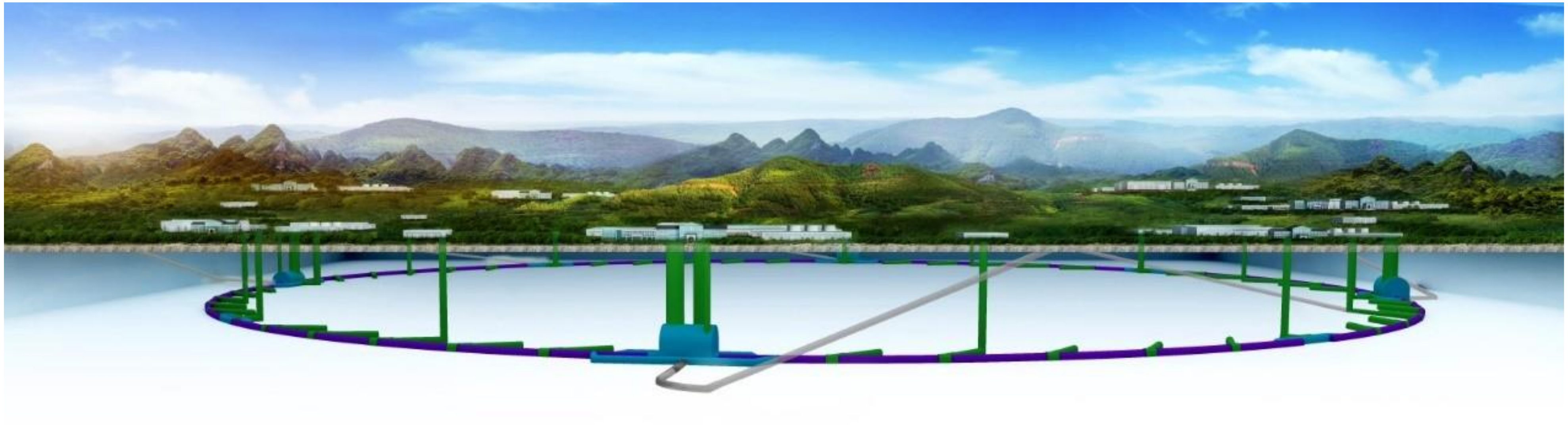
CEPC Accelerator Status and TDR Progress



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On behalf of CEPC Group

IARC meeting, May. 11, 2021

Institute of High Energy Physics

Chinese Academy of Sciences

CEPC Circular Electron Positron Collider

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CEPC Accelerator from Pre-CDR, CDR towards TDR

CEPC accelerator CDR completed in June 2018 (printed in July 2…

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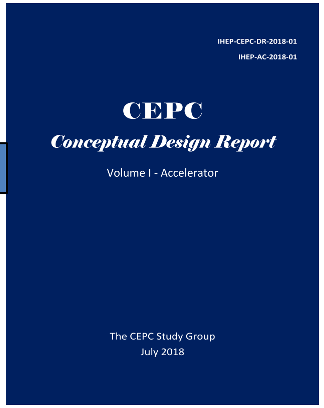
CEPC TDR R&D Started based on CDR since 2019

• High Luminosity; R&D for key technologies, …

…2015 April 2017 Draft CDR for Mini International Review in Nov. 2017

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



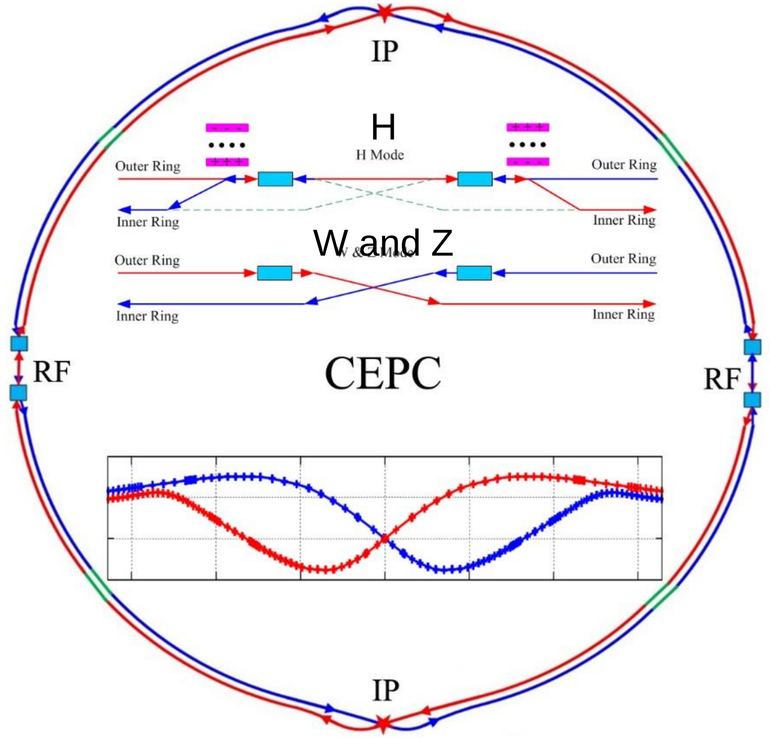
CEPC Accelerator Submitted to European Strategy in 2019

1) CEPC accelerator: ArXiv: 1901.03169
2) CEPC Physics/Detector: 1901.03170

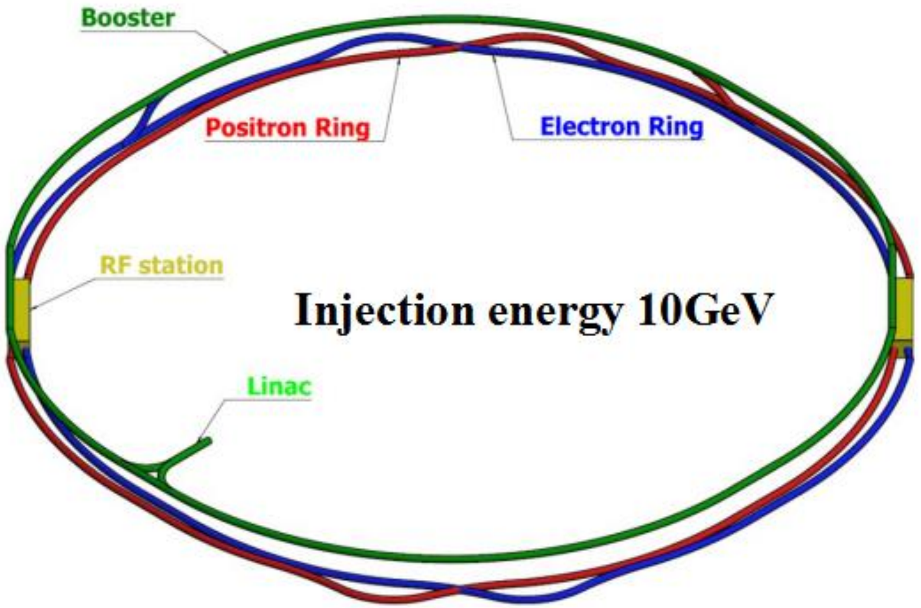
CDR Version for International Review June 2018
Formally released on Sept. 2, 2018:arXiv：1809.00285
http://cepc.ihep.ac.cn/CDR_v6_201808.pdf

CEPC CDR Baseline Layout

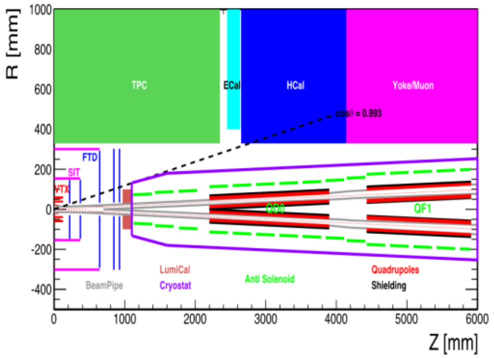
CEPC as a Higgs Factory： H, W, Z, followed by a SppC ~100TeV



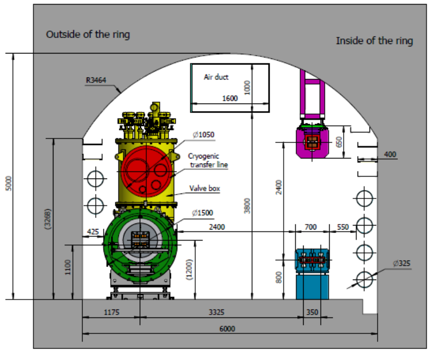
CEPC collider ring (100km)

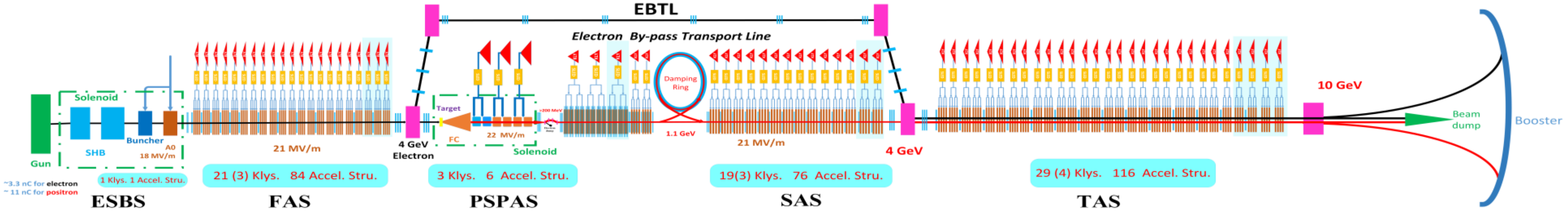


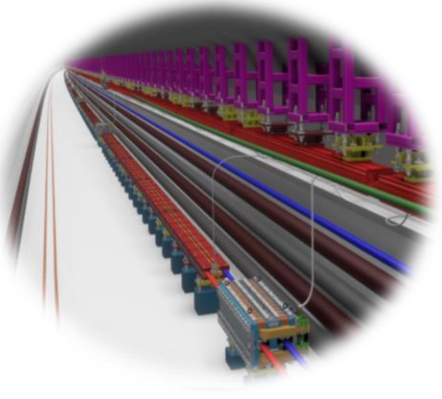
CEPC booster ring (100km)



TUNNEL CROSS SECTION OF THE ARC AREA







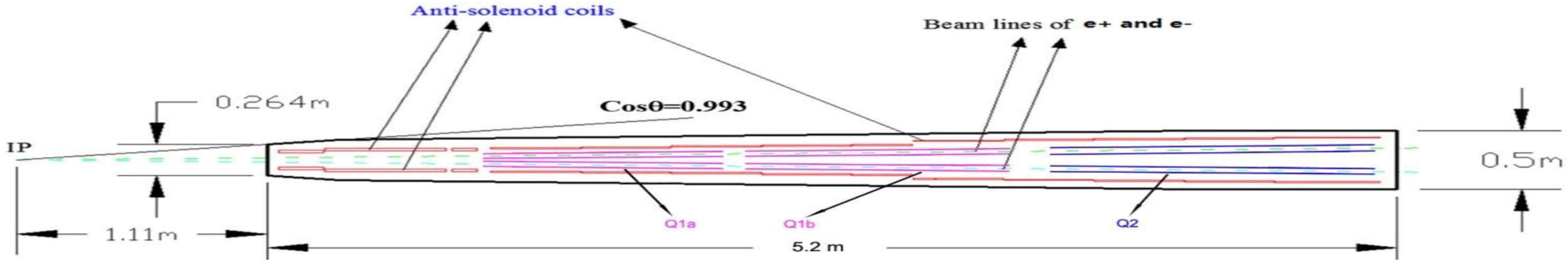
CEPC Linac injector (1.2km, 10GeV) (20GeV, new Baseline)

CEPC Collider Ring in high luminosity

- Modifications in the Interaction Region
- Major Parameters
- Lattice & DA
- Requirements to magnets
- Changes to the IP chamber
- RF staging & by-pass schemes

MDI in High Luminosity

- **High luminosity motivation: Looking forward to the higher physical goal**
- **The detectors won't be affected.**
  - **with lower emittance and smaller beam pipe aperture within the region of SCQ**
  - **with shorter anti-solenoid in front of QD0 (QD1a,b) without change the design of cryo-module**



CDR scheme (Higgs)

- ✓ **L*=2.2m, θc=33mrad, βx*=0.36m, βy*=1.5mm, Emittance=1.2nm**
  - Strength requirements of anti-solenoids (peak field B_z~7.2T)
  - Two-in-one type SC quadrupole coils (Peak field 3.8T & 136T/m)

High luminosity scheme (Higgs)

- ✓ **L*=1.9m, θc=33mrad, βx*=0.33m, βy*=1.0mm, Emittance=0.68nm**
  - Strength requirements of anti-solenoids (peak field B_z~7.2T)
  - Two-in-one type SC quadrupole coils (Peak field 3.8T & 141T/m) with room temperature vacuum chamber & Iron yoke

Collider Ring 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	
Half Crossing angle at IP (mrad)	16.5			
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	
SR 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	
Lifetime (hour)	0.67	1.4	4.0	2.1
Luminosity/IP L (10^{34}cm^{-2}s^{-1})	2.93	10.1	16.6	32.1

High Luminosity Parameters

tt	*Higgs*	*W*	*Z*	
2				
180	120	80	45.5	
100				
8.53	1.73	0.34	0.036	
16.5				
1.16	4.87	7.25	24.9	
20.1	16.3	15.0	15.2	
37 (4.45μs)	214 (0.7us)	1230 (0.27μs)	3816 (86ns)	11498 (26ns)
3.5	16.8	88.6	278.8	839.9
30	30	30	**10**	**30**
10.7				
0.73	0.73	1.48	1.48	
1.0/0.0027	0.33/0.001	0.18/0.001	0.15/0.001	
1.45/0.0047	0.68/0.0014	0.84/0.00187	0.27/0.00135	
37.9/0.11	15.0/0.037	12.3/0.043	6.36/0.037	
0.076/0.106	0.018/0.115	0.0096/0.11	0.0046/0.131	
9.52	2.27	0.62	0.1	
650 (216816)				
2.23	2.25	2.7	2.75	
2.66	4.42	5.4	9.6	
0.17	0.19	0.12	0.12	
2.0	1.7	1.3	1.3	
2.61	2.5	2.1	1.48	
0.59	0.35	1.4	1.7	1.4
0.5	**5.0**	**15.4**	**35.0**	**105.5**

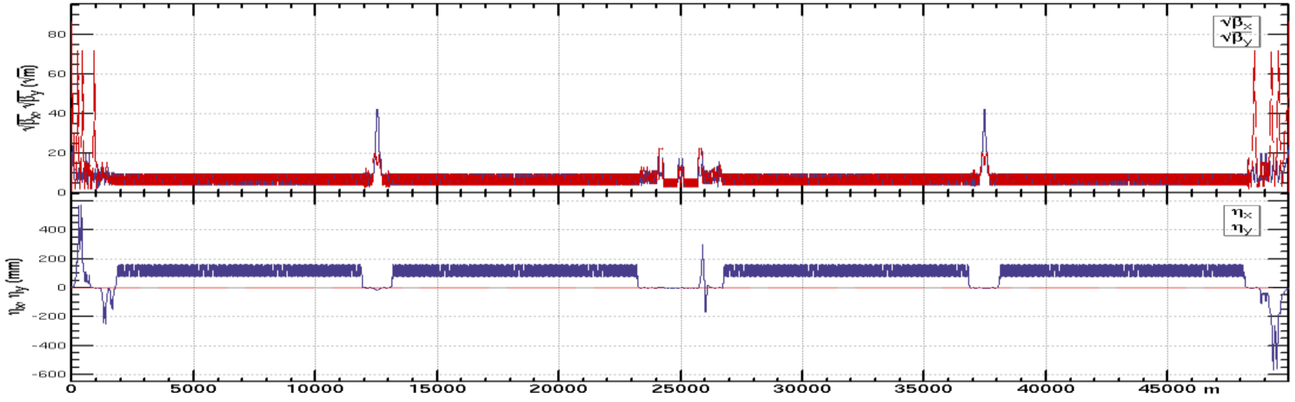
CEPC Higgs High Lumi Lattice and Dynamic Aperture Status

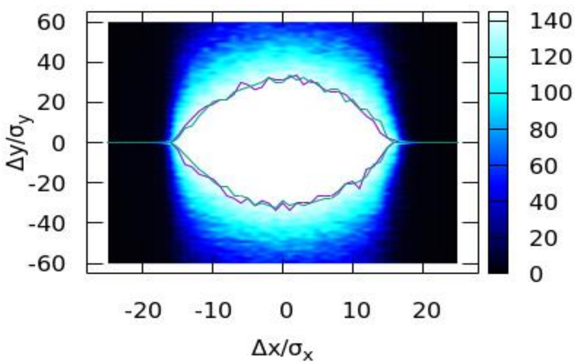
- The luminosity improves to be $5 \times 10^{34}/cm^2/s$ comparison with the CDR value of $2.93 \times 10^{34}/cm^2/s$
  - Physical optimization & Better hardware for enough DA
- Careful deliberation about the quadrupole radiation effect
  - Interaction region: Longer QD0 / QF1 (2m/1.48m => 3m/2m)
  - ARC region: Longer QUAD (2m => 3m)
- Relaxed requirement to the DA from injection
  - Straight Section region: larger β_x at injection point (600m =>1800m)
- Maximization of bending filling factor to minimize the SR loss per turn
  - ARC region: Sextupoles in the dual rings changed from staggered to parallel; the left drift are used for a longer bend
  - RF region: shorter phase tuning sections

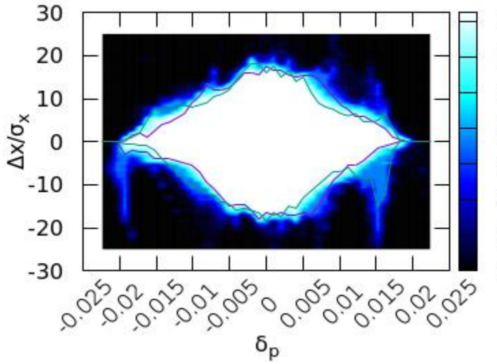
- With better correction of energy dependent aberration and shorter L* (without changing the front-end position of the final doublet cryo-module)

Achieved (no error): $16\sigma_x \times 32\sigma_y \times 1.9\%$

Goal (w/ error): $8\sigma_x \times 15\sigma_y \times 1.6\%$







Normal Conducting Magnets in Collider Ring (CDR & High Lumi.)

Main magnets in the ARC	Higgs (CDR) Quantity, length and field	Higgs (high lumi.) Quantity, length and field
Dipoles (dual aperture)	2320, 28.686 m, 373 Gs	2944, 21.7 m, 390 Gs (Quant +27%, total length -4%)
Quadpoles (dual aperture)	2320, 2 m, 8.4 T/m	2944, 3 m, 10.6 T/m (Quant +27%, total length 90%)
Sextupoles (single aperture)	SF: 896, 0.7 m, 506 T/m^2 SD: 896, 0.7 m*2, 506 T/m^2	SF: 1024, 0.7 m, 1100 T/m^2 SD: 1024, 0.7 m*2, 1129 T/m^2 (Quant +14%, total length 14%)

Superconducting Magnets in the Interaction Region (CDR & High Lumi.)

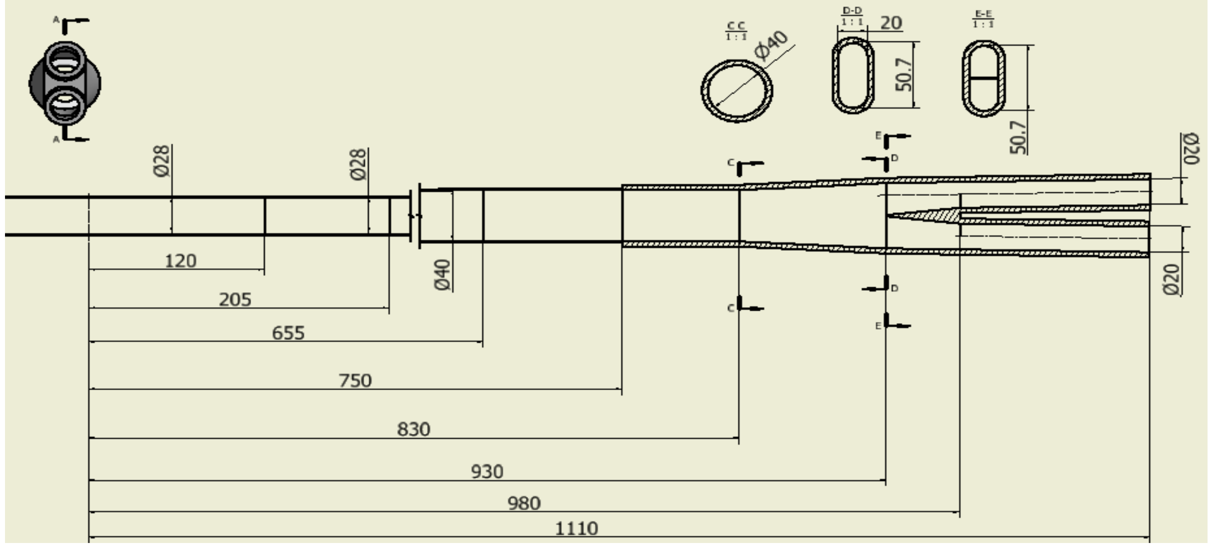
	Higgs (CDR)	Higgs (high lumi.)
SC QD0 and QF1	L*=2.2m, d=0.6m, QD0: 2.0m, 136T/m QF1: 1.48m, 111T/m	L*=1.9m, d=0.3m, QD0: 2.5m, 142T/m, 96T/m QF1=1.5m, 56T/m
SC anti-solenoids	maximum 7.2T	maximum 7.2T
SC sextupoles	VSIRD: 0.6m, 1635 T/m^2 HSIRD: 0.8m, 1882 T/m^2 VSIRU: 0.6m, 1562 T/m^2 HSIRU: 0.6m, 1999 T/m^2	VSIRD: 0.6m, 1511 T/m^2 HSIRD: 0.8m, 2099T/m^2 VSIRU: 0.6m, 1935 T/m^2 HSIRU: 0.6m, 1413 T/m^2 (safety factor 20% for strength)

High Luminosity Scheme at Higgs energy

Change of IP chamber

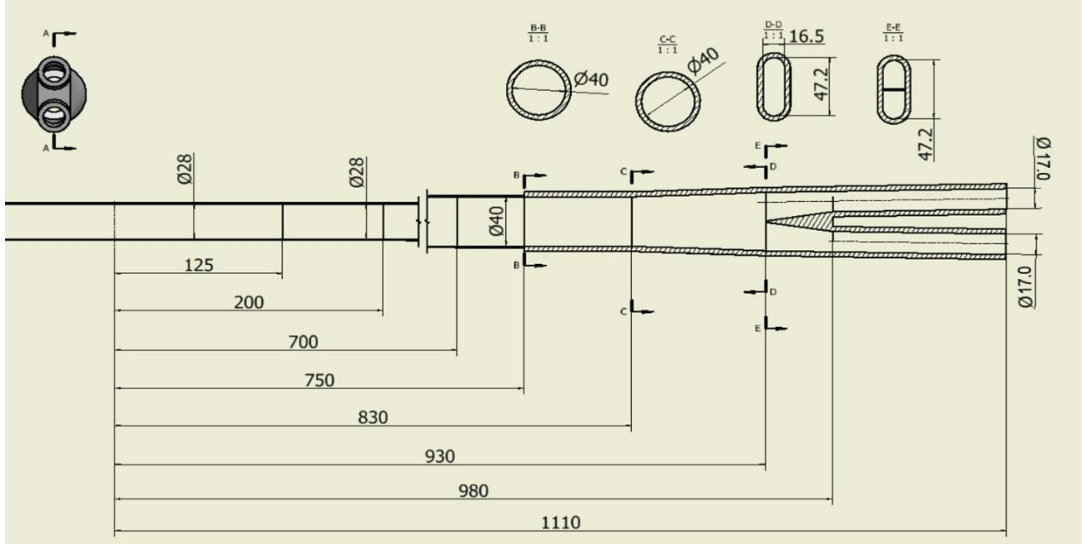
CDR

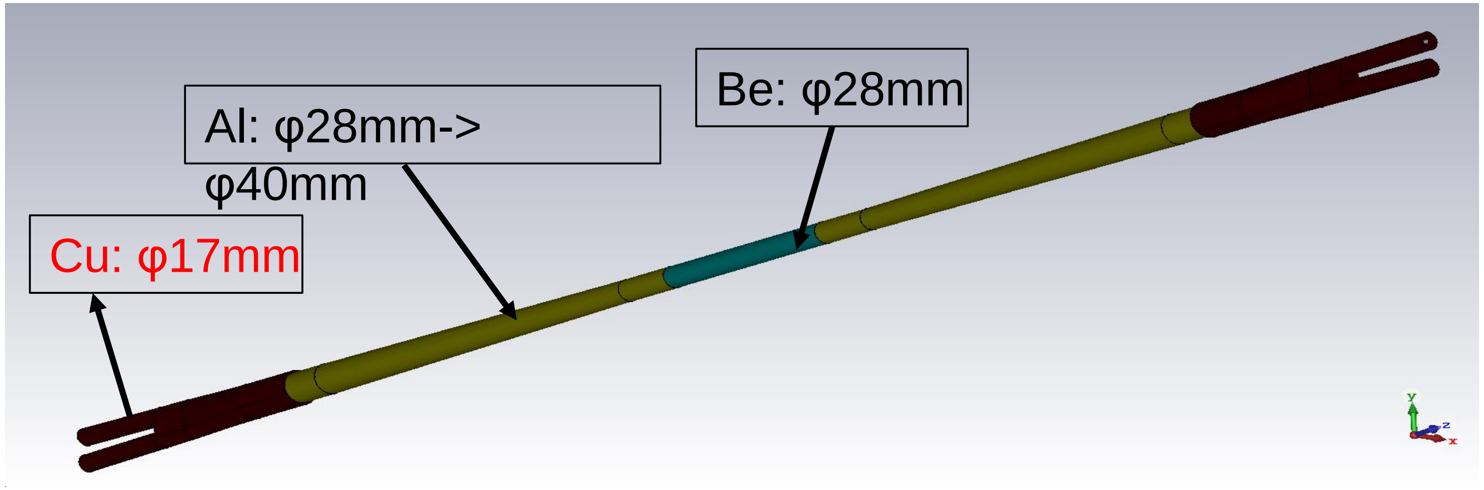
Be pipe: 28mm, SCQ Beam pipe:20mm

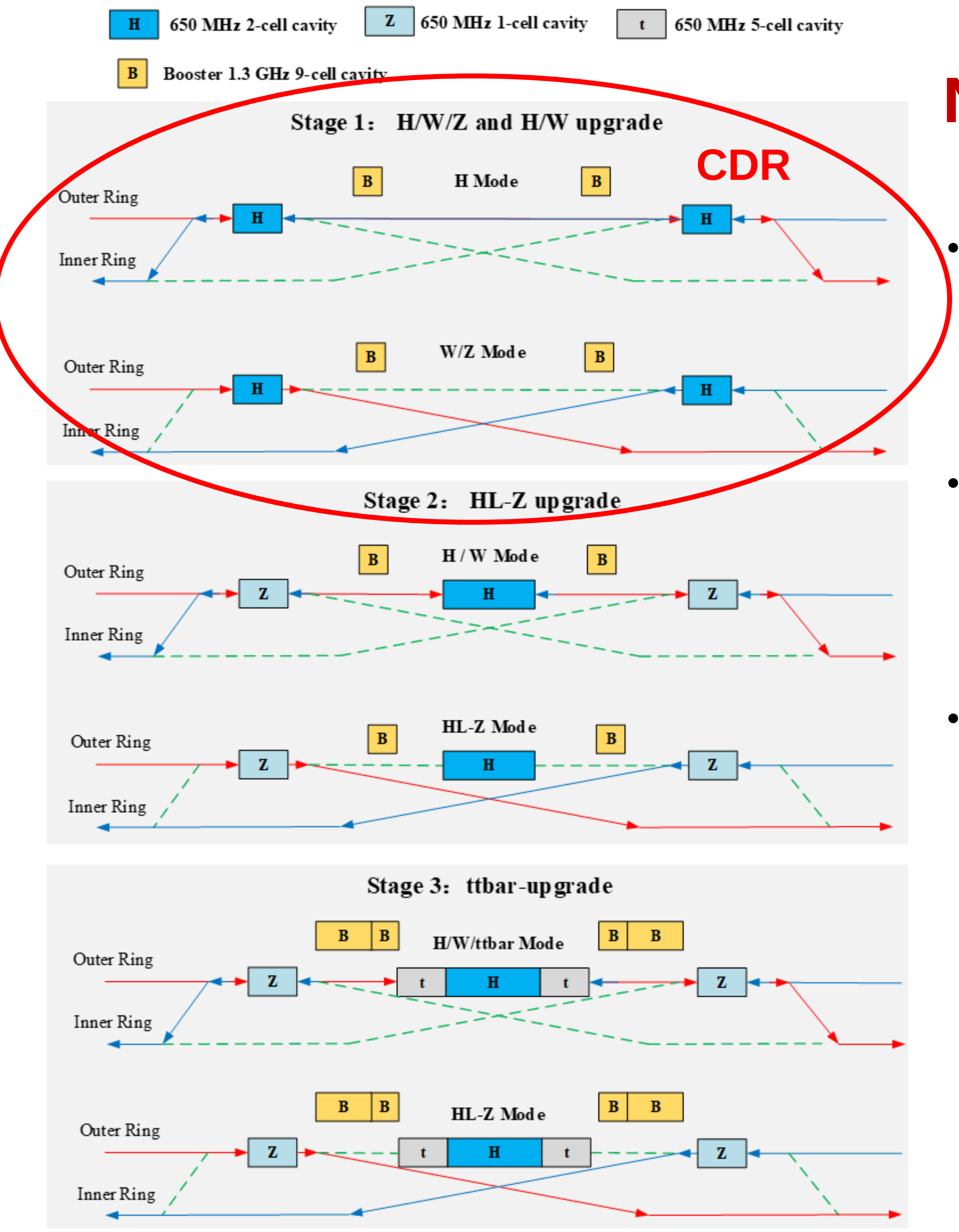


High luminosity

Be pipe: 28mm, Beam pipe:17mm







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 Parameters 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 TDR Z 30 MW 105E34	CEPC TDR H 30 MW 5E34	CEPC TDR W 30 MW 19E34	CEPC Ultimate Z 50 MW 167E34
Beam current (mA)	400 (600)	900	2 x 17.4	460	**840**	2 x 16.8	2 x 88.5	1400
Cell number	1	1	2		1	2/1	2/1	1
Cavity number / ring	1	2	2 x 120	60	60	2x(90+60)	2x(90+60)	60
Eacc (MV/m)	6 (1.5 MV)	10 (2.5 MV)	19.7	3.6	**9.4**	**19.7**	4.2	9.4
Q_0 @ 4.2 K / 2 K	1E9	1E9	1.5E10	1.5E10	**1.5E10**	**1.5E10**	1.5E10	1.5E10
Total wall loss (kW)			6.1	0.1	0.35	6.1	0.27	0.35
Input power (kW)	110	150	250	275	**500**	250/125	250/125	**835**
Cavity# / klystron	1	1 SSA	2		1	2/1	2/1	1
Klystron power (kW)	250	150 SSA	800	800	800	800	800	1200
Total KLY number	2	4	120		120	90+120	90+120	120
HOM damper	Absorber	Absorber	Hook+ Absorber		Absorber	Hook+ Absorber	Hook+ Absorber	Absorber
HOM power (kW)	8*	20	0.6	1.9	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 Booster Ring in high luminosity

- Parameters based on TME optimization
- Booster SRF parameters

Booster New Parameters after CDR based on TME

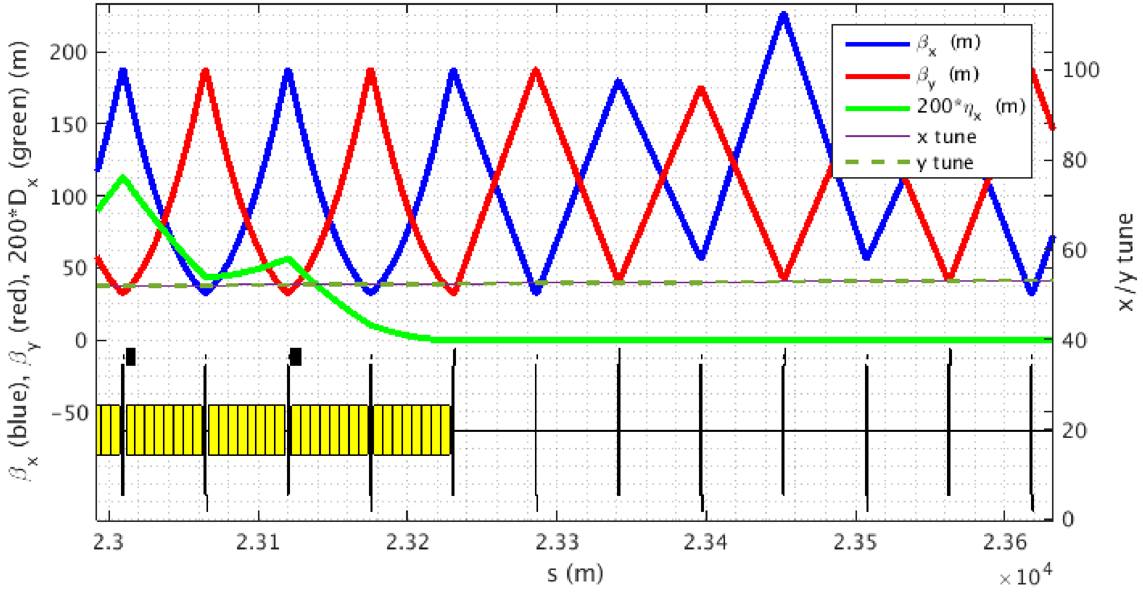
- Injection energy: 10GeV → 20GeV
- Max energy: 120GeV → 180GeV
- Lower emittance — new lattice

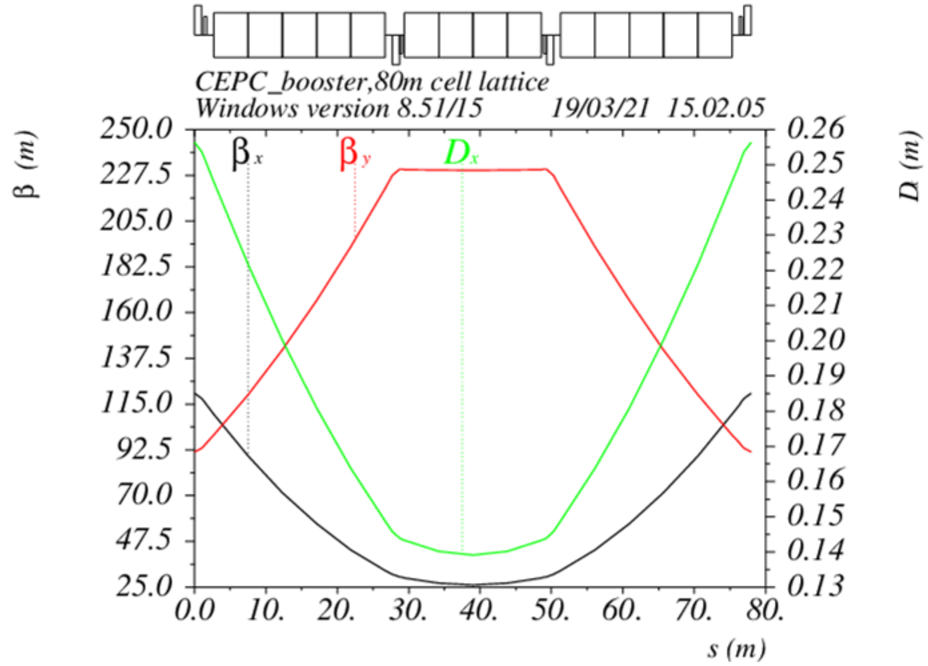
		tt	*H*	*W*	*Z*	
Beam energy	GeV	20				
Bunch number		37	214	1230	5750	3833
Threshold of single bunch current	μA	7.18	4.58	3.8		
Threshold of beam current (limited by coupled bunch instability)	mA	30				
Bunch charge	nC	1.07	0.89	0.81	0.93	1.0
Single bunch current	μA	3.2	2.7	2.4	2.8	3.0
Beam current	mA	0.12	0.57	2.99	16.1	11.5
Energy spread	%	0.016				
Synchrotron radiation loss/turn	MeV	1.3				
Momentum compaction factor	10^{-5}	1.12				
Emittance	nm	0.035				
Natural chromaticity	H/V	-372/-269				
RF voltage	MV	438.0	178.6	122.4		
Betatron tune ν_x/ν_y		321.23/117.18				
Longitudinal tune		0.13	0.083	0.069		
RF energy acceptance	%	5.4	3.4	2.8		
Damping time	s	10.4				
Bunch length of linac beam	mm	1.0				
Energy spread of linac beam	%	0.15				
Emittance of linac beam	nm	10~20				

		tt		*H*		*W*	*Z*
		Off axis injection	On axis injection	Off axis injection	On axis injection	Off axis injection	Off axis injection
Beam energy	GeV	180		120		80	45.5
Bunch number		37	35+2	214	207+7	1230	3833
Maximum bunch charge	nC	0.96	31.5	0.8	26.1	0.73	0.9
Maximum single bunch current	μA	2.9	94.6	2.4	78.5	2.2	2.7
Threshold of single bunch current	μA	95		79			
Threshold of beam current (limited by RF system)	mA	0.3		1		4	20
Beam current	mA	0.11	0.3	0.51	1.0	2.69	10.4
Bunches per pulse of Linac		1		1		1	2
Time for ramping up	s	7.3		4.5		2.7	1.6
Injection duration for top-up (Both beams)	s	31.7	33.4	24.3	32.8	39.3	135.1
Injection interval for top-up	s	65		38		155	153.5
Current decay during injection interval		3%					
Energy spread	%	0.15		0.099		0.066	0.037
Synchrotron radiation loss/turn	GeV	8.45		1.69		0.33	0.034
Momentum compaction factor	10^{-5}	1.12					
Emittance	nm	3.27		1.26		0.56	0.18
Natural chromaticity	H/V	-372/-269					
Betatron tune ν_x/ν_y		321.23/117.18					
RF voltage	GV	9.3		1.98		0.59	0.284
Longitudinal tune		0.13		0.083		0.069	0.069
RF energy acceptance	%	1.34		1.14		1.6	2.6
Damping time	ms	14.2		47.6		160.8	879
Natural bunch length	mm	2.0		2.1		1.7	0.96
Injection duration from empty ring	h	0.12		0.14	0.19	0.27	1.2

High Luminosity Scheme at Higgs Energy

Booster ring





- Standard TME cells with combined magnets are chosen for lower booster emittance to relax the DA requirement of the collider ring.
- **1.26nm@120Gev** is expected. (CDR: 3.6nm)

CEPC Booster SRF Parameters

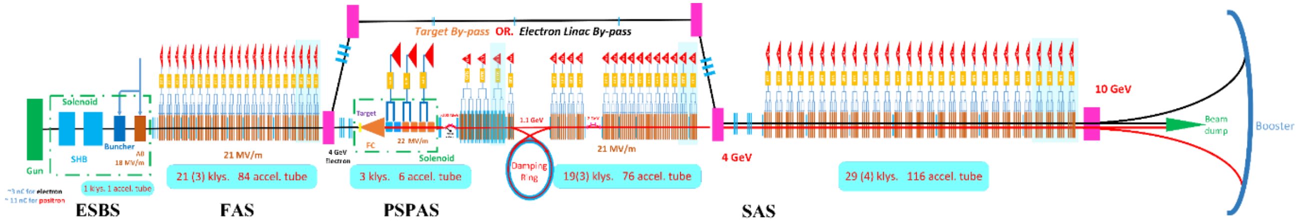
20 GeV injection	H	W	Z
Extraction beam energy [GeV]	120	80	45.5
Bunch number	242	1524	6000
Bunch charge [nC]	0.72	0.576	0.384
Beam current [mA]	0.52	**2.63**	**6.91**
Extraction RF voltage [GV]	1.97	0.585	0.287
Extraction bunch length [mm]	2.7	2.4	1.3
Cavity number in use (1.3 GHz TESLA 9-cell)	96	64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

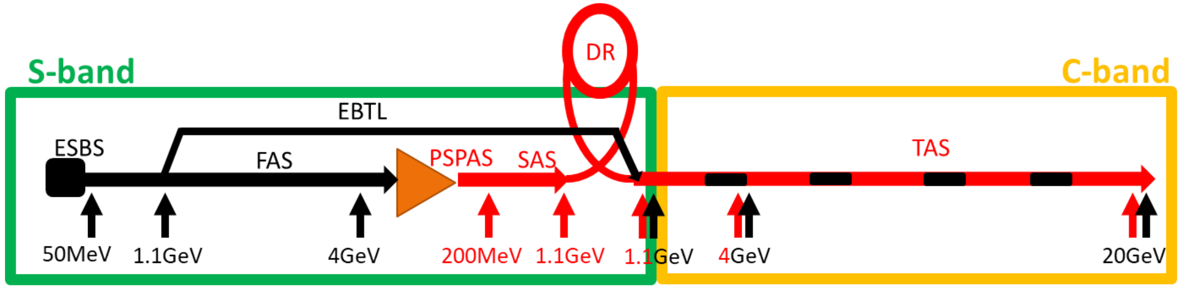
CEPC Linac in high luminosity

- Major modifications: Emittance, Extraction energy, EBTL energy.
- Hardware choices for the injection and Extraction System

High luminosity Scheme at Higgs energy

LINAC



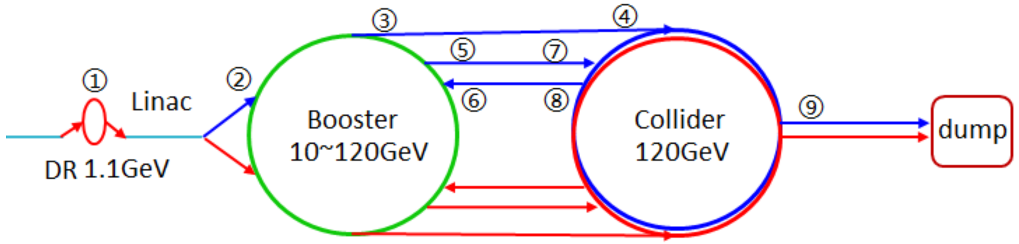


- In order to relax the DA requirement of booster the beam emittance of Linac should be controlled as **10 nm** with the damping ring of energy 1.1GeV. (CDR: 40nm)
- By-pass energy is reduced from 4GeV to 1.1GeV
- The extract energy the end of Linac is promoted for 10 to 20 GeV

Parameter	Symbol	Unit	Designed
e^-/e^+ beam energy	E_{e-}/E_{e+}	GeV	**20**
Repetition rate	f_{rep}	Hz	**100**
e^-/e^+ bunch population	N_{e-}/N_{e+}		**$> 9.4\times10^9$ / $>9.4\times10^9$**
		nC	**> 1.5**
Energy spread (e^-/e^+)	σ_e		**$< 2\times10^{-3}$ / $< 2\times10^{-3}$**
Emittance (e^-/e^+)	ε_r	nm· rad	**10**
Bunch length (e^-/e^+)	σ_l	mm	**1 / 1**
e^- beam energy on Target		GeV	**1.1**
e^- bunch charge on Target		nC	**10**

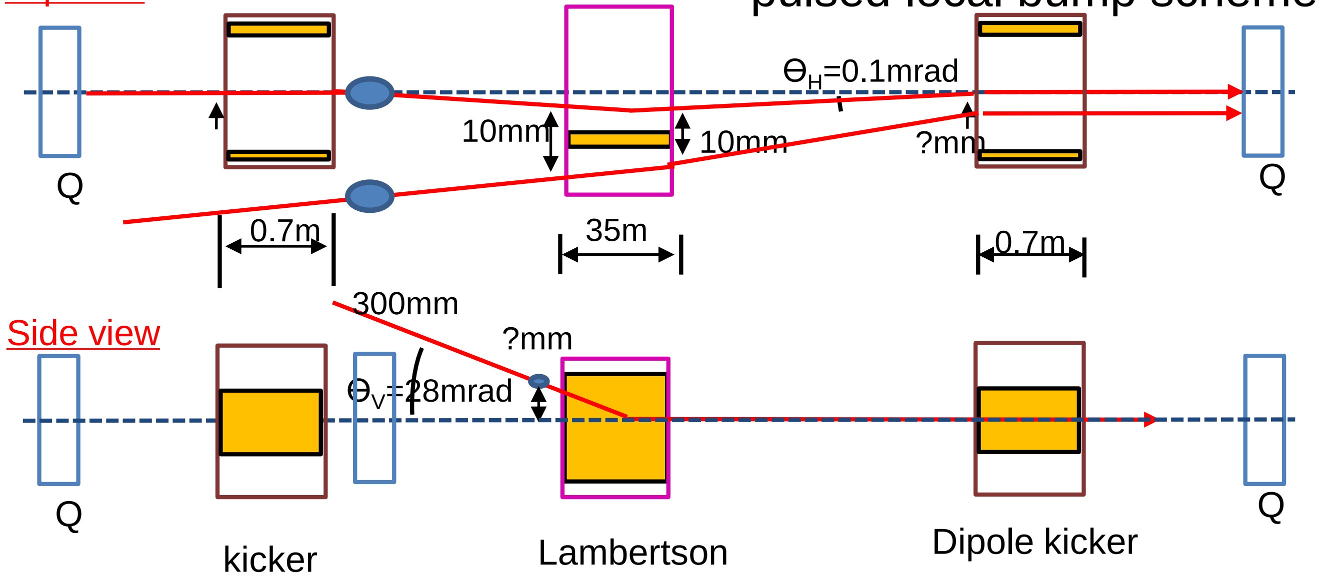
CEPC Injection and Extraction System Hardwares

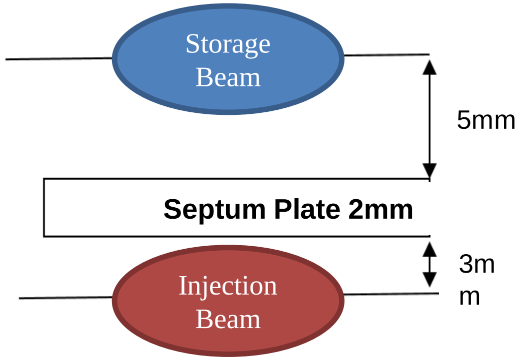
	Sub-system	Kicker Type	Kicker waveform	Septa Type	Thickness of septum
1	Damping ring inj./ext.	Slotted-pipe kicker	Half-sine/250ns	Horizontal LMS	ϕ22/3.5mm
2	Booster LE inj.	Strip-line kicker	Half-sine/50ns	Horizontal LMS	ϕ55/5.5mm
3	Booster ext. for CR off-axis inj.	Delay-line dipole kicker	Trapezoid /440-2420ns	Vertical LMS	Φ55/6mm
4	Collider off-axis inj.	Delay-line NLK kicker	Trapezoid /440-2420ns	Vertical LMS	Φ75x56/2mm
5	Booster ext. for CR on-axis inj.	Ferrite core dipole kicker	Half-sine/1360ns	Vertical LMS	Φ55/6mm
6	Booster HE inj.	NLK or Pulsed sextupole	Half-sine/0.333ms	Vertical LMS	Φ55/6mm
7	Collider swap out inj.	Ferrite core dipole kicker	Half-sine/1360ns	Vertical LMS	Φ75x56/6mm
8	Collider swap out ext.	Ferrite core dipole kicker	Half-sine/1360ns	Vertical LMS	Φ75x56/6mm
9	Collider beam dump	Delay-line dipole kicker	Trapezoid /440-2420ns	Vertical LMS	Φ75x56/6mm
10	RF region beam separating	Delay-line dipole kicker	CW square / 165us,50%	Horizontal Copper septa	Φ75x56/10mm



Collider Ring off-axis Injection

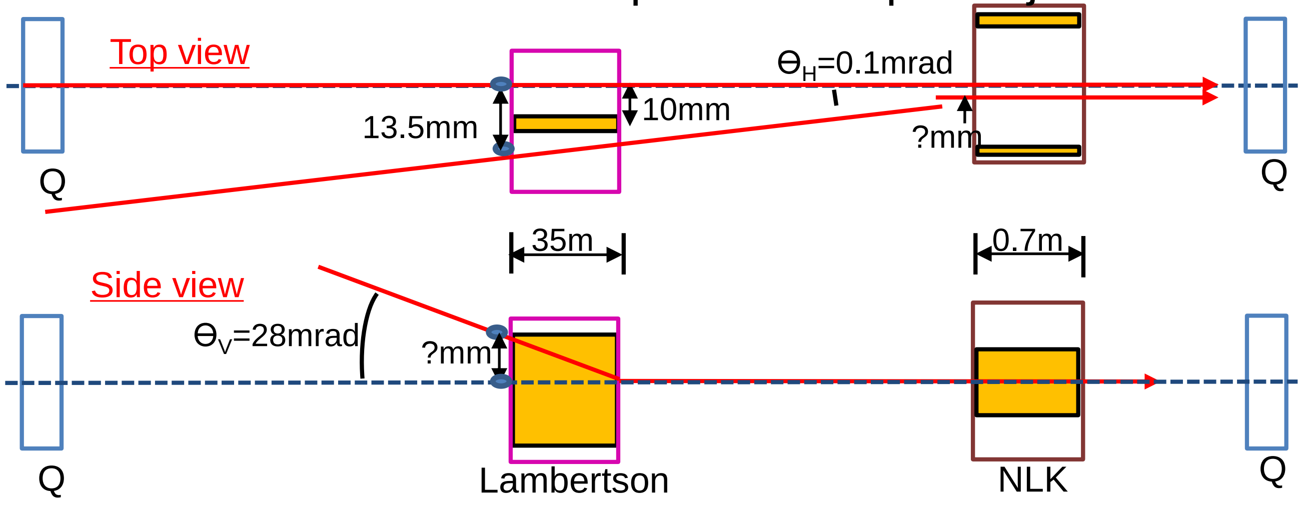
pulsed local bump scheme

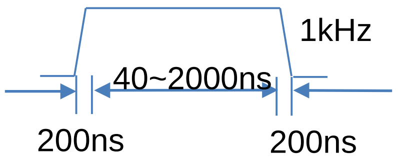




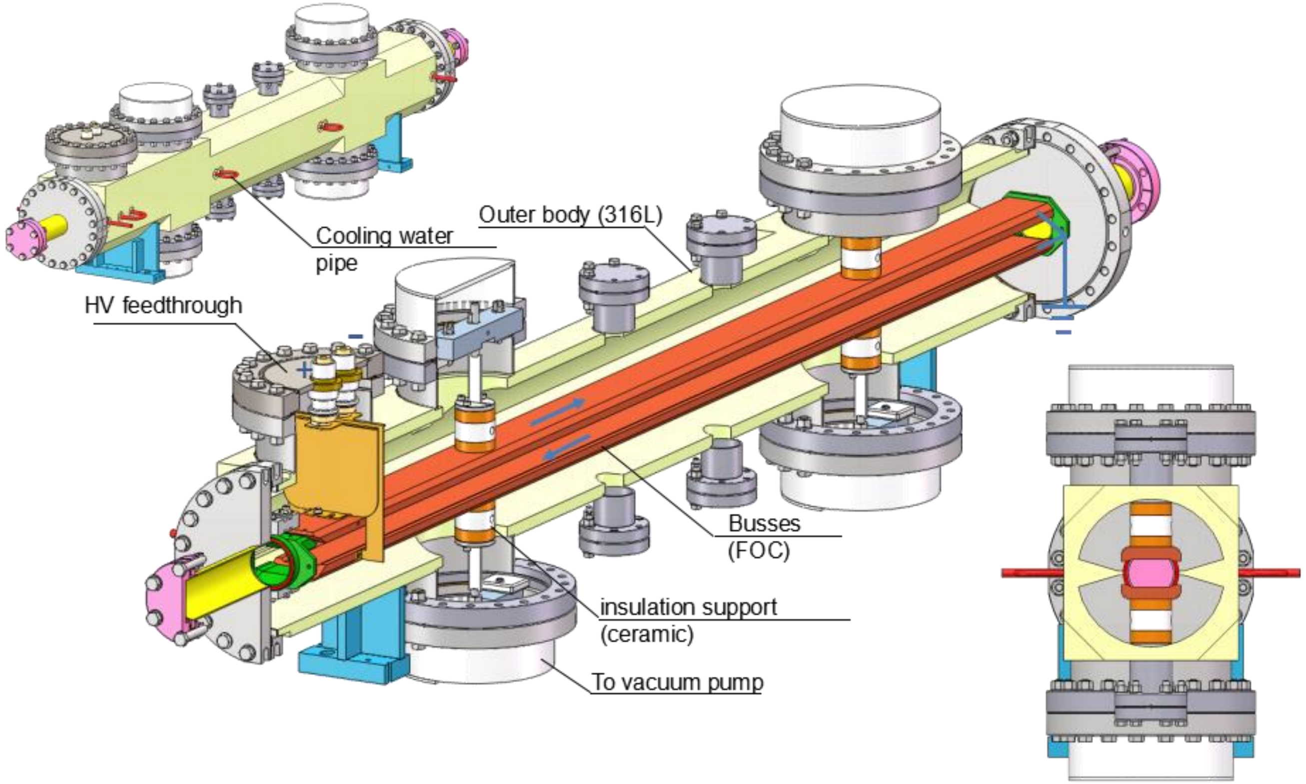
1. **Dipole kicker:** horizontal out-vacuum delay-line kicker+coating ceramic chamber+PFN-based solid-state pulser
2. **NLK kicker:** horizontal out-vacuum delay-line **NLK** kicker+coating ceramic chamber+PFN-based solid-state pulser
3. **Septa:** Vertical Lambertson magnet

pulsed multipole injection scheme

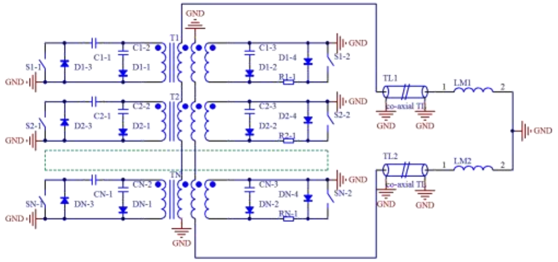


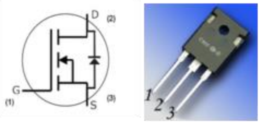


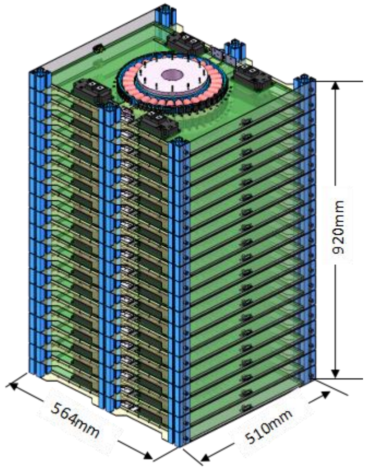
CEPC Slotted-pipe Kicker and 250ns-fast Kicker Pulser Engineering Design



- Scheme: 20-stage inductive adder based on SiC-MOSFETs.
- The co-axial transformer is configured as bipolar output.
- The pulser is located outside tunnel and 10 cables with length of 30m are applied to connect to kicker.
- Due to short end of the slotted-pipe kicker, the reflection energy should be return to the pulser.
- A proper absorption circuit must be designed at pulser end.







20-stage inductive adder

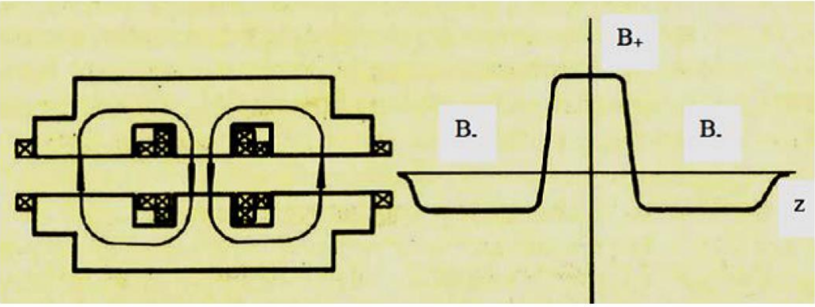
CEPC Self Polarization at Z-pole with Asymmetric Wigglers

- **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.**

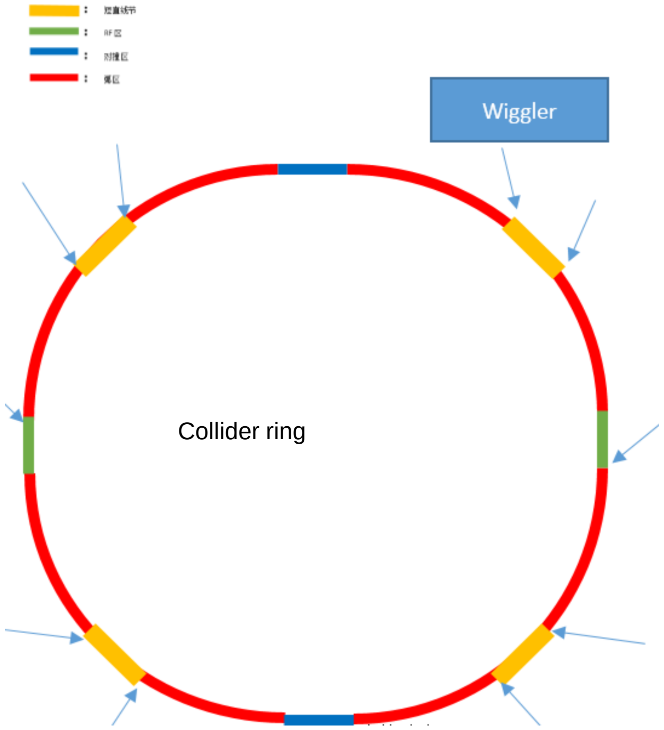


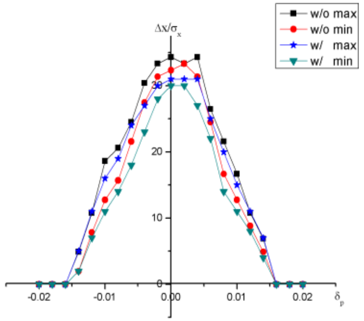
$$P(t) = P_0^w(1 - e^{\frac{-t}{\tau_p^w}})$$

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

$$t = 1.10h$$

5% is enough for energy calibration.





DA

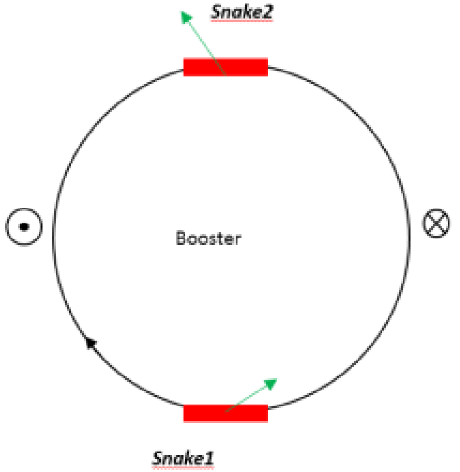
Longitudinal polarized beam collision and full polarization injection scheme are under studies

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.



● 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

The Siberian Snake will be inserted into the booster lattice

Orbital motion in Snake

Polarized electron beam generation in linac injector is under design

Contents

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

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

2) CEPC 650MHz SC accelerator system, including SC cavities and cryomodules (Complete test cryo-module in 2022)

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

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

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

6) SC magnets including cryostat (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)

…

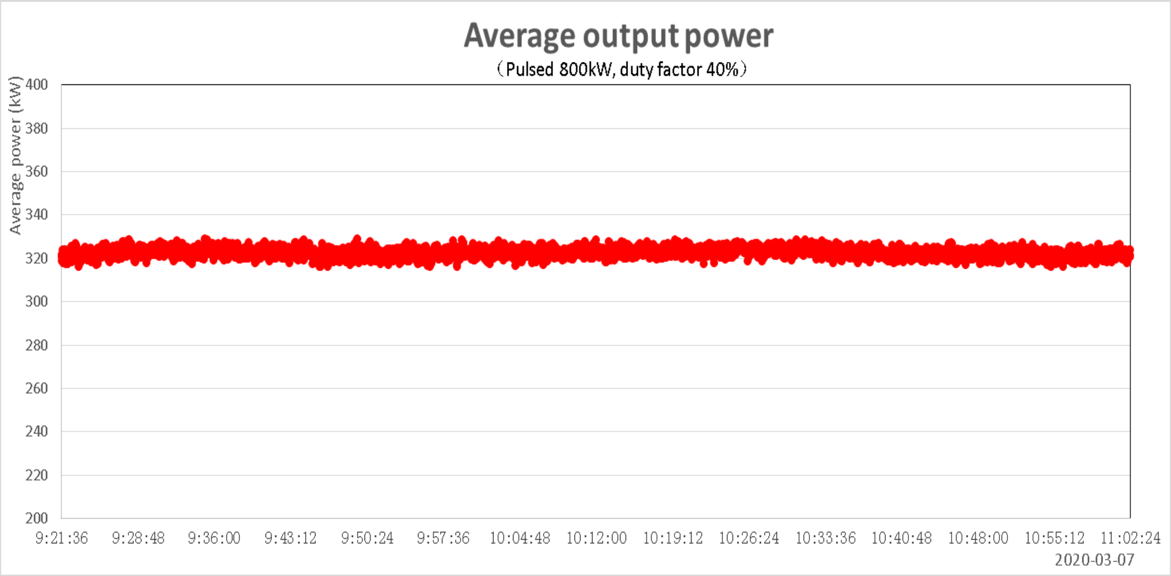
SppC technology R&D

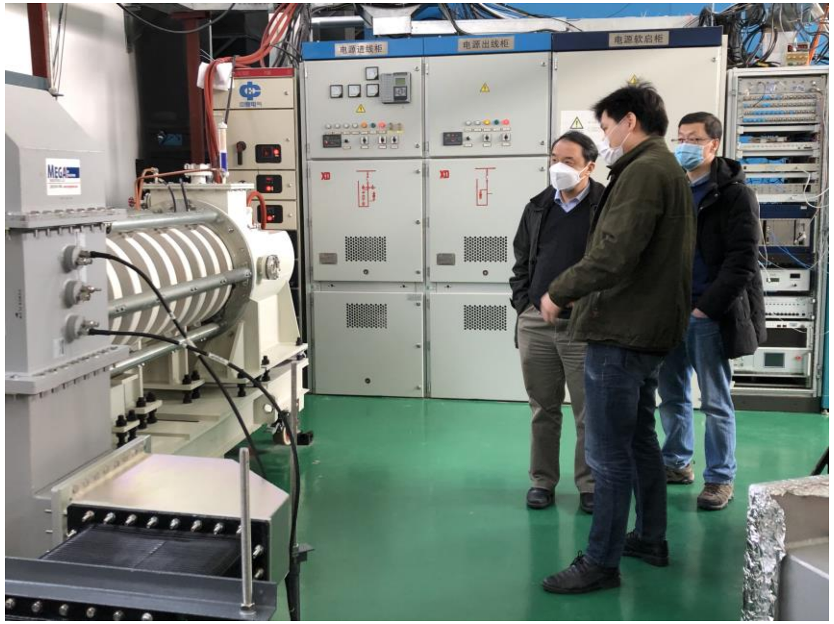
Ion based supercondcuting materials and high field magnets

High Efficiency Klystron for CEPC

◆ The 1st prototype finishes its fabrication and passes the maximum power test

- The output power achieves **700kW** as the CW mode and **800 kW** as the pulse mode. The electricity-RF power transfer rate reaches **62%**, an advanced efficiency in the world. 1dB bandwidth is higher than 1.0 MHz， RF gain is higher than 43 dB
- It is the first P-band high power klystron which works in both CW and pulse modes self-developed in China. The high efficient Klystron is one of the key technology and breakthrough for CEPC. It founds a solid base for the future advanced high efficient klystron R&D.





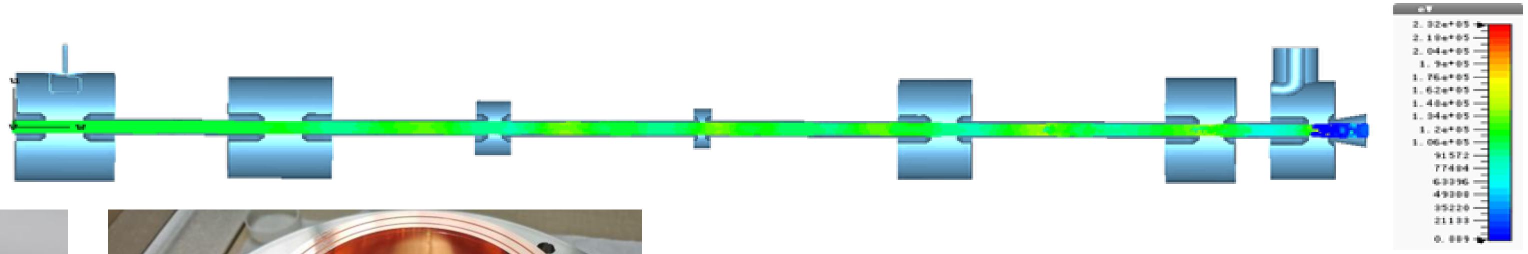
High Efficiency Klystron for CEPC

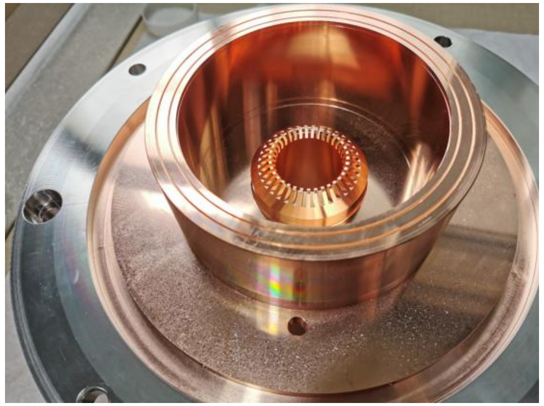
Even higher efficient Klystron finishes its design and the fabrication started

- The 2nd high efficient klystron for CEPC fixed its physical design. The expected RF transfer rate is up to **77%**, bandwith 1.6 MHz, gain 48.3 dB.
- The fabrication already started at the end of 2020, the accomplishment is foreseen by the end of June 2021.

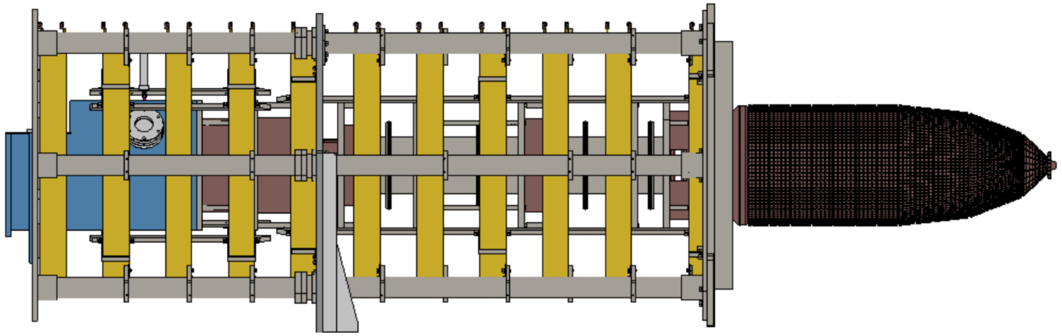
Multi-beam klystron finishes its physical design and the mechanical preparation is on going.

- Multi-beam klystron is expected to improve the RF transfer rate to the recorded **80.5%**, a leading theoretical number in the world.
- The initial mechanical design finished. After the related details determined it will starts the manufacture in the 2nd half year of 2021 and the first prototype is expected in the 1st half year of 2022.





Components for the 2nd prototype



Mechanical drawing for the multi-beam Klystron

CEPC SRF System TDR Status and Plan

TDR Phase 1: 2019-2020 (System Design, Components Prototyping)

- ✓ SRF system TDR design for higher luminosity (RF staging and bypass scheme proposed)
- ✓ High Q, high gradient cavity, high power components and other key technology R&D (close to CEPC spec)
- ✓ PAPS SRF facility construction (equipment installation)

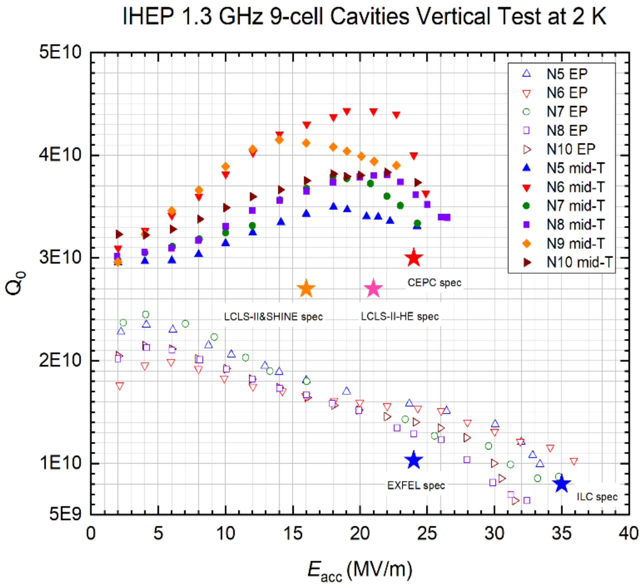
TDR Phase 2: 2021-2022 (System Design, Cryomodule Prototyping)

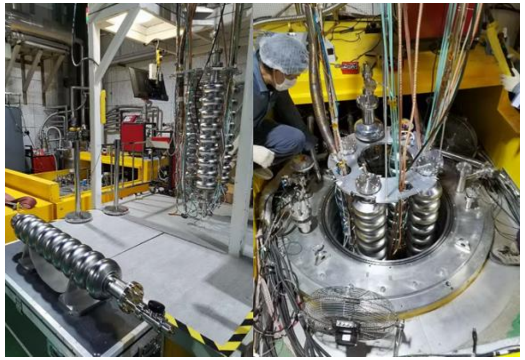
- ☐ SRF system TDR design re-baseline and optimization
- ☐ 650 MHz high Q short cryomodule assembly, operation and improvement (to meet CEPC spec)
- ☐ 1.3 GHz high Q full cryomodule prototyping (to meet CEPC and CW FEL spec)
- ☐ Nb_3Sn and other thin film cavity R&D
- ☐ SRF facility (PAPS commissioning, operation and upgrade)

Post-TDR: 2023-2025 (Cryomodule Prototyping, Mass-Production Preparation)

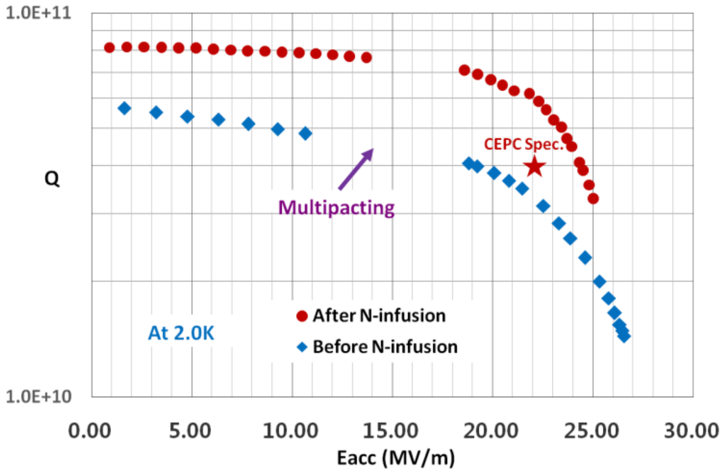
- SRF system Engineering Design, mass-production technology preparation
- 650 MHz full cryomodule prototyping
- 1.3 GHz high Q full cryomodule industrialization and mass production (for FEL projects)
- 650 MHz Z-pole high current cryomodule and ttbar cryomodule concept design
- Nb_3Sn cavity and cryomodule prototyping

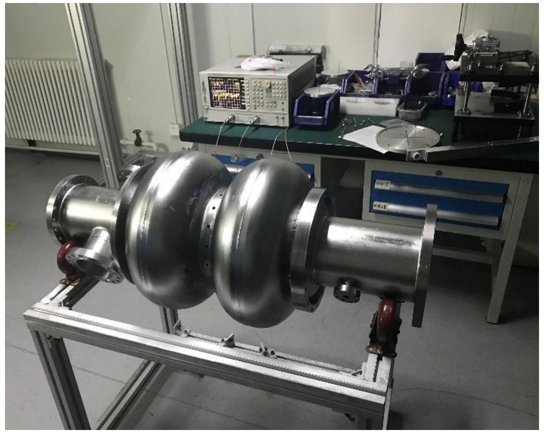
IHEP 650MHz 2-cell & 1.3GHz 9-cell Cavities





Booster 1.3GHz 9 cell cavity





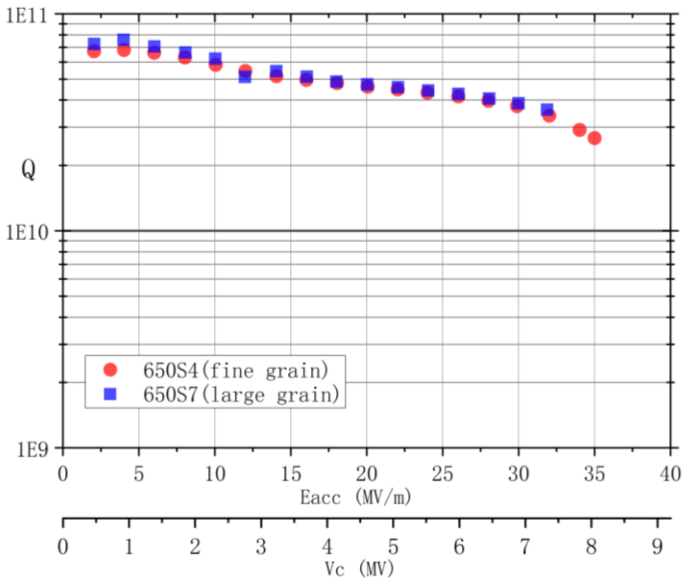
Collider ring 650Mhz 2 cell cavity

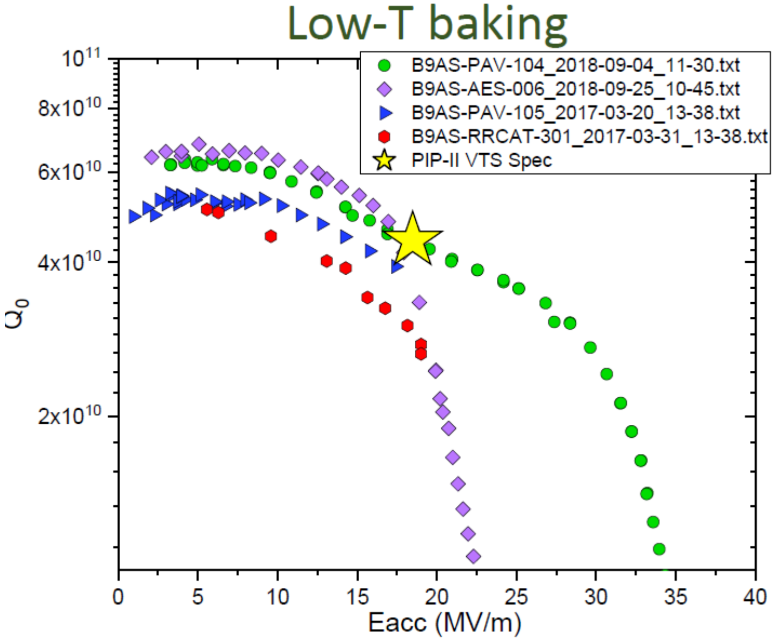
- Five EP 9-cells > 30 MV/m, max 36 MV/m, reach ILC spec.
- Six Mid-T Furnace Bake 9-cells: 3.4~4.5E10@16~22 MV/m, beyond CEPC, LCLS-II and LCLS-II-HE spec. World leading results comparable to LCLS-II-HE cavities.

- Nitrogen-infusion of the BCP cavity: 6E10@22MV/m, exceeds CEPC spec (4E10@Eacc=22MV/m)
- World record Q in BCP cavity. Q at 20 MV/m close to the N-dope+EP cavity of FNAL.
- EP to further improve the gradient and Q.

650MHz 1-cell Cavities

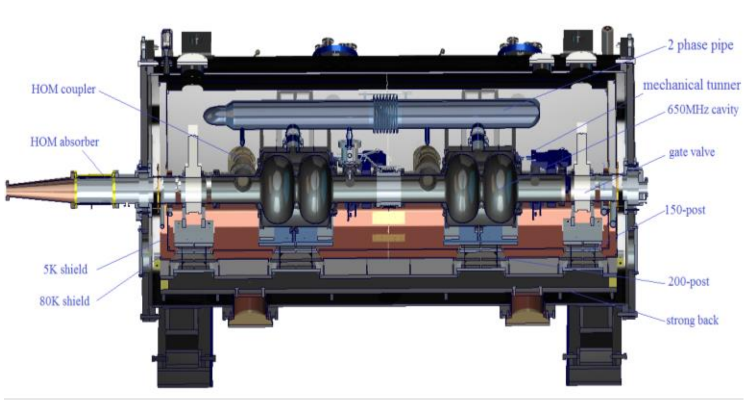
- **650 MHz 1-cell cavity (large grain) is favorable for HL-Z, which have higher Q and gradient than fine grain.**
- **650MHz 1-cell cavities reaches: 2.7E10 @ 35MV/m at 2.0 K; Aiming for 3E10@40MV/m**

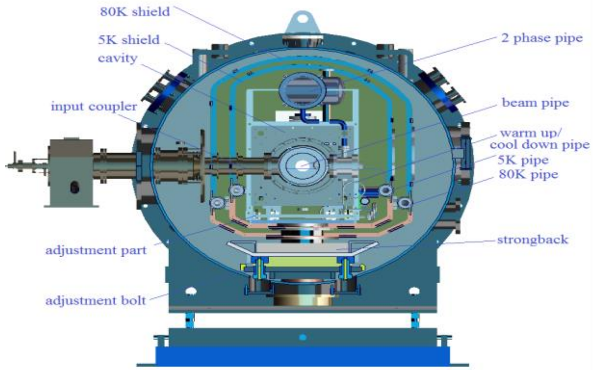


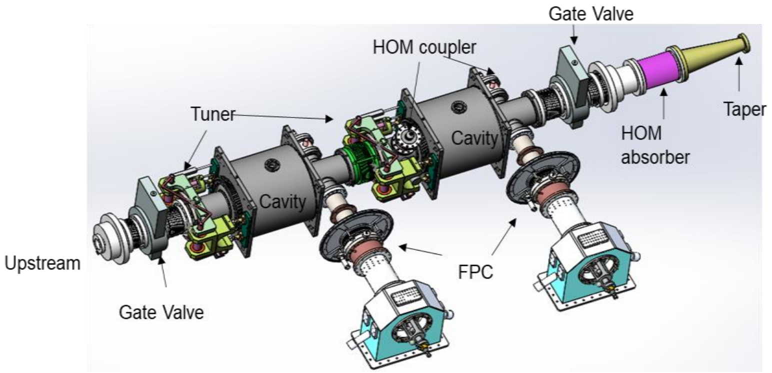


650 MHz Test Cryo-module with Beam (2 x 2 cell Module)

- Cavity string and module assembly in March to May 2021
- Horizontal and beam test at PAPS in summer
- Demonstrate 650 MHz cavity high Q operation mode
- Beam test with a 5 mA CW 460 kV beam from a DC photo-cathode gun.





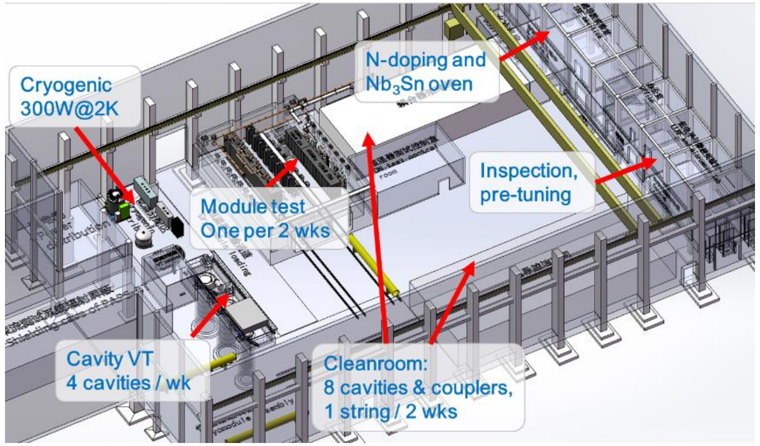


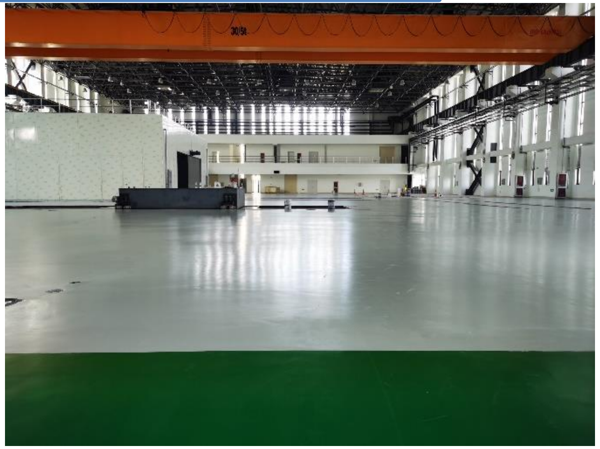
Cryomodule vacuum vessel and cold mass

Valve box

IHEP New SC Lab under Construction

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





New SC Lab Design (4500m^2)

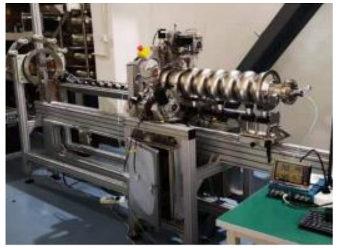
Cryogenic system hall in Jan. 16, 2020


Vacuum furnace (doping & annealing)


Nb3Sn furnace

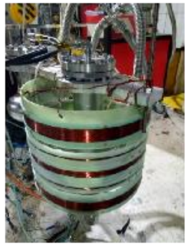

Nb/Cu sputtering device


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 Low Field Booster Dipole 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%

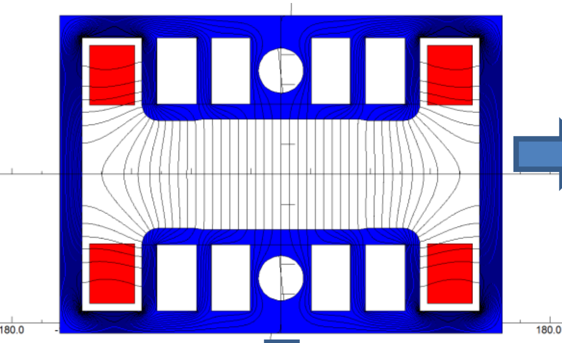
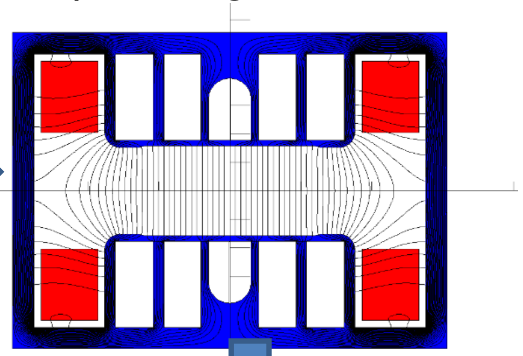
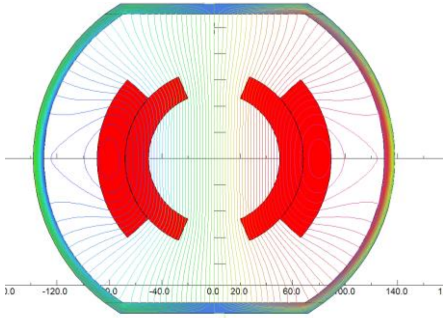
Original 10GeV injection enegy from LINAC to 100Km booster

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**

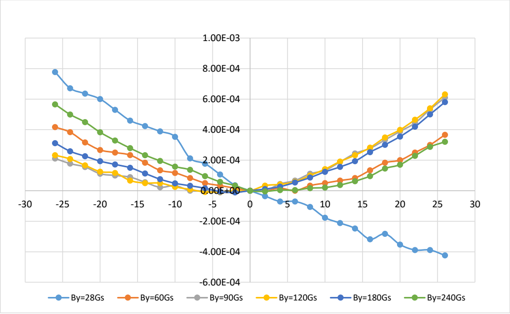
Booster High Precision Low Field Dipole

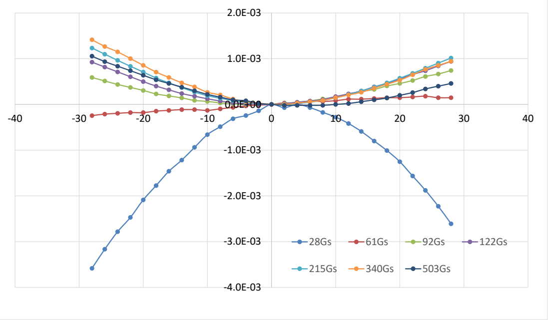
Two kinds of the dipole magnet with diluted iron cores and without iron core (CT) are proposed and designed

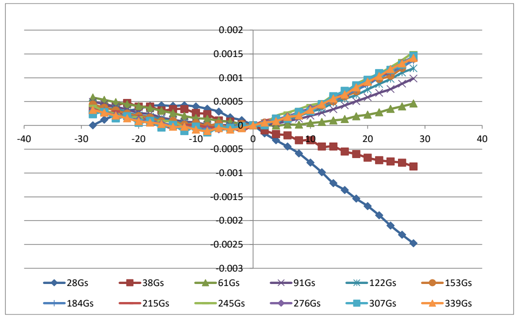





1m long CT test booster dipole magnet without iron core completed in Oct. 2019, and the test result shows that CT design reached the design goal.

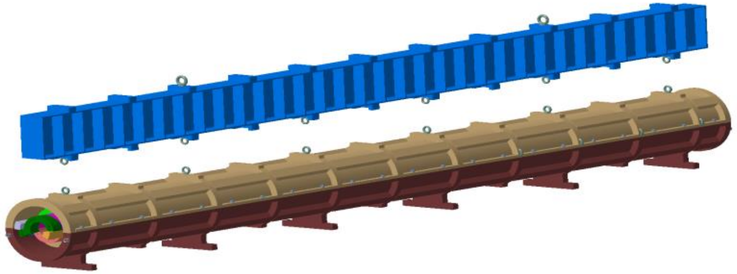








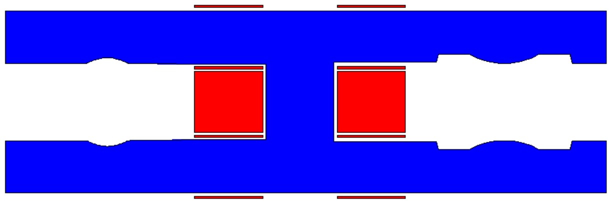
	BST-63B
Quantity	16320
Minimum field (Gs)	28
Maximum field (Gs)	338
Gap (mm)	63
Magnetic Length (mm)	4700
Good field region (mm)	55
Field uniformity	0.1%
Field reproducibility	0.05%



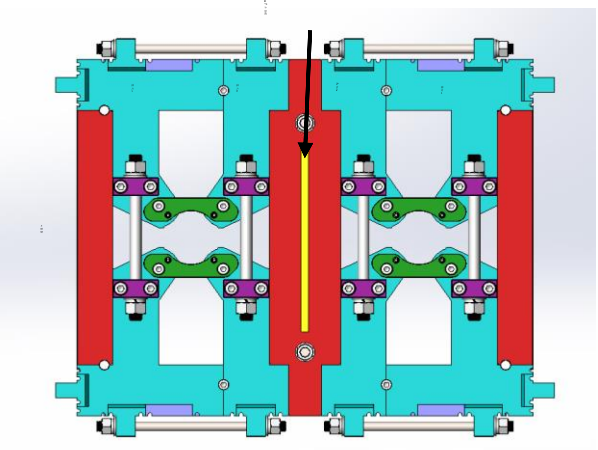
If injection energy is larger than 20GeV, which is the new baseline, iron core magntes could be used

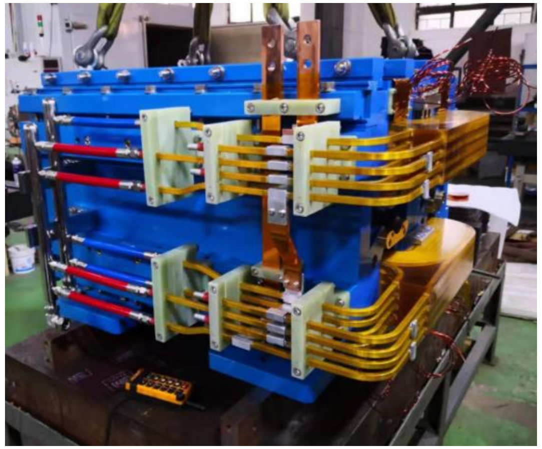
A full scale CT dipole magnet of 5.1m long is under design, and fabrication will be completed at the end of 2021

CEPC Collider Ring Dual Aperture Dipole, QUAD & Sextupole Design Progress



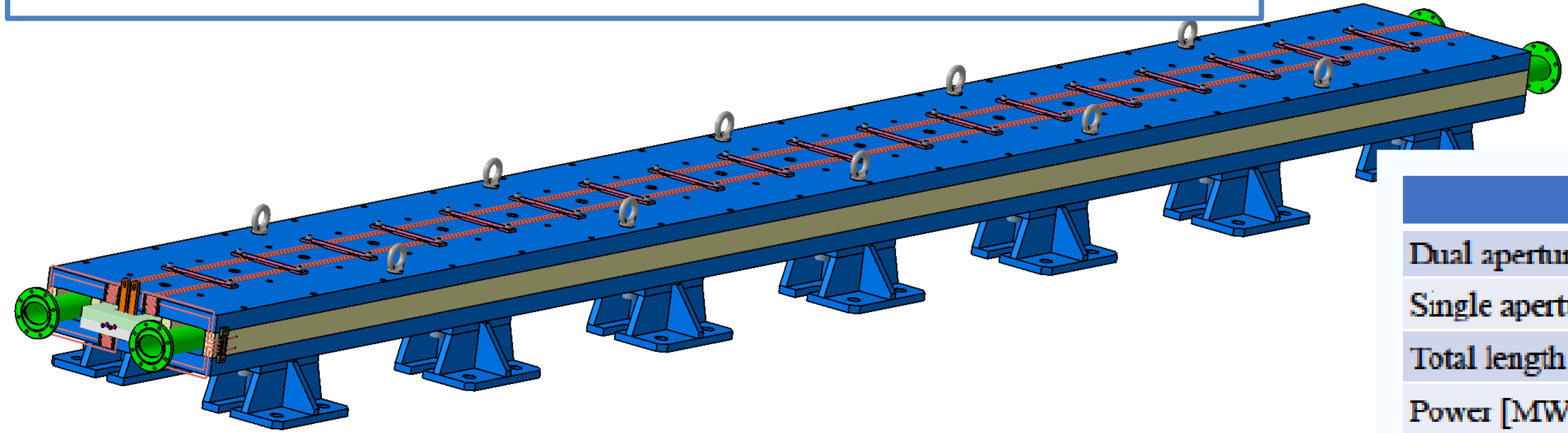
First dual aperture dipole test magnet of 1m long has been fnished in Nov, 2019





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

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

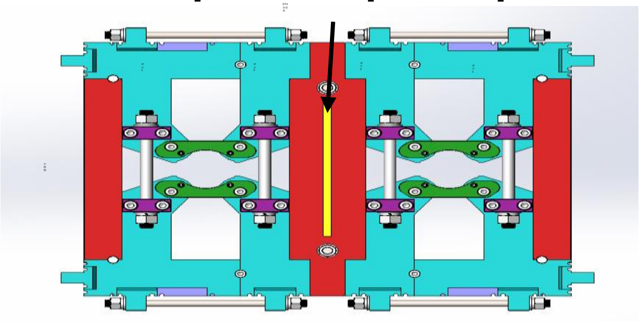


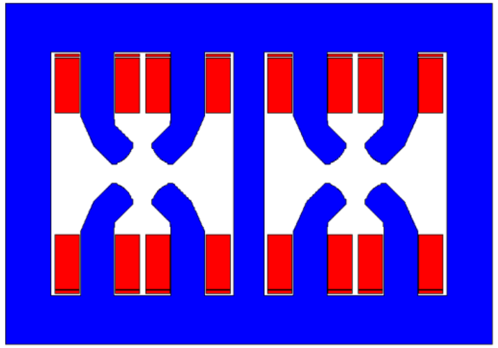
The mechanical design of a full size CEPC collider ring dual aperture dipole of 5.7m long has been designed and be fabricated at the end of 2021.

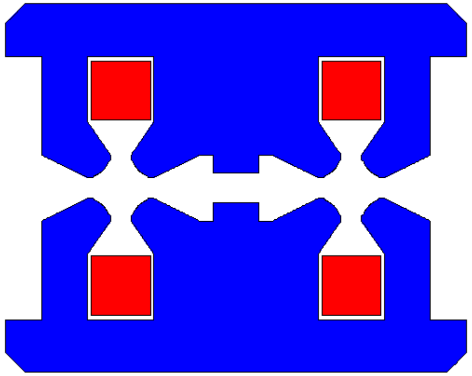
	Dipole	Quad.	Sext.	Corrector	Total
Dual aperture	2384	2392	-	-	13742
Single aperture	80*2+2	480*2+172	932*2	2904*2	
Total length [km]	71.5	5.9	1.0	2.5	80.8
Power [MW]	7.0	20.2	4.6	2.2	34

CEPC Collider Ring Dual Aperture Quadrupole & Sextupole Design

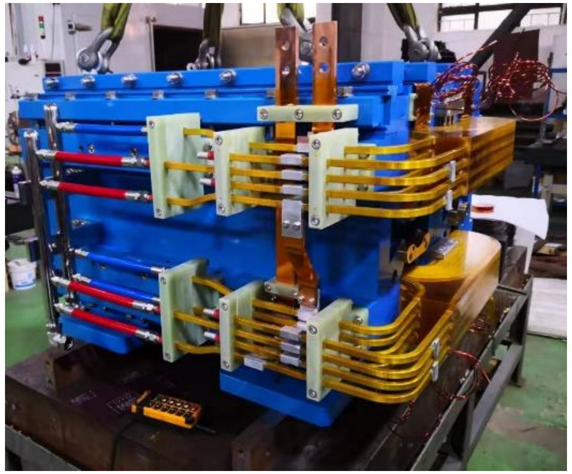
Dual aperture quadrupole



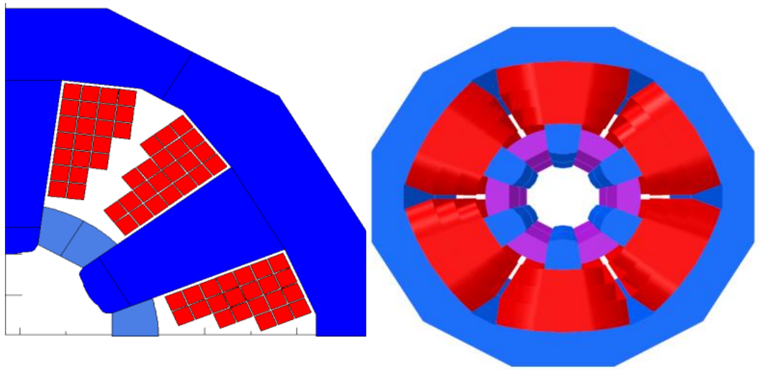




	Dipole	Quad.	Sext.	Corrector	Total
Dual aperture	2384	2392	-	-	13742
Single aperture	80*2+2	480*2+172	932*2	2904*2	
Total length [km]	71.5	5.9	1.0	2.5	80.8
Power [MW]	7.0	20.2	4.6	2.2	34

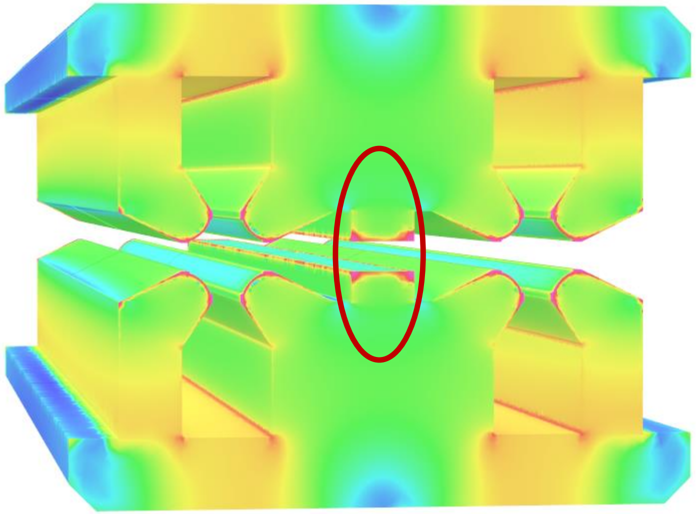


The first dual aperture quadrupole model, not matching requirement, **new design shows good results**

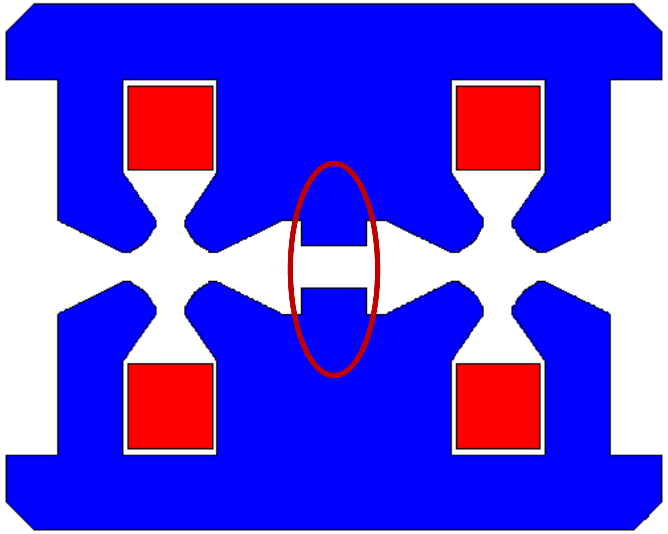


Sextupole design

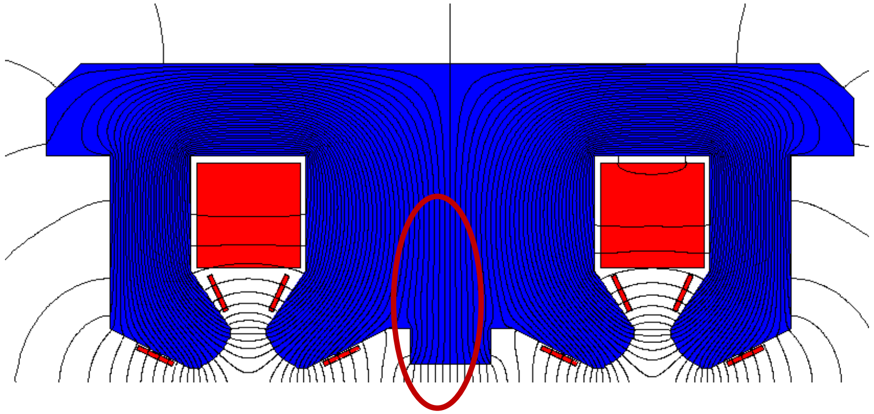
CEPC Collider Ring Dual Aperture Quadrupole Optimization



3D Model



F/D design



F/D design with trim coils

A shim at the Yoke centre

- The b1 and b3 polynomial coefficient can be reduced a lot
- Field harmonic components keep stable at different energies (45-180GeV)
- No large variation induced by the trim coils

The simulations show the field quality can meet the requirements.

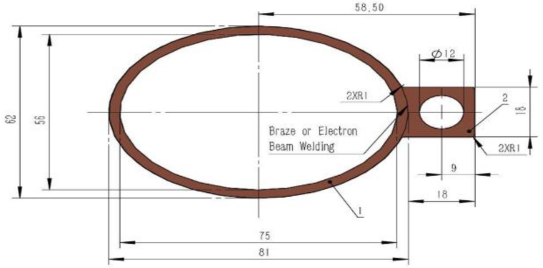
CEPC Vacuum System R&D

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

- NEG coating suppresses electron multipacting and beam induced pressure rise, as well as provides extra linear pumping
- The vacuum pressure is better than 2 x 10-10 Torr
- Total leakage rate is less than 2 x 10-10 torr.l /s.

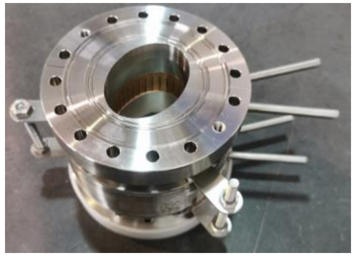
Elliptical vacuum chamber in the collider ring will be replaced by circular chambers.

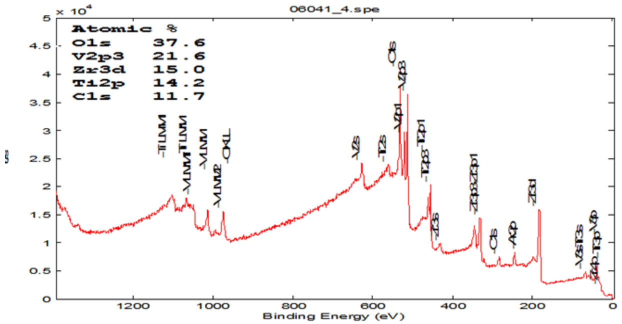
Positron ring

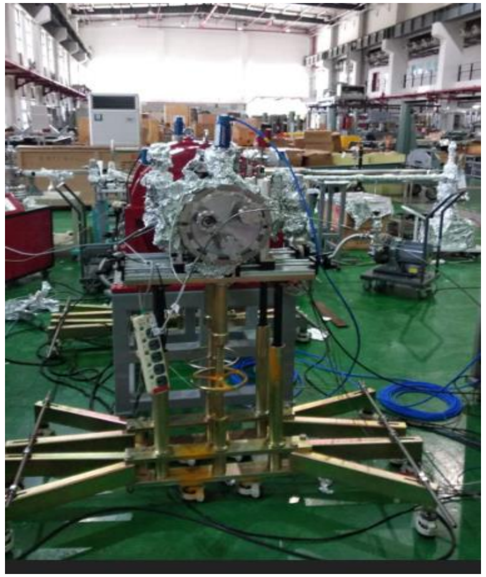


Copper vacuum chamber (Drawing) elliptic 75×56, thickness 3, length 6000)

Two 6m long vacuum chambers both with copper and aluminum

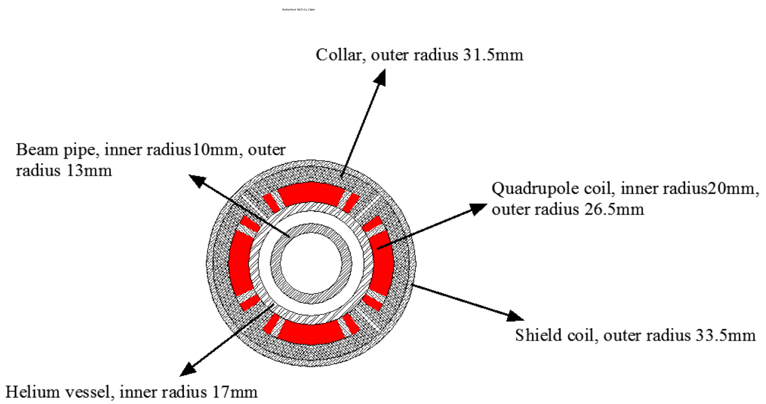






CEPC IR Superconducting Magnet (CDR)

Facility: CEPC IR SC magnet test facility (lab) is located in Keye company joinly with IHEP

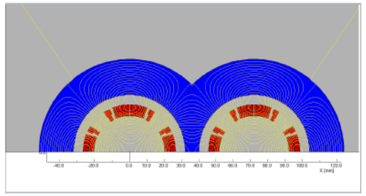


Room-temperature vacuum chamber with a clearance gap of 4 mm

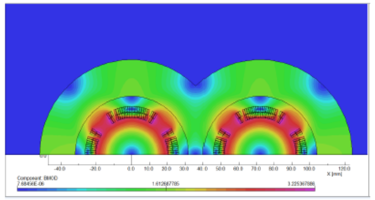
Magnet	Central field gradient (T/m)	Magnetic length (m)	Width of Beam stay clear (mm)	Min. distance between beams centre (mm)
QD0	136	2.0	19.51	72.61

Superconducting QD coils

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



2D Flux lines

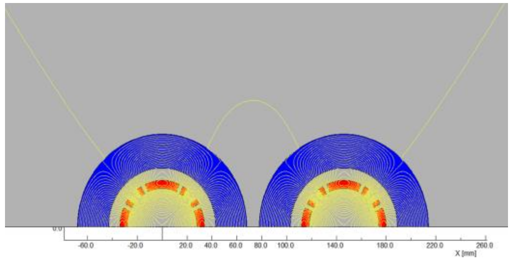


Bmod distribution

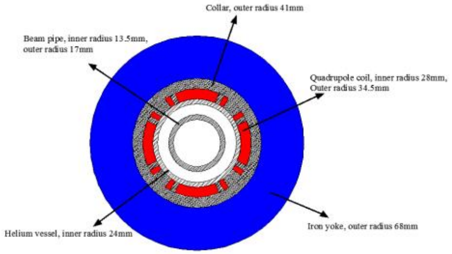
QF1 Integral field harmonics with shield coils (×10^{-4})

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

Superconducting QF coils



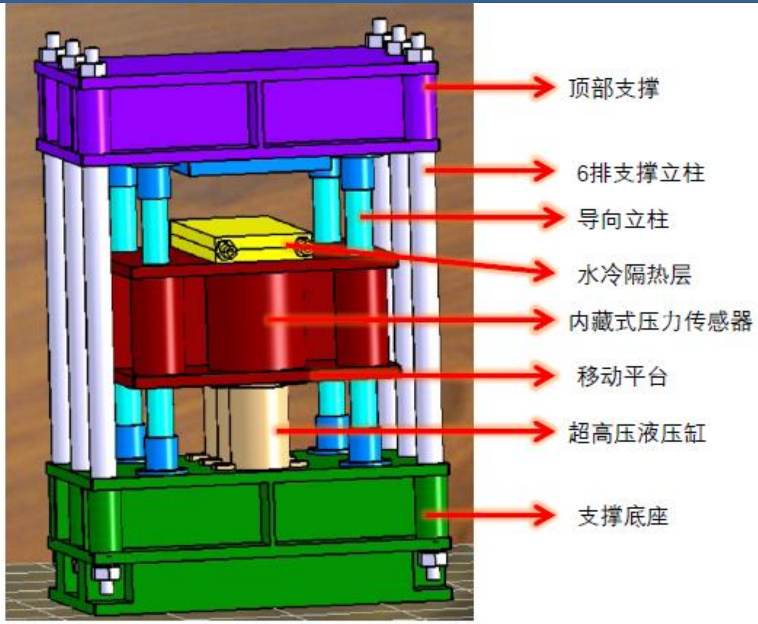
There is iron yoke around the quadrupole coil for QF1. Since the distance between the two apertures is large enough and there is iron yoke, the field crosstalk between two apertures of QF1 can be eliminated.

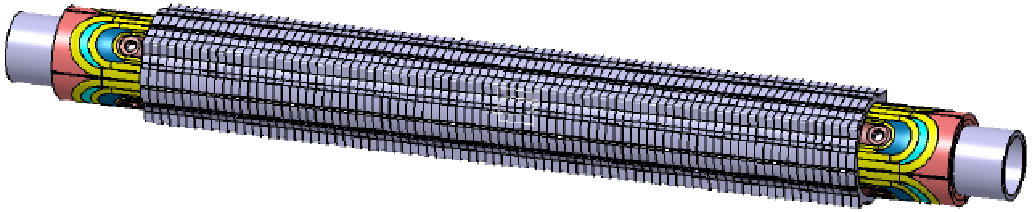


One of QF1 aperture (Peak field 3.8T)

Magnet	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

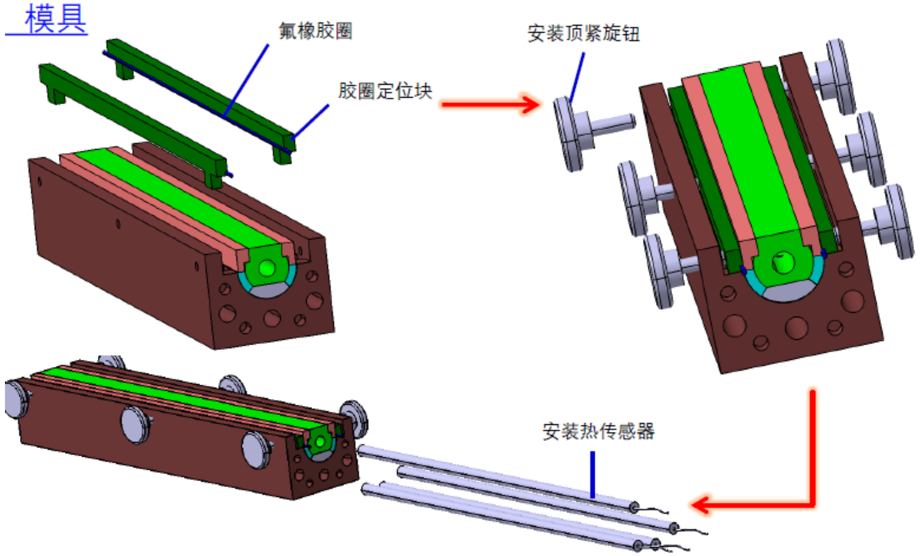


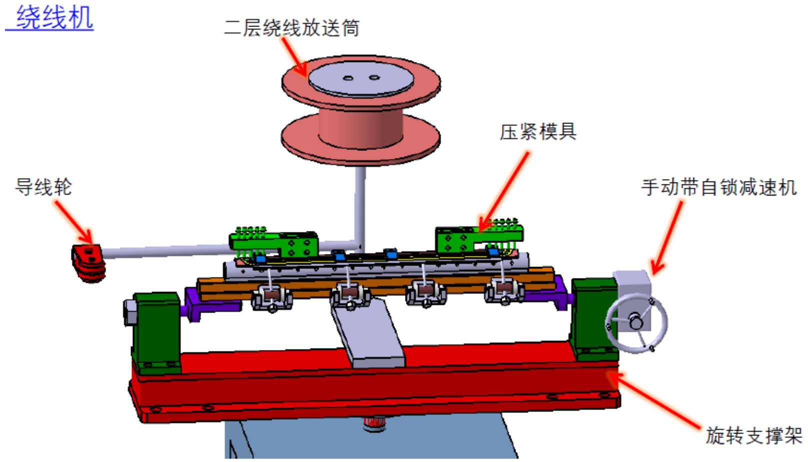


Field gradient 102T/m, coil bore diameter 38mm; The minimum distance between the center of the two apertures is 62.7mm

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.

Superconducting quadrupole coil heating and curing system.



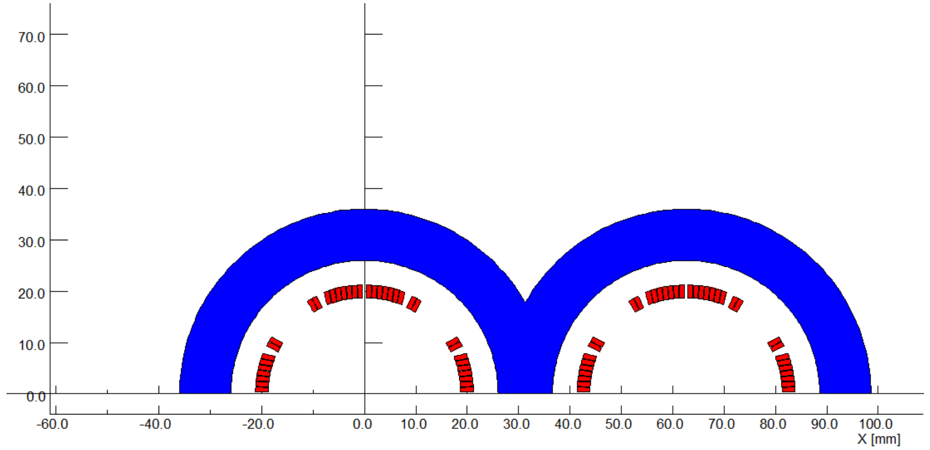


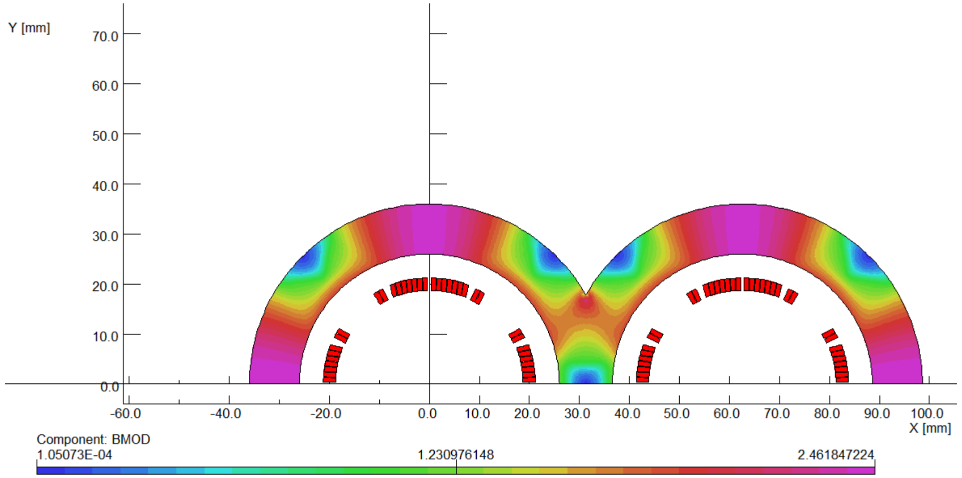
Weight Reduction for the MDI SC Quadrupole

- There are big challenges about the weight of SC QUAD
  - narrow space; - crosstalk
- Focused on reducing the magnet weight of Q1a.
- Paths:
  1. Relax the dipole field requirement of crosstalk (<30Gs)
  2. Use special iron material (FeCoV)
     using 1+2, Weight: 78.9Kg (55% of original value 143.6kg)
  3. Reduce coil layer to 1, expecting excitation current 3585A
     using 1+2+3, Weight: 60.2Kg (42% of original value)

High luminosity requirements

Magnet	Central field gradient (T/m)	Magnetic length (m)	Width of GFR (mm)	Minimal distance between two aperture beam lines (mm)
Q1a	141	1.21	15.21	62.71
Q1b	84.7	1.21	17.92	105.28
Q2	94.8	1.5	24.14	155.11



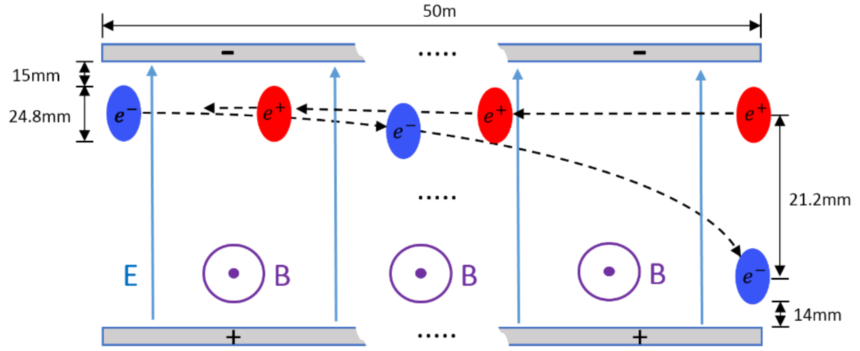


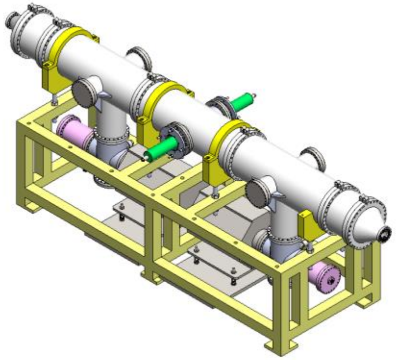
CEPC Electrostatic – Magnetic Deflector

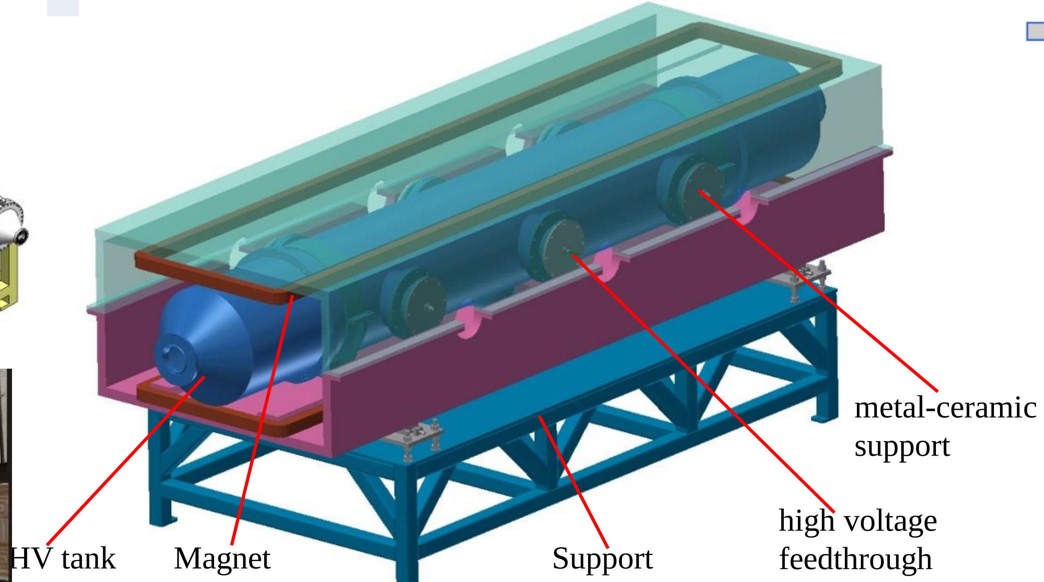
The Electrostatic-Magnetic Deflector is a device consisting of perpendicular electric and magnetic fields.

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

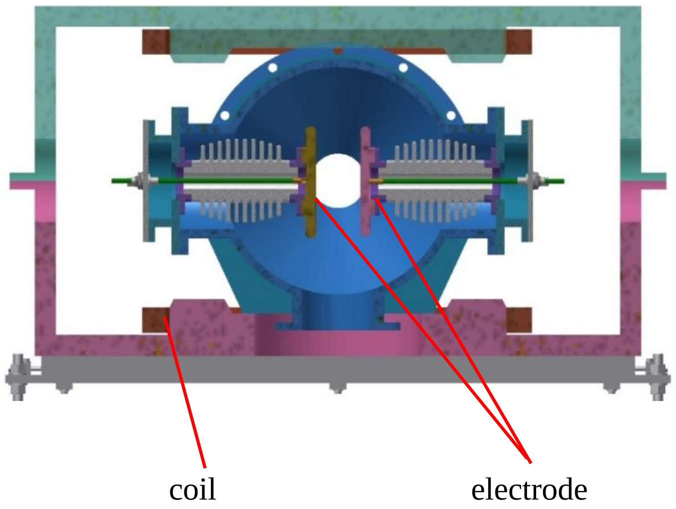
	Filed	Effective Length	Good field region	Stability
Electrostatic separator	2.0MV/m	4m	46mm x11mm	5×10^{-4}
Dipole	66.7Gauss	4m	46mm x11mm	5×10^{-4}







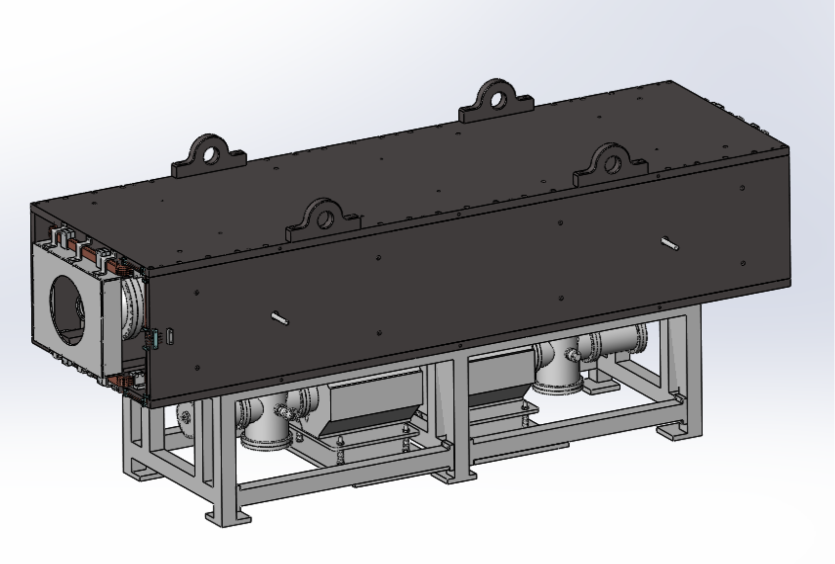
structure drawing of Electrostatic-Magnetic Deflector

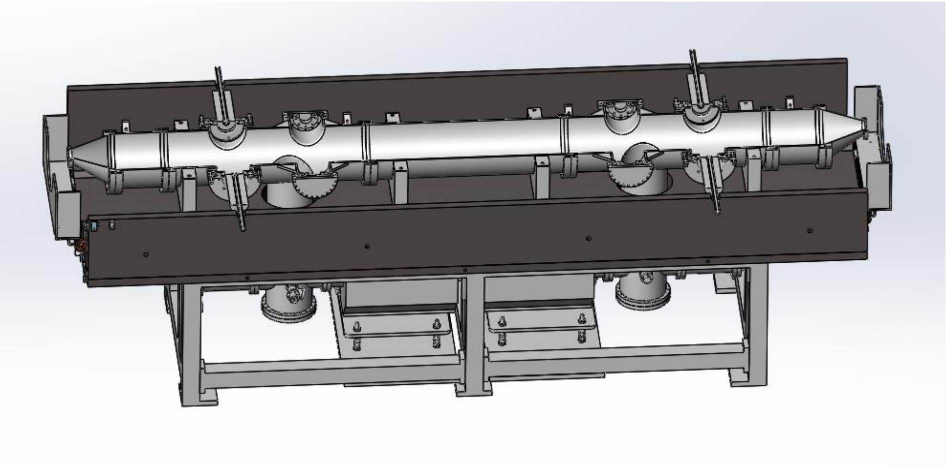


Progress of the Electrostatic – Magnetic Deflector

- All major components inside the vacuum chamber completes. The vacuum chamber, dipole board, flange, et. al, were polished, cleaned, passed the leakage test for vacuum
- Assembling finished, vacuum leakage ≤2.0E-10pa/m3.S
- After the vacuum baking, the pressure inside the chamber is 2.0E-8pa
- Currently the high voltage test is on going, the target value is ±135KV

- The magnet coil outside the vacuum is designed, the mechanical details are determined.
- The fabrication for all components of the magnet is on going.





Progress of the Electrostatic – Magnetic Deflector

Vacuum chamber Components

Insulation for the high voltage

High Voltage pole

Flange

Ceramics components

Pole for the main board

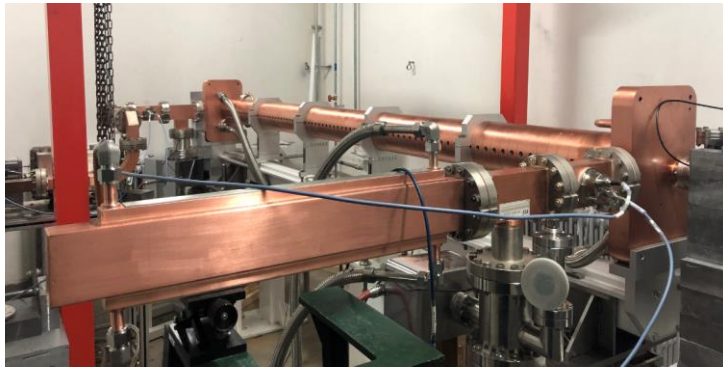
Vacuum test

CEPC Linac & Damping ring key technology R&D

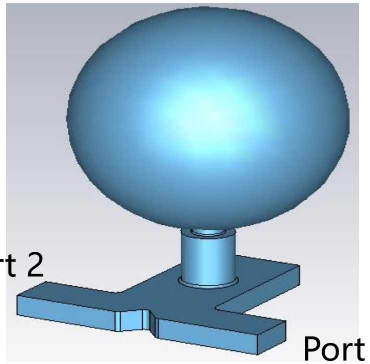
Facility: CEPC injection linac test facility (lab) is located in IHEP

Accelerating structure

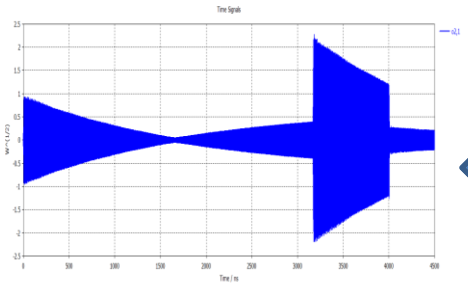
- The structure is 3 meters long with constant gradient design which work mode is 2π/3
- The high power test has finished and the gradient is up to 33 MV/m



The acclelerating strucutre on high power test bench



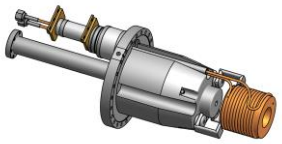
Simulation model



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.

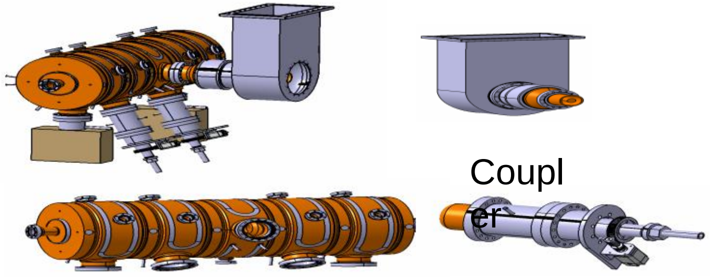
Positron source R&D



The mechanical design of FLUX concentrator

The finished FLUX concentrator

The test bench of the FLUX concentrator



Damping ring 5cell Cavity

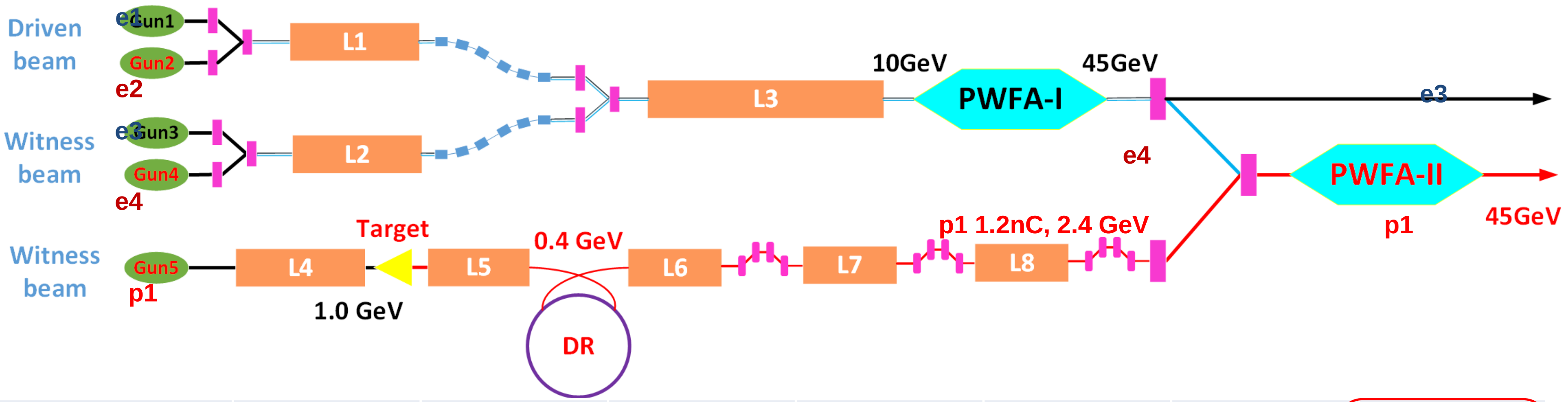
Tunner

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@4.5 K Cryogenic Plant R&D

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

CEPC Plasma Injector Design



The reason to increase the injection energy:

if injection energy is larger than 40 GeV, the booster dipole magnet can use normal iron material

with low price

	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

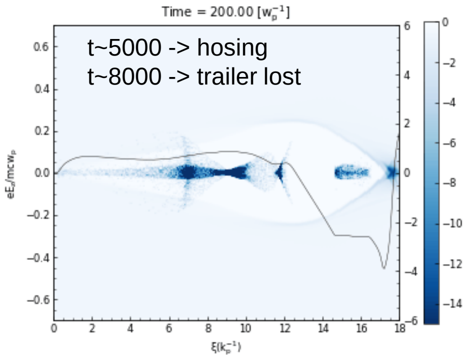
The plasma accelerator performance has been checked with the real linac beam quality, and it almost reached the design goal

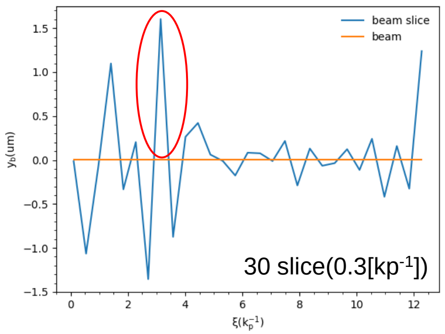
Requirment of Booster to Plasma Injector (@45.5 GeV)

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**	

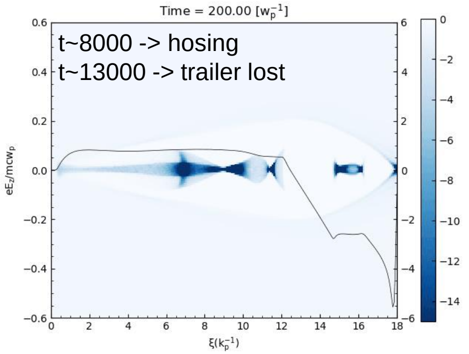
Start to End Simulations for CEPC Plasma Injector

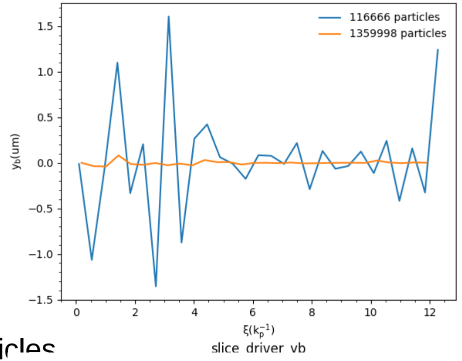
- Longitudinal shaping is well maintained → TR ☑
- Big slice jitter in PWFA acceleration → hosing → Transverse-Longitudinal coupling



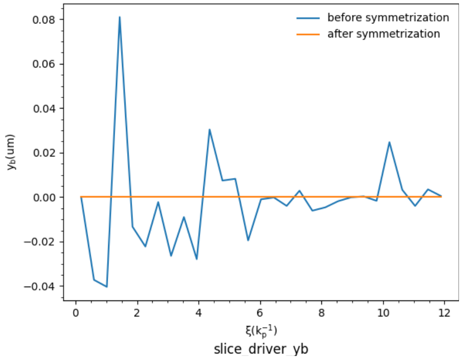


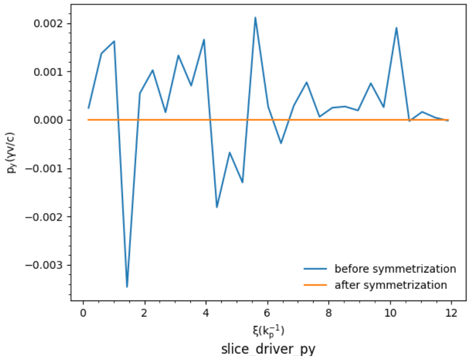
Driver initial beam centroid

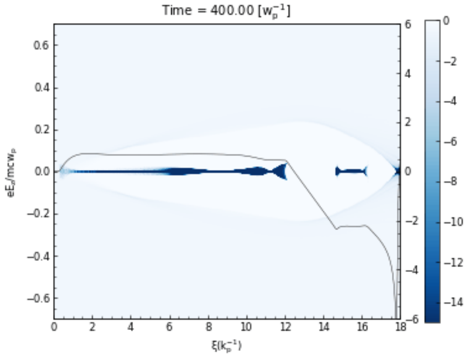


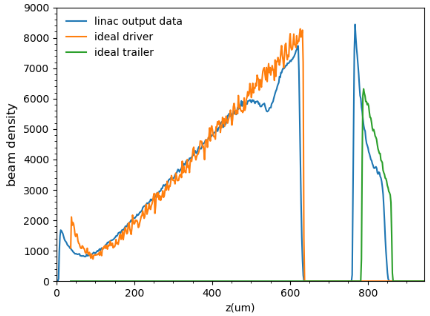


0.11m particles → 1.36m particles



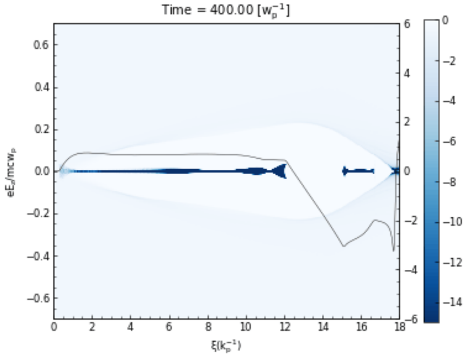


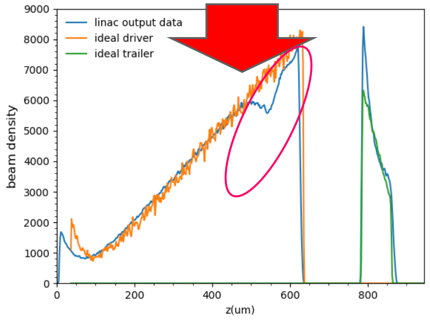




beam initial[x, y,px,py]~ [0,0,0,0]

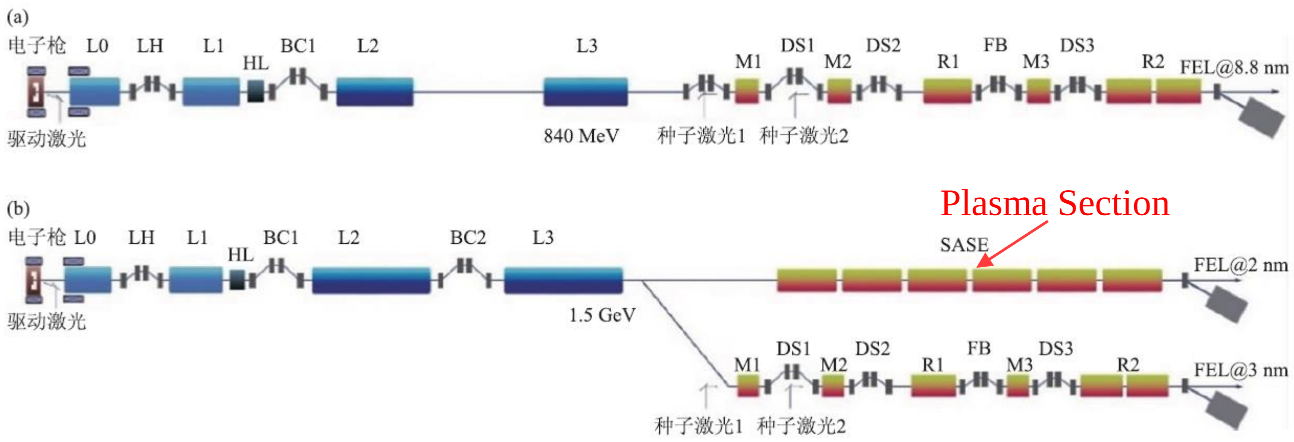
	Beam symmetrization	Change beam distance	Design
Δz(um)	126.7	149	149
Et(GeV)	40.6	42.80	45.5
Qt(nC)	0.9	0.7909	0.84

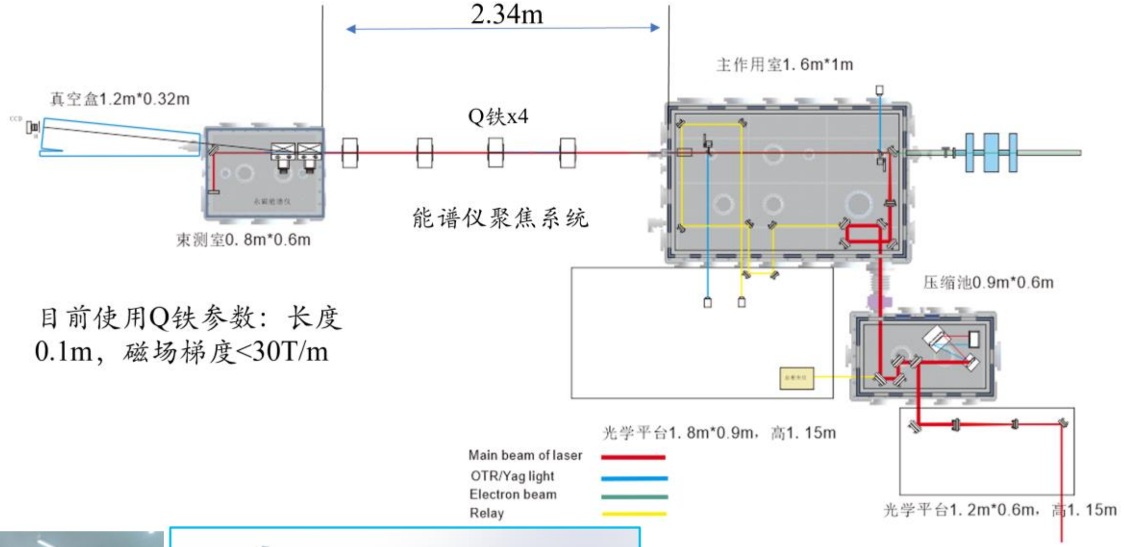


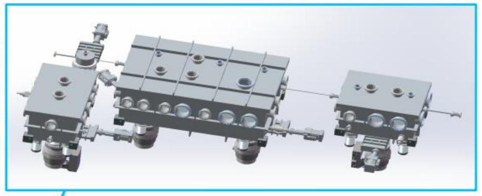


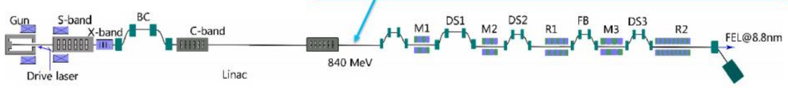
1kp^{-1}~52.52um

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

Status of the High Field Dipole Magnet R&D -2

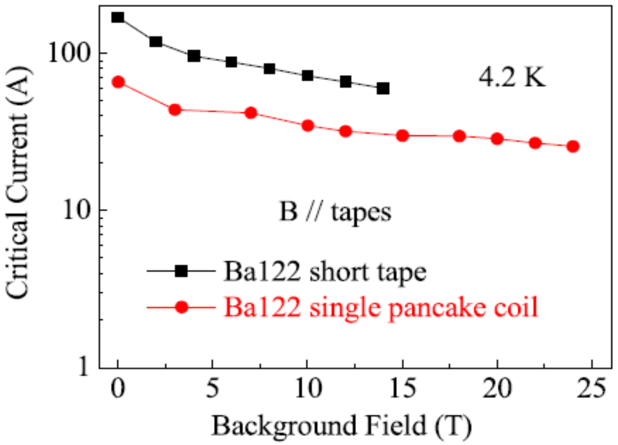
Facility: SppC high field magnets test facility (lab) is located in IHEP of 240m^2

Test of the 1st IBS solenoid coil at 24 T and the 1st IBS racetrack coil at 10 T

Table 2. Specification of single pancake coil

Parameter	Unit	Value
Inner diameter	mm	30
Outer diameter	mm	34.8
Height	mm	4.62
Thickness of stainless steel tape	mm	0.1
Turns		4.5
Total length of IBS wire	mm	450

25T-HM, RT bore Φ38 mm



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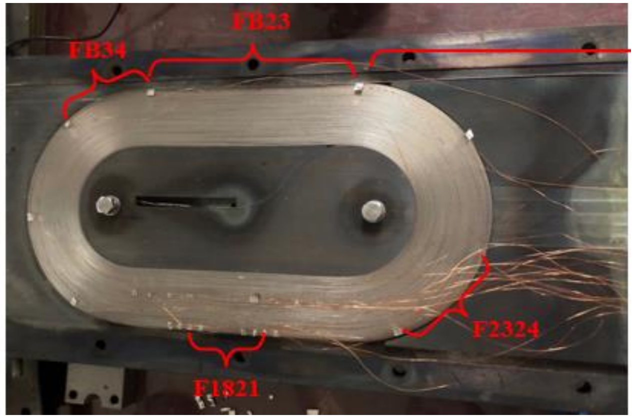
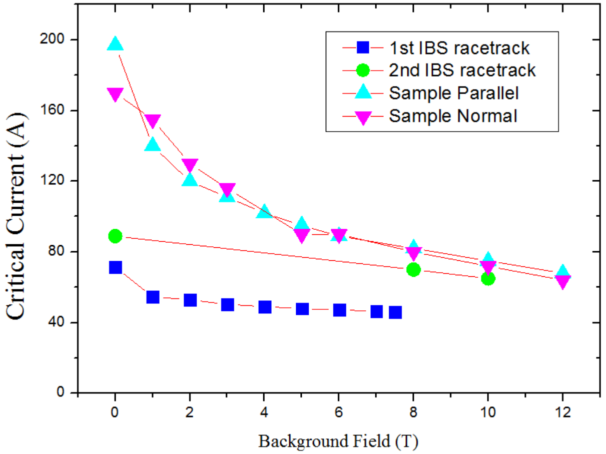
Very good performance!

Demonstrating that IBS are very promising for high-field magnet applications



Critical Current w.r.t Background Field of IBS Racetracks

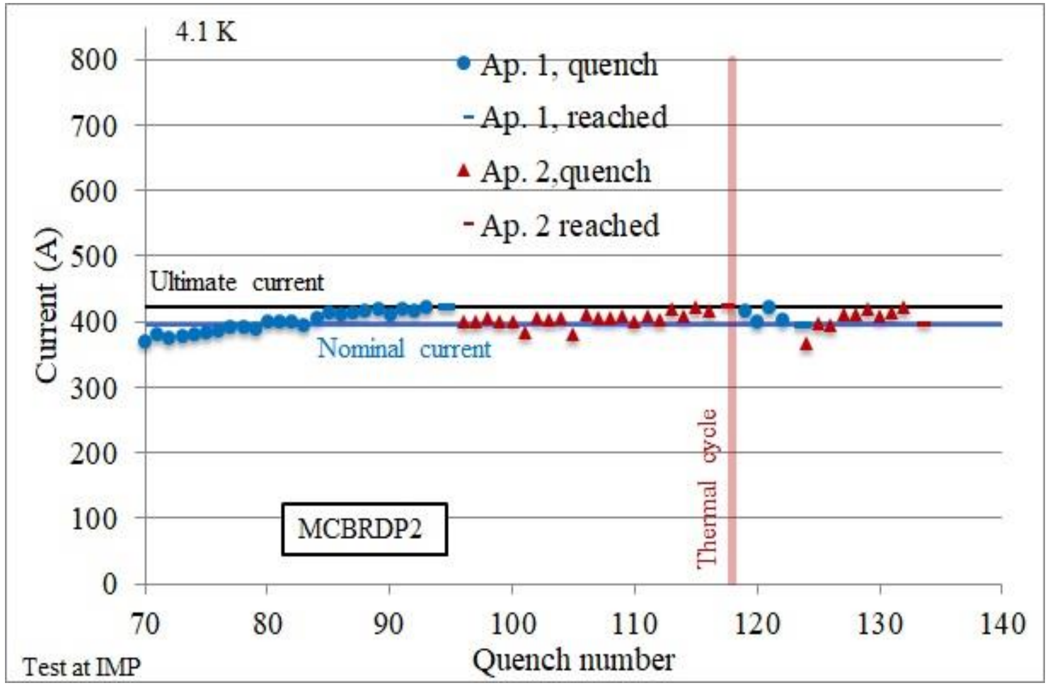


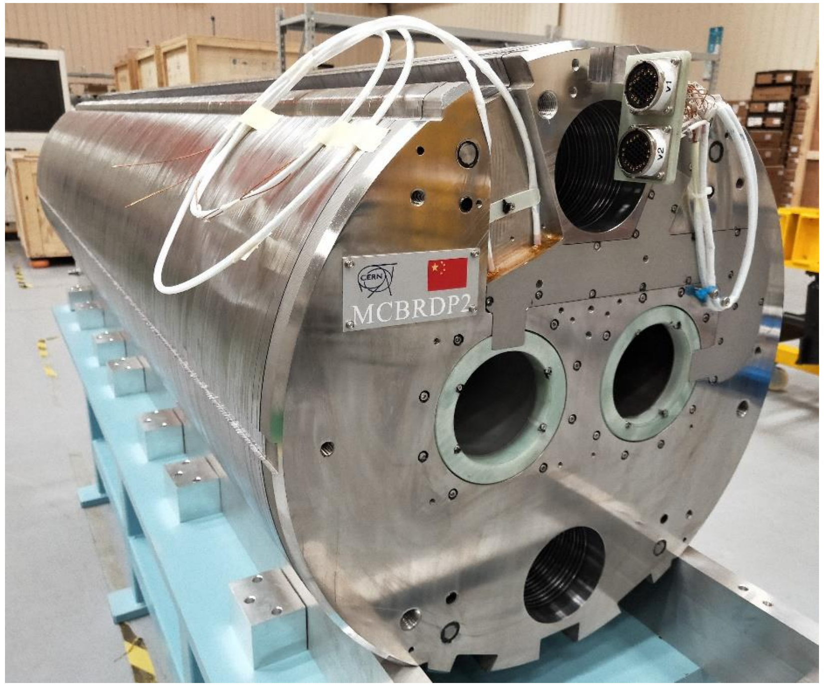
Supercond. Sci. Technol. 2020, in press

China – CERN HL-LHC CCT Project

China will provide 12+1 units CCT superconducting magnets for the HL-LHC project

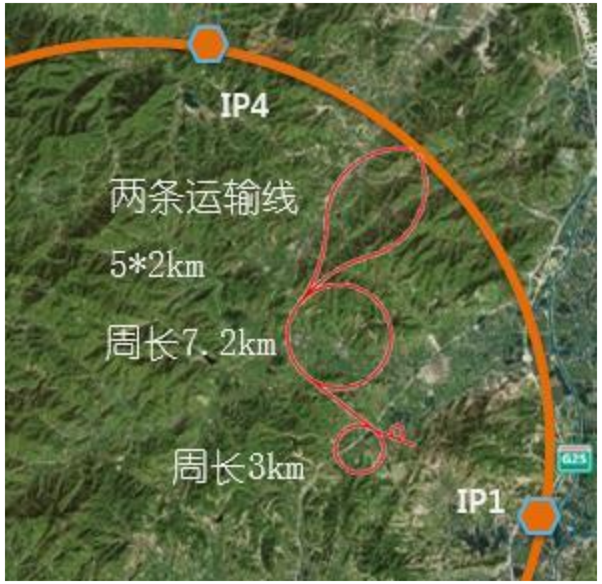
After more than 1 month test and training at 4.2K, both apertures reached the design current and ultimate current, and the field quality is within the limit.

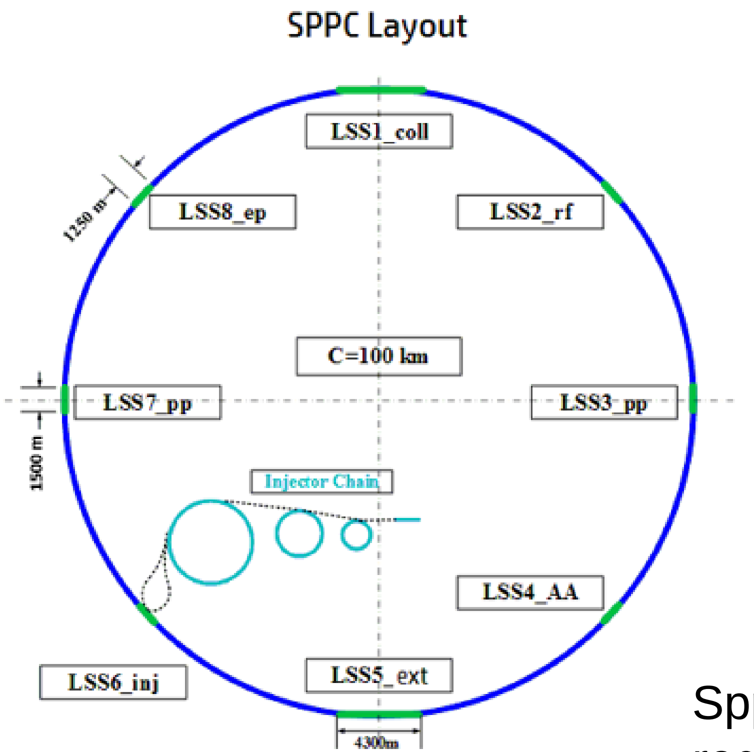




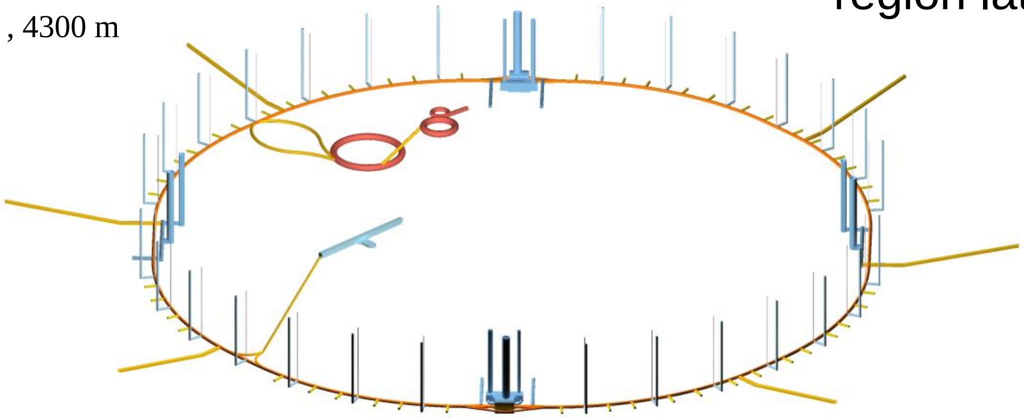
<u>The 1st prototype CCT magnethas been sent to CERN. A good start for the 12 units series production.</u>

General Layout and Implementation of SppC

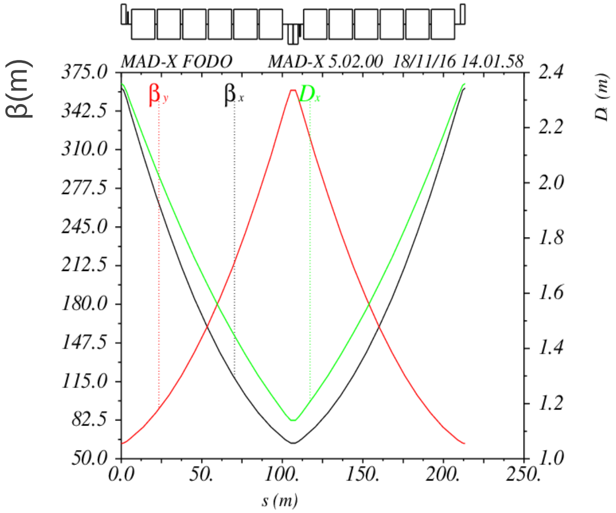




- Length of each section at present:
- 8 arcs, total length 83400 m
- 2 IPs for pp, 1500 m each
- 2 IRs for injection or RF, 1250 m each
- 2 IRs for ep or AA, 1250 m each
- 2 IRs for collimation(ee for CEPC ）, 4300 m each
- C = 100 km

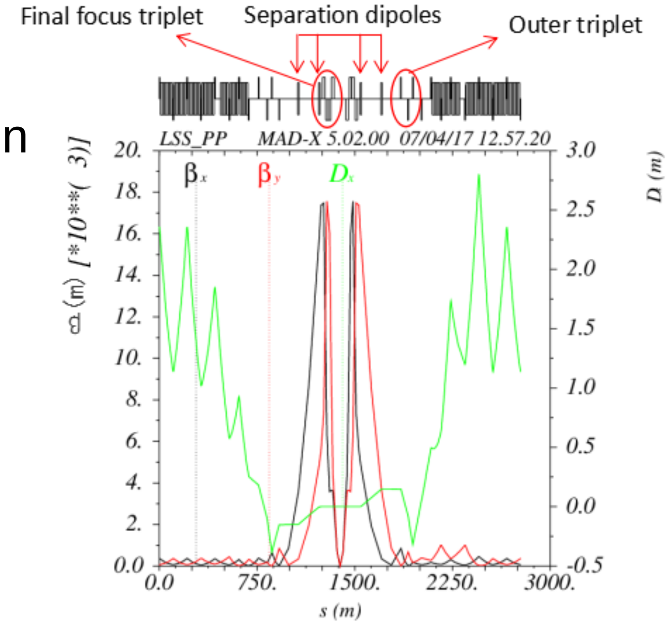


SppC ARC lattice



ARC FODO cell structure

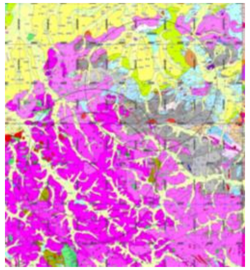
SppC interaction region lattice

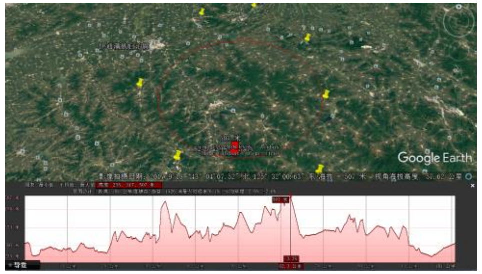


LSS_PP(beta*=0.75 m)

Contents

CEPC Site Selection Status

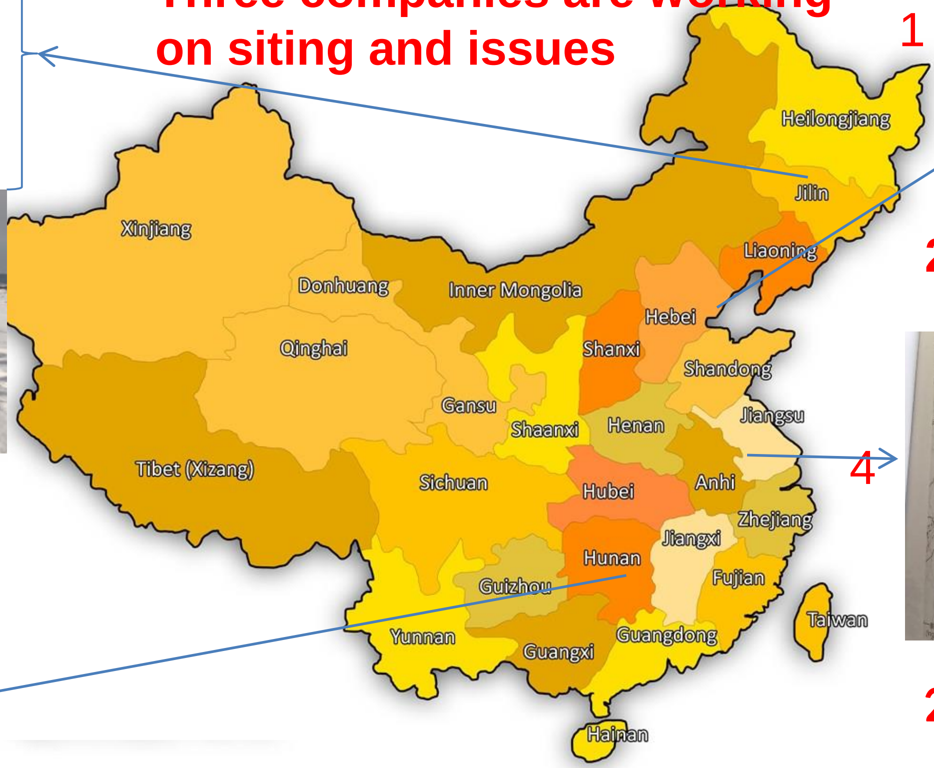


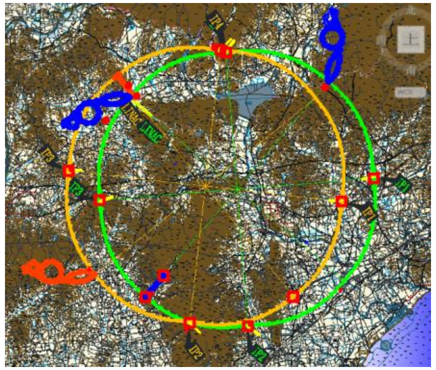


5

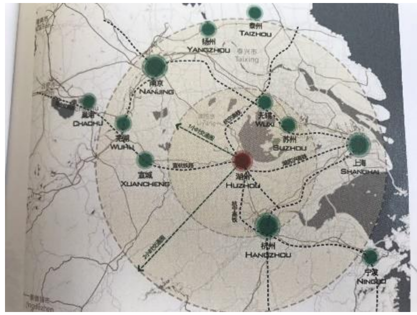
Three companies are working on siting and issues

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

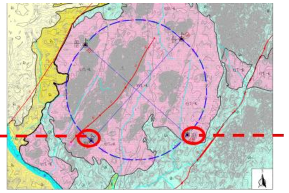




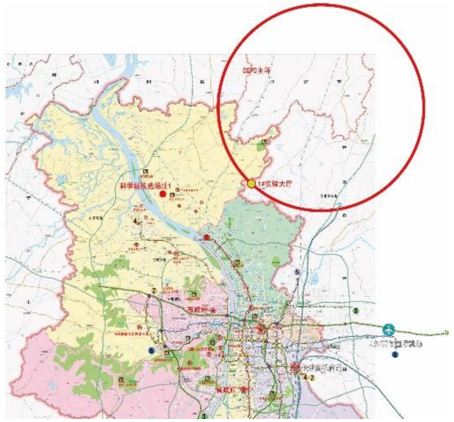
2020.9.14-18 Qinhuangdao updated



2019.12.16-17 Huzhou siting update



2019.08.19-20 Changsha siting update



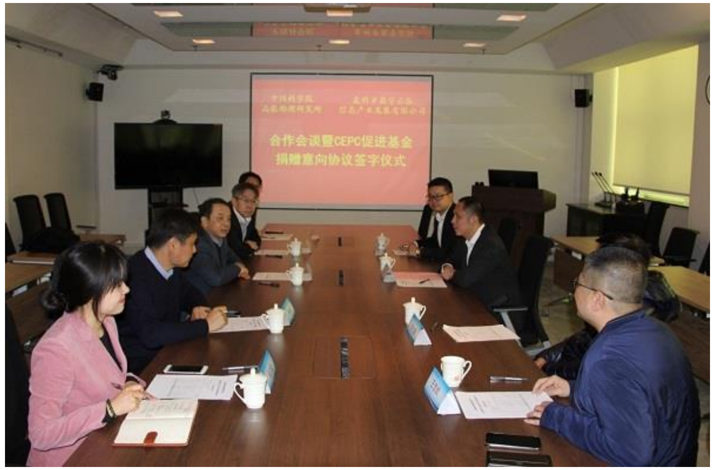
1) Qinhuangdao, Hebei Province（Completed in 2014）
2) Huangling, Shanxi Province（Completed in 2017)
3) Shenshan, Guangdong Province(Completed in 2016)
4) Huzhou, Zhejiang Province (Started in March 2018)
5) Chuangchun, Jilin Province (Started in May 2018)
6) Changsha, Hunan Province (Started in Dec. 2018)

CEPC Industrial Promotion Consortium (CIPC) Collaboration Status

Established in Nov. 7 , 2017

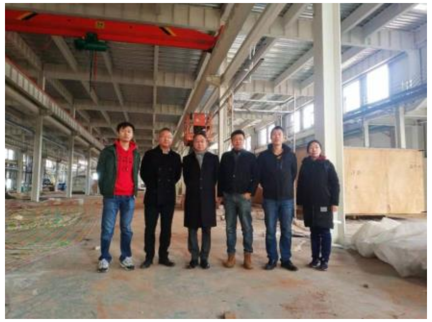
Task forces for CEPC and SppC R&D: Institutions such as IHEP +CIPC (>70 companies)

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

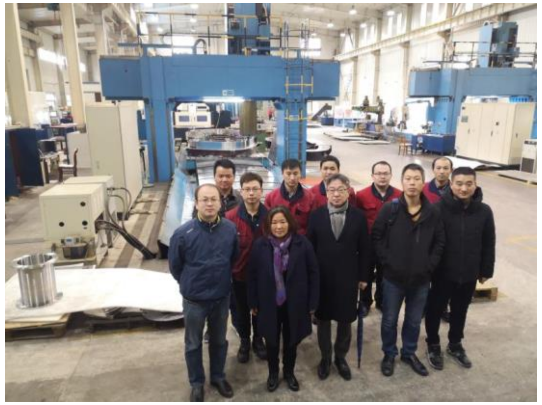
Fujian Digital Valey on information signed CEPC Propmotion Fund Contribution with IHEP



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

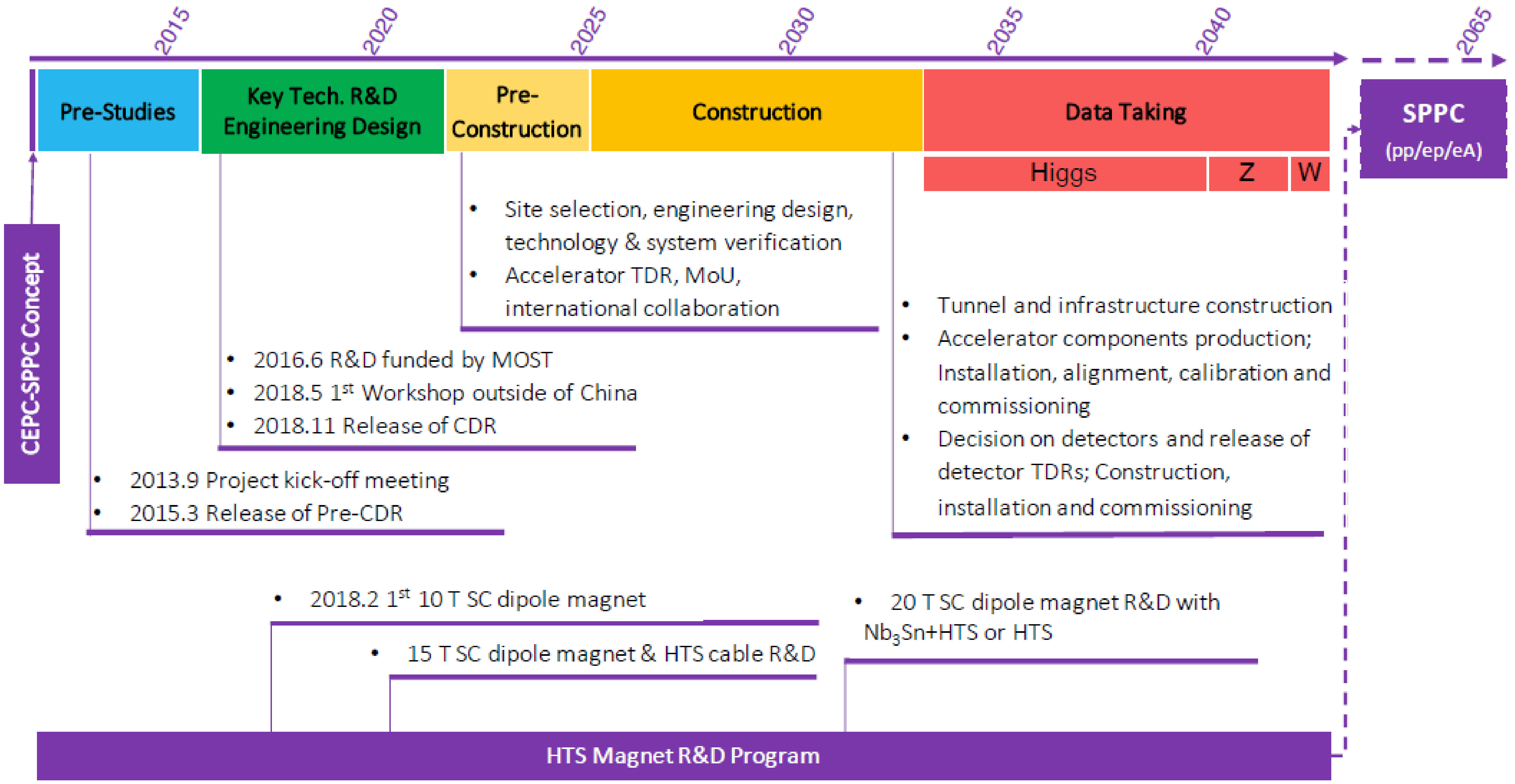
48 speakers

CIPC Parallel Session on CEPC R&D

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

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

CEPC Project Timeline



Summary

- CEPC accelerator R&D efforts towards TDR progress well, such as high luminosity optimization design, klystron, SCRF, magnets, vacuum system, etc. with the aim to complet TDR at the end of 2022
- 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 timeline is updated

Thank you for your attentions