CEPC-SPPC TOWARDS CDR

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Abstract

In this paper we will give an introduction to Circular Electron Positron Collider (CEPC). The scientific background, physics goal, the collider design requirements and the conceptual design principle of CEPC are described. On CEPC accelerator, the optimization of parameter designs for CEPC with different energies, machine lengthes, single ring and crab-waist collision partial double ring, advanced partial double partial ring and fully partial double ring options, etc. have been discussed systematically, and compared. CEPC accelerator baseline and alternative designs have been proposed based on the luminosity potential in relation with the design goals. The sub-systems of CEPC, such as collider main ring, booster, electron positron injector, etc. have also been introduced. The detector and MDI design have been briefly mentioned. Finally, the optimization design of Super Proton-Proton Collider (SppC), its energy and luminosity potentials, in the same tunnel of CEPC are also discussed. The CEPC-SppC Progress Report (2015-2016) has been published.

INTRODUCTION

With the discovery of the Higgs particle at the Large Hadron Collider at CERN in July 2012, after more than 50 years of searching, particle physics has finally entered the era of the Higgs, and the door for human beings to understand the unknown part of the Universe is wide open! Thanks to the low energy of Higgs, it is possible to produce clean Higgs with circular electron positron colliders, such CEPC and FCC(ee), in addition of linear colliders, such as ILC and CLIC, with reasonable luminosity, technology, cost, and power consumption.

The optimization design, relevant technologies and industry preparation could be ready after a five years dedicated R&D period before CEPC starts to be constructed around 2022 and completed around 2030. CEPC will operate 10 ten years with two detectors to accumulate one million Higgs as Higgs Factory and 100 million of Z particle.

In the beginning of 2015, Pre-Conceptual Design Reports (Pre-CDR) of CEPC-SppC [1] have been completed. Since 2015, based on crab-waist collision at two interaction points, Partial double Ring (PDA), Advanced Partial Double Ring (APDR) and Double Ring schemes have been studies systematically with the aim of comparing the luminosity potentials and proposing a baseline and an alternative options for CDR studies. On Jan. 14, 2017, CEPC accelerator baseline and alternative design options have been proposed and accepted, which will be described in this paper, which laid an important basis for the completion of CEPC CDR at the end of 2017. The CEPC baseline design is a 100 km double ring scheme with 30MW radiation power of single beam at Higgs energy, with the same SCRF accelerator system for both electron and positron beams, and CEPC could work both at Higgs and Z-pole energies. A CEPC-SppC Progress Report has been published in April of 2017 [2].

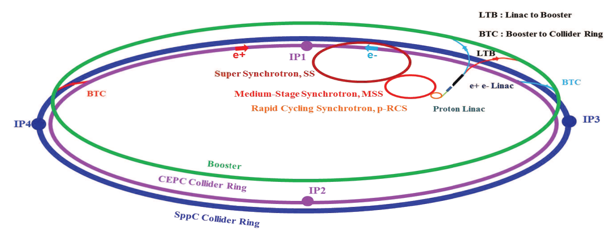

Figure 1: CEPC-SPPC schematic layout.

CEPC ACCELERATOR DESIGN

According to the physics goal of CEPC at Higgs and Z-pole energies, 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. CEPC has two IPs for e^+e^- collisions. At Z-pole energy the luminosity is required to be larger than 1×10^{34} $cm^{-2}s^{-1}$ per IP. Its circumference is around 100 km in accordance with SppC, which has 75 TeV of center of mass proton proton collision and 12 Tesla superconduction magnet dipole field. The schematic layout of CEPC-SppC is shown in Fig. 1, and CEPC accelerator complex is composed of a 10 GeV electron and positron linac injector with a 1 GeV positron damping ring (one of the options), a booster from 10 GeV to 120 GeV in the same channel of 120 GeV collider rings.

Main Parameters and Main Ring Designs

To make an optimization design of 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 [3] and Beamstrahlung [4], and also take into account of economical and technical limitations, such 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 methods have been developed both head-on collision and crab-waist collision [5].

The baseline CEPC parameter of 100 km is shown in Table 1 with new crossing angle of 33 mrad and L^*=2.2 m.

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Table 1: CEPC Main Ring Parameters of 100 km

	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	61	61	61	61
SR loss/turn (GeV)	3.1	2.96	2.96	0.58	0.061
Half crossing angle (mrad)	0	15	15	15	15
Piwinski angle	0	1.88	1.84	5.2	6.4
N_e/bunch (10^{11})	3.79	2.0	1.98	1.16	0.78
Bunch number	50	107	70	400	1100
Beam current (mA)	16.6	16.9	11.0	36.5	67.6
SR power /beam (MW)	51.7	50	32.5	21.3	4.1
Bending radius (km)	6.1	6.2	6.2	6.2	6.2
Momentum compaction (10^{-5})	3.4	1.48	1.48	1.44	2.9
β_{IP} x/y (m)	0.8/0.0012	0.272/0.0013	0.275 /0.0013	0.1/0.001	0.1/0.001
Emittance x/y (nm)	6.12/0.018	2.05/0.0062	2.05 /0.0062	0.93/0.0078	0.88/0.008
Transverse σ_{IP} (um)	69.97/0.15	23.7/0.09	23.7/0.09	9.7/0.088	9.4/0.089
ξ_x/IP	0.118	0.041	0.042	0.013	0.01
ξ_y/IP	0.083	0.11	0.11	0.073	0.072
V_{RF} (GV)	6.87	3.48	3.51	0.74	0.11
f_{RF} (MHz)	650	650	650	650	650
Nature σ_z (mm)	2.14	2.7	2.7	2.95	3.78
Total σ_z (mm)	2.65	2.95	2.9	3.35	4.0
HOM power/cavity (kw)	3.6	0.74	0.48	0.88	0.99
Energy spread (%)	0.13	0.13	0.13	0.087	0.05
Energy acceptance (%)	2	2	2		
Energy acceptance by RF (%)	6	2.3	2.4	1.7	1.2
n_γ	0.23	0.35	0.34	0.49	0.34
Life time due to beamstrahlung_cal (minute)	47	37	37		
F (hour glass)	0.68	0.82	0.82	0.92	0.93
L_{max}/IP (10^{34}cm^{-2}s^{-1})	2.04	3.1	2.01	4.3	4.48

In Pre-CDR, single ring (SR) head-on collision scheme has been studied with Pretzel scheme. The apparent low cost single ring Pretzel scheme has many problems, such as not flexible lattice solution, sawtooth effects, small dynamic aperture, low Z-pole energy luminosity (around 10^{32} cm$^{-2}s^{-1}$), and very high AC power consumption. To solve these critical problems, a Partial Double Ring (PDR) scheme has been proposed independently [6, 7]. In partial double ring scheme, it is found, however, that beam loading and the sawtooth effects are key bootle neck physics limitations to reached the desired luminosities both for Higgs and Z-pole energies. To solve these limiting problems, an Advanced Partial Double Ring (APDR) scheme [8] and a Fully Partial Double Ring (FPDR) scheme [9] have been proposed as shown in Fig. 2 and Fig. 3, respectively.

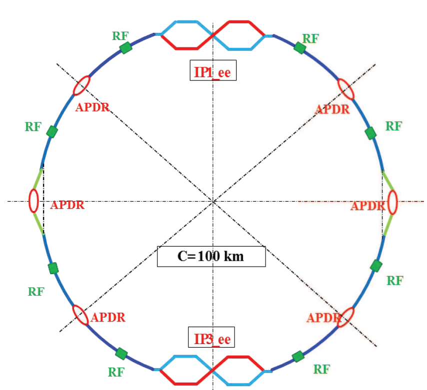

Figure 2: CEPC Advanced Partial Double Ring (APDR) scheme.

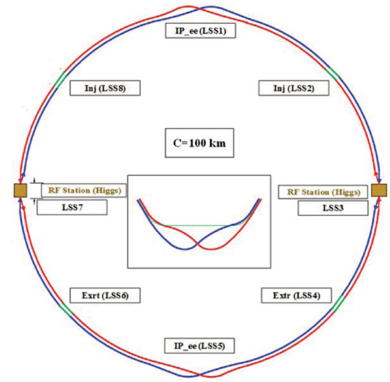

Figure 3: CEPC Fully Partial Double Ring (FPDR) scheme.

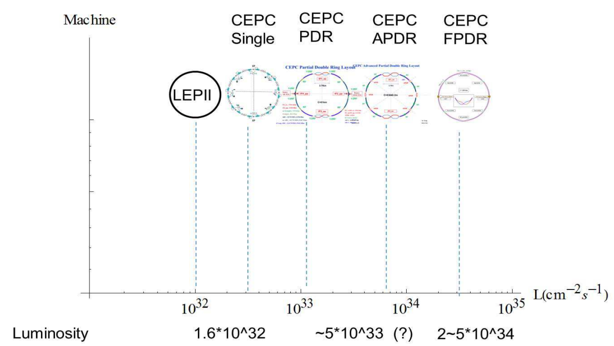

Figure 4: Luminosity of different schemes of CEPC.

After a series detailed studies on the four options (schemes), i.e. SR, PDR, APDR, and FPDR, it is found that the luminosity potential is shown in Fig. 4. Considering FPDR has higher luminosities and due to more detailed studies are need to understand well sawtooth and beam loading effects in APDR, it is decided that CEPC FPDR as baseline option and CEPC APDR as an alternative one.

As for baseline lattice design, in the Arc region, the FODO cell structure is chosen to provide a large filling factor. The 90/90 degrees phase advances is chosen to achieve a very small emittance of 2 nm. The non-interleaved sextupole scheme [10] was selected due to its property of small tune shift. Considering the symmetry of two IPs and two beams, the lattice CEPC PDR scheme has a two-fold symmetry and the maximum number of sextupole families in the ARC region is 96 [11].

The CEPC interaction region (IR) was designed with modular sections including the final transformer, chromaticity correction for vertical plane, chromaticity correction for horizontal plane and matching transformer. To achieve a momentum acceptance as large as 1.5%, local correction of the large chromaticity from final doublet is necessary.

The dynamic aperture of the ring is optimized by SAD and goal is to have dynamic aperture in both transverse planes lager than 5σ including all effects (such as magnets' error, beam-beam effects and detector solenoid effect) with energy spread of from $+1.5\%$ to -1.5%.

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In order to avoid the strong sawtooth and beam loading effects, a fully partial Double Ring scheme has been studied and proposed as CEPC baseline for CDR, which is shown in Fig. 3.

Linac Injector

To reduce the cost of the whole system, the length of the Linac is chosen to be as short as possible, and a booster ring is used to ramp the beams from the Linac energy to the full injection energy of the main collider. Therefore, the whole CEPC system is composed of three parts: a linac, a booster, the main collider ring. The Linac injector system is composed of a 10 GeV (for 100 km CEPC, the injection energy is 10 GeV) S-band linac with positron source and a 1 GeV damping ring (a linac injector scheme without damping ring is also proposed and studied).

Booster

The booster provides 120 GeV electron and positron beams to the CEPC collider for top-up injection at 0.1 Hz. The Booster is in the same tunnel as the collider, placed above the collider ring and has about same circumference. The design of the full energy booster ring of the CEPC is especially challenging due to the injected beam only 10 GeV, which corresponds to 30 Gauss low dipole magnet field at injection energy, and might cause difficulties. As an alternative design we studied also a wiggler dipole magnets to raise the initial magnetic field [12], as an alternative option.

Detector and MDI

The CEPC conceptual detector takes the ILD detector as starting point. [1, 13, 14] Similar to the ILD, the core part of this conceptual detector is a solenoid with 3.5 Tesla Magnet Field. To minimize the dead zone, the entire ECAL, HCAL and the tracking system are installed inside the solenoid. The tracking system is composed of a large volume TPC as the main tracker and the silicon tracking system. The interaction region of the CEPC partial double ring consists of two beam pipes, of which the crossing angle is 33mrad, surrounded by silicon tracker, luminosity calorimeter and the final quadrupoles QD0 and QF1, with * is 2.2 m. The inner radius of the vacuum chamber should be larger than the beam-stay-clear region. We chose 17 mm (2 mm for safety) both for QD0 and QF1. After CEPC baseline has determined, there are some modifications on MDI parameters, such as crossing angle has been changed from 30 mrad to 33 mrad, * from 1.5 m to 2.2 m, the detector solenoid field from 3.5 T to 3 T and the anti-solenoid field from 13 T to 6.6 T.

SPPC DESIGN

The CDR design goal of the SppC is about 75 TeV, using the same tunnel as the CEPC of 100 km, with SC dipole magnet field of about 12 Tesla of luminosity of $1{\times}10^{35}/cm^{-1}s^{-1}$. If 20 Tesla dipole is used for 100 km ring, a proton beam of 125 TeV of luminosity of $1{\times}10^{36}/cm^{-1}s^{-1}$ could be obtained, with SppC parameters of 100 km shown in Table 1. The parameter choice and optimization process is given in Ref. [15–17] .

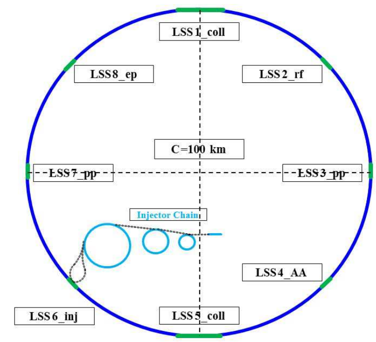

Figure 5: SPPC layout.

CONCLUSIONS

In this paper we have briefly reviewed the CEPC-SppC projects history, design philosophy and actual progress status. A dedicated R&D program both on accelerator and detectors has started with support of Chinese MOST. Based on the option study results for single ring, partial double ring, advanced partial double ring and fully partial double ring, taking into account of beam loading and sawtooth effects study results, it is decided that CEPC-SppC CDR baseline will be of 100 km circumference, fully partial double ring scheme with 30MW synchrotron radiation power per beam for Higgs energy and the advance partial double ring scheme be alternative option. The detailed corresponding designs on baseline are underway and will be completed by the end of 2017 as the main contents of CDR.

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