EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Large Hadron Collider Project

LHC Project Report 1114

PRELIMINARY EXPLORATORY STUDY OF DIFFERENT PHASE II COLLIMATORS

L.Lari1), R. Assmann, A. Bertarelli, C. Bracco1), M. Brugger, F. Cerutti, A. Dallocchio, E. Doyle2),
A. Ferrari, L. Keller2), S. Lundgren2), T. Markiewicz2), M. Mauri, S. Roesler, L. Sarchiapone,
J. Smith2), V. Vlachoudis

CERN, Geneva, Switzerland

LHC-PROJECT-REPORT-1114
03 Sep 2008

Abstract

The LHC collimation system is installed and commissioned in different phases, following the natural evolution of the LHC performance. To improve cleaning efficiency towards the end of the low beta squeeze at 7TeV, and in stable physics conditions, it is foreseen to complement the 30 highly robust Phase I secondary collimators with low impedance Phase II collimators. At this stage, their design is not yet finalized. Possible options include metallic collimators, graphite jaws with a movable metallic foil, or collimators with metallic rotating jaws. As part of the evaluation of the different designs, the FLUKA Monte Carlo code is extensively used for calculating energy deposition and studying material damage and activation. This report outlines the simulation approach and defines the critical quantities involved.

1) EPFL, Lausanne and CERN, Geneva, Switzerland
2) SLAC, Menlo Park, California, USA

Presented at
EPAC'08, 11th European Particle Accelerator Conference, Genoa, Italy - June 23-27, 2008

CERN,
CH-1211 Geneva 23
Switzerland

PRELIMINARY EXPLORATORY STUDY OF DIFFERENT PHASE II COLLIMATORS

L. Lari, C. Bracco, EPFL, Lausanne and CERN, Geneva, Switzerland
R. Assmann, A. Bertarelli, M. Brugger, F. Cerutti, A. Dallocchio, A. Ferrari, M. Mauri, S. Roesler, L. Sarchiapone, V. Vlachoudis, CERN, Geneva, Switzerland
E. Doyle, L. Keller, S. Lundgren, T. Markiewicz, J. Smith, SLAC, Menlo Park, California

Abstract

The LHC collimation system is installed and commissioned in different phases, following the natural evolution of the LHC performance. To improve cleaning efficiency towards the end of the low beta squeeze at 7TeV, and in stable physics conditions, it is foreseen to complement the 30 highly robust Phase I secondary collimators with low impedance Phase II collimators.

At this stage, their design is not yet finalized. Possible options include metallic collimators, graphite jaws with a movable metallic foil, or collimators with metallic rotating jaws.

As part of the evaluation of the different designs, the FLUKA Monte Carlo code is extensively used for calculating energy deposition and studying material damage and activation.

This report outlines the simulation approach and defines the critical quantities involved.

INTRODUCTION

The collimation system of the Large Hadron Collider (LHC) close to starting up at CERN, is a challenging project since the collimators constitute the limiting aperture for both high density proton beams with a total stored energy up to 360 MJ per beams, two orders of magnitude beyond the achievement in TEVATRON or HERA.

The full LHC collimation system (including the transfer lines) foresees more than 150 locations with the design goal of avoiding quenches of SuperConducting (SC) magnets, protecting LHC equipments and minimizing the halo induced background in the particle physics experiments. In particular, two insertion regions of the LHC, IR3 for momentum cleaning, and IR7 for betatron cleaning, are dedicated to beam cleaning in order to absorb most of the primary beam halo and its secondary radiation. These regions will be among the most radioactive areas of the LHC.

The collimators are supposed to be installed in different Phases [1]. The Phase I collimators provide a collimation system with maximum robustness, optimized cleaning efficiency and powerful passive protection. The Phase I system is already predicted to be limited by cleaning efficiency and the collimator-induced impedance, limiting the maximum intensity and thus the luminosity. For this reasons it is foreseen to complement the 30 high robustness secondary collimators with low impedance Phase II collimators that should also improve cleaning efficiency. They will be used only towards the end of the low beta squeeze and in stable physics conditions. Moreover, once LHC exceeds about 50% of the nominal design luminosity, additional Phase III collimators will be installed in order to capture the high luminosity collision debris downstream of the interaction points.

PHASE II DESIGN CALCULATIONS

The preliminary designs are under way. Special attention is given to collimators that will allow a new jaw surface to be moved into place after possible beam damage.

Because of the high beam power involved, an important parameter to evaluate different possible Phase II designs is the energy deposition due to the direct losses and to the particle showers that are generated at the interception of the primary halo by the Phase I collimators.

Extensive simulations with the Monte Carlo cascade code FLUKA [2, 3] were performed to study the consequences of the beam impact on such collimators. FLUKA simulates the proton interaction and the resulting cascade, starting with the proton coordinates/direction provided by the SIXTRACK code [4]. Results are then used as input for the engineering simulation (e.g. ANSYS) to predict static stresses on the collimator body.

Furthermore, the FLUKA simulations supported the studies of the different jaw materials, giving indication about important related quantities such as residual dose rates received by staff during handling of the components.

Simulation of the IR7collimation system

The different designs of Phase 2 collimators were implemented in the FLUKA IR7 model [5], with all possible details, including the jaw support, the cooling pipelines, the tank, the flanges, etc. Moreover, the tilting of the jaw following the beam divergence at the location of each collimator is implemented as well.

The IR7 description in FLUKA consists of a 1.5 km long tunnel section accurately modelled, including more than 200 elements (quadrupoles, bending magnets, orbit correctors, sextupoles, beam loss monitors, phase 1 primary and secondary collimators, passive and active absorbers). Each LHC magnet model has an associated magnetic field, which correctly reproduces the beam optics.

Collimators are the key element in the halo cleaning system. The Phase I primary collimators act as the bottleneck for the beam, the inner-jaw half-aperture being at 6 σ, while this value is fixed to 7 σ for the Phase II secondary collimators. The aperture and the orientation of the collimator models are adapted during runtime through a special routine (LATTIC), so that the same prototype can be used in all the foreseen locations.

For the operational scenario, the Phase II collimators should be able to handle increased particle losses, in order to avoid beam aborts and to allow correction of parameters and restoration of nominal conditions. The collimators should then be able to withstand beam loads of $4*10^{11}$ p/s (0.2h beam lifetime) for 10s and of $0.8*10^{11}$p/s (1h beam lifetime) continuously. These values correspond to about 450 kW and 90 kW power deposited in the IR7 cleaning region respectively.

To evaluate the energy deposition versus jaw length and to perform a full shower study, 11 Phase II collimators with different orientations were added in the most sensitive locations to the IR7 simulation line.

Three different promising designs were considered.

CERN Metallic Collimator design

A preliminary metallic collimator design, proposed by CERN, is investigated with different jaw materials. This step provides valuable information not only for energy deposition on the 1 m jaws themselves but also for power loads on the jaw support structures in Molybdenum and on the collimator tanks.

The geometry of the metallic collimators has been implemented in FLUKA (see Fig.1) to optimize material and design choice.

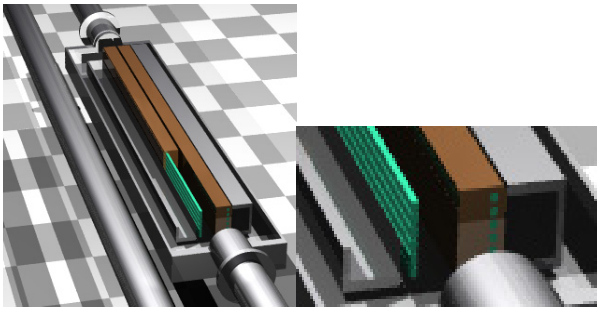

Figure 1: Metallic Collimator FLUKA Layout.

A set of simulations at top energy were needed in order to evaluate the feasibility of these collimators with Copper, Aluminum and Tungsten jaws with a thickness of 2.4 cm.

Results for the three scenarios are summarized in Table1. They refer to a horizontal loss scenario, which together with the vertical one, induces the largest energy deposition in the collimators.

The most loaded Phase II collimator is the first one TCSM.A6L7.B1, located about 45 m downstream of the primary collimators. Due to its position, it is expected that a significant part of the secondary shower will impact on it.

It is worth mentioning that the peak position on the jaw surface depends on the jaw material: at about 20 cm longitudinal depth for the Copper jaw, at 80 cm for the Aluminum and at 5 cm for the Tungsten ones.

Table 1: Summary of Energy Deposition results for collimator TCSM.A6L7.B1 with horizontal halo

Jaw material	**Energy deposition**	**0.2h [kW]**	**1h [kW]**
Cu	Whole collimator	115	23
Radiation length 1.44 cm	One jaw	45	9
	Peak on the jaw surface	0.55/cm^3	0.11/cm^3
Al	Whole collimator	60	12
Radiation length 8.9 cm	One jaw	15	3
	Peak on the jaw surface	0.055/cm^3	0.013/cm^3
W	Whole collimator	120	25
Radiation length 0.35 cm	One jaw	55	11
	Peak on the jaw surface	1.75/cm^3	0.35/cm^3

Generic studies for collimators with different jaw materials [6] have shown that the activated cooling circuits, tank, and support structures contribute significantly to the residual dose rates (more than 60%). Nevertheless, the overall activation level depends on the jaw material and, for example, is 20-50% higher for collimators with Tungsten jaws compared to those with Copper jaws. On the other hand, the cooling time dependence is found to be similar for all jaw materials.

Metallic Foil Collimator design

The metallic foil collimator design is under evaluation at CERN as a proposed solution to restore the functionality of the Phase II collimator after possible beam damage without changing the total “ensemble”. The idea is to move into place a new 1-3 mm thickness copper foil onto the graphite jaws.

Using the Graphite jaw behind guarantees a higher probability of collimator survival in comparison to a jaw made entirely of Copper. Indeed, because the energy deposition density depends strongly on the atomic number and on the density of the material, Graphite assures that only a small part of the cascade will be confined in the collimator jaws with an acceptable instantaneous temperature rise.

Furthermore, residual dose rates around a collimator with graphite jaws are about a factor of five lower than around a collimator with copper jaws [6].

For a first evaluation of this design, a FLUKA model with the foil fully adhering to the jaw (see Fig.2) has been set-up. In this study, the material chosen for the 1 m jaw is Copper-Diamond (35% Cu and 65% C).

This approximation to an ideal foil collimator design could represent itself an independent additional option.

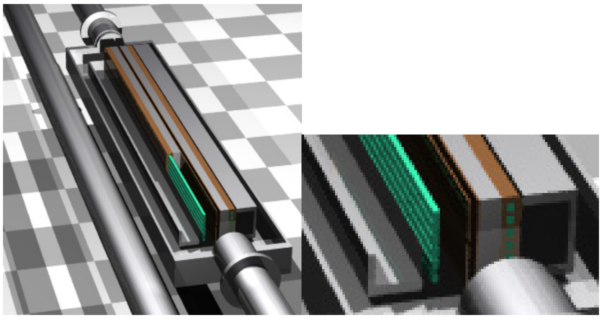

Figure 2: Metallic Foil Collimator FLUKA Layout.

Preliminary results show an energy deposition on TCSM.A6L7.B1 (horizontal loss scenario for 1h beam lifetime) of about 8 kW on each jaw of which 6 kW on the foil and 2 kW on the Cu-Diamond part.

Present simulations have been performed by loading loss maps referring to a whole Copper jaw and neglecting primary inelastic events outside of the 2 mm thick foil (less than 10% of total direct losses in the considered Phase II collimator). Future investigations will be done using loss maps to be computed through a dedicated tracking, taking into account the different layers.

Rotatable Jaw Collimator design

The SLAC laboratory, through the LARP program, proposes two cylindrical Glidcop (0.15% Al and 99.85% Cu) 93 cm long jaws which can rotate, moving into place a new surface in case of beam damage [7].

Extensive FLUKA simulations [8] have been done to support the design studies. The model was implemented in great detail, including the jaw support, the motor shafts, the mandrels, the cooling pipelines, the tank, the flanges, etc (see Fig.3).

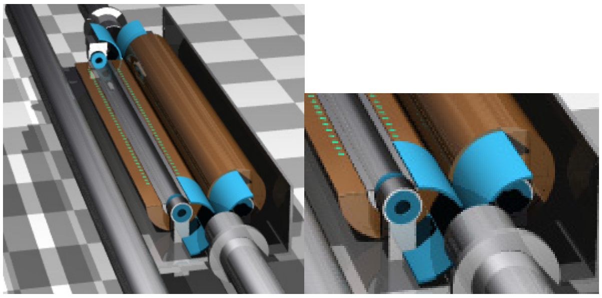

Figure 3: Rotatable Jaw Collimator FLUKA Layout.

The thickness of the active Glidcop jaw part is around 2.4 cm. Thus, the values of the energy deposition found are similar to those of the copper case in Table 1 for 1h beam lifetime and horizontal loss scenario: around 22 kW in total of which 8.5 kW on each jaw, with a peak of 0.11 kW/cm^3 localized at a longitudinal depth of 20 cm.

CONCLUSIONS

These preliminary calculations outline that the possible choice of Tungsten jaws for the most loaded Phase II collimator (TCSM.A6L7.B1) is to be avoided. Indeed already in operational conditions, its functionality could be limited because of the high values of the energy deposition peak on the jaw surface. Choice is therefore limited to Copper or Aluminum. The final decision will be supported by thermal analysis.

In particular these thermal evaluations have to be performed for the thin Copper foil design, investigating the thickness of the foil itself and the choice of the material behind it.

Further, combinations of different designs at different locations in the line and/or the introduction of other possible strategies (e.g. active or passive absorber, ceramic collimators, cryogenic collimators, etc.) will be evaluated in the next future, in order to maximize Phase II collimators protection purpose.

REFERENCES

[1] R. Assmann et al. “The final LHC Collimation System” CERN-LHC-Project-Report-919, EPAC06.

[2] A. Fasso’, A. Ferrari, J. Ranft and P. R. Sala, ”FLUKA: a multi-particle transport code”, CERN-2005-10(2005), INFN/TC_05/11, SLC-R-773.

[3] G. Battistoni et al. “Overview of the FLUKA code and examples of use for radiation detectors”, Invited talk at the Workshop on Use of Monte Carlo Techniques for Design and analysis of Radiation Detectors, Coimbra, Sep. 2006 (Proceedings in press)

[4] R. Assmann, S. Redaelli, G. Robert-Demolaize and F. Schmid “A new version of SixTrack with collimation and aperture interface”, Knoxville, USA, May 2005.

[5] V. Vlachoudis et al: “Energy Deposition Studies for the Betatron Cleaning Insertion (IR7) of LHC” Proc. PAC05. CERN-LHC-Project-Report-825.

[6] M. Brugger, D. Forkel-Wirth and S. Roesler, “Generic studies of radioactivity induced by high energy beams in different absorber materials”, to be published in Proceedings of the 11th International Conference on Radiation Shielding, ICRS-11, April 13-18, 2008, Callaway Gardens, GA, U.S.A.

[7] J. C. Smith et al. “Design of a Rotatable copper collimator for the LHC Phase II collimation upgrade”, EPAC08, Genoa, Italy.

[8] L. Lari et al. “Evaluation of beam loss and energy deposition for one possible Phase II design for LHC collimation”, EPAC08, Genoa, Italy.