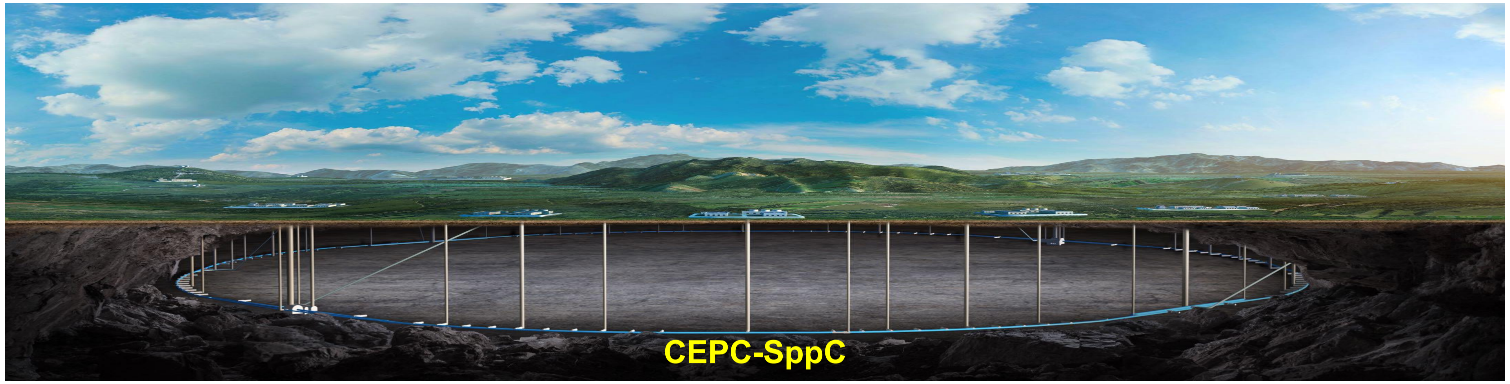
CEPC Accelerator Overall Status

J. Gao

IHEP
On behalf of CEPC Group



CEPC Workshop, US edition, Chicago University, USA
Sept. 16-18, 2019

Outline

- CEPC status
- SppC status
- CEPC-SppC R&D
- CEPC-SppC siting and civil engineering
- CEPC science city plan
- CEPC collaborations
- Summary

CEPC Status

Physics Goals of CEPC-SppC

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

Precision measurement + searches:

Complementary with each other !

CEPC Accelerator Chain and Systems

10 GeV

1) Injector

L=1.2km

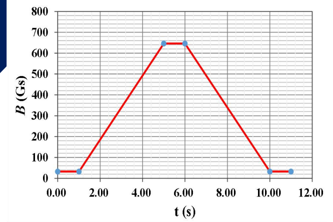
Electron

Positron

2) Booster

C=100km

Energy Ramp
10 ->45/120GeV



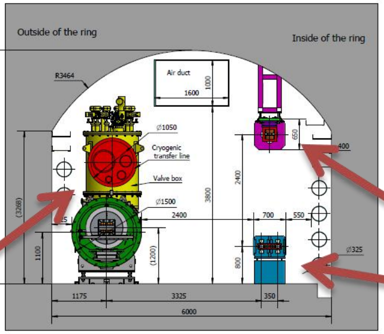
Booster Cycle (0.1 Hz)

Three rings in the same channel:
- ➢ **CEPC & booster**
- ➢ **SppC**

The key systems of CEPC:
1) Linac Injector
2) Booster
3) Collider ring
4) MDI
5) Civil Eng.

5) Civil Eng.

TUNNEL CROSS SECTION OF THE ARC AREA



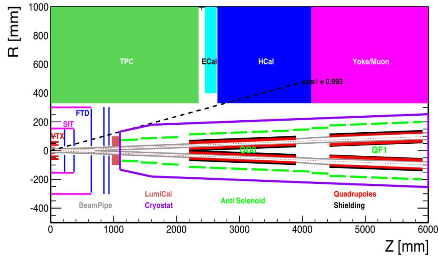
SppC

CEPC Booster
CEPC Collider

3) Main Ring

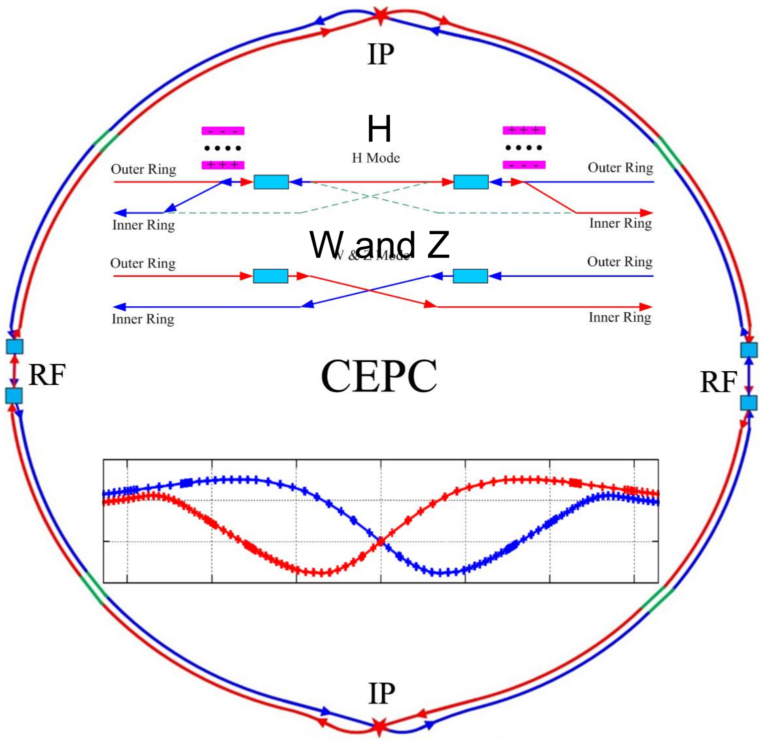
C=100km
2IP

45/120 GeV

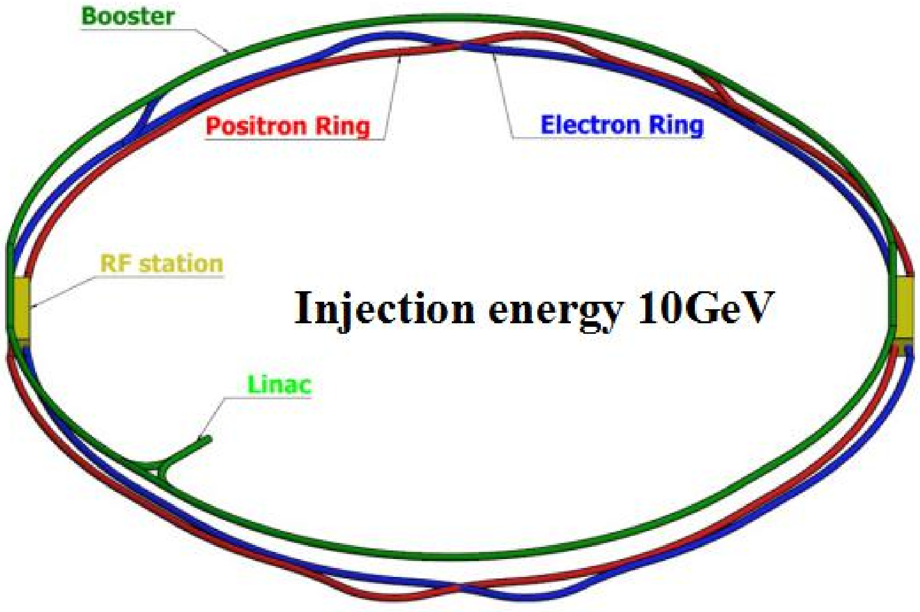


4) Detector Machine Interface (MDI)

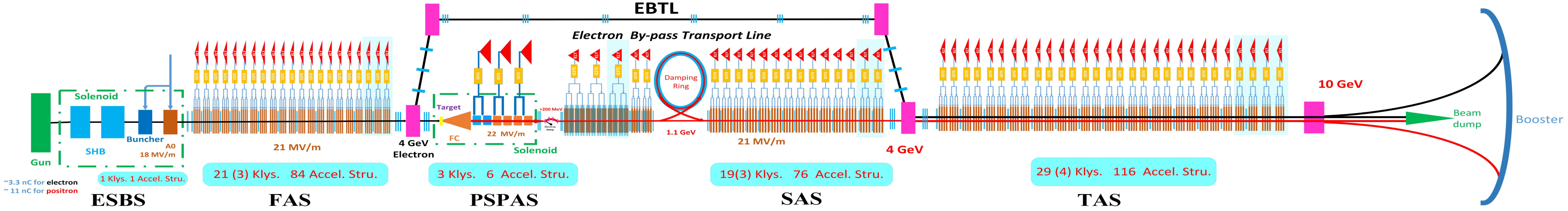
CEPC CDR Baseline Layout



CEPC collider ring (100km)



CEPC booster ring (100km)



CEPC Linac injector (1.2km, 10GeV)

CEPC CDR Parameters

	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 New Parameters for Higgs after CDR

	tt	*Higgs*	*W*	*Z（3T）*	*Z（2T）*
Number of IPs	2				
Beam energy (GeV)	**175**	**120**	**80**	**45.5**	
Circumference (km)	100				
Synchrotron radiation loss/turn (GeV)	7.61	1.68	0.33	0.035	
Crossing angle at IP (mrad)	16.5×2				
Piwinski angle	0.91	3.78	8.5	27.7	
Number of particles/bunch N_e (10^{10})	24.15	17.0	12.0	8.0	
Bunch number (bunch spacing)	**34 (4.9μs)**	**218 (0.76μs)**	**1568 (0.20μs)**	**12000 (25ns+10%gap)**	
Beam current (mA)	3.95	17.8	90.4	461.0	
Synchrotron radiation power /beam (MW)	**30**	**30**	**30**	**16.5**	
Bending radius (km)	10.7				
Momentum compact (10^{-5})	0.91				
β function at IP β_x^* / β_y^* (m)	1.2/0.0037	**0.33/0.001**	**0.33/0.001**	**0.2/0.001**	
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	2.24/0.0068	0.89/0.0018	0.395/0.0012	0.13/0.003	0.13/0.00115
Beam size at IP σ_x/σ_y (μm)	51.8/0.16	17.1/0.042	11.4/0.035	5.1/0.054	5.1/0.034
Beam-beam parameters ξ_x/ξ_y	0.077/0.105	0.024/0.113	0.012/0.1	0.004/0.053	0.004/0.085
RF voltage V_{RF} (GV)	8.93	2.4	0.43	0.082	
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)				
Natural bunch length σ_z (mm)	2.54	2.2	2.98	2.42	
Bunch length σ_z (mm)	2.87	3.93	5.9	8.5	
HOM power/cavity (kw)	0.53 (5cell)	0.58 (2 cell)	0.77 (2 cell)	**1.94** (2 cell)	
Energy spread (%)	0.14	0.19	0.098	0.080	
Energy acceptance requirement (%)	**1.57**	**1.7**	**0.90**	**0.49**	
Energy acceptance by RF (%)	2.67	3.0	1.27	1.55	
Photon number due to beamstrahlung	0.19	0.104	0.050	0.023	
Beamstruhlung lifetime /quantum lifetime* (min)	~ 60	30/50	>400		
Lifetime (hour)	**0.7**	**0.22**	**1.2**	**3.2**	**2.0**
F (hour glass)	0.89	0.85	0.92	0.98	
Luminosity/IP *L* (10^{34}cm^{-2}s^{-1})	**0.38**	**5.2**	**14.5**	**23.6**	**37.7**

*include beam-beam simulation and real lattice

CEPC vs FCC-ee: Z (2T)

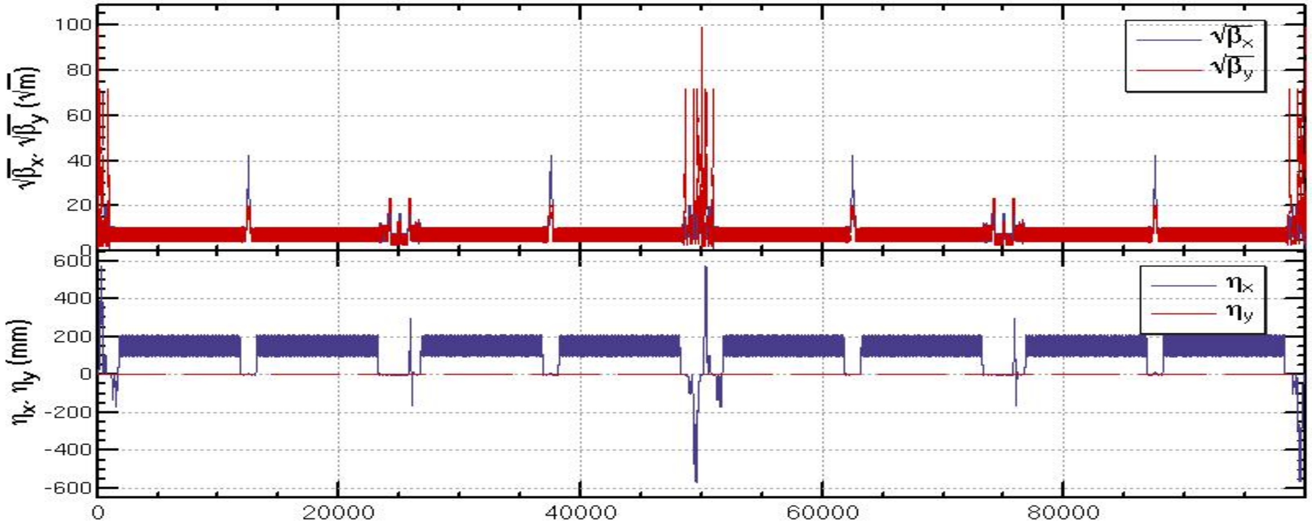
	CEPC-CDR	*CEPC-30MW*	*CEPC-38MW*	*FCC-ee*
Number of IPs	2	2	2	2
Energy (GeV)	45.5	**45.5**	**45.5**	45.6
Circumference (km)	100	100	100	100
SR loss/turn (GeV)	0.036	0.036	0.036	0.036
Half crossing angle (mrad)	16.5	16.5	16.5	15
Piwinski angle	23.8	27.9	33.0	28.5
N_e/bunch (10^{10})	8.0	12.0	15.0	17
Bunch number	12000	**14564 (20.6ns+10%gap)**	**15000**	16640
Beam current (mA)	461	839.9	1081.4	1390
SR power /beam (MW)	**16.5**	**30**	**38.6**	**50**
Bending radius (km)	10.7	10.7	10.7	10.76
Momentum compaction (10^{-5})	1.11	1.11	1.11	1.48
β_{IP} x/y (m)	0.2/0.001	**0.2/0.001**	**0.2/0.001**	0.15/0.0008
Emittance x/y (nm)	0.18/0.0016	0.18/0.0016	0.18/0.0016	0.27/0.001
Transverse σ_{IP} (um)	6.0/0.04	6.0/0.04	6.0/0.04	6.4/0.028
ξ_x/ξ_y/IP	0.004/0.079	0.004/0.093	0.004/0.098	0.004/0.133
V_{RF} (GV)	0.1	0.10	0.10	0.1
f_{RF} (MHz) (harmonic)	650	650	650	400
Nature bunch length σ_z (mm)	2.42	2.42	2.42	3.5
Bunch length σ_z (mm)	8.5	10.0	11.8	12.1
HOM power/cavity (kw)	1.94 (2cell)	**2.29 (1cell)**	**3.15 (1cell)**	?
Energy spread (%)	0.08	0.1	0.115	0.132
Energy acceptance (DA) (%)	1.5	**0.6**	**0.7**	1.3
Energy acceptance by RF (%)	1.7	1.7	1.7	1.9
Lifetime by rad. Bhabha scattering (hour)	2.9			1.13
Lifetime (hour)	2.5	**2.0**	1.8	1.0
L_{max}/IP (10^{34}cm^{-2}s^{-1})	**32.1**	**74.5**	**101.6**	**230**

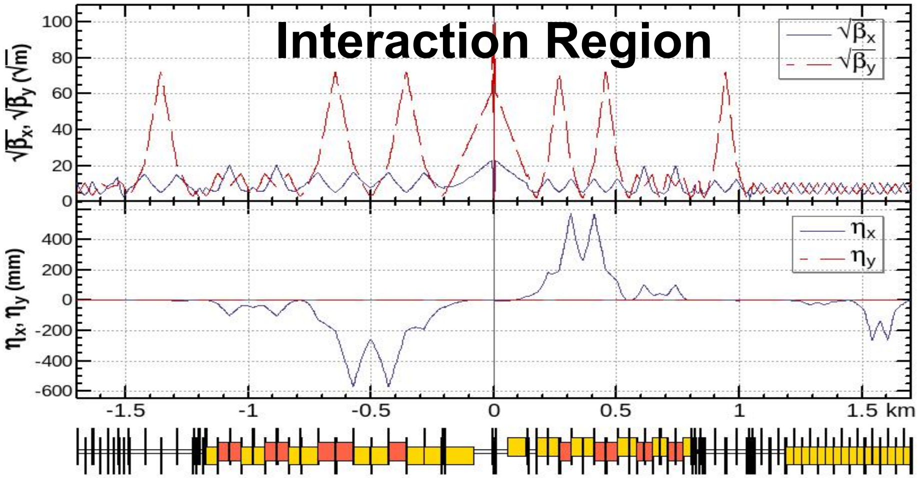
Z:1*10^36/cm^2/s now

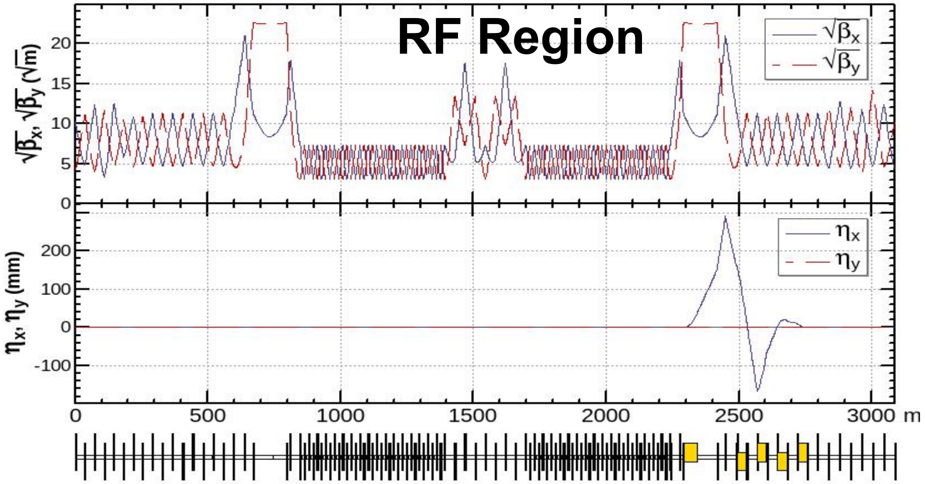
Lattice design with luminosity of $5 \times 10^{34}/\mathrm{cm}^2/s$

- Fit parameter list with luminosity of $5 \times 10^{34}/\mathrm{cm}^2/s$
  - Smaller emittance and βy at IP lead to larger chromaticity
  - **Stronger optimization and stricter hardware requirement should be made to get enough dynamic aperture compared with CDR**
- Optimization of the quadrupole radiation effect
  - Interaction region: longer QD0/QF1
  - ARC region: longer quadrupoles
- Reduction of dynamic aperture requirement from injection
  - Straight section region: larger βx at injection point
- Maximization of bend filling factor to increase single bunch charge
  - ARC region: sextupoles in two rings changed from staggered to parallel; The left drifts are used for longer bend.
  - RF region: shorter phase tuning sections
- Multipoles used to make up to 5th order chromaticity correction

Lattice design with luminosity of $5 \times 10^{34}/\mathrm{cm}^2/s$

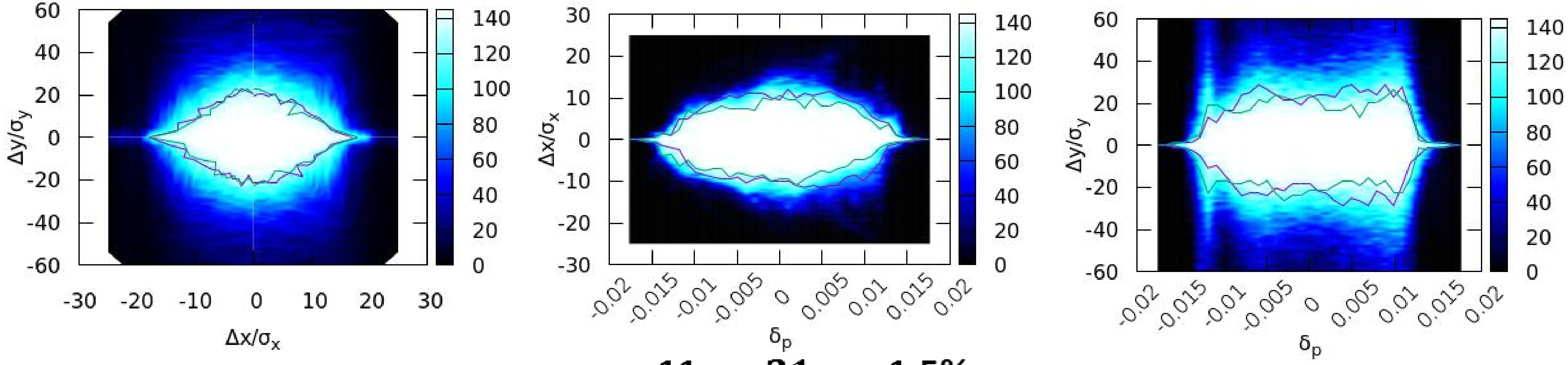






Dynamic Dperture Optimization

- Dynamic aperture optimized with the new lattice aiming at luminosity of $5 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$.
  - Effects of nonlinearity in lattice, synchrotron radiation, beam-beam interaction are included.
  - Multi-Object Deferential Evolution (MODE) algorithm used to make global optimization.
  - DA goal $8\sigma_x \times 15\sigma_y \times$ 1.7%
    - More efforts will be made to enlarge the momentum acceptance.
    - The goal will be adjusted with further beam lifetime study which is under going.



$11\sigma_x \times 21\sigma_y \times$ 1.5%

Analytical Method to Estimate Storage Ring Dynamic Aperture from all Multipoles

WEPEA022 Proceedings of IPAC2013, Shanghai, China

ANALYTICAL ESTIMATIONS OF THE DYNAMIC APERTURES OF BEAMS WITH MOMENTUM DEVIATION AND APPLICATION IN FFAG*

Ming Xiao†, Jie Gao, IHEP, Beijing, China

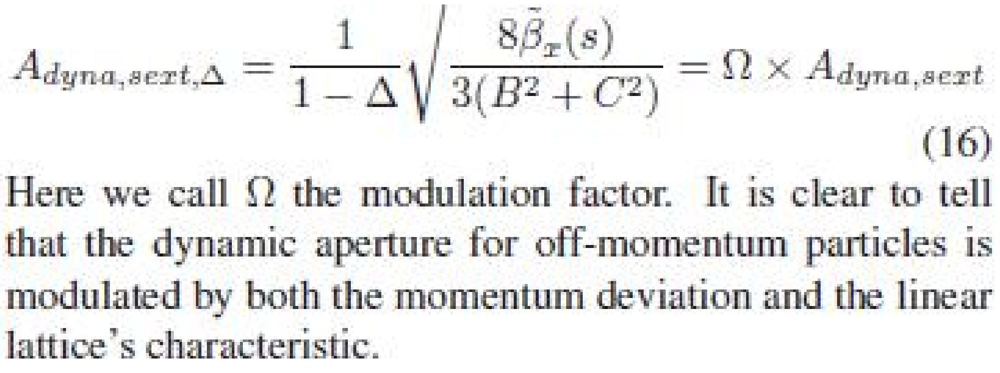
Abstract

Analytical formulae for estimating the dynamic apertures of synchrotron particles has been well established. Based on the standard mapping, we extend the analytical formulae of dynamic aperture for off-momentum particles in circular accelerator. And we compare the analytical results with the simulation ones in the BEPC-II positron ring lattice under some conditions. What's more, we give the analytical formulae of dynamic aperture for FFAG in the similar way.

Hamiltonian[2] including only one sextupole in the x plane

$$H = \frac{p_\beta^2}{2} - (1-\Delta)\left(K_x + \Delta SD\right)\frac{x_\beta^2}{2} + (1-\Delta)S\frac{x_\beta^3}{6} \quad (2)$$

where the quantity $\Delta \equiv (p - p_0)/p_0$ measures the deviation of the actual momentum from the momentum on the reference orbit, S is a periodic function and it is typically piecewise constant in the regions where the correction sextupoles are placed and zero elsewhere, $D(s)$ is the dispersion function in horizontal direction.



$$A_{dyna,sext,\Delta} = \frac{1}{1-\Delta}\sqrt{\frac{8\tilde{\beta}_x(s)}{3(B^2+C^2)}} = \Omega \times A_{dyna,sext} \quad (16)$$

Here we call Ω the modulation factor. It is clear to tell that the dynamic aperture for off-momentum particles is modulated by both the momentum deviation and the linear lattice's characteristic.

Comparison results of BEPC-II DA by numerical and analytical methods

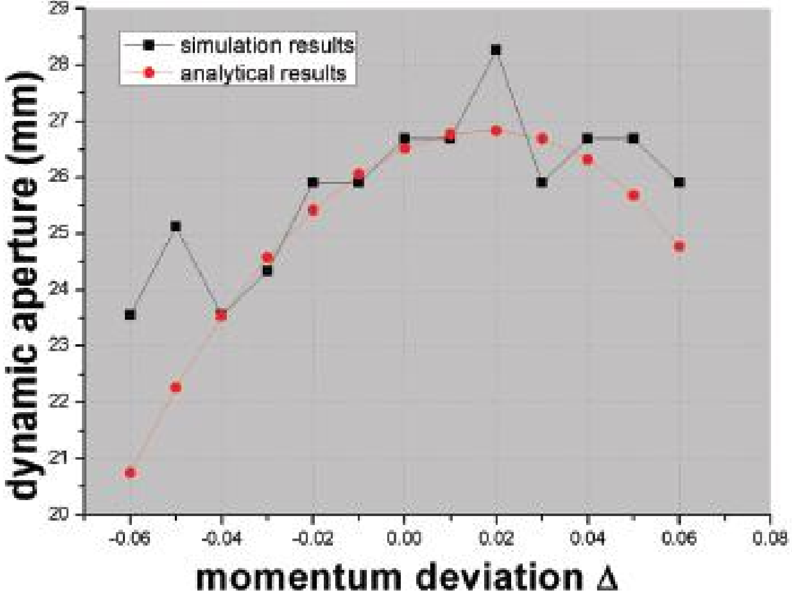


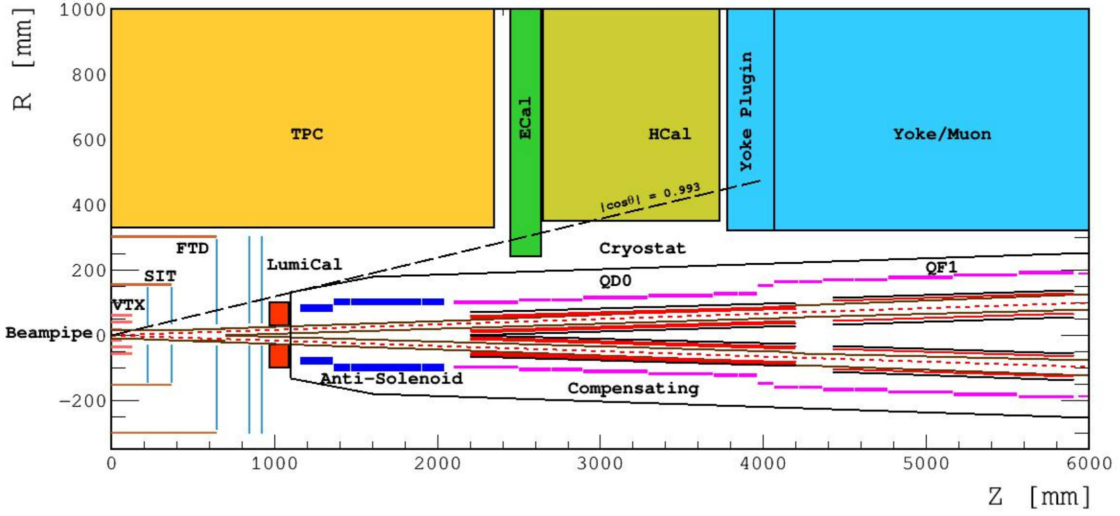
Figure 1: Results of horizontal dynamical aperture in both simulation method and analytical method at BEPC-II positron ring.

This analytical method has been applied successfully in BEPCII and will be used in CEPC DA optimaization to increase optimization efficiency

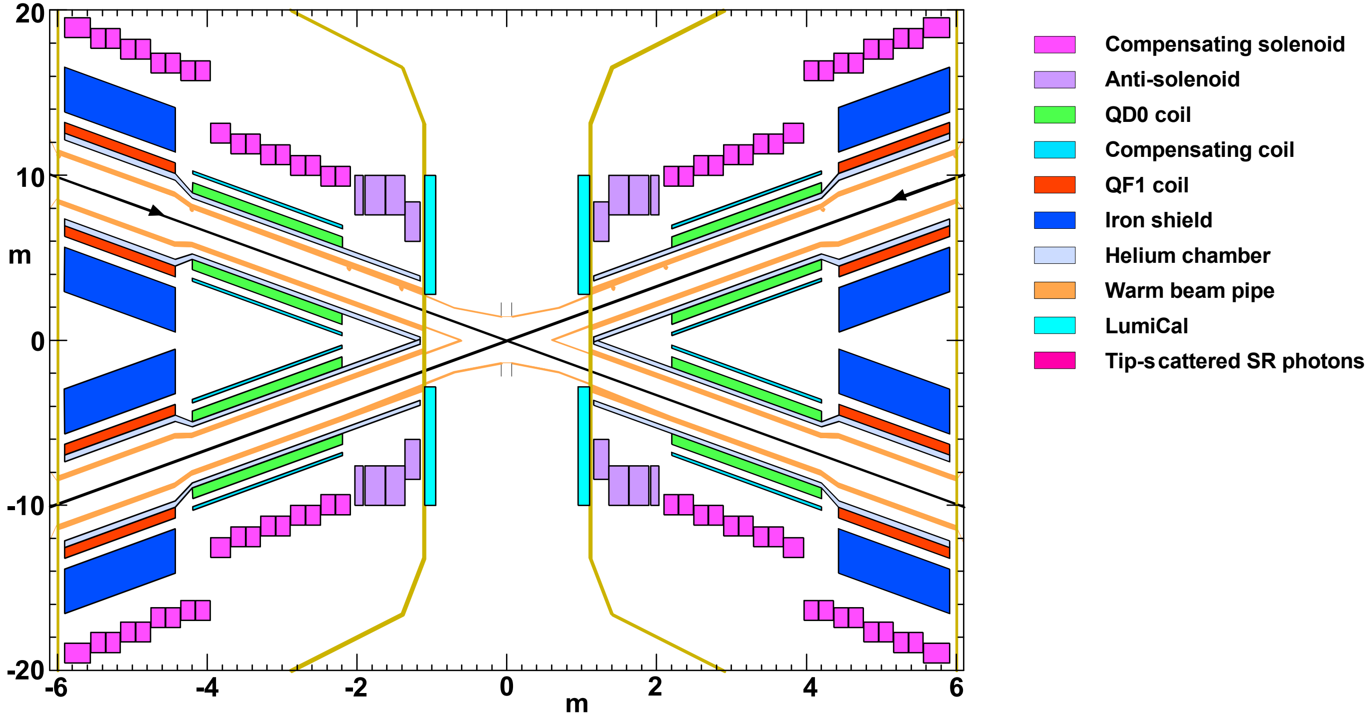
MDI Layout and IR Design

MDI dedicated talk will be given in Sept. 17, by J. Gao

With Detector solenoid



Without Detector solenoid
~cryostat in detail



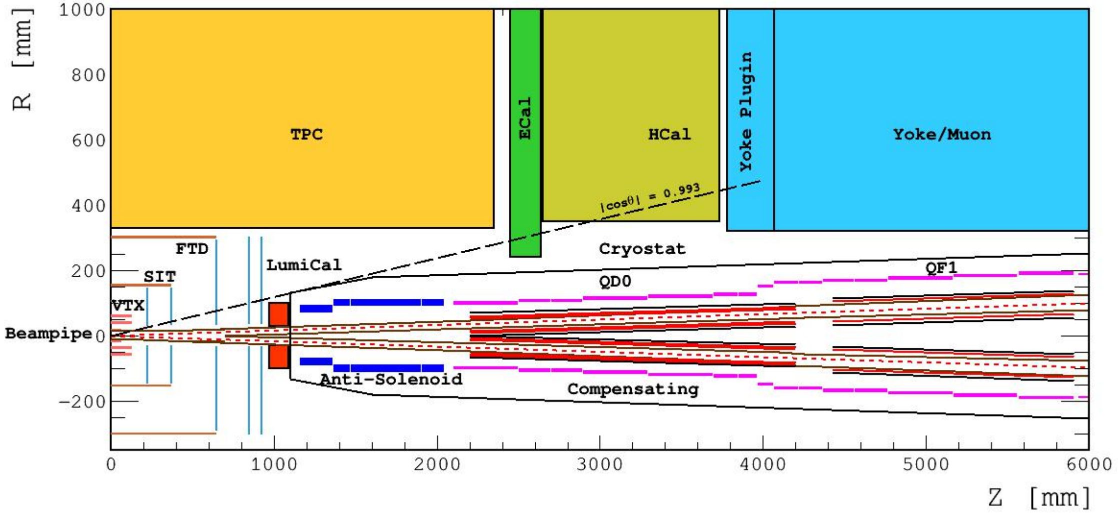
- The accelerator components inside the detector without shielding are within a conical space with an opening angle of cosθ=0.993.
- The e+e- beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is 2.2m
- Lumical will be installed in longitudinal 0.95~1.11m, with inner radius 28.5mm and outer radius 100mm.

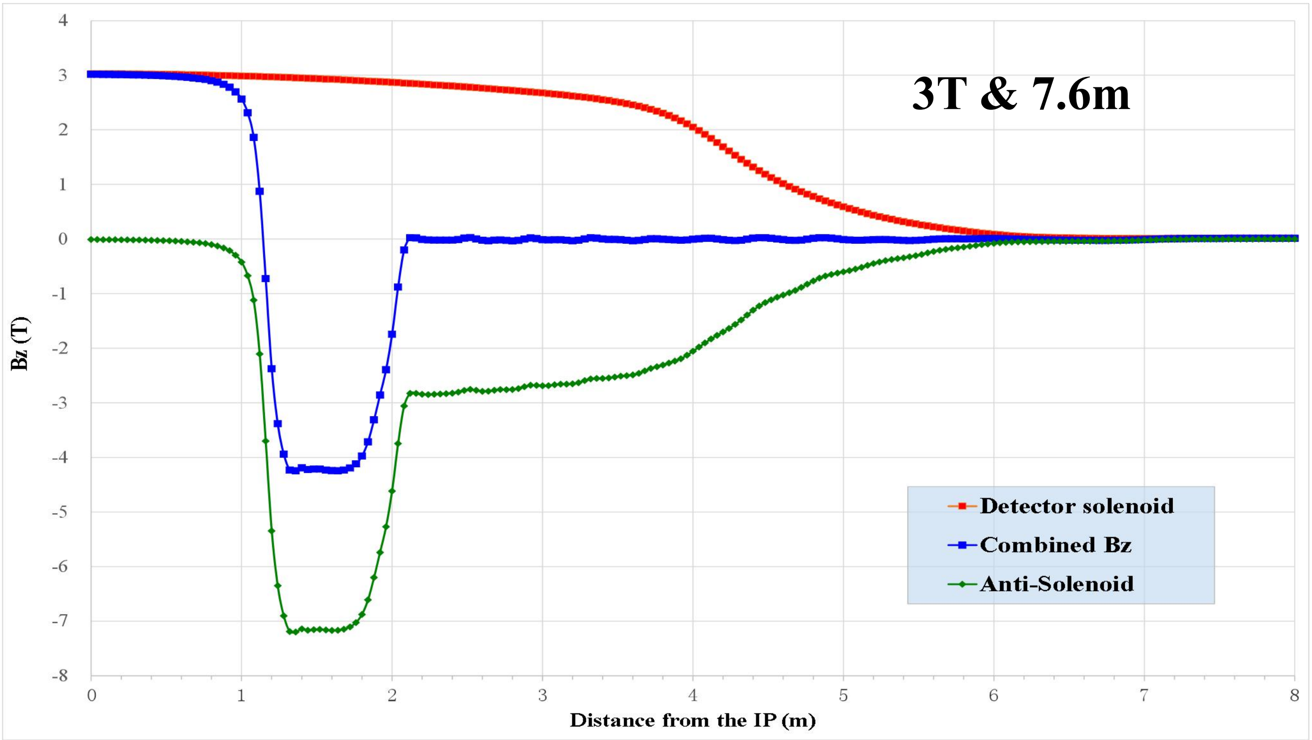
- The Machine Detector Interface (MDI) of CEPC double ring scheme is about ±7m long from the IP
- The CEPC detector superconducting solenoid with 3T magnetic field and the length of 7.6m.

MDI Parameters

	range	Peak filed in coil	Central filed gradient	Bending angle	length	Beam stay clear region	Minimal distance between two aperture	Inner diameter	Outer diameter	Critical energy (Horizontal)	Critical energy (Vertical)	SR power (Horizontal)	SR power (Vertical)
L*	0~2.2m				2.2m								
Crossing angle	33mrad												
MDI length	±7m												
Detector requirement of accelerator components in opening angle	13.6˚												
QD0		3.2T	136T/m		2m	19.51mm	72.61mm	40mm	53mm	1.3MeV	527keV	639W	292W
QF1		3.8T	110T/m		1.48m	26.85mm	146.2mm	56mm	69mm	1.6MeV	299keV	1568W	74W
Lumical	0.95~1.11m				0.16m			57mm	200mm				
Anti-solenoid before QD0		7.26T			1.1m			120mm	390mm				
Anti-solenoid QD0		2.8T			2m			120mm	390mm				
Anti-solenoid QF1		1.8T			1.48m			120mm	390mm				
Beryllium pipe					±7cm			28mm					
Last B upstream	67.66~161.04m			1.1mrad	93.38m					45keV			
First B downstream	46.06~107.04m			1.54mrad	60.98m					97keV			
Beampipe within QD0					2m							2.9W	
Beampipe within QF1					1.48m							3.1W	
Beampipe between QD0/QF1					0.23m							36.2W	

Solenoid Compensation



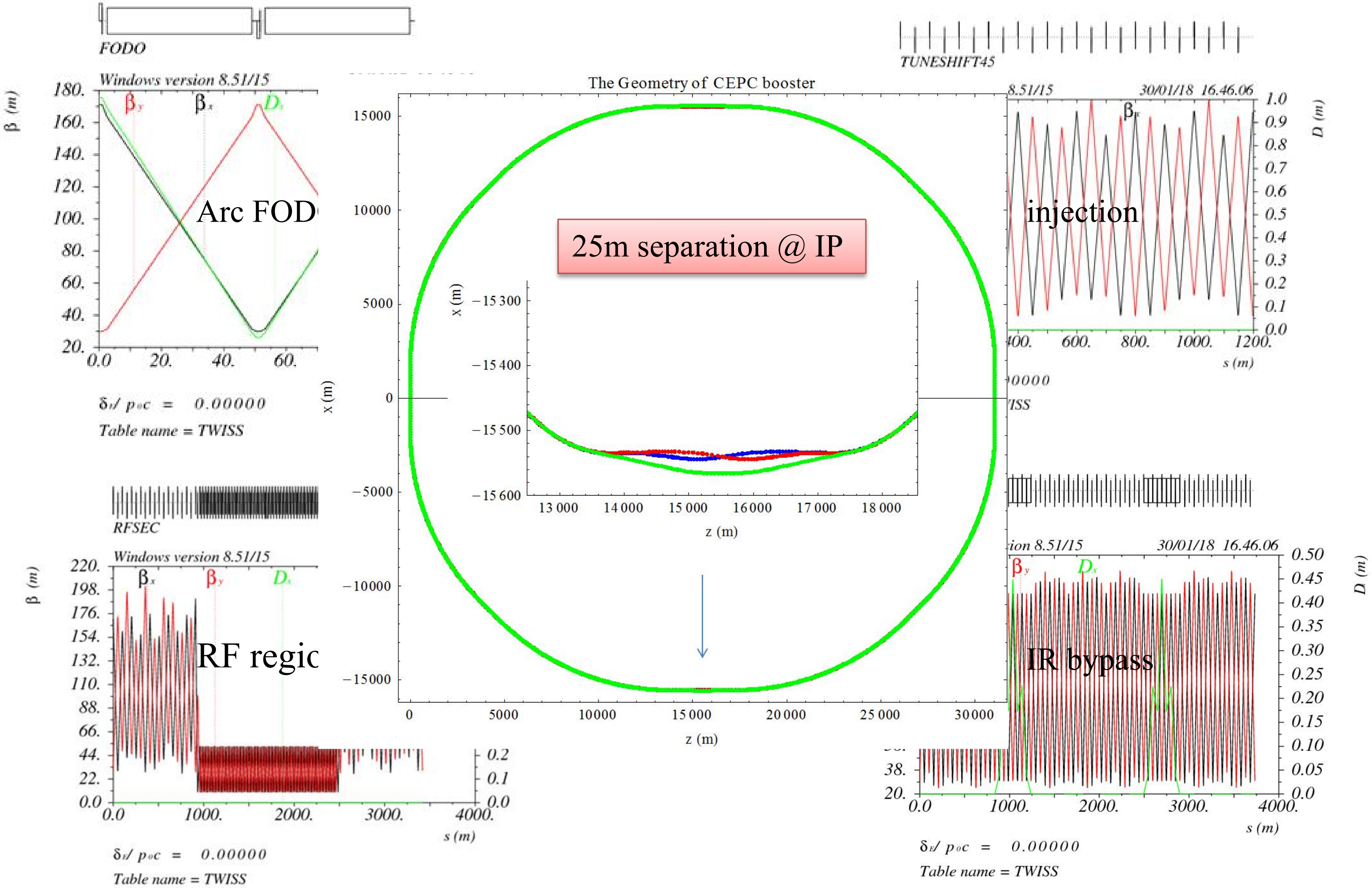


Specification of Anti-Solenoid

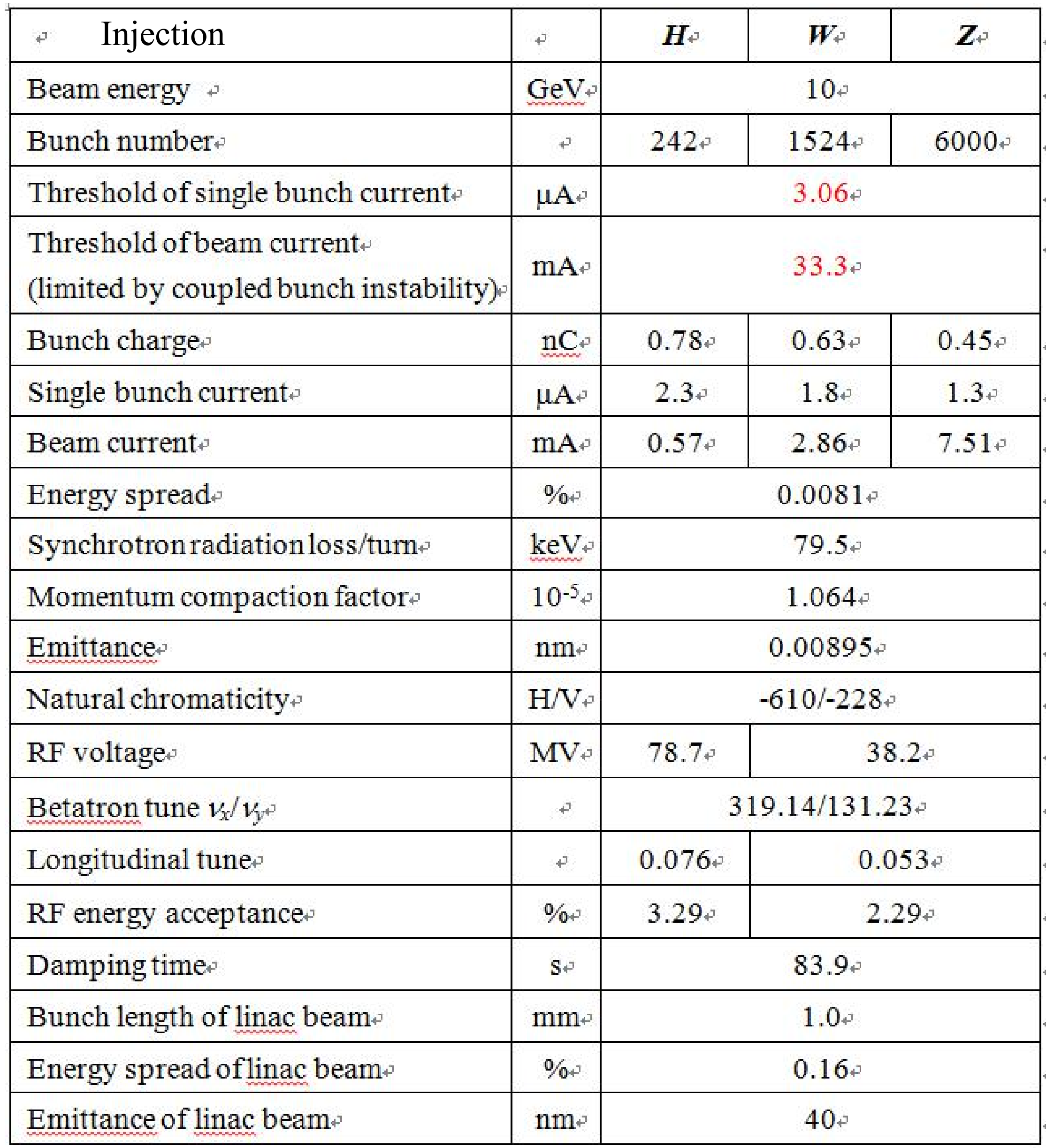
Anti-solenoid	Before QD0	Within QD0	After QD0
Central field（T）	7.2	2.8	1.8
Magnetic length（m）	1.1	2.0	1.98
Conductor (NbTi-Cu, mm)	2.5×1.5		
Coil layers	16	8	4/2
Excitation current（kA）	1.0		
Inductance（H）	1.2		
Peak field in coil (T)	7.7	3.0	1.9
Number of sections	4	11	7
Solenoid coil inner diameter (mm)	120		
Solenoid coil outer diameter (mm)	390		
Total Lorentz force F_z (kN)	-75	-13	88
Cryostat diameter (mm)	500		

- **$\int B_z ds$ within 0~2.12m. Bz < 300Gauss away from 2.12m**
- The skew quadrupole coils are designed to make fine tuning of Bz over the QF&QD region instead of the mechanical rotation.

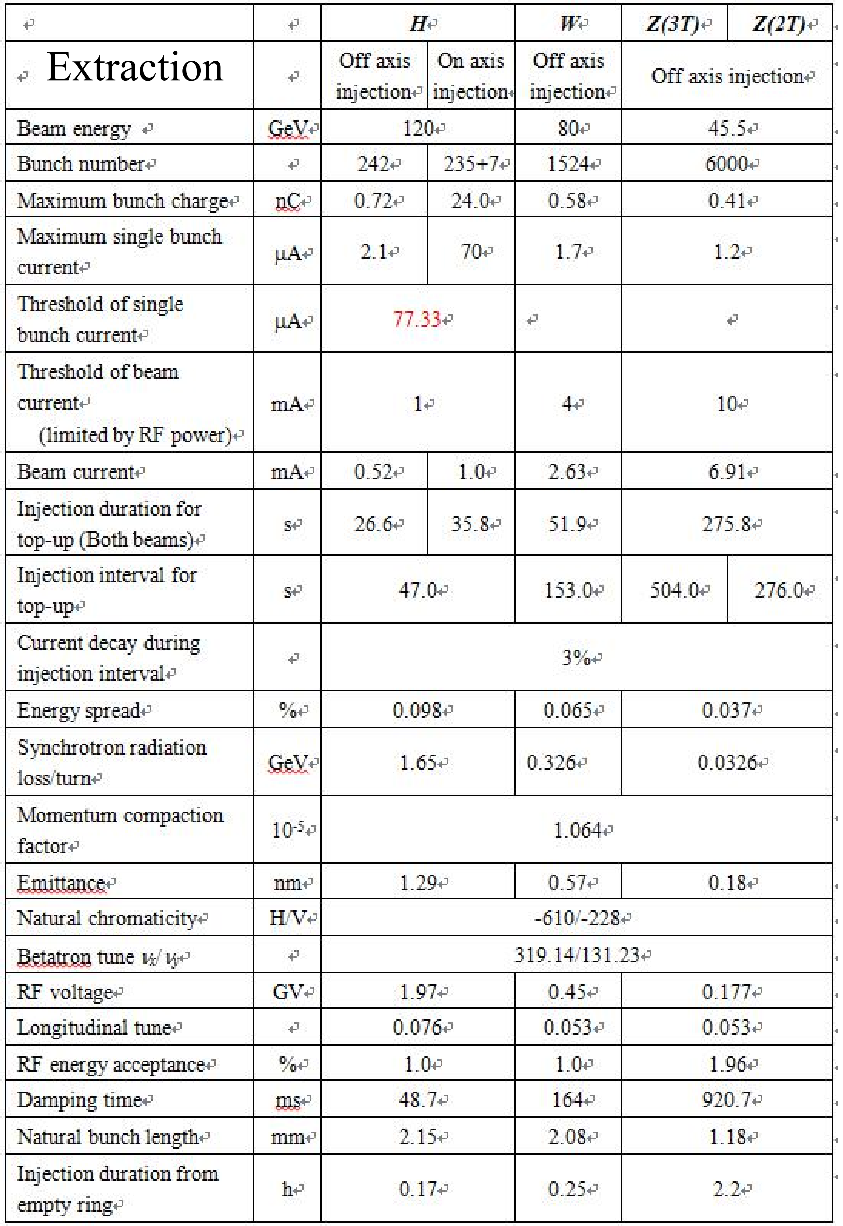
CEPC Booster Optics & Geometry



Booster New Parameters after CDR



Injection		*H*	*W*	*Z*
Beam energy	GeV	10		
Bunch number		242	1524	6000
Threshold of single bunch current	μA	3.06		
Threshold of beam current (limited by coupled bunch instability)	mA	33.3		
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	%	0.0081		
Synchrotron radiation loss/turn	keV	79.5		
Momentum compaction factor	10^{-5}	1.064		
Emittance	nm	0.00895		
Natural chromaticity	H/V	-610/-228		
RF voltage	MV	78.7	38.2	
Betatron tune ν_x/ν_y		319.14/131.23		
Longitudinal tune		0.076	0.053	
RF energy acceptance	%	3.29	2.29	
Damping time	s	83.9		
Bunch length of linac beam	mm	1.0		
Energy spread of linac beam	%	0.16		
Emittance of linac beam	nm	40		



		H		*W*	*Z(3T)*	*Z(2T)*
Extraction		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	77.33				
Threshold of beam current (limited by RF power)	mA	1		4	10	
Beam current	mA	0.52	1.0	2.63	6.91	
Injection duration for top-up (Both beams)	s	26.6	35.8	51.9	275.8	
Injection interval for top-up	s	47.0		153.0	504.0	276.0
Current decay during injection interval		3%				
Energy spread	%	0.098		0.065	0.037	
Synchrotron radiation loss/turn	GeV	1.65		0.326	0.0326	
Momentum compaction factor	10^{-5}	1.064				
Emittance	nm	1.29		0.57	0.18	
Natural chromaticity	H/V	-610/-228				
Betatron tune ν_x/ν_y		319.14/131.23				
RF voltage	GV	1.97		0.45	0.177	
Longitudinal tune		0.076		0.053	0.053	
RF energy acceptance	%	1.0		1.0	1.96	
Damping time	ms	48.7		164	920.7	
Natural bunch length	mm	2.15		2.08	1.18	
Injection duration from empty ring	h	0.17		0.25	2.2	

Booster Optimization Design after CDR

- ➢ Lower emittance lattice
  - Emittance@120GeV : 3.6 nm → 1.3 nm
  - Horizontal DA requirement for collider ring : 13σx → 10σx - ***Off axis injection @120 GeV for collier ring can work.***
  - Booster parameters for 4 energy modes were updated.
  - Larger off-momentum DA than CDR – higher transfer efficiency
- ➢ Smaller beam pipe
  - Diameter of beam pipe: 55mm → 44 mm
  - Significant power reduction for magnets and power supply
  - Lower cost of power supply

Optimization on the Size of Booster Beam Pipe Radius

- use smaller beam pipe thanks to smaller Linac emittance with DR
  - Emittance of Linac: 120nm → 40nm
  - BSC: 4σ+5mm → d= 34mm
  - Size of beam pipe: 55mm→ 44mm

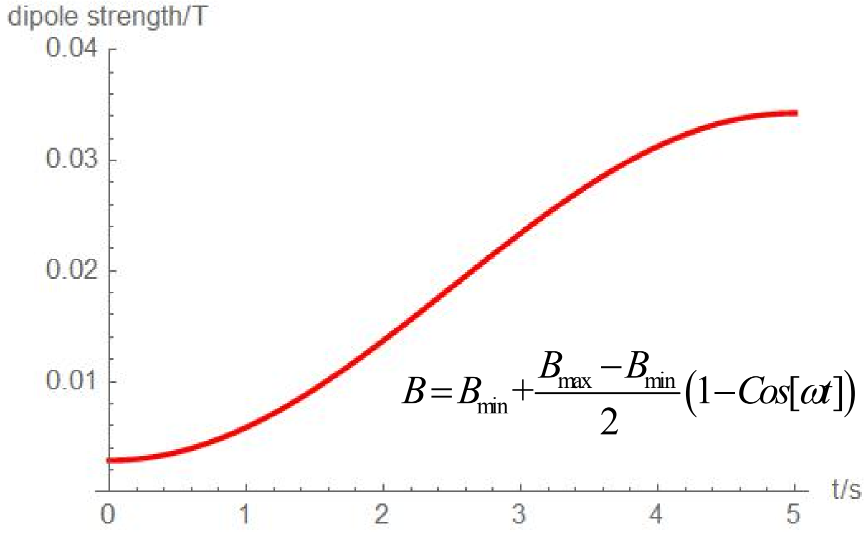
- 44mm inner diameter is enough for future high lum. Z
  - Max bunch current potential: 2.2 uA
  - Max beam current potential: 16.2mA
  - Instability was checked at both 10GeV & 120GeV

- Power for booster magnets and power supply is reduced by **~50% or ~3.7% less for total AC power**

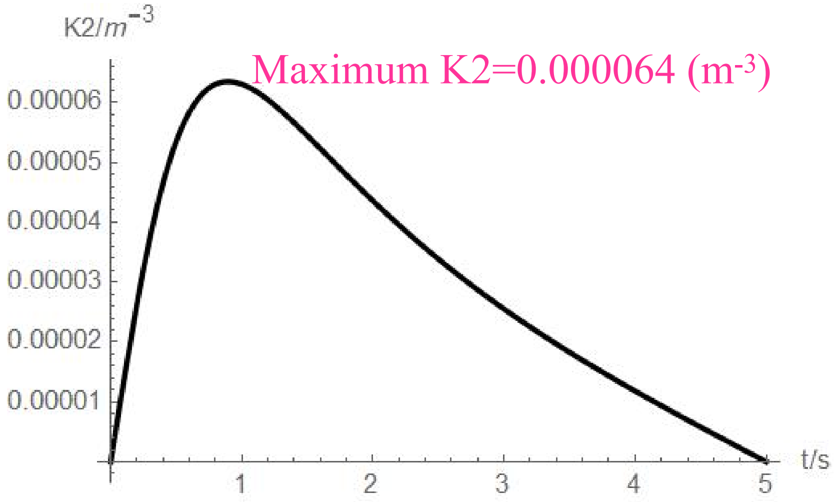
- Cost of booster power supply is reduced by **~30%, or 2.1% lower for the total accelerator cost**

Eddy Current Effect in Booster

- Dedicated ramping curve to control the maximum K2
- Analytical study was done – deeper understanding about eddy current
  - New formula created
  - Dipole w core → multipole field
  - Dipole w/o core → No multipole field
- K2 reach maximum at 20GeV
- Chromaticity distortion is corrected by 2 sext. families during ramping.
- Small DA reduction with dynamic chromaticity correction (~10%)



$$B = B_{\min} + \frac{B_{\max} - B_{\min}}{2}\left(1 - Cos[\omega t]\right)$$



Conclusion:
Both numerical and analytical calculation results show that Eddy currect in booster dipole is not a critical issue, and iron core based dipole magnets could be used.

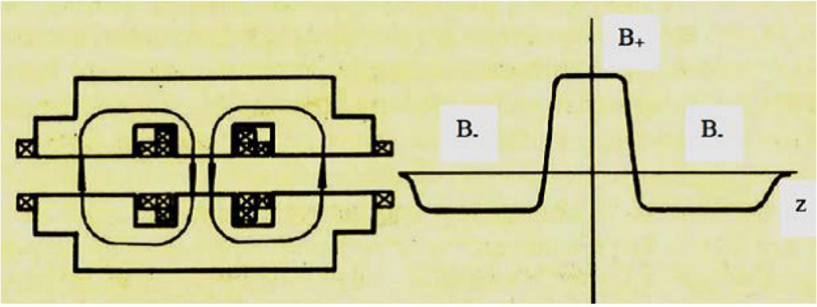
Experimental results will come later

CEPC Self Polarization at Z-pole with Asymmetric Wigglers

- **Special wigglers to speed up self-polarization:**

N_w	B_+	L_+	B_-	L_-	$\frac{\tau_p}{\tau_p^W}$	u	$\frac{\Delta E_W}{\Delta E}$	$\frac{P_0^W}{P_0}$
10	0.6T	1m	0.15T	2m	13.4	0.34	3.2	0.99

u: Fraction of radiation energy loss enhancement. **:Factor of beam energy spread enhancement.**

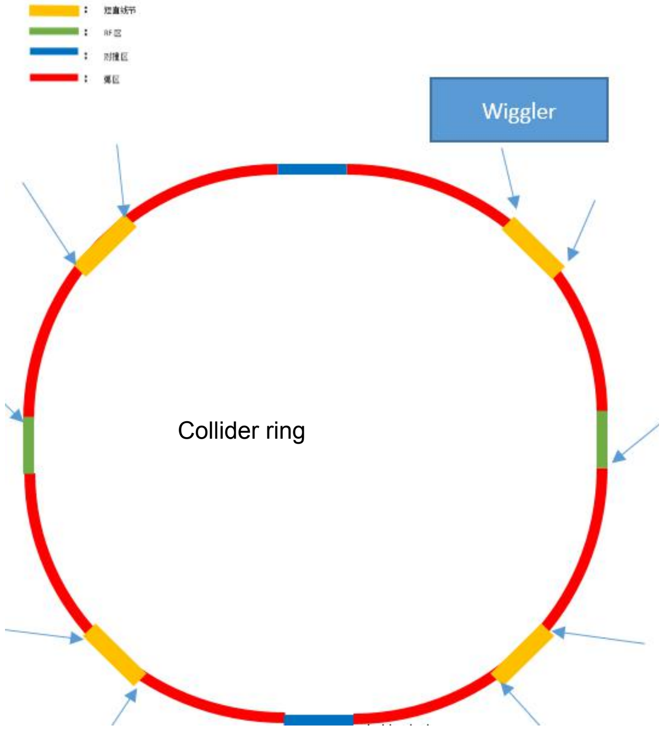


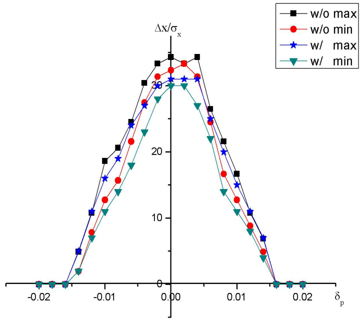
$$P(t) = P_0^W\left(1 - e^{\frac{-t}{\tau_p^W}}\right)$$

$$\tau_p^W = 19.6h,\ P(t) = 5\%,\ P_0^W = 0.913,$$

$$t = 1.10h$$

5% is enough for energy calibration.

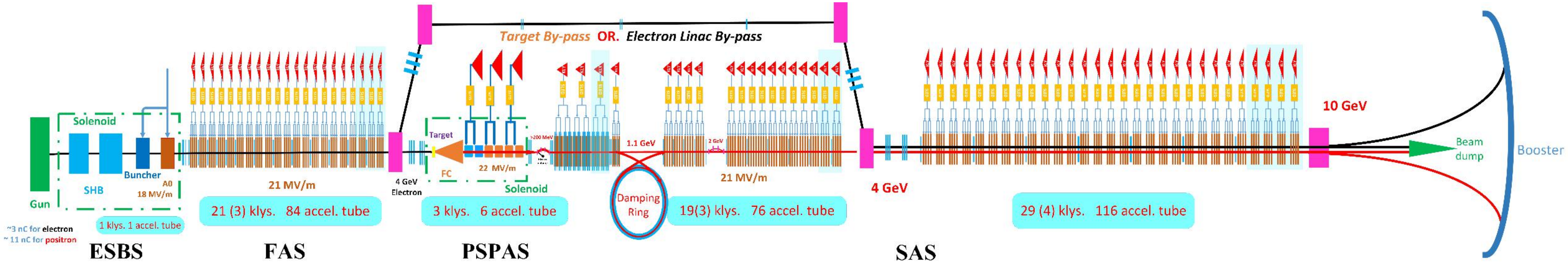




DA

Longitudinal polarized beam collision and full plozrization injection scheme are under studies

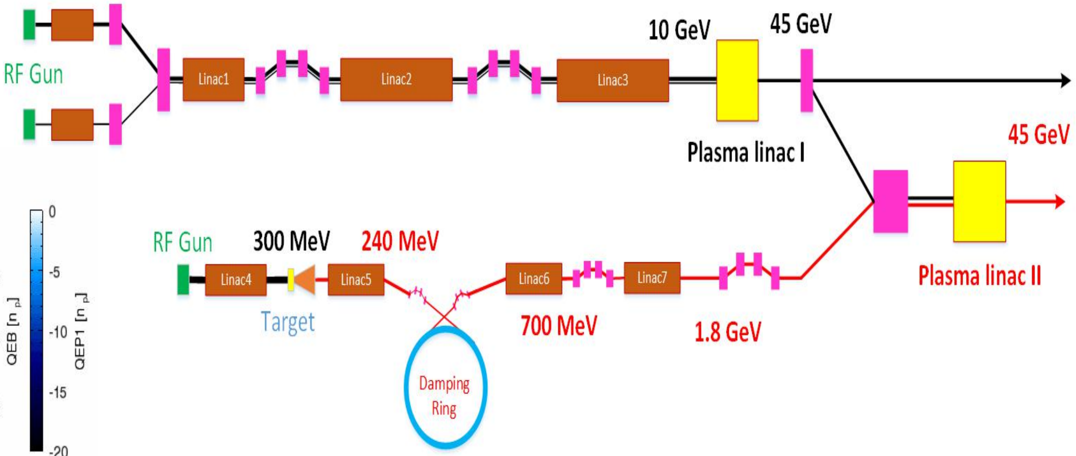
CEPC Linac Injector

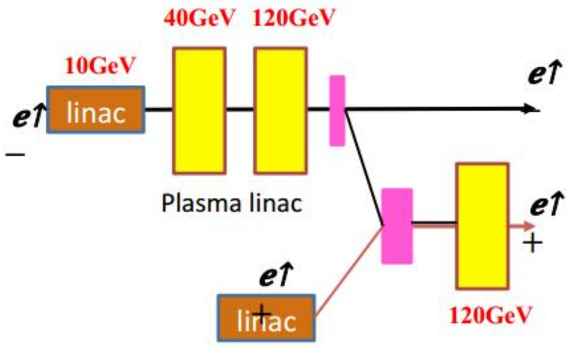


Parameter	Symbol	Unit	Baseline	**Design reached**
e^- /e^+ beam energy	E_{e-}/E_{e+}	GeV	**10**	**10**
Repetition rate	f_{rep}	Hz	**100**	**100**
e^- /e^+ bunch population	N_{e-}/N_{e+}		$> 9.4\times10^9$	**1.9×10^{10} / 1.9×10^{10}**
		nC	**> 1.5**	**3.0**
Energy spread (e^- /e^+)	σ_e		**$< 2\times10^{-3}$**	**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**

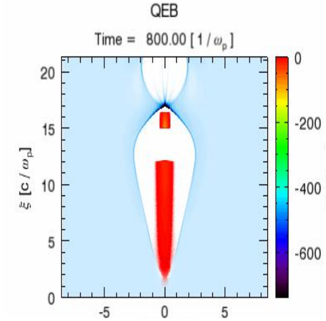
Experimental Verification Planfor CEPC Plasma Injector Scheme

A dedicated budget of 8Million has been alocated by IHEP



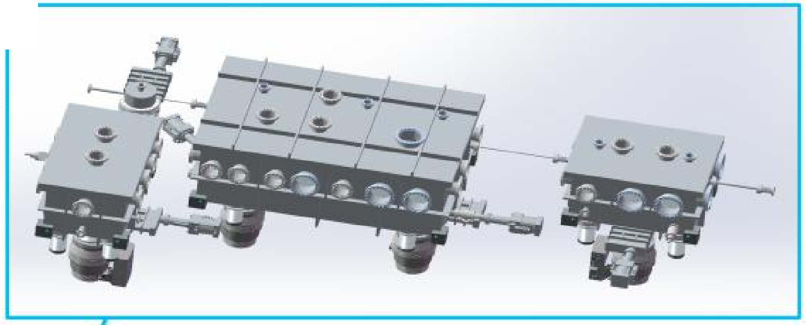


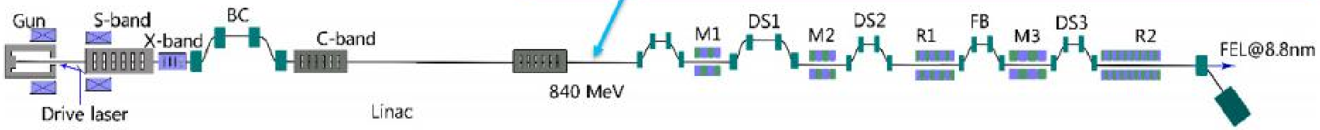
Technical design review has been done (August 22,2019)



Plasma density $n_0(cm^{-3})$	5.15×10^{16}
Driver charge $Q_d(nC)$	6.47
Driver energy $E_d(GeV)$	10
Driver length $L_d(\mu m)$	285
Driver RMS size $\sigma_d(\mu m)$	10
Driver normalized emittance $\epsilon_{nd}(mm\ mrad)$	10
Trailor charge $Q_t(nC)$	1.25
Trailor energy $E_t(GeV)$	10
Trailor length $L_t(\mu m)$	35
Trailor RMS size $\sigma_t(\mu m)$	5
Trailor normalized emittance $\epsilon_{nt}(mm\ mrad)$	100

Trailor energy $E_t(GeV)$	45.5
Trailor normalized emittance $\epsilon_{nt}(mm\ mrad)$	98.9
TR	3.55
Energy spread $\delta_E(\%)$	0.7
Efficiency (driver -> trailor)	68.6%





- **Electron plasma acceleration will be tested in Shanghai's Soft XFEL Facility**
- **Positron plasma acceleration scheme will be tested at FACET-II at SLAC**

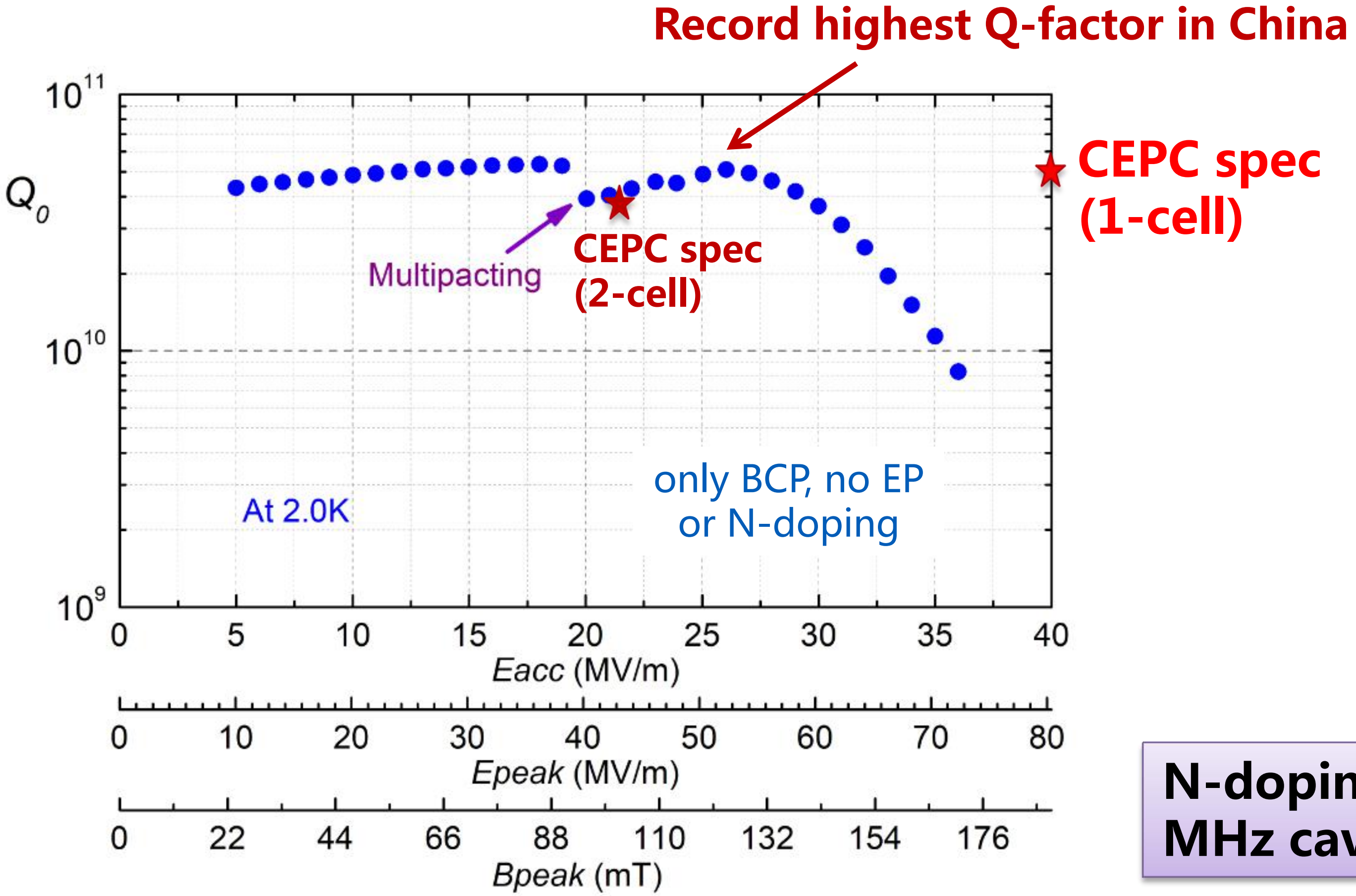
Requirment of Booster to Plasma Injector(@45.5GeV)

Parameter	Symbol	Unit	Requirement	Realized
e^- /e^+ beam energy	E_{e-}/E_{e+}	GeV	**45.5**	**45.3(-)/45.2(+)**
frequency	f_{rep}	Hz	**100**	**100**
e^- /e^+ bunch population	N_{e-}/N_{e+}	nC	**> 1.0**	**1.0(-)/1.0(+)**
Energy spread (e^- /e^+)	σ_e		**$< 2 \times 10^{-3}$**	**0.002(-)/0.0014(+)**
Emittance (e^- /e^+)	ε_r	nm· rad	**< 30**	**1.89(-)/1.0(+)**
Bunch length (e^- /e^+)	σ_l	mm	**< 3**	**0.3(-)/0.3(+)**
Switch time e^- /e^+		s	**< 20**	
Energy stability			**$< 2 \times 10^{-3}$**	
Longitudinal stability		mm	**< 2**	
Orbit stability		mm	**<5 (H) / 3 (V)**	
Failure rate		%	**< 1**	

High Q and High Gradient R&D (650 MHz FG)

Accelerating gradient (Eacc) reach 36.0 MV/m , **Q = 5.1E10 @ Eacc = 26 MV/m。**

Next, increase the Q and Eacc through N-doping, EP, etc. Target: **5E10@42MV/m** for vertical test.

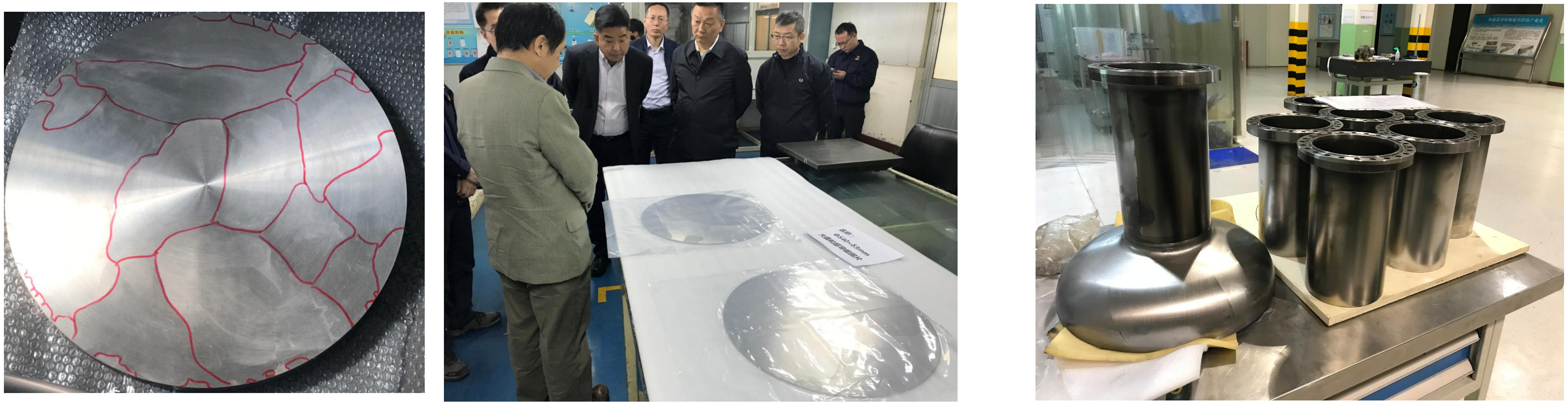


650 MHz 1-cell

N-doping + EP will increase the 650 MHz cavity performance in near future

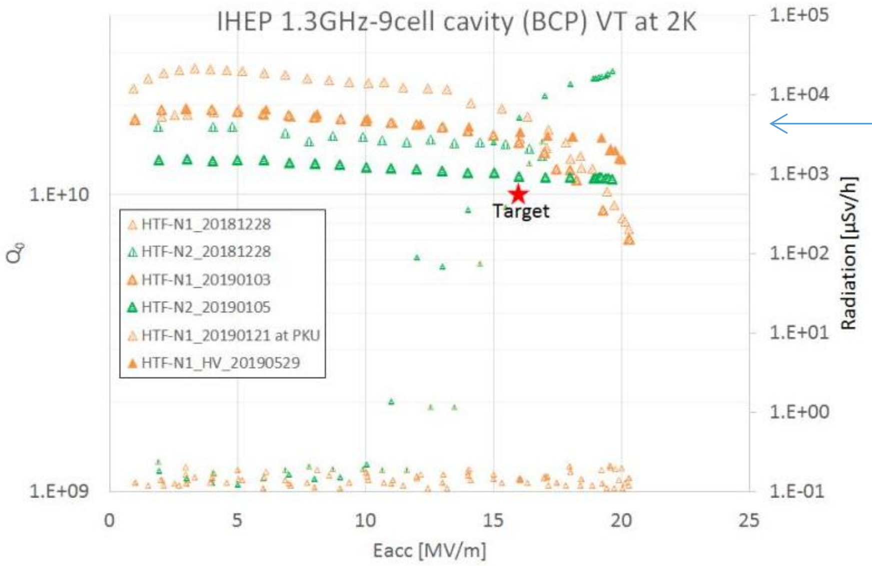
650 MHz 1-Cell Cavity (Large Grain)

- 650 MHz 1-cell cavity (large grain) is favorable for HL-Z, which have higher Q and gradient than fine grain.
- Target of Vertical test: **5E10 @ 42MV/m at 2.0 K**.
- Four cavities are under fabrication now, which will be tested in the middle 2019.

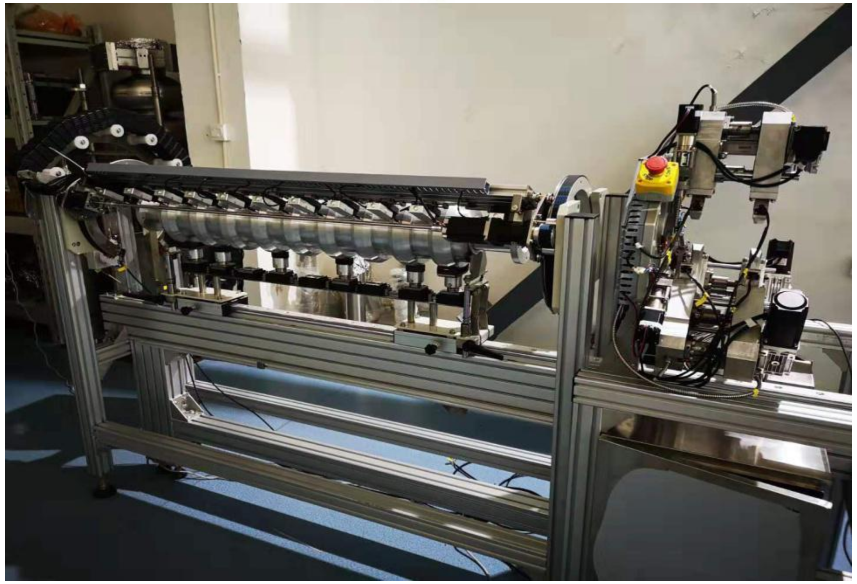


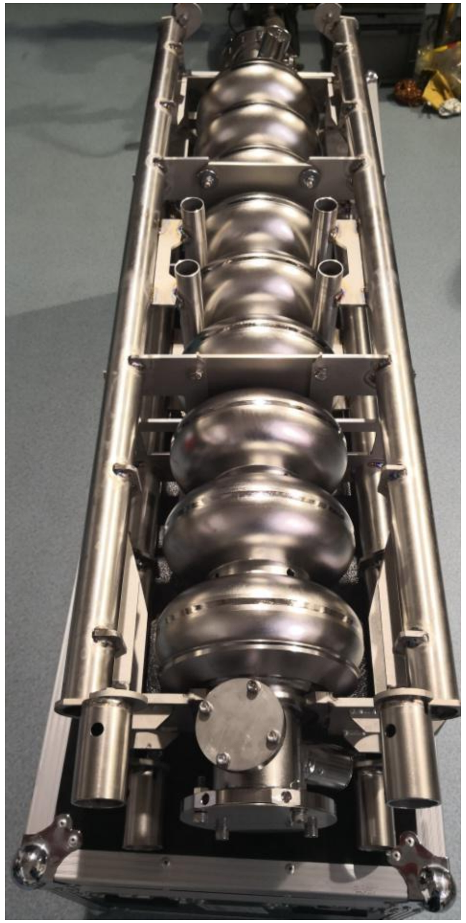
Large grain Nb sheets made by OTIC

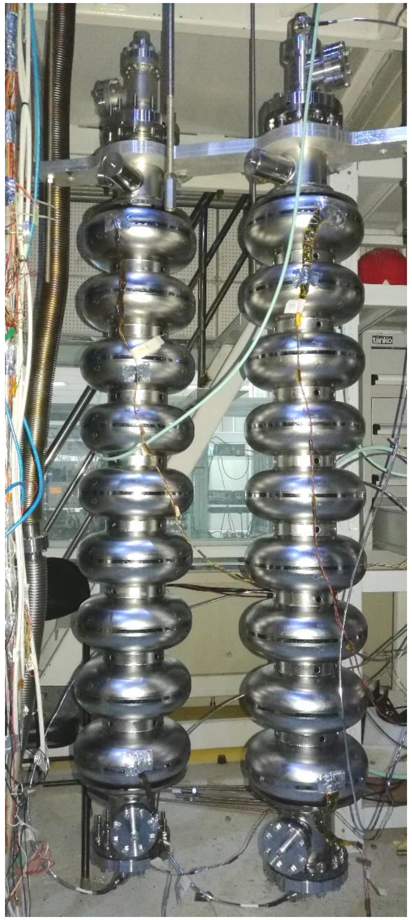
IHEP SHINE 1.3 GHz 9-cell cavities (BCP)

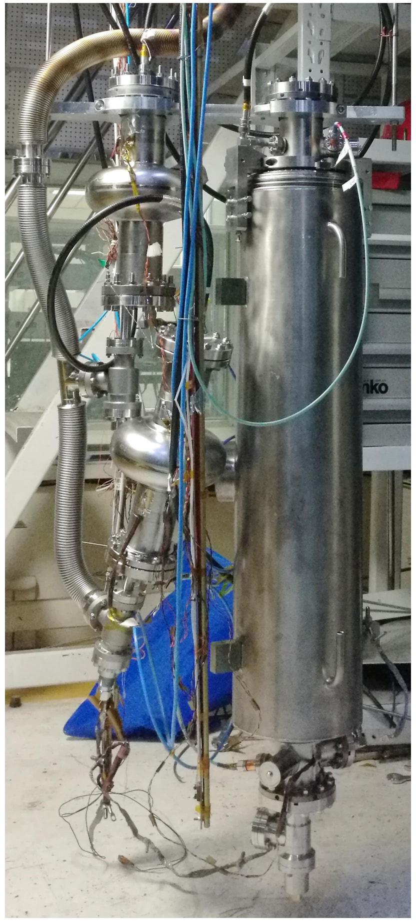


IHEP made 1.3GHz 9cell cavity reaches the goal of SHINE

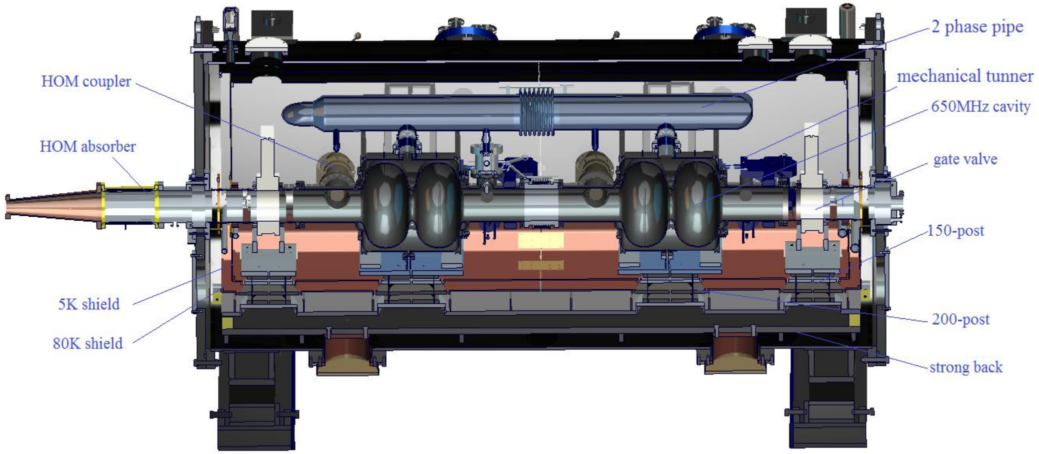


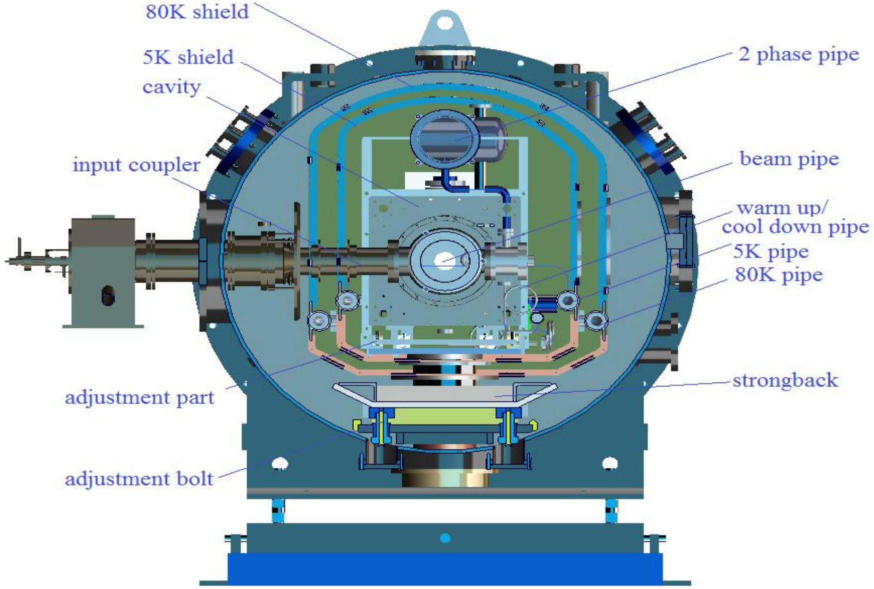


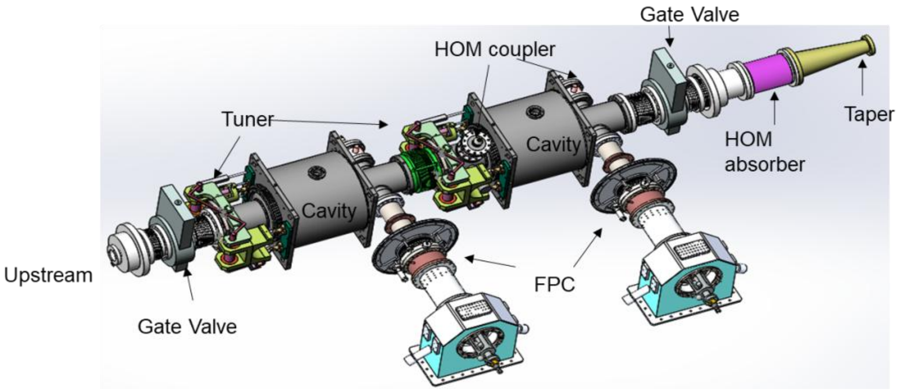




CEPC 650 MHz Cryomodule（ 2 x 2-cell Model ）



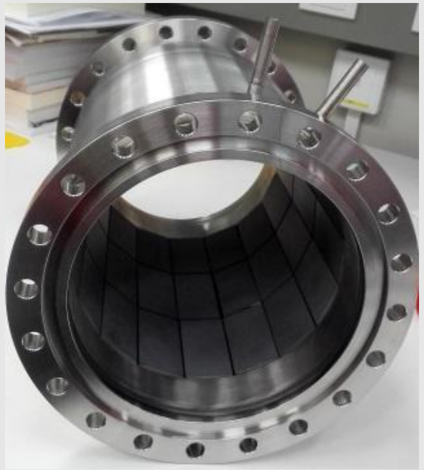




CEPC SCRF R&D in Progress

High power coupler

HOM



Absorber

CEPC 650 MHz Cryomodule

IHEP New SC Lab under Construction （Status August 2019)

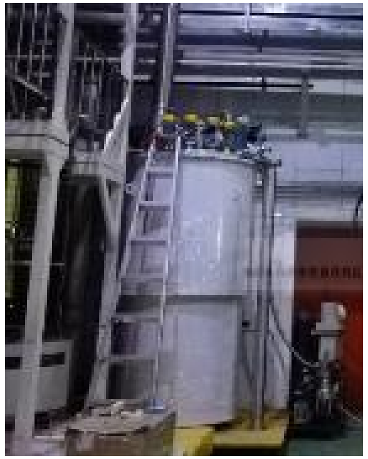
New SC Lab Design (4500m^2)

Bird view in August 2019

Experimental hall

Hellium recirculating tanks

2.5KW@4.5Kcold box



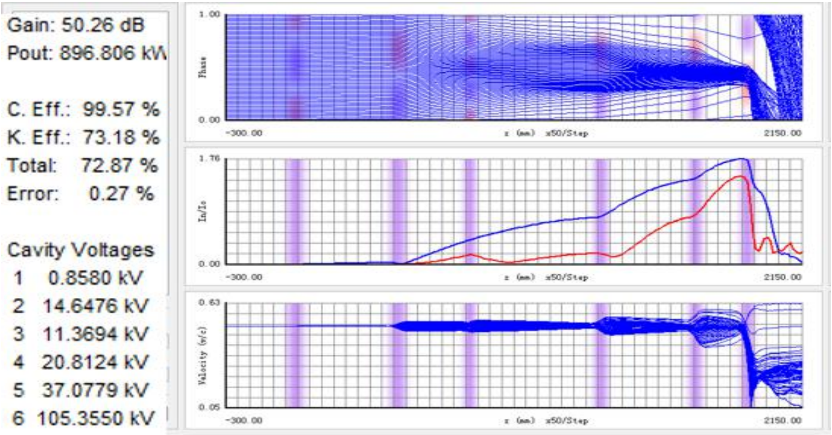
2K JT heat exchanger

CEPC 650MHz High Efficiency Klystron Development

Established "High efficiency klystron collaboration consortium", including IHEP & IE(Institute of Electronic) of CAS, and Kunshan Guoli Science and Tech.

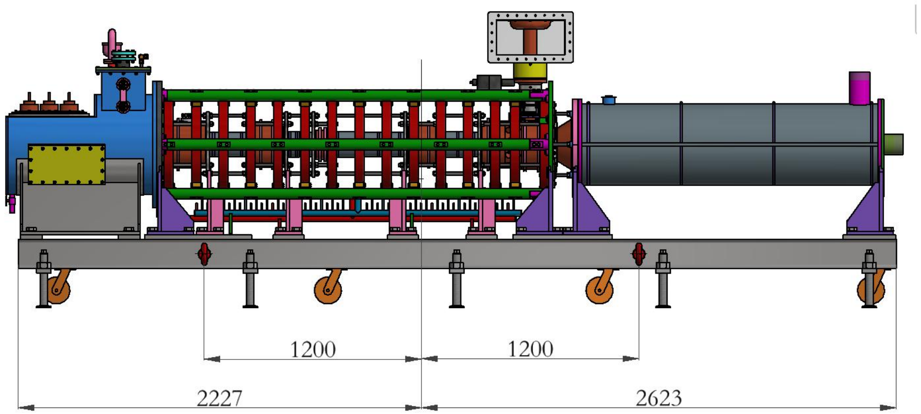
- 2016 – 2018： Design conventional & high efficiency klystron
- 2017 – 2018： Fabricate conventional klystron & test
- 2018 - 2019 ： Fabricate 1st high efficiency klystron & test
- 2019 - 2020 ： Fabricate 2nd high efficiency klystron & test
- 2020 - 2021 ： Fabricate 3rd high efficiency klystron & test

Parameters	Conventional efficiency	**High efficiency**
Centre frequency (MHz)	650+/-0.5	**650+/-0.5**
Output power (kW)	800	**800**
Beam voltage (kV)	80	**-**
Beam current (A)	16	**-**
Efficiency (%)	~ 65	**> 80**


Gain: 50.26 dB
Pout: 896.806 kW

C. Eff.: 99.57 %
K. Eff.: 73.18 %
Total: 72.87 %
Error: 0.27 %

Cavity Voltages
1 0.8580 kV
2 14.6476 kV
3 11.3694 kV
4 20.8124 kV
5 37.0779 kV
6 105.3550 kV



Mechanical design of conventional klystron

⇨ 73%/68%/65% efficiencies for 1D/2D/3D

1st CEPC 650MHz Klystron Prototype Manufacture

① Components

De-gassing facility

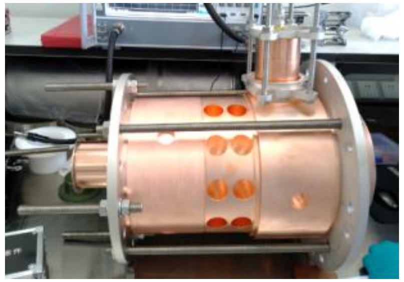
Modulator anode

Focusing electrode

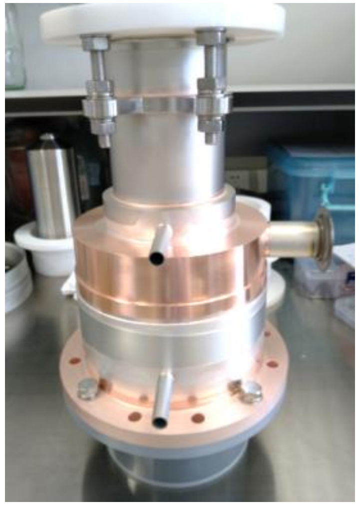
Cathode

Input coupler

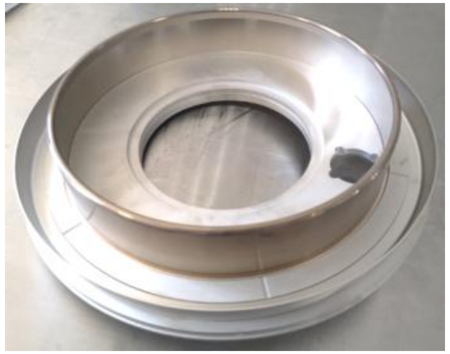
Pumping out pipe



Cavity



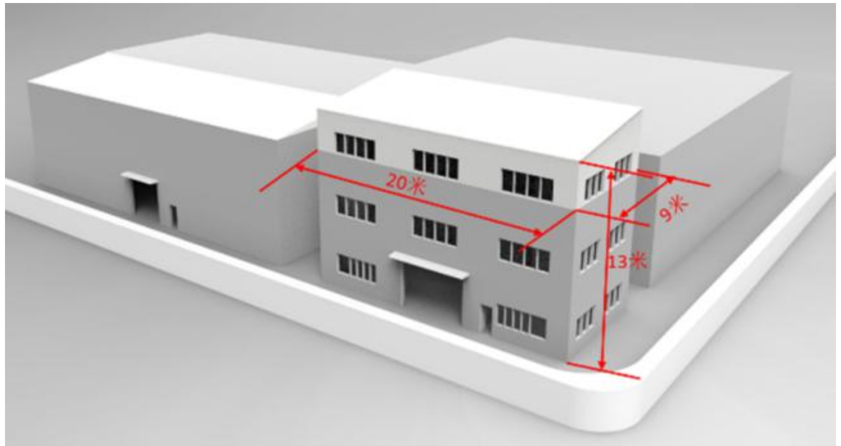
Output window



Gun support

1st 650Mhz Klystron Prototype Manufacture Facility

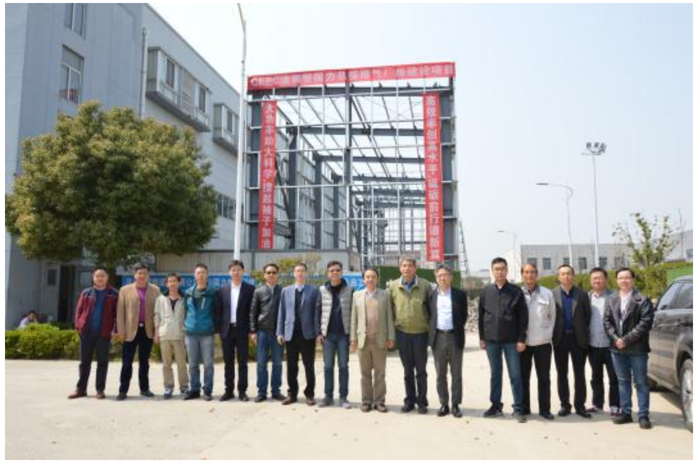
② Infrastructure preparation



Plant

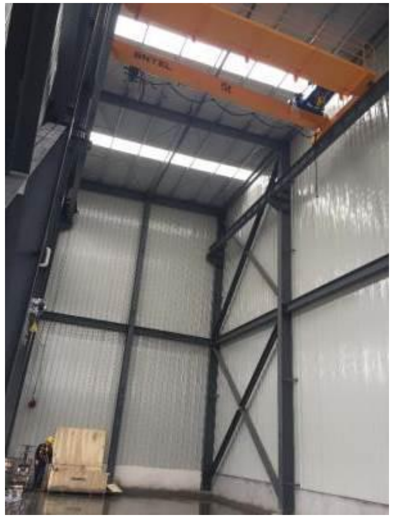
2018.12

2019.1



2019.3

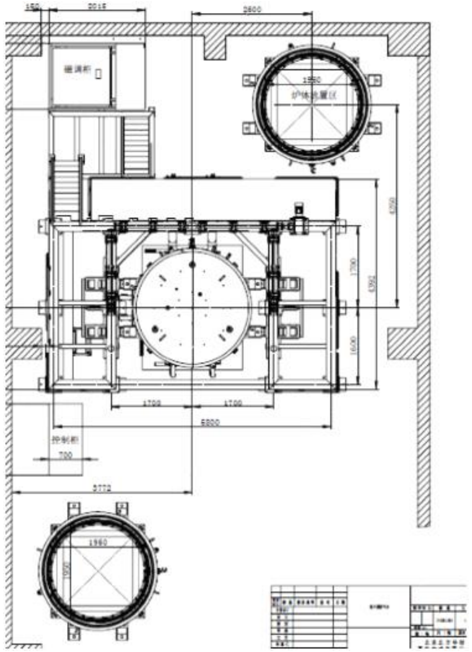
2019.5



2019.5

1st 650Mhz Klystron Prototype Manufacture Preparation

② Infrastructure preparation



Baking furnace

Factory acceptance

Site installation

Commissiong

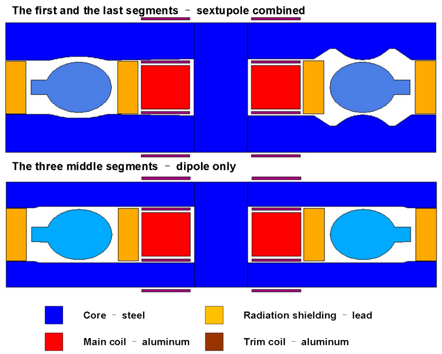
CEPC Collider and Booster Ring Conventional Magnets

China Astronotics Department 508 Institute participates CEPC magnets mechanical designs

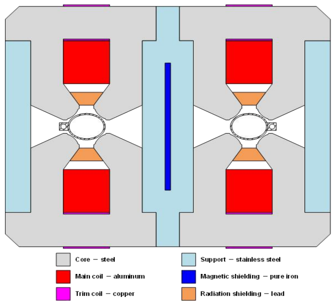
CEPC collider ring magnets

	Dipole	Quad.	Sext.	Corrector	Total
Dual aperture	2384	2392	-	-	13742
Single aperture	80*2+2	480*2+172	932*2	2904*2	
Total length [km]	71.5	5.9	1.0	2.5	80.8
Power [MW]	7.0	20.2	4.6	2.2	34

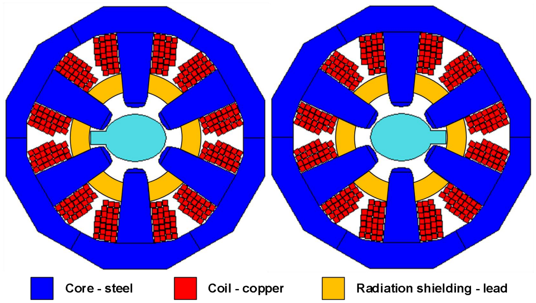
First short model magnets will be fnished in Nov, 2019



Dipole



Quadrupole

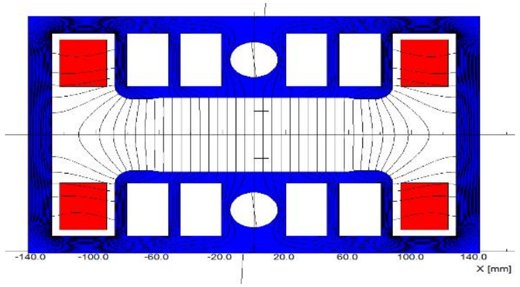


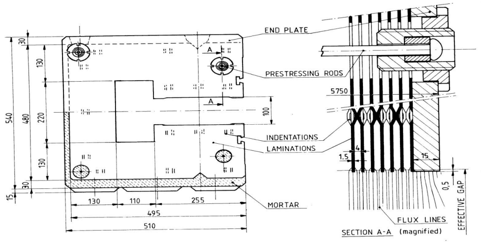
Sextupole

Booster ring low field magnets

Quantity	16320
Magnetic length(m)	4.711
Max. strength(Gs)	338
Min. strength(Gs)	28
Gap height(mm)	63
GFR(mm)	55
Field uniformity	5E-4

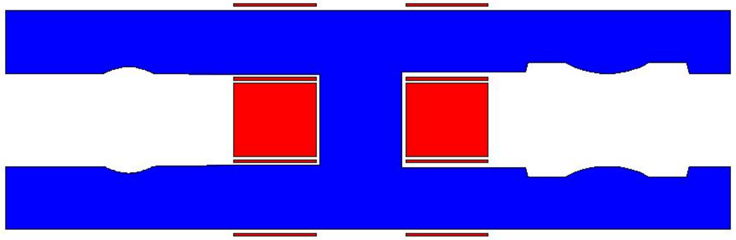
Dipole

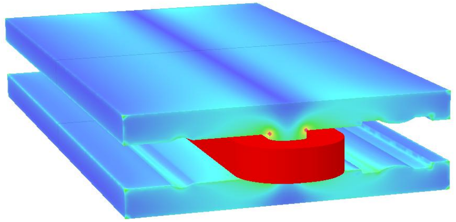


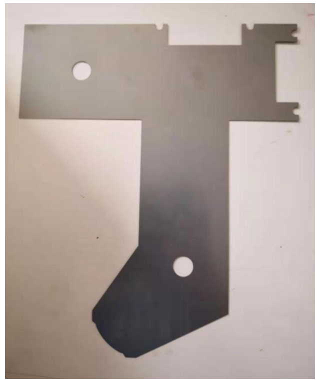


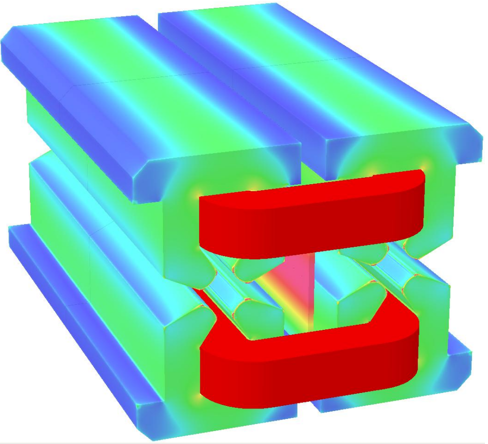
CEPC Collider Ring dual Aperture Dipole, Quadrupole and Sextupole Magnet Design Progress

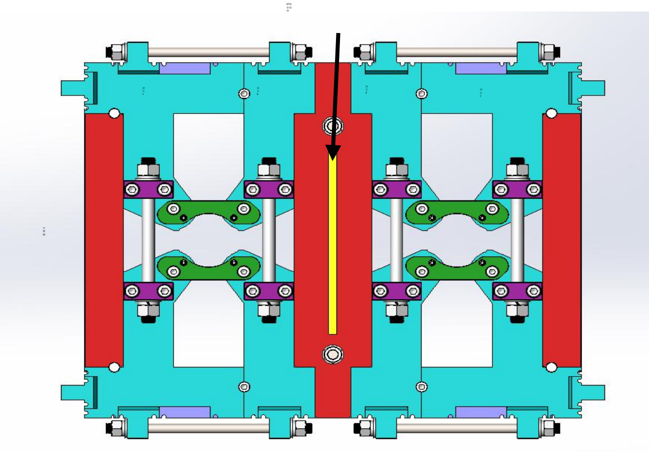
Technical design review has been done
(May 5, 2019)

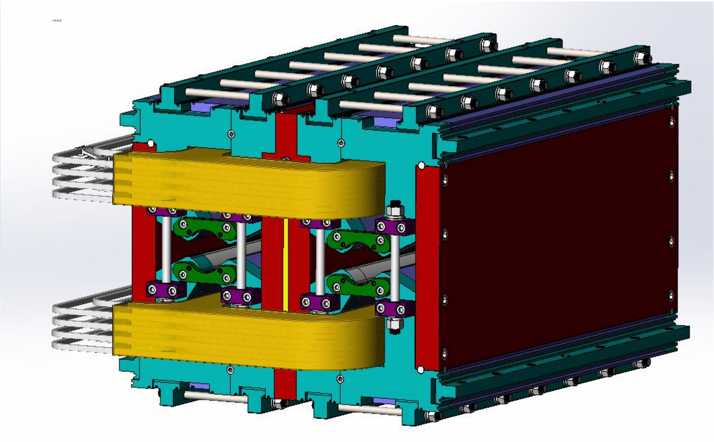




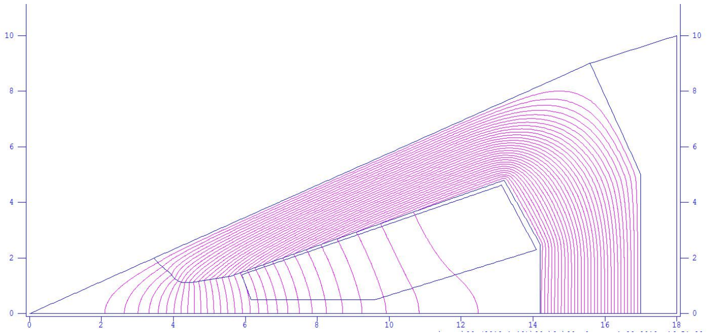


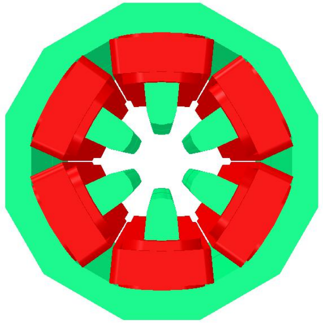


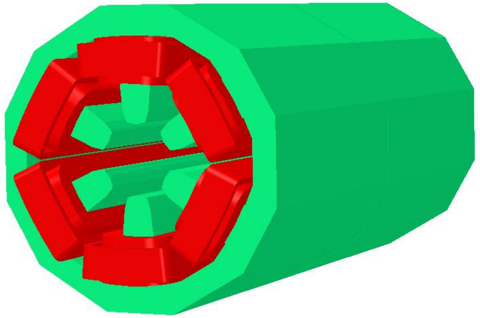




CEPC Collider ring and booster dipole magntes are under fabrications







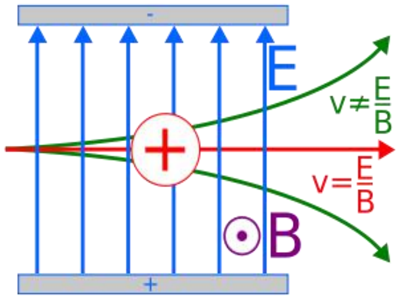
First short model magnets will be fnished in Nov, 2019

CEPC Collider Ring Electro-Magnet Separator

The **Electrostatic-Magnetic Deflector** is a device consisting of perpendicular **electric** and **magnetic** fields, just like **Wien filter**.

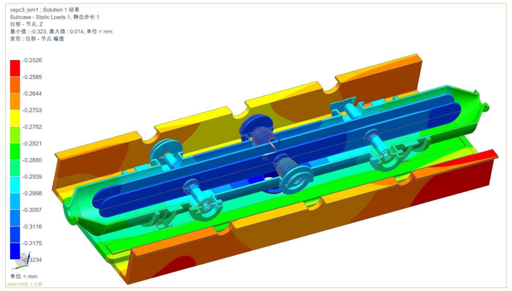
Challenges: To maintain E/B ration in fringe field region

Reduce the impedance and loss factor of the separator

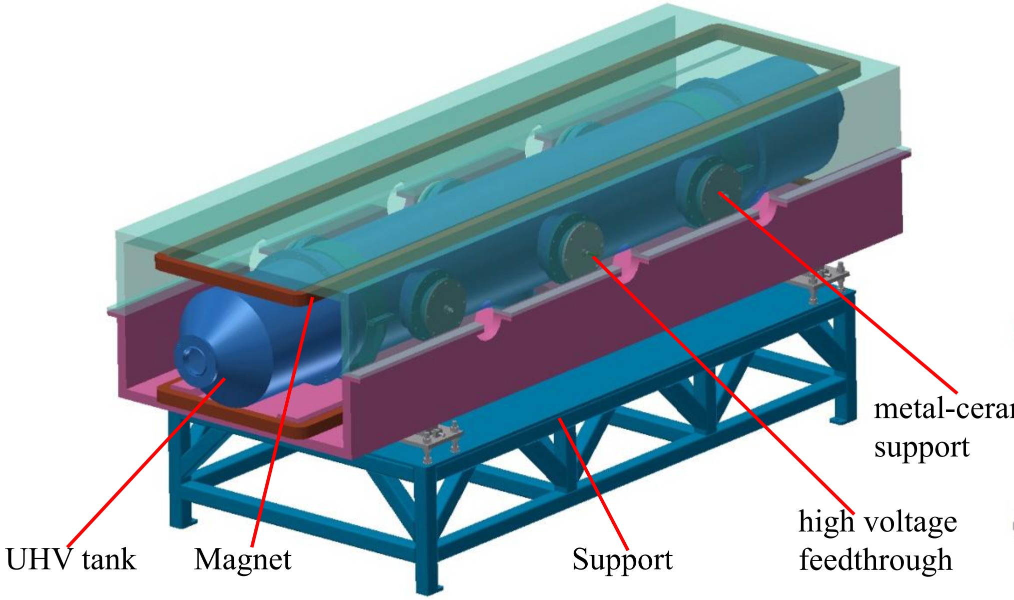


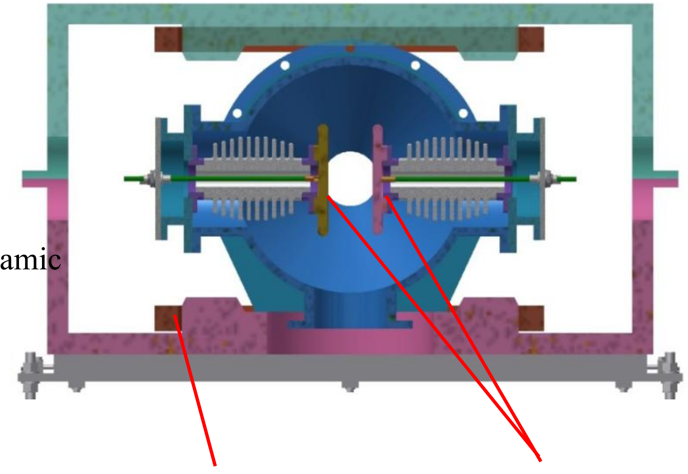
Technical design review has been done (Sept.3,2019)

	Filed	**Effective Length**	**Gap**	**Good field region**	**Stability**
Electrostatic separator	2.0MV/m	4m	110mm	70mm x 30mm	5 x 10^{-4}
Dipole	66.7Gauss	4m	600mm	70mm x 30mm	5 x 10^{-4}



A Wien filter





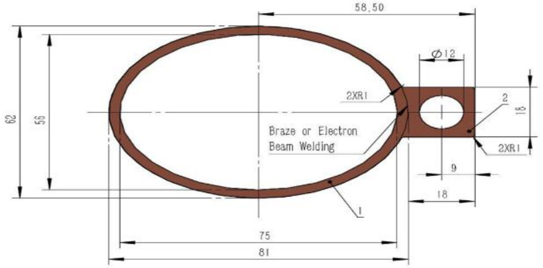
structure drawing of Electrostatic-Magnetic Deflector

CEPC Vacuum System R&D

High quality vacuum valve R&D in progress

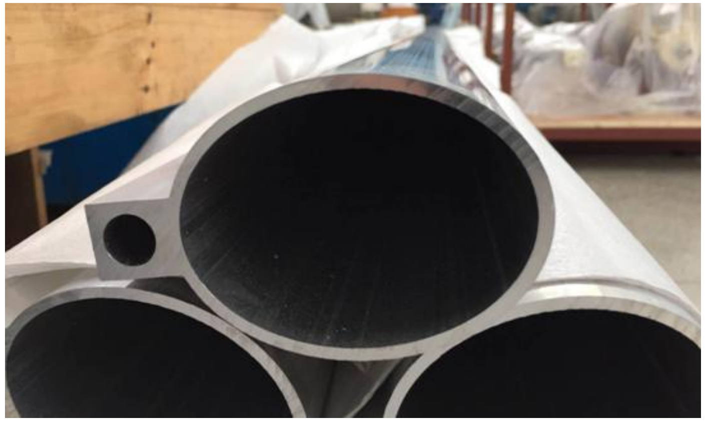
- The vacuum pressure is better than 2 x 10-10 Torr
- Total leakage rate is less than 2 x 10-10 torr.l /s.

Positron ring

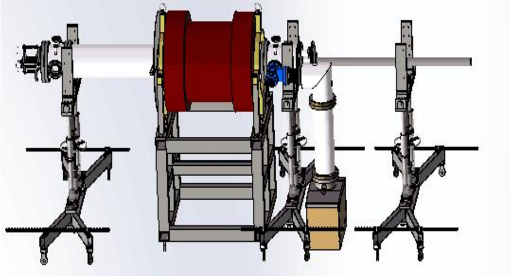


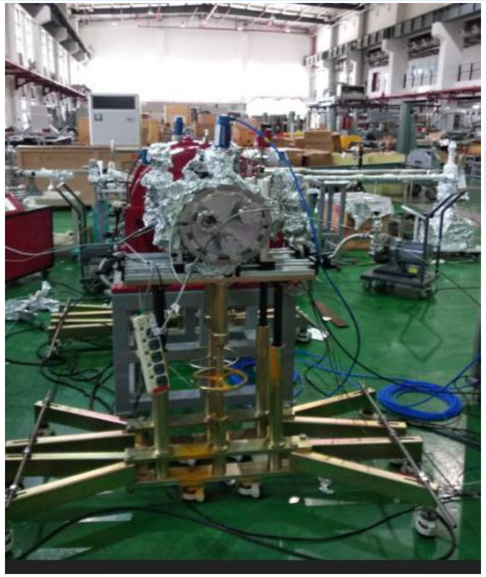
Copper vacuum chamber (Drawing) elliptic 75×56, thickness 3, length 6000)

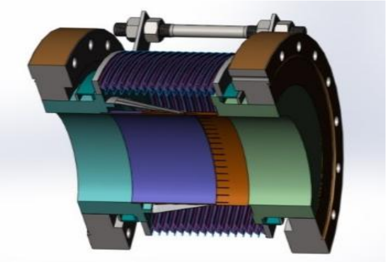
First test vacuum chamber



NEG coating suppresses electron multipacting and beam-induced pressure rises, as well as provides extra linear pumping. Direct Current Magnetron Sputtering systems for NEG coating was chosen.







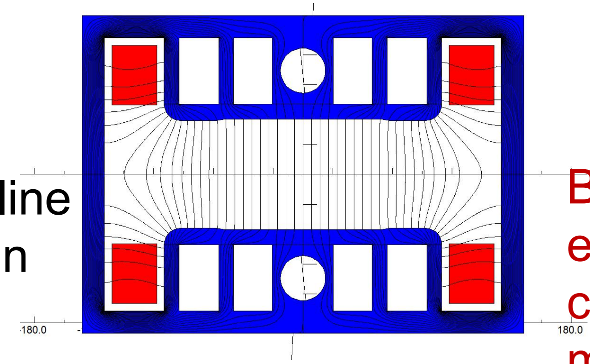
Booster High Precision Low Field Dipole Magnets

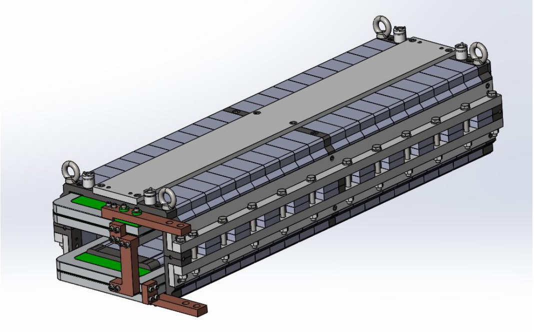
Technical design review has been done
(May 5, 2019)

One kind of the dipole magnet with diluted iron cores is proposed and designed

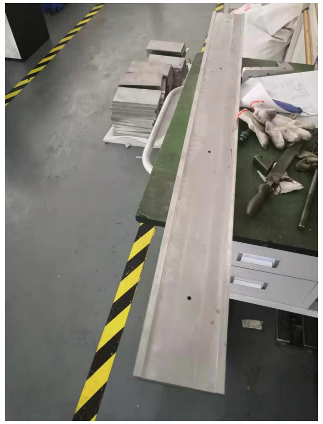
Two kinds of the dipole magnets without iron cores called Cos Theta (CT) and Canted Cos Theta (CCT) are proposed and designed

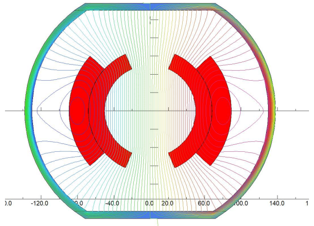
Baseline design

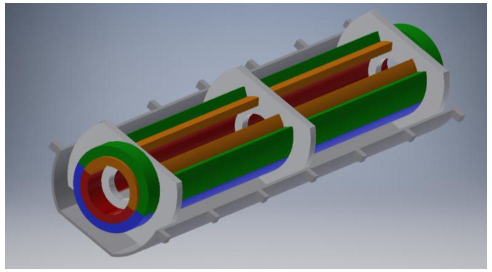


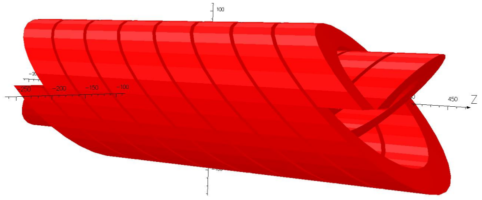


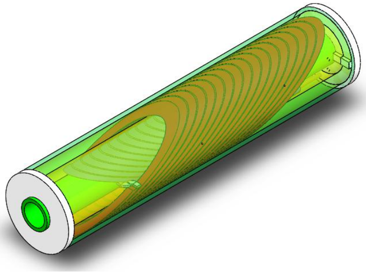
Boostermodel dipoe iron core based magnet is under construction



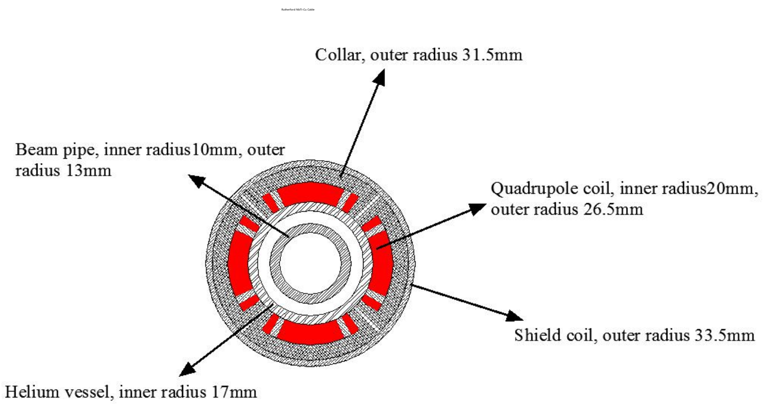








CEPC IR Superconducting Magnets

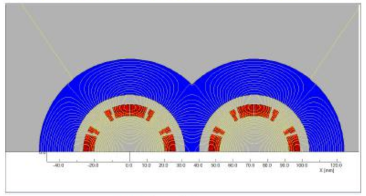


Room-temperature vacuum chamber
with a clearance gap of 4 mm

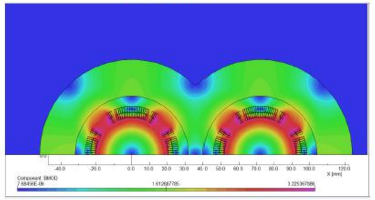
Mag net	Central field gradient (T/m)	Magnetic length (m)	Width of Beam stay clear (mm)	Min. distance between beams centre (mm)
QD0	136	2.0	19.51	72.61

Superconducting QD coils

- 2D field cross talk of QD0 two apertures near the IP side.



2D Flux lines

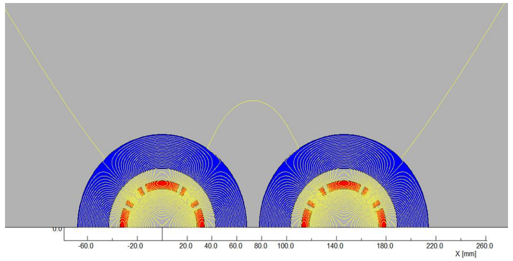


Bmod distribution

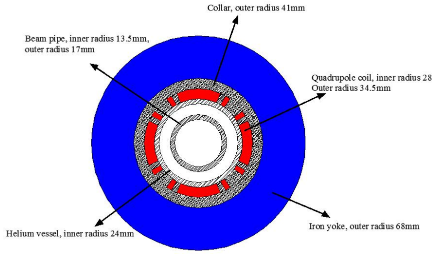
QF1 Integral field harmonics with shield coils（×10^{-4}）

n	B_n/B_2@R=13.5mm
2	10000
6	1.08
10	-0.34
14	0.002

Superconducting QF coils



There is iron yoke around the quadrupole coil for QF1. Since the distance between the two apertures is larger enough and there is iron yoke, the field cross talk between two apertures of QF1 can be eliminated.

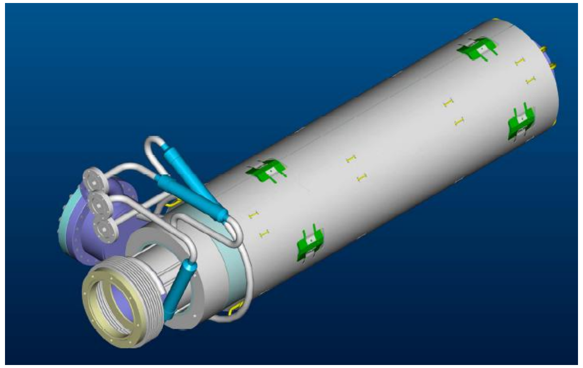


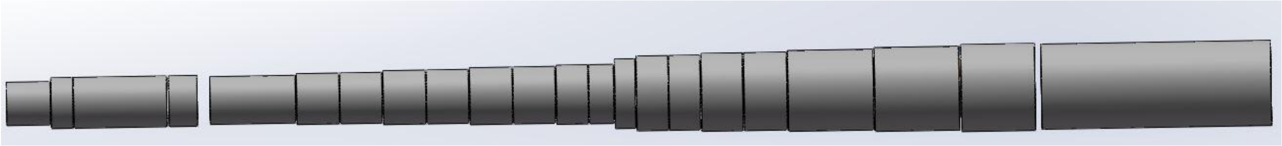
One of QF1 aperture (Peak field 3.8T)

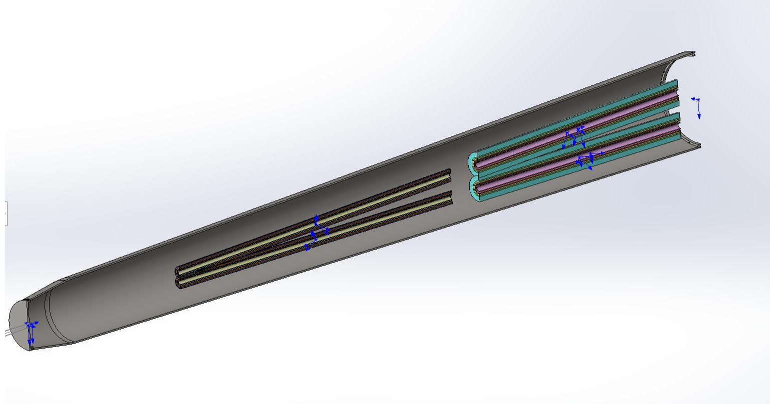
Mag net	Central field gradient (T/m)	Magnetic length (m)	Width of Beam stay clear (mm)	Min. distance between beams centre (mm)
QF1	110	1.48	27.0	146.20

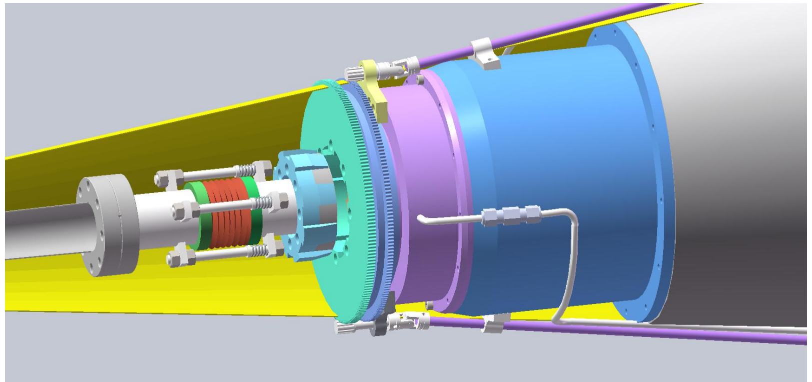
Technical design review has been done (July 19, 2019)

CEPC MDI SC Magnets and Mechanical Study

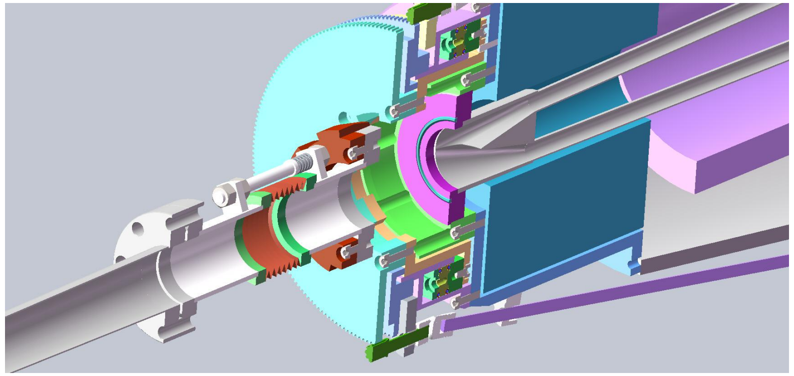


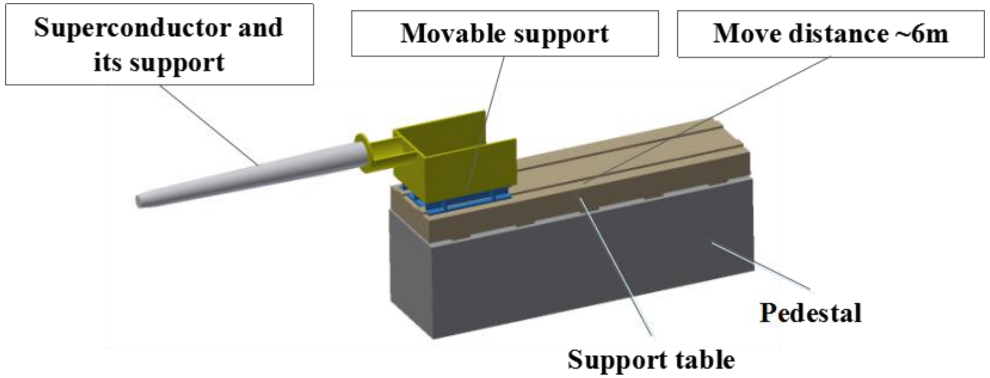






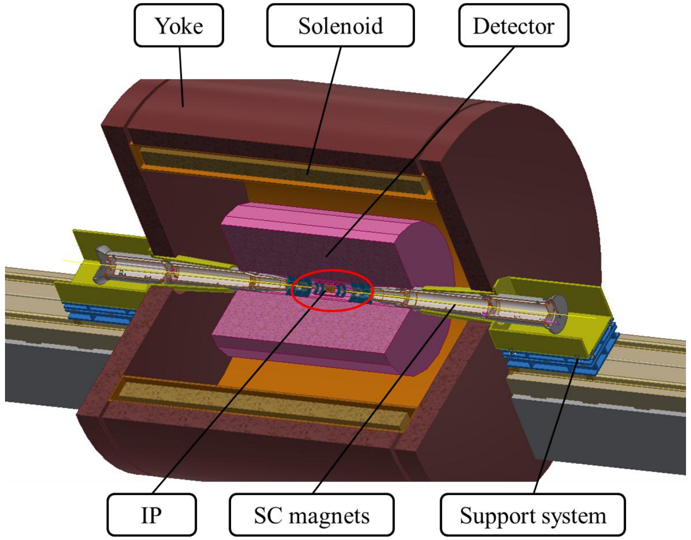
Technical design review has been done (July 23, 2019)

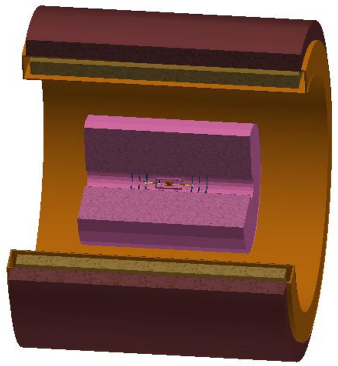




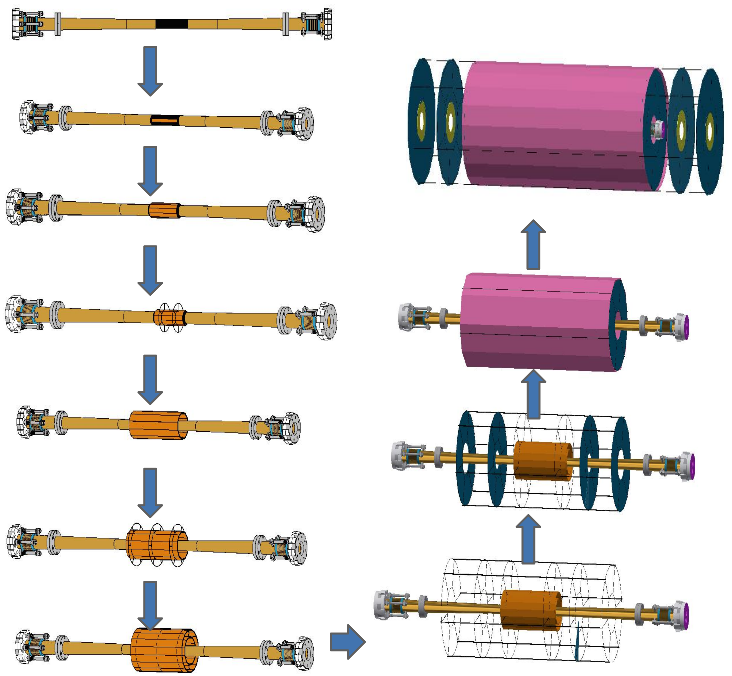
Schematic of support system of superconducting magnets

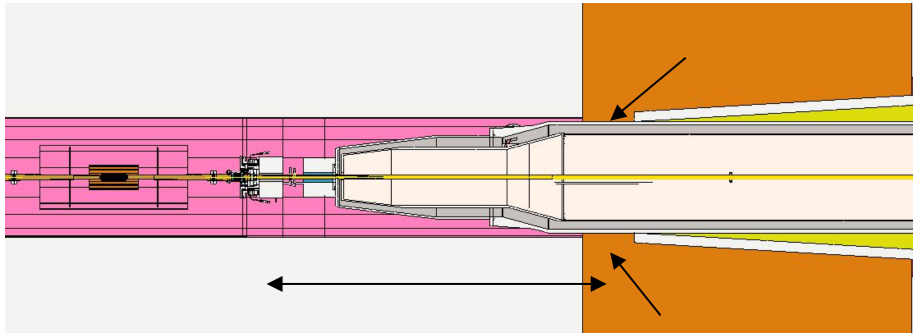
IR Mechanics Assembly





Technical design review has been done (July 23, 2019)





- Both sides of IP chamber are fixed to VTX transversally and are free longitudinally.
- The IP chamber, VTX, SIT and FTD can be considered as one assembly.
- The assembly above can be supported by TPC and be aligned transversally.
- Remote vacuum connector can be used.
- The high precision part of Lumical is with the detector and the main body is with the accelerator.

Little transversally space & long longitudinally distance. It is impossible to connect flanges by hands.

MDI Components R&D Status

Name	status
Superconducting magnet QD0	Designed
Superconducting magnet QF1	Designed
Cryostat	Under design
Detector solenoid	Designed
Anti-solenoid	Designed
BPM	Under design
Lumical	Under design
IR vacuum chamber	Under design
Berrylium pipe	Under design
RVC(remote vacuum connection)	Under design
Shielding	Under design
Cooling system	Under design
Vacuum pump	Under design
Supporting system	Under design
Flange	Under design
Bellows	Under design
Alignment	Under design
Trimming support in SC magnet	Under design
HOM absorber	Under design
Auxiliary coils in SC magnet	Under design
Coating	Under design

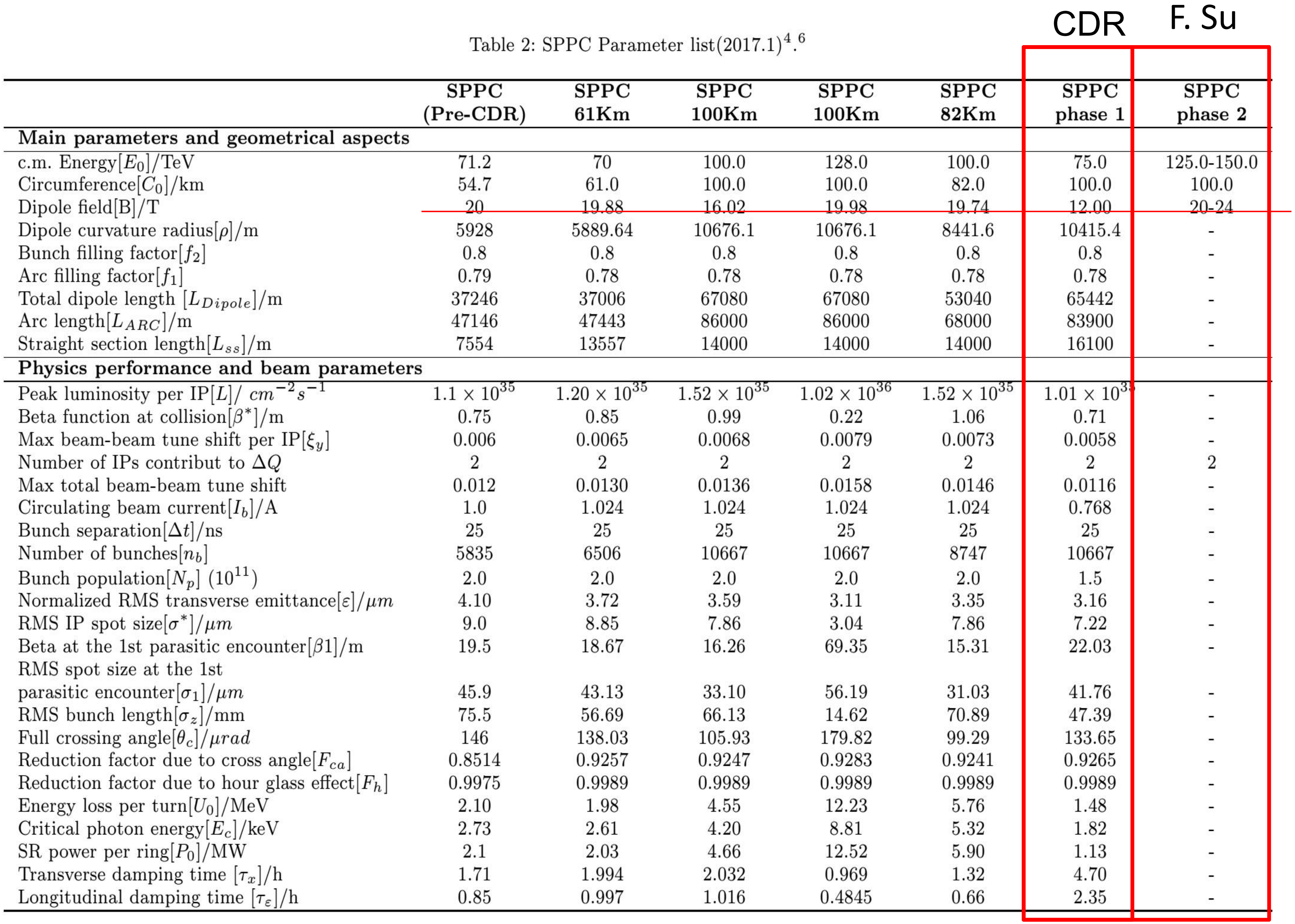
SppC Status

SppC Baseline Design

From Jan. 2017

- Baseline design
  - Tunnel circumference: 100 km
  - Dipole magnet field: 12 T, using full iron-based HTS technology
  - Center of Mass energy: >70 TeV
  - Injector chain: 2.1 TeV
  - Relatively lower luminosity for the first phase, higher for the second phase
- Energy upgrading phase
  - Dipole magnet field: 20 -24T, full iron-based HTS technology
  - Center of Mass energy: >125 TeV
  - Injector chain: 4.2 TeV (e.g., adding a high-energy booster ring in the main tunnel in the place of the electron ring and booster)
- Development of high-field superconducting magnet technology
  - Starting to develop required HTS magnet technology; before applicable iron-based HTS wire are available, models by YBCO and LTS wires can be used for specific studies (magnet structure, coil winding, stress, quench protection method etc.)

SPPC Parameter Choice and Comparation



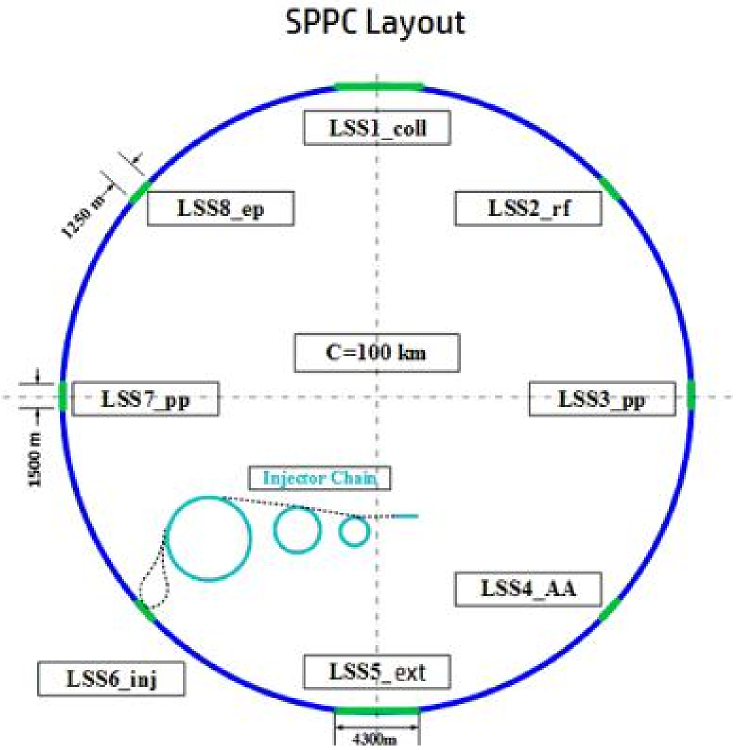
CDR

F. Su

Table 2: SPPC Parameter list(2017.1)$^{4.6}$

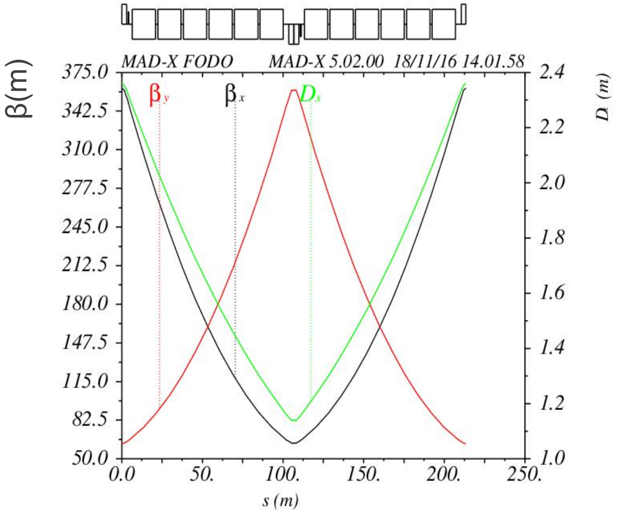
	SPPC (Pre-CDR)	SPPC 61Km	SPPC 100Km	SPPC 100Km	SPPC 82Km	SPPC phase 1	SPPC phase 2
Main parameters and geometrical aspects							
c.m. Energy[E_0]/TeV	71.2	70	100.0	128.0	100.0	75.0	125.0-150.0
Circumference[C_0]/km	54.7	61.0	100.0	100.0	82.0	100.0	100.0
Dipole field[B]/T	~~20~~	~~19.88~~	~~16.02~~	~~19.98~~	~~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}	1.20×10^{35}	1.52×10^{35}	1.02×10^{36}	1.52×10^{35}	1.01×10^{35}	-
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 contribut 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	-

General Layout of SPPC



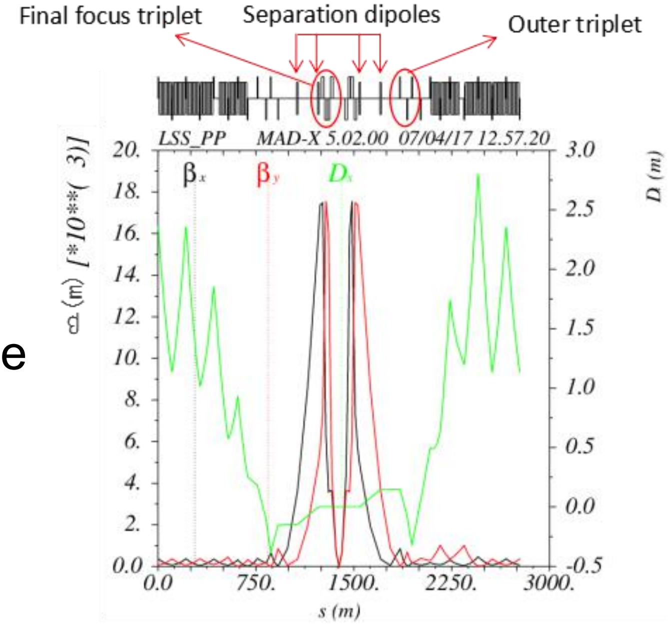
- Length of each section at present:
- 8 arcs, total length 83400 m
- 2 IPs for pp, 1500 m each
- 2 IRs for injection or RF, 1250 m each
- 2 IRs for ep or AA, 1250 m each
- 2 IRs for collimation(ee for CEPC ）, 4300 m each
- C = 100 km

SppC ARC lattice



ARC FODO cell structure

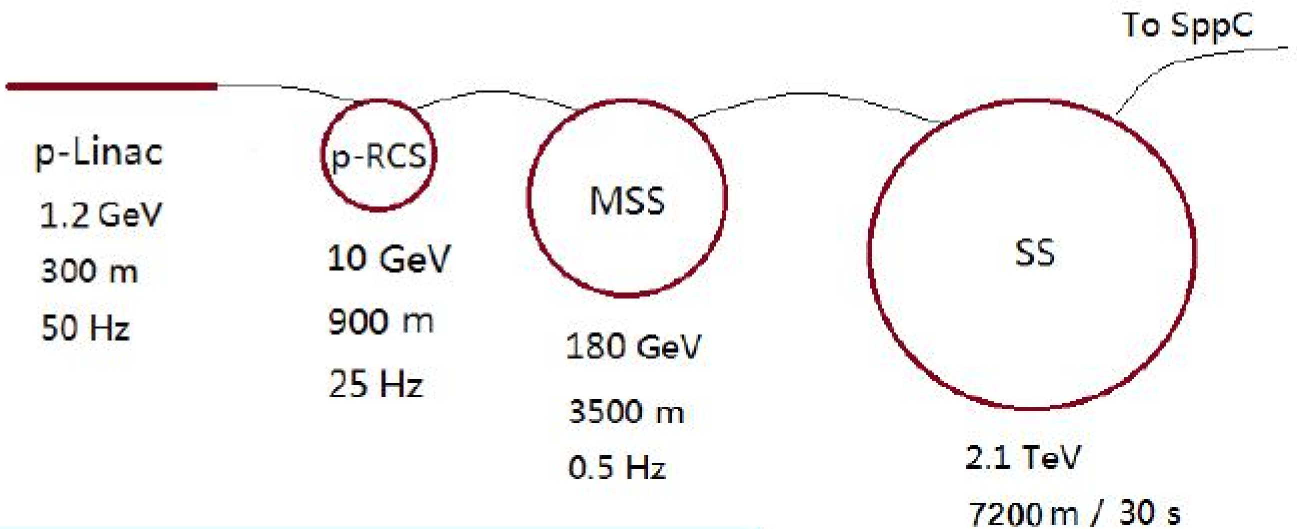
SppC interaction region lattice



LSS_PP(beta*=0.75 m)

SppC Injector Chain

(for proton beam)



p-Linac: proton superconducting linac

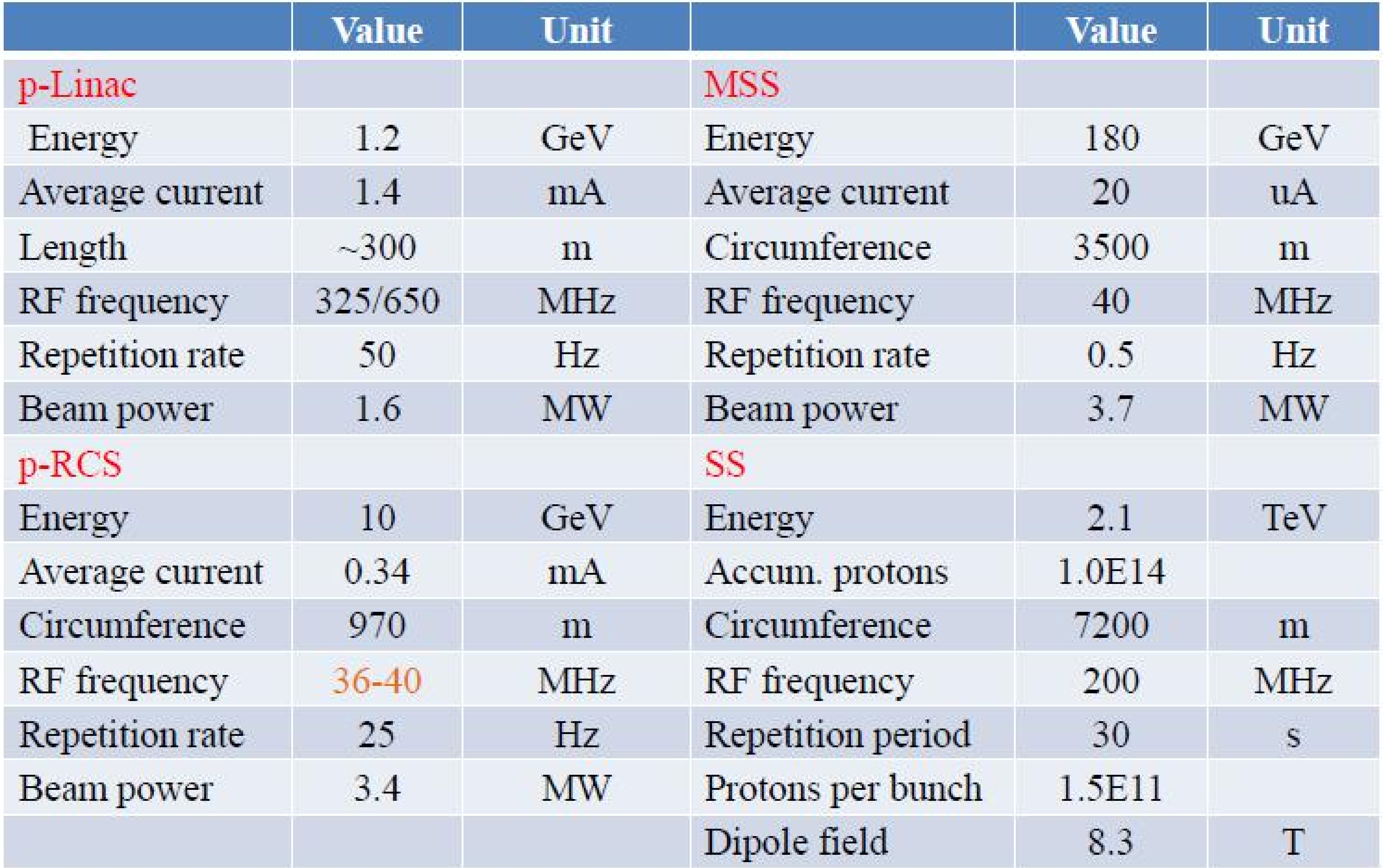
p-RCS: proton rapid cycling synchrotron

MSS: Medium-Stage Synchrotron

SS: Super Synchrotron

Ion beams have dedicated linac (I-Linac) and RCS (I-RCS)

Major Parameters for the SppC Injector Chain



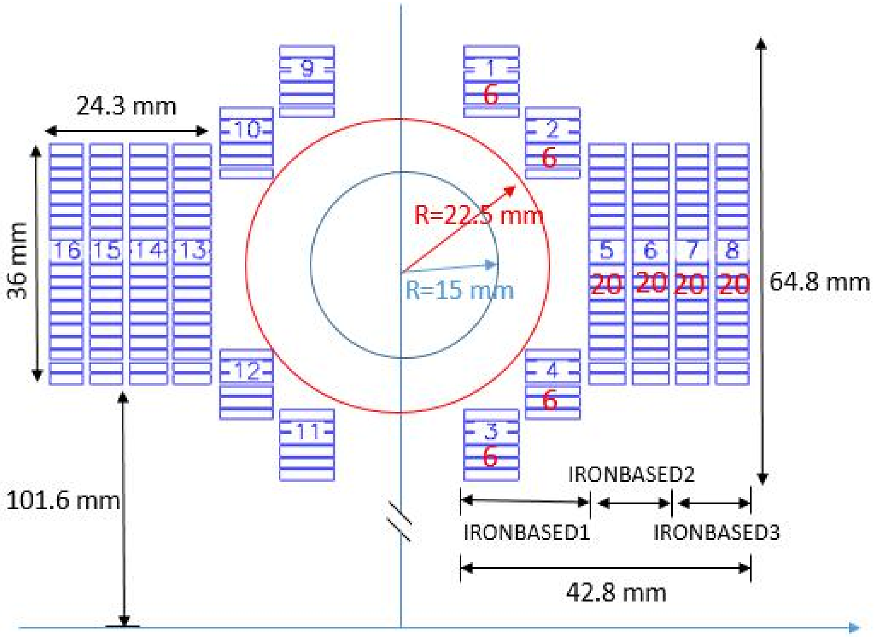
	Value	Unit		Value	Unit
p-Linac			MSS		
Energy	1.2	GeV	Energy	180	GeV
Average current	1.4	mA	Average current	20	uA
Length	~300	m	Circumference	3500	m
RF frequency	325/650	MHz	RF frequency	40	MHz
Repetition rate	50	Hz	Repetition rate	0.5	Hz
Beam power	1.6	MW	Beam power	3.7	MW
p-RCS			SS		
Energy	10	GeV	Energy	2.1	TeV
Average current	0.34	mA	Accum. protons	1.0E14	
Circumference	970	m	Circumference	7200	m
RF frequency	36-40	MHz	RF frequency	200	MHz
Repetition rate	25	Hz	Repetition period	30	s
Beam power	3.4	MW	Protons per bunch	1.5E11	
			Dipole field	8.3	T

Domestic Collaboration on HTS for SppC SC Dipole Magnet

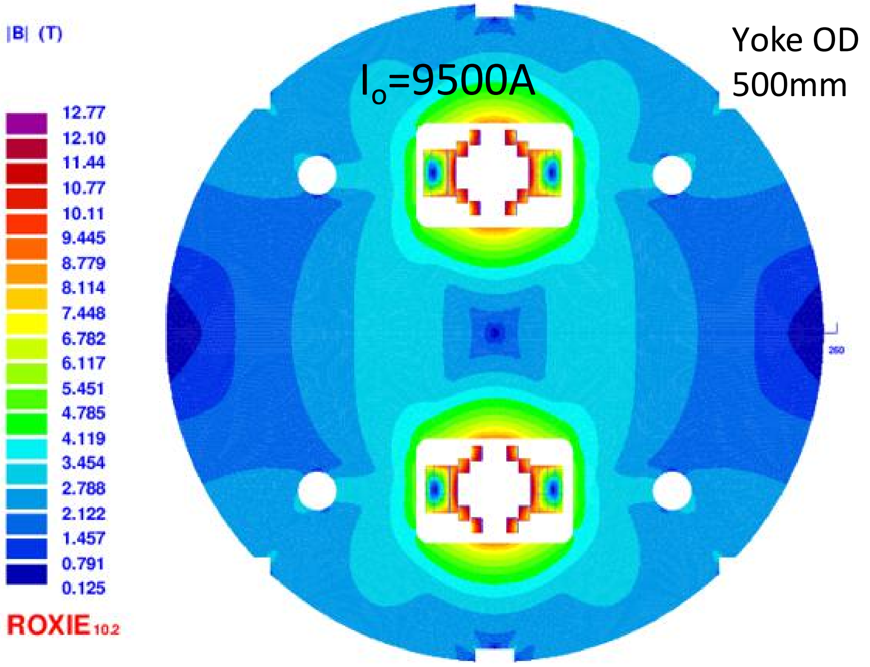
"Applied High Temperature Superconductor Collaboration" was established in Oct. 2016.

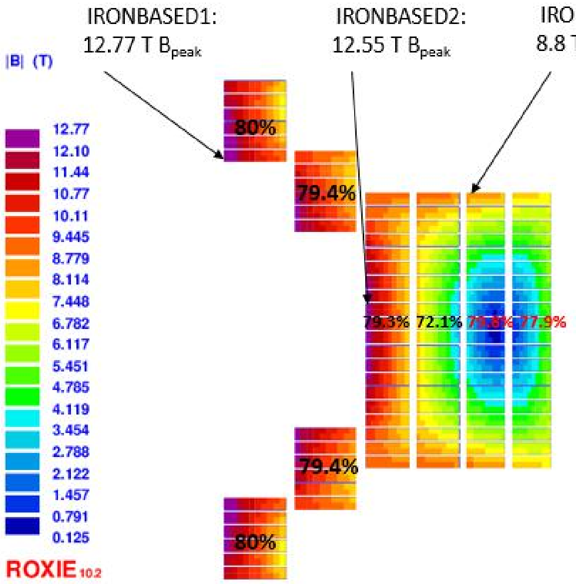
- **Goal：**
  1) To increase the J_c of **IBS** by 10 times, reduce the cost to **20 Rmb/kAm @ 12T & 4.2K**;
  2) To reduce the cost of **ReBCO and Bi-2212** conductors to 20 Rmb/kAm @ 12T & 4.2K;
  3) Realization and Industrialization of iron-based magnet and SRF technology.
- **Working groups：** 1) **Fundamental science** investigation; 2) **IBS** conductor R&D; 3) **ReBCO** conductor R&D; 4) **Bi-2212** conductor R&D; 5) **performance** evaluation; 6) **Magnet and SRF** technology.
- **Collaboration meetings**: every 3 months, to report the progress and discuss plan for next months.

The 12-T Fe-based Dipole Magnet



C. Wang, E. Kong (USTC), Q. Xu et al.





Design with expected J_e of IBS in 2025

Strand	diam.	cu/sc	RRR	Tref	Bref	Jc@ BrTr	dJc/dB
IBS	0.802	1	200	4.2	10	4000	111

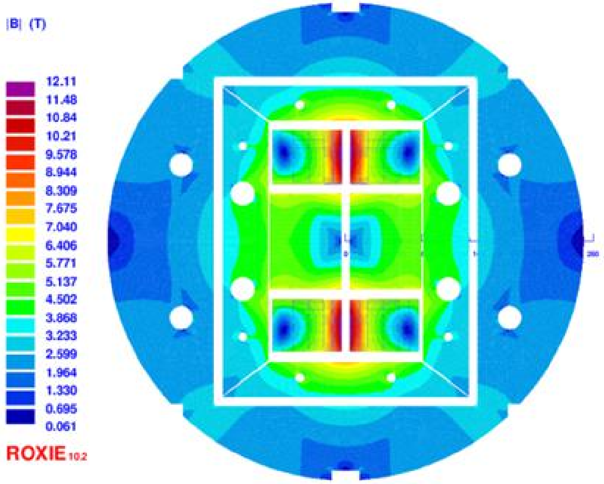
- The required length of the 0.8 mm IBS is 6.1 Km/m
- For 100-km SPPC accelerator, 3000 tons of IBS is needed
- Target cost of IBS: 20 RMB (~2.6 Eur) /kAm @12 T

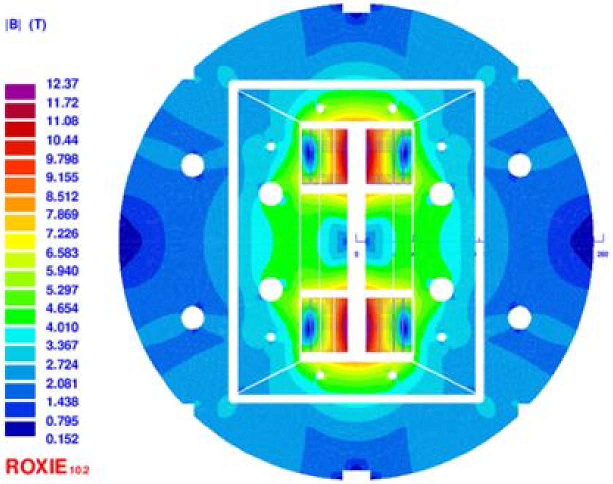
R&D of 12T Twin-Aperture Dipole Magnet

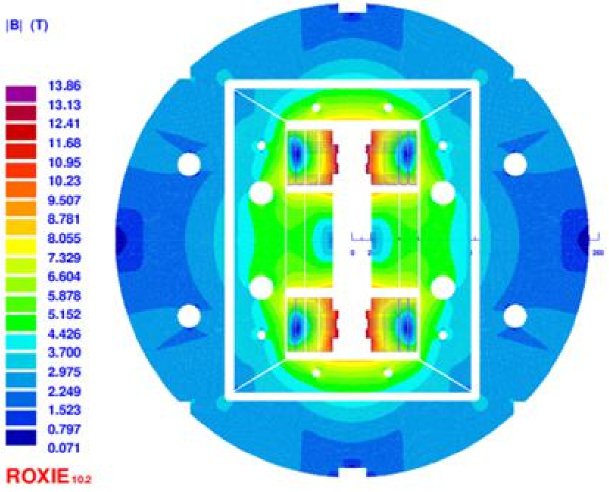
Operation load line at 12 T: ~80% at 4.2K

C. Wang, K. Zhang, Y. Wang, D. Cheng, E. Kong (USTC), Q. Xu et al.

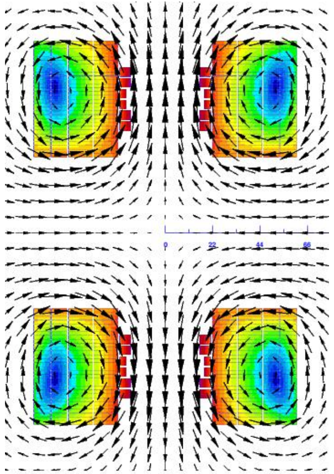
NbTi+Nb$_3$Sn, 2*ф10 → **All Nb$_3$Sn, 2*ф20 aperture** → **Nb$_3$Sn+HTS, 2*ф30**



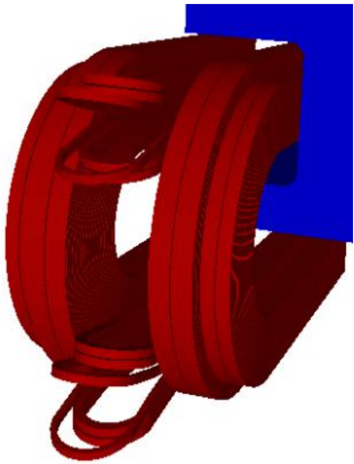




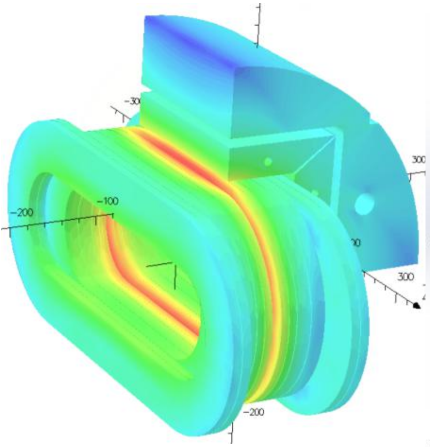
Magnetic flux distribution



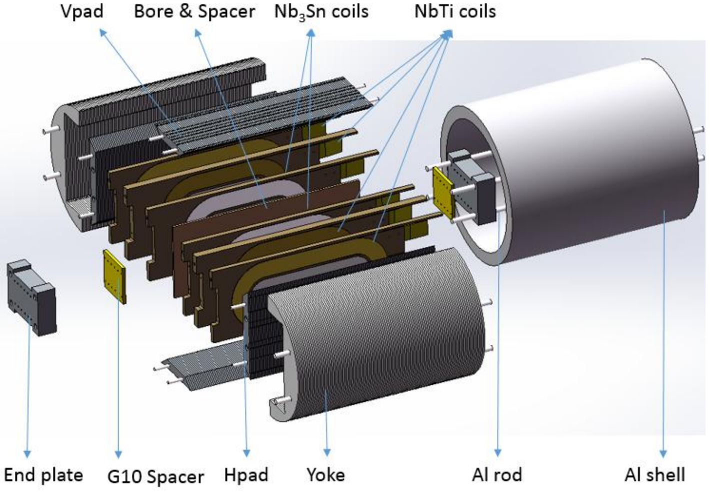
3d coil layout



3D magnetic field distribution



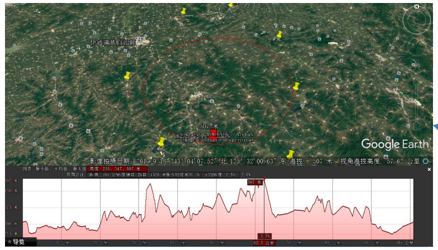
Components and assembly

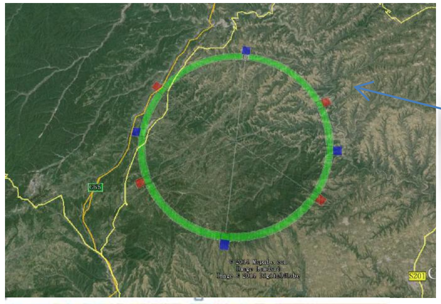


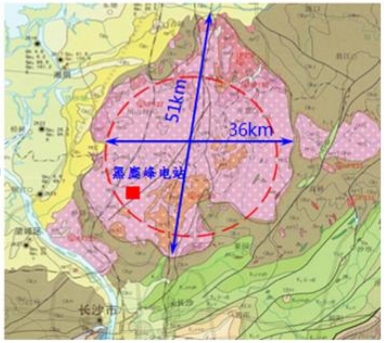
CEPC Site Selection and Civil Engineering

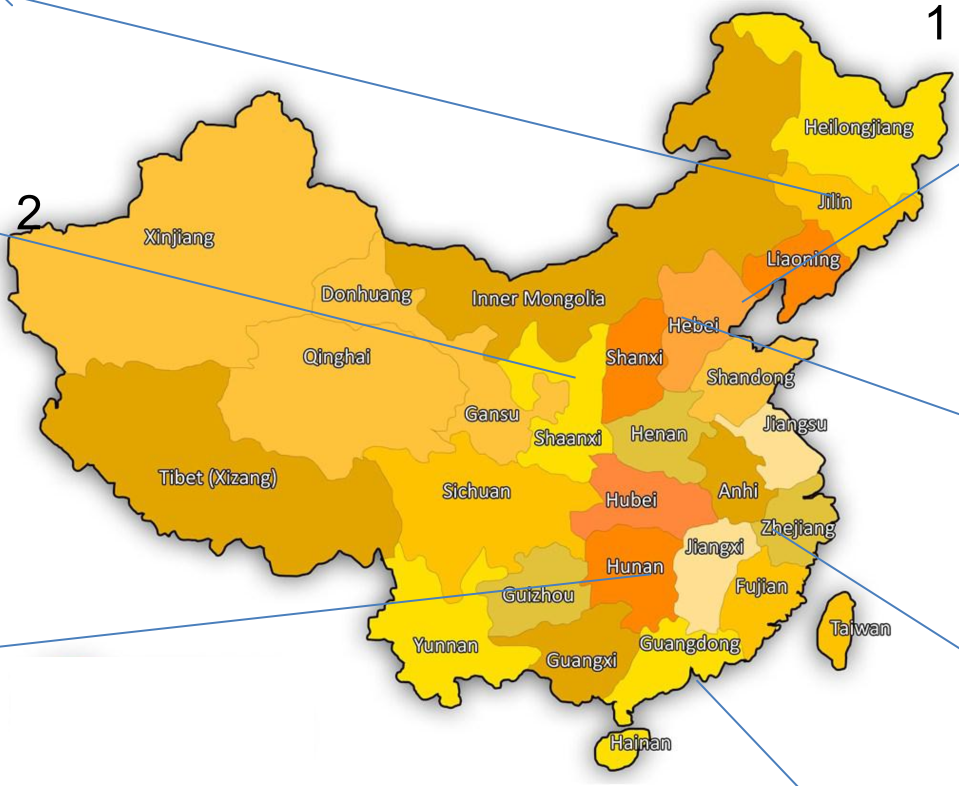
CEPC Site Selections

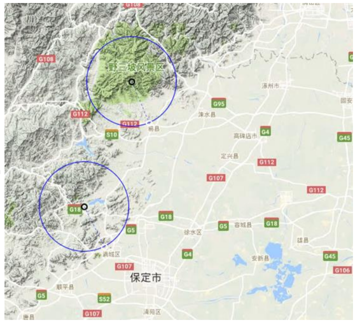
Huanghe Company particitated

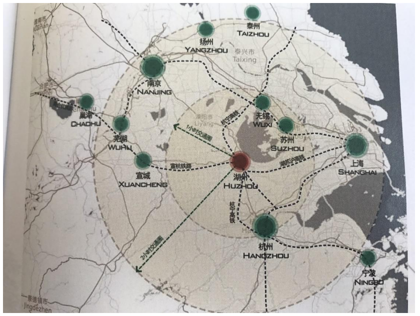






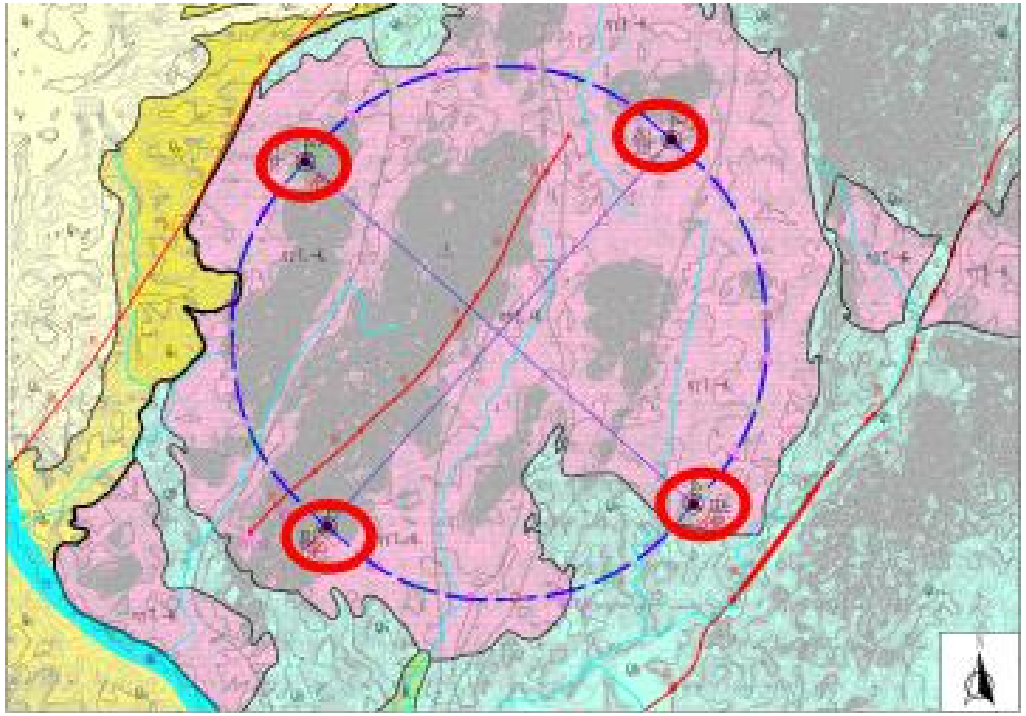


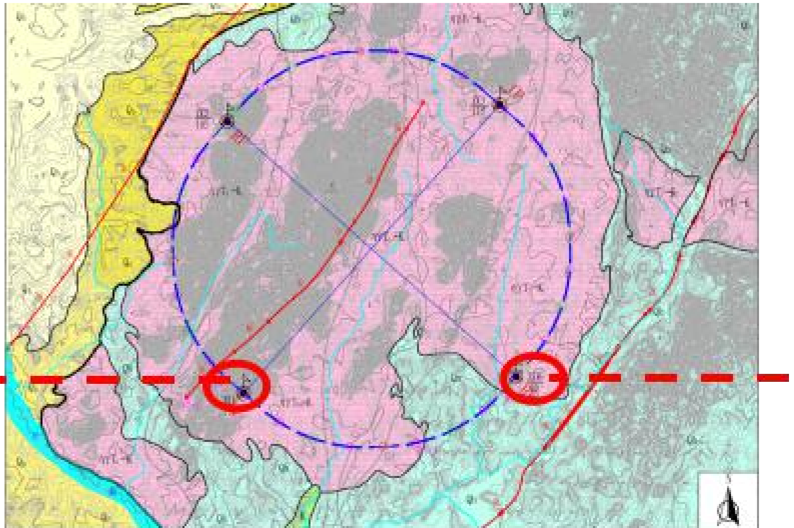




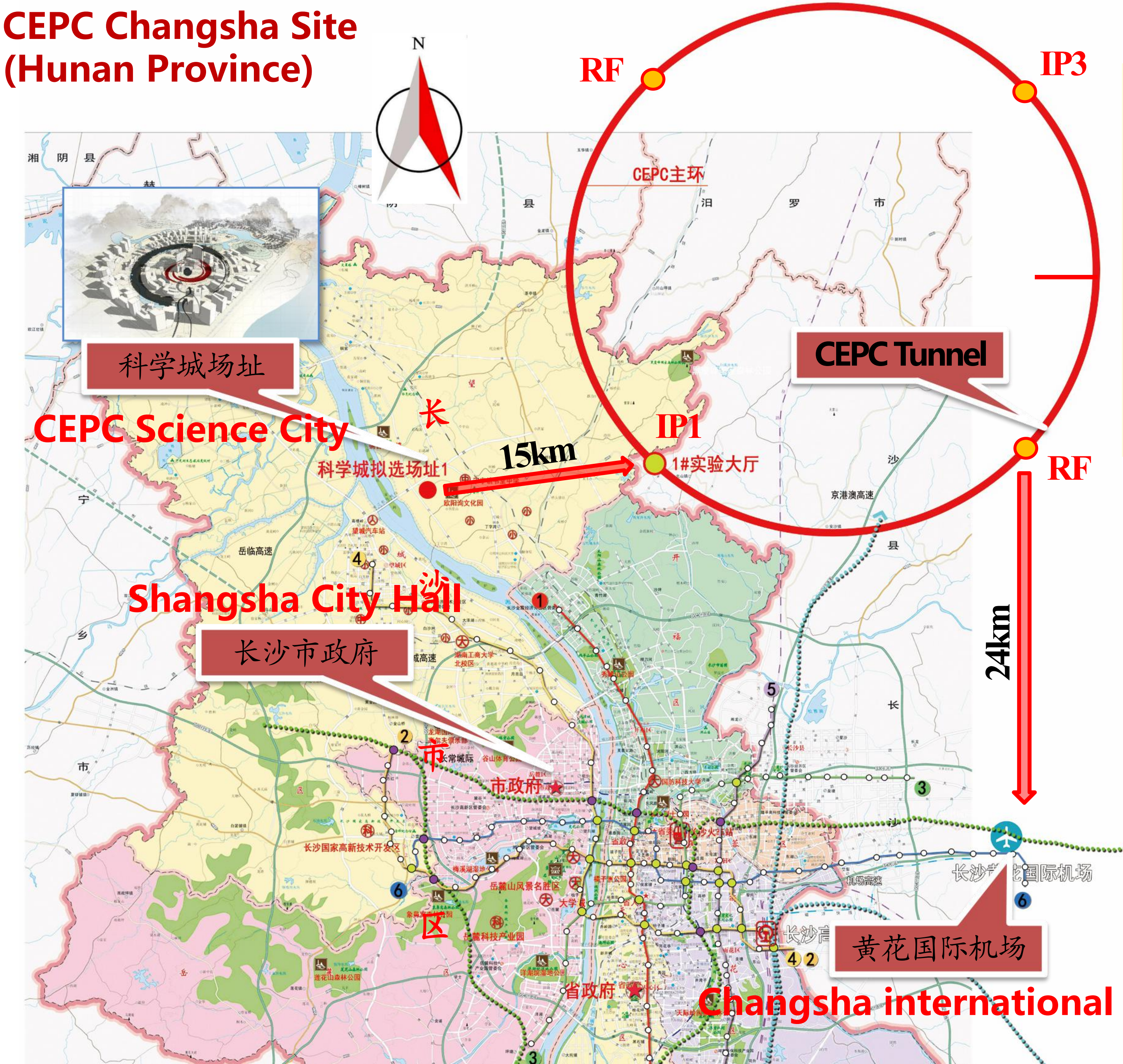
1) Qinhuangdao, Hebei Province（Completed in 2014）
2) Huangling, Shanxi Province（Completed in 2017)
3) Shenshan, Guangdong Province(Completed in 2016)
4) Baoding (Xiong an), Hebei Province (Started in August 2017)
5) Huzhou, Zhejiang Province (Started in March 2018)
6) Chuangchun, Jilin Province (Started in May 2018)
7) Changsha, Hunan Province (Started in Dec. 2018)

CEPC Site Selection in Changsha (Hunan Province)





CEPC Changsha Site (Hunan Province)



RF

IP3

RF

IP1

CEPC Tunnel

15km

24km

科学城场址

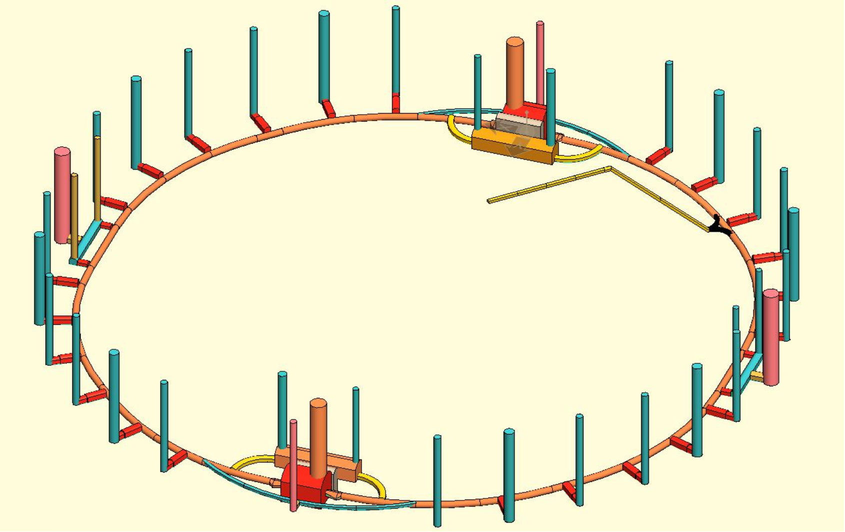
CEPC Science City

长沙市政府

Shangsha City Hall

黄花国际机场

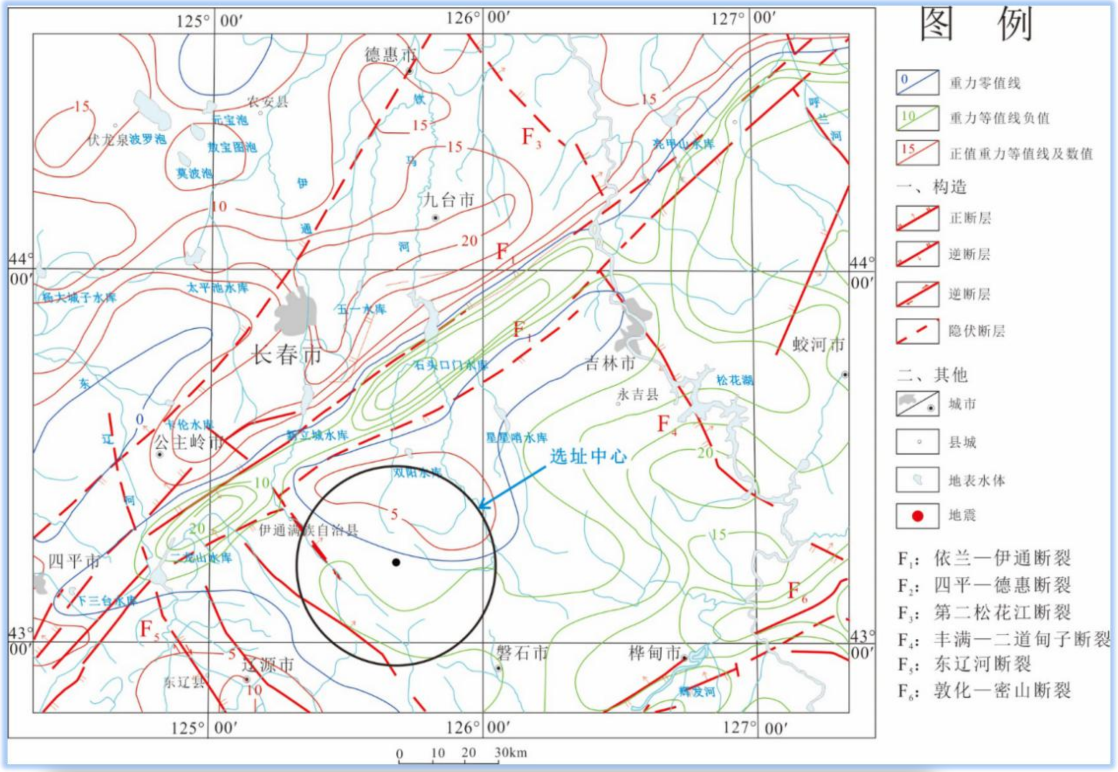
Changsha international airport

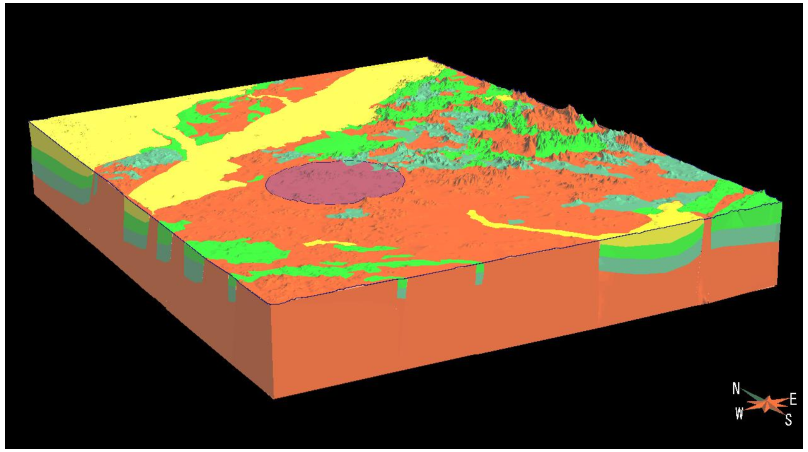


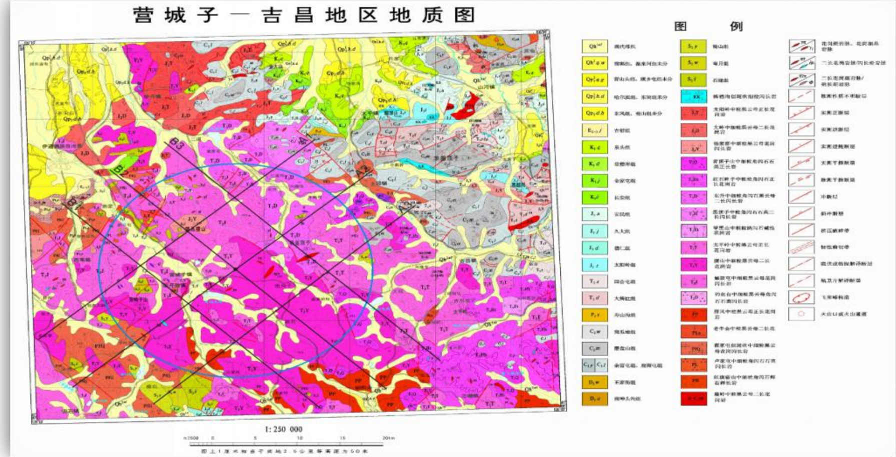
CEPC Tunnel Design

CEPC Scientific City

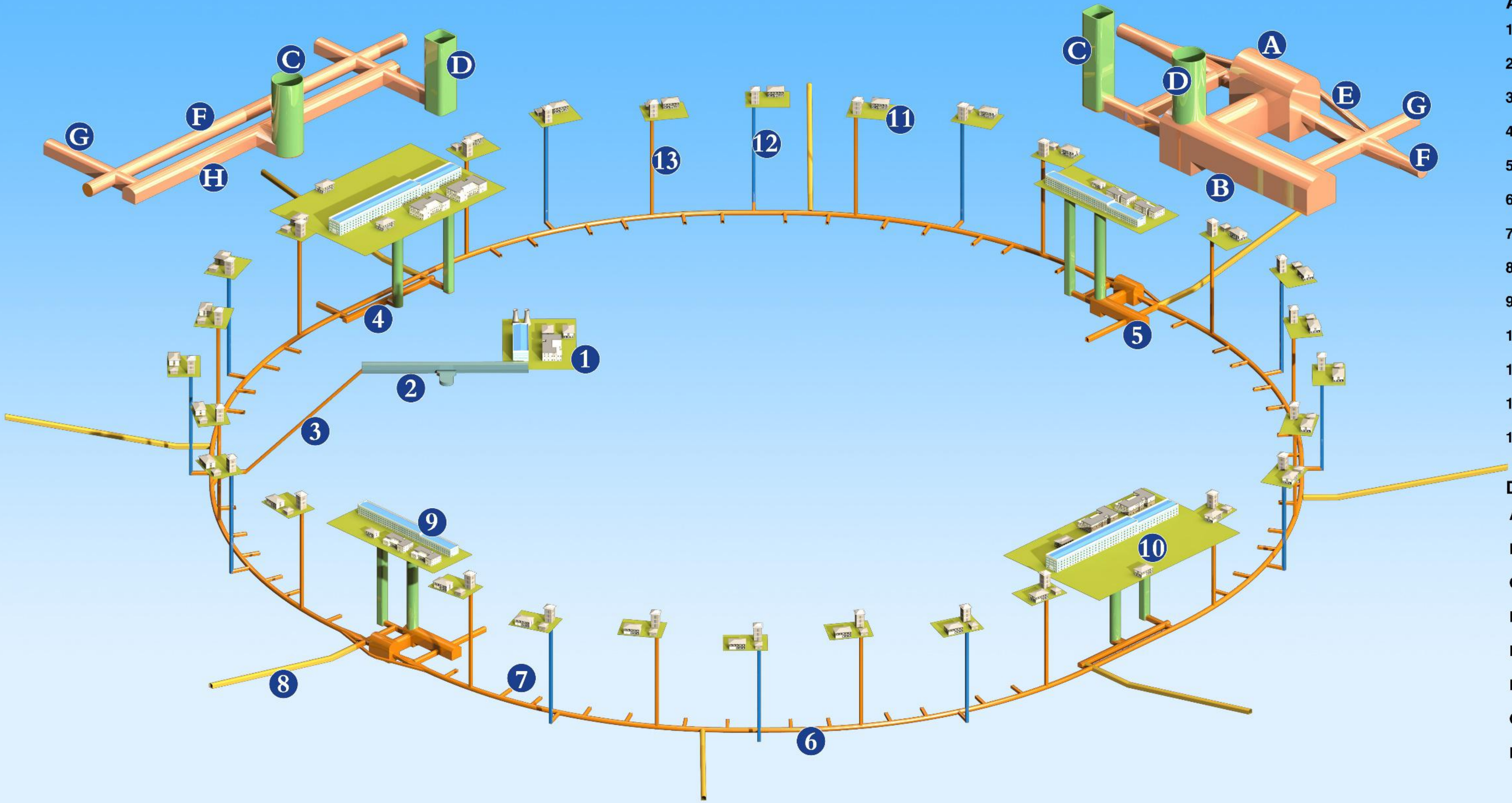
CEPC Site Selection in Chuangchun (Jilin Province)







CEPC



Accelerator Region Caverns:

1. Surface Buildings of Linac Segment
2. Linac Segment
3. Transfer Line
4. Tunnel Complex of RF Region
5. Detector Region Caverns
6. Main Ring Tunnel
7. Auxiliary Tunnel
8. Access Tunnel
9. Surface Buildings of Experiment Hall
10. Surface Buildings of RF Region
11. Surface Buildings of Shaft for Access and Cable
12. Shaft for Access and Cable
13、Shaft for Access，Cable and Measure

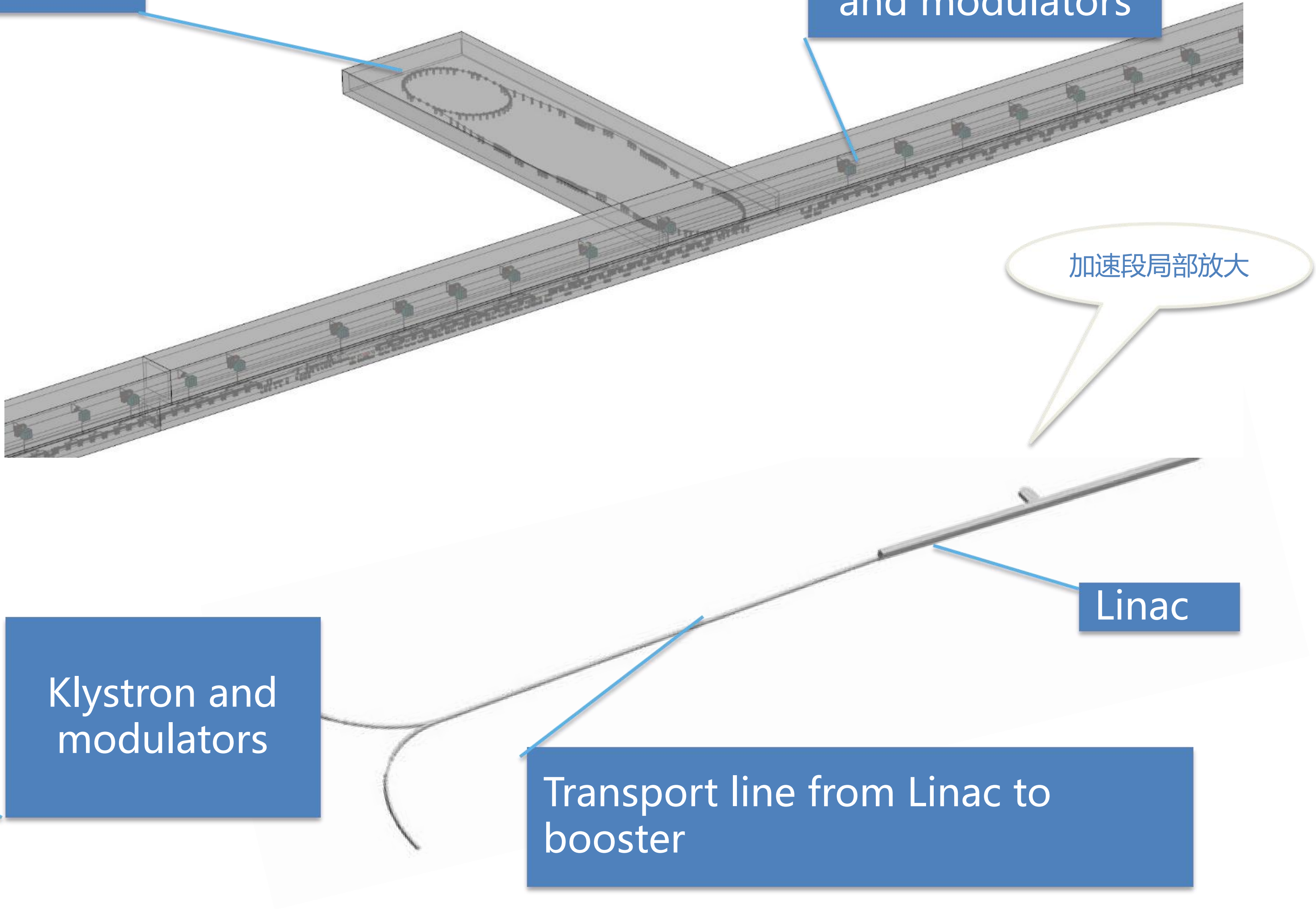
Detector Region Caverns:

A. Experiment Hall
B. Service Cavern
C. Transport Shaft
D. Shaft for Access, Cable and HVAC
E. Booster Bypass Tunnel
F. Main Ring Tunnel
G. Traffic Tunnel
H. Auxiliary Tunnel of RF Region

CEPC Tunnel Construction Methods Comparison

Tunnel construction arrangement	Blast and drill	Double shield TBM
Construction tunnel arrangement	Construction tunnel arrangment every 6.25km	Construction tunnel aarangment every 12.5km
Section drill distance	Single direction maxium length 4.325km (1.2km adit +3.125km Main tunnel)	Double shield TBM 53km (5 Machines)
Drill length parameter	Drill 100m/Month Shield 2x85m/Month	Drill/shield : 405m/Month
Construction period	52Months (not including preparation)	40Months (no including preparation)

CEPC Linac Injector



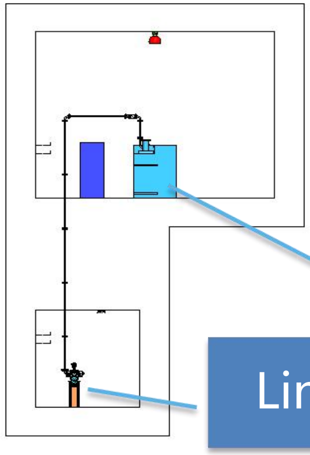
Dampoing ring

Klystron and modulators

加速段局部放大

Linac

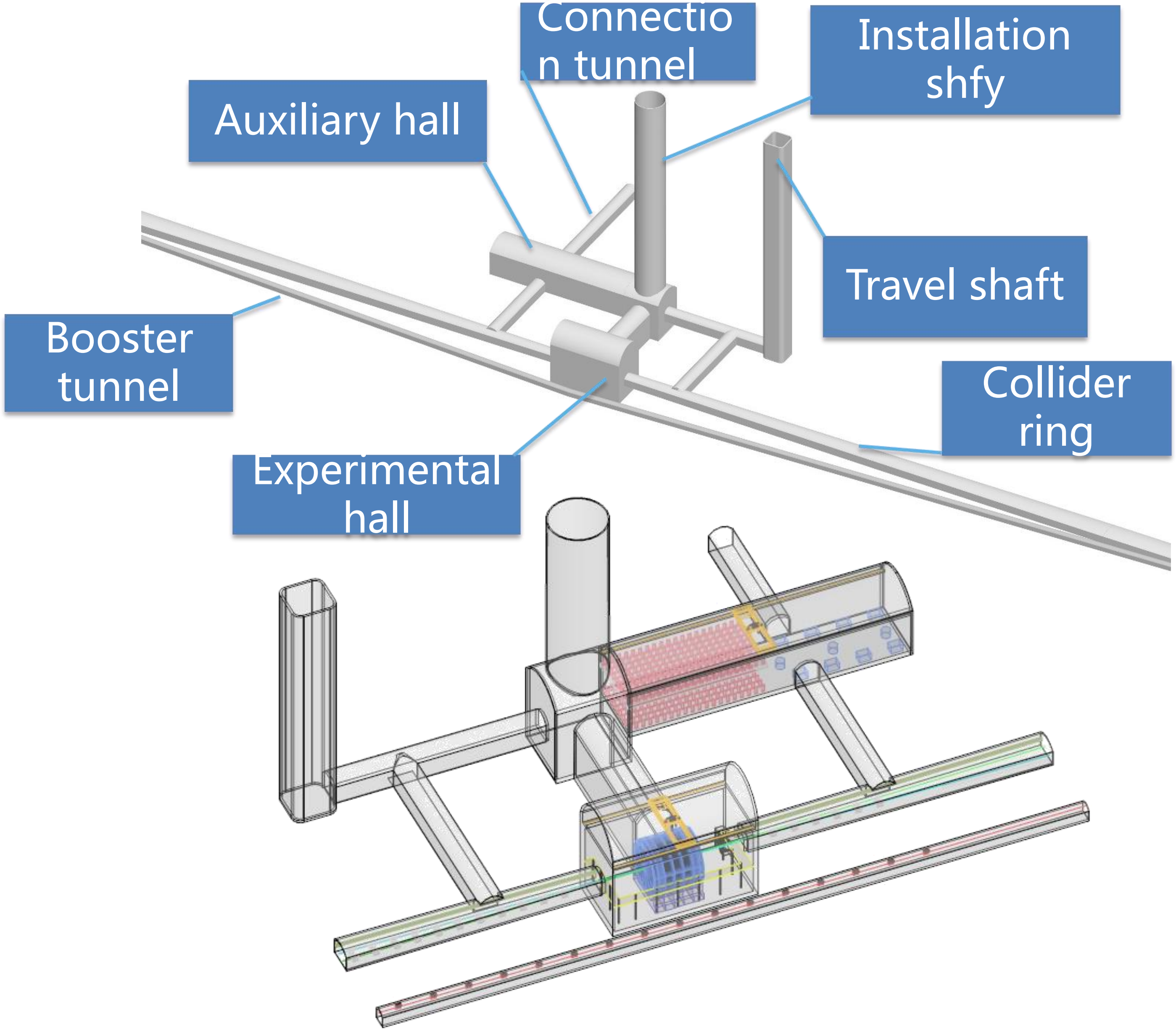
Transport line from Linac to booster



Linac

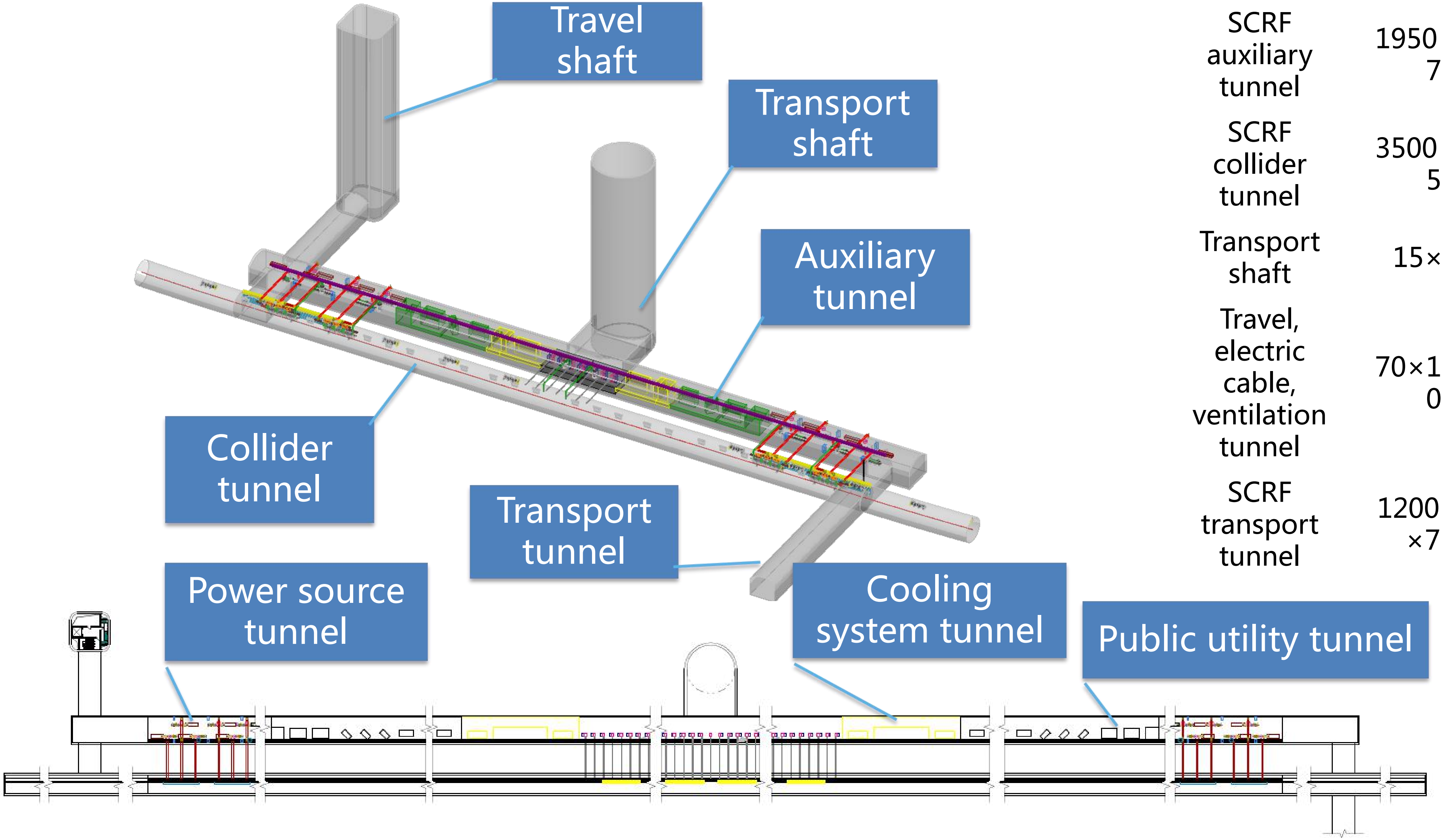
Klystron and modulators

CEPC IR



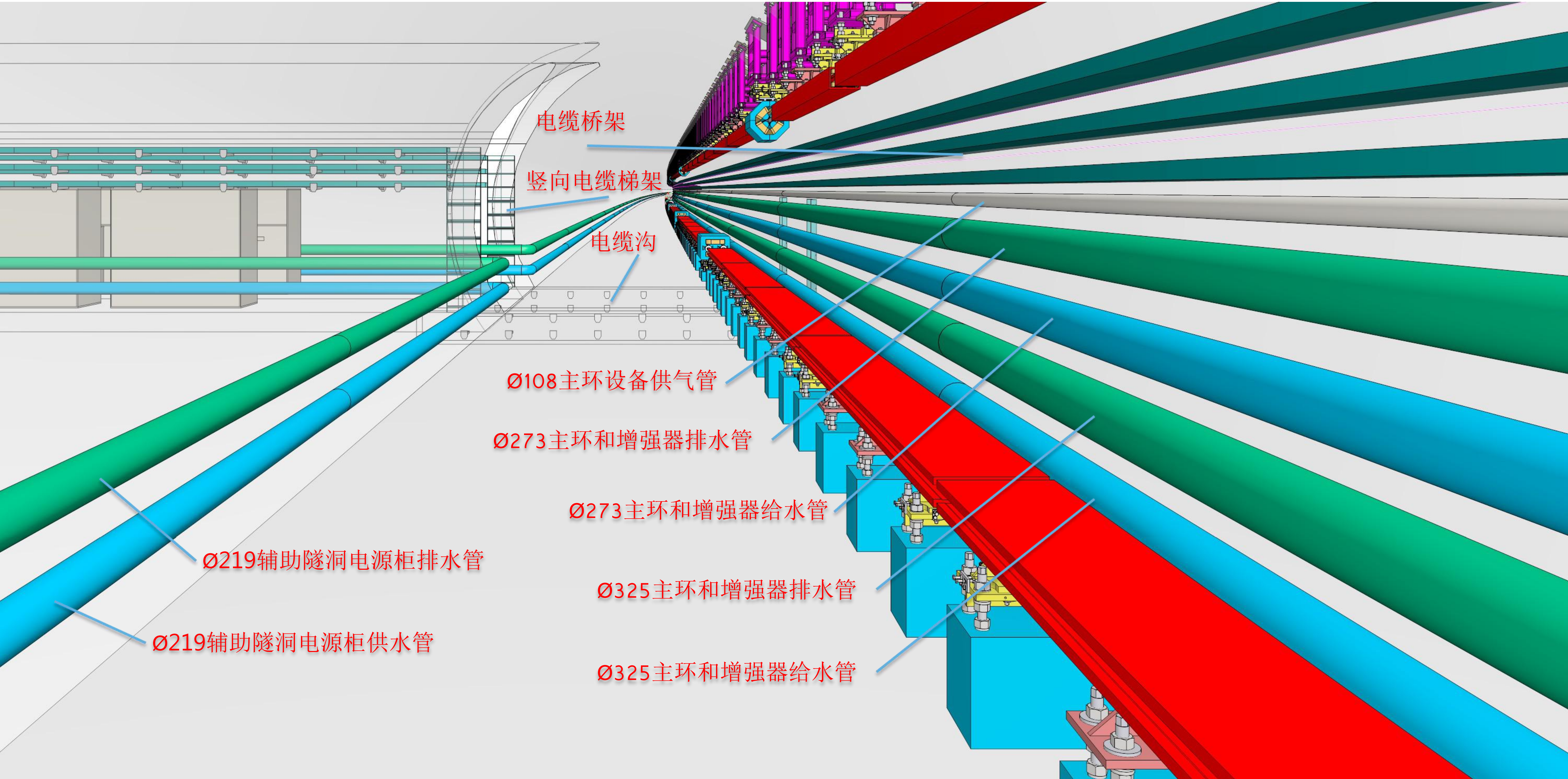
Experimental hall	39.4×20.4×31	×2
Axiliary hall	101.4×20×26.2	×2
Booster tunnel	1679×3.5×3.5	×4
Collider tunnel	1659.3x(6~11.4)x5	×4
Travel shaft	1200x7.5x7.5	×2
Connection, electric cable and ventilation shaft	70x10x10	×2

CEPC SCRF Region

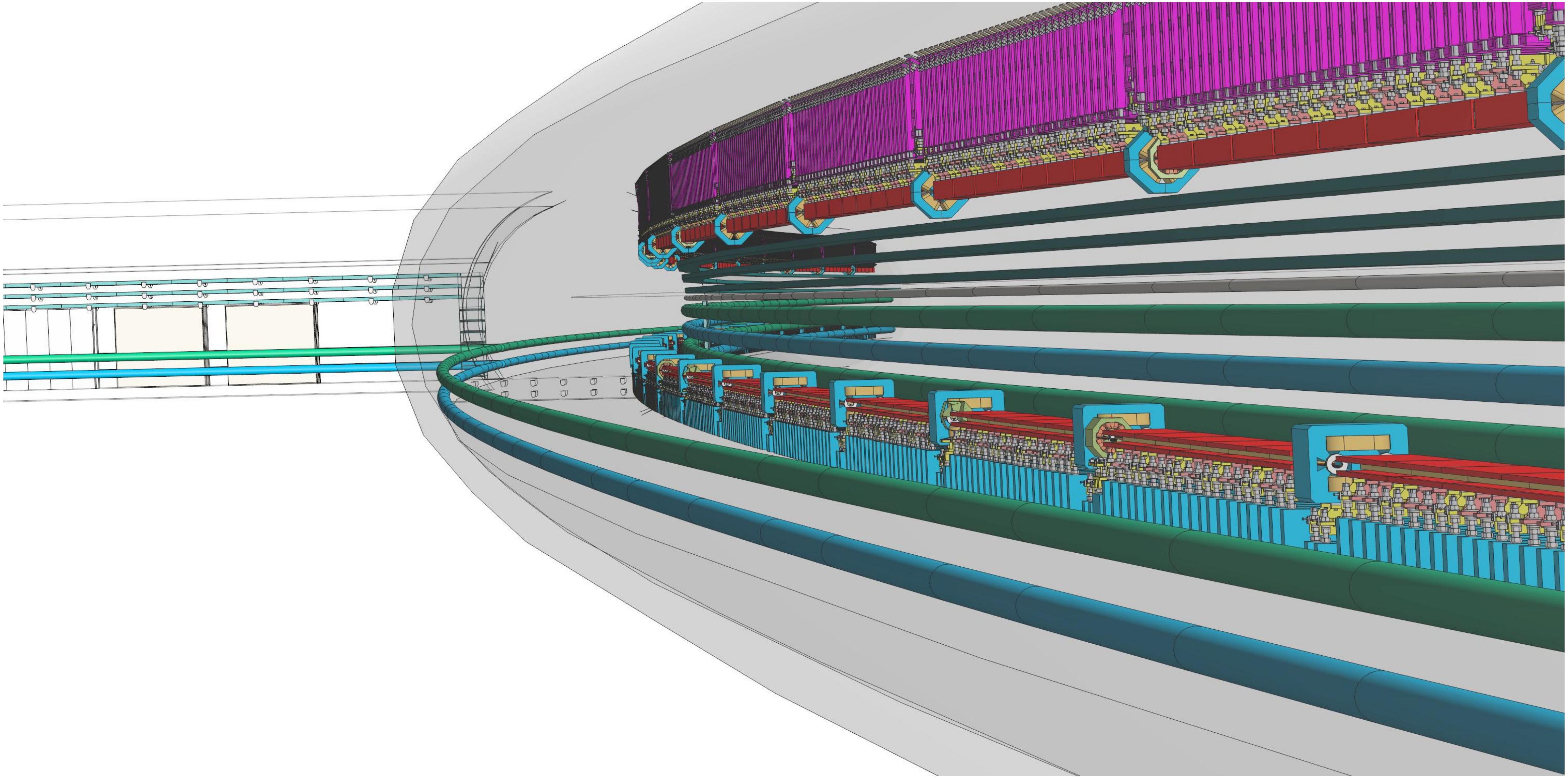


SCRF auxiliary tunnel	1950×8×7	×2
SCRF collider tunnel	3500×6×5	×2
Transport shaft	15×70	×2
Travel, electric cable, ventilation tunnel	70×10×10	×2
SCRF transport tunnel	1200×88×7.5	×2

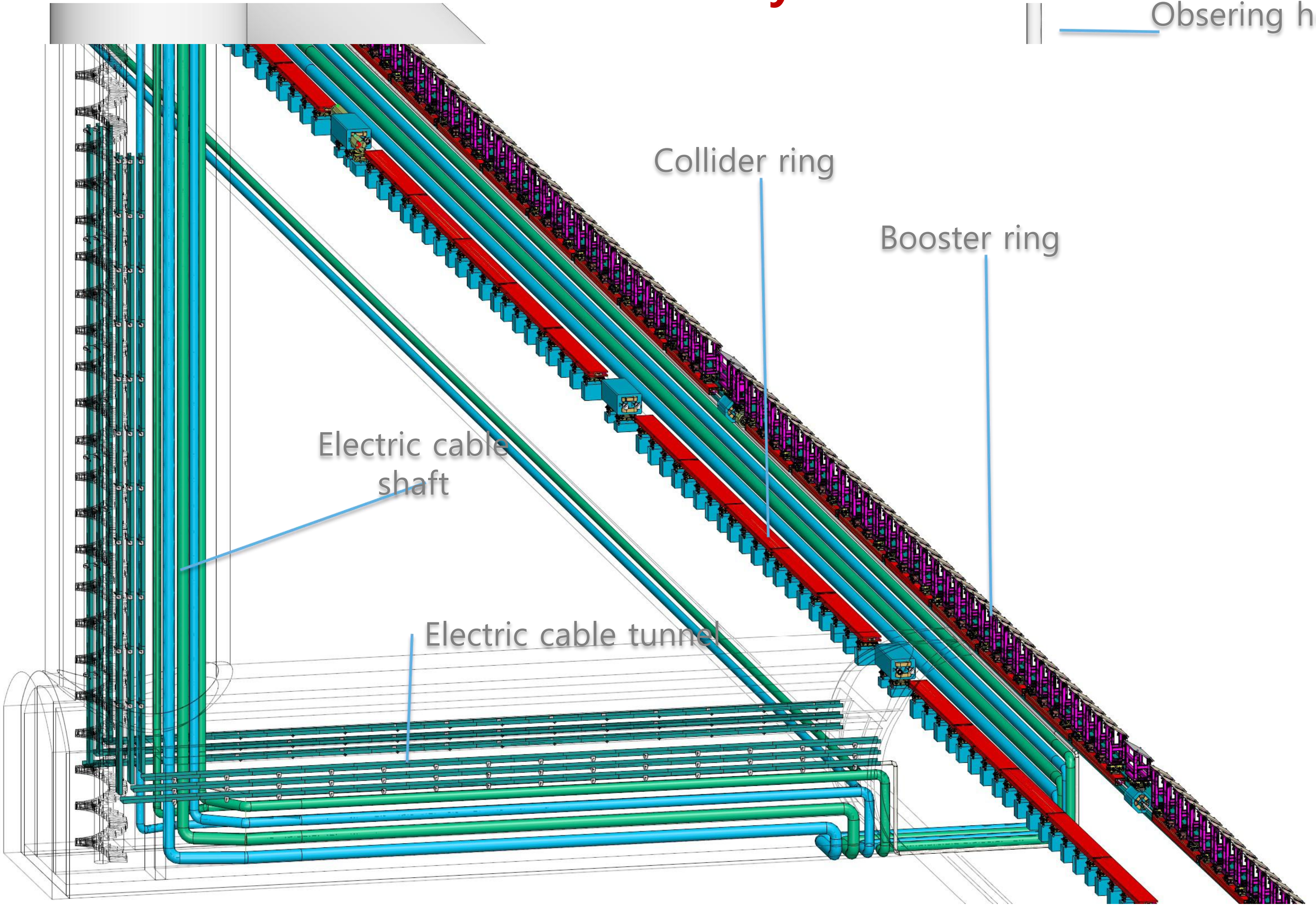
CEPC Main Tunnel and Auxiliary Tunnel Connection-1



CEPC Main Tunnel and Auxiliary Tunnel Connection-2



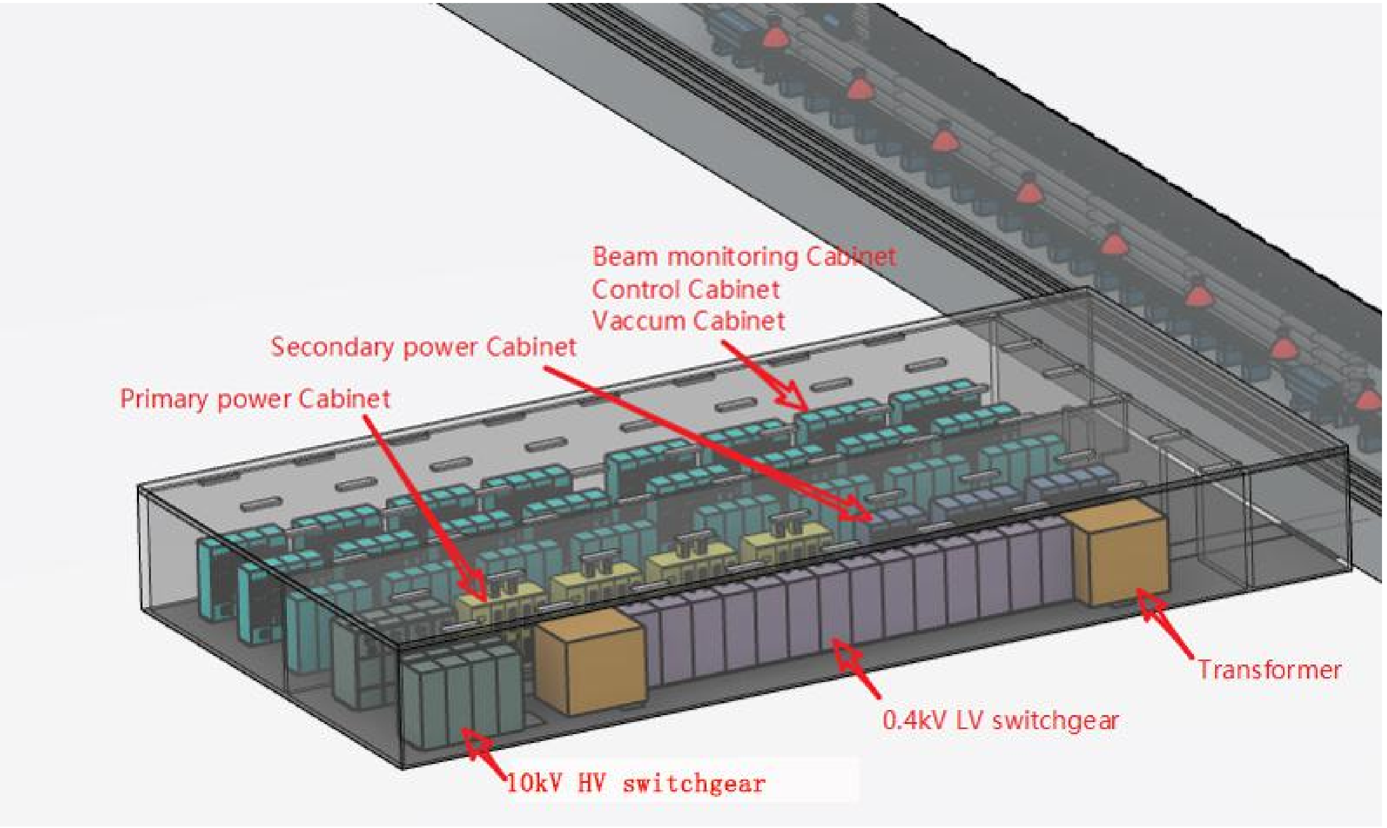
CEPC Main Tunnel and Auxiliary Tunnel Connection-3



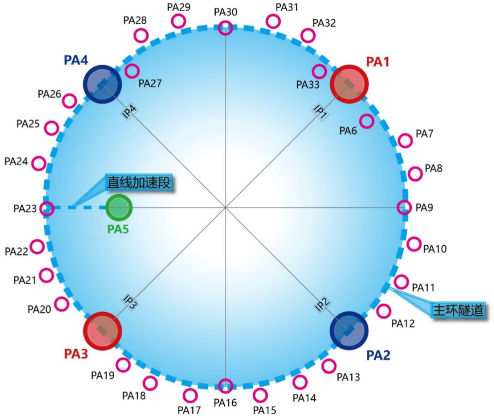
CEPC Conventional Facility and Civil Engineering

Electrical Equipment General Layout in Auxiliary

Description	Qty.	Installed in
Beam monitoring cabinet	10	Control room
Control cabinet	44	
Vacuum cabinet	42	
Primary power cabinet	4	Power distribution room
Secondary power cabinet	11	
10kV HV switchgear	8	
10/0.4kV transformer	2	
0.4kV LV switchgear	12	



CEPC Surface Unitity Buidings (Bird view)



Interaction region IP1

SCRF regions 1, 2

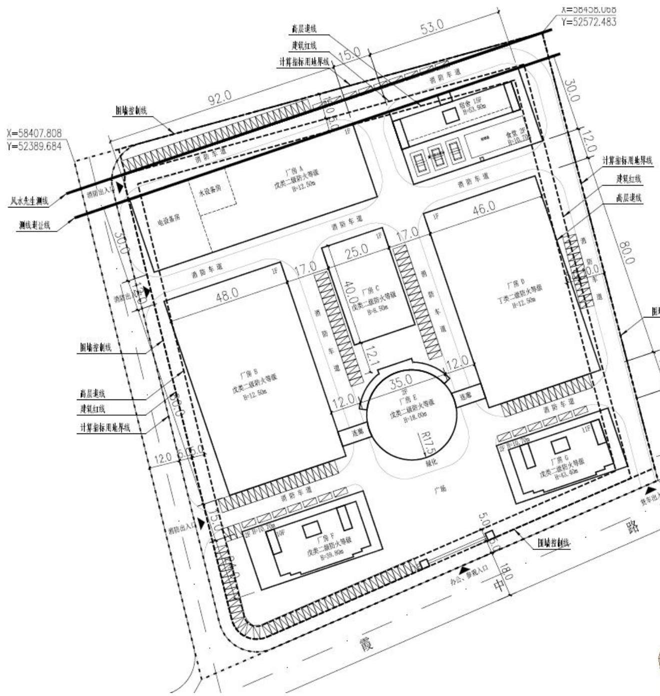
Interaction region IP2

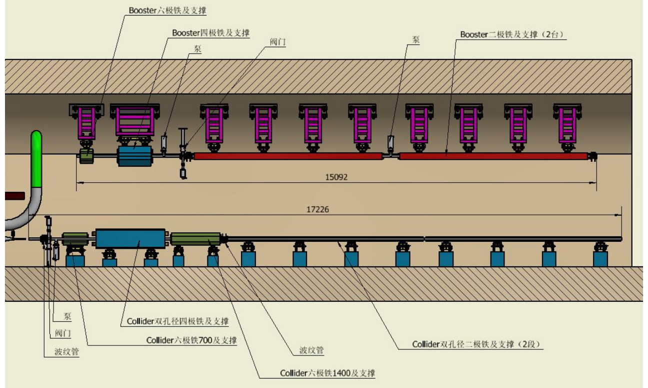
Linac injection accelerator

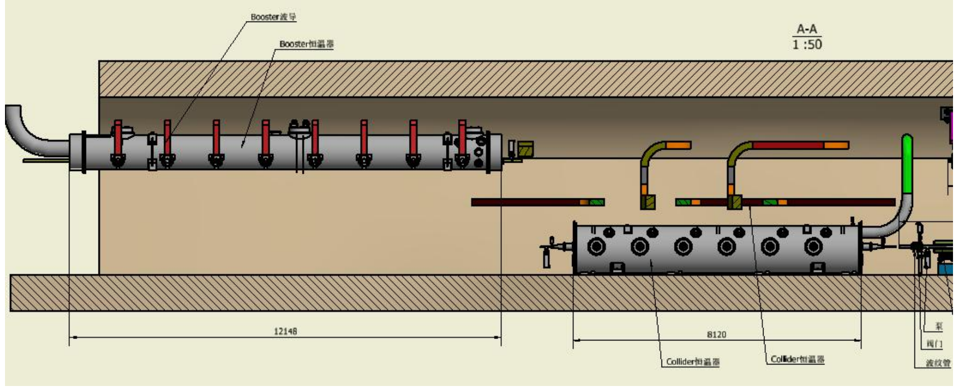
Electric power, cooling and ventilation stations in PA9、PA16、PA23、PA30

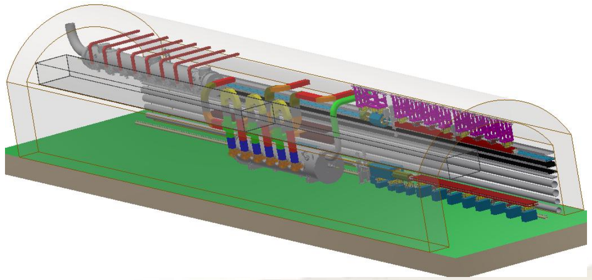
Electric power, cooling and ventilation stations in other places

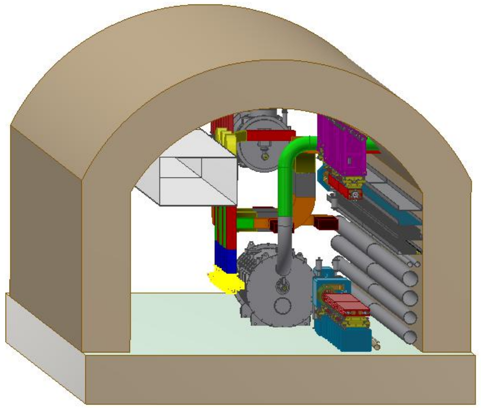
CEPC Tunnel Mockup Design

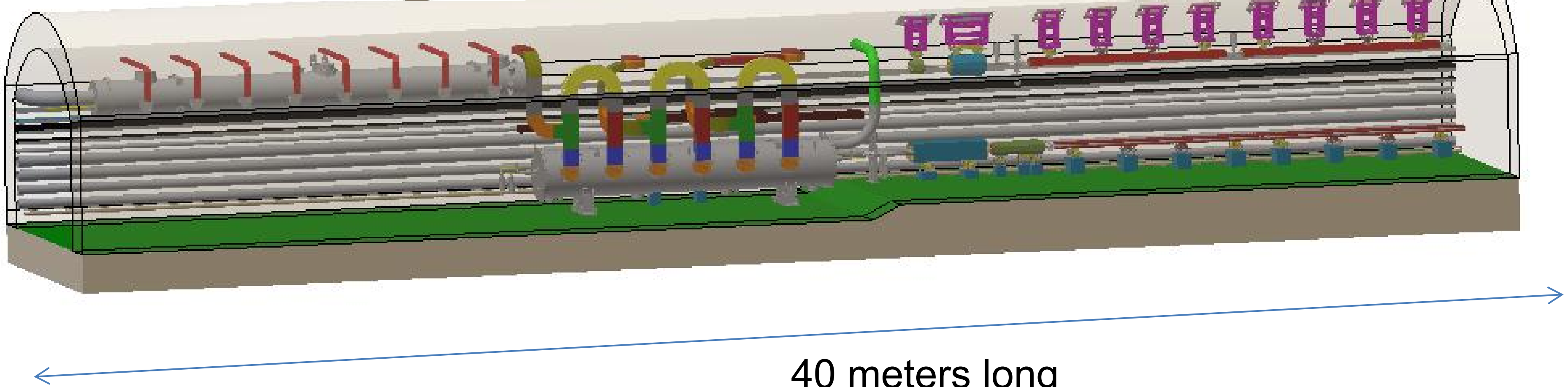






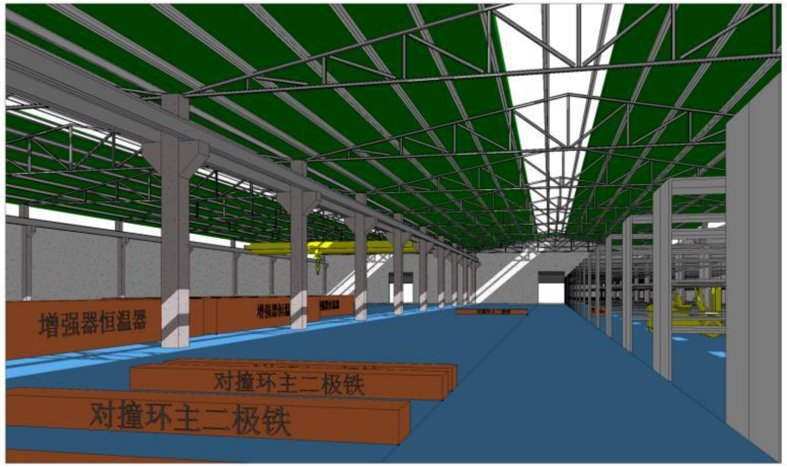


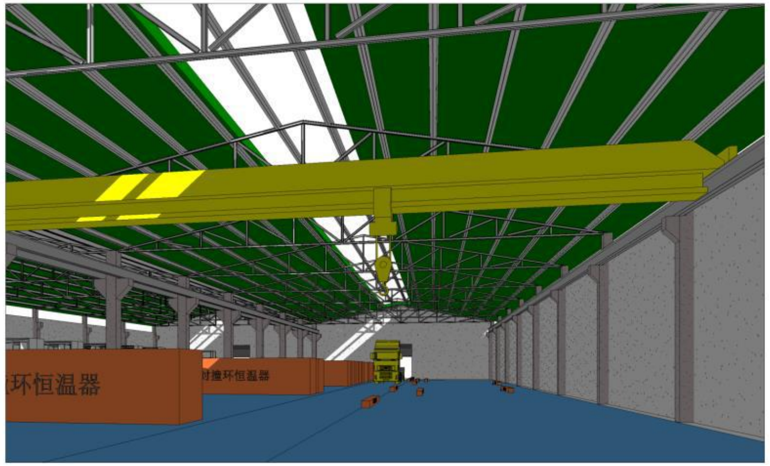


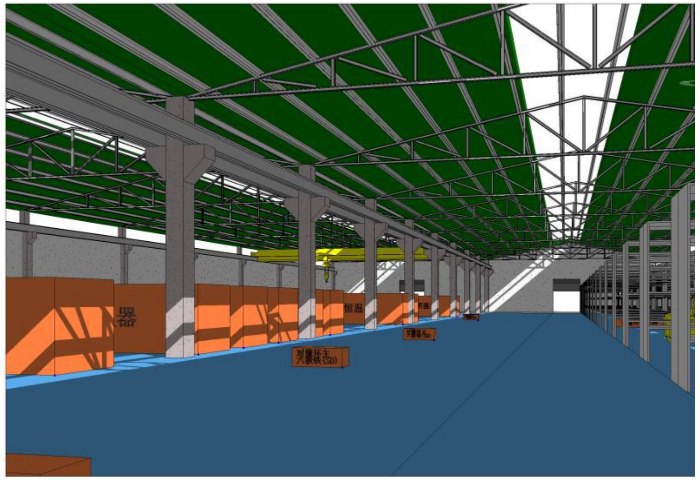


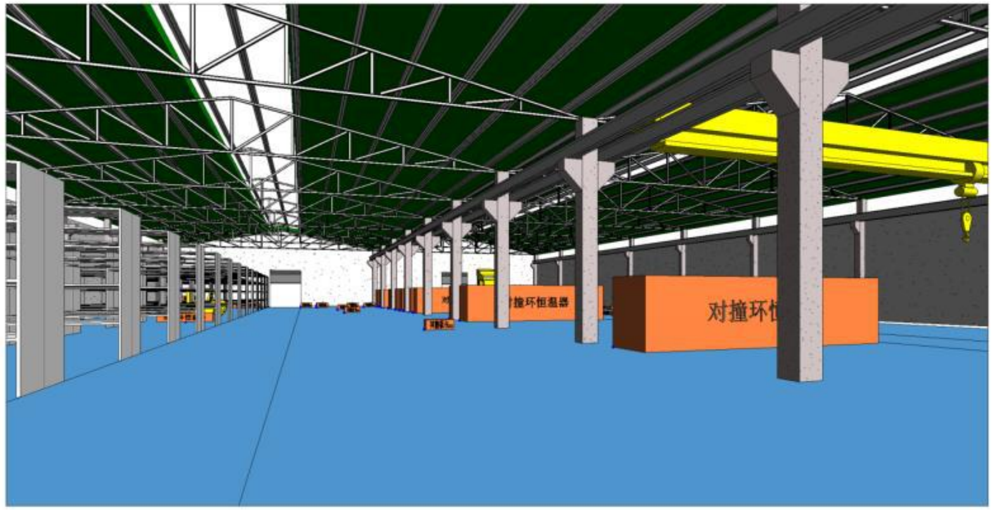
40 meters long

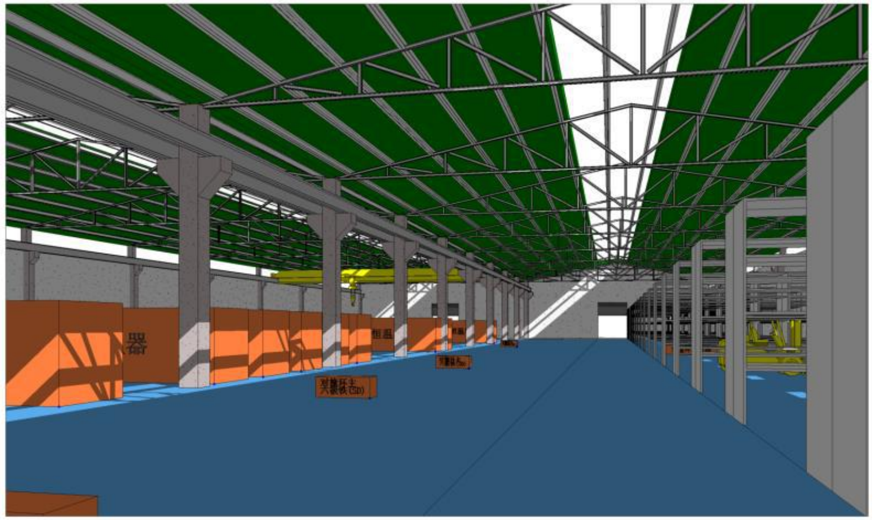
CEPC Component Stores for Installation











CEPC Science City
(under planning)

Bird View

Core Area

CEPC Core Building

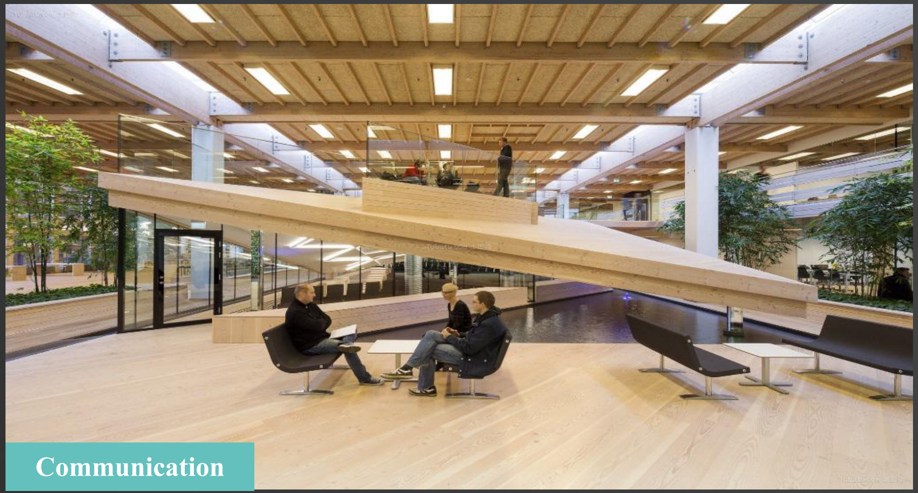
ARCHITECTURE

Unility Space


Office


Meeting room


Luxary


Communication


Auditorium

CEPC Core Building

ARCHITECTURE

Functional Area

xperimental labs

Experimental hall

Cafeteria

Exibition hall

Sport facility

CEPC Collaboratiosn

CEPC Industrial Promotion Consortium (CIPC) Collaboration Status

Established in Nov. 7 , 2017
CIPC Annual Meeting, July 26 , 2018

CEPC
环形正负电子对撞机
Circular Electron Positron Collider
Member of CEPC Industrial Promotion Consortium（CIPC）
CEPC产业促进会
成员单位
北京中科富海低温科技有限公司
BEIJING SINOSCIENCE FULLCRYO TECHNOLOGY CO., LTD.

1) Superconduting materials (for cavity and for magnets)
2) Superconducting cavities
3) Cryomodules
4) Cryogenics
5) Klystrons
6) Vacuum technologies
7) Electronics
8) SRF
9) Power sources
10) Civil engineering
11) Precise machinary.....

Now:

-Huanghe Company,Huadong Engineering Cooperation Company,on CEPC civil engineering design, site selection, implementation...

-Shenyang Huiyu Company on CEPC MDI mechanical connection design

-Zhongxin Heavy Industry on Elecletric-magnetic seperator design

-China Astronotics Department 508 Institute on CEPC MDIsupporting design and CEPC magnets mechanical designs...

-Kuanshan Guoli on CEPC 650MHz high efficiency klystron

-Huadong Engineering Cooperation Company,on CEPC alignement and installation logistics...

CEPC Accelerator Submitted to European Strategy

1) CEPC accelerator: ArXiv: 1901.03169
2) CEPC Physics/Detector: 1901.02170

May 12-17， 2019Granada, Spain

CEPC Accelerator International Collaboration Activities

Japan Super KEK B (e+e- circular collider, similar to CEPC) :

Since 2018, under the envelope of MoU between IHEP and KEK on Super KEK B and circular e+e- collider in general:

March 17, 2018 Jie Gao, Yiwei Wang(3) participated the first round Super KEK B commissioning and operation and collider ring collaboration for one week.

In May, Sha Bai visited Super KEK B on MDI for one month, Kanazawa-san provided RVC design materials of Super KEK B MDI for reference.

From June 10-17, Yuan Zhang visited Super KEK B for one week on beam beam study.

In June, 10-17, 2018, Yuan Zhang, visited Super KEK B on beam beam and dynamic apertures for one week.

In July 5,9-13 Jiyuan Zhai and Dianjun Gong visited Super KEK B on SCRF system of Super KEK B for one week.

From 2018.11.18-2019.1.12, Dr. Haoyu SHI at KEK, started to visit for three months under IHEP-KEK MoU with Hiroyuki Nakayama and Shuji Tanaka, on MDI detector part.

From Nov18-24. 2018. 2018, Jingru Zhang will visit KEK super B linac for one week.

From 2019.3.31-2019.5.21, Haoyu Shi visited KEK Super B on detector and MDI.

Russia Polarization :

In 2018 IHEP is working with BINP to form a new body of collaboration to be signed at the end of 2018, aiming at collaboration on key issues of e+e- colliders, such as lattice DA, polarization, SC magnets of MDI :

In 2019, since May 1, Wenhao Xia visited BINP for one month on polarization beam design.

USA Polarization :

In 2019, from Nov. 1, Wenhao Xia will visit BNL for one month on polarization beam design.

More than 20 MoUs have been signed, recenly, a new MoU has been Signed with Dubna

CEPC Accelertor International Review Committee
Established in August 2019

CEPC International Accelerator Review Committee (CEPC IARC) (11 members) :

k. Oide(CERN/KEK， **Chair**),

B. Forst (DESY/oxford)

E. Levichev(BINP, Russia),

Steinar Stapnes(CLIC, CERN)

KEK: Makoto Tobiyama (Super KEK B)

Italy：INFN (Italy) Marica Biagini(INFN)

USA: F. Willike (eRHIC, BNL, US)

Korea: I.S. Koo (PAL, Korea)

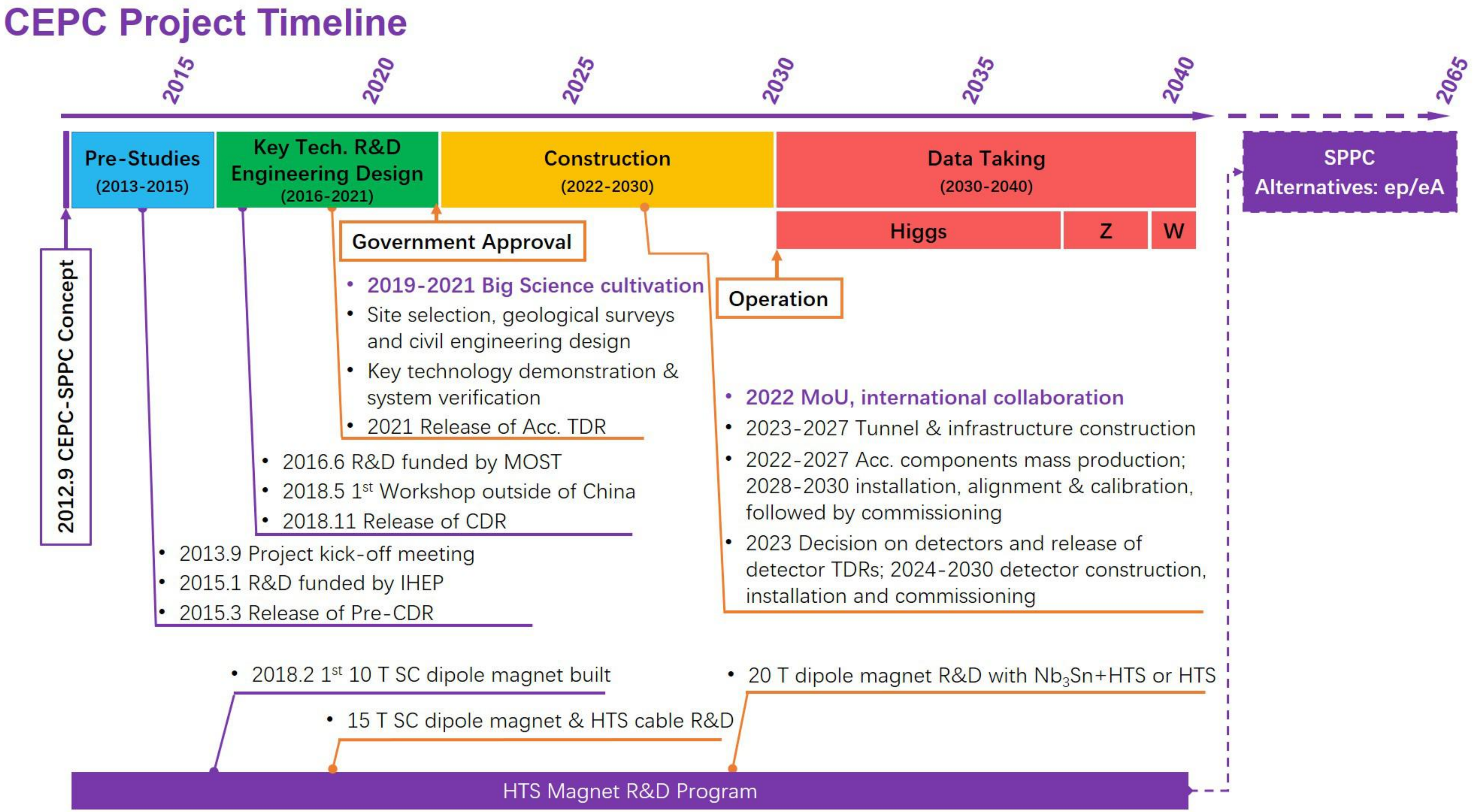
Dubna: Anatoly Sidorin (JINR)

France：Philip Bambade (LAL, France)

China: Zhentang Zhao (SINAP, Shanghai, China)

The first meeting will take place during CEPC Conference on Nov. 20， 2019 from 12:00am-2:00pm

CEPC Timeline



CEPC Project Timeline

2015 2020 2025 2030 2035 2040 2065

Pre-Studies (2013-2015)

Key Tech. R&D Engineering Design (2016-2021)

Construction (2022-2030)

Data Taking (2030-2040)

Higgs | **Z** | **W**

SPPC
Alternatives: ep/eA

2012.9 CEPC-SPPC Concept

- 2013.9 Project kick-off meeting
- 2015.1 R&D funded by IHEP
- 2015.3 Release of Pre-CDR

- 2016.6 R&D funded by MOST
- 2018.5 1st Workshop outside of China
- 2018.11 Release of CDR

Government Approval

- **2019-2021 Big Science cultivation**
- Site selection, geological surveys and civil engineering design
- Key technology demonstration & system verification
- 2021 Release of Acc. TDR

Operation

- **2022 MoU, international collaboration**
- 2023-2027 Tunnel & infrastructure construction
- 2022-2027 Acc. components mass production; 2028-2030 installation, alignment & calibration, followed by commissioning
- 2023 Decision on detectors and release of detector TDRs; 2024-2030 detector construction, installation and commissioning

- 2018.2 1st 10 T SC dipole magnet built
- 15 T SC dipole magnet & HTS cable R&D
- 20 T dipole magnet R&D with Nb_3Sn+HTS or HTS

HTS Magnet R&D Program

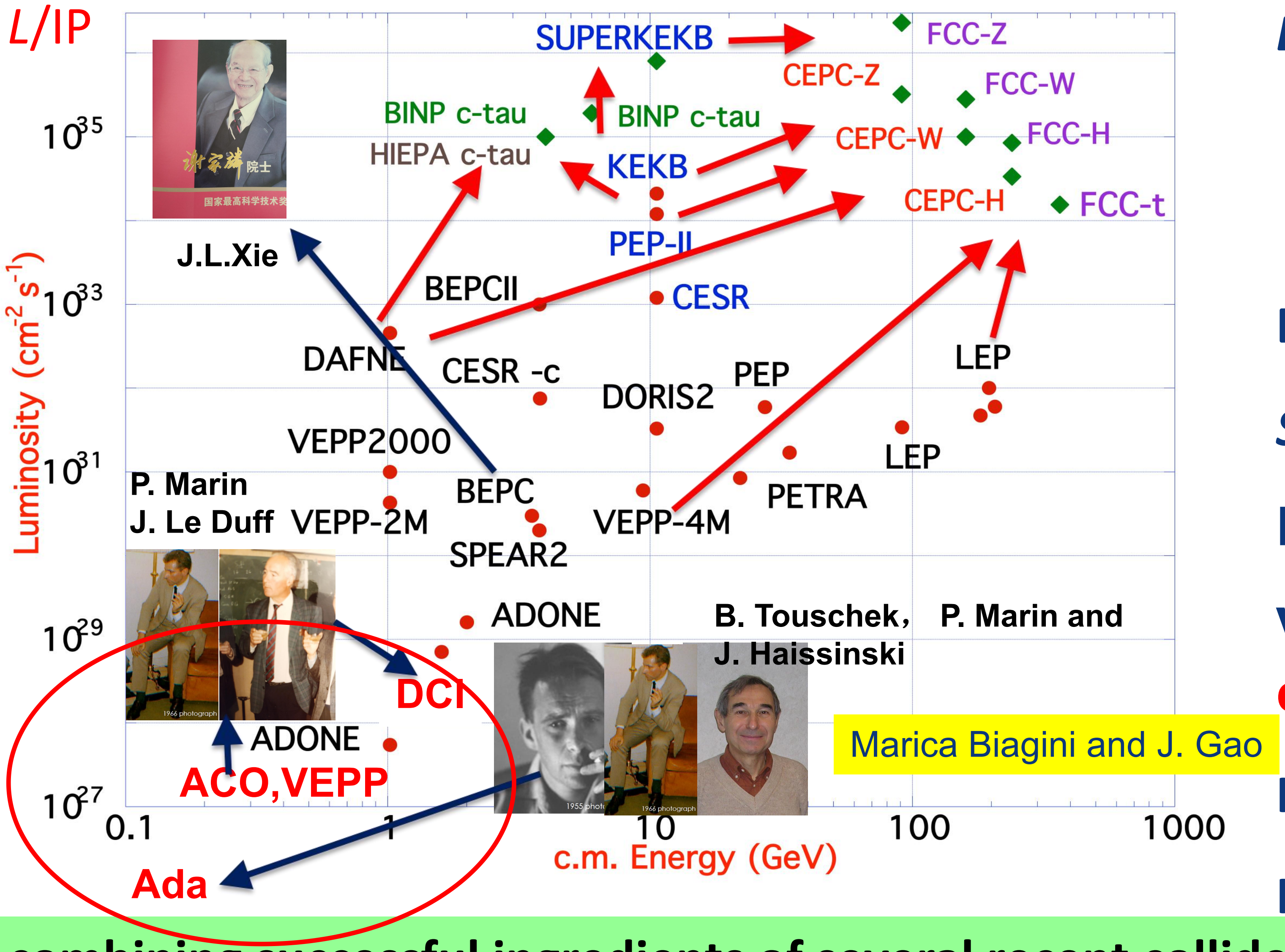
Summary

- After CEPC Accelerator CDR was released, CEPC optimization design efforts continue with the luminosities for H,W, and Z the same level as FCCee, but with lower SR power and same hardwares for different energies
- CEPC (+SppC) R&D efforts towards TDR are under way with the aim to complet TDR before 2023
- CEPC site selection, civil engineering design and progress well
- CEPC international collaboration and collaboration with industries go well
- US colleagues are welcome to join CEPC collaboration

Thanks go to CEPC-SppC team, CIPC and international partners and colleageus

Backup slides

Future circular lepton factories based on proven concepts and techniques from past colliders and light sources



Marica Biagini and J. Gao

B-factories: **KEKB & PEP-II:**
double-ring lepton colliders,
high beam currents,
top-up injection

DAFNE: crab waist, double ring

Super B-factories,* S-KEKB: low β_y

LEP: high energy, SR effects

VEPP-4M, LEP: precision E calibration

KEKB: *e*$^+$ source

HERA, LEP, RHIC: spin gymnastics

combining successful ingredients of several recent colliders → highest luminosities & energies

Luminosity from Colliding Beams

- **For equally intense Gaussian beams**

Collision frequency

Particles in a bunch

Geometrical factor:
- crossing angle
- hourglass effect

$$L = f \frac{N_b^{\,2}}{4\pi\sigma_x\sigma_y} R$$

Transverse beam size (RMS)

- **Expressing luminosity in terms of our usual beam parameters**

$$L[\mathrm{cm^{-2}s^{-1}}] = 2.17\times 10^{34}(1+r)\xi_y \frac{E[\mathrm{GeV}]I[\mathrm{A}]}{\beta_y[\mathrm{cm}]}$$

In ACO it is found that ξ_y has a maximum value

where

$$\boxed{\xi_y = \frac{r_e N_e \beta_y}{2\pi\sigma_y(\sigma_x+\sigma_y)}:}$$

For exampe, for DCI at 800MeV $\xi_y = 0.024$

Analyical expression for the maximum value of $\xi_{y,\max}$ is the keystone of a circular collider both for lepton and hadron one

Maximum Beam-beam Tune Shift Analytical Expressions for Lepton and Hadron Circular Colliders

$$\xi_y = \frac{r_e N_e \beta_y}{2\pi\sigma_y(\sigma_x+\sigma_y)}$$

For example: BEPCII@ 1.89GeV $\xi_{\mathrm{y}} = 0.04$

For lepton collider:

$$\xi_{\mathrm{y,\ max}} = \frac{2845}{2\pi}\sqrt{\frac{T_0}{\tau_y \gamma N_{IP}}} \qquad \xi_{\mathrm{y,max}} = \frac{2845\gamma}{1}\sqrt{\frac{r_e}{6\pi R N_{IP}}}$$

r_e is electron radius

γ is normalized energy

R is the dipole bending radius

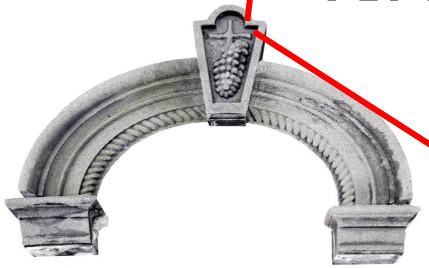
N_{IP} is number of interaction points

$$\xi_{\mathrm{x,\ max}} = \sqrt{2}\,\xi_{y,\ \mathrm{max}}$$

J. Gao, **Nuclear Instruments and Methods in Physics Research A** 533 (2004) 270–274

J. Gao, Nuclear Instruments and Methods in Physics Research A 463 (2001) 50–61

For hadron collider:



Keystones

$$\xi_{\max} = \frac{2845\gamma}{f(x)}\sqrt{\frac{r_p}{6\pi R N_{IP}}}$$

where r_p is proton radius

$$f(x) = 1 - \frac{2}{\sqrt{2\pi}}\int_0^x \exp\left(-\frac{t^2}{2}\right)dt$$

$$x^2 = \frac{4f(x)}{\pi\xi_{\max}N_{IP}} = \frac{4f^2(x)}{2845\pi\gamma}\sqrt{\frac{6\pi R}{r_p N_{IP}}}$$

J. Gao, “Review of some important beam physics issues in electron positron collider designs”, **Modern Physics Letters A**, Vol. 30, No. 11 (2015) 1530006 (20 pages)

J. Gao, et al, "Analytical estimation of maximum beam-beam tune shifts for electron-positron and hadron circular colliders", Proceedings of ICFA Workshop on High Luminosity Circular e+e- Colliders – Higgs Factory, 2014

For example: SppC@ 75TeV $\xi_{\mathrm{y}} = 0.0056$

Constraints for CEPC Parameter Choice

- Limit of Beam-beam tune shift

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

F_l: ξy enhancement by crab waist

J. Gao*

- Beam lifetime due to beamstrahlung

BS life time: 30 min

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

1) V. Telnov, arXiv:1203.6563v, 29 March 2012
2) V. Telnov, HF2012, November 15, 2012

- Beamstrahlung energy spread

$A=\delta_0/\delta_{BS}$ $(A\geq 3)$

- Beam currect limited by either radiation power or by HOM power per cavity

$$\mathrm{P}_{HOM} = \mathrm{k}(\sigma_z)eN_e * 2I_b \le 2KW$$

*1) J. Gao, emittance growth and beam lifetime limitations due to beam-beam effects in e+e- storage rings, **Nucl. Instr. and methods** A533（2004）p. 270-274.

* 2) J. Gao, Review of some important beam physics issues in electron positron collider designs, **Modern Physics Letters A**, Vol. 30, No. 11 (2015) 1530006 (20 pages)

3) D. Wang, J. Gao, et al, Optimization parameter design of a circular e+e- Higgs factory, **Chinese Physcis C**，Vol. 40, No. 1 (2016) 017001-017007

4) D. Wang. J. Gao, eta al, Optimization parameter design of a circular e+e- collider with crab-waist, to be submitted to **Chinese Physcis C**

Basic Theroy of Dynamic Aperture in Circular Accelerator-1

Linear Habiltonion +nonlinear perriodi kicks

$$H=\frac{p^2}{2}+\frac{K(s)}{2}x^2+\frac{1}{m!B_0\rho}\frac{\partial^{m-1}B_z}{\partial x^{m-1}}x^mL\sum_{k=-\infty}^{\infty}\delta(s-kL)$$

Circular machine

A nonlinear multipole

Beam-beam effects, sextupoles,octupoles, wigglers, space charge effects...

$$B_z=B_0(1+xb_1+x^2b_2+x^3b_3+\cdots+x^{m-1}b_{m-1}+\cdots)$$

For one multipole $B_z=B_0x^{m-1}b_{m-1}$ m≥3

Analytical treatment of dynamics aperture is the basestone to understand the performance of circular accelerators

$$\Psi=\int_0^s\frac{\mathrm{d}s'}{\beta_x(s')}+\phi_0$$

$$J=\frac{\varepsilon_x}{2}=\frac{1}{2\beta_x(s)}\left(x^2+\left(\beta_x(s)x'-\frac{\beta_x'x}{2}\right)^2\right)$$

$$H(J,\Psi)=\frac{J}{\beta_x(s)}.$$

$$\Psi_1=\Psi+\frac{2\pi v}{L}-\int_0^s\frac{\mathrm{d}s'}{\beta_x(s')}$$

$$J_1=J$$

$$H_1=\frac{2\pi v}{L}J_1.$$

$$H=\frac{x^2B_y|_{x=0,y=0}}{2\rho^2B_0}+\frac{1}{B_0\rho}\sum_{n=1}^{\infty}\frac{1}{n!}\frac{\partial^{n-1}B_y}{\partial x^{n-1}}\bigg|_{x=0,y=0}(x+\mathrm{i}y)^n-(1+x/\rho)\left(1+\frac{\Delta P}{P_0}-\left(\bar{p}_x-\frac{eA_x}{P_0}\right)^2-\left(\bar{p}_y-\frac{eA_y}{P_0}\right)^2\right)^{1/2}-\frac{e\Phi}{P_0}$$

$$x=\sqrt{2J_1\beta_x(s)}\cos\left(\Psi_1-\frac{2\pi v}{L}s+\int_0^s\frac{\mathrm{d}s'}{\beta_x(s')}\right).$$

$$\frac{\mathrm{d}J_1}{\mathrm{d}s}=-\frac{\partial H_1}{\partial\Psi_1}$$

$$\frac{\mathrm{d}\Psi_1}{\mathrm{d}s}=\frac{\partial H_1}{\partial J_1}$$

$$\overline{J_1}=\overline{J_1}(\Psi_1,J_1)$$

$$\overline{\Psi_1}=\overline{\Psi_1}(\Psi_1,J_1)$$

$$\bar{I}=I+K_0\sin\theta$$

$$\bar{\theta}=\theta+\bar{I}$$

$|K_0|\le 1$ (0.97164)

Analytical DA expressions

J. Gao, “Analytical estimation of the dynamic apertures of circular accelerators”, **Nuclear Instruments and Methods in Physics Research A** 451 (2000) 545-557.