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

CEPC Accelerator General Status:
-from TRD to EDR

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IHEP

On behalf of the CEPC accelerator group

11th IHEP-KEK SCRF Collaboration Meeting
Nov. 20-21, 2023, IHEP, Beijing

Contents

A Brief Historical Review

IHEP-KEK ILC 1.3GHz SC Technology related Collaboration started in 2005

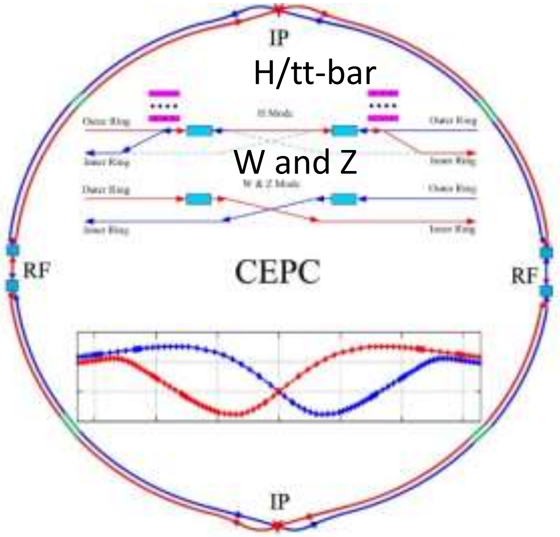
1) 1th IHEP-KEK SCRF Collaboration Meeting, June 2009, IHEP
2) 2th IHEP-KEK SCRF Collaboration Meeting, December 2009, IHEP
3) 3th IHEP-KEK SCRF Collaboration Meeting, December 2010, IHEP
4) 4th IHEP-KEK SCRF Collaboration Meeting, December 2011, IHEP
5) 5th IHEP-KEK SCRF Collaboration Meeting, January 2013, IHEP
6) 6th IHEP-KEK SCRF Collaboration Meeting, July 15, 2017, IHEP
7) 7th IHEP-KEK SCRF Collaboration Meeting, September 22, 2018, IHEP
8) 8th IHEP-KEK SCRF Collaboration Meeting, Dec. 2-3, 2019, KEK
9) 9th IHEP-KEK SCRF Collaboration Meeting, Dec. 9, 2020, (Online)
10) 10th IHEP-KEK SCRF Collaboration Meeting, Feb. 16, 2022, (Online)
11) 11th IHEP-KEK SCRF Collaboration Meeting, Nov. 20-21, 2023, IHEP

9th and 10th IHEP-KEK SCRF Collaboration Meetings were held online in 2022 and 2022, and finally, 11th IHEP-KEK SCRF Collaboration Meeting is held in person at IHEP successfully. You are welcome to come to IHEP again in person after CoVid19.

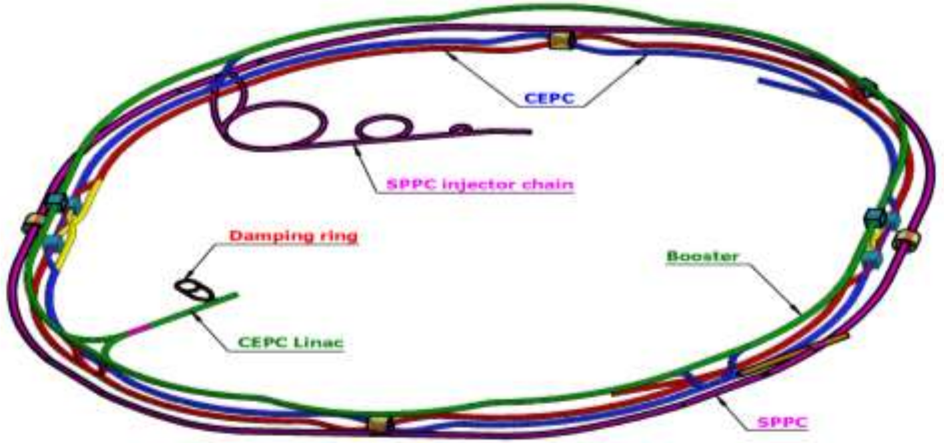
Our collaborations on SCRF is very fruitful in last ~20 years, and wish a good and successful continuation!

CEPC Higgs Factory and SppC in TDR (EDR)

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) , high energy gamma ray 100Kev~100MeV

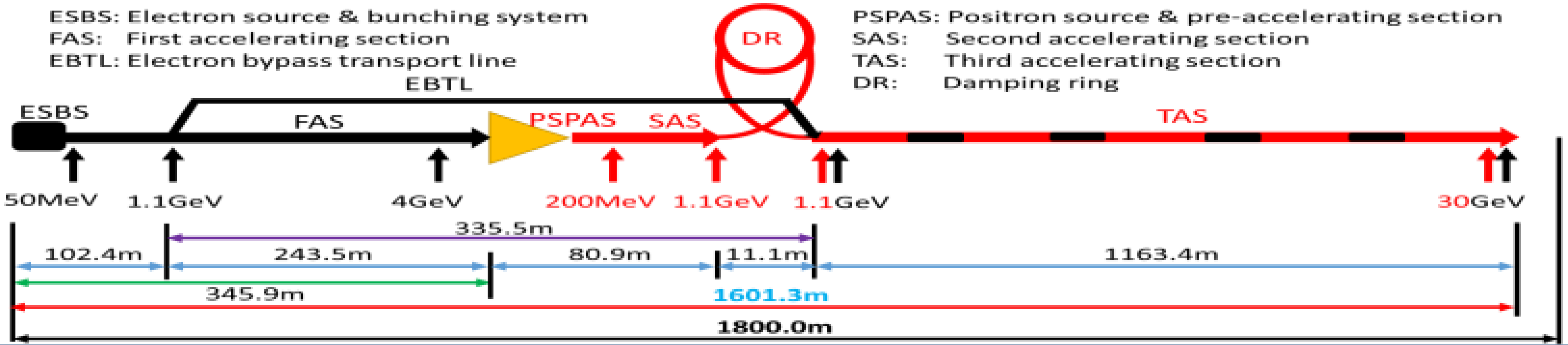


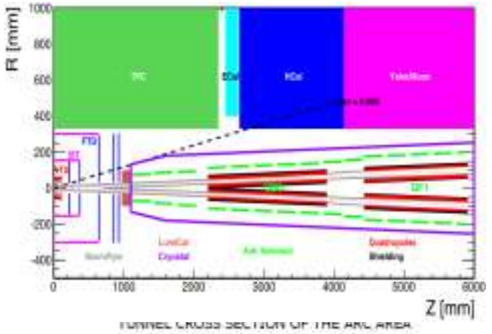
CEPC collider ring (100km)

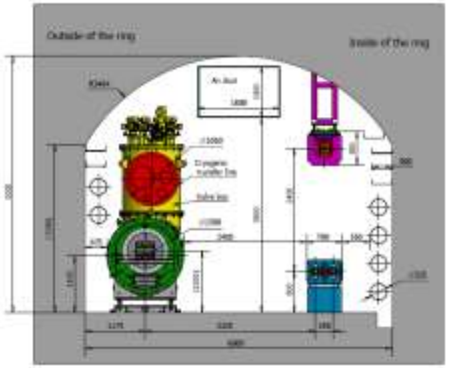


CEPC booster ring (100km)

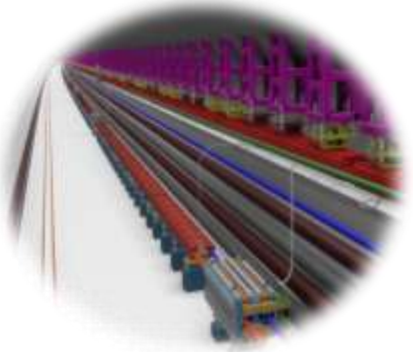
CEPC TDR S+C-band 30GeV linac injector







CEPC Civil Engineering



CEPC TDR Accelerator System Parameters

Linac

Parameter	Symbol	Unit	Baseline
Energy	E_{e-}/E_{e+}	GeV	30
Repetition rate	f_{rep}	Hz	100
Bunch number per pulse			1 or 2
Bunch charge		nC	1.5 (3)
Energy spread	σ_E		1.5×10^{-3}
Emittance	ε_r	nm	6.5

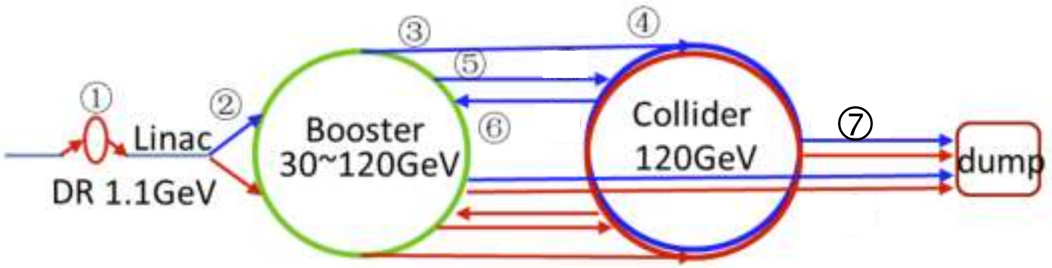
Booster

		tt	*H*		*W*	*Z*	
		Off axis injection	Off axis injection	On axis injection	Off axis injection	Off axis injection	
Circumfer.	km	100					
Injection energy	GeV	30					
Extraction 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
Beam current	mA	0.11	0.94	0.98	2.85	9.5	14.4
SR power	MW	0.93	0.94	1.66	0.94	0.323	0.49
Emittance	nm	2.83	1.26		0.56	0.19	
RF frequency	GHz	1.3					
RF voltage	GV	9.7	2.17		0.87	0.46	
Full injection from empty	h	0.1	0.14	0.16	0.27	1.8	0.8

Collider

	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	**100.0**			
SR power per beam (MW)	**30**			
Energy (GeV)	**120**	**45.5**	**80**	**180**
Bunch number	268	11934	1297	35
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
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	2.5/8.7	2.5/4.9	2.2/2.9
Beam-beam parameters ξ_x/ξ_y	0.015/0.11	0.004/0.127	0.012/0.113	0.071/0.1
RF frequency (MHz)	650			
Luminosity per IP (10^{34} cm^{-2} s^{-1})	**5.0**	**115**	**16**	**0.5**

Transport line

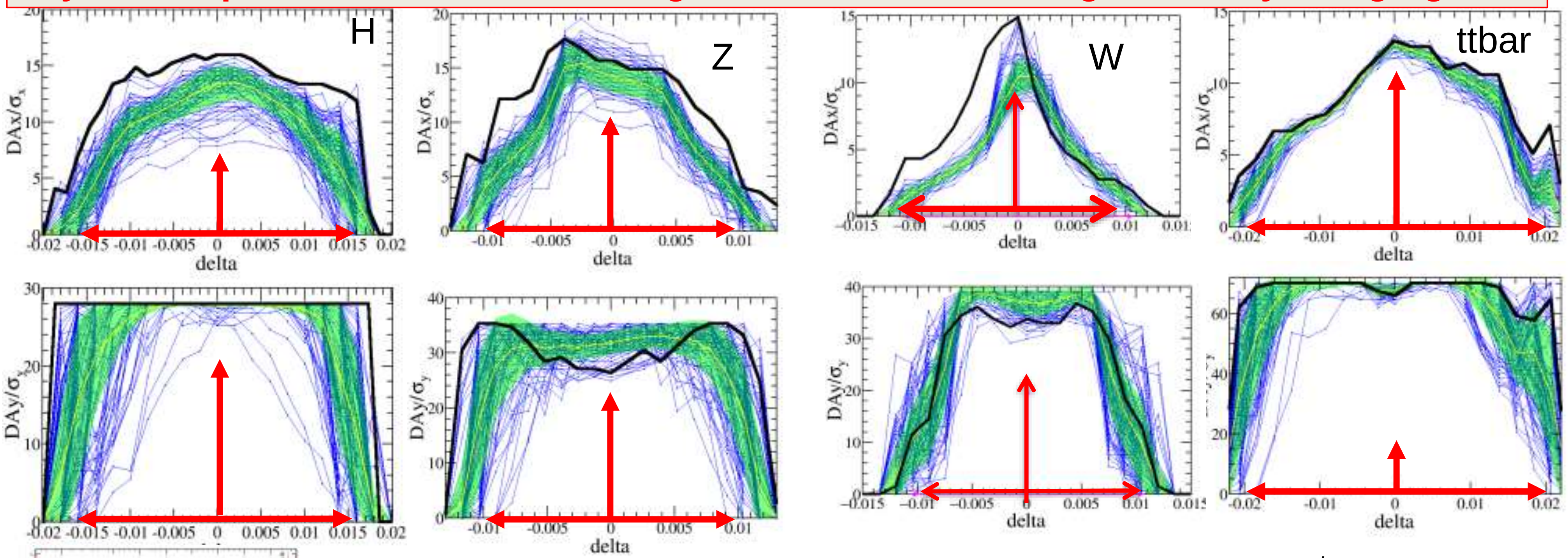


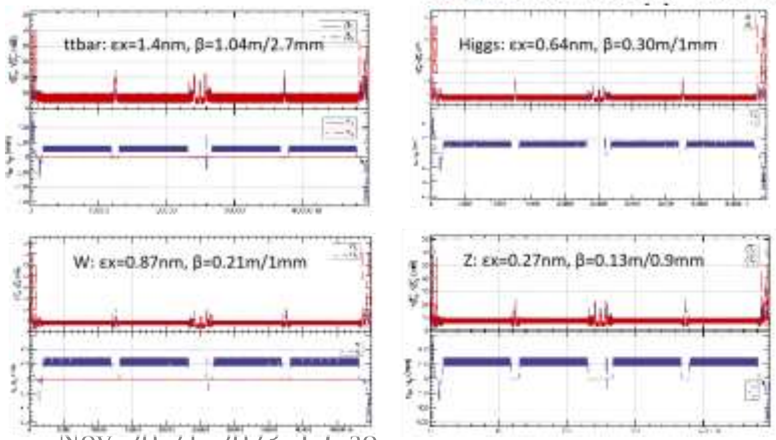
1. Injection/Extraction to the Damping ring (e^+)
2. Injection to the Booster ring from Linac (e^+/e^-)
3. Booster ring extraction system (e+/e-)
4. Collider off-axis injection system (e+/e-)
5. collider on-axis swap-out injection (e+/e-)
6. Collider swap-out extraction (e+/e-)
7. beam dump system (e+/e-)

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



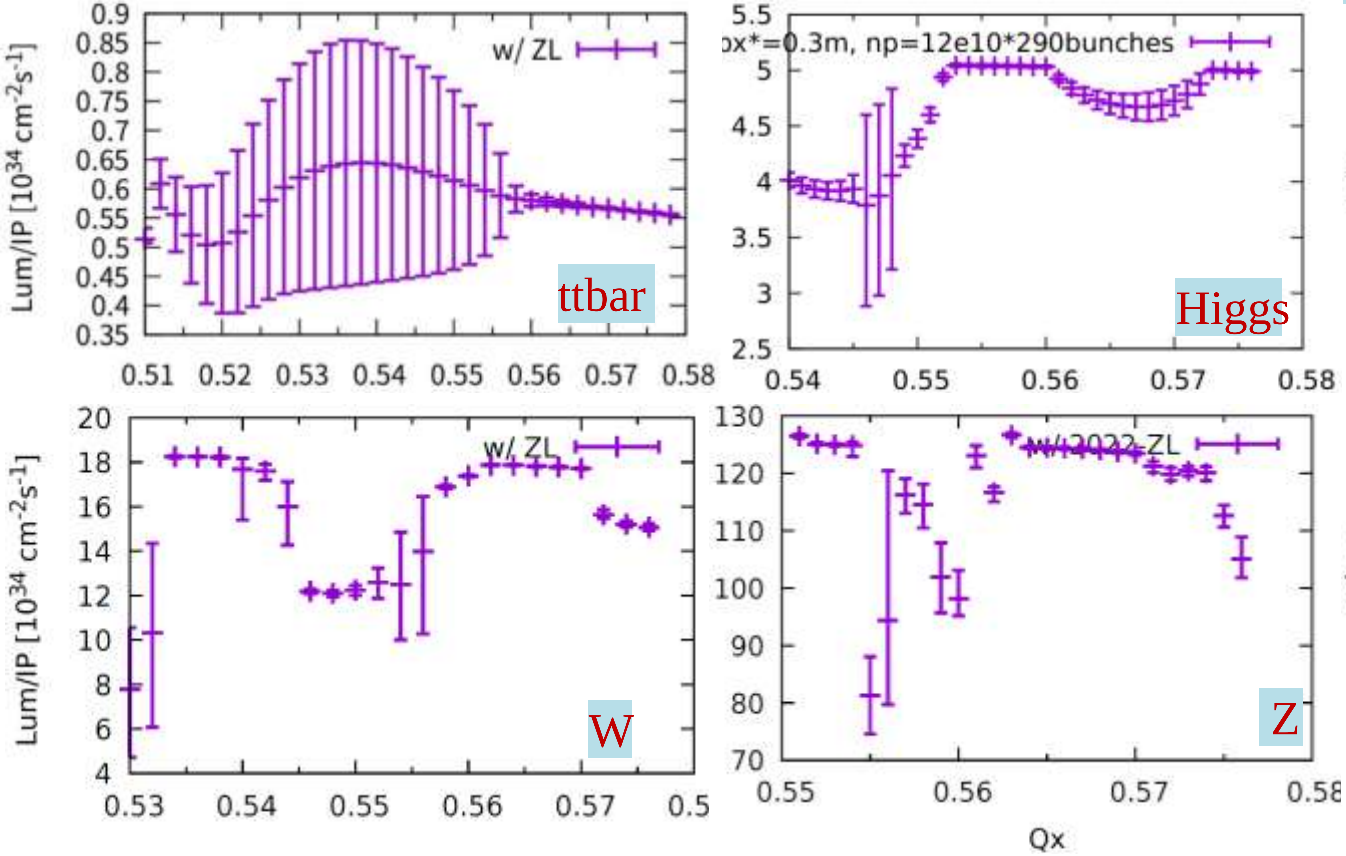


Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
Dipole	0.10	0.10	0.10	0.01%
Arc Quadrupole	0.10	0.10	0.10	0.02%
IR Quadrupole	0.10	0.10	0.10	0.02%
Sextupole	0.10*	0.10*	0.10	0.02%

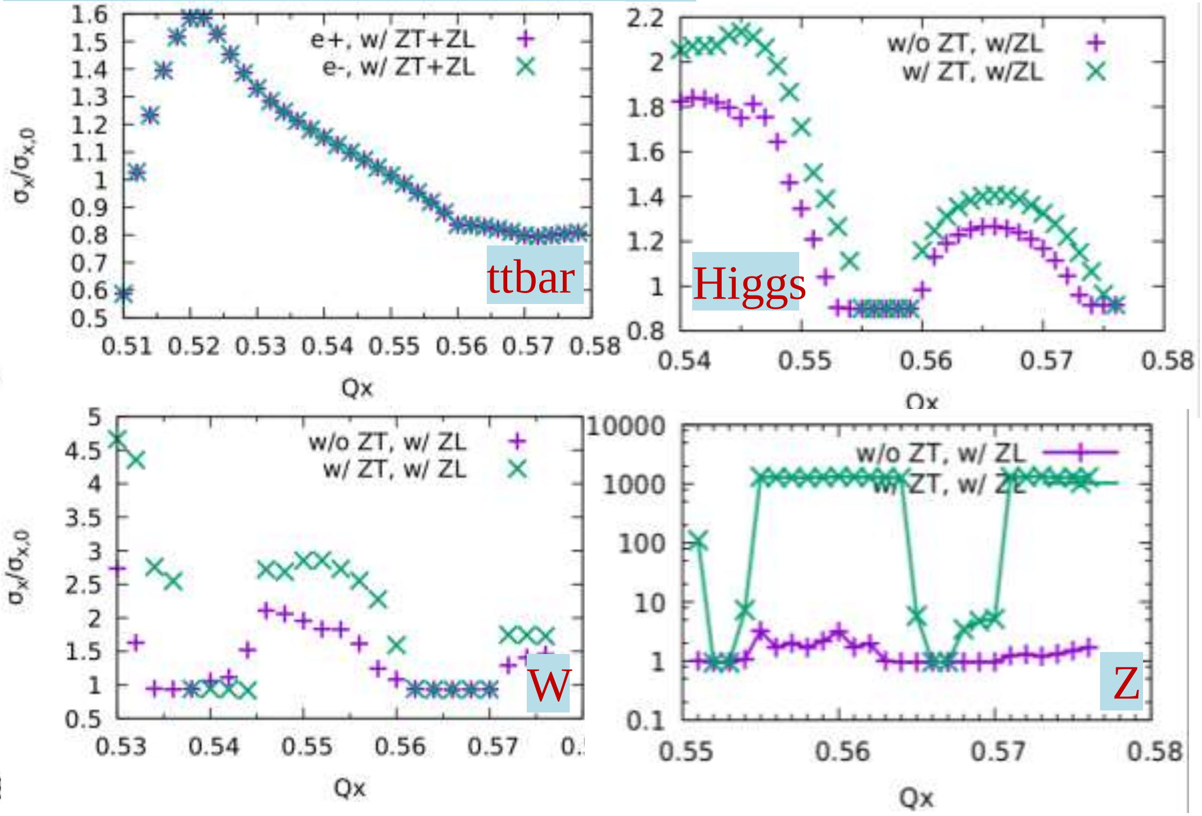
—w/o error
—mean value
—statistic errors
—seeds
—requirement

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.

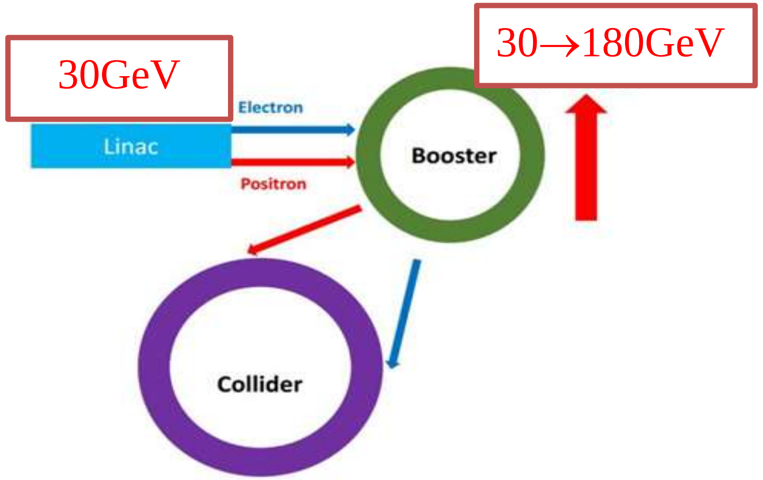
- **Luminosity & Lifetime is evaluated by strong-strong simulation**
- **X-Z instability is well suppressed even considering Potential Well Distortion**
- **Lifetime optimization with both beam-beam\lattice nonlinearity is done**

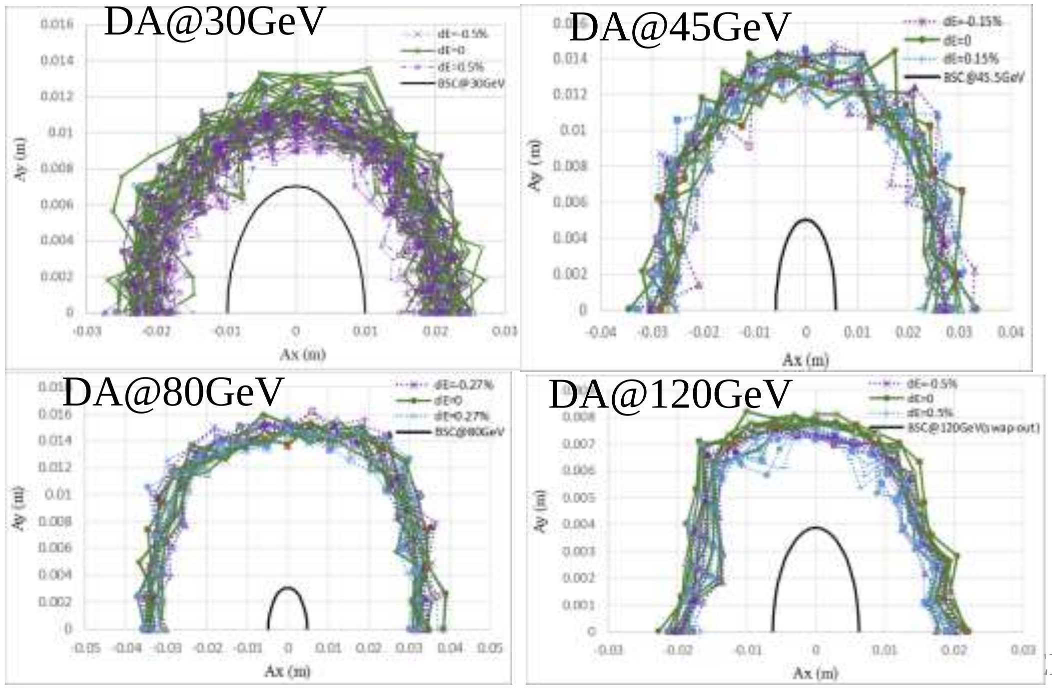
Parameters of CEPC Booster

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				

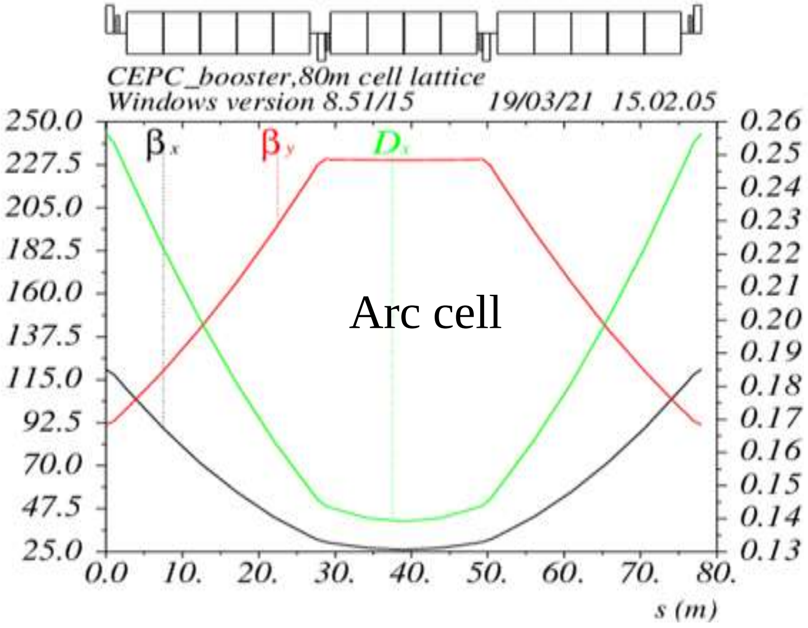
Extraction		*tt*	*H*		*W*	*Z*	
		Off axis injection	Off axis injection	On axis injection	Off axis injection	Off axis injection	
Beam energy	GeV	180	120		80	45.5	
Bunch number		35	268	261+7	1297	3978	5967
Maximum bunch charge	nC	0.99	0.7	20.3	0.73	0.8	0.81
Maximum single bunch current	μA	3.0	2.1	61.2	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

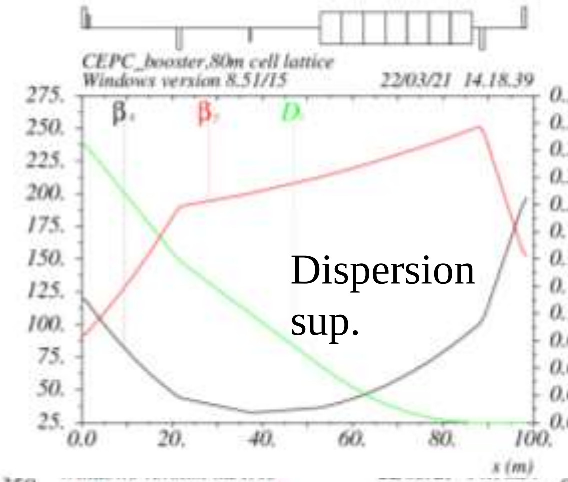
CEPC Booster Design

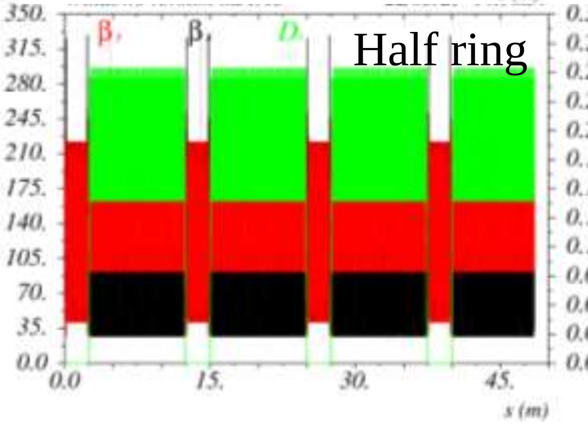




- TME like structure (cell length=78m)
- Interleave sextupole scheme
- Emittance@120GeV=1.26nm







- **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 SRF System Design and Upgrade Plan

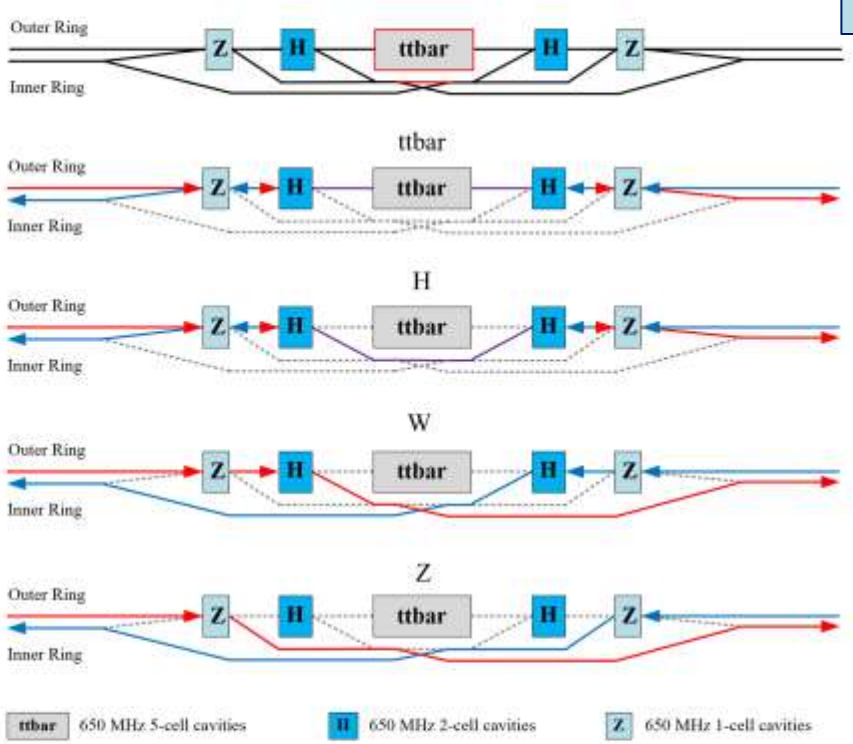
Collider 650MHz Parameters

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

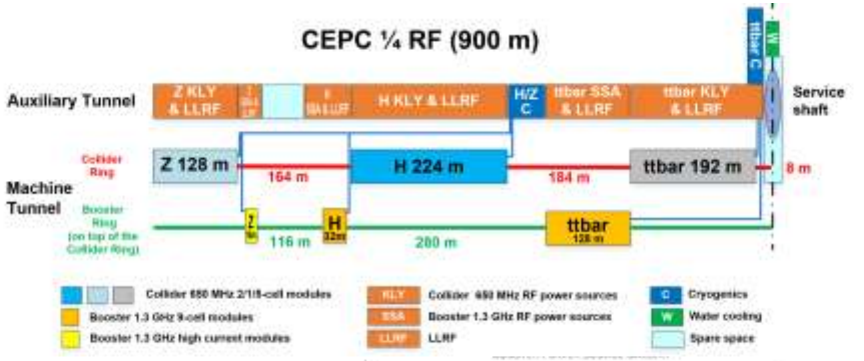
Booster 1.3GHz Parameters

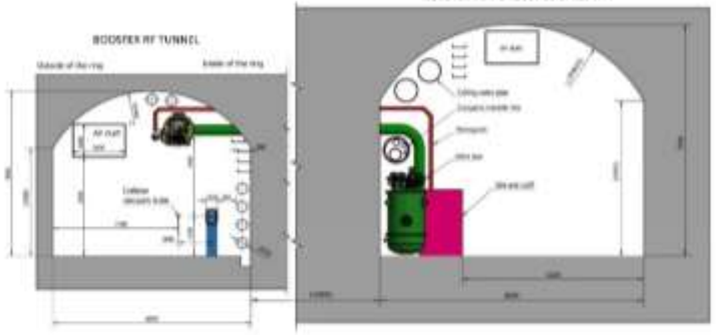
30/50 MW Collider SR power per beam. 30 GeV injection. Higgs & ttbar half filled. Higgs on-axis injection with bunch swapping. Z injection from empty ring.	ttbar 30/50 MW		Higgs 30/50 MW	W 30/50 MW	Z 30/50 MW
	New cavities	Higgs cavities			
Extraction beam energy [GeV]	180		120	80	45.5
Extraction average 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.

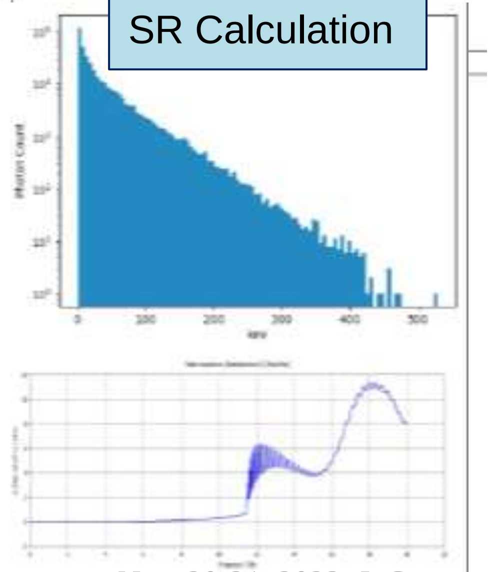
CEPC MDI Design

MDI Layout

General Parameters

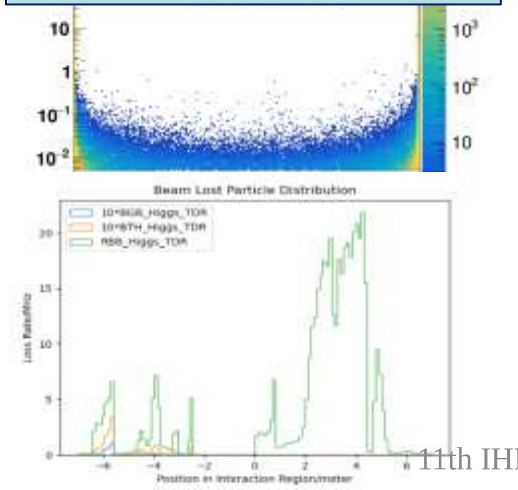
				bend angle	length	Beam stay clear region	Mini. distance between apertures	Beam pipe inner diameter	Beam pipe outer diameter	Critical energy (Hor.)	Critical energy (Vert.)	SR power (Hor.)	SR power (Vert.)
L*	0~1.9m				1.9m								
Crossing angle	33mrad												
MDI length	±7m												
Acc. components 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]								

SR Calculation

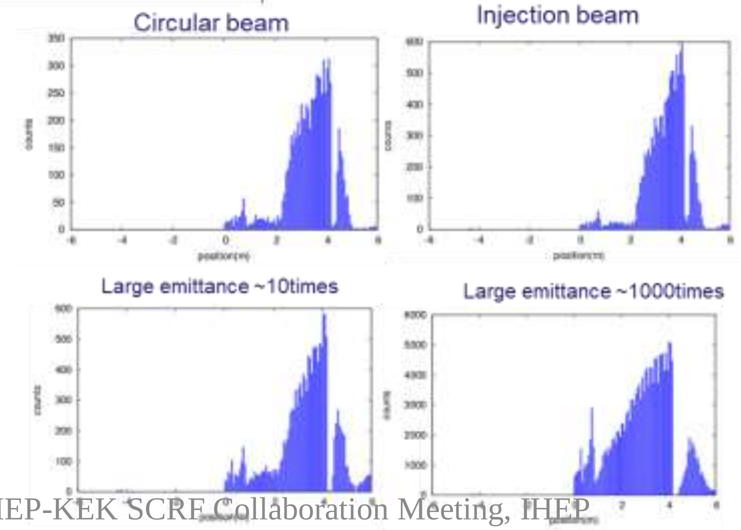


Radiation background

Radiative barbar, Beam-Gas, beam thermal photon scattering

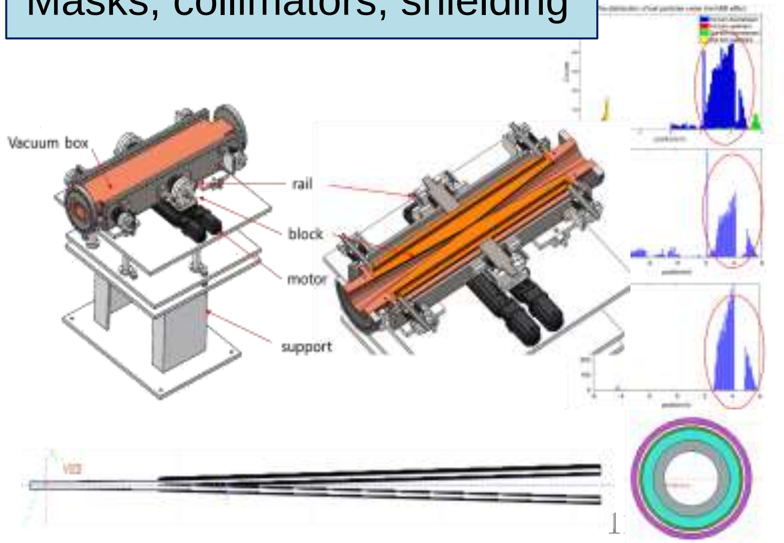


Injection background

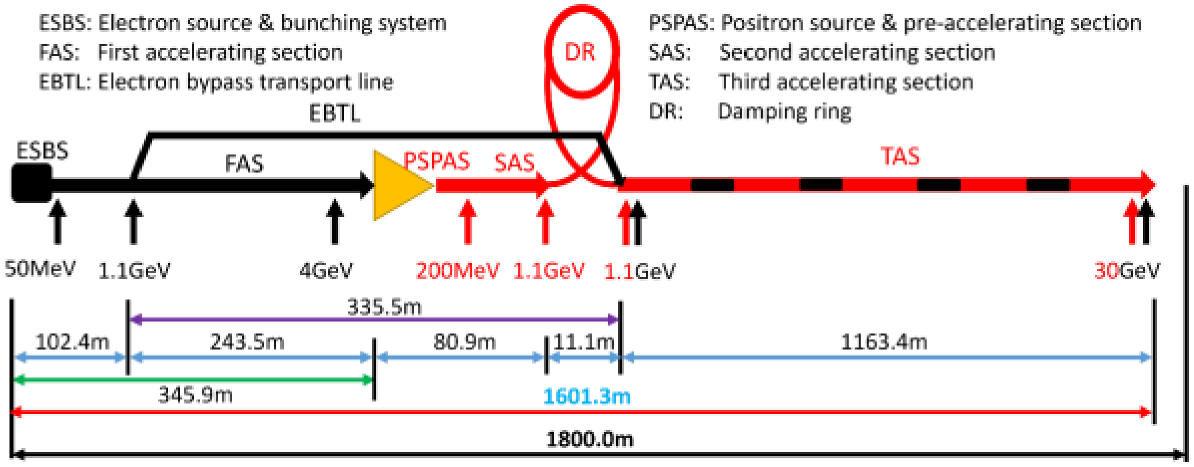


Radiation Mitigation

Masks, collimators, shielding

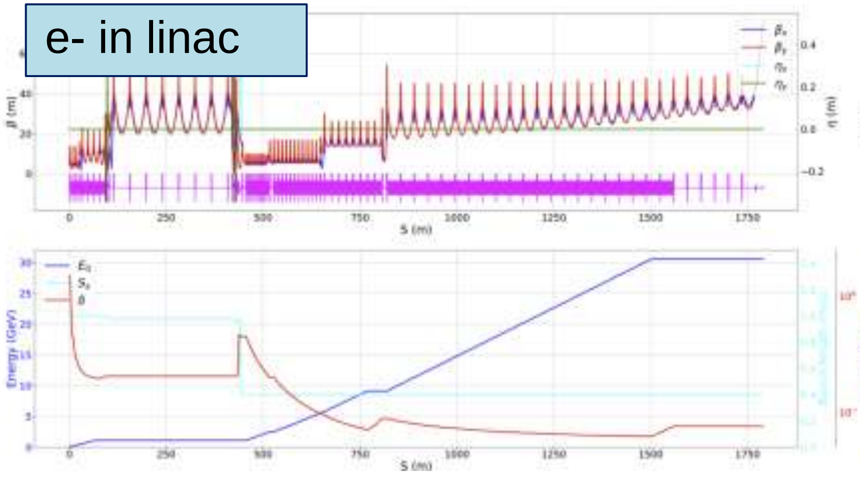


CEPC Electron and Positron Injection Linac Designs

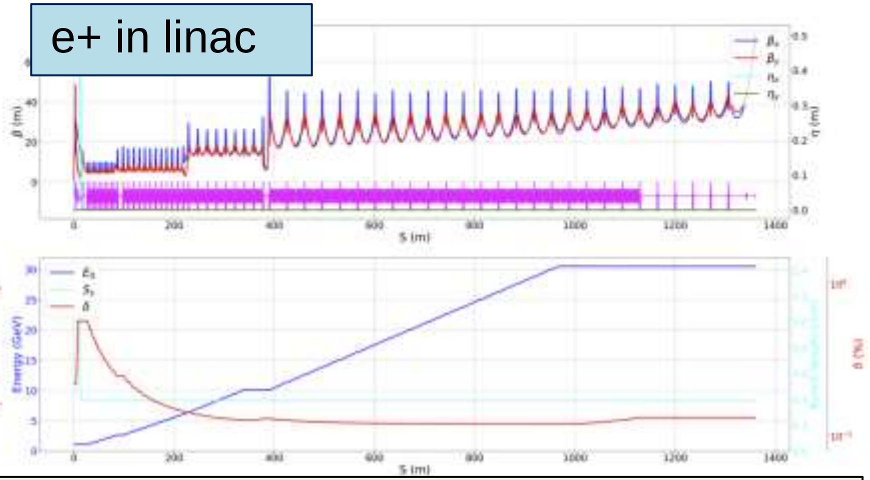


Parameter	Symbol	Unit	Design value
Energy	E	GeV	30
Repetition rate	f_{rep}	Hz	100
Number of bunches per pulse			1 or 2
Bunch charge		nC	1.5
Energy spread	σ_E		1.5×10^{-3}
Emittance	ε_r	nm	6.5
Electron energy at target		GeV	4
Electron bunch charge at target		nC	10
Tunnel length	L	m	1800

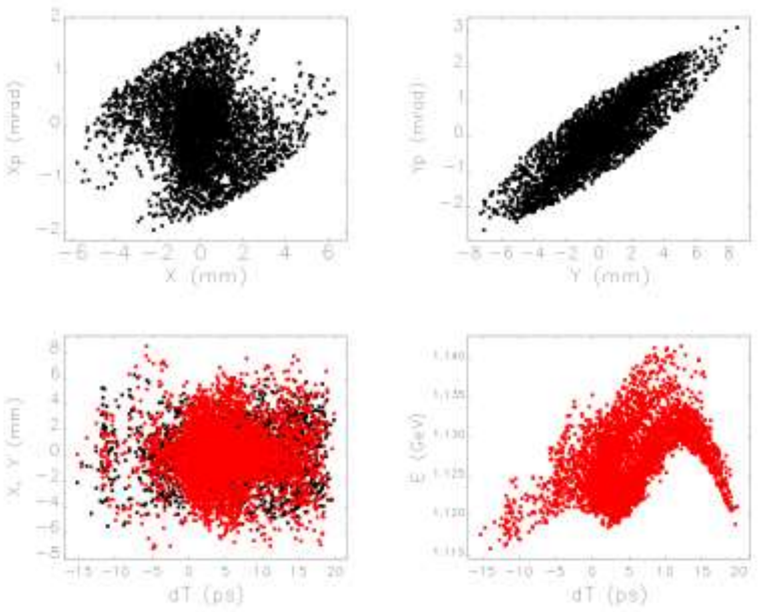
e- in linac



e+ in linac



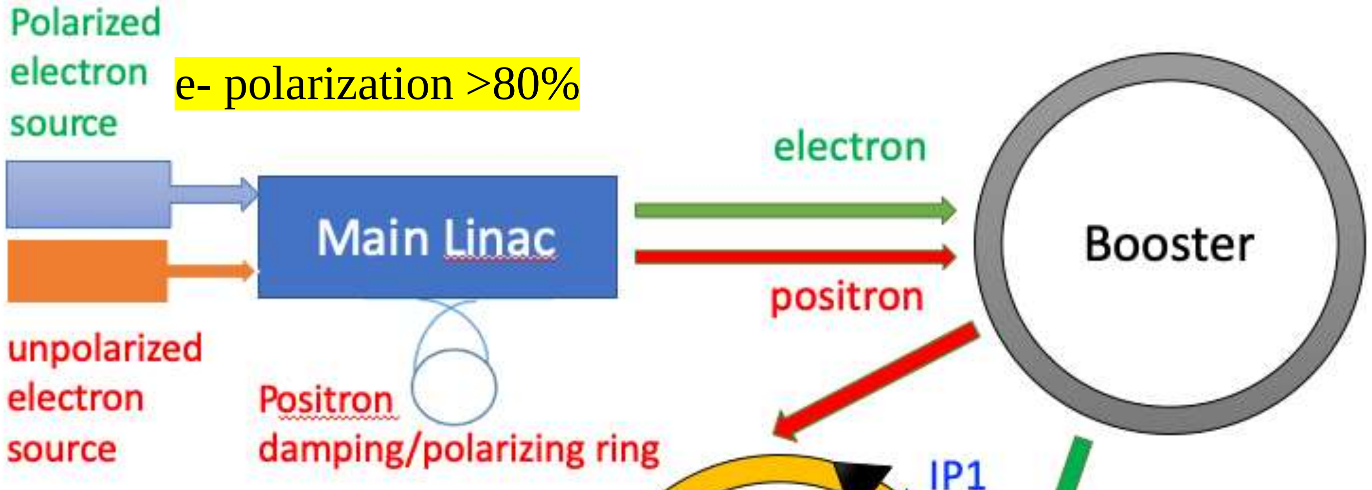
Phase space @ SAS exit

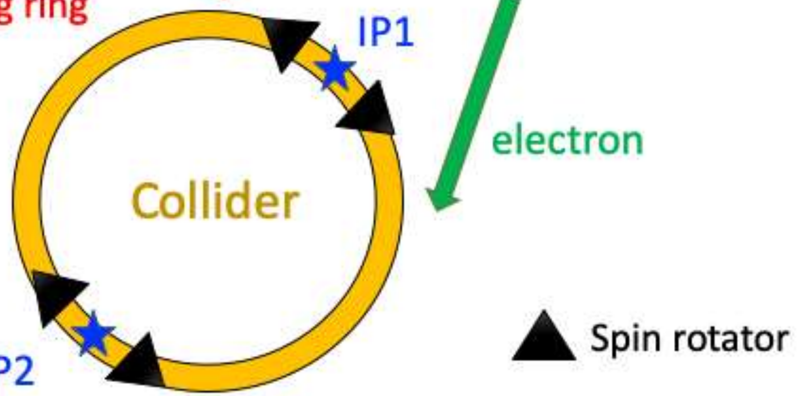


- **Linac energy increases to 30 GeV, with S+C band Accelerator;**
- **Start-to-end simulations were conducted for both electron/positron beams, with quality satisfying requirements.**

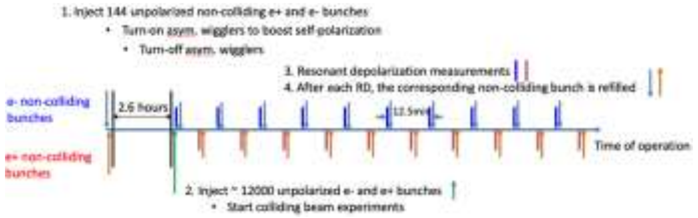
CEPC Polarized Beam Studies(alternative option)

e- polarization >80%



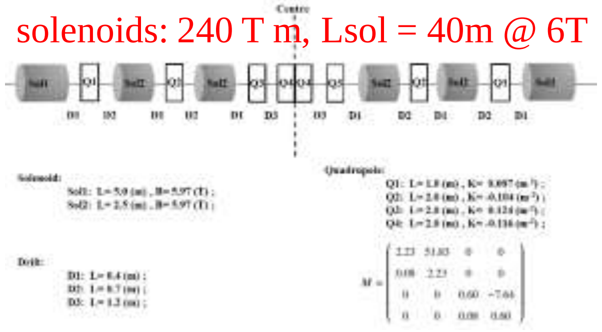


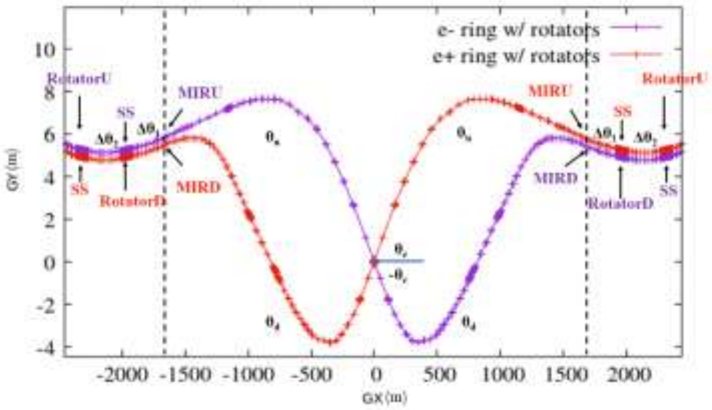
Self polarization (energy calibration)



Spin rotator design

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





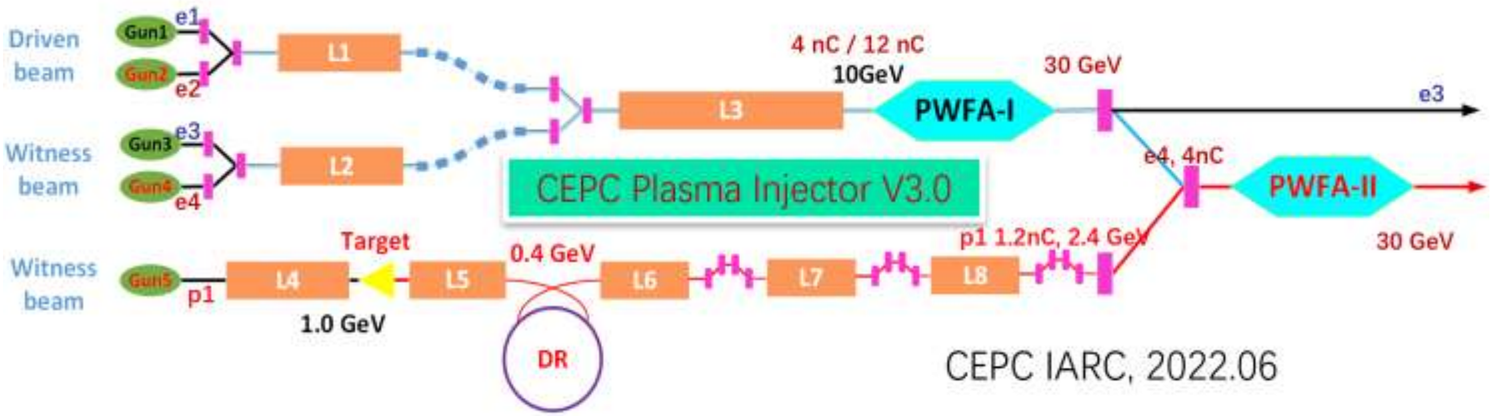
Key issues of study:

- 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

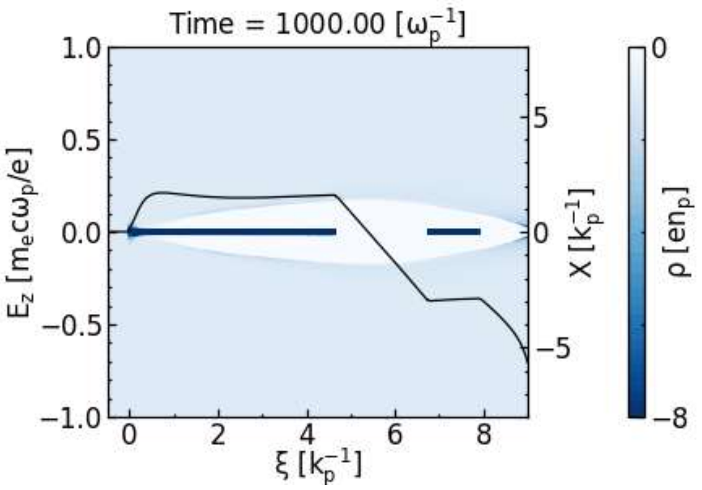
CEPC injector's baseline was changed:

10 GeV → 30 GeV → **TR ≥ 2**

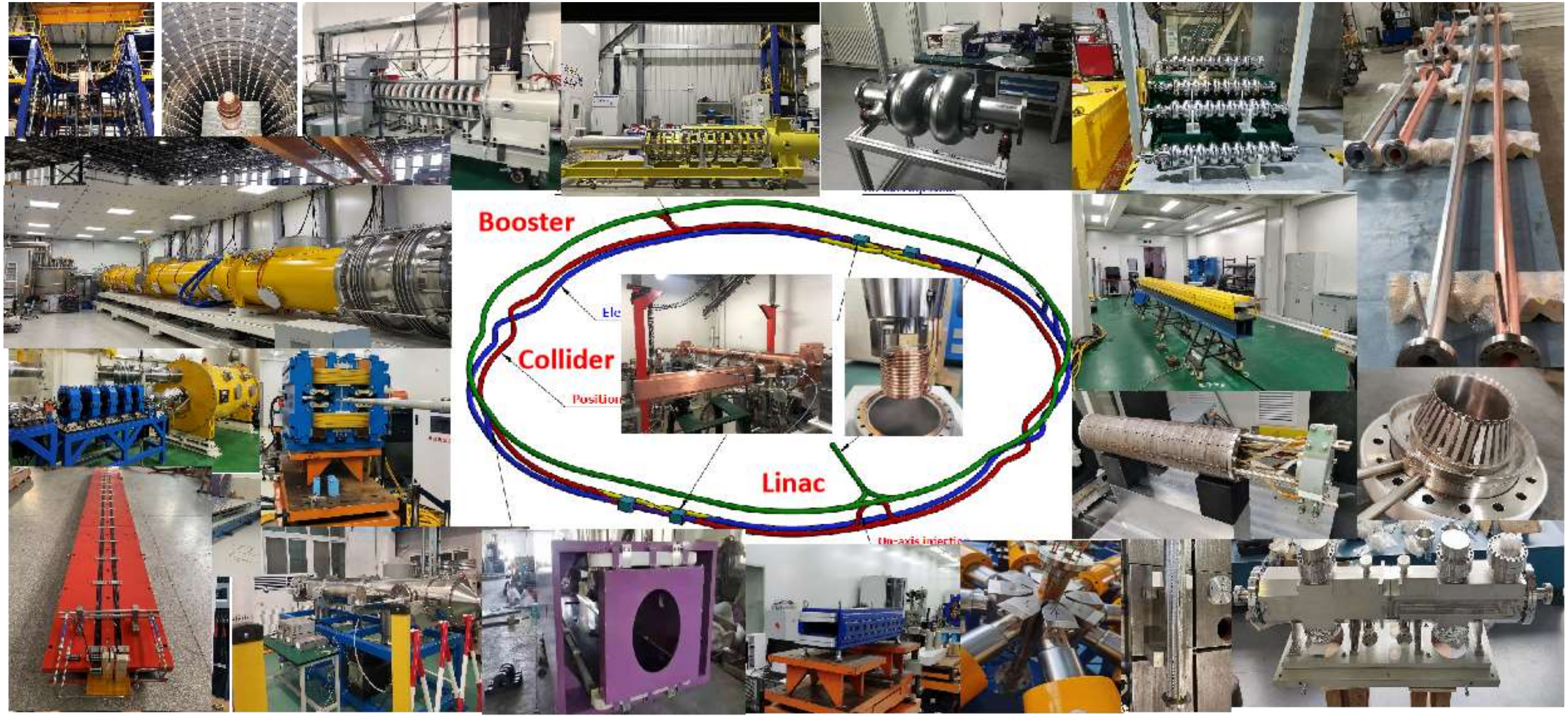


Parameters	Driver	Trailer
plasma density $n_p(\times 10^{16} cm^{-3})$	0.50334	
Driver energy E(GeV)	12	12
Normalized emittance ϵ_N $(\mu m\ rad)$	20	10
Length L (μm)	350	90
(matched) Spot size σ_r (μm)	3.72	2.63
Charge Q (nC)	4.0	1.2
Beam distance d (μm)	155	

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 Key Technology R&D



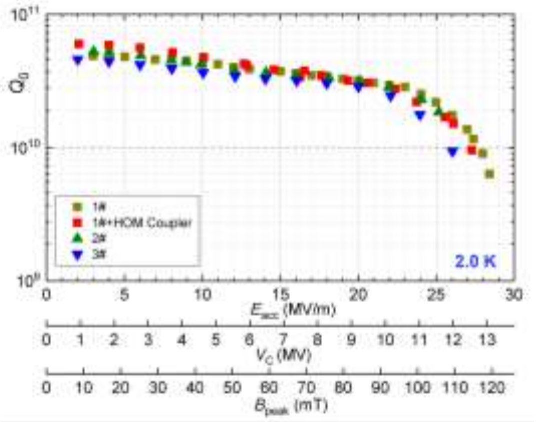
Key technology R&D spans all component lists in CEPC TDR

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)**

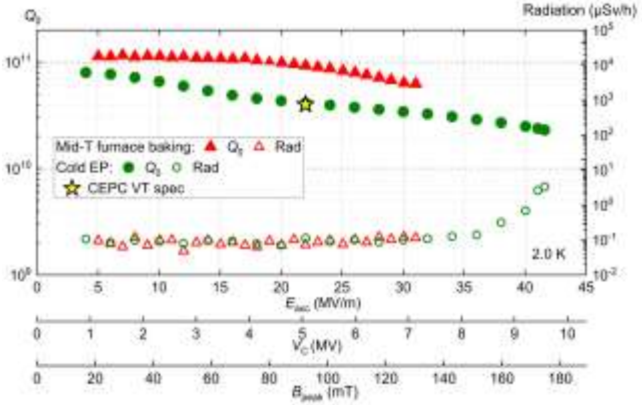
IHEP PAPS is in full operation since 2021

CEPC 650 MHz 2-cell Cavity



3E10@20MV/m.

CEPC 650 MHz 1-cell Cavity

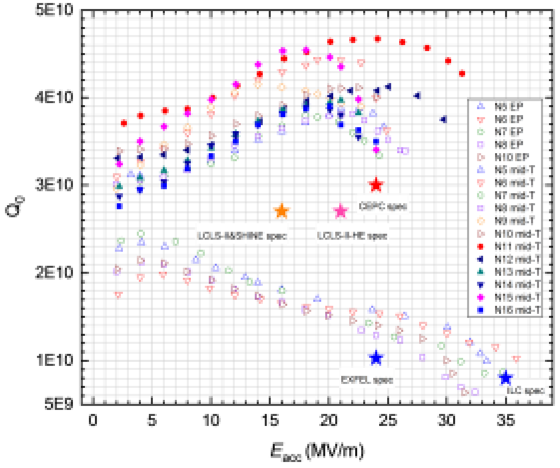


High G High Q 650 MHz 1-cell Cavity

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

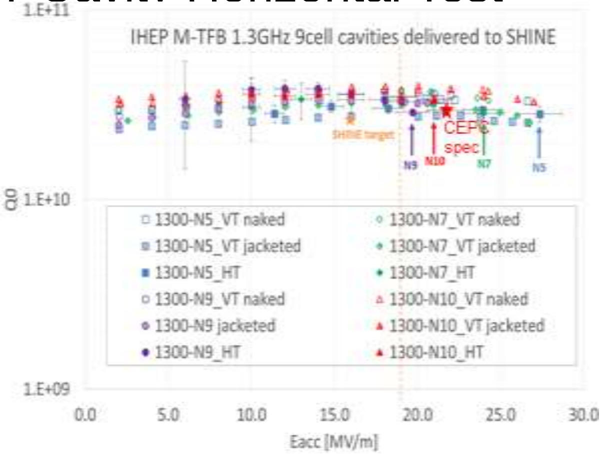
Mid-T treated: 6.3E10@31 MV/m@2 K

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

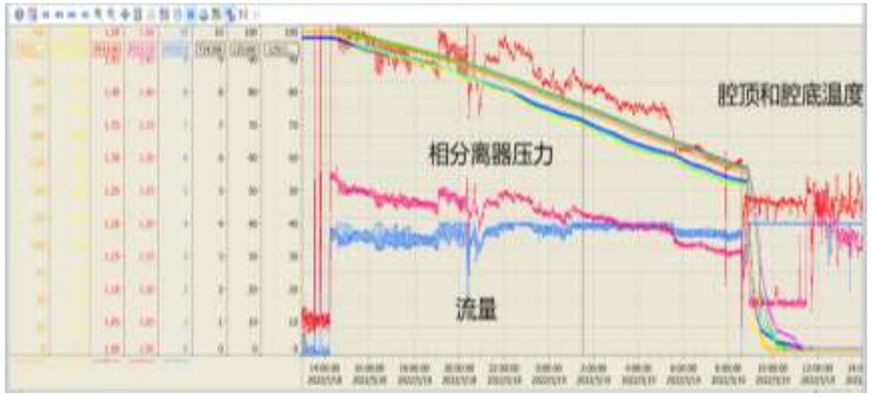


Mid-T 1.3 GHz 9-cell horizontal test (SEL)

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

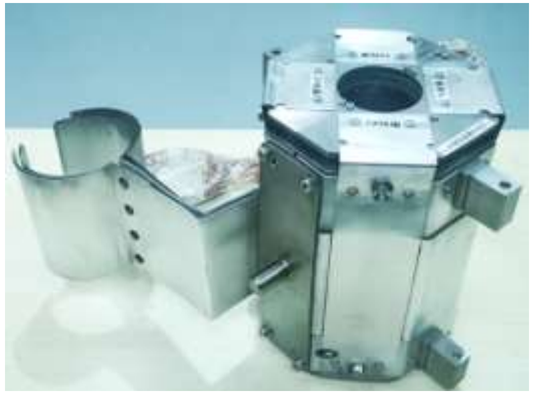
1. 300 to 150 K: < 10 K/hr. Cavity top and bottom ΔT < 20 K
2. 150 to 4.5 K: Cavity surface > 1 K/min
3. 4.5 to 2 K

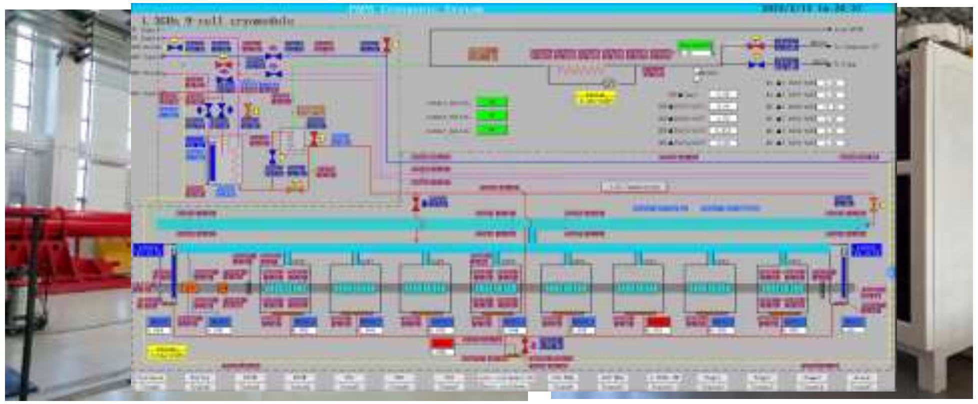
CEPC Booster 1.3 GHz 8 x 9-cell High Q Cryomodule

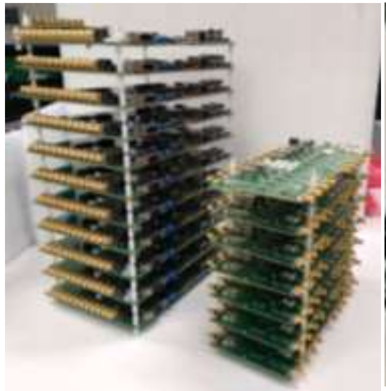
CEPC booster 1.3 GHz SRF R&D and industrialization in synergy with CW FEL projects.

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}			



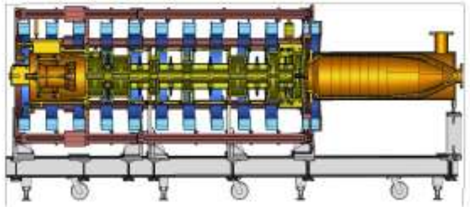





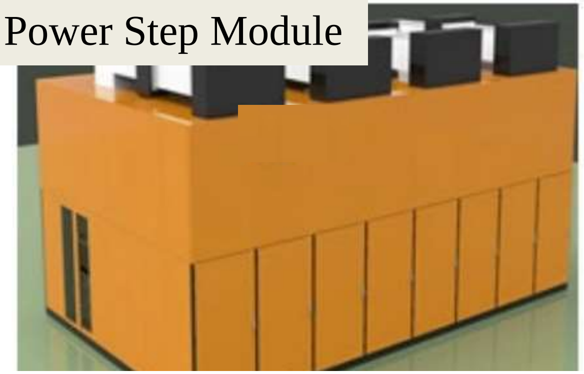

CEPC High Efficiency High Power Klystron Development and RF Power Distribution

Klystron R&D

Klystron No. 2
Efficiency 77%
(2021)



Power Step Module



Klystron No. 1
Efficiency 65%
(2020)

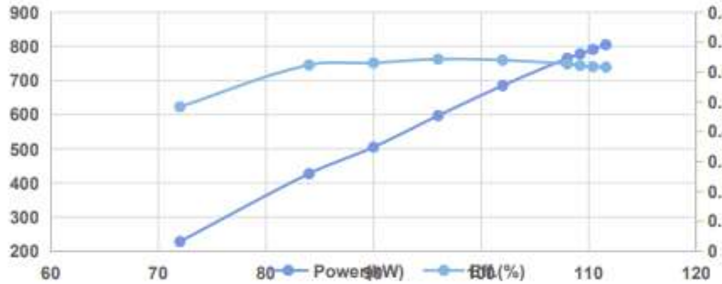
Klystron No. 3 （MBK
Efficiency 80.5%
(under fabrication)

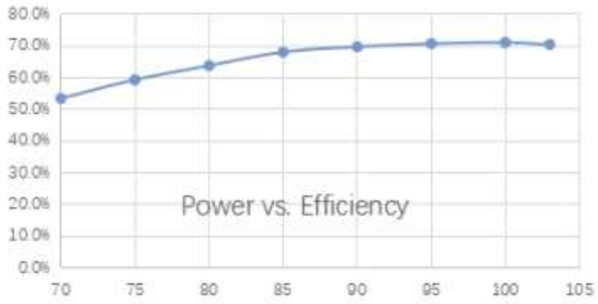
2022

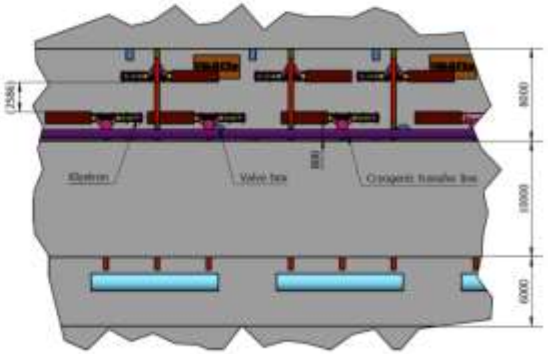
Pulsed RF Mode (30% duty factor, 60ms/5Hz)

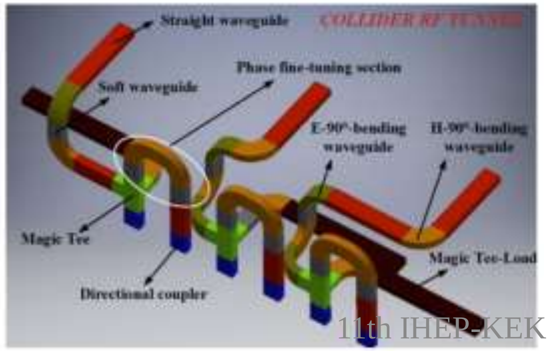
70.5% @ 630kW

High Voltage vs. Power&Efficency





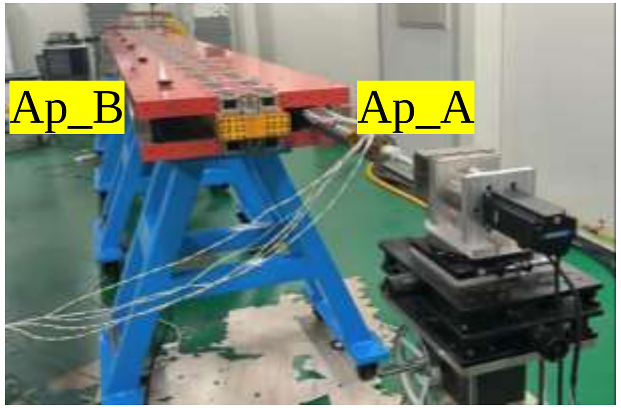




- Three prototypes of the 650MHz 800KW CW klystrons are developed. The efficiency reaches 70%
- PSM is developed with the industrial collaboration
- RF tunnel distribution was planed

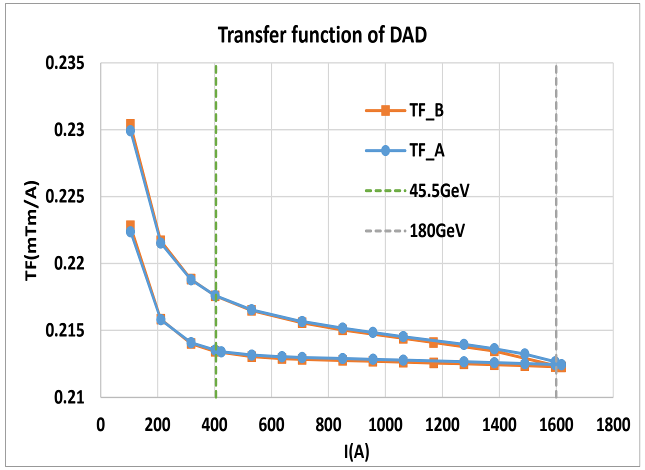
CEPC Collider Ring Full-scale Dual-aperture Magnets

Full-length 5.67m Dual aperture dipole



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

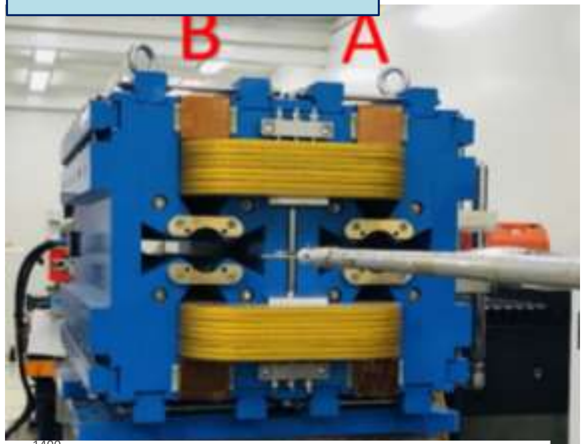
n	bn_A	bn_B
2	0	0
3	3.92	3.88
4	1.03	-1.22
5	0.47	0.54
6	0.08	-0.46



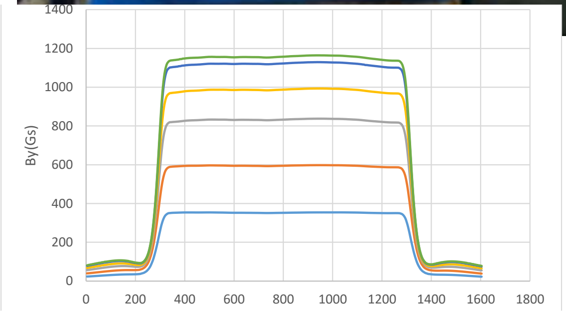
Two apertures differ <0.1%, transfer function in two apertures are consistent.

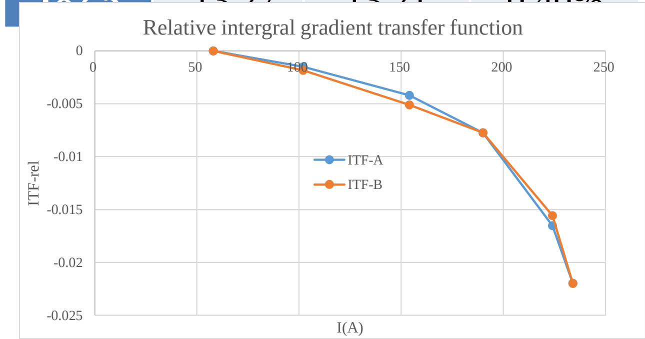
High harmonics are nearly the same at four energies and all less than 5 units, which can meet the requirements.

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%

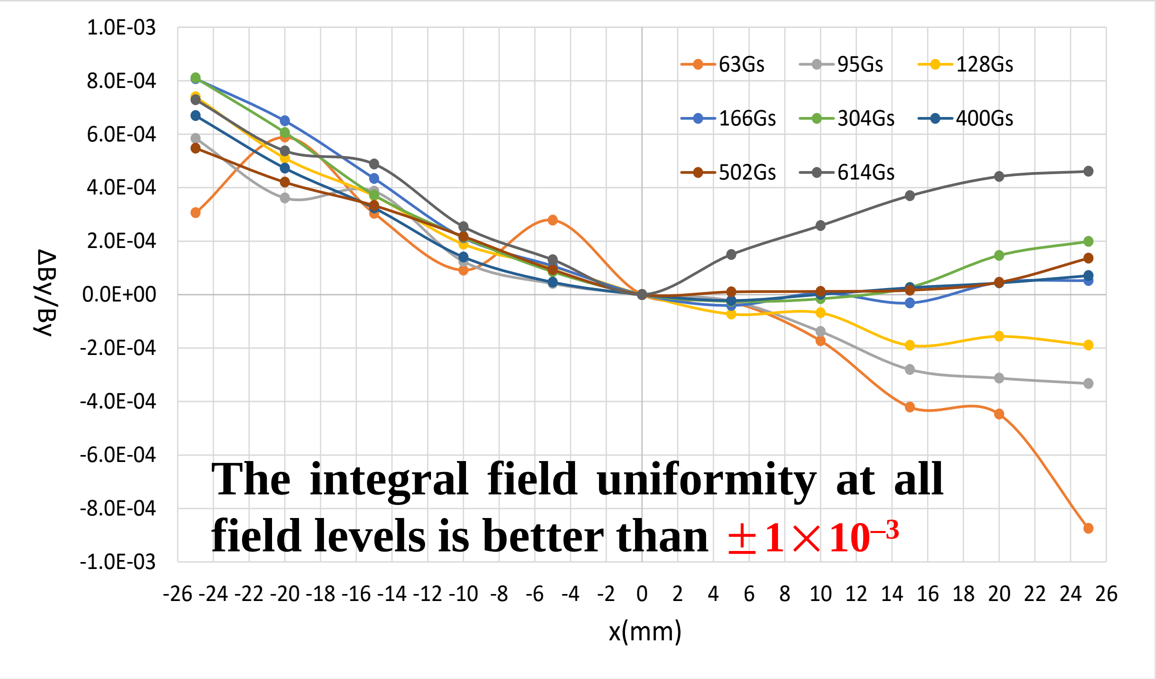




- Large quantities of dual-aperture dipoles (69km) and quad. (10km) are required;
- Full length dual-aperture dipole and dual aperture QUAD (short length) have been fabricated, under test;
- Dipole/QUAD prototypes meet the requirements.

CEPC Full-scale Weak Field Dipole for Booster

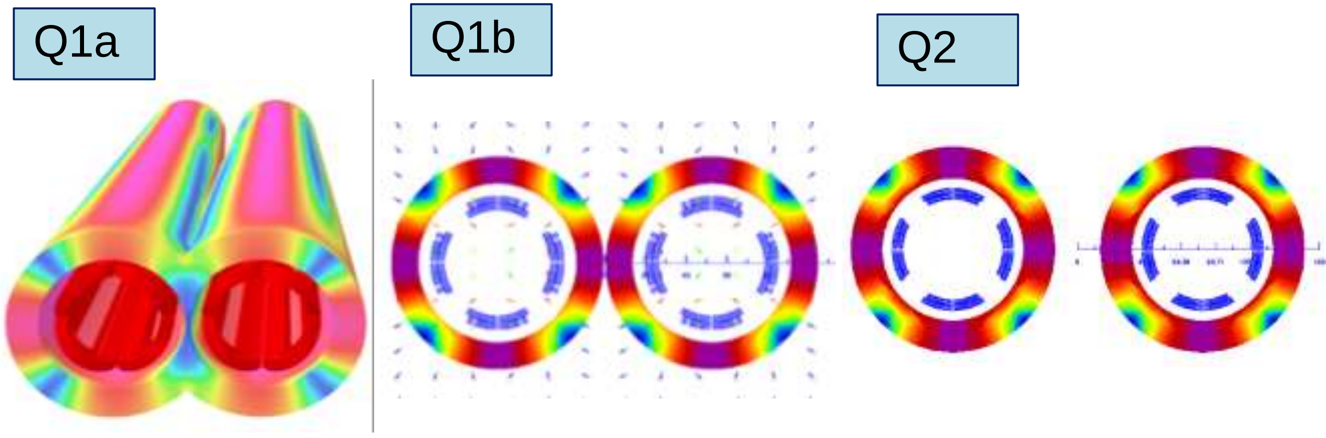
Magnet name	BST-63B-Arc	BST-63B-Arc-SF	BST-63B-Arc-SD	BST-63B-IR
Quantity	10192	2017	2017	640
Aperture [mm]	63	63	63	63
Dipole Field [Gs] @180 GeV	564	564	564	549
Dipole Field [Gs] @120 GeV	376	376	376	366
Dipole Field [Gs] @30 GeV	95	95	95	93
Sextupole Field [T/m^2] @180 GeV	0	16.0388	19.1423	0
Sextupole 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	$\pm1\times10^{-3}$	$\pm1\times10^{-3}$	$\pm1\times10^{-3}$	$\pm1\times10^{-3}$

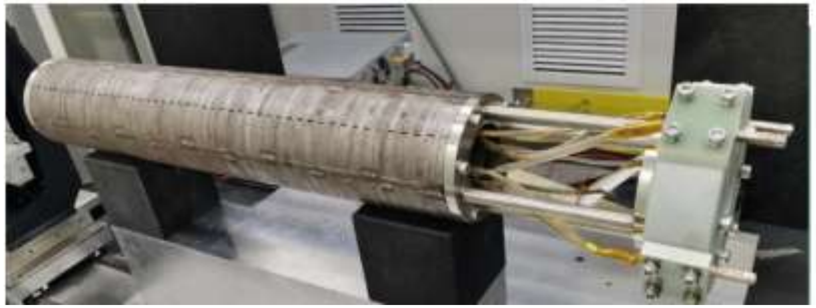


- Booster requires ~19k pieces of magnets (68km);
- Booster dipoles are required to work at the low field of 95 Gs (30GeV) with an error smaller than 1×10^{-3} ;
- Full length (4.7m) dipole was developed, and it meets the field specification;

CEPC 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	$\leq 5\times10^{-4}$	$\leq 5\times10^{-4}$	$\leq 5\times10^{-4}$	
Dipole field	≤3	≤3	≤3	mT

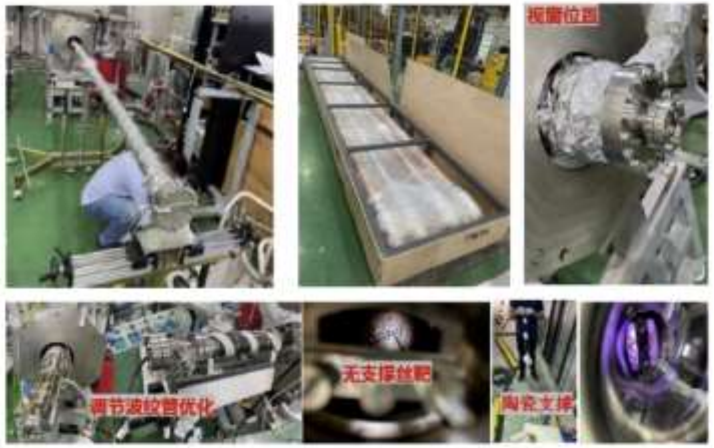




- CCT and Cos2θ type SCQs were modeled, and their fields were calculated; the CEPC specifications have been met;
- A 0.5-m single aperture SCQ using Cos2θ technology has been developed. The electro-magnet excitation test showed the highest current reached 2500A (176 T/m), which exceeds the CEPC requirement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

CEPC Vacuum System

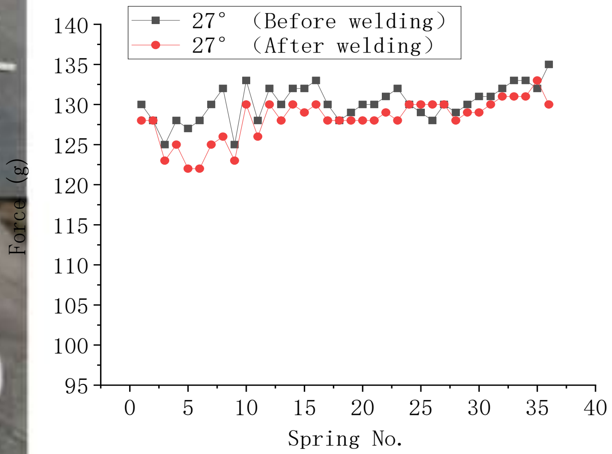
New round pipe of Copper (3mm) with NEG coating (200nm) for collider ring in TDR
SEY<1.2



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



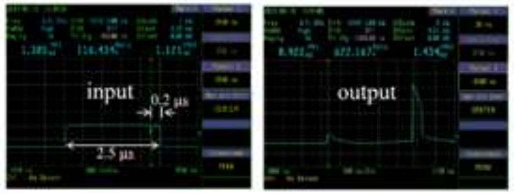
- Vacuum chamber prototypes, copper & aluminum, with different shape/length were fabricated;
- NEG coating technology were developed;
- RF shielding bellow manufactured
- Vacuum technology applied and was tested at HEPS

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

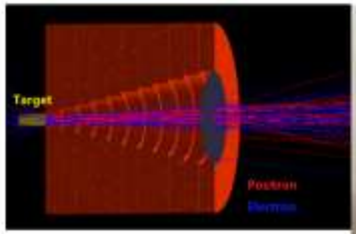


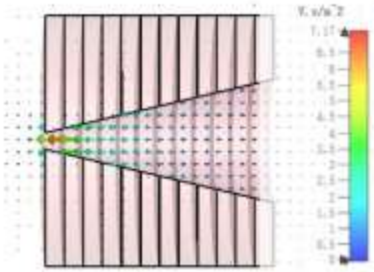
Test results of IHEP C-band SLED

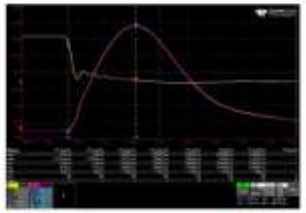
SACLA C-band SLED

IHEP C-band BOC

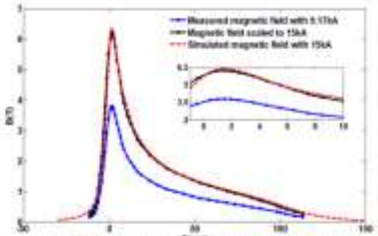
PSI BOC





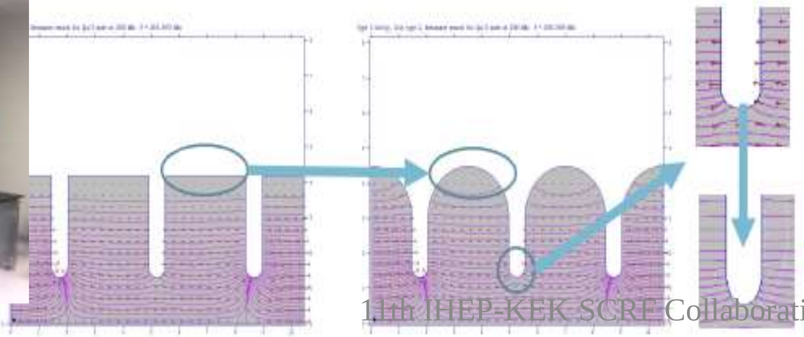


R&D of the solid state



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

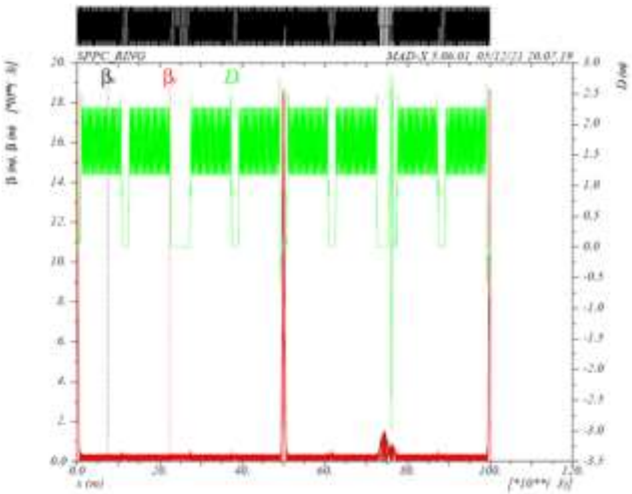
SN	System	Higgs 30MW							Higgs 50MW						
		Collider	Booster	Linac	BTL	IR	Surface building	Total	Collider	Booster	Linac	BTL	IR	Surface building	Total
1	RF Power Source	96.90	1.40	11.10				109.40	161.60	1.73	14.10				177.40
2	Crygenic system	9.72	1.71			0.14		11.57	9.17	1.77			0.14		11.08
3	Vacuum System	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

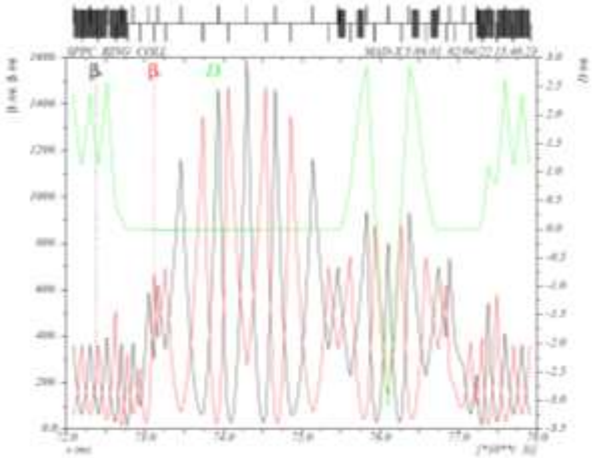
-Parameter list (updated Feb. 2022)

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	

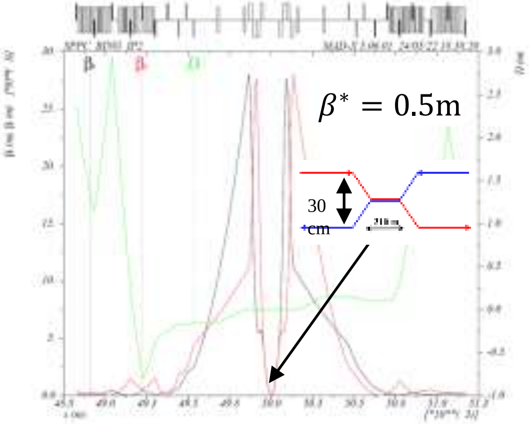
Lattice of SPPC



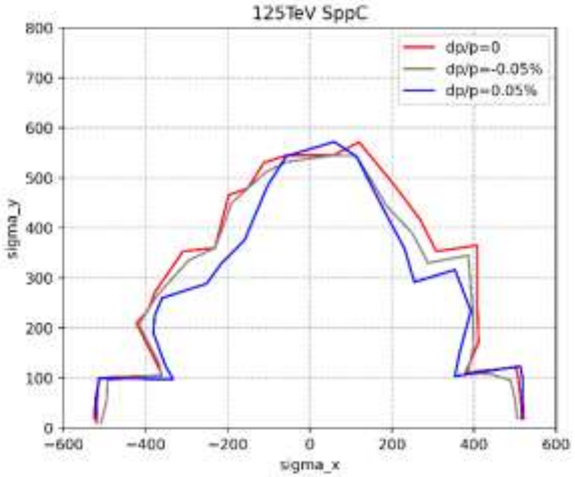
Whole ring



Collimation



IP



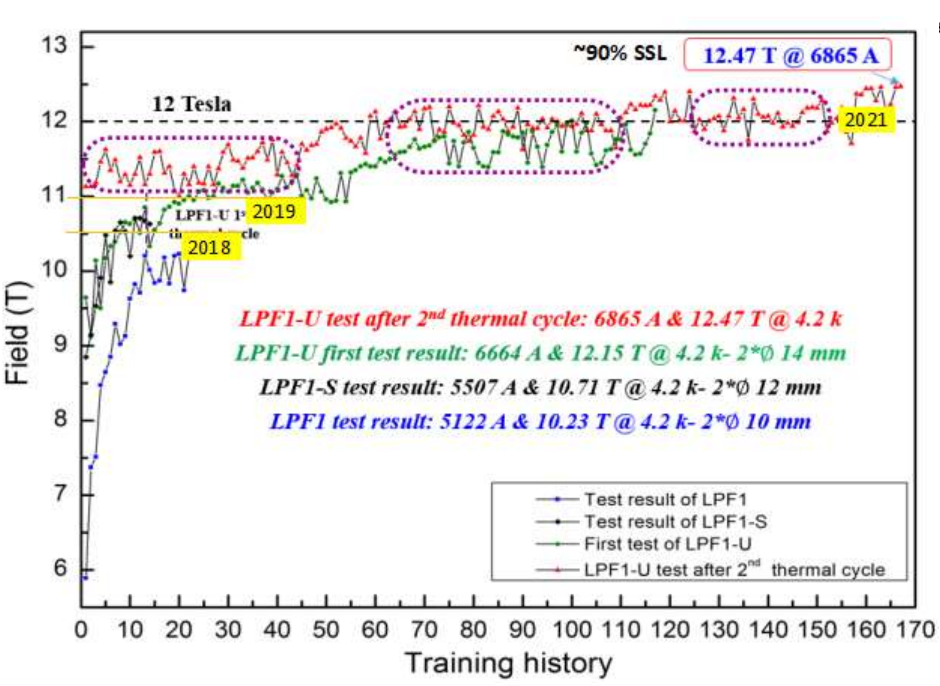
Dynamic Aperture

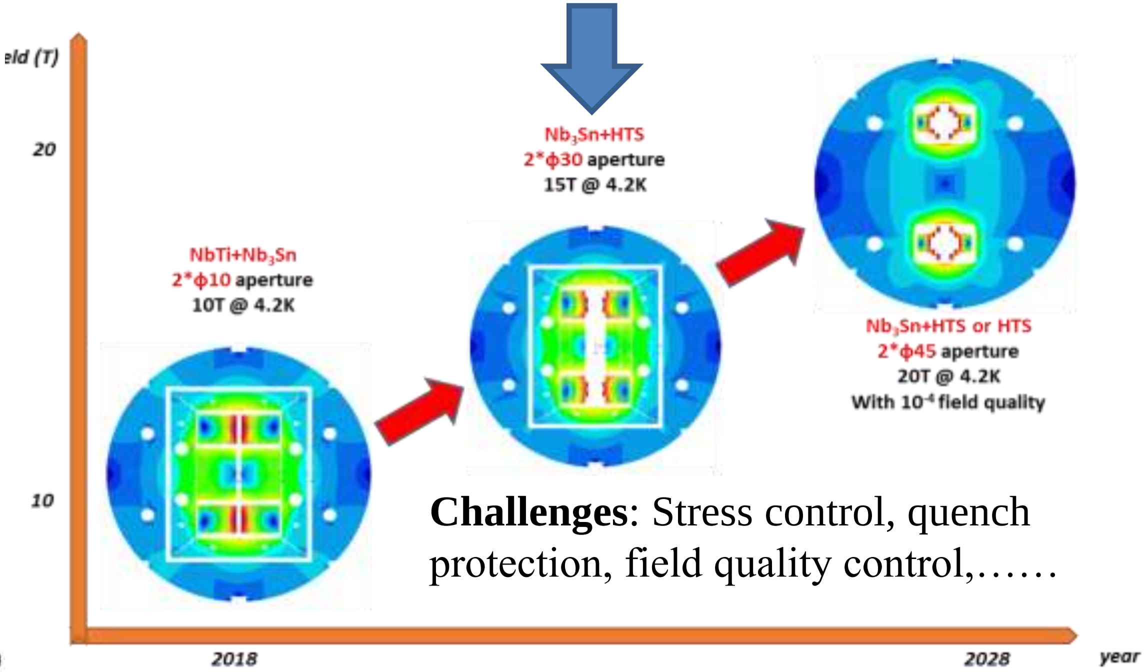
Ecm=125TeV with dipole field of 20T

SppC HF Magnet Development

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

Picture of LPF1-U





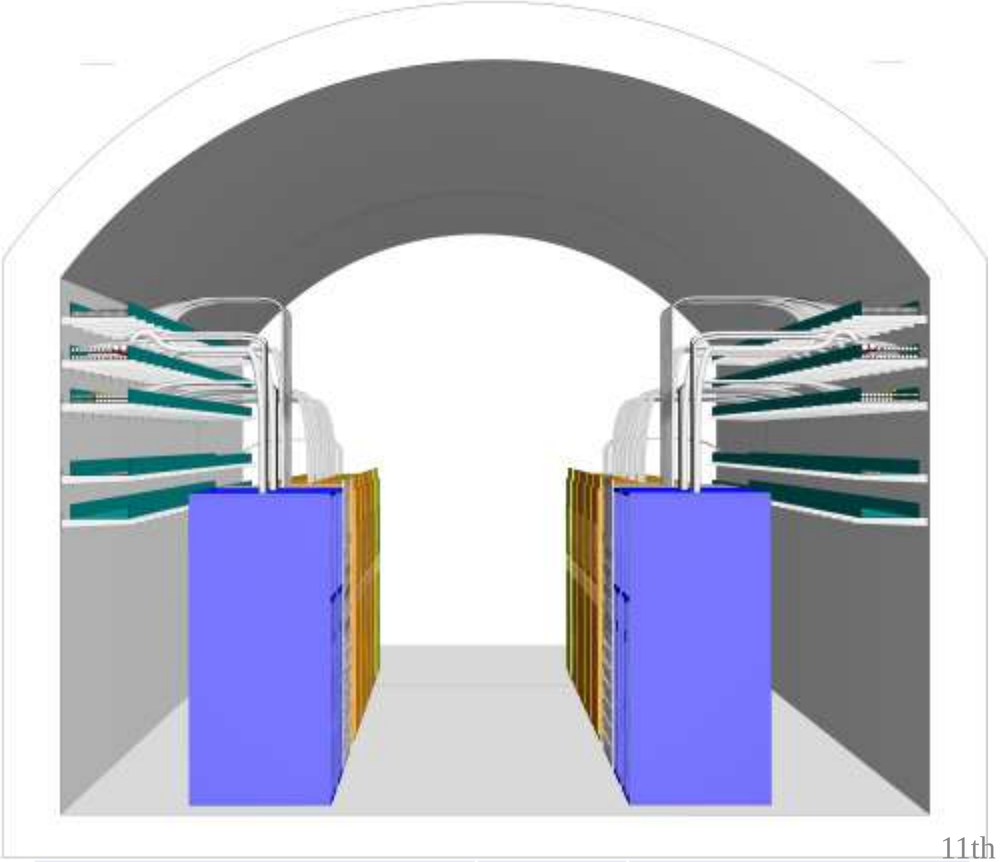
Challenges: Stress control, quench protection, field quality control,……

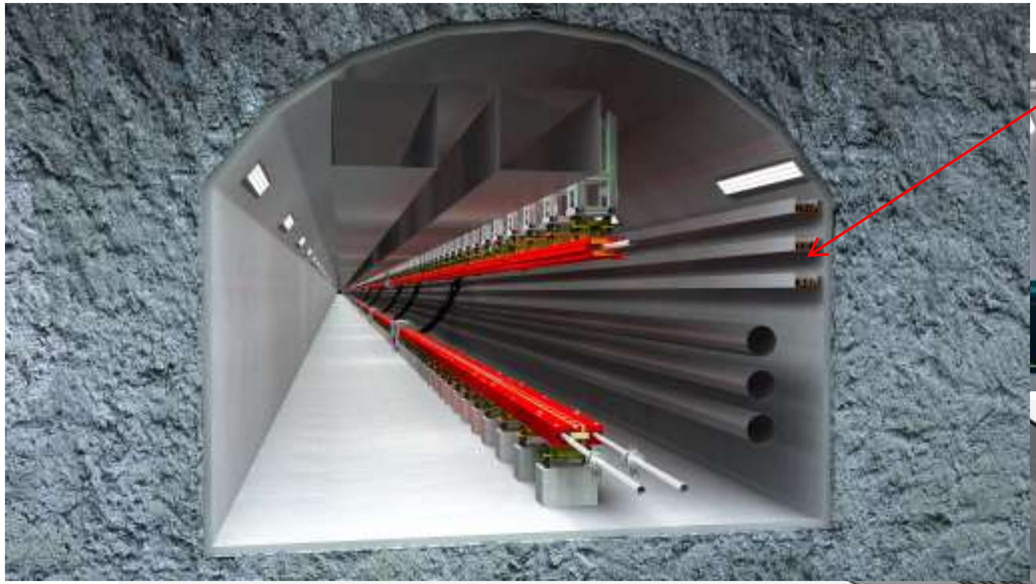
Dual aperture superconducting dipole achieves 12.47 T at 4.2 K
Entirely fabricated in China. The next step is reaching 16-20T

CEPC Site Preparations (three examples)

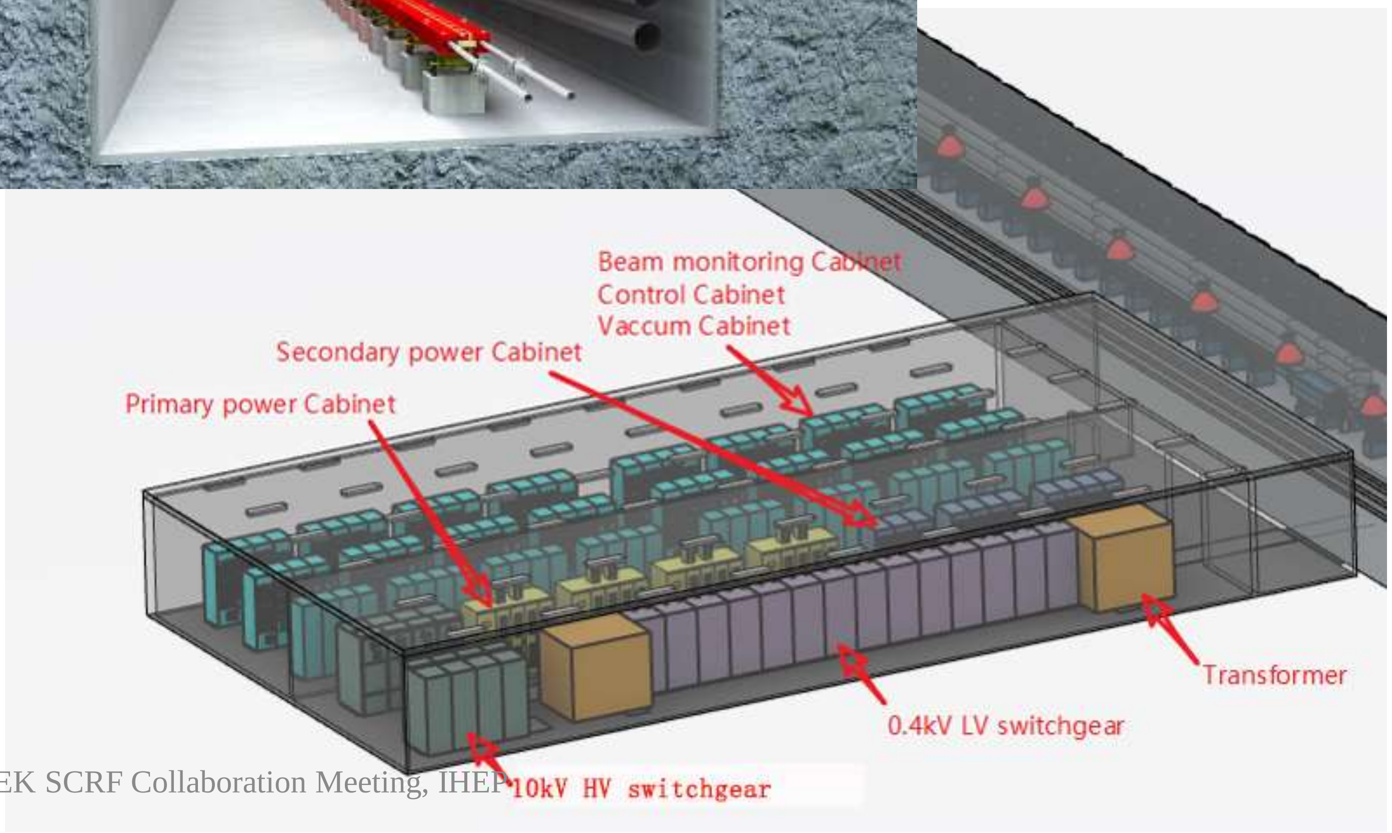
CEPC Conventional Facility and Civil Engineering

Electrical Equipment General Layout in Auxiliary





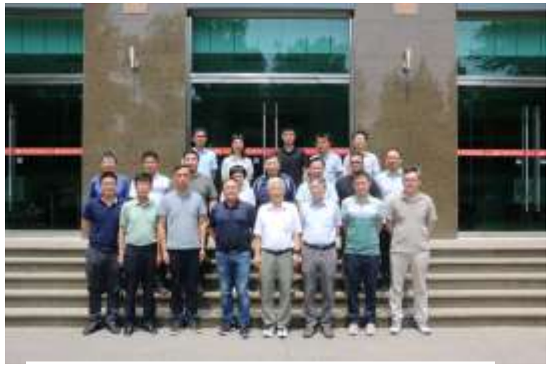
Cables installed!



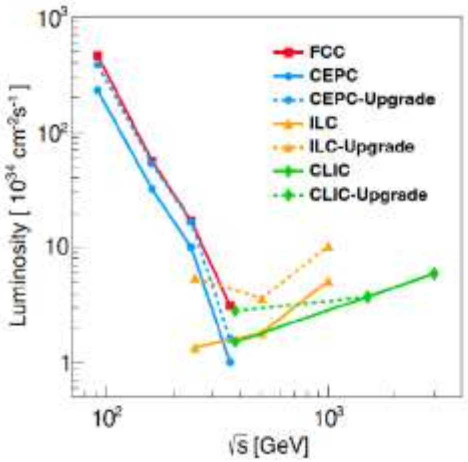
CEPC Accelerator International TDR Review and Cost Review
June 12-16, and Sept. 11-15, 2023, in HKUST-IAS, Hong Kong

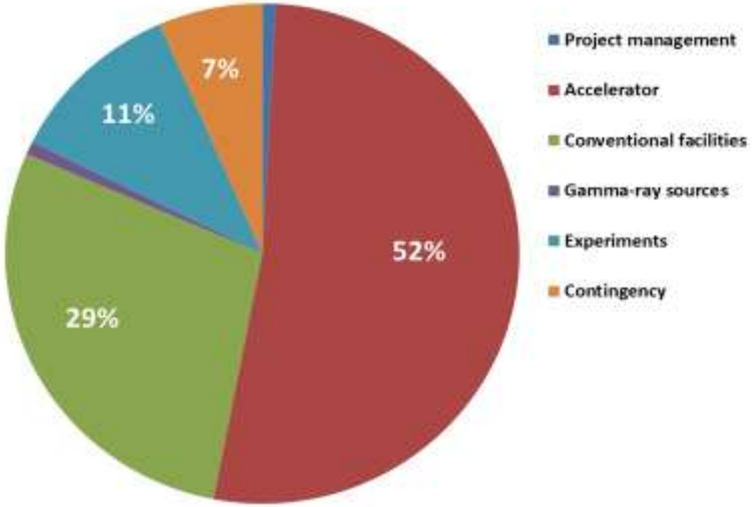
CEPC Accelerator TDR Review
June 12-16, 2023

CEPC Accelerator TDR Cost Review
Sept. 11-15, 2023



Domestic Civil Engineering
Cost Review, June 26, 2023





CEPC TDR cost distribution

CEPC accelerator TDR to be released formally soon in 2023

CEPC Accelerator TDR International Review Report

Phase 1 CEPC TDR Review Report

CEPC TDR Technical Review Committee

15 July 2023

Chaired by Frank Zimmermann

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 was held June 12-16, 2023, in HKUST-IAS, Hong Kong

https://indico.ihep.ac.cn/event/19262/timetable/

CEPC Accelerator TDR International Cost Review Report

CEPC Accelerator TDR Cost Review

Chaired by Loinid Rivkin

The CEPC Accelerator TDR Cost Review committee examined the cost estimate of the TDR of accelerator systems for the first stage of the CEPC project operated as a Higgs factory with synchrotron radiation power up to 30 MW per beam (including all infrastructure that is not easily upgradeable and is already designed to operate up to the ttbar energy and at 50 MW). The cost estimate under review does not include the civil engineering, the detectors at the IPs with their technical services, and the central computing services.

In the opinion of the committee the cost estimate presented is sufficiently complete to form a proper basis for the next iteration that will be done during the EDR stage.

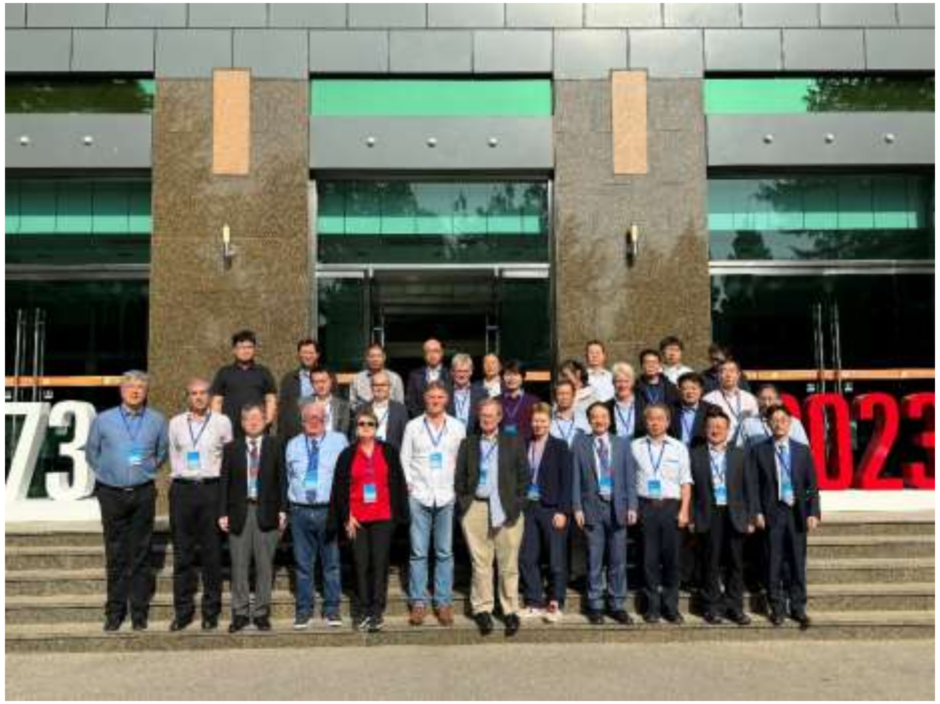
The responses to the Charge are set out below, followed by some general observations, and then some specific issues on which we have more to say.

CEPC Accelerator International TDR Cost Review was held Sept. 11-15, 2023, in HKUST-IAS, Hong Kong

https://indico.ihep.ac.cn/event/19262/timetable/

9th CEPC IAC 2023 Meeting (important!)

9th CEPC IAC 2023 Meeting
Oct. 30-31, 2023, IHEP, China



https://indico.ihep.ac.cn/event/20107

Chaired by Brian Foster

The CEPC accelerator TDR status and EDR plan have been reported to IAC and the report (draft) from the IAC:

-IAC endorse the CEPC TDR Review Report including recommendations in the report.

-Another key conclusion in the TDR Review Report , supported by the IAC, is that the accelerator team is well prepared to enter EDR phase

-The CEPC accelerator will be ready for construction after the successful completion…outlined in TDR Review Report, the engineering, and industrial preparation work and site studies being addressed in the EDR phase.

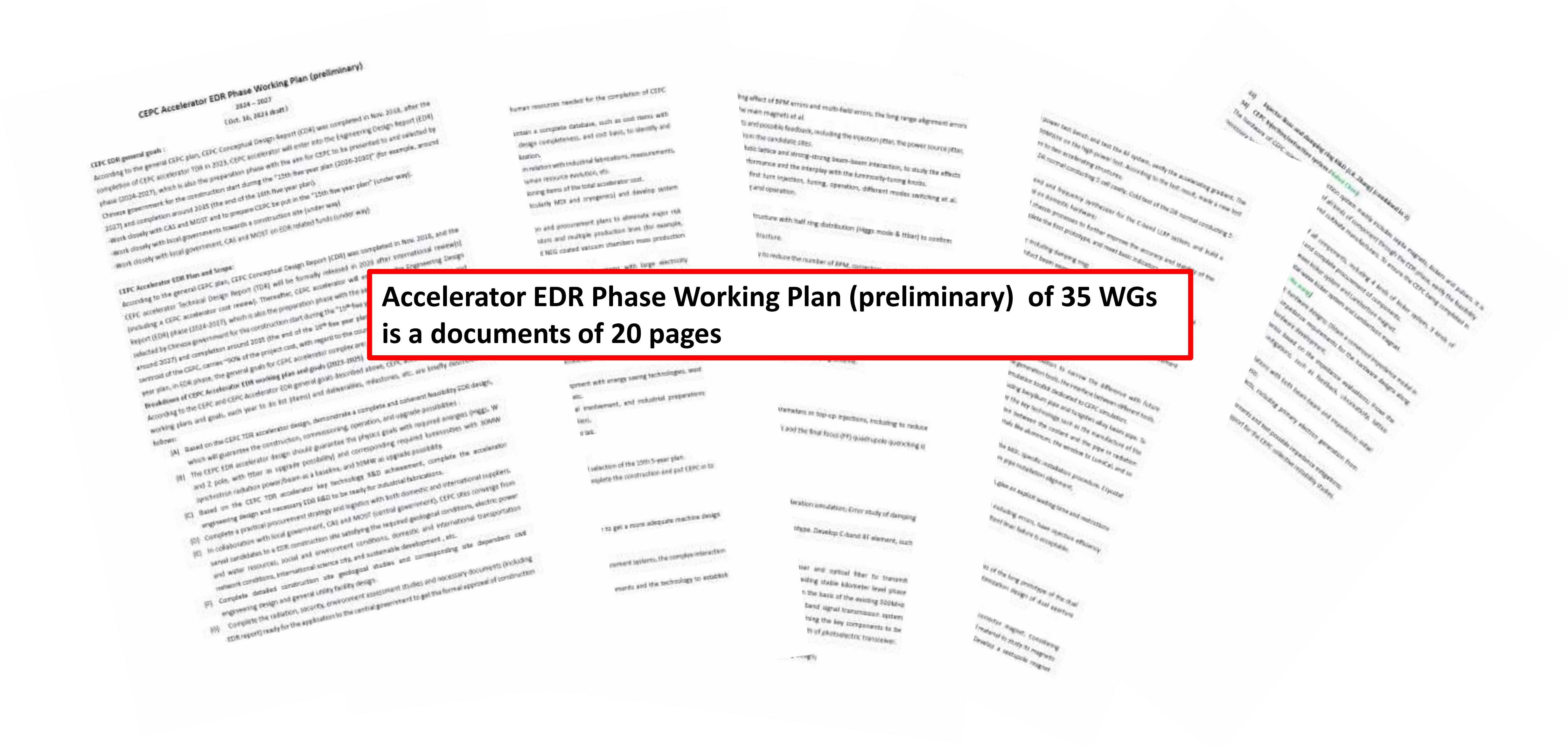
CEPC Engineering Design Report (EDR) Goal

2012.9	2015.3	2018.11	2023.10	2025	2027	15th five year plan
CEPC proposed	Pre-CDR	CDR	TDR	CEPC Proposal	EDR	Start of construction

CEPC EDR Phase General Goal: 2024-2027

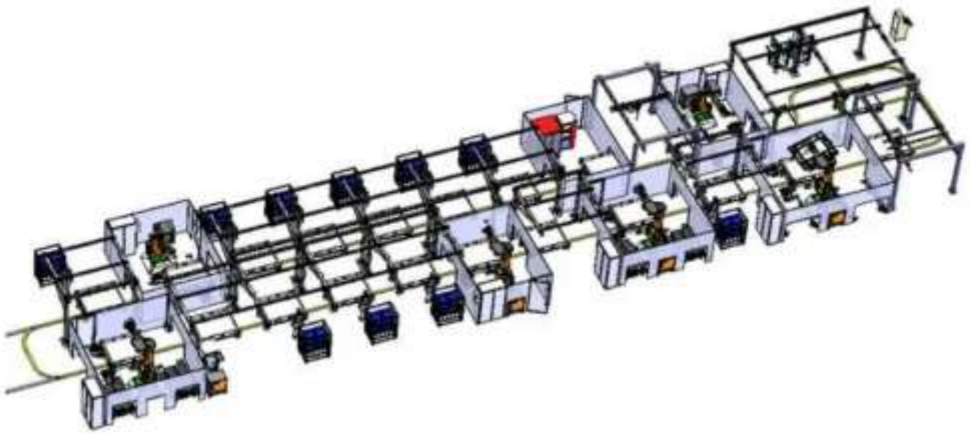
After completion CEPC accelerator TDR in 2023, CEPC accelerator will enter into the Engineering Design Report (EDR) phase (2024-2027), which is also the preparation phase with the aim for CEPC PROPOSAL to be presented to and selected by Chinese government around 2025 for the construction start during the "15th five year plan (2026-2030)" (for example, around 2027) and completion around 2035 (the end of the 16th five year plan).

CEPC EDR Goal, Plan and Scope

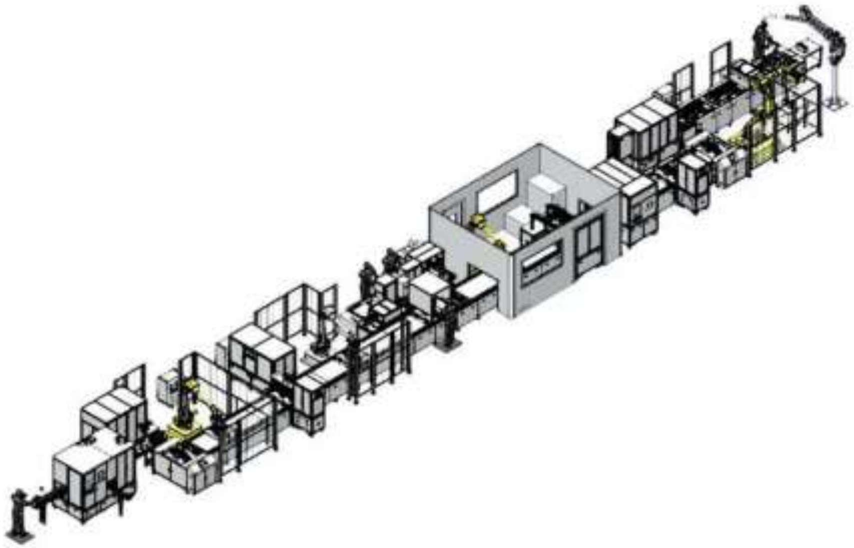


Accelerator EDR Phase Working Plan (preliminary) of 35 WGs is a documents of 20 pages

Automatic Production Lines of the CEPC Magnets in EDR



Conceptual design type-I

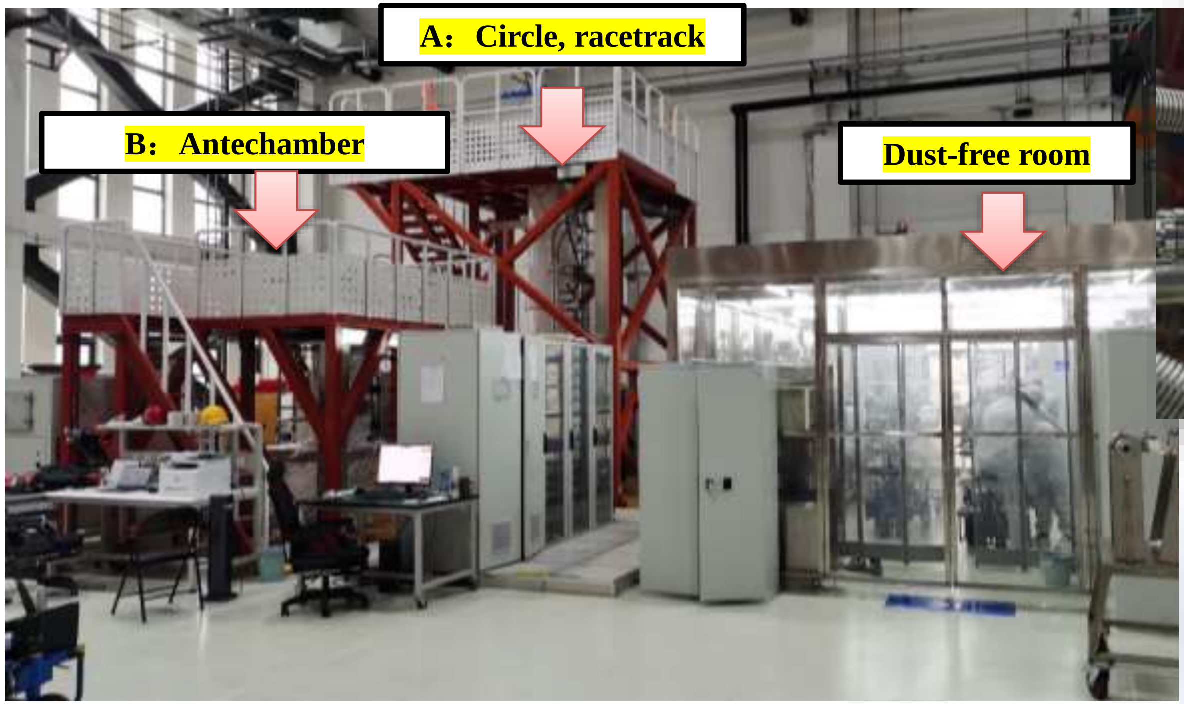


Conceptual design type-II

To reduce the fabrication cost of the magnets of CEPC, automatic magnet production lines will be demonstrated in EDR and used during construction

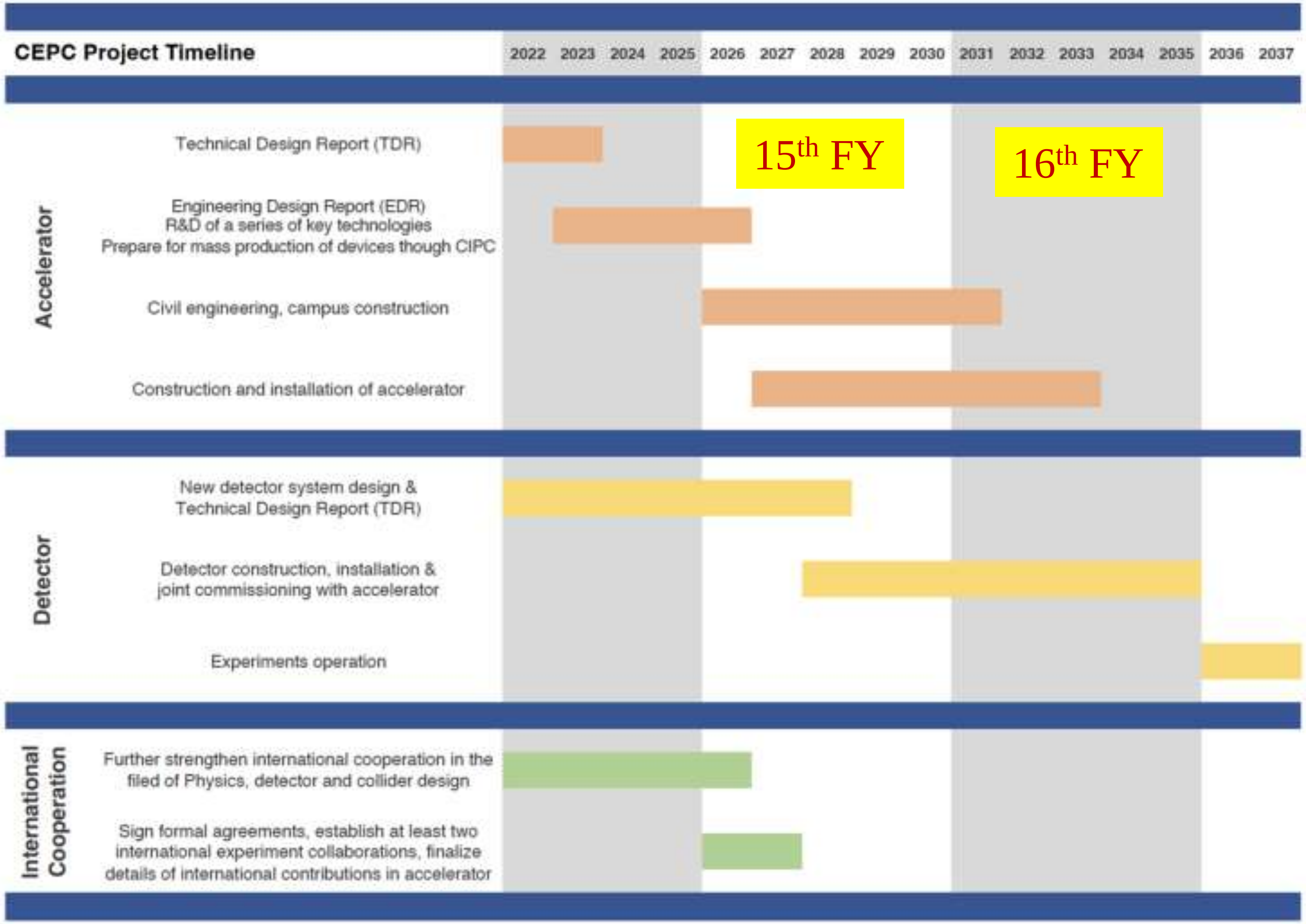
Massive Production Line of NEG Coating Vacuum Chambers in EDR

- The coating device A: Vacuum chambers are connected in parallel to 6 groups, each group of vacuum chambers length should be lower than 3.5m, outer diameter is about 0.47m;
- The coating device B: Antechamber are connected in parallel to 4 groups, each group of vacuum chambers length should be lower than 1.5m, due to its discharge difficulty.
- Two setups of NEG coating have been built for vacuum pipes of HEPS at IHEP Lab. And a lot of test vacuum pipes have been coated, which shows that NEG film has good adhesion and thickness distribution.
- **In EDR phase a dedicated CEPC NEG coated vacuum chamber production line is planned**



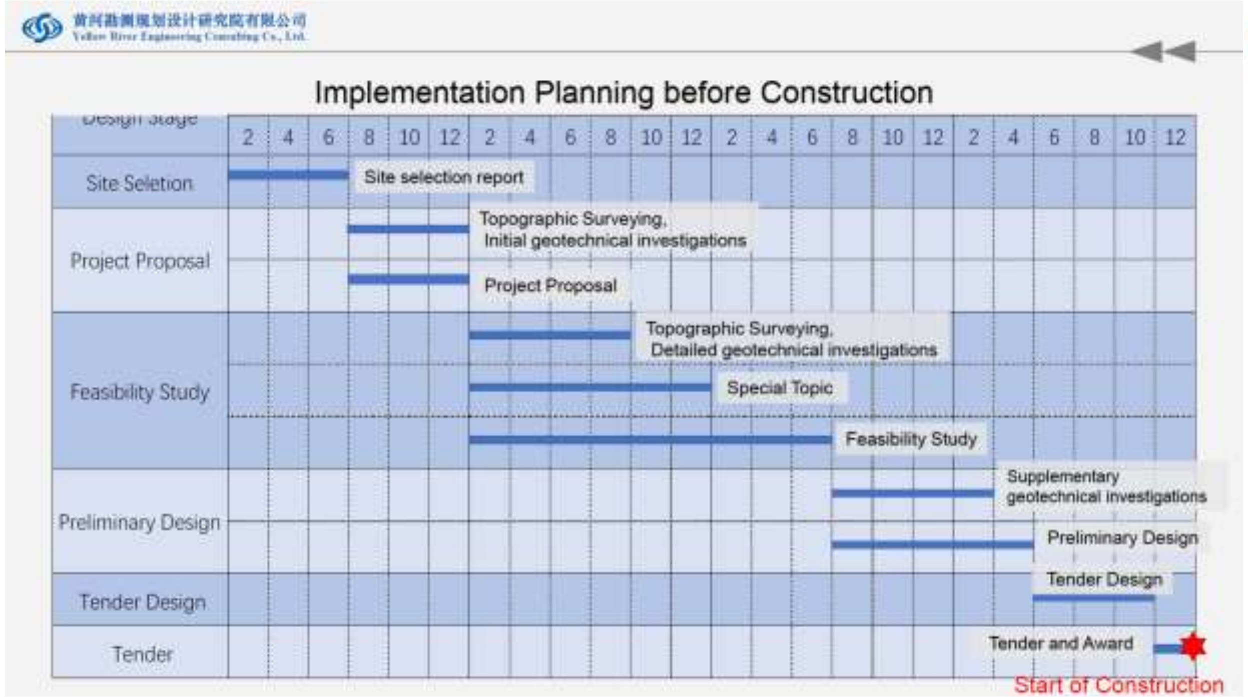
CEPC Planning and Schedule

TDR (2023), EDR(2027), start of construction (2027-8)



CEPC Site Implementation and Construction Plans

CEPC site implementation plan in EDR



CEPC construction plan

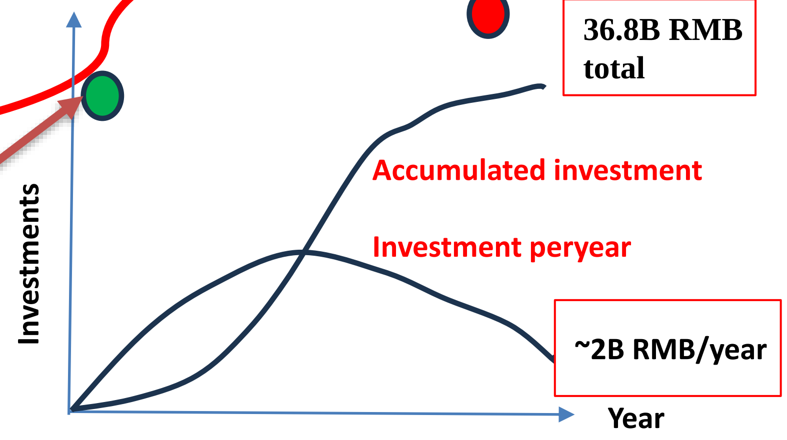
CEPC Evolution Milestones with Human Resources

Year	2015	2018	2023	2025	2027	2030	2035
Human resource	~50	~100	~200	~300	~500	~2800	~2500

Year	Accelerator human resource	Accumulated spending Billion RMB
2015	50	-
2018	100	-
2023	200	0.2
2025	300	0.3
2027	500	0.4
2031	2800	9
2035	2500	20

Proposal (2025) for CEPC entering 15th five year plan

EDR is the critical path Towards CEPC construction Starting around 2027



2012.9 CEPC proposed

2015.3 Pre-CDR

2018.11 CDR

2023.10 TDR

2024 ~ 2027 EDR start of construction

~2035 Completion

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

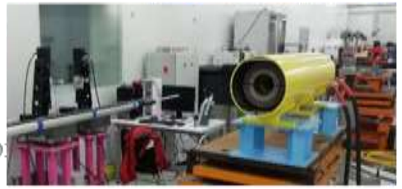
	System
1	Magnet
2	Power supplier
3	Vacuum
4	Mechanics
5	RF Power
6	SRF/ RF
7	Cryogenics
8	Instrumentation
9	Control
10	Survey and alignment
11	Radiation protection
12	e-e+Sources

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

Potential international collaborating suppliers worldwide





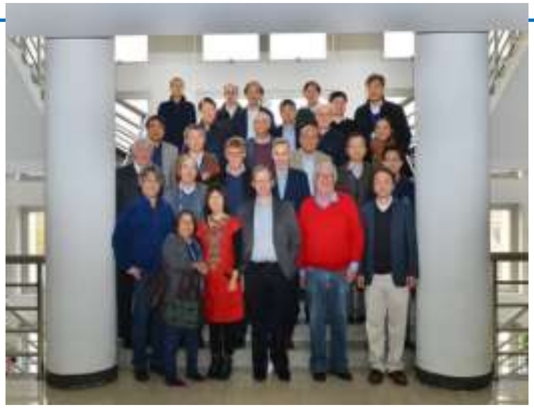




41

CEPC International Collaboration -1

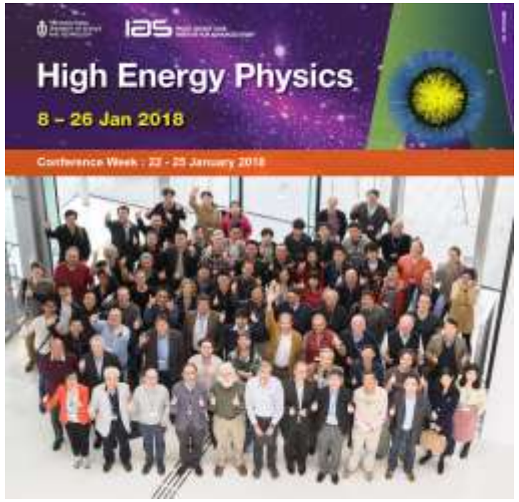
The first CEPC-SppC international Collaboration Workshop
Nov 6-8, 2017, IHEP, Bejing
http://indico.ihep.ac.cn/event/6618

Workshop on the Circuar Electron Positron Collider-EU edition
May 24-26, 2018, Università degli Studi Roma Tre, Rome, Italy
https://agenda.infn.it/conferenceDisplay.py?ovw=True&confId=14816



3rd CEPC IAC, Nov 8-9, 2017,
IHEP, Beijing

More than 20 MoUs have been signed with international institutions and universities



IAS Higgh Energy Physics Workshop
(Since 2015)
http://iasprogram.ust.hk/hep/2018

CEPC Workshop-EU , 2019 Sep 2019, Oxford,UK
https://agenda.infn.it/conferenceDisplay.py?ovw=True&confId=14816

CEPC Workshop, EU-Eidition, 3-6 July 2023, Edinburg, UK

CEPC Workshop, 22-23 April 2020, USA
https://indico.cern.ch/event/863751/

CEPC International Collaborations-2

HKIAS23 HEP Conference
Feb. 14-16, 2023

https://indico.cern.ch/event/1215937/

The 2023 International Workshop on Circular Electron Positron Collider, EU-Edition,University of Edinburgh, July 3-6, 2023

https://indico.ph.ed.ac.uk/event/259/overview

The 2024 HKUST IAS Mini workshop and conference will be held from Jan. 18-9, and Jan. 22-25, 2024, respectively.

The 2024 international workshop of CEPC, EU-Edition Is planned to be held in France

CEPC International Collaborations-3

International workshop CEPC 2023
Oct. 23-27, 2023, Nanjing, China

https://indico.ihep.ac.cn/event/19316/

FCPPL2023
Nov. 6-10, 2023, Zhuhai, China

https://indico.ihep.ac.cn/event/20622/

Invitation to sign up CEPC TDR

CEPC TDR preparation is currently in its final stage and is scheduled to be published soon. **We invite you to read the latest version of CEPC TDR draft:** （ https://docs.ihep.ac.cn/anyshare/zh-cn/link/AA9FC882F906714CE1BC59DAF3BB048A60?_tb=none&expires_at=2023-12-30T15%3A28%3A28%2B08%3A00&item_type=&password_required=false&title=CEPC-TDR-draft-v4.pdf&type=anonymous ）

(This version is almost converged to the final one, but we will make the necessary adjustments and polishing later.)

We sincerely inquire if you would be willing to sign the TDR authorship. Your continued support and recognition would greatly contribute to the future development of the CEPC.

- **If you agree to sign, please fill in your information in** TDR Authorship Collection （https://indico.ihep.ac.cn/event/20817/registrations/1668/） **page.**
- **We will also appreciate if you could kindly help to invite people from your institutes or collaboration group, please also update information in** TDR Authorship Collection （https://indico.ihep.ac.cn/event/20817/registrations/1668/） **page.**
- **The Deadline for collection is Nov. 20th .**

Thanks for your cooperation. We greatly appreciate your support and dedication to CEPC Project.

Summary

- The CEPC TDR parameter and design optimizations with high luminosity (30MW and 50MW) operations, for all four energies (Higgs, W/Z and ttbar) have been 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 in EDR.
- CEPC accelerator TDR international review and cost review were held from June 12-16, 2023 and Sept. 11-15, 2023, respectively, and TDR will be released formally soon in 2023.
- Detailed preparation of CEPC accelerator EDR phase (2024-2027) before construction working plan and beyond have been established (preliminary), with the aim of starting the construction in "15th five-year-plan" (2026-2030), and completing the construction around 2035.
- International collaboration and participation are warmly welcome.

Acknowledgements

Thanks go to CEPC-SppC accelerator team’s hard works,
international and CIPC collaborations

Special thanks to CEPC, IAC, IARC and TDR review (cost) committee’s
critical comments, suggestions and encouragement

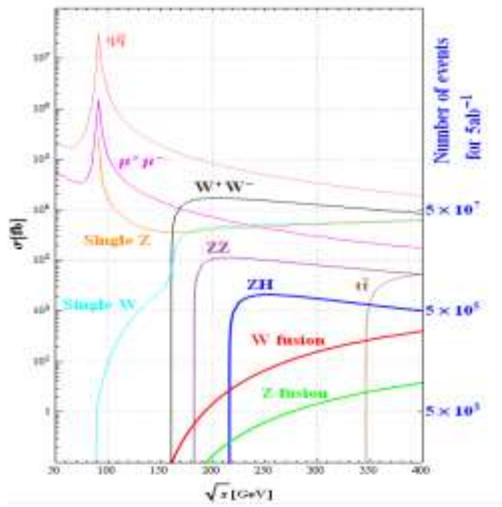
Thanks

Backup Slides

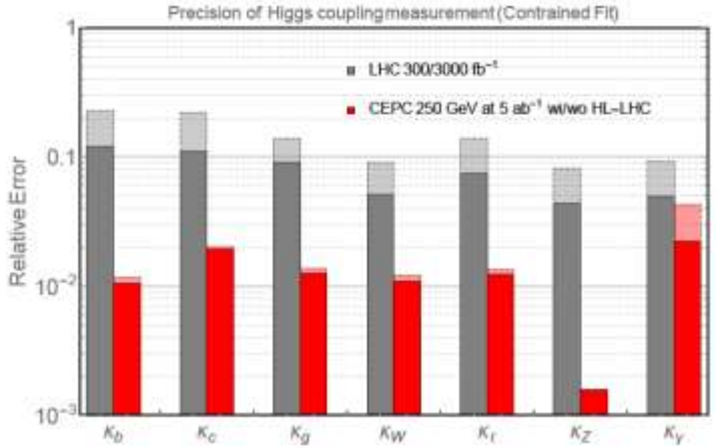
Physics Goals of CEPC-SppC

- **Circular Electron-Positron Collider (CEPC) as a Higgs Facory (91, 160， 240, 360 GeV)**
  - Higgs Factory（>10^6 Higgs）：
    - Precision study of Higgs(mH, JPC, couplings)，Similar & complementary to ILC
    - Looking for hints of new physics, DM...
  - Z & W factory（>10^10 Z0）：
    - precision test of SM
    - Rare decays ?
  - Flavor factory: b, c, t and QCD studies
- **Super proton-proton Collider(SppC) (~100 TeV)**
  - Directly search for new physics beyond SM
  - Precision test of SM
    - e.g., h3 & h4 couplings

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



Cross sections for major SM physics processes at the electron positron collider



Anticipated accuracy on Higgs properties at CEPC and at LHC/HL-LHC

Precision measurement + searches for new physics: Complementary with each other !

CEPC Operation Plan

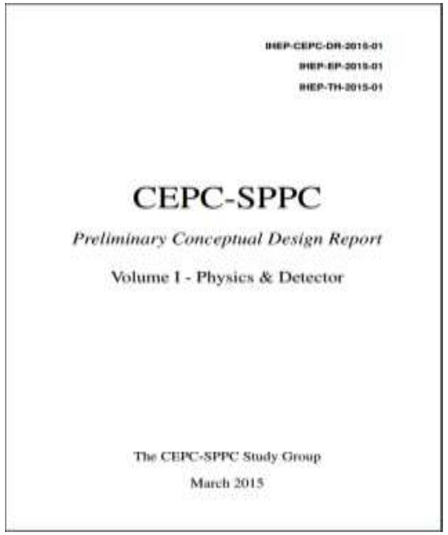
Particle	$E_{c.m.}$ (GeV)	Years	SR Power (MW)	Lumi. per IP ($10^{34}cm^{-2}s^{-1}$)	Integrated Lumi. per year (ab^{-1}, 2 IPs)	Total Integrated L (ab^{-1}, 2 IPs)	Total no. of events
H*	240	10	50	8.3	2.2	21.6	4.3×10^6
			30	5	1.3	13	2.6×10^6
Z	91	2	50	192**	50	100	4.1×10^{12}
			30	115**	30	60	2.5×10^{12}
W	160	1	50	26.7	6.9	6.9	2.1×10^8
			30	16	4.2	4.2	1.3×10^8
$t\bar{t}$	360	5	50	0.8	0.2	1.0	0.6×10^6
			30	0.5	0.13	0.65	0.4×10^6

* Higgs is the top priority. The CEPC will commence its operation with a focus on Higgs.

** Detector solenoid field is 2 Tesla during Z operation, 3Tesla for all other energies.

*** Calculated using 3,600 hours per year for data collection.

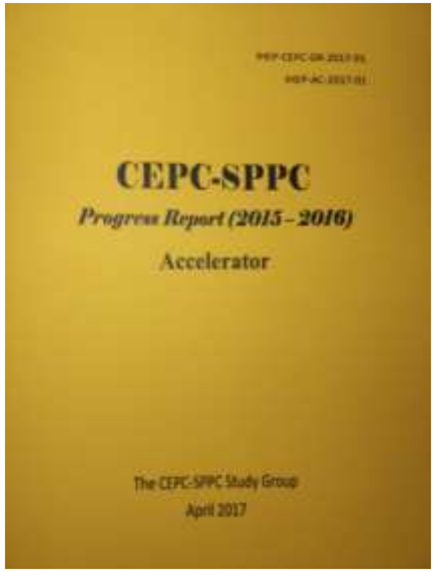
Main Timelines of CEPC Accelerator Development



Pre-CDR in 2015

1) CEPC CDR Vol. I, Accelerator
http://cepc.ihep.ac.cn/CEPC_CDR_Vol1_Accelerator.pdf
2) CEPC CDR Vol. II, Physics and Detector
http://cepc.ihep.ac.cn/CEPC_CDR_Vol2_Physics-Detector.pdf
3) CEPC Accelerator white paper
to Snowmass21, arXiv:2203.09451

CEPC Video (BIM design)
1) http://cepc.ihep.ac.cn/Qinhuang_Island.mp4
2) http://cepc.ihep.ac.cn/Huzhou.mp4
3) http://cepc.ihep.ac.cn/Changsha.mp4



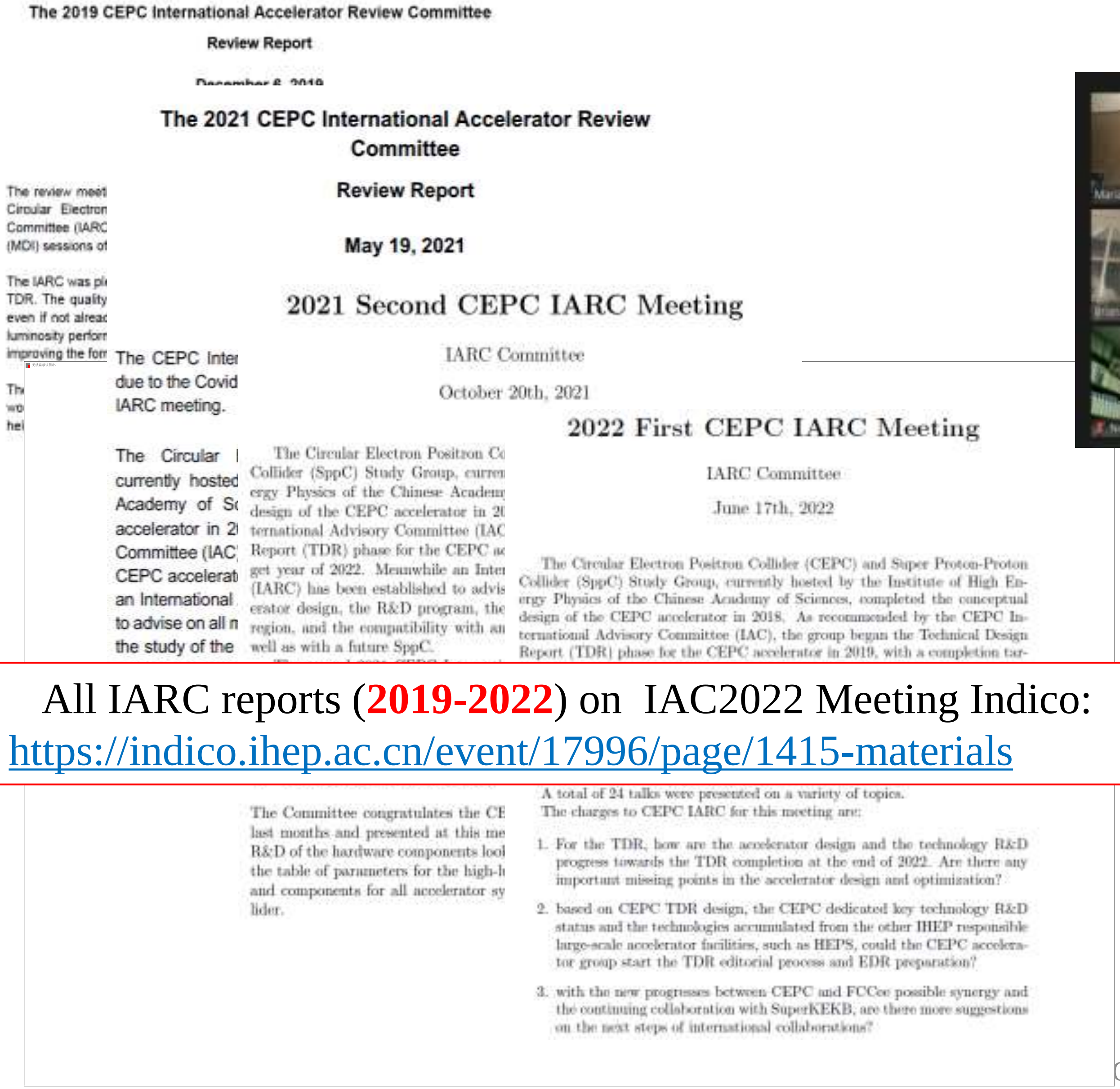
Progress report in 2016

CEPC CDR Released (2018.11)

CDR Accelerator and Detector/Exp. in 2028

CEPC Accelerator IARC Meeting 2019-2022

International Accelerator Review Committee (IARC) under IAC


The 2019 CEPC International Accelerator Review Committee

Review Report

The 2021 CEPC International Accelerator Review Committee

Review Report

May 19, 2021

2021 Second CEPC IARC Meeting

IARC Committee

October 20th, 2021

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/

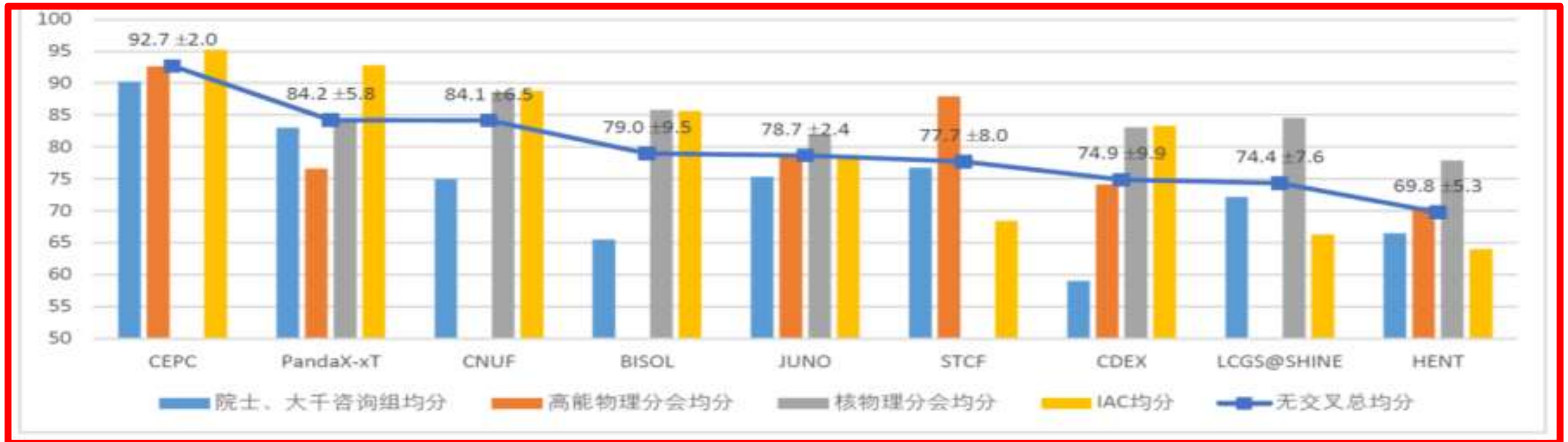
All IARC reports (**2019-2022**) on IAC2022 Meeting Indico: https://indico.ihep.ac.cn/event/17996/page/1415-materials

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 Project Development

X. Lou

- **TDR has been completed** (review + revision) to be released in 2023
- CAS is planning for the 15th 5-years plan for large science projects, and a steering committee has been established, chaired by the president of CAS
- **High energy physics**, as one of the 8 groups, has been working on this for a year:
  - Setting up rules and the standard(based on scientific and technological merits, strategic value and feasibility, R&D status, team and capabilities, etc.), established domestic and international advisory committees
  - Collected 15 proposals and selected 9, based on the above-mentioned standard
  - Evaluations and ranking by committees after oral presentations by each project
- **CEPC is ranked No. 1, with the smallest uncertainties, by every committee**
- A final report will be submitted to CAS for consideration



IHEP International Assessment Sept.20-24, 2023)

International Assessment of the Institute of High Energy Physics

Preliminary Draft Report

September 20-24, 2023, IHEP, Beijing, China

Ursula Bassler, Roger Blandford, Andrew Glen Cohen, Cristinel Diaconu, Georges El Fakhri, Angeles Faus-Golfe, Wolfgang Parak, Harald Reichert, Yang Ren, Ian Shipsey, W. Michael Snow, Hans Weise, Harry Westfahl Jr., Frank Zimmermann.

6. CEPC Accelerators

	A+	A	B	C	D
Overall ranking	X				
Is the scientific goal(s) well defined, significant, and credible?	X				
Is there a clear and credible research and R&D plan to realize the scientific goal(s)?	X				
How has the program performed over the last 5 years?	X				
Is the progress of research, R&D and personnel development going according to the plan?		X			
Are the research resources, e.g. funding and laboratories, adequate to support the R&D?		X			