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CEPC partial double ring scheme and crab-waist parameters

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In order to avoid the pretzel orbit, CEPC is proposed to use partial double ring scheme in CDR. Based on crab waist scheme, we hope to either increase the luminosity with same beam power as Pre-CDR, or reduce the beam power while keeping the same luminosity in Pre-CDR. FFS with crab sextupoles has been developed and the arc lattice was redesigned to acheive the lower emittance for crab waist scheme.

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1. Introduction

CEPC is a ring with a circumference of 54 km to house an electron - positron collider in phase-I and be upgraded to a super proton-proton Collider (SPPC) in phase-II. The designed beam energy for CEPC is 120 GeV, aims for Higgs study. Meanwhile CEPC should be compatible with Z study. The main constraint in the design is the beam lifetime due to beamstruhlung and the synchrotron radiation power, which should be limited to 50 MW per beam, in order to control the total AC power of the whole machine. The target luminosity is ~$2*10^{34}$ $cm^{-2}s^{-1}$ for Higgs and ~$1*10^{34}$ $cm^{-2}s^{-1}$ for Z.

After Pre-CDR, we developed a new idea called partial double ring scheme showed in Fig.1. Therefore, a pretzel orbit is not needed. With partial double ring scheme, we can consider crab waist on CEPC. The most important advantage of crab waist is that the beam-beam limit can be increased greatly.

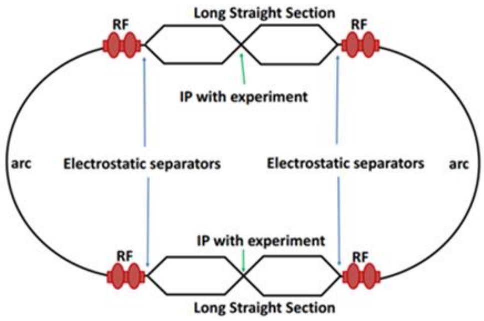

Fig. 1. CEPC partial double ring scheme.

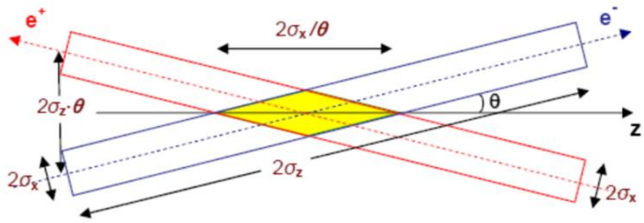

Fig. 2. Sketch of collision with crab waist.

2. CEPC Parameter Choice for Partial Double Ring

A general method of how to make an consistant machine parameter design of CEPC with crab waist 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 has been developed. Using this method, we get a set of new designs of CEPC overall parameters for 54km, 88km and 100km circumference. 54km CEPC parameter design was shown in table 1.

Table 1. CEPC crab waist parameters

	Pre-CDR	H-high lumi.	H-low power	W	Z
Number of IPs	2	2	2	2	2
Energy (GeV)	120	120	120	80	45.5
Circumference (km)	54	54	54	54	54
SR loss/turn (GeV)	3.1	2.96	2.96	0.59	0.062
Half crossing angle (mrad)	0	15	15	15	15
Piwinski angle	0	2.5	2.6	5	7.6
Ne/bunch (10^{11})	3.79	2.85	2.67	0.74	0.46
Bunch number	50	67	44	400	1100
Beam current (mA)	16.6	16.9	10.5	26.2	45.4

SR power /beam (MW)	51.7	50	31.2	15.6	2.8
Bending radius (km)	6.1	6.2	6.2	6.1	6.1
Momentum compaction (10^{-5})	3.4	2.5	2.2	2.4	3.5
$\beta_{IP\ x/y}$ (m)	0.8/0.0012	0.25/0.00136	0.268 /0.00124	0.1/0.001	0.1/0.001
Emittance x/y (nm)	6.12/0.018	2.45/0.0074	2.06 /0.0062	1.02/0.003	0.62/0.0028
Transverse σ_{IP} (um)	69.97/0.15	24.8/0.1	23.5/0.088	10.1/0.056	7.9/0.053
ξ_x/IP	0.118	0.03	0.032	0.008	0.006
ξ_y/IP	0.083	0.11	0.11	0.074	0.073
V_{RF} (GV)	6.87	3.62	3.53	0.81	0.12
f_{RF} (MHz)	650	650	650	650	650
Nature σ_z (mm)	2.14	3.1	3.0	3.25	3.9
Total σ_z (mm)	2.65	4.1	4.0	3.35	4.0
HOM power/cavity (kw)	3.6	2.2	1.3	0.99	0.99
Energy spread (%)	0.13	0.13	0.13	0.09	0.05
Energy acceptance (%)	2	2	2		
Energy acceptance by RF (%)	6	2.2	2.1	1.7	1.1
n_γ	0.23	0.47	0.47	0.3	0.24
Life time due to beamstrahlung_cal (minute)	47	36	32		
F (hour glass)	0.68	0.82	0.81	0.92	0.95
L_{max}/IP (10^{34}cm^{-2}s^{-1})	2.04	2.96	2.01	3.09	3.09

3. FFS design and Crab sextupole parameter

The lattice design of FFS (betax=0.25m, betay=0.00136m) for CEPC partial double ring is shown in Fig. 3. The L^* is 1.5m and the strength of first quadrupole (twin aperture) is 200T/m. The critical energy of the whole system is under 190keV.

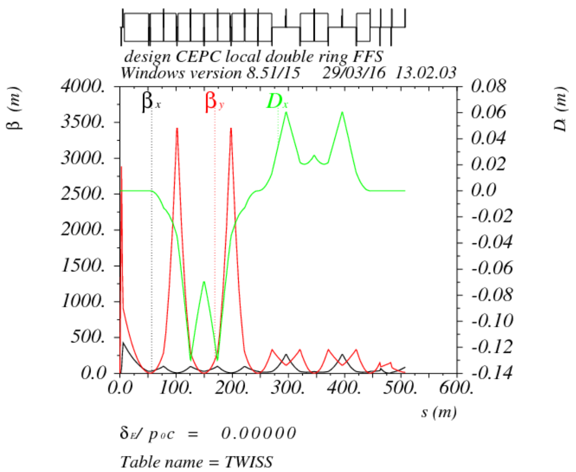

Fig. 3. FFS optics for CEPC partial double ring.

The crab sextupole should be placed on both sides of the IP in phase with the IP in the horizontal plane and at $\pi/2$ in the vertical one. As Oide said, the second FFS sextupoles of the CCS-Y section can work as the crab sextupoles, if their strengths and phases to the IP are properly chosen.

The crab sextupole strength should satisfy the following condition depending on the crossing angle and the beta functions at the IP and the sextupole locations:

$$KL = \frac{1}{2\theta}\frac{1}{\beta_y^*\beta_y}\sqrt{\frac{\beta_x^*}{\beta_x}} = 1.27m^{-2}$$

$$K_2 = 4.2m^{-3}$$

4. Low emittance arc

We tried to get smaller emittance as the parameter table 1. By reducing the FODO length from 47m to 37m and increase the phase of FODO cell, we got 2.3 nm emittance.

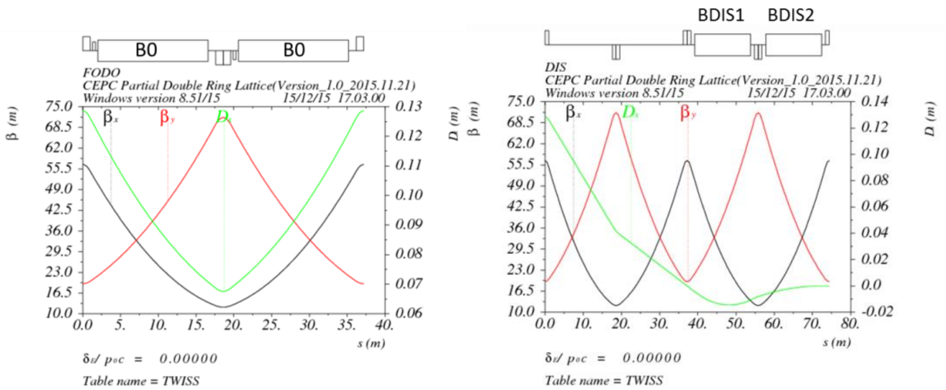

Fig. 4. Low emittance arc with 90°/60° phase advance (left: FODO, right: dispersion supressor)

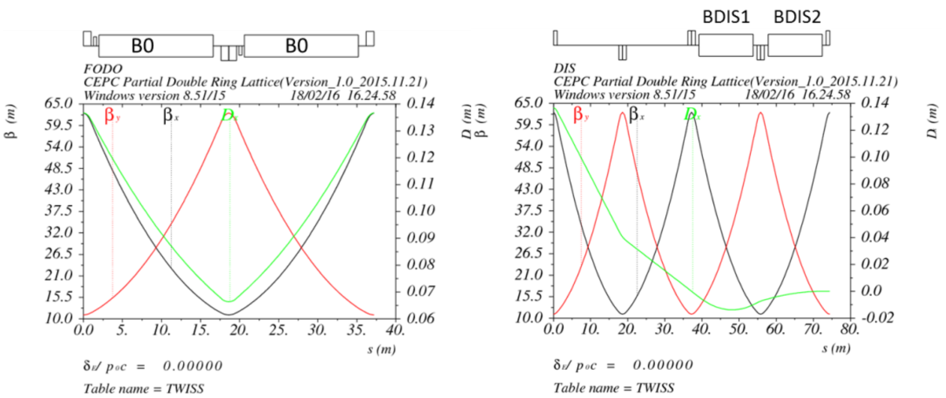

Fig. 5. Low emittance arc with 90°/90° phase advance (left: FODO, right: dispersion supressor)

5. Dynamic aperture

With FFS, partial double ring, low emittance arc (90°/90°) and the bypasses of pp detectors together, we got a satisfying dynamic aperture for on momentum particle. So far, we have used 192 groups of sextupoles in the arc. The further optimization of DA bandwidth is underway.

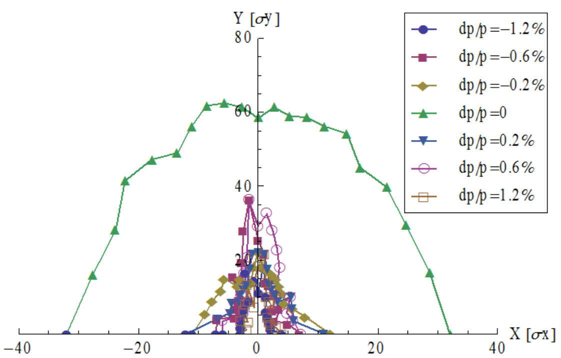

Fig. 6. FFS optics for CEPC partial double ring.

6. Conclusion

In this paper, a general method of how to make an consistant machine parameter design of CEPC with crab waist 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 was developed. Based on this method, a set of optimized parameter designs for 54 km CEPC with partial double ring scheme were proposed. Crossing angle was fixed at 30mrad both for Higgs W and Z. Thanks to the beam-beam limit enhancement effect of crab waist, we can either get higher luminosity with same beam power as Pre-CDR, or reduce the beam power by 40% keeping the same luminosity in Pre-CDR. Both proposals should improve the performance of CEPC. For "H-high lumi" mode, the HOM power per cavity can not be reduced under 1kw. The minimum value is about 2 kw. In addition, the optics of FFS has been designed and the strength of crab sextupole has been estimated, and so far this kind of sextupole is available.

Based on partial double ring scheme, we get a set of Z parameter with $3.1\times10^{34}cm^{-2}s^{-1}$ luminosity using 1100 bunches.

Lower emittance arc with 2.3 nm emittance has been designed both for 90°/60° case and 90°/90° case. 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.

Acknowledgements

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