FIRST OPERATIONAL EXPERIENCE WITH AN INTERNAL HALO TARGET AT RHIC *

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Abstract

An internal halo target has been installed in the STAR detector at RHIC to extend the energy range towards lower energies and increase the event rates in the search for the critical point in the QCD phase diagram. We discuss geometric considerations that led to the present target layout and present first operational results.

INTRODUCTION

One of the major RHIC Physics programs is the search for the critical point in the QCD phase diagram depicted in Figure 1. For this purpose gold-gold collisions with a center-of-mass energy in the range from 5 to 30 $\mathrm{GeV/n}$ are required. To achieve these energies in collider mode, RHIC has to operate below its nominal injection energy of 9.8 GeV/n.

Operating at such low energies is challenging for a number of reasons. Beam emittances are large and therefore limit the achievable β-functions at the interaction point (IP) due to aperture limitations in the low-β triplets, resulting in low luminosity. Large space charge tune shifts in conjunction with beam-beam effects limit the bunch intensities and require operation at a near-integer working point [1]. Multipole errors in the accelerator magnets are large, and not known very well outside the nominal energy range of the machine.

During the first phase of the beam energy scan (BES-I) RHIC has successfully operated at four different beam energies at or below the regular injection energy, collecting several million events at each of these energies over the course of a few weeks, as listed in Table 1. Operation at a fifth energy of 2.5 GeV/n was not very successful, resulting in only a single gold-gold event during several hours of running.

During low energy operation large numbers of collision events between the gold beam and the aluminum STAR detector beam pipe were recorded. This led to the proposal of installing a dedicated gold halo target in the Yellow RHIC beam, 2.05 m upstream of the nominal IP in the STAR detector. However, operating an internal halo target in a storage ring is challenging, as the experience with the HERA-B target has shown [2, 3]. Beam orbit jitter and/or insufficient diffusion to replenish the halo can result in widely varying target interaction rates. Variations in the transverse size of individual bunches result in only those bunches with the

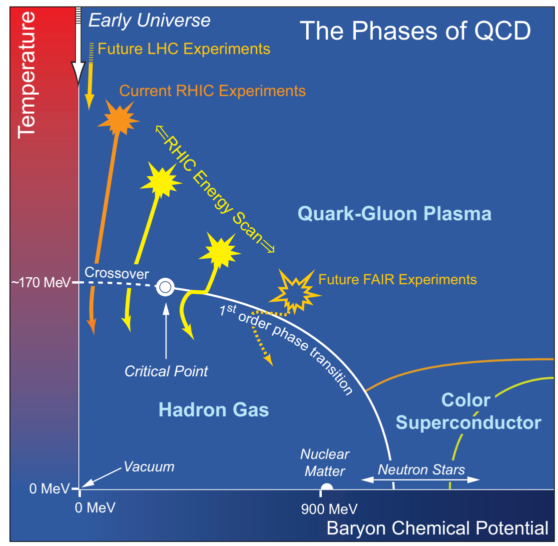

Figure 1: The QCD phase diagram with the critical point expected in the center-of-mass energy range between $\sqrt{s_{\mathrm{NN}}} = 5$ and $30\,\mathrm{GeV}$.

largest transverse emittance contributing to the target interaction rate, thus potentially overwhelming the detector electronics with bursts of interaction rates associated with those few large bunches. Since the STAR halo target is not moveable, the interaction rate has to be controlled by adjusting machine parameters such as orbit and tunes. On the other hand, and in contrast to the situation at HERA-B, the STAR target will only be operated in dedicated target mode. Therefore no special care has to be taken to preserve the beam emittance of the beam core while enhancing the halo population, as would be the case in simultaneous operation with the collider mode.

As a first step proof-of-principle experiments were carried out using a vertical RHIC collimator to simulate the target [4]. Interaction rates were monitored with dedicated beam loss monitors in the vicinity of the collimator. These tests confirmed that even with proton beams, which have very low IBS growth rates, the halo gets replenished fast enough to result in stable, high interaction rates over long periods of time. Bunch-by-bunch interaction rates were found to be uniform over the entire bunch train in RHIC, and no fast fluctuations were found when sampling the interaction rates at 720 Hz, see Figure 2.

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Table 1: Beam Energies, Run Durations, and Recorded Number of Au-Au Events During BES-I.

beam energy [GeV/n]	$\sqrt{s_{\mathrm{NN}}}$ [GeV/n]	run duration [days]	no. of events
9.8	19.6	10	36 M
7.3	14.6	24	20 M
5.75	11.5	10	12 M
3.85	7.7	32	4 M
2.5	5.0	0.2	1

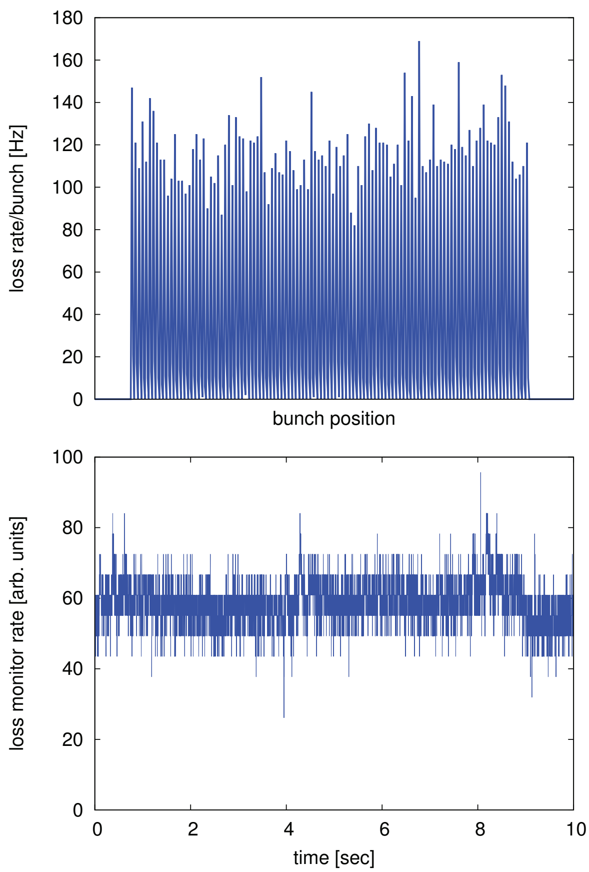

Figure 2: Bunch-by-bunch loss rates during the collimator test at a fixed point in time with tunes set to $(Q_x, Q_y) = (28.698, 29.678)$ (top), and loss monitor rates in the vicinity of the vertical collimator, sampled at 720 Hz (bottom).

Based on these positive results a dedicated halo target consisting of a thin ($750\,\mu$m) gold foil was designed, as shown in Figure 3. The aperture of this target was carefully chosen such that it does not interfere with regular collider operations while it can intercept the beam halo in dedicated target mode. With the detector beam pipe radius being 20 mm these conditions are fulfilled at a target aperture of 16 mm, as depicted in Figure 4. The target (magenta) at $s = -2.05$ m intercepts the beam halo with a -10 mm

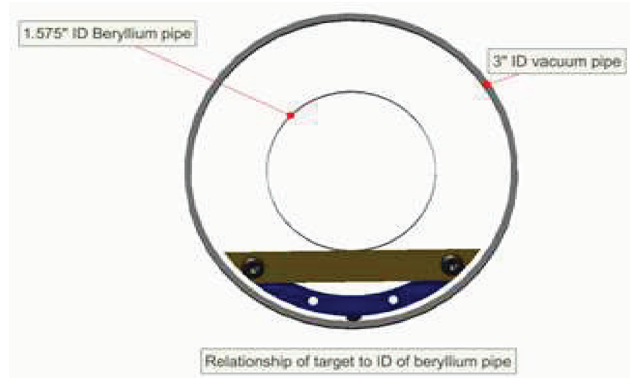

Figure 3: Schematic view of the STAR gold target in the lower part of the 75 mm ID vacuum pipe 2.05 m from the IP, with its aperture identical to the 40 mm ID beryllium detector beam pipe.

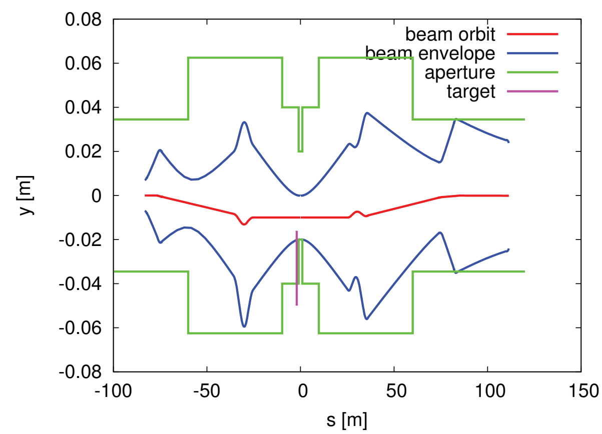

Figure 4: Geometry in target mode with $\beta^* = 8$ m. When a -10 mm orbit bump (red) is applied, the target (magenta) becomes the limiting aperture. The beam emittance is chosen such that the resulting beam envelope (blue) just barely fits into the beam pipe aperture (green).

orbit bump applied at the IP; the vertical β-function at the IP is set to $\beta^* = 8$ m.

To gain experience with potentially increased background rates from fragments impinging on the target during regular collider operations, the target was installed at a lower-than-nominal position in Run-14, leaving an aperture of 20 mm instead of the nominal 16 mm required for dedicated target operation. With the target in this lower position no significant detrimental effects on detector operation were observed at STAR. However, STAR was able to create an image of the target from vertex cuts of collision events in the target vicinity, as shown in Figure 5.

In Run-15, the target was raised by 4 mm to its design aperture of 16 mm. In this configuration a dedicated test and subsequent short Physics run were performed with Au beam at the nominal RHIC injection energy of 9.8 GeV/n. With a single bunch circulating in the Yellow RHIC ring, the orbit at the STAR IP was lowered in steps of 0.5 mm,

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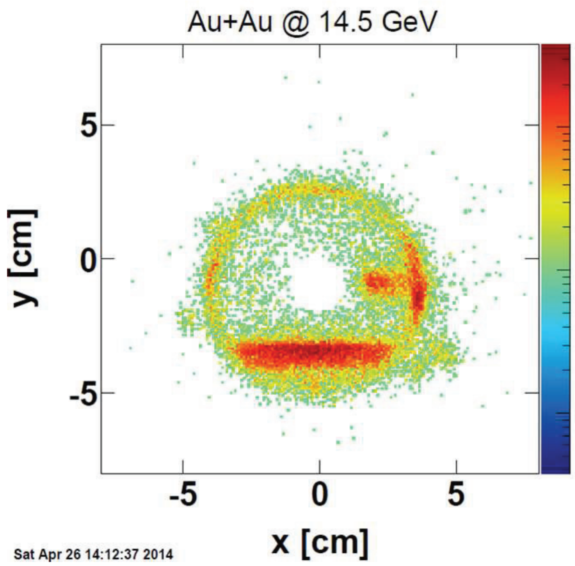

Figure 5: Reconstructed vertex distribution in the longitudinal vicinity of the halo target, with the target aperture set to 20 mm. The target is clearly visible at the bottom of the beam pipe. The high vertex density on the right side of the beam pipe was later found to be due to some beam pipe alignment issues.

to a final position of -10 mm. During the last two 0.5 mm steps momentary increases in the STAR BBC rate were recorded, but these decayed within a few seconds. Once the final target position was reached the vertical tune was nudged down from its nominal value of .23 towards the fifth-order resonance at .20, which eventually resulted in a stable rate of 100 kHz as measured by the STAR BBC counter. In this configuration STAR reported an event rate of 30 Hz from beam-target interactions. When the STAR trigger timing was adjusted to account for the 2.05 m long drift from the target position to the nominal IP this rate increased to 300 Hz.

After this initial setup, six bunches were injected into the Yellow ring for a short Physics run of half an hour, see Figure 6. This yielded one million beam-target Au-Au events at $\sqrt{s_{\mathrm{NN}}} = 4.5\,\mathrm{GeV/n}$ that are currently being analyzed by the STAR collaboration. A vertex cut in the longitudinal vicinity of the target reveals the Au beam halo impinging on the target, Figure 7.

CONCLUSION

Operating RHIC with an internal target constitutes a vast improvement over the RHIC performance in collider mode at $\sqrt{s_{\mathrm{NN}}} = 5\,\mathrm{GeV/n}$ which resulted in a single event during several hours of Physics running (Table 1) compared to a million events during 30 min in internal target mode. Since RHIC has successfully stored Au beams with energies as low as 3.85 GeV/n (Table 1), this successful demonstration also extends the energy reach in Au-Au collisions in RHIC down to $\sqrt{s_{\mathrm{NN}}} = 3\,\mathrm{GeV/n}$.

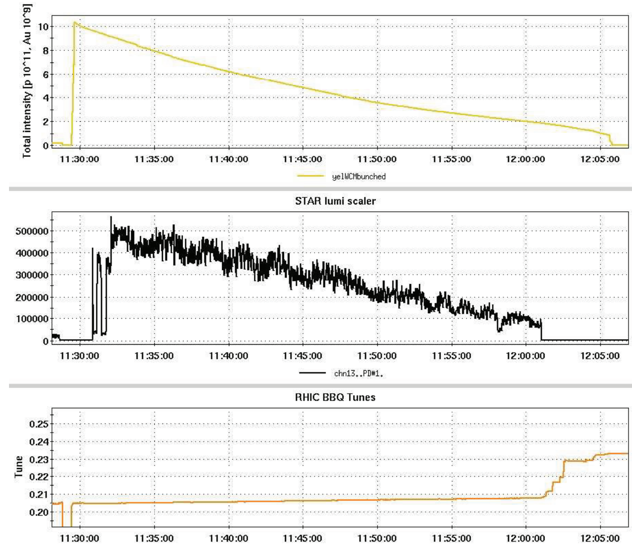

Figure 6: YELLOW RHIC beam intensity (top), STAR luminosity scaler (middle), and vertical tune (bottom) during the 30 min Physics store.

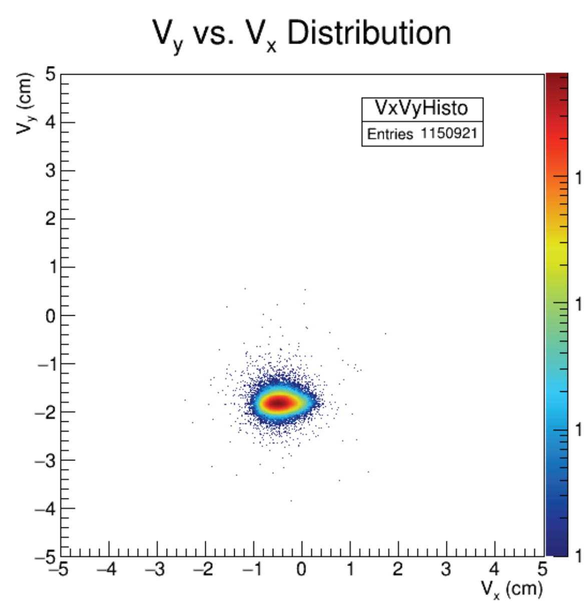

Figure 7: Reconstructed vertex distribution in the longitudinal vicinity of the halo target, with the target at its nominal 16 mm aperture position, during the 30 min Physics run.

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