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SPECIAL COLLIMATION SYSTEM CONFIGURATION FOR THE LHC HIGH-BETA RUNS

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Abstract

Special LHC high-β^* optics is required for the forward physics program of TOTEM and ATLAS-ALFA. In this configuration, the beam is de-squeezed (the β-function at the collision point is increased) in order to minimize the divergence for measurements at very small scattering angles. In these low beam intensity runs, it is important to place the Roman Pots (RPs) as close as possible to the beam, which demands special collimator settings.

During Run I, a significant amount of background was observed in the forward detectors due to particles outscattered from the primary collimator. During Run II, a different collimation configuration was used where a tungsten collimator was used as primary collimator instead of the usual one made of carbon. Using this configuration, a significant reduction of the background at the RPs was observed. In this paper we present a description of the new collimator configuration and the results obtained during the high-β^* run carried out in 2016.

INTRODUCTION

The Large Hadron Collider (LHC) [1,2] is equipped with a multi-stage collimation system [3,4] to protect superconducting magnets from quench and to reduce the beam induced background in the experimental regions. During Run I (2009-2013) and Run II (2015-2017), the LHC collimation system has been proven to have an excellent performance [6, 7].

During a high-β^* physics run, the beam is de-squeezed at the interaction points (IPs) of the high-luminosity experiments, ATLAS and CMS. The aim is to provide data for the forward physics experiments TOTEM [8] and ATLAS-ALFA [9], which have roman pot (RP) detectors installed about 200 meters from each side of the IP on the outgoing beams By increasing the beam size at the IP through an increased β-function at the IP (β^*), the beam divergence is reduced and the forward detectors can probe the proton-proton elastic-scattering regime at small angles.

In the 2016 high-β^* run, at 6.5 TeV energy per beam, $\beta^* =$ 2.5 km was used. To capture scattered protons, the RPs are set very close to the beam (usually down to 3σ). Due to this very tight configuration, RPs are exposed to large amounts of induced background from the collimation system, reducing the quality of the data obtained. This article describes the alternative collimation scheme devised in order to overcome this limitation. The new scheme was implemented in 2016 and allowed a clean data-taking.

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COLLIMATION SYSTEM DURING HIGH-β^* PHYSICS RUN

In previous high-β^* runs, in order to ensure the protection of the RPs placed very close to the beam, the betatron primary collimator (TCP) located in IR7, made of carbon-fiber-composite (CFC), had to be tightened (configuration C1 in Table 1) [5]. The density of the collimator material is relatively low to avoid damage from the beam halo. Therefore, many particles interacting with the primary collimator are not absorbed and they continue circulating (secondary halo). IR7 is equipped with secondary collimators (TCSGs) downstream of the primary ones that intercept the secondary halo. However, RPs were set in the shadow of the TCPs only, being exposed to the secondary halo, thus generating significant amounts of background, hence reducing the accuracy of the measurments. These conditions were acceptable for Run I but the experiments expressed the strong request to improve the situation. Therefore, it was planned to find a better cleaning configuration for future runs, in particular in the vertical plane, where RPs are placed.

Table 1: RP and collimator setting configuration when TCP is used as primary collimator (C1), using TCLA as primary collimator (C2) and adding the TCTs as secondary collimators (C3).

Roman Pot	**IR**	**Plane**	**C1**	**C2**	**C3**
ATLAS-ALFA	1	V	3.0	3.0	3.0
TOTEM	5	V	3.0	3.0	3.0
Collimator	**IR**	**Plane**	**C1**	**C2**	**C3**
TCP	7	V	2.5	3.0	3.0
TCLA	3	V	20.0	2.5	2.5
TCT	1/5	V	Parking	Parking	3.0
TCP	7	H	4.0	4.0	4.0
TCP	3	H	5.3	5.3	5.3

An idea to reduce the background was to use other collimator with a higher-density material as primary, which is expected to result in a lower amount of secondary halo. This would not be possible during the normal high-intensity runs with about 2500 bunches and where only robust carbon collimators are allowed close to the beam. However, in the special high-beta runs, where only a few nominal bunches (10^{11} protons per bunch) are used, the collimator robustness is less critical and non-standard collimation schemes could be used.

Several collimators in the LHC are made of tungsten, which has more than a factor 10 higher density than CFC. Among these collimators there are tertiary collimators

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(TCTs) around the IPs and absorbers (TCLAs) in IR3. Due to their symmetrical distribution with respect to the forward detectors, located in IP1 and IP5, TCTs in IR2 for beam 1 and IR8 and beam 2 were initially considered. However, the beam size at these locations is very small and the collimator anti-collision interlock was triggered when we tried to go to the desired collimator gap ($\sim 2.5\sigma$). To overcome this limitation, vertical TCLAs in IR3 (TCLA.A5R3.B1 and TCLA.A5L3.B2) were used instead, as primary collimators. At this location the β-function is larger and the anti-collision interlock is no longer a problem. The new configuration (C2 in Table 1) is based on a single-stage collimation system using tungsten collimators. This new collimator configuration is only used for the vertical plane as only vertical pots were used for this run, while in the horizontal plane the regular multi-stage system was kept for machine protection reasons.

SIMULATIONS

In order to evaluate the performance of the new collimator configuration we have performed tracking simulations with SixTrack [10] using a similar setup as in [6]. The aim of the simulations is to asses the differences in multi-turn halo population of the nominal collimator configuration with respect to the new configuration with tungsten made collimators as primary collimators. The efficiency can be evaluated using loss maps, where losses in the collimators and the magnet aperture are recorded, as well as by studying the beam halo distribution at the RP locations. A transverse vertical halo around the minimum collimator gap ($\sim 2.5\sigma$) is tracked for 200 turns.

In Fig. 1, the vertical halo distribution at one of the ALFA RPs, in cell A7R1, is shown for the case using the regular collimator configuration (C1) and the new configuration using TCLA as primary collimator (C2). The simulation takes a sample of 6400 vertical halo particles circulating for 200 turns and records their position at each turn accounting for interactions only with collimators and not RPs. The blue histogram represents the configuration C1 while the orange histogram represents the beam distribution for the new configuration (C2). The green areas represent the space occupied by the RPs for a half-gap of 3σ. One can see that the beam distribution using the new collimator configuration is indeed much cleaner than the previous one. If we compare the amount of particles beyond the RP cut we can see that, for the new configuration, there is a reduction of about a factor of 10, showing that the new configuration is more efficient in reducing halo particle at the RPs, thus more efficient for background reduction in this small sample.

Table 2: Ratio between the particles absorbed using C1 with respect to those using C2 at the different RPs for B1.

Roman Pot (cell)	**Reduction factor (B1)**
ALFA(A7R1)	7
ALFA(B7R1)	18
TOTEM(B6R5)	2
TOTEM(D6R5)	6

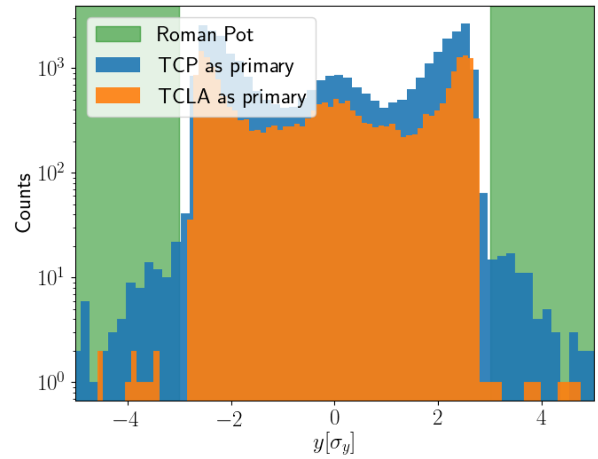

Figure 1: Comparison of the simulated beam distribution at the ATLAS-ALFA detector (A7R1) location using TCP or TCLA as primary collimator.

We can evaluate in more detail the efficiency of the collimation system simulating the loss maps for both configurations. In Fig. 2, the simulated loss map for B1 using $6.4 \cdot 10^6$ halo particles in the vertical plane is shown using C1 (top) and C2 (bottom) for the full ring. Roman pots are not implemented as physical elements in the tracking code by default. We included them as thin collimators of about 5 centimeters of copper, with the thickness scaled to give the same interaction probability as the real stainless steel of the RPs. An order of magnitude decrease of the spike at the RP locations is visible (green bars) in IR1 and IR5 showing the better cleaning efficiency of C2. We can define the reduction factor as the ratio between the amount of particles absorbed in the RPs using C1 with respect to those aboserd using C2. In Table 2, the reduction factor for B1 in the different RPs is shown. Globally, there is an improvement of the particles absorbed by all detectors, with the largest effect at ATLAS-ALFA. These results are in qualitatively agreement with the observations made during the machine tests described in the next section.

MACHINE TESTS

Two machine tests were carried out before the actual high-β^* run. During these sessions, the new collimation scheme proposed above was tested and the background in the RPs was observed. In addition, the collimation system efficiency was evaluated observing the distribution of losses in the collimators and in the aperture by means of loss maps (controlled excitations of a low-intensity beam to study the loss distributions around the ring).

First Machine Test

During the first test, the background produced by the C1 and the new proposed configuration (C2) were compared. For each configuration, the background at the forward detectors was evaluated for 30 minutes. As expected from

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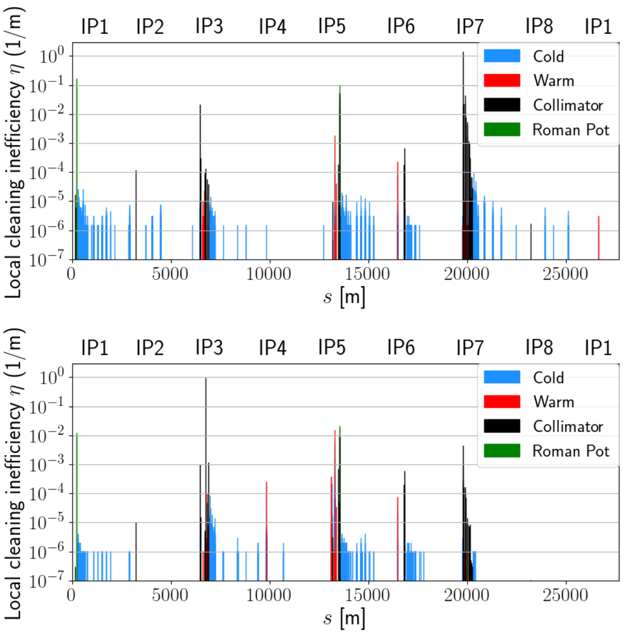

Figure 2: Simulated betatron loss maps for vertical halo configuration 1 (top) and configuration 2 (bottom) settings in Table 1 for the full ring.

simulations, the induced background when we used C1 was very high from the very beginning of the acquisition. Whith the new scheme using C2 in Table 1, the initial background was reduced by one order of magnitude. Nevertheless, after several minutes, the background rates started to rise again due to the repopulation of the beam halo. Therefore, during the actual high-β^* physics run, the beam needed to be re-scraped when the background rates were too high.

This was done by temporarily moving in the vertical IR3 TCLAs to 2.0σ and then retract them again to 2.5σ, leaving an empty phase space area close to the collimators. In such a way, we could recover the initial low level of background. The time dedicated to the re-scraping was small and did not affect the time for data acquisition significantly.

Finally, in addition to the use of TCLA in IR3, the gaps of the TCTs around IP1 and IP5 were reduced to 3σ with the aim to reduce further the secondary halo produced in the TCLA thus creating a two-stage collimation system also in the vertical plane (configuration C3 in Table 1). This system was found not to improve the background rates at the forward detectors significantly and was discarded.

Second Machine Test

The second test was devoted to refine and to find the final collimator configuration to use in operation during the high-β^* physics run. During this test, the background rates were acquired for the two configurations again as well as loss maps to evaluate the global collimation efficiency.

The background rates at the RPs were continuosly recorded for the different conditions during 30 minutes. When the TCLA was used as primary collimator, a background-rate reduction by about a factor 10 was observed [11] relative to the usual configuration with the TCP as primary collimator. This is in approximate agreement with the results obtained from the simulations described above for ATLAS-ALFA. For TOTEM, a slightly smaller background reduction was observed in comparison.

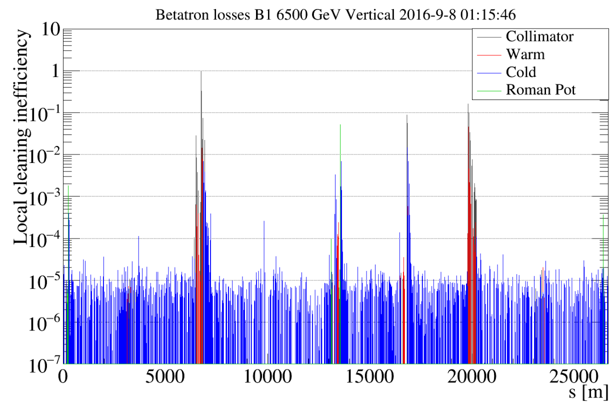

Figure 3: Measured vertical loss maps for B1 during test 2 with the collimator settings shown in Table 1.

The simulated loss map using C2 shown in Fig. 2 (bottom) can be compared with the measured loss map obtained during the second test, it is shown in Fig. 3. In both cases, one can see the clear spike corresponding to the TCLA IR3 TCLA (close to s = 6800 m) acting as the primary collimator in a single stage collimation system.

The spikes corresponding to the losses at the RP location are also clearly visible and comparable in both cases although the magnitudes are slightly different. Note that some discrepancy between measurements and simulations is expected due to the different BLM response from different BLMs around the ring [6]. Therefore, in general, the agreement between simulations and measurements is considered good.

CONCLUSIONS

A novel collimation system configuration was used for the first time during the 2016 high-β^* run. This new system proved to reduce the collimator-induced background in the forward detectors with respect to the levels observed in the past using the regular collimator scheme.

In this new configuration, a collimator made of tungsten (TCLA) located in IR3 was used as primary collimator instead of the usual carbon made collimator in IR7. After two different tests, this configuration demonstrated to reduce the experimental background at the roman pots by approximately a factor 10, increasing the quality of the data acquired by the experiments.

These studies already delivered interesting results for the forward physics program [12] and will serve as a reference for future special physics runs with high-β^*.

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