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REVIEW OF THE FIXED TARGET OPERATION AT RHIC IN 2020*

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Abstract

As part of the Beam Energy Scan phase-II (BES-II) program, RHIC operated in the fixed target mode with Gold beam at energies 5.75, 7.3, 9.8, 13.5, 19.5 and 31.2 GeV/nucleon in 2020. The gold beams at these energies were moved vertically to scrape the halo on a gold fixed target. In addition to beam orbit control, tune and chromaticity adjustments and external excitation were used to produce and maintain the event rate. This paper will review the operational experience of RHIC in the fixed target mode at various energies in 2020.

INTRODUCTION

Beam Energy Scan (BES) at RHIC [1] is a multi-year nuclear physics program operating with Gold beam in a wide energy range. The purpose is to investigate the first-order phase transition between Quark-Gluon Plasma and Hadronic gas, and to locate the possible critical point [2–4]. The program includes both the collision mode and the fixed target mode operation. The achievable luminosity decreases significantly with decreased center-of-mass (CoM) energy in the collision mode and RHIC operation becomes increasingly difficult at lower energies as well. However, the fixed target mode produces significantly more collision rates with much less demanding beam requirements. Therefore, the fixed target experiments [5] were proposed as part of the BES to extend the lower energy range. A few beam energies (for example, 31.2 GeV/n which was operated at in 2020) were chosen for the fixed target experiments so that the center-of-mass energies are the same as those operated at in the collision mode. The operation of the fixed target experiments at some beam energies had already been tested or conducted in recent years at RHIC [6–8].

In addition to the fixed target mode, RHIC also operated in collision mode in 2020 at 5.75 and 4.59 GeV/n beam energy which is reported in [9].

Table 1 summarizes the fixed target (FXT) experiments at various beam energies conducted at RHIC in 2020. The corresponding center-of-mass energy for FXT at beam energy 31.2 GeV/n is 7.7 GeV. This CoM energy is equal to the one for beam in collision mode at 3.85 GeV/n, which is the lowest energy in that mode. The operation of all other energies listed in the table extend the CoM energy down below 7.7 GeV, at which it is extremely difficult to operate RHIC and to collect enough collision events in a reasonable amount of time. The tunes for these FXT operation are around (0.234, 0.228). The beta functions at the center of the detector (beta star) were chosen to be 10 m for all other energies except for 31.2 GeV/n which has a 5 m beta star. The beta stars were larger than those for the collision lattice because it is beneficial to have large beam at the target for controlling the rates. The lifetime and the store length generally become longer with higher beam energy, however, there are exceptions shown in the table due to different machine configuration. At 31.2 GeV/n, there was no active lifetime optimization by tune and chromaticity adjustments because the experimental goal was reached in just one store. The lifetime at 7.3 GeV/n was better than that at 9.8 GeV/n due to the use of the demagnetization cycle [10]. The latter energy 9.8 GeV/n was ramped up to from 7.3 GeV/n so persistent current decay induced drift of orbit, tune and chromaticity. At 5.75 GeV/n, in addition to the demagnetization cycle, a second RF cavity system was used to provide extra longitudinal focusing therefore better bunched beam lifetime. Due to the variation of store length, the number of stores at these energies were different to reach the total event goal of 100 M.

Only 12 Gold bunches from the AGS [11] were injected into equally distributed buckets in one of the RHIC rings (so-called yellow ring) for the fixed target experiments. The bunches travel counter-clockwise in the machine. The fixed target is located 2.05 m upstream of the center of the STAR detectors in the beam direction. Figure 1 shows the fixed target, which is 1 mm thick gold foil with the edge 2 cm away from the center of the beam pipe. The beam was lowered vertically using a local orbit bump to scrape beam halo on the target. The FXT experiments were executed in a different order than that listed in Table 1. The operation of fixed target experiment at these energies will be presented below in the order of execution.

31.2 GeV/nucleon

Beam was injected at 7.3 GeV/n and ramped up to 31.2 GeV/n. The vertical emittance increased during the

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Table 1: Summary Table for the Fixed Target Experiments at RHIC in 2020

Beam Energy (GeV/n)	CoM (GeV)	Tunes	β^* (m)	Store Length (hrs)	Number of stores	Total Events (M)
5.75	3.5	0.233/0.230	10	6	4	114
7.3	3.9	0.235/0.222	10	5	6	115
9.8	4.5	0.234/0.228	10	4	8	109
13.5	5.2	0.234/0.228	10	15	2	103
19.5	6.2	0.234/0.228	10	21	1	119
31.2	7.7	0.236/0.228	5	13.5	2	114

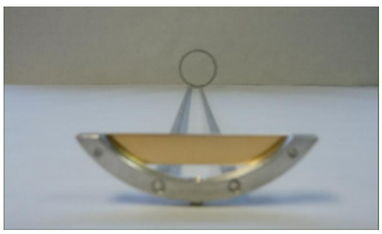

Figure 1: Picture of the STAR gold fixed target. The target was inserted in the lower part of the beam pipe.

energy acceleration with the chromaticity set to ~ 2. The beam intensity at the beginning of the store was 1.5E9 ions per bunch. The rate was controlled by adjusting the orbit bump at the fixed target. The step size for the orbit movement was 50 µm.

Due to experimental detector data acquisition rate limit, the trigger rate (min-bias rate) was kept in the range of 3-4 kHz to maximize the data collection and minimize the "dead time", background and pileup events in the detector. The beam intensity and experimental trigger rates at 31.2 GeV/n are shown in Fig. 2.

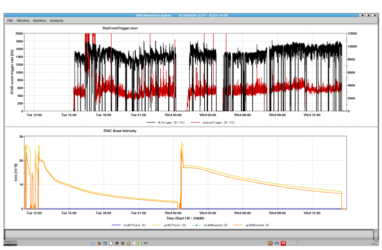

Figure 2: The upper plot shows the fixed target event rate (in black) and min-bias rate (in red) over the time period of two physics stores at 31.2 GeV/n. The lower plot shows the beam intensity evolution during the stores, total beam intensity in light yellow and bunched beam intensity in dark yellow.

9.8 GeV/nucleon

The de-bunching rate was fast at this energy due to intra-beam scattering. Reducing the bunch intensity down to 1E9 was helpful to reduce the de-bunching rate and the STAR background. The beam intensity and experimental trigger rates at 9.8 GeV/n are shown in Fig. 3.

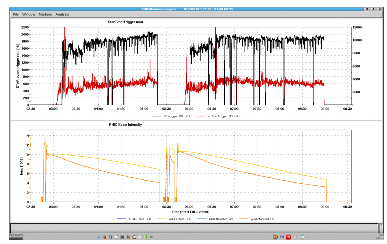

Figure 3: The upper plot shows the fixed target event rate (in black) and min-bias rate (in red) over the time period of two physics stores at 9.8 GeV/n. The lower plot shows the beam intensity evolution during the stores, total beam intensity in light yellow and bunched beam intensity in dark yellow.

19.5 GeV/nucleon

The beam lifetime was excellent so the data was collected in one single store. Only orbit control was used to maintain the rate. The background was very clean due to low beam loss rate. The beam intensity and experimental trigger rates at 19.5 GeV/n are shown in Fig. 4.

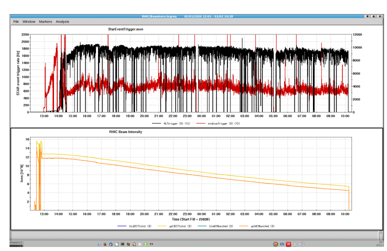

Figure 4: The upper plot shows the fixed target event rate (in black) and min-bias rate (in red) over the time period of a physics store at 19.5 GeV/n. The lower plot shows the beam intensity evolution during the store, total beam intensity in light yellow and bunched beam intensity in dark yellow.

13.5 GeV/nucleon

The store length was over 12 hours at 13.5 GeV/n with good beam lifetime. The de-bunching rate is higher at 13.5 GeV/n compared to 19.5 GeV/n. At the end of the store, the bunched beam intensity dropped to below 0.2E9 ions per bunch for which BPMs would not report meaningful data. The beam intensity and experimental trigger rates at 13.5 GeV/n are shown in Fig. 5.

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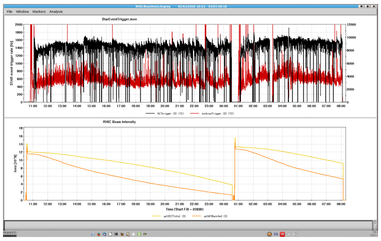

Figure 5: The upper plot shows the fixed target event rate (in black) and min-bias rate (in red) over the time period of two physics stores at 13.5 GeV. The lower plot shows the beam intensity evolution during the stores, total beam intensity in light yellow and bunched beam intensity in dark yellow.

7.3 GeV/nucleon

The injection energy for RHIC was lowered from 9.8 to 7.3 GeV/n in 2020 due to reconfiguration of the injection kicker [12] which reduced the kicker strength. We were only able to use demagnetization cycle [10] at 7.3 GeV/n and below when no energy ramp was necessary. For stores at 7.3 GeV, the Base-Band Tune measurement system [13] was turned on to increase the transverse emittance. The beam intensity and experimental trigger rates at 7.3 GeV/n are shown in Fig. 6.

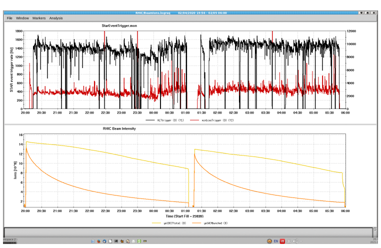

Figure 6: The upper plot shows the fixed target event rate (in black) and min-bias rate (in red) over the time period of two physics stores at 7.3 GeV. The lower plot shows the beam intensity evolution during the stores, total beam intensity in light yellow and bunched beam intensity in dark yellow.

5.75 GeV/nucleon

RHIC was operating in the collision mode at beam energy 5.75 GeV/n for the first two-month of operation in 2020. The operation of fixed target at 5.75 GeV/n was conducted on 2/13 and 2/14 without having to switch energy. The lattice was switched from the collision lattice with 4.5 m beta star to a lattice with 10 m beta star as shown in Table. 1. The beam intensity and experimental trigger rates at 5.75 GeV/n are shown in Fig. 7.

SUMMARY

This report summarized the operational experience for the fixed target experiments at 5.75, 7.3, 9.8, 13.5, 19.5 and 31.2 GeV/nucleon in 2020. Various measures were taken to level the fixed target event rate and and to control the background. These measures include large beta function at the collision point, blowing up transverse emittance with the BBQ kickers, orbit control for event rate leveling, tune and chromaticity adjustments.

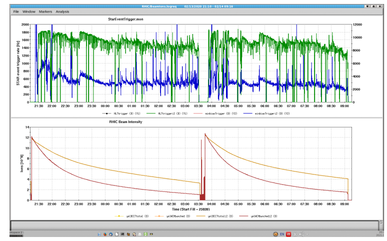

Figure 7: The upper plot shows the fixed target event rate (in green) and min-bias rate (in blue) over the time period of two physics stores at 5.75 GeV. The lower plot shows the beam intensity evolution during the stores.

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