BEAM DIFFUSION MEASUREMENTS AT RHIC *

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Abstract

During a store, particles from the beam core continually diffuse outwards into the halo through a variety of mechanisms. Understanding the diffusion rate as a function of particle amplitude can help discover which processes are important to halo growth. A collimator can be used to measure the amplitude growth rate as a function of the particle amplitude. In this paper we present results of diffusion measurements performed at the Relativistic Heavy Ion Collider (RHIC) with fully stripped gold ions, deutrons, and protons. We compare these reults with measurements from previous years, and simulations, and discuss any factors that relate to beam growth in RHIC.

1 INTRODUCTION

The understanding of beam halo is important for current and future accelerators. Beam halo can be a major source of detector background. Halo can also reduce component lifetime through induced radiation. Understanding beam halo is very impartant for the next generation of accelerators[1]. In superconducting machines, significant halo can induce magnet quenches. All of these effects can ultimately limit accelerator performance by reducing the amount of beam than can be injected.

Beam halo grows because various processes slowly move particles from the core of the beam into the halo. One way to measure this halo growth is using a collimator to measure the diffusion rate of the beam. By measuring the loss rate at a collimator after it moves relative to the beam, it is possible to reconstruct the diffusion coefficient as a function of the particle action. In this paper we discuss experiments carried out at RHIC to measure the diffusion coefficient with gold, deuteron, and proton beams at $100\ \mathrm{GeV/u}$.

2 THEORY

The theory of how to measure beam diffusion with a collimator is treated in detail in references [2]and [3]. A shortened treatment is given here. The diffusion equation is

$$\frac{\partial}{\partial t} f(J,t) = \frac{1}{2}\frac{\partial}{\partial J} B(J) \frac{\partial}{\partial J} f(J,t) \quad (1)$$

where $f(J,t)$ is the beam distribution as a function of the particle action J and time, and $B(J)$, given by

$$B(J) = \frac{< \Delta J^2 >}{\Delta t} \quad (2)$$

is the diffusion coefficient to be measured. $B(J)$ is generally postulated to be a monomial. If it is assumed that only particles that are initially close to the collimator will eventually hit the collimator, or equivalently, that $B(J)$ is not "too large", then near the collimator $B(J)$ can be written,

$$B(J) = b_0 \left(\frac{J}{J_c}\right)^n \quad (3)$$

where J_c is the action of a particle that just touches the collimator, $J_c = x_c/\sqrt{2\beta}$, x_c is the distance between the collimator and the beam center, and β is the β function at the collimator. $b_0 = b{J_c}^n$ is the diffusion coefficient at $J = J_c$. Assuming that $f(J_c,t)$ vanishes at the collimator, and that $f(J_c,0)$ increases linearly away from the collimator, then the left hand side of Eqn. 1 is just the particle loss rate due to the collimator, $\dot{N}(t)$. For actions near the collimator action, $B(J \approx J_c) \approx b_0$ one can introduce the variables

$$z = \frac{J_c - J}{J_c} \quad (4)$$

$$R = \frac{b_0}{2{J_c}^2} \quad (5)$$

the fractional change in the collimator action, and the normalized diffusion rate to be determined by a fit, and solve Eqn. 1 for the loss rate at the collmator. For the instance when the collimator moves towards or away from the beam, one obtains:

$$\dot{N}^{(1)}(t) = a_0 \left\{1 + \frac{\Delta z}{\sqrt{\pi R(t-t_0)}}\right\} + a_1 \quad (6)$$

$$\dot{N}^{(2)}(t) = a_0\, \mathrm{erfc}\left(\frac{\Delta z}{\sqrt{4R(t-t_0)}}\right) + a_1 \quad (7)$$

$\Delta z = 2|\Delta x_c|/x_c$ is the absolute change in z due to the change in collimator position Δx_c, a_1 is the count rate from background or an activated collimator, measured when the collimator is fully retracted, and a_0 is an arbitrary constant. By fitting one of these solutions to the loss rate after moving the collimator, it is possible to obtain the normalized diffusion coefficient R and then $B(J_c) = 2{J_c}^2 R$. Sampling over many collimator positions, it is possible to reconstruct the diffusion coefficient for the beam halo.

3 EXPERIMENT

The RHIC collimaton system is shown in Fig. 1. The collimators are $450\ \mathrm{mm}$ long copper blocks with an inverted L shape residing downstream of the PHENIX detector in both the blue (clockwise) and yellow (counter–clockwise) rings. Downstream of each collimator there are

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four PIN diodes that are used to monitor the beam losses due to the collimator. The crystal collimator and its associated detectors were not used for these studies.

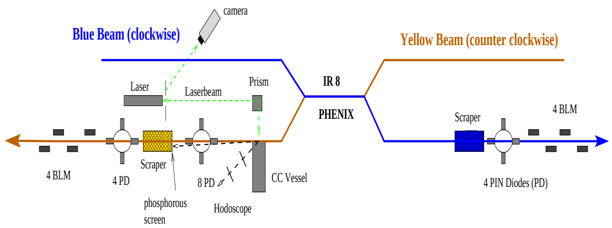

Figure 1: The RHIC collimation system

The collimators were inserted into the beam and rotated to align the face of the collimator to the beam to minimize the secondary halo due to particles scattering from the collimator. Then the collimator was stepped horizontally into and out of the beam varying the collimator position and the stepsize. This way, various actions are sampled, and self-consistancy is checked by using different step sizes and/or directions to measure at the same action.

Fig. 2 shows the loss rate at the PIN diodes for the collimator moving toward and away from the beam with fits to the data. The left picture shows how the losses respond with the collimator moving toward the beam. An inital scraping of the beam occurs as it contacts the collimator, with a reduction in the losses to a steady state as beam is removed. The right picture shows the losses when the collimator is moved away from the beam. Diffusion slowly pushes particles toward the scraper, eventually filling up the availible space in typically $30s$.

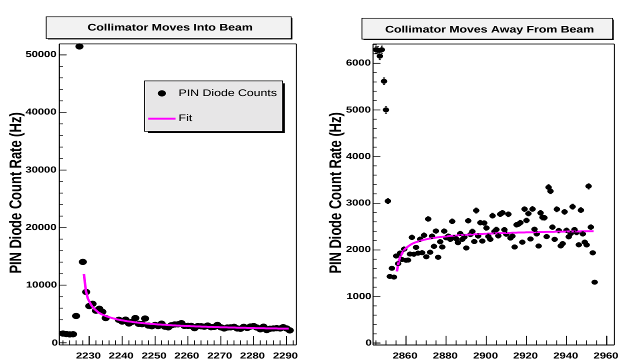

Figure 2: The effect of the collimator motion on beam loss rates with fit.

For each type of movement of the collimator, the loss rate is fit to either of Eqns. 6 or 7. As one can see from Fig. 2, the fit to the loss rate when the collimator is retracted yields a higher R value than the data indicate. This was found in some fills during the last RHIC run as well [3].

The normalized diffusion coefficient, R is averaged over the four PIN diodes. This is used to reconstruct $B(J_c)$ and the results are fit to $B(J) = b_0 J^n$. Fig. 3 shows the reconstuction of the $B(J)$ for fill 02797. The horizontal and vertical error bars are dominated by the uncertainty in the collimator action. This uncertainty is equally due to the uncertainty in the distance between the collimator and the beam and the knowledge of the β function at the collimator [4].

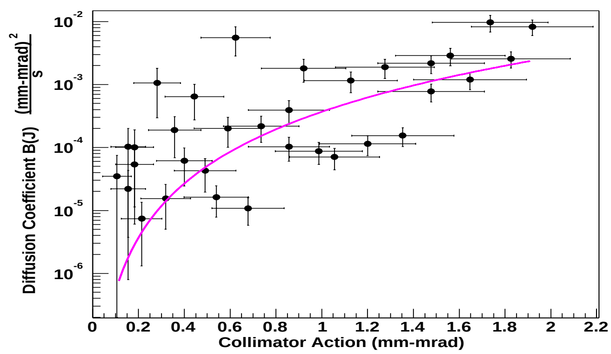

Figure 3: Reconstructed diffusion coefficient for Fill 02797. Note the vertical axis has a log scale.

Fig. 4 shows the reconstructed diffusion coefficient for the first data set of Fill 03155. There is a large variation in the diffusion coefficient for this data set that is not yet understood.

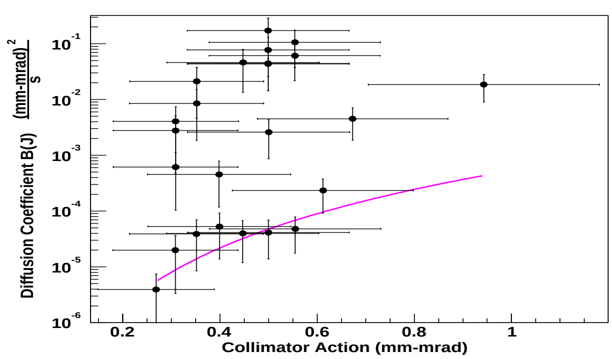

Figure 4: Reconstructed diffusion coefficient for first data set of Fill 03155. Note the vertical axis has a log scale.

4 RESULTS

Table 1 shows the preliminary results of the fits for all runs. There are two data sets missing from the analysis. Both were taken in the blue (clockwise) ring of RHIC with a deuteron beam. Because of a missing BPM and time contraints it was not possible to analyze the data. For Fill 03155, two data sets were taken, the first immediately after the ramp to storage energy. The second was taken two and a half hours later. For this fill, the diffusion measurement was done in the vertical plane because of an oscillation of the beam orbit caused by the AGS Booster cycle seen in

Table 1: Results of Fit to $B(J) = bJ^n$

Store Number	Year	Ring	Beam	b μm^{2-n}s^{-1}	n
01413	2001	yellow	Au	0.17 ± 0.09	10.3 ± 1.2
02797(i)	2003	yellow	Au	$(3.6 \pm 0.8) \times 10^{-4}$	2.8 ± 0.3
02959	2003	yellow	Au	0.0081 ± 0.0014	8.3 ± 0.8
03155-01	2003	yellow	Au	$(5.3 \pm 4.4) \times 10^{-4}$	3.5 ± 1.0
03155-02	2003	yellow	Au	1.8 ± 1.12	8.7 ± 0.8
01874(i)	2002	yellow	p	0.045 ± 0.026	8.5 ± 1.5
01924(i)	2002	blue	p	0.06 ± 0.02	7.0 ± 0.8
02136	2002	yellow	p	7.8 ± 5.5	5.7 ± 0.6
02175	2002	blue	p	0.0036 ± 0.0005	3.0 ± 0.3

(i) indicates injection energy

the horizontal plane. All other measurements were done in the horizontal plane. Three data sets were taken at injection energy.

The data for the 2003 run were fit with a slightly different method than the other data. We are in the process of reanalyzing the data.

We are still in the process of determining the systematic errors and correlations in the data. Fig. 5 shows the distribution of n in all of the data sets. The average $< n >= 5.7 \pm 1.3$ is fairly consistant between the data sets.

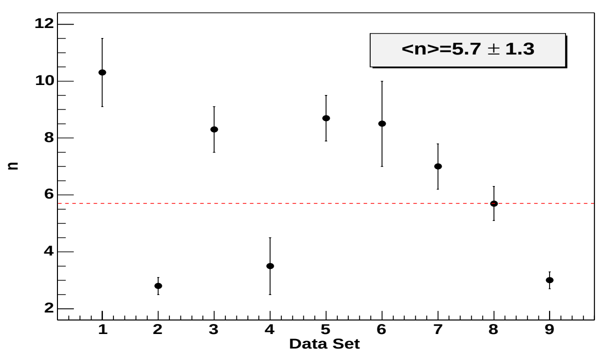

Figure 5: B(J) exponents in same order as Table 1. The dotted line is the weighted average.

The b coefficient generally has a large relative error, this is because of the large error in the action. There seems to be no consistant change in b with different beams. However, there is one interesting correlation. Before the data was taken in Fill 02136, a van der Meer scan was done in the PHENIX IR [5], and before the second data set in Fill 03155, orbit bumps were done through the same IR [6]. Both of these measurements have a large b as compared to all other measurements. In these cases, the beam passes off center through the IR triplet magnets and samples nonlinear magnetic fields. This may cause the relatively large b in these cases. However, we are still investigating other possible reasons such pressure rises, tune shifts, and chromaticity changes.

5 CONCLUSION

Diffusion measurments were performed in RHIC with Au, proton, and deuteron beams. The data does show that n is relatively constant over the variety of measured conditions. Data analysis will continue, with the emphasis on understanding the errors in the measurements and finding correlations between the measurements and the configuration of the machine.

6 REFERENCES

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