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A PRELIMINARY DESIGN OF THE CEPC INTERACTION REGION*

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Abstract

CEPC (Circular Electron and Positron Collider) is a circular Higgs Factory with optimized energy 240 GeV. In order to achieve luminosity as high as $2\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, CEPC calls for a small vertical beta function at IP ($\beta_y^* = 1.2$ mm) which was provided by the final focus of the interaction region. In this paper, a preliminary design of the CEPC interaction region was presented. The optimization of dynamic aperture with interaction region insertion and the machine detector interface was discussed as well.

INTRODUCTION

CEPC (Circular Electron and Positron Collider) is a circular Higgs Factory with optimized energy 240 GeV [1]. In order to achieve luminosity as high as $2\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, CEPC calls for a small vertical beta function at the interaction point (IP) ($\beta_y^* = 1.2$ mm) which was provided by the final focus of the interaction region. In this paper, a preliminary design of the CEPC interaction region (IR) was presented. The optimization of dynamic aperture with IR insertion and the machine detector interface was discussed as well. Table 1 shows the key parameters of the interaction region.

Table 1: Key Parameters of the Interaction Region [1]

Parameters	Unit	Value
Distance from QD0 to IP [L^*]	m	1.5
Number of IP [N_{IP}]	-	2
Beam energy [E]	GeV	120
Emittance [$\varepsilon_x/\varepsilon_y$]	m • rad	6.12E-09 / 1.84E-11
Beta function at IP [β_x^*/β_y^*]	mm	800 / 1.2
Bunch length total [$\sigma_{z,tot}$]	mm	2.88
Energy spread total [$\sigma_{\delta,tot}$]	%	0.177
Luminosity / IP [L]	$\mathrm{cm}^2\mathrm{s}^{-1}$	2.04E+34

The IR of CEPC has been designed with the following requirements:

- Provide small beam sizes at the IP.
- The large chromaticity generated by final doublet (FD) must be compensated locally in order to achieve a large momentum acceptance of 2% for the whole ring.
- The solenoid field from the detector compensated to minimize its perturbation on the beam motion .
- The sizes of the accelerator equipment inserted into the detector should be constrained to provide the largest possible angular acceptance for the detector.
- The beam-induced background should be acceptable for the detector.

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INTERACTION REGION

Optics Design

In order to achieve very high luminosity, CEPC calls for a small vertical beta function at IP ($\beta_y^* = 1.2$ mm). The small β_y^* require the final quadrupole as close to the IP as possible in order to minimize the chromaticity and keep the beta function lowest possible at the final quadrupole, as shown in Eq. 1. ξ_y is the vertical chromaticity generated in the final quadrupole QD0, β_y is the vertical beta function at QD0 and L^* is the distance from the IP to QD0. To facilitate the design of final focus, we choose $L^* = 1.5$ m.

$$\xi_y \simeq \frac{L^*}{\beta_y^*},\ \beta_y \simeq \frac{L^{*2}}{\beta_y^*} \quad (1)$$

The chromaticity correction scheme of final focus (FF) had been well developed for the linear collider programs from 1980s, such as SLC, NLC, FFTB [2-4], and adopted by the circular collider programs such as SuperB [5] and SuperKEKB [6]. CEPC also adopt a FF optics similar to the linear colliders'. Unlike the single pass feature in a linear collider, the final focus design of a circular collider has to fix many specific issues.

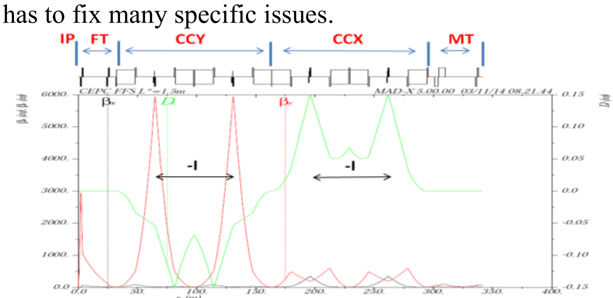

Figure 1: Lattice functions of the final focus.

The final focus system is a telescopic transfer line, starting from IP, which includes: a final telescopic transformer (FT), chromaticity correction section on the vertical plane (CCY), chromaticity correction section on the horizontal plane (CCX) and matching telescopic transformer (MT), see Fig. 1.

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The FT consists of two quadrupole doublets. The phase advance is π on the vertical plane and a bit less than π on the horizontal plane as the not very small β_x^*. At the end of FT, we have the first image point.

The CCY is actually consist of four FODO cells whose phase advances are $\pi/2$ for both planes and begin with a half defocusing quadrupole. Four identical dipoles are used to make dispersion bumps. A pair of sextupoles is placed at the two peaks of β_y to compensate the vertical chromaticity generated by the final defocusing quadrupole. The geometric sextupole aberrations are cancelled by the $-\mathbf{I}$ transformation between the paired sextupoles. At the end of CCY, we have the second image point which is identical to the first one. The CCX is similar to the CCY while begin with a half focusing quadrupole.

The MT also consists of two quadrupole doublets. With MT, The twiss functions are matched to the ARC section of the ring and make the total phase advances of FF to be 6π.

We use the longitudinal cyclical symmetry of CCY and CCX to adjust the phase advances between the final doublet and the sextupoles to minimize the second order chromaticity [7]. The residual W functions [8] at the exit of FF are W_x=6.6, W_y=5.6 and second order dispersion is D_x'=-0.15 m.

Dynamic Aperture

The four FF were inserted into the ring by matching the twiss functions between the FF and ARC. The twiss functions of the whole ring were shown in Fig. 2, where the peak of the β_y occur at the two IPs. The two families of sextupoles in the ARC were re-matched to obtain as larger bandwidth as possible. The results are shown in the left figure of Fig. 3.

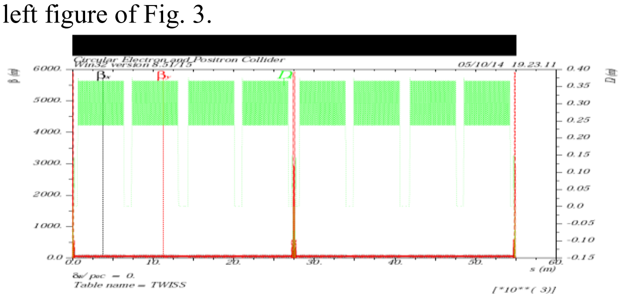

Figure 2: Lattice functions of the ring.

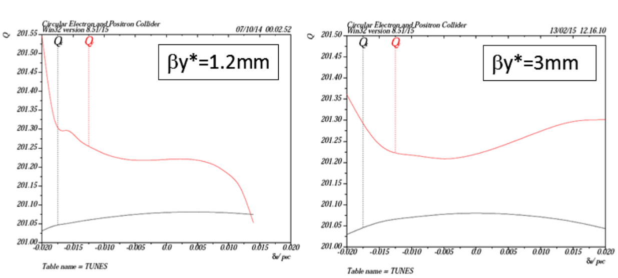

Figure 3: Tune vs. energy deviation.

The dynamic aperture for the whole ring was estimated numerically with the six-dimensional tracking code SAD [9]. The particles were tracked with 240 turns which corresponding to three transverse damping times, including synchrotron motion but without radiation damping nor any errors of the magnets. The dynamic aperture is defined by as the boundary between the surviving and lost particles. For the on-momentum particle, the dynamic aperture is 17 σ_x (6.12 nm·rad) and 70 σ_y (0.018 nm·rad) in the horizontal and vertical planes respectively. For the off-momentum particles, the dynamic aperture decreased significantly. The results are shown in the left figure of in Fig. 4.

As shown in the beam-beam simulation [10], the luminosity will not decrease much when β_y^* increased from 1.2mm to 3mm. We also got a preliminary IR optics design for $\beta_y^* = 3$ mm by simply re-matching the final telescopic transformer and the sextupoles. The results are shown in the right figures of Fig. 3 and 4. As expected, the dynamic aperture was significantly increased though it's still small. Further optimization is undergoing.

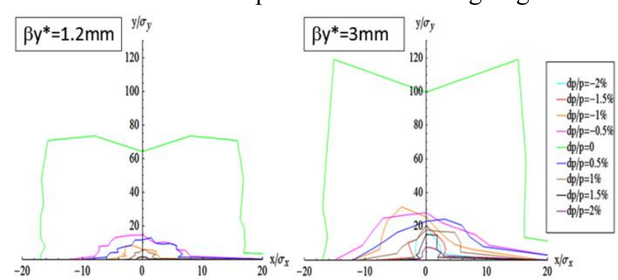

Figure 4: Dynamic aperture of the ring.

MACHINE-DETECTOR INTERFACE

Layout of the Interaction Region

The interaction region of the CEPC consist of beam pipe, surrounding silicon tracker, luminosity calorimeter and the final quadrupoles QD0 and QF1. Figure 5 shows the preliminary layout of interaction region.

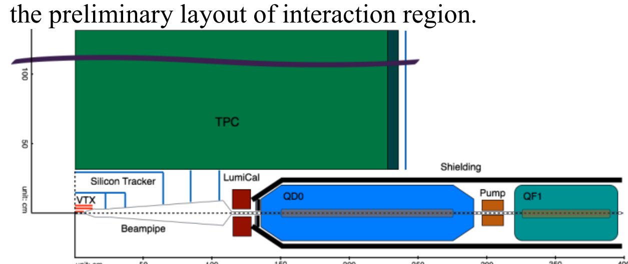

Figure 5: Interaction-region layout [11].

Final Doublet

The beam-stay-clear region has been determined by considering the requirements for injection [12]. It's defined as the distance between the centre of beam pipe and the outer edge of the injected beam. Vertical injection was chosen to avoid the affection on the pretzel orbit. The acceptance required for beam injection is assumed as $2\mathrm{J_x} = 3.5 \times 10^{-7}\mathrm{m \cdot rad}$ for the horizontal plane and $2\mathrm{J_y} = 7.7 \times 10^{-8}\mathrm{m \cdot rad}$ for the vertical plane. With the acceptance and the Twiss functions, the beam-stay-clear region is $\sqrt{2\mathrm{J_x}\beta_\mathrm{x} + (\mathrm{D_x}\sigma_\mathrm{E})^2}$ for the horizontal plane and

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$\sqrt{2J_y\beta_y}$ for the vertical plane. The beam-stay-clear region at the final doublet is shown in Fig. 6.

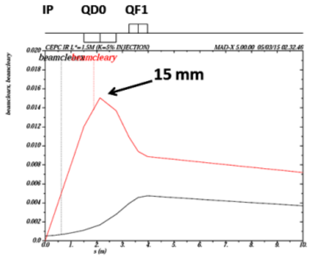

Figure 6: Beam-stay-clear region at the final doublet.

The inner radius of the vacuum chamber should be larger than beam-stay-clear region. We chose 17 mm (2 mm for safety) both for the QD0 and the QF1. This result in 76 σ_x and 74 σ_y at QD0 and 28 σ_x and 118 σ_y at QF1, where σ denotes the size of the circulating beam. The inner radius of the coil is 21 mm for the final doublet. This includes the 2 mm thickness of the vacuum chamber wall and 2mm installation gap between vacuum chamber and coil. The outer radius of the cryostat for the final doublet is estimated to be 200 mm which provide large enough angular acceptance for the TPC design. The parameters of the FD are listed in Tab. 2.

Solenoid Field Compensation

Coupling between horizontal and vertical betatron motion will enlarge the vertical beam size at the IP. Thus the coupling control is one of the key issues in high luminosity colliders. With the small vertical emittance, the coupling correction is very important in the CEPC design. Work on the compensation scheme of the solenoid field is undergoing.

Synchrotron Radiation Load and Shielding

The parameter of the synchrotron radiation in the last bend of final focus were estimated analytically with constant beam energy, see Tab. 3. The critical energy of the radiated photons is around 1 MeV and the average radiation power is 50 kW. These numbers are quite high and may make the shielding difficult.

CONCLUSION

We got a preliminary design for the CEPC interaction region with L^*=1.5m and β_y^*=1.2mm. A preliminary final focus design, the dynamic aperture of whole ring with the final focus insertion and the machine detector interface was discussed. We found that it's quite difficult to reach a 2% momentum acceptance which is one of the key issues of a circular Higgs Factory.

As shown in the beam-beam simulation, the luminosity will not decrease much when β_y^* increased from 1.2mm to 3mm. We also got a preliminary IR optics design for β_y^* =3mm by simply re-matching the final telescopic transformer and the sextupoles. As expected, the dynamic aperture significantly increased though it's still small. Further optimization is undergoing.

This is a preliminary design and further optimization will be carried out in future.

Table 2: Parameters of Final Doublet

Parameters	**Unit**	**Value (QD0 / QF1)**
Distance to the IP [z]	m	1.5 / 3.25
Effective length [L_{eff}]	m	1.25 / 0.72
Field gradient [G]	T/m	-300 / 300
Type	-	Super conducting
Inner radius of vac. ch.	mm	17
Inner radius of coil	mm	21
outer radius of cryostat	mm	200

Table 3: Parameters of the Last Bend in the Final Focus

Parameters	**Unit**	**Value**
Distance to the IP [z]	m	32.5
Effective length [L_{eff}]	m	15.5
Bending radius [ρ]	m	3762
Critical energy of the radiated photons	keV	958
Average radiation power	kW	50

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