EVALUATION OF THE COMBINED BETATRON AND MOMENTUM CLEANING IN POINT 3 IN TERMS OF CLEANING EFFICIENCY AND ENERGY DEPOSITION FOR THE LHC COLLIMATION UPGRADE

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Abstract

The Phase I LHC Collimation System Upgrade could include moving part of the Betatron Cleaning from LHC Point 7 to Point 3 to improve both operation flexibility and intensity reach. In addition, the partial relocation of beam losses from the current Betatron cleaning region at Point 7 will mitigate the risks of Single Event Upsets to equipment installed in adjacent and partly not adequate shielded areas. A combined Betatron and Momentum Cleaning scenario at Point 3 implies the installation of new collimators and a new collimator aperture layout. This paper shows the whole LHC Collimator Efficiency variation with the new layout proposed at different beam energies. As part of the evaluation, energy deposition distribution in the IR3 region gives indications about the effect of this new implementation not only on the collimators themselves but also on the other beam line elements.

INTRODUCTION

Pursuing the goal of reaching the beam energy of 7 TeV and luminosity of 10^{34} $cm^{-2}s^{-1}$ makes the operation and layout of the Large Hadron Collider (LHC) at CERN extremely complex. In order to reach the nominal beam intensity, combined Momentum and Betatron Cleaning was proposed as an alternative solution to the present Collimation System layout to the Single Event Upsets (SEU) problems in Point 7. This scenario could imply the installation of 10 additional collimators in the Straight Section at Point 3 (SS3) as well as a new collimator aperture layout in the whole machine. One of the main consequences of this SS3 upgrade will be the increase of the radiation induced by the direct proton losses in collimators at Point 3. In this paper we evaluate the need of installing additional passive absorbers upstream the SS3 resistive magnets close to the primary collimators for both 3.5TeV (actual operation energy) and 7TeV nominal beam energies.

NEW LAYOUT OF POINT 3

The 5 possible additional collimators for each beam line in Point 3 would be installed in place of the Phase II collimators, which are already equipped in the present LHC layout [1]. One primary (TCP type) and 4 secondaries (TCSG type) collimators with carbon jaws could be added to perform cleaning in the vertical plane in addition to the already installed horizontally oriented TCP and TCSGs, making the collimation at Point 3 suitable for both Momentum and Betatron cleaning. Table 1 shows the apertures for collimator families in all LHC ring used in these studies. They refer to a total relocation of Betatron cleaning at Point 3. Since most of the particle losses take place in the first two primary collimators, 2 scenarios have been studied separately for each beam energy (i.e. in total 4 different scenarios): all losses due to a so called "sheet beam halo" distribution concentrated in the first "vertical" (i.e. 1st scenario) or "horizontal" primary collimator (i.e. 2nd scenario) at Point 3. The real distribution of losses will be a mix of the above two halo limit cases. A fractional energy spread of 1.129×10^{-4} was taken into account for all the scenarios studied.

Table 1: LHC collimator setting used for both 3.5 TeV and 7 TeV beam energy studies for both the beam lines

LHC sector	Collimator type	Half gap (beam sigma)
IR3 (Momentum and Betatron cleaning)	TCP	5.7
	TCSG	6.7
	TCLA	10
IR7	TCP	Totally opened
	TCSG	Totally opened
	TCLA	Totally opened
IR6 (dump)	TCDQ	8
	TCSG	7.5
IR1, 2, 5, 8 (experimental insertion regions)	TCT (1, 2, 5, 8)	8.3
	TCL (1, 5)	10

RESULTS

Loss maps along the whole LHC ring have been produced via the SixTrack tracking code [2] under the hypothesis of perfect LHC machine (imperfections amongst which the most relevant are the LHC misalignments were not considered in these preliminary studies). Collimation Inefficiency results in vertical and horizontal planes for both 3.5TeV and 7TeV scenarios are shown in Figure 1, 2, 3, and 4, where the dotted blue lines correspond to the beam dump threshold provided by the Beam Loss Monitors (BLM) in the LHC cold sections for

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the different operation energies respectively. Results show that the combined cleaning at Point 3 is more than a factor 5 worst than with Betatron Cleaning at Point 7 in terms of cleaning efficiency for the nominal 7TeV scenario [3]. For both the operation energies considered the vertical beam halo results are worst if compared to the horizontal ones, because of the higher contribution into the Dispersion Suppressor region in Point 3 (DS3) from the single diffracting scattering and the higher leakage close to the experiments (see also [4]). The loss maps calculated refer to the LHC Beam 1.

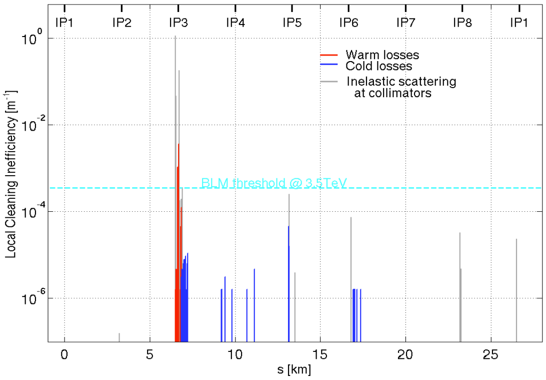

Figure 1: Collimation Inefficiency results for the horizontal plane scenario at 3.5TeV beam energy.

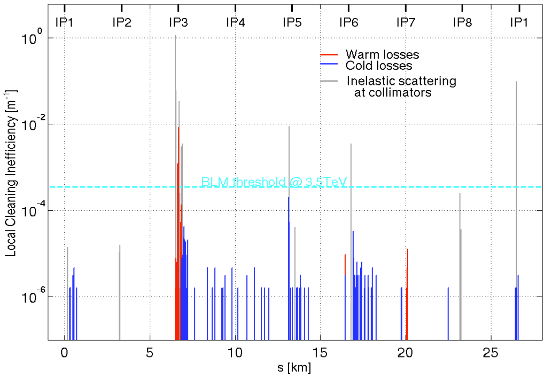

Figure 2: Collimation Inefficiency results for the vertical plane scenario at 3.5TeV beam energy.

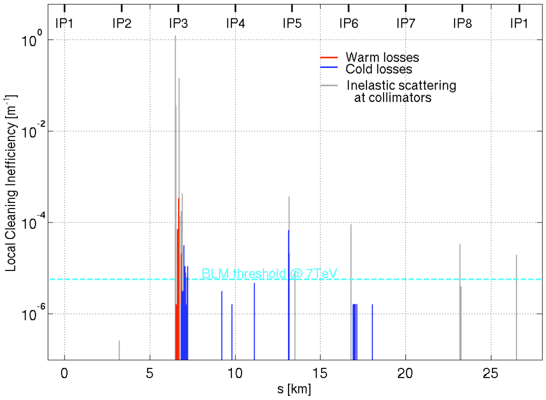

Figure 3: Collimation Inefficiency results for the horizontal plane scenario at 7TeV beam energy.

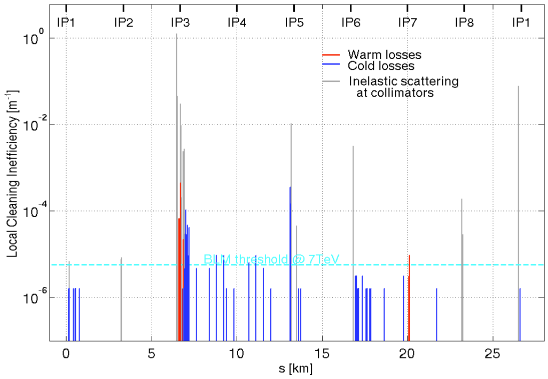

Figure 4: Collimation Inefficiency results for the vertical plane scenario at 7.0TeV beam energy. Note that in this case as well as for the horizontal plane scenario in Figure 3, the beam losses in the cold magnets reach the BLM thresholds, however statistics is low and error large in the cold section regions.

The effects of the direct losses on the warm magnets are negligible if compared to those of the particle showers developed by the collimators. Thus, only the inelastic scattering interactions at the collimators resulting from the SixTrack loss maps have been used as input data to perform a full particle shower study, using the Fluka MonteCarlo code [5,6]. The complex layout of the collimation region at Point 3 has required to model in Fluka a 500m long section of the LHC tunnel with different beam line elements (i.e. primary and secondary collimators, warm dipoles and quadrupoles, passive absorbers, etc.).

In addition to the already present 1m long active length passive absorber (TCAPA type) downstream the primary collimators and upstream the first warm dipole separation magnet (MBW.C6L3) in SS3, 2 passive absorber have been considered, in order to maximize the protection of the warm quadrupole magnets (MQW). The first one has been proposed with an active length of 0.6m (TCAPC type at ~154m from IP3), while 0.2m is the proposed active length of the second one (TCAPCB type at ~140m from IP3). The choice of their active length and their location was driven by the space availability in the LHC tunnel. In particular, the additional TCPAC has been proposed to be downstream the MBW magnets and upstream the first series of MQW (i.e. upstream MQWA.E5L3), matching the ellipsoid aperture of the first MQW magnet beam pipe, while the additional TCPAB has been proposed to be placed downstream the first two secondary collimators and upstream the second MQW series (i.e. upstream MQWA.C5L3).

Since the layout of the LHC Beam 2 line is mirror symmetric to the Beam 1 with respect to the Point 3 centre, symmetric locations for the Beam 2 additional passive absorbers are also identified. Results for Beam 1 are also representative for Beam 2.

One of the 4 scenarios studied separately results in higher power deposited in the SS3. It refers to the vertical halo distribution at 7TeV. Figure 5 shows the energy

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deposition distribution results in the first 14 beam line elements downstream the 2 primary collimators with or without the 2 additional passive absorbers. The effectiveness of the proposed passive absorbers is limited (about 10% in average) in order to reduce the total power deposition in each downstream element if compared to the case without them.

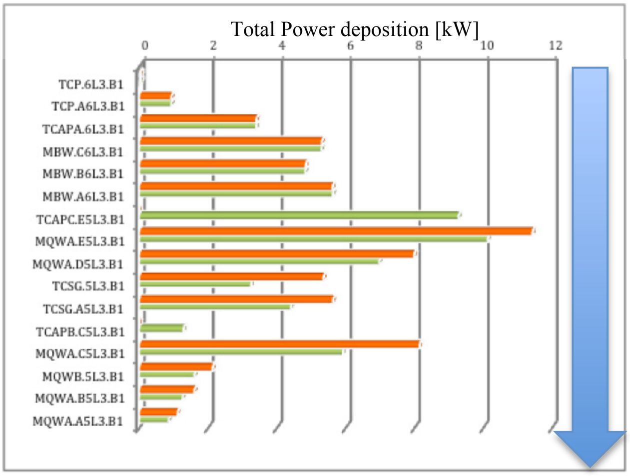

Figure 5: Power deposition distribution per elements along SS3, considering 1h beam lifetime at 7TeV and nominal intensity (i.e. 2808 bunches with 1.15E11 protons each). Results with passive absorber in are in green bars while in the orange bars are without them. The blue arrow shows the Beam 1 direction.

However, if looking to the annual dose peaks in the warm magnet coils, the introduction of these passive absorbers reduces by a factor of 2 the dose peaks in the resins of the closest and most exposed quadrupoles of the SS3 line. This factor of 2 is a common output for all the 4 scenarios studied.

Table 2: Peak dose in the first 2 MQW magnet coils downstream the additional passive absorbers. All the peaks are reached inside each magnet, close to the beam axis. Statistical errors are below 5% for peak values.

IR3 MQW magnets	**Peak Dose with additional passive absorbers [MGy/years]**	**Peak Dose without additional passive absorbers [MGy/years]**
7TeV Beam Energy		
Downstream the TCAPC (0.6 m) proposed location		
MQWA.E5L3	7.5	11.2
MQWA.D5L3	4.5	5.5
Downstream the TCAPB (0.2 m) proposed location		
MQWA.C5L3	4.3	7.1
MQWB.5L3	1.5	3.2
3.5TeV Beam Energy		
Downstream the TCAPC (0.6 m) proposed location		
MQWA.E5L3	1.8	4.1
MQWA.D5L3	2	2.4
Downstream the TCAPB (0.2 m) proposed location		
MQWA.C5L3	1.5	2.3
MQWB.5L3	0.9	1.3

Table 2 shows the peak dose values resulting for different magnets in the two closest downstream locations with respect to the places proposed for the passive absorbers. Results are normalized to 1.465E16 proton losses per year [7]. They refer to vertical halo simulations at 3.5TeV and 7TeV beam energies for the most loaded Beam 1 elements, being the vertical case more constraining than the horizontal one.

CONCLUSIONS

Moving part of all the Betatron cleaning in Point 3 has as consequence not only a reduction of the LHC Cleaning Efficiency but also additional constrains such an increment of the annual dose to resins of the resistive SS3 magnets close to the primary or secondary collimators. In particular, the annual dose limit for quadrupoles (i.e. MQW type) is more restrictive if compared to the dipole ones, i.e. ~10MGy/year against ~50MGy/years [8]. In order to protect the MQW magnets, specific locations for additional passive absorbers have been investigated.

In case of moving all the Betatron cleaning in Point 3, a factor 2 in reduction of the peak dose was calculated as function of the location of 2 additional passive absorbers in the present LHC layout. It has to be pointed out that a factor 2 means to double the lifetime of the most exposed MQW magnets. This factor could also be improved by optimizing the length of the additional passive absorbers in the present LHC layout. Moving the most loaded resistive magnets to accommodate a longer passive absorbers could also be considered in future studies as an additional measure to reduce their radiation load.

The preliminary results on Beam 1 have also underlined the critical position of the MQWA.E4R3 installed about 230m downstream the primary collimators but between the additional secondaries required to perform the combined cleaning in Point 3. The power deposition on this element is of the same order of the most loaded SS3 MQW. Additional passive absorber should be also required for this location.

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