CALCULATION OF PARTICLE LOSS MAPS
FOR 2016 RHIC GOLD-GOLD RUN*

Y. Luo, A. Drees, W. Fischer, X. Gu, A. Marusic, G. Robert-Demolaize, V. Schoefer
Brookhaven National Laboratory, Upton, NY USA

Abstract

In the 2016 RHIC 100 GeV gold-gold (Au-Au) run, 20 mm orbit bumps were installed in the arcs to protect the experimental detectors from damage due to severe beam loss caused by abort kicker prefires. Chronic particle losses were observed in the arcs with these orbit bumps. Those particle losses are mainly from the $^{197}Au^{78+}$ and $^{196}Au^{79+}$ particles generated from bound-free pair production (BFPP) and electromagnetic dissociation (EMD) associated with the Au-Au collision at the Interaction Points (IP). In this article, we simulate the particle losses of $^{197}Au^{78+}$ and $^{196}Au^{79+}$ ions and calculate the particle loss distribution in the ring. Simulation results are compared with observations.

INTRODUCTION

A beam abort system is designed to protect the elements and systems of accelerators and detectors. It intentionally dumps the stored particles at dedicated locations. In RHIC, the abort system consists of 5 abort kicker modules per ring with a total horizontal kick strength of 1.68 mrad. Thyratrons serve as switches used to discharge the stored electrical energy onto the kickers. The advantage of using a thyratron is its very short response time of about $1\mu s$ allowing an abort gap of less than 8% of one RHIC revolution. However, RHIC experiences a varying number of thyratron prefires every year [1]. When a prefire happens, about 10% of the stored beam will get lost outside of the dump area and may damage the detectors due to secondary particles created in the low β insertion triplets. In the 2012 Cu-Au operation, one abort kicker prefire destroyed the MPC, a detector component of PHENIX. In the 2015 p-Al run, the same MPC detector got destroyed again over the course of two prefires while another detector componenct, the VTX, showed signs of damage.

In the 2016 Au-Au run, to prevent the unacceptable amount of particle flux into the detectors in case of a prefire, we installed horizontal orbit protection bumps in the arcs of each ring [2] as shown in Fig. 1. The s-coordinate is calculated clockwise from IP6. The maximum amplitude of these bumps reached 20 mm. To compensate the optics distortion, a compensation bump is included in the adjacent arcs. The maximum amplitude of the compensation bumps is smaller than that of the protection bumps. Originally, the arc between IP10 and IP12 accommodated two bumps, one from each ring.

With those protection bumps in place, we started to observe single event upsets of the in-tunnel network node cards in equipment alcoves close to where these bumps are. These upsets are due to chronic radiation from losses in the bump area. After 4 weeks of physics operation, a diode of a superconducting dipole magnet in the arc between IP10 and IP12 was partially shorted. Physics operation was interrupted for 19 days to replace the diode. Before beam operation was restored, we moved the protection and compensation bumps in the Blue ring to the arcs between IP2 and IP6.
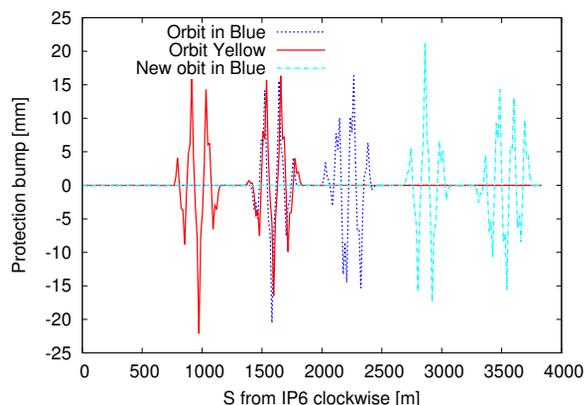

Figure 1: Protection bumps used in the 2016 Au-Au run.

PARTICLE LOSS MECHANISM

Without above protection bumps, the loss rate of the design particles $^{197}Au^{79+}$ is determined by the off-momentum dynamic aperture. Since 2012, the standard lattices with a working point (28.23, 29.22) have been used [3]. The β^*s at IP6 and IP8 are 0.70 m. Thanks to 3-d stochastic cooling, particle loss from luminosity production can be more than 90% of all losses [4]. Due to a new bunch merging scheme, the average $^{197}Au^{79+}$ bunch intensity increased from 1.4×10^9 in 2014 to 1.85×10^9 in 2016.

For collisions of $^{197}Au^{79+}$ particles at 100 GeV, the total calculated cross section is 218 b [4]. The largest contributions to the cross section are not from overlapping of the colliding ions but from two electromagnetic processes: bound free electron positron pair (BFPP) production and electromagnetic dissociation (EMD) of the nucleus. The analytically calculated cross sections for those two processes are 117 b and 98 b. BFPP generates $^{197}Au^{78+}$, while EMD generates $^{196}Au^{79+}$.

Compared to $^{197}Au^{79+}$, the relative momentum deviations for $^{197}Au^{78+}$ and $^{196}Au^{79+}$ are equivalent to 12.7×10^{-3} and -5.1×10^{-3}. However, the acceptance of the RF systems for $^{197}Au^{79+}$ is falling short with only $\pm 1.8 \times 10^{-3}$. Since these particles are related to the design $^{197}Au^{79+}$ collision, chronic losses will be seen during the physics run. These losses are illustrated in particle loss maps.

PARTICLE LOSS MAP

$^{197}Au^{78+}$ and $^{196}Au^{79+}$ particles are generated at the interaction points IP6 and IP8. They initially have the same transverse distributions as $^{197}Au^{79+}$. Since losses due to momentum deviation is a horizontal process, we only focus on the horizontal particle motion in our simulation.

A 6-d symplectic element-by-element particle tracking code SimTrack [5] is used for this study. RHIC physical apertures are incorporated. The tightest physical apertures are located in IR6, IR8 and IR2. In the simulation we consider a particle lost when it hits the beam pipe wall. We divide the RHIC ring into 600 equal-distant segments and count particles lost in each segment. Two Masks were used in 2016 to intercept $^{197}Au^{79+}$ from abort kick prefires. They are not included in the simulation.

Loss Map of $^{197}Au^{78+}$

With a large initial relative momentum deviation, $^{197}Au^{78+}$ cannot survive a single turn. In the simulation, 10000 macro-particles are generated with the exact Gaussian horizontal particle distribution as $^{197}Au^{79+}$ at IP6 and IP8. These macro-particles are tracked up to 1000 turns. For $^{197}Au^{78+}$ generated at IP6, 91% of them get lost in the area 1524 ± 3 m. For $^{197}Au^{78+}$ generated at IP8, 95% of them get lost in the same area. Fig. 2 shows the loss map of $^{197}Au^{78+}$ in the Blue bump areas. Both losses of $^{197}Au^{78+}$ generated from IP6 as well as IP8 are included. Highlighted by high losses (red vertical line), the area s=1524±3 m is the exact location where the maximum positive horizontal orbit bump is.

$^{197}Au^{78+}$ cannot survive a single turn in the Yellow ring either. For $^{197}Au^{78+}$ generated at IP6, 82% of them get lost in the area 1657 ± 3.2 m. For $^{197}Au^{78+}$ generated at IP8, 51% of them get lost in the area 1690 ± 3.2 m. Another 13% and 14% of $^{197}Au^{78+}$ get lost at the areas of 2342 ± 3.2 m and 3677 ± 3.2 m respectively. The area of 1657 ± 3.2 m is the exact location of the maximum positive orbit of the compensation bump in the Yellow ring. Fig. 3 shows the loss map of $^{197}Au^{78+}$ in the Yellow ring.

Loss Map of $^{196}Au^{79+}$

Compared to $^{197}Au^{78+}$, it takes a longer time for $^{196}Au^{79+}$ to get lost due to its smaller initial relative momentum deviation. In one simulation, for an initial horizontal Gaussian distribution of $^{196}Au^{79+}$, only 11% of them get lost in the first 10000 turns. To save computing time,
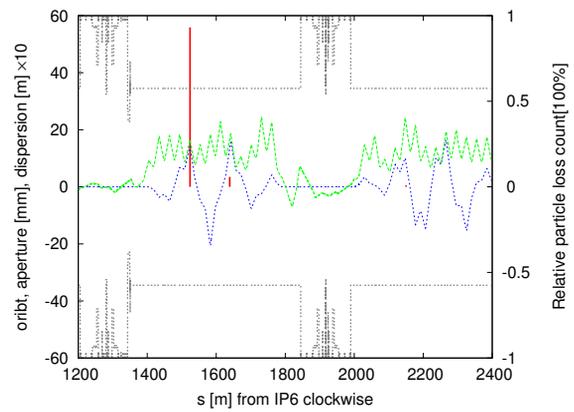

Figure 2: $^{197}Au^{78+}$ loss map in the Blue ring.

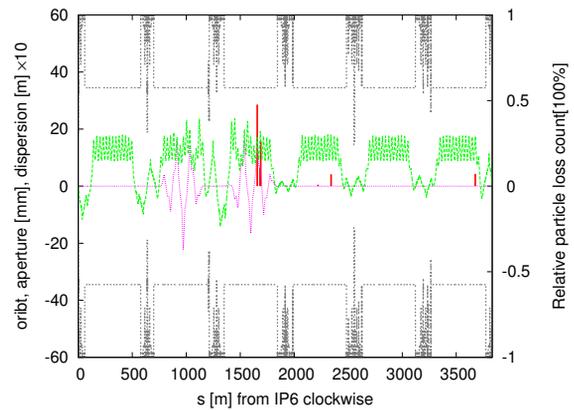Figure 3: $^{197}Au^{78+}$ loss map in the Yellow ring.

in the following we only track $^{196}Au^{79+}$ particles with an initial $3\ \sigma_x$ up to 1000 turns. These particles are initially uniformly distributed on the normalized horizontal phase space circle.

Of the $^{196}Au^{79+}$ particles generated at IP6 in the Blue ring, all get lost in 1000 turns at the area 1581 ± 2 m, which is the exact location of the maximum negative orbit bump in the Blue ring. Of the $^{196}Au^{79+}$ ion generated at IP8, 90% get lost in the first 1000 turns at the same area 1581 ± 2 m as can be seen in Fig. 4.

For the $^{196}Au^{79+}$ particles generated in the Yellow ring, it takes an even longer time to get lost than in the Blue ring. This may be caused by different phase advances between the physical aperture bottlenecks and the IPs. For $^{196}Au^{79+}$ particles generated at IP6, 14% of them get lost in 1000 turns in the area 973 ± 2 m. Of $^{196}Au^{79+}$ particles generated at IP8, 14% get lost in 1000 turns at the area 973 ± 2 m, another 8% and 3% are lost in the areas 1000 ± 2 m and 1248 ± 2 m respectively. The loss map is shown in Fig. 5.

From the above loss map calculations, the area which got the most radiation is the area from 1581 m to 1658 m. Most of $^{197}Au^{78+}$ from both rings and $^{196}Au^{79+}$ from the Blue ring get lost in this area. The shortened diode is located at 1625 m, which is in the most radiated area.
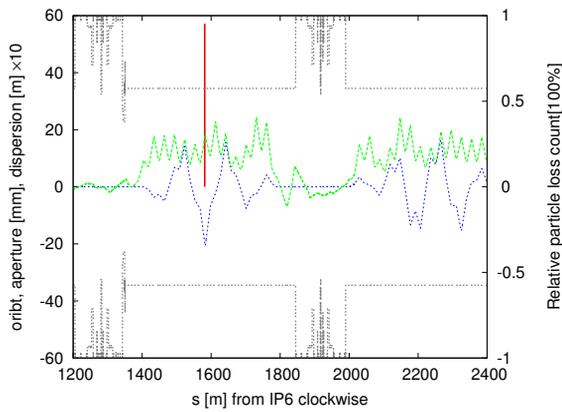
01 Circular and Linear Colliders

A01 Hadron Colliders
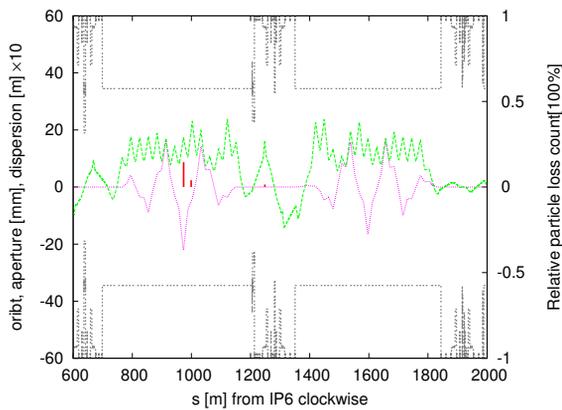
Figure 4: $^{196}Au^{79+}$ loss map in the Blue ring.

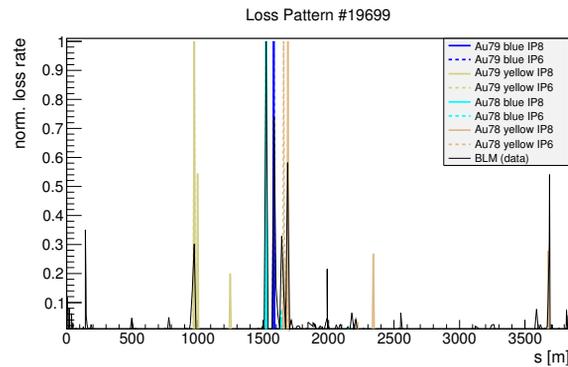Figure 5: $^{196}Au^{79+}$ loss map in the Yellow ring.

Figure 6: Comparision of BLM readings with beam loss maps from simulation.

Figure 6 compares the all above simulated loss maps with real beam loss monitor (BLM) readings from one fill, 19699. The black line corresponds to the BLM data. Simulation reproduces the large beam losses at the area from 1581 m to 1658 m. However, there are two peaks at 1250 m and 2250 m from simulation that are not reproduced by the BLM data. This can be explained by particles actually getting lost before reaching those places. This indicates that the physical aperture model used in simulation needs to be improved.

With New Bumps

After the replacement of the shortened diode, to minimize the beam loss in the arc between IP10 and IP12, we intentionally moved the Blue protection and compensation orbit bumps to the arcs between IP2 to IP6. In addition, we shifted the maximum of the protection bump in the Yellow ring by one FODO cell. Fig. 7 shows the loss map of $^{197}Au^{78+}$ in the Blue ring with the new orbit bumps. 99% of $^{197}Au^{78+}$ generated at both IPs get lost in the area 2859 ± 2 m, where the maximum positive orbit bump is. The new bump relocated the particle loss and therefore reduced the radiation dose in the area of the shortened diode (1581 m to 1658 m).
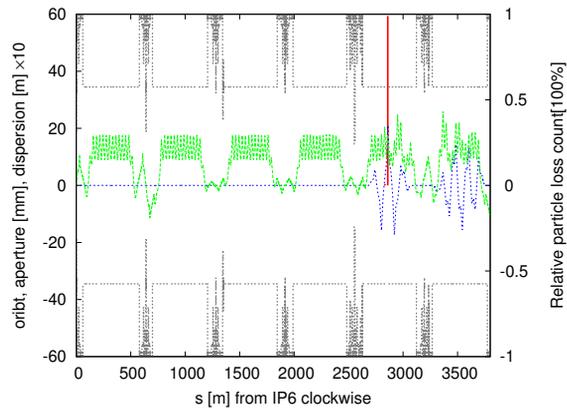

Figure 7: $^{197}Au^{78+}$ loss map with new Blue ring orbit bumps.

SUMMARY

During collisions of 100 GeV $^{197}Au^{79+}$, $^{197}Au^{78+}$ from BFPP and $^{196}Au^{79+}$ from EMD are generated. Due to their large momentum deviation with respect to $^{197}Au^{79+}$, they will get lost and present a chronic radiation source in both rings. The loss maps of $^{197}Au^{78+}$ and $^{196}Au^{79+}$ in both rings were calculated through numerical simulation and were compared to operational observations. Simulation shows that the shortened diode is located in the most radiated area with the old bumps. Moving the Blue orbit bumps to the arcs between IP2 and IP6 successfully reduced the particle loss in the area of the damaged diode.

REFERENCES

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