LOSS MAPS OF RHIC*

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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]. These tools are fully transportable, meaning that any accelerator lattice that includes a collimation system can be simulated. Each of the two Relativistic Heavy Ion Collider (RHIC) [2] beam lines features a multi-stage collimation system, therefore dedicated datasets from RHIC operations with proton beams can be used to benchmark the tracking codes and assess the accuracy of the predicted hot spots along the LHC.

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. The trajectories recorded from the tracking code can be compared to a detailed aperture model of the machine [5], and longitudinal beam loss maps similar to the one shown in Figure 1 are then obtained for different machine setups (i.e. beam energy, collimator openings or orbit perturbation).

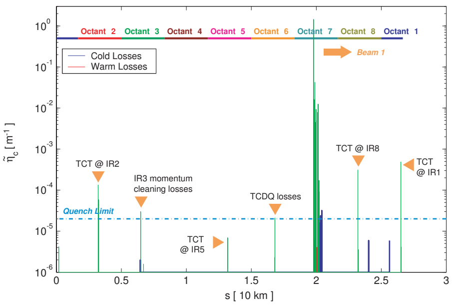

Figure 1: Sample simulated longitudinal beam loss map in the LHC Top Energy case.

These studies also have an impact on how the machine protection system will be set-up for operations. The simulated loss maps can identify possible hot spots along the beam lines, which helps installing beam loss monitors (BLMs) appropriately. It then becomes important to check how accurate the predictions are, both for the locations and the relative amplitudes of losses. To do so, one needs to reproduce real machine conditions of a lattice using collimators and compare the simulated loss map with measurements from BLMs. This can be done with data taken in the RHIC machine during one of its proton runs.

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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. Figure 2 shows a schematic layout of RHIC. The machine was designed to run both gold ions and protons, but other species have also been injected over the course of operations (e.g. copper ions and deuterons). The data considered in this paper was taken during the 2005 proton run, whose parameters are listed in Table 1.

Table 1: Main 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 [μm]	20.0
L_{peak} [cm^2.s^{-1}]	10^{30}
β^* STAR,PHENIX [m]	0.9
β^* IR10, IR4 [m]	10.0
β^* IR12 [m]	5.0
β^* IR2 [m]	3.0

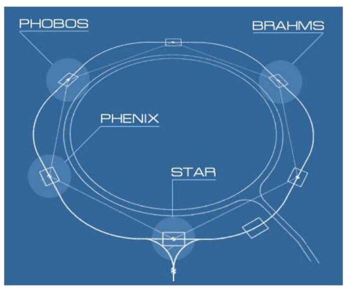

Figure 2: Schematic of the RHIC layout and its experiments.

The RHIC collimation system is made of 1 primary and 3 secondary collimators for each beam line that only intercept one side of the beam per transverse plane. As a comparison, in the LHC case one counts 4 primary and 16 secondary collimators per beam in IR7 which feature 2 parallel jaws per transverse plane. As shown in Figure 3, the RHIC primary jaw is L-shaped, allowing to collimate in both transverse planes at the same time. These elements are located around the PHENIX experiment and aim at minimizing the background level in all experimental insertions.

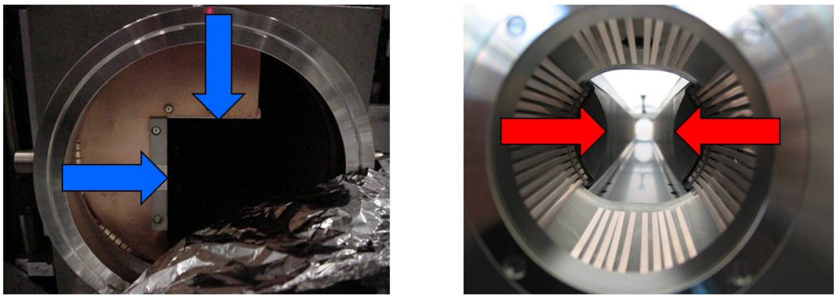

Figure 3: Comparison of mechanical layouts between the RHIC primary scraper (left) and a LHC horizontal collimator (right).

REQUIRED TRACKING TOOLS

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,
- simulate the trajectories of protons impacting on collimators using the actual collimator openings in the input files,
- compare these trajectories with a detailed aperture model of the RHIC beam lines.

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. The computing resources should also allow tracking large particle ensembles, i.e. at least 2×10^5 particles per job.

A new RHIC aperture model is therefore required, that must include all modifications since the original model. Most of the available database files only list the transverse dimensions at the beginning or the end of a given element; to obtain accurate beam loss maps, the aperture database should include the complete description along that element. 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. The model must also match the simulated lattice, hence the aperture database needs to be compared with the MAD-X lattice in order to find any element that was either moved, removed or replaced. Finally, all collimator tanks are taken as drift spaces, since the corresponding aperture restrictions are applied in the tracking routines.

Some machine elements needed more details than others, especially close to the interaction points. Figure 4 shows an example of 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 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 4, there is a closed-orbit offset that sets the beam closer to the aperture limits. For practical reasons, the DX elements (along with all elements that feature this orbit offset) have their aperture data given with the center of the pipe as reference, and the orbit offest for each 10 cm bin along the element is included in a separate column. When checking for beam losses, the aperture program adds the orbit offset to the recorded coordinates along the considered element.

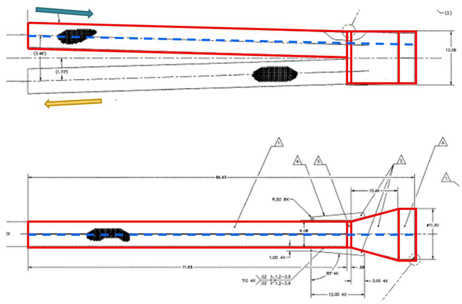

Figure 4: Top view (top) and side view (bottom) of a RHIC DX separation magnet. The red solid lines show how the transverse openings of this element were inserted in the new RHIC aperture model following a block method. The dashed line represents the linear approximation of the closed-orbit followed by the blue beam going from left to right through the element.

MEASUREMENTS VS. PREDICTIONS

The following presents the results of comparison between measurements taken during the FY05 $p^+ - p^+$ run and the corresponding simulations. The data was collected on April 28, 2005 during the fill #06981 for the Blue beam. Figure 5 shows the movements and positions of the collimator jaws that are reproduced in the tracking tools. The beam loss maps obtained from the tracking code are then compared to the longitudinal loss locations as indicated in the BLM signal. A sample map of the logged BLM signal can aslo be seen in Figure 5: the horizontal axis stands for the s location around the machine and the vertical axis gives the time of the measurement. The intensity of the sig-

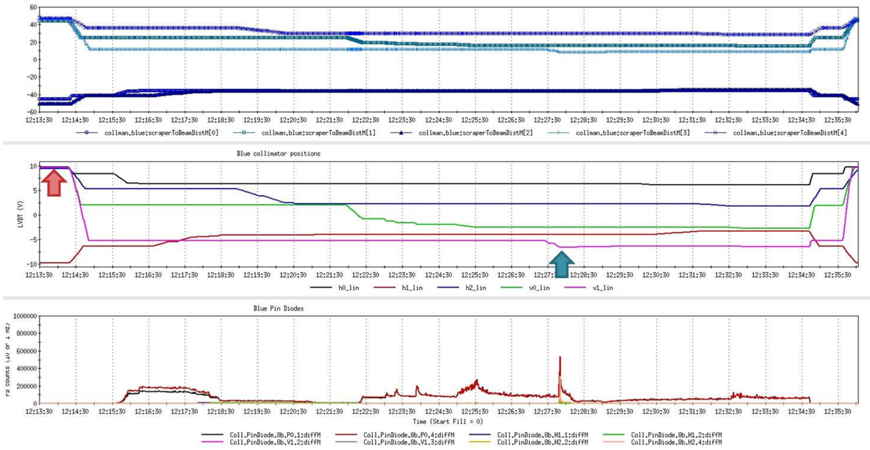

Figure 5: Collimator jaw positions in millimeters (top) and LVDT arbitrary units (middle) compared to the pin diode signals (bottom) versus time. Data is taken once the beam is at store. The red arrow points to the reference position ”all out” of the collimator jaws for the BLM signal. The green arrow points to the ”all in” position of the collimator jaws that are used for the tracking.

nal from each loss monitor is then displayed in color bins, with red indicating the highest value. The data shown in Figure 6 illustrates the goal of the RHIC collimation system: once the beam is at store, collimators should be set into positions that would minimize beam losses occuring at the triplet magnets located in the high luminosity insertions (the STAR experiment in this example). This would lower the background levels in the detectors and improve significantly the signal-to-noise ratio.

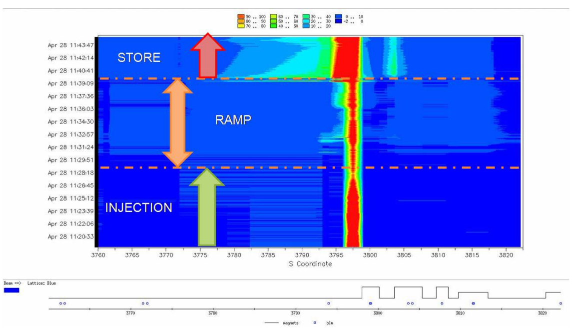

Figure 6: Zoom of the RHIC BLM data around the triplet magnet upstream of the STAR experiment following the Blue beam. Beam losses are increased coming into the triplet when the beam is at store. A schematic of the beam line is included below the BLM signal as a reference; the locations of each triplet quadrupoles are given by the rectangular shapes.

Preliminary simulated loss maps around the RHIC Blue beam line are shown in Figure 7. The impact parameter on the primary collimator was taken as 5 μm. Each transverse planes was tracked separatelyl; tracking results are then presentend individually (horizontal plane on top, vertical on bottom) so as to correlate the loss patterns with the collimation planes. The BLM data is also shown for comparison and corresponds to the difference in the intensity of the signal at each loss monitor between the collimator positions ”all out” (red arrow in Figure 5) and ”all in” (green arrow in Figure 5).

One can see from Figure 7 that the predicted loss locations actually match most of the peaks in the BLM signal all around the machine. This strengthens the accuracy of prediction of the tracking tools developped for LHC collimation studies. Figure 8 shows details of these results around the collimation region. Losses seen at the triplet magnet upstream of the collimation system are due to some of the halo protons that were scattered by the collimators and managed to travel around the machine for nearly a full turn. These protons face an aperture bottleneck at the triplet quadrupoles since β^* in IR8 is squeezed down to 0.9 m for higher luminosity. This also explains the peaks in Figure 7 for IR2 and IR6 (low β^* insertions too, see Table 1), both for the BLM signal and the simulated loss maps. It is also worth noticing that the BLM data can be much higher than the simulated loss peaks in IR8. In Figure 8, the BLM signal around 700m is dominated by the showering of secondary particles from the collimator jaws, while the tracking tools are designed to show the locations where the protons scattered by the collimation system are lost. One would then have to use some additional numerical models to generate the showers induced by the proton-matter inelastic interactions in each collimator jaw, and include the results in the simulated loss maps.

When looking at the loss pattern given by the BLM data, there are a few locations that are not predicted by the simulations. Figure 9 shows the details of the beam losses around IR10. The peak in the loss monitor signal around 1320 m corresponds to losses taking place at an abort kicker magnet (Blue Kicker Abort, BKA): these losses are known to occur during regular RHIC operations and are not collimation related. Losses detected by BLMs at a focusing quadrupole (labeled QF in Figure 9) in the arc downstream of IR10 are still investigated.

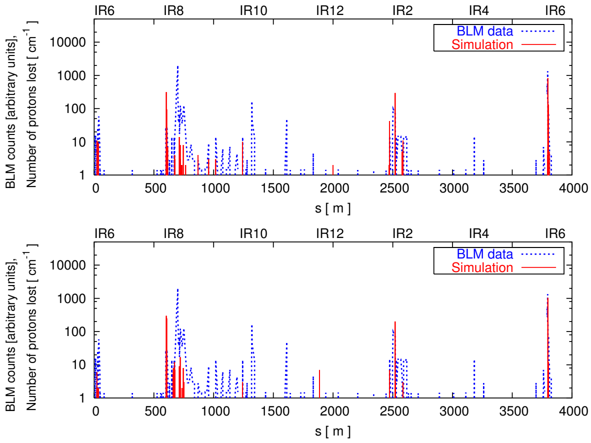

Figure 7: Comparison between RHIC BLM measurements and simulated loss maps due to beam impacts on the horizontal (top) and vertical (bottom) primary collimator jaw for the Blue beam, circulating from left to right. The solid lines show the number of protons lost per 10 cm bins obtained from the tracking tools; the dashed lines represent the BLM signal as measured in the machine.

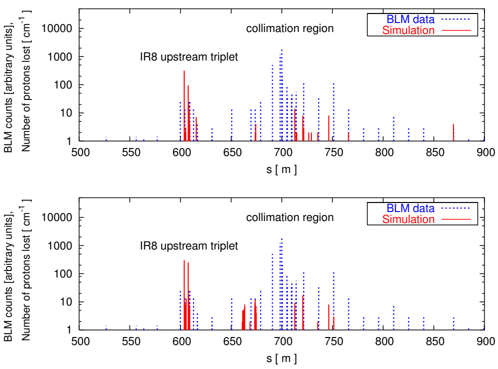

Figure 8: Zoom of the simulated loss maps and BLM signal around the collimation region following the Blue beam. In addition to the peaks downstream of the collimators, beam losses can be spotted at the triplet magnet upstream of the collimators.

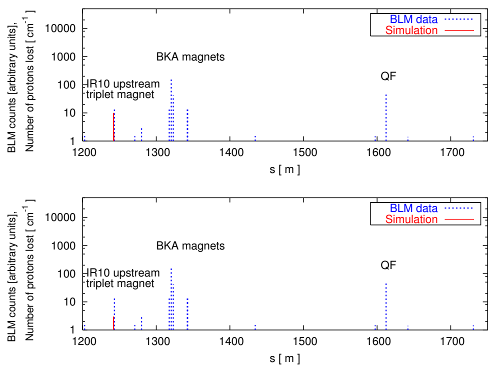

Figure 9: Zoom of the simulated loss maps and BLM signal around IR10 following the Blue beam. Beam losses can be spotted at the triplet magnet upstream of IP10 and at the Blue Kicker Abort (BKA) magnet.

CONCLUSION

Simulations were performed for the RHIC collimation system using machine optics given by live measurements. With an updated aperture model, it was possible to compare the predicted proton loss locations with the measured BLM signal obtained with a dedicated set of collimator positions: there is a good agreement between the tracking tools and the real data on the locations of the losses around the machine. On that aspect, the code is successfully benchmarked.

Work is currently ongoing to check for the quantitative agreement between predicitons and measurements. This includes running the previous simulations with higher statistics as well as the analysis of the inelastic scattering processes taking place in the collimator jaws, that could explain the discrepancy in the amplitude of the losses in regions located a couple hundred meters downstream of the collimation insertion.

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