

# EXTRACTION AND INJECTION IN THE ELECTRON INJECTOR FOR THE ELECTRON-ION COLLIDER\*

K. E. Deitrick<sup>†1</sup>, D. Marx<sup>2</sup>, C. Montag<sup>2</sup>, I. Neththikumara<sup>1</sup>, V. Ranjbar<sup>2</sup>,  
T. Satogata<sup>1</sup>, N. Sereno<sup>1</sup>, M. Wendt<sup>2</sup>

<sup>1</sup>Thomas Jefferson National Accelerator Facility, Newport News, VA, USA

<sup>2</sup>Brookhaven National Laboratory, Upton, NY, USA

## Abstract

The electron injector for the Electron-Ion Collider (EIC) consists of a linear accelerator, a beam accumulation ring, and the Rapid Cycling Synchrotron (RCS) before the electrons are injected into the Electron Storage Ring (ESR) and collided. Extraction from the RCS is complicated by limited space and the nominal beam pipe aperture, while injection into the ESR is complicated due to the limitation of kicker strength, so that the kickers will not impact the proton beam in the adjacent Hadron Storage Ring (HSR); additionally, the ESR kickers must also provide enough kick to the stored bunch for the swap-out scheme. This paper covers the injection into and extraction from the RCS, as well as injection into the ESR, detailing layout, optics, and anticipated parameters of the septa and different kickers.

## INTRODUCTION

The Electron-Ion Collider (EIC) is a partnership project between Brookhaven National Lab (BNL) and Thomas Jefferson National Accelerator Facility (TJNAF) to be constructed at BNL, using much of the existing infrastructure of the Relativistic Heavy Ion Collider (RHIC). Collisions occur between the hadrons in the Hadron Storage Ring (HSR) and the electrons supplied by the Electron Storage Ring (ESR); to maintain a high average polarization of the ESR, bunches are frequently replaced using the Rapid Cycling Synchrotron (RCS). The EIC Project construction scope includes one interaction region (IR), sited at the current IR6 of RHIC with a top energy of 9 GeV; however, the results presented here are based on an older version of the design, with a top energy of 18 GeV, which needs to be considered now to allow for a more simple pathway for an energy upgrade in the future [1].

## GENERAL APPROACH

As a concept without constraints or complications, injection is relatively simple – the injected bunch exits a septum magnet with some offset and angle relative to the nominal circulating orbit, before a kicker downstream allows for the injected bunch to achieve the nominal circulating orbit. Similarly for extraction, a kicker gives the extracted bunch some angle relative to the nominal circulating orbit, which after some distance translates into an offset from the nominal orbit. The extracted bunch enters the downstream septum

magnet with some offset and angle relative to the nominal orbit and is bent into the transfer line.

However, as restrictions and requirements are added, the situation becomes more complex. There is a limit to how strong septa or kickers can be built, magnets between the kicker and septum magnet alter the trajectory of the bunch, and if the bunch orbit or size is too large, the bunch is either scraping through the magnet or a special large-bore magnet is required. While reducing the circulating aperture in the septum region does help in reducing kicker and septum strength, this has consequences for the impedance budget and dynamic aperture of the ring. So while simple in theory, in practice injection and extraction are often a compromise between conflicting requirements.

One of the more easily given criteria is the required offset at the face of the septum magnet within the ring. The minimum offset is the required circulating aperture plus the beam pipe and septum wall thickness plus the injection/extraction aperture. The circulating aperture can either be the nominal inner radius or can be reduced to some factor of the largest circulating beam size (i.e.,  $7\sigma$  to give an envelope for the circulating aperture). Similarly, the injection/extraction aperture is some factor of the largest beam size. Specifying “largest” is important for cases where the geometric emittance changes with energy and the goal is for the layout to remain fixed for different energy configurations.

## EIC PARAMETERS

The specific parameters for the injections and extraction scenarios in the electron chain of the EIC are given in Table 1. RCS injection and extraction is for a single bunch up to 28 nC at 1 Hz, while ESR injection is single-bunch swap-out. The reason that the envelope for circulation is left blank for RCS injection is because the circulating aperture is not being reduced, so that requirement is not necessary. Otherwise, these numbers in combination with the horizontal beta values at the face of the septum magnet give the appropriate offset values for each case. A diagram demonstrating how the parameters given dictate the offset at the septum is shown for ESR injection in Fig. 1.

## RCS INJECTION

Injection into the RCS is the simplest case – one kicker, one septum magnet, and only one quadrupole separating the two. The injection line from the linac and the beam accumulator ring makes a 9 degree angle with respect to the RCS straight. The layout of the injection chicane is

\* Work supported by Jefferson Science Associates, LLC under U.S. DOE Contract DE-AC05-06OR23177 and Brookhaven Science Associates, LLC, Contract DE-SC0012704.

<sup>†</sup> kirstend@jlab.org

Table 1: Injection and Extraction Parameters

Parameter	RCS Injection	RCS Extraction	ESR Injection
Nominal inner radius [mm]	18.16	18.16	40
Largest transported emittance [nm-rad]	123	40	30
Largest circulating emittance [nm-rad]	123	123	24
Envelope for transport	10	7	7
Envelope for circulation		7	15
Highest energy [GeV]	0.75	18	18
Restriction of circulating aperture	No	Yes	Yes

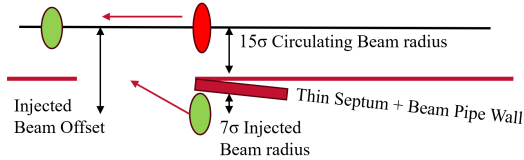


Figure 1: A representative diagram of injection and how bunch sizes relate to the offset of the injected bunch at the septum.

shown in Fig. 2. The parameters of the offset, septum, and kicker are given in Table 2. While updated, an older version of this design was described in more detail in a previous proceeding [2].

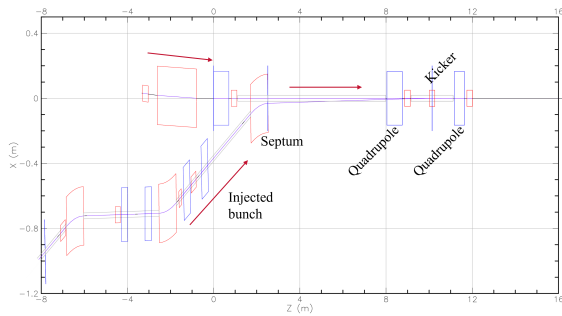


Figure 2: Layout of the injection chicane into the RCS, with relevant labels.

Table 2: RCS Injection Parameters

Parameter	Value
Septum length [m]	0.8
Septum angle [mrad]	153
Kicker length [m]	0.25
Kicker strength [mrad]	2.95
Offset at septum [mm]	30.9

## RCS EXTRACTION

The extraction scheme for the RCS is unfortunately less simple and requires three kickers and two septa in order for the extraction line to make a 3 degree angle with respect to the RCS straight. This is driven by a limit on how strong the septa and kickers can reasonably be and by the limited space

in the RCS – a smaller number of kickers can not be moved upstream to provide the same offset after a longer distance to the first septum magnet because upstream slots are otherwise occupied in future energy upgrades. The layout of the RCS extraction scheme is shown in Fig. 3, the optics and orbit are shown in Fig. 4, and the relevant parameters given in Table 3.

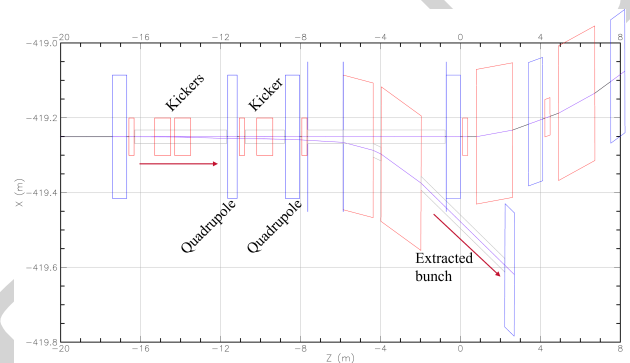


Figure 3: Layout of the RCS extraction region, with relevant labels.

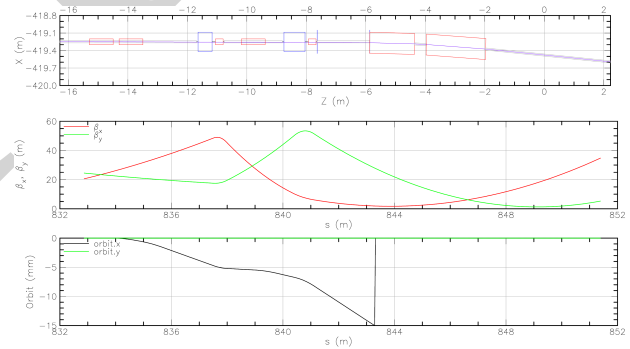


Figure 4: Top: layout of the RCS extraction region, beam goes left to right. Middle: horizontal and vertical beta functions through section. Bottom: Orbit offset of extracted bunch through section.

## ESR INJECTION

The primary difficulties of injecting into the ESR is preventing scraping between the septum and the kickers and preventing scraping in the kickers. Due to the requirement that the ESR kickers do not perturb the beam in the HSR, the

Table 3: RCS Extraction Parameters

Parameter	Value
First septum length [m]	1.5
First septum angle [mrad]	22.1
Second septum length [m]	2
Second septum angle [mrad]	27.1
Kicker length [m]	0.8
Maximum kicker strength [mrad]	0.860
Offset at septum [mm]	15.01

ESR kicker strength is limited to 0.12 mrad, and 12 kickers are required, with an inner diameter of 30 mm – this is how scraping in the kickers becomes a concern. Additionally, the ESR is using a swap-out scheme, so a bunch is injected and replaces a spent bunch that is put into a swap-out dump. The layout of the ESR injection area is shown in Fig. 5.

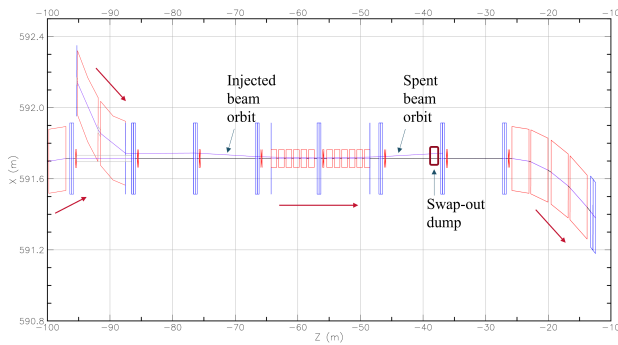


Figure 5: Layout of the ESR injection region, with relevant labels.

Due to the layout, the quadrupoles between the second septum magnet and the beginning of the kicker string are doing two things simultaneously – controlling the injected beam orbit and keeping the beam size small enough that when combined with the orbit offset, the  $7\sigma$  envelope does not scrape against the beam pipe wall.

Additionally, these quadrupoles set up the optics for the beam going through the kicker string. To prevent scraping through the kicker string, the sum of the injected bunch orbit offset, 7 times the injected bunch radius, and 15 times the circulating beam radius must be less than the kicker inner diameter of 30 mm – this aperture restriction is demonstrated in Fig. 6. There is a similar consideration for the separation between the spent bunch and circulating beam at the end of the kicker string. The quadrupole after the kicker string does need to be set to sufficient strength so that the spent bunch orbit offset is sufficiently large so that the swap-out dump does not interfere with the circulating beam. The optics in the injection region are shown in Fig. 7, with relevant parameters given in Table 4.

## CONCLUSION

Solutions have been presented for RCS injection, RCS extraction, and ESR injection, taking into account the swap-out

scheme of the ESR. These solutions limit scraping, do not require special quadrupoles with larger apertures, and have

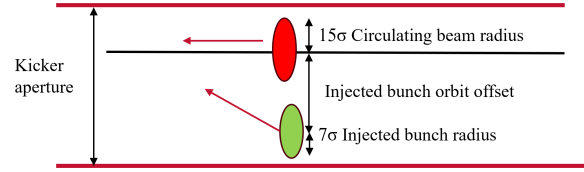


Figure 6: Visualization of how the injected orbit offset and beam sizes in combination need to satisfy the 30 mm inner diameter aperture of the kickers.

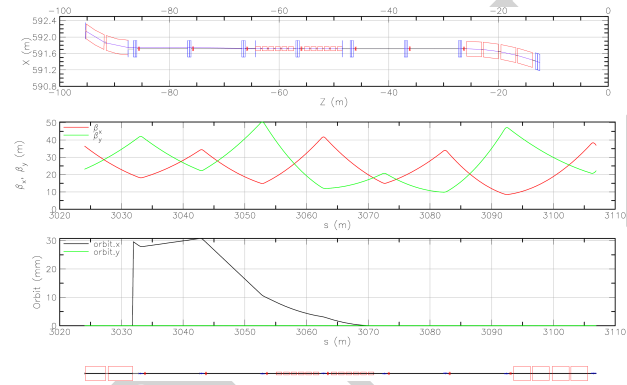


Figure 7: Top: layout of the ESR injection region, beam goes left to right. Middle: horizontal and vertical beta functions through section. Bottom: Orbit offset of injected bunch through section.

Table 4: ESR Injection Parameters

Parameter	Value
First septum length [m]	3.3
First septum angle [mrad]	49.9
Second septum length [m]	4.0
Second septum angle [mrad]	53.3
Active kicker length [m]	0.9
Physical kicker length [m]	1.2
Kicker strength [mrad]	0.111
Offset at septum [mm]	29.7

septum and kicker parameters consistent with demonstrated technology. Consequently, these solutions make good starting points as the RCS and ESR designs are iterated for other considerations.

## REFERENCES

- [1] D. Marx *et al.*, “Design and Recent Developments of the Electron Storage Ring for the Electron-Ion Collider”, presented at the IPAC’26, Deauville, France, May 2026, paper WEP1332, this conference.
- [2] B. Gamage *et al.*, “Linac to BAR/RCS transfer line design for EIC electron injection system”, in *Proc. NAPAC2025*, Sacramento, CA, USA, Aug. 2025, pp. 502-504.  
doi:10.18429/JACoW-NAPAC2025-TUP061