BEAM CLEANING IN EXPERIMENTAL IRS IN HL-LHC FOR THE INCOMING BEAM[*]

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Abstract

The HL-LHC will store 675 MJ of energy per beam, about 300 MJ more than the nominal LHC. Due to the increase in stored energy and a different interaction region (IR) optics layout, the collimation system for the incoming beam must be revisited in order to avoid dangerous losses that could cause quenches or machine damage. This paper studies the effectiveness of the current LHC collimation system in intercepting cleaning losses close to the experiments in the HL-LHC. The study reveals that additional tertiary collimators would be beneficial in order to protect not only the final focusing triplets but also the two quadrupoles further upstream.

INTRODUCTION AND MOTIVATION

The optics of the HL-LHC [1] is based on the Achromatic Telescope Squeezing (ATS) scheme [2]. This scheme allows to push the LHC nominal β^* to about 15 cm at IP1 and IP5. The reduction of β^* implies an increase of the β-function at the Final Triplet (FT) region, as well as in the matching section. In addition, the bunch charge and consequently the stored energy in the beam is aimed to increase by almost a factor 2. Therefore, it is foreseen to replace the FT and the quadrupoles Q4 and Q5 by new magnets with larger apertures. Nevertheless, the available normalized aperture is tight, which might expose these magnets to beam losses that could potentially cause quenches. Therefore, the collimation system must be revisited in order to ensure acceptable loss levels.

MACHINE CONDITIONS

The betatron cleaning insertion allows to limit the transverse extension of the beam halo by "cleaning" particles with large betatron amplitudes. The momentum cleaning system catches the longitudinal losses induced by off-momentum particles. The whole system provides a multi-stage cleaning [3, 4] with primary collimators closest to the beam, followed by secondary collimators. Special attention must be put in the Interaction Regions (IRs) in order to avoid high levels of beam background deposited in the detector and possible quenches and damages in the FT due to the aperture bottleneck. For that reason, additional tertiary collimators (TCTs) are introduced just upstream of the FT.

The collimation performance is assessed in simulations using SixTrack [5, 6] and quantified in terms of the local cleaning inefficiency η, defined as the ratio of the local losses N_{loc} over a distance Δs to the total losses on collimators N_{tot} [7],

$$\eta = \frac{N_{\text{loc}}}{N_{\text{tot}}\Delta s} \tag{1}$$

Table 1: Nominal TCT Openings at Different IRs.

	IR1	IR2	IR5	IR8
$n_{\text{TCT}}[\sigma]$	8.3	30	8.3	30

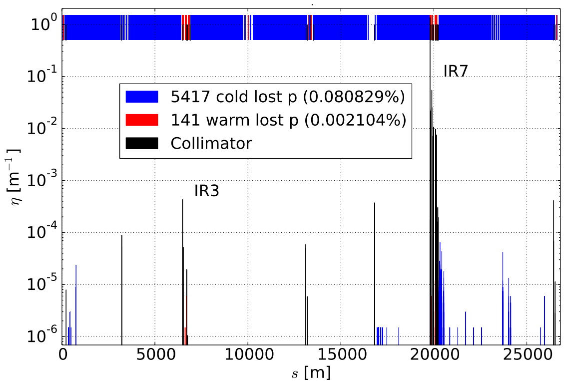

Figure 1: Example of a loss map representing the losses along the ring for Beam1 considering nominal apertures and Tertiary collimators in their nominal setting (8.3σ). Black lines represent losses in collimators, blue lines losses in cold regions and red lines are losses in warm regions.

In Fig. 1 the loss map for the HL-LHC version 1 optics and $\beta^* = 15$ cm for beam 1 and horizontal halo (initial losses on horizontal TCP), as simulated with SixTrack, is shown under nominal collimator configuration. The betatron (IR7) and momentum cleaning (IR3) insertions are clearly identified with large black spikes representing losses in collimators. Blue and red spikes represent losses in cold and warm regions respectively.

QUADRUPOLE APERTURE SCAN

The FT aperture represents a key parameter in the upgrade of the LHC optics towards the HL-LHC. In order to evaluate the beam losses, we have performed simulations using SixTrack where magnet aperture has been reduced as an effective approach to take into account several sources of errors. Pessimistic conditions of the machine such as alignment, orbit and optics errors can be seen as an effective aperture reduction.

The magnet aperture in IR1 and IR5 have been scanned individually for different magnets of the FT as well as Q4

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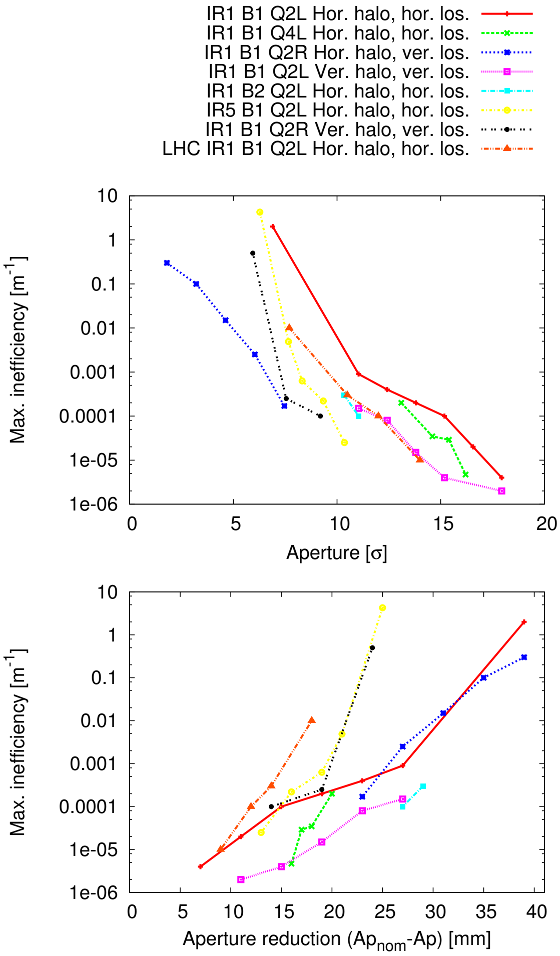

Figure 2: Maximum inefficiency η for different magnets and different halos and beams for aperture in beam size units (top) and as a function of the aperture reduction in millimeters (bottom) and TCT fully open.

and Q5. We have studied both B1 and B2 and horizontal and vertical halo

A point worth to mention is that, while the aperture in millimeters is a well defined quantity, when the aperture is expressed in units of the local beam size, a source of ambiguity is introduced since the beam size is not constant all along the magnet. For that reason and because we are working with apertures close to the TCT gaps, some particles might hit the magnetic aperture although it is in principle shadowed by the TCT protection. We estimate that the uncertainty in the aperture is about $\pm 0.5\sigma$. Nevertheless, we took special care in some cases where some important discrepancies were found and the minimum aperture in that case was taken.

In order to assess the need for local IR protection in HL-LHC, we simulate first the case where the TCTs have been opened completely. In Fig. 2 the maximum η on the magnet considered as a function of its aperture is represented. On the upper plot, aperture is expressed in units of the beam size σ and on the lower plot as an aperture reduction in millimeters. The triplet magnets present similar losses for both halos and significant losses appear for apertures already at 14σ apertures. We observe a margin of about 5 mm on which no losses are seen. This is the safety margin in which the magnet is protected even under pessimistic condition.

PROTECTION OFFERED BY TERTIARY COLLIMATORS

When reduced magnet apertures (about 8.7σ) are considered, the current protection of the FT using TCT in cell 4 (TCT4) is not enough. As seen in Fig. 3 (top), some particles hit Q4 when just TCT in cell 4 is included. A new set of collimators upstream of Q5 (TCT5) is required in order to reduce the losses in the Final Triplet region. In Fig. 3 (bottom) the loss maps in the Q5 and Q4 region with the installation of the additional protection of TCT5 and TCT4 at 8.3σ is shown. In that case, all the particles previously lost in Q4 are fully absorbed by TCT5.

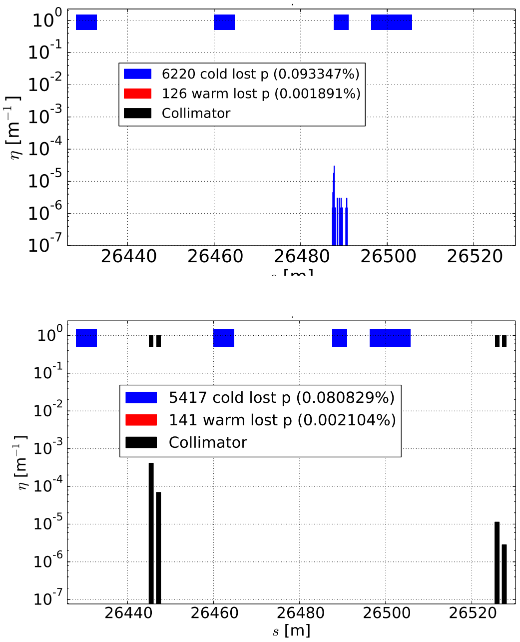

Figure 3: Loss maps in the Q5 and Q4 upstream IP5 with reduced apertures (8.7σ) and without (top) and with (bottom) the installation of the TCT5 and TCT4 at 8.3σ. The losses in Q4 are fully absorbed when TCT5 is included.

TERTIARY COLLIMATOR GAP SCAN

The collimator gap must be chosen as a compromise between a good cleaning efficiency and protection performance and the own collimator protection. Too many hits in the collimator might deteriorate the collimator material and thus, the collimator performance is reduced. In Fig. 4 the inefficiency in TCT is plotted as a function of the collimator gap for nominal magnetic apertures. As expected, the larger the gap, the lower the inefficiency. But very high inefficiencies may lead to a rapid degradation of the collimator material. Therefore, the number of impacts in the collimator must be kept below a certain level determined by the material lifetime.

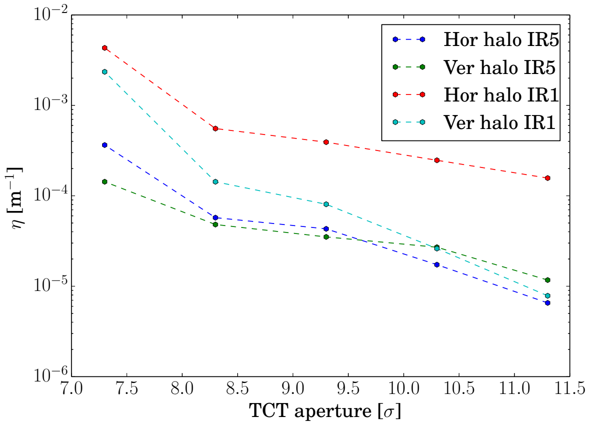

Figure 4: TCT inefficiency in IR1 and IR5 as a function of the collimator gap for horizontal and vertical halo.

Scan with Reduced Apertures and TCT5

In order to provide a final validation of the effectiveness of the proposed collimation layout, including TCTs in both cell 4 and cell 5, a SixTrack study was performed with all apertures (FTs, Q4, and Q5 in both IR1 and IR5) reduced simultaneously to 8.7 sigma, while different TCT openings are scanned. The aperture reduction aims to reproduce very pessimistic machine conditions. In Fig. 5 proton loss rate in protons per second in the Final Triplet region as a function of the TCT gap is shown. Below a TCT setting of 8.3σ no losses appear in the triplet. When the collimator gap is set above the magnet aperture the loss rate increases rapidly. The maximum loss rate that the superconducting magnets can tolerate sets the minimal collimator gap for the TCTs. As a comparison, [8] gives a quench limit of $7.8 \cdot 10^6$ p/m/s. Although it is believed today that this is pessimistic, it shows possible orders of magnitudes where quenches risk to occur.

CONCLUSIONS

The performance of the present collimation system in the HL-LHC has been studied for the incoming beam in the Interaction Regions 1 and 5. We have applied an effective aperture reduction, to represent the combination of several imperfection sources, and we have analyzed the beam losses from betatron cleaning, using SixTrack, in the Final Triplet as well as in Q4 and Q5 apertures.

The study concludes that, in order to perform an efficient cleaning and to protect the superconducting quadrupoles in IR1 and IR5, the placement of a new pair of horizontal and vertical tertiary collimators in cell 5 is highly beneficial. Our studies show that the new HL-LHC baseline, with this new collimator installed, provides sufficient protection from betatron halo losses. The study has been done using nominal collimator settings and results with retracted settings are ongoing but no significant discrepancy with the shown results is expected. Other studies concerning beam induced background in the detector and protection against asynchronous beam dumps also show conclusions in the same direction [9, 10].

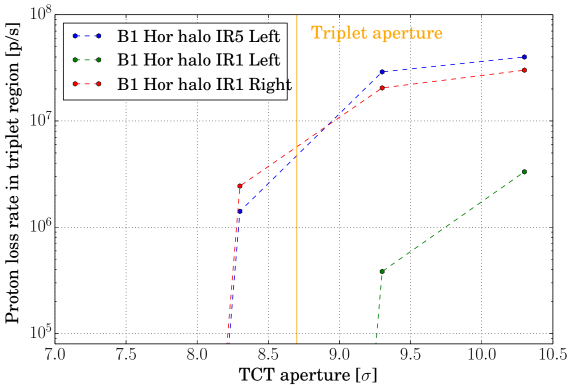

Figure 5: The integrated cleaning losses in the triplet as a function of the TCT setting, as simulated with SixTrack for HL-LHC with nominal collimator settings. The triplet apertures were simultaneously reduced to 8.7σ.

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