ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB002

THE INTERACTION REGION OF THE ELECTRON-ION COLLIDER EIC*

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Abstract

This paper presents an overview of the Interaction Region (IR) design for the planned Electron Ion Collider (EIC) at Brookhaven National Laboratory. The IR is designed to meet the requirements of the nuclear physics community as outlined in [1].

The IR design features a ±4.5 m free space for the detector; a forward spectrometer magnet is used for the detection of hadrons scattered under small angles. The hadrons are separated from the neutrons allowing detection of neutrons up to ±4 mrad. On the rear side the electrons are separated from photons using a weak dipole magnet for the luminosity monitor and to detect scattered electrons (e-tagger).

To avoid synchrotron radiation backgrounds in the detector no strong electron bending magnet is placed within 40 m upstream of the IP. The magnet apertures on the rear side are large enough to allow synchrotron radiation to pass through the magnets. The beam pipe has been optimized to reduce the impedance; the total power loss in the central vacuum chamber is expected to be less than 90 W.

To reduce risk and cost the IR is designed to employ standard NbTi superconducting magnets, which are described in a separate paper.

INTRODUCTION

The Electron Ion Collider is a planned new facility at Brookhaven National Laboratory, which is based on the existing RHIC (Relativistic Heavy Ion Collider) facility. The facility is discussed in more detail in [2].

The EIC is designed to deliver a peak luminosity of 1×10^{34} cm^{-2}s^{-1}. Maximum luminosity is achieved at a center-of-mass energy of 105 GeV, colliding 10 GeV electrons and 275 GeV protons. General layout of the interaction region is shown in Fig. 1.

For the interaction region a crossing angle of 25 mrad was chosen. The crossing angle is large enough to allow for reasonable magnets based on conventional technology.

To achieve this luminosity small beam cross-sections are necessary. Both beams are strongly focused to small β^*'s of several centimeters. To accomplish a large acceptance of the scattered protons, no magnetic elements are placed inside the detector. The magnet apertures of the forward hadron magnets are designed to transport scattered protons with a transverse momentum p_t = 1.3 GeV/c through the IR. Particles scattered under angles up to 5 mrad are detected downstream in Roman pots and off-momentum detectors; a detector placed within the B0pF dipole measures particles from 6-20 mrad.

The forward hadron magnet apertures also allow the neutron cone of ±4 mrad to reach the zero degree calorimeter about 35 m away from the IP. The forward optics helps to separate the hadron beam from the neutrons at this position.

Particular care is taken to ensure that synchrotron radiation from the electron beam is not an issue for detector components. To minimize synchrotron radiation no strong bending dipole is present up to 40 m from the IP. The apertures of the rear electron magnets are large enough to allow synchrotron radiation from the foward low-β quadrupole magnets to pass through. The synchrotron radiation is absorbed far away downstream, to minimize backscatter.

As shown in Fig. 1, a luminosity monitor is foreseen at the rear side, which detects γ-rays that are generated in the Bethe-Heitler process. The dipole magnet B2eR bends the electron beam away from the synchrotron radiation to facilitate this. B2eR also acts as a spectrometer magnet for low-Q^2 electrons.

LATTICE

Both the hadron (HSR) and electron (ESR) storage ring IRs have a quadrupole doublet on each side of the IR, with the vertically focusing quadrupole closest to the IP. The horizontal β-functions remain high to the crabs, creating a horizontal phase advance of nearly $\pi/2$ to the crabs and reducing the required crab cavity voltage (due to the large beta function) while keeping the beam within the crab cavity aperture. The vertical beta function is kept low through the crab cavity to ease the matching to the rest of the ring.

* Work supported by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the U.S. Department of Energy.
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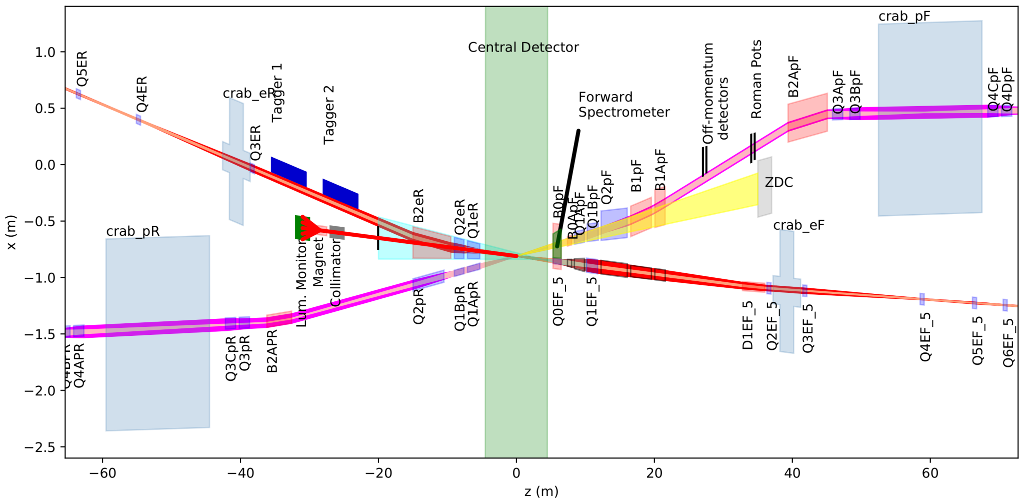

Figure 1: Layout of the interaction region of the EIC. In this figure the hadrons go from left to right. Shown in green is the central detector. Dipole and quadrupole magnet apertures are shown in pink and blue, respectively. Shown in grey are the crab cavities; the transverse size is illustrative of the size of the cavities. The neutron cone is shown in yellow and the synchrotron radiation fan in cyan.

Table 1: Forward Magnets, the Settings are for 275 GeV (Protons) and 18 GeV (Electrons)

FORWARD DIRECTION	**Hadron Magnets**							**Electron Magnets**		
	B0PF	**B0APF**	**Q1APF**	**Q1BPF**	**Q2PF**	**B1PF**	**B1APF**	**Q0eF**	**Q1eF**	**D1eF**
Center position [m]	5.9	7.7	9.23	11.065	14.170	18.070	20.820	5.9	11.065	34.389
Length [m]	1.2	0.6	1.46	1.6	3.8	3.0	1.5	1.2	1.61	3.238
Center position w.r.t. to x-axis [cm]	-1.50	5.5	1.40	2.38	4.07	3.90	8.00	-14.75	-27.66	-56.17
Angle w.r.t. to z-axis [mrad]	-25.0	0.0	-5.5	-10.0	-10.2	9.0	0.0	0.0	0.0	0.0
Inner radius [cm]	20.0	4.3	5.6	7.8	13.1	13.5	16.8	2.50	6.3	NA
Dipole field [T]	-1.3	-3.3	NA	NA	NA	-3.4	-2.7	NA	NA	0.067
Gradient [T/m]	NA	NA	-72.608	-66.180	40.737	NA	NA	-14.05	6.2624	NA

The HSR IR is matched to the existing RHIC ring, almost entirely using existing RHIC magnets. The crossing angle, geometric displacement of the IP, the large beta function at the crab, the unusable space between the IP and the crab, and the dispersion amplitude created by the dipoles near the detector cause the match to require very strong focusing and leave very little free space.

The parameters of the forward and rear magnets are summarized in Tables 1 and 2. The β-functions and dispersions for the hadron lattice are shown in Fig. 2.

Table 2: Rear Hadron and Electron Quadrupoles with Their Apertures Tapered in Proportion to Their Distance to the IP for 275 GeV and 18 GeV, Respectively

REARWARD DIRECTION	**Hadron Magnets**			**Electron Magnets**		
	Q1APR	**Q1BPR**	**Q2PR**	**Q1eR**	**Q2eR**	**B2ER**
Center position [m]	-6.2	-8.30	-12.75	-6.2	-8.30	-12.25
Length [m]	1.80	1.40	4.50	1.80	1.4	5.50
Angle w.r.t. to z-axis [mrad]	0.0	0.0	0.0	25.0	25.0	25.0
Entrance radius [cm]	2.6	2.80	5.40	6.60	8.30	9.70
Exit radius [cm]	2.8	2.8	5.4	7.9	9.4	13.9
Dipole field [T]	0.0	0.0	0.0	0.0	0.0	-0.198
Gradient [T/m]	-78.375	-78.375	33.843	-13.980	14.100	0.0

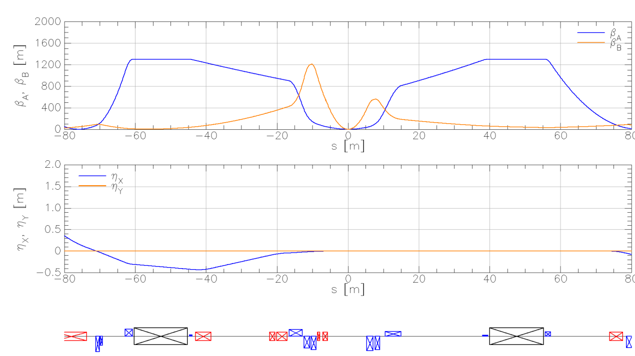

Figure 2: β function and dispersion of the hadron IR Lattice.

VACUUM CHAMBER

Figure 3 shows an overview of the present design of the IR vacuum chamber. In total the central chamber is about 9 m long. To meet the geometric requirements of the beampipe the diameter is varied carefully to enclose the two high energy beams with their respective beam sizes. On the rear side the beam pipe is tapered to stay clear of the synchrotron radiation fan.

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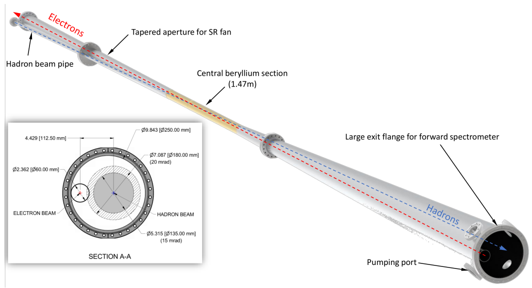

Figure 3: Beampipe for the EIC IR.

The central section of the beam pipe will be made out of beryllium and coated with a thin layer of gold. To allow the central detector to be as close as possible to the collision point the outside diameter of the central chamber is 64 mm (inside diameter 62 mm). The chosen size allows for clearances and positioning tolerances. The vacuum pressure profile is actively studied and optimized, results are presented in [3].

The main contributor to the impedance of the IR chamber is an area where the electron and the proton beam pipes are merging together. To minimize the impedance and to avoid generation of higher order modes, the upstream side of the IR chamber was optimized to a geometry of the electron beam pipe with an elliptical slot with its maximum opening of 40 mm. An impedance analysis of this geometry has been performed using the GdfidL code [4]. Figure 4 shows the calculated loss factor as a function of bunch length and the real part of the longitudinal impedance for the upstream side of the IR chamber with and without protection absorber against synchrotron radiation. To simplify simulations the diameter of the central beryllium section is taken as 60 mm. The obtained loss factor for the US of the IR chamber is 1.3 mV/pC. The loss factor is calculated for a bunch length of 7 mm (I_{av} = 2.5 A, N=1160, To = 12.79 µs). The estimated power loss is 90W. More details can be found in [5].

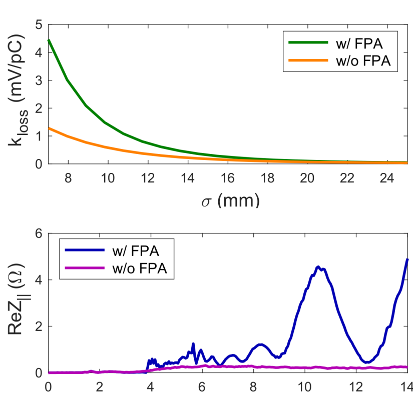

Figure 4: Impedance of the electron beam pipe.

SYNCHROTRON RADIATION

To study synchrotron radiation the simulation software SynRad+ [6] is used. Modeled are all upstream magnets up to about 50 m. The primary contributors to the synchrotron radiation are bending magnets around the electron crab cavity and the low-β quadrupole magnets. Non-Gaussian tails, which can lead to very high energy photons, are incorporated assuming a double Gaussian beam profile.

A dual stage masking scheme is used to limit the synchrotron radiation fan through the central detector. On the incoming side, its cross section will be identical to that of the masks before the central detector. Their size is determined by the 13σ horizontal beam size requirement at their specific location. Assuming radii of the upstream ellipse of 11 mm in the horizontal plane, and 10 mm vertically, at the downstream end of the central detector, the cone radii will have substantially increased, to 71 mm horizontally, and 19 mm vertically. This growth of the synchrotron radiation fan determines the minimum dimensions of the detector beam pipe that ensure strongly reduced background from primary photons generated by the electron beam.

Figure 5 shows results of a Synrad+ simulation. Shown is the anticipated power deposition at various parts of the beampipe; the figure shows this for the electron rear magnets. The results are verified using the independent code SYNC BKG (developed at SLAC), which was successfully used for several facilities. Preliminary studies show that with realistic tails a beam lifetime of 1-2 h should be achievable. This is acceptable, as bunches are replaced at a rate of 2 Hz to maintain high beam polarization.

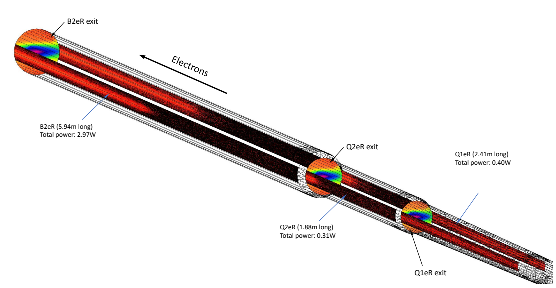

Figure 5: Anticipated synchrotron radiation power deposition on the rear-side beam pipes.

MAGNETS

The IR requires several new superconducting magnets, which are described in a separate paper [7].

CONCLUSION

The IR design of the EIC has matured significantly over the last months. Present work focuses on increasing the machine element free region by 0.5 m (from −4.5 to 5) m to allow more space for the detector. Another focus is on implementing the orbit and solenoid coupling correction scheme [8].

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