A Study of Betatron and Momentum Collimators in RHIC *

D. Trbojevic, A.J. Stevens, M.A. Harrison, F. Dell, and S. Peggs
Brookhaven National Laboratory, Upton, NY, 11973, USA

Abstract

The Relativistic Heavy Ion Collider (RHIC) has two interaction regions where β^*=1-2m, with large detectors PHENIX and STAR. The transverse and longitudinal emittances are expected to double in size between one to two hours due to intra-beam scattering which may lead to transverse beam loss. Primary betatron collimators are positioned in the ring to allow efficient removal of particles with large betatron amplitudes. We have investigated distributions and losses coming from the out-scattered particles from the primary collimators, as well as the best positions for the secondary momentum and betatron collimators.

1 INTRODUCTION

A primary goal of the Relativistic Heavy Ion Collider (RHIC) is to provide collisions of heavy-ions at six interaction regions (IR). Two IR are designed to be at a β^*=1-2 m to allow for luminosities of the order of L=$10^{27} cm^{-2} s^{-1}$. Two large detectors, STAR and PHENIX, are located at the high luminosity regions. The strong focusing quadrupoles at opposite sides of these two IP-s are the limiting apertures due to the large betatron amplitude functions of the order of $\beta \sim$ 1500 m. There will be collisions between different ion species as well as between polarized protons. The six dimensional emittance of the heavy ion beams is expected to double in size due to intra-beam scattering between one to two hours. Particle amplitudes can also grow due to other effects like beam gas interaction, beam diffusion due to the nonlinear beam dynamics etc. This results in beam loss at limiting apertures at the triplet magnets close to the large detectors. This beam loss created hadronic showers which leads to larger than desirable backgrounds in detectors. To reduce this background it is necessary to scrape the unwanted beam. The primary betatron collimator has to be able to remove particles with large amplitudes. This report studied the distribution of scattered particles from the primary collimators and their propagation throughout the RHIC accelerators. The optimum location for the secondary betatron and momentum collimator are reported.

2 PRIMARY COLLIMATORS

Positions of the primary collimators in the two (*blue* and *yellow*) rings are downstream of the large PHENIX detector at locations with high β value. The efficiency of the betatron collimator depends on the value of the betatron amplitude function. The best possible location is immediately downstream end of the high focusing quadrupoles where $\beta \sim$1000 m. Interaction of the gold ion and proton beams with the collimator target has been performed by using a computer code written by Van Ginneken [1]- [2]. The out-scattered particles were obtained in two steps:
-The betatron amplitude of particles in the ring is increased by a diffusion process based on measurements at the SPS-CERN [3]. The amplitude grows continuously if it reaches amplitudes larger than 4 σ.
The upstream edge of the collimator is set at 5.5 σ with a slope which corresponds to the betatron function slope. The emittance of the heavy-ions (gold) is assumed to be 40 π mm mrad, and 20 π mm mrad for the proton beam. The particles' orbit is tracked through the 0.45 m long collimator. Any orbit which emerges from the collimator without having inelastically interacted creates an initial particle distribution for further studies. Figure 1 represents the initial horizontal phase space of the gold ions orbits at nominal energy of 100 GeV/nucleon scattered from the primary collimator. The angle of the scattered ions is very narrow (as shown in 1).

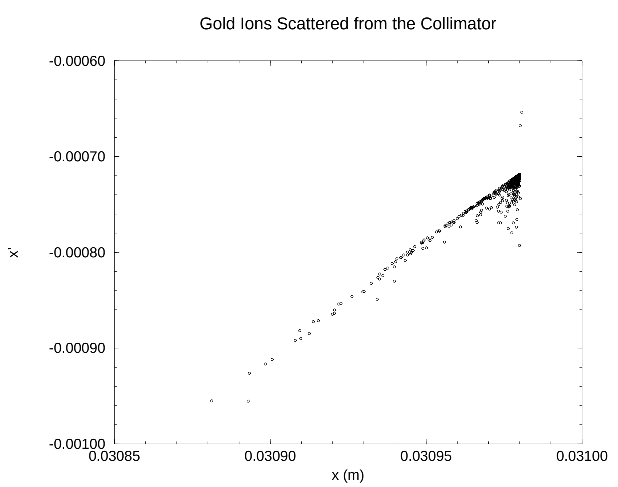

Figure 1: Initial distribution of gold ions scattered from the primary collimator

The momentum distribution of the scattered particles from the collimator shows (see Figure 2) that a large number of particles have momentum offsets much larger than the projected RHIC bucket size at storage $\sigma_p \pm 0.2\%$.

3 PHASE SPACE DISTRIBUTION OF THE SCATTERED PARTICLES

This initial particle distribution was then used as input for the tracking program TEAPOT [4]. The tracking was performed with the systematic and random multipoles within

* Work performed under the auspices of the U.S. Department of Energy

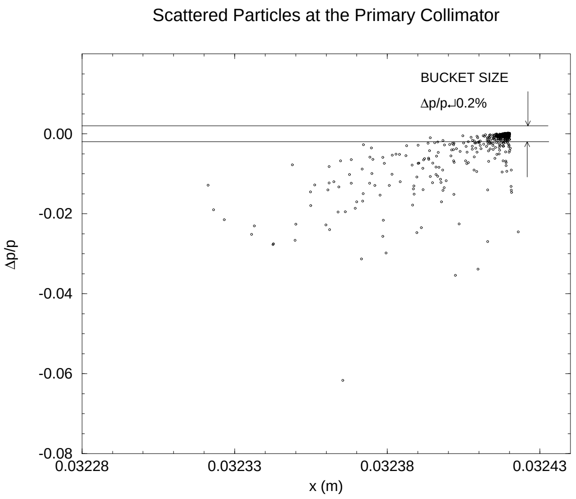

Figure 2: Initial momentum distribution of gold ions scattered from the primary collimator versus horizontal position.

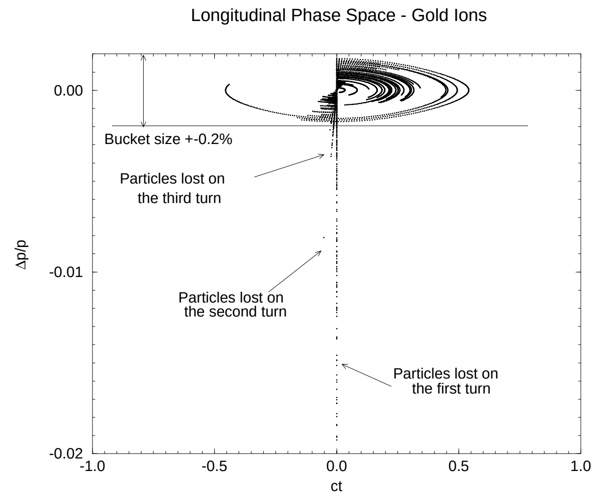

Figure 3: Longitudinal tracking

the quadrupoles and dipoles obtained from the measurement data, at the top energy of 100 GeV/nucleon for gold or 250 GeV for protons and for 256 turns. The misalignment and roll errors were estimated from the surveying data. The rms values for misalignment used for the arc quadrupoles were Δx,y=0.5 mm $\Delta\theta$=0.5 mrad, while from the measurements of the triplet quadrupoles the roll and misalignment errors for the rms values were $\Delta\theta$=0.5 mrad and Δx,y=0.5 mm.

3.1 Longitudinal Phase Space

During tracking the RF voltage was included and the longitudinal motion of the surviving particles was monitored. Particles with momentum offsets within the bucket size limit executed synchrotron oscillations. Particles projections in the longitudinal phase space show in Figure 3 that only particles within the bucket survive. Only few particles, which survived all 256 turns, finished almost one synchrotron oscillation. The phase space, shown in 3, is at the location downstream of the primary collimator.

3.2 Transverse Phase Space Distribution

The transverse positions of the scattered particles on the first turn show that most of the particles with large momentum offsets, are lost around the first bending elements. The particle distributions at different locations are presented in the normalized phase space:

$$\xi = \frac{x}{\sqrt{\beta}} \quad and \quad \chi = x'\sqrt{\beta} + \frac{x\alpha}{\sqrt{(\beta)}} \tag{1}$$

Locations with the betatron phase differences of $\sim 30^o, 165^o$ with respect to the position of the primary collimator, have been shown to be preferable [5] positions for the secondary scraper. One of the suitable positions (*Q9-D9 in th RHIC lattice*) for the secondary collimator is shown in Figure 4. The phase difference is 165^o.

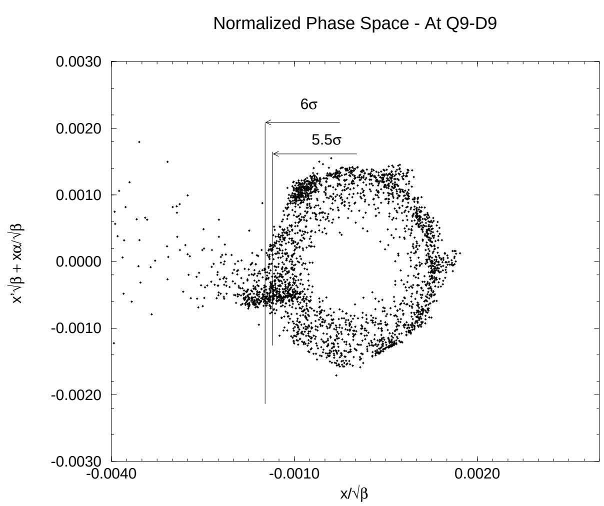

Figure 4: Possible position of the secondary collimator

3.3 Particles'momenta at the secondary scraper

Figure 5 represents projections of the particles positions at the possible secondary collimator but in a different space. The horizontal axis represents particles' momenta, while the vertical axis is chosen for their horizontal positions. This plot shows another advantage of having the secondary scraper at this location. When the secondary scraper is set to a horizontal offset larger than 7σ, particles out of the bucket are eliminated. It should be noted that the dispersion function has a large value at this location.

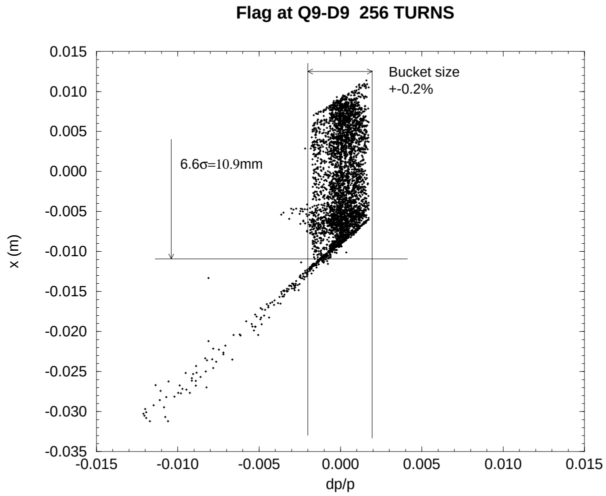

Figure 5: Horizontal positions of gold ions scattered from primary collimator at the secondary collimator with respect to their momenta.

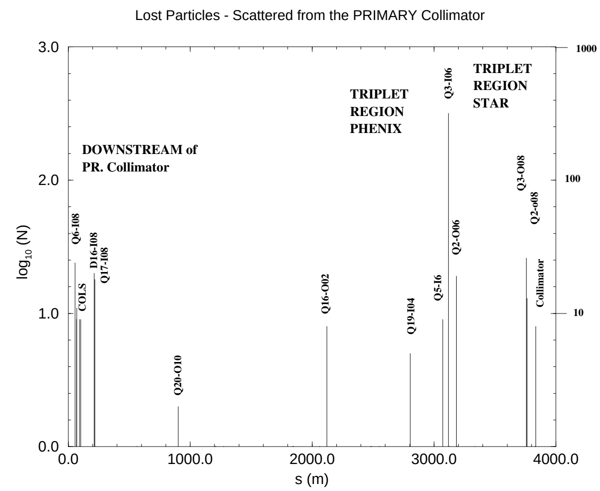

Figure 6: Losses around the ring from the primary collimator

4 BEAM LOSS LOCATIONS IN THE RING

The primary betatron collimators will reduce the background at the RHIC detectors, eliminating particles with the large betatron amplitudes. On the other hand the scattered particles from the primary collimator could influence the background if they get lost upstream of the detectors. At the large detectors with $\beta^* = 1m$ the strong focusing quadrupoles have their effective apertures reduced, due to the large values of the β functions. The losses of the scattered particles from the primary collimator occur at these quadrupoles, as shown in Figure 6. The lost particles are presented on a logarithmic scale. Figure 6 also shows losses at a set of magnets downstream of the primary collimator which are mostly due to the large momentum offset particles. The largest number of lost particles is at the strong focusing quadrupoles.

5 CONCLUSIONS

The primary collimators in RHIC are important for many reasons:

- To remove the beam halo and reduce the background noise for the detectors.
- As a very good tool for beam diagnostics [5]: acceptance measurements, transverse particle distribution of the beam, frequency analysis of the beam loss rate, etc.

A combination of the primary and secondary betatron collimators can be used to remove not only the scattered particles from the primary collimator but also to remove particles out of the buckets. The secondary betatron collimators are effective only if the betatron phase difference between the two scraping stages is correctly chosen. Efficient momentum collimation [6] had already been reported at the same location, as it is the optimum position of the secondary betatron collimator (found in this study). It would be possible to create *macro buckets* with the use of the RHIC 28 MHz cavities to trap the particles outside of the buckets and scrape them [6]. The secondary collimator position determined in this study removes particles with large momentum offsets scattered from the primary collimator. It should be noted that losses from the primary collimators will still be the same in the region between primary and secondary collimators. The spray at the triplets with the high values of β functions exists although it is significantly reduced.

6 REFERENCES

[1] A.Van Ginneken, *Elastic scattering in thick targets and edge scattering*, Physical Review D, Vol. 37, number 11, 1 June 1988, pp.3292-3307.

[2] A.Van Gineken, *ELSHIM, Program to simulate Elastic Processes of Heavy Ions*, BNL-47618, AD/RHIC-100, Informal Report, May 1992.

[3] W. Fischer, M. Giovannozzi and F. Schmidt, "Dynamic aperture experiment at a synchrotron", Phys. Rev. E, Vol. 55, Number 3, p. 3507 (1997).

[4] L.Schachinger and R. Talman, *A Thin Element Accelerator Program for Optics and Tracking*, SSC Central Design Group, Internal Report SSC-52 (1985).

[5] M. Seidel, *The Proton Collimation System of HERA*, Dissertation, DESY 94-103, June 1994, Hamburg 1994.

[6] S. Peggs and G.F. Dell, *Momentum Collimation at Q9*, Report-no:RHIC/AP/78, November 1995