FLUKA STUDIES OF THE ASYNCHRONOUS BEAM DUMP EFFECTS ON LHC POINT 6

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Abstract

The LHC is a record-breaking machine for beam energy and intensity. An intense effort has therefore been deployed in simulating critical operational scenarios of energy deposition. FLUKA is the most widely used code for this kind of simulations at CERN because of the high reliability of its results and the ease to custom detailed simulations all along hundreds of meters of beam line. We have investigated the effects of an asynchronous beam dump on the LHC Point 6 where, beams with a stored energy of 360 MJ, can instantaneously release up to a few J cm^{-3} in the cryogenic magnets which have a quench limit of the order of the mJ cm^{-3}. In the present paper we will describe the simulation approach, and discuss the evaluated maximum energy release onto the superconducting magnets during an asynchronous beam dump. We will then analyse the shielding provided by collimators installed in the area and discuss safety limits for the operation of the LHC.

INTRODUCTION

A fault with the LHC beam dump system [1] could lead to severe damage to the dumping system itself, to the LHC machine or to the LHC experiments, due to full or partial loss of the beam onto machine components. Despite the precautions taken, certain faults are nonetheless possible to occur and have been foreseen in the design of the system and in the load cases for other systems, in particular the LHC collimators.

An asynchronous beam dump event [2] occurs when the dump is triggered out of synchronization with the LHC dump gap. In all other aspects the dump functions normally, i.e. all the 15 dump kickers are synchronized, however the kicker rise time can be fully experienced by the LHC beam. It is assumed that it could happen at least once per year.

This work aims to investigate the effects, and possible reliefs, of an asynchronous beam dump in the case of a 4.5 TeV circulating proton beam, within the compass of the feasibility studies for a LHC run at this energy. More precisely, we have performed a `FLUKA` [3, 4] simulation devoted to the evaluation of the energy deposited in the dipole (MB[1]) coils, quadrupole (MQ) coils, interconnect (Q) busbars, and the distribution feedbox (DFB) busbars located in the Insertion Region 6 (IR6).

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[1] for a detailed description of the LHC geometry and acronyms see [1]

SIMULATION SET-UP

We have considered an asynchronous beam dump event for a 4.5 TeV beam 1 with 50 ns bunch separation. In this case, about 42 bunches corresponding to a total of $\sim 4.8 \cdot 10^{12}$ protons are swept from the ideal trajectory and either continue in the beam pipe or impinge on the Target Collimator Dump Quadrupole, TCDQ.4R6. The corresponding loss map is loaded on the front face of the TCDQ.4R6.

The IR6 `FLUKA` geometry (fig. 1) has been built using two tools being developed by the CERN `FLUKA` group, the LineBuilder and the `FLUKA` Element DataBase (FEDB). The former is a python application that generates the LHC `FLUKA` geometry starting from the TWISS files and the FEDB. The latter is a database containing the `FLUKA` models of various element of the LHC line (e.g.: magnets and collimators).

The IR6 `FLUKA` geometry is based on the LHC TWISS files. It extends from the "Interaction Point 6" (IP6), through the matching section and the Dispersion Suppressor (DS), up to the cell C13.R6, for about 550 meters. The reference system is defined as follows: the origin is in IP6; the x and y axes are directed outgoing from the center of LHC and opposite to the gravity respectively, while the z axis is orthogonal to the $x-y$ plane and directed toward Point 7.

RESULTS

Maximum peak of energy deposition The main subject of our investigation has been the maximum peak of energy deposition per each element considered. This is one of the relevant quantities with respect to possibility of quenching the line, being the limit of the order of some mJ cm^{-3}. Because of the length of the simulated geometry, the statistical uncertainty could be an issue. To avoid this, besides simulating a large amount of primaries (89 millions), we have discarded any particle having less than 100 GeV and located before the DFBAL.5R6. To evaluate the energy deposition on the first elements of the line, a dedicated simulation of 5 millions primaries without biasing has been performed. The results are shown in fig. 1, where the maximum peak of energy deposition is shown over the geometry model by means of a color code. The plots of the maximum peak of energy deposition and of the total energy deposition as function of the element Id (i.e.: z) are shown in fig. 2. Two quadrupoles and one dipole are well above the quench limit. Five magnets (4 MQs and 1 MB) and two intercon-

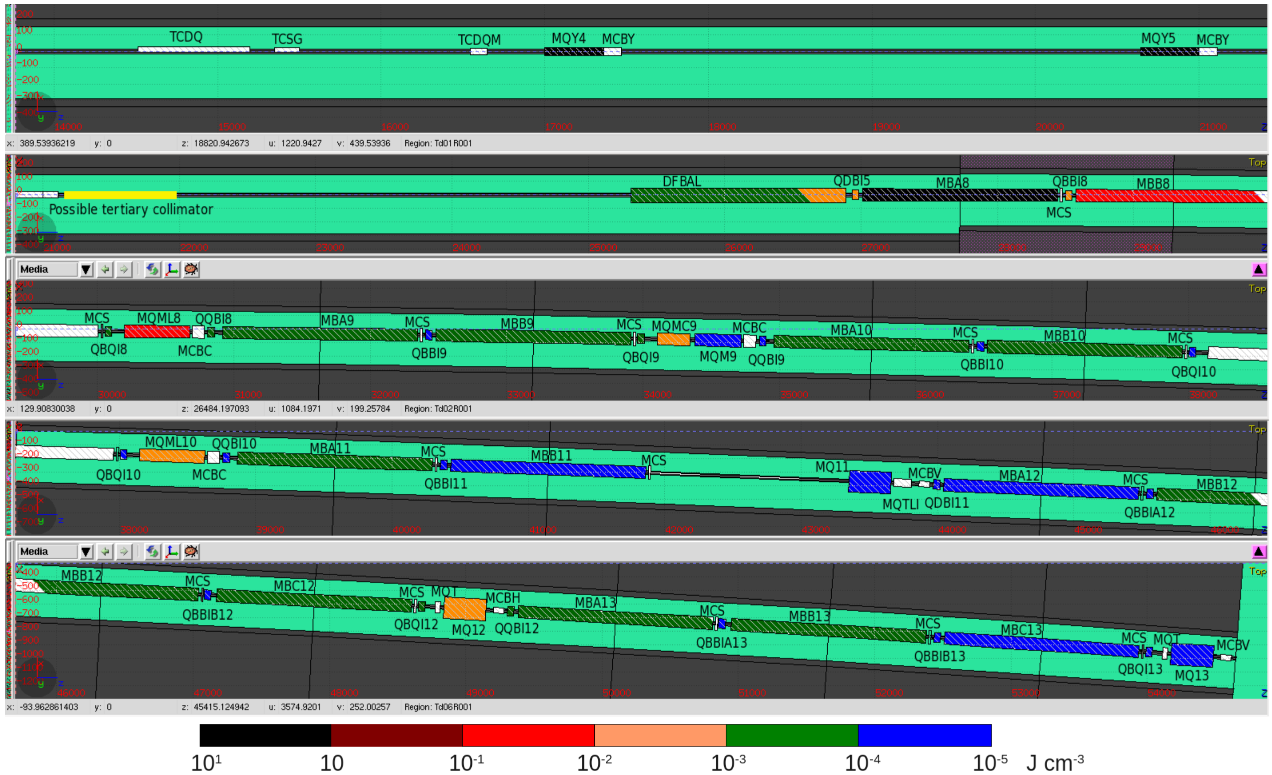

Figure 1: Schematic z-x view of the LHC IR6 FLUKA geometry. The five rows show, as function of z, different sections of the geometry starting from 140 m to 550 m right of IP6. The name of the elements are indicated. The maximum peak of energy deposition is indicated by means of a color code. A demonstrative location for the possible tertiary collimator discussed in the text, is shown.

nects have the maximum peak of energy deposition within a range where quenches may occur.

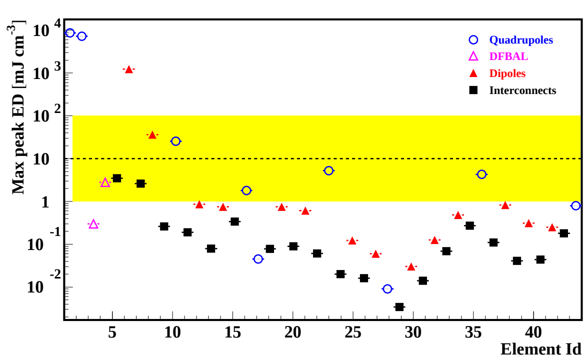

Figure 2: Maximum peak of energy deposition. The error bars indicating the statistical uncertainty are smaller than the marker size. The dotted line represents an indicative threshold for the magnets quench. The yellow band is obtained applying the systematic uncertainty directly on the quench limit rather than on the simulation results. Above the yellow band quenches have to be expected. Within the yellow band quenches are possible. Below the yellow band quenches are unlikely to happen.

Beam profile The second part of our study has been devoted to the evaluation of the effectiveness of a tertiary collimator to be inserted between the MCBY.5R6 and the DFBAL.5R6. The purpose of this collimator would be to shield downstream elements along the line. It could not be placed closer than 8σ from the ideal trajectory, without implying a global change of the entire LHC collimation system.

Five millions primary protons have been simulated to study the beam profile at the exit of the MCBY.5R6 and of the DFBAL.5R6 (fig. 3). About 35% of the simulated protons were able to exit cell C13.R6 without any interaction and have been subject of other studies [5, 6]. Most of the remaining protons (about 97.7%) interact with the TCDQ.4R6. The remaining 1.5% interacts with other elements within cell C13.R6. At the exit of the MCBY.5R6, (80 ± 1)% of the protons would be at more than 8σs from the ideal trajectory. This fraction reduces to (66 ± 1)% at the exit of the DFBAL. Therefore the insertion of a tertiary collimator would be quite effective to shield elements in the DS, especially if located closer to the end of the MCBY.5R6 corrector. It is also worth to notice that a tertiary collimator would stop as well, part of the protons not interacting in the DS. About a quarter of these would be at more than 8σs from the ideal trajectory, at the end of both the MCBY.5R6 (27%) and of the DFBAL.5R6 (25%).

Beside the aforementioned tertiary collimator insertion, further mitigation measures are under evaluation like the insertion of a TCLA type collimator upstream of the TCDQM.4R6 and the increase of the TCDQ.4R6 length.

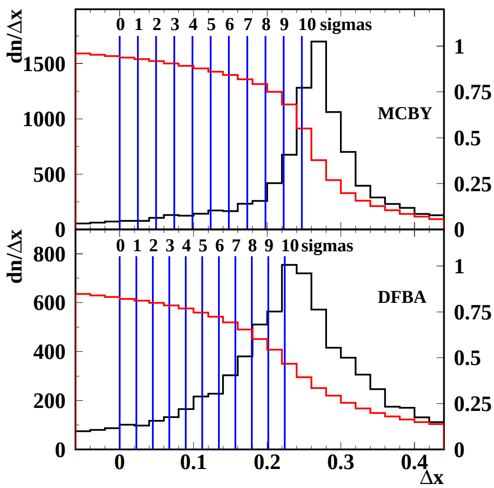

Figure 3: Projection along the x axis of the distribution of protons that are going to interact with some element along the line within cell C13.R6, at the exit of the MCBY.5R6 (top) and of the DFBAL.5R6 (bottom). The normalized cumulative, from outside to inside, is shown in red. The corresponding number of sigmas from the ideal trajectory is shown by means of blue lines.

SYSTEMATIC UNCERTAINTIES

The evaluation of the systematic uncertainty is extremely delicate, many sources are contributing and only a rough estimation can be provided. We have considered a few main sources. The physics model present in `FLUKA`, for interaction at 4.5 TeV, is expected to contribute to the uncertainty with a factor $\sim$ 2 for punctual quantities. The roughness of the collimators jaws becomes to be important for particles impinging at a very small angle; this contribution can be expected to be of about a factor 1.5. Last, the uncertainty due to the very large extension of the geometry simulated, together with the uncertainties due to imperfections such as collimators tilting, elements displacements and field accuracy, that we have estimated to be a factor $\sim$ 3 or higher. Then, the global uncertainty of the results is dominated by systematic effects and is expected to be within a factor 5 to 10.

CONCLUSIONS

In the event of an asynchronous beam dump an extremely large amount of energy $\mathcal{O}$(J cm^{-3}), would be deposited in the coils of the of the MQY.4R6, MQY.5R6, and MB.A8R6. Some tenths of Joules per cubic centimeter would be released in the coils of the MB.B8R6 and of the MQML.8R6. Therefore, quenches of the magnets in the matching section and at the beginning of the DS can be expected in at least five magnets. Other dipoles and quadrupoles have an expected maximum peak of energy deposition of the order of the milliJoule per cubic centimeter and can also suffer of quenches. For the magnets located in cells C11.R6 and C12.R6, the maximum peak of energy deposition has a drop and the minimum is located in the MQ.11R6 with 0.01 mJ cm^{-3}. Anyway, taking into account the systematic uncertainty of our estimates magnet quenches can happen all along the DS. The maximum peaks of energy deposition in the interconnections between the magnets during an asynchronous beam dump, have been estimated of the order of the tenth of milliJoule per cubic centimeter but for the interconnects in cell C8.R6, where the peaks will be about a factor ten higher.

We have also studied the beam profile in order to evaluate possible mitigation hypothesis to protect the line elements in the DS. A tertiary collimator inserted in cell C5.R6 between the MCBY.5R6 and the DFBAL.5R6, could shield about 25% of the all the protons entering the DS. This tertiary collimator could also be effective in stopping protons that are not going to be lost within cell C13.R6 but continue circulating even if diverted by the ideal trajectory. Additional mitigation measures are under investigation.

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