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An Early Separation Scheme for the LHC Luminosity Upgrade

Guido Sterbini

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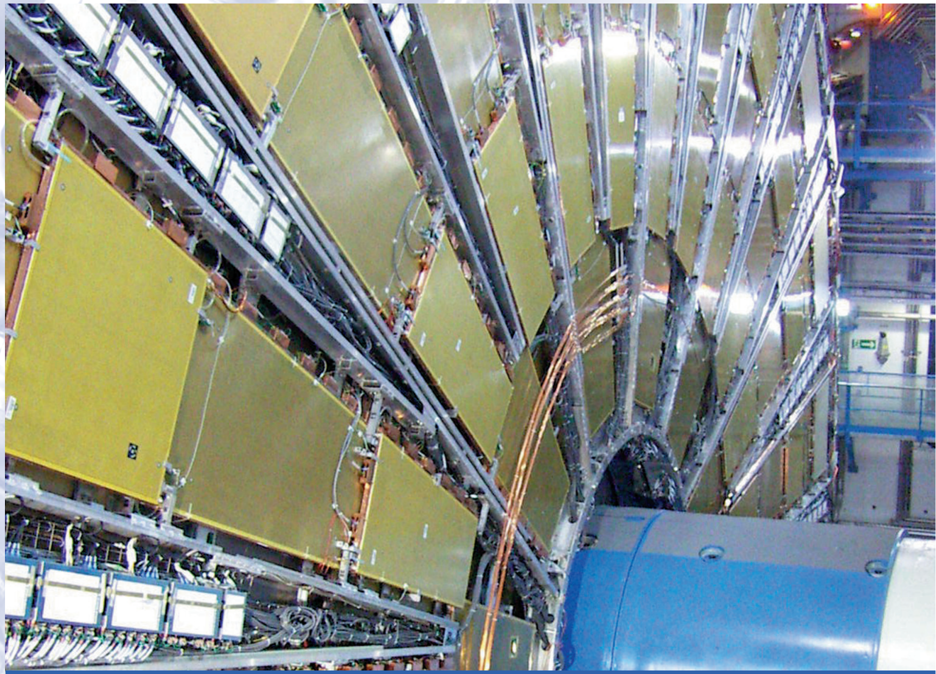

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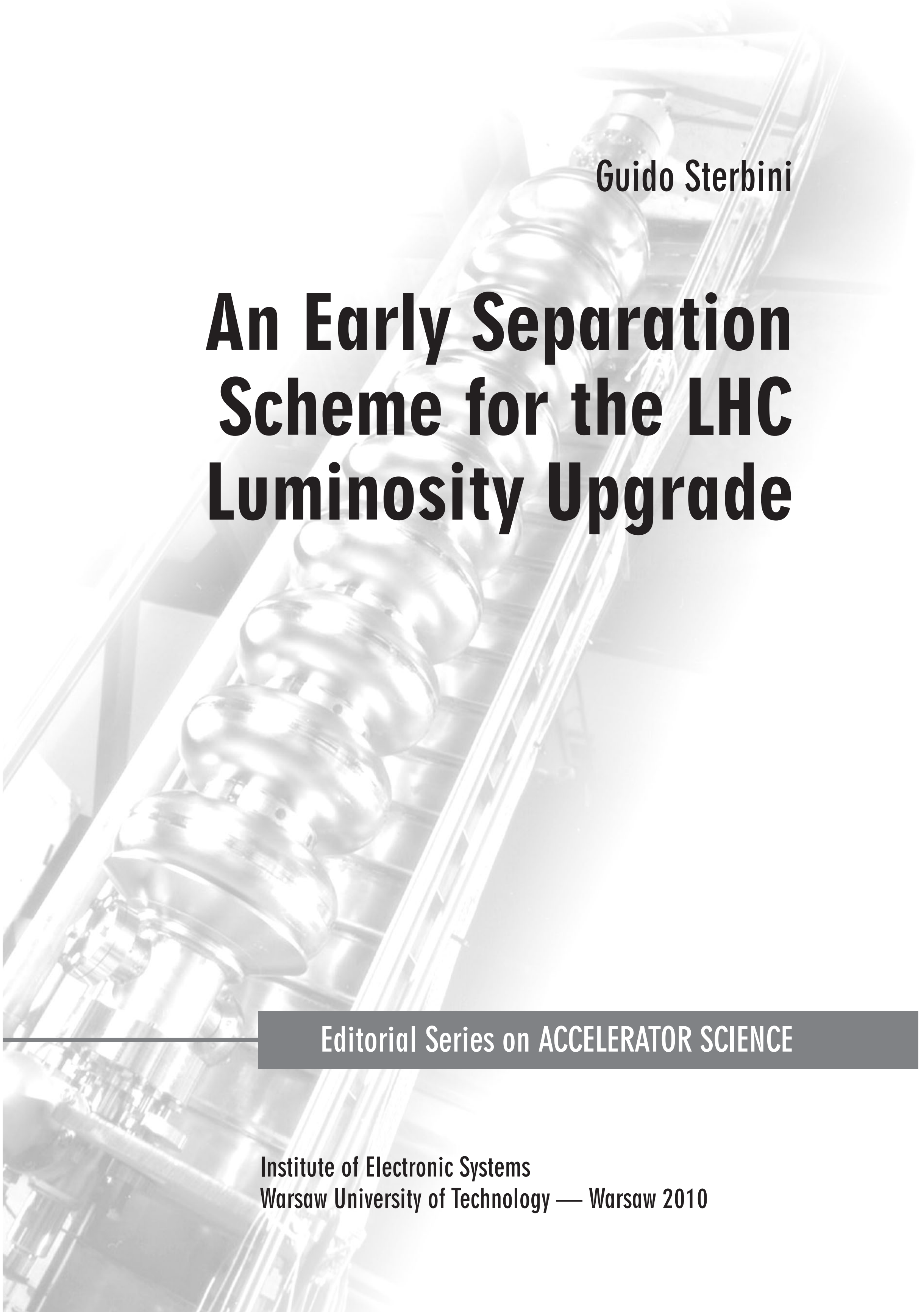

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PAR

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Introduction

The Large Hadron Collider (LHC) is a 7 TeV proton-proton collider presently under commissioning at CERN, the European Organization for Nuclear Research. Since 2002, studies are on going with the goal of increasing its performance beyond the nominal one. The feasibility of an upgrade of the collider's luminosity and energy was initially explored. Presently, a great part of the efforts and studies are dedicated to the LHC Luminosity Upgrade: the technology that will be adopted in the Luminosity Upgrade could, later on, pave the way for the even more challenging Energy Upgrade.

The physics motivation behind the LHC Luminosity Upgrade is two-fold: it would allow to do precision physics of rare interactions at LHC and to expand, in practice, the energy reach of the machine. There is, in addition, a technical and practical motivation: after about 8 years of operations, some components of the machine and of the detectors will be damaged by the high radiation dose and they will need to be replaced. It appears natural to substitute them with increased performance components and systems, taking advantage of the experience acquired during the machine operations and of the latest technology advances in the accelerator field.

Due to complexity of the project, a staged approach is followed involving two phases. The framework of this study is the very ambitious luminosity upgrade of Phase II: its target is to gain an order of magnitude on the nominal LHC luminosity. Several proposals for the Phase II upgrade are under evaluation: one of these is the Early Separation Scheme, the topic of this thesis.

In the nominal LHC, the beams cross at an angle in the interaction points. This allows a single beam collision in the detector and minimizes the detrimental electromagnetic interactions between the beams on either side of the crossing point (parasitic beam-beam interactions). The crossing angle reduces however the geometric overlap between the beams and, consequently, the machine luminosity. The primary goal of the Early Separation Scheme is to decrease the crossing angle at the interaction point while maintaining a sufficient separation at the parasitic beam-beam encounters. It opens the possibility of a further reduction of the value of the β-function at the Interaction Point and of luminosity leveling.

A major issue of this scheme is the introduction of new dipoles inside the detectors and their integration. A compromise has to be found between minimum impact on the detector and efficiency of the scheme to increase the luminosity. This study is intended to explore the potential the Early Separation Scheme and the terms of compromise for a possible implementation. The results will be pursued by means of analytical and numerical approaches, using existing software and/or implementing specific code for addressing more peculiar tasks. Experimental studies will be conducted and compared to the simulations.

The major questions to address in the present thesis will be the followings:

- to identify the parameter space of the Early Separation Scheme. Starting from there, to define its hardware requirements in terms of dipoles and to choose the most adequate magnet technology to be adopted in the scheme,
- to describe, for the different scenarios of the upgrade, the potential of the scheme evaluating its flexibility and its gain in terms of integrated luminosity,
- to address in details the linear and non-linear beam dynamics effects by means of analytical approach and numerical tools,
- to investigate to what degree the non-linear dynamics effect of sLHC can be reproduced in other machines and to perform experiments at the CERN Super Proton Synchrotron in order to extrapolate the sLHC beam dynamics,
- to identify for the LHC high luminosity experiments the specific integration problems in terms of position and magnetic field compatibility,
- to perform an energy deposition study for the dipole closer to the interaction point and consider, if needed, adequate shielding strategy,
- to propose a preliminary cross-section of the dipole closer to the interaction point paying particular attention to the mechanical stress of the magnet's coil.

All the previous points will finally converge in a realistic proposal, common to the two experiments, featuring the best compromise between hardware integration difficulties and beam dynamics stability.

The present document is organized in five chapters.

In the first chapter the framework of the study is described, developing the motivations, the goals and the requirements for the LHC Luminosity Upgrade. We analyze the need for the crossing angle and its impact on the peak luminosity of the collider. After having introduced the Early Separation Scheme, we explain how it may overcome some limitations of the present machine. We compare the nominal LHC crossing scheme with the proposed one underlining its potential in terms of performance and its issues with respect to the integration in the detectors. An analysis of the integrated magnetic field required is given.

In the second chapter we introduce one of the most powerful aspect of the scheme: the luminosity leveling. After the description of the physical model adopted, we compare the results of its analytical and numerical solutions. All the potential improvement due to the Early Separation Scheme are shown on the luminosity plane (peak luminosity versus integrated luminosity).

In the third chapter the linear and non-linear beam dynamics effects induced by the Early Separation Scheme are discussed. The linear effects are analytically developed and verified using the MAD-X code. The scaling laws needed to compare the non-linear dynamics of different machines are investigated: this is a fundamental introduction and justification to the following chapter.

In the fourth chapter we present the simulations and the experiments performed in order to evaluate the non-linear effect of the proposed scheme. The simulation code is written and compiled for a multi-processors graphics card. The simulations outcome is compared with the results collected during about 100 hours of experiments in the Super Proton Synchrotron at CERN.

The fifth and last chapter is dedicated to the integration studies of the Early Separation Scheme with particular emphasis on the dipole closer to the interaction region. The specific integration difficulties in the ATLAS and CMS experiments are described. The power deposited on the dipoles from the non-elastic collision at the interaction point is computed using the FLUKA code. Technical solutions of Nb-Ti and Nb_3Sn superconductors are considered and compared with particular emphasis to their mechanical stress limitation. A cross-section for the magnet is proposed and optimized using the ROXIE code.

Finally, the results achieved in the present work are summarized in the Conclusions.