FCC-ee FINAL FOCUS WITH CHROMATICITY CORRECTION

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Abstract

A 100 km circular electron-positron collider is considered as one of the possible future high energy facilities. In order to achieve a high luminosity, strong beam focusing at the Interaction Point (IP) is used requiring the correction of the chromatic aberrations. In this paper we study preliminary designs of a Final Focus System (FFS) for the FCC-ee collider with chromatic correction. Beam orbit stability and dynamic aperture calculations are also presented.

INTRODUCTION

The FCC-ee collider complex [1] consists of an accelerator ring and a storage ring so that a constant level of luminosity is provided in collisions. The current FCC-ee design considers four different energy stages: the Z pole ($\sqrt{s} \sim m_Z$); the WW threshold ($\sqrt{s} \sim 2m_W$); the HZ cross-section maximum ($\sqrt{s} \sim 240$ GeV) and the top-pair threshold ($\sqrt{s} \sim m_{\text{top}}$). The initial designs consider a circumference length of 80 to 100 km.

The preliminary values of the parameters for FCC-ee in the top threshold configuration are shown in Table 1. The β-functions at the IP and the corresponding beam sizes present a ratio between horizontal and vertical planes of 1000. Vertical β-functions such that are very challenging in circular colliders and special attention to the chromaticity will be required.

Table 1: Preliminary Values of the Parameters of FCC-ee in Each of the Four Planned Configurations

Parameters	**FCC-ee t**
E_{cm} [GeV]	350
beam current [mA]	6.7
bunches/beam	160
$e^{\pm}$/bunch [10^{11}]	0.88
$\epsilon_{x,y}$ [nm]	3, 0.002
$\beta^*_{x,y}$ [mm]	1000, 1
$\sigma^*_{x,y}$ [μm]	45, 0.045
$\sigma^{\text{tot}}_{z,\text{rms}}$ [mm]	0.77
$E^{\text{SR}}_{\text{loss}}$/turn [GeV]	7.5
$\xi_{x,y}$/IP	0.057
$\mathcal{L}$(IP) [10^{34}cm^{-2}s^{-1}]	1.3
IP's	4

CHROMATICITY CORRECTION

Historically, in circular accelerators, the focalization of the beam size at the IP has been done using quadrupole doublets or triplets and the chromaticity introduced by these and the rest of quadrupoles of the ring is compensated including sextupoles within the arcs. That is the case of the LEP and the LHC. FCC-ee requires stronger focalization (mainly in the vertical plane) than in the previous machines and a dedicated chromatic correction section based on linear colliders Final Focus System may be required. The SuperKEKb collider [2] follows this concept and it is under consideration for the LHeC [3]. The design of the FFS initially considered is based on the dedicated chromatic correction section, with two separated correction sections for the vertical and horizontal plane. The vertical chromaticity is large enough to require a dedicated chromatic correction apart from the correction performed in the sextupoles of the arcs. Since the horizontal β-function is 1 m we initially considered the possibility of not using local chromaticity correction for the horizontal plane. In a later designs iterations the horizontal local compensation of chromaticity proved useful. According to the expression, $\xi_{x,y} \sim \frac{L^*}{\beta^*_{x,y}}$, where L^* is the length of the last drift between the last quadrupole and the IP and $\beta^*_{x,y}$ is the β-function at the IP, under the same L^* the horizontal chromaticity is 1000 times smaller than the vertical. In order to reduce chromaticity, a small value of L^* is desirable but the minimum angle required for experiments will determine the geometry of the detector and therefore, the minimum value of L^*. After some considerations a reasonable value is found to be $L^* = 2.0$ m. In Fig. 1 the optics of the FFS is shown for the case of just vertical correction and in Fig. 2 for an improved optics with two chromatic correction sections.

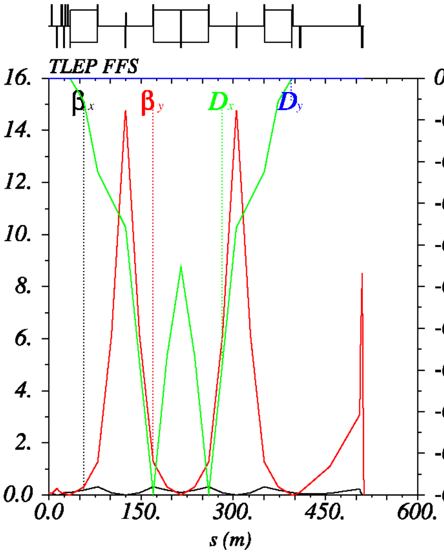

Figure 1: FCC-ee FFS optics layout per side with only vertical chromaticity correction section. The IP is located in the very right side of the figure. Vertical left axis is in km for β-functions and vertical right axis is in m for dispersion.

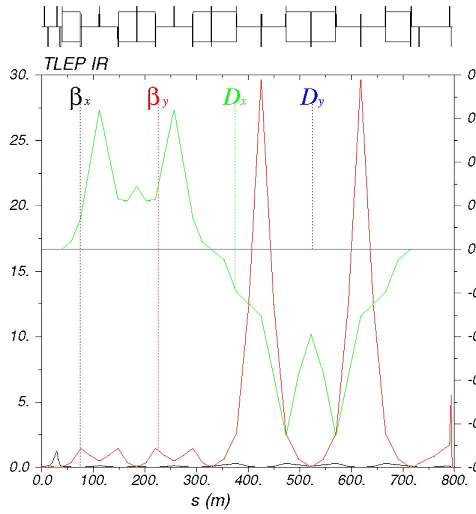

Figure 2: FCC-ee FFS optics layout per side with horizontal and vertical chromaticity correction. Vertical left axis is in km for β-functions and vertical right axis is in m for dispersion.

The two pairs of sextupoles that perform the chromatic correction are placed in the regions with high β-functions and high dispersion and the IP is located just downstream the Final Doublet (FD) on the right of the figure. The bending section used to generate the required dispersion is composed of bending dipoles with the same strength of the dipoles of the arcs. In such way, we ensure that the impact of the synchrotron radiation emitted in the correction section does not represent a very important fraction of the total radiation emitted all along the ring.

Chromaticity correction is performed using MADX [4] and MAPCLASS [5–7], that allows to calculate the RMS beam size at the IP at different orders. The four sextupole strengths are matched independently in order to achieve the nominal beam size. The optimization is done sequentially order by order until contributions from the next order are negligible. In Fig. 3 the result of the optimization is shown for the lattice with just vertical chromatic correction. We observe that beyond order 4 the beam size does not increase anymore. The final vertical beam size is below 1% bigger than the linear beam size and the horizontal beam size is overcompensated and it is a around a 1% smaller than the nominal beam size.

MOMENTUM ACCEPTANCE

One of the main limitations provoked by the strong focalization of the magnets close to the IP and the sextupoles introduced to correct chromaticity is the reduction of the dynamic aperture and the energy acceptance.

The energy acceptance can be estimated calculating the tune of particles with a certain deviation from the nominal value and looking at the beam stability and the number of resonance lines crossed and its order. The goal is that the ring must accept particles with an energy deviation of ±2%.

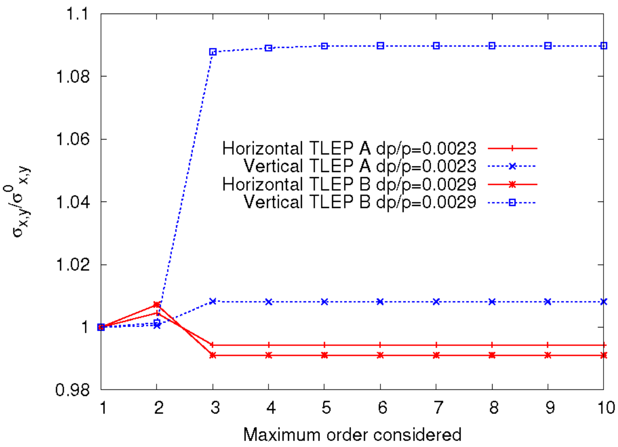

Figure 3: High order optimization using MAPCLASS for FCC-ee FFS for two different values of energy spread.

In Fig. 4 the variation of the horizontal and vertical tunes as a function of the momentum deviation is shown. One can observe that in the horizontal plane there is some remaining energy dependence but the variation of the tune is small enough in the range of almost ±2% to not cross any low order resonance line except for a small region between 0.8% and 1.5% where acceptance must be improved. A further optimization is required in order to get stable particles in the full range of ±2% of the nominal energy.

DYNAMIC APERTURE

As a particle travels around a storage ring, the amplitude with respect to the closed orbit may increase due to dynamical effects. The dynamic aperture is defined in terms of the variation in amplitude over time. A particle is said to be outside the dynamic aperture if its amplitude exceeds some large value after a certain number of turns. As it has been observed, the nonlinearities introduced by the strong focalization in the IP, might introduce resonances that can limit the dynamic aperture of the ring.

We estimate the dynamic aperture by tracking particles in MADX and PTC [8] with different initial positions in the phase space and see its evolution after 1000 turns. In Fig. 5 the result of the tracking after 1000 turns is shown for on and off momentum particles with ±1.5% of the nominal energy. We observe that for on momentum particles the dynamic aperture is about 10σ in the horizontal plane while in the vertical plane it is more than 20σ. When we introduce energy deviations of 1.5% from the nominal value, the dynamic aperture is notably reduced to about $4-5\sigma$ for positive energy deviations and to $2-15\sigma$ for negative energy deviations. Further optimization is required in order to increase the dynamic aperture of the system and to explore the entire phase space.

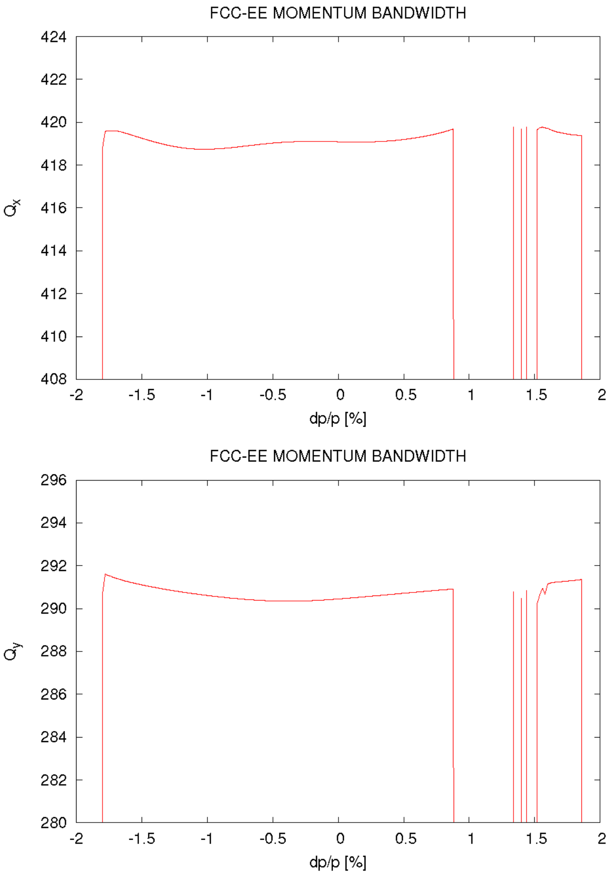

Figure 4: Variation of the horizontal tune (Top) and vertical tune (Bottom) as a function of the beam relative energy deviation for the lattice with horizontal and vertical chromaticity correction sections.

CONCLUSIONS AND FUTURE PROSPECTS

A preliminary design of the chromatic correction system for the future FCC-ee machine has been done and the main challenges are presented. It has been demonstrated that a dedicated section to locally correct chromaticity is needed in both planes. The main issues concerning such high chromaticity has been identified, being the momentum acceptance the most difficult to solve. Future detailed optimizations of this system are required in order to ensure a good machine performance.

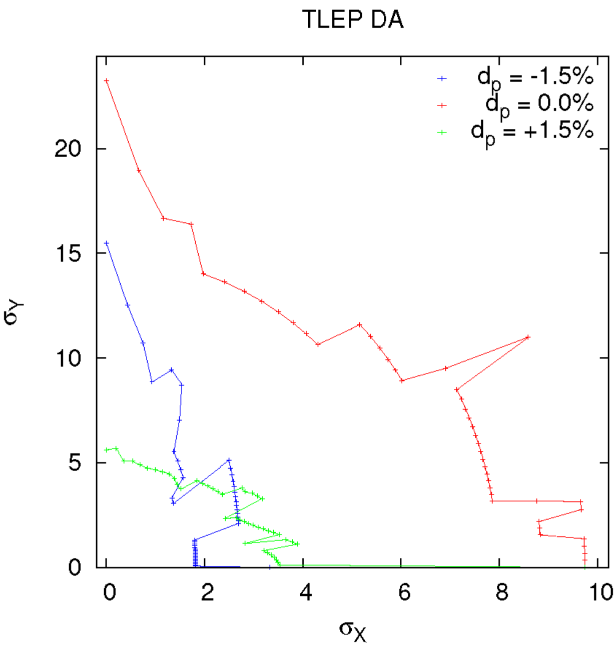

Figure 5: 1000 turns dynamic aperture in number of horizontal and vertical sigmas for a preliminary FCC-ee lattice including horizontal and vertical local chromaticity correction for 3 relative momentum settings.

REFERENCES

[1] Bloer at al., "First Look to the TLEP Physics case", arXiv:1308.6176 (2013).

[2] K. Kanazawa et al., Nucl. Instr. and Meth. A, 499, (2003).

[3] J. Abelleira, "Optics Designs of Final-Focus Systems for Future LHC Upgrades", CERN-THESIS-2013-278, (2014)

[4] MADX, Methodological Accelerator Design, http://mad.web.cern.ch/mad/.

[5] R. Tomás, “Nonlinear optimization of beam lines”, Phys.Rev. ST Accel. Beams **9**, 081001 (2006).

[6] R. Tomás, “MAPCLASS: a code to optimize high order aberrations”, CERN-AB-Note-2006-01.

[7] D. Martinez, A. Rosam, R. Tomás, R. De Maria, “MAPCLASS2: a code to aid the optimisation of lattice design”, CERN-ATS-Note-2012-087 TECH.

[8] P.K. Skowronski, F. Schmidt, R. de Maria and E. Forest, “New Developments of MAD-X Using PTC”, ICAP06, Chamonix, France.