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CEPC PARAMETER CHOICE*

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Abstract

The 100km Double Ring configuration with shared super conducting RF systems has been defined as baseline by CEPC steering committee. CEPC is compatible with W and Z experiment. Requirement for energy acceptance of Higgs has been reduced from 2% to 1.1% by enlarging the ring to 100 km. For CDR, W and Z will use the same lattice as Higgs, and the luminosity for Z is at the level of 10^{34}cm^{-2}s^{-1}.

INTRODUCTION

According to the physics goal of CEPC at Higgs and Z-pole energy, 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 at least larger than 1×10^{34}cm^{-2}s^{-1} per IP.

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 100km Double Ring configuration with shared SCRF has been defined as baseline by CEPC steering committee on Jan. 14th of 2016. The CDR report with 2mm βy* and 31 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 Higgs energy, all bunches distribute in the half ring due to the shared RF system. While for W and Z, bunches can 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. 1.

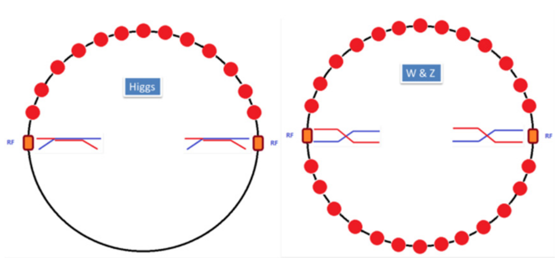

Figure 1: CEPC bunch distribution scheme (left: Higgs, right: W&Z).

BEAM LIFETIME LIMIT AND ENERGY SPREAD LIMIT DUE TO BEAMSTRAHLUNG

When two head-on colliding electron and positron beams penetrate each other, every particle in each beam will feel the electromagnetic field of the other beam and will be defected. This deflection process has some undesirable effects. Firstly, the deflected particle will lose part of its energy due to the synchrotron radiation, called as beamstrahlung, which will increase the energy spread of the colliding beams, and hence increase the uncertainty of the physical experiments. If the beamstrahung is so strong that particles' energy after collision is beyond the ring's energy acceptance, they may leave the beam and strike the vacuum chamber's walls, and hence beam lifetime is decreased. Secondly, the deflected particles will emit photons, hadrons, etc., which will increase the noise background level in the detector. Additionally, after the collision particles will change their flying direction with respect to the axis by a certain angle. If this angle is large enough the particles after the collision will interfere with the detection of small-angle events.

In order to control the extra energy spread by beamstrahlung to a certain degree, we introduce a constraint in this paper as

$$\delta_{BS} \le \frac{1}{5}\delta_0 \tag{1}$$

where δ_0 is the nature energy spread and δ_{BS} is the extra energy spread due to beamstrahlung.

V. I. Telnov [2] pointed out that at energy-frontier e+e− storage ring colliders, beamstrahlung determines the beam lifetime through the emission of single photons in the tail of the beamstrahlung spectra. Unlike the linear collider case, the long tails of the beamstrahlung energy loss spectrum are not a problem because beams are used only once. If we want to achieve a reasonable beamstrahlung-driven beam lifetime of at least 30 minutes, we need to confine the relation of the bunch population and the beam size as follows [3]

$$\frac{N_e}{\sigma_x\sigma_z} \le 0.1\eta\frac{\alpha}{3\gamma r_e^2} \tag{2}$$

where η is the energy acceptance of the ring and α is the fine structure constant (1/137).

COLLISION SCHEME WITH LARGE PIWINSKI ANGLE AND CRAB WAIST

The crab waist scheme of beam-beam collisions can substantially increase the luminosity of a collider since it combines several potentially advantageous ideas. The first one is the large Piwinski's angle.

It is well known that decreasing β_y at the IP is very profitable for the luminosity, but the main limitation is set by the lower limit on the achievable bunch length. With

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large Piwinski's angle the overlapping area becomes much smaller than σ_z, allowing significant β_y decrease:

$$\beta_y \approx \frac{\sigma_x}{\theta} \ll \sigma_z \tag{3}$$

And this can give us very significant gain in the luminosity! The additional advantages of such collision scheme are:

1. It's not necessary to decrease the bunch length which is the key factor of luminosity. This will certainly ease the problems of HOM heating, coherent synchrotron radiation of short bunches, excessive power consumption, etc.
2. The problem of parasitic collisions (PC) is automatically solved since with higher crossing angle and smaller horizontal beam size the beams separation at the PC is very large in terms of σx.

However, such a scheme of collision induces strong X-Y betatron resonances, which may cause troubles in making choice of the working point, and lower the achievable luminosity. Fortunately, the Crabbed Waist (CW) can solve this problem, which is the other attractive idea accomplishing the concept of crab waist collision. As it is seen in Fig. 2, the beta function waist of one beam is oriented along the central trajectory of the other one. In practice the CW vertical beta function rotation is provided by sextupole magnets placed on both sides of the IP in phase with the IP in the horizontal plane and at π/2 in the vertical one.

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 [4]:

$$K_2 = \frac{1}{2\theta}\frac{1}{\beta_y^*\beta_y}\sqrt{\frac{\beta_x^*}{\beta_x}} \tag{4}$$

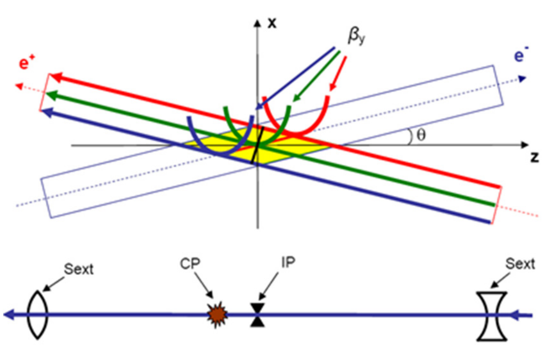

Figure 2: Collision in "Crabbed Waist" scheme.

BEAM-BEAM PARAMETER LIMIT COMING FROM BEAM EMITTANCE BLOW-UP

In e+ e- storage ring colliders, due to strong quantum excitation and synchrotron damping effects, the particles are confined inside a bunch. The position for each particle is random and the state of the particles can be regarded as a gas, where the positions of the particles follow statistic laws. Apparently, the synchrotron radiation is the main source of heating. Besides, when two bunches undergo collision at an interaction point (IP), every particle in each bunch will feel the deflected electromagnetic field of the opposite bunch and the particles will suffer from additional heating. With the increase of the bunch particle population N_e, this kind of heating effect will get stronger and the beam emittance will increase. There is a limit condition beyond which the beam emittance will blow up. This emittance blow-up mechanism introduce a limit for the first part of beam-beam tune shift [5]

$$\xi_y = \frac{2845}{2\pi}\sqrt{\frac{U_0}{2\gamma E_0 N_{IP}}} \times F_l \tag{5}$$

where F_l is the luminosity enhancement factor by crab waist scheme and so far we assume it is 1.5 for Higgs, 1.9 for W and 2.6 for Z.

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 carb-waist collision [7].

Constraints for Parameter Choice

1. Limit of Beam-beam tune shift
2. Beam lifetime due to beamstrahlung
3. Extra energy spread due to beamstrahlung
4. HOM power per cavity

$$P_{HOM} = k(\sigma_z)eN_e \cdot 2I_b \le 2kw \quad [8] \tag{6}$$

where the HOM loss factor is $k(\sigma_z) = \dfrac{1.8}{\sqrt{\sigma_z / 0.00265}} \quad V/pC$.

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 2mm βy* and lower SR power (31MW) for CDR report which will be published by the end of 2017. Using the method in reference 7, we got the parameter table for 2mm βy* as Table 1.

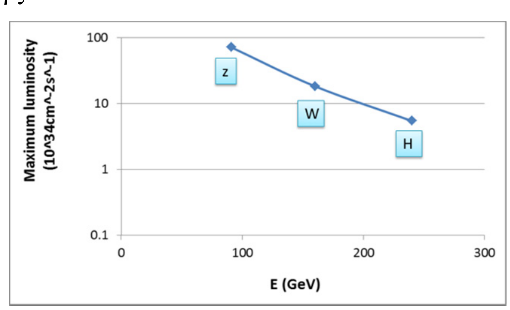

Figure 3: Luminosity potential of 100km CEPC with 1mm βy* and 50MW SR power/beam.

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We have found the vertical emittance growth for Z mode is most dangerous among the three energies due to the detector solenoid (3T) coupling effect. So we chose larger coupling factor (2.2%) at Z pole, while it is 0.3% for Higgs and W.

CEPC Upgrade

We have considered the upgrade of CEPC with higher luminosity using higher SR power and smaller βy*. Luminosity potential of 100km CEPC with 50MW SR power and 1mm βy* is shown in Fig. 3. Here we assume Z mode can use different lattice rather than Higgs and W, because Z needs larger emittance to increase luminosity which can be realized by closing half quadrupoles in Higgs lattice. Also Z mode may need dedicated 1 cell cavities to control the HOM power.

Table 1: CDR Parameters for 100km CEPC Double Ring with 2mm βy*

	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	1.61	0.32	0.033	
Half crossing angle (mrad)	0	16.5	16.5	16.5	
Piwinski angle Φ	0	2.28	3.6	6.33	
N_e/bunch (10^{11})	3.79	9.68	3.6	2.3	
Bunch number	50	420	5700	3510	27000
Beam current (mA)	16.6	19.5	98.6	38.8	298.5
SR power /beam (MW)	51.7	31.4	31.3	1.3	9.9
Bending radius (km)	6.1	11.4	11.4	11.4	
Momentum compaction (10^{-5})	3.4	1.15	1.15	1.15	
β_{IP} x/y (m)	0.8/0.0012	0.36/0.002	0.36/0.002	0.36/0.002	
Emittance x/y (nm)	6.12/0.018	1.18/0.0036	0.52/0.0017	0.17/0.0038	
Transverse σ_{IP} (um)	69.97/0.15	20.6/0.085	13.7/0.059	7.81/0.087	
ξx/ξy/IP	0.118/0.083	0.025/0.085	0.014/0.068	0.017/0.053	
RF Phase (degree)	153.0	128	134.7	151	
V_{RF} (GV)	6.87	2.03	0.45	0.069	
f_{RF} (MHz)	650	650	650	650 (217800)	
Nature σ_z (mm)	2.14	2.75	2.98	2.92	
Total σ_z (mm)	2.65	2.85	3.0	3.0	
HOM power/cavity (kw)	3.6 (5cell)	0.42 (2cell)	0.38 (2cell)	0.096 (2cell)	0.74 (2cell)
Energy spread (%)	0.13	0.096	0.064	0.036	
Energy acceptance (%)	2	1.1			
Energy acceptance by RF (%)	6	1.98	1.46	1.2	
n_γ	0.23	0.19	0.11	0.12	
Life time due to beamstrahlung_cal (minute)	47	63			
F (hour glass)	0.68	0.93	0.963	0.987	
L_{max}/IP (10^{34}cm^{-2}s^{-1})	2.04	2.0	5.6	1.0	7.7

CONCLUSION

We have developed a consistent method for CEPC parameter choice with carb 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. The luminosity can be crosschecked by beam-beam simulations. Based on double ring scheme with 100 km circumference, the requirement of energy acceptance for Higgs was reduced to 1.1%, and also the beam loading effect and sawtooth effect can be solved.

We chose 2mm βy* and 31MW SR power for CDR. The luminosity goal for Higgs is 2×10^{34}cm^{-2}s^{-1} and the luminosity for Z is at the level of 10^{34}cm^{-2}s^{-1}.

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