INTEGRATION OF THE FULL-ACCEPTANCE DETECTOR INTO THE JLEIC

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Abstract

For physics requirements, the JLEIC (Jefferson Lab Electron Ion Collider) has a full-acceptance detector, which brings many new challenges to the beam dynamics integration. For example, asymmetric lattice and beam envelopes at interaction region (IR), forward detection, and large crossing angle with crab dynamics. Also some common problems complicate the picture, like coupling and coherent orbit from detector solenoid, high chromaticity and high multipole sensitivity from low beta-star at interaction point (IP). Meanwhile, to get a luminosity level of a few 10^{33} cm^{-2}sec^{-1}, small β* are necessary at the IP, which also means large β in the final focus area, chromaticity correction sections, etc. This sets a constraint on the field quality of magnets in large beta areas, in order to ensure a large enough dynamic aperture (DA). This report will mention those contents.

DETECTION REQUIREMENTS

Electrons or positrons present a clean probe for studies of 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}. Following HERA, a new lepton-proton collider with a luminosity of several 10^{33} cm^{-2}sec^{-1}, which called the JLEIC, is designed to meet the new physics researches in quantum chromo-dynamics (QCD). To realize such high luminosity and physics purposes, a full-acceptance detector in the first IP is designed as shown in Fig. 1.

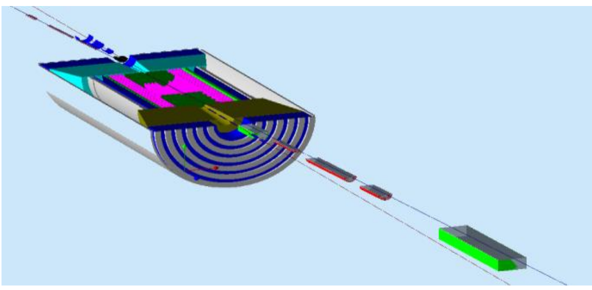

Figure 1: IR design in the first IP of the JLEIC.

The IR design needs a long space for detector solenoid. And considering forward hadron detection, a highly asymmetric IR optics is studied as shown in Fig. 2. This new structure [2] makes a β^*_x/β^*_y of 0.1/0.02 meter at IP (Interaction Point) with very different expended beta in upstream FFB (Final Focusing Block) and downstream FFB, ~ 750 m in upstream FFB and ~ 2500 m in downstream FFB.

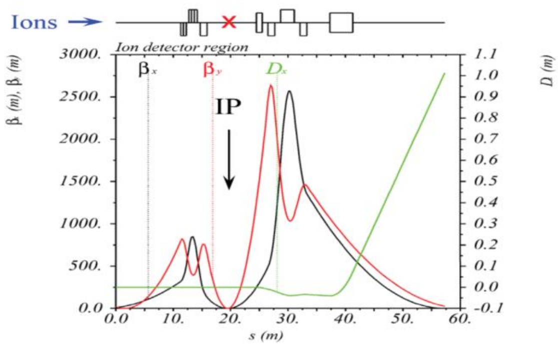

Figure 2: Asymmetric optics of IR design.

With the above asymmetric linear optics design, special attention was paid to 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. And parameters of those IR FFQs are list in table 1.

Table 1: IR triplets in the JLEIC ion collider ring

	Physical 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/-

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ION COLLEDER 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 chromatic β*. And remaining linear chromaticity is cancelled using two-family sextupoles in arc section [3].

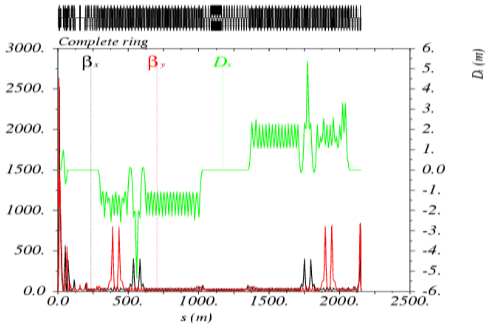

Figure 3: Linear optics of the JLEIC ion collider ring starting from IP.

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

DETECTOR SOLENOID COMPENSATION

For the JLEIC, an updated correction system provides local compensation of the solenoid effects independently for each side of the IR. It includes 2 IR triplets with skew quadrupoles beside, dipole correctors and anti-solenoids to cancel perturbations of the optics and spin symmetry shown in Fig. 4.

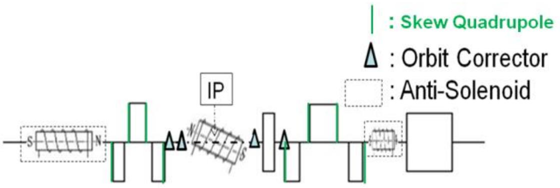

Figure 4: a proposed correction system for detector solenoid compensation.

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 at the 3rd corrector in vertical.

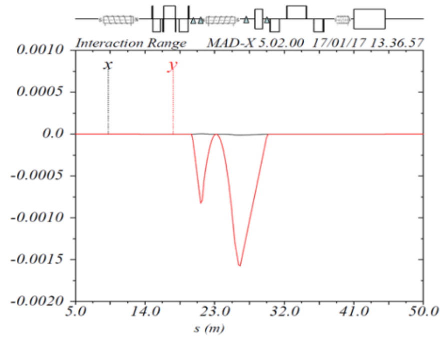

Figure 5: Coherent orbit in the IR of the JLEIC ion ring.

With the effective rotation angle produced in the IR triplets by nearby skew quadrupoles, the coupling effects can be controlled locally between the detector solenoid and anti-solenoid. This can be seen in Fig.6.

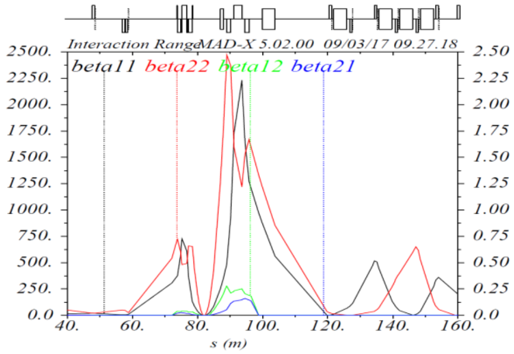

Figure 6: Local compensation of the coupling effect in IR of the JLEIC ion collider ring.

Although with effective rotation angles of the IR triplets, 3 independent values can be used for matching in the IR, for complete compensation, nearby quadrupoles are needed to do matching to compensate effects on the tune, beta function, dispersion, and linear chromaticity. Adjustments to chromatic sextupoles and their phase advances are also needed to restore the linear chromaticity compensation and W function. Considering a strong cooling emittances of 0.35/0.07 mm-mrad (H/V), we can get a dynamic aperture of 50 σ of the beam size as shown in Fig. 7.

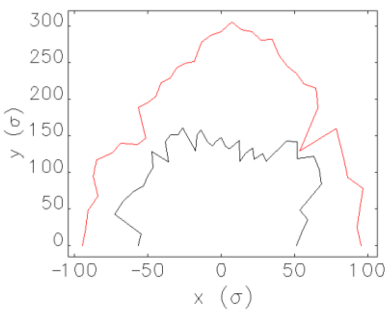

Figure 7: Dynamic aperture without (red) and with (black) detector solenoid

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 100 GeV proton at collision energy and 8 GeV proton at injection energy. The collision lattice is shown in Fig. 8. And the injection lattice considering beta squeeze was performed with a beta extension of factor of 30 at IP [5]. The resulting dynamic apertures at collision and at injection are shown in Fig. 8.

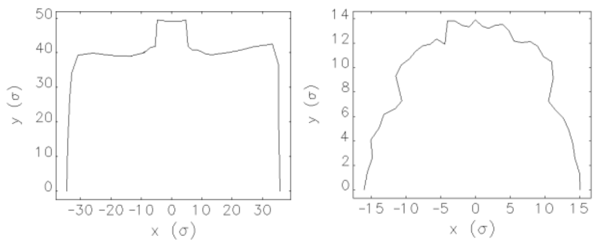

Figure 8: Dynamic apertures with multipole fields of the arc dipoles (left: at collision; right: at injection).

The results show that, considering a 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 case. And for the 8 GeV proton injection case, the dynamic aperture is about 12 σ with off-momentum. Further study is 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. Hence their influence is studied in detail. The multipole field data of the LHC IR triplets are applied into the JLEIC ion collider ring lattice to find the dynamic aperture. The resulting dynamic aperture considering strong cooling is shown in Fig. 9.

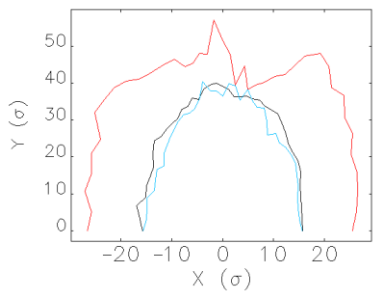

Figure 9: Dynamic aperture of the JLEIC ion ring where the LHC triplets multipole field is applied to the JLEIC triplets. (Red: with nominal LHC data; black: upstream IR triplets with nominal LHC data, downstream IR triplets with HL LHC average data; blue: upstream IR triplets with nominal LHC data,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

LHC have an upgrade from the nominal stage to the high luminosity stage (HL-LHC). The inner aperture of IR triplet is changed also, from 70 mm to 150 mm, depending on different superconducting technology. Compared with JLEIC IR triplet in Table 1, the nominal LHC IR triplet has a similar inner aperture with upstream IR triplet in the JLEIC. And the HL-LHC IR triplet can support more information for the downstream IR triplet because of larger inner aperture. So the measured magnet quality data of both nominal LHC IR triplet [6] and HL-LHC IR triplet [7] is considered in the dynamic aperture study, as shown in Fig. 9.

We performed three different magnet quality applications into the JLEIC IR triplets. Firstly, the nominal LHC IR triplet data is applied to all JLEIC IR triplets. The dynamic aperture is about 22 σ as shown in red curve in Fig. 9. Secondly, the nominal LHC IR triplet data is applied to JLEIC upstream IR triplets with HL-LHC multipole data applied to the downstream triplets. The dynamic aperture is about 16 σ as shown in black and blue curve in Fig. 9. The difference is black curve with only average multipole value, and blue curve with average plus standard deviation (Std. Dev.) value.

SUMMARY

IR design for the full-acceptance detection at the 1st IP of the JLEIC gives follow challenges: Chromaticity issue, Detector solenoid issue, Misalignment issue, Magnet quality, Beta squeeze, etc.

For Chromaticity Compensation, a non-interleaved –I pairs scheme is selected. Detector solenoid compensation is done with skew quadrupoles, dipole correctors and anti-solenoids. Magnet quality of the arc dipoles is also studied for the dynamic aperture. The most limit to the dynamic aperture is multipole field components of IR triplets. IR triplets with LHC measured data are good for strong cooling scheme. If cooling is better, we can release the magnet quality requirement.

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