INTEGRATION OF THE FULL-ACCEPTANCE DETECTOR INTO JLEIC

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Abstract

Fully meeting the nuclear physics goals of JLEIC (Jefferson Lab Electron Ion Collider) requires a full-acceptance detector. Integration of such a detector into the collider presents many challenges for design of the beam dynamics. Small β* values at the Interaction Point (IP) needed to reach a luminosity level of a few 10^{33} $cm^{-2}sec^{-1}$ cause large natural chromaticities. Their compensation involves installation of dedicated chromaticity correction sections in the collider rings. Small β* values and a large space occupied by the full-acceptance detector also mean large β in the final focus area. This sets a constraint on the field quality of the magnets in the large beta areas, in order to ensure a large enough dynamic aperture. Additional complications include asymmetric lattice and beam envelopes in the Interaction Region (IR), forward detection requirements, large crossing angle with associated crab dynamics, coupling and coherent orbit distortion from the detector solenoid, etc. This paper briefly describes how we address these issues.

DETECTION REQUIREMENTS

Electrons or positrons present a clean probe for studies of the internal structure of hadronic matter with high resolution. The history of these studies ranges from linacs with fixed targets, to storage rings with fixed targets, and ultimately to colliders like HERA, the first lepton-proton collider [1] with a luminosity of several 10^{31} $cm^{-2}sec^{-1}$. JLEIC is being designed as a new electron-ion collider with a luminosity of several 10^{33} $cm^{-2}sec^{-1}$ aimed at addressing new nuclear physics questions that arise due to progress in the Quantum Chromo Dynamics (QCD) following HERA. To realize such a high luminosity and meet the physics requirements, we design a full-acceptance detector for the primary IP.

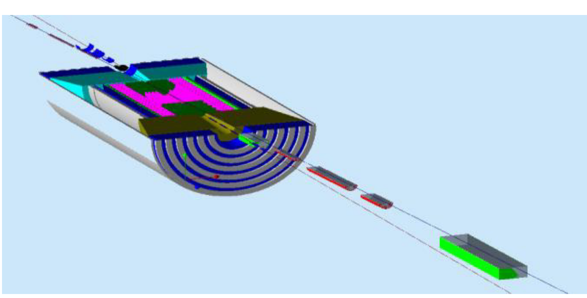

Figure 1: 3D model of the full-acceptance detector region.

A 3D rendering of the full-acceptance detector model is shown in Fig. 1. The IR design includes a large +5/-3.6 m space for the central solenoid. Due to asymmetry of the electron-ion collisions, the collision products are boosted in the forward ion direction. To optimize the detector's acceptance in this direction, we design an asymmetric IR optics as shown in Fig. 2. In this design [2], β^*_x/β^*_y of 0.1/0.02 m at the IP expand to very different values of ~750 and ~2500 m in the upstream and downstream Final Focusing Blocks (FFB), respectively.

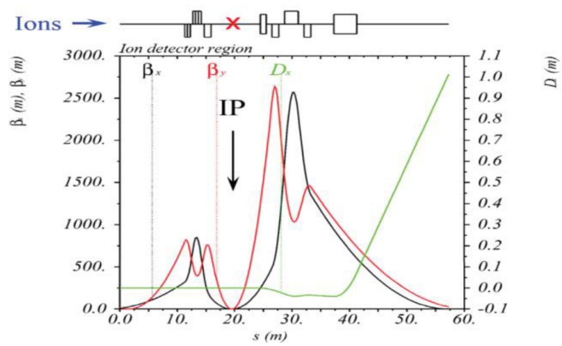

Figure 2: Asymmetric design of the IR optics.

In the above asymmetric linear optics design, special attention is paid to the sizes and positions of the detector region elements to avoid them interfering with each other and with the detector functionality. The forward ion FFB is designed so that its quads (FFQ) have about 0.7° polar angle aperture openings. This determines its acceptance to neutral reaction products. The parameters of the IR FFQs are listed in Table 1.

Table 1: IR Triplets in the JLEIC Ion Collider Ring

	Physical inner Aperture[mm]	Beta_max x/y[m]
Qffb3_us	80	538/- *
Qffb2_us	80	847/-
Qffb1_us	60	369/766.7
Qffb1	180	931/2640
Qffb2	314	2574/-
Qffb3	340	1724/-

*: vertical emittance is about 20% of horizontal emittance, so vertical betas at some FFQ don't determine the inner apertures which are not listed.

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ION COLLIDER RING LATTICE AND CHROMATICITY COMPENSATION

The overall collision lattice of the ion collider ring is shown in Fig. 3. The ring consists of two 261.7 ° arcs connected by two straight sections intersecting at an 81.7° angle. The total circumference of the ion collider ring is 2153.89 m. We use two non-interleaved –I sextupole pairs (X & Y) to compensate the chromatic effect of each of the ion FFB. The remaining linear chromaticity is compensated using two families of sextupoles in the 90° arc FODO cells [3].

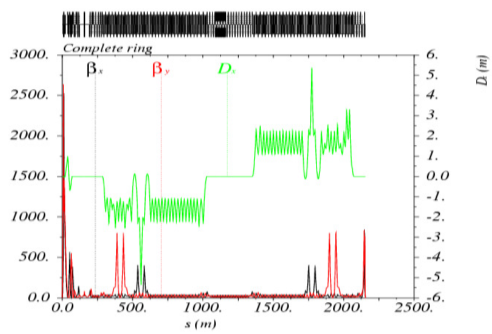

Figure 3: Linear optics of the JLEIC ion collider ring starting from the IP.

The beam emittance in the ion collider ring is determined by a balance between the intra beam scattering (IBS) and electron cooling. Strong cooling results in normalized rms emittances of 0.35/0.07 mm-mrad (H/V). With initial weak cooling, larger values of 1.2/1.2 mm-mrad (H/V) are assumed.

DETECTOR SOLENOID COMPENSATION

We design a correction system that provides local compensation of the solenoid effects independently for each side of the IR. It includes small skew quadrupoles next to all FFQs, dipole correctors and anti-solenoids as illustrated in Fig. 4. The scheme corrects coherent orbit distortion and transverse coupling and restores the spin symmetry of the figure-8 ring.

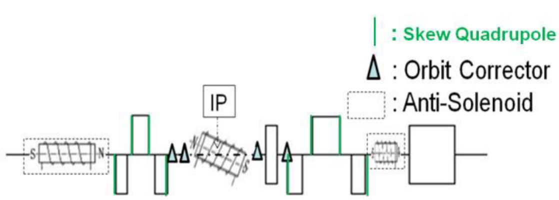

Figure 4: Detector solenoid compensation system.

The resultant orbit after correction is shown in Fig. 5. Here not only the orbit offset but the orbit slope is corrected at the IP as required for crabbing. The maximum offset is -1.7 mm vertically at the 3rd corrector.

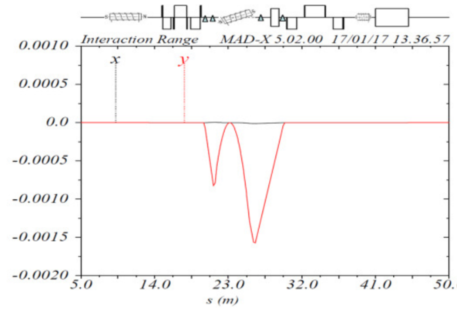

Figure 5: Coherent orbit in the IR of the JLEIC ion ring.

With the effective rotation angle produced in the IR triplets by the nearby skew quadrupoles, the coupling effects can be controlled locally between the detector solenoid and anti-solenoid. This can be seen in Fig.6. The coupling betas are less than 0.4 m, and 0 values at IP and outside of IR.

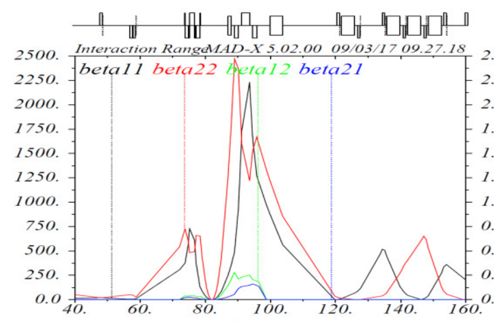

Figure 6: Local compensation of the coupling effect in the IR of the JLEIC ion collider ring.

The skew quadrupoles next to the FFQs produce an effective rotation of the IR triplets. Adjusting three independent values of their strengths is sufficient to compensate coupling locally on each side of the IP. Additional nearby quadrupoles are used to compensate the solenoid effects on the tunes, beta functions, horizontal dispersion, and linear chromaticities. The chromatic sextupoles and their phase advances are adjusted to restore the linear chromaticity compensation and chromatic beta function control. With the strong cooling emittances of 0.35/0.07 mm-mrad (H/V), we can get a dynamic aperture of $\pm 50\sigma$ of the beam size as shown in Fig. 7.

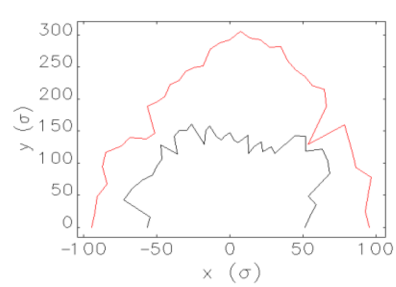

Figure 7: Dynamic aperture without (red) and with (black) detector solenoid.

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DYNAMIC APERTURE WITH MULTIPOLE FIELDS OF ARC DIPOLES

Using the multipole field data of the arc dipoles provided by magnet designers [4], a dynamic aperture study was performed. The simulations were done for protons at 100 GeV collision energy and 8 GeV injection energy. Due to a large beam size at injection, the maximum values of the beta functions in the IR are reduced from 2.5 km to about 100 m [5]. The resulting dynamic apertures in collision and at injection are shown in Fig. 8.

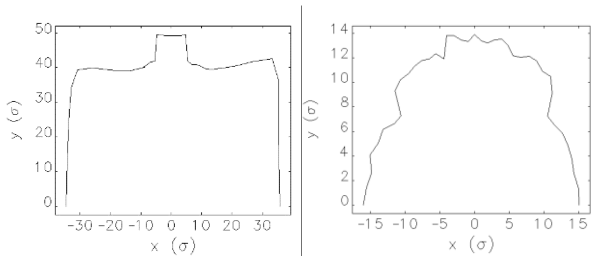

Figure 8: Dynamic apertures with multipole fields of the arc dipoles (left: in collision, right: at injection).

The results show that, with the strong cooling emittances of 0.35/0.07 mm-mrad (H/V), we can get a dynamic aperture of ~32 σ of the beam size at 100 GeV proton collision energy. For 8 GeV protons at injection, the dynamic aperture is about 12 σ for on-momentum particles. Further studies are needed.

DYNAMIC APERTURE WITH MULTIPOLE FIELDS OF IR TRIPLETS

In comparison to the arc magnets, multipole fields of the IR triplets have a dominating effect on the dynamic aperture in collision. Hence their influence is studied in detail. The multipole field data of the LHC IR triplets are applied to the JLEIC ion collider ring lattice to find the dynamic aperture. The resulting dynamic aperture considering strong cooling is shown in Fig. 9.

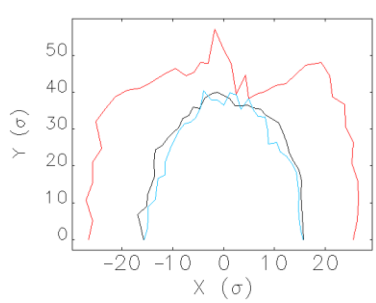

Figure 9: Dynamic aperture of the JLEIC ion ring where the LHC triplet multipole field is applied to the JLEIC triplets. (Red: with the nominal LHC data; black: the upstream IR triplets with the nominal LHC data, the downstream IR triplets with the HL LHC average data; blue: the upstream IR triplets with the nominal LHC data, the downstream IR triplets with the HL LHC average + Std. Dev. data).

LHC has an upgrade from the nominal stage to the high luminosity stage (HL-LHC). The inner aperture of the IR triplet is changed also, from 70 mm to 150 mm, depending on different superconducting technologies. Compared with the JLEIC IR triplet in Table 1, the nominal LHC IR triplet has an inner aperture similar to that of the upstream IR triplet in JLEIC. The HL-LHC IR triplet can provide information for the downstream IR triplet because of its larger inner aperture. Thus, the measured magnet quality data of both the nominal LHC IR triplet [6] and HL-LHC IR triplet model quadrupole [7] is considered in the dynamic aperture study, as shown in Fig. 9. We performed three different magnet quality studies of the JLEIC IR triplets. First, the nominal LHC IR triplet data is applied to all JLEIC IR triplets. The dynamic aperture is about 22 σ as shown by the red curve in Fig. 9. Second, the nominal LHC IR triplet data is applied to the JLEIC upstream IR triplets with the HL-LHC multipole data applied to the downstream triplet. The dynamic aperture is about 15 σ as shown by the black and blue curves in Fig. 9. The difference between the curves is that the black curve uses only the average multipole values while the blue curve uses the average plus the standard deviation (Std. Dev.) values.

SUMMARY

The JLEIC IR design for full-acceptance detection presents the following challenges: detector solenoid compensation, chromatic compensation, magnet quality requirement, beta squeeze, etc.

For chromatic compensation, a scheme with non-interleaved $-I$ sextupole pairs is selected. Detector solenoid compensation is done using skew quadrupoles, dipole correctors and anti-solenoids. Dynamic aperture limitation due to magnet quality of the arc dipoles is also studied. The greatest effect on the dynamic aperture in collision comes from the multipole field components of the IR triplets. The IR triplets with LHC measured data are good for strong cooling scheme. If cooling is better, we can relax the magnet quality requirement.

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REFERENCES

[1] M. Tigner *et al.*, in *Proc. IEEE PAC*, pp. 2910-2911.
[2] V.S. Morozov *et al.*, in *Proc. IPAC'14*, pp. 71-73.
[3] Y. Nosochkov *et al.*, in *Proc. IPAC'15*, pp. 2311-2314.
[4] P. McIntyre, "Update on Superferric Magnet Development at TAMU", JLEIC Collaboration Meeting Spring 2016.
[5] V.S. Morozov *et al.*, in *Proc. IPAC'16*, pp. 2445-2447.
[6] G.V. Velev *et al.*, FERMILAB-Conf-03/109-E June 2003.
[7] G. Ambrosio *et al.*, FERMILAB-CONF-16-440-TD.