth-level.

7.9.3.2.1 Uncertainty propagation Systematic uncertainties within LH-based unfolding are propagated by varying the signal in the response matrix, efficiency and background predictions simultaneously during the fit. In the two-step procedure this correlation has to be kept. The up-variation of the reco fit is propagated together with the up-variation of the response matrix and efficiency correction.

Explicit uncertainty propagation is only needed for the two-step procedure because for LH-based unfolding the uncertainties are directly available on truth-level via the impact table defined in Section 7.4.6. It is more time-consuming for the two-step procedure because all systematic variations need to be propagated. For statistical uncertainties typically propagation via toys is performed. For matrix inversion it is possible to use an explicit equation to propagate it [41, 103]. But this formula is only true for Gaussian uncertainties.

7.9.3.3 Different Handling of Out-of-Fiducial Region Events

The migration matrix is defined in the signal region plus low- m_{jj} control region. It could also be defined in the joint phase space of fiducial and reco-level selection. Similar to Equation 7.89, the unfolding can be rewritten with conditional probabilities:

$$\begin{aligned}
& \sum_{\mu} P(\nu|R \cap T \cap \mu) \cdot \frac{P(R|\mu \cap T)P(\mu \cap T)}{P(T|R \cap \nu)} \\
&= \sum_{\mu} \frac{P(\nu \cap R \cap T \cap \mu) \cdot P(R \cap \mu \cap T)P(\mu \cap T)P(R \cap \nu)}{P(R \cap T \cap \mu) \cdot P(\mu \cap T)P(T \cap R \cap \nu)} \\
&= P(R \cap \nu) \sum_{\mu} \frac{P(\nu \cap R \cap T \cap \mu)}{P(T \cap R \cap \nu)} \\
&= P(R \cap \nu)
\end{aligned} \tag{7.94}$$

The difference is the handling of events which do not pass fiducial selection, but reco level selection.

These events fail mainly the following requirements:

- 13% fail the truth-level high- m_{jj} requirement $m_{jj} > 500$ GeV,
- 11% fail the truth tau and b-hadron veto,
- 8% fail the truth-MET requirement $E_{T,miss} > 30$ GeV,
- 4% fail the truth jet p_T requirements $p_{T,jet1(2)} > 65(35)$ GeV,

The low- m_{jj} control region and truth tau and b-quark vetoed events are close to the signal region, for tau vetoed events due to lepton flavour universality. The jet p_T and MET requirement have a relatively low impact compared to their resolution, so they get probably reduced due to their resolution and not due to an object misidentification. In principle, they can be handled in three different ways:

1. scale depending on truth value: reco and truth information is used to correct for them,
2. scale depending on reco value: only reco information is used to correct for them, as shown in Figure 7.3,
3. keep as constant background: motivated by events from different phase space with completely different kinematic: do not scale signal events, but add an out-of-fiducial region signal contribution additive.

Because the out-of-fiducial region migrations are dominated by resolution effects and not mismodelling, one of the first two approaches is chosen.

Comparing the first two approaches, the first one is better motivated, because the dependence of ϵ_{fid} from T is better defined than dependence from R (which implies some assumed migrations). Therefore the first approach is used in this thesis.

In the following a numerical example inspired by the later shown $N_{gapJets}$ variable for EW $W^{\pm}W^{\pm jj}$ is presented. In the matrices, different rows show different reco-level bins, while different columns show different truth-level bins. In reco phase space R there are:

$$N_R = \begin{pmatrix} 233 & 7 \\ 18 & 21 \end{pmatrix}$$

events, in the joint phase space $R \cap T$ there are:

$$N_{R \cap T} = \begin{pmatrix} 154 & 4 \\ 10 & 17 \end{pmatrix}$$

events and in on truth level T there are:

$$N_{truth, nom} = \begin{pmatrix} 307 & 43 \end{pmatrix}$$

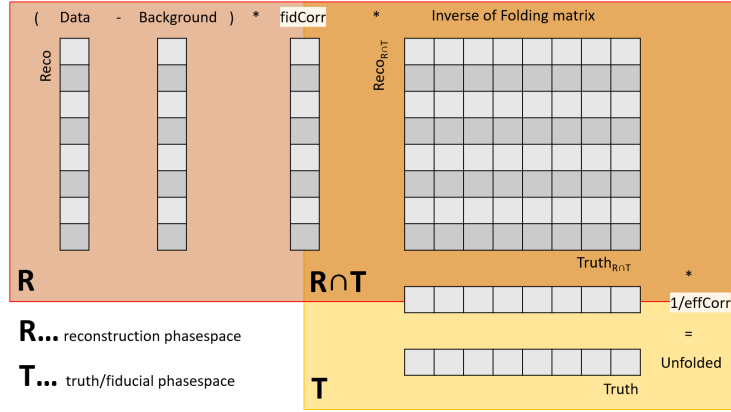


Figure 7.3: Big Picture of Unfolding (inspired by Figure 5 in [121]) as implemented in VIPUnfolding [122]. After subtracting the background in the reconstruction phase space $\mathbf{R}$ the data signal events get transferred into the joint phase space $\mathbf{R} \cap \mathbf{T}$ via the fiducial correction. There, the variable gets corrected for bin migrations before it gets transferred into the full truth phase space $\mathbf{T}$ by the efficiency correction.

events predicted by EW $W^\pm W^\pm jj$ signal sample.

The resulting efficiency correction is in all three cases:

$$\epsilon_{\text{eff}} = \begin{pmatrix} \frac{154+10}{307} & 0 \\ 0 & \frac{4+17}{43} \end{pmatrix} = \begin{pmatrix} 0.53 & 0 \\ 0 & 0.49 \end{pmatrix}. \quad (7.95)$$

For the first approach, used in this thesis, the fiducial correction is:

$$\epsilon_{\text{fid}} = \begin{pmatrix} \frac{154+10}{233+18} & 0 \\ 0 & \frac{4+17}{7+21} \end{pmatrix} = \begin{pmatrix} 0.65 & 0 \\ 0 & 0.75 \end{pmatrix} \quad (7.96)$$

and the migration matrix is:

$$M = \begin{pmatrix} \frac{233}{233+18} & \frac{7}{7+21} \\ \frac{18}{233+18} & \frac{21}{7+21} \end{pmatrix} = \begin{pmatrix} 0.93 & 0.25 \\ 0.07 & 0.75 \end{pmatrix}. \quad (7.97)$$

For the second approach the fiducial correction is:

$$\epsilon_{\text{fid, reco}} = \begin{pmatrix} \frac{154+4}{233+7} & 0 \\ 0 & \frac{10+17}{18+21} \end{pmatrix} = \begin{pmatrix} 0.66 & 0 \\ 0 & 0.69 \end{pmatrix} \quad (7.98)$$

with the migration matrix in the joint phase space:

$$M_{R \cap T} = \begin{pmatrix} \frac{154}{154+10} & \frac{4}{4+17} \\ \frac{10}{154+10} & \frac{17}{4+17} \end{pmatrix} = \begin{pmatrix} 0.94 & 0.19 \\ 0.06 & 0.81 \end{pmatrix}. \quad (7.99)$$

For the third approach, with the additive fiducial correction:

$$\epsilon_{\text{fid, additive}} = \begin{pmatrix} (233+7) - (154+4) \\ (18+21) - (10+17) \end{pmatrix} = \begin{pmatrix} 82 \\ 12 \end{pmatrix} \quad (7.100)$$

the migration matrix in the joint phase space from Equation 7.99 is used.

There are different migrations in the two phase spaces, comparing Equation 7.99 and 7.97.

If the nominal prediction

$$N_{\text{truth, nom}} = (307 \quad 43) \quad (7.101)$$

is folded, then in all three cases the same distribution emerges on reco-level, as shown before in Equation 7.89 and 7.94:

$$N_{\text{reco}}(N_{\text{truth, nom}}) = \begin{pmatrix} 251 \\ 28 \end{pmatrix} \quad (7.102)$$

If another prediction, e.g:

$$N_{\text{truth, obs}} = (319 \quad 77) \quad (7.103)$$

is folded, then there are different results for multiplicative fiducial correction depending on truth-values:

$$N_{\text{reco, 1}}(N_{\text{truth, obs}}) = M \cdot \epsilon_{\text{fid}}^{-1} \cdot \epsilon_{\text{eff}} \cdot N_{\text{truth, obs}}^T = \begin{pmatrix} 254.6 \\ 56.3 \end{pmatrix}, \quad (7.104)$$

for multiplicative fiducial correction depending on reco-values:

$$N_{\text{reco, 2}}(N_{\text{truth, obs}}) = \epsilon_{\text{fid, reco}}^{-1} \cdot M_{R \cap T} \cdot \epsilon_{\text{eff}} \cdot N_{\text{truth, obs}}^T = \begin{pmatrix} 253.9 \\ 59.0 \end{pmatrix} \quad (7.105)$$

and for additive fiducial correction:

$$N_{\text{reco, 3}}(N_{\text{truth, obs}}) = \epsilon_{\text{fid, additive}} + M_{R \cap T} \cdot \epsilon_{\text{eff}} \cdot N_{\text{truth, obs}}^T = \begin{pmatrix} 249.2 \\ 52.8 \end{pmatrix}. \quad (7.106)$$

Equation 7.104 and 7.105 are equal in case of same migrations in both phase spaces, i.e. if Equation 7.99 and 7.97 agree.

There are visible differences between these three equations. So, it matters that the out-of-fiducial region events are correctly included in the folding model. If wrongly reconstructed leptons or jets would cause these additional events, then the additive ansatz would be best. If it is due to resolution, then the multiplicative ansatz is better, because a scaling with the same factor as in the fiducial region would be physically motivated. In this case these out-of-fiducial phase space migrations are dominated by resolution effects and are close to the fiducial region. Because of this Approach 1 is used.

7.9.3.4 Unbinned Approaches

For unbinned approaches a probability is needed for each data event on reco-level from which truth bin it might have come from. One option would be to take the MC events which are closest to the data event on reco level. But because of the high dimensionality no good results are expected. There are 18 dimensions on reco level: $18 = 2(\text{MET}) + 4 \cdot 4(2 \text{ jets and } 2 \text{ leptons})$. If one requires 10 'bins' in each dimension then 10^{18} MC events are needed. The used signal sample has $\approx 4 \cdot 10^7$ MC events which generation took several orders of magnitude of CPU hours to generate. So, it is not possible to get enough MC events.

For lower dimensional objects reco-truth correction factors could be applied on each selected lepton in data as done in Ref. [123].

One alternative is to use machine learning to train a model of the truth-reco connection and reweight data from reco to truth level with this information. This is implemented e.g. in OmniFold [124]. It is similar to Bayesian Iterative unfolding [115] and converges towards the maximum likelihood estimate.

7.9.4 Using Unfolded Data in Reinterpretation

For interpretation the following information is published:

- unfolded distribution
- covariance matrix of systematic uncertainties
- covariance matrix of background uncertainties
- covariance matrix of statistical uncertainty
- impact table of nuisance parameters and their correlation
- response matrix

There are potentially large anti-correlation and fluctuations in the unfolded distribution. For easy interpretation by eye neighbouring bins could get merged. The equation for combining the covariances C of neighbouring bins b and c is: $V(a, b + c) = V(a, b) + V(a, c)$.

How these uncertainties could be used to compare the unfolded data with a new theory prediction is e.g. shown in Ref. [41].

For a more correct estimation of statistical uncertainties, the new theory prediction could get folded to calculate the uncertainties on reconstruction level and propagate them to truth-level.

To improve the modelling of efficiency and fiducial correction the new theory model could be passed through fast detector simulation [125]. With this reco-truth information updated efficiencies could be used.

An alternative approach is to publish the full statistical model. This is provided e.g. by pyhf [126]. It is a Python implementation of HistFactory which is also used in this thesis. Pyhf provides the option to transform the likelihood function into JSON. This JSON version can then be published on HEPdata and could thus be directly used for reinterpretations. This way test statistics involving the full information from reco-level could be constructed and the full information from data with correct uncertainty treatment could be there.

7.10 Uncertainties after Normalisation

Normalising histograms to 1 is needed when calculating p -values from toys, when normalising the response matrix or when calculating efficiencies.

The following Lemma 7.10.1 summarises the rules on how to propagate the uncertainties to the normalised distribution.

Lemma 7.10.1. *Let $A := \sum_{i=0}^N a_i$ be the sum of N Gaussian distributed random variables a_i with standard deviation Δa_i . Let a_j and a_i be uncorrelated for all $i, j, i \neq j$. Let*

$$\forall a_k, a_j : \Delta a_k \ll \frac{A}{2} - \delta_{jk} \left[\frac{A}{2} + \frac{A(A - a_j)}{A + 2a_j} \right]. \quad (7.107)$$

The uncertainty $\Delta \frac{a_j}{A}$ of the ratio $\frac{a_j}{A}$ is

$$\Delta \frac{a_j}{A} = \sqrt{\frac{A^2 - 2a_j A}{A^4} \Delta a_j^2 + \frac{a_j^2}{A^4} \Delta A^2} \quad (7.108)$$

For $|a_j| \ll |A|$ and $\frac{\Delta A^2}{A^2} \ll \frac{\Delta a_j^2}{a_j^2}$ this simplifies to

$$\Delta \frac{a_j}{A} \approx \frac{\Delta a_j}{A} \quad (7.109)$$

Proof. Gaussian error propagation result for ΔA is since a_i and $a_j (i \neq j)$ are uncorrelated and Gaussian distributed:

$$\Delta A = \sqrt{\sum_{i=0}^N \Delta a_i^2}. \quad (7.110)$$

Expanding the term $\frac{a_j}{A}$ gives:

$$r_j := \frac{a_j}{A} = \frac{a_j}{\sum_{i=0}^N a_i}. \quad (7.111)$$

Because of Equation 7.107 all Δa_k are small, such that r_j can be linearly extrapolated within the Δa_k uncertainty. $\forall a_k$:

$$\left| \frac{\delta^2 r_j}{\delta a_k^2} \right| \Delta a_k \ll \left| \frac{\delta r_j}{\delta a_k} \right| \quad (7.112)$$

$$\Leftrightarrow \left| \left(\frac{1}{A^2} \delta_{jk} + 2 \frac{a_j}{A^3} \right) \right| \Delta a_k \ll \left| \frac{1}{A} \delta_{jk} - \frac{a_j}{A^2} \right| \quad (7.113)$$

$$\Leftrightarrow \Delta a_k \ll \frac{\left| \frac{1}{A} \delta_{jk} - \frac{a_j}{A^2} \right|}{\left| \left(\frac{1}{A^2} \delta_{jk} + 2 \frac{a_j}{A^3} \right) \right|} = \frac{A |\delta_{jk} - a_j|}{A \delta_{jk} + 2a_j} \quad (7.114)$$

$$\Leftrightarrow \Delta a_k \ll \frac{A}{2} - \delta_{jk} \left[\frac{A}{2} + \frac{A(A - a_j)}{A + 2a_j} \right] \quad (7.115)$$

Gaussian error propagation can be used for calculating Δr_j since a_i and $a_j (i \neq j)$ are uncorrelated, Gaussian distributed and $\frac{a_j}{A}$ is assumed to be correctly linearly approximated within its uncertainties. It is:

$$\Delta \frac{a_j}{A} = \Delta r_j = \sqrt{\left(\frac{\partial r_j}{\partial a_j} \right)^2 \Delta a_j^2 + \sum_{k \neq j} \left(\frac{\partial r_j}{\partial a_k} \right)^2 \Delta a_k^2} \quad (7.116)$$

$$= \sqrt{\left(\frac{1}{A} - \frac{a_j}{A^2} \right)^2 \Delta a_j^2 + \sum_{k \neq j} \left(-\frac{a_j}{A^2} \right)^2 \Delta a_k^2} \quad (7.117)$$

$$= \sqrt{\frac{(A - a_j)^2}{A^4} \Delta a_j^2 + \sum_{k \neq j} \frac{a_j^2}{A^4} \Delta a_k^2} \quad (7.118)$$

$$= \sqrt{\frac{A^2 - 2a_j A}{A^4} \Delta a_j^2 + \frac{a_j^2}{A^4} \Delta A^2}. \quad (7.119)$$

In the above approximation this is:

$$\Delta \frac{a_j}{A} \approx \sqrt{\frac{A^2 - 0}{A^4} \Delta a_j^2 + \frac{a_j^2}{A^4} \Delta A^2} \approx \sqrt{\frac{A^2}{A^4} \Delta a_j^2} = \frac{\Delta a_j}{A}. \quad (7.120)$$

□

The Requirement in Equation 7.107 can be quite limiting. For example in the case $a_j = \frac{9A}{10}$ the requirement becomes $\delta a_j \ll \frac{A}{28}$.

For the special case of Poisson uncertainties $\Delta A = \sqrt{A}$ and $\Delta a_j = \sqrt{pA}$, where $p := \frac{a_j}{A}$, Equation 7.108 simplifies to:

$$\Delta \frac{a_j}{A} = \sqrt{\frac{A^2 - 2pA^2}{A^4} pA + \frac{p^2 A^2}{A^4} A} = \sqrt{\frac{p - p^2}{A}} \quad (7.121)$$

When requiring a maximal uncertainty of x , then:

$$\Delta \frac{pA}{A} \leq x \Rightarrow A \geq \frac{p - p^2}{x^2} \quad (7.122)$$

Table 7.4 contains some numerical values of Equation 7.122. For example for toys for limit setting, where $p = 0.05 \pm x$, with an uncertainty of $x = 0.001$ needs 50000 background-only toys. If the uncertainty on the median should be similarly low ($p = 0.5 \pm 0.01$), then 2500 signal+background toys are needed. In the p -value calculation for toys one is interested in $\frac{M = \text{number of toys above test statistic threshold}}{N = \text{total number of toys}} = p = 0.05$. The uncertainty on p should be maximal $x = 0.001$. From Equation 7.122 one gets $N \geq \frac{p - p^2}{x^2} = 47500$ toys.

For normalising plots, Equation 7.109 is used by default because there is typically no bin containing nearly all events. The more exact Equation 7.108 is only used for normalising migration and response matrices, calculating fiducial and efficiency correction and calculating the uncertainty on toy-driven p -values.

$x \setminus p$	0.001	0.01	0.025	0.05	0.16	0.32	0.5
0.0001	100 000	1 000 000	2 400 000	5 000 000	13 000 000	22 000 000	25 000 000
0.0002	25 000	250 000	600 000	1 200 000	3 000 000	5 000 000	6 000 000
0.0005	4 000	40 000	100 000	190 000	500 000	900 000	1 000 000
0.001	-	10 000	24 000	50 000	130 000	220 000	250 000
0.002	-	2 500	6 000	12 000	30 000	50 000	60 000
0.005	-	400	1 000	1 900	5 000	9 000	10 000
0.01	-	-	240	500	1 300	2 200	2 500
0.02	-	-	-	120	300	500	600
0.05	-	-	-	-	50	90	100
0.1	-	-	-	-	-	22	25
0.2	-	-	-	-	-	-	-

Table 7.4: Required number of events to get a relative uncertainty of x given a probability p of the process. Numbers are rounded to the order of magnitude and a second digit is shown if the first one is below three. This uses Equation 7.122 which assumes Poisson uncertainties. If less than four events are expected, i.e. $p \cdot n < 4$, in the tail of the distribution, then "-" is filled.

Chapter 8

Total Cross-Section Measurement

The total cross-section is measured in the fiducial phase space defined in Section 5.4. This Chapter presents the signal strength extraction and the resulting cross-section measurement in the fiducial phase space as described in Section 7.5. The cross-section of EW $W^\pm W^\pm jj$ is measured in a fiducial phase space with enhanced VBS contribution. This gives insights into electroweak symmetry breaking when comparing it to the Standard Model predictions. For larger deviations it could also give an indication of physics beyond the standard model. Also the inclusive $W^\pm W^\pm jj$ cross-section is measured to have a gauge invariant separable signal definition on NLO and beyond.

First, the fitting setup is defined in Section 8.1, followed by the binning optimisation in Section 8.2 and the handling of uncertainties in Section 8.3. Then, the pre-fit distributions are shown in Section 8.4. Afterwards, the expected results follow in Section 8.5. The final observed results are presented in Section 8.6.

8.1 Fitting Setup

The statistical model is defined in Section 7.3. The fit is performed over three regions:

signal region: this region is close to the fiducial region where the total cross-section is calculated,

low- m_{jj} control region: region enriched by conversions and non-prompt background to further constrain them close to the signal region and

WZ control region: region enriched by QCD $W^\pm Z jj$ background to constrain its normalisation.

There are two free-floating normalisation factors (ϕ) in the fit: the signal strength μ , which scales the signal sample and the QCD $W^\pm Z jj$ normalisation strength μ_{WZ} which scales the QCD $W^\pm Z jj$ background.

Two different cross-section fits are performed with the following signal definitions:

signal = " $W^\pm W^\pm jj$ EW" , where " $W^\pm W^\pm jj$ EW" is scaled with μ and " $W^\pm W^\pm jj$ Interference" with $\sqrt{\mu}$ and

signal = " $W^\pm W^\pm jj$ EW + Interference + QCD" = inclusive $W^\pm W^\pm jj$, where the sum is scaled with μ .

8.2 Binning Optimisation

The observable m_{jj} is used as discriminating variable for the total and differential cross-section measurement with the same binning. The signal-to-background ratio improves with increased m_{jj} . The binning optimisation of m_{jj} is defined in Section 9.2 describing the binning optimisation used for differential cross-section measurements. To further constrain non-prompt and conversions backgrounds in the total cross-section measurement the fit is performed in four flavour channels: ee , $e\mu$, μe and $\mu\mu$ depending on the signal lepton flavours sorted by p_T . These backgrounds are highly channel dependent as discussed in Section 4.3.2 and 4.3.3. Conversions background is dominated by electron charge flip and there are separate non-prompt rates for electrons and muons.

8.3 Handling of Uncertainties

A complete list of included experimental uncertainties can be found in Section 6.5 in Table 6.1 to 6.2. The background modelling and statistical modelling uncertainties, due to limited number of MC events, are listed in Table 6.5, the signal uncertainties for EW $W^\pm W^\pm jj$ are in Table 6.6 and for inclusive $W^\pm W^\pm jj$ in Table 6.7. Most theory uncertainties of the signal samples get normalised to nominal on truth-level as described in Section 6.4. This way the signal strength parameter including its uncertainty only needs to be multiplied with the nominal total cross-section to get the cross-section including uncertainties as defined in Section 7.5.

8.4 Pre-Fit Distributions

The inputs to the fits are shown in Figure 8.1 for the signal region, in Figure 8.2 for the low- m_{jj} control region and in Figure 8.3 for the WZ control region. The last bin contains always the overflow bin. This means that also events are added to that bin which have a larger x value than the quoted one.

One can clearly see the different fractions of non-prompt and conversions backgrounds in different channels. Conversions background has, as expected, its largest contribution in the ee channel and half the effect in $e\mu$ and μe channels. The non-prompt background has similar fractions in all channels, only a little bit more in channels containing μ .

The low- m_{jj} control region has, as designed, a larger ratio of non-prompt background and conversions compared to signal than in the signal region. This helps to constrain the backgrounds in the fit.

There is in general good agreement between data and theory prediction. Only in the WZ control region there is some significant difference. This disagreement has also been observed in the analysis with partial Run 2 data [74], the ATLAS observation of WZ EW production [127] and in the inclusive WZ production in the two jet bin at high m_{jj} values [128].

Tables 8.1 to 8.3 show the yields before the fit to Asimov data. The uncertainties show first the MC statistical uncertainty and the statistical uncertainty for the data. Secondly the theory uncertainty and at last the experimental uncertainties as described in Section 7.4.4. The pre-fit tables and plots are shown for EW $W^\pm W^\pm jj$, but inclusive $W^\pm W^\pm jj$ uses nearly the same inputs. Only the theory uncertainties are different for the inclusive cross-section measurement.

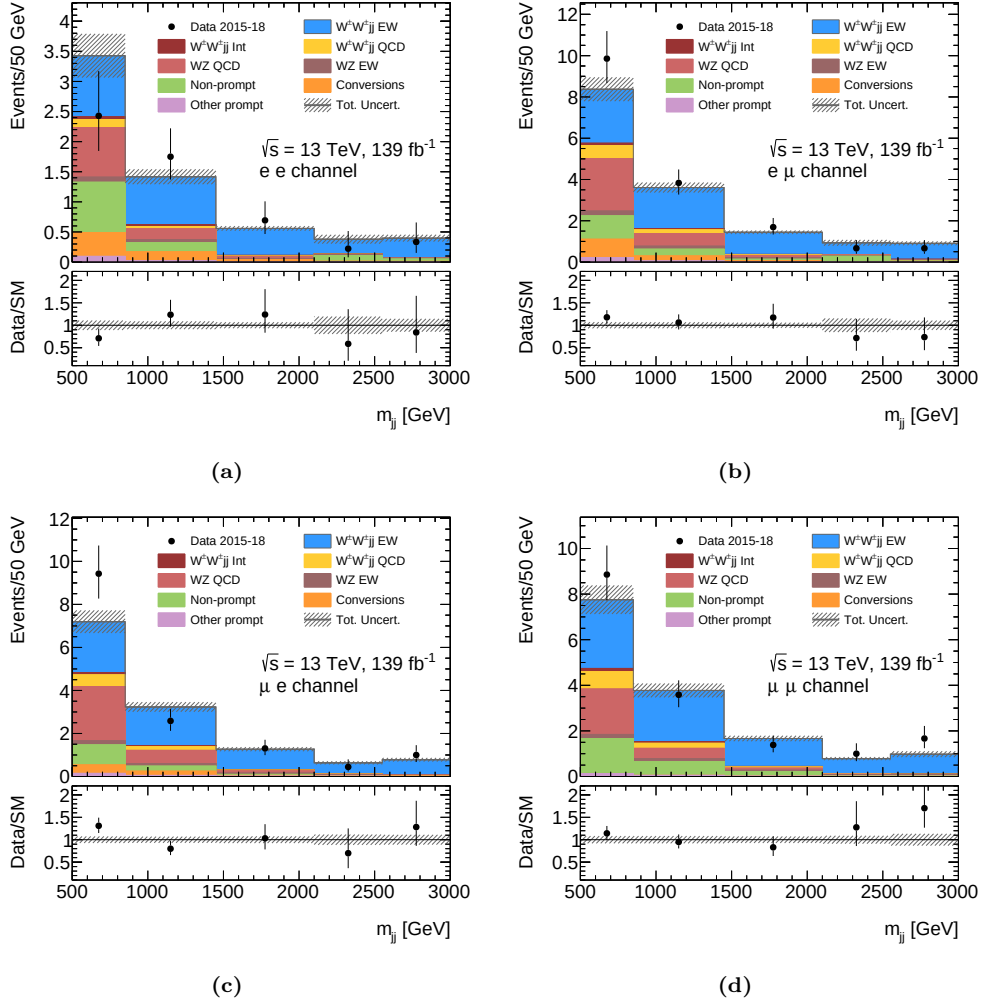


Figure 8.1: Pre-fit m_{jj} -distributions in the signal region for different flavour channels in bins as used in the total cross-section measurement: (a) ee , (b) $e\mu$, (c) μe and (d) $\mu\mu$. The hatched error band around the prediction represents the total uncertainty of the prediction, with statistical and systematic uncertainties added in quadrature.

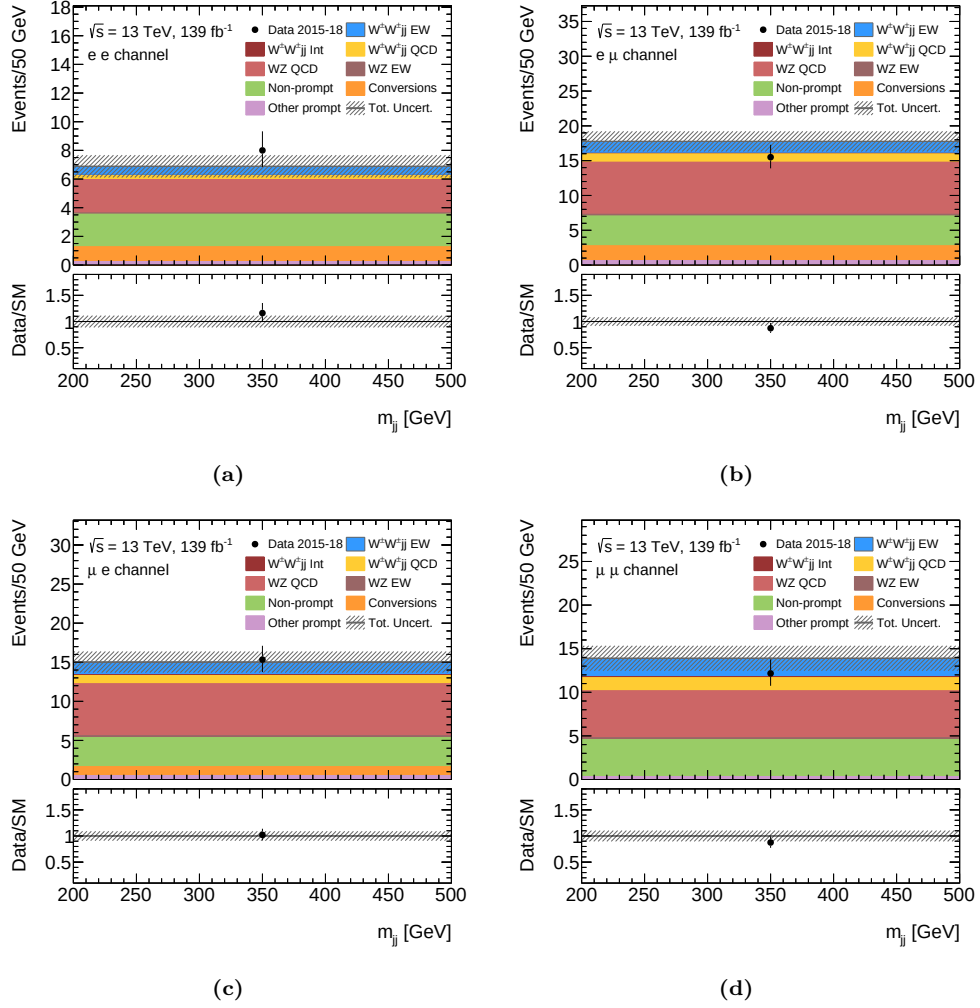


Figure 8.2: Pre-fit m_{jj} -distributions in low- m_{jj} control region for different flavour channels in bins as used in the total cross-section measurement: (a) ee , (b) $e\mu$, (c) μe and (d) $\mu\mu$. The hatched error band around the prediction represents the total uncertainty of the prediction, with statistical and systematic uncertainties added in quadrature.

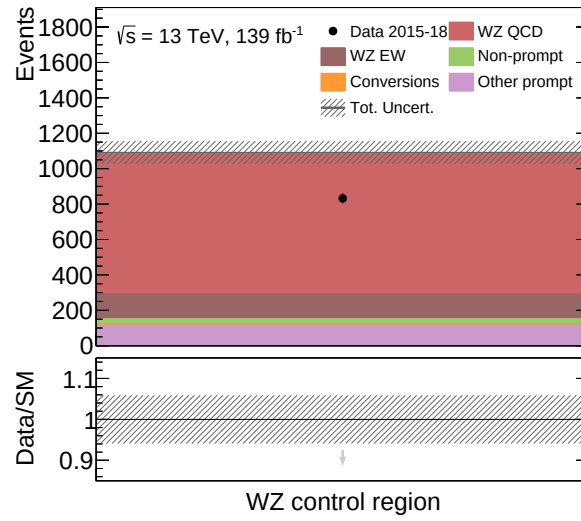


Figure 8.3: Pre-fit distributions in WZ control region as used in the total cross-section measurement. The hatched error band around the prediction represents the total uncertainty of the prediction, with statistical and systematic uncertainties added in quadrature.

Table 8.1: Pre-fit yields in the signal region as used in the total cross-section measurement. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	$e^\pm e^\pm$	$\mu^\pm \mu^\pm$	$e^\pm \mu^\pm$	$\mu^\pm e^\pm$	$\ell^\pm \ell^\pm$
Other prompt	$1.02 \pm 0.10 \pm 0.18 \pm 0.20$	$1.7 \pm 0.1 \pm 0.4 \pm 2.2$	$2.5 \pm 0.2 \pm 0.5 \pm 0.3$	$1.8 \pm 0.1 \pm 0.3 \pm 0.4$	$7.1 \pm 0.3 \pm 1.3 \pm 2.5$
Conversions	$5.1 \pm 0.5 \pm 0.5 \pm 2.1$	$0.003 \pm 0.003 \pm 0.001 \pm 0.004$	$10.1 \pm 0.8 \pm 1.9 \pm 1.5$	$5.8 \pm 0.9 \pm 1.8 \pm 1.7$	$21 \pm 1 \pm 4 \pm 4$
Non-prompt	$8.9 \pm 1.8 \pm 0.0 \pm 1.8$	$21 \pm 3 \pm 0 \pm 6$	$15.3 \pm 3.0 \pm 0.0 \pm 2.8$	$10.2 \pm 2.6 \pm 0.0 \pm 1.8$	$56 \pm 5 \pm 0 \pm 11$
WZ EW	$1.71 \pm 0.06 \pm 0.12 \pm 0.05$	$4.16 \pm 0.09 \pm 0.34 \pm 0.13$	$4.9 \pm 0.1 \pm 0.4 \pm 0.1$	$4.12 \pm 0.09 \pm 0.32 \pm 0.13$	$14.9 \pm 0.2 \pm 1.2 \pm 0.4$
WZ QCD	$8.4 \pm 0.3 \pm 0.7 \pm 0.7$	$20.9 \pm 0.4 \pm 1.8 \pm 1.2$	$26.8 \pm 0.6 \pm 2.4 \pm 1.7$	$26.7 \pm 0.8 \pm 2.5 \pm 1.5$	$83 \pm 1 \pm 7 \pm 5$
$W^\pm W^{\pm jj}$ QCD	$1.6 \pm 0.0 \pm 0.5 \pm 0.1$	$8.8 \pm 0.1 \pm 2.5 \pm 0.3$	$7.3 \pm 0.1 \pm 2.2 \pm 0.2$	$6.4 \pm 0.1 \pm 1.9 \pm 0.2$	$24 \pm 0 \pm 7 \pm 1$
$W^\pm W^{\pm jj}$ Int	$0.93 \pm 0.03 \pm 0.09 \pm 0.03$	$2.51 \pm 0.04 \pm 0.12 \pm 0.05$	$2.19 \pm 0.04 \pm 0.13 \pm 0.04$	$1.96 \pm 0.04 \pm 0.09 \pm 0.04$	$7.6 \pm 0.1 \pm 0.4 \pm 0.1$
obsData	$52 \pm 7 \pm 0 \pm 0$	$147 \pm 12 \pm 0 \pm 0$	$149 \pm 12 \pm 0 \pm 0$	$127 \pm 11 \pm 0 \pm 0$	$475 \pm 22 \pm 0 \pm 0$
$W^\pm W^{\pm jj}$ EW	$27.6 \pm 0.2 \pm 1.0 \pm 0.5$	$77.8 \pm 0.3 \pm 1.3 \pm 1.5$	$68.2 \pm 0.3 \pm 1.8 \pm 1.2$	$61.3 \pm 0.3 \pm 1.5 \pm 1.1$	$235 \pm 1 \pm 5 \pm 4$
Total Expected	$55.2 \pm 1.9 \pm 1.4 \pm 3.0$	$137 \pm 3 \pm 3 \pm 7$	$137 \pm 3 \pm 4 \pm 5$	$118 \pm 3 \pm 4 \pm 4$	$448 \pm 6 \pm 12 \pm 16$

Table 8.2: Pre-fit yields in the low- m_{jj} control region as used in the total cross-section measurement. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	$e^\pm e^\pm$	$\mu^\pm \mu^\pm$	$e^\pm \mu^\pm$	$\mu^\pm e^\pm$	$\ell^\pm \ell^\pm$
Other prompt	$1.36 \pm 0.14 \pm 0.24 \pm 0.14$	$2.0 \pm 0.1 \pm 0.4 \pm 0.2$	$3.6 \pm 0.2 \pm 0.6 \pm 0.2$	$2.8 \pm 0.2 \pm 0.5 \pm 0.2$	$9.8 \pm 0.3 \pm 1.8 \pm 0.6$
Conversions	$6.2 \pm 0.4 \pm 0.7 \pm 2.7$	$0.0 \pm 0.0 \pm 0.0 \pm 0.0$	$12.8 \pm 1.7 \pm 2.9 \pm 1.7$	$6.9 \pm 0.9 \pm 2.0 \pm 2.7$	$26 \pm 2 \pm 6 \pm 6$
Non-prompt	$13.7 \pm 2.6 \pm 0.0 \pm 1.6$	$25 \pm 3 \pm 0 \pm 7$	$26 \pm 4 \pm 0 \pm 4$	$22.5 \pm 3.0 \pm 0.0 \pm 3.0$	$87 \pm 6 \pm 0 \pm 14$
WZ EW	$0.49 \pm 0.03 \pm 0.01 \pm 0.04$	$1.13 \pm 0.05 \pm 0.01 \pm 0.05$	$1.56 \pm 0.05 \pm 0.02 \pm 0.07$	$1.19 \pm 0.05 \pm 0.02 \pm 0.06$	$4.36 \pm 0.09 \pm 0.06 \pm 0.16$
WZ QCD	$14.0 \pm 0.5 \pm 1.2 \pm 1.1$	$32.3 \pm 0.6 \pm 2.2 \pm 1.6$	$45 \pm 1 \pm 4 \pm 2$	$39.9 \pm 0.9 \pm 3.3 \pm 2.7$	$131 \pm 2 \pm 10 \pm 7$
$W^\pm W^{\pm jj}$ QCD	$1.6 \pm 0.0 \pm 0.4 \pm 0.1$	$9.0 \pm 0.1 \pm 2.3 \pm 0.3$	$7.1 \pm 0.1 \pm 1.7 \pm 0.2$	$6.5 \pm 0.1 \pm 1.6 \pm 0.2$	$24 \pm 0 \pm 6 \pm 1$
$W^\pm W^{\pm jj}$ Int	$0.182 \pm 0.017 \pm 0.003 \pm 0.023$	$0.79 \pm 0.03 \pm 0.11 \pm 0.03$	$0.63 \pm 0.03 \pm 0.14 \pm 0.03$	$0.553 \pm 0.027 \pm 0.011 \pm 0.022$	$2.16 \pm 0.05 \pm 0.25 \pm 0.05$
obsData	$48 \pm 7 \pm 0 \pm 0$	$73 \pm 9 \pm 0 \pm 0$	$93 \pm 10 \pm 0 \pm 0$	$92 \pm 10 \pm 0 \pm 0$	$306 \pm 17 \pm 0 \pm 0$
$W^\pm W^{\pm jj}$ EW	$3.8 \pm 0.1 \pm 0.8 \pm 0.1$	$12.7 \pm 0.1 \pm 2.2 \pm 0.2$	$10.4 \pm 0.1 \pm 2.0 \pm 0.2$	$9.8 \pm 0.1 \pm 1.8 \pm 0.2$	$37 \pm 0 \pm 7 \pm 1$
Total Expected	$41.3 \pm 2.7 \pm 1.6 \pm 3.5$	$83 \pm 3 \pm 4 \pm 7$	$107 \pm 4 \pm 5 \pm 5$	$90 \pm 3 \pm 5 \pm 6$	$321 \pm 7 \pm 15 \pm 18$

Table 8.3: Pre-fit yields in the WZ control region as used in the total cross-section measurement. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	$\ell\ell\ell$			
Other prompt	115	± 1	± 18	± 7
Conversions	$8.1 \pm$	$1.2 \pm$	$3.2 \pm$	3.4
Non-prompt	28	± 4	± 8	± 8
WZ EW	141	± 1	± 8	± 3
WZ QCD	800	± 0	± 10	± 40
obsData	832	± 29	± 0	± 0
Total Expected	1090	± 0	± 30	± 60

8.5 Results of the Asimov Fit

The main control plots are shown here for EW $W^\pm W^\pm jj$. More information can be found in Appendix B for the EW and inclusive $W^\pm W^\pm jj$ total cross-section measurements. Details about how the ranking plot, likelihood scan, impact table, pre- and post-fit plot and table and cross-section results are derived can be found in Section 7.

Distributions, after the Asimov fit in the signal region, are shown in Figure 8.4. Since it is a fit to expected data, only the uncertainties change slightly due to constraining and correlation during the fit.

Table 8.4 to 8.5 show the yields in the signal region and low- m_{jj} control region after the fit to Asimov data. The uncertainties show first the statistical uncertainty derived from the signal normalisation μ uncertainty. It is derived from the fit with only statistical uncertainties. Secondly, the theory uncertainty and at last the experimental uncertainties are shown.

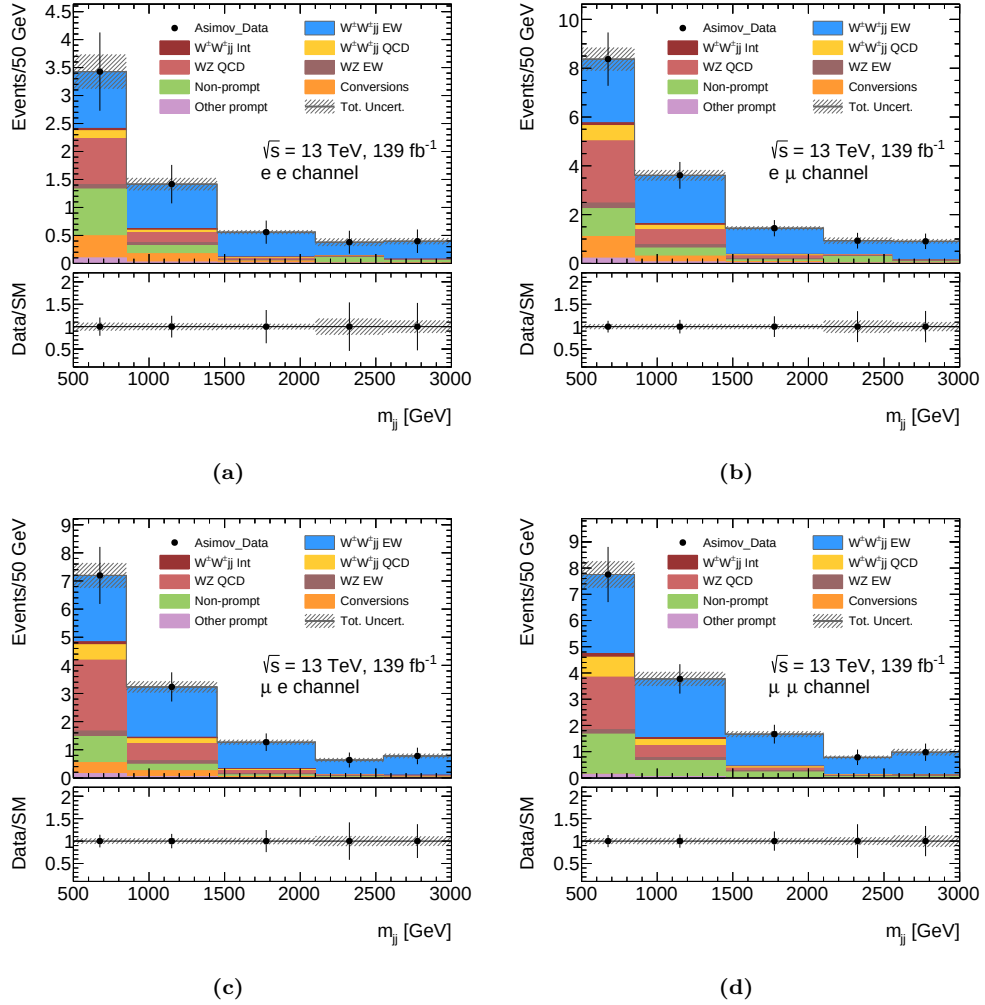


Figure 8.4: Post-fit m_{jj} -distributions in the signal region for different flavour channels in bins used in the total cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data: (a) ee , (b) $e\mu$, (c) μe and (d) $\mu\mu$. The hatched error band around the prediction represents the total uncertainty of the prediction, with statistical and systematic uncertainties added in quadrature.

Table 8.4: Post-fit yields in the signal region used in the total cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	$e^\pm e^\pm$	$\mu^\pm \mu^\pm$	$e^\pm \mu^\pm$	$\mu^\pm e^\pm$	$\ell^\pm \ell^\pm$
Other prompt	$1.02 \pm 0.00 \pm 0.19 \pm 0.19$	$1.7 \pm 0.0 \pm 0.4 \pm 2.1$	$2.5 \pm 0.0 \pm 0.5 \pm 0.3$	$1.8 \pm 0.0 \pm 0.3 \pm 0.4$	$7.1 \pm 0.0 \pm 1.3 \pm 2.4$
Conversions	$5.1 \pm 0.0 \pm 0.5 \pm 1.9$	$0.003 \pm 0.000 \pm 0.001 \pm 0.004$	$10.1 \pm 0.0 \pm 1.8 \pm 1.4$	$5.8 \pm 0.0 \pm 1.7 \pm 1.6$	$21 \pm 0 \pm 4 \pm 4$
Non-prompt	$8.9 \pm 0.0 \pm 0.4 \pm 1.7$	$21 \pm 0 \pm 0 \pm 5$	$15.3 \pm 0.0 \pm 0.4 \pm 2.3$	$10.2 \pm 0.0 \pm 0.3 \pm 1.6$	$56 \pm 0 \pm 1 \pm 9$
WZ EW	$1.71 \pm 0.00 \pm 0.13 \pm 0.06$	$4.16 \pm 0.00 \pm 0.35 \pm 0.15$	$4.9 \pm 0.0 \pm 0.4 \pm 0.2$	$4.12 \pm 0.00 \pm 0.33 \pm 0.15$	$14.9 \pm 0.0 \pm 1.2 \pm 0.5$
WZ QCD	$8.4 \pm 0.0 \pm 1.1 \pm 0.7$	$20.9 \pm 0.0 \pm 2.5 \pm 1.1$	$26.8 \pm 0.0 \pm 3.3 \pm 1.6$	$26.7 \pm 0.0 \pm 3.3 \pm 1.4$	$83 \pm 0 \pm 10 \pm 4$
$W^\pm W^\pm jj$ QCD	$1.6 \pm 0.0 \pm 0.5 \pm 0.1$	$8.8 \pm 0.0 \pm 2.5 \pm 0.3$	$7.3 \pm 0.0 \pm 2.1 \pm 0.2$	$6.4 \pm 0.0 \pm 1.8 \pm 0.2$	$24 \pm 0 \pm 7 \pm 1$
$W^\pm W^\pm jj$ Int	$0.93 \pm 0.04 \pm 0.09 \pm 0.03$	$2.51 \pm 0.11 \pm 0.13 \pm 0.06$	$2.19 \pm 0.09 \pm 0.14 \pm 0.06$	$1.96 \pm 0.08 \pm 0.10 \pm 0.05$	$7.6 \pm 0.3 \pm 0.4 \pm 0.2$
asimovData	$55.2 \pm 0.0 \pm 0.0 \pm 0.0$	$137.1 \pm 0.0 \pm 0.0 \pm 0.0$	$137.3 \pm 0.0 \pm 0.0 \pm 0.0$	$118.4 \pm 0.0 \pm 0.0 \pm 0.0$	$448.0 \pm 0.0 \pm 0.0 \pm 0.0$
$W^\pm W^\pm jj$ EW	$27.6 \pm 2.3 \pm 1.2 \pm 0.7$	$78 \pm 7 \pm 2 \pm 2$	$68 \pm 6 \pm 2 \pm 2$	$61 \pm 5 \pm 2 \pm 2$	$235 \pm 20 \pm 6 \pm 6$
Total Expected	$55.2 \pm 2.4 \pm 2.4 \pm 2.8$	$137 \pm 7 \pm 5 \pm 6$	$137 \pm 6 \pm 5 \pm 5$	$118 \pm 5 \pm 5 \pm 4$	$448 \pm 20 \pm 14 \pm 15$

Table 8.5: Post-fit yields in the low- m_{jj} control region used in the total cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	$e^\pm e^\pm$	$\mu^\pm \mu^\pm$	$e^\pm \mu^\pm$	$\mu^\pm e^\pm$	$\ell^\pm \ell^\pm$
Other prompt	$1.36 \pm 0.00 \pm 0.25 \pm 0.14$	$2.0 \pm 0.0 \pm 0.4 \pm 0.2$	$3.6 \pm 0.0 \pm 0.7 \pm 0.2$	$2.8 \pm 0.0 \pm 0.5 \pm 0.2$	$9.8 \pm 0.0 \pm 1.8 \pm 0.7$
Conversions	$6.2 \pm 0.0 \pm 0.7 \pm 2.4$	$0.0 \pm 0.0 \pm 0.0 \pm 0.0$	$12.8 \pm 0.0 \pm 2.8 \pm 1.6$	$6.9 \pm 0.0 \pm 1.9 \pm 2.6$	$26 \pm 0 \pm 5 \pm 5$
Non-prompt	$13.7 \pm 0.0 \pm 0.8 \pm 1.5$	$25 \pm 0 \pm 1 \pm 6$	$26 \pm 0 \pm 1 \pm 4$	$22.5 \pm 0.0 \pm 0.8 \pm 2.5$	$87 \pm 0 \pm 2 \pm 12$
WZ EW	$0.49 \pm 0.00 \pm 0.03 \pm 0.04$	$1.13 \pm 0.00 \pm 0.04 \pm 0.06$	$1.56 \pm 0.00 \pm 0.06 \pm 0.07$	$1.19 \pm 0.00 \pm 0.05 \pm 0.06$	$4.36 \pm 0.00 \pm 0.11 \pm 0.17$
WZ QCD	$14.0 \pm 0.0 \pm 1.7 \pm 1.0$	$32.3 \pm 0.0 \pm 3.5 \pm 1.5$	$45 \pm 0 \pm 5 \pm 2$	$40 \pm 0 \pm 5 \pm 3$	$131 \pm 0 \pm 14 \pm 7$
$W^\pm W^\pm jj$ QCD	$1.6 \pm 0.0 \pm 0.4 \pm 0.1$	$9.0 \pm 0.0 \pm 2.2 \pm 0.3$	$7.1 \pm 0.0 \pm 1.7 \pm 0.2$	$6.5 \pm 0.0 \pm 1.6 \pm 0.2$	$24 \pm 0 \pm 6 \pm 1$
$W^\pm W^\pm jj$ Int	$0.182 \pm 0.008 \pm 0.011 \pm 0.022$	$0.79 \pm 0.03 \pm 0.11 \pm 0.03$	$0.63 \pm 0.03 \pm 0.14 \pm 0.03$	$0.553 \pm 0.023 \pm 0.022 \pm 0.023$	$2.16 \pm 0.09 \pm 0.25 \pm 0.06$
asimovData	$41.3 \pm 0.0 \pm 0.0 \pm 0.0$	$83.4 \pm 0.0 \pm 0.0 \pm 0.0$	$106.6 \pm 0.0 \pm 0.0 \pm 0.0$	$90.1 \pm 0.0 \pm 0.0 \pm 0.0$	$321.5 \pm 0.0 \pm 0.0 \pm 0.0$
$W^\pm W^\pm jj$ EW	$3.8 \pm 0.3 \pm 0.7 \pm 0.1$	$12.7 \pm 1.1 \pm 1.9 \pm 0.3$	$10.4 \pm 0.9 \pm 1.8 \pm 0.3$	$9.8 \pm 0.8 \pm 1.6 \pm 0.3$	$37 \pm 3 \pm 6 \pm 1$
Total Expected	$41.3 \pm 0.3 \pm 3.0 \pm 3.1$	$83 \pm 1 \pm 5 \pm 6$	$107 \pm 1 \pm 6 \pm 5$	$90 \pm 1 \pm 6 \pm 6$	$321 \pm 3 \pm 16 \pm 16$

The correlations between the nuisance parameters and normalisation parameters is shown in Figure 8.5. It is shown for two different definitions of up- and down variation. Once for the physical motivated definition and once modified to make the statistical interpretation easier:

1. First for the one which is used in the rest of this thesis and corresponds to the physical motivated direction. These information about the direction are needed to correctly combine different analysis which are affected by the same systematic uncertainty. Systematics with large positive correlation, but inversely defined up- and down variation in the signal region are:

JET_Flavor_Response: This uncertainty is derived using analysis specific quark and gluon contribution. For the contributions in MC the up variation corresponds to fewer expected events in the signal region.

FF_Prompt: "Lepton misidentification prompt subtraction variation" is the uncertainty which gets subtracted during fake factor determination. Hence the up variation corresponds to fewer predicted events of the non-prompt background in the signal region.

MjjRewStat: QCD $W^\pm Z_{jj}$ m_{jj} reweighting statistic uncertainty is normalised in the signal region + low- m_{jj} control region. After normalisation, the up-variation corresponds to more predicted events in the low- m_{jj} control region, but fewer events in the signal region.

2. Secondly it is also shown for the case where the variations are adjusted such, that the up variation corresponds always to more expected events in the signal region compared to the down variation. This is shown in subfigure (b). The correlation is nearly always negative because the effect on the number of events in the signal region of one NP gets compensated by the other NP. Only if there are three NPs involved, then stronger positive correlations are possible. This happens e.g. for the normalisation parameters or for QCD $W^\pm Z_{jj}$ m_{jj} reweighting statistics (MjjRewStat) and Lepton misid.: prompt subtr. variation (FF_Prompt). For the last two it could be in principle helpful to create bins during binning optimisation where they have the same effect to destroy the correlation, further constrain them and thus making the total cross-section measurement more precise in the end. But because of the small impact the binning is not reoptimised in this thesis. This would be something to consider in a future analysis.

The pull plot is shown in Figure 8.6. There are, as expected, no pulls because of the used Asimov data. Strong correlations are also not observed, which means that there are no two systematics with the same effect on the signal yield which ensures a stable fit result. The following nuisance parameters have a lower post-fit uncertainty compared to the pre-fit uncertainty:

mu_FF_BTagged: $\mu^\pm$ misid.: light/heavy hadr. origin,

signal_EW6_TheoEwcorr: EW $W^\pm W^\pm jj$ NLO EW correction,

signal_EW6_TheoQCDCorr: EW $W^\pm W^\pm jj$ NLO QCD correction,

chFlipSF: Charge flip unc.,

FF_Prompt: Lepton misid.: prompt subtr. variation,

MjjRewStat: QCD $W^\pm Z_{jj}$ m_{jj} reweighting statistics.

In short, they get constrained. The one-sided NLO modelling nuisance parameters `signal_EW6_TheoEwcorr` and `signal_EW6_TheoQCDCorr` can only get constrained on that same side. Here Asimov data around LO predictions is assumed and thus constraining to not be NLO is expected. It was checked, that if the best available NLO signal would be used as signal template, that it would result in the same total cross-sections within uncertainties when either NLO signal or signal LO is used as Asimov data. The LO signal sample is chosen

because the alternative NLO prediction would not be fully NLO and thus an inconsistent theory prediction. Besides this there are some constraints of data-driven estimated backgrounds: `mu_FF_BTagged`, `chFlipSF`, `FF_Prompt` and `MjjRewStat`. These constraints are expected due to the additional information in signal region, low- m_{jj} control region and WZ control region which are not used in the initial pre-fit background prediction. For experimental uncertainties no constraint is expected, but also not observed, because these are centrally constrained in dedicated regions with more data information.

The strongest (anti-)correlations are included in Table 8.6. They are mainly negative with regard to the expected events, because they compensate each others predicted events around the maximum likelihood estimate. Most of the correlations are due to normalisation effects of a systematic uncertainty on the signal and QCD $W^\pm Zjj$ background which can be equalised by the corresponding signal or QCD $W^\pm Zjj$ normalisation strength. The strongest correlation not including a strength parameter is: Lepton misid.: prompt subtr. variation (`FF_Prompt`) vs. $\mu^\pm$ misid.: light/heavy hadr. origin (`mu_FF_BTagged`) with a correlation of -0.164 . This means they have the most similar effect on the predicted yield, but are still relatively different with an anticorrelation of -0.164 . This means that the numerical minimization is expected to be quite stable. The charge flip uncertainty (`chFlipSF`) gets mostly constrained in the ee channel of the low- m_{jj} control region (`CutLowMjj_ee_bin_0_0`) where it is correlated with 0.121 with the corresponding MC stat unc nuisance parameter. The NPs strongest correlated with the signal strength μ are: QCD $W^\pm Zjj$ m_{jj} reweighting statistics (`MjjRewStat`) and Lepton misid.: prompt subtr. variation (`FF_Prompt`). This correlation is expected because WZ and non-prompt are the largest backgrounds and their normalisation depends on these NPs. The impact on the uncertainty of μ is shown in the following ranking plot.

The dominant uncertainties are investigated with the ranking plot and impact table. To assess the impact of a nuisance parameter on the fit, the variation of the signal parameter μ is calculated for the nuisance parameters up and down uncertainties, as described in Section 7.4.6. The impact of the 20 nuisance parameters causing the largest variations are shown in Figure 8.7 for systematic, MC statistical uncertainties and QCD $W^\pm Zjj$ background normalisation μ_{WZ} . The effect of all the nuisance parameters considered in the fit is shown in Tables B.2 and B.3 for systematic and MC statistical uncertainties in Appendix B.1, respectively. The impacts of EW $W^\pm W^\pm jj$ NLO QCD correction (`signal_EW6_TheoQCDCorr`) and EW $W^\pm W^\pm jj$ NLO EW correction (`signal_EW6_TheoEwcorr`) are one-sided, because the nuisance parameters are also only one-sided.

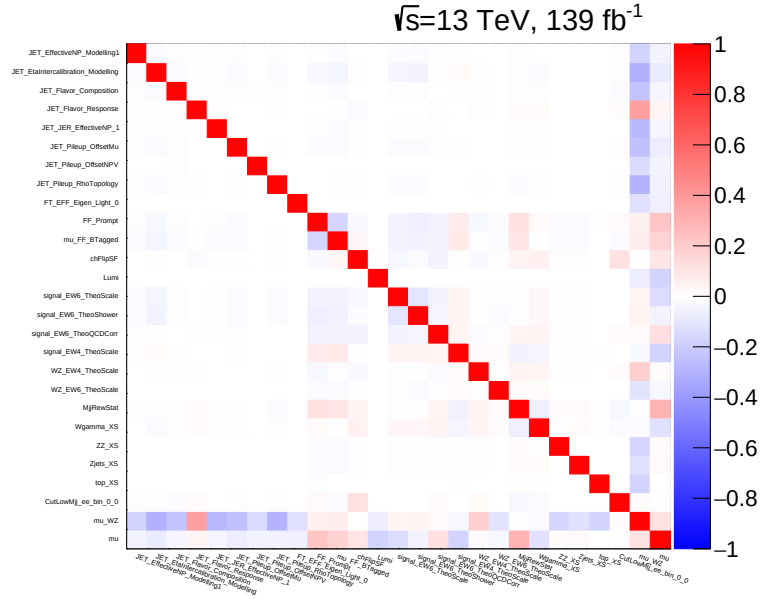
For the Asimov fit, the ranking is dominated by modelling uncertainty related nuisance parameters: The five dominant nuisance parameters could be reduced by using consistent NLO signal samples, better WZ m_{jj} modelling and continued work on the non-prompt background.

The impact of different components of systematic uncertainties on the measured fiducial cross-section is shown in Table 8.7. The procedure of how the uncertainty components are calculated is described in Section 7.4.3.1 and the nuisance parameters associated to a category can be found in Section 6.5. As discussed in Section 6.5 the largest impacts from data-driven estimated backgrounds need to be inferred from the ranking plot. The largest purely experimental uncertainty is from jet energy resolution and luminosity. Jet systematics have the largest absolute effect on QCD $W^\pm Zjj$, see Table 6.17 to 6.19, because they have more heavy flavour jets compared to the $W^\pm W^\pm jj$ processes. However, these are still small compared to modelling uncertainty and data statistical uncertainty. More recorded data events and improved theory modelling will help the most to get more precise results in future analysis.

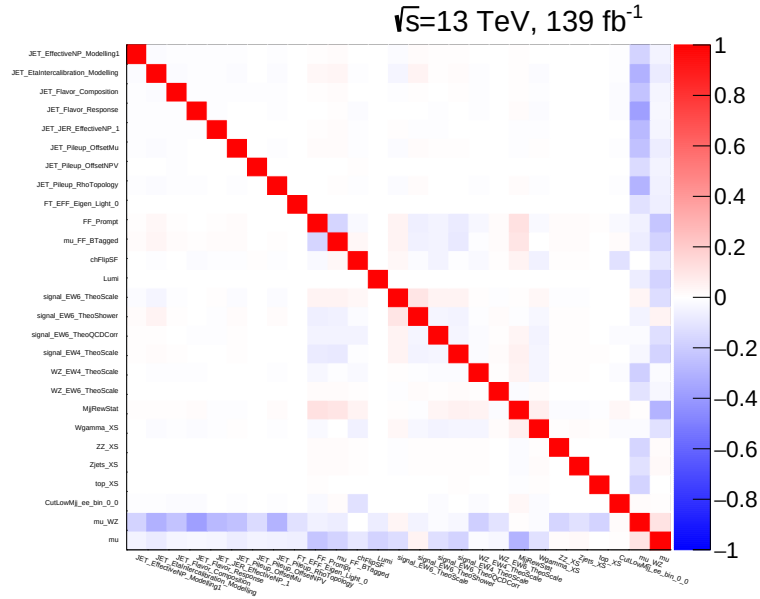
8.5.1 Cross-Section Extraction for EW $W^\pm W^\pm jj$

The expected signal strength from the fit to Asimov data is:

$$\mu_{\text{exp}}^{\text{EW}} = 1.00 \pm_{0.08}^{0.09} (\text{stat.}) \pm_{0.05}^{0.05} (\text{mod. syst.}) \pm_{0.04}^{0.05} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.})$$



(a)



(b)

Figure 8.5: Correlation of nuisance parameters with at least 10% correlation with another NP (a) as used in the fit and (b) with sign of up-down variation adjusted to effect on total yield in signal region in total cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with Asimov data.

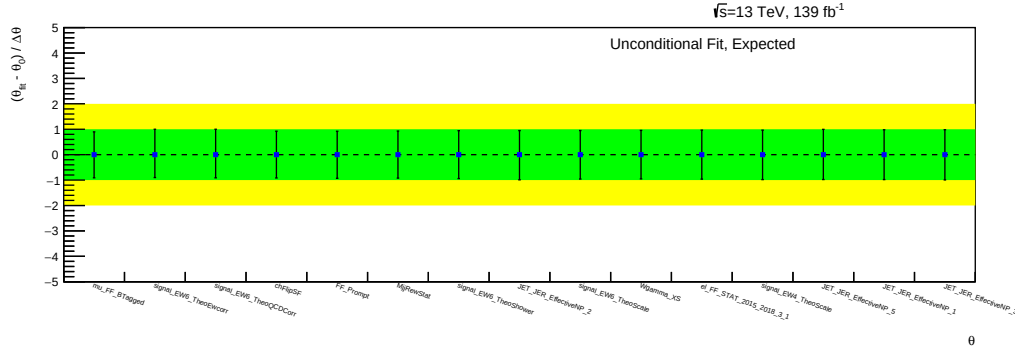


Figure 8.6: Nuisance parameter pulls of strongest constrained nuisance parameters in the total cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

Pre-fit impact on μ :

$$\square \theta = \theta_0 + \Delta\theta \quad \square \theta = \theta_0 - \Delta\theta$$

Post-fit impact on μ :

$$\blacksquare \theta = \hat{\theta} + \Delta\hat{\theta} \quad \blacksquare \theta = \hat{\theta} - \Delta\hat{\theta}$$

—+— Nuis. Param. Pull

- WZ QCD m_μ reweighting statistics
- EW $W^\pm W^\pm jj$ NLO QCD correction
- Lepton misid.: prompt subtr. variation
- QCD $W^\pm W^\pm jj$ NLO QCD correction
- Muon misid.: light/heavy hadr. origin
- Luminosity
- QCD $W^\pm W^\pm jj$ QCD scale uncertainty
- Jet η intercalibration modelling
- EW $W^\pm W^\pm jj$ NLO EW correction
- EW $W^\pm W^\pm jj$ QCD scale uncertainty
- Jet pile-up offset μ
- Jet energy resolution: NP 2
- WZ background normalisation
- $W\gamma$ cross section
- Jet pile-up ρ topology
- Jet in-situ modelling: NP 1
- b-tagging: efficiency (light), NP 0
- Charge flip unc.
- Muon misid.: stat. $p_{T,\mu} > 55$ GeV
- Muon misid.: stat. $35 < p_{T,\mu} < 55$ GeV

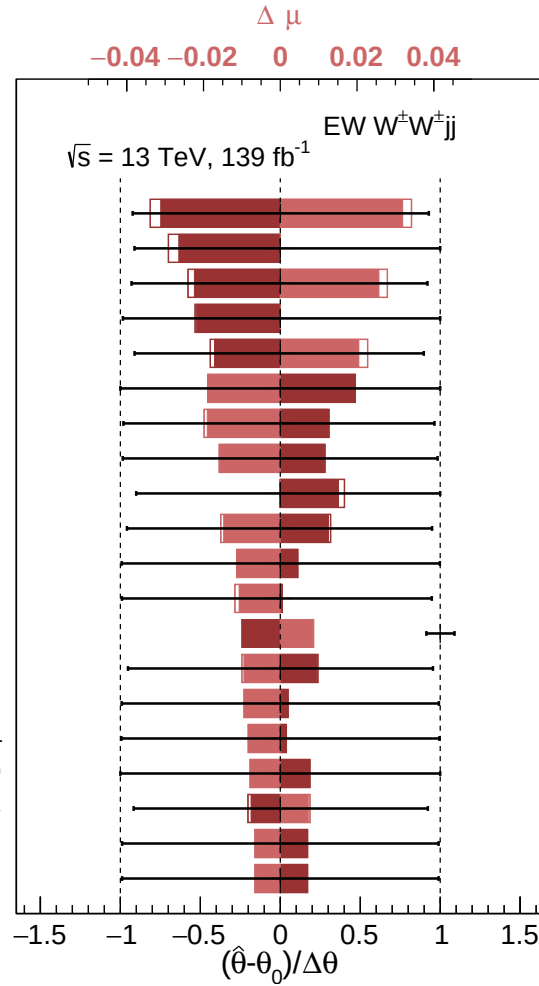


Figure 8.7: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured signal strength μ in total cross-section measurement of EW $W^\pm W^\pm jj$ using Asimov data. The empty brown rectangles correspond to the pre-fit impact on μ and the filled brown ones to the post-fit impact on μ , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}/\Delta\theta$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

Table 8.6: List of parameter correlations which are larger than 7.5% in the total cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	μ_{WZ}	0.374
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.305
JET_Pileup_RhoTopology	μ_{WZ}	-0.301
MjjRewStat	μ	0.301
JET_JER_EffectiveNP_1	μ_{WZ}	-0.276
JET_Pileup_OffsetMu	μ_{WZ}	-0.240
JET_Flavor_Composition	μ_{WZ}	-0.237
FF_Prompt	μ	0.226
WZ_EW4_TheoScale	μ_{WZ}	0.190
top_XS	μ_{WZ}	-0.176
Lumi	μ	-0.176
$\mu_{FF_BTagged}$	μ	0.176
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.174
signal_EW4_TheoScale	μ	-0.169
FF_Prompt	$\mu_{FF_BTagged}$	-0.164
ZZ_XS	μ_{WZ}	-0.162
JET_Pileup_OffsetNPV	μ_{WZ}	-0.141
signal_EW6_TheoScale	μ	-0.132
signal_EW6_TheoQCDCorr	μ	0.129
Wgamma_XS	μ	-0.122
chFlipSF	CutLowMjj_ee_bin_0_0	0.121
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.120
FF_Prompt	MjjRewStat	0.118
Zjets_XS	μ_{WZ}	-0.115
μ	μ_{WZ}	0.108
WZ_EW6_TheoScale	μ_{WZ}	-0.107
MjjRewStat	$\mu_{FF_BTagged}$	0.105
signal_EW6_TheoScale	signal_EW6_TheoShower	-0.101
chFlipSF	μ	0.098
$\mu_{FF_BTagged}$	CutLowMjj_mm_bin_0_0	0.095
signal_EW4_TheoQCDCorr	μ	0.095
$\mu_{FF_BTagged}$	signal_EW4_TheoScale	0.085
signal_EW6_TheoEwcorr	μ	-0.085
$\mu_{FF_STAT_2015_2018_2_1}$	μ	-0.080
$\mu_{FF_STAT_2015_2018_3_1}$	μ	-0.080
JET_EtaIntercalibration_Modelling	μ	-0.077
MET_SoftTrk_Scale	μ_{WZ}	0.077
chFlipSF	el_FF_STAT_2015_2018_3_1	0.077
signal_EW6_TheoEwcorr	signal_EW6_TheoShower	-0.075

Table 8.7: Breakdown of the uncertainty on the EW $W^\pm W^\pm jj$ cross-section measurement using Asimov data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma\gamma$, ZZ, top and Zjets.

Source	Impact [%]
Experimental	
Electron calibration	0.4
Muon calibration	0.5
Jet energy scale and resolution	1.8
E_T^{miss} scale and resolution	0.2
b -tagging inefficiency	0.7
Background, misid. leptons	3.8
Background, charge misrec.	1.1
Pileup modelling	0.1
Luminosity	1.9
Modelling	
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	1.0
EW $W^\pm W^\pm jj$, QCD corrections	1.9
EW $W^\pm W^\pm jj$, EW corrections	0.5
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.1
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	2.2
QCD $W^\pm W^\pm jj$, QCD corrections	1.0
Background, WZ scale, PDF & α_s	0.4
Background, WZ reweighting	2.5
Background, other	1.3
Model statistical	1.9
Experimental and modelling	6.8
Data statistical	8.4
Total	10.8

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{WZ, \text{exp}}^{\text{EW}} = 1.00 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.})$$

Using the fiducial cross-section $\sigma_{pred}^{\text{fid}}$ from Section 5.4 and equation 7.39 the expected cross-section becomes:

$$\sigma_{\text{exp}}^{\text{EW}} = 2.53 \pm_{0.21}^{0.22} (\text{stat.}) \pm_{0.12}^{0.12} (\text{mod. syst.}) \pm_{0.11}^{0.12} (\text{exp. syst.}) \pm_{0.04}^{0.05} (\text{lumi.}) \text{ fb}$$

8.5.2 Cross-Section Extraction for Inclusive $W^\pm W^\pm jj$

The expected signal strength from the fit to Asimov data is:

$$\mu_{\text{exp}}^{\text{EW}+\text{Int}+\text{QCD}} = 1.00 \pm_{0.07}^{0.08} (\text{stat.}) \pm_{0.04}^{0.04} (\text{mod. syst.}) \pm_{0.04}^{0.05} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.})$$

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{WZ, \text{exp}}^{\text{EW}+\text{Int}+\text{QCD}} = 1.00 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.})$$

Using the fiducial cross-section σ_{pred}^{fid} from Section 5.4 and equation 7.39 the expected cross-section becomes:

$$\sigma_{exp}^{EW+Int+QCD} = 2.93 \pm_{0.22}^{0.22} \text{ (stat.)} \pm_{0.12}^{0.10} \text{ (mod. syst.)} \pm_{0.13}^{0.14} \text{ (exp. syst.)} \pm_{0.05}^{0.06} \text{ (lumi.) fb}$$

The impact of different components of systematic uncertainties on the measured fiducial cross-section is shown in Table 8.8. The modelling and data statistical uncertainties are reduced a bit compared to Table 8.7, because the signal process consists of more events now, resulting in a lower relative uncertainty.

Table 8.8: Breakdown of the uncertainties on the inclusive $W^\pm W^\pm jj$ cross-section measurement using Asimov data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma$, ZZ , top and Zjets processes.

Source	Impact [%]
Experimental	
Electron calibration	0.4
Muon calibration	0.5
Jet energy scale and resolution	1.8
E_T^{miss} scale and resolution	0.2
b -tagging inefficiency	0.7
Background, misid. leptons	3.9
Background, charge misrec.	1.0
Pileup modelling	0.1
Luminosity	1.7
Modelling	
$W^\pm W^\pm jj$ shower, scale, PDF & α_s	0.7
EW $W^\pm W^\pm jj$, QCD corrections	2.1
EW $W^\pm W^\pm jj$, EW corrections	0.3
QCD $W^\pm W^\pm jj$, QCD corrections	0.1
Background, WZ scale, PDF & α_s	0.5
Background, WZ reweighting	2.0
Background, other	1.3
Model statistical	1.7
Experimental and modelling	6.2
Data statistical	7.5
Total	9.7

The ranking of the top 20 nuisance parameters contributing to the fit is shown in Figure 8.8 for systematic, MC statistical uncertainties and QCD $W^\pm Zjj$ normalisation μ_{WZ} . It looks very similar to the ranking with EW $W^\pm W^\pm jj$ signal in Figure 8.7. Only QCD $W^\pm W^\pm jj$ scale uncertainty (signal_EW4_TheoScale) and EW $W^\pm W^\pm jj$ scale uncertainty (signal_EW6_TheoScale) do not appear in the top 20 any more. The reason is, that they got combined into Inclusive $W^\pm W^\pm jj$ scale uncertainty (signal_ALLEW_TheoScale) and QCD $W^\pm W^\pm jj$ is now part of the signal. This annihilates the impact of EW and QCD $W^\pm W^\pm jj$ scale variation on μ . This is also visible in the decreased modelling uncertainty of QCD $W^\pm W^\pm jj$ in yields of the inclusive fit in Table B.4 and B.5 compared to the one from EW $W^\pm W^\pm jj$ fit in Table 8.4 and 8.5

8.6 Results of the Fit to Observed Data

Distributions after the fit to observed data are shown in Figure 8.9 to 8.11.

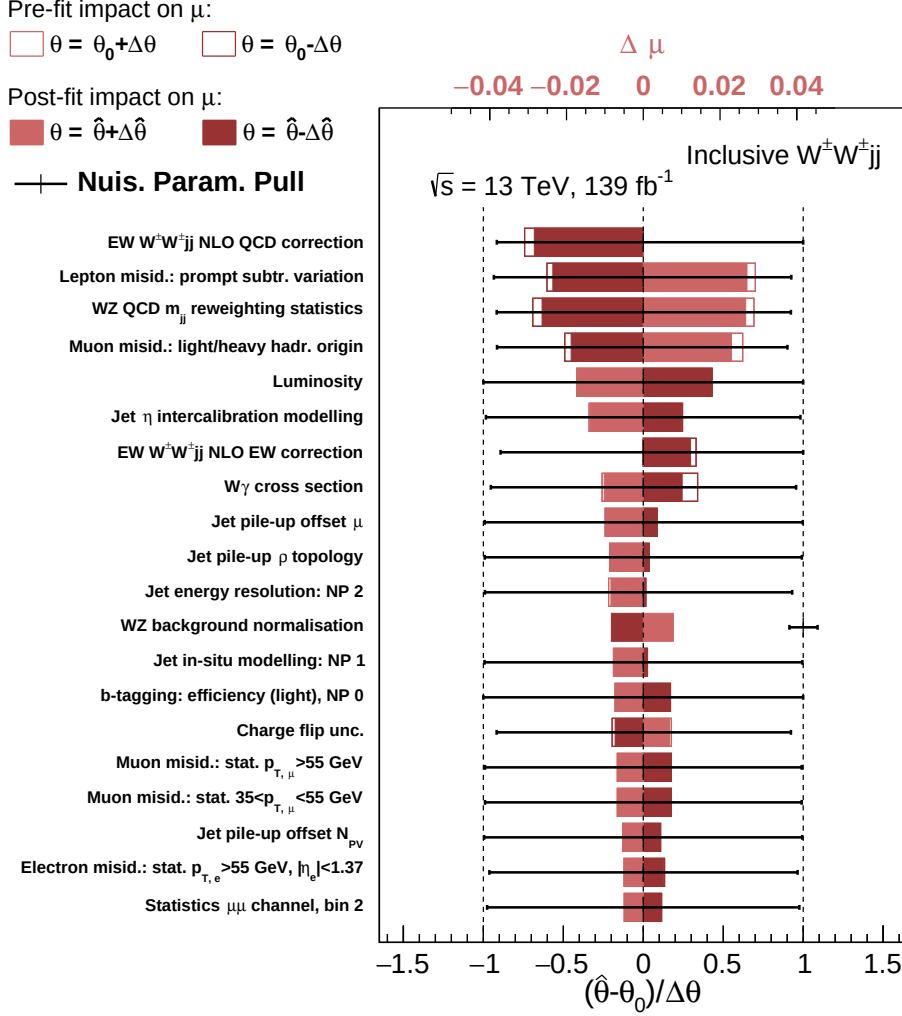


Figure 8.8: Ranking of the top 20 nuisance parameters included in the fit according to their impact on the measured signal strength μ in total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data. The empty brown rectangles correspond to the pre-fit impact on μ and the filled brown ones to the post-fit impact on μ , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}/\Delta\theta$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

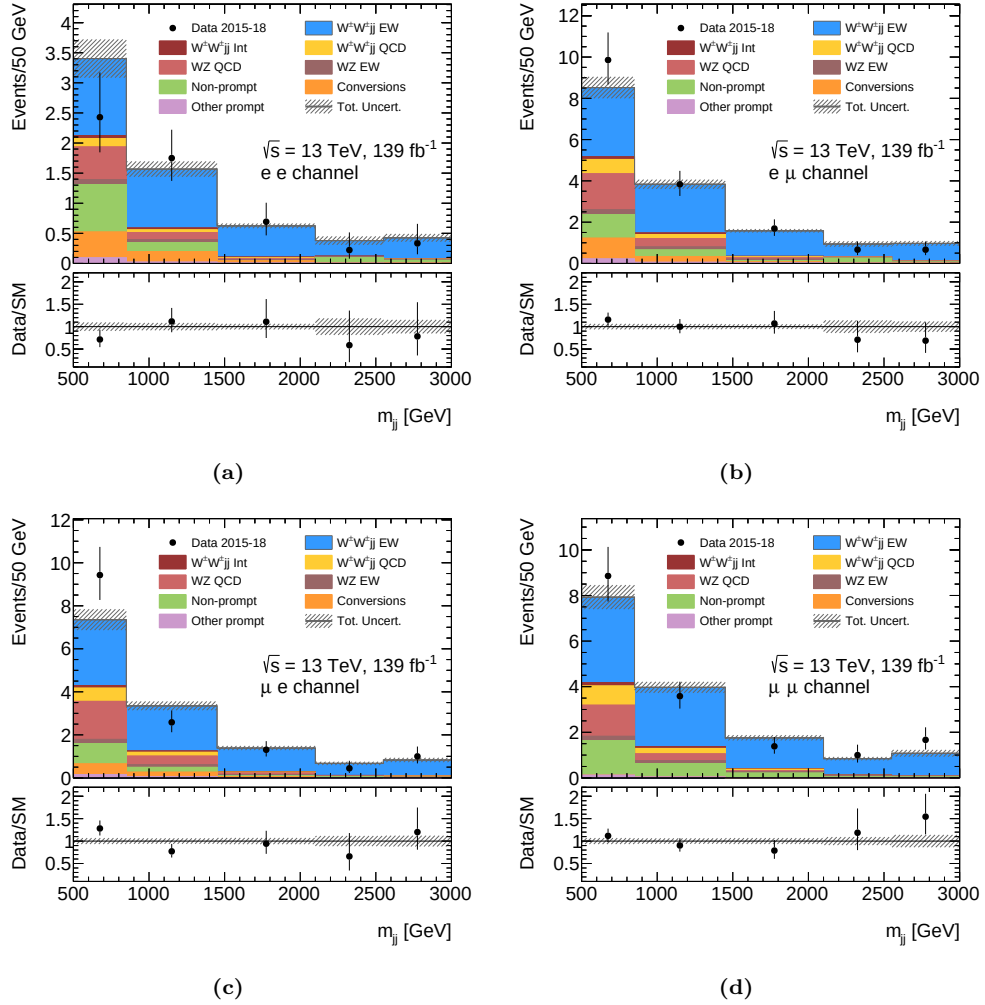


Figure 8.9: Post-fit m_{jj} -distributions in the signal region for different flavour channels in bins used in the total cross-section measurement of EW $W^\pm W^\pm jj$: (a) ee , (b) $e\mu$, (c) μe and (d) $\mu\mu$. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.

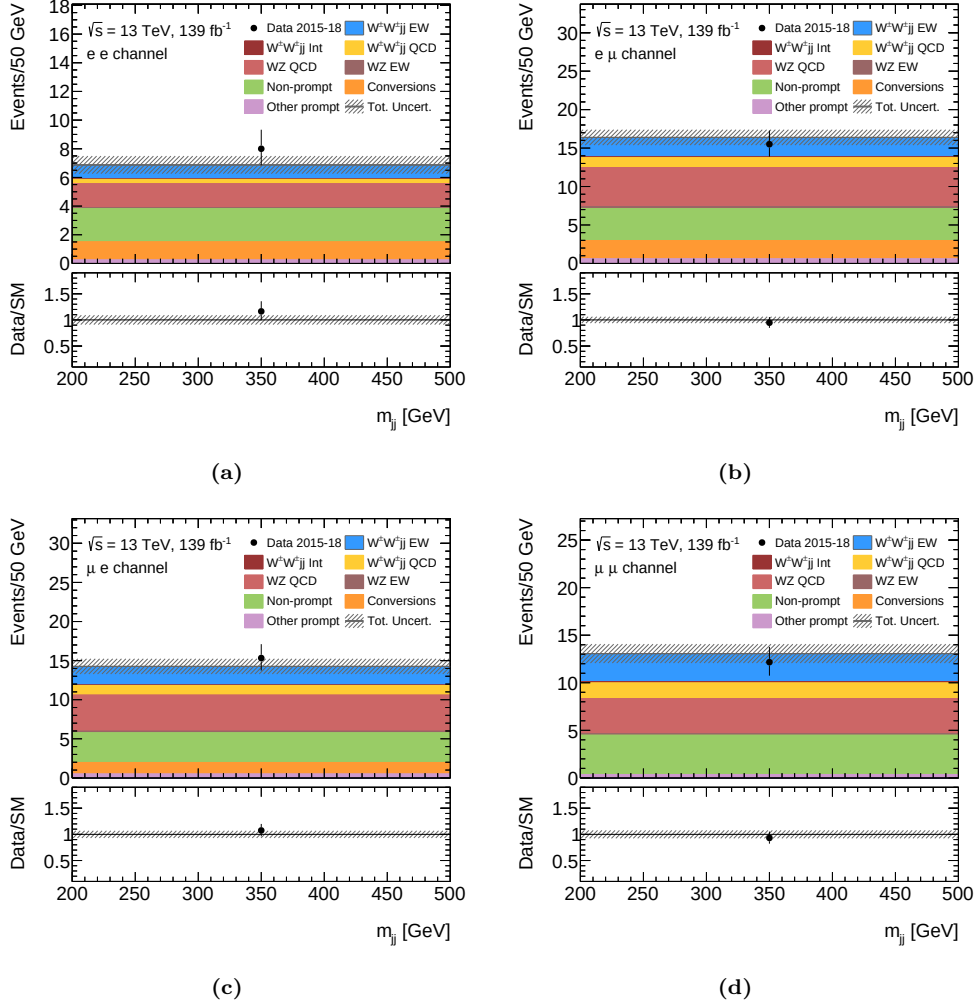


Figure 8.10: Post-fit m_{jj} -distributions in low- m_{jj} control region for different flavour channels in bins used in the total cross-section measurement of EW $W^\pm W^\pm jj$: (a) ee , (b) $e\mu$, (c) μe and (d) $\mu\mu$. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.

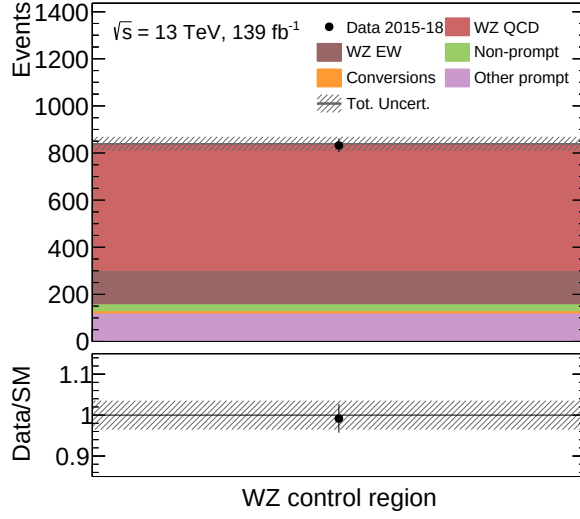


Figure 8.11: Post-fit distributions in WZ control region used in the total cross-section measurement of EW $W^\pm W^\pm jj$. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.

The pull plot and correlations are in Figure 8.12.

The strongest pulls are present for EW $W^\pm W^\pm jj$ NLO QCD correction (signal_EW6_TheoQCDCorr), EW $W^\pm W^\pm jj$ NLO EW correction (signal_EW6_TheoEwcorr) and $W\gamma$ cross-section unc. (Wgamma_XS). This means, data agrees better with a partial application of EW $W^\pm W^\pm jj$ NLO EW+QCD corrections and a larger $W\gamma$ normalisation. The NPs which are constrained the strongest are Jet energy resolution: NP 5 (JET_JER_EffectiveNP_5), Jet η intercalibration modelling (JET_EtaIntercalibration_Modelling) and Jet flavour composition (JET_Flavor_Composition). But it is still a moderate constraint. No significant pull or constraint of shower uncertainty was observed neither for Asimov data nor for observed data. This means that no splitting of this uncertainty is needed to make it more conservative.

Selected profile Likelihood scans are in Figure 8.13. These are the signal and QCD $W^\pm Zjj$ background normalisation factors, μ and μ_{WZ} , and the most constrained nuisance parameters. The profile likelihood scan is performed by setting a nuisance parameter constant to different values and determining the likelihood ratio again. Slightly tilted parabolas are expected for well-defined fits without local minima. No scan shows local minima - only the global minima with rising function values starting from there.

The strongest (anti-)correlations are included in Table 8.9. Most of the correlations are due to normalisation effects of a systematic on the signal and QCD $W^\pm Zjj$ background which can be equalised by the corresponding signal or QCD $W^\pm Zjj$ normalisation strength.

The ranking of the top 20 nuisance parameters contributing to the fit is shown in Figure 8.14 for systematic and MC statistical uncertainties and the QCD $W^\pm Zjj$ normalisation μ_{WZ} . The effect of all the nuisance parameters considered in the fit is shown in Tables B.13 and B.14 in the Appendix for systematic and MC statistical uncertainties, respectively.

The impacts of EW $W^\pm W^\pm jj$ NLO QCD correction (signal_EW6_TheoQCDCorr) and EW $W^\pm W^\pm jj$ NLO EW correction (signal_EW6_TheoEwcorr) are two-sided, even when the nuisance parameters are only one-sided. The predicted yields do not change, when the nuisance parameter is pulled to values larger than 0 because of its one-sidedness. When fixing the NP to its best-fit value (less than 0 for observed data) shifted up by its up uncertainty, then the predicted yields take on the value for a pull of 0, a value that is usually still

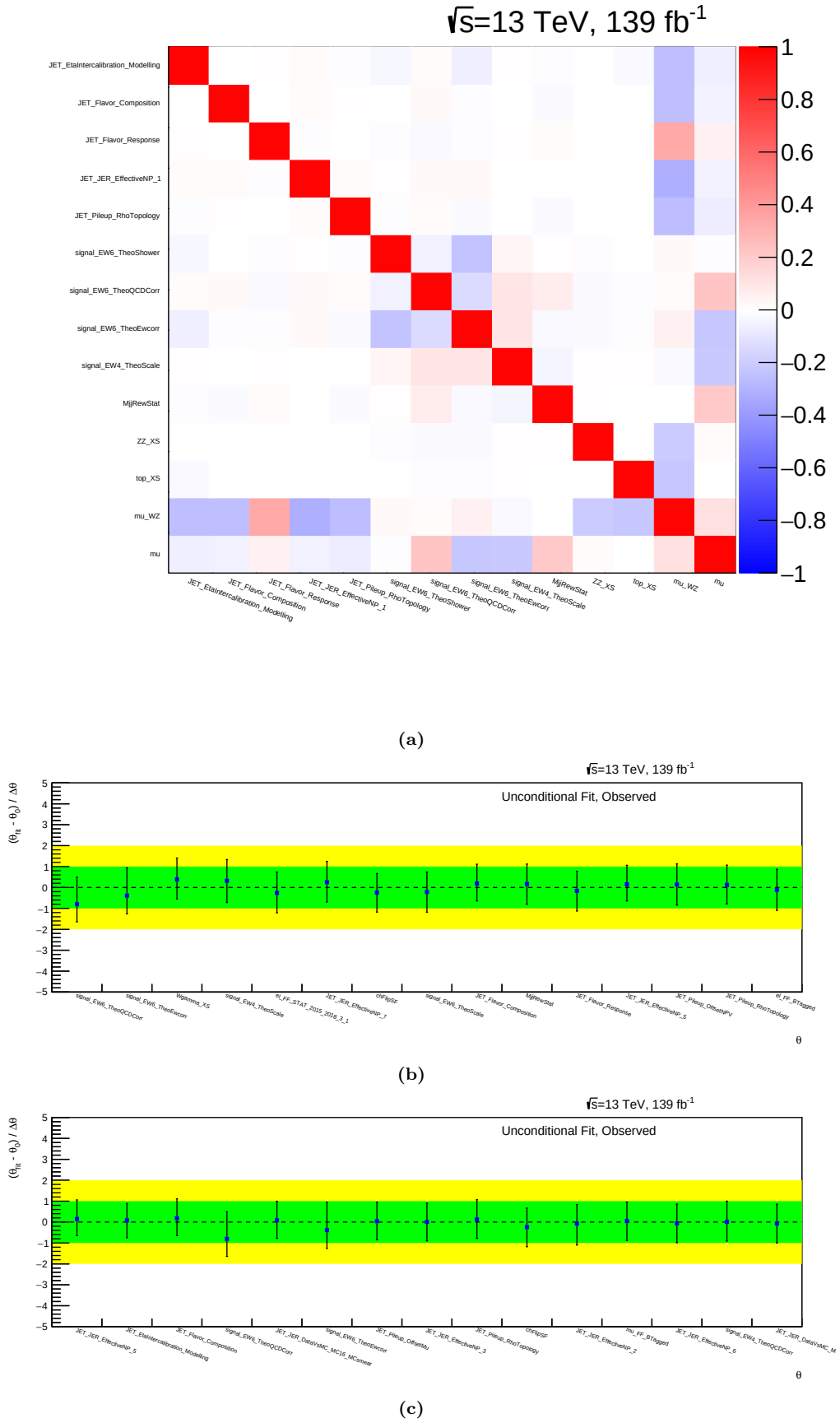


Figure 8.12: Correlation of nuisance parameters with at least 20% correlation with another nuisance parameter (a), most pulled (b) and strongest constrained (c) in the total cross-section measurement of EW $W^\pm W^\pm jj$.

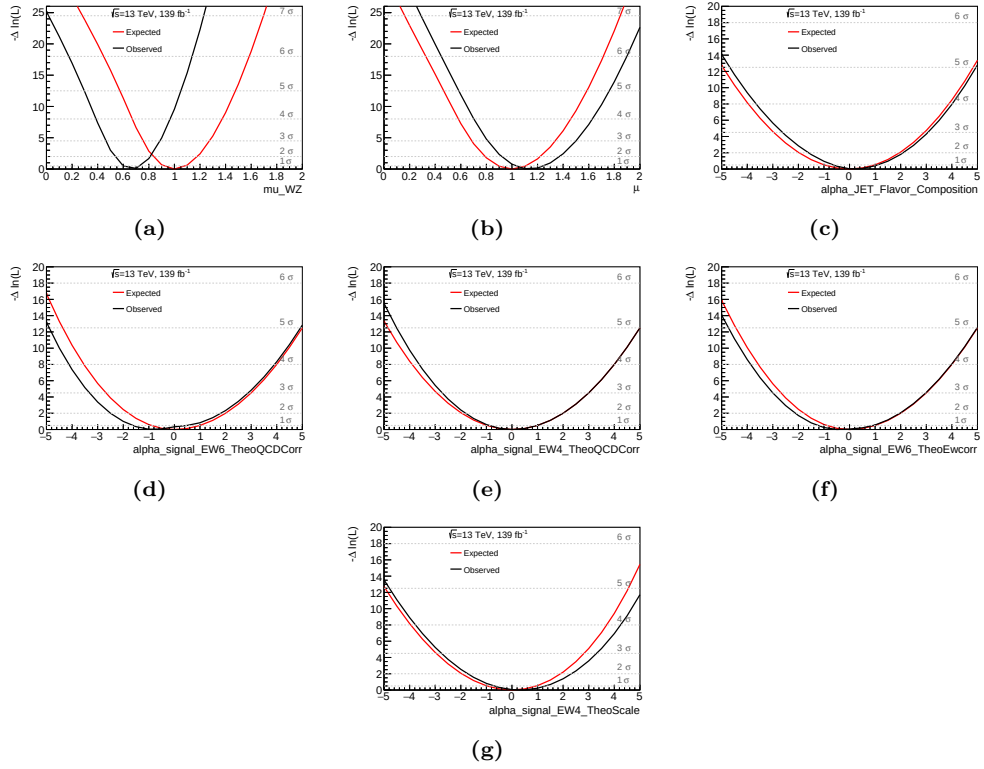


Figure 8.13: Likelihood scans of nuisance parameters with largest pulls and constraints in the total cross-section measurement of $EW^{\pm}W^{\pm}jj$ with Asimov data (red) and observed data (black). It is shown for the QCD $W^{\pm}Zjj$ normalisation parameter (a), signal strength (b), Jet flavour composition (c), $EW^{\pm}W^{\pm}jj$ NLO QCD correction (d), QCD $W^{\pm}W^{\pm}jj$ NLO QCD correction (e), $EW^{\pm}W^{\pm}jj$ NLO EW correction (f) and QCD $W^{\pm}W^{\pm}jj$ scale uncertainty (g).

Table 8.9: List of parameter correlations which are larger than 7.5% in the total cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	μ_{WZ}	0.341
JET_JER_EffectiveNP_1	μ_{WZ}	-0.311
JET_Pileup_RhoTopology	μ_{WZ}	-0.261
JET_Flavor_Composition	μ_{WZ}	-0.253
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.250
signal_EW6_TheoEwcorr	signal_EW6_TheoShower	-0.233
signal_EW6_TheoQCDCorr	μ	0.224
signal_EW6_TheoEwcorr	μ	-0.223
top_XS	μ_{WZ}	-0.221
MjjRewStat	μ	0.211
signal_EW4_TheoScale	μ	-0.209
ZZ_XS	μ_{WZ}	-0.207
JET_Pileup_OffsetMu	μ_{WZ}	-0.199
FF_Prompt	μ	0.199
Lumi	μ	-0.194
signal_EW6_TheoEwcorr	signal_EW6_TheoScale	-0.191
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.169
$\mu_{FF_BTagged}$	μ	0.167
Zjets_XS	μ_{WZ}	-0.157
FF_Prompt	$\mu_{FF_BTagged}$	-0.151
WZ_EW4_TheoScale	μ_{WZ}	0.145
JET_Pileup_OffsetNPV	μ_{WZ}	-0.141
signal_EW6_TheoEwcorr	signal_EW6_TheoQCDCorr	-0.139
WZ_EW6_TheoScale	μ_{WZ}	-0.137
Wgamma_XS	μ	-0.129
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.115
μ	μ_{WZ}	0.114
chFlipSF	CutLowMjj_ee_bin_0_0	0.111
FF_Prompt	signal_EW6_TheoQCDCorr	-0.109
signal_EW6_TheoScale	μ	-0.108
Wgamma_XS	signal_EW6_TheoQCDCorr	0.106
JET_JER_EffectiveNP_7	μ_{WZ}	-0.102
signal_EW4_TheoScale	signal_EW6_TheoEwcorr	0.100
signal_EW4_TheoScale	signal_EW6_TheoQCDCorr	0.099
Wgamma_XS	μ_{WZ}	-0.097
$\mu_{FF_BTagged}$	signal_EW6_TheoQCDCorr	-0.094
signal_EW4_TheoQCDCorr	μ	0.094
chFlipSF	signal_EW6_TheoQCDCorr	-0.094
signal_EW6_TheoScale	signal_EW6_TheoShower	-0.092
Lumi	μ_{WZ}	-0.092
$\mu_{FF_BTagged}$	CutLowMjj_mm_bin_0_0	0.090
chFlipSF	μ	0.086
triboson_XS	μ_{WZ}	-0.083
JET_Pileup_PtTerm	μ_{WZ}	-0.083
FF_Prompt	MjjRewStat	0.079
$\mu_{FF_STAT_2015_2018_3_1}$	μ	-0.078
$\mu_{FF_STAT_2015_2018_2_1}$	μ	-0.078
$\mu_{FF_BTagged}$	signal_EW4_TheoScale	0.078
$\mu_{FF_BTagged}$	signal_EW6_TheoEwcorr	-0.077
FF_Prompt	signal_EW6_TheoEwcorr	-0.077
CutSR_mm_bin_1_0	μ	-0.076

covered within uncertainties. The predicted yields will change proportional to the difference of the best-fit value and 0, and thus also the refitted signal strength μ . For down shifts the predicted yield is always affected and thus also the refitted signal strength μ changes. This is visible in the ranking plot as a two-sided impact. The smaller the down pull in observed data, the more the two-sided impact becomes a one-sided impact. The down pull is smaller for signal_EW6_TheoEwcorr than for signal_EW6_TheoQCDCorr and thus the signal_EW6_TheoEwcorr impact looks more asymmetric. The impact of the up shift is shown in light brown. Because a pull of 0 is covered within pre- and post-fit uncertainties, both, post-fit (filled) and pre-fit (empty) impacts are the same. For signal_EW6_TheoQCDCorr the post-fit down uncertainty is around -1.7, while pre-fit it was -1. This manifests in a smaller pre-fit (empty) than post-fit (filled) impact shown in dark brown. The empty bars are a bit thicker than the filled bars to make them visible when the filled bars reach higher values than the empty bars.

The ranking is also dominated by modelling uncertainties like for the Asimov fit. EW $W^\pm W^\pm jj$ NLO EW+QCD corrections get partly applied, while QCD $W^\pm W^\pm jj$ QCD NLO correction do not get applied.

The impact of different components of systematic uncertainty on the measured fiducial cross-section, calculated as in Section 8.5, is shown in Table 8.10.

Table 8.10: Breakdown of the uncertainties on the EW $W^\pm W^\pm jj$ cross-section measurement using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]
Experimental	
Electron calibration	0.4
Muon calibration	0.5
Jet energy scale and resolution	1.8
E_T^{miss} scale and resolution	0.2
b -tagging inefficiency	0.7
Background, misid. leptons	3.1
Background, charge misrec.	0.8
Pileup modelling	0.2
Luminosity	1.9
Modelling	
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.8
EW $W^\pm W^\pm jj$, QCD corrections	3.5
EW $W^\pm W^\pm jj$, EW corrections	0.8
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.1
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	2.3
QCD $W^\pm W^\pm jj$, QCD corrections	0.9
Background, WZ scale, PDF & α_s	0.2
Background, WZ reweighting	1.7
Background, other	1.0
Model statistical	1.8
Experimental and modelling	6.7
Data statistical	7.4
Total	10.0

The experimental systematic uncertainties have a similar impact like for Asimov data. Only some impacts are a bit lower after the pulls. WZ modelling uncertainty decreased, while EW $W^\pm W^\pm jj$ NLO QCD correction got larger. The data statistical uncertainty is smaller for observed data because there is a smaller absolute uncertainty in the WZ control

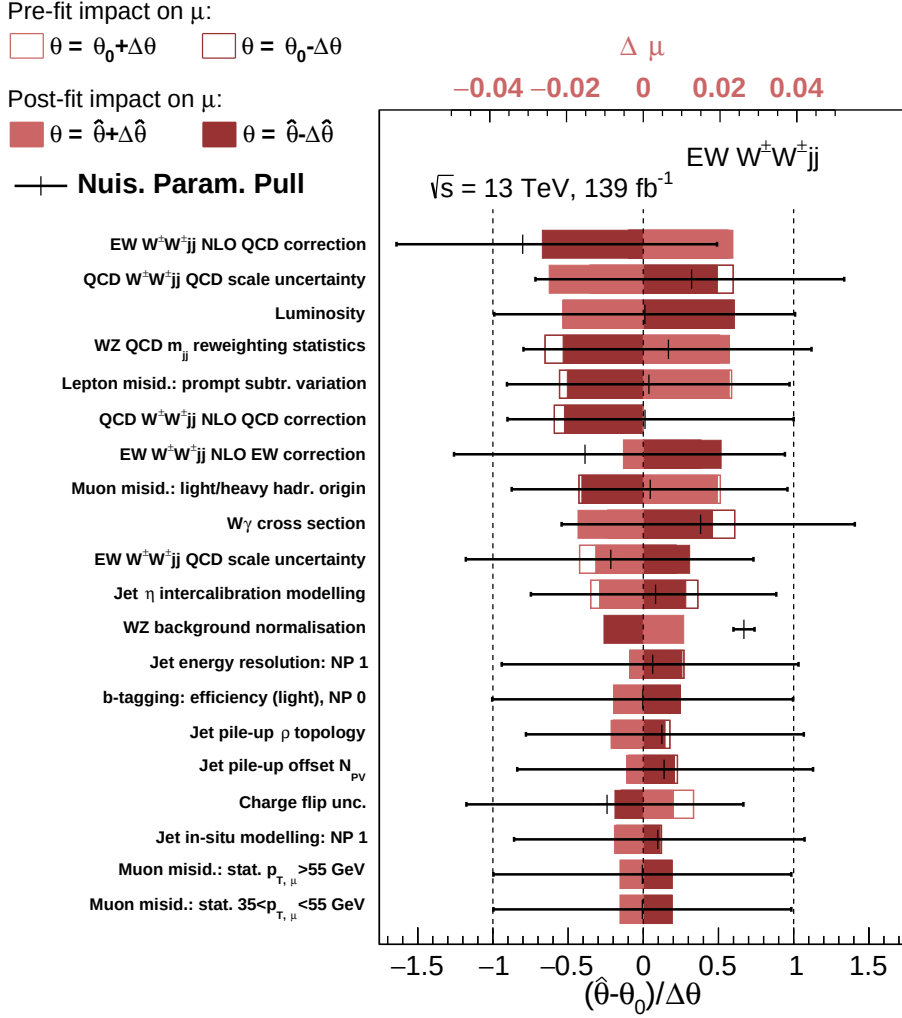


Figure 8.14: Ranking of the top 20 nuisance parameters included in the fit according to their impact on the measured signal strength μ in total cross-section measurement of EW $W^{\pm}W^{\pm}jj$ using observed data. The empty brown rectangles correspond to the pre-fit impact on μ and the filled brown ones to the post-fit impact on μ , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}/\Delta\theta$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

region due to the down scaling of QCD $W^\pm Zjj$.

8.6.1 Cross-Section Extraction for EW $W^\pm W^\pm jj$

The observed signal strength μ from the fit to observed data is:

$$\mu_{\text{obs}}^{\text{EW}} = 1.14 \pm_{0.08}^{0.09} (\text{stat.}) \pm_{0.06}^{0.06} (\text{mod. syst.}) \pm_{0.04}^{0.04} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.})$$

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{WZ, \text{obs}}^{\text{EW}} = 0.67 \pm_{0.03}^{0.03} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.})$$

The QCD $W^\pm Zjj$ normalisation factor differs from 1 significantly, which is consistent with previous ATLAS measurements using the same QCD $W^\pm Zjj$ model [129, 130]. Using the fiducial cross-section $\sigma_{\text{pred}}^{\text{fid}}$ from Section 5.4 and the formulas from Section 8.5.1 the observed cross-section becomes:

$$\sigma_{\text{obs}}^{\text{EW}} = 2.88 \pm_{0.21}^{0.22} (\text{stat.}) \pm_{0.14}^{0.16} (\text{mod. syst.}) \pm_{0.11}^{0.11} (\text{exp. syst.}) \pm_{0.05}^{0.06} (\text{lumi.}) \text{ fb}$$

8.6.2 Cross-Section Extraction for Inclusive $W^\pm W^\pm jj$

The observed signal strength μ from the fit to observed data is:

$$\mu_{\text{obs}}^{\text{EW+Int+QCD}} = 1.14 \pm_{0.07}^{0.08} (\text{stat.}) \pm_{0.04}^{0.05} (\text{mod. syst.}) \pm_{0.04}^{0.04} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.})$$

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{WZ, \text{obs}}^{\text{EW+Int+QCD}} = 0.67 \pm_{0.03}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.})$$

Using the fiducial cross-section $\sigma_{\text{pred}}^{\text{fid}}$ from Section 5.4 the observed cross-section becomes:

$$\sigma_{\text{obs}}^{\text{EW+Int+QCD}} = 3.35 \pm_{0.22}^{0.22} (\text{stat.}) \pm_{0.13}^{0.16} (\text{mod. syst.}) \pm_{0.13}^{0.12} (\text{exp. syst.}) \pm_{0.05}^{0.06} (\text{lumi.}) \text{ fb}$$

The observed signal strengths $\mu_{\text{obs}}^{\text{EW}}$ and $\mu_{\text{obs}}^{\text{EW+Int+QCD}}$ are very similar because the inclusive $W^\pm W^\pm jj$ process is dominated by EW $W^\pm W^\pm jj$. The nominal prediction is covered within uncertainties. Only the Sherpa + NLO prediction is not covered within 1σ , but it is covered within 2σ for both signal hypotheses. It looks like the NLO correction might get compensated by higher order corrections to match data in the end, but this is not significant with a deviation of less than 2σ with the current Run 2 data. More data collected in Run 3 will start to answer these questions.

The impact of different components of systematic uncertainties on the measured fiducial cross-section is shown in Table 8.11. The theory uncertainties associated to QCD $W^\pm W^\pm jj$ get reduced compared to the EW signal fit. This is also visible in the ranking plot.

The ranking of the top 20 nuisance parameters contributing to the fit is shown in Figure 8.15 for systematic and MC statistical (gammas) uncertainties and QCD $W^\pm Zjj$ normalisation μ_{WZ} . The main difference between EW and Inclusive $W^\pm W^\pm jj$ fits is again the scale uncertainty of EW and QCD $W^\pm W^\pm jj$ like for Asimov data.

When comparing the yields between Figure B.10 to B.11 and Figure B.15 to B.16 it can be seen that theory uncertainties of QCD $W^\pm W^\pm jj$ are much smaller because the effect of EW $W^\pm W^\pm jj$ and QCD $W^\pm W^\pm jj$ scale uncertainties annihilates in the inclusive fit where they are varied simultaneously.

Systematics "b-tagging efficiency c-mistag extrapolation unc. to high p_T " (FT_EFF_extrapolation_from_ charm) vs. "Jet flavour composition" (JET_Flavor_Composition) have a correlation of -0.251 in the inclusive fit shown in Table B.18 which is not that large for the EW $W^\pm W^\pm jj$ fit. The two systematics seem to have a similar effect for the observed data after merging EW+Int+QCD $W^\pm W^\pm jj$. No particular physical reason is known for this, so might be just a random correlation.

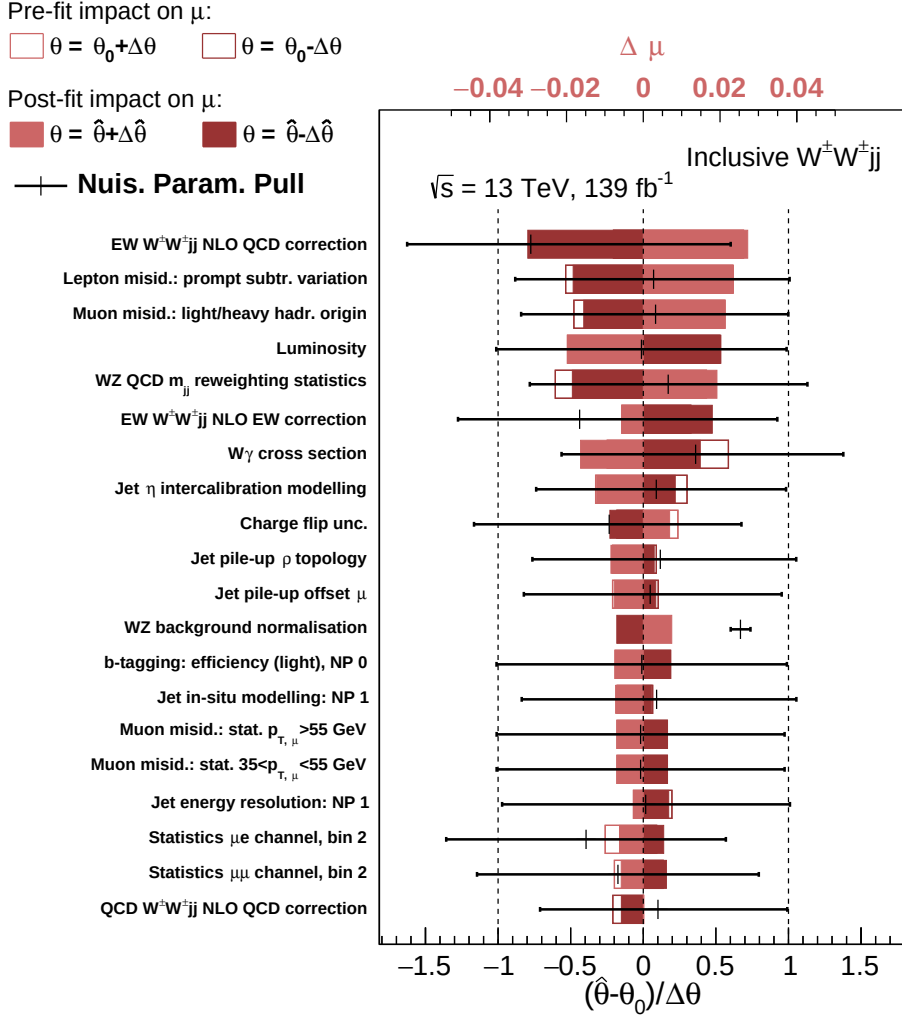


Figure 8.15: Ranking of the top 20 nuisance parameters included in the fit according to their impact on the measured signal strength μ in total cross-section measurement of inclusive $W^\pm W^\pm jj$ using observed data. The empty brown rectangles correspond to the pre-fit impact on μ and the filled brown ones to the post-fit impact on μ , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}/\Delta\theta$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

Table 8.11: Breakdown of the uncertainty on the inclusive $W^\pm W^\pm jj$ cross-section measurement using observed data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma\gamma$, ZZ , top and Zjets.

Source	Impact [%]
Experimental	
Electron calibration	0.4
Muon calibration	0.5
Jet energy scale and resolution	1.5
E_T^{miss} scale and resolution	0.1
b -tagging inefficiency	0.7
Background, misid. leptons	3.1
Background, charge misrec.	0.6
Pileup modelling	0.1
Luminosity	1.8
Modelling	
$W^\pm W^\pm jj$ shower, scale, PDF & α_s	0.7
EW $W^\pm W^\pm jj$, QCD corrections	3.6
EW $W^\pm W^\pm jj$, EW corrections	0.4
QCD $W^\pm W^\pm jj$, QCD corrections	0.1
Background, WZ scale, PDF & α_s	0.4
Background, WZ reweighting	1.3
Background, other	1.0
Model statistical	1.6
Experimental and modelling	5.9
Data statistical	6.6
Total	8.9

Chapter 9

Differential Cross-Section Measurement

Differential cross-section measurements show how the cross-section varies depending on different variables instead of giving a single value for the entire process. These measurements are particularly useful inputs to theorists to tune their calculations and allow them to compare a theory calculation with data without knowing the detector effects. Differential cross-section measurements can reveal unexpected patterns or deviations from theoretical predictions. Such anomalies may indicate the presence of new particles or interactions that were not previously known.

This section presents the extraction of the differential cross-section of the EW $W^\pm W^\pm jj$ production and EW+Int+QCD $W^\pm W^\pm jj$ production as a function of $m_{\ell\ell}$, m_T , m_{jj} , $N_{gapJets}$ and ξ_{j3} .

Several variables are considered for unfolding. Out of those the following are selected:

- the dilepton invariant mass $m_{\ell\ell}$, which is sensitive to EFT,
- the invariant mass between the tagging jets m_{jj} , which discriminates EW and QCD $W^\pm W^\pm jj$ very well, what can be used to study EW and QCD mismodelling in VBS topologies separately,
- the transverse mass m_T [131], defined as

$$m_T = \sqrt{\left(\sqrt{m_{\ell\ell}^2 + |\vec{p}_{T,\ell1} + \vec{p}_{T,\ell2}|^2} + |\vec{p}_{T,miss}|\right)^2 - |\vec{p}_{T,\ell1} + \vec{p}_{T,\ell2} + \vec{p}_{T,miss}|^2}, \quad (9.1)$$

which is sensitive to EFT,

- the number of preselected jets between the two tagging jets with respect to η , $N_{gapJets}$, which probes the colour flow connection of EW $W^\pm W^\pm jj$,
- the Zeppenfeld variable [132] of the third jet, $\xi_{j3} = \left| \frac{\eta_{j3} - \frac{1}{2}(\eta_{j1} + \eta_{j2})}{\eta_{j2} - \eta_{j1}} \right|$, which is hard to model in parton showers.

A more detailed physical motivation to look into these variables can be found e.g. in Ref. [63]. For the third and following jets, when used for $N_{gapJets}$ and ξ_{j3} , a p_T of at least 25 GeV is required, as opposed to the leading- and subleading- p_T jets, where at least 65 GeV and 35 GeV are required, respectively.

For the ξ_{j3} variable a third jet with a transverse momentum of at least 25 GeV is required in addition to the signal and low- m_{jj} region cuts. Also a fiducial phase space requiring this is used for ξ_{j3} .

The likelihood-based unfolding approach, explained in Section 7.9, is used. First, the fitting setup is summarised in Section 9.1, followed by the binning optimisation in Section 9.2. Afterwards, the handling of uncertainties is explained in Section 9.3. For the example of the

$m_{\ell\ell}$ variable with EW $W^\pm W^\pm jj$ signal the pre-fit distributions are shown in section 9.4. It is shown how the expected unfolded distributions are derived in Section 9.5 and the observed unfolded distributions in Section 9.6. Finally, in Section 9.7 the unfolded distributions of all variables and signal definitions are shown.

9.1 Fitting Setup

For unfolding of differential cross-sections, the fitting setup is nearly the same as presented in Section 8.1. The same regions and signal definitions are used. The main modification added is the usage of a bin-by-bin signal strength instead of a global one. To implement the bin-by-bin signal strength for the EW $W^\pm W^\pm jj$ differential cross-section measurement, the EW and interference $W^\pm W^\pm jj$ contribution is split in bins of the observable of interest, e.g. $m_{\ell\ell}$, at truth level. In the case of the inclusive $W^\pm W^\pm jj$ differential cross-section the $W^\pm W^\pm jj$ EW, Interference and QCD contributions are split in bins of the observable of interest at truth level. For these fits, there are dedicated signal strength parameters $\mu_{\text{bin } i}$ for each truth bin slice i . There is no overall signal strength μ , each truth bin is free to float. For background suppression the same regions as for the fiducial cross-section fit are used, but in this case, the channels are not split by flavour. Instead of the splitting by flavour, m_{jj} is used in a 2D fit to further disentangle signal from background.

The measured differential cross-section $\sigma_{\Delta x}^{fid,obs.}$ is computed for every truth bin as a product of the MC cross-section $\sigma_{\Delta x}^{fid,pred.}$ and of the fitted signal strength parameter for the corresponding bin $\mu_{\Delta x}$:

$$\sigma_{\Delta x}^{fid,obs.} = \sigma_{\Delta x}^{fid,pred.} \cdot \mu_{\Delta x}. \quad (9.2)$$

The theory uncertainties are normalised on truth level, such that the simplified uncertainty propagation, as introduced in Section 7.5, can be used:

$$\Delta\sigma_{\Delta x}^{fid,obs.} = \sigma_{\Delta x}^{fid,pred.} \cdot \Delta\mu_{\Delta x}. \quad (9.3)$$

This means that the uncertainty of the signal strengths $\mu_{\Delta x}$ do not include the normalisation effect of the theory uncertainties. There is a separate fit for each unfolded variable using the same observed data. Thus, only one of these distribution can be used in reinterpretation at a time.

9.2 Binning Optimisation and Resulting Migration Matrices

The binning was optimised first for unfolding $m_{\ell\ell}$.

A two-dimensional $m_{\ell\ell} \times m_{jj}$ binning is used in the signal region and the same $m_{\ell\ell}$ binning in the low- m_{jj} control region. Only one bin is used in the WZ CR. The binning is determined in a three-step procedure. It is started with a fine binning in $m_{\ell\ell}$ and m_{jj} . The fineness is limited by the run time and output size of the analysis framework. A reasonably small, but not too small initial binning was chosen. The chosen bin edges before the first step are:

SR: m_{jj} (500 - 3000 in steps of 50 GeV) x $m_{\ell\ell}$ (20 - 500 in steps of 10 GeV),
low- m_{jj} CR: m_{jj} (200 - 500 in steps of 50 GeV) x $m_{\ell\ell}$ (20 - 500 in steps of 10 GeV).

In the first step, bins are merged in order to have at least two raw¹ MC background events in each bin to have a reliable MC statistical uncertainty estimate, as motivated in Section 7.7. The bin edges after the first step are:

10 m_{jj} bins: [500, 550, 750, 850, 1100, 1250, 1450, 1700, 2100, 2550, ∞] and
18 $m_{\ell\ell}$ bins: [20, 30, 50, 60, 70, 80, 110, 130, 140, 160, 170, 190, 220, 230, 250, 290, 320, 460, ∞].

¹Raw MC events means in this context the number of generated MC events without reweighting to integrated luminosity.

In the second step, bins in $m_{\ell\ell}$ are merged such that each bin has a minimum signal significance of 5σ . The motivation for this is to have some significant signal contribution in each bin to have reasonable differential cross-section uncertainties in the end. Merging is started in the first bin. If the last bin has a significance close to 5σ , then it is not merged with the previous bin. This is done to have more information in the last bin where new physics might show up first. A simplified set of uncertainty is used for these steps. The bin edges after the second step are:

$$6 \text{ } m_{\ell\ell} \text{ bins: } [20, 80, 130, 170, 220, 320, \infty].$$

In the third step, those neighbouring m_{jj} bins that cause the least significance reduction when merged are merged recursively. A threshold of a maximum reduction of 0.05σ is set. The bin edges in the signal region after optimisation are:

$$\begin{aligned} m_{\ell\ell}: & [20, 80, 130, 170, 220, 320, \infty] \text{ and} \\ m_{jj}: & [500, 850, 1450, 2100, 2550, \infty]. \end{aligned}$$

The same $m_{\ell\ell}$ bins are used in the low- m_{jj} control region, with only one m_{jj} bin.

This optimisation is performed with EW $W^\pm W^\pm jj$ as signal. The same binning is also used for EW+Int+QCD $W^\pm W^\pm jj$ production.

The same m_{jj} binning is also used for m_T , $N_{gapJets}$ and ξ_{j3} for which only step 1-2 are repeated. It is checked if any other m_{jj} binning would help but no significant improvement is observed.

Because only the zero $N_{gapJets}$ bin fulfils the requirement of a significance of 5σ , this bin is used and all other bins are merged into the 'at least one gap jet' bin.

Since the phase space for ξ_{j3} is smaller, the minimum signal significance requirement is lowered from 5 to 4σ for this variable.

For binning optimisation of unfolded m_{jj} the same three-step procedure is applied but with $m_{\ell\ell}$ as second discriminating variable. Additionally, no low- m_{jj} CR is included to make no assumptions about m_{jj} close to the signal region.

The resulting binnings can be found in Table 9.1.

For the propagation of data statistical uncertainty it is favourable to have at least 20 signal events in each unfolded bin, as motivated in Ref. [41]. This is the case for the binning used in this thesis.

It is finally checked that the resulting migrations are not too small. If the main diagonal of the migration matrix is above 50%, then the matrix is always invertible. It can be seen in Figure 9.1 for EW $W^\pm W^\pm jj$ and in Figure 9.2 for inclusive $W^\pm W^\pm jj$ that it is always above 66%. The actually used migration matrix is 3D, because e.g. for $m_{\ell\ell}$ it maps from truth $m_{\ell\ell}$ to reco $m_{\ell\ell} \times m_{jj}$. The migration matrix in the before mentioned figures show the projection over the second reco variable. Additionally, the low- m_{jj} CR is included on reconstruction level while it is missing on truth-level. These extensions improve the uncertainties of the unfolded distributions.

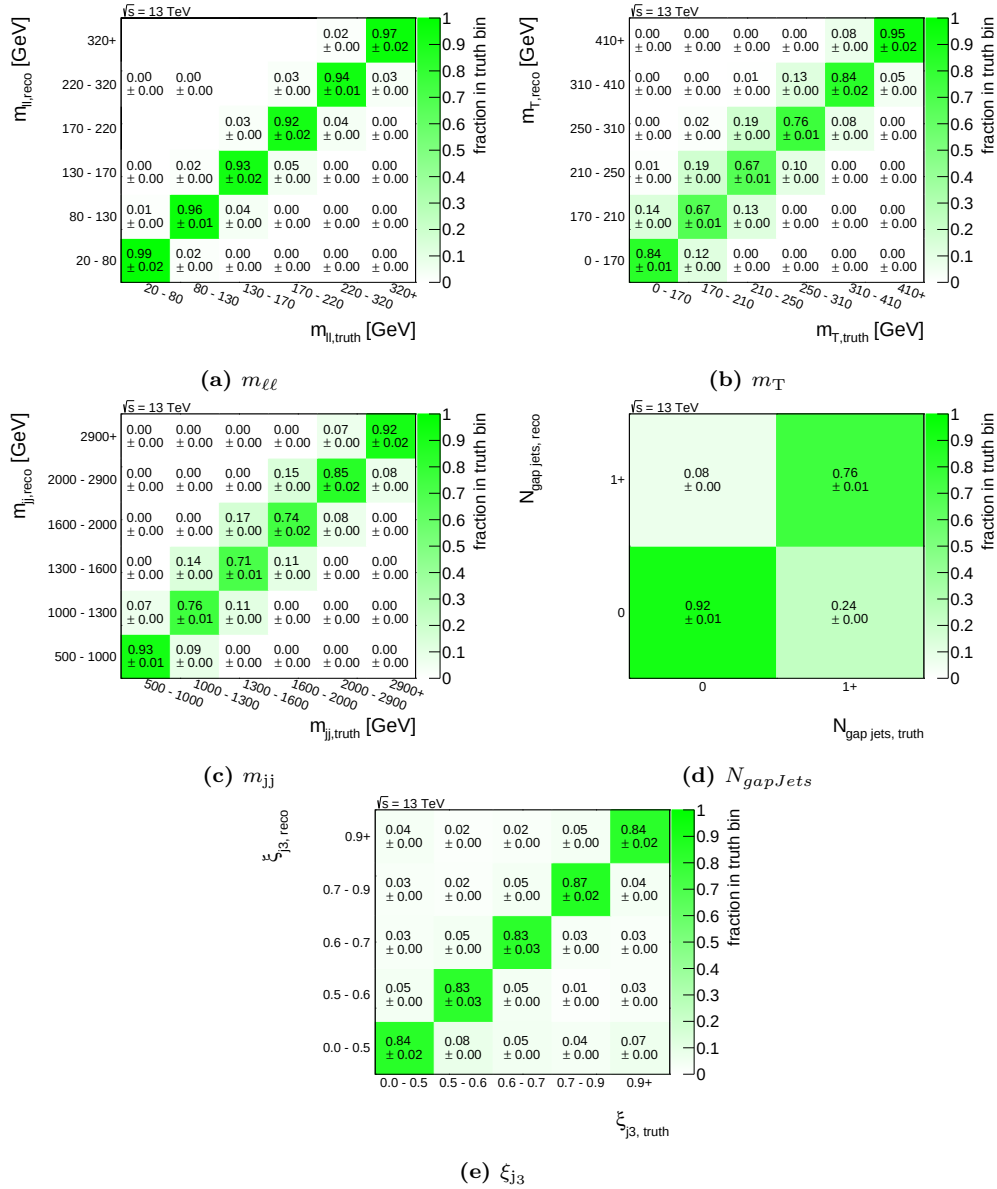
But at the same time it is made sure, that the truth and reco phase space are relatively close to each other to actually use mainly the information from data and not from the MC sample during extrapolation between the two phase spaces. The fiducial corrections, defined in Section 7.9, are shown in Figure 9.3 and Figure 9.4. The shown fractions of events which pass truth selection of the reco-level selected events are around 70% for EW $W^\pm W^\pm jj$ and around 65% for inclusive $W^\pm W^\pm jj$. The fiducial correction is around 80% for m_{jj} since the low- m_{jj} CR is not used. The efficiency corrections, being the fraction of truth-level selected events which pass reco-level selection defined in Section 7.9, are shown in Figure 9.5 and Figure 9.6. They are around 55%. For ξ_{j3} both corrections are a bit lower because of the requirement of the third jet. The combination of both corrections, the efficiency which is used in the end, is shown in Figure 9.7 and Figure 9.8. It is around 75%.

9.3 Handling of Uncertainties

The same uncertainties as in Section 8.3 are included in the fit. The theoretical uncertainties are treated separately with separate nuisance parameters for each truth $m_{\ell\ell}$ slice. They are

Table 9.1: Binning of variables after optimisation used in unfolding. The unit of masses in this table is GeV.

Unfolded variable and its binning		Second variable and its binning	
$m_{\ell\ell}$:	[20, 80, 130, 170, 220, 320, ∞]	m_{jj} :	[500, 850, 1450, 2100, 2550, ∞]
m_T :	[0, 170, 210, 250, 310, 410, ∞]	m_{jj} :	[500, 850, 1450, 2100, 2550, ∞]
$N_{gapJets}$:	[0, 1, ∞]	m_{jj} :	[500, 850, 1450, 2100, 2550, ∞]
ξ_{j3} :	[0, 0.5, 0.6, 0.7, 0.9, ∞]	m_{jj} :	[500, 850, 1450, 2100, 2550, ∞]
m_{jj} :	[500, 1000, 1300, 1600, 2000, 2900, ∞]	$m_{\ell\ell}$:	[20, 75, 175, 475, ∞]

**Figure 9.1:** Migration matrices of EW $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 in the signal region and for all but m_{jj} also the low- m_{jj} control region. A projection over the second discriminant variable on reconstruction level is shown. MC statistical uncertainties are presented for each bin. If a value range is shown, then the last value is not included in the interval.

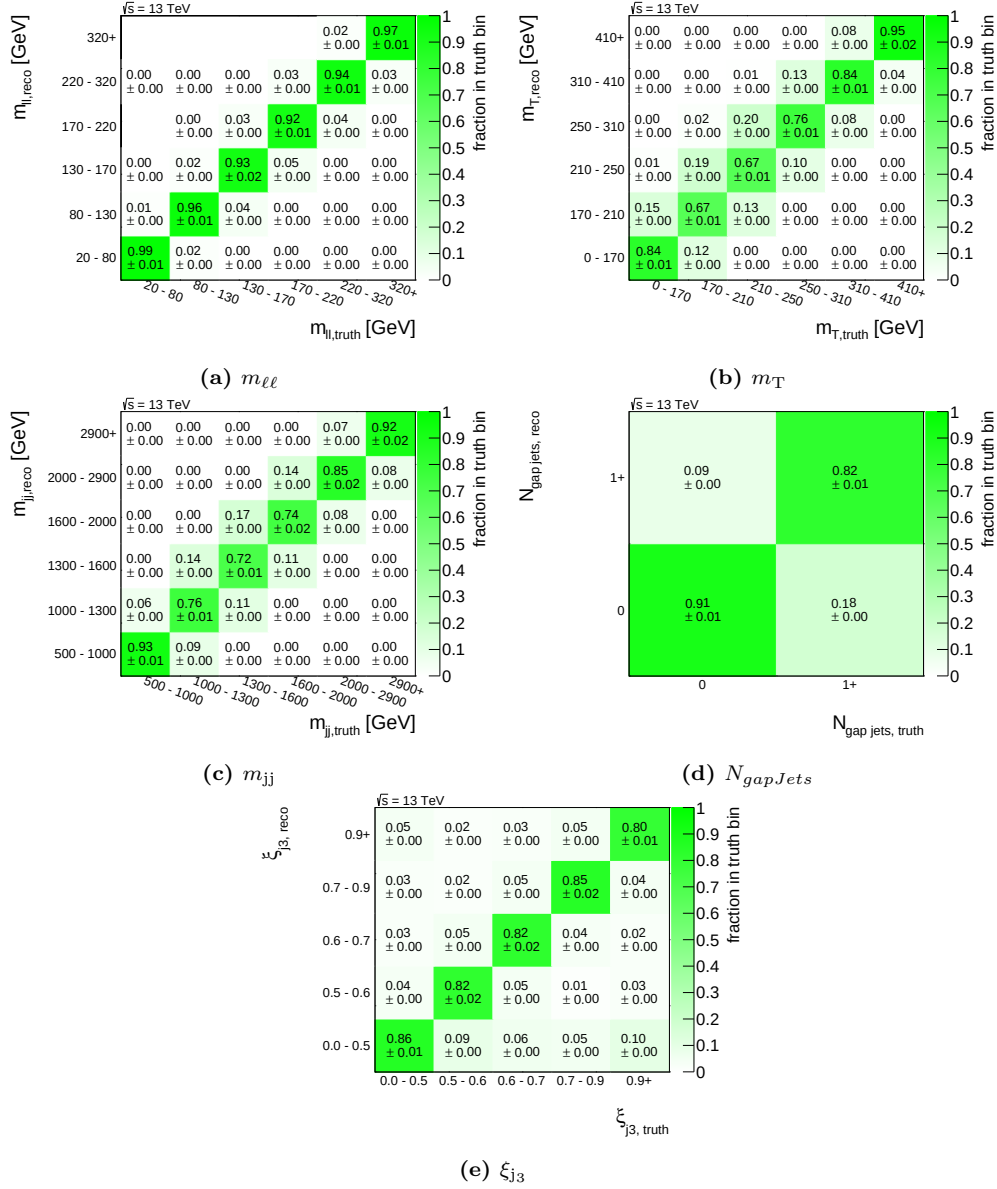


Figure 9.2: Migration matrices of inclusive $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 in the signal region and for all but m_{jj} also the low- m_{jj} control region. A projection over the second discriminant variable on reconstruction level is shown. MC statistical uncertainties are presented for each bin. If a value range is shown, then the last value is not included in the interval.

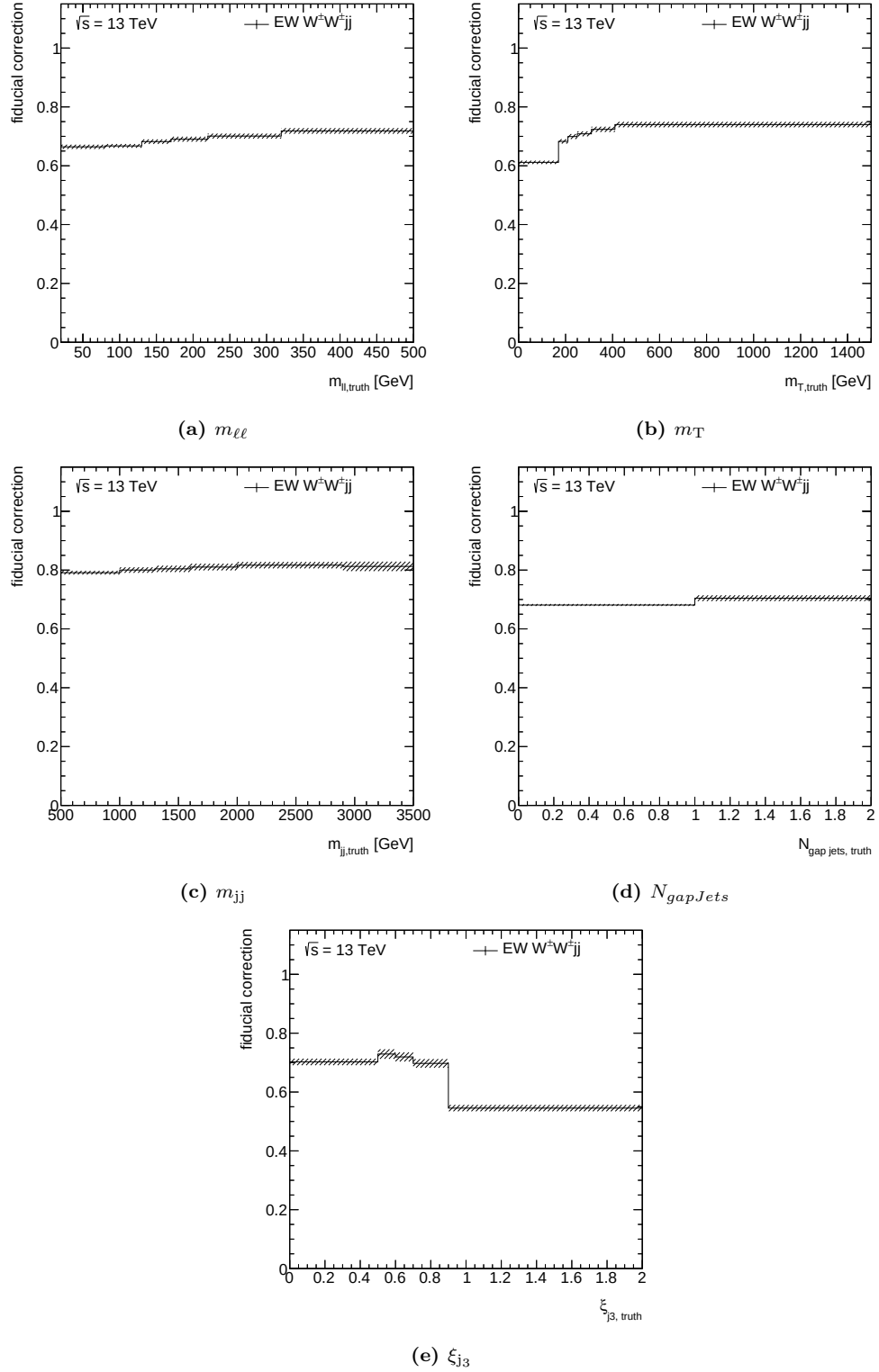


Figure 9.3: Fiducial correction of EW $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 being the fraction of events passing the reco selection which also pass the fiducial selection. For all but m_{jj} the low- m_{jj} control region is part of the reco selection. The hatched grey areas show the MC statistical uncertainty. Overflow events are included in the calculation of the last bin.

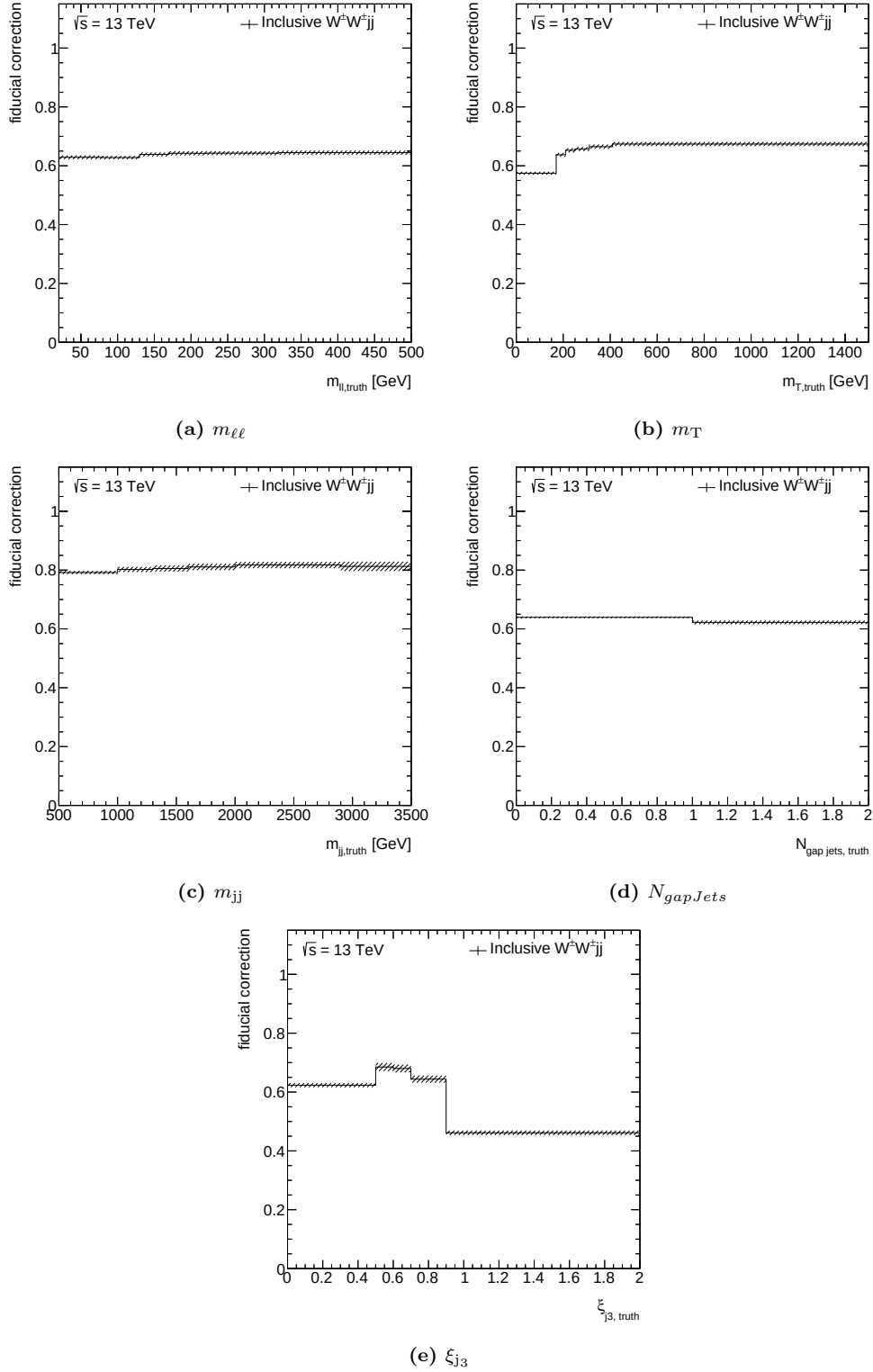


Figure 9.4: Fiducial correction of inclusive $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 being the fraction of events passing the reco selection which also pass the fiducial selection. For all but m_{jj} the low- m_{jj} control region is part of the reco selection. The hatched grey areas show the MC statistical uncertainty. Overflow events are included in the calculation of the last bin.

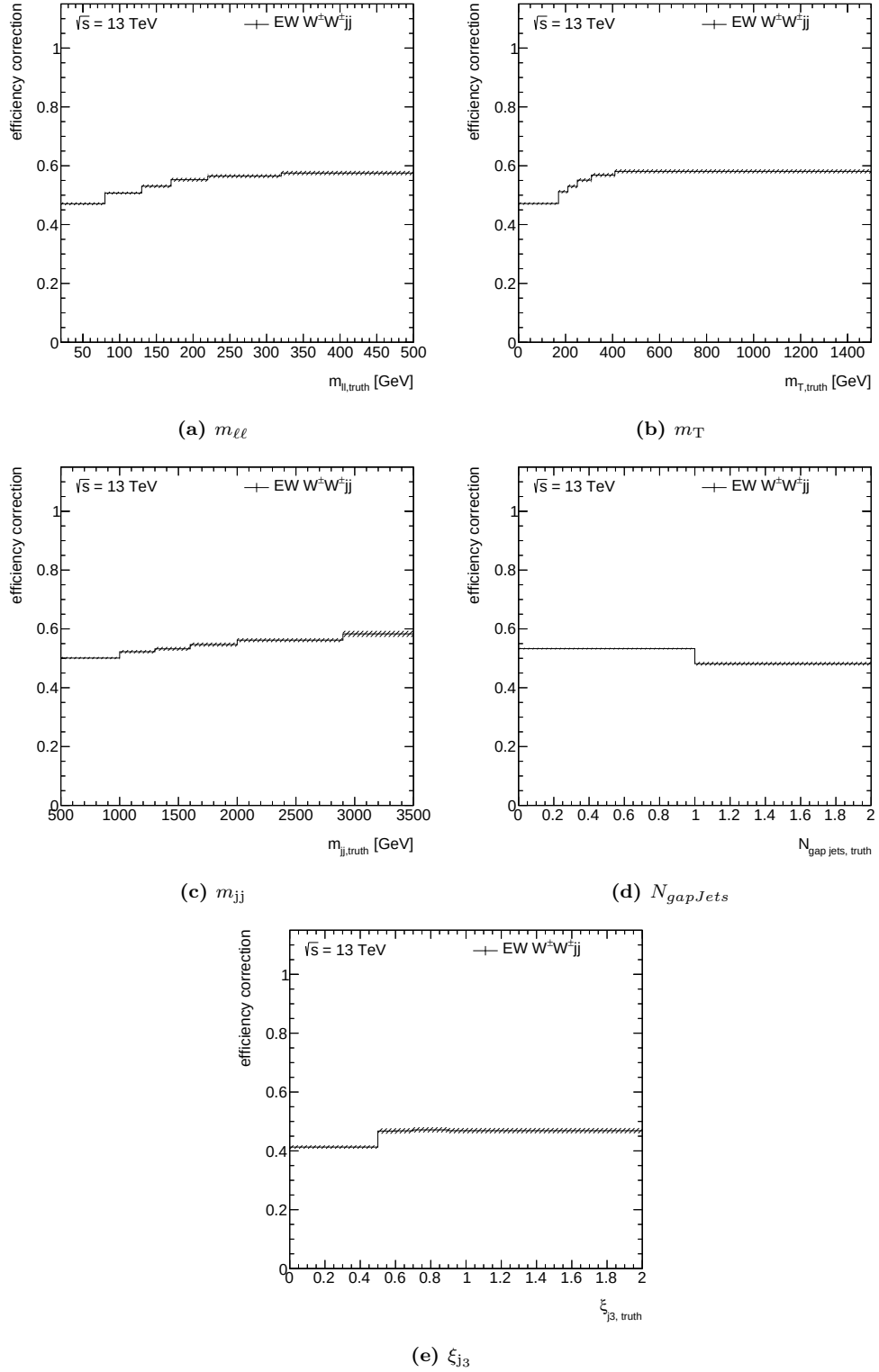


Figure 9.5: Efficiency correction of EW $W^\pm W^\pm jj$ for the nominal signal sample Mad-graph Herwig 7 being the fraction of events passing the fiducial selection which also pass the reco selection. For all but m_{jj} the low- m_{jj} control region is part of the reco selection. The hatched grey areas show the MC statistical uncertainty. Overflow events are included in the calculation of the last bin.

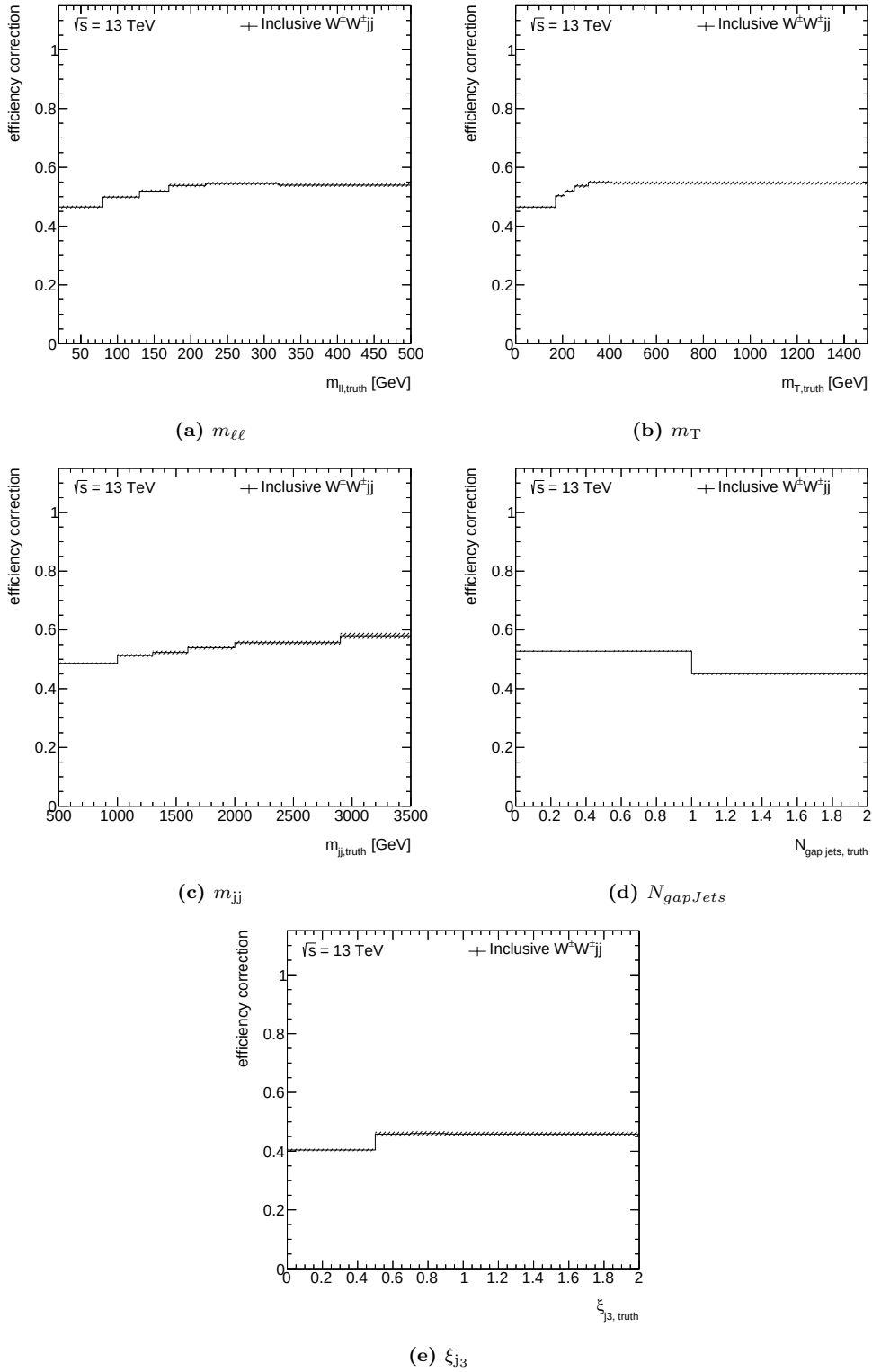


Figure 9.6: Efficiency correction of inclusive $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 being the fraction of events passing the fiducial selection which also pass the reco selection. For all but m_{jj} the low- m_{jj} control region is part of the reco selection. The hatched grey areas show the MC statistical uncertainty. Overflow events are included in the calculation of the last bin.

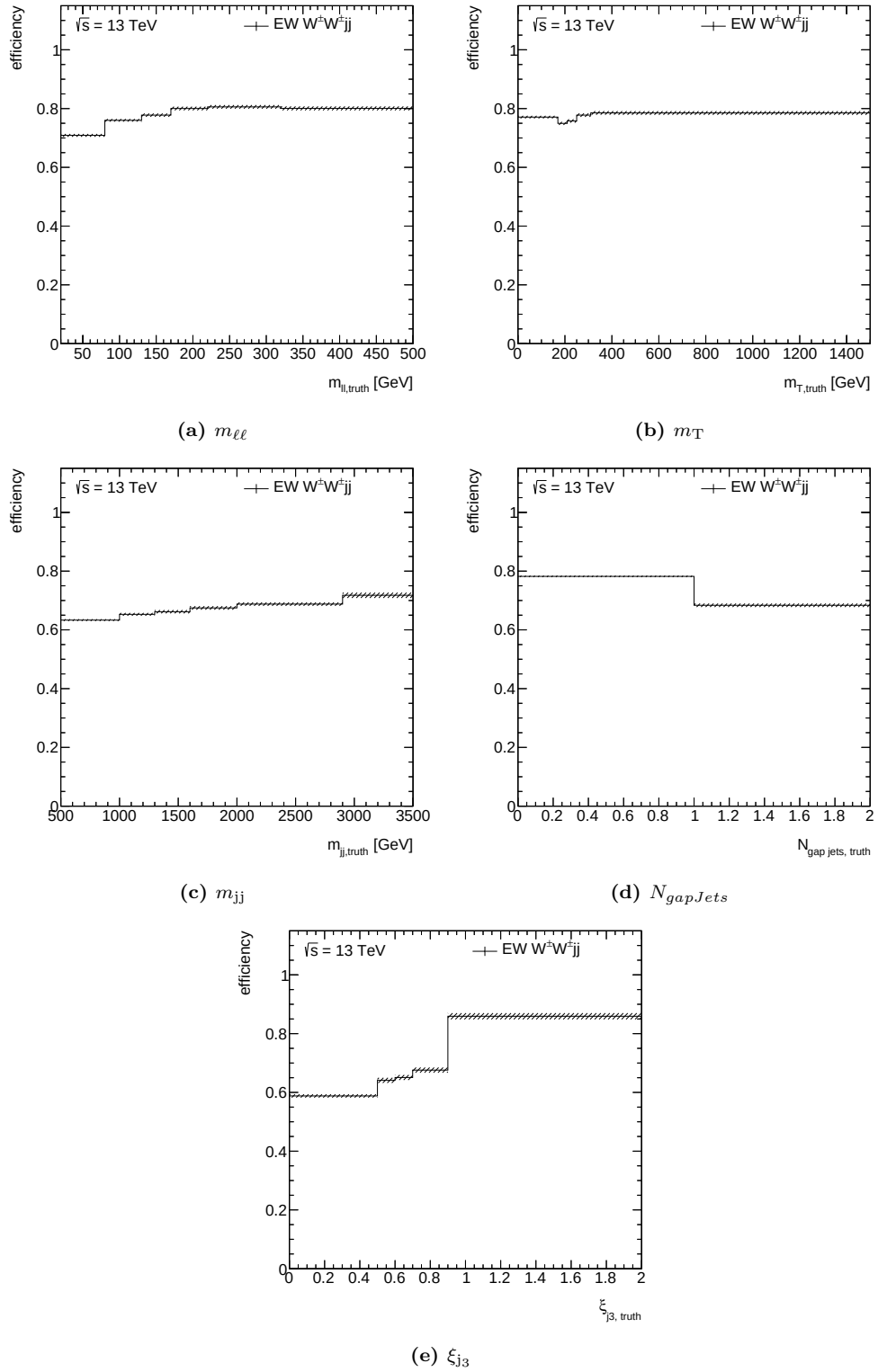


Figure 9.7: Efficiency of EW $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 being the fraction of events passing the reco selection divided by the number of events passing the fiducial selection. For all but m_{jj} the low- m_{jj} control region is part of the reco selection. The hatched grey areas show the MC statistical uncertainty. Overflow events are included in the calculation of the last bin.

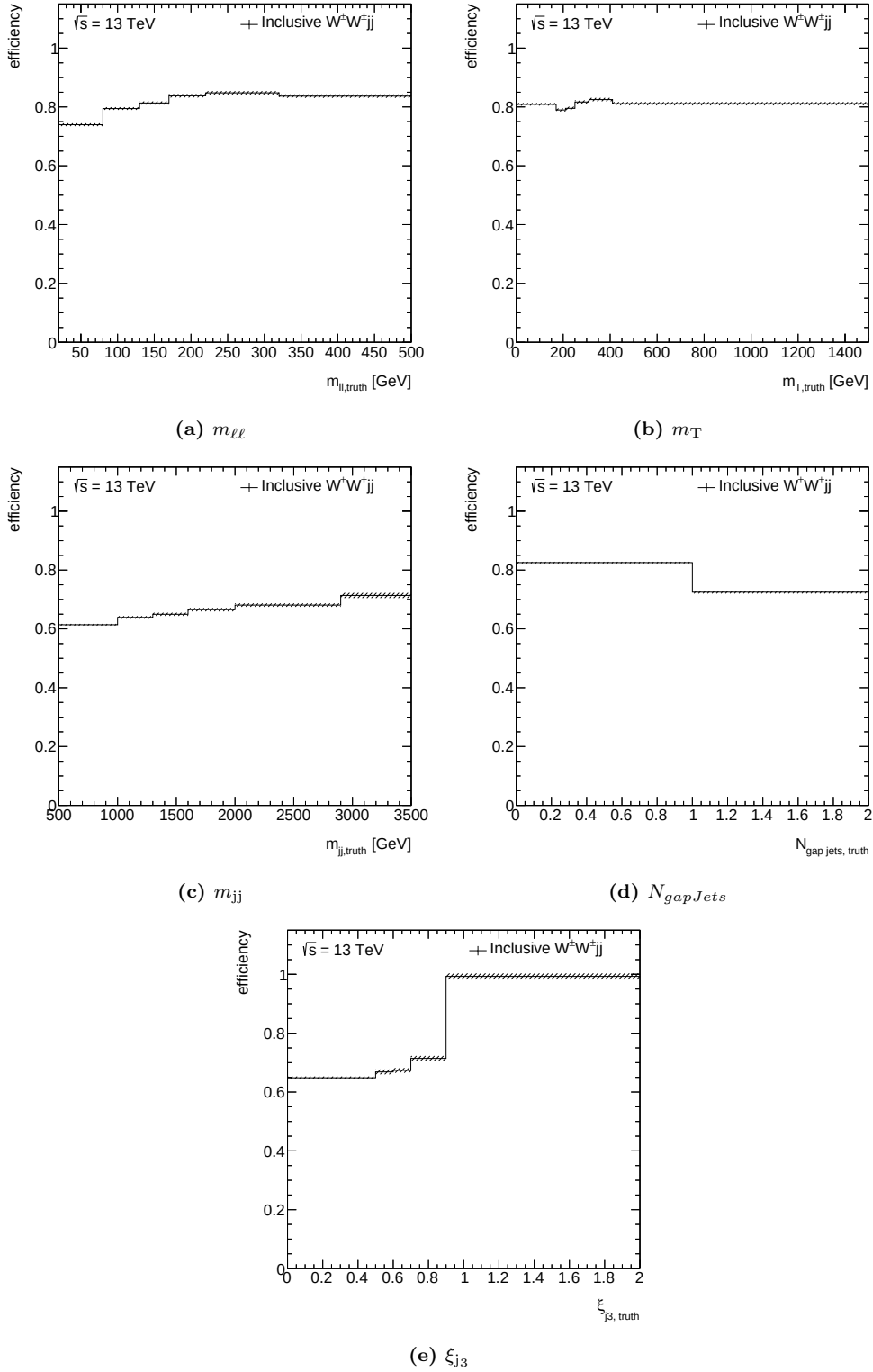


Figure 9.8: Efficiency of inclusive $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 being the fraction of events passing the reco selection divided by the number of events passing the fiducial selection. For all but m_{jj} the low- m_{jj} control region is part of the reco selection. The hatched grey areas show the MC statistical uncertainty. Overflow events are included in the calculation of the last bin.

also normalised to nominal predicted yield for each truth $m_{\ell\ell}$ bin separately. The complete list of signal modelling uncertainties in the differential EW and inclusive $W^\pm W^\pm jj$ $m_{\ell\ell}$ cross-section measurement are listed in Table 6.11 and Table 6.12 in Section 6.5.2.

A separate nuisance parameter for each truth slice means that the theory uncertainties are uncorrelated between truth bins in the fits. The recommendation is to take the approach (correlated vs. uncorrelated) which is more conservative. Conservative means, that the approach which results in larger uncertainty on the unfolded distribution/worse limits should be used.

For the unfolded distributions the choice of the more conservative approach depends on the unknown theory to which the unfolded distribution is compared in the future. If the future theory has the same shape, but a different normalisation, then the correlated approach is more conservative. If the future theory has an excess only in one bin, then the uncorrelated approach is more conservative. The correlated approach is chosen for the total cross-section measurement and the uncorrelated approach for the unfolded distribution. The motivation is that future theorists would only use the unfolded distribution for limit setting, if they expect some shape differences in that variable. Otherwise, they could also compare the total cross-sections.

9.4 Pre-fit Distributions for $m_{\ell\ell}$ for the Derived Binning

The following figures show the distributions of the fit inputs in the signal region (Figure 9.9) low- m_{jj} control region and WZ control region (Figure 9.10). Projections of the signal region and low- m_{jj} control region are shown in Figure 9.11. As discussed in Section 8.4, there are fewer observed events in the WZ control region than predicted.

9.5 Results of the Asimov Fit for $m_{\ell\ell}$ with EW Signal

Asimov data is used, being the sum of signal and background predictions. The expected signal strengths μ from the fit to Asimov data are:

$$\mu_{\text{exp}, m_{\ell\ell}, \text{bin } 1}^{\text{EW}} = 1.00 \pm_{0.20}^{0.22} (\text{stat.}) \pm_{0.08}^{0.08} (\text{mod. syst.}) \pm_{0.05}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\ell\ell}, \text{bin } 2}^{\text{EW}} = 1.00 \pm_{0.17}^{0.19} (\text{stat.}) \pm_{0.06}^{0.07} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\ell\ell}, \text{bin } 3}^{\text{EW}} = 1.00 \pm_{0.21}^{0.23} (\text{stat.}) \pm_{0.07}^{0.08} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\ell\ell}, \text{bin } 4}^{\text{EW}} = 1.00 \pm_{0.22}^{0.24} (\text{stat.}) \pm_{0.06}^{0.07} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\ell\ell}, \text{bin } 5}^{\text{EW}} = 1.00 \pm_{0.21}^{0.23} (\text{stat.}) \pm_{0.06}^{0.07} (\text{mod. syst.}) \pm_{0.04}^{0.04} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\ell\ell}, \text{bin } 6}^{\text{EW}} = 1.00 \pm_{0.23}^{0.25} (\text{stat.}) \pm_{0.09}^{0.10} (\text{mod. syst.}) \pm_{0.05}^{0.06} (\text{exp. syst.}) \pm_{0.02}^{0.03} (\text{lumi.})$$

and the QCD $W^\pm Z jj$ normalisation strength is:

$$\mu_{\text{WZ, exp}, m_{\ell\ell}}^{\text{EW}} = 1.00 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

The uncertainties are statistically dominated. A higher luminosity will improve the results. The relative down uncertainty is roughly 20% due to the at least 5σ significance the binning is optimised for. The upper uncertainty is always larger than the lower uncertainty. The reason for this is, that for theories, which predict more events, it is more probable to have the same absolute down fluctuation compared to a theory with less predicted events to observe

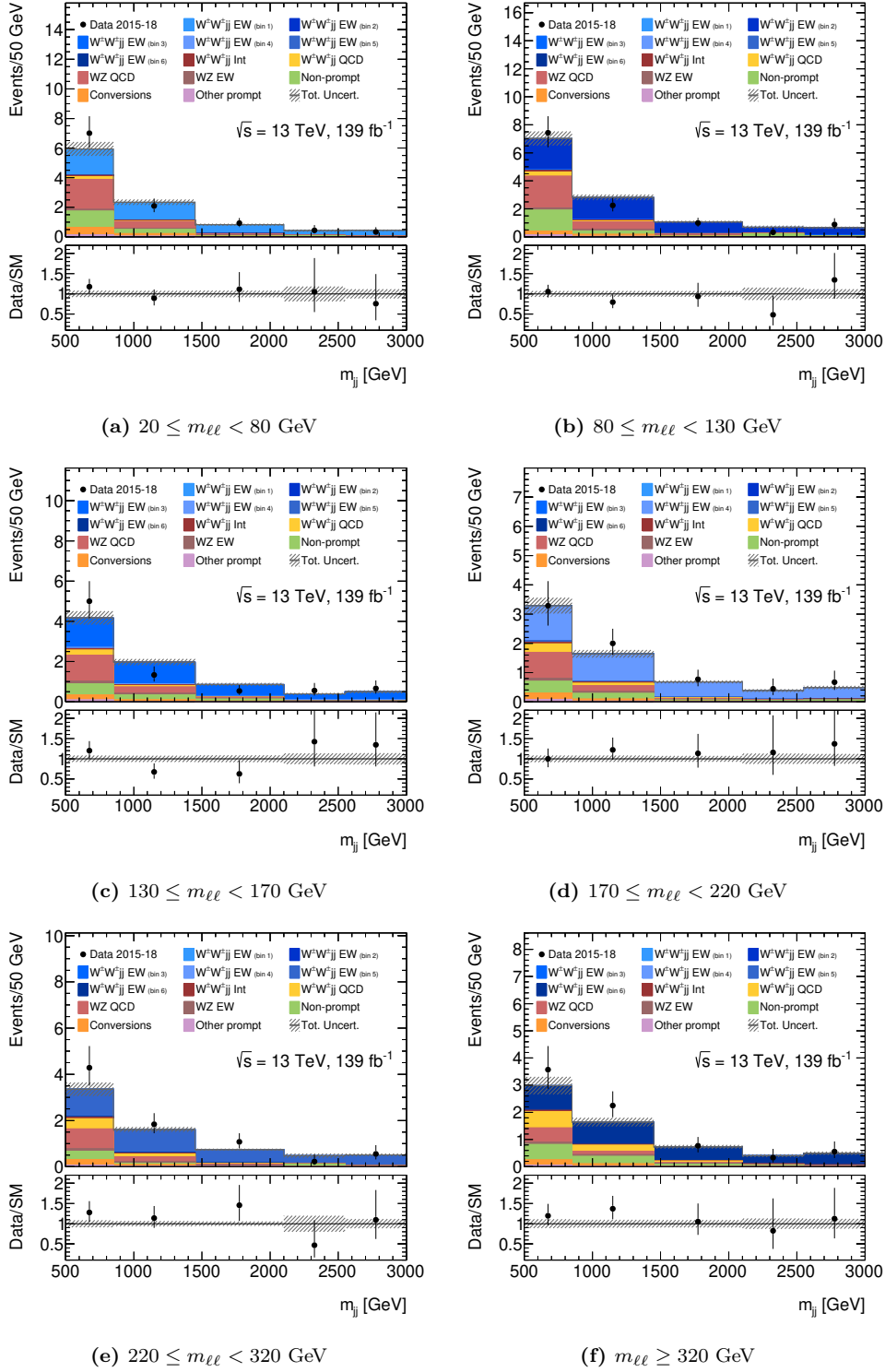


Figure 9.9: Pre-fit m_{jj} -distributions in signal region split into $m_{\ell\ell}$ slices (a-f) as used in the $m_{\ell\ell}$ -differential cross-section measurement. Zero correlation is assumed in the combination of systematic uncertainties in the hatched band. The observed data is shown with frequentist Poisson uncertainties as defined in Section 7.7.2.

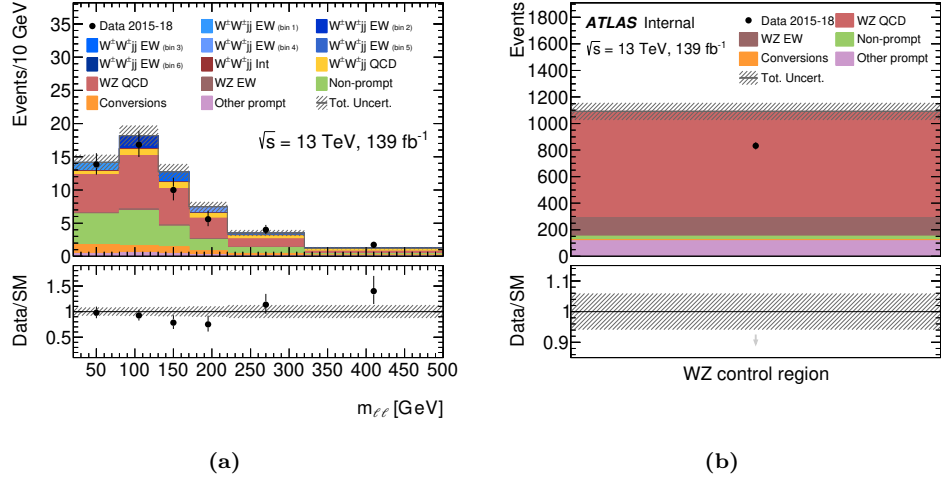


Figure 9.10: Pre-fit distributions in low- m_{jj} control region (a) and in WZ control region (b) as used in $m_{\ell\ell}$ -differential cross-section measurement. Zero correlation is assumed in the combination of systematic uncertainties in the hatched band. The observed data is shown with frequentist Poisson uncertainties as defined in Section 7.7.2.

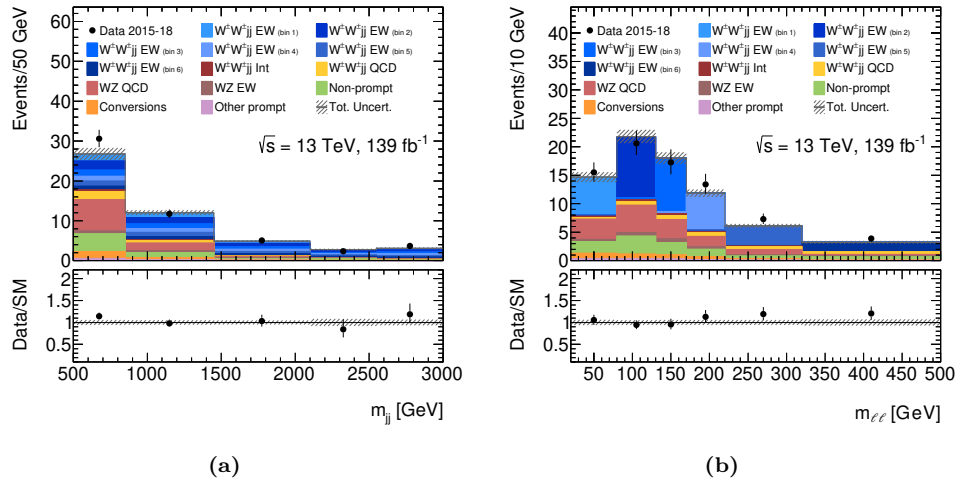


Figure 9.11: Pre-fit m_{jj} -distributions in SR summed over $m_{\ell\ell}$ slices (a) and $m_{\ell\ell}$ -distributions in SR summed over m_{jj} bins (b) of the $m_{\ell\ell}$ -differential cross-section measurement. Zero correlation is assumed in the combination of systematic uncertainties in the hatched band. The observed data is shown with frequentist Poisson uncertainties as defined in Section 7.7.2.

the same absolute up fluctuation within Poisson uncertainties. The modelling uncertainty is a little bit larger than the experimental uncertainties. This means for future analysis, where the statistical uncertainty is reduced, both uncertainty categories should be targeted for systematic uncertainty reduction.

Post-fit plots in the binning used in the fit are shown in Figure 9.12 and Figure 9.13. The uncertainties reduce slightly compared to the pre-fit distributions because of the included correlations.

The pull plot is shown in Figure 9.14. As for the Asimov fit of total EW $W^\pm W^\pm jj$ cross-section measurement the data-driven estimated backgrounds get slightly constrained as well as some modelling uncertainties.

A table of the strongest (anti-)correlations is shown in Table 9.2. Similar to the total cross-section measurement jet related systematics are anti-correlated with the QCD $W^\pm Zjj$ normalisation strength, meaning that QCD $W^\pm Zjj$ is mainly affected by these uncertainties.

The ranking plot is shown in Figure 9.15. It is discussed in more detail for the fit to observed data in Section 9.6 where similar impacts are observed.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table 9.3. The calculation of the impacts is described in Section 7.4.6.

Expected LH-unfolded distributions and correlations between bins are shown in Figure 9.17 and 9.16. They are extracted from four different fits: The full fit, the full fit without luminosity uncertainty, the fit with only theoretical and statistical uncertainties and the fit with only statistical uncertainties. As expected, there are anti-correlations between the bins in the fit with only statistical uncertainties, because it is not 100% clear from which neighbouring truth bin a reconstruction event comes, see Figure 9.1 and Figure 9.2. It would only be 100% clear from which neighbouring bin an event comes if the main diagonal of the migration matrix is 1.0. When adding theory and experimental uncertainties to the fit, then positive correlations between all bins increase. This is due to systematic uncertainties which have a similar effect in all $m_{\ell\ell}$ bins. Since there is a dedicated theory uncertainty parameter for $W^\pm W^\pm jj$ EW and Interference for each signal $m_{\ell\ell}$ slice, meaning that there are nearly no correlations between these NPs, the effect on the correlations of including the theory uncertainty parameters is very small.

9.6 Results of the Fit to Observed Data for $m_{\ell\ell}$ with EW Signal

The observed signal strengths μ from the fit to observed data are:

$$\mu_{\text{obs}, m_{\ell\ell}, \text{ bin 1}}^{\text{EW}} = 1.15 \pm_{0.21}^{0.23} (\text{stat.}) \pm_{0.10}^{0.10} (\text{mod. syst.}) \pm_{0.05}^{0.06} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{\ell\ell}, \text{ bin 2}}^{\text{EW}} = 0.96 \pm_{0.17}^{0.18} (\text{stat.}) \pm_{0.07}^{0.08} (\text{mod. syst.}) \pm_{0.04}^{0.05} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{\ell\ell}, \text{ bin 3}}^{\text{EW}} = 0.90 \pm_{0.20}^{0.22} (\text{stat.}) \pm_{0.06}^{0.07} (\text{mod. syst.}) \pm_{0.04}^{0.05} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{\ell\ell}, \text{ bin 4}}^{\text{EW}} = 1.24 \pm_{0.23}^{0.25} (\text{stat.}) \pm_{0.07}^{0.08} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.02}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{\ell\ell}, \text{ bin 5}}^{\text{EW}} = 1.35 \pm_{0.23}^{0.25} (\text{stat.}) \pm_{0.09}^{0.10} (\text{mod. syst.}) \pm_{0.04}^{0.05} (\text{exp. syst.}) \pm_{0.03}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{\ell\ell}, \text{ bin 6}}^{\text{EW}} = 1.35 \pm_{0.26}^{0.28} (\text{stat.}) \pm_{0.14}^{0.15} (\text{mod. syst.}) \pm_{0.06}^{0.07} (\text{exp. syst.}) \pm_{0.03}^{0.03} (\text{lumi.})$$

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{\text{WZ, obs, } m_{\ell\ell}}^{\text{EW}} = 0.68 \pm_{0.03}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.05}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

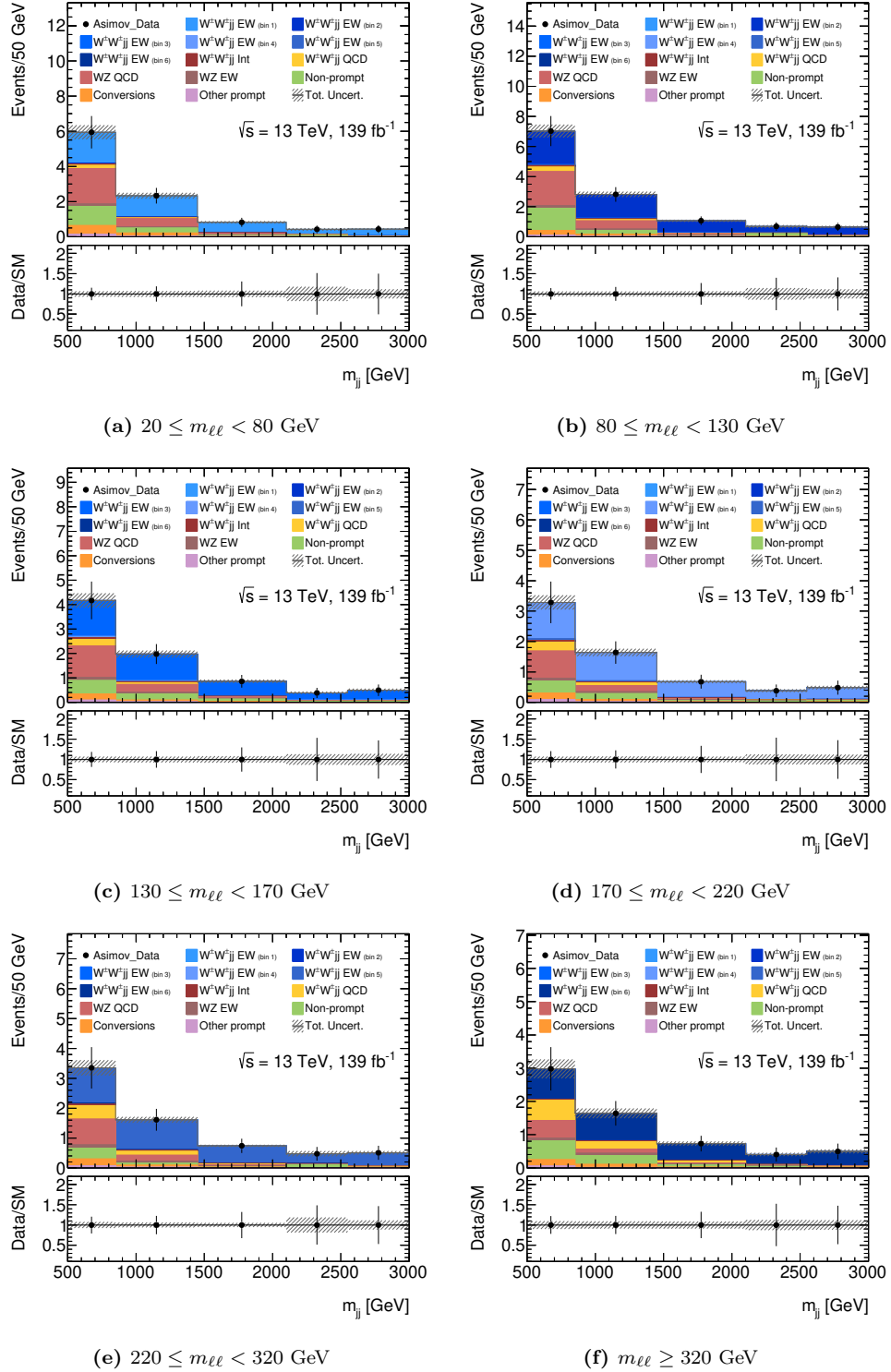


Figure 9.12: Post-fit m_{jj} -distributions in signal region split into $m_{\ell\ell}$ slices as used in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. The Asimov data is shown with plain Poisson uncertainties.

Table 9.2: List of parameter correlations which are larger than 10% in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	μ_{WZ}	0.380
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.314
JET_Pileup_RhoTopology	μ_{WZ}	-0.303
JET_JER_EffectiveNP_1	μ_{WZ}	-0.276
JET_Flavor_Composition	μ_{WZ}	-0.250
JET_Pileup_OffsetMu	μ_{WZ}	-0.244
signal_EW4_TheoScale	μ_{bin6}	-0.207
WZ_EW4_TheoScale	μ_{WZ}	0.196
MjjRewStat	μ_{bin2}	0.192
MjjRewStat	μ_{bin1}	0.184
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.175
top_XS	μ_{WZ}	-0.173
ZZ_XS	μ_{WZ}	-0.160
CutSR_all_bin_1_2	μ_{bin3}	-0.148
CutSR_all_bin_1_5	μ_{bin6}	-0.145
signal_EW6_truthBin20to80_TheoQCDCorr	μ_{bin1}	0.145
CutSR_all_bin_1_3	μ_{bin4}	-0.141
signal_EW6_truthBin130to170_TheoQCDCorr	μ_{bin3}	0.141
signal_EW6_truthBin80to130_TheoQCDCorr	μ_{bin2}	0.140
JET_Pileup_OffsetNPV	μ_{WZ}	-0.140
MjjRewStat	μ_{bin3}	0.135
CutSR_all_bin_1_0	μ_{bin1}	-0.133
CutSR_all_bin_1_1	μ_{bin2}	-0.132
FF_Prompt	μ_{bin3}	0.128
FF_Prompt	μ_{bin2}	0.125
Wgamma_XS	μ_{bin1}	-0.122
FF_Prompt	MjjRewStat	0.119
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.119
FF_Prompt	$\mu_{\text{FF_BTagged}}$	-0.118
$\mu_{\text{FF_BTagged}}$	μ_{bin2}	0.118
$\mu_{\text{FF_BTagged}}$	μ_{bin1}	0.116
signal_EW4_TheoScale	μ_{bin5}	-0.116
CutSR_all_bin_0_1	μ_{bin2}	-0.112
Zjets_XS	μ_{WZ}	-0.112
FF_Prompt	μ_{bin6}	0.110
CutSR_all_bin_2_5	μ_{bin6}	-0.110
CutSR_all_bin_0_2	μ_{bin3}	-0.110
MjjRewStat	$\mu_{\text{FF_BTagged}}$	0.109
CutSR_all_bin_0_0	μ_{bin1}	-0.109
CutSR_all_bin_2_2	μ_{bin3}	-0.105
WZ_EW6_TheoScale	μ_{WZ}	-0.104
$\mu_{\text{FF_BTagged}}$	μ_{bin3}	0.104
μ_{WZ}	μ_{bin5}	0.103
MjjRewStat	μ_{bin5}	0.102
CutSR_all_bin_3_4	μ_{bin5}	-0.102
FF_Prompt	μ_{bin4}	0.101

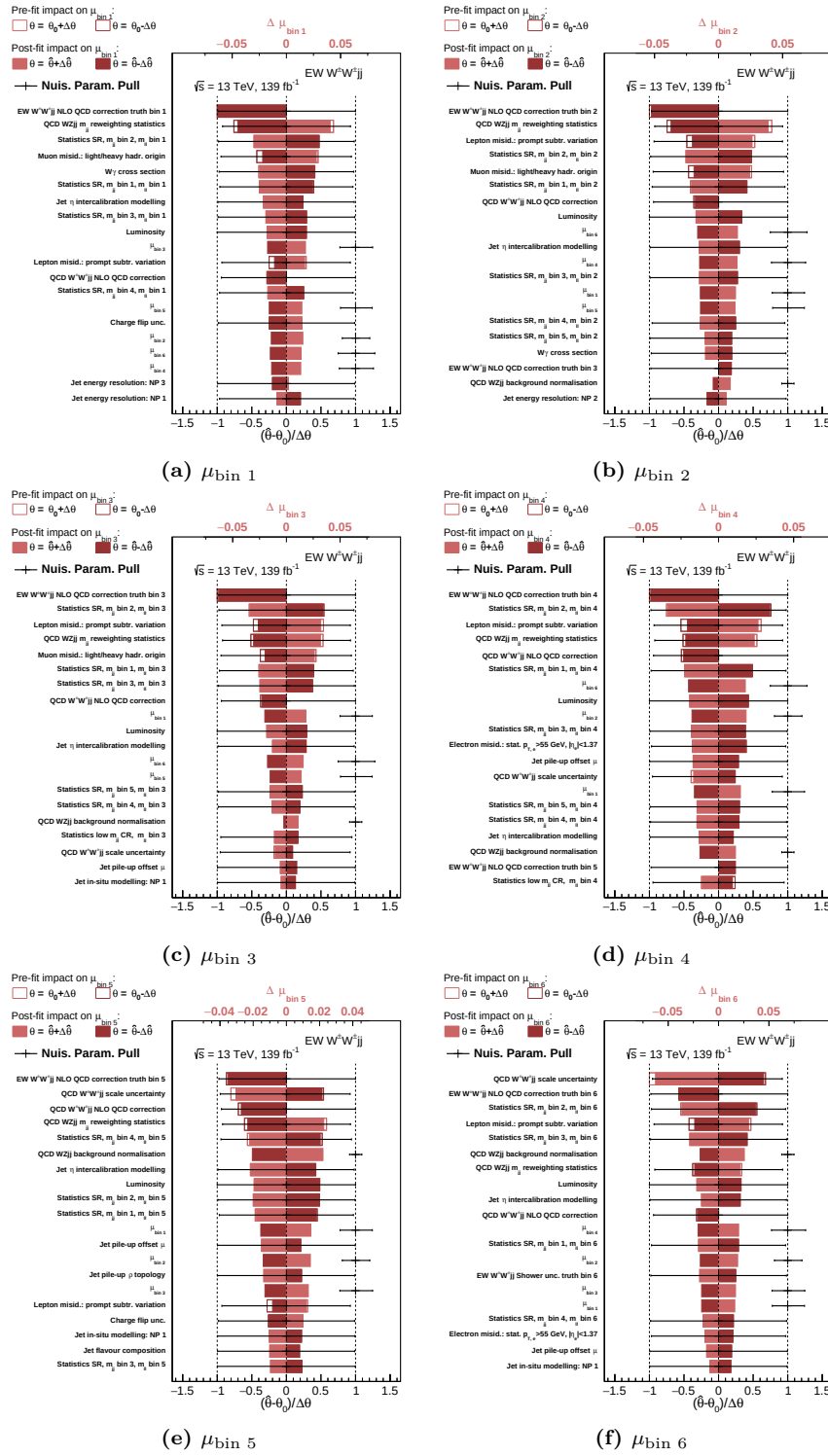


Figure 9.15: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) $m_{\ell\ell}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\theta_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

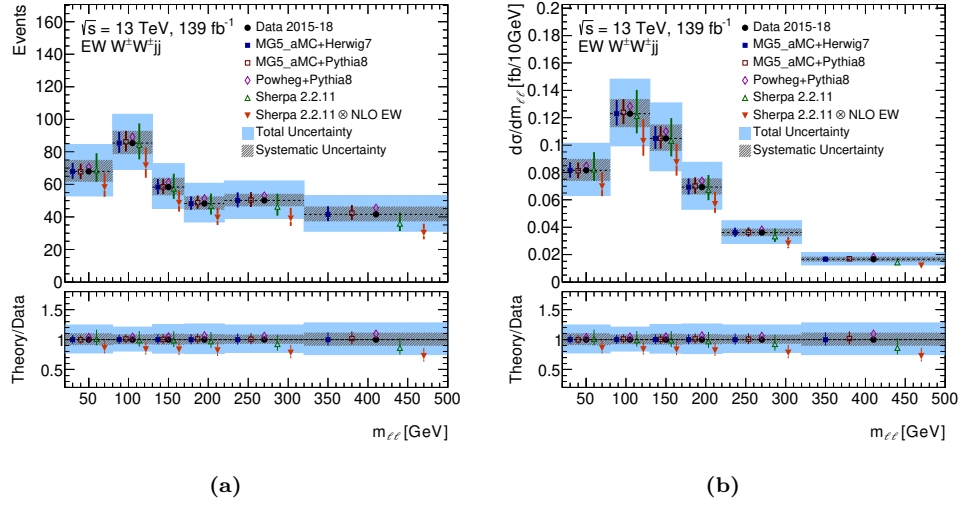


Figure 9.16: LH-based unfolded distributions showing events per bin (a) and showing differential cross-section per 100 GeV (b) of the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^{\pm}W^{\pm}jj$ with Asimov data. The measured data are shown as black points with horizontal bars indicating the bin range and black hatched (blue) boxes representing the systematic (total) uncertainty. The data are compared to a number of Standard Model predictions as described in Section 5.4. Overflow events are included in the last bin. [18]

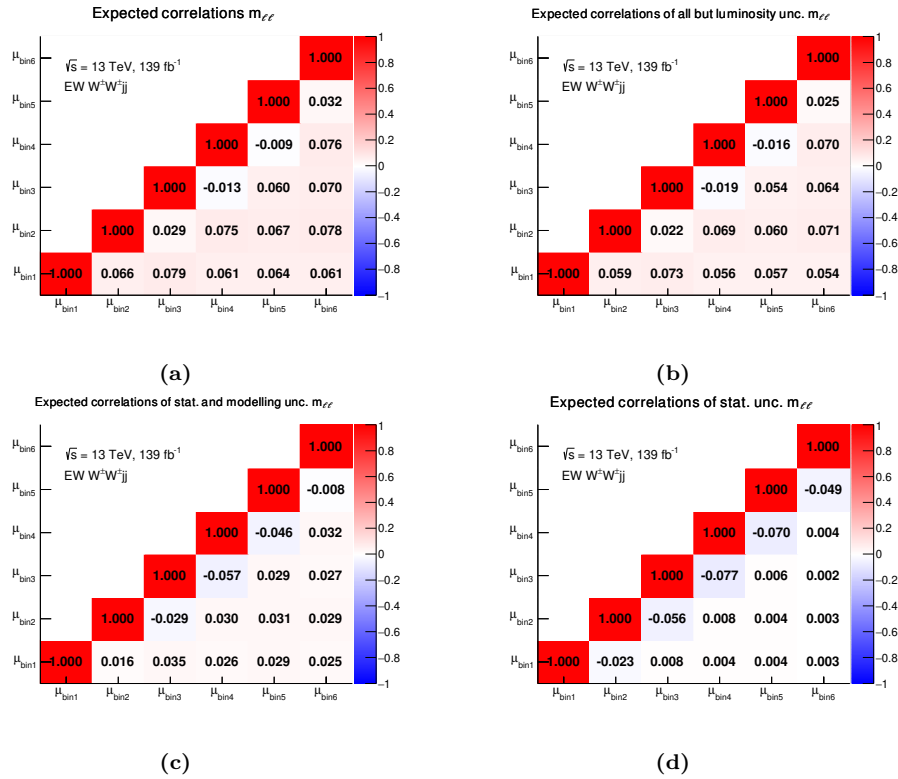


Figure 9.17: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^{\pm}W^{\pm}jj$ with Asimov data.

Table 9.3: Breakdown of the uncertainty on the EW $W^\pm W^\pm jj$ $m_{\ell\ell}$ differential cross-section measurement using Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.5	0.4	0.3	0.4	0.6	1.4
Muon calibration	0.4	0.4	0.5	0.5	0.6	1.0
Jet energy scale and resolution	3.1	2.3	2.0	2.3	3.2	2.7
E_T^{miss} scale and resolution	0.4	0.2	0.2	0.0	0.2	0.2
b -tagging inefficiency	0.7	0.6	0.7	0.7	0.8	0.9
Background, misid. leptons	3.8	4.1	4.5	4.1	2.0	4.4
Background, charge misrec.	2.0	1.0	1.3	1.3	1.3	1.2
Pileup modelling	0.6	0.4	0.1	0.2	0.1	0.0
Luminosity	1.8	1.8	1.8	1.9	2.0	2.2
Modelling						
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	1.6	0.8	0.8	0.8	1.2	1.7
EW $W^\pm W^\pm jj$, QCD corrections	3.5	3.0	3.5	2.6	2.1	2.3
EW $W^\pm W^\pm jj$, EW corrections	0.5	0.4	0.4	0.3	0.4	0.5
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.4	0.2	0.0	0.2	0.1	0.0
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.7	1.0	1.5	2.1	3.0	6.3
QCD $W^\pm W^\pm jj$, QCD corrections	0.8	0.9	1.0	1.0	1.2	0.7
Background, WZ scale, PDF & α_s	0.4	0.7	0.5	0.6	0.5	1.0
Background, WZ reweighting	3.6	3.1	2.4	1.7	2.0	1.7
Background, other	3.1	1.6	1.4	1.3	0.8	0.8
Model statistical	5.0	4.4	5.5	5.2	4.1	5.6
Experimental and modelling	9.9	8.4	9.2	8.6	7.7	11.0
Data statistical	21.1	18.0	21.8	23.2	21.6	24.1
Total	23.3	19.9	23.7	24.7	22.9	26.5

Post-fit plots are shown in Figure 9.18 and Figure 9.19. The projections on $m_{\ell\ell}$ and on m_{jj} are shown in Figure 9.20. Because of the free-floating normalisation factors nearly perfect agreement is expected in the signal region in the $m_{\ell\ell}$ projections. This is also observed. There are some small deviations because of the low- m_{jj} CR and the splitting into m_{jj} bins, with different signal to background fractions. This can also be seen for all other unfolded variables. Only for m_{jj} the agreement is exceptionally well. For differential measurement of m_{jj} the variable $m_{\ell\ell}$ is used as discriminating variable without the low- m_{jj} CR. Since there is a similar signal to background fraction in the $m_{\ell\ell}$ bins, nearly perfect agreement is seen in the post-fit m_{jj} distribution in the signal region in Figure C.28 (b).

Pull plots are shown in Figure 9.21. The scale uncertainty of QCD $W^\pm W^\pm jj$ is varied the most. A full NLO QCD $W^\pm W^\pm jj$ prediction should be able to reduce this uncertainty in the future and would thus also make the differential measurement more precise.

Selected profile likelihood scans are presented in Figure 9.22. The profile likelihood scans look similar for the different $m_{\ell\ell}$ signal strengths. The parabola of the last signal strength $\mu_{\text{bin 6}}$ is a bit broader due to a slightly lower significance from the binning optimisation. Also with all systematic uncertainties included, 5σ significance is expected and observed in each bin. Only in the last bin the 5σ is not reached for Asimov data.

A table of the strongest (anti-)correlations is shown in Table 9.4. They are similar to the correlation of the total cross-section measurement.

The ranking plot is shown in Figure 9.23. Similar nuisance parameters as for the total cross-section measurement are dominant: the NLO QCD corrections, WZ reweighting and non-prompt background uncertainties. Some statistical bin uncertainties appear also in the top five of the ranking plots. These statistical uncertainties are dominated by the statistical

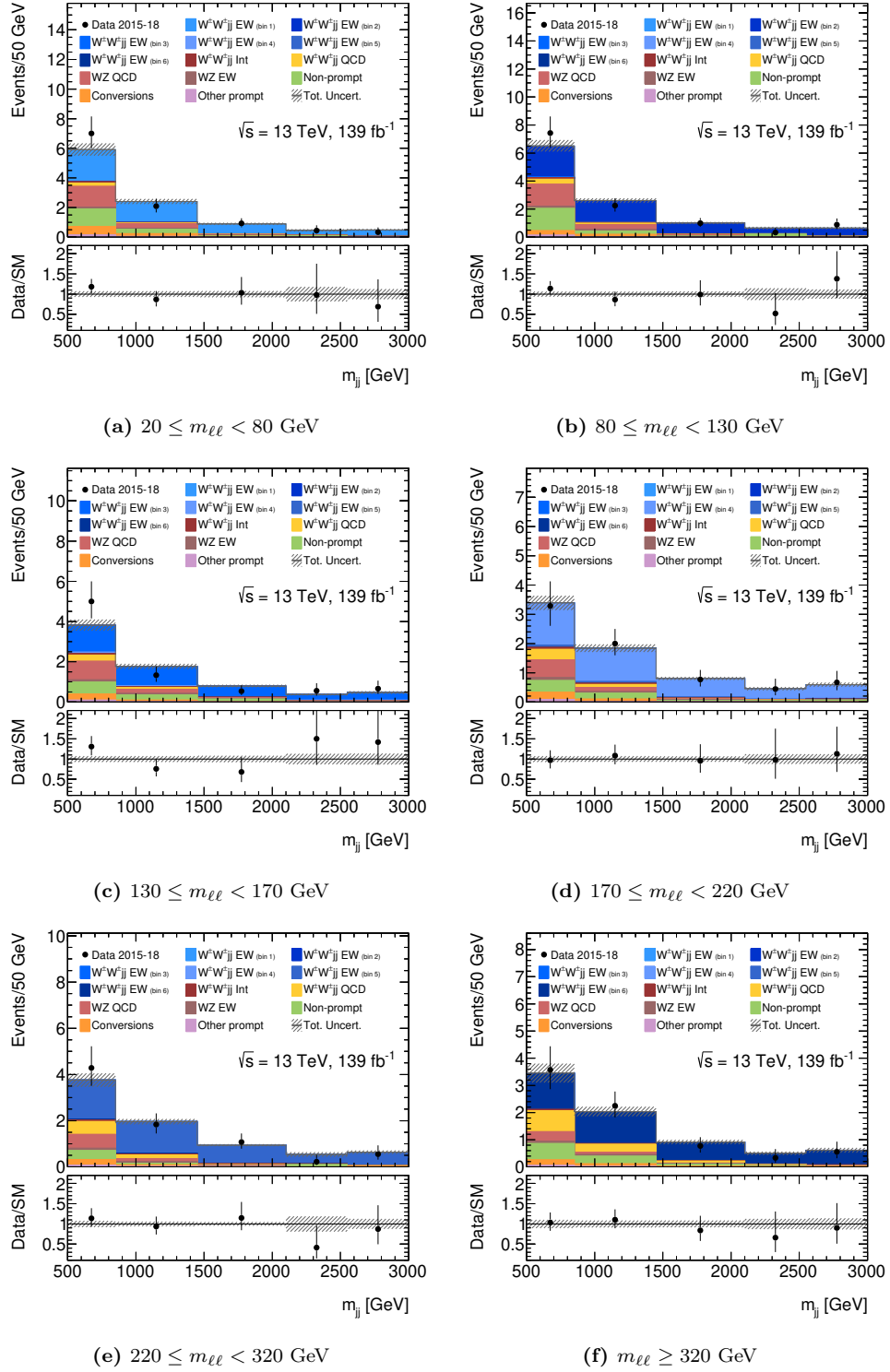


Figure 9.18: Post-fit m_{jj} -distributions in signal region split into $m_{\ell\ell}$ slices (a-f) as used in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

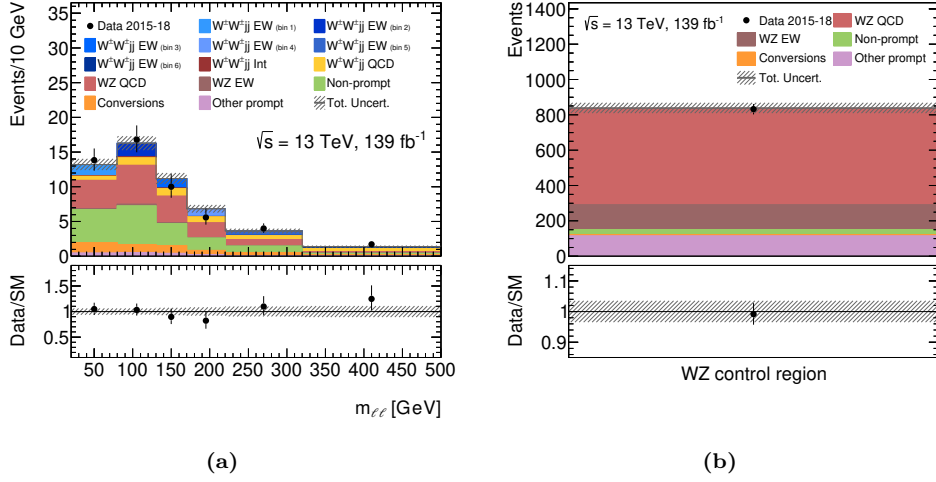


Figure 9.19: Post-fit distributions in low- m_{jj} control region (a) and WZ control region (b) as used in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

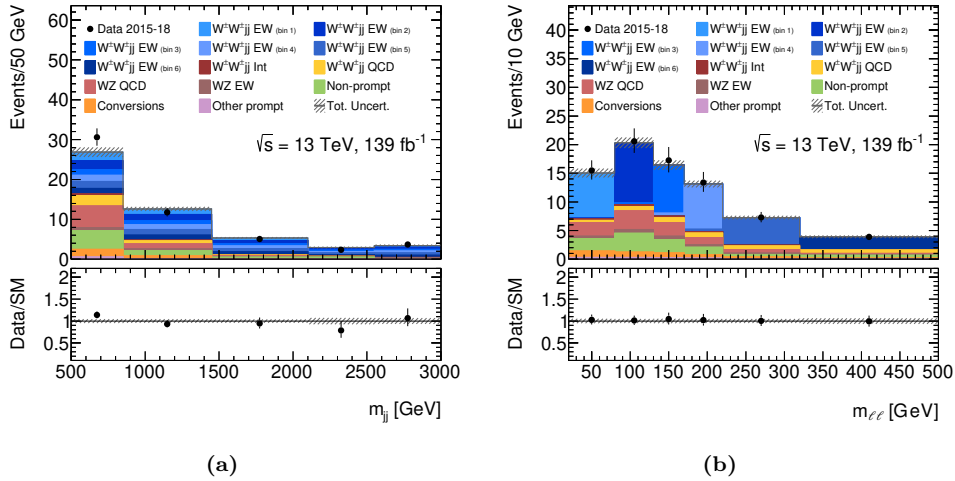


Figure 9.20: Post-fit m_{jj} -distributions in SR summed over $m_{\ell\ell}$ slices (a) and Post-fit $m_{\ell\ell}$ -distributions in SR (right) summed over m_{jj} bins (b) in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

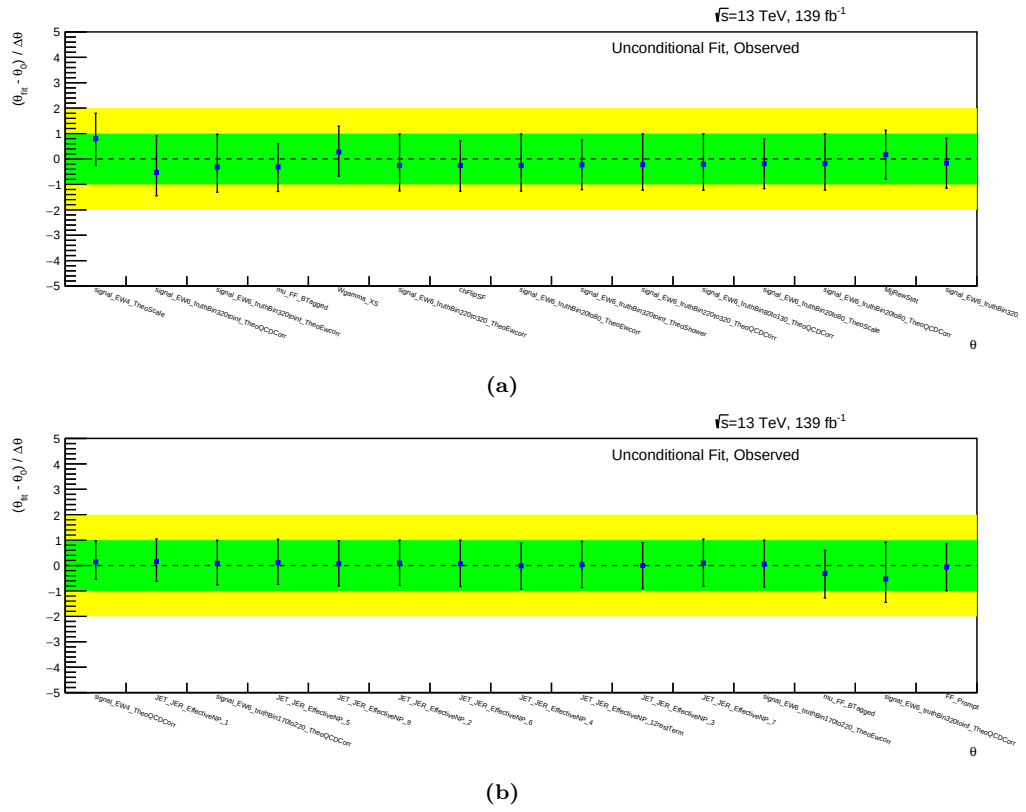


Figure 9.21: Nuisance parameter pulls of most pulled (a) and strongest constraint (b) nuisance parameters in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

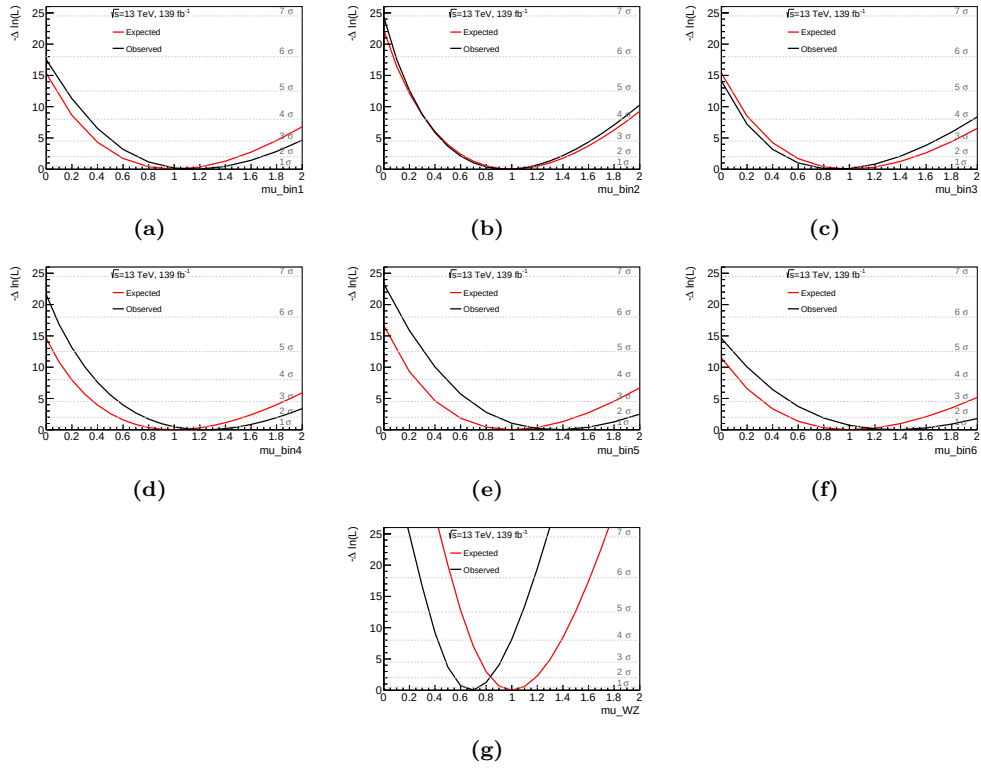


Figure 9.22: Likelihood scans of nuisance parameters with largest pulls and constraints in the $m_{\ell\ell}$ differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-f) and for the QCD $W^\pm Z jj$ normalisation parameter (g).

Table 9.4: List of parameter correlations in the fit to observed data which are larger than 10%.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	μ_{WZ}	0.326
JET_Flavor_Composition	μ_{WZ}	-0.301
signal_EW4_TheoScale	μ_{bin6}	-0.297
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.291
signal_EW6_truthBin20to80_TheoQCDCorr	μ_{bin1}	0.273
JET_Pileup_RhoTopology	μ_{WZ}	-0.259
JET_JER_EffectiveNP_1	μ_{WZ}	-0.255
signal_EW6_truthBin80to130_TheoQCDCorr	μ_{bin2}	0.253
top_XS	μ_{WZ}	-0.216
JET_Pileup_OffsetMu	μ_{WZ}	-0.216
ZZ_XS	μ_{WZ}	-0.201
signal_EW6_truthBin220to320_TheoQCDCorr	μ_{bin5}	0.172
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.171
CutSR_all_bin_1_5	μ_{bin6}	-0.170
signal_EW4_TheoScale	μ_{bin5}	-0.165
signal_EW4_TheoScale	signal_EW6_truthBin320toinf_TheoQCDCorr	0.164
WZ_EW4_TheoScale	μ_{WZ}	0.162
CutSR_all_bin_1_3	μ_{bin4}	-0.150
CutSR_all_bin_1_2	μ_{bin3}	-0.142
CutSR_all_bin_1_0	μ_{bin1}	-0.142
MjjRewStat	μ_{bin2}	0.137
Zjets_XS	μ_{WZ}	-0.135
WZ_EW6_TheoScale	μ_{WZ}	-0.129
CutSR_all_bin_1_1	μ_{bin2}	-0.128
JET_Pileup_OffsetNPV	μ_{WZ}	-0.127
signal_EW6_truthBin130to170_TheoQCDCorr	μ_{bin3}	0.124
CutSR_all_bin_2_5	μ_{bin6}	-0.123
signal_EW6_truthBin320toinf_TheoQCDCorr	μ_{bin6}	0.122
FF_Prompt	μ_{bin3}	0.121
Wgamma_XS	μ_{bin1}	-0.120
FF_Prompt	$\mu_{\text{FF_BTagged}}$	-0.120
MjjRewStat	μ_{bin1}	0.119
signal_EW6_truthBin320toinf_TheoEwcorr	μ_{bin6}	-0.119
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.116
CutSR_all_bin_0_0	μ_{bin1}	-0.115
$\mu_{\text{FF_BTagged}}$	μ_{bin1}	0.112
FF_Prompt	μ_{bin2}	0.109
FF_Prompt	signal_EW4_TheoScale	0.109
CutSR_all_bin_1_4	μ_{bin5}	-0.108
μ_{WZ}	μ_{bin5}	0.107
CutSR_all_bin_0_2	μ_{bin3}	-0.106
CutSR_all_bin_0_1	μ_{bin2}	-0.106
CutSR_all_bin_3_4	μ_{bin5}	-0.105
Lumi	μ_{bin5}	-0.104
signal_EW6_truthBin320toinf_TheoShower	μ_{bin6}	-0.102
signal_EW4_TheoScale	signal_EW6_truthBin320toinf_TheoEwcorr	0.101
CutSR_all_bin_0_4	μ_{bin5}	-0.101
CutSR_all_bin_2_2	μ_{bin3}	-0.100

uncertainty of the non-prompt background estimates.

Observed correlations between bins are shown in Figure 9.24.

9.7 Unfolded Distributions

Unfolded distributions of observed data are shown with EW $W^\pm W^\pm jj$ signal for all considered observables in Figure 9.25 and with inclusive $W^\pm W^\pm jj$ signal in Figure 9.26. The corresponding correlation matrices can be found in Figure 9.27 for EW $W^\pm W^\pm jj$ and in Figure 9.28 for inclusive $W^\pm W^\pm jj$. In general good agreement between unfolded data and prediction can be seen. This confirms the Standard Model of particle physics to model these distributions correctly. Some larger differences are discussed in Section 9.7.1. The largest anti-correlations are expected for variables with lowest main diagonal elements in the migration matrix. These are: m_T , m_{jj} and $N_{gapJets}$. For the other variables ξ_{j3} and $m_{\ell\ell}$ the main diagonal is above 80%. This is also what is observed in the correlation matrices. For the first three variables there are visible anti-correlation between the bins ranging up to -42% for m_T in the inclusive $W^\pm W^\pm jj$ production between the second and third truth bin. It is important to take these correlations into account for comparisons with theory predictions as explained in Section 7.9.4. For the other two variables, $m_{\ell\ell}$ and ξ_{j3} , the positive correlation from systematic variations compensate the small anti-correlation from migrations between neighbouring bins.

The break down of uncertainties is shown in Table 9.5 to 9.14 for EW and inclusive $W^\pm W^\pm jj$ production. The uncertainties are overall dominated by the statistical uncertainty. Future measurements with Run 3 data will improve the results significantly even if there are no methodological changes in the analysis. But the first bins of each distribution have a systematic uncertainty close to the statistical. There, improvements of the following uncertainty sources seem to be most promising:

- The "Model statistical" uncertainty: is dominated by the uncertainties of the data driven estimated non-prompt background. A higher integrated luminosity will help there in future measurements. Additionally, more generated MC events will also help. This is CPU time limit, where several efforts are in progress to make it faster. There is for example a fast simulation of detector simulation in place [125] and there are also improvements in MC generators studied [133].
- The "EW $W^\pm W^\pm jj$ NLO QCD corrections": can be improved by using a nominal NLO signal prediction.
- The "Background, WZ reweighting" uncertainty: could be improved by using a MC prediction which is not affected by the high- m_{jj} mismodelling in VBS.
- The "Backgrounds, misid. leptons" uncertainty: will go down with a higher integrated luminosity. This is true for the statistical nuisance parameters. For the systematic components future detailed studies would be needed. The "prompt subtraction variation" is the dominant uncertainty there as can be seen in the ranking plots, eg. in Figure C.4.
- The "Jet energy scale and resolution" uncertainty: is provided by a combined performance group within ATLAS, which continuously improves the uncertainties associated to jets.

9.7.1 Local and Global Significance of Deviations between Prediction and Observed Data

In the unfolded distributions there are in total four bins where a deviation of more than 2σ from the LO Standard Model prediction is observed. It is the first bin in the m_{jj} distribution for both EW, see Figure C.30, and inclusive $W^\pm W^\pm jj$ measurement, see Figure C.37. Also the 5th bin in m_T has such a deviation for both signal definitions, see Figure C.57 and

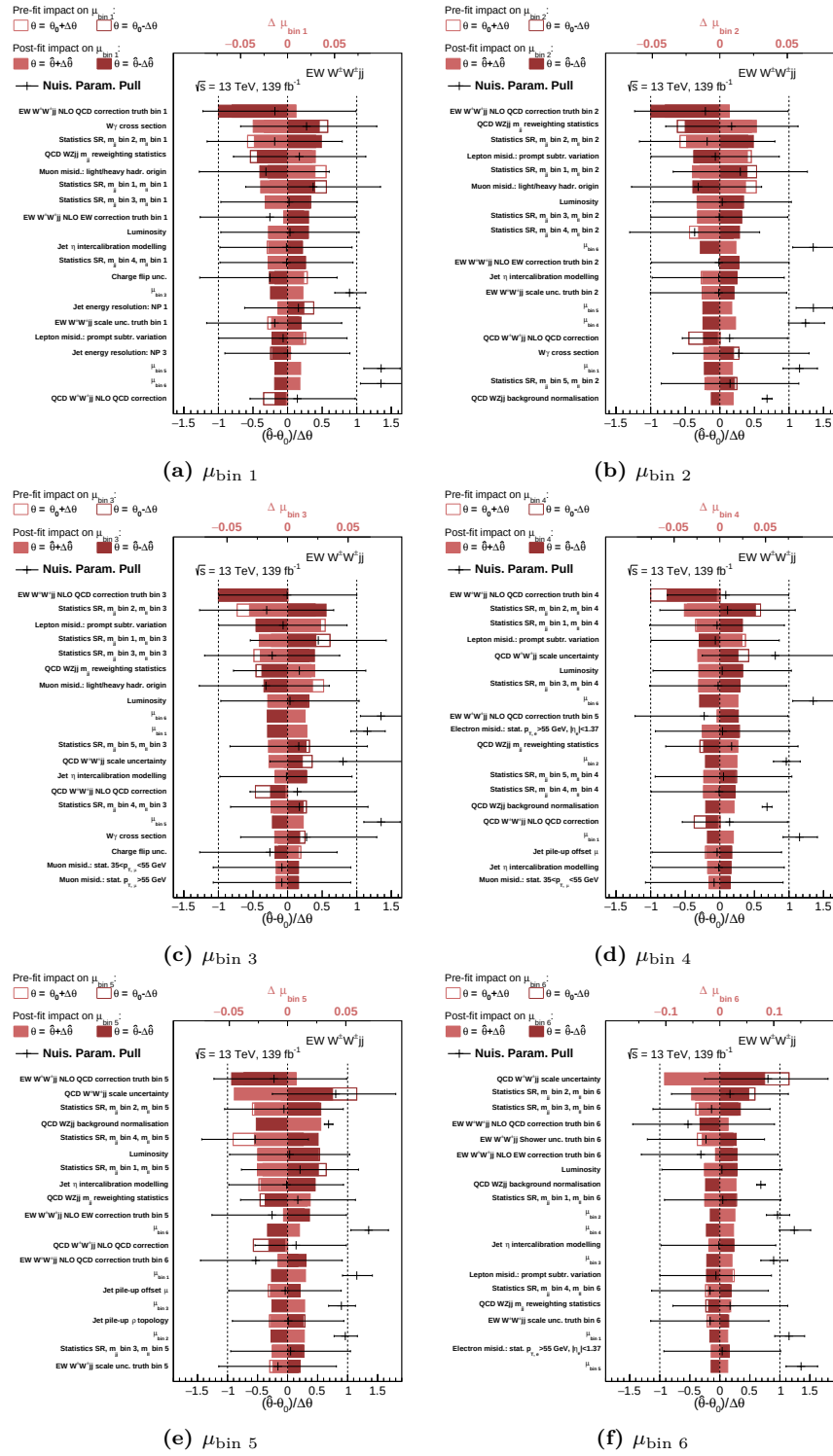


Figure 9.23: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the $m_{\ell\ell}$ -differential cross-section measurement of $\text{EW } W^\pm W^\pm jj$ using observed data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) $m_{\ell\ell}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\theta_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

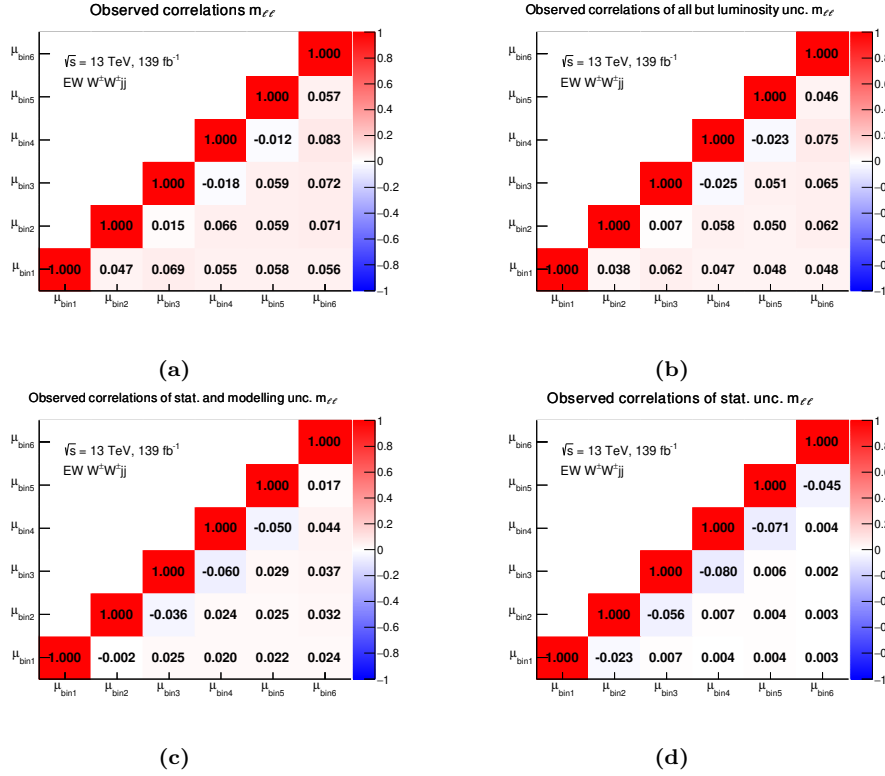


Figure 9.24: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

Figure C.64. There are more observed than expected events in both cases. This means that the LO standard model prediction is disfavoured in comparison to a model which predicts more signal process like events.

In addition to the local significance also the global significance is calculated. The global significance takes into account that some statistical fluctuations are expected when looking in multiple bins for a fluctuation. The global significance quantifies how often one would expect such a deviation in any bin. In this regard each unfolded distribution is considered separately. So, for m_T it is calculated how often the observed deviation would occur in any of the six m_T bins. The same is done for m_{jj} , following the recommendation for the equation for discrete regions defined in Ref. [134].

Without taking into account normalisation uncertainties on the theory prediction (frequentistic motivated where one theory prediction is compared to data): The observed fluctuation in the first m_{jj} bin of differential EW $W^\pm W^\pm jj$ measurement has a local significance of 2.5σ , corresponding to a global significance of 1.8σ . The observed fluctuation in the first m_{jj} bin of differential inclusive $W^\pm W^\pm jj$ measurement has a local significance of 2.7σ , corresponding to a global significance of 2.1σ . The observed fluctuation in the 5th m_T bin of differential EW $W^\pm W^\pm jj$ measurement has a local significance of 3.0σ , corresponding to a global significance of 2.4σ . The observed fluctuation in the 5th m_T bin of differential inclusive $W^\pm W^\pm jj$ measurement has a local significance of 3.1σ , corresponding to a global significance of 2.5σ . Taking into account normalisation uncertainties (effectively a bayesian approach) the significances reduce by up to 0.1σ for EW $W^\pm W^\pm jj$ and up to 0.3σ for inclusive $W^\pm W^\pm jj$.

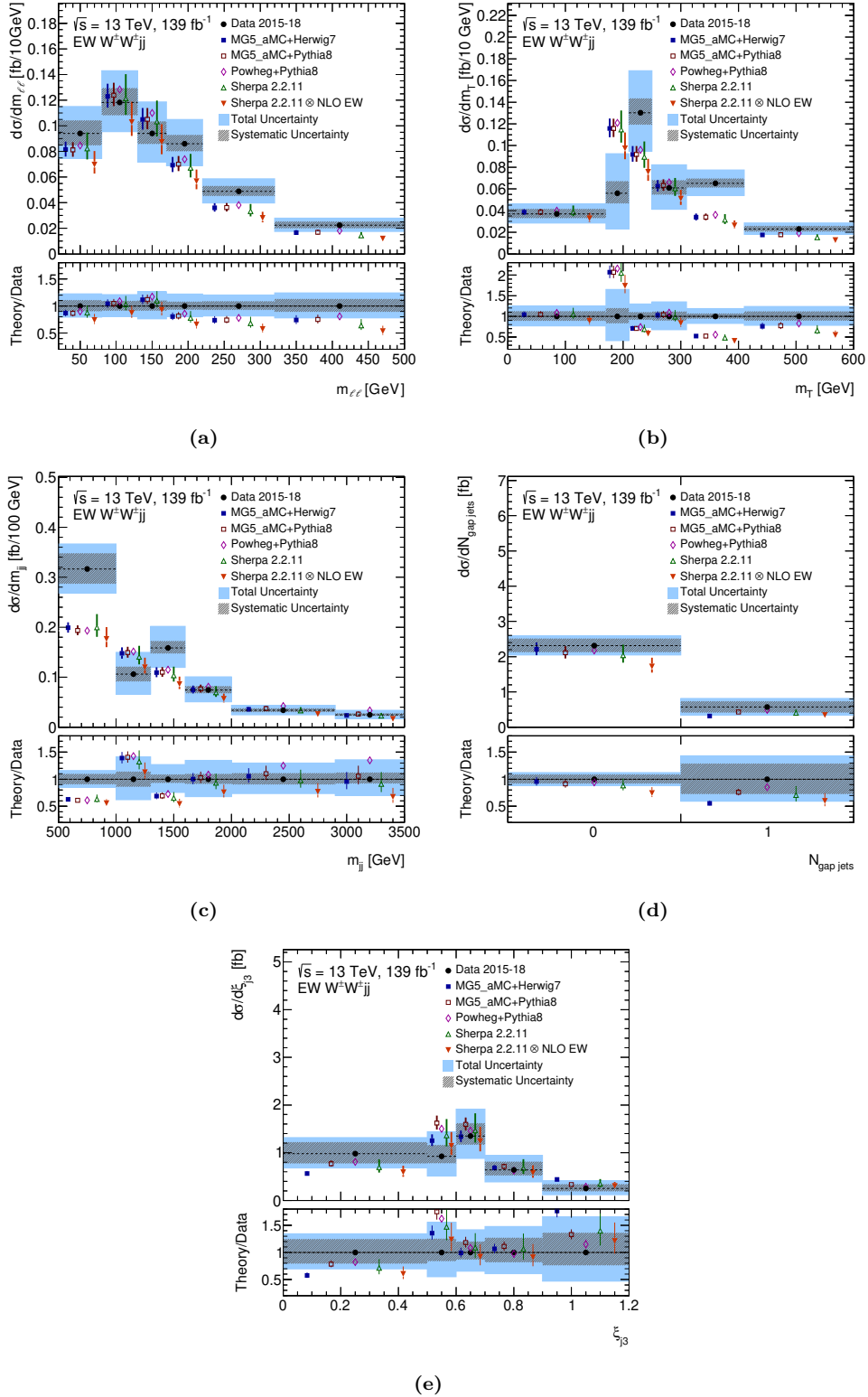


Figure 9.25: Fiducial differential cross-sections of EW $W^\pm W^\pm jj$ production as a function of: $m_{\ell\ell}$ (a), m_T (b), m_{jj} (c), $N_{gapJets}$ (d), and ξ_{j3} (e). The measured data are shown as black points with horizontal bars indicating the bin range and black hatched (blue) boxes representing the systematic (total) uncertainty. The data are compared to a number of Standard Model predictions as described in Section 5.4. Overflow events are included in the last bin. [18]

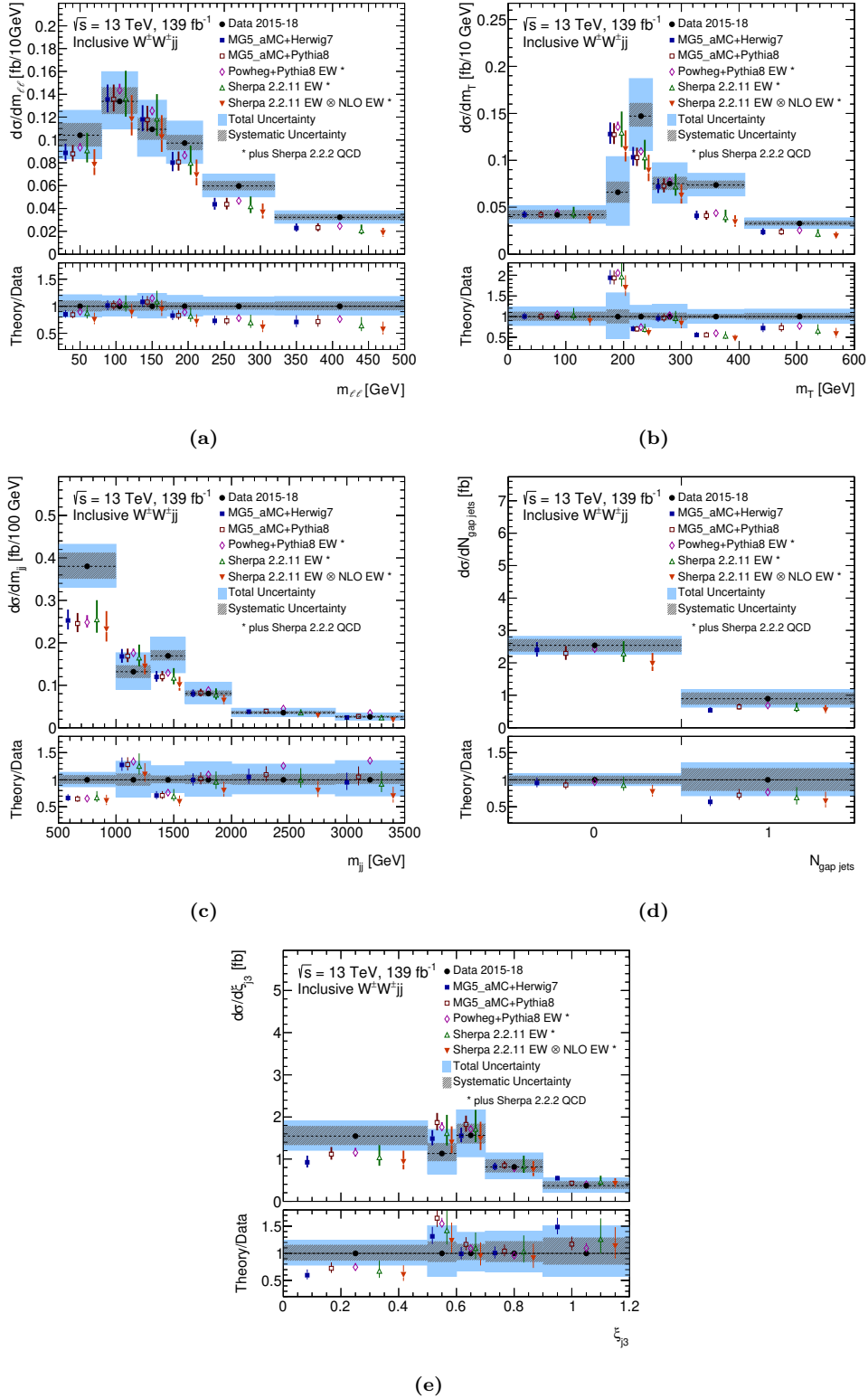


Figure 9.26: Measured fiducial cross-sections of inclusive $W^\pm W^\pm jj$ production as a function of: $m_{\ell\ell}$ (a), m_T (b), m_{jj} (c), N_{gapJets} (d), and ξ_{33} (e). The measured data are shown as black points with horizontal bars indicating the bin range and black hatched (blue) hatched boxes representing the systematic(total) uncertainty. The data are compared to a number of Standard Model predictions as described in Section 5.4. Overflow events are included in the last bin. [18]

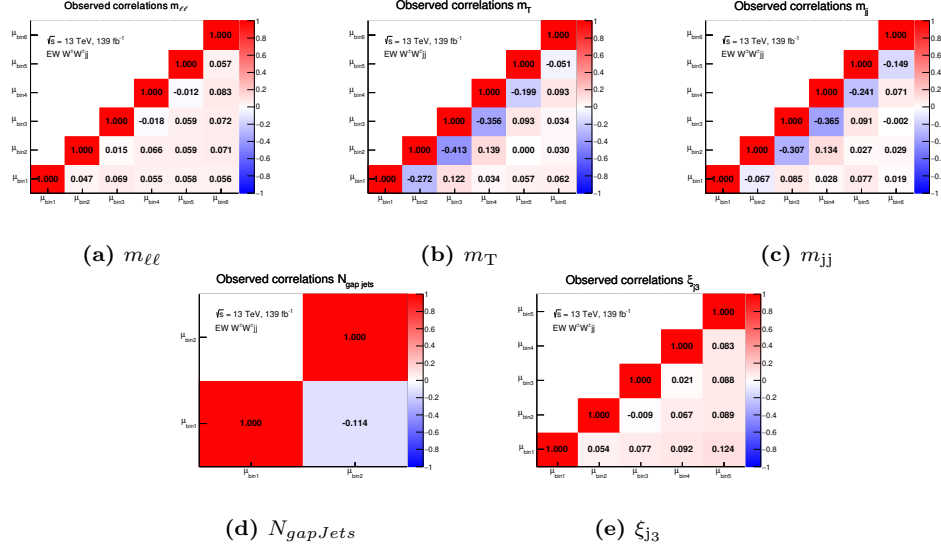


Figure 9.27: Correlations between the bins of the LH-unfolded distributions shown considering the total uncertainty for the unfolded variables $m_{\ell\ell}$ (a), m_T (b), m_{jj} (c), $N_{gapJets}$ (d), and ξ_{j3} (e) in the case of the EW $W^\pm W^\pm jj$ fit. [18]

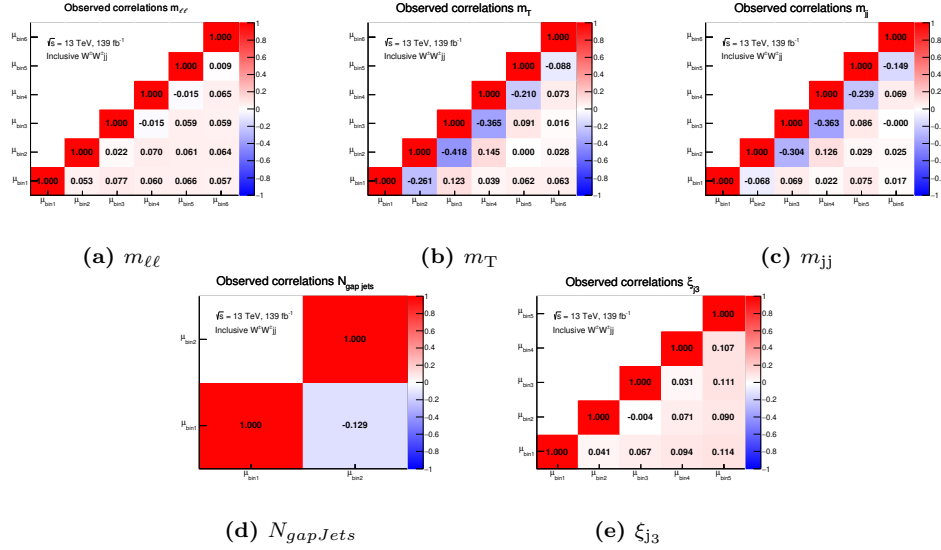


Figure 9.28: Correlations between the bins of the LH-unfolded distributions shown considering the total uncertainty for the unfolded variables $m_{\ell\ell}$ (a), m_T (b), m_{jj} (c), $N_{gapJets}$ (d), and ξ_{j3} (e) in the case of the inclusive $W^\pm W^\pm jj$ fit. [18]

9.7.2 Comparison of Summed Differential Cross-Sections and Total Cross-Section Measurements

The total cross-sections from Section 8 are compared with the summed differential cross-sections from Section 9 in the following cross-section lists. The expected cross-sections agree as expected and the observed cross-sections agree within uncertainties. The uncertainties of the total cross-section measurement with Asimov data are smaller than the uncertainties from differential cross-section measurement.

Only ξ_{j3} does not agree, because it is measured in a more restricted fiducial region where an additional third jet with transverse momentum above 25 GeV is required.

The Variable m_{jj} has a 9% higher summed cross-section. It is the only variable which does not include the low- m_{jj} control region and does not have a fixed shape in m_{jj} . This control region tends to pull the signal strengths down (see e.g. Figure C.62). If the low- m_{jj} control

Table 9.5: Breakdown of the uncertainty on the differential EW $W^\pm W^\pm jj$ cross-section measurement in the different ξ_{j3} truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]				
	$\mu_{\text{bin } 1}$	$\mu_{\text{bin } 2}$	$\mu_{\text{bin } 3}$	$\mu_{\text{bin } 4}$	$\mu_{\text{bin } 5}$
Experimental					
Electron calibration	0.6	0.5	0.5	0.6	0.7
Muon calibration	0.7	0.6	0.6	0.6	0.6
Jet energy scale and resolution	10.6	11.7	10.9	13.1	24.8
E_T^{miss} scale and resolution	0.2	0.1	0.1	0.1	0.1
b -tagging inefficiency	1.6	0.7	0.9	1.0	1.2
Background, misid. leptons	11.1	5.4	3.1	4.7	7.3
Background, charge misrec.	3.2	1.0	0.4	1.6	3.5
Pileup modelling	1.3	1.4	1.2	1.9	4.3
Luminosity	2.4	2.1	2.0	2.1	2.2
Modelling					
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	8.1	10.5	9.2	13.3	4.0
EW $W^\pm W^\pm jj$, QCD corrections	3.6	6.8	2.7	4.7	4.8
EW $W^\pm W^\pm jj$, EW corrections	3.5	0.6	0.4	0.1	0.7
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.0	0.0	0.1	0.0	0.1
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	8.1	2.1	1.8	3.5	6.8
QCD $W^\pm W^\pm jj$, QCD corrections	0.1	0.0	0.0	0.2	0.5
Background, WZ scale, PDF & α_s	0.7	1.0	0.4	0.3	0.2
Background, WZ reweighting	4.6	1.2	1.2	1.7	1.1
Background, other	3.7	0.7	0.4	2.7	2.1
Model statistical	7.8	8.4	6.4	8.1	9.2
Experimental and modelling	22.7	20.7	16.6	22.4	29.9
Data statistical	23.3	45.8	34.5	37.3	51.3
Total	32.6	50.4	38.3	43.6	59.5

region would not be there one would see nearly perfect agreement between data and MC prediction in the signal region. The m_{jj} shape in the observed data tends to increase the background and decrease the signal to match the observed data in the first two m_{jj} bins, see e.g. Figure C.8.

Expected results for EW signal:

$$\begin{aligned}
\sigma_{\text{exp}}^{\text{EW}} &= 2.534 \pm_{0.208}^{0.216} (\text{stat.}) \pm_{0.125}^{0.117} (\text{mod. syst.}) \pm_{0.108}^{0.118} (\text{exp. syst.}) \pm_{0.044}^{0.052} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{exp}, m_{\ell\ell}}^{\text{EW}} &= 2.534 \pm_{0.208}^{0.227} (\text{stat.}) \pm_{0.092}^{0.101} (\text{mod. syst.}) \pm_{0.086}^{0.094} (\text{exp. syst.}) \pm_{0.033}^{0.040} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{exp}, N_{\text{gap}J\text{ets}}}^{\text{EW}} &= 2.534 \pm_{0.231}^{0.244} (\text{stat.}) \pm_{0.147}^{0.135} (\text{mod. syst.}) \pm_{0.118}^{0.128} (\text{exp. syst.}) \pm_{0.041}^{0.048} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{exp}, m_{jj}}^{\text{EW}} &= 2.534 \pm_{0.248}^{0.265} (\text{stat.}) \pm_{0.124}^{0.136} (\text{mod. syst.}) \pm_{0.111}^{0.114} (\text{exp. syst.}) \pm_{0.034}^{0.042} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{exp}, \xi_{j3}}^{\text{EW}} &= 0.810 \pm_{0.121}^{0.135} (\text{stat.}) \pm_{0.057}^{0.077} (\text{mod. syst.}) \pm_{0.078}^{0.101} (\text{exp. syst.}) \pm_{0.011}^{0.016} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{exp}, m_T}^{\text{EW}} &= 2.534 \pm_{0.248}^{0.268} (\text{stat.}) \pm_{0.096}^{0.107} (\text{mod. syst.}) \pm_{0.087}^{0.094} (\text{exp. syst.}) \pm_{0.033}^{0.040} (\text{lumi.}) \text{ fb}
\end{aligned}$$

Table 9.6: Breakdown of the uncertainty on the differential EW $W^\pm W^\pm jj$ cross-section measurement in the different $N_{gapJets}$ truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma\gamma$, ZZ, top and Zjets.

Source	Impact [%]	
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$
Experimental		
Electron calibration	0.3	0.7
Muon calibration	0.5	0.7
Jet energy scale and resolution	1.6	17.6
E_T^{miss} scale and resolution	0.2	0.3
b -tagging inefficiency	0.5	2.0
Background, misid. leptons	1.3	11.3
Background, charge misrec.	0.7	3.0
Pileup modelling	1.0	2.9
Luminosity	1.9	2.4
Modelling		
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	2.1	5.7
EW $W^\pm W^\pm jj$, QCD corrections	6.8	7.4
EW $W^\pm W^\pm jj$, EW corrections	0.7	1.4
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.0	0.3
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	1.4	8.2
QCD $W^\pm W^\pm jj$, QCD corrections	1.0	0.4
Background, WZ scale, PDF & α_s	0.8	1.6
Background, WZ reweighting	0.6	7.8
Background, other	0.9	2.8
Model statistical	1.9	9.7
Experimental and modelling	8.3	28.2
Data statistical	8.4	31.1
Total	11.8	42.0

Expected results for EW+Int+QCD signal:

$$\begin{aligned}
\sigma_{\text{exp}}^{\text{EW+Int+QCD}} &= 2.934 \pm_{0.217}^{0.224} (\text{stat.}) \pm_{0.118}^{0.104} (\text{mod. syst.}) \pm_{0.128}^{0.138} (\text{exp. syst.}) \pm_{0.047}^{0.056} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{exp}, m_{\ell\ell}}^{\text{EW+Int+QCD}} &= 2.934 \pm_{0.217}^{0.235} (\text{stat.}) \pm_{0.086}^{0.094} (\text{mod. syst.}) \pm_{0.102}^{0.110} (\text{exp. syst.}) \pm_{0.036}^{0.043} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{exp}, N_{gapJets}}^{\text{EW+Int+QCD}} &= 2.934 \pm_{0.247}^{0.258} (\text{stat.}) \pm_{0.148}^{0.132} (\text{mod. syst.}) \pm_{0.163}^{0.167} (\text{exp. syst.}) \pm_{0.043}^{0.051} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{exp}, m_{jj}}^{\text{EW+Int+QCD}} &= 2.934 \pm_{0.255}^{0.273} (\text{stat.}) \pm_{0.112}^{0.130} (\text{mod. syst.}) \pm_{0.118}^{0.121} (\text{exp. syst.}) \pm_{0.036}^{0.044} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{exp}, \xi_{j3}}^{\text{EW+Int+QCD}} &= 1.096 \pm_{0.144}^{0.158} (\text{stat.}) \pm_{0.061}^{0.076} (\text{mod. syst.}) \pm_{0.105}^{0.125} (\text{exp. syst.}) \pm_{0.013}^{0.018} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{exp}, m_T}^{\text{EW+Int+QCD}} &= 2.934 \pm_{0.259}^{0.278} (\text{stat.}) \pm_{0.089}^{0.100} (\text{mod. syst.}) \pm_{0.102}^{0.110} (\text{exp. syst.}) \pm_{0.036}^{0.043} (\text{lumi.}) \text{ fb}
\end{aligned}$$

Table 9.7: Breakdown of the uncertainty on the differential EW $W^\pm W^\pm jj$ cross-section measurement in the different m_{jj} truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.4	0.4	0.5	0.4	0.4	0.4
Muon calibration	0.5	0.5	0.5	0.5	0.5	0.5
Jet energy scale and resolution	1.4	6.5	2.6	5.4	3.9	6.0
E_T^{miss} scale and resolution	0.2	0.2	0.2	0.1	0.2	0.2
b -tagging inefficiency	0.8	0.8	0.8	0.7	0.6	0.5
Background, misid. leptons	5.0	4.8	1.5	1.4	5.1	1.3
Background, charge misrec.	1.9	1.1	0.7	0.4	0.4	0.5
Pileup modelling	0.4	0.3	0.1	0.6	0.2	0.2
Luminosity	1.9	2.1	1.9	1.9	1.9	1.9
Modelling						
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	4.3	3.4	1.5	1.2	3.7	6.6
EW $W^\pm W^\pm jj$, QCD corrections	1.3	2.4	2.1	2.2	2.7	1.4
EW $W^\pm W^\pm jj$, EW corrections	0.1	0.5	0.1	0.2	0.1	0.2
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.4	0.2	0.1	0.1	0.1	0.1
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	3.7	3.1	1.1	0.9	0.5	0.3
QCD $W^\pm W^\pm jj$, QCD corrections	0.7	2.4	0.9	1.1	0.6	0.5
Background, WZ scale, PDF & α_s	0.4	0.7	0.3	0.5	0.8	0.8
Background, WZ reweighting	1.2	3.9	1.6	2.0	1.3	0.5
Background, other	2.2	1.5	1.2	0.4	0.2	0.7
Model statistical	3.9	8.4	5.7	5.9	6.3	3.9
Experimental and modelling	9.6	14.0	7.7	9.2	10.5	10.2
Data statistical	12.3	37.0	24.7	32.3	26.3	31.2
Total	15.6	39.5	25.9	33.6	28.3	32.9

Observed results for EW signal:

$$\begin{aligned}
\sigma_{\text{obs}}^{\text{EW}} &= 2.878 \pm_{0.209}^{0.216} (\text{stat.}) \pm_{0.141}^{0.158} (\text{mod. syst.}) \pm_{0.109}^{0.109} (\text{exp. syst.}) \pm_{0.051}^{0.060} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{obs}, m_{\ell\ell}}^{\text{EW}} &= 2.859 \pm_{0.214}^{0.232} (\text{stat.}) \pm_{0.105}^{0.116} (\text{mod. syst.}) \pm_{0.083}^{0.093} (\text{exp. syst.}) \pm_{0.040}^{0.048} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{obs}, N_{\text{gap}J\text{ets}}}^{\text{EW}} &= 2.889 \pm_{0.238}^{0.250} (\text{stat.}) \pm_{0.198}^{0.221} (\text{mod. syst.}) \pm_{0.135}^{0.137} (\text{exp. syst.}) \pm_{0.060}^{0.047} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{obs}, m_{jj}}^{\text{EW}} &= 3.133 \pm_{0.256}^{0.272} (\text{stat.}) \pm_{0.134}^{0.149} (\text{mod. syst.}) \pm_{0.119}^{0.122} (\text{exp. syst.}) \pm_{0.045}^{0.052} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{obs}, \xi_{j3}}^{\text{EW}} &= 0.922 \pm_{0.130}^{0.143} (\text{stat.}) \pm_{0.082}^{0.098} (\text{mod. syst.}) \pm_{0.097}^{0.123} (\text{exp. syst.}) \pm_{0.025}^{0.013} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{obs}, m_T}^{\text{EW}} &= 2.835 \pm_{0.251}^{0.272} (\text{stat.}) \pm_{0.108}^{0.121} (\text{mod. syst.}) \pm_{0.084}^{0.094} (\text{exp. syst.}) \pm_{0.042}^{0.047} (\text{lumi.}) \text{ fb}
\end{aligned}$$

Observed results for EW+Int+QCD signal:

$$\begin{aligned}
\sigma_{\text{obs}}^{\text{EW+Int+QCD}} &= 3.346 \pm_{0.216}^{0.222} (\text{stat.}) \pm_{0.131}^{0.160} (\text{mod. syst.}) \pm_{0.126}^{0.118} (\text{exp. syst.}) \pm_{0.054}^{0.063} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{obs}, m_{\ell\ell}}^{\text{EW+Int+QCD}} &= 3.402 \pm_{0.224}^{0.240} (\text{stat.}) \pm_{0.098}^{0.103} (\text{mod. syst.}) \pm_{0.101}^{0.112} (\text{exp. syst.}) \pm_{0.042}^{0.055} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{obs}, N_{\text{gap}J\text{ets}}}^{\text{EW+Int+QCD}} &= 3.442 \pm_{0.253}^{0.263} (\text{stat.}) \pm_{0.202}^{0.213} (\text{mod. syst.}) \pm_{0.160}^{0.174} (\text{exp. syst.}) \pm_{0.070}^{0.031} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{obs}, m_{jj}}^{\text{EW+Int+QCD}} &= 3.605 \pm_{0.263}^{0.280} (\text{stat.}) \pm_{0.121}^{0.150} (\text{mod. syst.}) \pm_{0.128}^{0.125} (\text{exp. syst.}) \pm_{0.047}^{0.051} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{obs}, \xi_{j3}}^{\text{EW+Int+QCD}} &= 1.317 \pm_{0.149}^{0.161} (\text{stat.}) \pm_{0.070}^{0.083} (\text{mod. syst.}) \pm_{0.119}^{0.139} (\text{exp. syst.}) \pm_{0.022}^{0.022} (\text{lumi.}) \text{ fb} \\
\sigma_{\text{obs}, m_T}^{\text{EW+Int+QCD}} &= 3.382 \pm_{0.263}^{0.281} (\text{stat.}) \pm_{0.095}^{0.111} (\text{mod. syst.}) \pm_{0.105}^{0.113} (\text{exp. syst.}) \pm_{0.043}^{0.050} (\text{lumi.}) \text{ fb}
\end{aligned}$$

Table 9.8: Breakdown of the uncertainty on the differential EW $W^\pm W^\pm jj$ cross-section measurement in the different $m_{\ell\ell}$ truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.1	0.1	0.1	0.2	0.2	1.4
Muon calibration	0.5	0.5	0.5	0.5	0.6	1.1
Jet energy scale and resolution	3.0	2.2	2.0	2.0	3.0	2.6
E_T^{miss} scale and resolution	0.1	0.0	0.1	0.0	0.2	0.1
b -tagging inefficiency	0.7	0.6	0.7	0.7	0.8	1.0
Background, misid. leptons	3.5	3.7	4.5	3.3	1.2	3.0
Background, charge misrec.	1.7	0.9	1.3	0.9	0.9	0.7
Pileup modelling	0.7	0.5	0.1	0.0	0.2	0.0
Luminosity	1.9	1.8	1.9	2.0	2.0	2.3
Modelling						
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	1.7	0.9	0.9	0.3	1.1	1.7
EW $W^\pm W^\pm jj$, QCD corrections	5.9	5.2	3.5	2.0	4.0	4.7
EW $W^\pm W^\pm jj$, EW corrections	1.4	0.5	0.3	0.0	0.8	1.4
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.2	0.1	0.0	0.1	0.0	0.0
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	1.0	1.4	2.3	2.4	3.5	7.3
QCD $W^\pm W^\pm jj$, QCD corrections	0.1	0.1	0.4	0.3	0.2	0.0
Background, WZ scale, PDF & α_s	0.3	0.6	0.5	0.3	0.3	0.6
Background, WZ reweighting	2.1	2.3	1.9	1.2	1.3	1.2
Background, other	2.8	1.4	1.4	0.9	0.5	0.3
Model statistical	4.8	4.3	5.6	4.6	3.7	5.5
Experimental and modelling	10.3	9.0	9.3	7.4	7.9	11.8
Data statistical	18.9	18.1	23.2	19.7	17.7	19.9
Total	21.6	20.2	25.0	21.0	19.4	23.2

Table 9.9: Breakdown of the uncertainty on the differential EW $W^\pm W^\pm jj$ cross-section measurement in the different m_T truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.6	0.4	0.4	0.2	0.5	1.5
Muon calibration	0.5	1.0	0.6	0.8	0.6	1.1
Jet energy scale and resolution	4.2	6.7	2.1	4.5	1.7	2.7
E_T^{miss} scale and resolution	0.9	2.5	1.1	1.7	0.2	0.5
b -tagging inefficiency	0.7	0.8	0.7	0.8	0.7	1.0
Background, misid. leptons	5.4	7.6	2.0	3.1	1.5	2.4
Background, charge misrec.	1.6	1.8	1.0	1.6	0.5	0.6
Pileup modelling	0.4	0.6	1.0	1.0	0.4	0.1
Luminosity	1.9	1.9	1.9	2.0	1.9	2.3
Modelling						
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.7	1.3	0.4	0.7	0.5	1.4
EW $W^\pm W^\pm jj$, QCD corrections	4.9	4.1	4.6	2.4	1.6	4.1
EW $W^\pm W^\pm jj$, EW corrections	0.4	2.0	1.7	1.0	0.3	0.4
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.2	0.4	0.1	0.1	0.0	0.1
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	1.1	2.9	1.8	3.7	2.4	7.1
QCD $W^\pm W^\pm jj$, QCD corrections	0.4	0.7	0.4	0.5	0.2	0.1
Background, WZ scale, PDF & α_s	0.1	0.1	0.1	0.1	0.1	0.1
Background, WZ reweighting	3.1	3.3	1.2	1.5	0.8	1.2
Background, other	3.0	0.9	1.1	1.1	0.3	0.1
Model statistical	5.3	12.8	6.1	6.6	4.5	5.1
Experimental and modelling	11.5	18.4	9.3	10.9	6.4	11.1
Data statistical	21.3	59.3	27.0	32.1	17.0	20.0
Total	24.2	62.1	28.6	33.9	18.1	22.9

Table 9.10: Breakdown of the uncertainty on the differential inclusive $W^\pm W^\pm jj$ cross-section measurement in the different ξ_{j_3} truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma$, ZZ, top and Zjets.

Source	Impact [%]				
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$
Experimental					
Electron calibration	0.4	0.4	0.4	0.5	0.5
Muon calibration	0.5	0.5	0.5	0.5	0.4
Jet energy scale and resolution	7.3	10.2	9.6	11.4	20.7
E_T^{miss} scale and resolution	0.1	0.2	0.1	0.3	0.1
b -tagging inefficiency	1.3	0.7	0.9	0.9	0.9
Background, misid. leptons	8.5	5.8	3.1	4.8	7.4
Background, charge misrec.	2.5	1.1	0.8	1.7	3.4
Pileup modelling	0.9	1.4	1.1	1.7	3.4
Luminosity	1.8	1.8	1.8	1.8	1.6
Modelling					
$W^\pm W^\pm jj$ shower, scale, PDF & α_s	5.2	9.1	8.0	11.2	3.9
EW $W^\pm W^\pm jj$, QCD corrections	0.8	7.2	3.1	3.0	5.5
EW $W^\pm W^\pm jj$, EW corrections	1.1	1.2	0.3	0.6	0.7
QCD $W^\pm W^\pm jj$, QCD corrections	0.2	0.6	0.3	0.2	0.9
Background, WZ scale, PDF & α_s	0.7	0.8	0.4	0.2	0.6
Background, WZ reweighting	2.6	1.0	0.9	1.2	0.5
Background, other	2.8	0.9	0.5	2.8	2.1
Model statistical	5.6	8.4	6.2	7.2	7.8
Experimental and modelling	14.7	19.0	15.0	19.0	25.0
Data statistical	17.2	42.4	32.2	32.3	39.1
Total	22.6	46.5	35.6	37.6	46.5

Table 9.11: Breakdown of the uncertainty on the differential inclusive $W^\pm W^\pm \text{jj}$ cross-section measurement in the different $N_{gapJets}$ truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]	
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$
Experimental		
Electron calibration	0.4	0.5
Muon calibration	0.5	0.5
Jet energy scale and resolution	1.6	13.0
E_T^{miss} scale and resolution	0.2	0.1
b -tagging inefficiency	0.5	1.7
Background, misid. leptons	1.4	10.6
Background, charge misrec.	0.7	2.9
Pileup modelling	0.9	2.3
Luminosity	1.8	1.7
Modelling		
$W^\pm W^\pm \text{jj}$ shower, scale, PDF & α_s	2.1	3.9
EW $W^\pm W^\pm \text{jj}$, QCD corrections	6.2	7.0
EW $W^\pm W^\pm \text{jj}$, EW corrections	0.4	0.2
QCD $W^\pm W^\pm \text{jj}$, QCD corrections	0.0	0.1
Background, WZ scale, PDF & α_s	0.9	1.4
Background, WZ reweighting	0.4	4.4
Background, other	1.0	2.8
Model statistical	1.8	6.9
Experimental and modelling	7.6	21.1
Data statistical	7.7	21.5
Total	10.9	30.1

Table 9.12: Breakdown of the uncertainty on the differential inclusive $W^\pm W^\pm \text{jj}$ cross-section measurement in the different m_{jj} truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.4	0.4	0.5	0.4	0.4	0.4
Muon calibration	0.4	0.5	0.5	0.5	0.5	0.5
Jet energy scale and resolution	1.1	5.2	2.5	4.9	3.8	5.9
$E_{\text{T}}^{\text{miss}}$ scale and resolution	0.1	0.2	0.2	0.1	0.2	0.2
b -tagging inefficiency	0.7	0.7	0.7	0.6	0.6	0.5
Background, misid. leptons	4.4	4.2	1.4	1.3	4.9	1.2
Background, charge misrec.	1.6	1.0	0.6	0.1	0.2	0.2
Pileup modelling	0.3	0.3	0.2	0.6	0.2	0.2
Luminosity	1.6	1.8	1.8	1.8	1.8	1.8
Modelling						
$W^\pm W^\pm \text{jj}$ shower, scale, PDF & α_s	4.7	3.3	1.6	1.0	3.4	6.4
EW $W^\pm W^\pm \text{jj}$, QCD corrections	1.1	1.8	2.0	2.0	2.6	1.4
EW $W^\pm W^\pm \text{jj}$, EW corrections	0.1	0.4	0.1	0.2	0.1	0.2
QCD $W^\pm W^\pm \text{jj}$, QCD corrections	0.3	0.3	0.3	0.1	0.1	0.0
Background, WZ scale, PDF & α_s	0.3	0.5	0.2	0.5	0.7	0.8
Background, WZ reweighting	1.0	3.2	1.6	1.9	1.2	0.5
Background, other	1.8	1.3	1.1	0.4	0.2	0.7
Model statistical	3.3	7.0	5.3	5.6	6.0	3.8
Experimental and modelling	8.1	11.3	7.2	8.5	10.1	10.0
Data statistical	10.5	30.7	23.6	30.6	25.5	30.8
Total	13.3	32.7	24.7	31.7	27.4	32.4

Table 9.13: Breakdown of the uncertainty on the differential inclusive $W^\pm W^\pm \text{jj}$ cross-section measurement in the different $m_{\ell\ell}$ truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.4	0.4	0.1	0.4	0.5	1.1
Muon calibration	0.5	0.4	0.5	0.5	0.5	0.8
Jet energy scale and resolution	2.6	2.0	1.8	1.8	2.7	1.8
$E_{\text{T}}^{\text{miss}}$ scale and resolution	0.3	0.1	0.3	0.0	0.2	0.2
b -tagging inefficiency	0.7	0.6	0.6	0.7	0.7	0.8
Background, misid. leptons	3.7	4.0	4.6	3.6	2.0	3.1
Background, charge misrec.	1.7	1.0	1.5	1.1	1.1	1.1
Pileup modelling	0.6	0.4	0.1	0.1	0.0	0.1
Luminosity	1.8	1.7	1.8	1.8	1.8	1.8
Modelling						
$W^\pm W^\pm \text{jj}$ shower, scale, PDF & α_s	1.9	0.3	0.9	1.0	1.7	0.1
EW $W^\pm W^\pm \text{jj}$, QCD corrections	5.7	5.4	3.9	2.0	3.9	5.1
EW $W^\pm W^\pm \text{jj}$, EW corrections	1.0	0.1	0.0	0.0	0.0	0.0
QCD $W^\pm W^\pm \text{jj}$, QCD corrections	0.2	0.0	0.0	0.4	0.0	0.1
Background, WZ scale, PDF & α_s	0.0	0.6	0.1	0.0	0.0	0.1
Background, WZ reweighting	1.7	1.8	1.3	0.8	0.7	0.3
Background, other	2.9	0.5	1.5	1.0	0.2	0.2
Model statistical	4.6	4.0	5.1	4.3	3.3	4.3
Experimental and modelling	9.9	8.9	8.8	6.9	6.8	8.1
Data statistical	17.6	16.5	20.7	17.8	15.1	14.8
Total	20.2	18.7	22.5	19.0	16.6	16.9

Table 9.14: Breakdown of the uncertainty on the differential inclusive $W^\pm W^\pm \text{j}\text{j}$ cross-section measurement in the different m_T truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma\gamma$, ZZ , top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.6	0.3	0.4	0.2	0.5	1.2
Muon calibration	0.5	0.9	0.5	0.7	0.5	0.9
Jet energy scale and resolution	3.9	5.5	1.6	4.5	1.3	1.7
E_T^{miss} scale and resolution	0.9	2.4	1.0	1.5	0.1	0.3
b -tagging inefficiency	0.3	0.1	0.2	0.2	0.7	0.8
Background, misid. leptons	5.6	7.2	0.7	3.3	1.7	2.7
Background, charge misrec.	1.7	1.5	1.1	1.8	0.8	1.1
Pileup modelling	0.4	0.4	0.8	0.8	0.3	0.1
Luminosity	1.8	1.7	1.8	1.8	1.8	1.8
Modelling						
$W^\pm W^\pm \text{j}\text{j}$ shower, scale, PDF & α_s	1.0	2.5	1.0	1.2	1.0	0.7
EW $W^\pm W^\pm \text{j}\text{j}$, QCD corrections	5.2	3.6	4.3	2.7	1.5	4.8
EW $W^\pm W^\pm \text{j}\text{j}$, EW corrections	1.4	1.5	1.1	1.1	0.0	0.0
QCD $W^\pm W^\pm \text{j}\text{j}$, QCD corrections	0.3	0.4	0.3	0.4	0.4	0.1
Background, WZ scale, PDF & α_s	0.3	0.3	0.1	0.2	0.0	0.4
Background, WZ reweighting	2.4	2.3	0.8	0.8	0.5	0.3
Background, other	3.1	0.4	0.4	0.6	0.5	0.8
Model statistical	5.0	12.0	5.8	5.8	4.3	4.1
Experimental and modelling	11.2	17.2	8.6	9.5	5.7	7.8
Data statistical	19.6	52.8	24.6	27.0	15.3	15.1
Total	22.6	55.6	26.1	28.6	16.3	17.0

Chapter 10

Limit Setting on Dimension-Eight EFT Parameters

It is known that the Standard Model of particle physics is incomplete, as discussed in Section 2.3. When measuring it more precisely at higher energies, there will be a point in time when new physics phenomena start to be visible.

There are different approaches to search for new physics. One approach is to look directly for new on-shell particles e.g. in an invariant mass distribution, like e.g. in Ref. [135]. The mass needs to be within the detectable range. Another approach is the indirect search which is performed in this thesis. It is looked for deviating interactions of known particles in order to search for new particles whose on-shell energy is too large to be measured directly.

This indirect search is performed model independently to be sensitive to a broad class of new physics. With the used Effective Field Theory (EFT) [136–139] the following characteristics are met:

- include symmetry of the SM: Lorentz invariance and $SU(3)_C \times SU(2)_L \times U(1)_Y$,
- retrieve the SM in the low-energy limit,
- directly probe operators to have a hint which possible Beyond the Standard Model (BSM) physics might cause it and
- calculation of radiative corrections is possible to any order, for the BSM interactions as well as for the SM interactions.

In the EFT model new operators, which are products of fields, are added with a factor, called Wilson coefficient, to the Standard Model lagrangian. In the Standard Model all operators are of dimension-four in energy of the fields, except the quadratic term in the Higgs potential which is of dimension-two. BSM models of higher dimensional operators are tested. In a perturbative approach the lowest powers are dominant for low energies. There is only one operator with dimension-five which is responsible for generating Majorana masses for neutrinos. The next ones are dimension-six and -eight. It is assumed that the energy of new physics Λ is large compared to accessible energies. So, EFT is a low-energy approximation of new physics, where low means, that it is studied below Λ .

A discussion of how the anomalous quartic coupling has converged to be tested in the framework of Effective Field Theory today can be found e.g. in Ref. [63].

10.1 EFT Formalism

The expansion of the Standard Model in terms of effective fields can be written as:

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{f_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_j \frac{f_j^{(8)}}{\Lambda^4} \mathcal{O}_j^{(8)} + \dots, \quad (10.1)$$

where:

- $\mathcal{L}_{\text{SM}}$: is the Standard model lagrangian,
- f_i : dimensionless Wilson coefficient,
- $\mathcal{O}_i$: dimension 6 and 8 EFT operators,
- Λ : mass scale of new physics.

In this thesis limits are set on dimension-eight operators. In principle, all dimensions could include parts of new physics, but low dimension terms dominate at low energies. Additionally, only even-dimensional operators conserve both lepton and baryon numbers [136]. Dimension-six operators are neglected in this work. For example in Ref. [63] it is shown, that the impact of including the dimension-six effect in $W^\pm W^\pm jj$ EFT analysis has only a very small impact. But with more data it might be worth looking into dimension-six operators also with VBS processes as suggested in Ref. [140, 141].

The EFT formalism includes all particles below Λ . Here, Standard Model including the Higgs Boson is assumed. If there are more particles (fermions, bosons or extended Higgs sector) in a BSM prediction, then this model needs to be revised - the limits shown in this thesis are not correct in this case.

The energy of the process Λ should be larger than the highest data point. Otherwise, potential new physics are better studied by a resonance search or different splitting of the Lagrangian. The largest data point in this thesis is at $m_{\ell\ell} = 1081$ GeV. For $\Lambda \rightarrow \infty$ the EFT model converges towards the Standard Model prediction.

10.1.1 Studied Operators

As shown in Ref. [142], the dimension-eight operators affecting WWWW scattering are:

- M_0 , M_1 and M_7 , containing $D_\mu \phi$ and field strength tensors, defined in Section 2.2.2,
- S_0 and S_1 , containing just $D_\mu \phi$,
- T_0 , T_1 and T_2 , containing just field strength tensors

The S-operators act on the Higgs field while T-operators contain only field strength tensors. The M-operators contain both. The studied operators are defined as:

$$\mathcal{O}_{S,0} = \left[(D_\mu \phi)^+ D_\nu \phi \right] \left[(D^\mu \phi)^+ D^\nu \phi \right], \quad (10.2)$$

$$\mathcal{O}_{S,1} = \left[(D_\mu \phi)^+ D^\mu \phi \right] \left[(D_\nu \phi)^+ D^\nu \phi \right], \quad (10.3)$$

$$\mathcal{O}_{S,2} = \left[(D_\mu \phi)^+ D_\nu \phi \right] \left[(D^\nu \phi)^+ D^\mu \phi \right], \quad (10.4)$$

$$\mathcal{O}_{M,0} = \text{Tr} \left[\hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \right] \left[(D_\beta \phi)^+ D^\beta \phi \right], \quad (10.5)$$

$$\mathcal{O}_{M,1} = \text{Tr} \left[\hat{W}_{\mu\nu} \hat{W}^{\nu\beta} \right] \left[(D_\beta \phi)^+ D^\mu \phi \right], \quad (10.6)$$

$$\mathcal{O}_{M,7} = \left[(D_\mu \phi)^+ \hat{W}_{\beta\nu} \hat{W}^{\beta\mu} D^\nu \phi \right], \quad (10.7)$$

$$\mathcal{O}_{T,0} = \text{Tr} \left[\hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \right] \text{Tr} \left[\hat{W}_{\alpha\beta} \hat{W}^{\alpha\beta} \right], \quad (10.8)$$

$$\mathcal{O}_{T,1} = \text{Tr} \left[\hat{W}_{\alpha\nu} \hat{W}^{\mu\beta} \right] \text{Tr} \left[\hat{W}_{\mu\beta} \hat{W}^{\alpha\nu} \right], \quad (10.9)$$

$$\mathcal{O}_{T,2} = \text{Tr} \left[\hat{W}_{\alpha\mu} \hat{W}^{\mu\beta} \right] \text{Tr} \left[\hat{W}_{\beta\nu} \hat{W}^{\nu\alpha} \right], \quad (10.10)$$

where $\mathcal{O}_{S,2}$ is the hermitian conjugate of $\mathcal{O}_{S,0}$ and they are thus scaled with the same Wilson coefficient $\frac{f_{S,02}}{\Lambda^4} := \frac{f_{S,2}}{\Lambda^4} = \frac{f_{S,0}}{\Lambda^4}$ as explained in Ref. [63].

10.1.2 Used MC Simulation

The EFT MC samples defined in Ref. [63] are used. The matrix element of a subprocess affected by EFT is:

$$\mathcal{M} = \left| A_{SM} + \sum_i c_i A_i \right|, \quad (10.11)$$

where:

- A_{SM} : SM amplitude of $W^\pm W^\pm jj$ or $WZjj$,
- A_i : amplitude of the dimension-eight operator,
- $c_j = \frac{f_j}{\Lambda^4}$: quotient of Wilson coefficient f_i and the energy scale of the new process Λ^4 .

In the end, only the squared matrix element is measurable¹:

$$|\mathcal{M}|^2 = |A_{SM} + \sum_i c_i A_i|^2 = |A_{SM}|^2 + \sum_i 2c_i \text{Re}(A_{SM} A_i) + \sum_i c_i^2 |A_i|^2 + \sum_{ij, i \neq j} c_i c_j 2\text{Re}(A_i A_j). \quad (10.12)$$

The total amplitude can be split into four contributions:

- the SM contribution $|A_{SM}|^2$,
- the interference between SM and i-th EFT operator $2\text{Re}(A_{SM} A_i)$, multiplied by the reduced Wilson coefficient c_i ,
- the EFT contribution squared $|A_i|^2$, multiplied with the corresponding reduced Wilson coefficient squared and
- the interference between two EFT contributions $2\text{Re}(A_i A_j)$, multiplied with the reduced Wilson coefficients c_i and c_j .

For each of the four contributions, dedicated Madgraph samples are used. For each operator there is the squared sample and one interference sample with the SM. With these three samples 1D limits can be set where always only one Wilson coefficient is different from zero. The last contribution is only needed when more than one coefficient is varied at once. They are generated for operators within one class where 2D limits are of interest.

The used EFT samples are listed in Table A.4. They are generated with Madgraph 2.6.5 [143] where phenomenological models, described with a lagrangian can be easily implemented. Amplitude decomposition as described above is used to calculate the EFT predictions for different parameter points. The validity of the decomposition method has been validated in Ref. [144].

The EFT samples are generated to have a resonant W and a resonant W/Z boson. Two bosons should decay leptonically - it does not need to be the resonant one if there are more than two heavy vector bosons involved in the event.

10.2 Unitarity Bounds

In vector boson scattering according to the Standard Model there is fine-tuned cancellation of different contributions, as described in Section 2.2.3, which makes the predicted cross-section

¹Origin of "Re" part:

$$\begin{aligned} & |b_1 + b_2|^2 \\ &= |a_1 e^{i\phi_1} + a_2 e^{i\phi_2}|^2 \\ &= (a_1 e^{i\phi_1} + a_2 e^{i\phi_2})^* \cdot (a_1 e^{i\phi_1} + a_2 e^{i\phi_2}) \\ &= a_1^2 + a_2^2 + 2a_1 a_2 e^{-i\phi_1} e^{i\phi_2} \\ &= |b_1|^2 + |b_2|^2 + 2\text{Re}(b_1^* b_2) \end{aligned}$$

finite also for large energies. This means that the SM fulfils unitarity constraints. For EFT expansions this is usually not the case and they can break unitarity at high energies.

The 1D and 2D unitarity bounds are taken from Ref. [145] from the eigenvalues in the partial wave expansion of the scattering amplitude.

For example in Equation 19 of Ref. [145] the eigenvalues are shown for S-operators. These have to have an absolute value equal to 1 or smaller than 1. Wilson coefficients which are not part of the 1D or 2D limits are set to 0.

The condition for the first eigenvalue is:

$$\left| \frac{s^2}{96\pi} \left(\frac{3f_{S,0} + f_{S,1} + f_{S,2}}{\Lambda^4} \right) \right| \leq 1, \quad (10.13)$$

where $\sqrt{s}$ is the centre-of-mass energy, set to be the clipping energy, defined in Section 10.2.1.

This can be rewritten since we use $\frac{f_{S,02}}{\Lambda^4} := \frac{f_{S,2}}{\Lambda^4} = \frac{f_{S,0}}{\Lambda^4}$:

$$\left| \frac{4f_{S,02} + f_{S,1}}{\Lambda^4} \right| \leq \frac{96\pi}{s^2}. \quad (10.14)$$

This condition is used in the 1D and 2D unitarity constraints for S-operators. Eigenvalues for M and T operators are taken from equations 20, 21 and 22 from Ref. [145].

The 2D unitarity bounds are polygons because there are at least two linear independent formulas for each shown operator pair.

There are other criteria, besides unitarization violation, which could be used to further constrain the EFT parameter space from a theoretical point of view. There are e.g. causality and positivity criteria [146] which could be considered in future EFT analysis.

10.2.1 Clipping

Following the recommendation in Ref. [147] a clipping mechanism is applied to account for unitarization violation. Different clipping energies are scanned and for each value E_c the EFT events are vetoed with $m_{WV} > E_c$.

The following clipping energy values are chosen: 0.6, 0.7, 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 3.5, 5.0 TeV and no clipping.

These are chosen such that the point can be determined where the derived limits are better than the unitarity constraints. Thus to find the energy where the experimental data can exclude more EFT parameter values than can be from a theoretical unitarity point of view.

For lower values direct resonance searches could be better tailored and more sensitive.

For clipping the typical energy of a process is needed to compare with E_c . If there is a dominant heavy resonance in the diagram, then the typical energy should be the invariant mass of that resonance. There are many different diagrams taking part in the EW and QCD process - sometimes a single W, sometimes the combination of two W have the dominant energy. For this paper m_{WW} and m_{WZ} are used to calculate the energy of the process.

10.3 Fitting Setup

The same fitting setup as defined in Section 8.1 is used, but a different signal definition is tested. There is no free-floating parameter for $W^\pm W^\pm jj$. The Standard Model prediction is assumed during limit setting as also done in other EFT limit setting analyses [144]. Instead, one, for 1D limit setting, or two, for 2D limit setting, operators and their contributions are included in the fits as signal to be tested.

The test statistic defined in Section 7.6.2 is used with the corresponding asymptotic formula shown in Section 7.6.3.2 to calculate the p-value for the 95% confidence level intervals. In Appendix D.1 it is shown that toy-driven estimated limits are similar to the asymptotic limits. Therefore the asymptotic formula is used to save computational time.

A dedicated EW $W^\pm W^\pm jj$ sample is used to be compatible with the EFT samples. They use a different renormalisation and factorisation scale than the nominal signal sample used for

cross-section measurements. This difference is part of the scale uncertainty of EFT samples as described in Section 6.2.1.

10.4 Binning Optimisation

The low- m_{jj} and WZ control regions are used in addition to the signal region as in the other fits to constrain the backgrounds. The $m_{\ell\ell}$ distribution is used as it is sensitive to EFT in the last bins. Another option would be the transverse mass m_T which would give similar results [148]. A potential improvement of this would be to do a two-dimensional fit in $m_{jj} \times m_{\ell\ell}$ or $m_T \times m_{jj}$ to be able to determine the SM cross-section during EFT limit setting with the help of the m_{jj} shape. The $m_{\ell\ell}$ binning in the signal region needs to be optimised to get the best limits from expected data. It is optimised for unclipped limits which benefit from a fine binning at large $m_{\ell\ell}$ values. For low clipping values also the published unfolded distributions could be used in a potential combination of different VBS EFT analyses. The binning is optimised in a two-step procedure:

1. Merge bins starting from high $m_{\ell\ell}$ until at least 10 (5, 3, 2 or 1) Standard Model events are expected in each bin.
2. Discard bin edges which increase the significance by less than 0.1σ considering only statistical uncertainties.

If there are less than three observed events in a bin, then the asymptotic formula eventually breaks down and computational time expensive toys are needed to confirm that asymptotic limits are still correct.

Bins are merged to make the limit setting computational less complex without losing too much information.

Using the above algorithm the following binning was determined, see Table 10.1. The "at least 1 event" binning gets further optimised. It is checked that the last bin contains at least one raw MC event of each background. This is only the case with the last bin edge at 975 GeV. An exponential falling tail is used to have not too many bins, but also have some sensitive bins for different clipping values in the 'tail 13, 2.6, 1.3 events' binning.

In the end, it turned out, that the exponential tail is too steeply falling for low clipping values. For future combinations at low clipping values, it might be worth using the unfolded m_T distribution to get even better limits.

Table 10.1: Binning after the optimisation for at least 10 to 1 background events in each bin.

Binning requirement	Binning in $m_{\ell\ell}$ [GeV]
at least 10 events	[20., 375., 425., 550., ∞]
at least 5 events	[20., 375., 425., 475., 550., 675., ∞]
at least 3 events	[20., 450., 500., 550., 625., 750., ∞]
at least 2 events	[20., 475., 500., 550., 575., 625., 725., 825., ∞]
at least 1 events	[20., 550., 575., 625., 700., 750., 800., 975., ∞]
tail 13, 2.6, 1.3 events	[20., 250., 500., 750., 975., ∞]

For limits with only statistical uncertainties these binnings are also compared with the 3σ and 5σ binning considered in LH-based unfolding. The 5σ binning is used there in the end to avoid negative expected yields in the observed unfolded distributions due to large anti-correlations from large migrations. The bin edges are shown in Table 10.2.

The EFT-SM interference term is not treated correctly for expected limits in the binning optimisation. The cross-section of the interference term is always considered positive, while in reality it is negative for some operators. This results in artificially better limits, but the

Table 10.2: Binning after the optimisation for at least 5σ and at least 3σ as explained in Section 9.2.

Binning requirement	Binning in $m_{\ell\ell}$ [GeV]
5σ binning	[20., 80., 130., 170., 220., 320., ∞]
3σ binning	[20., 80., 100., 120., 140., 160., 180., 200., 240., 300., 370., ∞]

trend is correct because the quadratic term is still dominant. For the choice of the binning only the trend, i.e. which binning is better in direct comparison, is important.

Table 10.3 shows expected limits for various $m_{\ell\ell}$ binning choices calculated with the asymptotic formula with only statistical uncertainties considered and without clipping. The binning version with 13, 2.6, 1.3 events in the last bins is chosen as a compromise between more stringent limits and reliable background modelling in the last bin.

Table 10.3: Limits on the Wilson coefficients for different binning choices without clipping with only statistical uncertainties.

Coefficient	5 σ binning [TeV ⁻⁴]		3 σ binning [TeV ⁻⁴]		at least 10 events [TeV ⁻⁴]		at least 5 events [TeV ⁻⁴]		at least 3 events [TeV ⁻⁴]		at least 2 events [TeV ⁻⁴]		tail 13,2,6,1,3 events [TeV ⁻⁴]	
f_{M0}/Λ^4	-6.67	6.65	-6.27	6.26	-5.19	5.19	-4.58	4.57	-4.42	4.41	-4.12	4.12	-3.97	3.97
f_{M1}/Λ^4	-10.07	9.97	-9.51	9.42	-8.11	8.05	-7.28	7.22	-7.10	7.05	-6.71	6.66	-6.59	6.54
f_{M7}/Λ^4	-14.83	14.71	-13.98	13.87	-11.75	11.67	-10.47	10.41	-10.16	10.11	-9.54	9.49	-9.28	9.24
f_{S02}/Λ^4	-8.11	8.02	-7.65	7.56	-6.45	6.40	-5.79	5.75	-5.64	5.60	-5.34	5.30	-5.25	5.22
f_{S1}/Λ^4	-32.45	32.18	-30.58	30.34	-25.82	25.67	-23.10	22.97	-22.51	22.39	-21.28	21.18	-20.95	20.85
f_{T0}/Λ^4	-0.67	0.66	-0.62	0.62	-0.51	0.50	-0.44	0.44	-0.42	0.42	-0.39	0.39	-0.37	0.37
f_{T1}/Λ^4	-0.32	0.30	-0.30	0.28	-0.25	0.23	-0.22	0.20	-0.21	0.20	-0.19	0.18	-0.18	0.17
f_{T2}/Λ^4	-1.06	0.92	-1.01	0.87	-0.87	0.77	-0.79	0.69	-0.77	0.67	-0.72	0.64	-0.71	0.63

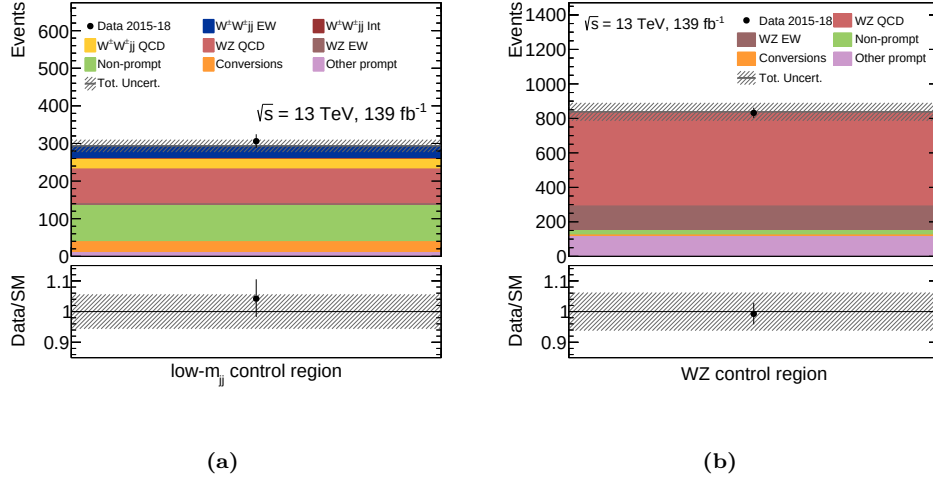


Figure 10.1: Post-fit distributions with observed data in low- m_{jj} control region (a) and in WZ control region (b). The hatched band represents the total model uncertainty, i.e. statistical and systematic uncertainties added in quadrature.

10.5 Handling of Uncertainties

A complete list of included experimental uncertainties can be found in Section 6.5 in Tables 6.1 to 6.2. The background modelling and statistical modelling uncertainties, due to the limited number of MC events, are listed in Table 6.13, the signal uncertainties for 1D limits are in Table 6.14 and for 2D limits in Table 6.15.

Table 6.16 lists the included theory uncertainties of $W^\pm W^\pm jj$ and EFT and their normalisation. It also lists which theory uncertainties are normalised to nominal on truth level. Only QCD $W^\pm Z jj$ is normalised to nominal on truth-level in the WZ control region. For the EFT operators there is also a free-floating Wilson coefficient in the fit. But for them we are not interested in the total cross-section, but the effect of the Wilson coefficient value. Hence they are not normalised.

10.6 Expected Limits

In this section expected limits are presented. For this, the expected QCD $W^\pm Z jj$ normalisation strength μ_{WZ} is first determined. Afterwards, control plots are shown for a representative variable. The final 1D and 2D limits are shown together with observed limits in Section 10.7 in Figure 10.7 for 1D limits and in Figure 10.16 and 10.17 for 2D limits.

A fit with only control regions is performed to derive μ_{WZ} for expected limits. Only the low- m_{jj} control region and WZ control region are included in the fit to observed data, see Figure 10.1.

A normalisation strength of QCD $W^\pm Z jj$ $\mu_{WZ} = 0.683$ is found. This value is used in the generation of Asimov data for the following expected limits.

Three different uncertainty configurations are considered to see how the different categories affect the final limits:

stat. only which contains only the EFT strength and the QCD $W^\pm Z jj$ normalisation strength as free-floating normalisation factors,

stat. theo. only which additionally includes modelling uncertainties of signal and backgrounds and

full which contains all uncertainties.

Table 10.4 shows the expected limits for the three configurations without any clipping.

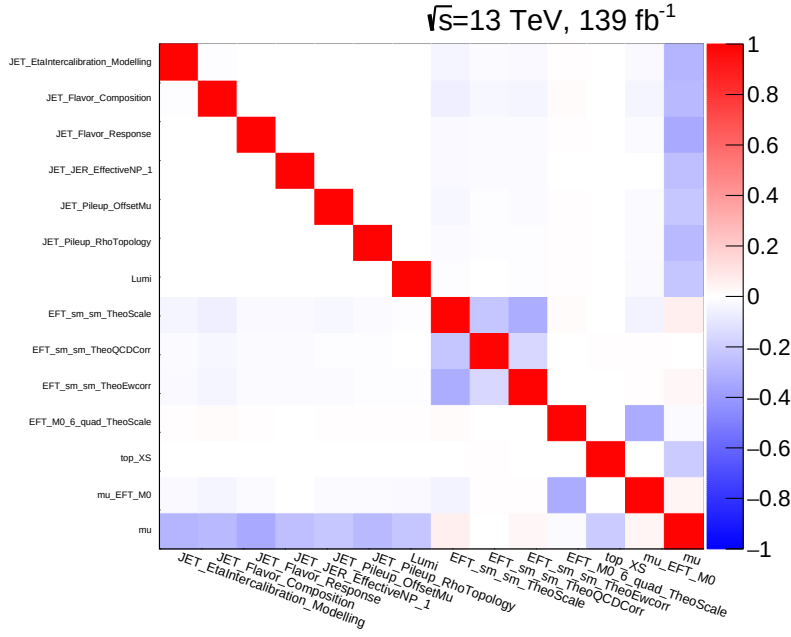


Figure 10.2: Correlation of nuisance parameters for best fit for coefficient f_{M0}/Λ^4 with Asimov data without clipping.

The expected limits for the three categories for all scanned clipping values are shown in Table D.4 and are later presented in Figure 10.7 together with the observed limits.

In Tables D.3 and D.2 the expected stat. only limits are shown for the case where the normalisation of EW $W^\pm W^\pm jj$ is allowed to float. These can be compared with Tables D.4 and 10.5, respectively. In all the other limit setting results this normalisation factor is fixed to 1. It might make sense to let it float to disentangle potential EFT effects from mismodelling of total EW $W^\pm W^\pm jj$ SM cross-section for dedicated studies. There is a significant difference for low clipping values while for high clipping values the expected limits do not change much.

For high clipping values the expected results will exclude Wilson coefficient strength which are already excluded by the violation of the unitarity bound. The clipping energies at which the expected limits cross the unitarity bound are shown in Table 10.5.

The pull plots of the 15 strongest pulled nuisance parameters are shown in Figure 10.2 for coefficient f_{M0}/Λ^4 without clipping. The complete list of figures for all coefficients without clipping can be found in Figure D.1. The scale uncertainty of the quadratic EFT term is always pulled the most in both upper and lower expected limits. But the pull is still well below 1σ indicating that the statistical uncertainty is the dominant uncertainty of the limits.

10.6.1 Detailed Information for Operator M0 without Clipping

As a representative example control plots and tables are shown for the M0 operator in this section. In Figure 10.3 and Table D.5 the expected pre-fit distributions are shown. There are in total 1.3 events predicted by the Standard Model in the last bin in the signal region. The dominant contributions are EW $W^\pm W^\pm jj$ and non-prompt background. These are the dominant contributions also in the second last bin with 2.6 predicted events. In the other bins there are many more predicted events. For the first two bins QCD $W^\pm Zjj$ becomes one of the dominant backgrounds. Figure 10.4 and Tables D.6, D.7 contain the post-fit distributions at the upper and lower limit bound without clipping. The last bin provides the most statistical power to restrict the EFT operators. The EFT prediction is highest there, while the quadratic

Table 10.4: Stat. only, stat. theo. unc only and full systematics expected limits on the Wilson coefficients without clipping calculated with the asymptotic formula. In each column the lower and upper limit is shown.

Coefficient	stat. only [TeV ⁻⁴]		stat., theo. unc. only [TeV ⁻⁴]		all unc. [TeV ⁻⁴]	
f_{M0}/Λ^4	-3.76	3.71	-3.86	3.81	-3.89	3.84
f_{M1}/Λ^4	-6.01	6.37	-6.20	6.57	-6.27	6.63
f_{M7}/Λ^4	-8.91	8.43	-9.18	8.68	-9.27	8.77
f_{S02}/Λ^4	-5.30	5.45	-5.46	5.61	-5.53	5.66
f_{S1}/Λ^4	-21.02	21.50	-21.66	22.12	-22.01	22.46
f_{T0}/Λ^4	-0.32	0.33	-0.33	0.34	-0.34	0.34
f_{T1}/Λ^4	-0.15	0.17	-0.16	0.17	-0.16	0.17
f_{T2}/Λ^4	-0.53	0.67	-0.56	0.70	-0.56	0.70

Table 10.5: Expected limits on the Wilson coefficients for all coefficients for the clipping value at the unitarity bound for different uncertainty sets calculated with asymptotic formula. "—" means that no crossing with the unitarity bound was found in the scanned region above 600 GeV.

Coefficient	fit type	lower limit		upper limit	
		clipping energy [TeV]	limit [TeV ⁻⁴]	clipping energy [TeV]	limit [TeV ⁻⁴]
f_{M0}/Λ^4	statOnly	1.01	-39.21	1.08	29.98
	statTheoOnly	0.91	-58.80	1.02	37.49
	full	0.89	-64.01	1.01	39.86
f_{M1}/Λ^4	statOnly	1.66	-21.66	1.57	27.28
	statTheoOnly	1.62	-23.91	1.54	29.36
	full	1.59	-25.48	1.52	31.02
f_{M7}/Λ^4	statOnly	1.85	-28.02	1.96	22.28
	statTheoOnly	1.81	-30.78	1.88	26.07
	full	1.77	-33.28	1.83	29.10
f_{S02}/Λ^4	statOnly	0.89	-59.51	0.79	96.28
	statTheoOnly	0.81	-88.78	0.75	116.92
	full	0.79	-94.40	0.74	122.48
f_{S1}/Λ^4	statOnly	—	—	—	—
	statTheoOnly	—	—	—	—
	full	—	—	—	—
f_{T0}/Λ^4	statOnly	1.30	-2.63	1.22	3.42
	statTheoOnly	1.26	-2.99	1.15	4.29
	full	1.24	-3.24	1.11	4.90
f_{T1}/Λ^4	statOnly	2.66	-0.30	2.49	0.39
	statTheoOnly	2.63	-0.32	2.45	0.42
	full	2.61	-0.32	2.42	0.44
f_{T2}/Λ^4	statOnly	1.85	-1.99	1.34	7.15
	statTheoOnly	1.77	-2.38	1.24	9.75
	full	1.73	-2.60	1.23	10.26

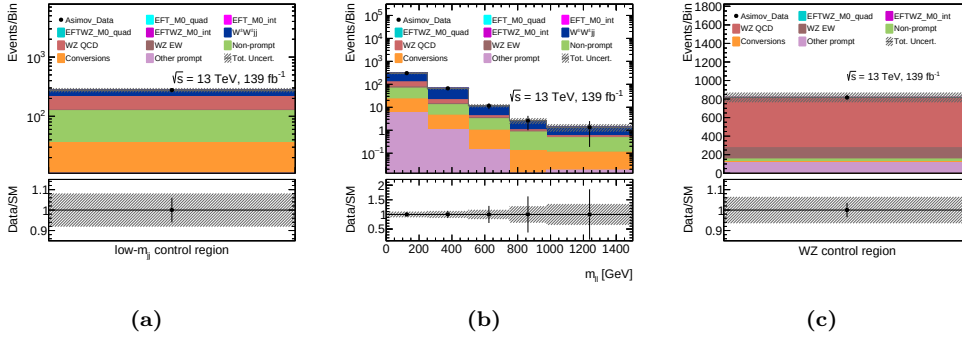


Figure 10.3: Pre-fit distributions: low- m_{jj} control region (a), $m_{\ell\ell}$ in signal region (b) and WZ control region (c). The hatched band represents the total model uncertainty, i.e. statistical and systematic uncertainties added in quadrature. All EFT parameters are set to zero.

contribution is much larger than the interference contribution. Furthermore, contributions from EFT effects of $W^\pm W^\pm jj$ are larger than the contribution from EFT effects of WZjj in the signal region. In the WZ control region contributions from EFT effects of WZjj are larger but have a comparable small impact on the derived limits. Effects of EFT $W^\pm W^\pm jj$ in WZ control region are predicting less than 0.01 events for the shown upper and lower limits. The correlation histogram does not show large (anti-)correlations in Figure 10.2 for the best fit. Like for cross-section measurements the QCD $W^\pm Zjj$ normalisation strength μ_{WZ} is mostly anticorrelated with jet systematics. The scale uncertainty affects the limits the most and is strongest anti correlated with the EFT strength. For better unclipped limits, after reducing the statistical uncertainty by increasing the luminosity or combining different channels, the next thing to do is to improve the scale uncertainty of the EFT samples by including higher orders. For clipped limits the scale and NLO correction uncertainties are most pulled and most correlated. These systematics need to be addressed to improve the limits with increased luminosity. The up and down variations of the nuisance parameter with the largest pull are shown in Figure 10.6.

10.6.2 Two-Dimensional Limits

In this section 2D limits are presented where two Wilson coefficients are allowed to be different from zero at the same time. The interference term between these two operators is included. Figure 10.16 shows the expected exclusion limits calculated with asymptotic formula without clipping. The results with clipping at 1.5 TeV is shown in Figure 10.17 The diagonal shape of the ellipses indicates (anti-)correlation between the expected numbers of events corresponding to the two respective operators. The expected yields of M0 vs. M1 and M1 vs. M7 are anticorrelated, while all other shown combinations are correlated.

The yellow and green band are not symmetric around the expected limit, because the dominant quadratic term let the yields scale quadratically with the Wilson coefficients making the outer bands smaller.

10.7 Observed Limits

Table 10.6 shows the observed limits without any clipping, with and without systematic uncertainties included. The limits are a bit less stringent compared to the expected ones because of more observed than expected events in the last two bins as shown in the pre-fit Table D.5. The observed limits are more stringent for included systematic uncertainties which could seem counterintuitive. This is caused by the pull of the scale uncertainty and NLO EW correction nuisance parameters of EW $W^\pm W^\pm jj$ (Figure 10.8). They increase the total expected yield of the SM processes. There are thus smaller Wilson coefficient values needed to reach the upper and lower limit in the case with full systematics. However the

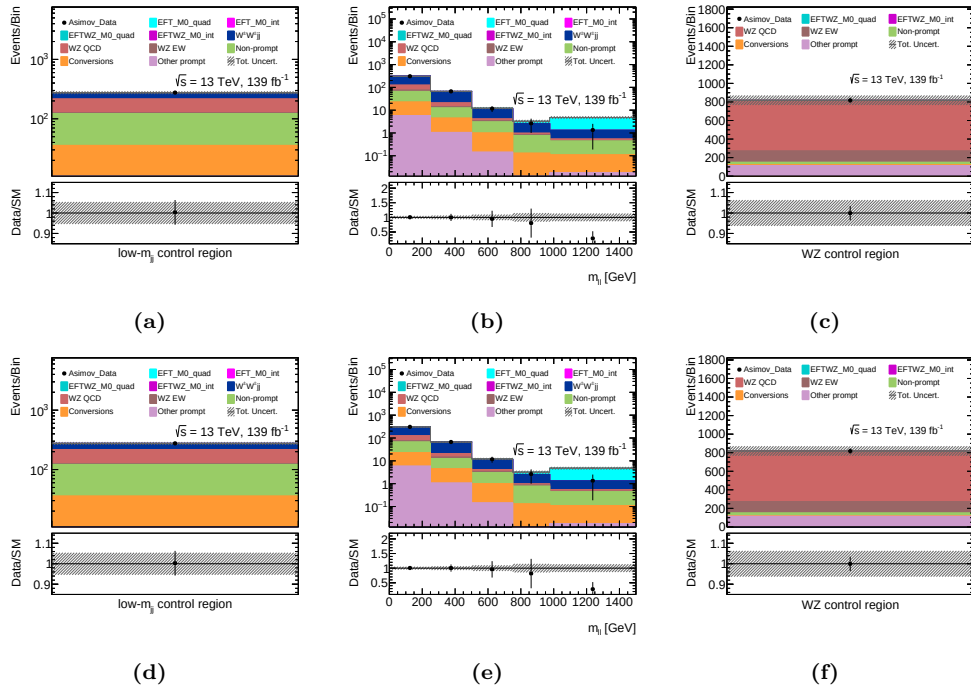


Figure 10.4: Post-fit distributions for (a-b) upper and (c-d) lower limit of M0 operator without clipping: low- m_{jj} control region (left), $m_{\ell\ell}$ in signal region (middle) and WZ control region (right). The hatched error band around the model prediction represents the total uncertainty of the model taking into account correlations between the nuisance parameters. Negative EFT interferences are subtracted from the quadratic EFT contribution in the histograms.

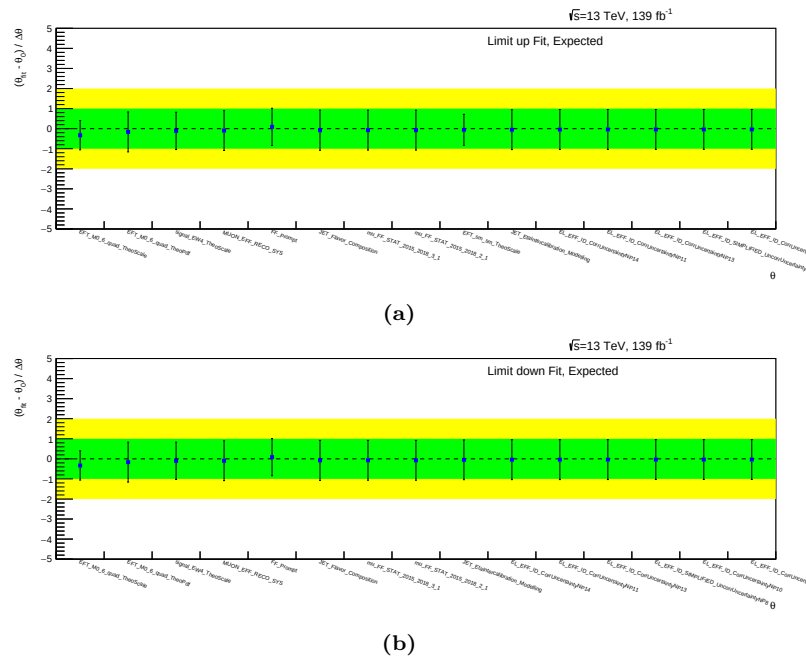


Figure 10.5: Most pulled nuisance parameters for (a) upper and (b) lower expected limit for coefficient f_{M0}/Λ^4 without clipping.

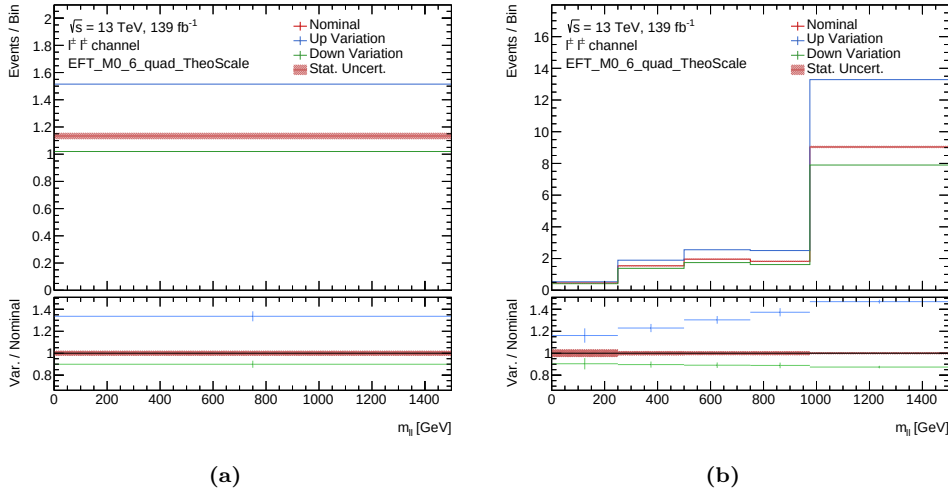


Figure 10.6: Pre-fit up and down variation of the scale uncertainty of the quadratic term in the (a) low- m_{jj} control region and (b) signal region for operator M0 without clipping.

observed limits with full systematics are still less stringent than the expected limits with full systematics.

Observed and expected limits derived for different clipping values with the full set of uncertainties are presented in Figure 10.7. With lower clipping values the limits get less stringent because of fewer predicted EFT events. Additionally, the bin with the main fraction of EFT events changes with the clipping value. Without clipping the last bin is most populated. For clipping around 700 GeV the first two bins are most populated as later shown for operator M0 in Table D.11. Since there is an up fluctuation observed in the second bin (see e.g. Table D.5) it is possible that the best fit includes so much EFT contribution such that the SM is excluded in comparison. For clipping energies around 1500 GeV this second bin becomes dominant. Thus, making both up or down variations of the Wilson coefficient more likely than the SM prediction. Because of the dominant quadratic term both up and down fluctuation will fill the gap between the expected background in the second bin and the observed data. For very low clipping energies the SM gets excluded at 95% confidence level. The observed limits for all scanned clipping values are shown in Table D.8 and for clipping values with additional SM exclusion in Table D.9. For high clipping energies the stat only limits are less stringent than the full systematics observed limits as previously discussed for the unclipped case. A dedicated EW $W^\pm W^\pm jj$ signal normalisation strength parameter, or taking its strength from the total cross-section measurement could change this unintuitive behaviour for high clipping values by improving the stat only limits.

For high clipping values the observed results will exclude Wilson coefficient strength which are already excluded by the violation of the unitarity bound. The clipping energies at which the observed limits cross the unitarity bound are shown in Table 10.7. For the operators S02, S1 and T2 no crossing is observed above 600 GeV. For lower clipping values dedicated resonance searches, e.g. Ref. [135], are better suited as discussed in Ref. [149]. The cited crossings are between 740 GeV for operator M0 and 2.5 TeV for operator T1.

Table 10.8 and Table 10.9 show the local and global significance of excluding the SM for different clipping energies. For the different clipping energies the EFT is dominant in one of the last four bins. The freedom, that any of these four bins could be affected by fluctuations is considered in the calculation of the global significance, as described in Section 9.7.1. The global significance of excluding the Standard Model is below 2σ for all operators and all clipping energies for the limits including all systematic uncertainties. No significant excess is found.

Table 10.6: Stat only and full systematics observed limits on the Wilson coefficients without clipping calculated with asymptotic formula. In each column the lower and upper limit is shown.

Coefficient	stat. only [TeV ⁻⁴]		stat., theo. unc. only [TeV ⁻⁴]		all unc. [TeV ⁻⁴]	
f_{M0}/Λ^4	-4.36	4.59	-4.13	4.14	-4.13	4.14
f_{M1}/Λ^4	-7.86	7.60	-6.75	7.00	-6.76	7.01
f_{M7}/Λ^4	-10.51	10.73	-9.72	9.49	-9.75	9.50
f_{S02}/Λ^4	-6.79	6.47	-5.88	5.93	-5.89	5.94
f_{S1}/Λ^4	-26.81	25.46	-23.35	23.39	-23.54	23.58
f_{T0}/Λ^4	-0.39	0.37	-0.36	0.36	-0.36	0.36
f_{T1}/Λ^4	-0.20	0.18	-0.17	0.19	-0.17	0.19
f_{T2}/Λ^4	-0.77	0.73	-0.63	0.74	-0.63	0.74

Table 10.7: Observed limits on the Wilson coefficients for all Operators for the clipping value at the unitarity bound for different uncertainty sets calculated with asymptotic formula. "–" means that no crossing with the unitarity bound was found in the scanned region above 600 GeV. The effects of WZ EFT got included in this table. WZ EFT-SM interference of M7 is still missing.

Coefficient	fit type	lower limit		upper limit	
		clipping energy [TeV]	limit [TeV ⁻⁴]	clipping energy [TeV]	limit [TeV ⁻⁴]
f_{M0}/Λ^4	statOnly	0.76	-124.29	0.79	104.02
	statTheoOnly	0.74	-135.29	0.78	112.63
	full	0.74	-139.75	0.77	117.45
f_{M1}/Λ^4	statOnly	1.28	-61.74	1.26	64.30
	statTheoOnly	1.45	-37.10	1.36	48.24
	full	1.39	-44.58	1.32	54.00
f_{M7}/Λ^4	statOnly	1.62	-47.35	1.55	56.85
	statTheoOnly	1.74	-35.63	1.71	38.24
	full	1.70	-38.97	1.67	41.84
f_{S02}/Λ^4	statOnly	–	–	–	–
	statTheoOnly	–	–	–	–
	full	–	–	–	–
f_{S1}/Λ^4	statOnly	–	–	–	–
	statTheoOnly	–	–	–	–
	full	–	–	–	–
f_{T0}/Λ^4	statOnly	0.90	-11.34	0.88	12.75
	statTheoOnly	1.03	-6.68	0.91	10.90
	full	1.00	-7.40	0.88	12.41
f_{T1}/Λ^4	statOnly	2.24	-0.59	2.50	0.39
	statTheoOnly	2.51	-0.38	2.37	0.47
	full	2.50	-0.38	2.36	0.49
f_{T2}/Λ^4	statOnly	1.32	-7.74	2.29	0.85
	statTheoOnly	–	–	–	–
	full	–	–	–	–

Table 10.8: Observed local SM exclusion significance for all Operators for different clipping values and different uncertainty sets with asymptotic formula.

Coefficient	fit type	Clipping value [GeV]										
		600	700	1000	1200	1500	2000	2500	3000	3500	5000	None
f_{M0}/Λ^4	statOnly	4.62	4.54	3.46	2.73	1.98	1.36	1.07	0.93	0.86	0.80	0.79
	statTheoOnly	2.32	2.20	0.98	0.50	0.24	0.18	0.17	0.18	0.18	0.18	0.18
	full	2.25	2.16	0.99	0.51	0.23	0.17	0.16	0.16	0.16	0.16	0.16
f_{M1}/Λ^4	statOnly	4.59	4.50	3.57	2.98	2.32	1.67	1.35	1.18	1.08	0.97	0.96
	statTheoOnly	2.27	2.27	1.25	0.76	0.40	0.24	0.20	0.18	0.18	0.18	0.18
	full	2.19	2.19	1.23	0.76	0.39	0.22	0.18	0.16	0.16	0.15	0.16
f_{M7}/Λ^4	statOnly	4.61	4.45	3.36	2.79	2.15	1.45	1.16	1.02	0.94	0.86	0.85
	statTheoOnly	2.30	2.17	1.13	0.73	0.45	0.31	0.26	0.24	0.23	0.22	0.22
	full	2.23	2.10	1.12	0.72	0.42	0.28	0.24	0.22	0.21	0.20	0.20
f_{S02}/Λ^4	statOnly	4.66	4.53	3.55	2.89	2.13	1.49	1.20	1.05	0.98	0.92	0.91
	statTheoOnly	2.40	2.33	1.36	0.75	0.29	0.15	0.14	0.14	0.15	0.16	0.16
	full	2.31	2.24	1.34	0.75	0.27	0.13	0.12	0.12	0.13	0.14	0.14
f_{S1}/Λ^4	statOnly	4.64	4.52	3.58	2.94	2.16	1.51	1.19	1.04	0.97	0.90	0.90
	statTheoOnly	2.38	2.30	1.42	0.84	0.33	0.18	0.16	0.16	0.16	0.17	0.17
	full	2.30	2.22	1.40	0.84	0.33	0.17	0.15	0.15	0.15	0.15	0.15
f_{T0}/Λ^4	statOnly	4.57	4.51	3.20	2.42	1.75	1.17	0.94	0.84	0.79	0.73	0.72
	statTheoOnly	2.25	2.24	0.90	0.47	0.29	0.21	0.19	0.18	0.18	0.18	0.18
	full	2.21	2.18	0.89	0.46	0.27	0.19	0.17	0.16	0.16	0.16	0.16
f_{T1}/Λ^4	statOnly	4.64	4.26	2.79	2.31	1.91	1.46	1.24	1.12	1.04	0.95	0.93
	statTheoOnly	2.41	1.87	0.58	0.41	0.37	0.32	0.28	0.26	0.25	0.23	0.23
	full	2.32	1.81	0.58	0.40	0.35	0.30	0.26	0.24	0.22	0.21	0.21
f_{T2}/Λ^4	statOnly	4.50	4.38	3.53	3.14	2.68	2.12	1.80	1.62	1.49	1.31	1.26
	statTheoOnly	2.11	1.90	1.73	0.75	0.57	0.42	0.35	0.31	0.29	0.26	0.25
	full	2.08	1.87	1.67	0.74	0.55	0.39	0.32	0.28	0.25	0.23	0.22

Table 10.9: Observed global SM exclusion significance for all Operators for different clipping values and different uncertainty sets with asymptotic formula.

Coefficient	fit type	Clipping value [GeV]										
		600	700	1000	1200	1500	2000	2500	3000	3500	5000	None
f_{M0}/Λ^4	statOnly	4.33	4.24	3.06	2.24	1.35	0.62	0.33	0.22	0.18	0.14	0.13
	statTheoOnly	1.76	1.61	0.26	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	full	1.68	1.56	0.27	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
f_{M1}/Λ^4	statOnly	4.29	4.20	3.19	2.53	1.76	0.97	0.61	0.43	0.34	0.26	0.24
	statTheoOnly	1.70	1.70	0.50	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	full	1.61	1.61	0.49	0.11	0.01	0.00	0.00	0.00	0.00	0.00	0.00
f_{M7}/Λ^4	statOnly	4.31	4.14	2.95	2.31	1.56	0.72	0.42	0.29	0.23	0.17	0.17
	statTheoOnly	1.73	1.58	0.39	0.10	0.02	0.00	0.00	0.00	0.00	0.00	0.00
	full	1.65	1.49	0.38	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00
f_{S02}/Λ^4	statOnly	4.37	4.22	3.17	2.43	1.53	0.77	0.45	0.32	0.26	0.21	0.21
	statTheoOnly	1.86	1.77	0.62	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	full	1.75	1.67	0.60	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
f_{S1}/Λ^4	statOnly	4.35	4.22	3.20	2.48	1.56	0.79	0.44	0.31	0.25	0.20	0.20
	statTheoOnly	1.82	1.73	0.68	0.16	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	full	1.73	1.64	0.66	0.16	0.01	0.00	0.00	0.00	0.00	0.00	0.00
f_{T0}/Λ^4	statOnly	4.27	4.20	2.78	1.88	1.07	0.43	0.23	0.16	0.13	0.10	0.10
	statTheoOnly	1.67	1.66	0.20	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	full	1.63	1.59	0.20	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
f_{T1}/Λ^4	statOnly	4.34	3.94	2.31	1.75	1.26	0.73	0.50	0.38	0.31	0.24	0.22
	statTheoOnly	1.87	1.22	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
	full	1.76	1.14	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
f_{T2}/Λ^4	statOnly	4.19	4.06	3.15	2.71	2.18	1.52	1.13	0.91	0.76	0.57	0.52
	statTheoOnly	1.50	1.26	1.05	0.11	0.04	0.01	0.01	0.00	0.00	0.00	0.00
	full	1.47	1.22	0.97	0.10	0.04	0.01	0.00	0.00	0.00	0.00	0.00

10.7.1 Detailed Information for Operator T1 Clipped at 1.5 TeV

The correlation is shown in Figure 10.9. EW $W^\pm W^\pm jj$ scale uncertainty is correlated the most with the EFT strength $\mu_{\text{EFT_T1}}$ indicating its impact on the derived limits.

The pulls of the upper and lower observed limit are presented in Figure 10.10. Similar to the unclipped case the EW $W^\pm W^\pm jj$ scale and NLO QCD correction uncertainty are pulled the most. Pre-fit distributions with observed data in Figure 10.11 and the post-fit distributions in Figure 10.12. The last two bins are dominantly populated by EFT contributions.

10.7.2 Detailed Information for Operator M0 Clipped at 700 GeV

As a representative example some more control plots are shown for the M0 operator clipped at 700 GeV in this subsection. Figures 10.13 and Tables D.10 to D.14 contain the post-fit distributions at the best fit, upper, inner upper, inner lower and lower limit bound with clipping at 700 GeV. The second bin provides the most statistical power to restrict the EFT operators. SM is excluded because of the up-fluctuation in data in the second bin. The pull plots do show large pulls for EW $W^\pm W^\pm jj$ NLO EW corrections and of $W^\pm W^\pm jj$ scale uncertainties in Figure 10.14 for the best fit, upper, inner upper, inner lower and lower limit. The uncertainty of non-prompt background and of WZ m_{jj} reweighting are the nuisance parameters with next largest pull. The up and down variations of the nuisance parameter with the largest pulls are shown in Figure 10.15.

10.7.3 Two-Dimensional Limits

Observed and expected two-dimensional limits with all systematic uncertainties are shown in Figure 10.16 without clipping and in Figure 10.17 with clipping at 1.5 TeV close to the unitarity bound. The unitarity constraints are derived from equations 19, 20, 21 and 22 from Ref. [145]. The predicted yields of nearly all operator pairs are positive correlated, except for the pairs M1-M7 and M0-M1, where the yields are anti-correlated. Because of the positive correlation, points are not as strongly excluded where one Wilson coefficient is negative and the other positive compared to points where both have the same sign. The predicted yields of S02 and S1 are nearly 100% correlated. Because of this a band can not be excluded. No particular reason for exactly 100% correlation is known. For a slightly different phase space a significant deviation from 100% correlation is seen. The predicted yields of M1 and M7 are near the 100% anti-correlation case but only reach it with the help of a pull of a systematic uncertainty of the cross interference and quadratic term in the unclipped case. Also there, a band in the 2D plot can not be excluded. For clipping at 1.5 TeV additional parameter points can be excluded compared to the unitarity constraints. Only for the S-operators no additional parameter points can get excluded for clipping at or above 1.5 TeV.

10.8 Comparison with Other Analyses

Table 10.10 summarizes the limits at different clipping values shown in Figure 10.7. These limits are compared with other analyses in the following sections.

10.8.1 Reinterpretation of Partial Run 2 ATLAS Data

There is the EFT reinterpretation paper [144] combining partial Run 2 data, taken 2015-16 with the ATLAS detector, published in Ref. [74] ($W^\pm W^\pm jj$) and in Ref. [127] (WZjj). Both papers publishing the observation of the respective EW VVjj process are not optimised for EFT limit setting.

The unclipped 1D and 2D limits derived for $W^\pm W^\pm jj$ final state can be directly compared with the results of this thesis. They are all better now due to the increased amount of recorded data. The 2D limits for the S-operator are not shown in Ref. [144]. For all other operators, the new 2D limits are more stringent in this thesis than the $W^\pm W^\pm jj$ and WZjj combined limits, except for the M1-M7 operator pair. Especially because of

Table 10.10: Expected and observed limits on the Wilson coefficients for all Operators for no clipping, clipping at 1 TeV and the clipping value at the unitarity bound for the full set of uncertainties calculated with the asymptotic formula for expected and observed data. "—" means that no crossing with the unitarity bound was found in the scanned region above 600 GeV.

Coefficient	data type	unclipped [TeV ⁻⁴]	clipping at 1 TeV [TeV ⁻⁴]	clipping at unitarity bound [TeV ⁻⁴]
f_{M0}/Λ^4	expected	[-3.89, 3.84]	[-45.06, 40.35]	[-64.01, 39.86]
	observed	[-4.13, 4.14]	[-59.28, 57.35]	[-139.75, 117.45]
f_{M1}/Λ^4	expected	[-6.27, 6.63]	[-66.16, 76.00]	[-25.48, 31.02]
	observed	[-6.76, 7.01]	[-97.72, 105.16]	[-44.58, 54.00]
f_{M7}/Λ^4	expected	[-9.27, 8.77]	[-109.80, 102.87]	[-33.28, 29.10]
	observed	[-9.75, 9.50]	[-142.20, 146.36]	[-38.97, 41.84]
f_{S02}/Λ^4	expected	[-5.53, 5.66]	[-46.93, 53.16]	[-94.40, 122.48]
	observed	[-5.89, 5.94]	[-69.70, 73.85]	—
f_{S1}/Λ^4	expected	[-22.01, 22.46]	[-185.41, 202.04]	—
	observed	[-23.54, 23.58]	[-274.37, 279.58]	—
f_{T0}/Λ^4	expected	[-0.34, 0.34]	[-5.34, 6.24]	[-3.24, 4.90]
	observed	[-0.36, 0.36]	[-7.48, 7.95]	[-7.40, 12.41]
f_{T1}/Λ^4	expected	[-0.16, 0.17]	[-3.06, 4.26]	[-0.32, 0.44]
	observed	[-0.17, 0.19]	[-3.92, 4.11]	[-0.38, 0.49]
f_{T2}/Λ^4	expected	[-0.56, 0.70]	[-9.21, 18.54]	[-2.60, 10.26]
	observed	[-0.63, 0.74]	[-17.29, 27.94]	—

these pairs a future combination of EFT limits between different VBS analyses has a high potential to further improve limits with even the existing Run 2 data set.

There are also 1D clipped results in Ref. [144]. For S and M operators they are better in this thesis. For T operators they are mainly better in the reinterpretation with a partial data set. The reason is, that T operators tend to have smaller $m_{\ell\ell}$ values than other operators for low clipping values like 1 TeV. The binning is not optimised in this thesis for sensitivity in such low $m_{\ell\ell}$ bins. In a potential future combination for reinterpretation of the data shown in this thesis, it would be beneficial to use the unfolded $m_{\ell\ell}$ distribution shown in Figure 9.26 to set limits for low clipping values.

10.8.2 Interpretation of Full Run 2 CMS Data

A combined $W^\pm W^\pm jj$ and $WZjj$ EFT interpretation with full Run 2 data with the CMS detector is published in Ref. [151]. Only 1D limits are presented there. The unclipped expected limits are approximately 15 % better, while the observed are 30% better. The observed are better because CMS did not observe such a strong up fluctuation in the last bin as ATLAS. The choice of m_T instead of $m_{\ell\ell}$ could cause some difference in the expected limits. For a potential reinterpretation of ATLAS data the m_T distribution could be considered. At the crossing with the unitarization bound the CMS limits are significantly better than the limits presented in this thesis. In a potential ATLAS reinterpretation/combination with unfolded distributions the ATLAS limits could be improved.

10.8.3 Combined Limits of ATLAS and CMS

An overview of the dimension-eight limits without clipping from both ATLAS and CMS from 2022 is shown in Ref. [63]. The best limits are currently coming from semileptonic final states published in Ref. [152] for 36 fb^{-1} . But they are comparable with the limits from CMS with $W^\pm W^\pm jj$ final state. Hence a combination of all channels and ATLAS and CMS might be fruitful. A combination of ATLAS and CMS results is planned as discussed e.g. in Ref. [153].

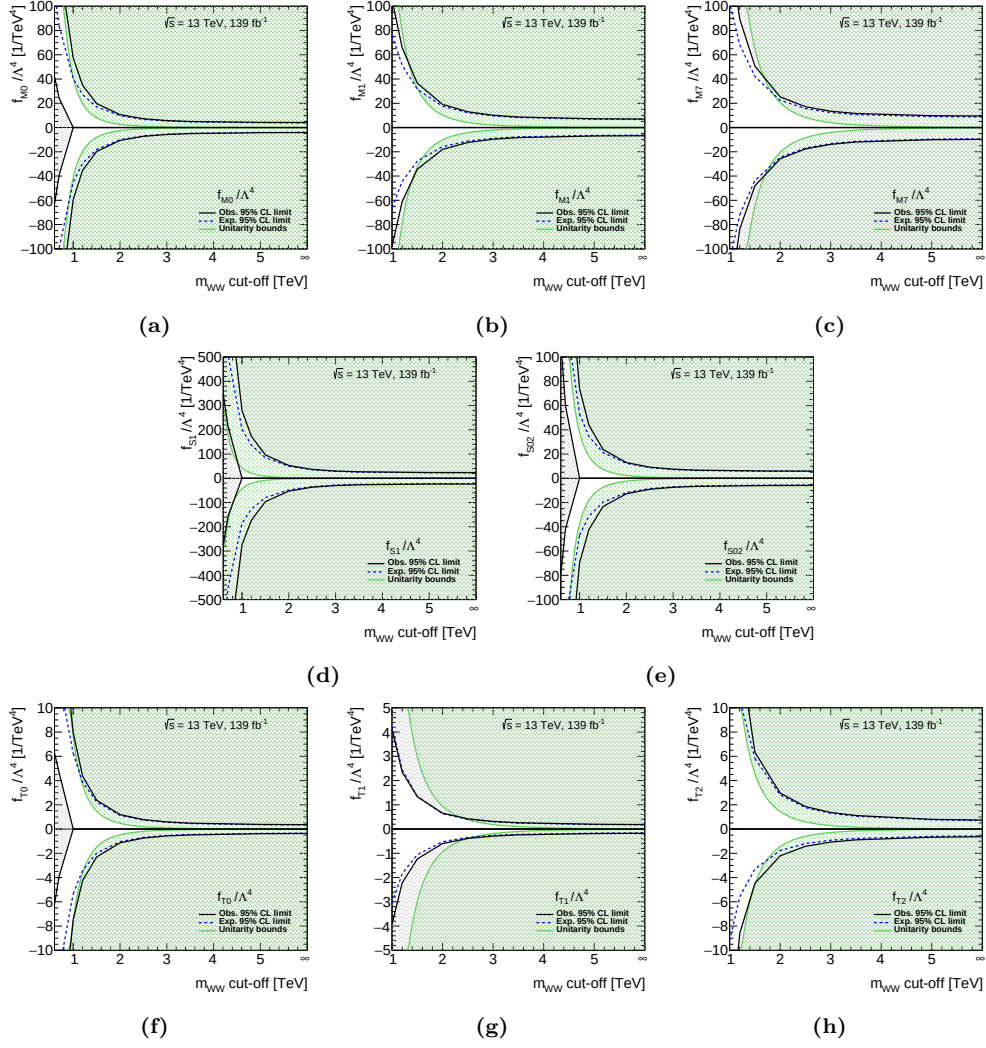
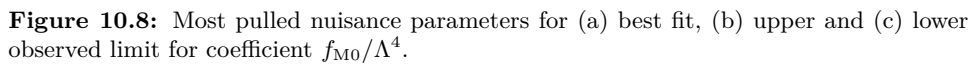


Figure 10.7: Evolution of the one-dimensional expected (blue dashed line) and observed (black line) limits at 95% CL on the parameters corresponding to the quartic operators with label (a) M0, (b) M1, (c) M7, (d) S1, (e) S02, (f) T0, (g) T1, and (h) T2 as a function of the cut-off scale. The unitarity bounds (green area) for each operator as a function of the cut-off scale are defined for one non-zero Wilson coefficient following Ref. [150]. The filled grey area corresponds to parameter values excluded by the data at 95% CL. The limits on M7 were obtained without taking into account the SM-EFT interference for the EW $W^\pm Z jj$ final state. [18]



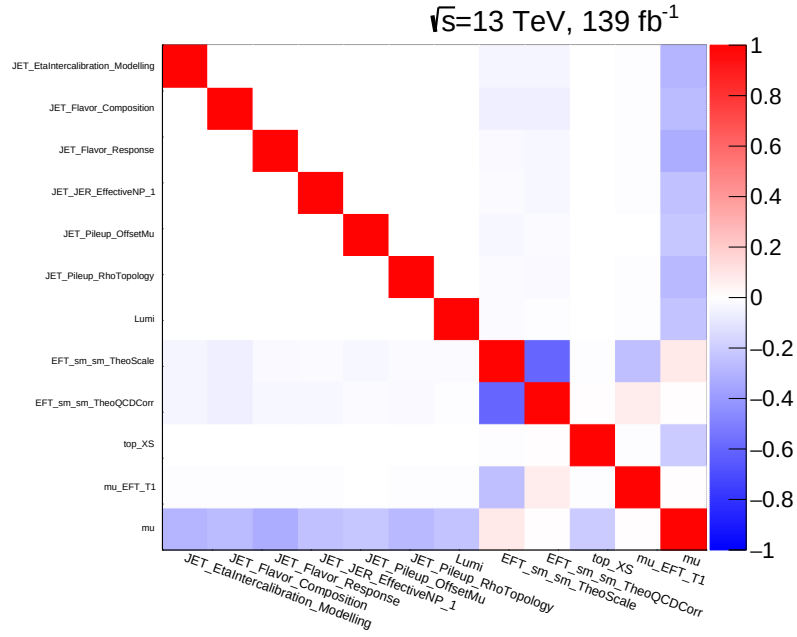


Figure 10.9: Correlation of nuisance parameters for best fit to observed data of operator T1 with clipping at 1.5 TeV.

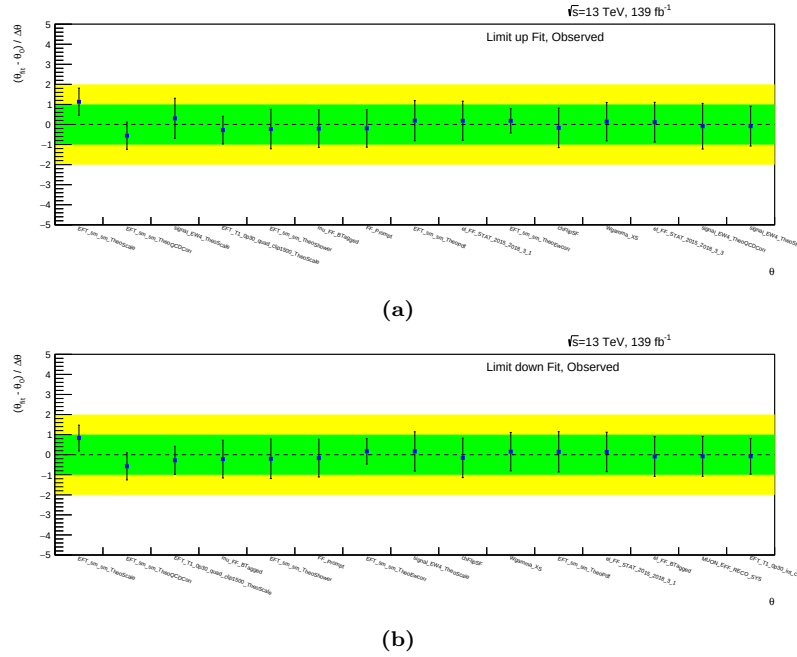


Figure 10.10: Most pulled nuisance parameters for (a) upper and (b) lower limit of T1 operator at a clipping energy of 1500 GeV for observed data.

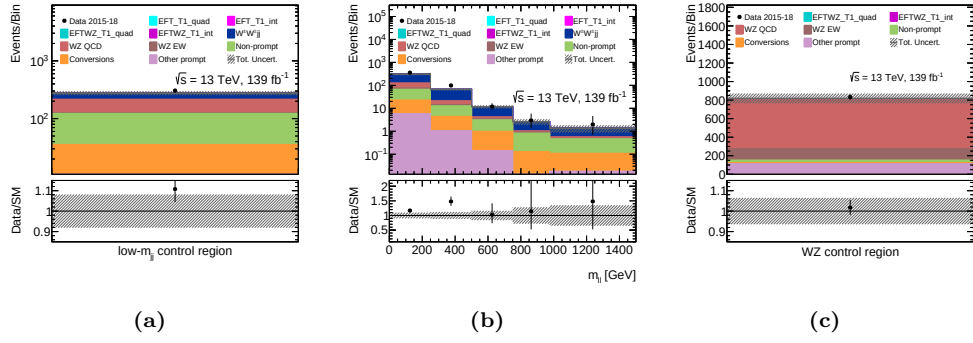


Figure 10.11: Pre-fit distributions with observed data: (a) low- m_{jj} control region, (b) $m_{\ell\ell}$ in the signal region and (c) WZ control region. The inner hatched error band on the model prediction represents the statistical uncertainties. The outer hatched band represents the total model uncertainty, i.e. statistical and systematic uncertainties added in quadrature.

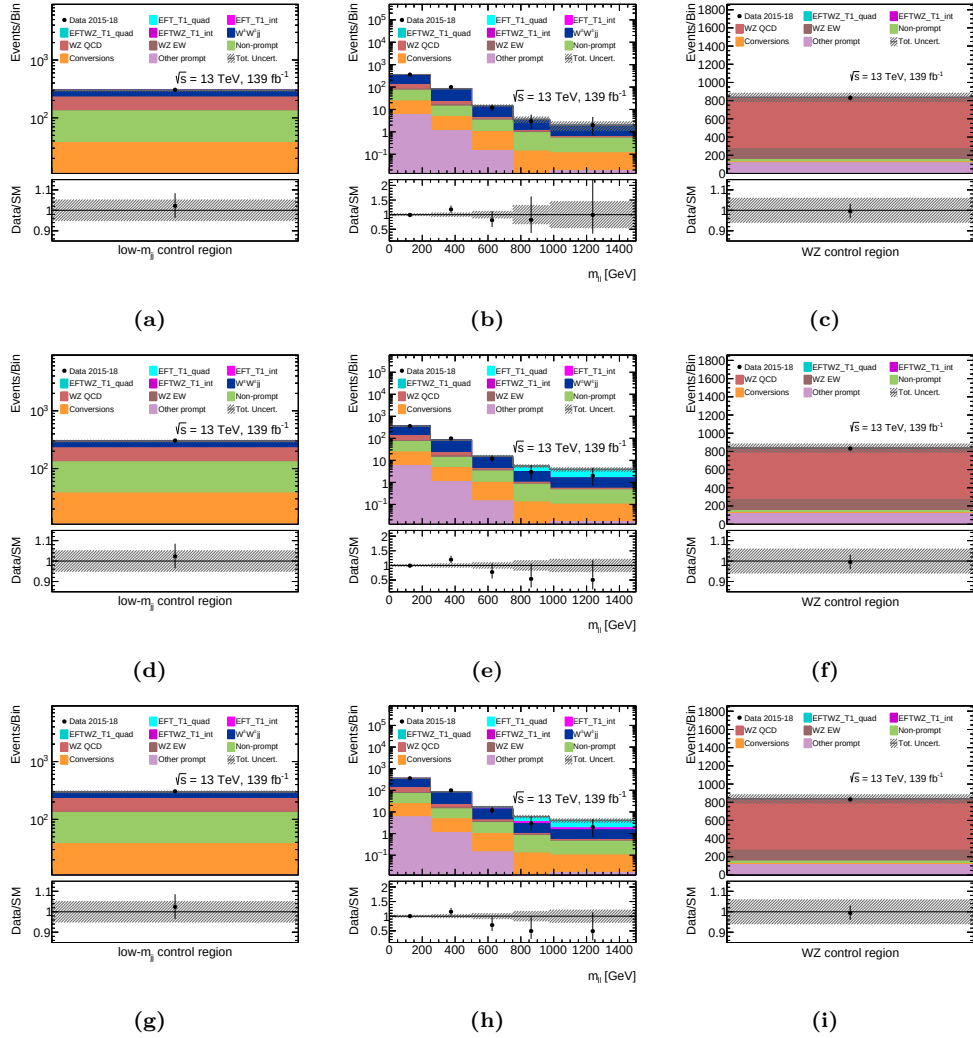


Figure 10.12: Post-fit distributions for operator T1 slipped at 1.5 TeV for observed best fit (a-c), upper limit (d-f) and lower limit (g-i) in low- m_{jj} control region (left), $m_{\ell\ell}$ in the signal region (middle) and WZ control region (right). The hatched error band around the model prediction represents the total uncertainty of the model taking into account correlations between the nuisance parameters.

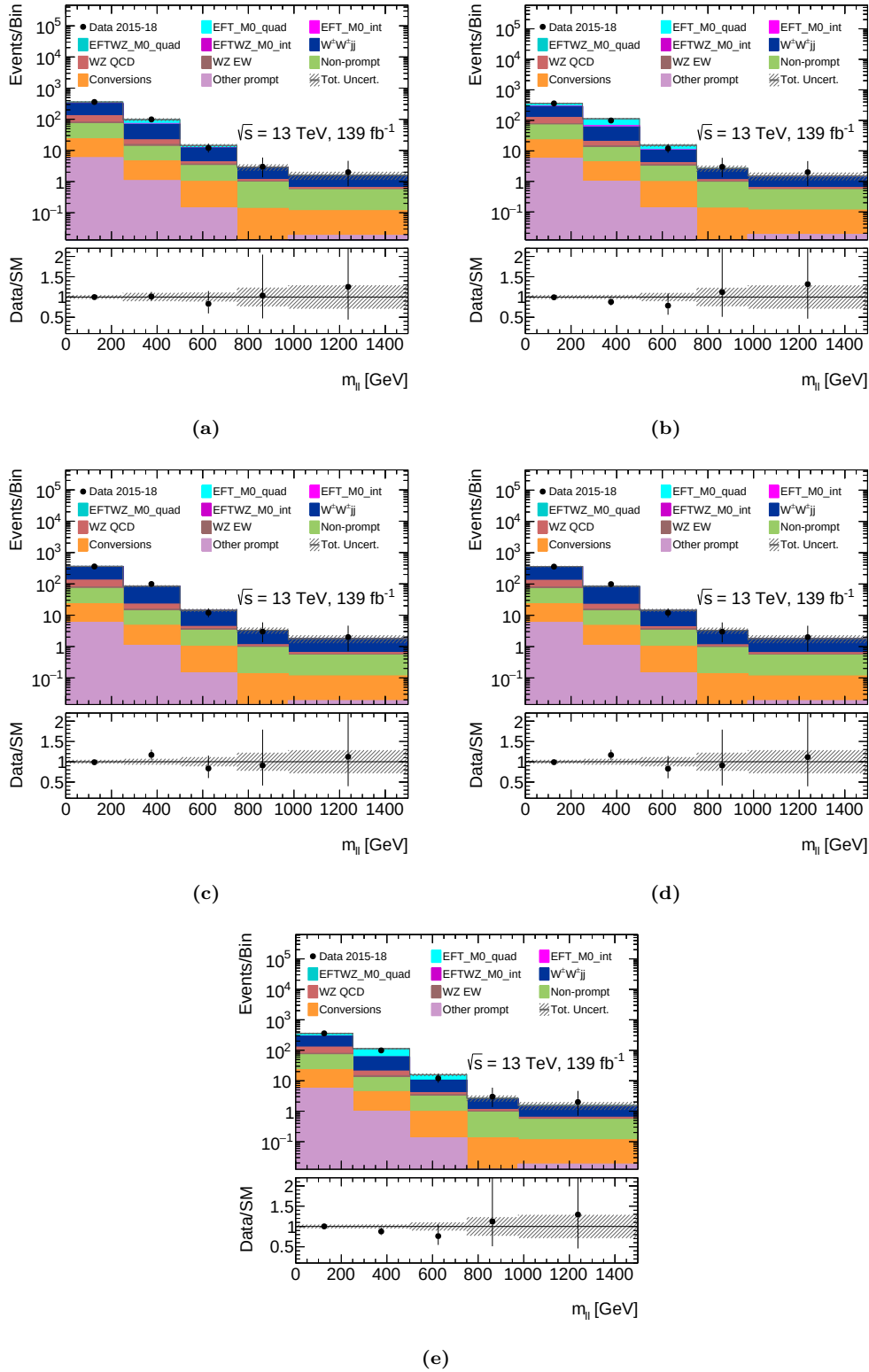


Figure 10.13: Post-fit $m_{\ell\ell}$ distributions for best fit (a), upper (b), inner upper (c), inner lower (d) and lower limit (e) bound with clipping at 700 GeV in the signal region. The hatched error band around the model prediction represents the total uncertainty of the model taking into account correlations between the nuisance parameters.

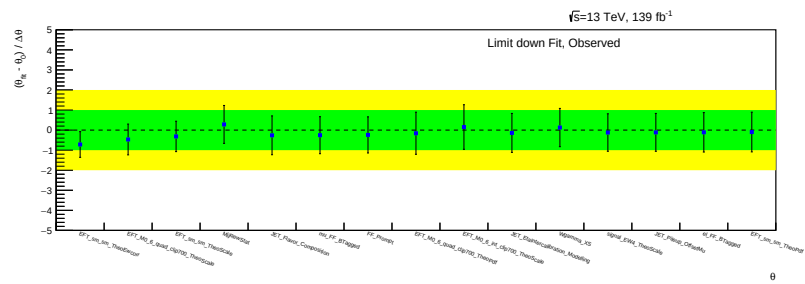
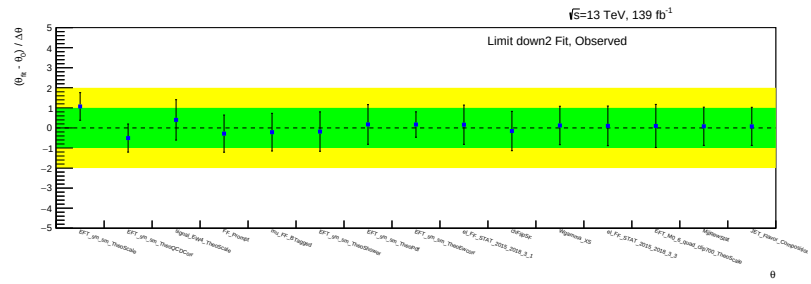
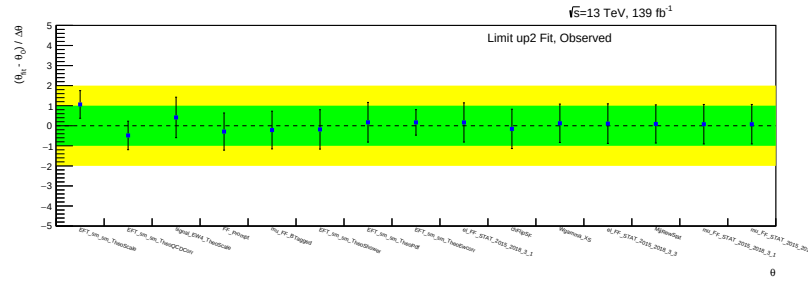
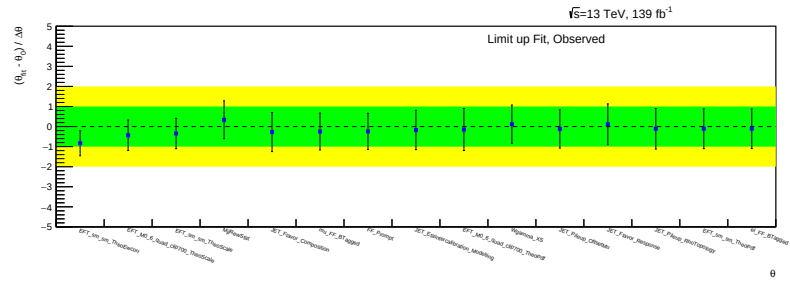
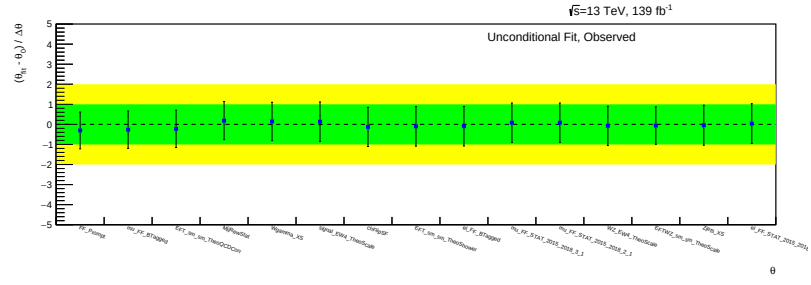


Figure 10.14: Most pulled nuisance parameters for (a) best fit, (b) upper limit, (c) inner upper limit, (d) inner lower limit and (e) lower limit for operator M0 clipped at 700 GeV.

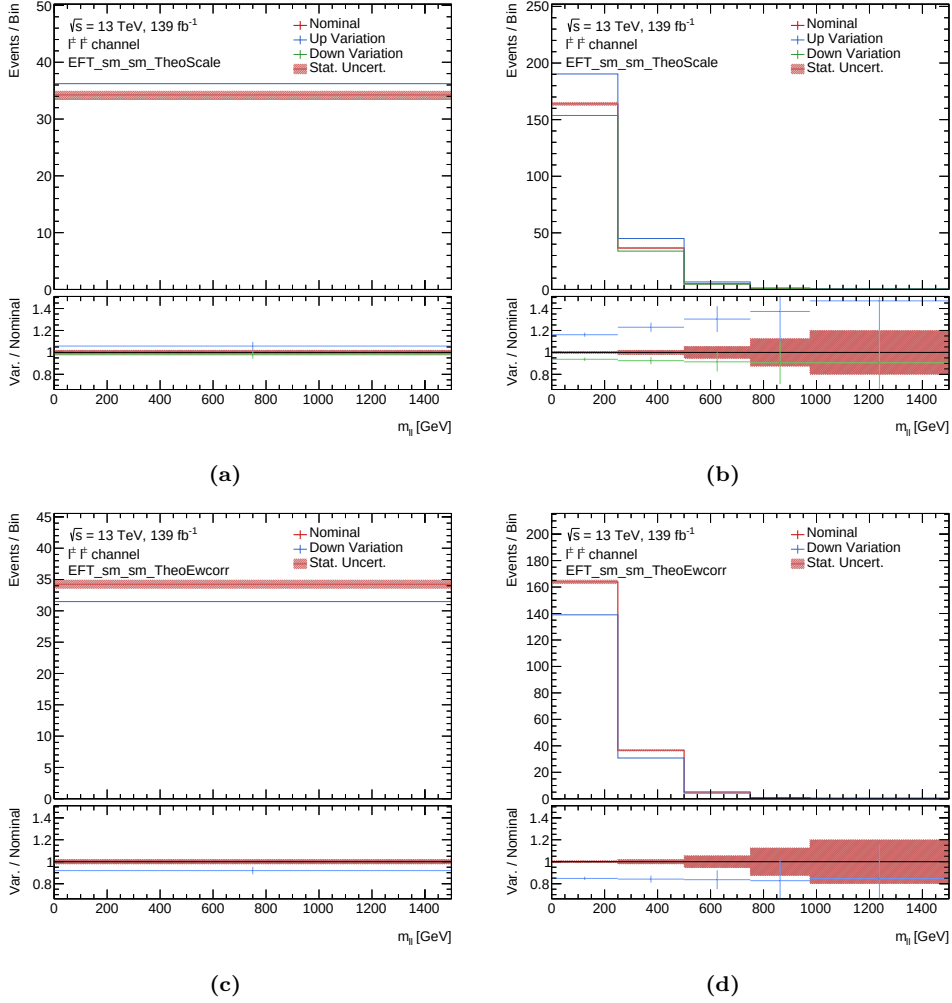


Figure 10.15: Pre-fit up and down variation of systematic with largest pull in the low- m_{jj} CR (a, c) and signal region (b, d) for EW $W^\pm W^\pm jj$ Scale Uncertainty (a, b) and EW $W^\pm W^\pm jj$ NLO EW correction uncertainty (c, d).

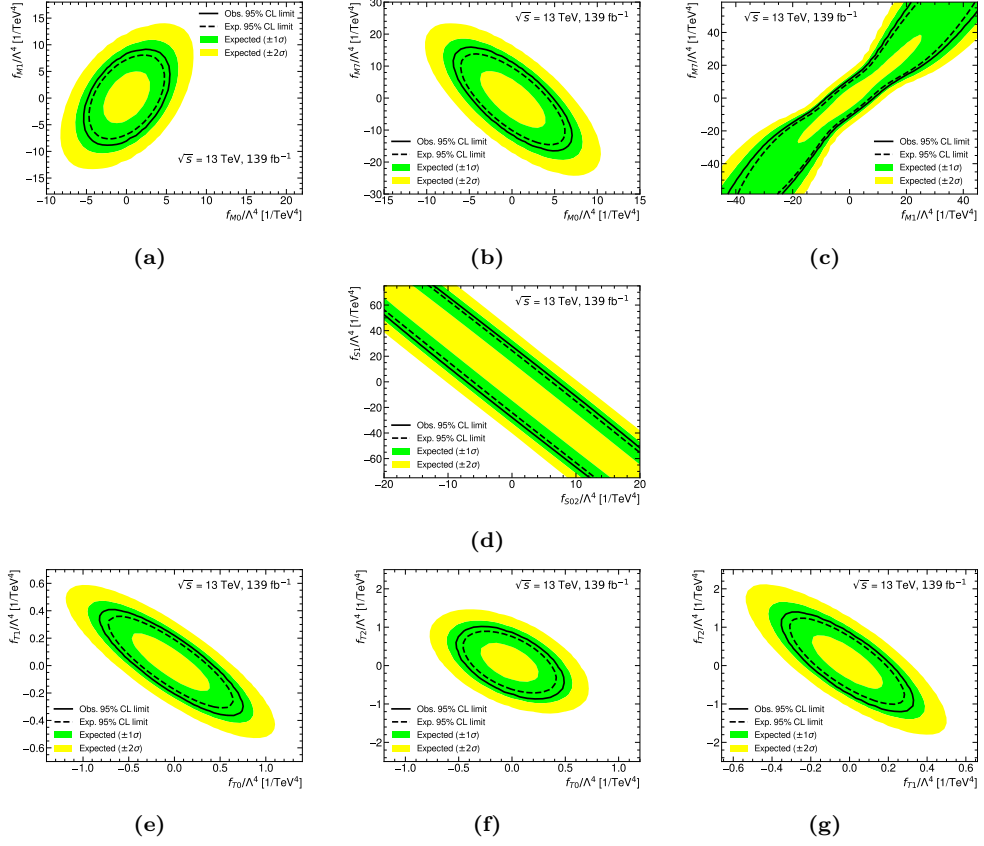


Figure 10.16: Two-dimensional median expected (dashed line) and observed (solid line) 95% CL intervals on parameters corresponding to the quartic operator combinations (a) M0-M1, (b) M0-M7, (c) M1-M7, (d) S1-S02, (e) T0-T1, (f) T0-T2 and (g) T1-T2 EFT parameters without any unitarization procedure. The 1 (green) and 2 (yellow) sigma bands indicate where the limit is expected in 68.3% and 95.4% of the cases, respectively. The limits on M7 were obtained without taking into account the SM-EFT interference term and EFT cross-term for the EW $W^\pm Zjj$ final state. [18]

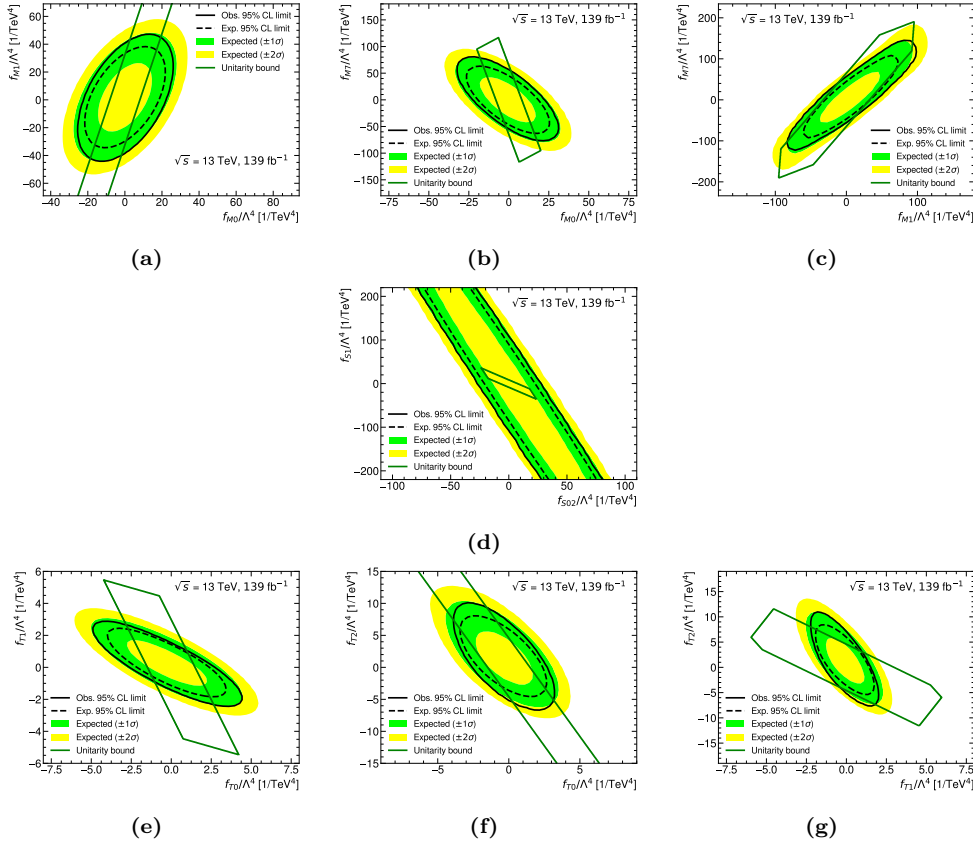


Figure 10.17: Two-dimensional median expected (dashed line) and observed (solid line) 95% CL intervals on parameters corresponding to the quartic operator combinations (a) M0-M1, (b) M0-M7, (c) M1-M7, (d) S1-S02, (e) T0-T1, (f) T0-T2 and (g) T1-T2 EFT parameters with a unitarization cut-off scale of 1.5 TeV and unitarity bounds (green line). The two-dimensional unitarity bounds for pairs of operators are obtained for the two non-zero Wilson coefficients from the eigenvalues from Ref. [150]. The 1 (green) and 2 (yellow) sigma bands indicate where the limit is expected in 68.3% and 95.4% of the cases, respectively. The limits on M7 were obtained without taking into account the SM-EFT interference term and EFT cross-term for the EW $W^\pm Z_{jj}$ final state. [18]

Chapter 11

Summary

Total and differential cross-sections are measured and EFT limits are determined in this thesis from one of the rarest scattering processes observed at the LHC.

The multi-purpose ATLAS detector with nearly full spatial coverage for the detection of almost all stable final state particles is used to collect data at a centre of mass energy of 13 TeV. Data recorded between 2015 and 2018 in Run 2 is analysed corresponding to an integrated luminosity of 139 fb^{-1} .

The cross-section for EW $W^\pm W^\pm \text{jj}$ is measured with the full Run 2 dataset and is $2.88 \pm_{0.21}^{0.22} (\text{stat.}) \pm_{0.14}^{0.16} (\text{mod. syst.}) \pm_{0.11}^{0.11} (\text{exp. syst.}) \pm_{0.05}^{0.06} (\text{lumi.}) \text{ fb}$ and for inclusive $W^\pm W^\pm \text{jj}$ a cross-section of $3.35 \pm_{0.22}^{0.22} (\text{stat.}) \pm_{0.13}^{0.16} (\text{mod. syst.}) \pm_{0.13}^{0.12} (\text{exp. syst.}) \pm_{0.05}^{0.06} (\text{lumi.}) \text{ fb}$ is found. They are both compatible with the Standard Model prediction.

For the final results of the differential cross-section measurement a newly established likelihood-based unfolding method is used because it is an unbiased method which yields the minimal possible variance in the unfolded result. Due to the knowledge of the full likelihood during unfolding, it is also possible to provide frequentist uncertainties from the likelihood ratio for statistical and systematic uncertainties. The first time differential distributions are derived for the variables N_{gapJets} , ξ_{j3} , m_{jj} , $m_{\ell\ell}$ and m_{T} for both signal definitions, EW and inclusive $W^\pm W^\pm \text{jj}$. In general, good agreement between the observed data and theory predictions is found, which confirms once more a prediction of the Standard Model in the form of the differential distributions including VBS in the $W^\pm W^\pm \text{jj}$ final state. Only four bins deviate from the LO prediction with a local (global) significance above 2σ :

- for $500 \leq m_{\text{jj}} < 1000 \text{ GeV}$ in EW $W^\pm W^\pm \text{jj}$ measurement with 2.5σ (1.8σ),
- for $500 \leq m_{\text{jj}} < 1000 \text{ GeV}$ in inclusive $W^\pm W^\pm \text{jj}$ measurement with 2.7σ (2.1σ),
- for $310 \leq m_{\text{T}} < 410 \text{ GeV}$ in EW $W^\pm W^\pm \text{jj}$ measurement with 3.0σ (2.4σ) and
- for $310 \leq m_{\text{T}} < 410 \text{ GeV}$ in inclusive $W^\pm W^\pm \text{jj}$ measurement with 3.1σ (2.5σ).

More recorded events are needed to understand the potential cause of these discrepancies or whether they are just statistical fluctuations.

The dominant sources of uncertainties for the total and differential cross-section measurements are:

- the limited number of recorded events and
- modelling uncertainties of the $W^\pm W^\pm \text{jj}$ and WZjj processes.

The dominant experimental and systematic uncertainties could be reduced by using a consistent NLO signal sample, a better WZ m_{jj} modelling and an updated non-prompt background estimate retrieved from more recorded events.

Our knowledge of physics beyond the Standard Model also increased with this analysis. The limits on unclipped EFT parameters improved compared to an analysis with the partial data set [144]. The unclipped limits are especially sensitive to the tail of the used $m_{\ell\ell}$ distribution and only 1.3 events are expected in the last bin, with two events observed. This makes the presented detailed analysis within the experiment necessary because unfolded distributions typically require at least ten expected events in each bin.

The published unfolded m_{jj} and $m_{\ell\ell}$ distribution could be used to set limits on clipped EFT predictions. In a future EFT analysis a combined optimized binning could be considered which is sensitive for low and high clipping values. Also other constraints than the unitarity violation bound could be considered when classifying the physical validity of the EFT prediction, like positivity and causality.

The theory uncertainty from scale variations affects the limits the most and is strongest anti-correlated with the EFT parameter value. For better unclipped limits, after reducing the statistical uncertainty by increasing the luminosity or combining different channels and experiments, the next most efficient improvement is the scale uncertainty of the EFT samples by including higher orders. For clipped limits the scale and NLO correction uncertainties of $W^\pm W^\pm jj$ are most pulled and most correlated. These systematics need to be addressed in order to improve the limits with increased luminosity.

In summary, more data and improved theory modelling are needed to improve the presented results in the future. But it will not only be a matter of improving the results with more data, but also to look into different properties, like the polarisation of the heavy vector bosons in the future with Run-3 and the High-Luminosity LHC.

Appendix A

Monte Carlo Samples Used in the Analysis

Table A.1 shows the signal samples and Table A.2 the alternative signal samples used for e.g. calculating uncertainties. The next Table A.3 presents prompt and $V\gamma$ background samples. The last Table A.4 summarises the used EFT samples for EFT limit setting. Information about the samples used for charge misidentification and non-prompt background, including Z+jets in WZ control region, can be found in Ref. [69] and Ref. [67]. The derivation STDM3 is used [61].

Only two triboson samples have a filter efficiency ϵ_{filter} different from 1.0: DSID 363507 has a filter efficiency of 0.4394 and DSID 363509 of 0.2206. DSIDs 410218 and 410220 have a k -factor of 1.12 and DSID 410155 of 1.096. All other samples have a k -factor of 1.0.

Table A.1: $W^\pm W^\pm jj$ Monte Carlo samples

DSID	Process	x-section [pb]	MC events	Generator
$W^\pm W^\pm jj$				
500989	MGH7EG_LO_EW6_ssWWjj	3.5168E-02	3988000	MadGraph(v.2.6.7p3.atlas5)+Herwig7(v.7.2.0p3)+EvtGen(v.1.7.0)
500990	MGH7EG_LO_EW4_ssWWjj	2.7960E-02	3995000	MadGraph(v.2.6.7p3.atlas5)+Herwig7(v.7.2.0p3)+EvtGen(v.1.7.0)
500991	MGH7EG_LO_INT_ssWWjj	3.0924E-03	3990000	MadGraph(v.2.6.7p3.atlas5)+Herwig7(v.7.2.0p3)+EvtGen(v.1.7.0)

Table A.2: Additional $W^\pm W^\pm jj$ samples used for systematic modelling uncertainties

DSID	Process	x-section [pb]	MC events	Generator
$W^\pm W^\pm jj$ shower variation				
500986	MGPY8EG_LO_EW6_ssWWjj	3.5170E-02	3984000	MadGraph(v.2.6.7p3.atlas5)+aMcAtNlo+Pythia8(v.244p3)+EvtGen(v.1.7.0)
500987	MGPY8EG_LO_EW4_ssWWjj	2.7961E-02	3995000	MadGraph(v.2.6.7p3.atlas5)+aMcAtNlo+Pythia8(v.244p3)+EvtGen(v.1.7.0)
500988	MGPY8EG_LO_INT_ssWWjj	3.0889E-03	3990000	MadGraph(v.2.6.7p3.atlas5)+aMcAtNlo+Pythia8(v.244p3)+EvtGen(v.1.7.0)
$W^\pm W^\pm jj$ EW6 third jet				
346643	PowhegPythia8EvtGen_NNPDF3_AZNLO_WmH125J_MINLO_lvWWlvqq_ss	8.3066E-03	2841530	Powheg+Pythia8(v.235)+EvtGen(v.1.6.0)
346644	PowhegPythia8EvtGen_NNPDF3_AZNLO_WpH125J_MINLO_lvWWlvqq_ss	1.3186E-02	5604823	Powheg+Pythia8(v.235)+EvtGen(v.1.6.0)
364336	Sherpa_222_NNPDF30NNLO_WpWpWn_sslvlvjj_EW6	9.6070E-03	105237	Sherpa(v2.2.2)
364337	Sherpa_222_NNPDF30NNLO_WnWnWp_sslvlvjj_EW6	5.3859E-03	65372	Sherpa(v2.2.2)
700357	Sh_2211_llvjj_ss_Min_N_TChannel	2.5285E-02	847939	Sherpa(v.2.2.11p4)
$W^\pm W^\pm jj$ EW6 Powheg				
600078	PhPy8EG_NNPDF30NLO_AZNLOC6L1_EWK_WmWm	7.8055E-03	1387000	Powheg+Pythia8(v.244p3)+EvtGen(v.1.7.0)+Photospp(v.3.61)
600079	PhPy8EG_NNPDF30NLO_AZNLOC6L1_EWK_WpWp	2.0878E-02	1396000	Powheg+Pythia8(v.244p3)+EvtGen(v.1.7.0)+Photospp(v.3.61)
$W^\pm W^\pm jj$ EW4 third jet				
364286	Sherpa_222_NNPDF30NNLO_llvjj_ss_EW4	2.5210E-02	2749000	Sherpa(v2.2.2)

Table A.3: WZ, Vgamma and other prompt, consisting of ZZ, triboson and top, background Monte Carlo samples

DSID	Process	x-section [pb]	MC events	Generator
WZ EW4				
364253	Sherpa_222_NNPDF30NNLO_lllv	4.5723E+00	74441300	Sherpa(v2.2.2)
WZ EW6				
364739	MGPY8EG_NNPDF30NLO_A14NNPDF23LO_lvlljjEW6_OFMinus	1.5430E-02	1398000	MadGraph(v.2.6.2)+Pythia8(v.235)+EvtGen(v.1.6.0)
364740	MGPY8EG_NNPDF30NLO_A14NNPDF23LO_lvlljjEW6_OFPlus	2.5667E-02	1996000	MadGraph(v.2.6.2)+Pythia8(v.235)+EvtGen(v.1.6.0)
364741	MGPY8EG_NNPDF30NLO_A14NNPDF23LO_lvlljjEW6_SFMinus	7.6951E-03	699000	MadGraph(v.2.6.2)+Pythia8(v.235)+EvtGen(v.1.6.0)
364742	MGPY8EG_NNPDF30NLO_A14NNPDF23LO_lvlljjEW6_SFPlus	1.2810E-02	898000	MadGraph(v.2.6.2)+Pythia8(v.235)+EvtGen(v.1.6.0)
V_γ				
363267	MGaMcAtNloPy8EG_EWKVgamma	5.2126E-02	-	MadGraph(v.2.6.5)+aMcAtNlo+Pythia8(v.240)+EvtGen(v.1.6.0)
363268	MGaMcAtNloPy8EG_EWKVgamma	5.1978E-02	-	MadGraph(v.2.6.5)+aMcAtNlo+Pythia8(v.240)+EvtGen(v.1.6.0)
363269	MGaMcAtNloPy8EG_EWKVgamma	5.1992E-02	-	MadGraph(v.2.6.5)+aMcAtNlo+Pythia8(v.240)+EvtGen(v.1.6.0)
363270	MGaMcAtNloPy8EG_EWKVgamma	8.3980E-01	-	MadGraph(v.2.6.5)+aMcAtNlo+Pythia8(v.240)+EvtGen(v.1.6.0)
363271	MGaMcAtNloPy8EG_EWKVgamma	8.3982E-01	-	MadGraph(v.2.6.5)+aMcAtNlo+Pythia8(v.240)+EvtGen(v.1.6.0)
363272	MGaMcAtNloPy8EG_EWKVgamma	8.3961E-01	-	MadGraph(v.2.6.5)+aMcAtNlo+Pythia8(v.240)+EvtGen(v.1.6.0)

DSID	Process	x-section [pb]	MC events	Generator
700398	Sh_2211_munugamma	1.0322E+02	15746330	Sherpa(v.2.2.1lp3)
700399	Sh_2211_eegamma	1.0318E+02	12578358	Sherpa(v.2.2.1lp3)
700400	Sh_2211_tautaugamma	1.0333E+02	1133788	Sherpa(v.2.2.1lp3)
700402	Sh_2211_munugamma	3.6484E+02	5813130	Sherpa(v.2.2.1lp3)
700403	Sh_2211_enugamma	3.6483E+02	5369579	Sherpa(v.2.2.1lp3)
700404	Sh_2211_tanugamma	3.6484E+02	1334807	Sherpa(v.2.2.1lp3)
364250	Sherpa_222_NNPDF30NNLO_III	1.2523E+00	17842900	Sherpa(v2.2.2)
364283	Sherpa_222_NNPDF30NNLO_IIIijj_EW6	1.0580E-02	512435	
363507	Sherpa_222_NNPDF30NNLO_WWZ_3l1v2l_EW6	1.7047E-02	224000	Sherpa(v2.2.2)
363508	Sherpa_222_NNPDF30NNLO_WZZ_4l2l_EW6	3.8998E-04	225000	Sherpa(v2.2.2)
363509	Sherpa_222_NNPDF30NNLO_WZZ_3l1v2l_EW6	1.1815E-02	225000	Sherpa(v2.2.2)
407311	Sherpa_221_NNPDF30NNLO_6l0v_EW6	1.0250E-04	-	Sherpa(v2.2.1)
407312	Sherpa_221_NNPDF30NNLO_5l1v_EW6	5.6763E-04	-	Sherpa(v2.2.1)
407313	Sherpa_221_NNPDF30NNLO_4l2v_EW6	4.3651E-03	-	Sherpa(v2.2.1)
407314	Sherpa_221_NNPDF30NNLO_3l3v_EW6	1.5773E-02	-	Sherpa(v2.2.1)
407315	Sherpa_221_NNPDF30NNLO_2l4v_EW6	5.8087E-03	-	Sherpa(v2.2.1)
410155	aMcAeNloPythia8EvtGen_MEN30NLO_A14N23LO_ttW	5.4828E-01	27036000	MadGraph5_aMC@NLO(v2.3.3.p0)+Pythia8(v8.210)+EvtGen(v1.2.0)
410218	aMcAeNloPythia8EvtGen_MEN30NLO_A14N23LO_ttee	3.6864E-02	4915000	MadGraph5_aMC@NLO(v2.3.3.p0)+Pythia8(v8.210)+EvtGen(v1.2.0)
410219	aMcAeNloPythia8EvtGen_MEN30NLO_A14N23LO_ttmumu	3.6865E-02	4922000	MadGraph5_aMC@NLO(v2.3.3.p0)+Pythia8(v8.210)+EvtGen(v1.2.0)
410220	aMcAeNloPythia8EvtGen_MEN30NLO_A14N23LO_ttttau	3.6555E-02	2793000	MadGraph5_aMC@NLO(v2.3.3.p0)+Pythia8(v8.210)+EvtGen(v1.2.0)
410560	MadGraphPythia8EvtGen_A14_tZ_4H_tchan_noAllHad	2.4042E-01	3322000	MadGraph+Pythia8+EvtGen

Table A.4: EFT Monte Carlo samples

DSID	Process	x-section [pb]	MC events	Generator
502174	MGPys8EG_lvlvjj_ss_EW6_LSMt_sm_sm	EFT $W^\pm W^\pm jj$ EW6 SM prediction	360000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502336	MGPys8EG_epemepvjj_EW6_LSMt_t1_sm	EFT WZ EW6 SM prediction	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502337	MGPys8EG_epememvjj_EW6_LSMt_t1_sm	3.6509E-03	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502338	MGPys8EG_epemumvpvjj_EW6_LSMt_t1_sm	2.2624E-03	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502339	MGPys8EG_epemumvjj_EW6_LSMt_t1_sm	3.6548E-03	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502340	MGPys8EG_epentapvjj_EW6_LSMt_t1_sm	2.2679E-03	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502341	MGPys8EG_epentamvjj_EW6_LSMt_t1_sm	3.6519E-03	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502342	MGPys8EG_mupmumepvjj_EW6_LSMt_t1_sm	2.2645E-03	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502343	MGPys8EG_mupmumemvjj_EW6_LSMt_t1_sm	3.6532E-03	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502344	MGPys8EG_mupmumupvjj_EW6_LSMt_t1_sm	2.2682E-03	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502345	MGPys8EG_mupmumumvjj_EW6_LSMt_t1_sm	3.6506E-03	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502346	MGPys8EG_mupmuntapvjj_EW6_LSMt_t1_sm	3.6479E-03	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502347	MGPys8EG_mupmuntamvjj_EW6_LSMt_t1_sm	2.2657E-03	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502348	MGPys8EG_taptamemvjj_EW6_LSMt_t1_sm	2.2651E-03	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502349	MGPys8EG_taptamemvjj_EW6_LSMt_t1_sm	3.7401E-03	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502350	MGPys8EG_taptamupvjj_EW6_LSMt_t1_sm	3.6556E-03	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502350	MGPys8EG_taptamupvjj_EW6_LSMt_t1_sm	3.7442E-03	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)

A Monte Carlo Samples Used in the Analysis

DSID	Process	x-section [pb]	MC events	Generator
502351	MGPy8EG_taptanmmuvjj_EW6_LSM_T_t1_sm	2.2936E-03	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502352	MGPy8EG_taptantapvjj_EW6_LSM_T_t1_sm	3.7326E-03	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502353	MGPy8EG_taptantamvjj_EW6_LSM_T_t1_sm	2.2813E-03	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
EFT S operator				
502175	MGPy8EG_lvlvjj_ss_EW6_LSM_T_S02_8_int	-1.5298E-04	360000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502176	MGPy8EG_lvlvjj_ss_EW6_LSM_T_S02_8_quad	1.0996E-03	360000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502177	MGPy8EG_lvlvjj_ss_EW6_LSM_T_s1_20_int	-9.3459E-05	360000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502178	MGPy8EG_lvlvjj_ss_EW6_LSM_T_s1_20_quad	4.6023E-04	360000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502179	MGPy8EG_lvlvjj_ss_EW6_LSM_T_S02_8_S1_20_int	1.3999E-03	3309000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502207	MGPy8EG_llvjj_EW6_LSM_T_s1_128_quad	5.2159E-03	697000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502213	MGPy8EG_llvjj_EW6_LSM_T_S02_82_S1_128_cross	1.0224E-02	694000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502300	MGPy8EG_epemepvjj_EW6_LSM_T_s1_S1_128	-8.0414E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502301	MGPy8EG_epemepvjj_EW6_LSM_T_s1_S1_128	-4.6789E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502302	MGPy8EG_epemupvjj_EW6_LSM_T_s1_S1_128	-7.8940E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502303	MGPy8EG_epemumvjj_EW6_LSM_T_s1_S1_128	-4.6372E-06	49000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502304	MGPy8EG_epemtapvjj_EW6_LSM_T_s1_S1_128	-7.8134E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502305	MGPy8EG_epemtanvjj_EW6_LSM_T_s1_S1_128	-4.7967E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502306	MGPy8EG_nupmumepvjj_EW6_LSM_T_s1_S1_128	-7.9041E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502307	MGPy8EG_nupmumemvjj_EW6_LSM_T_s1_S1_128	-4.6376E-06	48000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502308	MGPy8EG_nupmumupvjj_EW6_LSM_T_s1_S1_128	-8.0512E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502309	MGPy8EG_nupmumumvjj_EW6_LSM_T_s1_S1_128	-4.6736E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502310	MGPy8EG_nupmumtapvjj_EW6_LSM_T_s1_S1_128	-7.7839E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502311	MGPy8EG_nupmuntamvjj_EW6_LSM_T_s1_S1_128	-4.7886E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502312	MGPy8EG_taptanepvjj_EW6_LSM_T_s1_S1_128	-7.9914E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502313	MGPy8EG_taptanemvjj_EW6_LSM_T_s1_S1_128	-8.1184E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502314	MGPy8EG_taptanmupvjj_EW6_LSM_T_s1_S1_128	-7.8772E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502315	MGPy8EG_taptanmmuvjj_EW6_LSM_T_s1_S1_128	-4.5009E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502316	MGPy8EG_taptantapvjj_EW6_LSM_T_s1_S1_128	-7.8722E-06	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502317	MGPy8EG_taptantamvjj_EW6_LSM_T_s1_S1_128	-4.7805E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502318	MGPy8EG_epemepvjj_EW6_LSM_T_s0_S02_82	-1.1738E-05	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502319	MGPy8EG_epememvjj_EW6_LSM_T_s0_S02_82	-1.1383E-05	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502320	MGPy8EG_epemupvjj_EW6_LSM_T_s0_S02_82	-1.8691E-05	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502321	MGPy8EG_epemumvjj_EW6_LSM_T_s0_S02_82	-1.0743E-05	49000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502322	MGPy8EG_epemtapvjj_EW6_LSM_T_s0_S02_82	-1.8623E-05	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502323	MGPy8EG_epemtanvjj_EW6_LSM_T_s0_S02_82	-1.1131E-05	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502324	MGPy8EG_nupmumepvjj_EW6_LSM_T_s0_S02_82	-1.8671E-05	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502325	MGPy8EG_nupmumemvjj_EW6_LSM_T_s0_S02_82	-1.0744E-05	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502326	MGPy8EG_nupmumupvjj_EW6_LSM_T_s0_S02_82	-1.9000E-05	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502327	MGPy8EG_nupmumumvjj_EW6_LSM_T_s0_S02_82	-1.1408E-05	49000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502328	MGPy8EG_nupmumtapvjj_EW6_LSM_T_s0_S02_82	-1.8509E-05	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502329	MGPy8EG_nupmuntamvjj_EW6_LSM_T_s0_S02_82	-1.1033E-05	49000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502330	MGPy8EG_taptanepvjj_EW6_LSM_T_s0_S02_82	-1.8552E-05	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502331	MGPy8EG_taptanemvjj_EW6_LSM_T_s0_S02_82	-1.8943E-05	49000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502332	MGPy8EG_taptanmupvjj_EW6_LSM_T_s0_S02_82	-1.8486E-05	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502333	MGPy8EG_taptanmmuvjj_EW6_LSM_T_s0_S02_82	-1.1163E-05	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502334	MGPy8EG_taptantapvjj_EW6_LSM_T_s0_S02_82	-1.8732E-05	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502335	MGPy8EG_taptantamvjj_EW6_LSM_T_s0_S02_82	-1.0937E-05	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
507694	MGPy8EG_llvjj_EW6_LSM_T_S0_82_S2_82_int	7.6452E-03	149181	MadGraph(v.2.8.1p3.atlas9)+Pythia8(v.244p3.rangefix)+EvtGen(v.1.7.0)
507695	MGPy8EG_llvjj_EW6_LSM_T_S0_82_S2_quad	4.9999E-03	185550	MadGraph(v.2.8.1p3.atlas9)+Pythia8(v.244p3.rangefix)+EvtGen(v.1.7.0)

DSID	Process		x-section [pb]	MC events	Generator
507696	MGP>8EG_llvjj_EW6_LSM_T_S2_82_quad		5.0054E-03	187422	MadGraph(v.2.8.1p3.atlas9)+Pythia8(v.244p3.rangefix)+EvtGen(v.1.7.0)
EFT M operator					
502180	MGP>8EG_llvjj_ss_EW6_LSM_T_M0_6_int		7.1198E-05	360000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502181	MGP>8EG_llvjj_ss_EW6_LSM_T_M0_6_quad		1.0680E-03	360000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502182	MGP>8EG_llvjj_ss_EW6_LSM_T_M1_10_int		-9.1176E-05	359000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502183	MGP>8EG_llvjj_ss_EW6_LSM_T_M1_10_quad		1.2844E-03	345000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502184	MGP>8EG_llvjj_ss_EW6_LSM_T_M7_13_int		7.2970E-05	359000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502185	MGP>8EG_llvjj_ss_EW6_LSM_T_M7_13_quad		9.1050E-04	360000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502186	MGP>8EG_llvjj_ss_EW6_LSM_T_M0_6_M1_10_int		-1.0815E-03	359000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502187	MGP>8EG_llvjj_ss_EW6_LSM_T_M0_6_M1_10_int		1.3474E-03	360000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502188	MGP>8EG_llvjj_ss_EW6_LSM_T_M1_10_M7_13_int		-1.9592E-03	360000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502211	MGP>8EG_llvjj_EW6_LSM_T_M0_27_quad		7.6139E-03	697000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502212	MGP>8EG_llvjj_EW6_LSM_T_M1_28_quad		3.2151E-03	696000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502217	MGP>8EG_llvjj_EW6_LSM_T_M0_27_M1_28_cross		-5.1865E-03	696000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502264	MGP>8EG_epemepvjj_EW6_LSM_T_M0_M0_27		7.5925E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502265	MGP>8EG_epememvjj_EW6_LSM_T_M0_M0_27		4.6844E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502266	MGP>8EG_epemupvjj_EW6_LSM_T_M0_M0_27		7.4668E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502267	MGP>8EG_epemumvjj_EW6_LSM_T_M0_M0_27		4.4091E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502268	MGP>8EG_epentapvjj_EW6_LSM_T_M0_M0_27		7.9948E-06	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502269	MGP>8EG_epentamvjj_EW6_LSM_T_M0_M0_27		4.5422E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502270	MGP>8EG_nupmupvjj_EW6_LSM_T_M0_M0_27		7.4800E-06	58000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502271	MGP>8EG_nupmumemvjj_EW6_LSM_T_M0_M0_27		4.3953E-06	49000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502272	MGP>8EG_nupmumupvjj_EW6_LSM_T_M0_M0_27		7.5849E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502273	MGP>8EG_nupmumunvjj_EW6_LSM_T_M0_M0_27		4.6853E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502274	MGP>8EG_nupmuntapvjj_EW6_LSM_T_M0_M0_27		7.9486E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502275	MGP>8EG_nupmuntamvjj_EW6_LSM_T_M0_M0_27		4.5170E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502276	MGP>8EG_taptamepvjj_EW6_LSM_T_M0_M0_27		7.4664E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502277	MGP>8EG_taptamemvjj_EW6_LSM_T_M0_M0_27		7.5115E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502278	MGP>8EG_taptamupvjj_EW6_LSM_T_M0_M0_27		7.3797E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502279	MGP>8EG_taptannunvjj_EW6_LSM_T_M0_M0_27		4.5820E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502280	MGP>8EG_taptantapvjj_EW6_LSM_T_M0_M0_27		7.8179E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502281	MGP>8EG_taptantamvjj_EW6_LSM_T_M0_M0_27		4.7004E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502282	MGP>8EG_epemepvjj_EW6_LSM_T_M1_M1_28		-3.2942E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502283	MGP>8EG_epememvjj_EW6_LSM_T_M1_M1_28		-2.5193E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502284	MGP>8EG_epemupvjj_EW6_LSM_T_M1_M1_28		-3.2536E-06	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502285	MGP>8EG_epemumvjj_EW6_LSM_T_M1_M1_28		-2.5182E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502286	MGP>8EG_epentapvjj_EW6_LSM_T_M1_M1_28		-4.2576E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502287	MGP>8EG_epentamvjj_EW6_LSM_T_M1_M1_28		-2.5610E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502288	MGP>8EG_nupmupvjj_EW6_LSM_T_M1_M1_28		-3.3709E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502289	MGP>8EG_nupmumemvjj_EW6_LSM_T_M1_M1_28		-2.5063E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502290	MGP>8EG_nupmumupvjj_EW6_LSM_T_M1_M1_28		-3.2429E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502291	MGP>8EG_nupmumunvjj_EW6_LSM_T_M1_M1_28		-2.5211E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502292	MGP>8EG_nupmuntapvjj_EW6_LSM_T_M1_M1_28		-4.4578E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502293	MGP>8EG_nupmuntamvjj_EW6_LSM_T_M1_M1_28		-2.4933E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502294	MGP>8EG_taptamepvjj_EW6_LSM_T_M1_M1_28		-3.3120E-06	59000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502295	MGP>8EG_taptamemvjj_EW6_LSM_T_M1_M1_28		-3.2508E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502296	MGP>8EG_taptamupvjj_EW6_LSM_T_M1_M1_28		-3.3258E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502297	MGP>8EG_taptannunvjj_EW6_LSM_T_M1_M1_28		-2.4530E-06	50000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)
502298	MGP>8EG_taptantapvjj_EW6_LSM_T_M1_M1_28		-3.3947E-06	60000	MadGraph(v.2.7.3p3.atlas5)+Pythia8(v.244p3)+EvtGen(v.1.7.0)

DSID	Process	x-section [pb]	MC events	Generator
502241	MGP _s 8EG_taptamemvjj_EW6_LSM_T1_T1_1p60	-2.0619E-05	50000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502242	MGP _s 8EG_taptamumvjj_EW6_LSM_T1_T1_1p60	-2.0504E-05	60000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502243	MGP _s 8EG_taptamumvjj_EW6_LSM_T1_T1_1p60	-1.0496E-05	50000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502244	MGP _s 8EG_taptamtapvjj_EW6_LSM_T1_T1_1p60	-2.0601E-05	48000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502245	MGP _s 8EG_taptamtamvjj_EW6_LSM_T1_T1_1p60	-1.0412E-05	50000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502246	MGP _s 8EG_epemepvjj_EW6_LSM_T2_T2_5p50	-3.9021E-05	60000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502247	MGP _s 8EG_epememvjj_EW6_LSM_T2_T2_5p50	-1.9166E-05	50000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502248	MGP _s 8EG_epemumvjj_EW6_LSM_T2_T2_5p50	-3.9051E-05	60000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502249	MGP _s 8EG_epemumvjj_EW6_LSM_T2_T2_5p50	-1.9192E-05	50000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502250	MGP _s 8EG_epentapvjj_EW6_LSM_T2_T2_5p50	-3.9087E-05	59000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502251	MGP _s 8EG_epentamvjj_EW6_LSM_T2_T2_5p50	-1.9112E-05	50000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502252	MGP _s 8EG_muupmepvjj_EW6_LSM_T2_T2_5p50	-3.8972E-05	60000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502253	MGP _s 8EG_muupmumemvjj_EW6_LSM_T2_T2_5p50	-1.9214E-05	50000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502254	MGP _s 8EG_muupmumumvjj_EW6_LSM_T2_T2_5p50	-3.9072E-05	60000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502255	MGP _s 8EG_muupmumumvjj_EW6_LSM_T2_T2_5p50	-1.9090E-05	50000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502256	MGP _s 8EG_muupmuntapvjj_EW6_LSM_T2_T2_5p50	-3.9295E-05	60000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502257	MGP _s 8EG_muupmuntamvjj_EW6_LSM_T2_T2_5p50	-1.9139E-05	49000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502258	MGP _s 8EG_taptamepvjj_EW6_LSM_T2_T2_5p50	-3.8801E-05	60000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502259	MGP _s 8EG_taptamemvjj_EW6_LSM_T2_T2_5p50	-3.9156E-05	50000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502260	MGP _s 8EG_taptamumvjj_EW6_LSM_T2_T2_5p50	-3.8863E-05	60000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502261	MGP _s 8EG_taptamumvjj_EW6_LSM_T2_T2_5p50	-1.9257E-05	50000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502262	MGP _s 8EG_taptamtapvjj_EW6_LSM_T2_T2_5p50	-3.8661E-05	60000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)
502263	MGP _s 8EG_taptamtamvjj_EW6_LSM_T2_T2_5p50	-1.9182E-05	48000	MadGraph(v.2.7.3p3.atlas5) + Pythia8(v.244p3) + EvtGen(v.1.7.0)

Appendix B

Additional Information about Total Cross-Section Measurement

B.1 Results of the Asimov Fit with EW $W^\pm W^\pm jj$ Signal

Distributions after the Asimov fit are shown in Figure B.1 and Figure B.2. Since it is a fit to expected data only the uncertainties change slightly due to constraining and correlation during the fit.

Table 8.5 show the yields after the fit to Asimov data. The uncertainties show first the statistical uncertainty derived from the mu uncertainty from the statistic uncertainty only fit. Secondly the theory uncertainty and at last the experimental uncertainties.

Table B.1: Post-fit yields in the WZ control region in the total cross-section measurement of EW $W^\pm W^\pm jj$ using Asimov data. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	$\ell\ell\ell$			
Other prompt	115	± 0	± 18	± 7
Conversions	$8.1 \pm 0.0 \pm 3.2 \pm 3.3$			
Non-prompt	28	± 0	± 8	± 8
WZ EW	141	± 0	± 8	± 4
WZ QCD	800	± 0	± 70	± 40
asimovData	$1091.8 \pm 0.0 \pm 0.0 \pm 0.0$			
Total Expected	1090	± 0	± 70	± 60

Pull plot and correlations are in Figure B.3.

The effect of all the nuisance parameters considered in the fit is shown in Tables B.2 and B.3 for systematic and MC statistical (gammas) uncertainties, respectively.

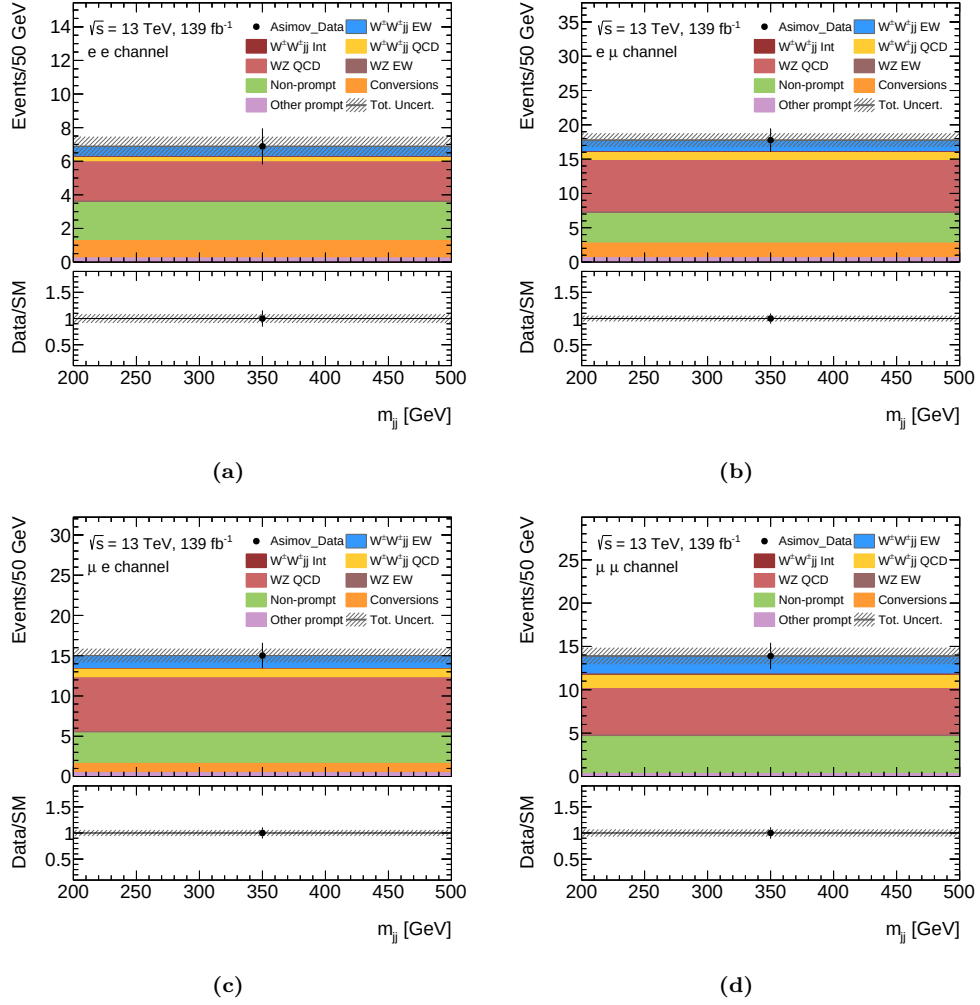


Figure B.1: Post-fit m_{jj} -distributions in low- m_{jj} control region for different flavour channels (a-d) as used in the total cross-section measurement of EW $W^\pm W^\pm jj$ using Asimov data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.

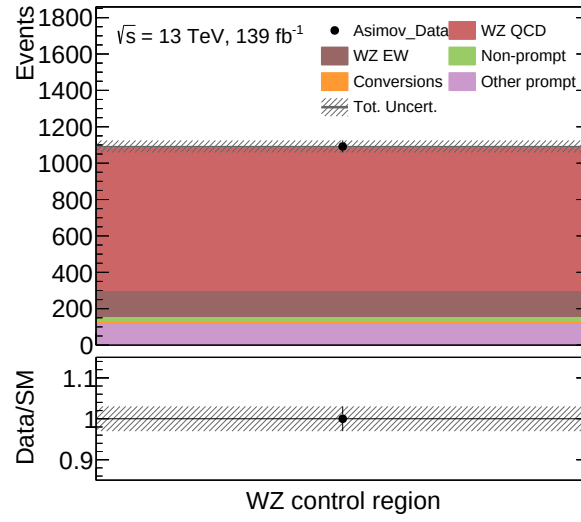


Figure B.2: Post-fit distributions in WZ control region used in the total cross-section measurement of EW $W^\pm W^\pm jj$ using Asimov data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.

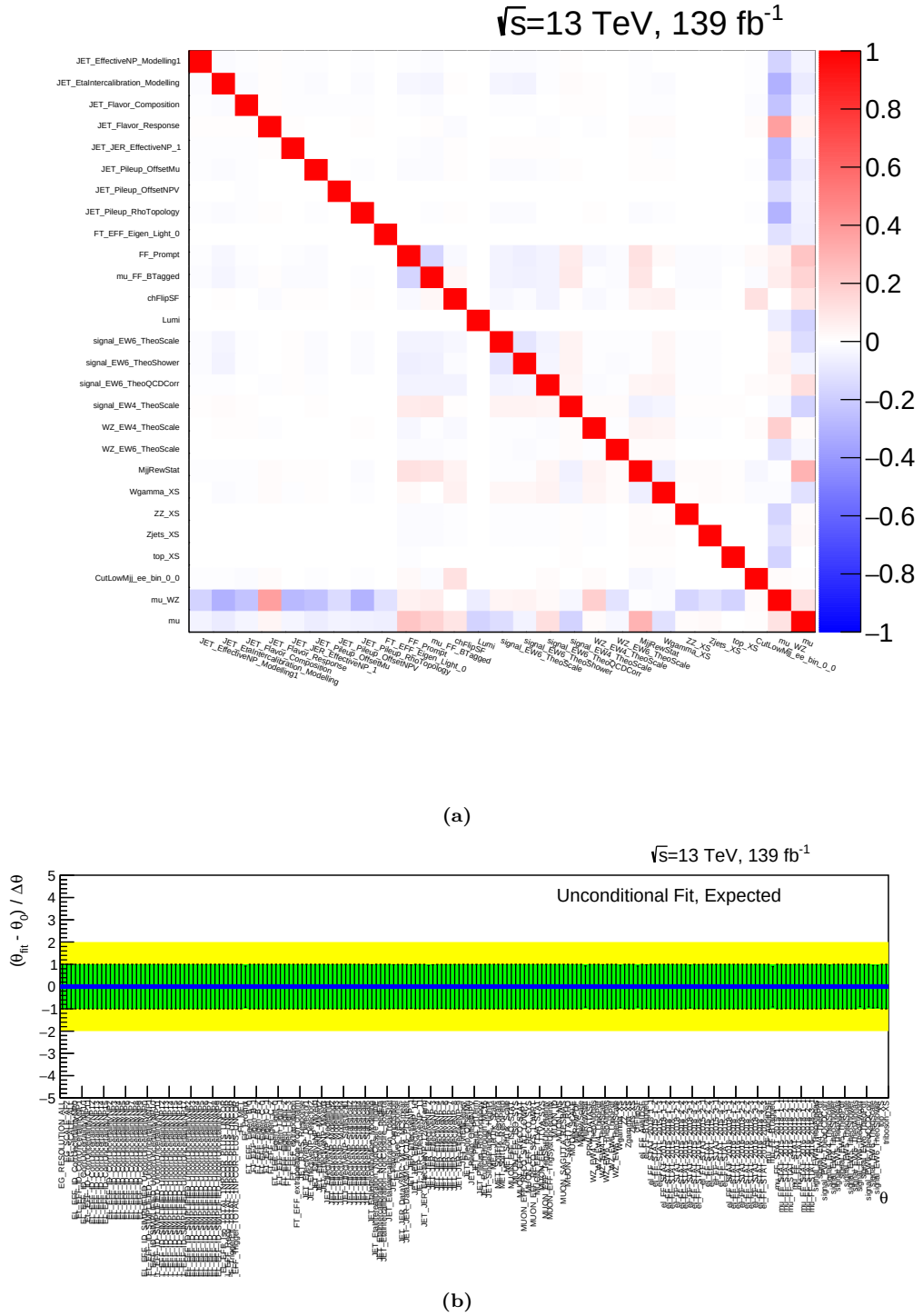


Figure B.3: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a) and nuisance parameter pull (b) used in the total cross-section measurement of EW $W^{\pm}W^{\pm}jj$ using Asimov data

Table B.2: Ranking of the systematic nuisance parameters included in the total cross-section measurement of EW $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using Asimov data.

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\theta_{\text{PF}}^{\text{up}}$	$\Delta\theta_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_MjRewStat	0.0000	0.9290	-0.9229	0.0319	-0.0311	0.0342	-0.0339
alpha_signal_EW6_TheoQCDCorr	0.0000	1.0000	-0.9118	0.0000	-0.0264	0.0000	-0.0291
alpha_FF_Prompt	-0.0000	0.9204	-0.9301	0.0257	-0.0224	0.0279	-0.0240
alpha_signal_EW4_TheoQCDCorr	0.0000	1.0000	-0.9843	0.0000	-0.0218	0.0000	-0.0222
alpha_mu_FF_BTagged	-0.0000	0.8974	-0.9113	0.0205	-0.0171	0.0228	-0.0182
Lumi	1.0000	0.0170	-0.0170	-0.0189	0.0196	-0.0189	0.0196
alpha_signal_EW4_TheoScale	-0.0000	0.9641	-0.9810	-0.0190	0.0125	-0.0198	0.0127
alpha_JET_EtaIntercalibration_Modelling	-0.0000	0.9836	-0.9851	-0.0156	0.0115	-0.0159	0.0116
alpha_signal_EW6_TheoEwcorr	0.0000	1.0000	-0.9010	0.0000	0.0152	0.0000	0.0167
alpha_signal_EW6_TheoScale	-0.0000	0.9491	-0.9589	-0.0147	0.0126	-0.0155	0.0131
alpha_JET_Pileup_OffsetMu	0.0000	0.9977	-0.9918	-0.0113	0.0045	-0.0114	0.0046
alpha_JET_JER_EffectiveNP_2	-0.0000	0.9474	-0.9902	-0.0107	0.0005	-0.0118	0.0005
alpha_Wgamma_XS	0.0000	0.9547	-0.9524	-0.0095	0.0094	-0.0100	0.0098
alpha_JET_Pileup_RhoTopology	0.0000	0.9917	-0.9919	-0.0094	0.0020	-0.0094	0.0020
alpha_JET_EffectiveNP_Modelling1	0.0000	0.9950	-0.9935	-0.0083	0.0016	-0.0083	0.0016
alpha_FT_EFF_Eigen_Light_0	-0.0000	0.9999	-0.9999	-0.0079	0.0077	-0.0079	0.0077
alpha_chFlipSF	-0.0000	0.9226	-0.9169	0.0073	-0.0076	0.0077	-0.0084
alpha_mu_FF_STAT_2015_2018_2_1	0.0000	0.9900	-0.9892	-0.0065	0.0070	-0.0066	0.0071
alpha_mu_FF_STAT_2015_2018_3_1	0.0000	0.9900	-0.9892	-0.0065	0.0070	-0.0066	0.0071
alpha_el_FF_STAT_2015_2018_3_1	0.0000	0.9648	-0.9620	-0.0052	0.0058	-0.0054	0.0060
alpha_JET_Pileup_OffsetNPV	0.0000	0.9937	-0.9952	-0.0055	0.0050	-0.0055	0.0050
alpha_JET_Flavor_Composition	-0.0000	0.9832	-0.9879	-0.0053	0.0023	-0.0054	0.0023
alpha_JET_Flavor_Response	0.0000	0.9929	-0.9911	0.0000	-0.0049	0.0000	-0.0049
alpha_JET_JER_EffectiveNP_1	-0.0000	0.9794	-0.9808	-0.0033	0.0049	-0.0034	0.0050
alpha_JET_JER_EffectiveNP_5	0.0000	0.9952	-0.9789	-0.0016	-0.0044	-0.0016	-0.0045
alpha_MUON_EFF_RECO_SYS	-0.0000	0.9994	-0.9995	-0.0038	0.0037	-0.0038	0.0037
alpha_signal_EW6_TheoShower	-0.0000	0.9438	-0.9407	-0.0038	0.0033	-0.0040	0.0034
alpha_WZ_EW6_TheoScale	-0.0000	0.9981	-0.9986	-0.0038	0.0029	-0.0038	0.0029
alpha_JET_JER_DataVsMC_MC16_MCsmeas	0.0000	1.0000	-0.9895	0.0000	-0.0037	0.0000	-0.0037

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\theta_{\text{PF}}^{\text{up}}$	$\Delta\theta_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_Zjets_XS	0.0000	0.9988	-0.9988	0.0036	-0.0037	0.0036	-0.0037
alpha_ZZ_XS	0.0000	0.9990	-0.9990	0.0031	-0.0033	0.0031	-0.0033
alpha_MjRewPDF	-0.0000	0.9990	-0.9989	0.0032	-0.0012	0.0032	-0.0012
alpha_JET_JER_EffectiveNP_3	-0.0000	0.9817	-0.9934	-0.0032	-0.0022	-0.0033	-0.0022
alpha_mu_FF_AntiDSF	-0.0000	0.9984	-0.9985	0.0030	-0.0029	0.0030	-0.0029
alpha_MET_SoftTrk_ResoPara	0.0000	1.0000	-0.9966	0.0000	0.0029	0.0000	0.0026
alpha_el_FF_STAT_2015_2018_3_3	0.0000	0.9894	-0.9890	-0.0026	0.0027	-0.0026	0.0027
alpha_JET_EtaIntercalibration_TotalStat	0.0000	0.9994	-0.9980	-0.0006	0.0023	-0.0006	0.0023
alpha_MUON_EFF_ISO_SYS	0.0000	0.9997	-0.9997	-0.0023	0.0022	-0.0023	0.0022
alpha_el_FF_BTagged	-0.0000	0.9818	-0.9824	0.0022	-0.0021	0.0022	-0.0021
alpha_signal_EW4_TheoShower	-0.0000	0.9993	-0.9993	0.0021	-0.0020	0.0021	-0.0021
alpha_JET_EffectiveNP_Mixed1	0.0000	0.9990	-0.9882	-0.0017	-0.0020	-0.0017	-0.0020
alpha_FF_MET	-0.0000	0.9954	-0.9977	0.0017	0.0018	0.0017	0.0018
alpha_JET_JER_EffectiveNP_4	0.0000	0.9941	-0.9948	-0.0017	0.0006	-0.0017	0.0006
alpha_FT_EFF_Eigen_C_0	-0.0000	0.9999	-0.9999	-0.0017	0.0017	-0.0017	0.0017
alpha_signal_EW6_TheoPdf	0.0000	0.9991	-0.9990	-0.0008	0.0016	-0.0008	0.0016
alpha_JET_Pileup_PtTerm	-0.0000	0.9959	-0.9979	-0.0011	0.0014	-0.0011	0.0014
alpha_JET_JER_EffectiveNP_6	0.0000	0.9935	-0.9931	-0.0013	-0.0000	-0.0014	-0.0000
alpha_FT_EFF_extrapolation_from_charm	-0.0000	0.9995	-0.9995	0.0012	-0.0012	0.0012	-0.0012
alpha_MET_SoftTrk_Scale	-0.0000	0.9997	-0.9996	0.0009	-0.0012	0.0009	-0.0012
alpha_JET_JER_DataVsMC_MC16_PDsmeas	-0.0000	0.9929	-1.0000	-0.0012	0.0000	-0.0012	0.0000
alpha_MUON_MS	-0.0000	0.9985	-0.9995	0.0011	0.0003	0.0011	0.0003
alpha_top_XS	0.0000	0.9997	-0.9997	0.0007	-0.0011	0.0007	-0.0011
alpha_MET_SoftTrk_ResoPerp	0.0000	1.0000	-0.9993	0.0000	0.0011	0.0000	0.0011
alpha_WZ_EW4_TheoScale	-0.0000	0.9858	-0.9902	-0.0003	-0.0010	-0.0003	-0.0010
alpha_JET_JER_EffectiveNP_7	-0.0000	0.9907	-0.9937	0.0000	-0.0010	0.0000	-0.0010
alpha_WZ_EW4_TheoPdf	0.0000	0.9990	-0.9983	0.0006	-0.0009	0.0006	-0.0009
alpha_JET_JER_EffectiveNP_11	-0.0000	0.9955	-0.9978	0.0009	-0.0005	0.0009	-0.0005
alpha_JET_EtaIntercalibration_NonClosure_negEta	-0.0000	0.9996	-1.0000	0.0008	0.0001	0.0008	0.0001
alpha_el_FF_STAT_2015_2018_2_1	0.0000	0.9980	-0.9980	-0.0008	0.0008	-0.0008	0.0008
alpha_JET_JER_EffectiveNP_12restTerm	0.0000	0.9976	-0.9952	0.0001	0.0008	0.0001	0.0008
alpha_JET_JER_EffectiveNP_9	-0.0000	0.9948	-0.9944	0.0007	-0.0008	0.0007	-0.0008

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\theta_{PF}^{up}$	$\Delta\theta_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
alpha_triboson_XS	0.0000	0.9997	-0.9997	0.0007	-0.0007	0.0007	-0.0007
alpha_el_FF_AntiDSF	-0.0000	0.9994	-0.9994	0.0007	-0.0007	0.0007	-0.0007
alpha_PRW_DATASF	-0.0000	0.9964	-0.9983	-0.0001	-0.0006	-0.0001	-0.0006
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP8	-0.0000	0.9993	-0.9993	-0.0006	0.0006	-0.0006	0.0006
alpha_Zgamma_XS	0.0000	0.9999	-0.9999	0.0006	-0.0006	0.0006	-0.0006
alpha_el_FF_STAT_2015_2018_1_1	0.0000	0.9987	-0.9987	-0.0005	0.0005	-0.0005	0.0005
alpha_JET_JER_EffectiveNP_10	0.0000	0.9991	-0.9978	0.0002	0.0005	0.0002	0.0005
alpha_JET_EffectiveNP_Mixed2	-0.0000	0.9997	-0.9994	0.0004	-0.0005	0.0004	-0.0005
alpha_signal_EW4_TheoPdf	-0.0000	0.9999	-0.9999	-0.0005	0.0005	-0.0005	0.0005
alpha_el_FF_STAT_2015_2018_2_3	0.0000	0.9989	-0.9989	-0.0005	0.0004	-0.0005	0.0004
alpha_EL_EFF_ID_CorrUncertaintyNP14	-0.0000	0.9998	-0.9998	-0.0004	0.0004	-0.0004	0.0004
alpha_signal_EW5_TheoShower	-0.0000	0.9997	-0.9997	0.0004	-0.0004	0.0004	-0.0004
alpha_EL_EFF_ID_CorrUncertaintyNP11	0.0000	0.9997	-0.9997	-0.0004	0.0004	-0.0004	0.0004
alpha_EL_EFF_Reco_TOTAL_1NPCOR_PLUS_UNCOR	0.0000	0.9999	-0.9999	-0.0004	0.0004	-0.0004	0.0004
alpha_EL_EFF_ID_CorrUncertaintyNP12	0.0000	0.9999	-0.9999	-0.0004	0.0004	-0.0004	0.0004
alpha_MUON_SCALE	0.0000	0.9998	-0.9998	0.0003	-0.0004	0.0003	-0.0004
alpha_mu_FF_STAT_2015_2018_1_1	0.0000	0.9999	-0.9999	-0.0004	0.0004	-0.0004	0.0004
alpha_JET_JER_EffectiveNP_8	-0.0000	0.9968	-0.9987	0.0001	0.0004	0.0001	0.0004
alpha_EL_EFF_ID_CorrUncertaintyNP15	-0.0000	0.9998	-0.9998	0.0003	-0.0003	0.0003	-0.0003
alpha_FT_EFF_Eigen_B_0	-0.0000	1.0000	-1.0000	-0.0003	0.0003	-0.0003	0.0003
alpha_JET_JvtEfficiency	0.0000	0.9999	-0.9999	0.0003	0.0000	0.0003	0.0000
alpha_EL_EFF_Iso_TOTAL_1NPCOR_PLUS_UNCOR	0.0000	0.9999	-0.9999	-0.0003	0.0003	-0.0003	0.0003
alpha_EL_EFF_ID_CorrUncertaintyNP9	-0.0000	0.9999	-0.9999	-0.0003	0.0003	-0.0003	0.0003
alpha_WZ_EW6_TheoPdf	0.0000	0.9999	-0.9999	-0.0002	0.0003	-0.0002	0.0003
alpha_MUON_EFF_TrigSystUncertainty	0.0000	0.9999	-0.9998	0.0002	-0.0002	0.0002	-0.0002
alpha_JET_EffectiveNP_Modelling3	0.0000	0.9999	-0.9994	0.0002	-0.0002	0.0002	-0.0002
alpha_MUON_ID	-0.0000	0.9998	-0.9998	-0.0001	-0.0002	-0.0001	-0.0002
alpha_MjRwScale	-0.0000	0.9997	-0.9996	0.0002	-0.0002	0.0002	-0.0002
alpha_FT_EFF_Eigen_Light_2	-0.0000	1.0000	-1.0000	-0.0002	0.0002	-0.0002	0.0002
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP17	0.0000	0.9998	-0.9998	-0.0002	0.0002	-0.0002	0.0002
alpha_MUON_EFF_RECO_STAT	0.0000	1.0000	-1.0000	-0.0002	0.0002	-0.0002	0.0002
alpha_FT_EFF_Eigen_C_1	0.0000	1.0000	-1.0000	-0.0002	0.0002	-0.0002	0.0002

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\theta_{\text{PF}}^{\text{up}}$	$\Delta\theta_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_JET_EffectiveNP_Detector1	0.0000	0.9998	-0.9999	-0.0001	0.0002	-0.0001	0.0002
alpha_JET_EffectiveNP_Statistical3	-0.0000	1.0000	-1.0000	0.0000	-0.0002	0.0000	-0.0002
alpha_MUON_EFF_ITVA_SYS	-0.0000	1.0000	-1.0000	-0.0002	0.0002	-0.0002	0.0002
alpha_el_FF_STAT_2015_3_1	0.0000	0.9999	-0.9999	-0.0002	0.0002	-0.0002	0.0002
alpha_JET_EffectiveNP_Statistical2	-0.0000	0.9999	-0.9998	0.0002	-0.0001	0.0002	-0.0001
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP6	0.0000	1.0000	-1.0000	-0.0002	0.0002	-0.0002	0.0002
alpha_JET_EtaIntercalibration_NonClosure_posEta	0.0000	1.0000	-0.9999	-0.0001	0.0002	-0.0001	0.0002
alpha_EL_EFF_ID_CorrUncertaintyNP13	-0.0000	0.9999	-0.9999	-0.0001	0.0001	-0.0001	0.0001
alpha_MUON_EFF_ITVA_STAT	0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_FT_EFF_extrapolation	0.0000	1.0000	-1.0000	0.0001	-0.0001	0.0001	-0.0001
alpha_MUON_EFF_ISO_STAT	-0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_signal_EW6_TheoAlphas	0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_FT_EFF_Eigen_B_1	0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_EL_EFF_ID_CorrUncertaintyNP10	-0.0000	0.9999	-0.9999	0.0001	-0.0001	0.0001	-0.0001
alpha_JET_EffectiveNP_Modelling2	-0.0000	0.9999	-0.9999	-0.0000	0.0001	-0.0000	0.0001
alpha_JET_EffectiveNP_Mixed3	0.0000	0.9999	-1.0000	-0.0000	0.0001	-0.0000	0.0001
alpha_JET_BJES_Response	0.0000	1.0000	-0.9999	0.0000	-0.0001	0.0000	-0.0001
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP7	-0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_MUON_EFF_TrigStatUncertainty	0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_JET_EffectiveNP_Statistical1	0.0000	1.0000	-1.0000	-0.0001	0.0000	-0.0001	0.0000
alpha_JET_EffectiveNP_Statistical4	-0.0000	0.9999	-0.9999	-0.0000	0.0001	-0.0000	0.0001
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP15	0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_WZ_EW4_TheoAlphas	0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_JET_EffectiveNP_Statistical5	-0.0000	1.0000	-0.9999	0.0001	-0.0000	0.0001	-0.0000
alpha_EG_RESOLUTION_ALL	0.0000	0.9995	-0.9995	-0.0000	-0.0001	-0.0000	-0.0001
alpha_FT_EFF_Eigen_B_2	-0.0000	1.0000	-1.0000	0.0001	-0.0001	0.0001	-0.0001
alpha_MUON_SAGITTA_RESBIAS	0.0000	0.9996	-0.9994	-0.0000	0.0001	-0.0000	0.0001
alpha_signal_EW5_TheoScale	-0.0000	1.0000	-1.0000	0.0001	-0.0001	0.0001	-0.0001
alpha_el_FF_STAT_2016_2018_3_3	0.0000	0.9999	-0.9999	-0.0000	0.0001	-0.0000	0.0001
alpha_JET_EffectiveNP_Modelling4	-0.0000	0.9999	-1.0000	-0.0000	0.0001	-0.0000	0.0001
alpha_JET_EffectiveNP_Statistical6	-0.0000	0.9999	-1.0000	0.0000	0.0001	0.0000	0.0001
alpha_el_FF_STAT_2015_2018_1_3	0.0000	0.9999	-0.9999	-0.0000	0.0001	-0.0000	0.0001

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\hat{\theta}_{\text{PF}}^{\text{up}}$	$\Delta\hat{\theta}_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP16	-0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP8	-0.0000	0.9999	-0.9999	-0.0000	0.0000	-0.0000	0.0000
alpha_EG_SCALE_ALL	-0.0000	0.9996	-0.9998	0.0000	-0.0000	0.0000	-0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP5	-0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_signal_EW4_TheoAlphas	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_mu_FF_STAT_2016_2018_3_1	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_signal_EW5_TheoPdf	-0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_FT_EFF_Eigen_C_2	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_JET_PunchThrough_MC16	-0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_mu_FF_STAT_2016_2018_2_1	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_WZ_EW6_TheoAlphas	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_Trigger_TOTAL_1NPCOR_PLUS_UNCOR	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP14	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_JET_EffectiveNP_Detector2	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_FT_EFF_Eigen_Light_3	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_mu_FF_STAT_2015_3_1	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_FT_EFF_Eigen_Light_1	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_signal_EW5_TheoAlphas	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP4	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP3	-0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_el_FF_STAT_2016_2018_2_3	-0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP6	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_el_FF_STAT_2016_2018_2_1	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP5	-0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_el_FF_STAT_2016_2018_1_3	-0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_el_FF_STAT_2015_2018_3_2	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_el_FF_STAT_2015_2018_1_2	-0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_mu_FF_STAT_2016_2018_1_1	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_el_FF_STAT_2016_2018_1_1	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_EL_EFF_TriggerEff_TOTAL_1NPCOR_PLUS_UNCOR	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP11	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	0.0000
alpha_MUON_EFF_REC0_SYS_LOWPT	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\theta_{\text{PF}}^{\text{up}}$	$\Delta\theta_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_el_FF_STAT_2015_1_3	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP0	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_1_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_MUON_EFF_RECO_STAT_LOWPT	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_1_1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP13	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_MET_JetTrk_Scale	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP12	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_JET_EtaIntercalibration_NonClosure_highE	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_JET_SingleParticle_HighPt	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP10	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP9	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2_1	-0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2_3	-0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_3_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_3_3	-0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_1_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_2_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_3_1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_3_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EG_SCALE_AF2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP7	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_mu_FF_STAT_2015_2_1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_mu_FF_STAT_2015_1_1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2018_2_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP4	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_MUON_SAGITTA_RHO	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP0	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\hat{\theta}_{PF}^{up}$	$\Delta\hat{\theta}_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP3	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000

Table B.3: Ranking of the MC statistical nuisance parameters included in the total cross-section measurement of EW $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using Asimov data.

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\hat{\theta}_{PF}^{up}$	$\Delta\hat{\theta}_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
gamma_stat_CutSR_mm_bin_1_0	1.0000	0.0366	-0.0358	-0.0057	0.0056	-0.0058	0.0058
gamma_stat_CutSR_me_bin_1_0	1.0000	0.0411	-0.0400	-0.0046	0.0046	-0.0048	0.0047
gamma_stat_CutSR_em_bin_1_0	1.0000	0.0377	-0.0368	-0.0043	0.0042	-0.0044	0.0043
gamma_stat_CutSR_mm_bin_2_0	1.0000	0.0473	-0.0458	-0.0038	0.0037	-0.0039	0.0038
gamma_stat_CutSR_me_bin_2_0	1.0000	0.0449	-0.0436	-0.0029	0.0029	-0.0030	0.0029
gamma_stat_CutSR_em_bin_3_0	1.0000	0.1217	-0.1125	-0.0029	0.0028	-0.0031	0.0029
gamma_stat_CutSR_ee_bin_1_0	1.0000	0.0585	-0.0563	-0.0029	0.0028	-0.0030	0.0029
gamma_stat_CutSR_mm_bin_0_0	1.0000	0.0359	-0.0351	-0.0029	0.0028	-0.0034	0.0029
gamma_stat_CutSR_me_bin_0_0	1.0000	0.0432	-0.0420	-0.0029	0.0028	-0.0030	0.0029
gamma_stat_CutSR_em_bin_0_0	1.0000	0.0389	-0.0379	-0.0028	0.0027	-0.0029	0.0029
gamma_stat_CutSR_em_bin_2_0	1.0000	0.0326	-0.0319	-0.0025	0.0025	-0.0025	0.0025
gamma_stat_CutSR_mm_bin_3_0	1.0000	0.0642	-0.0616	-0.0021	0.0021	-0.0022	0.0021
gamma_stat_CutSR_mm_bin_4_0	1.0000	0.0516	-0.0499	-0.0021	0.0021	-0.0021	0.0021
gamma_stat_CutSR_me_bin_3_0	1.0000	0.0820	-0.0778	-0.0021	0.0020	-0.0021	0.0020
gamma_stat_CutSR_ee_bin_3_0	1.0000	0.1680	-0.1510	-0.0020	0.0018	-0.0021	0.0019
gamma_stat_CutSR_ee_bin_0_0	1.0000	0.0606	-0.0582	-0.0017	0.0017	-0.0018	0.0017
gamma_stat_CutSR_ee_bin_4_0	1.0000	0.1093	-0.1019	-0.0017	0.0013	-0.0018	0.0013
gamma_stat_CutSR_em_bin_4_0	1.0000	0.0426	-0.0414	-0.0012	0.0012	-0.0012	0.0012
gamma_stat_CutCRWZ3Lep_all_bin_0	1.0000	0.0043	-0.0043	0.0012	-0.0012	0.0012	-0.0012
gamma_stat_CutSR_ee_bin_2_0	1.0000	0.0415	-0.0404	-0.0011	0.0010	-0.0011	0.0010
gamma_stat_CutSR_me_bin_4_0	1.0000	0.0210	-0.0208	-0.0006	0.0006	-0.0006	0.0006
gamma_stat_CutLowMjj_em_bin_0_0	1.0000	0.0388	-0.0378	0.0005	-0.0005	0.0006	-0.0006

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\hat{\theta}_{\text{PF}}^{\text{up}}$	$\Delta\hat{\theta}_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
gamma_stat_CutLowMjj_ee_bin_0_0	1.0000	0.0618	-0.0593	0.0005	-0.0005	0.0006	-0.0005
gamma_stat_CutLowMjj_mm_bin_0_0	1.0000	0.0353	-0.0345	0.0004	-0.0004	0.0004	-0.0004
gamma_stat_CutLowMjj_me_bin_0_0	1.0000	0.0355	-0.0347	-0.0000	-0.0001	-0.0000	-0.0002

B.2 Results of the Asimov Fit with Inclusive $W^\pm W^\pm jj$ Signal

Distributions after the Asimov fit are shown in Figure B.4, Figure B.5 and Figure B.6. Since it is a fit to expected data only the uncertainties change slightly due to constraining and correlation during the fit.

Table B.4 to B.6 show the yields after the fit to Asimov data. The uncertainties show first the statistical uncertainty derived from the mu uncertainty from the statistic uncertainty only fit. Secondly the theory uncertainty and at last the experimental uncertainties.

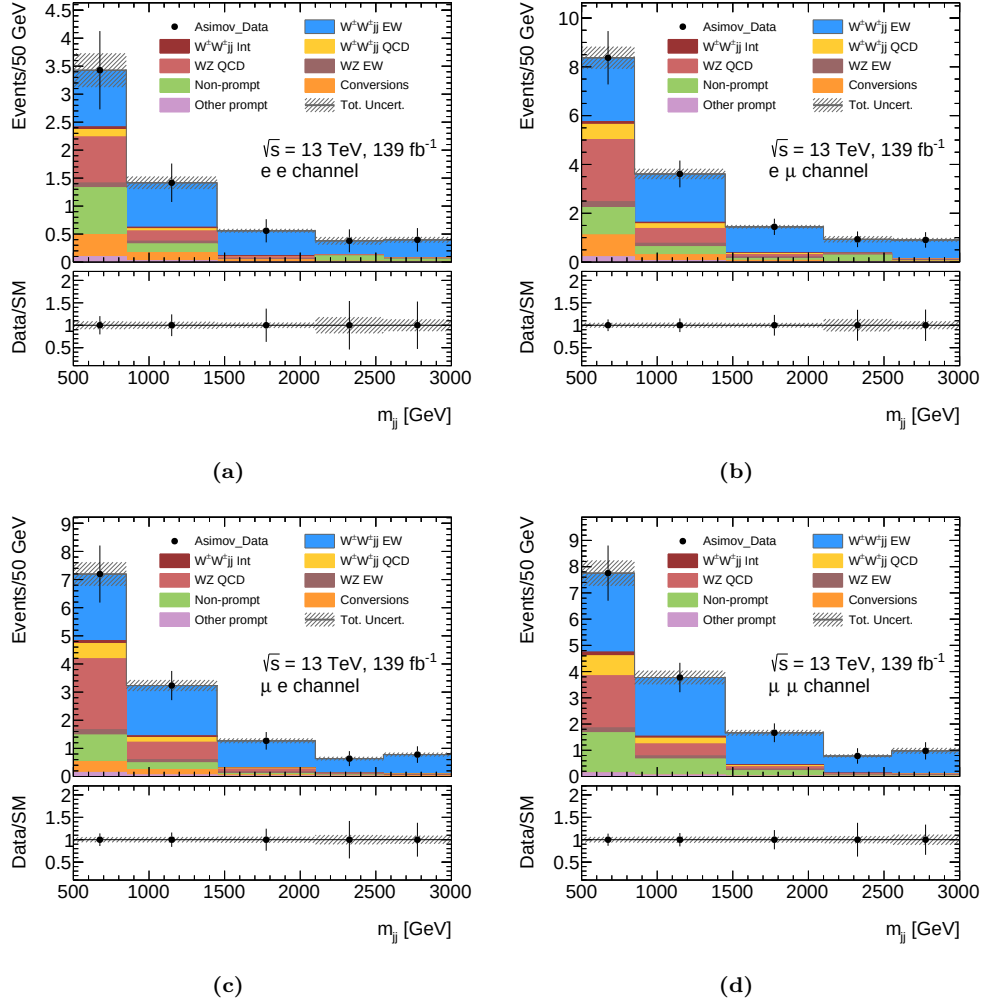


Figure B.4: Post-fit m_{jj} -distributions in signal region for different flavour (a-d) channels as used in the total cross-section measurement of inclusive $W^{\pm}W^{\pm}jj$ using Asimov data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.

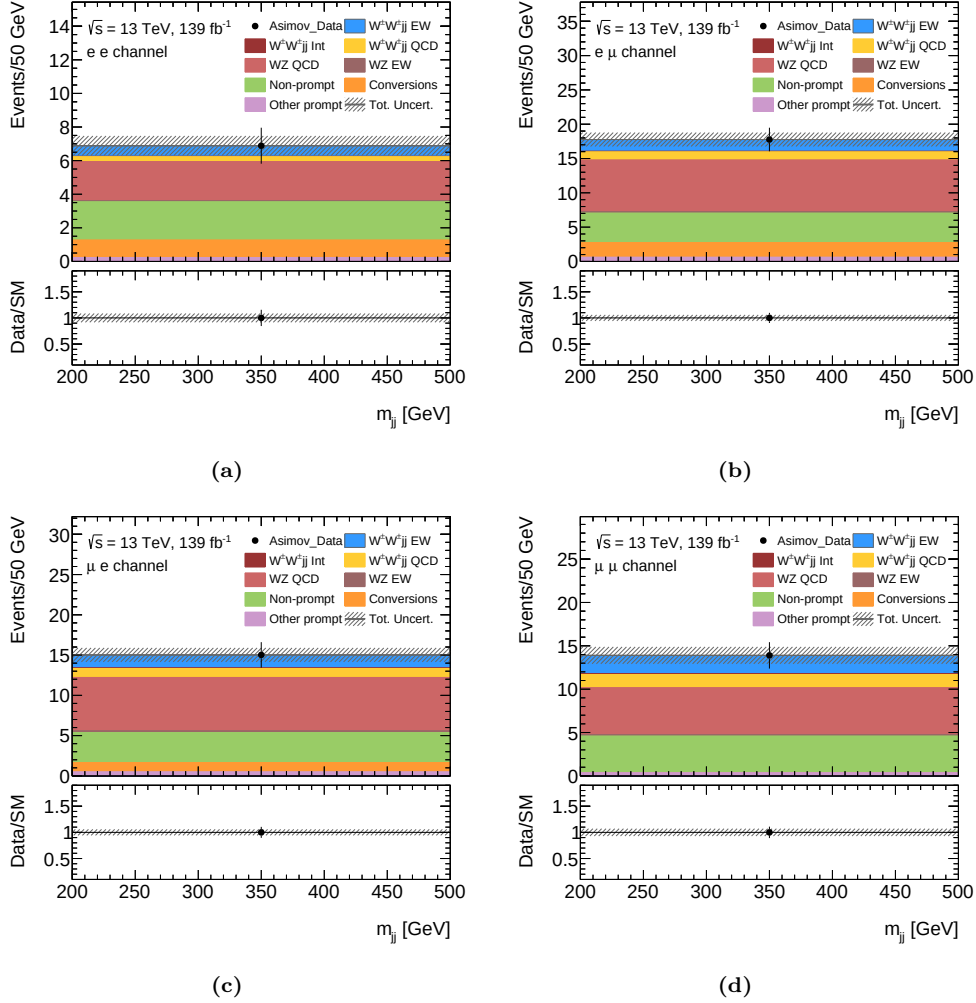


Figure B.5: Post-fit m_{jj} -distributions in low- m_{jj} control region for different flavour channels (a-d) as used in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.

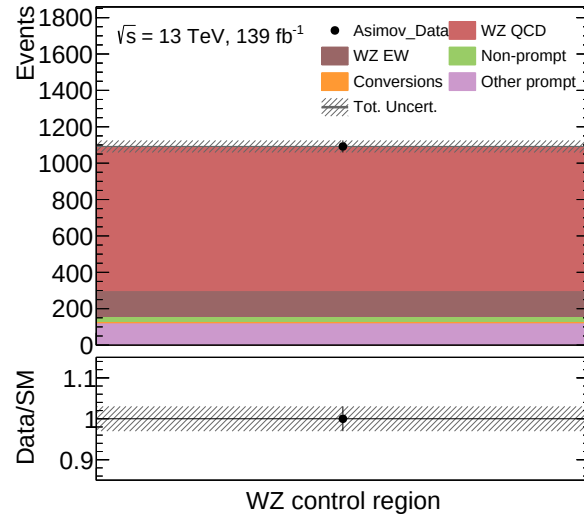


Figure B.6: Post-fit distributions in WZ control region used in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.

Table B.4: Post-fit yields in the signal region in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	$e^\pm e^\pm$	$\mu^\pm \mu^\pm$	$e^\pm \mu^\pm$	$\mu^\pm e^\pm$	$\ell^\pm \ell^\pm$
Other prompt	$1.02 \pm 0.00 \pm 0.19 \pm 0.19$	$1.7 \pm 0.0 \pm 0.4 \pm 2.1$	$2.5 \pm 0.0 \pm 0.5 \pm 0.2$	$1.8 \pm 0.0 \pm 0.3 \pm 0.4$	$7.1 \pm 0.0 \pm 1.3 \pm 2.4$
Conversions	$5.1 \pm 0.0 \pm 0.5 \pm 1.9$	$0.003 \pm 0.000 \pm 0.001 \pm 0.004$	$10.1 \pm 0.0 \pm 1.8 \pm 1.4$	$5.8 \pm 0.0 \pm 1.7 \pm 1.6$	$21 \pm 0 \pm 4 \pm 4$
Non-prompt	$8.9 \pm 0.0 \pm 0.4 \pm 1.7$	$21 \pm 0 \pm 0 \pm 5$	$15.3 \pm 0.0 \pm 0.4 \pm 2.4$	$10.2 \pm 0.0 \pm 0.3 \pm 1.6$	$56 \pm 0 \pm 1 \pm 9$
WZ EW	$1.71 \pm 0.00 \pm 0.13 \pm 0.06$	$4.16 \pm 0.00 \pm 0.35 \pm 0.15$	$4.9 \pm 0.0 \pm 0.4 \pm 0.2$	$4.12 \pm 0.00 \pm 0.33 \pm 0.15$	$14.9 \pm 0.0 \pm 1.2 \pm 0.5$
WZ QCD	$8.4 \pm 0.0 \pm 1.1 \pm 0.7$	$20.9 \pm 0.0 \pm 2.5 \pm 1.1$	$26.8 \pm 0.0 \pm 3.3 \pm 1.6$	$26.7 \pm 0.0 \pm 3.3 \pm 1.4$	$83 \pm 0 \pm 10 \pm 4$
$W^\pm W^\pm jj$ QCD	$1.55 \pm 0.12 \pm 0.13 \pm 0.06$	$8.8 \pm 0.7 \pm 0.4 \pm 0.3$	$7.3 \pm 0.5 \pm 0.3 \pm 0.2$	$6.4 \pm 0.5 \pm 0.2 \pm 0.2$	$24.0 \pm 1.8 \pm 0.8 \pm 0.8$
$W^\pm W^\pm jj$ Int	$0.93 \pm 0.07 \pm 0.04 \pm 0.03$	$2.51 \pm 0.19 \pm 0.08 \pm 0.06$	$2.19 \pm 0.16 \pm 0.06 \pm 0.06$	$1.96 \pm 0.15 \pm 0.05 \pm 0.05$	$7.6 \pm 0.6 \pm 0.2 \pm 0.2$
asimovData	$55.2 \pm 0.0 \pm 0.0 \pm 0.0$	$137.1 \pm 0.0 \pm 0.0 \pm 0.0$	$137.3 \pm 0.0 \pm 0.0 \pm 0.0$	$118.4 \pm 0.0 \pm 0.0 \pm 0.0$	$448.0 \pm 0.0 \pm 0.0 \pm 0.0$
$W^\pm W^\pm jj$ EW	$27.6 \pm 2.1 \pm 1.3 \pm 0.7$	$78 \pm 6 \pm 2 \pm 2$	$68 \pm 5 \pm 2 \pm 2$	$61 \pm 5 \pm 2 \pm 2$	$235 \pm 18 \pm 6 \pm 6$
Total Expected	$55.2 \pm 2.3 \pm 2.4 \pm 2.8$	$137 \pm 7 \pm 4 \pm 6$	$137 \pm 6 \pm 5 \pm 5$	$118 \pm 5 \pm 5 \pm 4$	$448 \pm 20 \pm 13 \pm 15$

Table B.5: Post-fit yields in the low- m_{jj} control region in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	$e^\pm e^\pm$	$\mu^\pm \mu^\pm$	$e^\pm \mu^\pm$	$\mu^\pm e^\pm$	$\ell^\pm \ell^\pm$
Other prompt	$1.36 \pm 0.00 \pm 0.25 \pm 0.14$	$2.0 \pm 0.0 \pm 0.4 \pm 0.2$	$3.6 \pm 0.0 \pm 0.7 \pm 0.2$	$2.8 \pm 0.0 \pm 0.5 \pm 0.2$	$9.8 \pm 0.0 \pm 1.8 \pm 0.7$
Conversions	$6.2 \pm 0.0 \pm 0.7 \pm 2.4$	$0.0 \pm 0.0 \pm 0.0 \pm 0.0$	$12.8 \pm 0.0 \pm 2.8 \pm 1.6$	$6.9 \pm 0.0 \pm 1.9 \pm 2.6$	$26 \pm 0 \pm 5 \pm 5$
Non-prompt	$13.7 \pm 0.0 \pm 0.8 \pm 1.5$	$25 \pm 0 \pm 1 \pm 6$	$26 \pm 0 \pm 1 \pm 4$	$22.5 \pm 0.0 \pm 0.8 \pm 2.6$	$87 \pm 0 \pm 2 \pm 12$
WZ EW	$0.49 \pm 0.00 \pm 0.03 \pm 0.04$	$1.13 \pm 0.00 \pm 0.04 \pm 0.06$	$1.56 \pm 0.00 \pm 0.06 \pm 0.07$	$1.19 \pm 0.00 \pm 0.05 \pm 0.06$	$4.36 \pm 0.00 \pm 0.11 \pm 0.17$
WZ QCD	$14.0 \pm 0.0 \pm 1.7 \pm 1.0$	$32.3 \pm 0.0 \pm 3.5 \pm 1.5$	$45 \pm 0 \pm 5 \pm 2$	$40 \pm 0 \pm 4 \pm 3$	$131 \pm 0 \pm 14 \pm 7$
$W^\pm W^\pm jj$ QCD	$1.65 \pm 0.12 \pm 0.22 \pm 0.06$	$9.0 \pm 0.7 \pm 1.4 \pm 0.3$	$7.1 \pm 0.5 \pm 1.0 \pm 0.2$	$6.5 \pm 0.5 \pm 0.9 \pm 0.2$	$24.3 \pm 1.8 \pm 3.4 \pm 0.8$
$W^\pm W^\pm jj$ Int	$0.182 \pm 0.014 \pm 0.014 \pm 0.022$	$0.79 \pm 0.06 \pm 0.06 \pm 0.03$	$0.63 \pm 0.05 \pm 0.04 \pm 0.03$	$0.55 \pm 0.04 \pm 0.04 \pm 0.02$	$2.16 \pm 0.16 \pm 0.13 \pm 0.06$
asimovData	$41.3 \pm 0.0 \pm 0.0 \pm 0.0$	$83.4 \pm 0.0 \pm 0.0 \pm 0.0$	$106.6 \pm 0.0 \pm 0.0 \pm 0.0$	$90.1 \pm 0.0 \pm 0.0 \pm 0.0$	$321.5 \pm 0.0 \pm 0.0 \pm 0.0$
$W^\pm W^\pm jj$ EW	$3.8 \pm 0.3 \pm 0.7 \pm 0.1$	$12.7 \pm 1.0 \pm 1.7 \pm 0.3$	$10.4 \pm 0.8 \pm 1.7 \pm 0.3$	$9.8 \pm 0.7 \pm 1.5 \pm 0.3$	$37 \pm 3 \pm 5 \pm 1$
Total Expected	$41.3 \pm 0.4 \pm 3.0 \pm 3.1$	$83 \pm 2 \pm 5 \pm 6$	$107 \pm 1 \pm 6 \pm 5$	$90 \pm 1 \pm 5 \pm 6$	$321 \pm 5 \pm 16 \pm 17$

Table B.6: Post-fit yields in the WZ control region in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	lll			
Other prompt	115	± 0	± 18	± 7
Conversions	8.1 ± 0.0	± 3.2	± 3.3	
Non-prompt	28	± 0	± 8	± 8
WZ EW	141	± 0	± 8	± 4
WZ QCD	800	± 0	± 70	± 40
asimovData	1091.8 ± 0.0	± 0.0	± 0.0	± 0.0
Total Expected	1090	± 0	± 70	± 60

Pull plot and correlations are in Figure B.7.

There is some constraint of signal_EWAll_TheoShower, but relatively small.

The strongest (anti-)correlations are included in Table B.7. Most of the correlations are due to normalisation effects of a systematic on the signal and QCD $W^\pm Zjj$ background which can be equalised by the corresponding signal or QCD $W^\pm Zjj$ normalisation strength.

The effect of all the nuisance parameters considered in the fit is shown in Tables B.8 and B.9 for systematic and MC statistical (gammas) uncertainties, respectively.

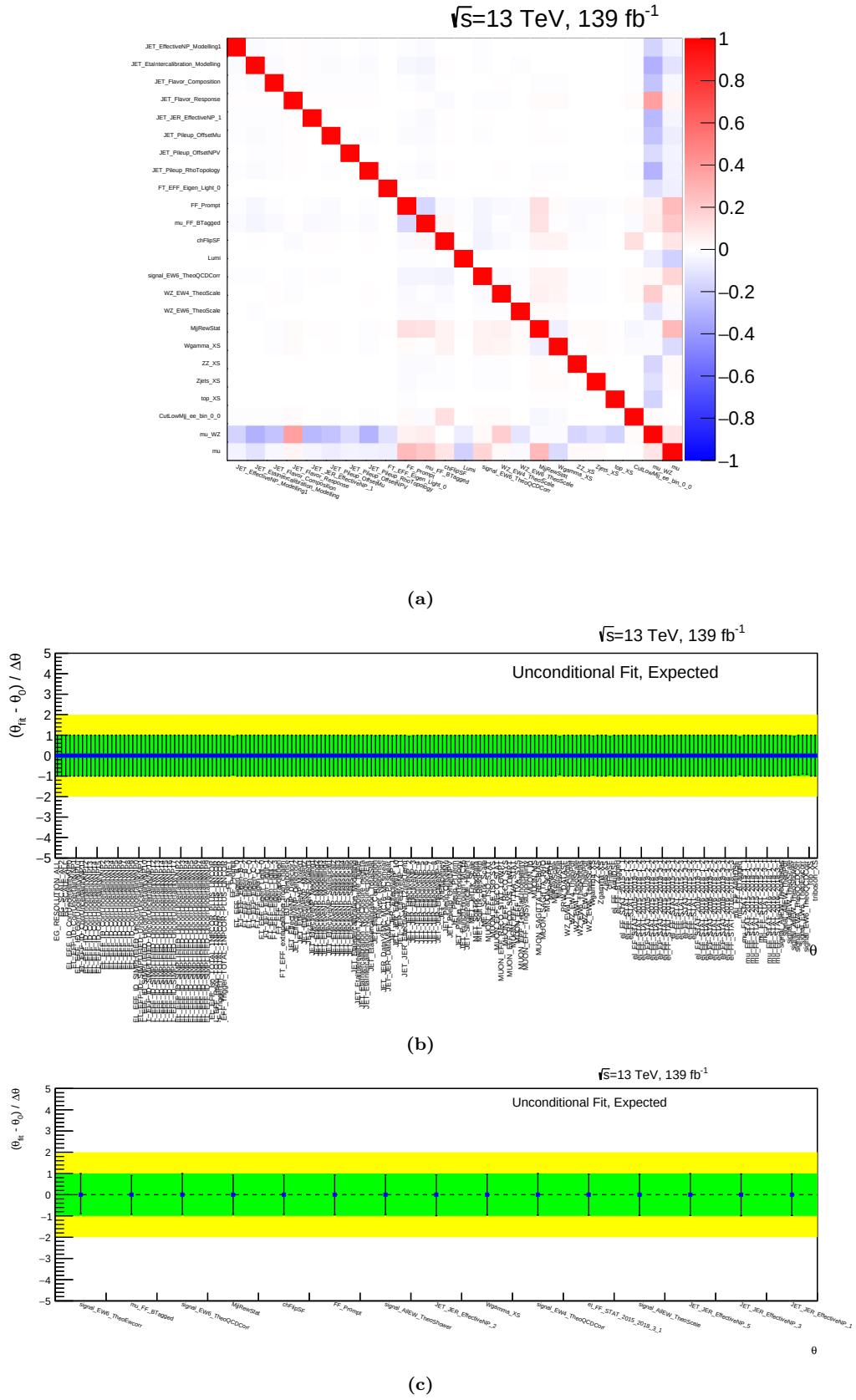


Figure B.7: Correlation of nuisance parameters with at least 20% correlation with another nuisance parameter (a) and nuisance parameter pull of all (b) and of strongest constrained nuisance parameters (c) used in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Table B.7: List of parameter correlations which are larger than 7.5% in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	μ_{WZ}	0.374
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.307
JET_Pileup_RhoTopology	μ_{WZ}	-0.299
MjjRewStat	μ	0.277
JET_JER_EffectiveNP_1	μ_{WZ}	-0.277
FF_Prompt	μ	0.264
JET_Flavor_Composition	μ_{WZ}	-0.237
JET_Pileup_OffsetMu	μ_{WZ}	-0.237
$\mu_{FF_BTagged}$	μ	0.219
WZ_EW4_TheoScale	μ_{WZ}	0.193
Lumi	μ	-0.179
top_XS	μ_{WZ}	-0.176
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.172
signal_EW6_TheoQCDCorr	μ	0.164
ZZ_XS	μ_{WZ}	-0.162
FF_Prompt	$\mu_{FF_BTagged}$	-0.154
Wgamma_XS	μ	-0.141
JET_Pileup_OffsetNPV	μ_{WZ}	-0.139
chFlipSF	CutLowMjj_ee_bin_0_0	0.123
FF_Prompt	MjjRewStat	0.122
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.119
Zjets_XS	μ_{WZ}	-0.114
MjjRewStat	$\mu_{FF_BTagged}$	0.112
JET_EtaIntercalibration_Modelling	μ	-0.108
WZ_EW6_TheoScale	μ_{WZ}	-0.106
μ	μ_{WZ}	0.104
chFlipSF	μ	0.102
$\mu_{FF_BTagged}$	CutLowMjj_mm_bin_0_0	0.093
signal_AlleW_TheoShower	signal_EW6_TheoEwcorr	-0.090
$\mu_{FF_STAT_2015_2018_3_1}$	μ	-0.090
$\mu_{FF_STAT_2015_2018_2_1}$	μ	-0.090
signal_AlleW_TheoScale	signal_AlleW_TheoShower	-0.077
MET_SoftTrk_Scale	μ_{WZ}	0.077
chFlipSF	el_FF_STAT_2015_2018_3_1	0.077

Table B.8: Ranking of the systematic nuisance parameters included in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using Asimov data.

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\theta_{\text{PF}}^{\text{up}}$	$\Delta\theta_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_signal_EW6_TheoQCDCorr	0.0000	1.0000	-0.9158	0.0000	-0.0284	0.0000	-0.0309
alpha_FF_Prompt	-0.0000	0.9256	-0.9344	0.0270	-0.0236	0.0292	-0.0251
alpha_MjjRewStat	0.0000	0.9231	-0.9166	0.0267	-0.0264	0.0288	-0.0288
alpha_mu_FF_BTagged	-0.0000	0.9014	-0.9147	0.0230	-0.0188	0.0259	-0.0205
Lumi	1.0000	0.0170	-0.0170	-0.0173	0.0179	-0.0173	0.0179
alpha_JET_EtaIntercalibration_Modelling	0.0000	0.9826	-0.9839	-0.0139	0.0101	-0.0141	0.0102
alpha_signal_EW6_TheoEwcorr	0.0000	1.0000	-0.8924	0.0000	0.0123	0.0000	0.0138
alpha_Wgamma_XS	0.0000	0.9557	-0.9535	-0.0102	0.0101	-0.0107	0.0142
alpha_JET_Pileup_OffsetMu	0.0000	0.9973	-0.9912	-0.0099	0.0036	-0.0099	0.0036
alpha_JET_Pileup_RhoTopology	0.0000	0.9915	-0.9915	-0.0087	0.0015	-0.0088	0.0015
alpha_JET_JER_EffectiveNP_2	-0.0000	0.9313	-0.9902	-0.0084	0.0006	-0.0090	0.0007
alpha_JET_EffectiveNP_Modelling1	0.0000	0.9949	-0.9930	-0.0077	0.0011	-0.0078	0.0011
alpha_FT_EFF_Eigen_Light_0	-0.0000	0.9999	-0.9999	-0.0073	0.0071	-0.0073	0.0071
alpha_chFlipSF	-0.0000	0.9234	-0.9171	0.0069	-0.0073	0.0073	-0.0081
alpha_mu_FF_STAT_2015_2018_3_1	0.0000	0.9903	-0.9896	-0.0067	0.0072	-0.0068	0.0073
alpha_mu_FF_STAT_2015_2018_2_1	0.0000	0.9903	-0.9896	-0.0067	0.0072	-0.0068	0.0073
alpha_JET_Pileup_OffsetNPV	0.0000	0.9937	-0.9952	-0.0053	0.0045	-0.0054	0.0045
alpha_el_FF_STAT_2015_2018_3_1	0.0000	0.9648	-0.9622	-0.0049	0.0053	-0.0050	0.0055
alpha_JET_Flavor_Response	0.0000	0.9926	-0.9910	-0.0002	-0.0048	-0.0002	-0.0048
alpha_JET_Flavor_Composition	-0.0000	0.9825	-0.9876	-0.0047	0.0013	-0.0048	0.0014
alpha_JET_JER_EffectiveNP_1	-0.0000	0.9791	-0.9810	-0.0025	0.0046	-0.0025	0.0047
alpha_ZZ_XS	0.0000	0.9991	-0.9991	0.0034	-0.0036	0.0034	-0.0036
alpha_MUON_EFF_RECO_SYS	-0.0000	0.9994	-0.9995	-0.0035	0.0022	-0.0035	0.0022
alpha_signal_AllEW_TheoScale	-0.0000	0.9702	-0.9747	-0.0029	0.0033	-0.0029	0.0034
alpha_signal_EW4_TheoQCDCorr	0.0000	1.0000	-0.9611	0.0000	-0.0032	0.0000	-0.0033
alpha_mu_FF_AntiDSF	-0.0000	0.9986	-0.9986	0.0030	-0.0029	0.0030	-0.0029
alpha_JET_JER_EffectiveNP_3	-0.0000	0.9779	-0.9933	-0.0029	-0.0017	-0.0030	-0.0018
alpha_MjjRewPDF	-0.0000	0.9989	-0.9988	0.0028	-0.0008	0.0028	-0.0008
alpha_WZ_EW6_TheoScale	-0.0000	0.9978	-0.9984	-0.0028	0.0021	-0.0028	0.0021

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\theta_{\text{PF}}^{\text{up}}$	$\Delta\theta_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_el_FF_STAT_2015_2018_3_3	0.0000	0.9894	-0.9891	-0.0025	0.0026	-0.0026	0.0027
alpha_MET_SoftTrk_ResoPara	0.0000	1.0000	-0.9966	0.0000	0.0025	0.0000	0.0025
alpha_Zjets_XS	0.0000	0.9988	-0.9988	0.0024	-0.0024	0.0024	-0.0024
alpha_el_FF_BTagged	-0.0000	0.9819	-0.9825	0.0023	-0.0023	0.0024	-0.0023
alpha_signal_AllEW_TheoShower	-0.0000	0.9305	-0.9276	0.0017	-0.0022	0.0018	-0.0024
alpha_JET_JER_DataVsMC_MC16_MCsmear	0.0000	1.0000	-0.9893	0.0000	-0.0022	0.0000	-0.0029
alpha_MUON_EFF_ISO_SYS	0.0000	0.9997	-0.9997	-0.0021	0.0021	-0.0021	0.0021
alpha_JET_JER_EffectiveNP_5	0.0000	0.9952	-0.9758	-0.0014	-0.0021	-0.0014	-0.0021
alpha_JET_EffectiveNP_Mixed1	0.0000	0.9990	-0.9853	-0.0014	-0.0021	-0.0014	-0.0021
alpha_JET_EtaIntercalibration_TotalStat	0.0000	0.9994	-0.9980	-0.0005	0.0021	-0.0005	0.0021
alpha_WZ_EW4_TheoScale	-0.0000	0.9859	-0.9902	0.0010	-0.0020	0.0010	-0.0020
alpha_FF_MET	-0.0000	0.9954	-0.9977	0.0018	0.0017	0.0018	0.0017
alpha_FT_EFF_Eigen_C_0	-0.0000	0.9999	-0.9999	-0.0017	0.0017	-0.0017	0.0017
alpha_signal_AllEW_TheoPdf	0.0000	0.9990	-0.9989	-0.0011	0.0014	-0.0011	0.0014
alpha_WZ_EW4_TheoPdf	0.0000	0.9990	-0.9983	0.0009	-0.0013	0.0009	-0.0013
alpha_top_XS	0.0000	0.9997	-0.9997	0.0010	-0.0013	0.0010	-0.0013
alpha_FT_EFF_extrapolation_from_charm	0.0000	0.9995	-0.9995	0.0013	-0.0013	0.0013	-0.0013
alpha_JET_JER_EffectiveNP_4	0.0000	0.9939	-0.9948	-0.0012	0.0006	-0.0012	0.0006
alpha_el_FF_AntiDSF	-0.0000	0.9994	-0.9994	0.0011	-0.0011	0.0011	-0.0011
alpha_JET_Pileup_PtTerm	-0.0000	0.9959	-0.9979	-0.0009	0.0011	-0.0009	0.0011
alpha_MUON_MS	-0.0000	0.9985	-0.9995	0.0011	0.0002	0.0011	0.0002
alpha_JET_JER_EffectiveNP_6	0.0000	0.9935	-0.9930	-0.0011	0.0003	-0.0011	0.0003
alpha_JET_JER_EffectiveNP_11	-0.0000	0.9955	-0.9979	0.0010	-0.0005	0.0010	-0.0005
alpha_JET_JER_DataVsMC_MC16_PDSmear	-0.0000	0.9929	-1.0000	-0.0010	0.0000	-0.0010	0.0000
alpha_JET_EtaIntercalibration_NonClosure_negEta	-0.0000	0.9996	-1.0000	0.0009	0.0001	0.0009	0.0001
alpha_MET_SoftTrk_Scale	-0.0000	0.9997	-0.9996	0.0007	-0.0009	0.0007	-0.0009
alpha_MET_SoftTrk_ResoPerp	0.0000	1.0000	-0.9993	0.0000	0.0009	0.0000	0.0009
alpha_triboson_XS	0.0000	0.9997	-0.9997	0.0009	-0.0008	0.0009	-0.0008
alpha_JET_JER_EffectiveNP_12restTerm	0.0000	0.9976	-0.9953	0.0002	0.0008	0.0002	0.0008
alpha_el_FF_STAT_2015_2018_2_1	0.0000	0.9980	-0.9980	-0.0008	0.0008	-0.0008	0.0008
alpha_JET_JER_EffectiveNP_9	-0.0000	0.9948	-0.9943	0.0008	-0.0004	0.0008	-0.0004
alpha_JET_JER_EffectiveNP_7	-0.0000	0.9907	-0.9937	0.0003	-0.0006	0.0003	-0.0006

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\hat{\theta}_{PF}^{up}$	$\Delta\hat{\theta}_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
alpha_el_FF_STAT_2015_2018_1_1	0.0000	0.9987	-0.9987	-0.0006	0.0006	-0.0006	0.0006
alpha_JET_JER_EffectiveNP_10	0.0000	0.9991	-0.9978	0.0002	0.0005	0.0002	0.0005
alpha_Zgamma_XS	0.0000	0.9999	-0.9999	0.0005	-0.0005	0.0005	-0.0005
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP8	-0.0000	0.9993	-0.9993	-0.0005	0.0005	-0.0005	0.0005
alpha_el_FF_STAT_2015_2018_2_3	0.0000	0.9989	-0.9989	-0.0005	0.0005	-0.0005	0.0005
alpha_JET_JER_EffectiveNP_8	-0.0000	0.9968	-0.9987	0.0003	0.0004	0.0003	0.0004
alpha_JET_EffectiveNP_Mixed2	-0.0000	0.9997	-0.9994	0.0003	-0.0004	0.0003	-0.0004
alpha_PRW_DATASF	-0.0000	0.9964	-0.9983	-0.0003	-0.0004	-0.0003	-0.0004
alpha_EL_EFF_ID_CorrUncertaintyNP14	-0.0000	0.9998	-0.9998	-0.0004	0.0004	-0.0004	0.0004
alpha_mu_FF_STAT_2015_2018_1_1	0.0000	0.9999	-0.9999	-0.0004	0.0004	-0.0004	0.0004
alpha_EL_EFF_ID_CorrUncertaintyNP11	0.0000	0.9997	-0.9997	-0.0004	0.0004	-0.0004	0.0004
alpha_MUON_SCALE	0.0000	0.9998	-0.9998	0.0003	-0.0003	0.0003	-0.0003
alpha_EL_EFF_Reco_TOTAL_1NPCOR_PLUS_UNCOR	0.0000	0.9999	-0.9999	-0.0003	0.0003	-0.0003	0.0003
alpha_EL_EFF_ID_CorrUncertaintyNP12	-0.0000	0.9999	-0.9999	-0.0003	0.0003	-0.0003	0.0003
alpha_FT_EFF_Eigen_B_0	-0.0000	1.0000	-1.0000	-0.0003	0.0003	-0.0003	0.0003
alpha_EL_EFF_ID_CorrUncertaintyNP15	-0.0000	0.9998	-0.9998	0.0003	-0.0003	0.0003	-0.0003
alpha_EL_EFF_Iso_TOTAL_1NPCOR_PLUS_UNCOR	0.0000	0.9999	-0.9999	-0.0003	0.0003	-0.0003	0.0003
alpha_JET_JvtEfficiency	0.0000	0.9999	-0.9999	0.0003	0.0000	0.0003	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP9	-0.0000	0.9999	-0.9999	-0.0002	0.0003	-0.0002	0.0003
alpha_MUON_EFF_TrigSystUncertainty	0.0000	0.9999	-0.9998	0.0002	-0.0002	0.0002	-0.0002
alpha_WZ_EW6_TheoPdf	0.0000	0.9999	-0.9999	-0.0002	0.0002	-0.0002	0.0002
alpha_JET_EffectiveNP_Modelling3	0.0000	0.9999	-0.9994	0.0002	-0.0002	0.0002	-0.0002
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP17	0.0000	0.9998	-0.9998	-0.0002	0.0002	-0.0002	0.0002
alpha_MUON_ID	-0.0000	0.9998	-0.9998	-0.0001	-0.0002	-0.0001	-0.0002
alpha_MUON_EFF_RECO_STAT	0.0000	1.0000	-1.0000	-0.0002	0.0002	-0.0002	0.0002
alpha_FT_EFF_Eigen_C_1	0.0000	1.0000	-1.0000	-0.0002	0.0002	-0.0002	0.0002
alpha_FT_EFF_Eigen_Light_2	-0.0000	1.0000	-1.0000	-0.0002	0.0002	-0.0002	0.0002
alpha_JET_EffectiveNP_Detector1	0.0000	0.9998	-0.9999	-0.0001	0.0002	-0.0001	0.0002
alpha_MUON_EFF_ITVA_SYS	-0.0000	1.0000	-1.0000	-0.0002	0.0001	-0.0002	0.0001
alpha_el_FF_STAT_2015_3_1	0.0000	0.9999	-0.9999	-0.0001	0.0002	-0.0001	0.0002
alpha_MjRewScale	-0.0000	0.9997	-0.9996	0.0002	-0.0001	0.0002	-0.0001
alpha_JET_EffectiveNP_Statistical2	-0.0000	0.9999	-0.9998	0.0002	-0.0001	0.0002	-0.0001

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\theta_{\text{PF}}^{\text{up}}$	$\Delta\theta_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_JET_EtaIntercalibration_NonClosure_posEta	0.0000	1.0000	-0.9999	-0.0001	0.0002	-0.0001	0.0002
alpha_JET_EffectiveNP_Statistical3	-0.0000	1.0000	-1.0000	0.0000	-0.0001	0.0000	-0.0001
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP6	-0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_MUON_EFF_ITVA_STAT	0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_MUON_EFF_ISO_STAT	-0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_FT_EFF_Eigen_B_1	-0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_EL_EFF_ID_CorrUncertaintyNP13	-0.0000	0.9999	-0.9999	-0.0001	0.0001	-0.0001	0.0001
alpha_FT_EFF_extrapolation	0.0000	1.0000	-1.0000	0.0001	-0.0001	0.0001	-0.0001
alpha_signal_ALLEW_TheoAlphas	0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_EL_EFF_ID_CorrUncertaintyNP10	-0.0000	0.9999	-0.9999	0.0001	-0.0001	0.0001	-0.0001
alpha_JET_BJES_Response	0.0000	1.0000	-0.9999	0.0000	-0.0001	0.0000	-0.0001
alpha_MUON_EFF_TrigStatUncertainty	0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_JET_EffectiveNP_Mixed3	0.0000	0.9999	-1.0000	-0.0000	0.0001	-0.0000	0.0001
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP7	-0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_WZ_EW4_TheoAlphas	0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_JET_EffectiveNP_Modelling2	-0.0000	0.9999	-0.9999	-0.0000	0.0001	-0.0000	0.0001
alpha_JET_EffectiveNP_Statistical5	-0.0000	1.0000	-0.9999	0.0001	-0.0000	0.0001	-0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP15	0.0000	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_el_FF_STAT_2016_2018_3_3	0.0000	0.9999	-0.9999	-0.0001	0.0001	-0.0001	0.0001
alpha_el_FF_STAT_2015_2018_1_3	0.0000	0.9999	-0.9999	-0.0001	0.0001	-0.0001	0.0001
alpha_JET_EffectiveNP_Statistical4	-0.0000	0.9999	-0.9999	-0.0000	0.0001	-0.0000	0.0001
alpha_FT_EFF_Eigen_B_2	0.0000	1.0000	-1.0000	0.0001	-0.0001	0.0001	-0.0001
alpha_MUON_SAGITTA_RESBIAS	0.0000	0.9996	-0.9994	-0.0000	0.0001	-0.0000	0.0001
alpha_JET_EffectiveNP_Statistical1	0.0000	1.0000	-1.0000	-0.0001	0.0000	-0.0001	0.0000
alpha_EG_RESOLUTION_ALL	0.0000	0.9995	-0.9995	-0.0000	-0.0001	-0.0000	-0.0001
alpha_JET_EffectiveNP_Statistical6	-0.0000	0.9999	-1.0000	0.0000	0.0001	0.0000	0.0001
alpha_JET_EffectiveNP_Modelling4	-0.0000	0.9999	-1.0000	0.0000	0.0001	0.0000	0.0001
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP16	-0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_EG_SCALE_ALL	-0.0000	0.9996	-0.9998	0.0000	-0.0000	0.0000	-0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP5	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_mu_FF_STAT_2016_2018_3_1	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_FT_EFF_Eigen_C_2	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\hat{\theta}_{PF}^{up}$	$\Delta\hat{\theta}_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
alpha_EL_EFF_ID_CorrUncertaintyNP8	-0.0000	0.9999	-0.9999	-0.0000	0.0000	-0.0000	0.0000
alpha_mu_FF_STAT_2016_2018_2_1	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_mu_FF_STAT_2015_3_1	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_FT_EFF_Eigen_Light_3	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP14	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_WZ_EW6_TheoAlphas	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_Trigger_TOTAL_1NPCOR_PLUS_UNCOR	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_JET_EffectiveNP_Detector2	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_JET_PunchThrough_MC16	-0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP6	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_el_FF_STAT_2016_2018_2_3	-0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP4	-0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP3	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_el_FF_STAT_2015_2018_3_2	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_el_FF_STAT_2016_2018_2_1	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_el_FF_STAT_2015_2018_1_2	-0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_el_FF_STAT_2016_2018_1_3	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_el_FF_STAT_2016_2018_3_1	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP5	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_mu_FF_STAT_2016_2018_1_1	0.0000	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_FT_EFF_Eigen_Light_1	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP2	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP1	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP9	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_el_FF_STAT_2015_2018_2_2	-0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP10	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_MUON_EFF_REC0_SYS_LOWPT	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP12	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_EG_SCALE_AF2	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_MUON_EFF_REC0_STAT_LOWPT	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_JET_EtaIntercalibration_NonClosure_highE	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP11	0.0000	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\theta_{\text{PF}}^{\text{up}}$	$\Delta\theta_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP13	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_MET_JetTrk_Scale	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP4	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_JET_SingleParticle_HighPt	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP3	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_2_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2_1	-0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2_3	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP0	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_3_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_3_3	-0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_1_1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_1_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP0	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_3_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP7	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_1_3	-0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_1_2	-0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_1_1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_mu_FF_STAT_2015_2_1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_mu_FF_STAT_2015_1_1	-0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_MUON_SAGITTA_RHO	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_TriggerEff_TOTAL_1NPCOR_PLUS_UNCOR	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000

Table B.9: Ranking of the MC statistical nuisance parameters included in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using Asimov data.

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\theta_{PF}^{up}$	$\Delta\theta_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
gamma_stat_CutSR_mm_bin_1_0	1.0000	0.0367	-0.0358	-0.0049	0.0047	-0.0050	0.0048
gamma_stat_CutSR_me_bin_1_0	1.0000	0.0411	-0.0400	-0.0042	0.0042	-0.0044	0.0043
gamma_stat_CutSR_em_bin_1_0	1.0000	0.0377	-0.0368	-0.0039	0.0038	-0.0040	0.0039
gamma_stat_CutSR_mm_bin_2_0	1.0000	0.0473	-0.0458	-0.0033	0.0032	-0.0033	0.0032
gamma_stat_CutSR_me_bin_0_0	1.0000	0.0432	-0.0420	-0.0030	0.0029	-0.0032	0.0030
gamma_stat_CutSR_mm_bin_0_0	1.0000	0.0359	-0.0351	-0.0030	0.0030	-0.0031	0.0030
gamma_stat_CutSR_em_bin_0_0	1.0000	0.0389	-0.0379	-0.0030	0.0029	-0.0031	0.0030
gamma_stat_CutSR_me_bin_2_0	1.0000	0.0449	-0.0436	-0.0026	0.0026	-0.0027	0.0026
gamma_stat_CutSR_em_bin_3_0	1.0000	0.1217	-0.1125	-0.0025	0.0023	-0.0026	0.0024
gamma_stat_CutSR_ee_bin_1_0	1.0000	0.0585	-0.0563	-0.0024	0.0023	-0.0025	0.0024
gamma_stat_CutSR_em_bin_2_0	1.0000	0.0326	-0.0319	-0.0023	0.0022	-0.0023	0.0023
gamma_stat_CutSR_mm_bin_3_0	1.0000	0.0642	-0.0616	-0.0019	0.0018	-0.0019	0.0019
gamma_stat_CutSR_mm_bin_4_0	1.0000	0.0516	-0.0499	-0.0019	0.0019	-0.0019	0.0019
gamma_stat_CutSR_me_bin_3_0	1.0000	0.0820	-0.0778	-0.0019	0.0018	-0.0019	0.0018
gamma_stat_CutSR_ee_bin_3_0	1.0000	0.1680	-0.1510	-0.0017	0.0015	-0.0017	0.0016
gamma_stat_CutSR_ee_bin_0_0	1.0000	0.0606	-0.0582	-0.0016	0.0015	-0.0016	0.0016
gamma_stat_CutSR_ee_bin_4_0	1.0000	0.1093	-0.1019	-0.0016	0.0015	-0.0016	0.0015
gamma_stat_CutSR_em_bin_4_0	1.0000	0.0426	-0.0414	-0.0014	0.0010	-0.0014	0.0010
gamma_stat_CutCRWZ3lep_all_bin_0	1.0000	0.0043	-0.0043	0.0014	-0.0014	0.0014	-0.0014
gamma_stat_CutSR_ee_bin_2_0	1.0000	0.0415	-0.0404	-0.0009	0.0009	-0.0009	0.0009
gamma_stat_CutLowMjj_mm_bin_0_0	1.0000	0.0353	-0.0345	-0.0007	0.0007	-0.0008	0.0008
gamma_stat_CutLowMjj_me_bin_0_0	1.0000	0.0355	-0.0347	-0.0007	0.0006	-0.0007	0.0006
gamma_stat_CutSR_me_bin_4_0	1.0000	0.0210	-0.0208	-0.0005	0.0005	-0.0005	0.0005
gamma_stat_CutLowMjj_ee_bin_0_0	1.0000	0.0618	-0.0593	0.0004	-0.0003	0.0004	-0.0004
gamma_stat_CutLowMjj_em_bin_0_0	1.0000	0.0388	-0.0378	-0.0003	0.0003	-0.0004	0.0003

B.3 Results of the Fit to Observed Data with EW $W^\pm W^\pm jj$ Signal

Table B.10 to B.12 show the yields after the fit to observed data. The uncertainties show first the statistical uncertainty derived from the mu uncertainty from the statistic uncertainty only fit. Secondly the theory uncertainty and at last the experimental uncertainties.

Table B.10: Post-fit yields in the signal region in the total cross-section measurement of EW $W^\pm W^\pm jj$ using observed data. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	$e^\pm e^\pm$		$\mu^\pm \mu^\pm$		$e^\pm \mu^\pm$		$\mu^\pm e^\pm$		$\ell^\pm \ell^\pm$	
Other prompt	0.99 ± 0.00 ± 0.18 ± 0.18	1.4 ± 0.0 ± 0.3 ± 1.4	2.5 ± 0.0 ± 0.5 ± 0.2	1.91 ± 0.00 ± 0.34 ± 0.35	6.8 ± 0.0 ± 1.2 ± 1.6					
Conversions	5.7 ± 0.0 ± 0.6 ± 2.0	0.004 ± 0.000 ± 0.002 ± 0.007	11.4 ± 0.0 ± 2.1 ± 1.5	6.8 ± 0.0 ± 1.9 ± 1.9	24 ± 0 ± 5 ± 4					
Non-prompt	8.4 ± 0.0 ± 0.4 ± 1.6	21 ± 0 ± 0 ± 5	14.9 ± 0.0 ± 0.4 ± 2.4	10.2 ± 0.0 ± 0.3 ± 1.6	55 ± 0 ± 1 ± 9					
WZ EW	1.69 ± 0.00 ± 0.13 ± 0.06	4.17 ± 0.00 ± 0.35 ± 0.14	4.9 ± 0.0 ± 0.4 ± 0.2	4.14 ± 0.00 ± 0.33 ± 0.14	14.9 ± 0.0 ± 1.2 ± 0.4					
WZ QCD	5.5 ± 0.0 ± 0.8 ± 0.4	14.0 ± 0.0 ± 1.9 ± 0.7	18.2 ± 0.0 ± 2.5 ± 1.0	18.2 ± 0.0 ± 2.5 ± 1.0	56 ± 0 ± 7 ± 3					
$W^\pm W^\pm jj$ QCD	1.7 ± 0.0 ± 0.5 ± 0.1	9.7 ± 0.0 ± 2.8 ± 0.3	8.0 ± 0.0 ± 2.4 ± 0.3	7.1 ± 0.0 ± 2.1 ± 0.2	27 ± 0 ± 8 ± 1					
$W^\pm W^\pm jj$ Int	0.99 ± 0.04 ± 0.10 ± 0.03	2.69 ± 0.10 ± 0.14 ± 0.07	2.35 ± 0.09 ± 0.15 ± 0.06	2.11 ± 0.08 ± 0.11 ± 0.06	8.1 ± 0.3 ± 0.5 ± 0.2					
obsData	52.0 ± 0.0 ± 0.0 ± 0.0	147.0 ± 0.0 ± 0.0 ± 0.0	149.0 ± 0.0 ± 0.0 ± 0.0	127.0 ± 0.0 ± 0.0 ± 0.0	475.0 ± 0.0 ± 0.0 ± 0.0					
$W^\pm W^\pm jj$ EW	33.0 ± 2.4 ± 2.1 ± 0.8	90 ± 7 ± 3 ± 2	81 ± 6 ± 4 ± 2	73 ± 5 ± 3 ± 2	277 ± 21 ± 11 ± 7					
Total Expected	58.0 ± 2.5 ± 2.8 ± 2.8	143 ± 7 ± 5 ± 6	143 ± 6 ± 6 ± 5	123 ± 5 ± 5 ± 4	468 ± 21 ± 15 ± 15					

Table B.11: Post-fit yields in the low- m_{jj} control region in the total cross-section measurement of EW $W^\pm W^\pm jj$ using observed data. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	$e^\pm e^\pm$		$\mu^\pm \mu^\pm$		$e^\pm \mu^\pm$		$\mu^\pm e^\pm$		$\ell^\pm \ell^\pm$	
Other prompt	1.41 ± 0.00 ± 0.26 ± 0.14	2.0 ± 0.0 ± 0.4 ± 0.2	3.5 ± 0.0 ± 0.7 ± 0.2	2.9 ± 0.0 ± 0.5 ± 0.2	9.8 ± 0.0 ± 1.8 ± 0.6					
Conversions	7.6 ± 0.0 ± 0.9 ± 2.7	0.0 ± 0.0 ± 0.0 ± 0.0	14.3 ± 0.0 ± 3.1 ± 1.7	9 ± 0 ± 3 ± 4	31 ± 0 ± 6 ± 6					
Non-prompt	13.9 ± 0.0 ± 0.8 ± 1.6	25 ± 0 ± 1 ± 6	25 ± 0 ± 1 ± 4	22.7 ± 0.0 ± 0.8 ± 2.6	86 ± 0 ± 2 ± 12					
WZ EW	0.50 ± 0.00 ± 0.03 ± 0.04	1.11 ± 0.00 ± 0.04 ± 0.06	1.55 ± 0.00 ± 0.06 ± 0.07	1.20 ± 0.00 ± 0.05 ± 0.06	4.36 ± 0.00 ± 0.11 ± 0.17					
WZ QCD	9.9 ± 0.0 ± 1.4 ± 0.7	22.0 ± 0.0 ± 2.7 ± 1.0	31 ± 0 ± 4 ± 1	28 ± 0 ± 4 ± 2	90 ± 0 ± 11 ± 5					
$W^\pm W^\pm jj$ QCD	1.8 ± 0.0 ± 0.5 ± 0.1	9.8 ± 0.0 ± 2.6 ± 0.3	7.7 ± 0.0 ± 2.0 ± 0.3	7.2 ± 0.0 ± 1.8 ± 0.2	26 ± 0 ± 7 ± 1					
$W^\pm W^\pm jj$ Int	0.199 ± 0.007 ± 0.012 ± 0.024	0.84 ± 0.03 ± 0.11 ± 0.03	0.67 ± 0.03 ± 0.15 ± 0.03	0.598 ± 0.022 ± 0.024 ± 0.025	2.31 ± 0.09 ± 0.27 ± 0.07					
obsData	48.0 ± 0.0 ± 0.0 ± 0.0	73.0 ± 0.0 ± 0.0 ± 0.0	93.0 ± 0.0 ± 0.0 ± 0.0	92.0 ± 0.0 ± 0.0 ± 0.0	306.0 ± 0.0 ± 0.0 ± 0.0					
$W^\pm W^\pm jj$ EW	5.9 ± 0.3 ± 1.6 ± 0.2	17.8 ± 1.1 ± 3.6 ± 0.4	15 ± 1 ± 4 ± 0	14.3 ± 0.9 ± 3.3 ± 0.4	53 ± 3 ± 12 ± 1					
Total Expected	41.3 ± 0.3 ± 3.0 ± 3.2	78 ± 1 ± 5 ± 6	98 ± 1 ± 6 ± 4	86 ± 1 ± 6 ± 6	304 ± 3 ± 16 ± 16					

Table B.12: Post-fit yields in the WZ control region in the total cross-section measurement of EW $W^\pm W^\pm jj$ using observed data. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	lll			
Other prompt	115	± 0	± 18	± 7
Conversions	9	± 0	± 4	± 4
Non-prompt	30	± 0	± 9	± 9
WZ EW	141	± 0	± 8	± 4
WZ QCD	540	± 0	± 60	± 30
obsData	$832.0 \pm 0.0 \pm 0.0 \pm 0.0$			
Total Expected	840	± 0	± 50	± 40

Pull plot and correlations are in Figure B.8.

The effect of all the nuisance parameters considered in the fit is shown in Tables B.13 and B.14 for systematic and MC statistical (gammas) uncertainties, respectively.

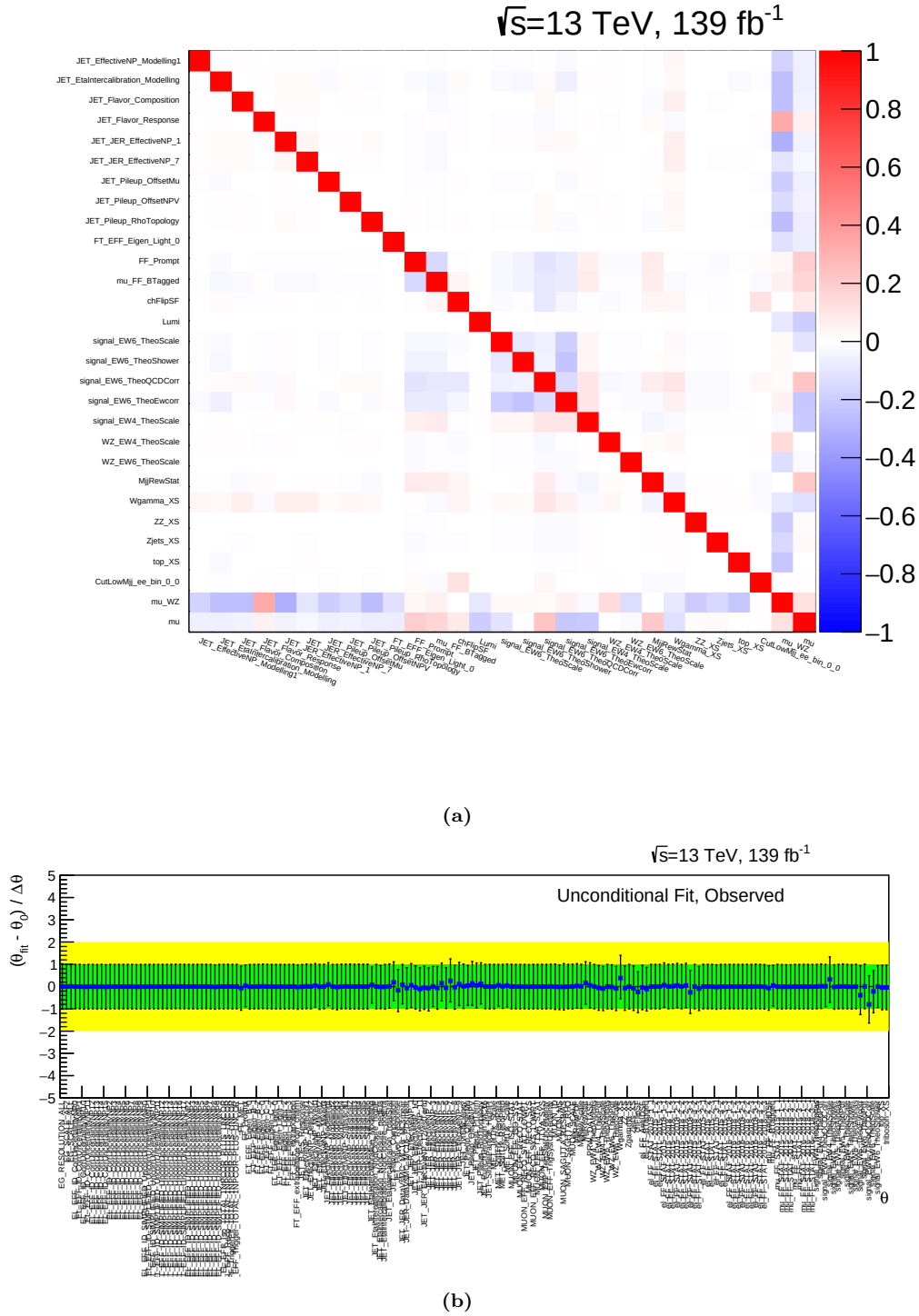


Figure B.8: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a) and nuisance parameter pull (b) for the total cross-section measurement of EW $W^\pm W^\pm jj$ using observed data

Table B.13: Ranking of the systematic nuisance parameters included in the total cross-section measurement of $EW\ W^\pm W^{\pm jj}$ sorted according to their impact on the measured signal strength μ using observed data.

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\hat{\theta}_{PF}^{up}$	$\Delta\hat{\theta}_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
alpha_signal_EW6_TheoQCDCorr	-0.8018	1.2922	-0.8393	0.0234	-0.0263	0.0221	-0.0038
alpha_signal_EW4_TheoScale	0.3214	1.0147	-1.0384	-0.0245	0.0193	-0.0138	0.0234
Lumi	1.0002	0.0170	-0.0170	-0.0210	0.0235	-0.0208	0.0237
alpha_MjRwStat	0.1673	0.9513	-0.9640	0.0225	-0.0209	0.0199	-0.0256
alpha_FF_Prompt	0.0375	0.9351	-0.9440	0.0224	-0.0198	0.0230	-0.0218
alpha_signal_EW4_TheoQCDCorr	0.0115	0.9886	-0.9146	-0.0000	-0.0205	-0.0000	-0.0232
alpha_signal_EW6_TheoEwcorr	-0.3875	1.3293	-0.8710	-0.0051	0.0203	-0.0051	0.0150
alpha_mu_FF_BTagged	0.0463	0.9126	-0.9214	0.0193	-0.0160	0.0201	-0.0168
alpha_Wgamma_XS	0.3810	1.0256	-0.9242	-0.0170	0.0180	-0.0092	0.0238
alpha_signal_EW6_TheoScale	-0.2160	0.9487	-0.9640	-0.0124	0.0121	-0.0166	0.0085
alpha_JET_EtaIntercalibration_Modelling	0.0817	0.8026	-0.8290	-0.0114	0.0111	-0.0137	0.0142
alpha_JET_JER_EffectiveNP_1	0.0627	0.9697	-1.0041	-0.0036	0.0101	-0.0034	0.0106
alpha_FT_EFF_Eigen_Light_0	-0.0031	0.9990	-1.0014	-0.0077	0.0097	-0.0077	0.0096
alpha_JET_Pileup_RhoTopology	0.1234	0.9441	-0.9036	-0.0084	0.0057	-0.0077	0.0069
alpha_JET_Pileup_OffsetNPV	0.1385	0.9905	-0.9767	-0.0044	0.0081	-0.0038	0.0089
alpha_chFlipSF	-0.2409	0.9067	-0.9352	0.0079	-0.0074	0.0131	-0.0057
alpha_JET_EffectiveNP_Modelling1	0.0963	0.9762	-0.9554	-0.0075	0.0044	-0.0069	0.0047
alpha_mu_FF_STAT_2015_2018_2_1	-0.0062	0.9907	-0.9906	-0.0059	0.0074	-0.0060	0.0075
alpha_mu_FF_STAT_2015_2018_3_1	-0.0062	0.9907	-0.9906	-0.0059	0.0074	-0.0060	0.0075
alpha_JET_Flavor_Composition	0.1873	0.9241	-0.8320	-0.0055	0.0071	-0.0047	0.0090
alpha_JET_Pileup_OffsetMu	0.0401	0.9109	-0.8829	-0.0070	0.0062	-0.0083	0.0078
alpha_JET_JER_EffectiveNP_2	-0.0700	0.9077	-1.0256	-0.0068	0.0005	-0.0090	0.0005
alpha_JET_Flavor_Response	-0.1588	0.9288	-0.9673	0.0043	-0.0055	0.0049	-0.0047
alpha_Zjets_XS	-0.0770	1.0013	-0.9964	0.0050	-0.0029	0.0053	-0.0026
alpha_el_FF_STAT_2015_2018_3_1	-0.2573	0.9903	-0.9517	-0.0038	0.0046	-0.0049	0.0037
alpha_ZZ_XS	-0.0665	0.9988	-0.9997	0.0046	-0.0025	0.0027	-0.0023
alpha_MUON_EFF_RECO_SYS	-0.0068	0.9986	-1.0000	-0.0036	0.0032	-0.0037	0.0032
alpha_WZ_EW6_TheoScale	-0.0808	0.9917	-0.9957	-0.0014	0.0033	-0.0016	0.0031
alpha_JET_EtaIntercalibration_TotalStat	0.0095	1.0088	-0.9807	-0.0007	0.0033	-0.0007	0.0033

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\hat{\theta}_{PF}^{up}$	$\Delta\hat{\theta}_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
alpha_MET_SoftTrk_ResoPara	0.0580	0.9402	-0.9378	0.0001	0.0031	0.0001	0.0034
alpha_JET_JER_EffectiveNP_7	0.2551	0.9913	-0.9465	-0.0031	0.0003	-0.0022	0.0018
alpha_mu_FF_AntiDSF	-0.0641	0.9982	-0.9990	0.0031	-0.0029	0.0033	-0.0027
alpha_el_FF_STAT_2015_2018_3_3	-0.0891	0.9938	-0.9867	-0.0022	0.0030	-0.0024	0.0022
alpha_MUON_EFF_ISO_SYS	-0.0009	0.9990	-0.9998	-0.0019	0.0030	-0.0019	0.0030
alpha_signal_EW6_TheoShower	0.0010	0.9403	-0.9386	-0.0016	0.0028	-0.0016	0.0030
alpha_FT_EFF_Eigen_C_0	0.0115	0.9997	-1.0003	-0.0009	0.0026	-0.0009	0.0026
alpha_JET_Pileup_PtTerm	0.0519	1.0091	-1.0184	0.0004	0.0026	0.0004	0.0026
alpha_top_XS	-0.0439	1.0005	-0.9997	0.0024	-0.0009	0.0025	-0.0009
alpha_signal_EW4_TheoShower	-0.0171	0.9996	-0.9993	0.0022	-0.0021	0.0023	-0.0021
alpha_MjJRewPDF	0.0318	0.9995	-0.9998	0.0022	-0.0004	0.0021	-0.0004
alpha_el_FF_BTagged	-0.1126	0.9787	-0.9828	0.0021	-0.0013	0.0023	-0.0012
alpha_WZ_EW4_TheoScale	-0.0867	0.9896	-0.9905	-0.0010	0.0021	-0.0012	0.0020
alpha_FF_MET	-0.0680	0.9897	-0.9947	0.0018	0.0019	0.0020	0.0018
alpha_JET_JER_EffectiveNP_11	-0.1110	0.9561	-0.9770	0.0019	-0.0017	0.0021	-0.0015
alpha_JET_EtaIntercalibration_NonClosure_negEta	-0.0198	0.9701	-0.9751	0.0019	0.0001	0.0020	0.0001
alpha_MET_SoftTrk_ResoPerp	0.0087	0.9915	-0.9908	0.0000	0.0018	0.0000	0.0018
alpha_JET_JER_EffectiveNP_4	-0.0592	0.9590	-0.9602	-0.0016	0.0018	-0.0018	0.0018
alpha_JET_JER_EffectiveNP_3	0.0064	0.8958	-0.9047	-0.0008	-0.0017	-0.0010	-0.0026
alpha_JET_JER_EffectiveNP_5	0.1517	0.9074	-0.7976	-0.0016	0.0002	-0.0015	0.0005
alpha_signal_EW6_TheoPdf	0.0051	1.0025	-1.0029	-0.0005	0.0015	-0.0005	0.0015
alpha_triboson_XS	-0.0365	1.0003	-0.9995	0.0015	0.0002	0.0029	0.0002
alpha_JET_EffectiveNP_Mixed1	0.0404	0.9955	-0.9562	-0.0013	-0.0004	-0.0013	-0.0005
alpha_JET_JER_DataVsMC_MC16_MCsmeas	0.0834	0.9116	-0.8590	-0.0001	-0.0013	-0.0001	-0.0018
alpha_el_FF_AntiDSF	-0.0404	0.9997	-0.9999	0.0012	-0.0007	0.0012	-0.0007
alpha_WZ_EW4_TheoPdf	-0.0597	1.0075	-1.0061	0.0012	0.0002	0.0012	0.0003
alpha_PRW_DATASF	0.0561	1.0134	-1.0231	0.0010	-0.0012	0.0010	-0.0012
alpha_JET_JER_EffectiveNP_12restTerm	-0.0515	0.9675	-0.9733	0.0001	0.0011	0.0001	0.0010
alpha_FT_EFF_extrapolation_from_charm	-0.0197	0.9999	-1.0000	0.0010	-0.0007	0.0010	-0.0007
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP8	-0.0174	0.9991	-0.9998	-0.0010	0.0006	-0.0010	0.0005
alpha_JET_JER_EffectiveNP_6	-0.0568	0.9134	-0.9313	0.0000	-0.0009	0.0017	-0.0009
alpha_MUON_MS	-0.0128	0.9938	-1.0205	0.0009	0.0002	0.0009	0.0002

Nuisance parameter θ	θ_{PF}	$\Delta\theta_{\text{PF}}^{\text{up}}$	$\Delta\theta_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_JET_EffectiveNP_Mixed2	-0.0111	1.0142	-1.0126	0.0003	-0.0009	0.0003	-0.0008
alpha_el_FF_STAT_2015_2018_2_3	0.0477	0.9975	-0.9965	-0.0006	0.0008	-0.0005	0.0009
alpha_el_FF_STAT_2015_2018_2_1	0.0471	0.9986	-0.9981	-0.0005	0.0008	-0.0005	0.0008
alpha_MET_SoftTrk_Scale	0.0448	0.9714	-0.9632	0.0008	-0.0002	0.0008	-0.0003
alpha_Zgamma_XS	-0.0020	0.9998	-1.0006	0.0007	-0.0006	0.0007	-0.0006
alpha_JET_JER_EffectiveNP_10	-0.0366	0.9709	-0.9760	0.0000	0.0007	0.0000	0.0007
alpha_EL_EFF_ID_CorrUncertaintyNP14	0.0023	0.9998	-1.0001	-0.0006	0.0004	-0.0006	0.0004
alpha_el_FF_STAT_2015_2018_1_1	0.0650	0.9992	-0.9985	-0.0003	0.0006	-0.0005	0.0006
alpha_EL_EFF_ID_CorrUncertaintyNP11	-0.0037	0.9997	-1.0000	-0.0006	0.0003	-0.0006	0.0003
alpha_signal_EW4_TheoPdf	0.0174	1.0014	-1.0014	-0.0006	0.0006	-0.0006	0.0006
alpha_MUON_SCALE	0.0012	1.0053	-1.0050	0.0002	-0.0006	0.0002	-0.0006
alpha_EL_EFF_Reco_TOTAL_1NPCOR_PLUS_UNCOR	0.0040	0.9999	-1.0002	-0.0006	0.0003	-0.0005	0.0003
alpha_EL_EFF_ID_CorrUncertaintyNP12	0.0003	0.9999	-1.0002	-0.0005	0.0003	-0.0005	0.0003
alpha_JET_JER_EffectiveNP_8	-0.0281	0.9835	-0.9888	0.0005	0.0001	0.0008	0.0001
alpha_signal_EW5_TheoShower	-0.0126	0.9999	-1.0000	0.0005	-0.0005	0.0005	-0.0005
alpha_EL_EFF_ID_CorrUncertaintyNP15	-0.0146	1.0000	-0.9999	0.0003	-0.0005	0.0003	-0.0005
alpha_EL_EFF_Iso_TOTAL_1NPCOR_PLUS_UNCOR	0.0005	1.0000	-1.0002	-0.0005	0.0002	-0.0005	0.0002
alpha_EL_EFF_ID_CorrUncertaintyNP9	-0.0039	0.9999	-1.0002	-0.0005	0.0002	-0.0005	0.0002
alpha_MUON_EFF_TrigSystUncertainty	0.0066	1.0000	-0.9997	0.0002	-0.0004	0.0002	-0.0004
alpha_JET_JER_DataVsMC_MC16_PDSmear	-0.0661	0.9167	-0.9314	-0.0004	-0.0000	-0.0006	-0.0000
alpha_JET_EffectiveNP_Modelling3	-0.0234	1.0214	-1.0183	0.0001	-0.0004	0.0001	-0.0004
alpha_mu_FF_STAT_2015_2018_1_1	-0.0085	1.0001	-1.0001	-0.0004	0.0004	-0.0004	0.0004
alpha_MUON_EFF_RECO_STAT	-0.0010	1.0001	-1.0003	-0.0004	0.0002	-0.0004	0.0002
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP17	0.0037	1.0000	-1.0001	-0.0004	0.0002	-0.0004	0.0002
alpha_FT_EFF_Eigen_C_1	0.0020	1.0001	-1.0003	-0.0003	0.0001	-0.0003	0.0001
alpha_MUON_EFF_ITVA_SYS	-0.0002	0.9999	-1.0001	-0.0003	0.0001	-0.0003	0.0001
alpha_FT_EFF_Eigen_B_0	-0.0083	0.9999	-1.0006	0.0003	-0.0003	0.0003	-0.0003
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP6	0.0040	1.0001	-1.0002	-0.0003	0.0001	-0.0003	0.0001
alpha_MUON_EFF_ISO_STAT	0.0029	1.0001	-1.0002	-0.0003	0.0001	-0.0003	0.0001
alpha_FT_EFF_Eigen_Light_2	-0.0049	1.0001	-1.0002	-0.0002	0.0003	-0.0002	0.0003
alpha_EL_EFF_ID_CorrUncertaintyNP13	-0.0106	0.9999	-1.0002	-0.0003	0.0001	-0.0003	0.0001
alpha_MUON_EFF_ITVA_STAT	-0.0006	1.0001	-1.0002	-0.0003	0.0001	-0.0003	0.0001

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\hat{\theta}_{PF}^{up}$	$\Delta\hat{\theta}_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
alpha_FT_EFF_Eigen_B_1	-0.0024	1.0000	-1.0003	-0.0003	0.0000	-0.0003	0.0000
alpha_FT_EFF_extrapolation	0.0036	1.0003	-1.0001	0.0002	-0.0003	0.0002	-0.0003
alpha_JET_JvtEfficiency	0.0110	0.9997	-0.9998	0.0003	-0.0001	0.0003	-0.0001
alpha_MUON_ID	-0.0071	1.0195	-1.0190	-0.0003	-0.0001	-0.0003	-0.0001
alpha_JET_EtaIntercalibration_NonClosure_posEta	-0.0090	1.0054	-1.0053	-0.0003	0.0000	-0.0003	0.0000
alpha_JET_EffectiveNP_Statistical2	0.0035	1.0091	-1.0086	0.0000	-0.0002	0.0000	-0.0002
alpha_JET_EffectiveNP_Modelling2	-0.0007	1.0004	-1.0007	0.0000	0.0002	0.0000	0.0002
alpha_JET_BJES_Response	-0.0039	0.9977	-0.9976	-0.0000	-0.0002	-0.0000	-0.0002
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP7	-0.0004	1.0001	-1.0002	-0.0002	0.0001	-0.0002	0.0001
alpha_MUON_EFF_TrigStatUncertainty	-0.0022	1.0002	-1.0003	-0.0002	0.0001	-0.0002	0.0001
alpha_JET_EffectiveNP_Detector1	0.0099	1.0041	-1.0050	-0.0002	0.0001	-0.0002	0.0001
alpha_EG_SCALE_ALL	0.0099	1.0054	-1.0060	0.0002	-0.0001	0.0002	-0.0001
alpha_EG_RESOLUTION_ALL	0.0048	1.0199	-1.0212	-0.0001	-0.0002	-0.0001	-0.0002
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP15	0.0066	1.0002	-1.0002	-0.0002	0.0001	-0.0002	0.0001
alpha_JET_EffectiveNP_Statistical4	0.0014	1.0057	-1.0061	-0.0000	0.0002	-0.0000	0.0002
alpha_FT_EFF_Eigen_B_2	0.0012	1.0003	-1.0001	-0.0001	-0.0002	-0.0001	-0.0002
alpha_WZ_EW4_TheoAlphas	-0.0010	1.0001	-1.0002	-0.0002	-0.0000	-0.0002	-0.0000
alpha_signal_EW6_TheoAlphas	0.0008	1.0002	-1.0002	-0.0002	0.0002	-0.0002	0.0002
alpha_EL_EFF_ID_CorrUncertaintyNP10	-0.0140	1.0000	-1.0001	0.0001	-0.0002	0.0001	-0.0002
alpha_el_FF_STAT_2015_2018_1_3	0.0137	1.0002	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP16	0.0028	1.0002	-1.0002	-0.0001	0.0001	-0.0001	0.0001
alpha_EL_EFF_ID_CorrUncertaintyNP8	-0.0094	1.0001	-1.0002	-0.0001	0.0001	-0.0001	0.0001
alpha_el_FF_STAT_2015_3_1	-0.0194	1.0001	-1.0001	-0.0001	0.0001	-0.0001	0.0001
alpha_WZ_EW6_TheoPdf	-0.0165	0.9994	-1.0001	0.0000	0.0001	0.0000	0.0001
alpha_JET_EffectiveNP_Statistical3	-0.0000	1.0049	-1.0048	0.0001	-0.0001	0.0001	-0.0001
alpha_FT_EFF_Eigen_C_2	-0.0024	1.0002	-1.0002	0.0000	-0.0001	0.0000	-0.0001
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP5	0.0021	1.0002	-1.0002	-0.0001	0.0001	-0.0001	0.0001
alpha_el_FF_STAT_2016_2018_3_3	-0.0089	1.0001	-1.0001	-0.0001	0.0001	-0.0001	0.0001
alpha_MUON_SAGITTA_RESBIAS	-0.0122	1.0451	-1.0416	-0.0000	-0.0001	-0.0000	-0.0001
alpha_WZ_EW6_TheoAlphas	-0.0019	1.0002	-1.0002	-0.0001	0.0001	-0.0001	0.0001
alpha_signal_EW5_TheoPdf	0.0092	1.0055	-1.0056	-0.0001	0.0000	-0.0001	0.0000
alpha_signal_EW4_TheoAlphas	0.0015	1.0002	-1.0002	-0.0001	0.0001	-0.0001	0.0001

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\theta_{\text{PF}}^{\text{up}}$	$\Delta\theta_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_MjRewScale	0.0086	0.9951	-0.9948	0.0001	-0.0001	0.0001	-0.0001
alpha_JET_EffectiveNP_Statistical1	0.0076	1.0035	-1.0037	-0.0001	0.0001	-0.0001	0.0001
alpha_JET_EffectiveNP_Mixed3	0.0034	1.0007	-1.0011	-0.0001	0.0000	-0.0001	0.0000
alpha_JET_JER_EffectiveNP_9	0.1098	0.9782	-0.9631	0.0000	0.0001	0.0001	0.0000
alpha_EL_EFF_Trigger_TOTAL_1NPCOR_PLUS_UNCOR	0.0006	1.0002	-1.0002	-0.0001	0.0001	-0.0001	0.0001
alpha_mu_FF_STAT_2016_2018_3_1	-0.0034	1.0002	-1.0002	-0.0001	0.0000	-0.0001	0.0000
alpha_FT_EFF_Eigen_Light_3	-0.0004	1.0002	-1.0002	-0.0001	0.0001	-0.0001	0.0001
alpha_JET_EffectiveNP_Detector2	0.0004	1.0010	-1.0010	-0.0001	0.0001	-0.0001	0.0001
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP14	0.0010	1.0002	-1.0002	-0.0000	0.0000	-0.0000	0.0000
alpha_signal_EW5_TheoScale	0.0014	1.0002	-1.0002	0.0000	-0.0000	0.0000	-0.0000
alpha_mu_FF_STAT_2016_2018_2_1	-0.0014	1.0002	-1.0002	-0.0000	0.0000	-0.0000	0.0000
alpha_JET_EffectiveNP_Statistical6	0.0007	1.0073	-1.0077	0.0000	-0.0000	0.0000	-0.0000
alpha_JET_EffectiveNP_Modelling4	0.0045	1.0052	-1.0057	0.0000	0.0000	0.0000	0.0000
alpha_JET_EffectiveNP_Statistical5	0.0007	1.0072	-1.0068	-0.0000	-0.0000	-0.0000	-0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP4	-0.0003	1.0002	-1.0002	-0.0000	0.0000	-0.0000	0.0000
alpha_signal_EW5_TheoAlphas	0.0009	1.0002	-1.0002	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP6	-0.0002	1.0002	-1.0002	-0.0000	0.0000	-0.0000	0.0000
alpha_mu_FF_STAT_2015_3_1	-0.0024	1.0002	-1.0002	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP3	-0.0002	1.0002	-1.0002	-0.0000	0.0000	-0.0000	0.0000
alpha_JET_PunchThrough_MC16	0.0015	0.9985	-0.9985	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP5	-0.0002	1.0002	-1.0002	-0.0000	0.0000	-0.0000	0.0000
alpha_el_FF_STAT_2016_2018_3_1	0.0087	1.0002	-1.0002	-0.0000	0.0000	-0.0000	0.0000
alpha_el_FF_STAT_2015_2018_1_2	0.0012	1.0002	-1.0002	-0.0000	0.0000	-0.0000	0.0000
alpha_el_FF_STAT_2016_2018_1_3	-0.0005	1.0002	-1.0002	0.0000	-0.0000	0.0000	-0.0000
alpha_el_FF_STAT_2015_2018_3_2	0.0008	1.0001	-1.0001	0.0000	-0.0000	0.0000	-0.0000
alpha_FT_EFF_Eigen_Light_1	-0.0028	1.0002	-1.0002	-0.0000	0.0000	-0.0000	0.0000
alpha_mu_FF_STAT_2016_2018_1_1	-0.0002	1.0002	-1.0002	-0.0000	0.0000	-0.0000	0.0000
alpha_JET_EtaIntercalibration_NonClosure_highE	-0.0006	0.9999	-0.9999	0.0000	-0.0000	0.0000	-0.0000
alpha_el_FF_STAT_2016_2018_2_3	-0.0019	1.0002	-1.0002	0.0000	-0.0000	0.0000	-0.0000
alpha_el_FF_STAT_2015_3_3	-0.0002	1.0001	-1.0001	0.0000	-0.0000	0.0000	-0.0000
alpha_el_FF_STAT_2016_2018_1_1	0.0008	1.0002	-1.0002	-0.0000	0.0000	-0.0000	0.0000
alpha_JET_SingleParticle_HighPt	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\hat{\theta}_{PF}^{up}$	$\Delta\hat{\theta}_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP11	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP10	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP1	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_MUON_SAGITTA_RHO	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2018_2_2	-0.0002	1.0001	-1.0001	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP0	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP0	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP9	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_1_2	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_mu_FF_STAT_2015_1_1	-0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_1_3	-0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_1_2	-0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_1_1	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_mu_FF_STAT_2015_2_1	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP7	-0.0004	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_TriggerEff_TOTAL_1NPCOR_PLUS_UNCOR	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP13	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP1	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_3_2	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP3	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP2	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_EG_SCALE_AF2	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP4	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_MUON_EFF_RECO_SYS_LOWPT	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2_3	-0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_2_2	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2_2	0.0001	1.0001	-1.0001	0.0000	0.0000	0.0000	0.0000
alpha_MUON_EFF_RECO_STAT_LOWPT	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP12	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2_1	-0.0001	1.0001	-1.0001	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP2	0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_3_2	-0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000

Nuisance parameter θ		$\hat{\theta}_{\text{PF}}$	$\Delta\hat{\theta}_{\text{PF}}^{\text{up}}$	$\Delta\hat{\theta}_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_MET_JetTrk_Scale		0.0000	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_2_1		0.0010	1.0002	-1.0002	0.0000	0.0000	0.0000	0.0000

Table B.14: Ranking of the MC statistical nuisance parameters included in the total cross-section measurement of EW $W^{\pm}W^{\pm}jj$ sorted according to their impact on the measured signal strength μ using observed data.

Nuisance parameter θ		$\hat{\theta}_{\text{PF}}$	$\Delta\hat{\theta}_{\text{PF}}^{\text{up}}$	$\Delta\hat{\theta}_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
gamma_stat_CutSR_mm_bin_1_0		0.9936	0.0364	-0.0356	-0.0060	0.0073	-0.0074	0.0063
gamma_stat_CutSR_me_bin_1_0		0.9840	0.0407	-0.0396	-0.0049	0.0069	-0.0085	0.0046
gamma_stat_CutSR_em_bin_1_0		0.9999	0.0377	-0.0368	-0.0047	0.0066	-0.0048	0.0068
gamma_stat_CutSR_mm_bin_2_0		0.9891	0.0470	-0.0456	-0.0036	0.0057	-0.0047	0.0033
gamma_stat_CutSR_ee_bin_1_0		1.0076	0.0586	-0.0564	-0.0031	0.0044	-0.0028	0.0051
gamma_stat_CutSR_mm_bin_0_0		1.0087	0.0361	-0.0352	-0.0035	0.0044	-0.0023	0.0055
gamma_stat_CutSR_me_bin_0_0		1.0287	0.0439	-0.0427	-0.0034	0.0044	-0.0007	0.0072
gamma_stat_CutSR_em_bin_0_0		1.0150	0.0392	-0.0383	-0.0034	0.0043	-0.0019	0.0060
gamma_stat_CutSR_me_bin_2_0		0.9979	0.0448	-0.0435	-0.0026	0.0031	-0.0028	0.0031
gamma_stat_CutSR_em_bin_2_0		1.0015	0.0326	-0.0319	-0.0020	0.0028	-0.0019	0.0029
gamma_stat_CutSR_em_bin_3_0		0.9619	0.1192	-0.1100	-0.0025	0.0027	-0.0036	0.0020
gamma_stat_CutSR_ee_bin_0_0		0.9739	0.0598	-0.0574	-0.0017	0.0023	-0.0026	0.0012
gamma_stat_CutSR_ee_bin_3_0		0.9608	0.1646	-0.1477	-0.0016	0.0020	-0.0022	0.0017
gamma_stat_CutSR_mm_bin_4_0		1.0139	0.0520	-0.0503	-0.0016	0.0019	-0.0010	0.0024
gamma_stat_CutSR_mm_bin_3_0		1.0058	0.0643	-0.0617	-0.0016	0.0017	-0.0011	0.0019
gamma_stat_CutSR_me_bin_3_0		0.9863	0.0814	-0.0772	-0.0015	0.0017	-0.0018	0.0015
gamma_stat_CutCRWZ3Lep_all_bin_0		0.9999	0.0043	-0.0043	0.0017	-0.0000	0.0017	-0.0008
gamma_stat_CutSR_ee_bin_4_0		0.9904	0.1087	-0.1013	-0.0010	0.0015	-0.0014	0.0014
gamma_stat_CutSR_em_bin_4_0		0.9951	0.0424	-0.0413	-0.0010	0.0014	-0.0013	0.0012
gamma_stat_CutLowMjj_em_bin_0_0		0.9911	0.0388	-0.0377	0.0012	-0.0004	0.0015	-0.0003
gamma_stat_CutLowMjj_me_bin_0_0		1.0086	0.0359	-0.0350	0.0011	-0.0004	0.0010	-0.0021
gamma_stat_CutSR_ee_bin_2_0		1.0015	0.0415	-0.0404	-0.0008	0.0010	-0.0007	0.0011

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\hat{\theta}_{\text{PF}}^{\text{up}}$	$\Delta\hat{\theta}_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
gamma_stat_CutLowMjj_mm_bin_0_0	0.9929	0.0353	-0.0344	0.0009	-0.0001	0.0010	-0.0000
gamma_stat_CutLowMjj_ee_bin_0_0	1.0282	0.0627	-0.0602	0.0008	-0.0001	0.0002	-0.0003
gamma_stat_CutSR_me_bin_4_0	1.0007	0.0211	-0.0208	-0.0004	0.0006	-0.0004	0.0006

B.4 Results of the Fit to Observed Data with Inclusive $W^\pm W^\pm jj$ Signal

Distributions after the fit to observed data are shown in Figure B.9, Figure B.10 and Figure B.11. Since it is a fit to expected data only the uncertainties change slightly due to constraining and correlation during the fit.

Table B.15 to B.17 show the yields after the fit to observed data. The uncertainties show first the statistical uncertainty derived from the mu uncertainty from the statistic uncertainty only fit. Secondly the theory uncertainty and at last the experimental uncertainties.

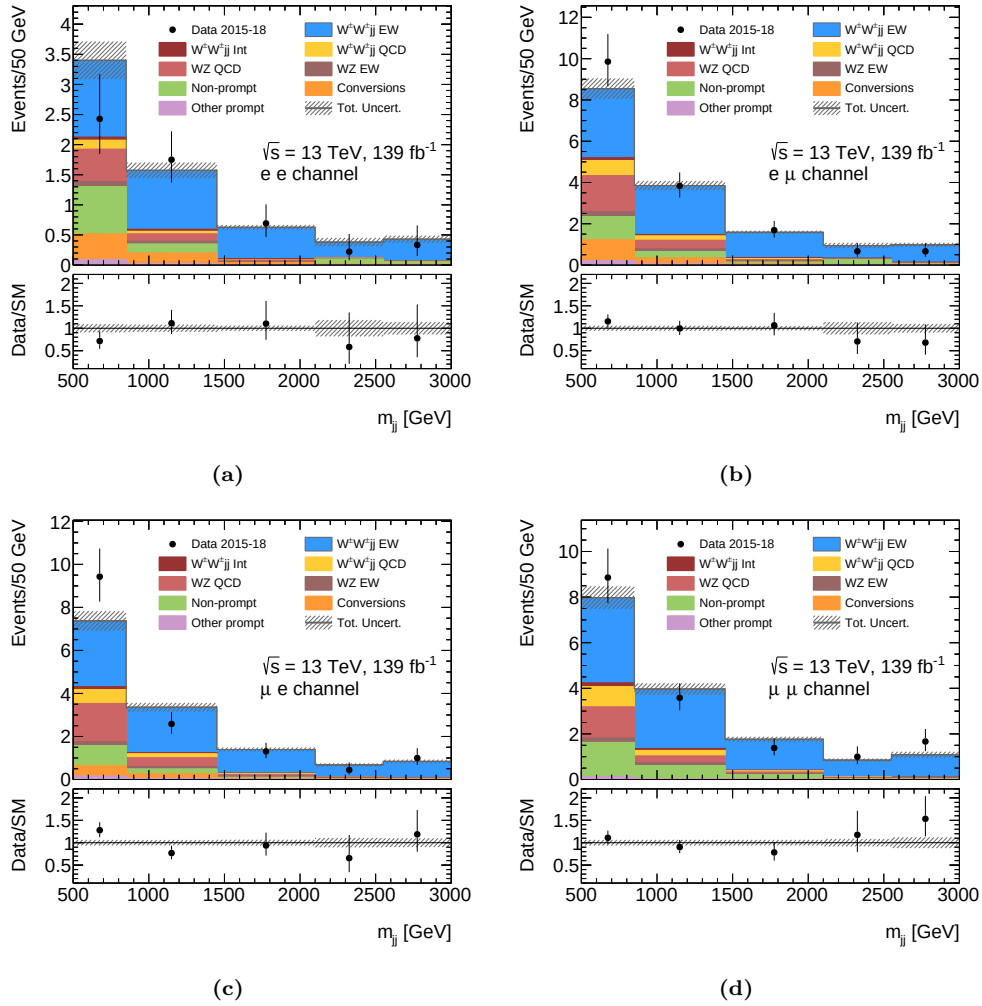


Figure B.9: Post-fit m_{jj} -distributions in signal region for different flavour channels (a-d) as used in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.

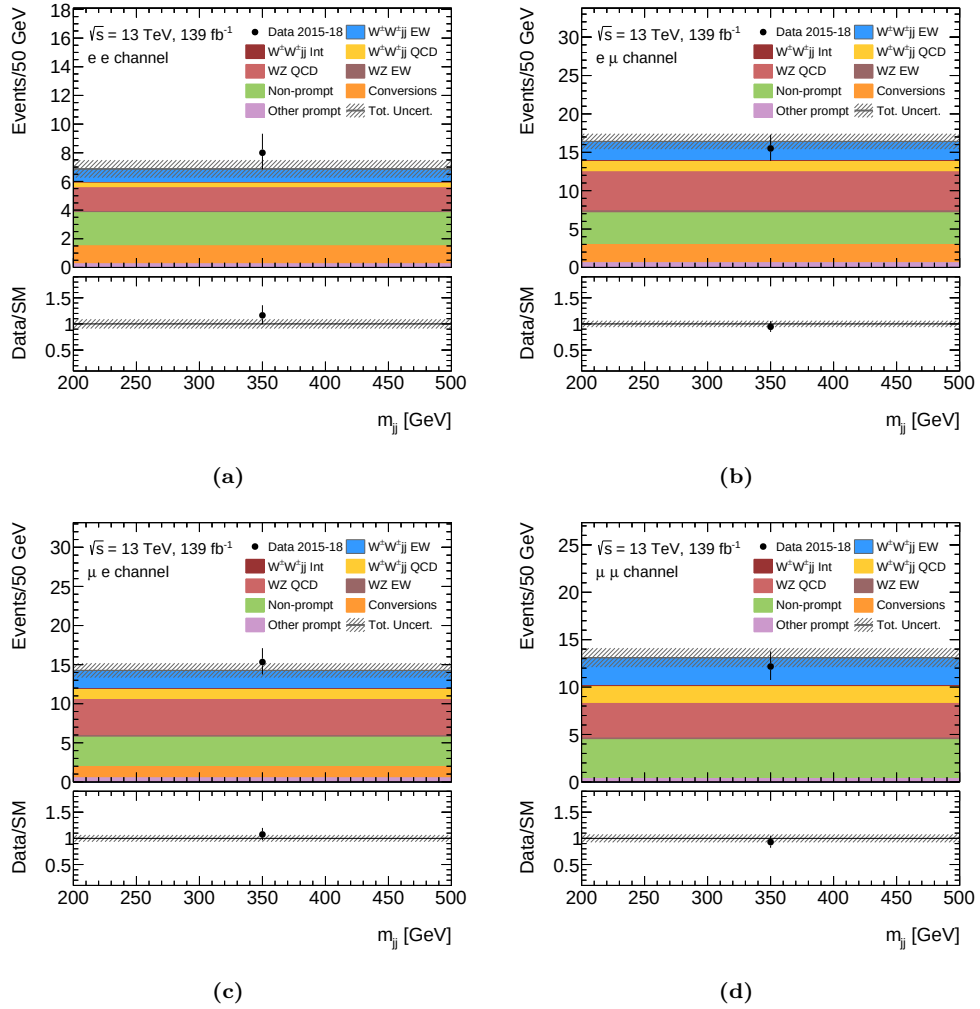


Figure B.10: Post-fit m_{jj} -distributions in low- m_{jj} control region for different flavour channels (a-d) as used in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.

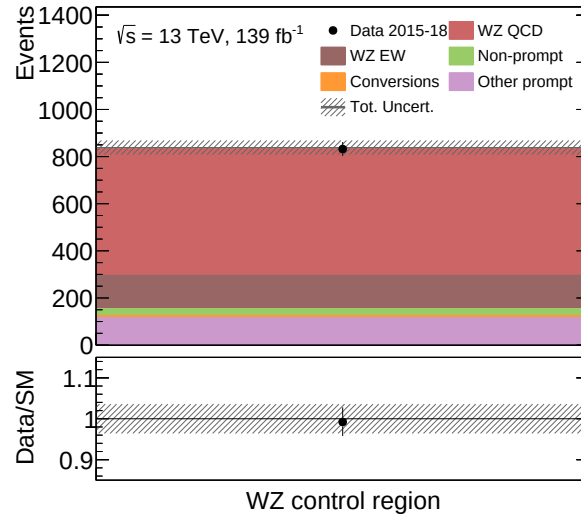


Figure B.11: Post-fit distributions in WZ control region used in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.

Table B.15: Post-fit yields in the signal region in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using observed data. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	$e^\pm e^\pm$	$\mu^\pm \mu^\pm$	$e^\pm \mu^\pm$	$\mu^\pm e^\pm$	$\ell^\pm \ell^\pm$
Other prompt	$0.98 \pm 0.00 \pm 0.18 \pm 0.17$	$1.3 \pm 0.0 \pm 0.2 \pm 1.6$	$2.5 \pm 0.0 \pm 0.5 \pm 0.2$	$1.90 \pm 0.00 \pm 0.33 \pm 0.33$	$6.7 \pm 0.0 \pm 1.2 \pm 1.9$
Conversions	$5.7 \pm 0.0 \pm 0.5 \pm 2.0$	$0.003 \pm 0.000 \pm 0.001 \pm 0.004$	$11.4 \pm 0.0 \pm 2.1 \pm 1.5$	$6.6 \pm 0.0 \pm 1.9 \pm 1.8$	$24 \pm 0 \pm 4 \pm 4$
Non-prompt	$8.4 \pm 0.0 \pm 0.4 \pm 1.6$	$21 \pm 0 \pm 0 \pm 5$	$14.8 \pm 0.0 \pm 0.4 \pm 2.3$	$10.1 \pm 0.0 \pm 0.3 \pm 1.6$	$54 \pm 0 \pm 1 \pm 9$
WZ EW	$1.69 \pm 0.00 \pm 0.13 \pm 0.06$	$4.16 \pm 0.00 \pm 0.35 \pm 0.14$	$4.9 \pm 0.0 \pm 0.4 \pm 0.2$	$4.13 \pm 0.00 \pm 0.33 \pm 0.14$	$14.9 \pm 0.0 \pm 1.2 \pm 0.4$
WZ QCD	$5.5 \pm 0.0 \pm 0.8 \pm 0.4$	$14.0 \pm 0.0 \pm 1.9 \pm 0.7$	$18.1 \pm 0.0 \pm 2.4 \pm 1.0$	$18.2 \pm 0.0 \pm 2.5 \pm 0.9$	$56 \pm 0 \pm 7 \pm 3$
$W^\pm W^\pm jj$ QCD	$1.75 \pm 0.12 \pm 0.13 \pm 0.07$	$10.2 \pm 0.7 \pm 0.4 \pm 0.3$	$8.4 \pm 0.6 \pm 0.3 \pm 0.3$	$7.4 \pm 0.5 \pm 0.3 \pm 0.2$	$27.7 \pm 1.9 \pm 0.9 \pm 0.9$
$W^\pm W^\pm jj$ Int	$1.06 \pm 0.07 \pm 0.04 \pm 0.03$	$2.88 \pm 0.20 \pm 0.09 \pm 0.07$	$2.51 \pm 0.17 \pm 0.07 \pm 0.06$	$2.25 \pm 0.15 \pm 0.06 \pm 0.06$	$8.7 \pm 0.6 \pm 0.2 \pm 0.2$
obsData	$52.0 \pm 0.0 \pm 0.0 \pm 0.0$	$147.0 \pm 0.0 \pm 0.0 \pm 0.0$	$149.0 \pm 0.0 \pm 0.0 \pm 0.0$	$127.0 \pm 0.0 \pm 0.0 \pm 0.0$	$475.0 \pm 0.0 \pm 0.0 \pm 0.0$
$W^\pm W^\pm jj$ EW	$33.1 \pm 2.2 \pm 2.2 \pm 0.8$	$91 \pm 6 \pm 3 \pm 2$	$81 \pm 5 \pm 4 \pm 2$	$73 \pm 5 \pm 3 \pm 2$	$278 \pm 18 \pm 11 \pm 6$
Total Expected	$58.1 \pm 2.4 \pm 2.8 \pm 2.8$	$144 \pm 7 \pm 4 \pm 6$	$144 \pm 6 \pm 5 \pm 5$	$124 \pm 5 \pm 5 \pm 4$	$470 \pm 21 \pm 14 \pm 15$

Table B.16: Post-fit yields in the low- m_{jj} control region in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using observed data. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	$e^\pm e^\pm$	$\mu^\pm \mu^\pm$	$e^\pm \mu^\pm$	$\mu^\pm e^\pm$	$\ell^\pm \ell^\pm$
Other prompt	$1.41 \pm 0.00 \pm 0.26 \pm 0.13$	$2.0 \pm 0.0 \pm 0.4 \pm 0.2$	$3.5 \pm 0.0 \pm 0.7 \pm 0.2$	$2.9 \pm 0.0 \pm 0.5 \pm 0.2$	$9.8 \pm 0.0 \pm 1.8 \pm 0.6$
Conversions	$7.5 \pm 0.0 \pm 0.9 \pm 2.7$	$0.0 \pm 0.0 \pm 0.0 \pm 0.0$	$14.2 \pm 0.0 \pm 3.0 \pm 1.7$	$8.7 \pm 0.0 \pm 2.4 \pm 2.9$	$30 \pm 0 \pm 6 \pm 6$
Non-prompt	$13.9 \pm 0.0 \pm 0.8 \pm 1.6$	$24 \pm 0 \pm 1 \pm 6$	$24.7 \pm 0.0 \pm 1.0 \pm 3.6$	$22.6 \pm 0.0 \pm 0.8 \pm 2.6$	$86 \pm 0 \pm 2 \pm 12$
WZ EW	$0.50 \pm 0.00 \pm 0.03 \pm 0.04$	$1.11 \pm 0.00 \pm 0.04 \pm 0.06$	$1.55 \pm 0.00 \pm 0.06 \pm 0.07$	$1.20 \pm 0.00 \pm 0.05 \pm 0.06$	$4.36 \pm 0.00 \pm 0.11 \pm 0.17$
WZ QCD	$9.9 \pm 0.0 \pm 1.3 \pm 0.7$	$22.0 \pm 0.0 \pm 2.7 \pm 1.0$	$31 \pm 0 \pm 4 \pm 1$	$27.6 \pm 0.0 \pm 3.5 \pm 1.8$	$90 \pm 0 \pm 11 \pm 4$
$W^\pm W^\pm jj$ QCD	$1.96 \pm 0.13 \pm 0.24 \pm 0.07$	$10.5 \pm 0.7 \pm 1.4 \pm 0.3$	$8.2 \pm 0.6 \pm 1.0 \pm 0.3$	$7.7 \pm 0.5 \pm 0.9 \pm 0.2$	$28.3 \pm 1.9 \pm 3.4 \pm 0.9$
$W^\pm W^\pm jj$ Int	$0.212 \pm 0.014 \pm 0.017 \pm 0.025$	$0.90 \pm 0.06 \pm 0.06 \pm 0.04$	$0.72 \pm 0.05 \pm 0.05 \pm 0.03$	$0.64 \pm 0.04 \pm 0.04 \pm 0.03$	$2.47 \pm 0.17 \pm 0.15 \pm 0.07$
obsData	$48.0 \pm 0.0 \pm 0.0 \pm 0.0$	$73.0 \pm 0.0 \pm 0.0 \pm 0.0$	$93.0 \pm 0.0 \pm 0.0 \pm 0.0$	$92.0 \pm 0.0 \pm 0.0 \pm 0.0$	$306.0 \pm 0.0 \pm 0.0 \pm 0.0$
$W^\pm W^\pm jj$ EW	$5.8 \pm 0.3 \pm 1.4 \pm 0.1$	$17.6 \pm 1.0 \pm 3.2 \pm 0.4$	$15.1 \pm 0.8 \pm 3.4 \pm 0.4$	$14.2 \pm 0.8 \pm 3.0 \pm 0.4$	$53 \pm 3 \pm 11 \pm 1$
Total Expected	$41.2 \pm 0.4 \pm 3.0 \pm 3.2$	$79 \pm 2 \pm 5 \pm 6$	$98 \pm 1 \pm 6 \pm 4$	$86 \pm 1 \pm 5 \pm 5$	$304 \pm 5 \pm 16 \pm 16$

Table B.17: Post-fit yields in the WZ control region in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using observed data. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	$\ell\ell\ell$			
Other prompt	115	± 0	± 18	± 7
Conversions	9	± 0	± 4	± 3
Non-prompt	30	± 0	± 9	± 8
WZ EW	141	± 0	± 8	± 4
WZ QCD	540	± 0	± 50	± 30
obsData	$832.0 \pm 0.0 \pm 0.0 \pm 0.0$			
Total Expected	840	± 0	± 50	± 40

Pull plot and correlations are in Figure B.12. Selected profile LH scans are in Figure B.13. These are the signal and QCD $W^\pm Zjj$ background normalisation factors, μ and μ_{WZ} , and the most constrained nuisance parameters. The profile likelihood scan is performed by setting a nuisance parameter constant to different values and determine the likelihood ratio again. Slightly tilted parabola are expected for well defined fits without local minima. Everything looks smooth as expected.

The strongest (anti-)correlations are included in Table B.18. Most of the correlations are due to normalisation effects of a systematic on the signal and QCD $W^\pm Zjj$ background which can be equalised by the corresponding signal or QCD $W^\pm Zjj$ normalisation strength.

The effect of all the nuisance parameters considered in the fit is shown in Tables B.19 and B.20 for systematic and MC statistical (gammas) uncertainties, respectively.

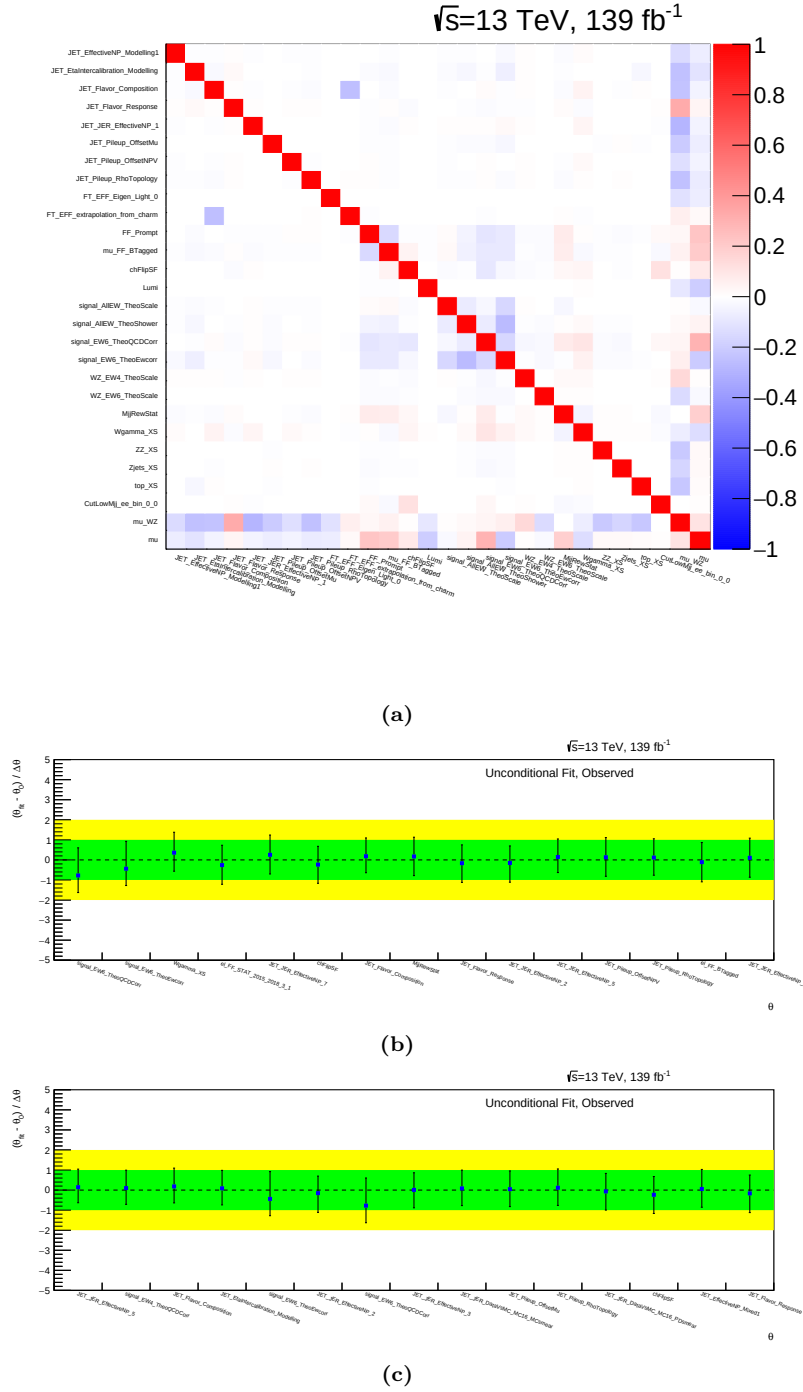


Figure B.12: Correlation of nuisance parameters with at least 20% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) for in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

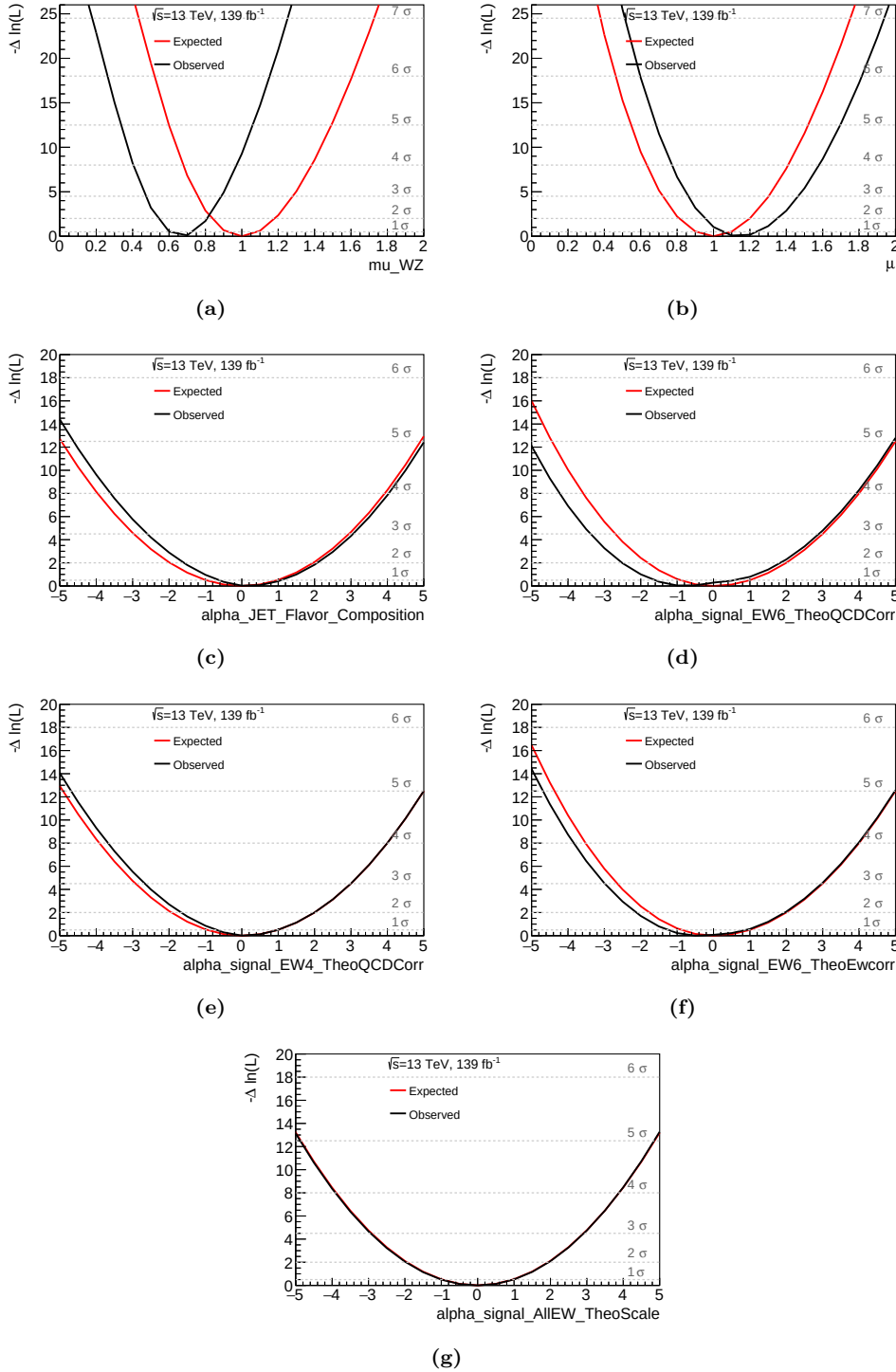


Figure B.13: Likelihood scans of nuisance parameters with largest pulls and constraints in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the QCD $W^\pm Zjj$ normalisation parameter (a), signal strength (b), Jet flavour composition (c), EW $W^\pm W^\pm jj$ NLO QCD correction (d), QCD $W^\pm W^\pm jj$ NLO QCD correction (e), EW $W^\pm W^\pm jj$ NLO EW correction (f) and inclusive $W^\pm W^\pm jj$ scale uncertainty (g).

Table B.18: List of parameter correlations which are larger than 7.5% in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using observed data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	μ_WZ	0.327
signal_EW6_TheoQCDCorr	μ	0.297
JET_JER_EffectiveNP_1	μ_WZ	-0.288
signal_AllEW_TheoShower	signal_EW6_TheoEwcorr	-0.269
FT_EFF_extrapolation_from_charm	JET_Flavor_Composition	-0.251
JET_Pileup_RhoTopology	μ_WZ	-0.246
JET_EtaIntercalibration_Modelling	μ_WZ	-0.244
JET_Flavor_Composition	μ_WZ	-0.235
FF_Prompt	μ	0.228
top_XS	μ_WZ	-0.223
ZZ_XS	μ_WZ	-0.213
signal_EW6_TheoEwcorr	μ	-0.204
$\mu_FF_BTagged$	μ	0.204
JET_Pileup_OffsetMu	μ_WZ	-0.201
Lumi	μ	-0.196
MjjRewStat	μ	0.190
Zjets_XS	μ_WZ	-0.166
signal_AllEW_TheoScale	signal_EW6_TheoEwcorr	-0.161
signal_EW6_TheoEwcorr	signal_EW6_TheoQCDCorr	-0.158
WZ_EW4_TheoScale	μ_WZ	0.151
FF_Prompt	$\mu_FF_BTagged$	-0.150
JET_EffectiveNP_Modelling1	μ_WZ	-0.142
WZ_EW6_TheoScale	μ_WZ	-0.140
Wgamma_XS	μ	-0.130
JET_Pileup_OffsetNPV	μ_WZ	-0.127
FT_EFF_Eigen_Light_0	μ_WZ	-0.118
chFlipSF	CutLowMjj_ee_bin_0_0	0.114
JET_EtaIntercalibration_Modelling	μ	-0.110
μ	μ_WZ	0.109
FF_Prompt	signal_EW6_TheoQCDCorr	-0.100
Wgamma_XS	signal_EW6_TheoQCDCorr	0.098
chFlipSF	signal_EW6_TheoQCDCorr	-0.092
Lumi	μ_WZ	-0.092
$\mu_FF_BTagged$	CutLowMjj_mm_bin_0_0	0.091
$\mu_FF_BTagged$	signal_EW6_TheoEwcorr	-0.089
$\mu_FF_BTagged$	signal_EW6_TheoQCDCorr	-0.086
JET_JER_EffectiveNP_7	μ_WZ	-0.086
triboson_XS	μ_WZ	-0.086
chFlipSF	μ	0.086
FF_Prompt	signal_EW6_TheoEwcorr	-0.084
JET_JER_EffectiveNP_2	μ	-0.083
$\mu_FF_STAT_2015_2018_3_1$	μ	-0.083
$\mu_FF_STAT_2015_2018_2_1$	μ	-0.083
FF_Prompt	MjjRewStat	0.082
signal_AllEW_TheoShower	signal_EW6_TheoQCDCorr	-0.078
MET_SoftTrk_Scale	μ_WZ	0.077
signal_AllEW_TheoScale	signal_AllEW_TheoShower	-0.077
MjjRewStat	signal_EW6_TheoQCDCorr	0.075

Table B.19: Ranking of the systematic nuisance parameters included in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using observed data.

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\theta_{PF}^{up}$	$\Delta\theta_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
alpha_signal_EW6_TheoQCDCorr	-0.7748	1.3767	-0.8515	0.0272	-0.0301	0.0261	-0.0078
alpha_FF_Prompt	0.0710	0.9367	-0.9529	0.0235	-0.0183	0.0233	-0.0202
alpha_mu_FF_BTagged	0.0846	0.9144	-0.9258	0.0213	-0.0155	0.0212	-0.0181
Lumi	0.9998	0.0170	-0.0170	-0.0197	0.0202	-0.0197	0.0200
alpha_MjRewStat	0.1716	0.9589	-0.9532	0.0192	-0.0185	0.0165	-0.0229
alpha_signal_EW6_TheoEwcorr	-0.4384	1.3616	-0.8376	-0.0056	0.0180	-0.0056	0.0124
alpha_Wgamma_XS	0.3604	1.0173	-0.9233	-0.0163	0.0149	-0.0094	0.0222
alpha_JET_EtaIntercalibration_Modelling	0.0896	0.8937	-0.8273	-0.0121	0.0083	-0.0124	0.0114
alpha_chFlipSF	-0.2347	0.9108	-0.9311	0.0069	-0.0087	0.0090	-0.0069
alpha_JET_Pileup_RhoTopology	0.1173	0.9361	-0.8810	-0.0084	0.0028	-0.0080	0.0034
alpha_JET_Pileup_OffsetMu	0.0475	0.9058	-0.8701	-0.0076	0.0032	-0.0080	0.0039
alpha_FT_EFF_Eigen_Light_0	-0.0102	0.9992	-1.0005	-0.0073	0.0070	-0.0073	0.0071
alpha_JET_EffectiveNP_Modelling1	0.0918	0.9626	-0.9290	-0.0072	0.0021	-0.0068	0.0024
alpha_mu_FF_STAT_2015_2018_2_1	-0.0185	0.9917	-0.9915	-0.0067	0.0063	-0.0069	0.0063
alpha_mu_FF_STAT_2015_2018_3_1	-0.0184	0.9917	-0.9915	-0.0067	0.0063	-0.0069	0.0063
alpha_JET_JER_EffectiveNP_1	0.0165	0.9936	-0.9886	-0.0026	0.0066	-0.0026	0.0075
alpha_signal_EW4_TheoQCDCorr	0.1011	0.8906	-0.8119	0.0001	-0.0057	0.0001	-0.0079
alpha_JET_Pileup_OffsetNPV	0.1327	0.9802	-0.9496	-0.0041	0.0057	-0.0037	0.0065
alpha_JET_Flavor_Response	-0.1634	0.9122	-0.9578	0.0013	-0.0054	0.0019	-0.0046
alpha_mu_FF_AntiIDSF	-0.0560	0.9984	-0.9989	0.0054	-0.0028	0.0055	-0.0048
alpha_JET_JER_EffectiveNP_2	-0.1508	0.8467	-0.9608	-0.0051	-0.0002	-0.0094	-0.0002
alpha_JET_Flavor_Composition	0.1831	0.9112	-0.8205	-0.0050	0.0036	-0.0047	0.0051
alpha_MUON_EFF_RECO_SYS	-0.0097	0.9989	-0.9992	-0.0039	0.0032	-0.0040	0.0032
alpha_el_FF_STAT_2015_2018_3_1	-0.2582	0.9873	-0.9576	-0.0036	0.0038	-0.0046	0.0030
alpha_MUON_EFF_ISO_SYS	-0.0041	0.9992	-0.9992	-0.0018	0.0037	-0.0018	0.0037
alpha_signal_AllEW_TheoShower	-0.0329	0.9215	-0.9251	0.0037	-0.0028	0.0041	-0.0028
alpha_JET_EtaIntercalibration_TotalStat	0.0236	0.9926	-0.9733	-0.0008	0.0032	-0.0008	0.0034
alpha_Zjets_XS	-0.0730	1.0012	-0.9960	0.0028	-0.0029	0.0030	-0.0026
alpha_signal_AllEW_TheoScale	-0.0020	0.9911	-0.9985	-0.0024	0.0029	-0.0024	0.0029

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\theta_{\text{PF}}^{\text{up}}$	$\Delta\theta_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_ZZ_XS	-0.0643	1.0002	-0.9979	0.0028	-0.0021	0.0027	-0.0022
alpha_MET_SoftTrk_ResoPara	0.0472	0.9515	-0.9351	0.0000	0.0028	0.0000	0.0030
alpha_JET_JER_EffectiveNP_3	0.0099	0.8534	-0.8931	-0.0020	-0.0027	-0.0023	-0.0017
alpha_el_FF_STAT_2015_2018_3_3	-0.0931	0.9912	-0.9891	-0.0021	0.0025	-0.0024	0.0023
alpha_WZ_EW6_TheoScale	-0.0833	0.9918	-0.9942	-0.0022	0.0019	-0.0023	0.0016
alpha_FF_MET	-0.0697	0.9918	-0.9939	0.0022	0.0016	0.0025	0.0015
alpha_el_FF_BTagged	-0.1104	0.9778	-0.9825	0.0020	-0.0018	0.0023	-0.0017
alpha_JET_JER_EffectiveNP_5	0.1453	0.8989	-0.7748	-0.0018	-0.0007	-0.0017	-0.0012
alpha_JET_JER_EffectiveNP_7	0.2544	0.9845	-0.9548	-0.0018	0.0001	-0.0005	-0.0002
alpha_JET_EffectiveNP_Mixed1	0.0567	0.9725	-0.9119	-0.0016	-0.0015	-0.0016	-0.0017
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP8	-0.0210	0.9992	-0.9993	-0.0011	0.0015	-0.0011	0.0015
alpha_PRW_DATASF	0.0455	1.0017	-1.0016	0.0005	-0.0014	0.0005	-0.0015
alpha_MjRwPDF	0.0344	1.0002	-1.0003	0.0014	-0.0003	0.0014	-0.0003
alpha_FT_EFF_extrapolation_from_charm	-0.0162	0.9966	-0.9999	0.0014	-0.0011	0.0014	-0.0011
alpha_JET_EtaIntercalibration_NonClosure_negEta	-0.0178	0.9755	-0.9777	0.0013	0.0002	0.0014	0.0002
alpha_JET_JER_EffectiveNP_4	-0.0525	0.9600	-0.9700	-0.0008	0.0013	-0.0026	0.0013
alpha_JET_JER_EffectiveNP_11	-0.0973	0.9632	-0.9781	0.0012	-0.0012	0.0014	-0.0010
alpha_triboson_XS	-0.0351	1.0005	-0.9989	0.0012	-0.0010	0.0013	-0.0010
alpha_signal_AllEW_TheoPdf	-0.0038	1.0030	-1.0029	-0.0012	0.0012	-0.0012	0.0012
alpha_top_XS	-0.0342	1.0003	-0.9992	0.0012	-0.0006	0.0012	-0.0006
alpha_FT_EFF_Eigen_C_0	0.0105	1.0003	-0.9989	-0.0011	0.0008	-0.0010	0.0017
alpha_JET_EffectiveNP_Mixed2	-0.0099	1.0117	-1.0104	0.0004	-0.0011	0.0004	-0.0011
alpha_JET_Pileup_PtTerm	0.0479	1.0044	-1.0128	-0.0004	0.0011	-0.0003	0.0011
alpha_JET_JER_DataVsMC_MC16_MCsmear	0.0855	0.9091	-0.8576	0.0000	-0.0011	0.0000	-0.0018
alpha_WZ_EW4_TheoPdf	-0.0579	1.0073	-1.0052	0.0008	-0.0010	0.0008	-0.0010
alpha_MUON_SCALE	0.0012	1.0047	-1.0047	0.0003	-0.0009	0.0003	-0.0009
alpha_MET_SoftTrk_ResoPerp	0.0101	0.9899	-0.9885	0.0000	0.0008	0.0000	0.0008
alpha_el_FF_STAT_2015_2018_2_1	0.0464	0.9982	-0.9981	-0.0007	0.0008	-0.0007	0.0008
alpha_Zgamma_XS	0.0001	0.9998	-1.0002	0.0007	-0.0006	0.0007	-0.0006
alpha_el_FF_AntiIDSF	-0.0387	0.9996	-0.9997	0.0007	-0.0007	0.0008	-0.0006
alpha_JET_JER_EffectiveNP_6	-0.0606	0.9268	-0.9377	-0.0002	-0.0007	-0.0003	-0.0007
alpha_JET_JER_EffectiveNP_12restTerm	-0.0635	0.9745	-0.9782	0.0001	0.0007	-0.0002	0.0007

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\hat{\theta}_{PF}^{up}$	$\Delta\hat{\theta}_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
alpha_JET_JER_EffectiveNP_10	-0.0488	0.9775	-0.9805	0.0001	0.0006	0.0002	0.0006
alpha_JET_JER_DataVsMC_MC16_PDsmeas	-0.0666	0.8973	-0.9306	-0.0006	-0.0000	-0.0007	-0.0000
alpha_el_FF_STAT_2015_2018_1_1	0.0649	0.9987	-0.9985	-0.0005	0.0006	-0.0005	0.0006
alpha_el_FF_STAT_2015_2018_2_3	0.0471	0.9971	-0.9965	-0.0005	0.0006	-0.0005	0.0006
alpha_MUON_MS	-0.0279	0.9859	-1.0054	0.0005	0.0001	0.0005	0.0001
alpha_FT_EFF_Eigen_Light_2	-0.0058	0.9999	-1.0000	-0.0001	0.0005	-0.0001	0.0005
alpha_EL_EFF_ID_CorrUncertaintyNP14	-0.0003	0.9997	-0.9998	-0.0005	0.0005	-0.0005	0.0005
alpha_EL_EFF_ID_CorrUncertaintyNP11	-0.0059	0.9996	-0.9997	-0.0004	0.0004	-0.0004	0.0004
alpha_EL_EFF_Reco_TOTAL_1NPCOR_PLUS_UNCOR	0.0015	0.9998	-0.9999	-0.0004	0.0004	-0.0004	0.0004
alpha_EL_EFF_ID_CorrUncertaintyNP12	-0.0021	0.9998	-0.9999	-0.0004	0.0004	-0.0004	0.0004
alpha_EL_EFF_ID_CorrUncertaintyNP15	-0.0120	0.9998	-0.9997	0.0004	-0.0004	0.0004	-0.0004
alpha_mu_FF_STAT_2015_2018_1_1	-0.0098	0.9999	-0.9999	-0.0003	0.0004	-0.0003	0.0004
alpha_MET_SoftTrk_Scale	0.0406	0.9719	-0.9643	0.0004	-0.0003	0.0003	-0.0003
alpha_JET_JER_EffectiveNP_8	-0.0216	0.9899	-0.9925	0.0003	0.0002	0.0004	0.0002
alpha_EL_EFF_Iso_TOTAL_1NPCOR_PLUS_UNCOR	-0.0015	0.9999	-0.9999	-0.0003	0.0003	-0.0003	0.0003
alpha_JET_JvtEfficiency	0.0117	0.9999	-0.9997	0.0003	0.0001	0.0003	-0.0002
alpha_EL_EFF_ID_CorrUncertaintyNP9	-0.0058	0.9998	-0.9999	-0.0003	0.0003	-0.0003	0.0003
alpha_MUON_EFF_TrigSystUncertainty	0.0064	0.9996	-0.9997	0.0003	-0.0003	0.0003	-0.0003
alpha_MUON_EFF_REC0_STAT	-0.0016	1.0000	-1.0000	-0.0002	0.0003	-0.0002	0.0003
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP17	0.0026	0.9998	-0.9999	-0.0002	0.0003	-0.0002	0.0003
alpha_FT_EFF_Eigen_C_1	0.0012	1.0000	-1.0000	-0.0002	0.0002	-0.0002	0.0002
alpha_FT_EFF_Eigen_B_0	-0.0062	1.0006	-0.9992	0.0002	0.0001	0.0001	0.0000
alpha_JET_EffectiveNP_Modelling3	-0.0223	1.0204	-1.0172	0.0002	-0.0002	0.0002	-0.0002
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP6	0.0028	0.9999	-1.0000	-0.0002	0.0002	-0.0002	0.0002
alpha_MUON_EFF_TTVA_SYS	-0.0005	0.9997	-0.9999	-0.0002	0.0002	-0.0002	0.0002
alpha_EL_EFF_ID_CorrUncertaintyNP13	-0.0112	0.9999	-0.9999	-0.0001	0.0002	-0.0001	0.0002
alpha_JET_EffectiveNP_Detector1	0.0099	1.0039	-1.0045	-0.0001	0.0002	-0.0001	0.0002
alpha_JET_EffectiveNP_Statistical2	0.0028	1.0080	-1.0077	0.0002	-0.0001	0.0002	-0.0001
alpha_FT_EFF_Eigen_B_1	-0.0020	1.0002	-0.9996	-0.0001	0.0002	-0.0001	0.0002
alpha_MUON_ID	-0.0065	1.0189	-1.0180	-0.0002	0.0000	-0.0001	0.0000
alpha_MUON_EFF_TTVA_STAT	-0.0009	1.0000	-1.0000	-0.0001	0.0002	-0.0001	0.0002
alpha_JET_EtaIntercalibration_NonClosure_posEta	-0.0087	1.0050	-1.0047	-0.0001	0.0002	-0.0001	0.0002

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\theta_{\text{PF}}^{\text{up}}$	$\Delta\theta_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_MUON_EFF_ISO_STAT	0.0021	1.0000	-1.0000	-0.0001	0.0002	-0.0001	0.0002
alpha_FT_EFF_extrapolation	0.0044	1.0000	-1.0000	0.0001	-0.0001	0.0000	-0.0001
alpha_MUON_EFF_TrigStatUncertainty	-0.0021	1.0001	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP7	-0.0010	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_JET_EffectiveNP_Mixed3	0.0036	1.0004	-1.0005	-0.0000	0.0001	-0.0000	0.0001
alpha_WZ_EW6_TheoPdf	-0.0172	0.9995	-0.9996	-0.0000	0.0001	-0.0000	0.0001
alpha_JET_BJES_Response	-0.0043	0.9973	-0.9976	0.0001	-0.0001	0.0001	-0.0001
alpha_MjRewScale	0.0093	0.9953	-0.9951	0.0001	0.0000	0.0001	0.0000
alpha_EG_RESOLUTION_ALL	0.0061	1.0175	-1.0183	-0.0000	-0.0001	-0.0000	-0.0001
alpha_JET_JER_EffectiveNP_9	0.1044	0.9794	-0.9685	-0.0001	0.0000	-0.0003	-0.0000
alpha_FT_EFF_Eigen_B_2	0.0007	0.9999	-1.0001	0.0001	-0.0001	0.0001	-0.0001
alpha_JET_EffectiveNP_Statistical5	0.0005	1.0068	-1.0067	0.0001	0.0000	0.0001	0.0000
alpha_WZ_EW4_TheoAlphas	-0.0011	1.0000	-1.0000	-0.0001	0.0001	-0.0001	0.0001
alpha_JET_EffectiveNP_Statistical6	0.0010	1.0070	-1.0072	0.0000	0.0001	0.0000	0.0001
alpha_JET_EffectiveNP_Statistical6	0.0046	1.0049	-1.0051	0.0000	0.0001	0.0000	0.0001
alpha_JET_EffectiveNP_Modelling4	-0.0817	0.9881	-0.9911	-0.0001	0.0000	0.0001	-0.0003
alpha_WZ_EW4_TheoScale	-0.0009	1.0002	-1.0005	0.0000	0.0001	0.0000	0.0001
alpha_JET_EffectiveNP_Modelling2	0.0098	1.0048	-1.0052	0.0000	-0.0000	0.0000	-0.0001
alpha_EG_SCALE_ALL	-0.0111	1.0428	-1.0400	0.0000	0.0000	0.0000	0.0000
alpha_MUON_SAGITTA_RESBIAS	0.0060	1.0000	-1.0000	-0.0000	0.0000	-0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP15	0.0076	1.0033	-1.0034	0.0000	0.0000	0.0000	0.0000
alpha_JET_EffectiveNP_Statistical1	0.0138	0.9999	-0.9999	-0.0000	0.0000	-0.0000	0.0000
alpha_el_FF_STAT_2015_2018_1_3	0.0001	1.0048	-1.0047	0.0000	0.0000	0.0000	0.0000
alpha_JET_EffectiveNP_Statistical3	-0.0133	0.9999	-0.9999	0.0000	-0.0000	0.0000	-0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP10	-0.0025	1.0000	-1.0000	0.0000	-0.0000	0.0000	-0.0000
alpha_FT_EFF_Eigen_C_2	-0.0090	0.9999	-0.9999	-0.0000	0.0000	-0.0000	0.0000
alpha_el_FF_STAT_2016_2018_3_3	0.0013	1.0054	-1.0056	-0.0000	0.0000	-0.0000	0.0000
alpha_JET_EffectiveNP_Statistical4	-0.0029	0.9999	-1.0001	0.0000	-0.0000	0.0000	-0.0000
alpha_FT_EFF_Eigen_Light_1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_MUON_EFF_RECO_STAT_LOWPT	-0.0003	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP3	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP11	0.0009	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP14	0.0009	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\hat{\theta}_{PF}^{up}$	$\Delta\hat{\theta}_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
alpha_MUON_EFF_RECO_SYS_LOWPT	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP16	0.0026	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EG_SCALE_AF2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_MUON_SAGITTA_RHO	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_3_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_3_1	0.0087	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_FT_EFF_Eigen_Light_3	-0.0005	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP13	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP12	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_2_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_JET_EffectiveNP_Detector2	0.0004	1.0008	-1.0008	0.0000	0.0000	0.0000	0.0000
alpha_MET_JetTrk_Scale	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_JET_SingleParticle_HighPt	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_JET_PunchThrough_MC16	0.0014	0.9983	-0.9983	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP10	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP0	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_WZ_EW6_TheoAlphas	-0.0019	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_JET_EtaIntercalibration_NonClosure_highE	-0.0006	0.9997	-0.9997	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP8	-0.0095	1.0000	-0.9999	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP7	-0.0003	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_Trigger_TOTAL_1NPCOR_PLUS_UNCOR	0.0004	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP0	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2018_1_2	0.0013	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_mu_FF_STAT_2016_2018_1_1	-0.0002	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_1_3	-0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_1_2	-0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_1_1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP5	-0.0003	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_mu_FF_STAT_2016_2018_2_1	-0.0014	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_mu_FF_STAT_2015_3_1	-0.0025	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000

Nuisance parameter θ	$\hat{\theta}_{\text{PF}}$	$\Delta\theta_{\text{PF}}^{\text{up}}$	$\Delta\theta_{\text{PF}}^{\text{down}}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{up}} - \hat{\mu}$	$\mu_{\text{PF}}^{\text{down}} - \hat{\mu}$
alpha_EL_EFF_TriggerEff_TOTAL_1NPCOR_PLUS_UNCOR	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_mu_FF_STAT_2016_2018_3_1	-0.0034	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_signal_ALLEW_TheoAlphas	0.0002	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP9	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP6	-0.0003	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP3	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP5	0.0017	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_3_1	-0.0193	0.9999	-0.9999	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_SIMPLIFIED_UncorrUncertaintyNP4	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_2_1	0.0011	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_1_3	-0.0005	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_1_2	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_1_1	0.0008	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_3_3	-0.0002	0.9999	-0.9999	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_3_2	-0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2016_2018_2_3	-0.0019	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2_3	-0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2_2	0.0001	0.9999	-0.9999	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2_1	-0.0001	0.9999	-0.9999	0.0000	0.0000	0.0000	0.0000
alpha_EL_EFF_ID_CorrUncertaintyNP4	-0.0003	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2018_3_2	0.0008	0.9999	-0.9999	0.0000	0.0000	0.0000	0.0000
alpha_mu_FF_STAT_2015_1_1	-0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_mu_FF_STAT_2015_2_1	0.0000	1.0000	-1.0000	0.0000	0.0000	0.0000	0.0000
alpha_el_FF_STAT_2015_2018_2_2	-0.0002	0.9999	-0.9999	0.0000	0.0000	0.0000	0.0000

Table B.20: Ranking of the MC statistical nuisance parameters in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using observed data.

Nuisance parameter θ	$\hat{\theta}_{PF}$	$\Delta\theta_{PF}^{up}$	$\Delta\theta_{PF}^{down}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$	$\mu_{PF}^{up} - \hat{\mu}$	$\mu_{PF}^{down} - \hat{\mu}$
gamma_stat_CutSR_me_bin_1_0	0.9838	0.0407	-0.0396	-0.0062	0.0053	-0.0099	0.0035
gamma_stat_CutSR_mm_bin_1_0	0.9936	0.0364	-0.0356	-0.0057	0.0060	-0.0075	0.0052
gamma_stat_CutSR_em_bin_1_0	0.9997	0.0377	-0.0367	-0.0051	0.0050	-0.0053	0.0050
gamma_stat_CutSR_mm_bin_0_0	1.0082	0.0360	-0.0352	-0.0037	0.0047	-0.0029	0.0065
gamma_stat_CutSR_mm_bin_2_0	0.9888	0.0470	-0.0455	-0.0036	0.0044	-0.0054	0.0034
gamma_stat_CutSR_me_bin_0_0	1.0284	0.0439	-0.0426	-0.0043	0.0037	-0.0013	0.0063
gamma_stat_CutSR_em_bin_0_0	1.0147	0.0392	-0.0382	-0.0042	0.0036	-0.0020	0.0051
gamma_stat_CutSR_ee_bin_1_0	1.0074	0.0586	-0.0564	-0.0025	0.0029	-0.0023	0.0034
gamma_stat_CutSR_me_bin_2_0	0.9977	0.0448	-0.0435	-0.0028	0.0025	-0.0030	0.0024
gamma_stat_CutSR_em_bin_2_0	1.0014	0.0326	-0.0319	-0.0025	0.0016	-0.0024	0.0023
gamma_stat_CutSR_em_bin_3_0	0.9615	0.1191	-0.1099	-0.0023	0.0023	-0.0032	0.0015
gamma_stat_CutSR_mm_bin_3_0	1.0055	0.0643	-0.0617	-0.0019	0.0014	-0.0018	0.0016
gamma_stat_CutSR_me_bin_3_0	0.9861	0.0814	-0.0771	-0.0017	0.0014	-0.0020	0.0011
gamma_stat_CutSR_ee_bin_0_0	0.9740	0.0598	-0.0574	-0.0017	0.0015	-0.0026	0.0009
gamma_stat_CutSR_ee_bin_3_0	0.9603	0.1645	-0.1475	-0.0016	0.0015	-0.0021	0.0011
gamma_stat_CutSR_mm_bin_4_0	1.0137	0.0520	-0.0502	-0.0016	0.0015	-0.0012	0.0019
gamma_stat_CutSR_ee_bin_4_0	0.9900	0.1086	-0.1012	-0.0013	0.0011	-0.0014	0.0010
gamma_stat_CutCRWZ3Lep_all_bin_0	0.9999	0.0043	-0.0043	0.0012	-0.0012	0.0012	-0.0011
gamma_stat_CutSR_em_bin_4_0	0.9949	0.0424	-0.0413	-0.0012	0.0011	-0.0013	0.0010
gamma_stat_CutLowMjj_ee_bin_0_0	1.0282	0.0627	-0.0602	0.0009	-0.0003	0.0005	-0.0006
gamma_stat_CutSR_ee_bin_2_0	1.0014	0.0415	-0.0404	-0.0006	0.0007	-0.0006	0.0008
gamma_stat_CutLowMjj_em_bin_0_0	0.9908	0.0387	-0.0377	0.0006	-0.0000	0.0011	0.0002
gamma_stat_CutLowMjj_mm_bin_0_0	0.9927	0.0353	-0.0344	-0.0002	0.0004	0.0005	0.0006
gamma_stat_CutSR_me_bin_4_0	1.0006	0.0211	-0.0208	-0.0003	0.0004	-0.0002	0.0004
gamma_stat_CutLowMjj_me_bin_0_0	1.0087	0.0358	-0.0350	0.0003	-0.0002	0.0000	-0.0001

Appendix C

Additional information about unfolded distributions

C.1 Additional Results for $m_{\ell\ell}$

More details for this variable for EW $W^\pm W^\pm jj$ are already shown in the main part.

C.1.1 Results of the Asimov Fit for $m_{\ell\ell}$ with EW+Int+QCD Signal

The expected signal strength μ from the fit to Asimov data is:

$$\mu_{\text{exp}, m_{\ell\ell}, \text{bin 1}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.19}^{0.21} (\text{stat.}) \pm_{0.08}^{0.08} (\text{mod. syst.}) \pm_{0.05}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\ell\ell}, \text{bin 2}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.16}^{0.17} (\text{stat.}) \pm_{0.06}^{0.06} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\ell\ell}, \text{bin 3}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.19}^{0.21} (\text{stat.}) \pm_{0.06}^{0.07} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\ell\ell}, \text{bin 4}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.20}^{0.22} (\text{stat.}) \pm_{0.05}^{0.06} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\ell\ell}, \text{bin 5}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.18}^{0.19} (\text{stat.}) \pm_{0.05}^{0.06} (\text{mod. syst.}) \pm_{0.04}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\ell\ell}, \text{bin 6}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.18}^{0.20} (\text{stat.}) \pm_{0.05}^{0.06} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.})$$

and the QCD $W^\pm Z jj$ normalisation strength is:

$$\mu_{\text{WZ, exp}, m_{\ell\ell}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

Post-fit plots are in Figure C.1 and Figure C.2.

Pull plot and correlations are in Figure C.3.

Table of the strongest (anti-)correlations are included in Table C.1.

The ranking plot is shown in Figure C.4.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.2.

The correlation between unfolded bins are shown in Figure C.5.

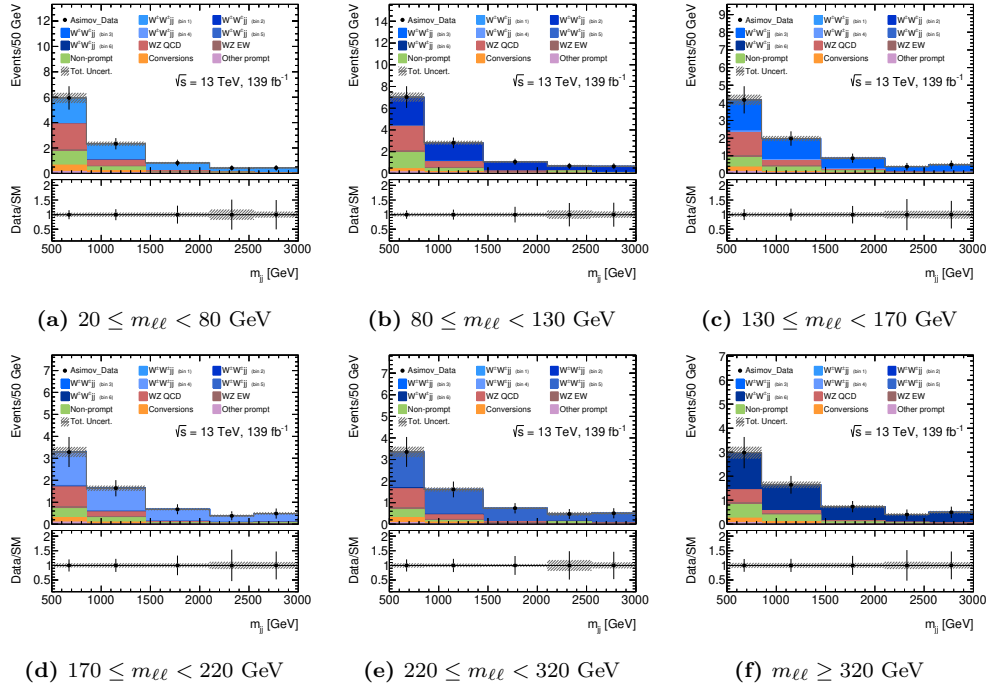


Figure C.1: Post-fit m_{jj} -distributions in signal region split into $m_{\ell\ell}$ slices as used in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

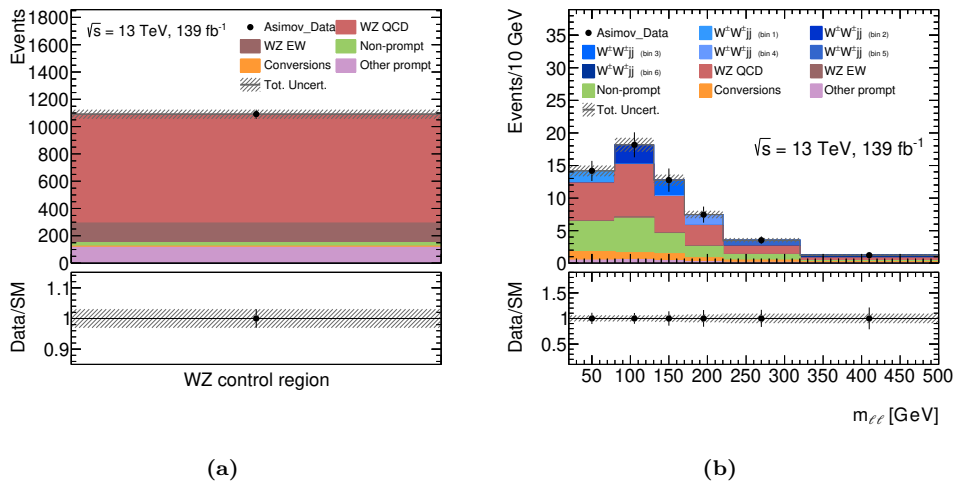


Figure C.2: Post-fit distributions in WZ control region (a) and low- m_{jj} CR (b) as used in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

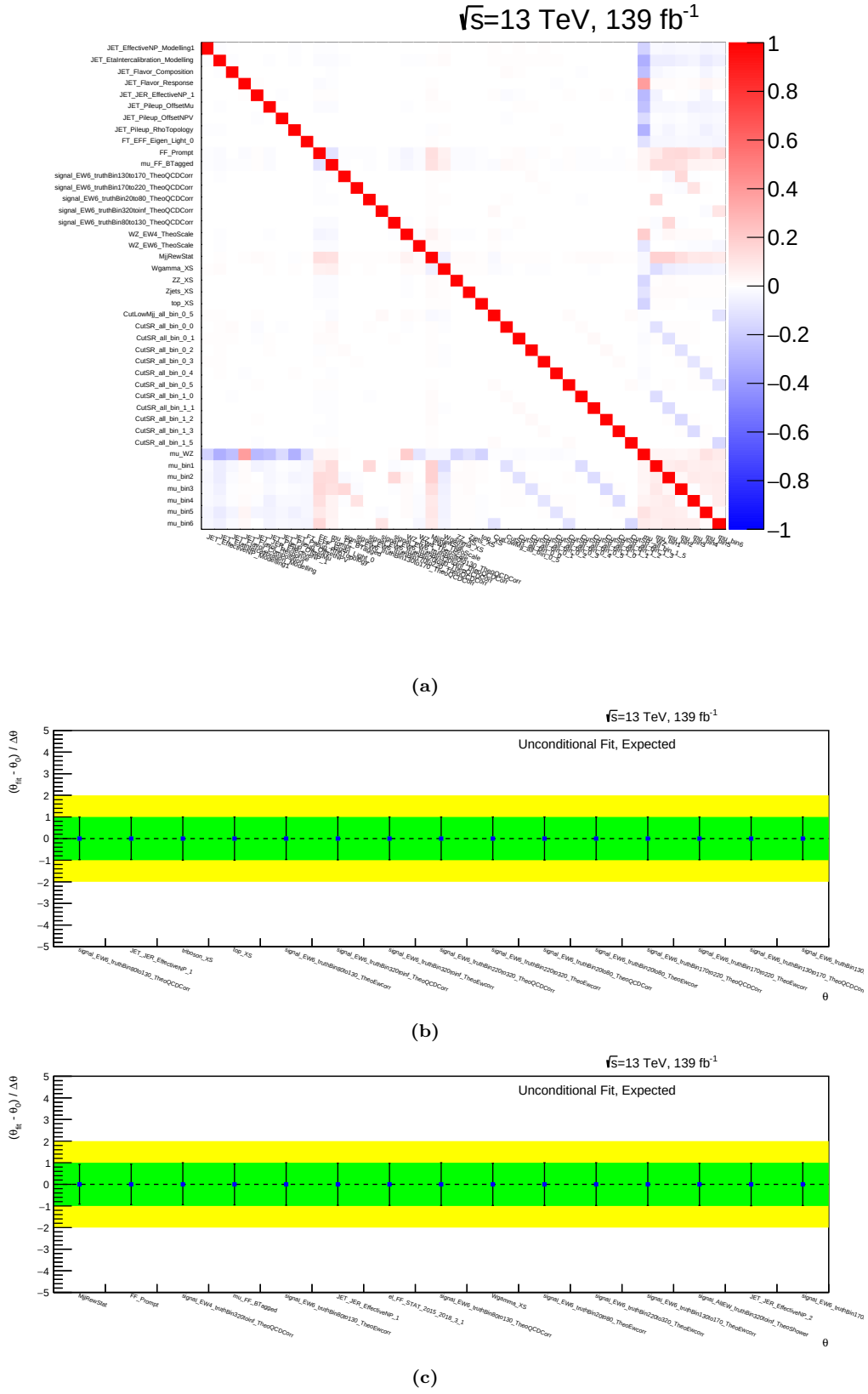


Figure C.3: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j j}$ with Asimov data.

Table C.1: List of parameter correlations in the Asimov fit which are larger than 10% in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	μ_WZ	0.381
JET_EtaIntercalibration_Modelling	μ_WZ	-0.312
JET_Pileup_RhoTopology	μ_WZ	-0.303
JET_JER_EffectiveNP_1	μ_WZ	-0.278
JET_Flavor_Composition	μ_WZ	-0.250
JET_Pileup_OffsetMu	μ_WZ	-0.243
WZ_EW4_TheoScale	μ_WZ	0.198
MjjRewStat	μ_bin2	0.182
MjjRewStat	μ_bin1	0.177
JET_EffectiveNP_Modelling1	μ_WZ	-0.174
top_XS	μ_WZ	-0.174
ZZ_XS	μ_WZ	-0.160
CutSR_all_bin_1_5	μ_bin6	-0.149
signal_EW6_truthBin130to170_TheoQCDCorr	μ_bin3	0.149
signal_EW6_truthBin20to80_TheoQCDCorr	μ_bin1	0.148
signal_EW6_truthBin80to130_TheoQCDCorr	μ_bin2	0.147
CutSR_all_bin_1_2	μ_bin3	-0.147
FF_Prompt	μ_bin3	0.146
FF_Prompt	μ_bin6	0.145
FF_Prompt	μ_bin2	0.143
JET_Pileup_OffsetNPV	μ_WZ	-0.140
CutSR_all_bin_1_3	μ_bin4	-0.140
Wgamma_XS	μ_bin1	-0.134
$\mu_FF_BTagged$	μ_bin2	0.134
CutSR_all_bin_1_0	μ_bin1	-0.131
CutSR_all_bin_1_1	μ_bin2	-0.131
$\mu_FF_BTagged$	μ_bin1	0.130
MjjRewStat	μ_bin3	0.127
FF_Prompt	MjjRewStat	0.126
FF_Prompt	μ_bin4	0.124
CutSR_all_bin_0_1	μ_bin2	-0.120
CutSR_all_bin_0_2	μ_bin3	-0.119
FT_EFF_Eigen_Light_0	μ_WZ	-0.119
$\mu_FF_BTagged$	μ_bin3	0.116
CutSR_all_bin_0_0	μ_bin1	-0.115
MjjRewStat	$\mu_FF_BTagged$	0.114
Zjets_XS	μ_WZ	-0.111
FF_Prompt	$\mu_FF_BTagged$	-0.111
CutSR_all_bin_0_4	μ_bin5	-0.111
CutSR_all_bin_0_5	μ_bin6	-0.110
CutLowMjj_all_bin_0_5	μ_bin6	-0.110
signal_EW6_truthBin170to220_TheoQCDCorr	μ_bin4	0.109
μ_WZ	μ_bin5	0.107
signal_EW6_truthBin320toinf_TheoQCDCorr	μ_bin6	0.106
CutSR_all_bin_0_3	μ_bin4	-0.104
WZ_EW6_TheoScale	μ_WZ	-0.103

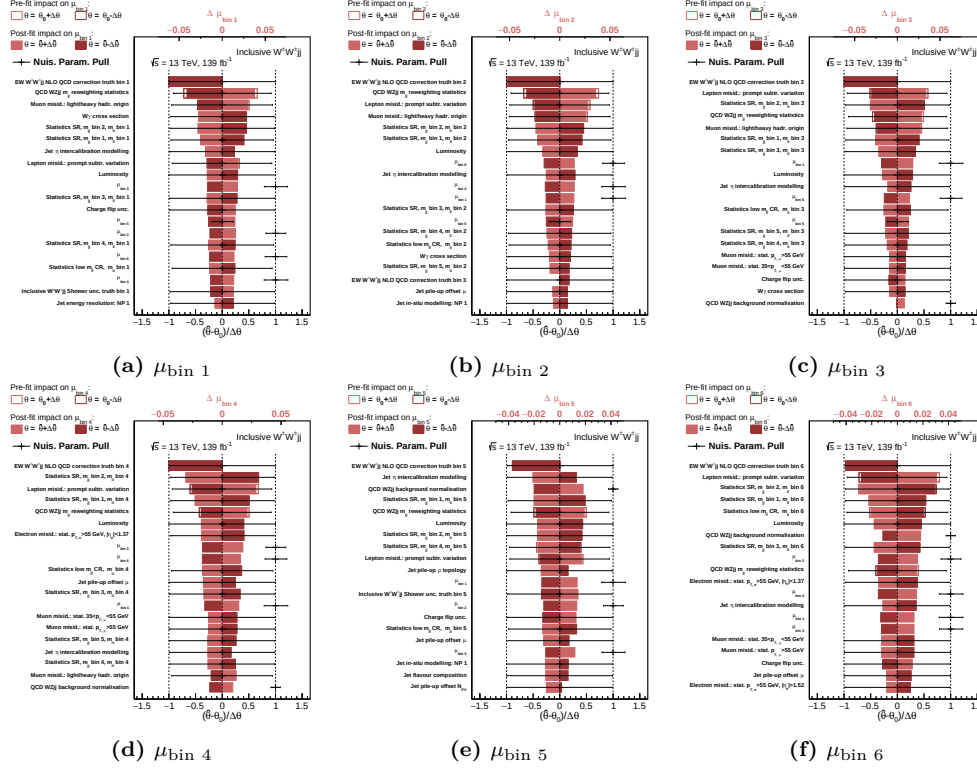


Figure C.4: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) $m_{\ell\ell}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

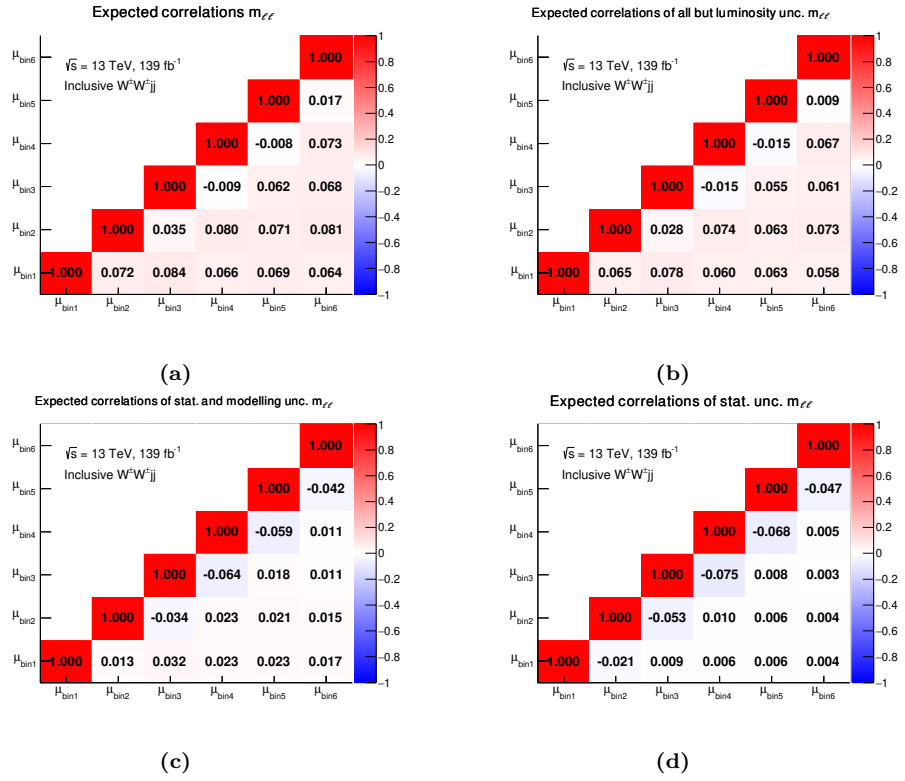


Figure C.5: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Table C.2: Breakdown of the uncertainty of signal strength in the different $m_{\ell\ell}$ truth slices in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{jj}$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.4	0.4	0.3	0.4	0.6	1.2
Muon calibration	0.4	0.4	0.5	0.5	0.5	0.9
Jet energy scale and resolution	3.0	2.2	1.7	2.1	3.1	2.0
$E_{\text{T}}^{\text{miss}}$ scale and resolution	0.3	0.2	0.2	0.1	0.2	0.2
b -tagging inefficiency	0.7	0.6	0.7	0.7	0.7	0.8
Background, misid. leptons	4.0	4.3	4.6	4.3	2.6	4.4
Background, charge misrec.	2.0	1.1	1.4	1.4	1.5	1.5
Pileup modelling	0.6	0.4	0.1	0.2	0.0	0.2
Luminosity	1.8	1.7	1.7	1.8	1.8	1.8
Modelling						
$W^\pm W^\pm \text{jj}$ shower, scale, PDF & α_s	1.9	0.9	0.7	0.6	1.8	0.4
EW $W^\pm W^\pm \text{jj}$, QCD corrections	3.5	3.0	3.4	2.6	2.1	2.3
EW $W^\pm W^\pm \text{jj}$, EW corrections	0.4	0.3	0.2	0.1	0.1	0.0
QCD $W^\pm W^\pm \text{jj}$, QCD corrections	0.1	0.0	0.1	0.1	0.1	0.6
Background, WZ scale, PDF & α_s	0.4	0.8	0.6	0.6	0.5	0.8
Background, WZ reweighting	3.2	2.6	1.9	1.2	1.4	0.8
Background, other	3.2	1.6	1.5	1.4	1.1	1.1
Model statistical	4.9	4.2	5.2	4.9	3.8	4.9
Experimental and modelling	9.7	8.1	8.7	8.0	7.0	8.0
Data statistical	19.9	16.8	20.0	20.7	18.7	18.8
Total	22.2	18.7	21.8	22.2	19.9	20.4

C.1.2 Results of the Fit to Observed Data for $m_{\ell\ell}$ with EW+Int+QCD Signal

The observed signal strength μ from the fit to observed data is:

$$\mu_{\text{obs}, m_{\ell\ell}, \text{bin 1}}^{\text{EW+Int+QCD}} = 1.17 \pm_{-0.20}^{+0.21} (\text{stat.}) \pm_{-0.10}^{+0.10} (\text{mod. syst.}) \pm_{-0.06}^{+0.06} (\text{exp. syst.}) \pm_{-0.02}^{+0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{\ell\ell}, \text{bin 2}}^{\text{EW+Int+QCD}} = 0.99 \pm_{-0.16}^{+0.17} (\text{stat.}) \pm_{-0.07}^{+0.07} (\text{mod. syst.}) \pm_{-0.04}^{+0.05} (\text{exp. syst.}) \pm_{-0.01}^{+0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{\ell\ell}, \text{bin 3}}^{\text{EW+Int+QCD}} = 0.93 \pm_{-0.18}^{+0.20} (\text{stat.}) \pm_{-0.06}^{+0.07} (\text{mod. syst.}) \pm_{-0.05}^{+0.05} (\text{exp. syst.}) \pm_{-0.01}^{+0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{\ell\ell}, \text{bin 4}}^{\text{EW+Int+QCD}} = 1.21 \pm_{-0.21}^{+0.22} (\text{stat.}) \pm_{-0.06}^{+0.07} (\text{mod. syst.}) \pm_{-0.05}^{+0.05} (\text{exp. syst.}) \pm_{-0.02}^{+0.03} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{\ell\ell}, \text{bin 5}}^{\text{EW+Int+QCD}} = 1.37 \pm_{-0.20}^{+0.21} (\text{stat.}) \pm_{-0.07}^{+0.08} (\text{mod. syst.}) \pm_{-0.05}^{+0.06} (\text{exp. syst.}) \pm_{-0.02}^{+0.03} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{\ell\ell}, \text{bin 6}}^{\text{EW+Int+QCD}} = 1.41 \pm_{-0.20}^{+0.22} (\text{stat.}) \pm_{-0.09}^{+0.10} (\text{mod. syst.}) \pm_{-0.06}^{+0.06} (\text{exp. syst.}) \pm_{-0.02}^{+0.03} (\text{lumi.})$$

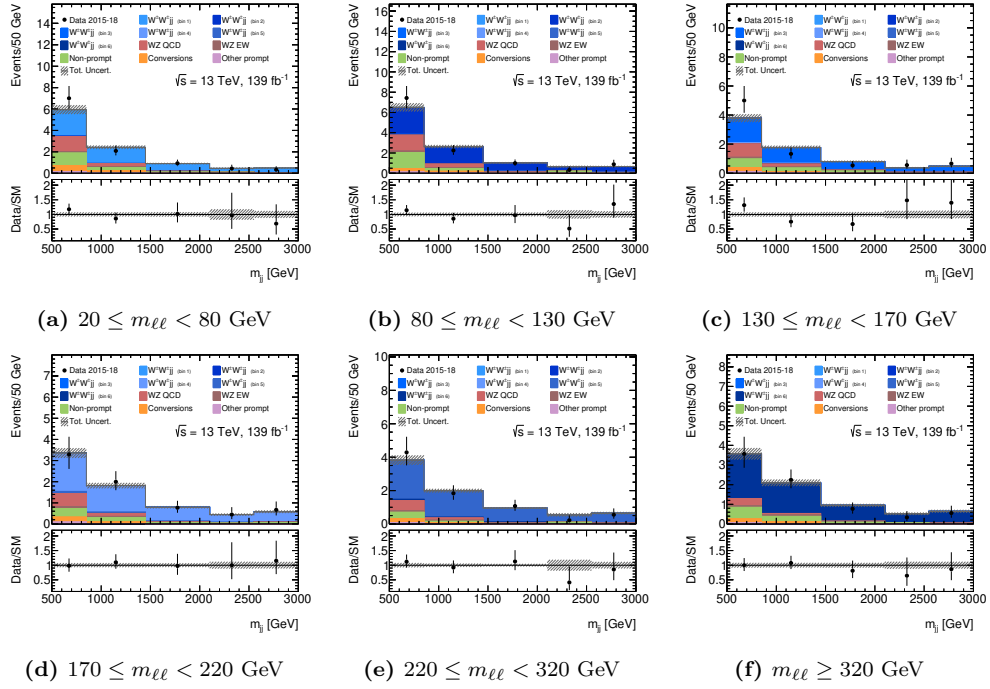


Figure C.6: Post-fit m_{jj} -distributions in signal region split into $m_{\ell\ell}$ slices as used in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

and the QCD $W^\pm Z jj$ normalisation strength is:

$$\mu_{\text{obs}, WZ, m_{\ell\ell}}^{\text{EW}+\text{Int}+\text{QCD}} = 0.69 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.04}^{0.04} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

Post-fit plots are in Figure C.6 and Figure C.7. The projections on $m_{\ell\ell}$ and on m_{jj} are shown in Figure C.8.

Pull plot and correlations are in Figure C.9.

Selected profile LH scans are in Figure C.10.

Table of the strongest (anti-)correlations are included in Table C.3.

The ranking plot is shown in Figure C.11.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.4.

The correlation between unfolded bins are shown in Figure C.12.

C.2 Results for m_{jj}

This section presents the extraction of the differential cross-section of the EW $W^\pm W^\pm jj$ production and inclusive $W^\pm W^\pm jj$ production as a function of m_{jj} .

C.2.1 Pre-Fit Distributions for m_{jj}

The following Figures show the distributions of the fit inputs in the high- $m_{\ell\ell}$ signal region (Figure C.13) and WZ control region (Figure C.14). Zero correlation is assumed in the combination of systematic uncertainties in the hatched band. The observed data is shown with Poisson uncertainties.

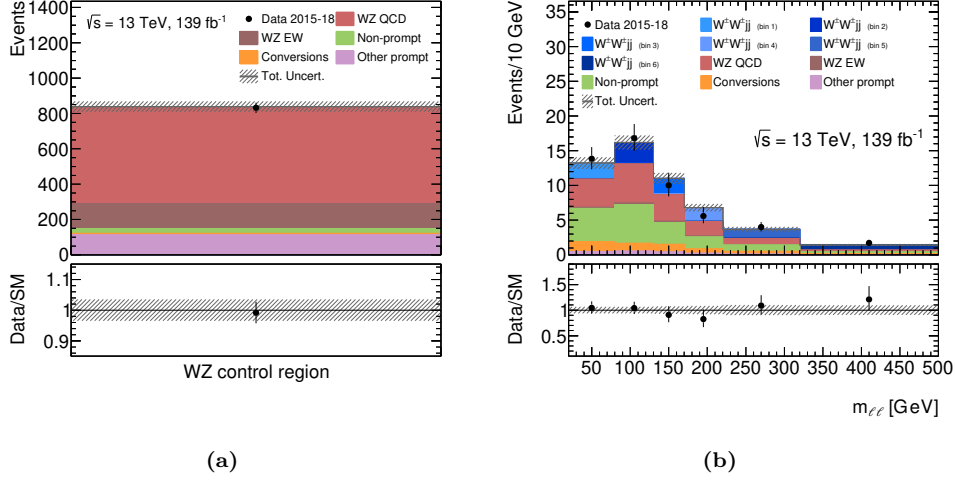


Figure C.7: Post-fit distributions in WZ control region (a) and low- m_{jj} CR (b) as used in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

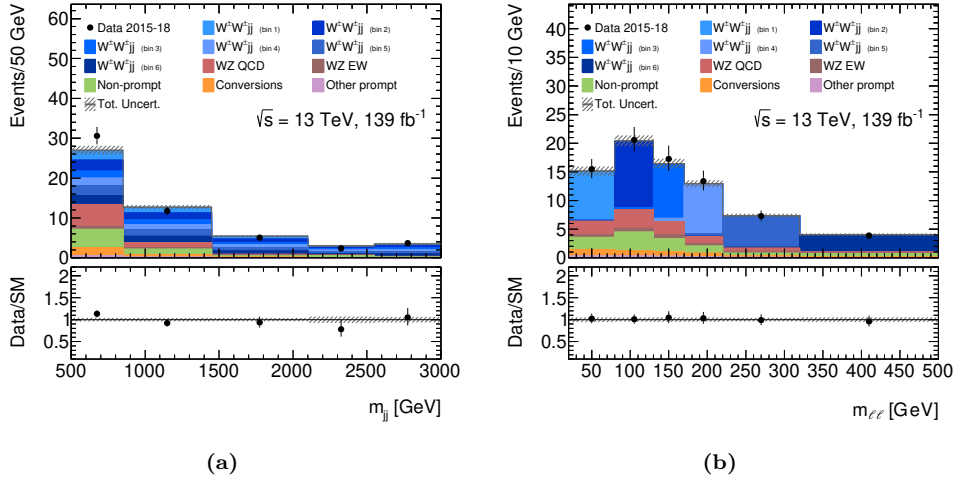


Figure C.8: Post-fit signal region $m_{\ell\ell}$ -distributions (a) and m_{jj} -distribution (b) in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

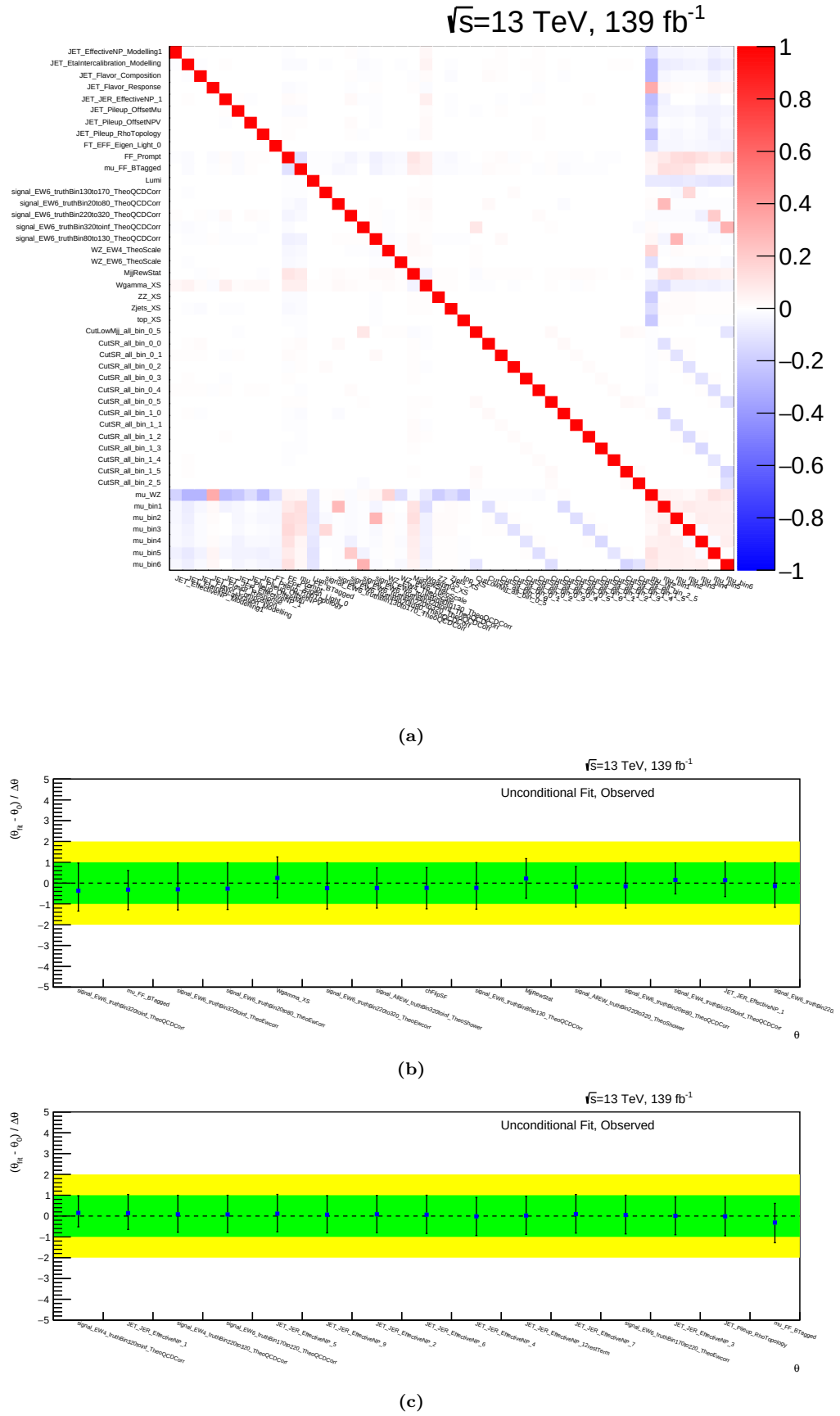


Figure C.9: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

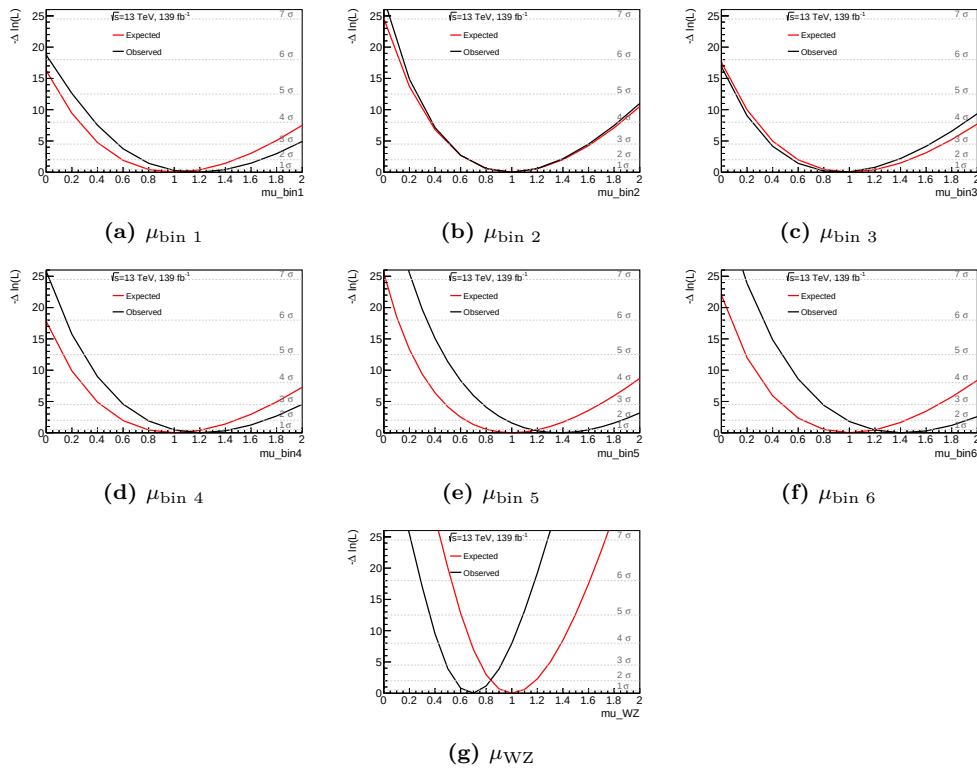


Figure C.10: Likelihood scans of nuisance parameters with largest pulls and constraints in the $m_{\ell\ell}$ differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-f) and for QCD $W^\pm Z jj$ normalisation parameter (g).

Table C.3: List of parameter correlations which are larger than 10% in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	$\mu_{_WZ}$	0.328
signal_EW6_truthBin320toinf_TheoQCDCorr	$\mu_{_bin6}$	0.309
JET_Flavor_Composition	$\mu_{_WZ}$	-0.293
JET_EtaIntercalibration_Modelling	$\mu_{_WZ}$	-0.293
signal_EW6_truthBin80to130_TheoQCDCorr	$\mu_{_bin2}$	0.289
signal_EW6_truthBin20to80_TheoQCDCorr	$\mu_{_bin1}$	0.272
JET_Pileup_RhoTopology	$\mu_{_WZ}$	-0.261
JET_JER_EffectiveNP_1	$\mu_{_WZ}$	-0.257
JET_Pileup_OffsetMu	$\mu_{_WZ}$	-0.217
top_XS	$\mu_{_WZ}$	-0.216
signal_EW6_truthBin220to320_TheoQCDCorr	$\mu_{_bin5}$	0.200
ZZ_XS	$\mu_{_WZ}$	-0.200
JET_EffectiveNP_Modelling1	$\mu_{_WZ}$	-0.172
WZ_EW4_TheoScale	$\mu_{_WZ}$	0.166
CutSR_all_bin_1_5	$\mu_{_bin6}$	-0.163
signal_EW6_truthBin130to170_TheoQCDCorr	$\mu_{_bin3}$	0.147
CutSR_all_bin_1_3	$\mu_{_bin4}$	-0.146
FF_Prompt	$\mu_{_bin3}$	0.145
CutSR_all_bin_1_2	$\mu_{_bin3}$	-0.141
CutSR_all_bin_1_0	$\mu_{_bin1}$	-0.140
Wgamma_XS	$\mu_{_bin1}$	-0.132
Zjets_XS	$\mu_{_WZ}$	-0.132
FF_Prompt	$\mu_{_bin2}$	0.131
JET_Pileup_OffsetNPV	$\mu_{_WZ}$	-0.131
MjjRewStat	$\mu_{_bin2}$	0.128
$\mu_{_FF_BTagged}$	$\mu_{_bin1}$	0.127
CutSR_all_bin_1_1	$\mu_{_bin2}$	-0.127
WZ_EW6_TheoScale	$\mu_{_WZ}$	-0.127
CutSR_all_bin_0_4	$\mu_{_bin5}$	-0.122
CutSR_all_bin_0_5	$\mu_{_bin6}$	-0.122
CutSR_all_bin_0_0	$\mu_{_bin1}$	-0.121
FF_Prompt	$\mu_{_bin6}$	0.120
FF_Prompt	$\mu_{_bin4}$	0.118
FF_Prompt	$\mu_{_FF_BTagged}$	-0.118
FT_EFF_Eigen_Light_0	$\mu_{_WZ}$	-0.115
CutSR_all_bin_0_2	$\mu_{_bin3}$	-0.115
$\mu_{_FF_BTagged}$	$\mu_{_bin2}$	0.114
CutSR_all_bin_0_1	$\mu_{_bin2}$	-0.112
$\mu_{_WZ}$	$\mu_{_bin5}$	0.110
MjjRewStat	$\mu_{_bin1}$	0.110
CutSR_all_bin_2_5	$\mu_{_bin6}$	-0.108
CutSR_all_bin_0_3	$\mu_{_bin4}$	-0.107
Lumi	$\mu_{_bin5}$	-0.107
CutSR_all_bin_1_4	$\mu_{_bin5}$	-0.106
Lumi	$\mu_{_bin6}$	-0.105
CutLowMjj_all_bin_0_5	$\mu_{_bin6}$	-0.103
$\mu_{_FF_BTagged}$	$\mu_{_bin3}$	0.102
FF_Prompt	MjjRewStat	0.101

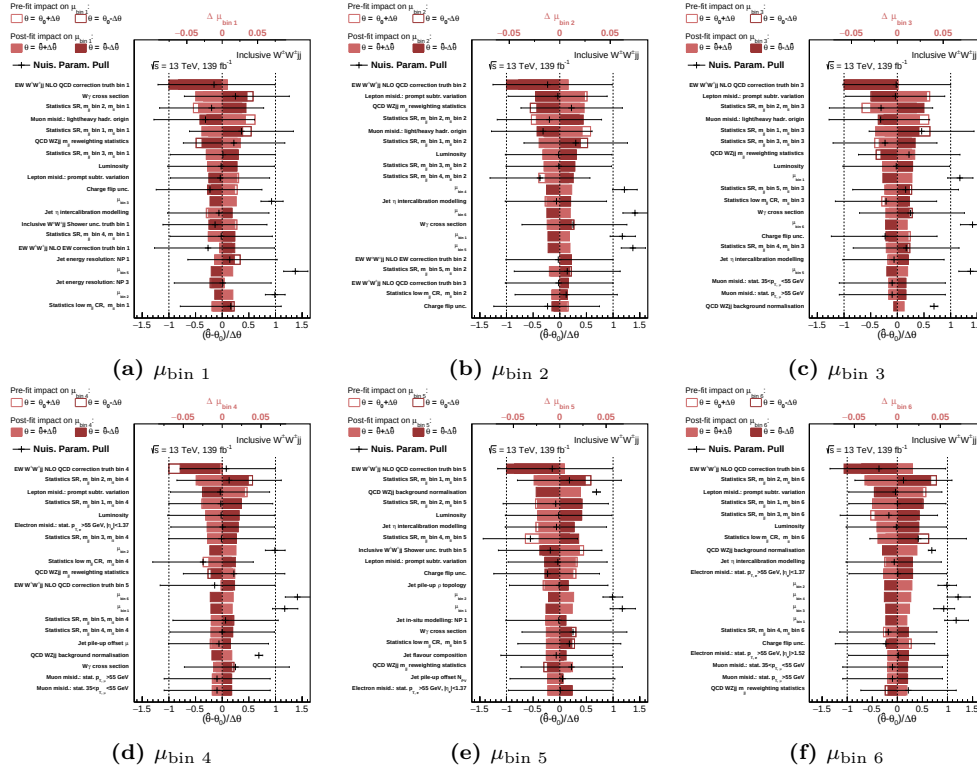


Figure C.11: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) $m_{\ell\ell}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

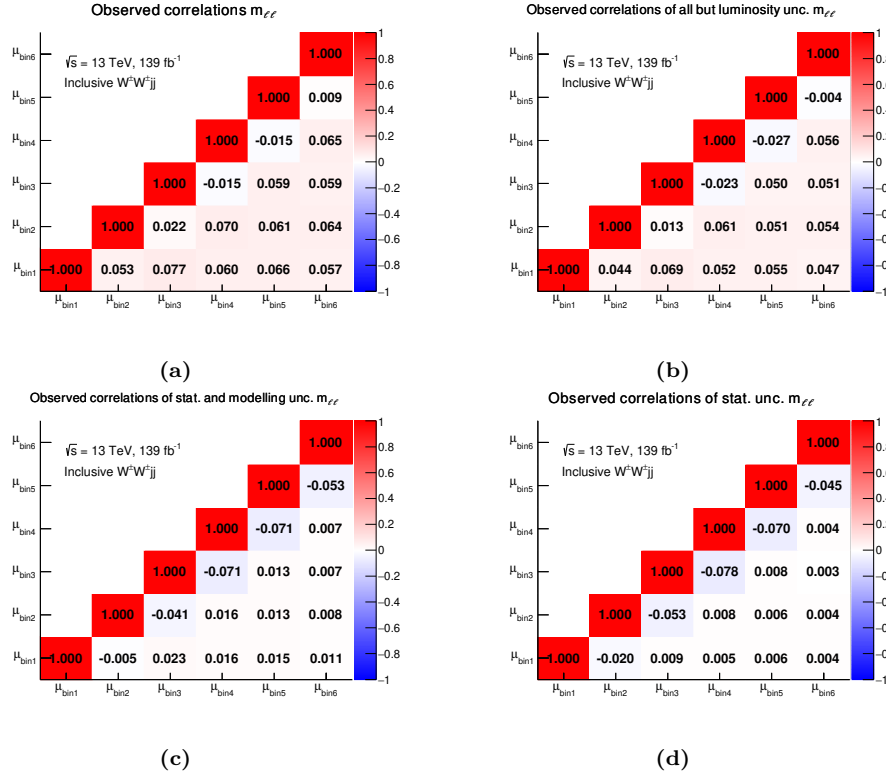


Figure C.12: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

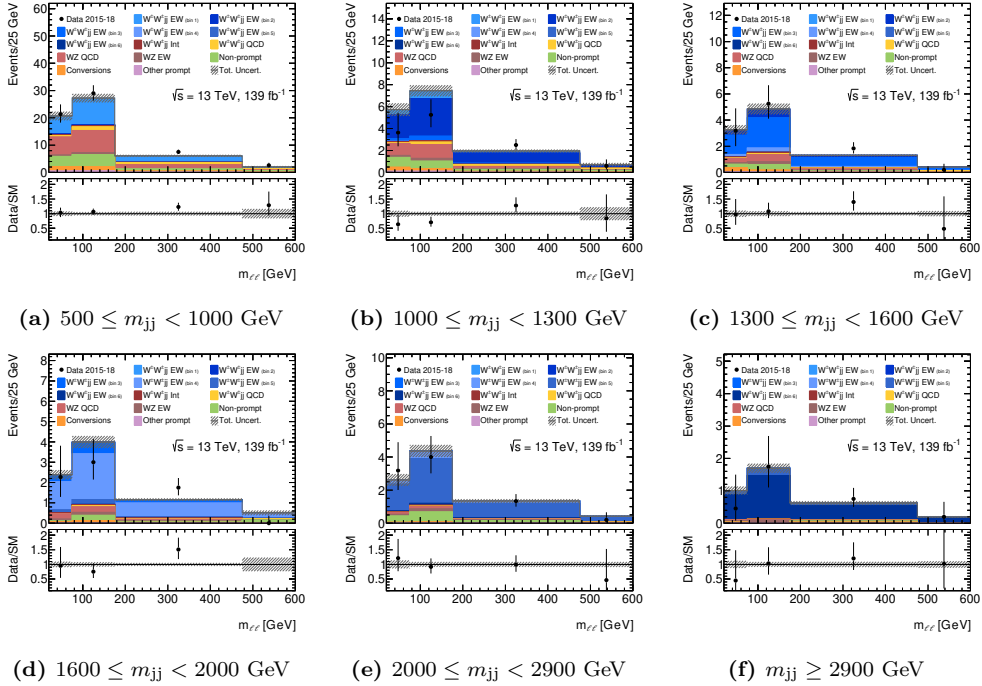


Figure C.13: Pre-fit $m_{\ell\ell}$ -distributions in signal region split into m_{jj} slices as used in m_{jj} -differential cross-section measurement.

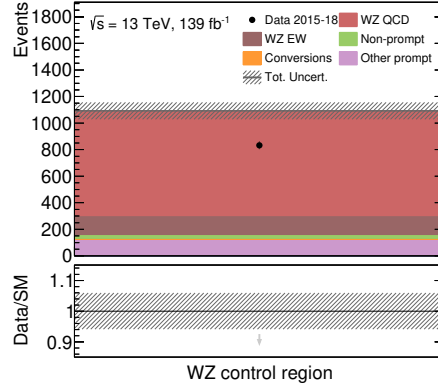


Figure C.14: Pre-fit distributions in WZ control region as used in m_{jj} -differential cross-section measurement.

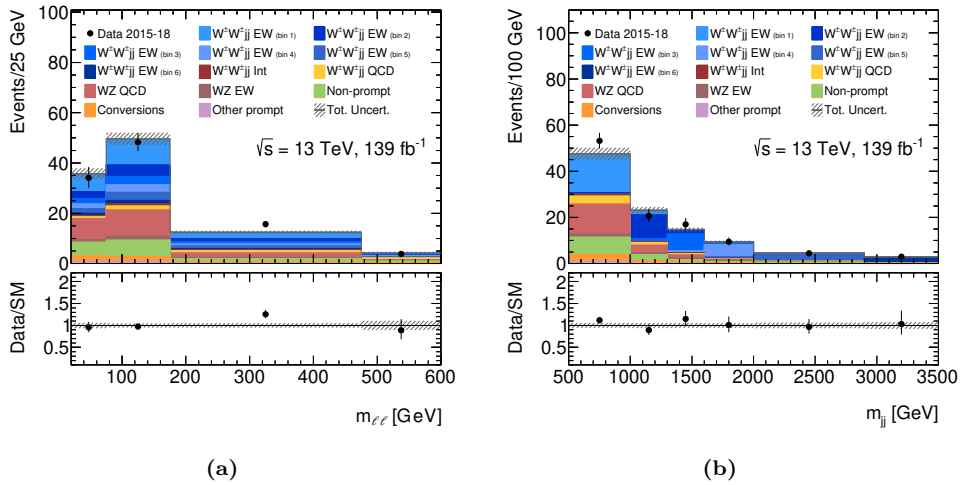


Figure C.15: Pre-fit $m_{\ell\ell}$ -distributions in SR summed over m_{jj} slices (a) and m_{jj} -distributions in SR summed over $m_{\ell\ell}$ bins (b) in m_{jj} -differential cross-section measurement.

Table C.4: Breakdown of the uncertainty of signal strength in the different $m_{\ell\ell}$ truth slices in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.4	0.4	0.1	0.4	0.5	1.1
Muon calibration	0.5	0.4	0.5	0.5	0.5	0.8
Jet energy scale and resolution	2.6	2.0	1.8	1.8	2.7	1.8
$E_{\text{T}}^{\text{miss}}$ scale and resolution	0.3	0.1	0.3	0.0	0.2	0.2
b -tagging inefficiency	0.7	0.6	0.6	0.7	0.7	0.8
Background, misid. leptons	3.7	4.0	4.6	3.6	2.0	3.1
Background, charge misrec.	1.7	1.0	1.5	1.1	1.1	1.1
Pileup modelling	0.6	0.4	0.1	0.1	0.0	0.1
Luminosity	1.8	1.7	1.8	1.8	1.8	1.8
Modelling						
$W^\pm W^\pm \text{j}\text{j}$ shower, scale, PDF & α_s	1.9	0.3	0.9	1.0	1.7	0.1
EW $W^\pm W^\pm \text{j}\text{j}$, QCD corrections	5.7	5.4	3.9	2.0	3.9	5.1
EW $W^\pm W^\pm \text{j}\text{j}$, EW corrections	1.0	0.1	0.0	0.0	0.0	0.0
QCD $W^\pm W^\pm \text{j}\text{j}$, QCD corrections	0.2	0.0	0.0	0.4	0.0	0.1
Background, WZ scale, PDF & α_s	0.0	0.6	0.1	0.0	0.0	0.1
Background, WZ reweighting	1.7	1.8	1.3	0.8	0.7	0.3
Background, other	2.9	0.5	1.5	1.0	0.2	0.2
Model statistical	4.6	4.0	5.1	4.3	3.3	4.3
Experimental and modelling	9.9	8.9	8.8	6.9	6.8	8.1
Data statistical	17.6	16.5	20.7	17.8	15.1	14.8
Total	20.2	18.7	22.5	19.0	16.6	16.9

C.2.2 Results of the Asimov Fit for $m_{\text{j}\text{j}}$ with EW Signal

The expected signal strength μ from the fit to Asimov data is:

$$\mu_{\text{exp}, m_{\text{j}\text{j}}, \text{bin 1}}^{\text{EW}} = 1.00 \pm_{0.18}^{0.19} (\text{stat.}) \pm_{0.10}^{0.10} (\text{mod. syst.}) \pm_{0.09}^{0.09} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\text{j}\text{j}}, \text{bin 2}}^{\text{EW}} = 1.00 \pm_{0.27}^{0.29} (\text{stat.}) \pm_{0.09}^{0.10} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\text{j}\text{j}}, \text{bin 3}}^{\text{EW}} = 1.00 \pm_{0.32}^{0.35} (\text{stat.}) \pm_{0.08}^{0.10} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\text{j}\text{j}}, \text{bin 4}}^{\text{EW}} = 1.00 \pm_{0.30}^{0.33} (\text{stat.}) \pm_{0.07}^{0.08} (\text{mod. syst.}) \pm_{0.05}^{0.04} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\text{j}\text{j}}, \text{bin 5}}^{\text{EW}} = 1.00 \pm_{0.24}^{0.27} (\text{stat.}) \pm_{0.07}^{0.09} (\text{mod. syst.}) \pm_{0.06}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{\text{j}\text{j}}, \text{bin 6}}^{\text{EW}} = 1.00 \pm_{0.30}^{0.35} (\text{stat.}) \pm_{0.06}^{0.10} (\text{mod. syst.}) \pm_{0.06}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.})$$

and the QCD $W^\pm Z \text{j}\text{j}$ normalisation strength is:

$$\mu_{\text{WZ, exp}, m_{\text{j}\text{j}}}^{\text{EW}} = 1.00 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

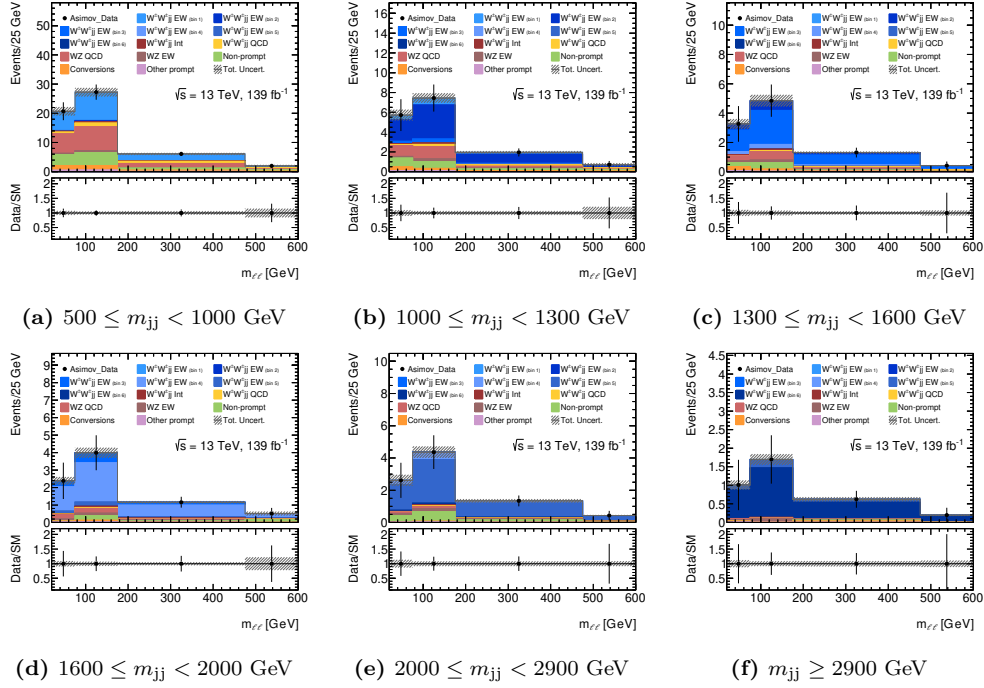


Figure C.16: Post-fit $m_{\ell\ell}$ -distributions in signal region split into m_{jj} slices as used in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

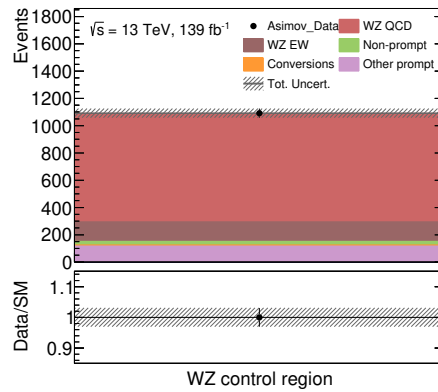


Figure C.17: Post-fit distributions in WZ control region as used in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.



278

Table C.5: List of parameter correlations which are larger than 10% in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	μ_{WZ}	0.376
μ_{bin3}	μ_{bin4}	-0.354
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.326
JET_Pileup_RhoTopology	μ_{WZ}	-0.307
μ_{bin2}	μ_{bin3}	-0.303
JET_JER_EffectiveNP_1	μ_{WZ}	-0.282
JET_Flavor_Composition	μ_{WZ}	-0.252
JET_Pileup_OffsetMu	μ_{WZ}	-0.246
μ_{bin4}	μ_{bin5}	-0.239
FF_Prompt	μ_{bin1}	0.221
signal_EW4_TheoScale	μ_{bin1}	-0.216
$\mu_{FF_BTagged}$	μ_{bin1}	0.204
signal_EW6_truthBin2900toinf_TheoShower	μ_{bin6}	-0.188
signal_EW6_truthBin500to1000_TheoShower	μ_{bin1}	0.185
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.183
WZ_EW4_TheoScale	μ_{WZ}	0.181
CutSR_all_bin_1_0	μ_{bin1}	-0.174
top_XS	μ_{WZ}	-0.173
ZZ_XS	μ_{WZ}	-0.163
CutSR_all_bin_1_2	μ_{bin3}	-0.154
CutSR_all_bin_2_4	μ_{bin5}	-0.153
μ_{bin5}	μ_{bin6}	-0.151
CutSR_all_bin_1_1	μ_{bin2}	-0.151
MjRwStat	μ_{bin2}	0.150
CutSR_all_bin_1_4	μ_{bin5}	-0.144
JET_Pileup_OffsetNPV	μ_{WZ}	-0.144
Wgamma_XS	μ_{bin1}	-0.140
CutSR_all_bin_2_0	μ_{bin1}	-0.139
JET_EtaIntercalibration_Modelling	μ_{bin6}	-0.131
μ_{bin2}	μ_{bin4}	0.130
chFlipSF	μ_{bin1}	0.129
signal_EW6_truthBin2000to2900_TheoShower	μ_{bin5}	-0.128
MjRwStat	μ_{bin1}	0.127
CutSR_all_bin_2_1	μ_{bin2}	-0.123
Zjets_XS	μ_{WZ}	-0.117
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.116
μ_{WZ}	μ_{bin6}	0.114
CutSR_all_bin_1_3	μ_{bin4}	-0.113
FF_Prompt	μ_{bin5}	0.113
WZ_EW6_TheoScale	μ_{WZ}	-0.112
signal_EW6_truthBin500to1000_TheoQCDCorr	μ_{bin1}	0.105
signal_EW6_truthBin1000to1300_TheoQCDCorr	μ_{bin2}	0.102

Post-fit plots are in Figure C.16 and Figure C.17.

Pull plot and correlations are in Figure C.18.

Table of the strongest (anti-)correlations are included in Table C.5.

The ranking plot is shown in Figure C.19.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.6.

The correlation between unfolded bins are shown in Figure C.20.

C.2.3 Results of the Asimov Fit for m_{jj} with EW+Int+QCD Signal

The expected signal strength μ from the fit to Asimov data is:

$$\mu_{\text{exp}, m_{jj}, \text{bin } 1}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.15}^{0.15} (\text{stat.}) \pm_{0.07}^{0.08} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{jj}, \text{bin } 2}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.24}^{0.26} (\text{stat.}) \pm_{0.08}^{0.09} (\text{mod. syst.}) \pm_{0.05}^{0.04} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{jj}, \text{bin } 3}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.30}^{0.33} (\text{stat.}) \pm_{0.07}^{0.09} (\text{mod. syst.}) \pm_{0.04}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{jj}, \text{bin } 4}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.29}^{0.32} (\text{stat.}) \pm_{0.06}^{0.08} (\text{mod. syst.}) \pm_{0.05}^{0.04} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{jj}, \text{bin } 5}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.23}^{0.26} (\text{stat.}) \pm_{0.06}^{0.08} (\text{mod. syst.}) \pm_{0.06}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_{jj}, \text{bin } 6}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.29}^{0.34} (\text{stat.}) \pm_{0.06}^{0.10} (\text{mod. syst.}) \pm_{0.06}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.})$$

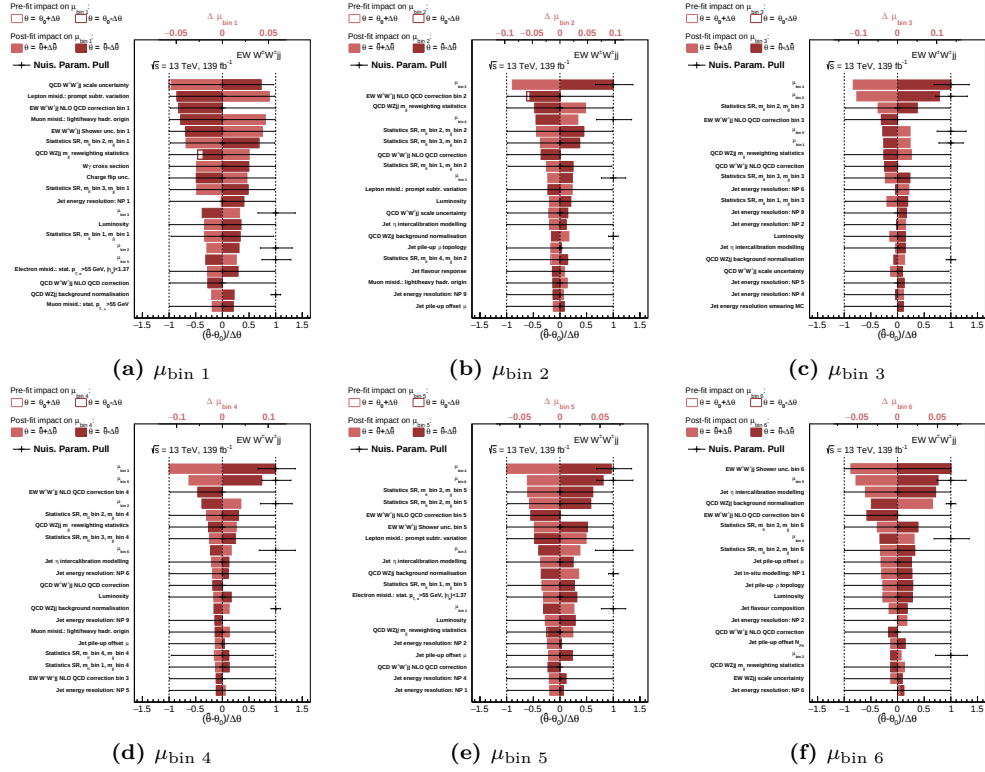


Figure C.19: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_{jj} -differential cross-section measurement of $\text{EW } W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_{jj} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

Table C.6: Breakdown of the uncertainty of signal strength in the different m_{jj} truth slices in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.5	0.4	0.5	0.4	0.4	0.4
Muon calibration	0.5	0.5	0.6	0.5	0.5	0.5
Jet energy scale and resolution	1.6	3.3	4.4	3.9	3.6	5.9
E_T^{miss} scale and resolution	0.3	0.2	0.3	0.1	0.2	0.2
b -tagging inefficiency	1.0	0.8	0.8	0.7	0.7	0.5
Background, misid. leptons	7.8	3.2	2.2	1.7	4.4	1.2
Background, charge misrec.	2.9	0.8	1.0	0.5	0.4	0.5
Pileup modelling	0.3	0.1	0.3	0.6	0.2	0.2
Luminosity	2.0	1.9	1.9	1.8	1.9	1.9
Modelling						
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	4.4	1.7	1.8	0.8	3.6	6.5
EW $W^\pm W^\pm jj$, QCD corrections	2.3	3.0	2.4	2.9	1.9	2.0
EW $W^\pm W^\pm jj$, EW corrections	0.1	0.2	0.2	0.2	0.1	0.2
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.5	0.2	0.1	0.1	0.1	0.1
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	5.1	1.7	1.5	0.8	0.5	0.2
QCD $W^\pm W^\pm jj$, QCD corrections	1.1	1.5	1.4	0.8	0.7	0.5
Background, WZ scale, PDF & α_s	0.7	0.5	0.4	0.5	0.7	0.8
Background, WZ reweighting	2.9	4.5	3.3	3.1	1.7	1.0
Background, other	3.4	1.1	1.7	0.4	0.2	0.7
Model statistical	5.4	6.6	7.3	5.7	6.2	3.9
Experimental and modelling	13.4	10.5	10.5	8.8	9.8	10.3
Data statistical	18.4	28.0	33.5	31.7	25.4	32.3
Total	22.8	29.9	35.1	32.9	27.3	33.9

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{\text{WZ, exp, } m_{jj}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

Post-fit plots are in Figure C.21 and Figure C.22.

Pull plot and correlations are in Figure C.23.

Table of the strongest (anti-)correlations are included in Table C.7.

The ranking plot is shown in Figure C.24.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.8.

The correlation between unfolded bins are shown in Figure C.25.

C.2.4 Results of the Fit to Observed Data for m_{jj} with EW Signal

The observed signal strength μ from the fit to observed data is:

$$\mu_{\text{obs, } m_{jj}, \text{ bin 1}}^{\text{EW}} = 1.59 \pm_{0.19}^{0.20} (\text{stat.}) \pm_{0.11}^{0.12} (\text{mod. syst.}) \pm_{0.09}^{0.09} (\text{exp. syst.}) \pm_{0.03}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{obs, } m_{jj}, \text{ bin 2}}^{\text{EW}} = 0.72 \pm_{0.25}^{0.28} (\text{stat.}) \pm_{0.07}^{0.08} (\text{mod. syst.}) \pm_{0.06}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

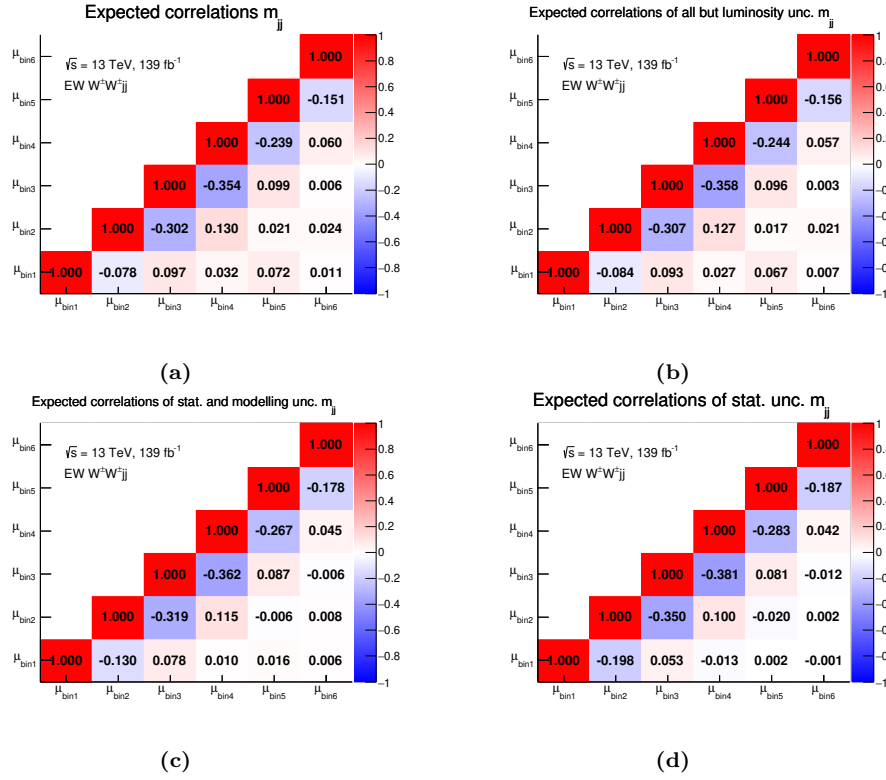


Figure C.20: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_{jj} -differential cross-section measurement of $EW W^\pm W^\pm jj$ with Asimov data.

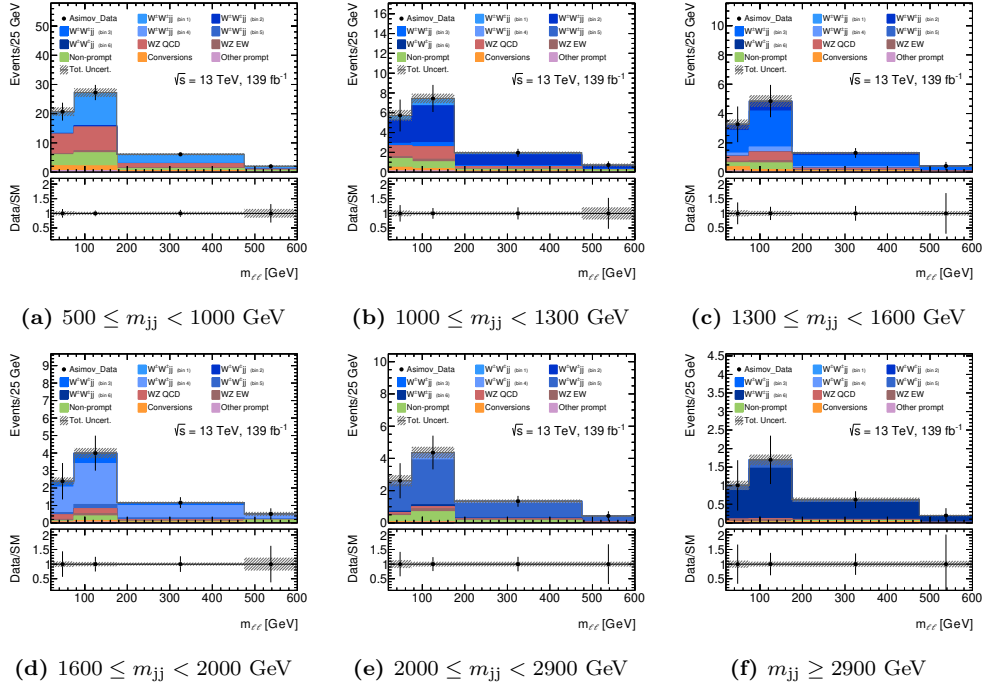


Figure C.21: Post-fit $m_{\ell\ell}$ -distributions in signal region split into m_{jj} slices as used in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

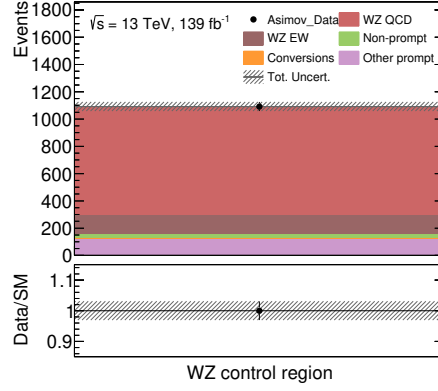


Figure C.22: Post-fit distributions in WZ control region as used in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Table C.7: List of parameter correlations which are larger than 10% in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	μ_WZ	0.376
μ_bin3	μ_bin4	-0.351
JET_EtaIntercalibration_Modelling	μ_WZ	-0.326
JET_Pileup_RhoTopology	μ_WZ	-0.307
μ_bin2	μ_bin3	-0.298
JET_JER_EffectiveNP_1	μ_WZ	-0.283
JET_Flavor_Composition	μ_WZ	-0.252
signal_AllEW_truthBin500to1000_TheoShower	μ_bin1	0.249
JET_Pileup_OffsetMu	μ_WZ	-0.246
FF_Prompt	μ_bin1	0.239
μ_bin4	μ_bin5	-0.237
$\mu_FF_BTagged$	μ_bin1	0.196
signal_AllEW_truthBin2900toinf_TheoShower	μ_bin6	-0.186
JET_EffectiveNP_Modelling1	μ_WZ	-0.183
WZ_EW4_TheoScale	μ_WZ	0.181
top_XS	μ_WZ	-0.173
ZZ_XS	μ_WZ	-0.163
CutSR_all_bin_2_0	μ_bin1	-0.160
CutSR_all_bin_1_0	μ_bin1	-0.157
CutSR_all_bin_2_4	μ_bin5	-0.154
CutSR_all_bin_1_2	μ_bin3	-0.150
μ_bin5	μ_bin6	-0.150
MjjRewStat	μ_bin2	0.149
CutSR_all_bin_1_1	μ_bin2	-0.145
JET_Pileup_OffsetNPV	μ_WZ	-0.144
CutSR_all_bin_1_4	μ_bin5	-0.143
Wgamma_XS	μ_bin1	-0.133
JET_EtaIntercalibration_Modelling	μ_bin6	-0.131
chFlipSF	μ_bin1	0.131
CutSR_all_bin_2_1	μ_bin2	-0.129
signal_AllEW_truthBin2000to2900_TheoShower	μ_bin5	-0.124
μ_bin2	μ_bin4	0.124
MjjRewStat	μ_bin1	0.121
FT_EFF_Eigen_Light_0	μ_WZ	-0.117
Zjets_XS	μ_WZ	-0.116
μ_WZ	μ_bin6	0.114
FF_Prompt	μ_bin5	0.114
WZ_EW6_TheoScale	μ_WZ	-0.112
CutSR_all_bin_1_3	μ_bin4	-0.111
el_FF_STAT_2015_2018_3_1	μ_bin1	-0.109

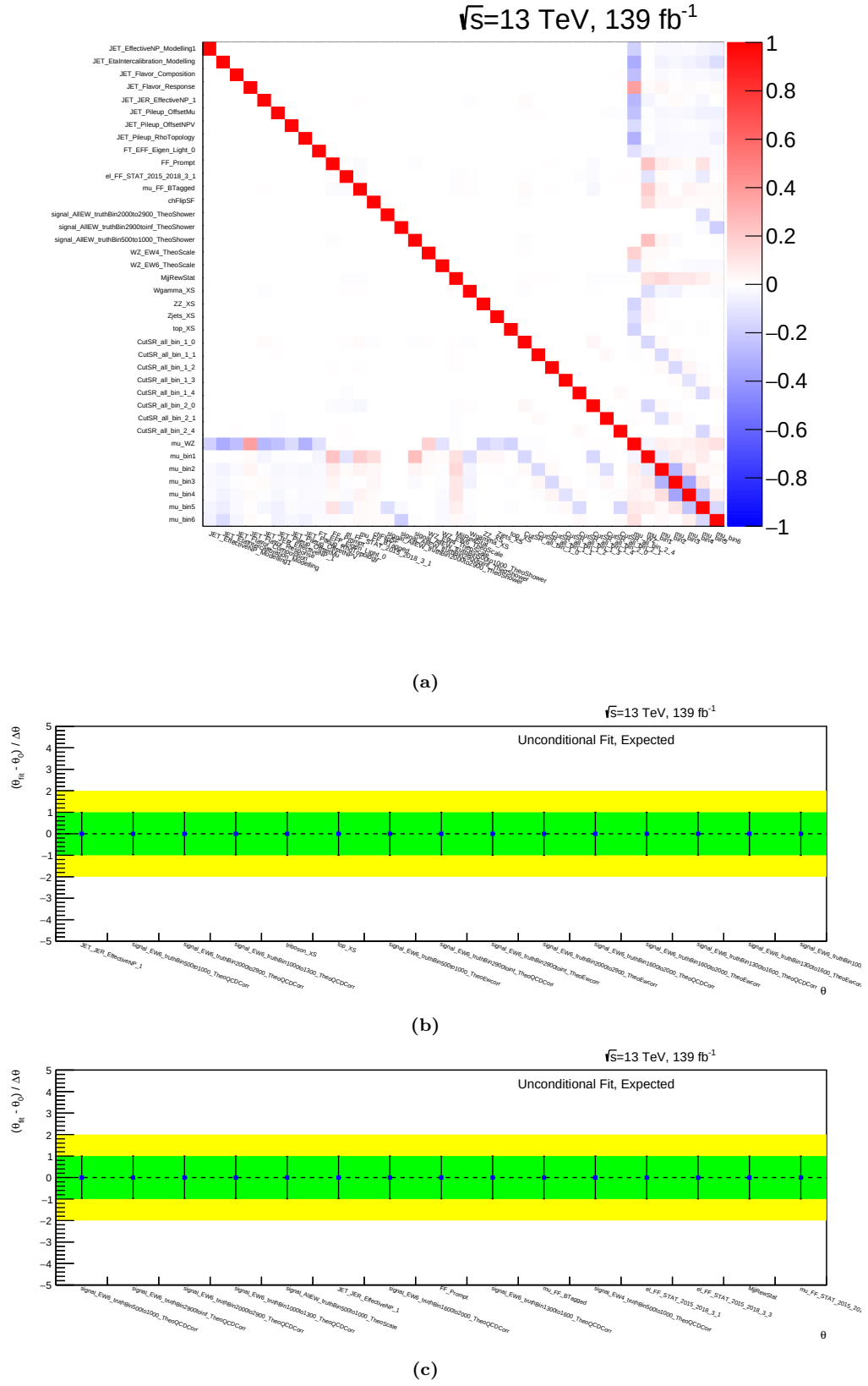


Figure C.23: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

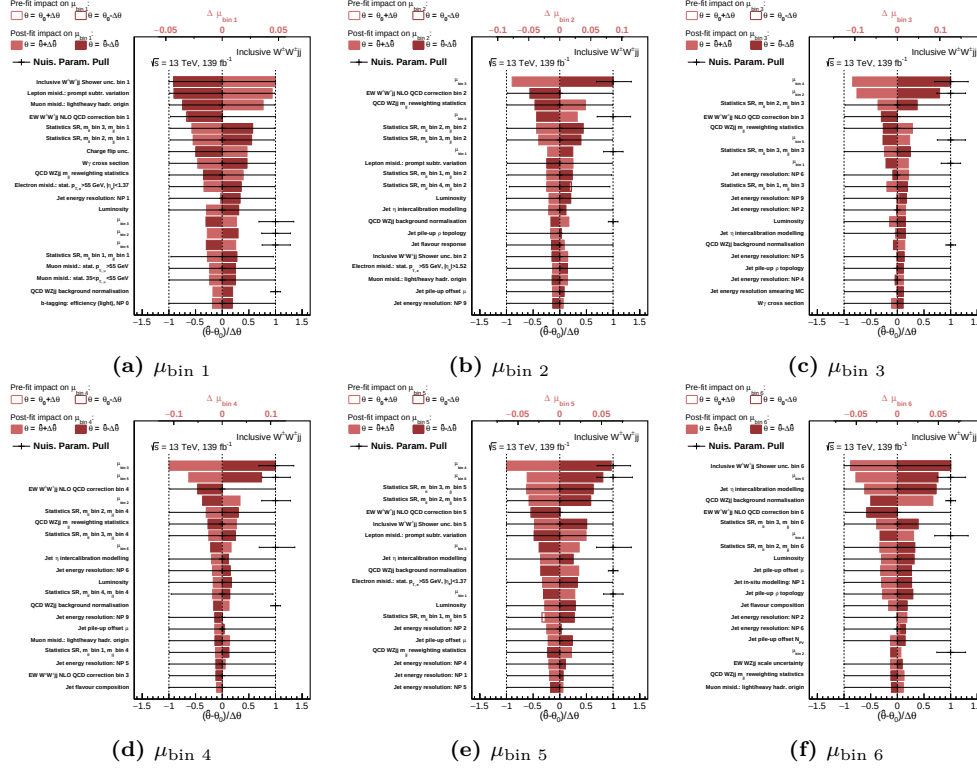


Figure C.24: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_{jj} -differential cross-section measurement of inclusive $W^{\pm}W^{\pm}jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_{jj} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

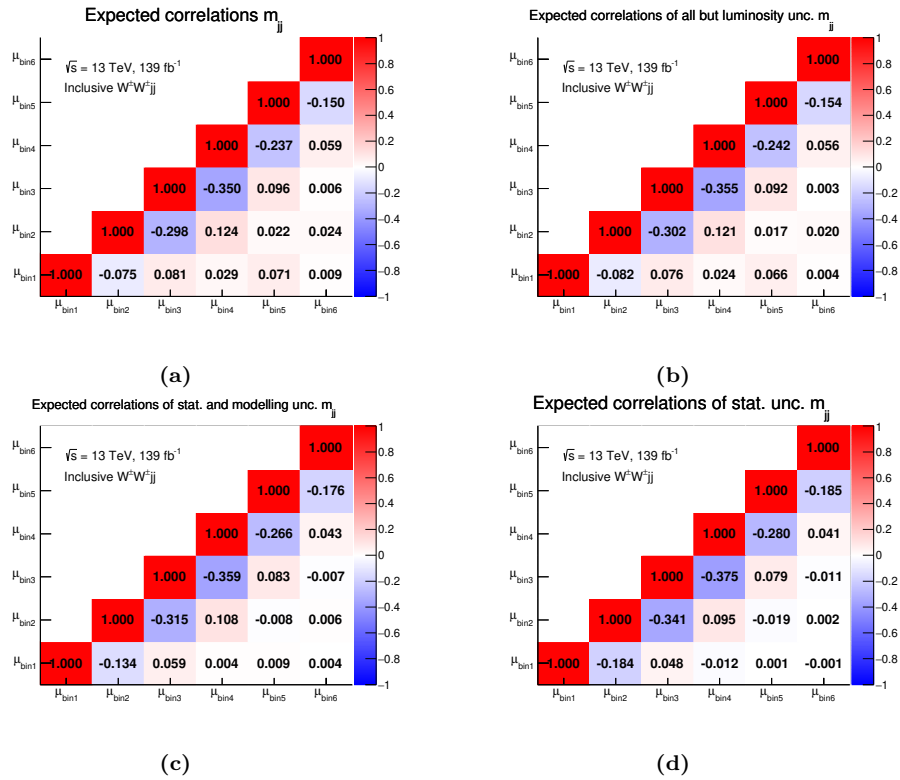


Figure C.25: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Table C.8: Breakdown of the uncertainty of signal strength in the different m_{jj} truth slices in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.4	0.4	0.5	0.4	0.4	0.4
Muon calibration	0.4	0.5	0.5	0.5	0.5	0.5
Jet energy scale and resolution	1.2	3.0	4.1	3.7	3.5	5.9
E_T^{miss} scale and resolution	0.2	0.2	0.3	0.1	0.2	0.2
b -tagging inefficiency	0.8	0.7	0.8	0.6	0.6	0.5
Background, misid. leptons	6.6	3.1	2.0	1.7	4.3	1.1
Background, charge misrec.	2.4	0.8	0.9	0.5	0.4	0.4
Pileup modelling	0.2	0.1	0.3	0.6	0.2	0.2
Luminosity	1.6	1.8	1.8	1.8	1.8	1.8
Modelling						
$W^\pm W^\pm jj$ shower, scale, PDF & α_s	4.7	2.1	2.0	0.9	3.4	6.4
EW $W^\pm W^\pm jj$, QCD corrections	1.6	2.6	2.1	2.7	1.9	1.9
EW $W^\pm W^\pm jj$, EW corrections	0.1	0.2	0.2	0.1	0.1	0.2
QCD $W^\pm W^\pm jj$, QCD corrections	0.4	0.3	0.3	0.1	0.1	0.1
Background, WZ scale, PDF & α_s	0.5	0.5	0.4	0.5	0.7	0.8
Background, WZ reweighting	2.2	4.0	3.1	2.9	1.6	0.9
Background, other	2.6	1.1	1.5	0.4	0.2	0.7
Model statistical	4.4	6.1	6.7	5.5	6.0	3.9
Experimental and modelling	10.5	9.5	9.6	8.4	9.5	10.1
Data statistical	15.0	25.3	31.3	30.2	24.7	31.8
Total	18.3	27.0	32.7	31.4	26.4	33.4

$$\mu_{\text{obs}, m_{jj}, \text{bin 3}}^{\text{EW}} = 1.45 \pm_{0.34}^{0.37} (\text{stat.}) \pm_{0.09}^{0.11} (\text{mod. syst.}) \pm_{0.04}^{0.06} (\text{exp. syst.}) \pm_{0.02}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{jj}, \text{bin 4}}^{\text{EW}} = 1.00 \pm_{0.31}^{0.34} (\text{stat.}) \pm_{0.06}^{0.07} (\text{mod. syst.}) \pm_{0.06}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{jj}, \text{bin 5}}^{\text{EW}} = 0.95 \pm_{0.24}^{0.26} (\text{stat.}) \pm_{0.06}^{0.09} (\text{mod. syst.}) \pm_{0.06}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{jj}, \text{bin 6}}^{\text{EW}} = 1.05 \pm_{0.30}^{0.35} (\text{stat.}) \pm_{0.06}^{0.10} (\text{mod. syst.}) \pm_{0.06}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.})$$

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{\text{WZ, obs}, m_{jj}}^{\text{EW}} = 0.67 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.06}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.00} (\text{lumi.}).$$

Post-fit plots are in Figure C.26 and Figure C.27. The projections on $m_{\ell\ell}$ and on $m_{\ell\ell}$ in the signal region are shown in Figure C.28.

Pull plot and correlations are in Figure C.29.

Selected profile LH scans are in Figure C.30.

Table of the strongest (anti-)correlations are included in Table C.9.

The ranking plot is shown in Figure C.31.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.10.

The correlation between unfolded bins are shown in Figure C.32.

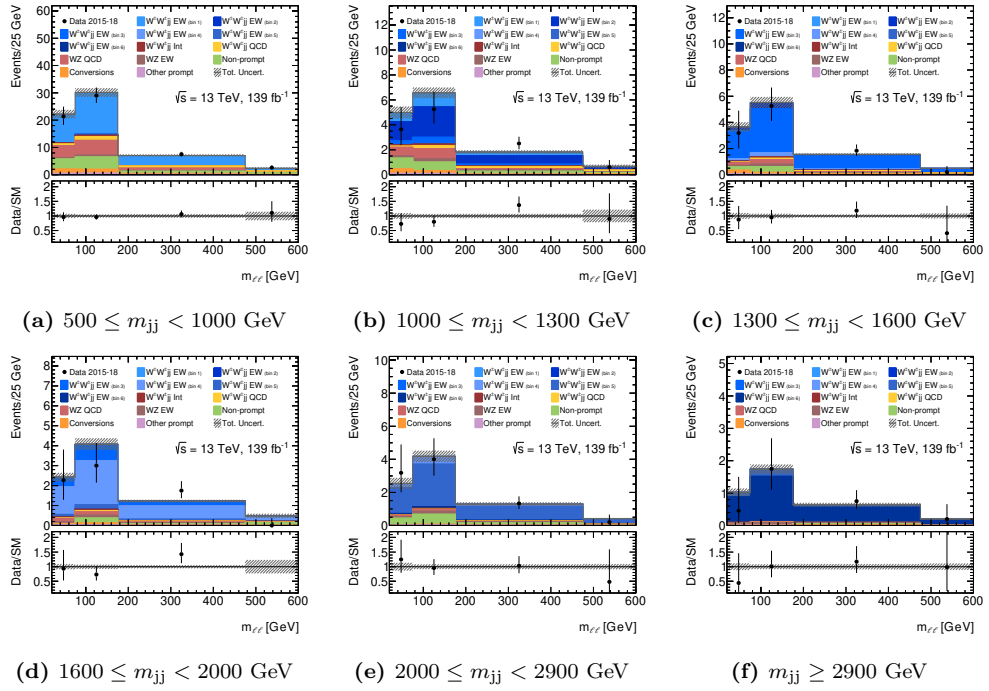


Figure C.26: Post-fit $m_{\ell\ell}$ -distributions in signal region split into m_{jj} slices as used in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

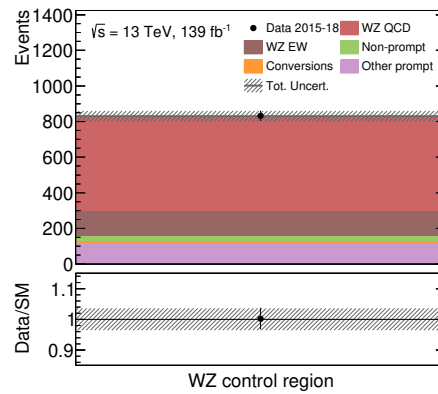


Figure C.27: Post-fit distributions in WZ control region as used in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

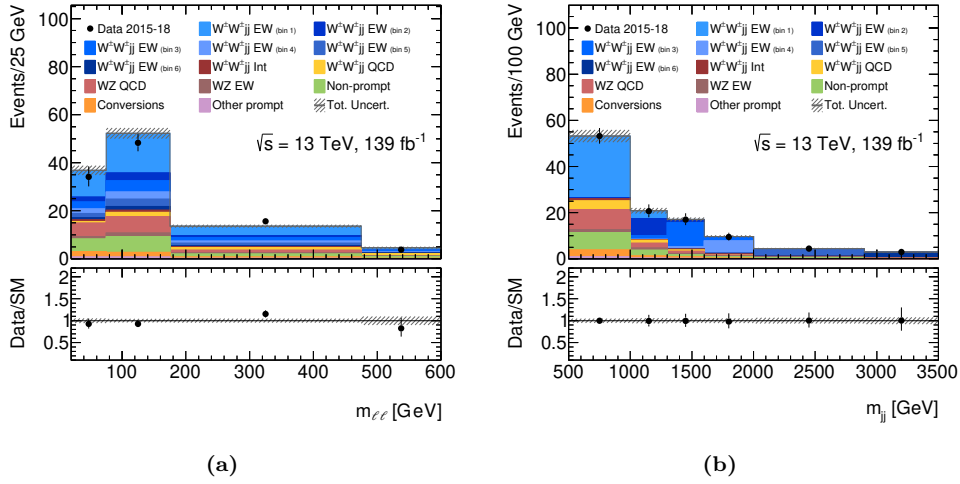


Figure C.28: Post-fit $m_{\ell\ell}$ -distributions in SR summed over m_{jj} slices (a) and m_{jj} -distributions in SR summed over $m_{\ell\ell}$ bins (b) in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data..

Table C.9: List of parameter correlations which are larger than 10% in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

Parameter 1	Parameter 2	Correlation
$\mu_{\text{bin}3}$	$\mu_{\text{bin}4}$	-0.367
JET_Flavor_Response	μ_{WZ}	0.351
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.319
$\mu_{\text{bin}2}$	$\mu_{\text{bin}3}$	-0.309
JET_Flavor_Composition	μ_{WZ}	-0.298
JET_Pileup_RhoTopology	μ_{WZ}	-0.281
signal_EW6_truthBin500to1000_TheoShower	$\mu_{\text{bin}1}$	0.269
JET_JER_EffectiveNP_1	μ_{WZ}	-0.254
$\mu_{\text{bin}4}$	$\mu_{\text{bin}5}$	-0.240
JET_Pileup_OffsetMu	μ_{WZ}	-0.237
signal_EW4_TheoScale	$\mu_{\text{bin}1}$	-0.232
FF_Prompt	$\mu_{\text{bin}1}$	0.205
top_XS	μ_{WZ}	-0.205
$\mu_{\text{FF}_B\text{Tagged}}$	$\mu_{\text{bin}1}$	0.196
signal_EW6_truthBin2900toinf_TheoShower	$\mu_{\text{bin}6}$	-0.195
ZZ_XS	μ_{WZ}	-0.194
CutSR_all_bin_1_0	$\mu_{\text{bin}1}$	-0.185
CutSR_all_bin_1_2	$\mu_{\text{bin}3}$	-0.166
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.165
$\mu_{\text{bin}5}$	$\mu_{\text{bin}6}$	-0.151
CutSR_all_bin_2_4	$\mu_{\text{bin}5}$	-0.149
CutSR_all_bin_1_1	$\mu_{\text{bin}2}$	-0.143
Zjets_XS	μ_{WZ}	-0.142
CutSR_all_bin_2_0	$\mu_{\text{bin}1}$	-0.141
WZ_EW4_TheoScale	μ_{WZ}	0.141
CutSR_all_bin_1_4	$\mu_{\text{bin}5}$	-0.141
JET_EtaIntercalibration_Modelling	$\mu_{\text{bin}6}$	-0.139
$\mu_{\text{bin}2}$	$\mu_{\text{bin}4}$	0.135
WZ_EW6_TheoScale	μ_{WZ}	-0.134
Wgamma_XS	$\mu_{\text{bin}1}$	-0.134
JET_Pileup_OffsetNPV	μ_{WZ}	-0.131
signal_EW6_truthBin2000to2900_TheoShower	$\mu_{\text{bin}5}$	-0.128
FF_Prompt	$\mu_{\text{bin}5}$	0.125
Lumi	$\mu_{\text{bin}1}$	-0.122
chFlipSF	$\mu_{\text{bin}1}$	0.120
CutSR_all_bin_2_1	$\mu_{\text{bin}2}$	-0.115
CutSR_all_bin_1_3	$\mu_{\text{bin}4}$	-0.113
μ_{WZ}	$\mu_{\text{bin}6}$	0.113
μ_{WZ}	$\mu_{\text{bin}2}$	0.113
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.105
CutSR_all_bin_0_0	$\mu_{\text{bin}1}$	-0.105
CutSR_all_bin_2_2	$\mu_{\text{bin}3}$	-0.104
μ_{WZ}	$\mu_{\text{bin}4}$	0.102

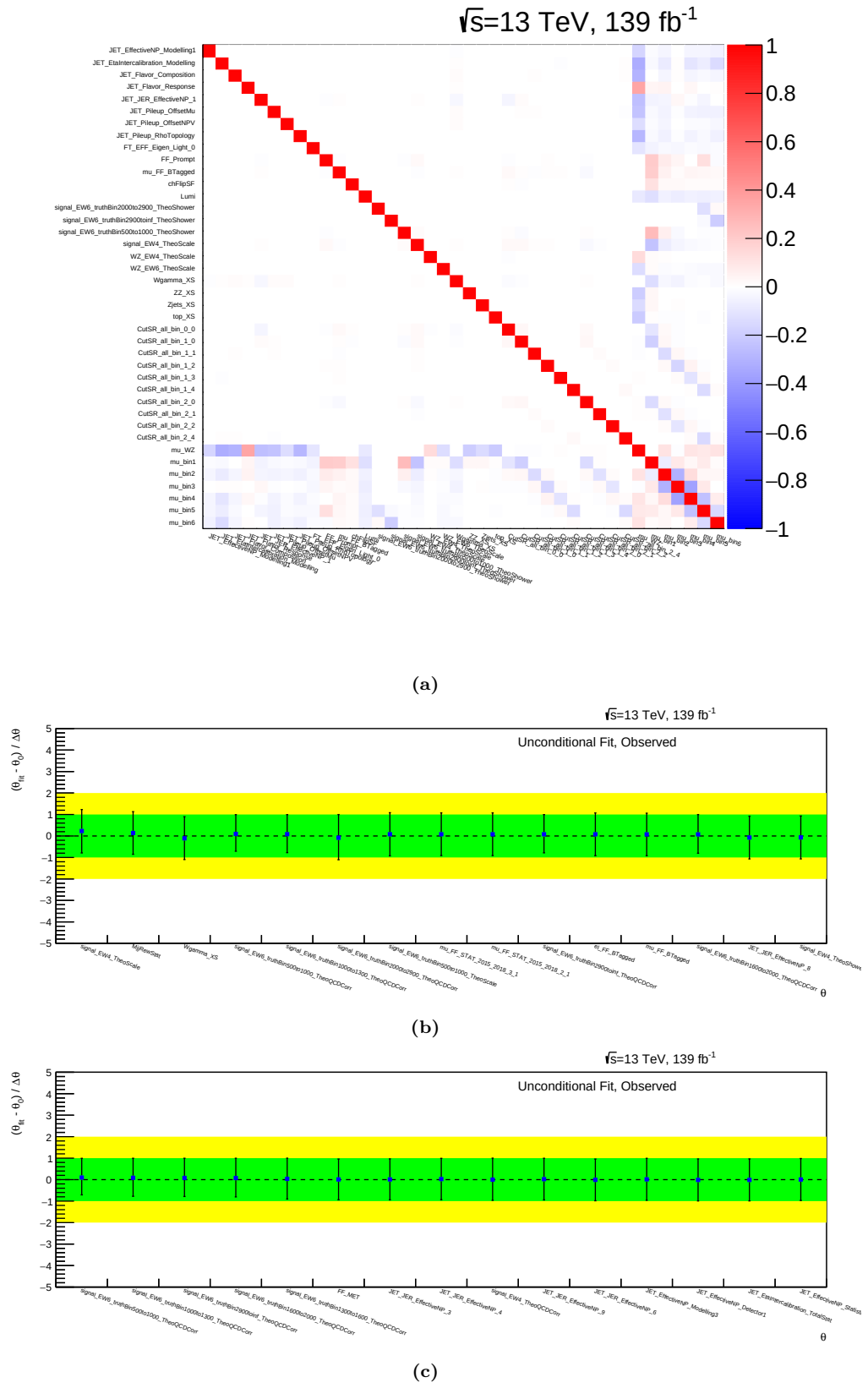


Figure C.29: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

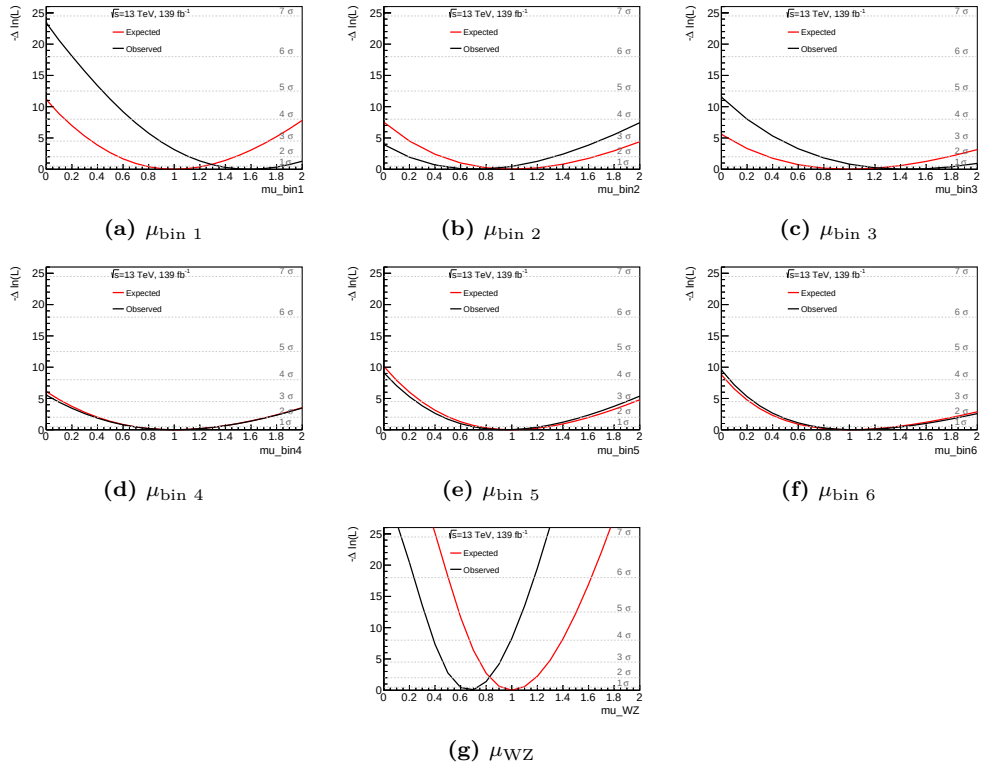


Figure C.30: Likelihood scans of nuisance parameters with largest pulls and constraints in the m_{jj} differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-f) and for QCD $W^\pm Z jj$ normalisation parameter (g).

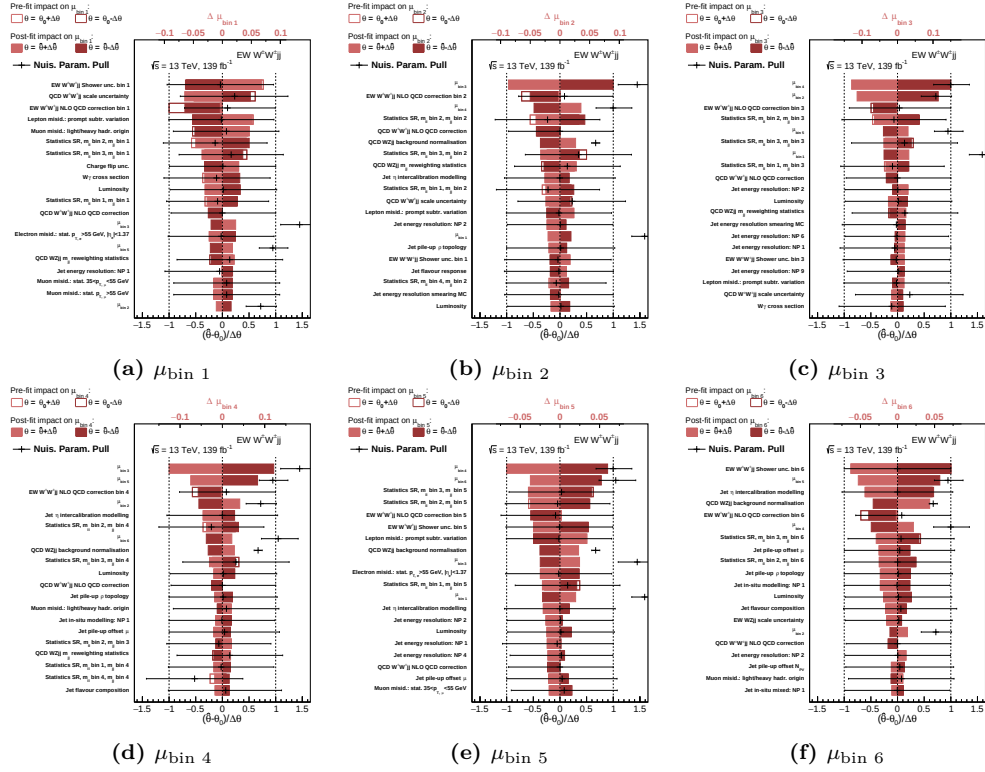


Figure C.31: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_{ij} -differential cross-section measurement of $\text{EW } W^\pm W^\pm jj$ with observed data. They are shown for the first (a), second (b), third (c), fourth (d), fifth (e) and sixth (f) m_{ij} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

Table C.10: Breakdown of the uncertainty of signal strength in the different m_{jj} truth slices in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.4	0.4	0.5	0.4	0.4	0.4
Muon calibration	0.5	0.5	0.5	0.5	0.5	0.5
Jet energy scale and resolution	1.4	6.5	2.6	5.4	3.9	6.0
E_T^{miss} scale and resolution	0.2	0.2	0.2	0.1	0.2	0.2
b -tagging inefficiency	0.8	0.8	0.8	0.7	0.6	0.5
Background, misid. leptons	5.0	4.8	1.5	1.4	5.1	1.3
Background, charge misrec.	1.9	1.1	0.7	0.4	0.4	0.5
Pileup modelling	0.4	0.3	0.1	0.6	0.2	0.2
Luminosity	1.9	2.1	1.9	1.9	1.9	1.9
Modelling						
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	4.3	3.4	1.5	1.2	3.7	6.6
EW $W^\pm W^\pm jj$, QCD corrections	1.3	2.4	2.1	2.2	2.7	1.4
EW $W^\pm W^\pm jj$, EW corrections	0.1	0.5	0.1	0.2	0.1	0.2
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.4	0.2	0.1	0.1	0.1	0.1
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	3.7	3.1	1.1	0.9	0.5	0.3
QCD $W^\pm W^\pm jj$, QCD corrections	0.7	2.4	0.9	1.1	0.6	0.5
Background, WZ scale, PDF & α_s	0.4	0.7	0.3	0.5	0.8	0.8
Background, WZ reweighting	1.2	3.9	1.6	2.0	1.3	0.5
Background, other	2.2	1.5	1.2	0.4	0.2	0.7
Model statistical	3.9	8.4	5.7	5.9	6.3	3.9
Experimental and modelling	9.6	14.0	7.7	9.2	10.5	10.2
Data statistical	12.3	37.0	24.7	32.3	26.3	31.2
Total	15.6	39.5	25.9	33.6	28.3	32.9

C.2.5 Results of the fit to Observed Data for m_{jj} with EW+Int+QCD Signal

The observed signal strength μ from the fit to observed data is:

$$\mu_{\text{obs}, m_{jj}, \text{bin 1}}^{\text{EW+Int+QCD}} = 1.51 \pm_{-0.16}^{+0.16} (\text{stat.}) \pm_{-0.09}^{+0.10} (\text{mod. syst.}) \pm_{-0.07}^{+0.07} (\text{exp. syst.}) \pm_{-0.02}^{+0.03} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{jj}, \text{bin 2}}^{\text{EW+Int+QCD}} = 0.78 \pm_{-0.23}^{+0.25} (\text{stat.}) \pm_{-0.06}^{+0.07} (\text{mod. syst.}) \pm_{-0.06}^{+0.05} (\text{exp. syst.}) \pm_{-0.01}^{+0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{jj}, \text{bin 3}}^{\text{EW+Int+QCD}} = 1.41 \pm_{-0.32}^{+0.35} (\text{stat.}) \pm_{-0.08}^{+0.10} (\text{mod. syst.}) \pm_{-0.04}^{+0.05} (\text{exp. syst.}) \pm_{-0.02}^{+0.03} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{jj}, \text{bin 4}}^{\text{EW+Int+QCD}} = 1.00 \pm_{-0.29}^{+0.32} (\text{stat.}) \pm_{-0.06}^{+0.07} (\text{mod. syst.}) \pm_{-0.06}^{+0.05} (\text{exp. syst.}) \pm_{-0.01}^{+0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{jj}, \text{bin 5}}^{\text{EW+Int+QCD}} = 0.95 \pm_{-0.23}^{+0.25} (\text{stat.}) \pm_{-0.06}^{+0.08} (\text{mod. syst.}) \pm_{-0.06}^{+0.06} (\text{exp. syst.}) \pm_{-0.01}^{+0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_{jj}, \text{bin 6}}^{\text{EW+Int+QCD}} = 1.05 \pm_{-0.30}^{+0.35} (\text{stat.}) \pm_{-0.06}^{+0.10} (\text{mod. syst.}) \pm_{-0.06}^{+0.07} (\text{exp. syst.}) \pm_{-0.01}^{+0.02} (\text{lumi.})$$

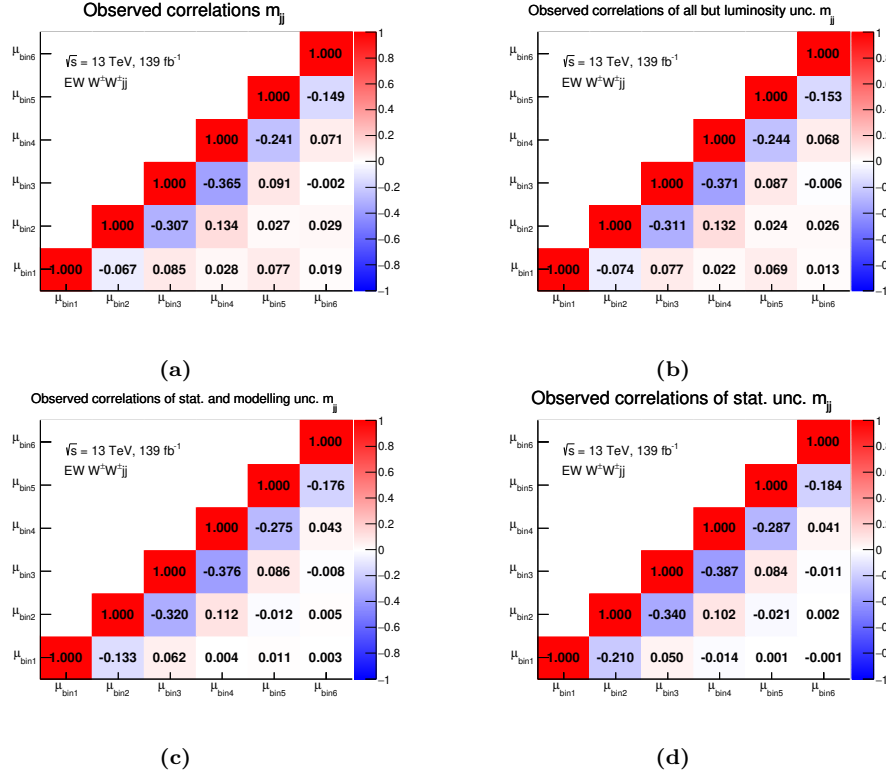


Figure C.32: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

and the QCD $W^\pm Z jj$ normalisation strength is:

$$\mu_{WZ, \text{ obs, } m_{jj}}^{\text{EW+Int+QCD}} = 0.67 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.02}^{0.02} (\text{mod. syst.}) \pm_{0.06}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

Post-fit plots are in Figure C.33 and Figure C.34. The projections on m_{jj} and on $m_{\ell\ell}$ are shown in Figure C.35.

Pull plot and correlations are in Figure C.36.

Selected profile LH scans are in Figure C.37.

Table of the strongest (anti-)correlations are included in Table C.11.

The ranking plot is shown in Figure C.38.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.12.

The correlation between unfolded bins are shown in Figure C.39.

C.3 Results for m_T

This section presents the extraction of the differential cross-section of the EW $W^\pm W^\pm jj$ production and EW+Int+QCD $W^\pm W^\pm jj$ production as a function of m_T .

C.3.1 Pre-Fit Distributions for m_T

The following Figures show the distributions of the fit inputs in the high- m_{jj} signal region (Figure C.40) low- m_{jj} control region and WZ control region (Figure C.41). Zero correlation is assumed in the combination of systematic uncertainties in the hatched band. The observed data is shown with Poisson uncertainties.

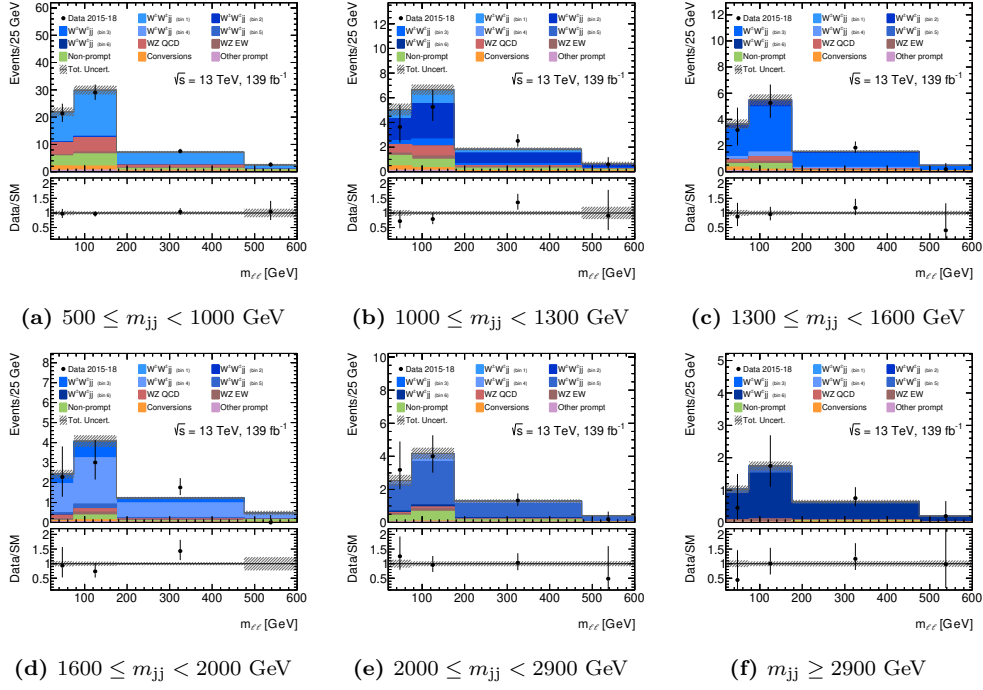


Figure C.33: Post-fit $m_{\ell\ell}$ -distributions in signal region split into m_{jj} slices as used in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

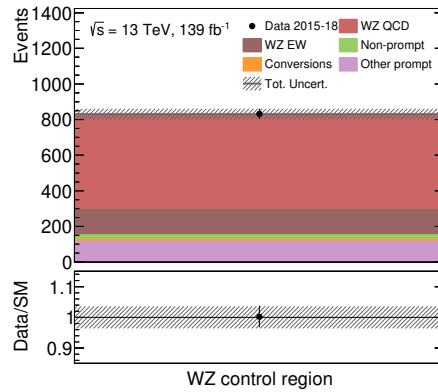


Figure C.34: Post-fit distributions in WZ control region as used in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

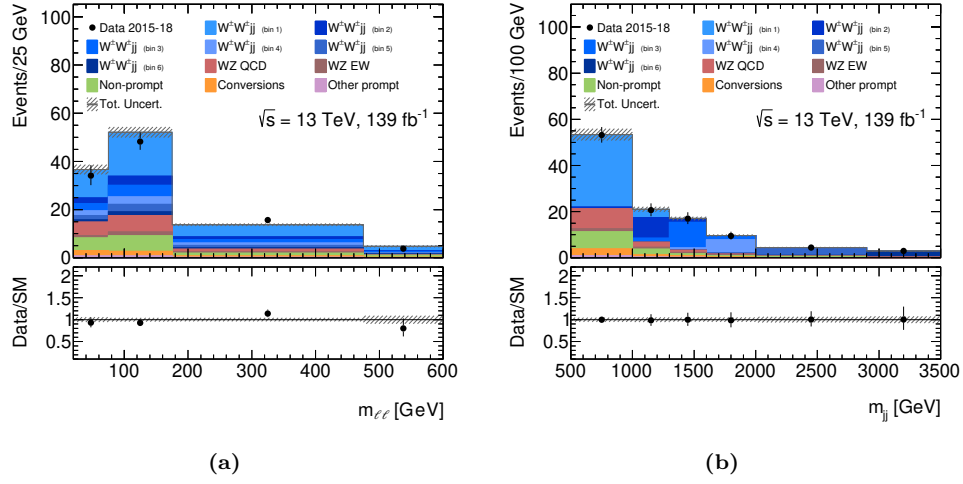


Figure C.35: Post-fit $m_{\ell\ell}$ -distributions in signal region summed over m_{jj} slices (a) m_{jj} -distributions in signal region summed over $m_{\ell\ell}$ bins (b) in the m_{jj} -differential cross-section measurement of inclusive $W^{\pm}W^{\pm}jj$ with observed data.

Table C.11: List of parameter correlations which are larger than 10% in the m_{jj} -differential cross-section measurement of inclusive $W^{\pm}W^{\pm}jj$ with observed data.

Parameter 1	Parameter 2	Correlation
μ_{bin3}	μ_{bin4}	-0.362
JET_Flavor_Response	μ_{WZ}	0.352
signal_AllEW_truthBin500to1000_TheoShower	μ_{bin1}	0.344
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.318
μ_{bin2}	μ_{bin3}	-0.302
JET_Flavor_Composition	μ_{WZ}	-0.297
JET_Pileup_RhoTopology	μ_{WZ}	-0.280
JET_JER_EffectiveNP_1	μ_{WZ}	-0.269
μ_{bin4}	μ_{bin5}	-0.238
JET_Pileup_OffsetMu	μ_{WZ}	-0.237
FF_Prompt	μ_{bin1}	0.220
top_XS	μ_{WZ}	-0.202
signal_AllEW_truthBin2900toinf_TheoShower	μ_{bin6}	-0.195
ZZ_XS	μ_{WZ}	-0.192
$\mu_{\text{FF}} \text{ BTagged}$	μ_{bin1}	0.185
CutSR_all_bin_2_0	μ_{bin1}	-0.166
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.164
CutSR_all_bin_1_0	μ_{bin1}	-0.164
CutSR_all_bin_1_2	μ_{bin3}	-0.162
CutSR_all_bin_2_4	μ_{bin5}	-0.151
μ_{bin5}	μ_{bin6}	-0.147
WZ_EW4_TheoScale	μ_{WZ}	0.143
CutSR_all_bin_1_4	μ_{bin5}	-0.140
Zjets_XS	μ_{WZ}	-0.139
CutSR_all_bin_1_1	μ_{bin2}	-0.138
JET_EtaIntercalibration_Modelling	μ_{bin6}	-0.138
WZ_EW6_TheoScale	μ_{WZ}	-0.134
JET_Pileup_OffsetNPV	μ_{WZ}	-0.130
Wgamma_XS	μ_{bin1}	-0.126
FF_Prompt	μ_{bin5}	0.126
μ_{bin2}	μ_{bin4}	0.125
Lumi	μ_{bin1}	-0.125
signal_AllEW_truthBin2000to2900_TheoShower	μ_{bin5}	-0.122
CutSR_all_bin_2_1	μ_{bin2}	-0.121
chFlipSF	μ_{bin1}	0.121
μ_{WZ}	μ_{bin6}	0.114
CutSR_all_bin_1_3	μ_{bin4}	-0.112
CutSR_all_bin_2_2	μ_{bin3}	-0.107
μ_{WZ}	μ_{bin2}	0.106
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.106
el_FF_STAT_2015_2018_3_1	μ_{bin1}	-0.101

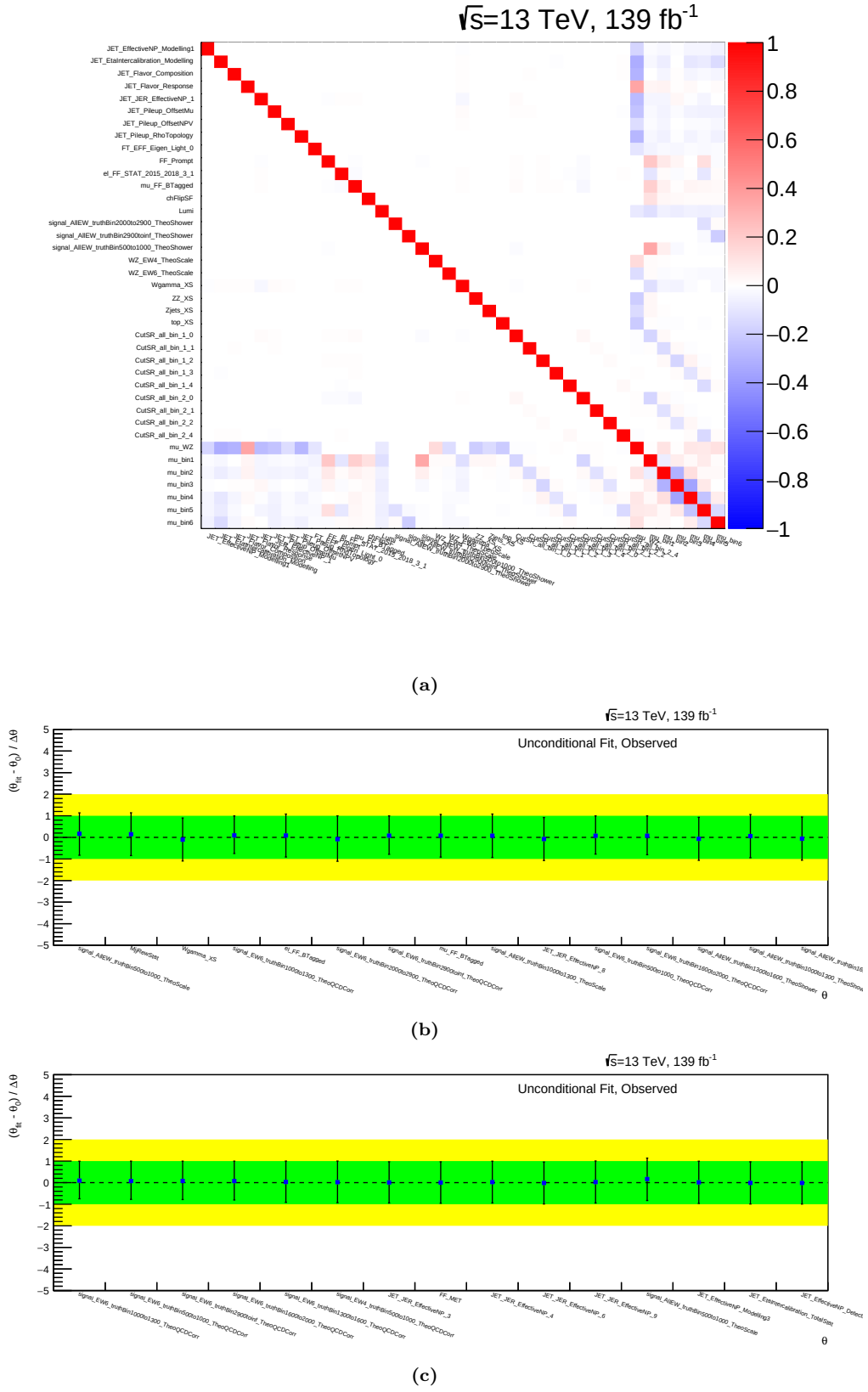


Figure C.36: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

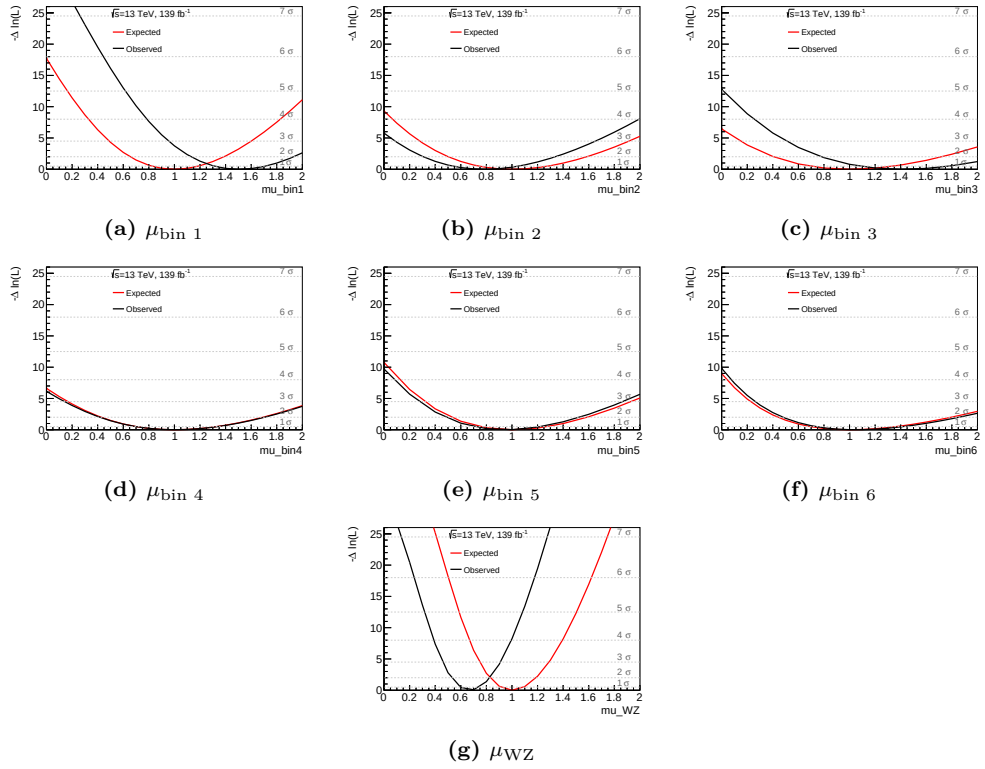


Figure C.37: Likelihood scans of nuisance parameters with largest pulls and constraints in the m_{jj} differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-f) and for QCD $W^\pm Z jj$ normalisation parameter (g).

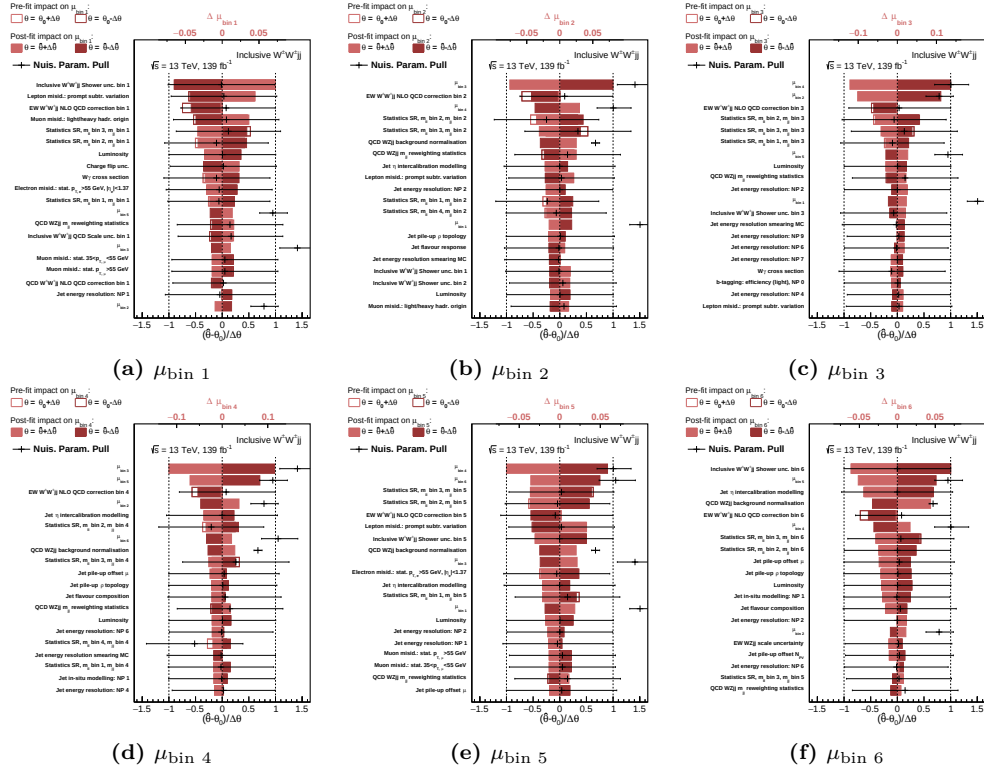


Figure C.38: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_{jj} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

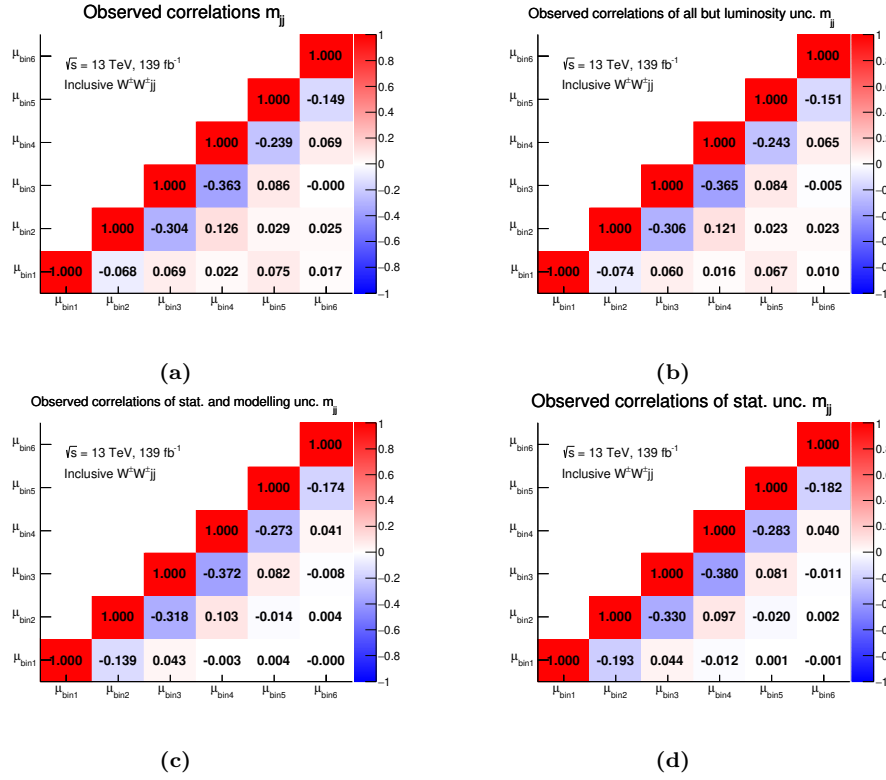


Figure C.39: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_{ij} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

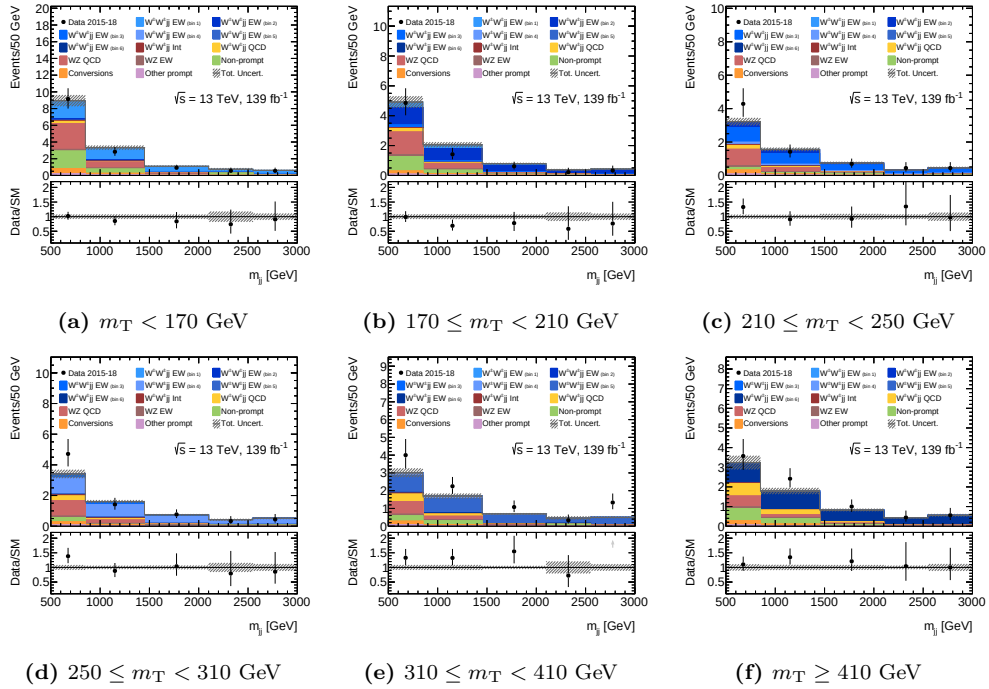


Figure C.40: Pre-fit m_{ij} -distributions in signal region split into m_T slices as used in m_T -differential cross-section measurement.

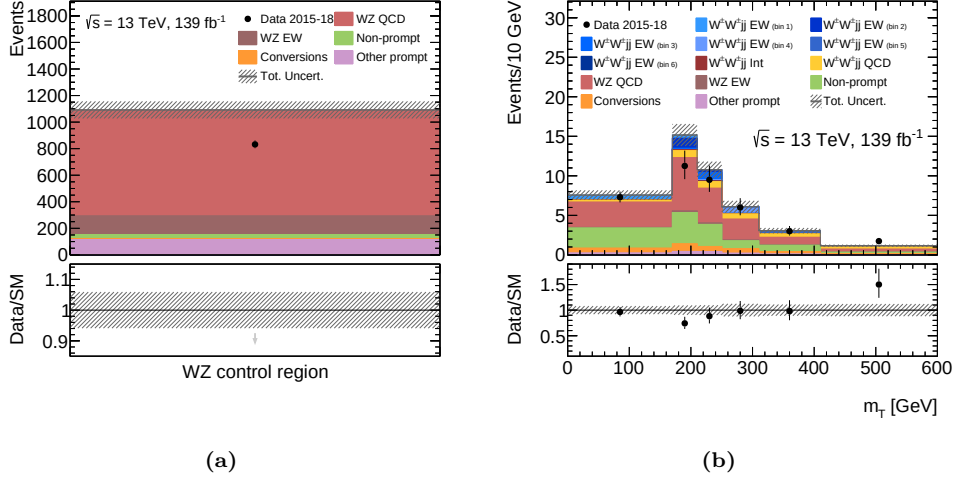


Figure C.41: Pre-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in m_T -differential cross-section measurement.

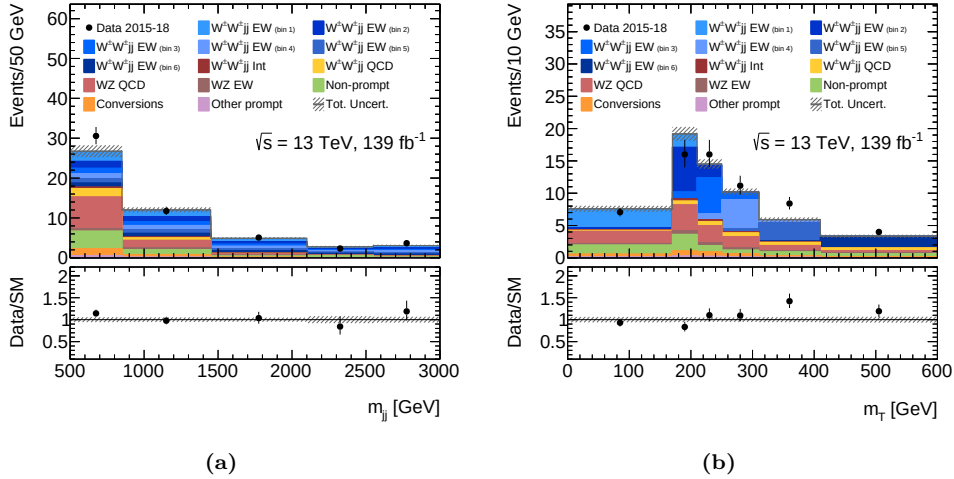


Figure C.42: Pre-fit m_{jj} -distributions in signal region summed over m_T slices (a) and summed over m_{jj} bins (b) in m_T -differential cross-section measurement.

Table C.12: Breakdown of the uncertainty of signal strength in the different m_{jj} truth slices in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.4	0.4	0.5	0.4	0.4	0.4
Muon calibration	0.4	0.5	0.5	0.5	0.5	0.5
Jet energy scale and resolution	1.1	5.2	2.5	4.9	3.8	5.9
E_T^{miss} scale and resolution	0.1	0.2	0.2	0.1	0.2	0.2
b -tagging inefficiency	0.7	0.7	0.7	0.6	0.6	0.5
Background, misid. leptons	4.4	4.2	1.4	1.3	4.9	1.2
Background, charge misrec.	1.6	1.0	0.6	0.1	0.2	0.2
Pileup modelling	0.3	0.3	0.2	0.6	0.2	0.2
Luminosity	1.6	1.8	1.8	1.8	1.8	1.8
Modelling						
$W^\pm W^\pm jj$ shower, scale, PDF & α_s	4.7	3.3	1.6	1.0	3.4	6.4
EW $W^\pm W^\pm jj$, QCD corrections	1.1	1.8	2.0	2.0	2.6	1.4
EW $W^\pm W^\pm jj$, EW corrections	0.1	0.4	0.1	0.2	0.1	0.2
QCD $W^\pm W^\pm jj$, QCD corrections	0.3	0.3	0.3	0.1	0.1	0.0
Background, WZ scale, PDF & α_s	0.3	0.5	0.2	0.5	0.7	0.8
Background, WZ reweighting	1.0	3.2	1.6	1.9	1.2	0.5
Background, other	1.8	1.3	1.1	0.4	0.2	0.7
Model statistical	3.3	7.0	5.3	5.6	6.0	3.8
Experimental and modelling	8.1	11.3	7.2	8.5	10.1	10.0
Data statistical	10.5	30.7	23.6	30.6	25.5	30.8
Total	13.3	32.7	24.7	31.7	27.4	32.4

C.3.2 Results of the Asimov Fit for m_T with EW Signal

The signal strength μ from the fit to Asimov data is:

$$\mu_{\text{exp}, m_T, \text{bin 1}}^{\text{EW}} = 1.00 \pm_{0.21}^{0.22} (\text{stat.}) \pm_{0.08}^{0.09} (\text{mod. syst.}) \pm_{0.06}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_T, \text{bin 2}}^{\text{EW}} = 1.00 \pm_{0.31}^{0.34} (\text{stat.}) \pm_{0.08}^{0.10} (\text{mod. syst.}) \pm_{0.05}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_T, \text{bin 3}}^{\text{EW}} = 1.00 \pm_{0.36}^{0.39} (\text{stat.}) \pm_{0.09}^{0.10} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_T, \text{bin 4}}^{\text{EW}} = 1.00 \pm_{0.29}^{0.31} (\text{stat.}) \pm_{0.06}^{0.08} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_T, \text{bin 5}}^{\text{EW}} = 1.00 \pm_{0.26}^{0.28} (\text{stat.}) \pm_{0.07}^{0.08} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_T, \text{bin 6}}^{\text{EW}} = 1.00 \pm_{0.22}^{0.25} (\text{stat.}) \pm_{0.08}^{0.09} (\text{mod. syst.}) \pm_{0.04}^{0.05} (\text{exp. syst.}) \pm_{0.02}^{0.03} (\text{lumi.})$$

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{\text{WZ, exp}, m_T}^{\text{EW}} = 1.00 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

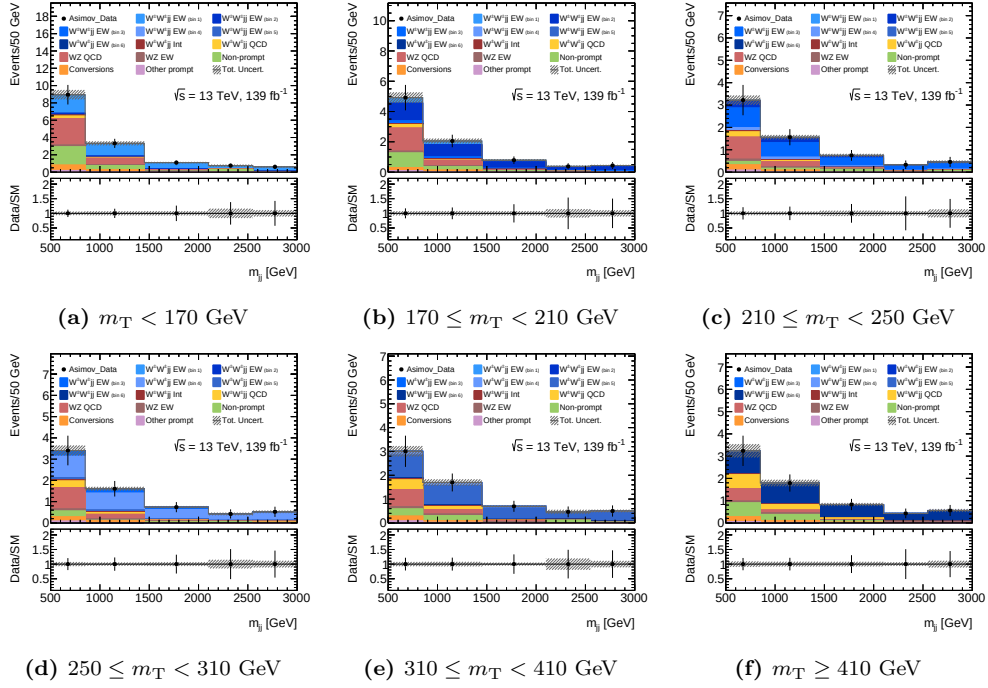


Figure C.43: Post-fit m_{jj} -distributions in signal region split into m_T slices as used in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

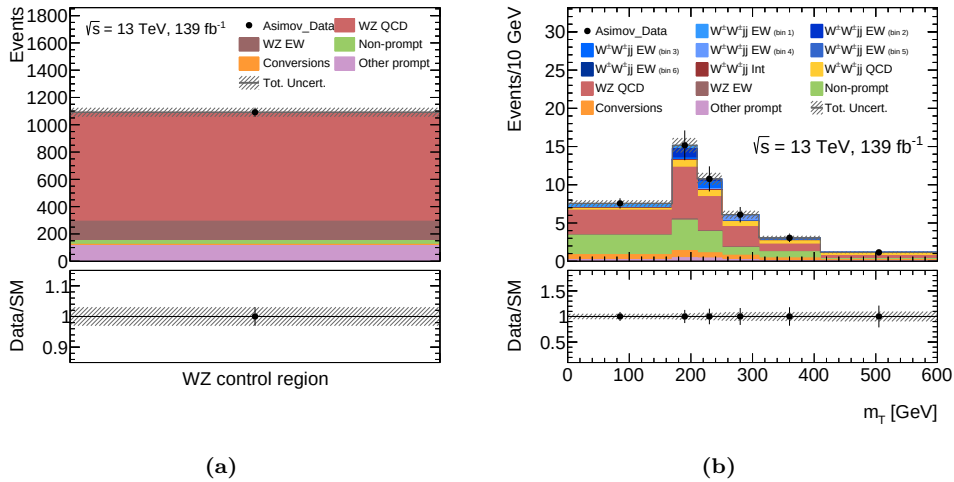


Figure C.44: Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

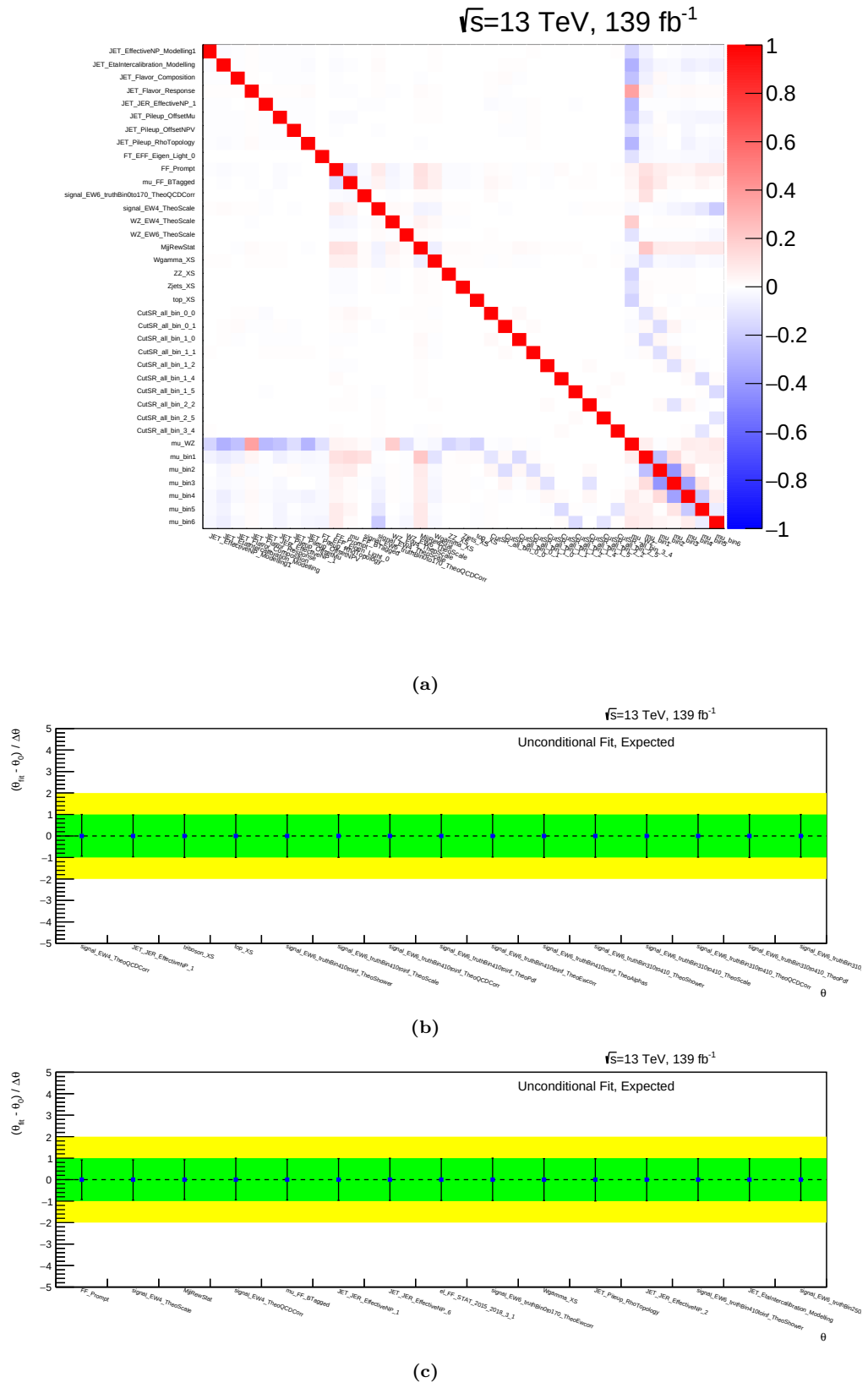


Figure C.45: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_T -differential cross-section measurement of $\text{EW } W^\pm W^\pm \text{jj}$ with Asimov data.

Table C.13: List of parameter correlations which are larger than 10% in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

Parameter 1	Parameter 2	Correlation
$\mu_{\text{bin}2}$	$\mu_{\text{bin}3}$	-0.419
JET_Flavor_Response	μ_{WZ}	0.371
$\mu_{\text{bin}3}$	$\mu_{\text{bin}4}$	-0.368
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.309
JET_Pileup_RhoTopology	μ_{WZ}	-0.292
JET_JER_EffectiveNP_1	μ_{WZ}	-0.273
$\mu_{\text{bin}1}$	$\mu_{\text{bin}2}$	-0.255
JET_Flavor_Composition	μ_{WZ}	-0.242
JET_Pileup_OffsetMu	μ_{WZ}	-0.235
MjjRewStat	$\mu_{\text{bin}1}$	0.223
$\mu_{\text{bin}4}$	$\mu_{\text{bin}5}$	-0.216
signal_EW4_TheoScale	$\mu_{\text{bin}6}$	-0.202
WZ_EW4_TheoScale	μ_{WZ}	0.197
top_XS	μ_{WZ}	-0.176
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.167
ZZ_XS	μ_{WZ}	-0.164
CutSR_all_bin_1_4	$\mu_{\text{bin}5}$	-0.143
$\mu_{\text{bin}2}$	$\mu_{\text{bin}4}$	0.142
CutSR_all_bin_1_0	$\mu_{\text{bin}1}$	-0.140
CutSR_all_bin_1_5	$\mu_{\text{bin}6}$	-0.139
$\mu_{\text{FF_BTagged}}$	$\mu_{\text{bin}1}$	0.139
$\mu_{\text{bin}1}$	$\mu_{\text{bin}3}$	0.136
JET_Pileup_OffsetNPV	μ_{WZ}	-0.131
CutSR_all_bin_0_1	$\mu_{\text{bin}2}$	-0.130
FF_Prompt	$\mu_{\text{FF_BTagged}}$	-0.127
CutSR_all_bin_1_1	$\mu_{\text{bin}2}$	-0.126
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.121
signal_EW6_truthBin0to170_TheoQCDCorr	$\mu_{\text{bin}1}$	0.120
FF_Prompt	$\mu_{\text{bin}1}$	0.117
FF_Prompt	MjjRewStat	0.115
CutSR_all_bin_1_2	$\mu_{\text{bin}3}$	-0.114
Zjets_XS	μ_{WZ}	-0.114
MjjRewStat	$\mu_{\text{FF_BTagged}}$	0.108
CutSR_all_bin_2_2	$\mu_{\text{bin}3}$	-0.108
WZ_EW6_TheoScale	μ_{WZ}	-0.107
Wgamma_XS	$\mu_{\text{bin}1}$	-0.107
CutSR_all_bin_2_5	$\mu_{\text{bin}6}$	-0.104
CutSR_all_bin_0_0	$\mu_{\text{bin}1}$	-0.101
$\mu_{\text{bin}3}$	$\mu_{\text{bin}5}$	0.101
CutSR_all_bin_3_4	$\mu_{\text{bin}5}$	-0.100

Post-fit plots are in Figure C.43 and Figure C.44.

Pull plot and correlations are in Figure C.45.

Table of the strongest (anti-)correlations are included in Table C.13.

The ranking plot is shown in Figure C.46.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.14.

The correlation between unfolded bins are shown in Figure C.47.

C.3.3 Results of the Asimov Fit for m_T with EW+Int+QCD Signal

The signal strength μ from the fit to Asimov data is:

$$\mu_{\text{exp}, m_T, \text{bin } 1}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.19}^{0.21} (\text{stat.}) \pm_{0.08}^{0.08} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_T, \text{bin } 2}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.30}^{0.32} (\text{stat.}) \pm_{0.08}^{0.09} (\text{mod. syst.}) \pm_{0.06}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_T, \text{bin } 3}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.33}^{0.35} (\text{stat.}) \pm_{0.08}^{0.10} (\text{mod. syst.}) \pm_{0.05}^{0.04} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_T, \text{bin } 4}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.26}^{0.28} (\text{stat.}) \pm_{0.06}^{0.07} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_T, \text{bin } 5}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.22}^{0.24} (\text{stat.}) \pm_{0.06}^{0.07} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, m_T, \text{bin } 6}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.18}^{0.19} (\text{stat.}) \pm_{0.05}^{0.06} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.})$$

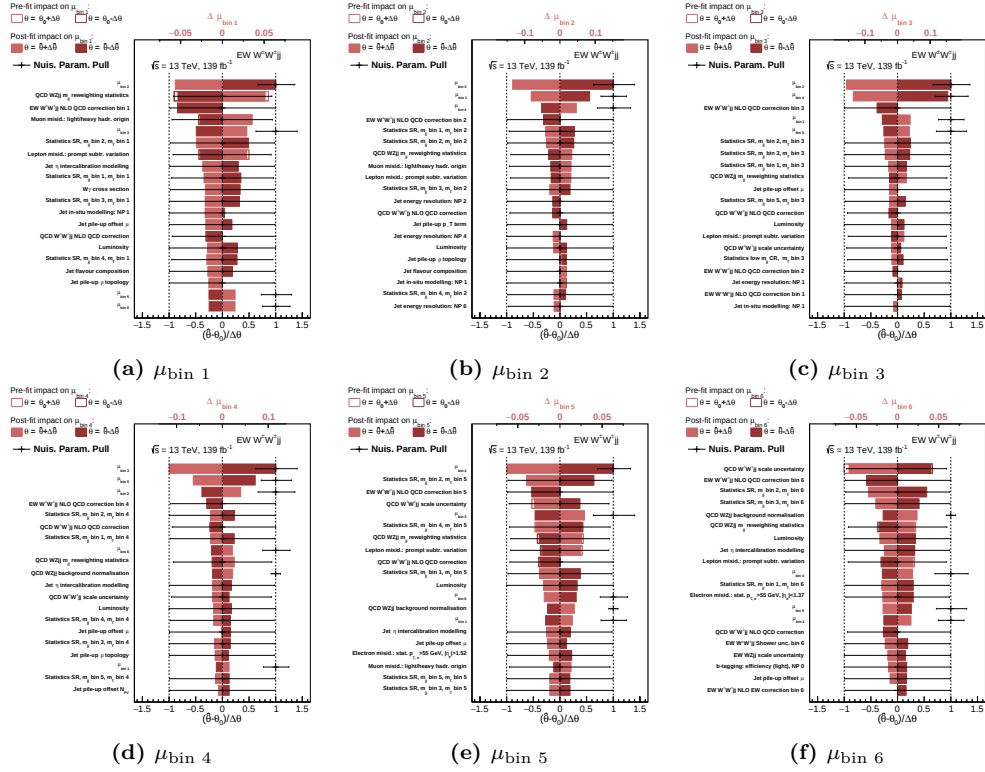


Figure C.46: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_T -differential cross-section measurement of $\text{EW } W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_T -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

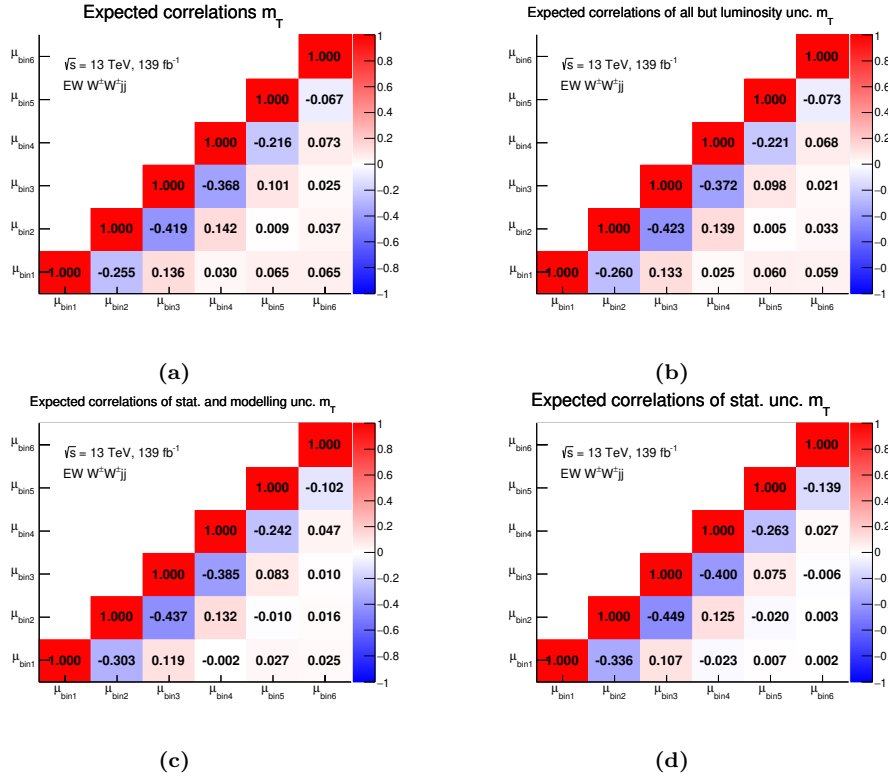


Figure C.47: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

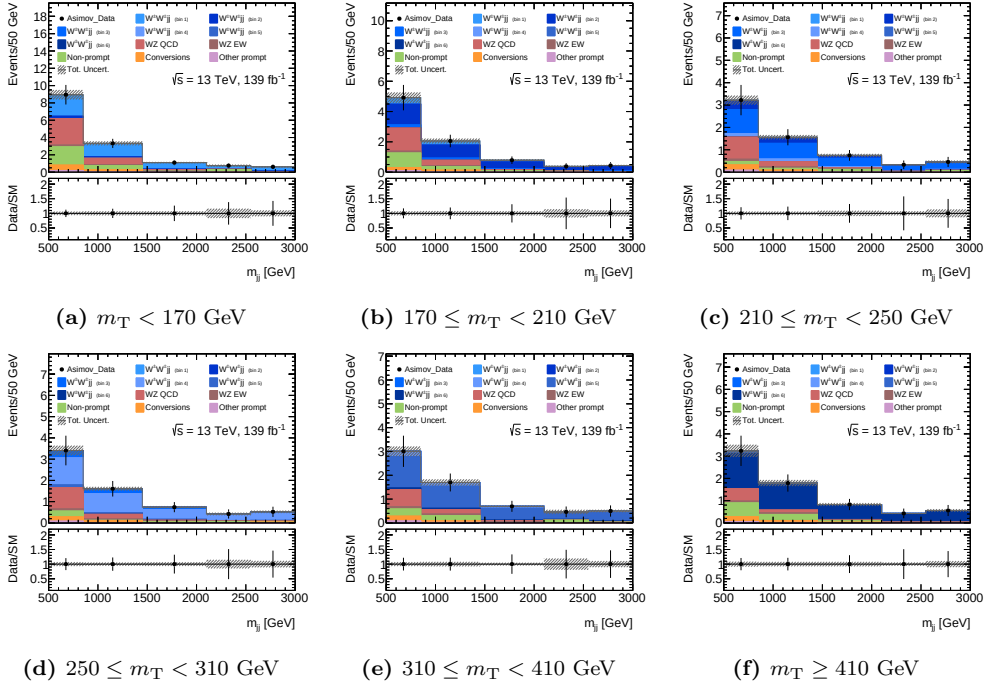


Figure C.48: Post-fit m_{jj} -distributions in signal region split into m_T slices as used in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Table C.14: Breakdown of the uncertainty of signal strength in the different m_T truth slices in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.7	0.3	0.4	0.4	0.7	1.4
Muon calibration	0.6	0.7	0.6	0.7	0.6	1.0
Jet energy scale and resolution	3.6	3.1	2.8	3.5	2.5	2.6
E_T^{miss} scale and resolution	0.9	0.8	1.0	1.0	0.6	0.4
b -tagging inefficiency	0.7	0.6	0.7	0.7	0.8	1.0
Background, misid. leptons	5.2	4.4	3.1	2.5	3.6	3.3
Background, charge misrec.	1.7	1.2	1.3	1.4	1.2	1.1
Pileup modelling	0.4	0.6	0.8	0.7	0.4	0.2
Luminosity	1.8	1.8	1.9	1.9	2.0	2.2
Modelling						
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	1.2	1.2	1.0	0.6	0.7	1.5
EW $W^\pm W^\pm jj$, QCD corrections	3.0	2.9	3.3	2.0	2.0	2.1
EW $W^\pm W^\pm jj$, EW corrections	0.6	0.4	0.3	0.2	0.4	0.5
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.2	0.2	0.2	0.1	0.0	0.1
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.7	1.2	1.7	2.2	3.2	5.8
QCD $W^\pm W^\pm jj$, QCD corrections	0.9	0.8	1.2	1.1	1.0	0.6
Background, WZ scale, PDF & α_s	0.5	0.7	0.5	0.5	0.4	0.9
Background, WZ reweighting	4.4	2.0	2.2	1.8	2.0	1.6
Background, other	2.9	1.3	1.3	1.3	0.6	0.7
Model statistical	5.4	7.9	8.2	5.8	6.1	5.1
Experimental and modelling	10.9	10.8	10.7	8.8	9.2	9.9
Data statistical	21.3	32.7	37.1	29.9	26.9	23.6
Total	23.9	34.5	38.6	31.1	28.4	25.6

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{\text{WZ, exp } m_T}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

Post-fit plots are in Figure C.48 and Figure C.49.

Pull plot and correlations are in Figure C.50.

Table of the strongest (anti-)correlations are included in Table C.15.

The ranking plot is shown in Figure C.51.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.16.

The correlation between unfolded bins are shown in Figure C.52.

C.3.4 Results of the Fit to Observed Data for m_T with EW Signal

The observed signal strength μ from the fit to observed data is:

$$\mu_{\text{obs, } m_T, \text{ bin 1}}^{\text{EW}} = 0.96 \pm_{0.20}^{0.21} (\text{stat.}) \pm_{0.08}^{0.09} (\text{mod. syst.}) \pm_{0.06}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{obs, } m_T, \text{ bin 2}}^{\text{EW}} = 0.48 \pm_{0.27}^{0.30} (\text{stat.}) \pm_{0.06}^{0.08} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.00}^{0.01} (\text{lumi.}),$$

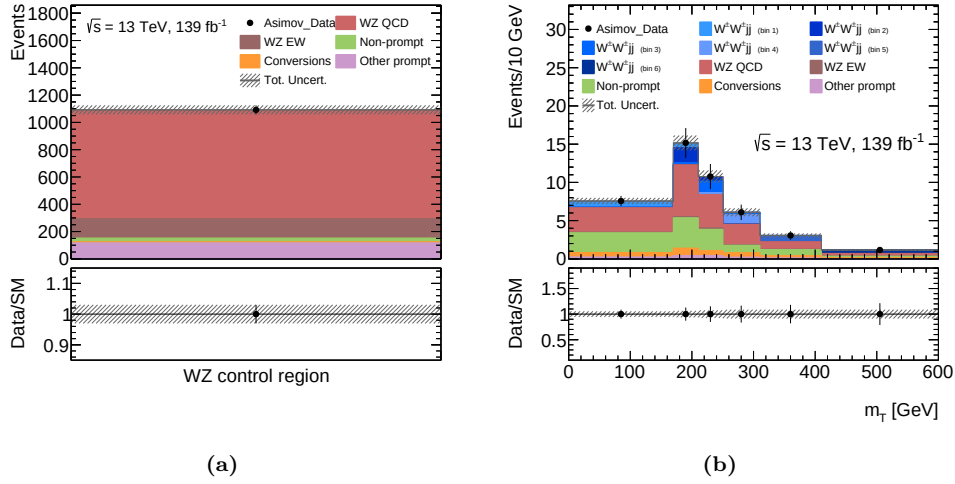


Figure C.49: Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Table C.15: List of parameter correlations which are larger than 10% in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Parameter 1	Parameter 2	Correlation
$\mu_{\text{bin}2}$	$\mu_{\text{bin}3}$	-0.426
$\mu_{\text{bin}3}$	$\mu_{\text{bin}4}$	-0.377
JET_Flavor_Response	μ_{WZ}	0.373
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.307
JET_Pileup_RhoTopology	μ_{WZ}	-0.293
JET_JER_EffectiveNP_1	μ_{WZ}	-0.274
$\mu_{\text{bin}1}$	$\mu_{\text{bin}2}$	-0.251
JET_Flavor_Composition	μ_{WZ}	-0.242
JET_Pileup_OffsetMu	μ_{WZ}	-0.234
$\mu_{\text{bin}4}$	$\mu_{\text{bin}5}$	-0.222
MjjRewStat	$\mu_{\text{bin}1}$	0.214
WZ_EW4_TheoScale	μ_{WZ}	0.199
top_XS	μ_{WZ}	-0.176
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.166
ZZ_XS	μ_{WZ}	-0.163
$\mu_{\text{FF_BTagged}}$	$\mu_{\text{bin}1}$	0.155
$\mu_{\text{bin}2}$	$\mu_{\text{bin}4}$	0.148
CutSR_all_bin_1_5	$\mu_{\text{bin}6}$	-0.146
CutSR_all_bin_1_4	$\mu_{\text{bin}5}$	-0.141
CutSR_all_bin_1_0	$\mu_{\text{bin}1}$	-0.139
CutSR_all_bin_0_1	$\mu_{\text{bin}2}$	-0.139
$\mu_{\text{bin}1}$	$\mu_{\text{bin}3}$	0.138
FF_Prompt	$\mu_{\text{bin}1}$	0.132
JET_Pileup_OffsetNPV	μ_{WZ}	-0.132
CutSR_all_bin_1_1	$\mu_{\text{bin}2}$	-0.124
signal_EW6_truthBin0to170_TheoQCDCorr	$\mu_{\text{bin}1}$	0.124
FF_Prompt	MjjRewStat	0.122
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.121
Wgamma_XS	$\mu_{\text{bin}1}$	-0.120
FF_Prompt	$\mu_{\text{FF_BTagged}}$	-0.120
Zjets_XS	μ_{WZ}	-0.114
MjjRewStat	$\mu_{\text{FF_BTagged}}$	0.113
CutSR_all_bin_1_2	$\mu_{\text{bin}3}$	-0.112
FF_Prompt	$\mu_{\text{bin}6}$	0.108
CutSR_all_bin_0_5	$\mu_{\text{bin}6}$	-0.108
CutSR_all_bin_0_0	$\mu_{\text{bin}1}$	-0.108
CutSR_all_bin_0_4	$\mu_{\text{bin}5}$	-0.106
WZ_EW6_TheoScale	μ_{WZ}	-0.106
FF_Prompt	$\mu_{\text{bin}5}$	0.105
el_FF_STAT_2015_2018_3_1	$\mu_{\text{bin}6}$	-0.102
CutSR_all_bin_2_2	$\mu_{\text{bin}3}$	-0.102
$\mu_{\text{bin}3}$	$\mu_{\text{bin}5}$	0.101
signal_EW6_truthBin410toinf_TheoQCDCorr	$\mu_{\text{bin}6}$	0.101

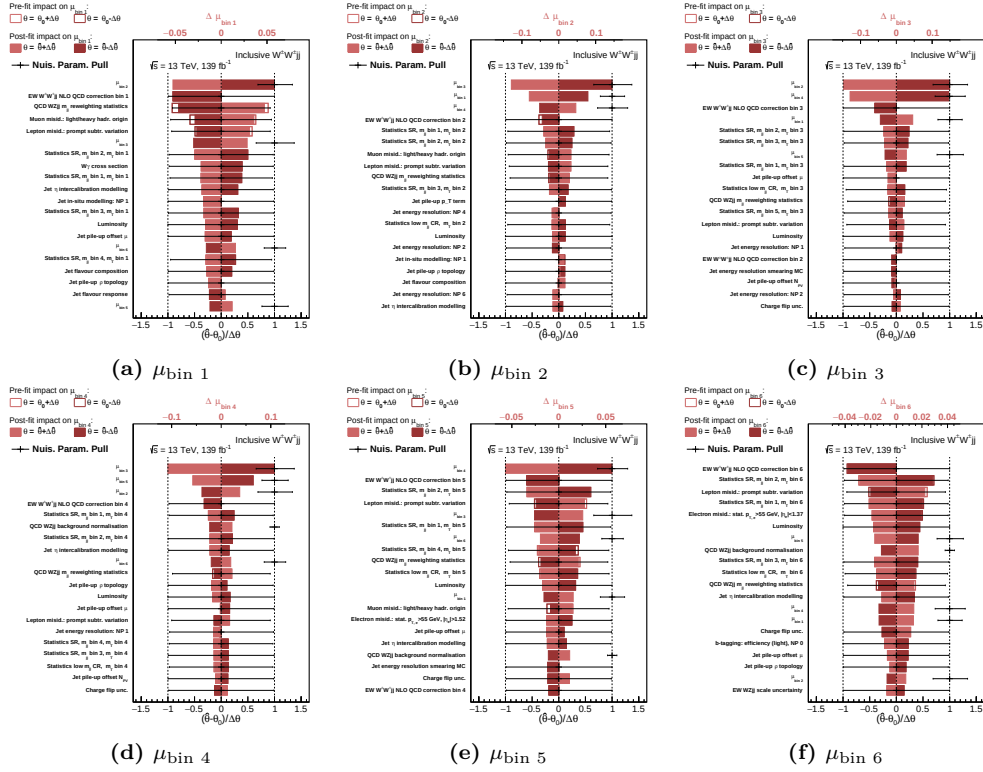


Figure C.51: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_T -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

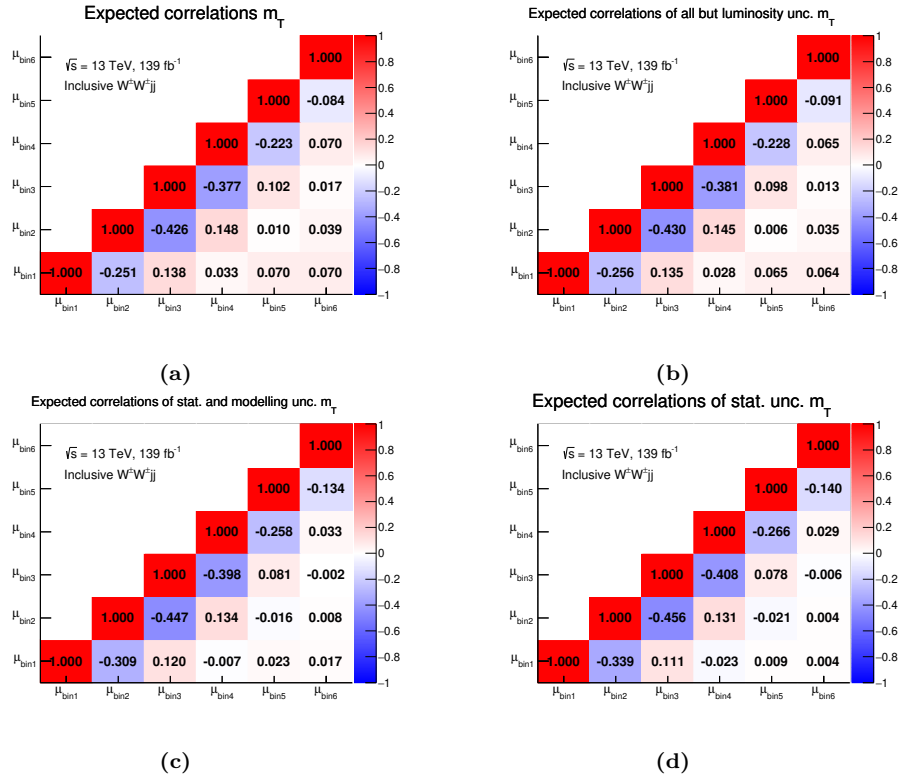


Figure C.52: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Table C.16: Breakdown of the uncertainty of signal strength in the different m_T truth slices in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.7	0.3	0.3	0.4	0.7	1.2
Muon calibration	0.6	0.6	0.6	0.7	0.5	0.9
Jet energy scale and resolution	3.4	2.8	2.7	3.8	2.1	1.9
E_T^{miss} scale and resolution	0.9	0.8	0.9	1.0	0.5	0.3
b -tagging inefficiency	0.7	0.6	0.7	0.7	0.7	0.8
Background, misid. leptons	5.5	4.7	3.0	2.8	3.9	3.6
Background, charge misrec.	1.7	1.3	1.4	1.6	1.4	1.4
Pileup modelling	0.4	0.6	0.6	0.7	0.3	0.4
Luminosity	1.7	1.7	1.7	1.7	1.8	1.8
Modelling						
$W^\pm W^\pm jj$ shower, scale, PDF & α_s	1.0	1.0	1.2	0.9	0.8	0.5
EW $W^\pm W^\pm jj$, QCD corrections	3.0	2.8	3.2	2.0	2.0	2.1
EW $W^\pm W^\pm jj$, EW corrections	0.5	0.3	0.1	0.0	0.1	0.1
QCD $W^\pm W^\pm jj$, QCD corrections	0.2	0.2	0.4	0.3	0.2	0.4
Background, WZ scale, PDF & α_s	0.6	0.8	0.5	0.6	0.3	0.7
Background, WZ reweighting	3.8	1.5	1.8	1.2	1.3	0.8
Background, other	3.1	1.3	1.5	1.4	0.9	1.0
Model statistical	5.2	7.7	7.8	5.4	5.6	4.5
Experimental and modelling	10.6	10.4	10.1	8.3	8.1	7.2
Data statistical	20.1	30.6	34.2	26.9	23.3	18.8
Total	22.7	32.3	35.7	28.2	24.6	20.1

$$\mu_{\text{obs}, m_T, \text{bin 3}}^{\text{EW}} = 1.42 \pm_{0.37}^{0.40} (\text{stat.}) \pm_{0.11}^{0.13} (\text{mod. syst.}) \pm_{0.04}^{0.06} (\text{exp. syst.}) \pm_{0.02}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_T, \text{bin 4}}^{\text{EW}} = 0.98 \pm_{0.30}^{0.32} (\text{stat.}) \pm_{0.08}^{0.09} (\text{mod. syst.}) \pm_{0.06}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_T, \text{bin 5}}^{\text{EW}} = 1.92 \pm_{0.31}^{0.34} (\text{stat.}) \pm_{0.10}^{0.11} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.03}^{0.04} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_T, \text{bin 6}}^{\text{EW}} = 1.32 \pm_{0.25}^{0.27} (\text{stat.}) \pm_{0.13}^{0.14} (\text{mod. syst.}) \pm_{0.05}^{0.06} (\text{exp. syst.}) \pm_{0.03}^{0.03} (\text{lumi.})$$

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{\text{WZ, obs}, m_T}^{\text{EW}} = 0.69 \pm_{0.03}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

Post-fit plots are in Figure C.53 and Figure C.54. The projections on m_T and on m_{jj} are shown in Figure C.55. Because of the free floating normalisation factors nearly perfect agreement is expected in the signal region in the m_T projections. This is also observed. There are some small deviations because of the low- m_{jj} CR, the splitting into m_{jj} fits in the fit and the migration of the truth level splitted samples into recoconstruction level bins.

Pull plot and correlations are in Figure C.56.

Selected profile LH scans are in Figure C.57.

Table of the strongest (anti-)correlations are included in Table C.17.

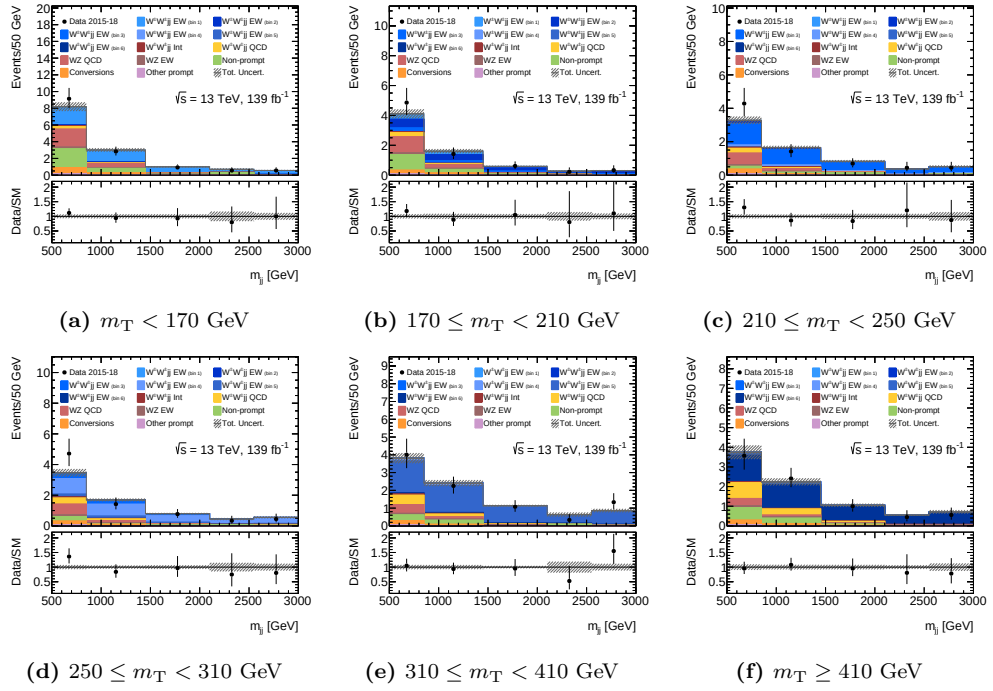


Figure C.53: Post-fit m_{jj} -distributions in signal region split into m_T slices as used in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

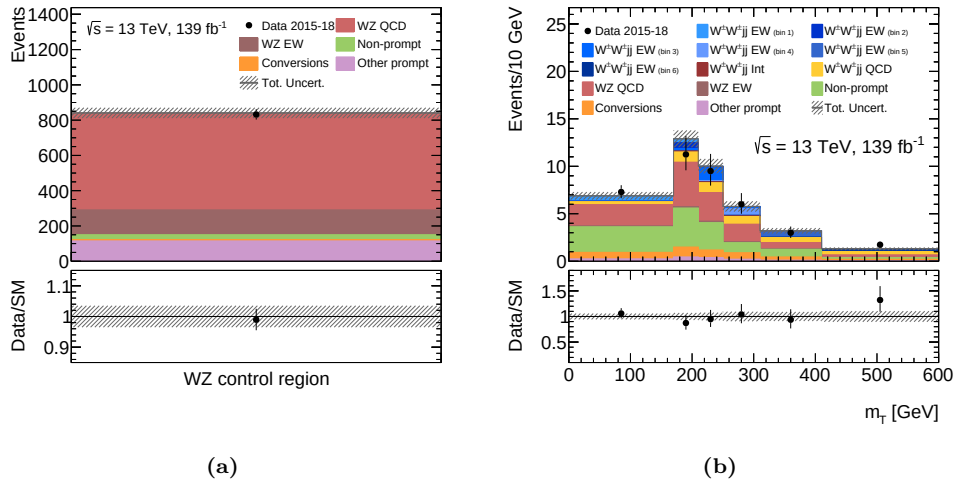


Figure C.54: Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

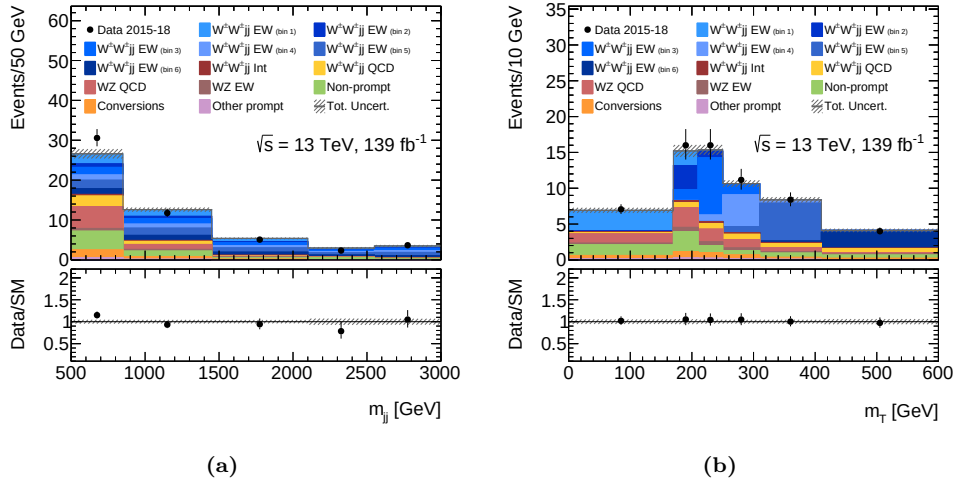


Figure C.55: Post-fit signal region summed over m_T slices (a) and summed over m_T slices (b) in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

Table C.17: List of parameter correlations which are larger than 10% in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

Parameter 1	Parameter 2	Correlation
$\mu_{_bin2}$	$\mu_{_bin3}$	-0.413
$\mu_{_bin3}$	$\mu_{_bin4}$	-0.357
JET_Flavor_Response	$\mu_{_WZ}$	0.334
signal_EW4_TheoScale	$\mu_{_bin6}$	-0.295
JET_EtaIntercalibration_Modelling	$\mu_{_WZ}$	-0.288
JET_Flavor_Composition	$\mu_{_WZ}$	-0.277
$\mu_{_bin1}$	$\mu_{_bin2}$	-0.273
JET_JER_EffectiveNP_1	$\mu_{_WZ}$	-0.246
JET_Pileup_RhoTopology	$\mu_{_WZ}$	-0.237
top_XS	$\mu_{_WZ}$	-0.225
JET_Pileup_OffsetMu	$\mu_{_WZ}$	-0.217
ZZ_XS	$\mu_{_WZ}$	-0.204
$\mu_{_bin4}$	$\mu_{_bin5}$	-0.200
signal_EW6_truthBin0to170_TheoQCDCorr	$\mu_{_bin1}$	0.192
CutSR_all_bin_1_4	$\mu_{_bin5}$	-0.172
JET_EffectiveNP_Modelling1	$\mu_{_WZ}$	-0.172
signal_EW6_truthBin210to250_TheoQCDCorr	$\mu_{_bin3}$	0.166
CutSR_all_bin_1_5	$\mu_{_bin6}$	-0.164
MjjRewStat	$\mu_{_bin1}$	0.161
signal_EW4_TheoScale	signal_EW6_truthBin410toinf_TheoQCDCorr	0.159
WZ_EW4_TheoScale	$\mu_{_WZ}$	0.158
CutSR_all_bin_1_0	$\mu_{_bin1}$	-0.140
$\mu_{_bin2}$	$\mu_{_bin4}$	0.139
Zjets_XS	$\mu_{_WZ}$	-0.138
$\mu_{_FF_BTagged}$	$\mu_{_bin1}$	0.135
WZ_EW6_TheoScale	$\mu_{_WZ}$	-0.130
FF_Prompt	$\mu_{_FF_BTagged}$	-0.127
CutSR_all_bin_1_2	$\mu_{_bin3}$	-0.122
$\mu_{_bin1}$	$\mu_{_bin3}$	0.121
CutSR_all_bin_2_5	$\mu_{_bin6}$	-0.116
FT_EFF_Eigen_Light_0	$\mu_{_WZ}$	-0.116
signal_EW6_truthBin410toinf_TheoEwcorr	$\mu_{_bin6}$	-0.116
CutSR_all_bin_3_4	$\mu_{_bin5}$	-0.116
JET_Pileup_OffsetNPV	$\mu_{_WZ}$	-0.116
signal_EW4_TheoScale	$\mu_{_bin5}$	-0.116
FF_Prompt	$\mu_{_bin1}$	0.115
CutSR_all_bin_0_1	$\mu_{_bin2}$	-0.113
CutSR_all_bin_2_2	$\mu_{_bin3}$	-0.112
CutSR_all_bin_1_1	$\mu_{_bin2}$	-0.108
Wgamma_XS	$\mu_{_bin1}$	-0.106
Lumi	$\mu_{_bin5}$	-0.105
CutSR_all_bin_0_4	$\mu_{_bin5}$	-0.104
FF_Prompt	signal_EW4_TheoScale	0.103
signal_EW4_TheoScale	signal_EW6_truthBin410toinf_TheoEwcorr	0.102

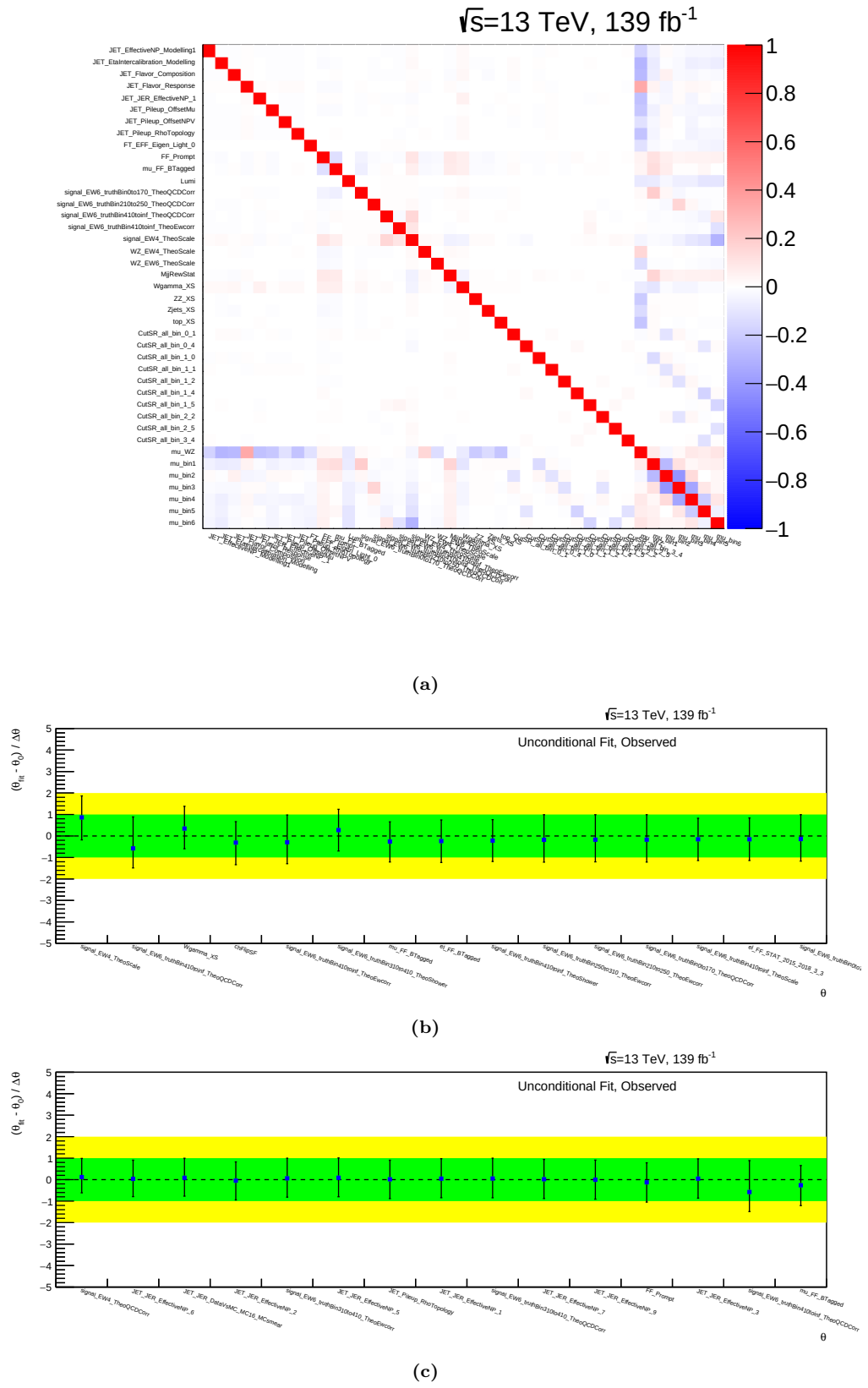


Figure C.56: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

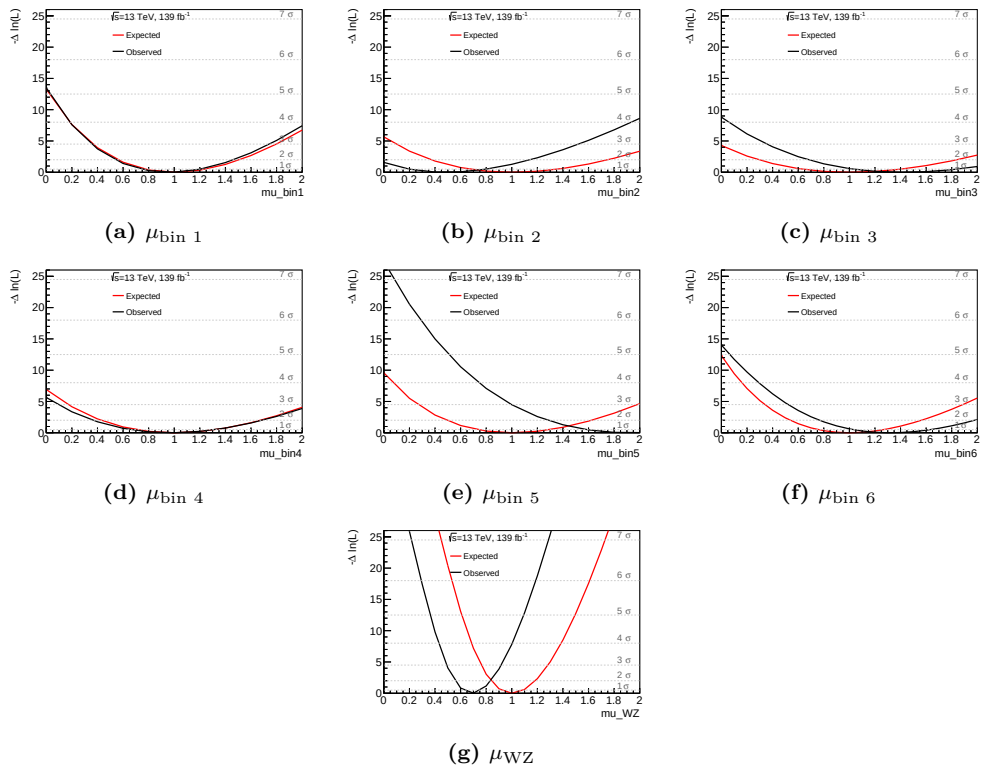


Figure C.57: Likelihood scans of nuisance parameters with largest pulls and constraints in the m_T differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-f) and for QCD $W^\pm Z jj$ normalisation parameter (g).

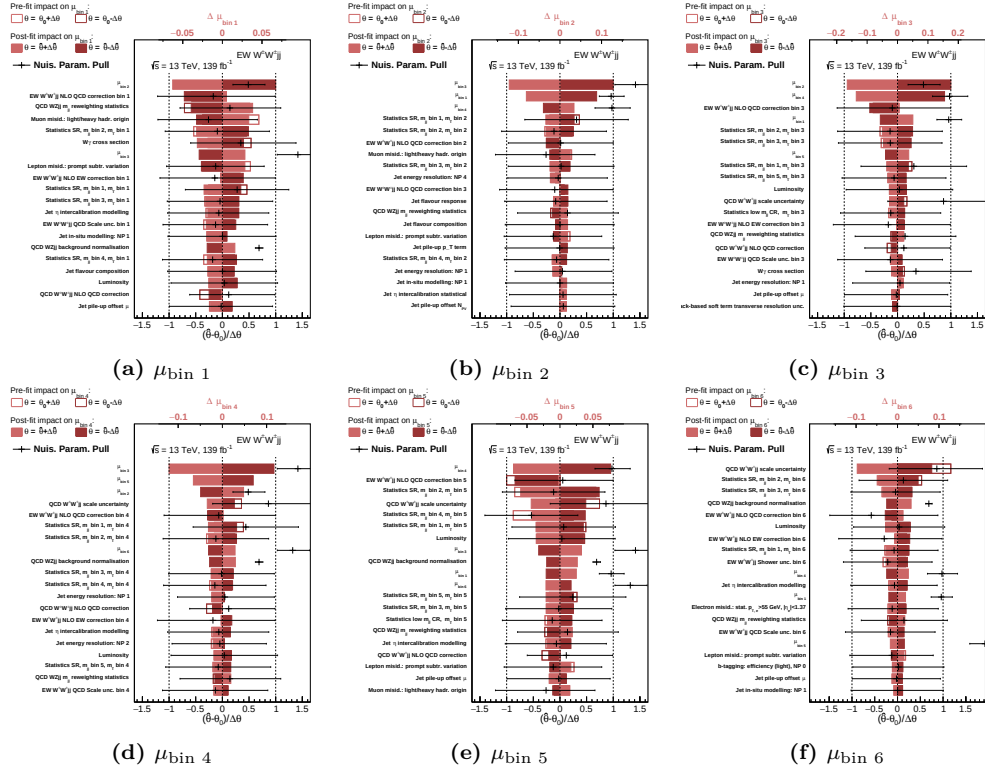


Figure C.58: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_T -differential cross-section measurement of $\text{EW } W^\pm W^\pm jj$ with observed data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_T -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

Table C.18: Breakdown of the uncertainty of signal strength in the different m_T truth slices in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma\gamma$, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.6	0.4	0.4	0.2	0.5	1.5
Muon calibration	0.5	1.0	0.6	0.8	0.6	1.1
Jet energy scale and resolution	4.2	6.7	2.1	4.5	1.7	2.7
E_T^{miss} scale and resolution	0.9	2.5	1.1	1.7	0.2	0.5
b -tagging inefficiency	0.7	0.8	0.7	0.8	0.7	1.0
Background, misid. leptons	5.4	7.6	2.0	3.1	1.5	2.4
Background, charge misrec.	1.6	1.8	1.0	1.6	0.5	0.6
Pileup modelling	0.4	0.6	1.0	1.0	0.4	0.1
Luminosity	1.9	1.9	1.9	2.0	1.9	2.3
Modelling						
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.7	1.3	0.4	0.7	0.5	1.4
EW $W^\pm W^\pm jj$, QCD corrections	4.9	4.1	4.6	2.4	1.6	4.1
EW $W^\pm W^\pm jj$, EW corrections	0.4	2.0	1.7	1.0	0.3	0.4
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.2	0.4	0.1	0.1	0.0	0.1
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	1.1	2.9	1.8	3.7	2.4	7.1
QCD $W^\pm W^\pm jj$, QCD corrections	0.4	0.7	0.4	0.5	0.2	0.1
Background, WZ scale, PDF & α_s	0.1	0.1	0.1	0.1	0.1	0.1
Background, WZ reweighting	3.1	3.3	1.2	1.5	0.8	1.2
Background, other	3.0	0.9	1.1	1.1	0.3	0.1
Model statistical	5.3	12.8	6.1	6.6	4.5	5.1
Experimental and modelling	11.5	18.4	9.3	10.9	6.4	11.1
Data statistical	21.3	59.3	27.0	32.1	17.0	20.0
Total	24.2	62.1	28.6	33.9	18.1	22.9

The ranking plot is shown in Figure C.58.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.18.

The correlation between unfolded bins are shown in Figure C.59.

C.3.5 Results of the Fit to Observed Data for m_T with EW+Int+QCD Signal

The observed signal strength μ from the fit to observed data is:

$$\mu_{\text{obs}, m_T, \text{bin 1}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.19}^{0.20} (\text{stat.}) \pm_{0.08}^{0.09} (\text{mod. syst.}) \pm_{0.07}^{0.08} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_T, \text{bin 2}}^{\text{EW+Int+QCD}} = 0.52 \pm_{0.26}^{0.28} (\text{stat.}) \pm_{0.06}^{0.08} (\text{mod. syst.}) \pm_{0.05}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.00} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_T, \text{bin 3}}^{\text{EW+Int+QCD}} = 1.43 \pm_{0.34}^{0.36} (\text{stat.}) \pm_{0.10}^{0.12} (\text{mod. syst.}) \pm_{0.04}^{0.05} (\text{exp. syst.}) \pm_{0.02}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_T, \text{bin 4}}^{\text{EW+Int+QCD}} = 1.04 \pm_{0.27}^{0.29} (\text{stat.}) \pm_{0.07}^{0.08} (\text{mod. syst.}) \pm_{0.07}^{0.06} (\text{exp. syst.}) \pm_{0.00}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{obs}, m_T, \text{bin 5}}^{\text{EW+Int+QCD}} = 1.80 \pm_{0.27}^{0.28} (\text{stat.}) \pm_{0.08}^{0.09} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.03}^{0.04} (\text{lumi.}),$$

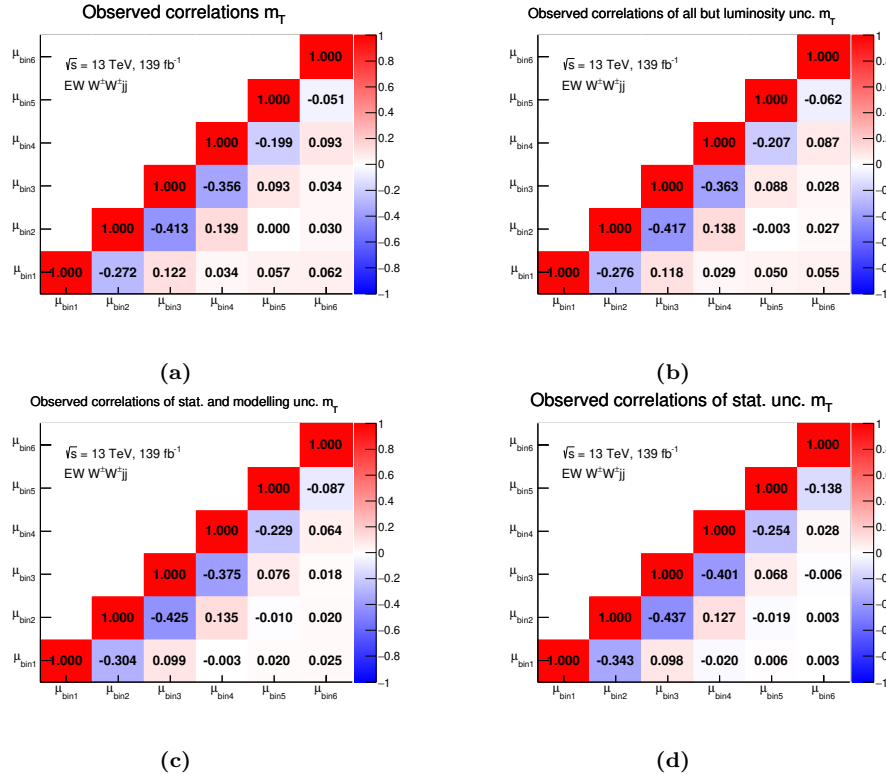


Figure C.59: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

$$\mu_{\text{obs}, m_T, \text{bin } 6}^{\text{EW+Int+QCD}} = 1.39 \pm_{0.20}^{0.22} (\text{stat.}) \pm_{0.08}^{0.10} (\text{mod. syst.}) \pm_{0.05}^{0.06} (\text{exp. syst.}) \pm_{0.02}^{0.03} (\text{lumi.})$$

and the QCD $W^\pm Z jj$ normalisation strength is:

$$\mu_{\text{WZ, obs}, m_T}^{\text{EW+Int+QCD}} = 0.69 \pm_{0.03}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.05}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.00} (\text{lumi.}).$$

Post-fit plots are in Figure C.60 and Figure C.61. The projections on m_T and on m_{jj} are shown in Figure C.62.

Pull plot and correlations are in Figure C.63.

Selected profile LH scans are in Figure C.64.

Table of the strongest (anti-)correlations are included in Table C.19.

The ranking plot is shown in Figure C.65.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.20.

The correlation between unfolded bins are shown in Figure C.66.

C.4 Results for N_{gapJets}

This section presents the extraction of the differential cross-section of the EW $W^\pm W^\pm jj$ production and inclusive $W^\pm W^\pm jj$ production as a function of N_{gapJets} .

C.4.1 Pre-Fit Distributions for N_{gapJets}

The following Figures show the distributions of the fit inputs in the high- m_{jj} signal region (Figure C.67) low- m_{jj} control region and WZ control region (Figure C.68). Zero correlation is assumed in the combination of systematic uncertainties in the hatched band. The observed data is shown with Poisson uncertainties.

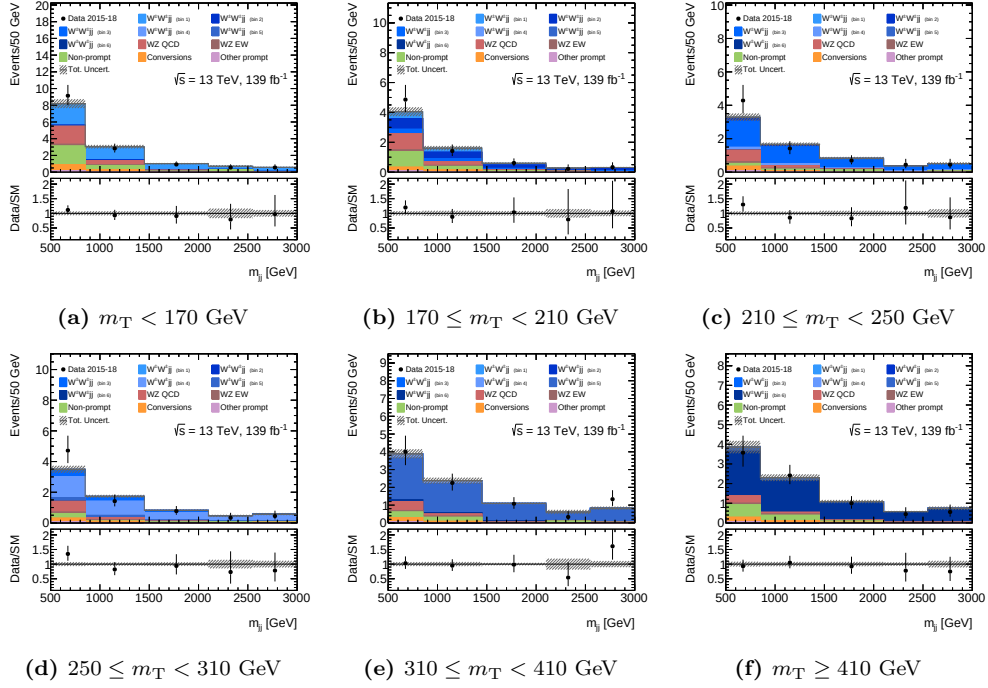


Figure C.60: Post-fit m_{jj} -distributions in signal region split into m_T slices as used in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

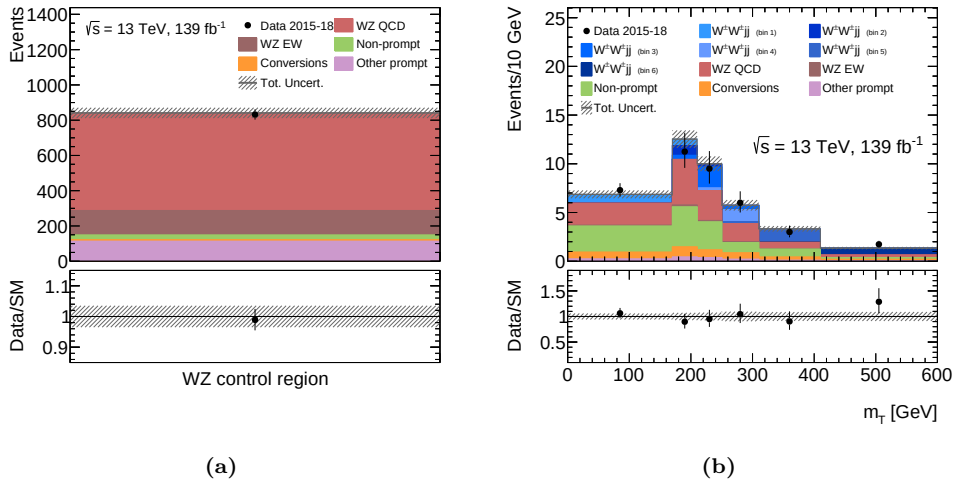


Figure C.61: Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

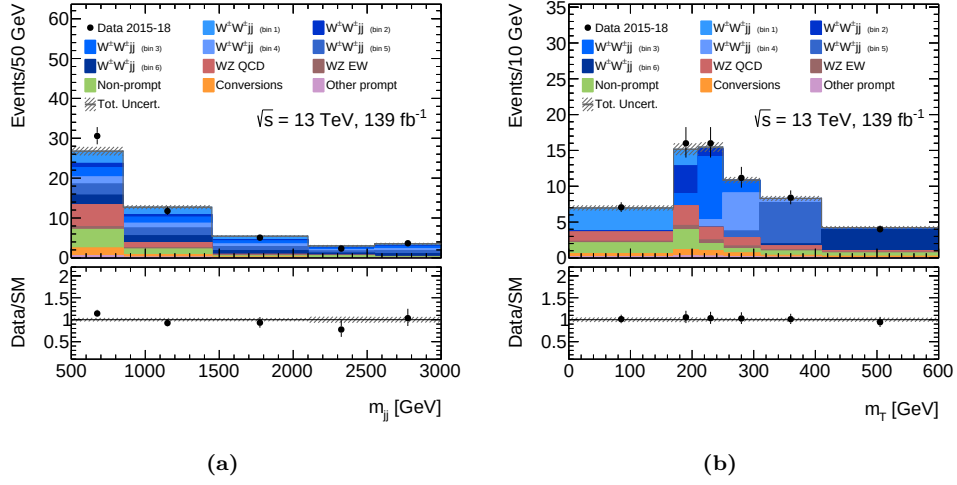


Figure C.62: Post-fit m_{jj} -distributions in signal region summed over m_T slices (a) and summed over m_{jj} bins (b) in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

Table C.19: List of parameter correlations which are larger than 10% in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

Parameter 1	Parameter 2	Correlation
$\mu_{\text{bin}2}$	$\mu_{\text{bin}3}$	-0.418
$\mu_{\text{bin}3}$	$\mu_{\text{bin}4}$	-0.366
JET_Flavor_Response	μ_{WZ}	0.338
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.290
signal_EW6_truthBin410toinf_TheoQCDCorr	$\mu_{\text{bin}6}$	0.288
JET_Flavor_Composition	μ_{WZ}	-0.277
$\mu_{\text{bin}1}$	$\mu_{\text{bin}2}$	-0.262
JET_JER_EffectiveNP_1	μ_{WZ}	-0.247
JET_Pileup_RhoTopology	μ_{WZ}	-0.239
top_XS	μ_{WZ}	-0.224
signal_EW6_truthBin0to170_TheoQCDCorr	$\mu_{\text{bin}1}$	0.221
JET_Pileup_OffsetMu	μ_{WZ}	-0.218
$\mu_{\text{bin}4}$	$\mu_{\text{bin}5}$	-0.211
ZZ_XS	μ_{WZ}	-0.202
signal_EW6_truthBin210to250_TheoQCDCorr	$\mu_{\text{bin}3}$	0.174
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.173
CutSR_all_bin_1_4	$\mu_{\text{bin}5}$	-0.165
WZ_EW4_TheoScale	μ_{WZ}	0.161
CutSR_all_bin_1_5	$\mu_{\text{bin}6}$	-0.159
$\mu_{\text{FF_BTagged}}$	$\mu_{\text{bin}1}$	0.152
MjjRewStat	$\mu_{\text{bin}1}$	0.150
$\mu_{\text{bin}2}$	$\mu_{\text{bin}4}$	0.145
CutSR_all_bin_1_0	$\mu_{\text{bin}1}$	-0.140
Zjets_XS	μ_{WZ}	-0.135
FF_Prompt	$\mu_{\text{bin}1}$	0.135
WZ_EW6_TheoScale	μ_{WZ}	-0.127
CutSR_all_bin_0_5	$\mu_{\text{bin}6}$	-0.125
CutSR_all_bin_0_4	$\mu_{\text{bin}5}$	-0.124
$\mu_{\text{bin}1}$	$\mu_{\text{bin}3}$	0.122
FF_Prompt	$\mu_{\text{FF_BTagged}}$	-0.122
CutSR_all_bin_0_1	$\mu_{\text{bin}2}$	-0.122
JET_Pileup_OffsetNPV	μ_{WZ}	-0.121
CutSR_all_bin_1_2	$\mu_{\text{bin}3}$	-0.118
Wgamma_XS	$\mu_{\text{bin}1}$	-0.117
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.115
CutSR_all_bin_1_1	$\mu_{\text{bin}2}$	-0.108
CutSR_all_bin_0_3	$\mu_{\text{bin}4}$	-0.107
Lumi	$\mu_{\text{bin}5}$	-0.107
CutSR_all_bin_0_0	$\mu_{\text{bin}1}$	-0.106
CutSR_all_bin_2_5	$\mu_{\text{bin}6}$	-0.105
CutSR_all_bin_2_2	$\mu_{\text{bin}3}$	-0.105
Lumi	$\mu_{\text{bin}6}$	-0.105
CutLowMjj_all_bin_0_4	$\mu_{\text{bin}5}$	-0.102
CutSR_all_bin_3_4	$\mu_{\text{bin}5}$	-0.101
signal_EW6_truthBin0to170_TheoEwcorr	$\mu_{\text{bin}1}$	-0.101

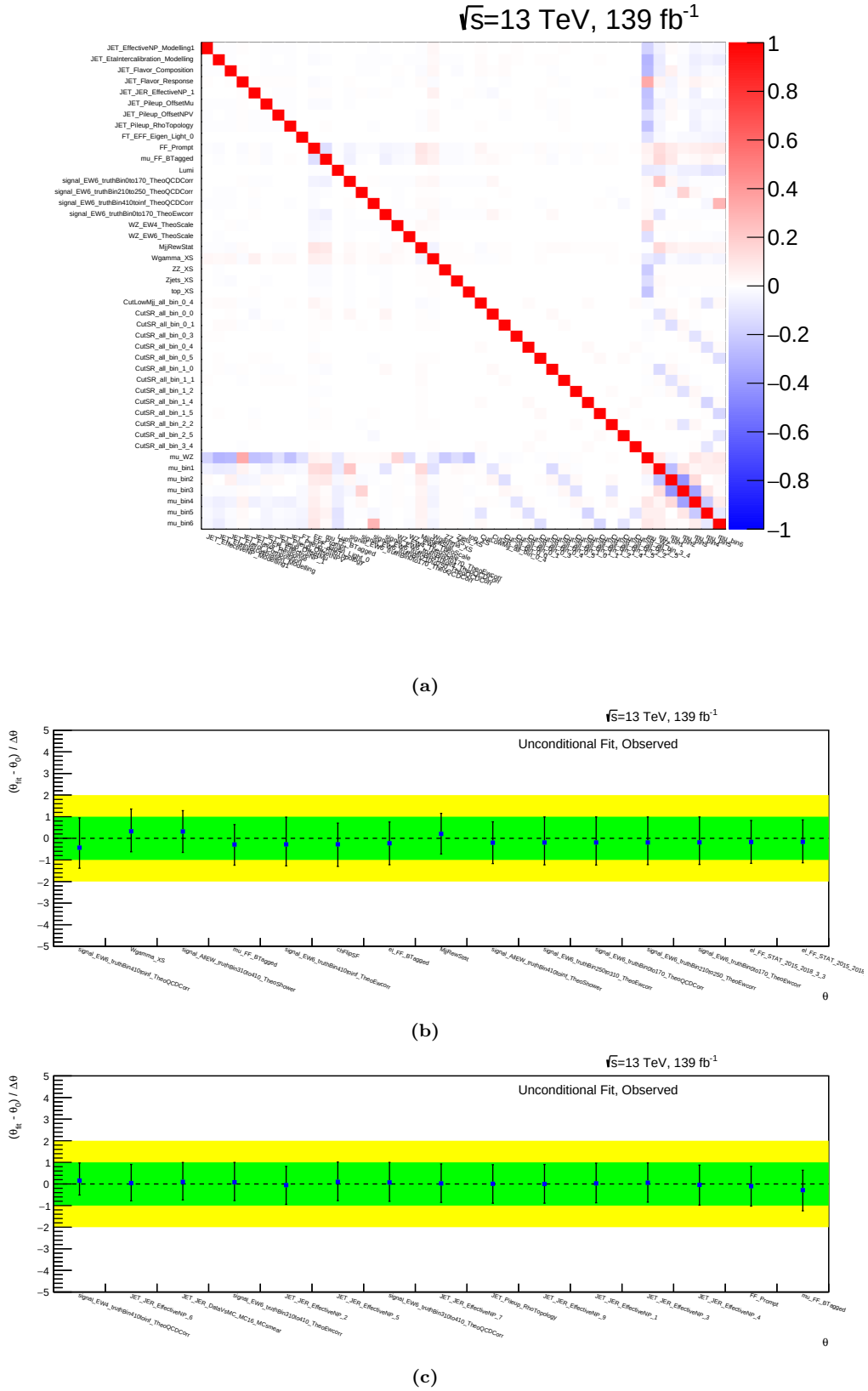


Figure C.63: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

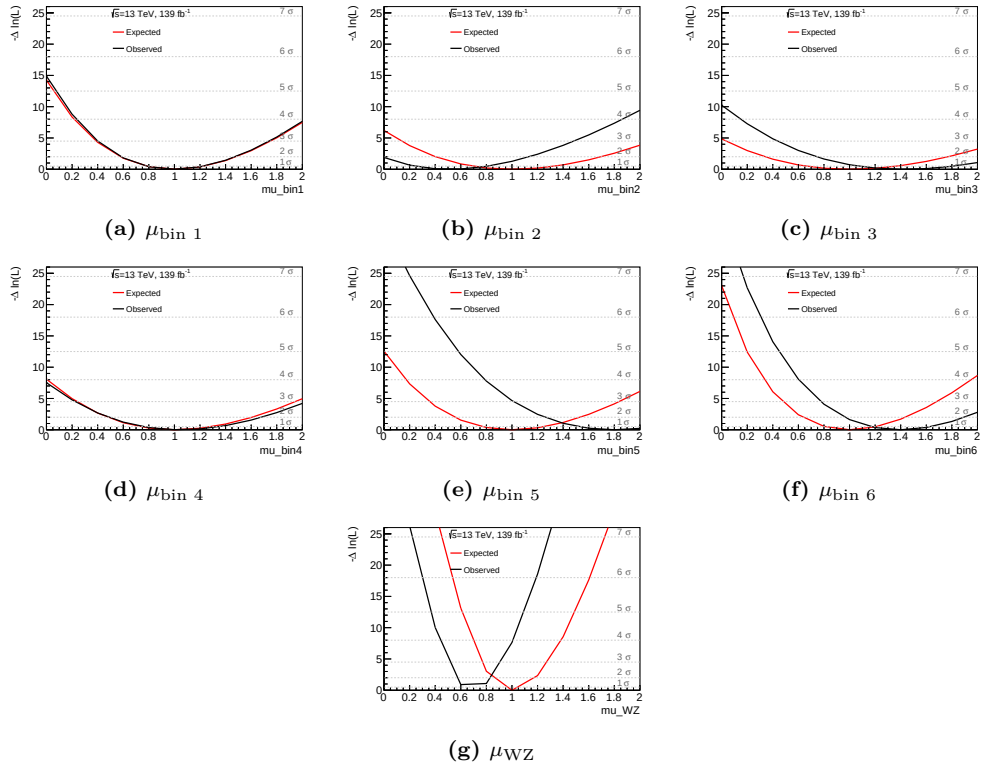


Figure C.64: Likelihood scans of nuisance parameters with largest pulls and constraints in the m_T differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-f) and for QCD $W^\pm Z jj$ normalisation parameter (g).

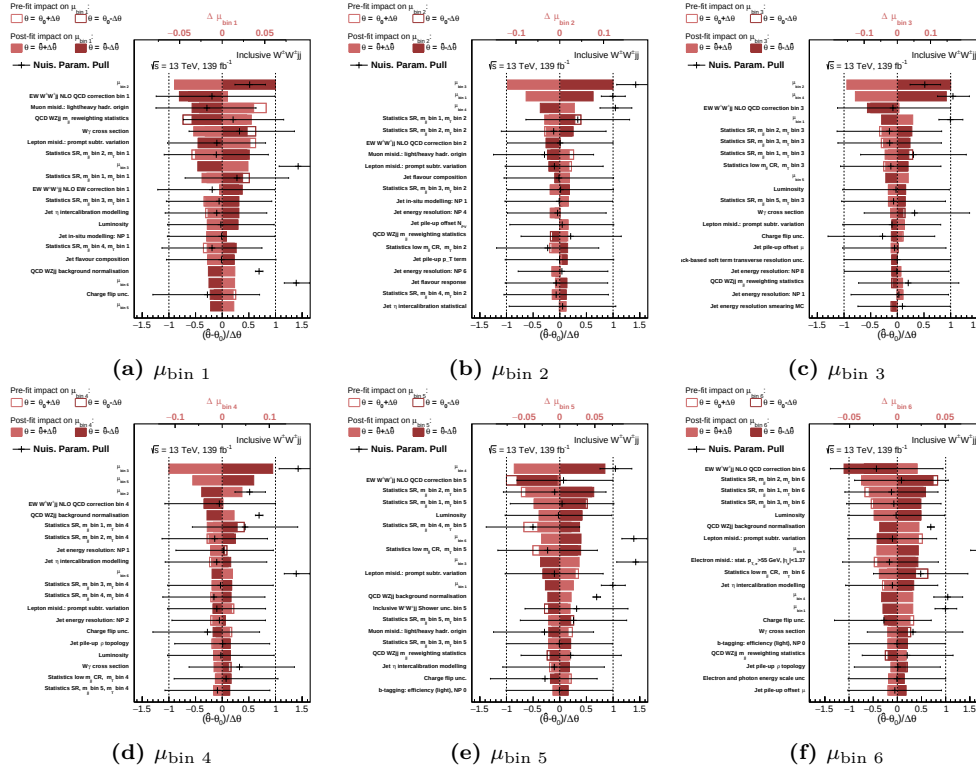


Figure C.65: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{bin i}$ in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_T -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

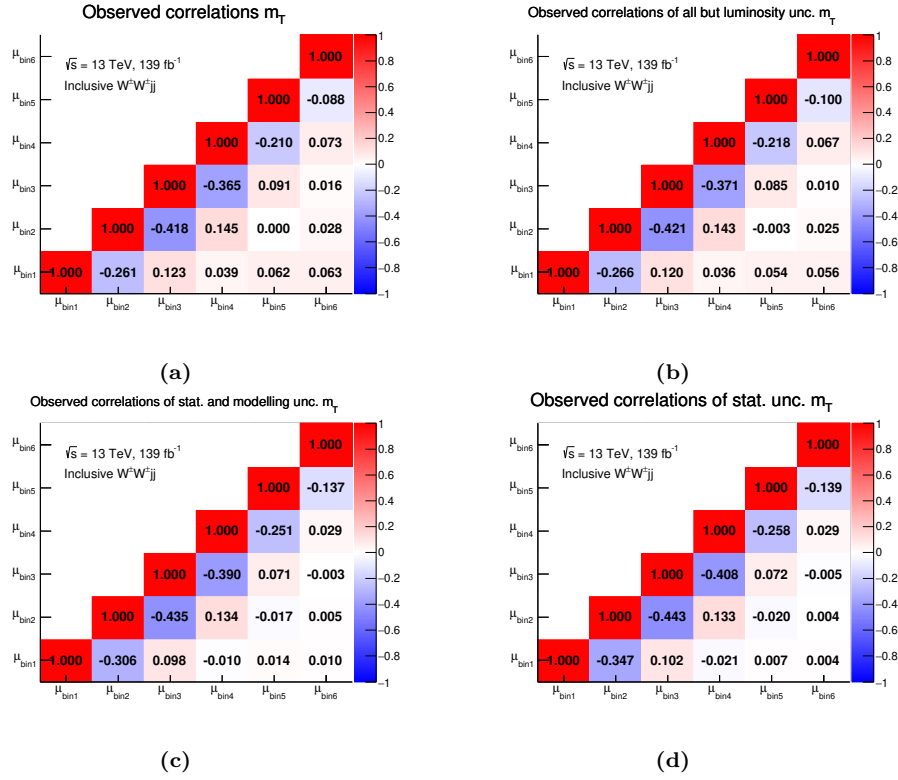


Figure C.66: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

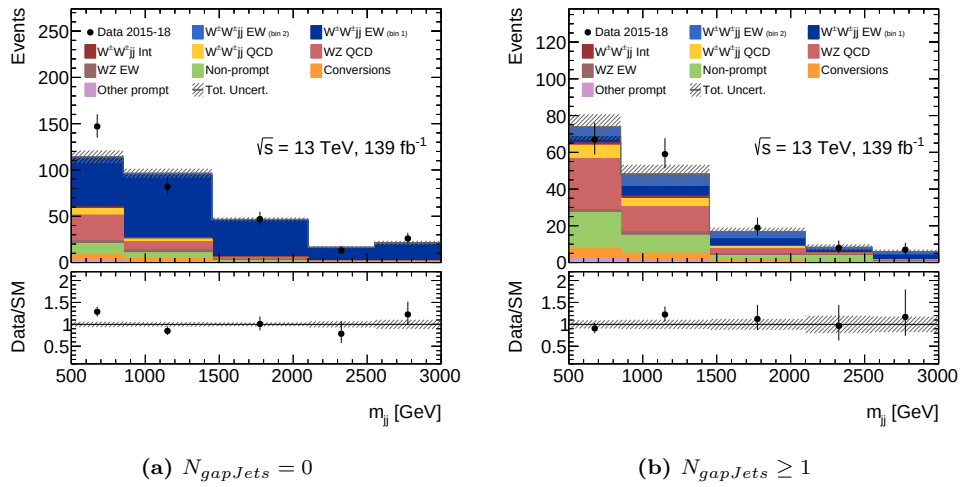


Figure C.67: Pre-fit m_{jj} -distributions in signal region split into $N_{\text{gap}Jets}$ slices as used in $N_{\text{gap}Jets}$ -differential cross-section measurement.

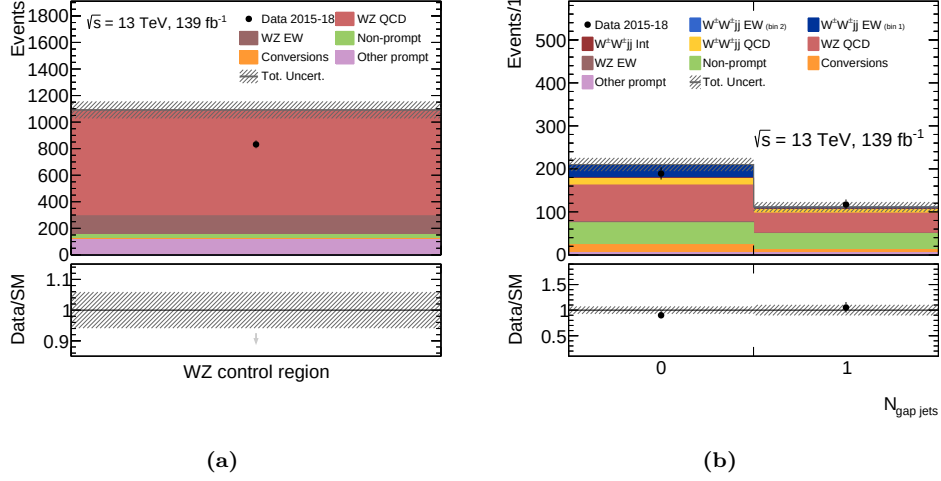


Figure C.68: Pre-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in $N_{gapJets}$ -differential cross-section measurement.

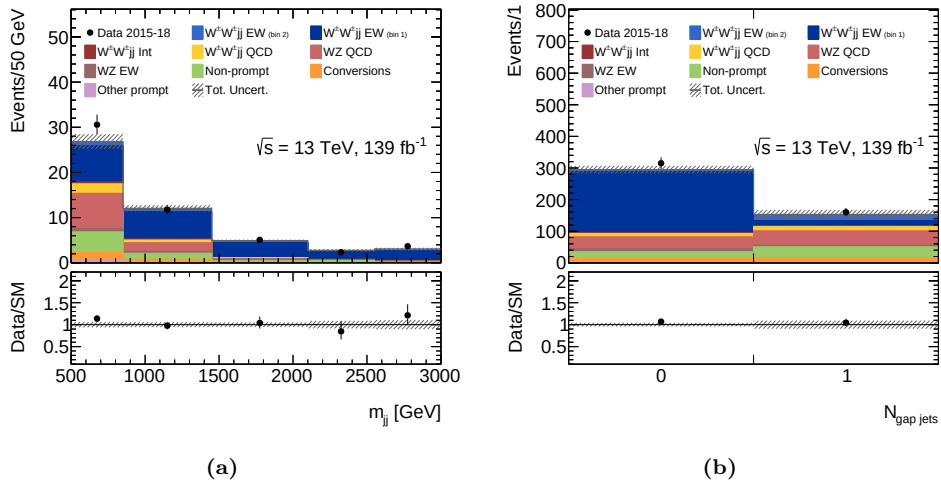


Figure C.69: Pre-fit m_{jj} -distributions in signal region summed over $N_{gapJets}$ slices (a) and summed over m_{jj} bins (b) in $N_{gapJets}$ -differential cross-section measurement.

Table C.20: Breakdown of the uncertainty of signal strength in the different m_T truth slices in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]					
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$	$\mu_{\text{bin 6}}$
Experimental						
Electron calibration	0.6	0.3	0.4	0.2	0.5	1.2
Muon calibration	0.5	0.9	0.5	0.7	0.5	0.9
Jet energy scale and resolution	3.9	5.5	1.6	4.5	1.3	1.7
E_T^{miss} scale and resolution	0.9	2.4	1.0	1.5	0.1	0.3
b -tagging inefficiency	0.3	0.1	0.2	0.2	0.7	0.8
Background, misid. leptons	5.6	7.2	0.7	3.3	1.7	2.7
Background, charge misrec.	1.7	1.5	1.1	1.8	0.8	1.1
Pileup modelling	0.4	0.4	0.8	0.8	0.3	0.1
Luminosity	1.8	1.7	1.8	1.8	1.8	1.8
Modelling						
$W^\pm W^\pm jj$ shower, scale, PDF & α_s	1.0	2.5	1.0	1.2	1.0	0.7
EW $W^\pm W^\pm jj$, QCD corrections	5.2	3.6	4.3	2.7	1.5	4.8
EW $W^\pm W^\pm jj$, EW corrections	1.4	1.5	1.1	1.1	0.0	0.0
QCD $W^\pm W^\pm jj$, QCD corrections	0.3	0.4	0.3	0.4	0.4	0.1
Background, WZ scale, PDF & α_s	0.3	0.3	0.1	0.2	0.0	0.4
Background, WZ reweighting	2.4	2.3	0.8	0.8	0.5	0.3
Background, other	3.1	0.4	0.4	0.6	0.5	0.8
Model statistical	5.0	12.0	5.8	5.8	4.3	4.1
Experimental and modelling	11.2	17.2	8.6	9.5	5.7	7.8
Data statistical	19.6	52.8	24.6	27.0	15.3	15.1
Total	22.6	55.6	26.1	28.6	16.3	17.0

C.4.2 Results of the Asimov Fit for N_{gapJets} with EW Signal

The expected signal strength μ from the fit to Asimov data is:

$$\mu_{\text{exp}, N_{\text{gapJets}}, \text{bin 1}}^{\text{EW}} = 1.00 \pm_{0.09}^{0.09} (\text{stat.}) \pm_{0.06}^{0.04} (\text{mod. syst.}) \pm_{0.02}^{0.03} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, N_{\text{gapJets}}, \text{bin 2}}^{\text{EW}} = 1.00 \pm_{0.51}^{0.55} (\text{stat.}) \pm_{0.29}^{0.31} (\text{mod. syst.}) \pm_{0.36}^{0.38} (\text{exp. syst.}) \pm_{0.01}^{0.04} (\text{lumi.})$$

and the QCD $W^\pm Z jj$ normalisation strength is:

$$\mu_{\text{WZ, exp}, N_{\text{gapJets}}}^{\text{EW}} = 1.00 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

Post-fit plots are in Figure C.70 and Figure C.71.

Pull plot and correlations are in Figure C.72.

Table of the strongest (anti-)correlations are included in Table C.21.

The ranking plot is shown in Figure C.73.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.22.

The correlation between unfolded bins are shown in Figure C.74.

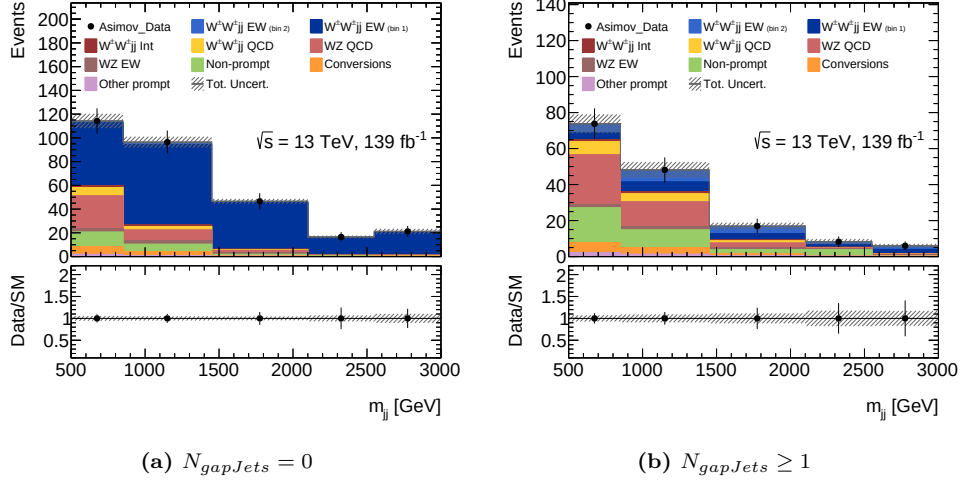


Figure C.70: Post-fit m_{jj} -distributions in signal region split into $N_{gapJets}$ slices as used in the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

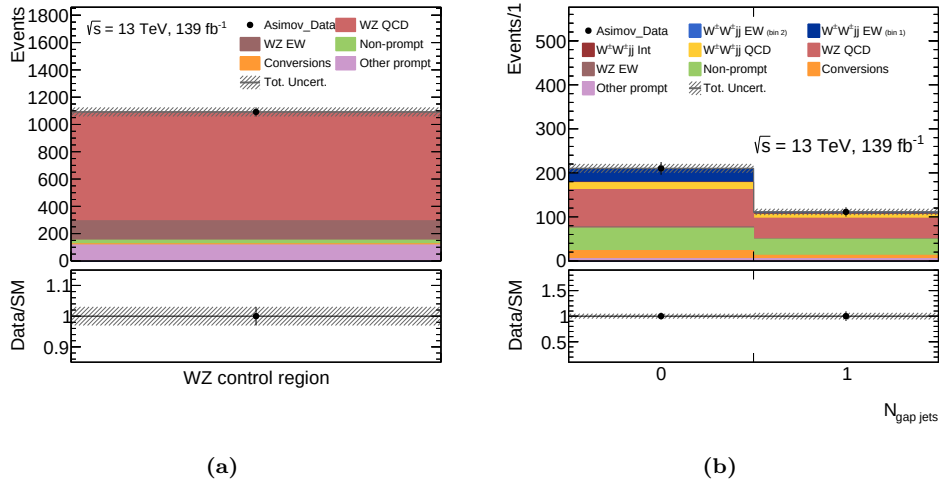


Figure C.71: Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

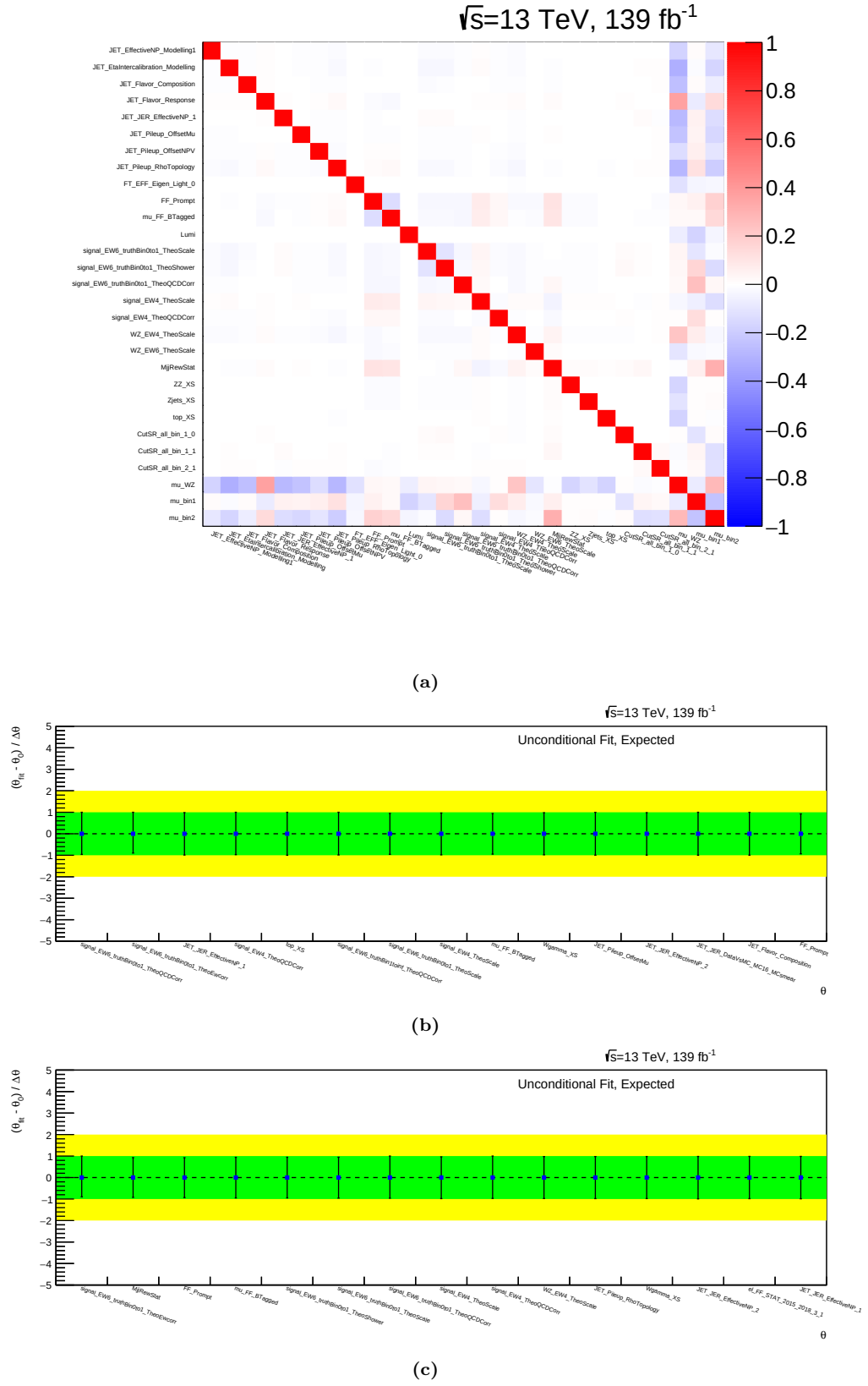
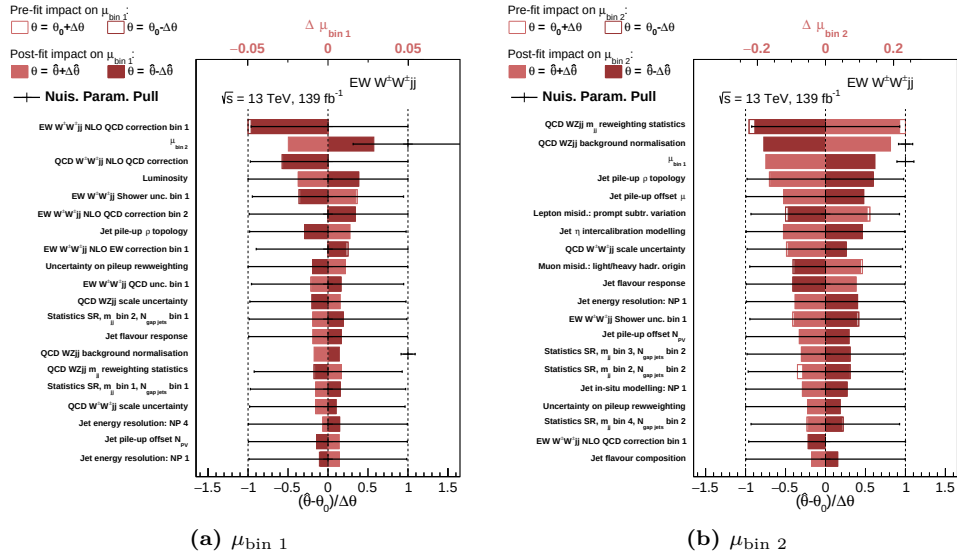


Figure C.72: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the $N_{gapJ\text{ets}}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with Asimov data.

Table C.21: List of parameter correlations in the Asimov fit which are larger than 10% in the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	μ_{WZ}	0.372
MjjRewStat	μ_{bin2}	0.313
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.311
JET_Pileup_RhoTopology	μ_{WZ}	-0.284
μ_{WZ}	μ_{bin2}	0.278
JET_JER_EffectiveNP_1	μ_{WZ}	-0.277
JET_Flavor_Composition	μ_{WZ}	-0.250
signal_EW6_truthBin0to1_TheoQCDCorr	μ_{bin1}	0.250
JET_Pileup_OffsetMu	μ_{WZ}	-0.239
μ_{bin1}	μ_{bin2}	-0.239
WZ_EW4_TheoScale	μ_{WZ}	0.226
JET_Pileup_RhoTopology	μ_{bin2}	-0.198
FF_Prompt	μ_{bin2}	0.182
Lumi	μ_{bin1}	-0.172
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.171
top_XS	μ_{WZ}	-0.171
signal_EW6_truthBin0to1_TheoShower	μ_{bin1}	0.165
ZZ_XS	μ_{WZ}	-0.162
JET_EtaIntercalibration_Modelling	μ_{bin2}	-0.161
JET_Pileup_OffsetMu	μ_{bin2}	-0.155
$\mu_{FF_BTagged}$	μ_{bin2}	0.151
JET_Flavor_Response	μ_{bin2}	0.140
signal_EW6_truthBin0to1_TheoShower	μ_{bin2}	-0.140
signal_EW4_TheoScale	μ_{bin2}	-0.132
signal_EW4_TheoQCDCorr	μ_{bin1}	0.132
JET_Pileup_OffsetNPV	μ_{WZ}	-0.130
FF_Prompt	$\mu_{FF_BTagged}$	-0.130
JET_JER_EffectiveNP_1	μ_{bin2}	-0.130
CutSR_all_bin_1_1	μ_{bin2}	-0.126
CutSR_all_bin_2_1	μ_{bin2}	-0.118
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.117
JET_Pileup_RhoTopology	μ_{bin1}	0.117
Zjets_XS	μ_{WZ}	-0.114
FF_Prompt	MjjRewStat	0.110
signal_EW6_truthBin0to1_TheoScale	signal_EW6_truthBin0to1_TheoShower	-0.110
CutSR_all_bin_1_0	μ_{bin1}	-0.107
WZ_EW6_TheoScale	μ_{WZ}	-0.106
JET_Pileup_OffsetNPV	μ_{bin2}	-0.104

**Figure C.73:** Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{bin i}$ in the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a) and second (b) $N_{gapJets}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

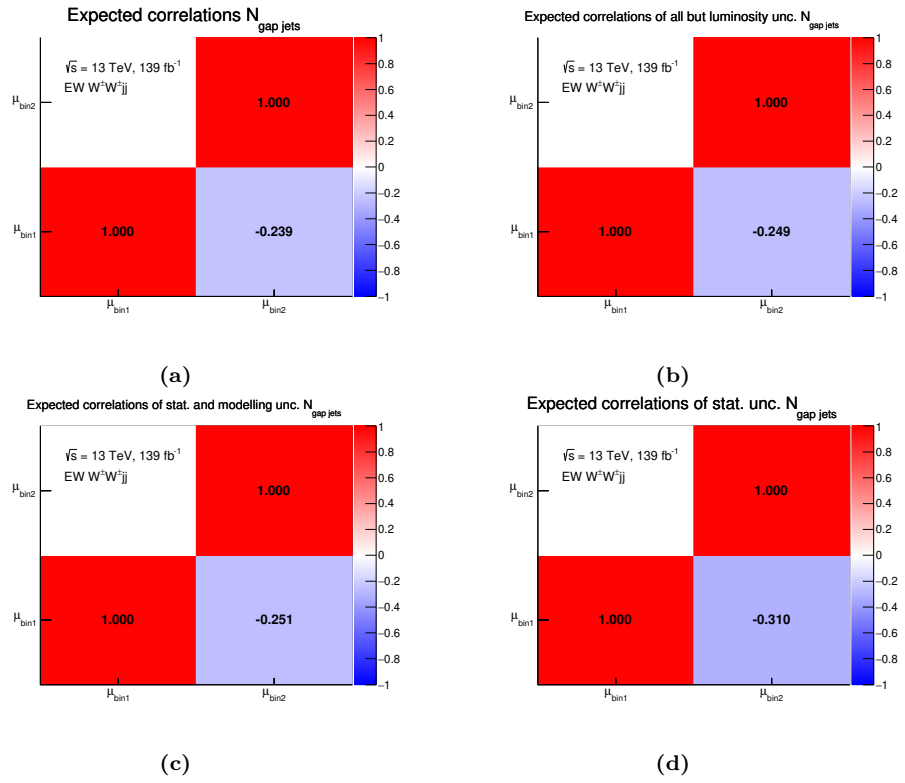


Figure C.74: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $N_{\text{gap jets}}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

Table C.22: Breakdown of the uncertainty of signal strength in the different $N_{gapJets}$ truth slices in the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma\gamma$, ZZ , top and Zjets.

Source	Impact [%]	
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$
Experimental		
Electron calibration	0.4	0.8
Muon calibration	0.5	0.8
Jet energy scale and resolution	2.0	29.2
E_T^{miss} scale and resolution	0.2	0.5
b -tagging inefficiency	0.5	2.9
Background, misid. leptons	0.9	21.1
Background, charge misrec.	0.5	6.7
Pileup modelling	1.0	5.8
Luminosity	1.8	2.6
Modelling		
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	2.0	9.4
EW $W^\pm W^\pm jj$, QCD corrections	3.3	4.3
EW $W^\pm W^\pm jj$, EW corrections	0.3	1.3
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.0	0.5
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.8	12.4
QCD $W^\pm W^\pm jj$, QCD corrections	1.5	1.2
Background, WZ scale, PDF & α_s	1.1	3.8
Background, WZ reweighting	0.6	18.3
Background, other	0.7	5.8
Model statistical	1.8	15.1
Experimental and modelling	5.9	47.6
Data statistical	8.8	52.9
Total	10.6	71.2

C.4.3 Results of the Asimov Fit for $N_{gapJets}$ with EW+Int+QCD Signal

The expected signal strength μ from the fit to Asimov data is:

$$\mu_{\text{exp}, N_{gapJets}, \text{bin 1}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.08}^{0.08} (\text{stat.}) \pm_{0.05}^{0.04} (\text{mod. syst.}) \pm_{0.02}^{0.03} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, N_{gapJets}, \text{bin 2}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.34}^{0.36} (\text{stat.}) \pm_{0.17}^{0.18} (\text{mod. syst.}) \pm_{0.30}^{0.30} (\text{exp. syst.}) \pm_{0.01}^{0.03} (\text{lumi.})$$

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{\text{WZ, exp}, N_{gapJets}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

Post-fit plots are in Figure C.75 and Figure C.76.

Pull plot and correlations are in Figure C.77.

Table of the strongest (anti-)correlations are included in Table C.23.

The ranking plot is shown in Figure C.78.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.24.

The correlation between unfolded bins are shown in Figure C.79.

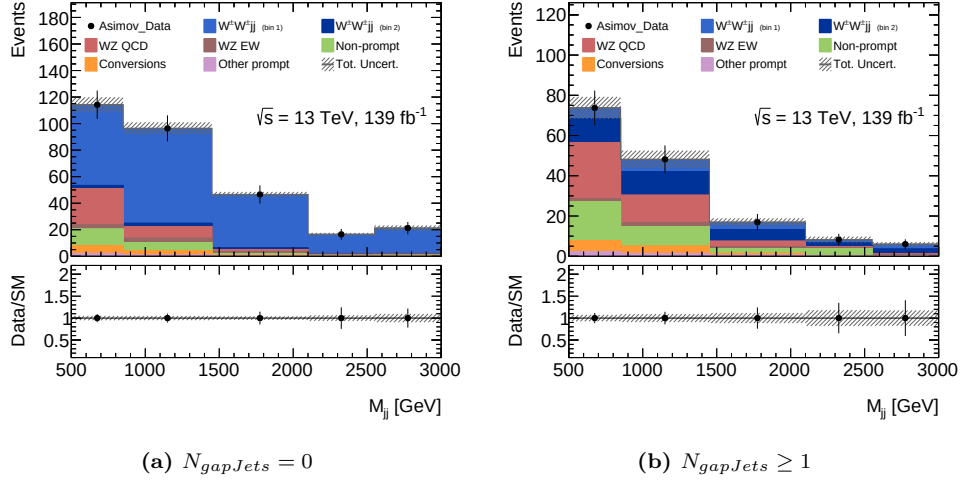


Figure C.75: Post-fit m_{jj} -distributions in signal region split into N_{gapJets} slices as used in the N_{gapJets} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

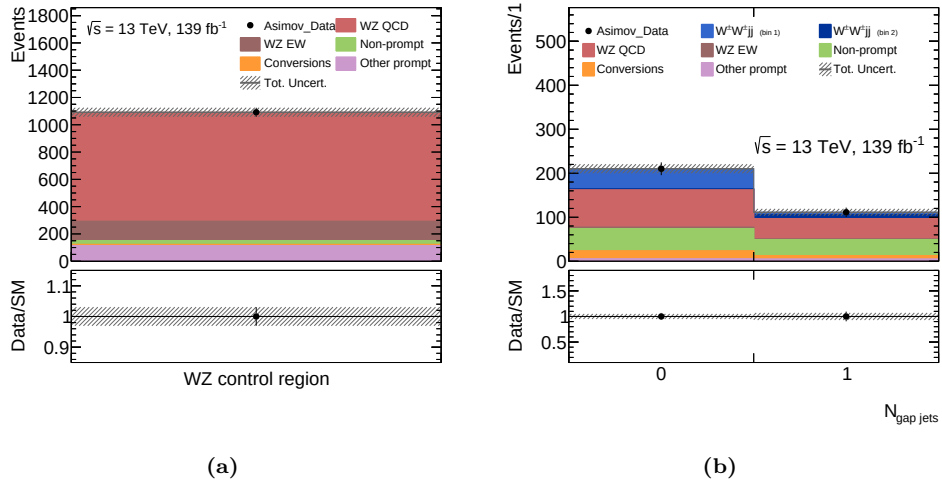


Figure C.76: Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the N_{gapJets} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

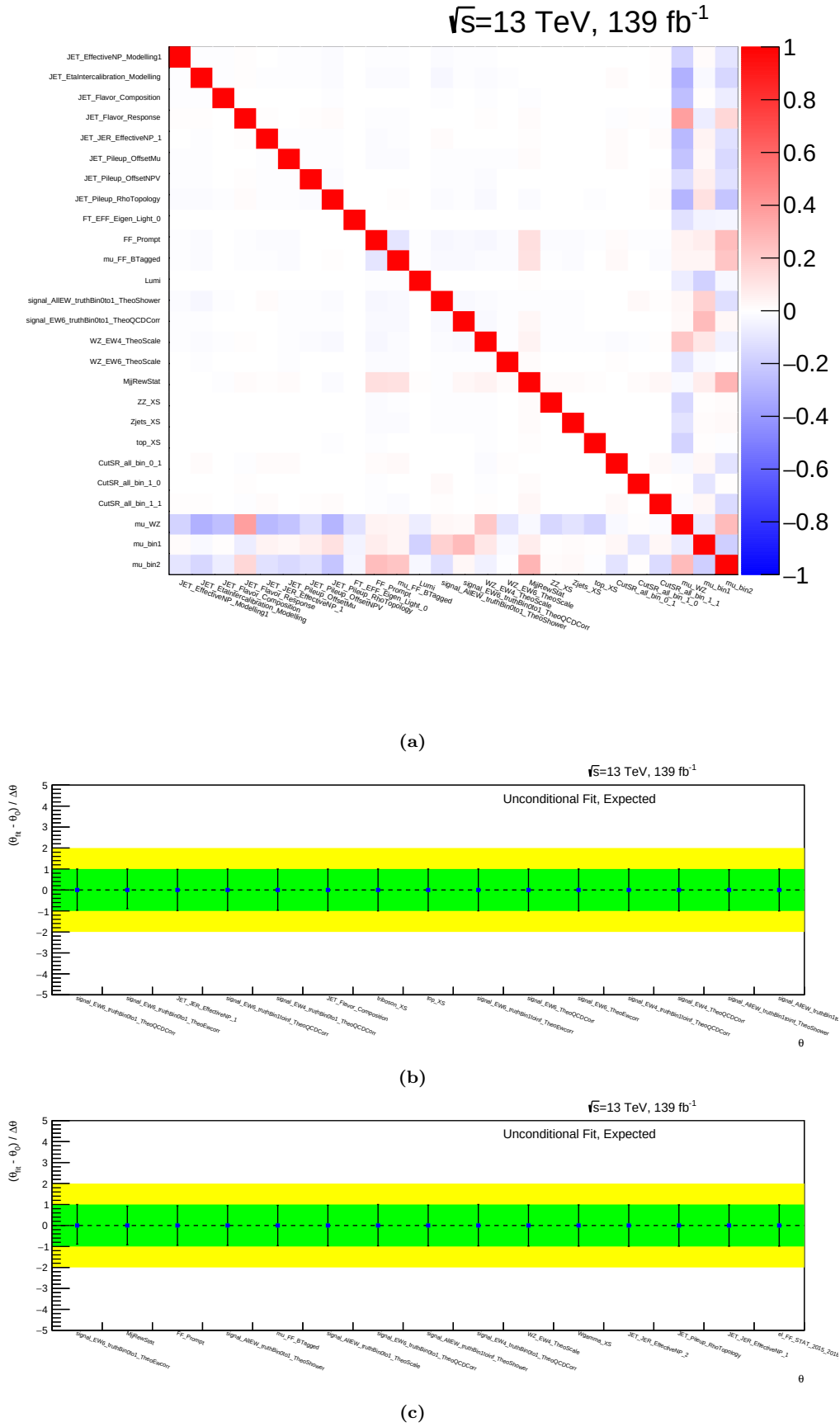


Figure C.77: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	μ_{WZ}	0.375
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.307
MjjRewStat	μ_{bin2}	0.288
JET_Pileup_RhoTopology	μ_{WZ}	-0.288
JET_JER_EffectiveNP_1	μ_{WZ}	-0.275
signal_EW6_truthBin0to1_TheoQCDCorr	μ_{bin1}	0.268
μ_{WZ}	μ_{bin2}	0.266
FF_Prompt	μ_{bin2}	0.257
JET_Flavor_Composition	μ_{WZ}	-0.251
JET_Pileup_OffsetMu	μ_{WZ}	-0.236
$\mu_{\text{FF_BTagged}}$	μ_{bin2}	0.230
JET_Pileup_RhoTopology	μ_{bin2}	-0.226
WZ_EW4_TheoScale	μ_{WZ}	0.220
μ_{bin1}	μ_{bin2}	-0.186
signal_ALLEW_truthBin0to1_TheoShower	μ_{bin1}	0.181
Lumi	μ_{bin1}	-0.180
top_XS	μ_{WZ}	-0.171
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.171
ZZ_XS	μ_{WZ}	-0.160
JET_EtaIntercalibration_Modelling	μ_{bin2}	-0.158
JET_Flavor_Response	μ_{bin2}	0.157
JET_Pileup_OffsetMu	μ_{bin2}	-0.147
CutSR_all_bin_1_1	μ_{bin2}	-0.144
JET_Pileup_OffsetNPV	μ_{WZ}	-0.133
FF_Prompt	MjjRewStat	0.125
signal_ALLEW_truthBin0to1_TheoShower	μ_{bin2}	-0.124
JET_JER_EffectiveNP_1	μ_{bin2}	-0.119
JET_Pileup_OffsetNPV	μ_{bin2}	-0.119
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.118
JET_Pileup_RhoTopology	μ_{bin1}	0.116
MjjRewStat	$\mu_{\text{FF_BTagged}}$	0.116
Zjets_XS	μ_{WZ}	-0.112
CutSR_all_bin_0_1	μ_{bin2}	-0.106
CutSR_all_bin_1_0	μ_{bin1}	-0.106
WZ_EW6_TheoScale	μ_{WZ}	-0.102
JET_EffectiveNP_Modelling1	μ_{bin2}	-0.101

Table C.23: List of parameter correlations which are larger than 10% in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

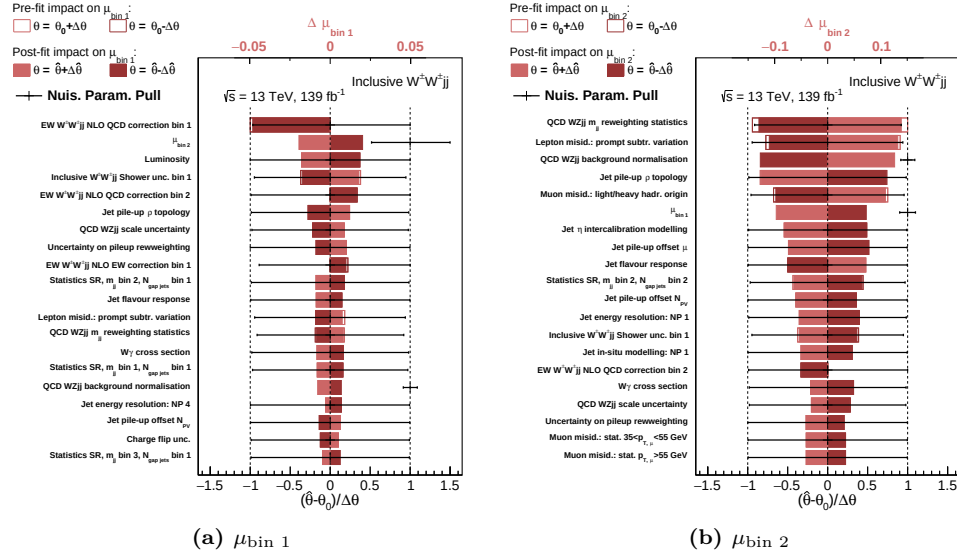


Figure C.78: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a) and second (b) $N_{gapJets}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

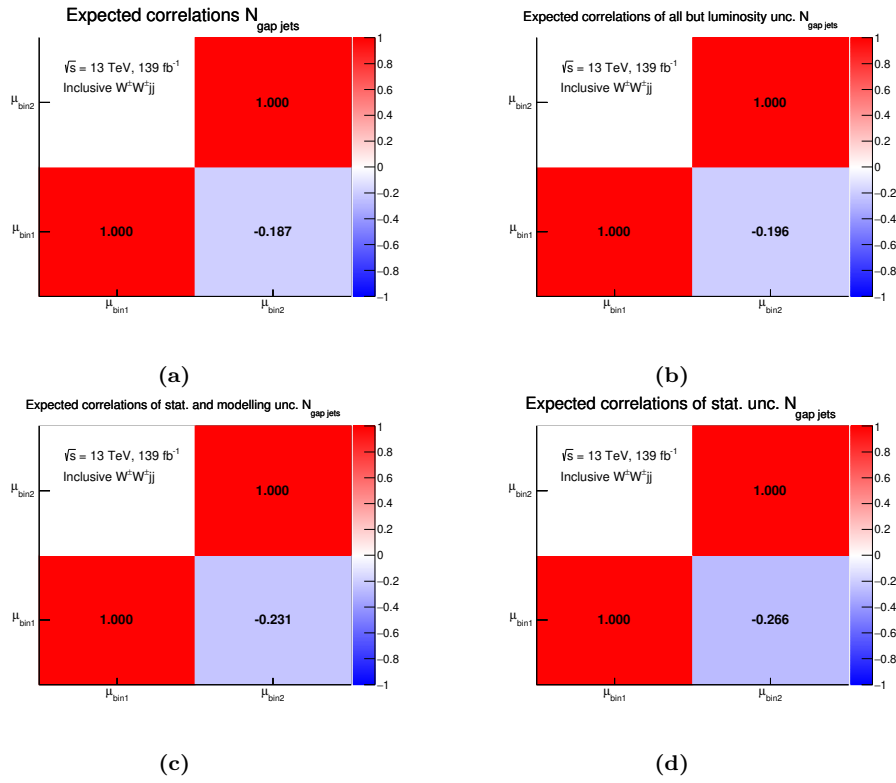


Figure C.79: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Table C.24: Breakdown of the uncertainty of signal strength in the different $N_{gapJets}$ truth slices in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma$, ZZ, top and Zjets.

Source	Impact [%]	
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$
Experimental		
Electron calibration	0.4	0.6
Muon calibration	0.5	0.5
Jet energy scale and resolution	1.8	21.1
E_T^{miss} scale and resolution	0.2	0.2
b -tagging inefficiency	0.4	2.4
Background, misid. leptons	1.1	19.2
Background, charge misrec.	0.6	5.8
Pileup modelling	0.9	4.4
Luminosity	1.7	1.7
Modelling		
$W^\pm W^\pm jj$ shower, scale, PDF & α_s	1.9	5.8
EW $W^\pm W^\pm jj$, QCD corrections	3.3	3.7
EW $W^\pm W^\pm jj$, EW corrections	0.2	0.3
QCD $W^\pm W^\pm jj$, QCD corrections	0.3	1.4
Background, WZ scale, PDF & α_s	1.2	3.2
Background, WZ reweighting	0.6	10.1
Background, other	0.9	5.5
Model statistical	1.7	10.6
Experimental and modelling	5.5	34.4
Data statistical	8.2	35.0
Total	9.9	49.1

C.4.4 Results of the fit to Observed Data for $N_{gapJets}$ with EW Signal

The observed signal strength μ from the fit to observed data is:

$$\mu_{\text{obs}, N_{gapJets}, \text{bin 1}}^{\text{EW}} = 1.04 \pm_{0.09}^{0.09} (\text{stat.}) \pm_{0.08}^{0.08} (\text{mod. syst.}) \pm_{0.03}^{0.03} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, N_{gapJets}, \text{bin 2}}^{\text{EW}} = 1.80 \pm_{0.54}^{0.58} (\text{stat.}) \pm_{0.31}^{0.35} (\text{mod. syst.}) \pm_{0.39}^{0.38} (\text{exp. syst.}) \pm_{0.03}^{0.06} (\text{lumi.})$$

and the QCD $W^\pm Z jj$ normalisation strength is:

$$\mu_{\text{WZ, obs}, N_{gapJets}}^{\text{EW}} = 0.68 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.05}^{0.05} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

Post-fit plots are in Figure C.80 and Figure C.81. The projections on $N_{gapJets}$ and on m_{jj} are shown in Figure C.82.

Pull plot and correlations are in Figure C.83.

Selected profile LH scans are in Figure C.84.

Table of the strongest (anti-)correlations are included in Table C.25.

The ranking plot is shown in Figure C.85.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.26.

The correlation between unfolded bins are shown in Figure C.86.

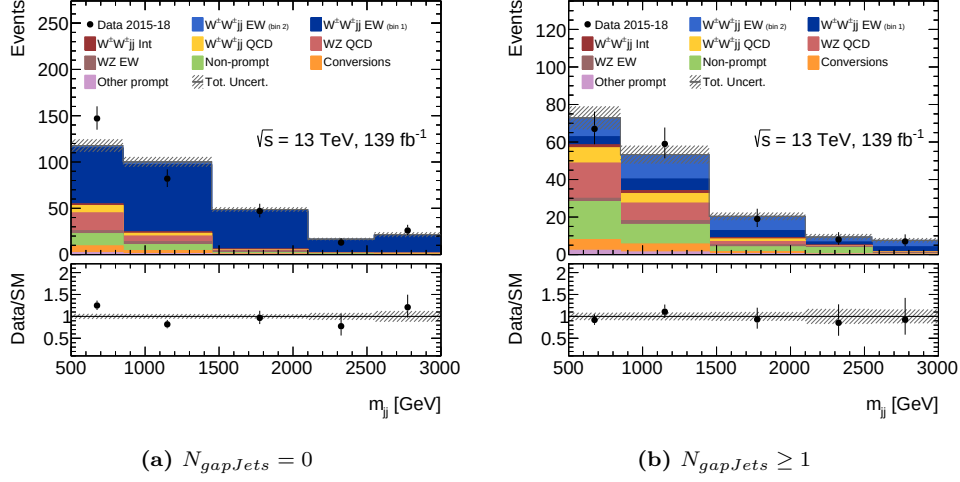


Figure C.80: Post-fit m_{jj} -distributions in signal region split into $N_{gapJets}$ slices as used in the $N_{gapJets}$ -differential cross-section measurement of EW $W^{\pm}W^{\pm}jj$ with observed data.

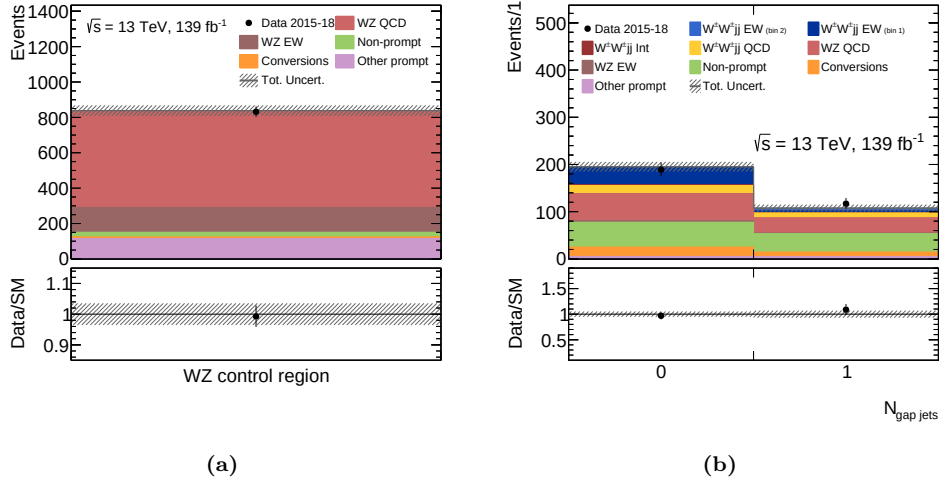


Figure C.81: Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the $N_{gapJets}$ -differential cross-section measurement of EW $W^{\pm}W^{\pm}jj$ with observed data.

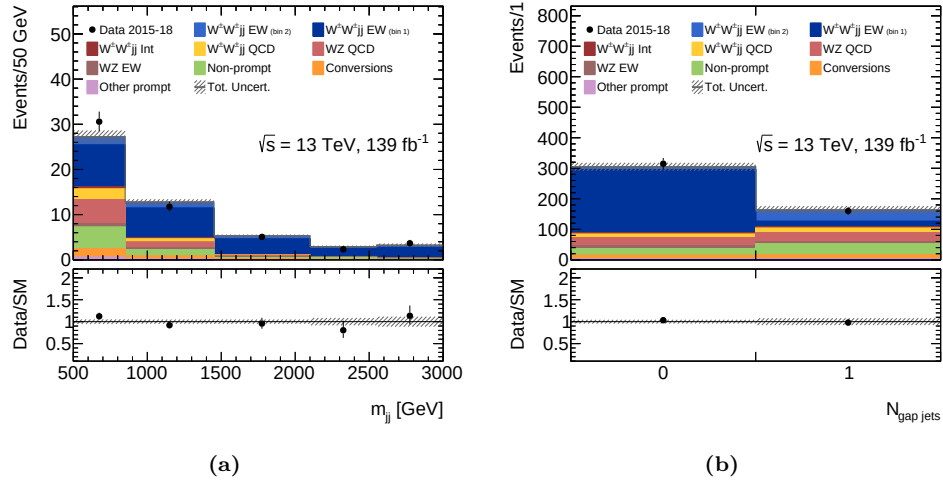


Figure C.82: Post-fit m_{jj} -distributions in signal region summed over $N_{gapJets}$ slices (a) and summed over m_{jj} bins (b) in the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

Table C.25: List of parameter correlations which are larger than 10% in the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

Parameter 1	Parameter 2	Correlation
signal_EW6_truthBin0to1_TheoQCDCorr	μ_bin1	0.507
JET_Flavor_Response	μ_WZ	0.347
JET_EtaIntercalibration_Modelling	μ_WZ	-0.285
signal_EW6_truthBin1toinf_TheoQCDCorr	μ_bin1	-0.284
JET_Flavor_Composition	μ_WZ	-0.271
μ_WZ	μ_bin2	0.265
JET_Pileup_RhoTopology	μ_WZ	-0.265
MjjRewStat	μ_bin2	0.228
JET_JER_EffectiveNP_1	μ_WZ	-0.227
JET_Pileup_RhoTopology	μ_bin2	-0.219
signal_EW6_truthBin0to1_TheoEwcorr	signal_EW6_truthBin0to1_TheoShower	-0.216
JET_Pileup_OffsetMu	μ_WZ	-0.215
top_XS	μ_WZ	-0.212
signal_EW6_truthBin0to1_TheoEwcorr	μ_bin1	-0.201
signal_EW6_truthBin0to1_TheoEwcorr	μ_bin1	-0.192
JET_EffectiveNP_Modelling1	signal_EW6_truthBin0to1_TheoScale	-0.189
FF_Prompt	μ_WZ	-0.186
WZ_EW4_TheoScale	μ_bin2	0.175
JET_EtaIntercalibration_Modelling	μ_WZ	0.174
signal_EW4_TheoScale	μ_bin2	-0.173
JET_Flavor_Response	μ_bin2	-0.170
CutSR_all_bin_1_1	μ_bin2	0.162
Lumi	μ_bin2	-0.155
$\mu_FF_BTagged$	μ_bin1	-0.154
JET_Pileup_OffsetMu	μ_bin2	0.148
FF_Prompt	μ_bin2	-0.147
signal_EW6_truthBin0to1_TheoShower	signal_EW6_truthBin1toinf_TheoQCDCorr	-0.142
$\mu_FF_BTagged$	μ_bin2	-0.138
Zjets_XS	signal_EW6_truthBin1toinf_TheoQCDCorr	-0.136
signal_EW6_truthBin0to1_TheoShower	μ_WZ	-0.135
JET_Pileup_OffsetNPV	μ_bin1	0.133
WZ_EW6_TheoScale	μ_WZ	-0.131
CutSR_all_bin_2_1	μ_WZ	-0.131
JET_Pileup_OffsetNPV	μ_bin2	-0.130
μ_bin1	μ_bin2	-0.124
JET_EffectiveNP_Modelling1	μ_bin2	-0.124
signal_EW6_truthBin0to1_TheoEwcorr	μ_bin2	-0.122
FT_EFF_Eigen_Light_0	signal_EW6_truthBin0to1_TheoQCDCorr	-0.117
signal_EW4_TheoScale	μ_WZ	-0.113
JET_JER_EffectiveNP_1	signal_EW6_truthBin1toinf_TheoQCDCorr	0.108
	μ_bin2	-0.103

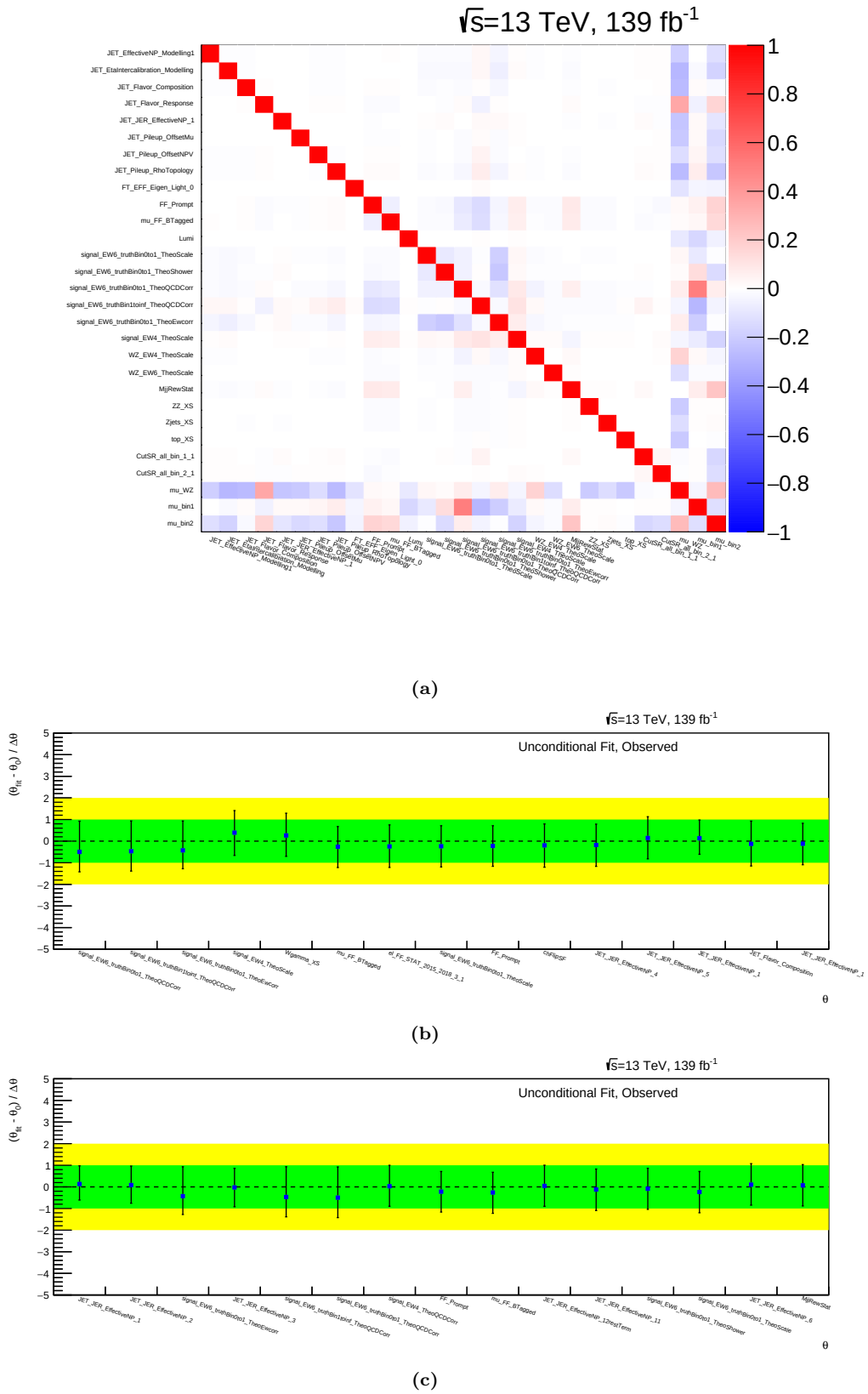


Figure C.83: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the $N_{gapJets}$ -differential cross-section measurement of EW $W^{\pm}W^{\pm}jj$ with observed data.

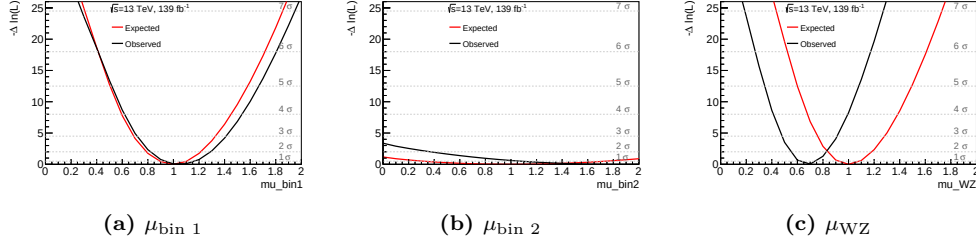


Figure C.84: Likelihood scans of nuisance parameters with largest pulls and constraints in the $N_{gapJets}$ differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a,b) and for QCD $W^\pm Zjj$ normalisation parameter (c).

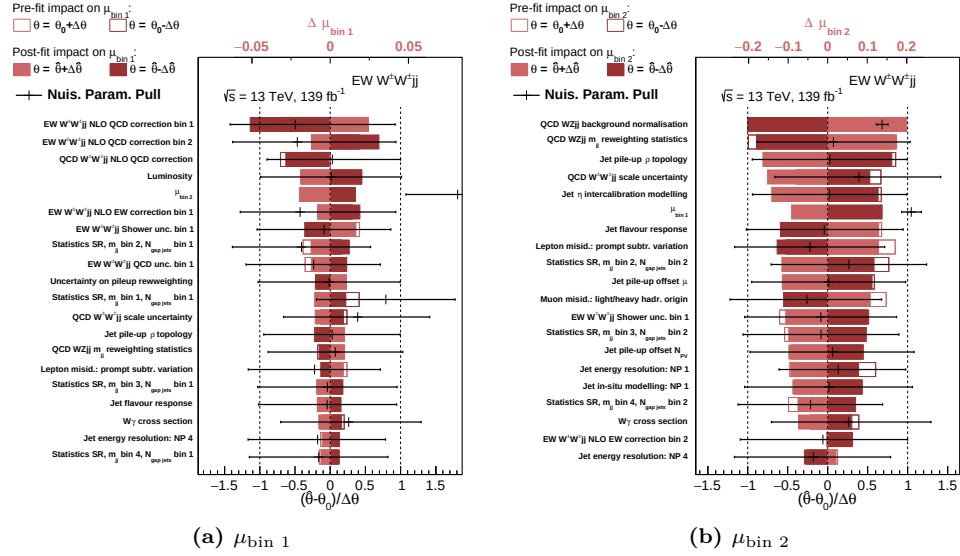


Figure C.85: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{bin\ i}$ in the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data. They are shown for the first (a) and second (b) $N_{gapJets}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

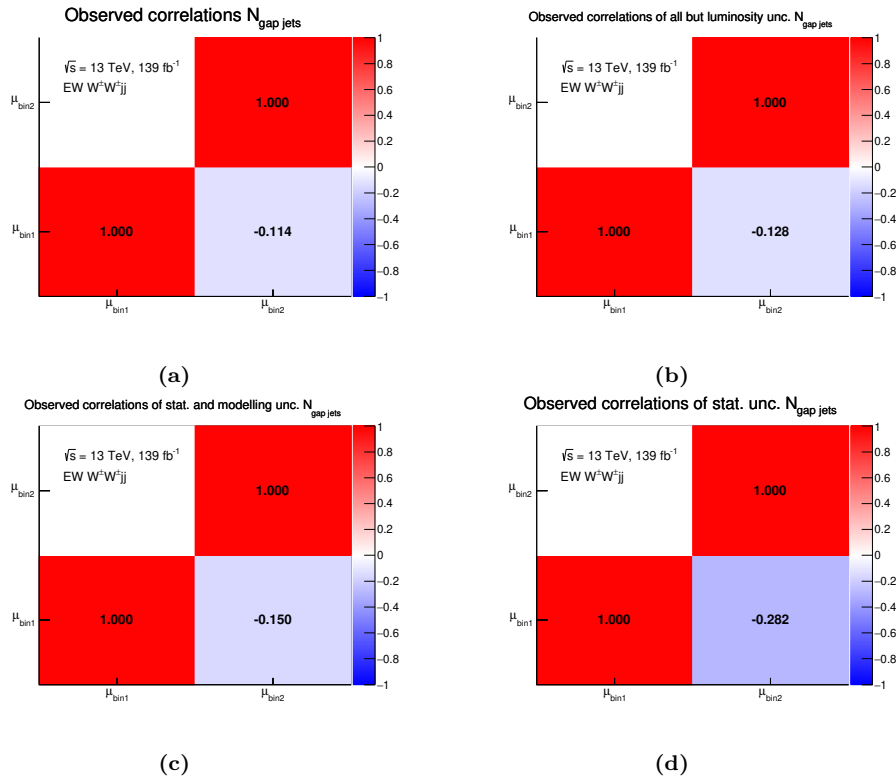


Figure C.86: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

Table C.26: Breakdown of the uncertainty of signal strength in the different $N_{gapJets}$ truth slices in the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma$, ZZ, top and Zjets.

Source	Impact [%]	
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$
Experimental		
Electron calibration	0.3	0.7
Muon calibration	0.5	0.7
Jet energy scale and resolution	1.6	17.6
E_T^{miss} scale and resolution	0.2	0.3
b -tagging inefficiency	0.5	2.0
Background, misid. leptons	1.3	11.3
Background, charge misrec.	0.7	3.0
Pileup modelling	1.0	2.9
Luminosity	1.9	2.4
Modelling		
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	2.1	5.7
EW $W^\pm W^\pm jj$, QCD corrections	6.8	7.4
EW $W^\pm W^\pm jj$, EW corrections	0.7	1.4
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.0	0.3
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	1.4	8.2
QCD $W^\pm W^\pm jj$, QCD corrections	1.0	0.4
Background, WZ scale, PDF & α_s	0.8	1.6
Background, WZ reweighting	0.6	7.8
Background, other	0.9	2.8
Model statistical	1.9	9.7
Experimental and modelling	8.3	28.2
Data statistical	8.4	31.1
Total	11.8	42.0

C.4.5 Results of the Fit to Observed Data for $N_{gapJets}$ with EW+Int+QCD Signal

The observed signal strength μ from the fit to observed data is:

$$\mu_{\text{obs}, N_{gapJets}, \text{bin 1}}^{\text{EW+Int+QCD}} = 1.06 \pm_{0.08}^{0.08} (\text{stat.}) \pm_{0.07}^{0.08} (\text{mod. syst.}) \pm_{0.02}^{0.03} (\text{exp. syst.}) \pm_{0.02}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, N_{gapJets}, \text{bin 2}}^{\text{EW+Int+QCD}} = 1.68 \pm_{0.35}^{0.37} (\text{stat.}) \pm_{0.19}^{0.21} (\text{mod. syst.}) \pm_{0.29}^{0.29} (\text{exp. syst.}) \pm_{0.02}^{0.04} (\text{lumi.})$$

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{\text{WZ, obs}, N_{gapJets}}^{\text{EW+Int+QCD}} = 0.68 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.02}^{0.02} (\text{mod. syst.}) \pm_{0.12}^{0.05} (\text{exp. syst.}) \pm_{-0.11}^{0.02} (\text{lumi.}).$$

Post-fit plots are in Figure C.87 and Figure C.88. The projections on $N_{gapJets}$ and on m_{jj} are shown in Figure C.89.

Pull plot and correlations are in Figure C.90.

Selected profile LH scans are in Figure C.91. The profile likelihood scan look similar for the different $N_{gapJets}$ signal strength. The last parabola is a bit broader due to a slightly lower significance from the binning optimisation.

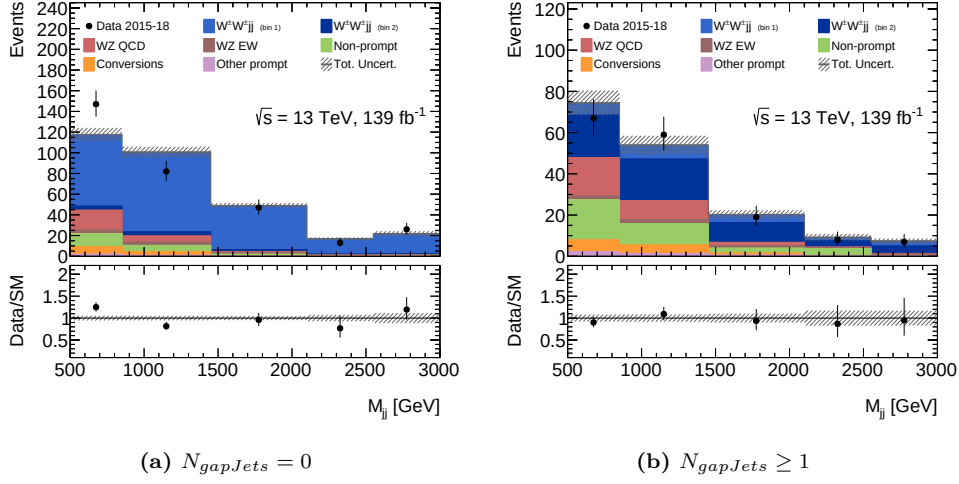


Figure C.87: Post-fit m_{jj} -distributions in signal region split into $N_{gapJets}$ slices as used in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

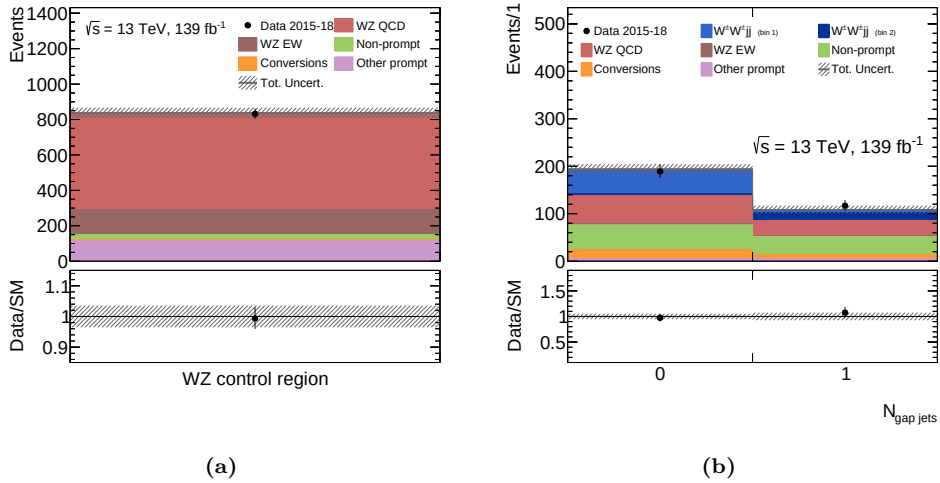


Figure C.88: Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

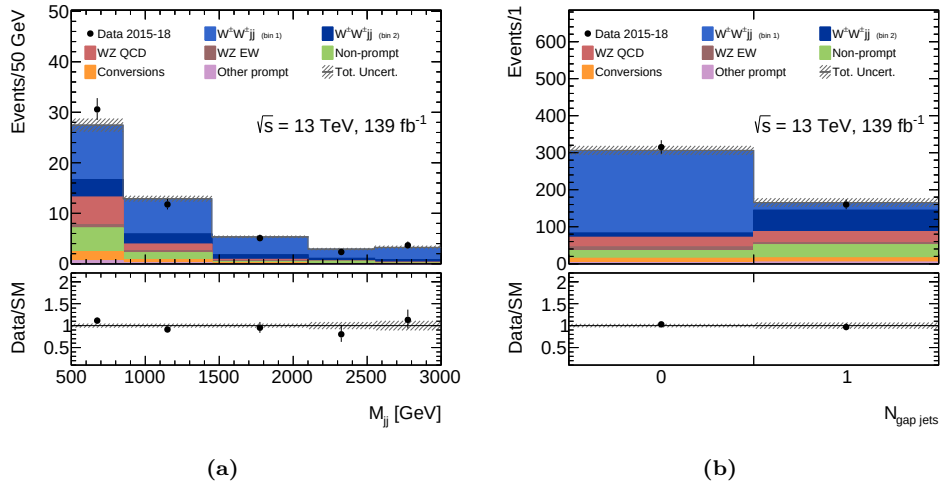


Figure C.89: Post-fit m_{jj} -distributions in signal region summed over $N_{gapJets}$ slices (a) and summed over m_{jj} bins (b) in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

Table C.27: List of parameter correlations which are larger than 10% in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

Parameter 1	Parameter 2	Correlation
signal_EW6_truthBin0to1_TheoQCDCorr	μ_bin1	0.564
JET_Flavor_Response	μ_WZ	0.346
JET_EtaIntercalibration_Modelling	μ_WZ	-0.282
JET_Pileup_RhoTopology	μ_WZ	-0.270
JET_Flavor_Composition	μ_WZ	-0.268
signal_EW6_truthBin1toinf_TheoQCDCorr	μ_bin1	-0.259
μ_WZ	μ_bin2	0.257
FF_Prompt	μ_bin2	0.233
JET_Pileup_RhoTopology	μ_bin2	-0.231
JET_JER_EffectiveNP_1	μ_WZ	-0.224
JET_Pileup_OffsetMu	μ_WZ	-0.215
top_XS	μ_WZ	-0.211
signal_AllEW_truthBin0to1_TheoShower	signal_EW6_truthBin0to1_TheoEwcorr	-0.206
$\mu_FF_BTagged$	μ_bin2	0.206
MjjRewStat	μ_bin2	0.202
ZZ_XS	μ_WZ	-0.200
JET_EffectiveNP_Modelling1	μ_WZ	-0.186
JET_Flavor_Response	μ_bin2	0.173
WZ_EW4_TheoScale	μ_WZ	0.172
signal_AllEW_truthBin0to1_TheoScale	signal_EW6_truthBin0to1_TheoEwcorr	-0.171
signal_EW6_truthBin0to1_TheoEwcorr	μ_bin1	-0.167
JET_EtaIntercalibration_Modelling	μ_bin2	-0.165
CutSR_all_bin_1_1	μ_bin2	-0.160
Lumi	μ_bin1	-0.155
signal_AllEW_truthBin0to1_TheoShower	μ_bin1	0.150
JET_Pileup_OffsetMu	μ_bin2	-0.138
JET_Pileup_OffsetNPV	μ_WZ	-0.134
signal_EW6_truthBin1toinf_TheoQCDCorr	μ_bin2	0.134
JET_Pileup_OffsetNPV	μ_bin2	-0.134
Zjets_XS	μ_WZ	-0.133
μ_bin1	μ_bin2	-0.129
WZ_EW6_TheoScale	μ_WZ	-0.128
signal_AllEW_truthBin0to1_TheoShower	μ_bin2	-0.123
JET_EffectiveNP_Modelling1	μ_bin2	-0.123
CutSR_all_bin_0_1	μ_bin2	-0.118
signal_EW6_truthBin0to1_TheoEwcorr	signal_EW6_truthBin0to1_TheoQCDCorr	-0.115
FT_EFF_Eigen_Light_0	μ_WZ	-0.113
CutSR_all_bin_2_1	μ_bin2	-0.105

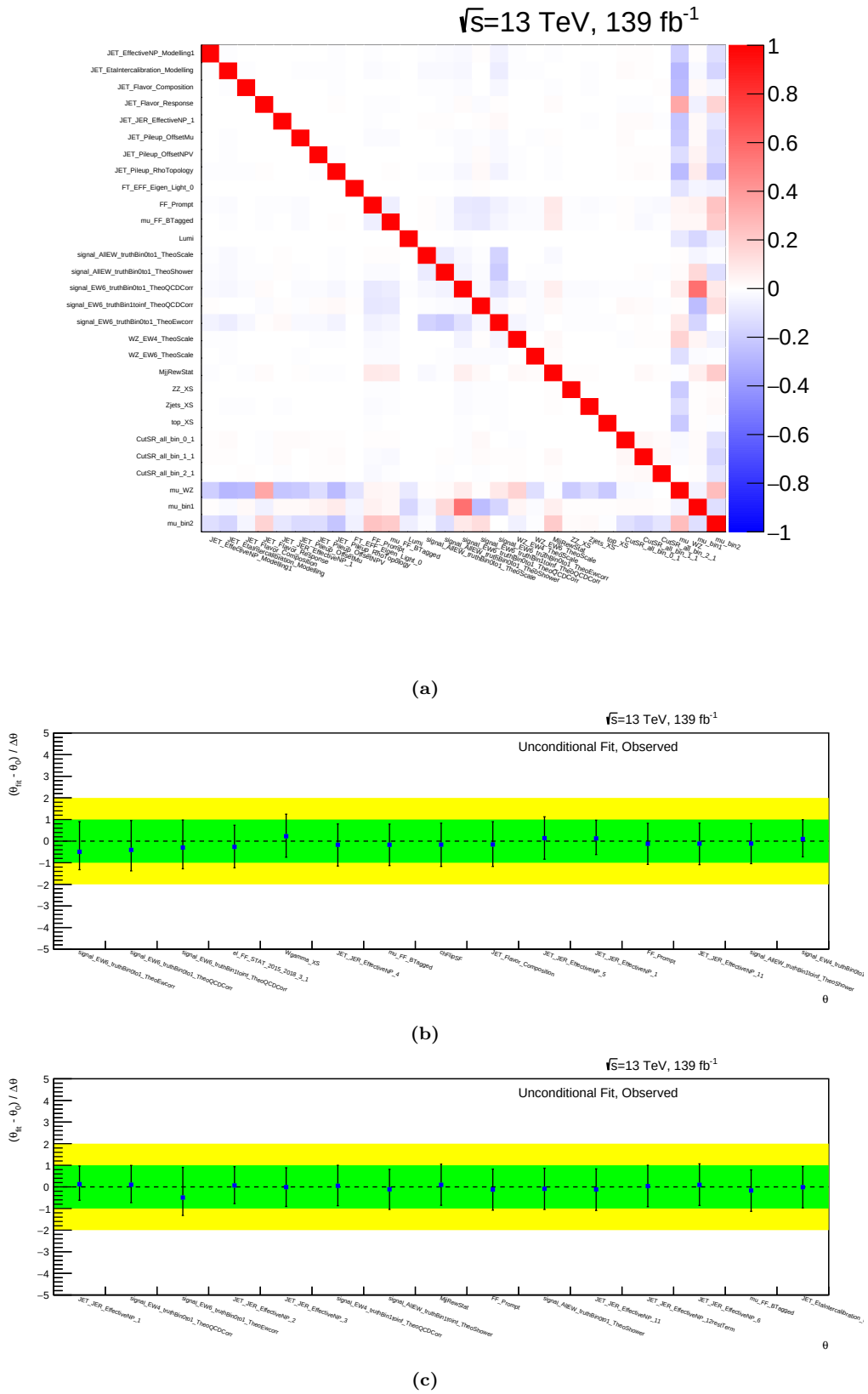


Figure C.90: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

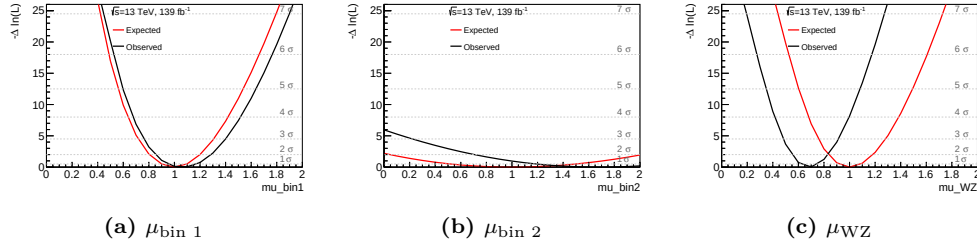


Figure C.91: Likelihood scans of nuisance parameters with largest pulls and constraints in the $N_{gapJets}$ differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a, b) and for QCD $W^\pm Zjj$ normalisation parameter (c).

Table of the strongest (anti-)correlations are included in Table C.27.

The ranking plot is shown in Figure C.92.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.28.

The correlation between unfolded bins are shown in Figure C.93.

C.5 Results for ξ_{j3}

This section presents the extraction of the differential cross-section of the EW $W^\pm W^\pm jj$ production and EW+Int+QCD $W^\pm W^\pm jj$ production as a function of ξ_{j3} . For this variable a third jet with a p_T of at least 25 GeV is required in addition to the signal and low- m_{jj} region requirements.

C.5.1 Pre-Fit Distributions for ξ_{j3}

The following Figures show the distributions of the fit inputs in the high- m_{jj} signal region (Figure C.94) low- m_{jj} control region and WZ control region (Figure C.95). Zero correlation is assumed in the combination of systematic uncertainties in the hatched band. The observed data is shown with Poisson uncertainties.

C.5.2 Results of the Asimov Fit for ξ_{j3} with EW Signal

The expected signal strength μ from the fit to Asimov data is:

$$\mu_{\text{exp}, \xi_{j3}, \text{bin } 1}^{\text{EW}} = 1.00 \pm_{0.34}^{0.37} (\text{stat.}) \pm_{0.17}^{0.22} (\text{mod. syst.}) \pm_{0.14}^{0.20} (\text{exp. syst.}) \pm_{0.02}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{exp}, \xi_{j3}, \text{bin } 2}^{\text{EW}} = 1.00 \pm_{0.36}^{0.41} (\text{stat.}) \pm_{0.09}^{0.17} (\text{mod. syst.}) \pm_{0.09}^{0.14} (\text{exp. syst.}) \pm_{0.01}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{exp}, \xi_{j3}, \text{bin } 3}^{\text{EW}} = 1.00 \pm_{0.34}^{0.39} (\text{stat.}) \pm_{0.09}^{0.15} (\text{mod. syst.}) \pm_{0.09}^{0.13} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, \xi_{j3}, \text{bin } 4}^{\text{EW}} = 1.00 \pm_{0.33}^{0.37} (\text{stat.}) \pm_{0.11}^{0.17} (\text{mod. syst.}) \pm_{0.10}^{0.16} (\text{exp. syst.}) \pm_{0.01}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{exp}, \xi_{j3}, \text{bin } 5}^{\text{EW}} = 1.00 \pm_{0.32}^{0.36} (\text{stat.}) \pm_{0.08}^{0.10} (\text{mod. syst.}) \pm_{0.16}^{0.23} (\text{exp. syst.}) \pm_{0.01}^{0.03} (\text{lumi.})$$

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{\text{WZ, exp}, \xi_{j3}}^{\text{EW}} = 1.00 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

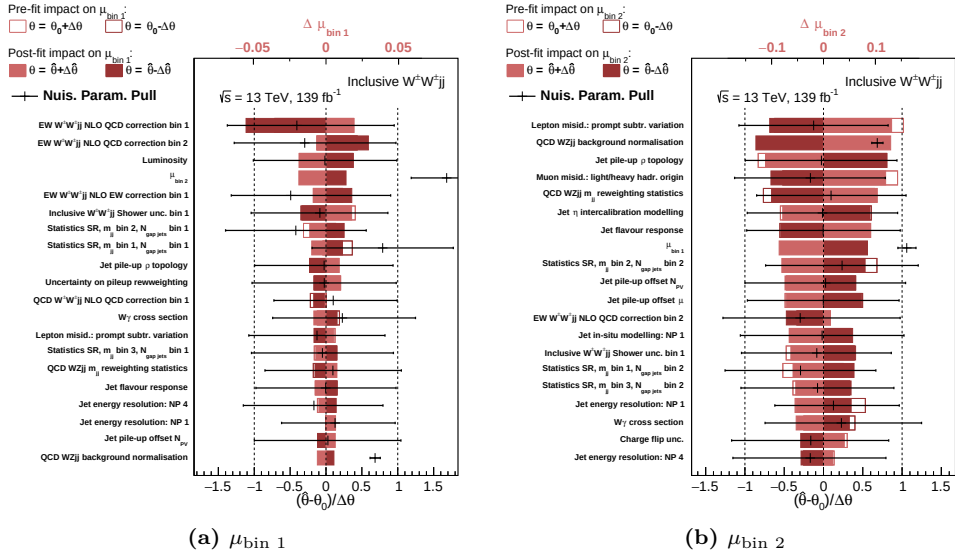


Figure C.92: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the $N_{\text{gap Jets}}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{jj}$ with observed data. They are shown for the first (a) and second (b) $N_{\text{gap Jets}}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

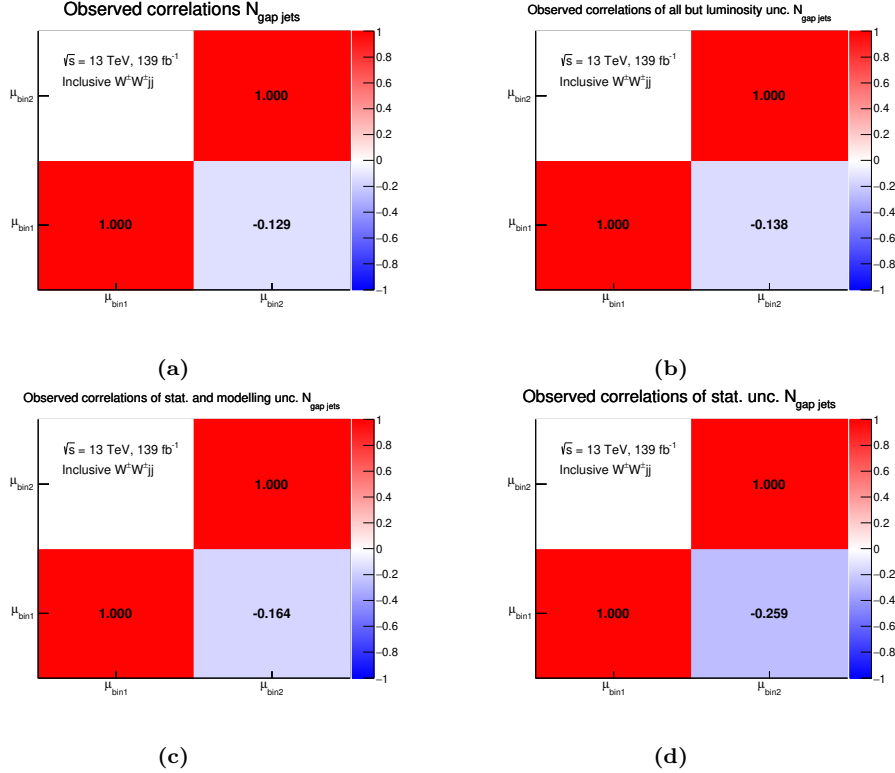


Figure C.93: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistical uncertainty only (d) of the $N_{\text{gap Jets}}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{jj}$ with observed data.

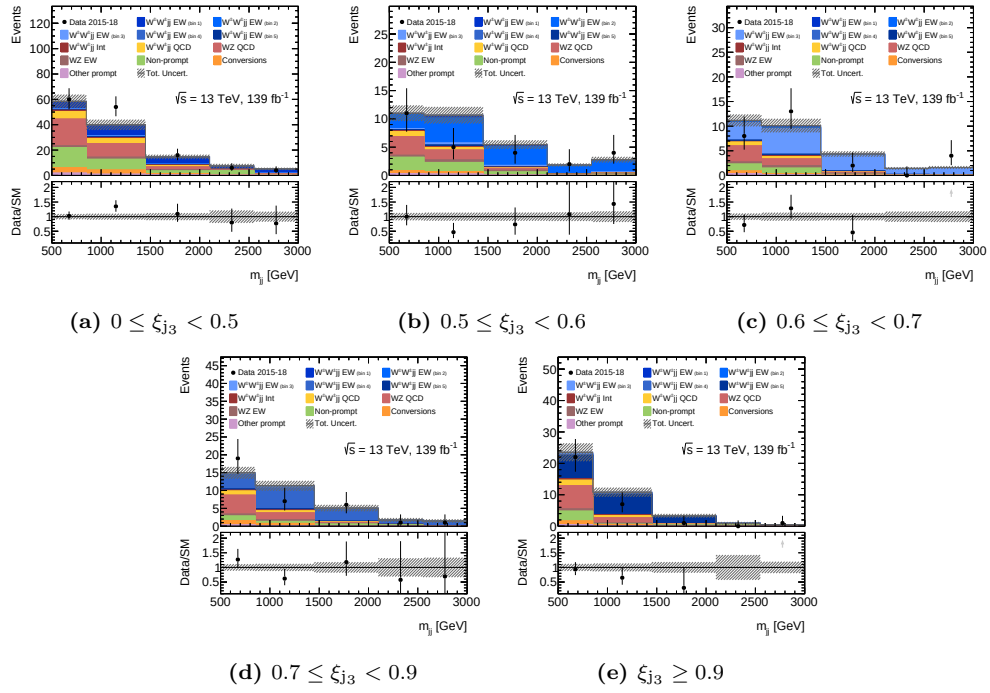


Figure C.94: Pre-fit m_{jj} -distributions in signal region split into ξ_{j3} slices as used in ξ_{j3} -differential cross-section measurement.

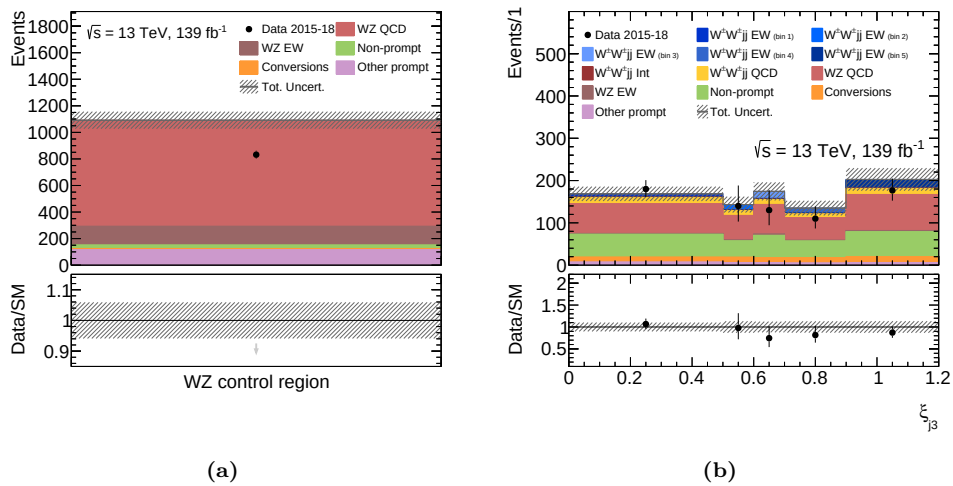


Figure C.95: Pre-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in ξ_{j3} -differential cross-section measurement.

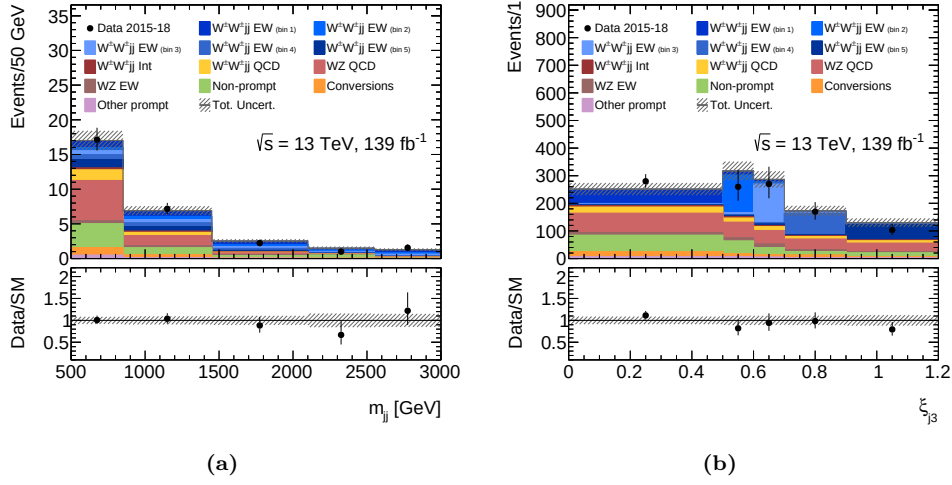


Figure C.96: Pre-fit m_{jj} -distributions in signal region summed over ξ_{j3} slices (a) and summed over m_{jj} bins (b) in ξ_{j3} -differential cross-section measurement.

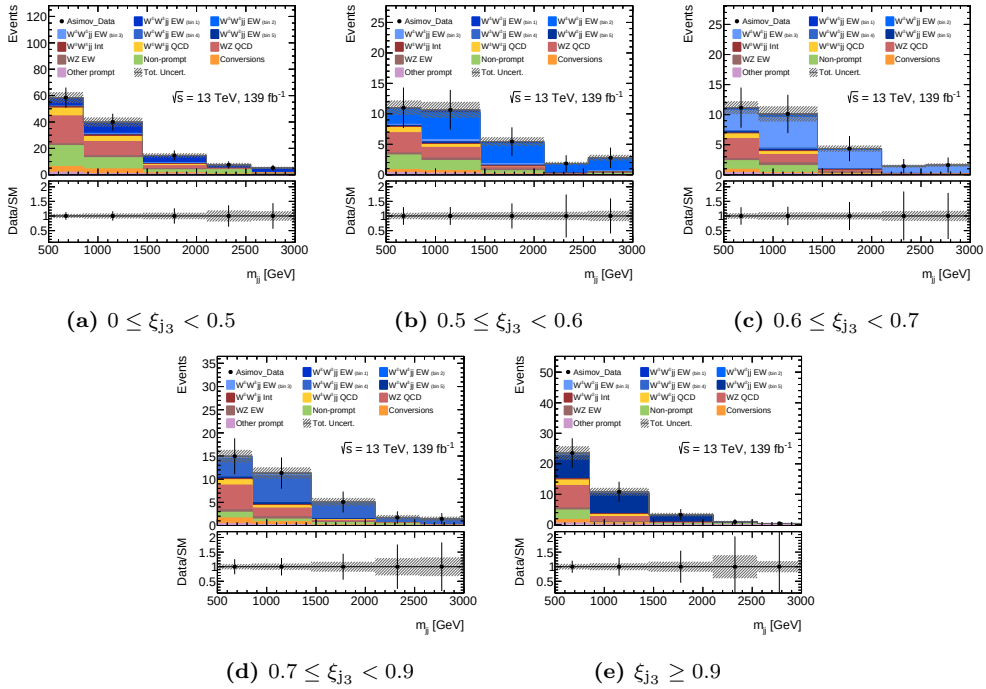


Figure C.97: Post-fit m_{jj} -distributions in signal region split into ξ_{j3} slices as used in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

Table C.28: Breakdown of the uncertainty of signal strength in the different $N_{gapJets}$ truth slices in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma$, ZZ, top and Zjets.

Source	Impact [%]	
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$
Experimental		
Electron calibration	0.4	0.5
Muon calibration	0.5	0.5
Jet energy scale and resolution	1.6	13.0
E_T^{miss} scale and resolution	0.2	0.1
b -tagging inefficiency	0.5	1.7
Background, misid. leptons	1.4	10.6
Background, charge misrec.	0.7	2.9
Pileup modelling	0.9	2.3
Luminosity	1.8	1.7
Modelling		
$W^\pm W^\pm jj$ shower, scale, PDF & α_s	2.1	3.9
EW $W^\pm W^\pm jj$, QCD corrections	6.2	7.0
EW $W^\pm W^\pm jj$, EW corrections	0.4	0.2
QCD $W^\pm W^\pm jj$, QCD corrections	0.0	0.1
Background, WZ scale, PDF & α_s	0.9	1.4
Background, WZ reweighting	0.4	4.4
Background, other	1.0	2.8
Model statistical	1.8	6.9
Experimental and modelling	7.6	21.1
Data statistical	7.7	21.5
Total	10.9	30.1

Post-fit plots are in Figure C.97 and Figure C.98.

Pull plot and correlations are in Figure C.99.

Table of the strongest (anti-)correlations are included in Table C.29.

The ranking plot is shown in Figure C.100.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.30.

The correlation between unfolded bins are shown in Figure C.101.

C.5.3 Results of the Asimov Fit for ξ_{j3} with EW+Int+QCD Signal

The expected signal strength μ from the fit to Asimov data is:

$$\mu_{\text{exp}, \xi_{j3}, \text{bin 1}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.26}^{0.28} (\text{stat.}) \pm_{0.12}^{0.14} (\text{mod. syst.}) \pm_{0.14}^{0.17} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, \xi_{j3}, \text{bin 2}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.33}^{0.38} (\text{stat.}) \pm_{0.09}^{0.15} (\text{mod. syst.}) \pm_{0.09}^{0.13} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, \xi_{j3}, \text{bin 3}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.31}^{0.36} (\text{stat.}) \pm_{0.08}^{0.13} (\text{mod. syst.}) \pm_{0.09}^{0.12} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{exp}, \xi_{j3}, \text{bin 4}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.30}^{0.34} (\text{stat.}) \pm_{0.10}^{0.15} (\text{mod. syst.}) \pm_{0.10}^{0.15} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

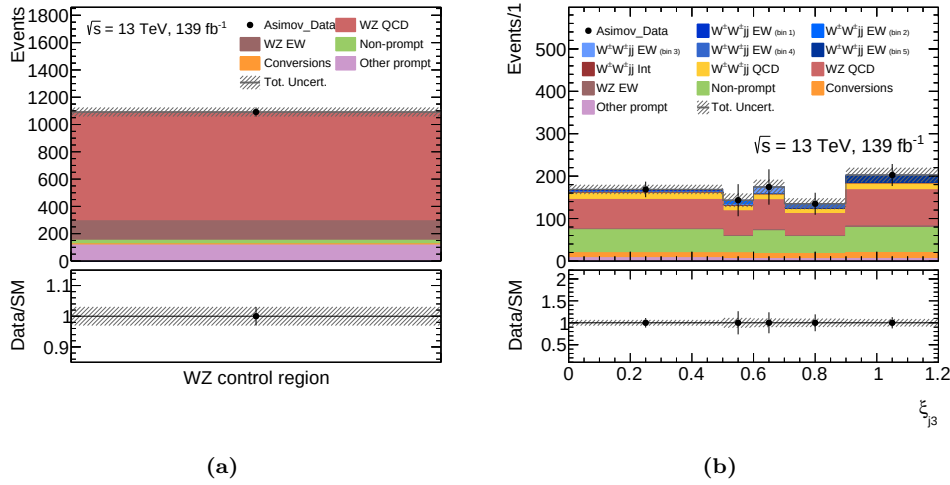


Figure C.98: Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W'^{\pm jj}$ with Asimov data.

Table C.29: List of parameter correlations in the Asimov fit which are larger than 10% in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W'^{\pm jj}$ with Asimov data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	μ_{WZ}	0.373
MjjRwStat	μ_{bin1}	0.303
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.302
JET_Pileup_RhoTopology	μ_{WZ}	-0.296
μ_{WZ}	μ_{bin5}	0.294
signal_EW6_truthBin0p7to0p9_TheoShower	μ_{bin4}	0.285
JET_JER_EffectiveNP_1	μ_{WZ}	-0.254
JET_Flavor_Composition	μ_{WZ}	-0.245
JET_Pileup_OffsetMu	μ_{bin5}	-0.231
JET_EtaIntercalibration_Modelling	μ_{bin5}	-0.223
JET_Pileup_OffsetMu	μ_{WZ}	-0.223
signal_EW6_truthBin0p5to0p6_TheoShower	μ_{bin2}	0.219
signal_EW6_truthBin0p6to0p7_TheoShower	μ_{bin3}	0.215
μ_{WZ}	μ_{bin4}	0.206
JET_JER_EffectiveNP_1	μ_{bin5}	-0.192
signal_EW6_truthBin0p0to0p5_TheoShower	μ_{bin1}	0.191
μ_{WZ}	μ_{bin3}	0.189
top_XS	μ_{WZ}	-0.181
μ_{WZ}	μ_{bin2}	0.176
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.175
WZ_EW4_TheoScale	μ_{WZ}	0.171
ZZ_XS	μ_{WZ}	-0.167
μ_{bin1}	μ_{WZ}	0.164
FF_Prompt	μ_{bin1}	0.158
JET_EtaIntercalibration_Modelling	μ_{bin4}	-0.143
JET_JER_EffectiveNP_1	μ_{bin4}	-0.136
$\mu_{FF_BTagged}$	μ_{bin1}	0.136
JET_Pileup_OffsetMu	μ_{bin4}	-0.135
JET_Pileup_RhoTopology	μ_{bin5}	-0.134
JET_Pileup_OffsetNPV	μ_{WZ}	-0.133
JET_JER_EffectiveNP_1	μ_{bin3}	-0.133
FF_Prompt	$\mu_{FF_BTagged}$	-0.131
CutSR3j_all_bin_1_2	μ_{bin3}	-0.128
JET_Pileup_RhoTopology	μ_{bin1}	-0.125
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.123
CutSR3j_all_bin_1_0	μ_{bin1}	-0.121
JET_EtaIntercalibration_Modelling	μ_{bin2}	-0.121
CutSR3j_all_bin_1_1	μ_{bin2}	-0.120
Zjets_XS	μ_{WZ}	-0.120
JET_EtaIntercalibration_Modelling	μ_{bin3}	-0.119
CutSR3j_all_bin_2_0	μ_{bin1}	-0.118
JET_Pileup_OffsetMu	μ_{bin2}	-0.117
signal_EW4_TheoScale	μ_{bin1}	-0.117
WZ_EW6_TheoScale	μ_{WZ}	-0.112
CutSR3j_all_bin_1_3	μ_{bin4}	-0.108
JET_EtaIntercalibration_Modelling	μ_{bin1}	-0.106
JET_Pileup_RhoTopology	μ_{bin4}	-0.105
CutSR3j_all_bin_0_4	μ_{bin5}	-0.103
μ_{bin2}	μ_{bin5}	0.103
μ_{bin4}	μ_{bin5}	0.102
JET_Pileup_OffsetMu	μ_{bin3}	-0.100

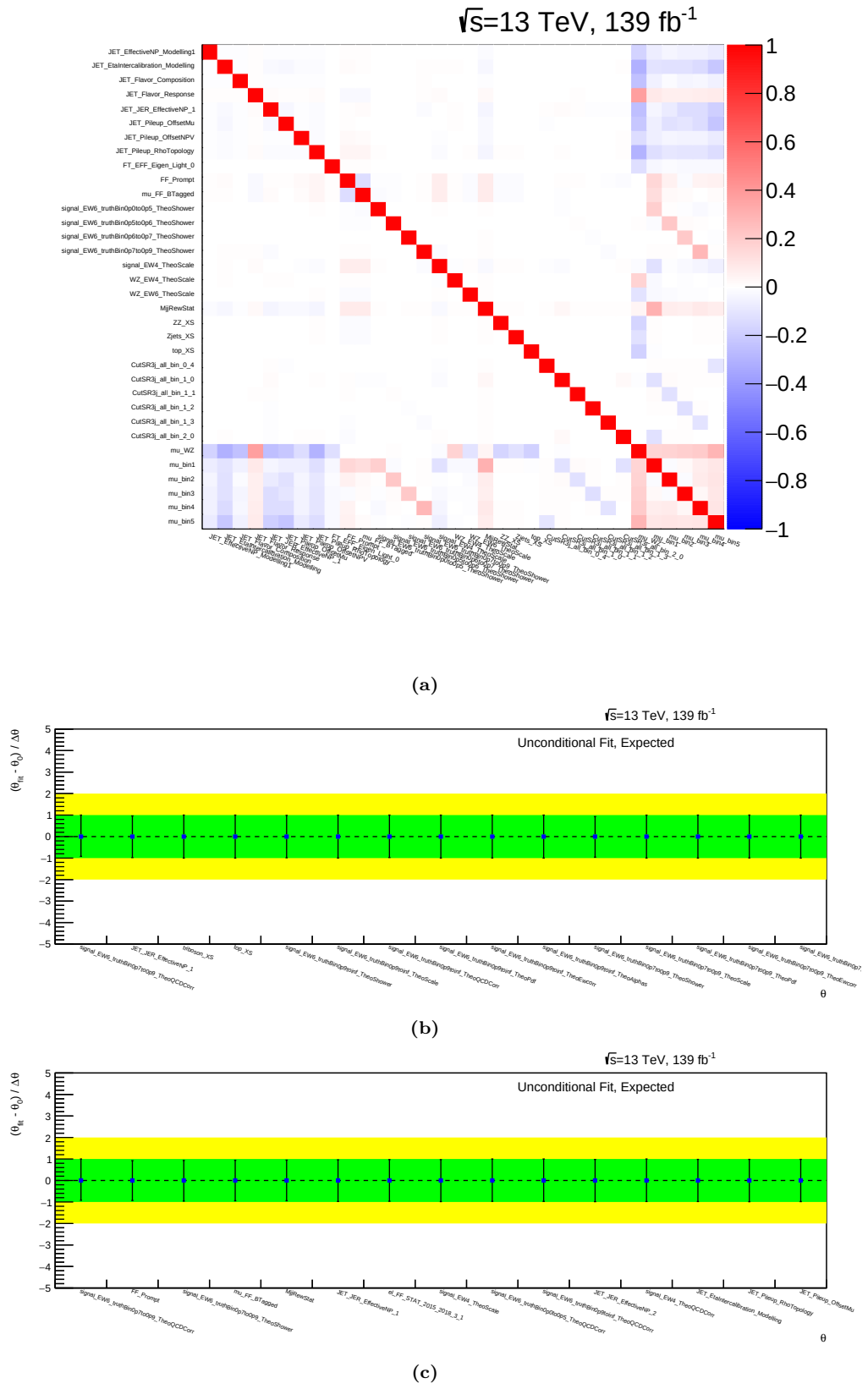


Figure C.99: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the ξ_{j3} -differential cross-section measurement of EW $W^{\pm}W^{\pm}jj$ with Asimov data.

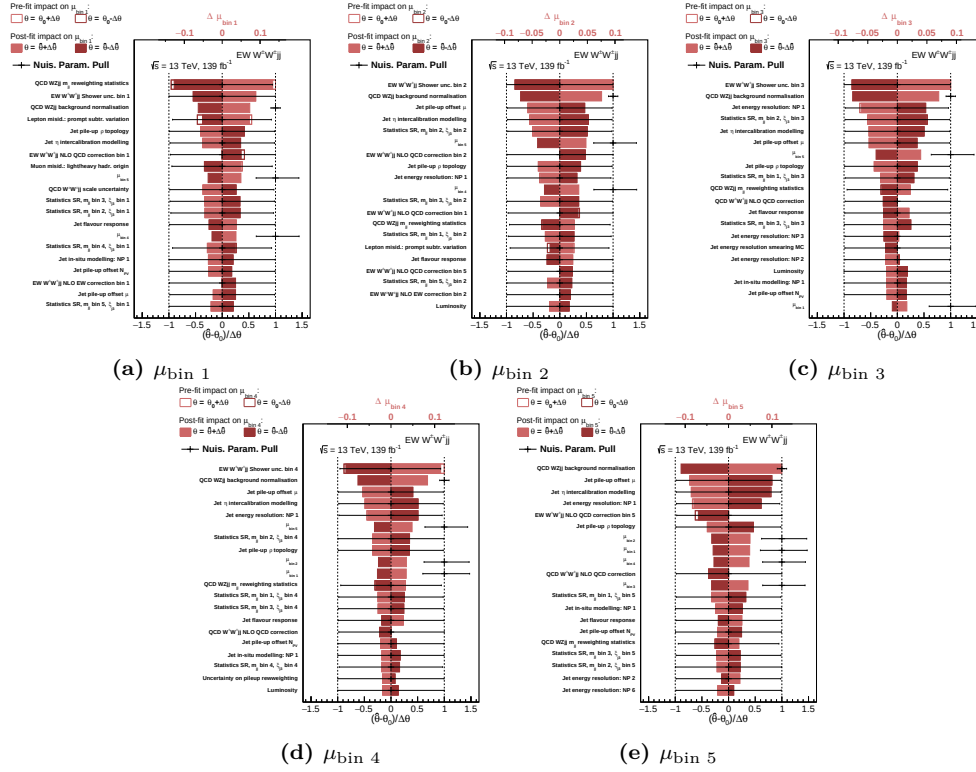


Figure C.100: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the ξ_{j3} -differential cross-section measurement of $\text{EW } W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d) and 5th (e) ξ_{j3} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

Table C.30: Breakdown of the uncertainty of signal strength in the different ξ_{j3} truth slices in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]				
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$
Experimental					
Electron calibration	0.6	0.4	0.4	0.5	0.5
Muon calibration	0.7	0.5	0.6	0.6	0.5
Jet energy scale and resolution	10.8	10.4	10.6	12.2	18.5
E_T^{miss} scale and resolution	0.3	0.3	0.2	0.1	0.1
b -tagging inefficiency	1.7	0.6	0.9	1.0	1.0
Background, misid. leptons	12.3	4.4	2.6	3.7	4.8
Background, charge misrec.	3.9	0.7	0.8	1.4	2.2
Pileup modelling	1.8	1.2	1.4	1.9	2.7
Luminosity	2.3	1.9	1.9	2.0	1.9
Modelling					
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	9.2	9.7	8.9	11.2	0.8
EW $W^\pm W^\pm jj$, QCD corrections	2.5	3.0	1.1	1.5	4.4
EW $W^\pm W^\pm jj$, EW corrections	1.6	1.1	0.8	0.7	0.2
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.3	0.2	0.4	0.5	0.2
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	7.2	1.0	1.3	2.3	3.4
QCD $W^\pm W^\pm jj$, QCD corrections	0.1	0.5	1.1	1.1	1.9
Background, WZ scale, PDF & α_s	1.4	0.6	0.4	0.3	0.3
Background, WZ reweighting	10.9	1.7	1.5	2.1	0.8
Background, other	4.1	0.4	0.3	2.2	1.4
Model statistical	9.6	7.9	6.9	7.3	6.8
Experimental and modelling	26.1	17.6	16.2	19.3	21.6
Data statistical	35.2	38.4	36.2	35.1	33.7
Total	43.9	42.3	39.7	40.2	40.1

$$\mu_{\text{exp}, \xi_{j3}, \text{bin 5}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.28}^{0.31} (\text{stat.}) \pm_{0.07}^{0.09} (\text{mod. syst.}) \pm_{0.15}^{0.22} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.})$$

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{\text{WZ, exp}, \xi_{j3}}^{\text{EW+Int+QCD}} = 1.00 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.07}^{0.07} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

Post-fit plots are in Figure C.102 and Figure C.103.

Pull plot and correlations are in Figure C.104.

Table of the strongest (anti-)correlations are included in Table C.31.

The ranking plot is shown in Figure C.105.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.32.

The correlation between unfolded bins are shown in Figure C.106.

C.5.4 Results of the Fit to Observed Data for ξ_{j3} with EW Signal

The observed signal strength μ from the fit to observed data is:

$$\mu_{\text{obs}, \xi_{j3}, \text{bin 1}}^{\text{EW}} = 1.74 \pm_{0.39}^{0.42} (\text{stat.}) \pm_{0.26}^{0.30} (\text{mod. syst.}) \pm_{0.25}^{0.31} (\text{exp. syst.}) \pm_{0.03}^{0.05} (\text{lumi.}),$$

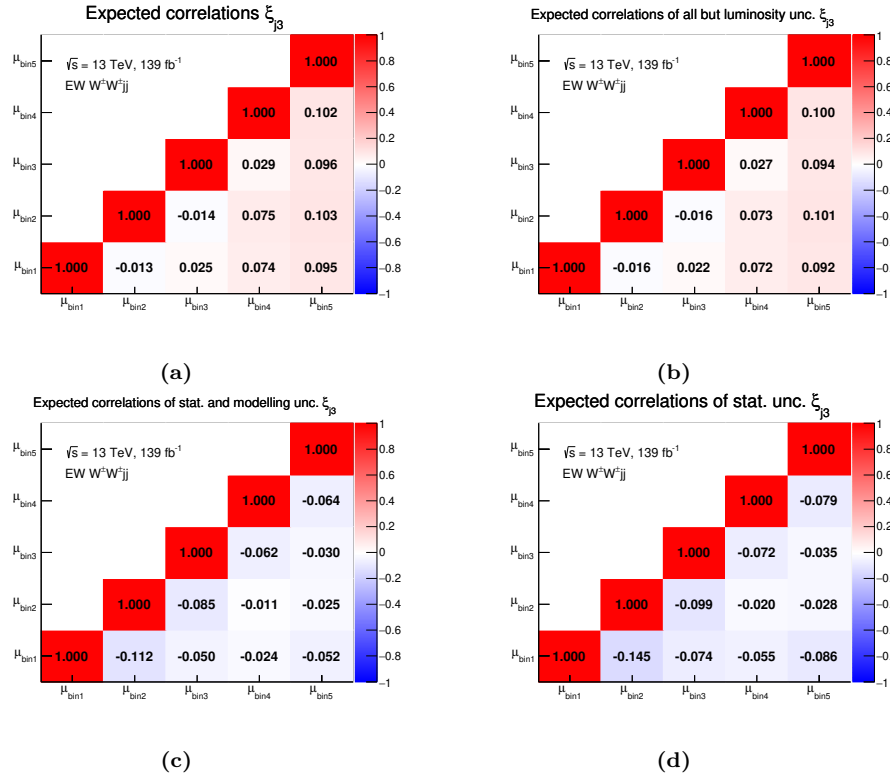


Figure C.101: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.

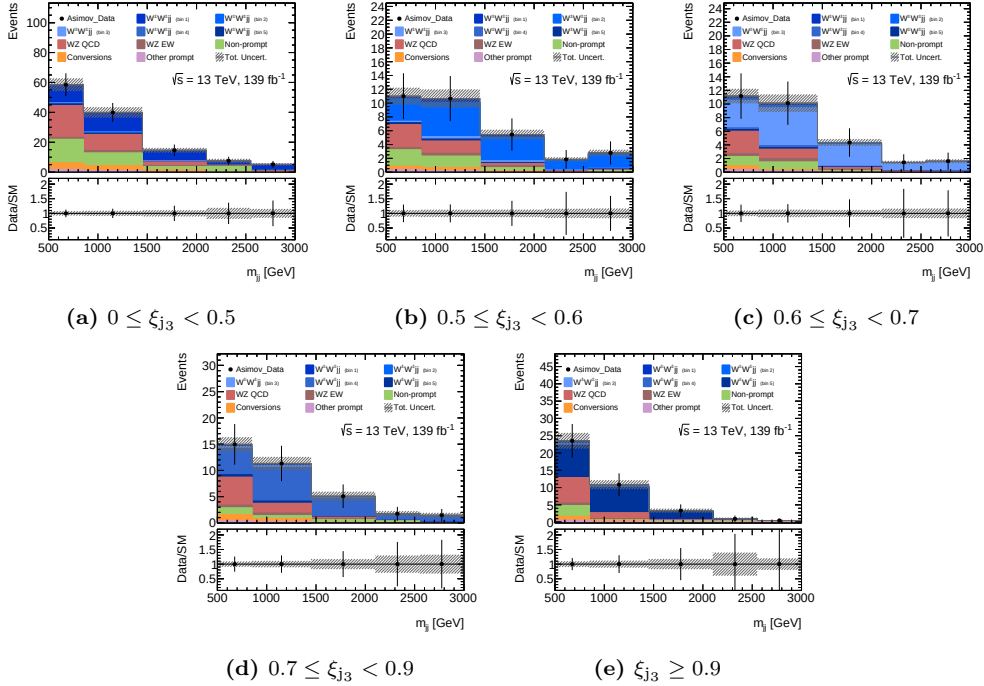


Figure C.102: Post-fit m_{jj} -distributions in signal region split into ξ_{j3} slices as used in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

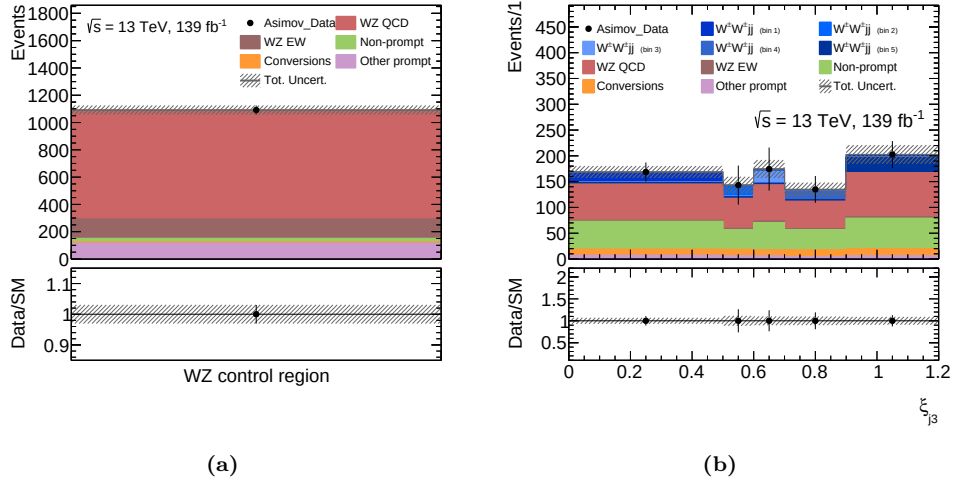


Figure C.103: Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Table C.31: List of parameter correlations which are larger than 10% in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	$\mu_{_WZ}$	0.375
$\mu_{_WZ}$	$\mu_{_bin5}$	0.303
JET_EtaIntercalibration_Modelling	$\mu_{_WZ}$	-0.301
JET_Pileup_RhoTopology	$\mu_{_WZ}$	-0.298
MjjRewStat	$\mu_{_bin1}$	0.287
signal_AllEW_truthBin0p7to0p9_TheoShower	$\mu_{_bin4}$	0.273
JET_JER_EffectiveNP_1	$\mu_{_WZ}$	-0.256
JET_Flavor_Composition	$\mu_{_WZ}$	-0.244
JET_Pileup_OffsetMu	$\mu_{_bin5}$	-0.243
JET_EtaIntercalibration_Modelling	$\mu_{_bin5}$	-0.232
JET_Pileup_OffsetMu	$\mu_{_WZ}$	-0.224
FF_Prompt	$\mu_{_bin1}$	0.219
signal_AllEW_truthBin0p6to0p7_TheoShower	$\mu_{_bin3}$	0.209
JET_JER_EffectiveNP_1	$\mu_{_bin5}$	-0.206
$\mu_{_WZ}$	$\mu_{_bin4}$	0.206
$\mu_{_FF_BTagged}$	$\mu_{_bin1}$	0.201
signal_AllEW_truthBin0p5to0p6_TheoShower	$\mu_{_bin2}$	0.197
$\mu_{_WZ}$	$\mu_{_bin3}$	0.190
top_XS	$\mu_{_WZ}$	-0.181
$\mu_{_WZ}$	$\mu_{_bin2}$	0.178
JET_EffectiveNP_Modelling1	$\mu_{_WZ}$	-0.175
WZ_EW4_TheoScale	$\mu_{_WZ}$	0.171
ZZ_XS	$\mu_{_WZ}$	-0.165
JET_Pileup_RhoTopology	$\mu_{_bin5}$	-0.146
JET_EtaIntercalibration_Modelling	$\mu_{_bin4}$	-0.144
$\mu_{_bin1}$	$\mu_{_WZ}$	0.144
JET_Pileup_RhoTopology	$\mu_{_bin1}$	-0.141
CutSR3j_all_bin_1_0	$\mu_{_bin1}$	-0.139
JET_JER_EffectiveNP_1	$\mu_{_bin4}$	-0.138
JET_Pileup_OffsetMu	$\mu_{_bin4}$	-0.137
JET_Pileup_OffsetNPV	$\mu_{_WZ}$	-0.135
JET_JER_EffectiveNP_1	$\mu_{_bin3}$	-0.134
CutSR3j_all_bin_1_2	$\mu_{_bin3}$	-0.129
JET_EtaIntercalibration_Modelling	$\mu_{_bin2}$	-0.123
FT_EFF_Eigen_Light_0	$\mu_{_WZ}$	-0.123
CutSR3j_all_bin_1_1	$\mu_{_bin2}$	-0.123
JET_Pileup_OffsetMu	$\mu_{_bin2}$	-0.121
JET_EtaIntercalibration_Modelling	$\mu_{_bin3}$	-0.120
signal_AllEW_truthBin0p0to0p5_TheoShower	$\mu_{_bin1}$	0.119
Zjets_XS	$\mu_{_WZ}$	-0.118
$\mu_{_bin2}$	$\mu_{_bin5}$	0.114
CutSR3j_all_bin_0_4	$\mu_{_bin5}$	-0.112
$\mu_{_bin4}$	$\mu_{_bin5}$	0.111
JET_Pileup_RhoTopology	$\mu_{_bin4}$	-0.111
CutSR3j_all_bin_2_0	$\mu_{_bin1}$	-0.110
WZ_EW6_TheoScale	$\mu_{_WZ}$	-0.108
FF_Prompt	$\mu_{_FF_BTagged}$	-0.108
CutSR3j_all_bin_1_3	$\mu_{_bin4}$	-0.107
signal_EW6_truthBin0p9toinf_TheoQCDCorr	$\mu_{_bin5}$	0.104
JET_Pileup_OffsetMu	$\mu_{_bin3}$	-0.103
JET_Pileup_RhoTopology	$\mu_{_bin3}$	-0.103
$\mu_{_bin3}$	$\mu_{_bin5}$	0.102

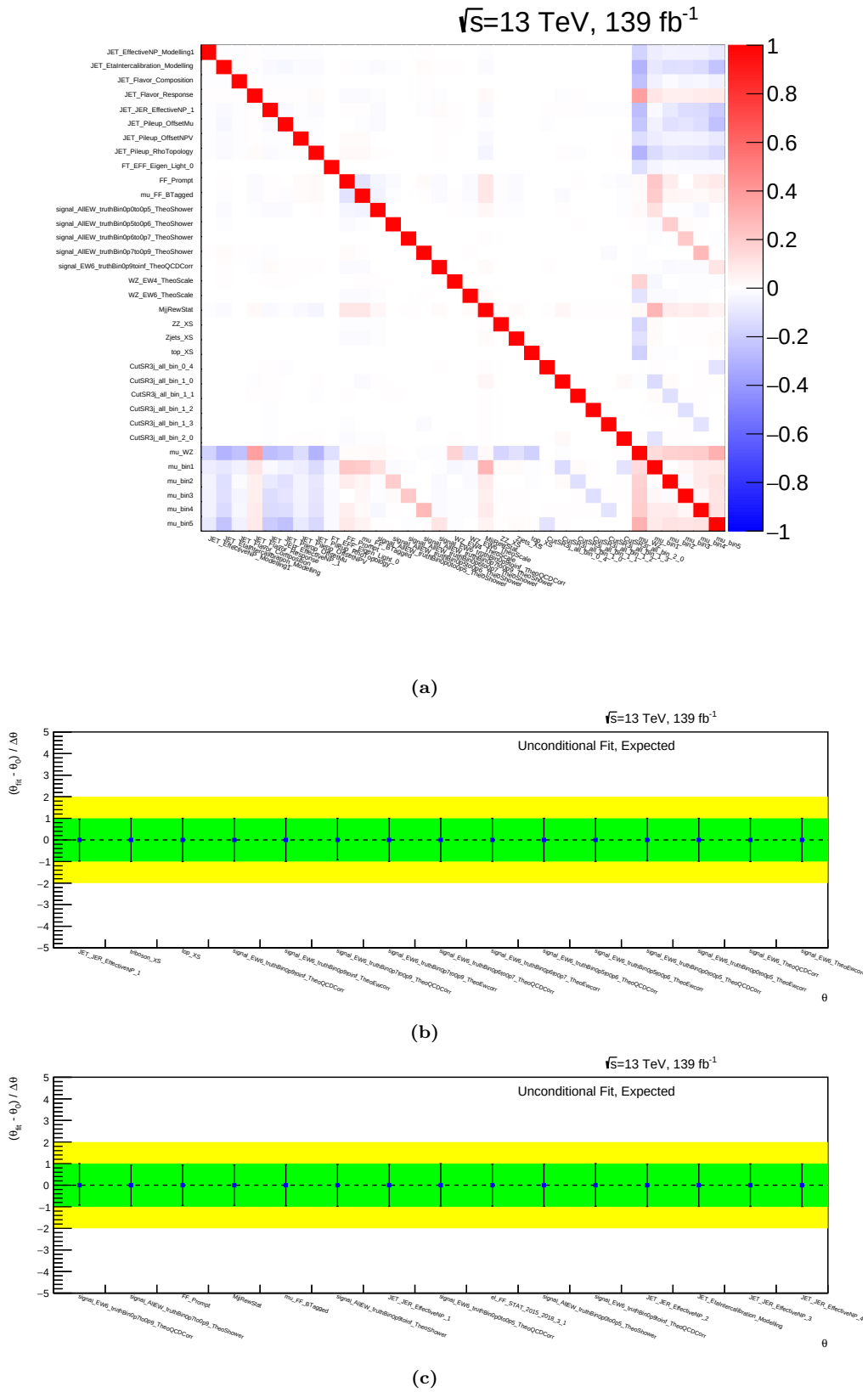


Figure C.104: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

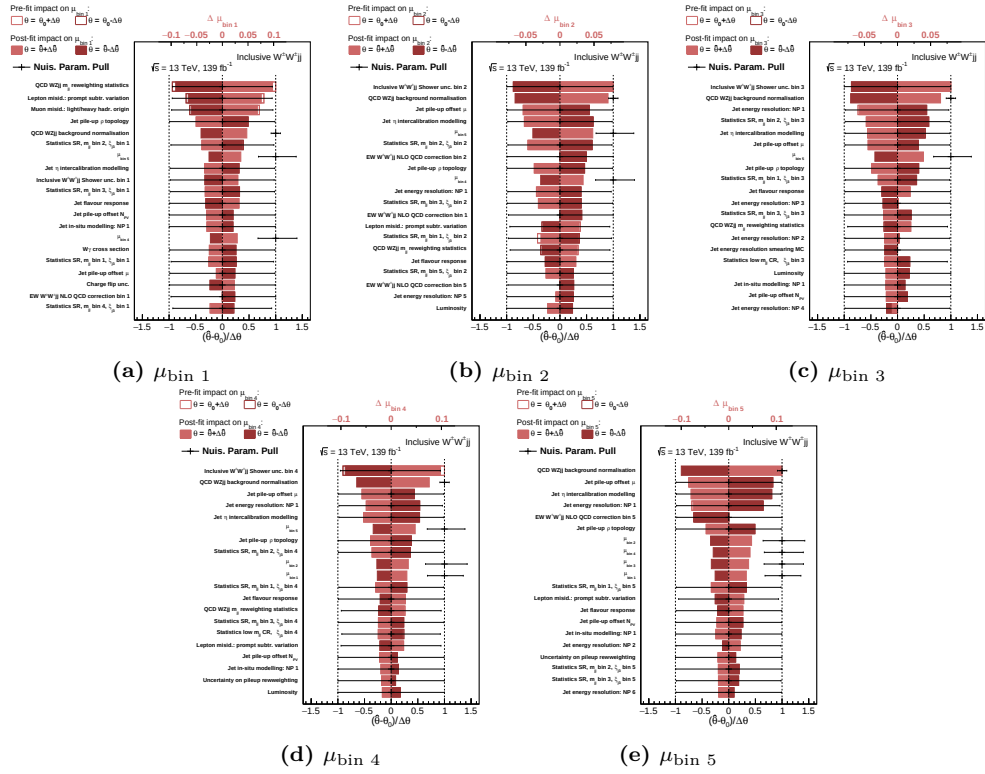


Figure C.105: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d) and 5th (e) ξ_{j3} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta \hat{\theta}_0 / \Delta \theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

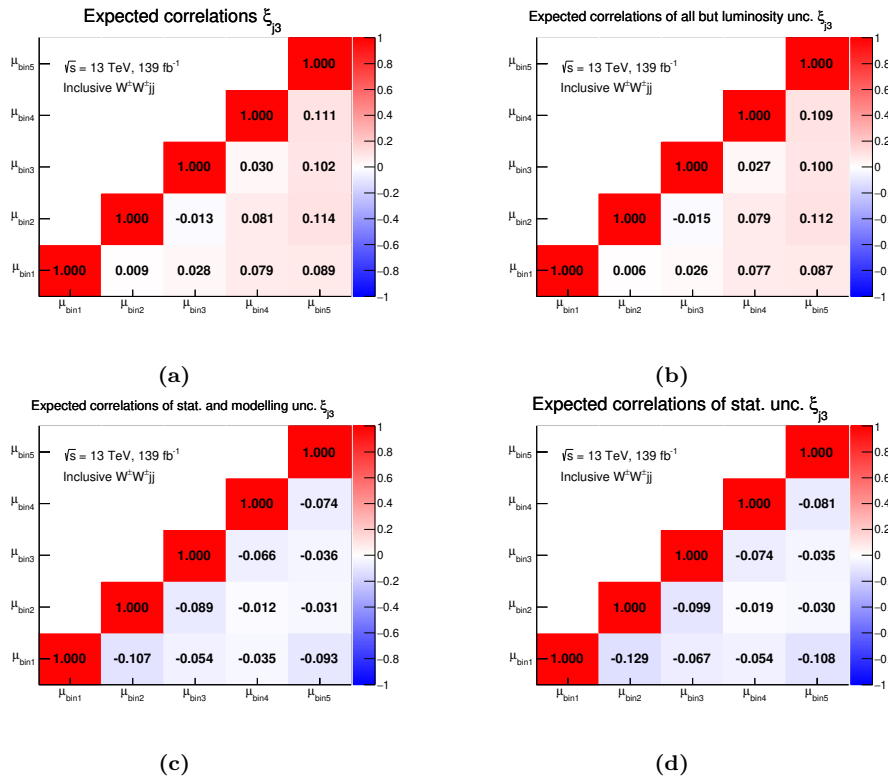


Figure C.106: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.

Table C.32: Breakdown of the uncertainty of signal strength in the different ξ_{j3} truth slices in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]				
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$
Experimental					
Electron calibration	0.5	0.4	0.4	0.5	0.4
Muon calibration	0.5	0.5	0.5	0.5	0.4
Jet energy scale and resolution	8.4	9.9	10.0	11.3	17.2
E_T^{miss} scale and resolution	0.2	0.3	0.2	0.2	0.1
b -tagging inefficiency	1.5	0.6	0.9	0.9	0.9
Background, misid. leptons	12.2	4.6	2.5	4.0	5.2
Background, charge misrec.	3.8	0.7	0.9	1.5	2.2
Pileup modelling	1.5	1.2	1.4	1.8	2.6
Luminosity	1.8	1.8	1.8	1.8	1.6
Modelling					
$W^\pm W^\pm jj$ shower, scale, PDF & α_s	5.1	8.1	8.0	9.8	0.8
EW $W^\pm W^\pm jj$, QCD corrections	1.0	2.6	1.0	0.8	4.2
EW $W^\pm W^\pm jj$, EW corrections	0.8	0.9	0.6	0.5	0.2
QCD $W^\pm W^\pm jj$, QCD corrections	0.4	0.3	0.4	0.3	0.7
Background, WZ scale, PDF & α_s	1.3	0.5	0.4	0.3	0.4
Background, WZ reweighting	7.3	1.8	1.3	1.7	0.3
Background, other	4.0	0.6	0.4	2.5	1.5
Model statistical	7.8	7.6	6.7	7.0	6.3
Experimental and modelling	20.1	16.2	15.1	17.6	20.0
Data statistical	26.9	35.5	33.7	31.9	29.1
Total	33.6	39.1	36.9	36.5	35.4

$$\mu_{\text{obs}, \xi_{j3}, \text{bin 2}}^{\text{EW}} = 0.74 \pm_{0.31}^{0.37} (\text{stat.}) \pm_{0.09}^{0.14} (\text{mod. syst.}) \pm_{0.07}^{0.12} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, \xi_{j3}, \text{bin 3}}^{\text{EW}} = 1.01 \pm_{0.32}^{0.37} (\text{stat.}) \pm_{0.09}^{0.15} (\text{mod. syst.}) \pm_{0.10}^{0.14} (\text{exp. syst.}) \pm_{0.01}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{obs}, \xi_{j3}, \text{bin 4}}^{\text{EW}} = 0.94 \pm_{0.33}^{0.37} (\text{stat.}) \pm_{0.13}^{0.19} (\text{mod. syst.}) \pm_{0.10}^{0.17} (\text{exp. syst.}) \pm_{0.01}^{0.03} (\text{lumi.}),$$

$$\mu_{\text{obs}, \xi_{j3}, \text{bin 5}}^{\text{EW}} = 0.57 \pm_{0.27}^{0.31} (\text{stat.}) \pm_{0.06}^{0.09} (\text{mod. syst.}) \pm_{0.12}^{0.18} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.})$$

and the QCD $W^\pm Zjj$ normalisation strength is:

$$\mu_{\text{WZ, obs}, \xi_{j3}}^{\text{EW}} = 0.69 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.05}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

Post-fit plots are in Figure C.107 and Figure C.108. The projections on ξ_{j3} and on m_{jj} are shown in Figure C.109.

Pull plot and correlations are in Figure C.110.

Selected profile LH scans are in Figure C.111. The profile likelihood scan look similar for the different ξ_{j3} signal strength. The last parabola is a bit broader due to a slightly lower significance from the binning optimisation.

Table of the strongest (anti-)correlations are included in Table C.33.

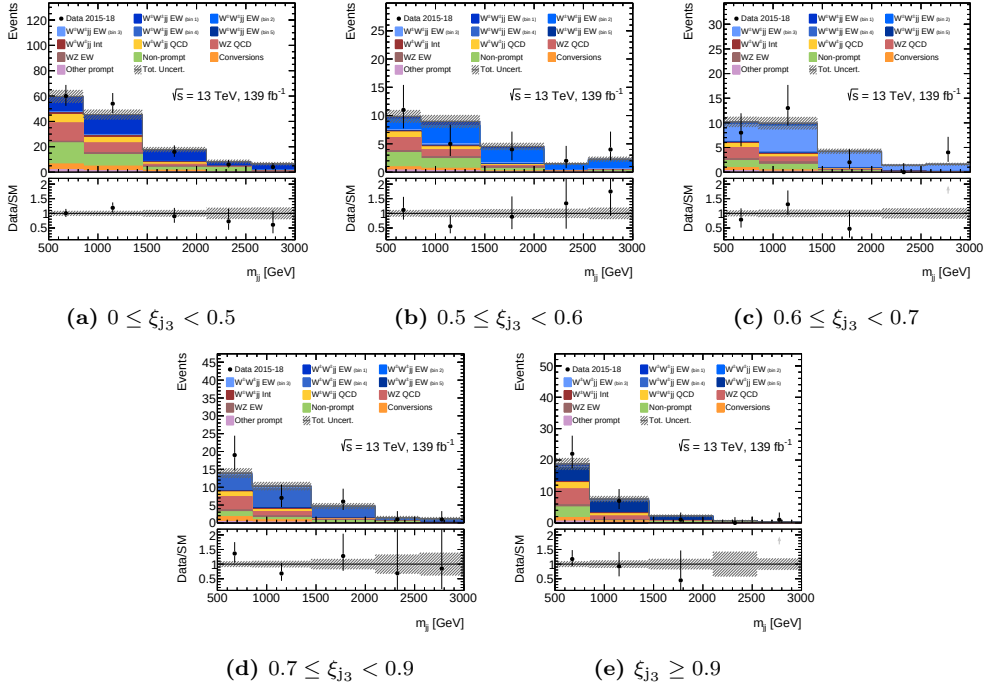


Figure C.107: Post-fit m_{jj} -distributions in signal region split into ξ_{j3} slices as used in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

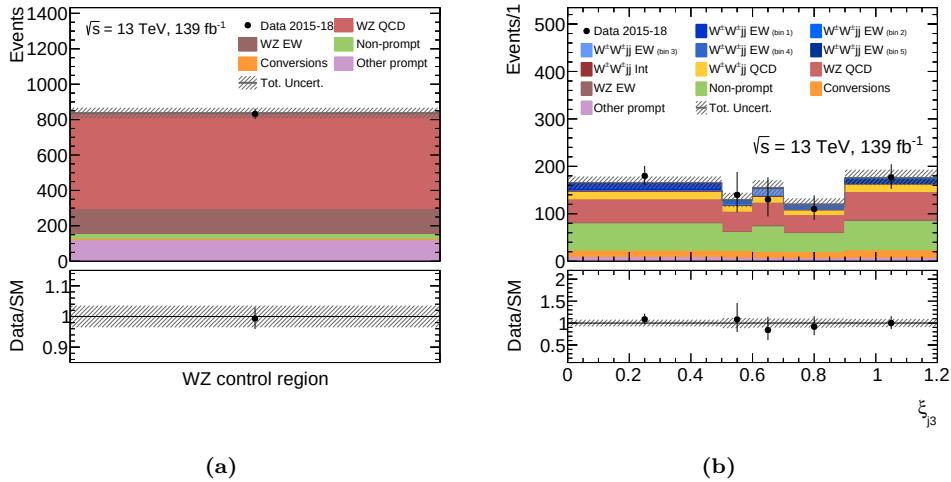


Figure C.108: Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

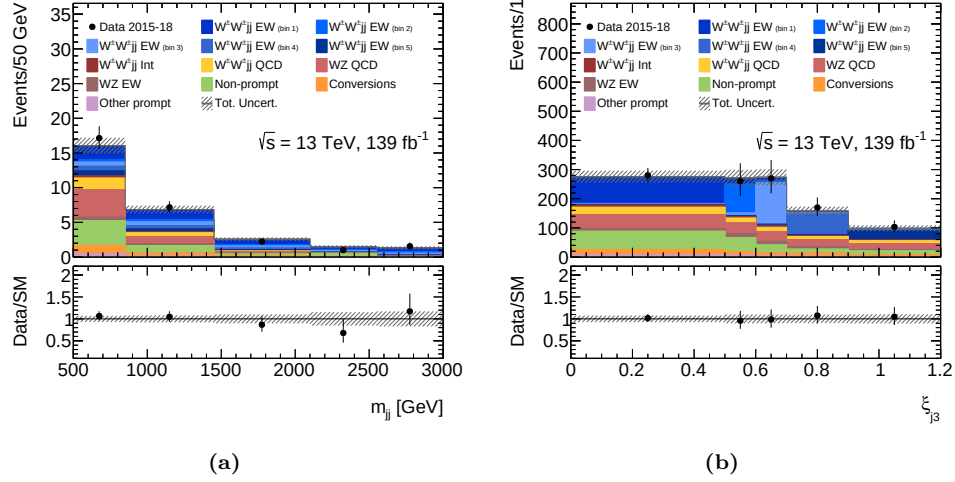


Figure C.109: Post-fit signal region summed over ξ_{j3} slices (a) and summed over m_{jj} slices (b) in the ξ_{j3} -differential cross-section measurement of EW $W^{\pm}W^{\pm}jj$ with observed data.

Table C.33: List of parameter correlations which are larger than 10% in the ξ_{j3} -differential cross-section measurement of EW $W^{\pm}W^{\pm}jj$ with observed data.

Parameter 1	Parameter 2	Correlation
JET_Flavor_Response	μ_{WZ}	0.355
signal_EW6_truthBin0p7to0p9_TheoShower	μ_{bin4}	0.316
JET_JER_EffectiveNP_1	μ_{WZ}	-0.292
JET_EtaIntercalibration_Modelling	μ_{WZ}	-0.272
JET_Flavor_Composition	μ_{WZ}	-0.270
JET_Pileup_RhoTopology	μ_{WZ}	-0.267
signal_EW6_truthBin0p0to0p5_TheoQCDCorr	μ_{bin1}	-0.256
μ_{WZ}	μ_{bin5}	0.237
signal_EW6_truthBin0p6to0p7_TheoShower	μ_{bin3}	0.233
top_XS	μ_{WZ}	-0.215
signal_EW4_TheoScale	μ_{bin1}	-0.209
MjjRewStat	μ_{bin1}	0.209
JET_Pileup_OffsetMu	μ_{bin5}	-0.203
FF_Prompt	μ_{bin1}	0.201
ZZ_XS	μ_{WZ}	-0.201
JET_JER_EffectiveNP_1	μ_{bin5}	-0.199
JET_Pileup_OffsetMu	μ_{WZ}	-0.197
μ_{bin1}	μ_{WZ}	0.196
signal_EW6_truthBin0p5to0p6_TheoShower	μ_{bin2}	0.194
signal_EW6_truthBin0p0to0p5_TheoShower	μ_{bin1}	0.190
JET_EffectiveNP_Modelling1	μ_{WZ}	-0.188
JET_EtaIntercalibration_Modelling	μ_{bin5}	-0.188
signal_EW6_truthBin0p0to0p5_TheoEwcorr	μ_{bin1}	-0.185
μ_{WZ}	μ_{bin3}	0.180
μ_{FF}	μ_{bin4}	0.178
μ_{FF} BTagged	μ_{bin1}	0.174
JET_Pileup_RhoTopology	μ_{bin1}	-0.170
CutSR3j_all_bin_1_0	μ_{bin1}	-0.168
signal_EW6_truthBin0p0to0p5_TheoQCDCorr	μ_{bin2}	-0.162
JET_JER_EffectiveNP_1	μ_{bin4}	-0.150
μ_{WZ}	μ_{bin2}	0.149
JET_JER_EffectiveNP_1	μ_{bin3}	-0.145
signal_EW6_truthBin0p7to0p9_TheoQCDCorr	signal_EW6_truthBin0p7to0p9_TheoShower	0.143
WZ_EW4_TheoScale	μ_{WZ}	0.142
Zjets_XS	μ_{WZ}	-0.141
JET_Pileup_OffsetNPV	μ_{WZ}	-0.141
CutSR3j_all_bin_2_0	μ_{bin1}	-0.131
WZ_EW6_TheoScale	μ_{WZ}	-0.130
JET_EtaIntercalibration_Modelling	μ_{bin4}	-0.129
JET_Pileup_OffsetMu	μ_{bin4}	-0.128
FF_Prompt	signal_EW6_truthBin0p0to0p5_TheoQCDCorr	-0.126
μ_{FF} BTagged	signal_EW6_truthBin0p0to0p5_TheoQCDCorr	-0.126
JET_Flavor_Response	μ_{bin1}	0.125
μ_{bin1}	μ_{bin5}	0.124
CutSR3j_all_bin_1_2	μ_{bin3}	-0.124
Wgamma_XS	μ_{bin1}	-0.119
FT_EFF_Eigen_Light_0	μ_{WZ}	-0.115
JET_EtaIntercalibration_Modelling	μ_{bin1}	-0.115
JET_Pileup_RhoTopology	μ_{bin5}	-0.112
signal_EW4_TheoScale	signal_EW6_truthBin0p0to0p5_TheoQCDCorr	0.111
CutSR3j_all_bin_1_3	μ_{bin4}	-0.110
JET_EtaIntercalibration_Modelling	μ_{bin3}	-0.108
signal_EW6_truthBin0p7to0p9_TheoQCDCorr	μ_{bin4}	-0.107
JET_JER_EffectiveNP_1	μ_{bin2}	-0.107
CutSR3j_all_bin_1_1	μ_{bin2}	-0.106
signal_EW4_TheoScale	μ_{bin5}	-0.103
JET_Pileup_RhoTopology	μ_{bin3}	-0.103

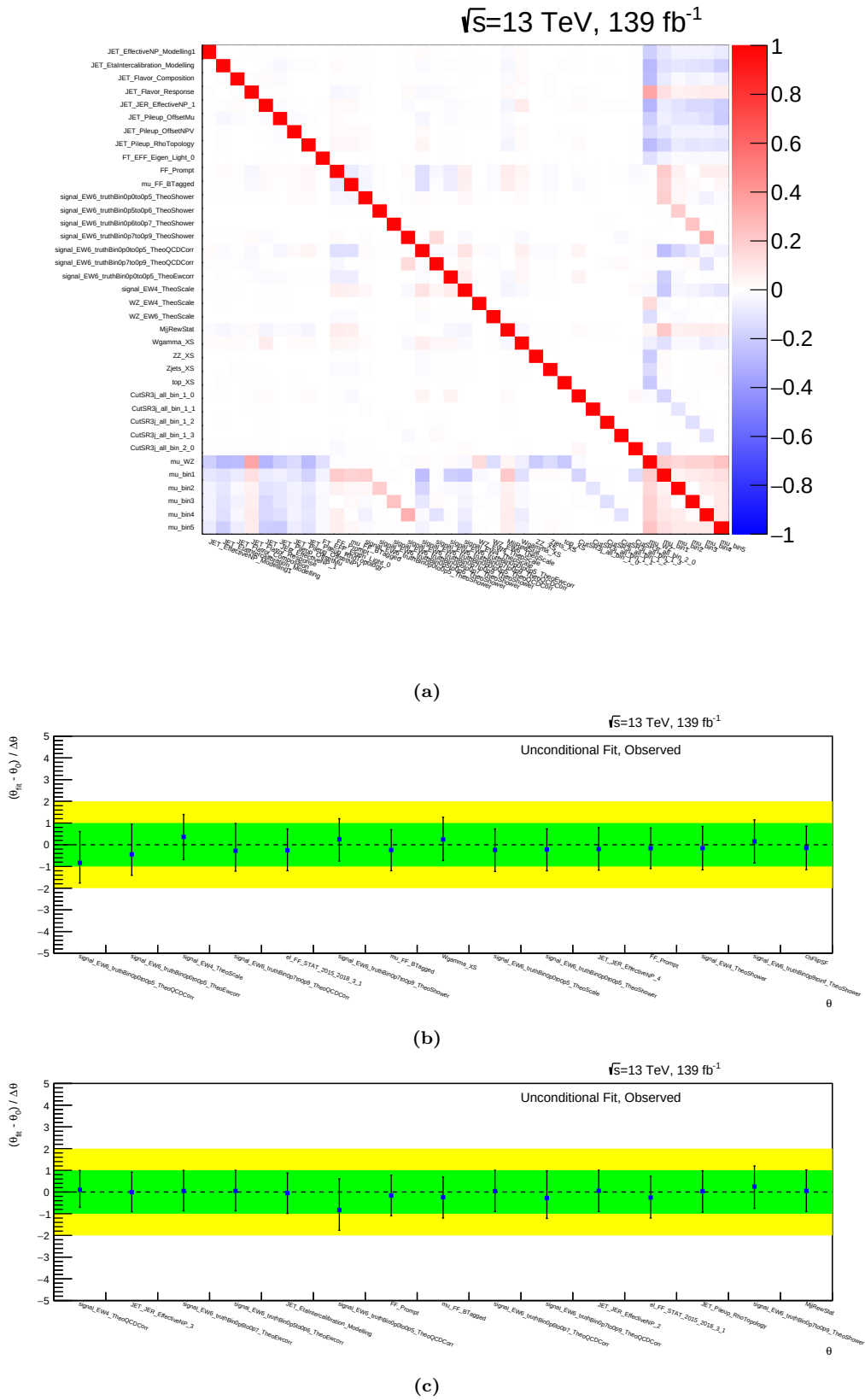


Figure C.110: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.

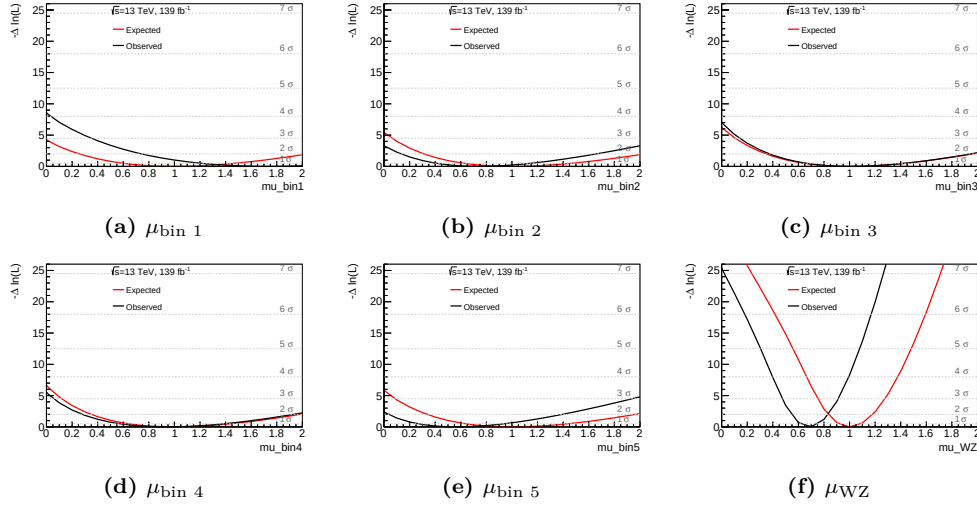


Figure C.111: Likelihood scans of nuisance parameters with largest pulls and constraints in the ξ_{j3} differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-e) and for QCD $W^\pm Z jj$ normalisation parameter (f).

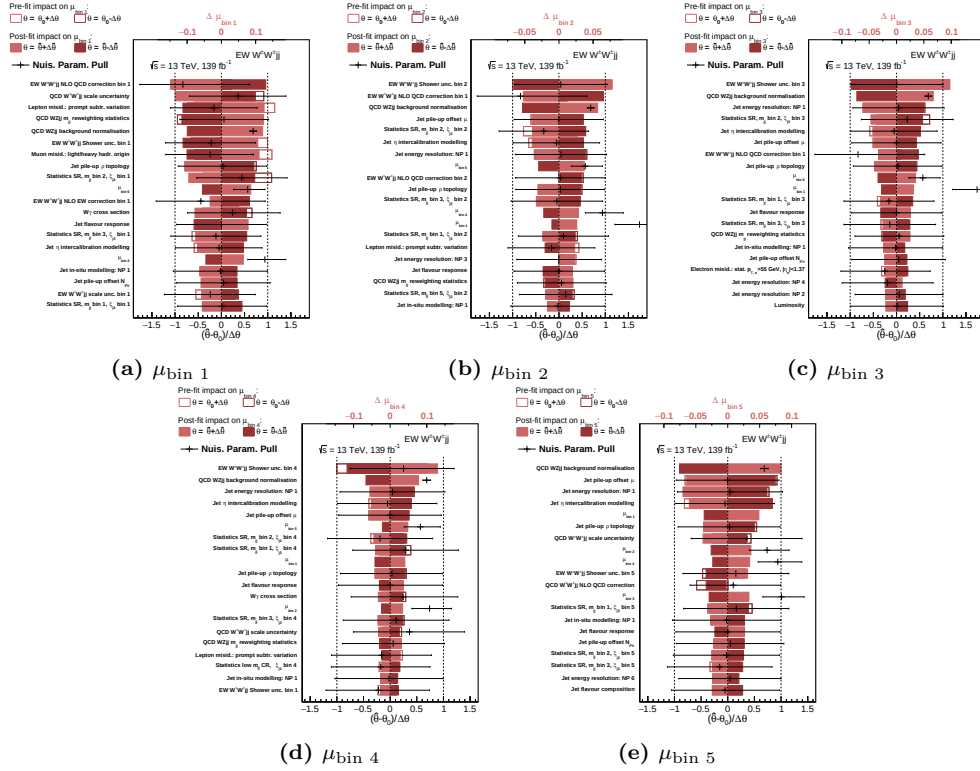


Figure C.112: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data. They are shown for the first (a), second (b), third (c), 4th (d) and 5th (e) ξ_{j3} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

Table C.34: Breakdown of the uncertainty of signal strength in the different ξ_{j3} truth slices in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]				
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$
Experimental					
Electron calibration	0.6	0.5	0.5	0.6	0.7
Muon calibration	0.7	0.6	0.6	0.6	0.6
Jet energy scale and resolution	10.6	11.7	10.9	13.1	24.8
E_T^{miss} scale and resolution	0.2	0.1	0.1	0.1	0.1
b -tagging inefficiency	1.6	0.7	0.9	1.0	1.2
Background, misid. leptons	11.1	5.4	3.1	4.7	7.3
Background, charge misrec.	3.2	1.0	0.4	1.6	3.5
Pileup modelling	1.3	1.4	1.2	1.9	4.3
Luminosity	2.4	2.1	2.0	2.1	2.2
Modelling					
EW $W^\pm W^\pm jj$, shower, scale, PDF & α_s	8.1	10.5	9.2	13.3	4.0
EW $W^\pm W^\pm jj$, QCD corrections	3.6	6.8	2.7	4.7	4.8
EW $W^\pm W^\pm jj$, EW corrections	3.5	0.6	0.4	0.1	0.7
Int $W^\pm W^\pm jj$, shower, scale, PDF & α_s	0.0	0.0	0.1	0.0	0.1
QCD $W^\pm W^\pm jj$, shower, scale, PDF & α_s	8.1	2.1	1.8	3.5	6.8
QCD $W^\pm W^\pm jj$, QCD corrections	0.1	0.0	0.0	0.2	0.5
Background, WZ scale, PDF & α_s	0.7	1.0	0.4	0.3	0.2
Background, WZ reweighting	4.6	1.2	1.2	1.7	1.1
Background, other	3.7	0.7	0.4	2.7	2.1
Model statistical	7.8	8.4	6.4	8.1	9.2
Experimental and modelling	22.7	20.7	16.6	22.4	29.9
Data statistical	23.3	45.8	34.5	37.3	51.3
Total	32.6	50.4	38.3	43.6	59.5

The ranking plot is shown in Figure C.112.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.34.

The correlation between unfolded bins are shown in Figure C.113.

C.5.5 Results of the Fit to Observed Data for ξ_{j3} with EW+Int+QCD Signal

The observed signal strength μ from the fit to observed data is:

$$\mu_{\text{obs}, \xi_{j3}, \text{bin 1}}^{\text{EW+Int+QCD}} = 1.67 \pm_{0.28}^{0.29} (\text{stat.}) \pm_{0.13}^{0.16} (\text{mod. syst.}) \pm_{0.19}^{0.20} (\text{exp. syst.}) \pm_{0.02}^{0.04} (\text{lumi.}),$$

$$\mu_{\text{obs}, \xi_{j3}, \text{bin 2}}^{\text{EW+Int+QCD}} = 0.76 \pm_{0.30}^{0.35} (\text{stat.}) \pm_{0.10}^{0.13} (\text{mod. syst.}) \pm_{0.07}^{0.11} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, \xi_{j3}, \text{bin 3}}^{\text{EW+Int+QCD}} = 1.01 \pm_{0.30}^{0.35} (\text{stat.}) \pm_{0.08}^{0.13} (\text{mod. syst.}) \pm_{0.09}^{0.12} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

$$\mu_{\text{obs}, \xi_{j3}, \text{bin 4}}^{\text{EW+Int+QCD}} = 0.99 \pm_{0.30}^{0.34} (\text{stat.}) \pm_{0.12}^{0.16} (\text{mod. syst.}) \pm_{0.10}^{0.15} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.}),$$

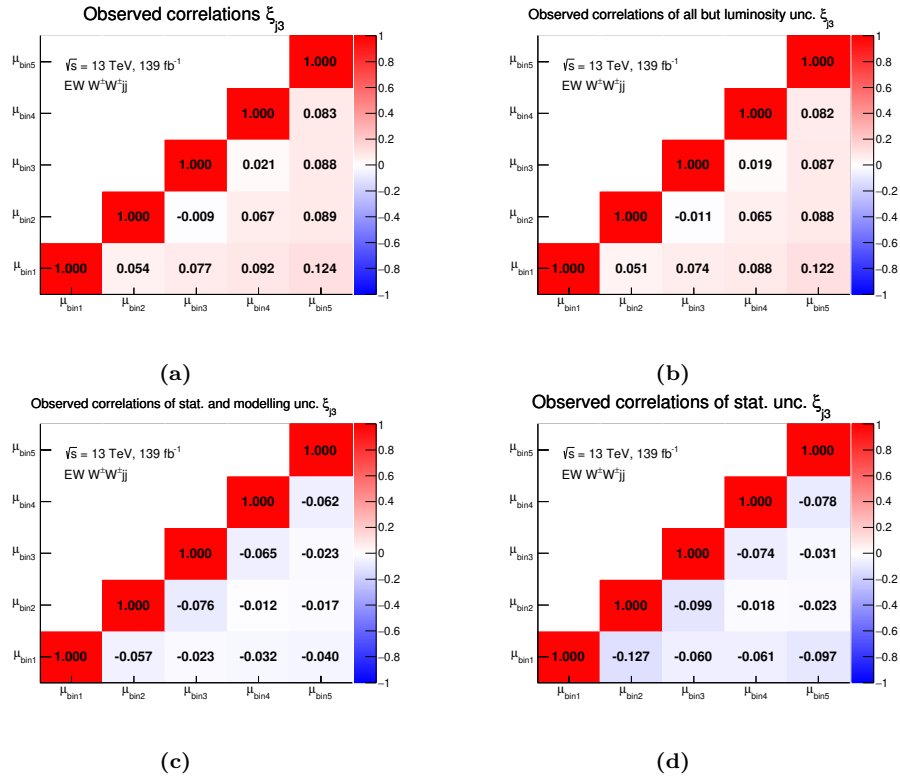


Figure C.113: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

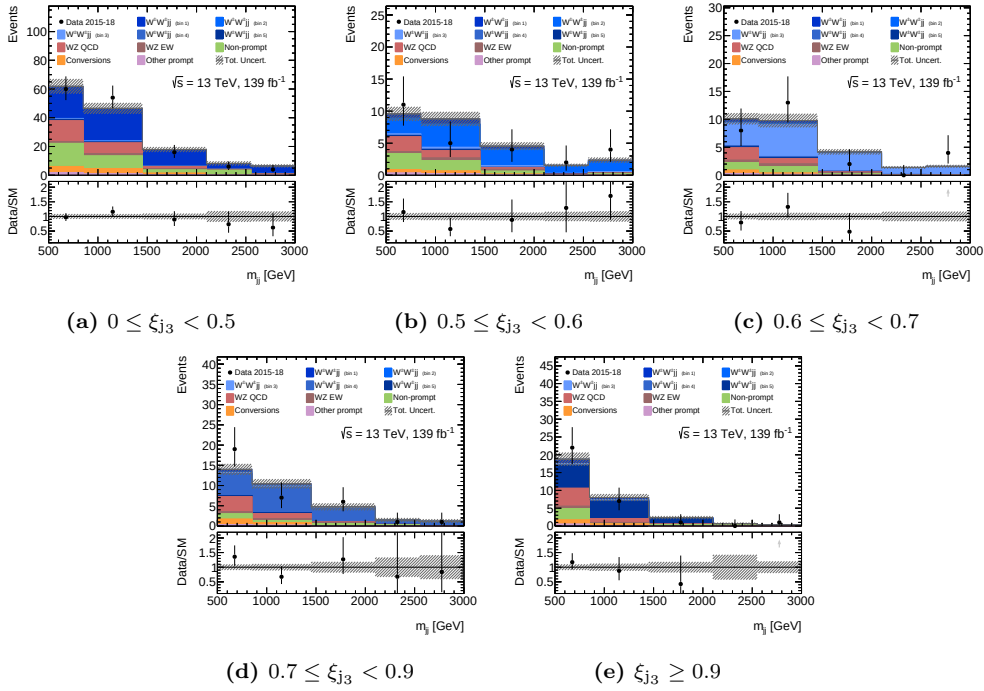


Figure C.114: Post-fit m_{jj} -distributions in signal region split into ξ_{j3} slices as used in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

$$\mu_{\text{obs}, \xi_{j3}, \text{bin } 5}^{\text{EW+Int+QCD}} = 0.67 \pm_{0.25}^{0.28} (\text{stat.}) \pm_{0.06}^{0.08} (\text{mod. syst.}) \pm_{0.12}^{0.18} (\text{exp. syst.}) \pm_{0.01}^{0.02} (\text{lumi.})$$

and the QCD $W^\pm Z jj$ normalisation strength is:

$$\mu_{\text{WZ, obs}, \xi_{j3}}^{\text{EW+Int+QCD}} = 0.69 \pm_{0.04}^{0.04} (\text{stat.}) \pm_{0.03}^{0.03} (\text{mod. syst.}) \pm_{0.05}^{0.06} (\text{exp. syst.}) \pm_{0.01}^{0.01} (\text{lumi.}).$$

Post-fit plots are in Figure C.114 and Figure C.115. The projections on ξ_{j3} and on m_{jj} are shown in Figure C.116.

Pull plot and correlations are in Figure C.117.

Selected profile LH scans are in Figure C.118.

Table of the strongest (anti-)correlations are included in Table C.35.

The ranking plot is shown in Figure C.119.

The impact of different components of systematic uncertainties on the measured differential fiducial cross-section is shown in Table C.36.

The correlation between unfolded bins are shown in Figure C.120.

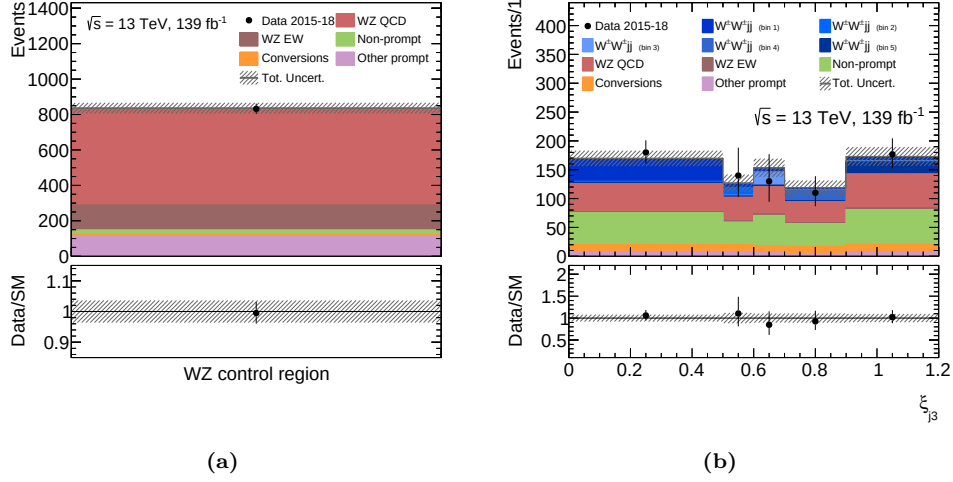


Figure C.115: Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

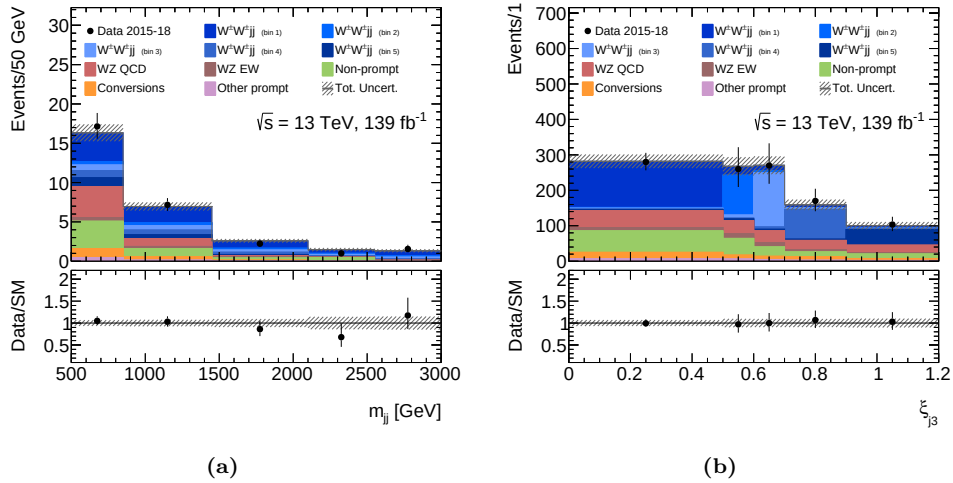


Figure C.116: Post-fit signal region summed over ξ_{j3} slices (a) and summed over m_{jj} slices (b) in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

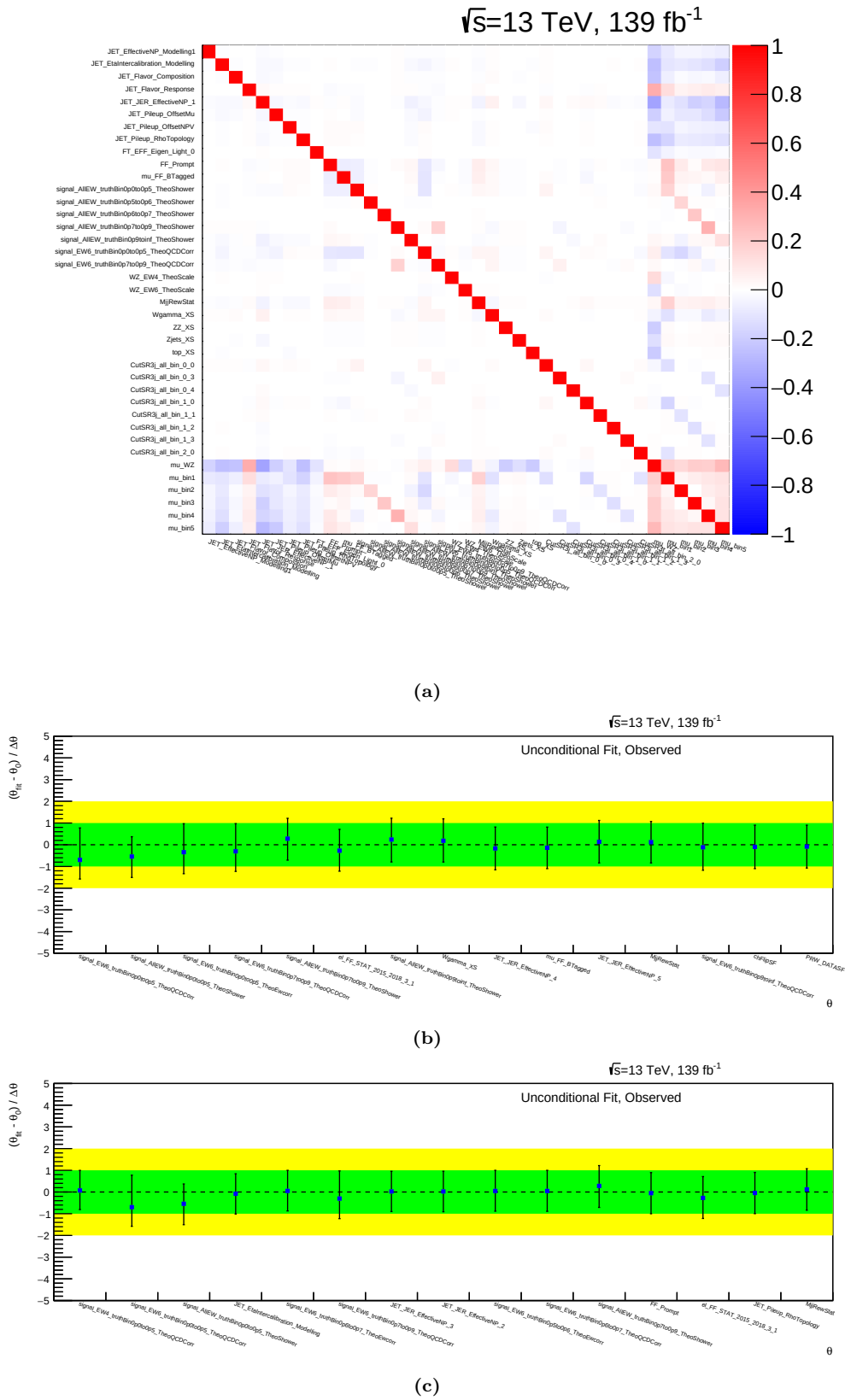


Figure C.117: Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

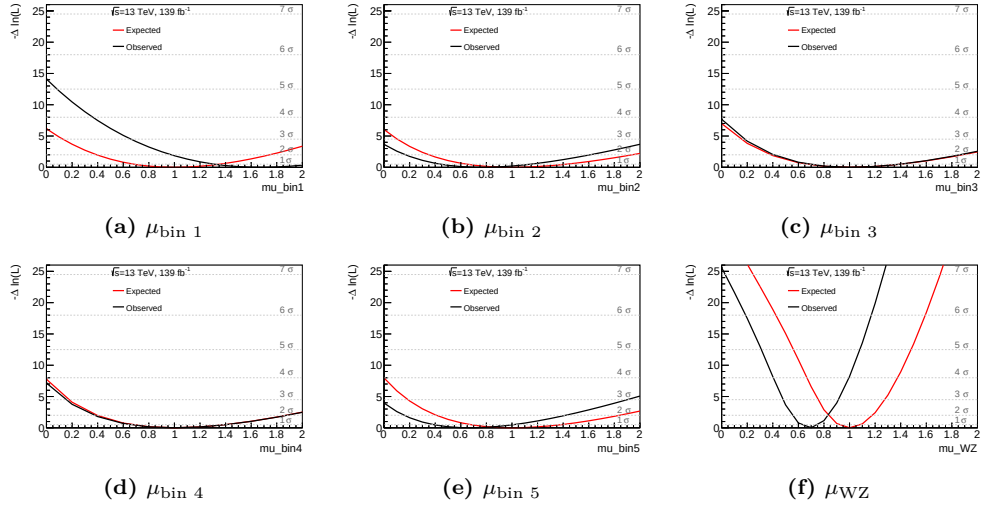


Figure C.118: Likelihood scans of nuisance parameters with largest pulls and constraints in the ξ_{j3} differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-e) and for QCD $W^\pm Z jj$ normalisation parameter (f).

Table C.35: List of parameter correlations which are larger than 10% in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

Parameter 1	Parameter 2	Correlation
JET_JER_EffectiveNP_1	μ_WZ	-0.365
JET_Flavor_Response	μ_WZ	0.321
signal_AllEW_truthBin0p7to0p9_TheoShower	μ_bin4	0.306
μ_WZ	μ_bin5	0.275
JET_JER_EffectiveNP_1	μ_bin5	-0.272
JET_Pileup_RhoTopology	μ_WZ	-0.252
JET_EtaIntercalibration_Modelling	μ_WZ	-0.250
JET_Flavor_Composition	μ_WZ	-0.238
FF_Prompt	μ_bin1	0.237
signal_AllEW_truthBin0p6to0p7_TheoShower	μ_bin3	0.220
JET_Pileup_OffsetMu	μ_bin5	-0.215
$\mu_FF_BTagged$	μ_bin1	0.210
top_XS	μ_WZ	-0.207
ZZ_XS	μ_WZ	-0.196
μ_WZ	μ_bin3	0.193
JET_Pileup_OffsetMu	μ_WZ	-0.192
μ_WZ	μ_bin4	0.189
JET_EtaIntercalibration_Modelling	μ_bin5	-0.188
JET_JER_EffectiveNP_1	μ_bin3	-0.185
μ_bin1	μ_WZ	0.185
signal_AllEW_truthBin0p7to0p9_TheoShower	signal_EW6_truthBin0p7to0p9_TheoQCDCorr	0.182
MjjRewStat	μ_bin1	0.180
JET_Pileup_RhoTopology	μ_bin1	-0.175
signal_AllEW_truthBin0p0to0p5_TheoShower	μ_bin1	0.174
JET_EffectiveNP_Modelling1	μ_WZ	-0.169
CutSR3j_all_bin_1_0	μ_bin1	-0.169
signal_AllEW_truthBin0p5to0p6_TheoShower	μ_bin2	0.168
JET_JER_EffectiveNP_1	μ_bin4	-0.163
signal_EW6_truthBin0p0to0p5_TheoQCDCorr	μ_bin2	-0.158
μ_WZ	μ_bin2	0.148
WZ_EW4_TheoScale	μ_WZ	0.140
JET_Flavor_Response	μ_bin1	0.136
JET_Pileup_OffsetMu	μ_bin4	-0.131
WZ_EW6_TheoScale	μ_WZ	-0.129
signal_AllEW_truthBin0p9toinf_TheoShower	μ_bin5	0.127
CutSR3j_all_bin_0_0	μ_bin1	-0.126
JET_EtaIntercalibration_Modelling	μ_bin4	-0.126
Zjets_XS	μ_WZ	-0.125
CutSR3j_all_bin_1_2	μ_bin3	-0.122
JET_JER_EffectiveNP_1	μ_bin2	-0.118
Wgamma_XS	μ_bin1	-0.118
JET_Pileup_RhoTopology	μ_bin5	-0.116
signal_EW6_truthBin0p0to0p5_TheoQCDCorr	μ_bin1	-0.114
μ_bin1	μ_bin5	0.114
JET_Pileup_OffsetNPV	μ_bin1	-0.113
CutSR3j_all_bin_1_1	μ_bin2	-0.112
FT_EFF_Eigen_Light_0	μ_WZ	-0.112
CutSR3j_all_bin_2_0	μ_bin1	-0.112
μ_bin3	μ_bin5	0.111
μ_bin4	μ_bin5	0.107
CutSR3j_all_bin_1_3	μ_bin4	-0.107
CutSR3j_all_bin_0_4	μ_bin5	-0.107
CutSR3j_all_bin_0_3	μ_bin4	-0.107
JET_Pileup_OffsetNPV	μ_WZ	-0.106
FF_Prompt	μ_bin5	0.104
$\mu_FF_BTagged$	signal_EW6_truthBin0p0to0p5_TheoQCDCorr	-0.103
JET_EtaIntercalibration_Modelling	μ_bin1	-0.102

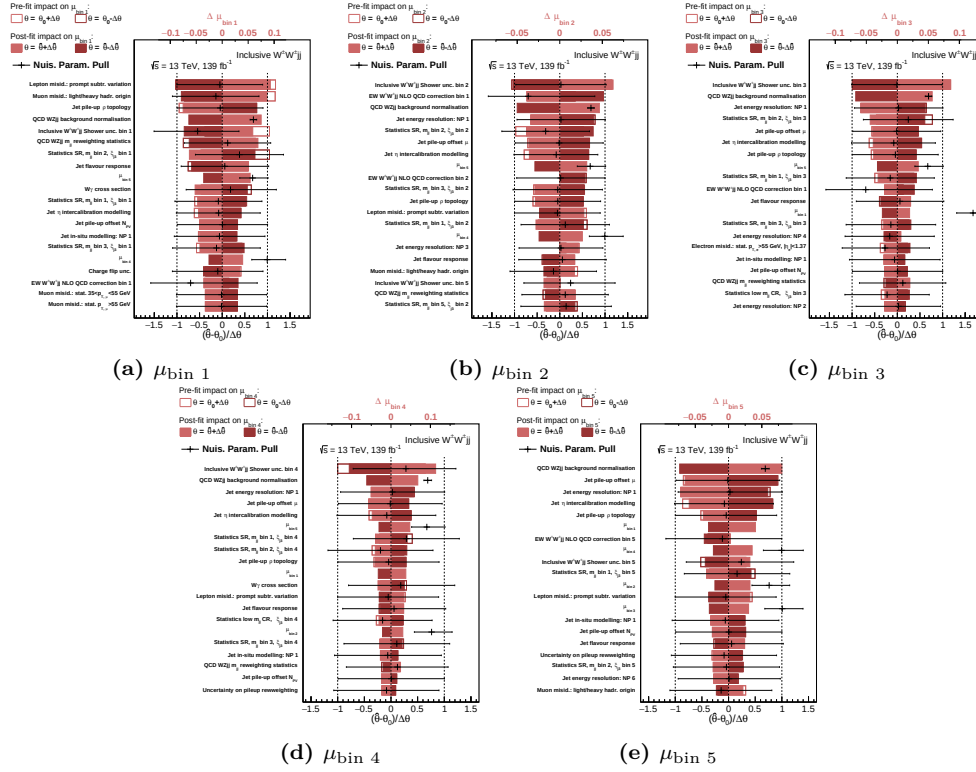


Figure C.119: Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. They are shown for the first (a), second (b), third (c), 4th (d) and 5th (e) ξ_{j3} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.

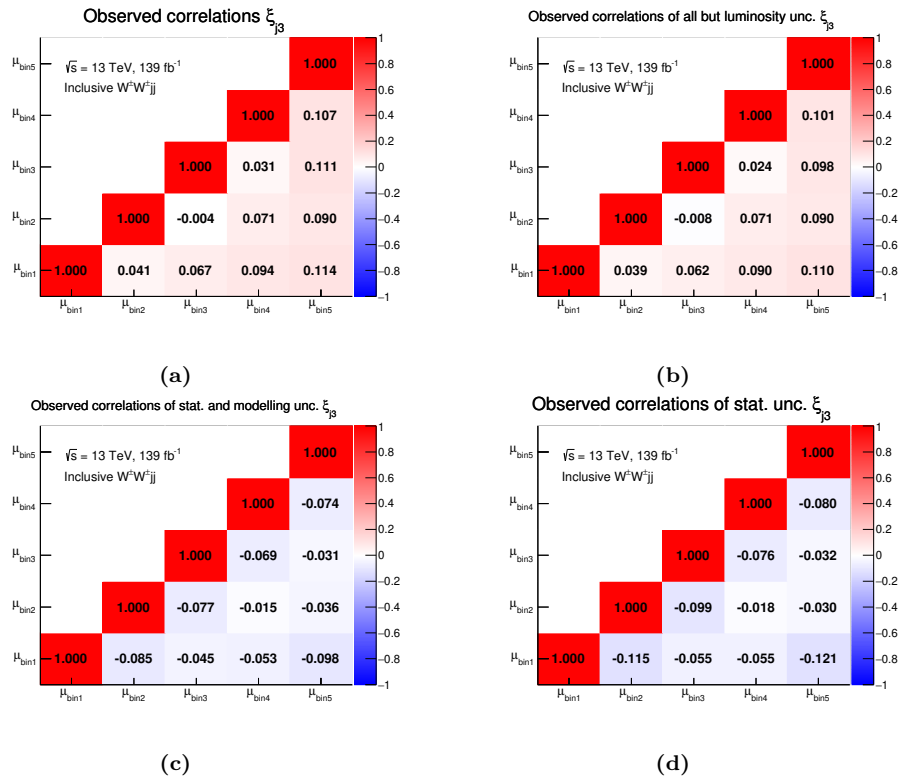


Figure C.120: The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.

Table C.36: Breakdown of the uncertainty of signal strength in the different ξ_{j3} truth slices in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.

Source	Impact [%]				
	$\mu_{\text{bin 1}}$	$\mu_{\text{bin 2}}$	$\mu_{\text{bin 3}}$	$\mu_{\text{bin 4}}$	$\mu_{\text{bin 5}}$
Experimental					
Electron calibration	0.4	0.4	0.4	0.5	0.5
Muon calibration	0.5	0.5	0.5	0.5	0.4
Jet energy scale and resolution	7.3	10.2	9.6	11.4	20.7
E_T^{miss} scale and resolution	0.1	0.2	0.1	0.3	0.1
b -tagging inefficiency	1.3	0.7	0.9	0.9	0.9
Background, misid. leptons	8.5	5.8	3.1	4.8	7.4
Background, charge misrec.	2.5	1.1	0.8	1.7	3.4
Pileup modelling	0.9	1.4	1.1	1.7	3.4
Luminosity	1.8	1.8	1.8	1.8	1.6
Modelling					
$W^\pm W^\pm jj$ shower, scale, PDF & α_s	5.2	9.1	8.0	11.2	3.9
EW $W^\pm W^\pm jj$, QCD corrections	0.8	7.2	3.1	3.0	5.5
EW $W^\pm W^\pm jj$, EW corrections	1.1	1.2	0.3	0.6	0.7
QCD $W^\pm W^\pm jj$, QCD corrections	0.2	0.6	0.3	0.2	0.9
Background, WZ scale, PDF & α_s	0.7	0.8	0.4	0.2	0.6
Background, WZ reweighting	2.6	1.0	0.9	1.2	0.5
Background, other	2.8	0.9	0.5	2.8	2.1
Model statistical	5.6	8.4	6.2	7.2	7.8
Experimental and modelling	14.7	19.0	15.0	19.0	25.0
Data statistical	17.2	42.4	32.2	32.3	39.1
Total	22.6	46.5	35.6	37.6	46.5

Appendix D

Additional EFT Studies

in this appendix additional information about EFT limits are provided. There is a toy vs. asymptotic formula limit comparison with only statistical uncertainties and no clipping in Section D.1. It is followed by clipped and unclipped limits with only statistical uncertainties with a free-floating EW $W^\pm W^\pm jj$ normalisation in Section D.2. Finally there are additional control plots for expected and observed limits in Section D.3 and Section D.4.

D.1 Expected Limits Calculated with Toys

To check the validity of the asymptotic formula toys are thrown according to the expectations. The following parameters get randomized:

- the number of observed events in each bin

According to the recommendation [154] the following global observables get varied in the toy generation to have an unconditional ensemble:

- the observed detector systematics,
- the observed theory uncertainty systematics and
- the ms of the gamma parameters for the MC stat. uncertainties

They get their initial value from an unconditional fit to observed data and get varied around them as being part of the global observables.

Unclipped and clipped at 1.5 TeV and 0.7 TeV results are derived with toys. The largest differences are expected due to the last bin. Without clipping the significance comes from there, because of this the main interest lies on the unclipped case. For clipped and unclipped values similar deviations are found. Because of this, as in CMS with similar binning, asymptotic formula is used. More detailed studies are needed to understand the remaining differences between toy-driven calculated and asymptotic formula calculated limits. The toy driven calculated limits (Table D.1) and the limits from asymptotic formula (Table 10.6 and D.8) are comparable.

D.2 Free Floating Normalisation EW $W^\pm W^\pm jj$ in EFT Limit Setting

Expected limits with only statistical uncertainties are shown in Table D.2 at the unitarity bound and in Table D.3 for different clipping values. The limits can be compared to Tables D.4 and 10.5. There is a significant difference for low clipping values while for high clipping values the expected limits do not change much. For low clipping values the EFT contributions becomes dominant in the first bins making the EFT effect more similar to the $W^\pm W^\pm jj$ prediction. Thus, a normalisation factor on $W^\pm W^\pm jj$ can compensate EFT effects for low clipping values easier.

Table D.1: Toy driven stat. only limits on the Wilson coefficients without clipping calculated for observed data. For each of the points 5000 toys around the scanned EFT parameter toy were generated. This results in a systematic uncertainty of 0.2% because of the limited number of toys.

Coefficient	no clipping [TeV ⁻⁴]		clipped at 1.5 TeV [TeV ⁻⁴]		clipped at 700 GeV [TeV ⁻⁴]	
f_{M0}/Λ^4	-4.52	4.61	-24.66	24.33	-140.76	123.68
f_{M1}/Λ^4	-7.89	7.96	-41.00	44.76	-235.44	257.29
f_{M7}/Λ^4	-10.93	10.79	-60.53	60.32	-428.02	391.43
f_{S02}/Λ^4	-6.81	6.76	-28.21	29.62	-186.80	210.79
f_{S1}/Λ^4	-27.02	26.38	-113.82	117.44	-710.76	790.80
f_{T0}/Λ^4	-0.40	0.39	-2.77	2.98	-17.59	18.08
f_{T1}/Λ^4	-0.20	0.20	-1.51	-0.21	-13.89	-7.08
f_{T2}/Λ^4	-0.77	0.85	-5.41	-1.50	-34.02	47.53

Table D.2: Expected limits on the Wilson coefficients for all Operators for the clipping value at the unitarity bound for different uncertainty sets calculated with asymptotic formula with floating μ_{EW} . "–" means that no crossing with the unitarity bound was found in the scanned region above 600 GeV.

Coefficient	fit type	lower limit		upper limit	
		clipping energy [TeV]	limit [TeV ⁻⁴]	clipping energy [TeV]	limit [TeV ⁻⁴]
f_{M0}/Λ^4	statOnly	0.88	-68.20	1.01	39.39
f_{M1}/Λ^4	statOnly	1.62	-24.00	1.54	28.94
f_{M7}/Λ^4	statOnly	1.81	-30.57	1.88	26.05
f_{S02}/Λ^4	statOnly	0.78	-101.09	0.75	120.91
f_{S1}/Λ^4	statOnly	–	–	–	–
f_{T0}/Λ^4	statOnly	1.26	-2.99	1.16	4.19
f_{T1}/Λ^4	statOnly	2.64	-0.31	2.48	0.40
f_{T2}/Λ^4	statOnly	1.76	-2.42	1.33	7.49

Table D.3: Expected limits on the Wilson coefficients for all Operators for different clipping values and different uncertainty sets for calculated with asymptotic formula with floating μ_{EW} .

Coefficient	fit type	Limits [TeV ⁻⁴] for clipping value [GeV]																					
		600	700	1000	1200	1500	2000	2500	3000	3500	5000	None											
f_{M0}/Λ^4	statOnly	-158.14	142.95	-105.17	94.51	-43.80	40.10	-28.22	26.37	-17.28	16.45	-9.70	9.44	-6.69	6.57	-5.32	5.23	-4.62	4.55	-3.91	3.87	-3.80	3.76
f_{M1}/Λ^4	statOnly	-298.06	309.57	-158.14	167.66	-65.52	73.73	-43.40	49.35	-26.67	30.09	-15.25	16.91	-10.82	11.83	-8.63	9.33	-7.47	8.01	-6.28	6.66	-6.10	6.45
f_{M7}/Λ^4	statOnly	-564.09	508.61	-307.77	272.86	-108.45	102.62	-69.93	66.87	-41.90	40.47	-23.64	21.71	-16.47	15.24	-13.02	12.14	-11.21	10.52	-9.40	8.89	-9.10	8.63
f_{S02}/Λ^4	statOnly	-221.86	241.41	-121.57	133.95	-46.16	51.22	-30.16	32.91	-18.85	20.22	-11.28	11.86	-8.19	8.52	-6.77	6.99	-6.07	6.24	-5.43	5.56	-5.36	5.49
f_{S1}/Λ^4	statOnly	-742.05	765.33	-477.28	510.73	-183.20	195.96	-123.60	131.71	-76.71	81.00	-45.78	47.53	-32.78	33.80	-27.00	27.70	-24.21	24.80	-21.59	22.04	-21.32	21.76
f_{T0}/Λ^4	statOnly	-18.53	18.60	-12.26	13.06	-5.24	6.04	-3.27	3.70	-1.89	2.12	-1.00	1.09	-0.67	0.72	-0.51	0.54	-0.44	0.45	-0.35	0.35	-0.33	0.33
f_{T1}/Λ^4	statOnly	-13.61	18.14	-9.06	12.16	-2.96	3.99	-1.76	2.30	-1.00	1.26	-0.50	0.60	-0.33	0.39	-0.25	0.29	-0.21	0.24	-0.16	0.18	-0.15	0.17
f_{T2}/Λ^4	statOnly	-45.49	56.85	-26.53	37.31	-8.65	14.18	-5.43	9.14	-3.18	5.24	-1.72	2.64	-1.16	1.68	-0.90	1.24	-0.75	1.00	-0.58	0.73	-0.55	0.67

D.3 Additional Information for Expected Limits

Expected limits for all operators for different clipping values are listed in Table D.4. Pre- and post-fit yields for M0 operator are listed in Tables D.5 to D.7.

The pull plots are shown for the upper and lower expected limits without clipping in Figure D.1, with clipping at 1.5 TeV in Figure D.2 and with clipping at 700 GeV in Figure D.3. They are all very similar for the same clipping value.

Table D.4: Expected limits on the Wilson coefficients for all operators for different clipping values and different uncertainty sets calculated with asymptotic formula.

Coefficient	fit type	Limits [TeV ⁻⁴] for clipping value [GeV]																					
		600	700	1000	1200	1500	2000	2500	3000	3500	5000	None											
f_{M0}/Λ^4	statOnly	-100.33	76.61	-77.84	61.09	-39.97	34.14	-26.74	23.96	-16.73	15.58	-9.51	9.16	-6.59	6.43	-5.25	5.14	-4.56	4.48	-3.86	3.81	-3.76	3.71
	statTheoOnly	-131.59	107.47	-96.73	81.21	-43.58	38.95	-28.33	26.12	-17.43	16.47	-10.80	9.50	-6.76	6.63	-5.38	5.29	-4.68	4.60	-3.97	3.92	-3.86	3.81
	full	-135.04	110.80	-99.15	83.64	-45.06	40.35	-29.42	27.16	-18.12	17.14	-10.07	9.77	-6.87	6.74	-5.44	5.35	-4.72	4.65	-4.00	3.95	-3.89	3.84
f_{M1}/Λ^4	statOnly	-180.39	223.65	-119.92	142.14	-56.55	67.65	-39.12	46.49	-24.93	28.93	-14.65	16.49	-10.51	11.59	-8.43	9.17	-7.32	7.89	-6.18	6.58	-6.01	6.37
	statTheoOnly	-241.66	277.64	-146.52	163.09	-63.87	73.65	-42.84	49.62	-26.58	30.35	-15.30	17.09	-10.91	11.97	-8.71	9.45	-7.56	8.13	-6.38	6.78	-6.20	6.57
	full	-249.15	285.09	-150.72	167.40	-66.16	76.00	-44.55	51.40	-27.70	31.50	-15.82	17.60	-11.15	12.20	-8.86	9.58	-7.66	8.23	-6.45	6.84	-6.27	6.63
f_{M7}/Λ^4	statOnly	-345.01	293.62	-230.23	195.34	-96.75	88.46	-64.74	60.13	-39.96	37.97	-22.90	20.89	-16.00	14.77	-12.69	11.81	-10.94	10.25	-9.19	8.68	-8.91	8.43
	statTheoOnly	-477.41	410.91	-282.89	244.25	-106.01	99.38	-69.16	65.72	-41.96	40.42	-23.76	21.73	-16.52	15.26	-13.07	12.17	-11.26	10.54	-9.45	8.93	-9.18	8.68
	full	-489.65	423.06	-289.85	251.20	-109.80	102.87	-71.94	68.31	-43.74	42.17	-24.53	22.53	-16.87	15.61	-13.27	12.37	-11.40	10.69	-9.54	9.02	-9.27	8.77
f_{S02}/Λ^4	statOnly	-139.44	187.85	-93.16	117.35	-40.62	47.84	-27.69	31.42	-17.92	19.66	-10.97	11.65	-8.03	8.41	-6.66	6.92	-5.98	6.19	-5.37	5.52	-5.30	5.45
	statTheoOnly	-184.64	223.81	-112.90	131.18	-45.34	51.52	-30.10	33.34	-19.01	20.57	-11.43	12.06	-8.31	8.67	-6.88	7.13	-6.17	6.36	-5.53	5.68	-5.46	5.61
	full	-191.06	229.63	-116.35	134.62	-46.93	53.16	-31.22	34.48	-19.71	21.27	-11.73	12.35	-8.47	8.82	-6.98	7.22	-6.25	6.44	-5.60	5.74	-5.53	5.66
f_{S1}/Λ^4	statOnly	-504.87	622.83	-359.35	437.62	-160.43	181.44	-112.63	124.69	-72.41	78.14	-44.25	46.43	-32.01	33.20	-26.48	27.28	-23.81	24.46	-21.27	21.77	-21.02	21.50
	statTheoOnly	-647.32	728.98	-439.51	496.19	-179.09	195.50	-122.30	132.14	-76.76	81.72	-46.11	48.04	-33.11	34.20	-27.31	28.06	-24.53	25.15	-21.92	22.40	-21.66	22.12
	full	-667.81	749.03	-453.07	509.94	-185.41	202.04	-127.02	137.11	-80.01	85.04	-47.89	49.81	-34.07	35.13	-27.93	28.65	-25.00	25.60	-22.28	22.74	-22.01	22.46
f_{T0}/Λ^4	statOnly	-12.21	12.06	-9.25	9.79	-4.64	5.43	-3.04	3.51	-1.82	2.06	-0.98	1.07	-0.65	0.71	-0.50	0.54	-0.43	0.44	-0.34	0.35	-0.32	0.33
	statTheoOnly	-15.75	15.65	-11.33	12.09	-5.15	6.03	-3.26	3.73	-1.91	2.15	-1.01	1.10	-0.67	0.72	-0.52	0.55	-0.44	0.45	-0.35	0.35	-0.33	0.34
	full	-16.13	16.03	-11.61	12.38	-5.34	6.24	-3.40	3.89	-2.00	2.24	-1.04	1.13	-0.68	0.73	-0.52	0.56	-0.45	0.45	-0.35	0.36	-0.34	0.34
f_{T1}/Λ^4	statOnly	-9.40	15.80	-6.65	11.18	-2.62	3.94	-1.62	2.28	-0.95	1.25	-0.49	0.60	-0.33	0.39	-0.25	0.29	-0.21	0.24	-0.16	0.18	-0.15	0.17
	statTheoOnly	-11.99	17.92	-8.38	12.61	-2.92	4.09	-1.75	2.35	-1.00	1.29	-0.51	0.61	-0.34	0.40	-0.26	0.29	-0.21	0.24	-0.17	0.18	-0.16	0.17
	full	-12.34	18.28	-8.67	12.98	-3.06	4.26	-1.84	2.46	-1.05	1.35	-0.52	0.63	-0.34	0.40	-0.26	0.30	-0.22	0.24	-0.17	0.19	-0.16	0.17
f_{T2}/Λ^4	statOnly	-21.41	35.52	-16.05	29.45	-6.96	13.64	-4.63	8.94	-2.86	5.17	-1.61	2.61	-1.11	1.66	-0.87	1.23	-0.73	0.99	-0.57	0.73	-0.53	0.67
	statTheoOnly	-31.04	46.11	-22.59	37.00	-8.85	18.18	-5.34	10.42	-3.15	5.65	-1.71	2.76	-1.16	1.74	-0.91	1.29	-0.76	1.05	-0.59	0.76	-0.56	0.70
	full	-32.02	47.35	-23.38	38.01	-9.21	18.54	-5.59	10.69	-3.30	5.82	-1.77	2.82	-1.19	1.76	-0.92	1.30	-0.78	1.06	-0.60	0.76	-0.56	0.70

Table D.5: Pre-fit yields in the signal region. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	(1, 1)			(1, 2)			(1, 3)			(1, 4)			(1, 5)			('tot', 'tot')		
Other prompt	5.8	± 0.2	± 1.0	± 0.5	1.07	± 0.12	± 0.23	± 0.18	0.145 ± 0.031 ± 0.029 ± 0.034	0.012 ± 0.009 ± 0.004 ± 0.012	0.018 ± 0.010 ± 0.004 ± 0.003	7.1	± 0.3	± 1.3	± 0.6			
Conversions	17	± 1	± 4	± 3	3.4	± 0.3	± 0.4	± 0.7	0.84 ± 0.17 ± 0.13 ± 0.12	0.12 ± 0.04 ± 0.01 ± 0.03	0.09 ± 0.06 ± 0.00 ± 0.02	21	± 1	± 4	± 4			
Non-prompt	44	± 5	± 0	± 9	8.1	± 2.1	± 0.0	± 1.9	2.1 ± 1.0 ± 0.0 ± 0.6	0.7 ± 0.5 ± 0.0 ± 0.3	0.4 ± 0.4 ± 0.0 ± 0.2	56	± 5	± 0	± 11			
WZ EW	8.7	± 0.3	± 1.0	± 0.4	1.98	± 0.13	± 0.30	± 0.11	0.42 ± 0.06 ± 0.08 ± 0.05	0.087 ± 0.030 ± 0.020 ± 0.017	0.025 ± 0.015 ± 0.007 ± 0.013	11.2	± 0.3	± 1.4	± 0.4			
WZ QCD	49	± 1	± 4	± 3	6.3	± 0.3	± 0.6	± 0.5	0.66 ± 0.08 ± 0.07 ± 0.07	0.12 ± 0.06 ± 0.05 ± 0.02	0.08 ± 0.05 ± 0.01 ± 0.01	56	± 1	± 5	± 3			
W [±] W [±] jj QCD	13	± 0	± 4	± 0	8.0	± 0.1	± 2.3	± 0.2	2.3 ± 0.0 ± 0.7 ± 0.1	0.64 ± 0.03 ± 0.20 ± 0.03	0.36 ± 0.02 ± 0.12 ± 0.02	24	± 0	± 7	± 1			
W [±] W [±] jj Int	6.0	± 0.1	± 1.3	± 0.1	1.33	± 0.03	± 0.22	± 0.03	0.186 ± 0.013 ± 0.030 ± 0.010	0.030 ± 0.006 ± 0.006 ± 0.009	0.013 ± 0.004 ± 0.005 ± 0.003	7.6	± 0.1	± 1.5	± 0.1			
W [±] W [±] jj EW	164	± 2	± 26	± 4	37	± 1	± 7	± 1	5.1 ± 0.3 ± 1.1 ± 0.3	0.93 ± 0.12 ± 0.25 ± 0.13	0.41 ± 0.08 ± 0.13 ± 0.06	207	± 2	± 34	± 5			
EFTWZ_M0_int	0.00	± 0.05	± 0.00	± 0.00	0.00	± 0.04	± 0.00	± 0.00	0.000 ± 0.026 ± 0.000 ± 0.000	0.000 ± 0.018 ± 0.000 ± 0.000	0.000 ± 0.021 ± 0.000 ± 0.000	0.00	± 0.08	± 0.00	± 0.00			
EFTWZ_M0_quad	0.000	± 0.028	± 0.000	± 0.000	0.00	± 0.05	± 0.00	± 0.00	0.00 ± 0.04 ± 0.00 ± 0.00	0.00 ± 0.04 ± 0.00 ± 0.00	0.00 ± 0.07 ± 0.00 ± 0.00	0.00	± 0.11	± 0.00	± 0.00			
EFT_M0_int	0.00	± 0.04	± 0.00	± 0.00	0.00	± 0.06	± 0.00	± 0.00	0.000 ± 0.020 ± 0.000 ± 0.000	0.000 ± 0.031 ± 0.000 ± 0.000	0.000 ± 0.022 ± 0.000 ± 0.000	0.00	± 0.08	± 0.00	± 0.00			
EFT_M0_quad	0.000	± 0.015	± 0.000	± 0.000	0.000	± 0.028	± 0.000	± 0.000	0.000 ± 0.032 ± 0.000 ± 0.000	0.000 ± 0.030 ± 0.000 ± 0.000	0.00 ± 0.07 ± 0.00 ± 0.00	0.00	± 0.09	± 0.00	± 0.00			
obsData	359	± 19	± 0	± 0	99	± 10	± 0	± 0	12.0 ± 3.5 ± 0.0 ± 0.0	3.0 ± 1.7 ± 0.0 ± 0.0	2.0 ± 1.4 ± 0.0 ± 0.0	475	± 22	± 0	± 0			
Total Expected	307	± 5	± 27	± 12	67	± 2	± 7	± 3	11.7 ± 1.1 ± 1.3 ± 0.7	2.6 ± 0.5 ± 0.3 ± 0.4	1.3 ± 0.4 ± 0.2 ± 0.2	390	± 6	± 35	± 16			

Table D.6: Post-fit yields of upper limit of M0 operator without clipping in the signal region. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	bin 1: $20 \leq m_{\ell\ell} < 250$ GeV				bin 2: $250 \leq m_{\ell\ell} < 500$ GeV				bin 3: $500 \leq m_{\ell\ell} < 750$ GeV				bin 4: $750 \leq m_{\ell\ell} < 975$ GeV				bin 5: $m_{\ell\ell} \geq 975$ GeV				Total			
Other prompt	5.8	± 0.0	± 1.0	± 0.5	1.05	± 0.00	± 0.23	± 0.18	0.142	± 0.000	± 0.030	± 0.033	0.011	± 0.000	± 0.004	± 0.011	0.018	± 0.000	± 0.004	± 0.003	7.0	± 0.0	± 1.3	± 0.6
Conversions	16.6	± 0.0	± 3.5	± 3.4	3.4	± 0.0	± 0.4	± 0.7	0.84	± 0.00	± 0.14	± 0.12	0.117	± 0.000	± 0.018	± 0.031	0.091	± 0.000	± 0.004	± 0.018	21	± 0	± 4	± 4
Non-prompt	44	± 0	± 1	± 7	8.0	± 0.0	± 0.2	± 1.6	2.0	± 0.0	± 0.1	± 0.5	0.64	± 0.00	± 0.06	± 0.29	0.33	± 0.00	± 0.01	± 0.15	55	± 0	± 1	± 9
WZ EW	8.6	± 0.0	± 0.9	± 0.4	1.97	± 0.00	± 0.29	± 0.11	0.41	± 0.00	± 0.08	± 0.05	0.085	± 0.000	± 0.021	± 0.016	0.025	± 0.000	± 0.007	± 0.013	11.1	± 0.0	± 1.3	± 0.5
WZ QCD	49	± 5	± 4	± 3	6.3	± 0.7	± 0.6	± 0.5	0.66	± 0.07	± 0.08	± 0.07	0.12	± 0.01	± 0.05	± 0.02	0.076	± 0.008	± 0.008	± 0.012	57	± 6	± 5	± 3
$W^\pm W^\pm jj$	181	± 0	± 16	± 5	45	± 0	± 4	± 1	7.4	± 0.0	± 1.0	± 0.3	1.55	± 0.00	± 0.26	± 0.13	0.76	± 0.00	± 0.13	± 0.06	236	± 0	± 20	± 6
EFTWZ_M0_int	0.016	± 0.000	± 0.003	± 0.007	0.0028	± 0.0000	± 0.0017	± 0.0026	0.0023	± 0.0000	± 0.0010	± 0.0021	0.0071	± 0.0000	± 0.0019	± 0.0035	0.0000	± 0.0000	± 0.0000	± 0.0000	0.028	± 0.000	± 0.007	± 0.012
EFTWZ_M0_quad	0.0084	± 0.0000	± 0.0012	± 0.0004	0.026	± 0.000	± 0.004	± 0.001	0.023	± 0.000	± 0.005	± 0.001	0.018	± 0.000	± 0.005	± 0.001	0.052	± 0.000	± 0.015	± 0.003	0.128	± 0.000	± 0.030	± 0.006
EFT_M0_int	0.36	± 0.00	± 0.04	± 0.01	0.27	± 0.00	± 0.04	± 0.02	0.089	± 0.000	± 0.019	± 0.011	0.027	± 0.000	± 0.009	± 0.006	0.028	± 0.000	± 0.011	± 0.018	0.77	± 0.00	± 0.12	± 0.04
EFT_M0_quad	0.179	± 0.000	± 0.017	± 0.008	0.60	± 0.00	± 0.07	± 0.03	0.75	± 0.00	± 0.11	± 0.03	0.69	± 0.00	± 0.12	± 0.03	3.4	± 0.0	± 0.6	± 0.2	5.6	± 0.0	± 0.8	± 0.3
asimovData	307.5	± 0.0	± 0.0	± 0.0	66.9	± 0.0	± 0.0	± 0.0	11.7	± 0.0	± 0.0	± 0.0	2.6	± 0.0	± 0.0	± 0.0	1.3	± 0.0	± 0.0	± 0.0	390.0	± 0.0	± 0.0	± 0.0
Total Expected	306	± 5	± 16	± 11	67	± 1	± 4	± 2	12.3	± 0.1	± 1.2	± 0.6	3.3	± 0.0	± 0.4	± 0.3	4.8	± 0.0	± 0.6	± 0.3	393	± 6	± 20	± 14

Table D.7: Post-fit yields of lower limit of M0 operator without clipping in the signal region. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	bin 1: $20 \leq m_{\ell\ell} < 250$ GeV				bin 2: $250 \leq m_{\ell\ell} < 500$ GeV				bin 3: $500 \leq m_{\ell\ell} < 750$ GeV				bin 4: $750 \leq m_{\ell\ell} < 975$ GeV				bin 5: $m_{\ell\ell} \geq 975$ GeV				Total				
Other prompt	5.8	± 0.0	± 1.0	± 0.5	1.06	± 0.00	± 0.23	± 0.18	0.143	± 0.000	± 0.030	± 0.033	0.012	± 0.000	± 0.004	± 0.011	0.018	± 0.000	± 0.004	± 0.003	7.0	± 0.0	± 1.3	± 0.6	
Conversions	16.6	± 0.0	± 3.5	± 3.4	3.4	± 0.0	± 0.4	± 0.7	0.84	± 0.00	± 0.14	± 0.12	0.117	± 0.000	± 0.018	± 0.031	0.091	± 0.000	± 0.004	± 0.018	21	± 0	± 4	± 4	
Non-prompt	44	± 0	± 1	± 7	8.0	± 0.0	± 0.2	± 1.6	2.0	± 0.0	± 0.1	± 0.5	0.64	± 0.00	± 0.06	± 0.29	0.33	± 0.00	± 0.01	± 0.15	55	± 0	± 1	± 9	
WZ EW	8.6	± 0.0	± 0.9	± 0.4	1.97	± 0.00	± 0.30	± 0.11	0.41	± 0.00	± 0.08	± 0.05	0.086	± 0.000	± 0.021	± 0.016	0.025	± 0.000	± 0.007	± 0.013	11.1	± 0.0	± 1.3	± 0.5	
WZ QCD	49	± 5	± 4	± 3	6.3	± 0.7	± 0.6	± 0.5	0.66	± 0.07	± 0.08	± 0.07	0.12	± 0.01	± 0.05	± 0.02	0.076	± 0.008	± 0.008	± 0.012	57	± 6	± 5	± 3	
$W^\pm W^\pm jj$	182	± 0	± 16	± 5	46	± 0	± 4	± 1	7.4	± 0.0	± 1.0	± 0.3	1.55	± 0.00	± 0.26	± 0.13	0.76	± 0.00	± 0.13	± 0.06	237	± 0	± 20	± 6	
EFTWZ_M0_int	-0.017	± 0.000	± 0.003	± 0.008	-0.0028	± 0.0000	± 0.0017	± 0.0026	-0.0023	± 0.0000	± 0.0010	± 0.0021	-0.0072	± 0.0000	± 0.0019	± 0.0035	0.0000	± 0.0000	± 0.0000	± 0.0000	20	-0.029	± 0.000	± 0.007	± 0.012
EFTWZ_M0_quad	0.0086	± 0.0000	± 0.0012	± 0.0004	0.026	± 0.000	± 0.004	± 0.001	0.024	± 0.000	± 0.005	± 0.001	0.018	± 0.000	± 0.005	± 0.001	0.053	± 0.000	± 0.016	± 0.003	0.130	± 0.000	± 0.030	± 0.006	
EFT_M0_int	-0.37	± 0.00	± 0.04	± 0.01	-0.27	± 0.00	± 0.04	± 0.02	-0.090	± 0.000	± 0.019	± 0.011	-0.028	± 0.000	± 0.010	± 0.006	-0.028	± 0.000	± 0.011	± 0.018	-0.79	± 0.00	± 0.12	± 0.04	
EFT_M0_quad	0.183	± 0.000	± 0.018	± 0.008	0.61	± 0.00	± 0.07	± 0.03	0.76	± 0.00	± 0.12	± 0.03	0.71	± 0.00	± 0.12	± 0.03	3.5	± 0.0	± 0.6	± 0.2	5.7	± 0.0	± 0.9	± 0.3	
asimovData	307.5	± 0.0	± 0.0	± 0.0	66.9	± 0.0	± 0.0	± 0.0	11.7	± 0.0	± 0.0	± 0.0	2.6	± 0.0	± 0.0	± 0.0	1.3	± 0.0	± 0.0	± 0.0	390.0	± 0.0	± 0.0	± 0.0	
Total Expected	306	± 5	± 16	± 11	67	± 1	± 4	± 2	12.2	± 0.1	± 1.2	± 0.6	3.2	± 0.0	± 0.4	± 0.3	4.8	± 0.0	± 0.6	± 0.3	393	± 6	± 20	± 14	

D.4 Additional Information for Observed Limits

Observed limits for all operators for different clipping values are listed in Table D.8 and Table D.9. Pre- and post-fit yields for observed data for M0 operator clipped at 700 GeV are listed in Tables D.10 to D.14.

The pull plots are shown for the upper and lower observed limits without clipping in Figure D.4, with clipping at 1.5 TeV in Figure D.5 and with clipping at 700 GeV in Figure D.6. They are all very similar for the same clipping value.

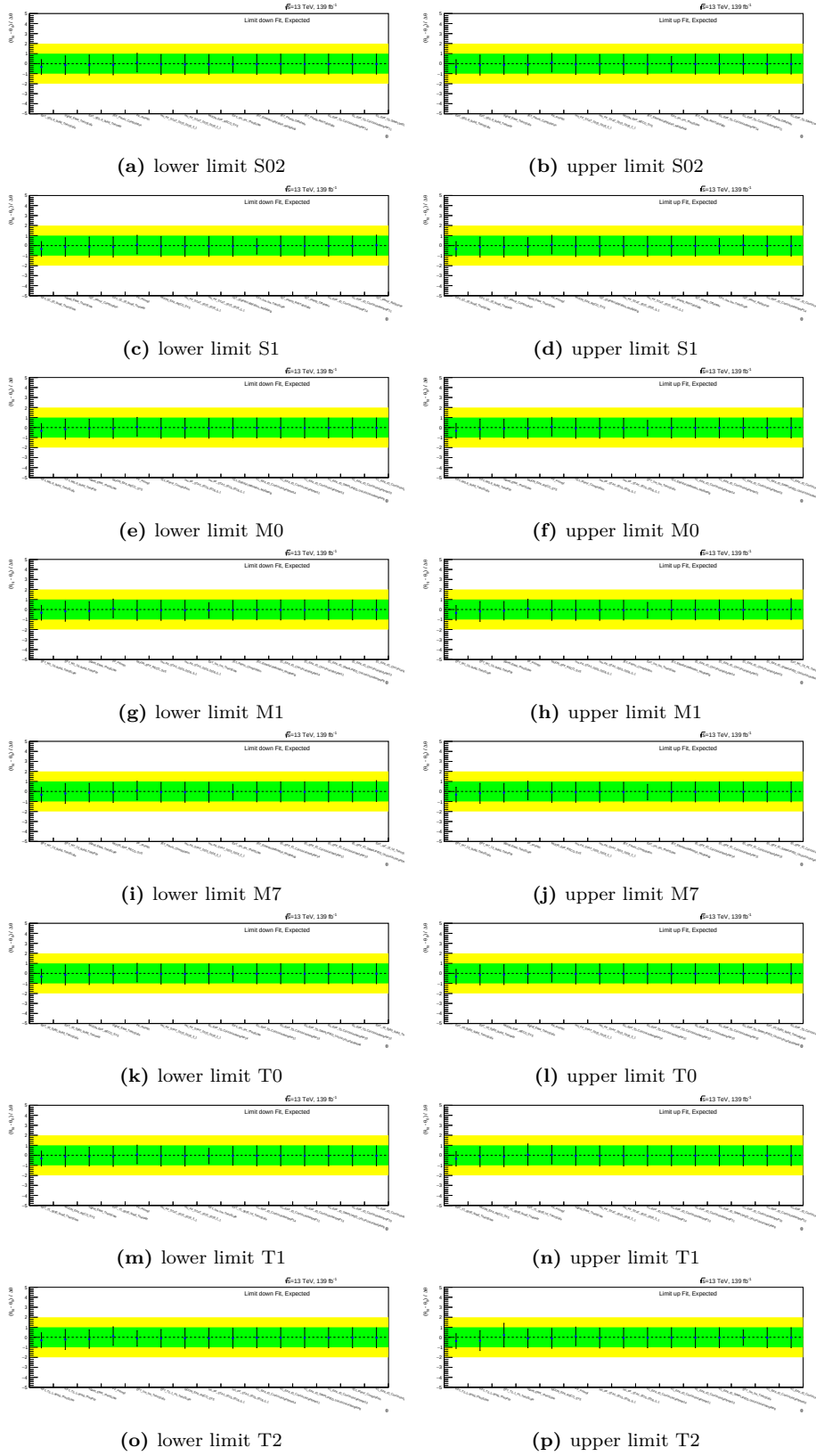


Figure D.1: Pulls of 15 most pulled nuisance parameters for lower (left) and upper (right) expected limits without clipping.

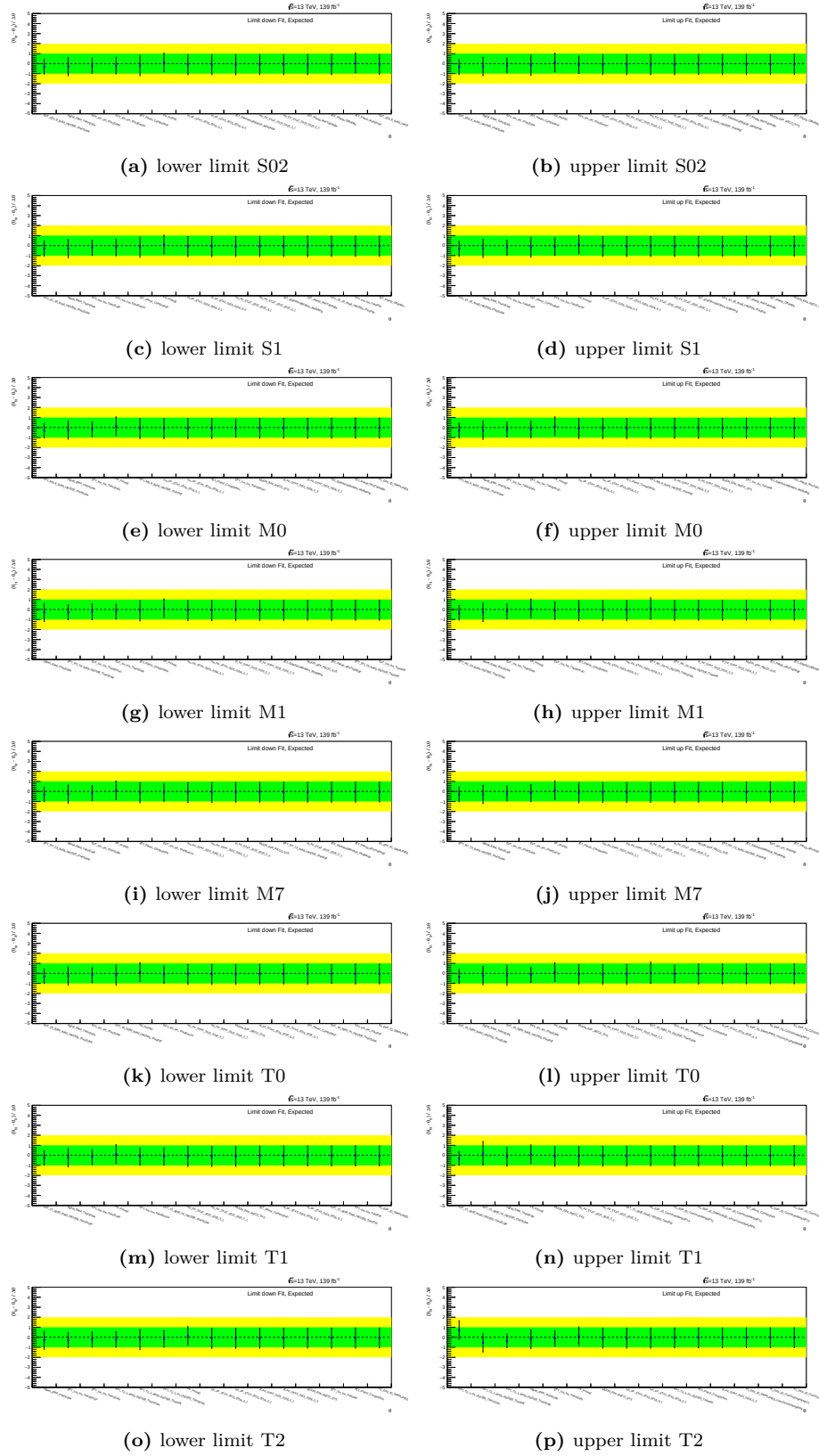


Figure D.2: Pulls of 15 most pulled nuisance parameters for lower (left) and upper (right) expected limits with clipping at 1.5 TeV.

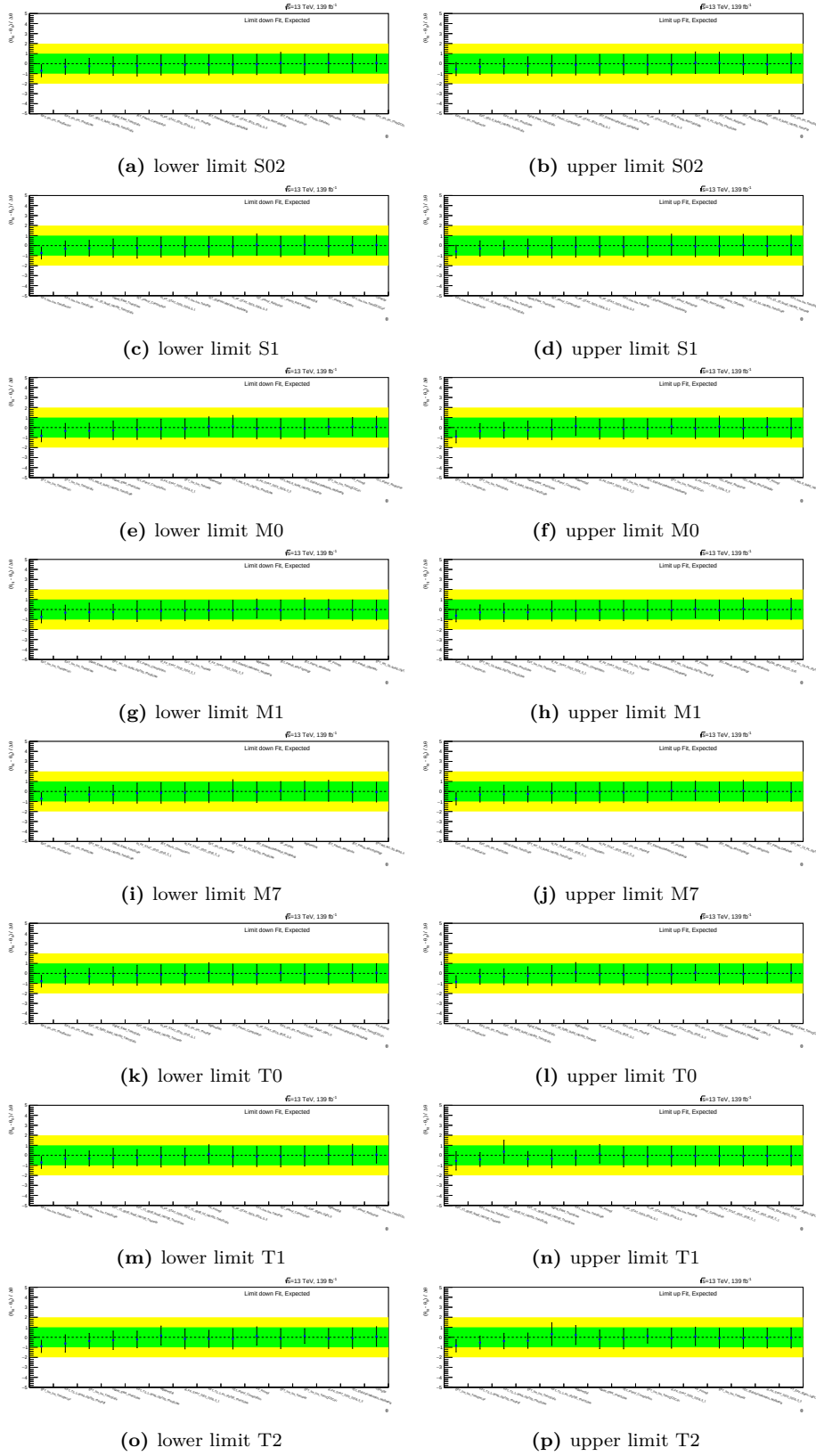


Figure D.3: Pulls of 15 most pulled nuisance parameters for lower (left) and upper (right) expected limits with clipping at 0.7 TeV.

Table D.8: Observed limits on the Wilson coefficients for all operators for different clipping values and different uncertainty sets calculated with asymptotic formula. The most upper and most lower limits are shown, also if there is some exclusion area near the SM prediction. The effects of WZ EFT is included in this table. WZ EFT-SM interference of M7 is still missing.

Coefficient	fit type	Limits [TeV ⁻⁴] for clipping value [GeV]																					
		600	700	1000	1200	1500	2000	2500	3000	3500	5000	None											
f_{M0}/Λ^4	statOnly	-178.70	153.42	-139.14	122.60	-62.33	62.29	-38.55	40.93	-22.17	24.25	-11.80	12.89	-7.92	8.54	-6.21	6.62	-5.35	5.67	-4.50	4.74	-4.36	4.59
	statTheoOnly	-203.03	175.69	-148.04	132.44	-56.88	55.09	-33.71	33.26	-18.97	18.92	-10.38	10.41	-7.16	7.18	-5.72	5.72	-4.98	4.99	-4.25	4.25	-4.13	4.14
	full	-205.38	178.44	-150.85	135.40	-59.28	57.35	-35.32	34.89	-19.77	19.75	-10.61	10.66	-7.23	7.25	-5.74	5.75	-4.99	4.98	-4.24	4.25	-4.13	4.14
f_{M1}/Λ^4	statOnly	-354.57	400.19	-234.97	251.97	-104.02	108.89	-68.87	70.74	-41.07	40.66	-22.10	21.54	-15.04	14.62	-11.64	11.29	-9.88	9.59	-8.12	7.86	-7.86	7.60
	statTheoOnly	-392.18	432.09	-237.65	252.58	-94.48	101.93	-58.45	62.97	-32.87	35.04	-17.50	18.60	-12.14	12.82	-9.58	10.06	-8.26	8.65	-6.95	7.21	-6.75	7.00
	full	-400.41	439.83	-243.18	257.29	-97.72	105.16	-61.10	65.71	-34.35	36.53	-18.00	19.08	-12.31	12.99	-9.65	10.13	-8.30	8.68	-6.96	7.23	-6.76	7.01
f_{M7}/Λ^4	statOnly	-636.63	590.24	-416.37	386.59	-150.29	157.83	-89.29	101.57	-53.30	59.82	-29.11	30.43	-19.74	20.38	-15.36	15.75	-13.10	13.40	-10.87	11.09	-10.51	10.73
	statTheoOnly	-736.15	673.24	-427.68	394.11	-135.53	140.94	-79.29	85.46	-45.70	48.34	-24.92	24.50	-17.32	16.88	-13.73	13.35	-11.86	11.54	-10.00	9.75	-9.72	9.49
	full	-744.10	681.88	-436.67	402.62	-142.20	146.36	-83.69	89.44	-48.09	50.66	-25.73	25.29	-17.62	17.14	-13.87	13.45	-11.94	11.59	-10.03	9.77	-9.75	9.50
f_{S02}/Λ^4	statOnly	-282.70	331.60	-185.97	203.49	-73.99	75.15	-47.58	46.73	-28.34	27.09	-15.71	14.88	-10.93	10.38	-8.82	8.39	-7.80	7.42	-6.89	6.57	-6.79	6.47
	statTheoOnly	-309.85	351.08	-186.47	203.84	-67.43	71.46	-40.56	42.10	-22.55	23.08	-12.55	12.76	-8.98	9.11	-7.40	7.49	-6.64	6.71	-5.96	6.01	-5.88	5.93
	full	-316.27	357.80	-191.20	208.27	-69.70	73.85	-42.19	43.78	-23.33	23.85	-12.74	12.95	-9.03	9.16	-7.42	7.52	-6.65	6.72	-5.96	6.02	-5.89	5.94
f_{S1}/Λ^4	statOnly	-1004.65	1116.35	-710.11	767.02	-289.39	282.33	-192.34	182.18	-114.23	107.27	-63.42	59.29	-43.38	40.80	-34.87	32.93	-30.87	29.26	-27.17	25.81	-26.81	25.46
	statTheoOnly	-1073.45	1154.70	-718.20	769.30	-265.43	269.81	-165.78	165.74	-91.79	92.03	-50.90	50.91	-35.82	35.89	-29.44	29.50	-26.42	26.49	-23.63	23.67	-23.35	23.39
	full	-1096.63	1178.89	-737.60	786.98	-274.37	279.58	-172.96	173.47	-96.16	96.39	-52.70	52.66	-36.61	36.66	-29.86	29.91	-26.71	26.78	-23.82	23.87	-23.54	23.58
f_{T0}/Λ^4	statOnly	-22.75	22.43	-17.58	18.11	-8.36	9.03	-5.11	5.21	-2.78	2.71	-1.34	1.29	-0.85	0.82	-0.64	0.62	-0.54	0.51	-0.42	0.40	-0.39	0.37
	statTheoOnly	-24.98	24.64	-18.21	18.91	-7.16	7.57	-4.03	4.14	-2.19	2.28	-1.11	1.17	-0.74	0.77	-0.56	0.59	-0.48	0.48	-0.38	0.38	-0.36	0.36
	full	-25.35	25.06	-18.60	19.36	-7.48	7.95	-4.25	4.37	-2.30	2.39	-1.14	1.19	-0.74	0.78	-0.57	0.59	-0.49	0.49	-0.38	0.38	-0.36	0.36
f_{T1}/Λ^4	statOnly	-20.20	26.35	-13.84	-7.14	-4.75	-1.34	-2.76	-0.42	-1.51	0.05	-0.72	0.54	-0.46	0.39	-0.34	0.30	-0.28	0.25	-0.21	0.20	-0.20	0.18
	statTheoOnly	-20.99	26.99	-13.80	16.33	-3.71	3.90	-2.09	2.23	-1.17	1.28	-0.58	0.64	-0.38	0.42	-0.29	0.31	-0.24	0.26	-0.19	0.20	-0.17	0.19
	full	-21.36	27.34	-14.15	16.85	-3.92	4.11	-2.22	2.35	-1.23	1.33	-0.60	0.65	-0.39	0.42	-0.29	0.32	-0.24	0.26	-0.19	0.20	-0.17	0.19
f_{T2}/Λ^4	statOnly	-44.44	52.29	-34.04	42.95	-14.29	-5.85	-9.21	-3.16	-5.39	-1.31	-2.82	-0.21	-1.84	1.63	-1.38	1.30	-1.12	1.08	-0.83	0.79	-0.77	0.73
	statTheoOnly	-50.39	57.08	-36.54	43.48	-16.89	27.44	-8.21	14.36	-4.27	6.11	-2.14	2.91	-1.40	1.84	-1.07	1.36	-0.89	1.11	-0.67	0.80	-0.63	0.74
	full	-51.37	59.51	-37.62	45.56	-17.29	27.94	-8.60	14.81	-4.47	6.33	-2.21	2.96	-1.42	1.86	-1.07	1.37	-0.89	1.11	-0.67	0.80	-0.63	0.74

Table D.9: Observed inner limits on the Wilson coefficients for all Operators for different clipping values and different uncertainty sets with asymptotic formula. "–" is written if the area around the SM is not excluded

Coefficient		Limits [TeV^{-4}] for clipping value [GeV]											
fit type		600	700	1000		1200	1500	2000	2500	3000	3500	5000	None
f_{M0}/Λ^4	statOnly	-116.79	94.45	-90.07	72.74	-41.05	28.77	-21.50	13.76	-4.15	0.69	-	-
	statTheoOnly	-67.79	47.84	-41.56	27.13	-	-	-	-	-	-	-	-
	full	-63.03	42.19	-39.10	24.31	-	-	-	-	-	-	-	-
f_{M1}/Λ^4	statOnly	-209.30	252.14	-135.38	163.89	-49.61	67.09	-26.33	39.39	-8.78	16.61	-	-
	statTheoOnly	-99.86	128.54	-57.80	75.16	-	-	-	-	-	-	-	-
	full	-85.68	116.33	-49.92	68.10	-	-	-	-	-	-	-	-
f_{M7}/Λ^4	statOnly	-426.39	371.92	-269.79	230.66	-100.65	74.04	-59.17	36.95	-18.93	10.05	-	-
	statTheoOnly	-240.42	170.03	-117.17	73.76	-	-	-	-	-	-	-	-
	full	-221.84	151.78	-100.45	57.45	-	-	-	-	-	-	-	-
f_{S02}/Λ^4	statOnly	-164.90	215.17	-105.99	137.95	-35.08	48.28	-17.73	25.80	-4.00	8.13	-	-
	statTheoOnly	-89.09	120.75	-47.70	65.36	-	-	-	-	-	-	-	-
	full	-78.75	111.37	-41.53	59.56	-	-	-	-	-	-	-	-
f_{S1}/Λ^4	statOnly	-590.21	724.00	-407.96	511.54	-139.74	189.37	-73.80	108.02	-18.04	34.09	-	-
	statTheoOnly	-304.74	372.39	-179.83	237.26	-	-	-	-	-	-	-	-
	full	-274.94	345.75	-157.45	216.41	-	-	-	-	-	-	-	-
f_{T0}/Λ^4	statOnly	-13.84	13.81	-10.45	10.94	-3.58	4.62	-1.28	2.14	-	-	-	-
	statTheoOnly	-6.48	6.63	-4.32	5.14	-	-	-	-	-	-	-	-
	full	-6.20	6.28	-3.87	4.64	-	-	-	-	-	-	-	-
f_{T1}/Λ^4	statOnly	-11.21	18.03	-	-	-	-	-	-	-	-	-	-
	statTheoOnly	-5.19	10.52	1.60	4.09	-	-	-	-	-	-	-	-
	full	-4.54	9.98	-	-	-	-	-	-	-	-	-	-
f_{T2}/Λ^4	statOnly	-24.39	45.46	-17.88	36.69	-	-	-	-	0.23	0.76	-	-
	statTheoOnly	-5.28	28.64	1.73	17.51	-	-	-	-	-	-	-	-
	full	-4.81	27.07	3.09	15.87	-	-	-	-	-	-	-	-

Table D.10: Post-fit yields of best fit to observed data in the signal region. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	bin 1: $20 \leq m_{\ell\ell} < 250$ GeV	bin 2: $250 \leq m_{\ell\ell} < 500$ GeV	bin 3: $500 \leq m_{\ell\ell} < 750$ GeV	bin 4: $750 \leq m_{\ell\ell} < 975$ GeV	bin 5: $m_{\ell\ell} \geq 975$ GeV	Total
Other prompt	$5.8 \pm 0.0 \pm 1.0 \pm 0.5$	$1.06 \pm 0.00 \pm 0.23 \pm 0.18$	$0.142 \pm 0.000 \pm 0.031 \pm 0.033$	$0.012 \pm 0.000 \pm 0.004 \pm 0.012$	$0.019 \pm 0.000 \pm 0.006 \pm 0.003$	$7.0 \pm 0.0 \pm 1.3 \pm 0.6$
Conversions	$17 \pm 0 \pm 4 \pm 3$	$3.5 \pm 0.0 \pm 0.4 \pm 0.7$	$0.86 \pm 0.00 \pm 0.14 \pm 0.12$	$0.124 \pm 0.000 \pm 0.028 \pm 0.031$	$0.096 \pm 0.000 \pm 0.025 \pm 0.019$	$22 \pm 0 \pm 4 \pm 4$
Non-prompt	$48 \pm 0 \pm 1 \pm 8$	$8.8 \pm 0.0 \pm 0.3 \pm 1.8$	$2.2 \pm 0.0 \pm 0.2 \pm 0.5$	$0.81 \pm 0.00 \pm 0.15 \pm 0.35$	$0.43 \pm 0.00 \pm 0.11 \pm 0.18$	$60 \pm 0 \pm 1 \pm 10$
WZ EW	$8.6 \pm 0.0 \pm 0.9 \pm 0.4$	$1.97 \pm 0.00 \pm 0.28 \pm 0.11$	$0.40 \pm 0.00 \pm 0.08 \pm 0.05$	$0.086 \pm 0.000 \pm 0.024 \pm 0.017$	$0.026 \pm 0.000 \pm 0.009 \pm 0.014$	$11.1 \pm 0.0 \pm 1.2 \pm 0.5$
WZ QCD	$49 \pm 5 \pm 4 \pm 3$	$6.3 \pm 0.7 \pm 0.6 \pm 0.5$	$0.64 \pm 0.07 \pm 0.08 \pm 0.06$	$0.12 \pm 0.01 \pm 0.05 \pm 0.02$	$0.077 \pm 0.009 \pm 0.021 \pm 0.013$	$56 \pm 6 \pm 5 \pm 3$
$W^\pm W^\pm jj$	$186 \pm 0 \pm 22 \pm 5$	$47 \pm 0 \pm 6 \pm 1$	$7.5 \pm 0.0 \pm 1.3 \pm 0.3$	$1.7 \pm 0.0 \pm 0.4 \pm 0.1$	$0.84 \pm 0.00 \pm 0.28 \pm 0.07$	$243 \pm 0 \pm 29 \pm 6$
EFTWZ_M0_int	$0.35 \pm 0.00 \pm 0.08 \pm 0.14$	$0.016 \pm 0.000 \pm 0.004 \pm 0.015$	$0.034 \pm 0.000 \pm 0.009 \pm 0.028$	$0.020 \pm 0.000 \pm 0.006 \pm 0.007$	$0.002 \pm 0.000 \pm 0.001 \pm 0.013$	$0.42 \pm 0.00 \pm 0.10 \pm 0.16$
EFTWZ_M0_quad	$0.73 \pm 0.00 \pm 0.35 \pm 0.03$	$0.7 \pm 0.0 \pm 0.4 \pm 0.0$	$0.060 \pm 0.000 \pm 0.029 \pm 0.002$	$0.011 \pm 0.000 \pm 0.006 \pm 0.001$	$0.032 \pm 0.000 \pm 0.018 \pm 0.002$	$1.6 \pm 0.0 \pm 0.8 \pm 0.1$
EFT_M0_int	$7.8 \pm 0.0 \pm 1.9 \pm 0.3$	$4.1 \pm 0.0 \pm 1.0 \pm 0.3$	$0.19 \pm 0.00 \pm 0.05 \pm 0.02$	$0.0 \pm 0.0 \pm 0.0 \pm 0.0$	$0.0022 \pm 0.0000 \pm 0.0008 \pm 0.0014$	$12.1 \pm 0.0 \pm 2.9 \pm 0.6$
EFT_M0_quad	$36 \pm 0 \pm 17 \pm 2$	$25 \pm 0 \pm 12 \pm 1$	$2.3 \pm 0.0 \pm 1.1 \pm 0.1$	$0.061 \pm 0.000 \pm 0.032 \pm 0.003$	$0.08 \pm 0.00 \pm 0.04 \pm 0.00$	$63 \pm 0 \pm 30 \pm 3$
obsData	$359.0 \pm 0.0 \pm 0.0 \pm 0.0$	$99.0 \pm 0.0 \pm 0.0 \pm 0.0$	$12.0 \pm 0.0 \pm 0.0 \pm 0.0$	$3.0 \pm 0.0 \pm 0.0 \pm 0.0$	$2.0 \pm 0.0 \pm 0.0 \pm 0.0$	$475.0 \pm 0.0 \pm 0.0 \pm 0.0$
Total Expected	$360 \pm 5 \pm 18 \pm 13$	$98 \pm 1 \pm 10 \pm 4$	$14.4 \pm 0.1 \pm 1.6 \pm 0.7$	$2.9 \pm 0.0 \pm 0.6 \pm 0.4$	$1.6 \pm 0.0 \pm 0.4 \pm 0.2$	$476 \pm 6 \pm 26 \pm 17$

Table D.11: Post-fit yields of upper limit for observed data in the signal region for M0 operator clipped at 700 GeV. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	bin 1: $20 \leq m_{\ell\ell} < 250$ GeV	bin 2: $250 \leq m_{\ell\ell} < 500$ GeV	bin 3: $500 \leq m_{\ell\ell} < 750$ GeV	bin 4: $750 \leq m_{\ell\ell} < 975$ GeV	bin 5: $m_{\ell\ell} \geq 975$ GeV	Total
Other prompt	$5.7 \pm 0.0 \pm 1.0 \pm 0.4$	$1.00 \pm 0.00 \pm 0.22 \pm 0.17$	$0.135 \pm 0.000 \pm 0.030 \pm 0.031$	$0.011 \pm 0.000 \pm 0.004 \pm 0.011$	$0.018 \pm 0.000 \pm 0.006 \pm 0.003$	$6.8 \pm 0.0 \pm 1.3 \pm 0.5$
Conversions	$16.9 \pm 0.0 \pm 3.4 \pm 3.4$	$3.4 \pm 0.0 \pm 0.4 \pm 0.7$	$0.84 \pm 0.00 \pm 0.14 \pm 0.11$	$0.120 \pm 0.000 \pm 0.026 \pm 0.031$	$0.096 \pm 0.000 \pm 0.025 \pm 0.018$	$21 \pm 0 \pm 4 \pm 4$
Non-prompt	$47 \pm 0 \pm 1 \pm 7$	$8.3 \pm 0.0 \pm 0.3 \pm 1.7$	$2.1 \pm 0.0 \pm 0.2 \pm 0.5$	$0.79 \pm 0.00 \pm 0.15 \pm 0.33$	$0.42 \pm 0.00 \pm 0.11 \pm 0.17$	$59 \pm 0 \pm 1 \pm 10$
WZ EW	$8.5 \pm 0.0 \pm 0.8 \pm 0.4$	$1.92 \pm 0.00 \pm 0.26 \pm 0.11$	$0.39 \pm 0.00 \pm 0.07 \pm 0.05$	$0.086 \pm 0.000 \pm 0.024 \pm 0.017$	$0.026 \pm 0.000 \pm 0.009 \pm 0.014$	$10.9 \pm 0.0 \pm 1.2 \pm 0.4$
WZ QCD	$47 \pm 5 \pm 4 \pm 3$	$5.9 \pm 0.7 \pm 0.6 \pm 0.5$	$0.61 \pm 0.07 \pm 0.08 \pm 0.06$	$0.11 \pm 0.01 \pm 0.05 \pm 0.02$	$0.076 \pm 0.008 \pm 0.021 \pm 0.013$	$54 \pm 6 \pm 5 \pm 3$
$W^\pm W^\pm jj$	$155 \pm 0 \pm 17 \pm 4$	$39 \pm 0 \pm 4 \pm 1$	$6.3 \pm 0.0 \pm 0.9 \pm 0.3$	$1.39 \pm 0.00 \pm 0.33 \pm 0.11$	$0.71 \pm 0.00 \pm 0.22 \pm 0.06$	$202 \pm 0 \pm 21 \pm 5$
EFTWZ_M0_int	$0.48 \pm 0.00 \pm 0.01 \pm 0.19$	$0.022 \pm 0.000 \pm 0.001 \pm 0.021$	$0.04 \pm 0.00 \pm 0.00 \pm 0.04$	$0.029 \pm 0.000 \pm 0.005 \pm 0.010$	$0.005 \pm 0.000 \pm 0.001 \pm 0.019$	$0.58 \pm 0.00 \pm 0.01 \pm 0.21$
EFTWZ_M0_quad	$1.45 \pm 0.00 \pm 0.02 \pm 0.07$	$1.47 \pm 0.00 \pm 0.05 \pm 0.06$	$0.119 \pm 0.000 \pm 0.010 \pm 0.005$	$0.022 \pm 0.000 \pm 0.004 \pm 0.001$	$0.064 \pm 0.000 \pm 0.017 \pm 0.004$	$3.13 \pm 0.00 \pm 0.06 \pm 0.13$
EFT_M0_int	$10.9 \pm 0.0 \pm 0.2 \pm 0.4$	$5.5 \pm 0.0 \pm 0.2 \pm 0.4$	$0.258 \pm 0.000 \pm 0.023 \pm 0.031$	$0.0 \pm 0.0 \pm 0.0 \pm 0.0$	$0.0032 \pm 0.0000 \pm 0.0008 \pm 0.0020$	$16.7 \pm 0.0 \pm 0.2 \pm 0.8$
EFT_M0_quad	$68.5 \pm 0.0 \pm 1.1 \pm 2.8$	$46.4 \pm 0.0 \pm 1.4 \pm 2.1$	$4.4 \pm 0.0 \pm 0.4 \pm 0.2$	$0.113 \pm 0.000 \pm 0.022 \pm 0.006$	$0.102 \pm 0.000 \pm 0.027 \pm 0.008$	$120 \pm 0 \pm 2 \pm 5$
obsData	$359.0 \pm 0.0 \pm 0.0 \pm 0.0$	$99.0 \pm 0.0 \pm 0.0 \pm 0.0$	$12.0 \pm 0.0 \pm 0.0 \pm 0.0$	$3.0 \pm 0.0 \pm 0.0 \pm 0.0$	$2.0 \pm 0.0 \pm 0.0 \pm 0.0$	$475.0 \pm 0.0 \pm 0.0 \pm 0.0$
Total Expected	$362 \pm 5 \pm 17 \pm 12$	$113 \pm 1 \pm 5 \pm 4$	$15.2 \pm 0.1 \pm 1.5 \pm 0.7$	$2.7 \pm 0.0 \pm 0.5 \pm 0.4$	$1.5 \pm 0.0 \pm 0.4 \pm 0.2$	$494 \pm 6 \pm 22 \pm 17$

Table D.12: Post-fit yields of inner upper limit for observed data in the signal region for M0 operator clipped at 700 GeV. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	bin 1: $20 \leq m_{\ell\ell} < 250$ GeV				bin 2: $250 \leq m_{\ell\ell} < 500$ GeV				bin 3: $500 \leq m_{\ell\ell} < 750$ GeV				bin 4: $750 \leq m_{\ell\ell} < 975$ GeV				bin 5: $m_{\ell\ell} \geq 975$ GeV				Total			
Other prompt	5.8	± 0.0	± 1.0	± 0.5	1.10	± 0.00	± 0.24	± 0.17	0.144	± 0.000	± 0.031	± 0.032	0.013	± 0.000	± 0.004	± 0.011	0.019	± 0.000	± 0.006	± 0.003	7.1	± 0.0	± 1.3	± 0.6
Conversions	17	± 0	± 4	± 3	3.6	± 0.0	± 0.4	± 0.7	0.86	± 0.00	± 0.15	± 0.12	0.123	± 0.000	± 0.028	± 0.030	0.096	± 0.000	± 0.025	± 0.018	22	± 0	± 4	± 4
Non-prompt	48	± 0	± 1	± 8	9.0	± 0.0	± 0.3	± 1.9	2.3	± 0.0	± 0.2	± 0.5	0.79	± 0.00	± 0.15	± 0.34	0.42	± 0.00	± 0.11	± 0.18	60	± 0	± 1	± 11
WZ EW	8.7	± 0.0	± 0.9	± 0.4	2.01	± 0.00	± 0.30	± 0.11	0.41	± 0.00	± 0.08	± 0.05	0.085	± 0.000	± 0.025	± 0.016	0.026	± 0.000	± 0.009	± 0.013	11.2	± 0.0	± 1.3	± 0.5
WZ QCD	50	± 5	± 4	± 3	6.6	± 0.7	± 0.6	± 0.5	0.66	± 0.07	± 0.09	± 0.06	0.12	± 0.01	± 0.05	± 0.02	0.078	± 0.008	± 0.022	± 0.012	58	± 6	± 5	± 3
$W^\pm W^\pm jj$	229	± 0	± 19	± 6	60	± 0	± 6	± 1	9.8	± 0.0	± 1.4	± 0.4	2.2	± 0.0	± 0.5	± 0.2	1.14	± 0.00	± 0.34	± 0.08	302	± 0	± 25	± 7
EFTWZ_M0_int	0.09	± 0.00	± 0.00	± 0.04	0.004	± 0.000	± 0.000	± 0.004	0.009	± 0.000	± 0.001	± 0.007	0.0052	± 0.000	± 0.0010	± 0.0018	0.0003	± 0.0000	± 0.0001	± 0.0032	0.11	± 0.00	± 0.00	± 0.04
EFTWZ_M0_quad	0.0480	± 0.0000	± 0.0008	± 0.0023	0.0502	± 0.0000	± 0.0016	± 0.0021	0.00395	± 0.0000	± 0.00035	± 0.00016	0.00071	± 0.00000	± 0.00013	± 0.00004	0.0021	± 0.0000	± 0.00015	± 0.00035	0.105	± 0.000	± 0.002	± 0.004
EFT_M0_int	2.02	± 0.00	± 0.03	± 0.08	1.07	± 0.00	± 0.03	± 0.08	0.048	± 0.000	± 0.004	± 0.006	0.0	± 0.0	± 0.0	± 0.0	0.00056	± 0.00000	± 0.00015	± 0.00035	3.13	± 0.00	± 0.05	± 0.14
EFT_M0_quad	2.38	± 0.00	± 0.04	± 0.10	1.67	± 0.00	± 0.05	± 0.08	0.156	± 0.000	± 0.014	± 0.006	0.0040	± 0.0000	± 0.0008	± 0.0002	0.0050	± 0.0000	± 0.0013	± 0.0003	4.21	± 0.00	± 0.07	± 0.18
obsData	359.0	± 0.0	± 0.0	± 0.0	99.0	± 0.0	± 0.0	± 0.0	12.0	± 0.0	± 0.0	± 0.0	3.0	± 0.0	± 0.0	± 0.0	2.0	± 0.0	± 0.0	± 0.0	475.0	± 0.0	± 0.0	± 0.0
Total Expected	363	± 5	± 18	± 13	85	± 1	± 6	± 3	14.4	± 0.1	± 1.6	± 0.7	3.3	± 0.0	± 0.7	± 0.4	1.8	± 0.0	± 0.5	± 0.2	468	± 6	± 24	± 16

Table D.13: Post-fit yields of inner lower limit for observed data in the signal region for M0 operator clipped at 700 GeV. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	bin 1: $20 \leq m_{\ell\ell} < 250$ GeV			bin 2: $250 \leq m_{\ell\ell} < 500$ GeV			bin 3: $500 \leq m_{\ell\ell} < 750$ GeV			bin 4: $750 \leq m_{\ell\ell} < 975$ GeV			bin 5: $m_{\ell\ell} \geq 975$ GeV			Total								
Other prompt	5.8	± 0.0	± 1.0	± 0.5	1.10	± 0.00	± 0.24	± 0.17	0.144	± 0.000	± 0.032	± 0.032	0.013	± 0.000	± 0.004	± 0.011	0.018	± 0.000	± 0.006	± 0.003	7.1	± 0.0	± 1.3	± 0.6
Conversions	17	± 0	± 4	± 3	3.6	± 0.0	± 0.4	± 0.7	0.86	± 0.00	± 0.15	± 0.12	0.123	± 0.000	± 0.028	± 0.030	0.095	± 0.000	± 0.025	± 0.018	22	± 0	± 4	± 4
Non-prompt	48	± 0	± 1	± 8	9.0	± 0.0	± 0.3	± 1.9	2.3	± 0.0	± 0.2	± 0.5	0.79	± 0.00	± 0.15	± 0.34	0.42	± 0.00	± 0.11	± 0.18	60	± 0	± 1	± 11
WZ EW	8.7	± 0.0	± 0.9	± 0.4	2.01	± 0.00	± 0.30	± 0.11	0.41	± 0.00	± 0.08	± 0.05	0.085	± 0.000	± 0.025	± 0.016	0.026	± 0.000	± 0.009	± 0.013	11.2	± 0.0	± 1.3	± 0.5
WZ QCD	50	± 5	± 4	± 3	6.6	± 0.7	± 0.6	± 0.5	0.66	± 0.07	± 0.09	± 0.06	0.12	± 0.01	± 0.05	± 0.02	0.078	± 0.008	± 0.022	± 0.012	58	± 6	± 5	± 3
$W^\pm W^\pm ij$	230	± 0	± 19	± 6	60	± 0	± 6	± 1	9.8	± 0.0	± 1.4	± 0.4	2.2	± 0.0	± 0.5	± 0.2	1.14	± 0.00	± 0.34	± 0.08	303	± 0	± 25	± 7
EFTWZ_M0_int	-0.15	± 0.00	± 0.00	± 0.06	-0.007	± 0.000	± 0.000	± 0.006	-0.014	± 0.000	± 0.001	± 0.011	-0.0083	± 0.0000	± 0.0016	± 0.0029	0.000	± 0.000	± 0.000	± 0.005	-0.18	± 0.00	± 0.00	± 0.06
EFTWZ_M0_quad	0.124	± 0.000	± 0.002	± 0.006	0.130	± 0.000	± 0.004	± 0.005	0.0102	± 0.0000	± 0.0009	± 0.0004	0.00183	± 0.00000	± 0.00035	± 0.00009	0.0054	± 0.0000	± 0.0014	± 0.0003	0.272	± 0.000	± 0.005	± 0.011
EFT_M0_int	-3.22	± 0.00	± 0.05	± 0.13	-1.70	± 0.00	± 0.05	± 0.12	-0.077	± 0.000	± 0.007	± 0.009	0.0	± 0.0	± 0.0	± 0.0	-0.0009	± 0.0000	± 0.0002	± 0.0006	-5.00	± 0.00	± 0.08	± 0.22
EFT_M0_quad	6.21	± 0.00	± 0.10	± 0.26	4.37	± 0.00	± 0.14	± 0.21	0.41	± 0.00	± 0.04	± 0.02	0.0105	± 0.0000	± 0.0020	± 0.0005	0.0133	± 0.0000	± 0.0035	± 0.0008	11.0	± 0.0	± 0.2	± 0.5
obsData	359.0	± 0.0	± 0.0	± 0.0	99.0	± 0.0	± 0.0	± 0.0	12.0	± 0.0	± 0.0	± 0.0	3.0	± 0.0	± 0.0	± 0.0	2.0	± 0.0	± 0.0	± 0.0	475.0	± 0.0	± 0.0	± 0.0
Total Expected	363	± 5	± 18	± 13	85	± 1	± 6	± 3	14.5	± 0.1	± 1.7	± 0.7	3.3	± 0.0	± 0.7	± 0.4	1.8	± 0.0	± 0.5	± 0.2	467	± 6	± 24	± 16

Table D.14: Post-fit yields of lower limit for observed data in the signal region for M0 operator clipped at 700 GeV. Shown are central values with statistical, theory, and experimental systematic uncertainties.

	bin 1: $20 \leq m_{\ell\ell} < 250$ GeV	bin 2: $250 \leq m_{\ell\ell} < 500$ GeV	bin 3: $500 \leq m_{\ell\ell} < 750$ GeV	bin 4: $750 \leq m_{\ell\ell} < 975$ GeV	bin 5: $m_{\ell\ell} \geq 975$ GeV	Total
Other prompt	$5.7 \pm 0.0 \pm 1.0 \pm 0.4$	$1.00 \pm 0.00 \pm 0.22 \pm 0.17$	$0.134 \pm 0.000 \pm 0.030 \pm 0.031$	$0.011 \pm 0.000 \pm 0.004 \pm 0.011$	$0.018 \pm 0.000 \pm 0.006 \pm 0.003$	$6.9 \pm 0.0 \pm 1.3 \pm 0.5$
Conversions	$17.0 \pm 0.0 \pm 3.5 \pm 3.4$	$3.4 \pm 0.0 \pm 0.4 \pm 0.7$	$0.84 \pm 0.00 \pm 0.14 \pm 0.11$	$0.121 \pm 0.000 \pm 0.027 \pm 0.031$	$0.096 \pm 0.000 \pm 0.025 \pm 0.018$	$21 \pm 0 \pm 4 \pm 4$
Non-prompt	$47 \pm 0 \pm 1 \pm 8$	$8.3 \pm 0.0 \pm 0.3 \pm 1.7$	$2.1 \pm 0.0 \pm 0.2 \pm 0.5$	$0.79 \pm 0.00 \pm 0.15 \pm 0.33$	$0.42 \pm 0.00 \pm 0.11 \pm 0.18$	$59 \pm 0 \pm 1 \pm 10$
WZ EW	$8.5 \pm 0.0 \pm 0.8 \pm 0.4$	$1.92 \pm 0.00 \pm 0.26 \pm 0.11$	$0.39 \pm 0.00 \pm 0.07 \pm 0.05$	$0.085 \pm 0.000 \pm 0.024 \pm 0.016$	$0.026 \pm 0.000 \pm 0.009 \pm 0.013$	$10.9 \pm 0.0 \pm 1.2 \pm 0.4$
WZ QCD	$47 \pm 5 \pm 4 \pm 3$	$6.0 \pm 0.7 \pm 0.6 \pm 0.5$	$0.61 \pm 0.07 \pm 0.08 \pm 0.06$	$0.11 \pm 0.01 \pm 0.05 \pm 0.02$	$0.076 \pm 0.008 \pm 0.021 \pm 0.013$	$54 \pm 6 \pm 5 \pm 3$
$W^\pm W^\pm jj$	$159 \pm 0 \pm 17 \pm 4$	$39 \pm 0 \pm 4 \pm 1$	$6.4 \pm 0.0 \pm 0.9 \pm 0.3$	$1.41 \pm 0.00 \pm 0.34 \pm 0.11$	$0.72 \pm 0.00 \pm 0.23 \pm 0.06$	$207 \pm 0 \pm 21 \pm 5$
EF-TWZ_M0_int	$-0.54 \pm 0.00 \pm 0.01 \pm 0.22$	$-0.024 \pm 0.000 \pm 0.001 \pm 0.023$	$-0.05 \pm 0.00 \pm 0.00 \pm 0.04$	$-0.032 \pm 0.000 \pm 0.006 \pm 0.012$	$-0.006 \pm 0.000 \pm 0.001 \pm 0.020$	$-0.65 \pm 0.00 \pm 0.01 \pm 0.24$
EF-TWZ_M0_quad	$1.81 \pm 0.00 \pm 0.03 \pm 0.09$	$1.83 \pm 0.00 \pm 0.06 \pm 0.08$	$0.146 \pm 0.000 \pm 0.013 \pm 0.006$	$0.027 \pm 0.000 \pm 0.005 \pm 0.001$	$0.079 \pm 0.000 \pm 0.021 \pm 0.004$	$3.89 \pm 0.00 \pm 0.07 \pm 0.16$
EFT_M0_int	$-12.6 \pm 0.0 \pm 0.2 \pm 0.5$	$-6.4 \pm 0.0 \pm 0.2 \pm 0.5$	$-0.300 \pm 0.000 \pm 0.026 \pm 0.035$	$0.0 \pm 0.0 \pm 0.0 \pm 0.0$	$-0.0038 \pm 0.0000 \pm 0.0010 \pm 0.0023$	$-19.3 \pm 0.0 \pm 0.3 \pm 0.9$
EFT_M0_quad	$84.9 \pm 0.0 \pm 1.3 \pm 3.5$	$57.5 \pm 0.0 \pm 1.8 \pm 2.6$	$5.5 \pm 0.0 \pm 0.5 \pm 0.2$	$0.140 \pm 0.000 \pm 0.027 \pm 0.007$	$0.123 \pm 0.000 \pm 0.032 \pm 0.009$	$148 \pm 0 \pm 2 \pm 6$
obsData	$359.0 \pm 0.0 \pm 0.0 \pm 0.0$	$99.0 \pm 0.0 \pm 0.0 \pm 0.0$	$12.0 \pm 0.0 \pm 0.0 \pm 0.0$	$3.0 \pm 0.0 \pm 0.0 \pm 0.0$	$2.0 \pm 0.0 \pm 0.0 \pm 0.0$	$475.0 \pm 0.0 \pm 0.0 \pm 0.0$
Total Expected	$358 \pm 5 \pm 17 \pm 13$	$113 \pm 1 \pm 5 \pm 4$	$15.7 \pm 0.1 \pm 1.6 \pm 0.7$	$2.7 \pm 0.0 \pm 0.5 \pm 0.4$	$1.5 \pm 0.0 \pm 0.4 \pm 0.2$	$491 \pm 6 \pm 22 \pm 17$

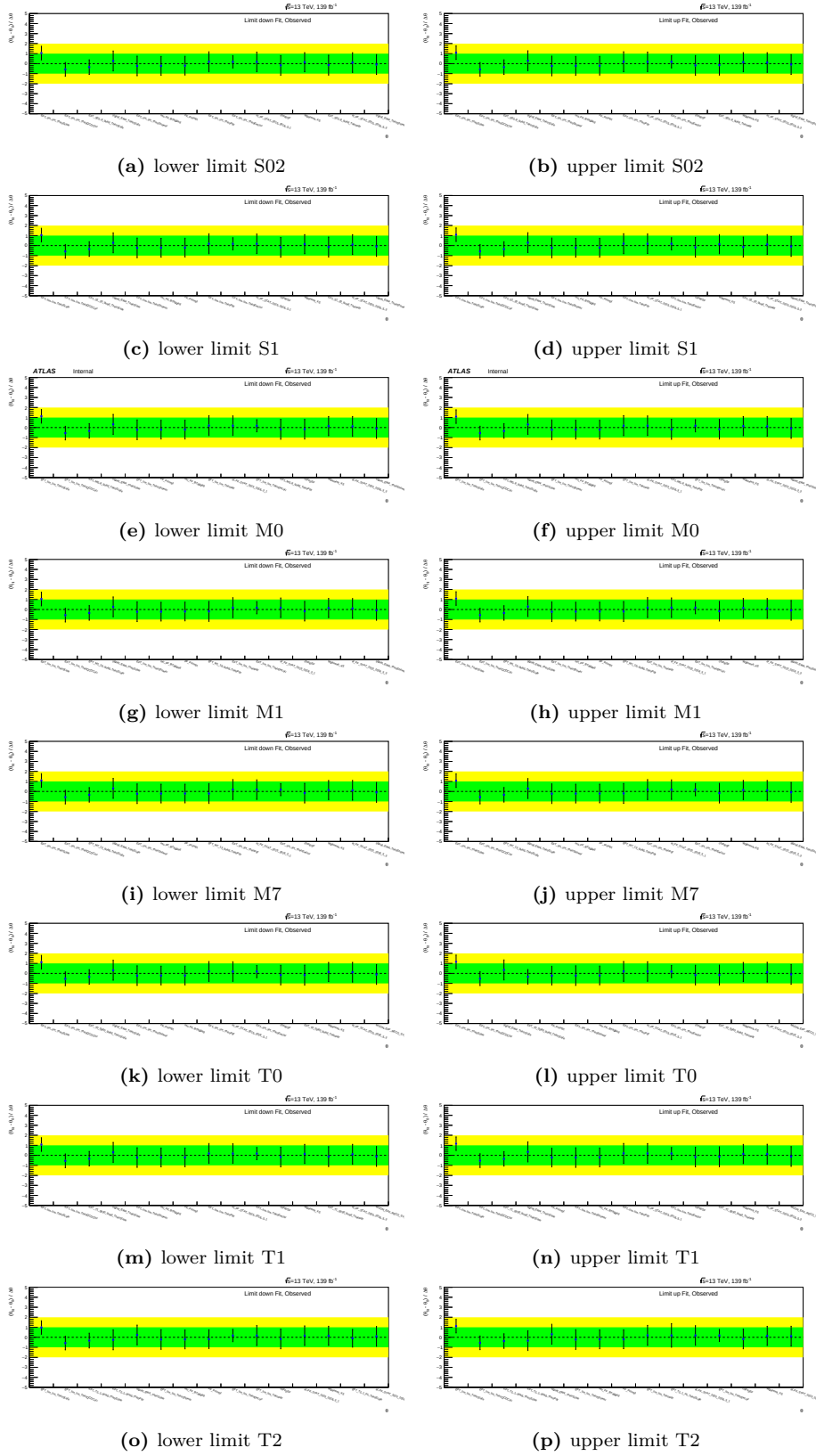


Figure D.4: Pulls of 15 most pulled nuisance parameters for lower (left) and upper (right) expected limits without clipping.

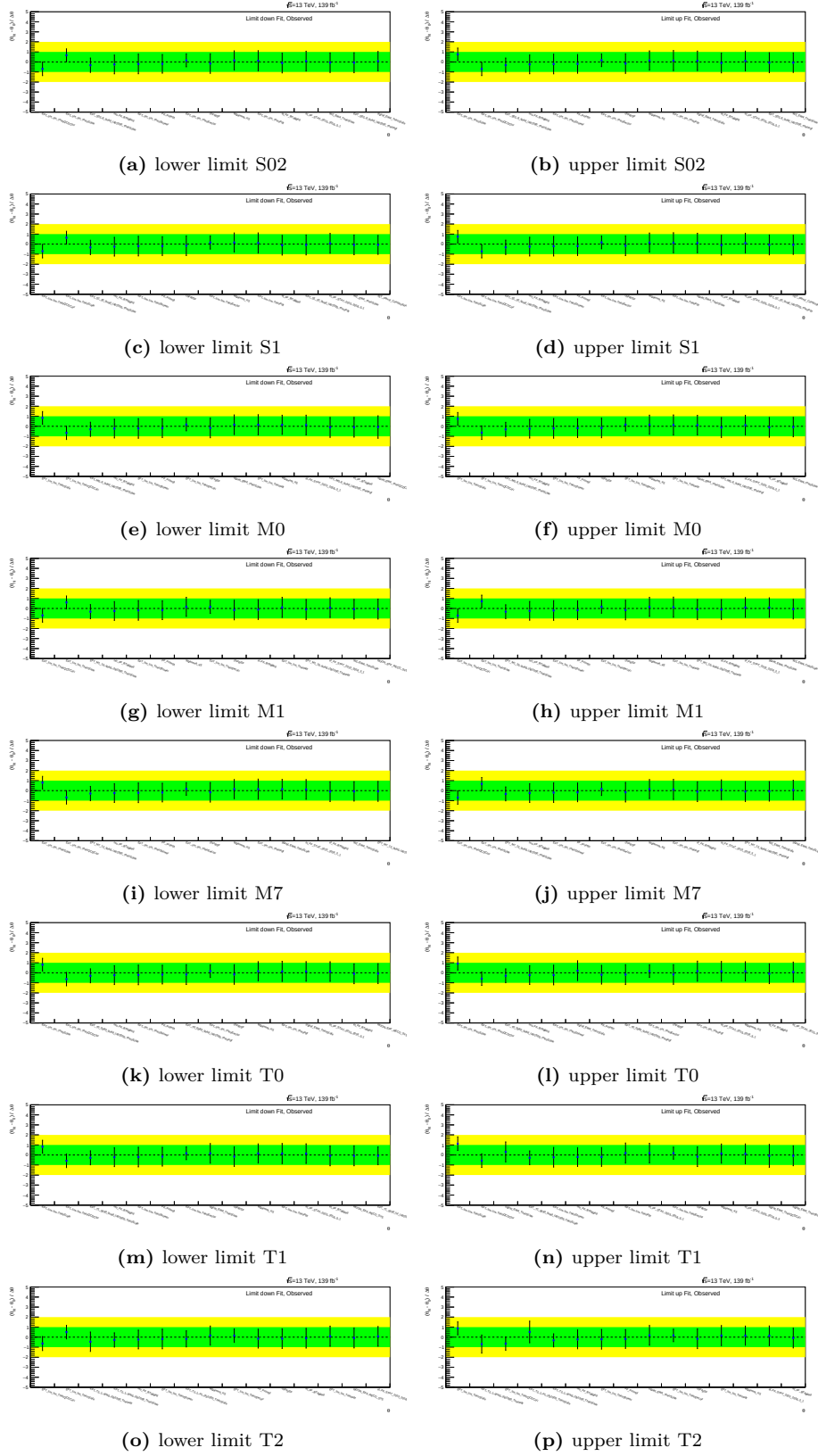


Figure D.5: Pulls of 15 most pulled nuisance parameters for lower (left) and upper (right) expected limits with clipping at 1.5 TeV.

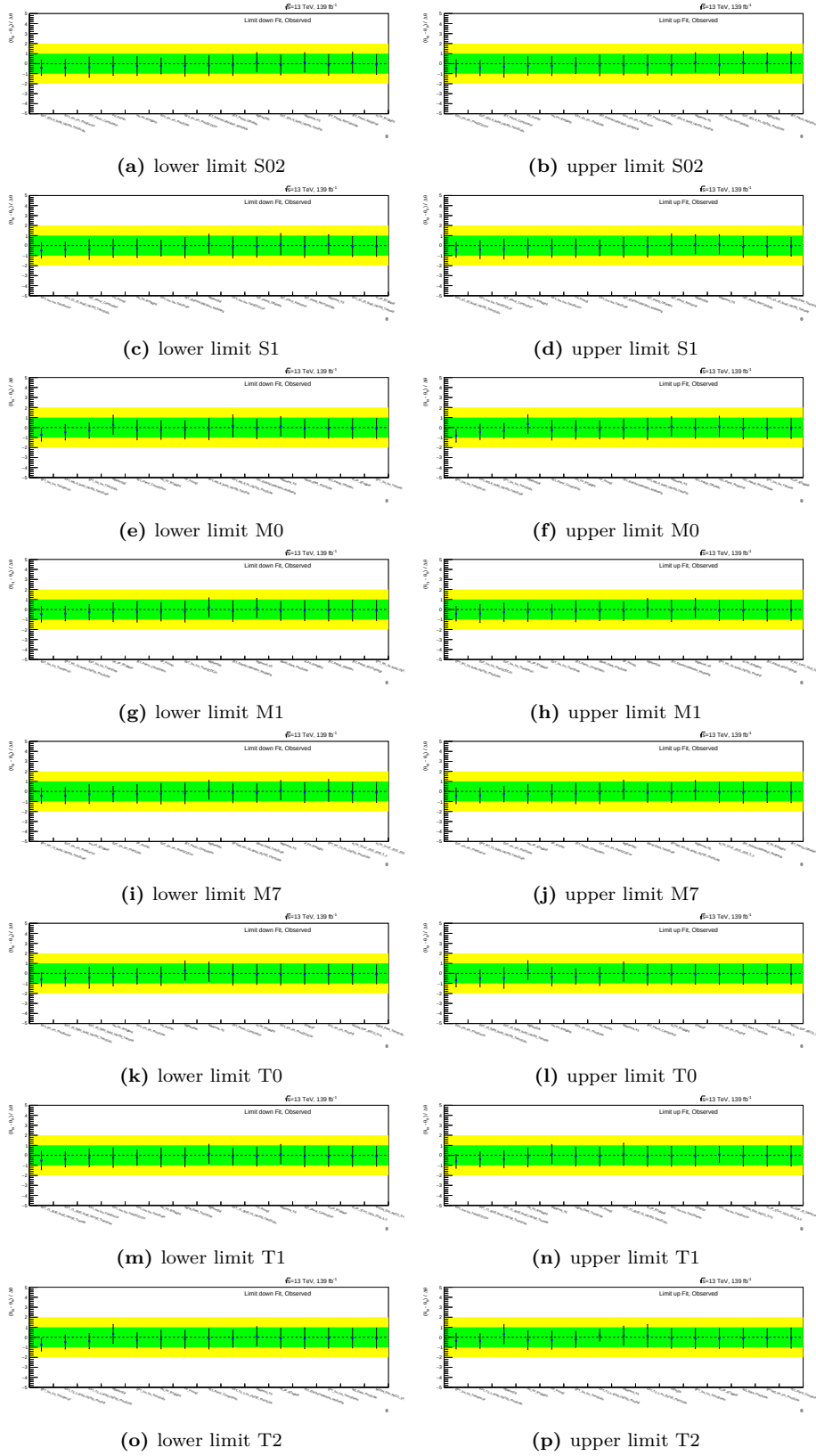


Figure D.6: Pulls of 15 most pulled nuisance parameters for lower (left) and upper (right) expected limits with clipping at 0.7 TeV.

List of Figures

2.1	VBS diagrams with WZ in final state	11
2.2	VBS diagrams with $W^\pm W^\pm$ in final state	11
2.3	Different example Feynman diagrams for two incoming quarks or gluons and two outgoing jet together with $W^\pm Z$ or $W^\pm W^\pm$. Diagrams of type (d) with gluons in the initial state are not possible for $W^\pm W^\pm$ in the final state because of charge conservation.	12
2.4	“Pictorial representation of a $t\bar{t}h^-$ event as produced by an event generator. The hard interaction (big red blob) is followed by the decay of both top quarks and the Higgs boson (small red blobs). Additional hard QCD radiation is produced (red) and a secondary interaction takes place (purple blob) before the final-state partons hadronise (light green blobs) and hadrons decay (dark green blobs). Photon radiation occurs at any stage (yellow).” [17]	14
2.5	“The bands are x times the unpolarized (a,b) parton distribution $f(x)$ (where $f = u_v, d_v, \bar{u}, \bar{d}, s \approx \bar{s}, c \approx \bar{c}, b \approx \bar{b}, g$) obtained in NNLO NNPDF3.0 global analysis at scales $\mu^2 = 10 GeV^2$ (left) and $\mu^2 = 10^4 GeV^2$ (right), with $\alpha_S(M_Z^2) = 0.118$. ” [33]	15
3.1	“The LHC injector complex” from Ref. [34]	17
3.2	“Schematic layout of the LHC (Beam 1- clockwise, Beam 2 — anticlockwise).” from Ref. [34]	18
3.3	“Number of Interactions per Crossing Shown is the luminosity-weighted distribution of the mean number of interactions per crossing for the 2015 – 2018 pp collision data at 13 TeV centre-of-mass energy. All data recorded by ATLAS during stable beams is shown, and the integrated luminosity and the mean mu value are given in the figure. The mean number of interactions per crossing corresponds to the mean of the Poisson distribution of the number of interactions per crossing calculated for each bunch. It is calculated from the instantaneous per bunch luminosity as $\mu = L_{\text{bunch}} \times \sigma_{\text{inel}}/f_r$ where L_{bunch} is the per bunch instantaneous luminosity, σ_{inel} is the inelastic cross-section which we take to be 80 mb for 13 TeV collisions, and f_r is the LHC revolution frequency.” from [39]	19
3.4	“Delivered Luminosity versus time for 2011-2018 (p-p data only) Cumulative luminosity versus day delivered to ATLAS during stable beams and for high energy p-p collisions. ” from [39]	20
3.5	“Cut-away view of the ATLAS detector. The dimensions of the detector are 25 m in height and 44 m in length. The overall weight of the detector is approximately 7000 tonnes.” from: [42]	21
3.6	“The peak instantaneous luminosity delivered to ATLAS during stable beams for pp collisions at 13 TeV centre-of-mass energy is shown for each LHC fill as a function of time in 2018. The luminosity is determined using counting rates measured by the luminosity detectors, and is based on an initial estimate from van-der-Meer beam-separation scans during 2017. ” from [43]	22

3.7	"Total Integrated Luminosity and Data Quality in 2015-2018 Cumulative luminosity versus time delivered to ATLAS (green), recorded by ATLAS (yellow), and certified to be good quality data (blue) during stable beams for pp collisions at 13 TeV centre-of-mass energy in 2015-2018. The complete pp data sample in 2018 is shown. The delivered luminosity accounts for the luminosity delivered from the start of stable beams until the LHC requests ATLAS to put the detector in a safe standby mode to allow a beam dump or beam studies. The recorded luminosity reflects the DAQ inefficiency, as well as the inefficiency of the so-called "warm start": when the stable beam flag is raised, the tracking detectors undergo a ramp of the high-voltage and, for the pixel system, turning on the preamplifiers. The data quality assessment shown corresponds to the All Good efficiency shown in the 2015-2018 Full Dataset DQ tables here. The All Good Data Quality criteria require all reconstructed physics objects to be of good data quality. " from [43]	23
6.1	Parton shower uncertainties calculated for QCD $W^\pm W^\pm jj$ (a), Interference $W^\pm W^\pm jj$ (b) and EW $W^\pm W^\pm jj$ (c) summed over all channels in the signal region and low- m_{jj} control region. The EW $W^\pm W^\pm jj$ parton shower uncertainty is normalised on truth level in the fiducial region to nominal as done in the total cross-section measurement of EW $W^\pm W^\pm jj$. The hatched black area represents the MC statistical uncertainty of the nominal parton shower Herwig 7. The total uncertainty is the symmetrized envelope taking into account Pythia 8 around the nominal prediction from Herwig 7.	49
6.2	NLO QCD correction uncertainties calculated for QCD $W^\pm W^\pm jj$ (a) and EW $W^\pm W^\pm jj$ (b) summed over all channels in the signal region and low- m_{jj} control region. The EW $W^\pm W^\pm jj$ NLO QCD correction uncertainty is normalised on truth level in the fiducial region to nominal as done in the total cross-section measurement of EW $W^\pm W^\pm jj$. The hatched black area represents the MC statistical uncertainty of the nominal LO prediction from Madgraph Herwig 7. The total uncertainty is defined as down variation in the fit and is defined by the Sherpa sample including a third jet in the matrix element.	50
6.3	PDF uncertainties calculated for QCD $W^\pm W^\pm jj$ (a), Interference $W^\pm W^\pm jj$ (b), EW $W^\pm W^\pm jj$ (c), WZ EW (d) and QCD $W^\pm Zjj$ (e) summed over all channels in the signal region and low- m_{jj} control region and WZ EW (f) and QCD $W^\pm Zjj$ (g) in the WZ control region. The hatched yellow area represents the PDF uncertainty calculated from 100 variations within the nominal NNPDF. Two alternative shower predictions from MMHT and CT14 are shown in red and green. The total PDF uncertainty is the envelope around the yellow band and the two different PDF predictions.	53
6.4	Scale uncertainties calculated for QCD $W^\pm W^\pm jj$ (a), Interference $W^\pm W^\pm jj$ (b), EW $W^\pm W^\pm jj$ (c), WZ EW (d) and QCD $W^\pm Zjj$ (e) summed over all channels in the signal region and low- m_{jj} control region and WZ EW (f) and QCD $W^\pm Zjj$ (g) in the WZ control region. The hatched grey area represents the MC statistical uncertainty. Seven combinations of up (multiplied by 2) and down (multiplied by 0.5) variations of the renormalisation and factorisation scale are shown. The total scale uncertainty is the envelope around all variations.	54
6.5	α_S uncertainties calculated for QCD $W^\pm W^\pm jj$ (a), Interference $W^\pm W^\pm jj$ (b), EW $W^\pm W^\pm jj$ (c), WZ EW (d) and QCD $W^\pm Zjj$ (e) summed over all channels in the signal region and low- m_{jj} control region and WZ EW (f) and QCD $W^\pm Zjj$ (g) in the WZ control region. The EW $W^\pm W^\pm jj$ α_S uncertainty is normalised on truth level in the fiducial region to nominal as done in the total cross-section measurement of EW $W^\pm W^\pm jj$ and QCD $W^\pm Zjj$ α_S uncertainty is normalised on truth level to nominal in the WZ CR. The hatched black area represents the MC statistical uncertainty of the nominal prediction.	55

6.6	NLO EW correction uncertainties calculated for EW $W^\pm W^\pm jj$ summed over all channels in the signal region and low- m_{jj} control region. The EW $W^\pm W^\pm jj$ NLO EW correction uncertainty is normalised on truth level in the fiducial region to nominal as done in the total cross-section measurement of EW $W^\pm W^\pm jj$. The hatched black area represents the MC statistical uncertainty of the nominal LO prediction from Madgraph Herwig 7. The NLO EW uncertainty is defined as down variation in the fit and is calculated as described in Ref. [11].	56
7.1	Conditions under which t_μ is χ^2 distributed from Ref. [112].	80
7.2	Different selection levels of events in unfolding.	86
7.3	Big Picture of Unfolding (as implemented in VIPUnfolding)	91
8.1	Pre-fit m_{jj} -distributions in the signal region for different flavour channels in bins as used in the total cross-section measurement: (a) ee , (b) $e\mu$, (c) μe and (d) $\mu\mu$. The hatched error band around the prediction represents the total uncertainty of the prediction, with statistical and systematic uncertainties added in quadrature.	99
8.2	Pre-fit m_{jj} -distributions in low- m_{jj} control region for different flavour channels in bins as used in the total cross-section measurement: (a) ee , (b) $e\mu$, (c) μe and (d) $\mu\mu$. The hatched error band around the prediction represents the total uncertainty of the prediction, with statistical and systematic uncertainties added in quadrature.	100
8.3	Pre-fit distributions in WZ control region as used in the total cross-section measurement. The hatched error band around the prediction represents the total uncertainty of the prediction, with statistical and systematic uncertainties added in quadrature.	101
8.4	Post-fit m_{jj} -distributions in the signal region for different flavour channels in bins used in the total cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data: (a) ee , (b) $e\mu$, (c) μe and (d) $\mu\mu$. The hatched error band around the prediction represents the total uncertainty of the prediction, with statistical and systematic uncertainties added in quadrature.	104
8.5	Correlation of nuisance parameters with at least 10% correlation with another NP (a) as used in the fit and (b) with sign of up-down variation adjusted to effect on total yield in signal region in total cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	108
8.6	Nuisance parameter pulls of strongest constrained nuisance parameters in the total cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	109
8.7	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured signal strength μ in total cross-section measurement of EW $W^\pm W^\pm jj$ using Asimov data. The empty brown rectangles correspond to the pre-fit impact on μ and the filled brown ones to the post-fit impact on μ , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}/\Delta\theta$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	109
8.8	Ranking of the top 20 nuisance parameters included in the fit according to their impact on the measured signal strength μ in total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data. The empty brown rectangles correspond to the pre-fit impact on μ and the filled brown ones to the post-fit impact on μ , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}/\Delta\theta$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	113

8.9	Post-fit m_{jj} -distributions in the signal region for different flavour channels in bins used in the total cross-section measurement of EW $W^\pm W^\pm jj$: (a) ee , (b) $e\mu$, (c) μe and (d) $\mu\mu$. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.	114
8.10	Post-fit m_{jj} -distributions in low- m_{jj} control region for different flavour channels in bins used in the total cross-section measurement of EW $W^\pm W^\pm jj$: (a) ee , (b) $e\mu$, (c) μe and (d) $\mu\mu$. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.	115
8.11	Post-fit distributions in WZ control region used in the total cross-section measurement of EW $W^\pm W^\pm jj$. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.	116
8.12	Correlation of nuisance parameters with at least 20% correlation with another nuisance parameter (a), most pulled (b) and strongest constrained (c) in the total cross-section measurement of EW $W^\pm W^\pm jj$	117
8.13	Likelihood scans of nuisance parameters with largest pulls and constraints in the total cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the QCD $W^\pm Zjj$ normalisation parameter (a), signal strength (b), Jet flavour composition (c), EW $W^\pm W^\pm jj$ NLO QCD correction (d), QCD $W^\pm W^\pm jj$ NLO QCD correction (e), EW $W^\pm W^\pm jj$ NLO EW correction (f) and QCD $W^\pm W^\pm jj$ scale uncertainty (g).	118
8.14	Ranking of the top 20 nuisance parameters included in the fit according to their impact on the measured signal strength μ in total cross-section measurement of EW $W^\pm W^\pm jj$ using observed data. The empty brown rectangles correspond to the pre-fit impact on μ and the filled brown ones to the post-fit impact on μ , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}/\Delta\theta$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	121
8.15	Ranking of the top 20 nuisance parameters included in the fit according to their impact on the measured signal strength μ in total cross-section measurement of inclusive $W^\pm W^\pm jj$ using observed data. The empty brown rectangles correspond to the pre-fit impact on μ and the filled brown ones to the post-fit impact on μ , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}/\Delta\theta$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	123
9.1	Migration matrices of EW $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 in the signal region and for all but m_{jj} also the low- m_{jj} control region. A projection over the second discriminant variable on reconstruction level is shown. MC statistical uncertainties are presented for each bin. If a value range is shown, then the last value is not included in the interval.	128
9.2	Migration matrices of inclusive $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 in the signal region and for all but m_{jj} also the low- m_{jj} control region. A projection over the second discriminant variable on reconstruction level is shown. MC statistical uncertainties are presented for each bin. If a value range is shown, then the last value is not included in the interval.	129

9.3	Fiducial correction of EW $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 being the fraction of events passing the reco selection which also pass the fiducial selection. For all but m_{jj} the low- m_{jj} control region is part of the reco selection. The hatched grey areas show the MC statistical uncertainty. Overflow events are included in the calculation of the last bin.	130
9.4	Fiducial correction of inclusive $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 being the fraction of events passing the reco selection which also pass the fiducial selection. For all but m_{jj} the low- m_{jj} control region is part of the reco selection. The hatched grey areas show the MC statistical uncertainty. Overflow events are included in the calculation of the last bin.	131
9.5	Efficiency correction of EW $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 being the fraction of events passing the fiducial selection which also pass the reco selection. For all but m_{jj} the low- m_{jj} control region is part of the reco selection. The hatched grey areas show the MC statistical uncertainty. Overflow events are included in the calculation of the last bin.	132
9.6	Efficiency correction of inclusive $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 being the fraction of events passing the fiducial selection which also pass the reco selection. For all but m_{jj} the low- m_{jj} control region is part of the reco selection. The hatched grey areas show the MC statistical uncertainty. Overflow events are included in the calculation of the last bin.	133
9.7	Efficiency of EW $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 being the fraction of events passing the reco selection divided by the number of events passing the fiducial selection. For all but m_{jj} the low- m_{jj} control region is part of the reco selection. The hatched grey areas show the MC statistical uncertainty. Overflow events are included in the calculation of the last bin.	134
9.8	Efficiency of inclusive $W^\pm W^\pm jj$ for the nominal signal sample Madgraph Herwig 7 being the fraction of events passing the reco selection divided by the number of events passing the fiducial selection. For all but m_{jj} the low- m_{jj} control region is part of the reco selection. The hatched grey areas show the MC statistical uncertainty. Overflow events are included in the calculation of the last bin.	135
9.9	Pre-fit m_{jj} -distributions in signal region split into $m_{\ell\ell}$ slices (a-f) as used in the $m_{\ell\ell}$ -differential cross-section measurement. Zero correlation is assumed in the combination of systematic uncertainties in the hatched band. The observed data is shown with frequentist Poisson uncertainties as defined in Section 7.7.2.	137
9.10	Pre-fit distributions in low- m_{jj} control region (a) and in WZ control region (b) as used in $m_{\ell\ell}$ -differential cross-section measurement. Zero correlation is assumed in the combination of systematic uncertainties in the hatched band. The observed data is shown with frequentist Poisson uncertainties as defined in Section 7.7.2.	138
9.11	Pre-fit m_{jj} -distributions in SR summed over $m_{\ell\ell}$ slices (a) and $m_{\ell\ell}$ -distributions in SR summed over m_{jj} bins (b) of the $m_{\ell\ell}$ -differential cross-section measurement. Zero correlation is assumed in the combination of systematic uncertainties in the hatched band. The observed data is shown with frequentist Poisson uncertainties as defined in Section 7.7.2.	138
9.12	Post-fit m_{jj} -distributions in signal region split into $m_{\ell\ell}$ slices as used in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. The Asimov data is shown with plain Poisson uncertainties.	140
9.13	Post-fit $m_{\ell\ell}$ -distribution in low- m_{jj} control region and m_{jj} -distribution in WZ control region as used in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. The Asimov data is shown with plain Poisson uncertainties.	141
9.14	Nuisance parameter pulls of strongest constrained nuisance parameters in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. The Asimov data is shown with plain Poisson uncertainties. . .	141

9.15	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) $m_{\ell\ell}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	143
9.16	LH-based unfolded distributions showing events per bin (a) and showing differential cross-section per 100 GeV (b) of the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with Asimov data. The measured data are shown as black points with horizontal bars indicating the bin range and black hatched (blue) boxes representing the systematic (total) uncertainty. The data are compared to a number of Standard Model predictions as described in Section 5.4. Overflow events are included in the last bin. [18]	144
9.17	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with Asimov data.	144
9.18	Post-fit $m_{\text{j}\text{j}}$ -distributions in signal region split into $m_{\ell\ell}$ slices (a-f) as used in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with observed data.	146
9.19	Post-fit distributions in low- $m_{\text{j}\text{j}}$ control region (a) and WZ control region (b) as used in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with observed data.	147
9.20	Post-fit $m_{\text{j}\text{j}}$ -distributions in SR summed over $m_{\ell\ell}$ slices (a) and Post-fit $m_{\ell\ell}$ -distributions in SR (right) summed over $m_{\text{j}\text{j}}$ bins (b) in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with observed data.	147
9.21	Nuisance parameter pulls of most pulled (a) and strongest constraint (b) nuisance parameters in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with observed data.	148
9.22	Likelihood scans of nuisance parameters with largest pulls and constraints in the $m_{\ell\ell}$ differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-f) and for the QCD $W^\pm Z \text{j}\text{j}$ normalisation parameter (g).	149
9.23	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ using observed data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) $m_{\ell\ell}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	152
9.24	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with observed data.	153

9.25	Fiducial differential cross-sections of EW $W^\pm W^\pm jj$ production as a function of: $m_{\ell\ell}$ (a), m_T (b), m_{jj} (c), $N_{gapJets}$ (d), and ξ_{j3} (e). The measured data are shown as black points with horizontal bars indicating the bin range and black hatched (blue) boxes representing the systematic (total) uncertainty. The data are compared to a number of Standard Model predictions as described in Section 5.4. Overflow events are included in the last bin. [18]	154
9.26	Measured fiducial cross-sections of inclusive $W^\pm W^\pm jj$ production as a function of: $m_{\ell\ell}$ (a), m_T (b), m_{jj} (c), $N_{gapJets}$ (d), and ξ_{j3} (e). The measured data are shown as black points with horizontal bars indicating the bin range and black hatched (blue) hatched boxes representing the systematic(total) uncertainty. The data are compared to a number of Standard Model predictions as described in Section 5.4. Overflow events are included in the last bin. [18]	155
9.27	Correlations between the bins of the LH-unfolded distributions shown considering the total uncertainty for the unfolded variables $m_{\ell\ell}$ (a), m_T (b), m_{jj} (c), $N_{gapJets}$ (d), and ξ_{j3} (e) in the case of the EW $W^\pm W^\pm jj$ fit. [18] .	156
9.28	Correlations between the bins of the LH-unfolded distributions shown considering the total uncertainty for the unfolded variables $m_{\ell\ell}$ (a), m_T (b), m_{jj} (c), $N_{gapJets}$ (d), and ξ_{j3} (e) in the case of the inclusive $W^\pm W^\pm jj$ fit. [18]	156
10.1	Post-fit distributions with observed data in low- m_{jj} control region (a) and in WZ control region (b). The hatched band represents the total model uncertainty, i.e. statistical and systematic uncertainties added in quadrature.	174
10.2	Correlation of nuisance parameters for best fit for coefficient f_{M0}/Λ^4 with Asimov data without clipping.	175
10.3	Pre-fit distributions: low- m_{jj} control region (a), $m_{\ell\ell}$ in signal region (b) and WZ control region (c). The hatched band represents the total model uncertainty, i.e. statistical and systematic uncertainties added in quadrature. All EFT parameters are set to zero.	177
10.4	Post-fit distributions for (a-b) upper and (c-d) lower limit of M0 operator without clipping: low- m_{jj} control region (left), $m_{\ell\ell}$ in signal region (middle) and WZ control region (right). The hatched error band around the model prediction represents the total uncertainty of the model taking into account correlations between the nuisance parameters. Negative EFT interferences are subtracted from the quadratic EFT contribution in the histograms. . .	178
10.5	Most pulled nuisance parameters for (a) upper and (b) lower expected limit for coefficient f_{M0}/Λ^4 without clipping.	178
10.6	Pre-fit up and down variation of the scale uncertainty of the quadratic term in the (a) low- m_{jj} control region and (b) signal region for operator M0 without clipping.	179
10.7	Evolution of the one-dimensional expected (blue dashed line) and observed (black line) limits at 95% CL on the parameters corresponding to the quartic operators with label (a) M0, (b) M1, (c) M7, (d) S1, (e) S02, (f) T0, (g) T1, and (h) T2 as a function of the cut-off scale. The unitarity bounds (green area) for each operator as a function of the cut-off scale are defined for one non-zero Wilson coefficient following Ref. [150]. The filled grey area corresponds to parameter values excluded by the data at 95% CL. The limits on M7 were obtained without taking into account the SM-EFT interference for the EW $W^\pm Z jj$ final state. [18]	185
10.8	Most pulled nuisance parameters for (a) best fit, (b) upper and (c) lower observed limit for coefficient f_{M0}/Λ^4	186
10.9	Correlation of nuisance parameters for best fit to observed data of operator T1 with clipping at 1.5 TeV.	187
10.10	Most pulled nuisance parameters for (a) upper and (b) lower limit of T1 operator at a clipping energy of 1500 GeV for observed data.	187

10.11	Pre-fit distributions with observed data: (a) low- m_{jj} control region, (b) $m_{\ell\ell}$ in the signal region and (c) WZ control region. The inner hatched error band on the model prediction represents the statistical uncertainties. The outer hatched band represents the total model uncertainty, i.e. statistical and systematic uncertainties added in quadrature.	188
10.12	Post-fit distributions for operator T1 slipped at 1.5 TeV for observed best fit (a-c), upper limit (d-f) and lower limit(g-i) in low- m_{jj} control region (left), $m_{\ell\ell}$ in the signal region (middle) and WZ control region (right). The hatched error band around the model prediction represents the total uncertainty of the model taking into account correlations between the nuisance parameters.	188
10.13	Post-fit $m_{\ell\ell}$ distributions for best fit (a), upper (b), inner upper (c), inner lower (d) and lower limit (e) bound with clipping at 700 GeV in the signal region. The hatched error band around the model prediction represents the total uncertainty of the model taking into account correlations between the nuisance parameters.	189
10.14	Most pulled nuisance parameters for (a) best fit, (b) upper limit, (c) inner upper limit, (d) inner lower limit and (e) lower limit for operator M0 clipped at 700 GeV.	190
10.15	Pre-fit up and down variation of systematic with largest pull in the low- m_{jj} CR (a, c) and signal region (b, d) for EW $W^\pm W^\pm jj$ Scale Uncertainty (a, b) and EW $W^\pm W^\pm jj$ NLO EW correction uncertainty (c, d).	191
10.16	Two-dimensional median expected (dashed line) and observed (solid line) 95% CL intervals on parameters corresponding to the quartic operator combinations (a) M0-M1, (b) M0-M7, (c) M1-M7, (d) S1-S02, (e) T0-T1, (f) T0-T2 and (g) T1-T2 EFT parameters without any unitarization procedure. The 1 (green) and 2 (yellow) sigma bands indicate where the limit is expected in 68.3% and 95.4% of the cases, respectively. The limits on M7 were obtained without taking into account the SM-EFT interference term and EFT cross-term for the EW $W^\pm Zjj$ final state. [18]	192
10.17	Two-dimensional median expected (dashed line) and observed (solid line) 95% CL intervals on parameters corresponding to the quartic operator combinations (a) M0-M1, (b) M0-M7, (c) M1-M7, (d) S1-S02, (e) T0-T1, (f) T0-T2 and (g) T1-T2 EFT parameters with a unitarization cut-off scale of 1.5 TeV and unitarity bounds (green line). The two-dimensional unitarity bounds for pairs of operators are obtained for the two non-zero Wilson coefficients from the eigenvalues from Ref. [150]. The 1 (green) and 2 (yellow) sigma bands indicate where the limit is expected in 68.3% and 95.4% of the cases, respectively. The limits on M7 were obtained without taking into account the SM-EFT interference term and EFT cross-term for the EW $W^\pm Zjj$ final state. [18]	193
B.1	Post-fit m_{jj} -distributions in low- m_{jj} control region for different flavour channels (a-d) as used in the total cross-section measurement of EW $W^\pm W^\pm jj$ using Asimov data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.	206
B.2	Post-fit distributions in WZ control region used in the total cross-section measurement of EW $W^\pm W^\pm jj$ using Asimov data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.	207
B.3	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a) and nuisance parameter pull (b) used in the total cross-section measurement of EW $W^\pm W^\pm jj$ using Asimov data	208

B.4	Post-fit m_{jj} -distributions in signal region for different flavour (a-d) channels as used in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.	218
B.5	Post-fit m_{jj} -distributions in low- m_{jj} control region for different flavour channels (a-d) as used in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.	219
B.6	Post-fit distributions in WZ control region used in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.	220
B.7	Correlation of nuisance parameters with at least 20% correlation with another nuisance parameter (a) and nuisance parameter pull of all (b) and of strongest constrained nuisance parameters (c) used in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	223
B.8	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a) and nuisance parameter pull (b) for the total cross-section measurement of EW $W^\pm W^\pm jj$ using observed data	235
B.9	Post-fit m_{jj} -distributions in signal region for different flavour channels (a-d) as used in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.	245
B.10	Post-fit m_{jj} -distributions in low- m_{jj} control region for different flavour channels (a-d) as used in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.	246
B.11	Post-fit distributions in WZ control region used in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. The hatched error band around the model prediction represents the total uncertainty of the model, with statistical and systematic uncertainties added in quadrature.	247
B.12	Correlation of nuisance parameters with at least 20% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) for in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	250
B.13	Likelihood scans of nuisance parameters with largest pulls and constraints in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the QCD $W^\pm Zjj$ normalisation parameter (a), signal strength (b), Jet flavour composition (c), EW $W^\pm W^\pm jj$ NLO QCD correction (d), QCD $W^\pm W^\pm jj$ NLO QCD correction (e), EW $W^\pm W^\pm jj$ NLO EW correction (f) and inclusive $W^\pm W^\pm jj$ scale uncertainty (g).	251
C.1	Post-fit m_{jj} -distributions in signal region split into $m_{\ell\ell}$ slices as used in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	262
C.2	Post-fit distributions in WZ control region (a) and low- m_{jj} CR (b) as used in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	262
C.3	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	263

C.4	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) $m_{\ell\ell}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	265
C.5	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with Asimov data.	266
C.6	Post-fit $m_{\text{j}\text{j}}$ -distributions in signal region split into $m_{\ell\ell}$ slices as used in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with observed data.	268
C.7	Post-fit distributions in WZ control region (a) and low- $m_{\text{j}\text{j}}$ CR (b) as used in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with observed data.	269
C.8	Post-fit signal region $m_{\ell\ell}$ -distributions (a) and $m_{\text{j}\text{j}}$ -distribution (b) in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with observed data.	269
C.9	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with observed data.	270
C.10	Likelihood scans of nuisance parameters with largest pulls and constraints in the $m_{\ell\ell}$ differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-f) and for QCD $W^\pm Z \text{j}\text{j}$ normalisation parameter (g).	271
C.11	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with observed data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) $m_{\ell\ell}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	273
C.12	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with observed data.	274
C.13	Pre-fit $m_{\ell\ell}$ -distributions in signal region split into $m_{\text{j}\text{j}}$ slices as used in $m_{\text{j}\text{j}}$ -differential cross-section measurement.	274
C.14	Pre-fit distributions in WZ control region as used in $m_{\text{j}\text{j}}$ -differential cross-section measurement.	275
C.15	Pre-fit $m_{\ell\ell}$ -distributions in SR summed over $m_{\text{j}\text{j}}$ slices (a) and $m_{\text{j}\text{j}}$ -distributions in SR summed over $m_{\ell\ell}$ bins (b) in $m_{\text{j}\text{j}}$ -differential cross-section measurement.	275
C.16	Post-fit $m_{\ell\ell}$ -distributions in signal region split into $m_{\text{j}\text{j}}$ slices as used in the $m_{\text{j}\text{j}}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with Asimov data.	277

C.17	Post-fit distributions in WZ control region as used in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	277
C.18	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	278
C.19	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_{jj} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	280
C.20	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	282
C.21	Post-fit $m_{\ell\ell}$ -distributions in signal region split into m_{jj} slices as used in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	282
C.22	Post-fit distributions in WZ control region as used in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	283
C.23	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	284
C.24	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_{jj} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	285
C.25	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	286
C.26	Post-fit $m_{\ell\ell}$ -distributions in signal region split into m_{jj} slices as used in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	288
C.27	Post-fit distributions in WZ control region as used in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	288
C.28	Post-fit $m_{\ell\ell}$ -distributions in SR summed over m_{jj} slices (a) and m_{jj} -distributions in SR summed over $m_{\ell\ell}$ bins (b) in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.. . . .	289
C.29	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	290

C.30	Likelihood scans of nuisance parameters with largest pulls and constraints in the m_{jj} differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-f) and for QCD $W^\pm Zjj$ normalisation parameter (g).	291
C.31	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_{jj} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	292
C.32	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	294
C.33	Post-fit $m_{\ell\ell}$ -distributions in signal region split into m_{jj} slices as used in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	295
C.34	Post-fit distributions in WZ control region as used in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	295
C.35	Post-fit $m_{\ell\ell}$ -distributions in signal region summed over m_{jj} slices (a) m_{jj} -distributions in signal region summed over $m_{\ell\ell}$ bins (b) in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	296
C.36	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	297
C.37	Likelihood scans of nuisance parameters with largest pulls and constraints in the m_{jj} differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-f) and for QCD $W^\pm Zjj$ normalisation parameter (g).	298
C.38	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_{jj} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	299
C.39	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	300
C.40	Pre-fit m_{jj} -distributions in signal region split into m_T slices as used in m_T -differential cross-section measurement.	300
C.41	Pre-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in m_T -differential cross-section measurement.	301

C.42	Pre-fit m_{jj} -distributions in signal region summed over m_T slices (a) and summed over m_{jj} bins (b) in m_T -differential cross-section measurement. . .	301
C.43	Post-fit m_{jj} -distributions in signal region split into m_T slices as used in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	303
C.44	Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	303
C.45	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	304
C.46	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_T -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	306
C.47	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	307
C.48	Post-fit m_{jj} -distributions in signal region split into m_T slices as used in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	307
C.49	Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	309
C.50	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	310
C.51	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_T -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	311
C.52	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	312
C.53	Post-fit m_{jj} -distributions in signal region split into m_T slices as used in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	314

C.54	Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	314
C.55	Post-fit signal region summed over m_T slices (a) and summed over m_T slices (b) in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	315
C.56	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	316
C.57	Likelihood scans of nuisance parameters with largest pulls and constraints in the m_T differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-f) and for QCD $W^\pm Zjj$ normalisation parameter (g).	317
C.58	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_T -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	318
C.59	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	320
C.60	Post-fit m_{jj} -distributions in signal region split into m_T slices as used in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	321
C.61	Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	321
C.62	Post-fit m_{jj} -distributions in signal region summed over m_T slices (a) and summed over m_{jj} bins (b) in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	322
C.63	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	323
C.64	Likelihood scans of nuisance parameters with largest pulls and constraints in the m_T differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-f) and for QCD $W^\pm Zjj$ normalisation parameter (g).	324

C.65	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with observed data. They are shown for the first (a), second (b), third (c), 4th (d), 5th (e) and 6th (f) m_T -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	325
C.66	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with observed data.	326
C.67	Pre-fit $m_{\text{j}\text{j}}$ -distributions in signal region split into $N_{\text{gap}\text{Jets}}$ slices as used in $N_{\text{gap}\text{Jets}}$ -differential cross-section measurement.	326
C.68	Pre-fit distributions in WZ control region (a) and low- $m_{\text{j}\text{j}}$ control region (b) as used in $N_{\text{gap}\text{Jets}}$ -differential cross-section measurement.	327
C.69	Pre-fit $m_{\text{j}\text{j}}$ -distributions in signal region summed over $N_{\text{gap}\text{Jets}}$ slices (a) and summed over $m_{\text{j}\text{j}}$ bins (b) in $N_{\text{gap}\text{Jets}}$ -differential cross-section measurement.	327
C.70	Post-fit $m_{\text{j}\text{j}}$ -distributions in signal region split into $N_{\text{gap}\text{Jets}}$ slices as used in the $N_{\text{gap}\text{Jets}}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with Asimov data.	329
C.71	Post-fit distributions in WZ control region (a) and low- $m_{\text{j}\text{j}}$ control region (b) as used in the $N_{\text{gap}\text{Jets}}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with Asimov data.	329
C.72	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the $N_{\text{gap}\text{Jets}}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with Asimov data.	330
C.73	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the $N_{\text{gap}\text{Jets}}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with Asimov data. They are shown for the first (a) and second (b) $N_{\text{gap}\text{Jets}}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	331
C.74	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $N_{\text{gap}\text{Jets}}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with Asimov data.	332
C.75	Post-fit $m_{\text{j}\text{j}}$ -distributions in signal region split into $N_{\text{gap}\text{Jets}}$ slices as used in the $N_{\text{gap}\text{Jets}}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with Asimov data.	334
C.76	Post-fit distributions in WZ control region (a) and low- $m_{\text{j}\text{j}}$ control region (b) as used in the $N_{\text{gap}\text{Jets}}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with Asimov data.	334
C.77	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the $N_{\text{gap}\text{Jets}}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with Asimov data.	335

C.78	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the $N_{\text{gap}J\text{ets}}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with Asimov data. They are shown for the first (a) and second (b) $N_{\text{gap}J\text{ets}}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	336
C.79	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $N_{\text{gap}J\text{ets}}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with Asimov data.	337
C.80	Post-fit $m_{\text{j}\text{j}}$ -distributions in signal region split into $N_{\text{gap}J\text{ets}}$ slices as used in the $N_{\text{gap}J\text{ets}}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with observed data.	339
C.81	Post-fit distributions in WZ control region (a) and low- $m_{\text{j}\text{j}}$ control region (b) as used in the $N_{\text{gap}J\text{ets}}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with observed data.	339
C.82	Post-fit $m_{\text{j}\text{j}}$ -distributions in signal region summed over $N_{\text{gap}J\text{ets}}$ slices (a) and summed over $m_{\text{j}\text{j}}$ bins (b) in the $N_{\text{gap}J\text{ets}}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with observed data.	340
C.83	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the $N_{\text{gap}J\text{ets}}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with observed data.	341
C.84	Likelihood scans of nuisance parameters with largest pulls and constraints in the $N_{\text{gap}J\text{ets}}$ differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a,b) and for QCD $W^\pm Z \text{j}\text{j}$ normalisation parameter (c).	342
C.85	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the $N_{\text{gap}J\text{ets}}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with observed data. They are shown for the first (a) and second (b) $N_{\text{gap}J\text{ets}}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	342
C.86	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $N_{\text{gap}J\text{ets}}$ -differential cross-section measurement of EW $W^\pm W^\pm \text{j}\text{j}$ with observed data.	343
C.87	Post-fit $m_{\text{j}\text{j}}$ -distributions in signal region split into $N_{\text{gap}J\text{ets}}$ slices as used in the $N_{\text{gap}J\text{ets}}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with observed data.	345
C.88	Post-fit distributions in WZ control region (a) and low- $m_{\text{j}\text{j}}$ control region (b) as used in the $N_{\text{gap}J\text{ets}}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with observed data.	345
C.89	Post-fit $m_{\text{j}\text{j}}$ -distributions in signal region summed over $N_{\text{gap}J\text{ets}}$ slices (a) and summed over $m_{\text{j}\text{j}}$ bins (b) in the $N_{\text{gap}J\text{ets}}$ -differential cross-section measurement of inclusive $W^\pm W^\pm \text{j}\text{j}$ with observed data.	346

C.90	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	347
C.91	Likelihood scans of nuisance parameters with largest pulls and constraints in the $N_{gapJets}$ differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a, b) and for QCD $W^\pm Zjj$ normalisation parameter (c).	348
C.92	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{bin\ i}$ in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. They are shown for the first (a) and second (b) $N_{gapJets}$ -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	349
C.93	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	349
C.94	Pre-fit m_{jj} -distributions in signal region split into ξ_{j3} slices as used in ξ_{j3} -differential cross-section measurement.	350
C.95	Pre-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in ξ_{j3} -differential cross-section measurement.	350
C.96	Pre-fit m_{jj} -distributions in signal region summed over ξ_{j3} slices (a) and summed over m_{jj} bins (b) in ξ_{j3} -differential cross-section measurement. . .	351
C.97	Post-fit m_{jj} -distributions in signal region split into ξ_{j3} slices as used in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	351
C.98	Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	353
C.99	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	354
C.100	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{bin\ i}$ in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d) and 5th (e) ξ_{j3} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	355
C.101	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	357
C.102	Post-fit m_{jj} -distributions in signal region split into ξ_{j3} slices as used in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	357

C.103	Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	358
C.104	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	359
C.105	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. They are shown for the first (a), second (b), third (c), 4th (d) and 5th (e) ξ_{j3} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	360
C.106	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	361
C.107	Post-fit m_{jj} -distributions in signal region split into ξ_{j3} slices as used in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	363
C.108	Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	363
C.109	Post-fit signal region summed over ξ_{j3} slices (a) and summed over m_{jj} slices (b) in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	364
C.110	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	365
C.111	Likelihood scans of nuisance parameters with largest pulls and constraints in the ξ_{j3} differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-e) and for QCD $W^\pm Z jj$ normalisation parameter (f).	366
C.112	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data. They are shown for the first (a), second (b), third (c), 4th (d) and 5th (e) ξ_{j3} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	366
C.113	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	368

C.114	Post-fit m_{jj} -distributions in signal region split into ξ_{j3} slices as used in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	369
C.115	Post-fit distributions in WZ control region (a) and low- m_{jj} control region (b) as used in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	370
C.116	Post-fit signal region summed over ξ_{j3} slices (a) and summed over m_{jj} slices (b) in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	370
C.117	Correlation of nuisance parameters with at least 10% correlation with another nuisance parameter (a), most pulled nuisance parameters (b) and strongest constrained (c) in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	371
C.118	Likelihood scans of nuisance parameters with largest pulls and constraints in the ξ_{j3} differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data (red) and observed data (black). It is shown for the signal normalisation in the i -th truth bin (a-e) and for QCD $W^\pm Z jj$ normalisation parameter (f).	372
C.119	Ranking of the top 20 nuisance parameters sorted according to their impact on the measured differential signal strength $\mu_{\text{bin } i}$ in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. They are shown for the first (a), second (b), third (c), 4th (d) and 5th (e) ξ_{j3} -slice on truth level. The empty brown rectangles correspond to the pre-fit impact on μ_i and the filled brown ones to the post-fit impact on μ_i , both referring to the upper scale. The black points show the pulls of the nuisance parameters with respect to their nominal values, θ_0 . These pulls and their relative post-fit errors, $\Delta\hat{\theta}_0/\Delta\theta_0$, refer to the lower scale. For normalisation parameters a pre-fit nominal value of 0 and a pre-fit uncertainty of 1 is assumed in this figure as described in Section 7.4.6.	373
C.120	The correlations between the bins are shown for total uncertainties (a), without luminosity (b), only theoretical and statistical (c) and statistic uncertainty only (d) of the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	374
D.1	Pulls of 15 most pulled nuisance parameters for lower (left) and upper (right) expected limits without clipping.	385
D.2	Pulls of 15 most pulled nuisance parameters for lower (left) and upper (right) expected limits with clipping at 1.5 TeV.	386
D.3	Pulls of 15 most pulled nuisance parameters for lower (left) and upper (right) expected limits with clipping at 0.7 TeV.	387
D.4	Pulls of 15 most pulled nuisance parameters for lower (left) and upper (right) expected limits without clipping.	393
D.5	Pulls of 15 most pulled nuisance parameters for lower (left) and upper (right) expected limits with clipping at 1.5 TeV.	394
D.6	Pulls of 15 most pulled nuisance parameters for lower (left) and upper (right) expected limits with clipping at 0.7 TeV.	395

List of Tables

2.1	Overview of fermions in the Standard Model of particle physics. All fermions have spin of $\frac{1}{2}$ within in Standard Model. The particles' electric charge Q , weak charge Y_W and third component of the weak isospin T_3 (L), where only left-handed particles and right-handed antiparticles have non-zero isospin, are shown. For participation in the strong force, only 1 or 0 is shown in the column 'QCD'. Quarks can have three different colour charges. Masses are taken from Ref. [8]. "The u-, d-, and s-quark masses are the $\bar{M}\bar{S}$ masses at the scale $\mu=2\text{ GeV}$. The c- and b-quark masses are the $\bar{M}\bar{S}$ masses renormalized at the $\bar{M}\bar{S}$ mass, i.e. $\bar{m} = \bar{m}(\mu = m)$. The t-quark mass is extracted from event kinematics." [8] The digits in parenthesis are the uncertainties. For neutrinos only an upper bound is known.	4
2.2	Overview of bosons in the Standard Model of particle physics. The particles' electric charge Q , weak charge Y_W and third component of the weak isospin T_3 (L), where only left-handed particles and right-handed antiparticles have non-zero isospin, are shown. For participation in the strong force, only 1 or 0 is shown in the column 'QCD'. Gluons can have a linear combination of products of colour and anticolour charge. Masses are taken from Ref. [8]. The digits in parenthesis are the uncertainties. For photons an upper bound of 10^{-27} GeV is known.	5
2.3	Vertices and their coupling strength involving gluons, i.e. strong coupling $g_S = \sqrt{4\pi\alpha_S}$	6
2.4	Vertices and their coupling strength involving a Higgs boson. The coupling to other particles is proportional to their mass.	9
2.5	Vertices and their coupling strength involving electroweak fields. The couplings can be transformed according to $g_W = \frac{e}{\sin\theta_W}$ and $g_Y = \frac{e}{\cos\theta_W}$. When $W^\pm$ is written, all combinations are possible which are allowed within charge conservation. It is: $e = \sqrt{4\pi\alpha_{em}} = 0.3$ and $\sin^2\theta_W = 0.23$ in the context of couplings. Due to quadratic matrix element this becomes a normal α_{em} for each tri-vertex	10
4.1	"A summary of MC samples used to simulate signal and major background processes in the signal region. The notation V is used to represent either W or Z/γ ." [18]	28
4.2	Dijet event selection used in the fake factor estimation as described in Ref. [67].	30
4.3	Region where charge flip probabilities are calculated from $Z \rightarrow ee$ process. Probabilities depend on η and p_T . All requirements are also applied in the signal region defined in Section 5.2.1 with the exception of the FSR requirement on truth level. FSR-induced electrons are removed at truth level to avoid the influence in charge misidentification from their contributions following Ref. [73].	32
5.1	Overview of samples and their predicted contribution in each region. $W^\pm W^\pm jj$ is grouped as a signal in the signal region and as a non-prompt background in the WZ control region.	36
5.2	Baseline selection criteria of electrons and muons. Details about identification working points, the minimal kinematic and geometrical requirements can be found in Section 3.2.4.	36
5.3	Baseline selection criteria of jets.	37

5.4	Signal electron and muon selection criteria. Details about the identification and isolation working points can be found in Section 3.2.4. Those working points are chosen which maximise the expected significance.	38
5.5	Signal jet and b-jet selection criteria. Details about the b-tagging working point can be found in Section 3.2.4.3.	38
5.6	Veto, third and signal electron and muon truth-level selection.	40
5.7	Signal jet and b-jet truth level object selection.	40
5.8	Overview of signal samples and their predicted cross-section in the fiducial phase space. [18]	41
6.1	Experimental uncertainties included in the statistical analysis part one. . . .	47
6.2	Experimental uncertainties included in the statistical analysis part two. . . .	48
6.3	Theory uncertainties of smaller prompt backgrounds as used in the fit	50
6.4	Contributions to top background in different regions. Relative theory uncertainties are taken from Ref. [87, 88].	50
6.5	Background modelling and model statistical uncertainties of total cross-section measurement	51
6.6	Signal modelling uncertainties of total cross-section measurement of EW $W^\pm W^\pm jj$	52
6.7	Signal modelling uncertainties of total cross-section measurement of EW $W^\pm W^\pm jj$	52
6.8	Theory uncertainties used in total and differential cross-section measurement of EW $W^\pm W^\pm jj$ and their normalisation: '-' not included, 's' included normalised, 'sn' included with shape and normalisation. Only WZ EW4 is normalised to nominal in the truth WZ control region. All other normalised variables are normalised in the fiducial signal region.	56
6.9	Theory uncertainties used in total and differential cross-section measurement of inclusive $W^\pm W^\pm jj$ and their normalisation: '-' not included, 's' included normalised, 'sn' included with shape and normalisation	56
6.10	Background modelling and model statistical uncertainties for differential cross-section measurement	57
6.11	Signal Modelling uncertainties for differential $m_{\ell\ell}$ cross-section measurement of EW $W^\pm W^\pm jj$	58
6.12	Signal Modelling uncertainties for differential $m_{\ell\ell}$ cross-section measurement of inclusive $W^\pm W^\pm jj$	58
6.13	WZjj and $W^\pm W^\pm jj$ Modelling and Model statistical uncertainties for 1D and 2D EFT limit setting.	60
6.14	EFT uncertainties for 1D EFT limit setting of M0.	61
6.15	EFT uncertainties for 2D EFT limit setting of M0-M1.	61
6.16	Theory uncertainties used in limit setting and their normalisation: '-' not included, 's' included normalised, 'sn' included with shape and normalisation	61
6.17	Uncertainties split by sample and uncertainty category in the signal region.	62
6.18	Uncertainties split by sample and uncertainty category in the low- m_{jj} control region.	63
6.19	Uncertainties split by sample and uncertainty category in the WZ control region. The experimental uncertainties of Wgamma are covered by the 100% MC statistical uncertainty of this sample in the WZ control region.	64
7.1	Pre-fit nuisance parameter value θ_0 and its pre-fit uncertainty $\Delta\theta_0$ for the nuisance parameters of luminosity λ , systematics α_i and MC statistical uncertainty γ_i . The uncertainty of luminosity is explained in Section 3.2.2.5.	68
7.2	Hypotheses and raw test statistics used for observations and limit setting.	77
7.3	Estimated Significance in a Bin for Different Use Cases.	84

7.4	Required number of events to get a relative uncertainty of x given a probability p of the process. Numbers are rounded to the order of magnitude and a second digit is shown if the first one is below three. This uses Equation 7.122 which assumes Poisson uncertainties. If less than four events are expected, i.e. $p \cdot n < 4$, in the tail of the distribution, then "-" is filled.	95
8.1	Pre-fit yields in the signal region as used in the total cross-section measurement. Shown are central values with statistical, theory, and experimental systematic uncertainties.	102
8.2	Pre-fit yields in the low- m_{jj} control region as used in the total cross-section measurement. Shown are central values with statistical, theory, and experimental systematic uncertainties.	102
8.3	Pre-fit yields in the WZ control region as used in the total cross-section measurement. Shown are central values with statistical, theory, and experimental systematic uncertainties.	103
8.4	Post-fit yields in the signal region used in the total cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. Shown are central values with statistical, theory, and experimental systematic uncertainties.	105
8.5	Post-fit yields in the low- m_{jj} control region used in the total cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. Shown are central values with statistical, theory, and experimental systematic uncertainties.	105
8.6	List of parameter correlations which are larger than 7.5% in the total cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	110
8.7	Breakdown of the uncertainty on the EW $W^\pm W^\pm jj$ cross-section measurement using Asimov data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma$, ZZ, top and Zjets.	111
8.8	Breakdown of the uncertainties on the inclusive $W^\pm W^\pm jj$ cross-section measurement using Asimov data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma$, ZZ, top and Zjets processes.	112
8.9	List of parameter correlations which are larger than 7.5% in the total cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	119
8.10	Breakdown of the uncertainties on the EW $W^\pm W^\pm jj$ cross-section measurement using observed data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma$, ZZ, top and Zjets.	120
8.11	Breakdown of the uncertainty on the inclusive $W^\pm W^\pm jj$ cross-section measurement using observed data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma$, ZZ, top and Zjets.	124
9.1	Binning of variables after optimisation used in unfolding. The unit of masses in this table is GeV.	128
9.2	List of parameter correlations which are larger than 10% in the $m_{\ell\ell}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	142
9.3	Breakdown of the uncertainty on the EW $W^\pm W^\pm jj$ $m_{\ell\ell}$ differential cross-section measurement using Asimov data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma$, ZZ, top and Zjets.	145
9.4	List of parameter correlations in the fit to observed data which are larger than 10%.	150
9.5	Breakdown of the uncertainty on the differential EW $W^\pm W^\pm jj$ cross-section measurement in the different ξ_{j3} truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma$, ZZ, top and Zjets.	157
9.6	Breakdown of the uncertainty on the differential EW $W^\pm W^\pm jj$ cross-section measurement in the different $N_{gapJets}$ truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, $V\gamma$, ZZ, top and Zjets.	158

9.7	Breakdown of the uncertainty on the differential EW $W^\pm W^\pm jj$ cross-section measurement in the different m_{jj} truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	159
9.8	Breakdown of the uncertainty on the differential EW $W^\pm W^\pm jj$ cross-section measurement in the different $m_{\ell\ell}$ truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	160
9.9	Breakdown of the uncertainty on the differential EW $W^\pm W^\pm jj$ cross-section measurement in the different m_T truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	161
9.10	Breakdown of the uncertainty on the differential inclusive $W^\pm W^\pm jj$ cross-section measurement in the different ξ_{j3} truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	162
9.11	Breakdown of the uncertainty on the differential inclusive $W^\pm W^\pm jj$ cross-section measurement in the different $N_{gapJets}$ truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	163
9.12	Breakdown of the uncertainty on the differential inclusive $W^\pm W^\pm jj$ cross-section measurement in the different m_{jj} truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	164
9.13	Breakdown of the uncertainty on the differential inclusive $W^\pm W^\pm jj$ cross-section measurement in the different $m_{\ell\ell}$ truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	165
9.14	Breakdown of the uncertainty on the differential inclusive $W^\pm W^\pm jj$ cross-section measurement in the different m_T truth slices using observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	166
10.1	Binning after the optimisation for at least 10 to 1 background events in each bin.	171
10.2	Binning after the optimisation for at least 5σ and at least 3σ as explained in Section 9.2.	172
10.3	Limits on the Wilson coefficients for different binning choices without clipping with only statistical uncertainties.	173
10.4	Stat. only, stat. theo. unc only and full systematics expected limits on the Wilson coefficients without clipping calculated with the asymptotic formula. In each column the lower and upper limit is shown.	176
10.5	Expected limits on the Wilson coefficients for all coefficients for the clipping value at the unitarity bound for different uncertainty sets calculated with asymptotic formula. "-" means that no crossing with the unitarity bound was found in the scanned region above 600 GeV.	176
10.6	Stat only and full systematics observed limits on the Wilson coefficients without clipping calculated with asymptotic formula. In each column the lower and upper limit is shown.	180
10.7	Observed limits on the Wilson coefficients for all Operators for the clipping value at the unitarity bound for different uncertainty sets calculated with asymptotic formula. "-" means that no crossing with the unitarity bound was found in the scanned region above 600 GeV. The effects of WZ EFT got included in this table. WZ EFT-SM interference of M7 is still missing.	180
10.8	Observed local SM exclusion significance for all Operators for different clipping values and different uncertainty sets with asymptotic formula.	181

10.9	Observed global SM exclusion significance for all Operators for different clipping values and different uncertainty sets with asymptotic formula.	182
10.10	Expected and observed limits on the Wilson coefficients for all Operators for no clipping, clipping at 1 TeV and the clipping value at the unitarity bound for the full set of uncertainties calculated with the asymptotic formula for expected and observed data. "—" means that no crossing with the unitarity bound was found in the scanned region above 600 GeV.	184
A.1	$W^\pm W^\pm jj$ Monte Carlo samples	198
A.2	Additional $W^\pm W^\pm jj$ samples used for systematic modelling uncertainties . .	198
A.3	WZ, Vgamma and other prompt, consisting of ZZ, triboson and top, background Monte Carlo samples	198
A.4	EFT Monte Carlo samples	199
B.1	Post-fit yields in the WZ control region in the total cross-section measurement of EW $W^\pm W^\pm jj$ using Asimov data. Shown are central values with statistical, theory, and experimental systematic uncertainties.	205
B.2	Ranking of the systematic nuisance parameters included in the total cross-section measurement of EW $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using Asimov data.	209
B.3	Ranking of the MC statistical nuisance parameters included in the total cross-section measurement of EW $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using Asimov data.	215
B.4	Post-fit yields in the signal region in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data. Shown are central values with statistical, theory, and experimental systematic uncertainties.	221
B.5	Post-fit yields in the low- m_{jj} control region in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data. Shown are central values with statistical, theory, and experimental systematic uncertainties.	221
B.6	Post-fit yields in the WZ control region in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data. Shown are central values with statistical, theory, and experimental systematic uncertainties.	222
B.7	List of parameter correlations which are larger than 7.5% in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using Asimov data.	224
B.8	Ranking of the systematic nuisance parameters included in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using Asimov data.	225
B.9	Ranking of the MC statistical nuisance parameters included in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using Asimov data.	231
B.10	Post-fit yields in the signal region in the total cross-section measurement of EW $W^\pm W^\pm jj$ using observed data. Shown are central values with statistical, theory, and experimental systematic uncertainties.	233
B.11	Post-fit yields in the low- m_{jj} control region in the total cross-section measurement of EW $W^\pm W^\pm jj$ using observed data. Shown are central values with statistical, theory, and experimental systematic uncertainties.	233
B.12	Post-fit yields in the WZ control region in the total cross-section measurement of EW $W^\pm W^\pm jj$ using observed data. Shown are central values with statistical, theory, and experimental systematic uncertainties.	234
B.13	Ranking of the systematic nuisance parameters included in the total cross-section measurement of EW $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using observed data.	236
B.14	Ranking of the MC statistical nuisance parameters included in the total cross-section measurement of EW $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using observed data.	242

B.15	Post-fit yields in the signal region in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using observed data. Shown are central values with statistical, theory, and experimental systematic uncertainties.	248
B.16	Post-fit yields in the low- m_{jj} control region in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using observed data. Shown are central values with statistical, theory, and experimental systematic uncertainties.	248
B.17	Post-fit yields in the WZ control region in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using observed data. Shown are central values with statistical, theory, and experimental systematic uncertainties.	249
B.18	List of parameter correlations which are larger than 7.5% in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ using observed data.	252
B.19	Ranking of the systematic nuisance parameters included in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using observed data.	253
B.20	Ranking of the MC statistical nuisance parameters in the total cross-section measurement of inclusive $W^\pm W^\pm jj$ sorted according to their impact on the measured signal strength μ using observed data.	259
C.1	List of parameter correlations in the Asimov fit which are larger than 10% in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	264
C.2	Breakdown of the uncertainty of signal strength in the different $m_{\ell\ell}$ truth slices in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	267
C.3	List of parameter correlations which are larger than 10% in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	272
C.4	Breakdown of the uncertainty of signal strength in the different $m_{\ell\ell}$ truth slices in the $m_{\ell\ell}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	276
C.5	List of parameter correlations which are larger than 10% in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	279
C.6	Breakdown of the uncertainty of signal strength in the different m_{jj} truth slices in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	281
C.7	List of parameter correlations which are larger than 10% in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	283
C.8	Breakdown of the uncertainty of signal strength in the different m_{jj} truth slices in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	287
C.9	List of parameter correlations which are larger than 10% in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	289
C.10	Breakdown of the uncertainty of signal strength in the different m_{jj} truth slices in the m_{jj} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	293
C.11	List of parameter correlations which are larger than 10% in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	296
C.12	Breakdown of the uncertainty of signal strength in the different m_{jj} truth slices in the m_{jj} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	302
C.13	List of parameter correlations which are larger than 10% in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	305

C.14	Breakdown of the uncertainty of signal strength in the different m_T truth slices in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	308
C.15	List of parameter correlations which are larger than 10% in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	309
C.16	Breakdown of the uncertainty of signal strength in the different m_T truth slices in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	313
C.17	List of parameter correlations which are larger than 10% in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	315
C.18	Breakdown of the uncertainty of signal strength in the different m_T truth slices in the m_T -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	319
C.19	List of parameter correlations which are larger than 10% in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	322
C.20	Breakdown of the uncertainty of signal strength in the different m_T truth slices in the m_T -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	328
C.21	List of parameter correlations in the Asimov fit which are larger than 10% in the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	331
C.22	Breakdown of the uncertainty of signal strength in the different $N_{gapJets}$ truth slices in the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	333
C.23	List of parameter correlations which are larger than 10% in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	336
C.24	Breakdown of the uncertainty of signal strength in the different $N_{gapJets}$ truth slices in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	338
C.25	List of parameter correlations which are larger than 10% in the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	340
C.26	Breakdown of the uncertainty of signal strength in the different $N_{gapJets}$ truth slices in the $N_{gapJets}$ -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	344
C.27	List of parameter correlations which are larger than 10% in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	346
C.28	Breakdown of the uncertainty of signal strength in the different $N_{gapJets}$ truth slices in the $N_{gapJets}$ -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	352
C.29	List of parameter correlations in the Asimov fit which are larger than 10% in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data.	353
C.30	Breakdown of the uncertainty of signal strength in the different ξ_{j3} truth slices in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	356
C.31	List of parameter correlations which are larger than 10% in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data.	358

C.32	Breakdown of the uncertainty of signal strength in the different ξ_{j3} truth slices in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with Asimov data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	362
C.33	List of parameter correlations which are larger than 10% in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data.	364
C.34	Breakdown of the uncertainty of signal strength in the different ξ_{j3} truth slices in the ξ_{j3} -differential cross-section measurement of EW $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	367
C.35	List of parameter correlations which are larger than 10% in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data.	372
C.36	Breakdown of the uncertainty of signal strength in the different ξ_{j3} truth slices in the ξ_{j3} -differential cross-section measurement of inclusive $W^\pm W^\pm jj$ with observed data. "Background, other" includes the modelling uncertainties of triboson, Vgamma, ZZ, top and Zjets.	375
D.1	Toy driven stat. only limits on the Wilson coefficients without clipping calculated for observed data. For each of the points 5000 toys around the scanned EFT parameter toy were generated. This results in a systematic uncertainty of 0.2% because of the limited number of toys.	378
D.2	Expected limits on the Wilson coefficients for all Operators for the clipping value at the unitarity bound for different uncertainty sets calculated with asymptotic formula with floating μ_{EW} . "-" means that no crossing with the unitarity bound was found in the scanned region above 600 GeV.	378
D.3	Expected limits on the Wilson coefficients for all Operators for different clipping values and different uncertainty sets for calculated with asymptotic formula with floating μ_{EW}	379
D.4	Expected limits on the Wilson coefficients for all operators for different clipping values and different uncertainty sets calculated with asymptotic formula.	381
D.5	Pre-fit yields in the signal region. Shown are central values with statistical, theory, and experimental systematic uncertainties.	382
D.6	Post-fit yields of upper limit of M0 operator without clipping in the signal region. Shown are central values with statistical, theory, and experimental systematic uncertainties.	382
D.7	Post-fit yields of lower limit of M0 operator without clipping in the signal region. Shown are central values with statistical, theory, and experimental systematic uncertainties.	383
D.8	Observed limits on the Wilson coefficients for all operators for different clipping values and different uncertainty sets calculated with asymptotic formula. The most upper and most lower limits are shown, also if there is some exclusion area near the SM prediction. The effects of WZ EFT is included in this table. WZ EFT-SM interference of M7 is still missing.	388
D.9	Observed inner limits on the Wilson coefficients for all Operators for different clipping values and different uncertainty sets with asymptotic formula. "-" is written if the area around the SM is not excluded	389
D.10	Post-fit yields of best fit to observed data in the signal region. Shown are central values with statistical, theory, and experimental systematic uncertainties.	390
D.11	Post-fit yields of upper limit for observed data in the signal region for M0 operator clipped at 700 GeV. Shown are central values with statistical, theory, and experimental systematic uncertainties.	390
D.12	Post-fit yields of inner upper limit for observed data in the signal region for M0 operator clipped at 700 GeV. Shown are central values with statistical, theory, and experimental systematic uncertainties.	391
D.13	Post-fit yields of inner lower limit for observed data in the signal region for M0 operator clipped at 700 GeV. Shown are central values with statistical, theory, and experimental systematic uncertainties.	391

D.14 Post-fit yields of lower limit for observed data in the signal region for M0 operator clipped at 700 GeV. Shown are central values with statistical, theory, and experimental systematic uncertainties.	392
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