First Considerations on Beam Optics and Lattice Design for the Future Electron-Positron Collider FCC-ee

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Abstract

Following the recommendations of the European Strategy Group for High Energy Physics, CERN launched the **Future Circular Collider Study (FCC)** to investigate the feasibility of a new large circular collider for high energy physics research. This paper presents the constraints on the design of the lattice and optics of the lepton collider version of FCC, that has to be optimised for **four different beam energies and parameter sets**. Special emphasis is put on the need for a **highly flexible magnet lattice** in order to achieve the required beam emittances for the four energies and on the **layout of the interaction region** that will have to combine an **advanced mini-beta concept, an effective beam separation scheme and a local chromaticity control** to optimise the momentum acceptance and dynamic aperture of the ring.

Introduction

- Racetrack geometry with 100 km circumference
- Running at **four different centre-of-mass energies** from 45.5 GeV to 175 GeV
- The general parameters [2] optimised for each beam energy and determined by the overall synchrotron radiation load (**P_γ =50 MW**)
  → Higher number of bunches for low energies
- Performance limited by Beamstrahlung for 120 GeV and 175 GeV, by the beam-beam effect for 45.5 GeV and 80 GeV
  → **Large variation of required beam emittances**

Table 1: FCC-ee parameters at four different beam energies

	Z	W	H	t
Beam Energy (GeV)	45.5	80	120	175
Current (mA)	1450	152	30	6.6
Bunch population (10^{11})	1.8	0.7	0.46	1.4
Bunch number	16700	4490	1360	98
Hor. Emittance (nm)	29	3.3	0.94	2
Vert. Emittance (pm)	60	7	1.9	2
β_x function at IP(m)	0.5	0.5	0.5	1
β_y function at IP(mm)	1	1	1	1

General Lattice

- The basic FODO cell shown in fig. 1 has been chosen for 175 GeV operation
- The parameters are optimised for max. dipole fill factor and design emittance
- Phase advance per cell: 90°/60°
- Half-bend dispersion suppressors between arcs and straight sections
- Matching sections provide smooth transition to straight section optics

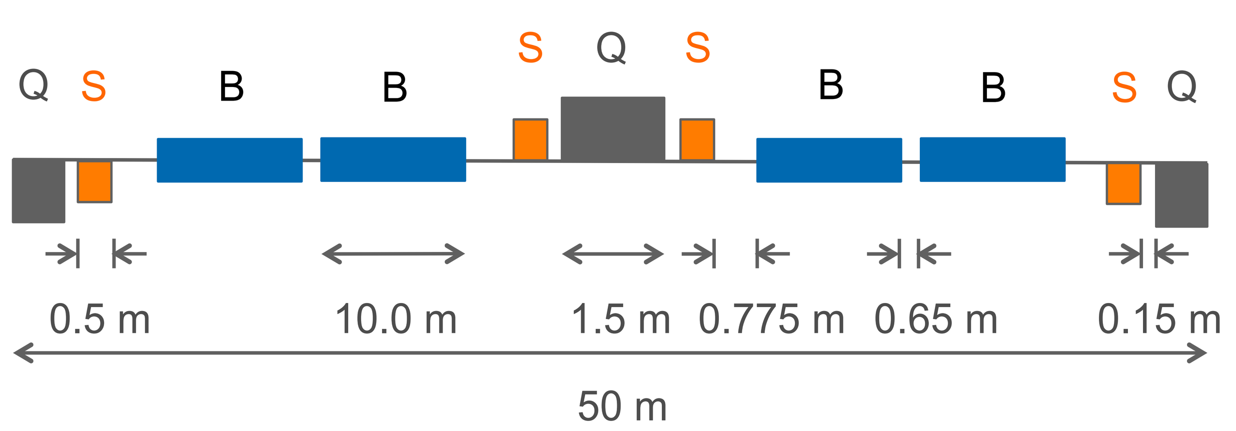


Figure 1: Non-scale sketch of the FODO cell chosen for the arc design. B stands for bending magnet, Q for quadrupole and S for sextupole

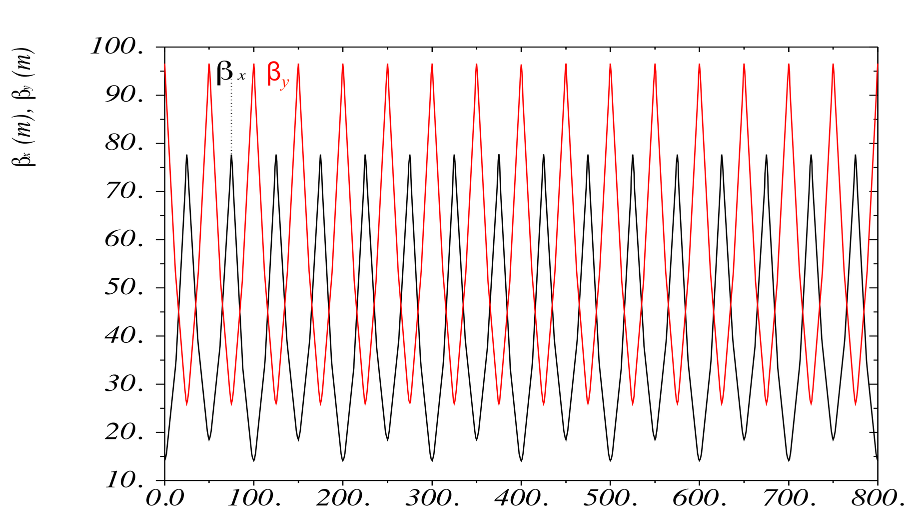


Figure 2: Optics in the periodic structure of the arc

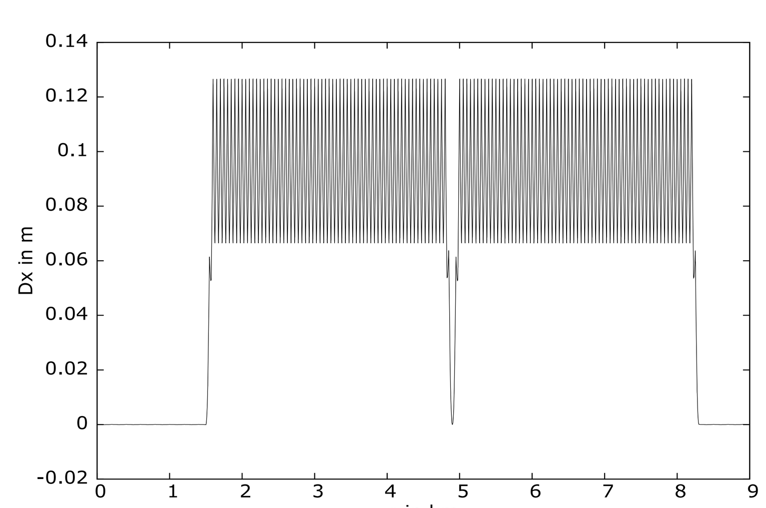


Figure 3: Dispersion function. Dispersion free sections are foreseen in the long straight sections for RF installation and experiments.

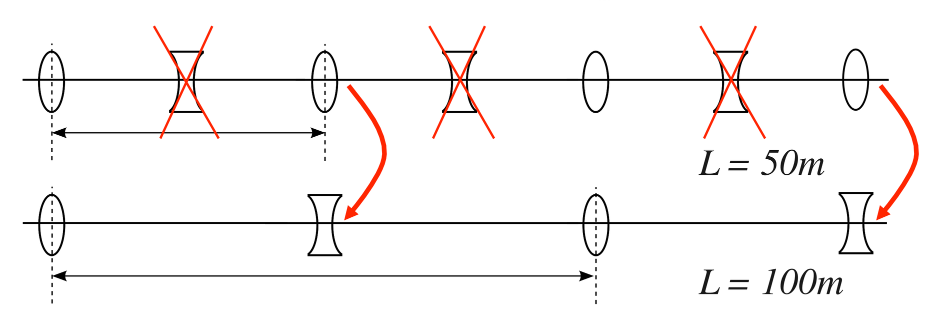
Optics for lower energies

Scaling laws:

$$\varepsilon = \left(\frac{\delta p}{p}\right)^2 \left(\gamma D^2 + 2\alpha D D' + \beta D'^2\right)$$

$$\hat{D} = \frac{L_{cell}^2}{\rho} \cdot \left(1 + \frac{1}{2}\sin\left(\frac{\psi_{cell}}{2}\right)\right) \Big/ \sin^2\left(\frac{\psi_{cell}}{2}\right)$$

Modification of the cell length:



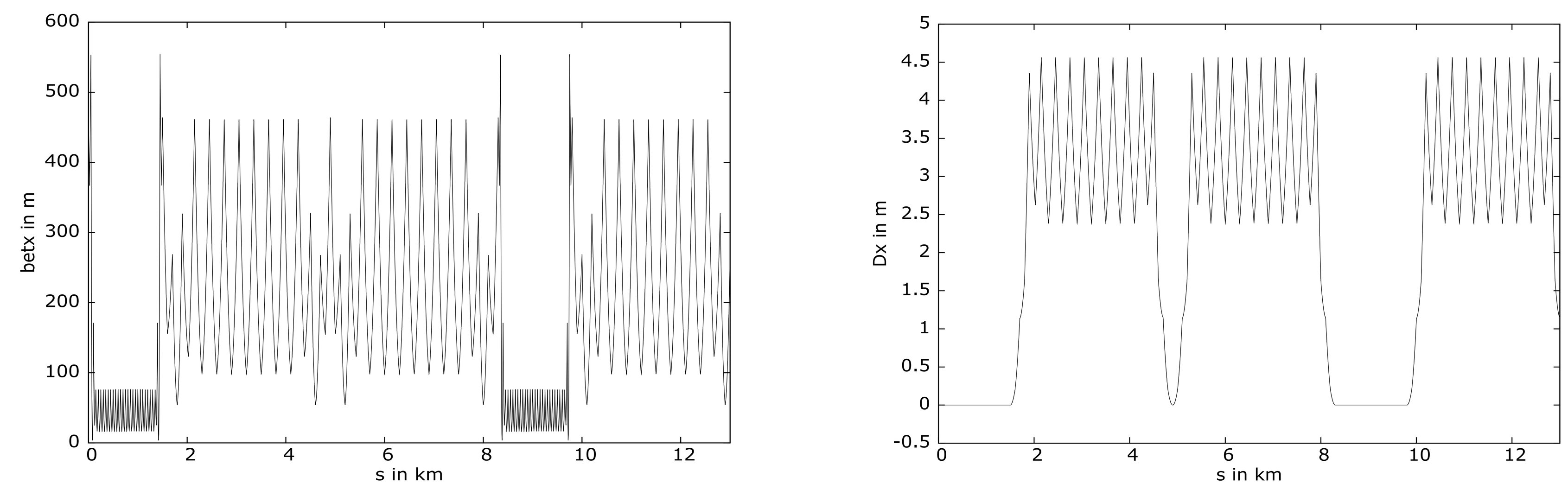


Figure 4 & 5: Beam optics for the 45 GeV low energy case. A longer cell design has been chosen to achieve higher values of β and D_x. In the straight sections the optics remains unchanged.

Interaction Region

Luminosity of L = 1.8 × 10^{34} $cm^{-2}s^{-1}$ set requirements for the interaction region:

- **β_y = 1 mm** at four interaction points
- Arc sextupoles must be combined with a **local chromaticity correction scheme** in straight sections next to the interaction region [3] to compensate **high chromaticities** and provide the **momentum acceptance of Δp/p=±2%**
- **Crossing angle** to avoid parasitic bunch crossings
- The large beta functions impose **serious tolerances for magnet alignment and coupling** compensation schemes

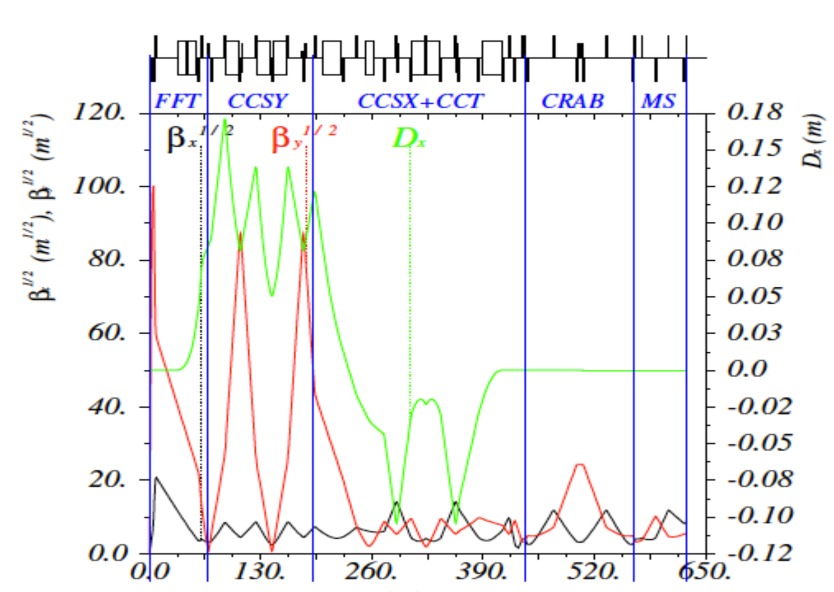


Figure 6: Proposed layout of the interaction region: the mini-beta insertion is combined with a local chromaticity compensation scheme.

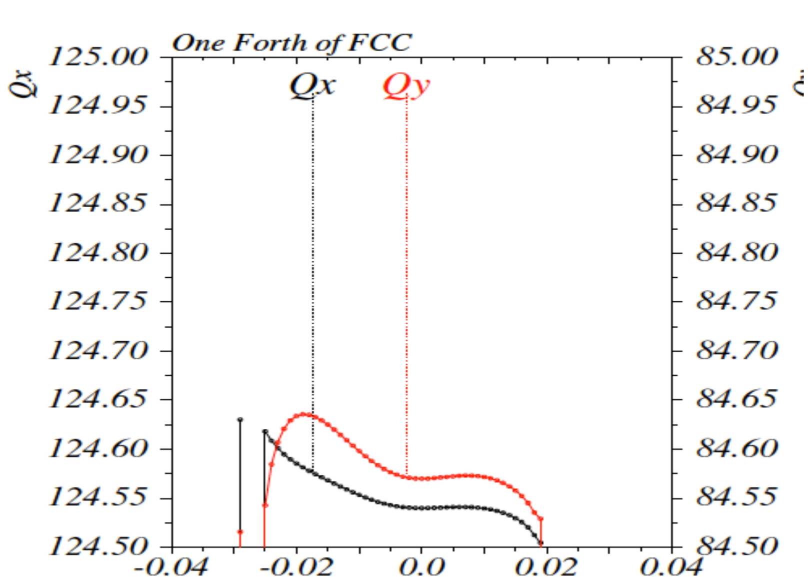


Figure 7: Tune variation as a function of the expected momentum spread on the beam. A value of Δp/p ≈ ±2% is considered as sufficient

Conclusions

- The present lattice design features **highly flexible lattice providing the foreseen emittances** and optics for operation at **all four energies**
- Machine detector interface and synchrotron radiation background are under investigation as well as the chromaticity correction scheme for low energies
- The required **±2% momentum acceptance are in reach** thanks to the sextupole arrangement close to the interaction region in the straight sections

[1] Challenges for Highest Energy Colldiers, F. Zimmermann et al, proceedings IPAC 2014
[2] Combined Operation and Staging Scenarios for the FCC Lepton Collider, M. Benedikt et al., these proceedings
[3] A. Bogomyagkov et al., Interaction Region of the Future Electron-Positron Collider FCC-ee, these proceedings

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