PROGRESS ON THE DESIGN OF THE INTERACTION REGION OF THE ELECTRON-ION COLLIDER EIC*

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Abstract

We present an update on the design of the Interaction Region (IR) for the the Electron Ion Collider (EIC) being built at Brookhaven National Laboratory (BNL). The EIC will collide high energy and highly polarized hadron and electron beams with a center of mass energy up to 140 GeV with luminosities of up to 10^{34} cm^{-2} s^{-1}. The IR, located at RHIC's IR6, is designed to meet the requirements of the nuclear physics community as outlined in [1]. A second IR is technically feasible but not part of the project.

The magnet apertures are sufficiently large to allow desired collision products to reach the far-forward detectors; the electron magnet apertures in the rear direction are chosen to be large enough to pass the synchrotron radiation fan. In the forward direction the electron apertures are large enough for non-Gaussian tails.

The paper discusses a number of recent recent changes to the design. The machine free region was recently increased from 9 to 9.5m to allow for more space in the forward direction for the detector. The superconducting magnets on the forward side now operate at 1.9K, which helps crosstalk and space issues.

INTRODUCTION

The Electron Ion Collider is a new facility, which is presently under design at Brookhaven National Laboratory [4]. While EIC is based on the existing RHIC facility, a new Interaction Region is required which is shown schematically in Fig. 1. In this paper we describe several recent changes to the design present in [9].

* WORK SUPPORTED BY BROOKHAVEN SCIENCE ASSOCIATES, LLC UNDER CONTRACT NO. DE-SC0012704 WITH THE US DEPARTMENT OF ENERGY.

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The next section discusses the lattice. A major change to the IR concept described earlier is an enlarged space for the central detector; the clear stay region now extends from −4.5 m to +5 m. Magnet apertures are left unchanged from the previous design, which leads to a slightly reduced acceptance, which has been found acceptable.

The new magnet locations are shown in Table 1 and Table 2 for the forward and rear side of the IR. The tables show the centre locations of the magnets and the orientation angle with respect to the horizontal z-axis.

LATTICE

We maximize luminosity in the EIC by colliding flat beams. This requires the vertical beta function to be significantly smaller than the horizontal one at the IP. Thus our focusing structure near the IP is a doublet, with the vertically focusing quadrupole(s) closest to the IP. Our beams have a 25 mrad crossing angle, and the magnets in the ESR and HSR are relatively close to each other. To achieve high magnetic fields in the HSR, the HSR magnets are placed as far from the ESR line as possible. On the rear side, this is accomplished by tapering some quadrupole apertures and using two magnets with different apertures for the vertically focusing quadrupole.

On the HSR forward side, there is an additional requirement that forward-directed collision products pass through magnet apertures to far-forward detectors. The first magnet downstream of the detector (B0PF) is a large aperture dipole which will contain a detector to measure protons leaving the detector at large angles. This magnet will operate at the same field for all collision energies, leading to the trajectories through the IR magnets that vary with beam energy and quadrupole focusing. The B0APF and B1PF dioles restore the beam to the design trajectory. The magnets are aligned to simultaneously pass the desired detector products (protons

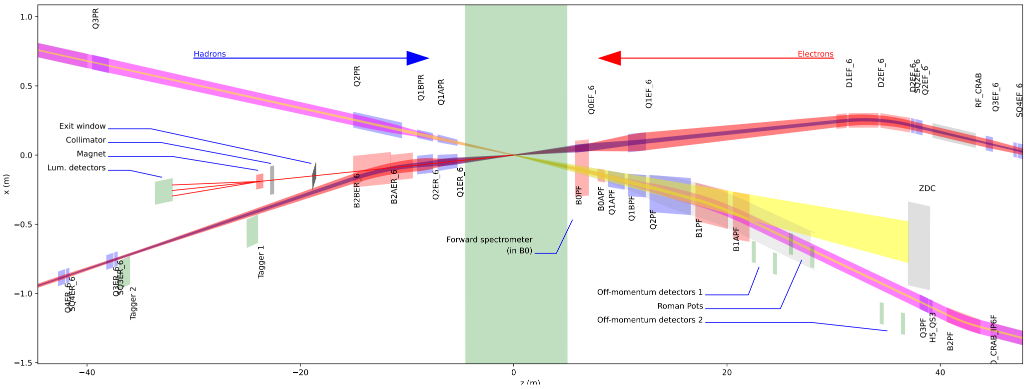

Figure 1: Layout of the interaction region. The IP is located at the origin. Shown in green is the central detector. Dipole and quadrupole magnet apertures are shown in pink and blue, respectively. The neutron cone is shown in yellow. Beam envelopes (13.5σ and 10σ for electrons and protons, respectively) are shown for 275 GeV protons and 18 GeV electrons.

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
Center position z [m]	6.401	8.201447	9.63175	11.5671	14.6727	18.57352	21.3242	6.3998	11.5646
Center position x [m]	-0.09457	-0.14810	-0.18113	-0.220533	-0.28869	-0.366288	-0.44524	0.0512	0.0925
Length [m]	1.2	0.6	1.46	1.6	3.8	3.0	1.5	1.2	1.61
Angle w.r.t. to z-axis [mrad]	-17.129	-18.214	-19.29	-20.073	-21.736	-19.712	-21.164	8.0	8.0
Inner radius [cm]	20.0	4.3	5.6	7.8	13.1	13.5	16.8	2.50	6.3
Dipole field [T]	-1.3	-3.3	NA	NA	NA	-3.4	-2.7	NA	NA
Gradient [T/m]	NA	NA	-88.94	-56.07	40.737	NA	NA	-14.05	6.2624

as high as 1.23 GeV/c_0 for 275 GeV protons, 4 mrad neutral particles) and keep them as far as possible from the ESR beam line. This leads to the beam trajectories being offset in the quadrupoles, which therefore provide bending to the design trajectories. The Q1BPF design aperture ultimately limits the transverse momentum of the transmitted protons. The dipoles on the forward side are needed to separate the proton beam sufficiently from the neutral particles for the latter to be detected in the ZDC. The ZDC is placed as close to the IP as possible while being centered on the hadron beam axis at the IP, and having sufficient clearance to the hadron beam pipe. For more details see [3].

Following the ZDC, there is a room-temperature quadrupole, a superconducting dipole to steer the beam to meet meet the existing RHIC arc, and the crab cavity. For 275 GeV protons, the horizontal beta function at the crab cavity must be least 1300 m given the limitations on the available crab cavity voltage (true for both the forward and rear sides). Figure 2 shows the lattice functions for the HSR forward side. The resulting horizontal phase advance from the IP to the crab cavity is less then 90°, leading to a small residual crabbing in the HSR. For lower beam energies, the beta function at the crab can be lower, and the horizontal phase advances from IP to the crab cavities can be made exactly 90°.

Replacing the two vertically focusing quadrupoles on the forward side with a single tapered quadrupole is under consideration. The tapered quadrupole can be aligned with the 275 GeV proton beam, unlike for the separate Q1APF and Q1BPF. Because the defocusing quadrupoles no longer steer the beam significantly, the B0APF field needs to be reduced from its original value of 3.3 T down to 1.2 T to avoid increasing the aperture required for detector products in the downstream IR magnets. The field in B0APF required at 41 GeV will be higher, but still below the 3.3 T of the original design.

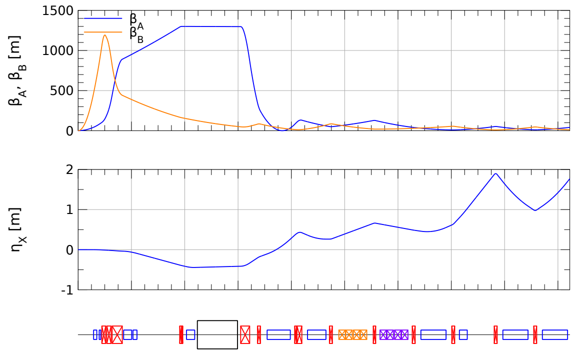

Figure 2: Lattice functions for the hadron forward side, 275 GeV protons, from the IP through a cell of the existing RHIC arc.

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	B2AER	B2BER
Center position z [m]	-6.1991	-8.2988	-12.7481	-6.1998	-8.29973	-10.4997	-13.2745
Center position x [m]	0.1053949	0.14109	0.216739	-0.0496	-0.0664	-0.084	-0.1062
Length [m]	1.80	1.40	4.50	1.80	1.4	2.0	3.45
Angle w.r.t. to z-axis [mrad]	-17.0	-17.0	-17.0	8.0	8.0	8.0	8.0
Entrance radius [cm]	2.6	2.80	5.40	6.60	8.30	9.045	11.145
Exit radius [cm]	2.8	2.8	5.4	7.9	9.4	9.045	11.145
Dipole field [T]	0.0	0.0	0.0	0.0	0.0	0.192	0.238
Gradient [T/m]	-78.375	-78.375	33.843	-13.980	14.100	0.0	0.0

Figure 3: Spin rotator section of the EIC IR.

SPIN ROTATOR SECTION

The spin-rotator concept is based on a series of solenoids, dipoles, and matching quadrupoles, as shown schematically in Fig. 3. The solenoids and dipoles together rotate the spin vector from vertical in the arcs to longitudinal at the IP. This requires specific solenoid strengths and dipole bending angles. The quadrupoles between the solenoids ensure transverse decoupling and horizontal spin matching. At 18 GeV only the long solenoids are turned on, whereas at 5 GeV only the short solenoids are turned on. Both are used at 10 GeV. The bending angle between the solenoid modules is set to 97.81 mrad and is achieved through the use of five 3.8-m dipoles. A bending angle of 38.79 mrad is required between the long-solenoid module and the IP.

Strong fields in the solenoids will be required, which calls for superconducting magnets. Efforts have been made to lengthen the solenoids while respecting the stringent constraints imposed by the geometry. The current design, which is still being studied, has solenoid lengths of 6.2 m and 2.5 m. The quadrupoles located between the two solenoids are also very challenging. We consider normal conducting quadrupoles; the length constraints mean they will be operating at the limit for good field quality, with the lengths individually optimized to reduce the overall length between the solenoids. Studies are currently in progress to match the optics of these solenoid modules to achieve the required conditions at all three energies.

Each of the modules requires a beam pipe radius of 28.75 mm and a cryostat inner radius of 50 mm. Simulations show that the beam pipe is subject to several hundred watts of synchrotron radiation, which cannot reach the solenoids. We consider various shielding options with tungsten. Due to the close proximity of the spin rotator modules to the RHIC tunnel wall the outer cryostat radius is limited to 600 mm. The required integrated solenoid strength field is 15.3 Tm and 46.75 Tm respectively, which is equivalent to a peak on-axis field of 6.12 and 7.54 T. The maximum stray magnetic field of the solenoids at the location of the nearby rapid cycling synchrotron is 3 G. Several solutions have been identified, which are based on conventional NbTi at 2 and 4.55K.

MAGNETS

We anticipate that the hadron forward magnets Q1ApF to B1ApF are realized as Rutherford cable based collared magnets. The status of the magnet designs is described in [2,5,6,8,10]. All other magnets are planned as direct wind magnets, which is a technology pioneered at Brookhaven National Laboratory [7].

Changes in the harmonics for the hadron forward magnets due to persistent currents have been simulated and will be reported elsewhere. First dynamic aperture simulations indicate that these are not a concern. Persistent current simulations for the direct wind magnets are ongoing. Progress was made on quench simulations for the collared magnets as well as the direct wind magnets; results will be presented in a future paper.

WARM B2ER

We consider replacing the superconducting magnets B2AeR and B2BeR with a normal conducting 5.5 m long dipole magnet. The magnet, located further downstream, would require a good field region of about 125 mm, with a gap of 250 mm to clear the synchrotron radiation fan on the rear side. This change is driven by the desire to power all ESR dipole magnets in series, which greatly reduces the stability requirement for the ESR power supply.

CORRECTION SCHEME

For orbit correction we plan for four BPMs in the electron beam line, one near each quadrupole magnet. For the hadron beamline we plan for a BPM between Q1BpR and Q2pR and a second one after Q2pR. On the hadron forward side we plan for a BPM between B0pF and B0ApF and Q2pF/B1pF. Another BPM might be placed after B1ApF. The final focusing quads on the rear side have additional windings for weak skew quadrupoles to compensate for the detector solenoid. On the forward side skew quadrupoles are located at B0ApF and Q1eF. B0ApF has an additional winding for a vertical corrector.

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