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LAYOUT OF THE 12 O'CLOCK COLLIMATION STRAIGHT SECTION FOR THE EIC HADRON STORAGE RING*

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Abstract

The design of the Electron-Ion Collider (EIC) Hadron Storage Ring (HSR) calls for using parts of both of the Relativistic Heavy Ion Collider (RHIC) Blue and Yellow rings. With the HSR having to circulate low (41 GeV/u) and high (100+ GeV/u) energy hadron beams while matching the time of flight in the Electron Storage Ring (ESR), it becomes necessary for the ring lattice to switch from an outer arc to an inner arc in order to accommodate the change in circumference. To do so, a switchyard is planned for installation in the HSR straight section at 12 o'clock with the other switchyard being placed in the straight section immediately downstream, 10 o'clock. The 12 o'clock area is simultaneously dedicated to the EIC 2-stage collimation system. The following reviews the layout constraints in the 12 o'clock straight section that come with installing such a switchyard, along with the implications on the linear optics for that straight section at all HSR rigidities. The space allocation, Twiss parameters and the mechanical requirements of the HSR betatron collimators that will be installed in this section are also discussed.

INTRODUCTION

The Electron-Ion Collider (EIC) [1–3] features two storage rings, one for electrons and one for hadrons. The Hadron Storage Ring (HSR) accommodates a broad range of energies in order to deliver collisions at center of mass energies from $\sqrt{s_{e-h}}$ = 20 GeV to 140 GeV. To enforce the synchronicity between electron (ESR) and hadron (HSR) rings, and since electrons are ultra-relativistic at their EIC energies, it becomes necessary to adjust the HSR circumference. Table 1 lists the required circumference changes, along with the equivalent radius changes, for HSR operations.

The ΔC for protons at 100-275 GeV, as well as for Au ions at 110 GeV/u, can be accommodated by dedicated Radial Shift schemes [4]. The operations at lower energies (protons at 41 GeV, Au at 40.7 GeV/u) require such a large change that it can only be achieved if one of the three outer arcs from the baseline HSR design is replaced by one of the inner arcs left over from RHIC, since the difference in arc length between inner and outer is around 900 mm. In the baseline design there are three outer HSR arcs, located between the "clock" markers 4-6, 8-10, and 10-12. Out of these three, only the 10-12 outer arc can have an alternate inner arc since the 6 o'clock and 8 o'clock areas are designed as hosts for experimental detectors. For low energy operations, the hadron beam is rerouted through this inner arc using two switchyards placed in the neighboring straight sections: 10 o'clock [5], and 12 o'clock.

Table 1: Primary hadron beam parameters and circumference changes for EIC operations over the range $\sqrt{s_{e-h}}$ = 20-140 GeV [1], including energy E, Lorentz factor γ_{rel}, velocity β, required circumference change ΔC, and the average radial offset $\langle \Delta R \rangle$. Protons pass through 3 inner and 3 outer arcs except at 41 GeV, when they pass through 4 inner and 2 outer arcs.

E_{tot} GeV(/u)	γ_{rel}	$1-\beta$ 10^{-3}	C m	ΔC mm	$\langle \Delta R \rangle$ mm
PROTONS					
41.0	43.70	0.2619	3832.92	-908.7	–
100	106.58	0.0440	3833.75	-73.4	-11.7
133	141.75	0.0249	3833.82	0.0	0.0
275	293.09	0.0058	3833.90	73.1	11.6
GOLD IONS					
40.7	43.70	0.2619	3832.92	-908.7	–
110	118.09	0.0359	3833.78	-42.1	-6.7

The 12 o'clock straight section is also planned as the location of the multi-staged HSR collimation system, on top of being the ESR injection region and having a crossover of the ESR ring as well. This has strong implications on the placement of the switchyard itself, which in turns affect the placement of the HSR collimators. Additionally, having two possible paths for the circulating hadron bunches implies that parts of the collimation system have to be duplicated to make sure that the multi-stage approach applies to all energies. The HSR linear optics of the 12 o'clock area are therefore adjusted by taking into account simultaneously the beam size requirements from the switchyard and the phase advance constraint from the collimation system.

MECHANICAL LAYOUT OF THE INNER/OUTER SWITCHYARD

The main difference between the RHIC and HSR layouts comes from the removal of the DX magnets that are the innermost bending dipoles placing the counter-rotating RHIC beams on their common colliding path. These dipoles cannot be used in the HSR due to mechanical (transverse aperture) and magnetic (attainable peak field at 275 GeV) limitations. As a consequence, the common section is removed and it is the D0 dipoles, the dipoles closest to the DX locations, that transport the beam from one side of the straight section to the other. With the 12 o'clock area having to allow for a switch between the inner and outer arcs on the downstream

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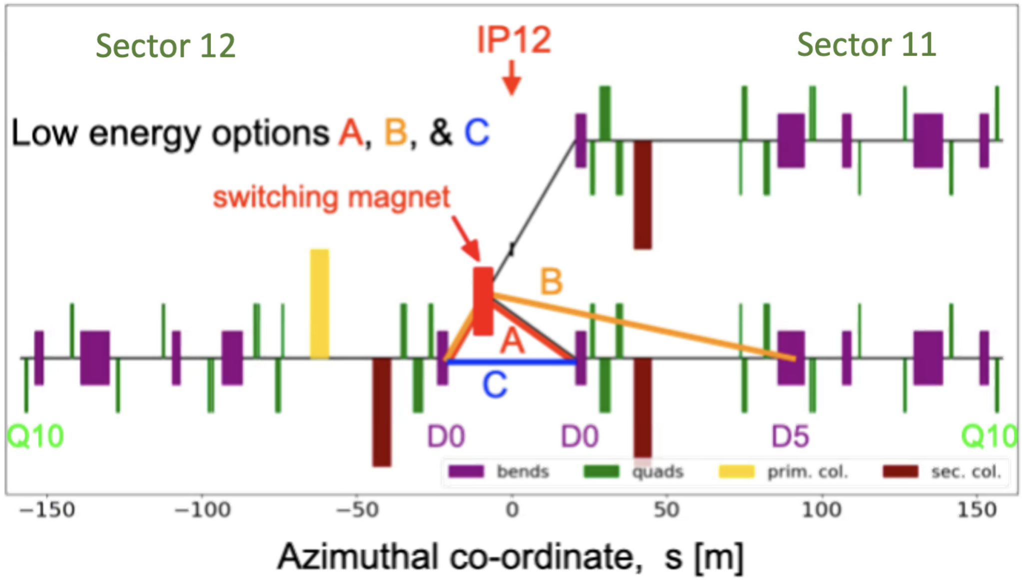

Figure 1: Schematic view of the layout of the HSR 12 o'clock straight section between the edges of the neighboring arcs. On the Sector 11 side (right), both the outer 100+ GeV/u (top) and inner 41 GeV/u (bottom) beamlines are shown, along with the proposed options A, B and C for the switchyard. The positions of the inner and outer Sector 11 layouts, as well as the angles of the A, B and C beam paths are exaggerated for illustrative purposes. Preliminary locations for the colimators of the HSR multi-stage machine protection system are also indicated.

side of that straight section, two options are being evaluated regarding how to best use the D0 dipoles. Both options assume the same beam trajectory for high energy (100+ GeV/u) operations, with the Sector 12 inner D0 aiming directly at the Sector 11 outer D0. The following focuses on how each option allows for rerouting the hadrons into the Sector 11 inner line.

Option 1: Using Existing Superconducting D0s

The first option is to keep the RHIC D0 dipoles, which are superconducting. Figure 1 shows a schematic view of the proposed layout of the HSR 12 o'clock straight section following the hadron beam direction from left to right. The last magnetic element on each side is the first quadrupole (Q10) of the neighboring arc; the bottom lines connect on the left and right side to the inner 12-2 and 10-12 arcs respectively, and the top line links to the outer 10-12 arc.

Options A and B in Figure 1 depict the switchyard setups that are possible when keeping the existing cold D0 magnets. This is based on the idea that the Sector 12 D0 (left side) is always powered in such a way that it aims the hadron beam at the Sector 11 outer D0 (right side, top line) for all energies, from injection to the collision energies. This means that an additional switching magnet (*SWM*) needs to be added on the outgoing path of the Sector 12 D0:

- for 41 GeV/u operations, the switching magnet is powered to redirect the beam toward the Sector 11 inner D0 (right side, bottom);
- for 100+ GeV/u operations, the switching magnet is not powered and lets the hadron beam through onto the Sector 11 outer line.

Based on preliminary estimates, the SWM can be designed as a warm dipole with a length of 5 m and a peak field of 1.1 T. Since the ESR layout crosses over near the midway point of the 12 o'clock area ("IP12" tag on Figure 1), the SWM needs to be located in close proximity to the Sector 12 D0. The beam path for 41 GeV operations can then go toward either the Sector 11 inner D0 (Option A) or the Sector 11 inner D5 (Option B) if the Sector 11 inner D0 is removed. Figure 1 over-states the difference between the beam paths A and B, i.e. the SWM-D5 path would not require significant realignment of the magnets and collimators along that path on the Sector 11 inner line. Only the strength of the D5 dipole needs an adjustment on the order of a few 100 μrad.

Option 2: Using New Warm D0s

This is the Option C path in Figure 1. In this scenario, the Sector 12 D0 and both Sector 11 D0s are replaced by longer warm dipole magnets, similar in design to the SWM that would be used if the superconducting D0s were kept as described above. With warm D0 magnets, the Sector 12 D0 would act as the SWM by pointing to the appropriate Sector 11 D0, inner or outer depending on HSR operations. Due to mechanical aperture constraints and uniformity of design for the new warm Sector 12 and Sector 11 D0 dipoles, switching the physics program from 100-275 GeV/u hadrons to 41 GeV/u hadrons (and vice-versa) would require a realignment of the Sector 12 D0 in order for its exit face to point to the correct beam line on the Sector 11 side.

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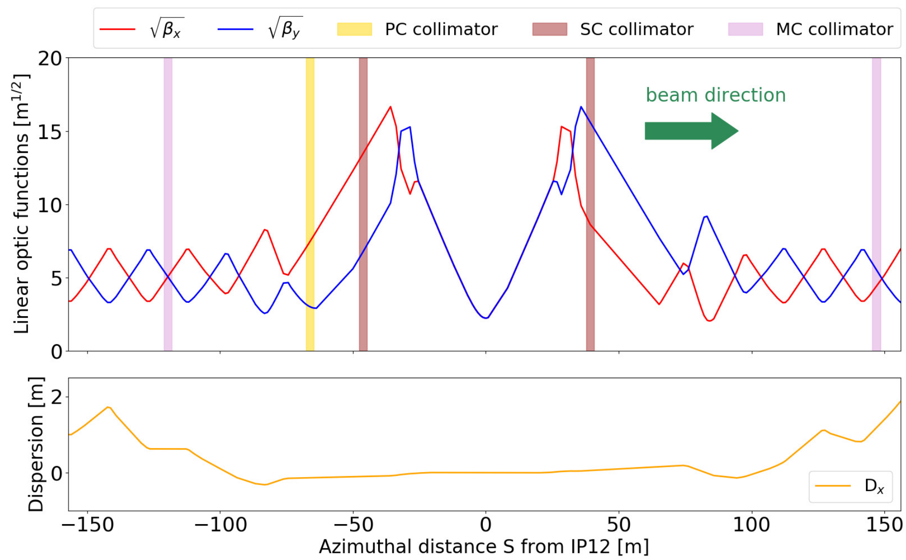

Figure 2: Linear optic functions (square root values, top) and dispersion (bottom) for 275 GeV protons in the HSR 12 o'clock insertion region of the HSR-220524a lattice. Preliminary locations for the colimators of the HSR multi-stage machine protection system are also indicated.

MULTI-STAGE COLLIMATION SYSTEM

The 12 o'clock area of the HSR also hosts collimators as part of the Machine Protection System (**MPS**). The betatron collimators shown in Figure 1 are part of a multi-stage system: **Primary Collimators** (**PC**, one per transverse plane) are set as the tightest aperture in the HSR in order to intercept circulating hadrons at large normalized amplitudes in the beam tails or *halo*. Impacting particles that do not have inelastic interactions inside the PC material are scattered back into the HSR and toward **Secondary Collimators** (**SC**, two per transverse plane), designed with a different material to have higher absorption rates. The typical aperture of a PC is around 6 $\sigma_{x,y}$, while the SC apertures are calculated based on the phase advance difference between PCs and SCs.

The available spaces for collimators are the two warm drifts upstream (Sector 12) and downstream (Sector 11) of the triplet quadrupoles leading to the Q4 quadrupole on each side of the straight section. The optimal locations for the PCs are closer to the Sector 12 Q4 such that the SCs can be placed closer to the triplets where the linear optic functions $\beta_{x,y}$ get much larger. This is true for both the anti-symmetric inner-to-outer (100-275 GeV/u) and the symmetric inner-to-inner (41 GeV/u) Twiss setups. However the switchyard implies that the MPS needs to be duplicated on the Sector 11 side to ensure all HSR configurations are protected the same way. Figure 2 shows the linear optic functions and dispersion for 275 GeV protons in the HSR 12 o'clock insertion region of the HSR-220524a lattice. Preliminary PC and SC locations are highlighted to illustrate the constraints in terms of available beam sizes and phase advance separation between each stage of the MPS collimators.

Additionally, a **Momentum Collimator** (**MC**) is needed to intercept hadrons with large momentum offsets. This MC has to be placed in a location which maximizes the ratio $D_x/\sqrt{\beta_x}$. Two preliminary spots are highlighted on Figure 2 for the 12 o'clock insertion, and similar suitable locations around the HSR lattice are being explored. All tentative MC locations are part of the cold areas of the HSR and would therefore require some significant modifications to the cryostatic tanks.

Multi-turn tracking studies with particle-matter interaction routines are underway to optimize the PCs, SCs and MCs locations, as well as the choice of material for their respective jaws. The efficiency of the MPS needs to be reviewed in the context of the large radial excursions discussed in this document and the new aperture restrictions coming from the need to fit the HSR beam pipe with inner sleeves [6].

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