PREDICTED PERFORMANCE OF COMBINED CLEANING WITH DS-COLLIMATORS IN THE LHC

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Abstract

The LHC has two dedicated cleaning insertions: IR3 for momentum cleaning and IR7 for betatron cleaning. During the first months of beam experience the presently installed Phase-I system performed as predicted earlier in detailed studies with tracking simulations. As the current system is not sufficient to allow LHC operation with nominal or ultimate intensity at 7 TeV/c, simulations with an upgraded system are ongoing to overcome these limitations. In this contribution a collimation scheme with combined momentum and betatron cleaning in the interaction region 3 (IR3) with additional collimators in the IR3 dispersion suppressor is presented. The predicted improvements compared to the Phase-I system and the limitations of this scheme are discussed.

INTRODUCTION

At nominal momentum ($7\,\mathrm{TeV/c}$) and intensity ($\sim 3 \cdot 10^{14}$ protons) the LHC will have a stored energy of 362 MJ per beam. The uncontrolled loss of only a small fraction of beam in the superconductive magnets of the LHC can cause the loss of their superconducting state (quench limit at 450 GeV/c: $R_q = 7 \cdot 10^8\,\mathrm{ps^{-1}m^{-1}}$; at 7 TeV/c: $R_q = 7.6 \cdot 10^6\,\mathrm{ps^{-1}m^{-1}}$) [1, 2]. Therefore, a powerfull collimation system is needed to intercept these unavoidable beam losses. In addition the collimators shall provide a passive machine protection [3, 4, 5]. The measure for the performance of a collimation system is the local cleaning inefficiency

$$\eta_c = \frac{N_{local}}{N_{total} \cdot \Delta s}, \qquad (1)$$

with N_{local} the number of protons lost within an aperture bin Δs and N_{total} the total number of lost particles.

To achieve these goals a phased approach was taken. The present Phase-I system consists of 44 collimators per beam, which are mainly installed in two dedicated cleaning insertions. IR3 collimators are used for the cleaning of off-momentum particles and IR7 to intercept particles with too large betatron amplitudes. A sketch of the layout of the Phase-I collimation system is shown in Figure 1. The calculated local cleaning inefficiency of this system with imperfections ($\eta_c = 5 \times 10^{-4}\,\mathrm{m^{-1}}$) is expected to limit the maximal possible beam intensity stored in the LHC to 4% of the nominal [6, 7].

In addition to the installed collimators empty slots in the cleaning insertions for future Phase-II collimators were prepared. The main intensity limit due to cleaning was

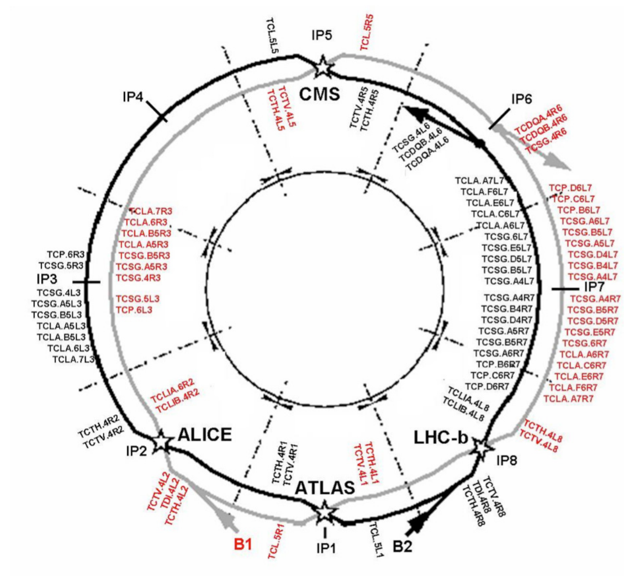

Figure 1: Sketch of the layout of the present phase-I collimation system. Beam 1 (beam 2) collimators are shown in red (black). [7].

identified to losses in the cold dispersion suppressor (DS) region at the end of the cleaning insertions. Simulations with an improved system using collimators in the prepared Phase-II slots and two collimators in the dispersion suppressor of the betatron cleaning insertion (IR7) in addition to Phase-I showed that a gain in cleaning efficiency of a factor 30 could be achieved [8].

Another future limitation for the LHC intensity could be collimation related radiation to electronics. Therefore a combined betatron and momentum cleaning in IR3 was studied. Compared to the present Phase-I system this would reduce the performance by a factor of two [9].

These two results lead to the idea to combine the two proposals and study a system with combined betatron and momentum cleaning in IR3 with additional collimators in the superconductive dispersion suppressor of IR3 without using the collimators in IR7. The cleaning performance of such a system is discussed and presented below. This system was proposed and approved for installation in the long shutdown of the LHC in 2012.

MULTISTAGE CLEANING

Figure 2 shows a simplified sketch of the gap opening arrangement of the different classes of collimators normalized by beam size for the multistage cleaning in the

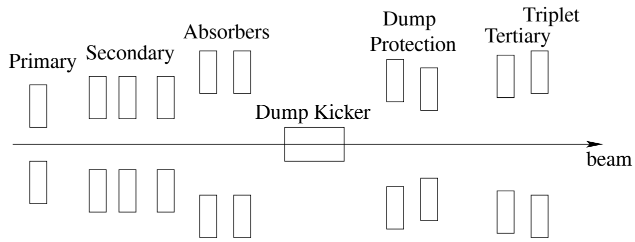

Figure 2: Simplified sketch of the gap opening arrangement of collimator classes normalized by beam size.

Figure 3: Simplified sketch of the beam 1 collimator arrangement for combined momentum and betatron cleaning in IR3. Only primary and secondary collimators are shown here.

LHC. The primary collimators (TCPs) are the ones closest to the beam and cut the primary beam halo. The secondaries (TCSGs) intercept the secondary halo, i.e. particles scattered by the primaries, and absorbers (TCLAs) catch showers produced by the other collimators at the end of each cleaning insertion. The dump protection collimators (TCSG-IR6, TCDQs) protect the superconductive arcs against mis-kicked beams. The tertiary collimators (TCTs) are arranged around the experimental insertions, to clean the tertiary halo and to protect the triplets against mis-kicked beams. The debris during collisions is caught by so-called TCLPs [6, 10].

SIMULATION LAYOUT FOR COMBINED CLEANING WITH DS COLLIMATORS

As basis for the simulated layout of the combined cleaning collimation system in IR3 the currently installed Phase-I collimation system was used and slightly modified. Furthermore, the installation of additional collimators in slots foreseen for Phase-II was assumed. As for Phase-I the jaw material used for primary and secondary collimators is carbon. The tungsten absorbers (TCLAs) were kept as in Phase-I. A list of the IR3 collimators for beam 1 is given in Table 1 and for beam 2 in Table 2.

In addition two tungsten collimators per beam were added into the cold dispersion suppressor region of IR3 in front of the quadrupoles called Q8 and Q10. Sketches of the layout of the IR3 collimation region and the positions of the DS collimators both for beam 1 are shown in Figure 3 and Figure 4.

SIMULATION PARAMETERS

To determine the efficiency of the proposed layout, simulations were performed with SixTrack [11]. SixTrack combines optical tracking of single particles in the accelera-

Table 1: List of beam 1 collimators in IR3 for combined momentum and betatron cleaning including collimators in the dispersion suppressor (TCRYO).

Collimator	angle, material	s position [m]
TCP.6L3.B1	hor, carbon	6487.67
TCP.A6L3.B1	ver, carbon	6489.27
TCSG.5L3.B1	hor, carbon	6521.99
TCSG.A5L3.B1	ver, carbon	6523.04
TCSG.4R3.B1	hor, carbon	6707.58
TCSG.B4R3.B1	ver, carbon	6709.53
TCSG.A5R3.B1	170 deg, carbon	6718.92
TCSG.C5R3.B1	ver, carbon	6720.92
TCSG.B5R3.B1	113 deg, carbon	6724.74
TCSG.D5R3.B1	ver, carbon	6726.74
TCLA.A5R3.B1	ver, tungsten	6718.92
TCLA.B5R3.B1	hor, tungsten	6757.22
TCLA.6R3.B1	hor, tungsten	6843.77
TCLA.7R3.B1	hor, tungsten	6915.18
TCRYO.AR3.B1	hor, tungsten	6964.94
TCRYO.BR3.B1	hor, tungsten	7044.47

Table 2: List of beam 2 collimators in IR3 for combined momentum and betatron cleaning including collimators in the dispersion suppressor (TCRYO).

Collimator	angle, material	s position [m]
TCP.6R3.B2	hor, carbon	19817.11
TCP.A6R3.B2	ver, carbon	19818.71
TCSG.5R3.B2	hor,carbon	19850.48
TCSG.A5R3.B2	ver, carbon	19852.48
TCSG.4L3.B2	hor, carbon	20037.02
TCSG.B4L3.B2	ver, carbon	20039.02
TCSG.A5L3.B2	170 deg, carbon	20048.36
TCSG.C5L3.B2	ver, carbon	20050.36
TCSG.B5L3.B2	11 deg, carbon	20054.18
TCSG.D5L3.B2	ver, carbon	20056.18
TCLA.A5L3.B2	ver, tungsten	20084.66
TCLA.B5L3.B2	hor, tungsten	20086.66
TCLA.6L3.B2	hor, tungsten	20173.21
TCLA.7L3.B2	hor, tungsten	20244.62
TCRYO.AL3.B2	hor, tungsten	20294.38
TCRYO.BL3.B2	hor, tungsten	20373.92

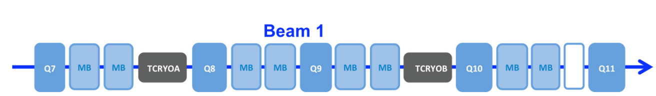

Figure 4: Simplified sketch of positions of the additional tungsten collimators in the IR3 dispersion suppressor. Superconductive magnets are shown in blue. *Q* indicates a quadrupole magnet and *MB* a bending magnet.

Table 3: Half gap openings of different collimator families as used for the IR3 combined cleaning simulations.

Collimator family	half gap opening [σ]
TCP IR7	open
TCSG IR7	open
TCLA IR7	open
TCDQ	8
TCS IR6	7.5
TCP IR3	6
TCSG IR3	7
TCLA IR3	10
TCRYO IR3	15
TCTH IR1/IR5	8.3
TCTV IR1/IR5	8.3
TCL IR1/IR5	10
TCTH IR2/IR8	8.3
TCTV IR2/IR8	8.3

tor lattice with proton-matter interactions in the collimator jaws. The simulation output shows the particle losses on the aperture around the ring as well as particles absorbed in collimators. The optic inputs for these simulations were created with the help of MAD-X [12] using the current LHC optics version 6.503. The simulations were performed for the nominal particle momentum of $7\,\mathrm{TeV/c}$, with nominal crossing angles on, separation bumps off and the experimental solenoids turned on in all IRs. The collimator half gap openings in units of the beam size are given in Table 3. A sheet beam distribution with a Gaussian transverse distribution and an impact parameter of $7\,\mu\mathrm{m}$ was used. In total 19 million protons were tracked. The simulations were performed without imperfections and separately for beam 1 and beam 2.

SIMULATION RESULTS

The simulation results for beam 1 are shown in Figures 5 to 8. For a horizontal beam halo the cleaning inefficiency is lower than $\eta_c = (3.5 \pm 1.4) \cdot 10^{-6}\,\mathrm{m}^{-1}$. In the vertical plane the cleaning inefficiency is below $\eta_c = (6 \pm 1.8) \cdot 10^{-6}\,\mathrm{m}^{-1}$. As indicated by the red (purple) line, the leakage into cold magnets is in both cases below the quench limit at $7\,\mathrm{TeV/c}$ with nominal (ultimate) beam intensity for a beam life time of 0.22h. As these simulations were performed without imperfections, the real system will not reach this performance.

In Figures 6 and 8 it can be clearly seen that the additional collimators in the dispersion suppressor of IR3 (TCRYO) catch losses which otherwise would end up in the quadrupoles of the dispersion suppressor.

Figure 7 shows a high leakage of particles in the vertical plane from the cleaning insertion in IR3 into the tertiary collimators around the experimental IRs. In IR1 this means that the losses in the TCTs are only one order of magnitude smaller than the losses in the primary collimator in IR3.

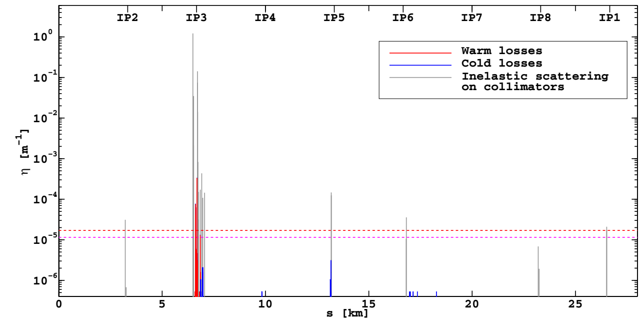

Figure 5: Cleaning inefficiency in beam 1 for a horizontal beam halo. In total 19 million particles were simulated. The red (purple) line marks the quench limit at $7\,\mathrm{TeV/c}$ for nominal (ultimate) intensity and a beam life time of 0.22h.

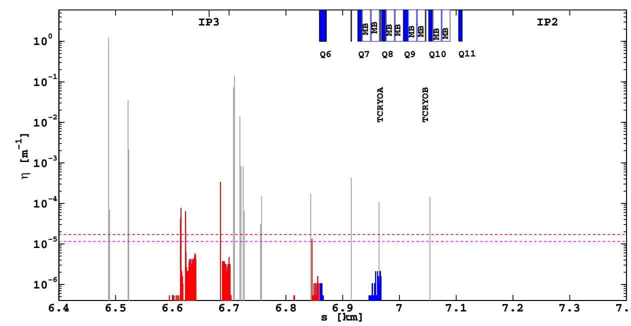

Figure 6: Cleaning inefficiency in beam 1 for a horizontal beam halo with zoom into IR3. In total 19 million particles were simulated. The red (purple) line marks the quench limit at $7\,\mathrm{TeV/c}$ for nominal (ultimate) intensity and a beam life time of 0.22h.

This behaviour could limit the performance of the combined cleaning scheme as it would increase the background in the experimental IRs. In addition the limit of the maximal allowed power deposition could be exceeded for some TCTs. Currently studies are ongoing to determine how a subset of the Phase-I collimators in IR7 (the current betatron cleaning insertion) can be used to intercept the tertiary halo and reduce the leakage into the TCTs.

The simulations for beam 2 show comparable results.

CONCLUSION

The simulated combined betatron and momentum cleaning in IR3 with two additional collimators per beam in the dispersion suppressor downstream of IR3 shows a good cleaning performance. Without imperfections the system reaches a cleaning inefficiency below the quench limit at $7\,\mathrm{TeV/c}$ for ultimate beam intensity.

In this scheme there are 11 collimators less needed per beam than for the currently operating Phase-I collimation system (44 collimators per beam). This translates into a 25% shorter setup time for the system.

As the collimators in IR7 will not be removed from the tunnel, they can be used as a backup solution for an addi-

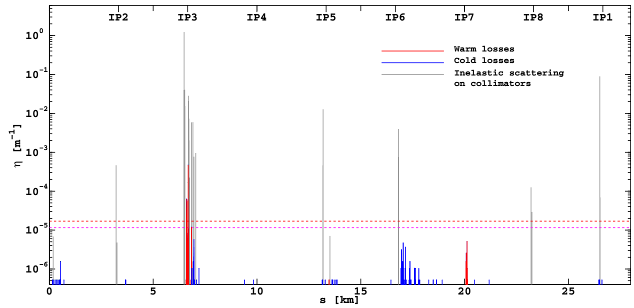

Figure 7: Cleaning inefficiency in beam 1 for a vertical beam halo. In total 19 million particles were simulated. The red (purple) line marks the quench limit at $7\,\mathrm{TeV/c}$ for nominal (ultimate) intensity and a beam life time of 0.22h.

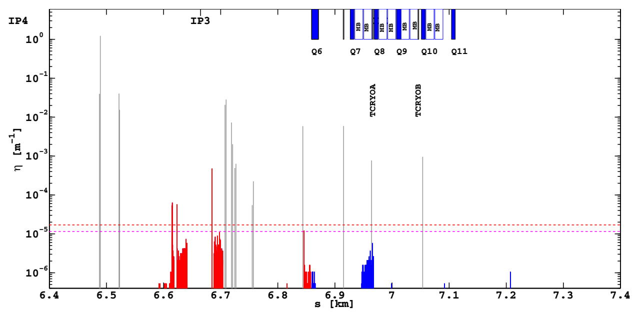

Figure 8: Cleaning inefficiency in beam 1 for a vertical beam halo with zoom into IR3. In total 19 million particles were simulated. The red (purple) line marks the quench limit at $7\,\mathrm{TeV/c}$ for nominal (ultimate) intensity and a beam life time of 0.22h.

tional increase in intensity or as spares in case of radiation damage to the IR3 collimators. The whole system is concentrated in IR3, therefore the collimation related radiation to electronics would be reduced by a factor of 12-100 compared to the present Phase-I system [9].

The presented simulations show for the vertical beam halo a high leakage to the tertiary collimators in the experimental IRs. This effect could limit the performance of the system as it would increase the background in the experimental regions. Studies are ongoing to determine a subset of the Phase-I collimators in IR7 to intercept the tertiary halo and reduce the leakage into the TCTs.

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