RHIC POLARIZED PROTON OPERATION FOR 2013 *

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Abstract

The 2013 operation of the Relativistic Heavy Ion Collider (RHIC) marks the second year of running under the RHIC II era. This year saw the implementation of several important upgrades designed to push the intensity frontier. Two new electron lenses to compensate beam-beam effects (e-lenses) have been partially installed, along with a new lattice designed for the e-lens operation. A new polarized proton source which generates about factor of 2 more intensity was commissioned as well as a host of RF upgrades ranging from a new longitudinal damper a new Landau cavity in RHIC to a new low level RF system and new beam bunching structure in AGS. We present an overview of the challenges and results from this years run.

INTRODUCTION

During the 2013 255 GeV polarized proton run we commissioned new e-lens lattices for both rings as well upgrades to the source and RF systems. The e-lens lattice required different integer tunes for both rings. For Blue the integer tune went from (Qx=28,Qy=29) to (Qx=27,Qy=29) and for Yellow from (Qx=28, Qy=29) to (Qx=29,Qy=30). The e-lens lattice also required maintaining a fixed phase between the colliding IP's and the e-lens IP. To accomplish this a new shunt power supply, called a phase shifter, was used to provide separate control for a subset of the main quadrupoles. Commissioning of the new e-lens lattice proved very challenging and we quickly reached the limits of the lattice's intensity. This was compounded by the larger emittance at RHIC injection which resulted in low polarization values at RHIC store. Based on concerns of low polarization, we reverted to the 2012 255 GeV polarized proton lattice. With the 2012 lattice, reductions of injection emittances and the upgrades to the RF system we were able to reach 1.9×10^{11}/bunch intensity for both rings and deliver record luminosity and polarization (see Table. 1).

Table 1: Luminosity and Polarization Compared to Last Year

	Run-12	Run-13
L_{peak} ($\times10^{30}$cm^{-2}s^{-1})	165	210
L_{avg} ($\times10^{30}$cm^{-2}s^{-1})	105	125
L_{int} ($pb^{-1}/weak$)	32	40
Blue Jet $\mathrm{Pol}_{\mathrm{avg}}$	$51 \pm 0.9\%$	$57.0 \pm 0.9\%$ [a]
Yel. Jet $\mathrm{Pol}_{\mathrm{avg}}$	$53 \pm 0.9\%$	$57.7 \pm 0.9\%$ [b]

[a] Average polarization for periods after emittance and Blue coupling correction

[b] Average polarization for periods after emittance correction

PERFORMANCE OF E-LENS LATTICE

The e-lens lattice demonstrated much lower lifetime at injection and store for both rings. This was worse for the Yellow ring. We attribute this to the larger $3\nu_x$ and $3\nu_y$ resonance driving terms which occur near a fractional tune of 2/3rd's. As a result we operated the yellow ring tunes at injection above 0.7 for a while to increase the distance from the 2/3rd's tune . While this improved beam lifetime at injection it created beam loss issues crossing the 7/10th resonance during the energy ramp. After careful local and global nonlinear tuning we later found we could inject below 0.7 with beam lifetime comparable to above 0.7. These nonlinear corrections also expanded the available tune space during the rotator ramp, thus avoiding significant polarization losses on the rotator ramp, and resulting in improved beam lifetime at store. However despite these efforts as can be seen in Fig. 1 we couldn't reproduce the lifetime and efficiencies that the 2012 250 GeV polarized proton lattice provided. This combined with low polarization values due to large emittances was impacting our ability to reach the integrated luminosity and polarization goals for run 2013. So after about two months of operations we reverted to the run 2012 lattice.

Polarization performance of e-lens lattice

Compared with the run 2012 lattice, both the yellow and blue ring e-lens lattices had lower values for the three very strong spin intrinsic resonances above 100 GeV (see Fig. 2). However the two neighboring weak resonances were larger than the run 2012 lattice. This was due in part to the effect of the broken symmetry imposed by the e-lens lattice. The polarization performance of the e-lens lattice is still unclear, since its efficiency was obscured by the larger emittance typically run during the first two months of RHIC operations. Spin tracking studies are currently being

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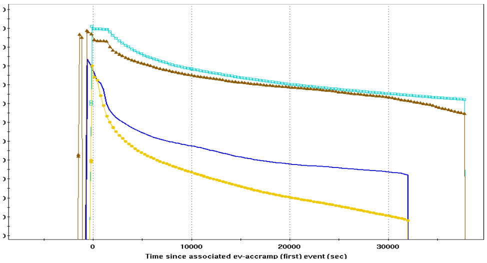
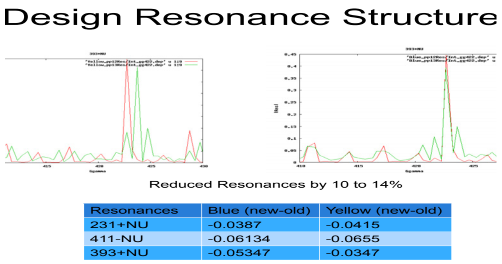


Figure 1: Comparison of the intensity over time during one of the highest intensity stores with the e-lens lattice (yellow and blue trace) with a typical run 12 lattice store (brown and light blue trace)


Design Resonance Structure

Reduced Resonances by 10 to 14%

Resonances	Blue (new-old)	Yellow (new-old)
231+NU	-0.0387	-0.0415
411-NU	-0.06134	-0.0655
393+NU	-0.05347	-0.0347

Figure 2: Comparison of e-lens intrinsic resonance strengths with run 2012 lattice.

run to understand the net benefit or loss the e-lens optics could cause. Using the metric of jet polarization values (see Table. 2), we found average Blue polarization during e-lens optics to be 48% and Yellow to be 44%. This compares with the operation of the run 12 Lattice before emittance reduction, which gave 43% in Blue and 53% in Yellow. This would suggest that the Blue e-lens optics might have an advantage over the run 12 Blue optics while Yellow would be dis-advantaged. After emittances were reduced in mid April the average jet polarization rose to 53% in Blue and 58% in Yellow. The values in Blue can be further segmented into before and after coupling changes with the Blue before coupling changes 47% and 57% after coupling changes.

Table 2: Average Jet Values for FY13 Lattices Used and Emittances

Lattice	Emittance	Avg. Jet Pol
e-lens Blue	$> 15\pi$	48%
FY12 Blue	$> 15\pi$	43%
e-lens Yellow	$> 15\pi$	44%
FY12 Yellow	$> 15\pi$	53%
FY12 Blue	$< 15\pi$	53%
FY12 Yellow	$< 15\pi$	58%

EMITTANCE CONTROL

During the first two months of this run we struggled with lower polarization values during the store. This was due in large part to larger emittances coming into RHIC and blown up during injection and along the energy and rotator ramp. The larger emittances coming into RHIC were related to longitudinal RF phase issues in the AGS injection and transition period. After these issues were fixed, RHIC injection emittances were reduced. Once emittances were controlled and kept under 11π mm-mrad (normalized at 95%) before the energy ramp, we reached record polarization values at RHIC store. In Fig. 3 you can see a comparison of our emittances in the early and later periods of the run.

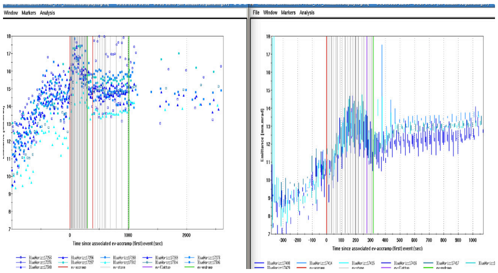


Figure 3: Horizontal Blue emittance growth along the ramp for first two months (left) since mid April (right).

Emittance growth at injection in RHIC

Prior to mid April emittances coming into RHIC were typically larger horizontally than 12π mm-mrad and then would proceed to grow as high as 15π mm-mrad before the start of the energy ramp. We attributed higher injection values to RF issues in the AGS and Booster and the growth at injection to tune and orbit instability and polarization measurements.

Emittance growth on the Ramp and Multi-bunch Effects

Tests with 6x7 bunches using 1.9×10^{11}/bunch intensity showed no appreciable emittance growth on the energy and rotator ramp (see Fig. 4). However with 111x111 bunches at 1.9×10^{11}/bunch intensity, transverse emittance growth in excess of 6π mm-mrad was observed. This together with a bunch train dependent emittance growth and pressure rises suggested e-cloud effects. Delaying the timing of the change to the collisional RF system and minimizing the time between the energy ramp and rotator ramp when feedback is disengaged helped alleviate some of the effects of e-cloud and we were able to take 2.2×10^{11}/bunch up the ramp keeping the emittances under 16 π mm-mrad by the end of the rotator ramp. However once in collision, the higher intensity did lead to emittance blow up due to beam-beam effects.

Emittance Growth at Collision

With higher intensity there was a pronounced blow-up of the yellow transverse emittance. This we attribute to beam-beam effects which could also be aggravated by

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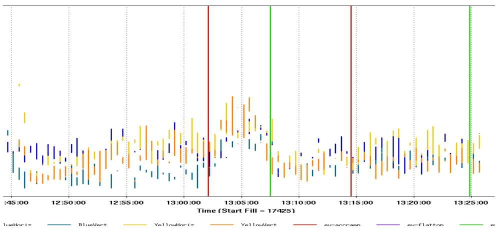

Figure 4: Emittance growth on ramp with 1.9×10^{11}/bunch for 6x7. Ramp with few but intense bunches shows very minimal emittance growth.

mis-steering at collision. To date this blow up in Yellow emittance has set our intensity threshold in Blue to be 2.0×10^{11}/bunch. Yellow is presently limited to 2.0×10^{11}/bunch by longitudinal instabilities.

POLARIZATION TRANSMISSION EFFICIENCY ON THE ENERGY RAMP

Apart from emittance, we attempted to affect polarization losses on the ramp through tune and coupling effects. Generally results from theory and simulation show that the beam is most resistant to depolarizing effects near the 2/3rd tune in both vertical and horizontal planes. For this reason we introduced localized and global tune swings on the energy ramp to bring our vertical tunes to 0.671 during the two strongest intrinsic resonances crossings and to 0.68 horizontally above 100 GeV and through the strong intrinsic resonance crossings. These tune bumps were applied in both the e-lens lattice and the run 2012 lattice to varying degrees. The replacement of a skew quadrupole power supply on April 22nd dramatically changed how global coupling was applied in feedback during the energy and rotator ramp. At the time of this writing the reason for this change is not well understood. This change seemed to correlate with a rise in both the Blue jet polarization values and the Carbon CNI values.

RF UPGRADES

The commissioning of the longitudinal bunch-by-bunch damper at injection and on the ramp raised the effective limit of intensity we could take up the RHIC energy ramp. The bunch-by-bunch damper controlled the bunch length and alleviated the squeeze-out losses on the ramp. This is when the rate of change of Dipole Field reaches a maximum and the accelerating RF phase space acceptance is the smallest. The shorter bunch length also contributed to increasing the integrated luminosity. Still the Yellow ring demonstated a lower intensity limit than the Blue ring. At 2.1×10^{11}/bunch intensity the Yellow ring had reached its longitudinal stability limit. In Blue 2.2×10^{11}/bunch intensity has been achieved and we have not reached Blue's limit on the ramp yet. It is surmised that there is a higher impedance in the yellow ring which may account for this difference.

SOURCE UPGRADES

A major upgrade of the RHIC polarized H- ion source was done for Run 2013. A novel polarization technique was implemented in the operational polarized ion source for the first time. In this source the primary ECR-source based proton beam was replaced with the high-brightness external atomic hydrogen injector developed in collaboration with the Budker Institute of Nuclear Physics. The atomic H beam is then injected into the superconducting solenoid (3.0 T field), where it is stripped to protons in the pulsed He gaseous ionizer cell and polarized via a spin exchange mechanism with optically pumped Rubidium vapor [1, 2] The new source has been shown capable of reliably delivering between 5.0×10^{11} particles for Booster input at polarization of 83 - 84% to 9.0×10^{11} particle for Booster input at 77% polarization (0.53 mA beam current in 300 us pulse duration accelerated in Linac to 200 MeV). This polarization is 3-4% higher for intensity 5.0×10^{11} ions/pulse and nearly double our previous ECR-based source current at 77% polarization.

CONCLUSION

The 2013 255 GeV polarized proton run presented several challenges during the first several months of operations due to un-controlled transverse emittances, as well as lifetime and ramp efficiency issues of the new e-lens lattice. After switching back to the run 2012 lattice and control of transverse emittance was established, RHIC was able to deliver record intensities to collision with polarization near 60%. Intensities were so high that beam-beam emittance blow up required us to reduce intensities to below 2.0×10^{11}/bunch. Clearly to push above this threshold the technology of the e-lens will be needed. While the Yellow e-lens lattice proved problematic a new solution using the run 12 energy ramped lattice was devised with the polarity of the phase shifters switched. We hope to test this lattice before the end of this run. In Blue such a solution was not obtainable for the run 12 lattice given the power supply constraints for the phase shifters. However the polarization and intensity performance of the Blue e-lens lattice was better than Yellow and perhaps a new solution can be devised.

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