# A MORE COMPACT DESIGN FOR THE JLEIC ION PRE-BOOSTER RING*

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*Abstract*

The original design of the JLEIC pre-booster was a 3-GeV figure-8 synchrotron with a circumference of about 240 m. In the current baseline design, the 3-GeV pre-booster was converted into an 8-GeV booster of the same shape and size but using super-ferric magnets with fields up to 3 Tesla. In order to reduce the foot-print of the JLEIC ion complex, we have designed a more compact and cost-effective octagonal 3-GeV ring about half the size of the original design. At 3 GeV, the figure-8 shape is not required to preserve ion polarization; Siberian snakes with reasonable magnetic fields can be used for spin correction. As the ion collider ring requires higher injection energy, we propose to use the existing electron storage ring, which is part of the electron complex, as a large booster for the ions up to 12 GeV. The design optimization of the pre-booster, leading to a final octagonal ring design is presented along with preliminary beam simulation results.

## INTRODUCTION

In an effort to lower the risk and reduce the footprint of the JLEIC ion accelerator complex, we have proposed an alternative design approach [1]. An essential part of the alternative approach is to replace the 8-GeV figure-8 booster of the current baseline design [2] with a more compact 3-GeV pre-booster ring and to use the electron storage ring (e-ring) as large ion booster up to 12 GeV or higher. The current 8-GeV booster was based on the original 3-GeV figure-8 pre-booster design [3] where super-ferric magnets [4] replaced the original room-temperature magnets. At 3 GeV, the figure-8 shape is not required for spin preservation as Siberian snakes with reasonable magnetic fields can be used. After a brief review of the original figure-8 pre-booster design, we present the design iterations for a race-track type ring which have led to the selection of an octagonal design with half the circumference of the original figure-8.

## THE ORIGINAL FIGURE-8 DESIGN

The layout of the original 3-GeV accumulator and pre-booster ring is shown in figure 1. The design parameters are listed in table 1. The main requirements for this original design were to accumulate and accelerate ion beams from the linac for injection to a large booster. The design uses room-temperature magnets and the spin polarization is preserved by its figure-8 shape.

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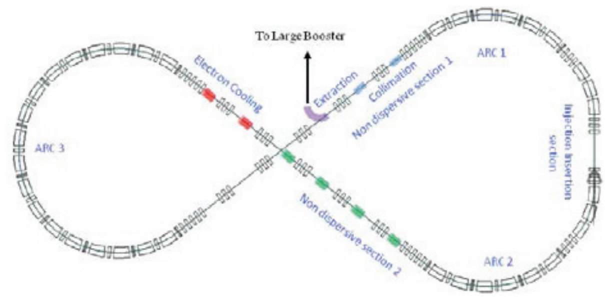


Figure 1: Layout of the original 3-GeV pre-booster.

Table 1: Design parameters of the original 3-GeV pre-booster.

| Parameter | Value |
|---|---|
| Circumference, m | 234 |
| Maximum $\beta_x$, m | 16 |
| Maximum $\beta_y$, m | 32 |
| $\beta_x$ at injection, m | 14.9 |
| Maximum dispersion, m | 3.4 |
| Normalized dispersion at injection | 2.5 |
| Tune in X | 7.96 |
| Tune in Y | 6.79 |
| Transition $\gamma$ | 5 |
| Extraction $\gamma$ (at 3 GeV) | 4.22 |
| Momentum compaction factor | 0.04 |
| Number of Quadrupoles | 94 |
| Quadrupole length, n | 0.4 |
| Quadrupole half aperture, cm | 5 |
| Maximum quadrupole field, T | 1.1 |
| Number of dipoles | 36 |
| Dipole bend radius, m | 9 |
| Dipole angle, deg | ~14 |
| Dipole full gap, cm | 3 |
| Maximum dipole field, T | 1.5 |

## DESIGN ITERATIONS FOR A MORE COMPACT PRE-BOOSTER

The main requirements for a more compact design are:

- A circumference of about half the original design.
- All ions extracted below the energy transition.
- Beta and dispersion functions comparable to those of the original design.

Starting from a simple race-track geometry, we found that in order to keep the design parameters close to the original design, the ring would be of similar circumference. This may be explained by the fact that the figure-8 shape is simply a twisted race-track. After fixing the circumference to 120 m, we have investigated higher order shapes that would satisfy the requirements. Figure 2 shows the different design iterations from square to hexagon and ending with an octagonal shape.

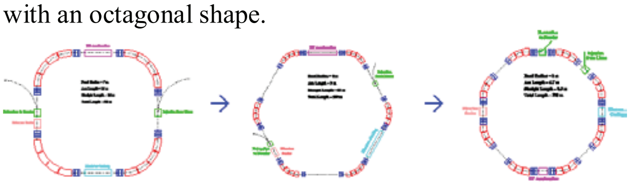

Figure 2: Design iterations for a more compact pre-booster.

Table 2: Parameters for different design iterations of the pre-booster.

| Parameter | Square | Hexagon | Octagon |
|---|---|---|---|
| Arc length, m | 13.6 | 9 | 6.7 |
| Straight section length, m | 16.4 | 11 | 8.3 |
| Maximum $\beta_x$, m | 18 | 15.6 | 15.3 |
| Maximum $\beta_y$, m | 30 | 21.5 | 21 |
| $\beta_x$ at injection, m | 14.9 | 5.9 | 6.0 |
| Maximum dispersion, m | 11.6 | 6.6 | 4.2 |
| Normalized dispersion at injection | 3.01 | 2.72 | 1.71 |
| Tune in X | 2.09 | 2.34 | 3.01 |
| Tune in Y | 0.90 | 1.22 | 1.18 |
| Transition $\gamma$ | 2.46 | 3.57 | 4.7 |
| Momentum compaction factor | 0.164 | 0.078 | 0.045 |
| Number of Quadrupoles | 20 | 30 | 40 |
| Number of dipoles | 24 | 24 | 24 |

Table 2 shows a comparison of the design parameters for the same 120 m circumference. At the extraction energy of 3 GeV, the relativistic parameter $\gamma \sim 4.2$, therefore the only design that satisfies the condition of no transition crossing is the octagonal design. It also has a dispersion and compaction factor very close to the original design. The dipoles and quadrupoles used in these lattices are similar to the original design.

## THE NEW OCTAGONAL DESIGN

The layout of the proposed compact 3-GeV pre-booster ring is shown in figure 3. This design has a circumference of 120 m with four dispersive and four dispersion-free straight sections. The four dispersion-free sections will be used for rf acceleration, electron cooling, spin correction and beam extraction to the e-ring serving as a large ion booster. One of the dispersive sections is used for injection from the linac while other sections will be used for higher order corrections. The non figure-8 shape will require Siberian snakes for spin correction.

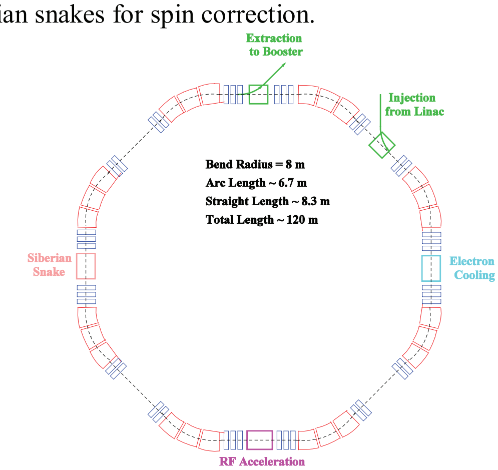


Figure 3: Layout of the new octagonal pre-booster design.

### *Comparison to the Original Design*

Table 3: Comparison between the original figure-8 and the new octagonal designs of the pre-booster.

| Parameter | Figure-8 | Octagonal |
|---|---|---|
| Circumference, m | 234 | 120 |
| Maximum $\beta_x$, m | 16 | 15.3 |
| Maximum $\beta_y$, m | 32 | 21 |
| $\beta_x$ at injection, m | 14.9 | 6.0 |
| Maximum dispersion, m | 3.4 | 4.2 |
| Normalized dispersion at injection | 2.5 | 1.7 |
| Tune in X | 7.96 | 3.01 |
| Tune in Y | 6.79 | 1.18 |
| Transition $\gamma$ | 5 | 4.7 |
| Momentum compaction factor | 0.04 | 0.045 |
| Number of Quadrupoles | 94 | 40 |
| Number of dipoles | 36 | 24 |

Table 3 presents a comparison of the lattice design parameters between the original figure-8 and the new octagonal designs of the pre-booster. In addition to reducing the circumference, the total number of magnets is also reduced by a half.

### *Beam Optics and Space Charge Effects*

The beam optics design of the new octagonal ring was performed using the code MADX [5]. The corresponding beta and dispersion functions are shown in figure 4.

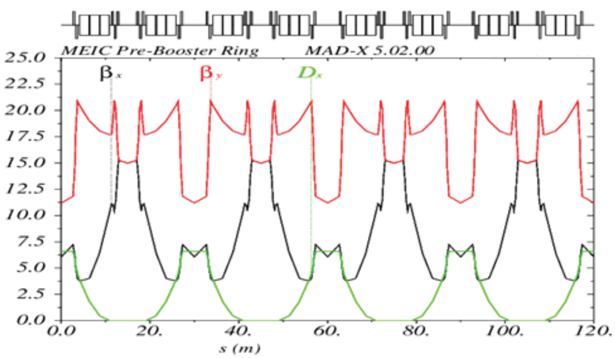


Figure 4: Beam optics functions from MADX (betas and dispersion) around the new octagonal pre-booster ring. Note that the dispersion is divided by the beam velocity.

In conjunction with the re-design of the injector linac [6] to be more compact with lower output energy, we have calculated the corresponding space charge (SC) tune shift at lower injection energy to the pre-booster. Table 4 presents the beam parameters from the new linac as well as the SC tune shift in the pre-booster. We note that for both protons and lead ions, the SC tune shift remains below the conventional limit of 0.25. More detailed studies of SC effects are underway.

Table 4: Beam parameters from the linac and SC tune shifts in the pre-booster.

| **Parameter** | **Protons** | **Lead ions** |
|---|---|---|
| Charge at the source | 1 | 30 |
| Energy at the stripper (MeV/u) | 33 | 8.2 |
| Charge after stripper | 1 | 62 |
| Energy at Linac exit (MeV/u) | 135 | 44 |
| Number of ions in pre-booster ring | $2.5\ 10^{12}$ | $4.5\ 10^{10}$ |
| SC tune shift | 0.19 | 0.22 |

## SUMMARY & FUTURE WORK

A more compact 3-GeV pre-booster ring was designed for the JLEIC ion complex. Following a design optimization, an octagonal shape with half the circumference of the original design was selected. More detailed simulations are underway using COSY, MAD-X and other codes to address the following issues:

- Beam dynamics including longitudinal dynamics and space charge effects.
- Spin preservation with Siberian snakes in a 3-GeV non figure-8 pre-booster ring.
- Beam injection from the linac and formation in the pre-booster.
- Beam extraction to the electron storage ring to be used as a large booster for the ions
- Start-to-end simulation of the beam in the pre-booster.

## REFERENCES

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