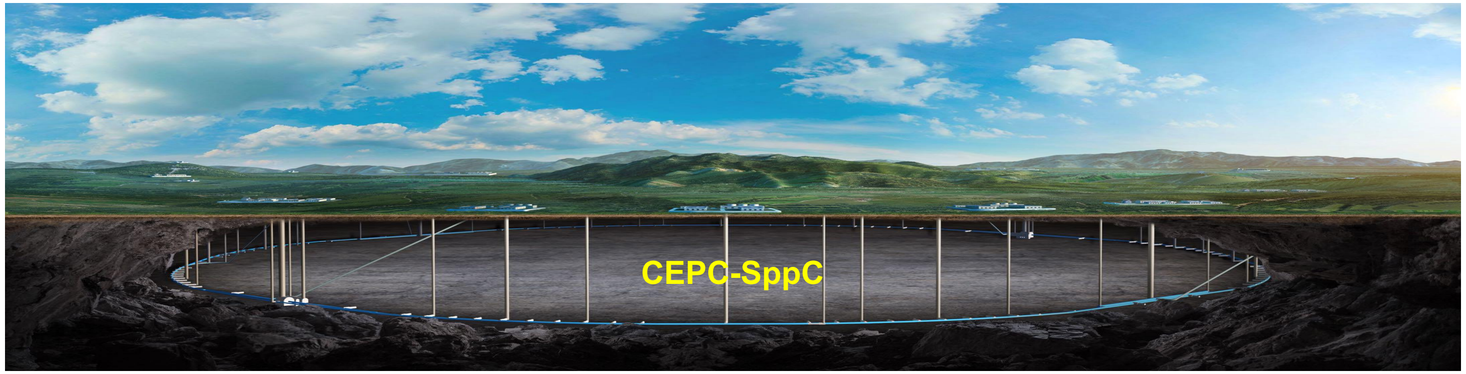
CEPC Accelerator Status and TDR Progress

J. Gao

IHEP

On behalf of CEPC Group

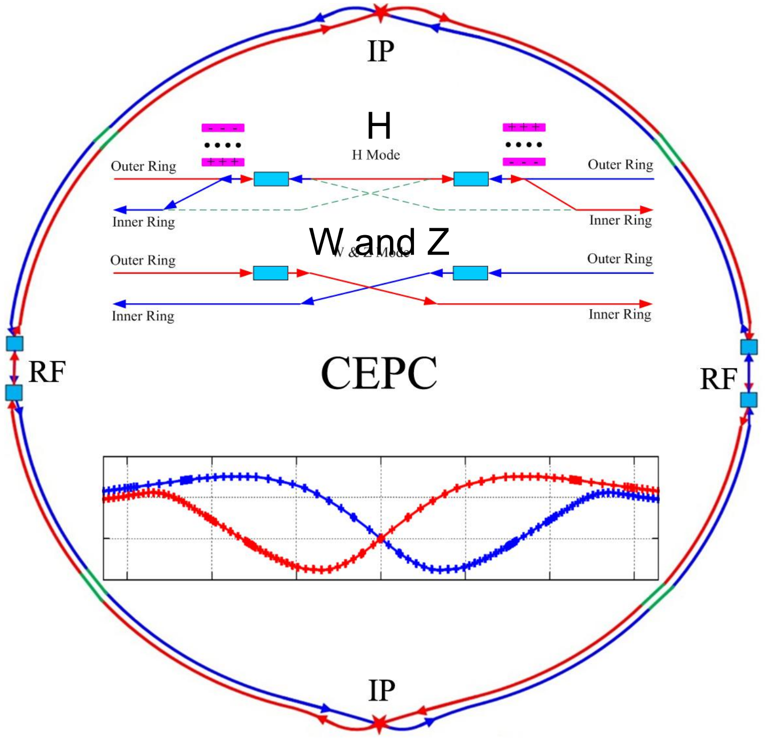


CEPC IAC Meeting 2020, Oct. 29-30，2020

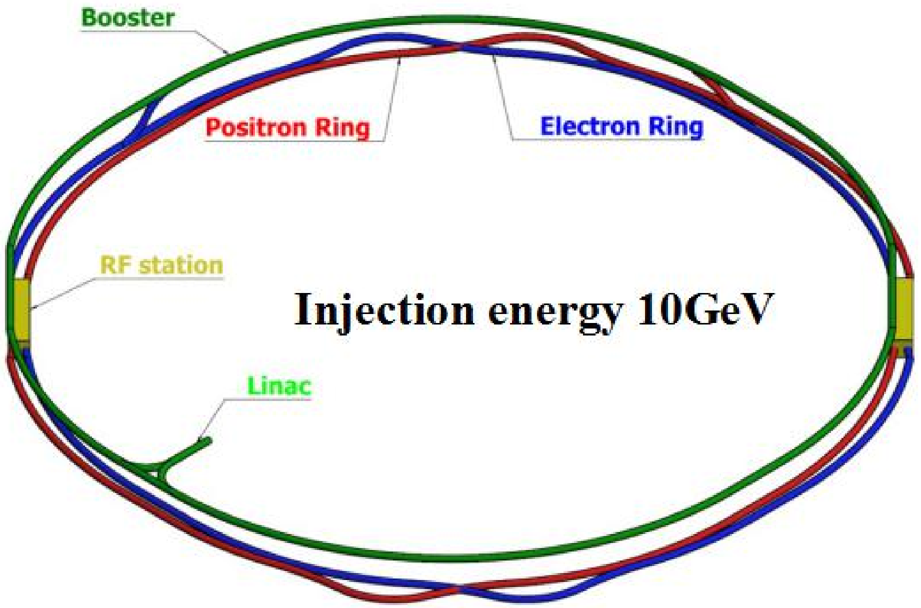
Contents

CEPC CDR Baseline Layout

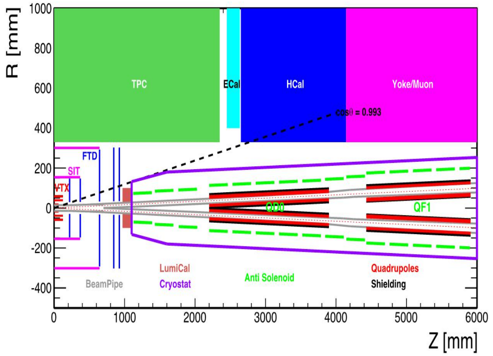
CEPC as a Higgs Factory： H, W, Z, followed by a SppC ~100TeV

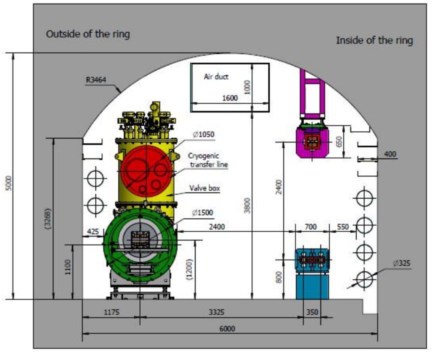


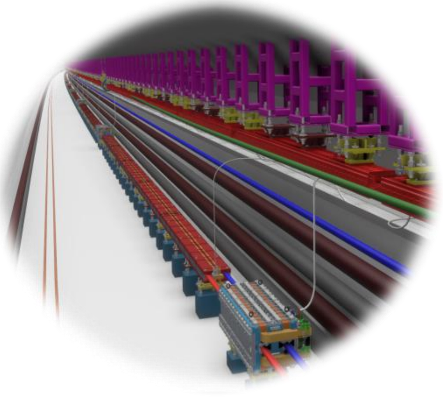
CEPC collider ring (100km)

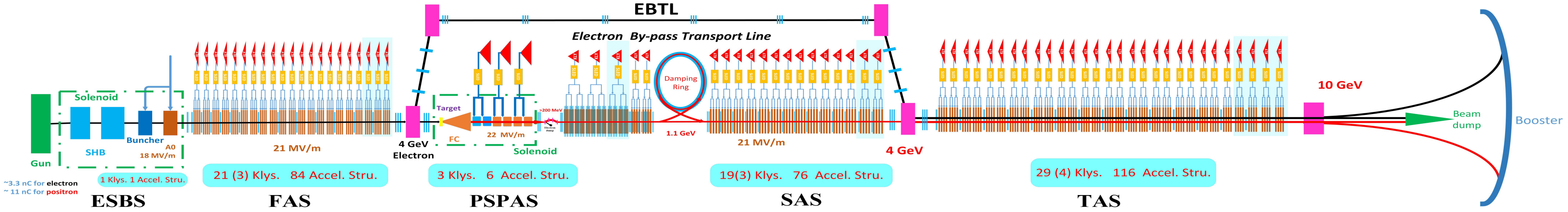


CEPC booster ring (100km)









CEPC Linac injector (1.2km, 10GeV)

CEPC CDR Parameters

	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	
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 CDR Lattice DA with Errors

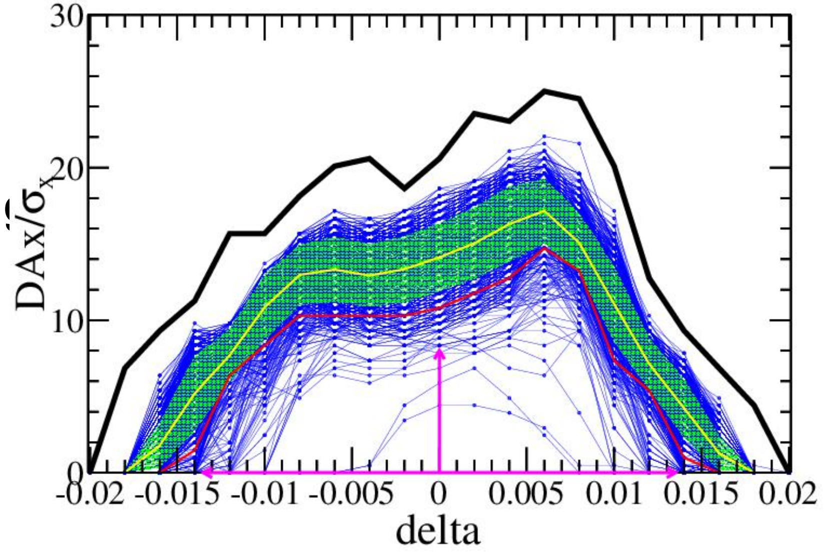
Achieved DA (with errors)@ Higgs: 10σx/21σy/0.00 (on momentum), 2σx/9σy/0.0135 (off momentum)

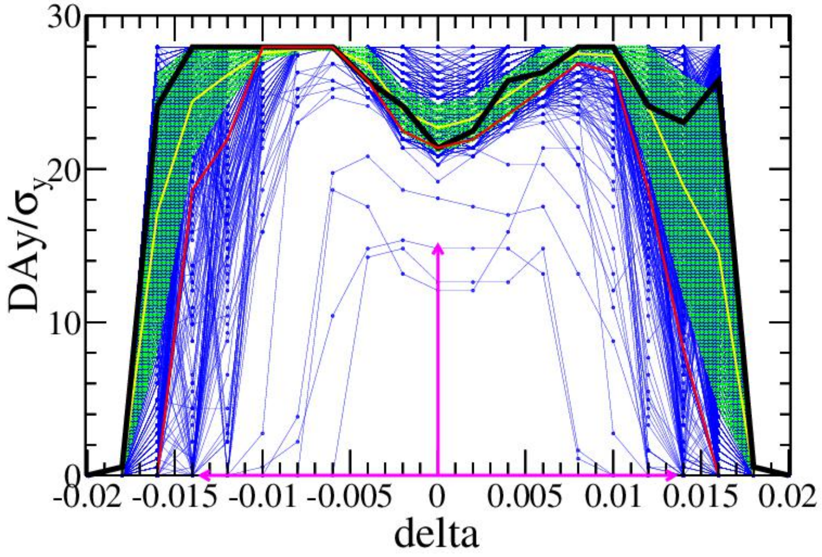
Design DA goal (with errors)@Higgs: 8σx/15σy/0.00 (on momentum), 1σx/1σy/0.0135 (off momentum)

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

CDR lattice design with errors reached the DA design goal

Hi



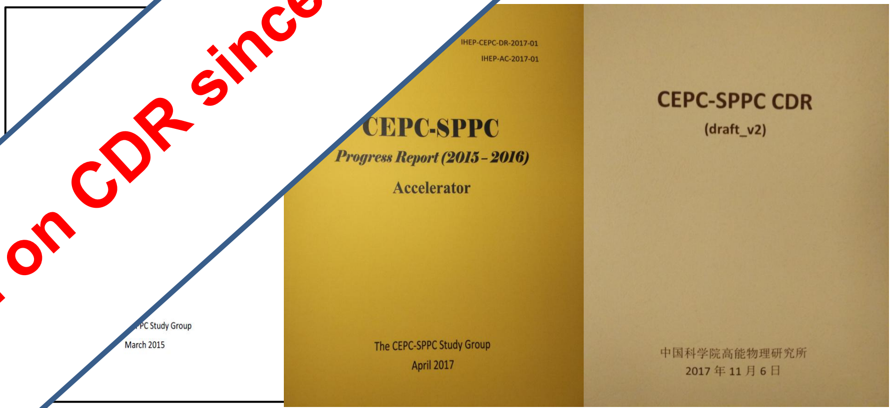


CEPC Accelerator from Pre-CDR R towards TDR

CEPC accelerator CDR completed in June 2018 (to be y 2018)

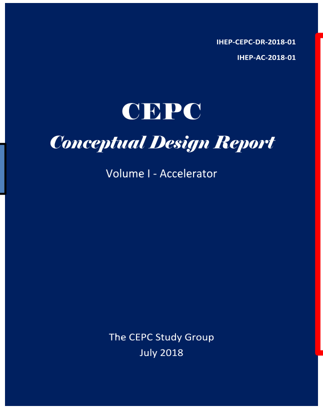
- Executive Summary
1. Introduction
2. Machine Layout and Performance
3. Operation Scenarios
4. CEPC Collider
5. CEPC Booster
6. CEPC Linac
7. Systems Common to the CEPC Linac, Bo and Collider
8. Super Proton Proton Collider
9. Conventional Facilities
10. Environment, Health and Saf
11. R&D Program
12. Project Plan, Cost and S
- Appendix 1: CEPC
- Appendix 2: CE ent List
- Appendix 3: C Requirement
- Appendix Double Ring
- Append Based on Plasma Wakefield Accelerator
- App s a High Intensity γ-ray Source
- A for e-p, e-A and Heavy Ion Collision
- tunities for Polarization in the CEPC
- ernational Review Report

CEPC TDR R&D Started based on CDR since 2019



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: 1901.03170

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 High Luminosity Parameter after CDR

	Higgs (high_lum.)	*Z (high_lum.)*
Number of IPs	2	2
Beam energy (GeV)	120	45.5
Circumference (km)	100	100
Synchrotron radiation loss/turn (GeV)	1.8	0.036
Crossing angle at IP (mrad)	16.5	16.5
Piwinski angle	4.87	18.0
Number of particles/bunch N_e (10^{10})	16.3	16.1
Bunch number (bunch spacing)	214 (0.7us)	10870 (27ns)
Beam current (mA)	16.8	841.0
Synchrotron radiation power /beam (MW)	30	**30**
Bending radius (km)	10.2	10.7
Momentum compact (10^{-5})	7.34	2.23
β function at IP β_x* / β_y* (m)	0.33/0.001	0.15/0.001
Emittance e_x/e_y (nm)	0.68/0.0014	0.52/0.0016
Beam size at IP σ_x/σ_y (μm)	15.0/0.037	8.8/0.04
Beam-beam parameters ξ_x/ξ_y	0.018/0.115	0.0048/0.129
RF voltage V_{RF} (GV)	2.27	0.13
RF frequency f_{RF} (MHz)	650	650
Natural bunch length σ_z (mm)	2.25	2.93
Bunch length σ_z (mm)	4.42	9.6
Energy spread (%)	0.19	0.12
Energy acceptance requirement (%)	1.7	1.4
Energy acceptance by RF (%)	2.5	1.5
Beamstruhlung lifetime /quantum lifetime (min)	41	-
Lifetime (hour)	0.35	1.8
Luminosity/IP L (10^{34}cm^{-2}s^{-1})	**5.0**	**101.1**

* High luminosity Z's lattice is same as Higgs CDR lattice. but high luminosity Higgs has a new lattice than that of CDR

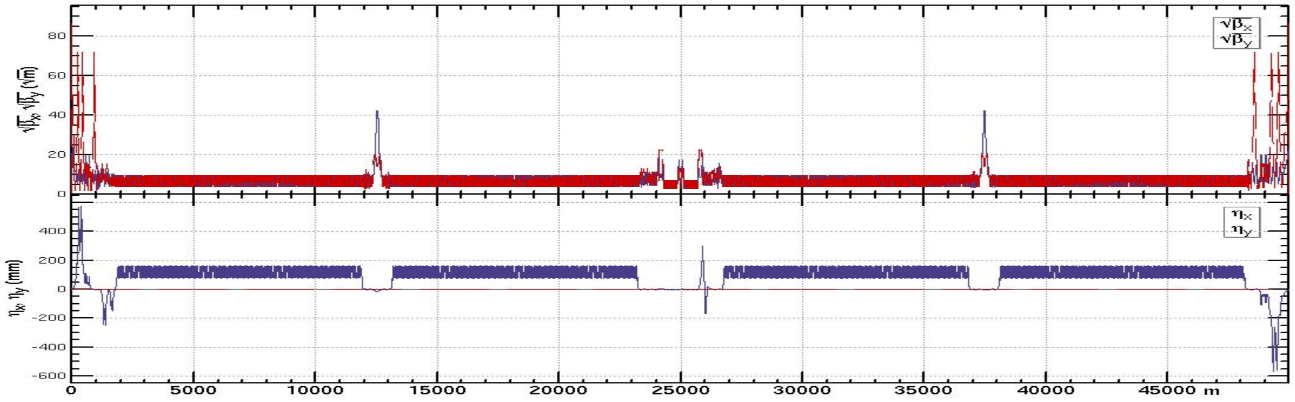
CEPC Higgs High Lumi Lattice and Dynamic Aperture Status

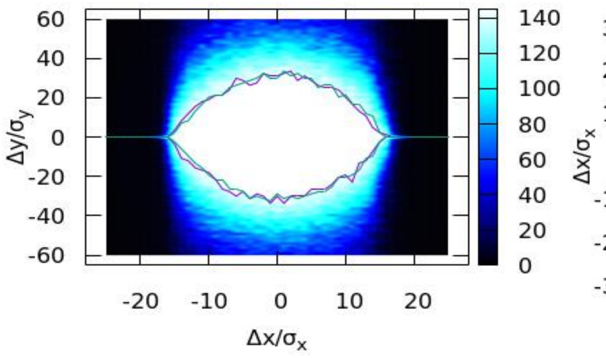
- Fit parameter list with luminosity of $5.2 \times 10^{34}/\mathrm{cm}^2/s$
  - Stronger optimization and stricter hardware requirement should be made to get enough dynamic aperture
- Optimization of the quadrupole radiation effect
  - Interaction region: longer QD0/QF1 (2m/1.48m => 3m/2m)
  - ARC region: longer quadrupoles (2m => 3m)
- Reduction of dynamic aperture requirement from injection
  - Straight section region: larger βx at injection point (600m => 1800m)
- 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

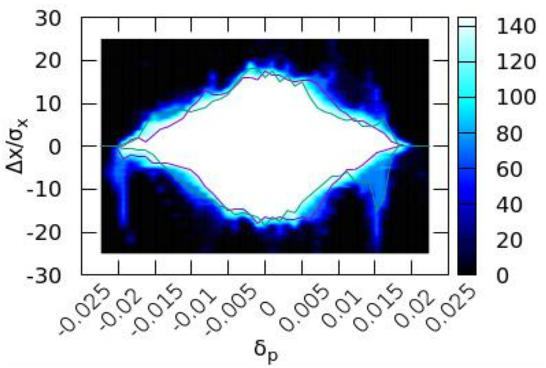
- With better correction of energy dependent aberration and shorter L* (without changing the front-end position of the final doublet cryo-module)

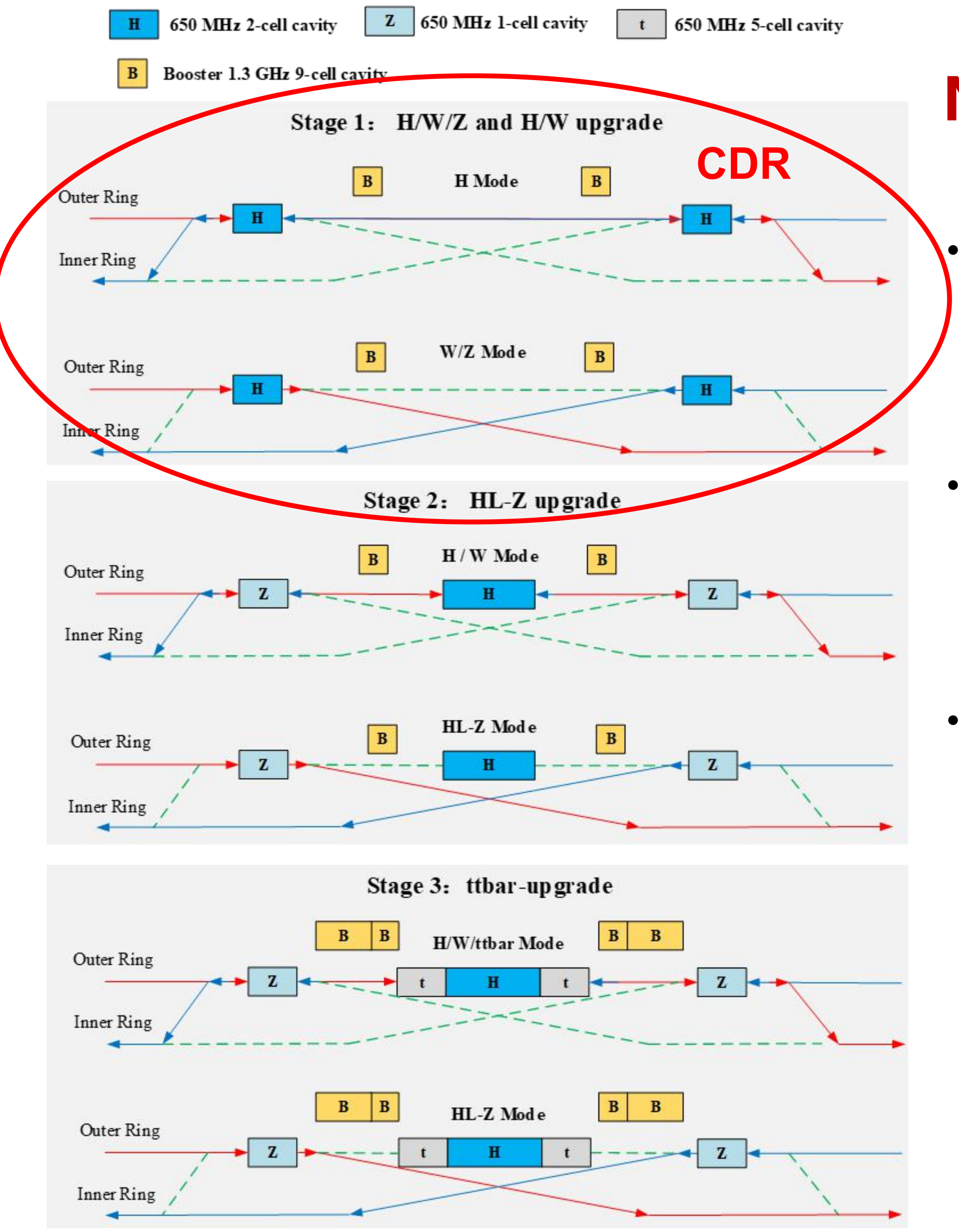
Goal (w/ error): $8\sigma_x \times 15\sigma_y \times 1.7\%$

Achieved (w/o error): $16\sigma_x \times 32\sigma_y \times 1.9\%$









New RF Staging & By-pass Scheme for CEPC

- **Stage 1 (H/W run for 8 years):** Keep CDR RF layout for H(HL-H)/W and 50 MW upgrade. Common cavities for H. Separate cavities for W/Z. Z initial operation for energy calibration and could reach CDR luminosity. **Minimize phase 1 cost and hold Higgs priority**.
- **Stage 2 (HL-Z upgrade)**: Move Higgs cavities to center and add high current Z cavities. **By-pass low current H cavities**. International sharing (modules and RF sources): Collider + 130 MV 650 MHz high current cryomodules.
- **Stage 3 (ttbar upgrade):** add ttbar Collider and Booster cavities. International sharing (modules and RF sources): Collider + 7 GV 650 MHz 5-cell cavity. Booster + 6 GV 1.3 GHz 9-cell cavity. Both low current, high gradient and high Q, Nb_3Sn etc. 4.2 K?

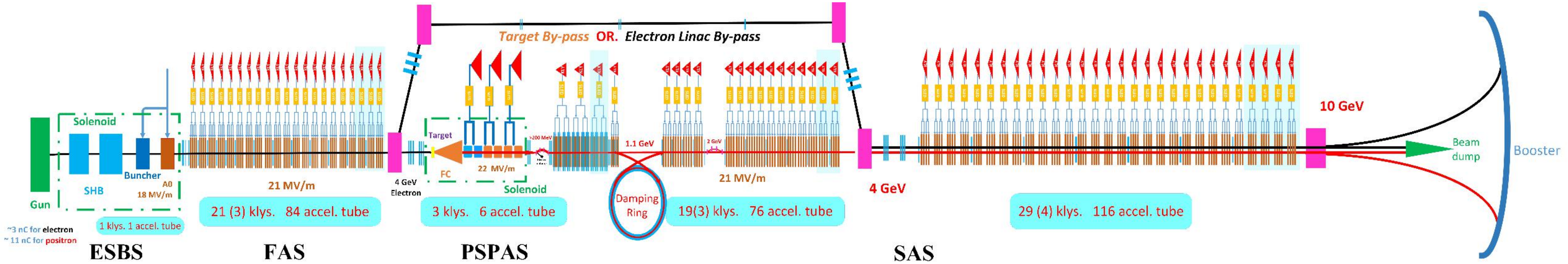
Unleash full potential of CEPC with flexible operation. **Seamless mode switching** with unrestricted performance at each energy until AC power limit. **Stepwise cost, technology and international involvement with low risk.**

CEPC SRF Parameter with By Pass Schemes

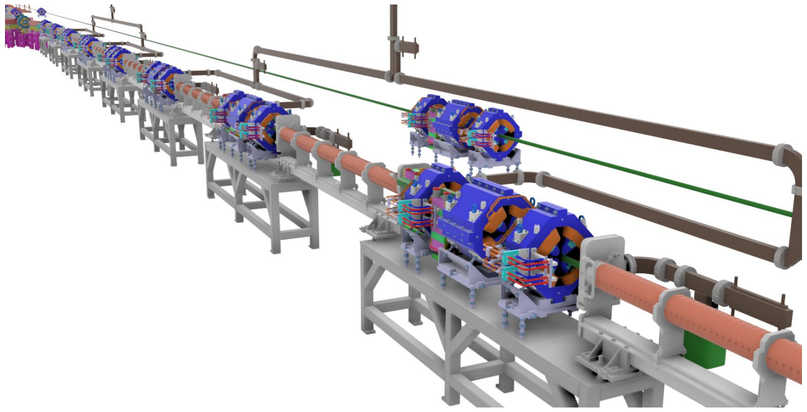
	BEPCII 500 MHz 4.2 K	**BEPC3** 500 MHz 4.2 K	**CEPC CDR H** 30 MW 3E34	**CEPC CDR Z** 16.5 MW 32E34	**CEPC 1-cell H** 30 MW 3E34	**CEPC TDR Z** 30 MW 100E34	**CEPC TDR H** 30 MW 3E34	**CEPC TDR W** 30 MW 10E34	**CEPC Ultimate Z 50 MW 167E34**
Beam current (mA)	400 (600)	900	2 x 17.4	460	2 x 17.4	**838**	2 x 17.4	2 x 87.7	1400
Cell number	1	1	2		1	1	2/1	2/1	1
Cavity number / ring	1	2	2 x 120	60	2 x 120	60	2x(90+60)	2x(90+60)	60
Eacc (MV/m)	6 (1.5 MV)	10 (2.5 MV)	**19.7**	3.6	**40**	**9.4**	**19.7**	4.2	9.4
Q_0 @ 4.2 K / 2 K	1E9	1E9	**1.5E10**	1.5E10	**3E10**	**1.5E10**	**1.5E10**	1.5E10	1.5E10
Total wall loss (kW)			6.1	0.1	6.1	0.35	6.1	0.27	0.35
Input power (kW)	110	150	250	275	250	**500**	250/125	250/125	**835**
Cavity# / klystron	1	1 SSA	2		2/1	1	2/1	2/1	1
Klystron power (kW)	250	150 SSA	800	800	800	800	800	800	1200
Total KLY number	2	4	120		60+120	120	90+120	90+120	120
HOM damper	Absorber	Absorber	Hook+ Absorber		Hook+ Absorber	Absorber	Hook+ Absorber	Hook+ Absorber	Absorber
HOM power (kW)	8*	20	0.6	1.9	0.23	2.4	0.46 / 0.23	**1.5** / 0.75	**4**

* Bunch length 15 mm, cavity cell HOM loss factor 0.1 V/pC, tapers 0.06 V/pC, absorbers 0.26 V/pC.

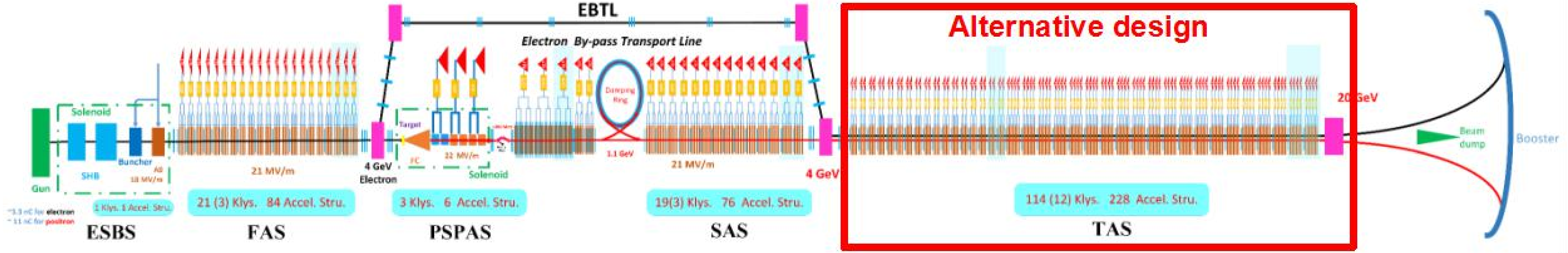
CEPC Linac Injector (CDR)



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



CEPC 20-GeV Linac Injector Alternative Scheme



- **Parameters**

S-band Accelerating structure

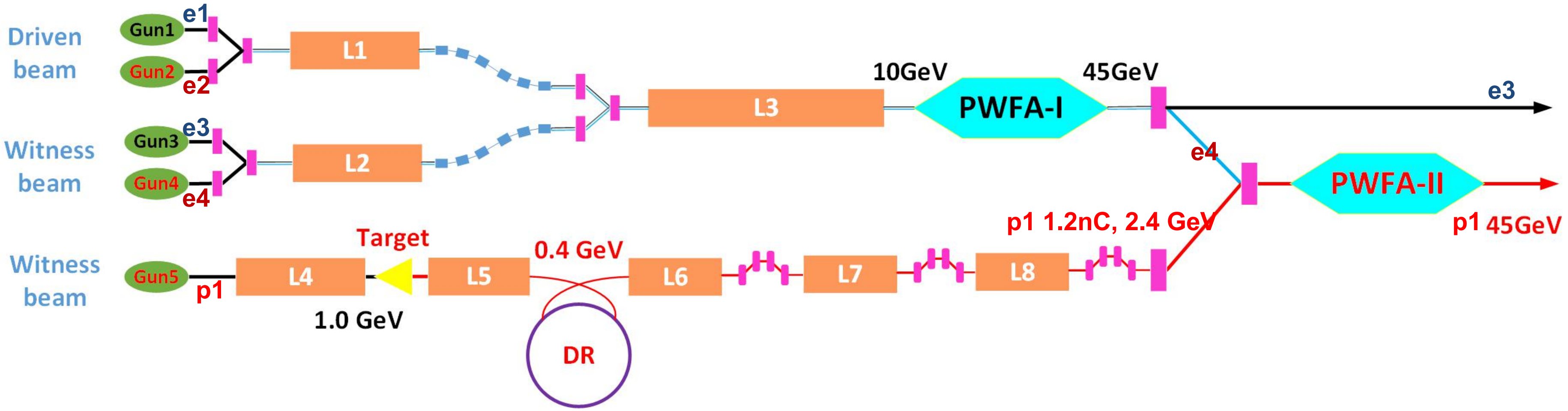
C-band Accelerating structure

C-band: 4GeV → 20GeV

Parameter	Symbol	Unit	Baseline	Alternative
e^-/e^+ beam energy	E_{e-}/E_{e+}	GeV	10	20
Repetition rate	f_{rep}	Hz	100	100
Bunches/pulse			1	1
e^-/e^+ bunch population	$Ne-/Ne+$	nC	>1.5 (3)	>1.5 (3)
Energy spread (e^-/e^+)	σ_E		$<2\times10^{-3}$	$<2\times10^{-3}$
Emittance (e^-/e^+)	ε_r	nm	40	20

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

CEPC Plasma Injector Design

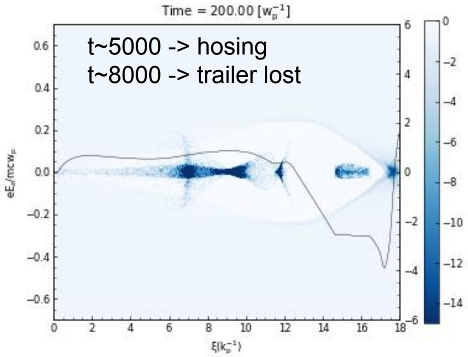


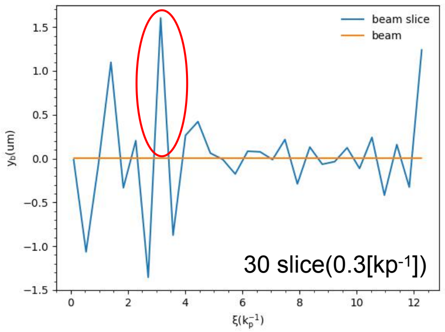
	e1/e3 Before PWFA-I	e3 After PWFA-I	e2/e4 Before PWFA-I	e4 After PWFA-I	p1 Before PWFA-II	p1 After PWFA-II	Booster Requirement
Energy (GeV)	10/10	45.5	10/10	45.5	2.4	45.5	45.5
Bunch Charge (nC)	5.8/0.84	1	15/4.5	>3	1.2	1	0.78
Bunch length (ps)	2/0.257	<1	3/0.7	<1	0.07	<1	<10
Energy Spread	~/0.2%	~1%	~/0.2%	1%	0.2%	~1%	0.2%
E_{normal} (μm rad)	<20*/<100	~100	<50*/<100	~100	<50	~100	<800
Bunch Size (μm)	3.87/8.65	<20	30/20	<20	20	<20	<2000

The plasma accelerator performance has been checked with the real linac beam quality, and it almost reached the design goal

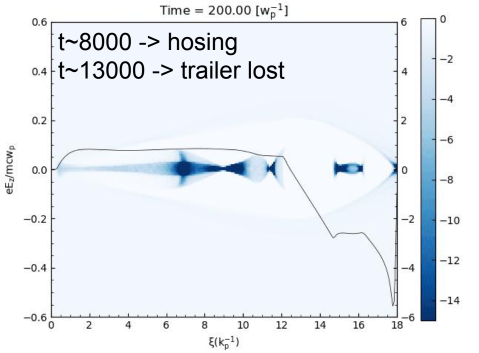
CEPC Plasma Injector Start to End Simulation

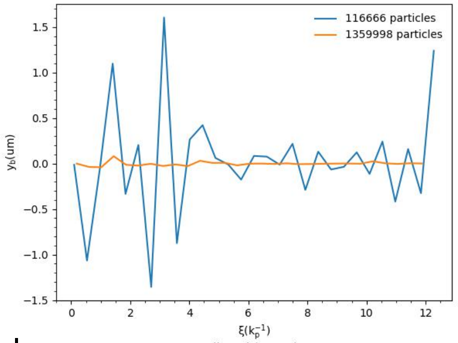
- ➢ Longitudinal shaping is well maintained → TR ☼
- Big slice jitter in PWFA acceleration → hosing → Transverse-Longitudinal coupling





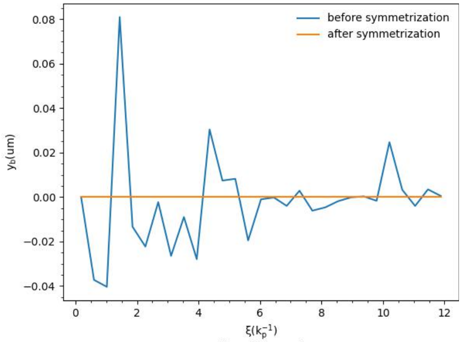
Driver initial beam centroid



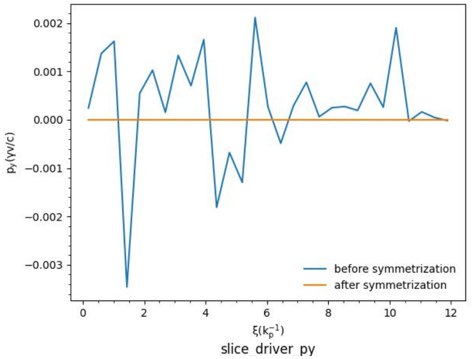


0.11m particles → 1.36m particles

slice driver yb

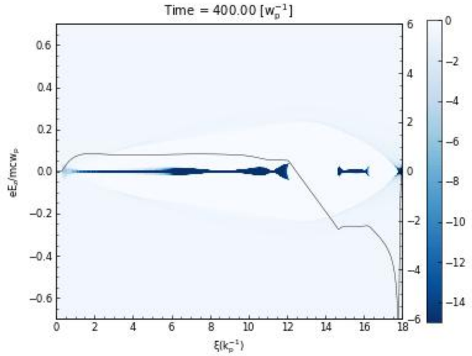


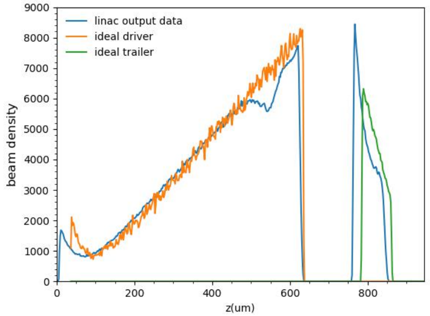
slice driver yb



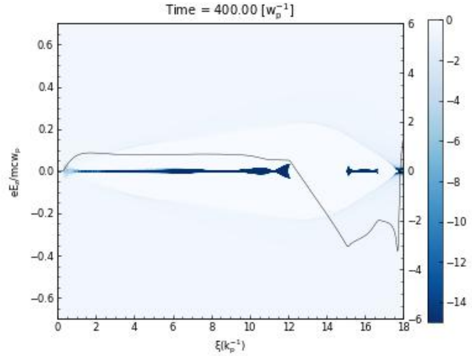
slice driver py

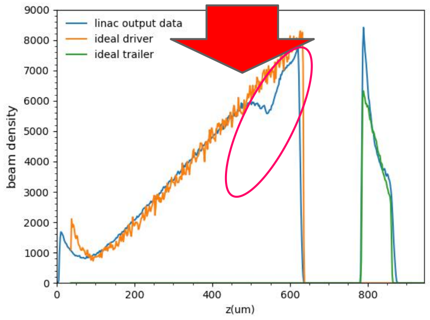
beam initial$[x, y.px.py]\sim[0,0,0,0]$





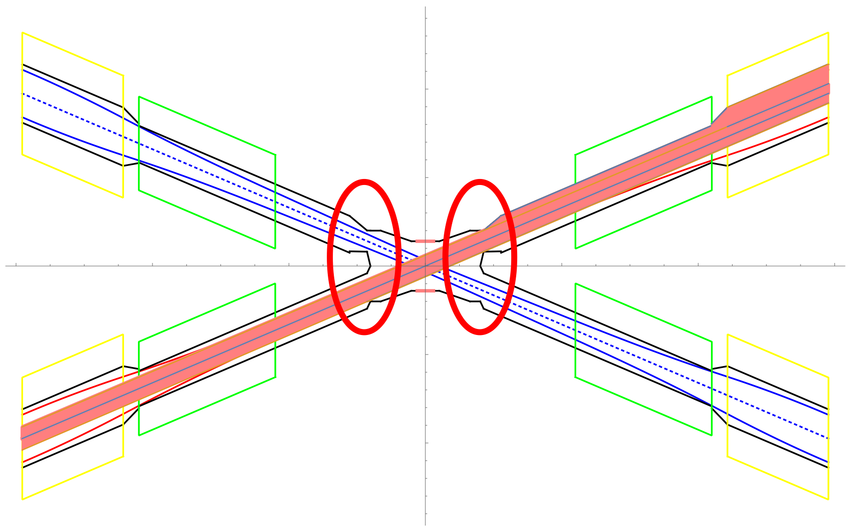
	Beam symmetrization	Change beam distance	Design
Δz(um)	126.7	149	149
Et(GeV)	40.6	42.80	45.5
Qt(nC)	0.9	0.7909	0.84





$1kp^{-1}\sim52.52um$

CEPC CDR MDI updated Design: Beam Pipe and Vacuum Chamber-1



- **Most important update:** **asymmetric up & down stream beampipe apertures**

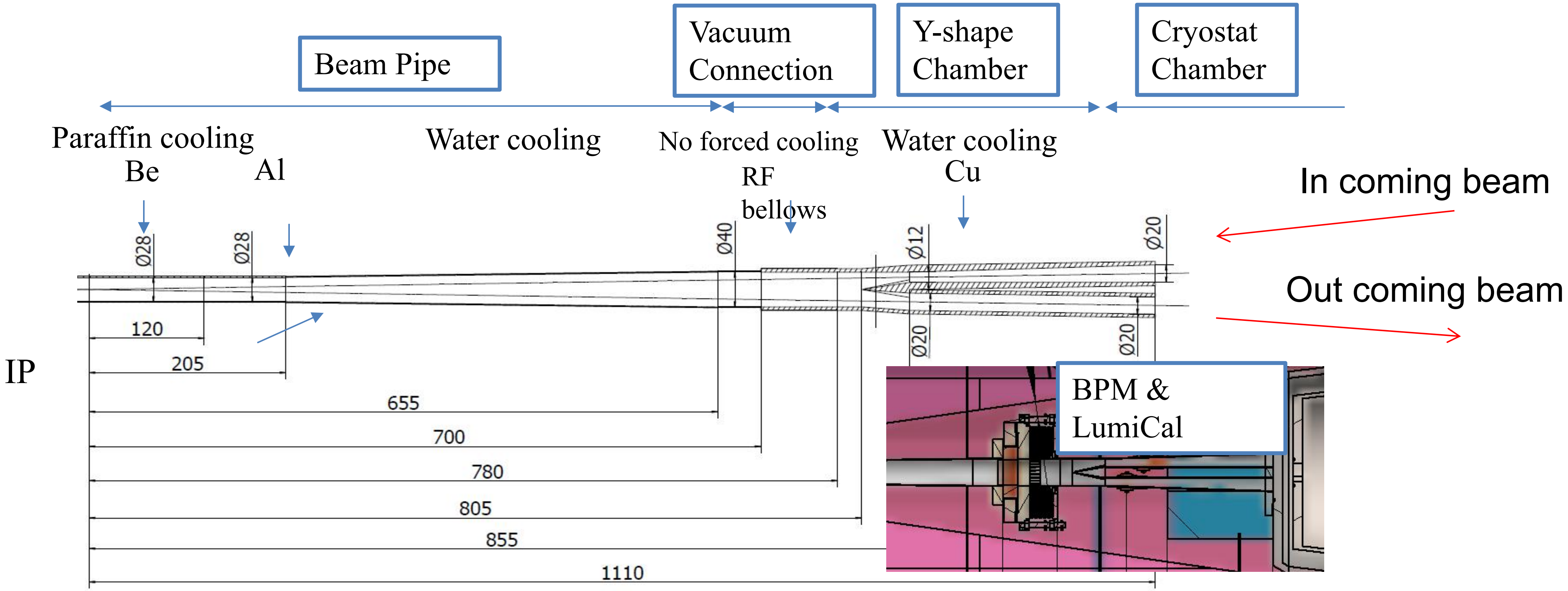
Feasibility confirmed by accelerator physics and mechanics design

↓

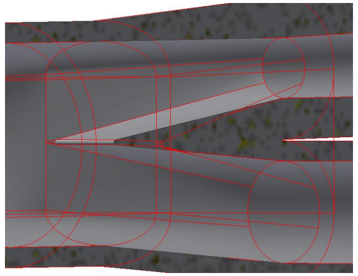
Guaranteed: no SR power deposition between **±0.855 m**

	Power Deposition	Average Power Density
0.855m~1.11m	36.53 W	39.79 W/cm^2
1.11m~2.2m	2.24 W	0.57 W/cm^2
QD0	4.34 W	0.6 W/cm^2
QD0~QF1	48.04 W	58.02 W/cm^2
QF1	4.56 W	0.86 W/cm^2

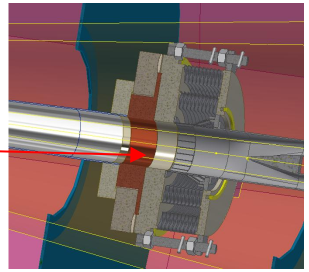
CEPC CDR MDI updated Design: Beam Pipe and Vacuum Chamber-2



Asymmetric design to prevent direct hitting of synchrotron radiation photons

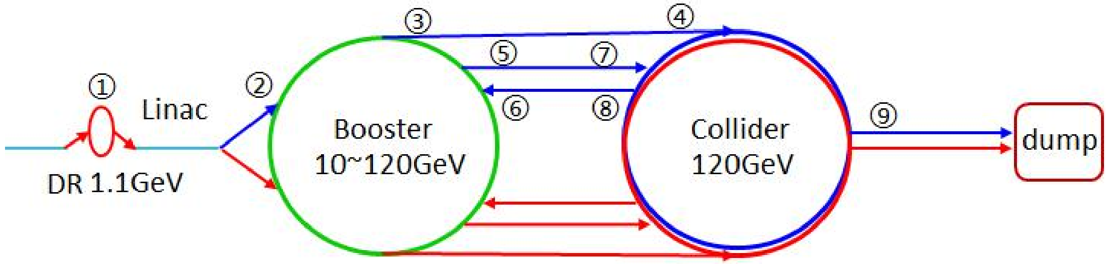


Remaining issue: difficult to dissipate the heat around the RF finger



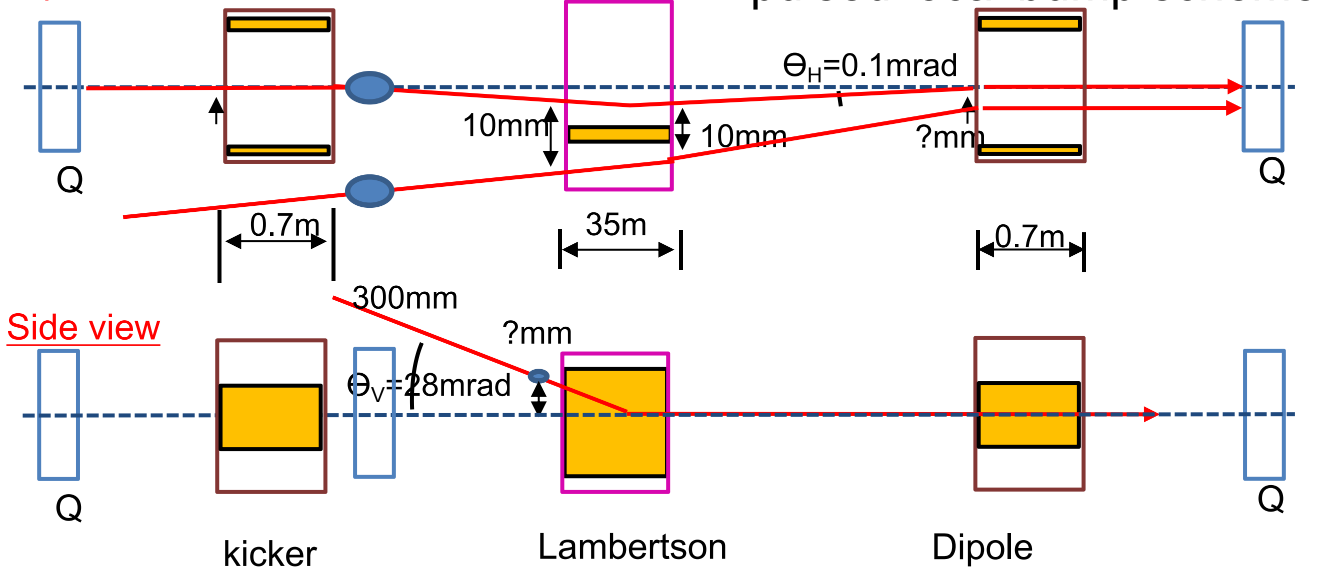
CEPC Injection and Extraction Systems

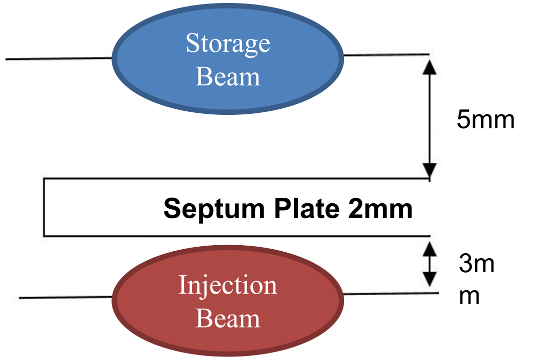
	Sub-system	Kicker Type	Kicker waveform	Septa Type
1	Damping ring inj./ext.	Slotted-pipe kicker	Half-sine/250ns	Horizontal LMS
2	Booster LE inj.	Strip-line kicker	Half-sine/50ns	Horizontal LMS
3	Booster ext. for CR off-axis inj.	Delay-line dipole kicker	Trapezoid /440-2420ns	Vertical LMS
4	Collider off-axis 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



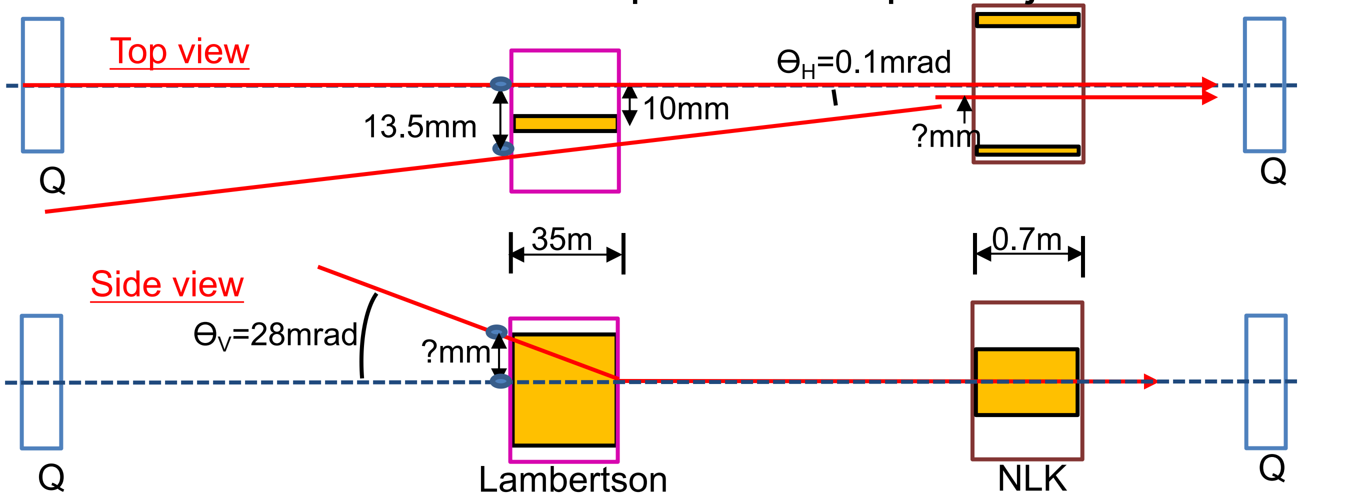
Collider Ring off-axis Injection

pulsed local bump scheme

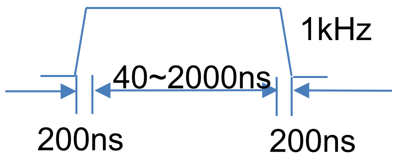




pulsed multipole injection scheme



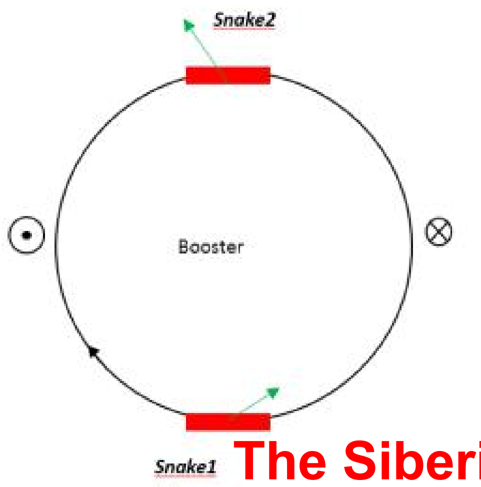
1. **Dipole kicker:** horizontal out-vacuum delay-line kicker+coating ceramic chamber+PFN-based solid-state pulser
2. **NLK kicker:** horizontal out-vacuum delay-line **NLK** kicker+coating ceramic chamber+PFN-based solid-state pulser
3. **Septa:** Vertical Lambertson magnet



Siberian Snake in the Booster Ring for the Ramping of the Vertically Polarized Beam to the Z-pole Energy

- **Snake configuration:**
  - $\eta_1 = \eta_4, \eta_2 = \eta_3$.
  - $r_{h1} = -r_{h4}, r_{h2} = -r_{h3}$.
  - $N_1 = N_4, N_2 = N_3$, where N_j is the number of periods in the jth helix.
  - The magnetic field at the entrance of each helix is vertical ($\alpha_i = 0$).

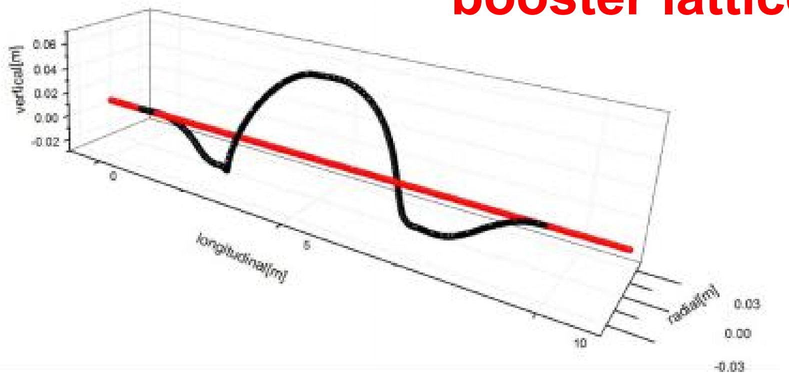
Here we choose η1=η2=η3=η4=1, N1=N2=N3=N4=1.



The Siberian Snake will be inserted into the booster lattice

- **Preliminary parameters of Snake:**

Helical Magnets				
#	length	Field helicity	Field orientation at entrance/exit	Field strength
1	2.4m	right-handed	vertical	1.01T
2	2.4m	right-handed	vertical	-3.26T
3	2.4m	right-handed	vertical	3.26T
4	2.4m	right-handed	vertical	-1.01T
Max. orbit excursion(hor/ver) (at 10GeV)				76mm/240mm
Radiation energy loss per turn in snakes U0[MeV] (at 10GeV/45.5GeV)				7.08/146.62



Orbital motion in Snake

CEPC Accelerator TDR R&D Priority, Plan and Test Facilities

Red Color means R&D issues have test facilities

1) CEPC 650MHz 800kW high efficiency klystron (80%) (at the end of 2021 complete the fabriation, finish test in 2022)

2) High precision booster dipole magnet (critical for booster operation) (Complete real size magnet model in 2021)

3) CEPC 650MHz SC accelerator system, including SC cavities and cryomules (Complete test cryomodule in 2022)

4) Collider dual aperture dipole magnets, dual aperture qudrupoles and sextupole magntes(Complete real size model in 2022)

5) Vacuum chamber system (Complete fabrication and costing test in 2022)

6) SC magnets including cryostate (Complete short test model in 2022)

7) MDI mechanic system (Remote vacuum connection be test in 2022)

8) Collimator (Complete model test in 2022)

9) Linac components (Complete key components test in 2022)

10) Civil engineering design (Reference implementation design complete in 2022)

11) Plasma injector (Complete electron accelerator test in 2022)

12) 18KW@4.5K cryoplant (Company)

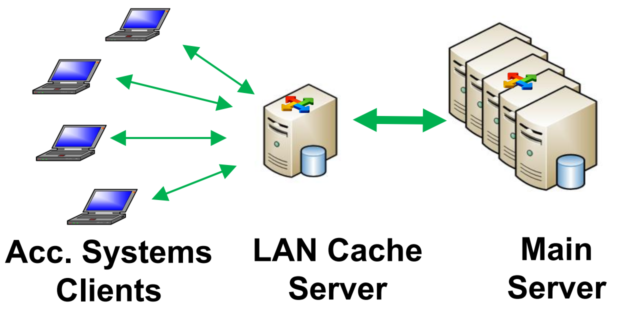
...

SppC technology R&D

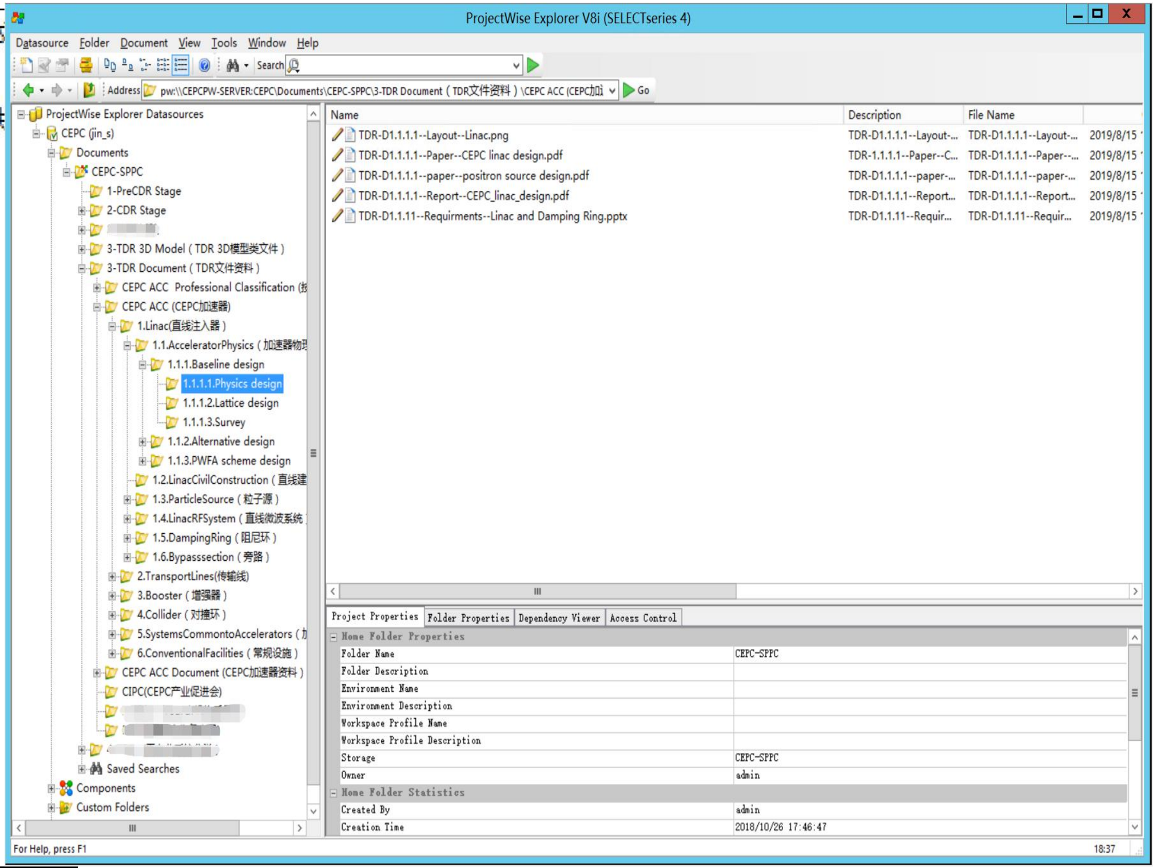
Ion based supercondcuting materials and high field magnets

CEPC Accelerator Documents Management

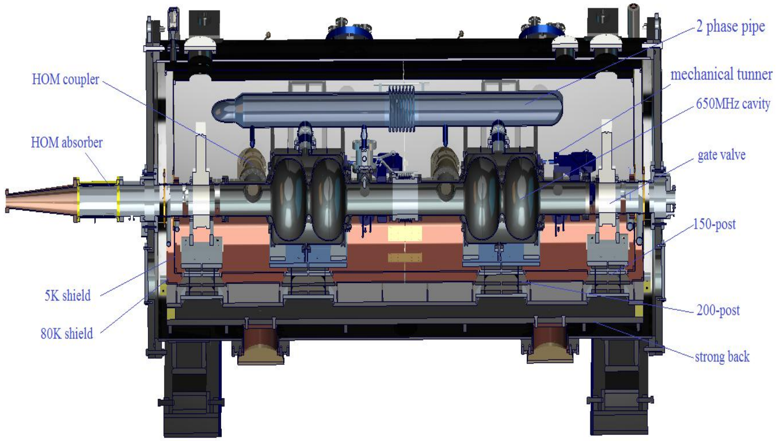
- Documents management for CEPC accelerator based on a professional software--ProjectWise.



CEPC accelerator documents storage



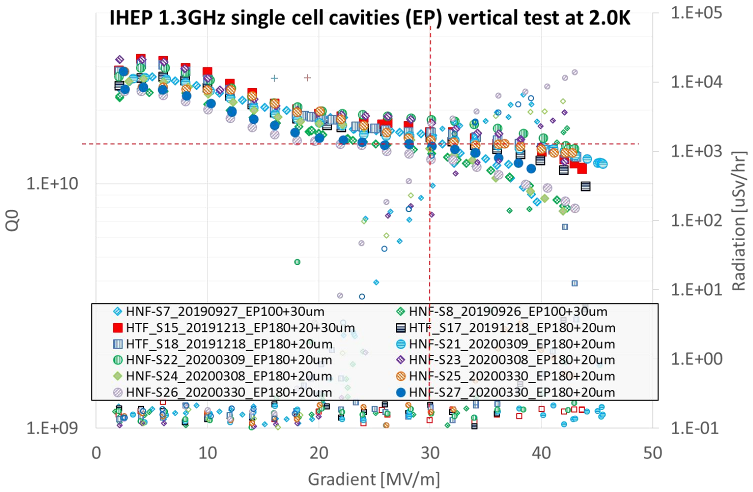
CEPC SCRF R&D Progresses



CEPC 2*2cell 650MHz cryomodule with beam test later

General superconducting cavity test cryomodule in IHEP New SC Lab

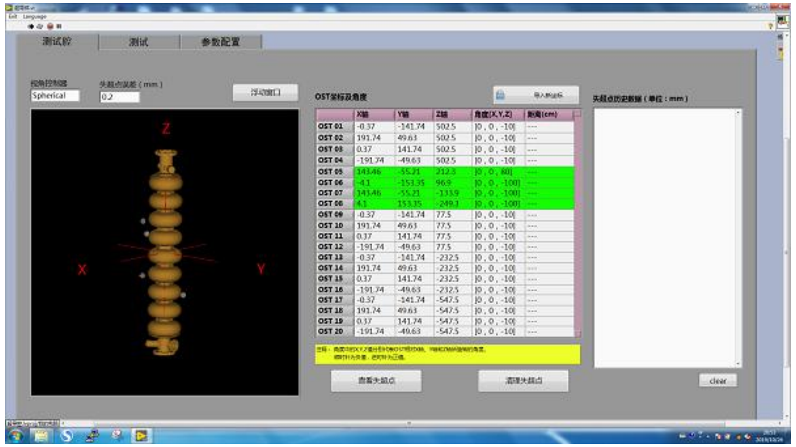
SC cavity vertical test temperature monitor system established



1.3GHz fine grain single cell:

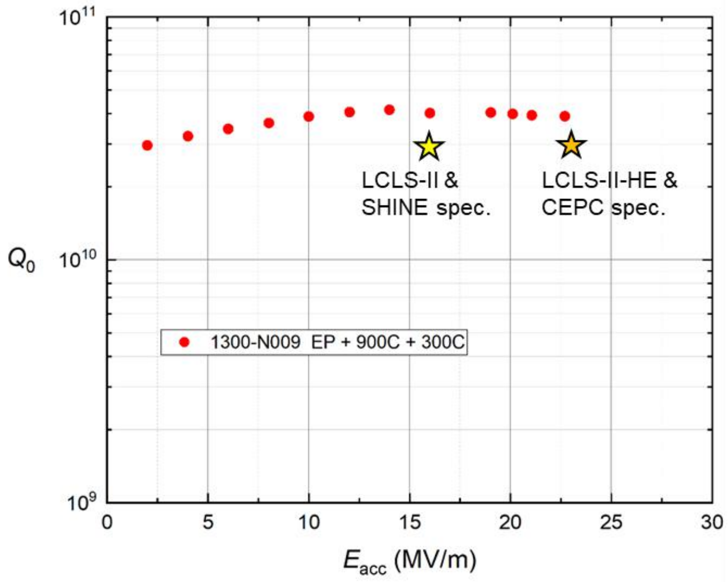
1) 46MV/m

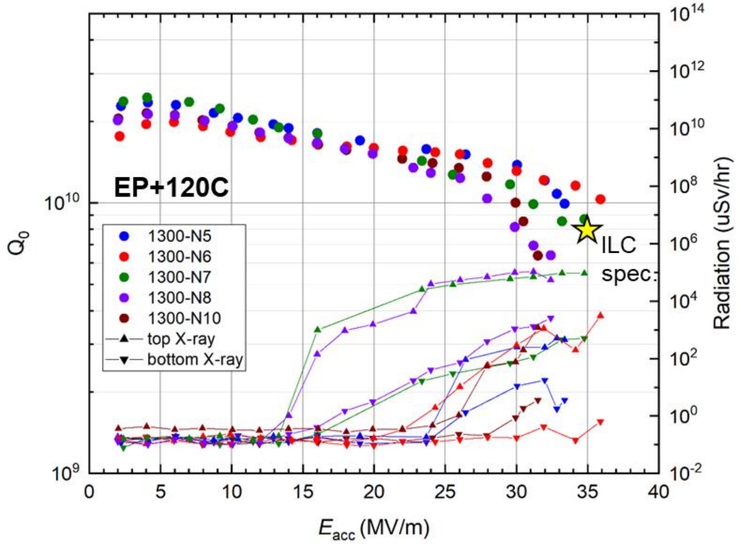
2) 43MV/m@Q01.3×10[10]

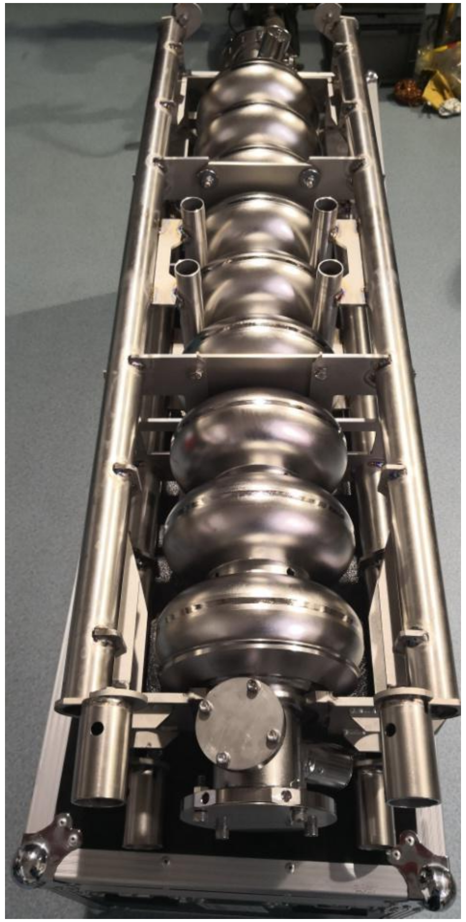


General superconducting cavity test cryomodule in IHEP New SC Lab

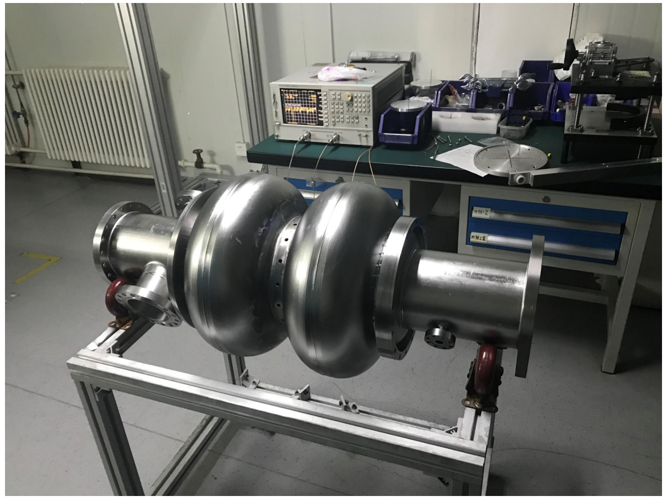
IHEP 650MHz 2cell and 1.3 GHz 9-cell Cavities



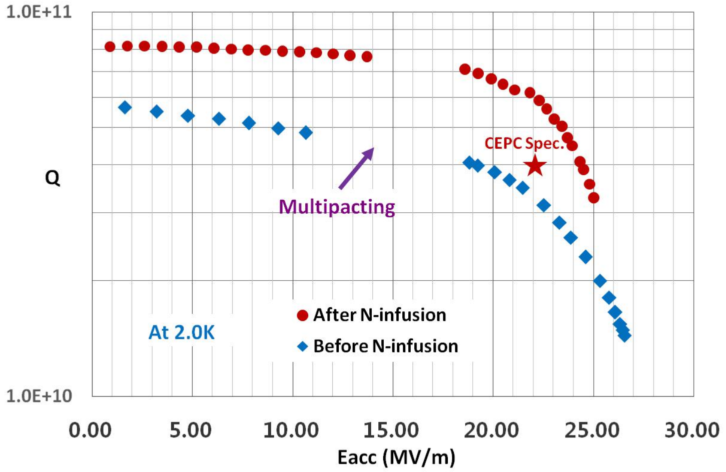




Booster 1.3GHz 9 cell cavity



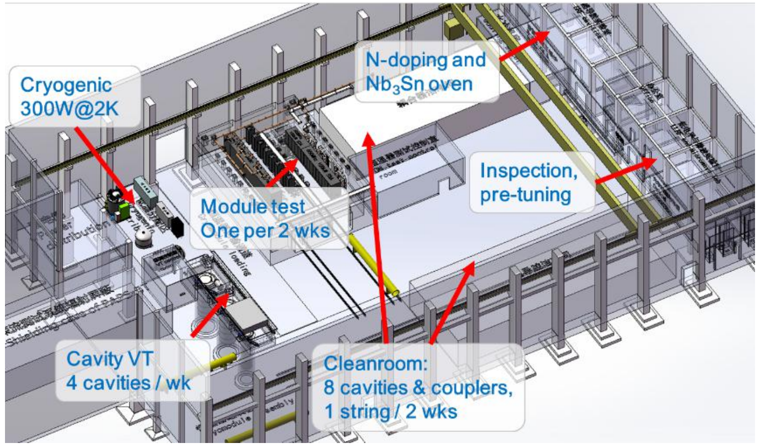
Collider ring 650Mhz 2 cell cavity

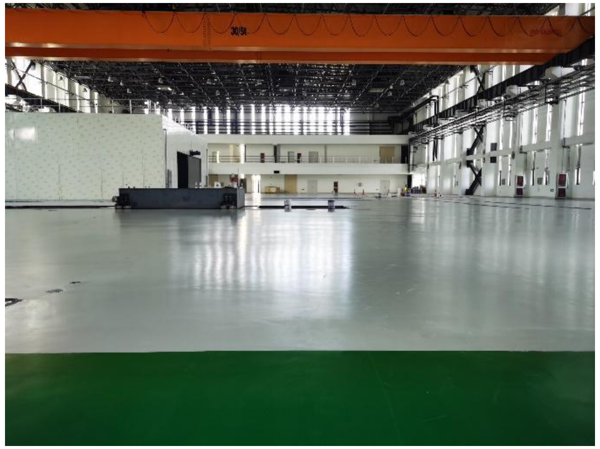


650 MHz 2-cell cavity reached **6E10@22MV/m** after N-infusion, which has exceeded CEPC Spec （**Q=4E10@Eacc=22MV/m**）.

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

Facility: CEPC SCRF test facility (lab) is located in IHEP Huairong Area of 4500m^2





New SC Lab Design (4500m^2)

SC New Lab will be available in 2021

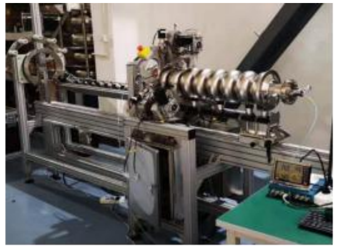
Crygenic system hall in Jan. 16, 2020

Vacuum furnace (doping & annealing)

Nb3Sn furnace

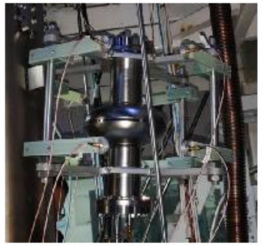
Nb/Cu sputtering device

Cavity inspection camera and grinder

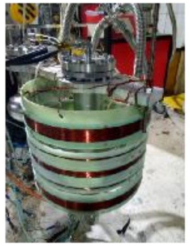


9-cell cavity pre-tuning machine

Temperature & X-ray mapping system



Second sound cavity quench detection system



Helmholtz coil for cavity vertical test

Vertical test dewars

Horizontal test cryostat

CEPC 650MHz High Efficiency Klystron Development

Facility: CEPC high power and high efficincy test facility (lab) is located in IHEP

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

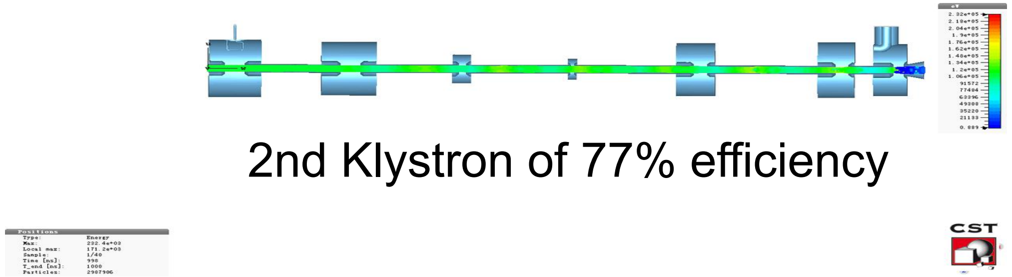
- 2016 – 2018： Design conventional & high efficiency klystron
- 2017 – 2018： Fabricate conventional klystron & test
- 2018 - 2019： Fabricate 1st high efficiency klystron & test
- 2020 - 2021： Fabricate 2nd high efficiency klystron & test
- 2021 - 2022： Fabricate 3rd high efficiency klystron & test

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**

1st Klystron of 62% efficiency

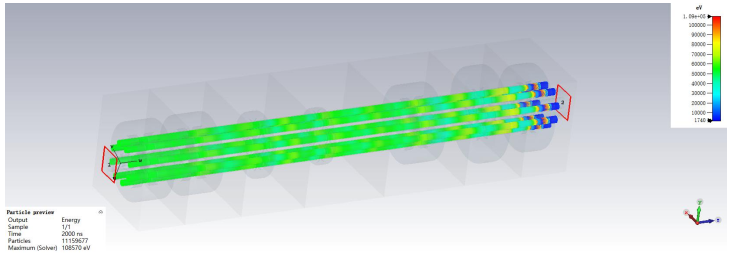
On March 10， 2020， the first CEPC650Mhz klystron output power has reached pulsed power of 800kW (400kW CW due to test load limitation), efficiency 62% and band width>+-0.5Mhz.

800kW Load

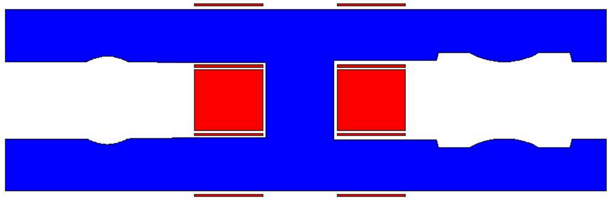


2nd Klystron of 77% efficiency

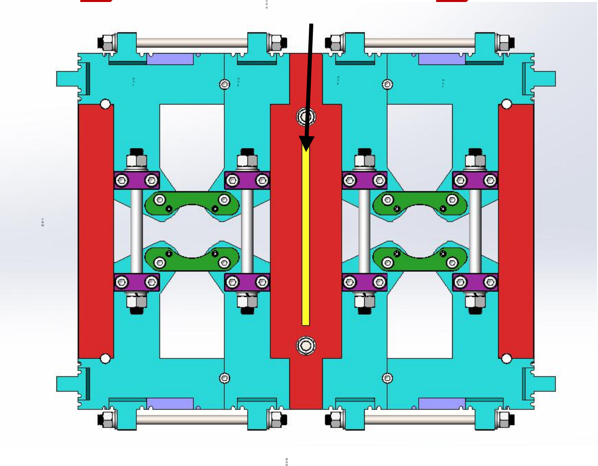
3nd Klystron of 80% efficiency

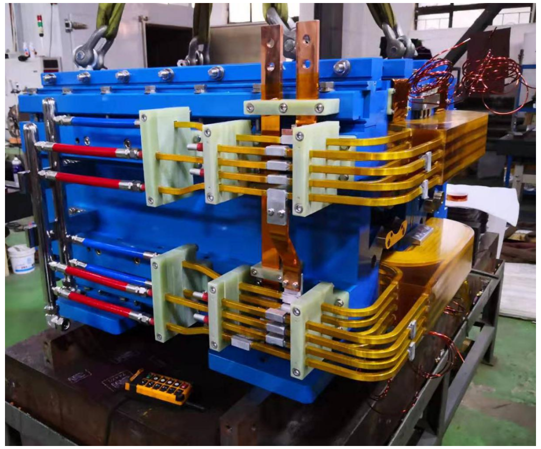


CEPC Collider Ring dual Aperture Dipole, Quadrupole and Sextupole Magnet Design Progress



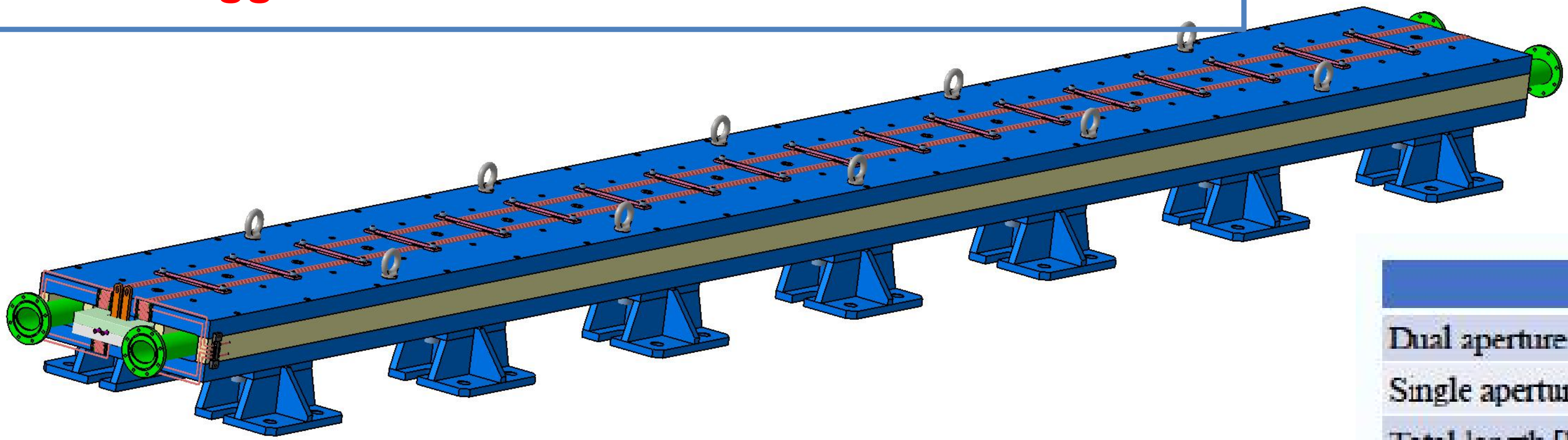
First dual aperture dipole test magnet of 1m long has been fnished in Nov, 2019





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

Facility: CEPC magnet test facility (lab) is located in IHEP Dongguan CSNS

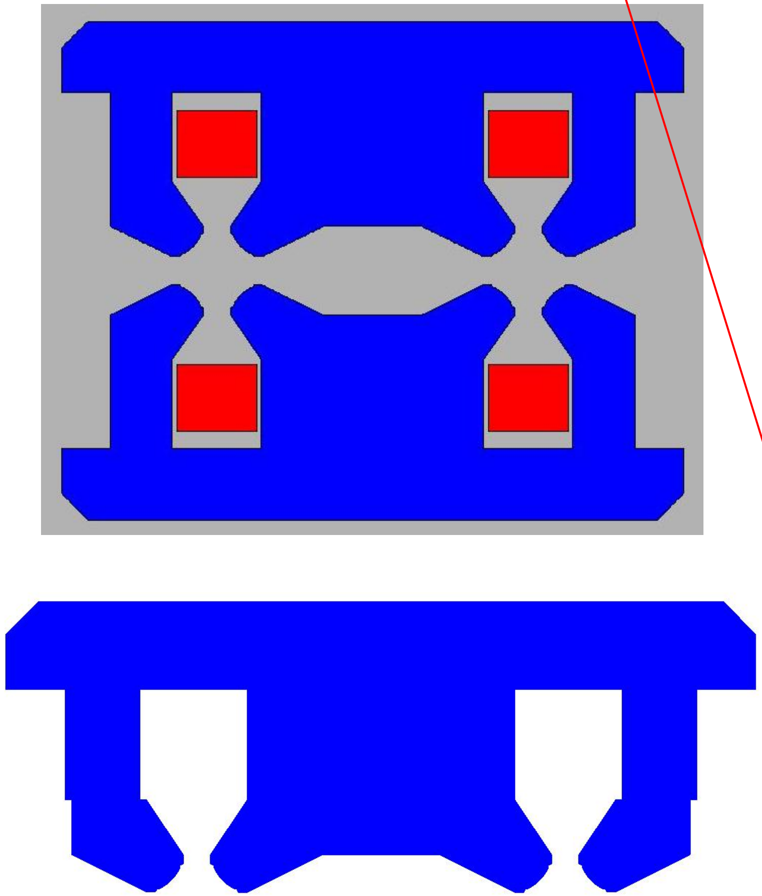


The mechanical design of a full size CEPC collider ring dual aperture dipole of 5.7m long has been designed and be fabricated at the end of 2021.

	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

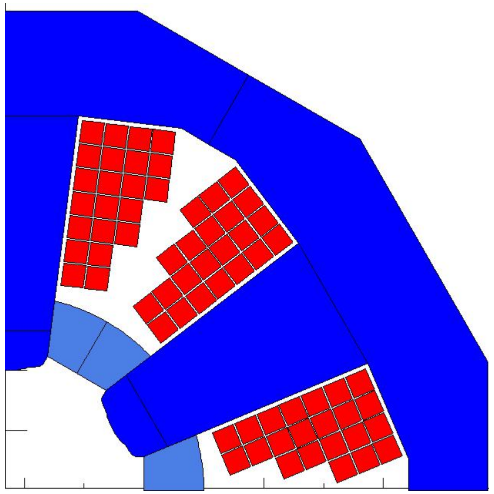
CEPC Collider Ring Quadropole and Sextupole Designs

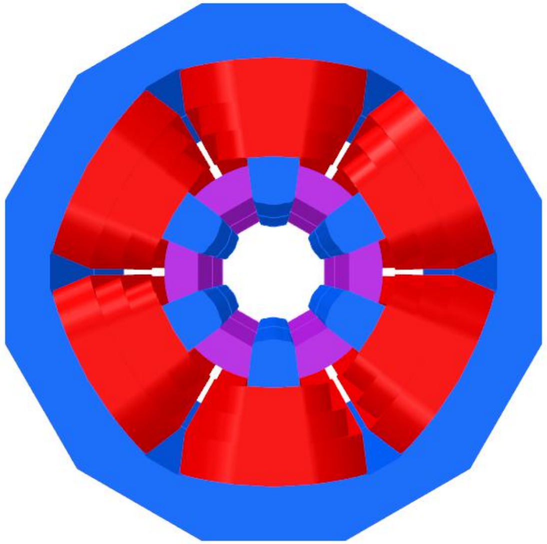
Dual aperture quadrupol



Using asymmetry poles or offset the cavity to reduce the b1 component.

- **Further physical optimization of the sextupole magnet.**
  - **Wedge-shaped magnetic poles are used to reduce magnetic pole saturation and improve excitation efficiency**
  - **Further optimization to the position of the lead block and the arrangement of coil wires to reserve space for magnet assembly.**
- **Mechanical design is in progress.**





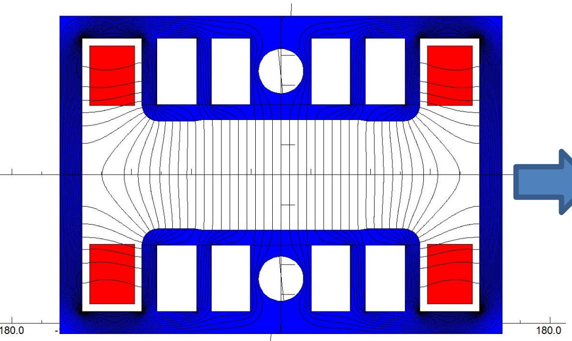
Field harmonics

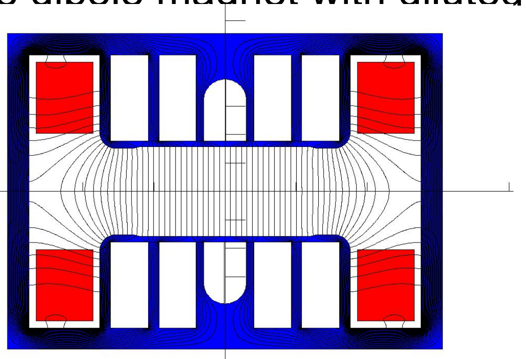
n	B_nL/B_3L
3	10000
9	1.0
15	-0.5
21	-0.1

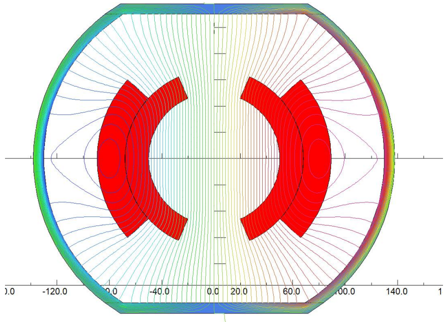
Key R&D item

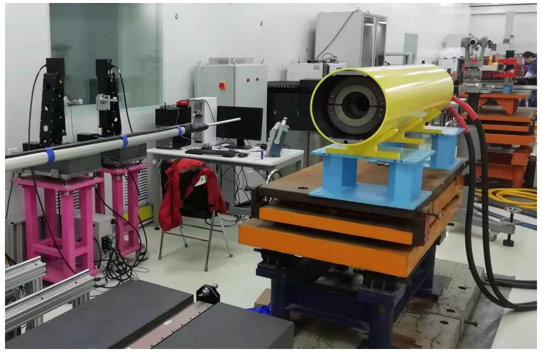
Booster High Precision Low Field Dipole Magnets

Two kinds of the dipole magnet with diluted iron cores and without iron core (CT) are proposed and designed

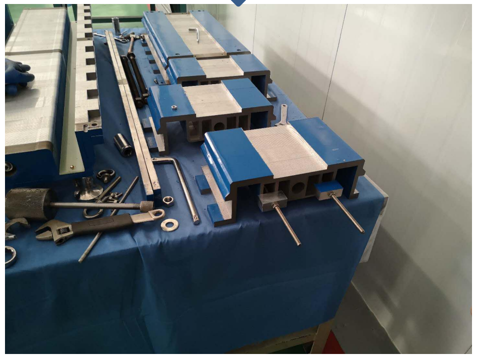


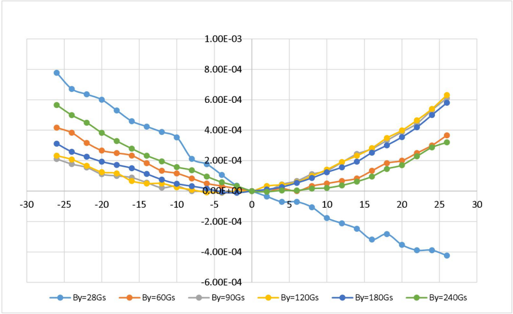


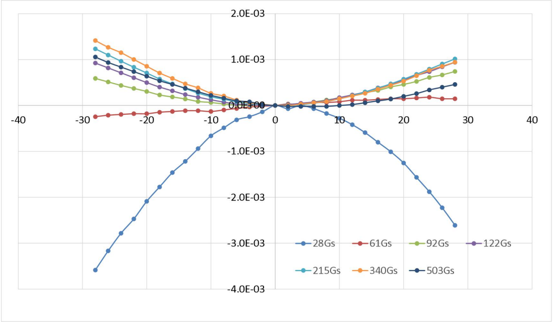




1m long CT test booster dipole magnet without iron core completed in Oct. 2019, and the test result shows that CT design reached the design goal.

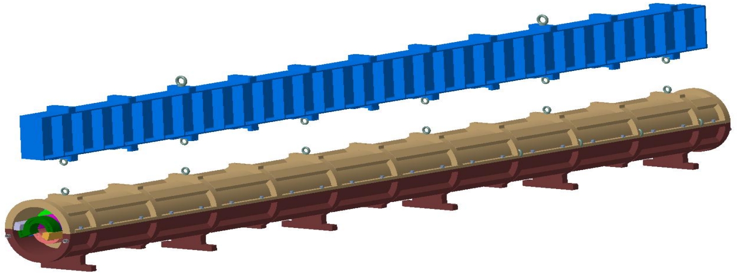






The first 1m long test booster dipole magnet with iron core, completed in Nov. 2019, and not yet reached design goal, improvement is under way

	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%



A full scale CT dipole magnet of 5.1m long is under design, and fabrication will be completed at the end of 2021

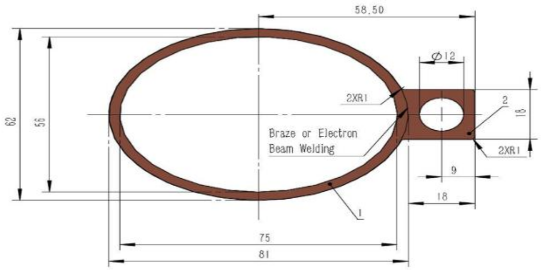
CEPC Vacuum System R&D

Facility: CEPC vaccum test facility (lab) is located in IHEP Dongguan CSNS

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.

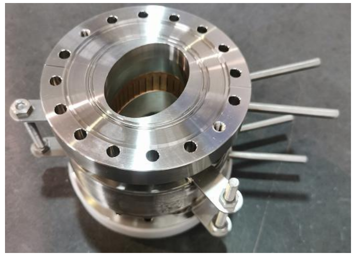
- The vacuum pressure is better than 2 x 10-10 Torr
- Total leakage rate is less than 2 x 10-10 torr.l /s.

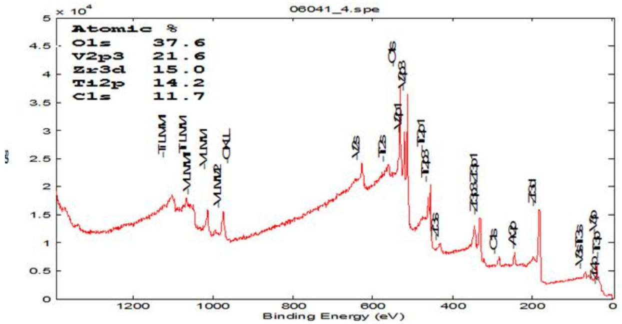
Positron ring

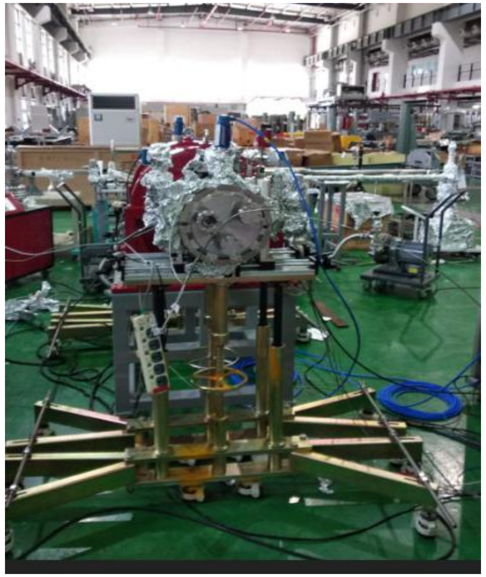


Copper vacuum chamber (Drawing) elliptic 75×56, thickness 3, length 6000)

Two 6m long vacuum chambers both for copper and aluminum





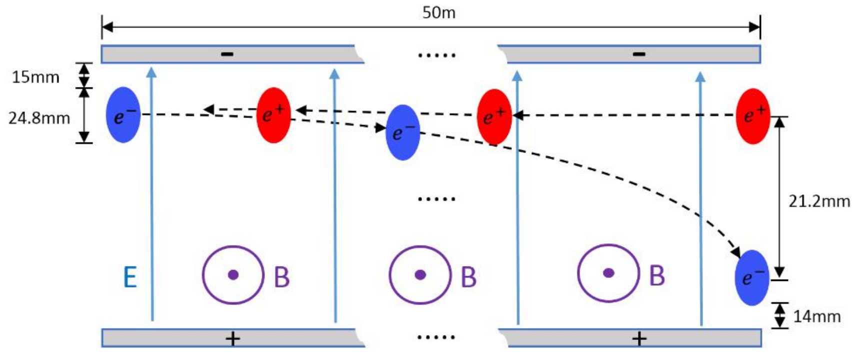


CEPC Electrostatic-Magnetic Deflector

The Electrostatic-Magnetic Deflector is a device consisting of perpendicular electric and magnetic fields.

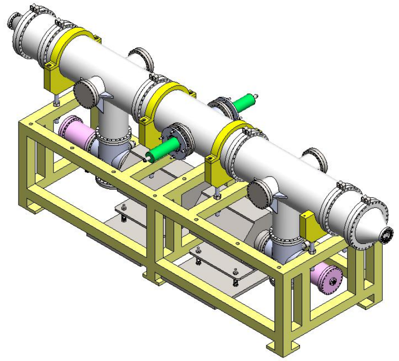
One set of Electrostatic-Magnetic Deflectors including 8 units, total 32 units will be need for CEPC.

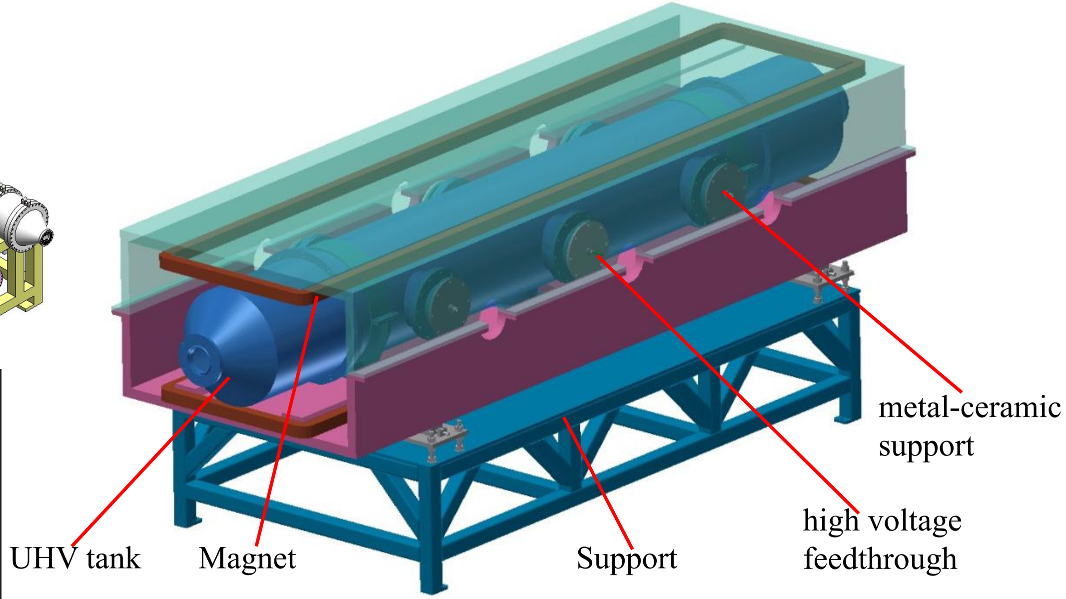
	Filed	Effective Length	Good field region	Stability
Electrostatic separator	2.0MV/m	4m	46mm x 11mm	5 x 10^{-4}
Dipole	66.7Gauss	4m	46mm x 11mm	5 x 10^{-4}



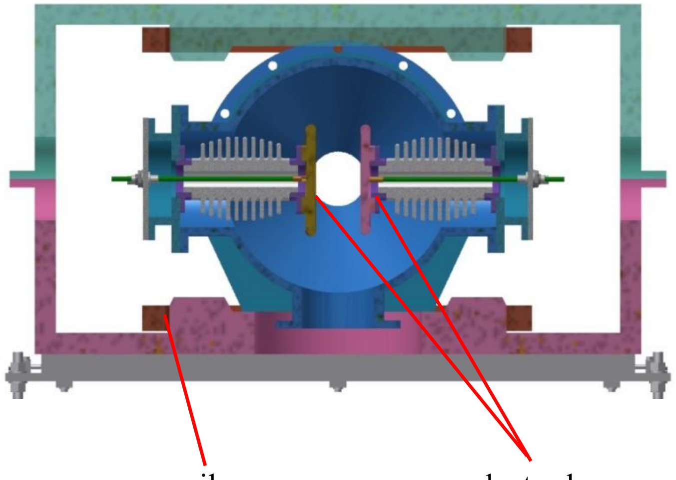
Schematic of Electrostatic-Magnetic Deflector

under fabrication





structure drawing of Electrostatic-Magnetic Deflector



CEPC Instrumentation

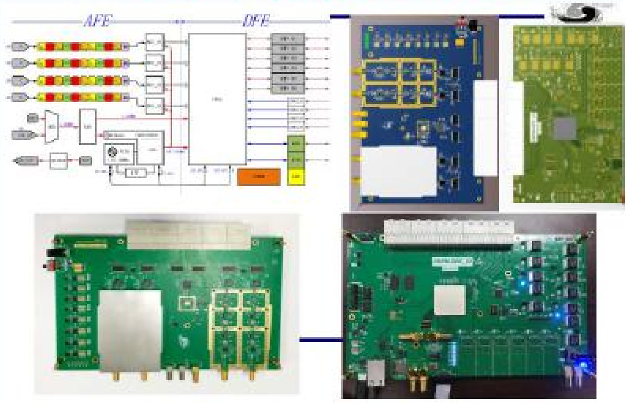
Beam Instrumentation

	Item	Method	Parameter	Amounts
Linac	Beam position	Stripline BPM	Resolution： 30um	140
	Beam current	ICT	2.5%@1nC-10nC	42
	Beam profile	YAG/OTR	Resolution: 30um	80
	Beam emittance	Q+PR	10%	3
	Beam energy & spread	AM+PR	0.1%	3
Damping ring	Average current	DCCT	Resolution :50uA@0.1mA-30mA	1
	Beam position	Button BPM	Resolution : 20um @ 5mA TBT	40
	Tune measurement	Frequency sweeping	Resolution:0.001	1

	Item		Method	Parameter	Amounts
Booster	Beam position monitor	Turn by turn	Button electrode BPM	Measurement area (x × y)：±20mm×±10mm Resolution: <0.02mm Measurement time of COD: <4 s	1808
		Bunch by bunch	Button electrode BPM	Measurement area (x × y)：±40mm×±20mm Resolution: 0.1mm	
	Bunch current		BCM	Measurement range: 10mA / per bunch Relatively precision: 1/4095	2
	Average current		DCCT	Dynamic measurement range: 0.0~1.5A Resolution:50uA@0.6-8mA Linearity: 0.1 % Zero drift: <0.05mA	2
	Beam size		Double slit interferometer x ray pin hole	Resolution:0.2 μm	2
	Bunch length		Streak camera Two photon intensity interferometer	Resolution:1 ps	2
	Tune measurement		Frequency sweeping method	Resolution:0.001	2
			DDD	Resolution:0.001	
	Beam loss monitor		optical fiber	Space resolution:0.6m	400
	Feedback system		TFB	Damping time<=3ms	2
	Feedback system		LFB	Damping time<=35ms（50ms）	2

	Item		Method	Parameter	Amounts
Storage ring	Beam position monitor	Closed orbit	Button electrode BPM	Measurement area (x × y)：±20mm×±10mm Resolution: <0.6um Measurement time of COD: <4 s	2900
		Bunch by bunch	Button electrode BPM	Measurement area (x × y)：±40mm×±20mm Resolution: 0.1mm	
	Bunch current		BCM	Measurement range: 10mA / per bunch Relatively precision: 1/4095	2
	Average current		DCCT	Dynamic measurement range: 0.0~1.5A Linearity: 0.1 % Zero drift: <0.05mA	2
	Beam size		Double slit interferometer x ray pin hole	Resolution:0.2 μm	4
	Bunch length		Streak camera Two photon intensity interferometer	Resolution:1ps@10ps	2
	Tune measurement		Frequency sweeping method	Resolution:0.001	2
			DDD	Resolution:0.001	
	Beam loss monitor		PIN-diode	Dynamic range:120 dB Maximum counting rates≥10 MHz	5800
	Feedback system		TFB	Damping time<=47ms	2
			LFB	Damping time<=100ms	2

BPM electronics version 2.0



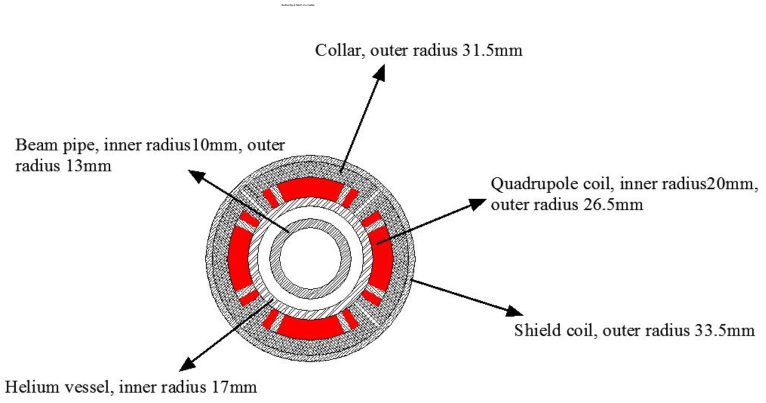
R&D items and tests in BEPCII

- Beam position monitor system
  - BPM electronics
  - Feed through R&D
  - BPM at interaction point（IP）
- Beam loss monitor
- Feedback systems

CEPC IR Superconducting Magnets

Facility: CEPC IR SC magnet test facility (lab)

is located in Keye company joinly with IHEP

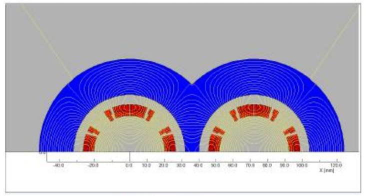


Room-temperature vacuum chamber with a clearance gap of 4 mm

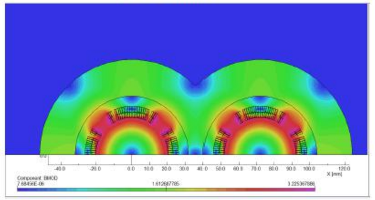
Mag net	Central field gradient (T/m)	Magnetic length (m)	Width of Beam stay clear (mm)	Min. distance between beams centre (mm)
QD0	136	2.0	19.51	72.61

Superconducting QD coils

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



2D Flux lines

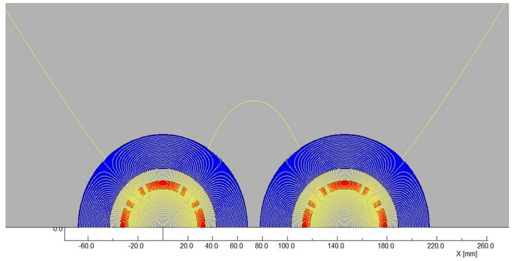


Bmod distribution

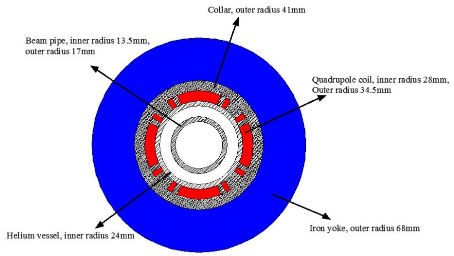
QF1 Integral field harmonics with shield coils (×10^{-4})

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

Superconducting QF coils



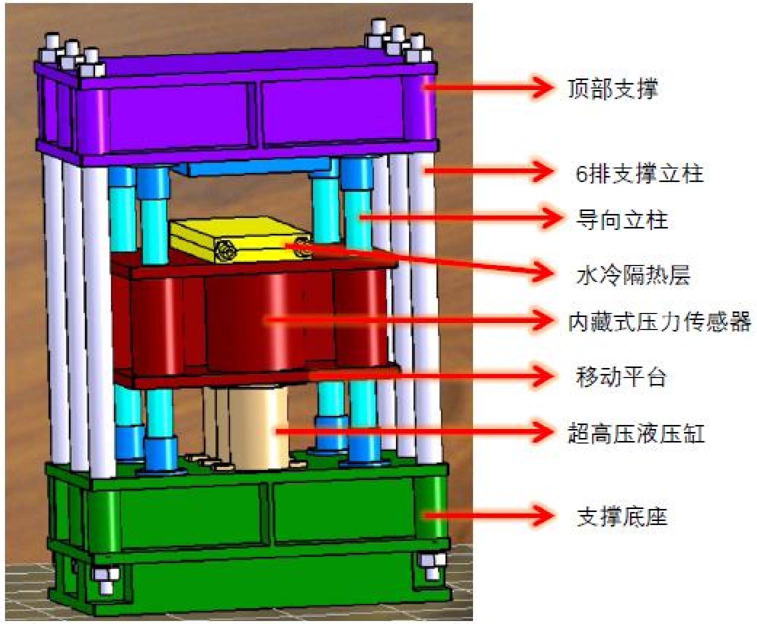
There is iron yoke around the quadrupole coil for QF1. Since the distance between the two apertures is larger enough and there is iron yoke, the field cross talk between two apertures of QF1 can be eliminated.



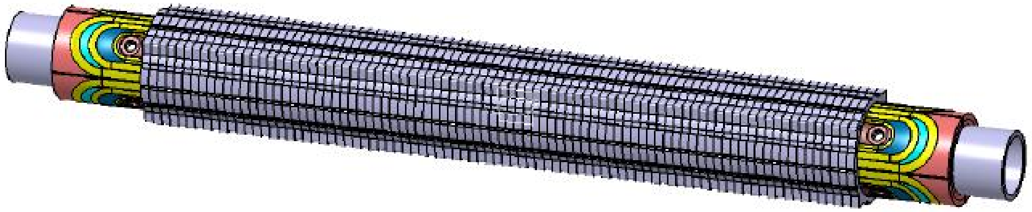
One of QF1 aperture (Peak field 3.8T)

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

CEPC MDI SC Quadrupole R&D

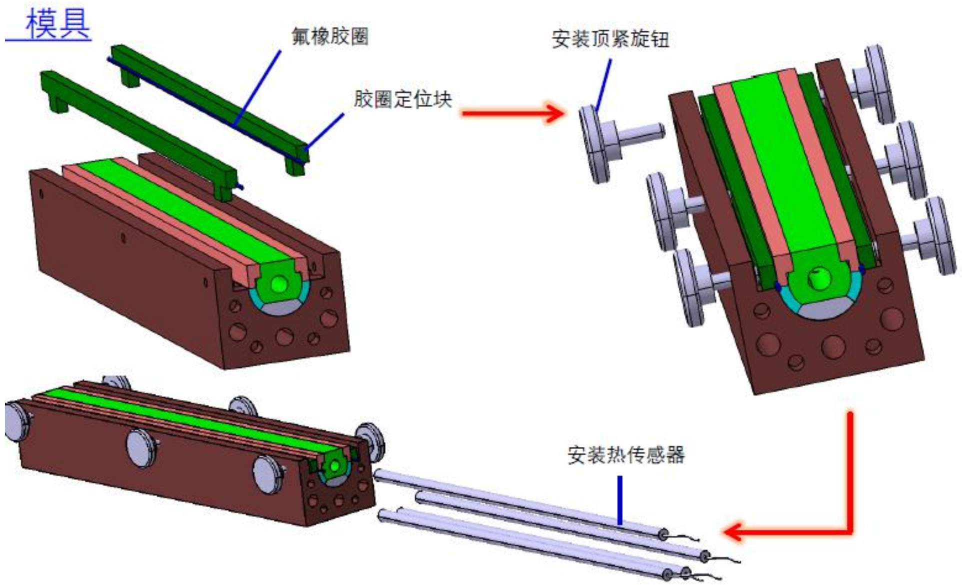


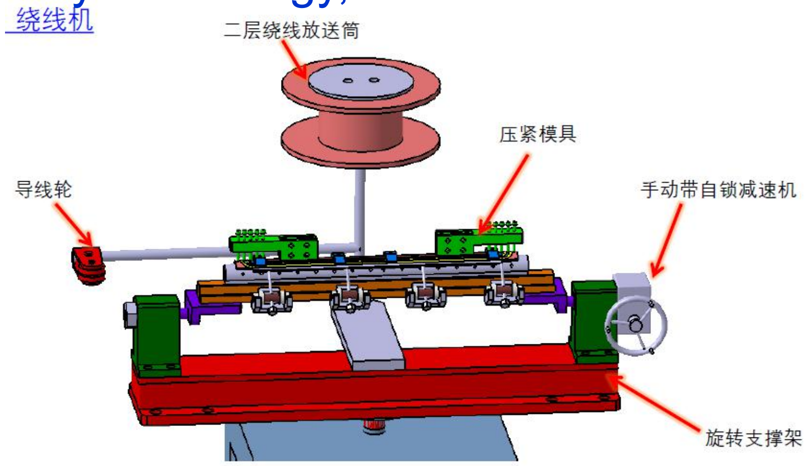
Superconducting quadrupole coil heating and curing system.



Field gradient 102T/m, coil bore diameter 38mm; The minimum distance between the center of the two apertures is 62.7mm

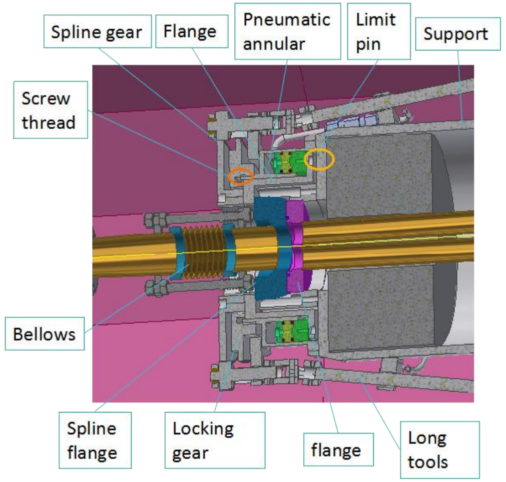
SC quadrupole mechanical design, coil winding technology, fabrication procedure study of quadrupole coil with small diameter, stress applying and monitoring, quadrupole magnet assembly technology, etc.



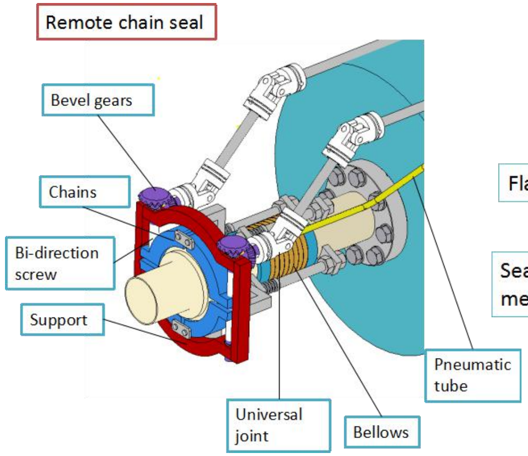


Progress of Remote Vacuum Connectors for MDI Beam Pipe

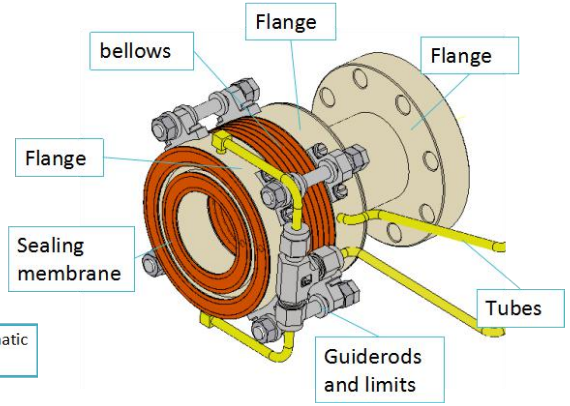
Sealing methods	Within detection angle	Leak rate estimation	Remarks
1-RVC	NO	★★★★★	Successful used in S-KEKB
2-Remote chain	Yes	★★	Eliminated
3-Inflatable seal*	Yes	★★★	Experience from CSNS
4-Improved inflatable seal	Yes		Mainly focused on



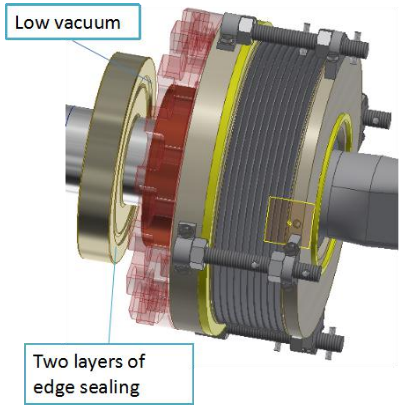
1



2



3



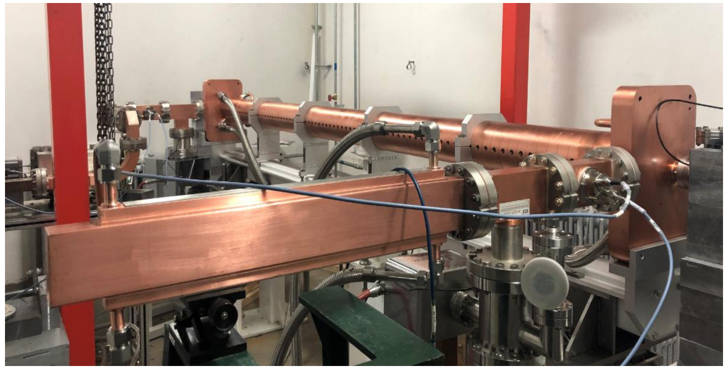
4

CEPC Linac and damping ring key technology R&D

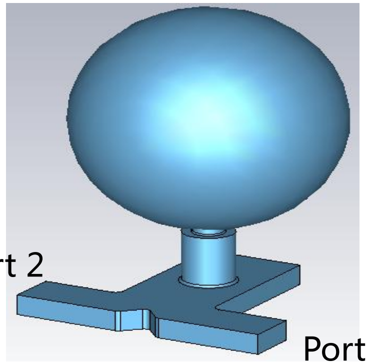
Facility: CEPC injection linac test facility (lab) is located in IHEP

Accelerating structure

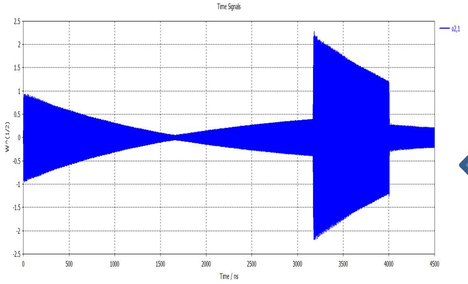
- The structure is 3 meters long with constant gradient design which work mode is 2π/3
- The high power test has finished and the gradiet is up to 33 MV/m



The acclelerating strucutre on high power test bench



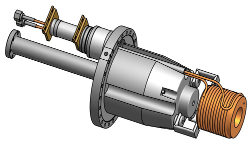
Simulation model



Simulated waveform

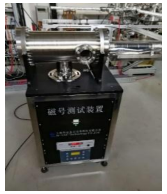
Pulse compressor:
Spherical cavity pulse compressor has devoloped
The TE_{113} mode is selected and the RF design is finished.
The Q value is about 140000
The Maximum Energy Multiplication Factor M=1.84.

Positron source R&D

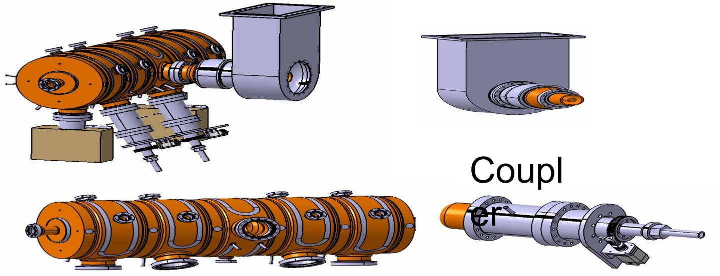


The mechanical design of FLUX concentrator

The finished FLUX concentrator



The test bench of the FLUX concentrator



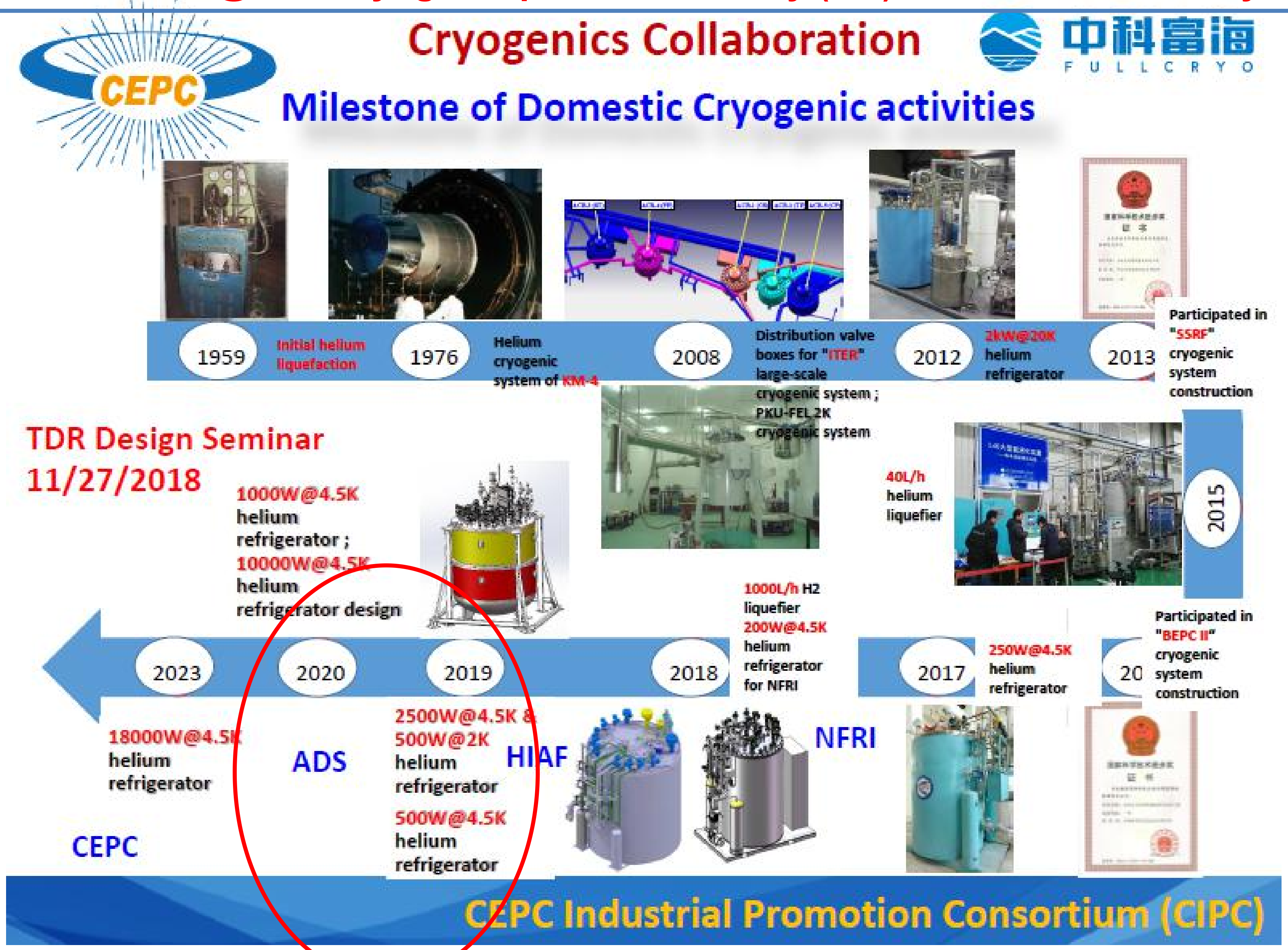
Damping ring 5cell Cavity

Tunner

Damping Ring 5 cell cavity: The The 1.1 GeV damping ring need the RF system provide 2 MV.Two 5 cell constant temperature cavities have recommended and the frequency is 650 MHz. According to the simulation, each cavity can provide 1.2 MV cavity voltage when the cavity consumption is 54 kw

CEPC 18kW@4.5K Cryogenic Plant R&D

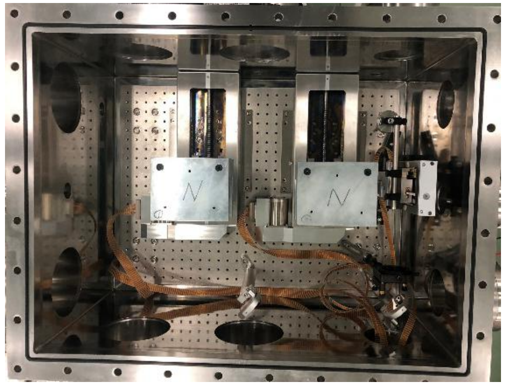
Facility: CEPC18kW@4.5K cryogenic plant test facility (lab) is located in Full Cryo company



CEPC Plasma Injector Experimental Platform

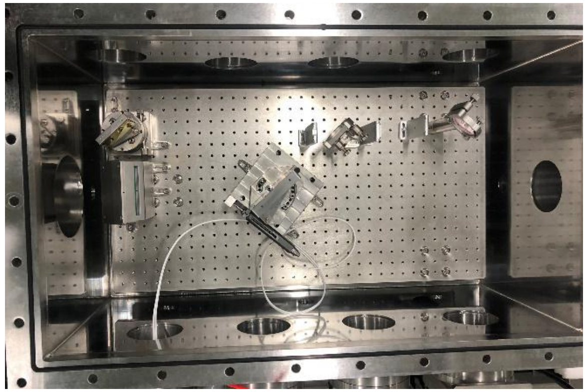
Facilities: Shanghai S-XFEL facility for electron acceleration and FACETII at SLAC for positron

- Plasma experimental station: preliminary set up on Shanghai Soft XFEL facility
  - Vacuum system: installation & testing
  - Light path
  - Beam diagnostic system



Beam test room

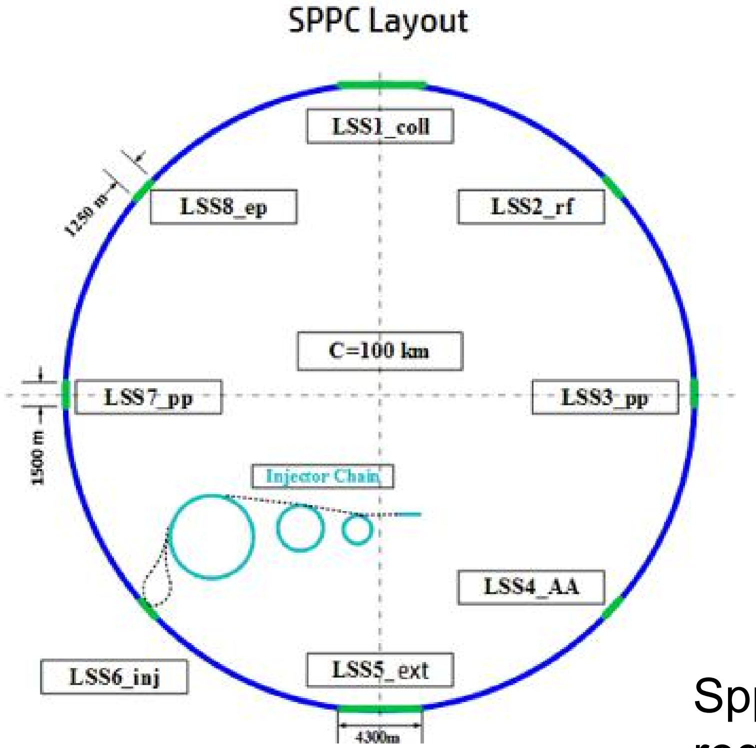
main room

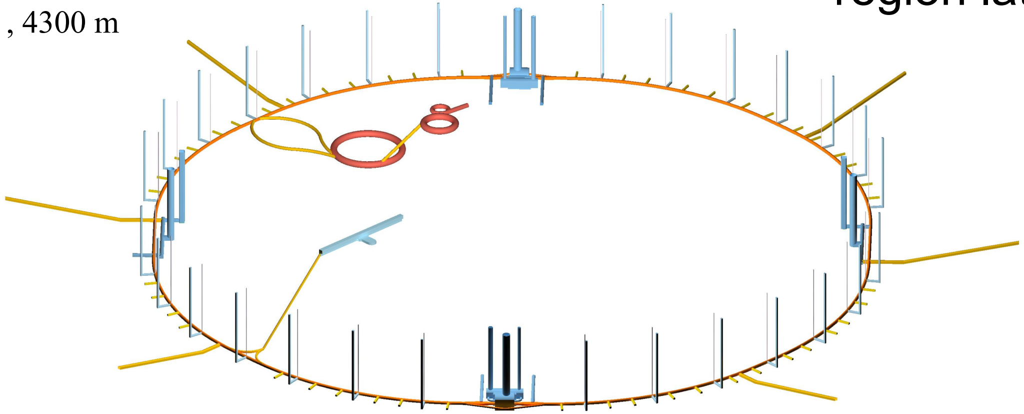


Laser compressor

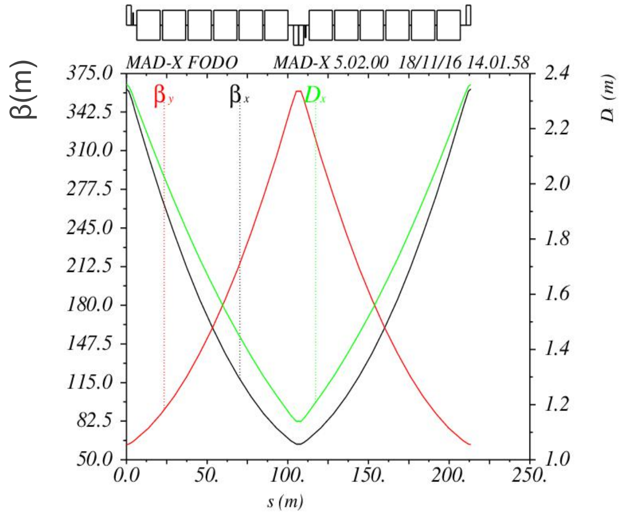
General Layout and Implementation of SppC

- 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



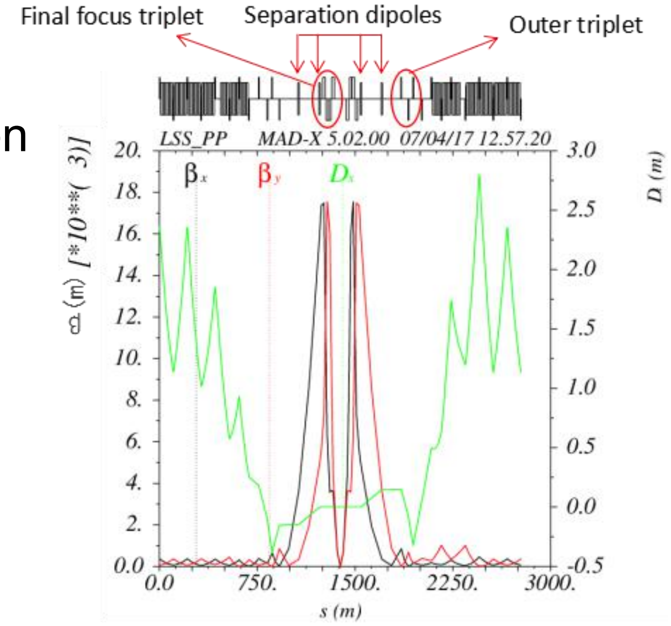


SppC ARC lattice



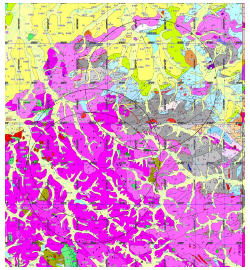
ARC FODO cell structure

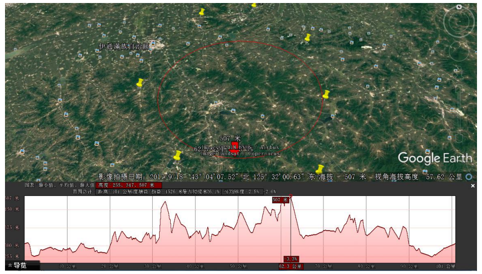
SppC interaction region lattice



LSS_PP(beta*=0.75 m)

CEPC Site Selection Status

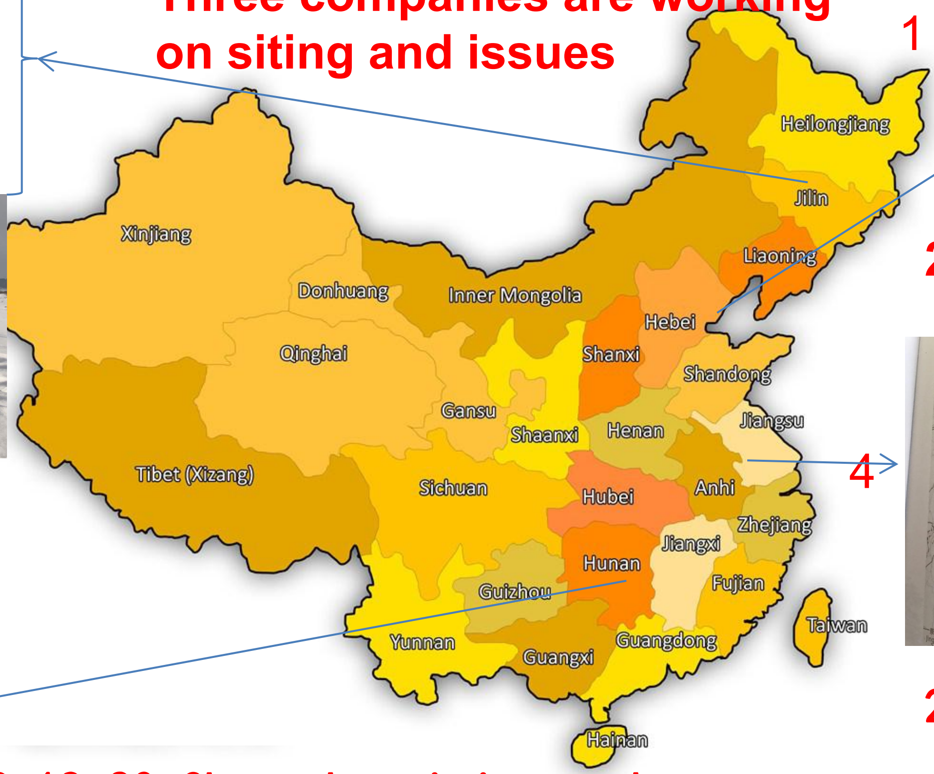


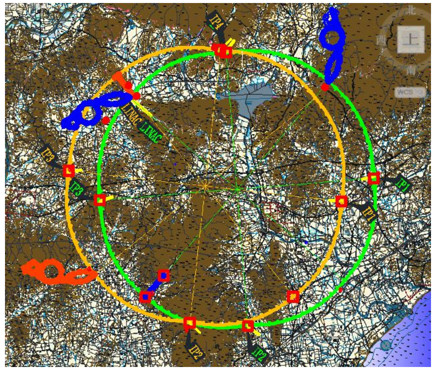


5

Three companies are working on siting and issues

1

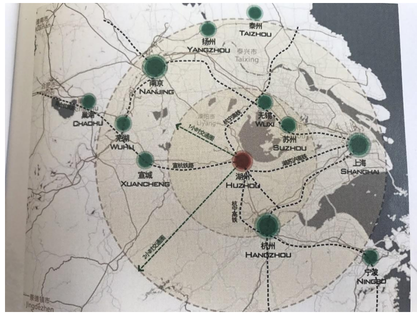


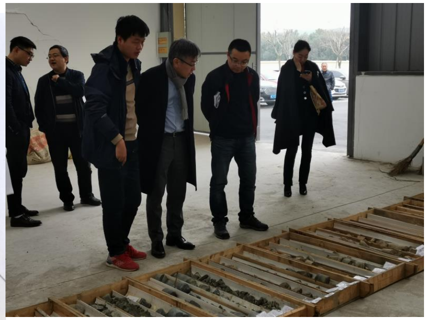


2020.9.14-18 Qinhuangdao updated

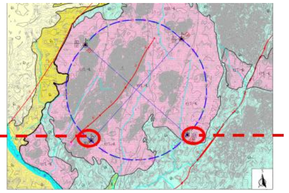
2019.12月8-11 and 2020.1.8-10 Chuangchun sitings update

4



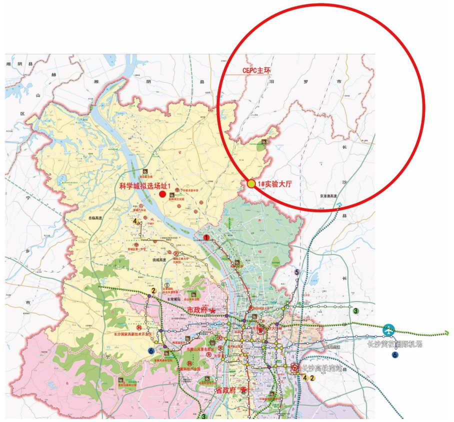


2019.12.16-17 Huzhou siting update



6

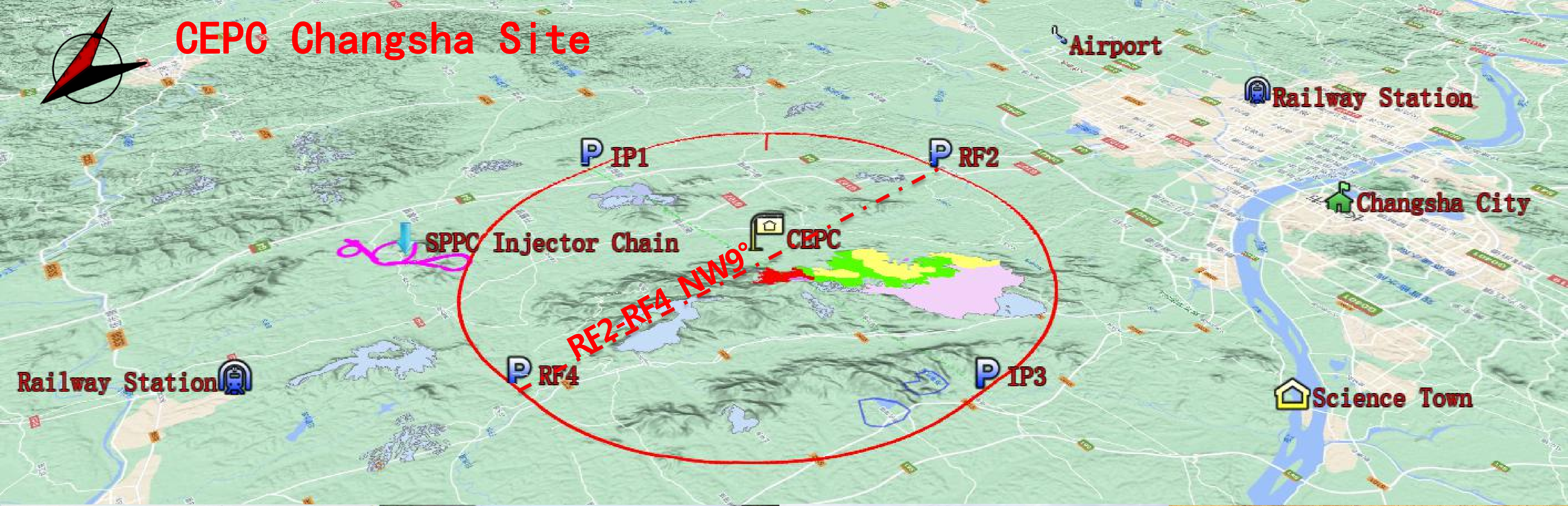
2019.08.19-20 Changsha siting update

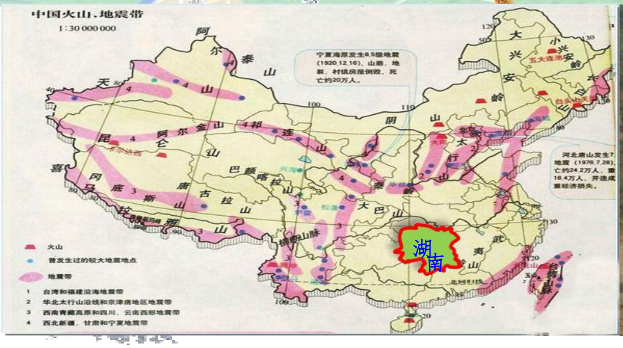


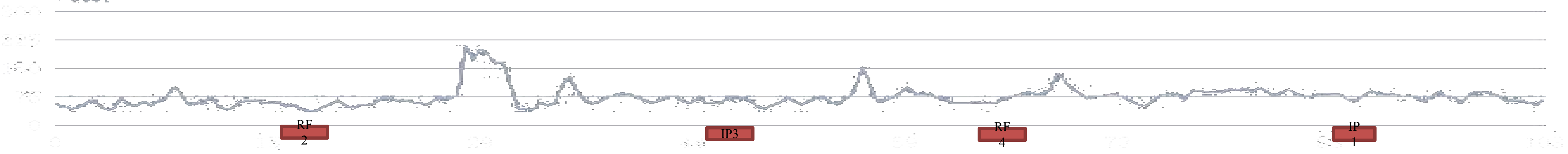
1) Qinhuangdao, Hebei Province（Completed in 2014）
2) Huangling, Shanxi Province（Completed in 2017)
3) Shenshan, Guangdong Province(Completed in 2016)
4) Huzhou, Zhejiang Province (Started in March 2018)
5) Chuangchun, Jilin Province (Started in May 2018)
6) Changsha, Hunan Province (Started in Dec. 2018)

The red color sites are more focused

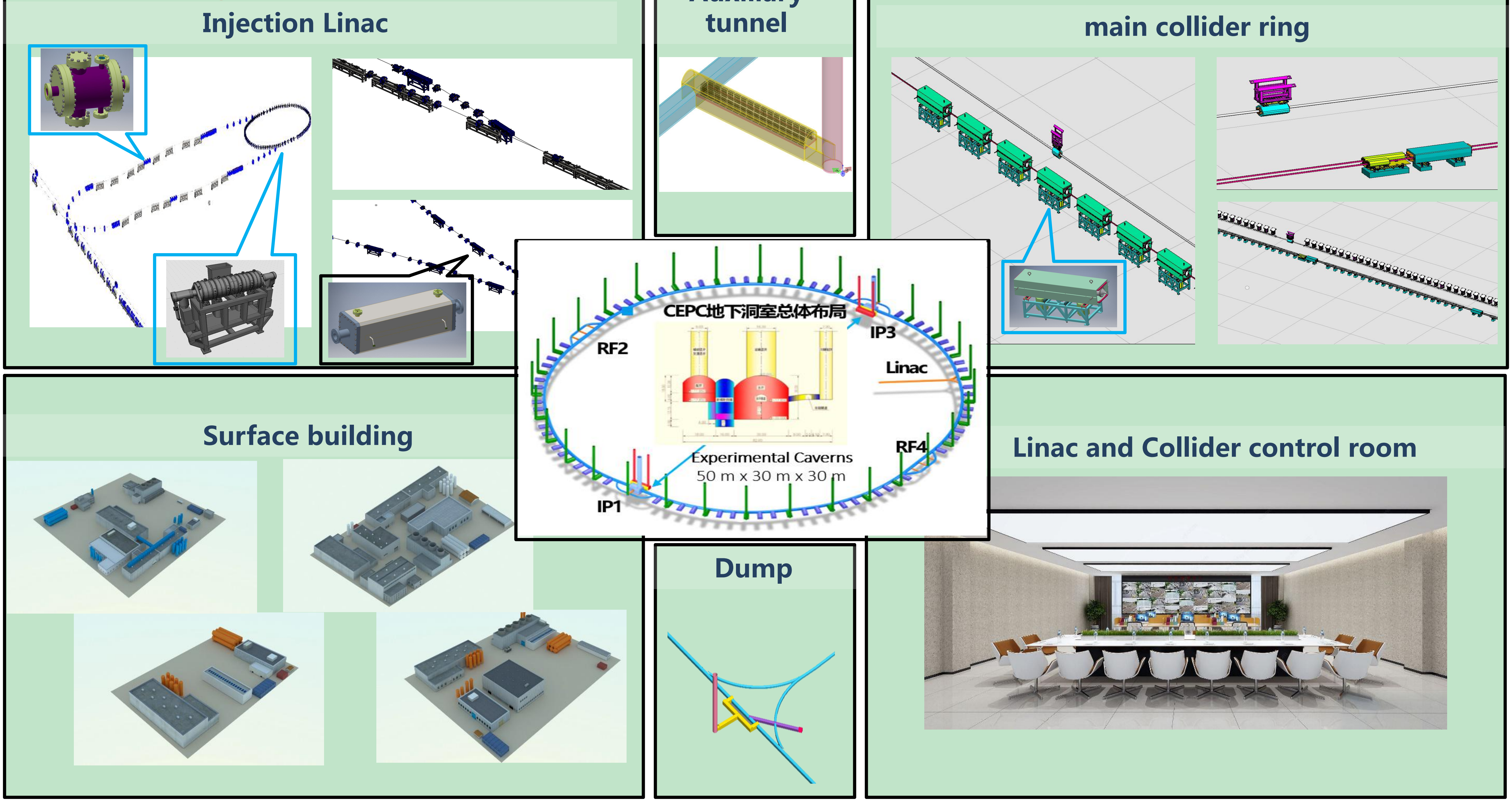
CEPC Changsha Site







CEPC Changsha Site



CEPC Industrial Promotion Consortium (CIPC) Collaboration Status

Established in Nov. 7 , 2017

Task forces for CEPC and SppC R&D: Institutions such as IHEP +CIPC (>70 companies)

Now:

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

-Shenyang Huiyu Company on CEPC MDIRVC design

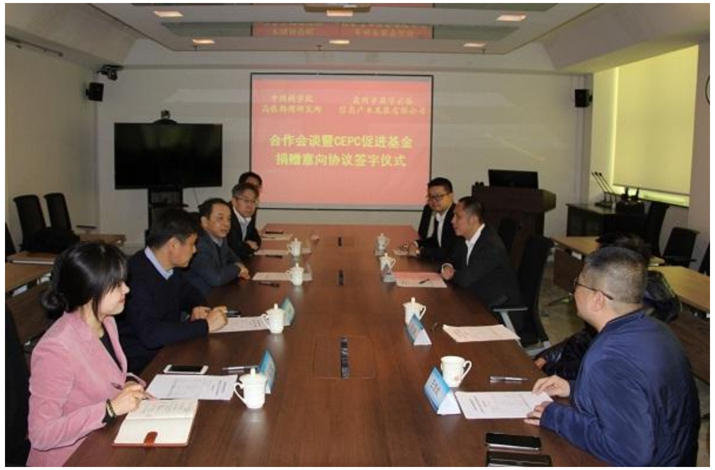
-Keye Compant on CEPC magntes desgins and SC Quadupole, DR cavity, detector hall...

-.Wuhan University:Alignmnent,

-Kuanshan Guoli on CEPC 650MHz high efficiency klystron

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

-Beijing Pudaditai company: on Alignment and instatation



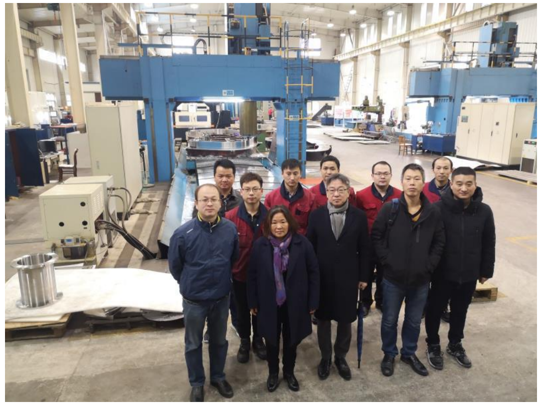
2020.1.2

Fujian Digital Valey on information signed CEPC Propmotion Fund Contribution with IHEP

2019.12.25-26,Nanchong, Sichuan Jiutian Vacuum company

2020.6.5

Hefei Keye and Beijing Puda Ditai Company signed CEPC Propmotion Fund Contribution with IHEP



2019.1218-19 visit Keye Company

CEPC-CIPC Collaboratios in CEPC R&D towards TDR

CEPC2020 Program Layout (Day-3)

	Monday (10/26)	Tuesday (10/27)	Wednesday (10/28)
	8:30 – 10:00 ACC, CIPC, HIGGS, Silicon	8:30 – 10:00 ACC, CIPC,	
	10:00 – 10:30 Break	10:00 – 10:30 Break	
	10:30 – 12:00 ACC, CIPC, Gas	10:30 – 12:00 ACC, CIPC	
	12:00 – 14:00 Break	12:00 – 14:00 Break	
	14:00 – 16:00 ACC, CIPC, HIGGS, Silicon	14:00 – 16:00 ACC, CIPC	
	16:00 – 16:30 Break	16:00 – 16:30 Break	
	16:30 – 18:30 ACC, CIPC, SMEW, Gas	16:30 – 18:30 MDI, BSM	
	18:30 – 20:00 Break	18:30 – 20:00 Break	
	20:00 – 23:00 Plenary-I	20:00 – 23:00 Plenary-II	
	23:00 – 1:00 AM HIGGS + SMEW	23:00 – 24:00 PERF (Disc	

CIPC speakers (part) in CEPC workshop in Shanghai, Oct. 26-28, 2020

40 speakers

CEPC Accelerator Parallel Session

CEPC Conference, Oct. 26-28, 2020, Shanghai, China

48 speakers

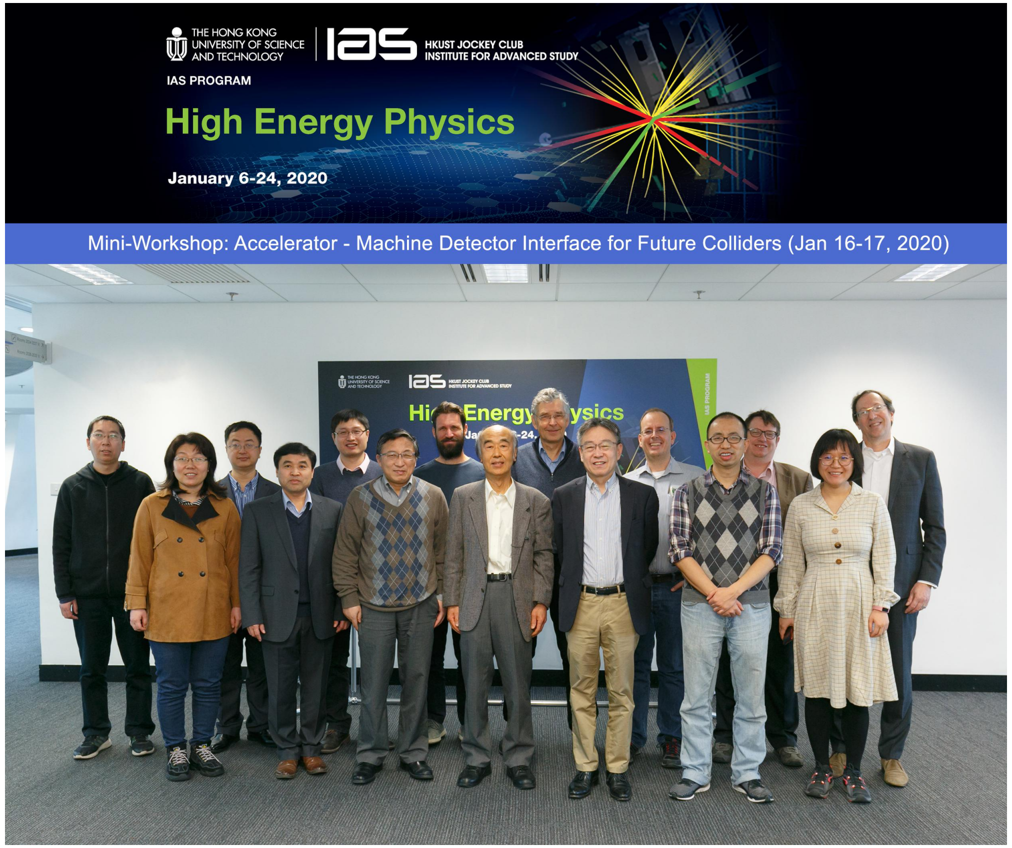
CIPC Parallel Session on CEPC R&D

https://weidijia.zoom.com.cn/j/62874286168

CEPC International Collaboration Meetings

IAS HEP ConferenceJan. 20-23, 2020 (Since 2015)

Mini-workshop: Accelerator - Machine Detector Interface (**MDI**) for Future Colliders
Dates: Jan 16-17, 2020



For 2021, HKIAS mini workshop on plasma accelerator physics an technologies Jan. 14-15, 2021) and HKIAS HEP conference (Jan. 18-21, 2021) will take place online.

CEPC submissions to Snowmass21

CEPC Input to the ESPP 2018

-Accelerator

CEPC Accelerator Study Group

Executive summary

The discovery of the Higgs boson at CERN's Large Hadron Collider (LHC) in July 2012 raised new opportunities for a large-scale accelerator. Due to the low mass of the Higgs, it is possible to produce it in the relatively clean environment of a circular electron–positron collider with reasonable luminosity, technology, cost and power consumption. The Higgs boson is a crucial cornerstone of the Standard Model (SM). It is at the center of some of its biggest mysteries, such as the large hierarchy between the weak scale and the Planck scale, the nature of the electroweak phase transition, and many other related questions. Precise measurements of the properties of the Higgs boson serve as excellent tests of the underlying fundamental physics principles of the SM, and they are instrumental in explorations beyond the SM. In September 2012, Chinese scientists proposed a 240 GeV *Circular Electron Positron Collider* (CEPC), serving two large detectors for Higgs studies. The tunnel for such a machine could also host a *Super Proton Proton Collider* (SPPC) to reach energies beyond the LHC.

The CEPC is a large international scientific project initiated and hosted by China. It was presented for the first time to the international community at the ICFA Workshop "*Accelerators for a Higgs Factory: Linear vs. Circular*" (HF2012) in November 2012 at Fermilab. A Preliminary Conceptual Design Report (Pre-CDR, the *White Report*)[1]was published in March 2015, followed by a Progress Report (the *Yellow Report*)[2] in April 2017, where CEPC accelerator baseline choice was made. The Conceptual Design Report (CEPC Accelerator CDR, the *Blue Report*) [3]has been completed in July 2018 by hundreds of scientists and engineers after international review from June 28-30, 2018 and formally released on Sept 2, 2018.

Including SppC and siting

LOI

CEPC -Accelerator Technologies to Snowmass2021 AF7

CEPC Accelerator Study Group

Executive summary

The discovery of the Higgs boson at CERN's Large Hadron Collider (LHC) in July 2012 raised new opportunities for a large-scale accelerator. Due to the low mass of the Higgs, it is possible to produce it in the relatively clean environment of a circular electron–positron collider with reasonable luminosity, technology, cost and power consumption. The Higgs boson is a crucial cornerstone of the Standard Model (SM). It is at the center of some of its biggest mysteries, such as the large hierarchy between the weak scale and the Planck scale, the nature of the electroweak phase transition, and many other related questions. Precise measurements of the properties of the Higgs boson serve as excellent tests of the underlying fundamental physics principles of the SM, and they are instrumental in explorations beyond the SM. In September 2012, Chinese scientists proposed a 240 GeV *Circular Electron Positron Collider* (CEPC), serving two large detectors for Higgs studies. The tunnel for such a machine could also host a *Super Proton Proton Collider* (SPPC) to reach energies beyond the LHC. The CEPC Preliminary Conceptual Design Report (Pre-CDR, the *White Report*)[1]was published in March 2015, followed by a Progress Report (the *Yellow Report*)[2] in April 2017, where CEPC accelerator baseline choice was made. The Conceptual Design Report (CEPC Accelerator CDR, the *Blue Report*) [3] has been publically realsed in Nov. 2018, and also submitted to European High Energy Strategy in May, 2019 [4].

Technologies

- Collider Design
- SCRF
- Klystron
- Linac+plasma accelerator injector
- Cost

CEPC Contributions to Snowmass21

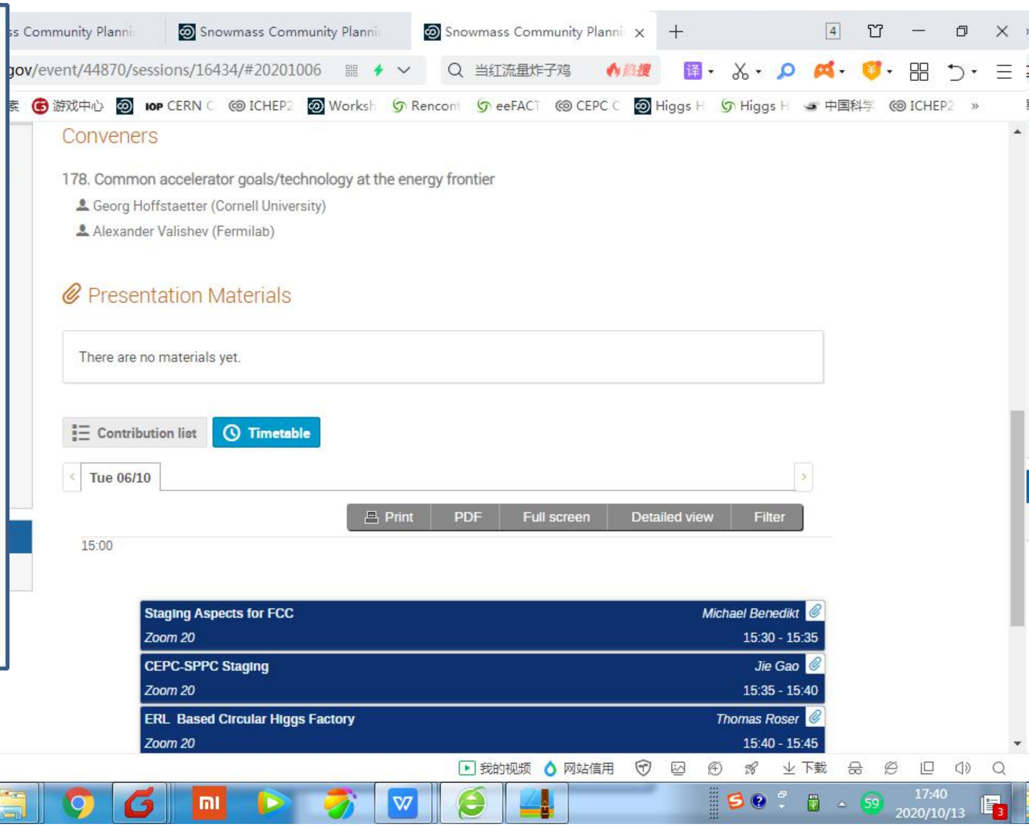
Session 190

Discussions on implementation

Session
190. Discussion of accelerator project implementation
Oct 7, 2020, 12:15 PM
Virtual
Conveners
190. Discussion of accelerator project implementation
Tor Raubenheimer (SLAC)
Thomas Roser (BNL)

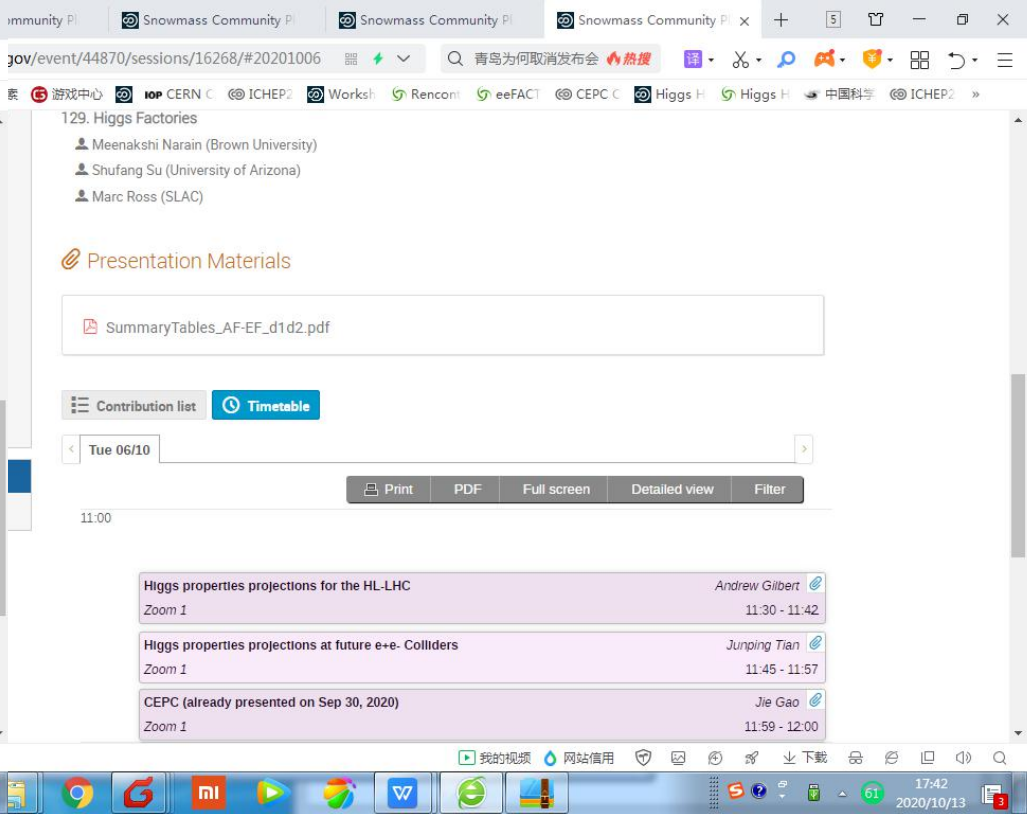
Session 178

Staging of CEPC and SppC for High Energy Frontier



Session 129

CEPC Status and Perspectives



Summary

- CEPC R&D efforts towards TDR progress well such as optimization design, klystron, SCRF, magnets, vacuum system, etc. with the aim to complet TDR before **2023**
- **CEPC and SppC key technologies R&D have correspongding test facilities**
- **CIPC (> 70 companies) is an important task force for both CEPC and SppC in addition to institution and univerity ones…**
- **CEPC siting and civil engineering designs are in progress**
- **CEPC LOI and CEPC Technologies** for **AF** of Snowmass21 have been submitted online on June 29, 2020 at: https://www.snowmass21.org/docs/files/?dir=summaries/AF

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

IAC Recommendation 9 and IARC 11-1

IAC Recommendation 9: Clarify the timetable with appropriate milestones, including prototyping. Not every technical detail and drawing will be necessary at the completion of the TDR.
IARC Recommendations 11-1: It is important to make a clear distinction between long-term R&D, such as high-Tc coating of cavities, peripheral development, such as Centrifugal Barrel Polishing, and high-priority items to produce industrial-scale production required for CEPC construction. Given limited resources, particularly of staff, priority must be given to the latter.

Response: CEPC SRF system TDR R&D and Industrialization Plan

2019-2020:

- SRF system TDR design and optimization
- High Q, high gradient cavity, high power components and other key technology R&D
- 650 MHz high Q short cryomodule prototyping
- PAPS SRF facility construction

2021-2022:

- SRF system TDR design re-baseline, engineering design
- 650 MHz high Q short cryomodule operation and improvement
- 1.3 GHz high Q full cryomodule prototyping
- 650 MHz high current cryomodule design (and prototyping?)
- PAPS SRF facility commissioning, operation and upgrade
- Industrialization in synergy with other SRF projects in China

IAC Recommendation 9 and IARC 11-1

IAC Recommendation 9: Clarify the timetable with appropriate milestones, including prototyping. Not every technical detail and drawing will be necessary at the completion of the TDR.
IARC Recommendations 11-1: It is important to make a clear distinction between long-term R&D, such as high-Tc coating of cavities, peripheral development, such as Centrifugal Barrel Polishing, and high-priority items to produce industrial-scale production required for CEPC construction. Given limited resources, particularly of staff, priority must be given to the latter.

Response: CEPC SRF system TDR R&D and Industrialization Plan

2019-2020:

- SRF system TDR design and optimization
- High Q, high gradient cavity, high power components and other key technology R&D
- 650 MHz high Q short cryomodule prototyping
- PAPS SRF facility construction

2021-2022:

- SRF system TDR design re-baseline, engineering design
- 650 MHz high Q short cryomodule operation and improvement
- 1.3 GHz high Q full cryomodule prototyping
- 650 MHz high current cryomodule design (and prototyping?)
- PAPS SRF facility commissioning, operation and upgrade
- Industrialization in synergy with other SRF projects in China

IAC Recommendation 11

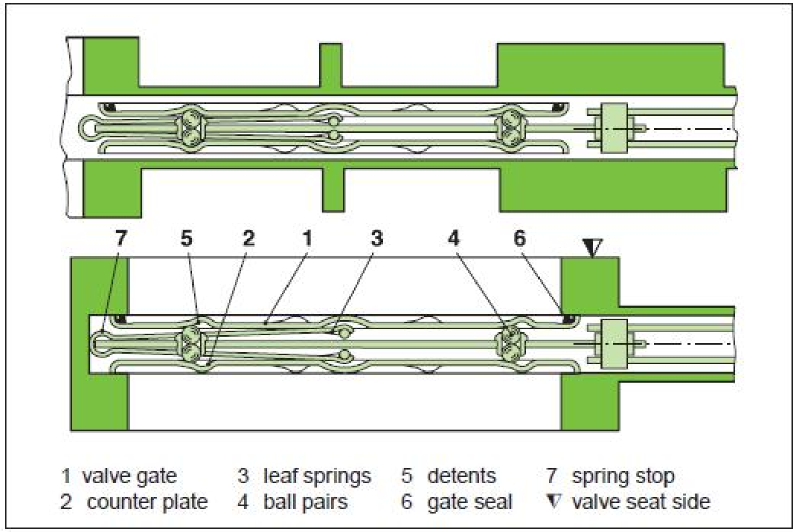
Build international and domestic collaborations in several critical areas, e.g., MDI, SC-RF, polarization, beam dynamics (beam-beam, dynamic aperture, etc.), C-band linac, and RF sources.

Response:

- **CEPC SRF domestic collaboration**
  - **Organization: CEPC SRF Collaboration kick-off soon. Members: IHEP, PKU and 5 companies.**
  - **Activities: Already have collaborations on CEPC SRF technology and various SRF projects.**
  - **Future collaborations: SHINE and other CW SRF FEL projects in China.**
- **CEPC SRF international collaboration**
  - **Organization: TBD**
  - **Funding: apply for international team program (CAS Lu Jiaxi etc.) to support personal exchanges.**
  - **Activities: ILC/SuperKEKB (KEK), INFN-LASA, JLAB: SRF system design, technology and infrastructure, annual SRF collaboration meeting with KEK, personal exchanges.**
  - **Future collaborations: FCC-ee (CERN, Univ. Rostock), EIC (JLAB, BNL), PIP-II and LCLS-II-HE (FNAL), DESY, CEA-Saclay etc.**

Reply to IAC from vacuum and linac

- Draw up a list of components likely to require a second source, and identify potential international suppliers.
  - ✓ **All metal gate valves can only be supplied by VAT in globe, it need to require a second source. And others components can be supplied by different company in the world or China.**



- ✓ **Components of the linac are normal conducting material. They are made of high-purity oxygen free copper (C10100) . International supply is required**

CEPC Accelerator Components Import Lists (part)

(Alignment, Vacuum, Beam Instrumentation, Cryogenic system, Radiation protection, etc)

System	Name	Num	Cost (10kRMB)	Typical parameters	remarks	Inport
Magnet	low temperature isolator, low temperature sensor, magnetic field measurment: signal integrator, motor, encoder, motion control card					Y
survey and alignment	GPS	16	384	0.5mm/km		Y
survey and alignment	Zenith plummet	8	232	1 / 200000		Y
survey and alignment	gyroscope	4	400	3"		Y
survey and alignment	Relative gravimeter	2	300	1μgal		Y
survey and alignment	FARO arm	8	480	0.025-0.036mm/2.4M		Y
survey and alignment	optical level	32	320	0.1mm/km		Y
survey and alignment	digital level	8	192	0.2mm/km		Y
survey and alignment	transit square	32	1216	0.0254mm		Y
survey and alignment	laser collimator	4	120	0.1mm/100m		Y
survey and alignment	indoor GPS	4	3400	0.1mm		Y
survey and alignment	CMM	4	400	0.005mm		Y
survey and alignment	laser interferometer	8	480	0.005mm		Y
survey and alignment	Epoxy glue	35872	667	Araldite		Y
Beam Instrumentation device	DCCT	2	140			Y
Beam Instrumentation device	BCM	2	140			Y
Beam Instrumentation device	ICT	50	1500			Y
Vacuum	Valve	1040	15600	RF-CF100		Y
Vacuum	Valve	520	5200	DN100		Y
Vacuum	Valve	30	490	CF100		Y
Cryogenic system	High pressure helium gas recycling compressor	8	1840	flow rate:100m3/h,working pressure: 20MPa		Y
Cryogenic system	High pressure helium gas recycling compressor	4	920	flow rate:100m3/h,working pressure: 20MPa		Y
Radiation Protection	PLC	38	760		PPS	Y
Radiation Protection	OSL Personal Dose Detector System	3	180		Dose detection	Y
Radiation Protection	CR-39 Personal Dose Detector System	2	160		Dose detection	Y
Radiation Protection	Cooling Water Monitoring Detector	16	800		Dose detection	Y
Radiation Protection	Air Ventilation Monitoring Detector	16	960		Dose detection	Y
Radiation Protection	Portable Monitoring Detectors	21	315		Dose detection	Y
Radiation Protection	Low background gamma spectrum	2	640		Dose detection	Y
Radiation Protection	Liquid scintillation counter	2	400		Dose detection	Y