BEAM EXPERIMENTS RELATED TO THE HEAD-ON BEAM-BEAM COMPENSATION PROJECT AT RHIC *

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Abstract

Beam experiments have been performed in RHIC to determine some key parameters of the RHIC electron lenses, and to test the capability of verifying lattice modifications by beam measurements. We report the status and recent results of these experiments.

INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) consists of two superconducting storage rings that intersect at six locations around its circumference. Beams collide in interaction points (IPs) 6 and 8, which are equipped with the detectors STAR and PHENIX, respectively (Fig. 1). With the polarized proton working point constrained between $2/3$ and $7/10$ to achieve good luminosity lifetime and maintain polarization, the proton bunch intensity is limited to $2 \cdot 10^{11}$ protons per bunch by the resulting beam-beam tuneshift. To overcome this limitation, installation of an electron lens in IP 10 is foreseen to partially compensate the beam-beam effect and reduce the beam-beam tuneshift parameter [1]. As part of this project, beam experiments are being performed at RHIC to determine key parameters of the electron lens as well as to verify lattice modifications.

BETATRON PHASE ADVANCE MEASUREMENTS

Full compensation of the nonlinear beam-beam effect experienced in the collision with an oncoming proton beam can be achieved by providing collisions with an electron beam of the same density distribution as the oncoming proton beam, with a betatron phase advance of $\Delta\psi = k \cdot \pi$ between the two locations, as schematically depicted in Figure 2.

In the RHIC beam-beam compensation effort, the phase advance between IPs 8 and 10 will be adjusted to the desired value by additional shunt supplies over the main quadrupoles in that arc, such that the electron lens will act as a compensator for the beam-beam effect experienced in IP 8. Operationally, it is desirable to be able to accurately measure this phase advance, rather than having to scan it for best compensation performance.

Since these additional shunt supplies are not yet available at RHIC, we devised an alternate way to test our capabilities of accurately measure the phase advance between IPs 8 and 10. Due to the six-fold symmetry of RHIC, a tune change ΔQ translates into a betatron phase advance change over one arc of $\Delta\psi = 2\pi \cdot \Delta Q/6$. Using the AC dipole, we therefore measured the betatron phase advance for each pair of adjacent BPMs around the RHIC ring, first for the regular working point Q_x and then for a modified tune $Q_x + \Delta Q_x$. Using $\Delta Q_x = 0.1$, the expected change in phase advance over one arc is therefore $\Delta\psi_x = 2\pi \cdot 0.1/6 = 36°/6 = 6°$. As Figure 3 shows, measurements agree very well with our expectations.

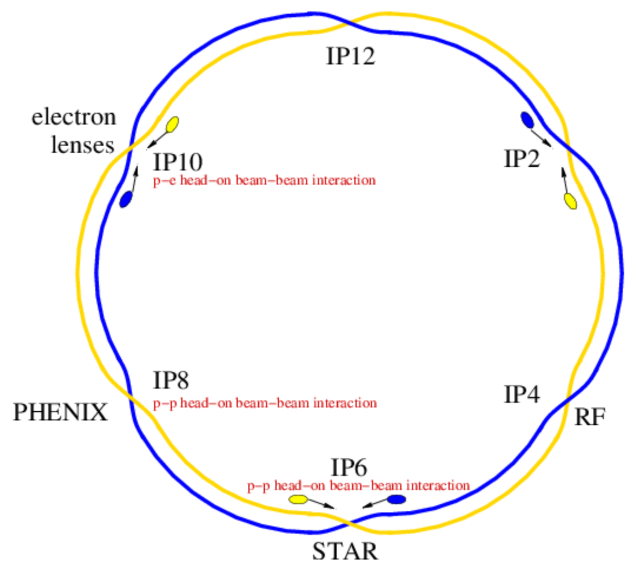

Figure 1: Schematic view of RHIC. Beams collide in IPs 6 and 8. IP 10 will be equipped with an electron lens for head-on beam-beam compensation.

EFFECT OF THE LIMITED CATHODE SIZE

To optimize the head-on beam-beam compensation effect, the transverse distribution of the electron lens beam has to match the Gaussian proton beam distribution. This is achieved by a special design of the electron lens cathode [2]. However, due to the limited size of the cathode the resulting Gaussian electron beam distribution is not Gaussian at large amplitudes and may be approximated by sharp edges, as shown in Figure 4. In the case of the RHIC electron lens, the cathode radius corresponds to 2.8σ of the proton beam. Since sharp edges in beam distributions

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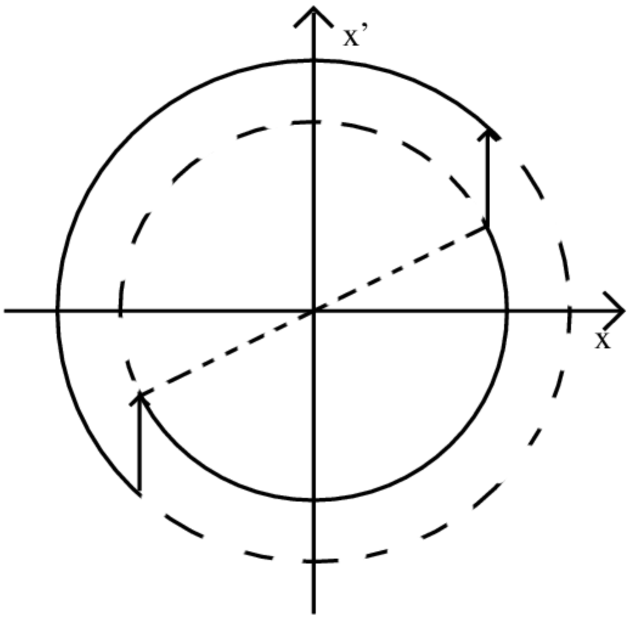

Figure 2: Beam-beam compensation concept. The nonlinear beam-beam kick experienced in the collision with an oncoming proton beam is exactly compensated after a betatron phase advance of 180 degrees by colliding with an electron beam of equal density distribution.

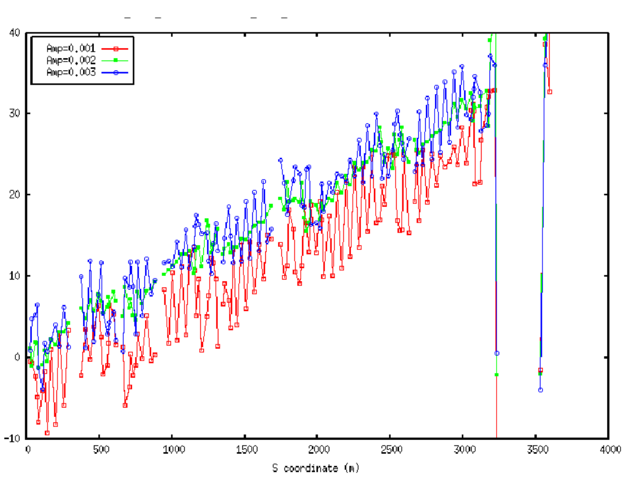

Figure 3: Measured accumulated phase shift $\Delta Q(s) = \Delta\psi(s)/(2\pi)$ around the ring, vs. longitudinal position s.

are known to lead to poor beam lifetime of the oncoming beam, the limited cathode size of the RHIC electron lens is a concern. On the other hand, the number of particles beyond 2.8σ is already very low anyway, and the beam-beam kick of an unlimited Gaussian beam beyond 2.8σ practically shows the same $1/r$ dependency as that of a truncated Gaussian.

To mimick the effect of a truncated Gaussian electron lens beam, two gold beams were brought into collision at injection energy in IP 8. Collimators were inserted into

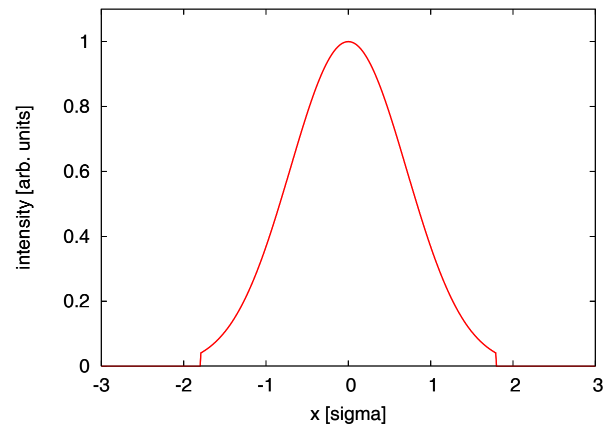

Figure 4: Transverse profile of the Gaussian electron lens beam with its sharp edge at the cathode radius. For better visibility, a cathode radius of 1.8σ is shown here.

the Yellow beam, creating a truncated Gaussian distribution by scraping away the transverse tails, and the Blue beam lifetime was recorded as a function of the Yellow collimator position. Figure 5 shows the results of this experiment.

Before the Yellow collimators were inserted, the Blue beam lifetime was slowly improving after injection, indicated by a slowly decreasing hourly beam loss rate. This improvement stopped abruptly when the collimators reached a position corresponding to 3σ of the Yellow transverse beam size. When the collimators were inserted to 1.5σ, the Blue beam decay increased significantly, though by this time the Yellow beam intensity had dropped to half its initial value. Shortly after the the Yellow collimators were retracted the Blue lifetime began to improve.

This experiment indicates that the truncated electron beam distribution in the RHIC electron lens may have detrimental effects on the proton beam lifetime. However, on two subsequent attempts these results could not be reproduced due to poor lifetime in both beams. It is therefore planned to repeat these tests with proton beams at full energy. This has the advantage of much better beam lifetime, and the effect would be enhanced by the larger beam-beam parameter of protons compared to gold beams.

LOWERING γ_T AT INJECTION

The lattices with the proper phase advance between IP 8 and the electron lenses in IR 10 require modified integer tunes [3]. Since both tunes in the Yellow ring have to be raised by one integer, this will subsequently lead to an increase in γ_t. With proton beams being injected at $\gamma = 25.4$, γ_t this increased transition energy would result in a bucket mismatch between the AGS and RHIC that cannot be compensated by lowering the RF voltage in RHIC. It is therefore necessary to reduce the transition energy at injection by appropriate lattice modifications.

As reported in an earlier paper [4], lowering γ_t can be

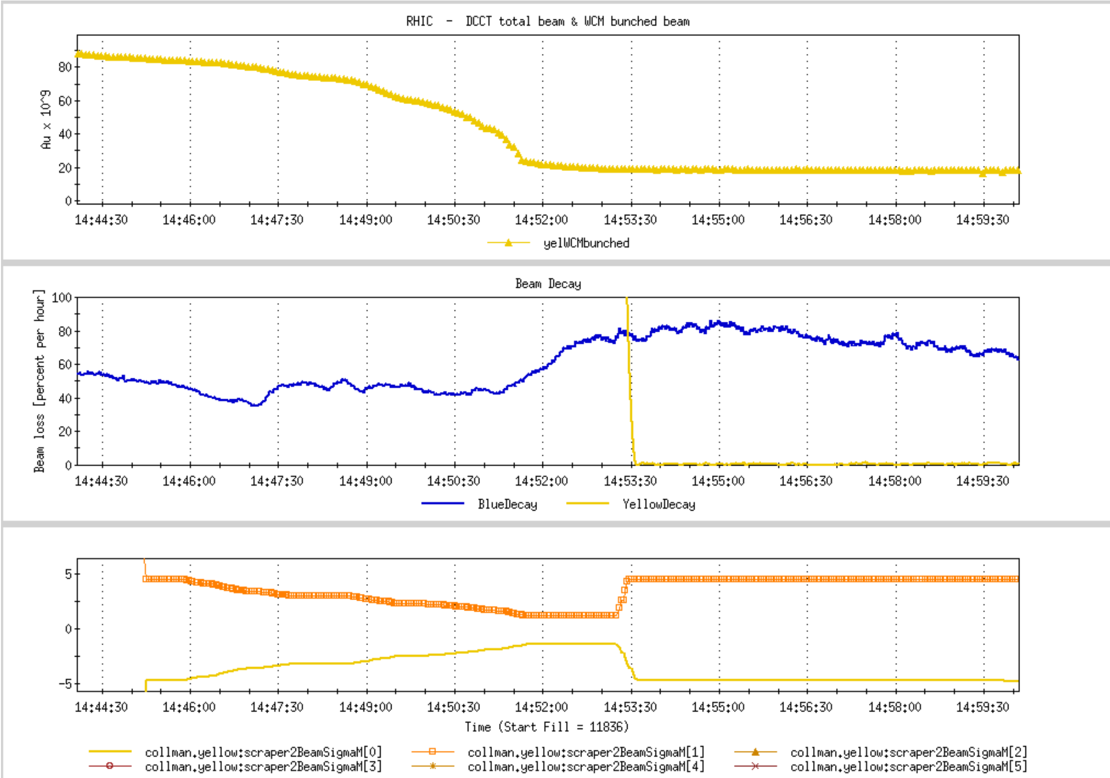

Figure 5: Yellow beam intensity, Blue hourly beam decay, and Yellow collimator position vs. time during aggressive scraping of the Yellow beam.

achieved using the γ_t jump quadrupoles. With the transition energy proportional to the horizontal phase advance in the arcs, where the dispersion function is non-zero, γ_t is lowered by lowering the horizontal phase advance in the arcs. The resulting tune shift is compensated by a set of γ_t quadrupoles in the dispersion-free region at the end of the arcs. In a dedicated beam experiment we were able to reduce the transition energy by $\Delta\gamma_t = -0.35$ relative to its regular value without detrimental effects on beam lifetime due to the associated β-beat; the limitation being imposed by the limited current of the γ_t power supplies.

To further decrease the transition energy at injection, the γ_t jump power supplies could be replaced by regular DC supplies. Since this would also increase the β-beat, additional beam experiments will have to be performed to ensure sufficient beam lifetime. Alternatively, the AGS extraction energy could be raised to $\gamma = 26.0$, at the expense of a two percent decrease in proton beam polarization.

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