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RHIC POLARIZED PROTON OPERATION IN RUN24

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Abstract

The Relativistic Heavy Ion Collider (RHIC) Run 24 was 27 cryo-weeks, operating with collisions at the STAR and sPHENIX detectors. The primary running mode was polarized protons at 100 GeV, where there was 22 weeks of physics production. sPHENIX continued its commissioning effort from Run23, becoming fully operational after 13 weeks and the addition of isobutane to their Time Projection Chamber (TPC) gas mixture. STAR operated with two weeks of low luminosity data collection followed by twenty weeks of high luminosity and radially polarized beams at their interaction point (IP). With two colliding IPs and nominal beam conditions, the beam-beam limit is exceeded. To reduce the beam-beam parameter and maximize the number of collisions within a small vertex region at sPHENIX, the intent was for sPHENIX to operate with a crossing angle. To meet sPHENIX's needs through the run, there was a 7 week period where they operated with head-on collisions. This necessitated collisions only at sPHENIX until the beam-beam parameter was sufficiently low to support the additional collisions at STAR. A significant number of power dips, especially earlier in the run, greatly affected machine performance and availability.

INTRODUCTION

For Run24, RHIC was in physics production for 22 weeks of polarized protons at 100 GeV. The sPHENIX detector continued its commissioning of systems from Run23 [1] until isobutane was introduced to their gas mixture after 13 weeks [2]. The STAR detector had a 17 day low luminosity run before switching to maximum luminosity. Following the low luminosity run, STAR operated with radially polarized collisions for the remainder of the run. This was the first operation of RHIC with protons at 100 GeV since 2015 [3]. Run15 performance was used as the projected luminosity for this run. In Run15, the RHIC electron lenses were used to compensate the beam-beam effect from one IP [4]. The intended configuration for collisions had a 2 mrad full crossing angle at SPHENIX and a 0 mrad full crossing angle at STAR, where the 2 mrad full crossing angle would reduce the interaction of colliding bunches and, in turn, reduce the beam beam effect [5]. As a result, the electron lenses were not made available for this run. The delivered luminosity is shown in Fig. 1 with three regions labeled as A, B, and C. The total delivered luminosity for sPHENIX and STAR was 182 and 277 pb^{-1}.

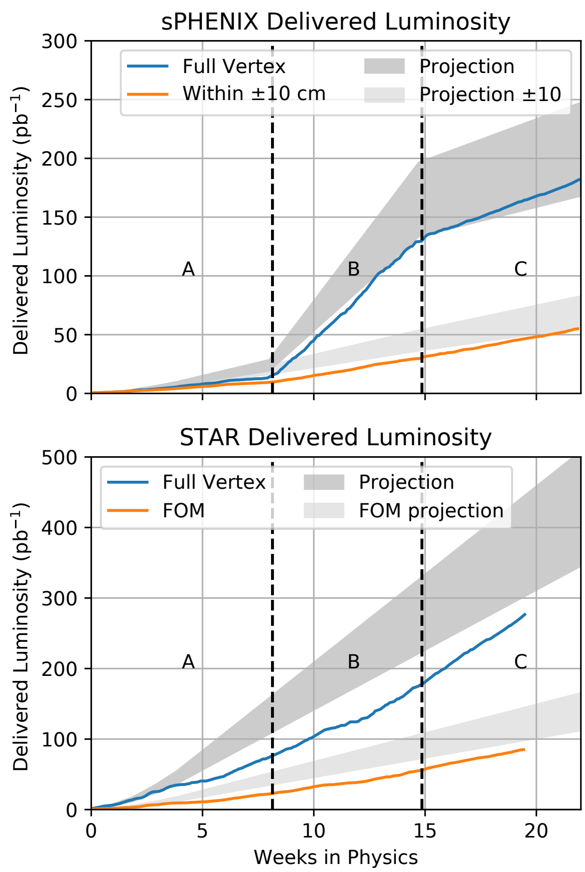

Figure 1: Luminosity performance of sPHENIX (top) and STAR (bottom) with the three operating modes labeled.

Due to the ongoing commissioning of sPHENIX, there were three distinct operating modes for RHIC that affected the luminosity delivered to each experiment. These modes being:

A: sPHENIX operating with a -2 mrad full crossing angle, STAR operating with head-on collisions.

B: sPHENIX and STAR operating with head-on collisions. Stores initiated with sPHENIX in collisions and STAR receiving collisions after the beam-beam parameter was sufficiently low to support two colliding IPs.

C: sPHENIX and STAR operating with a 1.5 mrad and 0 mrad full crossing angle, respectively.

For this run, there was interest in reaching up to $2.5{\times}10^{11}$ protons/bunch at the start of store [6]. The maximum per-

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formance, equated to 25 pb^{-1}/week, was achieved with 2.25×10^{11} protons/bunch. This is seen in Fig. 2 which shows the running 7-day average luminosity delivered/week. Further advances in luminosity were limited by four factors: intensity limit by the blue accelerating RF power amplifier, intensity from the injectors, losses at rebucketing, and dynamic aperture.

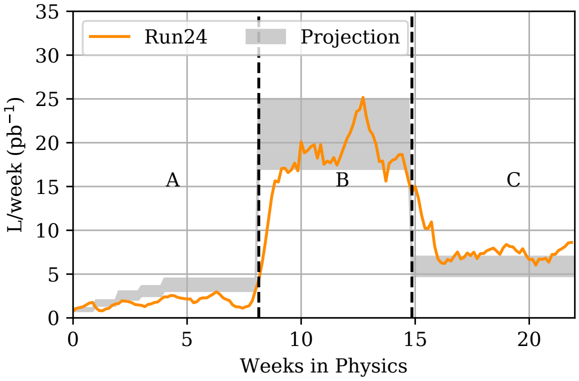

Figure 2: Running 7-day average of delivered luminosity, with projections, for sPHENIX.

Mode A suffered from poor emittance from a non-fully damped higher order mode excited in the 56 MHz cavity and an optics error, seen in Fig. 3. This mode ended with the 56 MHz fundamental power couplers being fully inserted to damp these excited modes, updates to the magnet transfer functions to correct the optics, and the sPHENIX full crossing angle changing from -2 mrad to 0 mrad.

Mode B had stores initialized with sPHENIX in collisions. STAR would be brought into collisions after the beam-beam parameter at sPHENIX was below 10×10^{-3}. Several stores during this period exceeded the performance of the best stores of Run15, in terms of maximum and integrated luminosity for a single IP. The maximum achieved beam-beam parameter for IP8 was $\xi_B = 14.6\times10^{-3}$.

Mode C delivered 52.4 pb^{-1} over all vertices and 25.4 pb^{-1} delivered within ±10 cm in just 7 weeks. Initial estimates projected 22 weeks to reach 75 pb^{-1} delivered luminosity over all vertices [6]. This improvement was primarily from improved machine availability and the change of the full crossing angle to 1.5 mrad over the intended 2 mrad.

The large emittance growth from the undamped 56 MHz cavity can be observed in section A of Fig. 3, and also hindered the polarization performance, as seen in Fig. 4.

During Run24, there were twenty-two power dips, only two of which occurred during mode C. These greatly impacted the availability of RHIC and its subsystems.

POLARIZATION PERFORMANCE

The run average polarization for blue and yellow rings was P_{blue} = 54.7% and P_{yellow} = 57.8%, with a run average source polarization of 78.7%. These RHIC averages

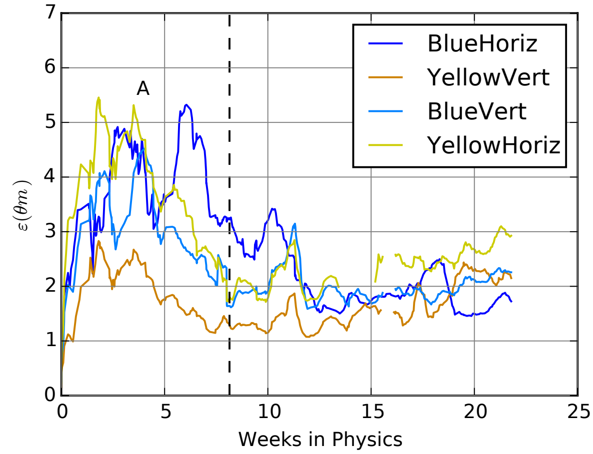

Figure 3: Measured emittances for blue and yellow rings in the horizontal and vertical planes, showing a running average over 10 stores.

include the low polarization early in the run. The polarization performance at the 200 MeV polarimeter, Alternating Gradient Synchrotron (AGS), and for the blue and yellow RHIC rings is shown in Fig. 4.

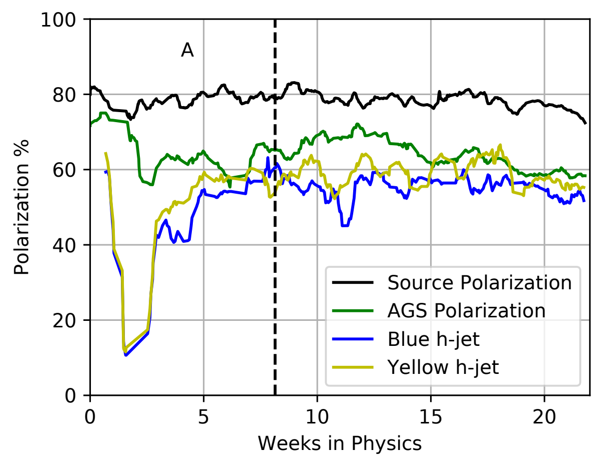

Figure 4: Polarization performance for each physics store at the source (black), the AGS (green), and the RHIC blue and yellow rings (blue and yellow).

Previous configurations for polarized protons at 100 GeV either had vertical or longitudinal polarization at STAR. To facilitate radially polarized collisions at STAR, the rotator magnets were used. The rotator magnets consist of four helical dipoles with alternating helicity, with the outer and inner coils being powered separately, namely I_{out} and I_{in} [7]. With polarized protons at 100 GeV, there are two options to achieve radial polarization as seen in Fig. 5, where the option of I_{out}, I_{in} =76.8, 273.6 A were used. Here, θ_y is the residual vertical angle and $\theta_{s,x}$ is the angle at STAR relative to the longitudinal axis. The ramp for the helical dipoles had a duration of 13 minutes to reach these settings.

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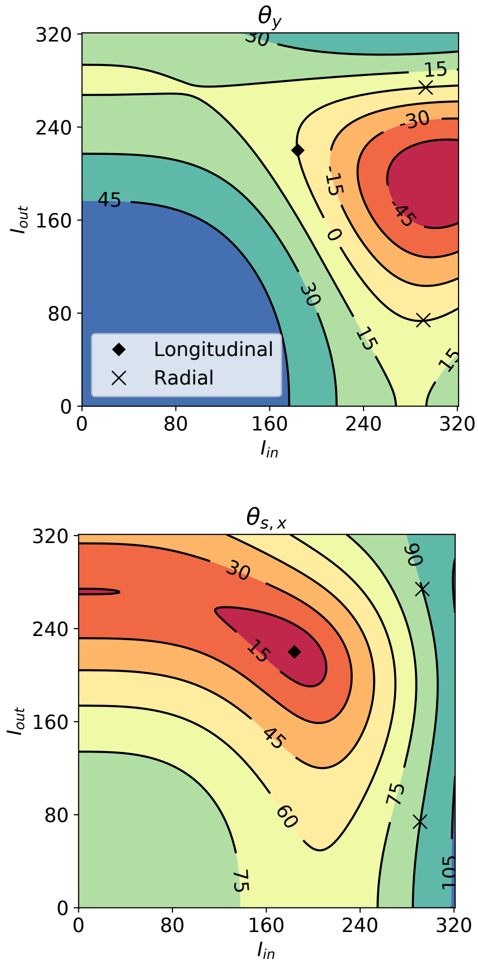

Figure 5: Rotator settings and their: angle in the vertical plane, θ_y (top), and the corresponding angle in the horizontal plane at IP6 $\theta_{s,x}$(bottom).

The AGS skew quadrupole system for direct correction of snake resonance driving terms was commissioned. This system was used, in lieu of the AGS tune jump system, operationally for the final 3 weeks of the run [8]. This system brought improved injection efficiency into RHIC, allowing higher intensities as seen in Fig. 6. This is the result of scraping in the Booster being the main intensity control, correlating higher intensity with larger emittances. Any additional emittance growth, such as modest tune jump in the AGS at the 82 depolarizing resonances resulted in a limit of our extracted intensity from AGS. This skew quadrupole system is more adiabatic than the jump quadrupole system resulting in reduced emittances, while also requiring tighter tolerances on the orbit. Commissioning of the system continues, with an expected gain of polarization of 5-10% over the jump quad system [9].

SUMMARY

Despite the reduced availability early in the run coupled with early configuration issues, the polarized proton run for

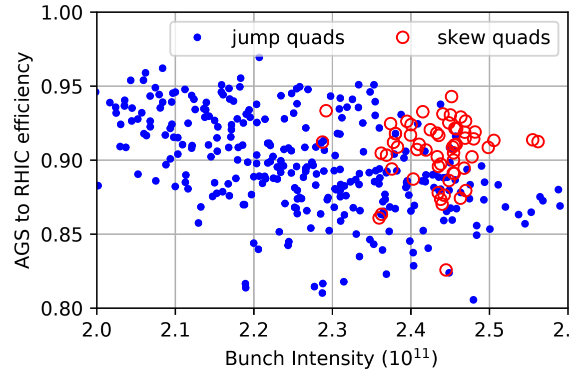

Figure 6: RHIC injection efficiency from AGS as a function of intensity, comparing jump quadrupoles (blue) with skew quadrupoles (red).

2024 was very successful. In the final 7 weeks of the run, 70% of the required luminosity for sPHENIX was delivered, which was initially expected to take 22 weeks to deliver 100%. This was the highest total delivered luminosity run for polarized protons at 100 GeV. Despite the poor polarization performance early in the run, the run average polarization exceeded previous 100 GeV polarized proton runs. A large number of configurations for RHIC were supported to meet the needs of the experiments.

ACKNOWLEDGEMENTS

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