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BEAM OPTICS OF THE INJECTION/EXTRACTION AND BEAM TRANSFER IN THE ELECTRON RINGS OF THE EIC PROJECT*

Nicholaos Tsoupas†, Bijan Bhandari, Douglas Holmes, Chuyu Liu, Christoph Montag, Vadim Ptitsyn, Vahid Ranjbar, John Skaritka, Joseph Tuozzolo, Erdong Wang, and Ferdinand J. Willeke
Brookhaven National Laboratory Upton NY, 11973, USA

Abstract

The Electron-Ion Collider (EIC) project has been approved by the Department of Energy to be built at the site of Brookhaven National Laboratory (BNL). The goal of the project is the collision of energetic (many GeV/amu) ion species with electron bunches of energies up to 18 GeV. The electron accelerator of the EIC is comprised of a 400 MeV LINAC, and two electron rings, the Rapid Cycling Synchrotron (RCS) which accelerates the electron beam up to 18 GeV, and the Electron Storage Ring (ESR) which stores the electron beam for collisions with hadron beam, both to be built in the same tunnel as the Hadron Storage Ring (HSR). This paper discusses the layout and the beam optics of the beam injection/extraction into the electron rings and the beam optics of the transfer line from the RCS to the ESR.

INTRODUCTION

The EIC accelerator complex [1] will collide various ions species at energies up to 270 GeV/amu with electrons of energies 5, 10, and 18 GeV. The ions will be injected and accelerated to the final energy in the hadron accelerators [1] with the final acceleration stage, the Hadron Storage Ring (HSR) [2], and the electrons will be accelerated in the electron accelerators [1] which consists of a 400 MeV LINAC, the RCS ring which will accelerate the electrons up to 18 GeV and the ESR storage ring which will store the electron bunches for collisions with the hadrons. Fig. 1. The electron beam transfer from the 400 MeV LINAC to the ESR including the spin rotator is discussed in ref. [3]. In this paper we disuss the latest version of the beam optics of the injection/extraction in RCS and ESR and beam transfer form RCS to ESR. Specifically the following information will be provided regarding the EIC.

- Beam optic of RCS injection
- Beam optic of extraction from RCS
- Beam optics of transfer line form RCS to ESR
- Beam injection and extraction in ESR

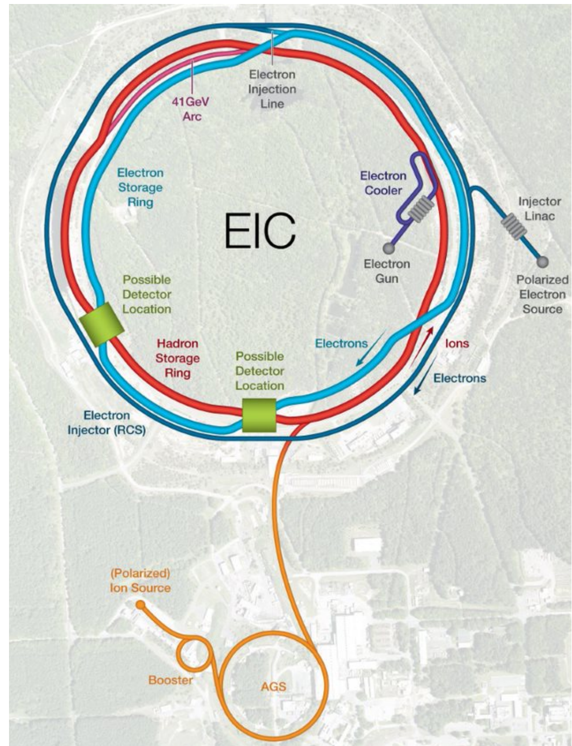

Figure 1: Schematic diagram of the EIC complex.

BEAM OPTICS OF RCS INJECTION

Following the Spin Rotator [3] the electron bunches are transported to the RCS for injection. This section describes the optics at injection into the RCS. To inject beam into the RCS, two sets of four bunches each are injected from the 400 MeV LINAC into the RCS at a frequency of 1 Hz. Each set is separated by 2 μsec, and the bunches in each set are separated by 1.6 nsec as shown in Fig. 2. This small separation (1.6 nsec) between the four consecutive bunches requires an injection RF-kicker which is described in [4]. An RF kicker is not strong enough to place the injected

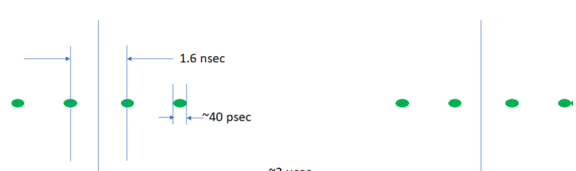

Figure 2: Bunch pattern at RCS injection.

bunch into the reference orbit without locally bumping the

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† tsoupas@bnl.gov

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circulating beam. The local beam bump of the reference orbit which is shown in Fig. 3 is generated by three magnets which are 20 cm long and ~1 mrad of strength for the 18 GeV electron beam. To complete this section of the beam injection, and also make the calculations easier, the beam direction is extracted, instead of "injected" starting from the RF-kicker. Figure 4 shows the injected beam trajectory (third plot from the top). Note the that the strength of the 0.5 mrad kicker displaces the injected beam by more than 40 mm.

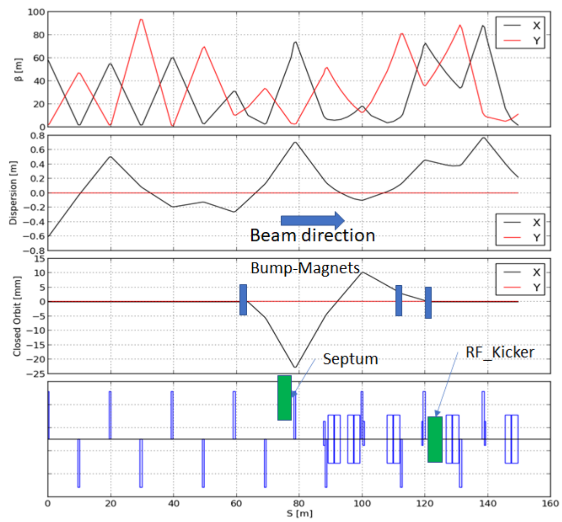

Figure 3: Beam parameters and bump, of injection section.

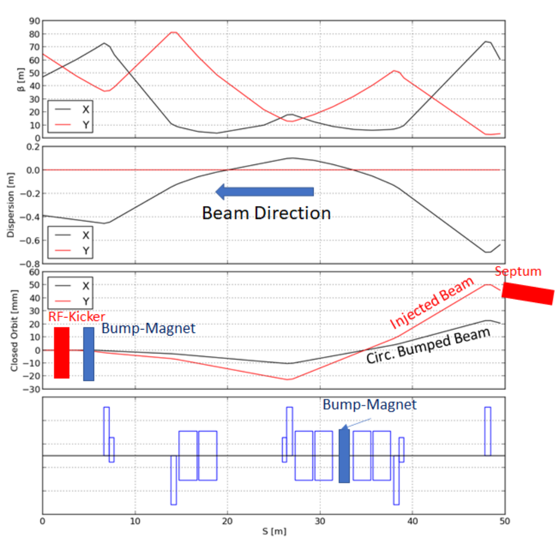

Figure 4: Circulating and injected beam trajectories in RCS.

RCS TO ESR TRANSFER

Following the beam injection into the RCS each set of four 7 nCb each bunches, shown in Fig. 2 is merged into a single bunch, and depending on the physics experiment, the final beam energy of the two bunches can be 5, 10 or 18 GeV thus having two circulating beam bunches into the RCS to be transferred into the ESR. For reason of clarity, the RCS-to-ESR transfer line is separated in few sections:
a) The "RCS extraction Section"; beam extraction from the RCS to the entrance of of the RCS extraction septum Fig. 5
b) The "1^{st} Beam Matching Section" to the "FODO with the Vertical Bend Section".
c) The "FODO with the Vertical Bend Section" which transfers the beam from the RCS level to the ESR level.
d) The "2^{nd} Beam Matching Section" from the exit of the "FODO with the Vertical Bend Section" to the exit of the ESR injection septum.
e) The last section is the "ESR Injection Section".
Due to limited space of this paper the sections b), c), and d) are combined in a single Fig. 6.

RCS Extraction Section

The beam parameters of the extraction section is shown in Fig. 5. It consists of a local beam bump in RCS, the extraction kicker, which kicks the bumped bunch at the entrance of the extraction septum. The location of the 3.5 mm thick Induction type extraction septum [5] is also shown. This RCS-extraction section determines the beam parameters at the entrance of the RCS extraction septum. These parameters appear in Table 1 and Table 2.

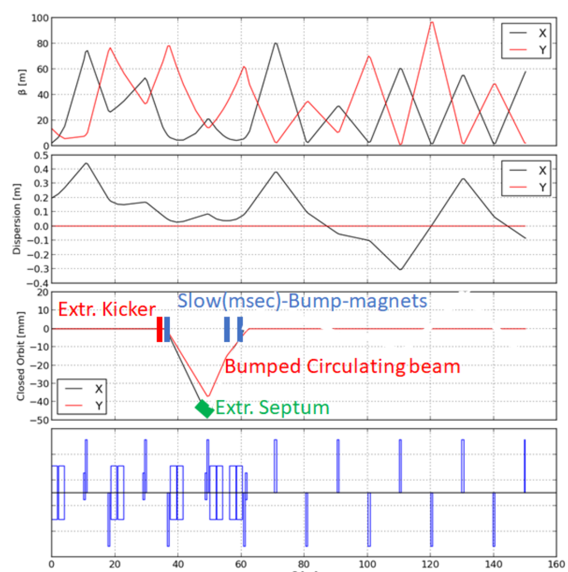

Figure 5: RCS Extraction.

Table 1: Horizontal Beam Parameters at the Entrance and Exit of the RCS and ESR Induction Septa Respectively

	β_x [m]	α_x	$\eta_x[m]$	η'_x
RCS_Entr.	9.958	-1.100	0.607	0.0033
ESR_Exit	60.601	-3.114	-279	-0.002

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Table 2: Vertical Beam Parameters at the Entrance and Exit of the RCS and ESR Induction Septa Respectively

	β_y [m]	α_y	$\eta_y[m]$	η_y'
RCS_Entr.	27.862	2.194	0.000	0.000
ESR_Exit	12.371	1.171	0.000	0.000

The 1st Beam Matching Section

The beam parameters of the "1st matching beam section" are plotted under the green highlighted part of Fig. 6. This section matches the beam parameters at the entrance of the RCS extraction Septum to those at the beginning of the "FODO with the Vertical Bend Section".

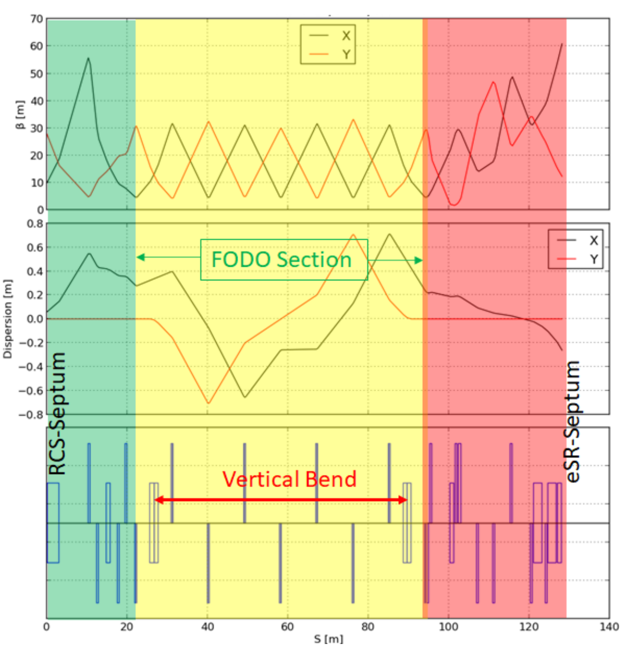

Figure 6: Parameters from Entrance RCS to Exit ESR septa.

The FODO with the Vertical Bend Section

The "FODO with the Vertical Bend Section" is the highlighted in yellow-section of Fig. 6. It consists of a FODO lattice with two vertical bends to transport the beam from the RCS level to the ESR level. The vertical bends make a vertically achromatic optical system.
This section raises the beam from the level of the RCS ring to the level of the ESR beam with two vertical bends placed in within the FODO lattice.

2nd Beam Matching Section

This section matches the beam parameters at the exit of the vertical bend to the exit of the ESR injection Septum. The beam parameters of this section are shown in the red highlighted section of Fig. 6.

ESR Injection Section

This section is the beam injection system into the ESR. It determines the beam parameters at the exit of the ESR injection septum. The beam parameters of the injection section into the ESR are shown in Fig. 7. The parameters at the exit of the of the injection section are shown in Table 1 and Table 2. The Injection kicker shown in Fig. 7 serves also as an extraction kicker of the spend beam.

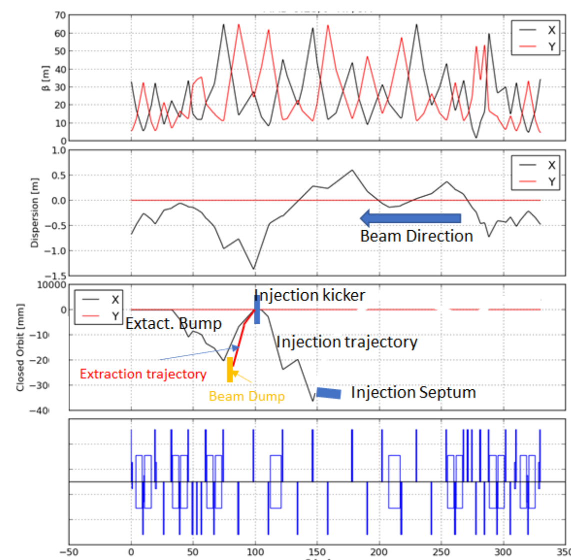

Figure 7: Parameters/trajectory at ESR injection region.

CONCLUSION

This paper presents the beam line optics of the transfer line from the extraction point of the RCS to the injection point of the ESR. This particular beam optics is the latest design of the beam optics as the design of the EIC complex is evolves. In particular there is an effort at the present time to eliminate both local injection and extraction beam bumps as discussed in this paper of the ESR. This of course requires a stronger kicker for the simultaneous injection and extraction of the beam bunches.

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