Design of the FCC-ee Positron Damping Ring and Transfer Line

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Background

The John Adams Institute for Accelerator Science (JAI) is a UK-based accelerator physics consortium comprised of researchers from the University of Oxford, Imperial College London, and Royal Holloway, University of London. As part of the JAI postgraduate training course, a preliminary design study of various components of the FCC-ee Positron Damping Ring and corresponding Transfer Line was conducted. Components were modelled using commercially-available software: MADX, FEMM, Poisson Superfish, and CST Studio. Models were then optimised to meet FCC-ee beam requirements while taking consideration of cost and environmental impact. Designs largely achieved target parameters (bunch compression, good field region, quality factor, etc). Further research with more specialist tools and a wider range of considerations (such as material) is required.

Transfer Line Bunch-Compressor Lattice

Performance criterion:

- Bunch compressors typically consist of a RF cavity followed by optics.
- The RMS bunch length is minimized by setting the R65 and R56 parameters of the cavity such that:

$$R_{56}^{optics} = -\frac{1}{R_{65}^{cavity}}$$

Dog-Leg Bunch Compressor:

- Achieves compression through oppositely-bending dipole magnets. Quadrupoles are used to ensure beam achromaticity by performing a 2π dispersive phase shift.
- Successful bunch compression from 2 mm to 1 mm is achieved; future work would be to introduce sextupoles for higher-order chromatic corrections

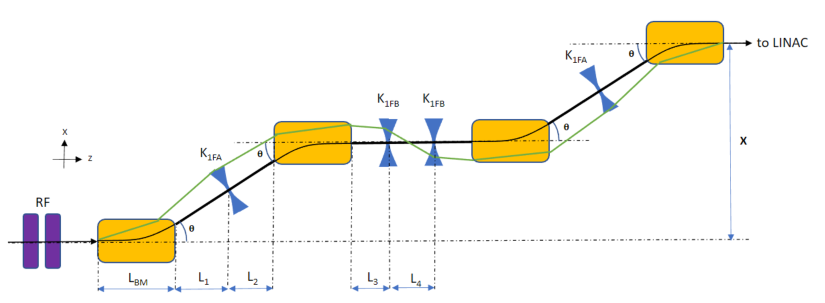


Figure 1. Dog-leg bunch compressor consisting of RF cavities (purple), dipoles (yellow) and quadrupoles (blue).

Parameter	Value	Parameter	Value
L_{BM}	1.0 m	L_1	8.0 m
θ_{BM}	60 ± 1^{o}	L_2	2.0 m
L_Q	0.5 m	L_2	2.0 m
K_{1f}	$1.02 \pm 0.01\ m^{-2}$	X	24.25 m
K_{1d}	$-0.61 \pm 0.01\ m^{-2}$	Z	14.0 m

Table 1. Optimized parameter settings with error bars to account for MADX reduced matching sensitivity.

C-Bend Achromat Compressor:

- R56 parameter tuned by varying magnetic field gradient of two additional focusing quadrupoles
- RMS bunch length also reduced from 2 mm to 1 mm
- Large size (3 cells ~80 m)
- Requires dedicated RF cavity at 3 GHz and 10 MV, and additional matching section to guide compressed bunches back into the Common Linac

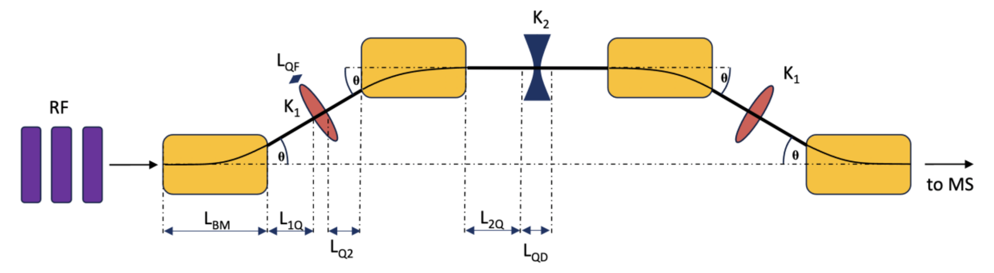


Figure 2. C-bend bunch compressor consisting of RF cavities (purple), dipoles (yellow), focusing and defocusing quadrupoles (red and blue respectively).

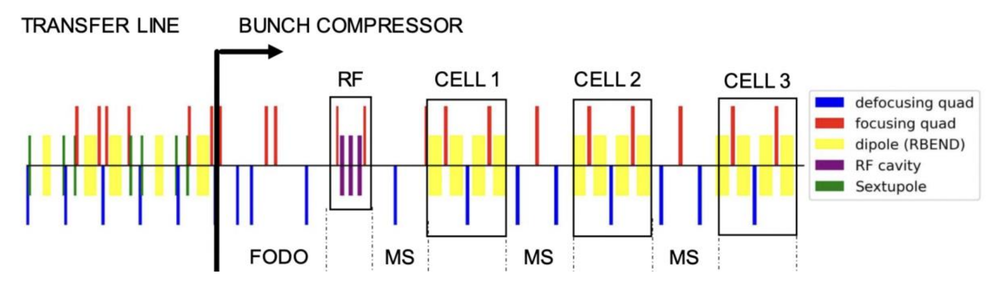


Figure 3. Element sequence of the C-bend achromat lattice, including matching sections (MS). Added lattice length ~80m.

Positron Damping Ring Magnets

Performance criterion:

- Good Field Region (GFR) >= 2/3 beampipe diameter

$$\left|\frac{\frac{\partial^n}{\partial x^n}(B_{\text{pole}} - B)}{\frac{\partial^n}{\partial x^n}B_{\text{pole}}}\right| \sim \begin{cases} 10^{-4},\ n = 0 \text{ for dipoles} \\ 10^{-3},\ n = 1 \text{ for quadrupoles} \\ 10^{-3},\ n = 2 \text{ for sextupoles} \\ 10^{-3},\ n = 0 \text{ for wiggler} \\ 10^{-1},\ n = 0 \text{ for kicker and septum} \end{cases}$$

Dipoles :

- B-field of 0.0595T
- GFR of 30 mm >= beampipe radius of 25 mm

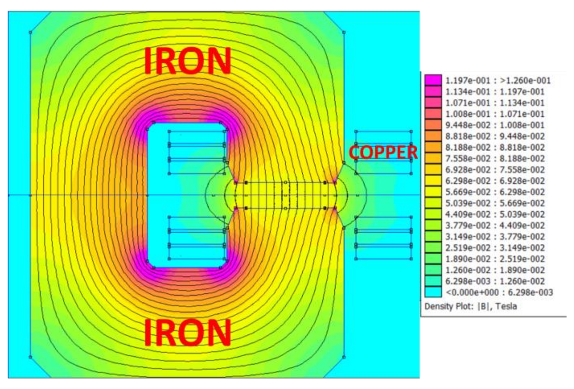


Figure 1. Cross-section of a potential dipole design

Quadrupoles:

- Magnetic gradient of 3.717 T/m
- GFR of 16.97 mm above target of 16.67 mm

Sextupoles:

- Focusing: 523.81 T/m^2, 104.7A
- Defocusing: -743.74 T/m^2, 148.7A
- GFR of 16.05 mm (1D), 18.01 mm (2D) above target

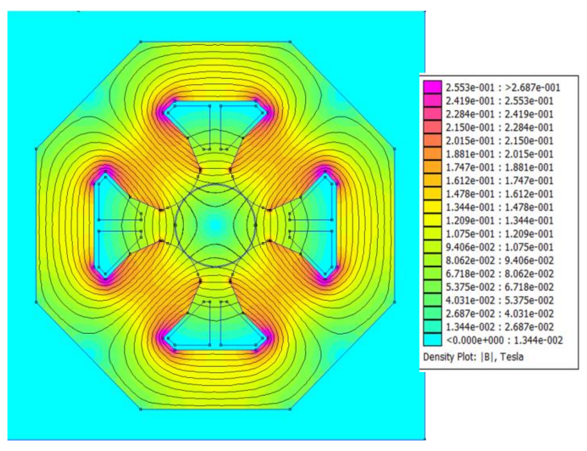


Figure 2. Cross-section of a quadrupole with shimming

Kicker:

- Average B-field = $1.558 \pm 0.003 \times 10^{-5}$ T
- 20 turns at 0.025A, field outside negligible (10^{-9} T)

Lambertson Septum:

- Average B-field = $1.18 \pm 0.05 \times 10^{-5}$ T
- 4 turns at 0.025A, beam pipe field negligible (10^{-9} T)

Wiggler:

- Designed a **ferrite** wiggler using two opposing Halbach arrays; an example is shown in Fig. 2.
- B-field of 0.1616 T
- There were issues with modelling the wiggler in 2D as edge effects are not considered.
- Also modelled a wiggler with **electromagnets**, thereby allowing variable magnetic fields at higher cost
- Remained far from saturation but with a "one-dimensional GFR" of roughly 1mm

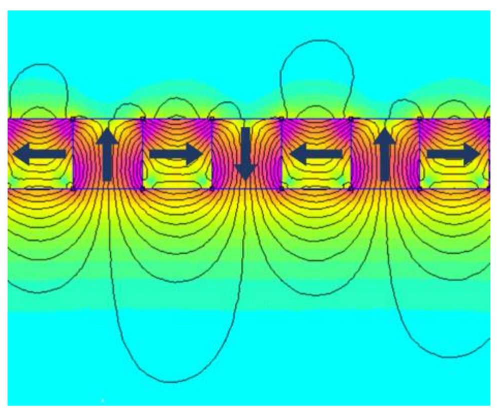


Figure 3. Halbach array, simulated in FEMM.

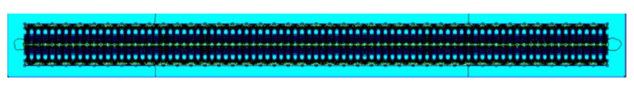


Figure 4. Cross-section of wiggler with electromagnets.

Positron Damping Ring RF Cavities

Performance criterion

- 5 MV RF voltage in a maximum length of 1.5 m
- Chose a compact RF cavity design with good efficiency
- Geometry of each design was optimized in Superfish (SF)
- A benchmark of SF against CST Microwave was performed

Normal conducting (NC)

- 400 MHz NC cavity did not meet the space requirement
- No cryogenics required, but worse efficiency than SC

Superconducting (SC)

- 800 MHz SC design has a low transit time factor and is compact
- 400 MHz SC has a high efficiency and is in use at the LHC

⇨ **The 400 MHz SC design was chosen for the pDR.**

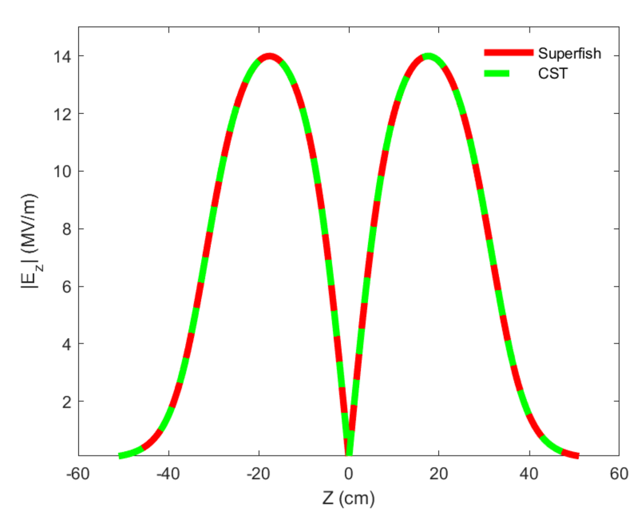
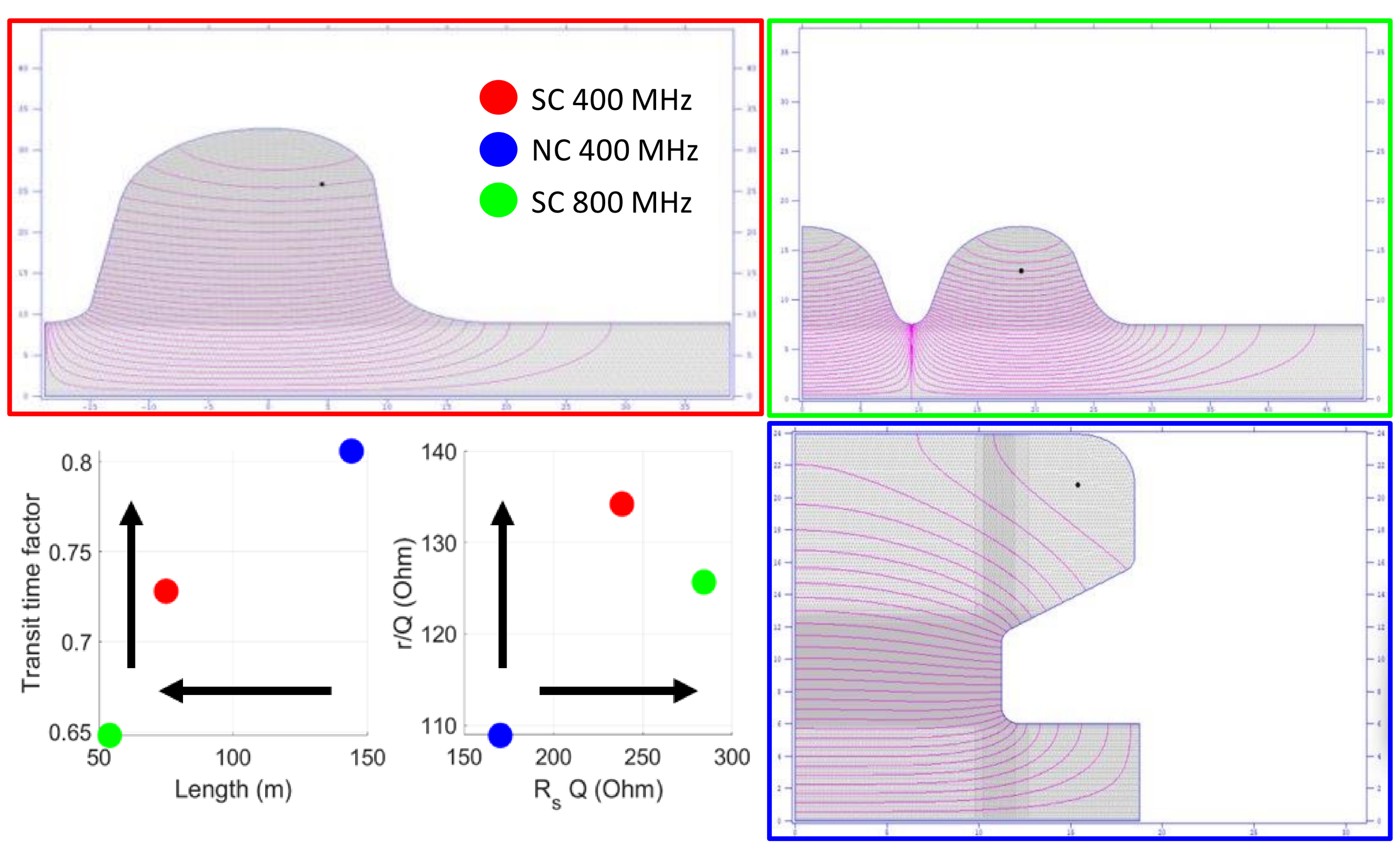


Figure 1. E-field on-axis across the SC 400 MHz cavity, computed in CST and Superfish.



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