HALO CONTROL AND GENERATION IN RHIC *

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Abstract

In the next 5-10 years, RHIC will be colliding gold ions in the center-of-mass energy range of 5 to 20 GeV, which is below the regular injection energy. Though the machine has already successfully provided collisions at CM-energies of 7.7 and 11.5 GeV, a significantly higher luminosity than so far achieved is required for a meaningful physics program. While an electron cooler is presently being designed to provide the desired luminosity gain, this is a long-term project that is expected to be completed in 2018. As a short-term alternative the STAR collaboration has proposed installation of an internal halo target in the STAR detector beam pipe. To study the generation and control of the beam halo, we have performed dedicated beam experiments aimed at the bunch-by-bunch uniformity, and long as well as short-term stability of collimator loss rates.

INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) consists of two superconducting storage rings with a circumference of 3.8 km. In heavy ion collider mode, beams are injected at a rigidity of $B\rho = 81\,\mathrm{Tm}$ and accelerated to $B\rho = 833\,\mathrm{Tm}$ before they are brought into collision in the two detectors STAR and PHENIX. In the case of fully stripped gold ions, these beam rigidities correspond to an injection energy of 9.8 GeV/nucleon and a storage energy of 100 GeV/nucleon.

In recent years, nuclear physicists have become increasingly interested in searching for the critical point in the phase diagram of nuclear matter, which is expected to occur in the center-of-mass energy range between $\sqrt{s_{\mathrm{NN}}} = 5$ and $30\,\mathrm{GeV}$, see Figure 1. To provide collisions in the desired energy range in collider mode, gold beams therefore have to be stored and collided at energies as low as a quarter of the nominal RHIC injection energy, which is extremely challenging due to large multipole errors in the superconducting magnets at these energies, as well as space charge and intrabeam scattering effects.

In 2010, RHIC has been successfully operated at center-of-mass energies of 7.7 and 11.5 GeV per nucleon pair [1]. However, to reach the desired integrated luminosities for the beam energy scan, RHIC would have to operate for a total of 70 weeks at these energies. Furthermore, performance at $\sqrt{s_{\mathrm{NN}}} = 5\,\mathrm{GeV}$ has not yet reached any level sufficient for meaningful physics operations, though beams have already been stored successfully at this energy [2], albeit at tiny intensities, and studies are underway to improve the performance [3].

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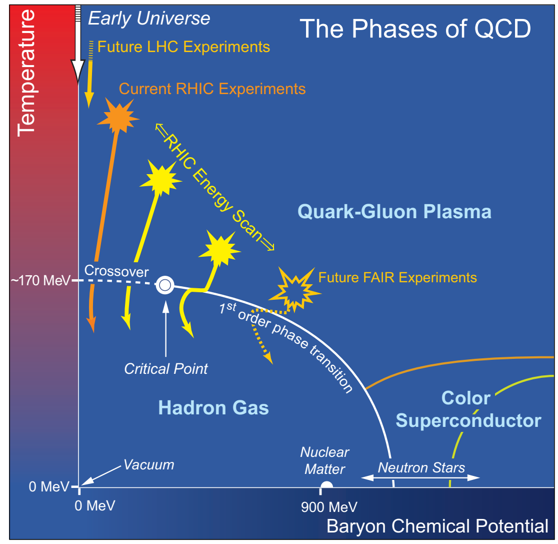

Figure 1: The QCD phase diagram, with the critical point expected in the center-of-mass energy range between $\sqrt{s_{\mathrm{NN}}} = 5$ and $30\,\mathrm{GeV}$.

To improve the luminosity at low energies, an electron cooling system is currently being designed [4]. However, since this new device is scheduled to become operational in 2018, and because the lowest desired beam energy of 2.5 GeV per nucleon may turn out to be outside the useful reach of RHIC, the STAR collaboration has proposed the installation of a thin gold target in their detector area to study low energy gold-gold collisions in fix target mode rather than in collider mode [5].

The proposed internal target consists of a 30 mil (750 μm) thick gold foil that is installed in the RHIC beam pipe 2 m away from the STAR interaction point such that it intercepts the halo of the circulating Yellow beam upstream of the STAR detector, see Figure 2. To avoid potential damage to the target in case of an abort kicker pre-fire, which deflects the beam horizontally, the proposed target geometry is chosen such that it intercepts the beam halo only in the vertical plane. Furthermore, only the lower part of the beam pipe is equipped with the target foil, so in case the foil comes lose it does not drop into the beam path where it could block the aperture.

The aperture of the gold foil target needs to be chosen smaller than the 40 mm inner diameter detector beam pipe to make the target the local aperture limitation. On the

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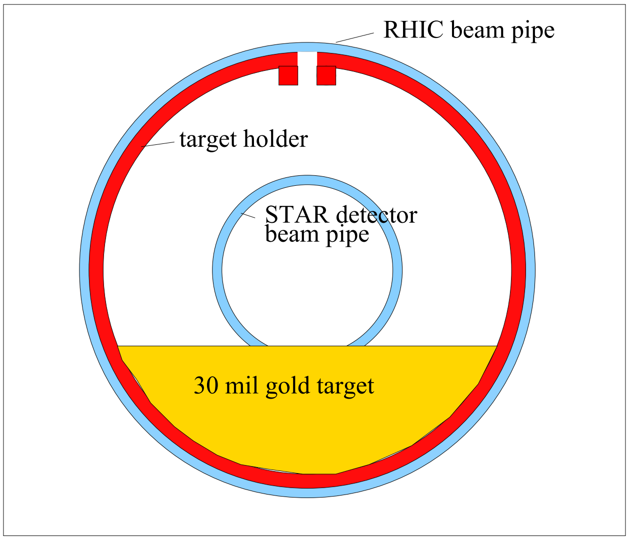

Figure 2: Schematic drawing of the proposed STAR internal target (Not to scale). The target will be installed at a distance of 2 m from the interaction point in the 3 inch inner diameter beam pipe. The aperture of the target is chosen slightly smaller than the 40 mm ID detector beam pipe.

other hand, the target must not interfere with regular collider operation. This can be accomplished by selecting a 16 mm half aperture for the target. This provides sufficient aperture at store as well as at injection, even when taking into account the $\pm 5\,\mathrm{mm}$ separation bumps around the interaction point. In dedicated target mode the target can deliberately be made the limiting aperture by increasing the separation bumps and blowing up the beam emittance.

Operating an internal halo target in a storage ring is challenging for various reasons, as the experience with the HERA-B target has shown [6, 7]. For instance, target interaction rates can vary greatly if the beam position is not stable enough due to mechanical vibrations of accelerator magnets, and/or the diffusion is not sufficient to replenish the transverse tails of the distribution. These large variations in the interaction rates tend to overwhelm the detectors with bursts of interactions, followed by periods without any rates at all, which makes data taking very difficult.

If transverse beam emittances vary greatly bunch-by-bunch, only the few bunches that have the largest emittances contribute to the interaction rates, resulting in similar detrimental effects as orbit jitter, albeit on a much faster time scale.

Finally, since the proposed STAR internal target is not moveable, interaction rate control has to be accomplished by manipulating the beam instead of adjusting the target position. While the target can be made the limiting aperture by applying a larger amplitude separation bump and increasing the emittance, sufficient diffusion has to be created to stabilize the interaction rates. Since the target will only be operated in a dedicated mode no special care has to be taken to preserve the emittance of the beam core for collider operation.

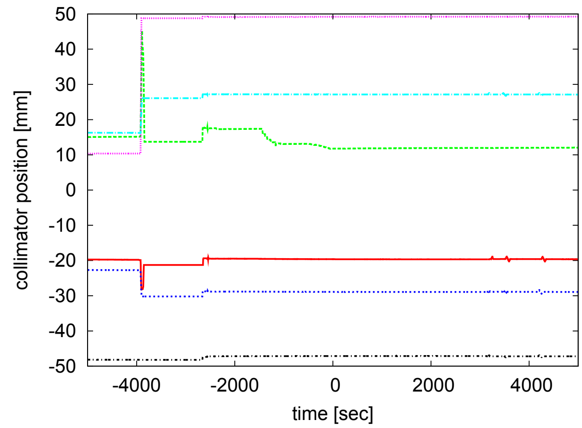

Figure 3: Recorded RHIC collimator positions during the beam experiment. The vertical collimator (green line) reached its final position at 11.5 mm. The horizontal axis is consistent with the one used in Figure 4.

To study the controlability and bunch-by-bunch uniformity of the target interaction rates as well as their stability at typical vibration frequencies up to hundreds of Hertz, beam experiments were performed during the FY 2013 polarized proton run.

EXPERIMENTS

Using the stored polarized proton beam at injection energy, a vertical collimator jaw was inserted into the beam halo until a loss rate of about 100 Hz per bunch was recorded by the local PIN diodes, which corresponds to a total rate of roughly 10 kHz from the 109 stored bunches. The resulting collimator position was measured by the BPMs and the collimator mechanics to be 11.5 mm from the beam center, as shown in Figure 3. With the tunes initially set to $(Q_x/Q_y) = (28.696/29.691)$, collimator loss rate control was attempted by moving the working point closer to the nonlinear resonances at $2/3$ and $7/10$, as shown in Figure 4.

In the first step, the horizontal tune was raised to $Q_x = 28.698$, which had little effect on the collimator loss rate, as can be expected since the collimator intercepts the halo vertically. Next, the vertical tune was raised towards $7/10$ as well, which also moves the working point closer to the coupling resonance. This resulted in the loss rates increasing from 100 to 200 Hz per bunch. However, when the tunes were kept constant at these new values the interaction rate dropped to its initial value within two to three minutes.

Finally, the vertical tune was slowly lowered towards the third order resonance at $2/3$, resulting in a rapid increase of the collimator loss rates as soon as it reached 28.683. Lowering it further to 28.678 raised the loss rates to 400 Hz per bunch. After about two minutes with stable tunes, the loss rate had dropped to 200 Hz per bunch, and remained

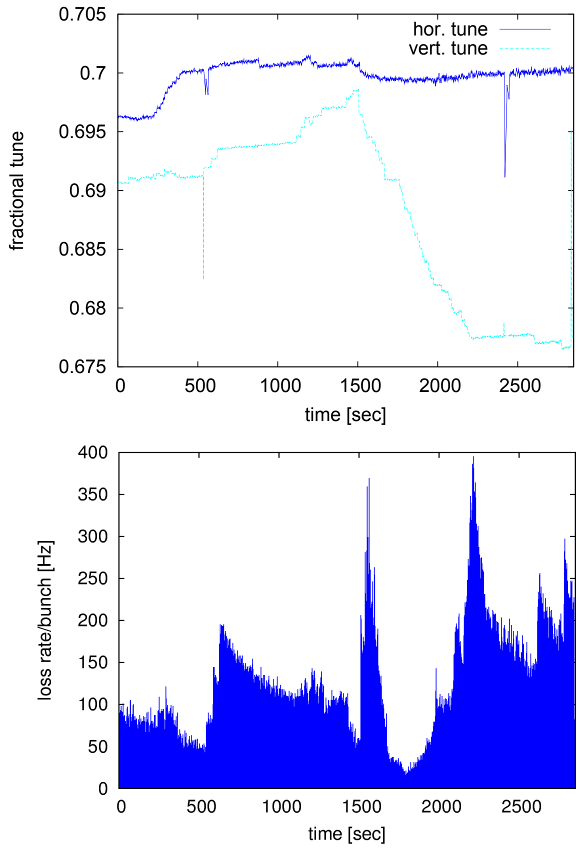

Figure 4: Loss rates during the tune scan. The horizontal scale is consistent with the one used in Figure 3, i.e. the tune scan starts after the collimators have reached their final position.

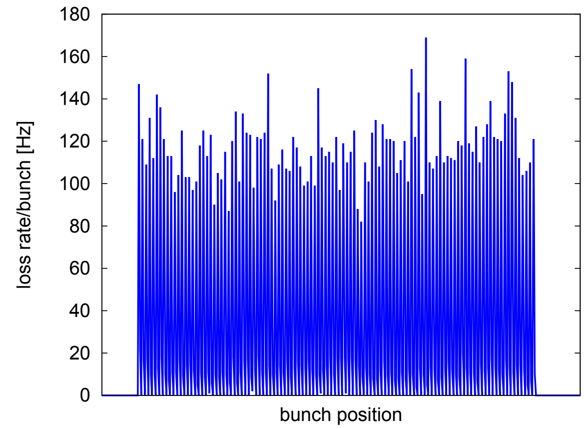

Figure 5: Bunch-by-bunch loss rates at a fixed point in time during the tune scan.

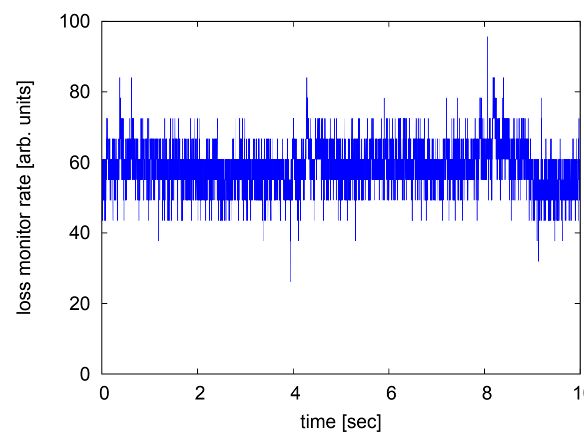

Figure 6: Loss monitor rates in the vicinity of the vertical collimator, sampled at 720 Hz.

reasonably constant there with a slow decrease from 200 to 120 Hz during the next five minutes.

Zooming in on the data during this stable period reveals the bunch-by-bunch structure of the collimator loss rates, Figure 5. As this plot shows, the bunch-by-bunch loss rate is very uniform along the entire train of 109 bunches.

Finally, the short-term stability of the target interaction rate can be studied using RHIC loss monitors in the collimator vicinity sampled at a high frequency of 720 Hz. As Figure 6 shows, the loss rates fluctuate very little over a time scale of 10 sec, indicating that high frequency rate variations due to effects like beam orbit jitter are practically non-existent.

SUMMARY

As these experiments have demonstrated, the interaction rate at the proposed internal target at STAR can be controlled by proper choice of a working point near a low-order resonance, in this case 2/3. While these experiments were carried out with a stored proton beam, the actual physics run will use gold ions. The higher IBS rates of such a gold beam compared to the proton beam used in this test are expected to improve the performance even further, making it possibly unnecessary to continuously move the tune towards a resonance to keep the interaction rate constant.

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