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BENCHMARKING OF COLLIMATION TRACKING USING RHIC BEAM LOSS DATA*

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Abstract

State-of-the-art tracking tools were recently developed at CERN to study the cleaning efficiency of the Large Hadron Collider (LHC) collimation system [1]. In order to estimate the prediction accuracy of these tools, benchmarking studies can be performed using actual beam loss measurements from a machine that already uses a similar multistage collimation system. This paper reviews the main results from benchmarking studies performed with specific data collected from operations at the Relativistic Heavy Ion Collider (RHIC) [2].

INTRODUCTION

Simulations were performed with an extended version of the well-established SixTrack code to predict the cleaning efficiency of the LHC multi-stage collimation system [3, 4]. The primary goal of this system is to minimize the risks of beam-induced quenches, especially for all sensitive magnets (e.g. the triplet quadrupoles) in the high luminosity experimental insertions. Various optics and/or collimation system settings can be studied; for each case, trajectories of the tracked particles are recorded and then compared to a detailed aperture model of the machine [5]. This allows predicting with a very good resolution the beam loss locations around the machine.

To check the accuracy of these predictions, one can reproduce real machine conditions of a lattice using collimators and compare simulated beam loss map with measurements from beam loss monitors (BLMs). This is done here by studying beam losses in the Relativistic Heavy Ion Collider (RHIC) during one of its proton runs. RHIC is a circular accelerator made of two individual beam lines (Blue and Yellow) with 6 common regions, 4 of which are dedicated to experiments. The data considered in this paper was taken during the 2005 proton run, whose parameters are listed in Table 1.

SETTING UP THE TRACKING

Dedicated data sets were taken by moving the RHIC collimators close to the beam, with all relevant informations (jaw positions, closed orbit, BLMs signal) being logged during the entire operation. One then needs to get the lattice and optics files corresponding to the machine conditions at the time of the measurements. Trajectories of protons impacting on collimators using the actual collimator openings in the input files are then simulated and compared these trajectories with a detailed aperture model of the beam lines.

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Table 1: Target RHIC parameters for the FY05 $p^+ - p^+$ run.

Number of bunches	111
Protons per bunch	2.0×10^{11}
E_{store} [GeV]	100
Working point Q_x, Q_y	0.690/0.685
ϵ_N [π mm.mrad]	20.0
L_{peak} [$cm^2.s^{-1}$]	10^{30}
β^* STAR // PHENIX [m]	0.94 // 0.92
β^* IR10, IR4 [m]	10.0
β^* IR12 [m]	5.0
β^* IR2 [m]	3.0

Numerical models of the machine are obtained via the MAD-X code. An online model is used to store the magnet strengths into a file after each succsesful ramp, allowing to reproduce realistic machine conditions (i.e. tunes and β^* mainly). An outdated aperture model was available from previous collimation studies [6], that is not compatible with the output from SixTrack. A new RHIC aperture model is therefore required and must include all modifications since the original model. As for the LHC studies, the new RHIC model is split into 10 cm bins in order to be as close as possible to the real shape of all elements.

Figure 1: 3D model of the mechanical aperture in the IR8 insertion. The solid red line represents the closed orbit. The two regions with a larger transverse opening and a large orbit offset correspond to the DX separation magnets. The three "discs"on the right hand side are the location of the RHIC collimators.

Some machine elements needed more details than others, especially those close to the interaction points. Figure 1 is a 3D representation of the IR8 insertion following the Blue beam line and shows how a DX separation magnet can be modeled. These separation elements ensure the transition from two separate vacuum pipes into a common pipe in which both beams pass each other. While the transverse opening in the common area is larger than the single vacuum pipe, neither beam actually travels through the center of the common transition region: as indicated in Figure

1, there is a closed-orbit offset that sets the beam closer to the aperture limits. In the database, the DX elements (along with all elements that feature this orbit offset) have their aperture given with the center of the pipe as reference, compared to the coordinates of the tracked particles which are given with respect to the closed orbit. The orbit offest for each 10 cm bin along each element is then included in a separate column. When checking for beam losses, the aperture program adds the orbit offset to the recorded coordinates in the tracking.

COMPARING SIMULATION RESULTS WITH LIVE MEASUREMENTS

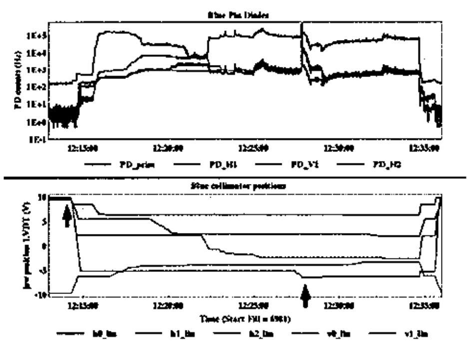

Figure 2: Positions of the Blue collimator jaws in LVDT units (top) and collimator pin diodes signal (bottom) versus time during Fill #06981 of the RHIC FY05 p^+-p^+ run. The red (green) arrow points to the reference position "all out" ("all in") of the collimator jaws.

The datasets used for benchmarking were collected over the Fill #06981 for the Blue beam during the FY05 p^+-p^+ run. Figure 2 shows the positions of the collimator jaws and the signal from their respective pin diodes (each jaw is equipped with one, installed 1 m dowsntream). One can clearly state when a given jaw is scraping the beam, as it generates particle showers detected by the corresponding pin diode. For the benchmarking studies, the collimator positions are reproduced from their value at 12:27:50 (green arrow on Figure 2), when the secondary jaw V1 is the closest to the beam. The simulated beam loss map is then compared to the longitudinal loss locations given by the BLMs.

Preliminary results from simulations are shown in Figure 3. The impact parameter on the V1 collimator jaw was taken as 5 μm. The BLM data is shown for comparison and corresponds to the difference in the intensity of the signal at each loss monitor between the collimator positions "all out" and "all in". The predicted loss locations are given by the solid red lines and match with most of the BLM peaks, which means that the tracking tools developped for LHC collimation studies have a very good level of prediction. One should note that while the simulation tools allow locating proton losses with a 10 cm resolution, the live signal from the BLMs is only given at predetermined positions

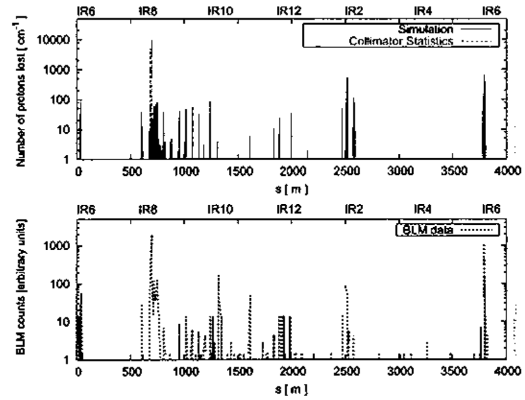

Figure 3: Comparison between simulated loss maps (top) and BLM measurements (bottom) due to beam impacts on the V1 collimator jaw for the Blue beam, circulating from left to right.

around the machine.

Figure 4 shows details of the simulations around the collimation region (IR8) and the STAR experiment (IR6). Losses seen at the triplet magnet upstream of the collimation system (s = 600 m) and around IP6 (s = 0 m) are due to some of the halo protons that were scattered by the collimators and managed to escape further downstream. These protons face an aperture bottleneck at these quadrupoles since β^* in both experimental insertions is squeezed down to 0.9 m for higher luminosity. The high level of losses seen by the BLMs in IR8 around s = 700 m is due to showers of secondary particles coming from the collimator jaws. This is shown by the green dashed lines in the simulated loss maps, giving the statistics of the inelastic interaction taking place in each jaw.

Table 2: Comparison between simulations and live measurements for the statistics shown in Figure 4 of beam losses induced by the RHIC collimation system.

BLM location [from IP6]	BLM signal [arbitrary units]	N_{losses} upstream of s over $d = 5$ m
(1) s = 705.5 m	38.021	89 ± 9
(2) s = 710 m	50.979	132 ± 11
(3) s = 714.2 m	55.743	127 ± 11
(4) s = 721.7 m	124.600	496 ± 22
(5) s = 736.5 m	35.136	97 ± 10
(6) s = 751.2 m	125.331	495 ± 22

The relative height of the peaks in the simulations can be compared with the live measurements too. When studying the statistics of the predicted losses, one can consider that each BLM can only "see" beam losses up to a certain distance upstream of it, taken as d = 5 m here. Table 2 presents a quantitative comparison between simulations and measurements for the region close to the collimators (between s = 700 m and s = 750 m as seen in Figure 4). It shows that the overall variation of loss amplitudes at the various BLM locations is to the first order reproduced by

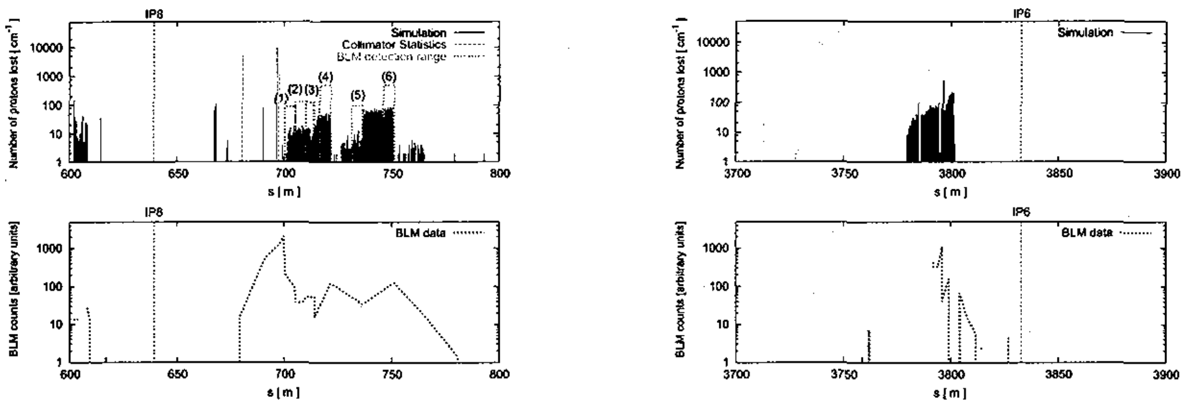

Figure 4: Zoom of the simulated loss maps and BLM signal around the collimation region (left) and the STAR experiment (right) following the Blue beam. Beam losses can be spotted at the triplet magnet upstream of the collimators.

the simulations.

Deriving a scaling law from the statistics shown in Table 2 remains complicated. One of the reason is that the tracking tools are designed to show only the locations where the protons scattered by the collimation system are lost, while particle showers induced by the proton-matter inelastic interactions in each collimator are also seen by the BLMs. One would have to use some additional numerical models to track these secondary particles and include the results in the simulated loss maps.

In addition, BLMs are installed in the machine so as to look at beam losses in a given direction; the statistics shown in Figures 3 and 4, on the other hand, are given without regard for the transverse plane in which the losses took place. One could then update the values in Table 2 by sorting the simulated loss locations according to the transverse plane in which each BLM is located.

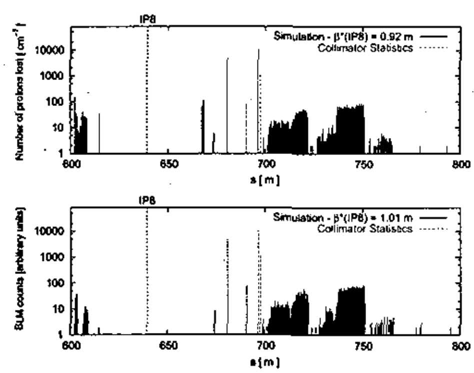

Figure 5: Comparison of simulated beam losses in IR8 for β^* = 0.92 m (top) and β^* = 1.01 m (bottom). The relaxed settings show less losses at the triplets.

Since the simulations rely on a numerical model of the live machine, the predicted loss maps are only as good as the model is. Figure 4 shows losses at the IR8 triplets that are not seen by any BLM close by, which could mean that the β^* value used for that insertion is lower than its actual value in the machine at the time of the measurement. Figure 5 compares the predicted losses for β^*(IP8) = 0.92 m as in the model with a scenario in which the β^* is relaxed by 10 %. One can see that losses at the upstream triplet (s = 600 m) are significantly lowered, from $N_{lost}^{total} = 441 \pm 21$ to $N_{lost}^{total} = 150 \pm 12$; losses at the downstream triplet are them practically canceled. Downstream of the collimators, the level of beam losses is about the same (within the statistical fluctuations) in both cases, since the optics in this region are unaffected by the change in β^* value.

CONCLUSION

Simulations were performed for the RHIC collimation system using machine optics given by live measurements. There is a very good agreement between the predicted proton losses and the measured BLM signal. The analysis of the inelastic scattering processes in the collimators could explain the discrepancy in the amplitude of the losses in the downstream region close to the collimators. On the first order though, the tracking code can be considered as successfully benchmarked.

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