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HADRON STORAGE RING 4 O'CLOCK INJECTION DESIGN AND OPTICS FOR THE ELECTRON-ION COLLIDER

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Abstract

The Hadron Storage Ring (HSR) of the Electron-Ion Collider (EIC) [1] will accelerate protons and heavy ions up to a proton energy of 275 GeV and Au^{+79} 110 GeV/u to collide with electrons of energies up to 18 GeV. To accomplish the acceleration process, the hadrons are pre-accelerated in the Alternating Gradient Synchrotron (AGS), extracted, and transferred to HSR for injection. The planned area for injection is the current Relativistic Heavy Ion Collider (RHIC) [2] 4 o'clock utility straight section (USS). To inject hadrons, a series of modifications must be made to the existing RHIC 4 o'clock straight section to accommodate 20 new 18 ns injection kickers [3] and a new injection septum, while providing sufficient space and proper beam conditions for polarimetry equipment. These modifications will be discussed in this paper.

INTRODUCTION

The EIC, to be built on the Brookhaven National Laboratory campus, will exceed the capabilities of previous collider beam accelerator facilities by providing center-of-mass energies ranging from 20 GeV to 140 GeV, collisions of both polarized protons and electrons, luminosities to 10^{34}, and a variety of ion species available for collisions with electron beams.

The pre-injector is a 400 MeV linear accelerator (LINAC) that injects into a Rapid Cycling Synchrotron (RCS). The RCS then ramps the polarized electron beam to an energy of 5 GeV, 10 GeV, or 18 GeV. The polarized electron beam is transferred to the ESR [4] at a frequency of 1 Hz. For polarized protons, the HSR pre-injector is the 200 MeV LINAC. The Electron Beam Ion Source (EBIS) will provide heavy ions and polarized He^{+3} for the HSR. The beam is transported through two accelerators, the AGS-booster and the AGS, to the HSR injection energy and extracted through a transfer line to the HSR. Modifications to each of the HSR straight sections will be needed [5]. The injection of the HSR is in the 4 o'clock USS. The beam will then travel counter clockwise around the ring to the cooling section of the 2 o'clock USS [6], the 12 [7] and 10 [8]o'clock switch yards, the 8 o'clock Interaction Region (IR) of another future experiment [9], which is not part of the current EIC scope, and then the 6 o'clock IR [10].

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4 O'CLOCK USS

The 4 o'clock USS from the Q10 slot to the Q4 slot magnetic lattice layout will not differ from RHIC.The D9 to D5 are optimized for dispersion matching and the doublets Q5 and Q4 designed for optics matching. The "D" designates a dipole magnet and "Q" a quadrupole. The RHIC triplet quadrupole magnets are preserved while 5 m warm dipoles are used to bend the hadron beam from the outer ring to the inner ring. The change of the position of the downstream warm dipole will cause a transverse shift of the triplet quadrupoles. Twenty injection kickers are located at the center of the 4 o'clock USS with an 8 m gap between the two groups of 10 kickers to allow for the ESR crossover. An injection septum and two warm quadrupoles are also proposed the injection system. Figure 1 is a schematic of the 4 o'clock USS.

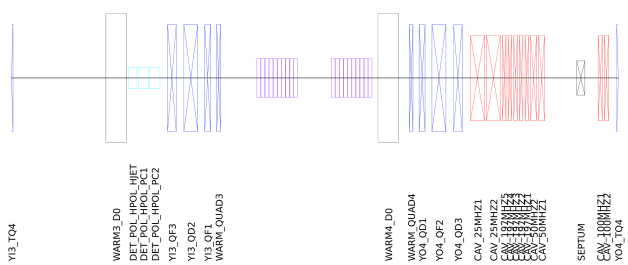

Figure 1: Magnetic lattice of the 4 o'clock USS from outer TQ4 to inner TQ4. The hadron beam travels from right to left.

The 4 o'clock USS contains the normal conduction copper radiofrequency (RF) cavities of the HSR in the same sector of the as the current RHIC cavities. In addition to the two 28 MHz cavities which will be tuned to a frequency of 24.6 MHz and 197.1 MHz cavities, two new RF systems will be added. The HSR will have two adiabatic bunch splittings from the injected 290 bunches to 580 and 1160. This will require the new RF systems of 49.3 MHz and 98.5 MHz.

The absolute polarimeter using a polarized hydrogen jet (H-jet) and two fast proton-carbon (pC) polarimeters will be located in the 4 o'clock USS. For $He^{+}3$ polarization measurements, forward taggers required to veto breakup of the $He^{+}3$ from the collisions of the H-jet. To separate the breakup products, protons, deuterons, and neutrons, a dipole downstream of the H-jet and allotted space for the taggers is necessary. This requirement is a driver for a 4 o'clock USS lattice configuration where the warm D0 dipole magnets positions

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are asymmetric to each other. The sector 4 warm dipole is located on the inside of the triplets while the sector 3 dipole is outside of the triplets. The absolute value of the warm dipole angle is 3.59 mrad. The polarimeters are located upstream of the sector 3 D0 magnet. A helical dipole snake is added to the sector 3, D7 dummy slot for polarization preservation through energy ramps.

Injection

The single turn fast injection [11] of the HSR requires a change in the optics from the normal storage optics to compensate for the strong horizontal focusing of the triplet Q2 magnets. Warm quadrupoles are used as additional horizontal defocusing for the horizontal injection. The addition of the warm quadrupole focusing changes the triplet optics into doublet optics (TripletDoublet). Figure 2 shows the β-functions and dispersion for the circulating beam in the 4 o'clock USS.

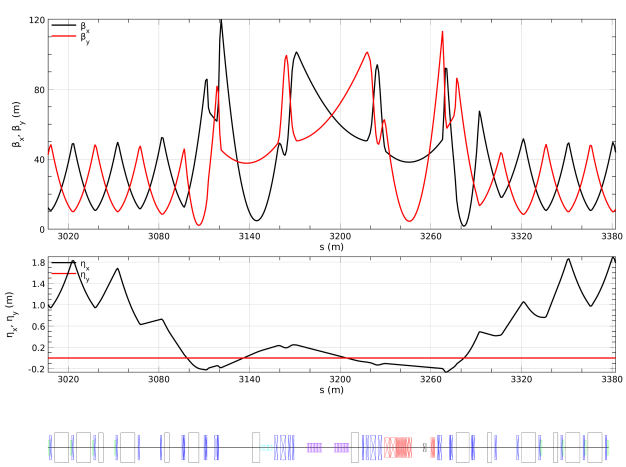

Figure 2: Circulating beam dynamics. Top: β-functions, middle: η-functions, bottom: lattice layout.

The kickers, with apertures of 59 mm diameter, will kick the beam by 1 mrad total. The septum is located 49.8 m upstream of the kickers and 27.8 m for the horizontally defocusing triplets. The septum aperture of 60 mm will accommodate a 5σ beam envelope and a 3σ injected beam envelope. If the septum wall of the DC injection septum is 15 mm, then the total angular kick needed is 0.8 mrad reducing the number of kickers needed for injection. An induction septum with a thinner septum wall can also reduce the number of kickers. Figure 3 shows the beam envelopes of the circulating and injected beam. The 3σ injected beam will not scrape on any of the physical apertures when being injected. Figure 4 shows the angles required to achieve a stable injection into the HSR.

The optics at injection require modifications to the feedthroughs of the current RHIC triplet cryostat module. The penetration rating for the Q3 of triplet for the HSR is 600 A which is twice that of the current RHIC.

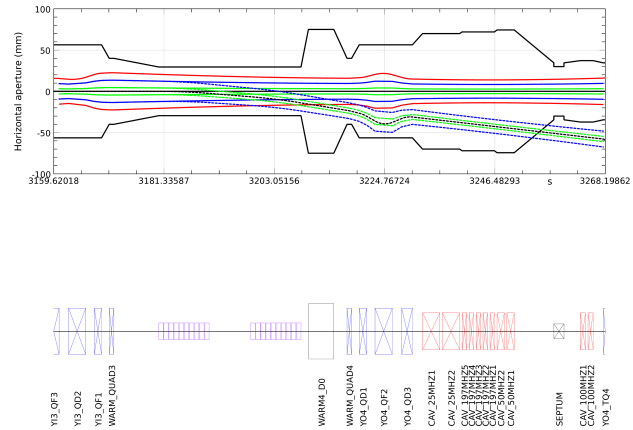

Figure 3: Injected beam with apertures magnet apertures. Top: 5σ (red), 3σ (blue), 1σ (green) beam envelopes of circulating (solid) and injected (dashed) beam.

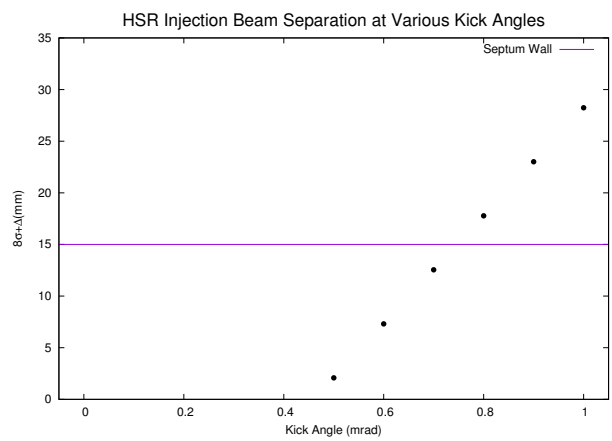

Figure 4: Injected beam horizontal trajectory at septum. The 8σ beam envelope is subtracted from y-axis. Δ is the separation of injected from the circulating beam. The purple line indicates the a septum wall of 15 mm thickness.

Ramp and Store Optics

The ramp and store optics of the 4 o'clock USS are very similar to the current RHIC optics. The triplet optics are preserved at the beginning of the ramp, Fig. 5, with a β^* of 10 m. To have these optics pre-ramp, the warm quads will need to be ramped down and the Q2 quadrupole strengths will increase. As the energy ramps, the 4 o'clock USS β^* will decrease to 5 m around the gamma transition, γ_t, of the HSR lattice for transition crossing [12].

The store optics, Fig. 6, show beam optics with a 5 m β^*. The β_{max} for the horizontal plane is 274.9 m and for vertical is 267.3 m. The field of the warm dipoles at store energy, 275 GeV protons, is 0.66 T.

SUMMARY

The HSR 4 o'clock USS was presented. The major modifications to the RHIC lattice for the EIC upgrade will take place between the TQ4 quadrupoles of the 4 o'clock

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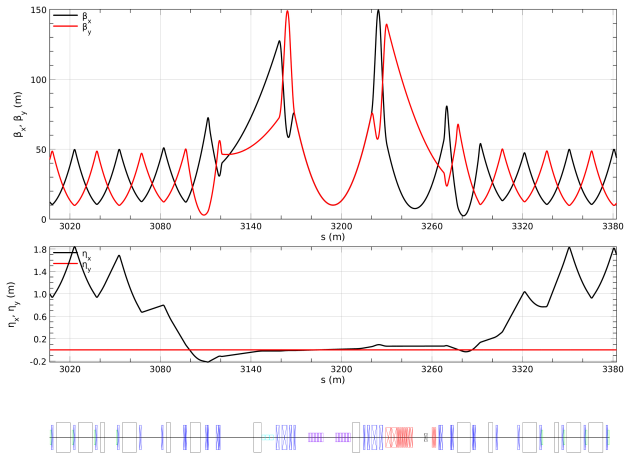

Figure 5: Ramp optics for 4 o'clock USS.

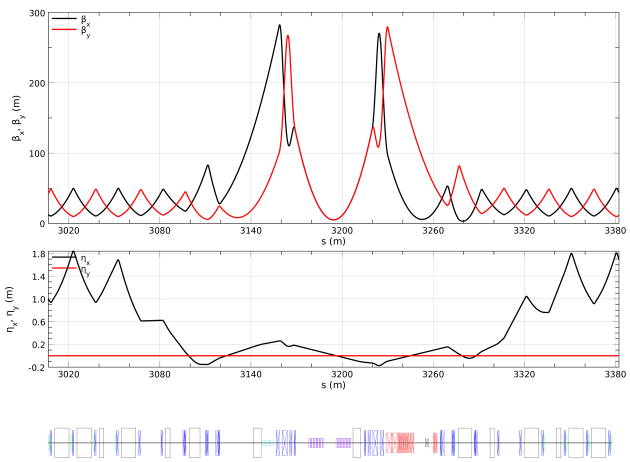

Figure 6: Store optics for 4 o'clock USS.

USS. Two warm dipoles, 20 injection kickers, two warm quadrupoles, and the polarimetry subsystems will be placed in the 4 o'clock USS. An additional snake will be placed in the D7 dummy slot.

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