

*Large Hadron Collider Project*

**LHC Project Report 184**

## **CASCADE SIMULATIONS FOR THE LHC BETATRON CLEANING INSERTION**

I. Azhgirey\*, I. Baishev\*, N. Catalan Lasheras and J.B. Jeanneret

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\*Member of the Russian collaboration to the LHC project,  
IHEP, Protvino, Russia.

Administrative Secretariat  
LHC Division  
CERN  
CH-1211 Geneva 23  
Switzerland

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# CASCADE SIMULATIONS FOR THE LHC BETATRON CLEANING INSERTION

I. Azhgirey, I. Baishev, IHEP, Protvino, Russia  
N. Catalan Lasheras, J.B. Jeanneret, CERN, Geneva, Switzerland

## Abstract

A cascade calculation is done in the IR7 betatron cleaning insertion of LHC. It uses a detailed map of the primary losses and an accurate model of the straight section. One aim is to design a compact shielding which fits in the tight section of the tunnel. The same study allows to define radiation hardness properties of the equipment to be installed in the section and to locate areas of low activity for the installation of sensitive equipment.

## 1 INTRODUCTION

The expected beam losses in collision at LHC might be as large as  $8 \times 10^{16}$  7 TeV protons per year in the betatron collimation insertion IR7 [1, 2, 3]. This implies the installation of a tight shielding in this area. The primary losses before cascading will be distributed among 20 collimators. The small transverse size of the tunnel imposes to fit the shielding close to the equipments. Cascade calculations must therefore be made with a detailed model of the straight section.

In this paper, we report on some preliminary calculations. A first code is used to define a map of primary interactions. Then cascade simulations are made with two versions of the geometry, one with a test version of shielding and one without it. Hadron fluences and absorbed doses are computed at the surface of a cylinder surrounding the beam lines.

## 2 THE CLEANING INSERTION IN IR7

The collimation system of LHC requires a section of ring which offers a betatronic phase advance of  $\Delta\mu_x = \Delta\mu_y \approx 2\pi$ . This section must not be superconducting to sustain a high level of power deposition [1]. It will be made of six quadrupoles each made of several modules. Two bending magnets will be installed at each end of the section to keep the beam line free of the high flux of neutral particles emitted at the primary collimators.

The principles of optics used for a collimation insertion and a discussion of the specific case of the version 5.0 of IR7 in LHC can be found in [3]. The description in [1] was related to the older version 4.2 of the insertion, but the basics of the geometry has not changed.

In this calculation, the primary collimators are made of 200 mm long aluminium jaws and the secondary ones of 500 mm long copper jaws. These numbers are still open parameters, but are very unlikely to change drastically.

A map of primary inelastic collisions is prepared with the K2 code [3, 4] for further cascade calculations. To get

an approximately realistic map of impact on primary collimators, a proton is circulated inside the primary aperture using one turn linear motion superimposed with a variable transverse drift speed until it touches a collimator. Then, a tracking with smaller steps is made, with linear betatronic motion between collimators.

In the collimator a Monte-Carlo method is used to simulate coherent and incoherent nuclear elastic and Rutherford scattering. Multiple Coulomb scattering is treated as a continuous diffusion process, iterating the motion near the edge of the collimator with high care. When an inelastic interaction occurs, the tracking is stopped and the coordinates of the proton at the interaction point are stored. The map of inelastic interactions is obtained by tracking ten thousand protons.

## 3 3D MODEL OF IR7

The model of the cleaning section is based on the lattice version 5.0. It is described as a sequence of elements aligned in accordance with the optical layout. The elements are primary and secondary collimators, warm dipoles, warm quadrupoles and dipole correctors. Beam pipes in the drift spaces between magnets and collimators are also treated as separate elements.

In the right Cartesian coordinate system  $(x, y, z)$  the longitudinal axes of symmetry of dipoles and quadrupoles belong to the axis  $z$ . Beam axes of Ring 1 and Ring 2 lie in parallel to the axis  $z$  in the horizontal plane  $(x, z)$ . The entire chain of elements is fully symmetric with respect to the horizontal plane i.e. has vertical symmetry and is horizontally asymmetric because of the location of the orbit correctors and collimators.

Every collimator tank is presented as a pair of jaws in a vacuum box. The longitudinal axis of a collimator coincides with the beam axis of Ring 1 or Ring 2. There are four primary collimators in the system : horizontal, vertical, and at normalised  $X - Y$  azimuths  $45^\circ$  and  $135^\circ$ . Every secondary collimators has an individual position and an individual  $X - Y$  azimuth [5].

The warm dipole and quadrupole modules MBW and MQW are described in [6]. The two-dimensional maps of the magnetic field [7] are used to simulate the correct transport of charged particles in the dipoles and the quadrupoles. The warm dipole correctors are placed near every quadrupole in pairs so that the vertical corrector of Ring 1 is accompanied by the horizontal corrector of Ring 2 and vice versa. Every corrector consists of one module MCBW [8].

The beam pipes of both rings are copper tubes. The beam

pipe inside magnets and in the short drift spaces between magnets has 44 mm inner diameter and 48 mm outer diameter and the inner diameter of the regular beam pipe in the long drift spaces is 100 mm and the outer diameter is 105 mm [9].

Reasonable maximum of material around the beam lines is the first approach to the shielding design of the cleaning system. Iron shielding covers all the long drifts between magnets. The typical transverse cross-section of the shielding is shown in Figure 1. Its outer dimensions are limited mainly by the free space for the passage-way in the tunnel. The inner dimensions are determined by the minimum space required for the beam pipes or collimators.

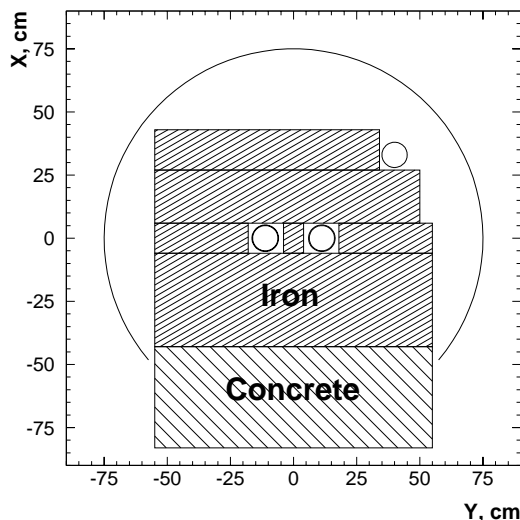


Figure 1: The shielding cross-section. The small central circles are the beam pipes in drift sections. The upper right circle is a survey device. The large circle is a scoring surface.

## 4 RESULTS

Hadronic and electromagnetic cascades simulations were performed with the last version of the MARS code [10]. Energy cut-off for hadron transport was 10 MeV. A thin (1 cm) cylindrical vacuum layer surrounding the whole assembly of elements was used for scoring the rate of outgoing particles (see Figure 1). The scoring shell was subdivided longitudinally in one metre long steps. To compute doses, the same cylinder layer was filled with polystyrene in a separate calculation.

The results for hadron flux density presented in Figure 2 were obtained assuming  $10^9$  primary interactions per second at 7 TeV in the collimators of one ring [2]. The structure of the single-beam distributions 2a) and 2b) reflects both the map of primary interactions and the spread of high energy secondaries along the beamline. The superposition 2c) of the single-beam distributions is practically symmetric with respect to the crossing point IP7 at  $z = 251$  m.

Fluence attenuation by the shielding is the better the longer is the distance from the closest source of radiation. The attenuation factor is equal to approximately 4 near the collimators and grows up to 20 a few metres downstream of them.

Hadron fluence is a good indicator with respect to the radioactivation of the machine components, cooling water, air in the tunnel and rock outside. Absorbed dose is the better indicator with respect to the radiation damage of cable insulation and other organic parts of equipment. The annual doses in Figure 3 were obtained for average expected losses of  $1.6 \times 10^{16}$  primary interactions in the collimators of one ring per year [2].

Shielding effect in the case of absorbed dose is much better than in the case of hadron fluence as can be seen in Fig.3. The dose attenuation factor is equal to 20 near the collimators and above a hundred at a distance from them. Absorbed dose in the case without shielding exceeds  $10^4$  Gy/year almost everywhere. This level is dangerous for the generic organic insulations. With shielding only a few hot spots with the annual dose above  $10^3$  Gy can be found. More detailed maps of doses and fluences may be found in [11].

## 5 FURTHER WORK

Under the present assumptions, the calculated fluences at the coils of the magnets are low enough to allow for using organic insulation. But, to avoid peaks of irradiation at some locations additional internal shielding will be modelled with further simulations. Calculation of activation of the air and of the rock outside the tunnel are under work using the present map of fluences.

## 6 ACKNOWLEDGMENTS

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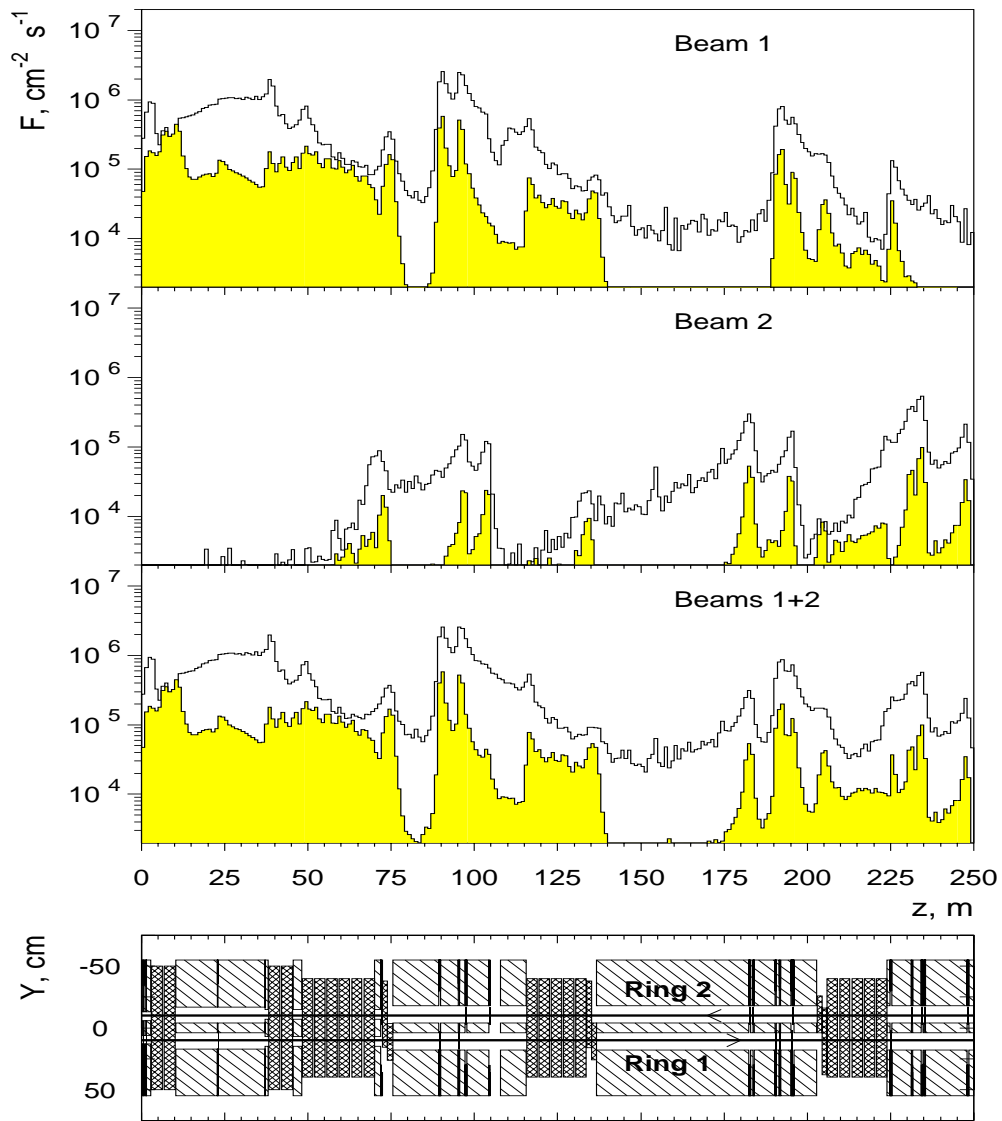


Figure 2: Hadron flux density around the beam lines. Clear histograms - the case without shielding, grey histograms - the case with shielding. The z-range covers a half of the straight section. Beam enters at  $z=0$ , where the primary collimators are located.  $F(z)$  in  $z=[250,500]$  for beam 2 is similar to  $F(z)$  for beam 1 left-right reflected.

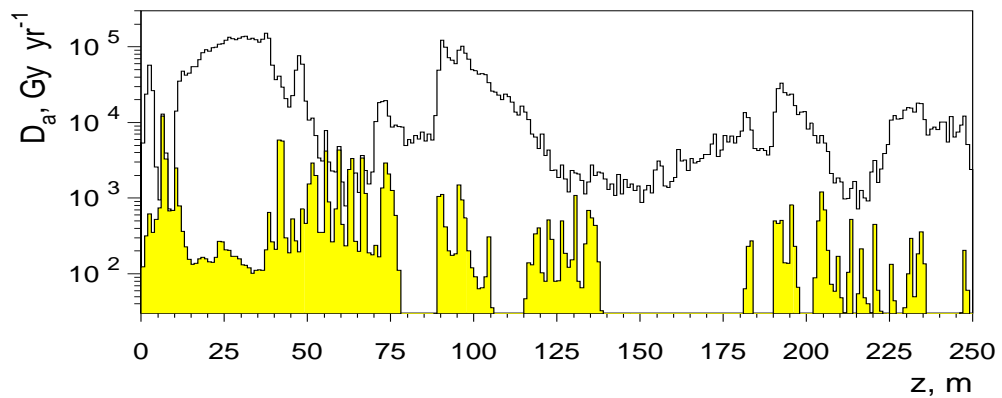


Figure 3: Above, a schematic layout of the cleaning insertion. Dark hatched surfaces stand for magnets and light hatched ones for shielding. Collimators appear as thin vertical lines in the shielding elements. Below, annual absorbed dose in organic material around the beam lines.