

Heavy Flavour Electron Elliptic Flow

by

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Abstract

Due to the large mass of the Charm and Beauty quarks, they are created in the very first moments of the ultra-high energy nucleus-nucleus collisions taking place at the CERN LHC, therefore, they should be unaware of the geometry of the collision system and carry no azimuthal anisotropies. Similarly, the energy loss via gluon radiation for these massive quarks should be suppressed, the so-called dead cone effect. Although the observation of elliptic flow in the electrons produced through the semileptonic decay of these heavy mesons is an indirect measurement, throughout this thesis it will be shown that a strong correlation exists between the momentum anisotropy of the mother and daughter particles. In the low transverse momentum region such measurement would establish whether or not the system reaches local thermal equilibrium. While at large transverse momentum, the observation of collectivity for the heavy flavours can be understood only if the collisional and radiative in-medium interactions are strong enough. Therefore, this measurement will cast light on the energy loss mechanism and heavy-quark scattering cross section. The aim of this thesis is to discuss the challenges such measurement presents and to analyze the results obtained by analyzing the data taken by ALICE in the winter of 2010. Remarkably, a large electron elliptic flow was observed, both for the integral and differential cases. It will be shown that for intermediate transverse momentum, this measurement suggests a large elliptic flow for the heavy flavour mesons.

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Chapter 1

Introduction

1.1 Warming Up

In a typical Heavy-Ion collision several thousands of charged particles are produced and their collective behavior can be studied. One of the first observables is the fluctuation in the total number (multiplicity) of charged particles. Naturally, if the ions collide head on, more tracks should be produced than when the ions are not perfectly aligned and the overlap region has an ellipsoidal shape. Hence, it is possible to correlate the “centrality” of the collision with the measured track multiplicity.

These collisions create such energy density that it is expected that a Quark-Gluon-Plasma (QGP) is generated; medium where the quarks and gluons are deconfined from the nucleons. During the cooldown and subsequent expansion of this medium, heavy quarks, such as Charm and Beauty, which are produced in the very first instants of the collision will undergo a number of interactions. This number depends on the properties of the medium, such as volume, temperature and pressure. Clearly, the

medium will have a larger effect on these “heavy-probes” for a more central than for a more peripheral collision. Therefore, by comparing the signal of these probes for different centralities, with respect to a reference measurement in proton-proton collision, it is possible to extract information about the thermal properties of the QGP.

Observables that compare heavy-ion collisions with smaller systems have the inconvenience of the additional measurement in proton-proton collisions. Momentum anisotropy, is an observable which is directly correlated with the centrality of the collision. When the QGP is created there will be a pressure difference between the inside and the outside of the system, hence, a pressure gradient is generated. For a central collision, with a circular nucleus-nucleus overlap region, this pressure gradient will be equal in any direction. For a more peripheral collision this pressure gradient will be asymmetric. The ellipsoidal nuclear overlap region, induces a preferred direction in the expansion of the medium.

Summarizing, an ellipsoidal system will generate an asymmetric pressure gradient, which in turn will give the particles a larger “kick” in the medium’s expansion preferential direction. Hence, the spatial asymmetry will be transferred into a momentum asymmetry, which can be measured experimentally. Elliptic flow quantifies the strength of this transfer by looking at the ellipsoidal component of the transverse momentum (p_T) distribution.

Previous experiments at SPS [12] and RHIC [6], and more recently at LHC [2] have measured a large value of integrated (averaged over p_T and rapidity) elliptic flow. This changed the interpretation of the QGP as an ideal gas evolving into a strongly interacting fluid, with a near to zero viscosity [14]. Furthermore, the measurement

of the differential elliptic flow (as a function of p_T) revealed the quark-like degrees of freedom [7], and suggested that pions, kaons and protons are formed through the coalescence of light-quarks [23].

Using the heavy-quarks as probes of the in-medium interaction strength, the measurement of the elliptic flow of Heavy-Flavour-Mesons (HFM) will shed light on the energy loss mechanisms and heavy-quark scattering cross section. However, it is unavoidable to face either the challenge of tagging HFM from within tens of thousands of tracks or extracting the HFM signal through the electrons from their semileptonic decays. Moreover, whatever method is used, it should provide enough candidates for the statistical tools, used for the estimation of the elliptic flow to provide sensitive information.

In this thesis, the challenge of measuring the elliptic flow of HFM through the electrons from their semileptonic decays will be addressed. Both experimental and statistical aspects will be discussed and the results, based on the data taken by ALICE¹ in the winter of 2010, will be shown.

¹Please visit <http://alimonitor.cern.ch/configuration/>

1.2 ALICE experiment

1.2.1 Detector description

A Large Ion Collider Experiment (ALICE) is a general-purpose heavy-ion detector at the CERN LHC which focuses on QCD, the strong interaction section of the Standard Model. The overall dimensions are 16x16x26 cubic meters with a total weight of around 10000 tones. Its central barrel, designed to measured hadrons, electrons and photons, covers polar angles from 45° to 135° and its inside of the solenoid magnet recycled from the L3 [8] experiment at LEP.

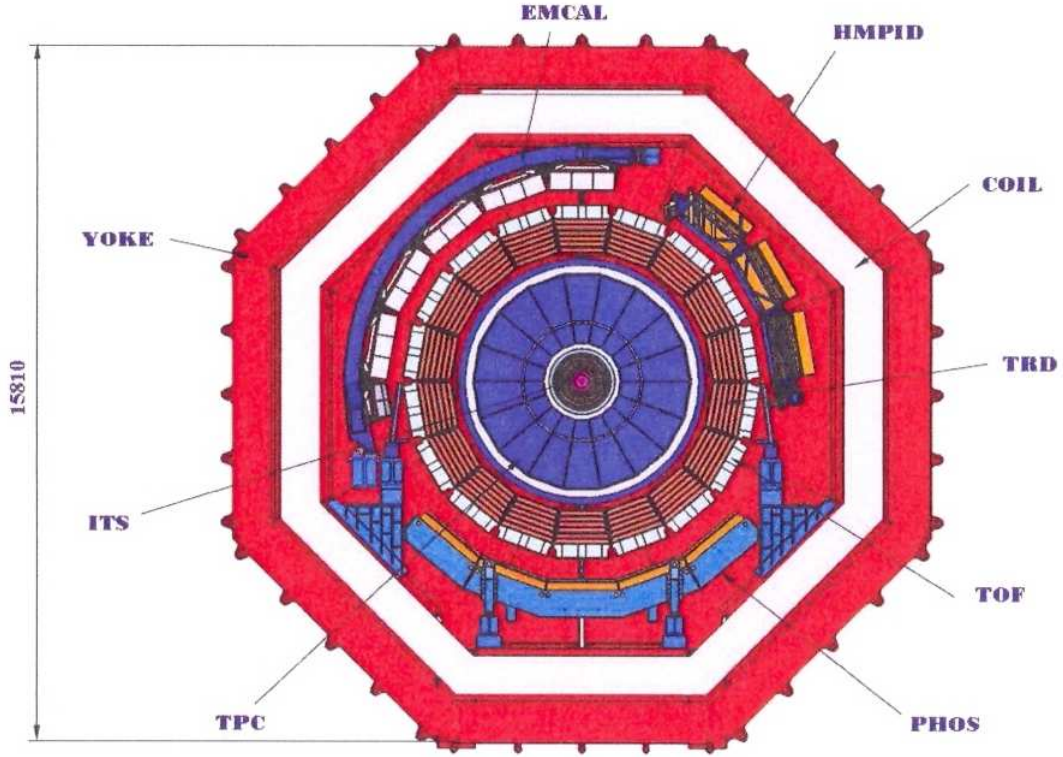


Figure 1.1: *ALICE central barrel 2D transverse cut view. This figure is taken from [21, 11].*

The central barrel detector layout, as shown in Figure 1.1 consist from the inside out, of an Inner Tracking System (ITS) with six panels of high-resolution silicon pixel (SPD), drift (SDD) and strip (SSD) detectors, a cylindrical Time-Projection-Chamber (TPC), three particle identification arrays of Time-of-Flight (TOF), Ring Imaging Cherenkov (HMPID), a Transition Radiation (TRD) detector and two electromagnetic calorimeters (PHOS and EMCal). With the exception of the HMPID, PHOS, and EMCal, all detectors cover the full azimuth. Additionally, a muon arm and several small detectors (zero degree calorimeters (ZDC), photon multiplicity detector (PMD), forward multiplicity detector (FMD), T0, V0) are located at small angles with respect to the beam pipe.

With the exception of the TRD, which were added more recently and are only now nearing completion, the experiment is essentially fully installed, commissioned and operational. The TRD has currently about 40% of their active area installed and will be completed in 2011.

Features, such as the physics requirements and expected performance of ALICE are given in detail in the Physics Performance Report [21, 11] and will be briefly summarized below according to the aspect of the collision of which they provide some valuable information for this thesis.

1.2.2 Charged Particle Tracking

The ITS and TPC detectors provide the charged-particle tracking of ALICE, in addition, at high p_T the TRD information is added to improve the resolution. Three of the functions of the ITS are: (i) heavy-flavour and strange particles decay vertex recon-

struction (ii) low-momentum particle tracking and identification (iii) impact parameter and momentum resolution improvement. In order to obtain a good performance in high-particles-density events the first four ITS layers, out of six, combine silicon pixel and drift detectors. The outer layers provide the ITS stand-alone capability as a low momentum particle spectrometer. Due to an analog readout the independent particle identification in the non-relativistic region is possible via energy-loss (dE/dx) measurement.

As the main tracking detector, the TPC is an efficient and robust device which guarantees reliable performance even with tens of thousands charged particles within the acceptance. With an outer radius of 2.5 m the TPC goes beyond 5-7% resolution in dE/dx . This allows the TPC particle identification (PID) in the region of the relativistic rise, up to 50 GeV/c in momentum.

The Kalman filter [17] is the track finding and fitting algorithm used at ALICE. It uses pairs of space points reconstructed at separated pad rows of the outer TPC and the reconstructed primary vertex. These pairs are used to set the initial values (seeds) for the track parameters and their covariance matrix. In essence, the Kalman filter consist on the following steps: first, the state vector and covariant matrix of the track parameters are propagated to next pad row, next, a noise term is added to the inverted covariance matrix in order to include possible information loss due to for instance to multiple scatterings. Finally, if the new pad space point is compatible with the extrapolation of the track, the filter increases the information by adding this measurement. For secondary tracks the seeds are created without using the primary vertex. The ITS+TPC track-finding efficiency is shown in Figure 1.2.

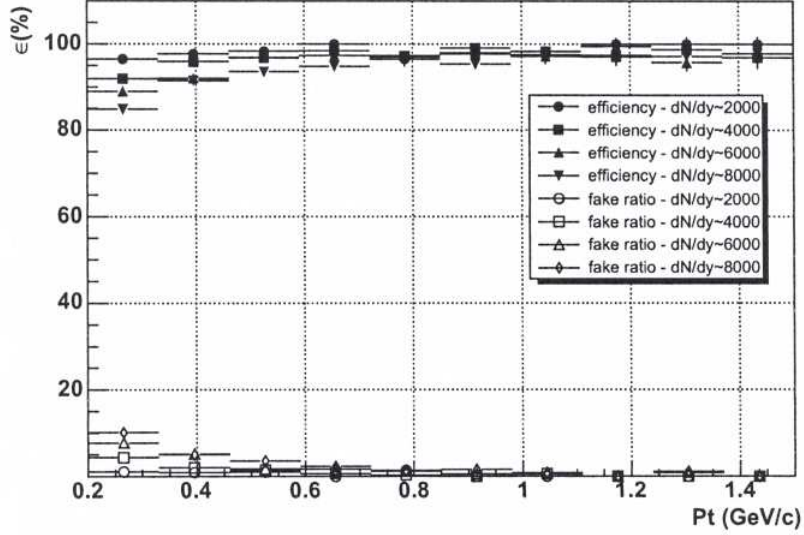


Figure 1.2: *TPC+ITS combined track-finding efficiency and fraction of fake tracks, as a function of p_T , for different track multiplicities. This figure is taken from [21, 11].*

In addition to the process mentioned above, the Kalman filter runs outwards reaching the TRD, TOF and HMPID space points whenever possible. Then, the process runs inwards once again. The tracks, which satisfy both, the outwards and inwards re-runs in the TPC or the ITS, are given the flag of $kTPC_{refit} = TRUE$ and $kITS_{refit} = TRUE$ respectively.

1.2.3 Primary Vertex Determination

Based on the information provided by the two innermost layers of the ITS, the SPD, a primary vertex is reconstructed. Pairs of points that are close in azimuth are selected in the two layers. Then, using the pair's z-coordinates (along the beam axis) the z-position of the primary vertex is estimated with a linear extrapolation. The

primary vertex position-resolution as a function of the track multiplicity is shown in Figure 1.3, together with the fitting function. The simulations used in the ALICE Physics Performance Report [21, 11] to study the primary vertex position resolution, were carried out using the ALICE offline simulation and reconstruction framework AliRoot ² Pb-Pb events were simulated with the HIJING ³ event generator and the detector response with GEANT3⁴.

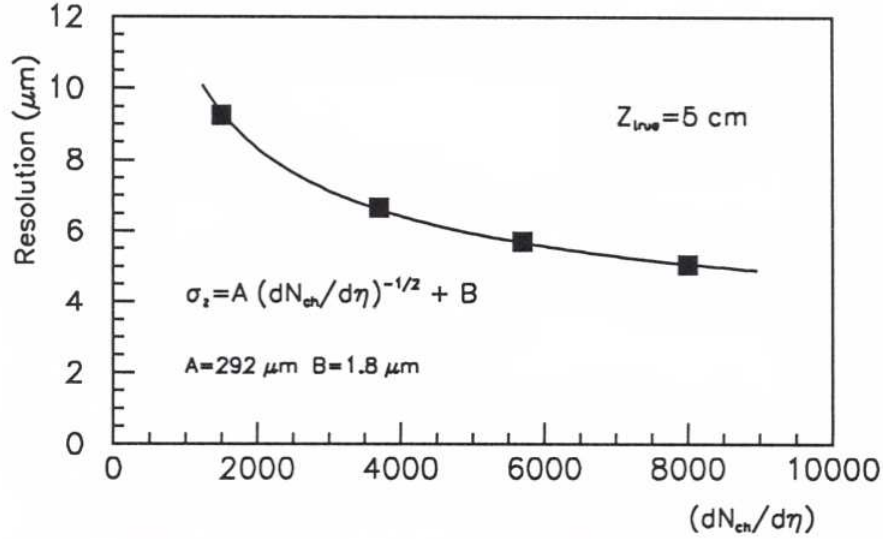


Figure 1.3: *Primary vertex z-coordinate resolution. This figure is taken from [21, 11].*

In order to determine the vertex position in the transverse plane, only the point pairs (tracklets) within $4\sigma_z$ around the estimated z-axis positions are selected. Due to the small radii of the SPD, the effect of the magnetic field in the determination of vertex's x and y coordinates can be ignored, especially for high-momentum particles.

²Please visit <http://aliceinfo.cern.ch/Offline/>

³Please visit <http://www-nsdth.lbl.gov/xnwang/hijing/>

⁴Please visit <http://wwwasd.web.cern.ch/wwwasd/geant/index.html>

The distribution of the intersections of all the straight lines connecting the points $(x_1, y_1), (x_2, y_2)$ has a minimum width (best resolution) at the values X', Y' close to the true vertex coordinates. This minimizing value can be found through an iterative procedure. Finally, by taking the most-likely value of the x_v, y_v, z_v distribution, an estimate of the 3D position of the primary vertex is calculated.

The primary vertex, estimated with the SPD tracklets, is used as hypothesis for the tracking which, in turn, determine the track parameters, such as curvature and angle with respect to the coordinate axis. These are then used to recalculate the primary vertex position.

1.2.4 Centrality Determination

The VZERO detector consist of two arrays of 32 scintillator tiles placed at distances $z = 3.3 \text{ m}$ and $z = -0.9 \text{ m}$ from the geometrical center of the ALICE central barrel. The VZERO-A covers the full azimuth within $2.8 < \eta < 5.1$, with $\eta = -\ln \tan(\theta/2)$, where θ is the polar angle between the charged-particle direction and the beam axis (z). Similary, the VZERO-C covers $-3.7 < \eta < -1.7$. Both, the amplitude and the time signal in each scintillator are recorded. Because of the time resolution of the VZERO is better than 1 ns , beam-beam collisions can be separated from beam-related backgrounds. Moreover, as the events become more central, with smaller impact parameter, the VZERO amplitude increases. Therefore a strong correlation between the centrality of the collision and the amplitude of the VZERO exists.

The summed amplitudes in the VZERO scintillators, reported by the ALICE Collaboration [3] in its latest analysis of the centrality dependence of the charged-

particle multiplicity, are shown in Figure 1.4. Here the measurement is fitted with the Glauber model of particle production [13]. This model uses two components: the number of participant nucleons N_{part} and the number of binary nucleon-nucleon collisions N_{bin} , as $f \times N_{part} + (1 - f) \times N_{bin}$, where f quantifies the relative contribution of each component.

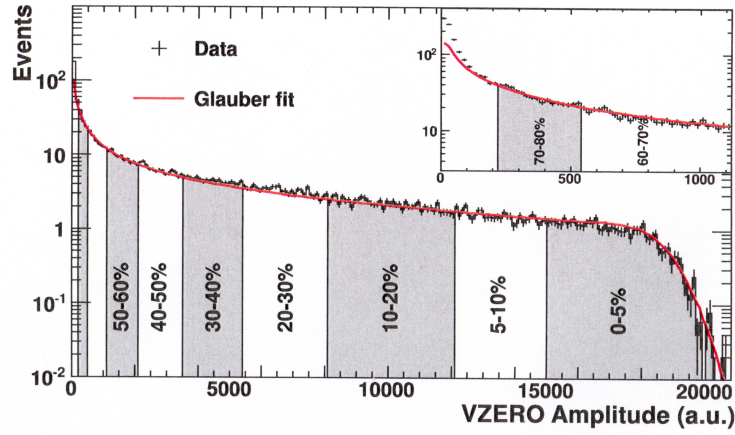


Figure 1.4: *Distribution of the summed amplitudes in the VZERO scintillator tiles (histogram); inset shows the low amplitude part of the distribution. The curve shows the result of the Glauber model fit to the measurement. The vertical lines separate the centrality classes used. This figure is taken from [3].*

The Glauber model describes the nuclear density for ^{208}Pb by the Woods-Saxon distribution [13] for a spherical nucleus with a radius of 6.62 fm and a skin depth of 0.546 fm, these parameters are based on data from low energy electron-nucleus scattering experiments [32]. In addition, a hard-sphere exclusion distance of 0.4 fm between nucleons is employed. The Glauber model allows for correlation of the centrality classes shown in Figure 1.4 with N_{part} . In order to study possible detector

bias in the centrality determination, it is usual to evaluate the correlation between the different estimators, as shown for the ZDC-VZERO and VZERO-TPC in Figure 1.5.

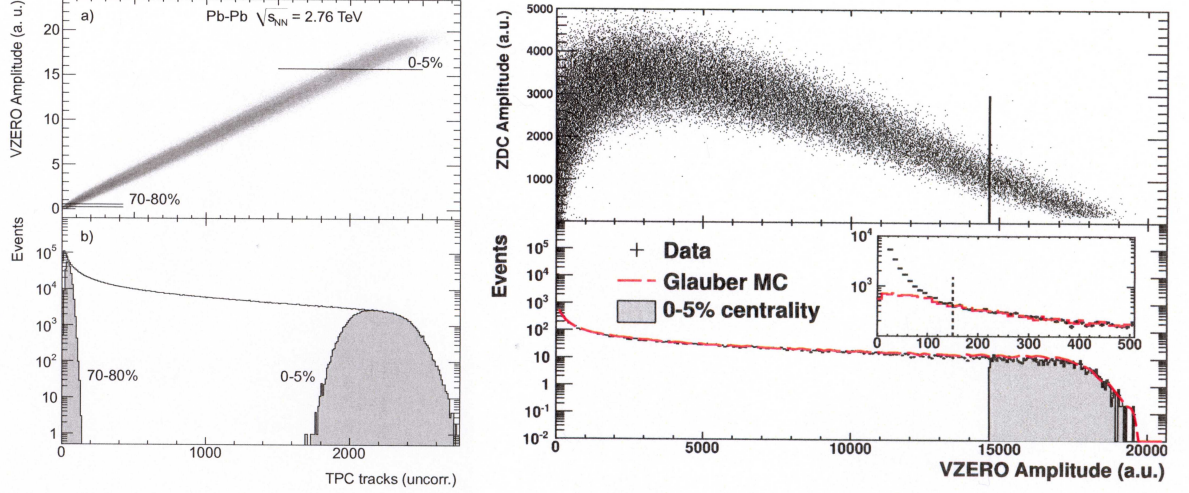


Figure 1.5: *Correlation between the VZERO Amplitude and the TPC tracks [5](Left), and the ZDC [1](Right).*

1.2.5 Particle Identification

The identification of electrons and positrons, in the range between 0.5 GeV/c and 3.0 GeV/c in momentum, is performed with the TPC and TOF detectors. The former uses the energy loss, while the latter measures the time a particle takes to travel from the vertex to the TOF. With a combined TPC+TOF Bayesian particle identification strategy (PID), a high-purity electron sample is obtained. A brief description of the TPC and TOF PID, together with the ideas behind the Bayesian and the Bethe-Bloch parameters used both in the Monte Carlo and Data analysis, will be discussed below.

Charged particles traveling through the TPC ionize the detector's gas, as this is a statistical process only the average energy loss per unit path length (dE/dx) can be calculated. The typical Bethe-Bloch parametrization of dE/dx is given by:

$$\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi N e^4}{mc^2} \frac{z^2}{\beta^2} \left(\ln \frac{2mc^2 \beta^2 \gamma^2}{I^2} - \beta^2 - \frac{\delta(\beta)}{2} \right), \quad (1.1)$$

where mc^2 is the rest energy of the electron, z the projectile's charge, N the number density of electrons in the matter inside the detector, e the elementary charge, β the velocity and I the mean excitation energy of the atom. An alternative parametrization proposed by Blum and Rolandi for the ALEPH TPC [18] is given by:

$$\left\langle \frac{dE}{dx}(\beta\gamma) \right\rangle = \frac{P_1}{\beta^{P_4}} \left(P_2 - \beta^{P_4} - \ln \left(\frac{1}{(\beta\gamma)^{P_5}} \right) \right), \quad (1.2)$$

where the parameters are unique for the gas mixture of the ALICE TPC (85.7% Ne, 9.5% CO₂ and 4.8% N₂) and are obtained through a calibration which is performed independently for Monte Carlo and Data, where for this latter a centrality-dependent calibration was performed. The obtained parameters are listed in the Table 1.1.

The dE/dx measurement is based on the following items:

- Digit: this is a digitized signal obtained from a pad of the TPC at a certain time.
- Cluster: this is a set of adjacent (in space and/or in time) digits that were presumably generated by the same particle.

- Reconstructed space point: this is the estimate of the particle's position the pad. This is often done by calculating the Cluster's center of gravity.
- Reconstructed track: this is a set of five parameters, such as curvature and angles with respect to the coordinate axes, of the particle's trajectory together with the corresponding covariance matrix estimated at a given point in space.

Table 1.1: Bethe-Bloch ALEPH-parametrization

All-Centralites	HIJING					
	P ₁	P ₂	P ₃	P ₄	P ₅	
	2.15898e ⁰⁰ /50	1.75295e ⁰¹	3.40030e ⁻⁰⁹	1.96178e ⁰⁰	3.91720e ⁰⁰	
	ALICE Data-Winter-2010 Pass2					
	0-5%	7.68595e ^{-0.2}	1.01781e ⁰¹	9.34864e ^{-0.6}	2.40323e ⁰⁰	2.13599e ⁰⁰
	5-10%	7.79393e ^{-0.2}	1.00337e ⁰¹	9.34864e ^{-0.6}	2.40323e ⁰⁰	2.13072e ⁰⁰
	10-20%	7.87563e ^{-0.2}	9.91265e ⁰⁰	9.34864e ^{-0.6}	2.42280e ⁰⁰	2.13296e ⁰⁰
	20-30%	8.23869e ^{-0.2}	9.50211e ⁰⁰	1.40230e ^{-0.5}	2.42899e ⁰⁰	2.05572e ⁰⁰
	30-40%	8.25626e ^{-0.2}	9.47698e ⁰⁰	1.40230e ^{-0.5}	2.43731e ⁰⁰	2.06060e ⁰⁰
	40-50%	8.27528e ^{-0.2}	9.44676e ⁰¹	1.40230e ^{-0.5}	2.44433e ⁰⁰	2.06498e ⁰⁰
	50-60%	8.29615e ^{-0.2}	9.41909e ⁰⁰	1.40230e ^{-0.5}	2.44894e ⁰⁰	2.06676e ⁰⁰
	60-70%	8.31397e ^{-0.2}	9.41126e ⁰⁰	1.40230e ^{-0.5}	2.44848e ⁰⁰	2.06326e ⁰⁰
	70-80%	8.38910e ^{-0.2}	9.30736e ⁰⁰	1.40230e ^{-0.5}	2.45844e ⁰⁰	2.07334e ⁰⁰

Now, the dE/dx information is extracted from the N_{cl} (number-of-clusters out of 159) associated with a track. As each cluster will have a total charge, the track

energy-deposition can be estimated by adding the total charge in each cluster.

A particle's velocity $\beta = L/t_{TOF}$ is obtained by combining the measured time of flight t_{TOF} and the reconstructed track flight path L between the point of closest approach to the event vertex and the TOF pad. The time-of-flight resolution, around 180 ps , depends on the TOF timing and flight path resolution, and the accuracy of the event start time t_0 . In order to determine these parameters a combinatorial algorithm, which compares the measured t_{TOF} with a calculated value for different mass hypotheses, was used. With this method the average precision on the event start-time is around 85 ps .

The Bayesian PID requires two ingredients: (i) the probability of a particle to belong to a kind i ($i = e, \mu, \pi, K, p, \dots$) if a signal s is observed, $r(i|s)$ (ii) an *a priori* probability, C_i , which indicates how often this type of particle is found. The former reflects only properties of the detector “detector response functions”, while the latter represents external conditions “relative concentrations”. These ingredients can be merged inside the Bayes' formula:

$$w(i|s) = \frac{r(i|s)C_i}{\sum_{k=e,\mu,\pi,\dots} r(s|k)C_k}. \quad (1.3)$$

Now, the PID procedure goes as follows: (i) the detector response function is obtained (ii) each track is assigned a value of $r(s|i)$ (iii) the relative concentrations C_i , that have been previously tuned on Pb-Pb minimum bias(MB) events, combined with (i) and (ii), are used to calculate the array of probabilities $w(i|s)$ as given by Eq. 1.3.

The combined TPC+TOF PID strategy, requires the tracks to have a Bayesian probability above 80% and, in addition, a 3σ cut in the TPC dE/dx . In both, the Monte Carlo and Data chapter of this thesis, TPC+TOF PID will be illustrated in more detail.

1.3 Elliptic Flow

Defined as the second order coefficient of the transverse-momentum-distribution Fourier expansion, shown in Eq. 1.4, the Anisotropic Flow, is also known as elliptic flow because it quantifies the ellipsoidal shape of the interaction region as shown in Figure 1.6. This spatial anisotropy would vanish in the case when the fireball has isotropic three-dimensional expansion. In the process of thermalization, which is assumed in the QGP, this spatial anisotropy will be transferred into a momentum anisotropy, where it can be measured through the elliptic flow Eq. 1.5.

$$E \frac{d^3N}{d^3p} = \frac{1}{2\pi} \frac{d^2N}{p_t dp_t dy} \left(1 + 2 \sum_{n=1}^{\infty} v_n \cos [n (\varphi - \Psi_{RP})] \right), \quad (1.4)$$

$$v_2(p_t, y) = \langle \cos [2 (\varphi - \Psi_{RP})] \rangle. \quad (1.5)$$

That transfer from spatial to momentum anisotropy is given by the pressure gradient generated by the different amount of matter a particle encounter, when leaving the fireball, as a function of its relative orientation with the Reaction Plane (RP) angle. The reaction plane angle is defined as the azimuthal angle of the impact parameter in the laboratory frame, as shown in Figure 1.6. Unfortunately, the RP angle can not be unambiguously determined in the experiment, as it changes randomly event-

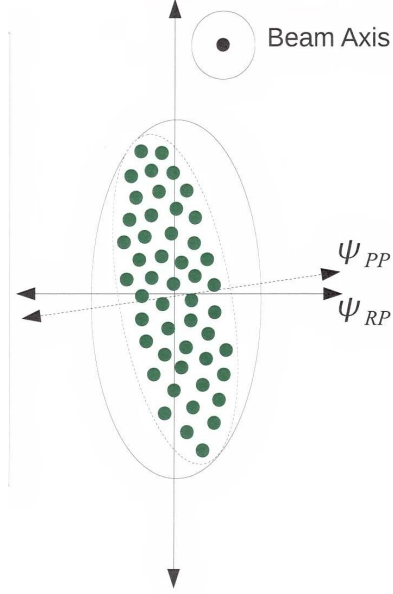


Figure 1.6: *Transverse view of the collision geometry.*

by-event. Although some methods [29, 15] give an estimate of the reaction plane angle, they came into disuse because they require multiple passes over data, or are too susceptible to non-flow effects. To address this lack of the RP angle new methods that use multi-particle correlations, are employed. The idea behind such methods goes as follows: starting with the two particle correlation:

$$\langle\langle\cos[2(\varphi_1 - \varphi_2)]\rangle\rangle, \quad (1.6)$$

where the double bracket denotes that the average is performed first in an event, and then in many events, can be split in the correlation each particle has with respect to the reaction plane as:

$$\begin{aligned}
\langle\langle\cos[2(\varphi_1 - \varphi_2)]\rangle\rangle &= \langle\langle\cos[2(\varphi_1 - \Psi_{RP} - (\varphi_2 - \Psi_{RP}))]\rangle + \delta_2\rangle \\
&= \langle\langle\cos[2(\varphi_1 - \Psi_{RP})]\rangle\langle\cos[2(\varphi_2 - \Psi_{RP})]\rangle + \delta_2\rangle \\
&= \langle v_2^2 + \delta_2 \rangle,
\end{aligned} \tag{1.7}$$

where the factor δ_2 denotes the two particle correlations, which does not point towards the reaction plane and can be produced by decays and momentum conservation among others. This term is usually called “non-flow”, and in principle will bias the elliptic flow measurement. In general it will be a stronger effect for events with less particles, because it scales as $\delta_2 \propto 1/N_{pairs}$. From Eq. 1.7 it is clear that by using multiparticle correlations it is possible to estimate, in this case, the average of the square of the elliptic flow.

The Cumulant [19] method, looks for genuine multiparticle correlations in an event, which for the case of the two-particles will have a trivial relation with what is shown in Eq. 1.6, as:

$$c_2\{2\} = \langle\langle\cos[2(\varphi_1 - \varphi_2)]\rangle\rangle, \tag{1.8}$$

where in $c_2\{2\}$ the subscript denotes it estimates the second harmonic of Eq. 1.4, as other harmonics could be estimated in the same way, and $\{2\}$ reflects the use of two-particles. Then, $c_2\{2\}$ is called 2^{nd} order Cumulant.

Now, in order to obtain a 4^{th} order Cumulant it is necessary to take into consideration the trivial two particle correlations within the quadruple. It is written as:

$$\begin{aligned}
c_2\{4\} &= \langle \langle \cos[2(\varphi_1 + \varphi_2 - \varphi_3 - \varphi_4)] \rangle \rangle - 2 \langle \langle \cos[2(\varphi_1 - \varphi_2)] \rangle \rangle^2 \\
&= \langle v_2^4 + \delta_4 + 4v_2^2\delta_2 + 2\delta_2^2 \rangle - 2\langle v_2^2 + \delta_2 \rangle^2 \\
&= \langle -v_2^4 + \delta_4 \rangle,
\end{aligned} \tag{1.9}$$

where δ_4 denotes the four-particle “non-flow”, which involves four or more particle correlations as jets and momentum conservation and scales as $\delta_4 \propto 1/N_{quadruplets}^3$. From this, it is clear that the 4th order Cumulant provides a better estimate of v_2 than the 2nd order. Now, it is possible to write Eq.s 1.8 and 1.9 in terms of the Q-vector which is defined as:

$$Q_2 = \sum_{i=1}^M \cos 2\varphi_i, \tag{1.10}$$

where M denotes the number of reference particles, or multiplicity. Here, a difference between Reference Particles (RP) and Particles of Interest (POI) is introduced. In general v_2 will depend on p_T and y . Then, in a first step the elliptic flow of the RP is calculated, then with respect to this value, the v_2 of the POI is calculated. Now by squaring the Q-vector as:

$$|Q_2|^2 = \sum_{i,j=1}^M \cos 2(\varphi_i - \varphi_j), \tag{1.11}$$

and expanding as :

$$|Q_2|^2 = \langle \cos 2(\varphi_i - \varphi_j) \rangle \binom{M}{2} 2! + M, \quad (1.12)$$

the two-particle correlation in a single event can be written as:

$$\langle \cos 2(\varphi_i - \varphi_j) \rangle = \frac{|Q_2|^2 - M}{M(M-1)}, \quad (1.13)$$

where by averaging over many events the 2^{nd} order Q-Cumulant [16] is obtained:

$$c_2\{2\} = \frac{\sum_j^N (|Q_2|_j^2 - M_j)}{\sum_j^N M_j (M_j - 1)}, \quad (1.14)$$

where the index j runs over the number of events. In a similar way, the 4^{th} order Cumulant can be written in terms of Q-vectors, a full expression and detailed derivation can be found in the Appendix A of [16].

Summarizing, the Q-vector in Eq. 1.10 is introduced in order to calculate the Cumulant, Eq. 1.8 and 1.9, in a fast and exact way. Then, for a detector with a uniform acceptance and assuming that statistical fluctuations in the elliptic flow are negligible, $\langle v_2^2 \rangle = \langle v_2 \rangle^2$, its value can be estimated with the 2^{nd} order Q-Cumulant (QC) method as:

$$v_2\{2\} = \sqrt{c_2\{2\}}, \quad (1.15)$$

or with the 4^{th} order QC as:

$$v_2\{4\} = \sqrt[4]{-c_2\{4\}}. \quad (1.16)$$

Corrections exist for any other case, such as non-uniform detector acceptance [16]. Finally, it is worth mentioning that the difference between $v_2\{2\}$ and $v_2\{4\}$ is sensitive to “non-flow” and fluctuations. It can be written as:

$$\begin{aligned} v_2\{2\} &= \langle v_2 \rangle + \frac{1}{2} \frac{\sigma^2}{\langle v_2 \rangle} \\ v_2\{4\} &= \langle v_2 \rangle - \frac{1}{2} \frac{\sigma^2}{\langle v_2 \rangle}. \end{aligned} \quad (1.17)$$

Those fluctuations will be important when discussing the interpretation of the results in the Data chapter.

1.4 Monte Carlo Generators

Throughout this thesis, Monte Carlo generators (MC) will be used to address issues such as: kinematic-corrections, signal selection and background subtraction analysis. In addition, in order to disentangle different contributions to the measurement of electron v_2 , the measured electron p_T spectrum will be fitted as a combination of the background and signal provided by MC generators. In this section PYTHIA [30] and HIJING [33], which are used to simulate the heavy-flavour signal and electron backgrounds respectively, will be introduced and the motivation to use them will be presented. Furthermore, in order to study the kinematic and detector effects inherent

to the measurement of v_2 in unstable particles a generator named AfterBurner⁵, which adds the v_2 to a previously generated set of primary particles, was used and will be described at the end of this section.

The above mentioned generators are embedded inside the ALICE offline framework AliRoot⁶, which, together with the AliEn⁷ environment, provide a user-friendly environment and allows for analysis of a large sample of events to be performed.

HIJING, a specialized Heavy-Ion generator, uses as input the results of previous heavy ion experiments. The physical process within, combine the Dual Parton Model [20], which has a unique picture of the nucleus-nucleus particle production at high energies, with the Lund FRITOF [28] perturbative QCD process in PYTHIA. The HIJING generator accurately describes the density of charged-particles in Pb-Pb collisions at 2.76 TeV measured by ALICE [1], as shown in Figure 1.7.

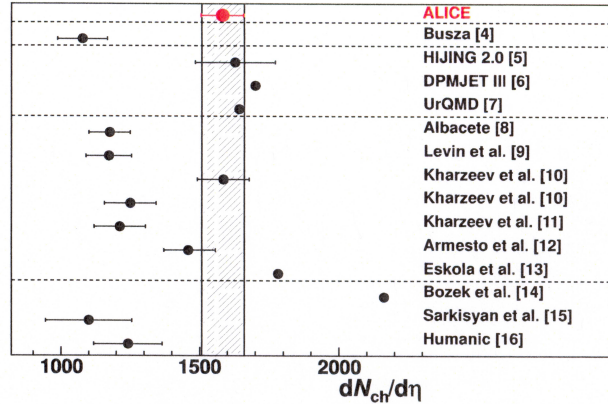


Figure 1.7: Comparison of this measurement with model predictions. This figure is taken from [1].

⁵Please visit <http://aliceinfo.cern.ch/static/aliroot-new/html/roothtml/AliGenAfterBurnerFlow.html>

⁶Please visit <http://aliceinfo.cern.ch/Offline/>

⁷Please visit <http://alien2.cern.ch/>

PYTHIA, a generator based on string fragmentation, which uses perturbative QCD, describes reasonably the primary-charged-particle p_T differential yield. Within the ALICE Collaboration the use of the PYTHIA tunes D6T [10], ATLAS-CSC [27] and Perugia-0 [31], is customary in order to study the heavy-flavour production.

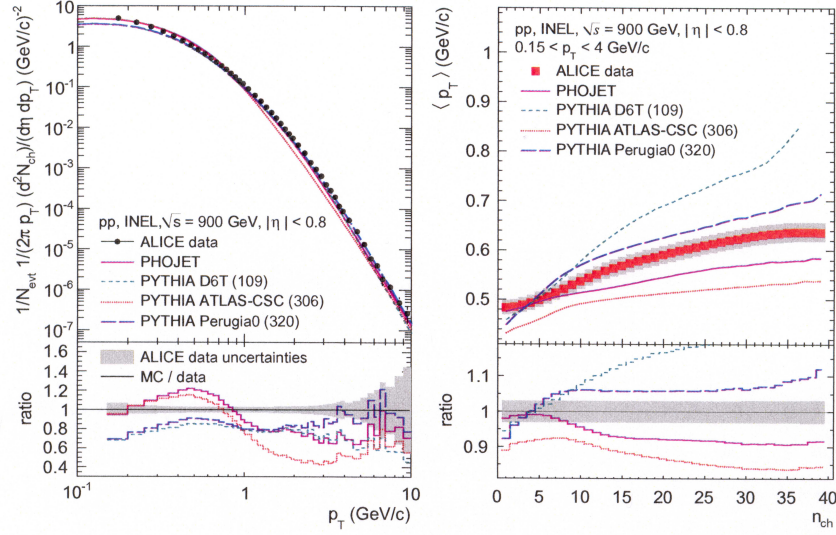


Figure 1.8: *Left: primary charged particle p_T -differential yield in INEL pp collisions $\sqrt{s} = 900 \text{ GeV}$ ($|\eta| < 0.8$), compared with different generators. Right: the average transverse momentum of charged particles for $0.15 < p_T < 4 \text{ GeV}$ as a function of n_{ch} , in comparison to models. This figure is taken from [22].*

The AfterBurner, a code developed by the ALICE Collaboration ⁸, loops over all the primary particles on an event and rotates its momentum vector and decay vertex. This rotation angle is correlated with the strength of the v_2 input signal as:

⁸Please visit <http://aliceinfo.cern.ch/static/alroot-new/html/roothtml/AliGenAfterBurnerFlow.html>

$$\varphi \rightarrow \varphi + \Delta\varphi \text{ , with } \Delta\varphi = v_2 \sin[2(\varphi - \Psi_{RP})] \text{ ,} \quad (1.18)$$

then a Newton-Raphson iteration runs until the desired resolution is achieved. This process of adding the v_2 signal preserves the correlations between the mother and daughters which is important when studying Heavy-Flavour-Mesons decay products v_2 . The code that was implemented to add the flow signal to a mixture of HIJING and PYTHIA, with the signal proportional to a eccentricity given by a Glauber code, is given and explained in detail in the Appendix A.

Chapter 2

Monte Carlo Analysis

2.1 Introduction and objectives

In the previous chapter some of the features inside Monte Carlo (MC) generators, such as HIJING and PYTHIA, were discussed. In the following section these MC tools will be used to analyze the kinematic and detector effects inherent to measurements performed in the electronic channel. Moreover, it will be shown that the Heavy-Flavour-Electrons (HFE) are just one of the many sources that contribute to the electron spectrum. The subtraction and disentanglement of each source from the measured electron elliptic flow will prove to be the biggest challenge in the measurement of the HFE elliptic flow.

There are four issues to be addressed. Firstly, the transverse momentum range, for which this analysis has validity, will be estimated by making use of hardware constraints, such as the current Particle Identification (PID) capabilities of the ALICE detector and, statistical constraints, such as the effect that jet-like correlations have in

the resolution of the methods used to estimate the elliptic flow, and their capability to resolve between flow and non-flow contributions.

Secondly, it will be shown that the decay of the HFM into electrons induces a difference between the flow measured in the latter and what was originally in the former. Thus, to address this issue a correction strategy will be proposed, for which analytical and MC studies will be performed.

Thirdly, it is well known that HFE are only one of the many contributions to the total electron spectrum, in fact, sources such as photo-conversions and light meson Dalitz decays are several orders of magnitude more abundant than those electrons produced by the semi-leptonic decay of Charm and Beauty mesons. Therefore, a set of background subtraction cuts, involving low-invariant-mass electron-positron pairs and the first layer of the Internal Tracking System (ITS), will be analyzed.

Finally, even after the above mentioned selection criteria are applied, it will be shown that some of the sources, such as light meson decays, remain as irreducible backgrounds. An strategy will be introduced, based on the information provided by the MC generators and on the knowledge acquired in the previous three steps. This strategy, will allow for the disentanglement of the different sources, assuming a proper calibration of these MC generators is carried out. This latter task, due its extension, is left to future interested readers.

2.2 Transverse Momentum Range

As shown in the left panel of Figure 2.1, up to 3 GeV/c in momentum the electron and pion lines are clearly split in terms of the TPC signal. However, the kaon and proton lines cross over the electron's around 0.5 and 1.0 GeV/c respectively. To address this issue, the TOF pid qualities, shown in the right panel of Figure 2.1, can be used by requiring the charged particles to move near to the speed of light ($\beta=1$), which rejects kaons and protons up to 3 GeV/c. In addition, this combined TPC+TOF PID strategy sets a minimum requirement of 0.3 GeV/c in momentum, in order for the tracks to reach the TOF detector.

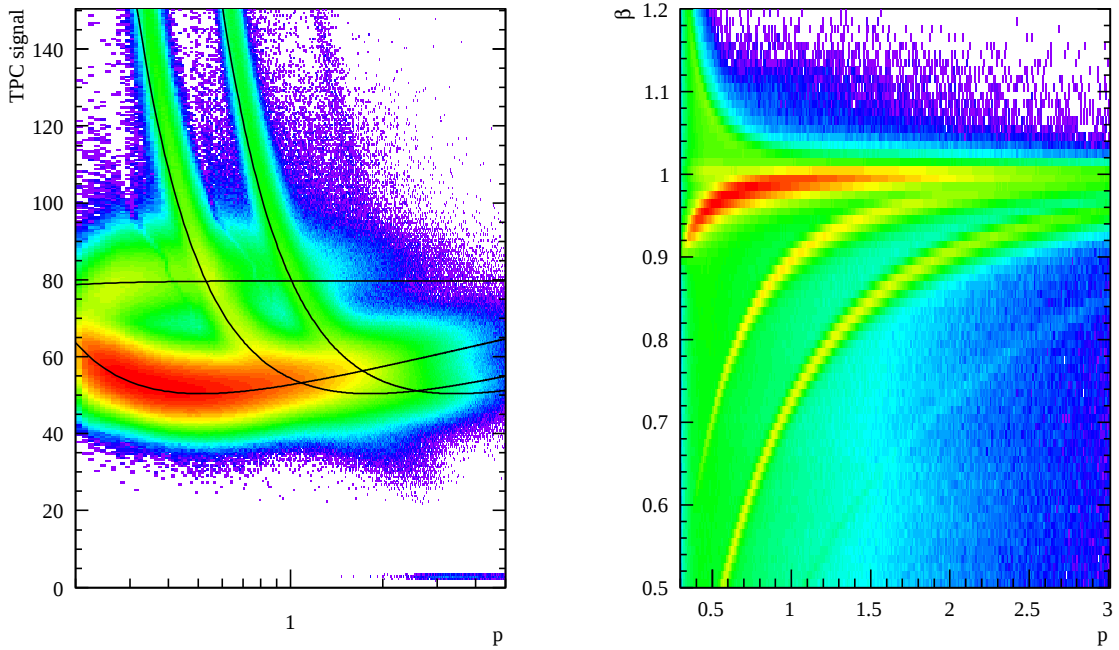


Figure 2.1: *TPC (Left) and TOF (Right) signals as a function of the momentum.*

The Elliptic flow measured by ALICE [2] is large enough to ensure that it is the dominant contribution to collective correlations in heavy-ion-collisions, however, several studies [4] suggest that is not the only contribution. When looking at HFM decay products, such as an electron emerging from a secondary vertex, it is unavoidable to face the correlations resulting from Jets because of several tracks; within a small window in ϕ - η , will be correlated with a vector pointing in the direction of the HFM momentum. This short range correlation induces a bias in the estimated value of the elliptic flow known as “non-flow”.

Recent developments in the methods used to estimate the elliptic flow [16], where rather than two particle correlations, only genuine four particles correlations are used in the elliptic flow estimation. This improves the capability to resolve between “true” and “non-flow”. In order to illustrate this point a MC data set was generated, where the HFE were embedded inside peripheral HIJING events, where at least, a pair of Beauty and Charm quarks were included in each event, and the HFE were the dominant source of electrons.

The results of that simulation are shown in Figure 2.2, where the splitting between the 2^{nd} and 4^{th} order Q-Cumulant (QC) methods and the fact that only this latter reproduces the “true” value, in green, clearly illustrate that the 4^{th} -QC method provides a less biased measurement. Furthermore, the jet-like correlations are the driving force of this splitting, because the pion-electron admixture; an alternative explanation, decreases for a larger transverse momentum for what the splitting should behave in a similar way, in contrast to what is observed in Figure 2.2.

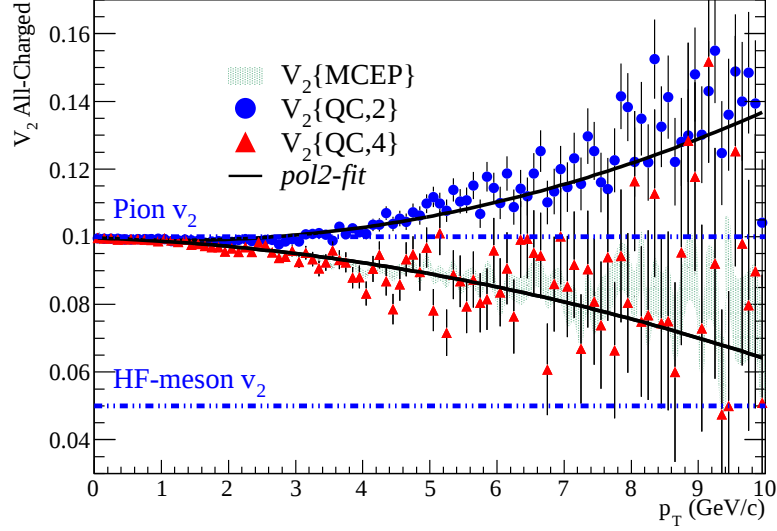


Figure 2.2: *Elliptic flow of All-Charged-Particles as a function of the transverse momentum, where the true value MCEP, is compared with the value estimated through the 2nd-QC and 4th-QC methods.*

As a consequence of using higher order correlators in the estimate of the elliptic flow, one faces a new problem: the 4th-QC method, on the one hand, provides a less unbiased measurement, but, on the other hand, is more susceptible to low-statistics issues. This point is clear when looking at Eq. 2.1, where N denotes the number of entries, v_2 the elliptic flow and $M^{\frac{k}{2}}$ is the number of pairs ($k = 2$) or quadruples ($k = 4$) that can be constructed within the sample. This latter term will enforce larger error bars in the 4th-QC method compared to those of the 2nd-QC method. This will be true for both, the integrated and differential v_2 , and will be a matter of concern in the following chapter, when the actual size of the data sample will be known.

$$\sigma(v_2, M, N) \approx \frac{1}{\sqrt{N} M^{\frac{k}{2}} v_2^{2k-1}}. \quad (2.1)$$

2.3 Pointing Angle Correction

It has been stated already that the HFE v_2 is an indirect measurement of it's asociated meson v_2 . Naturally, this will induce discrepancies between what is measured in the electron and what was originally induced in the meson. These discrepancies are primarily due to the kinematics of the semi-leptonic decay, where just part of the momentum is transferred into the electron. Consequently, neither the azimuthal orientation nor the v_2 of the electron will coincide with those of the meson. To illustrate this point a MC data set, similar to that used in Figure 2.2, was generated setting a constant v_2 input value on the primary HFM. Figure 2.3 compares that input value with the v_2 observed in the electrons, whereas only the “true” is shown and any “non-flow” effect has been excluded. The small difference between the MCEP method and the direct calculation of $\langle \cos 2\phi \rangle$ is due to some background that was included in the former but excluded in the latter.

It is clear from Figure 2.3 that for a larger transverse momentum the difference between the HFE's and HFM's v_2 decreases, which is understood as a result of the boost of the rest-frame; where the decay takes place, in the direction of motion of the HFE. In the previous section, the validity momentum range of this analysis set to be between 0.3 and 3 GeV/c, and Figure 2.3 clearly shows how in this range the HFE and HFM v_2 still do not agree. It is necessary to understand the sources of this

difference and formulate a correction which should be valid for the most general case.

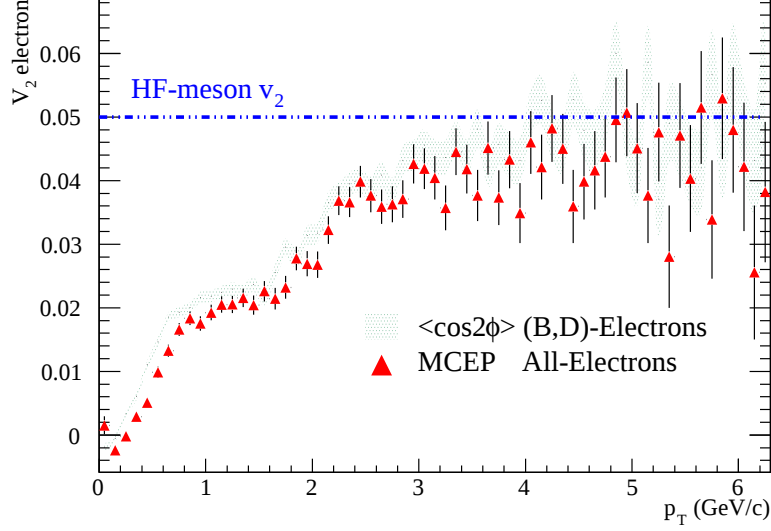


Figure 2.3: *Electron v_2 as a function of transverse momentum. The difference between the green mesh and the red marker is due to the presence of background electrons.*

From the definition of v_2 , shown in the left side of Eq. 2.2, it is possible to add a fluctuation from the “true” value, due to a decay process, as shown in the right side of Eq. 2.2.

$$\langle \cos 2\phi \rangle \rightarrow \langle \cos 2(\phi + \Delta\phi_{M,E}) \rangle, \quad (2.2)$$

where for simplicity the angle of the RP has been set to zero. Now, assuming that the physical process behind the meson v_2 is not correlated with the semi-leptonic decay, which is reasonable because the v_2 is associated with a QCD process, while the semi-leptonic decay is associated with a Weak-Interaction process, Eq. 2.2 becomes:

$$\langle \cos 2(\phi + \Delta\phi_{M,E}) \rangle = \langle \cos 2\phi \cos 2\Delta\phi_{M,E} - \sin 2\phi \sin 2\Delta\phi_{M,E} \rangle \quad (2.3)$$

$$= \langle \cos 2\phi \rangle \langle \cos 2\Delta\phi_{M,E} \rangle, \quad (2.4)$$

where the sine term vanishes, because it is an antisymmetric function and the averaging runs over the entire azimuthal angle. Eq. 2.4 implies that the v_2 of the HFM can be reconstructed from the HFE v_2 as:

$$\langle \cos 2\phi_M \rangle = \frac{\langle \cos 2\phi_E \rangle}{\langle \cos 2\Delta\phi_{M,E} \rangle}. \quad (2.5)$$

From Eq. 2.5 it can be argued that “true” value of the HFM v_2 will be shadowed by a positive factor equal or smaller than one. This factor will depend on the width of the displacement $\Delta\phi_{M,E}$ distribution, which is shown in Figure 2.4. Furthermore, in order to obtain the exact value of the correction factor; once again as a function of p_T , the yield-weighted mean of each distribution in Figure 2.4 should be calculated.

The evolution of the displacement distribution as a function of p_T , shown in Figure 2.4, reflects one of the motivations for this study, in particular, of looking into the electronic channel. From Figure 2.4 it is clear that the azimuthal orientation of the HFE is correlated with that of the HFM. What is more, this correlation grows as a function of the transverse momentum, which naturally makes it interesting to look at the v_2 of the HFE to learn about the v_2 of the HFM.

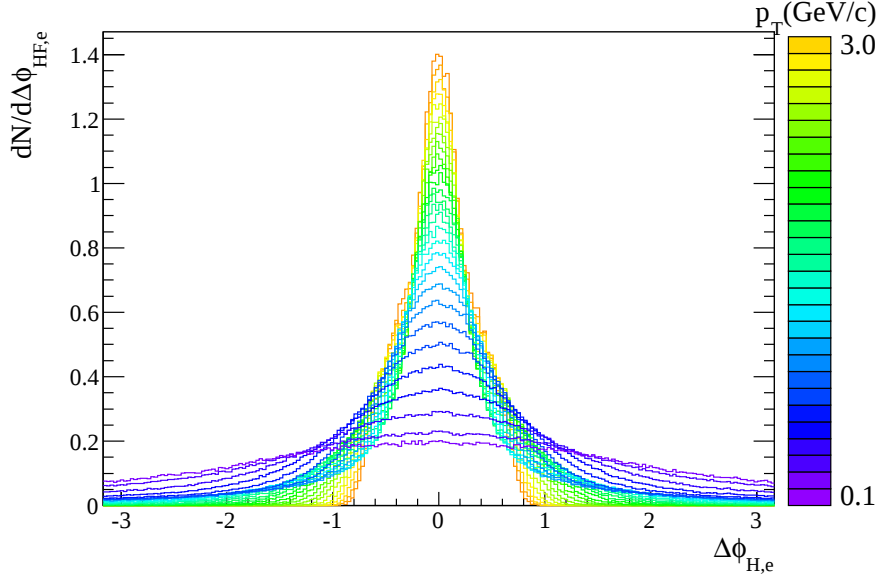


Figure 2.4: *Azimuthal displacement of the electrons with respect to the mesons for several p_T bins. The “narrowing” of the distribution shows how for larger momentum the electron and the meson become collinear.*

To ensure that the correction factor in Eq. 2.5 is the dominant factor in the difference between the HFE and HFM v_2 , observed in Figure 2.3, it should be checked that the output-to-input (HFE-to-HFM) ratio does not depend on the value of the v_2 . The results of this analysis are shown in Figure 2.5, where the correction factor is compared with the output-to-input ratio for three different values of v_2 . From Figure 2.5 it is obvious that the correction factor describes the difference between the HFM and HFE v_2 . Although some differences exist for the smallest value of v_2 , this is well described by an increase in the statistical fluctuation due to the small value of the v_2 . This happens in a similar way to that in Eq. 2.1, where the statistical uncertainty is inversely proportional to the value of v_2 .

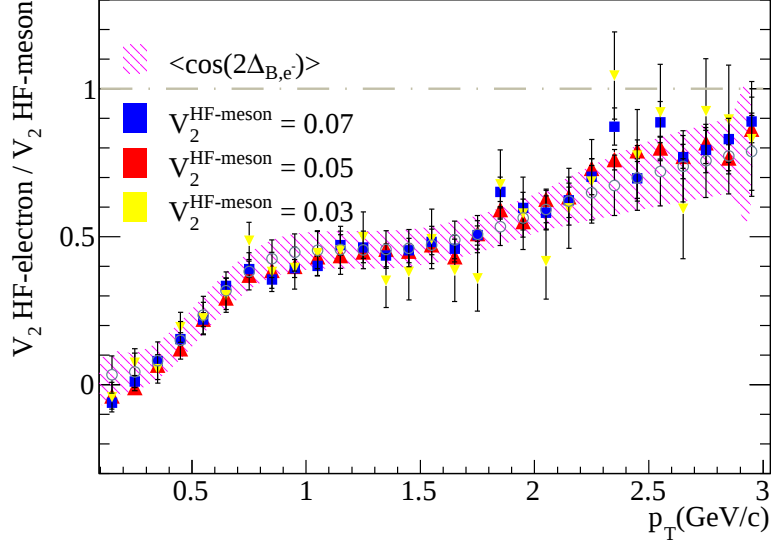


Figure 2.5: *Output-to-input (HFE-to-HFM) ratio for three different values of v_2 (markers), compared with the correction factor (magenta mesh).*

In addition, the case whether the v_2 is p_T dependent was explored. The results of this analysis are shown in Figure 2.6, where the v_2 was set to have the same p_T dependence typical for other particles as Pions, Kaons and Protons [9]. A good agreement was observed and understood in terms of the large mass of the Charm and Beauty mesons. In other words, the transverse momentum of the HFM will be always around or above the saturation point, for which the v_2 becomes constant, consequently, no mayor difference would be observed in the HFE v_2 , neither for a constant nor a p_T dependent HFM v_2 .

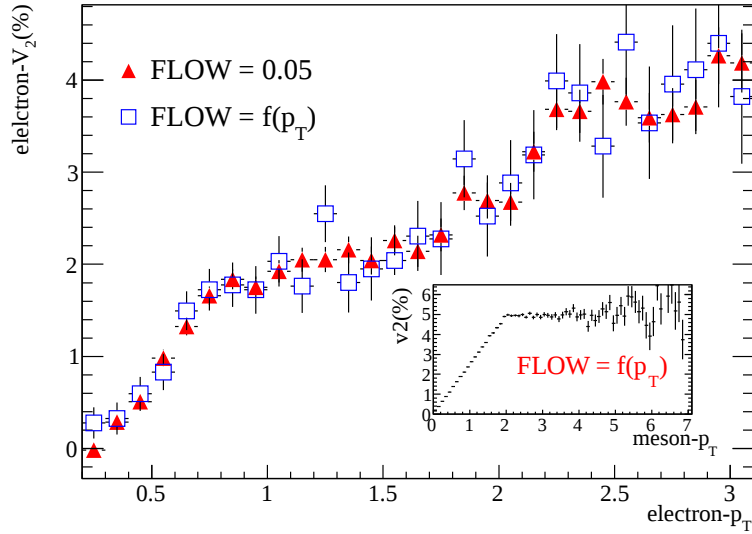


Figure 2.6: Comparison between the v_2 of HFE, for the case of a constant HFM v_2 and a p_T dependent HFM v_2 .

2.4 Electron candidate selection criteria

In the previous section it was argued that the HFE and HFM v_2 are correlated, and, although differences exist, these are well understood. A correction strategy has been proposed in Eq. 2.5. However, from all the electrons in a typical heavy-ion collision just a few are HFE. To illustrate this point a HIJING sample was analyzed, and the transverse momentum distribution for each source was extracted. The results of such analysis are shown in Figure 2.7 where, although the HFE sources were enhanced, some of the backgrounds are observed to dominate most of the spectrum, in particular, sources as photo-conversions, neutral Pions and other neutral mesons, such as the ρ and ω . For an electron to be included in the sample shown in Figure 2.7 some minimum track-quality requirements, which are listed in the second column of

Table 2.1, had to be satisfied. This is done, in order to ensure that only measurable electrons are included as candidates.

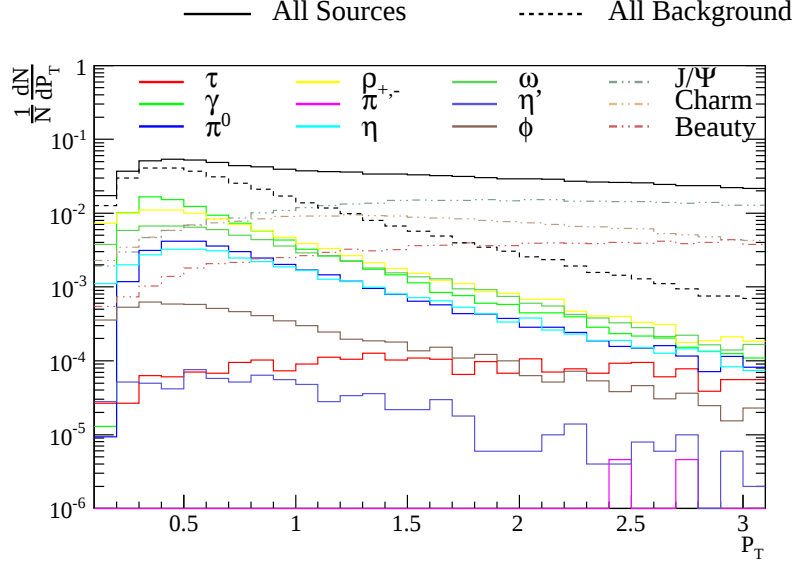


Figure 2.7: *Transverse momentum distribution of the electrons for each different source, where the sources of HFE, as J/Ψ , Charm and Beauty, were enhanced.*

Previous studies [25] led similar tracking capabilities to those of the ALICE detector, to subtract the photonic contribution in the total electron spectrum by using an invariant mass criteria. This strategy was implemented as follows: first the electron candidate is selected by applying the cuts listed in the second column of Table 2.1, then, by looping over the same set of candidates, electron-positron pairs are constructed. Next, candidates that formed a pair with an invariant mass below 100 MeV were rejected, as long as the two tracks lie within a small window in the transverse plane. The value of this opening angle was estimated as $\frac{\pi}{10}$ by using the photon-conversion kinematics, given by $\Delta\phi_{e^+,e^-} \approx 2m_e E_\gamma$. In addition, due to the

setup of the ALICE Internal Tracking System (ITS), it is possible to subtract the low p_T background by requiring the selected candidates to have a hit on the 1st layer of the ITS. This cut rejects electrons produced by the conversion of radiation emitted by charged particles when interacting with the material inside the ALICE detector.

After the conversion of photons into pairs, it is possible that one of the tracks is not properly reconstructed or it does not pass the selection criteria listed in the second column of Table 2.1. To take into account this missed pairs, a second set of electrons with loose requirements was build in each event. These electrons are not used as candidates, but as a more wide sample of electrons to build up the pairs. As shown in Figure 2.8, by removing the ITS refit requirement, meaning that the track parameters should coincide whether the tracking runs outwards or inwards, a much larger set of tracks would be included. The selection criteria for this second set of electrons is summarized in the third column of Table 2.1. Furthermore, the use of a third set of candidates was studied, where neither the TPC nor ITS refits were required. Nevertheless, a large drop in the efficiency, meaning that most of the tracks were being reject as photo-conversions, was observed. This drop was understood as an increase in the probabibity of random pairing, which is not adequate for the purpose of this study, consequently, this third set of candidates was discarded.

In addition to the above mentioned cut on the electron-positron pair invariant mass, the Distance of Closest Approach (DCA) parameter was studied. By requiring a DCA between the electron candidate and the primary vertex position in the transverse plane of about $200\mu m$, it is expected that the background, due to sources such as the decay of strange mesons, would be subtracted. The result of the analysis of this DCA cut, together with the analysis of the cut on the electron-positron invariant

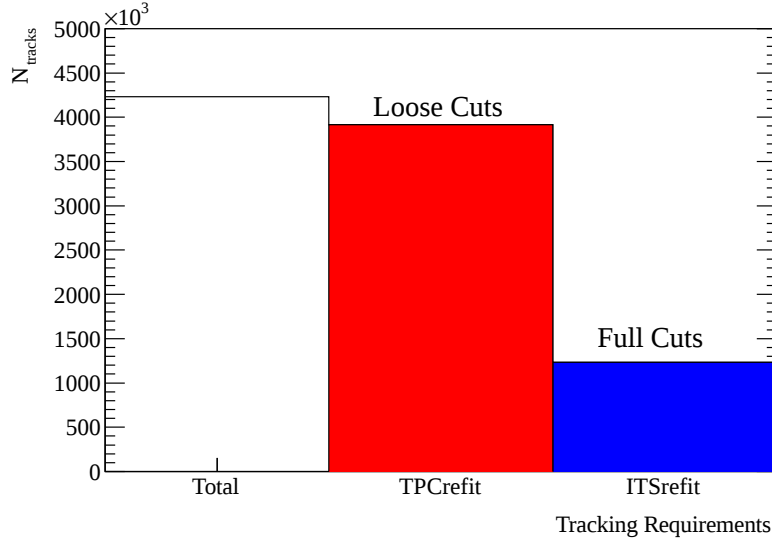


Figure 2.8: *From left to right, total number of electrons, those satisfying the TPC-refit and the TPC-refit + ITS-refit criteria, respectively.*

mass, for both, a single and a double set of electrons, is shown in Figure 2.9. By looking at the difference between the red and blue lines in Figure 2.9, it is clear that the cut on the transverse DCA has a larger effect on the signal than in the background. This result is understood as the effect of the characteristic displaced secondary vertex of the HFM [24], where together with the background many HFM are rejected because their decay occur outside this $200 \mu m$. In addition, by looking at the difference between the continuous and dashed lines in Figure 2.9, it is clear that the inclusion of a second set of electrons does not have a considerable effect on the background subtraction, whereas it has a negative effect on the candidate selection efficiency. Therefore, for the following sections, the signal enhancement strategy will be that of rejecting electrons with a pair within the same set of candidates, and in

the same way, the background enhancement strategy will be that of selecting those paired candidates. This latter electrons, are indicated by green in Figure 2.9, where ,obviously, the background has been enhanced.

Table 2.1: Electron candidate selection criteria

Selection Criteria	First Set	Second Set
Max p_T	3.1 GeV/c	3.1 GeV/c
η range	-0.8 to 0.8	-0.9 to 0.9
Min # of TPC clusters	70	70
Max χ^2 per TPC cluster	4.0	4.0
Max DCA to Vertex XY	0.3 cm	0.3 cm
Max DCA to Vertex Z	0.3 cm	0.3 cm
Accept Kink Daughters	false	false
Require ITS Refit	true	false
Require TPC Refit	true	true
Min # of ITS clusters	2	0
Require Hit on ITS 1 st layer	true	false

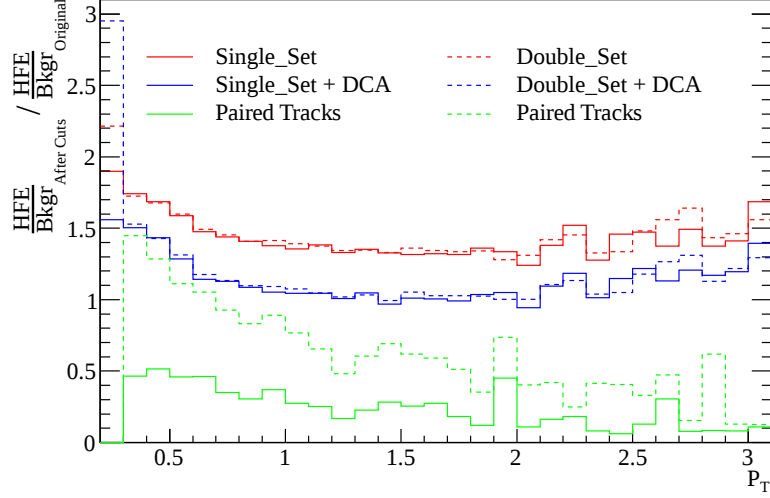


Figure 2.9: *Signal-to-Background ratio after the application of each different set of cuts. This ratio is normalized to the Signal-to-Background ratio in the original set of candidates.*

2.5 HFE v_2

When looking into detail at the per-source p_T -distribution of the electrons, after the application of the signal enhancement cuts, shown in Figure 2.10, it is clear that the relative contribution of sources, such as photo-conversions and neutral meson decays, has decrease with respect to the contribution of the HFE, however, the remnant background is still too large to be discarded. In order to have a more realistic picture of the signal-to-background ratio, a Minimum-Bias HIJING sample, shown in Figure 2.11, was analyzed and it was observed that, in fact, the background is larger than the signal all along the p_T range.

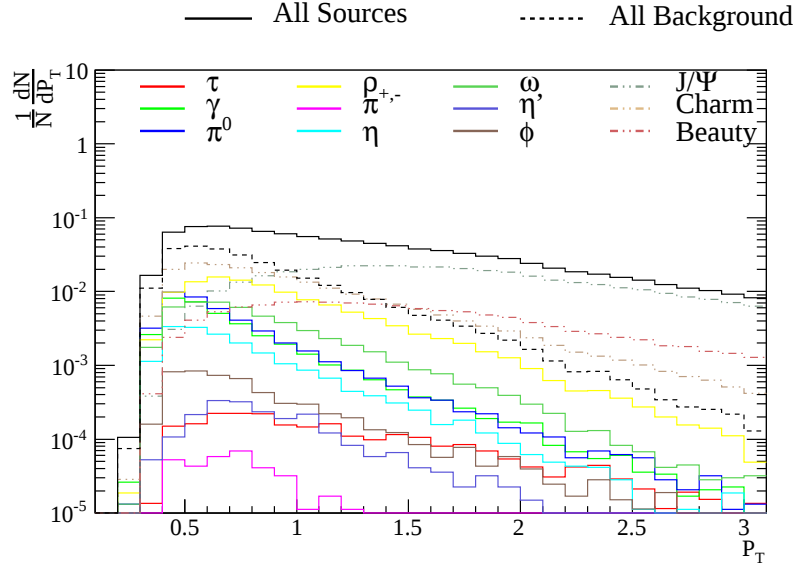


Figure 2.10: *Electron transverse momentum distribution of a HIJING sample where the HFE signals are enhanced.*

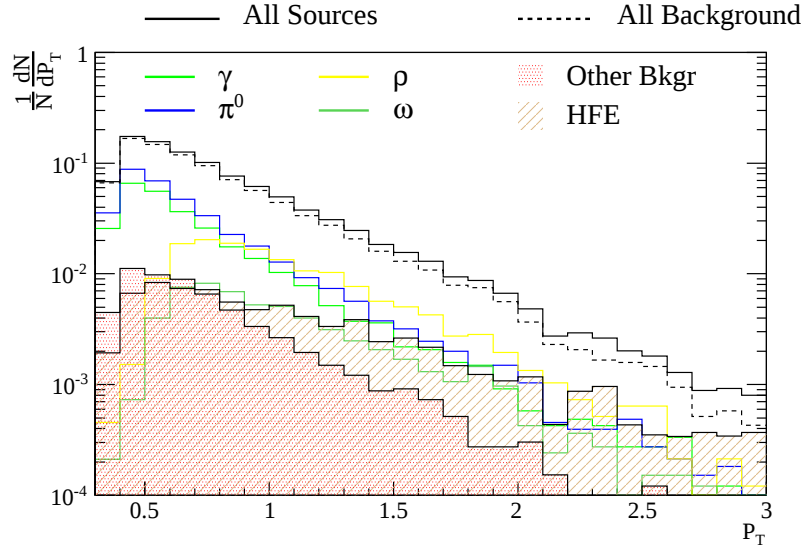


Figure 2.11: *Electron transverse momentum distribution of a Minimum-Bias HIJING sample.*

As a consequence of those irreducible backgrounds, observed in Figures 2.10 and 2.11, for any value of p_T the measured differential v_2 , will be given by:

$$v_2^{i-cuts}(p_T) = \frac{N_{BKGR}^{i-cuts} v_2^{BKGR} + N_{HFE}^{i-cuts} v_2^{HFE}}{N_{BKGR}^{i-cuts} + N_{HFE}^{i-cuts}}, \quad (2.6)$$

where the index i -cuts runs over the different sets of cuts, in particular, the relative number of background and HFE; given by N_{BKGR}^{i-cuts} and N_{HFE}^{i-cuts} respectively, will be different after the application of each set of cuts. Of course, N_{BKGR}^{i-cuts} and N_{HFE}^{i-cuts} will also be p_T -dependent.

As was mentioned in Section 2.3, the value of v_2^{HFE} in Eq. 2.6 is different from v_2^{HFM} , where the correction factor is that given in Eq. 2.4. The application of the selection cuts will certainly have an effect over this correction factor. In order to illustrate this point a PYTHIA sample, where the Beauty-to-Charm ratio was tuned to one of the values predicted for LHC [26], was analyzed. The results of this analysis are shown in Figure 2.12, where 10% steps around this base value were performed. In a latter stage, when the values of N_{BKGR}^{i-cuts} and N_{HFE}^{i-cuts} are known, the value of v_2^{HFE} will be extracted from v_2^{i-cuts} , consequently, v_2^{HFM} will be extracted from v_2^{HFE} , where the different Beauty-to-Charm ratios, shown in Figure 2.12, and their respective p_T -dependent correction factors will play a role as hypothesis.

By merging the terms in Eq. 2.6 corresponding to the number of background and HFE into a single term, Eq. 2.6 turns into:

$$v_2^{i-cuts}(p_T) = \frac{v_2^{BKGR} + R^{i-cuts} v_2^{HFE}}{1 + R^{i-cuts}}, \quad (2.7)$$

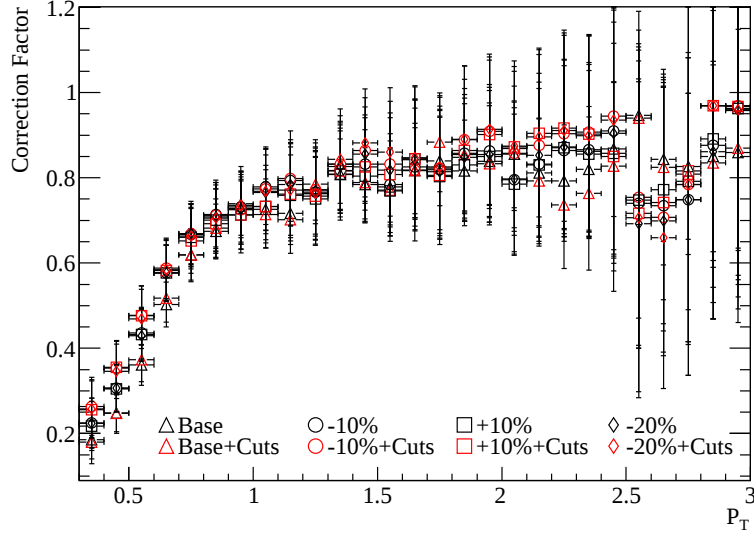


Figure 2.12: *Correction factor before (Black) and after (Red) the application of the signal enhancement cuts, for a Beauty-to-Charm ration of 0.03182 (Base) and 10% steps*

where R^{i-cuts} is the p_T -dependent value of the signal-to-background ratio, after the application of the i -cuts. Clearly, Eq. 2.7 has three variables, because neither of the v_2 terms nor the ratio are known. Therefore, in order to extract v_2^{HFE} , the number of variables should be reduced to a one, for what two additional steps are required. Firstly, in order to estimate the value of v_2^{BKGR} , a second measurement of the elliptic flow of electrons will be performed, where the value of R^{j-cuts} should be minimum. Secondly, in order to determinate R^{i-cuts} , MC generators will be used to describe the measured electron p_T -spectrum as a superposition of a background, such as that shown in Figure 2.11, and a HFE signal, as shown in Figure 2.12, this latter point will be address further on this section.

Back to the issue of the estimation of v_2^{BKGR} , a set of cuts, which minimizes the HFE, has been discussed in a previous section. In Figure 2.9, the electron candidates, for which a low invariant mass pair was found within the same event, were shown in green. These electron candidates have more than a 50% less HFE signal than the original MB-HIJING sample, which already had less than a 10% HFE signal. Therefore, a measurement of v_2 using candidates for which a pair is built, is an excellent estimate of v_2^{BKGR} . The results of this measurement will be shown in the following chapter.

Once v_2^{BKGR} is measured only the determination of R^{i-cuts} is missing, for what the electron transverse momentum can be decomposed as:

$$\frac{dN}{dp_T} = \frac{N_{BKGR} \frac{dN_{BKGR}}{dp_T} + N_{HFE} \frac{dN_{HFE}}{dp_T}}{N_{BKGR} + N_{HFE}}, \quad (2.8)$$

which for convenience should be written in terms of a single linear parameter k as:

$$\frac{dN}{dp_T} = (1 - k) \frac{dN_{BKGR}}{dp_T} + k \frac{dN_{HFE}}{dp_T} \quad (2.9)$$

where, obviously, k and R^{i-cuts} share the following trivial relation:

$$R = \frac{k}{1 - k}. \quad (2.10)$$

Now, Eq. 2.9 will be used as the hypothesis inside the χ^2 as:

$$\chi^2 = \sum_{p_T bins} \left[\frac{dN}{dp_T} - \left((1-k) \frac{dN_{BKGR}}{dp_T} + k \frac{dN_{HFE}}{dp_T} \right) \right]^2, \quad (2.11)$$

where the sum runs over the number of degrees of freedom, which in this case corresponds to the number of bins in the transverse momentum axis. Finally, the best fit for the value of k can be estimated by requiring the minimization of the χ^2 as:

$$k = - \frac{\sum_{p_T bins} \left[\left(\frac{dN}{dp_T} - \frac{dN_{BKGR}}{dp_T} \right) \left(\frac{dN_{BKGR}}{dp_T} - \frac{dN_{HFE}}{dp_T} \right) \right]}{\sum_{p_T bins} \left(\frac{dN_{BKGR}}{dp_T} - \frac{dN_{HFE}}{dp_T} \right)^2}, \quad (2.12)$$

In order to illustrate the fitting procedure, described by Eq. 2.11 and 2.12, the electron p_T spectrum of the HIJING samples in Figures 2.10 and 2.11 can be used. The results of this analysis are shown in Figure 2.13, where the candidates with a pair have been subtracted, and where the MB sample is shown in red and the HFE enhanced sample is shown in blue. From the value of k next to the red line in Figure 2.13, a value of $R \approx 8.01\%$ can be extracted by making use of 2.11, which shows a likely HFE signal size with respect to the background. The value of χ^2 observed for both samples in Figure 2.13 is quite small, this is due to the fact that the fitting is performed over samples which are exactly described by the hypothesis in Eq. 2.9.

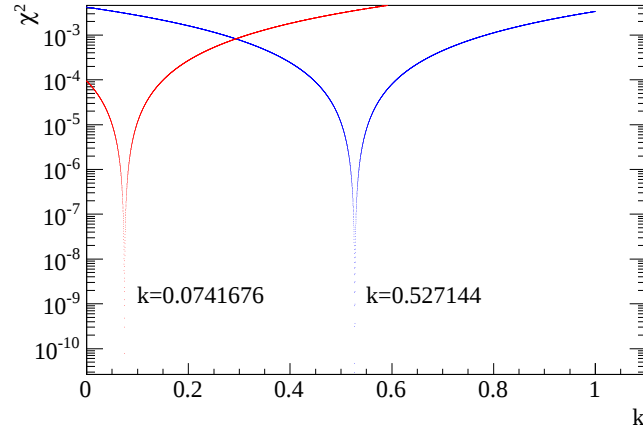


Figure 2.13: χ^2 as a function of the fitting parameter k . The MB sample is shown in red while the HFE enhanced sample is shown in blue.

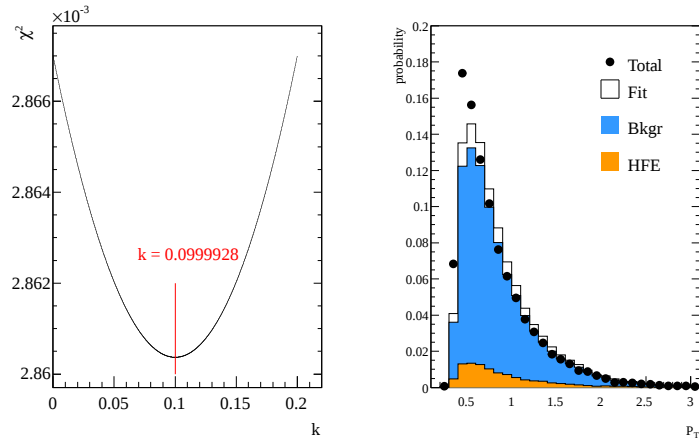


Figure 2.14: Left, χ^2 as a function of k . Right, probability distribution for all the ingredients and results involved in the fitting procedure stress test.

Finally, in order to perform a stress-test of the fitting procedure, a mixed sample of: the background from the sample shown in Figure 2.10 and one of the HFE signals in Figure 2.12, were used to fit the total electron p_T spectrum of the MB sample in Figure 2.11, this latter plays the role of the measured electron p_T spectrum. The results of this analysis are shown in Figure 2.14.

Chapter 3

Data Analysis

3.1 Centrality Classes

The centrality dependence of the elliptic flow connects the geometrical and thermodynamical properties of the medium, as discussed in Chapter 1. Hence, the first step is to illustrate the centrality classes used in this analysis. The data for this study was collected with the ALICE detector [21, 11]. For an event to be selected a Minimum Bias trigger was required. This trigger setup selects events with at least two out of the following three conditions [3]: (i) two pixel chips hit in the outer layer of the SPD (ii) a signal in the VZERO-A (iii) a signal in the VZERO-C. In addition, a vertex position along the beam axis of $|z| < 0.7$ was required. A sample of 4.5×10^6 events passed the selection criteria.

The centrality estimation was performed by using the information deposited in the VZERO detectors. However, the tracks included in this analysis were those reconstructed by the TPC, in the central barrel of the detector. The comparison between

the VZERO-multiplicity and the uncorrected number of TPC tracks is shown in the upper part of Figure 3.1 where, as expected, those values are strongly correlated. The centrality classes divide the VZERO-Multiplicity in percentile bins, which are then convoluted into the TPC tracks providing, as a result, the nine centrality classes shown in different colors in the lower part of Figure 3.1.

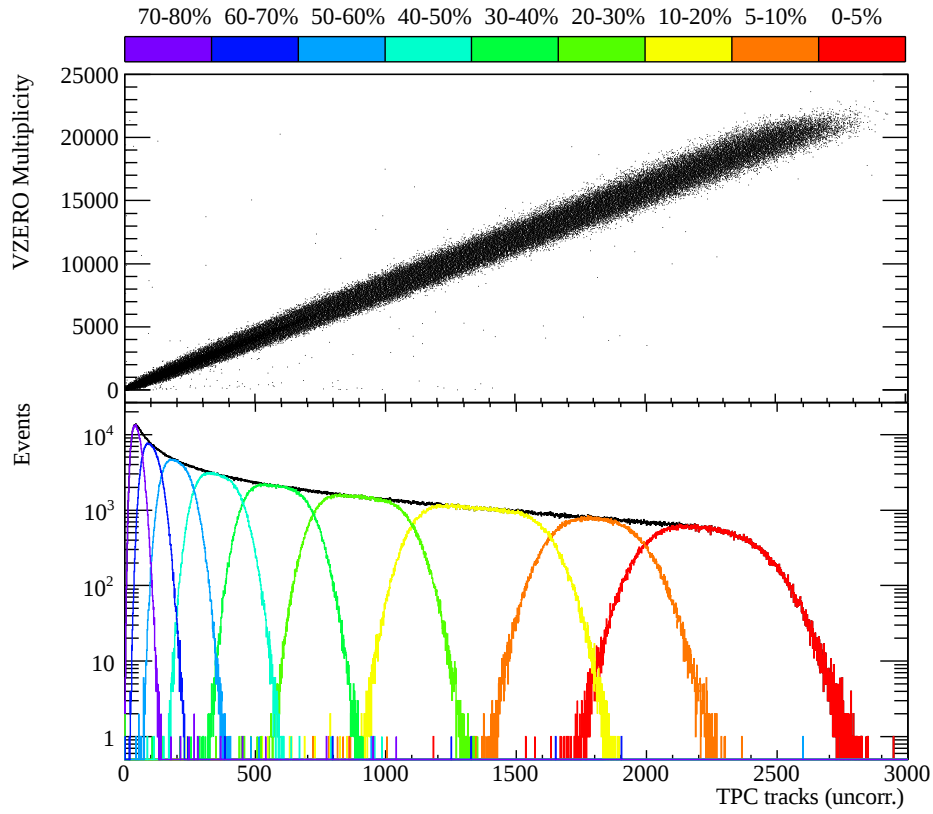


Figure 3.1: *In black, distribution of the summed amplitudes in the VZERO scintillator. In color, same distribution for each centrality bin.*

3.2 Particle Identification

The particle identification strategy, discussed in Section 1.2.5, was used to select a sample of electrons, in addition, the minimum track-quality requirements listed in the second column of Table 2.1 were applied. The Bethe-Bloch parametrization, given by Eq. 1.2 with the parameters listed in Table 1.1, was used to select a sample of charged tracks with the correct TPC-TOF agreement from the left panel of Figure 3.2. From this sample those with a 80% probability of being identified as electrons after the application of the Bayesian PID, described in Section 1.2.5, were selected.

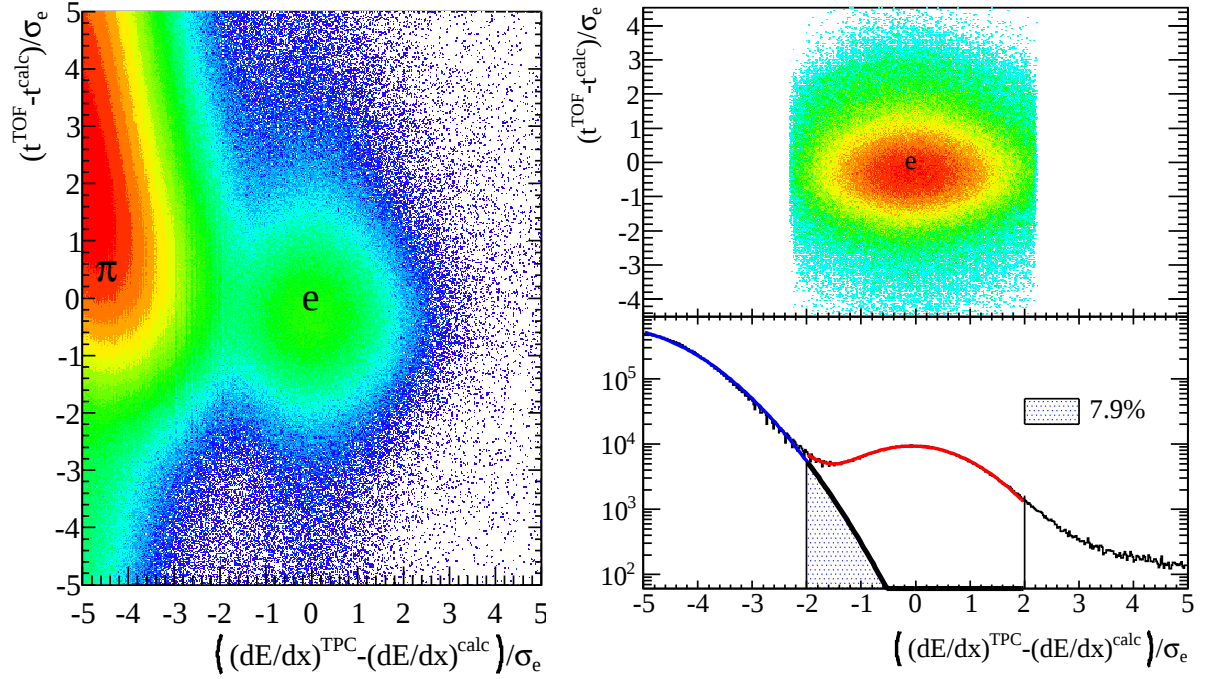


Figure 3.2: *TOF+TPC combined PID performance. From the sample of all charged particles (Left) a sample of electrons (Right) is obtained.*

After the application of above mentioned PID and track-quality requirements a sample of 14×10^6 electrons were Selected, giving an average of 3 *per – event*. This sample is shown in the right panel of Figure 3.2 , where the p_T averaged contamination was found to be around 7.9%.

The low M_{e+e-} and 1st ITS layer hit cuts were applied in a second pass over data. A sample of 6.2×10^6 electrons was obtained, where a similar average contamination was found.

3.3 Integrated Flow

The integrated elliptic flow (averaged over p_T) was analyzed after the application of each one of the criteria discussed in Section 2.4, which were illustrated in Figure 2.9. The measurements are shown in Figure 3.3, where in green is the v_2 of all charged particles (All_{ch}), in red is the v_2 of All electrons and in blue those Selected as single electrons. Here, for most of the centrality bins, the electron v_2 is observed to be above that of All_{ch} . The systematic uncertainty is given by the spread of the measurement for different centrality estimators around that estimated with the VZERO detectors and was calculated independently for each bin and each set of tracks.

As a whole, the measurement shown in Figure 3.3 reflects all the properties of a collective correlation with respect to the Reaction Plane as from left to right, central towards peripheral, the v_2 is observed to grow as is expected from a system which is increasingly asymmetric. Similarly, the splitting between the 2nd and 4th order QC estimated v_2 increases, as is expected for centralities where the non-flow contribution rises due the reduction in the average number of tracks, as shown in Eq. 1.17.

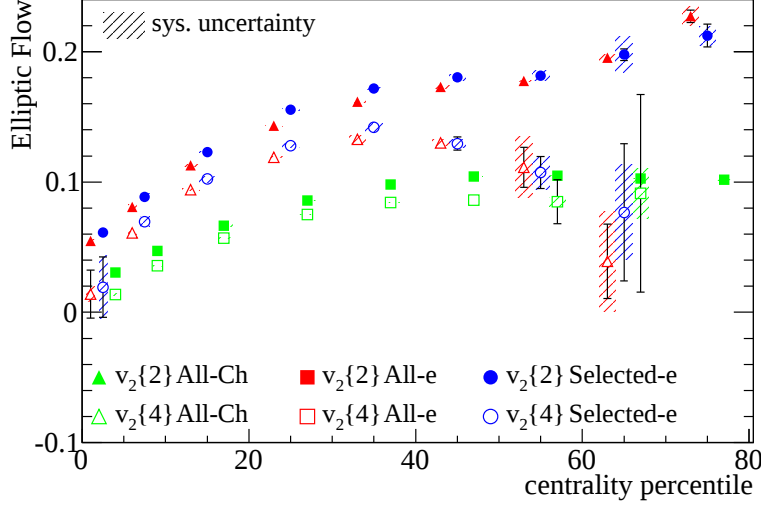


Figure 3.3: *Integrated elliptic flow for All_{ch}, All and Selected electrons as a function of the centrality.*

Furthermore, the similarity in the measured v_2 for each set of electrons is intriguing, given that, as discussed in Section 2.4, the selection criteria establishes a large kinematic difference between the two electron samples. Then, if the integrated v_2 does not change, the only possible explanation would be to have an equally strong flow for all the sources involved in the electron production.

From the Minimum-Bias HIJING sample, shown in Figure 2.10, the heavy-flavour-electron(HFE) signal was estimated to be around 8% of the total electron sample, in addition, that Monte Carlo analysis suggested that only for p_T larger than 2 GeV/c the HFE are expected to make a considerable contribution to the spectrum. Therefore, in order to have a more clear understanding of the contribution of each source to the observed elliptic flow, it is necessary to look into the p_T differential elliptic flow.

3.4 Differential Flow

In order to understand the p_T differential elliptic flow, it is necessary to look first at the spectrum. In Figure 3.4 the electron yield is shown for both, All the electrons and those Selected as single electrons. When looking at the ratio between the normalized yield for each centrality and the most peripheral, it is clear that the electrons carry a rich centrality-dependent information.

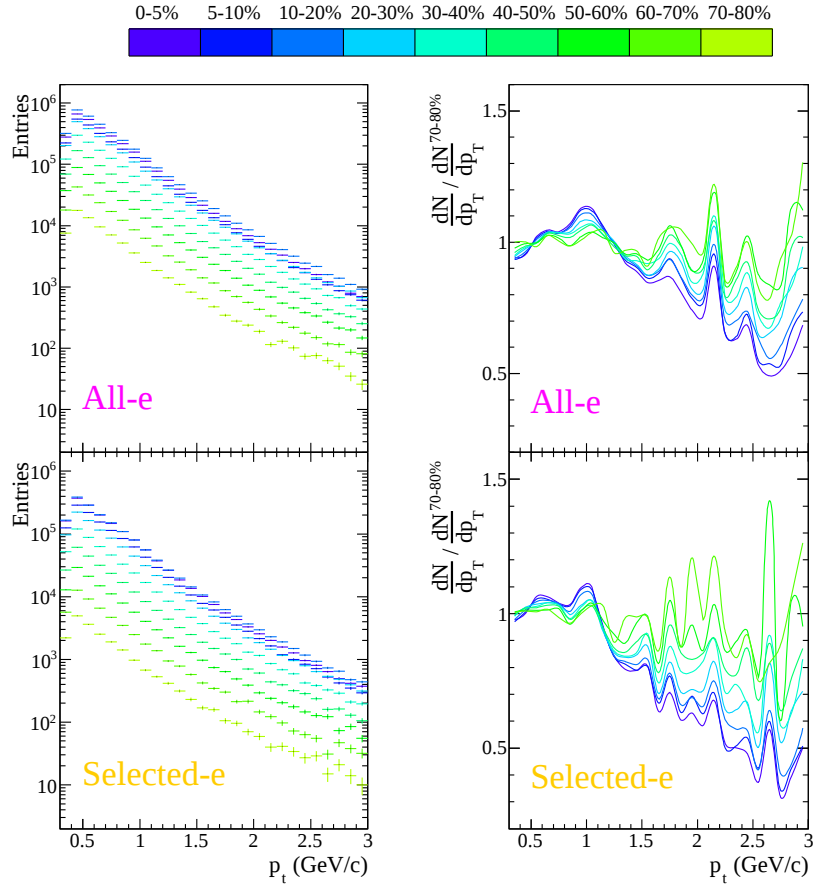


Figure 3.4: *Left: electron p_T yield for All (Top) and the Selected (Bottom) electrons. Right: ratio between the yield of each centrality with that of the most peripheral events.*

That centrality dependence has many different contributions, such as R_{CP} , R_{AA} and radial flow. However, it is worthy to point out that there is a difference between All and Selected electrons in the apparent suppression of the most central with respect to the most peripheral events. For the full sample of electrons, the maximum in the low p_T region is observed to reach higher than for the Selected electrons. In contrast, the minimum in the intermediate p_T region reaches lower for the Selected than for All the electrons.

The difference between the top and bottom plots of the right side of Figure 3.4 is the first indication that the selection criteria, discussed in Section 2.4, effectively establishes different kinematic regions of the electron sample. However, it was observed that HIJING do not have a similar behavior when comparing electron spectrum for different values of the collision impact parameter, this fact is quite a setback whether a Monte Carlo to data fitting is to be attempted.

The p_T differential elliptic flow is shown in Figure 3.5 in the interval between 0.3 and 3.0 GeV/c, where, once again, a comparison is done between the full sample of electrons and those Selected. This is shown for three different centralities from bottom to top as: (i) 0-5% most central (ii) 10-20% (iii) peripheral 30-40%. Within statistical fluctuation the most central events show a near-zero v_2 , while for the other centralities there is an increasing elliptic flow, both for the $2^{nd}(QC)$ and $4^{th}(QC)$ estimates. For the 10-20% and 30-40% the v_2 increases up to 15% and 2%, respectively. The systematic uncertainty is given by the spread of the measurement for different centrality estimators around that estimated with the VZERO detectors and was calculated bin by bin for each centrality class.

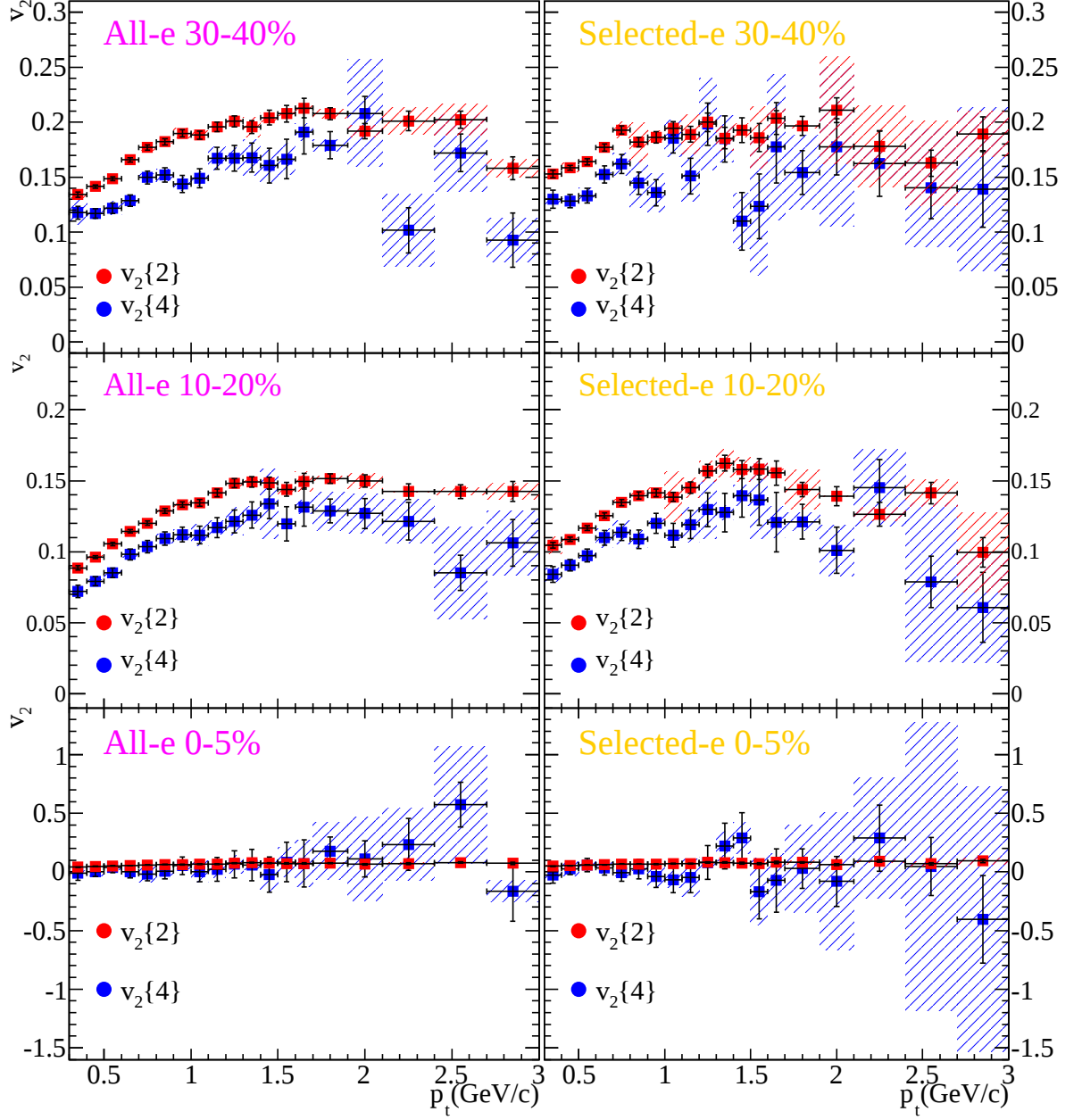


Figure 3.5: *Transverse momentum differential v_2 for the Selected (Left) and Photo (Right) electrons. From bottom to top, the most central 0-5%, next 10-20%, and then 30-40%.*

In order to analyze how much does the HFE contribute to the Selected electron sample, three factors should be taken into consideration: (i) direct Monte Carlo p_T yield interpretation (ii) fitting of the Data to Monte Carlo (iii) direct comparison between the electron samples.

In Figure 2.11 it was observed that HFE makes up for a large fraction of the electron yield for p_T beyond 2 GeV/c, for what the differential v_2 , shown in Figure 3.5, suggest a non-zero elliptic flow value for the HFE. The observed “wiggling” and apparent decrease of v_2 for the 10-20% and 30-40% after 2 GeV/c can be understood as the combination between light and heavy meson with similar v_2 , where this latter is affected by the pointing-angle correction given by Eq. 2.5 and shown in Figure 2.12.

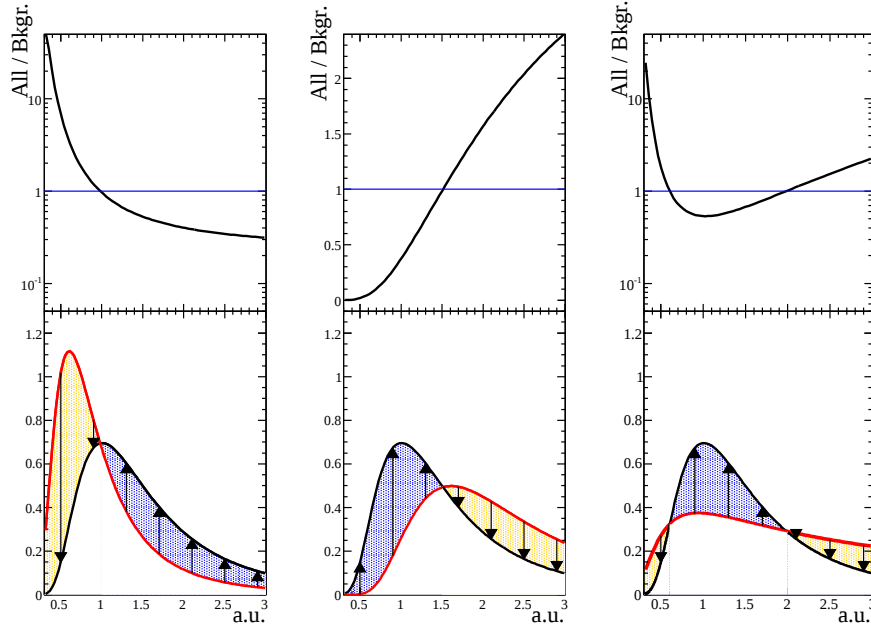


Figure 3.6: *Three different cases of the All over background electrons ratio (Top), and a illustration of the possible spectrum.*

The fitting procedure, that was described in Eq. 2.8 to 2.12, and the hypothesis within requires that when comparing the HIJING background and the measured electron yield, the case must be similar to that shown in the central panel of Figure 3.6, where an hypothetical measured spectrum, in red, appears to be shifted towards higher p_T , with respect to the background, in black. On the contrary, a case when the measured spectrum is shifted backwards in p_T , such that the low p_T background has been underestimated by HIJING, is shown in the left panel of Figure 3.6.

The ratio between the measured electron yield and the HIJING background cocktail was analyzed for both extremes of the centrality classes, such that the 0-5% and 70-80% were compared with the 0-6 and 12-30 impact parameter ranges, respectively. For both centralities, this ratio was observed to be similar to that shown by the left panel of Figure 3.6 but less pronounced for the latter. Consequently, the fitting procedure resulted in a two-digit χ^2 for both cases and, $k = 0.324$ and $k = 0.76$ for 0-5% and 70-80%, respectively.

Although no definite conclusion can be drawn about the HFE fraction, due to the large χ^2 , from the fact that the HIJING signal-to-background ratio does not show any centrality dependence, it can be argued that HIJING does not describe the data in any way. Neither the electron spectrum nor its change with the centrality, and thus, does not contain the required medium-related effects.

The only approach that is left to quantify the HFE contribution to the total electron p_T yield, is that of comparing directly data after and before the candidate selection criteria is applied. In order to do so, the efficiency of the cuts have to be taken into account in such way that the normalized spectrum of the Selected electrons is divided by that of All electrons times the efficiency, which was obtain

through Monte Carlo, as shown in Figure 3.7. Here the case is similar to that of the right panel of Figure 3.6, where the spectrum has gone through a spreading, as a result, it is observed that the ratio have a maximum in low and intermediate p_T . This observation is compatible with an relative increase of the high p_T electrons, consequently, with a growth on the relative fraction of HFE. Since the ratio shown in Figure 3.7 compares data in a direct way and for the same centralities, contamination and centrality-dependent reconstruction effects can be discarded.

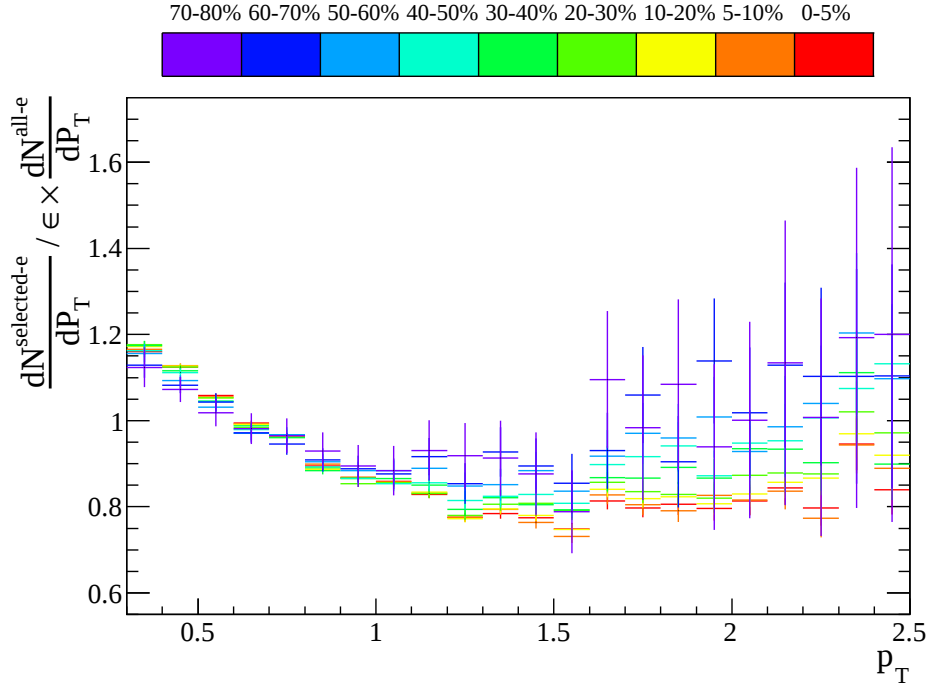


Figure 3.7: *Ratio between the the measured Selected-electron spectrum, and it of All-electrons, taking into account the cuts efficiency for different centralities.*

Chapter 4

Conclusions

Throughout this thesis the measurement of the heavy flavour meson elliptic flow through the electrons of its semileptonic decay has been analyzed. As for any other indirect observable, the strength of the conclusions that can be drawn depends on the understanding of the things that may interfere, such as other medium effects and background.

With a Monte Carlo analysis it was argued that the momentum correlation between the meson and the electron, induced by the decay, also transfers information about the elliptic flow, which turns identical once a pointing angle correction is performed. In addition, a selection criteria was studied in order to enhance the proportion of the heavy flavour electrons over the several sorts of backgrounds. However, in order to obtain a clear sample an understanding of each source, including in-medium effects, was found to be essential.

By using the data collected by ALICE in the winter of 2010, a measurement of the electron integrated and differential elliptic flow together with the yield was presented.

Here a rich centrality-dependent phenomena was observed, which should increase the interest in the electronic channel as a prove of the QGP. Furthermore, the behavior of the elliptic flow was in excellent agreement with the its interpretation through the geometry of the collision system.

Although it was not possible to extract a clear sample of heavy flavour electrons, by comparing the spectrum before and after the application of the selection criteria, an important contribution of intermediate transverse momentum electrons, which can be associated with the heavy flavour electrons, was observed. In this transverse momentum region a large differential flow was measured, for what interested readers should be encouraged to continue the research on the heavy flavour meson elliptic flow.

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Appendix A

Appendix title

```

                                     Config.C
/////////////////////////////////////////////////////////////////
//
//      Configuration for PYTHIA Heavy-Flavour Perugia0
//      embedded in HIJING EVENTS at 2.76 TeV.
//      The glauber code inside PWG2/FLOW/AliFlowTools/
//      is used to generate a random eccentricity
//      which is in turn used by the AfterBurner at:
//      EVGEN/AliGenAfterBurnerFlow.h
//      to add flow to all the primary particles.
//
//
//      50% ccbar pair per event
//      decays forced semileptonically D->e+X
//      at least one electron from charm in |y|<1
//      50% bbbar pair per event
//      decays forced semileptonically D->e+X
//      at least one electron from charm or beauty in |y|<1
//      + HIJING
//      -----
//      = Cocktail
//      + AfterBurner
//      -----
//      = Generator configured by this macro
//
/////////////////////////////////////////////////////////////////
```

```

#if !defined(__CINT__) || defined(__MAKECINT__)
#include <Riostream.h>
#include <TRandom.h>
#include <TDateTime.h>
#include <TSystem.h>
#include <TVirtualMC.h>
#include <TGeant3TGeo.h>
#include "STEER/AliRunLoader.h"
#include "STEER/AliRun.h"
#include "STEER/AliConfig.h"
#include "PYTHIA6/AliDecayerPythia.h"
#include "PYTHIA6/AliGenPythia.h"
#include "TDPMjet/AliGenDPMjet.h"
#include "STEER/AliMagFCheb.h"
#include "STRUCT/AliBODY.h"
#include "STRUCT/AliMAG.h"
#include "STRUCT/AliABSOv3.h"
#include "STRUCT/AliDIPOv3.h"
#include "STRUCT/AliHALLv3.h"
#include "STRUCT/AliFRAMEv2.h"
#include "STRUCT/AliSHILv3.h"
#include "STRUCT/AliPIPEv3.h"
#include "ITS/AliITSv11Hybrid.h"
#include "TPC/AliTPCv2.h"
#include "TOF/AliTOFv6T0.h"
#include "HMPID/AliHMPIDv3.h"
#include "ZDC/AliZDCv3.h"
#include "TRD/AliTRDv1.h"
#include "TRD/AliTRDgeometry.h"
#include "FMD/AliFMDv1.h"
#include "MUON/AliMUONv1.h"
#include "PHOS/AliPHOSv1.h"
#include "PHOS/AliPHOSSimParam.h"
#include "PMD/AliPMDv1.h"
#include "T0/AliT0v1.h"
#include "EMCAL/AliEMCALv2.h"
#include "ACORDE/AliACORDEv1.h"
#include "VZERO/AliVZEROv7.h"
#endif

enum PprTrigConf_t
{
    kDefaultPPTrig, kDefaultPbPbTrig

```

```

};

const char * pprTrigConfName[] = {
    "p-p", "Pb-Pb"
};

// This part for configuration

static AliMagF::BMap_t smag = AliMagF::k5kG;
static AliMagF::BeamType_t beamType = AliMagF::kBeamTypeAA;
static Double_t beamEnergy = 7000.*82./208;
//static Int_t sseed = 12345; //Set 0 to use the current time
static PprTrigConf_t strig = kDefaultPbPbTrig; // default pp trigger configuration

//=====//
// Set Random Number seed //
//=====//
TDateTime dt;
static UInt_t sseed = dt.Get()/1000;

// Comment line
static TString comment;

//—— Functions ——
class AliGenPythia;
Float_t EtaToTheta(Float_t arg);
AliGenerator* GeneratorFactory(Int_t typeHF, Double_t
    partEccentricity);
AliGenerator* MbPythiaTunePerugia0chadr();
AliGenerator* MbPythiaTunePerugia0bchadr();
AliGenerator* MbPythiaTunePerugia0cele();
AliGenerator* MbPythiaTunePerugia0bele();
AliGenerator *Hijing();

Int_t bMin = 9;
Int_t bMax = 12;

void Config()
{
    if (gSystem->Getenv("SEED")) {
        sseed = atoi(gSystem->Getenv("SEED"));
    }
}

```

```

// Set Random Number seed
gRandom->SetSeed(sseed);
cout<<"Seed for random number generation="<<gRandom->GetSeed()<<
endl;

// libraries required by geant321
#if defined(__CINT__)
gSystem->Load("liblhpdf");
gSystem->Load("libEGPythia6");
gSystem->Load("libpythia6");
gSystem->Load("libAliPythia6");
gSystem->Load("libgeant321");

gSystem->Load("libhijing");
gSystem->Load("libTHijing");

gSystem->AddIncludePath("-I${ALICE_ROOT}/include");

gROOT->SetMacroPath("/data/alice1/nicolas/HFE/AfterBurner/StoomBoot
/Generators/GlauberHiStandardCocktailAfBurned/GlauberCode/");
gROOT->LoadMacro("AliGlauberNucleon.cxx");
gROOT->LoadMacro("AliGlauberNucleus.cxx");
gROOT->LoadMacro("AliGlauberMC.cxx");

#endif

AliGlauberMC glauber;
glauber.SetBmin(bMin);
glauber.SetBmax(bMax);

new TGeant3TGeo("C++_Interface_to_Geant3");

// Output every 100 tracks
((TGeant3*)gMC)->SetSWIT(4,1000);

AliRunLoader* rl=0x0;

cout<<"Config.C: Creating Run Loader..."<<endl;
rl = AliRunLoader::Open("galice.root",
                        AliConfig::GetDefaultEventFolderName(),
                        "recreate");

if (rl == 0x0)
{

```

```

        gAlice->Fatal(" Config.C", "Can_not_instantiate_the_Run_Loader");
        return;
    }
    rl->SetCompressionLevel(2);
    rl->SetNumberOfEventsPerFile(1000);
    gAlice->SetRunLoader(rl);

    // Set the trigger configuration
    AliSimulation::Instance()->SetTriggerConfig(pprTrigConfName[strig]);
    ;
    cout<<" Trigger_configuration_is_set_to_"<<pprTrigConfName[strig]<<
        endl;

    //
    //

```

```

// ***** STEERING parameters FOR ALICE SIMULATION
// *****
// — Specify event type to be tracked through the ALICE setup
// — All positions are in cm, angles in degrees, and P and E in
//    GeV

//=====//
// Set External decayer //
//=====//
AliDecayer* decayer = new AliDecayerPythia();
decayer->SetForceDecay(kAll);
decayer->Init();
gMC->SetExternalDecayer(decayer);

gMC->SetProcess("DCAY",1);
gMC->SetProcess("PAIR",1);
gMC->SetProcess("COMP",1);
gMC->SetProcess("PHOT",1);
gMC->SetProcess("PFIS",0);
gMC->SetProcess("DRAY",0);
gMC->SetProcess("ANNI",1);
gMC->SetProcess("BREM",1);
gMC->SetProcess("MUNU",1);
gMC->SetProcess("CKOV",1);
gMC->SetProcess("HADR",1);
gMC->SetProcess("LOSS",2);
gMC->SetProcess("MULS",1);

```

```

gMC->SetProcess("RAYL",1);

Float_t cut = 1.e-3;           // 1MeV cut by default
Float_t tofmax = 1.e10;

gMC->SetCut("CUTGAM", cut);
gMC->SetCut("CUTELE", cut);
gMC->SetCut("CUTNEU", cut);
gMC->SetCut("CUTHAD", cut);
gMC->SetCut("CUTMUO", cut);
gMC->SetCut("BCUTE", cut);
gMC->SetCut("BCUTM", cut);
gMC->SetCut("DCUTE", cut);
gMC->SetCut("DCUTM", cut);
gMC->SetCut("PPCUTM", cut);
gMC->SetCut("TOFMAX", tofmax);

// RANDOM SELECTION OF ONE OF THE FOUR GENERATION TYPES
//
Int_t typeHF = -1;
Float_t randHF = gRandom->Rndm();
cout<<"*****THE_RANDOM_GENERATOR_SELECTOR_VALUE_IS:_"<<randHF<<
endl;
if(randHF<0.5) {
    typeHF=2;
} else {
    typeHF=3;
}

// RANDOM GENERATION OF A GLAUBER EVENT
// Calling Glauber
Double_t partEccentricity = 0;
glauber.NextEvent();
partEccentricity = glauber.GetEccentricityPart();

//
// Size of the interaction diamond
// Longitudinal
Float_t sigmaz = 5.4 / TMath::Sqrt(2.); // [cm]

//
// Transverse
Float_t betast = 3.5; // beta* [m]
Float_t eps = 3.75e-6; // emittance [m]

```

```

Float_t gamma    = beamEnergy/ 2.0 / 0.938272;  // relativistic
           gamma [1]
Float_t sigmaxy  = TMath::Sqrt(eps * betast / gamma) / TMath::Sqrt
           (2.) * 100.;  // [cm]

printf("\n\nDiamond_size_x-y:_%10.3e_z:_%10.3e\n\n", sigmaxy,
           sigmaz);

// Generator Configuration
AliGenerator* gener = GeneratorFactory(typeHF,partEccentricity);
gener->SetSigma(sigmaxy, sigmaxy, sigmaz);          // Sigma in (X,Y,Z)
           (cm) on IP position
gener->SetVertexSmear(kPerEvent);
gener->Init();

// Field
TGeoGlobalMagField::Instance()->SetField
           (new AliMagF("Maps","Maps", -1., -1., smag,beamType,beamEnergy));
rl->CdGAFile();

Int_t iABSO  = 0;
Int_t iACORDE= 0;
Int_t iDIPO  = 0;
Int_t iEMCAL = 0;
Int_t iFMD   = 0;
Int_t iFRAME = 0;
Int_t iHALL  = 0;
Int_t iITS   = 0;
Int_t iMAG   = 0;
Int_t iMUON  = 0;
Int_t iPHOS  = 0;
Int_t iPIPE  = 0;
Int_t iPMD   = 0;
Int_t iHMPID = 0;
Int_t iSHIL  = 0;
Int_t iT0    = 0;
Int_t iTOF   = 0;
Int_t iTPC   = 0;
Int_t iTRD   = 0;
Int_t iVZERO = 0;
Int_t iZDC   = 0;

//===== Alice BODY parameters

```

```

=====
AliBODY *BODY = new AliBODY("BODY", "Alice_envelop");

if (iMAG)
{
    //===== MAG parameters
    =====
    // — Start with Magnet since detector layouts may be
    depending —
    // — on the selected Magnet dimensions —
    AliMAG *MAG = new AliMAG("MAG", "Magnet");
}

if (iABSO)
{
    //===== ABSO parameters
    =====
    AliABSO *ABSO = new AliABSOv3("ABSO", "Muon_Absorber");
}

if (iDIPO)
{
    //===== DIPO parameters
    =====

    AliDIPO *DIPO = new AliDIPOv3("DIPO", "Dipole_version_3");
}

if (iHALL)
{
    //===== HALL parameters
    =====

    AliHALL *HALL = new AliHALLv3("HALL", "Alice_Hall");
}

if (iFRAME)
{
    //===== FRAME parameters
    =====

```

```

        AliFRAMEv2 *FRAME = new AliFRAMEv2("FRAME" , "Space_Frame");
        FRAME->SetHoles(1);
    }

    if (iSHIL)
    {
        //===== SHIL parameters
        =====

        AliSHIL *SHIL = new AliSHILv3("SHIL" , "Shielding_Version_3");
    }

    if (iPIPE)
    {
        //===== PIPE parameters
        =====

        AliPIPE *PIPE = new AliPIPEv3("PIPE" , "Beam_Pipe");
    }

    if (iITS)
    {
        //===== ITS parameters
        =====

        AliITS *ITS = new AliITSv11Hybrid("ITS" ,"ITS_v11Hybrid");
    }

    if (iTPC)
    {
        //===== TPC parameters
        =====

        AliTPC *TPC = new AliTPCv2("TPC" , "Default");
    }

    if (iTOF) {
        //===== TOF parameters =====

        AliTOF *TOF = new AliTOFv6T0("TOF" , "normal_TOF");
    }

```

```

if (iHMPID)
{
    //===== HMPID parameters
    =====

    AliHMPID *HMPID = new AliHMPIDv3("HMPID" , "normal_HMPID");

}

if (iZDC)
{
    //===== ZDC parameters
    =====

    AliZDC *ZDC = new AliZDCv3("ZDC" , "normal_ZDC");
}

if (iTRD)
{
    //===== TRD parameters
    =====

    AliTRD *TRD = new AliTRDv1("TRD" , "TRD_slow_simulator");
    AliTRDgeometry *geoTRD = TRD->GetGeometry();
    // Partial geometry: modules at 0,1,7,8,9,16,17
    // starting at 3h in positive direction
    geoTRD->SetSMstatus(2,0);
    geoTRD->SetSMstatus(3,0);
    geoTRD->SetSMstatus(4,0);
    geoTRD->SetSMstatus(5,0);
    geoTRD->SetSMstatus(6,0);
    geoTRD->SetSMstatus(11,0);
    geoTRD->SetSMstatus(12,0);
    geoTRD->SetSMstatus(13,0);
    geoTRD->SetSMstatus(14,0);
    geoTRD->SetSMstatus(15,0);
    geoTRD->SetSMstatus(16,0);
}

if (iFMD)
{
    //===== FMD parameters

```

```

=====

AliFMD *FMD = new AliFMDv1("FMD", "normal_FMD");
}

if (iMUON)
{
//===== MUON parameters
//=====
// New MUONv1 version (geometry defined via builders)

AliMUON *MUON = new AliMUONv1("MUON", "default");
}

if (iPHOS)
{
//===== PHOS parameters
//=====

AliPHOS *PHOS = new AliPHOSv1("PHOS", "noCPV_Modules123");
}

if (iPMD)
{
//===== PMD parameters
//=====

AliPMD *PMD = new AliPMDv1("PMD", "normal_PMD");
}

if (iT0)
{
//===== T0 parameters
//=====

AliT0 *T0 = new AliT0v1("T0", "T0_Detector");
}

if (iEMCAL)
{
//===== EMCAL parameters
//=====

```

```

    AliEMCAL *EMCAL = new AliEMCALv2("EMCAL" , "EMCALFIRSTYEAR");
}

if (iACORDE)
{
    //===== ACORDE parameters
    =====

    AliACORDE *ACORDE = new AliACORDEv1("ACORDE" , "normal_ACORDE");
}

if (iVZERO)
{
    //===== ACORDE parameters
    =====

    AliVZERO *VZERO = new AliVZEROv7("VZERO" , "normal_VZERO");
}

}

Float_t EtaToTheta(Float_t arg){
    return (180./TMath::Pi())*2.*atan(exp(-arg));
}

AliGenerator* GeneratorFactory(Int_t typeHF, Double_t
    partEccentricity){
    //Initializing
    AliGenerator * gGener = 0x0;

    // The cocktail
    AliGenCocktailAfterBurner* gener = new AliGenCocktailAfterBurner();

    //After Burner
    AliGenAfterBurnerFlow *flow = new AliGenAfterBurnerFlow();
    flow->SetEllipticSimple(211,0.1);
    flow->SetEllipticSimple(310,0.1);
    flow->SetEllipticSimple(311,0.1);
    flow->SetEllipticSimple(313,0.1);
    flow->SetEllipticSimple(321,0.1);
    flow->SetEllipticSimple(323,0.1);
    flow->SetEllipticSimple(2212,0.5*partEccentricity);
    //B-Mesons
    flow->SetEllipticSimple(511,0.8);
}

```

```

flow->SetEllipticSimple(513,0.8);
flow->SetEllipticSimple(521,0.8);
flow->SetEllipticSimple(523,0.8);
flow->SetEllipticSimple(531,0.8);
flow->SetEllipticSimple(533,0.8);

//The HF generator
AliGenerator* genHF = 0x0;

if(typeHF==0){
    genHF = MbPythiaTunePerugia0chadr();
}
else if(typeHF==1){
    genHF = MbPythiaTunePerugia0bchadr();
}
else if(typeHF==2){
    genHF = MbPythiaTunePerugia0cele();
}
else if(typeHF==3){
    genHF = MbPythiaTunePerugia0bele();
}

//FUTURE PLACE FOR HIJING !!!
genHi = Hijing();

// Add everything to the cocktail and shake ...
gener->AddGenerator(genHi,"700_Hijing_primary_particles", 1);
gener->AddGenerator(genHF,"Random_HF_generator", 1);
gener->AddAfterBurner(flow,"FLOW_PROCESSOR",1);
gGener = gener;

return gGener;
}

AliGenerator* MbPythiaTunePerugia0chadr()
{
    comment = comment.Append(" _pp:_Pythia_(Perugia0)_chadr_(1_ccbar_per
        _event,_1_c-hadron_in_|y|<1.5,_chadrons_decay_to_hadrons");
    //
    //      Pythia
    AliGenPythia* pythia = new AliGenPythia(-1);
    pythia->SetMomentumRange(0, 999999.);
    pythia->SetThetaRange(0., 180.);
    pythia->SetYRange(-1.5,1.5);

```

```

pythia->SetPtRange(0,1000.);

pythia->SetProcess(kPyCharmPbPbMNR); //from PbPb
pythia->SetStrucFunc(kCTEQ4L); //from PbPb
pythia->SetPtHard(2.75,-1.0); //from PbPb
//pythia->SetNuclei(208,208); //from PbPb
pythia->SetFeedDownHigherFamily(kFALSE); //from PbPb
pythia->SetCountMode(AliGenPythia::kCountParents); //from PbPb
pythia->SetProjectile("A", 208, 82); //from PbPb
pythia->SetTarget("A", 208, 82); //from PbPb

pythia->SetEnergyCMS(beamEnergy);
// Tune
// 320 Perugia 0
pythia->SetTune(320);
//pythia->UseNewMultipleInteractionsScenario();
//
// decays
pythia->SetForceDecay(kHadronicD);

return pythia;
}

AliGenerator* MbPythiaTunePerugia0bchadr()
{
    comment = comment.Append("_pp:_Pythia_(Perugia0)_bchadr_(1_bbbar_
        per_event, _1_c-hadron_in_|y|<1.5,_chadrons_decay_to_hadrons");
    //
    // Pythia
    AliGenPythia* pythia = new AliGenPythia(-1);
    pythia->SetMomentumRange(0, 999999.);
    pythia->SetThetaRange(0., 180.);
    pythia->SetYRange(-1.5,1.5);
    pythia->SetPtRange(0,1000.);

    pythia->SetProcess(kPyBeautyPbPbMNR); //from PbPb
    pythia->SetStrucFunc(kCTEQ4L); //from PbPb
    pythia->SetPtHard(2.75,-1.0); //from PbPb
    pythia->SetNuclei(208,208); //from PbPb
    pythia->SetFeedDownHigherFamily(kFALSE); //from PbPb
    pythia->SetCountMode(AliGenPythia::kCountParents); //from PbPb
    pythia->SetProjectile("A", 208, 82); //from PbPb
    pythia->SetTarget("A", 208, 82); //from PbPb

```

```

    pythia->SetEnergyCMS(beamEnergy);
    //      Tune
    //      320      Perugia 0
    pythia->SetTune(320);
    //pythia->UseNewMultipleInteractionsScenario();
    //
    //      decays
    pythia->SetForceDecay(kHadronicD);

    return pythia;
}

AliGenerator* MbPythiaTunePerugia0cele()
{
    comment = comment.Append("_pp:_Pythia_(Perugia0)_cele_(1_ccbar_per_
        event,_1_electron_in_|y|<1.2)");
    //
    //      Pythia
    AliGenPythia* pythia = new AliGenPythia(-1);
    pythia->SetMomentumRange(0, 999999.);
    pythia->SetThetaRange(0., 180.);
    //pythia->SetYRange(-2.,2.);
    pythia->SetPtRange(0,1000.);

    pythia->SetProcess(kPyCharmPbPbMNR); //from PbPb
    pythia->SetStrucFunc(kCTEQ4L); //from PbPb
    pythia->SetPtHard(2.75, -1.0); //from PbPb
    //pythia->SetNuclei(208,208); //from PbPb
    pythia->SetFeedDownHigherFamily(kFALSE); //from PbPb
    pythia->SetCountMode(AliGenPythia::kCountParents); //from PbPb
    pythia->SetProjectile("A", 208, 82); //from PbPb
    pythia->SetTarget("A", 208, 82); //from PbPb

    pythia->SetEnergyCMS(beamEnergy);
    //      Tune
    //      320      Perugia 0
    pythia->SetTune(320);
    //pythia->UseNewMultipleInteractionsScenario();
    //
    //      decays
    pythia->SetCutOnChild(1);
    pythia->SetPdgCodeParticleforAcceptanceCut(11);
    pythia->SetChildYRange(-1,1);
    pythia->SetChildPtRange(0.1,10000.);

```

```

    pythia->SetForceDecay(kSemiElectronic);

    return pythia;
}

AliGenerator* MbPythiaTunePerugia0bele()
{
    comment = comment.Append(" _pp: _Pythia_(Perugia0)_bele_(1_bbbar_per_
        event, _1_electron_in_|y|<1.2)");
    //
    //      Pythia
    AliGenPythia* pythia = new AliGenPythia(-1);
    pythia->SetMomentumRange(0, 999999.);
    pythia->SetThetaRange(0., 180.);
    //pythia->SetYRange(-2.,2.);
    pythia->SetPtRange(0,1000.);

    pythia->SetProcess(kPyBeautyPbPbMNR); //from PbPb
    pythia->SetStrucFunc(kCTEQ4L); //from PbPb
    pythia->SetPtHard(2.75, -1.0); //from PbPb
    //pythia->SetNuclei(208,208); //from PbPb
    pythia->SetFeedDownHigherFamily(kFALSE); //from PbPb
    pythia->SetCountMode(AliGenPythia::kCountParents); //from PbPb
    pythia->SetProjectile("A", 208, 82); //from PbPb
    pythia->SetTarget("A", 208, 82); //from PbPb

    pythia->SetEnergyCMS(beamEnergy);
    //      Tune
    //      320      Perugia 0
    pythia->SetTune(320);
    //pythia->UseNewMultipleInteractionsScenario();
    //
    //      decays
    pythia->SetCutOnChild(1);
    pythia->SetPdgCodeParticleforAcceptanceCut(11);
    pythia->SetChildYRange(-1,1);
    pythia->SetChildPtRange(0.1,10000.);
    pythia->SetForceDecay(kSemiElectronic);

    return pythia;
}

AliGenerator* Hijing()
{

```

```

AliGenHijing *gener = new AliGenHijing(-1);
// centre of mass energy
gener->SetEnergyCMS(2760.);
gener->SetImpactParameterRange(bMin, bMax);
// reference frame
gener->SetReferenceFrame("CMS");
// projectile
gener->SetProjectile("A", 208, 82);
gener->SetTarget      ("A", 208, 82);
// tell hijing to keep the full parent child chain
gener->KeepFullEvent();
// enable jet quenching
gener->SetJetQuenching(1);
// enable shadowing
gener->SetShadowing(1);
// neutral pion and heavy particle decays switched off
gener->SetDecaysOff(1);
// Don't track spectators
gener->SetSpectators(0);
// kinematic selection
gener->SetSelectAll(0);
return gener;
}

```