DESIGN OF THE PROPOSED LOW ENERGY ION COLLIDER RING AT JEFFERSON LAB*

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Abstract

The polarized Medium energy Electron-Ion Collider (MEIC) envisioned at Jefferson Lab will cover a range of center-of-mass energies up to 70 GeV. The present MEIC design could also allow the accommodation of low energy electron-ion collisions for additional science reach. This paper presents the first design of the low energy ion collider ring which is converted from the large ion booster of MEIC. It can reach up to 25 GeV energy for protons and equivalent ion energies of the same magnetic rigidity. An interaction region and an electron cooler designed for MEIC are integrated into the low energy collider ring, in addition to other required new elements including crab cavities and ion spin rotators. A vertical chicane which brings the low energy ion beams to the plane of the electron ring and back to the low energy ion ring is also part of the design.

INTRODUCTION

The Medium energy Electron Ion Collider (MEIC) is being designed to collide 3-12 GeV electrons with ions of an energy equivalent to 20-100 GeV protons. An initial conceptual design for the MEIC has been created [1]. With minor changes, this design also presents a straightforward way to enable electron-ion collisions at a much lower CM energy [2]. The basic idea is to convert the large booster to a low energy collider ring which could accommodate protons with energy 10 to 25 GeV and light to heavy ions with the same magnetic rigidity. The collider ring will include only one interaction point (IP) for one physics detector and an electron cooling section for achieving high luminosities [2]. The Low energy Electron-Ion Collider (LEIC) could be either an additional capability of MEIC or a low cost first phase collider at JLab.

In this paper, we present a design of the LEIC ion collider ring [3] based on the present version of the ion large booster design and integrate a vertical chicane to bring the ion beams to the plane of the electron ring and a low-beta interaction region (IR).

It should be noted that, because the MEIC large booster and two collider rings are vertically stacked in one tunnel, the large booster design has been updated recently with significant modification to accommodate changes of the electron and medium energy ion collider rings of MEIC due to their continuous design optimization [1]. Therefore, in the following we first briefly summarize the design update of the large booster, then proceed to present the design of the low energy collider ring using the updated booster design.

LARGE BOOSTER DESIGN UPDATE

The primary changes made recently to the ion collider ring of the MEIC were (1) the removal of the short straight sections within the arcs of the machine as a result of the optimization of the ion polarization design scheme [1]; (2) a lengthening of the long straight sections of the figure-8 shaped rings to allow sufficient space for the interaction regions [1] and electron cooling (located in the vertex of the figure-8); and (3) a longer arc for an increase of the electron bending radius needed for reduction of the radiation induced depolarization [1]. In order to follow the MEIC collider ring footprints, the ion large booster ring has been updated appropriately. A comparison of the layouts of the large booster before and after the update is shown in Fig. 1. These changes also allowed the radius of the arcs to be increased to close the geometry.

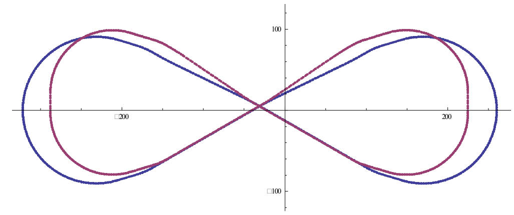

Figure 1: This overlay shows footprints of the original (in purple color) and the new (in blue color) booster rings.

In the previous design, the large booster ring was made of four identical 120° arc sections, separated by two short straight sections (for Siberian snakes) and two long straights (for IR and other machine elements). Since the short snake straight sections now have been removed, the booster ring will have two 240° arcs in the new design. Further, the old 120° arc consists of two bending arc subsections, 106.8° and 13.2° respectively, separated by a short straight, in order to follow the footprint of the electron universal spin rotator [1]. This feature will be preserved in the new design of the large booster ring, Under these design modifications and constraints, each of the two arcs consist of a 213.6° bending section with two straight sections (referred to here as mini straight sections) on each end followed by two final bending sections each with a total angle of 13.2°.

In the old design a 106.8° arc was composed of 24 5.91 m long cells each with a phase advance of 85.7°, the increased radius has allowed the new quarter arc to be composed of 28 cells that are 6.02m long with an 83.5° phase advance. This increased space has been used to increase the length of the arc dipoles from 1.65m to 1.75m which allow the bending at 25 GeV to be

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accomplished with the same peak dipole field of 1.64T as the 20 GeV version. The final bending section is made up of 3 FODO cells, with 2 m long dipoles.

The long straight sections have been lengthened to match the new lengths of the long straight sections in the redesigned ion collider ring. As with the old large booster design, a series of bends have been placed in the long straight section to follow the change in angle caused by the dipoles in the local chromatic compensation block in the interaction region of the ion collider. A diagram of the large booster is shown in Fig 2. The lattice functions for the new design of the large booster are shown in Fig 3.

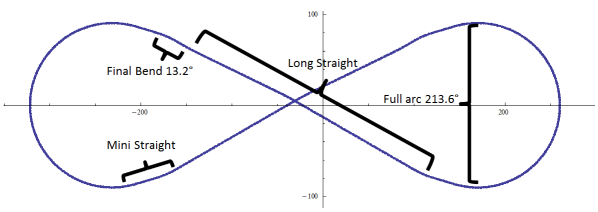

Figure 2: Above is a machine survey comparison of the large booster and the ion collider with the booster shown in blue and the collider ring shown in purple. Below is a diagram of the relevant areas of the large booster.

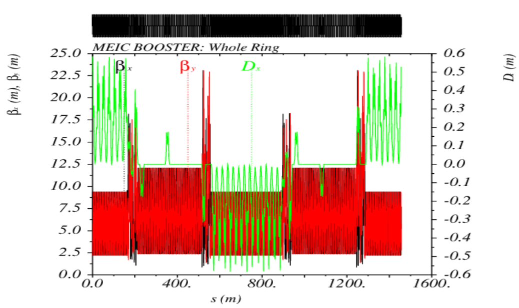

Figure 3: This is a MAD-X plot of the lattice functions of the large booster.

THE LOW ENERGY ION COLLIDER

The LEIC is formed by transforming the mini straight sections into vertical doglegs which bring the interaction region and the long straight of the collider ring down to the level of the electron ring 1 m below the large booster. This physical arrangement is shown in Fig 4.

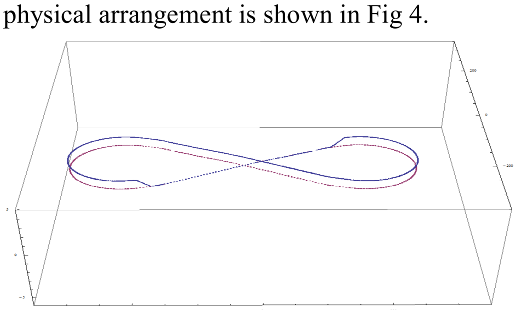

Figure 4: Physical arrangement of the LEIC above the plane of the electron ring, the vertical axis uses a different scale from the two horizontal axes for better visibility.

Since only one interaction point was planned it was decided to retain one of the long straights from the large booster at the top level, both for simplicity and to avoid the additional chromatic effects of the interaction region.

The mini straight sections have to be lengthened by 2 cm each to account for the increased distance, while two vertical dipoles have been added to each. In order to fit these dipoles into the available space they are only 1.5 m long, and with the bending angle required of 2.343°, this gives a bending field of 2.31T which is too large for a warm dipole. Since only four of these magnets will be required for LEIC, and a refrigeration system will be required for the superconducting magnets in the collider section anyway the current plan is to simply use superconducting dipoles for this part. An overlay of the LEIC on the ion collider ring is shown in Fig 5. Presently, the lattice design of the MEIC interaction region supporting a full acceptance detector has been adopted for LEIC, due to a requirement of nuclear science program for achieving a similar detection capability as MEIC [4]. The lattice functions of the LEIC are shown in Fig 6. A review of relevant quantities for the old and new large booster, as well as the LEIC is shown in Table 1.

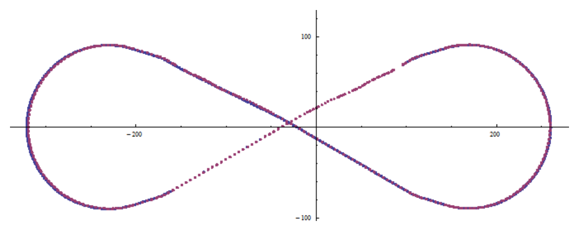

Figure 5: This shows the physical arrangement of the LEIC overlaid on the arrangement of the ion collider.

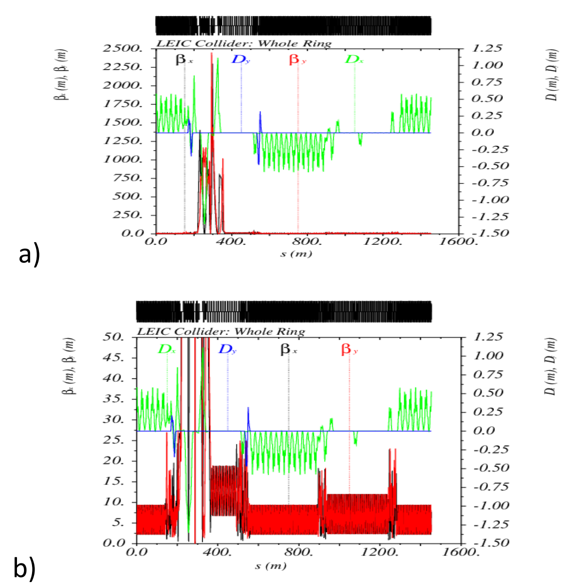

Figure 6: a) The complete lattice functions of the LEIC ring, the large beta functions are a result of the matching for the interaction region. b) This is a truncated version that allows a closer inspection of the lattice functions of the rest of the ring.

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Table 1: Ring specifications for the original large booster, the new large booster, and the LEIC

Quantity	Unit	Original	New Booster	LEIC
Proton kinetic energy	GeV	3 to 20	3 to 25	3 to 25
Ion rigidity at injection	Tm	12.76	12.76	12.76
Ion Rigidity at Top Energy	Tm	69.77	86.46	86.46
Ring circumference	m	1343.9	1456.19	1453.48
Figure-8 crossing angle	Deg.	60	60	60
Quarter arc length	m	189.1	213.9	213.9
Length of long straight	m	267.8	300.31	298.96
Length of short straight	m	25.9	0	0
Lattice base cell		FODO	FODO	FODO
Arc cell length	m	5.91	6.02	6.02
Straight section cell length	m	6.1	7.51	7.47
Phase Advance per cell in arc	Deg.	85.7	83.5	83.5
Phase advance per cell in straight	Deg.	90	90	90
FODO cells in quarter arcs		32	35	35
FODO cells in straights		43	40	40
Dispersion Suppression Method		Phase	Phase Advance	Phase Advance
Max. horiz. beta function	m	15.0	23.12	2299.62
Max. vert. beta function	m	19.0	23.1	2457.01
Maximum horiz. Dispersion	m	0.73	0.583	1.356
Horizontal betatron tunes		53.41	53.34	47.63
Vertical betatron tune		52.58	51.21	45.74
Natural horiz. chromaticity		-67.42	-68.81	-156.59
Natural vertical chromaticity		-67.36	-66.315	-157.02
Transition Energy factor γ_{tr}		25.028	28.87	30.005

CONCLUSIONS

The analysis has shown that the top energy of the large booster could be successfully raised to 25 GeV with changes made to the size and bending radius of the accelerator. Furthermore this new booster can be modified with a vertical dogleg to become a Low energy Electron Ion Collider which could be used as a first stage for the MEIC project, or as a separate add-on to MEIC's medium energy operations. As a first stage, LEIC would allow us to begin colliding earlier, and at a lower cost than going straight to the MEIC. As an add-on to the MEIC it would increase the physics output of the machine by utilizing the large booster at a higher workload.

REFERENCES

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