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SIMULATIONS OF POLARIZED HELIONS IN THE HSR

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Abstract

The Electron Ion Collider calls for collisions of helion beam on polarized electron beams. Polarized helions will be injected into the Hadron Storage Ring at $|G\gamma| = 49.5$ and have a maximum energy corresponding to $|G\gamma| = 820$. Simulations of helions in this energy range have been performed using zgoubi. These studies quantify the polarization transmission with six snakes and also categorize the lattice constraints.

INTRODUCTION

The Hadron Storage Ring (HSR) is part of the future Electron Ion Collider (EIC) project at Brookhaven National Laboratory and will be primarily constructed using existing components of the Relativistic Heavy Ion Collider (RHIC). Polarized protons and neutrons are essential for the EIC spin program for determining the contribution from quark and gluon spins to the total orbital angular momentum of hadrons. Polarized helions and polarized deuterons can serve as a proxy for polarized neutrons. For polarized helions, up to 86% of the polarization is comprised from the neutron polarization. Polarized helions allow for similar polarization preservation techniques as to polarized protons, except for time-sensitive methods such as fast tune jumps for resonance crossings. This is due to the larger anomalous gyromagnetic g-factor, G, which causes the resonance crossings per unit energy to be 1.6 times higher than with protons, and thus there is a reduction in the timing resolution. The EIC calls for 1.2×10^{11} helions per bunch at 70% polarization for collisions, where the source is expected to deliver 2×10^{11} ions with a polarization of 80%. This requires high intensity and polarization transmission through the injectors and the HSR [1].

The primary source of polarization loss is from depolarizing resonances caused by the particles motion in the spin perturbing horizontal fields, such as in quadrupoles. The strength of an intrinsic resonance is defined as [2],

$$\epsilon = \frac{1 + G\gamma}{4\pi} \sum_{quad,i} \Big(\cos(G\gamma\theta_i \pm \phi_{y,i}) + i\sin(G\gamma\theta_i \pm \phi_{y,i})(K_1L)_i\sigma_y \Big), \quad (1)$$

where γ is the Lorentz Factor, θ_i is the azimuth around the ring, $\phi_{y,j}$ is the vertical phase advance, K_1L is the strength of a quadrupole, and σ_y is the RMS vertical beam size. The intrinsic resonance occurs when $G\gamma = nP \pm \nu_y$, where n is an integer, P is the periodicity, and ν_y is the vertical betatron tune. The planned working point for the HSR has horizontal and vertical betatron tunes of ν_x, ν_y=28.228, 26.21, although adjustments of the phase-advance per cell are under investigation [3]. The calculated intrinsic resonance strengths for the two and one interaction point lattices, and a comparison with the RHIC lattice, is shown in Fig. 1. The

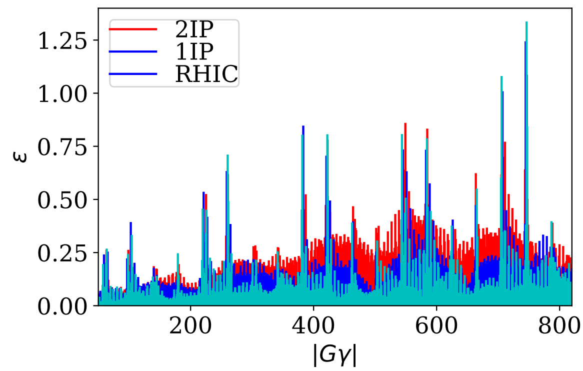

Figure 1: Resonance strength spectra for polarized helions from injection energy of $|G\gamma| = 49.5$ up to the maximum energy of $|G\gamma| = 820$ with a comparison between: 2 IPs (red), 1 IP (blue), and RHIC (cyan).

2 IP lattice shows much stronger non-systematic resonances compared to the 1 IP lattice, which also exhibits stronger non-systematic resonances than RHIC. The primary source of these differences in non-systematic resonance strengths is from the absence of the sector 8 low beta insertions in the 1 IP lattice. This is seen in Fig. 2 which shows the contribution to Eq. 1 from arcs 7 through 9.

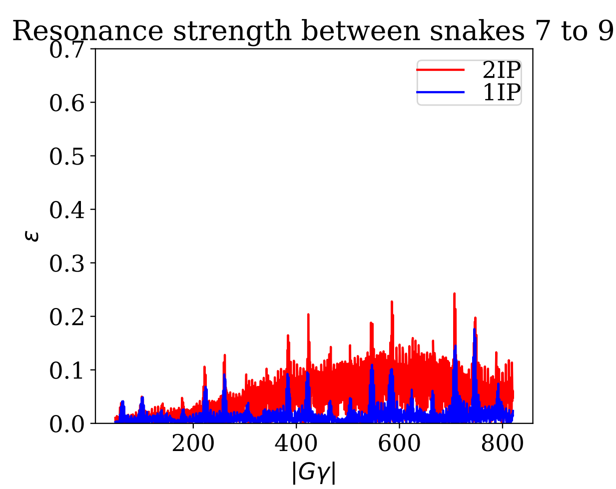

Figure 2: Contribution to Eq.1 from arcs 7 through 9 with (red) and without (blue) the IR8 low-beta insertions.

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Static simulations, where particles are allowed to freely precess at fixed energy in order to determine the stable precession direction, show that many higher order resonances are excited by this lattice, such as the $|G\gamma| = n - 2Q_y$ with Q_y being the fractional component of ν_y, as seen in Fig. 3.

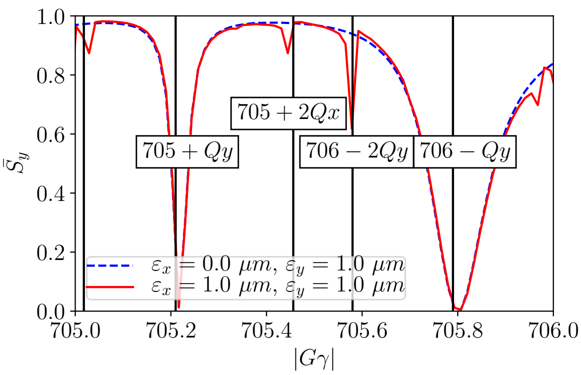

Figure 3: Static tracking results for a single particle with ε.

RESONANCE CROSSING SIMULATIONS

To quantify the effects of these depolarizing resonances, particle tracking simulations using 1,000 helion particles are performed using Zgoubi [4]. To preserve polarization of helions in the HSR from their injection energy of 10 GeV/u up to the maximum collision energy of 183 GeV/u, six full snakes will be used. For the 1 IP lattice the snake placement is perfectly symmetric, 60° apart, whereas the 2 IP lattice has each pair 180° degrees apart with one pair out of phase with the other two pairs. The simulations shown in this section only consider the 1 IP lattice.

The HSR cycle for polarized helions is shown in Fig. 4. The maximum ramp rate supported by the existing RHIC main magnet power supplies for helions is $d\gamma/dt = 1.075\ s^{-1}$ which corresponds to a total RF cavity voltage of V_{cav}=56.5 kV operating at a phase of $\phi_s = 2.7925$. The simulations shown in Fig. 5 use 60 kV at the given ϕ_s.

The spin tune, ν_s, as a function of snake arrangement and precession axis is given by [5]

$$\nu_s = \frac{1}{\pi}\sum_{k=1}^{N_s}(-1)^k\phi_k, \tag{2}$$

where ϕ_k is the precession axis of the snake, k is the snake number and N_s is the total number of snakes. For uncooled beams presented in Fig. 5, ν_s=1.5 corresponds to snake axes of $\phi_k = \pm 45°$ and ν_s=0.5 corresponds to snake axes of $\phi_k \pm 15°$. The uncooled emittance simulations consider a round beam with $\varepsilon_{x,y}$=2.5 μm where the cooled emittances consider a flat beam with $\varepsilon_{x,y}$=2.5, 0.5 μm. The two different snake configurations show a 10% difference in polarization transmission with uncooled beams. Each of the uncooled configurations results in a minimum of 30% polarization loss. The case of pre-cooled beams exhibit zero polarization loss,

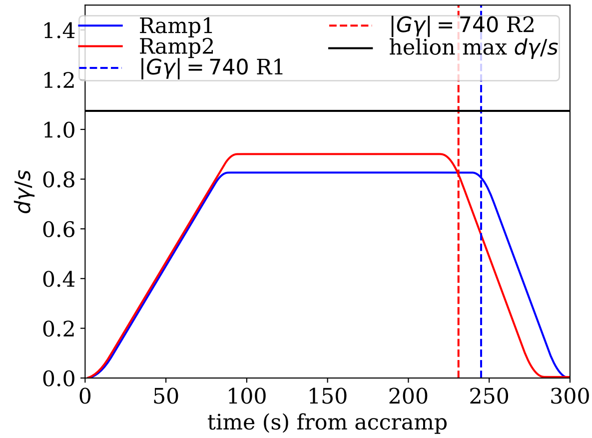

Figure 4: Example ramps for helions in the HSR based on maximum ramp rates of the RHIC main magnets. Ramp 2 is slightly shorter than ramp 1 and uses a higher ramp rate.

however it is not determined at what stage that cooling will be available. This is in contrast with simulations of polarized helons in RHIC which exhibited negligible polarization loss with uncooled emittances [6].

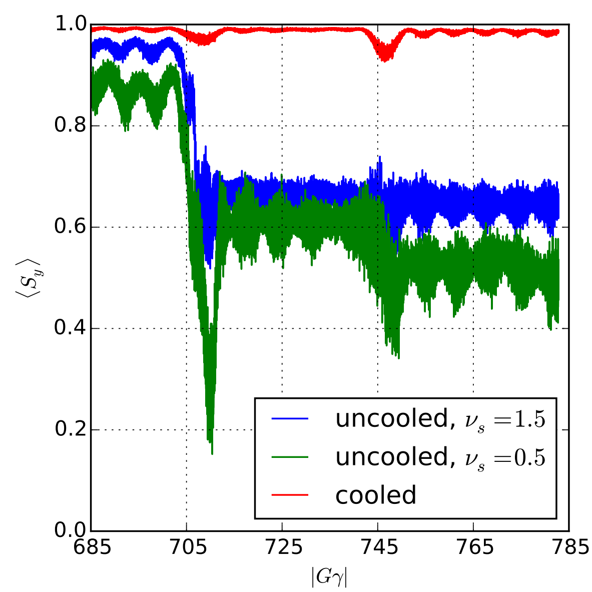

Figure 5: Resonance crossing simulations of the $|G\gamma| = 681 + \nu_y$ and $763 - \nu_y$ using 1,000 particles with a comparison of transmission of cooled and uncooled emittances.

A scan of polarization transmission for helions with cooled emittances from $|G\gamma| = 380$ to 450 as a function of ν_y is shown in Fig. 6. This shows a narrow region near the intended vertical tune where high polarization transmission can be achieved.

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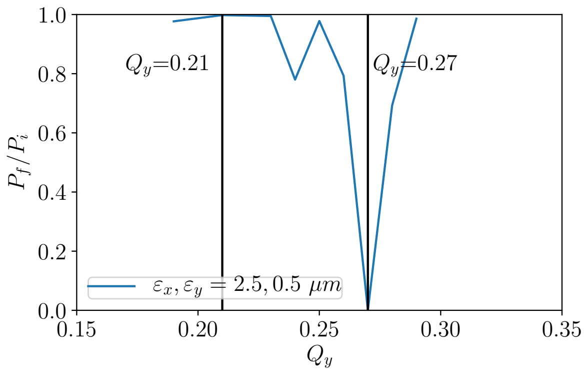

Figure 6: Polarization transmission of 1,000 helion particles as a function of vertical tune with cooled emittances across from $|G\gamma|$=380 to 450.

SUMMARY

Polarization transmission in the HSR is sufficient for collisions at the EIC with the addition of cooling. Currently, the uncooled beams would be unsuitable, resulting in a store polarization of 48% and assuming no additional losses. The vertical tune of ν_y=26.21 supports high polarization transmission. The effects of the snake angle on polarization transmission is an area for improvement. These simulations also assume a perfectly aligned machine, whereas when orbit defects are introduced, they will allow additional depolarizing mechanisms.

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