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MATCHING THE BEAM FROM AGS TO THE EIC HADRON STORAGE RING WITH EXCELLENT EMITTANCE PRESERVATION*

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Abstract

The Electron-Ion Collider (EIC), a next-generation accelerator facility, is being jointly developed by Brookhaven National Laboratory (BNL) and Jefferson Lab (JLab), and will be constructed at BNL. The EIC design builds on the existing RHIC heavy-ion infrastructure, transforming the RHIC rings into the Hadron Storage Ring (HSR) with necessary modifications. To ensure optimal performance, it is critical to accurately match the beam from the injectors to the HSR in a six-dimensional phase space, in addition to the match of positions and angles. Inadequate matching can lead to emittance growth, which negatively impacts the achievable luminosity of the collider. This report outlines the key constraints involved in the matching process and presents a systematic approach to achieving high-fidelity beam matching while preserving emittance quality.

EIC OVERVIEW

The Electron-Ion Collider (EIC) [1] is a planned particle accelerator designed to study the internal structure of protons and nuclei. It will collide proton/heavy ion beams with energy up to 275 GeV with electron beam up to 18 GeV with an average spin polarization of 70% and 80% respectively. The ultimate luminosity to be delivered is of the order of 10^{34} cm^{-2}s^{-1}. The layout of EIC is shown in Fig. 1.

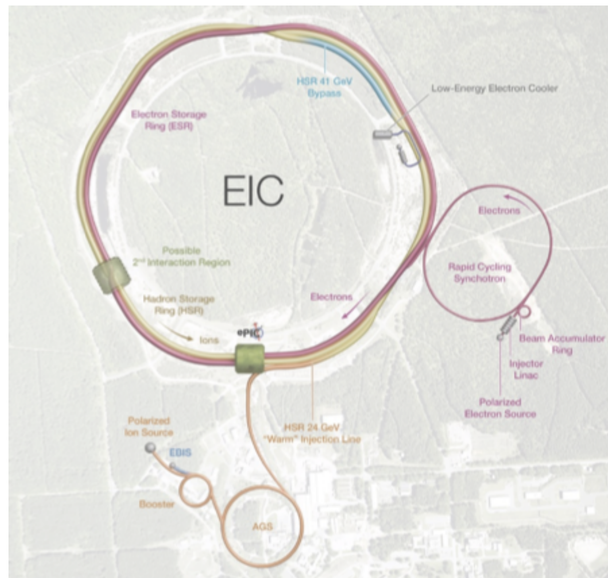

Figure 1: The Electron-Ion Collider layout. The RHIC facility, with modifications to the RHIC rings, will provide hadron beams. The electron Linac, Bunch Accumulation Ring, the Rapid Cycling Synchrotron and the Electron Storage Ring will be added as the electron facility to provide polarized electron up to 18 GeV.

In addition to the existing Relativistic Heavy Ion Collider (RHIC) [2] facility, electron injectors and a storage ring will be added with the storage ring located in the same RHIC tunnel. A 740 MeV linear accelerator will generate an electron beam with a bunch charge from 1 to 1.7 nC for injection into a Bunch Accumulation Ring (BAR). The output bunch charge for the BAR is up to 28 nC. The electron bunches will be accelerated in the Rapid Cycling Synchrotron (RCS) before being sent to the Electron Storage Ring (ESR).

The RHIC rings will be modified and reconfigured [3] to become the Hadron Storage Ring (HSR) to provide proton and heavy ions for the EIC facility. Its modification includes, but not limited to, a straight section modification to allow an energy upgrade to 275 GeV, an injection system upgrade for the injection of 290 bunches, the insertion of beam screens in the superconducting magnet beampipe for three times more beam current, the addition of electric cooling, the upgrade of RF and the instrumentation system. The HSR mostly comprises the yellow RHIC ring plus one sector of the blue ring for the operation of 41 GeV.

The HSR injection system, which includes a transfer line, septum magnets, and injection kickers, is required to inject 290 bunches into the HSR. Therefore, the rising time of the kickers is much shorter (7 ns) compared to that of the current RHIC injection kicker, which would require a stripline design. To provide enough kicker strength, 20 1-meter long kickers are required. Therefore, the location of IR4 is chosen to accommodate these devices since IR8 is reserved for a potential second experimental area. To bring the beam from the end of the ATR line to IR4 we have decided to use warm transfer line. The main purpose of this paper is to design this transfer line with a perfect match of the transverse phase space.

HADRON STORAGE RING (HSR) INJECTION LINE

The HSR injection line consists of the upstream matching section (UP), the periodical cells (CELL) and the down-

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stream matching section (DOWN). It is shown in Fig. 2 as part of the HSR injection system. The AGS to RHIC transfer line (ATR), which connects the AGS and RHIC, ends at a higher level than the plane of RHIC, which is required for the vertical injection scheme. The upstream matching section, which connects the end of the ATR to the periodic cells, needs to bring the beam to the same elevation of the RHIC. In addition, the upstream and downstream matching sections need to match the beam phase space to preserve beam emittance. In the following sections, the method and results of matching the elevation and phase space in the HSR injection line will be presented.

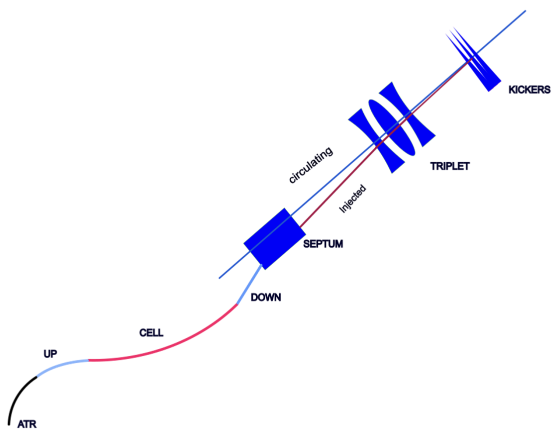

Figure 2: HSR injection system layout (not-to-scale). The AGS to RHIC transfer line (ATR) will be extended to bring beam to IR4, where the septum magnets and injection kickers are located. The extended transfer line includes the upstream matching section, 9 periodic cells and the downstream matching section.

MATCHING THE ELEVATION

The elevation match is accomplished by using two vertical dipoles. They are placed at the beginning and towards the end of the upstream matching section. The matching constraints are that the vertical height of the beam and the vertical angle after the second vertical dipole are set to zero. The implementation of the matching was performed in MAD-X [4] simulation.

MATCHING THE PHASE SPACE

In the HSR injection line, the beam trajectory matches the design orbit, and the local coordination system has X pointing to the left, Y pointing up, and Z pointing forward. The matching conditions for the upstream matching section can be expressed as follows.

$$\begin{pmatrix} \beta_x \\ \alpha_x \\ \beta_y \\ \alpha_y \\ \eta_x \\ \eta'_x \\ \eta_y \\ \eta'_y \end{pmatrix}_{UP} = \begin{pmatrix} \beta_x \\ \alpha_x \\ \beta_y \\ \alpha_y \\ \eta_x \\ \eta'_x \\ \eta_y \\ \eta'_y \end{pmatrix}_{PC} \tag{1}$$

The upstream matching section matches the Twiss parameters and dispersion functions with the periodic solution of the cells. The optics of the upstream section is shown in Fig. 3.

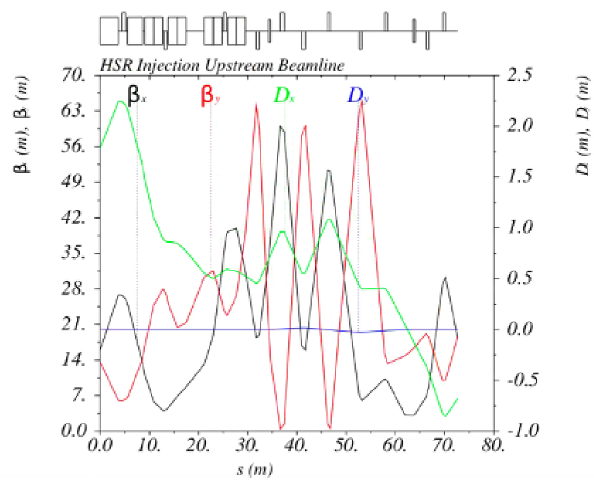

Figure 3: The Twiss parameters in the upstream matching section. The end matches the periodic solution of the cells.

The periodic solution of one of the cells (9 in total) [5], which the upstream matching section matches to, is shown in Fig. 4.

In the HSR, beam goes in the counterclockwise direction, but the design orbit is clockwise. The local coordinate system has X pointing outwards, Y pointing up and Z follows clockwise. The interface point of the injection line and the HSR ring sees the flip of X, Z and S coordinate. Therefore, the downstream matching section follows the following matching constraints.

$$\begin{pmatrix} \beta_x \\ \alpha_x \\ \beta_y \\ \alpha_y \\ \eta_x \\ \eta'_x \\ \eta_y \\ \eta'_y \end{pmatrix}_{DN} = \begin{pmatrix} \beta_x \\ -\alpha_x \\ \beta_y \\ -\alpha_y \\ -\eta_x \\ \eta'_x \\ \eta_y \\ -\eta'_y \end{pmatrix}_{HSR} \tag{2}$$

The Twiss parameters of the downstream matching section is shown in Fig. 5.

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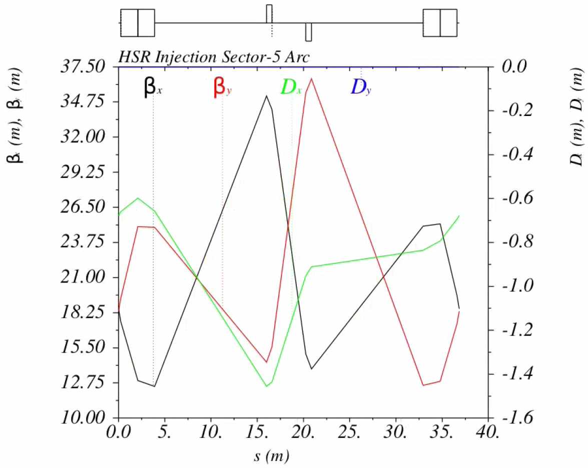

Figure 4: The Twiss parameters in one of the 9 periodic cells.

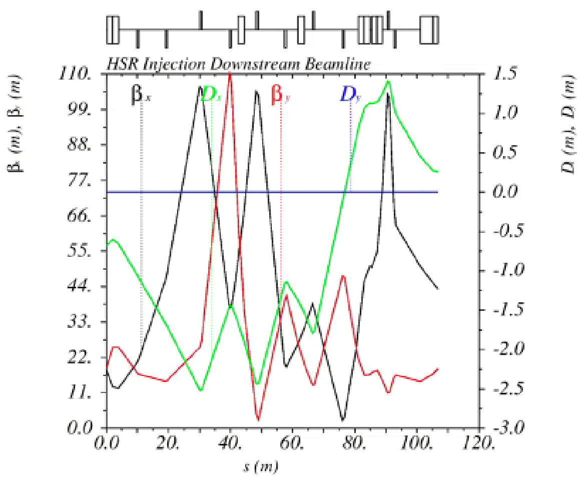

Figure 5: The Twiss parameters in the downstream matching section. The end matches to the HSR beam parameters at the end of the septum magnet.

SUMMARY

The HSR injection line is designed to match the beam parameters at the end of the ATR line to the injection point in the HSR. The matching constraints for the upstream and the downstream matching sections have been presented and simulation results presented. This design will ensure the preservation of beam emittance. In addition to that, the injection transfer line is also required to preserve the spin polarization. The study of spin will be presented in the future.

REFERENCES

[1] F. Willeke and J. Beebe-Wang, “Electron Ion Collider Conceptual Design Report 2021”, Office of Scientific and Technical Information (OSTI), Feb. 2021. doi:10.2172/1765663

[2] M. Harrison, S. Peggs, and T. Roser, “The RHIC accelerator”, *Annu. Rev. Nucl. Part. Sci.*, vol. 52, no. 1, pp. 425–469, Dec. 2002. doi:10.1146/annurev.nucl.52.050102.090650

[3] C. Liu *et al.*, “Reconfiguration of RHIC Straight Sections for the EIC”, in *Proc. IPAC’22*, Bangkok, Thailand, Jun. 2022, pp. 1916–1919. doi:10.18429/JACoW-IPAC2022-WEPOPT034

[4] H. Grote and F. Schmidt, “MAD-X – An Upgrade from MAD8”, in *Proc. PAC’03*, Portland, OR, USA, May 2003, paper FPAG014, pp. 3497–3499. doi:10.1109/PAC.2003.1289960

[5] H. Oh, S. Peggs, N. Tsoupas, and C. Liu, “A technical comparison of four optical cells for a normal conducting HSR injection beamline”, in EIC Tech Note, Brookhaven National Laboratory, Upton, NY, USA, Rep. EIC-ADD-TN-079. Dec. 2023. https://technotes.bnl.gov/PDF?publicationId=225059