2.5 Strategy, Site Selection Process and CE Studies for CEPC-SppC

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2.5.1 CEPC-SppC Strategy and Status

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 in addition of linear colliders, such as ILC and CLIC, with reasonable luminosity, technology, cost, and power consumption.

In September 2012, Chinese scientists proposed a Circular Electron Positron Collider (CEPC) in China at 240 GeV centre of mass for Higgs studies with two detectors situated in a very long tunnel more than twice the size of the LHC at CERN. It could later be used to host a Super Proton Proton Collider (SppC) well beyond LHC energy potential to reach a new energy frontier in the same channel as shown in Fig. 1.

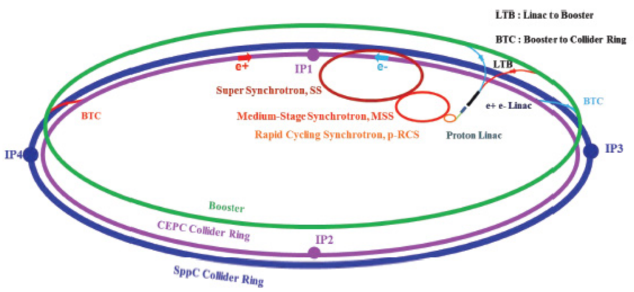

Figure 1: CEPC-SppC schematic layout

After ICFA Higgs Factory Workshop held at Fermi Laboratory in Nov 2012, CERN proposed also a similar one, Future Circular Collider (FCC) with a much longer tunnel than that of LHC.

From 12 to 14 June 2013, the 464th Fragrant Hill Meeting was held in Beijing on the strategy of Chinese high energy physics development after Higgs discovery, and the following consensuses were reached: 1) support ILC and participate to ILC construction with in kind contributions, and request R&D fund from Chinese government; 2) as the next collider after BEPCII in China, a circular electron positron Higgs factory (CEPC) and a Super proton-proton Collier (SppC) afterwards in the same tunnel is an important option as a historical opportunity, and corresponding R&D is needed.

In Feb. and July of 2014, ICFA has given two successive statements, respectively, that ICFA supports studies of energy frontier circular colliders and encourages global coordination; ICFA continues to encourage international studies of circular colliders, with an ultimate goal of proton-proton collisions at energies much higher than those of the LHC.

In April 2016, during the AsiaHEP and ACFA meeting in Kyoto , a positive statement of AsiaHEP/ACFA Statement on ILC+CEPC/SppC has been made with strong endorsement of the ILC and encouraging the effort led by China on CEPC/SppC.

On Sept 12, 2016, in the meeting of the Chinese High Energy Physics of Chinese Physics Society, a statement on the future Chinese high energy physics based on accelerator has been made that CEPC is the first option for future high energy accelerator project in China as a strategic action with the aim of making CEPC as a large international scientific project proposed by China.

From Oct. 18-19, 2016, the 572th Fragrant Hill Meeting dedicated to CEPC has been held and it is concluded that CEPC has a solid physics reason to be built with big physics potential in SppC.

In the beginning of 2015, Pre-Conceptual Design Reports (Pre-CDR) of CEPC-SppC have been completed with international review, where a single ring based pretzel orbit scheme has been studies [1]. The International Advisory Committee (IAC) of CEPC was also established in 2015. In 2016, Chinese Ministry of Science and Technology has allocated several tens of million RMB on CEPC R&D to start with.

Since Mid 2015, based on crab-waist collision at two interaction points, Partial double Ring (PDA) [2][3], Advanced Partial Double Ring (APDR) [4] and the Fully Partial Double Ring (FPDA) [5] 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-SppC baseline and alternative designs for Conceptual Design Report (CDR) [6] have been decided by the Steering Committee of CEPC-SppC, which laid an important basis for the completion of CEPC CDR at the end of 2017.

The CEPC baseline design is a 100km Fully Partial Double Ring (FPDR) scheme as shown in Fig 2 (left) with 30MW radiation power of single beam at Higgs energy, and with the same SCRF accelerator system for both electron and positron beams. CEPC could work both at Higgs and Z-pole energies with the luminosity of $2\cdot10^{34}$/cm^{2}s and $1\cdot10^{34}$/cm^{2}s, respectively， as shown in Tab. 1. The alternative design of CEPC is based on APDR scheme as shown in Fig. 2 (rifht). The CEPC whole subsystems is shown in Fig. 3, and the two detectors are as shown in Fig. 4 with L^* =2.2m and full crossing angle of 33mrad.

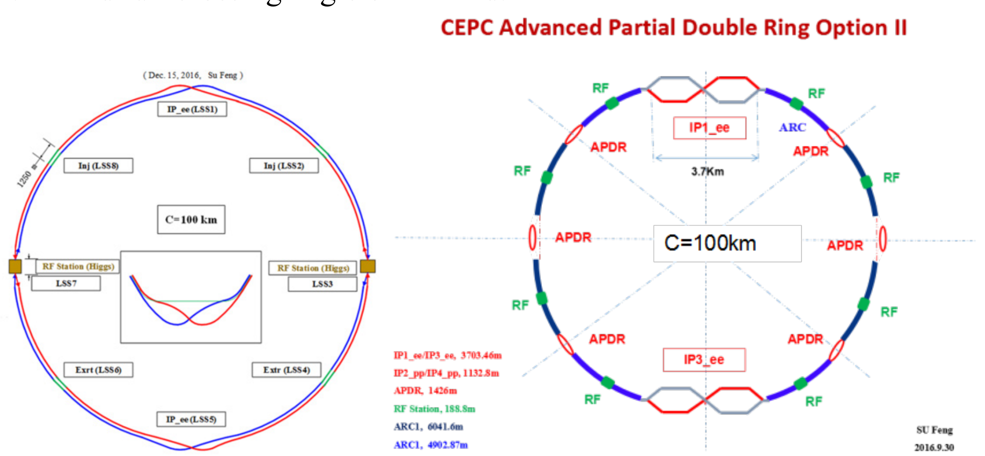

Figure 2: CEPC baseline (left) and alternative (right) design schematic layouts

	tt	*Higgs*	*Z*
Number of IPs		2	
Energy (GeV)	175	120	45.5
Circumference (km)		100	
SR loss/turn (GeV)	7.61	1.68	0.035
Half crossing angle (mrad)		16.5	
Piwinski angle	0.91	2.58	12.1
N_e/bunch (10^{10})	24.15	15	4.8
Bunch number	34	248	9524
Beam current (mA)	3.95	17.9	219.7
SR power /beam (MW)	30	30	7.6
Bending radius (km)		10.9	
Momentum compaction (10^{-5})		1.14	
β_{IP} x/y (m)	1.2/0.0037	0.36/0.001	0.2/0.001
Emittance x/y (nm)	2.24/0.0068	1.21/0.0037	0.17/0.0029
Transverse σ_{IP} (um)	51.8/0.16	20.9/0.061	5.9/0.054
ξ_x/ξ_y/IP	0.077/0.105	0.031/0.082	0.0094/0.0626
V_{RF} (GV)	8.93	2.14	0.1
f_{RF} (MHz) (harmonic)		650 (217500)	
Nature bunch length σ_z (mm)	2.54	2.72	2.38
Bunch length σ_z (mm)	2.87	3.26	4.33
HOM power/cavity (kw)	0.53 (5cell)	0.56 (2cell)	0.95(2cell)
Energy spread (%)	0.14	0.098	0.037
Energy acceptance requirement (%)	1.57	1.52	
Energy acceptance by RF (%)	2.67	2.06	1.7
Photon number due to beamstrahlung	0.19	0.29	0.33
Lifetime due to beamstrahlung (hour)	1.0	1.0	
Lifetime (hour)		0.33 (20 min)	
F (hour glass)	0.89	0.81	0.97
L_{max}/IP (10^{34}cm^{-2}s^{-1})	0.38	3.1	13.2

Table 1: CEPC parameters

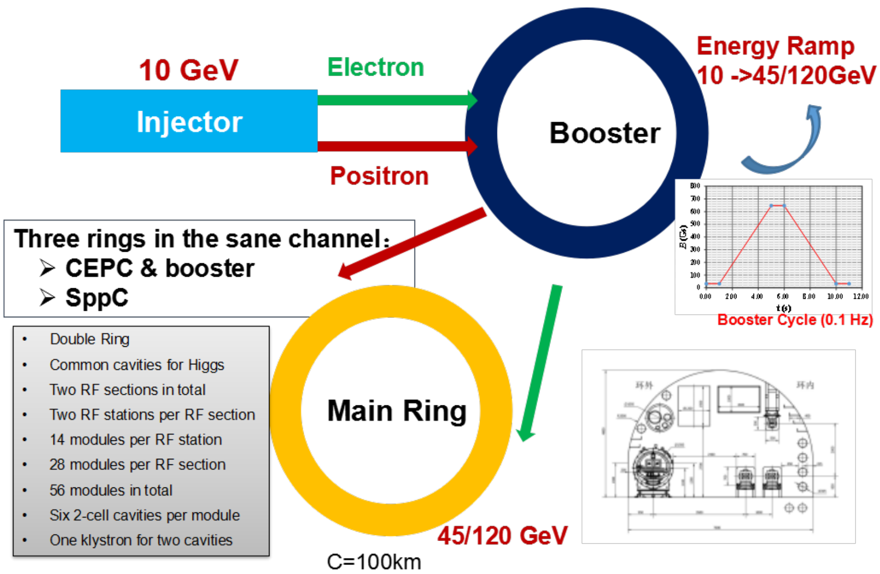

Figure 3: CEPC subsystem schematic layout

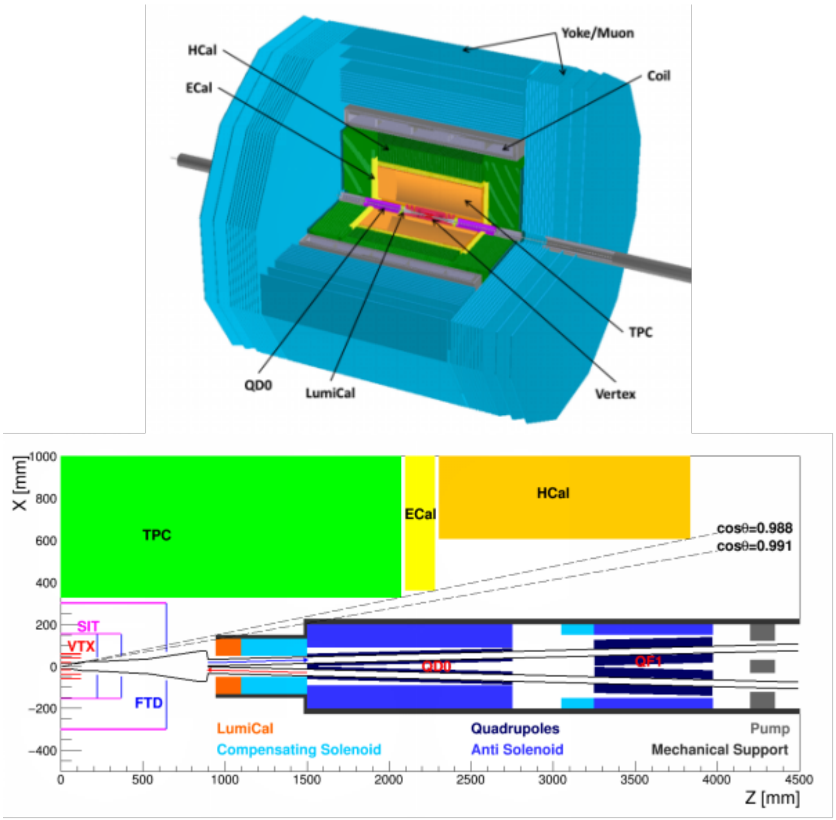

Figure 4: CEPC detector and MDI schematic layout

Concerning SppC baseline as shown in Fig. 6, it is decided to start with 12T dipole of iron based high temperature superconducting magnets, at the center of mass energy of 75TeV and luminosity of $1 \cdot 10^{35}/\mathrm{cm}^2\mathrm{s}$ as shown in Tab. 2 .

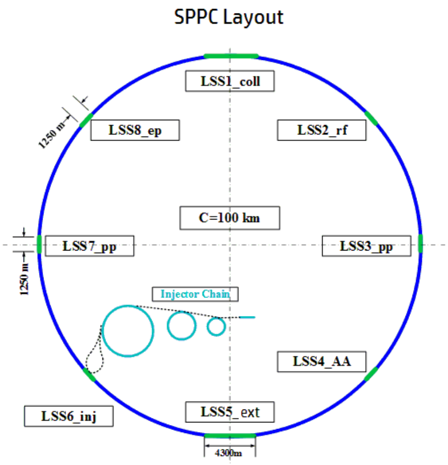

Figure 5: SppC baseline schematic layout

	SPPC (Pre-CDR)	SPPC 61Km	SPPC 100Km	SPPC 100Km	SPPC 82Km	SPPC phase 1	SPPC phase 2
Main parameters and geometrical aspects							
c.m. Energy[E_0]/TeV	71.2	70	100.0	128.0	100.0	75.0	125.0-150.0
Circumference[C_0]/km	54.7	61.0	100.0	100.0	82.0	100.0	100.0
Dipole field[B]/T	20	19.88	16.02	19.98	19.74	12.00	20-24
Dipole curvature radius[ρ]/m	5928	5889.64	10676.1	10676.1	8441.6	10415.4	-
Bunch filling factor[f_2]	0.8	0.8	0.8	0.8	0.8	0.8	-
Arc filling factor[f_1]	0.79	0.78	0.78	0.78	0.78	0.78	-
Total dipole length [L_{Dipole}]/m	37246	37006	67080	67080	53040	65442	-
Arc length[L_{ARC}]/m	47146	47443	86000	86000	68000	83900	-
Straight section length[L_{ss}]/m	7554	13557	14000	14000	14000	16100	-
Physics performance and beam parameters							
Peak luminosity per IP[L]/ $cm^{-2}s^{-1}$	1.1×10^{35}	1.2×10^{35}	1.5×10^{35}	1.0×10^{36}	1.5×10^{35}	1.0×10^{35}	1.0×10^{36}
Beta function at collision[β^*]/m	0.75	0.85	0.99	0.22	1.06	0.71	-
Max beam-beam tune shift per IP[ξ_y]	0.006	0.0065	0.0068	0.0079	0.0073	0.0058	-
Number of IPs contributes to ΔQ	2	2	2	2	2	2	2
Max total beam-beam tune shift	0.012	0.0130	0.0136	0.0158	0.0146	0.0116	-
Circulating beam current[I_b]/A	1.0	1.024	1.024	1.024	1.024	0.768	-
Bunch separation[Δt]/ns	25	25	25	25	25	25	-
Number of bunches[n_b]	5835	6506	10667	10667	8747	10667	-
Bunch population[N_p] (10^{11})	2.0	2.0	2.0	2.0	2.0	1.5	-
Normalized RMS transverse emittance[ε]/μm	4.10	3.72	3.59	3.11	3.35	3.16	-
RMS IP spot size[σ^*]/μm	9.0	8.85	7.86	3.04	7.86	7.22	-
Beta at the 1st parasitic encounter[$\beta 1$]/m	19.5	18.67	16.26	69.35	15.31	22.03	-
RMS spot size at the 1st parasitic encounter[σ_1]/μm	45.9	43.13	33.10	56.19	31.03	41.76	-
RMS bunch length[σ_z]/mm	75.5	56.69	66.13	14.62	70.89	47.39	-
Full crossing angle[θ_c]/μrad	146	138.03	105.93	179.82	99.29	133.65	-
Reduction factor due to cross angle[F_{ca}]	0.8514	0.9257	0.9247	0.9283	0.9241	0.9265	-
Reduction factor due to hour glass effect[F_h]	0.9975	0.9989	0.9989	0.9989	0.9989	0.9989	-
Energy loss per turn[U_0]/MeV	2.10	1.98	4.55	12.23	5.76	1.48	-
Critical photon energy[E_c]/keV	2.73	2.61	4.20	8.81	5.32	1.82	-
SR power per ring[P_0]/MW	2.1	2.03	4.66	12.52	5.90	1.13	-
Transverse damping time [τ_x]/h	1.71	1.994	2.032	0.969	1.32	4.70	-
Longitudinal damping time [τ_ε]/h	0.85	0.997	1.016	0.4845	0.66	2.35	-

Table 2: SppC baseline parameter (phase-1)

As for CEPC-SppC study fund situation, in 2016, Chinese Ministry of Science and Technology (MOST) has allocated 36 Million RMB for CEPC study, and in 2018, another 40 Million RMB on CEPC R&D will be allocated also. Surely, MOST is only one of funding channels, there are other channels also to fund CEPC-SppC studies, such as NSFC, CAS and local Governments. For example, in 2017, CAS allocated 200 Million RMB to study high temperature materials for magnets, including studies on materials science, industries and projects, such as SppC.

A CEPC-SppC Progress Report has been published in April of 2017 [7], and the Conceptual Design Report (CDR) will be finished by the end of 2017.

On Nov. 2017, CEPC-SppC Industrial Promotion Consortium (CIPC) has been established with the aim of mutual supporting between CEPC-SppC and Industries.

The optimization design, relevant technologies and industrialization preparation could be ready after a five years R&D dedicated Technical Design Report (TDR) period started from 2018 before CEPC starts its construction around 2022 and completed around 2028. CEPC will operate about 10 ten years with two detectors to accumulate one million Higgs as Higgs Factory and 100 million of Z particle. As for SppC, it is planed to start the SppC construction from 2038 and complete the construction in 2045.

The CEPC-SppC TDR phase after CDR is very critical, both for key components' R&D and industrialization.The R&D on high Q high field 1.3GHz and 650MHz SC cavities; 650MHz high power high efficiency klystron; 12kW@4K cryogenic system, 12T iron based high temperature superconducting dipole, etc. have started. Taking CEPC SCRF R&D for example, the civil construction of Platform of Advanced Photon Source (PAPS)- SCRF facility has been started since May 31, 2017 in Beijing, which is a modern 4500m^2 SCRF Laboratory to be completed in 2020.

In 2017, Chinese Government has established a new decision making process for large scientific projects with international collaboration, such as CEPC-SppC.

CEPC-SppC is a Chinese scientists proposed project to be built in China, but its nature is an International Collaboration Project for the high energy physics community world wide. In 2015, an International Advisory Committee of CEPC-SppC has been established, and many MoUs have been signed with many Institutes and Universities around the world.

In August 2017, ICFA endorsed International Linear Collider (ILC) 250GeV (center of mass energy) with upgrade possibilities in the future. Even CEPC and ILC250 starts with the same Higgs energy, but their ultimate goals are totally different from each other, SppC is for 100TeV proton proton collider and ILC is for 1TeV electron positron collider. Apparently, the relation between CEPC-SppC and ILC is complementary.

The specific feature of CEPC is its small scale SCRF system (2GeV in the main collider ring for Higgs) instead of 125GeV for ILC, and relative large AC power consumption of ~350MW for CEPC instead of ~110MW for ILC250. As for the cost, CEPC in the first phase has included part of the cost of SppC for its long tunnel, however, ILC have to upgrade its energy by increasing tunnel length accordingly later.

2.5.2 CEPC-SppC Site Selection Process and Status

CEPC-SppC site selection technical criteria can be roughly quantified as follows: earthquake intensity less than 7; earthquake gravitation less than 0.1g; ground surface vibration amplitude less than 20nm@1-100Hz; grantine bed rock is around 50~100m underground, etc. The site selection has been started since Feb. 2015, till 2017, four sites have been considered, Qinhuangdao in Hebei Province, Shenshan Special District in Guangdong Provice, Huangling county in Shanxi Province, and Baoding (Xiongan) in Heibei Province as shown in Fig. 6, where the first three sites have been prospected underground. More sites will be considered in the future before a final selection decision.

Figure 6: CEPC-SppC site selection status

2.5.3 Civil Engineering Studies

CEPC-SppC is designed as a whole facility with both machines co-existing in the same tunnel. CEPC-SppC have totally 4 detector experimental halls of around 2000m^2, two for CEPC and another two for SppC. The tunnel width is around 7m in width and 4.8m in height, where hosts CEPC main ring (two beam pipes), CEPC booster and SppC. The SppC could be inside (as shown in Fig. 7 left) or outside (as shown in Fig. 7 right) of CEPC, and the final decision is depending on more studies on radiation protection and other collision modes, for example, electron proton collision scheme in the far future.

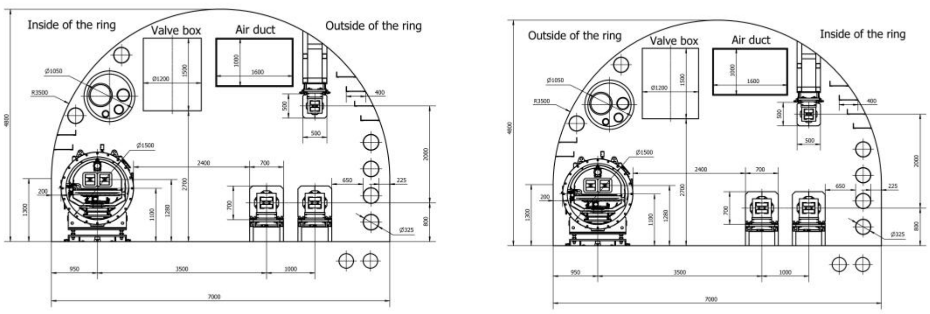

Figure 7: CEPC-SppC tunnel layouts:CEPC is out side of SPPC (left); CEPC is inside of SppC (right)

2.5.4 Conclusions

In this article we have given a general strategy (both national and international) and historical progress review of CEPC-SppC project. CEPC-SppC baseline and alternative schemes have been introduced for CDR to be finished by the end of 2017. Key issues, such as, CEPC-SppC R&D, funding situation, international collaboration, CEPC-SppC/ILC relations, government decision making process, costing, siting, and civil engineering, etc. have been discussed.

In short, CEPC-SppC has kept the scheduled pace both in design and R&D together with team development.

2.5.5 Acknowledgments

The author of this article thanks for the great efforts from CEPC-SppC team and international collaborations.

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2.6 CEPC Design Highlights

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2.6.1 Introduction

CEPC is a double ring collider with two interaction points (IP). According to the goal of high energy physics, it is required that the CEPC provides e+ e- collisions at the center-of-mass energy of 240GeV and delivers a peak luminosity of 2×10^{34} cm^{-2}s^{-1} at each interaction point. CEPC should be compatible with W and Z experiments which the energies are 160GeV and 91GeV respectively. The luminosity at the Z-pole should be above 1×10^{34} cm^{-2}s^{-1} per IP. The CEPC design highlights will be introduced in detail in this paper.

2.6.2 Main parameters

The circumference of CEPC is decided by the geometry requirement of SPPC. The synchrotron radiation (SR) power per beam is limited around 30 MW due to the project power budget. The luminosity constraint of Z mode is mainly from the consideration of machine cost. The parameters for Z mode are designed without increasing machine budget base on the Higgs factory. The main parameters are listed in Table 1.

Table 1: CEPC parameters

	Higgs	***W***	***Z***
Number of IPs	2		
Beam Energy (GeV)	120	80	45.5
Circumference (km)	100		
SR loss/turn (GeV)	1.68	0.33	0.035
Half crossing angle (mrad)	16.5		
Piwinski angle	2.75	4.39	10.8
N_e/bunch (10^{10})	12.9	3.6	1.6
Bunch number	286	5220	10900
Beam current (mA)	17.7	90.3	83.8
SR power /beam (MW)	30	30	2.9
Bending radius (km)	10.9		
Momentum compaction (10^{-5})	1.14		
β_{IP} x/y (m)	0.36/0.002		