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POLARIZED PROTON BEAM FOR eRHIC*

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Abstract

RHIC has provided polarized proton collisions from 31 GeV to 255 GeV in past decade. To preserve polarization through numerous depolarizing resonances over the whole accelerator chain, harmonic orbit correction, partial snakes, horizontal tune jump system and full snakes have been used. In addition, close attentions have been paid to betatron tune control, orbit control and beam line alignment. The polarization of 60% at 255 GeV has been delivered to experiments with 1.8×10^{11} bunch intensity. For the eRHIC era, the beam brightness has to be maintained to reach the desired luminosity. Since we only have one hadron ring in the eRHIC era, existing spin rotator and snakes can be converted to six snake configuration for one hadron ring. With properly arranged six snakes in RHIC and additional reduction of emittance growth in AGS, the polarization can reach 70% at 250 GeV. This paper summarizes the effort and plan to reach high polarization with small emittance for eRHIC.

INTRODUCTION

The parameters for eRHIC proton beam is 70% polarization with 3×10^{11}/bunch and 0.2 πmm-mrad normalized emittance [1]. This emittance is at store and is expected to be cooled down by coherent electron cooling(CeC) [2]. On the ramp, the emittance will be larger as delivered by AGS. The resonance strength associated with the larger emittance will be stronger. This paper will discuss how the 70% polarization can be achieved based on current status of RHIC polarized proton operation and possible snake configuration changes.

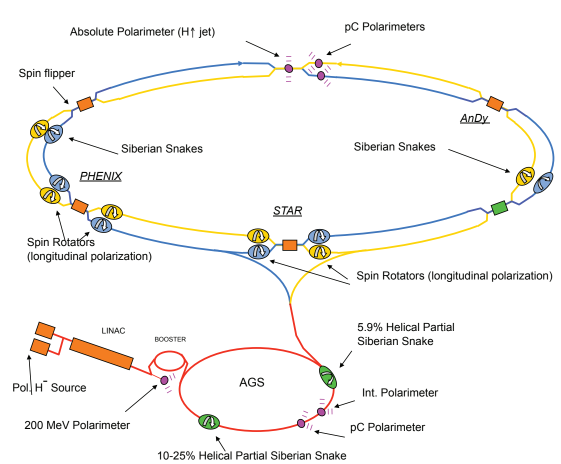

Figure 1: Layout of RHIC complex.

The current proton acceleration chain is shown in Fig. 1. High intensity and high polarization H^- is produced from the polarized proton source. The H^- beam polarization is measured at the end of 200 MeV linac as 80-82%. The beam is then strip-injected into AGS Booster. The Booster vertical tune is set high so that $0 + \nu_y$ intrinsic resonance is avoided. Two imperfection resonances are corrected by orbit harmonic correction. In the AGS, two partial Siberian snakes separated by 1/3 of the ring are used to overcome the imperfection and vertical intrinsic resonances [3]. The vertical tune on the energy ramp is mostly above 8.98, so that it is in the spin tune gap and away from the high order snake resonances. To avoid the horizontal intrinsic resonances driven by the partial snakes, a pair of pulsed quadrupoles are employed to jump cross the many weak horizontal intrinsic resonances on the ramp [4]. Two full Siberian snakes are used in each of the two RHIC rings to maintain polarization [5]. The betatron tune, coupling and orbit feedback on the energy ramp are also crucial for polarization preservation.

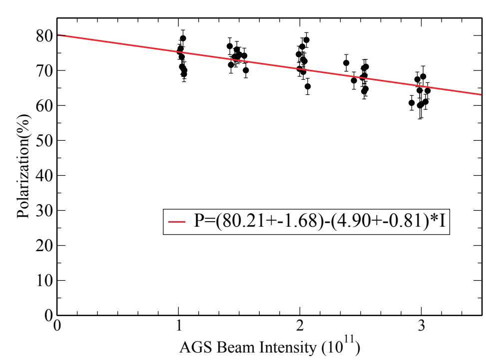

Figure 2: AGS polarization at extraction as function of bunch intensity. The polarized proton source can deliver intensity of 9×10^{11} at the Booster input. Booster scraping (both horizontal and vertical) is used to reduce the beam emittance for AGS injection. The intensity in this figure is changed by varying the Booster scraping level.

The polarization measured at the AGS extraction is shown in Fig. 2 as function of beam intensity. The intensity was reduced by Booster scraping. The polarization dependence on intensity is really dependence on emittance. As higher intensity is always associated with larger emittance, and consequently stronger depolarizing resonance resonance strength, lower polarization is expected for higher intensity. As shown in Fig. 2, the polarization at 3×10^{11} is about 65%. The AGS Ionization Profile Monitor(IPM) can measure beam emittance but the measured beam size is affected by space charge force. To mitigate the effect, the RF is turned off at flattop. The emittance reported by IPM with RF off is plotted in Fig.3. Since there is pos-

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sible emittance growth in the Booster and mismatch in the transfer line, the projected emittance with zero intensity is not zero.

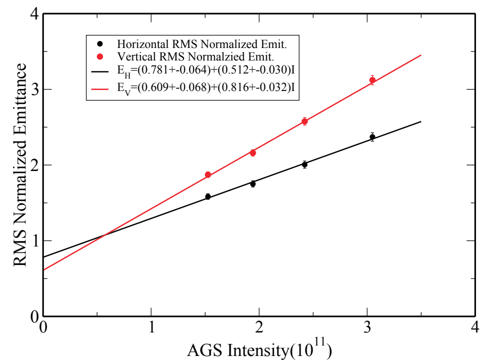

Figure 3: AGS emittance measured by IPM vs. intensity at the AGS extraction.

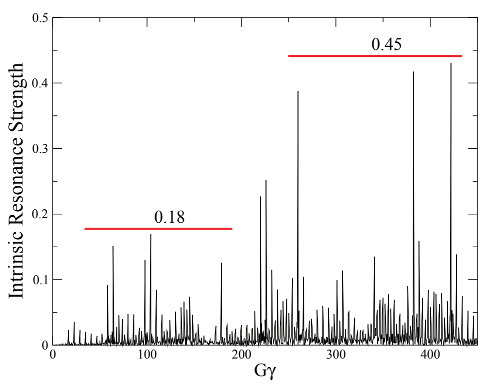

Figure 4: The intrinsic resonance strength of RHIC lattice for a particle on a 10π normalized emittance invariant. Below 100 GeV, the resonance strength is less than 0.18. To accelerate proton beam to 250 GeV, the stronger resonance strength of 0.45 has to be overcome.

At 3×10^{11}, rms normalized vertical emittance is about 3π, rms normalized horizontal emittance is about 2.3π. These are emittances we are going to dealt with on the energy ramp. As the running experience shows, the polarization transmission efficiency up to 100 GeV in RHIC is close to 100% but about 85% for 250 GeV and 1.8×10^{11} bunch intensity, due to stronger intrinsic resonances. The intrinsic resonance strength can be calculated from DEPOL [6]. The results are shown in Fig. 4. As it is shown in Fig. 4, the highest resonance strength for particle on 10π normalized emittance invariant is about 0.18 below 100 GeV and is about 0.45 beyond 100 GeV. The resonance strength threshold for 100% polarization transmission efficiency with two snakes may lie between 0.18 and 0.45.

In the electron-ion collider stage, only one hadron ring is needed. In this case, the spin manipulating devices in both hadron rings can be used in one ring. Six snakes can be made from combining four existing snakes into one hadron ring, and reconstructing additional two snakes from spin rotators. In this case, six snakes will be available in the hadron ring. As a rule of thumb, the resonance strength threshold should increase by the same factor as number of snakes. Since the real resonance threshold is unknown, simulations are needed to see if polarization can be preserved for six snake case.

SPIN SIMULATIONS

To estimate the polarization transmission efficiency on the ramp, spin tracking was done for one of three strongest resonances $411 - Q_y$ with ZGOUBI code [7]. The tracking were done for 8 particles on $\sigma = 2.5\pi$ vertical emittance ellipse. To speed up the tracking, the acceleration is 7 times of normal acceleration rate. It should be noted that with snake inserted, polarization loss is not sensitive to resonance crossing speed. Only vertical betatron motion is in the simulation. For comparison purpose, the simulations are also done for 2-snake case.

The results are shown in Fig. 5. As shown in Fig. 5, the 2-snake is not enough to preserve polarization for beam particles outside normalized rms emittance 2.5π.

6-SNAKE CONFIGURATION

For multiple snakes scenario, the snake arrangement has to satisfy the condition for energy independent spin tune, namely

$$\sum_{k=1,3,5} \theta_{k,k+1} = \pi, \quad \sum_{k=2,4,6} \theta_{k,k+1} = \pi.$$

The axis angles are at $\phi = \pm 45^\circ$ from longitudinal axis in the local Serret-Frenet frame, so ensuring respectively $Q_s = 3/2$, following

$$Q_s = \frac{1}{\pi} \left| \sum_{k=1}^{N_s=6} (-)^k \phi_k \right|.$$

Not all snake arrangements satisfying above conditions will preserve polarization. However, a simple arrangement with the 6 snakes equally spaced by $2\pi/6$ can preserve polarization.

The simulations with ZGOUBI are also done for 6-snake configuration and the results are shown in Fig. 6. It shows that the polarization is preserved for the small and large emittance cases.

SUMMARY

Currently, RHIC proton ring is able to deliver 60% polarization at 250 GeV for collisions with 1.8×10^{11} bunch intensity [8]. AGS can deliver 65% polarization with 3×10^{11}. The additional gain in polarization comes from vertical emittance preservation in the AGS, so that the resonance

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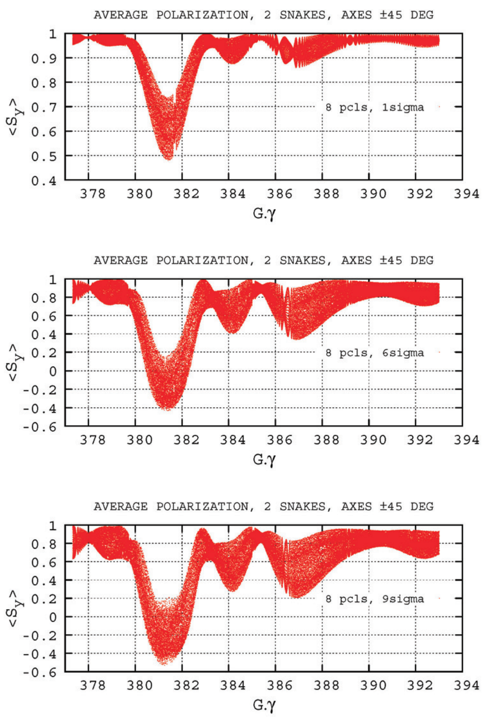

Figure 5: Spin simulation results for 2 snakes, snake axis as ±45 degrees. From top to bottom, the vertical invariant is $\epsilon_y = 1,\ 6,\ 9\sigma$, with $\sigma = 2.5\pi$mm.mrad normalized emittance. Each plot shows the average vertical projection of the spin, computed from the tracking of 8 particles evenly distributed on the invariant. The horizontal invariant is negligible. The polarization is preserved for the 2.5πmm.mrad case, but not the realistic large emittance case.

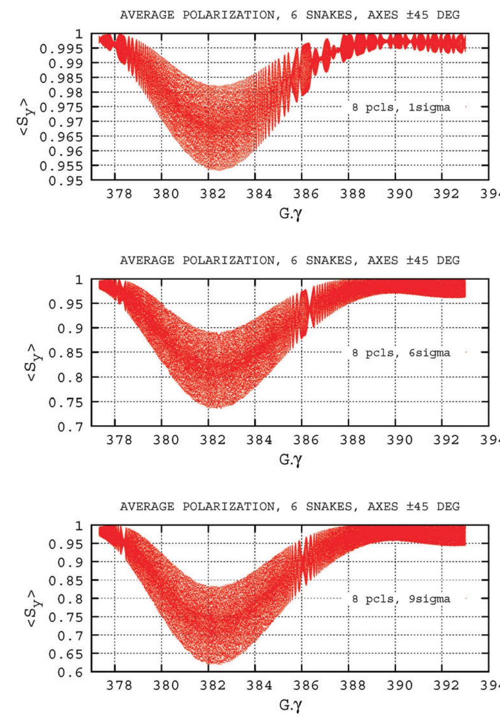

Figure 6: The simulation results for 6 snakes, snake axis as ±45 degrees. From top to bottom, the vertical invariant is $\epsilon_y = 1,\ 6,\ 9\sigma$, with $\sigma = 2.5\pi$mm.mrad normalized emittance. Each plot shows the average vertical projection of the spin, computed from the tracking of 8 particles evenly distributed on the invariant. The horizontal invariant is negligible. The polarization is preserved for all cases.

strength in the AGS can be reduced. This then can lead to higher polarization required for eRHIC. At 250 GeV, with 6-snake configuration, the polarization transmission efficiency is close to 100% in RHIC. The required low emittance will be done by CeC. Simulations with multi-particles and 6-D distribution for real acceleration rate will follow.

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