中国科学院高能物理研究所
Institute of High Energy Physics
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CEPC

CEPC Accelerator

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- CEPC Accelerator Key Hardware R&D Progresses in TDR
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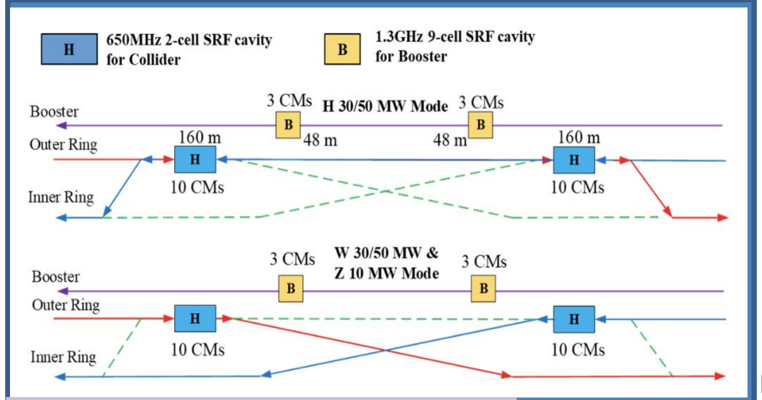
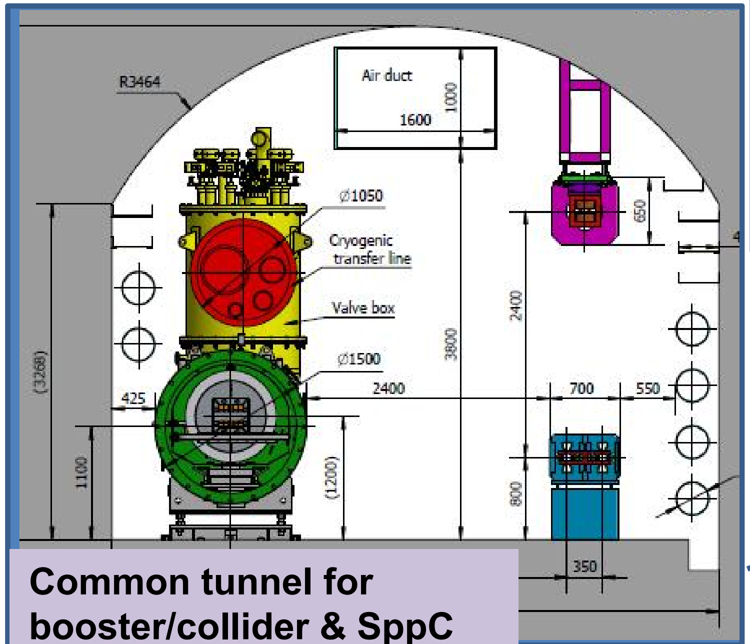
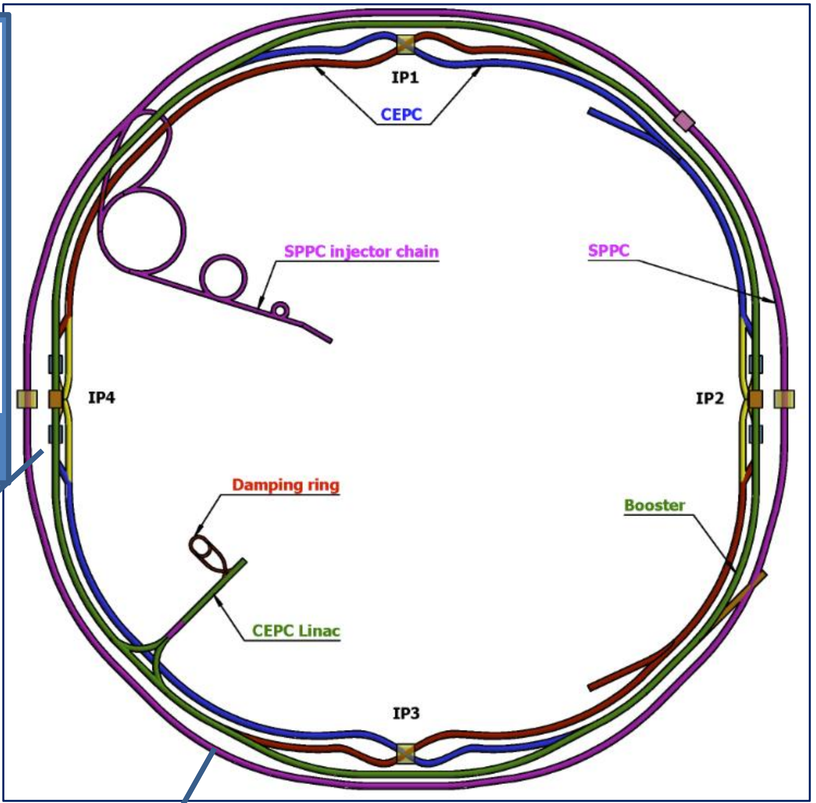
CEPC Optimization Design Philosophy



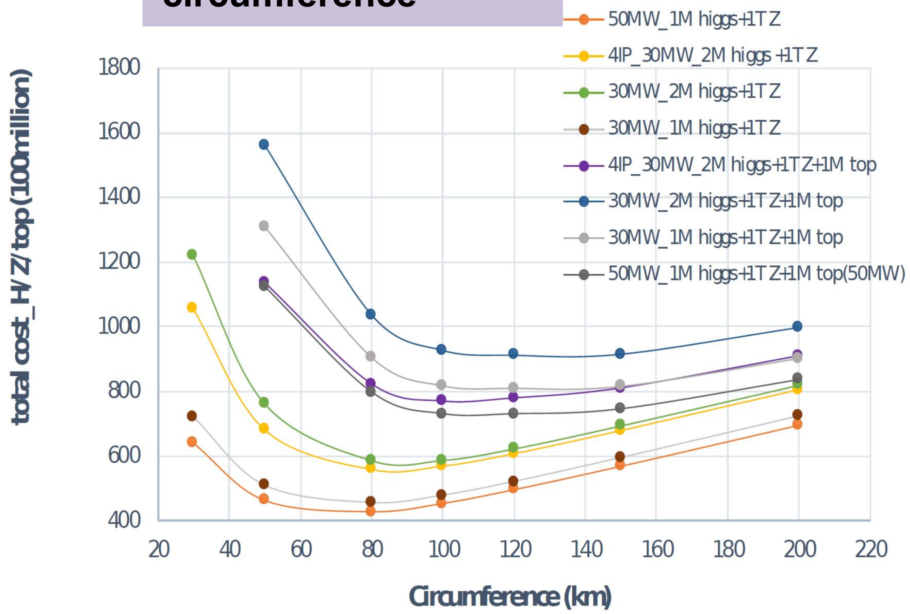
Switchable operation for Higgs W and Z



Common tunnel for booster/collider & SppC



Cost optimization v.s. circumference

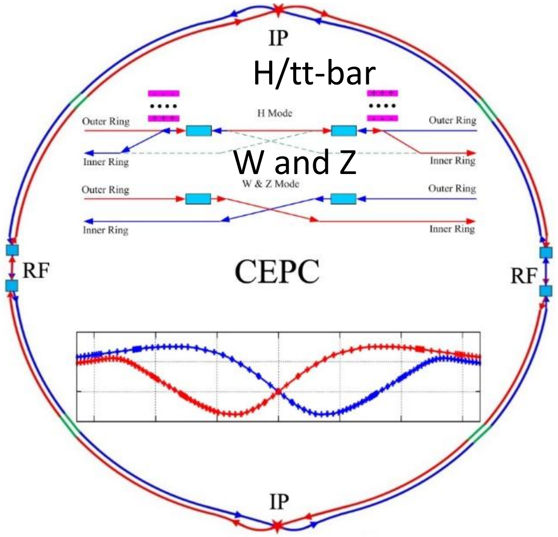


D. Wang *et al* 2022 *JINST* **17** P10018

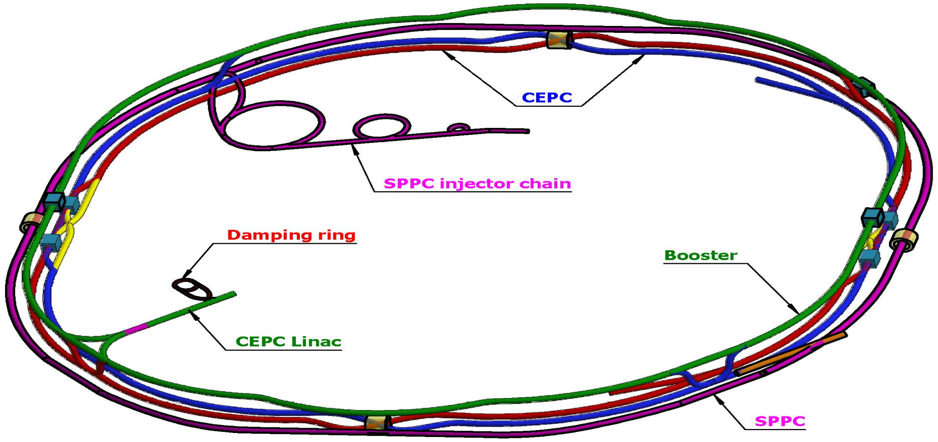
- **Circular collider**: Higher luminosity with crabwaist collision of double ring
- **100km circumference**: Optimum total cost
- **Shared tunnel**: Compatible design for CEPC and SppC
- **Switchable operation**: Higgs, W/Z, ttbar
- **High energy gamma ray application:** (100keV~100MeV)

CEPC Higgs Factory and SppC in TDR

CEPC as a Higgs Factory: H, W, Z, upgradable to tt-bar, followed by a SppC (a Hadron collider) ~125TeV
30MW SR power per beam (upgradale to 50MW)

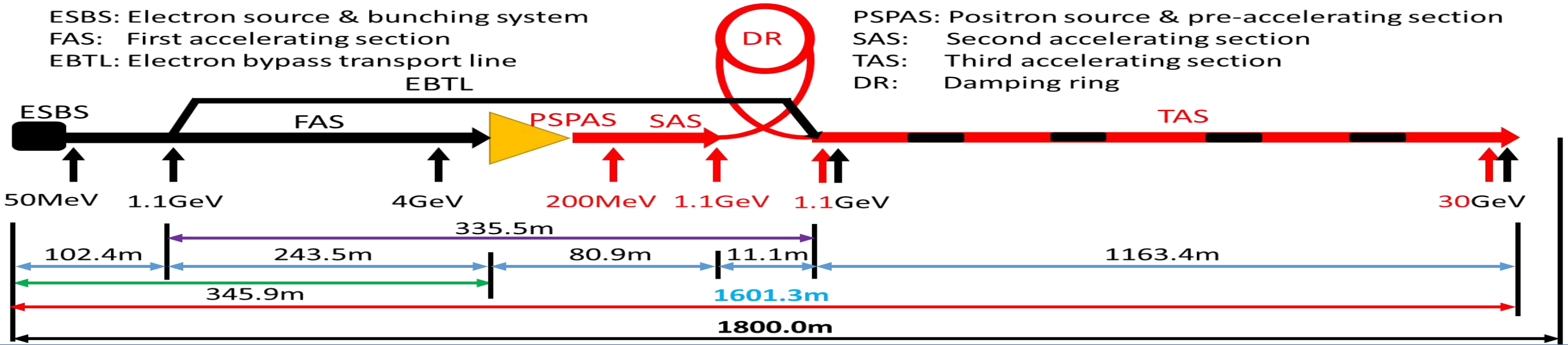


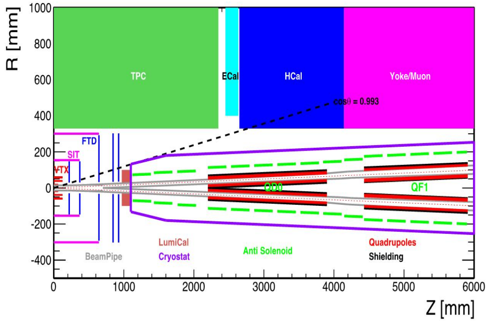
CEPC collider ring (100km)

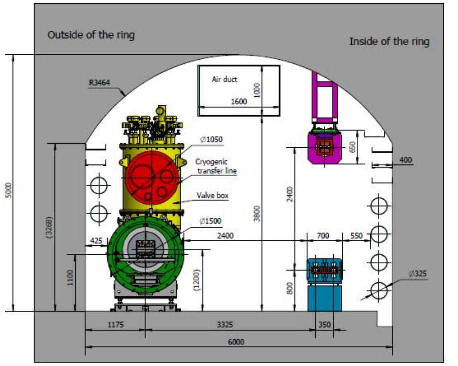


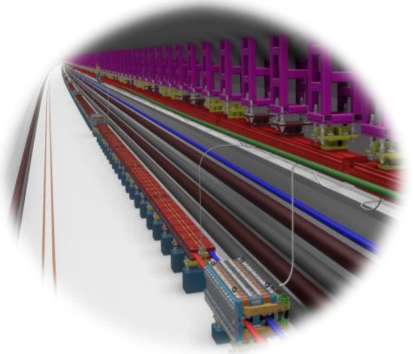
CEPC booster ring (100km)

CEPC TDR S+C-band 30GeV linac injector







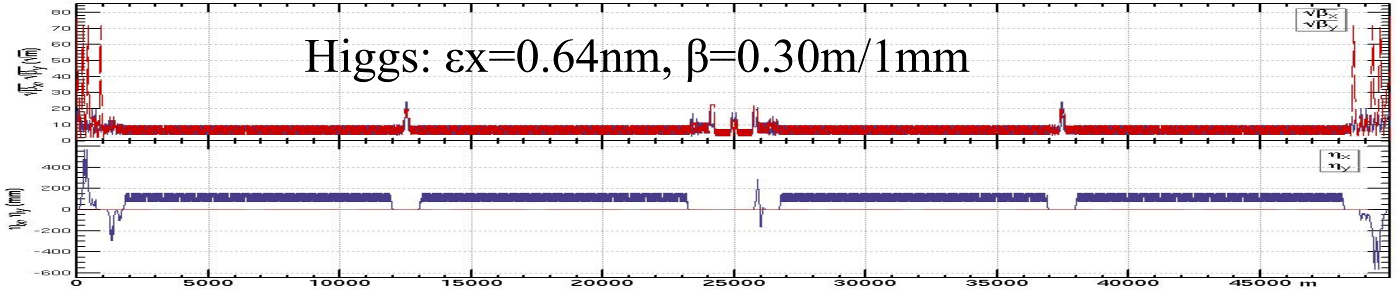


CEPC Civil Engineering

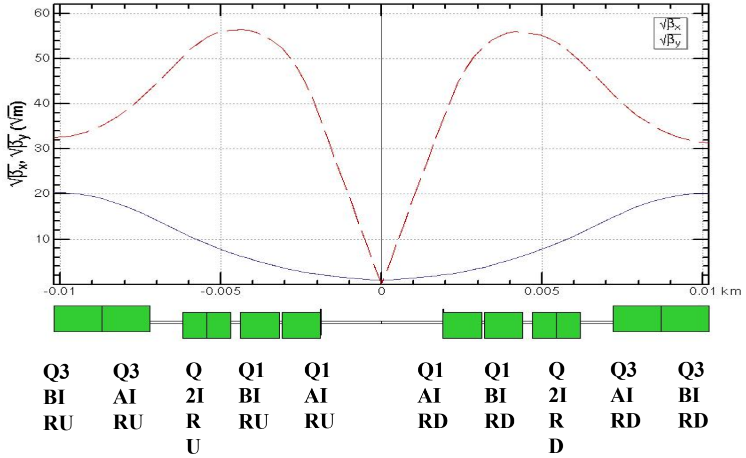
CEPC TDR Parameters

	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	100.0			
SR power per beam (MW)	**50**			
Half crossing angle at IP (mrad)	16.5			
Bending radius (km)	10.7			
Energy (GeV)	120	45.5	80	180
Energy loss per turn (GeV)	1.8	0.037	0.357	9.1
Damping time $\tau_x/\tau_y/\tau_z$ (ms)	44.6/44.6/22.3	816/816/408	150/150/75	13.2/13.2/6.6
Piwinski angle	4.88	29.52	5.98	1.23
Bunch number	446	13104	2162	58
Bunch spacing (ns)	355 (53% gap)	23 (10% gap)	154	2714 (53% gap)
Bunch population (10^{11})	1.3	2.14	1.35	2.0
Beam current (mA)	27.8	1340.9	140.2	5.5
Momentum compaction (10^{-5})	0.71	1.43	1.43	0.71
Beta functions at IP β_x^*/β_y^* (m/mm)	0.3/1	0.13/0.9	0.21/1	1.04/2.7
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Betatron tune ν_x/ν_y	445/445	266/267	266/266	445/445
Beam size at IP σ_x/σ_y (um/nm)	14/36	6/35	13/42	39/113
Bunch length (natural/total) (mm)	2.3/4.1	2.7/10.6	2.5/4.9	2.2/2.9
Energy spread (natural/total) (%)	0.10/0.17	0.04/0.15	0.07/0.14	0.15/0.20
Energy acceptance (DA/RF) (%)	1.6/2.2	1.3/1.5	1.2/2.5	2.0/2.6
Beam-beam parameters ξ_x/ξ_y	0.015/0.11	0.0045/0.13	0.012/0.113	0.071/0.1
RF voltage (GV)	2.2	0.1	0.7	10
RF frequency (MHz)	650			
Longitudinal tune ν_s	0.049	0.032	0.062	0.078
Beam lifetime (Bhabha/beamstrahlung) (min)	39/40	86/400	60/700	81/23
Beam lifetime (min)	20	71	55	18
Hourglass Factor	0.9	0.97	0.9	0.89
Luminosity per IP (10^{34} cm^{-2} s^{-1})	**8.3**	**192**	**26.7**	**0.8**

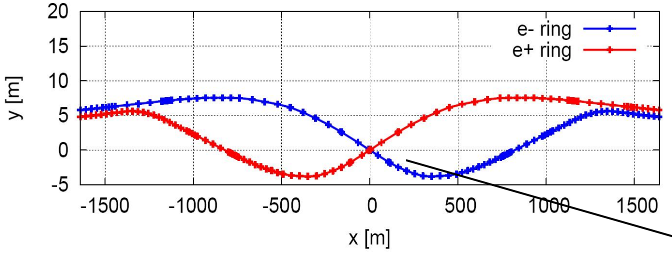
Advanced CEPC Collider Ring Lattice Design



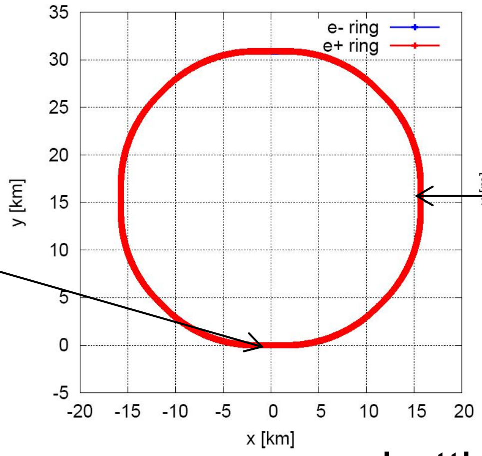
Lattice of half collider ring@Higgs energy

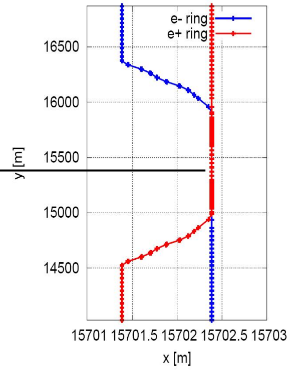


Lattice in IP region



Lattice in IP region





Lattice in RF region

	QD	QF
Z	Q1A	Q1B
W/H	Q1A+Q1B	Q2
ttbar	Q1A+Q1B+Q2	add quad Q3A and Q3B

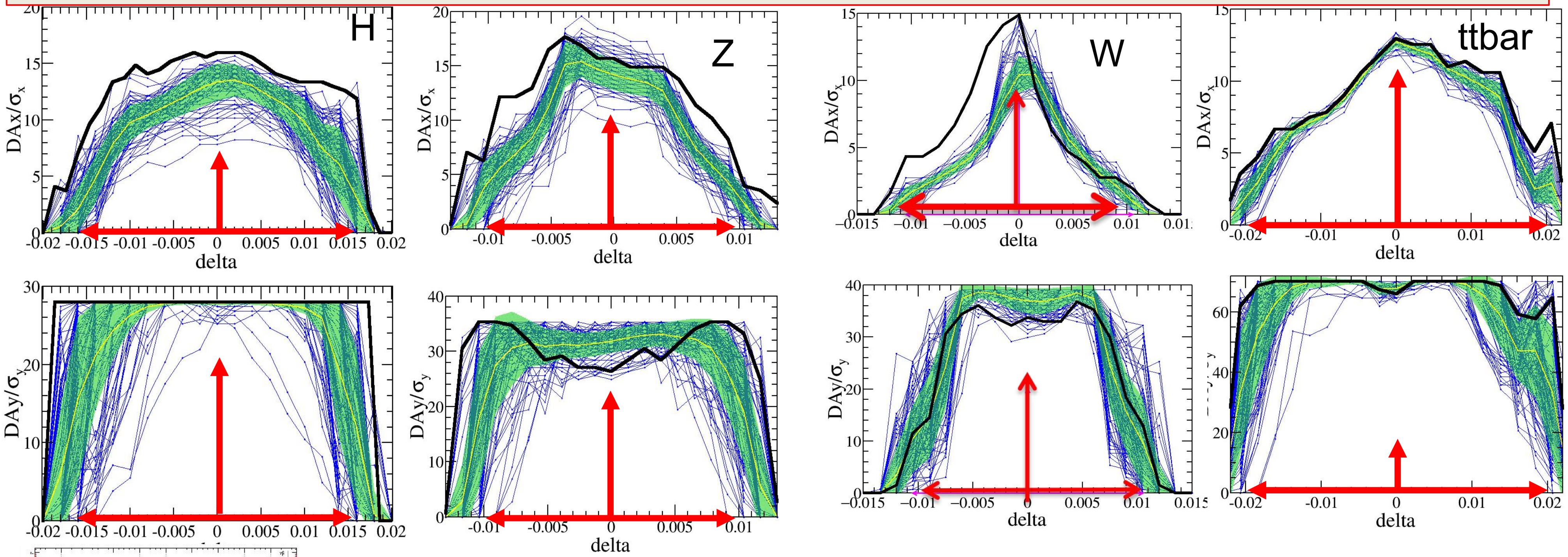
SC quadupole setting for four eneries

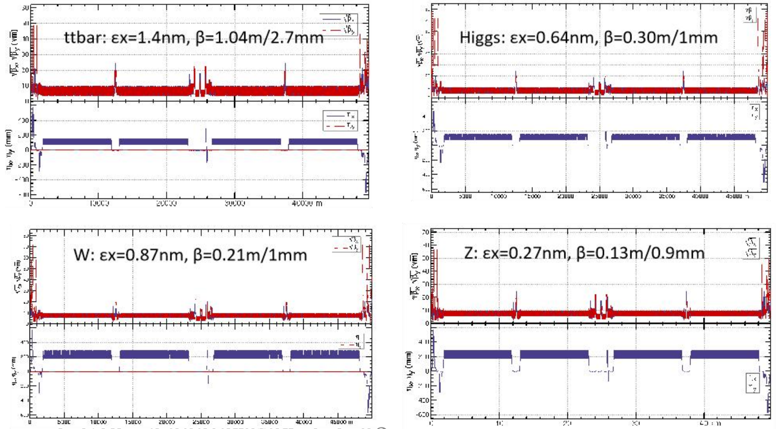
Advanced collider design: 1) Crabwaist collision， 2） small β_y=1mm， 3） Fullly partial double ring scheme with reduced rf stations , 4) Four energy free switching, 5) High energy gamma ray

CEPC Collider Ring Daynamic Apertures

Dynamic apertures with errors at Higss, W/Z and ttbar energies satisfy design goals

Effects included in tracking
Synchrotron motion
Radiation loss in all magnets
Tapering
Crab waist sextupole
Maxwellian fringes
Kinematic terms
Finite length of sextupole



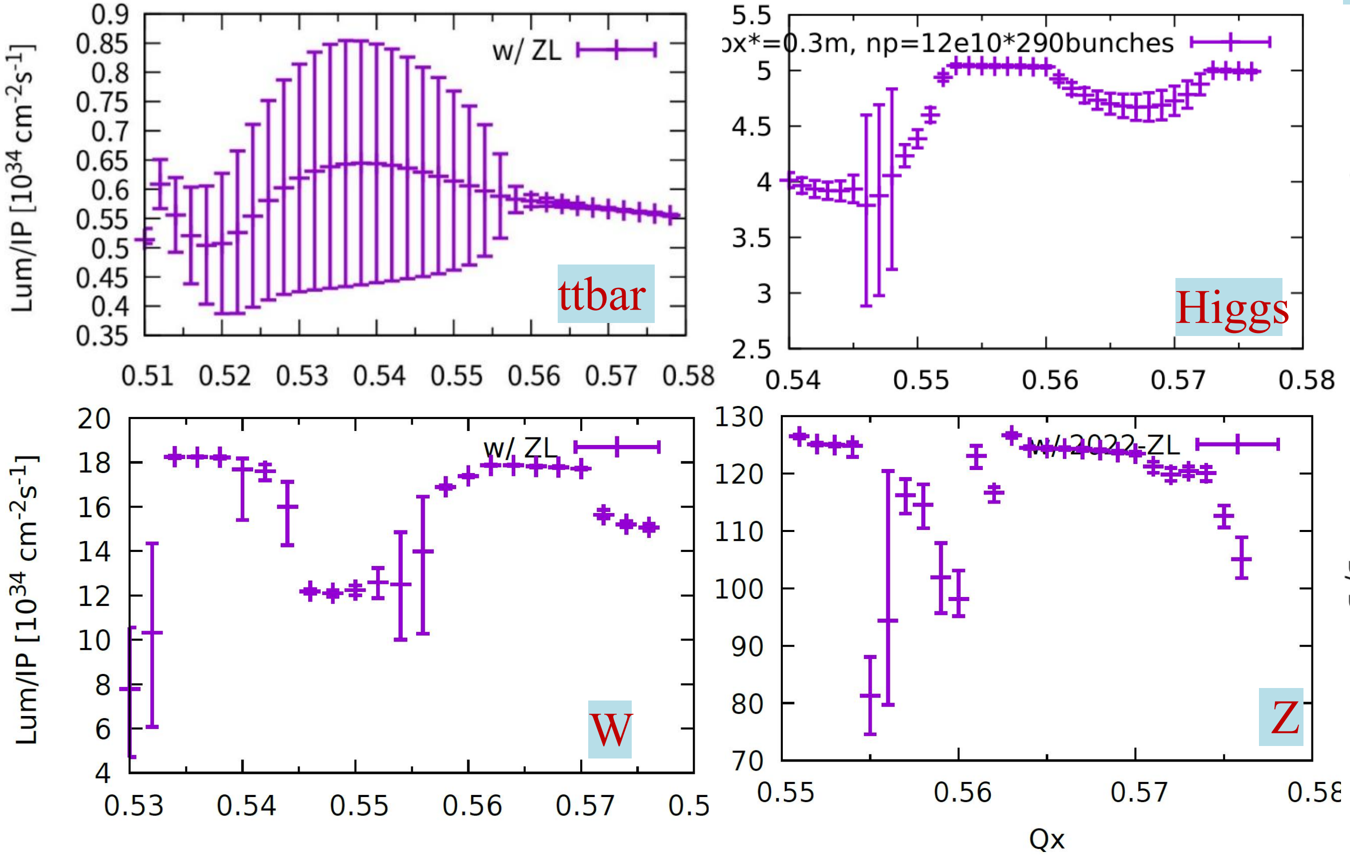


Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
Dipole	0.10	0.10	0.10	0.01%
Arc Quadrupole	0.10	0.10	0.10	0.02%
IR Quadrupole	0.10	0.10	0.10	0.02%
Sextupole	0.10*	0.10*	0.10	0.02%

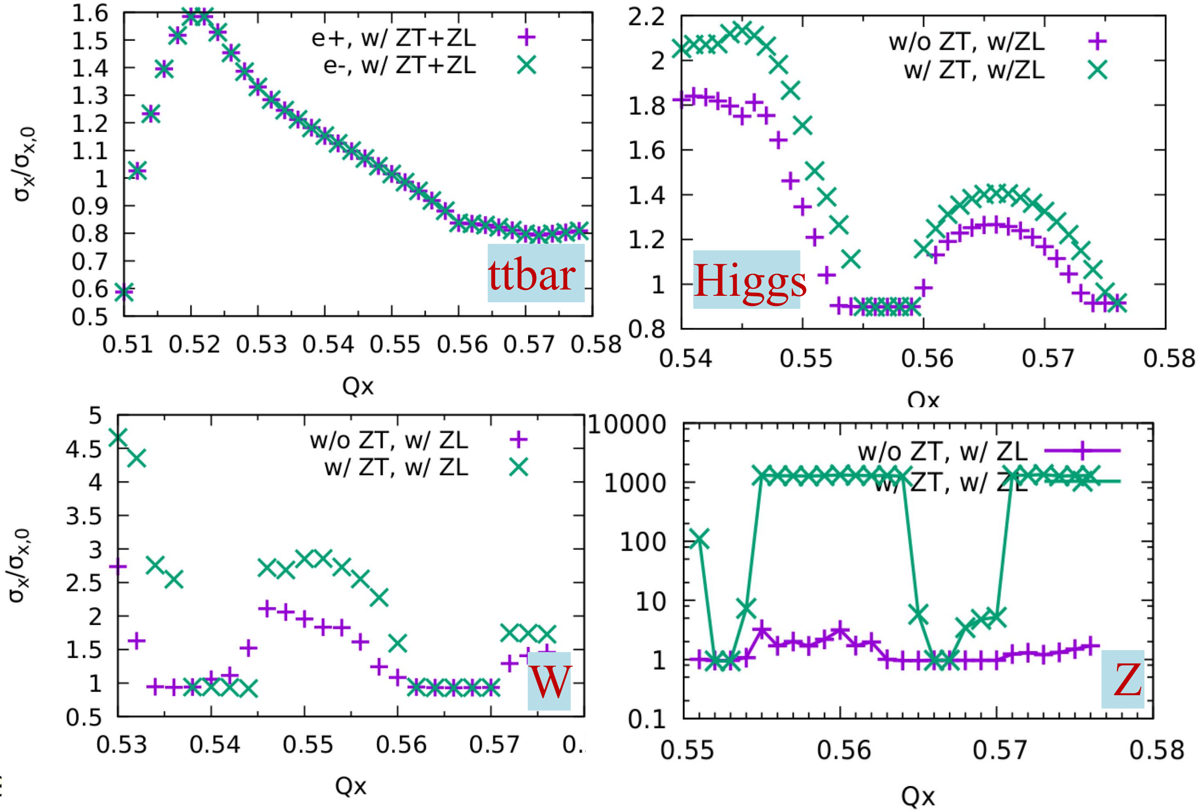
—**w/o error**
—**mean value**
—**statistic errors**
—**seeds**
—**requirement**

Studies of Beam-Beam Effects in CEPC

Luminosity simulations w/ZL



Transverse size simulations



Beam-beam simulation results are consistent with the TDR parameter tables.

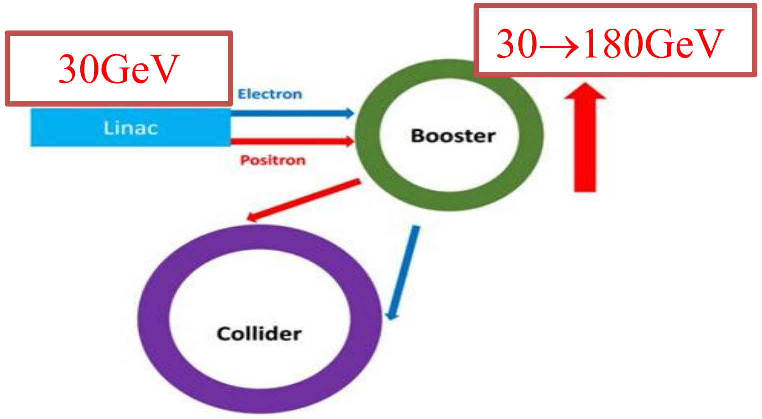
- **Luminosity & Lifetime is evaluated by strong-strong simulation**
- **X-Z instability is well suppressed even considering Potential Well Distortion**
- **Lifetime optimization with both beam-beam\lattice nonlinearity is done**

Parameters of CEPC Booster

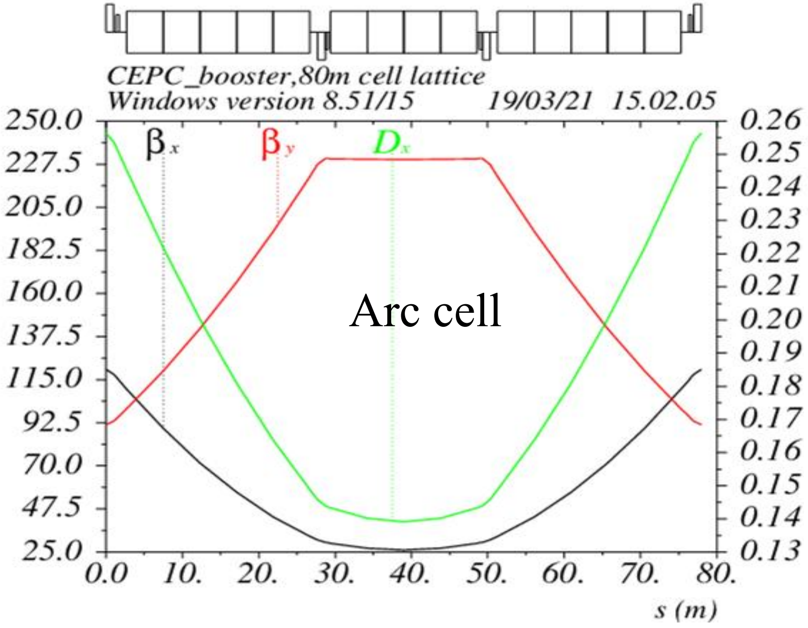
Injection		***tt***	***H***	***W***	***Z***	
Beam energy	GeV	30				
Bunch number		35	268	1297	3978	5967
Bunch charge	nC	1.1	0.78	0.81	0.87	0.9
Single bunch current	μA	3.4	2.3	2.4	2.65	2.69
Beam current	mA	0.12	0.62	3.1	10.5	16.0
Energy spread	%	0.025				
Synchrotron radiation loss/turn	MeV	6.5				
Momentum compaction factor	10^{-5}	1.12				
Emittance	nm	0.076				
Natural chromaticity	H/V	-372/-269				
RF voltage	MV	761.0	346.0	300.0		
Betatron tune ν_x/ν_y		321.23/117.18				
Longitudinal tune		0.14	0.0943	0.0879		
RF energy acceptance	%	5.7	3.8	3.6		
Damping time	s	3.1				
Bunch length of linac beam	mm	0.4				
Energy spread of linac beam	%	0.15				
Emittance of linac beam	nm	6.5				

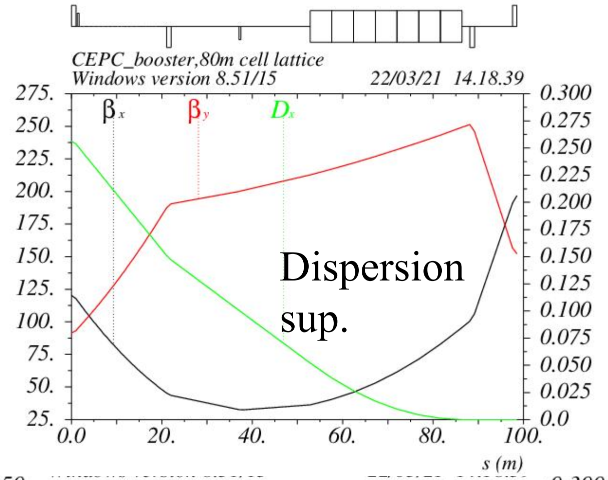
Extraction		***tt***	***H***		***W***	***Z***	
		Off axis injection	Off axis injection	On axis injection	Off axis injection	Off axis injection	
Beam energy	GeV	180	120		80	45.5	
Bunch number		35	268	261+7	1297	3978	5967
Maximum bunch charge	nC	0.99	0.7	20.3	0.73	0.8	0.81
Maximum single bunch current	μA	3.0	2.1	61.2	2.2	2.4	2.42
Beam current	mA	0.11	0.56	0.98	2.85	9.5	14.4
Bunches per pulse of Linac		1	1		1	2	
Time for ramping up	s	7.1	4.3		2.4	1.0	
Injection duration for top-up (Both beams)	s	29.2	23.1	31.8	38.1	132.4	
Current decay in Collider		3%					
Energy spread	%	0.15	0.099		0.066	0.037	
Synchrotron radiation loss/turn	GeV	8.45	1.69		0.33	0.034	
Emittance	nm	2.83	1.26		0.56	0.19	
Betatron tune ν_x/ν_y		321.27/117.19					
RF voltage	GV	9.7	2.17		0.87	0.46	
Longitudinal tune		0.14	0.0943		0.0879		
RF energy acceptance	%	1.78	1.59		2.6	3.4	
Damping time	ms	14.2	47.6		160.8	879	
Natural bunch length	mm	1.8	1.85		1.3	0.75	
Full injection from empty ring	h	0.1	0.14	0.16	0.27	1.8	0.8

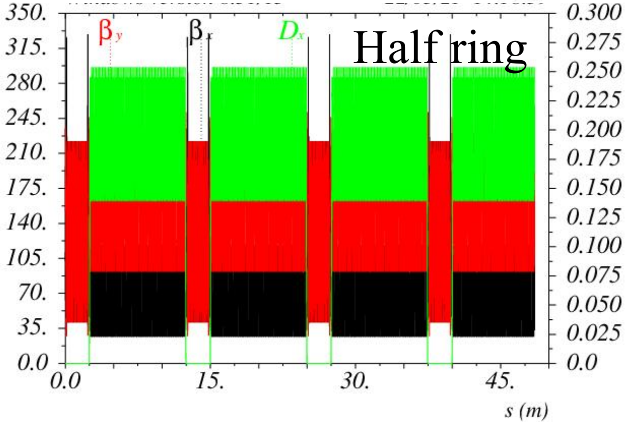
CEPC Booster Design

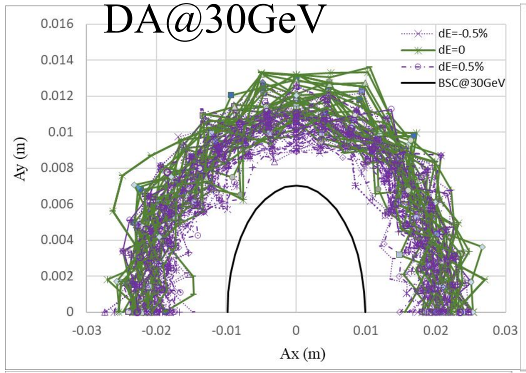


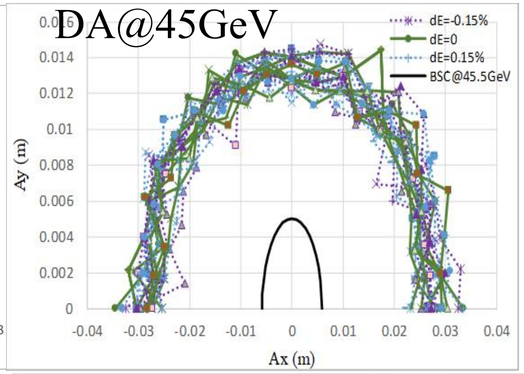
- TME like structure (cell length=78m)
- Interleave sextupole scheme
- Emittance@120GeV=1.26nm

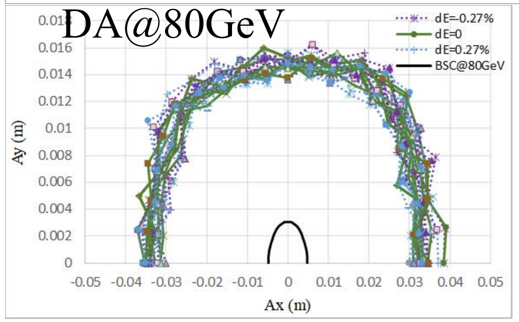


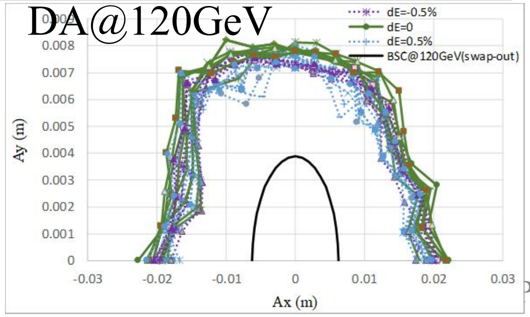












- **30 GeV injection energy, Maximum extraction energy @ 180GeV**
- **Lattice design with TME structure, lower emittance than CDR**
- **Sufficient Dynamic Aperture for all energies with errors**

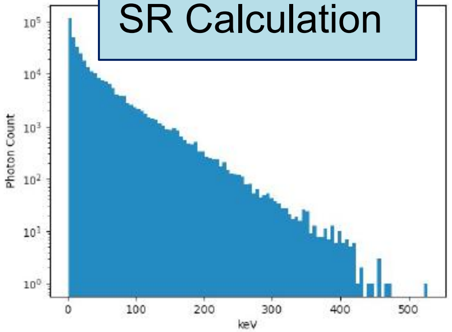
CEPC MDI Design

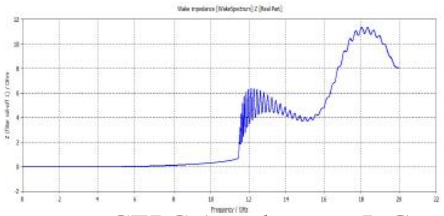
MDI Layout

General Parameters

				end ngle	length	Beam stay clear region	Mini. distance between apertures	Beam pipe Inner diameter	Beam pipe outer diameter	Critical energy (Hor.)	Critical energy (Vert.)	SR power (Hor.)	SR power (Vert.)
L*	0~1.9m				1.9m								
Crossing angle	33mrad												
MDI length	±7m												
Acc. components in opening angle	8.11˚												
QDa/QDb		3.5/2.8T	142/85T/m		1.21m	14.9/18.2mm	62.71/105.28mm	20/23mm	26/29mm	724.7/663.1keV	396.3/263keV	212.2/239.23W	99.9/42.8W
QF1		3.3T	96.7T/m		1.5m	24.48mm	155.11mm	32mm	38mm	675.2keV	499.4keV	472.9W	135.1W
Lumical	0.65~1.11m				0.16m								
Anti-solenoid before QD0		8.6T			1.1m								
Anti-solenoid QD0		3T			2.5m								
Anti-solenoid QF1		3T			1.5m								
Beryllium pipe					±85mm			20mm					
Last B upstream	64.97~153.5m			0.77mrad	88.5m					33.3keV			
First B downstream	44.4~102m			1.17mrad	57.6m					77.9keV			
Beampipe within QDa/QDb					1.21m							1.19/1.31W	
Beampipe within QF1					[illegible]								
[illegible]					[illegible]								

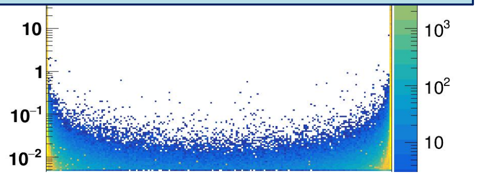
SR Calculation

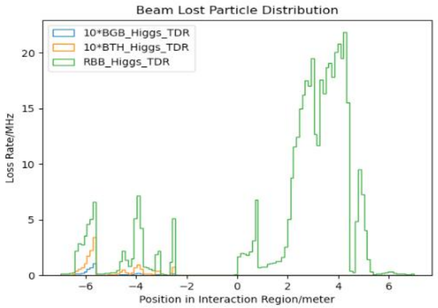




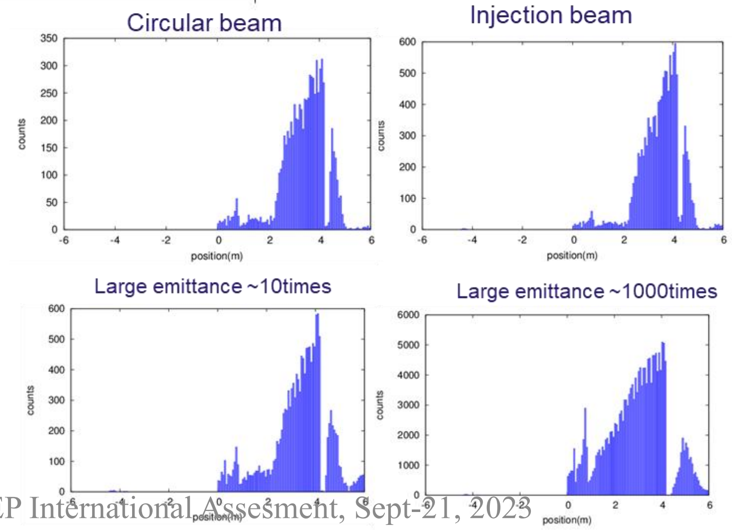
Radiation background

Radiative barbar, Beam-Gas, beam thermal photon scattering



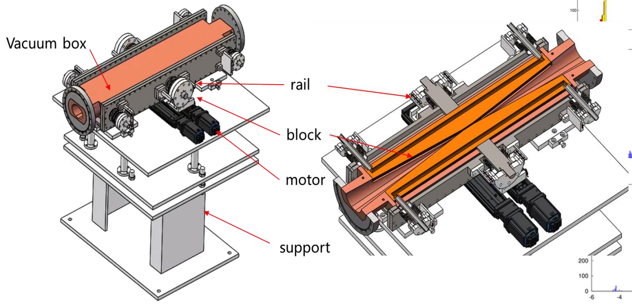


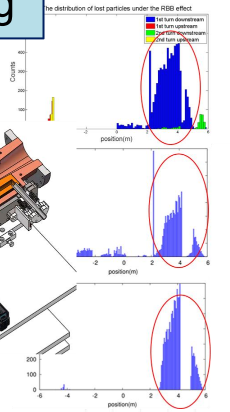
Injection background

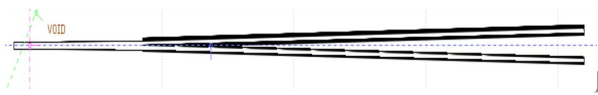


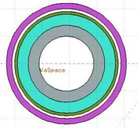
Radiation Mitigation

Masks, collimators, shielding









CEPC SRF System Design and Upgrade Plan

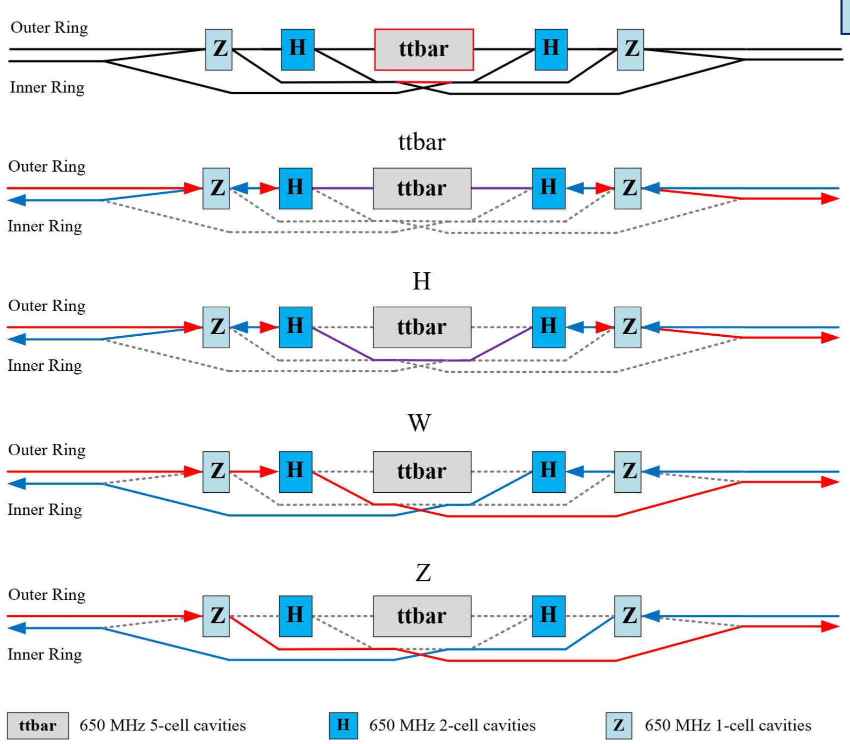
Collider 650MHz Parameters

30/50 MW SR power per beam for each mode. Higgs/ttbar shared cavities for the two rings. W/Z separate cavities. HL-Z cavities bypass.	ttbar 30/50 MW		Higgs 30/50 MW	W 30/50 MW	Z 30/50 MW
	New cavities	Higgs cavities			
Luminosity / IP [10^{34} $cm^{-2}s^{-1}$]	0.5 / 0.8		5 / 8.3	16 / 26.7	115 / 192
RF voltage [GV]	10 (6.1 + 3.9)		2.2	0.7	0.12 / 0.1
Beam current / beam [mA]	3.4 / 5.6		16.7 / 27.8	84 / 140	801 / 1345
Bunch charge [nC]	32		21	21.6	22.4 / 34.2
Bunch length [mm]	2.9		4.1	4.9	8.7 / 10.6
650 MHz cavity number	192	336	192/336	96 / 168 / ring	30 / 50 / ring
Cell number / cavity	5	2	2	2	1
Gradient [MV/m]	27.6	25.2	24.9 / 14.2	15.9 / 9.1	17.4 / 8.7
Q_0 @ 2 K at operating gradient	3E10	3E10	3E10	3E10	2E10
HOM power / cavity [kW]	0.4 / 0.66	0.16 / 0.26	0.4 / 0.67	0.93 / 1.54	2.9 / 6.2
Input power / cavity [kW]	188 / 315	71 / 118	313 / 298	313 / 298	1000
Optimal Q_L	1E7 / 6E6	9E6 / 5.4E6	1.6E6 / 9.5E5	8E5 / 2.7E5	1.5E5 / 3.8E4
Optimal detuning [kHz]	0.01 / 0.02	0.02 / 0.03	0.1 / 0.2	0.7 / 2	6.7 / 21.7
Cavity number / klystron	4 / 2	2	2	2	1
Klystron power [kW]	800	800	800	800	1200
Klystron number	48 / 96	168	96 / 168	96 / 168	60 / 100
Cavity number / cryomodule	4	6	6	6	1
Cryomodule number	48	56	32 / 56	32 / 56	60 / 100
Total cavity wall loss @ 2 K [kW]	12.1	7.1	3.9 / 2.3	1.6 / 0.9	0.45 / 0.2

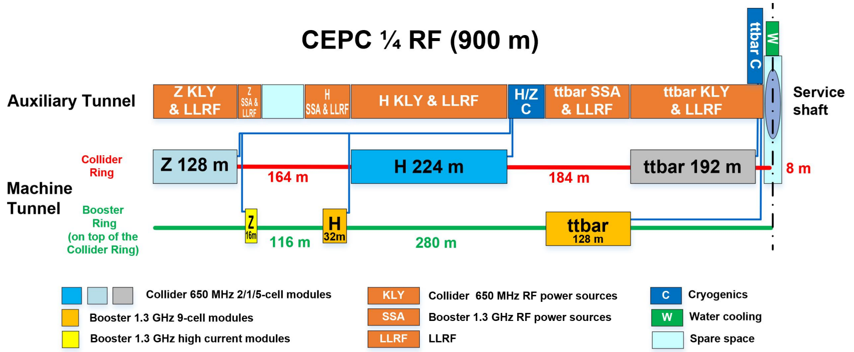
Booster 1.3GHz Parameters

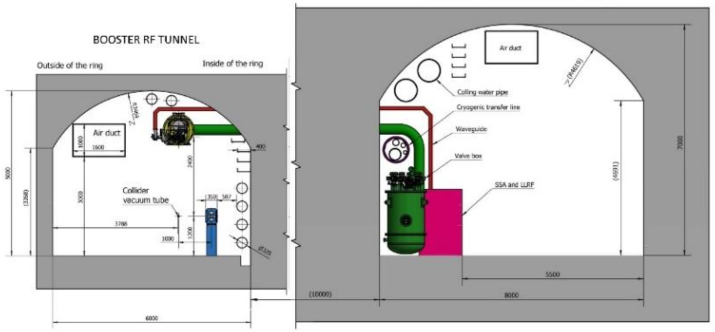
30/50 MW Collider SR power per beam. 30 GeV injection. Higgs & ttbar half filled. Higgs on-axis injection with bunch swapping. Z injection from empty ring.	ttbar 30/50 MW		Higgs 30/50 MW	W 30/50 MW	Z 30/50 MW
	New cavities	Higgs cavities			
Extraction beam energy [GeV]	180		120	80	45.5
Extraction average SR power [MW]	0.05		0.5 / 0.67	0.02 / 0.04	0.05 / 0.1
Bunch charge [nC]	1.1		0.78 (20.3)	0.73	0.81
Beam current [mA]	0.12 / 0.19		0.63 (1) / 1 (1.4)	3.1 / 5.3	16 / 30
Injection RF voltage [GV]	0.761		0.346	0.3	0.3
Extraction RF voltage [GV]	9.7 (7.53 + 2.17)		2.17	0.87	0.46
Extraction bunch length [mm]	1.8		1.86	1.3	0.75
Cavity number (1.3 GHz 9-cell)	256	96	96	96	32
Module number (8 cavities / module)	32	12	12	12	4
Extraction gradient [MV/m]	28.3	21.8	21.8	8.7	13.8
Q_0 @ 2 K at operating gradient	2E10	3E10	3E10	3E10	3E10
Q_L	4E7	4E7	1.2E7	7.3E6 / 4.4E6	1.2E7 / 6.3E6
Cavity bandwidth [Hz]	33	33	110	178 / 296	111 / 208
Peak HOM power per cavity [W]	0.5 / 0.8		~ 75 / ~ 100	11.8 / 19.6	146 / 272
Average HOM power per cavity [W]	0.2 / 0.32		~ 10 / ~ 15	3.8 / 6.3	80 / 150
Input peak power per cavity [kW]	8.3 / 9.2	5.1 / 5.9	22 / 32	10.9 / 18.1	17 / 32
Input average power per cavity [kW]	0.3	0.2	6.5 / 9.2	0.3 / 0.5	2.5 / 4.5
SSA power [kW] (1 cavity / SSA)	10	10	25 / 30	25 / 30	25 / 40
Total cavity wall loss @ 2 K [kW]	0.36	0.05	0.5	0.02	0.08

H/W/Z/ttbar bypass scheme



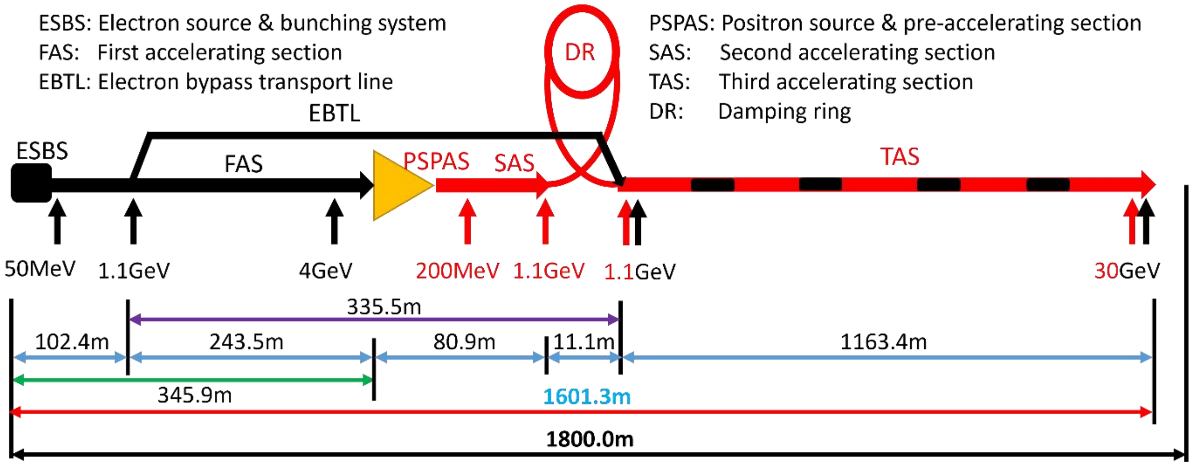
SRF power supply auxiliary tunnel





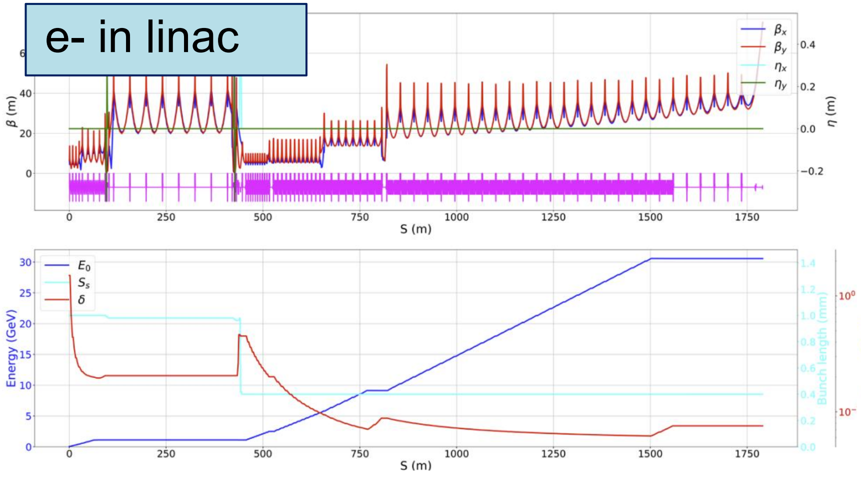
- **CEPC TDR SRF layout and parameters are designed to meet physics requirements;**
- **RF system design optimized for Higgs 30/50 MW. Power and energy upgrade by adding cavities, RF power sources and cryogenic plants and other systems are compatible;**
- **Use dedicated high current 1-cell cavity for 10-50 MW Z. Solve the FM & HOM CBI problems.**

CEPC Electron and Positron Injection Linac Designs

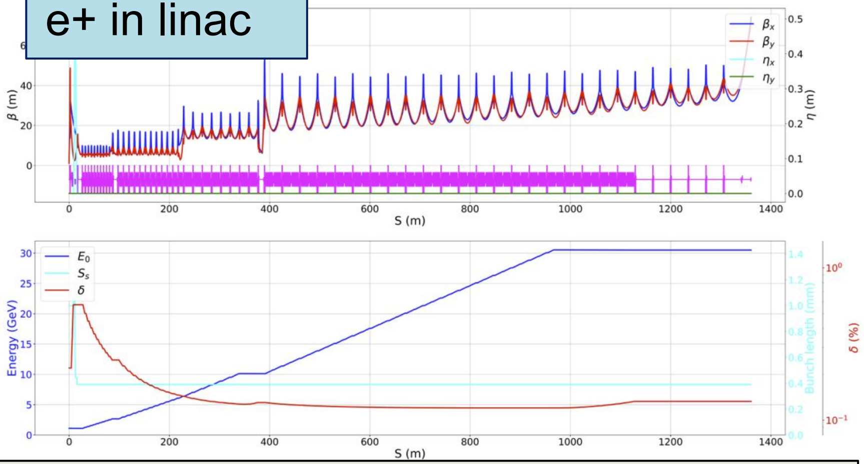


Parameter	Symbol	Unit	Design value
Energy	E	GeV	30
Repetition rate	f_{rep}	Hz	100
Number of bunches per pulse			1 or 2
Bunch charge		nC	1.5
Energy spread	σ_E		1.5×10^{-3}
Emittance	ε_r	nm	6.5
Electron energy at target		GeV	4
Electron bunch charge at target		nC	10
Tunnel length	L	m	1800

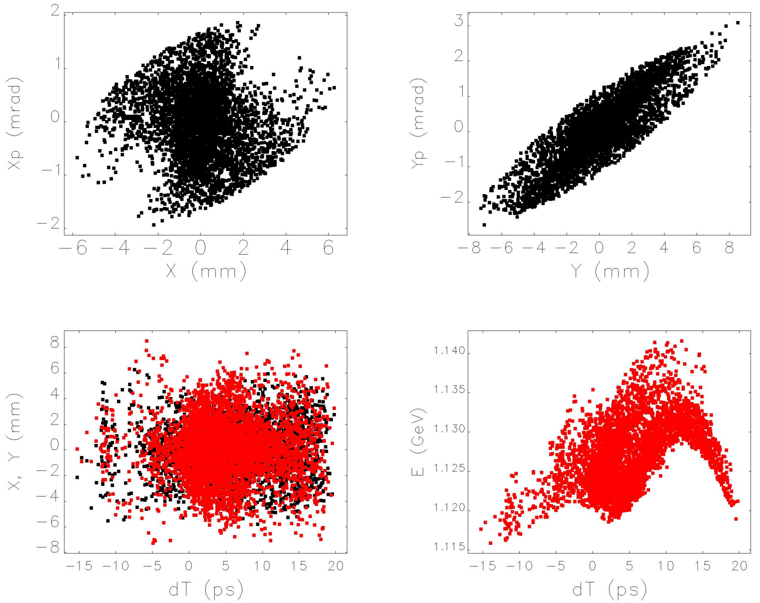
e- in linac



e+ in linac

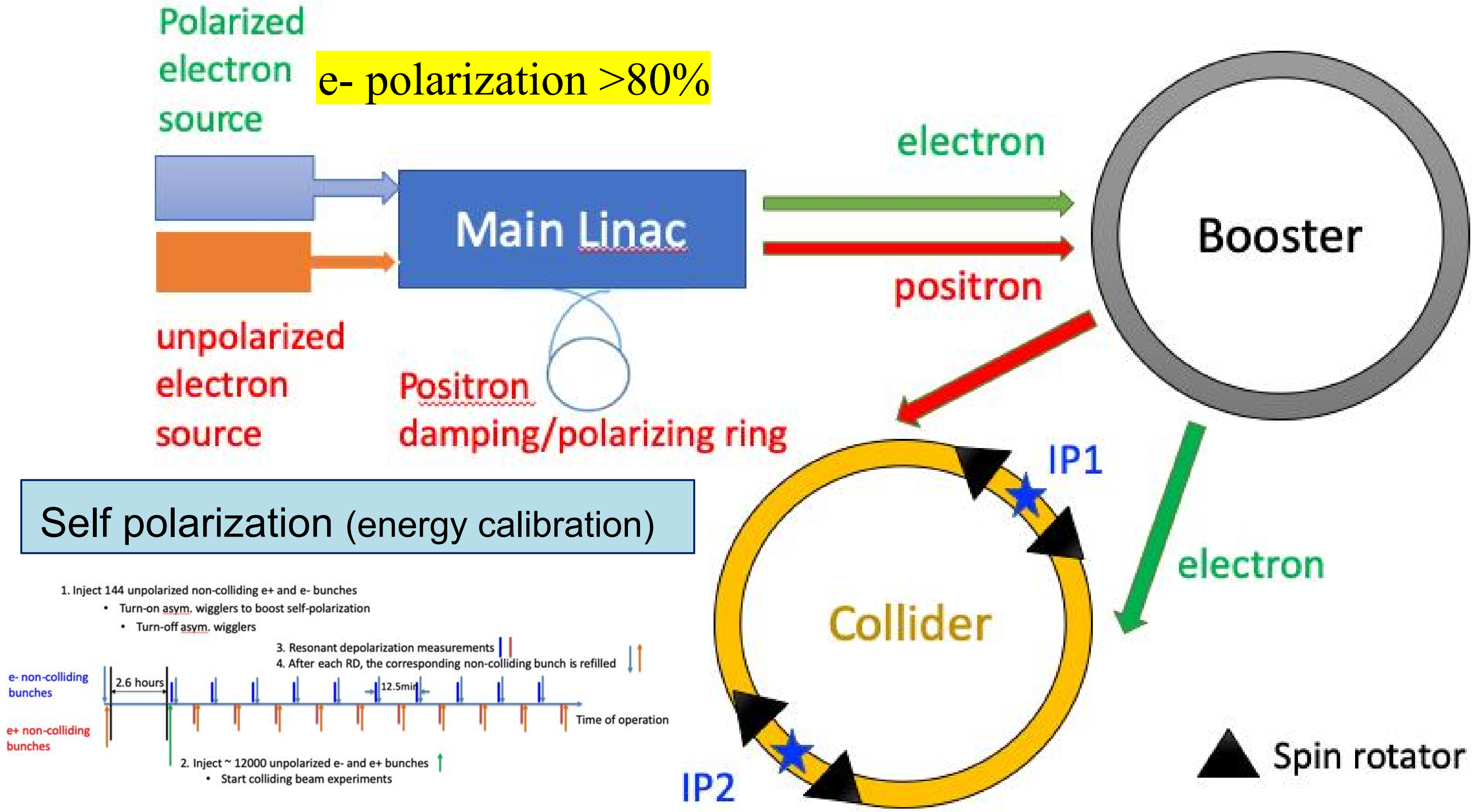


Phase space @ SAS exit



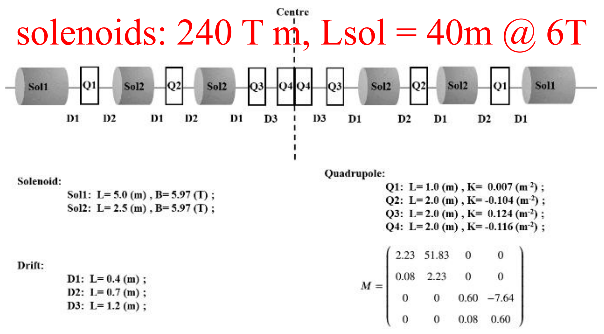
- **Linac energy increases to 30 GeV, with S+C band Accelerator;**
- **Start-to-end simulations were conducted for both electron/positron beams, with quality satisfying requirements.**

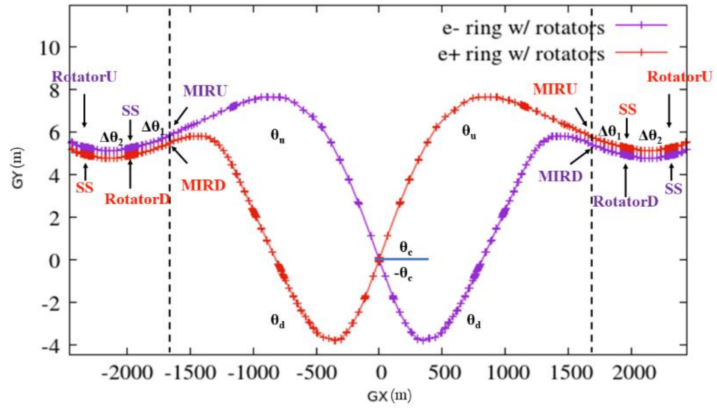
CEPC Polarized Beam Studies(alternative option)



Spin rotator design

solenoids: 240 T m, Lsol = 40m @ 6T





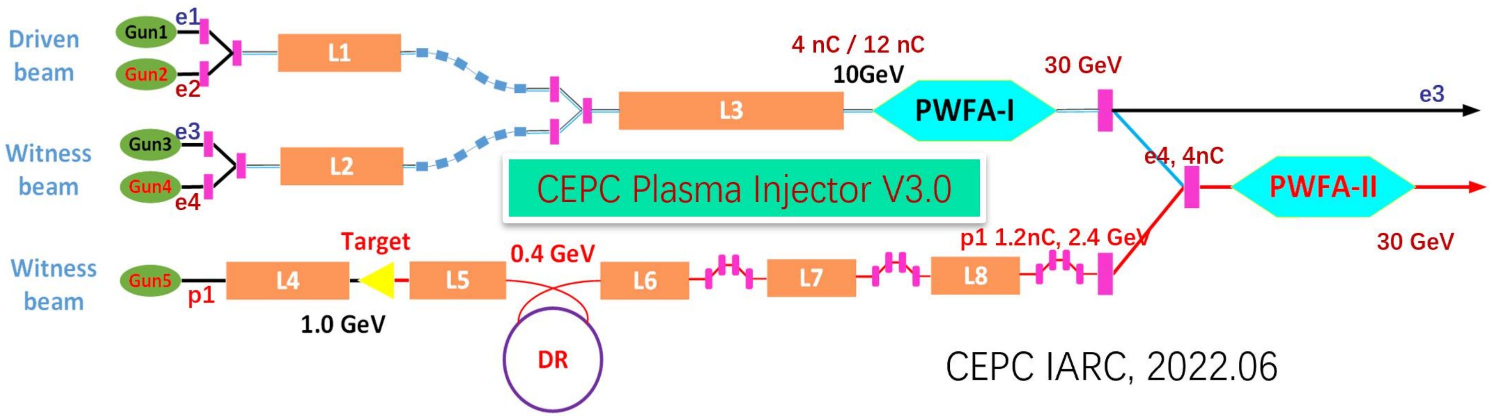
Key issues of study:

- Energy calibration in collider ring with transverse polarization (self polarization & inj. polarization)
- Longitudinal polarization for collision
- Polarization beam injection, positron polarization and ramping in booster

CEPC Plasma Injector (alternative option) and TF Plan

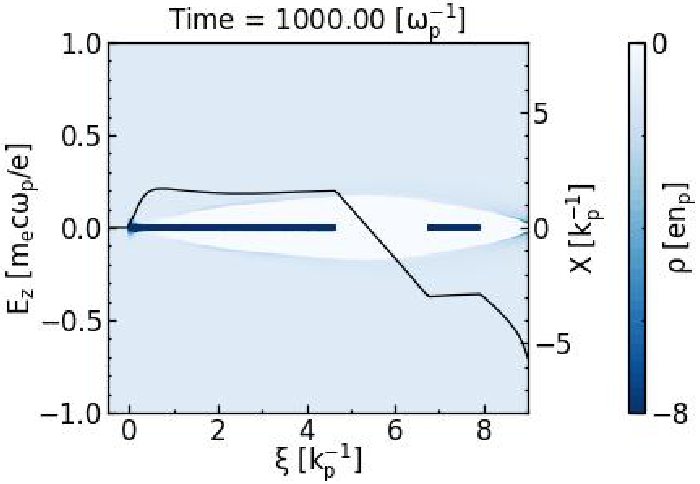
CEPC injector's baseline was changed:

10 GeV → 30 GeV → **TR ≥ 2**



Parameters	Driver	Trailer
plasma density $n_p(\times 10^{16} cm^{-3})$	0.50334	
Driver energy E(GeV)	12	12
Normalized emittance ϵ_N ($\mu m\ rad$)	20	10
Length L (μm)	350	90
(matched) Spot size σ_r (μm)	3.72	2.63
Charge Q (nC)	4.0	1.2
Beam distance d (μm)	155	

Parameters	Trailer
Accelerating distance (m)	7.3 (97300 w_p^{-1})
Trailer energy $E(GeV)$	30
Normalized emittance $\epsilon_n(mm\ mrad)$	10
Charge(nC)	1.2
Energy spread δ_E(%)	0.58
R	1.8
Efficiency(%) (driver -> trailer)	55



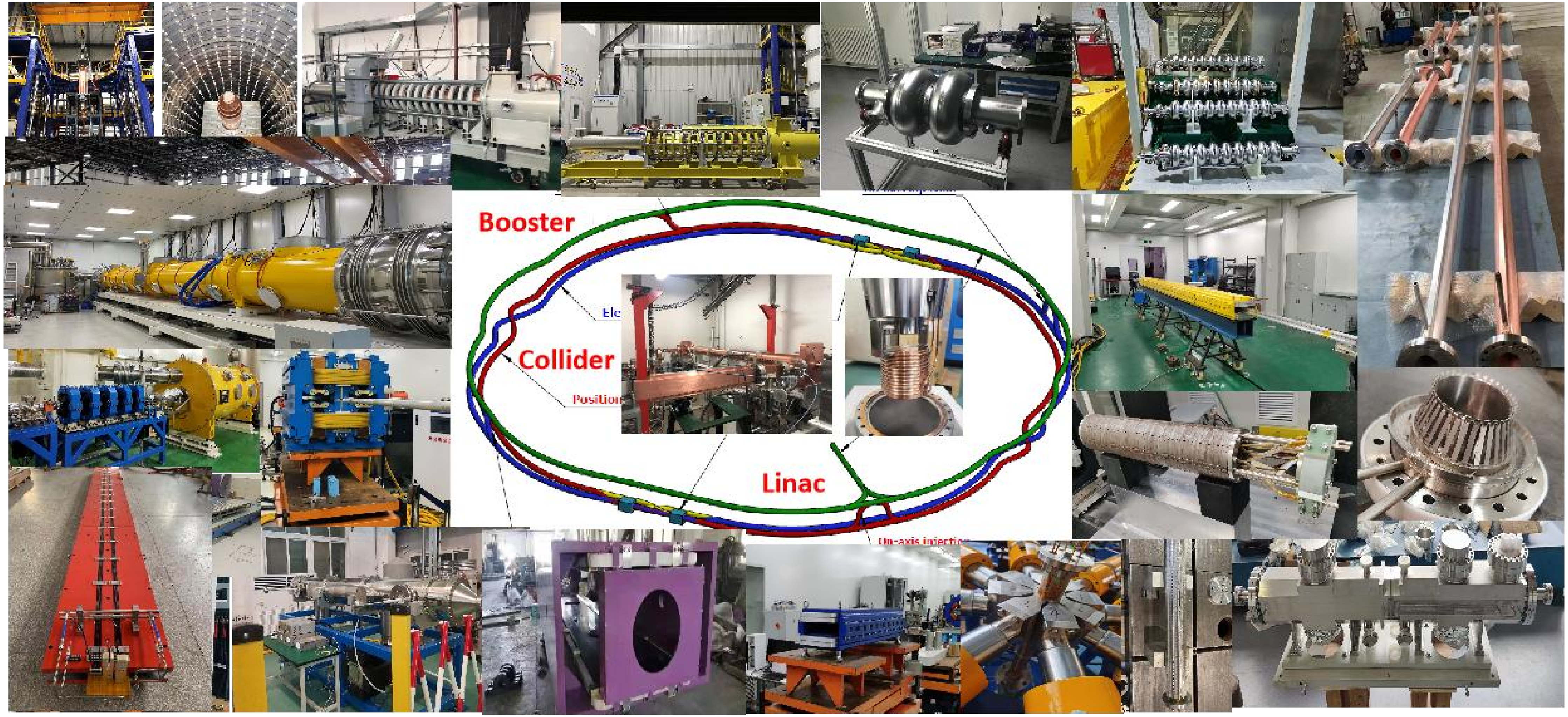
CEPC TDR R&D Maturity

- CEPC received ~ 260 Million CNY from MOST, CAS, NSFC, etc for the key technology R&D
- Large amount of key technology validated in other project by IHEP: BEPCII, HEPS, …

CEPC R&D **~ 40% cost of acc. components**	➢ **High efficiency klystron** ➢ **SRF cavities** ➢ **Positron source** ➢ **High performance accelerator**	➢ **Novel magnets: Weak field dipole, dual aperture magnets** ➢ **Extremely fast injection/extraction** ➢ **Electrostatic deflector** ➢ **MDI**
BEPCII / HEPS **~ 50% cost of acc. components**	➢ **High precision magnet** ➢ **Stable magnet power source** ➢ **Vacuum chamber with NEG coating** ➢ **Instrumentation, Feedback system**	➢ **Survey & Alignment** ➢ **Ultra stable mechanics** ➢ **Radiation protection** ➢ **Cryogenic system** ➢ **MDI**

~10% remaining (the machine integration, commissioning etc.) and is anticipated to be completed by 2026, and the international contribution/collaboration may be needed.

CEPC Key Technology R&D



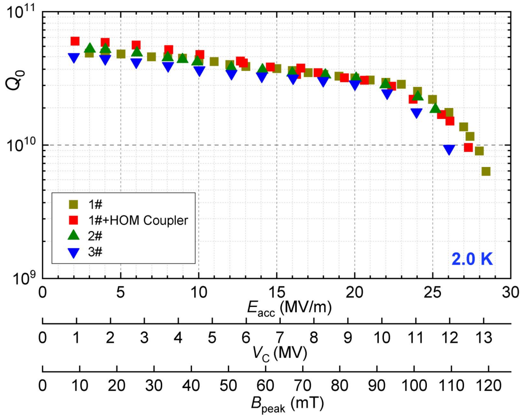
Key technology R&D spans all component lists in CEPC TDR

CEPC SRF Facilities and Components

Mid-T (medium temperature furnace baked) cavities have higher gradient and Q than Nitrogen doped cavities with less EP process (1 vs 3)

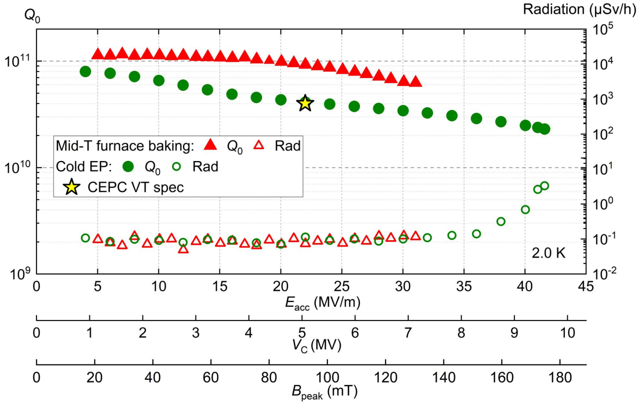
IHEP PAPS is in full operation since 2021

CEPC 650 MHz 2-cell Cavity



3E10@20MV/m.

CEPC 650 MHz 1-cell Cavity

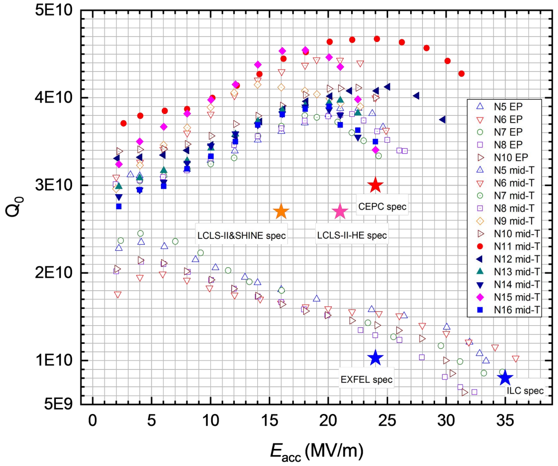


High G High Q 650 MHz 1-cell Cavity

EP treated: 2.3E10@41.6 MV/m@2 K

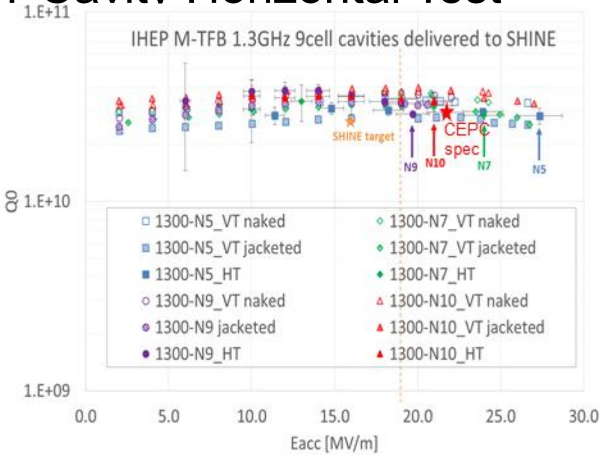
Mid-T treated: 6.3E10@31 MV/m@2 K

1.3 GHz High Q Mid-T Cavity Horizontal Test



Mid-T 1.3 GHz 9-cell vertical test

avg.4.3E10@ 31 MV/m



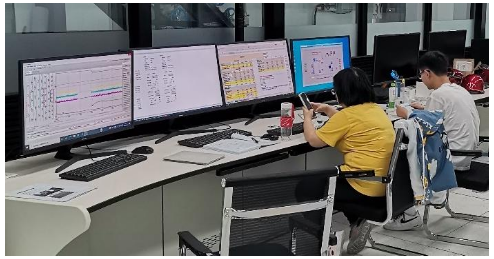
Mid-T 1.3 GHz 9-cell horizontal test (SEL)

3.1E10@21 MV/m, avg. 24.6 MV/m

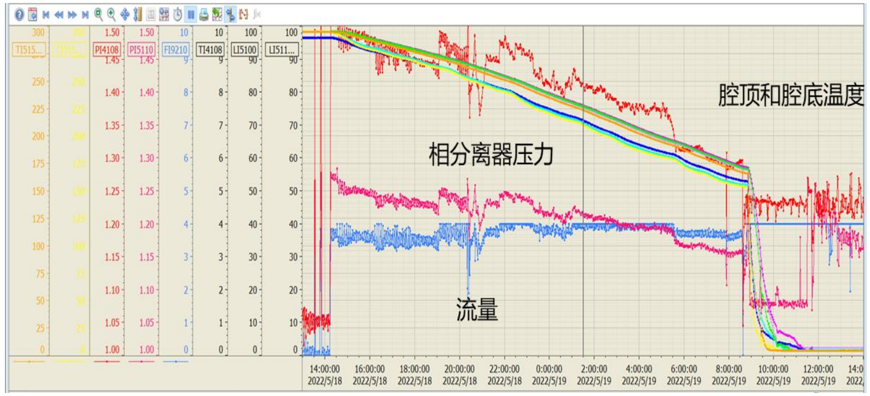
CEPC Collider 650 MHz 2 x 2-cell Test Cryomodule







- DC photo-cathode gun voltage conditioned up to 400 kV
- Cavity frequency, HOM coupler double notch filter, tuner, vacuum, cryogenics perform well
- Cavity magnetic field at 2 K < 2 mG (large beam pipe North to South)
- LLRF system commissioning and high power test ongoing
  - Optimizing the outer conductor helium gas cooling of the input coupler. Cavity early quench if with poor coupler cooling.



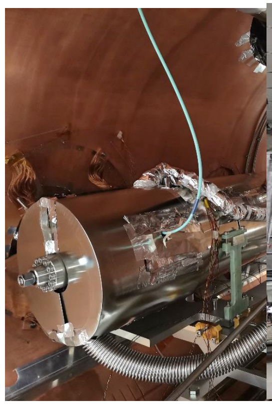
Module automatic cool-down experiment

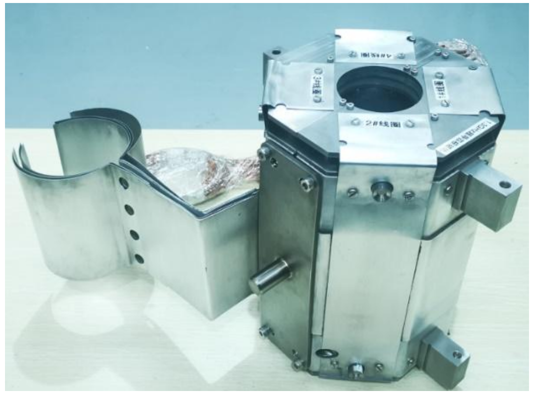
1. 300 to 150 K: < 10 K/hr. Cavity top and bottom ΔT < 20 K
2. 150 to 4.5 K: Cavity surface > 1 K/min
3. 4.5 to 2 K

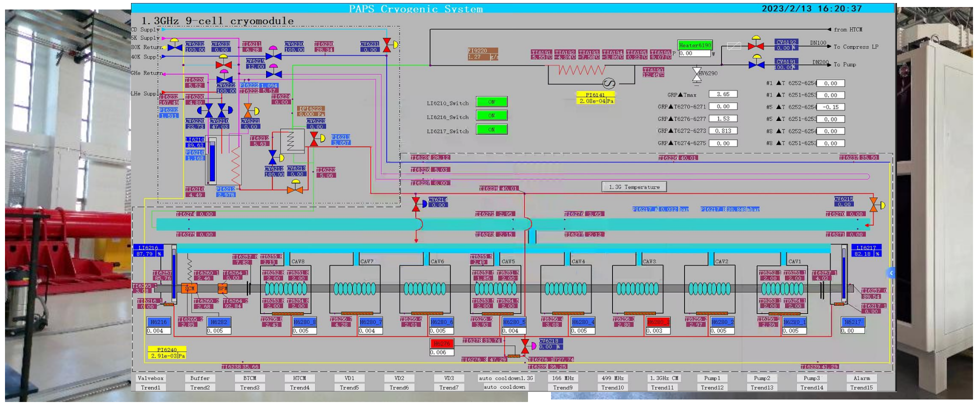
CEPC Booster 1.3 GHz 8 x 9-cell High Q Cryomodule

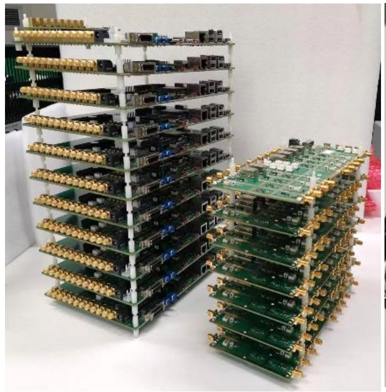
CEPC booster 1.3 GHz SRF R&D and industrialization in synergy with CW FEL projects.

Parameters	Horizontal test results	CEPC Booster Higgs Spec	LCLS-II, SHINE Spec	LCLS-II-HE Spec
Average usable CW E_{acc} (MV/m)	23.1	3.0×10^{10} @ 21.8 MV/m	2.7×10^{10} @ 16 MV/m	2.7×10^{10} @ 20.8 MV/m
Average Q_0 @ 21.8 MV/m	3.4×10^{10}			



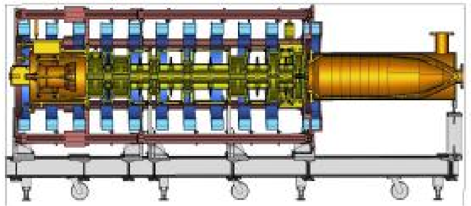



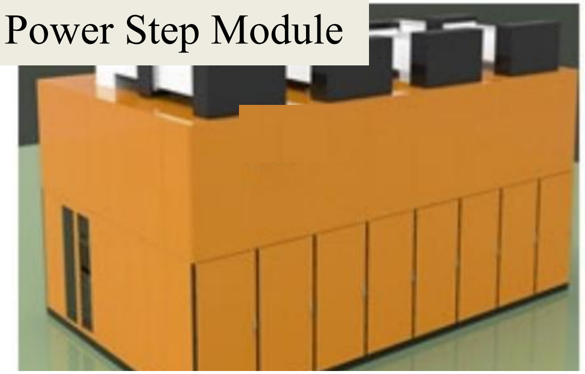

CEPC High Efficiency High Power Klystron Development and RF Power Distribution

Klystron R&D

Klystron No. 2
Efficiency 77%
(2021)



Power Step Module



Klystron No. 1
Efficiency 65%
(2020)

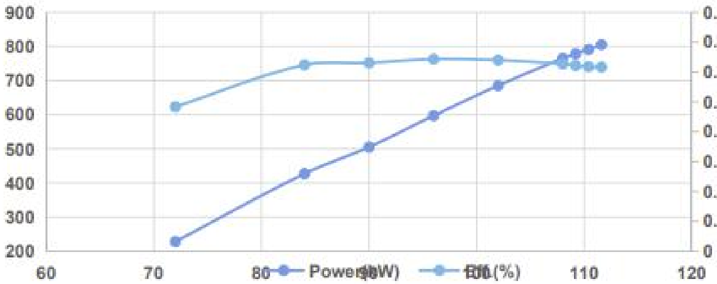
Klystron No. 3 （MBK
Efficiency 80.5%
(under fabrication)

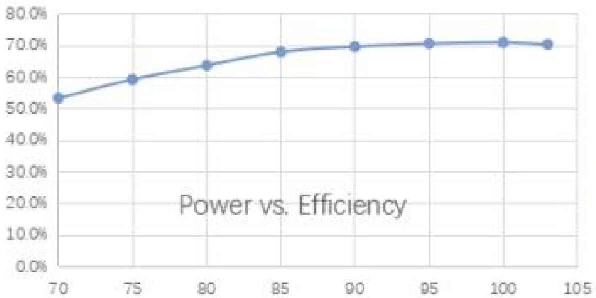
2022

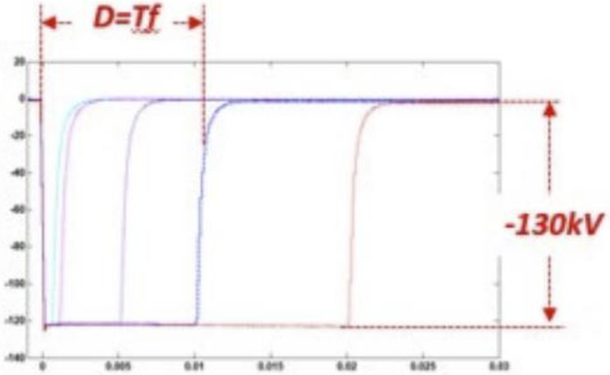
Pulsed RF Mode (30% duty factor, 60ms/5Hz)

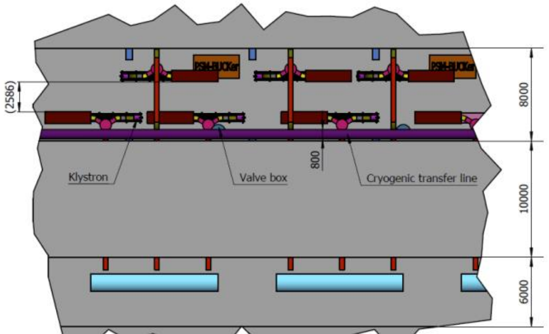
70.5% @ 630kW

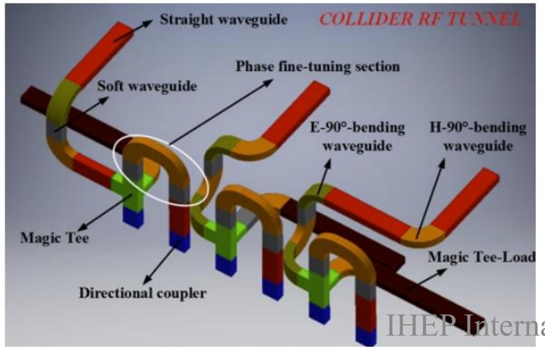
High Voltage vs. Power&Efficency







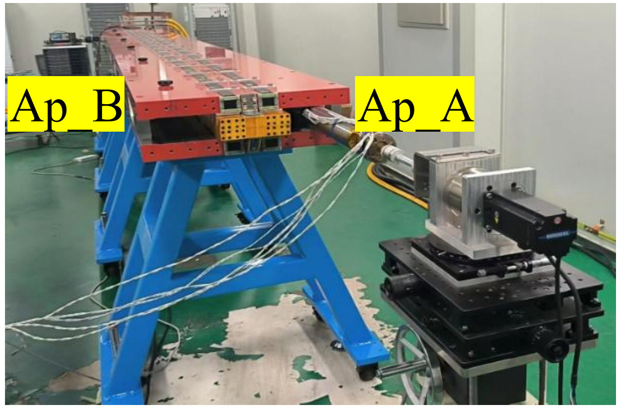




- Three prototypes of the 650MHz 800KW CW klystrons are developed. The efficiency reaches 70%
- PSM is developed with the industrial collaboration
- RF tunnel distribution was planed

CEPC Collider Ring Full-scale Dual-aperture Magnets

Full-length 5.67m Dual aperture dipole

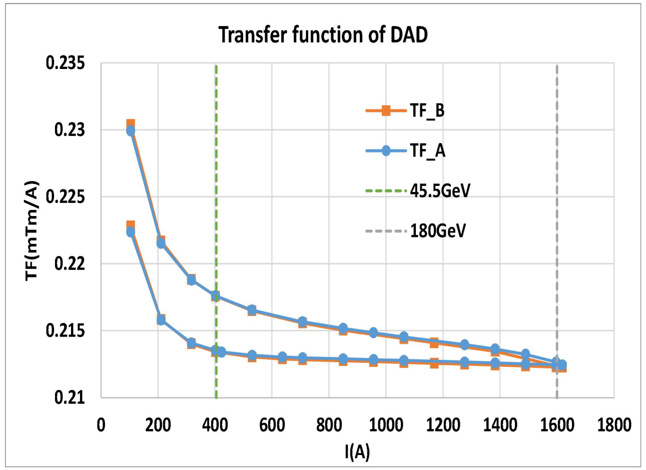


High harmonics @120GeV (units:1e-4)

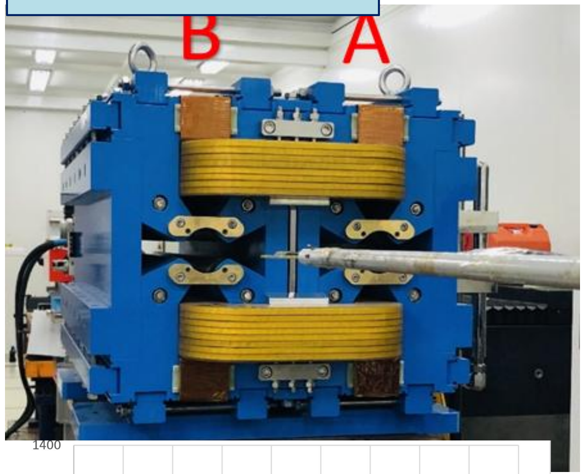
n	bn_A	bn_B
2	0	0
3	3.92	3.88
4	1.03	-1.22
5	0.47	0.54
6	0.08	-0.46

Two apertures differ <0.1%, transfer function in two apertures are consistent.

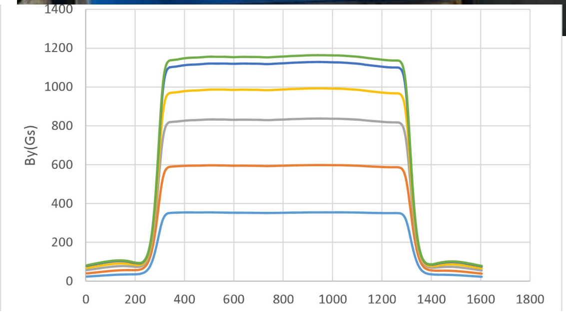
High harmonics are nearly the same at four energies and all less than 5 units, which can meet the requirements.

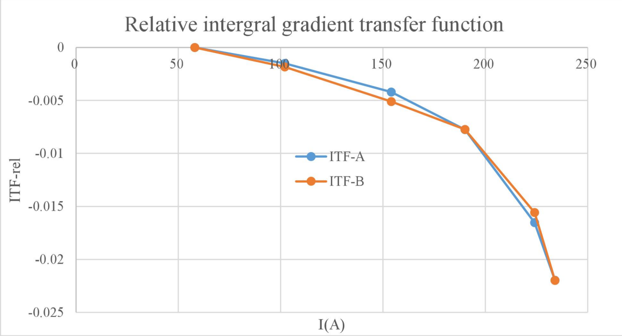


Dual aperture QUAD



E(GeV)	GL(T)-A	GL(T)-B	difference
45	-3.36	3.35	0.40%
80	-5.91	5.88	**0.59%**
120	-8.89	8.85	0.49%
148	-10.93	10.89	0.40%
175	-12.77	12.73	0.30%
182.5	-13.27	13.21	0.40%

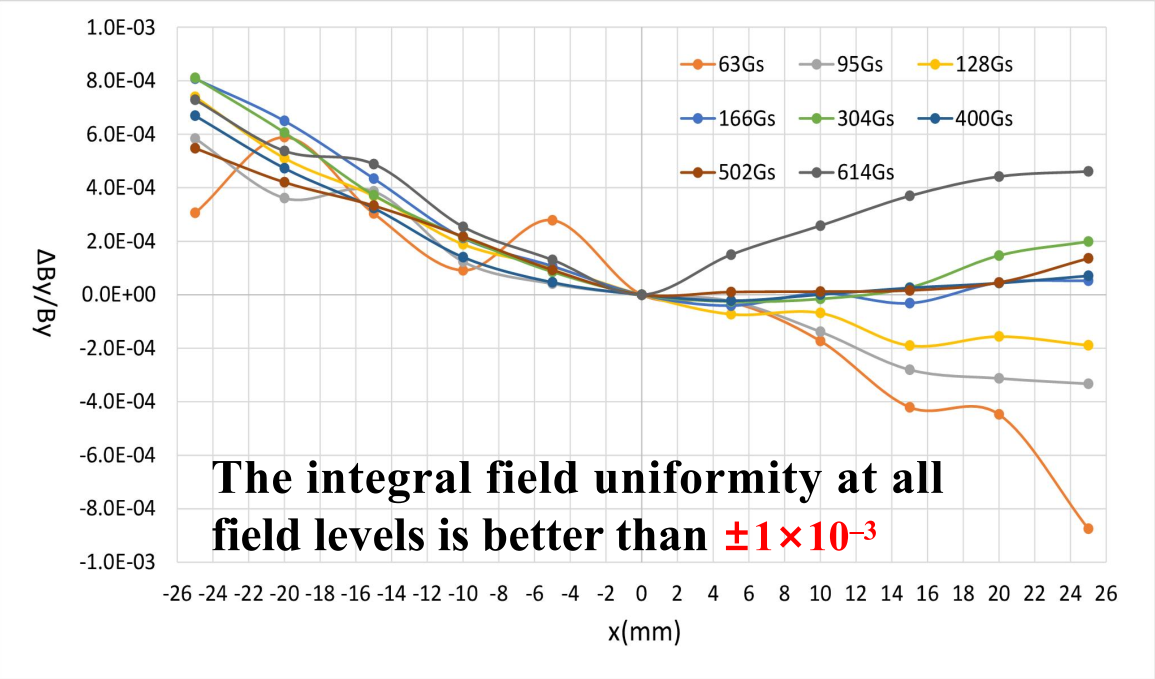




- **Large quantities of dual-aperture dipoles (69km) and quad. (10km) are required;**
- **Full length dual-aperture dipole and dual aperture QUAD (short length) have been fabricated, under test;**
- **Dipole/QUAD prototypes meet the requirements.**

CEPC Full-scale Weak Field Dipole for Booster

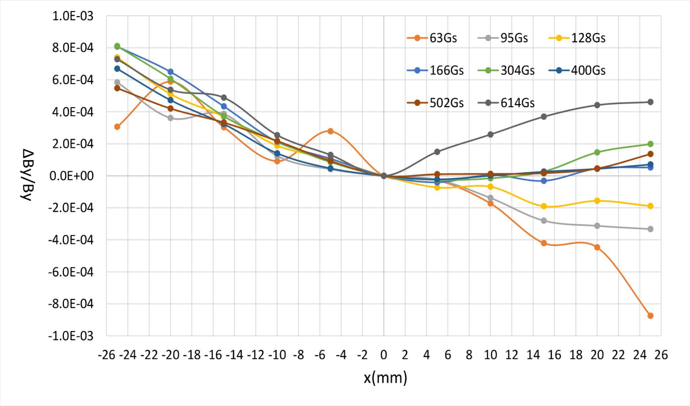
Magnet name	BST-63B-Arc	BST-63B-Arc-SF	BST-63B-Arc-SD	BST-63B-IR
Quantity	10192	2017	2017	640
Aperture [mm]	63	63	63	63
Dipole Field [Gs] @180 GeV	564	564	564	549
Dipole Field [Gs] @120 GeV	376	376	376	366
Dipole Field [Gs] @30 GeV	95	95	95	93
Sextupole Field [T/m^2] @180 GeV	0	16.0388	19.1423	0
Sextupole Field [T/m^2] @120 GeV	0	10.6925	12.7615	0
Sextupole Field [T/m^2] @30 GeV	0	2.67315	3.19035	0
Magnetic length [mm]	4700	4700	4700	2350
GFR [mm]	±22.5	±22.5	±22.5	±22.5
Field errors	$\pm 1\times10^{-3}$	$\pm 1\times10^{-3}$	$\pm 1\times10^{-3}$	$\pm 1\times10^{-3}$

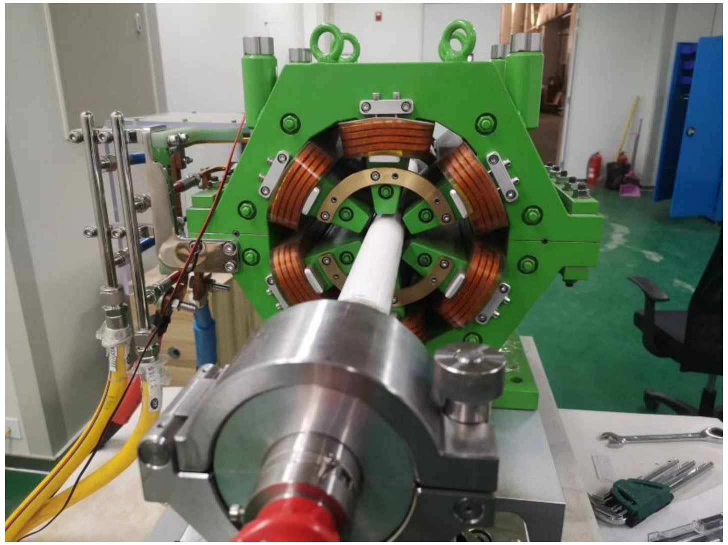


- Booster requires ~19k pieces of magnets (68km);
- Booster dipoles are required to work at the low field of 95 Gs (30GeV) with an error smaller than 1×10^{-3} ;
- Full length (4.7m) dipole was developed, and it meets the field specification;

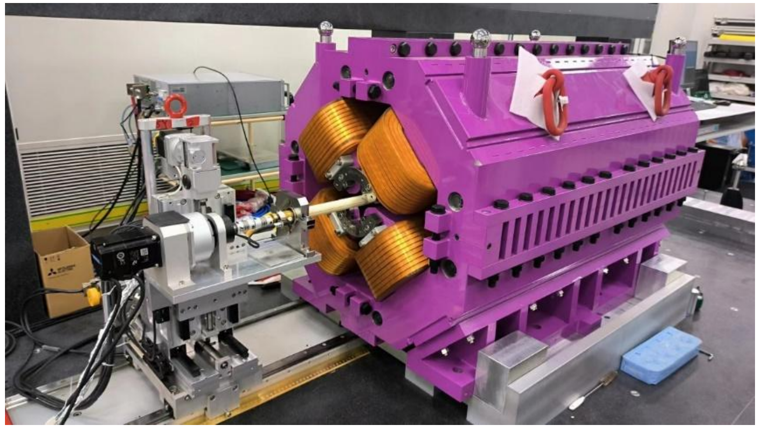
CEPC Full-scale Booster Magnets (quadrupole, sextupole, corrector in synergy with HEPS)

Booster dipole





Sextupole



Quadrupole

The integral field uniformity at all field levels of full size booster dipole is better than $\pm 1\times10^{-3}$, and meet the specification

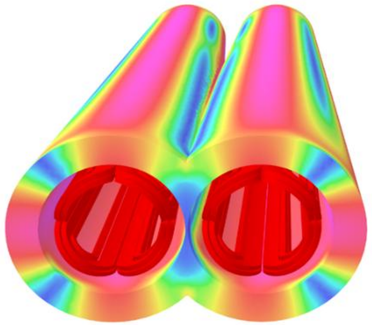
The field reproducibility of four excited cycles is better than $\pm 2.5\times10^{-4}$

Corrector

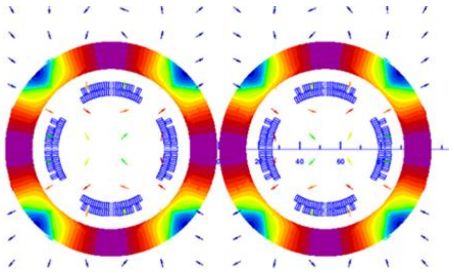
CEPC Final Focus Superconducting Quadrupoles

SCQ Specifications	Q1a	Q1b	Q2	
Field gradient	142.3	85.4	96.7	T/m
Magnetic length	1210	1210	1500	mm
Reference radius	7.46	9.085	12.24	mm
Mini. distance between aperture center	62.71	105.28	155.11	mm
High order field harmonics	$\le 5\times10^{-4}$	$\le 5\times10^{-4}$	$\le 5\times10^{-4}$	
Dipole field	≤3	≤3	≤3	mT

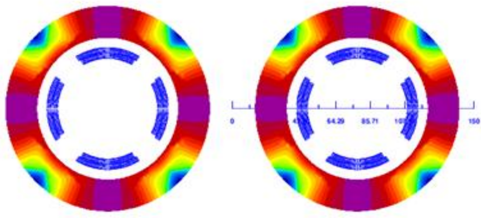
Q1a

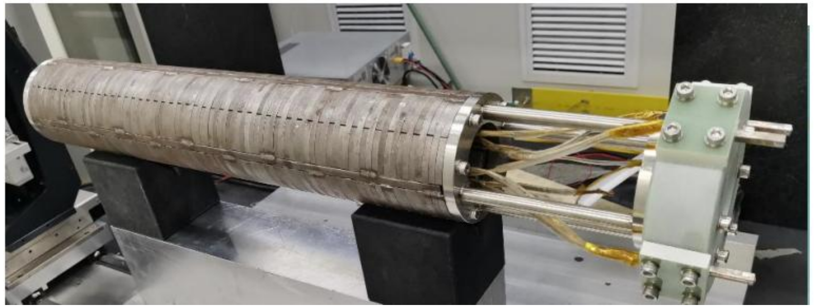


Q1b



Q2

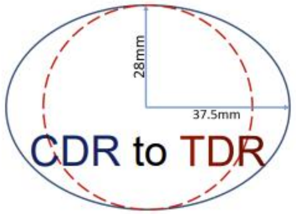


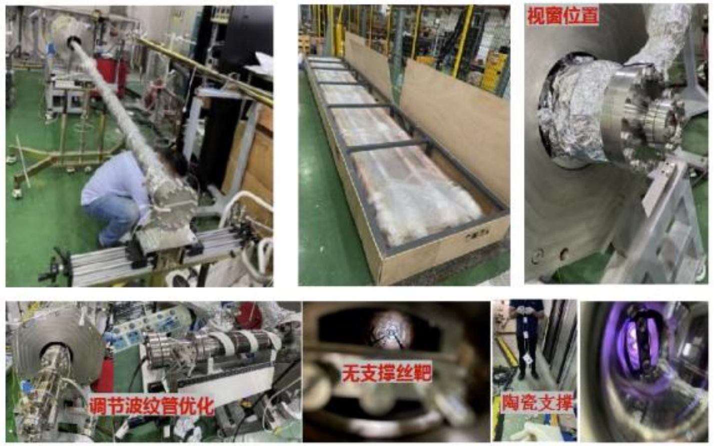


- CCT and Cos2θ type SCQs were modeled, and their fields were calculated; the CEPC specifications have been met;
- A 0.5-m single aperture SCQ using Cos2θ technology has been developed. The electro-magnet excitation test showed the highest current reached 2500A (176 T/m), which exceeds the CEPC requirement (142T/m)

CEPC Vacuum System

New round pipe of Copper (3mm) with NEG coating (200nm) for collider ring in TDR
SEY<1.2

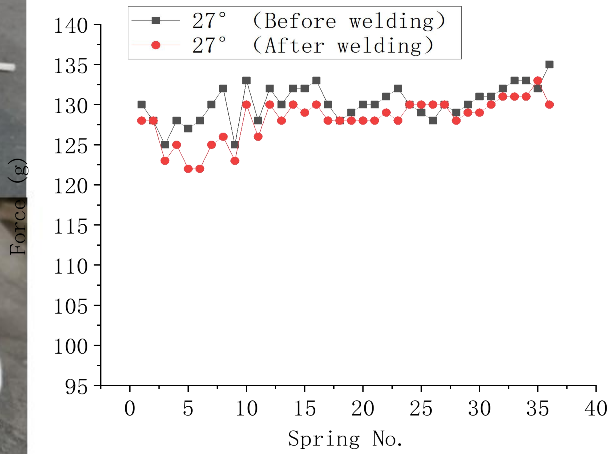




6 m vacuum pipe have been installed on the NEG coating setup

- ✓ 180℃/24h activation 4.5×10^{-10} Torr
- ✓ 200℃/24h activation 2.5×10^{-10} Torr

Vacuum pipes and RF shielding bellows



- Vacuum chamber prototypes, copper & aluminum, with different shape/length were fabricated;
- NEG coating technology were developed;
- RF shielding bellow manufactured
- Vacuum technology applied and was tested at HEPS

Facility of pumping speed test have been finished in Dongguan

CEPC Linac Injector Key Technology R&D

- Flux concentrator for positron source
- RF pulse compressor
- High perform. S/C-band Acc. Struc.

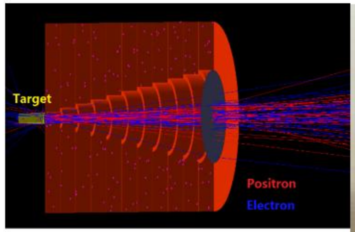

IHEP C-band SLED

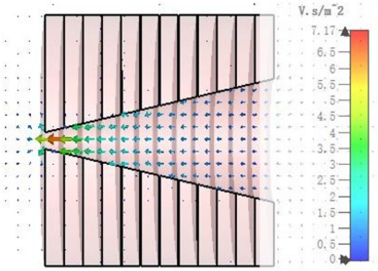
Test results of IHEP C-band SLED

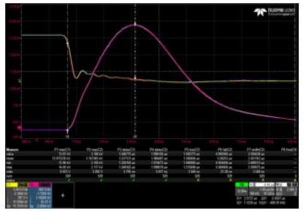

SACLA C-band SLED

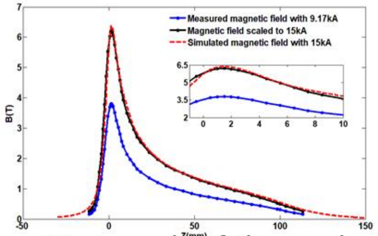

IHEP C-band BOC


PSI BOC



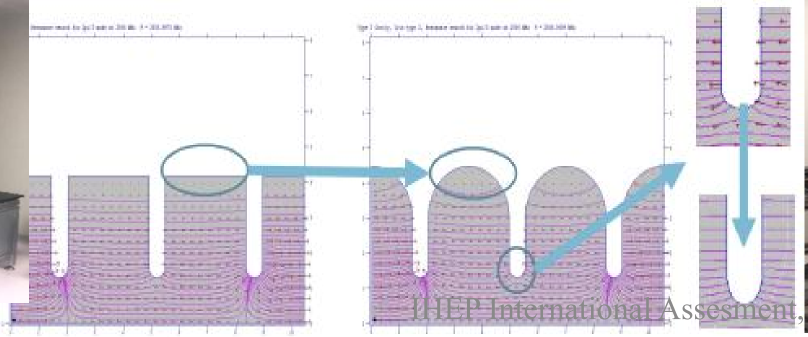


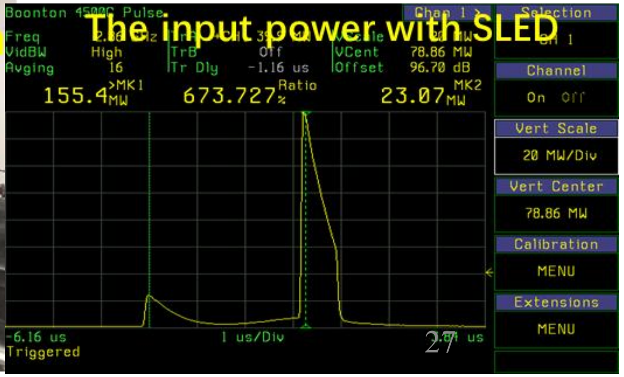

R&D of the solid state



Test result of the peak

- **Positron pulsed magnetic field of 6 T to 0.5 T**
- **15kA/15kV/50Hz solid state pulse source**





Power consumption of CEPC - Higgs

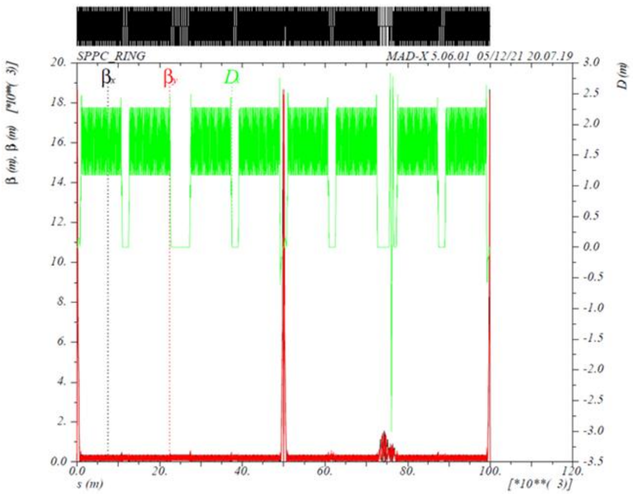
SN	System	Higgs 30MW							Higgs 50MW						
		Collider	Booster	Linac	BTL	IR	Surface building	Total	Collider	Booster	Linac	BTL	IR	Surface building	Total
1	RF Power Source	96.90	1.40	11.10				109.40	161.60	1.73	14.10				177.40
2	Crygenic system	9.72	1.71			0.14		11.57	9.17	1.77			0.14		11.08
3	Vacuum System	5.40	4.20	0.60				10.20	5.40	4.20	0.60				10.20
4	Magnet Power Supplies	44.50	9.80	2.50	1.10	0.30		58.20	44.50	9.80	2.50	1.10	0.30		58.20
5	Instrumentation	1.30	0.70	0.20				2.20	1.30	0.70	0.20				2.20
6	Radiation Protection	0.30		0.10				0.40	0.30		0.10				0.40
7	Control System	1.00	0.60	0.20				1.80	1.00	0.60	0.20				1.00
8	Experimental devices					4.00		4.00					4.00		4.00
9	Utilities	37.80	3.20	1.80	0.60	1.20		44.60	46.40	3.80	2.50	0.60	1.20		54.50
10	General services	7.20		0.30	0.20	0.20	12.00	19.90	7.20		0.30	0.20	0.20	12.00	19.90
	Total	204.12	21.61	16.80	1.90	5.84	12.00	262.27	276.87	22.60	20.50	1.90	5.84	12.00	339.71

SppC Collider Parameters in TDR

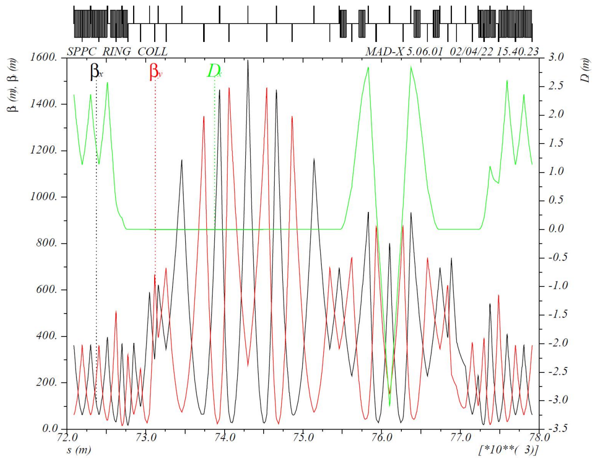
-Parameter list (updated Feb. 2022)

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

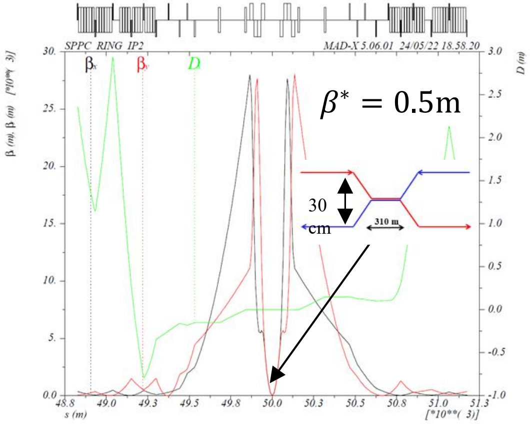
Lattice of SPPC



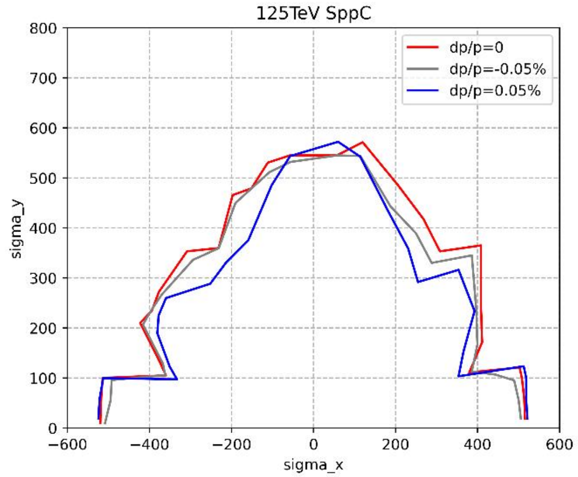
Whole ring



Collimation



IP



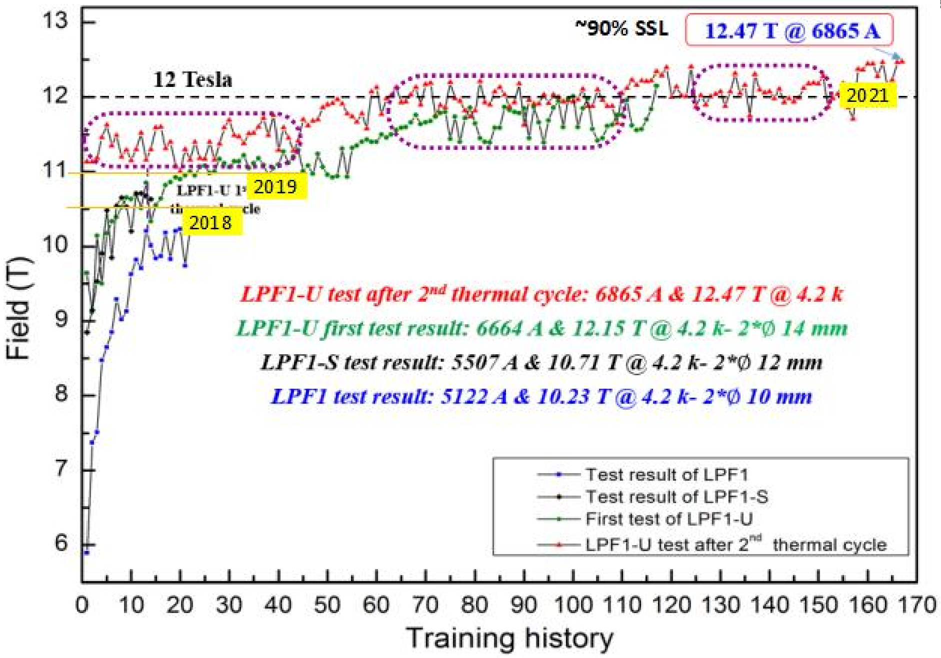
Dynamic Aperture

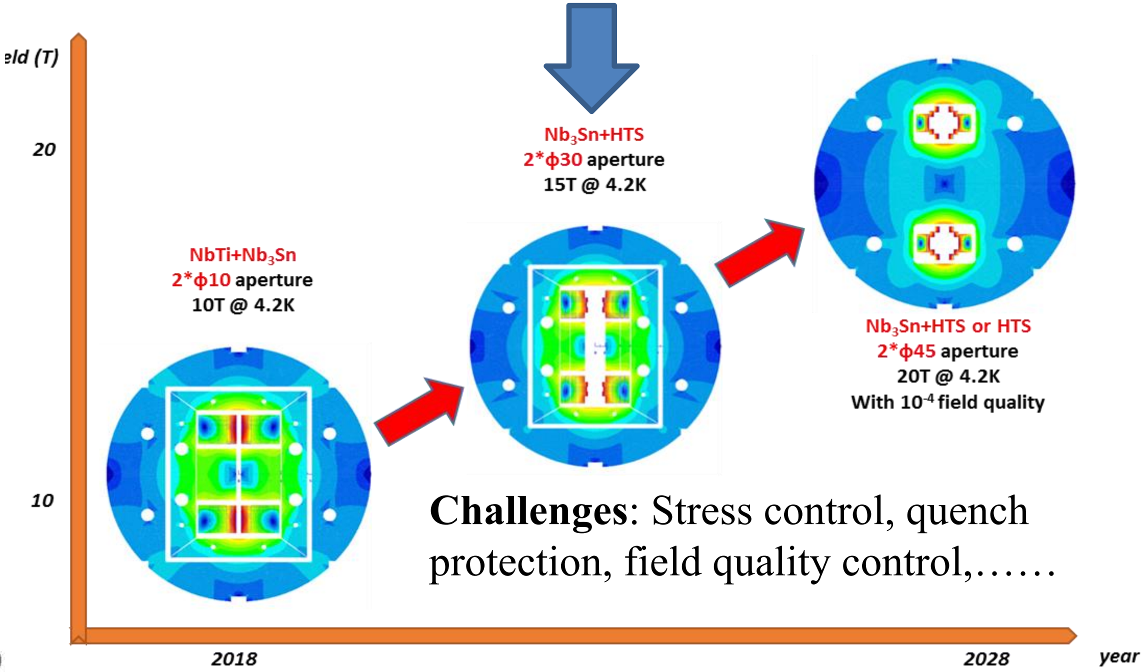
Ecm=125TeV with dipole field of 20T

Latest Performance of LPF1-U (SppC)

16 T Model Dipole: Nb_3Sn 12~13 T + HTS 3~4 T; ***To be tested in Sep-Dec 2023***

Picture of LPF1-U



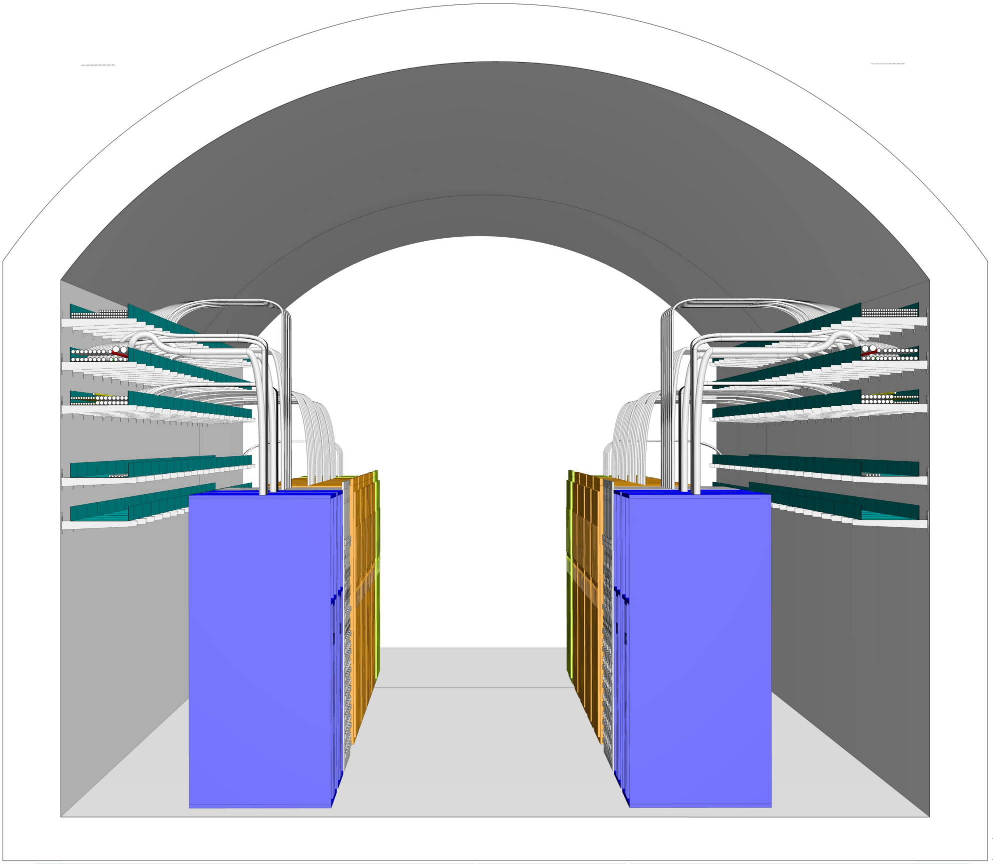


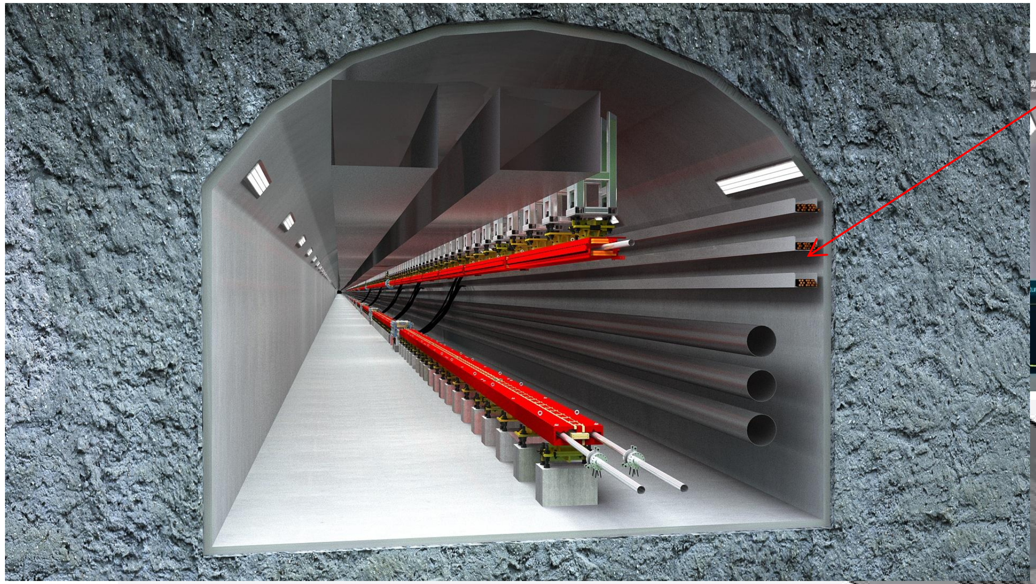
Challenges: Stress control, quench protection, field quality control,……

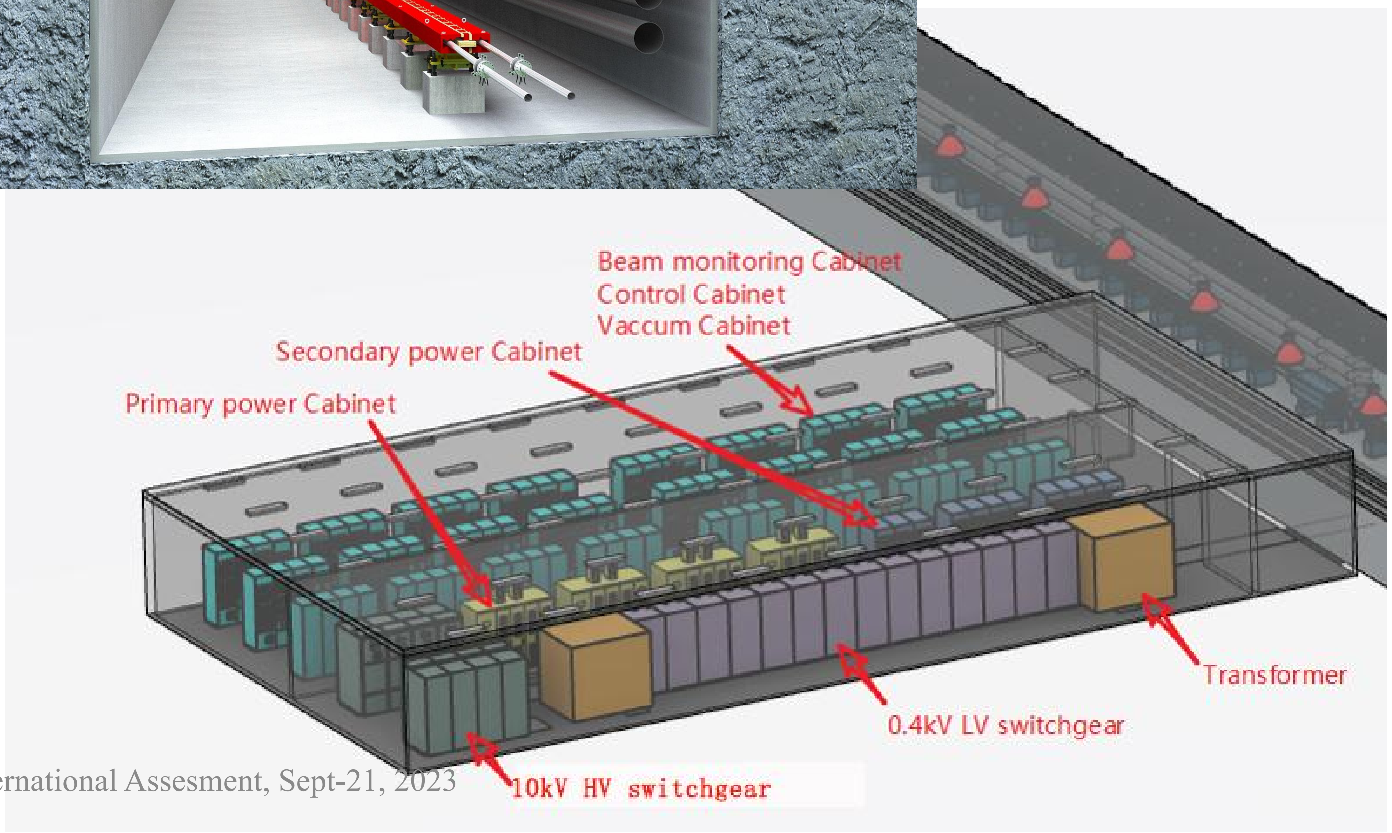
Dual aperture superconducting dipole achieves 12.47 T at 4.2 K
Entirely fabricated in China. The next step is reaching 16-20T

CEPC Conventional Facility and Civil Engineering

Electrical Equipment General Layout in Auxiliary







Participating and Potential Collaborating Companies in China (CIPC) and Worldwide

	System
1	Magnet
2	Power supplier
3	Vacuum
4	Mechanics
5	RF Power
6	SRF/ RF
7	Cryogenics
8	Instrumentation
9	Control
10	Survey and alignment
11	Radiation protection
12	e-e+Sources

CEPC Industrial Promototion Consortium (CIPC, established in Nov. 2017)

Potential international collaborating suppliers worldwide

CEPC Accelerator IARC Meeting 2019-2022

International Accelerator Review Committee (IARC) under IAC

The 2019 CEPC International Accelerator Review Committee

Review Report

December 6, 2019

The review meeti
Circular Electron
Committee (IARC
(MDI) sessions of

The IARC was pl
TDR. The quality
even if not alreac
luminosity perforr
improving the forr

The IARC is plea
would like to thai
help and hospitali

The 2021 CEPC International Accelerator Review Committee

Review Report

May 19, 2021

The CEPC Inter
due to the Covid
IARC meeting.

The Circular
currently hosted
Academy of Sc
accelerator in 2
Committee (IAC
CEPC accelerat
an International
to advise on all n
the study of the

2021 Second CEPC IARC Meeting

IARC Committee

October 20th, 2021

The Circular Electron Positron Cc
Collider (SppC) Study Group, currer
ergy Physics of the Chinese Academ
design of the CEPC accelerator in 2(
ternational Advisory Committee (IAC
Report (TDR) phase for the CEPC ac
get year of 2022. Meanwhile an Inter
(IARC) has been established to advis
erator design, the R&D program, the
region, and the compatibility with an
well as with a future SppC.

The Committee congratulates the CE
last months and presented at this me
R&D of the hardware components lool
the table of parameters for the high-l
and components for all accelerator sy
lider.

2022 First CEPC IARC Meeting

IARC Committee

June 17th, 2022

The Circular Electron Positron Collider (CEPC) and Super Proton-Proton Collider (SppC) Study Group, currently hosted by the Institute of High Energy Physics of the Chinese Academy of Sciences, completed the conceptual design of the CEPC accelerator in 2018. As recommended by the CEPC International Advisory Committee (IAC), the group began the Technical Design Report (TDR) phase for the CEPC accelerator in 2019, with a completion tar-

A total of 24 talks were presented on a variety of topics.
The charges to CEPC IARC for this meeting are:

1. For the TDR, how are the accelerator design and the technology R&D progress towards the TDR completion at the end of 2022. Are there any important missing points in the accelerator design and optimization?
2. based on CEPC TDR design, the CEPC dedicated key technology R&D status and the technologies accumulated from the other IHEP responsible large-scale accelerator facilities, such as HEPS, could the CEPC accelerator group start the TDR editorial process and EDR preparation?
3. with the new progresses between CEPC and FCCee possible synergy and the continuing collaboration with SuperKEKB, are there more suggestions on the next steps of international collaborations?

Nov. 2019: https://indico.ihep.ac.cn/event/9960/

May, 2021: https://indico.ihep.ac.cn/event/14295

October, 2021: https://indico.ihep.ac.cn/event/15177

June, 2022: https://indico.ihep.ac.cn/event/16801/

All IARC reports (**2019-2022**) on IAC2022 Meeting Indico: https://indico.ihep.ac.cn/event/17996/page/1415-materials

After the completeion of CEPC CDR in Nov. 2018, since the first CEPC IARC meeting in **2019**, there has been **toally 4 IARC meetings till 2022**, with each meeting a carefully written IARC report, which are very helpful for CEPC accelerator in TDR phase and beyond.

CEPC Accelerator TDR International Review Report

Phase 1 CEPC TDR Review Report

CEPC TDR Technical Review Committee

15 July 2023

1 Executive Summary

Five years after the completion of the CDR, the draft TDR for the CEPC accelerator has been prepared. The TDR will be completed taking into account the feedback from this Committee. The key technologies for CEPC have been developed. Prototypes meeting or exceeding the specifications are available. The CEPC team is on track to launch an engineering-design effort. After a site has been selected, the construction of the CEPC could start in 2027 or 2028. The Committee endorses this plan.

The Committee wishes to congratulate the CEPC team on the excellent progress. The Committee is impressed by the amount and quality of the work performed and presented.

The next section provides answers to the different charge questions, the following sections contain comments and recommendations related to the individual presentations.

CEPC Accelerator International TDR Review and Cost Review were held June 12-16, and Sept. 11-15, 2023, repectively, in HKUST-IAS, Hong Kong, China

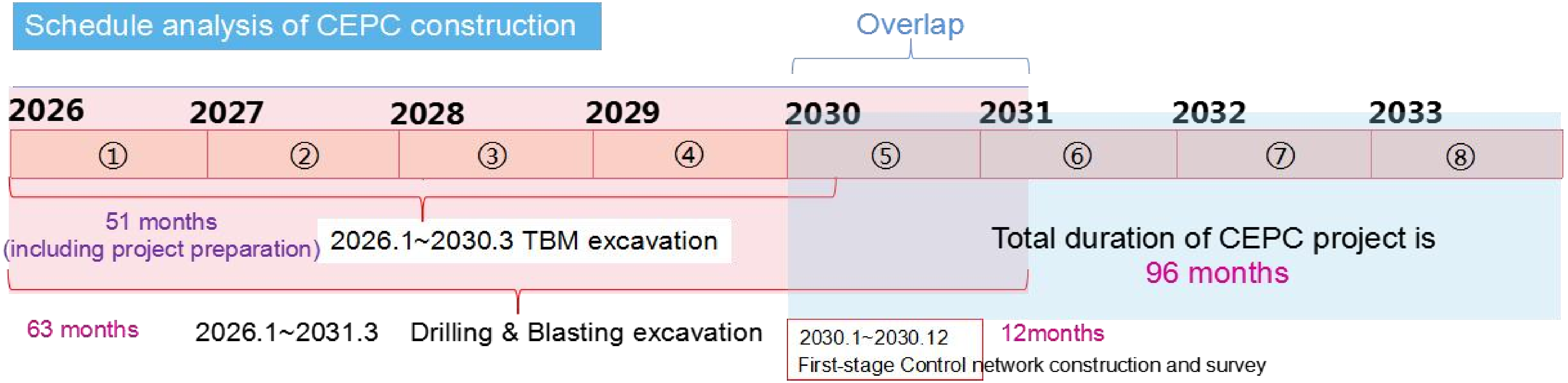
Summary

- The CEPC TDR parameter and design optimizations with high luminosity (30MW and 50MW) operations, for all four energies are studied. The results demonstrate that the physics design satisfies the scientific goals.
- A comprehensive key technology R&D program has been carried out in TDR with CEPC key technplogies in hands ready for industrialization preparation.
- The TDR design of the CEPC is compatible with future SppC.
- CEPC accelerator TDR international review and cost review were held from June 12-16, 2023 and Sept. 11-15, 2023, repectively.
- Detailed preparation of CEPC accelerator EDR phase before construction working plan and beyond are underway, with the aim of starting the construction in "15th five-year-plan" (2026-2030) .
- International collaboration and participation are warmly welcome.

Thanks

CEPC Accelerator Construction Timeline

2023: Accelerator TDR; 2026: EDR; Start construction upon approval



1.CEPC production Including civil works and installation of physical equipment. It will begin in 2026 and end in 2033, The total duration of CEPC project is 96 months.

2.The total civil works period is 63 months.

3.The total installation period of physical equipment is 48 months

4. The Overlapping period of civil works and equipment installation is 15 months

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

2031.1~2032.6 Support installation and alignment — 18 months

2031.3~2032.8 Dipole magnets installation — 18 months

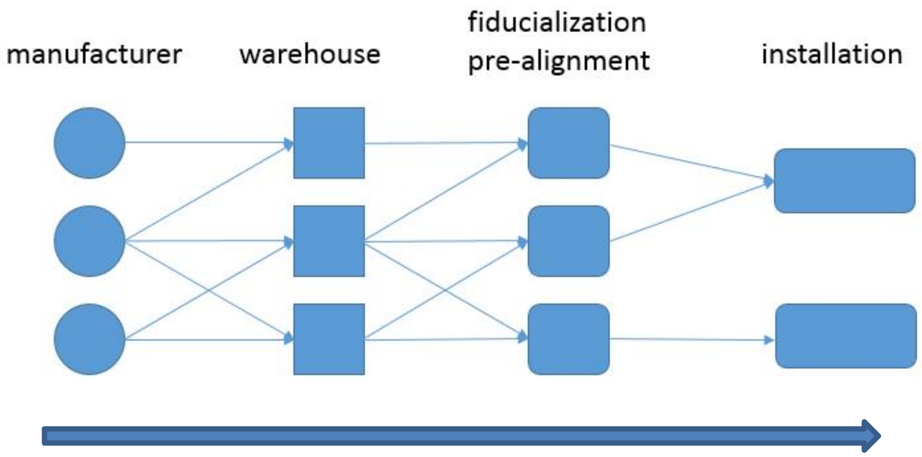
26032.9~2033. Installation of other equipment — 10 months

2033.7~ 2033.12 Overall alignment and commissioning — 6 months

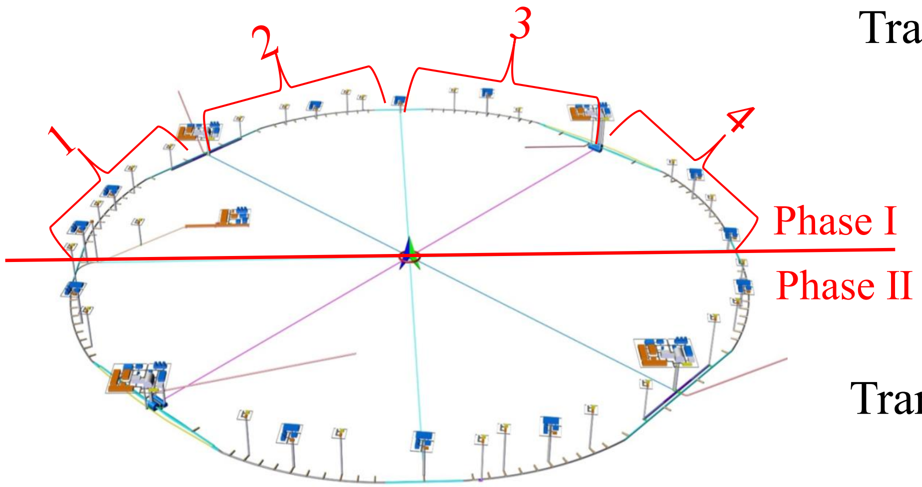
CEPC Installation Strategy

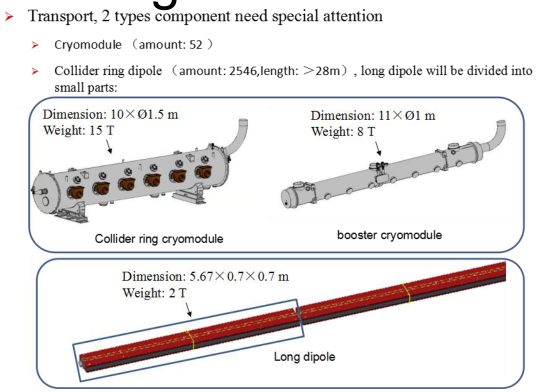
Installation and alignment scheme

-Ring installation: phase Ⅰ, phase Ⅱ, each phase： half a ring



Transportation





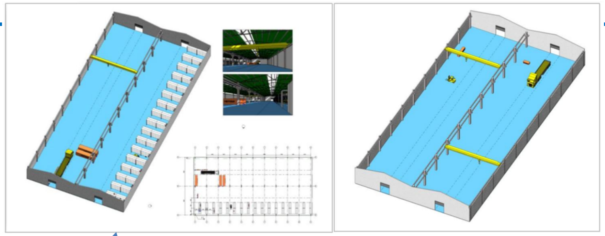
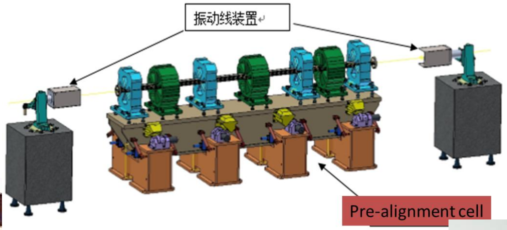
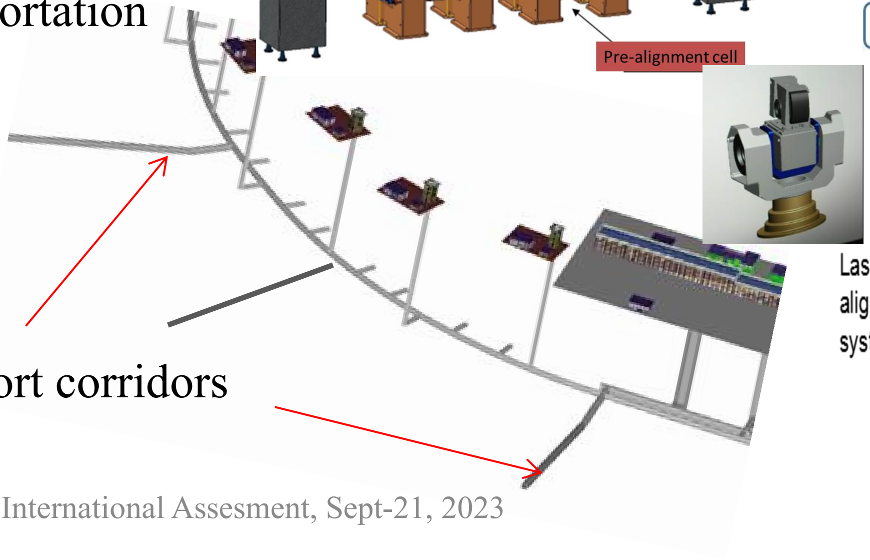


Figure 4 warehouse layout (1)

Figure 5 warehouse layout (2)





Transport corridors

Warehouses