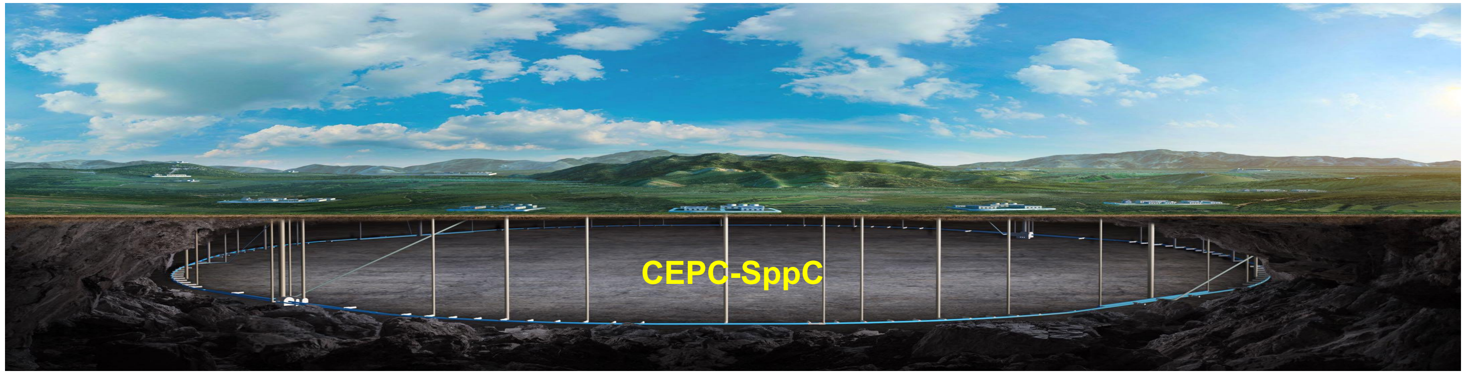
Status of the CEPC Project

J. Gao

IHEP
On behalf of CEPC Group

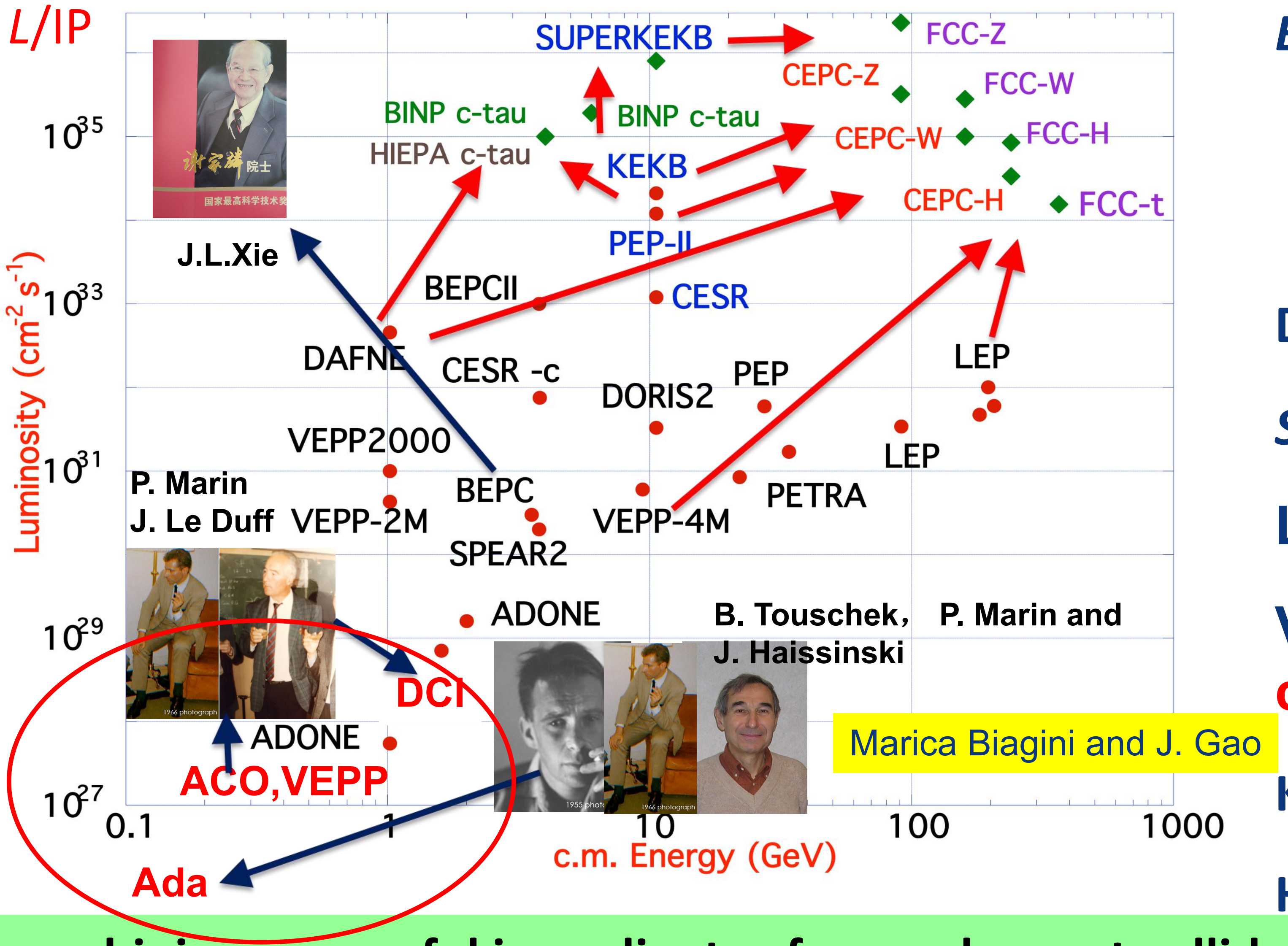


3rd FCC Physics and Experiments Workshop
January 13-17，2020，CERN

Outline

- CEPC optimization design in TDR
- CEPC TDR R&D plan and status
- CEPC-SppC compatibility
- CEPC-SppC siting and civil engineering
- CEPC collaborations
- Summary

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

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

CEPC-SppC was proposed by Chinese scientists in Sept. 2012 after Higgs Boson was discovered on July 4，2012 at CERN

Precision measurement + searches: Complementary with each other !

CEPC Design –Higgs Parameters

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	2*120 GeV
Luminosity (peak)	>2*10^34/cm^2s
No. of IPs	2

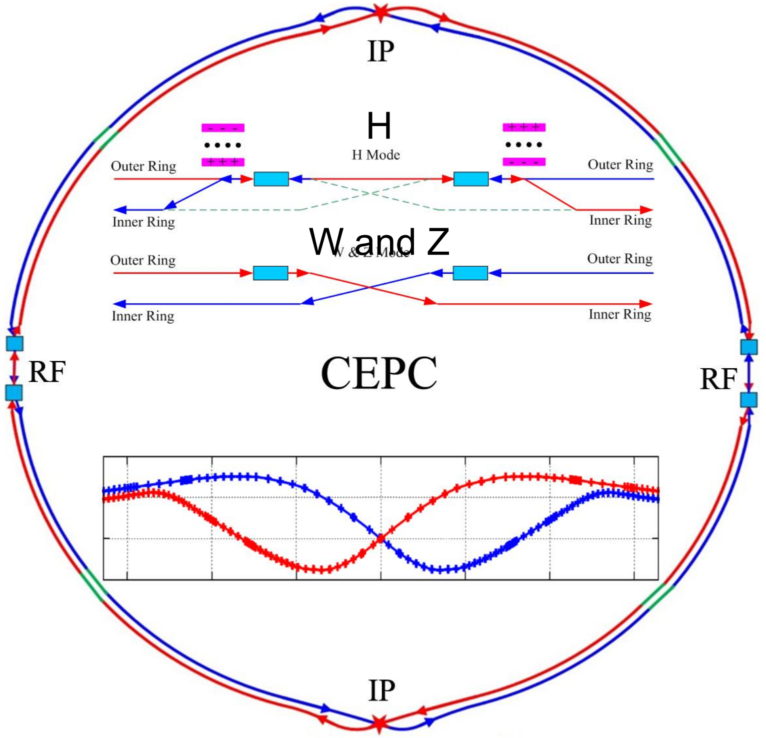
CEPC Design – Z-pole Parameters

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	2*45.5 GeV
Integrated luminosity (peak)	>10^34/cm^2s
No. of IPs	2
Polarization	**Z-pole polarization under design**

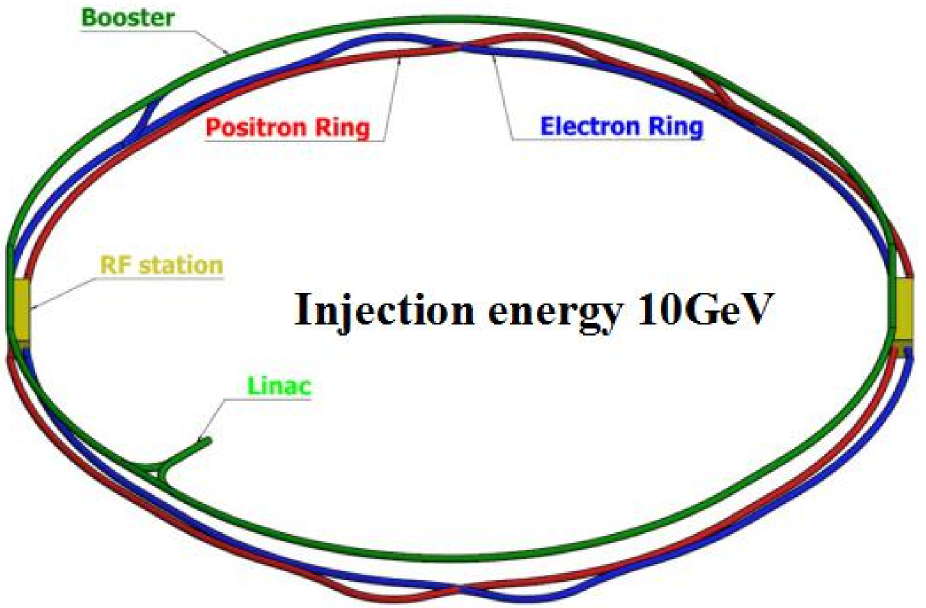
***Be noted that here the luminosities are the lowest reuiqrement to accomodate different collider schemes**

CEPC Optimization Design

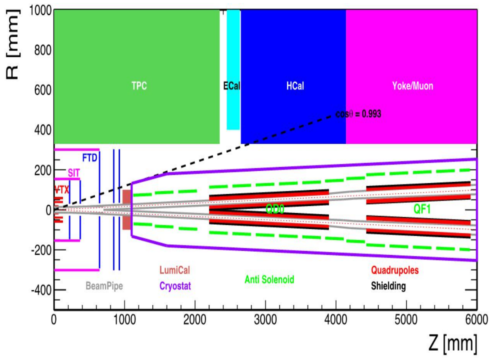
CEPC CDR Baseline Layout

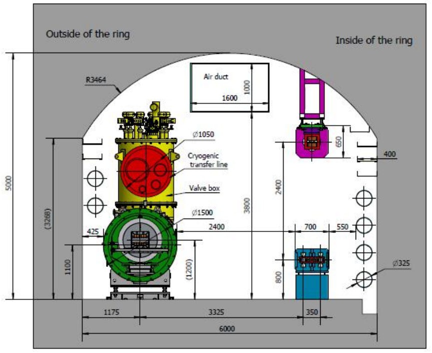


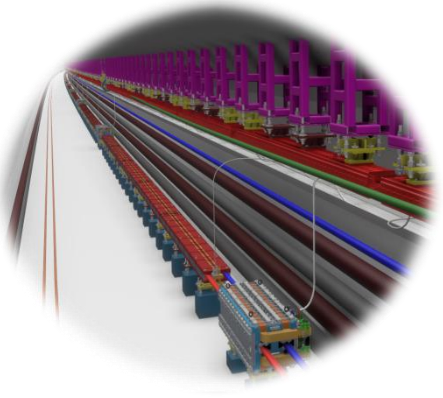
CEPC collider ring (100km)

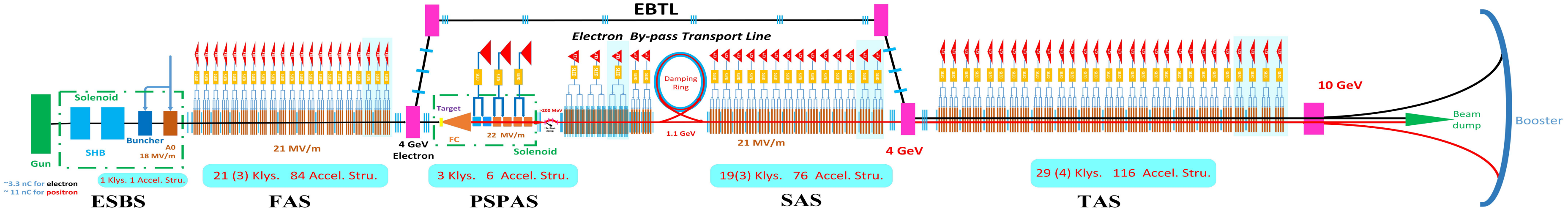


CEPC booster ring (100km)









CEPC Linac injector (1.2km, 10GeV)

Luminosity from Colliding Beams

- **For equally intense Gaussian beams**

Collision frequency

Particles in a bunch

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

Geometrical factor:
- crossing angle
- hourglass effect

Transverse beam size (RMS)

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

$$L[\mathrm{cm}^{-2}\mathrm{s}^{-1}] = 2.17\times10^{34}(1+r)\xi_y \frac{E[\mathrm{GeV}]I[\mathrm{A}]}{\beta_y[\mathrm{cm}]}$$

where

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

In ACO it is found that ξ_y has a maximum value

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 lepton collider:

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

r_e is electron radius
γ is normalized energy
R is the dipole bending radius
N_{IP} is number of interaction points

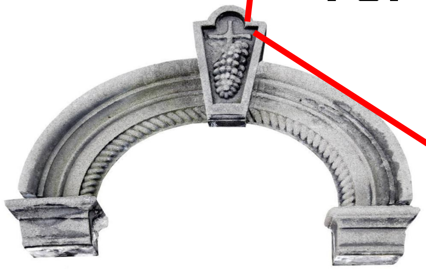
For example: BEPCII@ 1.89GeV $\xi_y = 0.04$

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

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)

For example: SppC@ 75TeV $\xi_y = 0.0056$

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

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=δ_0/δ_{BS} (A≥3)

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

$$P_{HOM} = k(\sigma_z) e N_e * 2I_b \le 2KW$$

*1) J. Gao, emittance growth and beam lifetime limitations due to beam-beam effects in e+e- storage rings, **Nucl. Instr. and methods A**533（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**

CEPC CDR Parameters

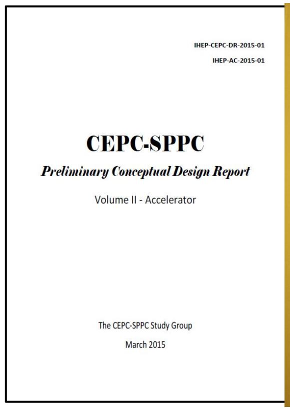
	Higgs	*W*	*Z* (3T)	*Z* (2T)
Number of IPs	2			
Beam energy (GeV)	**120**	**80**	**45.5**	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (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 Accelerator from Pre-CDR, CDR towards TDR

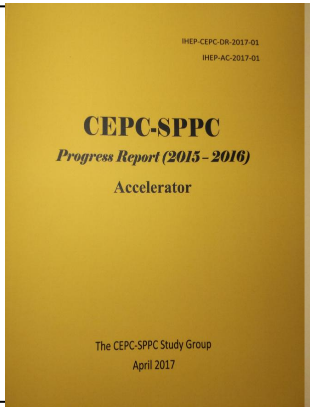
CEPC accelerator CDR completed in June 2018 (to be printed in July 2018)

- Executive Summary
1. Introduction
2. Machine Layout and Performance
3. Operation Scenarios
4. CEPC Collider
5. CEPC Booster
6. CEPC Linac
7. Systems Common to the CEPC Linac, Booster and Collider
8. Super Proton Proton Collider
9. Conventional Facilities
10. Environment, Health and Safety
11. R&D Program
12. Project Plan, Cost and Schedule

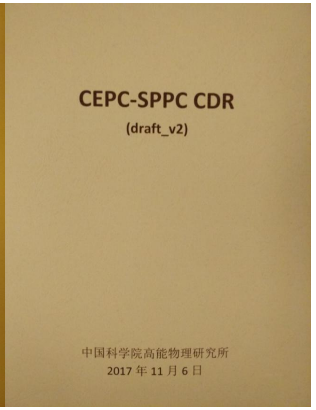
- Appendix 1: CEPC Parameter List
- Appendix 2: CEPC Technical Component List
- Appendix 3: CEPC Electric Power Requirement
- Appendix 4: Advanced Partial Double Ring
- Appendix 5: CEPC Injector Based on Plasma Wakefield Accelerator
- Appendix 6: Operation as a High Intensity γ-ray Source
- Appendix 7: Operation for e-p, e-A and Heavy Ion Collision
- Appendix 8: Opportunities for Polarization in the CEPC
- Appendix 9: International Review Report



March 2015

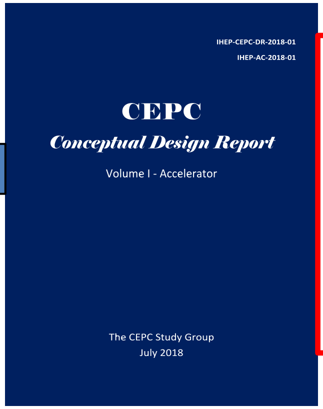


April 2017



Draft CDR for Mini International Review in Nov. 2017

CEPC CDR Vol. I and II was publically released in Nov. 2018



CEPC Accelerator Submitted to European Strategy in 2019

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

CDR Version for International Review June 2018
Formally relased on Sept. 2, 2018:arXiv： 1809.00285
http://cepc.ihep.ac.cn/CDR_v6_201808.pdf

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**

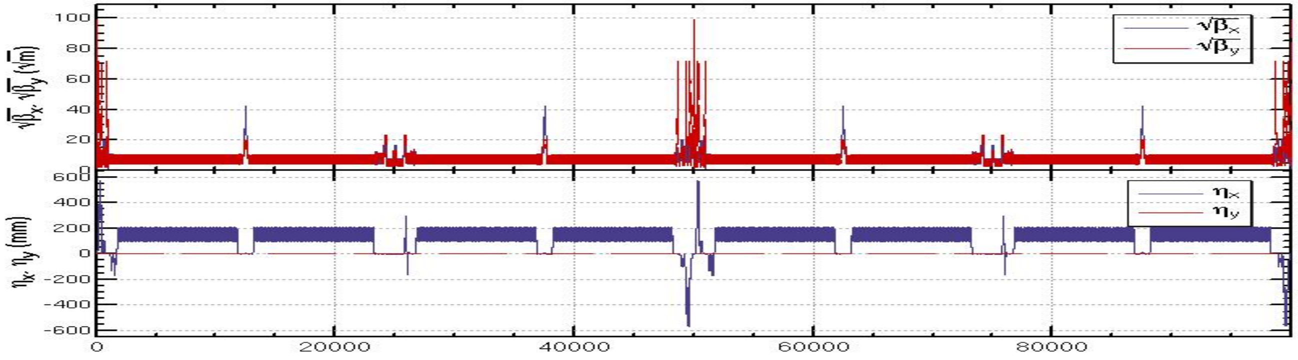
Z:1*10^36/cm^2/s now with single cell 650Mhz large grain cavity

CEPC Lattice Design for Higher Luminosity

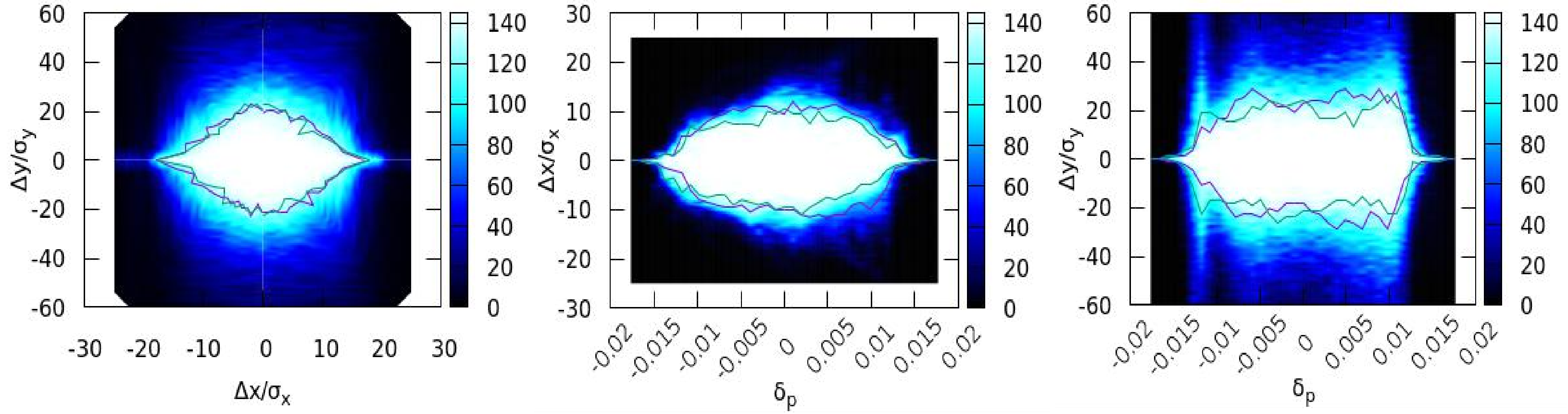
- Fit parameter list with luminosity of $5.2 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$
  - Stronger optimization and stricter hardware requirement should be made to get enough dynamic aperture
- Optimization of the quadrupole radiation effect
  - Interaction region: longer QD0/QF1
  - ARC region: longer quadrupoles
- Reduction of dynamic aperture requirement from injection
  - Straight section region: larger βx at injection point
- Maximization of bend filling factor to minimize the synchrotron radiation loss per turn
  - 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

CEPC Dynamic Aperture Status

- To make sure the effect of several changes, different versions were studied
- Lattice of V4, bx*=0.33m, by*=0.001m, ex=0.89nm rad, shorten the RF region, add octupole and decapole for vertical chromaticity correction, lattice + beam-beam + SR fluctuation, w/o error
  - **$18\sigma_x$*$21\sigma_y$*1.5%** which fullfling the DA requirement for on-momentum particle



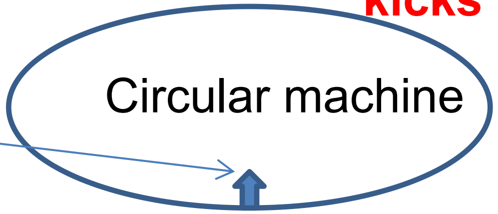
Jin Wu, Yuan Zhang



Basic theory of dynamic aperture in circular accelerator

Linear Hamiltonion +nonlinear perriodic kicks

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



A nonlinear multipole

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

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

$$A_{\mathrm{dyna},2m}=\sqrt{2\beta_x(s)}\left(\frac{1}{m\beta_x^m(s(2m))}\right)^{\frac{1}{2(m-2)}}\left(\frac{\rho}{|b_{m-1}|L}\right)^{1/(m-2)}$$

Standard Mapping
Chirikov Criterion

DA relation between X and Y $A_{\mathrm{dyna},2m,y}=\sqrt{\frac{\beta_x(s(2m))}{\beta_y(s(2m))}(A^2_{\mathrm{dyna},2m,x}-x^2)}$

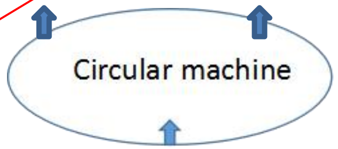
Hénon and Heiles problem

Analytical expression of dynamic apertures

Dynamic aperture analytical expressions are basestones for circular accelerators

For more independent multipoles

$$A_{\mathrm{dyna,total}}=\frac{1}{\sqrt{\sum_i\frac{1}{A^2_{\mathrm{dyna,sext},i}}+\sum_j\frac{1}{A^2_{\mathrm{dyna,oct},j}}+\sum_k\frac{1}{A^2_{\mathrm{dyna,deca},k}}+\cdots}}$$



Many multipoles

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

Comparison of analytic and simulation result-1

Nuclear Instruments and Methods in Physics Research A 451 (2000) 545–557

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.nl/locate/nima

Analytical estimation of the dynamic apertures of circular accelerators

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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

$$A_{dyna,sext,x} = \sqrt{2J_{max}\beta_x(s)} = \sqrt{\frac{8\beta_x(s)}{3(B^2+C^2)}}$$

On momentum

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

Off momentum

$$A_i = \beta_x(s_i)^{3/2} S_i \qquad B = \sum_i A_i \cos 3\Delta\Psi_i \text{ and } C = \sum_i A_i \sin 3\Delta\Psi_i,$$

$$\tilde{\beta}_x(s) = \beta_x(s)\left(1+\frac{1}{2\sin(2\pi\nu)}\oint \beta_x(t) k \cos\alpha \mathrm{d}t\right)$$

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

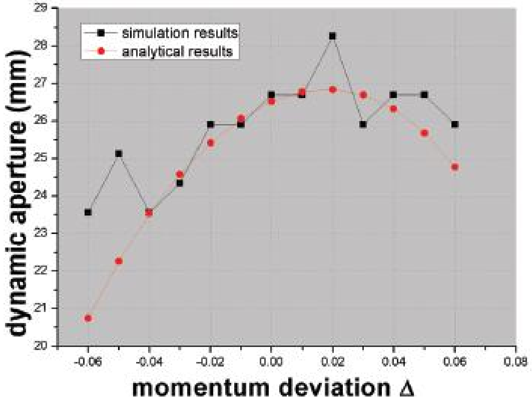
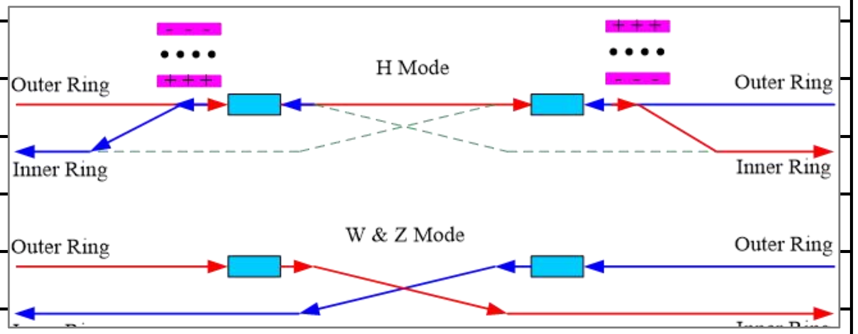


Figure 1: Results of horizontal dynamical aperture in both simulation method and analytical method at BEPC-II positron ring.

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

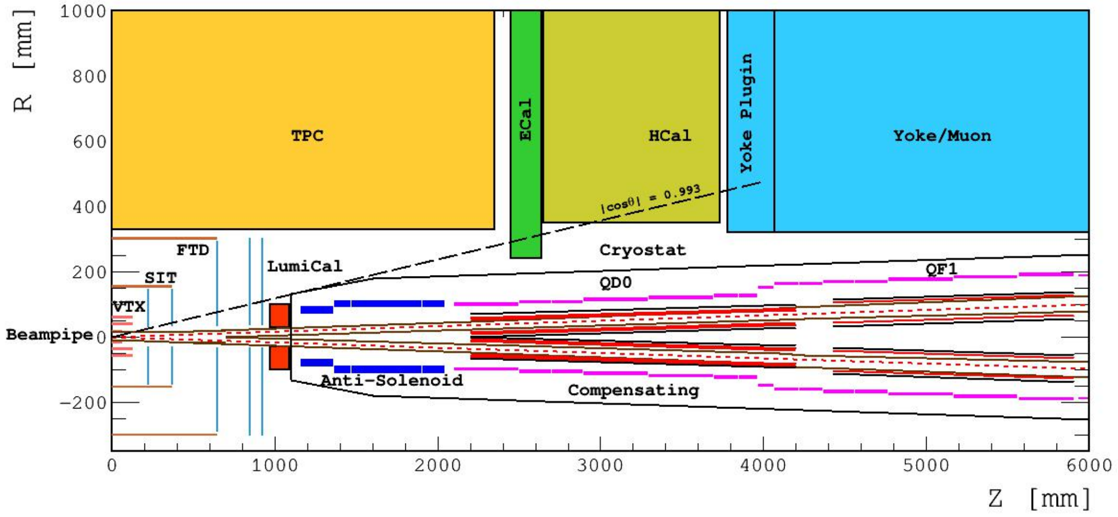
CEPC Collider Ring SRF Parameters

New machine parameters 20190226 SRF parameters 20190301	CDR (2-cell)			HL-Z (new2) (1-cell)				HL-Z (2-cell)	Performance Limits & Risks
	H	W	Z	H	W	Z (a)	Z (b)	Z	
Luminosity / IP [10^{34} $cm^{-2}s^{-1}$]	2.93	10.1	**32.1**	2.93	10.1	**74.5**	**74.5**	**74.5**	
SR power / beam [MW]	30	30	16.5	30	30	30	30	30	
RF voltage [GV]	2.17	0.47	0.1	2.17	0.47	0.1	0.1	0.1	
Beam current / beam [mA]	17.4	87.7	460	17.4	87.7	838	838	838	
Bunch charge [nC]	24	19.2	12.8	24	19.2	19.2	19.2	19.2	
Bunch number / beam	242	1524	12000	242	1524	14564	14564	14564	
Bunch length [mm]	3.26	5.9	8.5	3.26	5.9	10	10	10	
Cavity number (650 MHz)	**240**	2 x 108	**2 x 60**	**240**	2 x 120	**2 x 120**	**2 x 60**	**2 x 120**	Smart by-pass could be a better approach than 1-cell.
Cell number / cavity	**2**	2	**2**	**1**	1	**1**	1	**2**	Common 1-cell for Z & H/W necessary or different cavity?
Idle cavities on line / ring	0	12	60	0	0	0	**60**	0	Z 2x60 symmetry detune parked half cavities for FM CBI
Cavity gradient [MV/m]	**20**	9.5	3.6	**40**	17	3.6	7.2	1.8	Current status: ~ 10 MV/m in storage ring. Field emission
Q_0 for long term operation	**1.5E10**	1.5E10	1.5E10	**3E10**	3E10	3E10	3E10	1.5E10	~ 1E9 in storage ring. Field emission. Magnetic shield
Input power / cavity [kW]	250	278	**275**	250	250	**250**	**500**	250	~ 300 kW in storage ring. Window events and damages
Klystron max power [kW]	800	800	800	800	800	800	**1400**	800	Klystron max power limit: 1200 kW? KLY # & $
Number of cavities / klystron	2	2	2	2	2	2	**2**	2	Avoid RF power source reconfiguration
HOM power / cavity [kW]	0.57	0.75	**1.94**	0.29	0.37	**2.28**	2.28	**4.57**	HOM coupler capacity (not HOM power per cavity) : 1 kW
Optimal Q_L	1.5E6	3.2E5	4.7E4	3.1E6	5.8E5	2.6E4	5.2E4	1.3E4	Coupler variation range, coupler kick to beam
Optimal detuning [kHz]	0.2	1.0	**17.8**	0.1	0.5	**32.3**	**16.1**	**64.6**	Fundamental mode coupled bunch instability
Wall loss / cavity @ 2 K [W]	25.6	5.9	0.9	25.6	4.8	0.2	0.9	0.2	Field emission will drastically increase the cryogenic load.
Total cavity wall loss [kW]	6.1	1.3	0.1	6.1	1.2	0.05	0.05	0.05	(cryogenic wall loss in two rings)

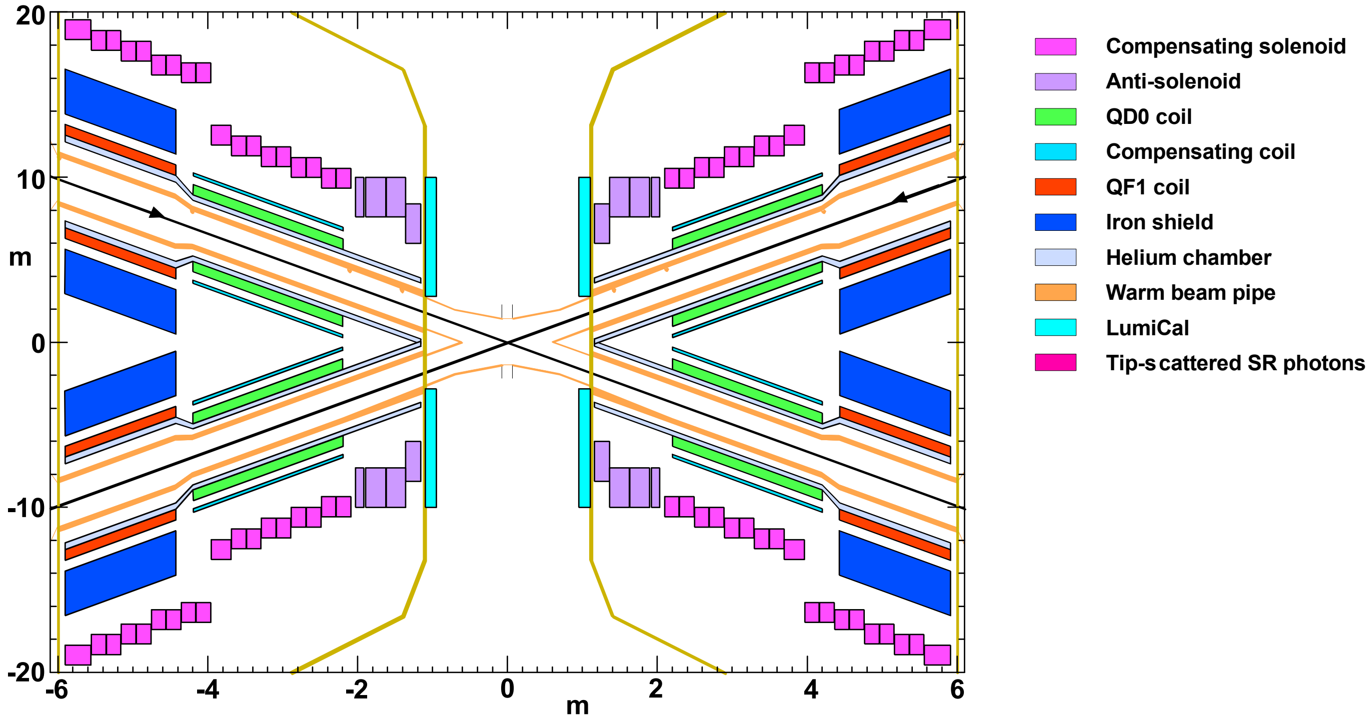


MDI Layout and IR Design

With Detector solenoid



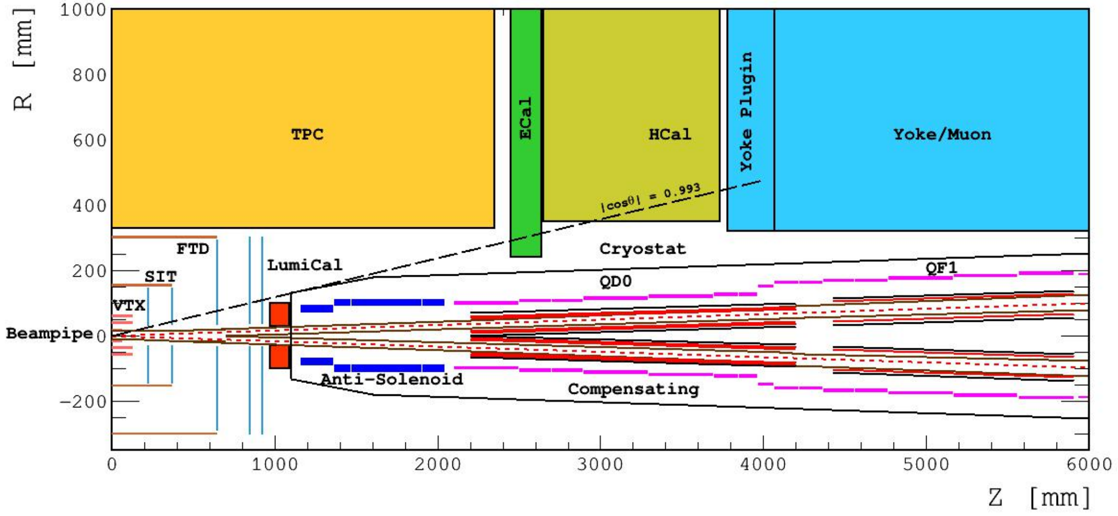
Without Detector solenoid ~cryostat in detail

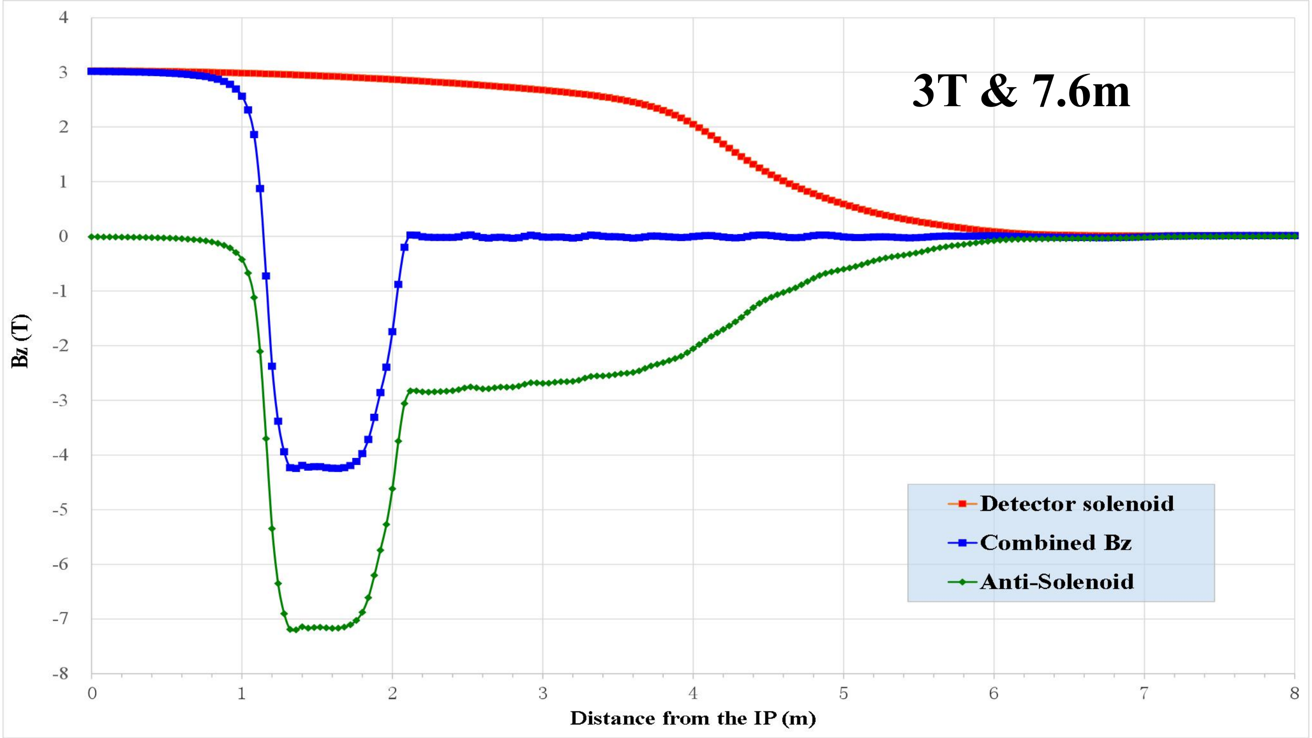


- The accelerator components inside the detector without shielding are within a conical space with an opening angle of cosθ=0.993.
- The e+e- beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is 2.2m
- Lumical will be installed in longitudinal 0.95~1.11m, with inner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

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.

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		

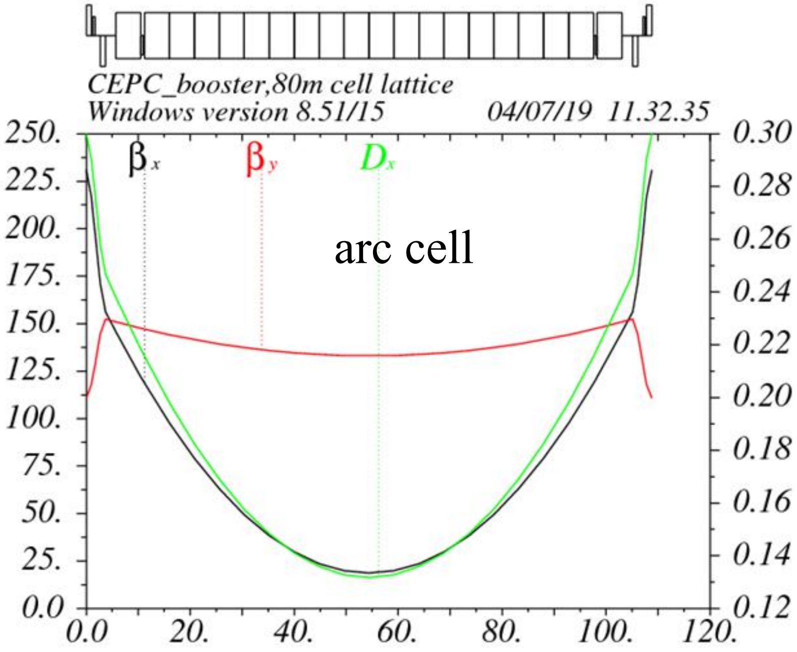
		H		W	Z(3T)	Z(2T)
Extraction		Off axis injection	On axis injection	Off axis injection	Off axis injection	
Beam energy	GeV	120		80	45.5	
Bunch number		242	235+7	1524	6000	
Maximum bunch charge	nC	0.72	24.0	0.58	0.41	
Maximum single bunch current	μA	2.1	70	1.7	1.2	
Threshold of single bunch current	μA	77.33				
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	

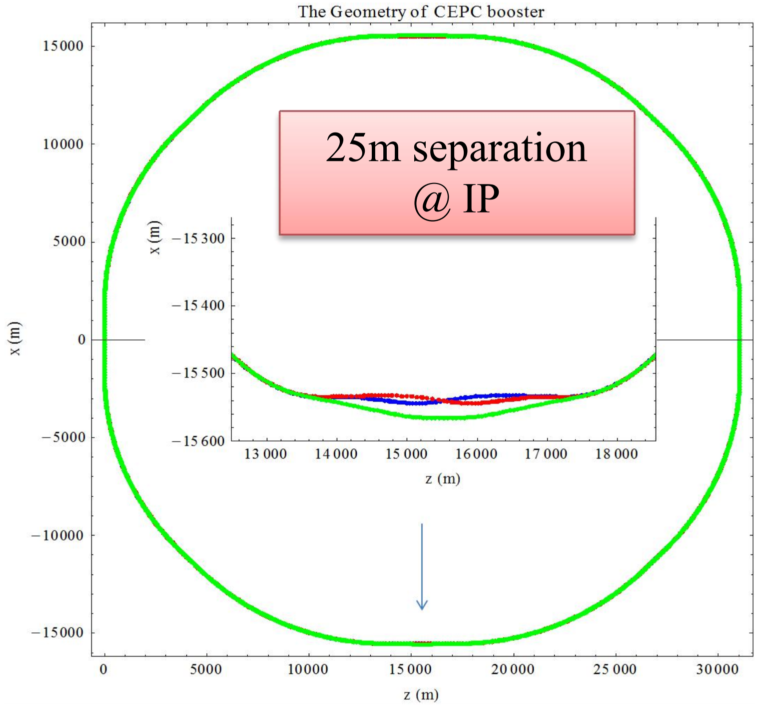
New Booster Design based on TME Lattice after CDR

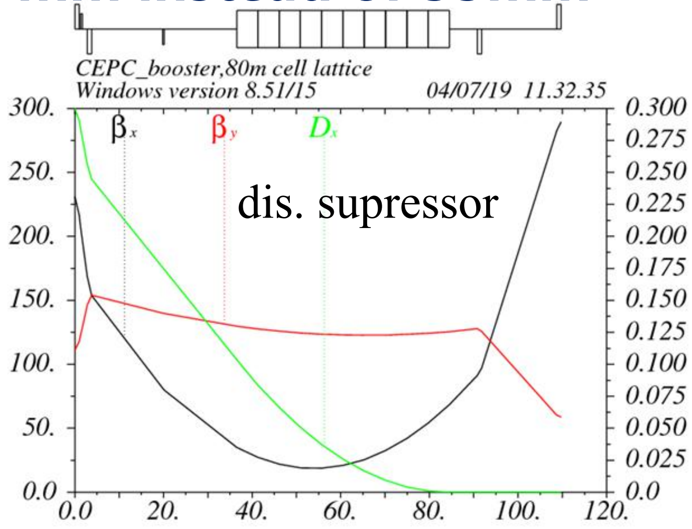
The emittance of booster is reduced from 3.6nm to 1.2nm

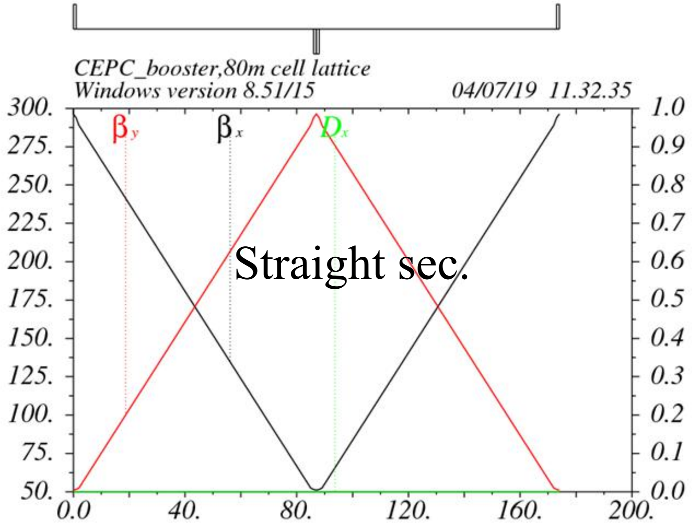
Inner aperture of the vacuum chamber is chosen to be 44 mm instead of 55mm

- emittance=**1.29nm** @120GeV
- TME lattice
- Cell length: 110m
- Interleave sextupole scheme









CEPC Booster SRF Parameters

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

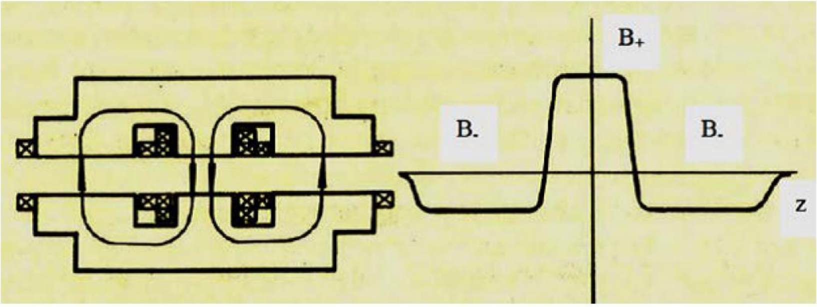
CEPC Self Polarization at Z-pole with Asymmetric Wigglers

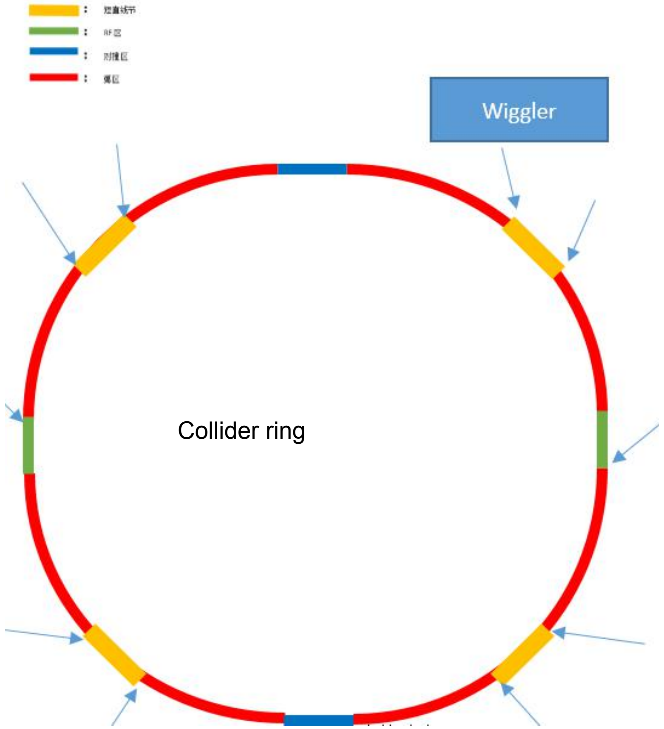
- **Special wigglers to speed up self-polarization:**

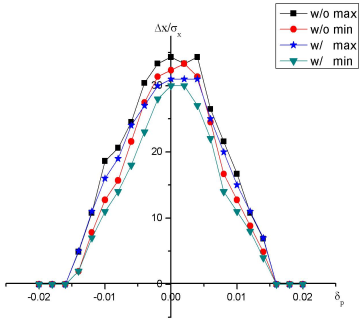
N_w	B_+	L_+	B_-	L_-	$\frac{\tau_p}{\tau_p^w}$	u	$\frac{\Delta E_w}{\Delta E}$	$\frac{P_0^w}{P_0}$
10	0.6T	1m	0.15T	2m	13.4	0.34	3.2	0.99

In collaboration with Sergei Nikitin of BINP

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







DA

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

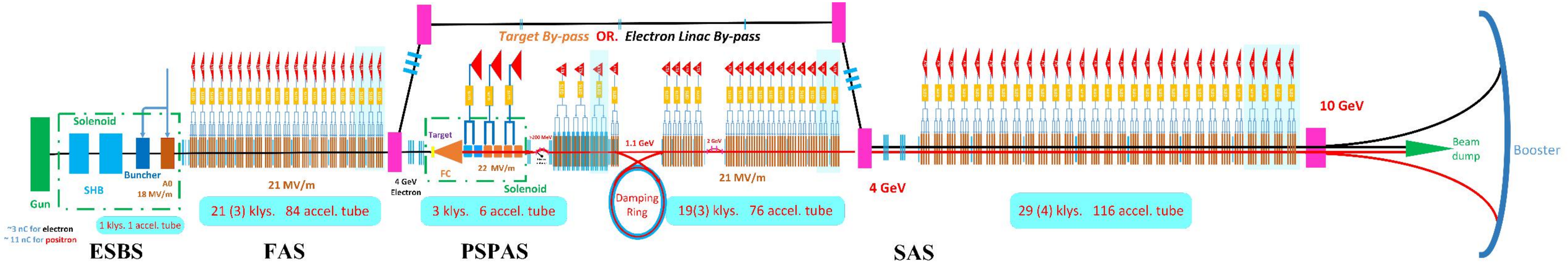
$$\tau_p^w = 19.6h,\ P(t) = 5\%,\ P_0^w = 0.913,$$

$$t = 1.10h$$

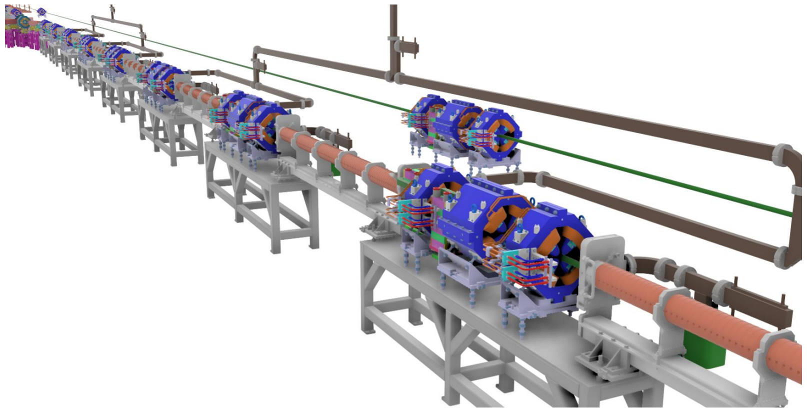
5% is enough for energy calibration.

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

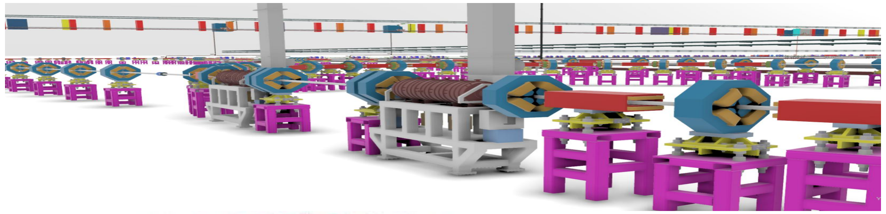
CEPC Linac Injector

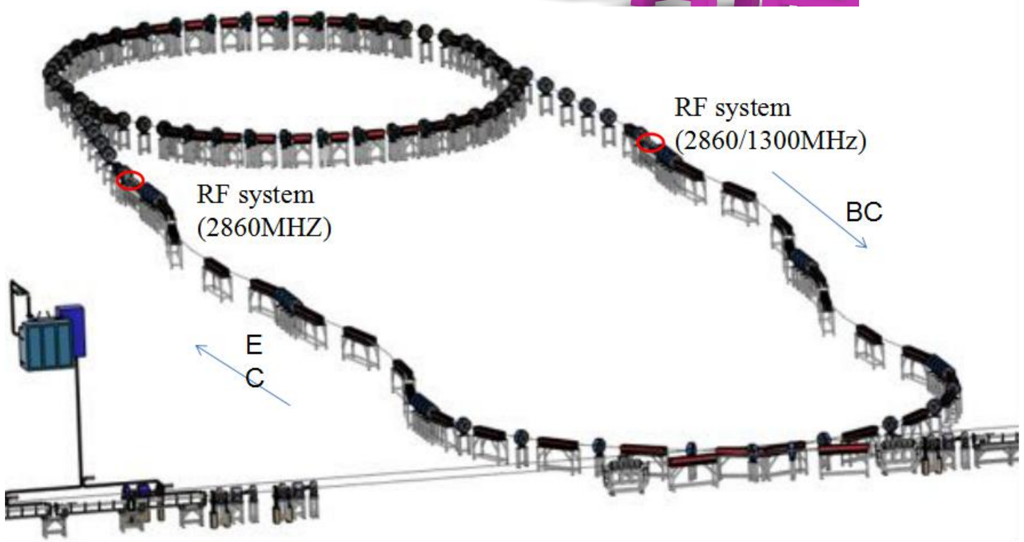


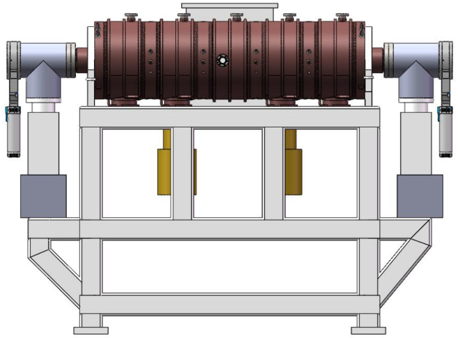
Parameter	Symbol	Unit	Baseline	Design reached
e^- /e^+ beam energy	E_{e-}/E_{e+}	GeV	**10**	**10**
Repetition rate	f_{rep}	Hz	**100**	**100**
e^- /e^+ bunch population	N_{e-}/N_{e+}		$> 9.4\times10^9$	**1.9×10^{10} / 1.9×10^{10}**
		nC	**> 1.5**	**3.0**
Energy spread (e^- /e^+)	σ_e		**$< 2\times10^{-3}$**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



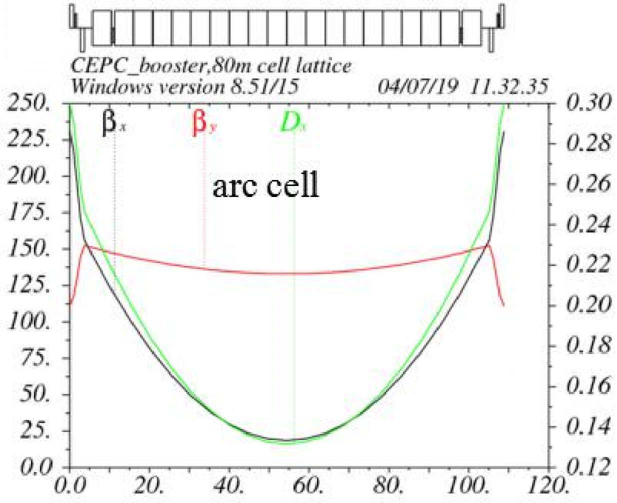
Design of Damping Ring System

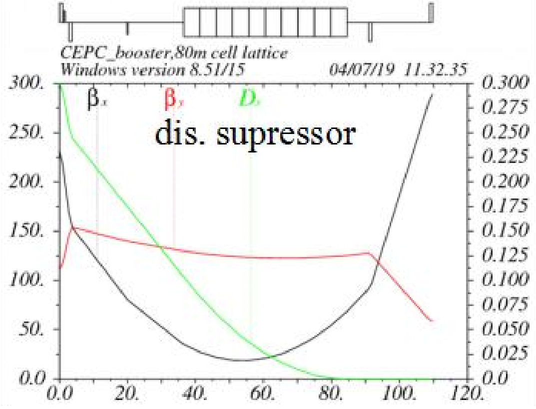


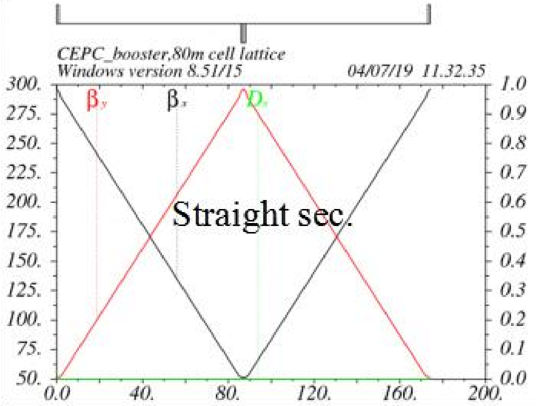




- emittance=**1.29nm** @120GeV
- TME lattice
- Cell length: 110m
- Interleave sextupole scheme

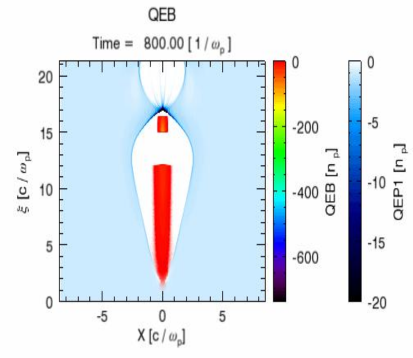


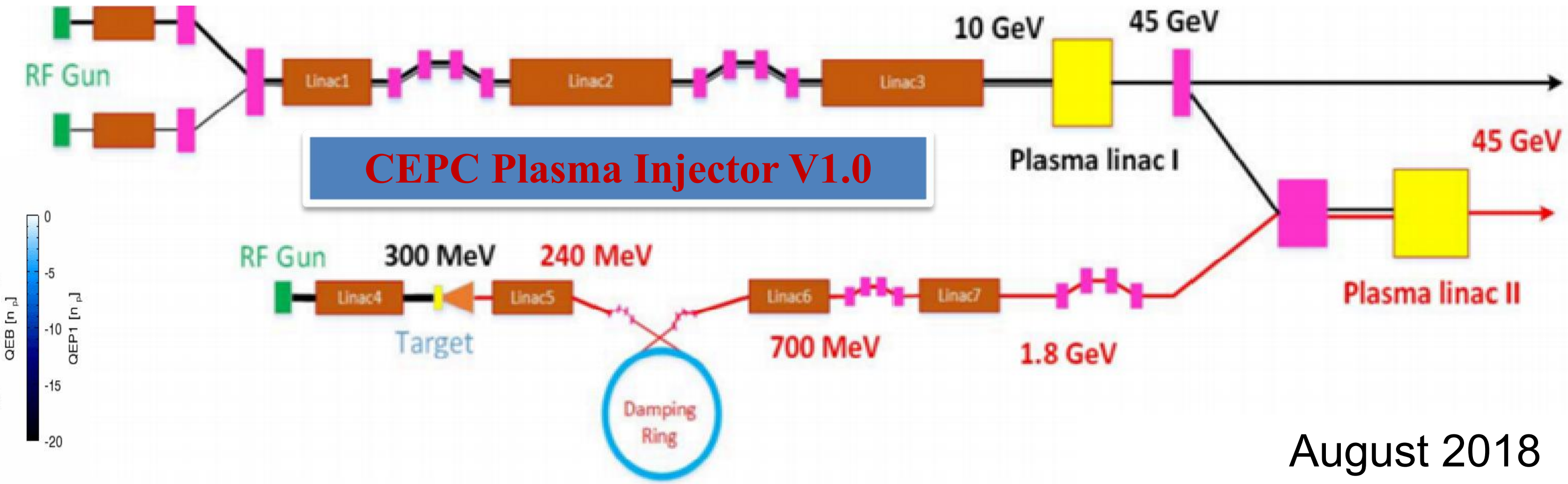




parameters	damping ring for SuperKEKB	damping ring for CEPC
Energy	1.1Gev	1.1Gev
circumference	135.5	75.4
Beta tune	8.24/7.265	3.84/4.81
Bunch lenght	11.12mm	5mm
Bunch number	4	2
synchtron tune	0.0153	0.062
Beam current	70 mA	10 mA

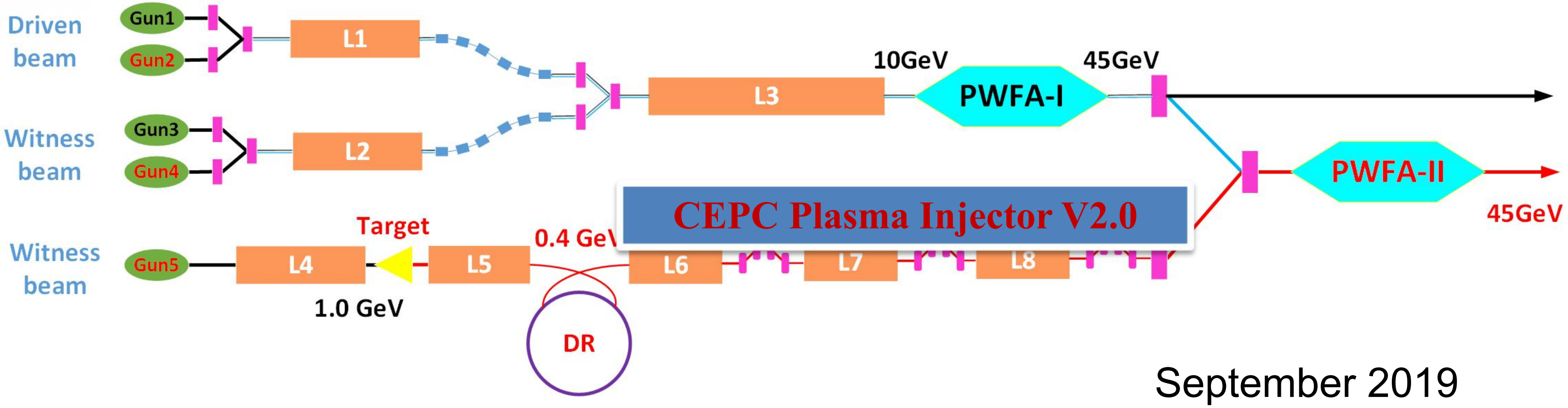
Conceptual Design for CEPC Plasma Injector: V1.0→V2.0 (Alternative injection scheme)





August 2018

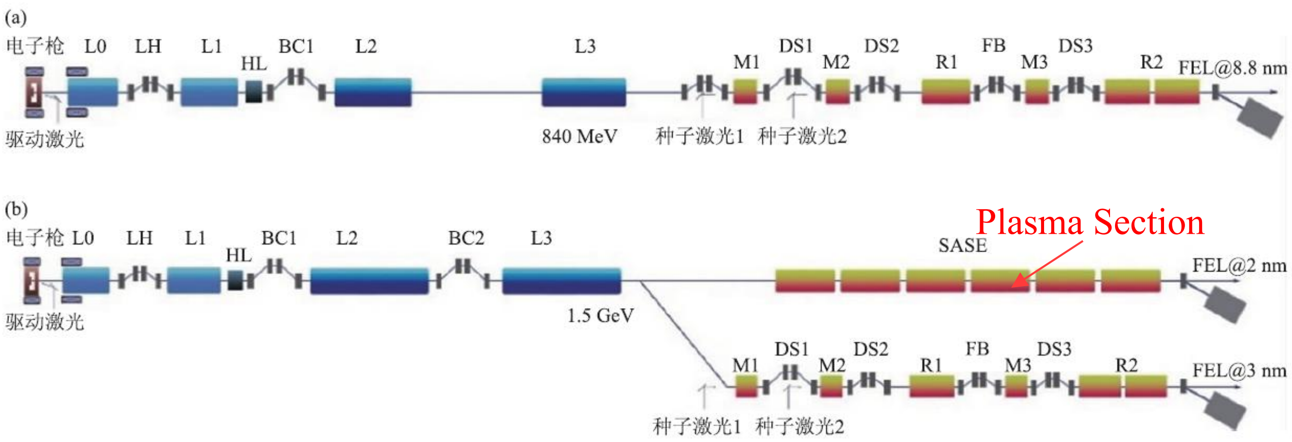
Technical design review has been done (August 22,2019)

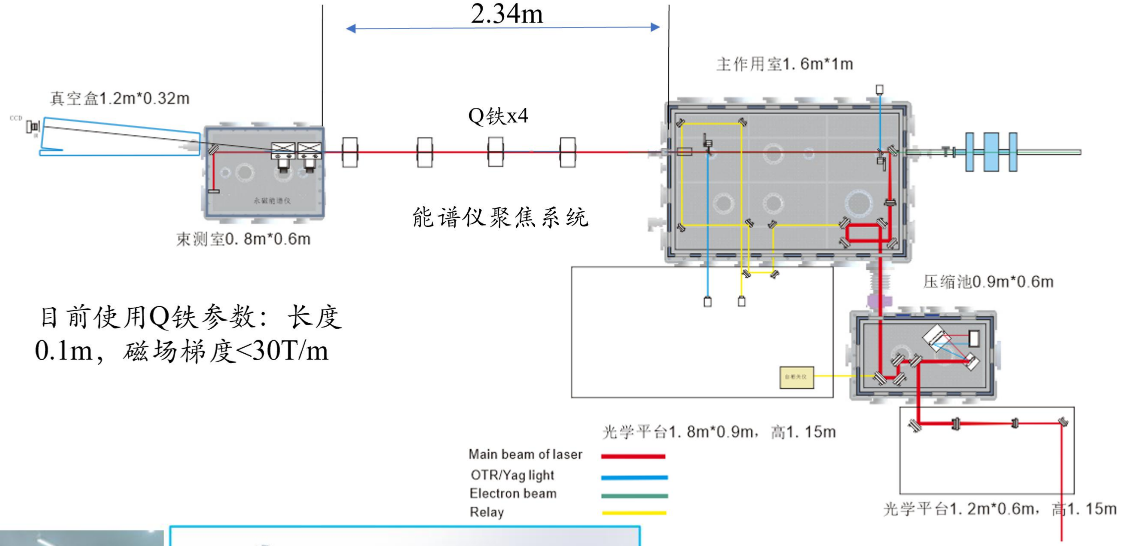


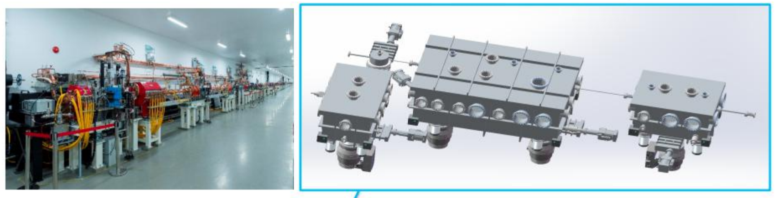
September 2019

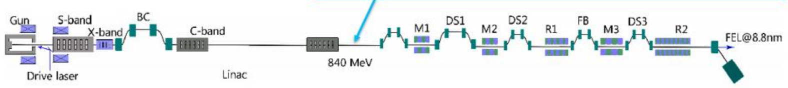
- **Electron plasma acceleration will be tested in Shanghai's Soft XFEL Facility**
- **Positron plasma acceleration scheme might be tested at FACET-II at SLAC**

Plasma Dechirper & HTR Experiment Preparation@ SXFEL









Parameter	Value
Energy	0.8GeV
Charge	50pC
Emittance	0.8µm
Beam size	10µm
Peak current	2.4kA
Energy Chirp	~8MeV

Dechirper experiment schedule

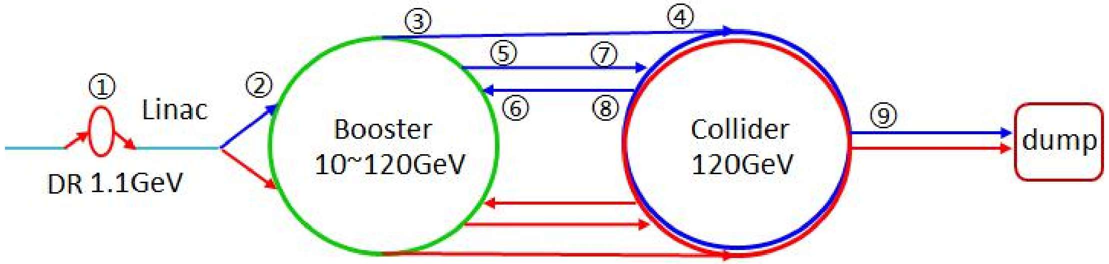
- First step: Obtaining a stable positively-chirped beam with few percent energy spread
- Second step: Post-processing the beam using a passive dechirper

Requirment of Booster to Plasma Injector(@45.5GeV)

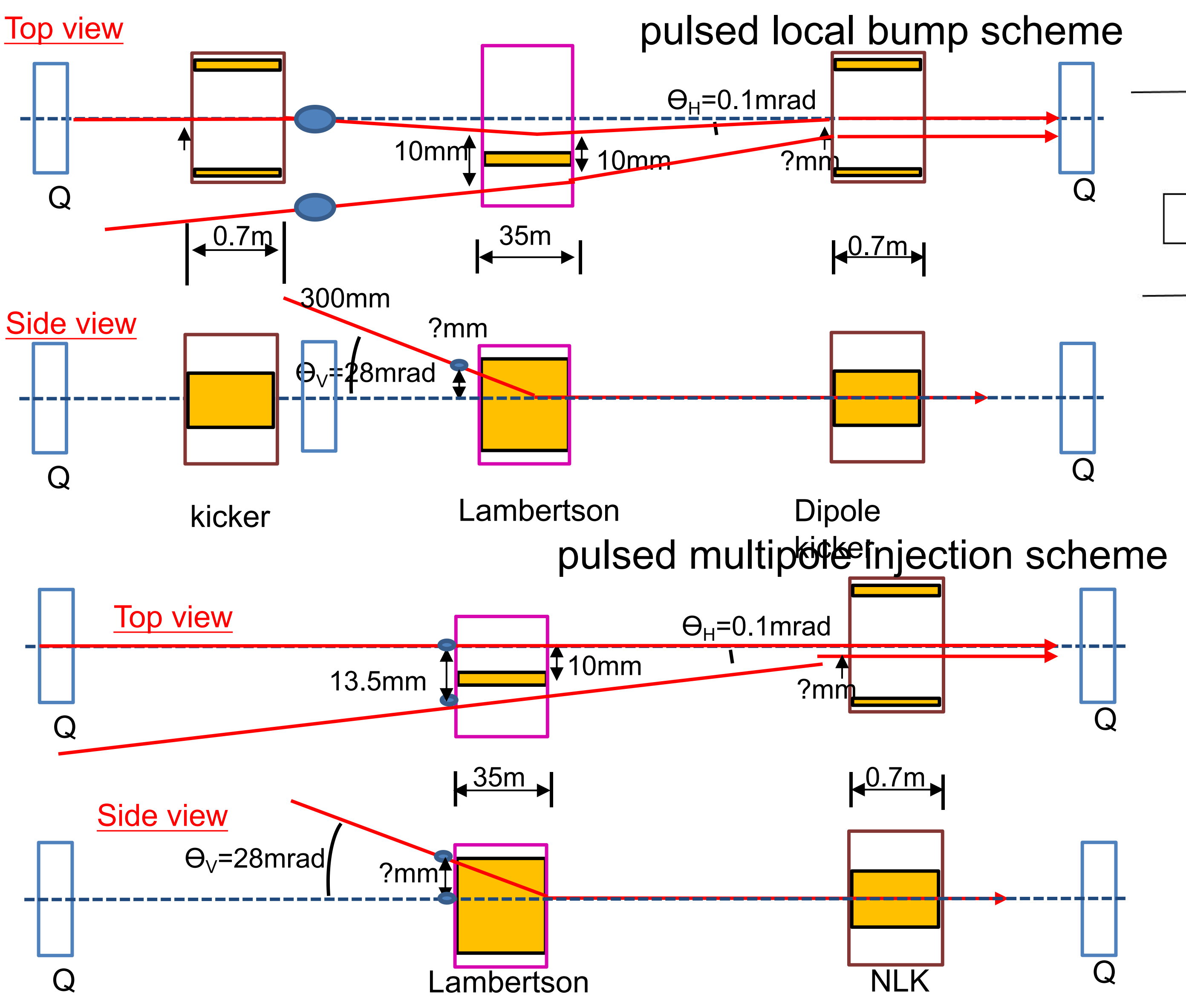
Parameter	Symbol	Unit	Requirement	Realized
e^- /e^+ beam energy	E_{e-}/E_{e+}	GeV	**45.5**	**45.3(-)/45.2(+)**
frequency	f_{rep}	Hz	**100**	**100**
e^- /e^+ bunch population	N_{e-}/N_{e+}	nC	**> 1.0**	**1.0(-)/1.0(+)**
Energy spread (e^- /e^+)	σ_e		**$< 2\times 10^{-3}$**	**0.002(-)/0.0014(+)**
Emittance (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**	

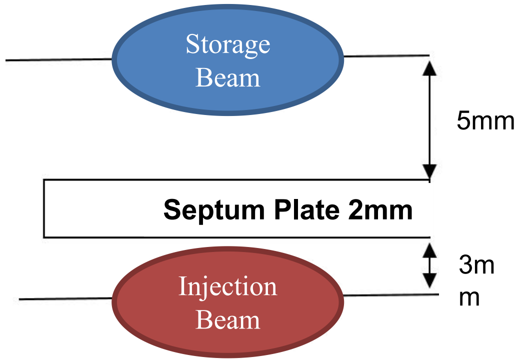
CEPC Injection and Extraction Systems

	Sub-system	Kicker Type	Kicker waveform	Septa Type
1	Damping ring inj./ext.	Slotted-pipe kicker	Half-sine/250ns	Horizontal LMS
2	Booster LE inj.	Strip-line kicker	Half-sine/50ns	Horizontal LMS
3	Booster ext. for CR off-axis inj.	Delay-line dipole kicker	Trapezoid /440-2420ns	Vertical LMS
4	Collider off-axis inj.	Delay-line NLK kicker	Trapezoid /440-2420ns	Vertical LMS
5	Booster ext. for CR on-axis inj.	Ferrite core dipole kicker	Half-sine/1360ns	Vertical LMS
6	Booster HE inj.	NLK or Pulsed sextupole	Half-sine/0.333ms	Vertical LMS
7	Collider swap out inj.	Ferrite core dipole kicker	Half-sine/1360ns	Vertical LMS
8	Collider swap out ext.	Ferrite core dipole kicker	Half-sine/1360ns	Vertical LMS
9	Collider beam dump	Delay-line dipole kicker	Trapezoid /440-2420ns	Vertical LMS
10	RF region beam separating	Delay-line dipole kicker	CW square / 165us,50%	Horizontal Copper septa

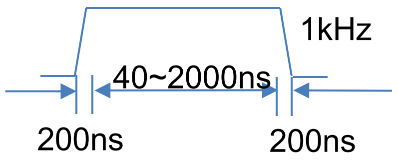


Collider Ring off-axis Injection





1. **Dipole kicker:** horizontal out-vacuum delay-line kicker+coating ceramic chamber+PFN-based solid-state pulser
2. **NLK kicker:** horizontal out-vacuum delay-line **NLK** kicker+coating ceramic chamber+PFN-based solid-state pulser
3. **Septa:** Vertical Lambertson magnet

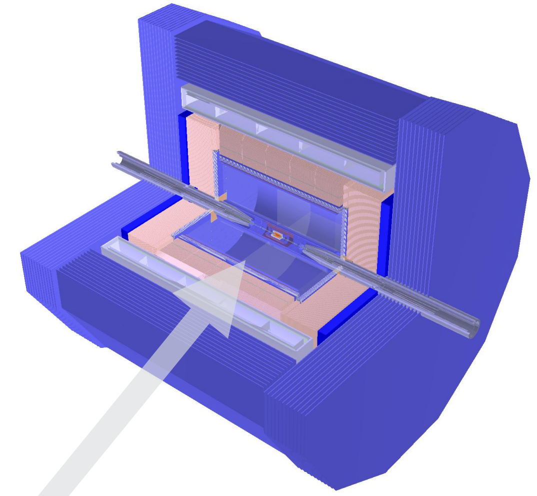


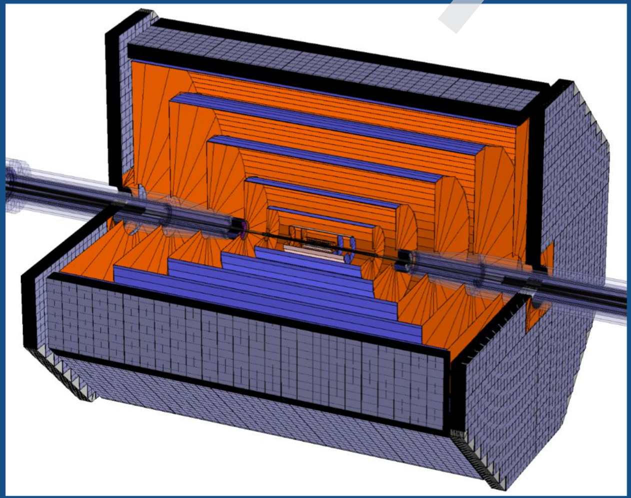
CEPC Detector Concepts included in CDR

CEPC plans for
2 interaction points

Particle Flow Approach

ILD-like
TPC-based dete
(3 Tesla)

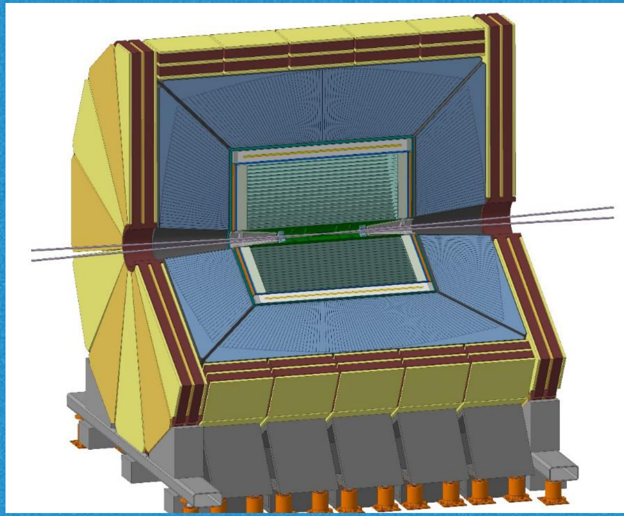




Full silicon
tracker
concept

IDEA Concept
also proposed for FCC-ee

Low
magnetic field
concept
(2 Tesla)



Joao Guimaraes da Costa

Final two detectors likely to be a mix and match of different options

CEPC TDR R&D Plan and Status

CEPC Accelerator R&D Priority

1) CEPC 650MHz 800kW high efficiency klystron (80%) (No commercial products)

2) High precision booster dipole magnet (critical for booster operation)

3) CEPC 650MHz SC accelerator system, including SC cavities and cryomules

4) Collider dual aperture dipole magnets and dual aperture qudrupoles

5) Vacuum chamber system

6) SC magnets including cryostate

7) MDI mechanic system

8) Collimator

9) Linac components

10) Civil engineering design

11) Plasma injector

12) 18KW@4.5K cryoplant (Company)

Main On-going CEPC Detector R&D Activities

Tracking

Time Projection Chamber
Silicon Vertex Detector

Drift Chamber
Muon detectors - RPC, μRwell

Solenoid design

Machine Detector Interface

Calorimetry

High Granularity Calorimeter:
ECAL with Silicon and Tungsten
ECAL with Scintillator+SiPM and Tungsten
SDHCAL with RPC and Stainless Steel
SDHCAL with ThGEM/GEM and Stainless Steel
HCAL with Scintillator+SiPM and Stainless Steel

Dual Readout Calorimeter
Crystal Calorimeter

LumiCal

Funding from MOST, NSFC, CAS, INFN, and collaboration with international partners

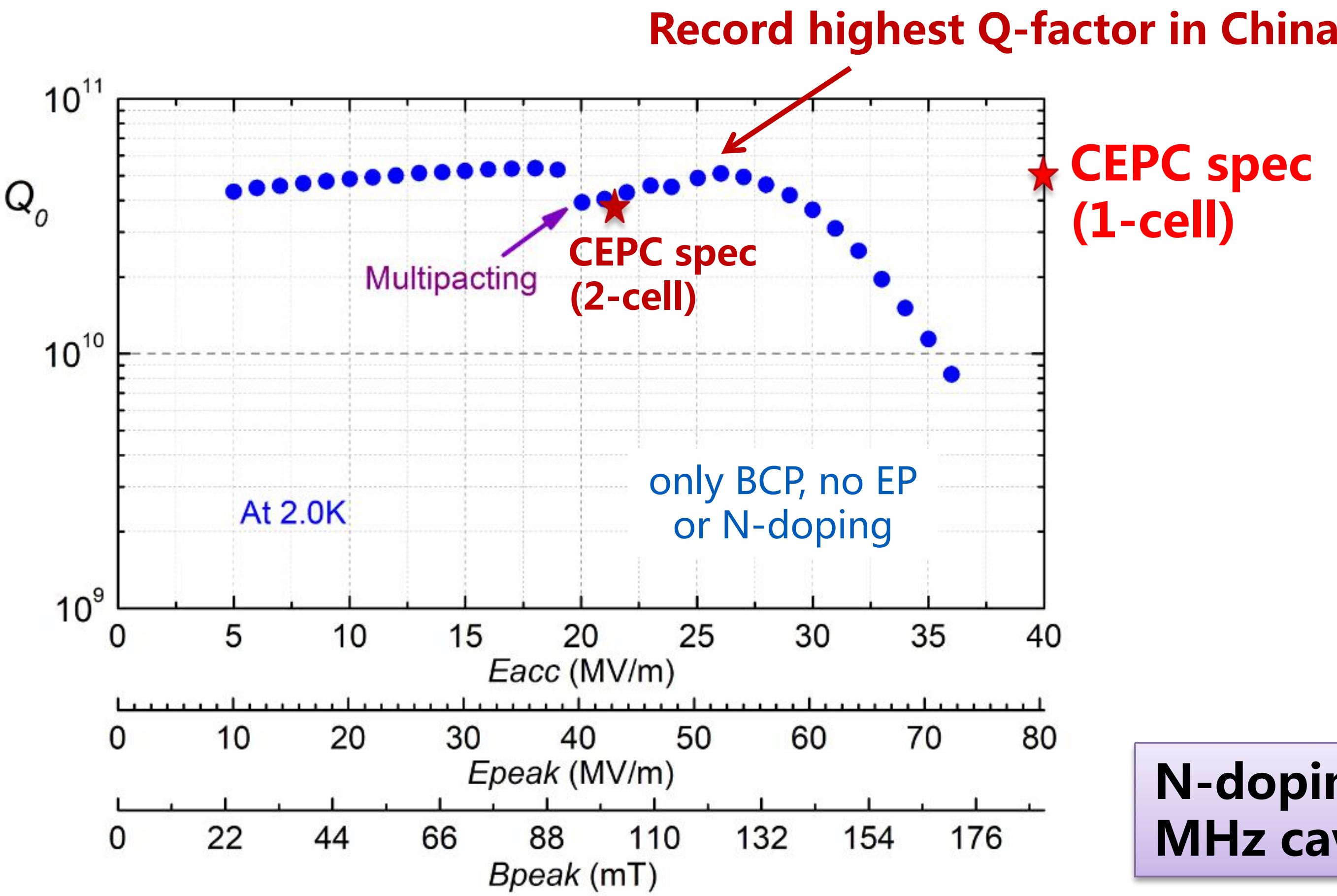
International Detector R&D Committee formed to evaluate research proposals
(First meeting November 2019)

CEPC R&D Status

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.

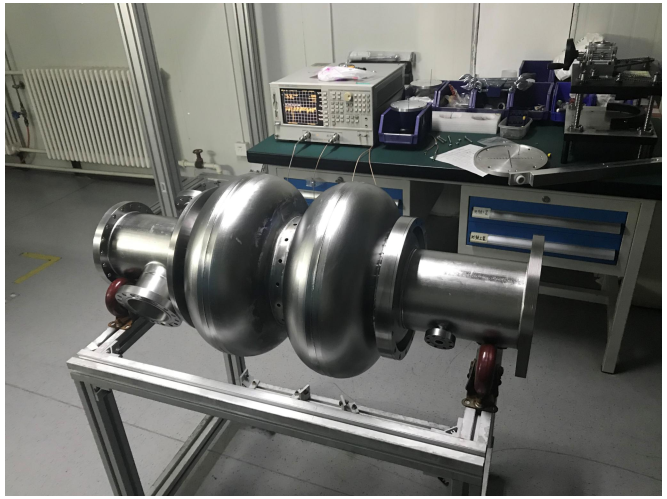


650 MHz 1-cell

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

650 MHz High Gradient High Q Cavity

- Previous 650 MHz single cell and 2-cell cavities reached max 36 MV/m and high Q.
- EP and N-doing development now focusing on 1.3 GHz and then apply to 650 MHz.
- PAPS large SRF lab and enabling advanced facilities will soon boost CEPC cavity R&D.

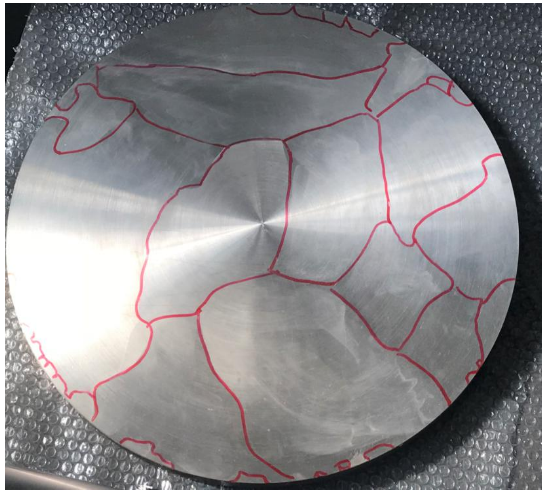


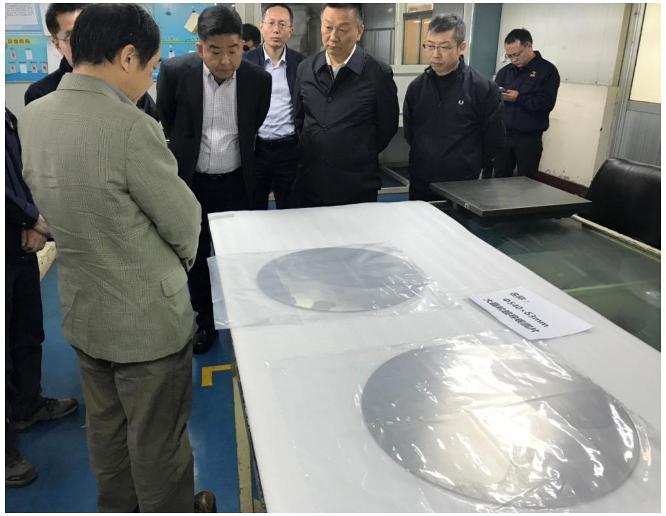
Three fine grain 650 MHz 2-cell cavities fabricated and processed (BCP). Soon to do vertical test, helium vessel weld and vertical test with HOM couplers. Two of them will install to the test cryomodule for horizontal test and beam test in 2020. Cavity helium vessel and tuner in fabrication.

Four large grain 650 MHz cavities for high gradient high Q study. Processed with BCP. Vertical test soon. EP and possible CBP later.

650 MHz 1-Cell Cavity (Large Grain)

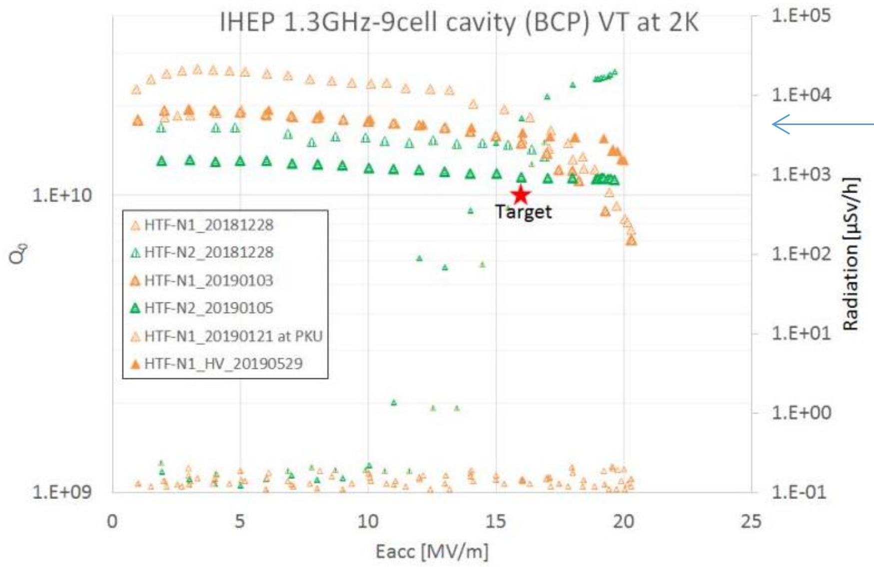
- 650 MHz 1-cell cavity (large grain) is favorable for HL-Z, which have higher Q and gradient than fine grain.
- Target of Vertical test: **5E10 @ 42MV/m at 2.0 K**.
- Four cavities are under fabrication now, which will be tested in the middle 2019.



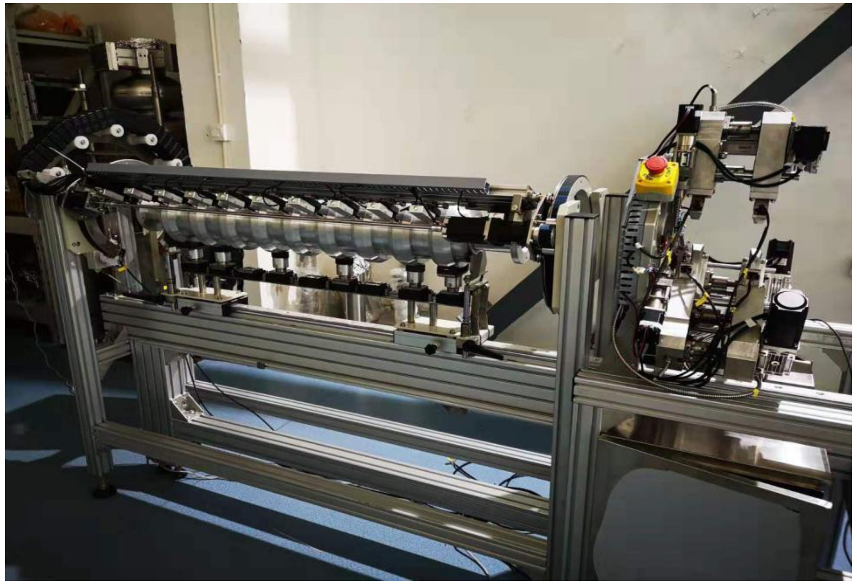


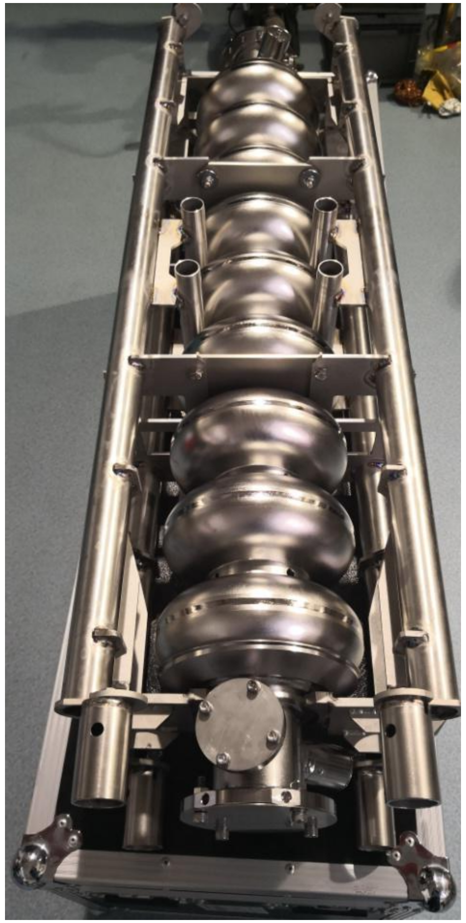
Large grain Nb sheets made by OTIC

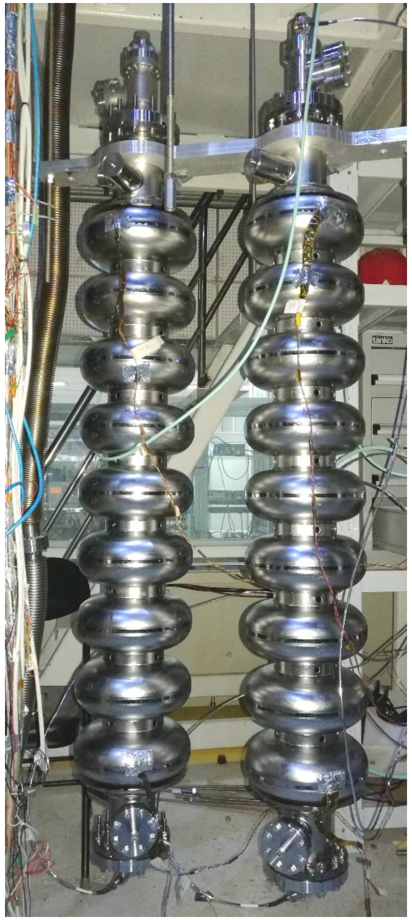
IHEP SHINE 1.3 GHz 9-cell Cavities (BCP)

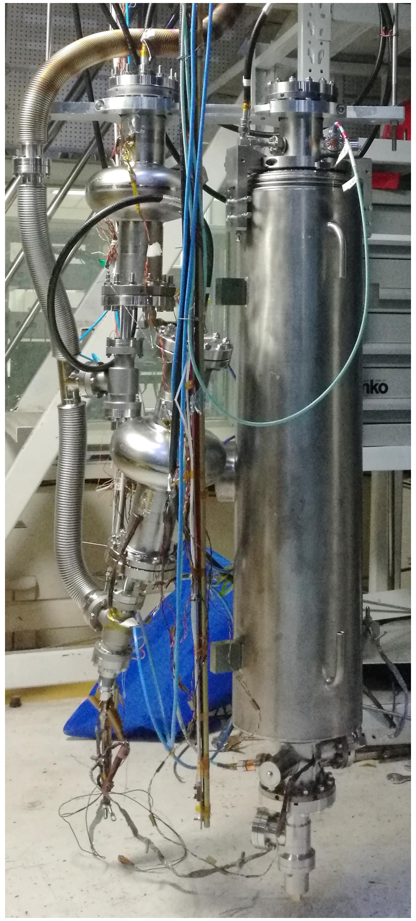


IHEP made 1.3GHz 9cell cavity reaches the goal of SHINE



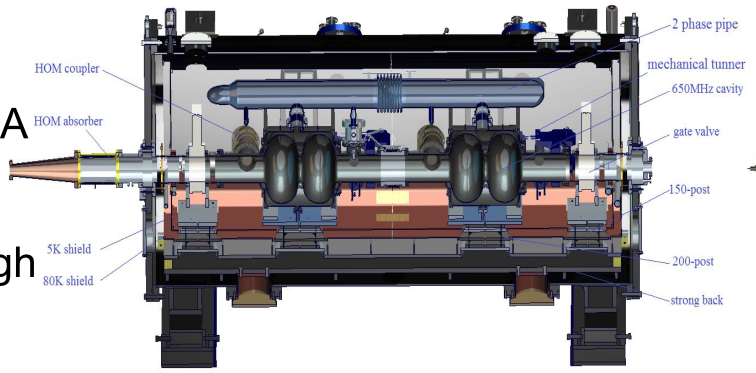


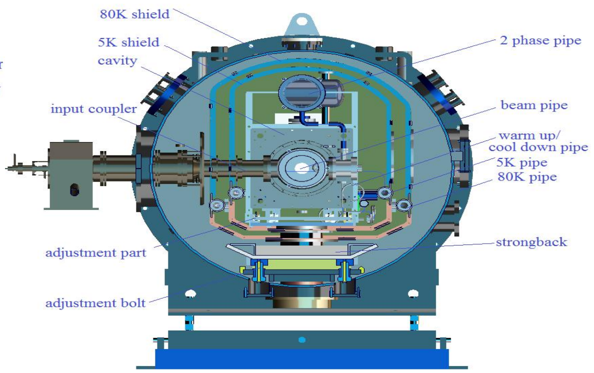




650 MHz Test Cryomodule with Beam（ 2 x 2-cell Model ）

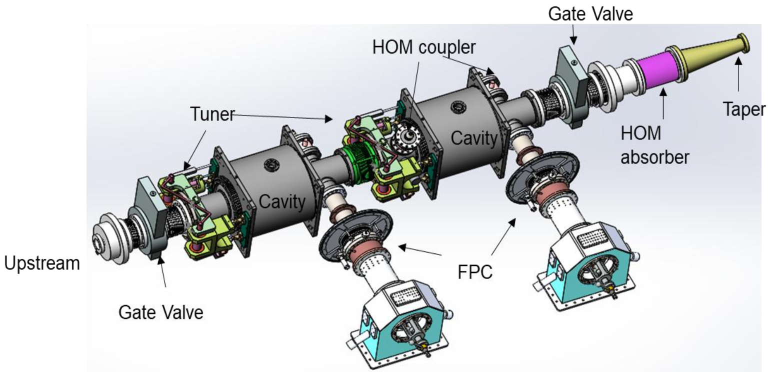
- Two 650 MHz 2-cell cavities with input couplers, HOM couplers and absorbers, tuners etc.
- Module assembly and 15 MeV beam test with 1 ~ 10 mA from DC photo-cathode gun in 2020.
- Demonstrate system integration and performance of high Q 650 MHz cavity (but with low input power and HOM power).



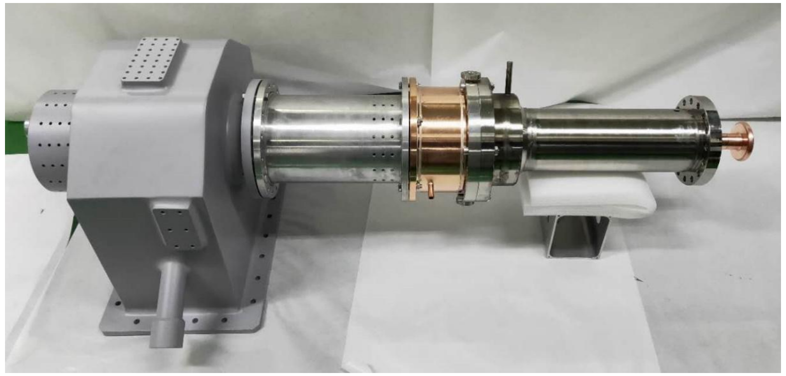


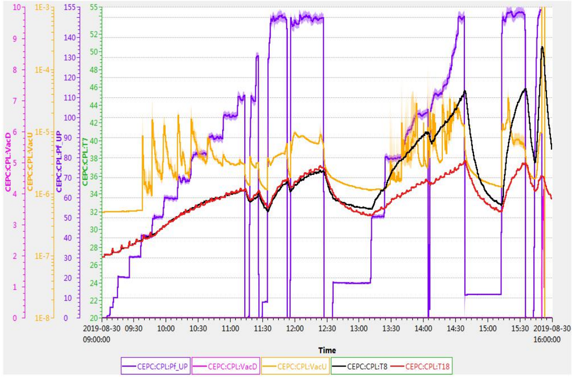
Cryomodule vacuum vessel and cold mass

Valve box

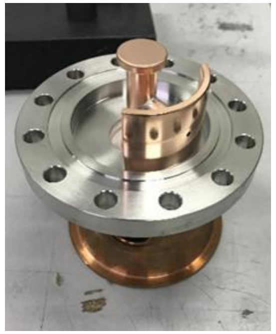


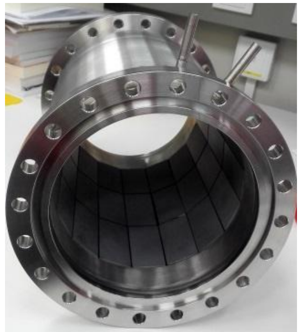
650 MHz High Power SRF Components





High power test of one 650 MHz fixed coupling input coupler reached 150 kW SW (corresponding to 400 kW TW at the window). Another coupler's window broke due to excess ceramic heating. New window and variable coupler in fabrication.





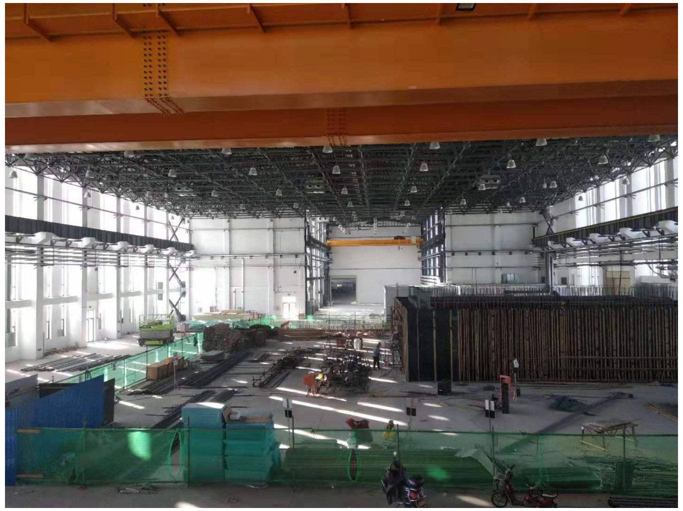
Four high power HOM couplers fabricated and low power tested. Three of them will mount on the 2-cell cavities. Vertical test soon with the cavity to verify the notch properties. High power test (1 kW) at cryogenic temperature planned.

Wideband high power HOM absorber with SiC+AlN material. 5 kW high power test planned.

IHEP New SC Lab under Construction (Status in Nov. 2019)

New SC Lab Design (4500m^2)

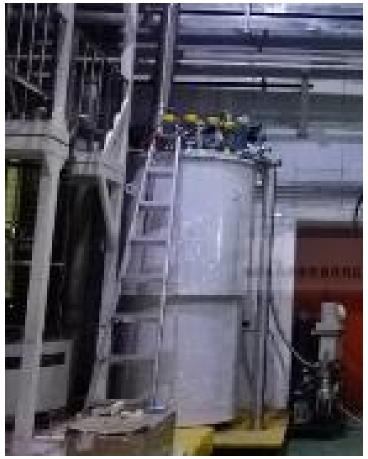
Bird view in Nov. 15, 2019



Experimental hall in Nov. 15, 2019

Hellium recirculating tanks

2.5KW@4.5Kcold box



2K JT heat exchanger

CEPC 650MHz High Efficiency Klystron Development

Programs:
1) Ajdisk
2) KlyC
3) CST

Collaborators:
Aaron Jensen (SLAC)

JinChi Cai (CERN)

S. Fukuda (KEK)

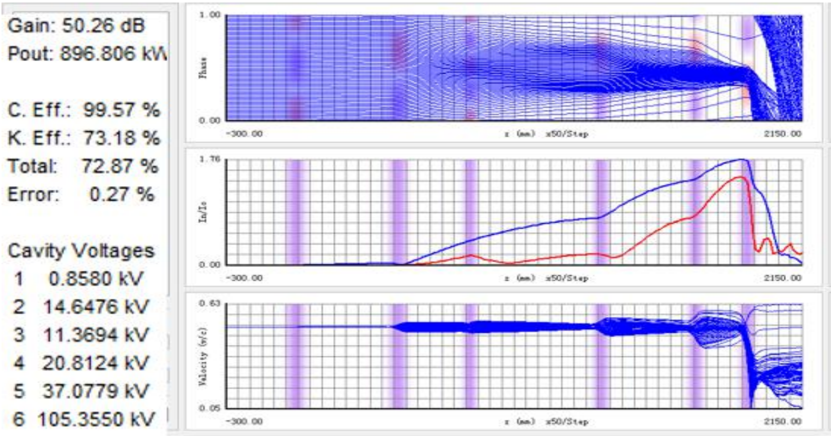
Abid Aleem

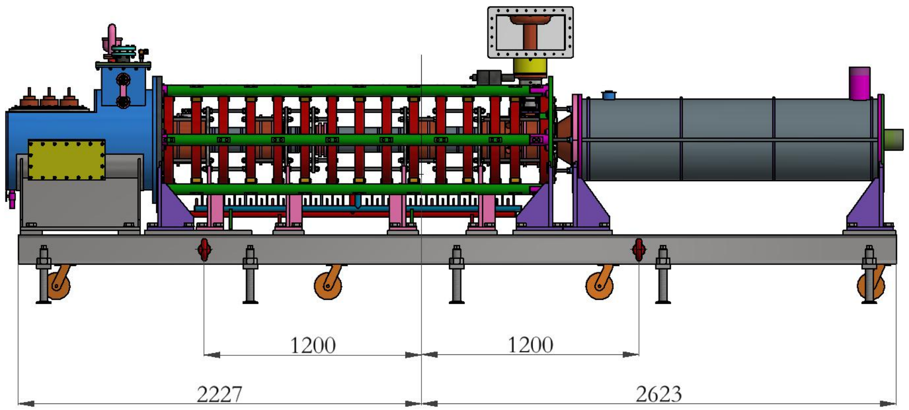
Munawar Iqbal (Bakistain)

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**





Mechanical design of conventional klystron

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

1st CEPC 650Mhz Klystron Prototype Manufacture

Prototype bake-out



Prototype installation

Top view

The prototype is installed on Oct.26 and finished bake out on Nov.24.

Packing and Transportation

Final state at factory

Packing

Loading

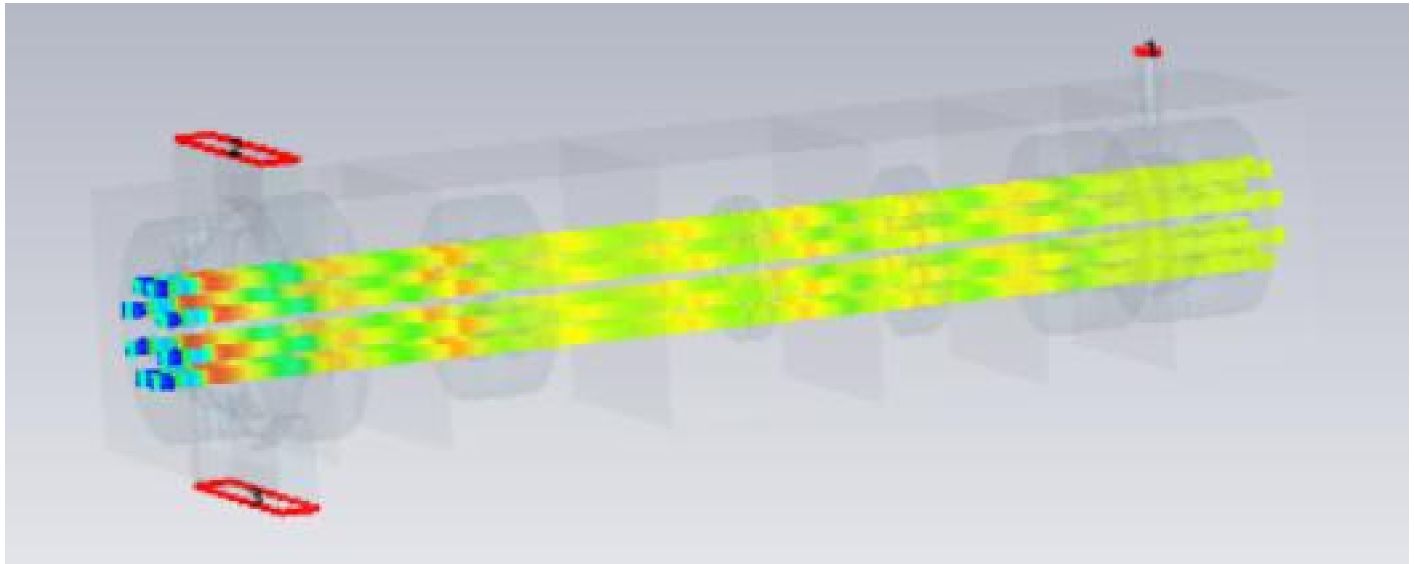
Leave factory on Dec.24, 2019

Arrived IHEP on Dec.25, 2019

In place at IHEP on Dec. 26, 2019

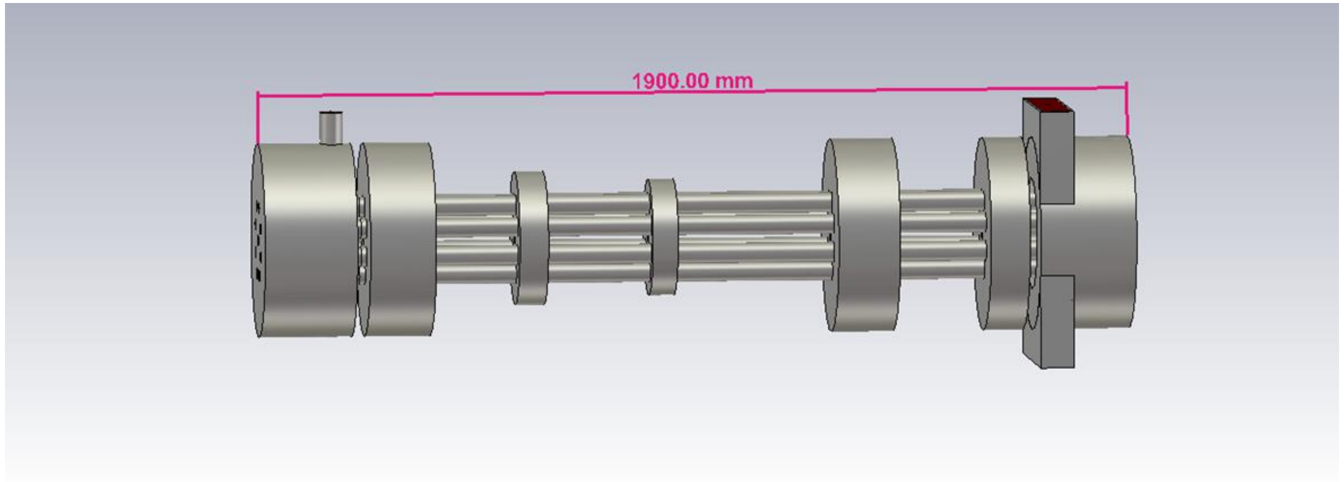
CEPC 650MHz High Effciency Multi-beam Klystron

Parameters	Unit	Value
Gun Voltage	kV	54
Beam number		8
Beam perveance	μP	0.2
Output power	kW	875
Gain	dB	44.2
Efficiency(3-D simulation)	%	80.7



MBK Length

Component	Unit	Value
RF interaction	m	1.9
Gun	m	0.5
Collector	m	1.0
Total	m	3.4



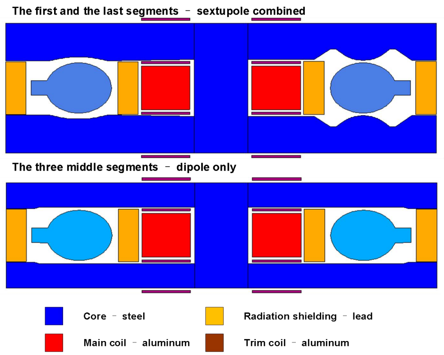
CEPC Collider and Booster Ring Conventional Magnets

China Astronotics Department 508 Institute participates CEPC magnets mechanical designs

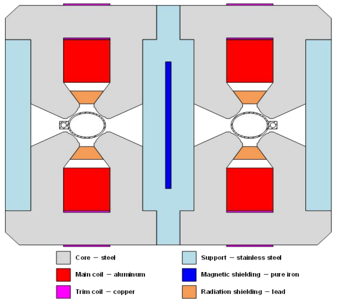
CEPC collider ring magnets

	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

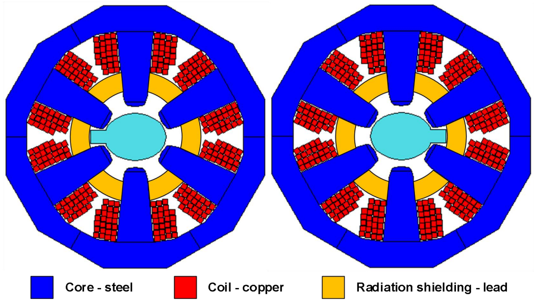
First short model magnets will be fnished in Nov, 2019



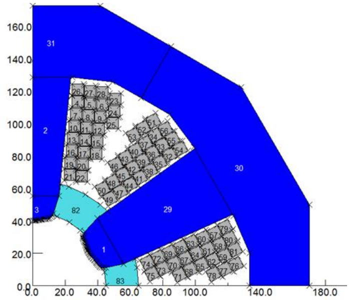
Dipole



Quadrupole



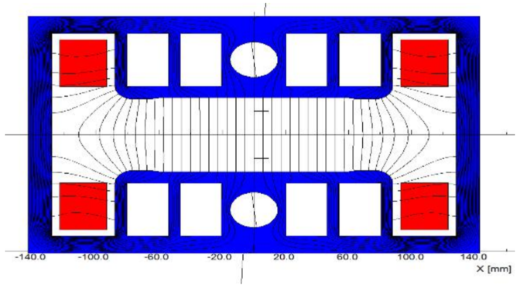
Sextupole

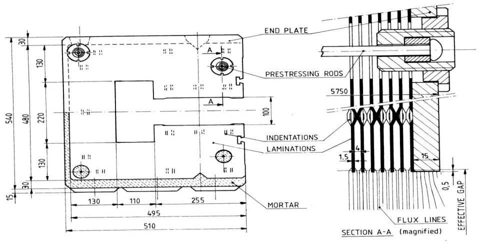


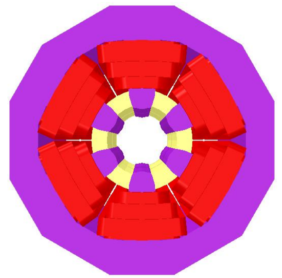
Booster ring low field magnets

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



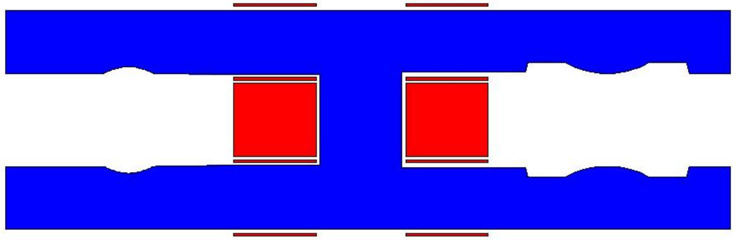




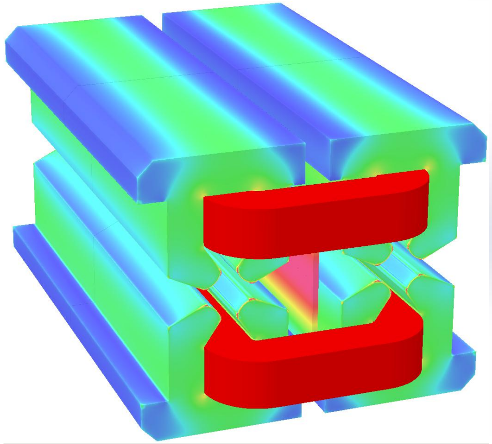
Sextupole

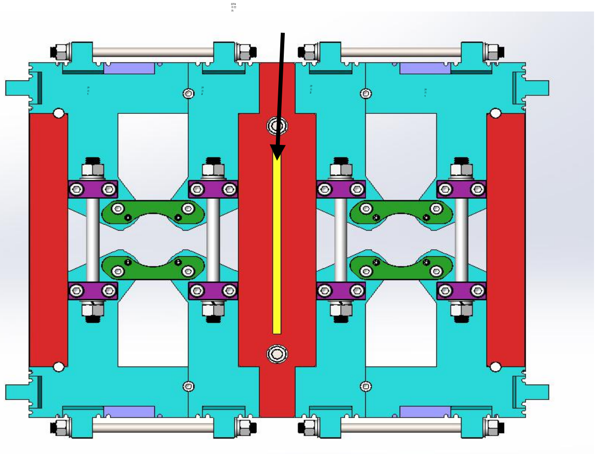
CEPC Collider Ring dual Aperture Dipole, Quadrupole and Sextupole Magnet Design Progress

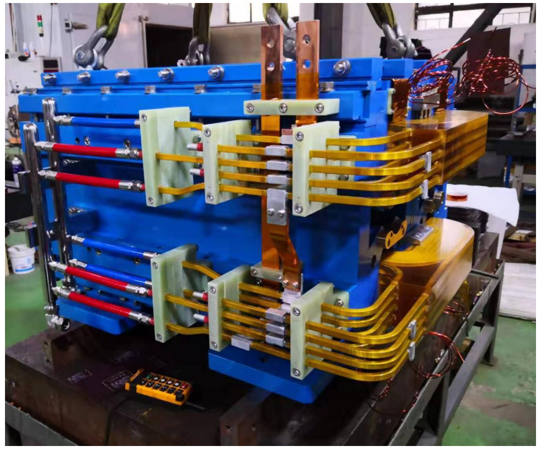
Technical design review has been done
(May 5, 2019)

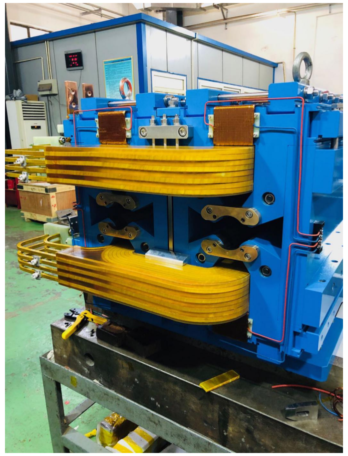


First dual aperture dipole test magnet of 1m long has been fnished in Nov, 2019









First dual aperture quadrupole magnet has been fnished in Nov, 2019

CEPC Low Field Booster Dipole Magntes' Specifications and Challenges

	BST-63B
Quantity	16320
Minimum field (Gs)	28
Maximum field (Gs)	338
Gap (mm)	63
Magnetic Length (mm)	4700
Good field region (mm)	55
Field uniformity	0.1%
Field reproducibility	0.05%

10GeV injection enegy fromlinac to 100Km booster

Challenges

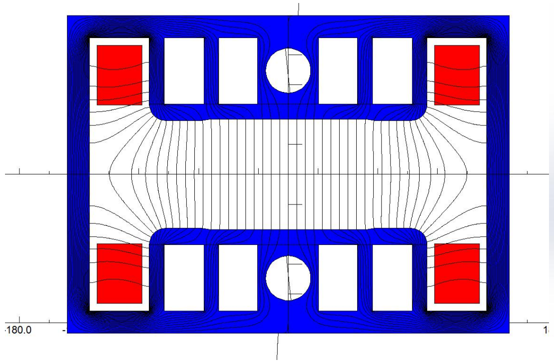
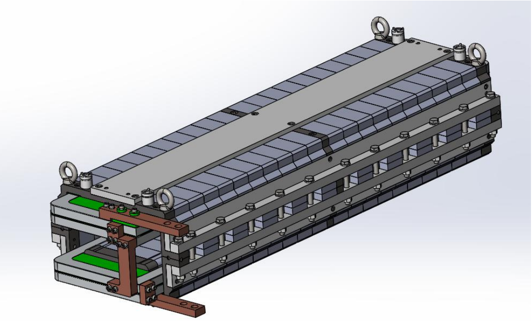
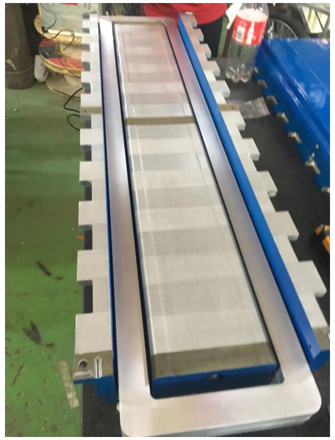
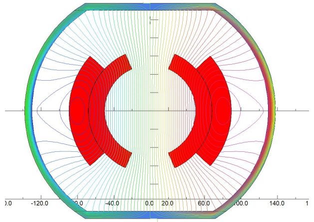
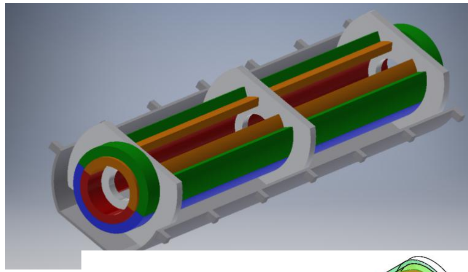
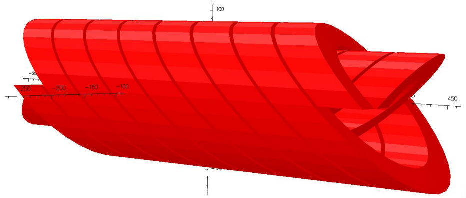
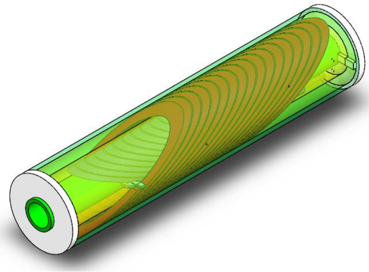
- Total length of the dipoles ~75km　　how to reduce cost
- Field error <29Gs*0.1%=0.029Gs　　how to design
- Field reproducibility<29Gs*0.05%=0.015Gs　　how to measure
- Magnet length ~4700mm　　how to fabricate

Booster High Precision Low Field Dipole Magnets

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

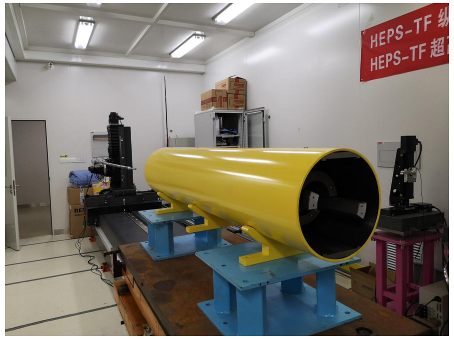
One kind of the dipole magnet with diluted iron cores is proposed and designed

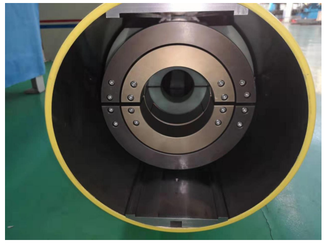
Two kinds of the dipole magnets without iron cores called Cos Theta (CT) and Canted Cos Theta (CCT) are proposed and designed

Baseline design

1m long test booster dipole magnet with iron core, completed in Nov. 2019

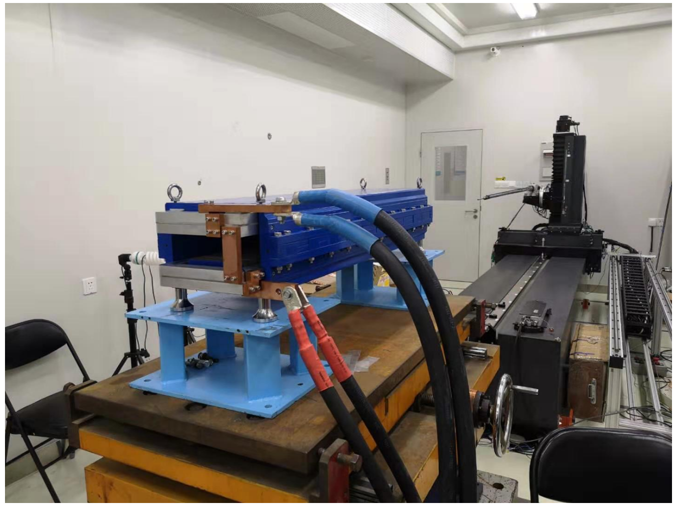


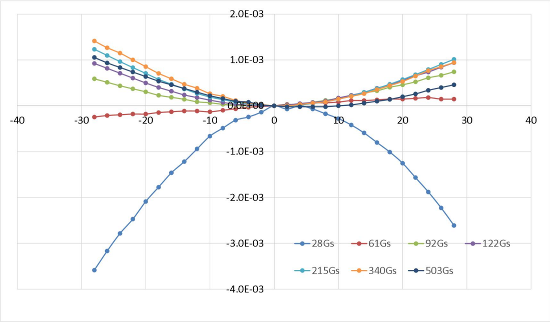


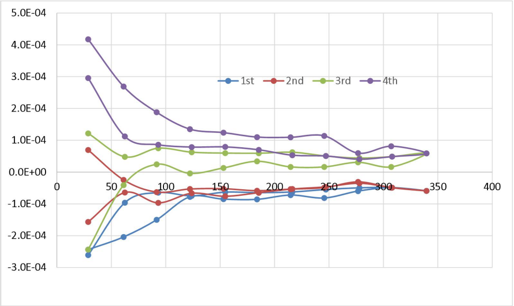
1m long test booster dipole magnet without iron core completed in Oct. 2019, under field measurement

Test of the subscale the Booster Dipole Magnets

1) Test of the dipole magnet with diluted iron core



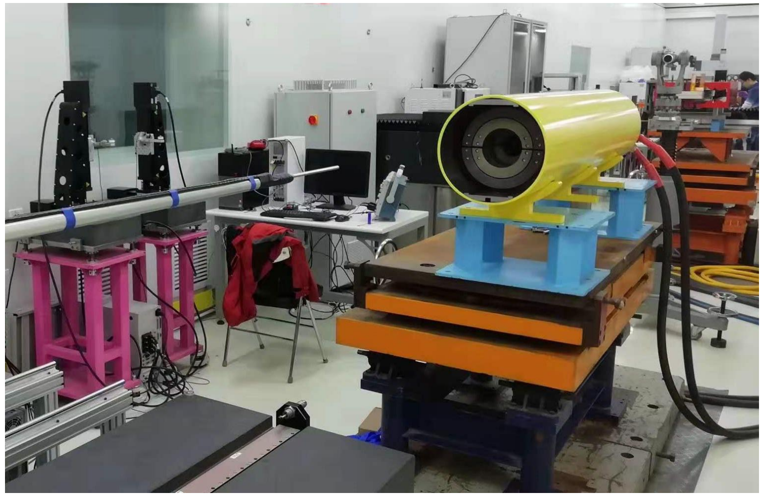


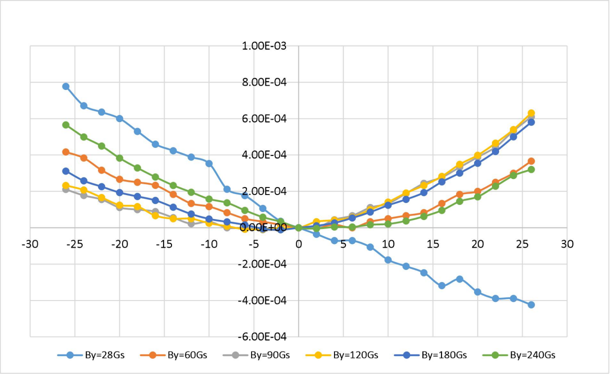


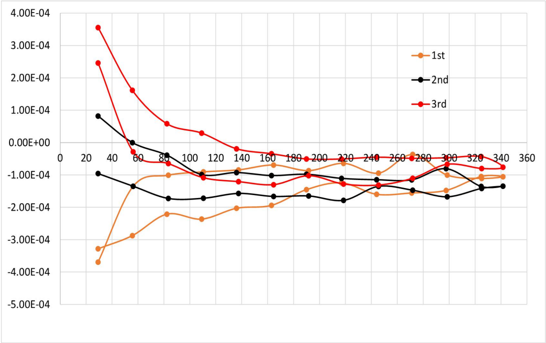
To be improved in the design, but with hope

Material is OK

2) Test of the CT coil dipole magnet without iron core







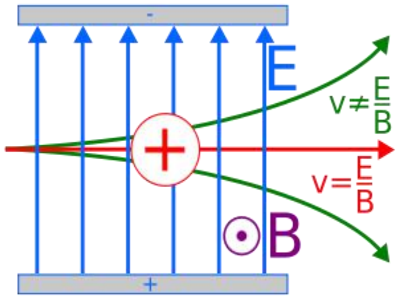
Satisfy design requirments

CEPC Collider Ring Electro-Magnet Separator

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

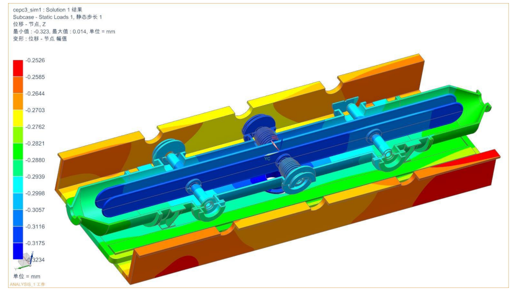
Challenges: To maintain E/B ration in fringe field region

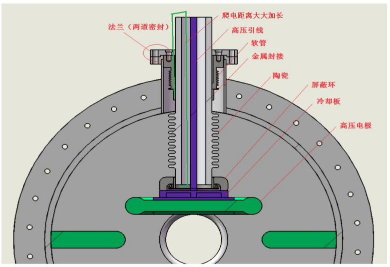
Reduce the impedance and loss factor of the separator



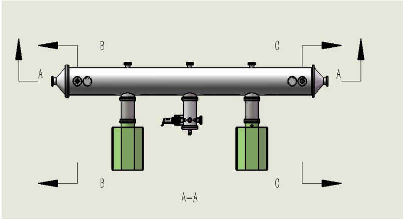
Technical design review has been done (Sept.3,2019)

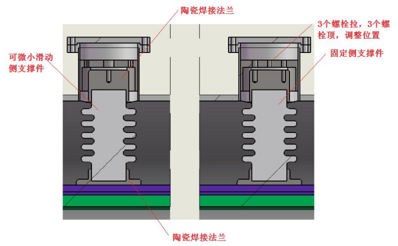
	Filed	Effective Length	Gap	Good field region	Stability
Electrostatic separator	2.0MV/m	4m	110mm	70mm x 30mm	5 x 10^{-4}
Dipole	66.7Gauss	4m	600mm	70mm x 30mm	5 x 10^{-4}

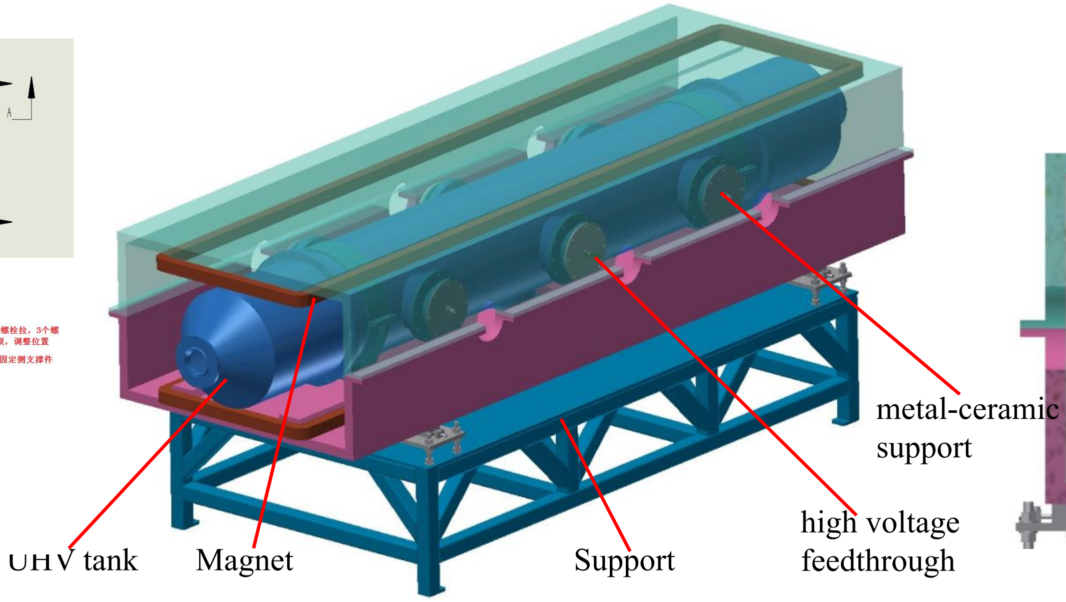




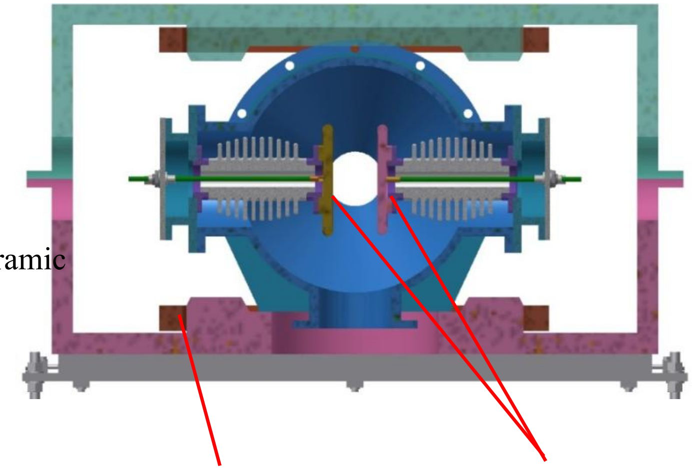
A Wien filter

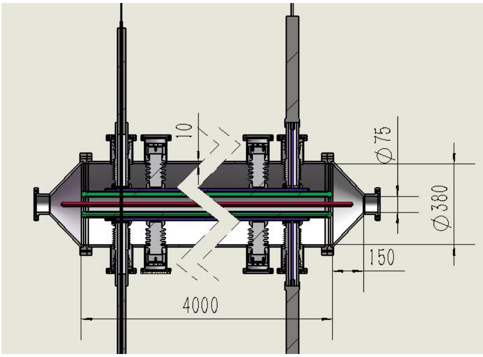






structure drawing of Electrostatic-Magnetic Deflector



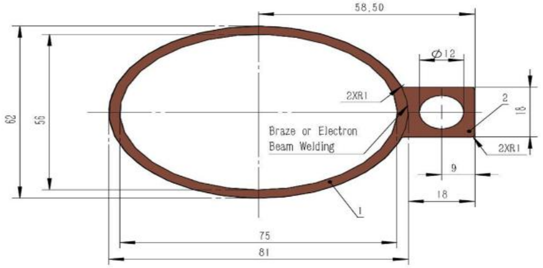


CEPC Vacuum System R&D

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.

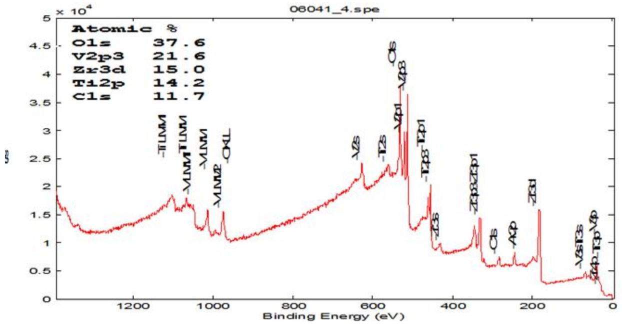
- The vacuum pressure is better than 2 x 10-10 Torr
- Total leakage rate is less than 2 x 10-10 torr.l /s.

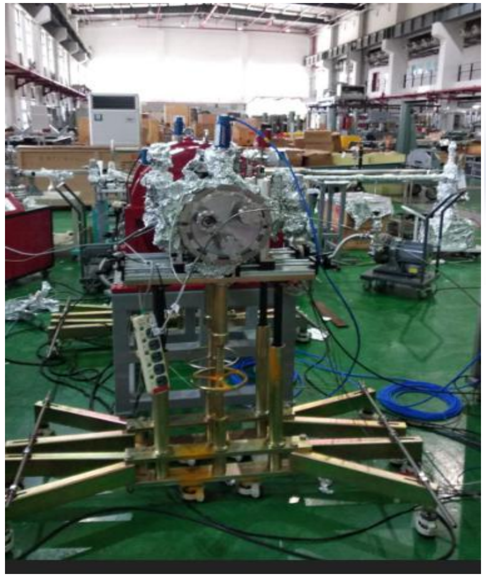
Positron ring

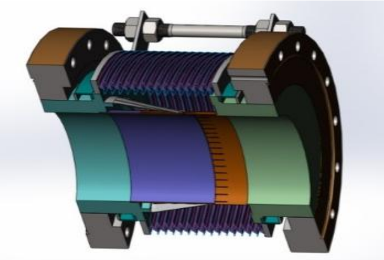


Copper vacuum chamber (Drawing) elliptic 75×56, thickness 3, length 6000)

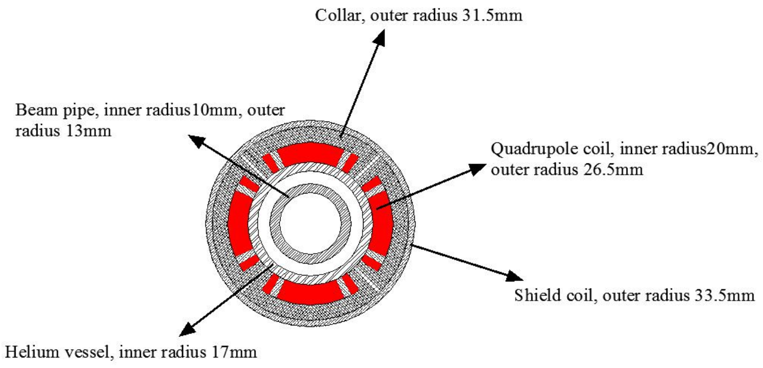
Two 6m long vacuum chambers both for copper and aluminum







CEPC IR Superconducting Magnets

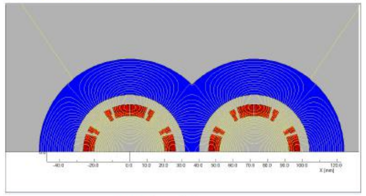


Room-temperature vacuum chamber with a clearance gap of 4 mm

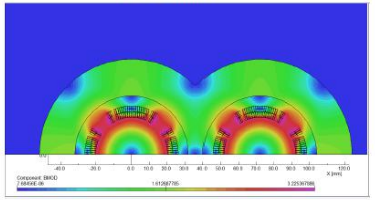
Mag net	Central field gradient (T/m)	Magnetic length (m)	Width of Beam stay clear (mm)	Min. distance between beams centre (mm)
QD0	136	2.0	19.51	72.61

Superconducting QD coils

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



2D Flux lines

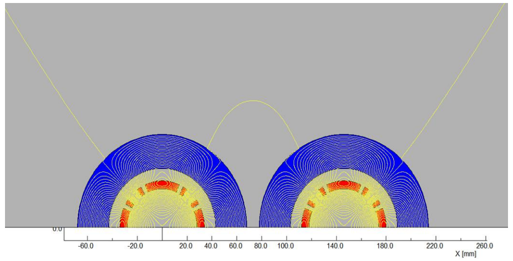


Bmod distribution

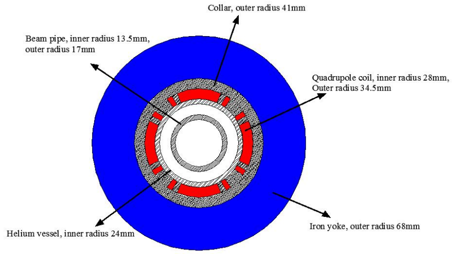
QF1 Integral field harmonics with shield coils ($\times 10^{-4}$)

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)	Magnet ic length (m)	Width of Beam stay clear (mm)	Min. distance between beams centre (mm)
QF1	110	1.48	27.0	146.20

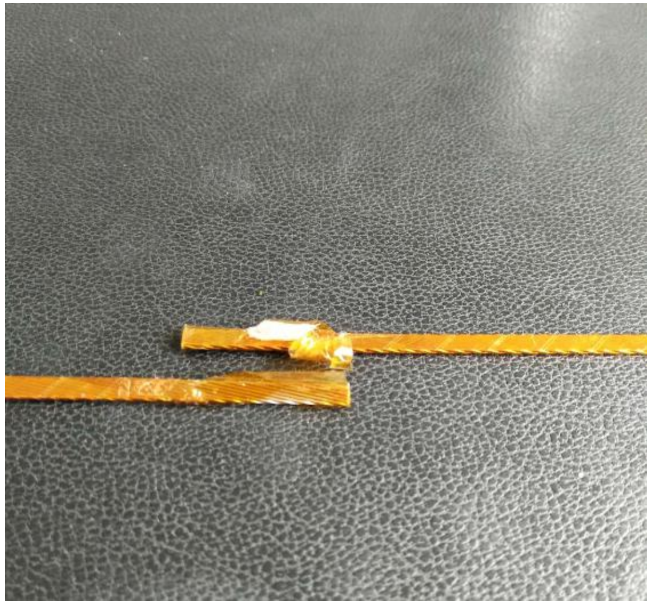
Technical design review has been done (July 19, 2019)

Fabrication Preparation of 0.5m QD0 Short Model SC Magnet

In 2018 Ordered: NbTi/Cu Strand, keystoned Rutherford Cable.

- ✓ **Strand:**
  NbTi/Cu, 0.5mm in diameter, Cu/Sc=1.3, Filament diameter < 8μm, @4.2K, Ic≥340A@3T， Ic≥280A@4T， Ic≥230A@5T.
- ✓ **Rutherford Cable:**
  Width: 3mm, mid thickness: 0.93 mm, keystone angle: 1.9 deg, No of stands: 12.

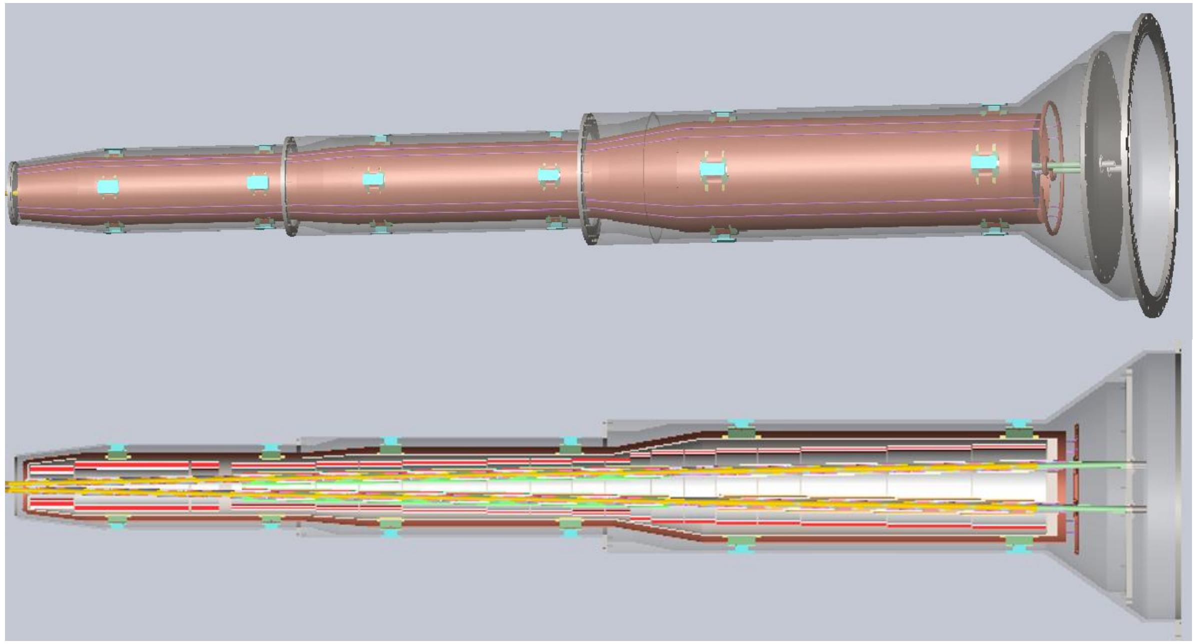
The basic hardware was investigated. Cost inquiry for QD0 short model magnet fabrication has been completed.



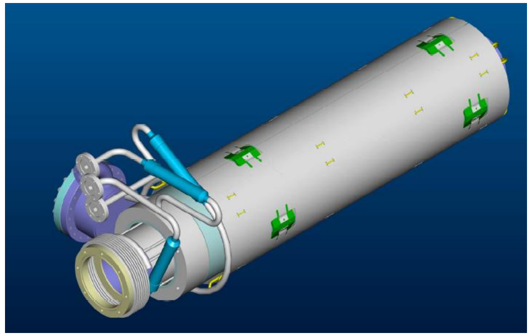
Cu Rutherford cable sample

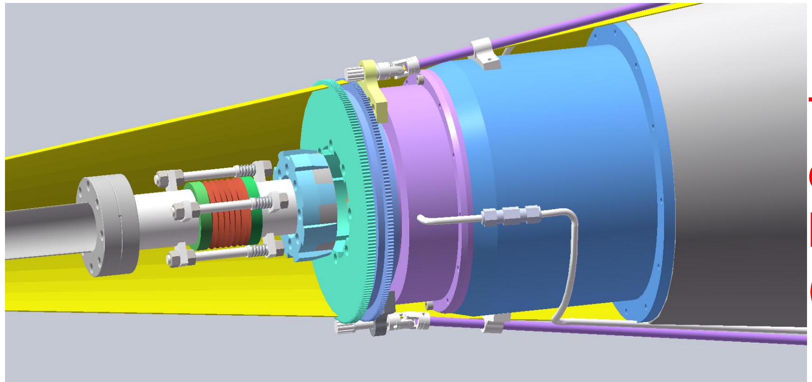
IHEP winding machine

CEPC MDI SC Magnets and Mechanical Study

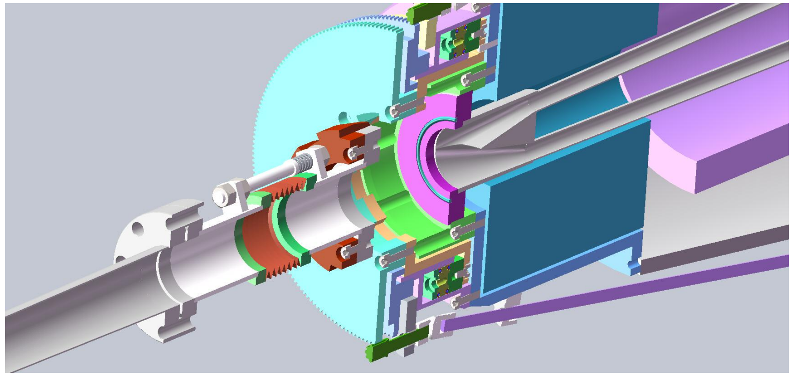


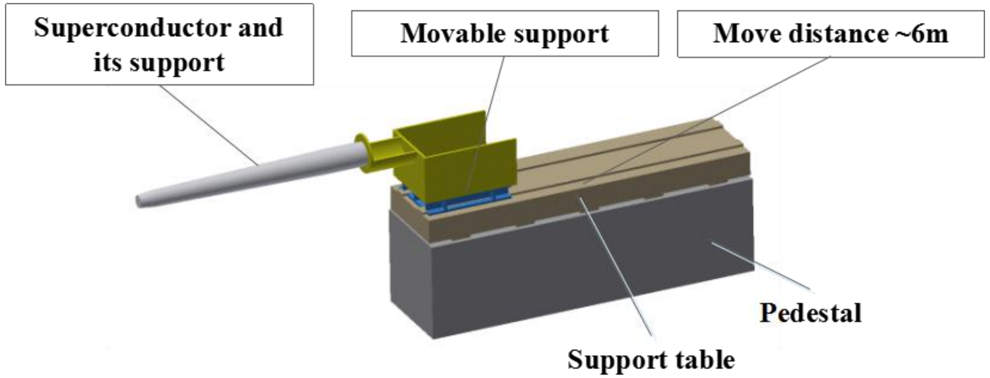
Design status of MDI SC magnet cryostat





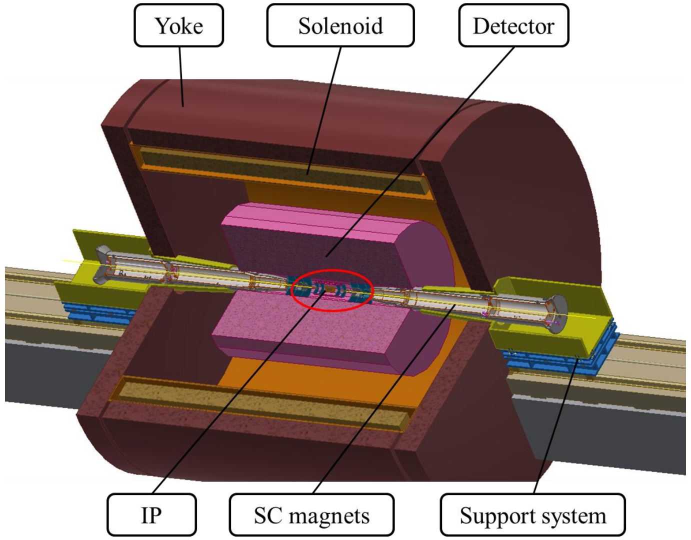
Technical design review has been done (July 23, 2019)

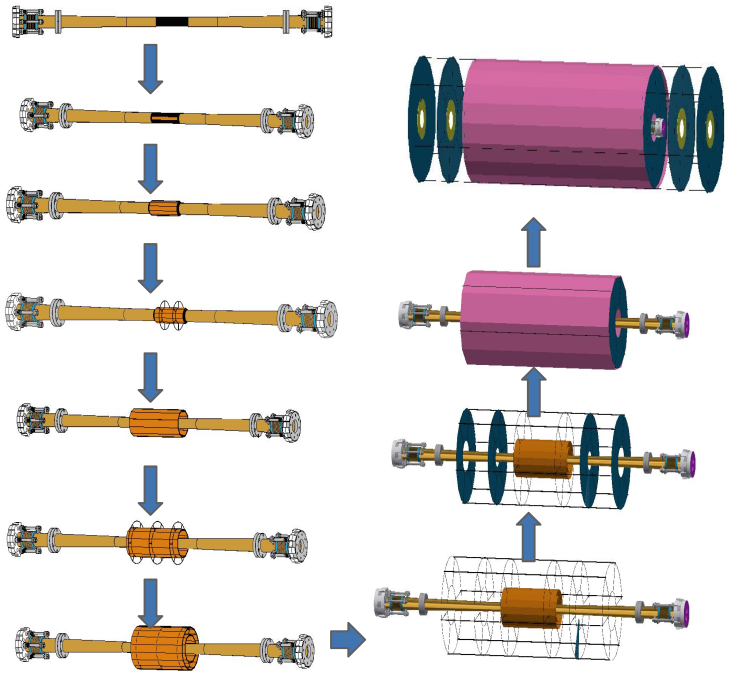




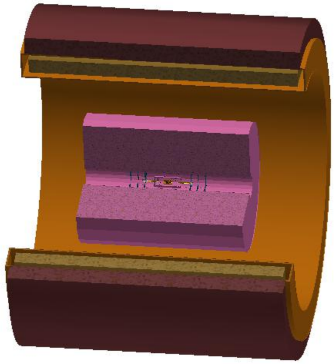
Schematic of support system of superconducting magnets

IR Mechanics Assembly

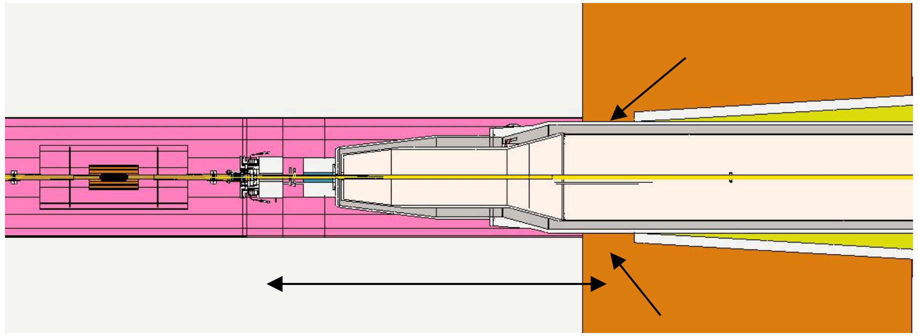




- Both sides of IP chamber are fixed to VTX transversally and are free longitudinally.
- The IP chamber, VTX, SIT and FTD can be considered as one assembly.
- The assembly above can be supported by TPC and be aligned transversally.
- Remote vacuum connector can be used.
- The high precision part of Lumical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



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

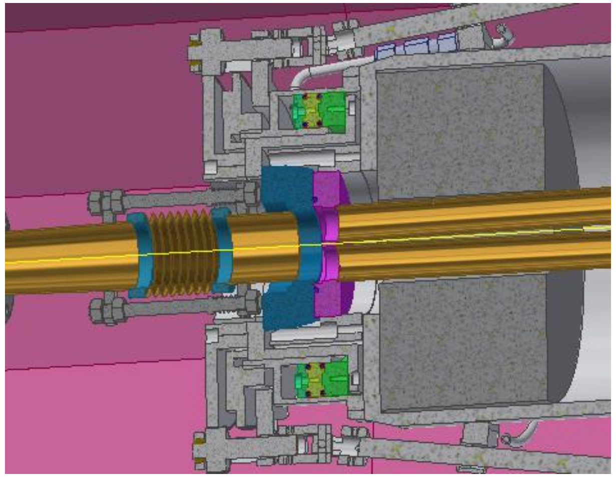


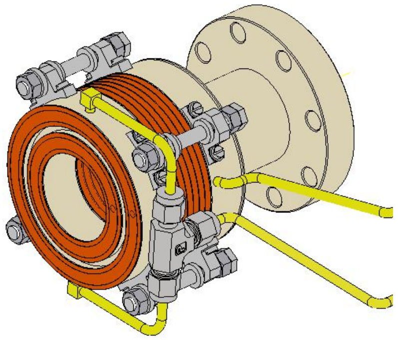
Little transversally space & long longitudinally distance. It is impossible to connect flanges by hands.

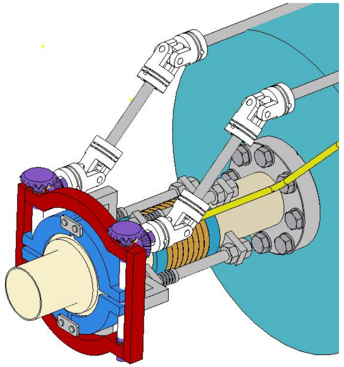
Study of Different MDI Remote Connecting Methods

RVC similar to SuperKEKB as baseline, and studying other schemes at the same time. The design has been reviewed.

	RVC	Inflatable seal	Remote chain seal	Long tools
Sealing methods	Pneumatic clamping with auxiliary locking	Pneumatic clamping	Pneumatic clamping with auxiliary locking	Screws clamping using long tools
Advantages	Successful experience from SuperKEKB	Successful experience from CSNS; Small	Simple and small structure	Simple and small structure
Disadvantages	Big and complex structure	Difficult for leak rate requirement	New idea, no experience.	Difficult in operation







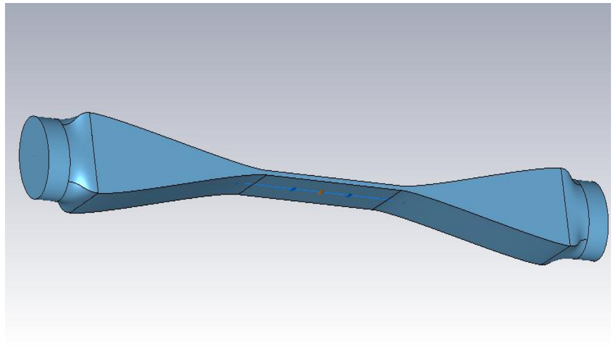
Leak rate requirement: ≤2e-10 Torr.L/s

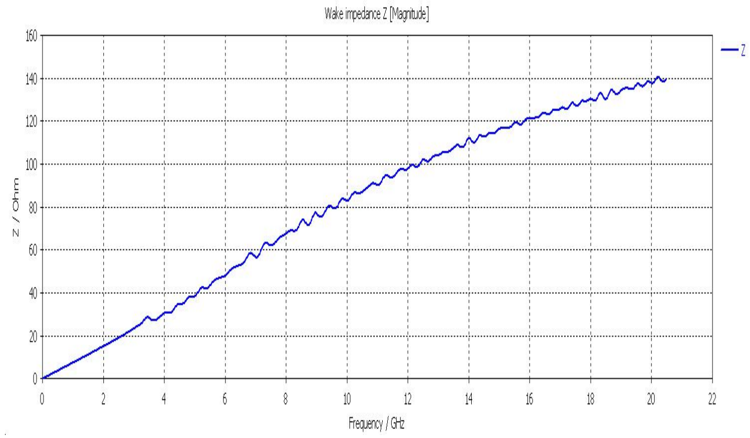
Some candidate methods

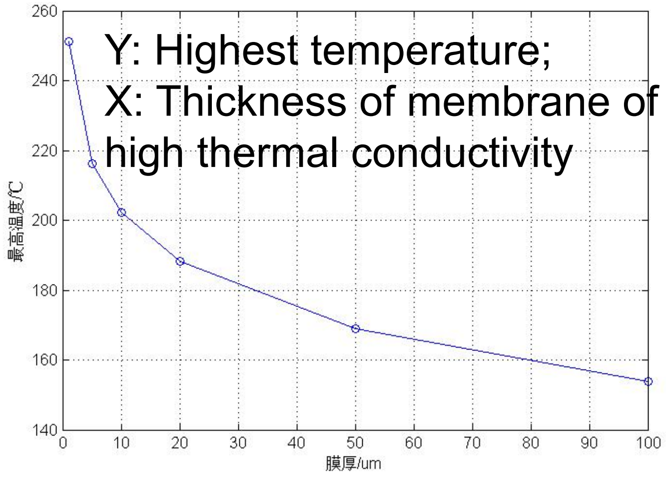
CEPC Movable Collimators

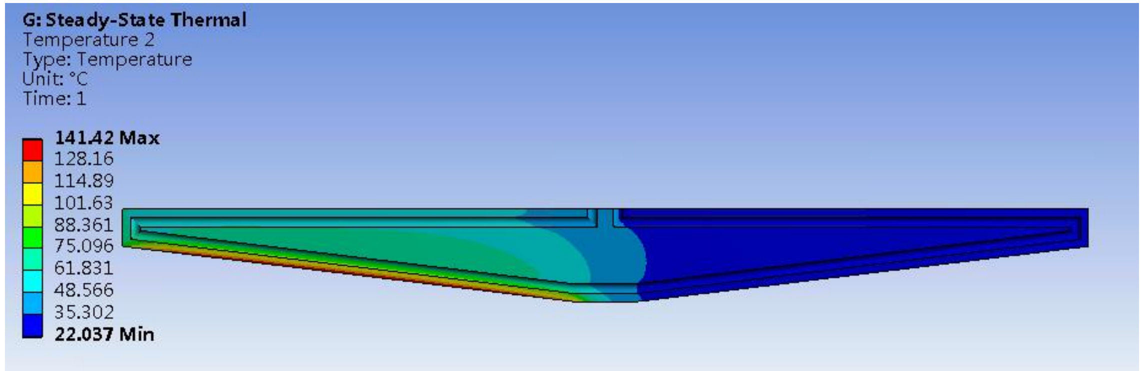
- Located in straight section between two dipoles, the length is 800 mm.
- Primary impedance estimation has been done.
- The synchrotron radiation is the main thermal load, the cooling method is under consideration.

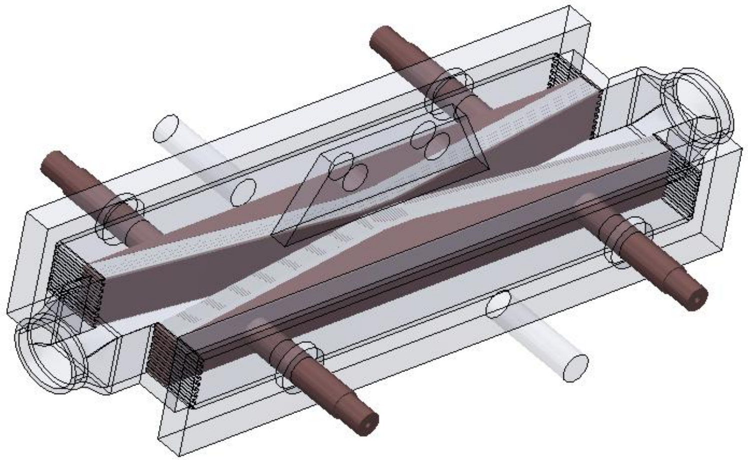
We proposed a design using laminated material with metal and membrane of high thermal conductivity, the photon absorber is also considered.











CEPC Linac Key Technology R&D-1

- S-band accelerating structure
  - Inner water-cooling has been adopted. 8 pipes are around the cavity.
  - Compact coupler arrangements. The splitter is milling together with the coupling cavity
  - Two faraday cups are in upstream and downstream of the structure to detect dark current respectively
  - The high power test gradient has reached 20 MV/m now

Before welding

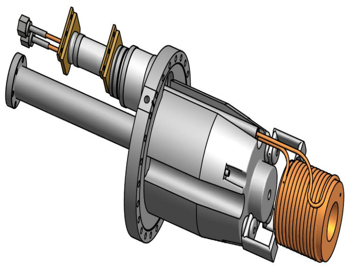
Single cell

The accelerating structure under tuning

High power test bench

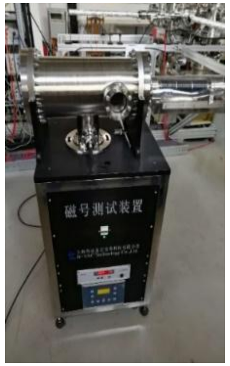
CEPC Linac Key Technology R&D-2

- Positron source flux concentrator
  - The FLUX concentrator is the important part of the positron source
  - It produces a pulsed magnetic field of 6 T to 0.5 T
  - The maximum output value of the solid-state pulsed power generator is 15 kA / 15 kV / 5 μs



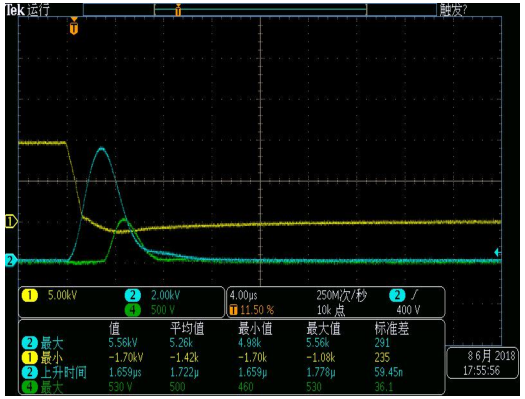
The mechanical design of FLUX concentrator

The finished FLUX concentrator



The test bench of the FLUX concentrator

solid-state pulsed power generator



The output of 10kA measurement

CEPC-SppC Compatibility

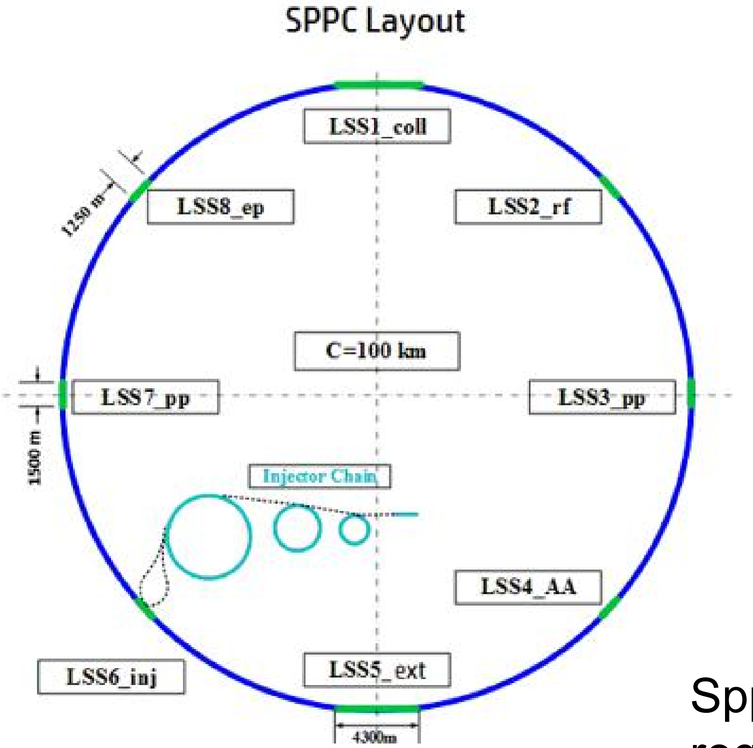
SPPC Parameter Choice and Comparation

CDR F. Su

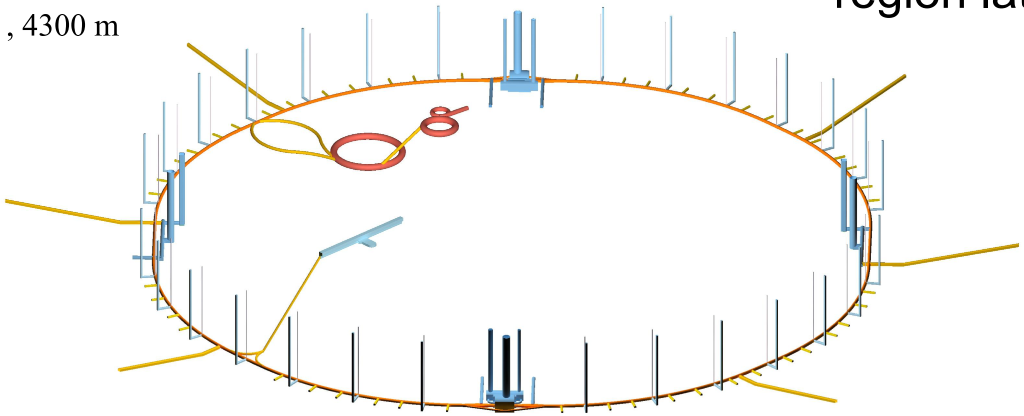
Table 2: SPPC Parameter list(2017.1)[4].6

	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	-

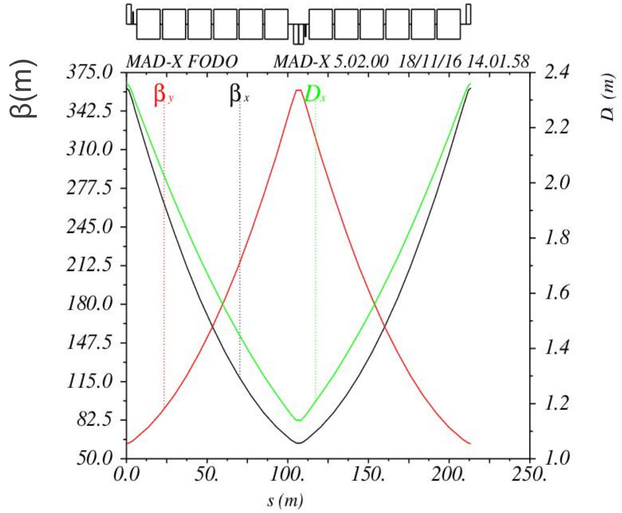
General Layout of SPPC



- 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

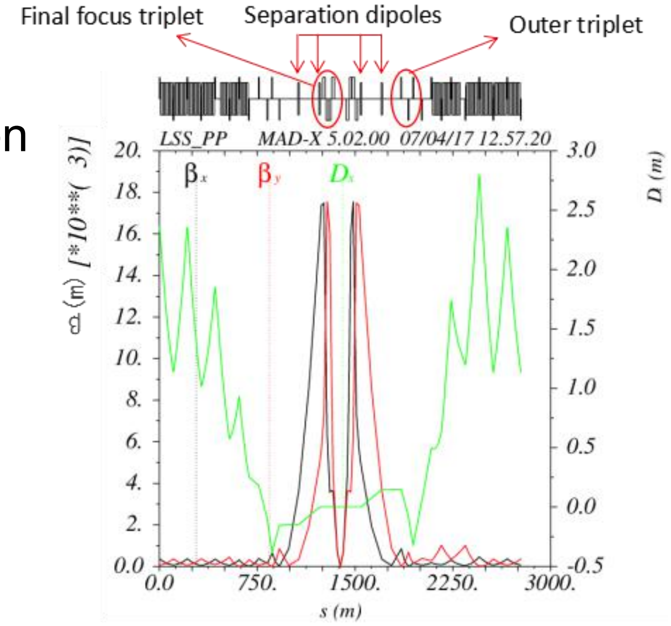


SppC ARC lattice



ARC FODO cell structure

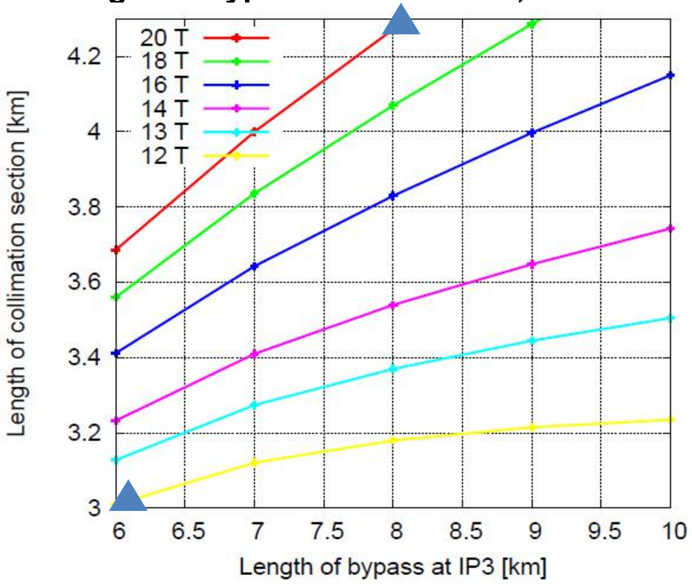
SppC interaction region lattice

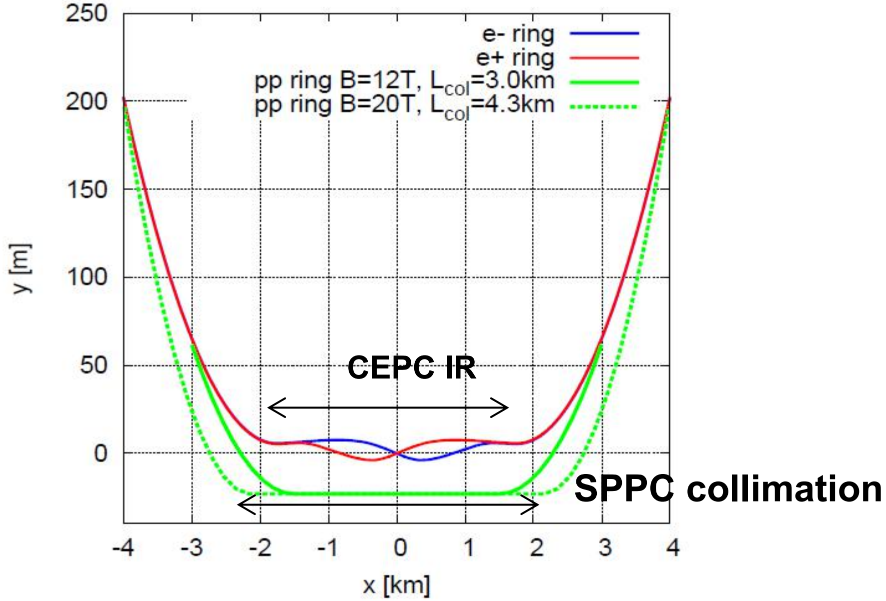


LSS_PP(beta*=0.75 m)

Compatibility of CEPC and SPPC at the IP1 and IP3

- The compatibility at the IP1 and IP3 need to be fixed
  - **A long section of SPPC at IP1 and IP3 is used for combining the transverse and momentum collimation in the same section.**
  - SPPC locates outside and is longer than CEPC at this region (SPPC 4.3km, CEPC 3.32km)
  - Geometry of CEPC kept, adjust the SPPC's
- No solutions of bypass with collimation=4.3km, B=12 T
  - **Solutions can be found with stronger bends or shorter collimation sections which means a different design of SPPC collimation section**





CEPC-SppC compatibility relation between collimation section length and SppC dipole maximum field has been found! CEPC and SppC could be compatible in the same tunnel

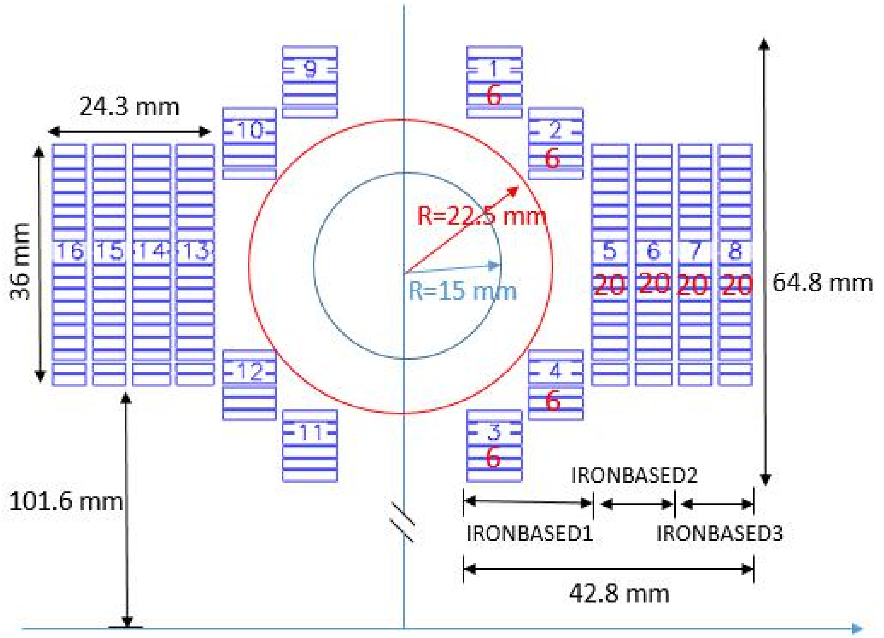
Domestic Collaboration on HTS for SppC SC Dipole Magnet

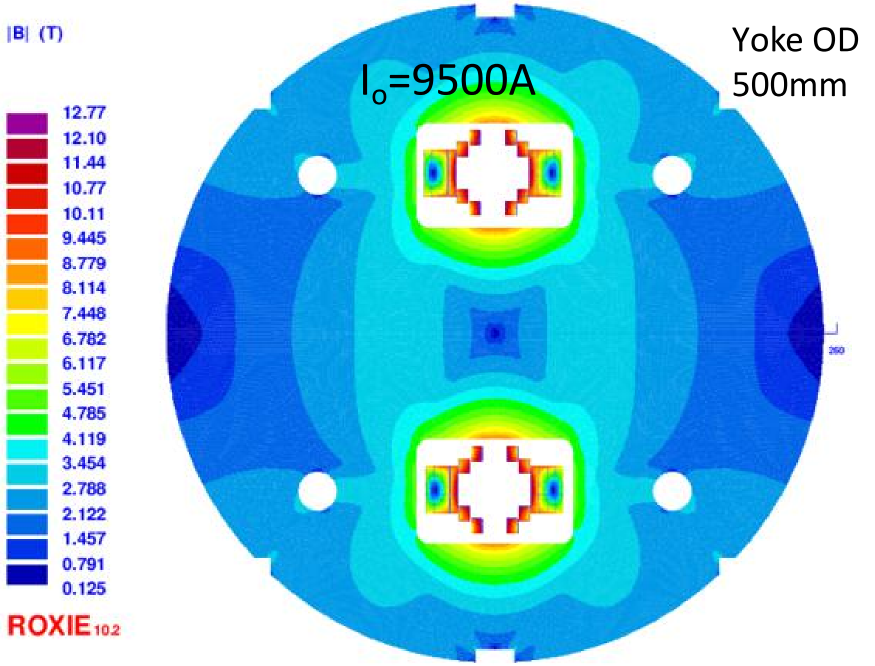
"Applied High Temperature Superconductor Collaboration" was established in Oct. 2016.

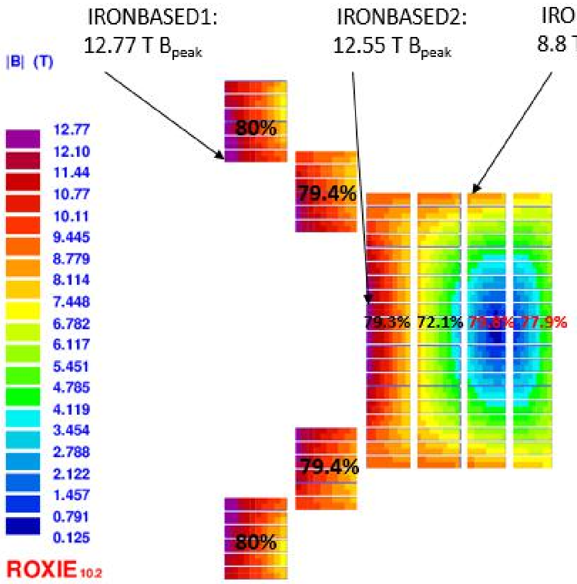
- **Goal:**
  1) To increase the J_c of **IBS** by 10 times, reduce the cost to **20 Rmb/kAm @ 12T & 4.2K**;
  2) To reduce the cost of **ReBCO and Bi-2212** conductors to 20 Rmb/kAm @ 12T & 4.2K;
  3) Realization and Industrialization of iron-based magnet and SRF technology.
- **Working groups:** 1) **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

Fabrication and test of IBS solenoid coil at 24T

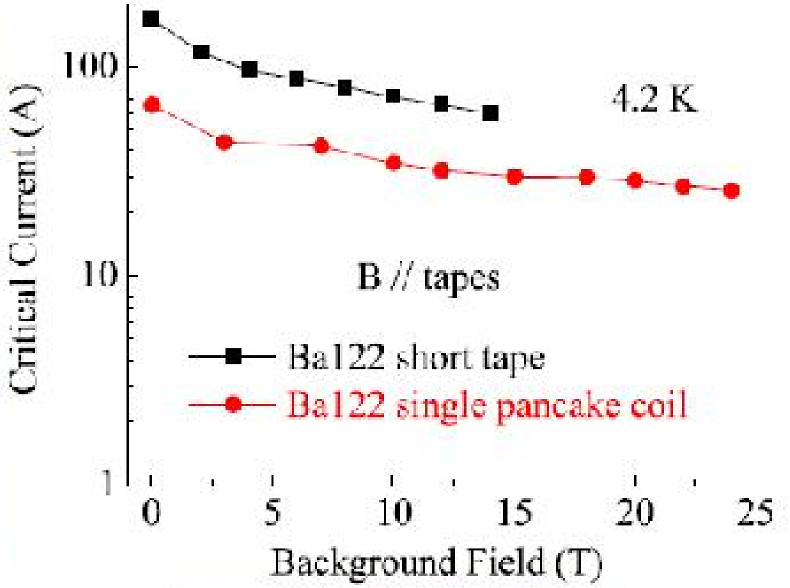
IOP Publishing
Superconductor Science and Technology
Supercond. Sci. Technol. 32 (2019) 04LT01 (5pp)
https://doi.org/10.1088/1361-6668/ab09a4

Letter

First performance test of a 30mm iron-based superconductor single pancake coil under a 24T background field

Dongliang Wang[1,2,3], Zhan Zhang[3,5], Xianping Zhang[1,2], Donghui Jiang[4], Chiheng Dong[1], He Huang[1,2], Wenge Chen[4], Qingjin Xu[3,6] and Yanwei Ma[1,2,6]

[1] Key Laboratory of Applied Superconductivity, Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing 100190, People's Republic of China
[2] University of Chinese Academy of Sciences, Beijing 100049, People's Republic of China
[3] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, People's Republic of China
[4] High Magnetic Field Laboratory, Chinese Academy of Sciences, Hefei 230031, People's Republic of China



Viewpoint by NHMFL

'From a practical point of view, **IBS are ideal candidates for applications**. Indeed, some of them have quite a **high critical current density, even in strong magnetic fields**, and a low superconducting anisotropy.
Moreover, **the cost of IBS wire can be four to five times lower than that of Nb_3Sn**……

IOP Publishing
Superconductor Science and Technology
Supercond. Sci. Technol. 32 (2019) 070501 (3pp)
https://doi.org/10.1088/1361-6668/ab1fc9

Viewpoint

CrossMark

Constructing high field magnets is a real tour de force

Jan Jaroszynski
National High Magnetic Field, Laboratory, Tallahassee, FL 32310, United States of America
E-mail: jaroszy@magnet.fsu.edu

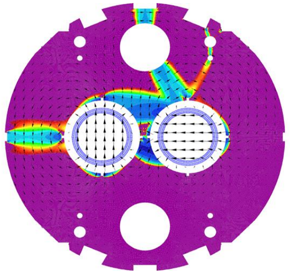
This is a viewpoint on the letter by Dongliang Wang *et al* (2019 *Supercond. Sci. Technol.* 32 04LT01).

Following the discovery of superconductivity in 1911, Heike Kamerlingh Onnes foresaw the generation of strong magnetic fields as its possible application. He designed a 10 T electromagnet made of lead–tin wire, citing only the difficulty

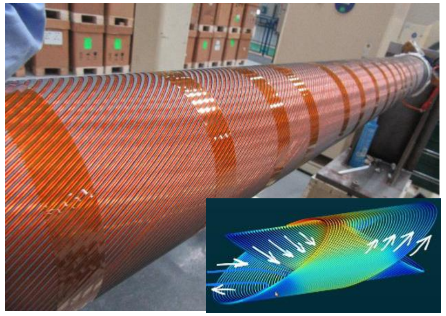
R&D of HL-LHC CCT Magnets

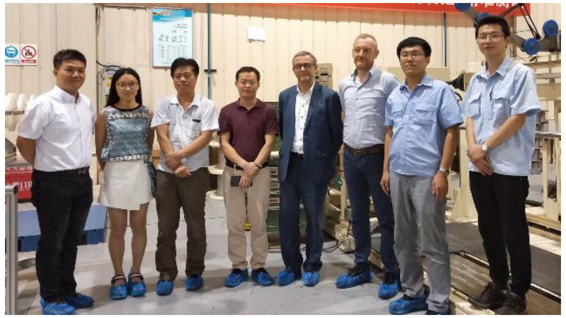
China provides 12+1 units CCT corrector magnets for HL-LHC before 2022

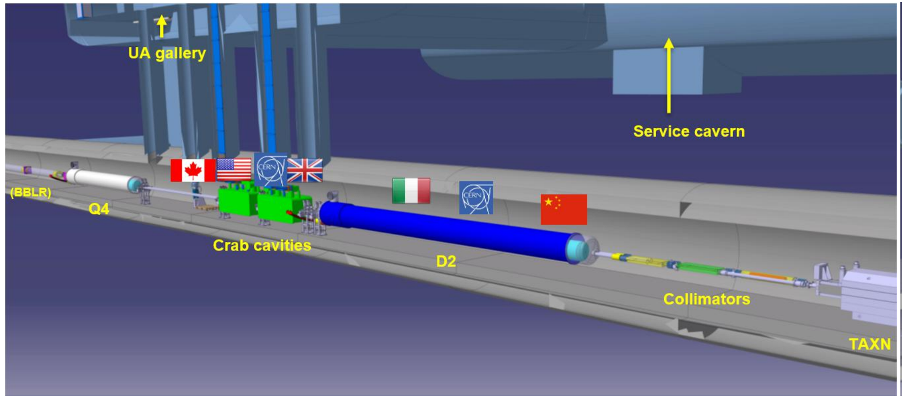
2*2.6T dipole field in the two apertures. 2.2m prototype being fabricated.

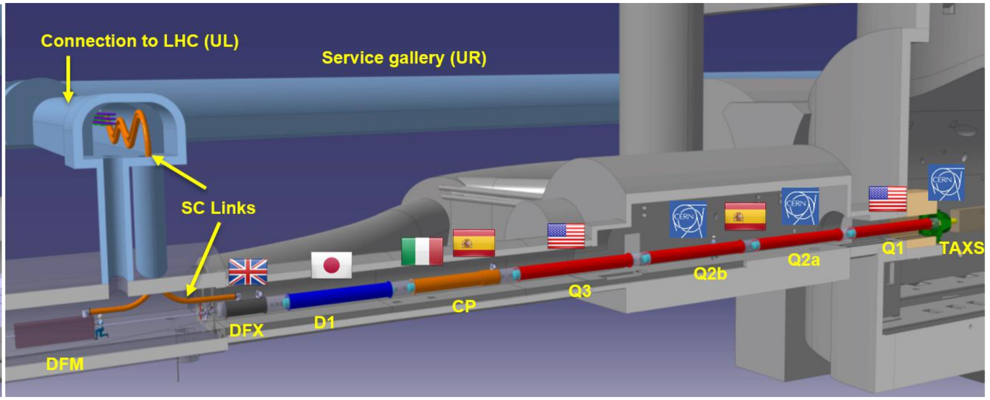


- *0.5m prototype completed*
- *2.2m prototype being fabricated.*
- *Production started in 2020.*







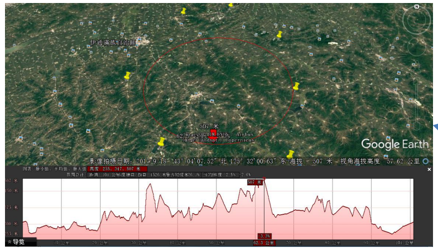


CEPC Site Selection and Civil Engineering

CEPC Site Selections

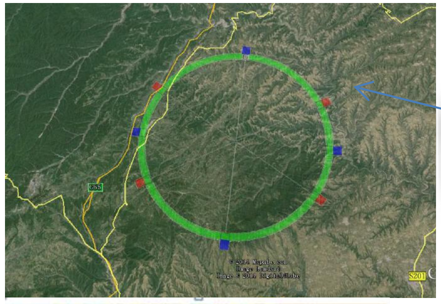
Huanghe Company particitated

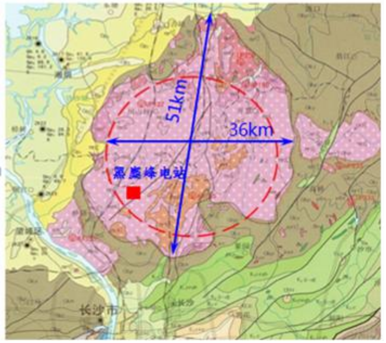
5



1

2





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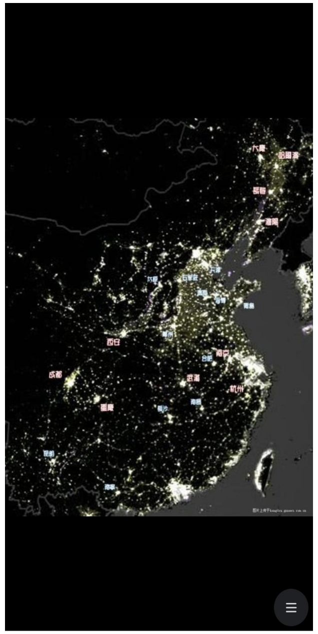
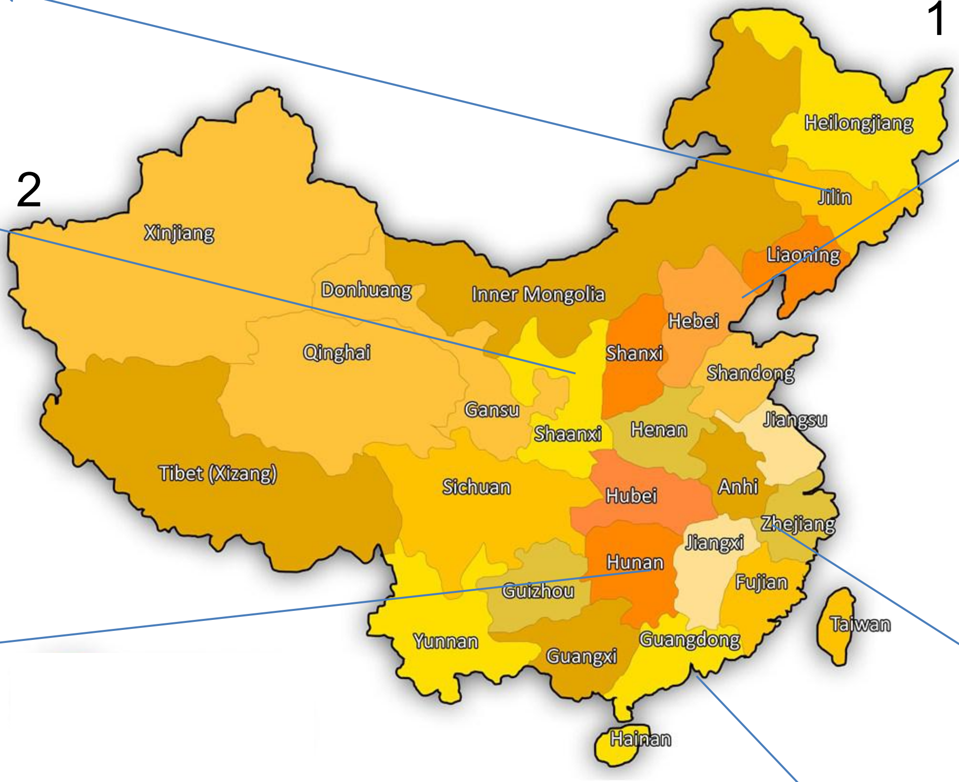


China at night



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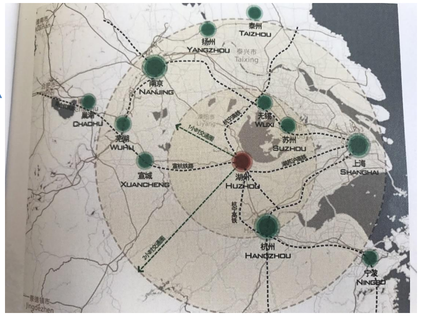


3

1) Qinhuangdao, Hebei Province（Completed in 2014）

2) Huangling, Shanxi Province（Completed in 2017)

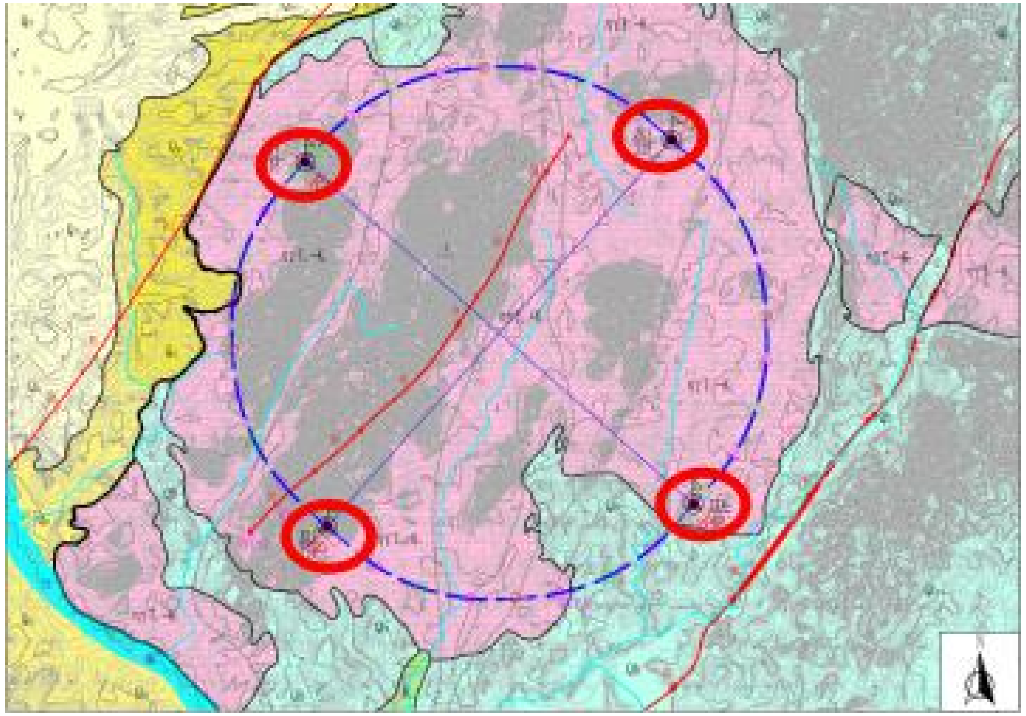
3) Shenshan, Guangdong Province(Completed in 2016)

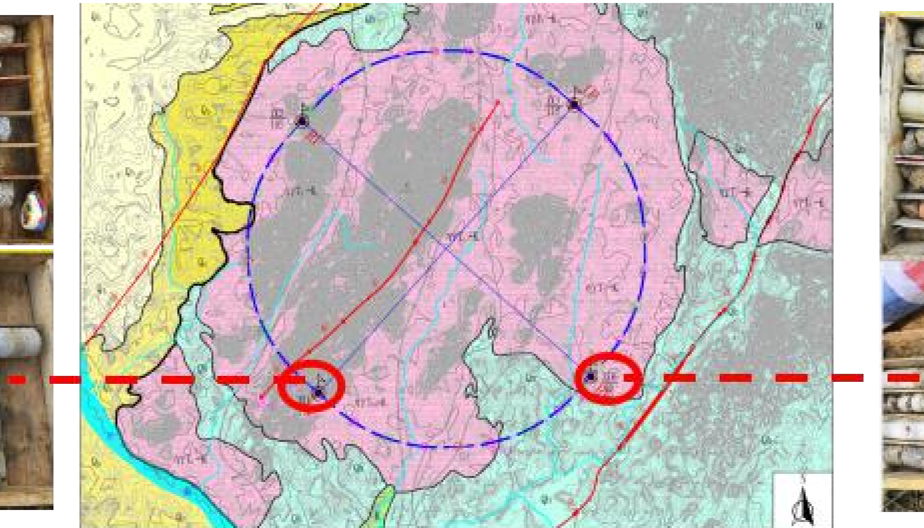
4) Huzhou, Zhejiang Province (Started in March 2018)

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

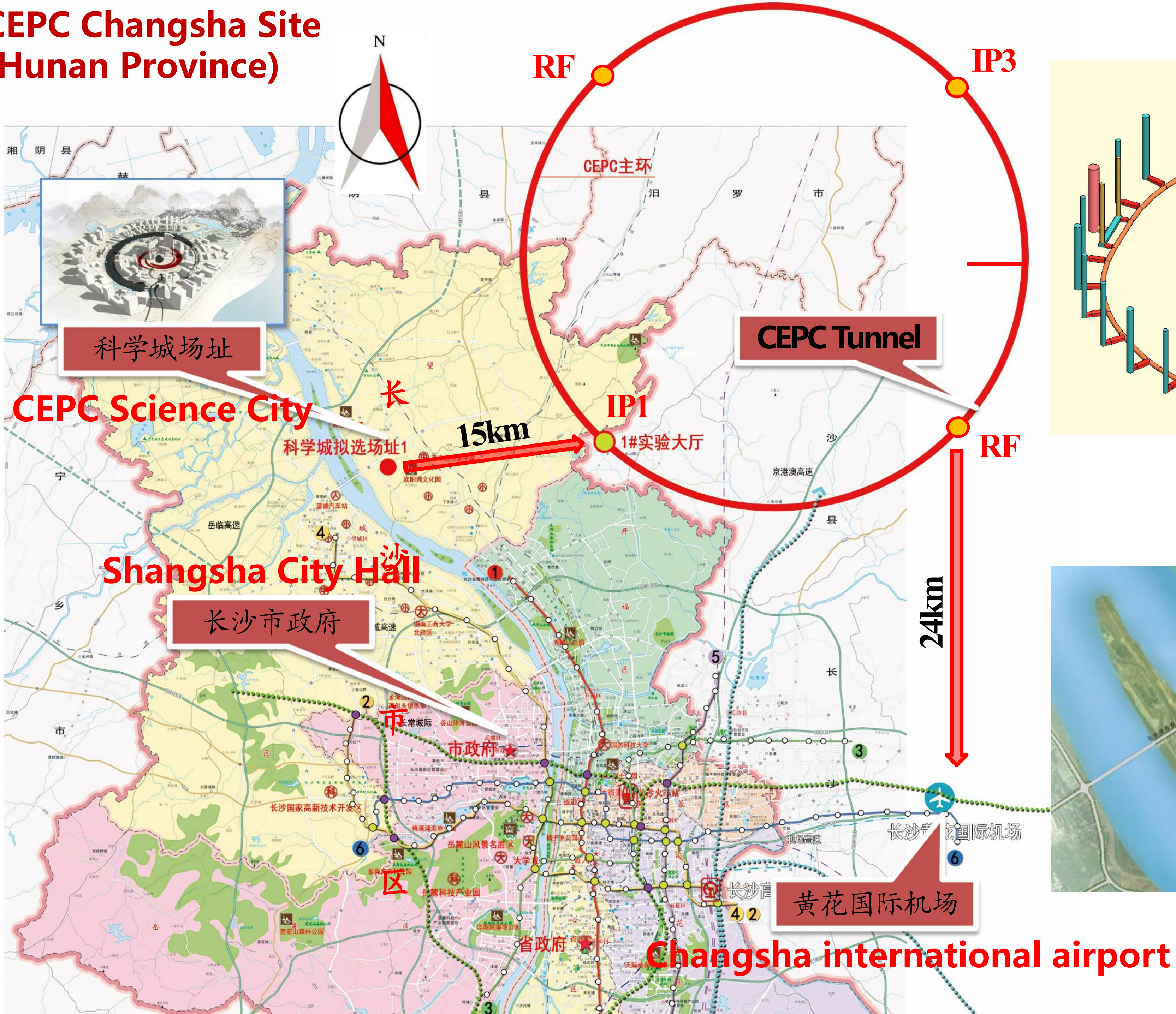
6) Changsha, Hunan Province (Started in Dec. 2018)

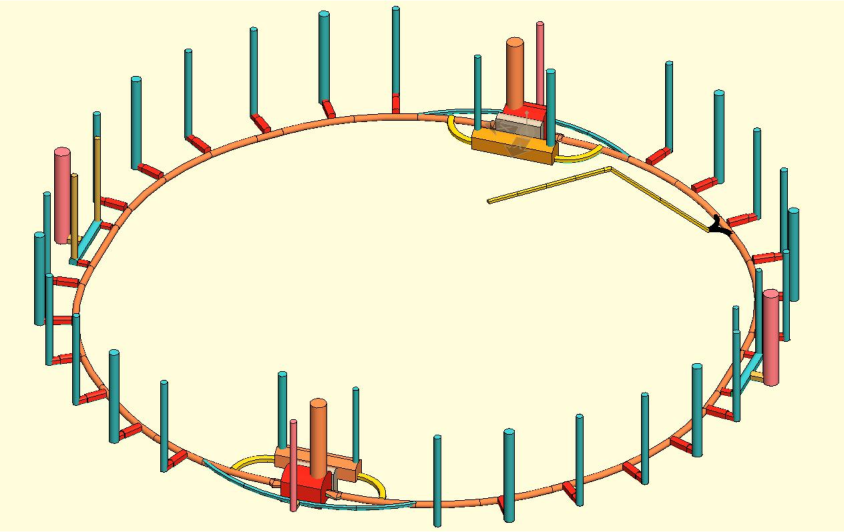
CEPC Site Selection in Changsha (Hunan Province)





CEPC Changsha Site (Hunan Province)

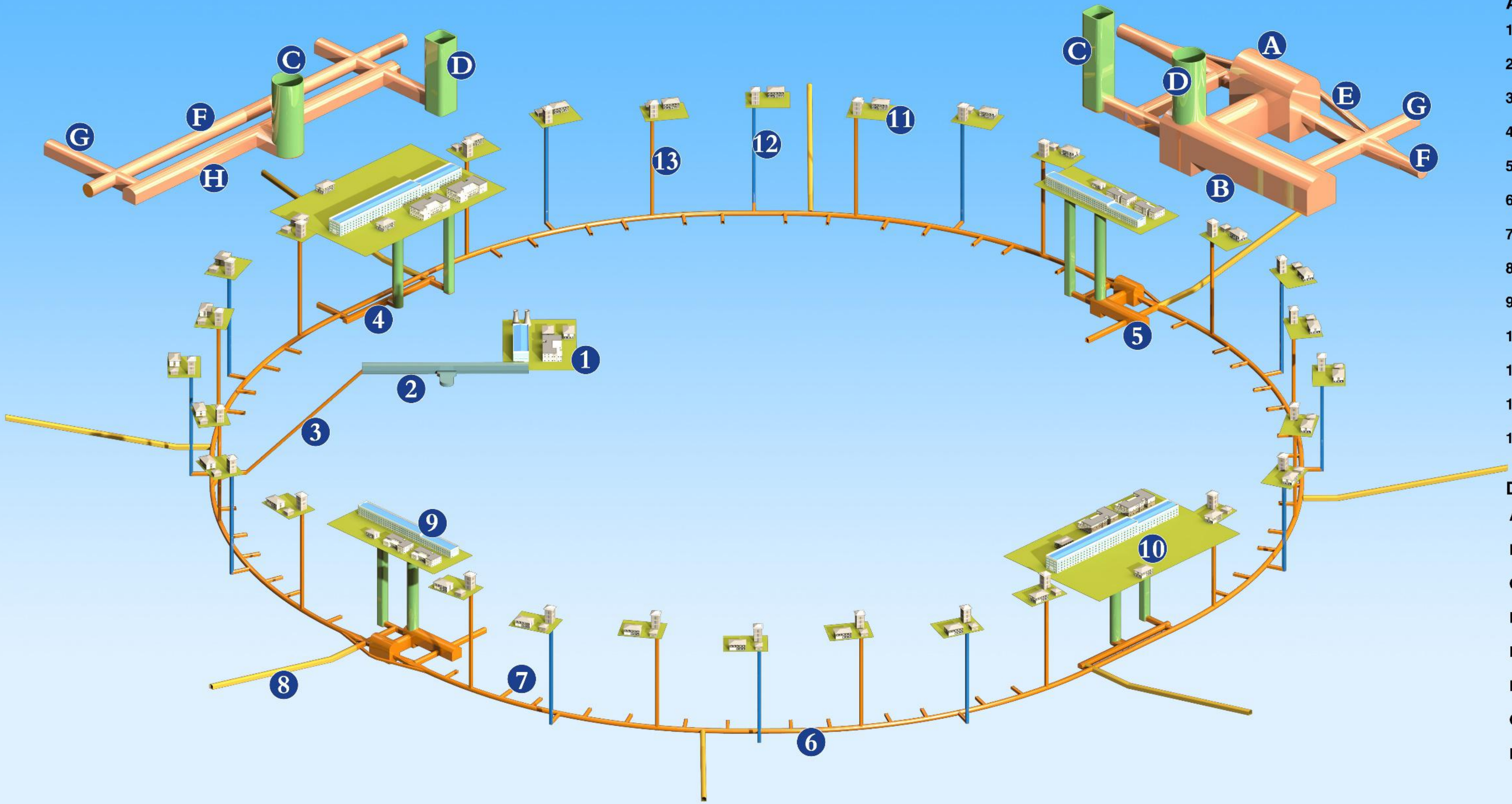




CEPC Tunnel Design

CEPC Scientific City

CEPC



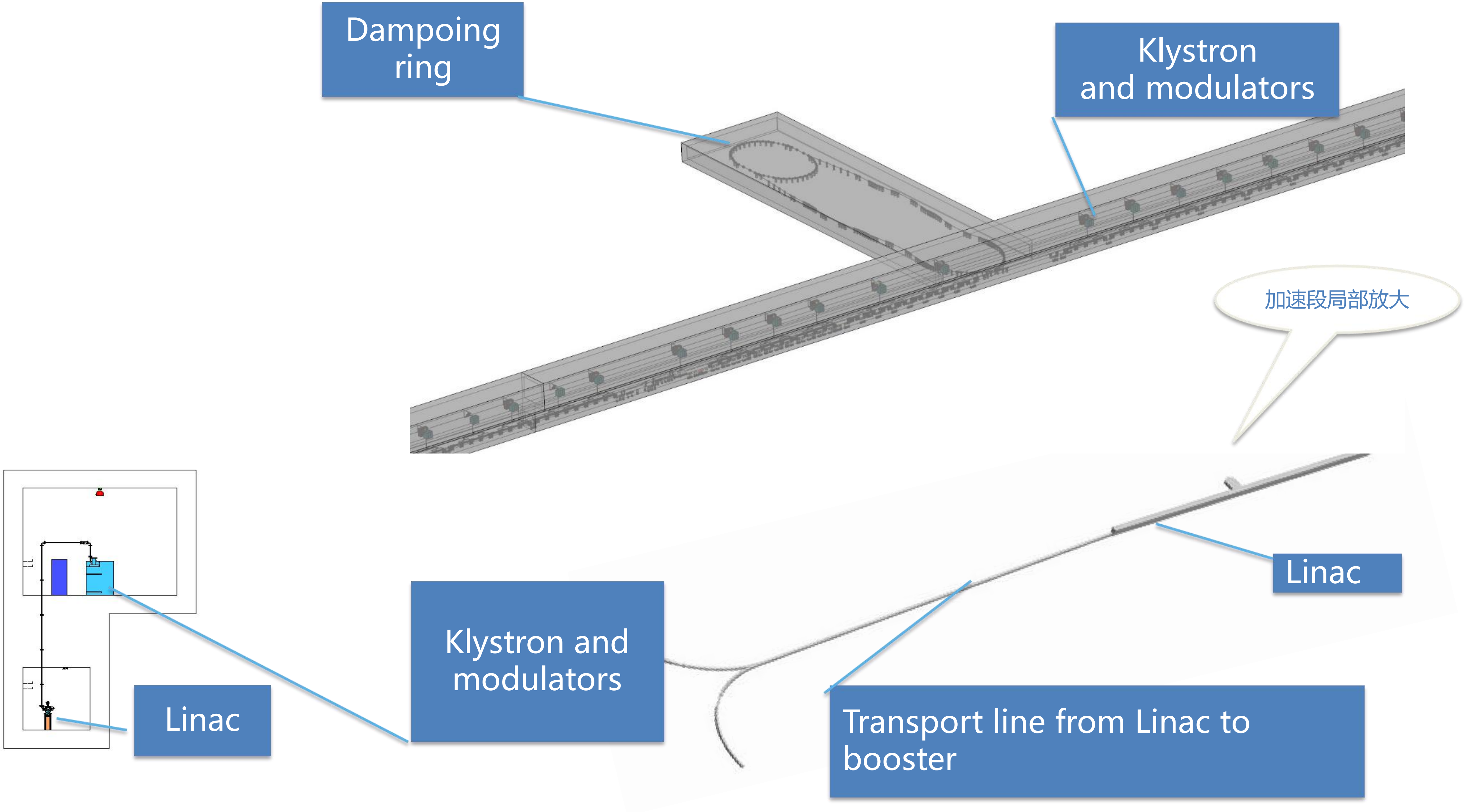
Accelerator Region Caverns:

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

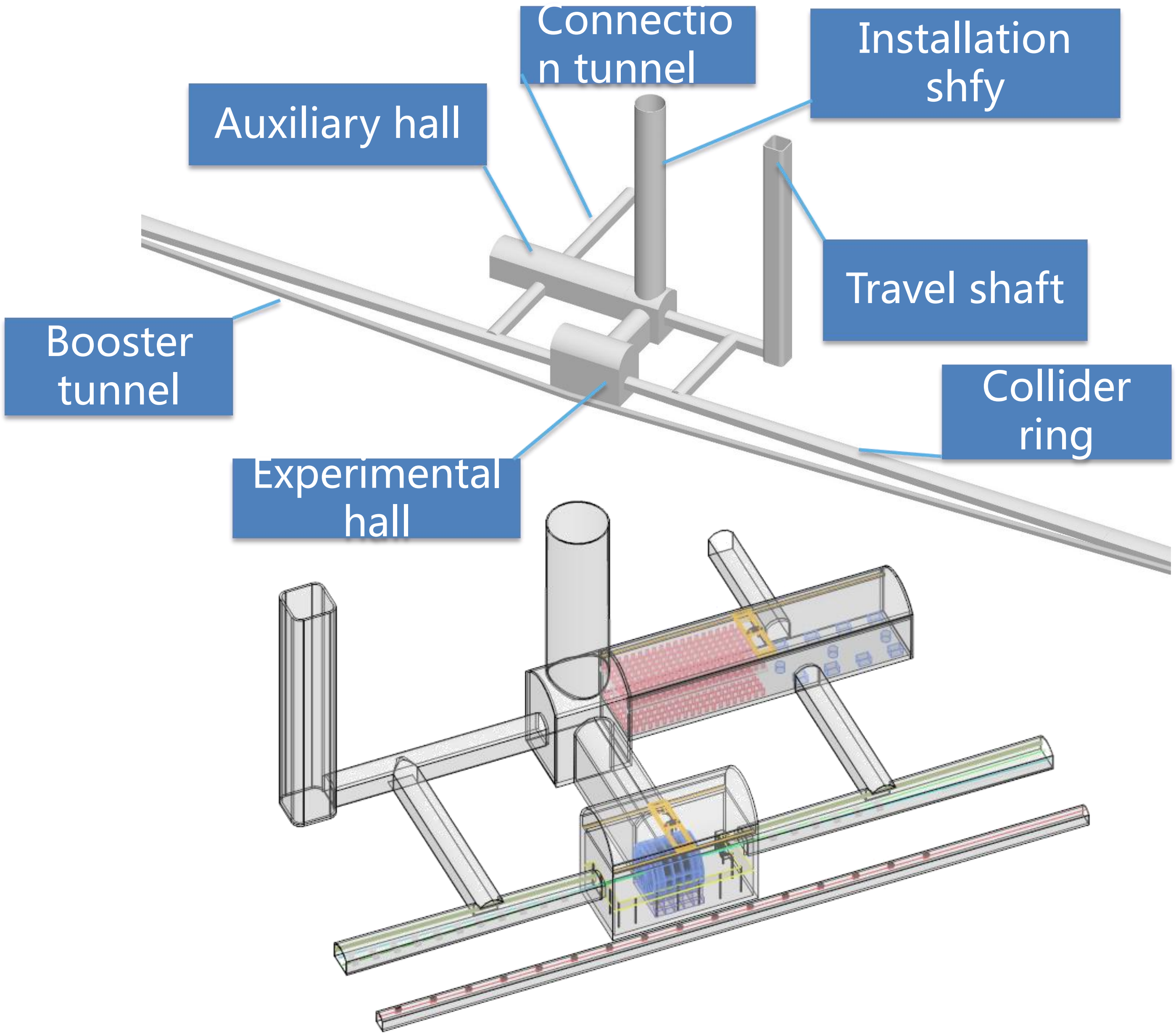
Detector Region Caverns:

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 Linac Injector

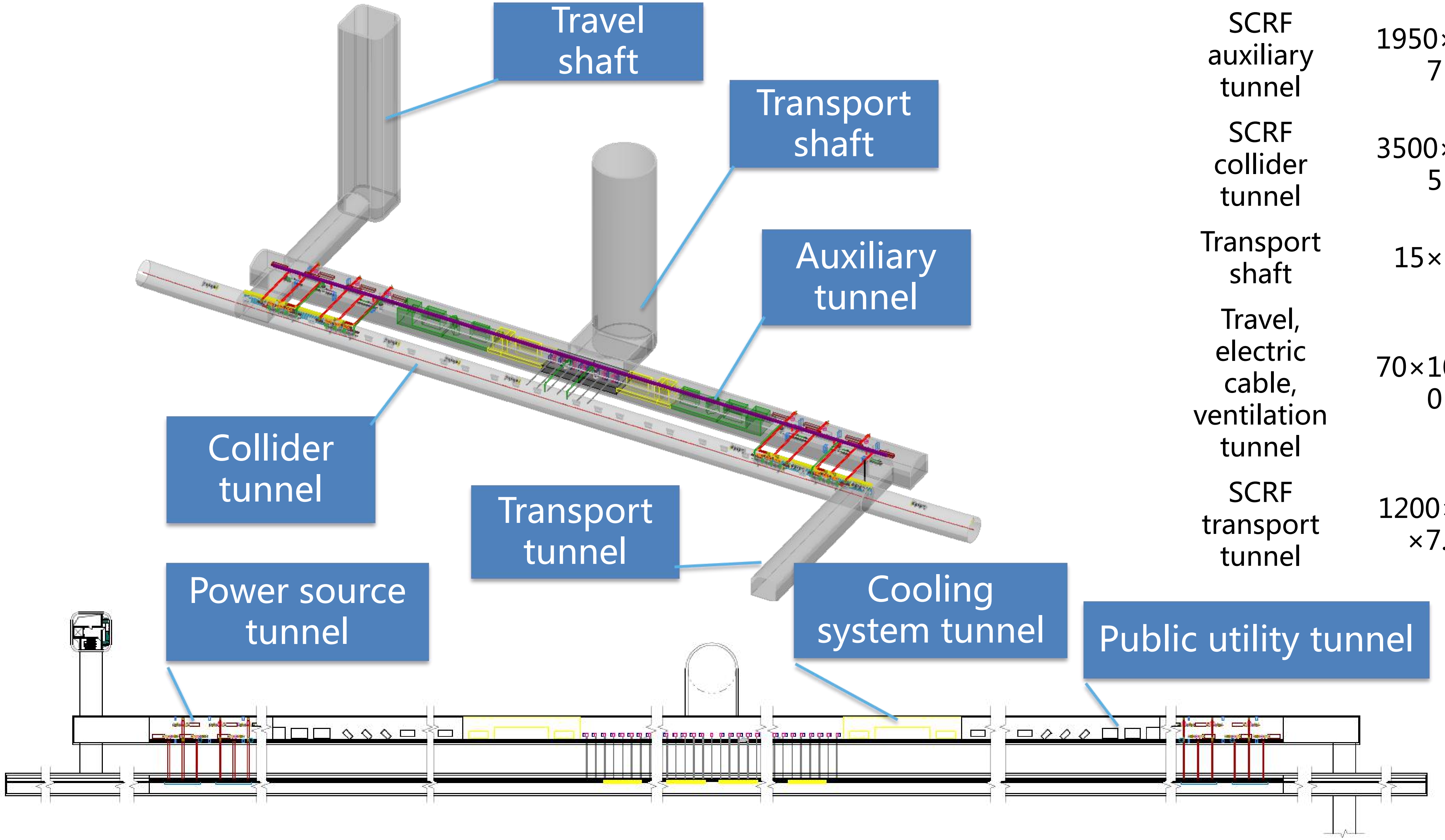


CEPC IR



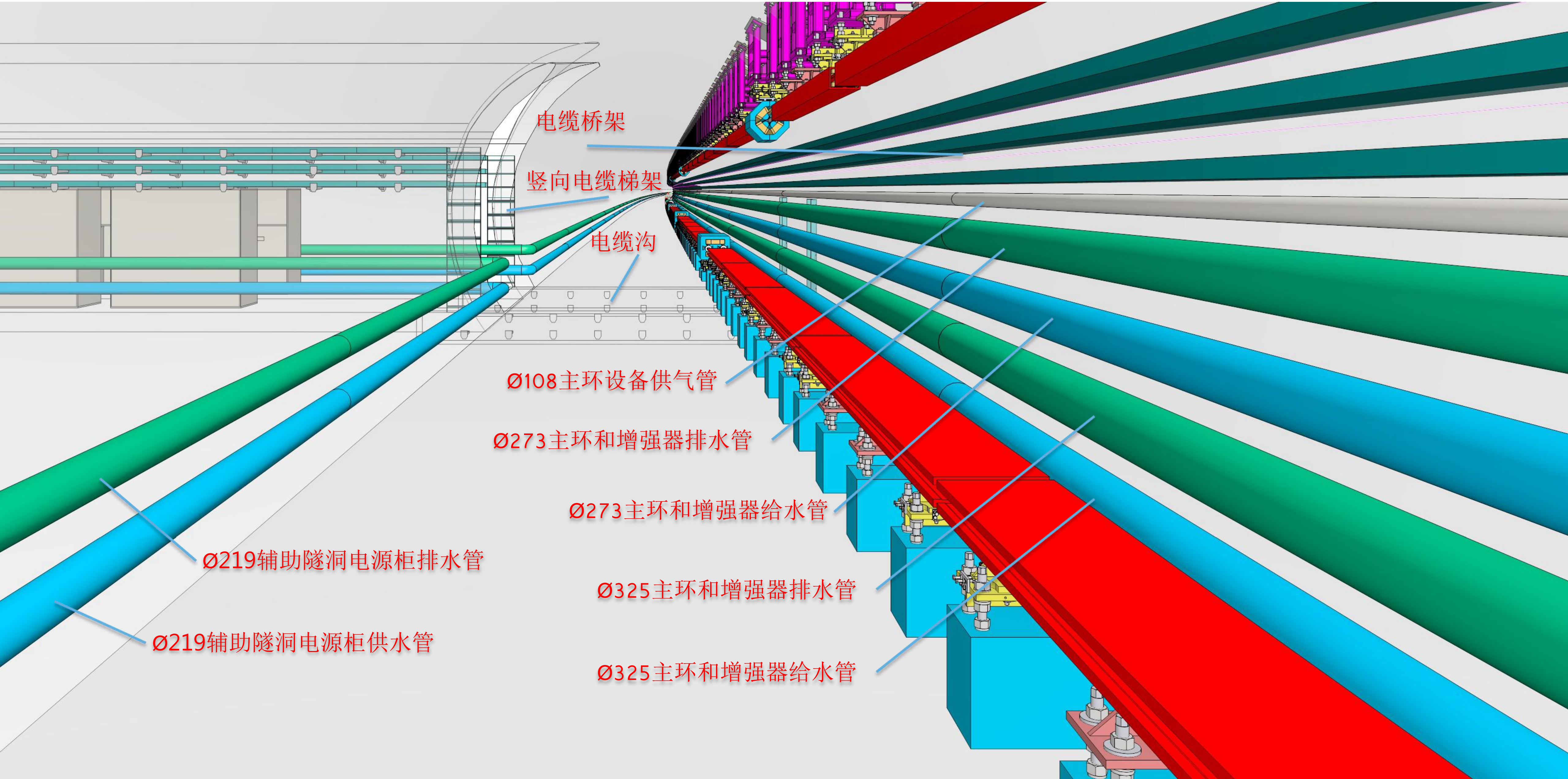
Experimental hall	39.4×20.4×31	×2
Axiliary hall	101.4×20×26.2	×2
Booster tunnel	1679×3.5×3.5	×4
Collider tunnel	1659.3x(6~11.4)x5	×4
Travel shaft	1200x7.5x7.5	×2
Connection, electric cable and ventilation shaft	70x10x10	×2

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

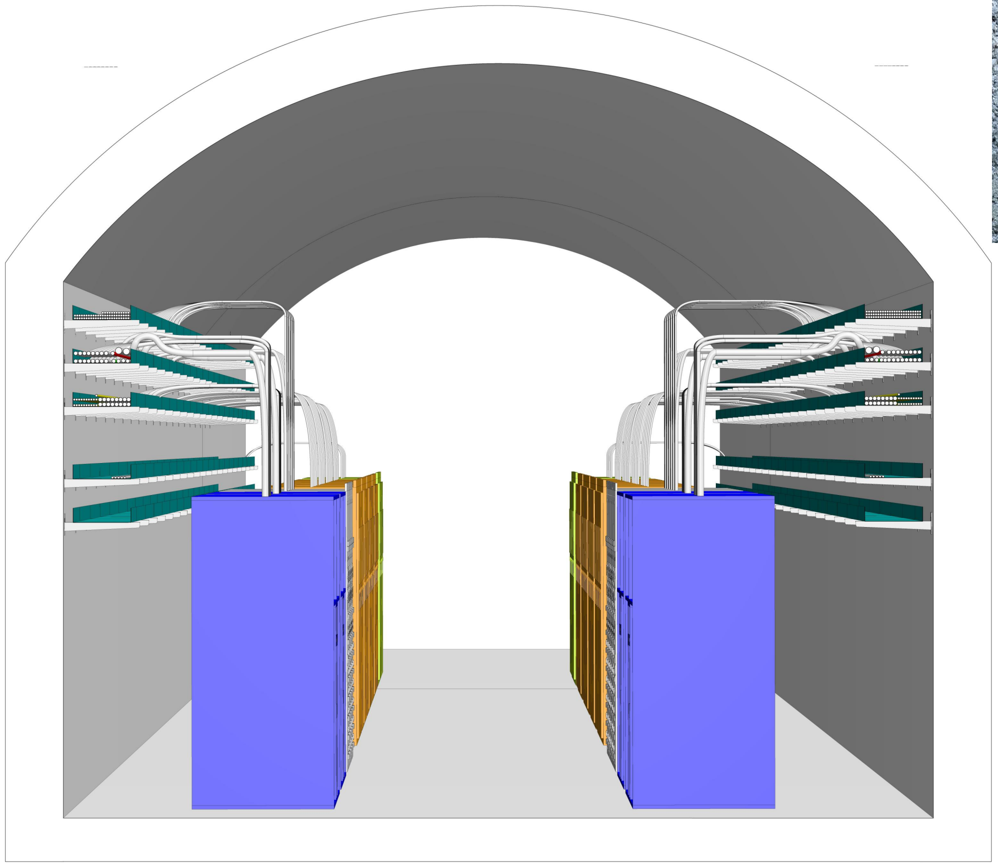
CEPC Main Tunnel and Auxiliary Tunnel Connection-1

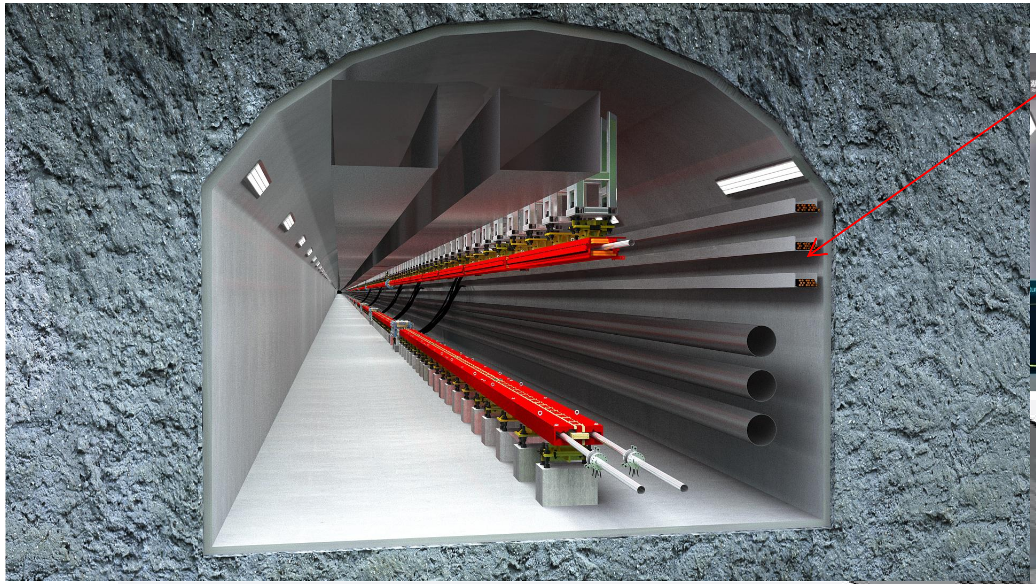


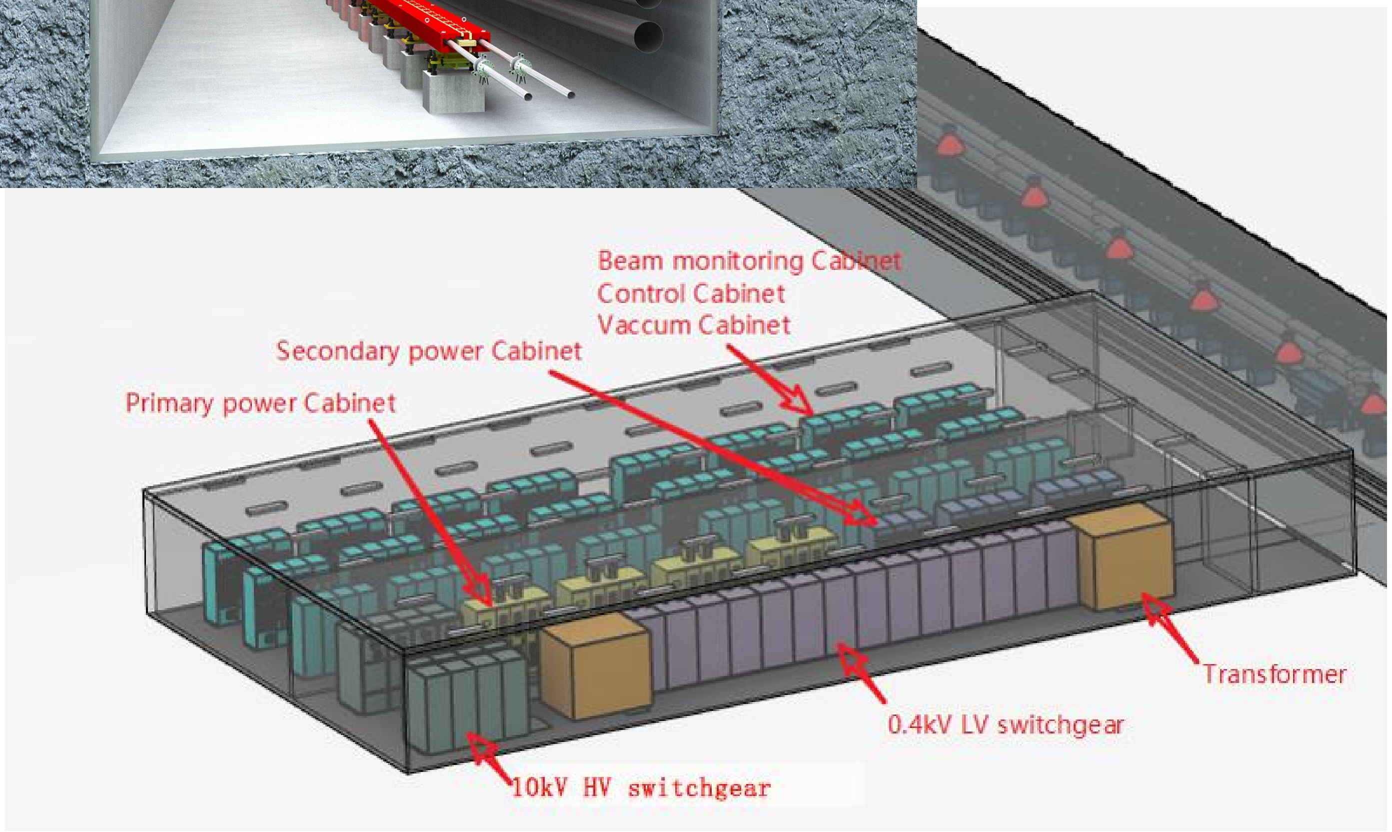
CEPC Conventional Facility and Civil Engineering

Cables installed!

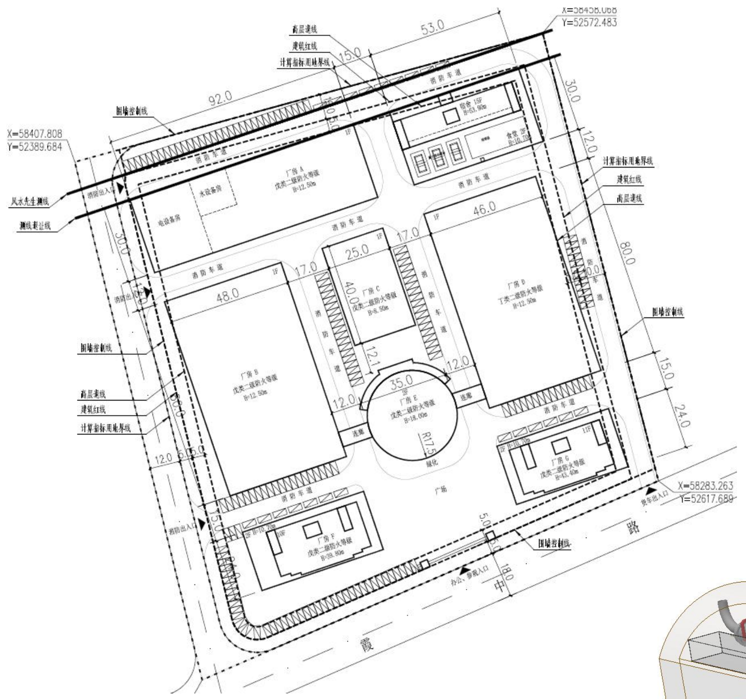
Electrical Equipment General Layout in Auxiliary

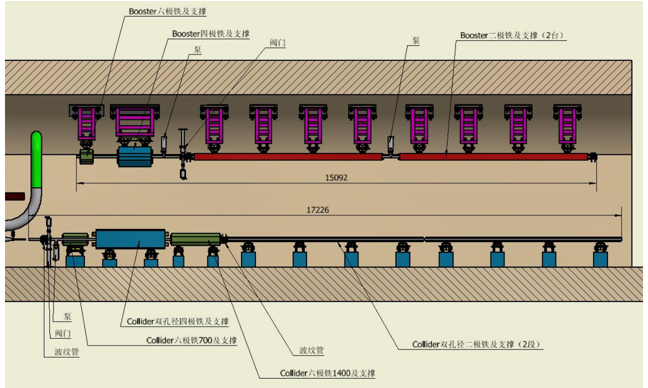


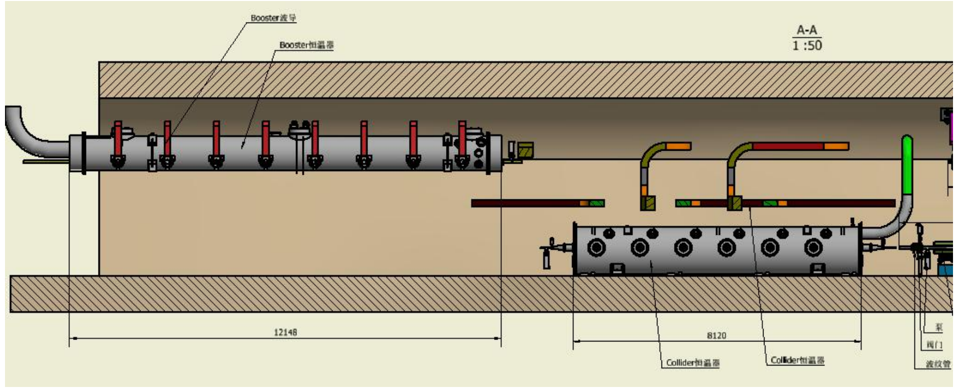


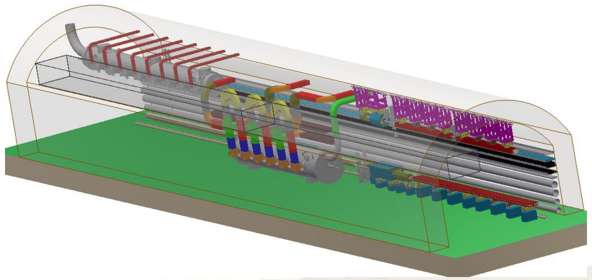


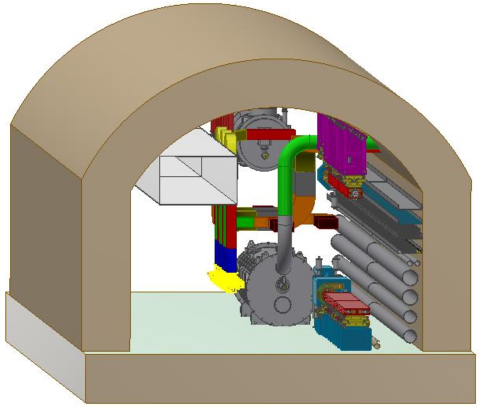
CEPC Tunnel Mockup Design

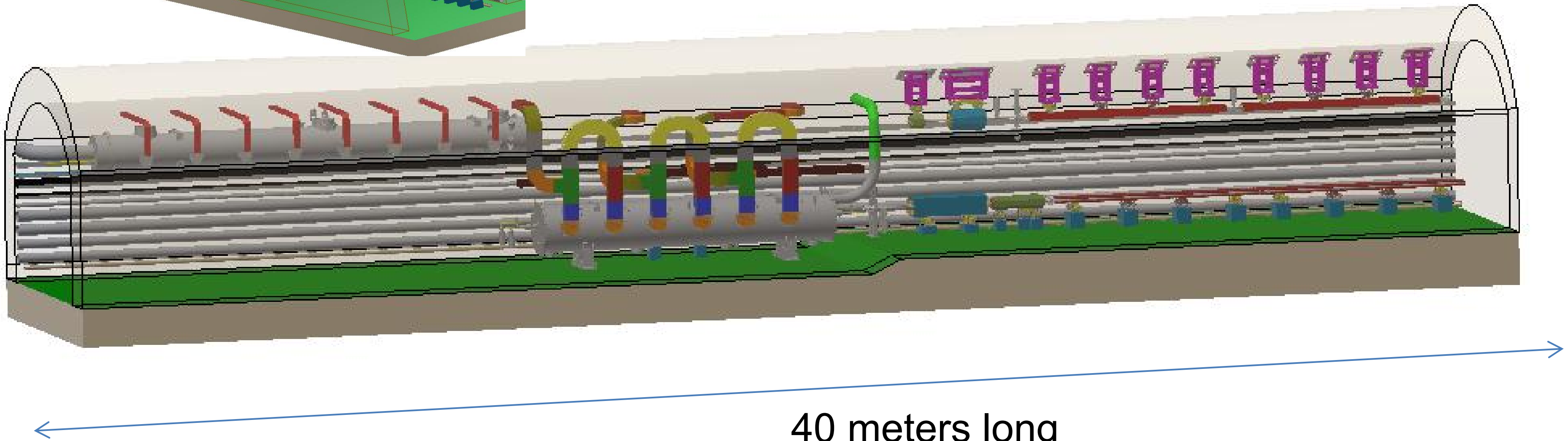






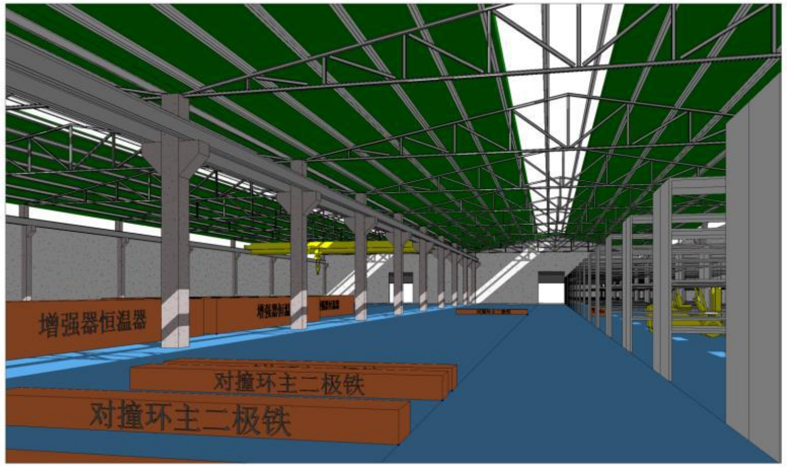


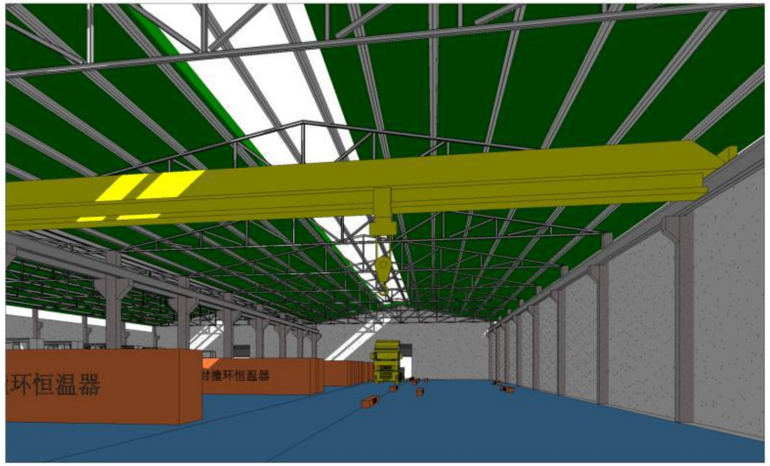


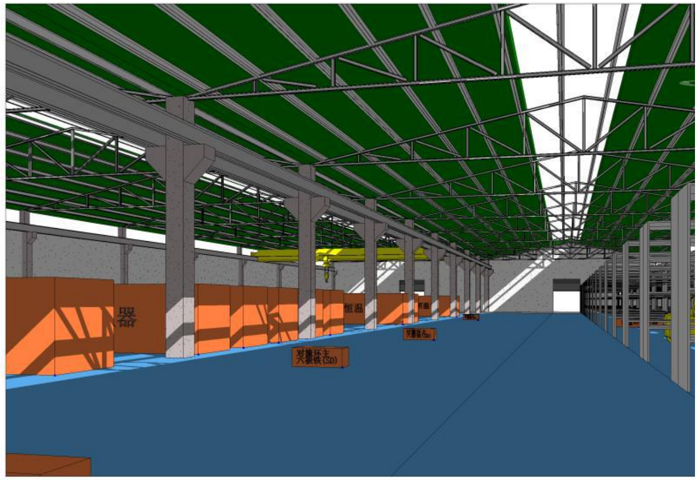


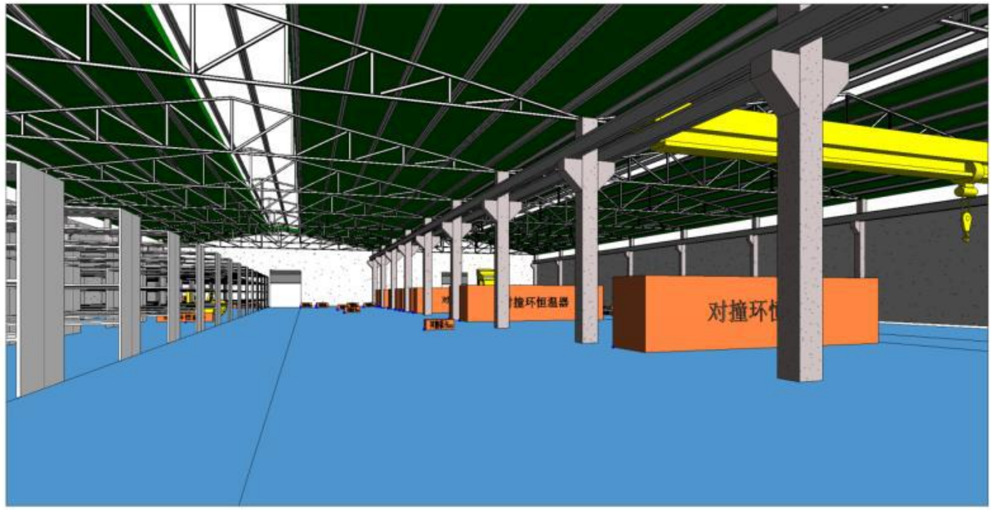
40 meters long

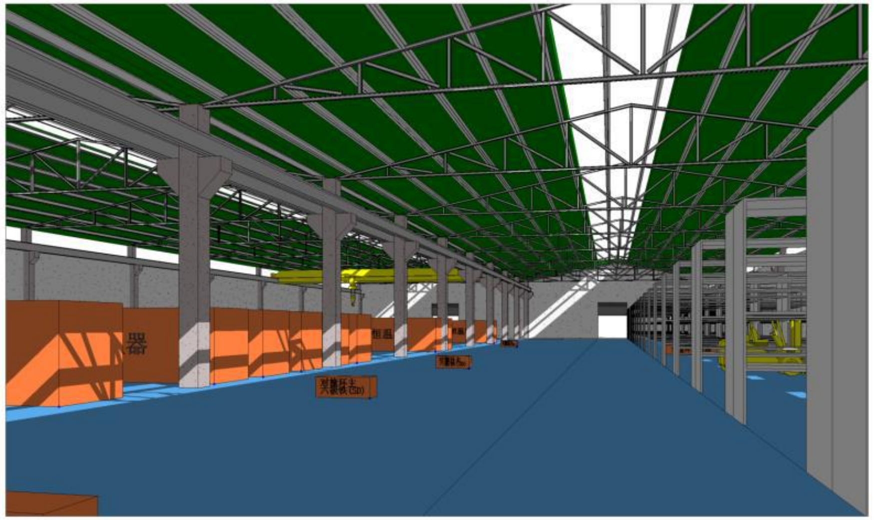
CEPC Component Stores for Installation Optimization











CEPC Collaboratiosn

CEPC Industrial Promotion Consortium (CIPC) Collaboration Status

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

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...

CIPC Member Logo (part of CIPC members' logo)

LEIKE 雷科电子

KAITENG SIFANG

汉 光 科 技

北广科技 BBEF

上创超导

统力电工 TOLY ELECTRIC

高能锐新 HE-RACING TECHNOLOGY

Superconductor Technology 苏州八匹马超导科技有限公司

上 海 普 东 科 技 PUSU

VACREE

慧宇 HUI YU

核工业井巷建设集团有限公司 HUZHOU CHINA

上海超导 SHANGHAI SUPERCONDUCTOR

地矿建设 DIKUANG CONSTRUCTION

昆山国力电子科技股份有限公司 Kunshan GuoLi Electronic Technology Co., Ltd.

Western Superconducting Technologies Co.,Ltd.

中科富海 FULLCRYO

上海辰光医疗科技股份有限公司 Shanghai Chenguang Medical Technologies Co. Ltd

中船重工鹏力（南京）超低温技术有限公司 CSIC PRIDe (NANJING) CRYOGENIC TECHNOLOGY CO.,LTD.

爱科赛博 ACTIONPOWER

江苏克劳特低温 JiangSu Cryote Co., Ltd.

JJJ vac 三井真空

普达迪泰 PRODETEC

北京航天广通科技有限公司 Beijing Grantel Technology Co., Ltd.

中铁装备 CREG

正帆科技 GENTECH

VACUUM PRODUCTS

SEALTECH

SKY

北 京 鼎 荣 达

HUALUN

瑞 隆 Rui Long

RA BRARC

HDKY浩德科仪 HoldKY Vacuum Technologies

RuiYuan

天 合 精 机 TIAN HE JING JI

CRCC 中国铁建

东方钽业 OTIC

中国有色集团成员企业

NVT

冰轮环境 MOON-TECH

JST

金盘科技 JINPAN TECHNOLOGY

东方晨景 East Changing

EDWARDS

CBVAC

黄河勘测规划设计研究院有限公司 Yellow River Engineering Consulting Co., Ltd.

中国电建 POWERCHINA 华东勘测设计研究院 HUADONG ENGINEERING CORPORATION

中国电建 POWERCHINA 中国电建集团昆明勘测设计研究院有限公司 KUNMING ENGINEERING CORPORATION LIMITED

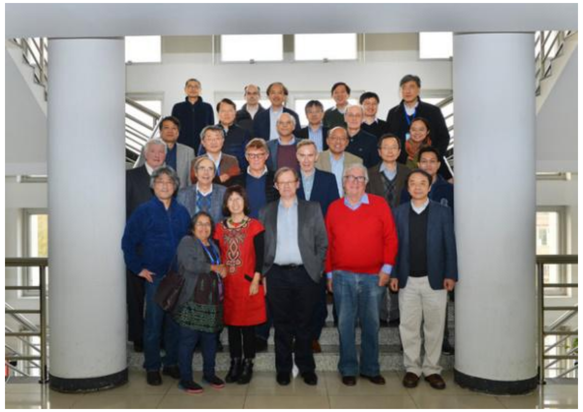
海南展创光电技术有限公司 HZC PHOTONICS

中国电建 POWERCHINA

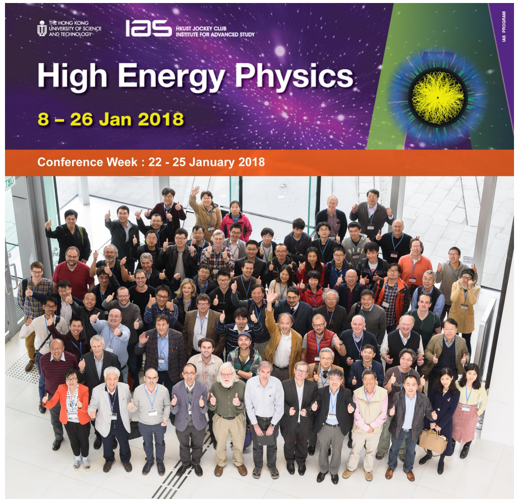
CEPC International Collaboration Meetings

The first CEPC-SppC international Collaboration Workshop
Nov 6-8, 2017, IHEP, Bejing (2018, 2019)

http://indico.ihep.ac.cn/event/6618



The the third CEPC-SppC International Advisory Committee Meeting, Nov 8-9, 2017, Beijing



IAS Higgh Energy Physics Workshop
(Since 2015 till now, every year

http://iasprogram.ust.hk/hep/2018

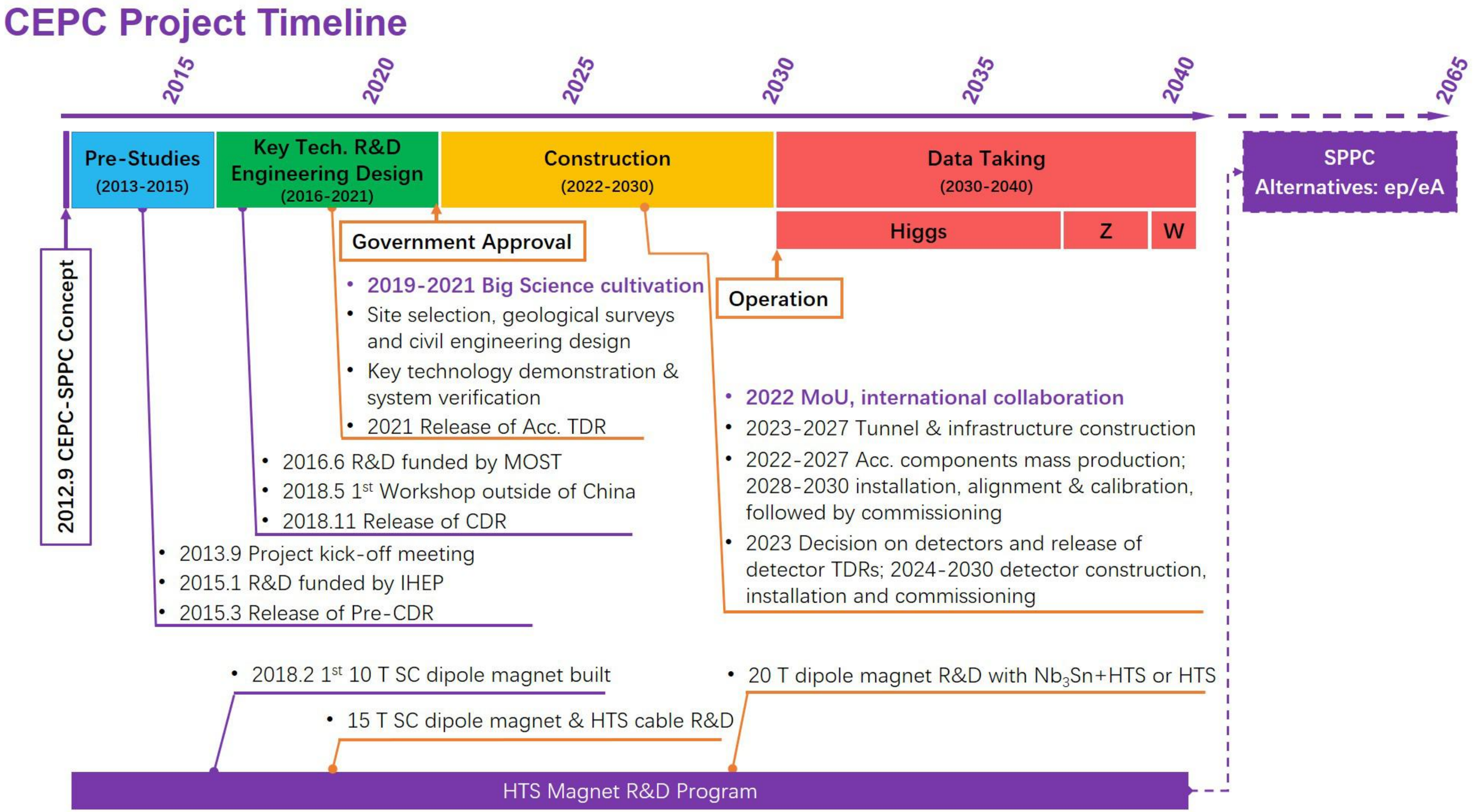
Workshop on the Circuar Electron Positron Collider-EU and US editions

May 24-26, 2018, Università degli Studi Roma Tre, Rome, Italy

https://agenda.infn.it/conferenceDisplay.py?ovw=True&confId=14816

2019 May Oxford,UK, 2019 Sept. Chicago,USA; 2020, May Marseille, France, Catholic University, Washington DC, April 2020

CEPC Timeline



Summary

- After CEPC Accelerator CDR was released, CEPC optimization design efforts continue with higer luminosities for H,W, and Z
- CEPC (+SppC) R&D efforts towards TDR progress well with the aim to complet TDR before 2023
- CEPC and SppC could be compatible in the same tunnel with the same circumference for later e-p collider
- CEPC site selection, civil engineering design and science city planning have new progresses
- CEPC international collaboration and collaboration with industries go well

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