Institute of High Energy Physics
Chinese Academy of Sciences

Circular Electron Positron Collider (CEPC) - Ecm / Lumi choices - Timeline

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On behalf of CEPC Accelerator Group

US Snowmass21 EF e+e- Forum
April 04, 2022

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- CEPC-SppC Physics Goals and TDR Accelerator Layout
- CEPC energy range and upgrade potential
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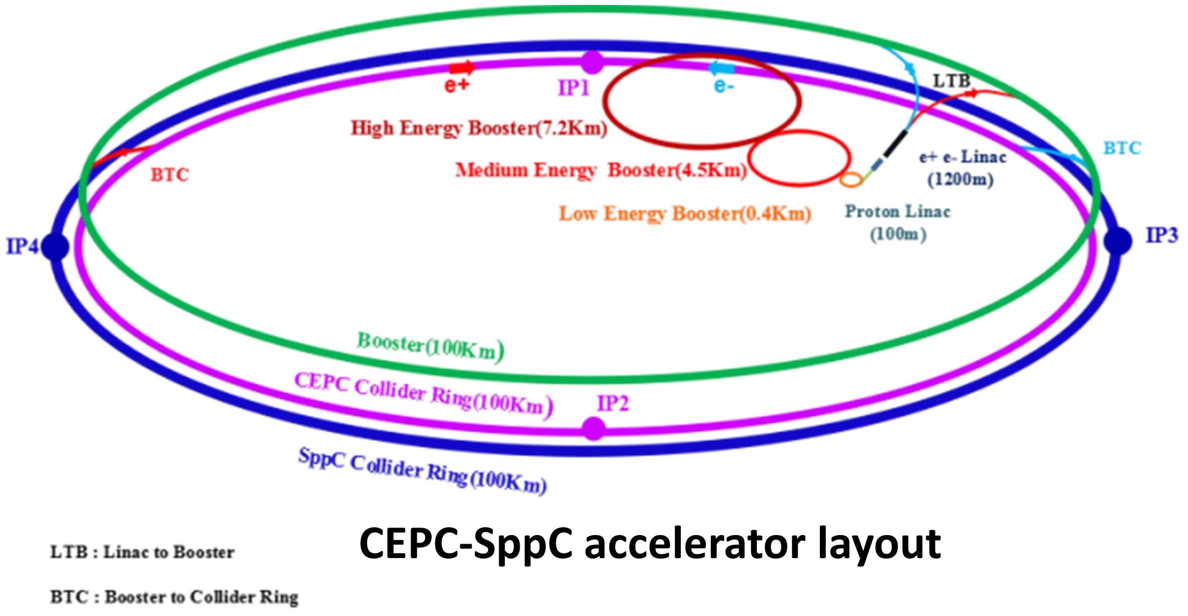
CEPC-SppC Physics Goals in TDR

- **Circular Electron-Positron Collider of Ecm(GeV): 240, 91, 160, upgradable to 360GeV)**
  - **Higgs Factory (>10^6 Higgs) :**
    - Precision study of Higgs(m_H, J^{PC}, couplings) , Similar & complementary to Linear Colliders
    - Looking for hints of new physics
  - **Z & W factory (10^{10}~10^{12} Z^0) :**
    - precision test of SM
    - Rare decays ?
  - **Flavor factory: b, c, t and QCD studies**
- **Super proton-proton Collider SppC (~100 TeV)**
  - **Directly search for new physics beyond SM**
  - **Precision test of SM**
    - **e.g., h^3 & h^4 couplings**

CEPC baseline SR power/beam: 30MW, upgradable to 50MW

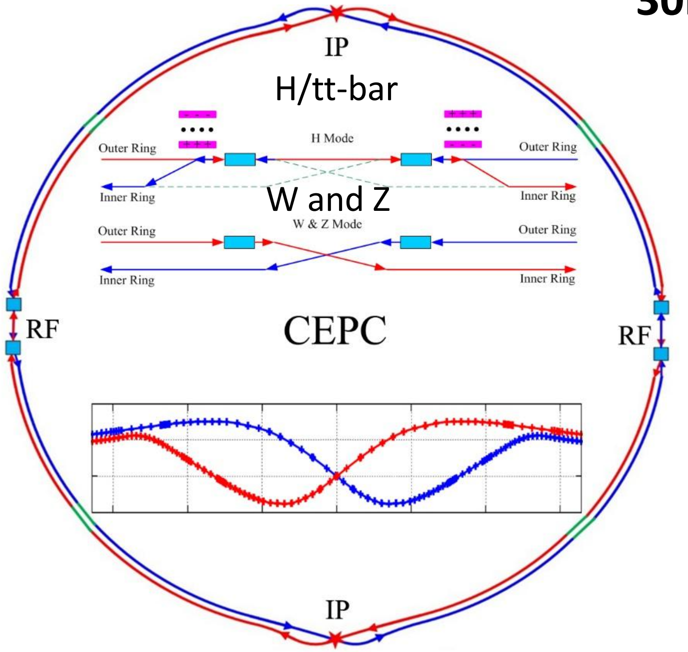


CEPC-SppC accelerator layout

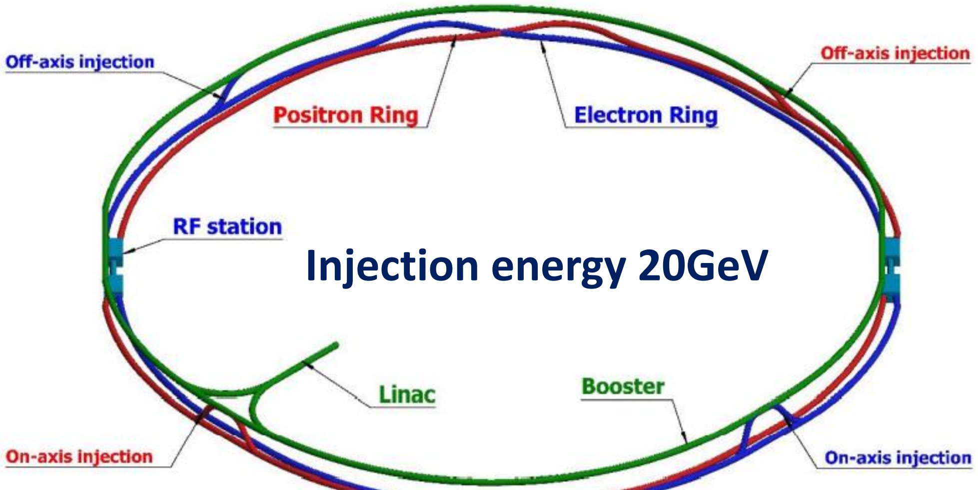
CEPC TDR Layout

CEPC as a Higgs Factory：H, W, Z, upgradable to tt-bar, followed by a SppC ~125TeV

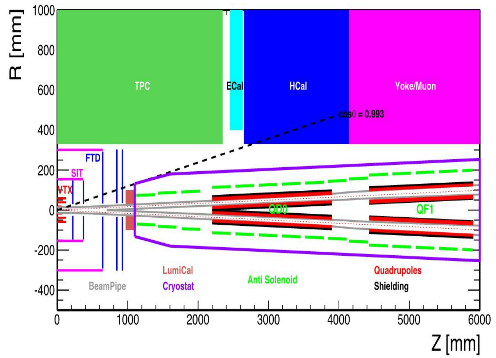
30MW SR power per beam (upgradale to 50MW)



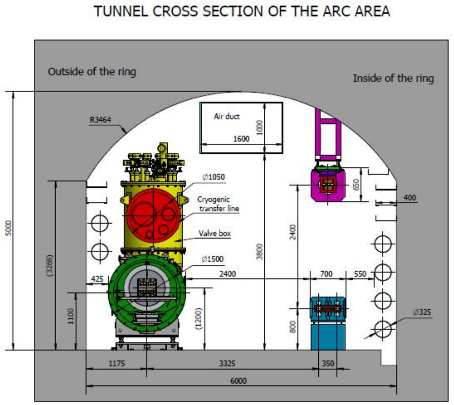
CEPC collider ring (100km)



CEPC booster ring (100km)

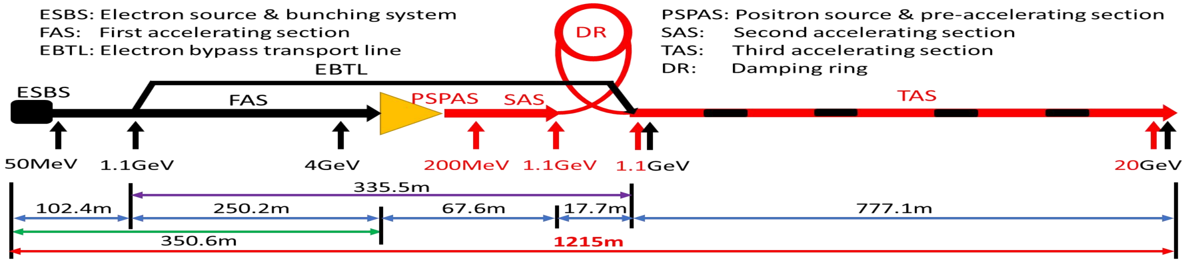


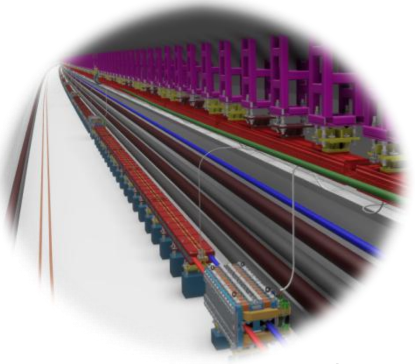
CEPC MDI



CEPC Civil Engineering

CEPC TDR S+C-band 20GeV linac injector





CEPC Energy Range and Upgrade Potential

CEPC Ecm Choices

- The **CEPC** is a circular e+e- collider **Higgs Factory** located in a 100 km circumference tunnel beneath the ground. The accelerator complex consists of a linear accelerator (Linac), a damping ring (DR), the full energy injection Booster and the Collider (both booster and collider rings are in the same tunnel) and several connecting transfer lines.
- The center-of-mass energy of the **CEPC** is set at **240 GeV**, and at that collision energy the CEPC will serve as a Higgs factory, generating millions of Higgs particles. The design also allows for operation at Ecm of **91 GeV** as a Z factory, and at **160 GeV** as a W factory, with the number of Z particles produced more than one trillion, and W+W- pairs more than 20 million.
- CEPC Ecm could also be upgradable to tt-bar energy of 360GeV.
- See CEPC Accelerator white paper to Snowmass21, arXiv:2203.09451

CEPC Luminosity Range and Upgrade Potential

CEPC Luminosity Choices

- According to the CEPC TDR design, the circulating CEPC beams radiate 30 MW (upgradable to 50MW) synchrotron radiation power per beam, and the total facility power consumption is kept below 300 MW (upgradable to 500MW).
- There are two detectors in CEPC.
- The luminosities (30MW SR power/beam) at the Higgs, W, Z-pole and tt-bar energies are 5×10^{34} $cm^{-2}s^{-1}$, 16×10^{34} $cm^{-2}s^{-1}$, 115×10^{34} $cm^{-2}s^{-1}$ and 0.5×10^{34} $cm^{-2}s^{-1}$ per interaction point, respectively. The AC power is 270MW.
- When beam SR power is upgraded to 50MW/beam, the luminosities at the **Higgs, W, Z-pole** and **ttbar** energies are **8.3×10^{34} $cm^{-2}s^{-1}$, 27×10^{34} $cm^{-2}s^{-1}$, 192×10^{34} $cm^{-2}s^{-1}$**, and **0.8×10^{34} $cm^{-2}s^{-1}$** per interaction point, respectively. The AC power is 350MW.
- **The CEPC luminosities submitted to Snowmass21 at Higgs, W, Z, and tt-bar energies are the luminisities with 50MW SR power/beam (upgrade case) for physics performance evalution** (CEPC Accelerator white paper to Snowmass21 arXiv:2203.09451)

CEPC TDR Parameters (upgrade)

	Higgs	W	Z	ttbar
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	50			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	120	80	45.5	180
Energy loss per turn [GeV]	1.8	0.357	0.037	9.1
Piwinski angle	5.94	6.08	24.68	1.21
Bunch number	415	2162	19918	58
Bunch spacing [ns]	385	154	15(10% gap)	2640
Bunch population [10^{10}]	14	13.5	14	20
Beam current [mA]	27.8	140.2	1339.2	5.5
Momentum compaction [10^{-5}]	0.71	1.43	1.43	0.71
Phase advance of arc FODOs [degree]	90	60	60	90
Beta functions at IP (bx/by) [m/mm]	0.33/1	0.21/1	0.13/0.9	1.04/2.7
Emittance (ex/ey) [nm/pm]	0.64/1.3	0.87/1.7	0.27/1.4	1.4/4.7
Beam size at IP (sx/sy) [um/nm]	15/36	13/42	6/35	39/113
Bunch length (SR/total) [mm]	2.3/3.9	2.5/4.9	2.5/8.7	2.2/2.9
Energy spread (SR/total) [%]	0.10/0.17	0.07/0.14	0.04/0.13	0.15/0.20
Energy acceptance (DA/RF) [%]	1.7/2.2	1.2/2.5	1.3/1.7	2.3/2.6
Beam-beam parameters (xx/xy)	0.015/0.11	0.012/0.113	0.004/0.127	0.071/0.1
RF voltage [GV]	2.2 (2cell)	0.7 (2cell)	0.12 (1cell)	10 (5cell)
RF frequency [MHz]	650			
Beam lifetime [min]	20	55	80	18
Luminosity per IP[10^{34}/cm^2/s]	8.3	26.6	191.7	0.8

This parameter table is used by US Snowmass21 for CEPC physics performance potential evaluation

CEPC Accelerator white paper to Snowss21 arXiv:2203.09451

The AC power is 350MW

CEPC TDR Norminal Parameters

	Higgs	W	Z	ttbar
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	**30**			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	120	80	45.5	180
Energy loss per turn [GeV]	1.8	0.357	0.037	9.1
Piwinski angle	5.94	6.08	24.68	1.21
Bunch number	249	1297	11951	35
Bunch spacing [ns]	636	257	23 (10% gap)	4524
Bunch population [10^{10}]	14	13.5	14	20
Beam current [mA]	16.7	84.1	803.5	3.3
Momentum compaction [10^{-5}]	0.71	1.43	1.43	0.71
Phase advance of arc FODOs [degree]	90	60	60	90
Beta functions at IP (bx/by) [m/mm]	0.33/1	0.21/1	0.13/0.9	1.04/2.7
Emittance (ex/ey) [nm/pm]	0.64/1.3	0.87/1.7	0.27/1.4	1.4/4.7
Beam size at IP (sx/sy) [um/nm]	15/36	13/42	6/35	39/113
Bunch length (SR/total) [mm]	2.3/3.9	2.5/4.9	2.5/8.7	2.2/2.9
Energy spread (SR/total) [%]	0.10/0.17	0.07/0.14	0.04/0.13	0.15/0.20
Energy acceptance (DA/RF) [%]	1.7/2.2	1.2/2.5	1.3/1.7	2.3/2.6
Beam-beam parameters (xx/xy)	0.015/0.11	0.012/0.113	0.004/0.127	0.071/0.1
RF voltage [GV]	2.2 (2cell)	0.7 (2cell)	0.12 (1cell)	10 (5cell)
RF frequency [MHz]	650			
Beam lifetime [min]	20	55	80	18
Luminosity per IP[10^{34}/cm^2/s]	**5.0**	**16.0**	**115.0**	**0.5**

CEPC Accelerator white paper to Snowss21 arXiv:2203.09451

The AC power is 270MW

CEPC CDR-Higgs

Peak Luminosity = 3 × $10^{34} cm^{-2}s^{-1}$

Ingetrated Luminosity = 5.6 ab^{-1}

Higgs annual luminosity =0.8 ab^{-1}

CEPC TDR-Higgs

Peak Luminosity = 5 × $10^{34} cm^{-2}s^{-1}$

Ingetrated Luminosity = 9.3 ab^{-1}

Higgs annual luminosity =1.3 ab^{-1}

CEPC TDR-Higgs (upgrade)

Peak Luminosity = 8.3 × $10^{34} cm^{-2}s^{-1}$

Ingetrated Luminosity = 15.4 ab^{-1}

Higgs annual luminosity =2.2 ab^{-1}

These parameters are used for Snowmass21

CEPC CDR Vol. I, Accelerator

IHEP-CEPC-DR-2018-01

IHEP-AC-2018-01

CEPC

Conceptual Design Report

Volume I - Accelerator

The CEPC Study Group

August 2018

CEPC Accelerator Snowmass 21 AF White Paper

Snowmass2021 White Paper AF3- CEPC

CEPC Accelerator Study Group[1]

1. Design Overview

1.1 Introduction and status

The discovery of the Higgs boson at CERN's Large Hadron Collider (LHC) in July 2012 raised new opportunities for large-scale accelerators. The Higgs boson is the heart of the Standard Model (SM), and is at the center of many biggest mysteries, such as the large hierarchy between the weak scale and the Planck scale, the nature of the electroweak phase transition, the original of mass, the nature of dark matter, the stability of vacuum, etc. and many other related questions. Precise measurements of the properties of the Higgs boson serve as probes of the underlying fundamental physics principles of the SM and beyond. Due to the modest Higgs boson mass of 125 GeV, it is possible to produce it in the relatively clean environment of a circular electron–positron collider with high luminosity, new technologies, low cost, and reduced power consumption. In September 2012, Chinese scientists proposed a 240 GeV *Circular Electron Positron Collider* (CEPC), serving two large detectors for Higgs studies and other topics as shown in Fig. 1. The ~100 km tunnel for such a machine could also host a *Super Proton Proton Collider* (SPPC) to reach energies well beyond the LHC.

The CEPC is a large international scientific project initiated and to be hosted by China. It was presented for the first time to the international community at the ICFA Workshop*"Accelerators for a Higgs Factory: Linear vs. Circular"* (HF2012) in November 2012 at Fermilab. A Preliminary Conceptual Design Report (Pre-CDR, the White Report)[1] was published in March 2015, followed by a Progress Report (the Yellow Report)[2] in April 2017, in which the CEPC accelerator baseline choice was made. The Conceptual Design Report (CEPC Accelerator CDR, *the Blue Report*) [3] has been completed in July 2018 by hundreds of scientists and engineers after an international review from June 28-30, 2018 and was formally released in Nov. 2018. In May 2019, CEPC accelerator document was submitted to European High Energy Physics Strategy workshop for worldwide discussions [4]. After the CEPC CDR, CEPC accelerator entered the phase of Technical Design Report (TDR) endorsed by CEPC International Advisory Committee (IAC). In TDR phase, CEPC optimization design with higher performance compared with CDR and the key technologies such as 650MHz high power and high efficiency klystron, high quality SRF accelerator technology, high precision magnets for booster and collider rings, vacuum system, MDI, etc. have been carried out, and the CEPC accelerator TDR will be completed at

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CEPC CDR Vol. II, Physics/Detector

IHEP-CEPC-DR-2018-02

IHEP-EP-2018-01

IHEP-TH-2018-01

CEPC

Conceptual Design Report

Volume II - Physics & Detector

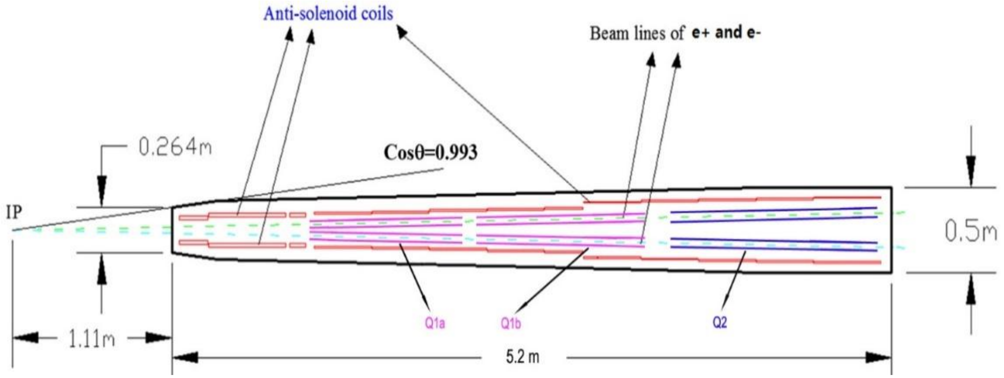
The CEPC Study Group

October 2018

CEPC Collider Ring IR for all Energies

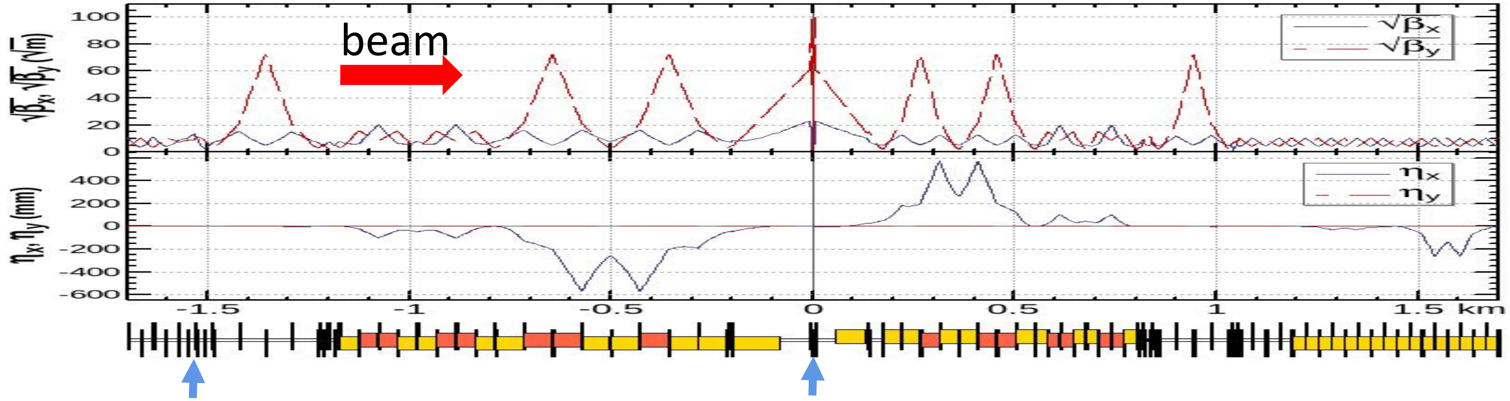
(Higgs, W, Z and tt-bar)

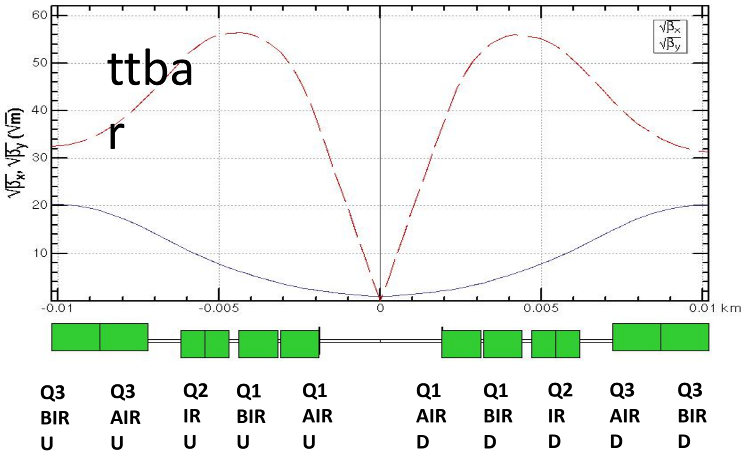
For the interaction region, the IP beta functions are refitted with the different combination of final doulets and the matching quadruples.



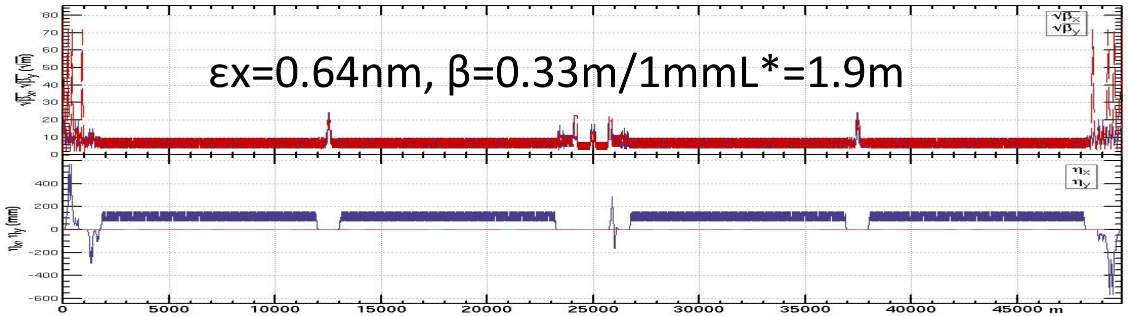
	QD	QF
Z	Q1A	Q1B
W/H	Q1A+Q1B	Q2
ttbar	Q1A+Q1B+Q2	add quad Q3A and Q3B

Higgs: L*=1.9m, LQ1A=1.22m, LQ1B=1.22m, LQ2=1.5m, d=0.3m, GQ1A=142T/m, GQ1B=96T/m, GQ2=56T/m



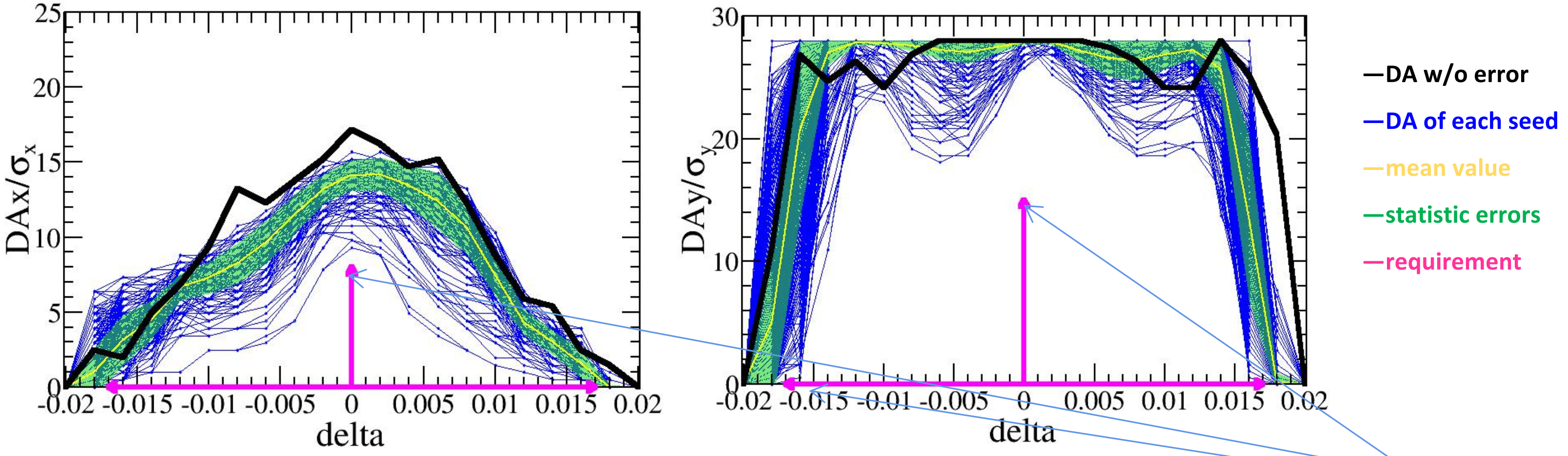


CEPC Collider Ring TDR Lattice Dynamic Apertures with Errors for Higgs



Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
Dipole	0.10	0.10	0.1	0.01%
Arc Quadrupole	0.10	0.10	0.1	0.02%
IR Quadrupole	**0.05**	**0.05**	**0.05**	
Sextupole	0.10	0.10	0.1	

Effects included in tracking
Synchrotron motion
Radiation loss in all magnets
Tapering
Crab waist sextupole
Maxwellian fringes
Kinematic terms
Finite length of sextupole



DA design goal
$8\sigma_x \times 15\sigma_y \,\&\, 0.017$

Lattice version cepc.lat.diff.8713.346.2p used
The DA with erros of TDR lattice satisfiy the design goal

Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
IR Quadrupole	**0.1**	**0.1**	**0.01**	

CEPC Booster TDR Parameters

- Injection energy: 20GeV
- Max energy: 120GeV → 180GeV
- Lower emittance – new lattice

Injection

		tt	*H*	*W*	*Z*	
Beam energy	GeV	20				
Bunch number		37	240	1230	3840	5760
Threshold of single bunch current	μA	7.18	4.58	3.8		
Threshold of beam current (limited by coupled bunch instability)	mA	27				
Bunch charge	nC	1.07	0.78	0.81	0.89	0.92
Single bunch current	μA	3.2	2.3	2.4	2.7	2.78
Beam current	mA	0.12	0.56	2.99	10.3	16.0
Energy spread	%	0.016				
Synchrotron radiation loss/turn	MeV	1.3				
Momentum compaction factor	10^{-5}	1.12				
Emittance	nm	0.035				
Natural chromaticity	H/V	-372/-269				
RF voltage	MV	438.0	197.1	122.4		
Betatron tune ν_x/ν_y		321.23/117.18				
Longitudinal tune		0.13	0.087	0.069		
RF energy acceptance	%	5.4	3.6	2.8		
Damping time	s	10.4				
Bunch length of linac beam	mm	0.5				
Energy spread of linac beam	%	0.16				
Emittance of linac beam	nm	10				

Extraction		*tt*	*H*		*W*	*Z*	
		Off axis injection	Off axis injection	On axis injection	Off axis injection	Off axis injection	
Beam energy	GeV	180	120		80	45.5	
Bunch number		37	240	233+7	1230	3840	5760
Maximum bunch charge	nC	0.96	0.7	23.2	0.73	0.8	0.83
Maximum single bunch current	μA	2.9	2.1	69.7	2.2	2.4	2.5
Threshold of single bunch current	μA	95	79				
Threshold of beam current (limited by RF system)	mA	0.3	1		4	10	16
Beam current	mA	0.11	0.51	0.99	2.69	9.2	14.4
Bunches per pulse of Linac		1	1		1	2	
Time for ramping up	s	7.3	4.5		2.7	1.6	
Injection duration for top-up (Both beams)	s	30. 0	23.3	32.8	39.3	134.7	128.2
Injection interval for top-up	s	65	38		155	153.5	
Current decay during injection interval		3%					
Energy spread	%	0.15	0.099		0.066	0.037	
Synchrotron radiation loss/turn	GeV	8.45	1.69		0.33	0.034	
Momentum compaction factor	10^{-5}	1.12					
Emittance	nm	2.83	1.26		0.56	0.19	
Natural chromaticity	H/V	-372/-269					
Betatron tune ν_x/ν_y		321.27/117.19					
RF voltage	GV	9.3	2.05		0.59	0.284	
Longitudinal tune		0.13	0.087		0.069	0.069	
RF energy acceptance	%	1.34	1.31		1.6	2.6	
Damping time	ms	14.2	47.6		160.8	879	
Natural bunch length	mm	2.0	2.0		1.7	0.96	
Full injection from empty ring	h	0.1	0.14	0.16	0.27	1.8	0.8

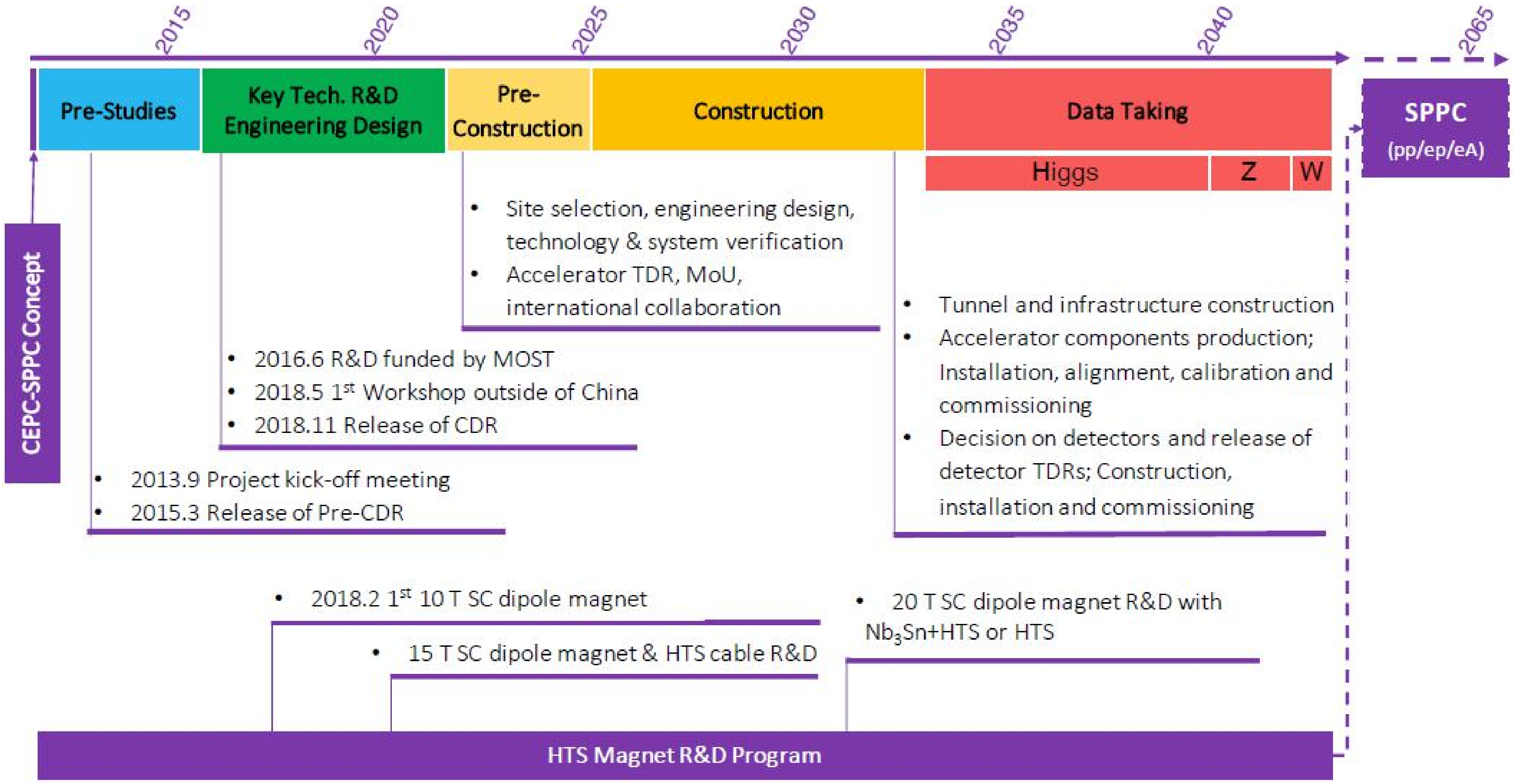
CEPC 20GeV Linac Injector TDR Parameters

- **Baseline scheme**
  - 20 GeV
    - Low magnetic field & large magnetic field range
    - C-band
      - Higher gradient → Shorter linac tunnel length
      - Small aperture & Strong wakefield
  - 10 nm
    - High luminosity
  - 100 Hz
    - Injection efficiency
    - High luminosity Z need faster injection process
      - 200 Hz
      - 100 Hz & two-bunch-per-pulse
      - 200 Hz & two-bunch-per-pulse (or)

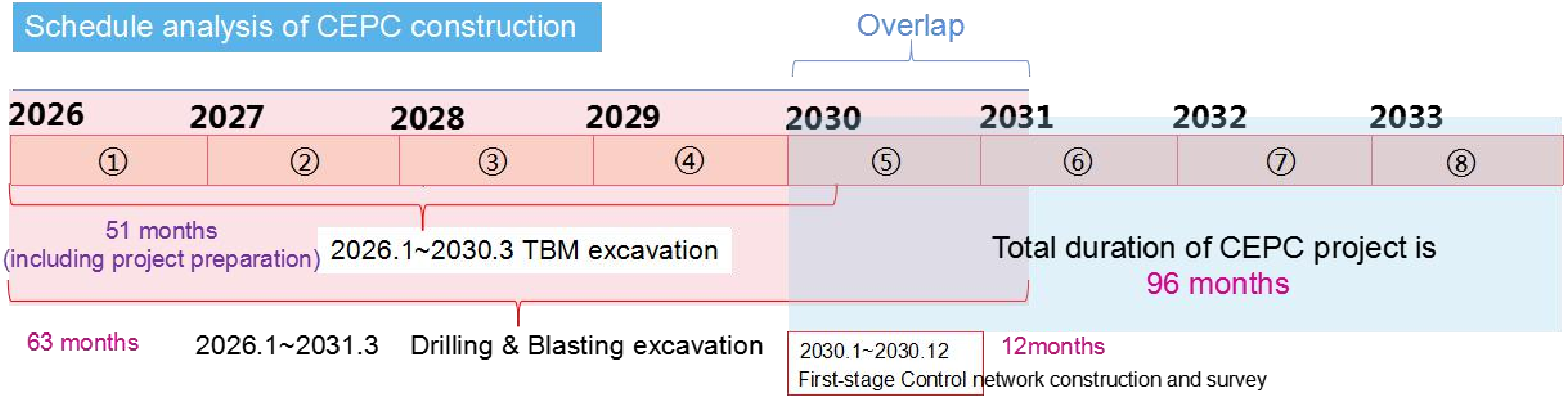
Parameter	Symbol	Unit	Baseline
e^- /e^+ beam energy	E_{e-}/E_{e+}	GeV	20
Repetition rate	f_{rep}	Hz	100
e^- /e^+ bunch population	Ne-/Ne+	$\times 10^{10}$	0.94(1.88)
		nC	1.5 (3)
Energy spread (e^- /e^+)	σ_E		1.5×10^{-3}
Emittance (e^- /e^+)	$\varepsilon_{x,y}$	nm	10

Parameter	Unit	S-band	C-band
Frequency	MHz	2860	5720
Length	m	3.1	1.8
Cavity mode		2π/3	3π/4
Aperture diameter	mm	20~24	11.8~16
Gradient	MV/m	21	45

CEPC Project Timeline



Civil Construction and Machine Installation Plan



1.CEPC production Including civil works and installation of physical equipment. It will begin in 2026 and end in 2033, The total duration of CEPC project is 96 months.

2.The total civil works period is 63 months.

3.The total installation period of physical equipment is 48 months

4. The Overlapping period of civil works and equipment installation is 15 months

2030.10~2031.9 Second-stage Control network construction and survey — 12months

2031.1~2032.6 Support installation and alignment — 18 months

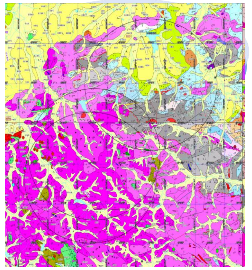
2031.3~2032.8 Dipole magnets installation — 18 months

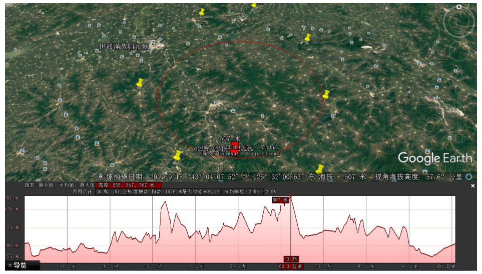
26032.9~2033. Installation of other equipment — 10 months

2033.7~ 2033.12 Overall alignment and commissioning — 6 months

CEPC Siting Status

Three companies are working on siting and issues





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2019.12月8-11 and 2020.1.8-10 Chuangchun sitings update

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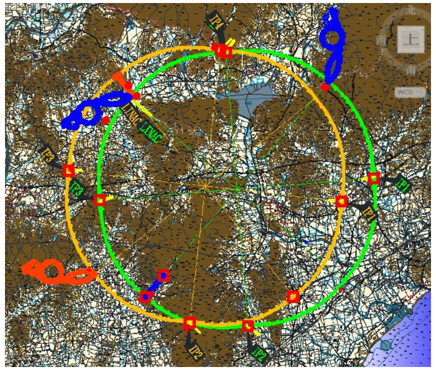
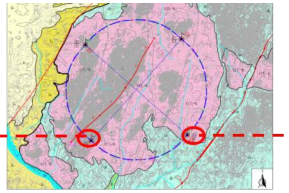


2020.9.14-18 Qinhuangdao updated



In 2021,Changsha site has some progress with local government starting a review process

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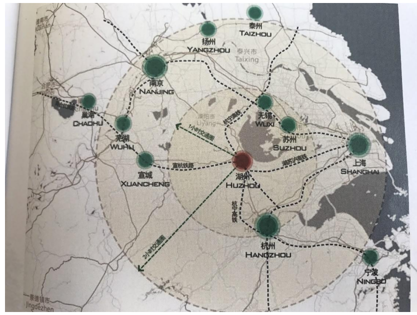
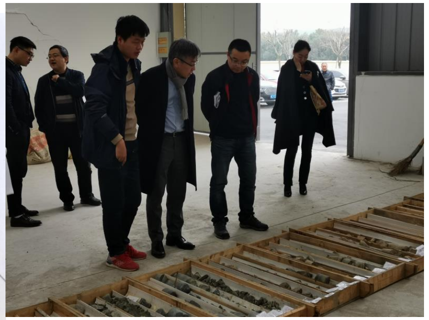
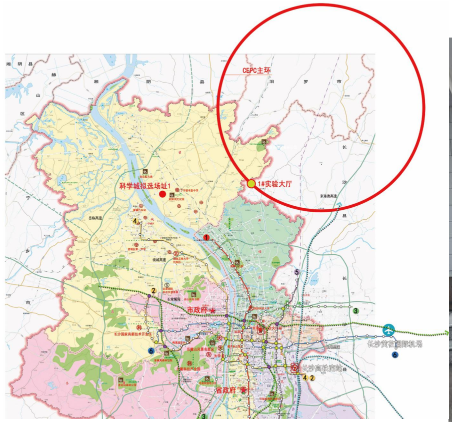




2019.12.16-17 Huzhou siting update



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2019.08.19-20 Changsha siting update

1) Qinhuangdao, Hebei Province (Completed in 2014)

2) Huangling, Shanxi Province (Completed in 2017)

3) Shenshan, Guangdong Province(Completed in 2016)

4) Huzhou, Zhejiang Province (Started in March 2018)

5) Chuangchun, Jilin Province (Started in May 2018)

6) Changsha, Hunan Province (Started in Dec. 2018)

Perspective for Accelerator TDR and EDR Plans

- **CEPC Accelerator TDR completion time: Dec. 2022**
  -Consistent TDR high luminosity parameter design as Higgs factory
  -Key components with prototyping, techincal feasibility demonstrated, no technical show stopper
  -Design and R&D technical documentation (Data, drawings, etc.)
  -CEPC accelerator TDR document release in 2023

- **CEPC Accelerator EDR Phase Plan:Jan. 2023-Dec. 2025**
  -CEPC site study converging to one or two with detailed feasibility studies (tunnel and infrastructures, environment)
  -Engineering design of CEPC accelerator systems and components towards fabrication in an industrial way
  -Site dependent civil engineering design implementation preparation
  -EDR document completed for government's approval of starting construction around 2026 (the starting of the "15th five year plan")

References and Useful Links

References:

1) CEPC accelerator white paper to US Snowmass21 AF3, arXiv:2203.09451

2) CEPC CDR Vol. I, Accelerator,http://cepc.ihep.ac.cn/CEPC_CDR_Vol1_Accelerator.pdf

3) CEPC CDR Vol. II, Physics and Detector, http://cepc.ihep.ac.cn/CEPC_CDR_Vol2_Physics-Detector.pdf

4) F. An, et al., Presicion Higgs physics at the CEPC, Chinese Physics C, Vol. 4, No. 4 (2019) 043002

CEPC Video (BIM design)

1) http://cepc.ihep.ac.cn/Qinhuang_Island.mp4

2) http://cepc.ihep.ac.cn/Huzhou.mp4

3) http://cepc.ihep.ac.cn/Changsha.mp4

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