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BEAM INDUCED BACKGROUND SIMULATION STUDIES AT IR1 WITH NEW HIGH LUMINOSITY LHC LAYOUT*

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Abstract

In the High Luminosity LHC (HL-LHC), the collimation system will be upgraded in the high-luminosity experimental regions. Additional protection is planned for the Q4 and Q5 magnets that are located further upstream of the tertiary collimators that protect the inner triplet magnets. We evaluate the effect of this proposed collimation layout for the incoming beam 1 on machine-induced background in the experimental area of IR1 (ATLAS). The main scenario is the round optics with β^* of 15 cm, but a flat scenario is also briefly discussed.

INTRODUCTION

The High Luminosity (HL) LHC is a major upgrade project to produce in total 3000 fb^{-1} integrated luminosity for each, ATLAS and CMS, starting installation around 2023 [1]. In particular, the upgrade plans affect the experimental insertion regions (IR) IR1 and IR5, housing ATLAS and CMS respectively, to reach higher luminosities. The optics have been re-designed (ATS – achromatic telescopic squeeze – optics [2]) and require e.g. larger-aperture magnets for squeezing the optics to 15 cm in the horizontal and vertical plane at the high-luminosity interaction points (IPs) 1 and 5 in order to achieve the luminosity goal. New possible aperture bottlenecks arise due to HL-LHC layout changes, and the quadrupoles Q5 and Q4 may no longer be sufficiently protected, see also Fig. 1. To address this, the collimation system [3, 4] will be upgraded in the experimental IRs. While these upgrades are in detailed in [5], the focus of this paper is on upgrade plans for the incoming beam. The new layout forsees to place in cell 5 a vertical and horizontal tertiary collimator (TCT5s for TCTH.5 and TCTV.5). As they are further away from the exisiting horizontal and vertical collimators (TCT4s that are TCTH.4 and TCTV.4), as illustrated in Fig. 1, they could help reducing beam-induced halo background. This paper presents a first estimate of the reduction based on simulations.

BEAM HALO BACKGROUND

Beam particles in the accelerator oscillate around an ideal orbit but diffuse out the beam core due to various beam dynamics effects (e.g. particle-particle scattering within a bunch, interactions between colliding bunches, scattering with residual gas-molecules) forming the *beam halo* and unavoidable losses. The task of the collimation system is to safely remove these halo particles in two dedicated insertion regions, IR7 for betatron and IR3 for momentum cleaning [3, 4]. Tertiary collimators (TCTs) in IR1 and IR5 complement the IR7/3 collimators and are installed to protect the inner triplet magnets. Halo protons leaking from IR7/3, should mostly be stopped by the TCTs. While interacting with the collimator material, they produce particle showers that contribute to the machine-induced halo background. This background source is considered in the following.

Table 1: HL half-gap collimator settings. Only the so-called 2σ-retracted settings are used in this paper. Full and updated settings can be found in [6].

collimators	nominal settings [σ]	2σ-retracted settings [σ]
TCP3	12 (now 15)	15
TCSG3	15.6 (now 18)	18
TCP7	6	5.7
TCSG7	7	7.7
TCT IR1/5	8.3	10.5

BEAM HALO SIMULATION SETUP

The simulation is performed in two parts, analogue to [7]. First, a tracking code, SixTrack [8], is used to track halo proton distributions customised by the user through a magnetic field lattice, see also [9]. The beam halo is usually simulated in horizontal (h) and vertical (v) distributions. When a collimator is hit, a built-in, recently updated Monte-Carlo model [10] decides on the physics process. Protons continue in the lattice until they dissociate in an inelastic interaction with the collimator material or (in a post-processing step) are lost on the aperture. As a result, loss locations around the ring can be identified and protons lost on the TCTs serve in second step as an initial distribution in FLUKA [11, 12].

Two cases were simulated, TCT4s only and TCT4s + TCT5s, to quantify the effect of the TCT5s for incoming beam 1 (B1). Inelastic interactions are forced in FLUKA at locations given by SixTrack on the TCT4s and (when included) TCT5s which generate a particle flux towards the experiment. All shower particles are recorded at the machine-detector interface plane at 22.6 m from the IP.

HL-LHC SIMULATION SCENARIOS

We assume the nominal HL-LHC scenario with 2.2×10^{11} protons per bunch, 2736 bunches per beam, 25 ns bunch spacing and a beam energy of 7 TeV. For the study of colli-

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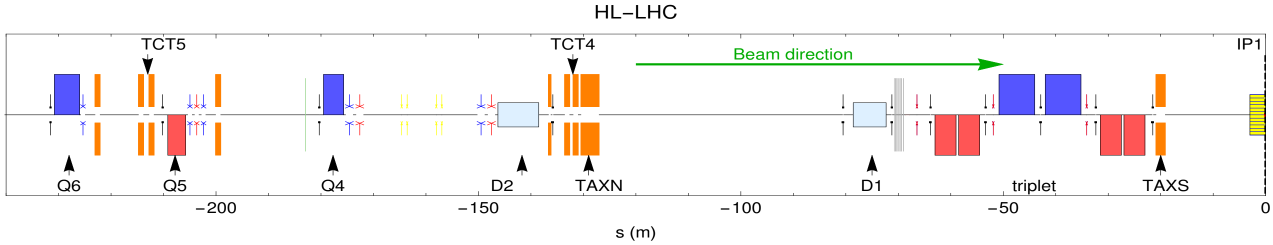

Figure 1: Planned HL-LHC layout [5] for the incoming beam in the experimental insertion region of ATLAS (IP1) with tertiary collimator pairs (TCT4s and TCT5s) highlighted above the beamline. Layout in IR5 is identical.

mator losses and halo background, so-called 2σ-retracted collimator settings w.r.t. nominal are used, which were based on the LHC Run I (2010 – 2013) experience and are more realistic, see Table 1 and [6]. Background studies with nominal collimator settings were presented in [13]. The current baseline of ATS optics for β^* of 15 cm for round beams (version HLLHCv1.0[1]) is used in the simulations. Unless otherwise indicated, the results are scaled to a beam lifetime of 12 minutes, which is the worst case scenario that the collimators are designed to withstand.

Another ATS optics scenario was also studied with the purpose of validating the new HL collimation layout. To maintain flexibility in low-β^* reach, e.g in the case of crab cavity failures in the experimental IRs, flat beam optics were developed. While in round optics, β^* is 15 cm in IP1/5 in the horizontal and vertical plane, it is for flat beams 7.5 cm in the horizontal plane and 30 cm in the vertical plane at IP1 (vice versa for IP5) [14].

SIXTRACK RESULTS

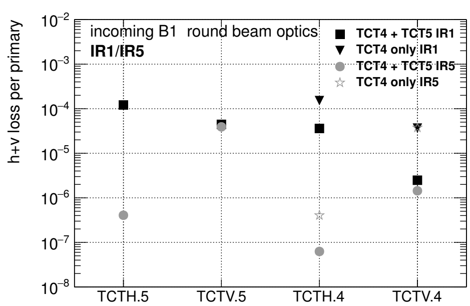

Figure 2: Summed h+v loss per simulated primary on the TCTs at IR1 and 5 for the cases TCT5s in and out.

Table 2: Losses from Fig. 2 summed over the respective TCTs and load reduction factor on TCT4s (ratio).

collimators	TCT5s *out*	TCT5s *in*	ratio *out/in*
TCT4s (IR1)	$1.9 \cdot 10^{-4}$	$3.9 \cdot 10^{-5}$	4.9
TCT5s (IR1)		$1.7 \cdot 10^{-4}$	
TCT4s (IR5)	$3.8 \cdot 10^{-5}$	$1.5 \cdot 10^{-6}$	25
TCT5s (IR5)		$4.0 \cdot 10^{-5}$	

[1] The FLUKA geometry contained layout updates of v1.1, but v1.0 collimator settings were used assuming the uncertainties from the version differences are negligable.

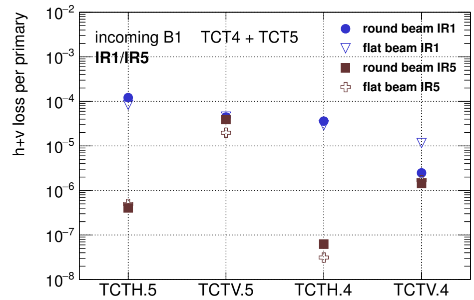

Figure 3: Comparison of losses on TCTs for round ($\beta^*_{x,y}$ is 15 cm) and flat ($\beta^*_{x/y}$ = 7.5 cm, $\beta^*_{y/x}$ = 30 cm) beam optics.

Table 3: Comparison of summed h+v losses per primary for different beam optics from Fig. 3 and total losses on both TCTs.

location	round	flat
TCT4s (IR1)	$3.9 \cdot 10^{-5}$	$4.1 \cdot 10^{-5}$
TCT5s (IR1)	$1.7 \cdot 10^{-4}$	$1.7 \cdot 10^{-4}$
sum IR1	$2.0 \cdot 10^{-4}$	$1.7 \cdot 10^{-4}$
TCT4s (IR5)	$1.5 \cdot 10^{-6}$	$1.7 \cdot 10^{-6}$
TCT5s (IR5)	$4.0 \cdot 10^{-5}$	$2.0 \cdot 10^{-5}$
sum IR5	$4.1 \cdot 10^{-5}$	$2.2 \cdot 10^{-5}$

The effect of the new TCT5s for proton losses

We focus on the different loads of TCT4s and TCT5s in IR1 and IR5 and are interested in how the TCT hits are shared amongst them. Both cases, having TCT5s in and out, are compared for B1 round beam optics in IR1 and IR5 in Fig. 2. One can observe as expected that the TCT5s take over a large fraction of halo protons when they are included. In return, nearly a factor 5 less load on the TCT4s in IR1 can be expected as it was computed from the values in Table 2. However, considering the losses of TCTH.4 from Fig. 2, there are a factor 4 less hits in IR1 and slightly more than a factor 6 in IR5. This gain will be decreased by contributions from TCT5s. Even more significant is the difference in IR5 with about 25 times less losses at the TCT4s. Generally, Table 2 highlights also that B1 losses are smaller in IR5 than in IR1. This can be expected for B1 since the halo protons that leak through the cleaning system of IR7 have a much shorter distance to travel to IR1 than to IR5. We also note that a slight increase of about 8 % of intercepted losses is found when both TCT4s and TCT5s are deployed. Since

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more particles are intercepted, more shower particles can be created which also affects the background level.

Comparison of round and flat beam optics

We studied also how the TCT load changes when the optics change from round to flat for the case that the TCT5s are included. The result is shown in Fig. 3 for the separate TCTs in IR1/5. In the figure, one can see per IR, that the number of hits are very similar for round and flat beam except for TCTV.4 in IR1 where a flat B1 would create about a factor 4 more hits. When summing the hits of TCT4s and TCT5s, as presented in Table 3, the number of TCT hits are very similar and so possibly is also the background level in IR1 and potentially even slightly better in IR5.

SHOWER SIMULATION RESULTS

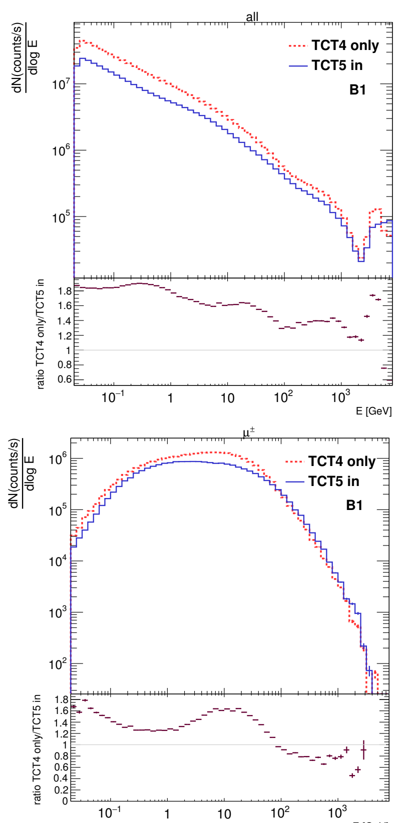

Figure 4: Energy spectra and their ratio at the interface plane for the cases TCT5s out and in of all particles (top) and muons (bottom).

In a further simulation step, we evaluate the actual change in particle flux at the interface plane in IR1 using FLUKA. Although the load on TCT4s is reduced by about a factor 4 for round B1 optics, shower particles created at TCT5s contribute to halo-induced background as well. The energy distribution for all particles and muons only reaching the interface location is depicted in Fig. 4, and their transversal radial distribution in Fig. 5. One can see in the ratio of the top plot of Fig. 4 that all particles will be reduced except

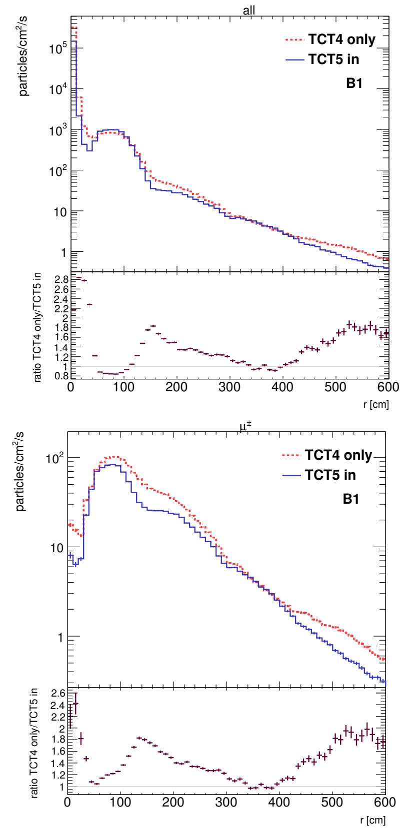

Figure 5: Transversal radial distributions for all particles (top) and muons (bottom) at the interface plane.

those with an energy reaching the beam energy when TCT5s are also installed. The integral ratio of the total number of particles indicates that close to 2 times less particles reach the interface plane when the TCT5s are in. The bottom plot of Fig. 4 shows the number of muons with an energy of 100 GeV decreases, however the number of higher energy muons will rather increase by about 20 % and even more. The lower bins of Fig. 5 represent the space close to the beampipe. They will be up to a factor 3 less populated (almost entirely due to photons and electrons, not shown) if the TCT5s are in. The bottom plot of Fig. 5 shows that muon distributions and their ratios feature a very similar shape.

CONCLUSION

The installation of additional TCT5s does help for halo background reduction as one could expect. Comparing to previous studies [13] the 2σ-retracted collimator settings already significantly reduces the halo-induced flux. With these settings, roughly a factor 2 less particles entering the detector can be achieved including the TCT5s. Opening the TCT4s more than the TCT5s could possibly further reduce the shower contribution from the TCT4s, however constraints from machine protection and beam cleaning have to be considered as well. Simulations should be carried out to verify this and should be extended for the other beam (B2) and IR5 to complete the estimate on machine-induced halo background.

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