ADAPTING THE JLEIC ELECTRON RING FOR ION ACCELERATION*

B. Mustapha†, J. Martinez Marin, Z. Conway and P. Ostroumov[2], ANL, Argonne, IL, USA,
F. Lin, V. Morozov, Y. Derbenev and Y. Zhang, JLab, Newport News, VA, USA

Abstract

A key component of the recently proposed alternative design approach for the JLab-EIC (JLEIC) ion complex is to consolidate the electron storage ring (e-ring) as a large booster for the ions. A preliminary parameter study showed that it is possible to do so for different design options of the e-ring. In this paper we report on adapting the e-ring lattice to accelerate ions. After studying the beam optics at the injection and extraction energies, we determine the RF requirements for ion acceleration, in particular the number of required accelerating sections and their locations. In a future stage, we will study the spin manipulation and determine if the spin rotators and flippers available for the electrons could be used for the ions. The effect of these lattice modifications on the electron beam will also be investigated.

THE ALTERNATIVE DESIGN APPROACH

The ion complex for the Jefferson Lab Electron-Ion Collider (JLEIC) [1] consists of a 280 MeV pulsed superconducting linac, an 8-GeV booster ring and a 20-100 GeV collider ring. Both the booster and collider rings are based on 3 Tesla super-ferric magnets [2]. The electron complex consists of the existing CEBAF machine as a full-energy injector to a new storage ring at 3-10 GeV. The electron ring (e-ring) re-uses the magnets and RF system from the decommissioned PEP-II e+e- collider at SLAC.

We have recently proposed an alternative design approach [3] to the baseline design described above. The alternative ion complex includes a more compact 130 MeV linac [4], a more compact 3-GeV pre-booster using RT magnets [5]. At this energy, the figure-8 shape is not necessary, Siberian snakes with reasonable fields could be used for spin corrections. We also propose to use the e-ring as a large booster for the ions, up to 11 GeV for protons with PEP-II magnets or 15 GeV with new magnets. In a first stage, the ion collider ring could use RT magnets to reach a proton energy of 60 GeV, to be later upgraded with 3 T super-ferric magnets or 6 T fully superconducting magnets, up to 100 GeV or 200 GeV, respectively. A possible layout of the alternative ion complex design is shown in figure 1.

The potential benefits from the proposed alternative design approach for the JLEIC ion complex are:

- Lowering the risk of the project by using the proven technology of room-temperature (RT) where possible, with the possibility of upgrading with super-ferric (SF) or superconducting magnets (SC).
- Reducing the footprint of the ion complex for potential cost savings by using a more compact linac and pre-booster ring, and consolidate the electron storage ring as a large booster for the ions.
- Using the e-ring as large booster for the ions offers the possibility of injecting all ions above the energy transition in the ion collider ring, avoiding transition crossing which represents a significant operation risk.
- Depending on the total cost and physics priorities of the project, consider staging of the ion collider ring, first with RT magnets up to 60 GeV, then later with SF magnets up to 100 GeV or SC magnets up to 200 GeV.

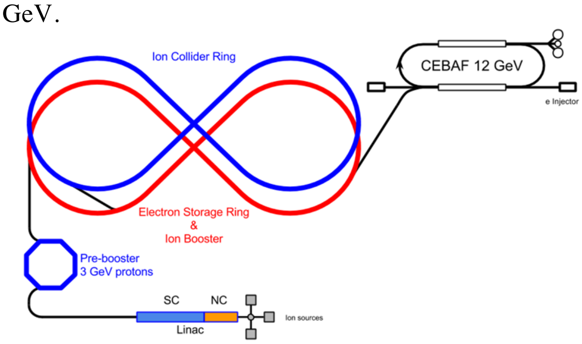

Figure 1: Layout of the alternative JLEIC design.

USING E-RING AS ION BOOSTER

A parameter study performed for three lattice design options of the e-ring showed that it is possible to use the e-ring as a large booster for the ions. The results of this study are summarized in Table I.

Table 1: Options for the e-Ring as Large Ion Booster

Parameter	**Baseline (PEP-II magnets)**	**Low-ε (New RT magnets)**	**TME design (RT dipoles, SF/SC quads)**
Cell length (m)	15.2	11.4	11.4
Transition γ	23	23	32
proton (GeV)	11	15	37.5
Pb (GeV/u)	4.4	6	15
Dipole (T)	0.36	0.5	1.3
Quad (T/m)	15	25	66
Limitation	Dipoles	Quads	-

* This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357 for ANL and by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177
† corresponding author: brahim@anl.gov, [2] Now at MSU.

ISBN 978-3-95450-182-3

In the baseline and low-emittance (Low-ε) designs, most ions will be injected below the transition energy into the ion collider ring (ICR). In the theoretically minimum emittance (TME) design option with SF/SC Quads, above transition energy injection to the ICR is possible for all ions at ~ 15 GeV/u.

INTRODUCING ION RF SECTIONS TO THE E-RING LATTICE

In order to introduce the rf sections required for ion acceleration in the e-ring, the following lattice modifications were made:

- The chromaticity correction block (CCB) was moved from the straight section to the dispersive arcs.
- The tune trombone sections devised to adjust the machine tunes were shrunk from five to three cells.
- The ion injection from the 3 GeV pre-booster will be located in the straight section, near the crossing point injecting ions in the direction of the left arc.
- Ion RF sections, similar in number and dimensions to the e^- RF sections, were added across from the e^- RF.
- The beam was re-matched to the same parameters required for beam circulation in the arcs

Figure 2 shows the e-ring lattice before and after introducing these modifications, and Figure 3 shows the beam optics for 3 GeV protons before and after adding the ion RF sections.

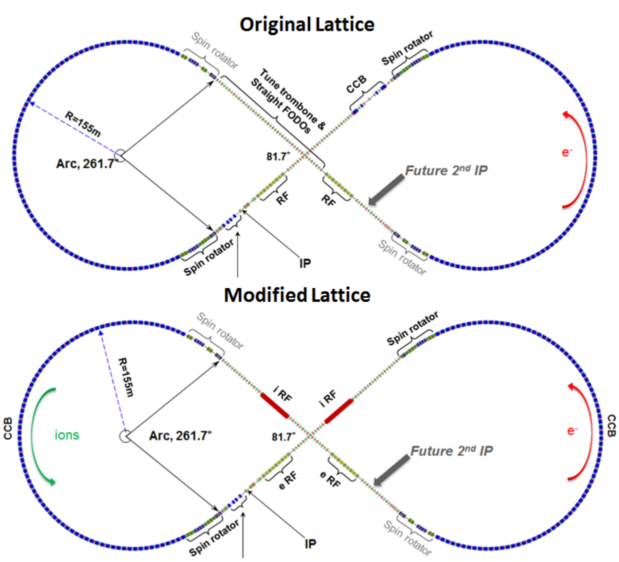

Figure 2: e-ring lattice before and after adding ion rf sections.

The required total RF voltage is estimated to be ~ 240 kV. The added ion RF sections house 8 x 4-gap cavities. For a 240 kV total voltage, each gap needs to provide 7.5 kV. It is important to note that more efficient MA-loaded cavities, similar to the ones being built for the FAIR project at GSI [6] and proposed for the HIAF project at IMP, could be used. 6 x 2-gap cavities with each gap providing 20 kV would be enough to provide 240 kV. In this way, the total voltage could be provided by a single more compact RF section, freeing much needed space in the e-ring straight sections (Fig. 3).

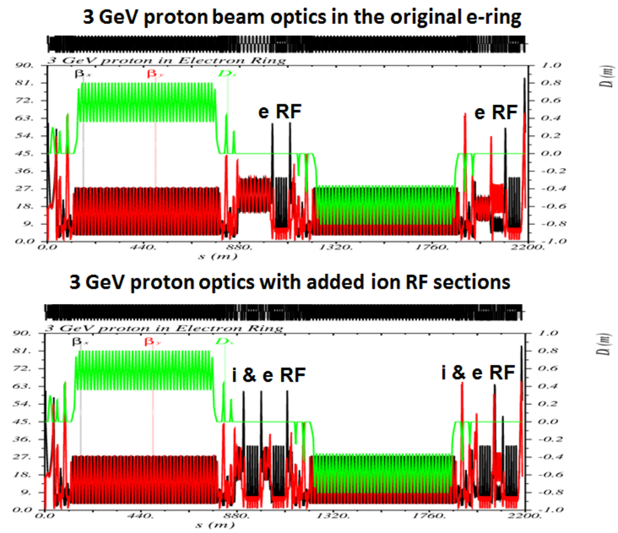

Figure 3: 3 GeV proton beam optics in the e-ring before and after adding the ion rf sections.

Table 2 lists the lattice parameters before and after introducing the ion RF sections. We notice that only the machine tunes have changed after adding the ion RF and re-matching the beam optics.

Table 2: e-ring Lattice Parameters for Protons Before and After Adding Ion RF Sections

Parameter	Original	Modified
Circumference, m	2186	2186
Maximum β_x, m	90	90
Maximum β_y, m	82	82
Maximum dispersion, m	0.8	0.8
β_x at injection, m	30	30
Tune in X	42.83	44.46
Tune in Y	47.34	52.42
Transition γ	22.7	22.7
Momentum compaction	0.002	0.002
Quad. half aperture, cm	5	5
Quad. max. grad. T/m	20	20
Dipole bend radius, m	110.5	110.5
Dipole bend angle, deg	2.1	2.1
Dipole full gap	5	5
Dipole max. field, T	0.36	0.36

RF REQUIREMENTS FOR ION ACCELERATION

The circumference of the e-ring is ~ 18 times that of the octagonal pre-booster (120 m). A bunch to bucket injection is possible at the 18th harmonic or higher depending on the bunch length from the pre-booster. Assuming a typical 1 T/s field ramping speed in the magnets, it will require only 0.25 s to ramp PEP-II magnets from 0.11 to 0.36 T for a proton equivalent energy of 11 GeV, or in 1.2 s to 37.5 GeV with new RT dipoles and SF or SC quads. After filling the e-ring, proton acceleration from 3 to 11 GeV could be done in ~ 35000 turns with 230 keV energy gain per turn, or in 150000 turns to 37.5 GeV with new RT dipoles and SF/SC quads. Table 2 lists the rf parameters for both options, where the energy is expressed in proton-equivalent (p-eq.) energy, where the energy for other ion beams can be obtained by simple scaling with the corresponding charge-to-mass ratio.

Table 2: RF parameters for ion acceleration in the e-ring for the baseline design with PEP-II magnets and the TME design with new RT dipoles and SF/SC quadrupoles.

Parameter	PEP-II Magnets	New Magnets
p-eq. injection energy, GeV	3	3
p-eq. extraction energy, GeV	11	37.5
RF harmonic	18	18
RF frequency, MHz	2.4-2.5	2.4-2.5
Maximum RF voltage, kV	240	240
Maximum RF phase, deg	16	16
Capture efficiency, %	~100	~100
Acceleration turns	35000	150000

SUMMARY AND FUTURE WORK

RF sections for ion acceleration were successfully added to the e-ring lattice and the beam optics rematched. Preliminary RF requirements were presented in terms of total RF voltage and frequency range. Future work will include the following:

- Study the possibility of using the universal spin rotators, designed for electrons, to control the spin of light ions. If possible, this will relieve the need for separate spin rotators for the ions and save space.
- Study the transverse beam dynamics for the ions and re-optimize the lattice for lower beta functions.
- Perform longitudinal beam dynamics studies for the proposed fast acceleration scheme.
- Since the original e-ring lattice was optimized for electrons, the electron beam optics needs to be verified in the new lattice. An iterative process may be needed to reach an optimum lattice for both electrons and ions.
- Study intra-beam scattering (IBS) and space charge effects for ions in the e-ring.
- Investigate the need and possibility of adding beam cooling in the e-ring at or above 3 GeV.
- Using E-ring as large ion booster at the 18th harmonic will at least eliminate one stage of the required bunch splitting in the ion collider ring [7]. The potential for further reduction will be investigated.

REFERENCES

[1] Y. Zhang et al, "JLEIC Ultimate Luminosity with Strong Electron Cooling", presented at IPAC'17, Copenhagen, Denmark, paper TUOCB2, these proceedings.
[2] J. Breitschopf et al, "Superferric arc dipoles for the Ion Ring and Booster of JLEIC", Proceedings of NA-PAC 2016, paper MOPOB54.
[3] B. Mustapha et al, "An Alternative Approach for the JLEIC Ion Accelerator Complex", Proceedings of NA-PAC 2016, paper TUPOB05.
[4] P. Ostroumov et al, "Design and Beam Dynamics Studies of a Multi-ion Linac Injector for the JLEIC Ion Complex", Proceedings of HB-2016, Malmo, Sweden, paper THPM5Y01.
[5] B. Mustapha et al, "A More Compact Design for the JLEIC Ion Pre-Booster Ring", Proceedings of NA-PAC 2016, paper TUPOB04.
[6] P. Spiller et al, "FAIR SIS-100 Features and Status of Realization", presented at IPAC'17, Copenhagen, Denmark, paper WEPVA030, these proceedings.
[7] R. Gamage and T. Satogata, "Bunch Splitting Simulations for the JLEIC Ion Collider Ring", Proceedings of IPAC 2016, paper WEPMW013.

ISBN 978-3-95450-182-3