CEPC Accelerator General Status Overview

Jie Gao

On behalf of the CEPC accelerator group

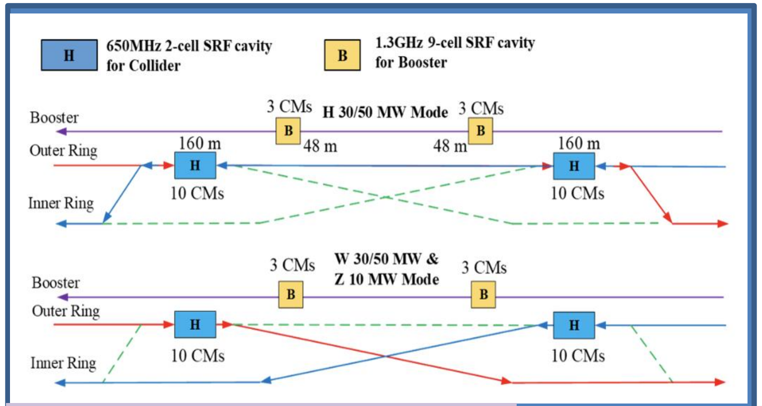
Edingurgh University, June 3, 2023

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

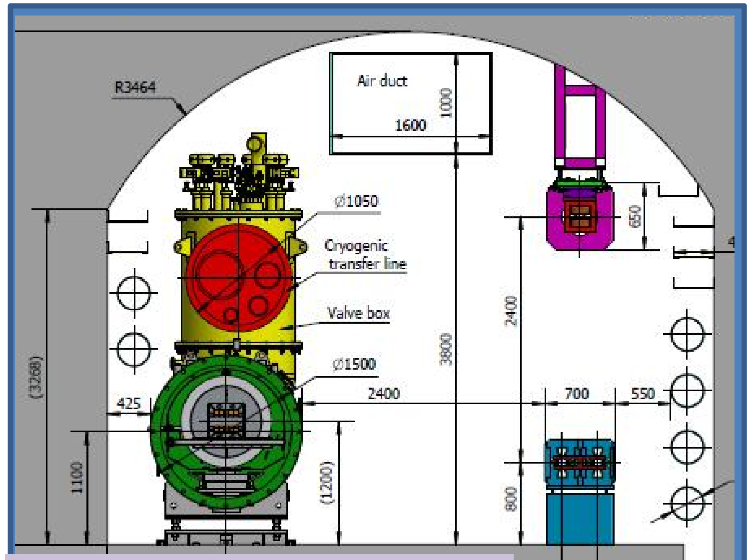
3-6. July. 2023, University of Edinburgh, The 2023 International Workshop on CEPC (EU Edition)

Contents

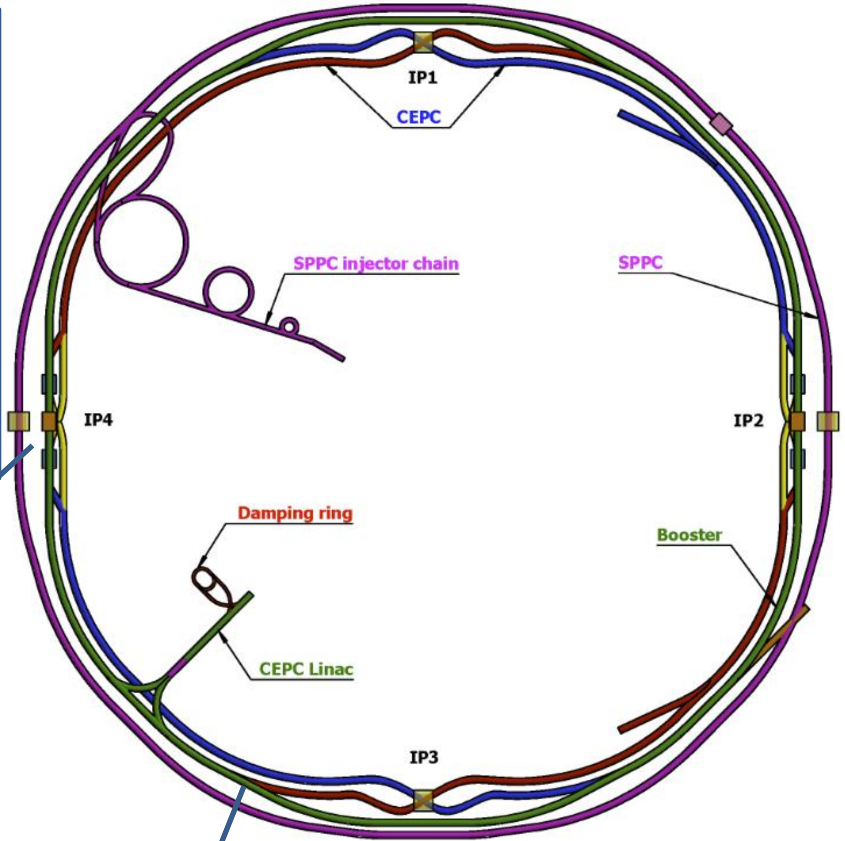
CEPC Optimization Design Philosophy



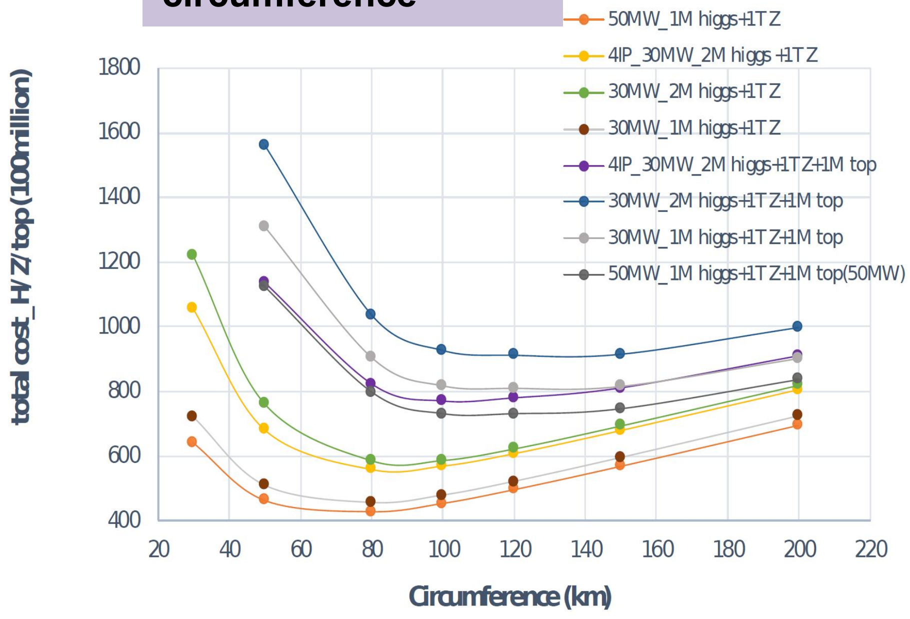
Switchable operation for Higgs W and Z



Common tunnel for booster/collider & SppC



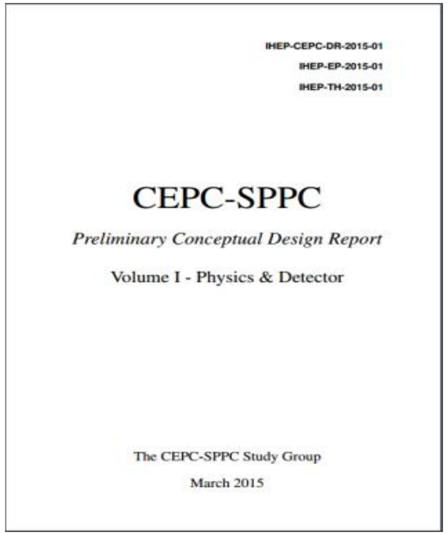
Cost optimization v.s. circumference



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

- **Circular collider**: Higher luminosity than a linear collider
- **100km circumference**: Optimum total cost
- **Shared tunnel**: Compatible design for CEPC and SppC
- **Switchable operation**: Higgs, W/Z, top

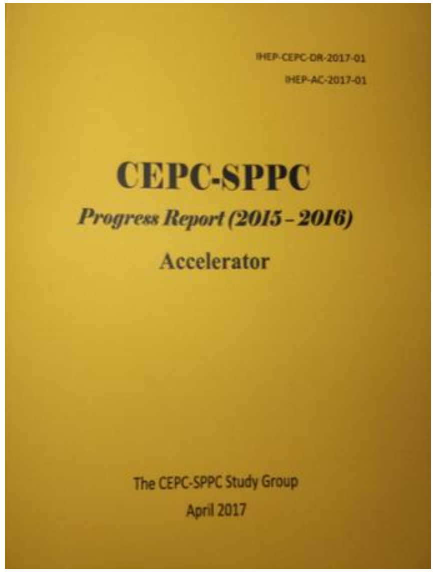
Main Timeline of CEPC Accelerator Development



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 in 2018

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 International TDR Review June 12-16, 2023 in HKUST-IAS, Hong Kong, China

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

IHEP-CEPC-DR-2023-01

IHEP-AC-2023-01

CEPC

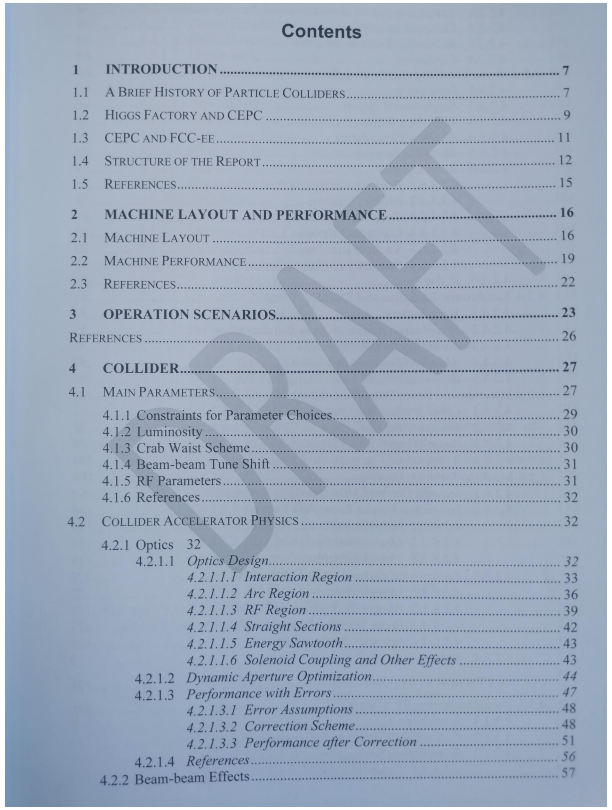
Technical Design Report

Part BB – Injectors and Common Systems

Draft

The CEPC Study Group

June 2023



Contents

Draft

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

The Evolution: from CDR to TDR

Main Parameters (30MW)

CDR（2018）

	Higgs	*W*	*Z （3T）*	*Z （2T）*
Number of IPs	2			
Circumference (km)	100			
Bunch number	242	1524	12000	
β function at IP β_x^* / β_y^* (m/mm)	0.36/1.5	0.36/1.5	0.2/1.5	0.2/1.0
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	1.21/3.1	0.54/1.6	0.18/4.0	0.18/1.6
Energy acceptance (%)	1.35	0.4	0.23	
Luminosity per IP ($10^{34}cm^{-2}s^{-1}$)	**2.93**	**10.1**	**16.6**	**32.1**

TDR（2023）

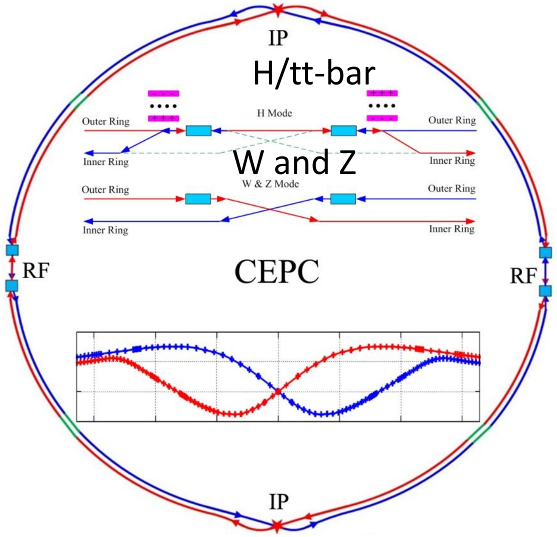
	Higgs	*W*	*Z (2T)*	*ttbar*
Number of IPs	2			
Circumference (km)	100.0			
Bunch number	268	1297	11934	35
β functions at IP β_x^*/β_y^* (m/mm)	0.3/1	0.21/1	0.13/0.9	1.04/2.7
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.87/1.7	0.27/1.4	1.4/4.7
Energy acceptance (%)	1.6	1.0	1.0	2.0
Luminosity per IP ($10^{34}cm^{-2}s^{-1}$)	**5.0**	**16**	**115**	**0.5**

Key technology R&D in TDR phase

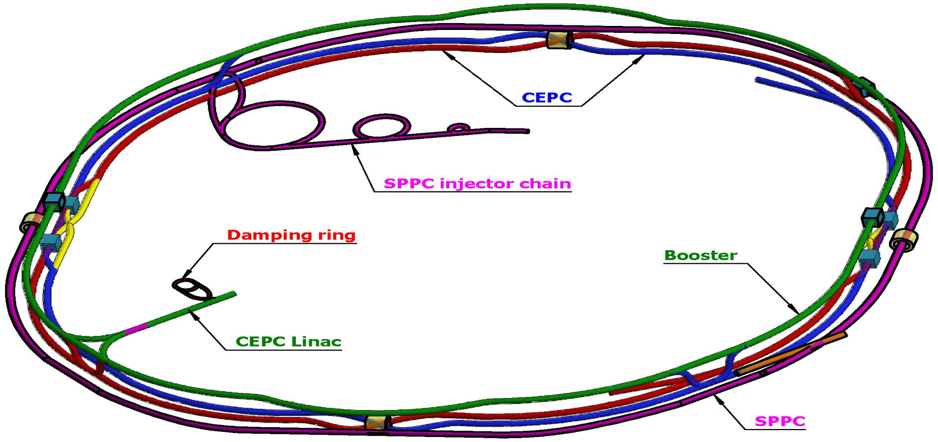
- **RF power supply and high efficiency klystron**
- **SRF cavities & modules (1.3G & 650MHz)**
- **Key components of the positron source**
- **High performance accelerator (S&C-band)**
- **Novel magnets: Weak field dipole, dual aperture magnets**
- **Injection/extraction**
- **Electrostatic deflector**
- **Vacuum chamber with NEG coating**
- **Instrumentation, Feedback system**
- **Cryogenic system**
- **Magnet power supply**

CEPC Higgs Factory and SppC in TDR

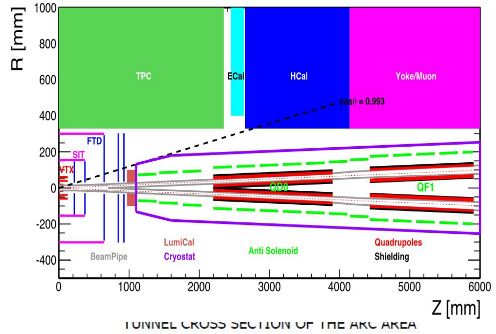
CEPC as a Higgs Factory： H, W, Z, upgradable to tt-bar, followed by a SppC (a Hadron collider) ~125TeV
30MW SR power per beam (upgradale to 50MW)

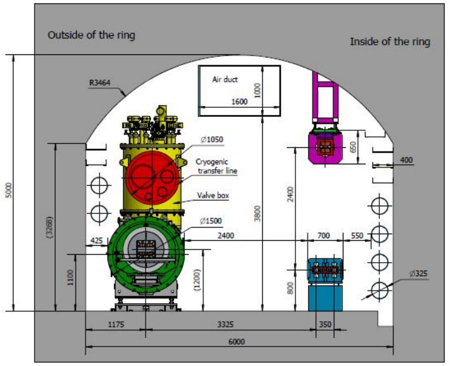


CEPC collider ring (100km)

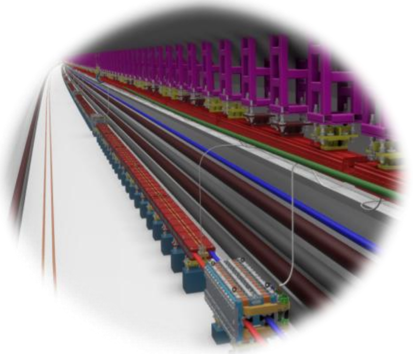


CEPC booster ring (100km)

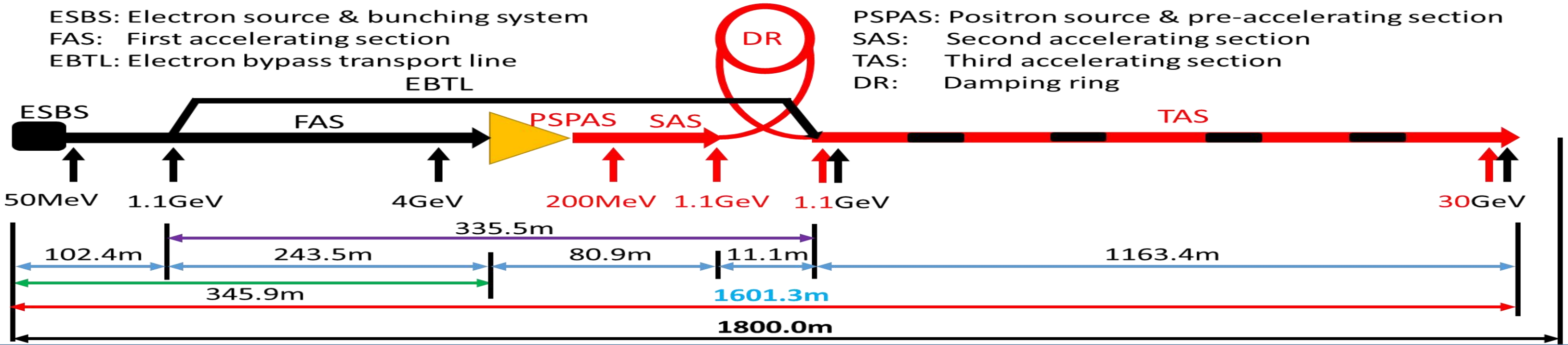




CEPC Civil Engineering



CEPC TDR S+C-band 30GeV linac injector



CEPC TDR Parameters

	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	100.0			
SR power per beam (MW)	**30**			
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	24.23	5.98	1.23
Bunch number	268	11934	1297	35
Bunch spacing (ns)	591 (53% gap)	23 (18% gap)	257	4524 (53% gap)
Bunch population (10^{11})	1.3	1.4	1.35	2.0
Beam current (mA)	16.7	803.5	84.1	3.3
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	2.5/8.7	2.5/4.9	2.2/2.9
Energy spread (natural/total) (%)	0.10/0.17	0.04/0.13	0.07/0.14	0.15/0.20
Energy acceptance (DA/RF) (%)	1.6/2.2	1.3/1.7	1.2/2.5	2.0/2.6
Beam-beam parameters ξ_x/ξ_y	0.015/0.11	0.004/0.127	0.012/0.113	0.071/0.1
RF voltage (GV)	2.2	0.12	0.7	10
RF frequency (MHz)	650			
Longitudinal tune ν_s	0.049	0.035	0.062	0.078
Beam lifetime (Bhabha/beamstrahlung) (min)	39/40	80/2800	60/700	81/23
Beam lifetime (min)	20	80	55	18
Hourglass Factor	0.9	0.97	0.9	0.89
Luminosity per IP (10^{34} cm^{-2} s^{-1})	**5.0**	**115**	**16**	**0.5**

CEPC TDR Parameters (upgrade)

	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**

CEPC Power and Energy Upgrade Plan

J.Y. Zhai

	Baseline			Power Upgrade			Energy Upgrade			
	Higgs	**W**	**Z**	**Higgs**	**W**	**Z**	$t\bar{t}$			
Collider SR power / beam [MW]	30			50			30		50	
Beam energy [GeV]	120	80	45.5	120	80	45.5	180			
Luminosity / IP [10^{34} $cm^{-2}s^{-1}$]	5	16	115	8.3	26.7	192	0.5		0.8	
Collider 650 MHz cavities	**2-cell**		**1-cell**	**2-cell**		**1-cell**	**Add 5-cell**	**Existing 2-cell**	**Add 5-cell**	**Existing 2-cell**
RF voltage [GV]	2.2	0.7	0.12	2.2	0.7	0.1	10 (6.1 + 3.9)		10 (6.1 + 3.9)	
Beam current / ring [mA]	16.7	84	801	27.8	140	1345	3.4		5.6	
Cavity number	192	96×2	30×2	336	168×2	50×2	192	336	192	336
Cryomodule number	32	32	60	56	56	100	48	56	48	56
Klystron number	96	96	60	168	168	100	48	168	96	168
Klystron power [kW]	800	800	1200	800	800	1200	800	800	800	800
Collider 4.5 K equiv. heat load [kW]	44.4	28.1	15.2	41.9	20	20.1	128.3		128.3	
Booster 1.3 GHz cavities	**9-cell**						**Add 9-cell**	**Existing 9-cell**	**Add 9-cell**	**Existing 9-cell**
Extraction RF voltage [GV]	2.17	0.87	0.46	2.17	0.87	0.46	9.7 (7.53 + 2.17)		9.7 (7.53 + 2.17)	
Beam current [mA]	1	3.1	16	1.4	5.3	30	0.12		0.19	
Cavity number	96	96	32	96	96	32	256	96	256	96
Cryomodule number	12	12	4	12	12	4	32	12	32	12
SSA number	96	96	32	96	96	32	256	96	256	96
SSA power [kW]	25	25	25	30	30	40	10	10	10	10
Booster 4.5 K equiv. heat load [kW]	7.8	3.1	3.5	8.1	3.2	3.7	11.4		11.4	
Total RF length [m]	**704**	**704**	**384**	**1088**	**1088**	**608**	**2368**		**2368**	
Total 4.5 K equiv. heat load [kW]	**52.2**	**31.2**	**18.7**	**50.0**	**23.2**	**23.8**	**139.7**		**139.7**	

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.

Collider Lattice Design for all Operational Modes (H,Z,W,ttbar)

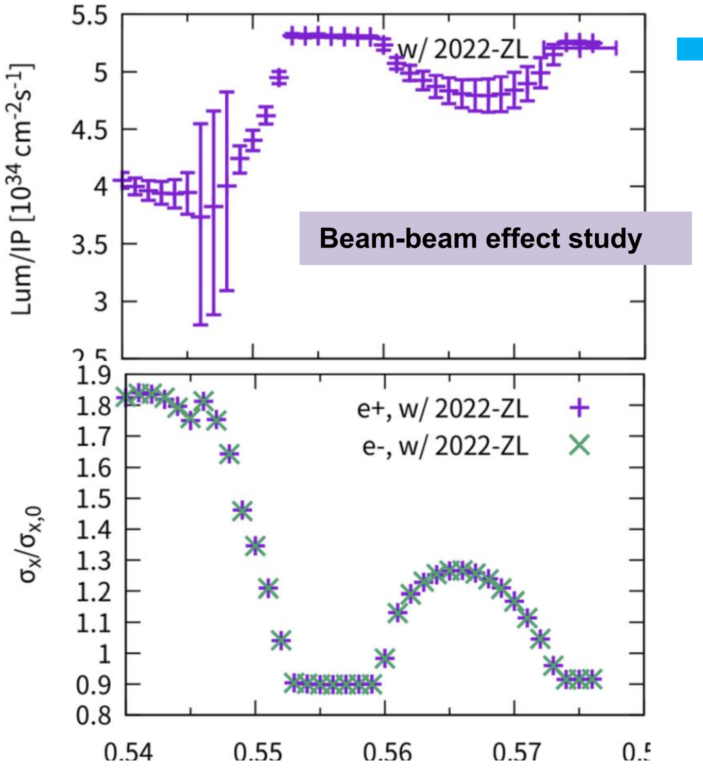
Goal

- e+e- circular collider as a high lumi. Higgs factory
- Compatible operation for Higgs, W, Z and Top runs
- Increasing Luminosity

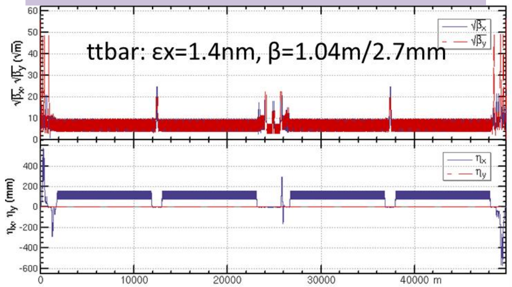
Design

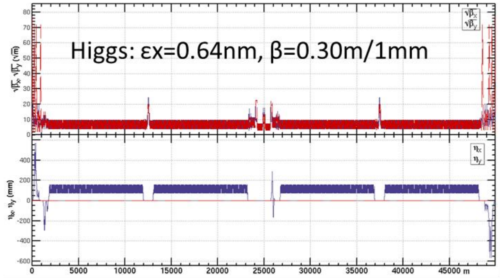
- Accelerator complex comprised of Linac, 100 km booster and collider ring
- Lattice optimization for all energies
- Sufficient DA for all four energies
- Beam-beam & collective instability
- Crab waist scheme with large cross angle and sextuples

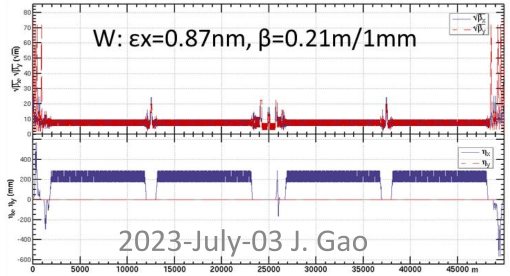
Beam-beam effect study

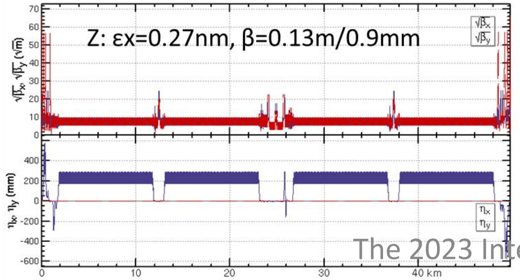


Lattice for all energies



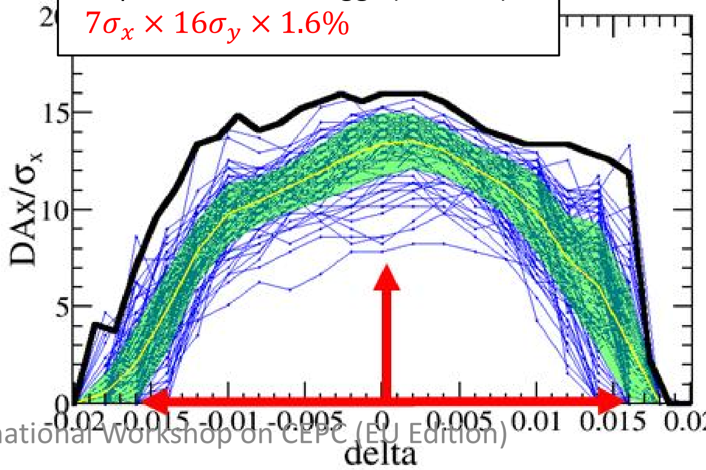


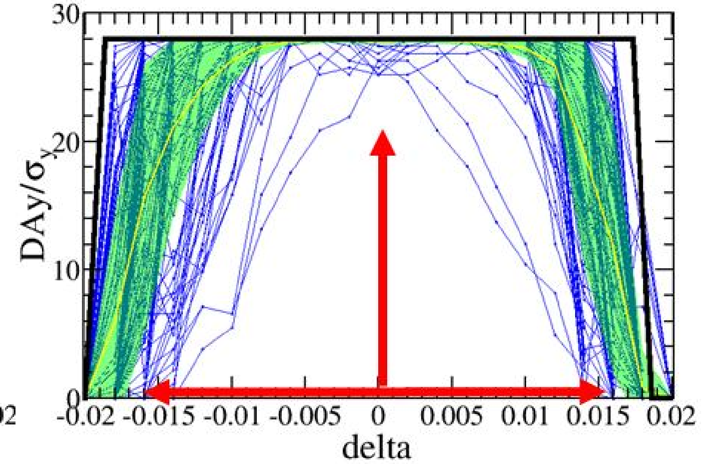




Dynamic Aperture (DA) optimization

Requirement met Higgs (w/error): $7\sigma_x \times 16\sigma_y \times 1.6\%$



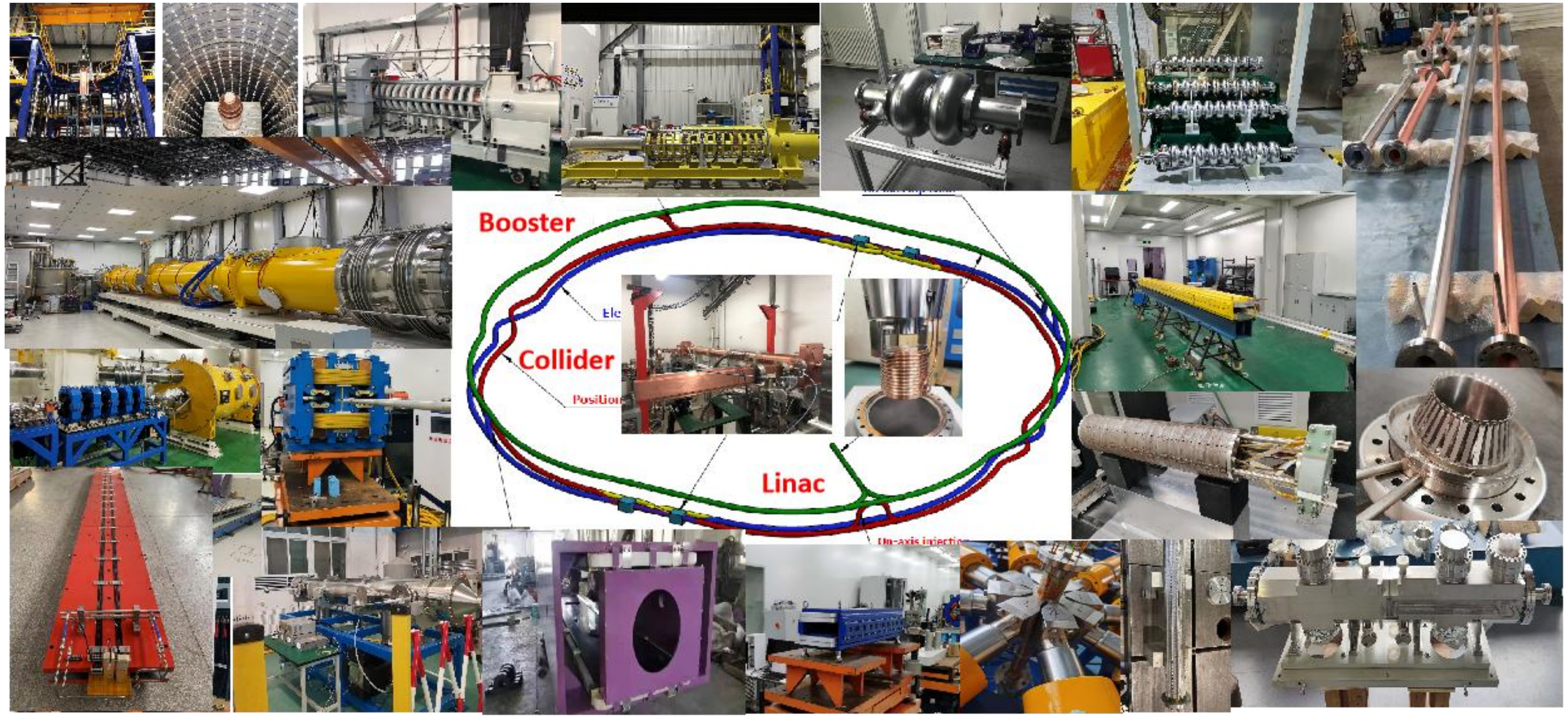


CEPC Key Technology R&D

Represented Key Technologies for the CEPC

Specification Met

Prototype Manufactured



Accelerator	Fraction
Magnets	27.3%
Vacuum	18.3%
RF power source	9.1%
Mechanics	7.6%
Magnet power supplies	7.0%
SC RF	7.1%
Cryogenics	6.5%
Linac and sources	5.5%
Instrumentation	5.3%
Control	2.4%
Survey and alignment	2.4%
Radiation protection	1.0%
SC magnets	0.4%
Damping ring	0.2%

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

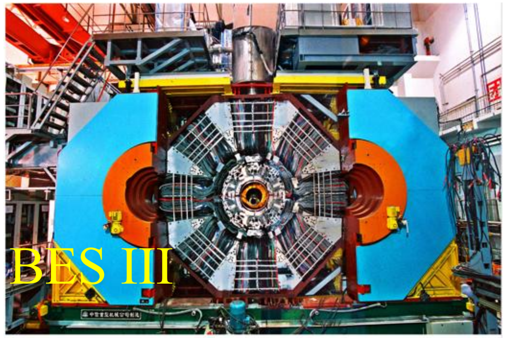
Key Technology Readiness

- 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, …

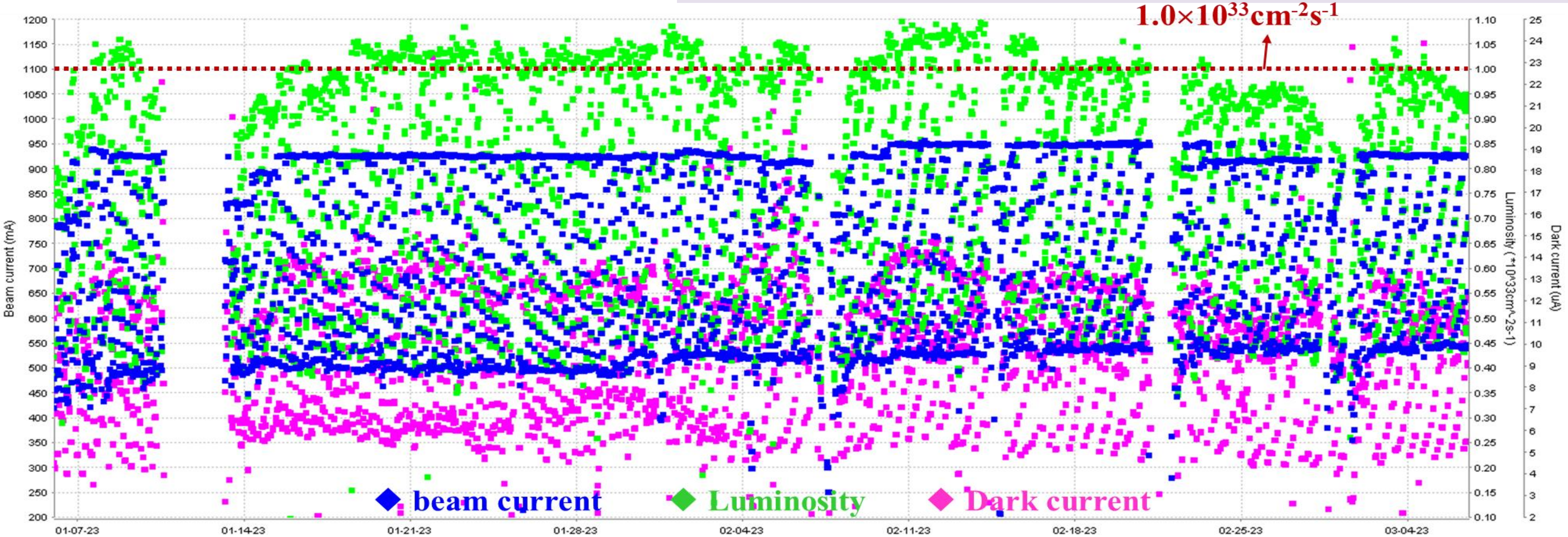
CEPC R&D **~ 30% cost of acc. components**	➢ **High efficiency klystron** ➢ **SRF cavities** ➢ **Positron source** ➢ **High performance accelerator**	➢ **Novel magnets: Weak field dipole, dual aperture magnets** ➢ **Extremely fast injection/extraction** ➢ **Electrostatic deflector** ➢ **MDI**
BEPCII / HEPS **~ 60% 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 and welcome.

Experiences in e+e- Collider Operation@IHEP



- BEPCII is in stable operation, and the beam current exceeds 900mA with the peak luminosity of $1.1\times10^{33}cm^{-2}s^{-1}$;
- In the last operation year, the accumulated luminosity reached as high as 8.1 fb^{-1};
- Rich experiences in achieving high luminosity have been accumulated;



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B. Wang

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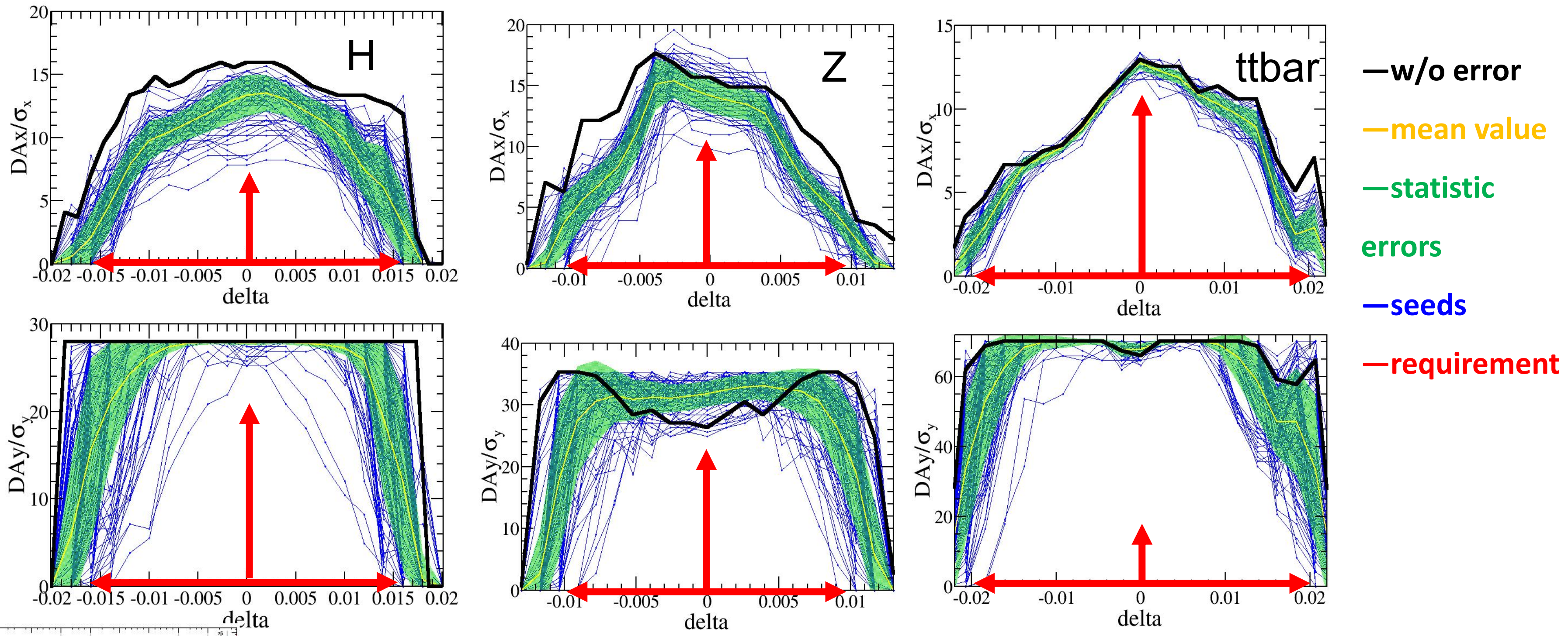
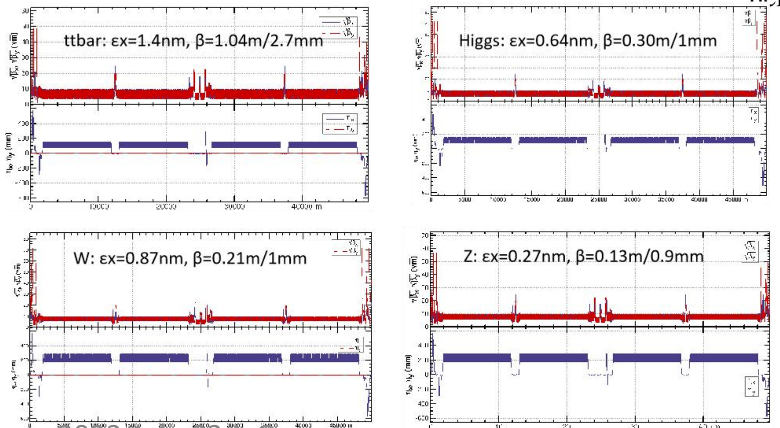


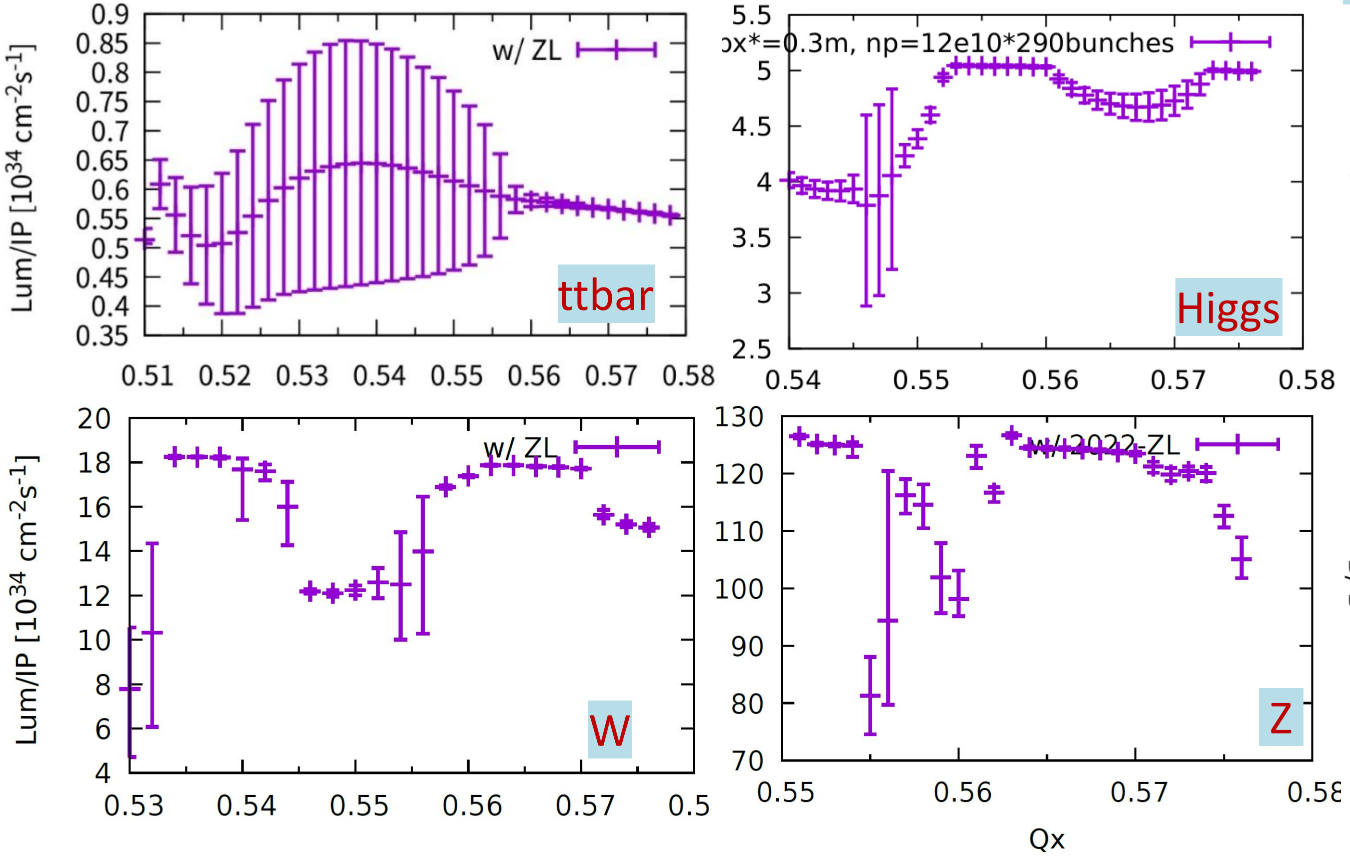


Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
Dipole	0.10	0.10	0.10	0.01%
Arc Quadrupole	0.10	0.10	0.10	0.02%
IR Quadrupole	0.10	0.10	0.10	0.02%
Sextupole	0.10*	0.10*	0.10	0.02%

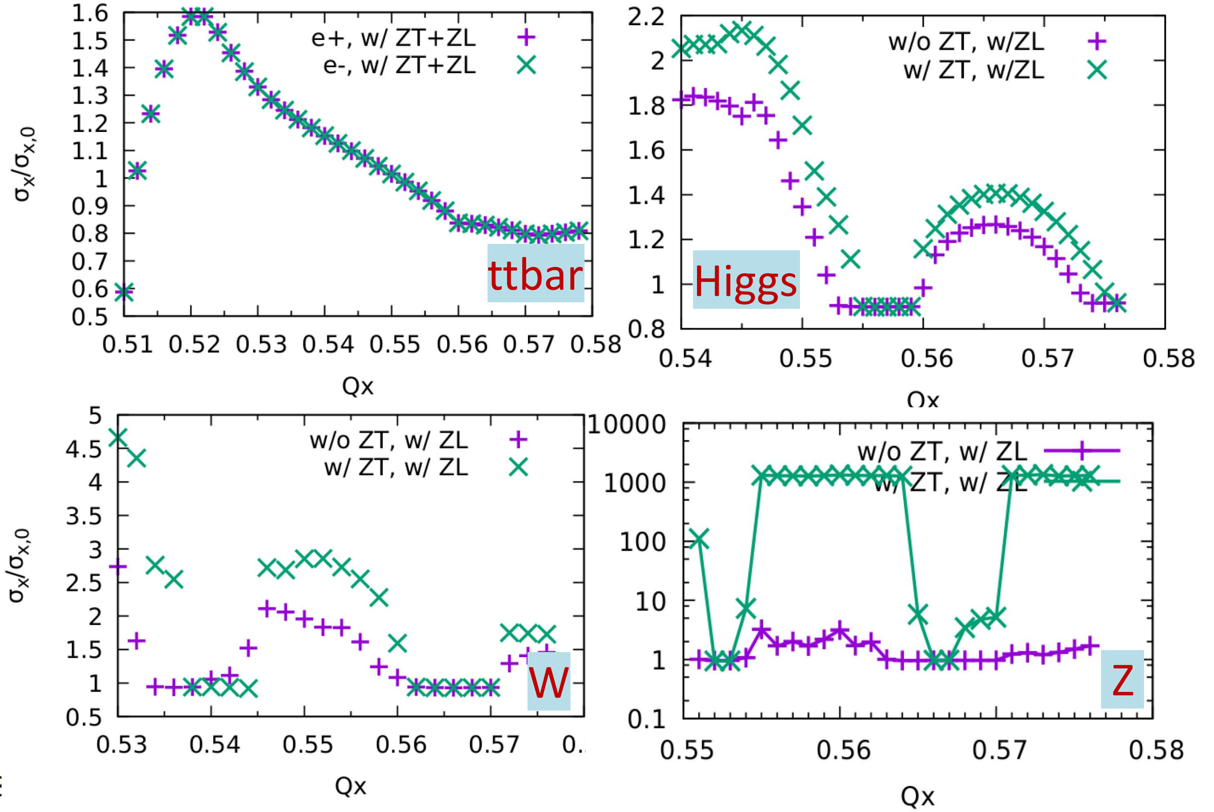
Study of Beam-Beam Effects in CEPC

Yuanzhang

■ 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

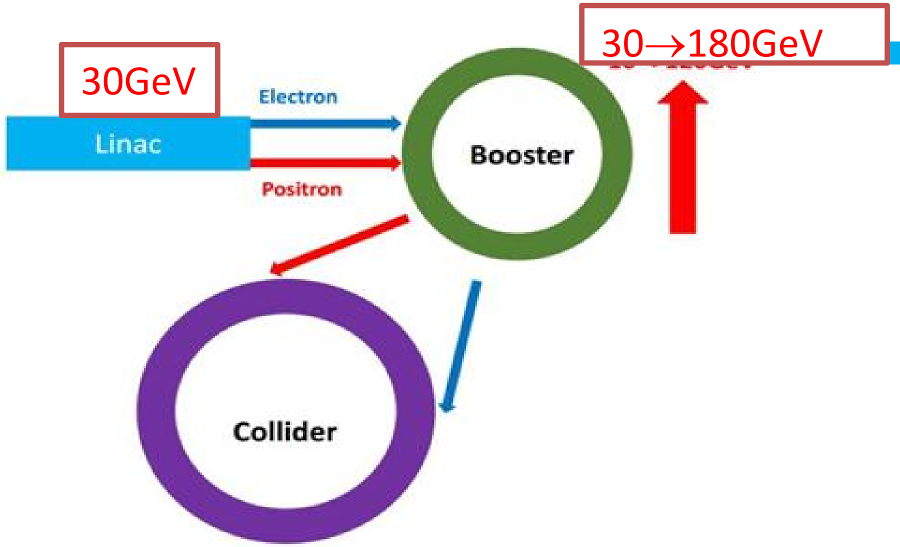
D. Wang

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				

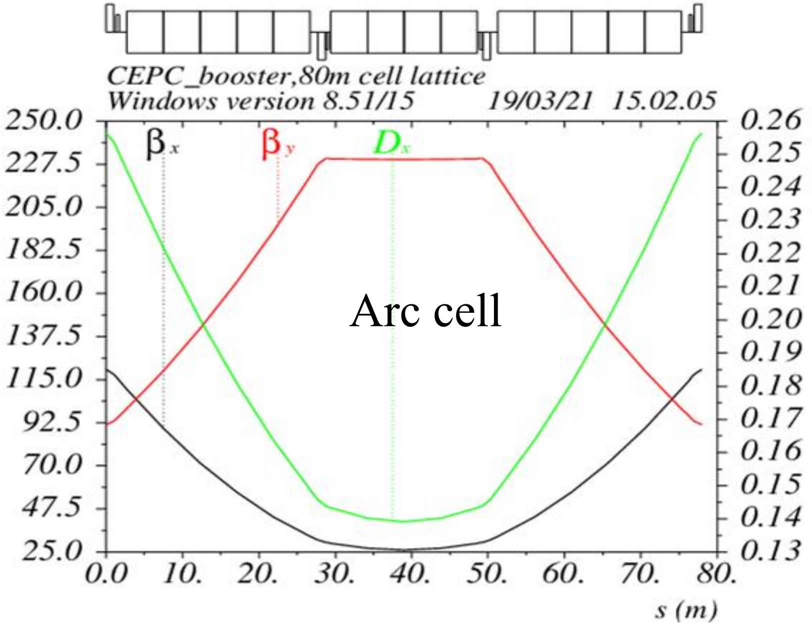
Extraction		*tt*	*H*		*W*	*Z*	
		Off axis injection	Off axis injection	On axis injection	Off axis injection	Off axis injection	
Beam energy	GeV	180	120		80	45.5	
Bunch number		35	268	261+7	1297	3978	5967
Maximum bunch charge	nC	0.99	0.7	20.3	0.73	0.8	0.81
Maximum single bunch current	μA	3.0	2.1	61.2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

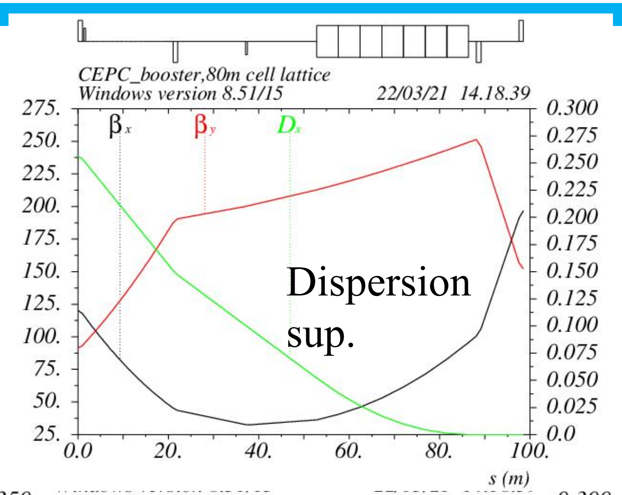
CEPC Booster Design

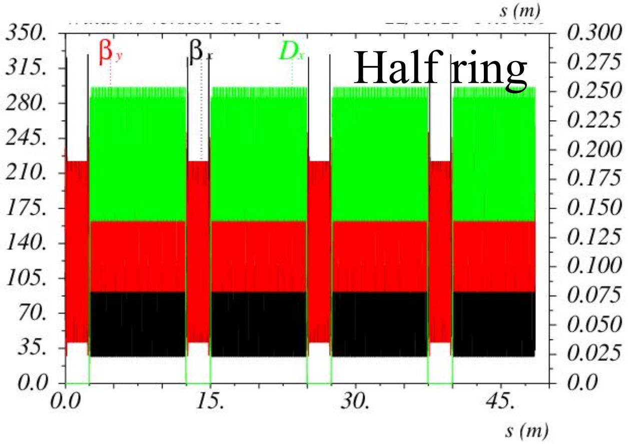
Dou Wang

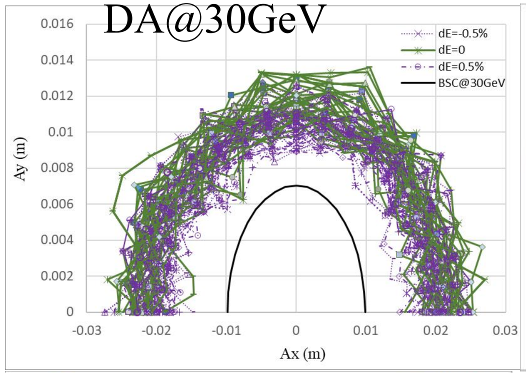


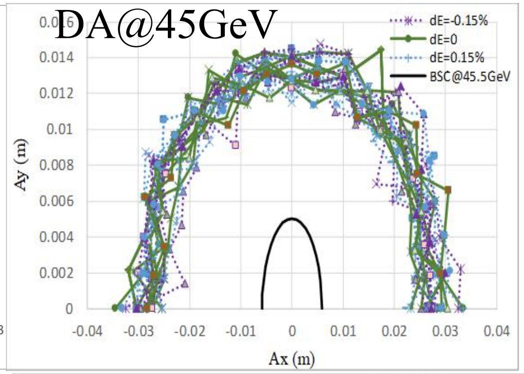
- TME like structure (cell length=78m)
- Interleave sextupole scheme
- Emittance@120GeV=1.26nm

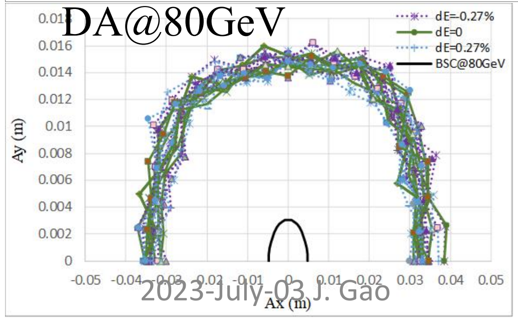


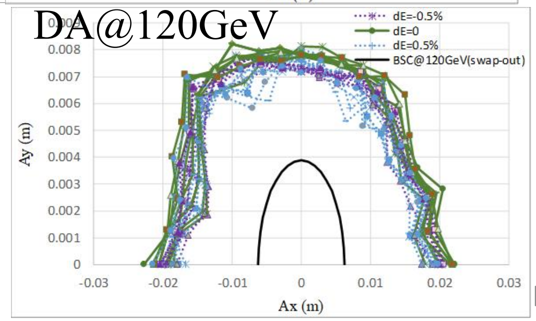










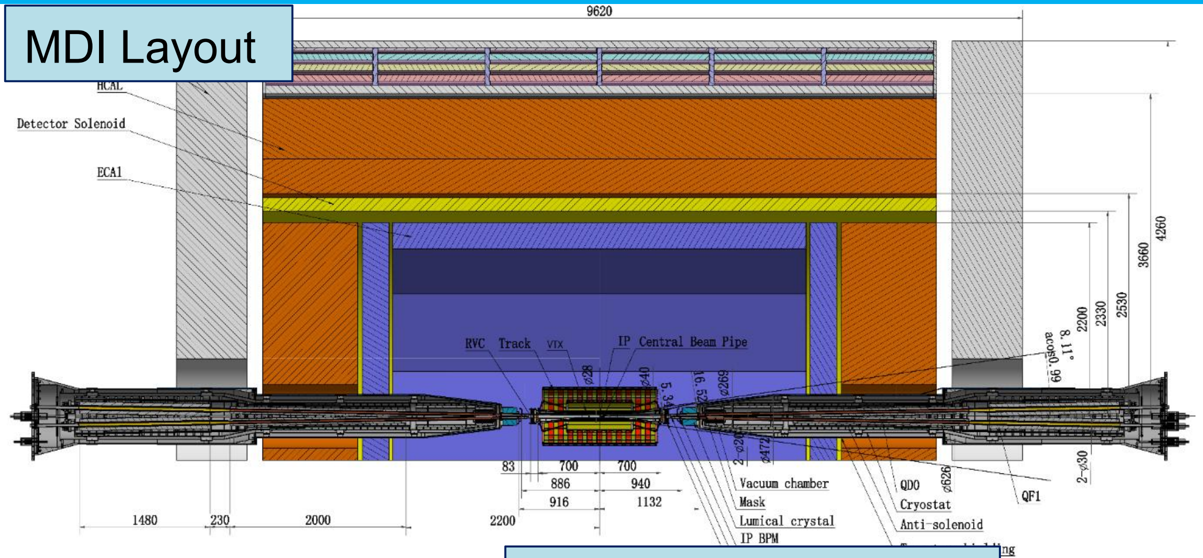


- 30 GeV injection energy, Maximum extraction energy @ 180GeV
- Lattice design with TME structure, lower emittance than CDR
- Sufficient Dynamic Aperture for all energies with errors

CEPC MDI Design

Sha Bai

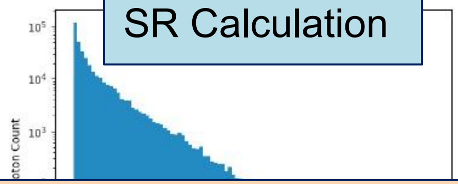
MDI Layout



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	62.71/105.2 8mm	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													

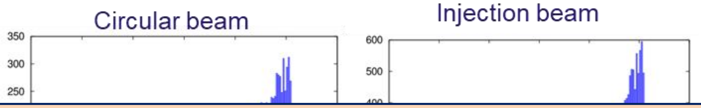
SR Calculation



Radiation background

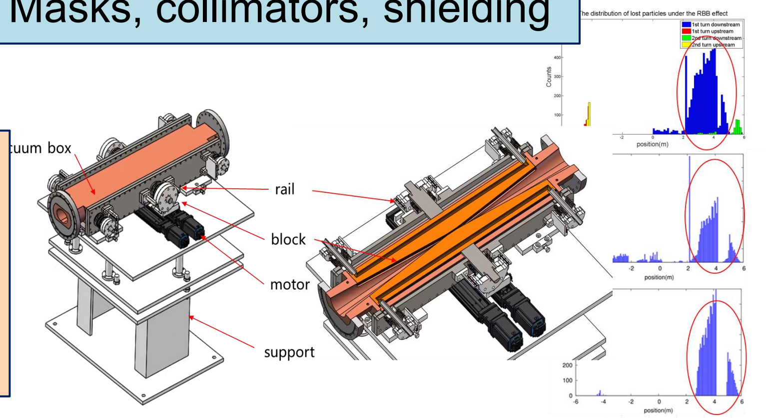
Radiative barbar, Beam-Gas, beam thermal photon scattering

Injection background

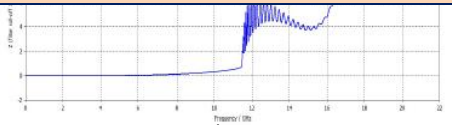


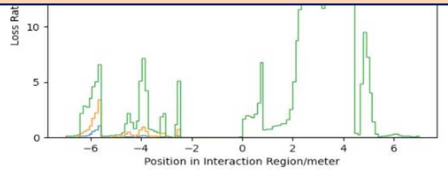
Radiation Mitigation

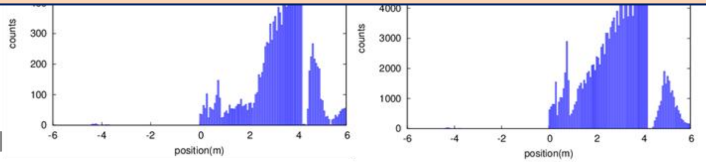
Masks, collimators, shielding

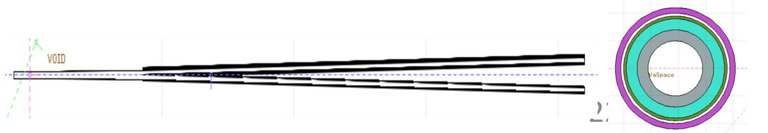


- A comprehensive design for MDI was made;
- The general parameters, including the superconducting magnet geometries, pipes sizes, masks, etc., were determined;
- Various radiation background was calculated and analyzed, and the mitigation measures were studied.









CEPC SRF System Design and Upgrade Plan

Jiyuan Zhai

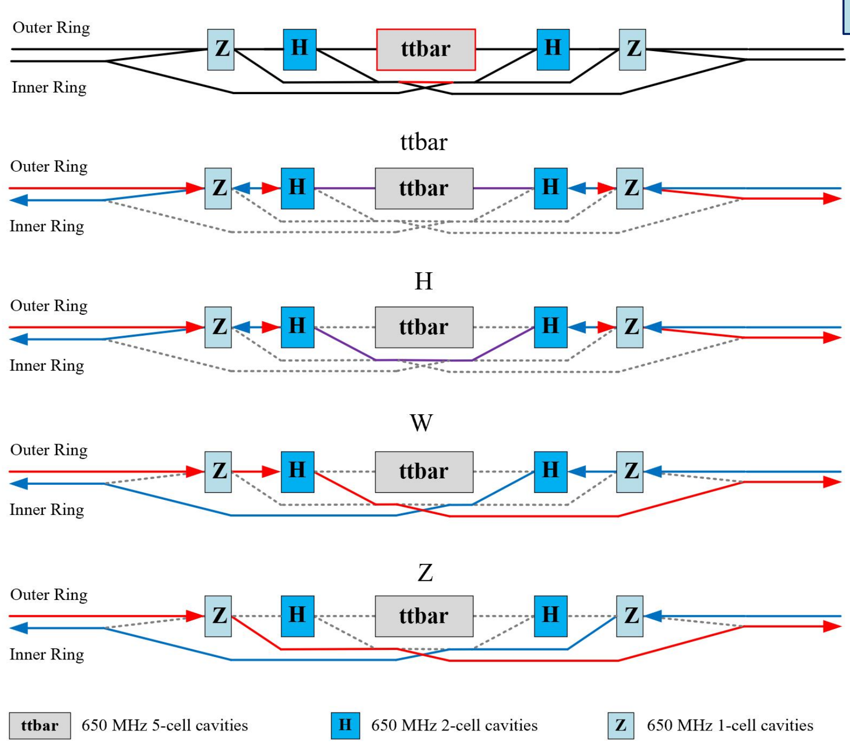
Collider 650MHz Parameters

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

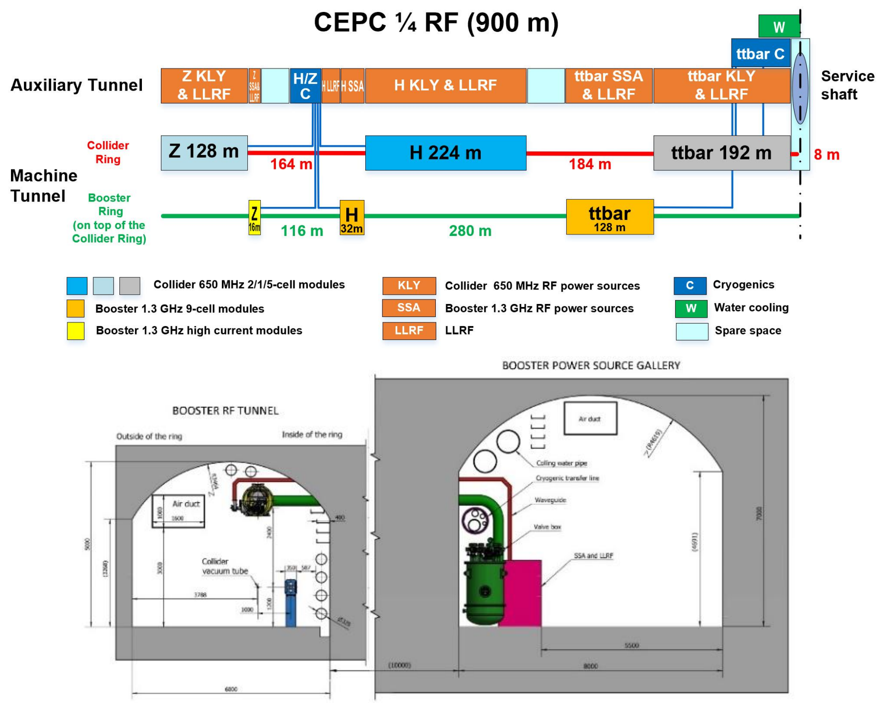
Booster 1.3GHz Parameters

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.

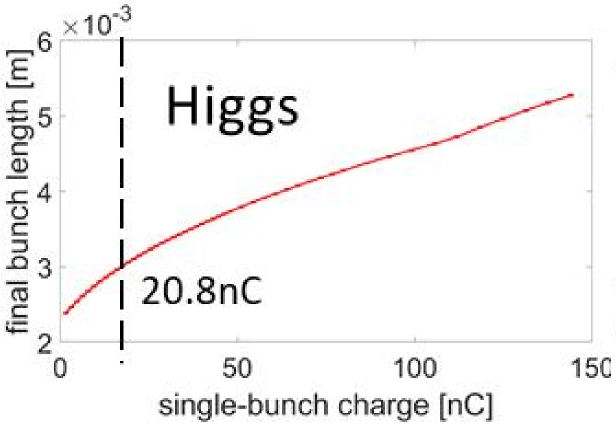
CEPC Collective Instabilities

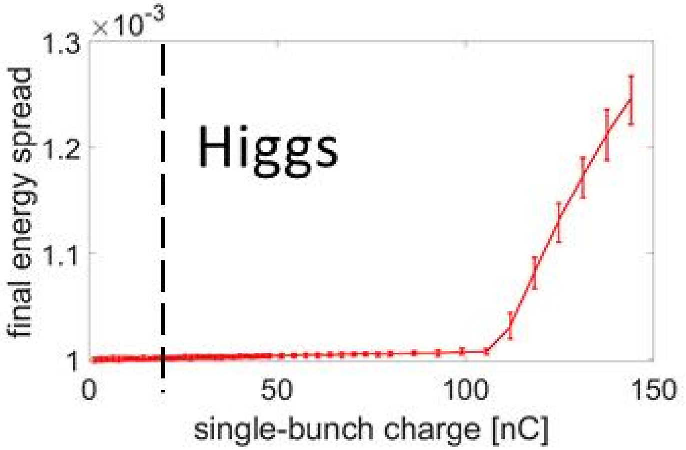
Na Wang

Impedance budget @ σ_z=3mm

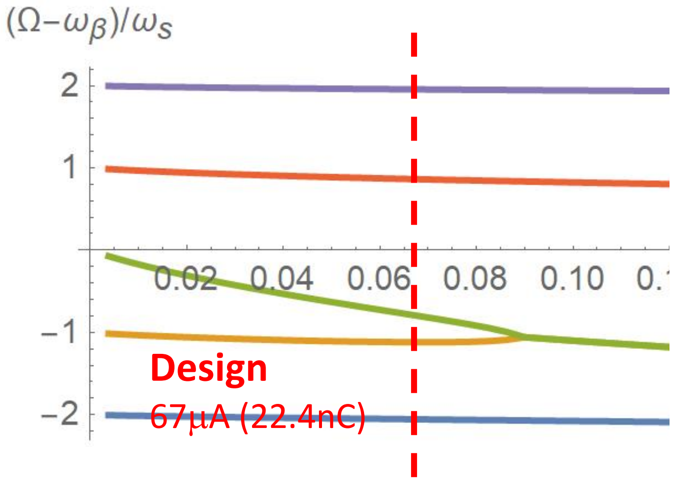
Components	Number	$Z_{\|\|}/n$, mΩ	L, nH	k_{loss}, V/pC	k_y, kV/pC/m
Resistive wall	-	6.2	329.2	363.7	11.3
RF cavities	60	0.5	24.8	101.2	0.5
Flanges	37714	5.2	276.1	37.3	5.2
BPMs	1808	0.04	2.0	9.5	0.2
Bellows	15949	2.9	154.6	87.4	3.9
Gate Valves	500	0.2	11.4	14.5	0.4
Pumping ports	5316	0.3	18.4	2.3	0.2
Collimators	16	0.04	1.7	23.4	0.6
IP chambers	2	0.004	0.2	0.3	0.05
Electro-separators	20	-0.1	-5.4	34.5	0.1
Taper transitions	48	0.04	2.3	2.5	0.09
Total		**15.3**	**815.3**	**676.6**	**22.5**

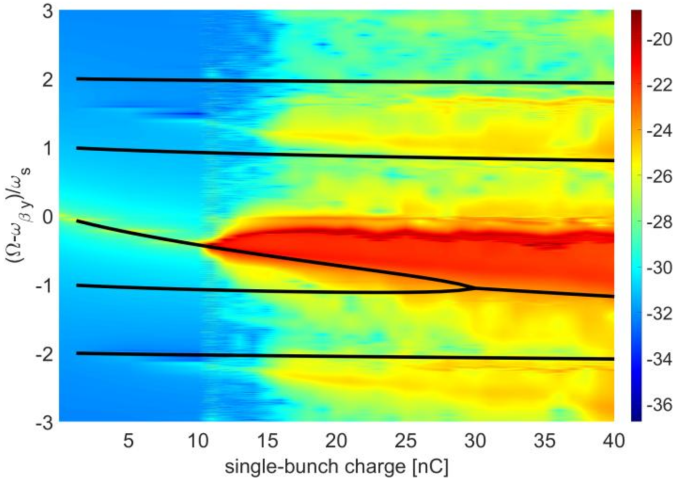
Bunch lengthening and microwave instability





TMCI w/ZL

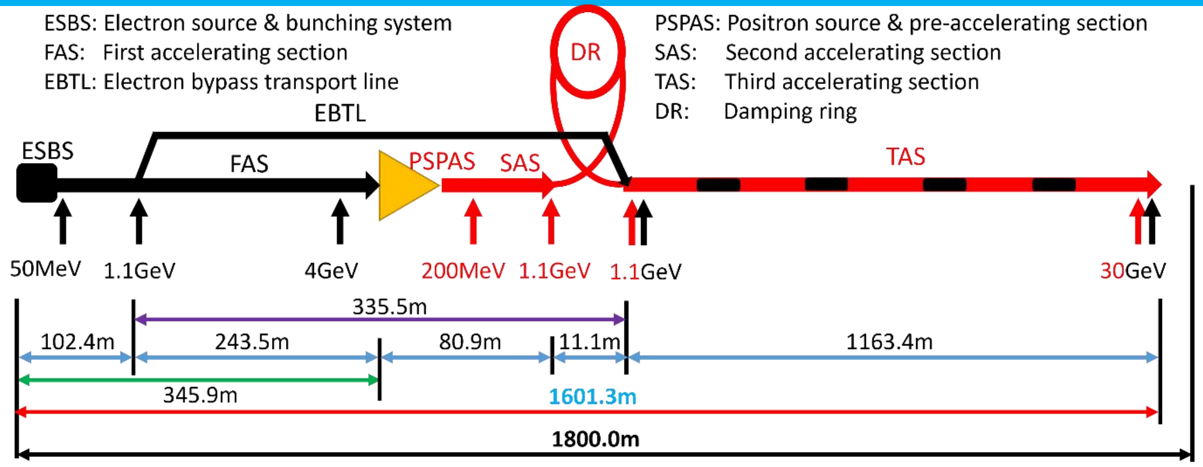




- No show stoppers exist for Higgs, W and ttbar;
- Main constraints from the beam collective effects are at the Z;
- The Booster show no constraints from single bunch and CSR effect, however, bunch-by-bunch feedback is required to damp the TRWI;
- No constraints observed from the Damping ring, and the impedance will lengthen the bunch by ~2%, which still meet the requirement from injections

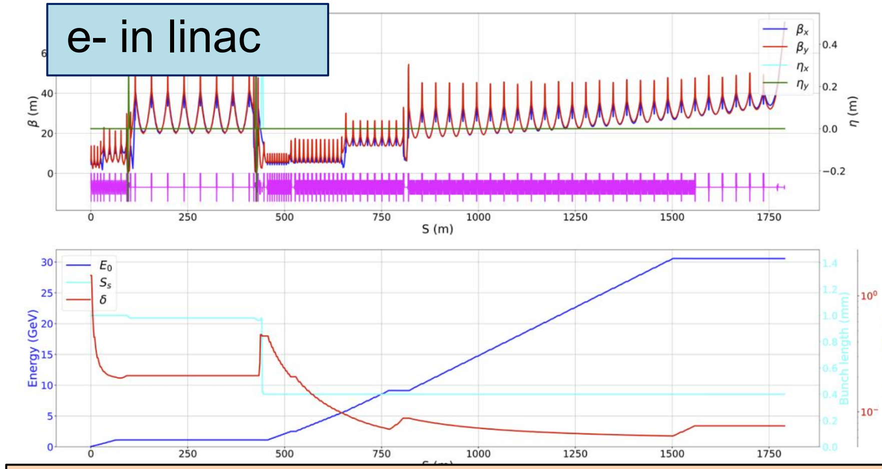
CEPC Electron and Positron Injection Linac Designs

Cai Meng

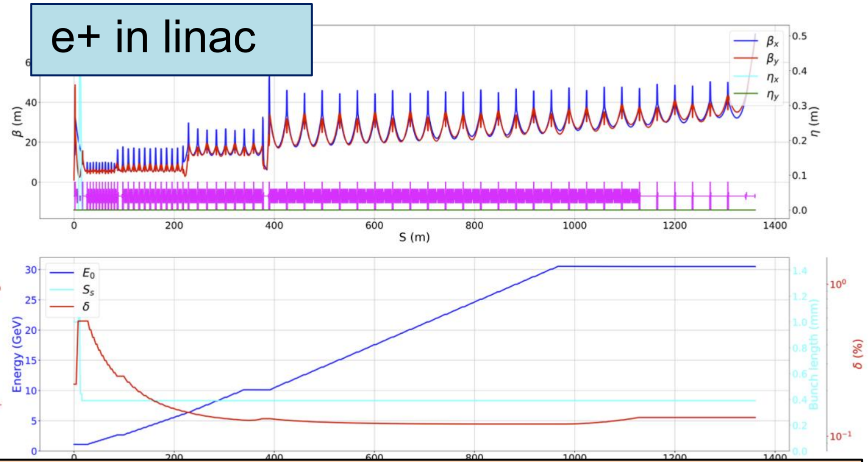


Parameter	Symbol	Unit	Design value
Energy	E	GeV	30
Repetition rate	f_{rep}	Hz	100
Number of bunches per pulse			1 or 2
Bunch charge		nC	1.5
Energy spread	σ_E		1.5×10^{-3}
Emittance	ε_r	nm	6.5
Electron energy at target		GeV	4
Electron bunch charge at target		nC	10
Tunnel length	L	m	1800

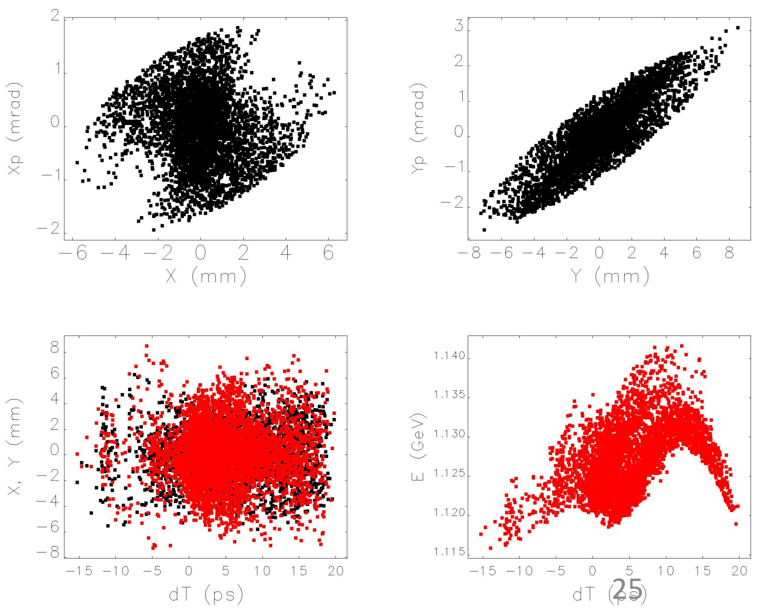
e- in linac



e+ in linac



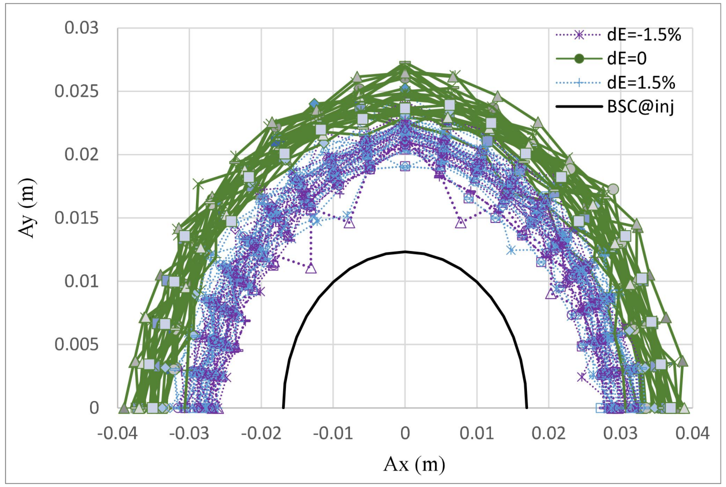
Phase space @ SAS exit



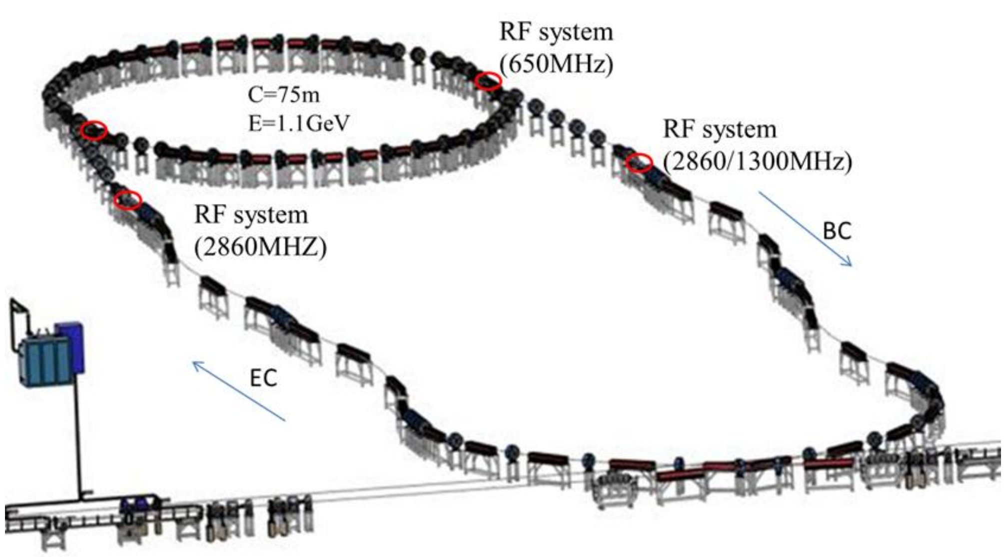
- Linac energy increases to 30 GeV, with S+C band Accelerator;
- Start-to-end simulations were conducted for both electron/positron beams, with quality satisfying requirements.

CEPC Damping Ring Parameters

D. Wang



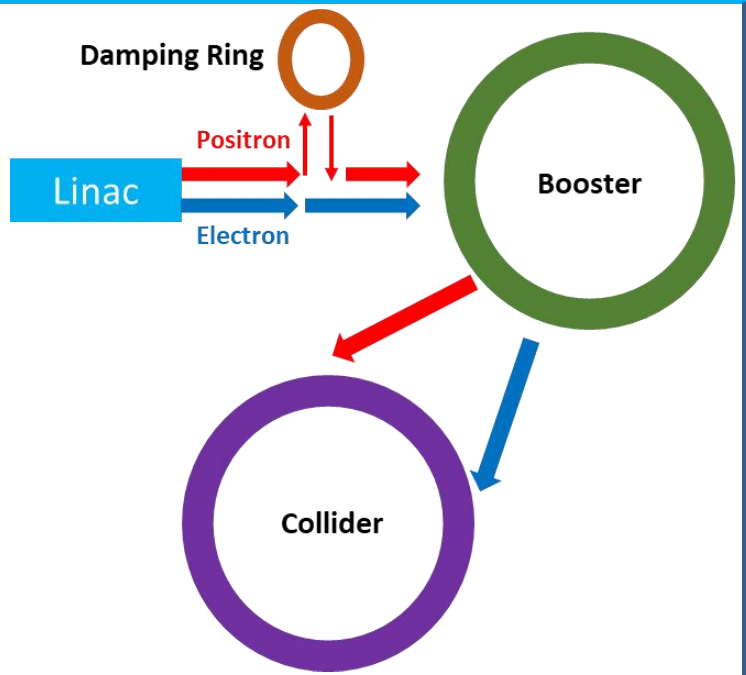
Dynamic aperture



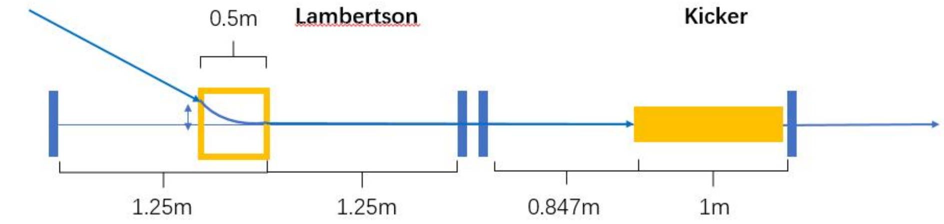
	DR V3.0
Energy (Gev)	1.1
Circumference (m)	147
Number of trains	2 (4)
Number of bunches/trian	2
Total current (mA)	12.4 (24.8)
Bending radius (m)	2.87
Dipole strength B_0 (T)	1.28
U_0 (kev/turn)	94.6
Damping time x/y/z (ms)	11.4/11.4/5.7
Phase/cell (degree)	60/60
Momentum compaction	0.013
Storage time (ms)	20 (40)
δ_0 (%)	0.056
ε_0 (mm.mrad)	94.4
injection σ_z (mm)	4.4
Extract σ_z (mm)	4.4
ε_{inj} (mm.mrad)	2500
$\varepsilon_{ext\ x/y}$ (mm.mrad)	166(97)/75(3)
δ_{inj} /δ_{ext} (%)	0.18 /0.056
Energy acceptance by RF(%)	1.8
f_{RF} (MHz)	650
V_{RF} (MV)	2.5
Longitudinal tune	0.0387

CEPC Transport Lines and Timing

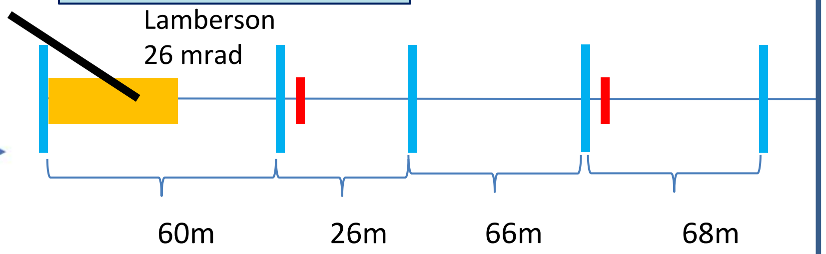
Xiaohao Cui



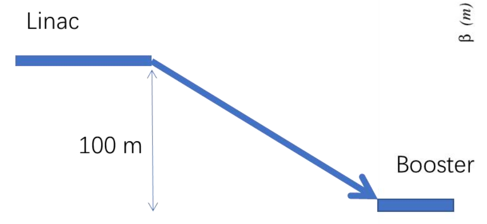
Linac to DR

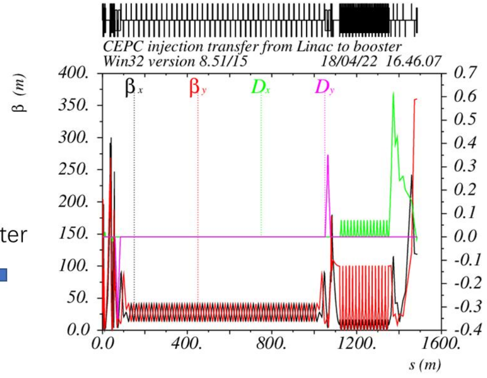


Booster to collider

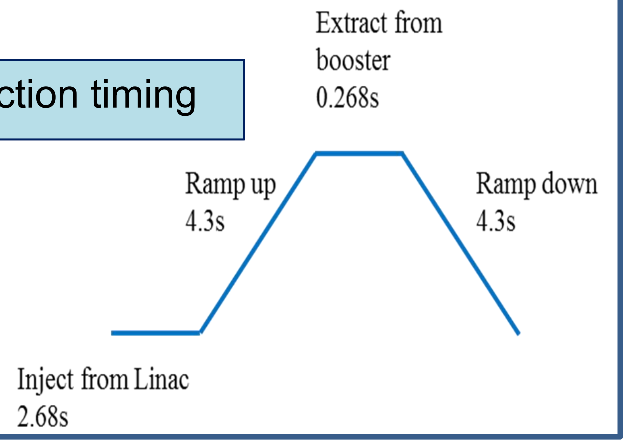


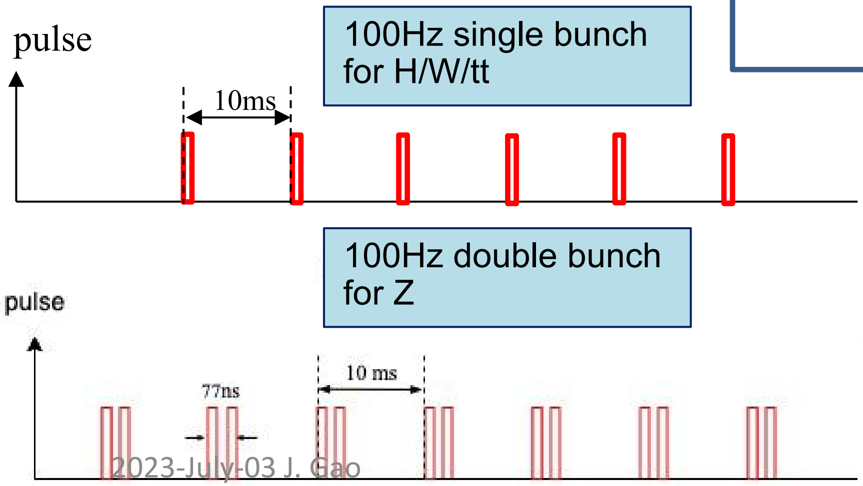
Injection to Booster



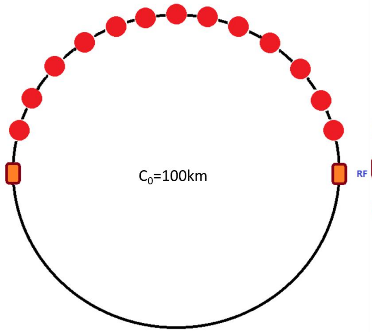


H injection timing

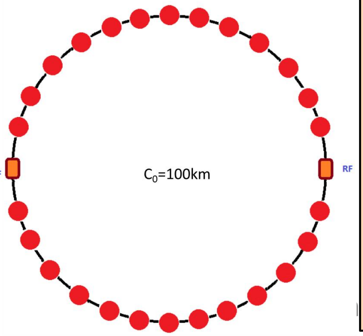




Higgs/ttbar



W/ Z

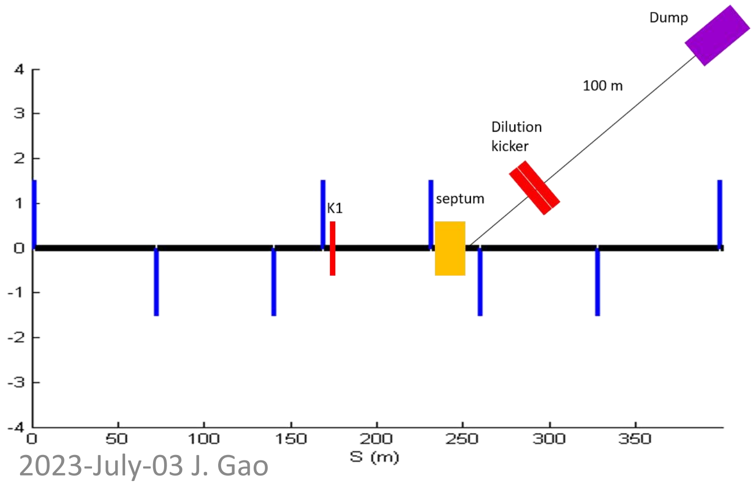


- There are a number of transport lines in the CEPC accelerator complex.
- All transport lines are designed;
- Injection/ramping timing was given for different energies

CEPC Machine Protection, Beam Abort and Dump System

X.H. Cui
G.Y. Tang

- A set of kicker magnets has been used to dilute the beam horizontally and vertically;
- The area of bunch distribution in front of dump is assumed to be 6cm x 6cm; These dimensions haven't been optimized yet.
- The length of transfer tunnel is about 100m; the diameter is about 2m, considering the vacuum equipment, pipe installation.



		Extraction kicker	Septum	Dilution kickers
Length (m)		2	20	10
Magnetic flux density (Gauss)	Z	281		40
	WW	494		
	Higgs	741	7000	
	ttbar	1110		

Beam dump graphite core (example) temperature rise

	Higgs	WW	Z	ttbar
Beam energy/GeV	120	80	45.5	182.5
Ne/bunch/10^{10}	14	13.5	14	20
Bunch number (50MW)	415	2162	19918	58
Max. temperature rise	510 ± 15℃	1020 ± 30℃	2620 ± 15℃	
Maximum temperature rise by one bunch	7.31 ± 0.03℃	5.38 ± 0.03℃	3.76 ± 0.02℃	10.08 ± 0.04℃

Radiation and Environment Studies

Radiation in the rock around the tunnel

			Case 1		
		Half-life	Specific activity/GB18871	Activity/GB18871	Stat. error (%)
Beam losses @Z-pole	Ar37	35d	4.45E-08	8.52E+01	0.697
	Cl36	3e5a	1.45E-11	2.77E-02	0.563
	S35	87d	9.35E-09	1.79E+00	6.826
	P33	25d	5.57E-09	1.07E+00	8.923
	P32	14d	1.44E-06	2.76E+03	5.557
	Si31	2.6h	6.82E-04	1.31E+05	0.123
	Na24	15h	3.26E-01	6.24E+06	0.113
	Na22	2.6y	7.20E-04	1.38E+03	1.322
	F18	1.8h	7.62E-04	1.46E+03	2.468
	O15	122s	1.34E-03	2.58E+01	0.694
	C14	5700y	3.47E-10	6.65E-02	1.337
	Be7	53d	2.09E-05	4.00E+02	1.632
	H3	12a	5.90E-09	1.13E+00	0.884

			Case 1		
		Half-life	Specific activity/GB18871	Activity/GB18871	Stat. error (%)
SR @ttbar	C14	5700a	1.5e-12	2.9e-4	99
	H3	12a	9.5e-11	1.8e-2	71

Radiation in the air of the tunnel

G.Y. Tang

			Case 1			Case 2		
		Half-life	Specific activity/GB18871	Activity/GB18871	Stat. error (%)	Specific activity/GB18871	Activity/GB18871	Stat. error (%)
Beam losses @Z-pole	O15	122s	2.7e-4	0.13	52	3.2e-4	0.15	17
	C14	5700a	7.7e-7	3.6	1	3.2e-7	1.5	0.5
	Be7	53d	1.1e-5	5.4	57	1.0e-5	4.8	27
	H3	12a	3.5e-9	1.7e-2	32	3.9e-9	1.8e-2	10
	P32	14d	---	---	---	1.9e-7	9.0	100
	P33	25d	1.9e-8	9.0e-2	100	3.8e-9	1.8e-2	100
	Cl36	3e5a	---	---	---	1.6e-14	7.7e-7	100
	Cl38	37m	---	---	---	7.e-5	3.6	61
	Ar37	35d	6.1e-9	0.29	59	1.4e-9	6.5e-2	38
	Ar41	2h	1.4e-3	0.65	12	5.4e-4	0.26	6
SR @ttbar	C14	5700a	6.5e-6	31	2	2.5e-6	11.7	3
	Ar41	2h	1.5e-2	7.2	20	3.3e-3	1.6	29

Radiation in the cooling water

			Case 1			Case 2		
		Half-life	Specific activity/GB18871	Activity/GB18871	Stat. error (%)	Specific activity/GB18871	Activity/GB18871	Stat. error (%)
Beam losses @Z-pole	O15	122s	2.44	2.76	10	2.37	2.67	3
	C14	5700a	3.5e-7	3.9e-3	23	3.4e-7	3.9e-3	9
	Be7	53d	1.3e-2	15.2	34	1.3e-2	14.4	12
	H3	12a	2.3e-6	2.6e-2	22	2.8e-6	3.2e-2	7
SR @ttbar	None							

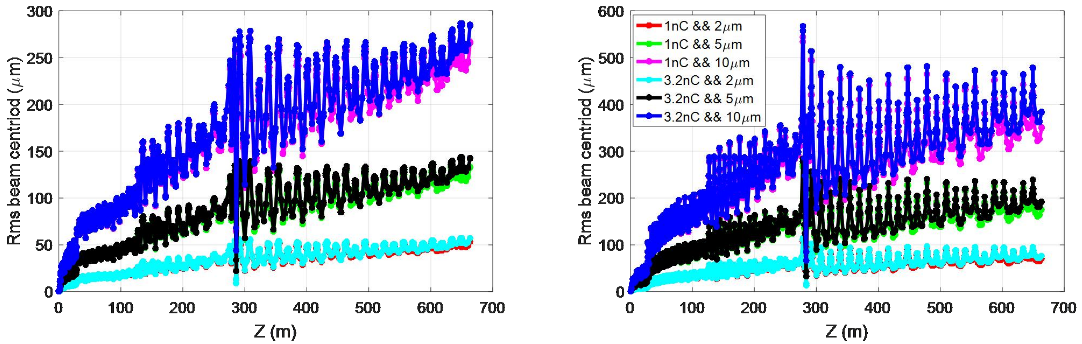
Preliminary Studies on CEPC Ground Motion

Y.W. Wang, C. Meng

- Ground motion will increase cause beam orbit variation and also beam emittance

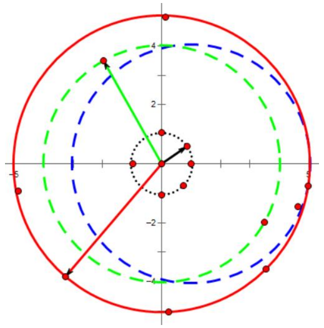
$$\frac{\Delta L}{L} \cong -\frac{(\Delta y/\sigma_y)^2}{4}$$

Amplitudes of ground motion (<100Hz) 4nm, 10nm, correspond to 1% or 6% Luminosity reduction

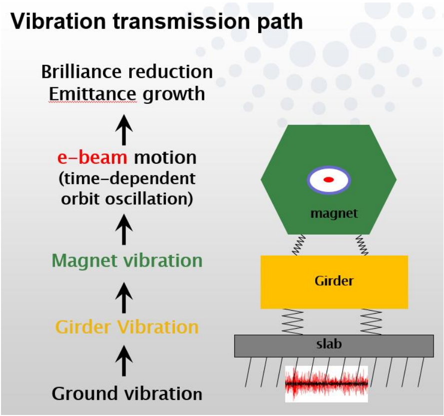


CEPC beam orbit variation in linac due to ground motion

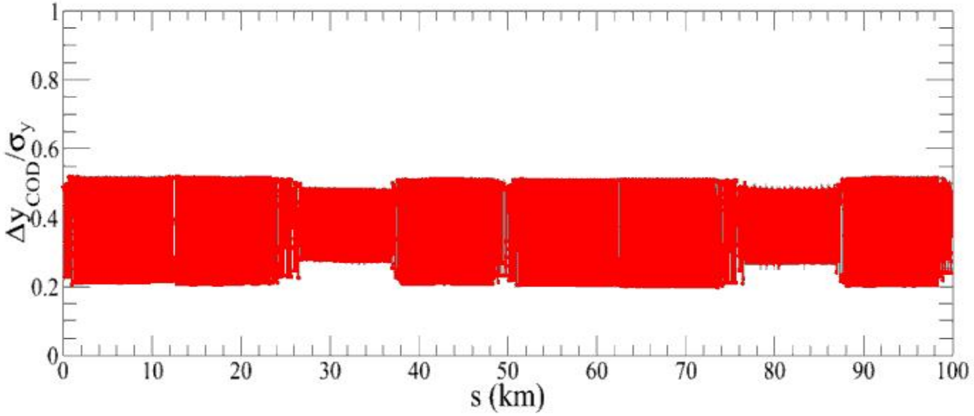
With ground motion amplitude of 100nm, linac effective emittance increse 20%



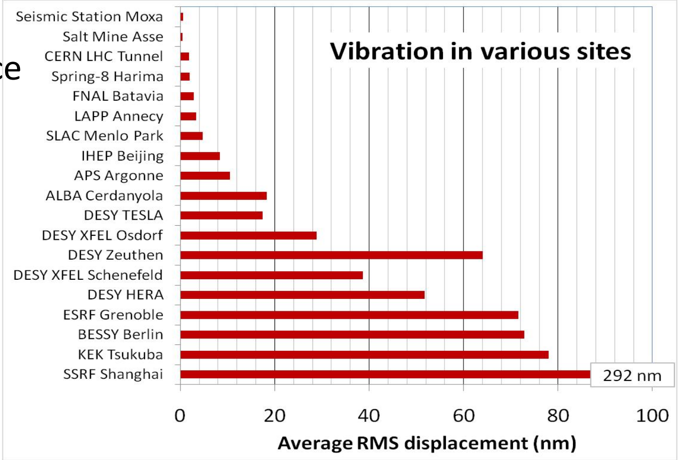
Effective emittance increase due to orbit variation



Ground vibration transmission to colliding beams



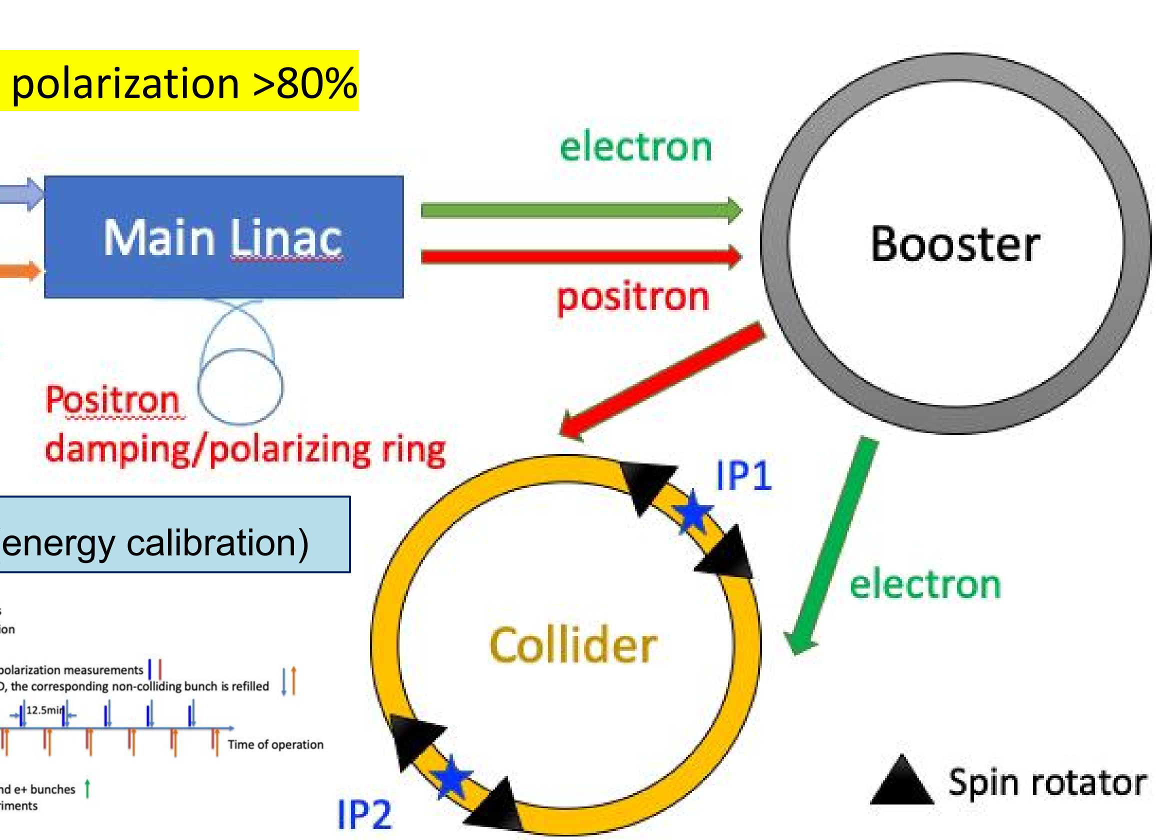
CEPC colliding beam orbit variation due to ground motion



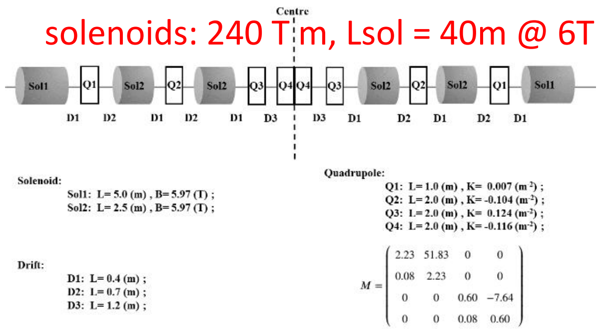
Ground vibration in different sites, LHC site is a good reference~3nm

CEPC Polarized Beam Studies

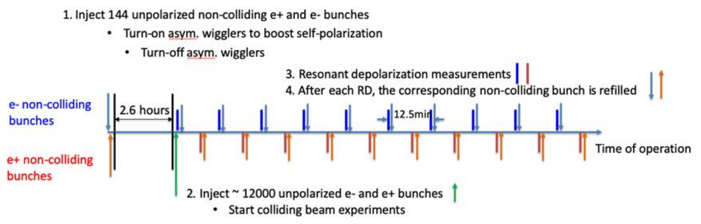
Z. Duan

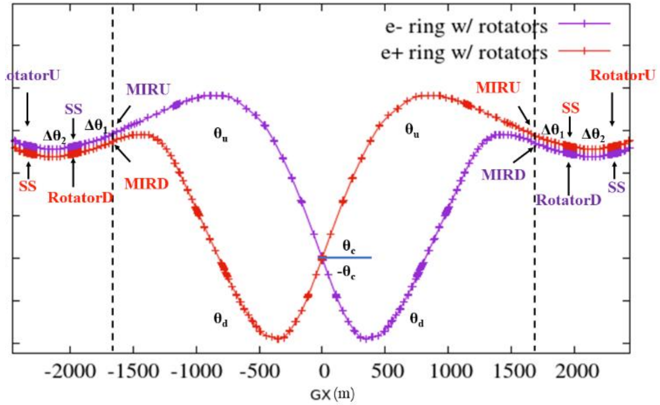


Spin rotator design



Self polarization (energy calibration)





Key issues of study:

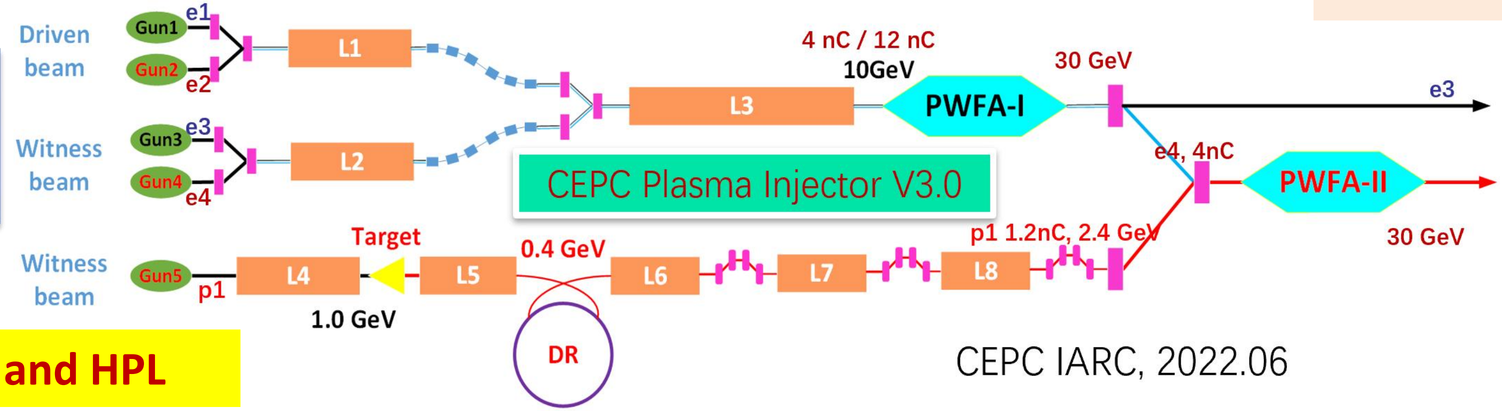
- Energy calibration in collider ring with transverse polarization (self polarization & inj. polarization)
- Longitudinal polarization for collision
- Polarization beam injection, positron polarization and ramping in booster

CEPC Plasma Injector (alternative option) and TF Plan

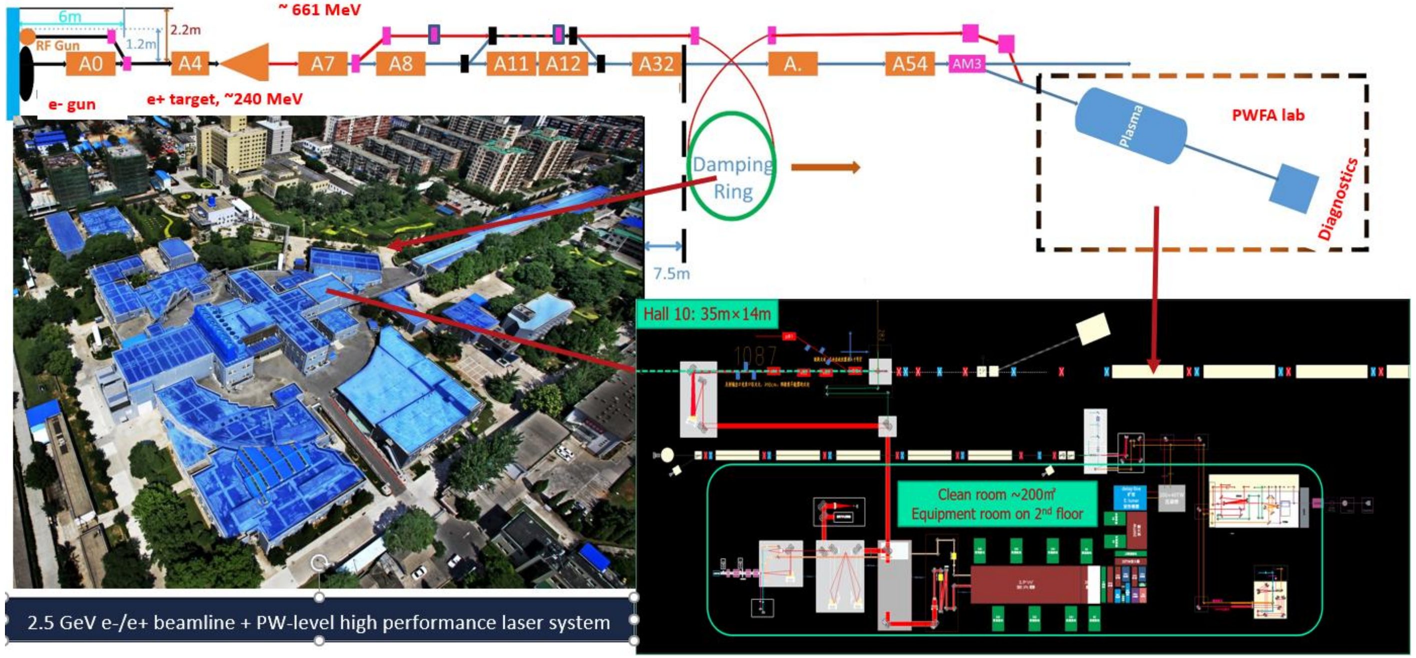
D.Z. Li

CEPC injector's baseline was changed:

10 GeV → 30 GeV → **TR ≥ 2**



PWFA TF based on BEPC-II Linac and HPL



Phase I（Year0-Year2）

1. Re-design and install transport beamline and FF system, optimize the e- / e+ beam quality
2. Clean room and high power laser system (200 / 400 TW) installation200TW
3. Beam instrumentation system installation
4. RF Gun platform construction
5. Commissioning and experimental test for all the systems

Phase II（Year3-Year4）

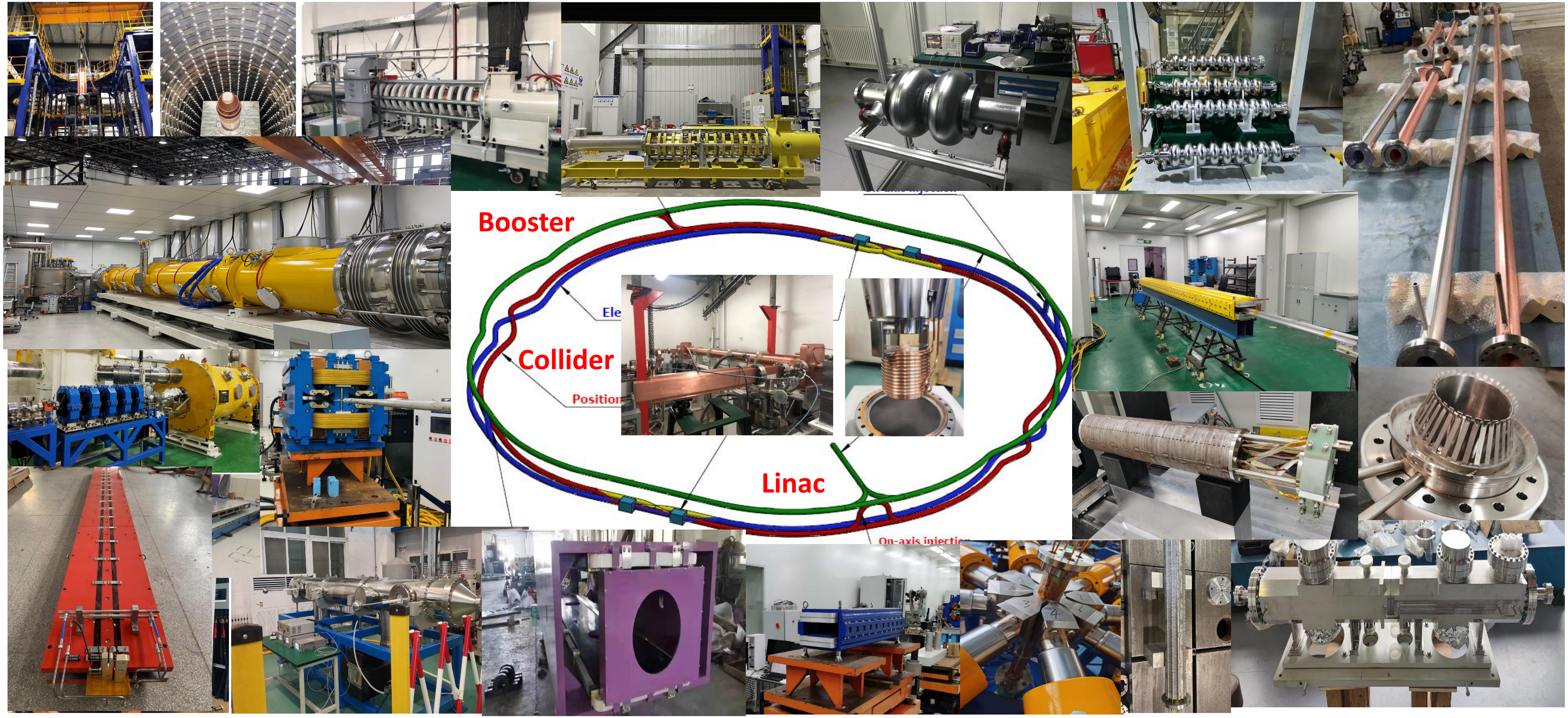
1. Upgrade the laser system, two beamlines (1PW + 20/40 TW)
2. Test the L-band RF gun on platform and install it on the BEPC-II linac

Phase III（Year5-）

1. Add a positron dumping ring the bunch compression beamline to improve the e+ quality
2. PBA-based FEL studies

Contents

CEPC TDR R&D Status of Key Technologies



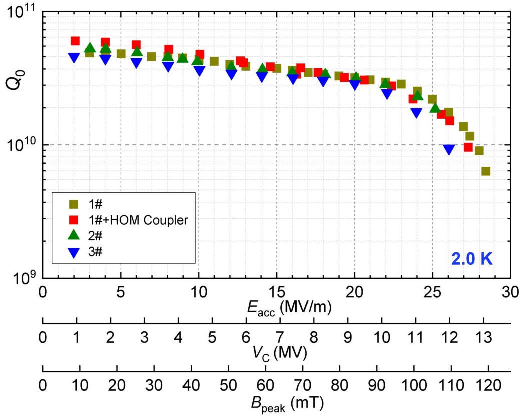
CEPC SRF Facilities and Components

J.Y.Zhai, Peng Sha

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

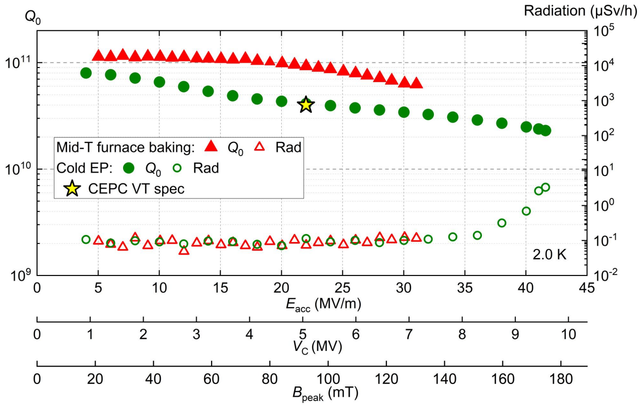
IHEP PAPS is in full operation since 2021

CEPC 650 MHz 2-cell Cavity

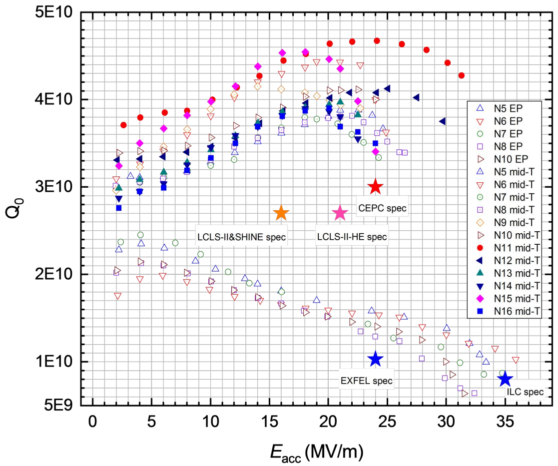


3E10@20MV/m.

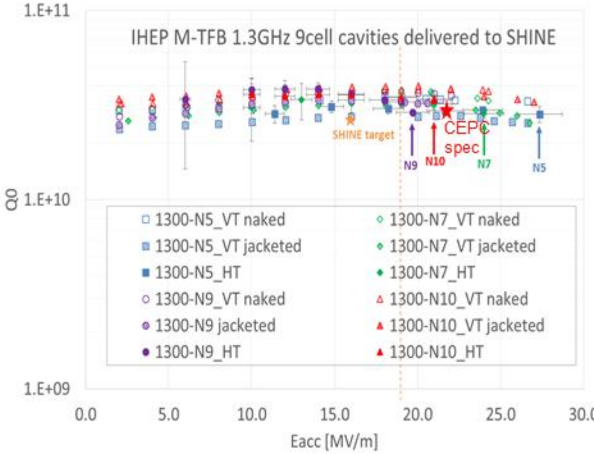
CEPC 650 MHz 1-cell Cavity



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

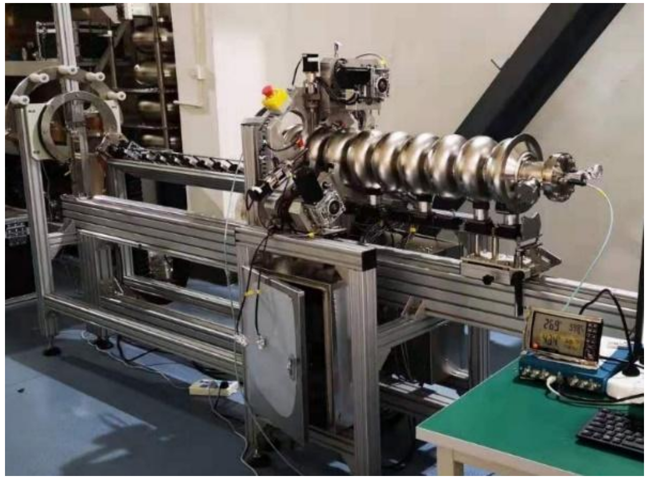


Mid-T 1.3 GHz 9-cell horizontal test (SEL)
3.1E10@21 MV/m, avg. 24.6 MV/m

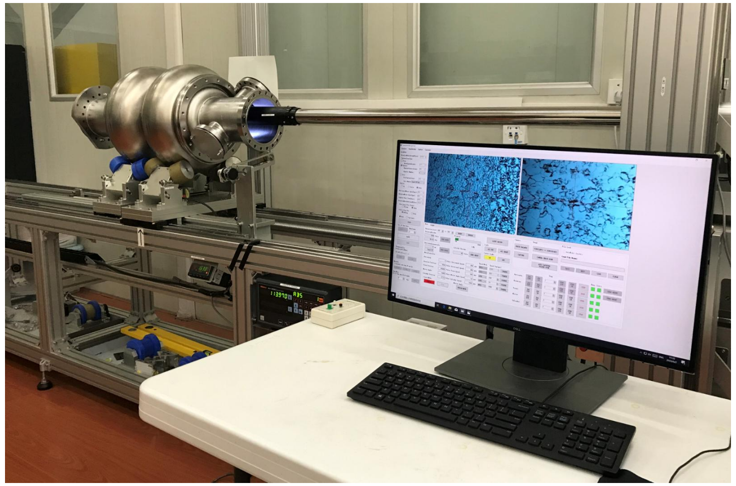
The New SRF facility at IHEP

J.Y. Zhai, P. Sha

Vacuum furnace: Nitrogen doping, annealing, baking

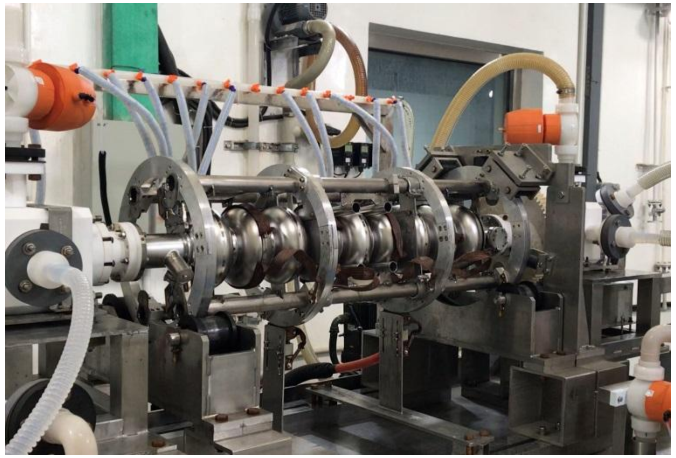


Pre-tuning of 1.3 GHz 9-cell cavity



Optical inspection

Vertical test Dewar



Electro-polishing

Pure water system

Furnace for Nb3Sn coating

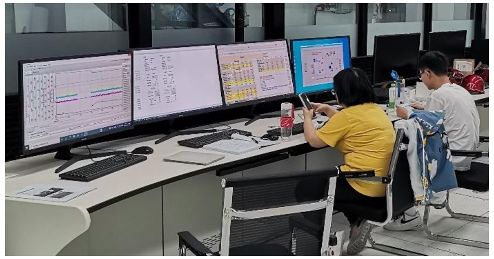
Vertical test of SRF cavities

CEPC Collider 650 MHz 2 x 2-cell Test Cryomodule

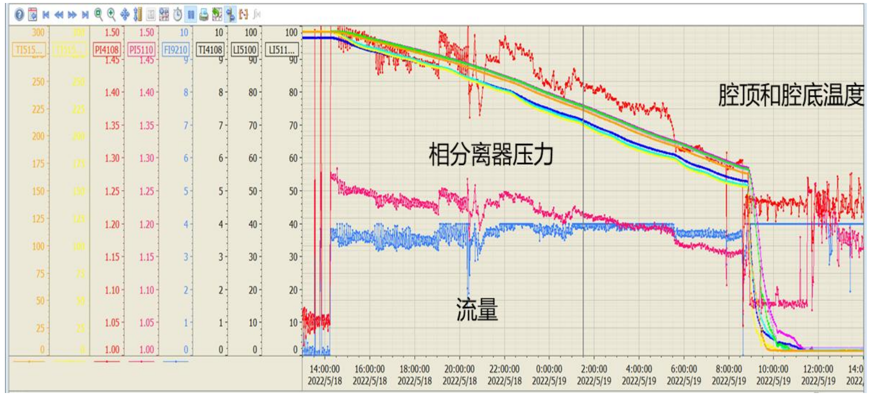
J.Y. Zhai, P. Sha







- 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

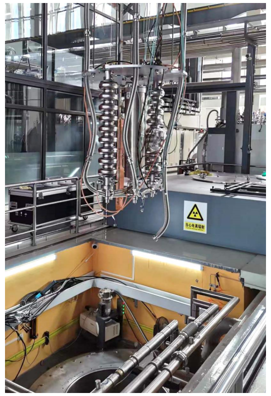
1. 300 to 150 K: < 10 K/hr. Cavity top and bottom ΔT < 20 K
2. 150 to 4.5 K: Cavity surface > 1 K/min
3. 4.5 to 2 K

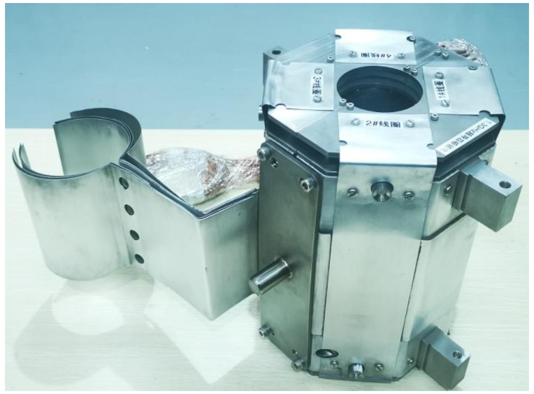
CEPC Booster 1.3 GHz 8 x 9-cell High Q Cryomodule

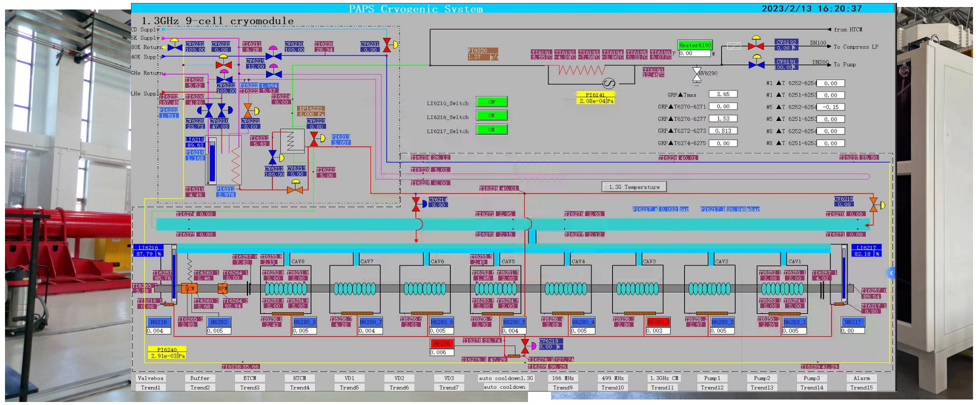
J.Y. Zhai, P. Sha

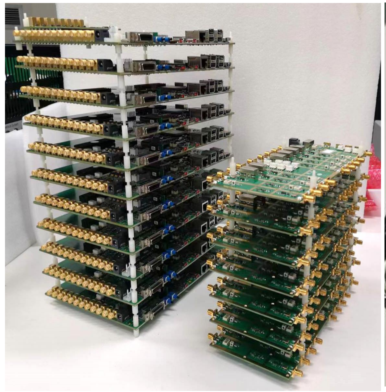
CEPC booster 1.3 GHz SRF R&D and industrialization in synergy with CW FEL projects.

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}			



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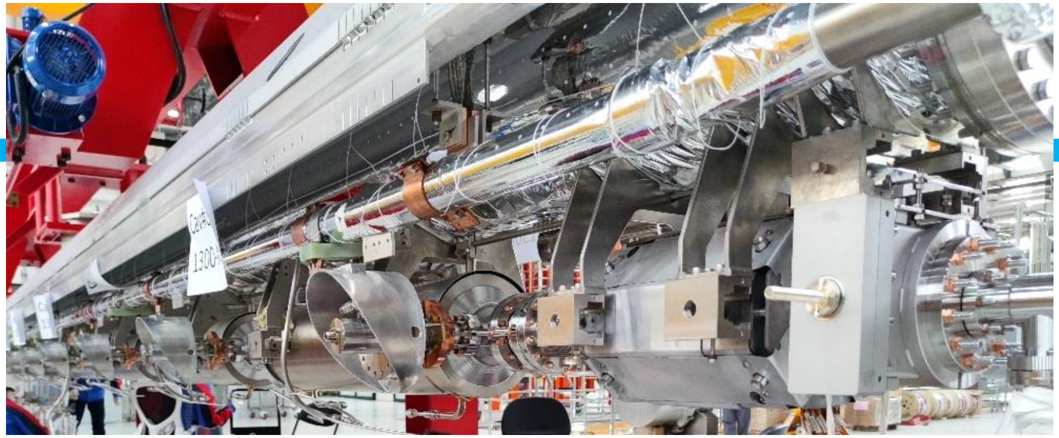
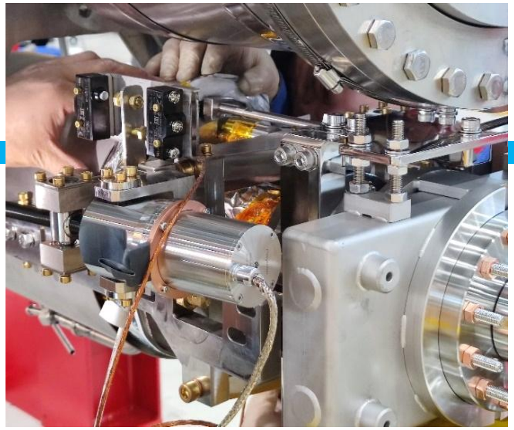
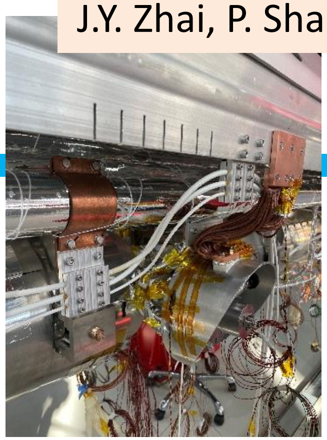
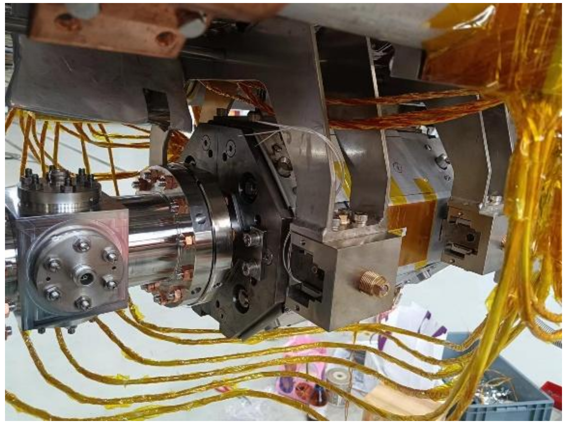
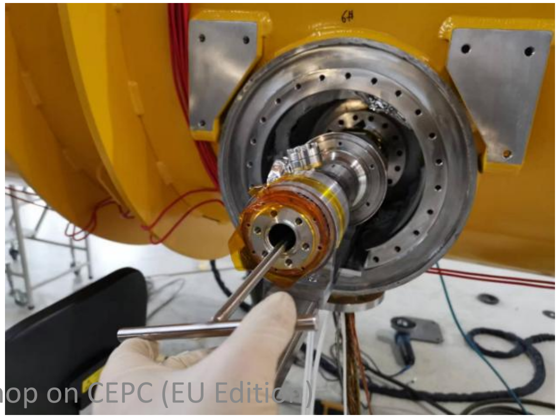
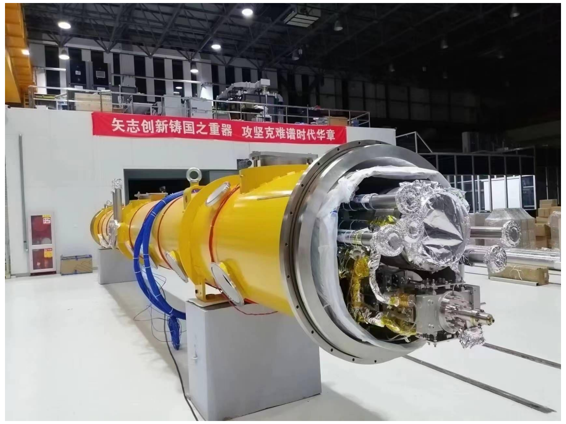








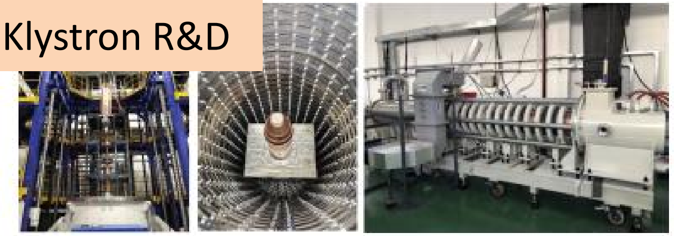




CEPC High Efficiency High Power Klystron Development and RF Power Distribution

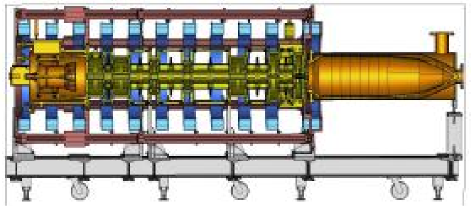
Zusheng Zhou

Klystron R&D



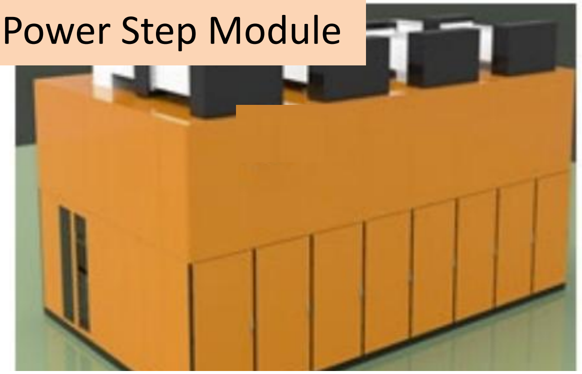
Klystron No. 1
Efficiency 65%
(2020)

Klystron No. 2
Efficiency 77%
(2021)

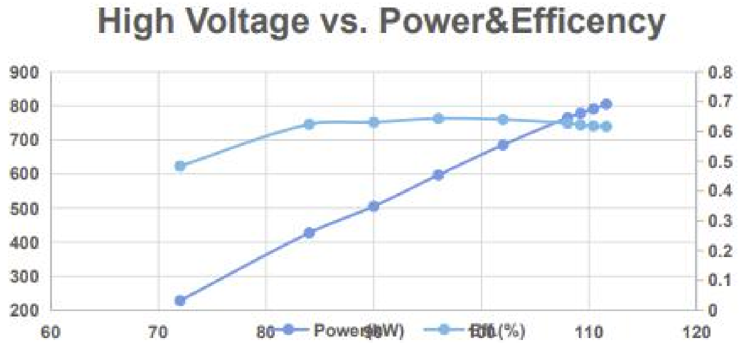


Klystron No. 3 （MBK
Efficiency 80.5%
(under fabrication)

Power Step Module

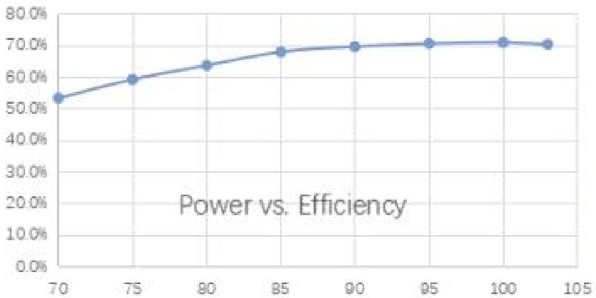


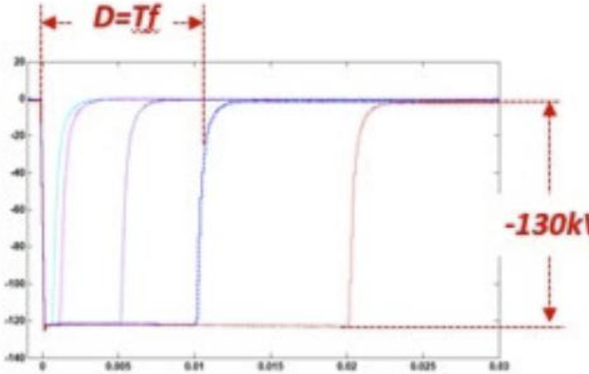
Pulsed RF Mode (30% duty factor, 60ms/5Hz)

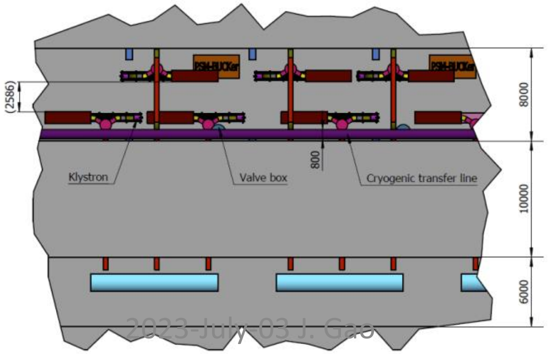


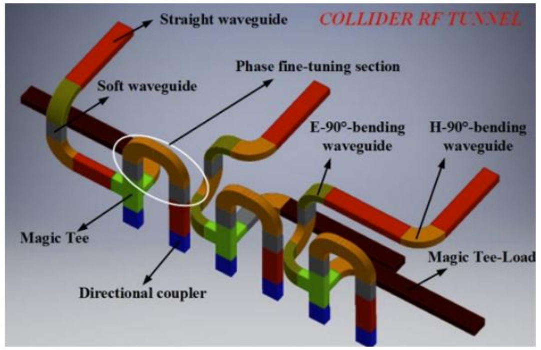
2022

70.5% @ 630kW









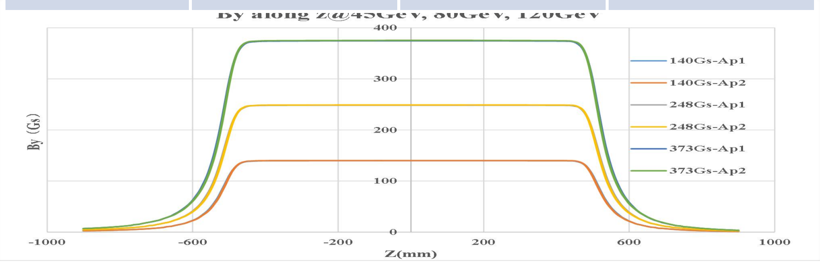
- Three prototypes of the 650MHz 800KW CW klystrons are developed. The efficiency reaches 70%
- PSM is developed with the industrial collaboration
- RF tunnel distribution was planed

CEPC Collider Ring Full-scale Dual-aperture Magnets

Mei Yang

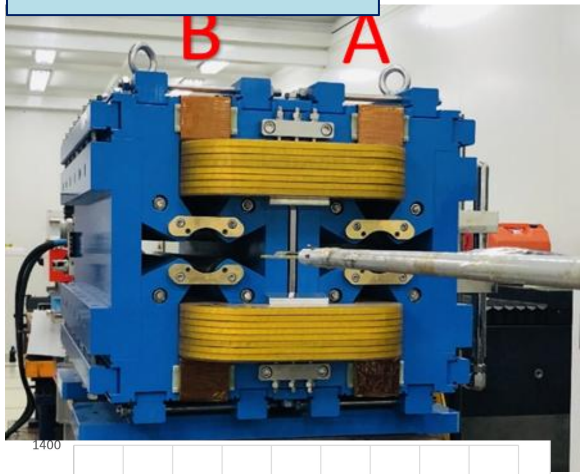
Full-length 5.67m Dual aperture dipole

E(GeV)	Ap1 ByL(T.mm)	Ap2 ByL(T.mm)	Differ
45	15.3972	15.3765	-0.13%
80	27.3358	27.3199	-0.06%
120	41.2001	41.1810	-0.05%

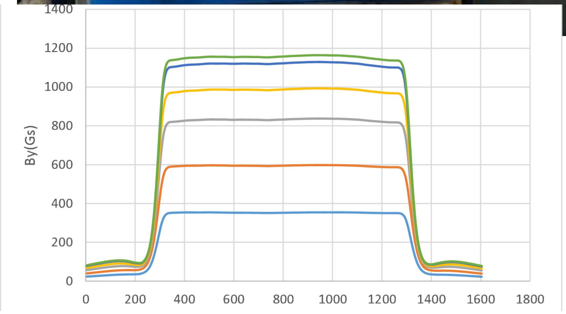


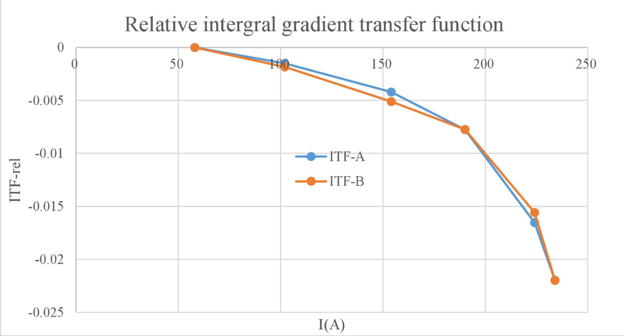
	Dipole	Quad.	Sext.	Corr.	Total
Dual aperture	3008	3008	-	-	17562
Single aperture	162	1120	3176	3544 *2	
Total length [km]	68.71	9.95	2.17	3.1	83.9
Power[MW] @120GeV	6	17.5	8.91	0.28	32.7

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%



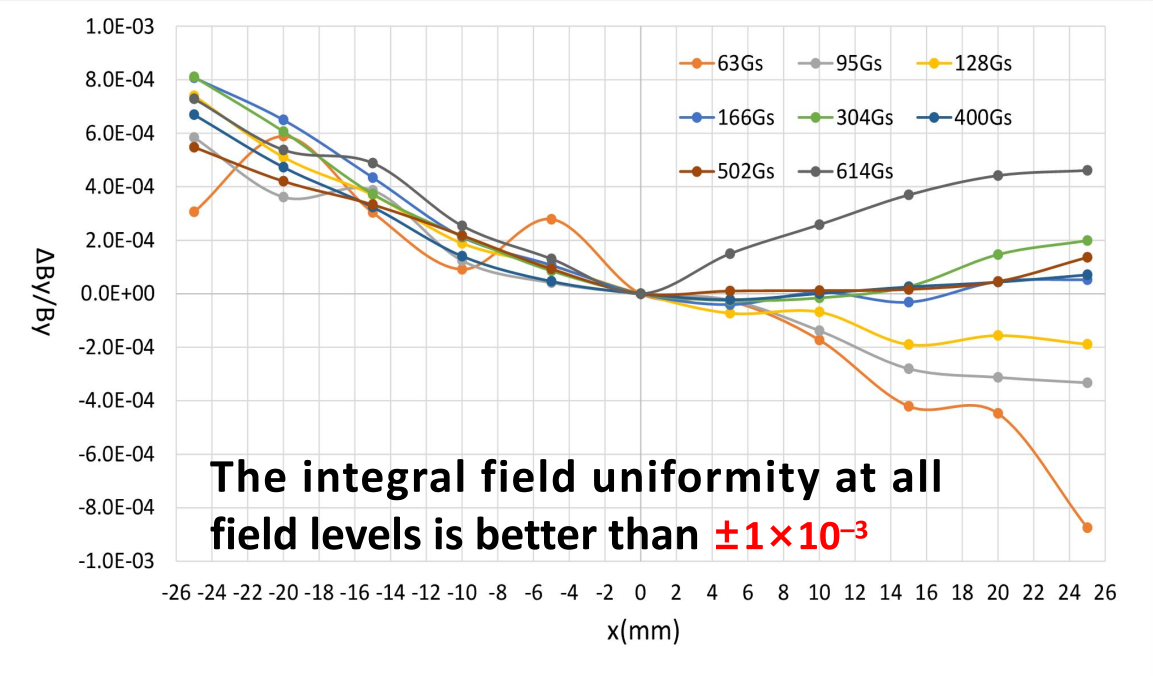


- Large quantities of dual-aperture dipoles (69km) and quad. (10km) are required;
- Full length dual-aperture dipole and dual aperture QUAD (short length) have been fabricated, under test;
- Dipole/QUAD prototypes meet the requirements.

CEPC Full-scale Weak Field Dipole for Booster

Wen Kang

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	$\pm1\times10^{-3}$	$\pm1\times10^{-3}$	$\pm1\times10^{-3}$	$\pm1\times10^{-3}$

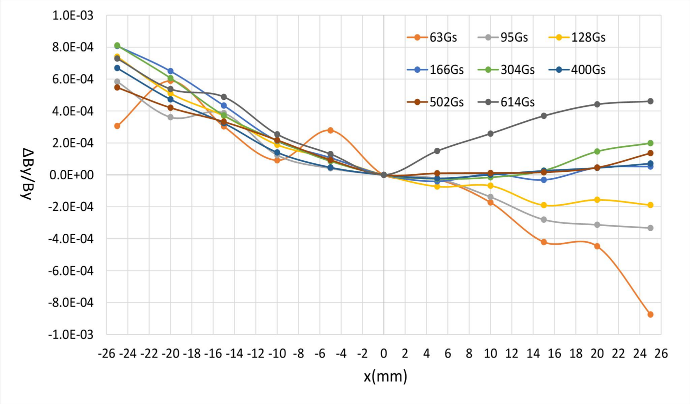


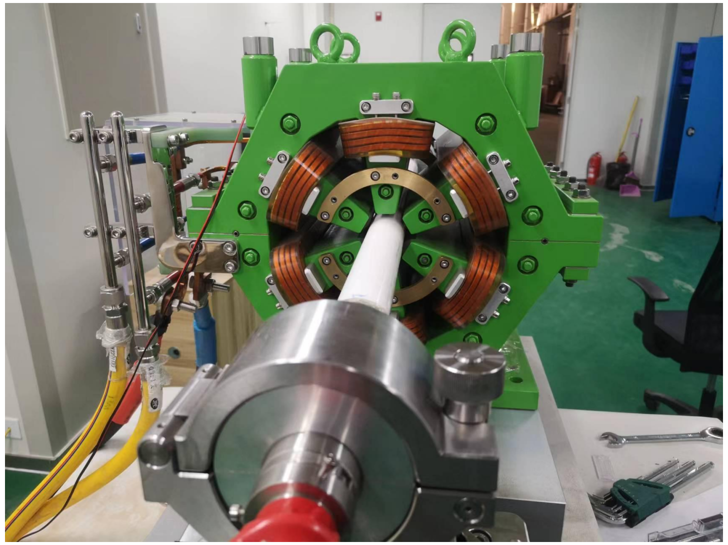
- Booster requires ~19k pieces of magnets (68km);
- Booster dipoles are required to work at the low field of 95 Gs (30GeV) with an error smaller than 1×10^{-3} ;
- Full length (4.7m) dipole was developed, and it meets the field specification;

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

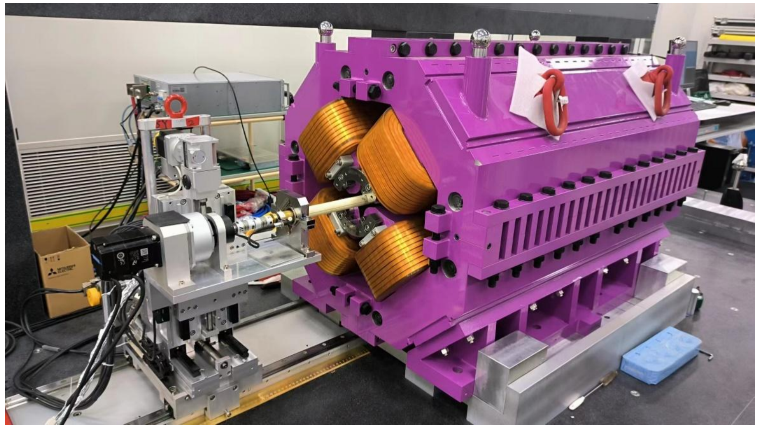
W. Kang

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 $\pm 2.5\times10^{-4}$

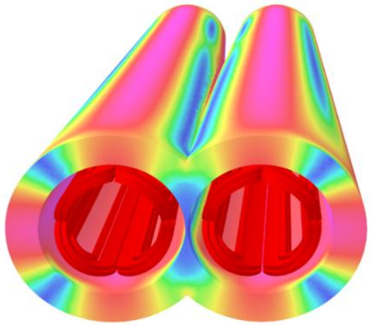
Corrector

CEPC Final Focus Superconducting Quadrupoles

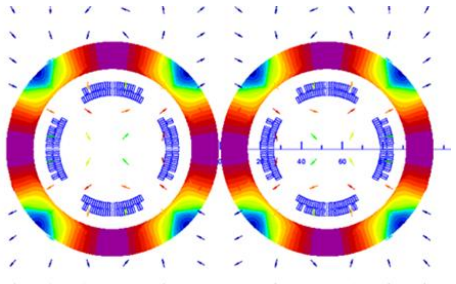
Yingshun Zhu

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	≤5×10^{-4}	≤5×10^{-4}	≤5×10^{-4}	
Dipole field	≤3	≤3	≤3	mT

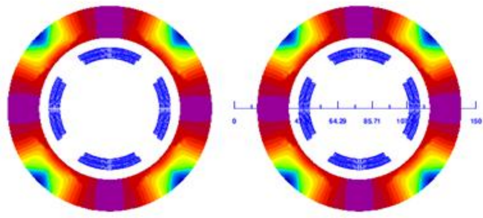
Q1a

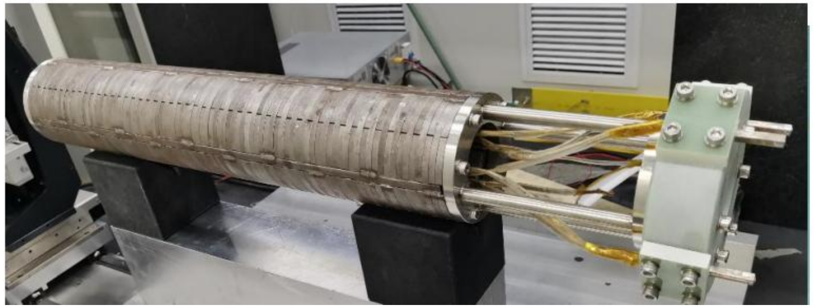


Q1b



Q2





- CCT and Cos2θ type SCQs were modeled, and their fields were calculated; the CEPC specifications have been met;

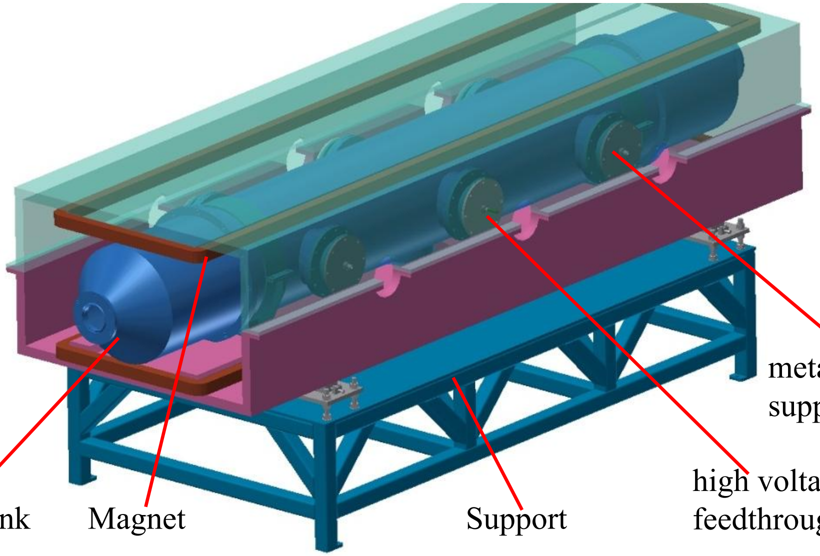
- A 0.5-m single aperture SCQ using Cos2θ technology has been developed. The electro-magnet excitation test showed the highest current reached 2500A (176 T/m), which exceeds the CEPC requirement (142T/m)

CEPC Electrostatic-Magnetic Deflector

Bin Chen

- The Electrostatic-Magnetic Deflector is a device consisting of perpendicular electric and magnetic fields.
- One set of Electrostatic-Magnetic Deflectors including 8 units, total 32 units will be need for CEPC.

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



Prototype of electrostatic magnetic separator

- Test result
  - ✓ Electric field uniformity (0.5‰) 46×30 mm^2 (simulation result) ;
  - ✓ Vacuum degree ≤ 2.6×10^{-8}Pa ;
  - ✓ Electric field intensity 3.15MV/m@±118 kV . Meet the specification

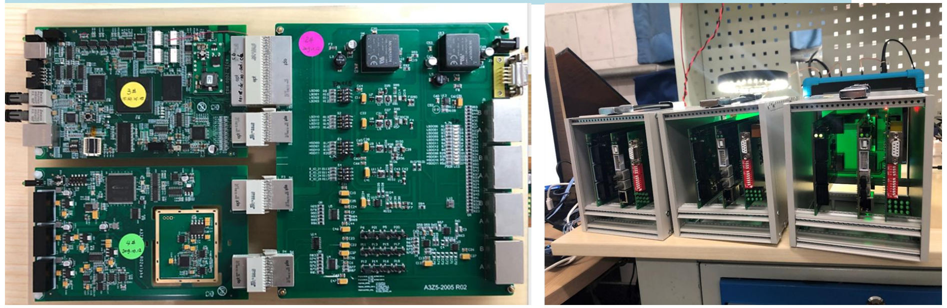
CEPC Magnet Power Supply System

Bin Chen

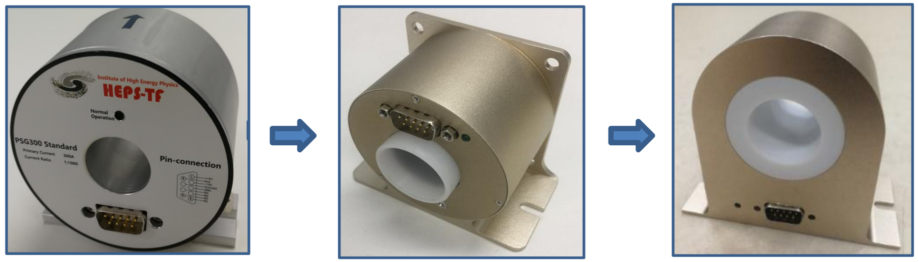
Counting the power supplies for the collider, booster, linac, DR, Transport line, the total magnet quantity： **38435**

Collider	Dipole		Quadrupole		Sextupole	Corrector	Magnet quantity
	D-aperture	S-aperture	D-aperture	S-aperture			
	3008	**162**	**3016**	**1116**	**3144**	**7088**	**17534**
Booster	Dipole		Quadrupole		Sextupole	Corrector	
	14866		**3458**		**100**	**1200**	**19624**
Linac	Dipole		Quadrupole		Solenoids	Corrector	
	15		**364**		**37**	**275**	**691**
Damping Ring	Dipole		Quadrupole		Sextupole	Corrector	
	86		**130**		**72**	**60**	**348**
Transport Line	Dipole		Quadrupole		Sextupole	Corrector	
	64		**120**		**0**	**54**	**238**
Total	**38435**						

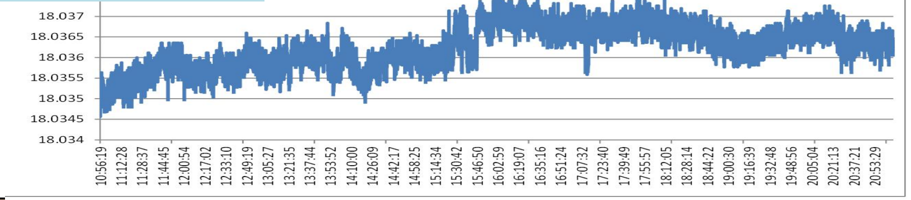
Digital Power Supply Control Module (DPSCM)



Current Transducer



Stability test



- Both high and low voltage power suppliers for different magnets were designed, with satisfactory stability
- Key components, such as the DPSCM and Current Transducer were developed, which are applied at HEPS

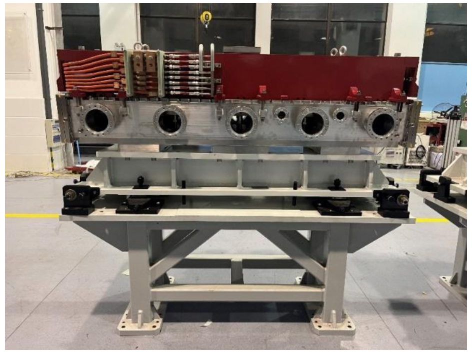
CEPC Injection & Extraction System

Jinhui Chen

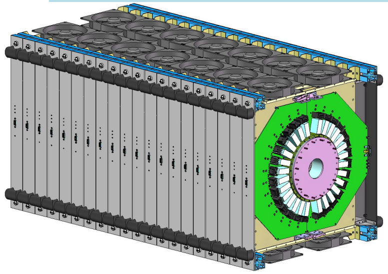
Various kickers and septums are required

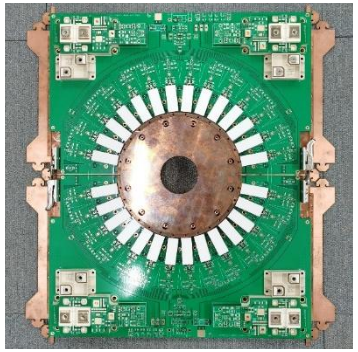
	Sub-system	Kicker Type	Kicker waveform	Septa Type	Thickness of septum
1	Damping ring inj./ext.	Slotted-pipe kicker	Half-sine/250ns	Horizontal LMS	ф22/3.5mm
2	Booster LE inj.	Strip-line kicker	Half-sine/50ns	Horizontal LMS	ф55/5.5mm
3	Booster ext. for CR off-axis inj.	Delay-line dipole kicker	Trapezoid /440-2420ns	Vertical LMS	Φ55/6mm
4	Collider off-axis inj.	Delay-line NLK kicker	Trapezoid /440-2420ns	Vertical LMS	Φ75x56/2mm
5	Booster ext. for CR on-axis inj.	Ferrite core dipole kicker	Half-sine/1360ns	Vertical LMS	Φ55/6mm
6	Booster HE inj.	NLK or Pulsed sextupole	Half-sine/0.333ms	Vertical LMS	Φ55/6mm
7	Collider swap out inj.	Ferrite core dipole kicker	Half-sine/1360ns	Vertical LMS	Φ75x56/6mm
8	Collider swap out ext.	Ferrite core dipole kicker	Half-sine/1360ns	Vertical LMS	Φ75x56/6mm
9	Collider beam dump	Delay-line dipole kicker	Trapezoid /440-2420ns	Vertical LMS	Φ75x56/6mm

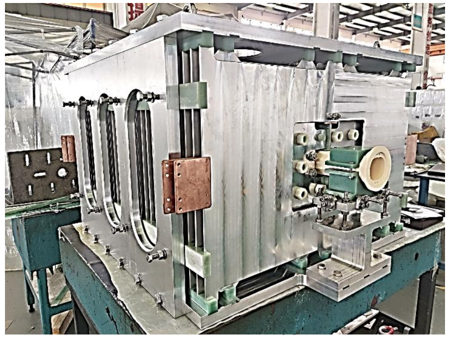
- The same team is in charge of both HEPS and CEPC inj. & ext. system
- Experience gained in HEPS applies for CEPC
- HEPS has developed various types of devices including Septum, Fast Kick, and Pulse Generator, which are compatible with the CEPC.



Fast kicker pulser





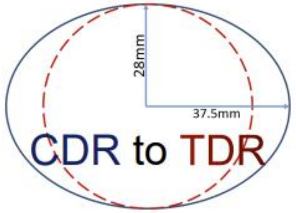


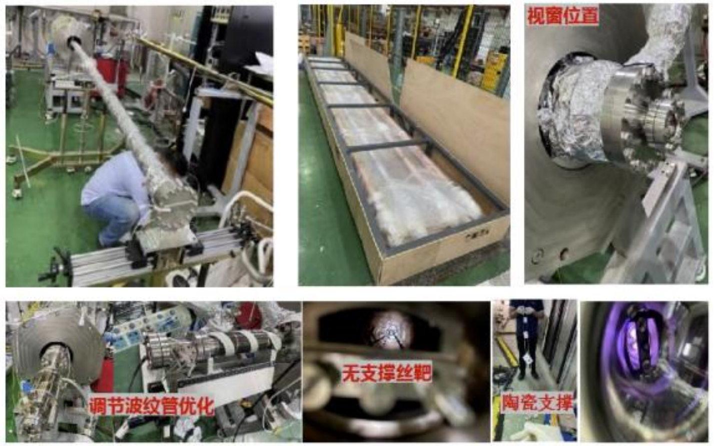
CEPC Vacuum System

Yongsheng Ma

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

SEY<1.2

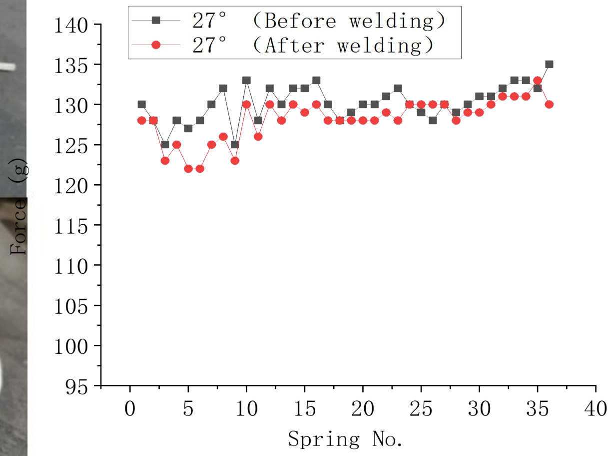




6 m vacuum pipe have been installed on the NEG coating setup

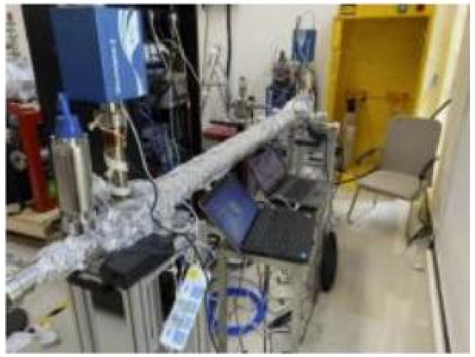
- ✓ 180℃/24h activation 4.5×10^{-10} Torr
- ✓ 200℃/24h activation 2.5×10^{-10} Torr

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

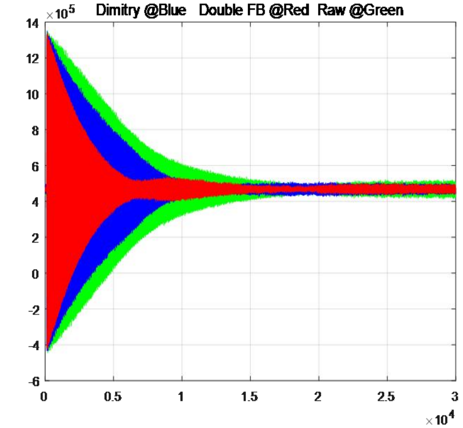
CEPC Beam instrumentation

Yanfeng Sui

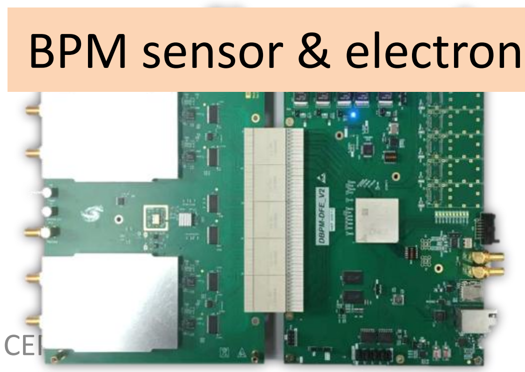
System	R&D Work supported by		
	BEPCII	HEPS/HEPS TF	CEPC R&D Funding
BPM electronics	√	√	√
Beam position monitor fabrication		√	√
Longitudinal feedback system	√	√	
Transverse feedback system	√	√	
BI at the interaction point			√
Bunch current monitor		√	
Beam loss monitor			√

Feedthrough

FB system



BPM sensor & electronics



- Various types of beam instrumentation were developed with funding from HEPS, BEPCII and CEPC
- The CEPC requirements are met

CPEC Linac Injector Key Technology R&D

Jingru Zhang

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

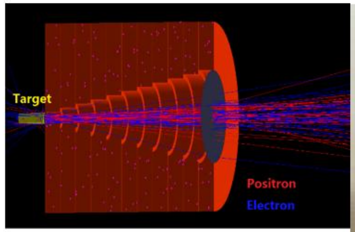
IHEP C-band SLED

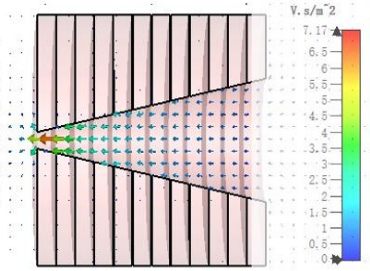
Test results of IHEP C-band SLED

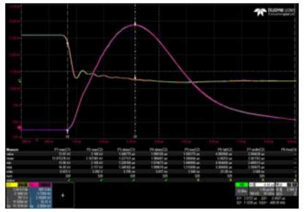
SACLA C-band SLED

IHEP C-band BOC

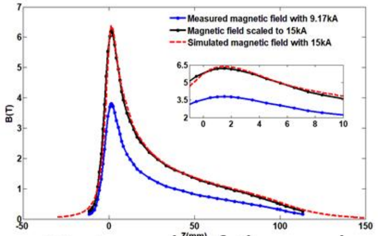
PSI BOC





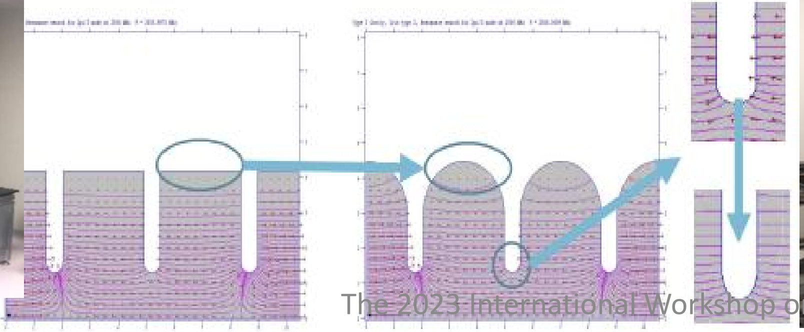


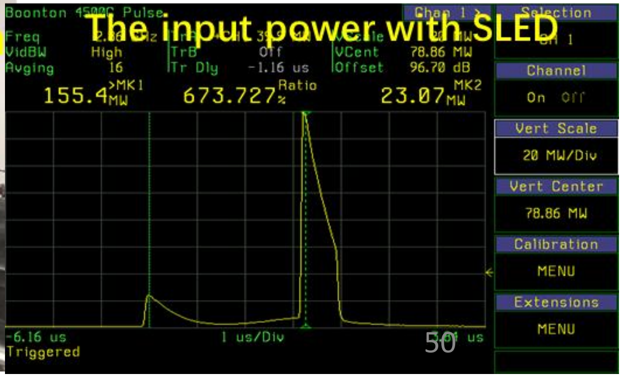
R&D of the solid state



Test result of the peak

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

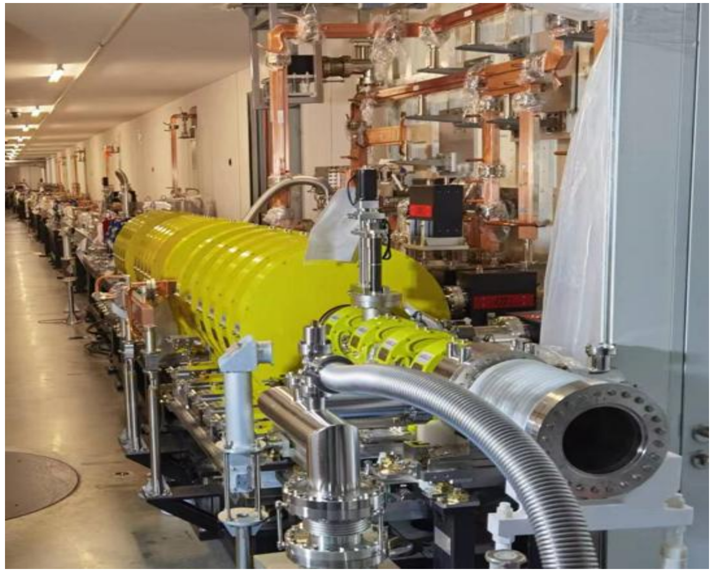




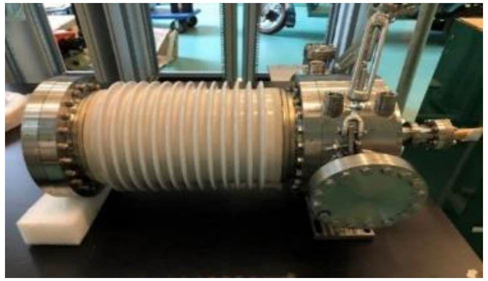
Successful Linac Key Technologies for HEPS (S-band)

J.YR. Zhang

- The HEPS linac is a 500MeV S-band normal conducting RF system
- It has been successfully operated recently in 2023

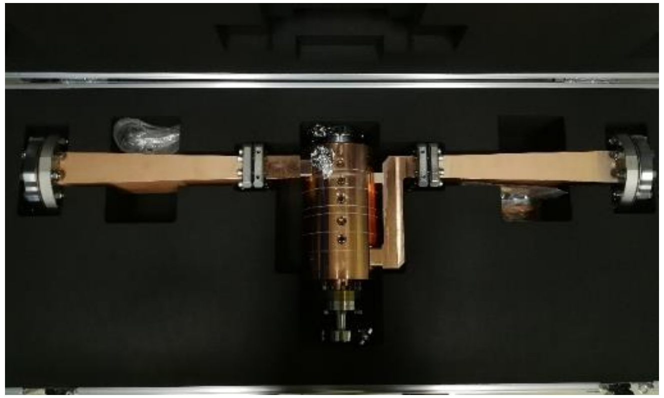


HEPS linac tunnel

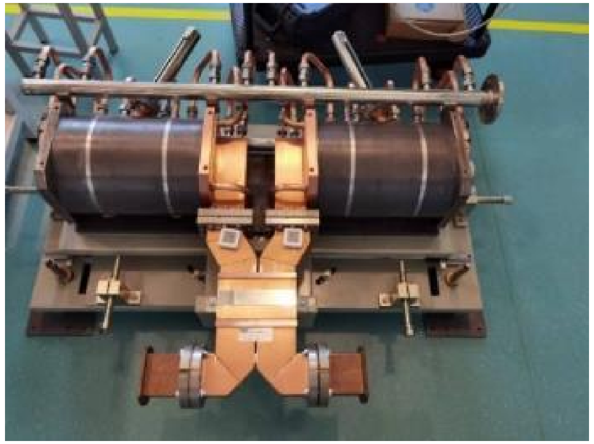


Electron gun

SHBs



Buncher



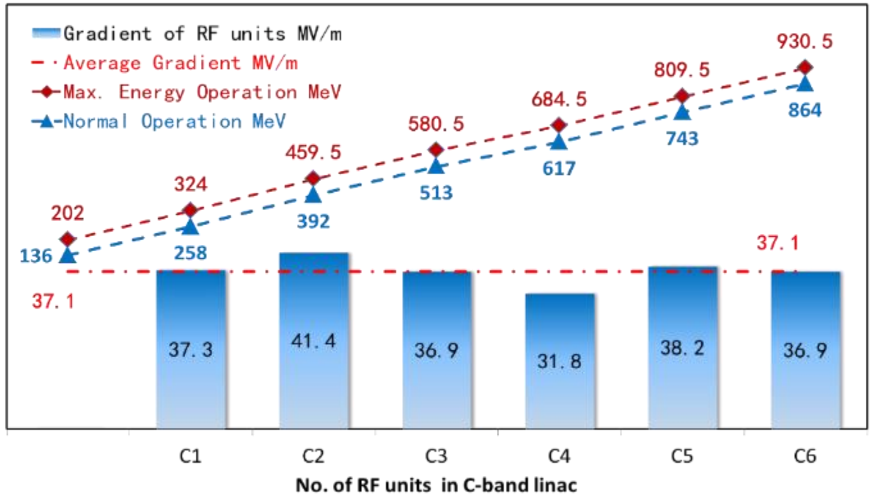
SLAC type pulse compressor

S-band accelerating structure

C-band Linac in Operation at SINAP

W.C. Fang

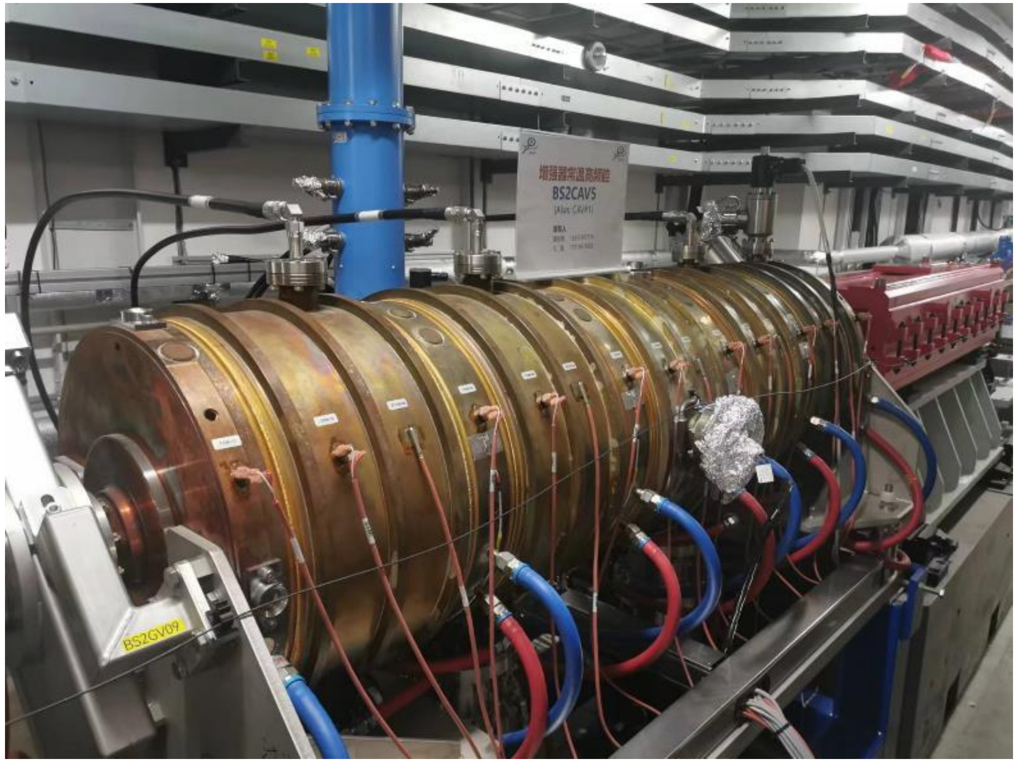
- C-band RF accelerating structure and compressor at SARI (SXFEL) Shanghai
- One 50MW klystron to two accelerating structures with pulse compressor
- Average gradient more than 37.1 MV/m. and maximum gradient 41.7 MV/m
- It has long time stable operation now



CEPC Damping Ring RF Cavity

P. Zhang

- 5 cell normal conducting cavity installed at HEPS booster (similar to CEPC damping ring RF cavity)



CEPC Technology Demonstration in Synergy with Other Projects

China company made 850kW@4K cryogenic plant installed in IHEP South Ligh Source test facility in **Dongguan** (May, 2022) (Next step is 10~18kw@4K)

HEPS S-band Linac in operation (March, 2023)

50MW 50Hz C-band klystron by Institute AIR of CAS for **Shanghai Soft XFEL** (Nov. 2021)

HEPS booster magnet unit (Jan. 2022)

HEPS power source for magnets (June 2022)

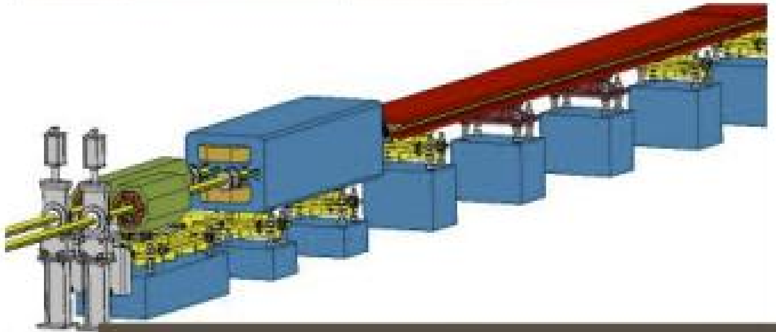
HEPS storage ring sextupole magnets (Dec. 2021)

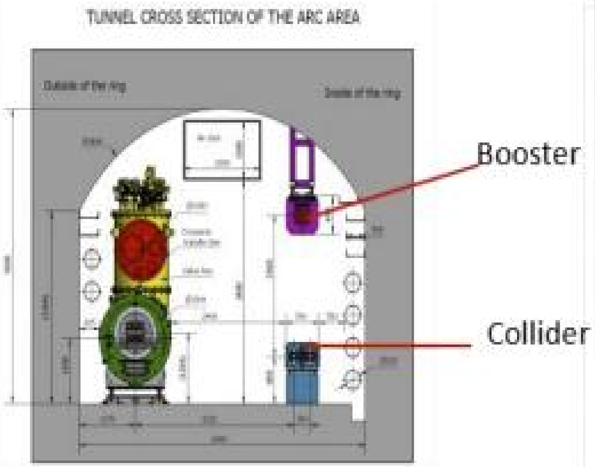
CEPC Mechanical Supports and Installation Tools

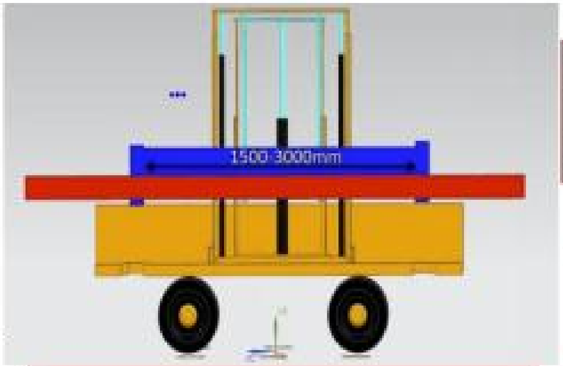
Haijing Wang

- Over 80% of the length is covered by magnets of about 138 types.

Adjustment Ranges of magnets			
X	≥±20 mm	Δθx	≥±10 mrad
Y	≥±30 mm	Δθy	≥±10 mrad
Z	≥±20 mm	Δθz	≥±10 mrad



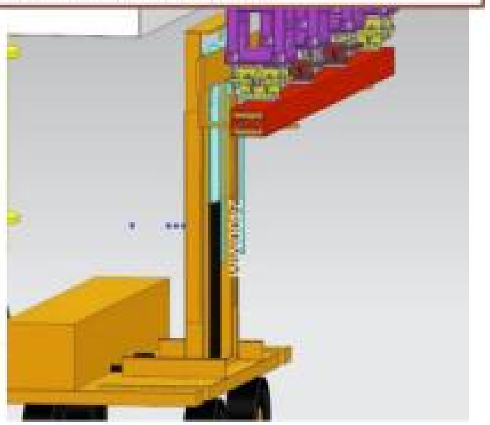


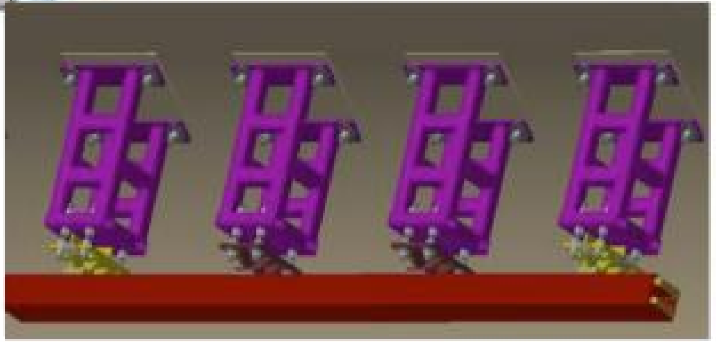


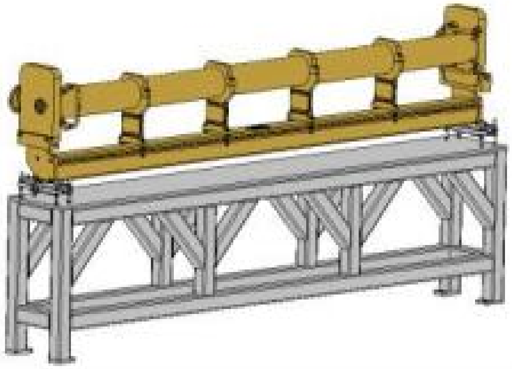
Flexible load support for "long" devices and "short" devices

Transportation and coarse location of magnets in Booster

Transportation and coarse location of magnets in Collider







* Cooperate with Beijing North Vehicle Group Corporation.

- The magnet supports in Collider, Booster, Linac and Damping Ring have been designed and analyzed.
- Transportation in the tunnel was considered.

CEPC Installation and Alignment Technologies

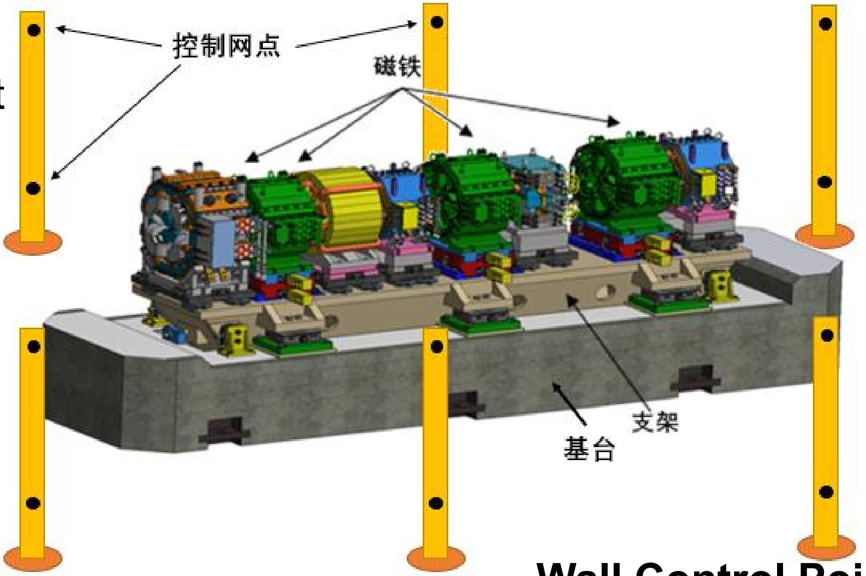
Xiaolong Wang

- Alignment accuracy requirement

Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)
Dipole	0.10	0.10	0.10
Arc Quadrupole	0.10	0.10	0.10
IR Quadrupole	0.10	0.10	0.10
Sextupole	0.10*	0.10*	0.10

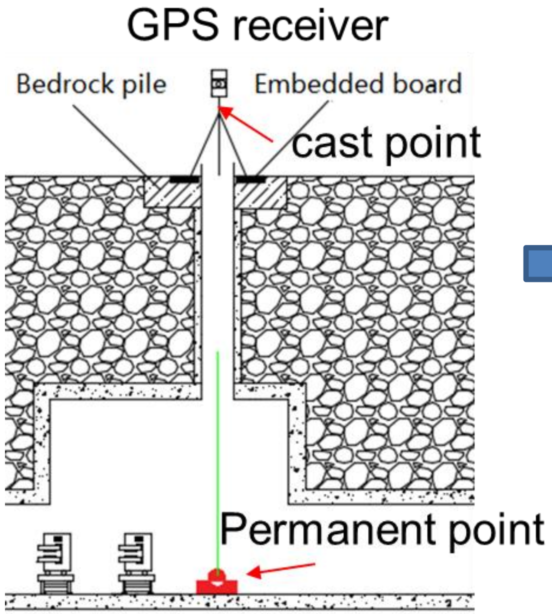
*implement beam-based alignment

Component Pre-alignment

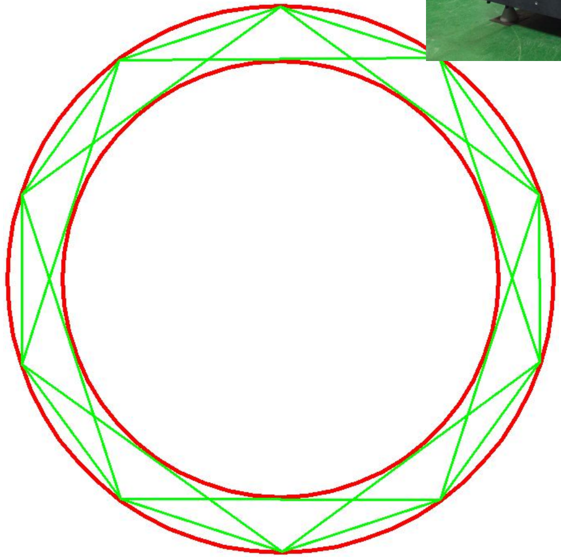


Wall Control Point

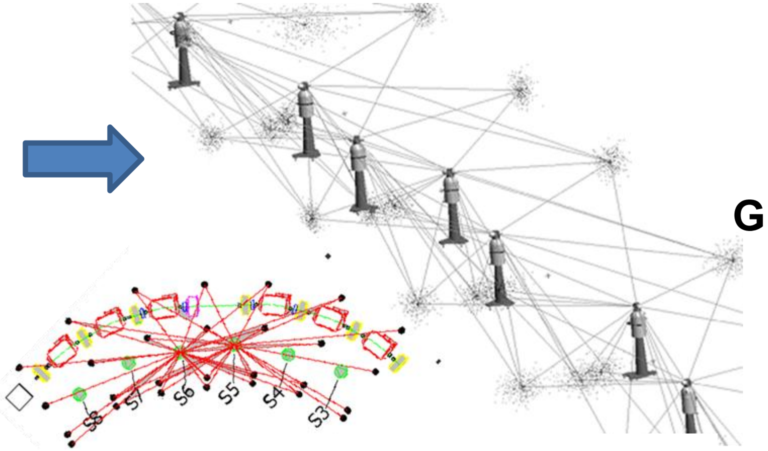
Ground Control Point



Surface Control network (14Points)



Backbone Control network
(short line:300m; long line 600m)



Tunnel Control network
(interval of 6 meters)

Contents

- **Introduction**
- CEPC Accelerator System Design and Optimizations in TDR
- CEPC Accelerator Key Hardware R&D Progresses in TDR
- **CEPC power consumption**
- SppC compatibility with CEPC
- CEPC siting, civil engineering, and installation
- Summary

Power consumption of CEPC - Higgs

Jinshu Huang

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

Power consumption of CEPC – W & Z

Jinshu Huang

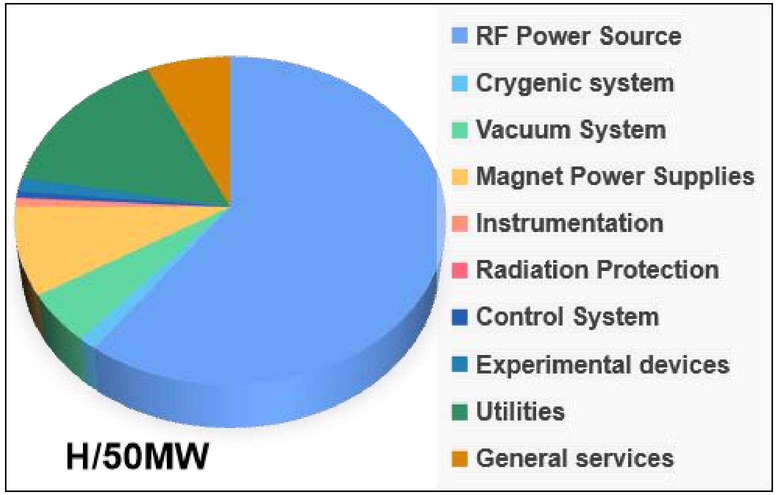
SN	System	W 50MW							Z 50MW						
		Collider	Booster	Linac	BTL	IR	Surface building	Total	Ring	Booster	Linac	BTL	IR	Surface building	Total
1	RF Power Source	161.60	0.10	14.10				175.80	169.30	0.34	14.10				183.74
2	Crygenic system	3.04	0.54			0.14		3.72	4.40	0.80			0.14		5.34
3	Vacuum System	9.90	4.20	0.60				14.70	9.90	4.20	0.60				14.70
4	Magnet Power Supplies	19.78	2.02	2.51	1.10	0.12		25.53	6.40	1.39	2.51	1.10	0.05		11.45
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				1.80
8	Experimental devices					4.00		4.00					4.00		4.00
9	Utilities	37.60	2.87	2.50	0.60	1.20		44.77	32.64	2.43	2.50	0.60	1.20		39.37
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	241.72	11.03	20.51	1.90	5.66	12.00	**292.82**	232.44	10.46	20.51	1.90	5.59	12.00	**282.90**

Power Consumption of CEPC - ttbar

Jinshu Huang

SN	System	ttbar 50MW						
		Collider	Booster	Linac	BTL	IR	Surface building	Total
1	RF Power Source	161.60	0.24	14.10				175.94
2	Crygenic system	27.53	2.32			0.14		29.99
3	Vacuum System	9.90	4.20	0.60				14.70
4	Magnet Power Supplies	100.10	13.00	2.50	1.10	0.30		117.00
5	Instrumentation	1.30	0.70	0.20				2.20
6	Radiation Protection	0.30		0.10				0.40
7	Control System	1.00	0.60	0.20				1.80
8	Experimental devices					4.00		4.00
9	Utilities	55.00	4.80	2.50	0.60	1.20		64.10
10	General services	7.20		0.30	0.20	0.20	12.00	19.90
	Total	363.93	25.86	20.50	1.90	5.84	12.00	430.03

MODE	Electricity consumption
H/30MW	262.27MW
H/50MW	339.71MW
tt/50MW	430.03MW
W/50MW	292.82MW
Z/50MW	282.9MW



Contents

SppC Collider Parameters in TDR

-Parameter list (updated Feb. 2022)

Jingyu Tang
Haocheng Xu
Y.W. Wang

Ecm=125TeV with dipole field of 20T

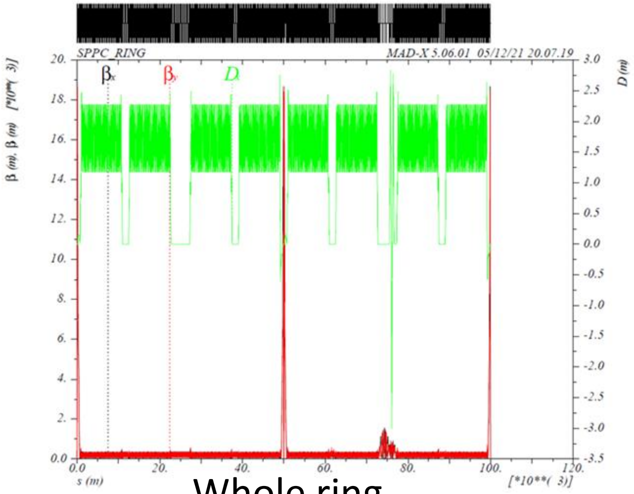
Main parameters		
Circumference	100	km
Beam energy	62.5	TeV
Lorentz gamma	66631	
Dipole field	20.00	T
Dipole curvature radius	10415.4	m
Arc filling factor	0.780	
Total dipole magnet length	65442.0	m
Arc length	83900	m
Total straight section length	16100	m
Energy gain factor in collider rings	19.53	
Injection 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	

Normalized rms transverse emittance	1.2	μm
Beam life time due to burn-off	8.1	hour
Turnaround time	2.3	hour
Total cycle time	10.4	hour
Total / inelastic cross section	161	mbarn
Reduction factor in luminosity	0.81	
Full crossing angle	73	μrad
rms bunch length	60	mm
rms IP spot size	3.0	μm
Beta at the 1st parasitic encounter	28.625	m
rms spot size at the 1st parasitic encoun	22.7	μm
Stored energy per beam	4.0	GJ
SR power per ring	2.2	MW
SR heat load at arc per aperture	26.3	W/m
Critical photon energy	8.4	keV
Energy loss per turn	11.40	MeV
Damping partition number	1	
Damping partition number	1	
Damping partition number	2	
Transverse emittance damping time	0.51	hour
Longitudinal emittance damping time	0.25	hour

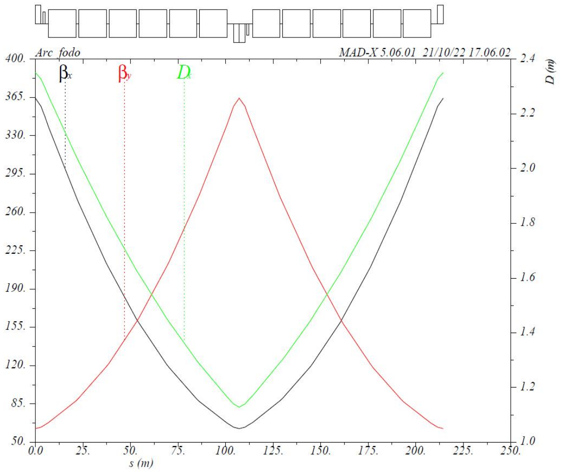
SppC Lattice Design@125TeV (20T) in TDR

Haocheng Xu
Yiwei Wang

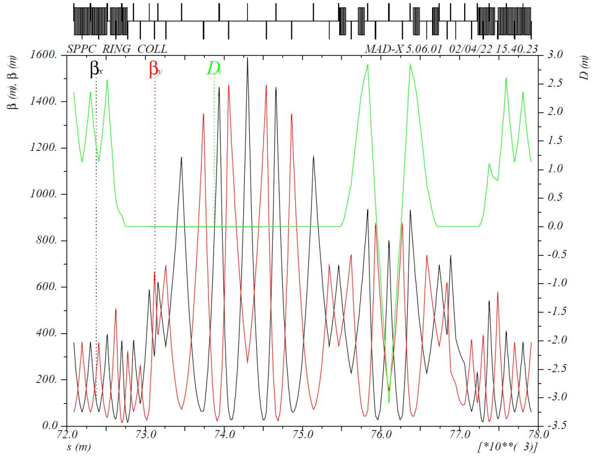
- Lattice of SPPC whole ring, Arc region, collimator section and IP region



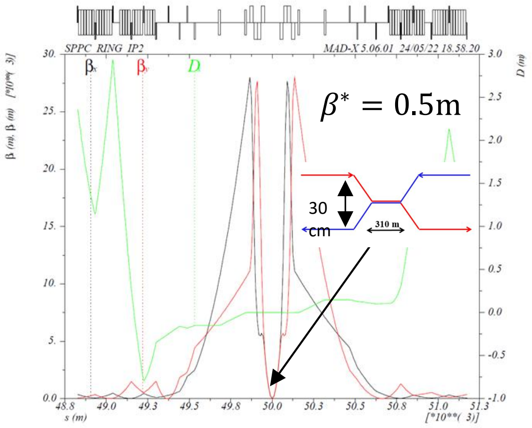
Whole ring



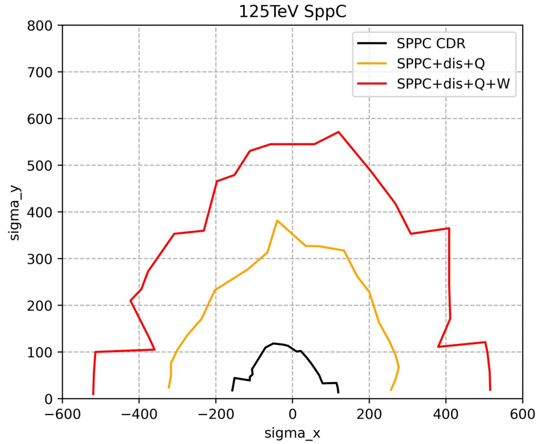
Arc cell

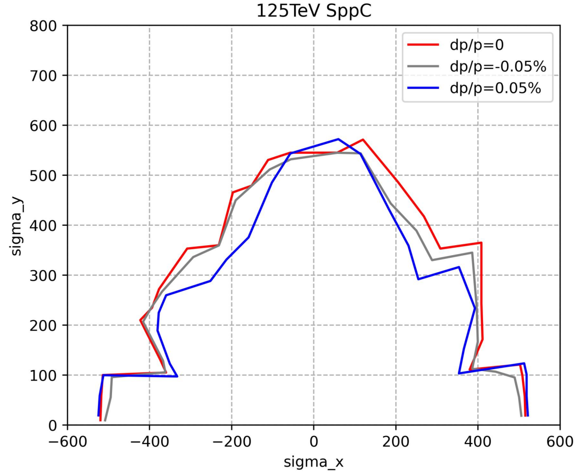


Collimation



IP



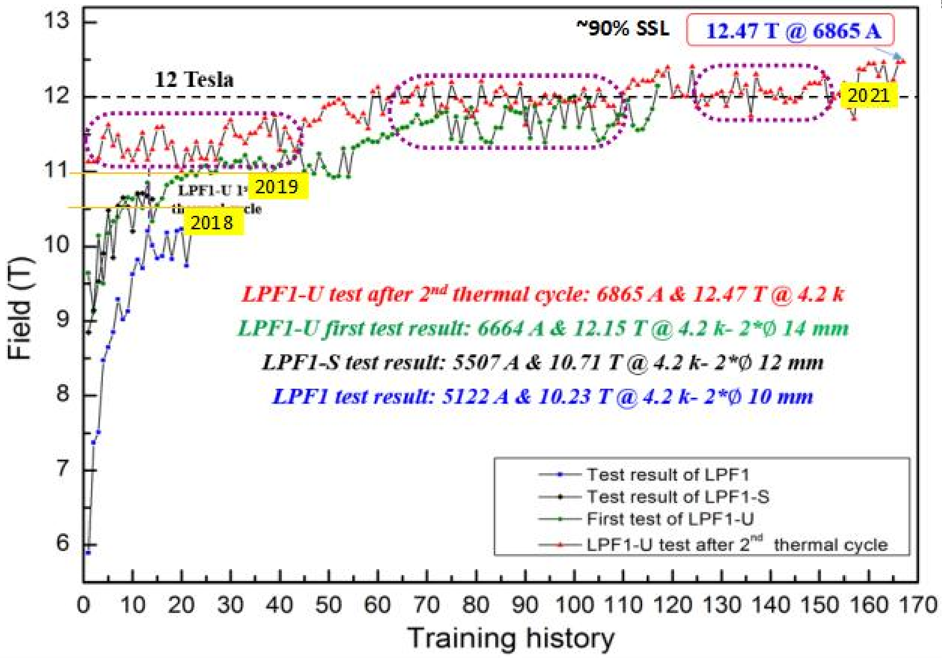


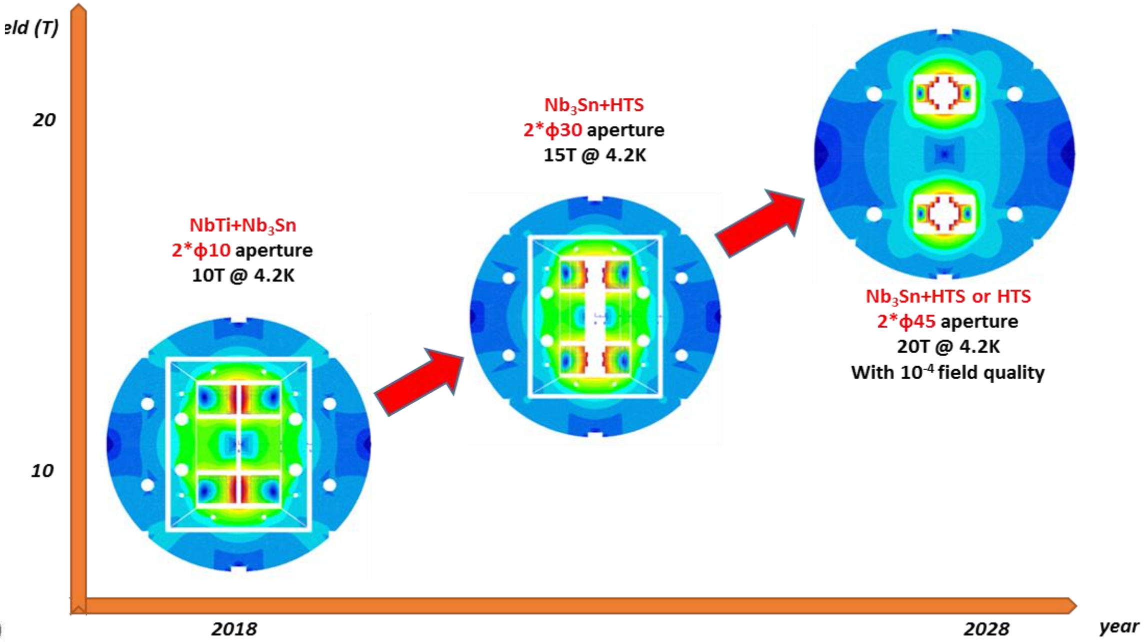
- Dynamic Aperture Optimization

Latest Performance of LPF1-U (SppC)

Qingjin Xu

Picture of LPF1-U



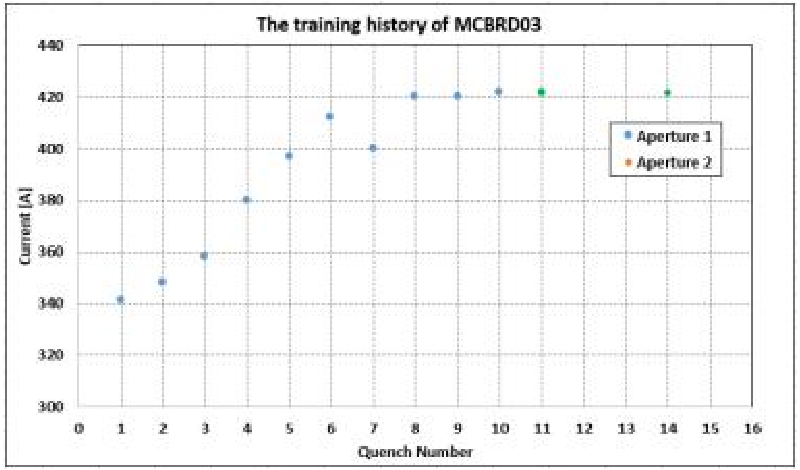


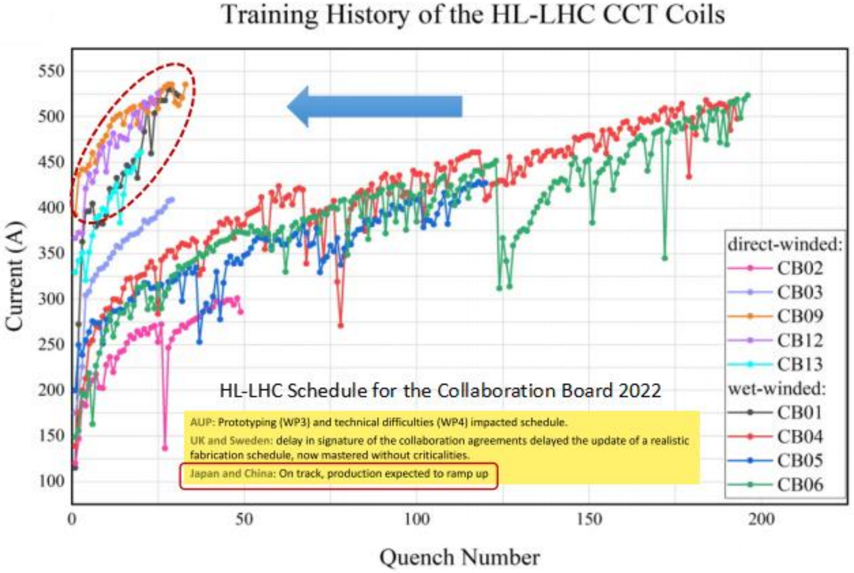
Dual aperture superconducting dipole achieves 12.47 T at 4.2 K
Entirely fabricated in China. The next step is reaching 16-20T

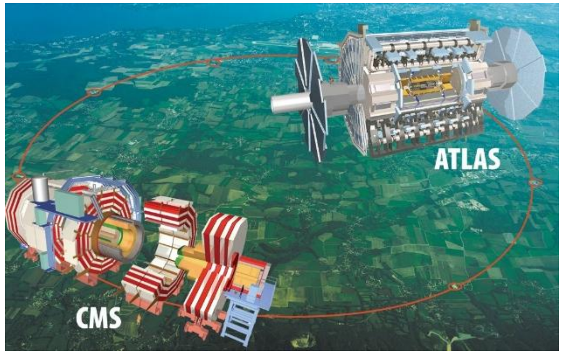
Development of CCT dipole magnets for HL-LHC by IHEP

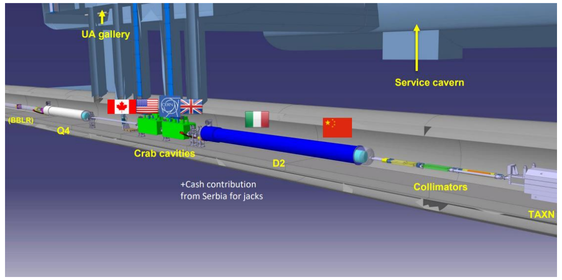
IHEP provides 13 units CCT twin-aperture dipole magnets for HL-LHC

Qingjin Xu







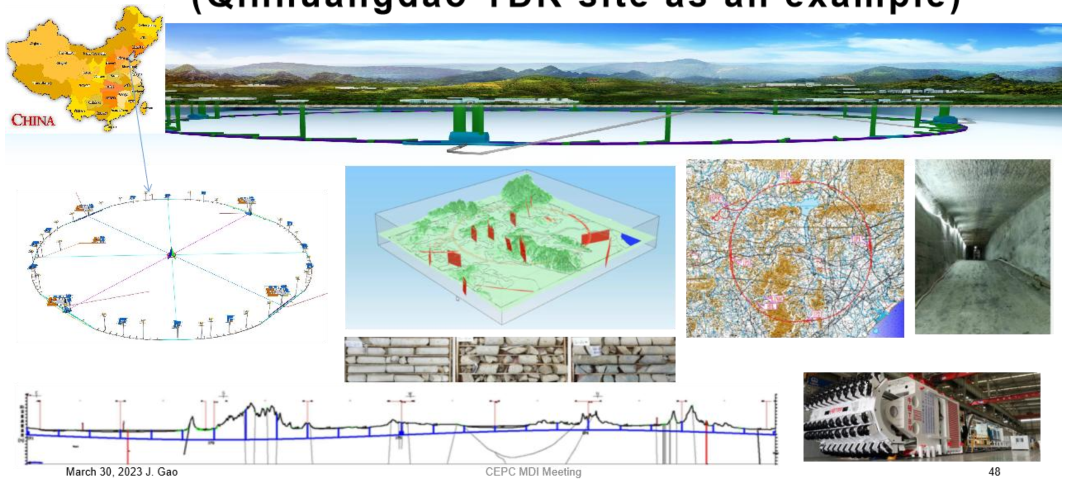


- AP1(CB12，25 quenches 526A) reached ±422A after 11 quenches.
- AP2(CB09, 33 quenches 530A; after thermal cycle ＞500A) reached ±422A without any quenches.

Contents

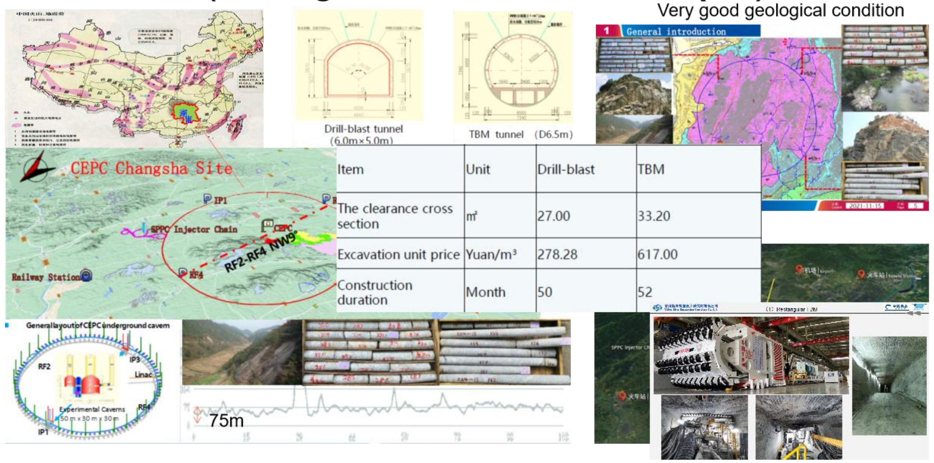
CEPC Siting and Civil Engineering

CEPC Siting and Civil Engineering (Qinhuangdao TDR site as an example)



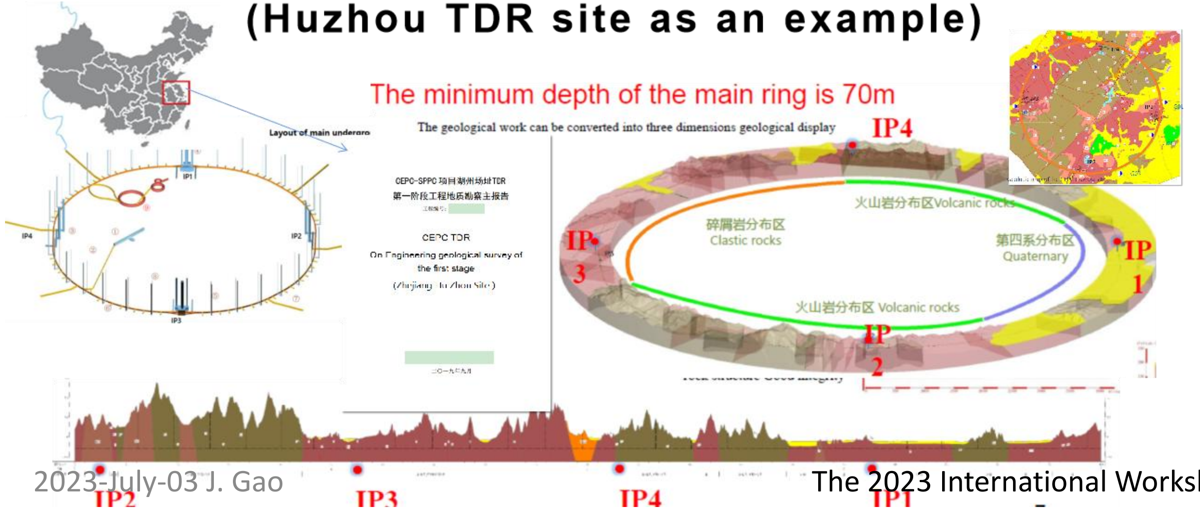
CEPC Siting, Civil Engineering (Changsha site as an example)

Very good geological condition

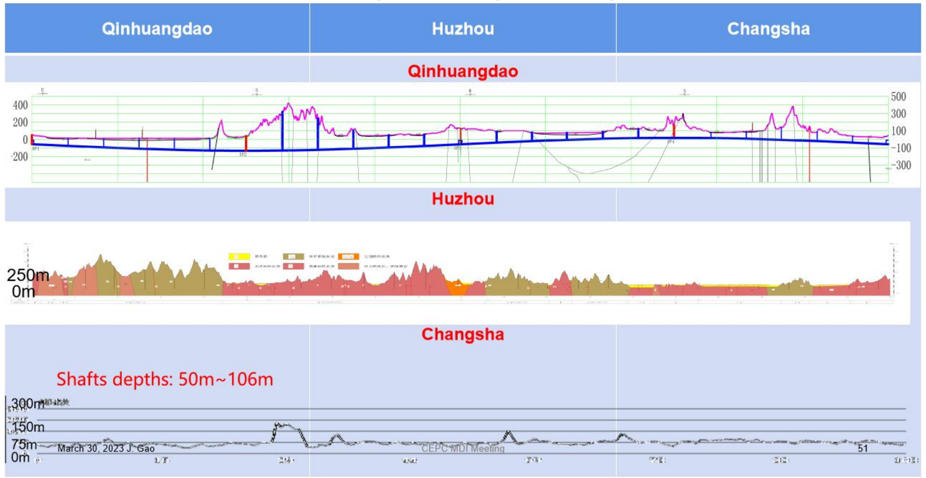


Item	Unit	Drill-blast	TBM
The clearance cross section	m²	27.00	33.20
Excavation unit price	Yuan/m³	278.28	617.00
Construction duration	Month	50	52

CEPC Siting and Civil Engineering (Huzhou TDR site as an example)

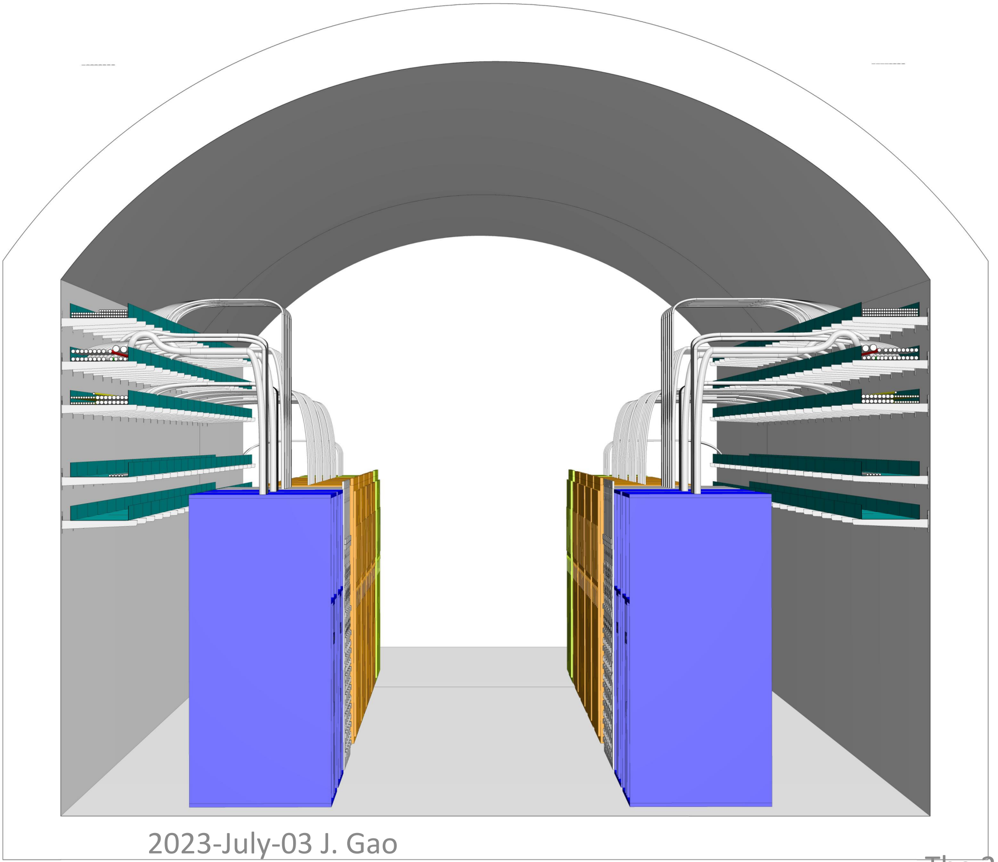


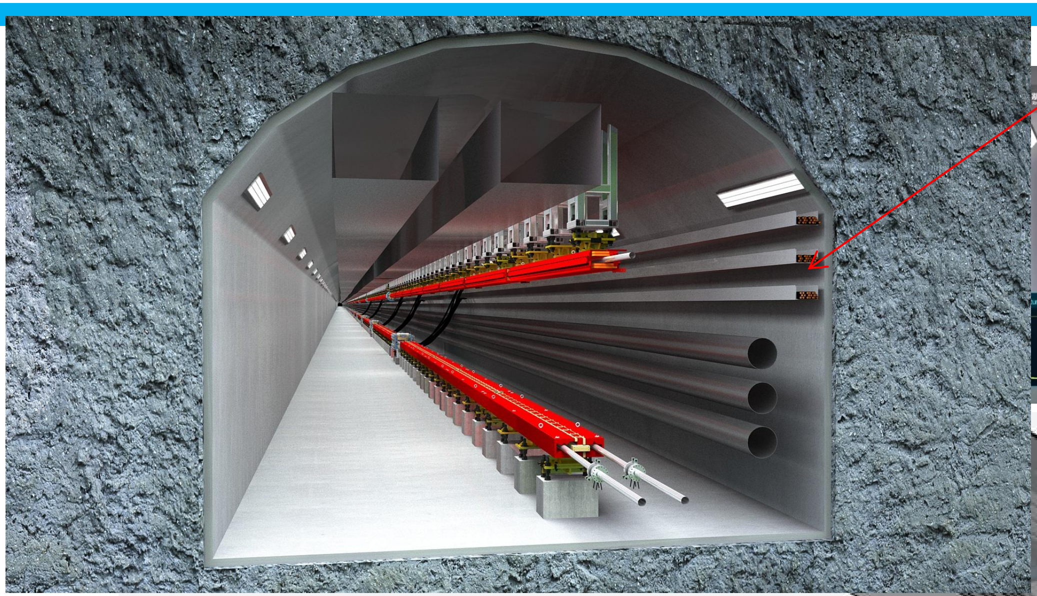
CEPC Sites Engineering Geologies in TDR

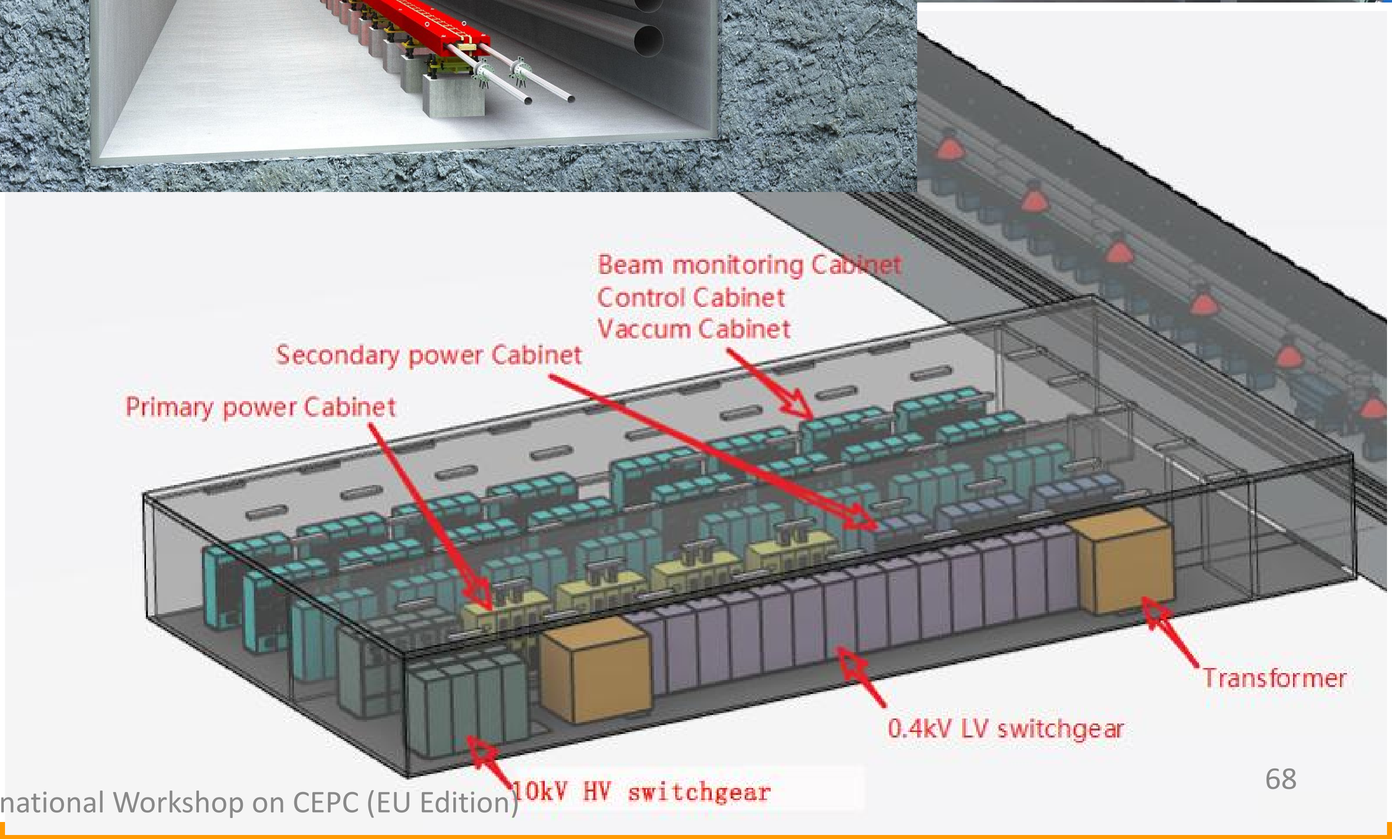


CEPC Conventional Facility and Civil Engineering

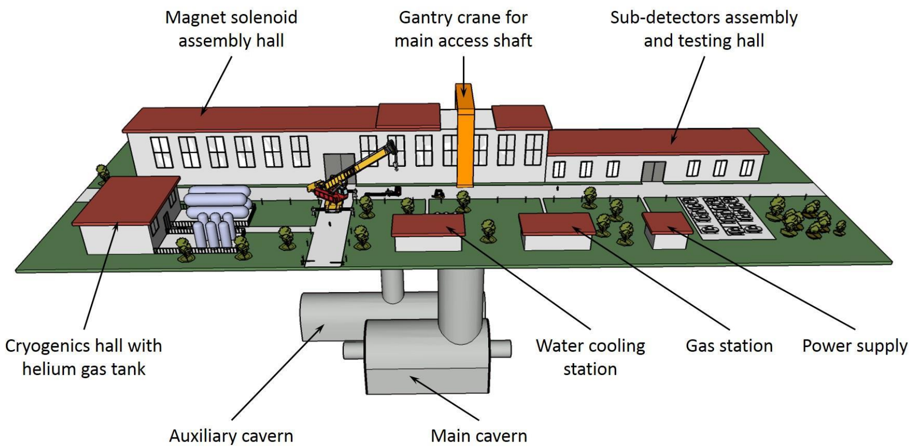
Electrical Equipment General Layout in Auxiliary

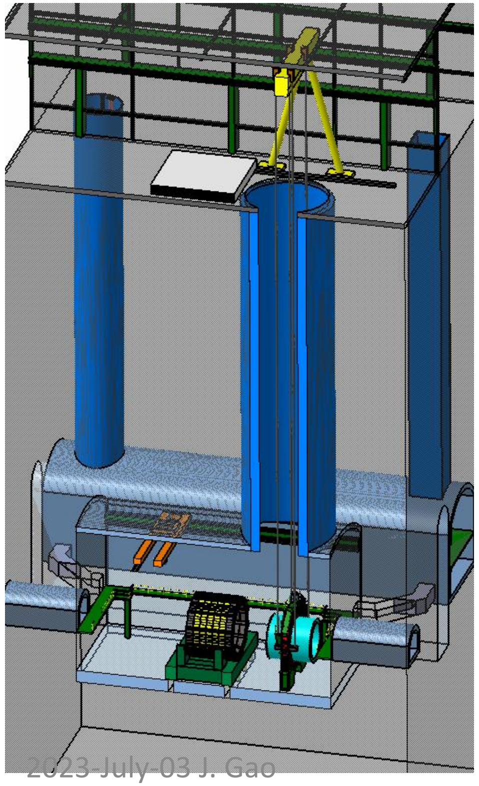


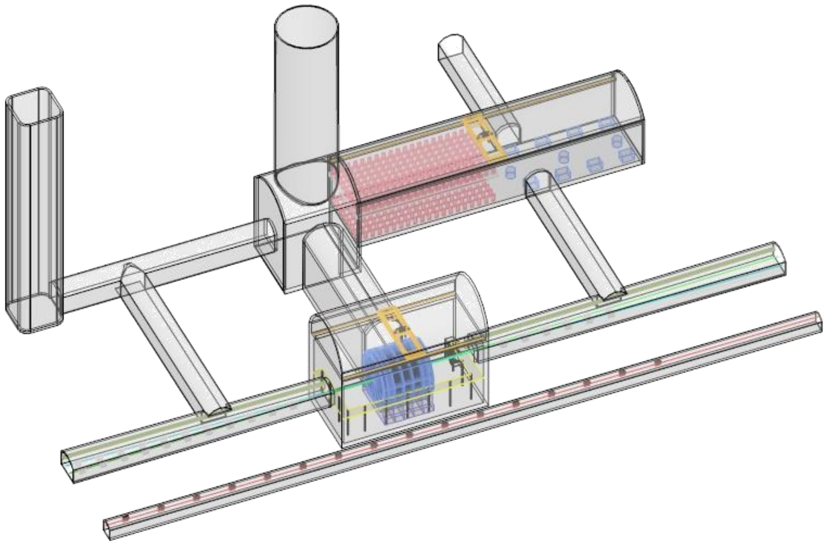




CEPC IR Region







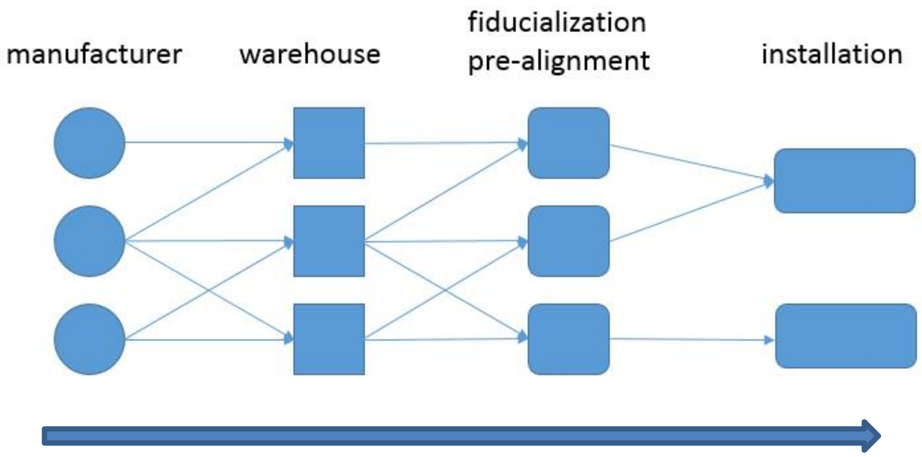
Name	L×W×H	Numb.
Experimental hall	50×30×30	×2
Axiliary hall	101.4×20×26.2	×2
Booster tunnel	1679×3.5×3.5	×4
Collider tunnel	1659.3x(6~11.4)x5	×4
Travel shaft	1200x7.5x7.5	×2
Connection, electric cable and ventilation shaft	70x10x10	×2

CEPC Installation Strategy

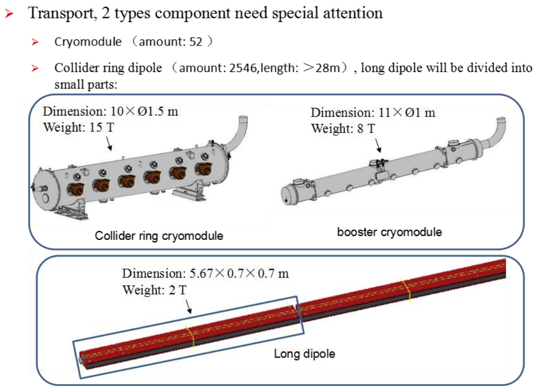
X.L. Wang

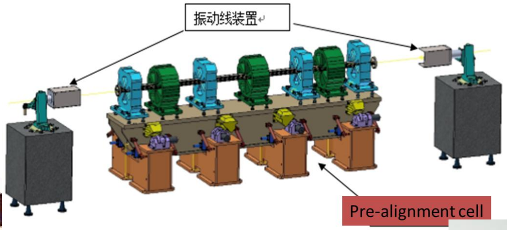
Installation and alignment scheme

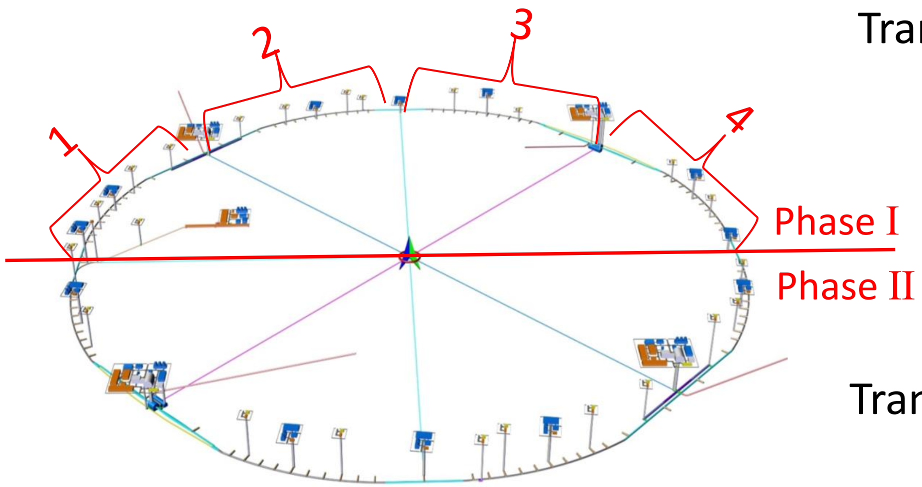
-Ring installation: phase Ⅰ, phase Ⅱ, each phase： half a ring

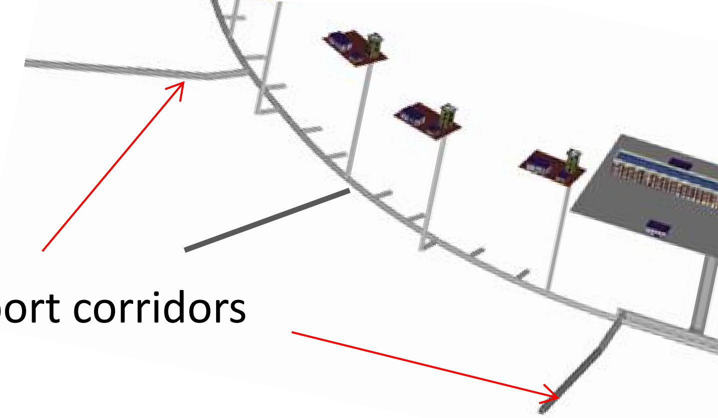


Transportation

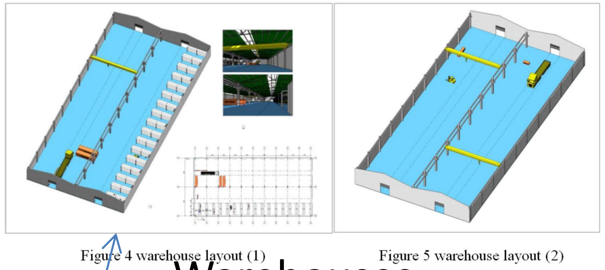


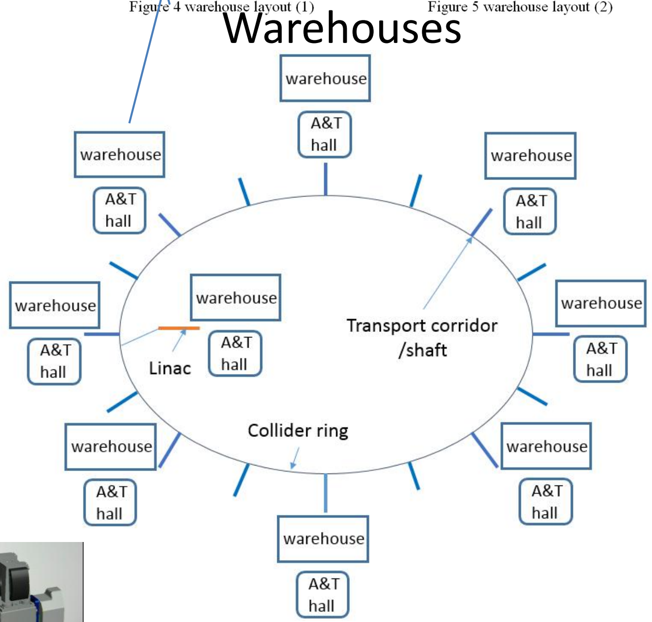


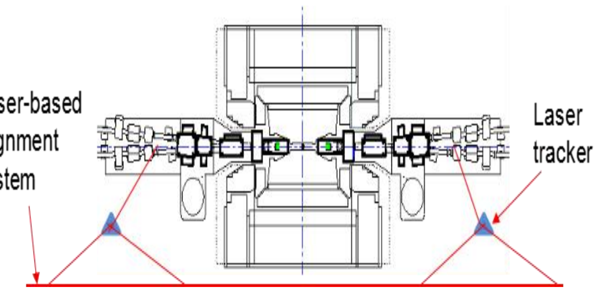




Transport corridors







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)

Song Jin

Potential international collaborating suppliers worldwide

CEPC Accelerator International TDR Review June 12-16, 2023 in HKUST-IAS, Hong Kong, China

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

IHEP-CEPC-DR-2023-01

IHEP-AC-2023-01

CEPC

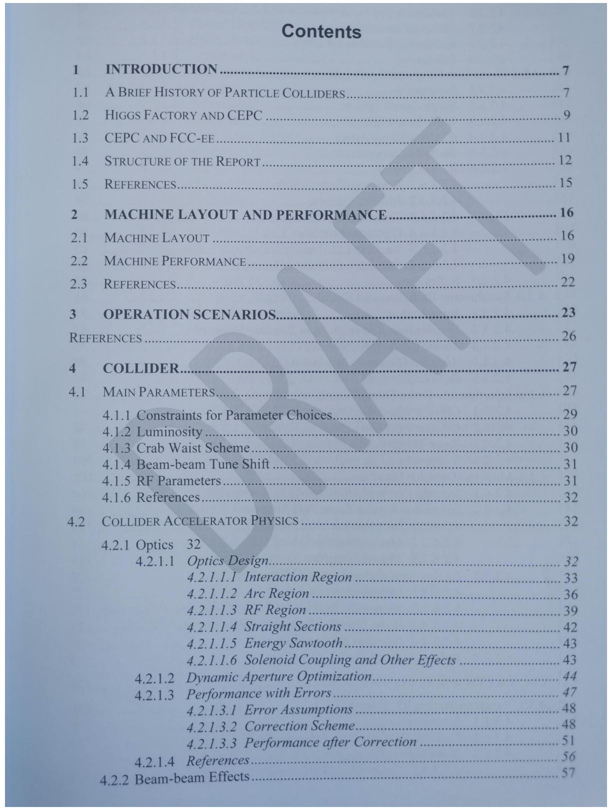
Technical Design Report

Part BB – Injectors and Common Systems

Draft

The CEPC Study Group

June 2023



Contents

DRAFT

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

Summary

- The CEPC 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 meeting was held from June 12-16, 2023.
- 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.

Acknowledgements

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

- Special thanks to CEPC IB, SC, IAC, IARC and TDR review committee's critical comments, suggestions and encouragement.