100 km CEPC PARAMETERS AND LATTICE DESIGN *

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Abstract

The 100km double ring configuration with shared superconducting RF system has been defined as baseline by the circular electron positron collider (CEPC) steering committee. Based on this new scheme, we will get higher luminosity for Higgs (+170%) keeping the beam power in preliminary conceptual design report (Pre-CDR) or to reduce the beam power (19 MW) while keeping same luminosity. CEPC will be compatible with W and Z experiment. The luminosity for Z is designed at the level of 10^{35} cm^{-2}s^{-1}. The requirement for the energy acceptance of Higgs has been reduced to 1.5% by enlarging the ring to 100 km. The optics of arc and final focus system (FFS) with crab sextupoles has been designed, and also some primary dynamic aperture (DA) results were introduced.

INTRODUCTION

According to the physics goal of CEPC at the energy of Higgs and Z-pole, it is required that the CEPC provides e^+e^- collisions at the center-of-mass energy of 240 GeV and delivers a peak luminosity of 2×10^{34} cm^{-2}s^{-1} at each interaction point. At Z-pole the luminosity is required to be larger than 1×10^{34} cm^{-2}s^{-1} per IP. The schematic layout of CEPC is shown in Fig. 1.

In the beginning of 2015, Pre-CDR of CEPC-SppC [1] has been completed with 54km circumference and single ring scheme. After that the size and the collision scheme of CEPC-SPPC was reconsidered. The 100 km double ring configuration with shared SCRF which is similar as FCC-ee [2-5] has been defined as baseline by CEPC steering committee on Jan. 14th of 2016. Meanwhile the advanced partial double ring scheme with 8 partial double ring regions was defined as CEPC alternative scheme with the aim of reducing the construction cost which may need long efforts to study the possible solution to the sawtooth and beamloading effects. The conceptual design report (CDR) with 2mm vertical β* and 32 MW beam power will be finished by the end of 2017.

CEPC was proposed as a compatible machine which will allow stringent tests of the Standard Model (SM) with precision measurements at the Z pole and WW thresholds. At the energy of Higgs, all bunches will distribute in the half ring due to the shared RF system. While for W and Z, bunches will distribute in the whole ring thanks to the independent RF system so that more bunches are possible. The scheme of CEPC bunch distribution is shown in Fig. 2.

CEPC PARAMETER CHOICE FOR 100KM DOUBLE RING

To make an optimization for a collider, started from the goals, such as energy, luminosity/IP, number of IPs, etc, one has to consider very key beam physics limitations, such as beam-beam effects and beamstrahlung effect, and also take into account of economical and technical limitations, such as synchrotron radiation power and high order mode power in each superconducting RF cavity. By taking into account all these limitations in an analytical way, an analytical electron positron circular collider optimized design method has been developed both for head-on collision [6] and crab-waist collision [7].
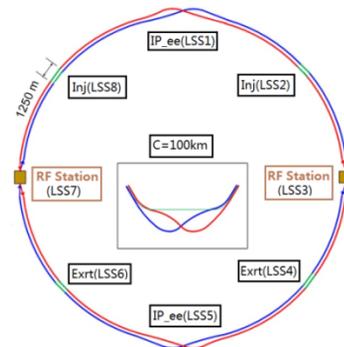
Figure 1: Layout of CEPC double ring scheme.
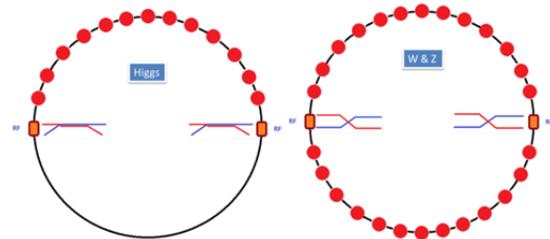
Figure 2: CEPC bunch distribution scheme (left: Higgs, right: W&Z).

Constraints for Parameter Choice

- Limit of beam-beam tune shift

$$\xi_y = \frac{2845}{2\pi}\sqrt{\frac{U_0}{2\gamma E_0 N_{IP}}}\times F_l \qquad (1)$$

The real beam-beam tune shift should not larger than the above limit. The first part of this formula is the beam-beam limit without crossing angle [8]. We introduced a factor F_l here which is the luminosity enhancement factor by crab waist scheme and so far we assume it is 1.5 for Higgs, 1.7 for W and 2.6 for Z.

- Beam lifetime due to beamstrahlung

$$\frac{N_e}{\sigma_x\sigma_z} \leq 0.1\eta\frac{\alpha}{3\gamma r_e^2} \qquad (2)$$

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We hope to make sure the beam life time is not shorter than half hour and we have used Telnov's formula [9].

• Extra energy spread due to beamstrahlung

$$A = \delta_0 / \delta_{BS} \quad (A \geq 5) \qquad (3)$$

The energy spread due to beamstrahlung should be much smaller than the natural energy spread in order to control the beam quality after collisions.

• Higher order mode (HOM) power per cavity

$$P_{HOM} = k(\sigma_z) e N_e \cdot 2 I_b \leq 2 \quad kw \quad [10] \qquad (4)$$

where the HOM loss factor is

$$k(\sigma_z) = \frac{1.8}{\sqrt{\sigma_z / 0.00265}} \quad V / pC \cdot$$

CEPC Parameter Potential with 1 mm β_y^*

Using the method in reference 7, we got the parameter design for CEPC double ring scheme with 1mm vertical β^*. At the energy of Higgs, with 50 MW synchrotron radiation (SR) power, the luminosity will be 5.4×10^{34} cm^{-2}s^{-1} which is 2.7 times of Pre-CDR luminosity. If we reduce SR power to 19 MW, still we can reach our luminosity goal 2×10^{34} cm^{-2}s^{-1}. Luminosity potential of 100 km CEPC with 50 MW SR power is shown in Fig. 3.
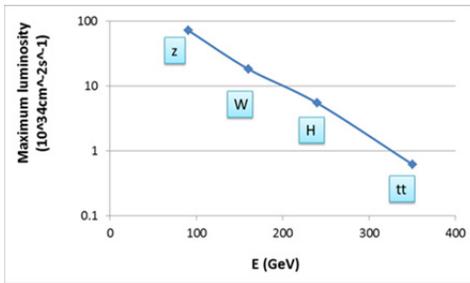
Figure 3: Luminosity potential of 100 km CEPC with 1mm vertical β^* and 50 MW SR power/beam.

CEPC Intermediate Parameters toward CDR

Since the FFS design and DA study is the bottleneck for CEPC physics design, as the first step, we decided to choose 2 mm vertical β^* and lower SR power (32 MW) for CDR report which will be published by the end of 2017. Using the method in reference 7, we got the parameter table for 2 mm vertical β^* as table 1. For Higgs, we will need 32 MW SR power to reach the luminosity goal 2×10^{34} cm^{-2}s^{-1}. For W, with 32 MW SR power, the luminosity will be 5×10^{34} cm^{-2}s^{-1}. At Z pole, we plan to use 21300 bunches and the luminosity will be 1.2×10^{35}cm^{-2}s^{-1}.

MAIN RING LATTICE DESIGN

We chose 90°/90° FODO cell and non-interleave sextupole scheme for the arc. The emittance of the ring is 1.3 nm. The twiss parameters of arc are shown in Fig. 4.

Figure 5 shows the design for FFS. We need a triplet following the final doublet to produce 90° phase difference between horizontal plane and vertical plane. Here IP beta function is 0.171 m/0.002 m as CDR parameter in table 1. Both main sextupoles can work as the crab sextu-

poles (in Fig. 5). According to the issue of detector background, we have controlled the critical energy of dipoles under 100 kev within 560 m distance from IP and under 200 keV within 800 m within this FFS design.

Here we need a pair of weak sextupoles with about -10% of the main sextupoles' strength to correct the nonlinearity of main sextupole length effect [11]. This approach is essential otherwise the on-momentum DA will be very small.
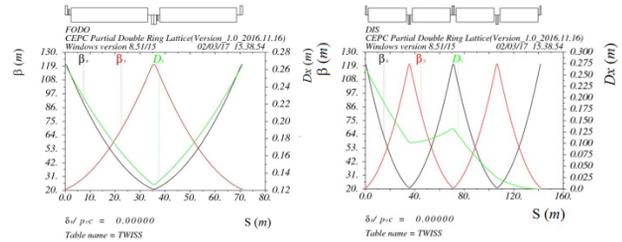
Figure 4: Twiss parameter of arc with 90°/90° phase advance per cell (left: FODO, right: dispersion suppressor).
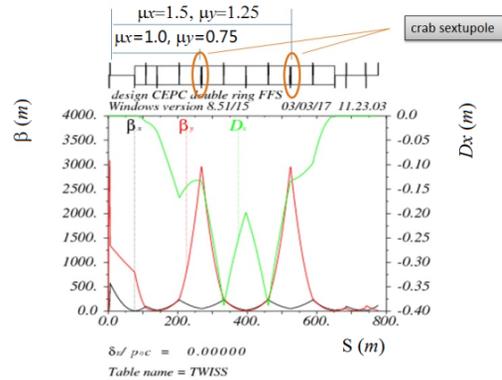
Figure 5: FFS optics with crab sextupoles.

DYNAMIC APERTURE

We made a whole ring by connecting the arc and FFS. The detail of RF sections and crossing collision was not included by this ideal lattice however the main nonlinearities for CEPC were there. The DA of the ideal ring with only two families sextupoles in the arc and without damping effect was shown in Fig. 6. The on-momentum DA is good enough while the energy acceptance is not satisfying (0.5%). The further optimization of DA bandwidth with multi-sextupoles is undergoing.
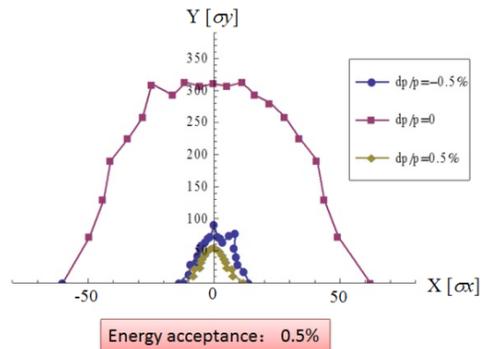
Figure 6: DA before optimization (radiation damping is close.).

CONCLUSION

We have developed a consistent method for CEPC parameter choice with crab waist scheme by using analytical expression of maximum beam-beam tune shift and beamstrahlung beam lifetime started from given IP vertical beta, beam power and other technical limitations. Based on 100 km double ring scheme, we hope to get higher luminosity for Higgs keeping the Pre-CDR beam power (52 MW) or to reduce the beam power by 40% keeping the Pre-CDR luminosity. The luminosity can be cross-checked by beam-beam simulations.

We chose 2 mm vertical β* and 32 MW SR power for CDR. The optics of arc and IR with crab waist has been designed. The dynamic aperture of the whole ring is good enough for on momentum particle while the off momentum DA is still need to been optimized.

Table 1: Parameters for 100 km CEPC Double Ring with 2 mm Vertical β*

	Pre-CDR	**Higgs**	**W**	**Z**
Number of IPs	2	2	2	2
Energy (Gev)	120	120	80	45.5
Circumference (km)	54	100	100	100
SR loss/turn (Gev)	3.1	1.67	0.33	0.034
Half crossing angle (mrad)	0	16.5	16.5	16.5
Piwinski angle Φ	0	3.19	5.69	4.29
Ne/bunch (10^{11})	3.79	0.968	0.365	0.455
Bunch number	50	412	5534	21300
Beam current (mA)	16.6	19.2	97.1	465.8
SR power /beam (MW)	51.7	32	32	16.1
Bending radius (km)	6.1	11	11	11
Momentum compaction (10^{-5})	3.4	1.14	1.14	4.49
β_{IP} x/y (m)	0.8/0.0012	0.171/0.002	0.171 /0.002	0.16/0.002
Emittance x/y (nm)	6.12/0.018	1.31/0.004	0.57/0.0017	1.48/0.0078
Transverse σ_{IP} (um)	69.97/0.15	15.0/0.089	9.9/0.059	15.4/0.125
ξx/ξy/IP	0.118/0.083	0.013/0.083	0.0055/0.062	0.008/0.054
V_{RF} (GV)	6.87	2.1	0.41	0.14
f_{RF} (MHz)	650	650	650	650 (217800)
Nature σ_{z} /Total σ_{z} (mm)	2.14/2.65	2.72/2.9	3.37/3.4	3.97/4.0
HOM power/cavity (kw)	3.6 (5cell)	0.41(2cell)	0.36(2cell)	1.99(2cell)
Energy spread (%)	0.13	0.098	0.065	0.037
Energy acceptance requirement (%)	2	1.5		
Energy acceptance by RF (%)	6	2.1	1.1	1.1
n_γ	0.23	0.26	0.15	0.12
Life time due to beamstrahlung_cal (minute)	47	52		
L_{max}/IP (10^{34}cm^{-2}s^{-1})	2.04	2.0	5.15	11.9

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