中国科学院高能物理研究所
Institute of High Energy Physics
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Circular Electron Positron Collider (CEPC)

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On behalf of CEPC Accelerator Group

65th ICFA Advanced Beam Dynamics Workshop on High Luminosity Circular e+e- Colliders (eeFACT2022)

Sept. 16, 2022

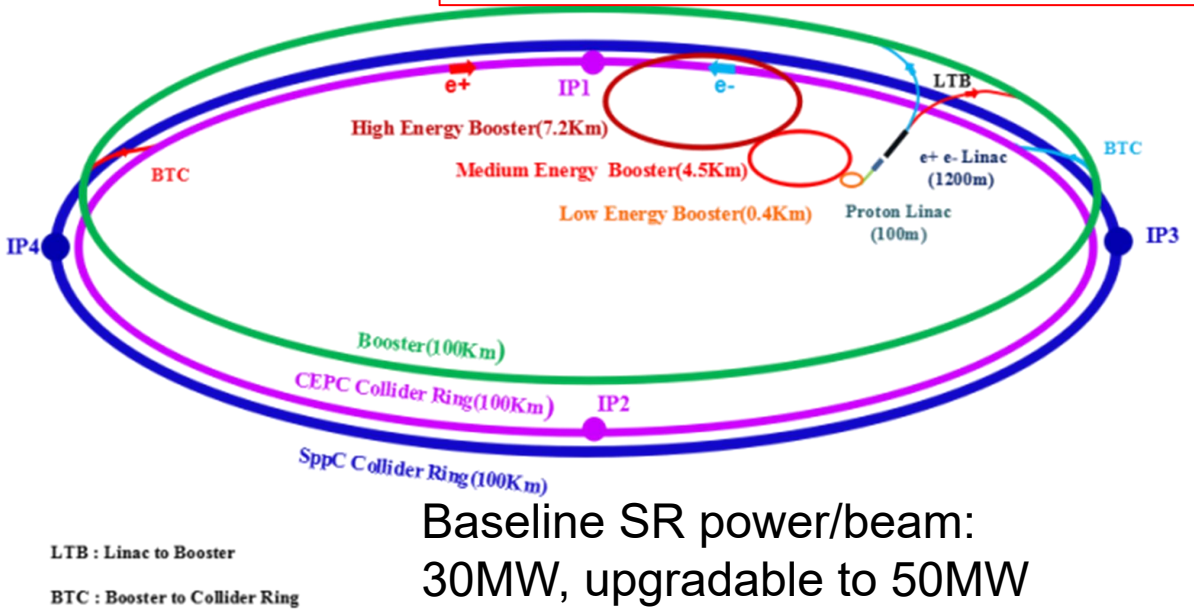
Contents

CEPC-SppC Physics Goals in TDR

Introduction

- **Circular Electron-Positron Collider** (91, 160, **240 GeV**, 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, τ and QCD studies**
- **Super proton-proton Collider(~125 TeV)**
  - **Directly search for new physics beyond SM**
  - **Precision test of SM**
    - **e.g., h^3 & h^4 couplings**

The discoveries of Higgs boson around 125GeV at CERN on LHC on July 4, 2012 and the gravitation waves on LIGO in USA on February 11, 2016 provide unprecedented opportunities to our better understandings of mysterious universe

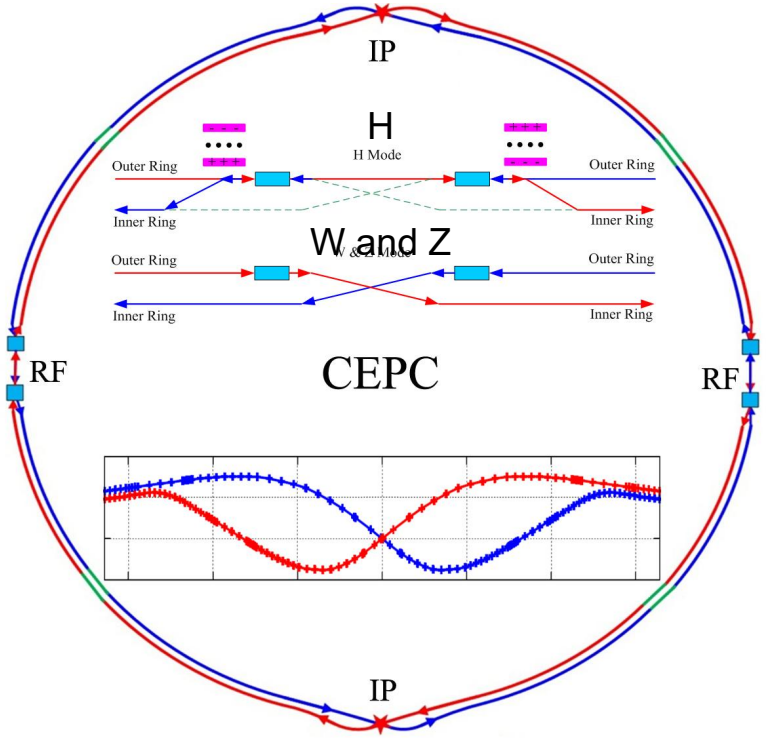


Baseline SR power/beam: 30MW, upgradable to 50MW

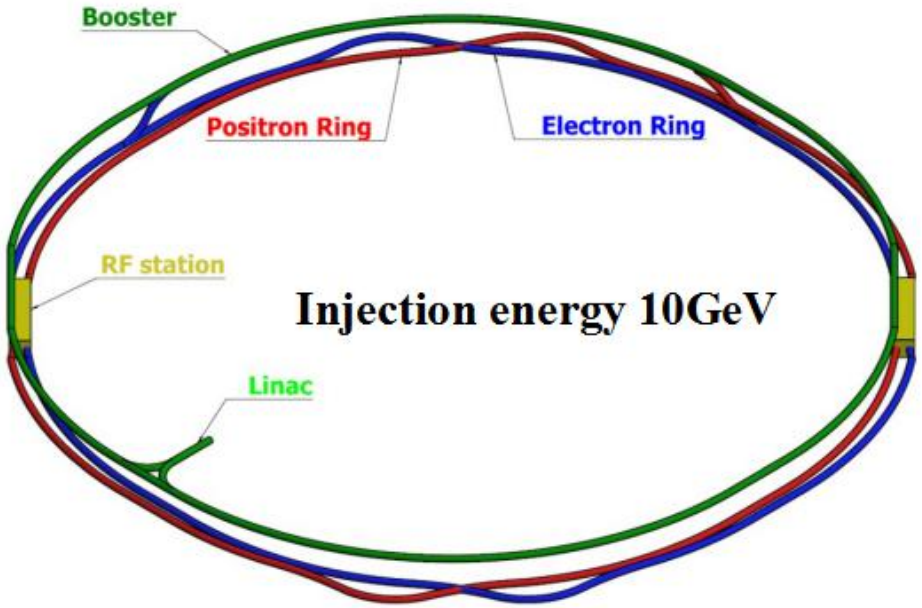
Review of CEPC Accelerator System Design and Power Consumptions in CDR

CEPC CDR Baseline Layout

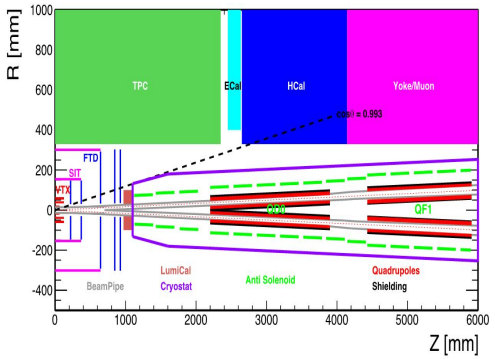
CEPC as a Higgs Factory: H, W, Z, followed by a SppC ~100TeV

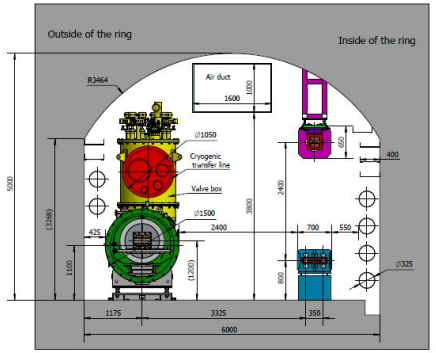


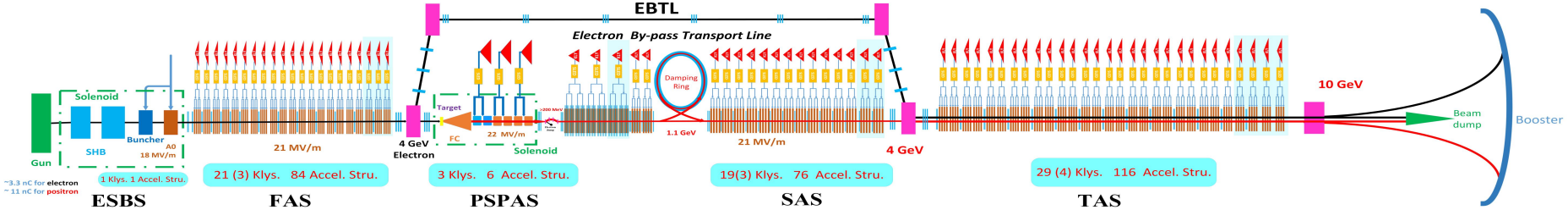
CEPC collider ring (100km)

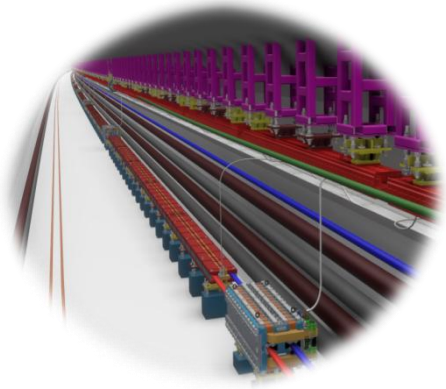


CEPC booster ring (100km)









CEPC Linac injector (1.2km, 10GeV)

CEPC CDR Parameters (30MW)

	Higgs	*W*	*Z (3T)*	*Z (2T)*
Number of IPs	2			
Beam energy (GeV)	**120**	**80**	**45.5**	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (bunch spacing)	**242 (0.68μs)**	**1524 (0.21μs)**	**12000 (25ns+10%gap)**	
Beam current (mA)	17.4	87.9	461.0	
Synchrotron radiation power /beam (MW)	**30**	**30**	**16.5**	
Bending radius (km)	10.7			
Momentum compact (10^{-5})	1.11			
β function at IP β_x^*/β_y^* (m)	**0.36/0.0015**	**0.36/0.0015**	**0.2/0.0015**	**0.2/0.001**
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_y	0.031/0.109	0.013/0.106	0.0041/0.056	0.0041/0.072
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Natural bunch length σ_z (mm)	2.72	2.98	2.42	
Bunch length σ_z (mm)	3.26	5.9	8.5	
HOM power/cavity (2 cell) (kw)	0.54	0.75	**1.94**	
Natural energy spread (%)	0.1	0.066	0.038	
Energy acceptance requirement (%)	**1.35**	**0.4**	**0.23**	
Energy acceptance by RF (%)	2.06	1.47	1.7	
Photon number due to beamstrahlung	0.1	0.05	0.023	
Lifetime _simulation (min)	100			
Lifetime (hour)	**0.67**	**1.4**	**4.0**	**2.1**
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP *L* ($10^{34}cm^{-2}s^{-1}$)	**2.93**	**10.1**	**16.6**	**32.1**

CEPC Collider Ring SRF Parameters (CDR)

J.Y. Zhai

Collider parameters: 20180222	H	W	Z
SR power / beam [MW]	30	30	16.5
RF voltage [GV]	2.17	0.47	0.1
Beam current / beam [mA]	17.4	87.9	461
Bunch charge [nC]	24	24	12.8
Bunch number / beam	242	1220	12000
Bunch length [mm]	3.26	6.53	8.5
Cavity number (650 MHz 2-cell)	240	2 x 108	2 x 60
Cavity gradient [MV/m]	19.7	9.5	3.6
Input power / cavity [kW]	250	278	276
Klystron power [kW] (2 cavities / klystron)	800	800	800
HOM power / cavity [kW]	0.54	0.86	1.94
Optimal Q_L	1.5E6	3.2E5	4.7E4
Optimal detuning [kHz]	0.17	1.0	18.3
Total cavity wall loss @ 2 K [kW]	6.6	1.9	0.2

CEPC Booster Parameters @ injection (10GeV)(CDR)

D. Wang

		H	*W*	*Z*
Beam energy	GeV	10		
Bunch number		242	1524	6000
Threshold of single bunch current	μA	25.7		
Threshold of beam current (limited by coupled bunch instability)	mA	127.5		
Bunch charge	nC	0.78	0.63	0.45
Single bunch current	μA	2.3	1.8	1.3
Beam current	mA	0.57	2.86	7.51
Energy spread	%	0.0078		
Synchrotron radiation loss/turn	keV	73.5		
Momentum compaction factor	10^{-5}	2.44		
Emittance	nm	0.025		
Natural chromaticity	H/V	-336/-333		
RF voltage	MV	62.7		
Betatron tune $\nu_x/\nu_y/\nu_s$		263.2/261.2/0.1		
RF energy acceptance	%	1.9		
Damping time	s	90.7		
Bunch length of linac beam	mm	1.0		
Energy spread of linac beam	%	0.16		
Emittance of linac beam	nm	40~120		

CEPC Booster Parameters @extraction (CDR)

D. Wang

		H		*W*	*Z*
		Off axis injection	On axis injection	Off axis injection	Off axis injection
Beam energy	GeV	120		80	45.5
Bunch number		242	235+7	1524	6000
Maximum bunch charge	nC	0.72	24.0	0.58	0.41
Maximum single bunch current	μA	2.1	70	1.7	1.2
Threshold of single bunch current	μA	300			
Threshold of beam current (limited by RF power)	mA	1.0		4.0	10.0
Beam current	mA	0.52	1.0	2.63	6.91
Injection duration for top-up (Both beams)	s	25.8	35.4	45.8	275.2
Injection interval for top-up	s	73.1		153.0	438.0
Current decay during injection interval		3%			
Energy spread	%	0.094		0.062	0.036
Synchrotron radiation loss/turn	GeV	1.52		0.3	0.032
Momentum compaction factor	10^{-5}	2.44			
Emittance	nm	3.57		1.59	0.51
Natural chromaticity	H/V	-336/-333			
Betatron tune ν_x/ν_y		263.2/261.2			
RF voltage	GV	1.97		0.585	0.287
Longitudinal tune		0.13		0.10	0.10
RF energy acceptance	%	1.0		1.2	1.8
Damping time	ms	52		177	963
Natural bunch length	mm	2.8		2.4	1.3
Injection duration from empty ring	h	0.17		0.25	2.2

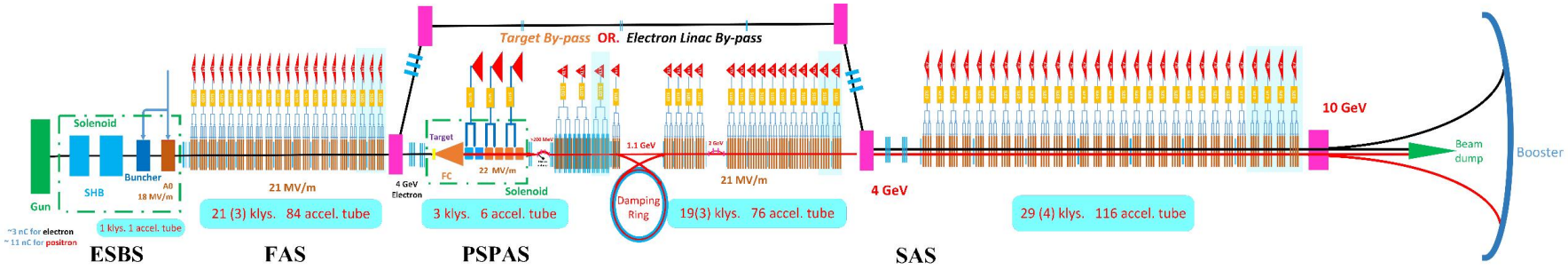
CEPC Booster SRF Parameters (CDR)

J.Y. Zhai

10 GeV injection	H	W	Z
Extraction beam energy [GeV]	120	80	45.5
Bunch number	242	1524	6000
Bunch charge [nC]	0.72	0.576	0.384
Beam current [mA]	0.52	**2.63**	**6.91**
Extraction RF voltage [GV]	1.97	0.585	0.287
Extraction bunch length [mm]	2.7	2.4	1.3
Cavity number in use (1.3 GHz TESLA 9-cell)	96	64	32
Gradient [MV/m]	19.8	8.8	8.6
Q_L	1E7	6.5E6	1E7
Cavity bandwidth [Hz]	130	200	130
Beam peak power / cavity [kW]	8.3	12.3	6.9
Input peak power per cavity [kW] (with detuning)	18.2	12.4	7.1
Input average power per cavity [kW] (with detuning)	0.7	0.3	0.5
SSA peak power [kW] (one cavity per SSA)	25	**25**	**25**
HOM average power per cavity [W]	0.2	0.7	**4.1**
Q_0 @ 2 K at operating gradient (long term)	1E10	1E10	1E10
Total average cavity wall loss @ 2 K eq. [kW]	0.2	0.01	0.02

CEPC Linac Injector-CDR

J. R. Zhang
C. meng



Parameter	Symbol	Unit	Baseline	Design reached
e^-/e^+ beam energy	E_{e-}/E_{e+}	GeV	**10**	**10**
Repetition rate	f_{rep}	Hz	**100**	**100**
e^-/e^+ bunch population	N_{e-}/N_{e+}		$> 9.4\times10^9$	**1.9×10^{10} / 1.9×10^{10}**
		nC	**> 1.5**	**3.0**
Energy spread (e^-/e^+)	σ_e		**$< 2\times10^{-3}$**	**1.5×10^{-3} / 1.6×10^{-3}**
Emittance (e^-/e^+)	ε_r	nm· rad	**< 120**	**5 / 40 ~120**
Bunch length (e^-/e^+)	σ_l	mm		**1 / 1**
e^- beam energy on Target		GeV	4	**4**
e^- bunch charge on Target		nC	10	**10**

CEPC 30MW (CDR)

	System for Higgs (30MW)	Location and electrical demand(MW)						Total (MW)
		Ring	Booster	LINAC	BTL	IR	Surface building	
1	RF Power Source	103.8	0.15	5.8				109.75
2	Cryogenic System	10.55	0.64			1.72		12.9
3	Vacuum System	9.784	3.792	0.646				14.222
4	Magnet Power Supplies	47.21	11.62	1.75	1.06	0.26		61.9
5	Instrumentation	0.9	0.6	0.2				1.7
6	Radiation Protection	0.25		0.1				0.35
7	Control System	1	0.6	0.2	0.005	0.005		1.81
8	Experimental devices					4		4
9	Utilities	31.79	3.53	1.38	0.63	1.2		38.53
10	General services	7.2		0.2	0.15	0.2	12	19.75
	Total	212.484	20.932	10.276	1.845	7.385	12	264.912

CEPC 50MW (CDR) (rough esitimate)

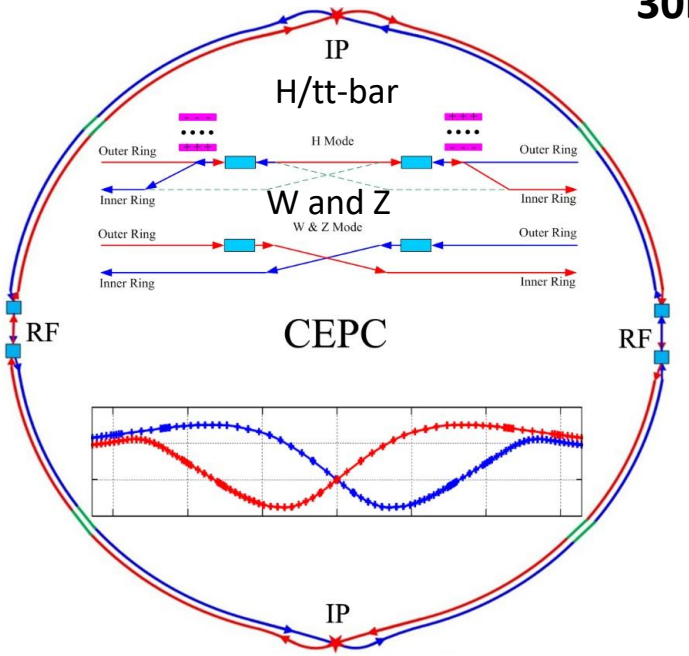
	Higgs （50MW）	Location and electrical demand(MW)						Total (MW)
		Ring	Booster	LINAC	BTL	IR	Surface building	
1	RF Power Source	182.238	0.15	5.8				187.188
2	Cryogenic System	10.55	0.64			1.72		12.9
3	Vacuum System	9.784	3.792	0.646				14.222
4	Magnet Power Supplies	47.21	11.62	1.75	1.06	0.26		61.9
5	Instrumentation	0.9	0.6	0.2				1.7
6	Radiation Protection	0.25		0.1				0.35
7	Control System	1	0.6	0.2	0.005	0.005		1.81
8	Experimental devices					4		4
9	Utilities	31.79	3.53	1.38	0.63	1.2		38.53
10	General services	7.2		0.4	0.15	0.2	12	19.95
	Total	291.295	20.932	10.476	1.845	7.385	12	342.55

CEPC TDR Accelerator System Design and Power Consumptions with Linac Injector Energy of of 30GeV

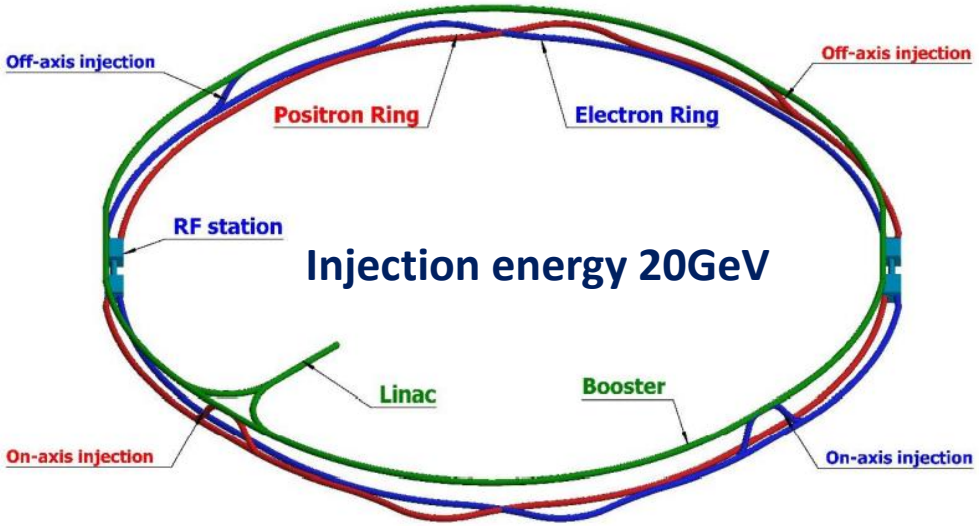
CEPC TDR Layout@20GeV Linac

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

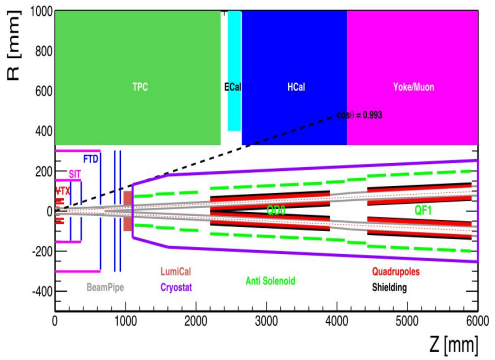
30MW SR power per beam (upgradale to 50MW)



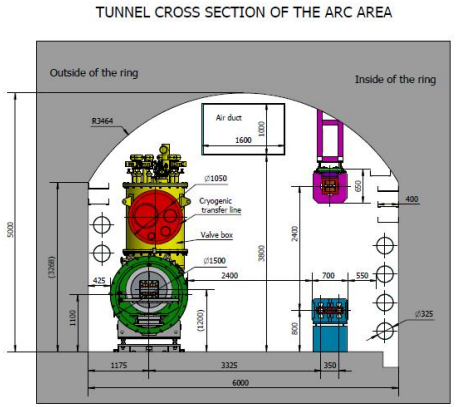
CEPC collider ring (100km)



CEPC booster ring (100km)

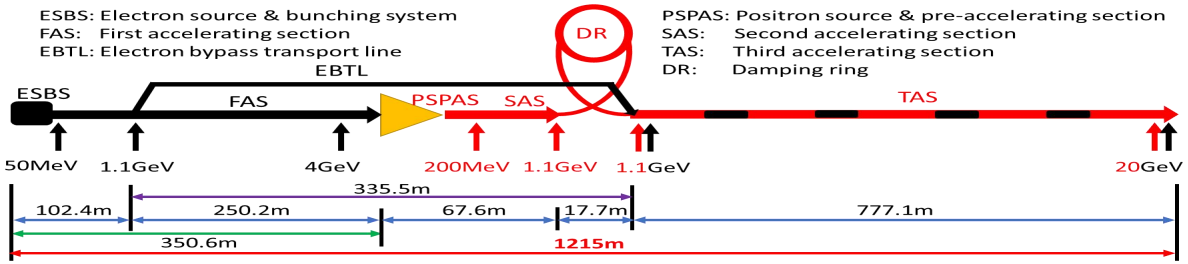


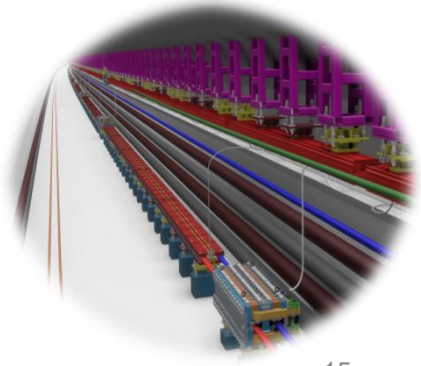
CEPC MDI



CEPC Civil Engineering

CEPC TDR S+C-band 20GeV linac injector

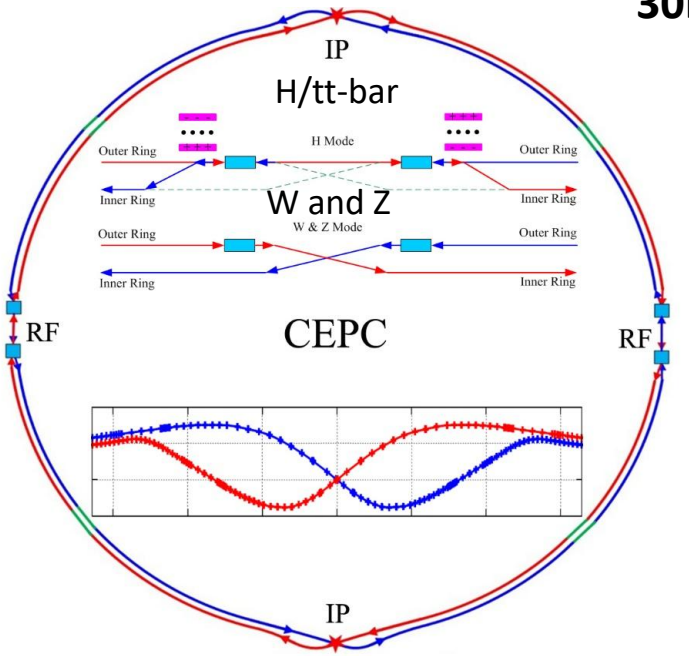




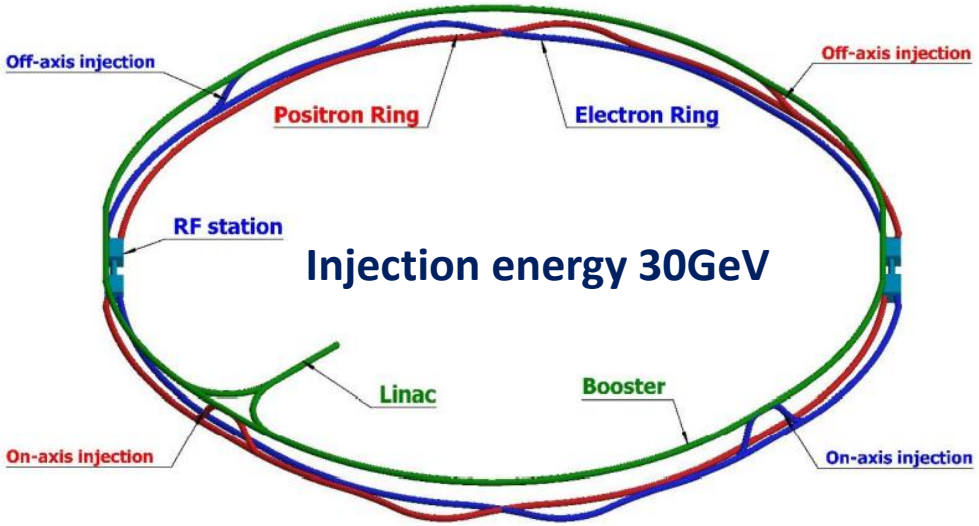
CEPC TDR Layout@30GeV Linac

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

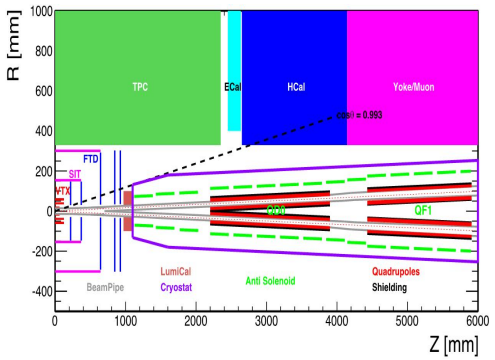
30MW SR power per beam (upgradale to 50MW)



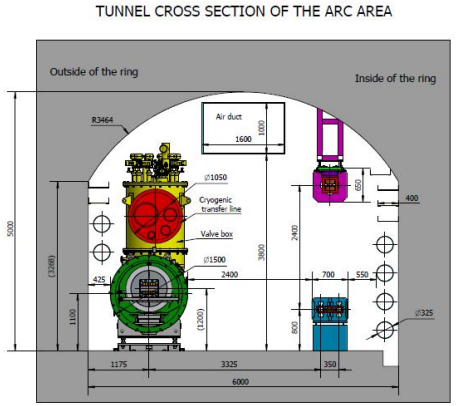
CEPC collider ring (100km)



CEPC booster ring (100km)



CEPC MDI

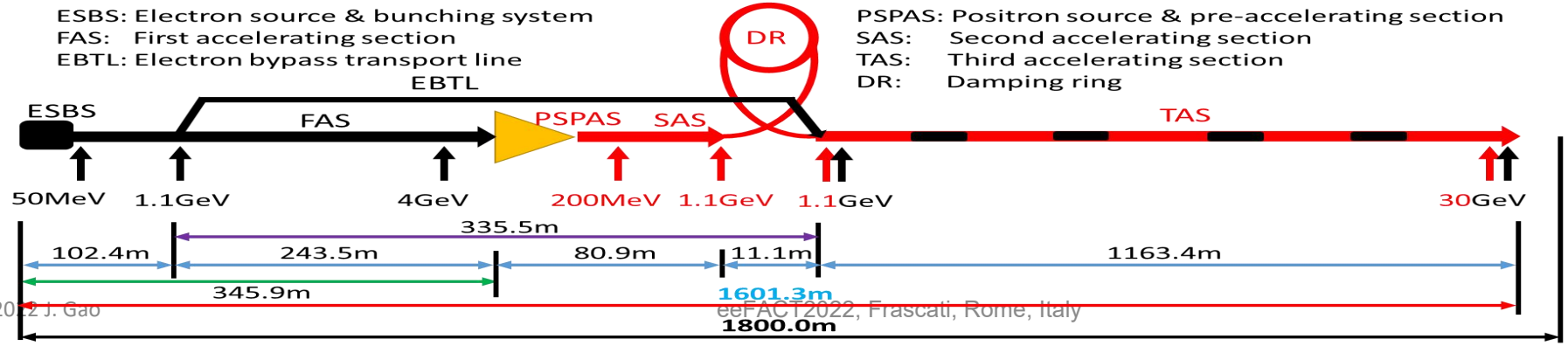


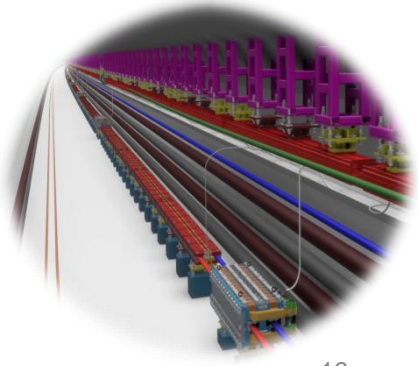
CEPC Civil Engineering

CEPC TDR S+C-band 30GeV linac injector

ESBS: Electron source & bunching system
FAS: First accelerating section
EBTL: Electron bypass transport line

PSPAS: Positron source & pre-accelerating section
SAS: Second accelerating section
TAS: Third accelerating section
DR: Damping ring





CEPC TDR Parameters (30MW)

	Higgs	Z	W	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	45.5	80	180
Energy loss per turn [GeV]	1.8	0.037	0.357	9.1
Piwinski angle	5.94	24.68	6.08	1.21
Bunch number	268	11934	1297	35
Bunch spacing [ns]	591 (53% gap)	23 (18% gap)	257	4524 (53% gap)
Bunch population [10^10]	13	14	13.5	20
Beam current [mA]	16.7	803.5	84.1	3.3
Momentum compaction [10^-5]	0.71	1.43	1.43	0.71
Beta functions at IP (bx/by) [m/mm]	0.3/1	0.13/0.9	0.21/1	1.04/2.7
Emittance (ex/ey) [nm/pm]	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Beam size at IP (sigx/sigy) [um/nm]	14/36	6/35	13/42	39/113
Bunch length (natural/total) [mm]	2.3/4.1	2.5/8.7	2.5/4.9	2.2/2.9
Energy spread (natural/total) [%]	0.10/0.17	0.04/0.13	0.07/0.14	0.15/0.20
Energy acceptance (DA/RF) [%]	1.6/2.2	1.3/1.7	1.2/2.5	2.3/2.6
Beam-beam parameters (ksix/ksiy)	0.015/0.11	0.004/0.127	0.012/0.113	0.071/0.1
RF voltage [GV]	2.2	0.12	0.7	10
RF frequency [MHz]	650	650	650	650
Longitudinal tune Qs	0.049	0.035	0.062	0.078
Beam lifetime (bhabha/beamstrahlung)[min]	39/40	80/18000	60/700	81/23
Beam lifetime [min]	20	80	55	18
Hour glass Factor	0.9	0.97	0.9	0.89
Luminosity per IP[1e34/cm^2/s]	5.0	115	16	0.5

CEPC TDR Parameters (50MW upgrade)

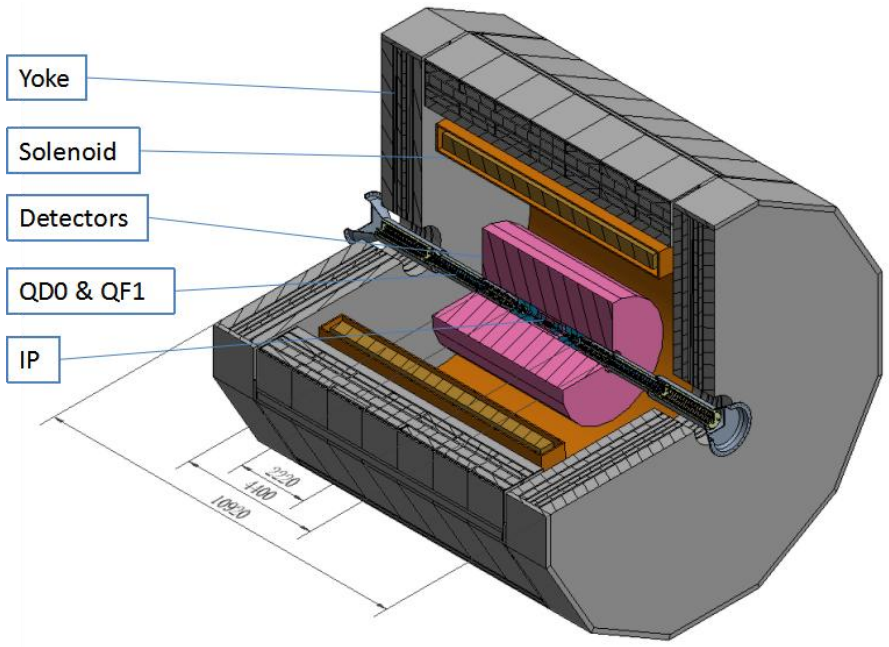
	Higgs	W	Z	ttbar
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	50			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	120	80	45.5	180
Energy loss per turn [GeV]	1.8	0.357	0.037	9.1
Piwinski angle	5.94	6.08	24.68	1.21
Bunch number	415	2162	19918	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

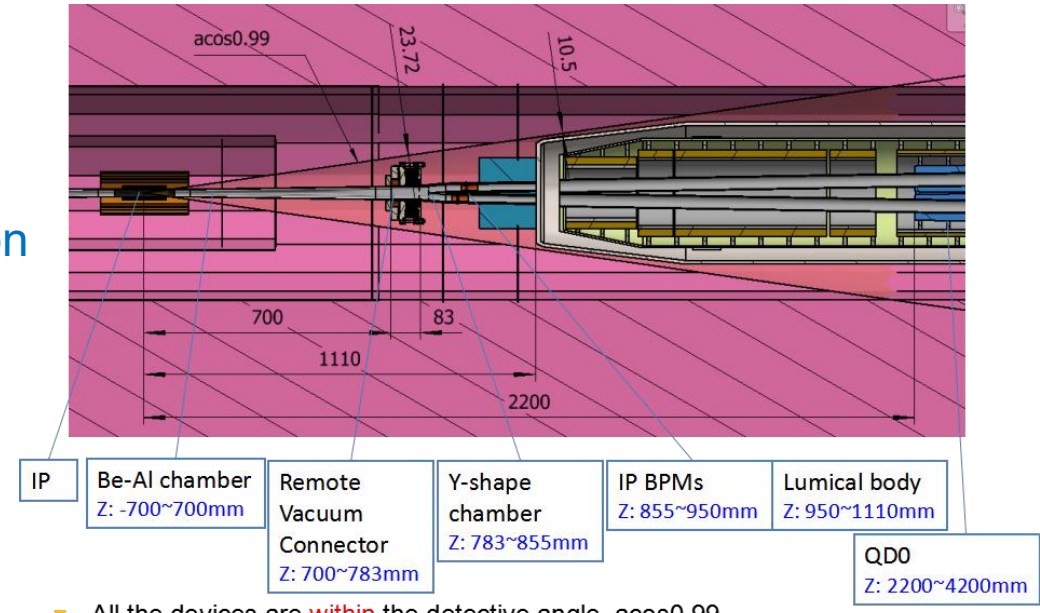
CEPC Accelerator white paper to Snowss21 arXiv:2203.09451

CEPC MDI

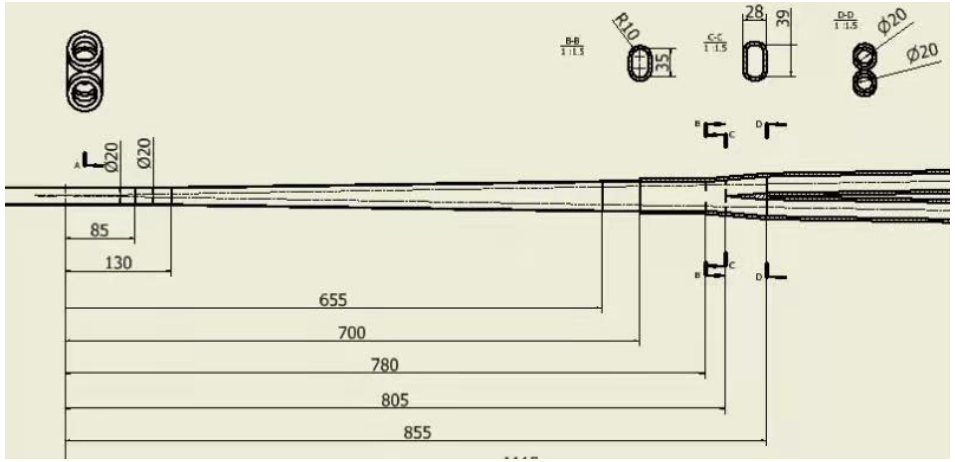
S. Bai



- IR Superconducting magnet design
- IR beam pipe
- Synchrotron radiation
- Beam loss background
- Shielding
- Mechanical support
- Full detector simulation



- All the devices are within the detective angle, acos0.99.



- Central beryllium pipe inner diameter changes from 28mm(CDR) to 20mm
- There is no SR photons hitting the central beam pipe in normal conditions.
- Single layer beam pipe with water cooling, SR heat load is not a problem.

L*=1.9m, θc=33mrad, βx*=0.33m, βy*=1.0mm, Emittance=0.68nm

- Strength requirements of anti-solenoids (peak field B_z~7.2T)
- Two-in-one type SC quadrupole coils (Peak field 3.8T & 141T/m) with room temperature vacuum chamber & Iron yoke

CEPC TDR RF Parameters (Collider Ring)

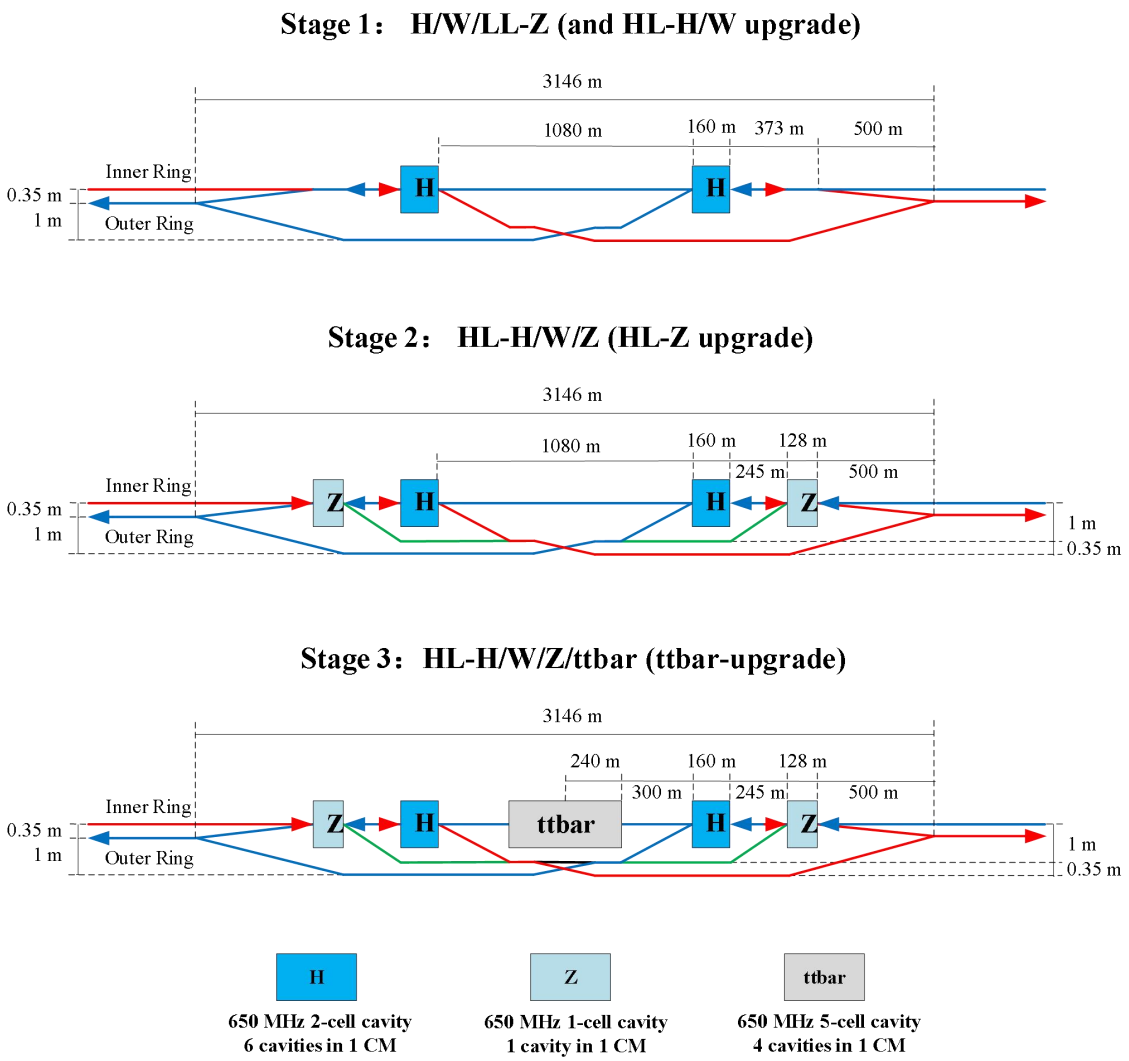
J.Y.Zhai

30 MW SR power per beam for each mode. ttbar and Higgs half fill with common cavities for two rings, W and Z with separate cavities for two rings.	ttbar		Higgs	W	Z bypass with 1-cell cavities
	additional 5-cell cavities	existing 2-cell cavities			
Luminosity / IP [10^{34} $cm^{-2}s^{-1}$]	0.5		5	16	115
RF voltage [GV]	10 (7.8 + 2.2)		2.2	0.7	0.12
Beam current / beam [mA]	3.3		16.7	84.1	803.5
Bunch charge [nC]	32		20.8	21.6	22.4
Bunch length [mm]	2.9		4.1	4.9	8.7
650 MHz cavity number	240	240	240	120/ring	30/ring
Cell number / cavity	5	2	2	2	1
Gradient [MV/m]	28.5	20	20	12.7	8.7
Q_0 @ 2 K at operating gradient (long term)	5E10	2E10			
HOM power / cavity [kW]	0.4	0.16	0.45	0.93	2.9
Input power / cavity [kW]	194	56	250	250	1000
Optimal Q_L	1E7	7E6	1.6E6	6.4E5	7.5E4
Optimal detuning [kHz]	0.01	0.02	0.1	0.9	13.3
Cavity number / klystron	4	12	2	2	1
Klystron power [kW]	1400	1400	800	800	1400
Klystron number	60	20	120	60	60
Cavity number / cryomodule	4	6			1
Cryomodule number	60	40			30
Total cavity wall loss @ 2 K [kW]	9.5	4.7		1.9	0.45

CEPC TDR RF Scheme Updated

J.Y. Zhai
Y.W. Wang

- Aiming for all-mode seamless switching in whole project lifecycle without hardware movement
- Highest luminosity in each energy. Maximize performance and flexibility for future circular electron positron collider
- Remained issue: Higgs operation after ttbar upgrade. Solution: add center connection line (short black line). Need to check if the dipole SR light will still hit the cavity after effective shielding.



CEPC Booster TDR Parameters

D. Wang

- Injection energy: 10GeV → 20GeV
- Max energy: 120GeV → 180GeV
- Lower emittance — new lattice (TME)

Injection		*tt*	*H*	*W*	*Z*	
Beam energy	GeV	20				
Bunch number		35	268	1297	3978	5967
Threshold of single bunch current	μA	5.79	4.20	3.92		
Threshold of beam current (limited by coupled bunch instability)	mA	27				
Bunch charge	nC	1.1	0.78	0.81	0.87	0.9
Single bunch current	μA	3.4	2.3	2.4	2.65	2.69
Beam current	mA	0.12	0.62	3.1	10.5	16.0
Growth time (coupled bunch instability)	ms	1690	358	67	19.4	12.5
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	531.0	230.2	200.0		
Betatron tune ν_x/ν_y		321.23/117.18				
Longitudinal tune		0.14	0.0943	0.0879		
RF energy acceptance	%	5.9	3.7	3.6		
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		35	268	261+7	1297	3978	5967
Maximum bunch charge	nC	0.99	0.7	20.3	0.73	0.8	0.81
Maximum single bunch current	μA	3.0	2.1	61.2	2.2	2.4	2.42
Threshold of single bunch current	μA	91.5	70		22.16	9.57	
Threshold of beam current (limited by RF system)	mA	0.3	1		4	16	
Beam current	mA	0.11	0.56	0.98	2.85	9.5	14.4
Growth time (coupled bunch instability)	ms	16611	2359	1215	297.8	49.5	31.6
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	39.4	139.0	
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	9.7	2.17		0.87	0.46	
Longitudinal tune		0.14	0.0943		0.0879	0.0879	
RF energy acceptance	%	1.78	1.59		2.6	3.4	
Damping time	ms	14.2	47.6		160.8	879	
Natural bunch length	mm	1.8	1.85		1.3	0.75	
Full injection from empty ring	h	0.1	0.14	0.16	0.27	1.8	0.8

*Diameter of beam pipe is 55mm for re-injection with high single bunch current @120GeV.

CEPC TDR SRF Parameters (Booster Ring)

30 MW Collider SR power per beam for each mode. 20 GeV injection.	**ttbar**	**Higgs** off/on-axis	**W**	**Z** high current
Extraction beam energy [GeV]	180	120	80	45.5
Extraction average SR power [MW]	0.087	0.09	0.01	0.004
Bunch charge [nC]	0.96	0.7	0.73	0.83
Beam current [mA]	0.11	0.56/0.98	2.85	14.4
Injection RF voltage [GV]	0.438	0.197	0.122	0.122
Extraction RF voltage [GV]	9.7	2.17	0.87	0.46
Extraction bunch length [mm]	1.8	1.85	1.3	0.75
Cavity number (1.3 GHz 9-cell)	336	96	64	32
Extraction gradient [MV/m]	27.8	21.8	13.1	13.8
Q_0 @ 2 K at operating gradient (long term)	1E10			
Q_L	4E7	1E7		
Cavity bandwidth [Hz]	33	130		
Peak HOM power per cavity [W]	0.4	1.4/2.7	9.8	108.5
Input peak power per cavity [kW]	7.9	15.3/21.3	15	33
SSA peak power [kW] (one cavity per SSA)	10	25	25	40
Cryomodule number (8 cavities per module)	42	12	8	4

J.Y. Zhai

CDR Higgs energy:

-collider ring: 240 2cell 650MHz cavities

-booster: 96 1.3GHz 9cell cavities

-Nb consumption: 20 tons

For ttbar energy:

In addition to CDR Higgs energy, SRF cavity numbers have to be increased:

-collider ring:+350 5cell 650MHz cavities

-booster ring:+350 1.3GHz 9 cell cavities

-Additional Nb consumption:65 tons

For 30MW SR/beam Mode at Higgs energy, the cryogenic system need **32000liter Hellium**

For 50MW/beam SR Mode:

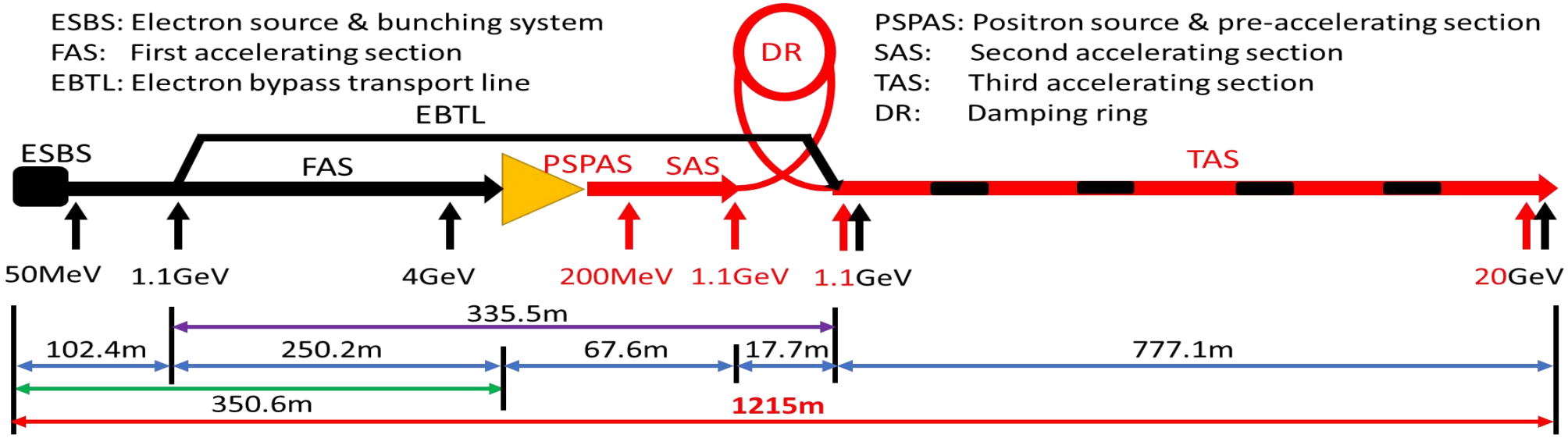
at Higgs energy, the cryogenic system needs 42000liter Hellium; at ttbar energy **130000liter Hellium needed**

Refrigerators: 4*18kW@4.5K

CEPC 20GeV Linac for TDR

J.R. Zhang
C. Meng

- EBTL is in vertical plane with 1.2 m separation
  - Avoid interference with energy analyzing station, transport lines between the Linac and damping ring, waveguide and positron source
  - Reduce the tunnel width
- Accelerating structure
  - S-band: FAS/PSPAS/SAS
  - C-band: TAS



CEPC 20GeV Linac TDR Parameters

J.R. Zhang
C. Meng

- **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 (?)

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

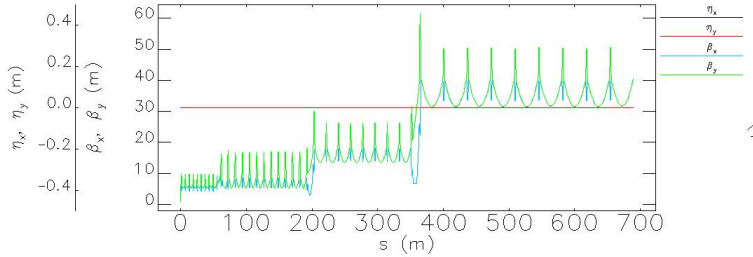
Parameter	Unit	S-band	C-band
Frequency	MHz	2860	5720
Length	m	3.1	1.8
Cavity mode		2π/3	3π/4
Aperture diameter	mm	20~24	11.8~16
Gradient	MV/m	21	45

CEPC 20GeV Positron Linac Design

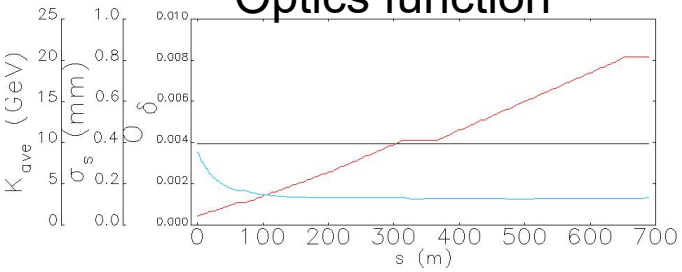
J.R. Zhang, C.Meng

- Positron Linac
  - Wakefield & CSR
  - Emittance(w/o error)
    - Growth: 5%
    - 5.2nm@20GeV

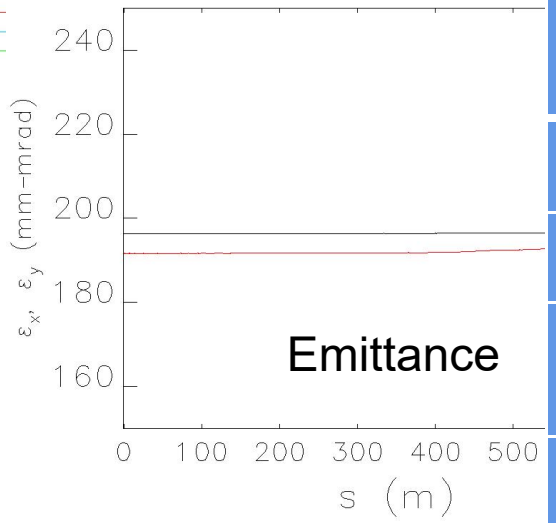
Parameter	Unit	Baseline	Electron	Positron
e^-/e^+ beam energy	GeV	20	20.38	20.37
Repetition rate	Hz	100	100	100
e^-/e^+ bunch population	$\times 10^{10}$	0.94(1.88)	1.88	1.88
	nC	1.5 (3)	3	3
Energy spread (e^-/e^+)		1.5×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
Emittance (e^-/e^+)	nm	10	2.5	5.2



Optics function

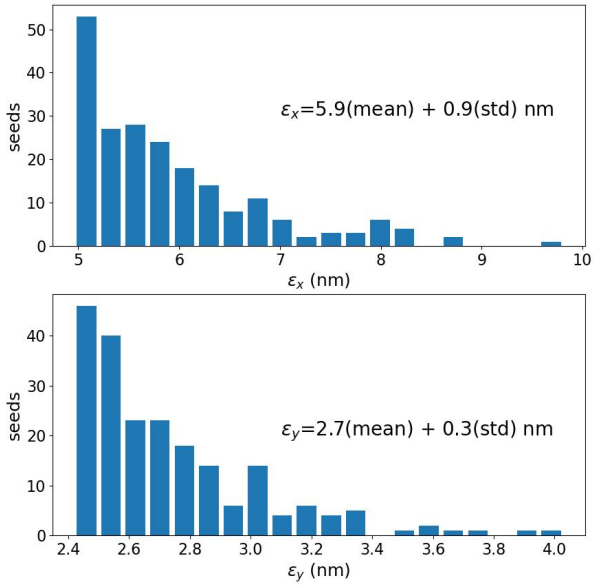


Energy/bunch length/energy spread



Emittance

Error description	Unit	Value
Misalignment error	mm	0.1
Rotation error	mrad	0.2
Magnetic element field error	%	0.1
BPM uncertainty	μm	30



CEPC linac injector reached design goals taking into account of errors

CEPC LINAC Design Evolution

The Linac energy was chosen as 30GeV at June 22, 2022

Energy: 30 GeV Emittance: 6.5nm

J.R. Zhang
C. Meng

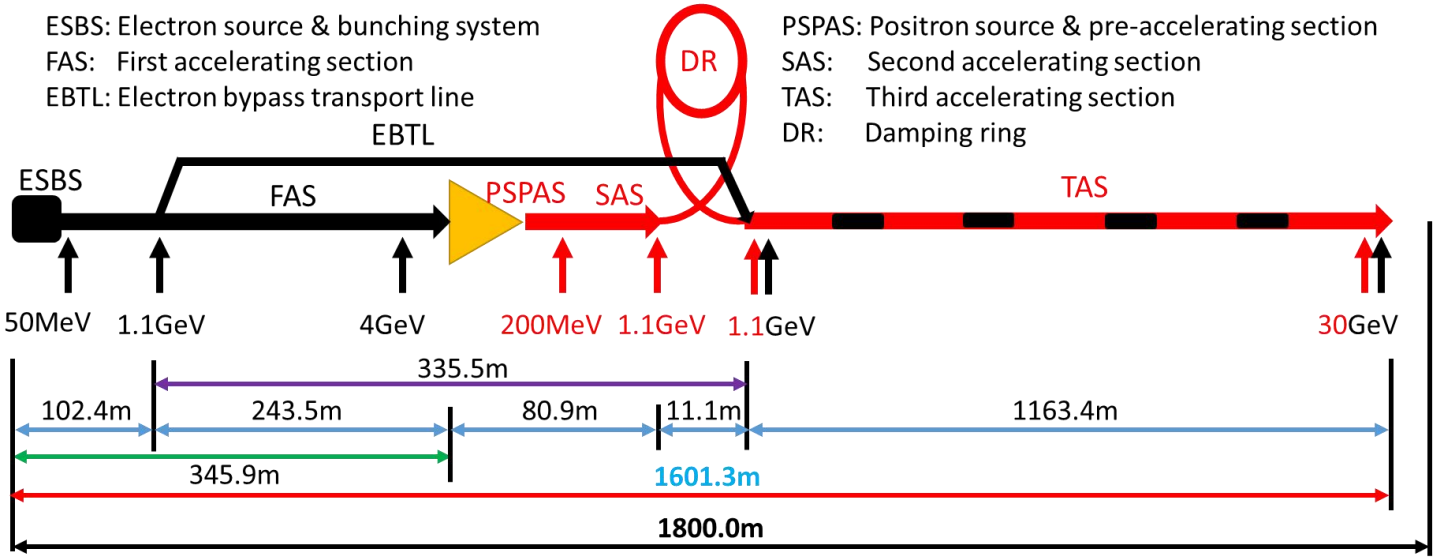
Stage			PreCDR	CDR									TDR				
Parameter		Unit	V1	V2			V3								V4		
				V2.1	V2.2	V2.3	V3.1	V3.2	V3.3	V3.4	V3.5	V3.6	V3.7	V3.8	V4.1	V4.2	V4.3
Beam energy (e+/e-)	E_{e-}/E_{e+}	GeV	6	10					4	10			20	10/20	20		30
Repetition rate	f_{rep}	Hz	50					100									
Bunch number per pulse			1													1&2	
Bunch population (e+/e-)	N_{e-}/N_{e+}	$\times 10^9$	20				6.25			6.25(18.8)	9.4 (18.8)						
		nC	3.2				1			1(3)	1.5 (3)						
Energy spread (e^+/e^-)	σ_E	$\times 10^{-3}$	1				2								1.5		
e^- bunch charge at target		nC	10														
e^- beam energy at target		GeV	4						2	4							
Emittance	ε	nm	300								120		60	40	10		6.5
Damping Ring			Yes			No					Yes	Yes			Yes		
	E_{e+}	GeV	1.1								1.1	1.1			1.1		
	C	m	58.5								58.5	75.4			147		
	ε_0	mm-mrad	287								287	377			94		
Bunch compressor			No							Yes	No		Yes				
Accelerating strucutre			S-band										S-band+C-band				
RF frequency	f_{RF}	MHz	2856.75									2860	2860/5720				
Accelerating gradient		MV/m	15/27	18/27 or. 18/21			21						22 & 27/45				
Klystron-to-ACC.Struc.			1-t-2	1-t-2 or. 1-t-4			1-t-4						1-t-4 & 1-t-2(S)/1-t-2(C)				
Shared Linac Energy range		MeV	200-1100		No												
Linac tunnel length		km	600	1200					500	1200			1400				1800
Collider circumference		km	54 & 61	61			100										
Layout			shared Linac	3 layout schemes			TGB or EBTL		Pre-BST	EBTL							
Date			Apr-16	Nov-16			Dec-16	Apr-17	Aug-17	Oct-17	Dec-17	Jul-18	Mar-19	Sep-19	May-21	Mar-22	Jun-22

CEPC LINAC of 30GeV

C. Meng

- 30GeV-Linac Scheme
  - C-band accelerating structure is used in TAS form 1.1GeV to 30GeV
  - S-band accelerating structure is used in FAS with energy of 4GeV and SAS with energy of 1.1 GeV
  - The bunch charge is 1.5nC and have the capability to reach 3nC both for electron and positron beam
- Electron Linac
  - ESBS+FAS+EBTL+TAS
- Positron Linac
  - ESBS+FAS+PSPAS+SAS+DR+TAS
- The Linac length is 1.6km and there is still 0.2km as reserved space, the Linac tunnel length is 1.8km
  - The circumference of the damping ring is about 0.15km

Parameter	Symbol	Unit	Baseline
Beam energy	E_{e-}/E_{e+}	GeV	30
Repetition rate	f_{rep}	Hz	100
Bunch population	$Ne-/Ne+$	$\times 10^{10}$	0.94
		nC	1.5
Energy spread	σ_E		1.5×10^{-3}
Emittance	ε_r	nm	6.5

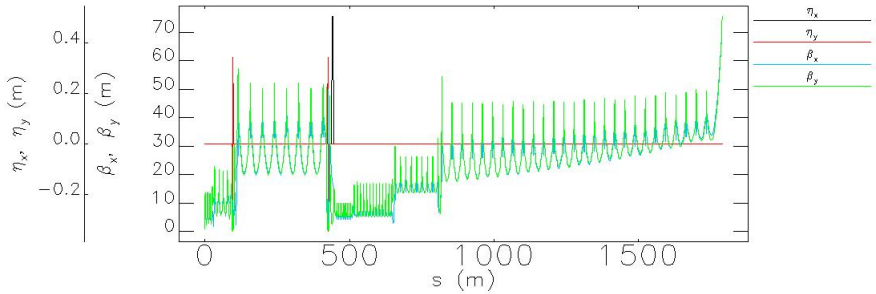


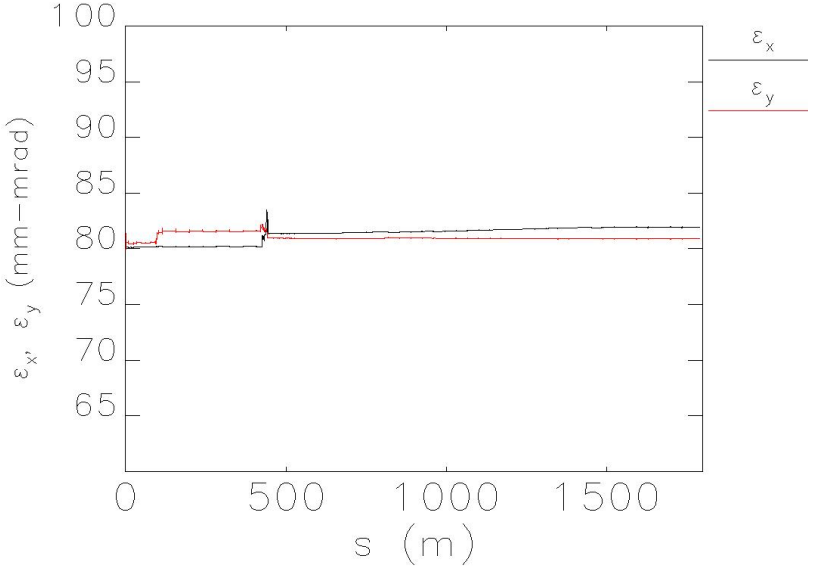
CEPC LINAC Design (30GeV)

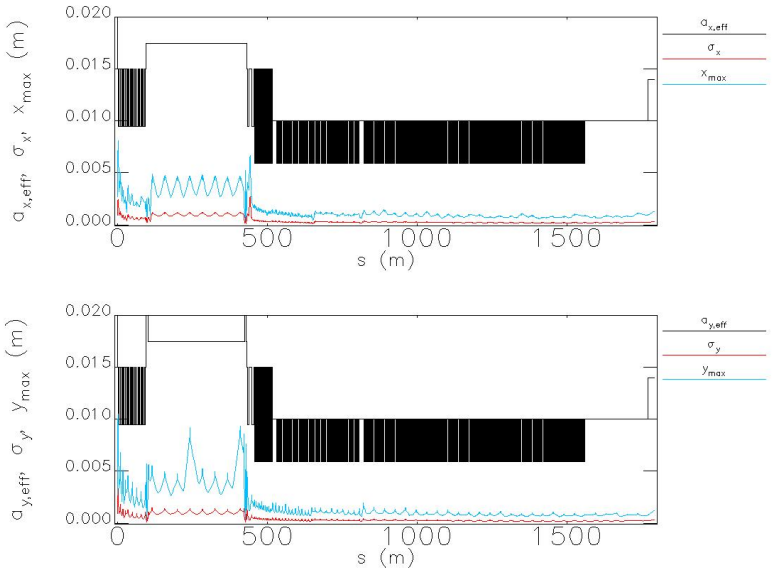
C. Meng

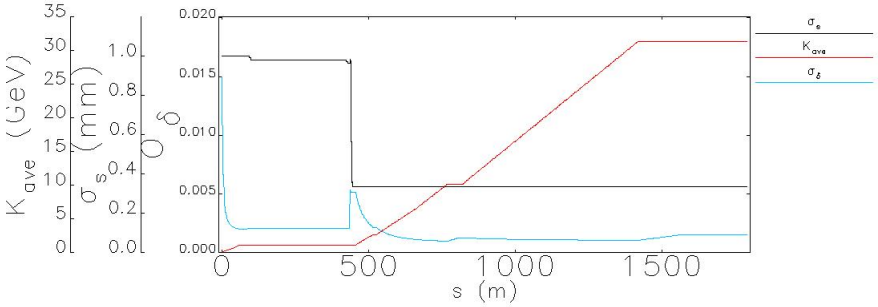
- Simulation results

Parameter	Unit	Value	Simulated			
			Electron		Positron	
Beam energy	GeV	30	31.3	30.8	31.1	30.8
Repetition rate	Hz	100	/			
Bunch charge	nC	1.5	1.5	3.0	1.5	3.0
Energy spread		1.5×10^{-3}	1.4×10^{-3}	1.7×10^{-3}	1.4×10^{-3}	1.9×10^{-3}
Emittance	nm	6.5	1.4	1.5	3.3(H)/1.7(V)	3.5(H)/1.8(V)
Bunch length (RMS)	mm	/	0.4			









CEPC-LINAC-TDR-POWER@30MW and 50MW

C. Meng

	Power [MW]	CDR	TDR
1	RF system	0.48	0.81
2	RF power source	5.77	11.12
3	Magnets	/	/
4	Magnet power supplies	1.75	2.42
5	Vacuum system	0.65	1.77
6	Instrumentation	0.20	0.20
7	Control system	0.20	0.20
8	Mechanical systems	/	/
9	Radiation Protection	0.10	0.10
10	Experimental devices	/	/
11	Utilities	1.38	1.98
12	General services	0.20	0.29
	Total	**10.7**	**18.9**

For 50MW operation, CEPC linac injector will use two bunch scheme, there is very small difference 30MW and 50MW operation modes for electron and positron source.

CEPC TDR Power Consumption Breakdowns@Higgs with 30GeV injection Linac and 30MW SR/beam

	Location and electrical demand(MW)						
	Ring	Booster	LINAC	BTL	IR	Surface building	TOTAL
RF Power Source	96.9	1.4	11.1				109.5
Cryogenic System	11.6	0.6	-		1.1		13.4
Vacuum System	1.0	3.8	1.8				6.5
Magnet Power Supplies	52.3	7.5	2.4	1.1	0.3		63.5
Instrumentation	1.3	0.7	0.2				2.2
Radiation Protection	0.3		0.1				0.4
Control System	1.0	0.6	0.2	0.0	0.0		1.8
Experimental devices					4.0		4.0
Utilities	31.8	3.5	2.0	0.6	1.2		39.1
General services	7.2		0.3	0.2	0.2	12.0	19.8
RF system			0.8				0.8
TOTAL	203.4	18.2	18.9	1.8	6.8	12.0	261.1

CEPC TDR Power Consumption Breakdowns@Higgs with 30GeV injection Linac and 50MW SR/beam

		Location and electrical demand(MW)						
		Ring	Booster	LINAC	BTL	IR	Surface building	TOTAL
1	RF Power Source	161.5	1.4	11.1				174.1
2	Cryogenic System	15.5	0.6	-		1.7		17.9
3	Vacuum System	1.0	3.8	1.8				6.5
4	Magnet Power Supplies	52.3	7.5	2.4	1.1	0.3		63.5
5	Instrumentation	1.3	0.7	0.2				2.2
6	Radiation Protection	0.3		0.1				0.4
7	Control System	1.0	0.6	0.2	0.0	0.0		1.8
8	Experimental devices					4.0		4.0
9	Utilities	42.4	3.5	2.0	0.6	1.2		49.7
10	General services	7.2		0.3	0.2	0.2	12.0	19.8
11	RF system			0.8				0.8
12	TOTAL	282.4	18.2	18.9	1.8	7.4	12.0	340.7

CEPC TDR Power Consumption Breakdowns@ttbar with 30GeV injection Linac and 50MW SR/beam

		Location and electrical demand(MW)						
		Ring	Booster	LINAC	BTL	IR	Surface building	TOTAL
1	RF Power Source	161.5	1.4	11.1				174.1
2	Cryogenic System	25.2	0.6	-		1.1		26.9
3	Vacuum System	2.0	3.8	1.8				7.6
4	Magnet Power Supplies	118.8	16.8	2.4	1.1	0.3		139.3
5	Instrumentation	1.3	0.7	0.2				2.2
6	Radiation Protection	0.3		0.1				0.4
7	Control System	1.0	0.6	0.2	0.0	0.0		1.8
8	Experimental devices					4.0		4.0
9	Utilities	44.7	3.5	2.0	0.6	1.2		52.0
10	General services	7.2		0.3	0.2	0.2	12.0	19.8
11	RF system			0.8				0.8
12	TOTAL	361.9	27.5	18.9	1.8	6.8	12.0	428.9

CEPC TDR Power Consumption Breakdowns@Z with 30GeV injection Linac and 30MW SR/beam

		Location and electrical demand(MW)						
		Ring	Booster	LINAC	BTL	IR	Surface building	TOTAL
1	RF Power Source	96.9	0.1	11.1				108.1
2	Cryogenic System	4.1	0.6	-		1.1		5.9
3	Vacuum System	1.0	3.8	1.8				6.5
4	Magnet Power Supplies	9.6	1.4	2.4	1.1	0.3		14.7
5	Instrumentation	1.3	0.7	0.2				2.2
6	Radiation Protection	0.3		0.1				0.4
7	Control System	1.0	0.6	0.2	0.0	0.0		1.8
8	Experimental devices					4.0		4.0
9	Utilities	28.1	3.5	2.0	0.6	1.2		35.5
10	General services	7.2		0.3	0.2	0.2	12.0	19.8
11	RF system			0.8				0.8
12	TOTAL	149.4	10.8	18.9	1.8	6.8	12.0	199.7

Snowmass Luminosity and Power Consumption Evaluations (CEPC)

Y.W.Wang

Proposal name	CEPC	CEPC	CEPC	CEPC
Beam energy [GeV]	45.5	120.0	120.0	180.0
Average beam current [A or mA]	803.5	16.7	27.8	5.5
SR power [MW]	30.0	30.0	50.0	50.0
Collider cryo power [MW]	5.2	12.7	17.2	26.3
Collider RF power [MW]	96.9	96.9	161.5	161.5
Collider magnet power [MW]	9.8	52.6	52.6	119.1
Cooling & ventilation power [MW]	35.5	39.1	49.7	52.0
General services power [MW]	19.8	19.8	19.8	19.8
Injector cryo power [MW]	0.6	0.6	0.6	0.6
Injector RF power [MW]	0.1	1.4	1.4	1.4
Injector magnet power [MW]	1.4	7.5	7.5	16.8
Pre-injector power (where applicable) [MW]	17.7	17.7	17.7	17.7
Detector power (if included) [MW]	4.0	4.0	4.0	4.0
Data center power (if included) [MW]	-	-	-	-
Total power [MW]	191.1	252.4	332.1	419.3
Luminosity [10^(34) /cm^2/s] (total 2 IP values)	230.0	10.0	16.7	1.7
Total integrated luminosity / year [1/fb/yr]	29900.0	1300.0	2171.0	217.1
Effective physics time per year asumed/needed to achieve integrated annual luminosity [10^7 s]	1.3	1.3	1.3	1.3
Energy Consumption / year [TWh]	0.7	0.9	1.2	1.5

The items listed in the Snowmass Luminosity Power table are less than the complete power bugets for a real machine on site

SppC Collider Parameters
-Parameter list (updated Feb. 2022)

Jingyu Tang
Haocheng Xu

Main parameters		
Circumference	100	km
Beam energy	62.5	TeV
Lorentz gamma	66631	
Dipole field	20.00	T
Dipole curvature radius	10415.4	m
Arc filling factor	0.780	
Total dipole magnet length	65442.0	m
Arc length	83900	m
Total straight section length	16100	m
Energy gain factor in collider rings	19.53	
Injection energy	3.20	TeV
Number of IPs	2	
Revolution frequency	3.00	kHz
Revolution period	333.3	μs
Physics performance and beam parameters		
Initial luminosity per IP	4.3E+34	$cm^{-2}s^{-1}$
Beta function at initial collision	0.5	m
Circulating beam current	0.19	A
Nominal beam-beam tune shift limit pe	0.015	
Bunch separation	25	ns
Bunch filling factor	0.756	
Number of bunches	10080	
Bunch population	4.0E+10	
Accumulated particles per beam	4.0E+14	

Normalized rms transverse emittance	1.2	μm
Beam life time due to burn-off	8.1	hour
Turnaround time	2.3	hour
Total cycle time	10.4	hour
Total / inelastic cross section	161	mbarn
Reduction factor in luminosity	0.81	
Full crossing angle	73	μrad
rms bunch length	60	mm
rms IP spot size	3.0	μm
Beta at the 1st parasitic encounter	28.625	m
rms spot size at the 1st parasitic encoun	22.7	μm
Stored energy per beam	4.0	GJ
SR power per ring	2.2	MW
SR heat load at arc per aperture	26.3	W/m
Critical photon energy	8.4	keV
Energy loss per turn	11.40	MeV
Damping partition number	1	
Damping partition number	1	
Damping partition number	2	
Transverse emittance damping time	0.51	hour
Longitudinal emittance damping time	0.25	hour

CEPC CDR-Higgs

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

Ingetrated Luminosity = $5.6\ ab^{-1}$

Higgs annual luminosity =$0.8\ ab^{-1}$

CEPC TDR-Higgs

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

Ingetrated Luminosity = $9.3\ ab^{-1}$

Higgs annual luminosity =$1.3\ ab^{-1}$

CEPC TDR-Higgs (upgrade)

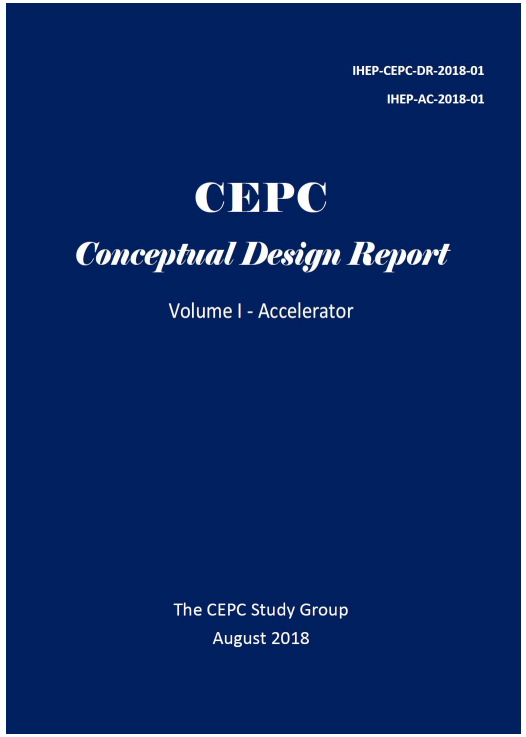
Peak Luminosity = $8.3\times 10^{34}cm^{-2}s^{-1}$

Ingetrated Luminosity = $15.4\ ab^{-1}$

Higgs annual luminosity =$2.2\ ab^{-1}$

These parameters are used for Snowmass21

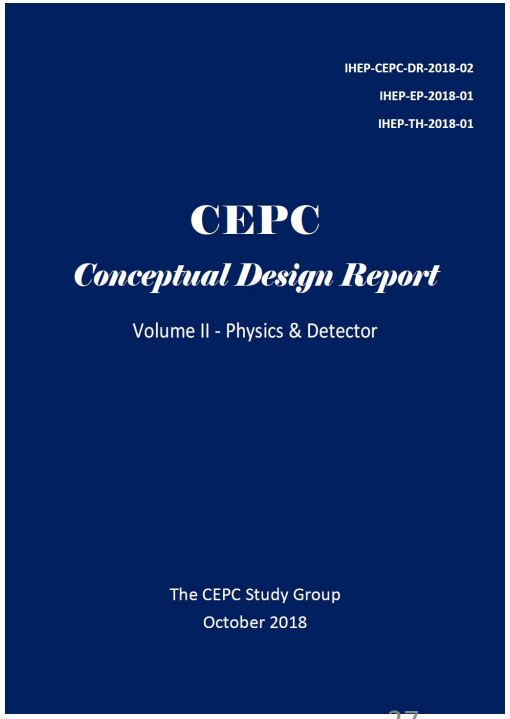
CEPC CDR Vol. I, Accelerator



CEPC Accelerator Snowmass 21 AF White Paper

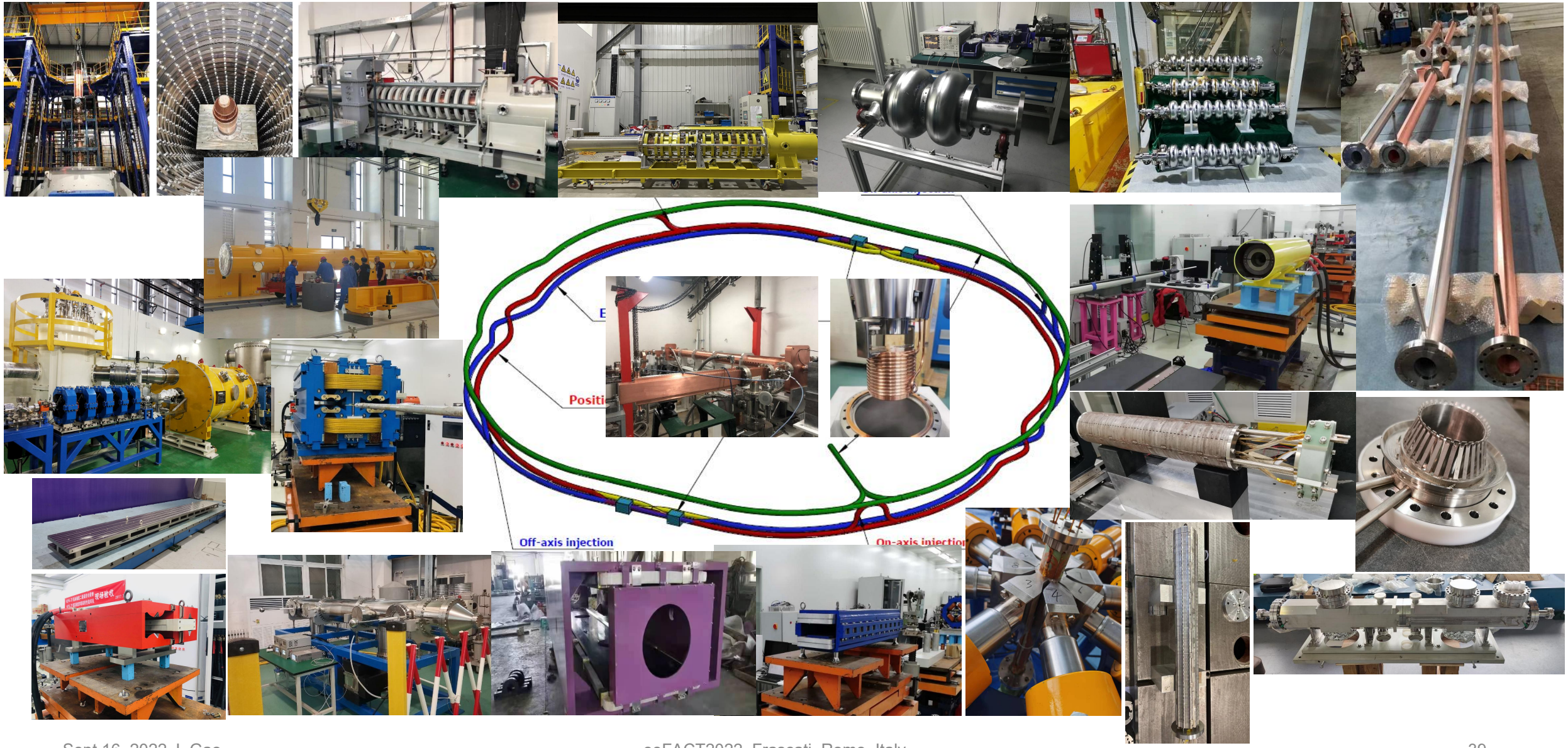
1) CEPC Accelerator white paper
to Snowmass21, arXiv:2203.09451
2) CEPC CDR Vol. I, Accelerator
http://cepc.ihep.ac.cn/CEPC_CDR_Vol1_Accelerator.pdf
3) CEPC CDR Vol. II, Physics and Detector
http://cepc.ihep.ac.cn/CEPC_CDR_Vol2_Physics-Detector.pdf
CEPC Video (BIM design)
1) http://cepc.ihep.ac.cn/Qinhuang_Island.mp4
2) http://cepc.ihep.ac.cn/Huzhou.mp4
3) http://cepc.ihep.ac.cn/Changsha.mp4

CEPC CDR Vol. II, Physics/Detector



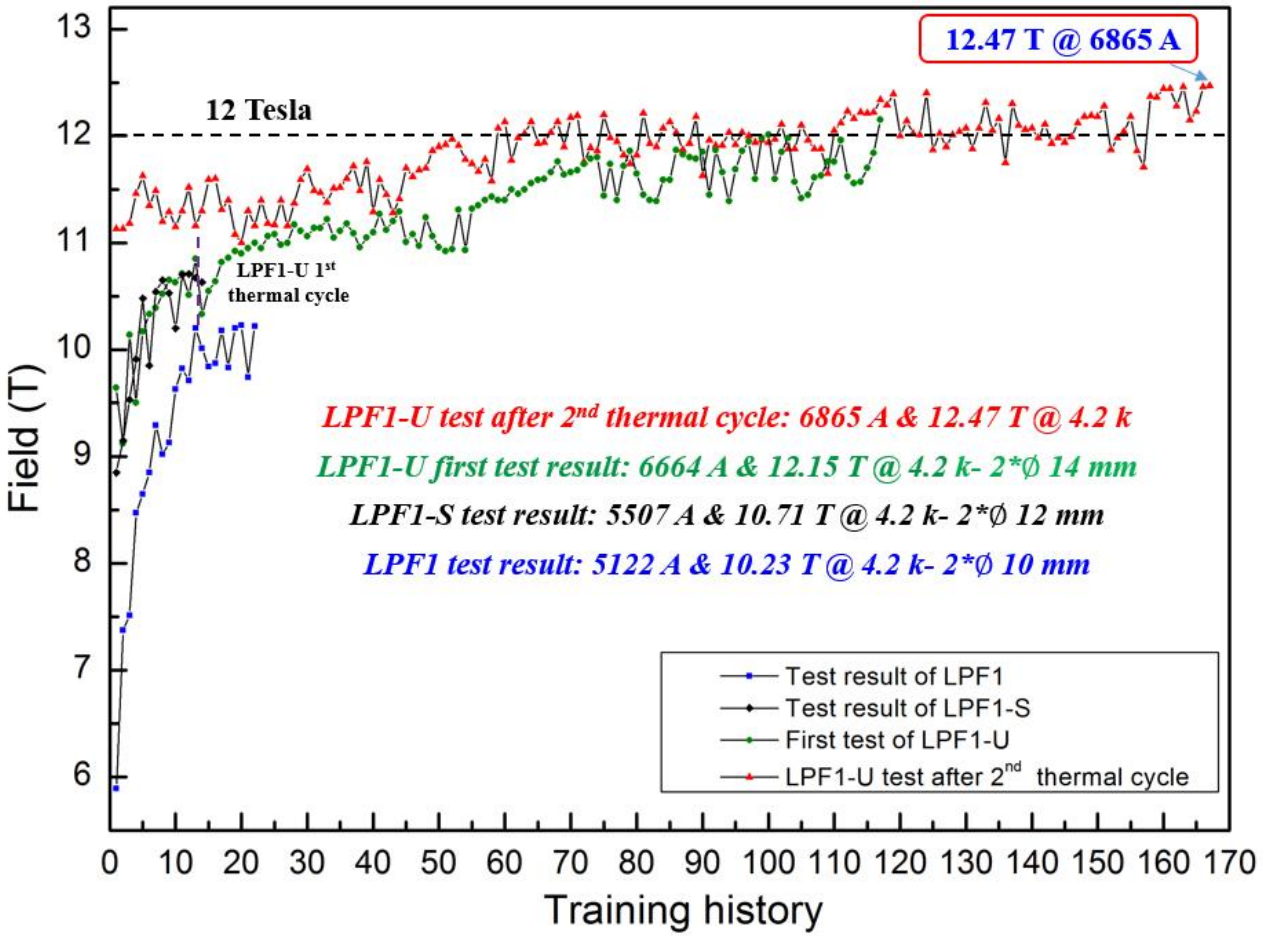
CEPC Accelerator System Key Hardware R&D Progresses in TDR

CEPC TDR R&D Status of Key Technologies



Latest performance of LPF1-U (SppC)

Picture of LPF1-U



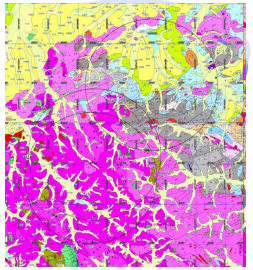
Qingjin Xu

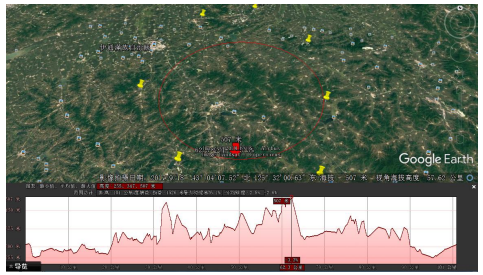
Dual aperture superconducting dipole achieves 12.47 T at 4.2 K
Entirely fabricated in China. The next step is reaching 16-19T field

CEPC TDR Siting and Civil Engineering

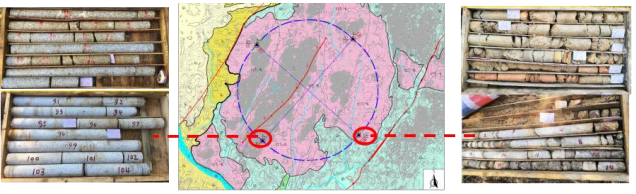
CEPC Siting Status

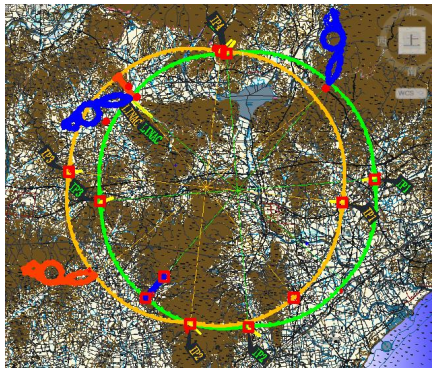
Three companies are working on siting and issues



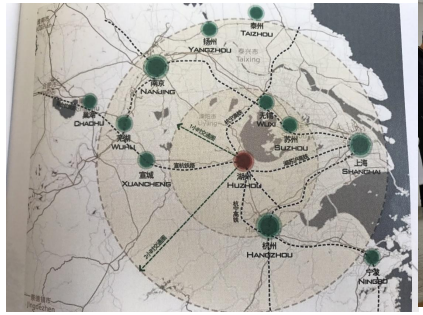


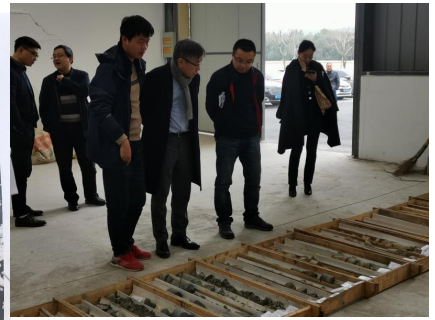
2019.12月8-11 and 2020.1.8-10
Chuangchun sitings update





2020.9.14-18 Qinhuangdao updated





2019.12.16-17 Huzhou siting update

2019.08.19-20 Changsha
siting update

1) Qinhuangdao, Hebei Province (Completed in 2014)

2) Huangling, Shanxi Province (Completed in 2017)

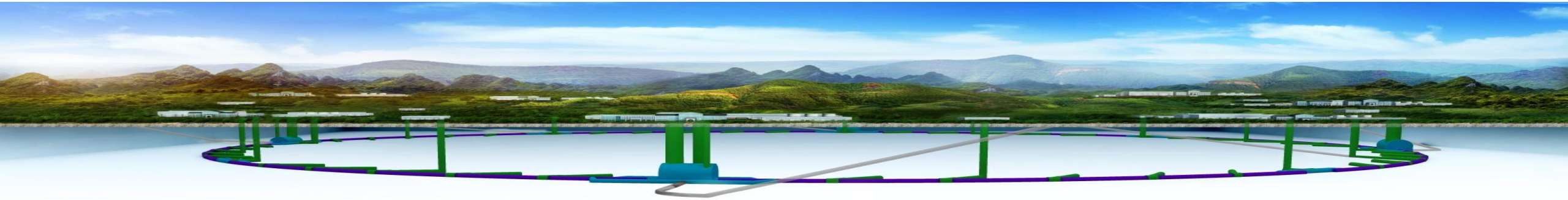
3) Shenshan, Guangdong Province(Completed in 2016)

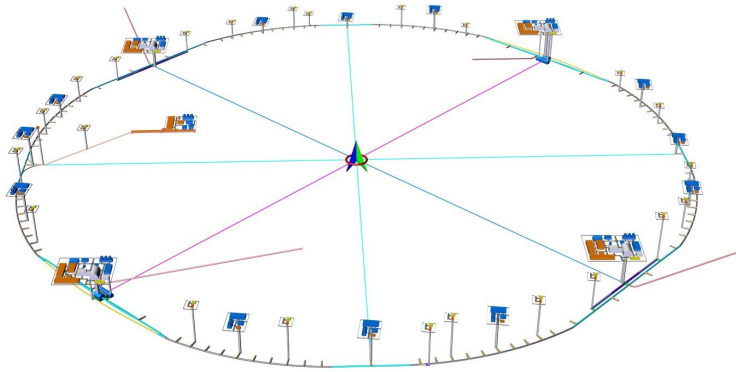
4) Huzhou, Zhejiang Province (Started in March 2018)

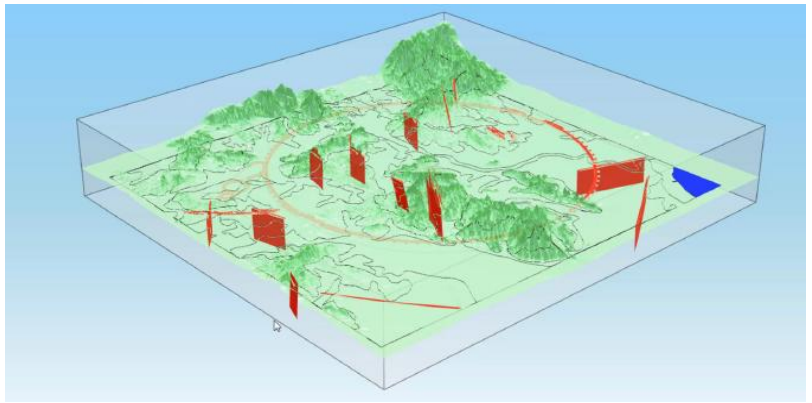
5) Chuangchun, Jilin Province (Started in May 2018)

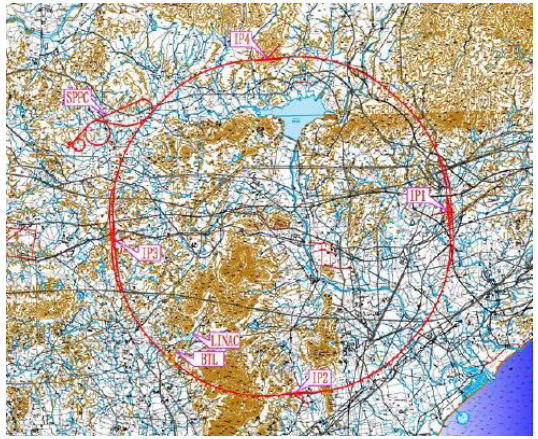
6) Changsha, Hunan Province (Started in Dec. 2018)

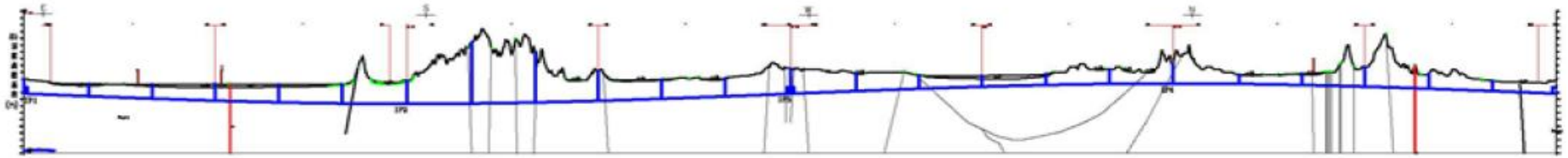
CEPC Siting and Civil Engineering (Qinhuangdao TDR site as an example)



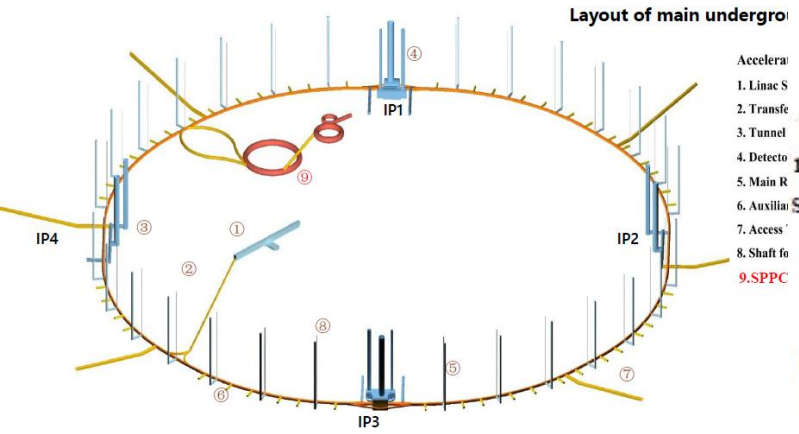








CEPC Siting and Civil Engineering (Huzhou TDR site as an example)

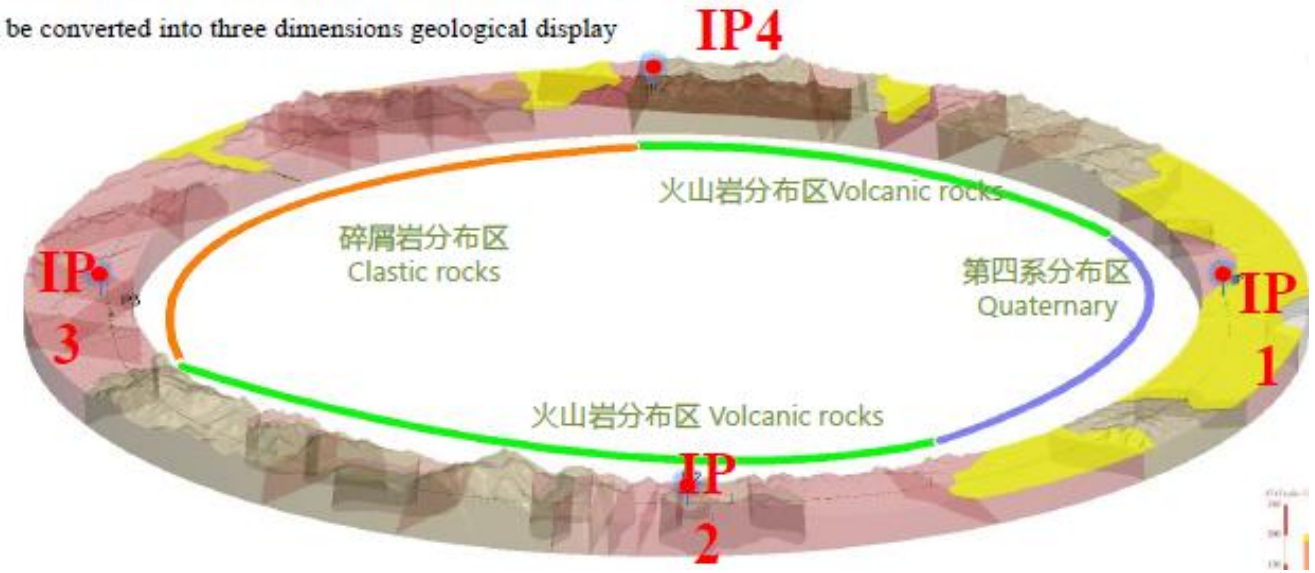


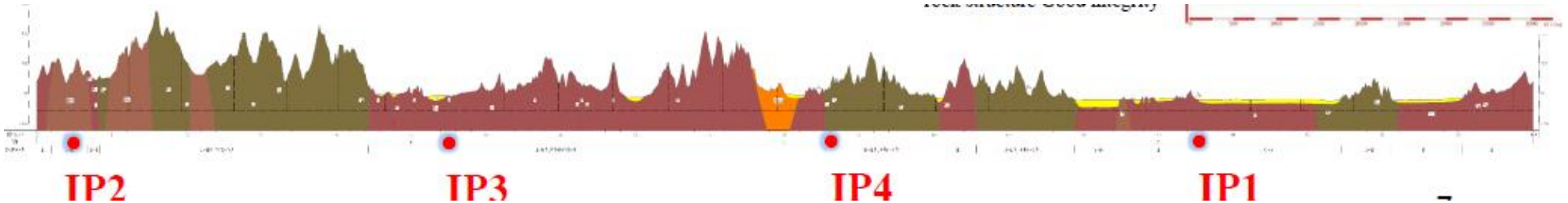
The minimum depth of the main ring is 70m

The geological work can be converted into three dimensions geological display

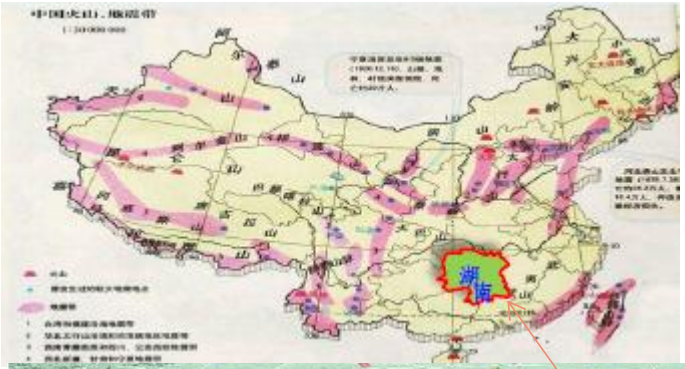
The sandstone and welded tuff in the site are relative moderate hard and stiff, respectively. The rock mass is intact along the tunnel.

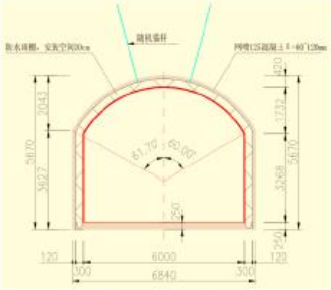
Therefore, it is believed that the rock shows high engineering quality here, and is suitable for the project constructions.



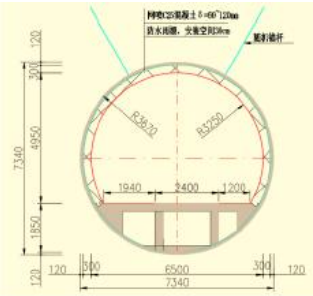


CEPC Siting and Civil Engineering (Changsha TDR site as an example)



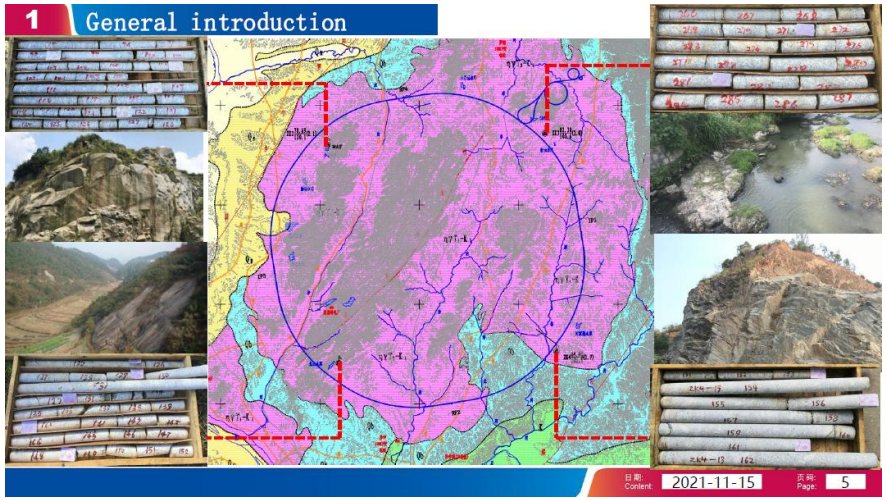


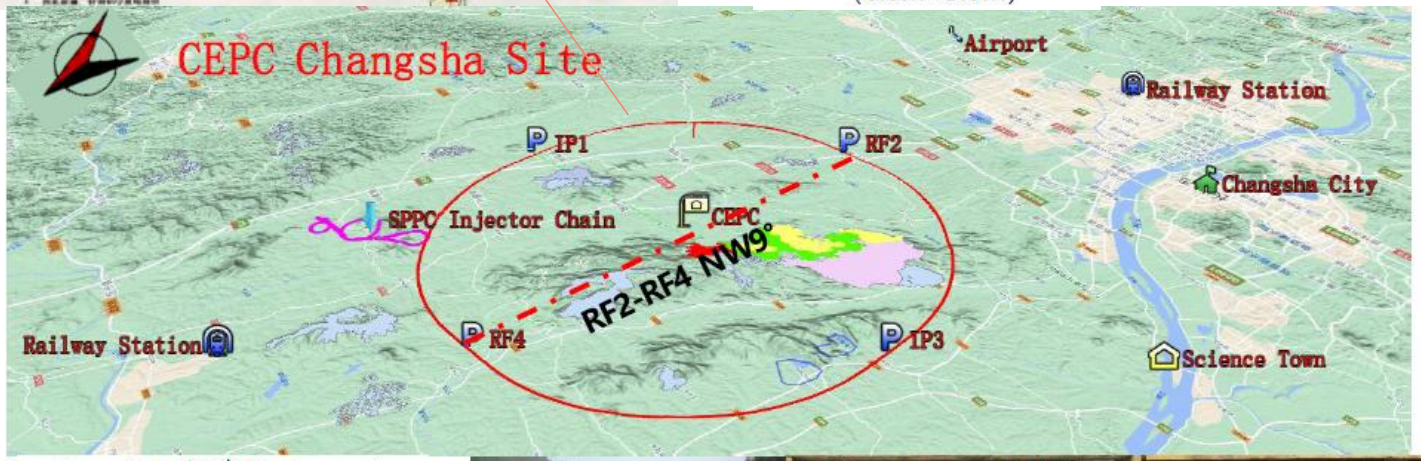
Drill-blast tunnel
(6.0m×5.0m)

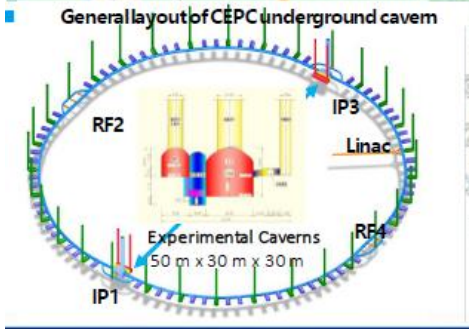


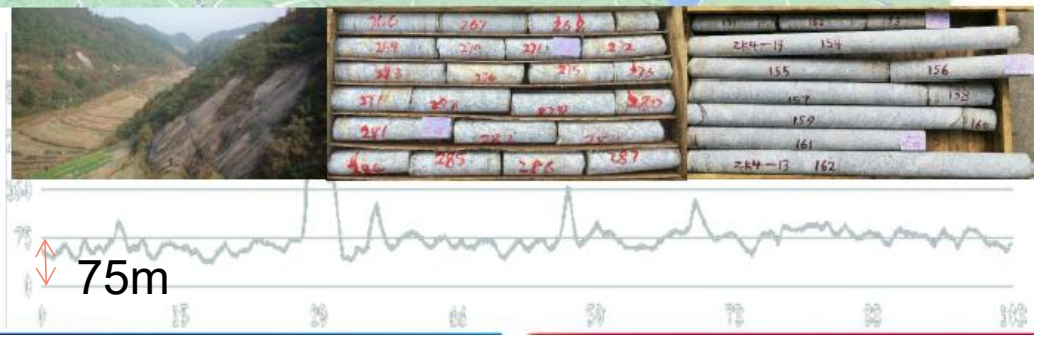
TBM tunnel (D6.5m)

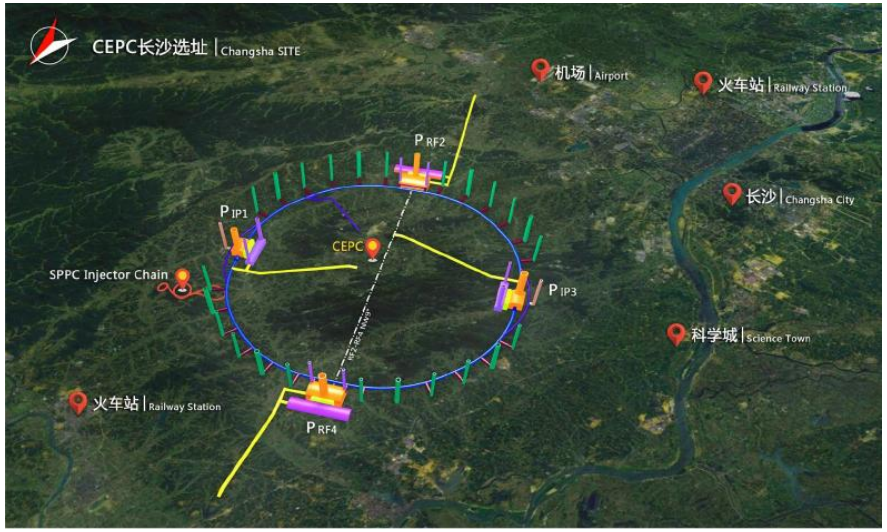
Very good geological condition



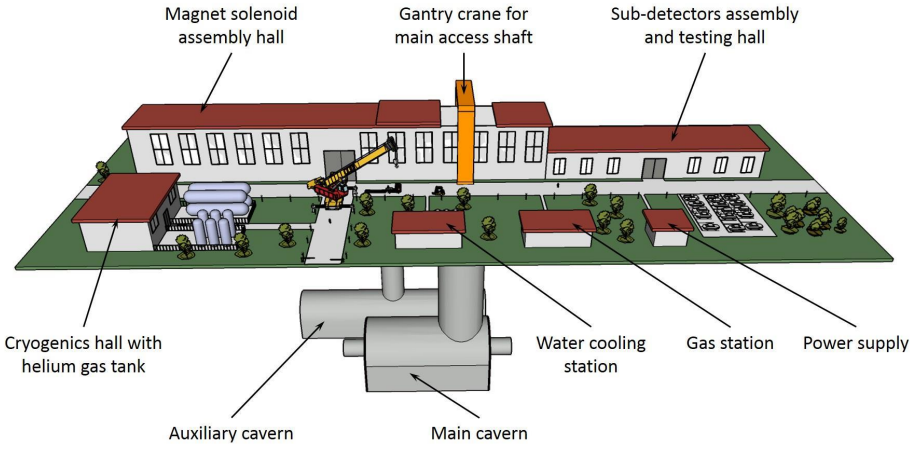


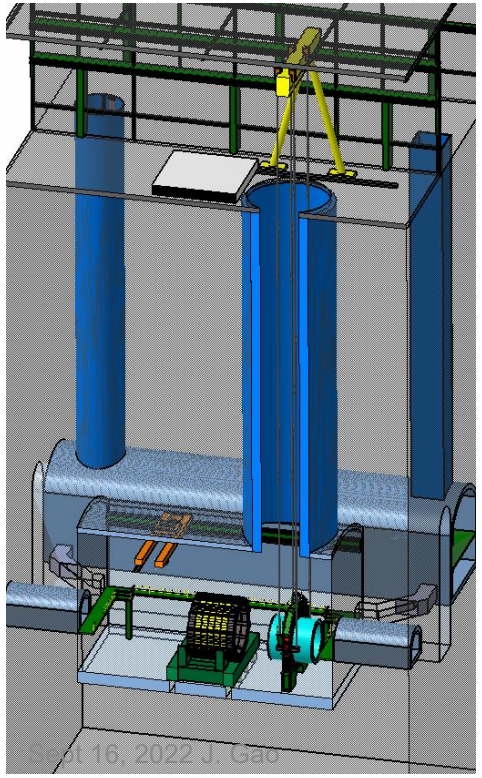


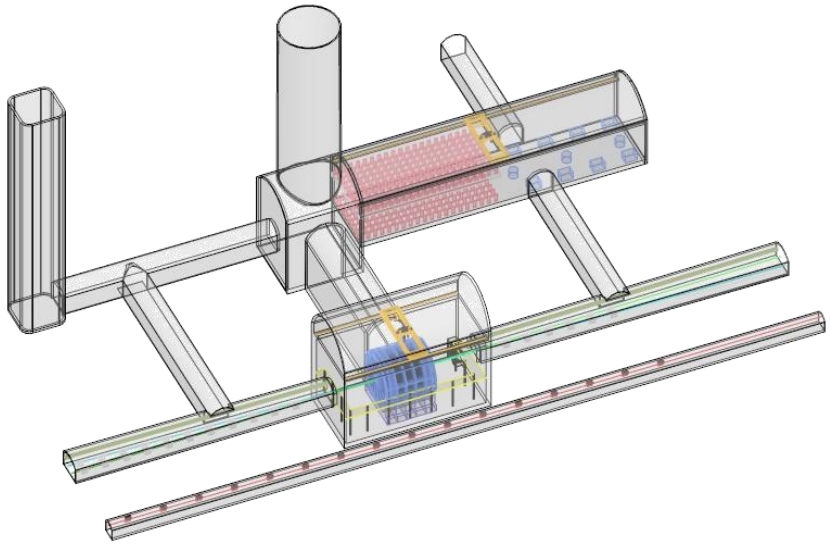




CEPC IR Region

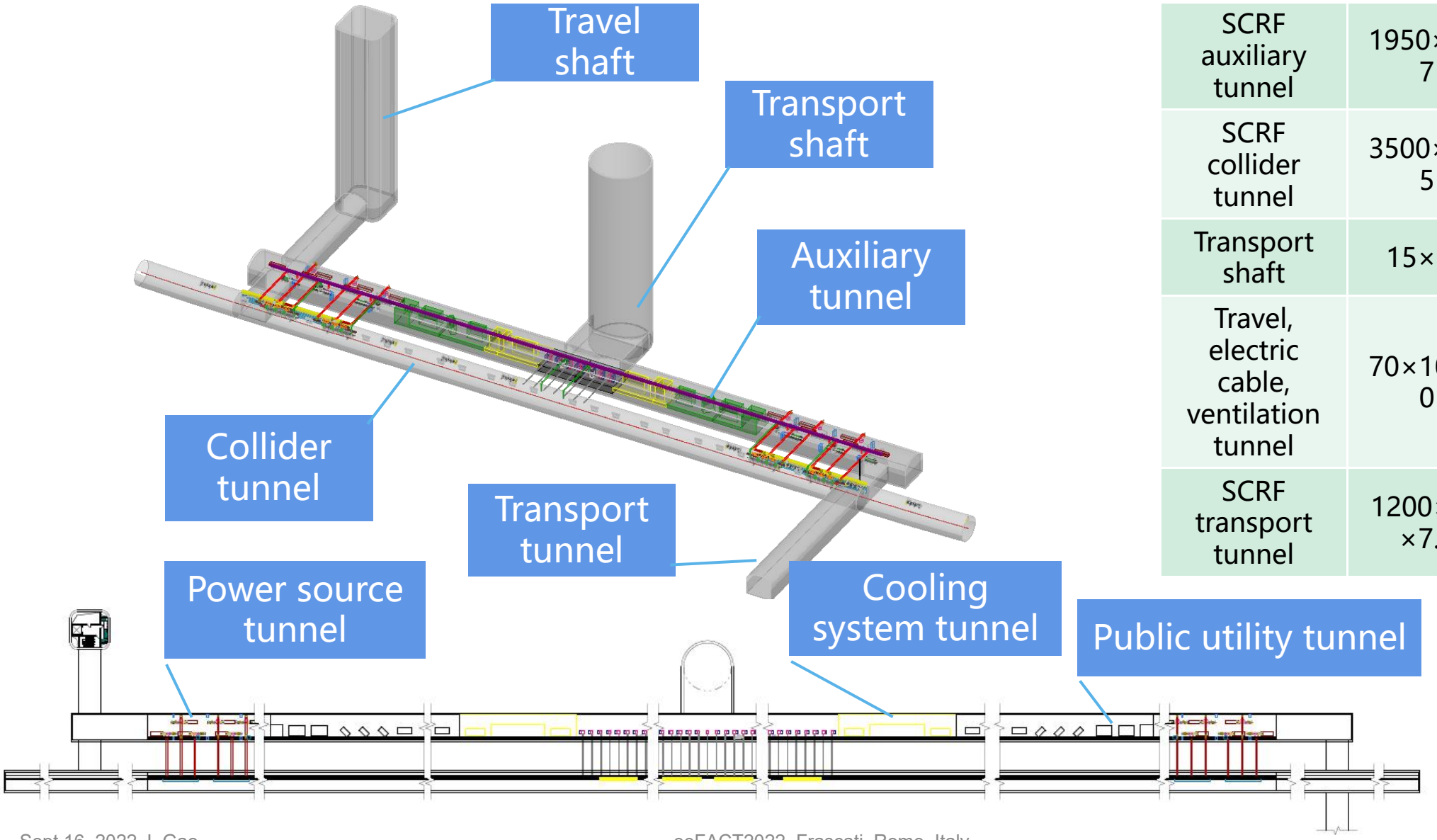






Name	L×W×H	Numb.
Experimental hall	39.4×20.4×31	×2
Axiliary hall	101.4×20×26.2	×2
Booster tunnel	1679×3.5×3.5	×4
Collider tunnel	1659.3x(6~11.4)x5	×4
Travel shaft	1200x7.5x7.5	×2
Connection, electric cable and ventilation shaft	70x10x10	×2

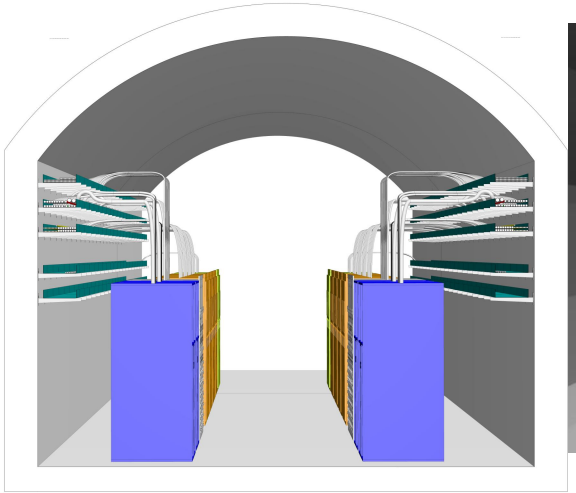
CEPC SCRF Region

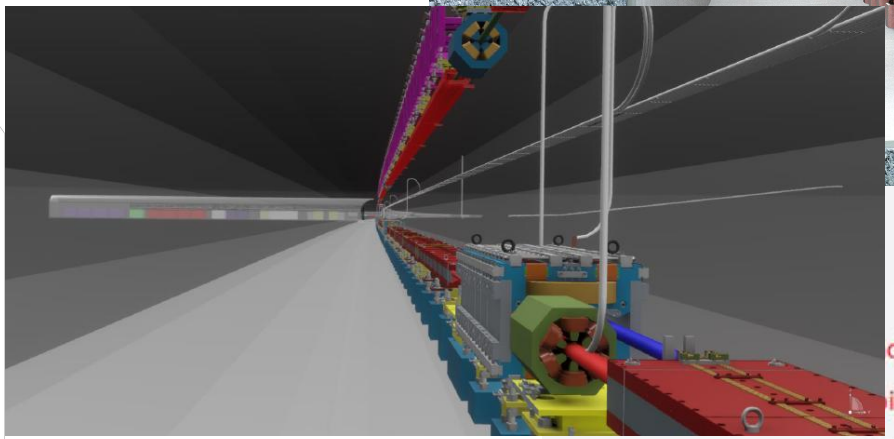


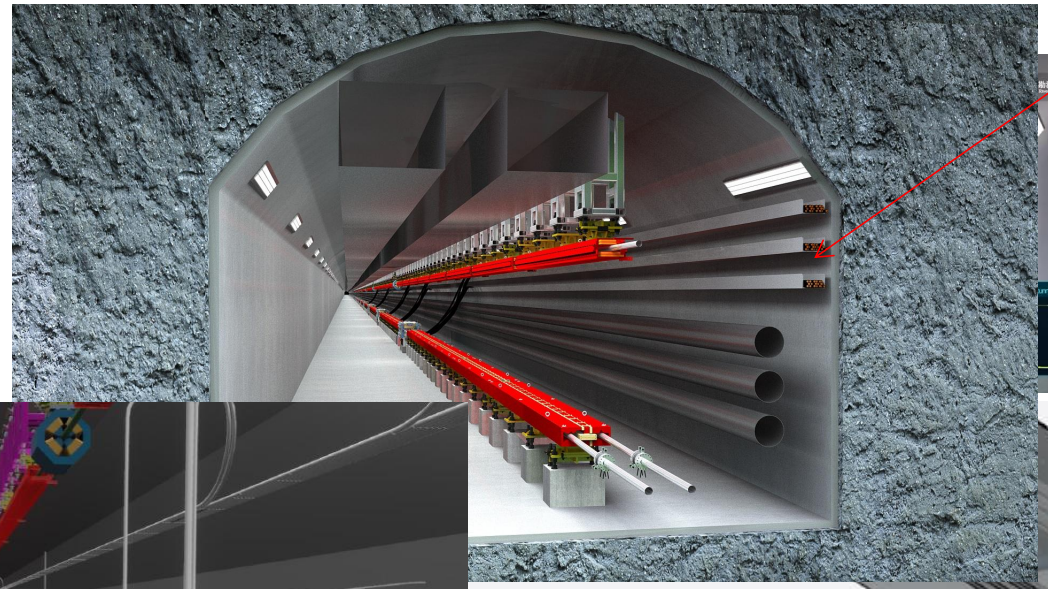
Name	L×W×H	Numb.
SCRF auxiliary tunnel	1950×8×7	×2
SCRF collider tunnel	3500×6×5	×2
Transport shaft	15×70	×2
Travel, electric cable, ventilation tunnel	70×10×10	×2
SCRF transport tunnel	1200×88×7.5	×2

CEPC Civil Engineering Design (BIM)

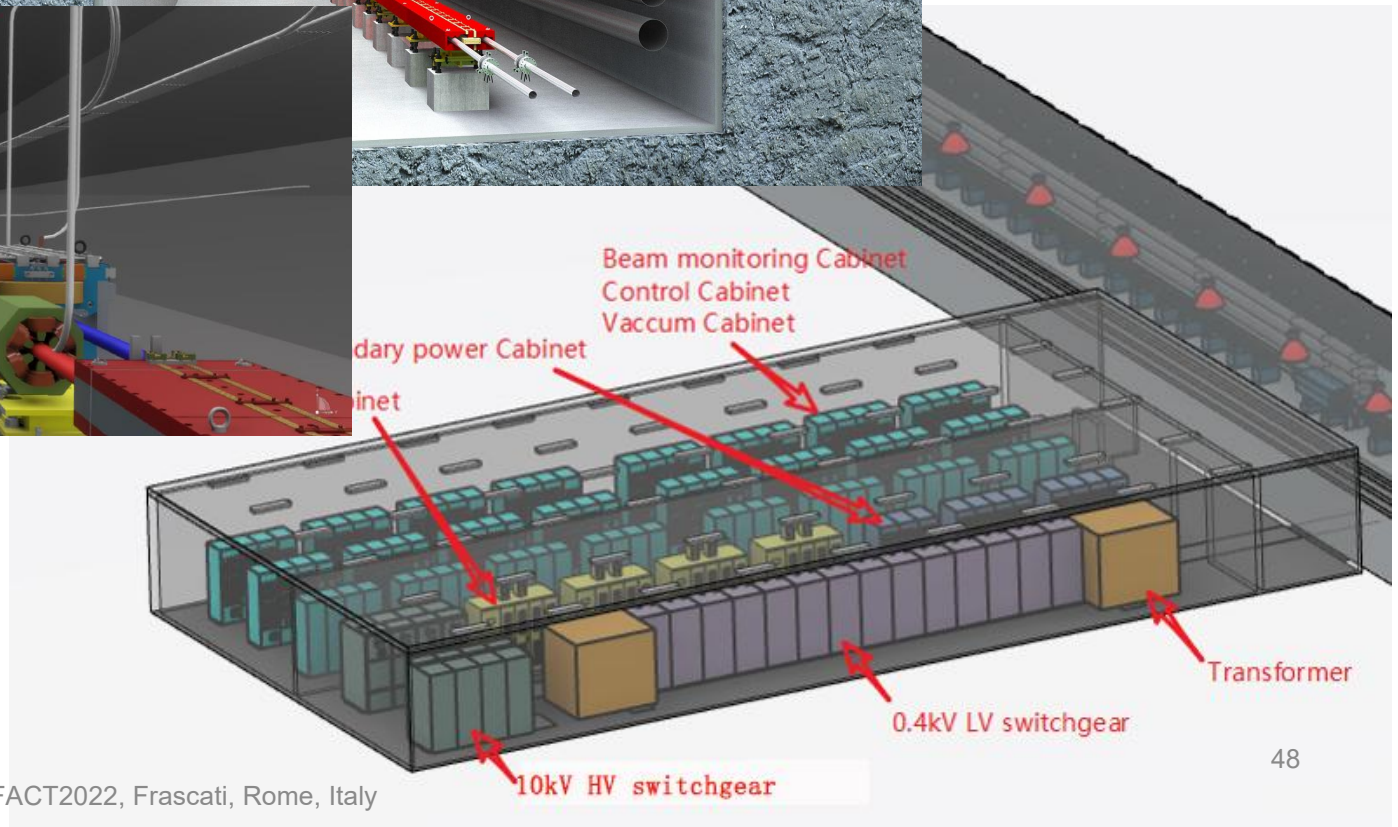
Electrical Equipment General Layout in Auxiliary







Cables installed!



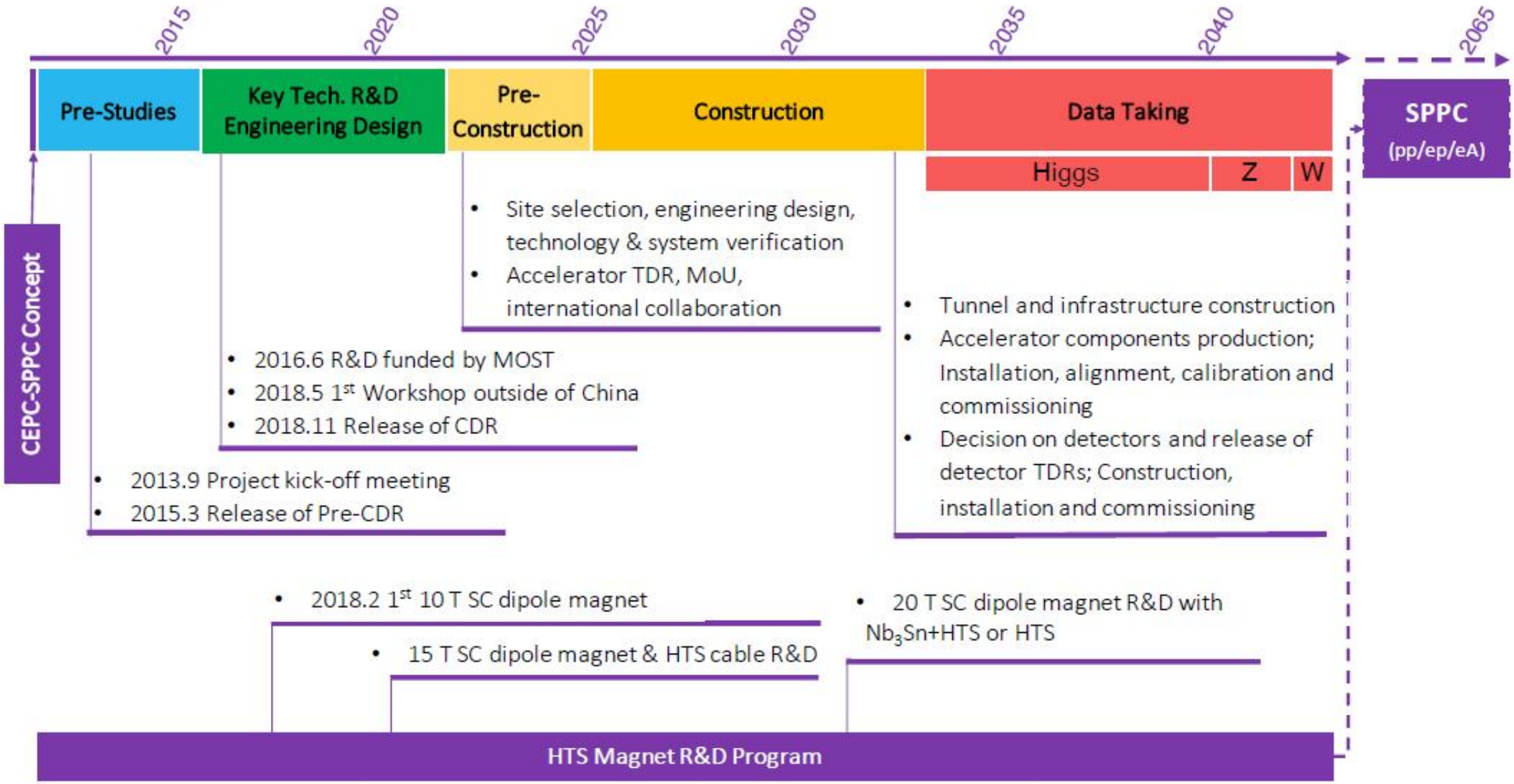
CEPC TDR and EDR Schedules and CEPC Timeline

CEPC Accelerator TDR Documentation Preparation and EDR Plans

TDR timeline:
TDR started to write after the first IARC reveiw in June 2022
TDR completes in Dec. 2022 (with IARC review, SC and IAC approval)

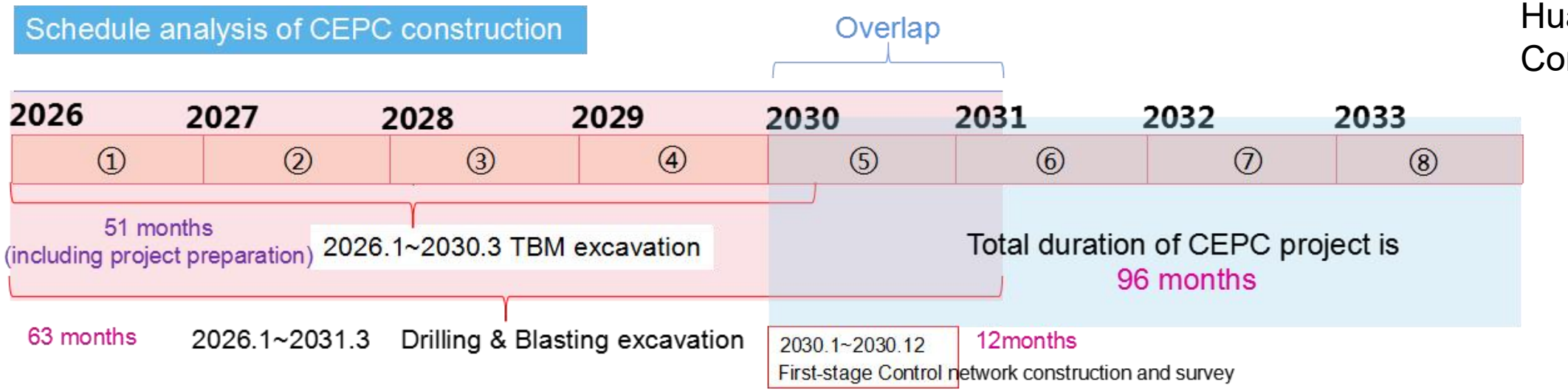
CEPC Accelerator EDR Phase Plan:Jan. 2023-Dec. 2025
-CEPC site study converging to one or two with detailed feasibility studies (tunnel and infrastructures, environment)
-Engineering design of CEPC accelerator systems and components towards fabrication in an industrial way
-Site dependent civil engineering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

CEPC Project Timeline



Civil Construction and Installation Timeline

Huadong Company



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

2031.1~2032.6 18 months
Support installation and alignment

2031.3~2032.8 18 months
Dipole magnets installation

26032.9~2033. 10 months
Installation of other equipment

6 months 2033.7~2033.12
Overall alignment and commissioning

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

Summary

- CEPC CDR parameters, designs and AC power consumptions are reviewed
- CEPC TDR parameters, designs and AC power consumptions are presented.
- **CEPC TDR AC power consumption has not been fully optimized, such as RF operation modes, magnets' power distribution networks, utilities, etc., further power reduction optimization will be conducted.**
- estimation is still on going to be more complete and precise
- CEPC accelerator key hardware R&D, CEPC TDR siting and civil engeering design are presented
- CEPC TDR and EDR Schedules and CEPC Timeline are given

Acknowledgements

- Thanks go to CEPC-SppC accelerator team's hardworks, international and CIPC collaborations
- Special thanks to CEPC SC, IAC and IARC's critical comments, suggestions and encouragement