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CLEANING PERFORMANCE OF THE COLLIMATION SYSTEM WITH XE BEAMS AT THE LARGE HADRON COLLIDER

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Abstract

The LHC heavy-ion programme with Pb ions has delivered substantial physics results since the startup of the LHC. There was a Xe run in 2017 in which collimation losses and betatron halo cleaning were assessed. These studies give a unique opportunity for very valuable benchmark of simulation models with measurements, which could also be very important to understand limitations for future runs with Pb and other ion species. In this paper, we present collimation loss maps measured in the first ever operation of the LHC with Xe ions. The measurements are compared with simulations and first conclusions are discussed for possible future operation.

INTRODUCTION

At the CERN Large Hadron Collider (LHC) proton [1] and heavy-ion [2] beams are collided for high-energy physics experiments. In the most recent Pb-Pb collision run in 2015, $^{208}Pb^{82+}$ ions were accelerated to energy of 6.37 Z TeV. The resulting stored beam energy reached was 9.5 MJ, well above the design value of 3.8 MJ [3]. Such scenarios put high demands and challenges on the performance of the collimation system, which must guarantee safe operation and prevent the superconducting magnets all around the machine from quenching.

Off-momentum and betatron collimation systems are housed in two LHC Insertion Regions (IR) [4], IR3 and IR7, respectively. Each system comprises a multi-stage collimation system with primary collimators (TCP) to intercept and scatter the beam halo particles at large momentum deviation and betatron amplitude. Downstream of the TCPs, the secondary collimators (TCSGs) and the absorbers (TCLAs) are installed to intercept the secondary and tertiary beam halo. In addition, tertiary collimators (TCTs), close to the experiments, protect the superconducting triplet magnets and reduce the background in the experiments.

The collimation cleaning efficiency of lead ions measured is a factor 100 worse than that of protons [3]. The interaction of the ions with the nuclei of the material of the collimators causes the fragmentation of the ions into isotopes with different magnetic rigidities. These isotopes circulate in the beam pipe until they reach regions with non-zero dispersion. The dispersion suppressors (DSs) downstream of the cleaning insertion in IR7 is where higher amount of losses are observed. With the upgrade to the High Luminosity of the LHC (HL-LHC), planning an increase on store beam energy of up to 24.1 MJ, a large effort is being made to optimize the system for the best possible performance. Understanding better simulation tools and beam losses is an important part of this effort.

On 12–13 October 2017 a special run [5] took place in which $^{129}Xe^{54+}$ ion beams were injected into the LHC and brought to collisions at 6.5 Z TeV. This offered a great opportunity to explore the possibility of using lighter ion species in the LHC and test recently developed simulation tools [6] for ion collimation cleaning studies. Here we present betatron loss maps measured in the first ever operation of the LHC with Xe ions as well as a first comparison with simulations.

MACHINE CONFIGURATION

The Xe beam was commissioned successfully in a first single fill to 6.5 Z TeV [5], then a second fill was dedicated to physics, and a third one to a crystal collimation study [7] (Fig. 1).

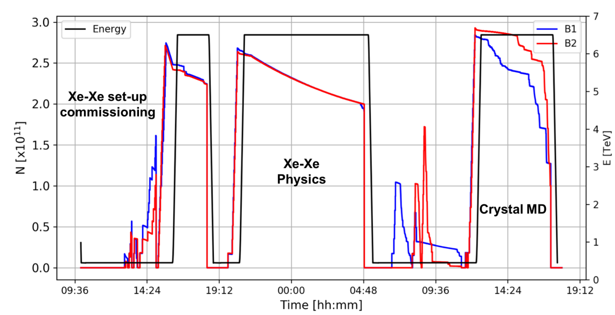

Figure 1: Intensity and energy during the Xe-Xe run.

In the first fill, about 20 Xe bunches of approximately 1×10^{10} charges were injected into the LHC, keeping the intensity below the setup limit of $3{\times}10^{11}$ charges. The transverse normalized beam emittance was about 1.6 μm in both planes. The validated proton-proton optics configuration from injection to the end of the squeeze where the β-function in the Interaction Points (IP) correspond to $\beta^* = (0.3, 10, 0.3, 3)$ m in (ATLAS, ALICE, CMS, LHCb) was used. The only difference to the nominal configuration implemented was the external crossing angle in IP2 changed from +200 μrad to +135 μrad for preserving the neutron cone acceptance for ALICE zero-degree calorimeters. The 2017 collimator configuration settings were used [8]. In this paper we focus on the results for the squeezed beams configuration for which the collimation settings are summarized in Table 1.

COLLIMATION CLEANING

The betatron collimation cleaning performance and hierarchy are validated thought loss maps. This is an essential

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Table 1: Collimator Settings for Squeezed Beams

Collimator	IR	Half gap [σ]
TCP/TCS/TCLA	7	5/6.5/10
TCP/TCS/TCLA	3	15/18/20
TCTP	1/2/5/8	9/37/9/15
TCL	1/5	out
TCSP/TCDQ	6	7.3/7.3

part of the machine commissioning that has to be done for each machine configuration. To perform the betatron loss maps, the beam is blown up in the transverse plane with the transverse damper (ADT) and the losses along the ring are recorded by the LHC Beam Loss Monitoring (BLM) system [9, 10]. The BLM system is composed by more than 3500 ionization chambers installed on many magnets and other important machine elements.

In Fig. 2 the full ring loss map performed with squeezed beams in the horizontal plane is shown for Beam 1 (top) and Beam 2 (bottom). The losses are classified as cold (blue), warm (red) or collimator (black). Cold losses in the superconducting magnet apertures are determining the cleaning performance. The BLM signal is normalized by the highest BLM signal measured in IR7 where primary beam losses are intercepted. In Fig. 3 the IR7 loss map for each beam is shown. The dominating cold losses are found in IR7 in the form of two clusters referred to as DS1 between cell 8-9 and DS2 between cell 10-11.

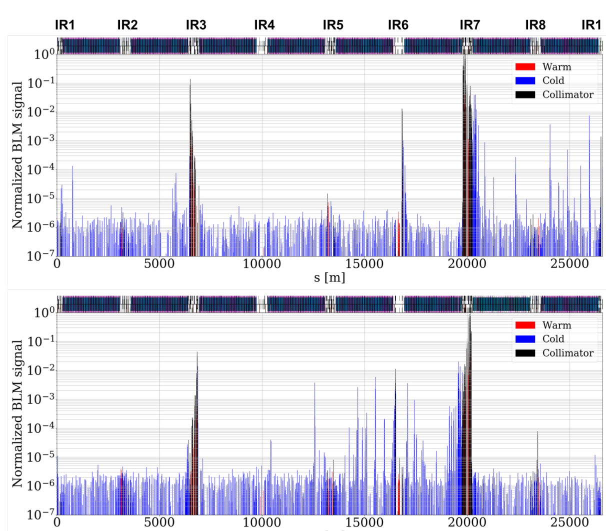

Figure 2: Betatron loss maps in the horizontal plane for squeezed Beam 1 (top) and Beam 2 (bottom). The different IRs are indicated.

A worsening of the cleaning inefficiency in DS1 and DS2 by more than two orders of magnitude with respect to protons is observed as in previous Pb ion runs [3]. Additional peaks are also seen in the arcs between IR7 and IR1 for Beam 1 and between IR5 and IR7 for Beam 2, close to dispersion maxima. Some of them are of similar magnitude as the maximum peak in DS1 and DS2 in IR7. The worst cleaning inefficiency is found for Beam 1 in the horizontal plane with a value of 3.9$\times$10^{-2} m^{-1} in DS1. These results were acceptable for the intensity of the run that was kept below the set-up limit. However the worsening in the cleaning inefficiency stressed the need of optimizing and better understanding the collimation cleaning performance for ions, in view of high intensity runs.

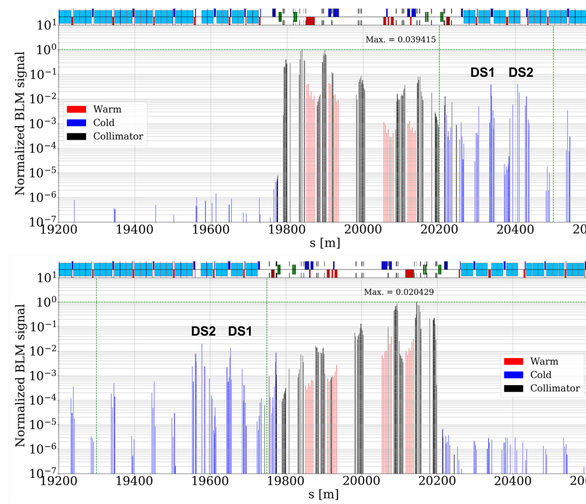

Figure 3: IR7 betatron loss maps in the horizontal plane for squeezed Beam 1(top) and Beam 2 (bottom).

LOSS MAP SIMULATIONS

The hiSixTrack-FLUKA coupling framework [6, 11–13] was used to simulate the cleaning performance of Xe beams. This framework allows us to perform tracking simulations taking into account the scattering and fragmentation of the ions in the LHC collimators. Accurate geometric models of the collimators are available, as well as an online aperture check to identify the longitudinal coordinate of particles lost on apertures along the ring. The loss maps have been constructed calculating the cleaning inefficiency, $\eta(s)$, as the integrated energy lost at a given location per unit length normalized by the maximum energy lost, E_{max}, in the ring.

The simulations presented in this paper have been carried out for the optics and collimator settings corresponding to the squeezed beams. An initial pencil beam distribution of 2×10^6 Xe ions of 6.5Z TeV has been generated at the horizontal TCP in IR7.

In a first set of simulations, the effect of the beam impact parameter (defined as the distance between the impacting horizontal coordinate and the surface of the collimator jaws) was studied. The inefficiency strongly depends on this parameter. For the presented simulations the value was conservatively set to 1 μm, which produces in simulations the worst cleaning inefficiency for the impact parameters studied in the range of 0.1-1000 μm.

In Fig. 4 the simulated horizontal loss map for Beam 1 is shown. Left and right collimator jaws were simulated

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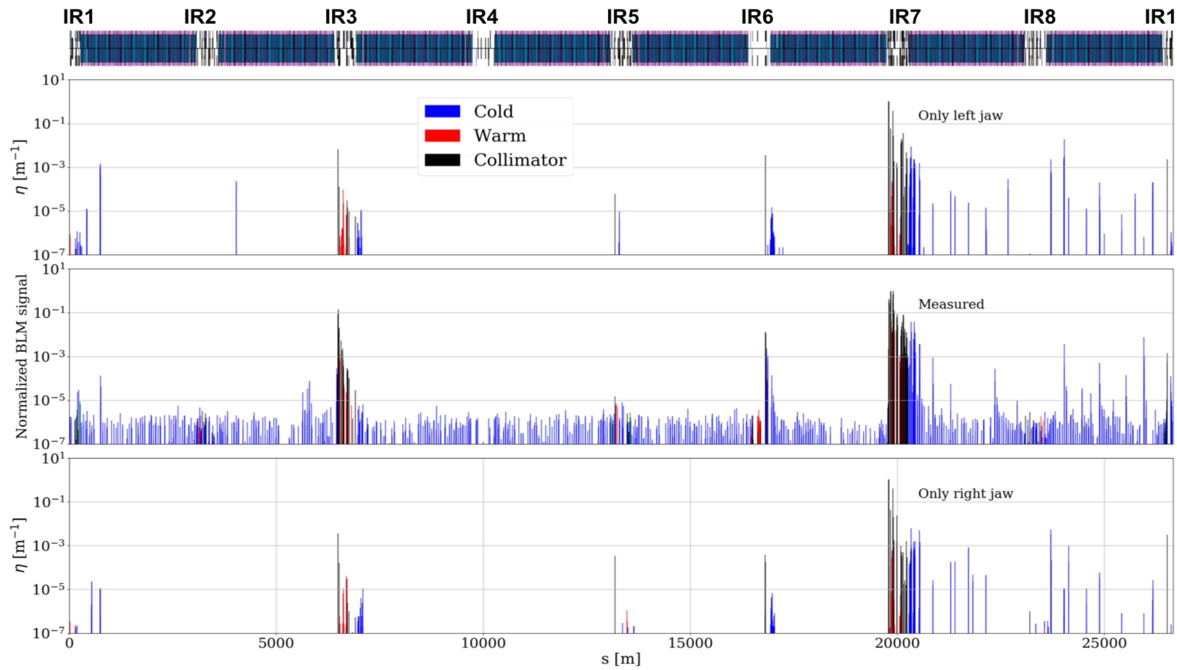

Figure 4: Beam 1 horizontal simulated left jaw (top), measured (middle) and simulated right jaw (bottom) loss map.

independently to investigate the possible effect of asymmetries. The top plot shows the cleaning inefficiency induced by heavy-ion fragments scattered out of the left jaw, the middle plot shows the loss map measured during operation, the bottom plot shows the simulated losses for fragments scattered out of the right collimator jaw. The losses in IR3 and IR7 are in good agreement and also the DS1 and DS2 clusters which are visible in simulations and measurements.

The losses in cold regions (shown as blue bars) in the apertures between IR7 and IR1 are partially reproduced in the simulations. All the peaks observed are predicted by the simulations, however some of them are slightly shifted and the simulations predict experimentally unobserved loss peaks. The losses in the IR1 TCT and in IR6 (dump region) are observed in both measurements and simulations while in the IR5 TCT losses are predicted but not observed. The left and right jaw loss maps are slightly different. Three peaks are predicted by simulations of the left jaw in cold apertures between IR1 and IR3 and only two on the simulation of the right jaw, the last one being in better agreement with the measurements. We have to keep in mind that only a qualitative comparison is possible at this stage, since the simulations do not include the shower generated by a particle lost in an aperture. Detailed quantitative comparison requires dedicated simulations of the radiation-matter interaction in the apertures and shower development reaching the BLMs.

From these first studies and comparison with measurements we conclude that both the impact parameter and the possibility of impacting only one jaw could change the resulting loss map. A good overall agreement is observed between simulation and measurements but some discrepancies are present. Machine imperfections as aperture misalignments and beam orbit offsets could explain the discrepancies observed. Some preliminary simulation and calculations including apertures without mechanical tolerances show a decrease and shift of the loss spikes and that an orbit offset between tens of μm to a few hundreds of μm can suppress some of the loss spikes. A more detailed analysis is in progress for a better understanding of the results.

SUMMARY AND CONCLUSIONS

In October 2017 Xe ion beams were injected and commissioned in one fill for the first time in the LHC. This was a unique opportunity to explore the possibility of using a new ion species and benchmark the recently developed collimation cleaning simulation tools for ions.

The measured betatron cleaning shows a degradation by more than two orders of magnitude with respect to protons in the DS after the betatron cleaning insertion as well as additional loss spikes in the arcs as high as the ones observed in the DS. These results were acceptable for the beam intensity used during the run but could limit future high intensity runs with this lighter ions.

A simulation campaign has been started using the hiSiXTrack-FLUKA coupling framework. The first comparison shows a good overall agreement of losses along the ring, although some discrepances are present. Simulated loss maps are very sensitive to the impacting beam parameters at the TCP, to the orbit offset, and possible aperture misalignments. Detailed studies are on going.

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REFERENCES

[1] O. S. Brüning *et al.* (Eds),"LHC design report v.1: the LHC main ring", CERN-2004-003-VI (2004).

[2] J. M. Jowett, "Colliding heavy ions in the LHC", presented at the 9th Int. Particle Accelerator Conf. (IPAC'18), Vancouver, British Columbia, Canada, paper TUXGBD2, this conference.

[3] J. M. Jowett, M. Schaumann, R. Alemany, R. Bruce, M. Giovannozzi, P. Hermes, W. Hofle, M. Lamont, T. Mertens, S. Redaelli, J. Uythoven, J. Wenninger, "The 2015 heavy-ion run of the LHC", proceedings of IPAC2016, Busan, Korea, paper TUPMW027.

[4] R. Bruce, R. W. Assmann, V. Boccone, C. Bracco, M. Brugger, M. Cauchi, F. Cerutti, D. Deboy, A. Ferrari, L. Lari, A. Marsili, A. Mereghetti, D. Mirarchi, E. Quaranta, S. Redaelli, G. Robert-Demolaize, A. Rossi, B. Salvachua, E. Skordis, C. Tambasco, G. Valentino,T. Weiler, V. Vlachoudis, D. Wollmann, "Simulations and measurements of beam loss patterns at the CERN Large Hadron Collider", Phys. Rev. ST Accel. Beams 17, 0810004, (2014).

[5] M. Schaumann, R. Alemany-Fernandez, P. Baudrenghien, T. Bohl, C. Bracco, M. A. Jebramcik, J. M. Jowett, T. Mertens, H. Timko, "First xenon-xenon collisions in the LHC", presented at the 9th Int. Particle Accelerator Conf. (IPAC'18), Vancouver, British Columbia, Canada, paper MOPMF039, this conference.

[6] P. Hermes, "Heavy-ion collimation at the Large Hadron Collider: simulations and measurements", CERN-THESIS-2016-230.

[7] R. Rossi, O. Aberle, O. O. Andreassen, M. Butcher, C. A. Dionisio Barreto , I. Lamas Garcia, A. Masi, D. Mirarchi, S. Montesano, S. Redaelli, A. Rijllart, W. Scandale, P. Serrano Galvez, G. Valentino, F. Galluccio, "Status of crystal collimation studies at the LHC", proceedings of IPAC2017, Copenhagen, Denmark, paper MOPAB007.

[8] R. Bruce, R. De Maria, M. Giovannozzi, P. D. Hermes, A. Mereghetti, and D. Mirarchi S. Redaelli, "β^*-reach in 2017", CERN-ACC-2017-094, proceedings of the 7th Evian Workshop, Evian, France, 2016.

[9] E. B. Holzer *et al.*, "Beam loss monitoring system for the LHC", IEEE Nuclear Science Symposium Conference Record 2, 1052 (2005).

[10] E. B. Holzer *et al.*, "Production and testing of 4500 beam loss monitors", proceedings of the 11th European Particle Accelerator Conference, Genoa, 2008, p. 1134.

[11] P. D. Hermes, R. Bruce, J. M. Jowett, S. Redaelli, B. Salvachua, G. Valentino, D. Wollmann, "Measured and simulated heavy-ion beam loss patterns at the CERN Large Hadron Collider", Nucl. Instrum. Methods Phys. Res. Sect. A, 819 (2016), 73-83.

[12] `http://sixtrack.web.cern.ch/SixTrack/`

[13] `http://www.fluka.org/fluka.php`