RHIC POLARIZED PROTON OPERATION IN RUN 22*

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Abstract

The Relativistic Heavy Ion Collider (RHIC) Run 22 physics program consisted of collisions with vertically polarized proton beams at a single collision point (the STAR detector). During initial startup of the collider, power outages damaged two of the coils in one of the RHIC helical dipole snake magnets used for polarization preservation in the Blue ring. That snake was reconfigured for use as a partial snake. We will outline some of the remediating measures taken to maximize polarization transmission in this configuration. These measures included changing the colliding beam energy from 255 GeV to 254.2 GeV to adjust the spin closed orbit at store and adjustment of the field in the other helical dipole in the Blue ring to improve injection spin matching. Later in the run, the primary motor generator for the AGS (the injector to RHIC) failed and a lower voltage backup had to be used, resulting in a period of lower polarization. Other efforts include detailed measurement of the stable spin direction at store and the commissioning of a machine protection relay system to prevent spurious firing of the RHIC abort kickers.

INTRODUCTION

The RHIC physics program in Run 22 required 16 weeks of colliding beam operations with 255 GeV polarized proton beams at one interaction point (the STAR detector). An additional sixteen days of collider operation were allotted for coherent electron cooling (CeC) experiments with gold beam which is discussed elsewhere in these proceedings [1].

The figures of merit for the STAR physics programs were LP_b^2 (for their forward physics) and LP_bP_y (for their mid-rapidity physics program), where L is the luminosity and P_b and P_y are the polarizations of the Blue and Yellow beams respectively. Each program required an integrated figure of merit of 120 pb^{-1}, which, assuming 55% average polarization in each beam, requires an integrated luminosity of about 400 pb^{-1}. It was also required that the instantaneous luminosity be leveled near a target value of $1.35 \times 10^{32} cm^{-2} s^{-1}$, which was accomplished using beta squeezes throughout the store. A nominal 8 hour store began at $\beta^* = 1.5$ m, squeezed to 1.2 m 3 hours into the store, and to 1.0 m at 6 hours into the store.

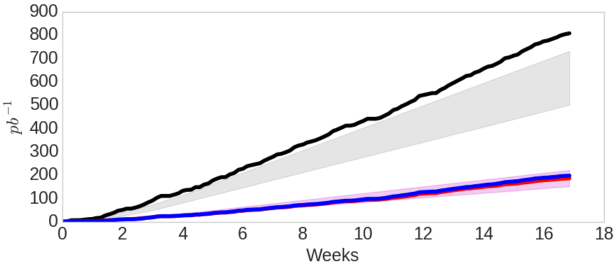

Figure 1: Integrated luminosity, L (black) and figures of merit LP_b^2 (blue) and LP_bP_y (red). Shaded regions show pre-run projections.

Delivered integrated luminosity and figures of merit are shown in Fig. 1.These delivered figures of merit correspond to total STAR-reported sampled figures of merit of 117.2 pb^{-1} (mid-rapidity) and 128 pb^{-1} (forward), which are97.7% and 107% of the respective targets.

HELICAL DIPOLE FAILURE

The primary method for preserving polarization during the RHIC acceleration ramp is a pair of helical dipole magnets (so-called Siberian snakes) in each ring. These snake magnets, placed opposite one another at 3 and 9 o'clock in the ring, each provide a full 180°spin rotation about an axis in the horizontal plane at ±45°to the beam direction. In this configuration depolarizing resonances are avoided since the design spin tune is fixed at 0.5 and the stable spin direcion aligned vertical at all energies [2].

Each RHIC snake consists of four helical modules (labeled #1-#4 in beamline order) [3]. In ordinary operation, the modules are wired in pairs, #1 with #4 and #2 with #3. In the first two weeks of beam operation, two coils in the Blue snake at 9 o'clock were damaged in two separate power outage incidents. After each incident, resistance measurements indicated that one of the coils had developed an open (coil #2 was damaged in the first incident and coil #4 in the second). Fortunately, the coils can be individually rewired from outside the cryostat. Wiring coils #1 and #3 in series, with coil #1 in the reversed polarity from normal operation, produces a "partial" snake, one that rotates the spin by < 180° in one pass. In the modified configuration, the partial snake rotated the spin by 163° about an angle still in the horizontal plane, but at only −42° to the longitudinal axis.

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This deviation from an ideal snake configuration caused depolarization due to mismatch of the stable spin field at injection. This mismatch was addressed by adjusting the opposing Blue snake at 3 o'clock to adjust that stable spin direction at the injection point. Details of the compensation can be found in [4].

The partial snake configuration also causes the spin direction to deviate from vertical at store energy. This causes systematic error in both the STAR physics data and polarimeter measurements. A scan of the store beam energy was performed over a range of 253.82 GeV to 254.87 GeV (the nominal store energy) in an attempt to precess the stable spin direction into an optimized configuration. The spin direction was measured with both the proton-carbon polarimetry (pC) in IR12 and with the STAR detector local polarimetry in IR6. A store energy of 254.2 GeV was selected as the best option for the spin closed orbit. The results are summarized in Table 1. Note that both STAR and the pC polarimeters can only measure the transverse components of the stable spin direction, so what is reported is the angle with respect to the vertical of the projection of the stable spin direction onto the transverse plane. Since the total asymmetry measured during the scan did not change substantially, it was inferred that the energy change did not substantially change the (unobserved) longitudinal component. Note that there is a spin tilt in both rings with even full snakes due to machine imperfections.

Table 1: Transverse Spin Tilt Angle w.r.t. Vertical (Degrees)

Ring	Location	Energy [GeV]	
		255	254.2
Blue	pC	18	0
	STAR	5	0
Yellow	pC	-1	5
	STAR	5	7

Stastical uncertainty for pC and STAR angle measurements are 3 and 0.5 degrees respectively.

STABLE SPIN DIRECTION MEASUREMENT

Only the two transverse components of the polarization are observable by the pC and STAR polarimeters, but knowing the hidden longitudinal component is important both for systematic errors in the physics data and polarimeter calibration. One way to gain access to the hidden component is to effect a known, local rotation of the stable spin to bring all or part of that component into the transverse plane.

The STAR IR contains a pair of spin rotators, normally used to rotate the nominally vertical stable spin into the longitudinal direction for double-spin asymmetry physics measurements [2]. That same rotation takes an initial residual longitudinal component and rotates it into the transverse plane, where it is measurable by the STAR detector. This measurement was made for both the Blue and Yellow beams at 254.2 GeV. Preliminary analysis of these data indicate that the longitudinal component during Run 22 was <10% in both rings (i.e. $|n_z|/|\hat{n}| < 0.1$), which is acceptable for the physics program.

There are no spin rotators at the location of the pC polarimetry in IR12. There the longitudinal component was measured by scanning the horizontal orbit angle at the polarimeter and measuring the horizontal component of the polarization. For a given orbital angle change $\Delta\theta$, the stable spin precesses by $G\gamma\Delta\theta$, where G is the anomalous magnetic ratio and γ the Lorentz factor. The machine aperture allowed a maximum angular range of $\pm 350\,\mu$rad, which produced $\pm 9°$ of spin precession. Figure 2 shows the measured radial component of the stable spin direction during the scan together with a sinusoidal fit. Though the measurement range is small, it is enough to constrain the sinusoidal fit with sufficient precision. The measurement indicates a spin tilt away from vertical of $7.8° \pm 3.4°$ and $7.4° \pm 3.0°$ in Blue and Yellow respectively, oriented toward the longitudinal. This corresponds to a <1% change in the calibration of the polarization measurements.

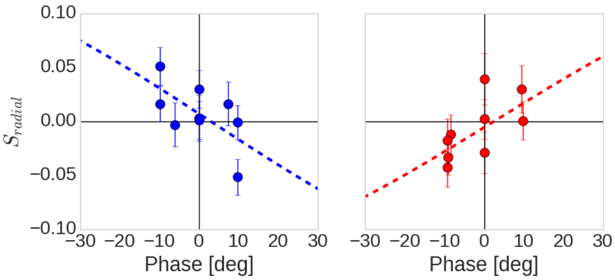

Figure 2: Measured radial component of the stable spin direction at the RHIC pC polarimeter as a function of spin precession induced by local horizontal orbit angle changes (Blue ring in left plot, Yellow on the right). Dashed lines indicate sinusoidal fit.

MACHINE PROTECTION

In order to protect against unexpected firing of the RHIC abort kickers, asynchronous to the bunch train (a so-called 'prefire' event [5]), mechanical relays were added to their triggering path. These relays prevent accidental discharges of the thyratrons into the magnet load, but also add several milliseconds of delay between the time a fault is detected and the time of a (justified) beam abort. Compensating for this delay requires detecting fault conditions earlier and to that end, the RHIC machine protection was upgraded to include additional inputs, such as detection of current faults in select orbit corrector magnets and additional conditioning on beam position signals (e.g. absolute position, rate of change and coherent motion). These systems were successfully commissioned as a whole during high energy operation for the first time during Run 22. With the full system engaged, there were no prefire events during beam operation in Run 22. A detailed account can be found in [6].

WESTINGHOUSE OPERATION

Six weeks into beam operation in RHIC, the Siemens motor generator, which powers the AGS main magnet, failed due to overheating of the motor brush rings. Diagnosis and correction of the failure took 7.5 weeks in the middle of the run, during which the AGS main magnet was powered using an older backup Westinghouse motor generator. The Westinghouse is rated for lower power than the Siemens, requiring an acceleration rate that is half as fast, which caused increased depolarization from resonance crossings. The Westinghouse also regulates current less well cycle-to-cycle and over time, which reduces the effectiveness of some resonance crossing techniques, like tune jumps in use at the AGS that rely sensitively on the timing of the correction [7]. Drift in the Westinghouse current regulation was improved by supply feedback loop gain adjustments and a potentiometer upgrade, but not to the same tolerance achievable with the Siemens. The Siemens was put back into service after roughening the surface finish of the collector rings and realigning the motor brushes eliminated the overheating problem.

During steady state operation with the Westinghouse (excluding setup time), the polarization measured via the hydrogen jet at RHIC store was 49%. This is a relative 8% lower than the 53% polarization measured during steady state operation with the Siemens. The slower ramp rate had negligible impact on the luminosity. The figure of merit for the 7.5 weeks of Westinghouse operation was therefore 15% lower than the pre-run expectations.

POLARIZATION

The grand average polarization for all RHIC physics fills during Run 22 as measured by the hydrogen jet polarimeter is 50.4% in Blue and 49.5% in the Yellow beam. This grand average, however, includes all of the unanticipated setup and reconfiguration time necessary to compensate for both the damaged helical dipole and the AGS motor generator failure. Figure 3 shows the beam polarization by RHIC fill for the full run, broken into periods of different operating configurations. The lower polarization periods associated with operation prior to optmizing the partial snake configuration and with setup and operation with Westinghouse are clearly visible.

By the end of the run, operating with Siemens and with an optimized snake configuration, the polarization in both rings was 53%, close to the pre-run expectation of 55% (which was based on the Run 17 experience [8]). For the Blue beam, transmission efficiency of polarization between the AGS and RHIC in the optimized setup was very similar to Run 17 performance with full snakes, indicating that operation with a partial snake in RHIC is a viable option in case of similar failures in the future.

CONCLUSION

RHIC operation in Run 22 was hindered by two major equipment problems: two failed helical dipole modules and a weeks-long failure of the AGS primary motor generators.

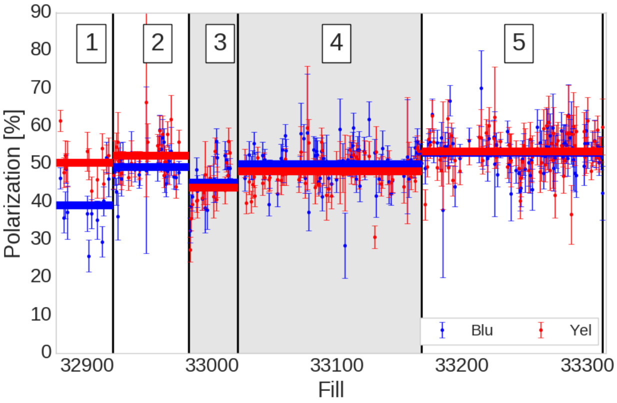

Figure 3: RHIC store polarization, measured with the hydrogen jet for Run 22 physics fills. The shaded region marks operation with the Westinghouse motor generator (Siemens otherwise). The run is divided into (1) initial setup with non-optimal partial snakes in Blue (2) regular operation with Siemens and optimized partial snakes, (3) setup period for Westinghouse (4) steady state operation with Westinghouse and (5) steady state operation after return to Siemens. Horizontal lines show period averages.

Nevertheless, physics goals for the run were substantially met. In addition, progress was made in fully characterizing the stable spin direction at STAR and the polarimetry and a machine protection upgrade was successfully commissioned.

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