RHIC POLARIZED PROTON OPERATION IN RUN 12*

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Abstract

Successful RHIC operation with polarized protons requires meeting demanding and sometimes competing goals for maximizing both luminosity and beam polarization. Run 12 consisted of four weeks of collisions with 100 GeV beams and five weeks colliding 255 GeV beams. We sought to fully integrate into operation the many systems that were newly commissioned in Run 11 as well as to enhance collider performance with incremental improvements throughout the acceleration cycle. Improvements to the luminosity were provided largely by increased intensity delivered by the polarized proton source. Increases in beam polarization came from improvements in both the injectors and in RHIC.

OVERVIEW

The Run 12 polarized proton run was divided between four weeks of physics at 100 GeV and five weeks of collisions at 255 GeV. At 100 GeV the stable spin direction at both interaction points (IPs 6 and 8) was vertical (no spin rotation), and for 255 GeV, longitudinally (achieved with helical dipole spin rotators on either side of each IP). Instantaneous, relative polarization measurements are made with carbon target polarimeters. The carbon polarimeter measurements are calibrated with a polarized atomic hydrogen jet target polarimeter ('the Jet'), which is capable of absolute polarization measurements made continuously over a full eight hour store length.

The store working point for both energies was between the 2/3 and 7/10 betatron resonances at (Q_x,Q_y) = (28.695, 29.685). Because 7/10 is also a strong spin depolarizing snake resonance, the vertical tune in both rings was lowered to 29.672 during the portion of the acceleration ramp between 100 GeV and 255 GeV, when depolarizing resonances are strongest [1]. The proximity to the 2/3 resonance makes tune, coupling and orbit feedback essential on every acceleration ramp [2].

Both programs benefitted from improvements in the injectors. In typical operation, the OPPIS source [3] delivers a factor of two or more higher intensity than is needed for collider operation. The excess is scraped in the Booster in any or all of the three planes in order to provide lower emittance beams. Increased intensity from the source allowed increased transverse scraping, which in particular improved both luminosity and polarization. Additionally, the AGS

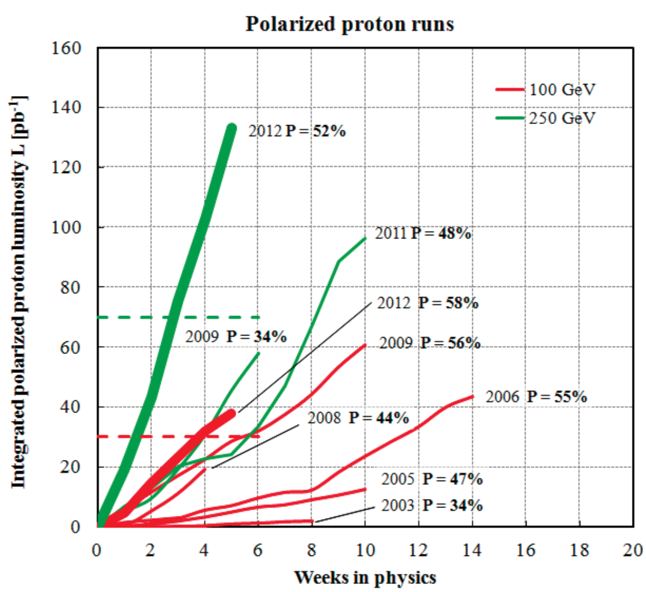

Figure 1: Integrated luminosity and polarization for RHIC polarized proton runs since 2003. Quoted polarization is the average of the Jet-measured polarization for all physics fills (blue and yellow measurements are averaged together). The 2012 runs are in bold and the five week integrated luminosity goals for each 2012 run appear as dashed lines.

carbon polarimeter was modified to allow for routine measurement of spin asymmetry at AGS injection energy. This allowed for more precise compensation of the imperfection resonance at $G\gamma = 3$ in the Booster yielding an overall improvement of 4% polarization (absolute), as measured by a p-carbon polarimeter at AGS extraction energy. See Fig. 1 for a summary of integrated luminosity and polarization performance for RHIC polarized proton runs including Run 12.

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100 GEV OPERATION

Luminosity

During the previous 100 GeV run in 2009-10, we discovered that a β^* at the two colliding IPs of 0.7 m was too small and led to short luminosity lifetime compared to earlier experience at 1 m [4]. For Run 12 we therefore elected to use a lattice with 0.85 m at both colliding IPs. As seen in Table 1 the Run 12 luminosity lifetime at β^*=0.85 m compares favorably even with the lifetime at 1 m. The improvement in the lifetime over even the 1 m β^* case is likely due to feedback control of tune and orbit, which were not used in operation in Run 8, and the removal in Run 11 of a source of intermittent transverse emittance blowup found in the Blue abort kicker [5].

Run 12 was also the first time we were able to use the 9 MHz RF system for 100 GeV operation. As demonstrated during the Run 11 250 polarized proton run, this RF system creates longer bunches during acceleration, allowing for the avoidance of electron cloud effects which may have limited intensities on previous runs. An RF gymnastic at top energy then provides the short bunches necessary for satisfying the collision vertex requirements of the experimental detectors. The per bunch intensity at store was typically 1.65×10^{11} protons, limited largely by beam-beam effects. The higher bunch intensity compensated nearly exactly for the higher β^* and made for a peak luminosity at 100 GeV of $52{\times}10^{30}\text{cm}^{-2}\text{s}^{-1}$, comparable to the previous Run 9 peak of $50 \times 10^{30}\text{cm}^{-2}\text{s}^{-1}$.

Table 1: Luminosity Lifetime and β^* at 100 GeV

Run	β^* [m]	Lumi Lifetime [hr]
Run 8	1.0	12.4
Run 9	0.7	7.3
Run 12	0.85	16.5

Polarization

The intensity averaged Jet polarimeter measured polarizations for the Blue and Yellow beams averaged over the whole 100 GeV run were 61% and 55% respectively.

During this run we found that the vertical emittance of the Yellow beam was particularly sensitive to beam-beam effects. When a Booster scraping scheme was introduced that included only vertical scraping and no longitudinal scraping, the beam-beam parameter proved to be outside of our tolerance. The effects were vertical emittance growth while at store and consequently a strongly decreased polarization lifetime, which explains some of the discrepancy between the measured Blue and Yellow store polarizations.

Split Tunes

It was observed 2004 that polarization decay at a betatron tune working point above 0.7 was unacceptably large [6]. Measurements made during Run 11, however, indicated that a correction of BPM offsets around the ring had reduced the strengths of the closed orbit driven depolarizing resonances above a tune of 0.7 during acceleration [1]. Motivated additionally by the suppression of coherent beam-beam modes afforded by operating the two rings at different working points, we tried several physics stores with beams colliding at working points of (Q_x, Q_y) = (0.695, 0.685) and (0.72, 0.73) in Blue and Yellow respectively.

The polarization lifetime of the Yellow beam (at the higher working point), however, still suffered. The polarization decay of the yellow beam for the four fills at the higher working point was 2.1 ± 0.2 %/hr compared to the decay for the four fills at the nominal working point just prior to the those, 1.4 ± 0.2 %/hr (absolute). The quoted measurements of polarization decay are calculated via linear fits of p-carbon CNI polarimeter measurements [7].

255 GEV OPERATION

Luminosity

The 9 MHz RF system, commissioned in Run 11, was used throughout 255 GeV operation this run. The maximum per bunch intensity at store was 1.7×10^{11} protons. During 255 GeV operation neither the luminosity lifetime nor the polarization lifetime was seen to suffer with increasing beam intensity. The primary impediment to increasing luminosity was beam loss during the energy ramp as the maximum acceleration rate was reached (a point of minimum RF bucket area), which limited the total intensity. Efforts to mitigate this problem included decreasing the longitudinal emittance growth while filling RHIC (bunch-by-bunch RF damping and shortening the injector cycle) and increasing the RF voltage on the 197 MHz cavities, which are ordinarily used on the ramp for Landau damping, but which also contribute to the bucket area. Each of these met with technical impediments outside the scope of this summary paper, but which can be addressed for future runs.

Polarization

The full run average of the Jet-measured polarizations for the 255 GeV run were $50 \pm 0.5\%$ and $53.4 \pm 0.5\%$ in Blue and Yellow respectively. This is to be compared with 48% in each ring from Run 11. As one can see from Figure 2, after the first few fills, the Yellow polarization average increases from just below 50% to an average of 55%. This increase was coincident with a change in the snake currents in both rings to account for the energy dependence of their spin rotation between 100 and 255 GeV. As of this writing the analysis effort continues toward an understanding of the discrepancy between the measured polarization in the two rings.

Several development efforts aimed at increasing the polarization and luminosity were commissioned or realized during Run 12:

- Broad scans of both the snake rotation magnitude and relative rotation axes, which revealed that the ramp

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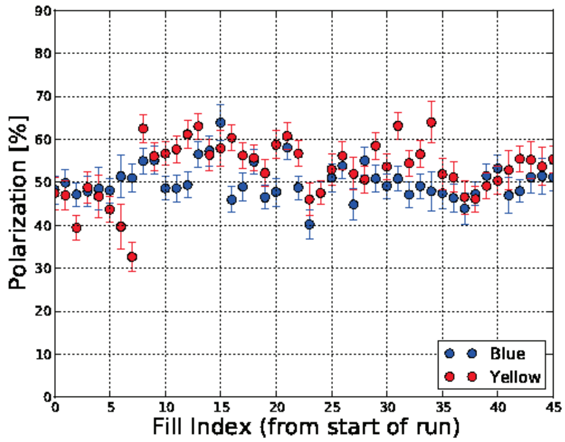

Figure 2: Beam polarization measurements (from the Jet) for all 255 GeV physics fills. Fills after fill index 7 have snake currents adjusted for the energy dependence of the spin rotation in the snakes.

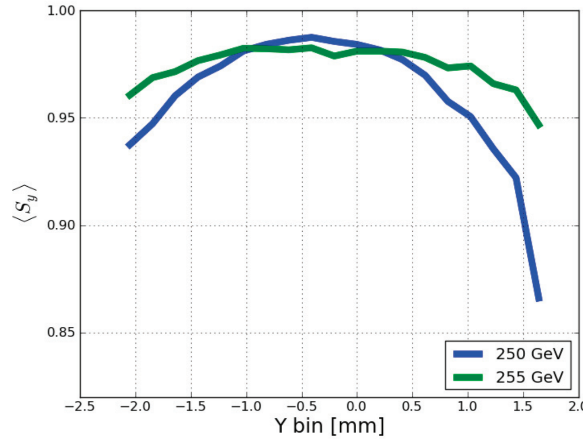

Figure 3: Average vertical projection of the spin vectors of a Gaussian bunch at two different store energies, $G\gamma$ = 488 (255 GeV) and $G\gamma$ = 477.5 (250 GeV) as a function of vertical betatron amplitude.

polarization transmission is insensitive to changes of order $\pm$ 0.01 in the spin tune and $\pm$ 10° in spin rotation angle of the snakes.

- An ongoing effort to correct local sources of coupling
- Simultaneous global coupling and vertical dispersion correction [8]
- 10 Hz feedback correction on the ramp: Operational for the Run 11 Au-Au run, first used for polarized proton operation this run [9].

Store Energy

Prior high energy RHIC polarized proton runs have all used a store energy of 250 GeV total proton energy. Simulation of stable spin direction as a function of energy indicated that the spread in stable spin direction as a function of particle amplitude was reduced by moving to a store energy of 255 GeV (Fig. 3). Reducing this spread, it was hoped, would decrease the decay of polarization over the course of a store. The typical store lifetime in Run 12, however, remained largely unchanged from that of Run 11 (at 250 GeV) of 0.5-1% absolute loss per hour.

AnDY

Six fills at the end of 255 GeV operations were used to deliver collisions to the A_NDY experiment at RHIC IP2, simultaneous with collisions at STAR and PHENIX. In order to mitigate deleterious effect of the beam-beam tune shift contribution from the third collision point, the beams were only put into collision for the latter half of each eight hour store. The vertical orbit separation between the two beams was removed using orbit feedback and tune shifts resulting from the additional collisions were compensated manually. The total integrated luminosity delivered to A_NDY during Run 12 was 2.5 pb^{-1} in 3 days of operation at β^* = 2 m.

SUMMARY

The 100 GeV and 255 GeV runs were very successful, exceeding their integrated luminosity goals by 30% and 90% respectively. Improvements to polarization came from many sources through the acceleration chain, including raised source intensity (allowing for increased scraping and thus lower emittance), careful emittance preservation in the injectors and changes to RHIC snake currents. We were able to make full use of developments in previous runs, like the 9 MHz cavity and full orbit, tune and coupling feedback to perform the initial accelerator setup and energy change from 100 GeV to 255 GeV in minimal time, allowing for maximum time for collider physics and development during a relatively short running period.

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