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

CEPC Accelerator TDR + R&D Status

J. Gao

On behalf of CEPC Accelerator Group

The 2022 CEPC MDI Workshop

March 30-April 1, 2023, 南华大学（湖南省衡阳市）

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- **CEPC International and industrial Collaborations, Conferences, worhshops and meetings**
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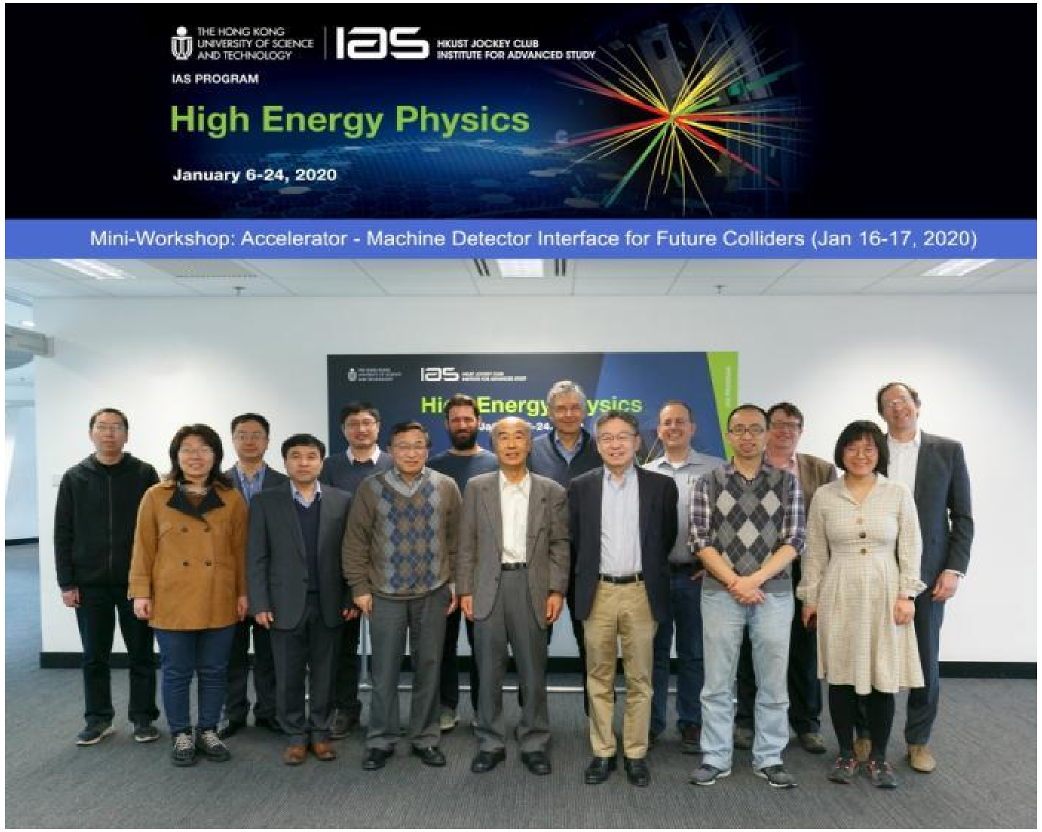


HKUST IAS Mini-workshop MDI (2020)
Jan. 16-17, 2020, IAS, Hongkang

http://iasprogram.ust.hk/hep/2020/workshop_accelerator.php

The CEPC MDI team is keep growthing!

The 2022 CEPC MDI Workshop, Hengyang
March 30-April 1, 2023

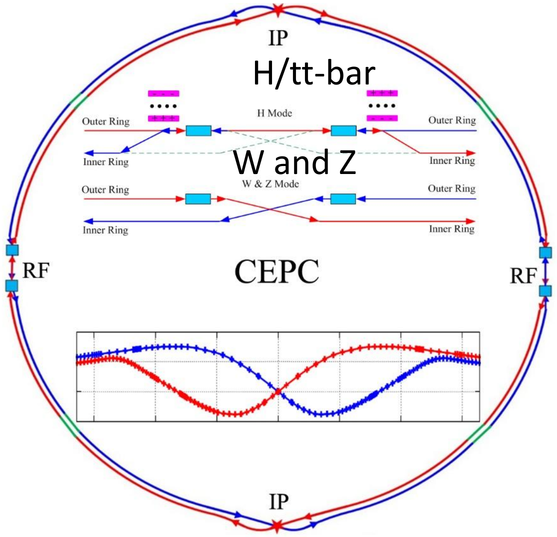
https://indico.ihep.ac.cn/event/19071/

~55 Participants

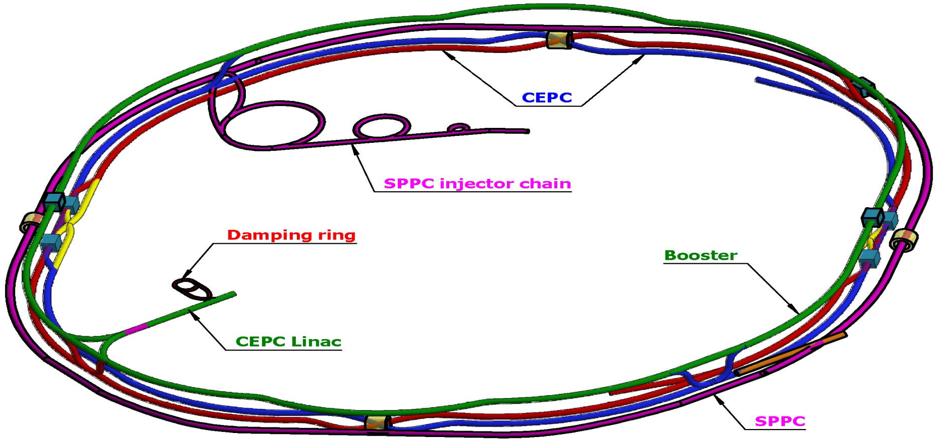
CEPC Accelerator System Design and Optimizations inTDR

CEPC Higgs Factory and SppC

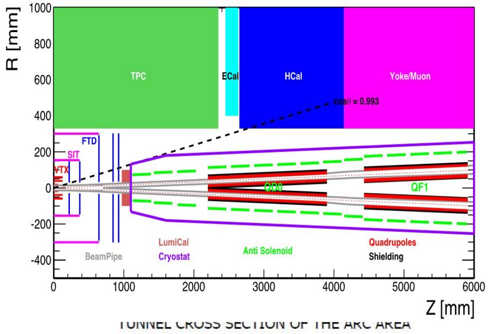
CEPC as a Higgs Factory： H, W, Z, upgradable to tt-bar, followed by a SppC (a Hadron collider) ~125TeV
30MW SR power per beam (upgradale to 50MW)

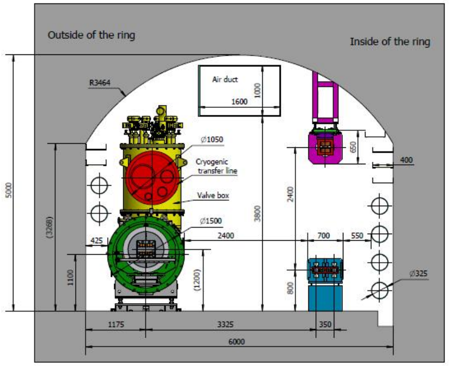


CEPC collider ring (100km)

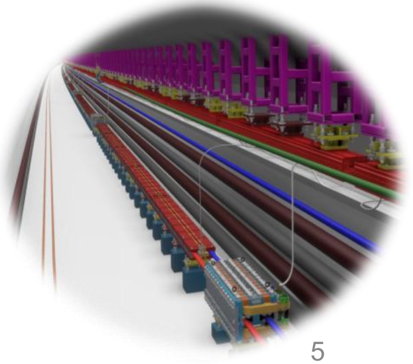


CEPC booster ring (100km)

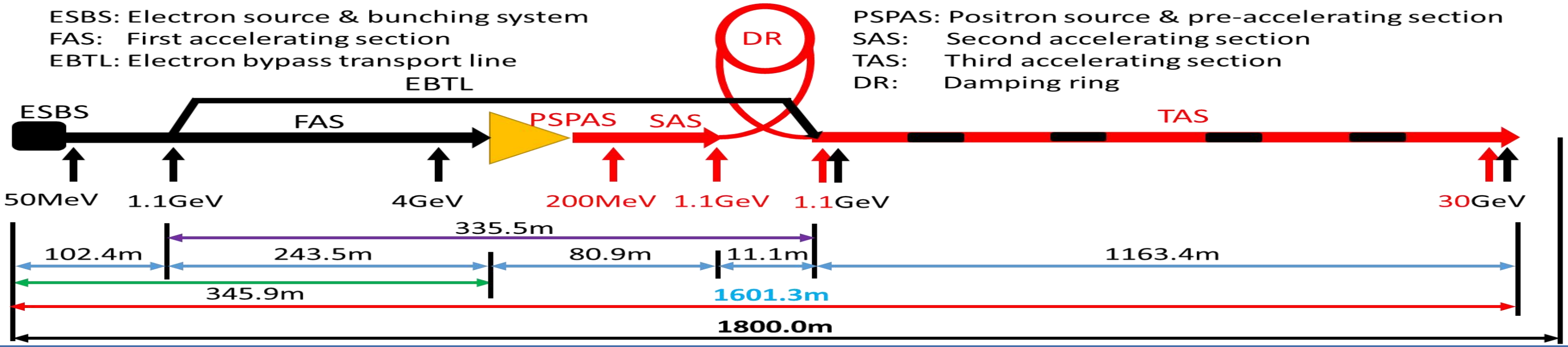




CEPC Civil Engineering



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	80/18000	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)

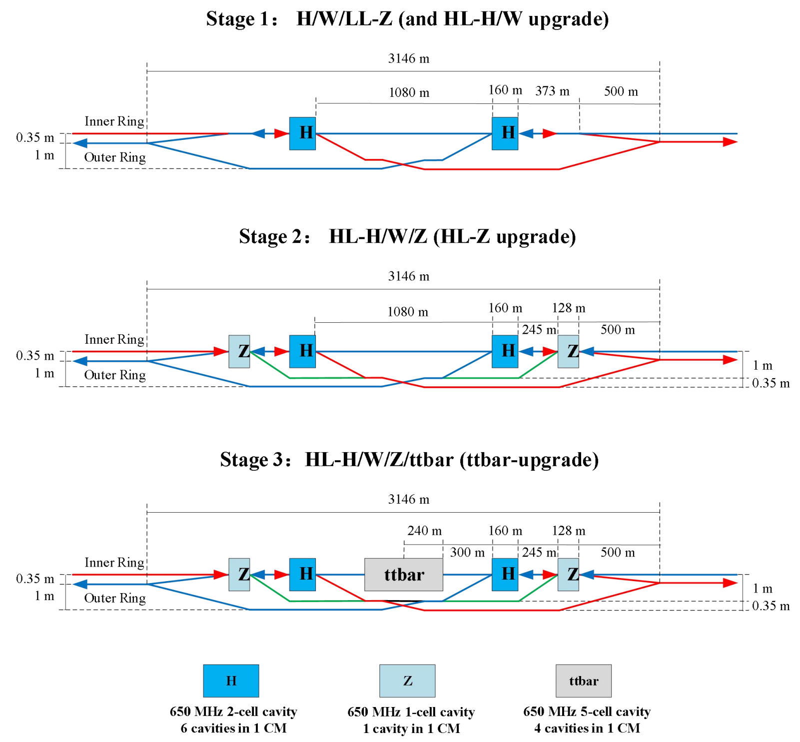
	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	100.0			
SR power per beam (MW)	**50**			
Half crossing angle at IP (mrad)	16.5			
Bending radius (km)	10.7			
Energy (GeV)	120	45.5	80	180
Energy loss per turn (GeV)	1.8	0.037	0.357	9.1
Damping time $\tau_x/\tau_y/\tau_z$ (ms)	44.6/44.6/22.3	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 TDR RF Parameters (Collider Ring)

J.Y.Zhai

30 MW SR power per beam for each mode. ttbar and Higgs half fill with common cavities for two rings, W and Z with separate cavities for two rings.	**ttbar** additional 5-cell cavities	**ttbar** existing 2-cell cavities	**Higgs**	**W**	**Z** bypass with 1-cell cavities
Luminosity / IP [10^{34} $cm^{-2}s^{-1}$]	0.5		5	16	115
RF voltage [GV]	10 (7.8 + 2.2)		2.2	0.7	0.12
Beam current / beam [mA]	3.3		16.7	84.1	803.5
Bunch charge [nC]	32		20.8	21.6	22.4
Bunch length [mm]	2.9		4.1	4.9	8.7
650 MHz cavity number	240	240	240	120/ring	30/ring
Cell number / cavity	5	2	2	2	1
Gradient [MV/m]	28.5	20	20	12.7	8.7
Q_0 @ 2 K at operating gradient (long term)	5E10	2E10			
HOM power / cavity [kW]	0.4	0.16	0.45	0.93	2.9
Input power / cavity [kW]	194	56	250	250	1000
Optimal Q_L	1E7	7E6	1.6E6	6.4E5	7.5E4
Optimal detuning [kHz]	0.01	0.02	0.1	0.9	13.3
Cavity number / klystron	4	12	2	2	1
Klystron power [kW]	1400	1400	800	800	1400
Klystron number	60	20	120	60	60
Cavity number / cryomodule	4	6			1
Cryomodule number	60	40			30
Total cavity wall loss @ 2 K [kW]	9.5	4.7		1.9	0.45

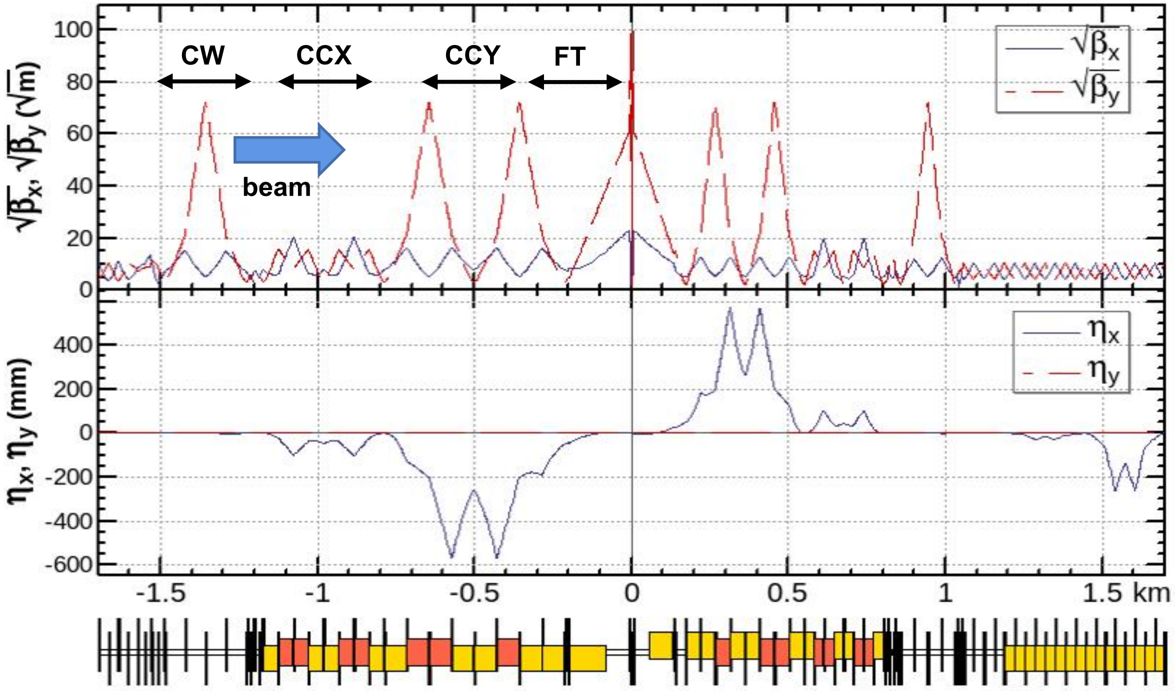
- Aiming for all-mode seamless switching in whole project lifecycle without hardware movement
- Highest luminosity in each energy. Maximize performance and flexibility for future circular electron positron collider



CEPC Collider Ring Interaction Region for Four Energies in TDR

Y.W. Wang

- For the interaction region, the IP beta functions are refitted with the different combination of final doulets and the matching quadruples.



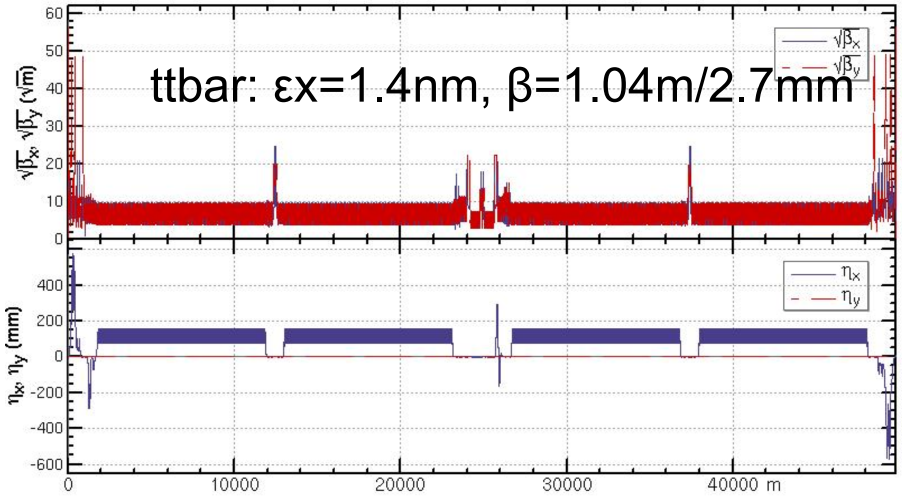
	QD	QF
Z	Q1A	Q1B
W/H	Q1A+Q1B	Q2
ttbar	Q1A+Q1B+Q2	add quad Q3A and Q3B

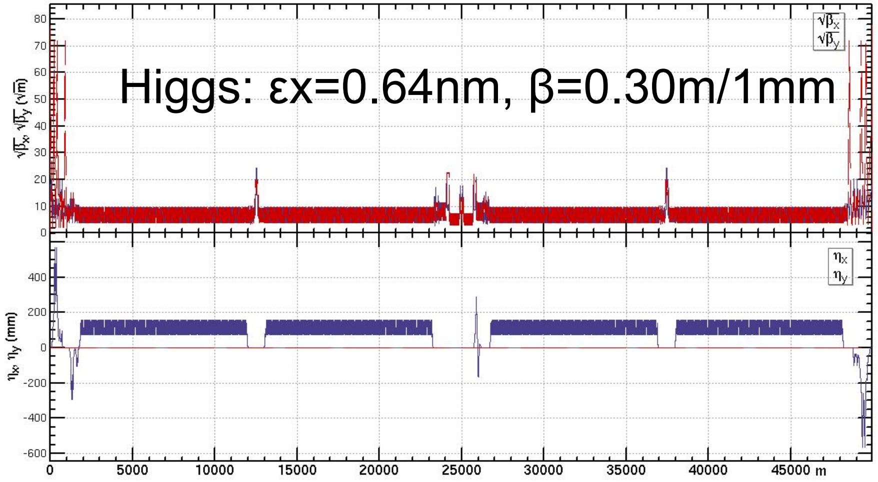
	L [m]	Strength [T/m]			
		ttbar	Higgs	W	Z
Q1AIRU	1.21	-141	-141	-94	-110
Q1BIRU	1.21	-59	-85	-56	+65
Q2IRU	1.5	-51	+95	+63	0
Q3AIRU	1.5	+40	0	0	+2
Q3BIRU	1.5	+40	0	0	+2
Q1AIRD	1.21	-142	-142	-95	-110
Q1BIRD	1.21	-64	-85	-57	+65
Q2IRD	1.5	-47	+96	+64	0
Q3AIRD	1.5	+40	0	0	+2
Q3BIRD	1.5	+40	0	0	+2

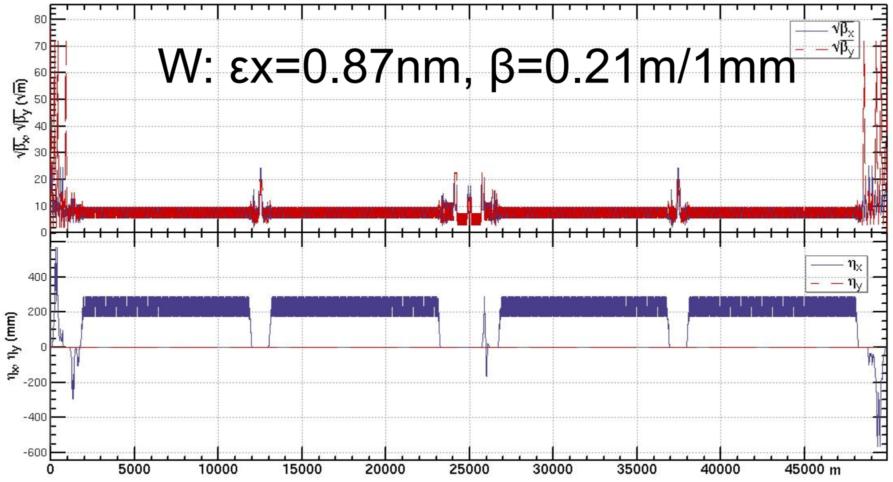
Strength of other modes doesn’t exceeded the one of Higgs mode.

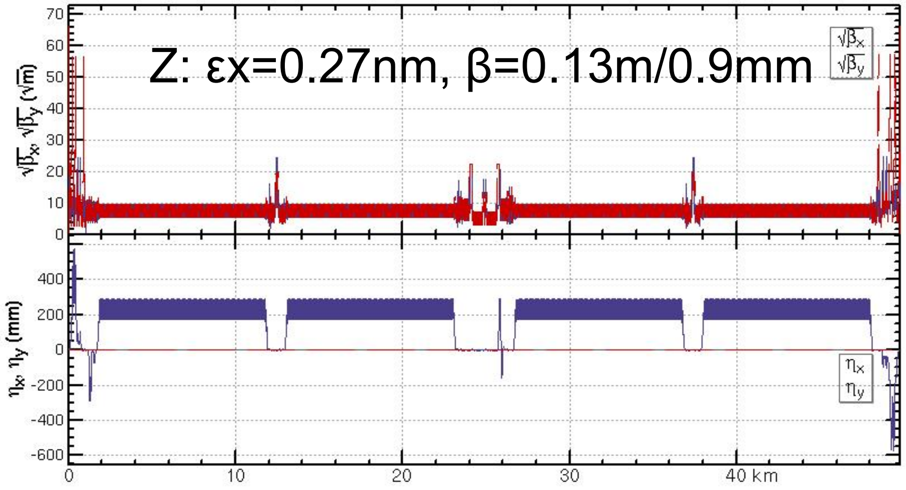
CEPC Collider Ring Lattice of Half Ring for Four Energy Operation Modes in TDR

Y.W. Wang







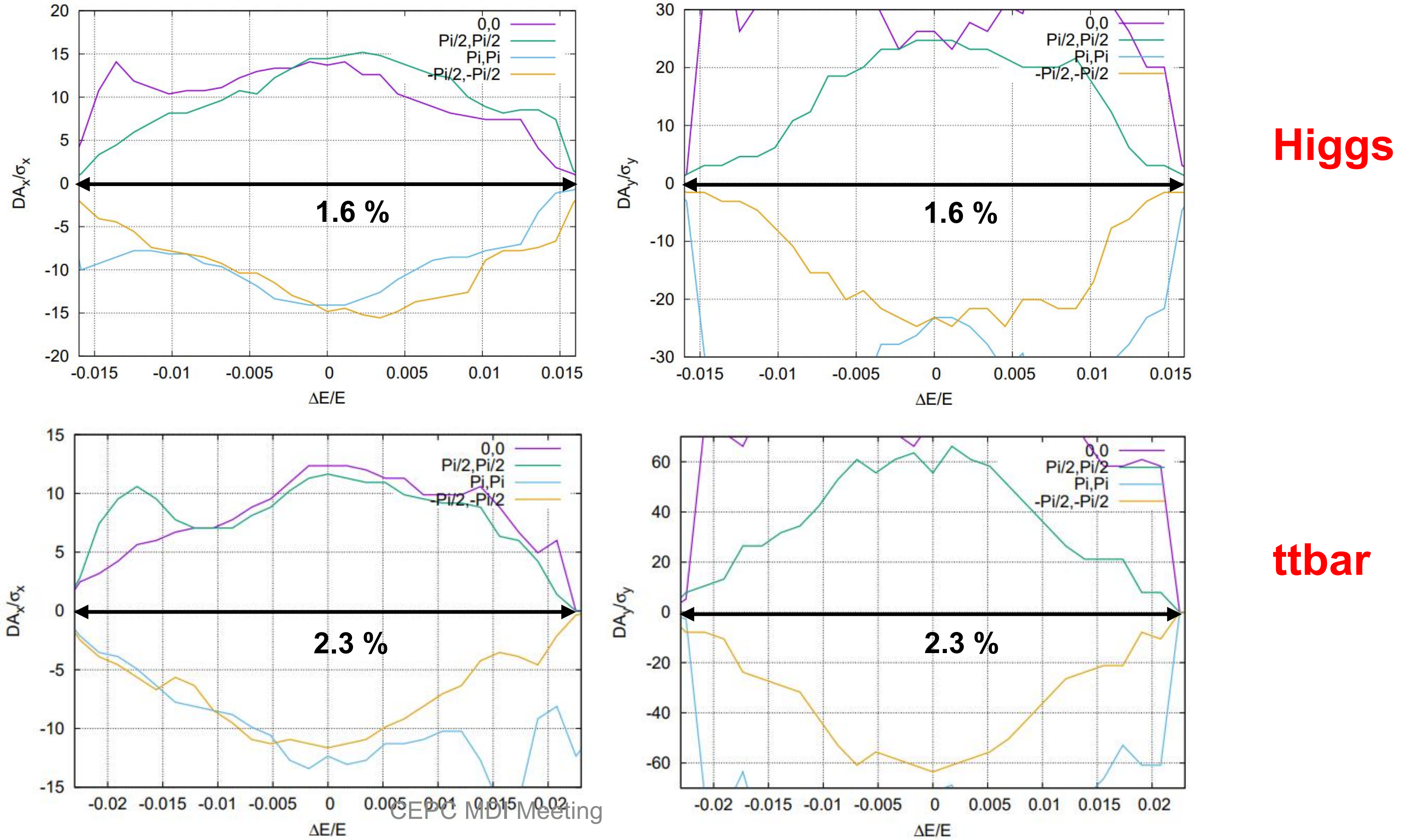


CEPC Collider Ring Dynamic Aperture Status @ Higgs and ttbar in TDR

Y.W. Wang

- Tracking to get DA **without errors**, with turns for one transvers damping time, with 4 initial phases
- DA optimized with 84 variables (64 arc sextupoles + 8 IR sextupoles + 4 multipoles + 8 phase advance)

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

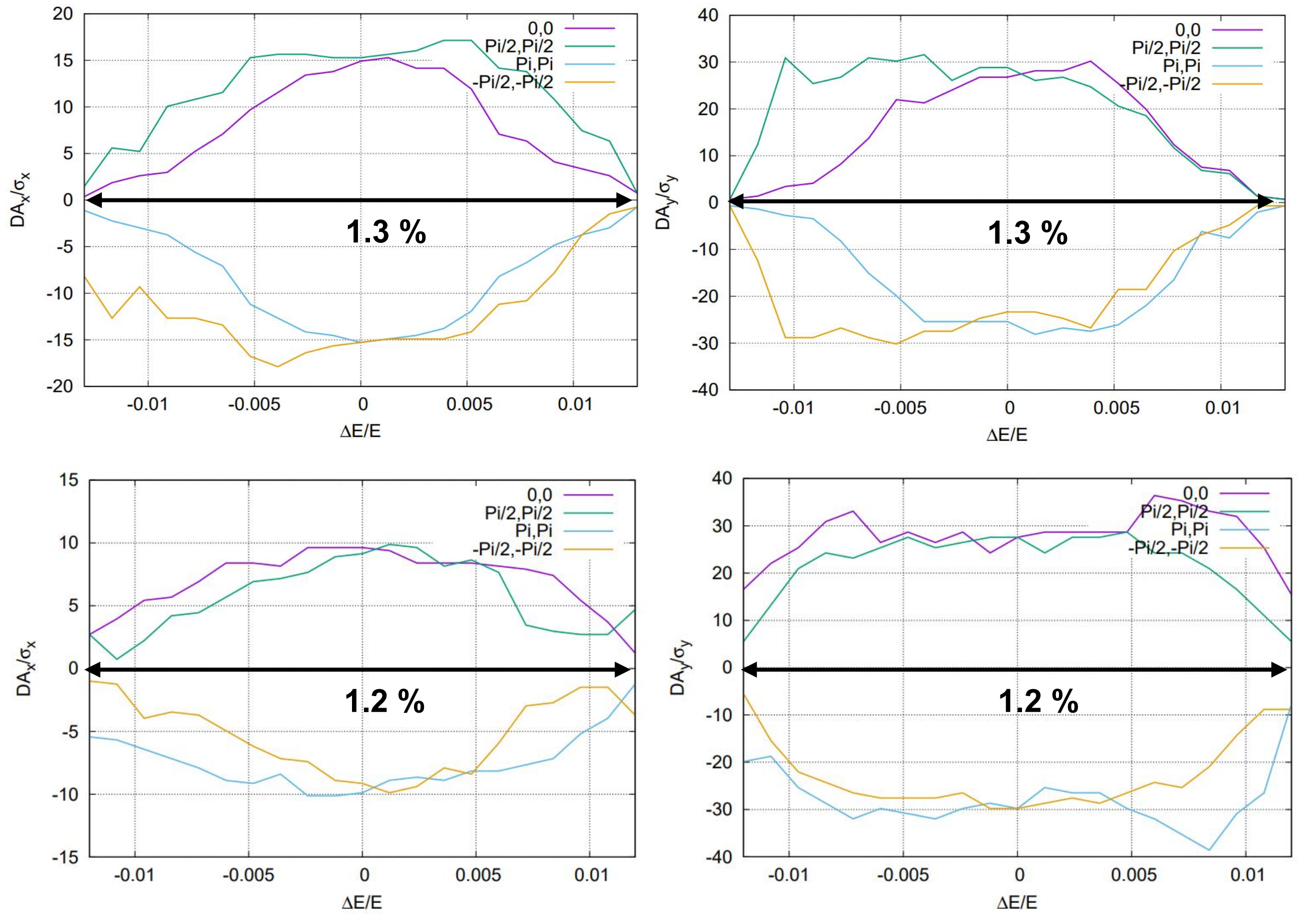


CEPC Collider Ring Dynamic Aperture Status @ Z and W in TDR

Y.W. Wang

- Tracking to get DA **without errors**, with turns for one transvers damping time, with 4 initial phases
- DA optimized with 116 variables (96 arc sextupole families + 8 IR sextupoles + 4 multipoles + 8 phase advance)

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

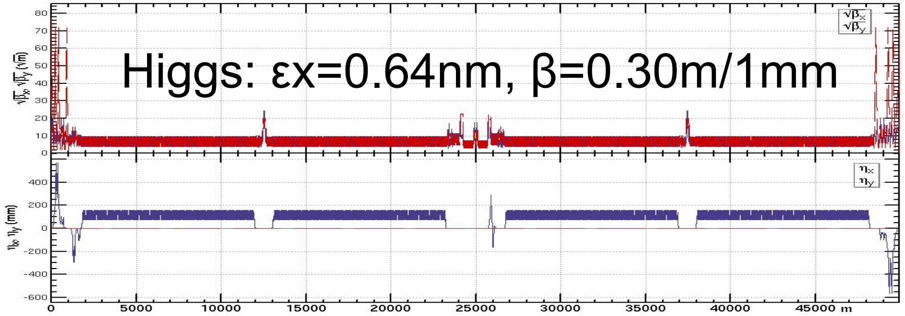


Z

W

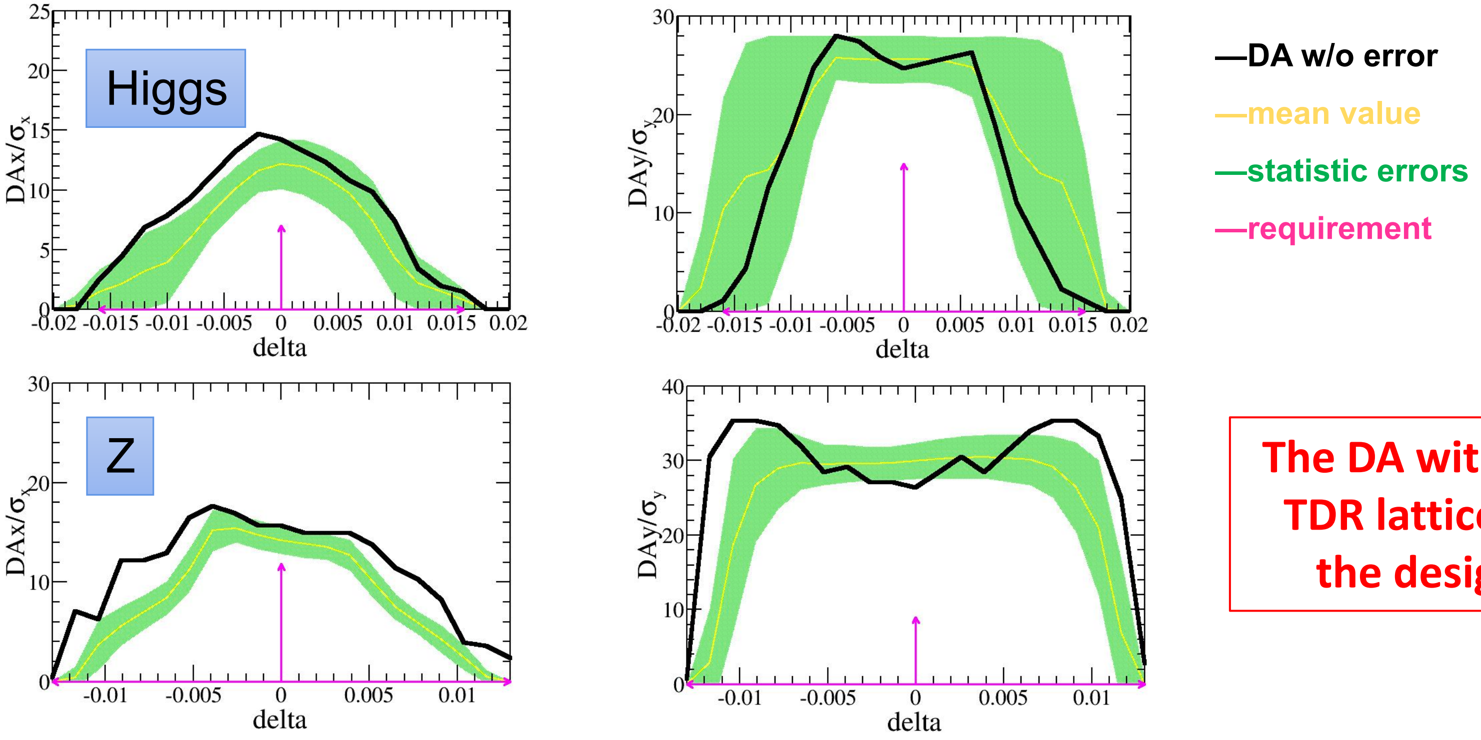
CEPC Collider Ring TDR Lattice Dynamic Apertures with Errors at Higgs and Z-pole Energies

Yiwei Wang
Bin Wang



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	

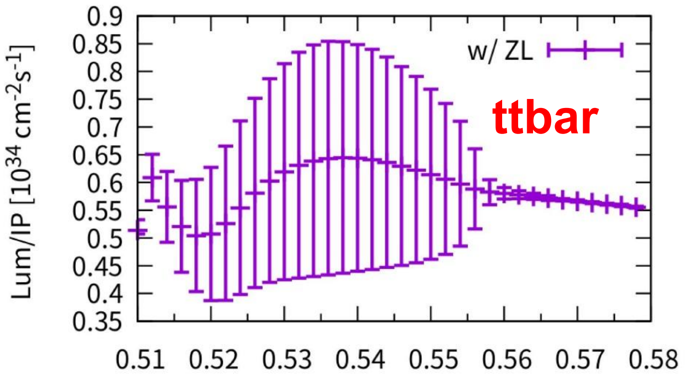
Effects included in tracking
Synchrotron motion
Radiation loss in all magnets
Tapering
Crab waist sextupole
Maxwellian fringes
Kinematic terms
Finite length of sextupole



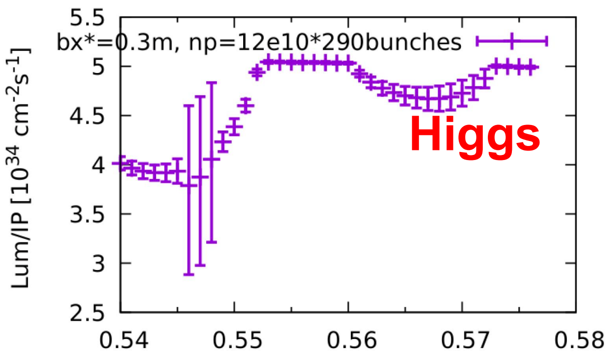
The DA with erros of TDR lattice satisfiy the design goal

CEPC TDR Parameter Luminosity Check by Beam-beam Simulations

Y. Zhang

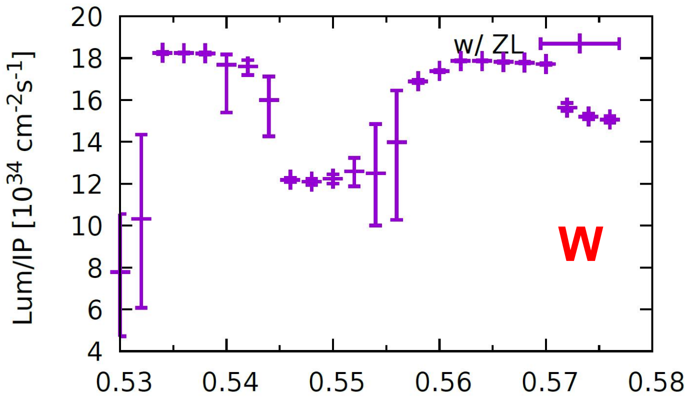


Ttbar: 0.55* 10^34/cm^2/s (BB Simulation)
Parameter table:0.5*10^34/cm^2/s

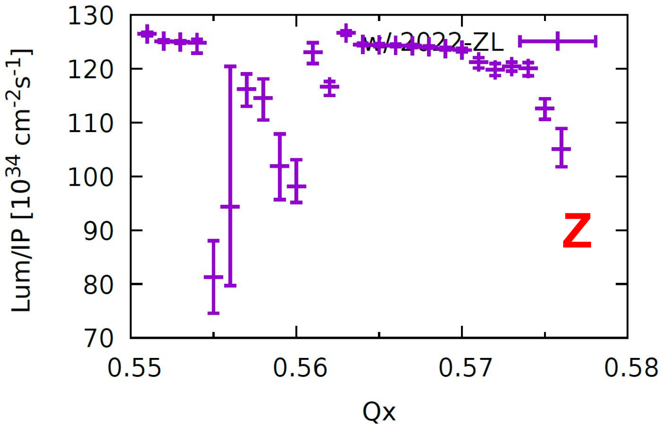


Higgs : 5*10^34/cm^2/s (BB Simulation)
Parameter table:5*10^34/cm^2/s

The beam-beam simulations results are consistent with the CEPC TDR parameter tables



W-pole : 18*10^34/cm^2/s(BB Simulation)
Parameter table:16*10^34/cm^2/s

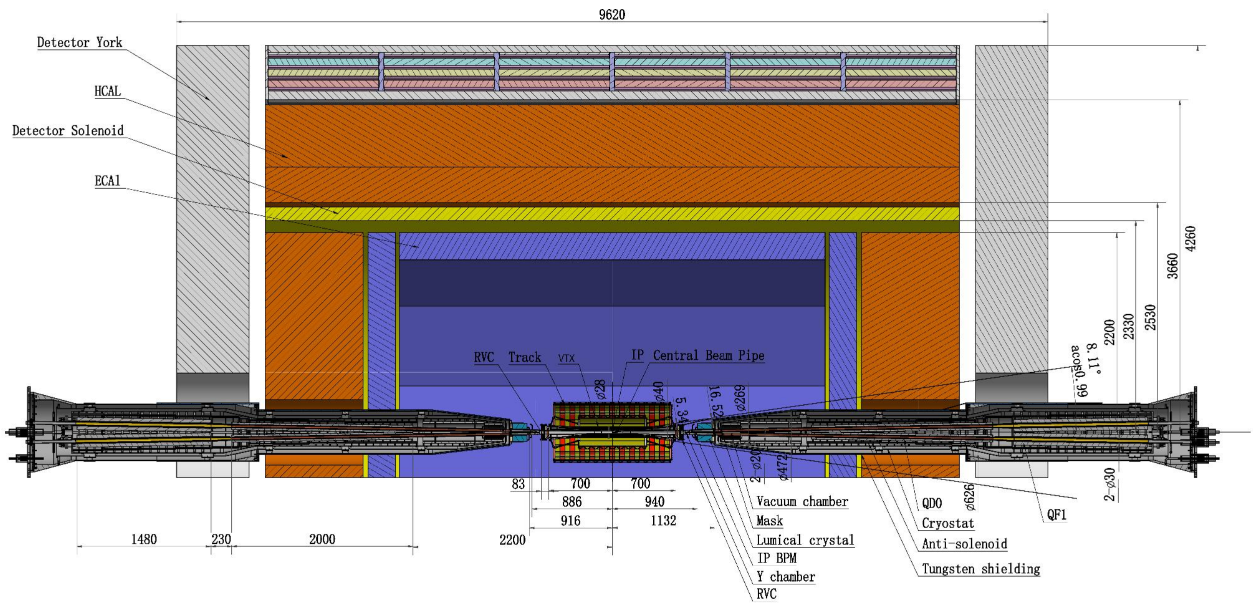


Z-pole : 125*10^34/cm^2/s (BB Simulation)
Parameter table:115*10^34/cm^2/s

S. Bai

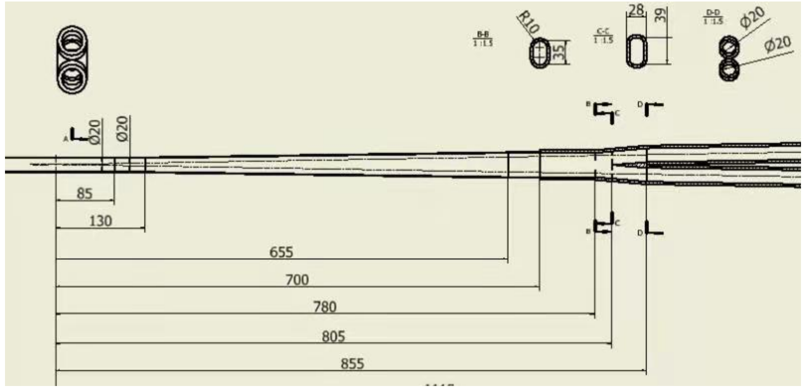
CEPC MDI in TDR

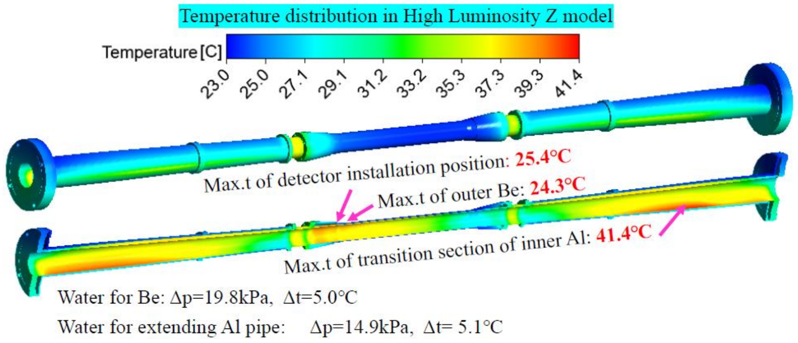
- IR Superconducting magnet design
- IR beam pipe
- Synchrotron radiation
- Beam loss background
- Shielding
- Mechanical support
- Full detector simulation



Central beryllium pipe inner diameter changes from 28mm(CDR) to 20mm

There is no SR photons hitting the central beam pipe in normal conditions.





L^*=1.9m, θc=33mrad, βx^*=0.33m, βy^*=1.0mm, Emittance=0.68nm

- Strength requirements of anti-solenoids (peak field B_z~7.2T)
- Two-in-one type SC quadrupole coils (Peak field 3.8T & 141T/m) with room temperature vacuum chamber & Iron yoke

CEPC TDR MDI Parameters

S. Bai

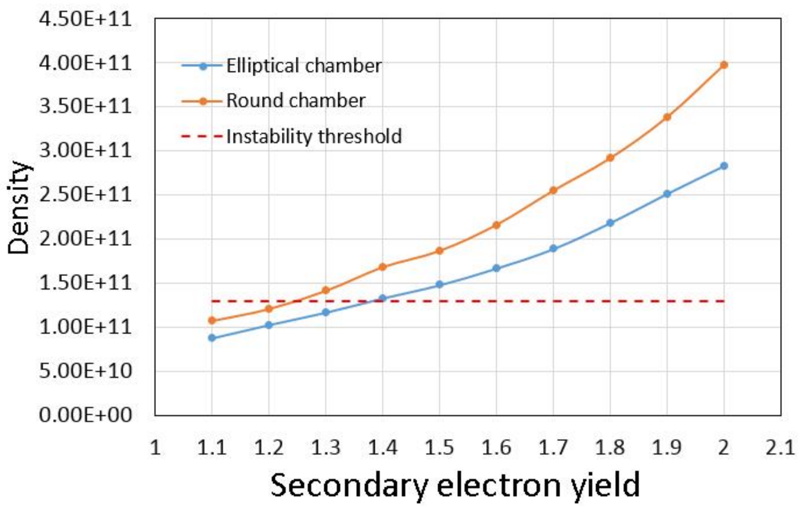
	range	Peak fieled in coil	Central fieled gradient	Bending angle	length	Beam stay clear region	Minimal distance between two aperture	Inner diameter of beam pipe	Outer diameter of beam pipe	Critical energy (Horizontal)	Critical energy (Vertical)	SR power (Horizontal)	SR power (Vertical)
L*	0~1.9m				1.9m								
Crossing angle	33mrad												
MDI length	±7m												
Detector requirement of accelerator 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	0.95~1.11m				0.16m								
Anti-solenoid before QD0		6.8T			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					1.5m							2.39W	
Beampipe between QD0/QF1					0.3m							26.5W	

CEPC Collective Effects in TDR

N. Wang
Y.D. Liu

- No apparent show stoppers for ttbar, Higgs, W from collective instability point of view for 50MW SR. The beam intensity of Z at 50MW SR is restricted by the resistive wall instability and electron cloud effects, but Z could work at 30MW SR. **Collective effects satisfy TDR requirments**
  - Resistive wall instability ⇒ Tough requirement on feedback damping

	30 MW	50 MW
Instability growth time [ms]	1.9 (~6 turns)	1.1 (~3 turns)
Radiation damping [ms]	850	
Bunch by bunch feedback [ms]	1.0 (~3 turns)	0.5 (~1.5 turns)



30MW (SEY<1.2 for round chamber Realized by NEG coating)

Total impedance budget @3mm@ Z

Components	Number	$Z_{||}/n$, mΩ	k_{loss}, V/pC	k_y, kV/pC/m
Resistive wall	-	6.7	425.6	13.8
RF cavities	60	0.5	101.2	0.5
Flanges	37714	5.2	37.3	5.2
BPMs	1808	0.04	9.5	0.2
Bellows	15949	2.9	87.4	3.9
Gate Valves	500	0.2	14.5	0.4
Pumping ports	5316	0.3	2.3	0.2
Collimators	16	0.04	23.4	0.6
IP chambers	2	0.004	0.3	0.05
Electro-separators	20	-0.1	34.5	0.1
Taper transitions	48	0.04	2.5	0.09
TDR Total		**15.8**	**738.5**	**25.0**
CDR Total		**11.4**	**786.8**	**20.2**

CEPC Booster TDR Parameters

D. Wang

- Injection energy: 10GeV → 20GeV → 30GeV
- Max energy: 120GeV → 180GeV
- Lower emittance — new lattice (TME)

		tt	*H*	*W*	*Z*	
Beam energy	GeV	30				
Bunch number		35	268	1297	3978	5967
Threshold of single bunch current	μA	8.68	6.3	5.8		
Threshold of beam current (limited by coupled bunch instability)	mA	97	106	100	93	96
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
Growth time (coupled bunch instability)	ms	2530	530	100	29.1	18.7
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
Threshold of single bunch current	μA	91.5	70		22.16	9.57	
Threshold of beam current (limited by RF system)	mA	0.3	1		4	16	
Beam current	mA	0.11	0.56	0.98	2.85	9.5	14.4
Growth time (coupled bunch instability)	ms	16611	2359	1215	297.8	49.5	31.6
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	
Injection interval for top-up	s	65	38		155	153.5	
Current decay during injection interval		3%					
Energy spread	%	0.15	0.099		0.066	0.037	
Synchrotron radiation loss/turn	GeV	8.45	1.69		0.33	0.034	
Momentum compaction factor	10^{-5}	1.12					
Emittance	nm	2.83	1.26		0.56	0.19	
Natural chromaticity	H/V	-372/-269					
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	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

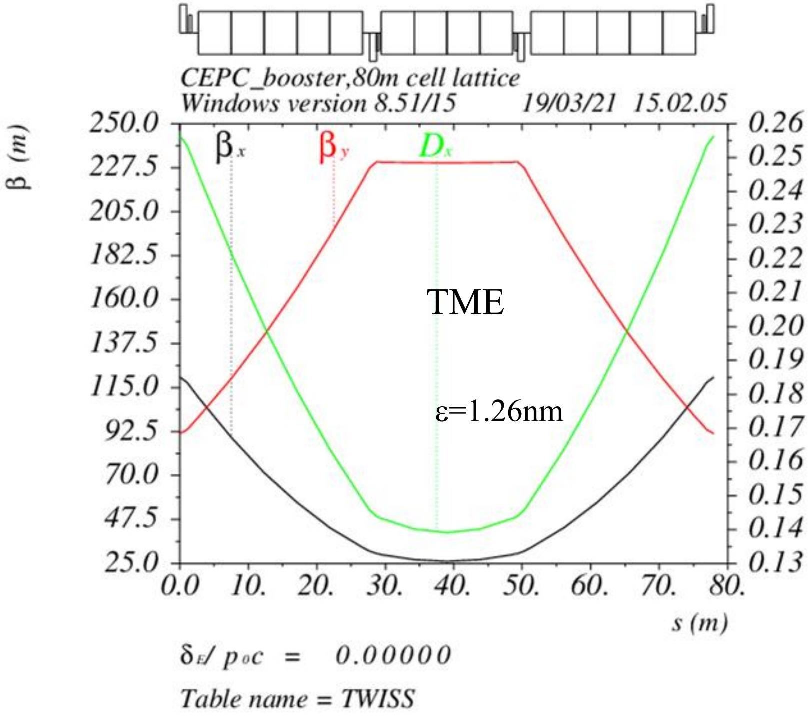
*Diameter of beam pipe is 55mm for re-injection with high single bunch current @120GeV.

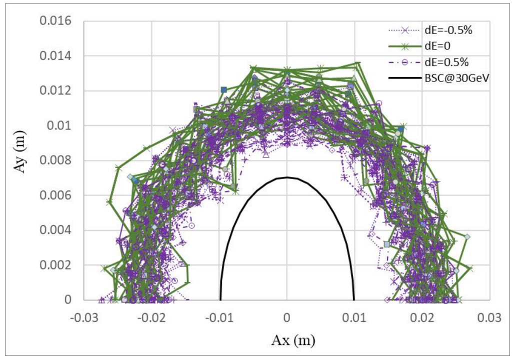
CEPC Booster TDR Optics and DA with Errors

D. Wang, D.H. Ji, C. H. Yu, Y. M. Peng..

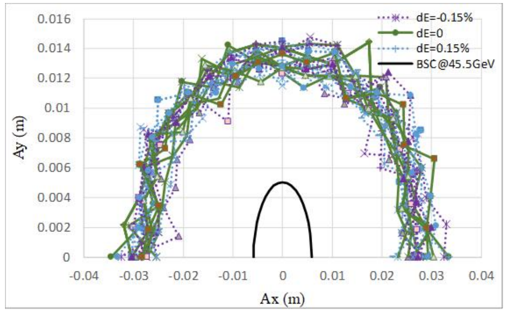
- TME like structure (cell length=80m)
- Overall idea: uniform distribution for the Q
- Combined magnet (B+S) scheme possible
- Interleave sextupole scheme
- Emittance@120GeV=1.26nm

Dispersion sup.

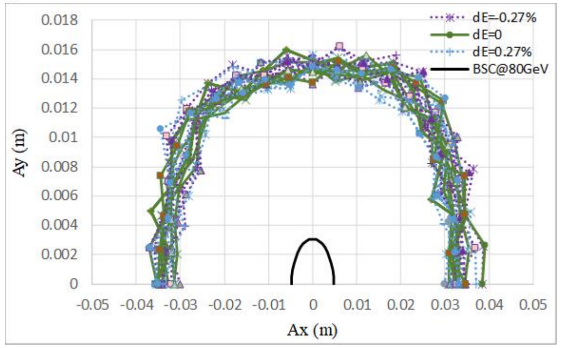




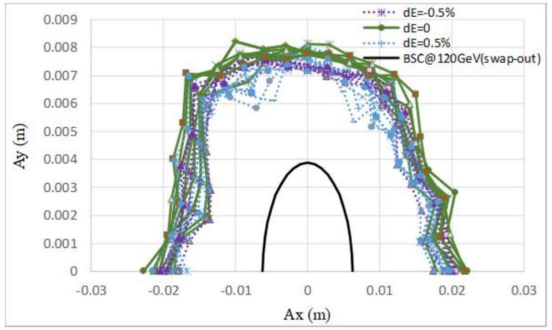
DA @30GeV



DA @45GeV

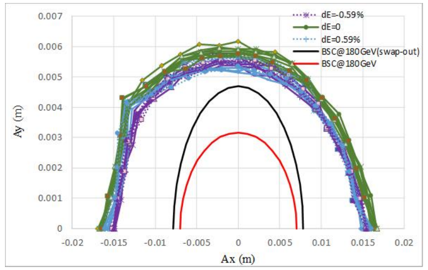


DA @80GeV



DA @120GeV

dipole	quadrupole	sextupole
$B1/B0 \le 2\times10^{-4}$		
$B2/B0 \le 3\times10^{-4}$	$B2/B1 \le 3\times10^{-4}$	
$B3/B0 \le 2\times10^{-5}$	$B3/B1 \le 1\times10^{-4}$	$B3/B2 \le 1\times10^{-3}$
$B4/B0 \le 8\times10^{-5}$	$B4/B1 \le 1\times10^{-4}$	$B4/B2 \le 3\times10^{-4}$
$B5/B0 \le 2\times10^{-5}$	$B5/B1 \le 1\times10^{-4}$	$B5/B2 \le 1\times10^{-3}$
$B6/B0 \le 8\times10^{-5}$	$B6/B1 \le 5\times10^{-5}$	$B6/B2 \le 3\times10^{-4}$
$B7/B0 \le 2\times10^{-5}$	$B7/B1 \le 5\times10^{-5}$	$B7/B2 \le 1\times10^{-3}$
$B8/B0 \le 8\times10^{-5}$	$B8/B1 \le 5\times10^{-5}$	$B8/B2 \le 3\times10^{-4}$
$B9/B0 \le 2\times10^{-5}$	$B9/B1 \le 5\times10^{-5}$	$B9/B2 \le 1\times10^{-3}$
$B10/B0 \le 8\times10^{-5}$	$B10/B1 \le 5\times10^{-5}$	$B10/B2 \le 3\times10^{-4}$



DA @180GeV

TME DA with installation errors
and multipole errors satisfy design goals

CEPC TDR SRF Parameters (Booster Ring)

30 MW Collider SR power per beam for each mode. 20 GeV injection.	**ttbar**	**Higgs** off/on-axis	**W**	**Z** high current
Extraction beam energy [GeV]	180	120	80	45.5
Extraction average SR power [MW]	0.087	0.09	0.01	0.004
Bunch charge [nC]	0.96	0.7	0.73	0.83
Beam current [mA]	0.11	0.56/0.98	2.85	14.4
Injection RF voltage [GV]	0.438	0.197	0.122	0.122
Extraction RF voltage [GV]	9.7	2.17	0.87	0.46
Extraction bunch length [mm]	1.8	1.85	1.3	0.75
Cavity number (1.3 GHz 9-cell)	336	96	64	32
Extraction gradient [MV/m]	27.8	21.8	13.1	13.8
Q_0 @ 2 K at operating gradient (long term)	1E10			
Q_L	4E7	1E7		
Cavity bandwidth [Hz]	33	130		
Peak HOM power per cavity [W]	0.4	1.4/2.7	9.8	108.5
Input peak power per cavity [kW]	7.9	15.3/21.3	15	33
SSA peak power [kW] (one cavity per SSA)	10	25	25	40
Cryomodule number (8 cavities per module)	42	12	8	4

CDR Higgs energy: J.Y. Zhai

-collider ring: 240 2cell 650MHz cavities

-booster: 96 1.3GHz 9cell cavities

-Nb consumption: 20 tons

For ttbar energy:

In addition to CDR Higgs energy, SRF cavity numbers have to be increased:

-collider ring:+350 5cell 650MHz cavities

-booster ring:+350 1.3GHz 9 cell cavities

-Additional Nb consumption:65 tons

For 30MW SR/beam Mode at Higgs energy, the cryogenic system need **32000liter Hellium**

For 50MW/beam SR Mode:

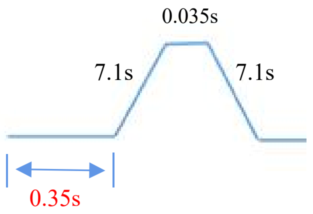
at Higgs energy, the cryogenic system needs 42000liter Hellium; at ttbar energy **130000liter Hellium needed**

Refrigerators: 4*18kW@4.5K

CEPC Booster Ramping Scheme in TDR

Dou Wang, Xiaohao Cui

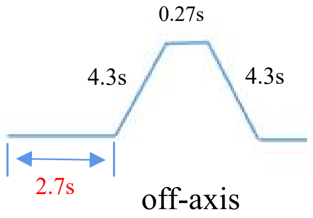
tt



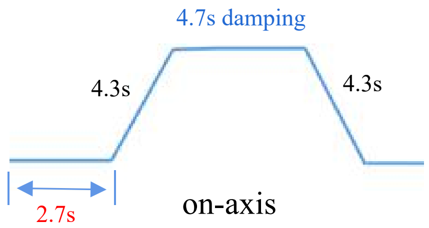
1 cycles/beam

0.35s+7.1s+0.035s+7.1s=14.6s

Higgs



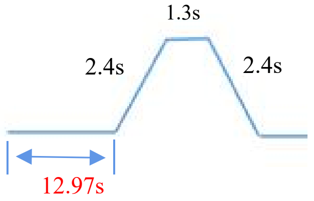
1 cycles/beam



2.7s+4.3s+4.7s+4.3s=16.0s

- On-axis injection @ Higgs
  - Step 1: Linac→booster (240 small bunches)
  - Step 2: Collider→booster (7 big bunches)
    off-axis injection
  - Step 3: Mix in booster
    (233 small bunches + 7 big bunches)
  - Step 4: Booster→collider (7 big bunches)
    on-axis injection
  - → Step 2
  - …

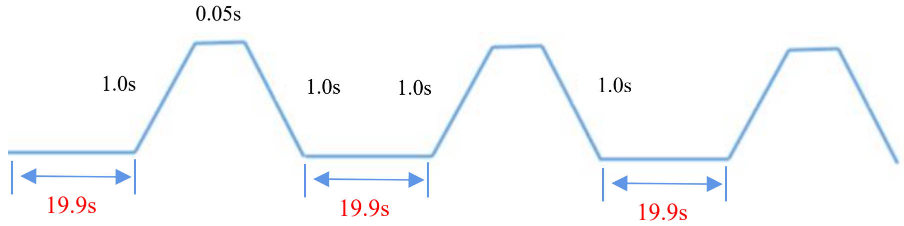
W



1 cycles/beam

12.97s+2.4s+1.3s+2.4s=19.1s

Z



(19.9s+1.0s+0.05s+1.0s)*3=65.9s

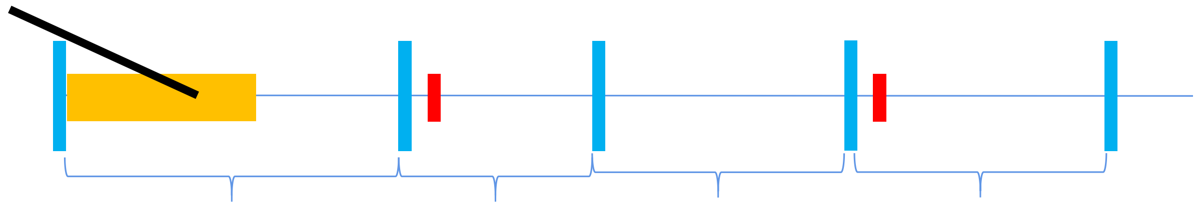
3 cycles/beam

Extraction from Booster Collider Ring in TDR

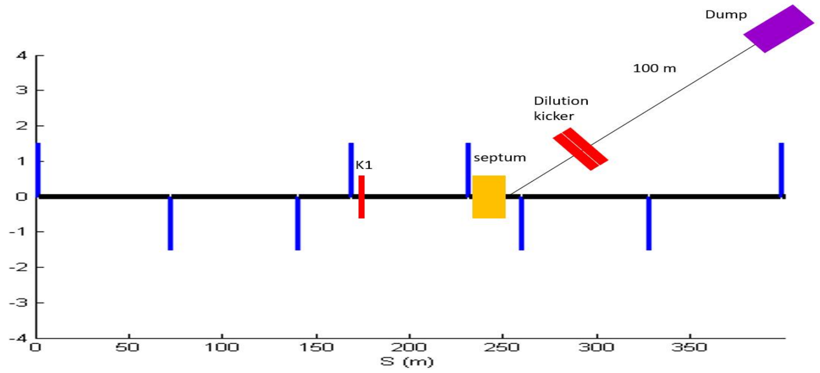
X.H. Cui

	tt	Higgs	W
Energy（GeV）	180	120	80
Bunch number	37	240	1230
Bunch seperation（us）	4.2	0.647	0.2677
Extraction scheme	bunch by bunch	bunch by bunch	bunch by bunch
Kicker frequency(Hz)	1000	1000	1000
Kicker pules duration (us)	<8.4	<1.29	<0.535
Kicker rise up/ fall down (us)	<4.2	<0.647	<0.2677
Timing delay(us)	4.2	0.647	0.2677
Extraction duration (s)	0.037	0.24	1.23

	Z
Energy（GeV）	45.5
Bunch number/train	80
Bunch separation（ns）	23.076
Number of trains	48
Train separation (us)	5.11
Extraction scheme	train by train
Kicker frequency(Hz)	1000
Flat top (us)	1.83
Kicker pules duration (us)	<12.05
Kicker rise up/ fall down (us)	<5.11
Timing delay(us)	6.94
Extraction duration (s)	0.048



From booster to collider



From colliderr to dump

Complete transport lines and timing from electron gun to damping ring, booster, collider ring till beam dump have been studied

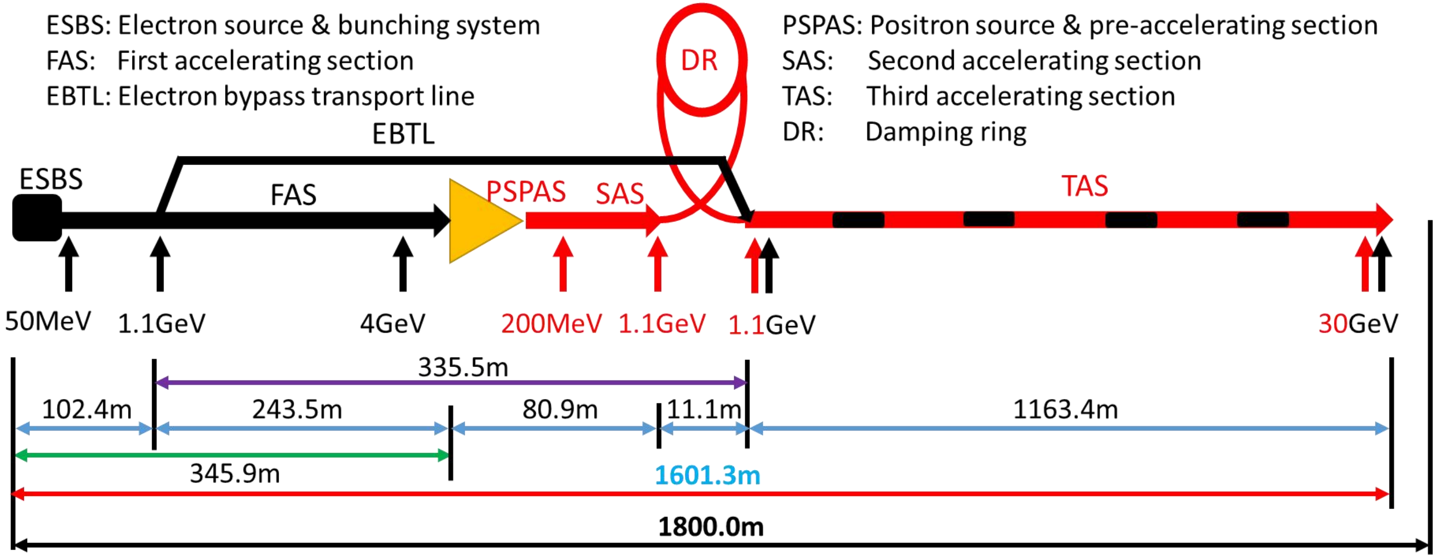
CEPC TDR Linac Injector of 30GeV

C. Meng

CEPC 20GeV Linac Injector design has also been completed

- 30GeV-Linac Scheme
  - C-band accelerating structure is used in TAS form 1.1GeV to 30GeV
  - S-band accelerating structure is used in FAS with energy of 4GeV and SAS with energy of 1.1 GeV
  - The bunch charge is 1.5nC and have the capability to reach 3nC both for electron and positron beam
- Electron Linac
  - ESBS+FAS+EBTL+TAS
- Positron Linac
  - ESBS+FAS+PSPAS+SAS+DR+TAS
- The Linac length is 1.6km and there is still 0.2km as reserved space, the Linac tunnel length is 1.8km
  - The circumference of the damping ring is about 0.15km

Parameter	Symbol	Unit	Baseline
Beam energy	E_{e-}/E_{e+}	GeV	30
Repetition rate	f_{rep}	Hz	100
Bunch population	Ne-/Ne+	$\times 10^{10}$	0.94
		nC	1.5
Energy spread	σ_E		1.5×10^{-3}
Emittance	ε_r	nm	6.5

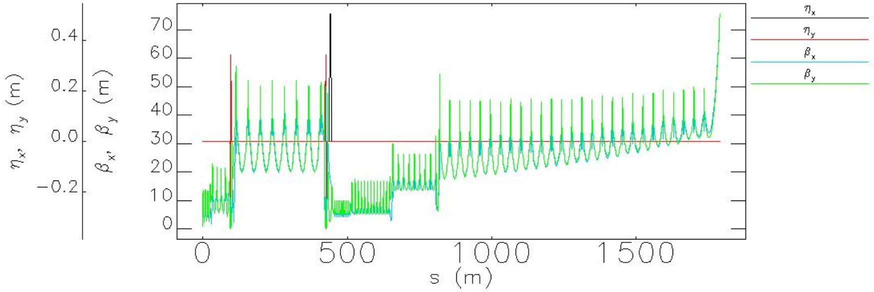


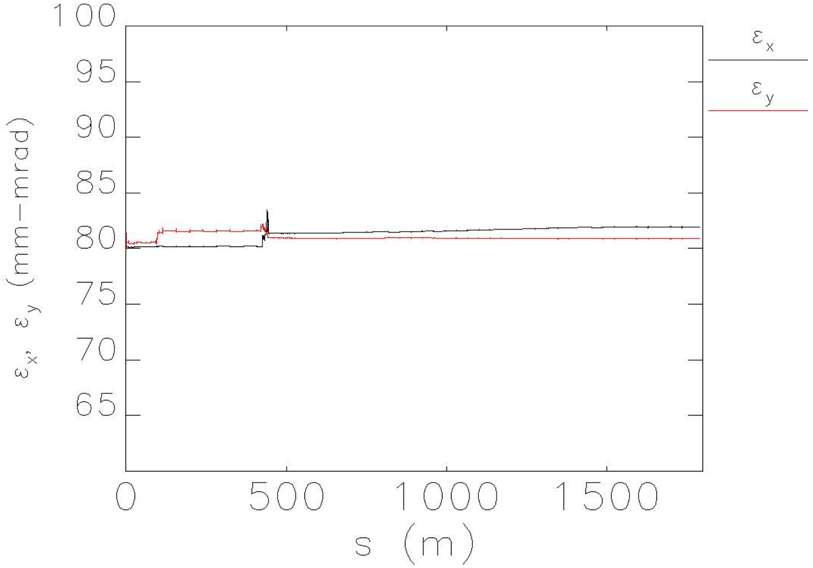
CEPC TDR Linac Injector Design (30GeV)

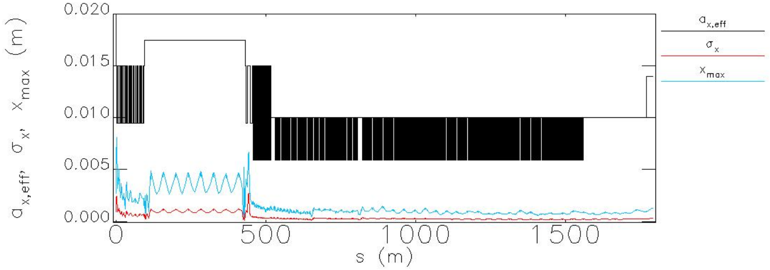
C. Meng

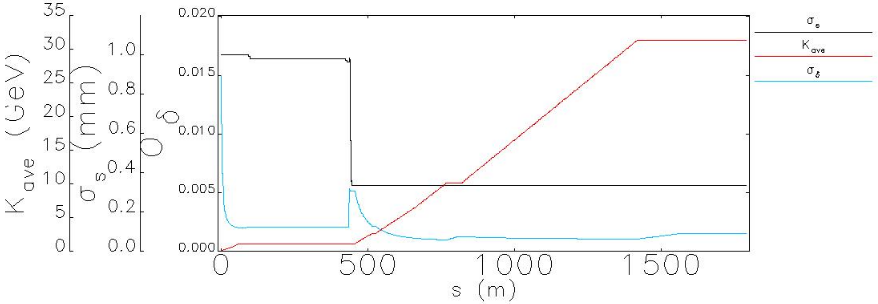
- Simulation results

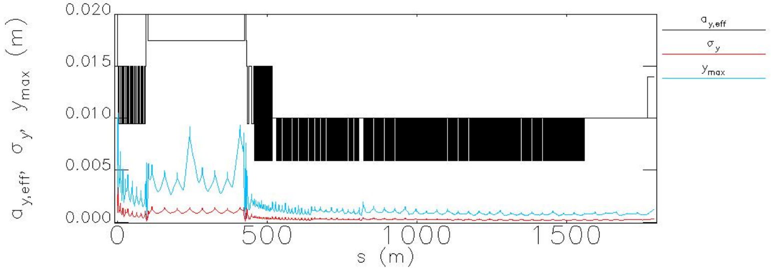
Parameter	Unit	Value	Simulated			
			Electron		Positron	
Beam energy	GeV	30	31.3	30.8	31.1	30.8
Repetition rate	Hz	100	/			
Bunch charge	nC	1.5	1.5	3.0	1.5	3.0
Energy spread		1.5×10^{-3}	1.4×10^{-3}	1.7×10^{-3}	1.4×10^{-3}	1.9×10^{-3}
Emittance	nm	6.5	1.4	1.5	3.3(H)/1.7(V)	3.5(H)/1.8(V)
Bunch length (RMS)	mm	/	0.4			







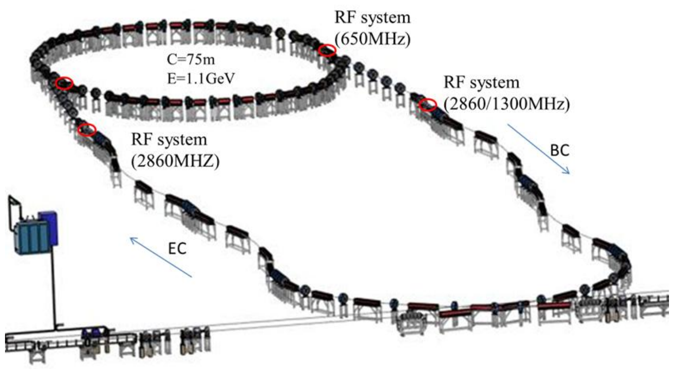


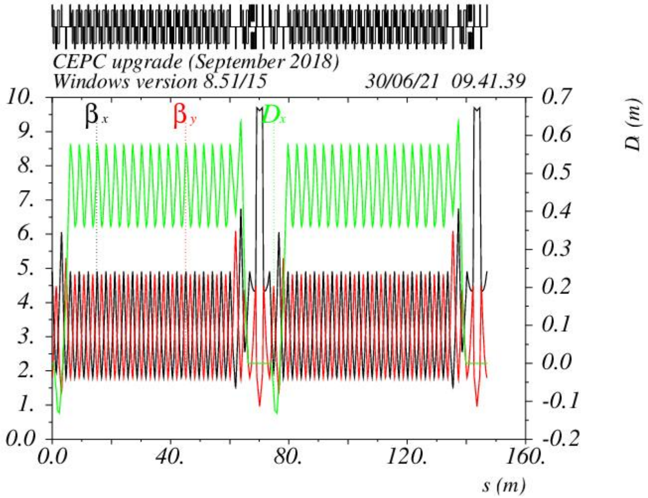


CEPC Positron DR TDR Parameters

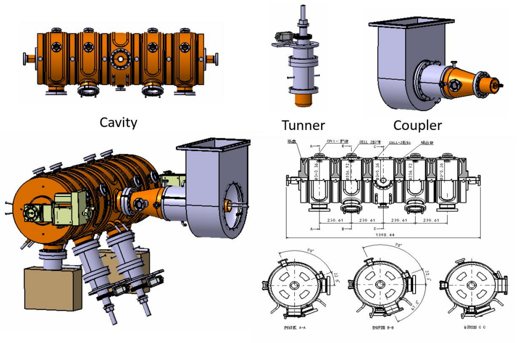
D. Wang, J.R. Zhang

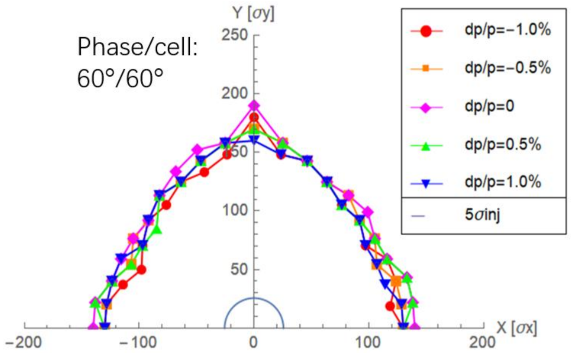
- Damping with **reversed bending magnet**
- 4 (max. 8)-bunch storage, storage time:20 (40) ms
- Emittance: 2500→ 166/75 (97/3) mm.mrad
- Flexibility for extr. emittance





RF Cavity Design

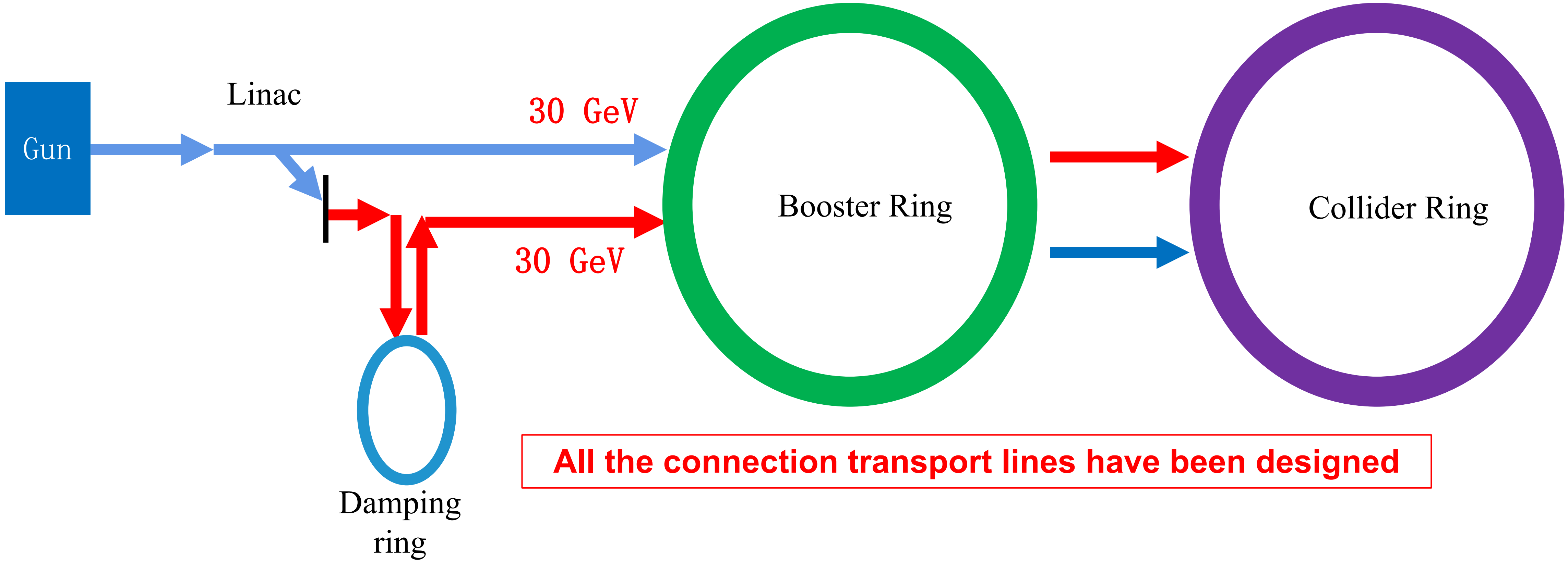




	DR V3.0
Energy (Gev)	1.1
Circumference (m)	147
Number of trains	2 (4)
Number of bunches/trian	2
Total current (mA)	12.4 (24.8)
Bending radius (m)	2.87
Dipole strength B_0 (T)	1.28
U_0 (kev/turn)	94.6
Damping time x/y/z (ms)	11.4/11.4/5.7
Phase/cell (degree)	60/60
Momentum compaction	0.013
Storage time (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 in TDR

X.H. Cui



All the connection transport lines have been designed

1. Injection and extraction from: Linac, damping ring, booster, and collider;
2. Energy: Higgs (120 GeV), W (80 GeV), Z (45.5 GeV), tt (180 GeV);

CEPC SRF Cryogenic Systems in TDR

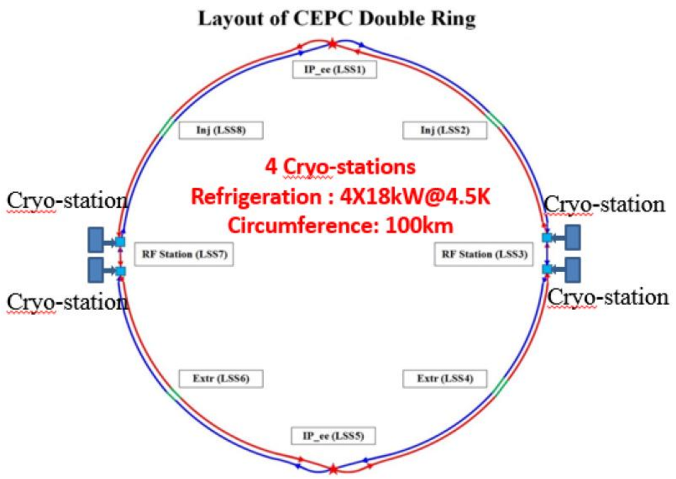
R. Ge
M. Li

Booster ring:

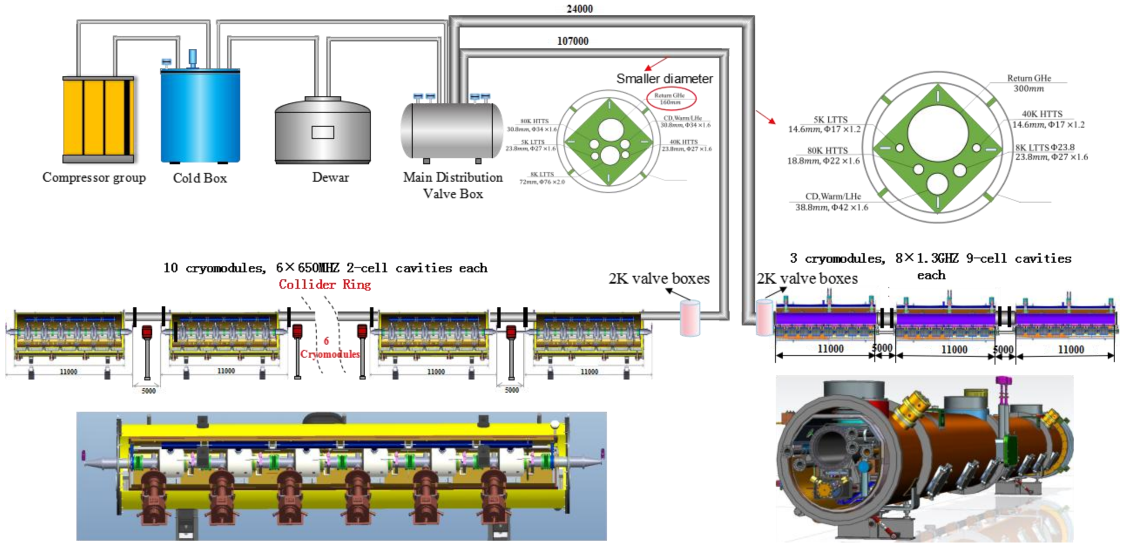
- 1.3 GHz 9-cell cavities, 96 cavities
- 12 cryomodules
- 3 cryomodules/each station
- Temperature: 2K/31mbar

Collider ring:

- 650MHz 2-cell cavities, 336 cavities
- 56 cryomodules
- 14 cryomodules/each station
- Temperature: 2K/31mbar



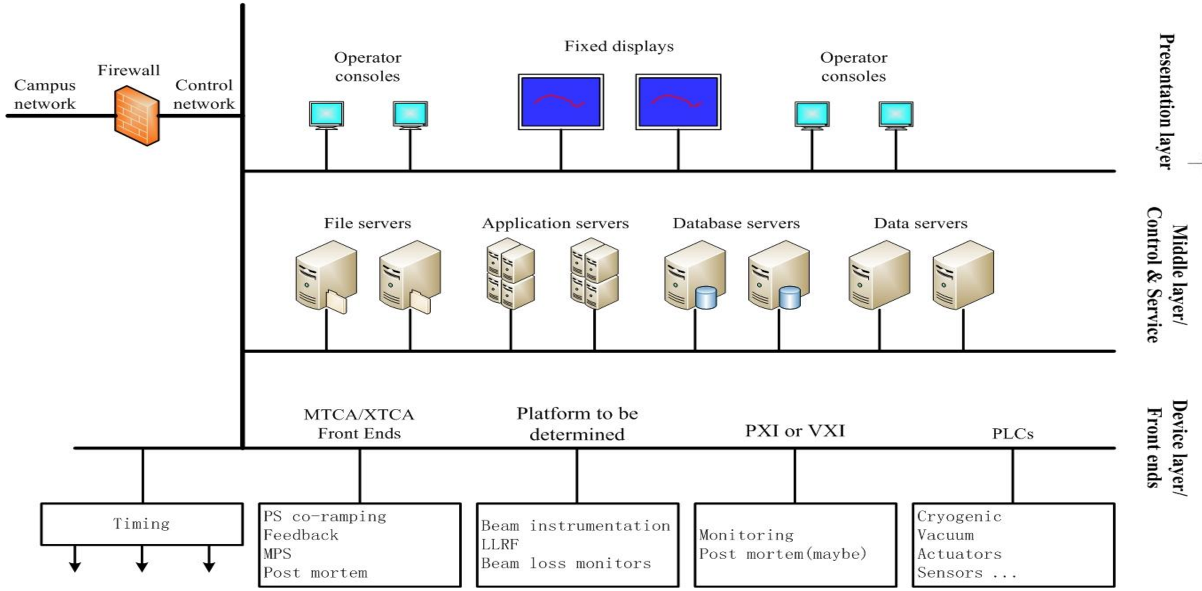
CEPC accelerator SRF cryogenic flow chart in TDR



For 30MW SR/beam Mode at Higgs energy, the cryogenic system need 32000liter Hellium

For 50MW/beam SR Mode:
at Higgs energy, the cryogenic system needs 42000liter Hellium; at ttbar energy 130000liter Hellium needed

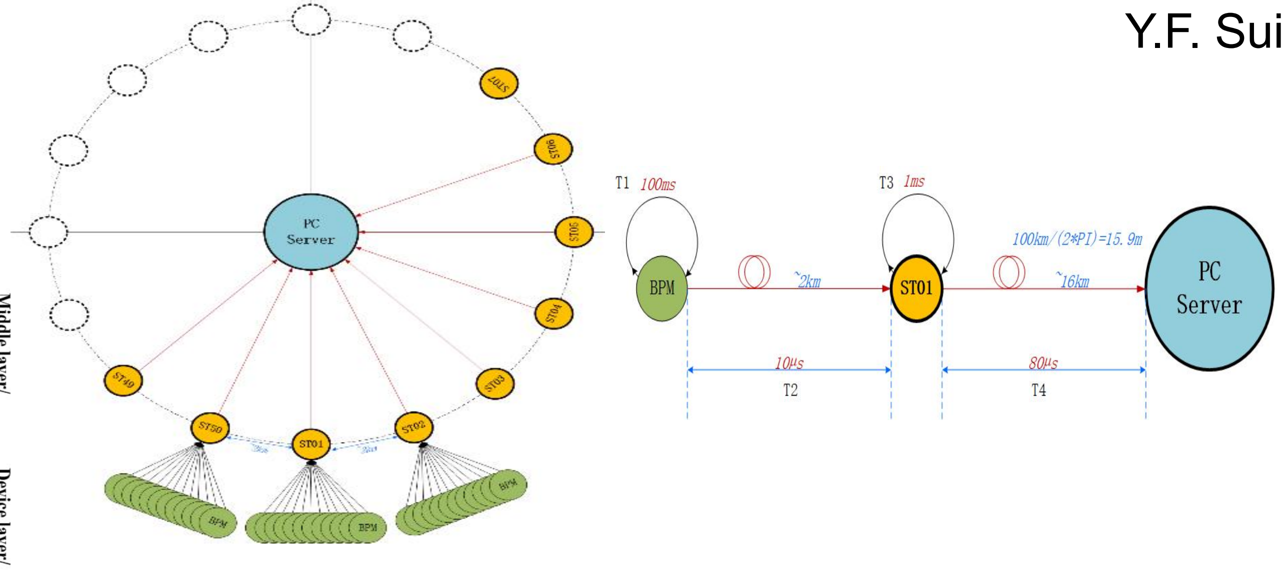
CEPC Control System and Beam Diagnostic System



Overall hardware architecture of the control system

Signal Time Delay Analysis of the COD Measurement (as an example for operation)

G. Li
Y.F. Sui

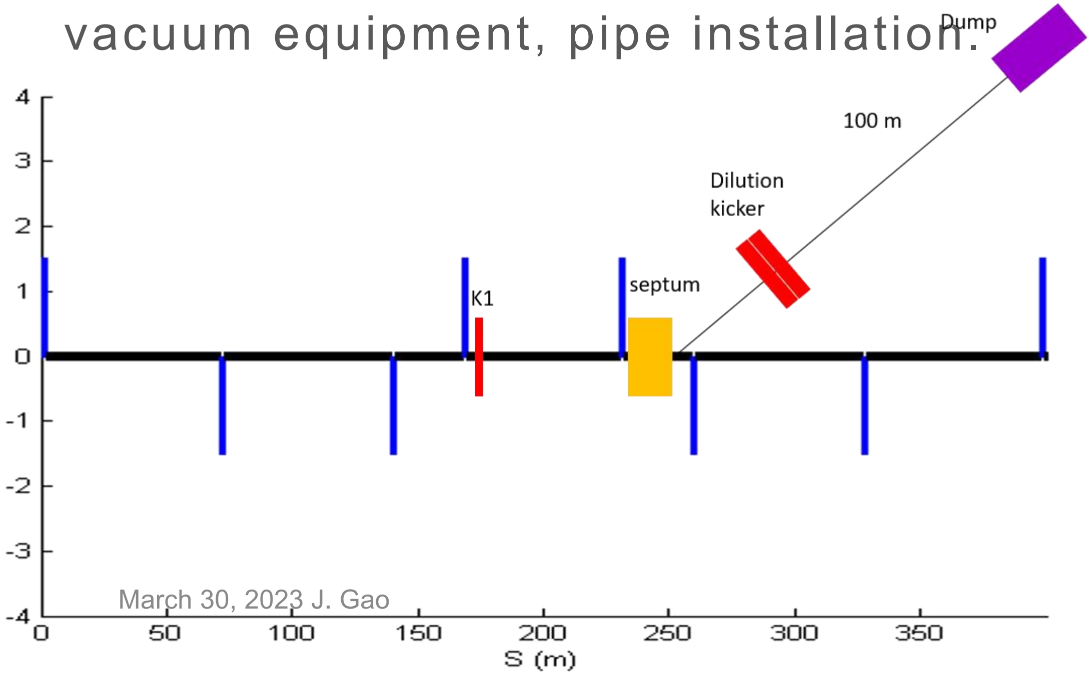


- 50 stations along the storage ring and connecting with PC sever station with the star topology fiber optic network.
- Consider the delay of whole system, the BPM COD measurement takes about 1s .

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.



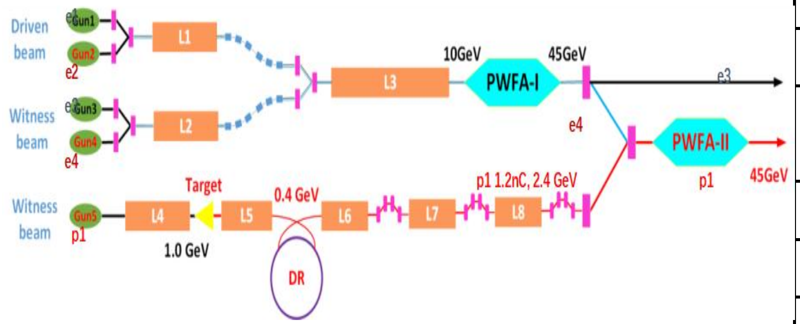
		Extraction kicker	Septum	Dilution kickers
Length (m)		2	20	10
Magnetic flux density (Gauss)	Z	281		40
	WW	494		
	Higgs	741	7000	
	ttbar	1110		

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℃

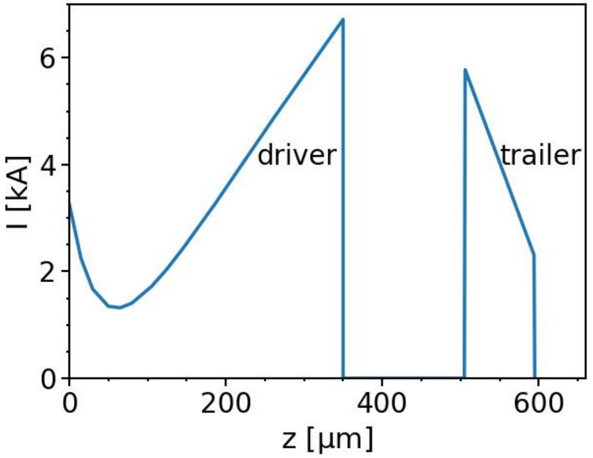
CEPC Plasma Injector 12 GeV → 30 GeV Pratically Feasible

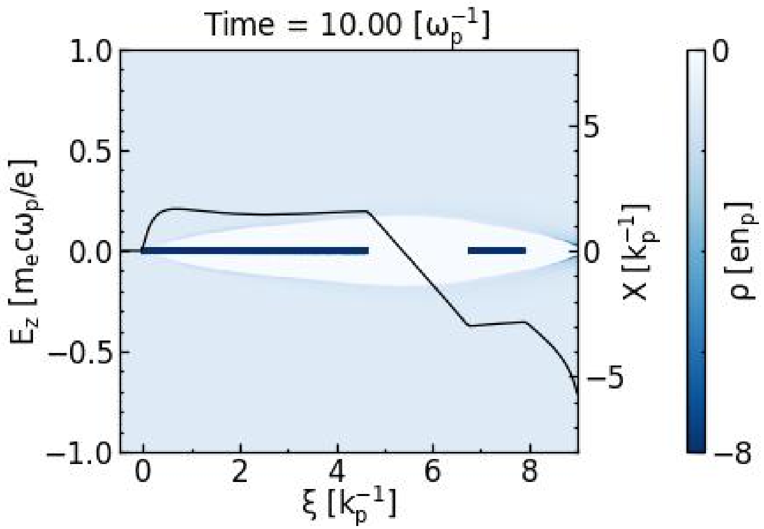
D.Z. Li, X.N. Wang

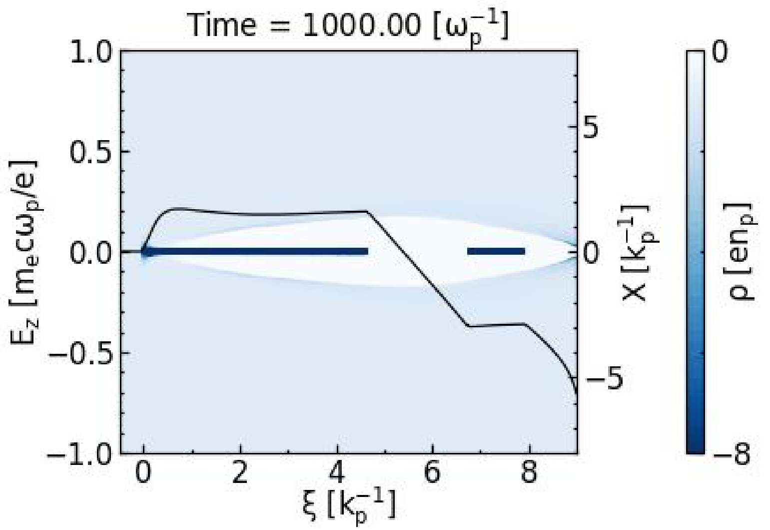


Parameters	Driver	Trailer
plasma density $n_p(\times 10^{16} cm^{-3})$	0.50334	
Driver energy E(GeV)	12	12
Normalized emittance ϵ_N ($\mu m\ rad$)	20	10
Length L (μm)	350	90
(matched) Spot size σ_r (μm)	3.72	2.63
Charge Q (nC)	4.0	1.2
Beam distance d (μm)	155	

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



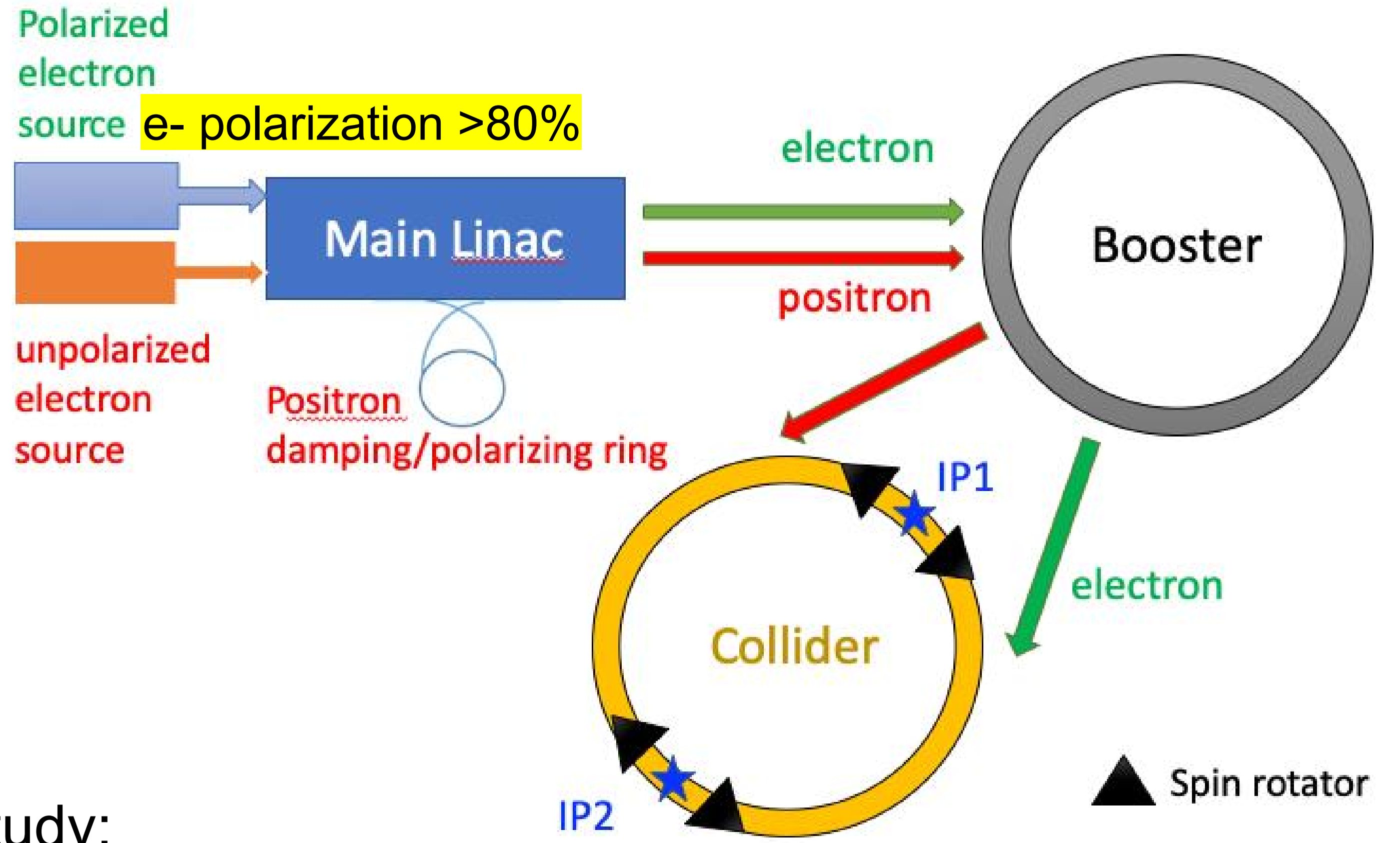




By Xiaoning Wang (2022, IHEP)

Polarized Beam Studies in CEPC

Z. Duan

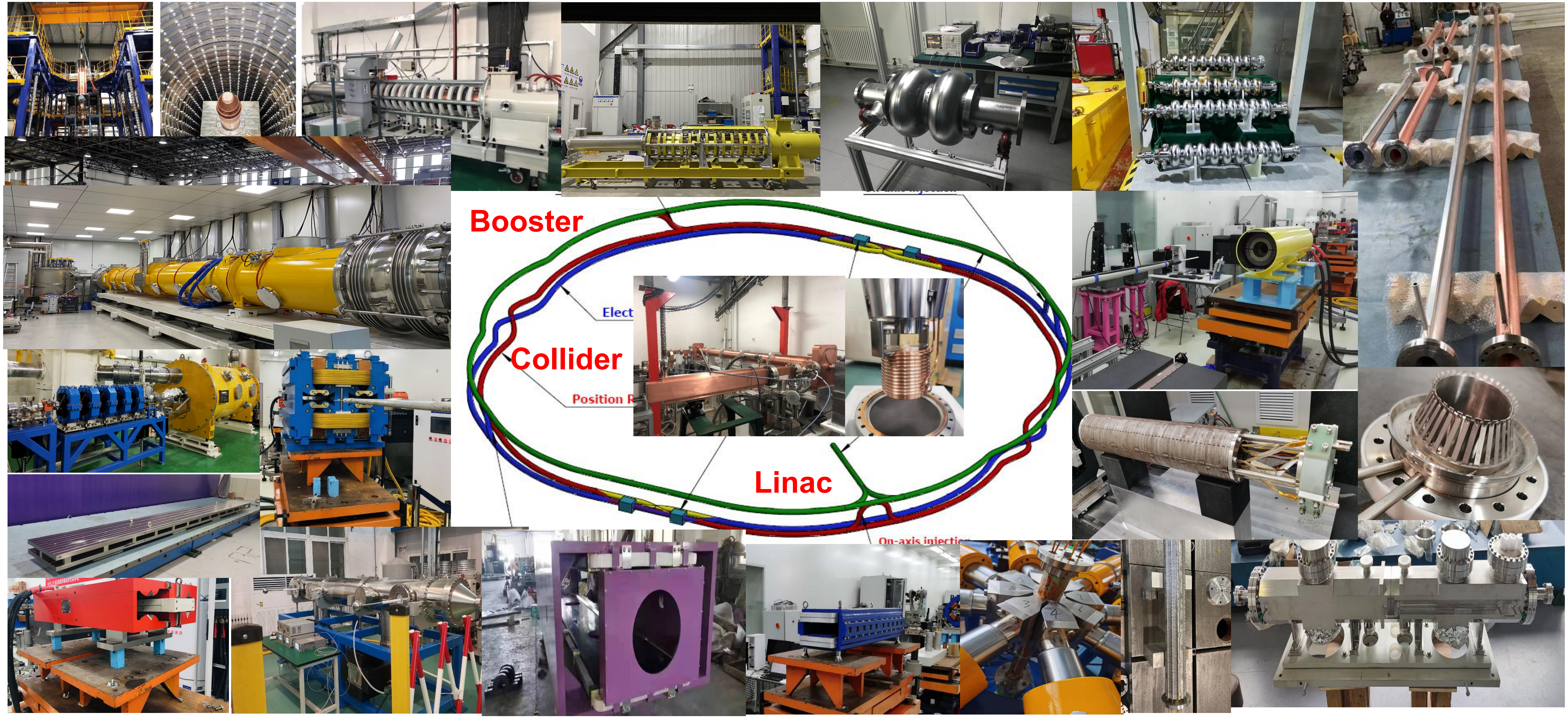


Key issues of study:

- Self polarization and energy calibriation in collider ring with transverse polarization
- Polarization beam injection, ramping in booster and collision with longitudinal polarization

CEPC Accelerator System Key Hardware R&D Progresses in TDR

CEPC TDR R&D Status of Key Technologies



CEPC SRF Facilities and Components

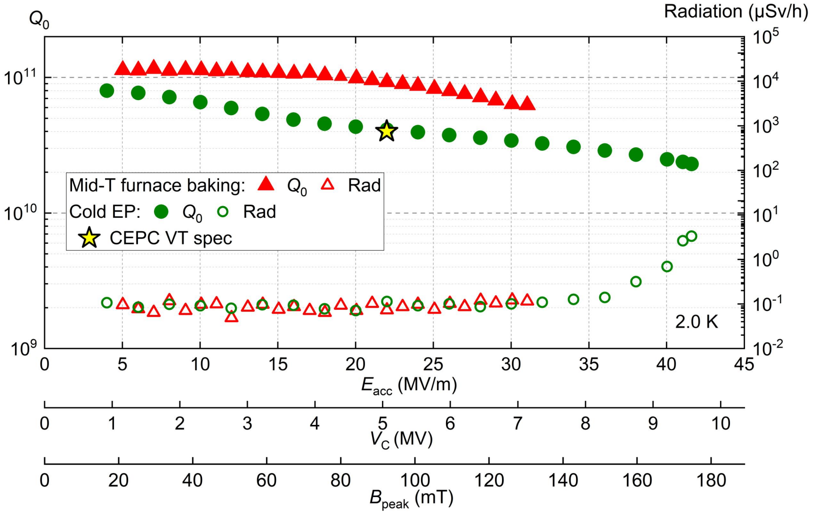
J.Y. Zhai, P. Sha




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 1-cell Cavity

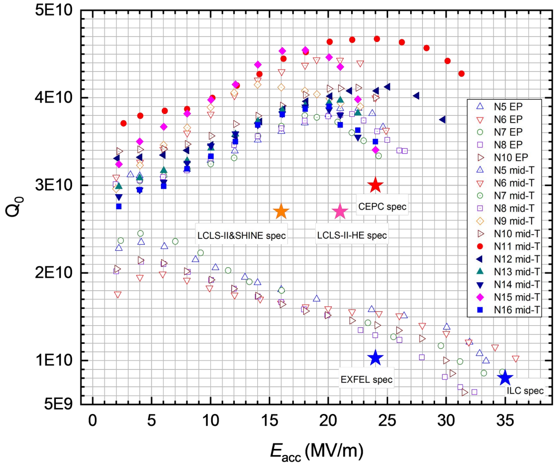


The 650Mhz 1-cell cavity's results (6.4E10@30MV/m, **2.3E10@41.6MV/m**)

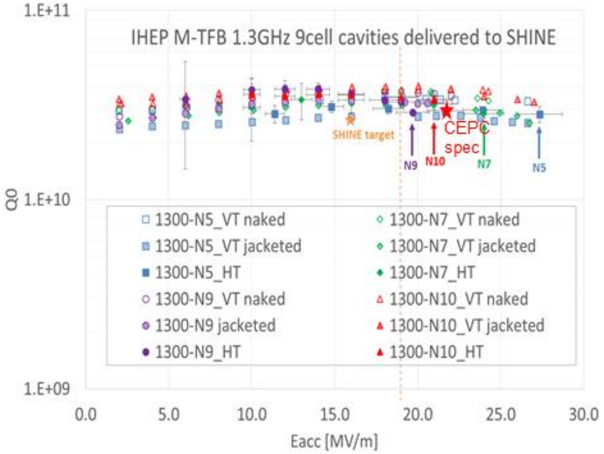
.

It is very promising to use 1-cell 650MHz cavity for Higgs, W, and Z modes with requirements: 3E10@40MV/m (horizontal)

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



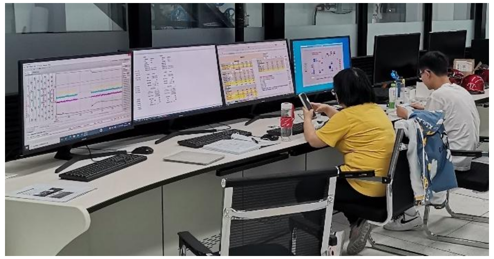
Mid-T 1.3 GHz 9-cell horizontal test (SEL)
3.1E10@21 MV/m, avg. 24.6 MV/m

CEPC 650 MHz 2 x 2-cell Test Cryomodule

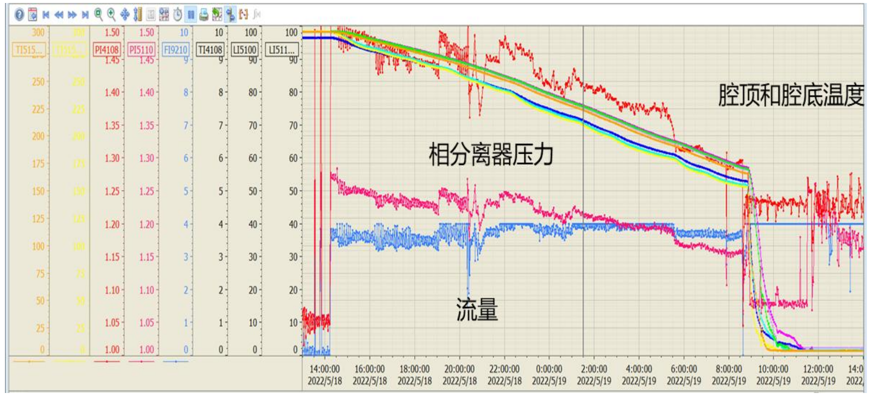
J.Y. Zhai







- 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.



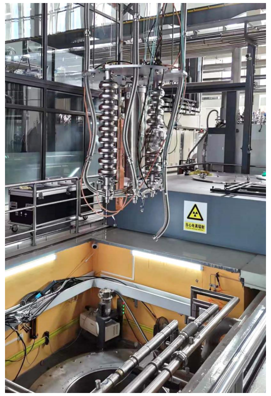
Module automatic cool-down experiment

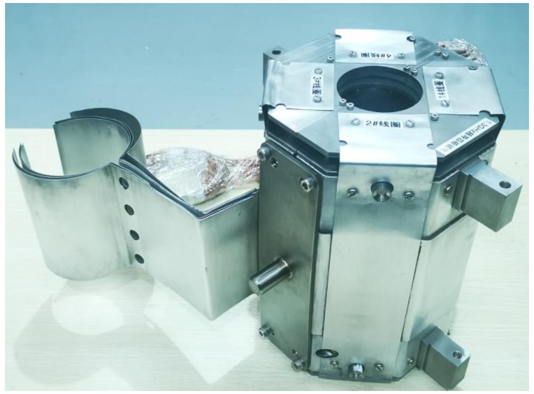
1. 300 to 150 K: < 10 K/hr. Cavity top and bottom ΔT < 20 K
2. 150 to 4.5 K: Cavity surface > 1 K/min
3. 4.5 to 2 K

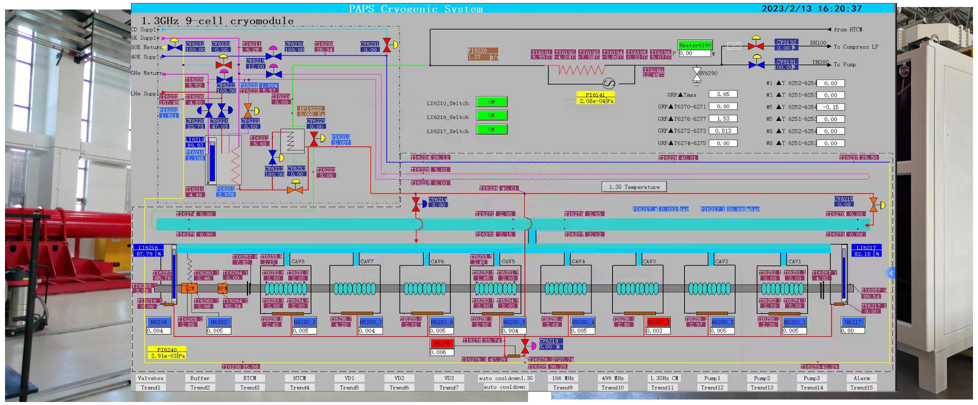
CEPC 1.3 GHz 8 x 9-cell High Q Cryomodule

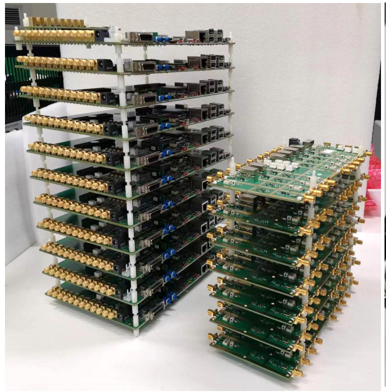
CEPC booster 1.3 GHz SRF R&D and industrialization in synergy with CW FEL projects. J.Y. Zhai

- Key technology R&D for FEL, CEPC booster and ILC
- 12 mid-T 9-cell cavities vertical test average Q 4.5E10@16-21 MV/m
- World's best high Q 1.3 GHz 9-cell cavity (N11): 5.4E10@21 MV/m, 4.9E10@31 MV/m
- 8 mid-T high Q 9-cell cavities integrated into cryomodule last year. 2 K module test ongoing.



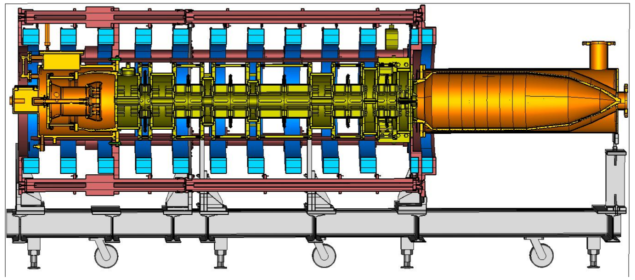



CEPC 650MHz High Efficiency Klystrons

Z.S.Zhou

Klystron No. 2
Efficiency 77%
(2021)



Klystron No. 1
Efficiency 65%
(2020)

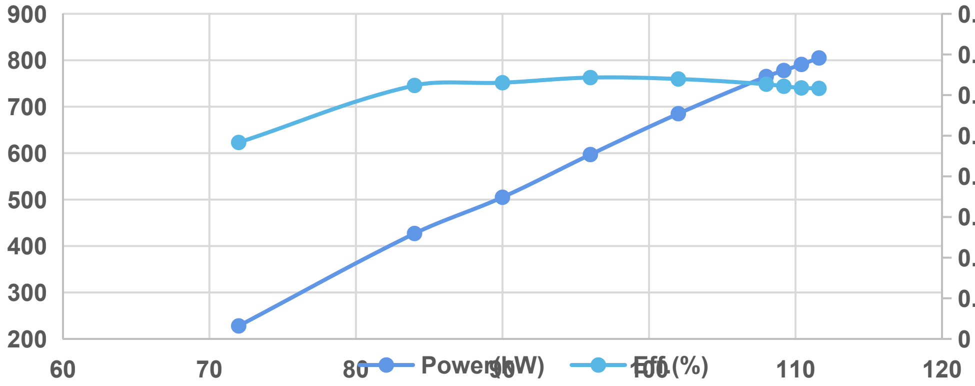
Klystron No. 3 （MBK)
Efficiency 80.5%
(under fabrication)

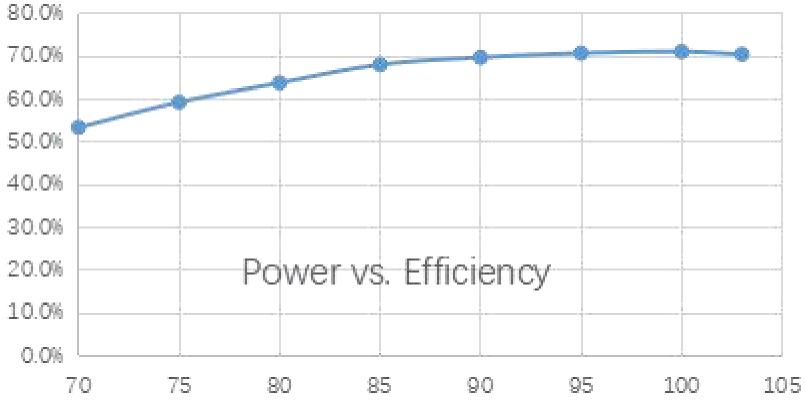
2022

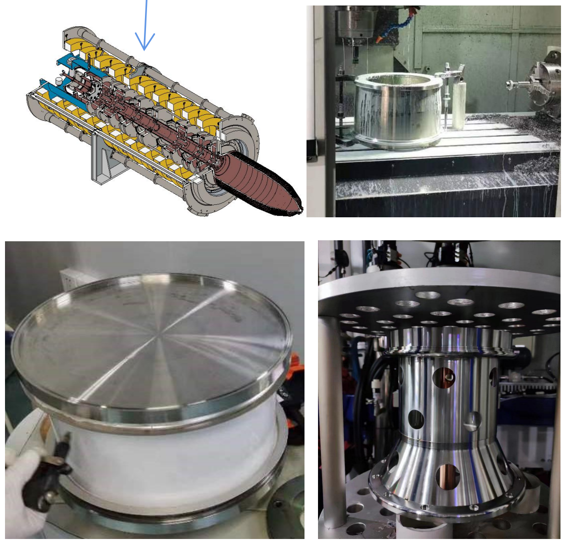
Pulsed RF Mode (30% duty factor, 60ms/5Hz)

70.5% @ 630kW

High Voltage vs. Power&Efficency

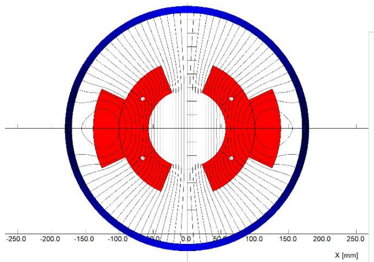


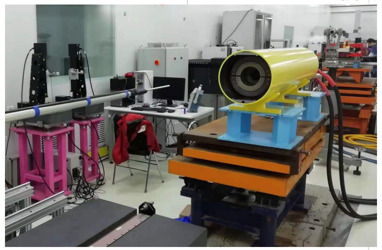


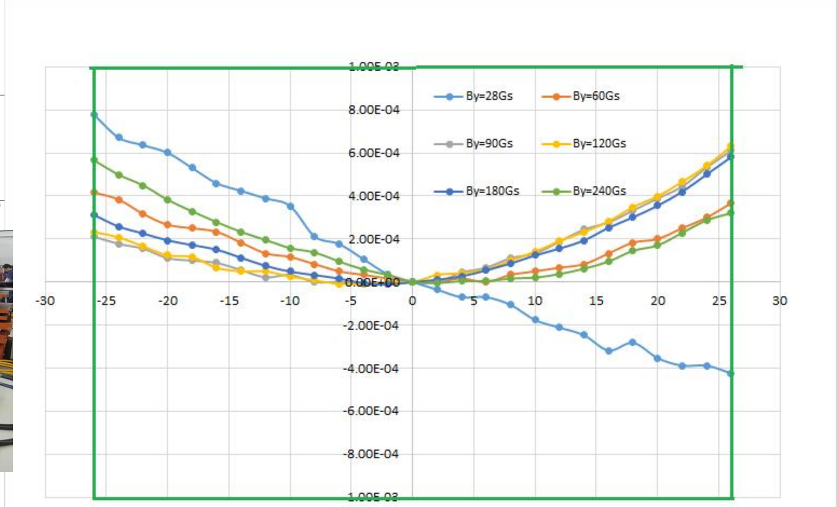


CEPC Full Size Booster Dipole Magnets

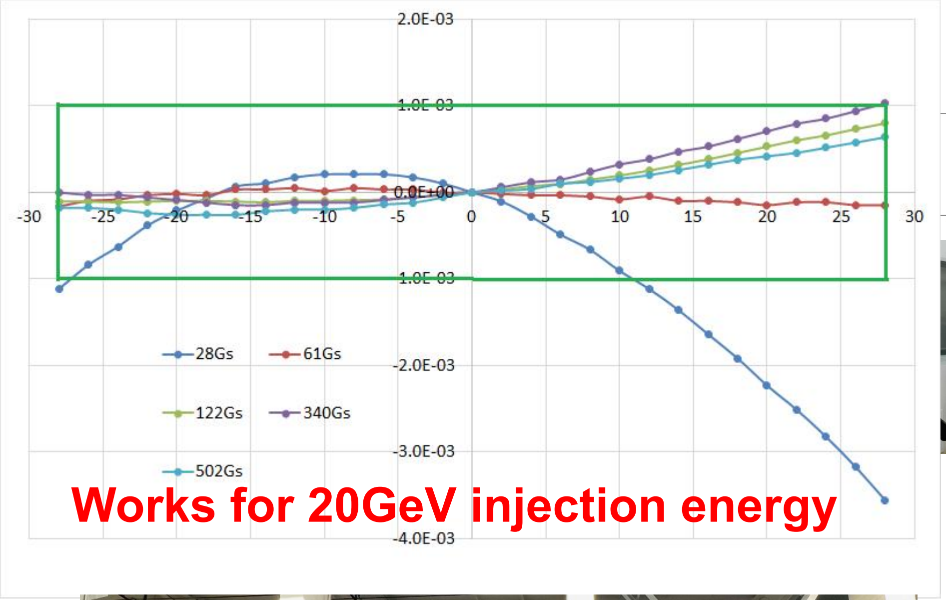
W. Kang



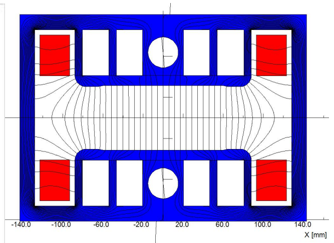




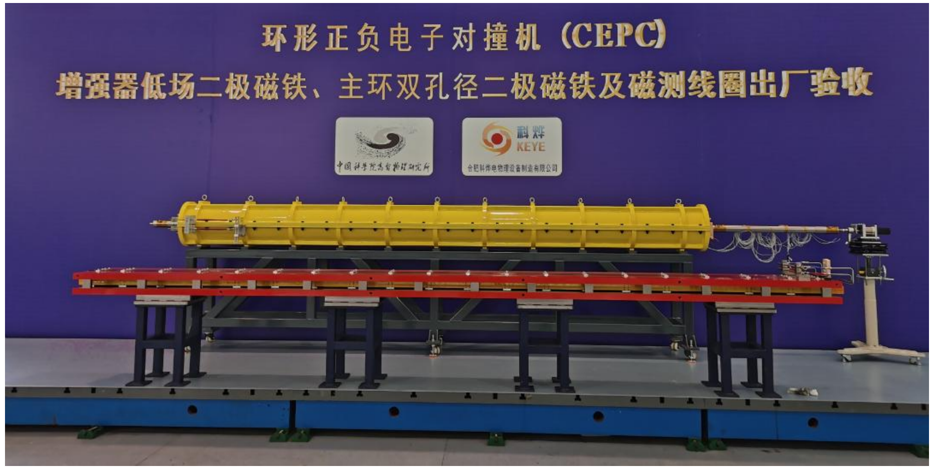
Works for 10GeV injection energy



Works for 20GeV injection energy



March 14, 2023

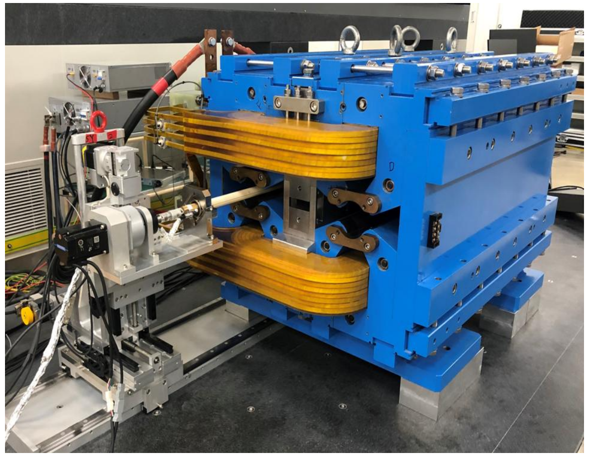


Oct. 20， 2022

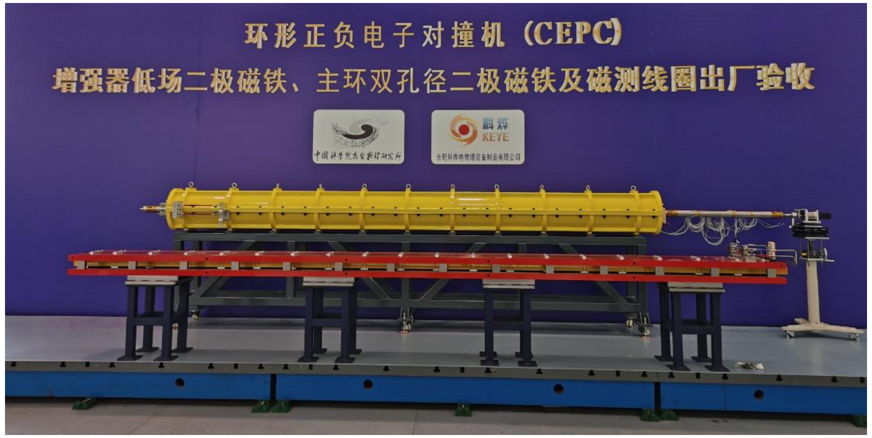
Iron core and without iron type of 4.7m long full size booster prototype dipoles fabrications completed

CEPC Collider Ring Magnets

M. Yang

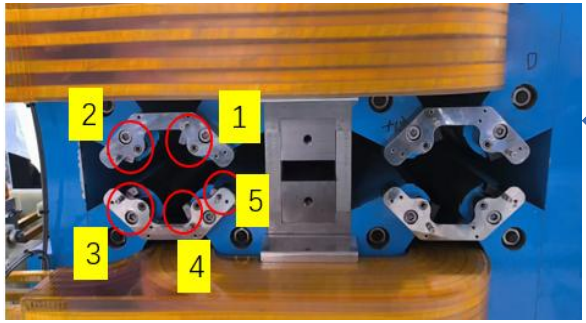


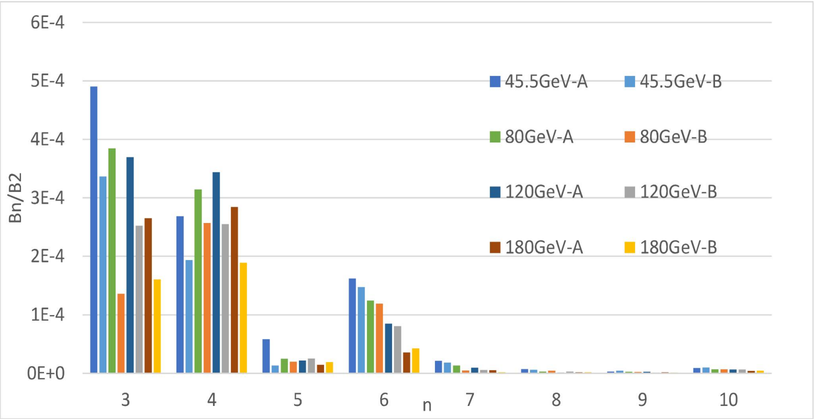
Harmonic modification with magic fingersHarmonics<5×10^{-4} satisfies the design requirement

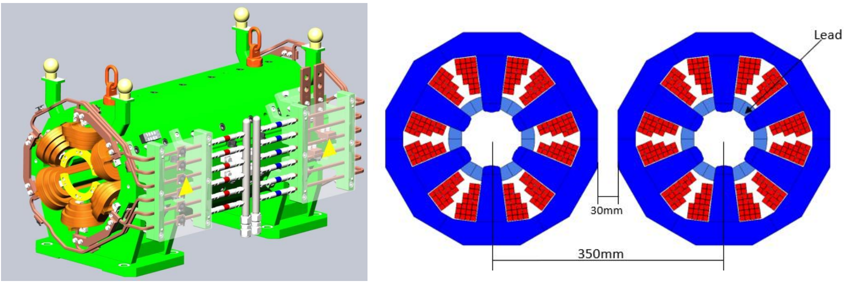


Full size 5.67m dural aperture dipole prototype completed on March 14, 2023

1m dural aperture dipole prototype completed on Nov., 2018, satisfies the design requirement







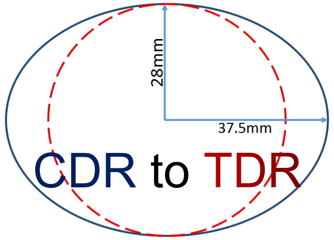
Collider ring sextupole design

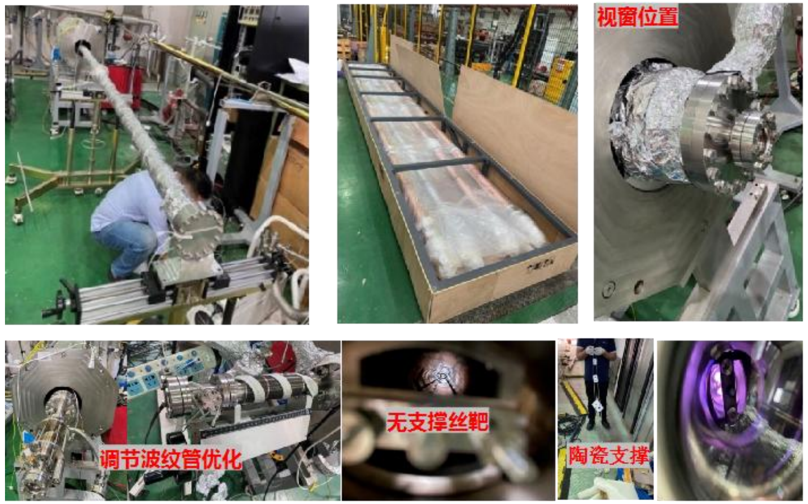
CEPC Vacuum System R&D

Y.S. Ma

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

SEY<1.2

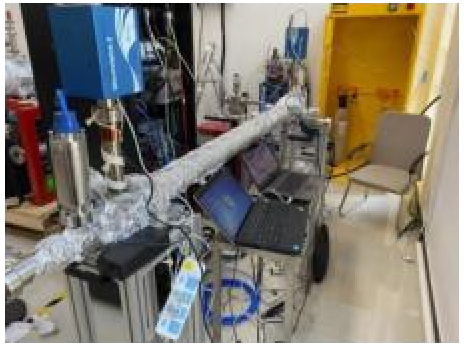




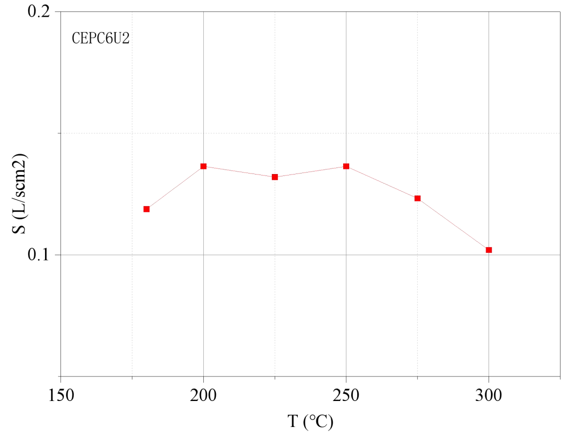
6 m vacuum pipe have been installed on the NEG coating setup

All metal gate valve different from VTA

Vacuum pipes and RF shielding bellows



Facility of pumping speed test have been finished in Dongguan



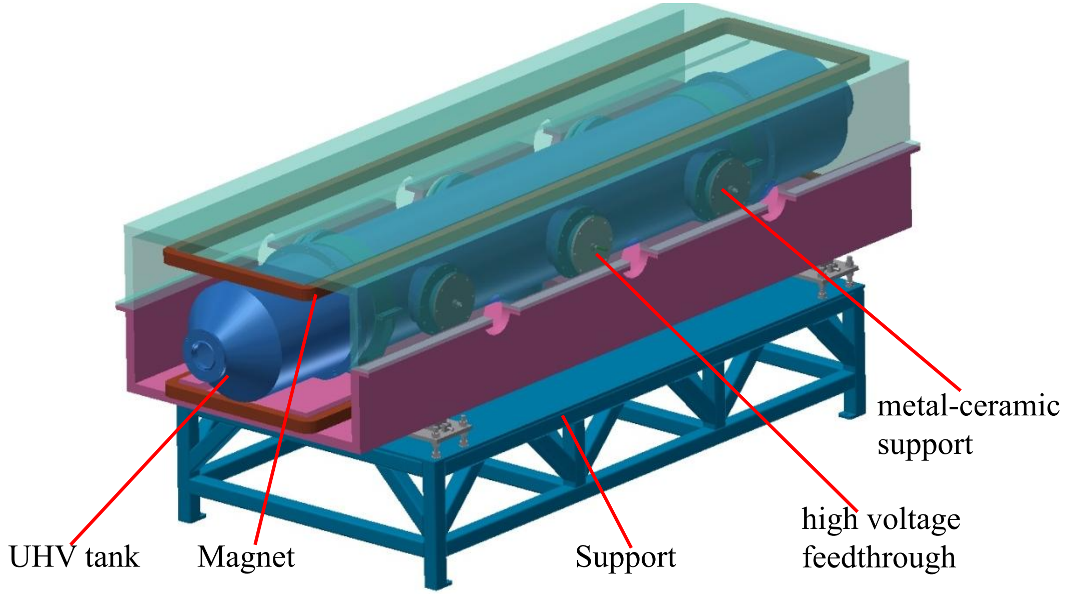
Pumping speed test of 2 meters long CEPC Cu pipe of NEG coating in IHEP

CEPC Electrostatic-Magnetic Deflector

B. 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	$5x10^{-4}$
Dipole	66.7Gauss	4m	46mm x11mm	$5x10^{-4}$



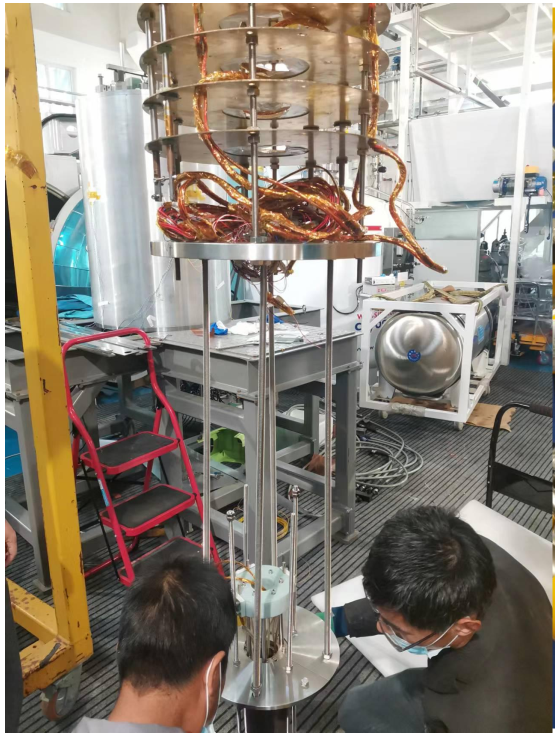
The high voltage of prototype test can reach ±90kV, which meets the requirements of Higgs Mode operation, the operating voltage of the electrostatic separator in Higgs Mode (120GeV) is ±75kV

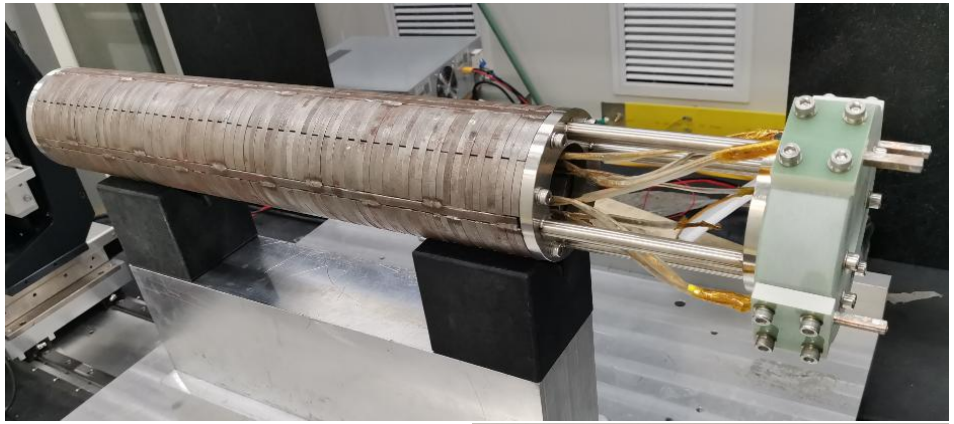
CEPC QD0 SC Magnet R&D (0.5m short model)

Magnet name	0.5m QD0 model magnet
Field gradient (T/m)	136
Magnetic length (m)	0.5
Coil turns per pole	21
Excitation current (A)	2070
Coil layers	2
Conductor	Rutherford Cable, width 3 mm, mid thickness 0.93 mm, keystone angle 1.9 deg, Cu:Sc=1.3, 12 strands
Stored energy (KJ) (Single aperture)	2.6
Inductance (H)	0.001
Peak field in coil (T)	3.4
Coil inner diameter (mm)	40
Coil outer diameter (mm)	53
Yoke outer diameter (mm)	108
X direction Lorentz force/octant (kN)	24.6
Y direction Lorentz force/octant (kN)	-23.7
Net weight (kg)	25

Y.S. Zhu

Fabrication of NbTi Rutherford cable is finished (12 strands). SC quadrupole coil winding machine, coil heating and curing system has been finished.



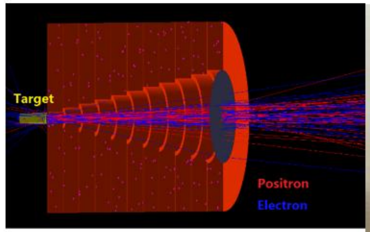


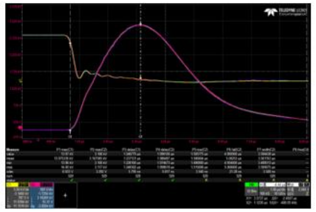
Fabrication of QD0 single aperture short model magnet (NbTi, 136T/m) has been completed in June, 2022, and test results in Nov.10 2022 reached 160T/m@2500A (TDR design value is 142T/m@2210A).

CPEC Linac Injector Key Technology R&D

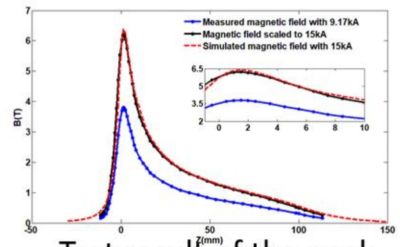
J. Zhang

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

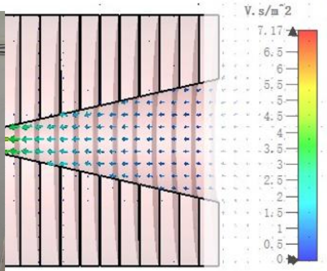




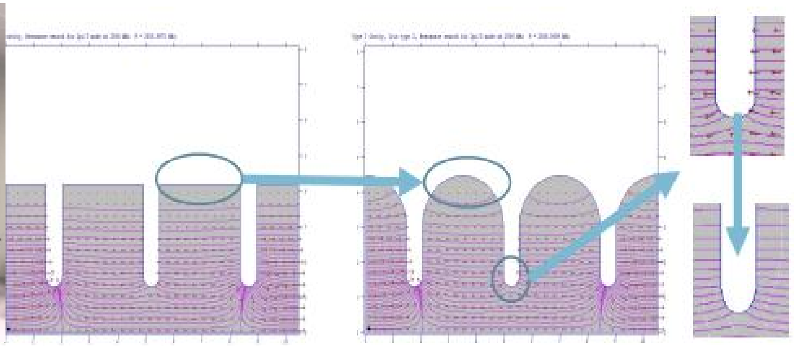
R&D of the solid state

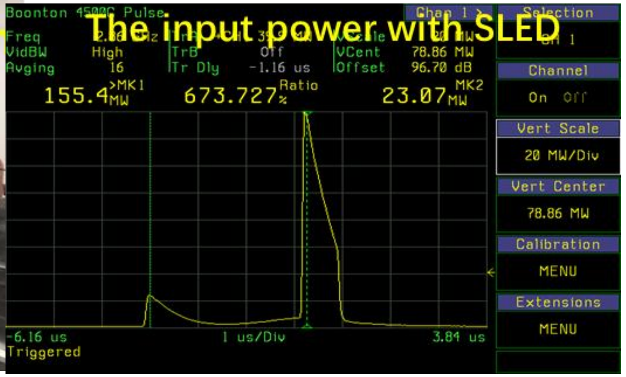


Test result of the peak



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



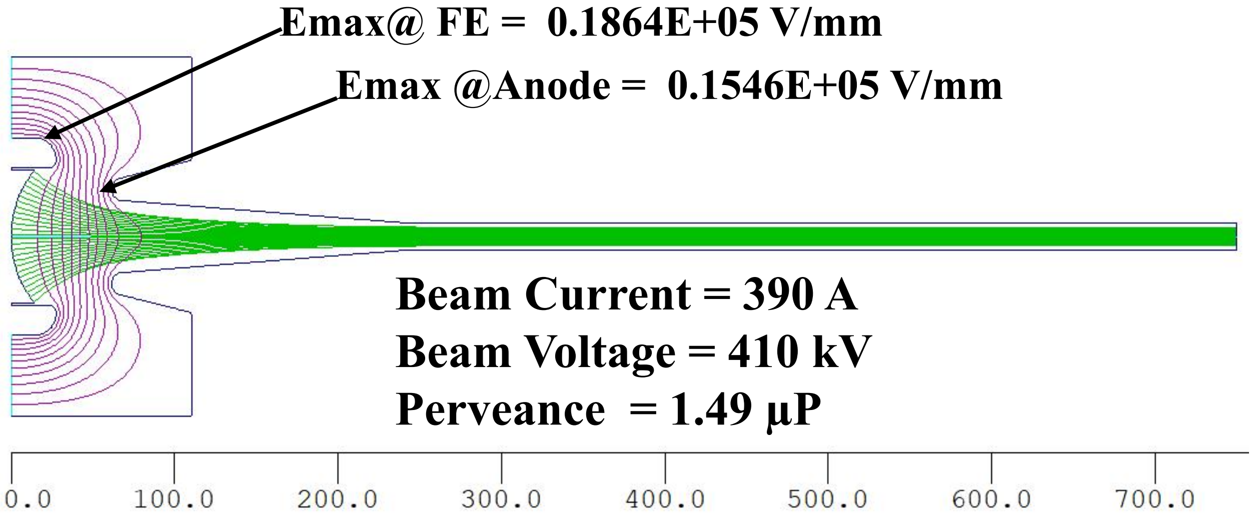


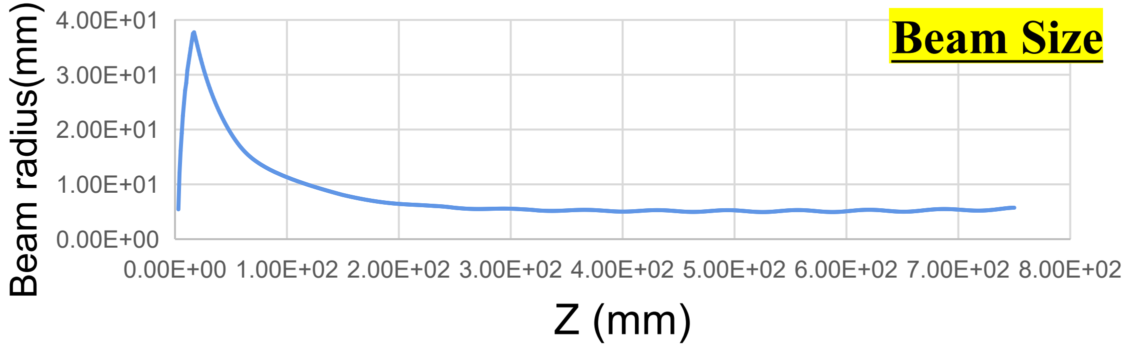
CEPC Linac Advanced Technology Development

J.R. Zhang

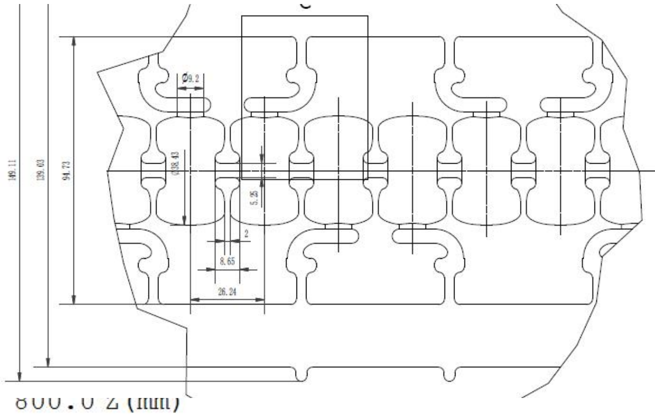
CEPC 80 MW C-Band(5720 MHz) Klystron Design

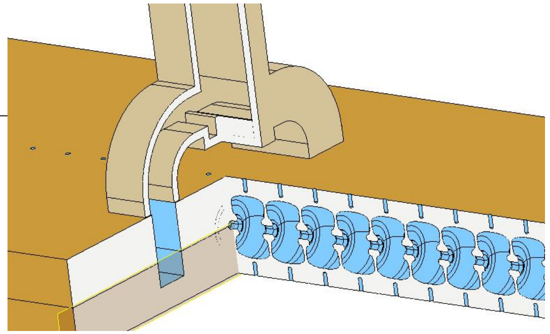
Z.S. Zhou

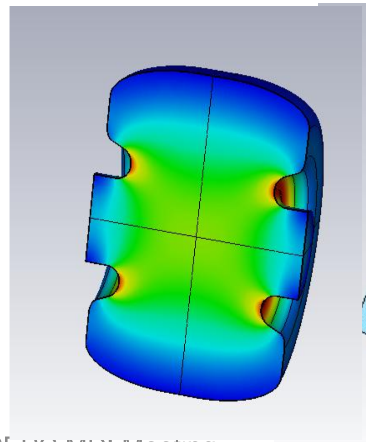


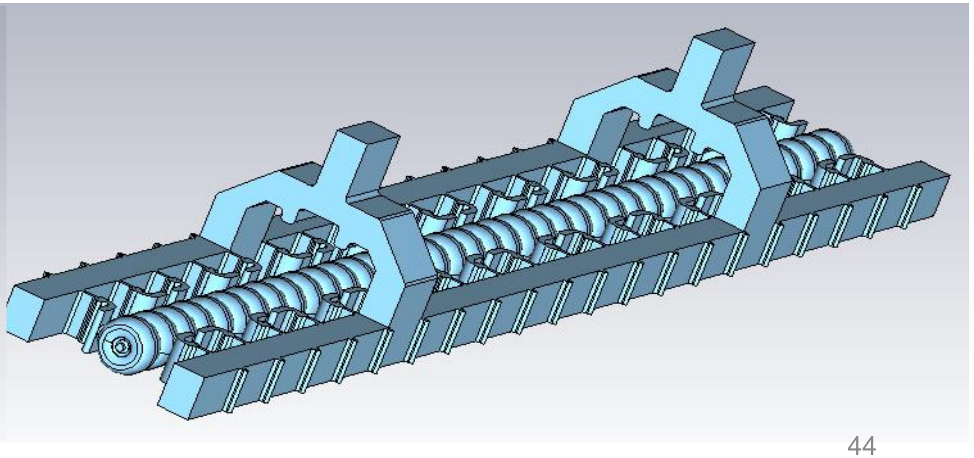


R&D on C3 C band accelerator technology as CEPC alternative C-band linac Eacc >70M/m





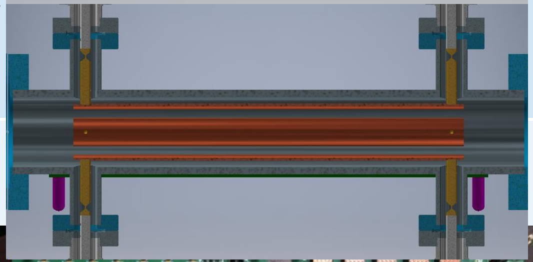


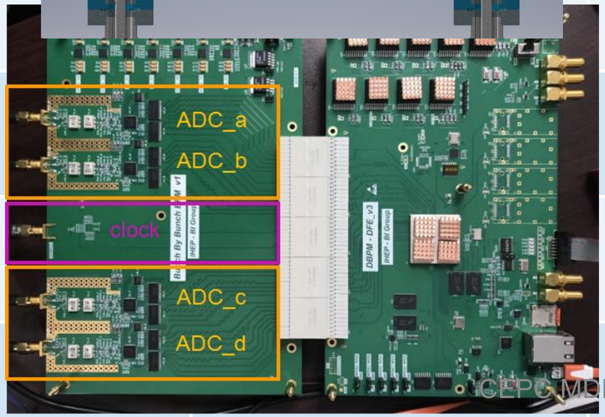


Status of CEPC Beam instrumentation R&D

Y.F. Sui

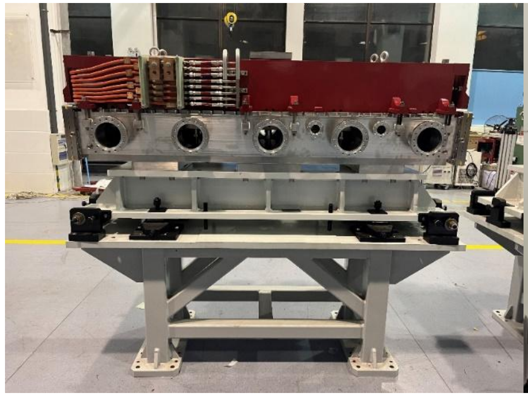
System	R&D Work supported by			Work to be done
	BEPCII	HEPS/HEPS TF	Funding	
BPM electronics	√	√	√	Radiation hardness Industrialization
Beam position monitor fabrication			√	detection;
Longitudinal feedback system	√			
Transverse feedback system	√			
Synchrotron radiation monitor				X-ray interferometer; Gas jet scanner……
BI at the interaction point			√	
Bunch current monitor				&D based home- mpany
Beam loss monitor			√	R&D;





CEPC Inj.&Ext. Hardwares' R&D

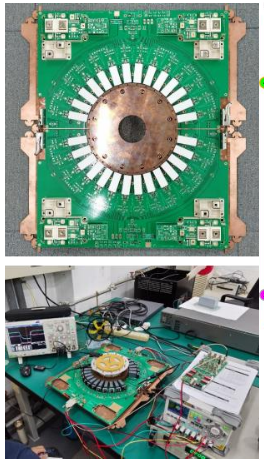
J.H. Chen

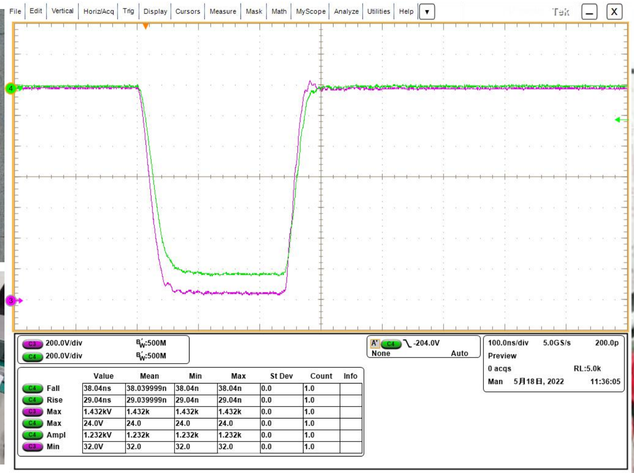


Lambertson magnets

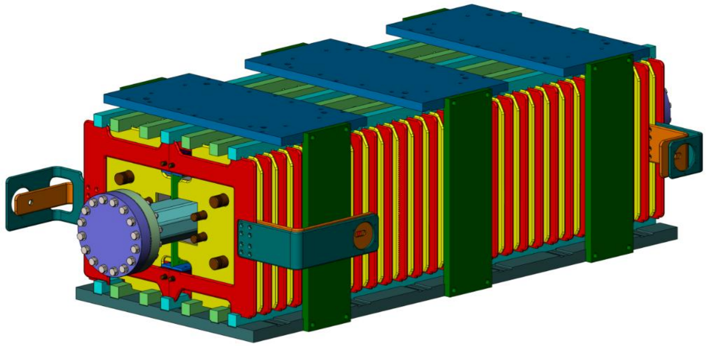
Slotted-pipe kicker

In synergy with HEPS project





250ns-fast kicker pulser

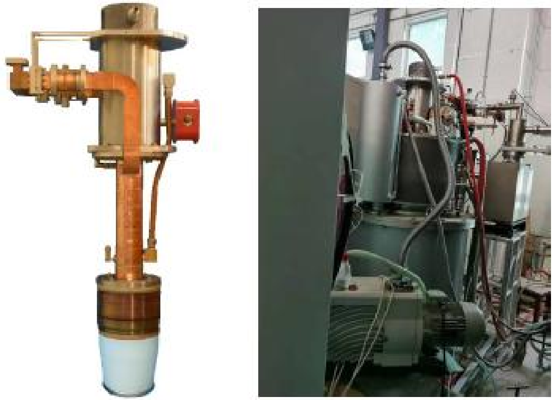


Delay-line dipole kicker

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)

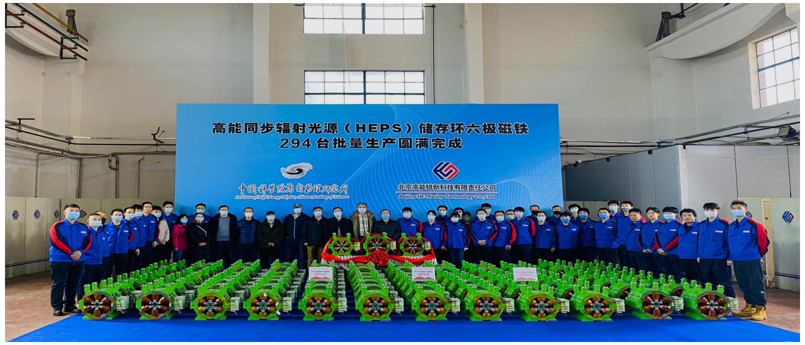
HEPS S-band Linac in operation (March, 2023)



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)

SppC Collider Parameters in TDR

-Parameter list (updated Feb. 2022)

Jingyu Tang
Haocheng Xu

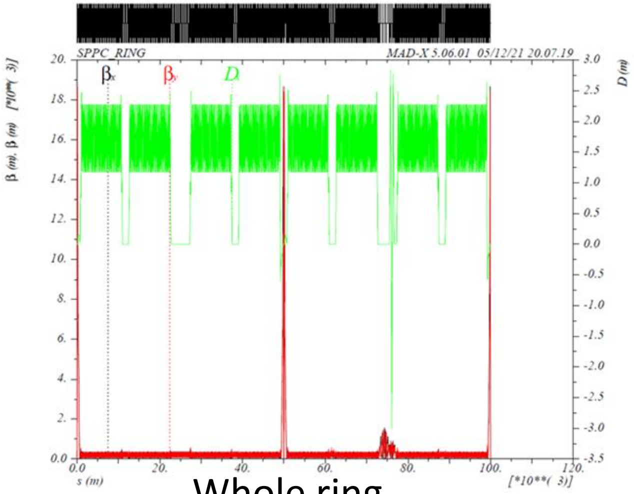
Main parameters		
Circumference	100	km
Beam energy	62.5	TeV
Lorentz gamma	66631	
Dipole field	20.00	T
Dipole curvature radius	10415.4	m
Arc filling factor	0.780	
Total dipole magnet length	65442.0	m
Arc length	83900	m
Total straight section length	16100	m
Energy gain factor in collider rings	19.53	
Injection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

Ecm=125TeV with dipole field of 20T

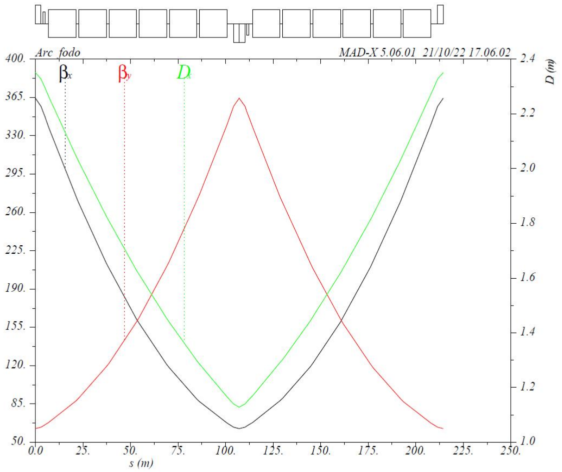
SppC Lattice Design@125TeV (20T) in TDR

Haocheng Xu
Yiwei Wang

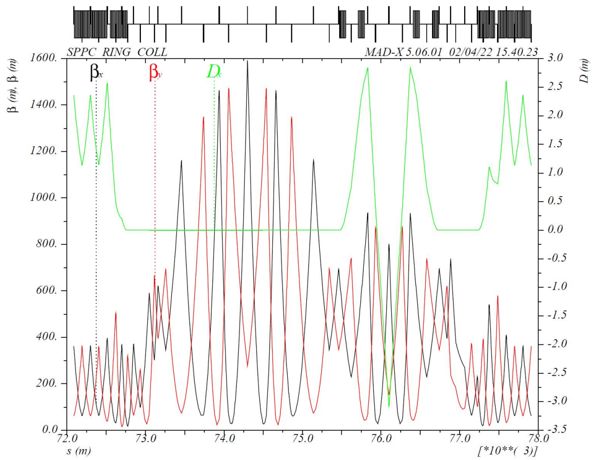
- Lattice of SPPC whole ring, Arc region, collimator section and IP region



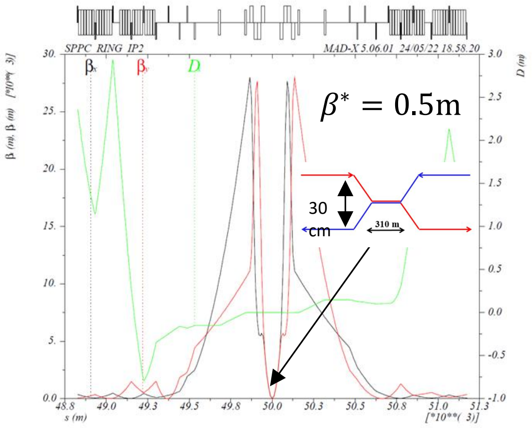
Whole ring



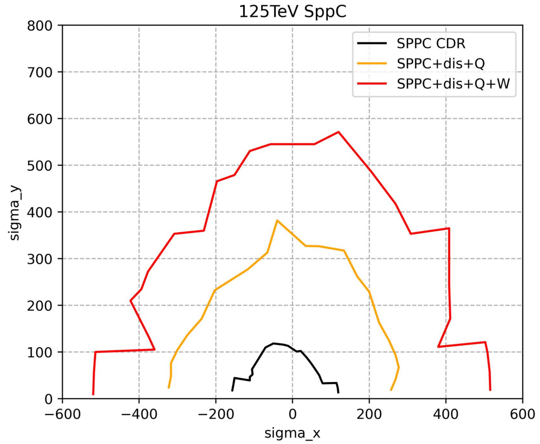
Arc cell

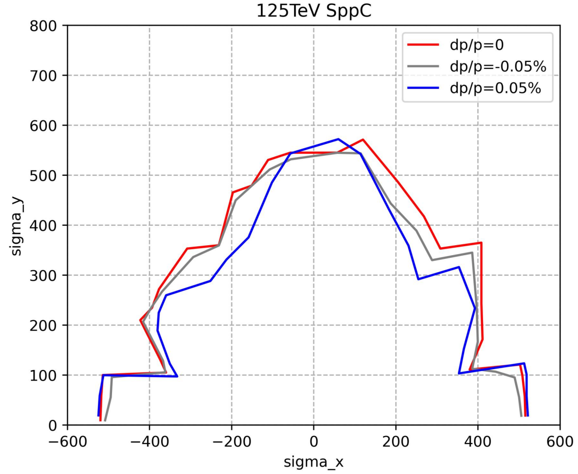


Collimation



IP



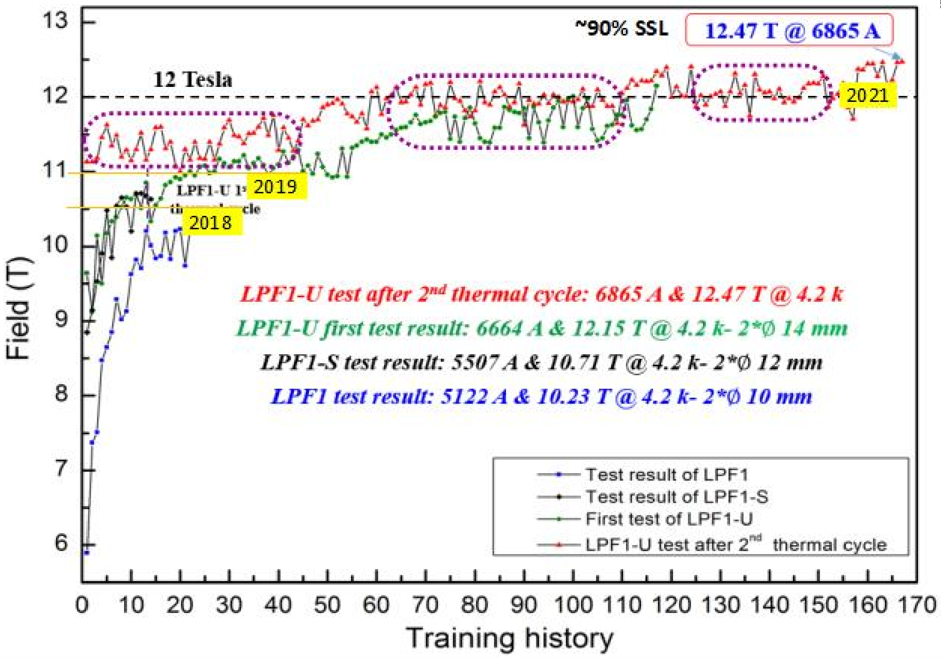


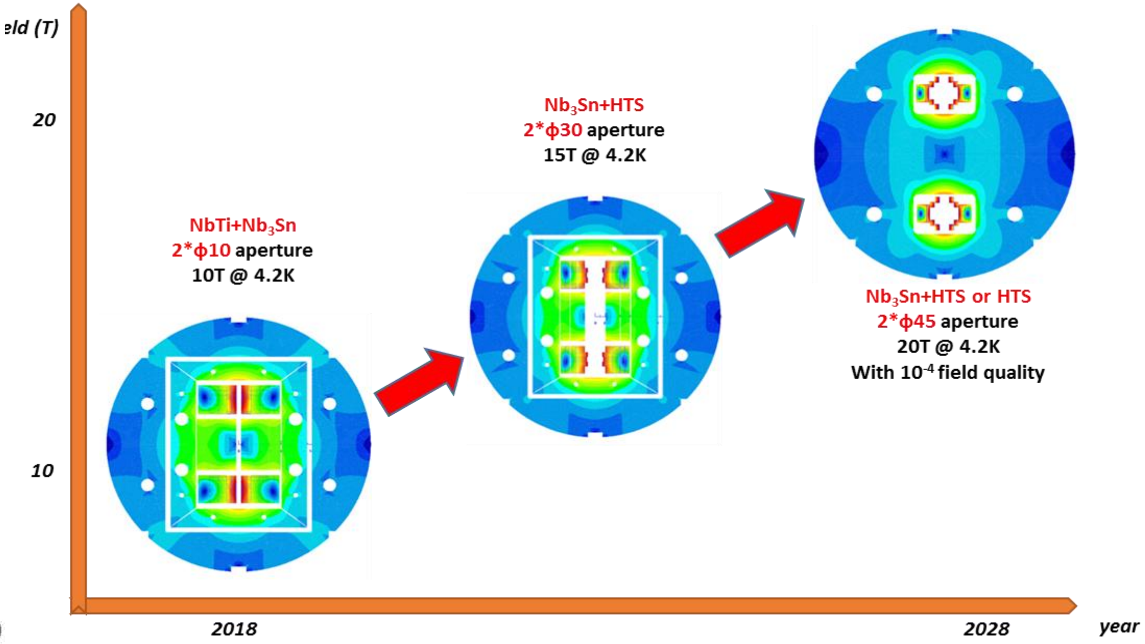
- Dynamic Aperture Optimization

Latest Performance of LPF1-U (SppC)

Qingjin Xu

Picture of LPF1-U



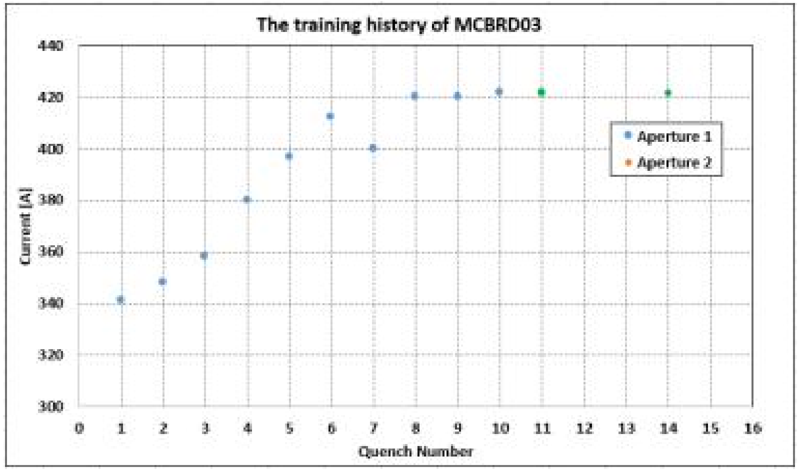


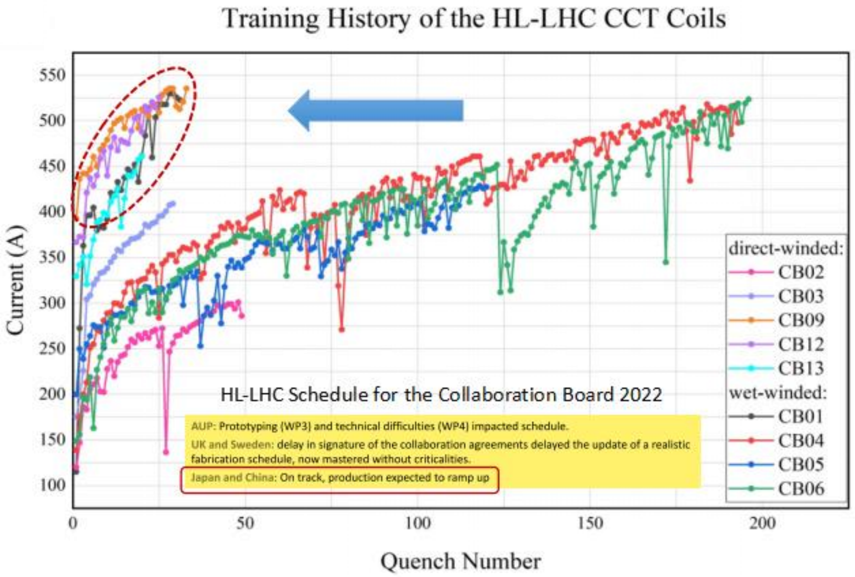
Dual aperture superconducting dipole achieves 12.47 T at 4.2 K
Entirely fabricated in China. The next step is reaching 16-19T field

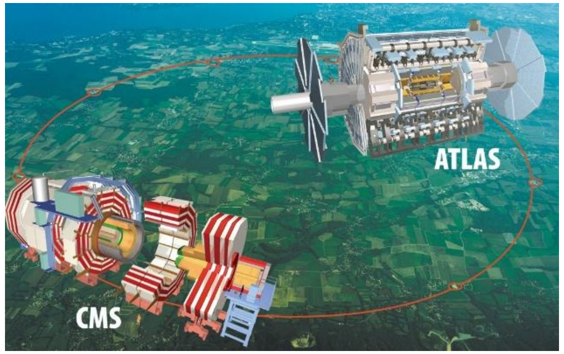
Development of CCT dipole magnets for HL-LHC by IHEP

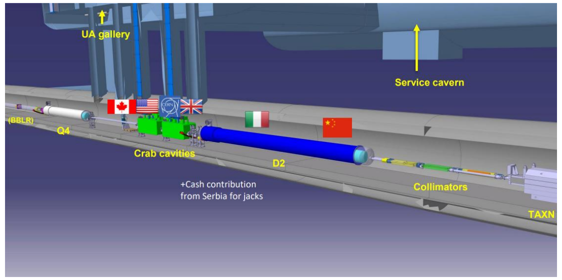
IHEP provides 13 units CCT twin-aperture dipole magnets for HL-LHC

Qingjin Xu





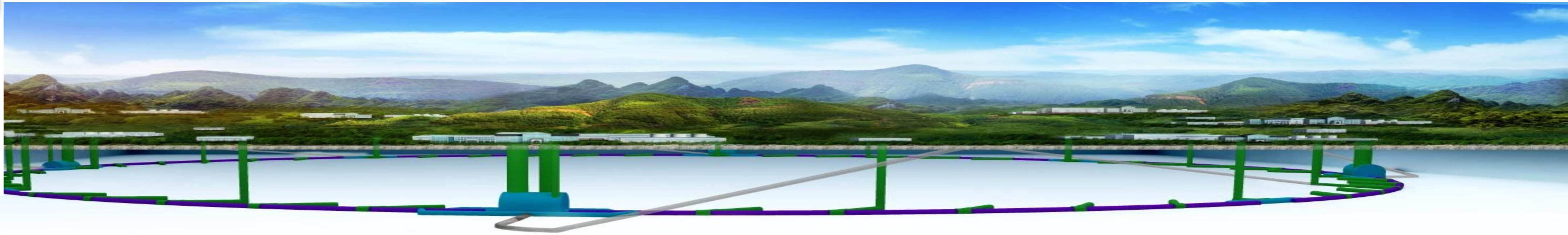


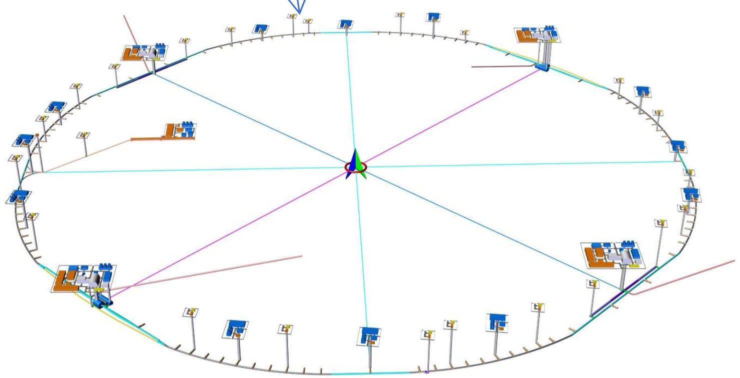


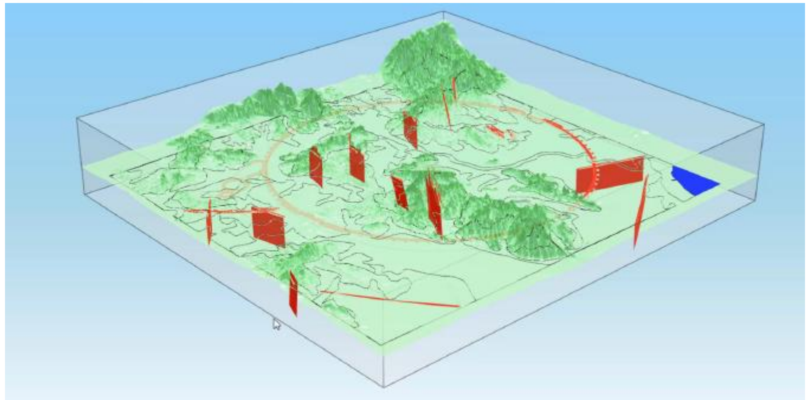
- AP1(CB12，25 quenches 526A) reached ±422A after 11 quenches.
- AP2(CB09, 33 quenches 530A; after thermal cycle ＞500A) reached ±422A without any quenches.

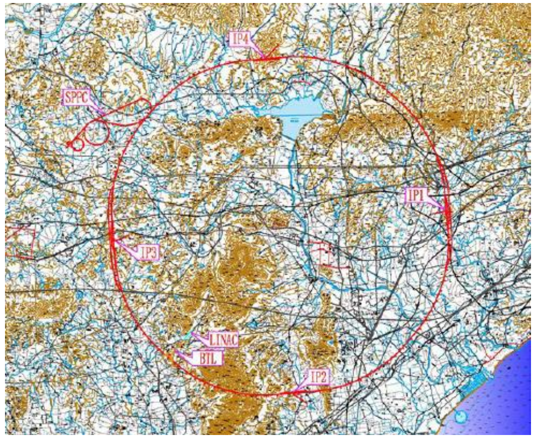
CEPC Siting, Civil Engineering, AC power consumptions,and Installation Strategy

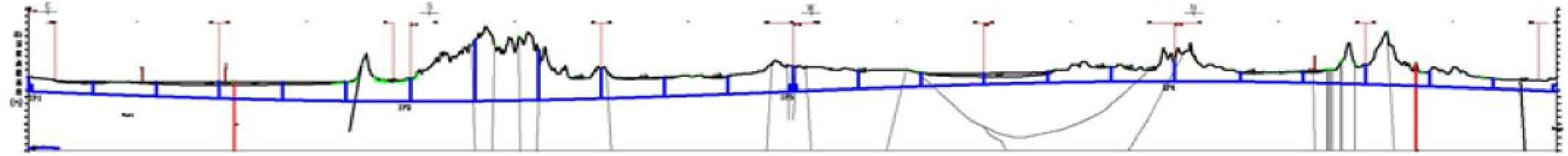
CEPC Siting and Civil Engineering (Qinhuangdao TDR site as an example)





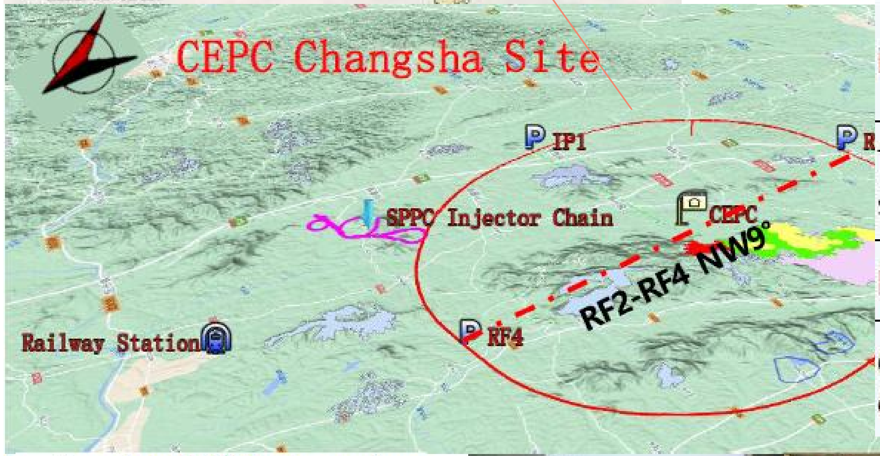


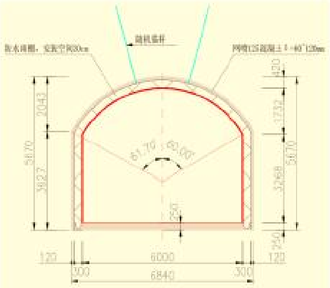




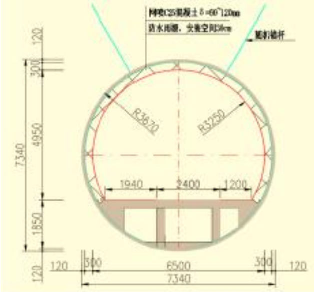
CEPC Siting, Civil Engineering (Changsha site as an example)

Very good geological condition

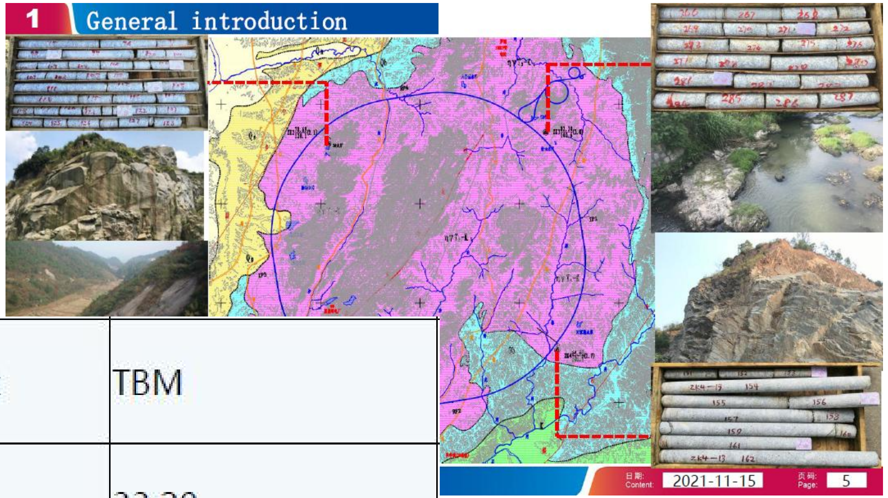




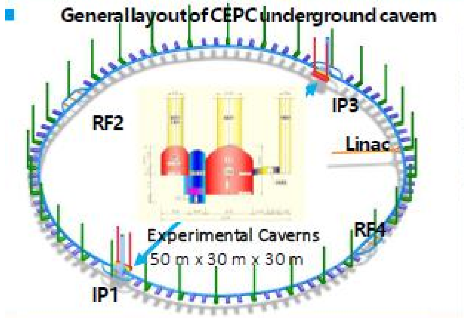
Drill-blast tunnel (6.0m×5.0m)

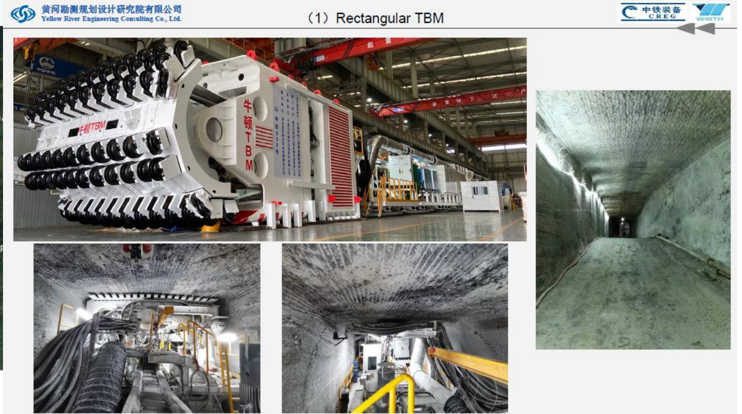


TBM tunnel (D6.5m)

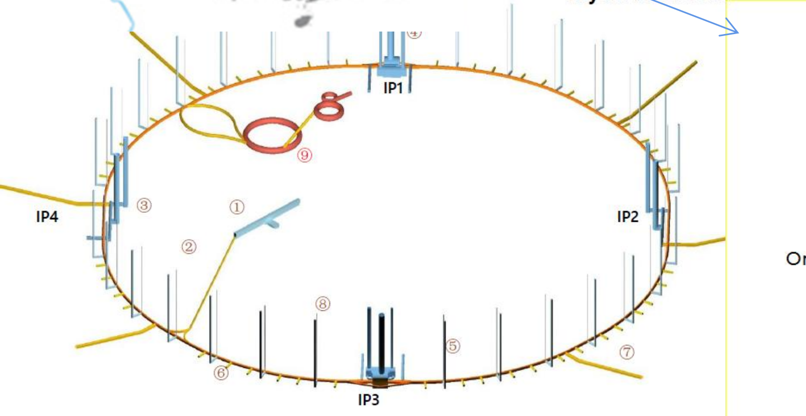


Item	Unit	Drill-blast	TBM
The clearance cross section	m²	27.00	33.20
Excavation unit price	Yuan/m³	278.28	617.00
Construction duration	Month	50	52





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



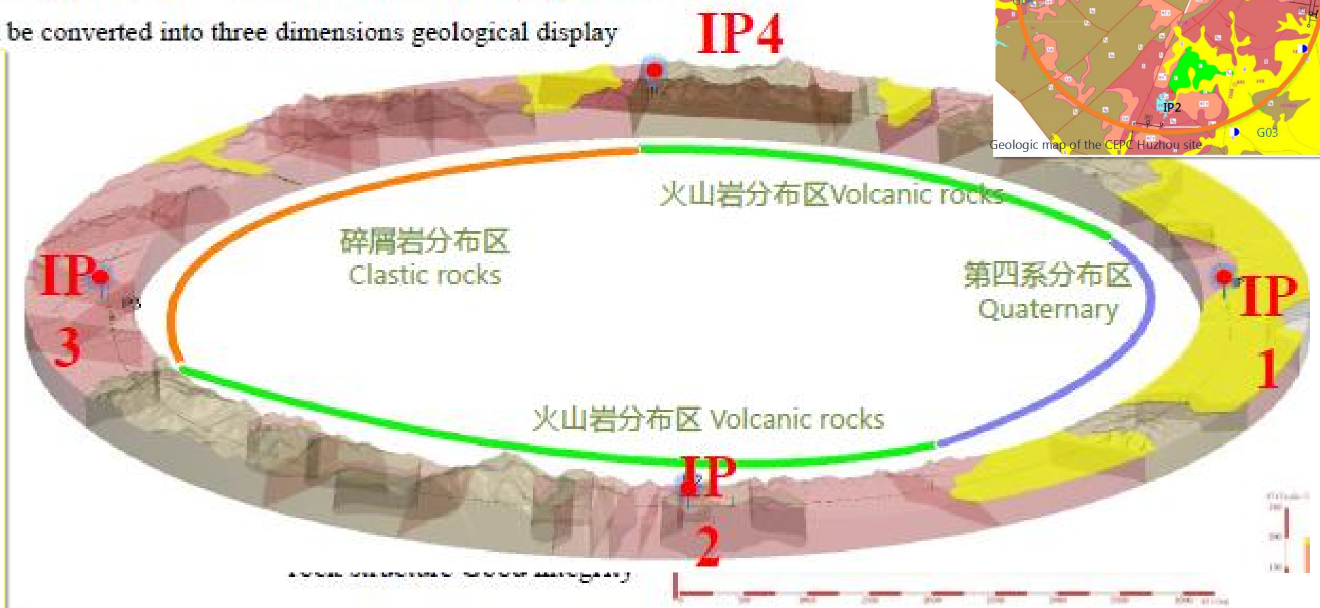
The minimum depth of the main ring is 70m

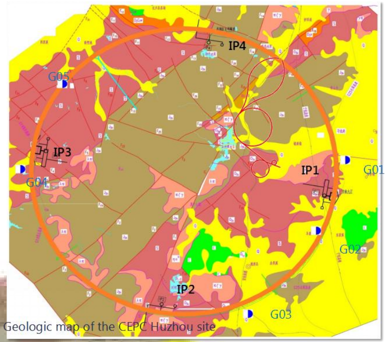
The geological work can be converted into three dimensions geological display

CEPC-SPPC 项目湖州场址TDR
第一阶段工程地质勘察主报告
工程编号：

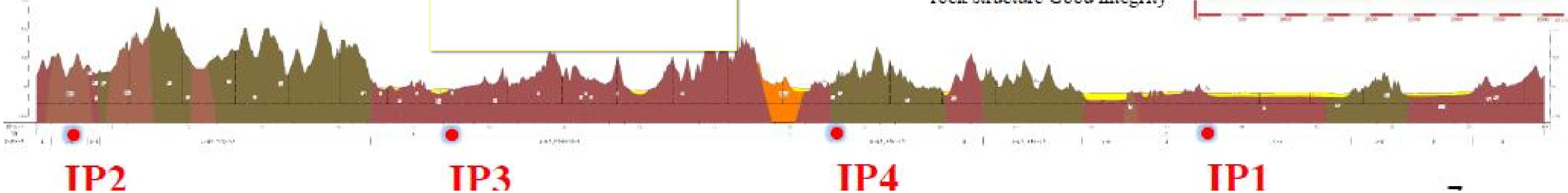
CEPC TDR
On Engineering geological survey of the first stage
(Zhejiang Hu Zhou Site)

二〇一九年九月





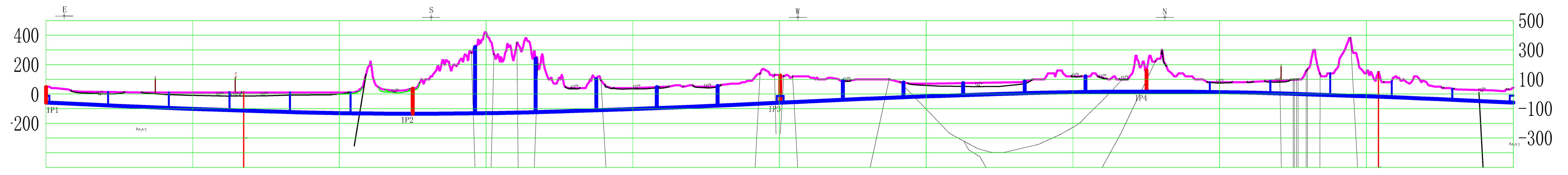
Geologic map of the CEPC Huzhou site



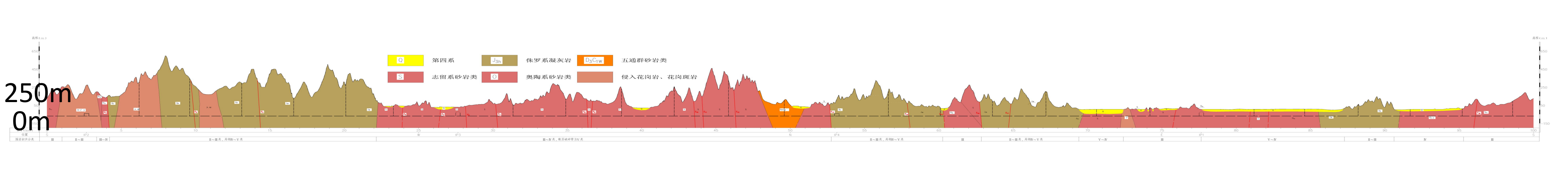
CEPC Sites Engineering Geologies in TDR

Qinhuangdao	Huzhou	Changsha

Qinhuangdao

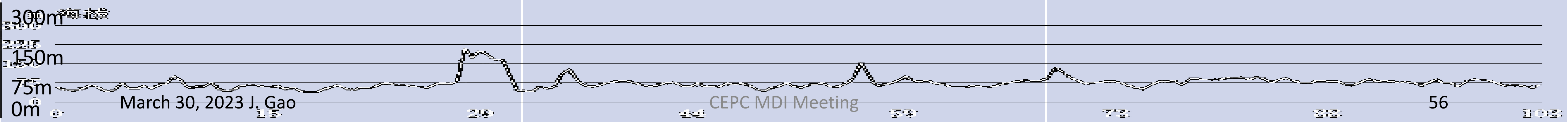


Huzhou

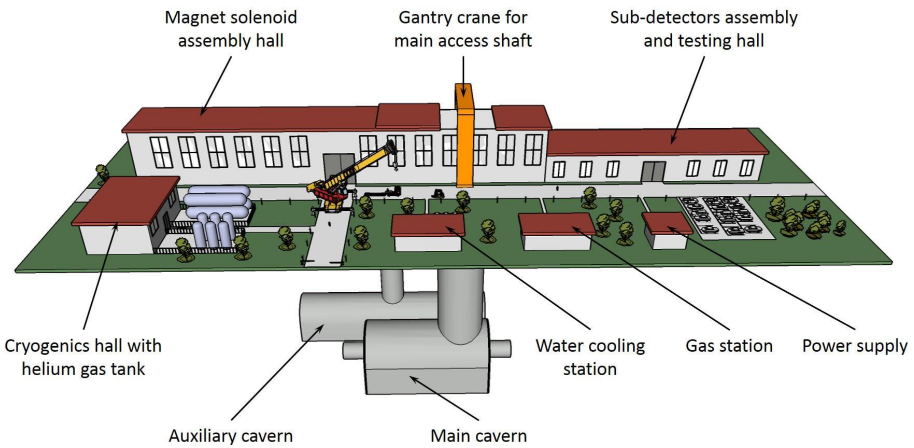


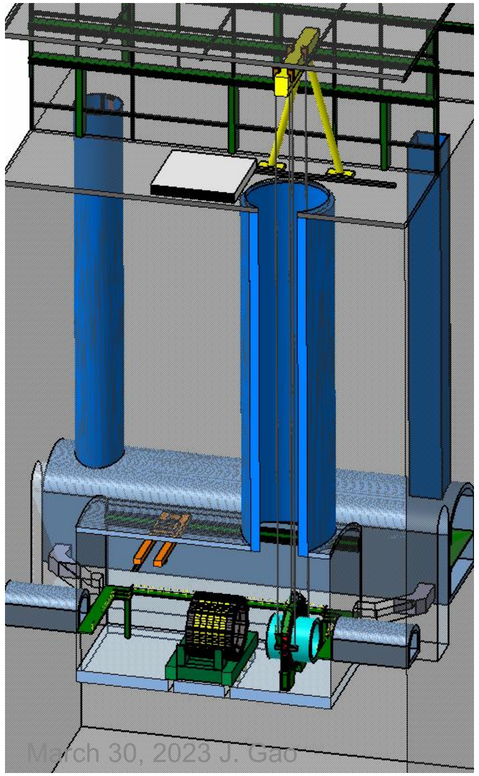
Changsha

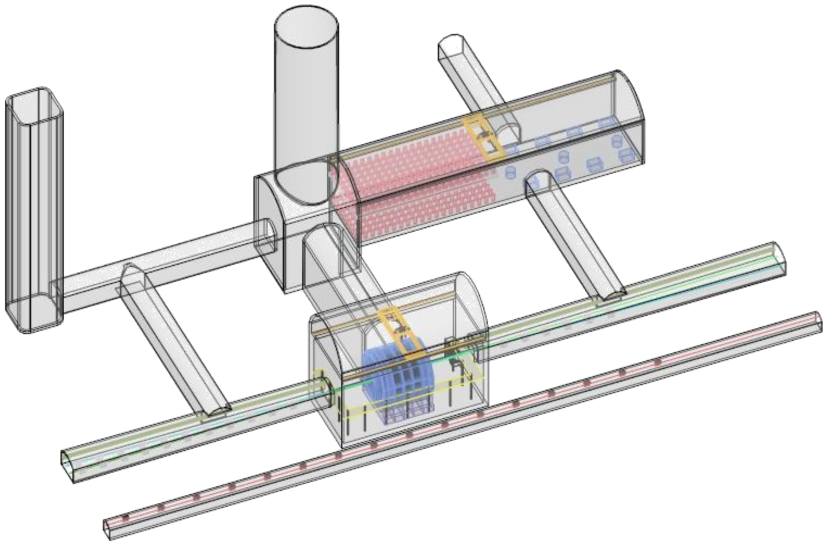
Shafts depths: 50m~106m



CEPC IR Region



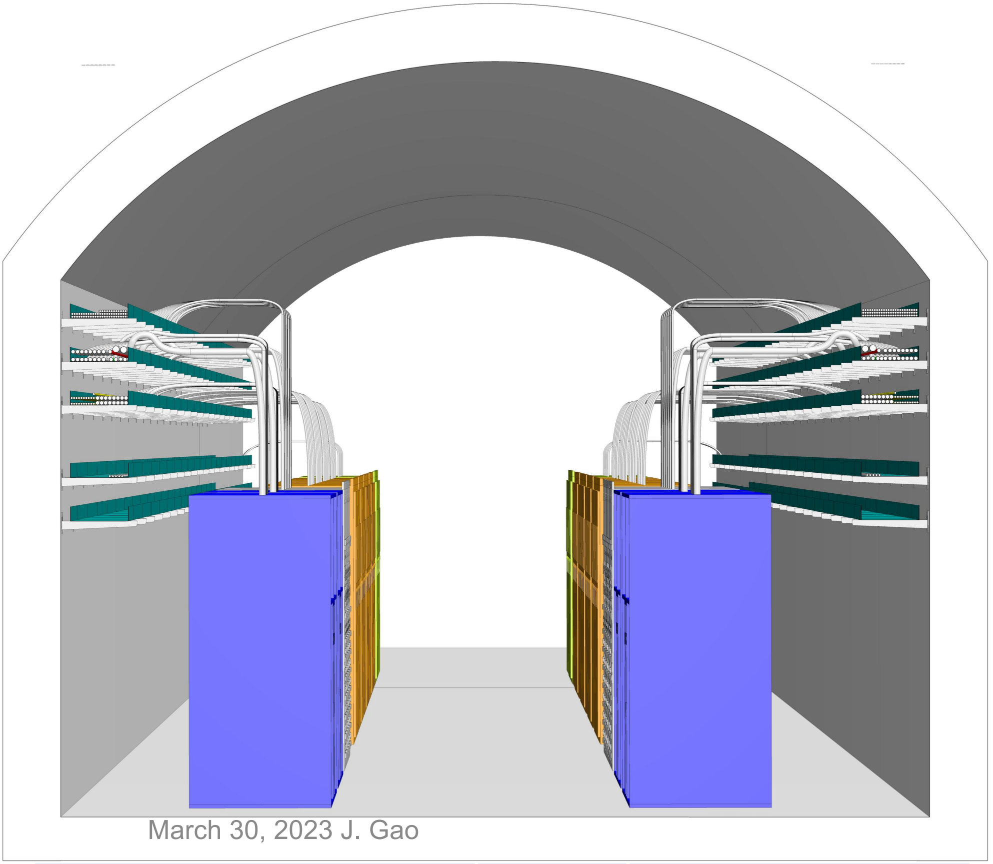




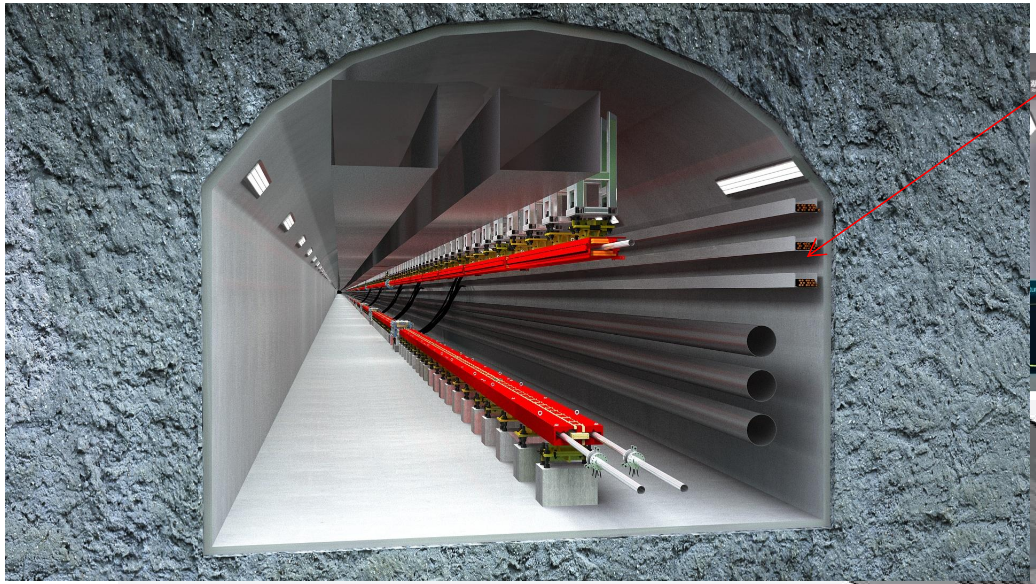
Name	L×W×H	Numb.
Experimental hall	39.4×20.4×31	×2
Axiliary hall	101.4×20×26.2	×2
Booster tunnel	1679×3.5×3.5	×4
Collider tunnel	1659.3x(6~11.4)x5	×4
Travel shaft	1200x7.5x7.5	×2
Connection, electric cable and ventilation shaft	70x10x10	×2

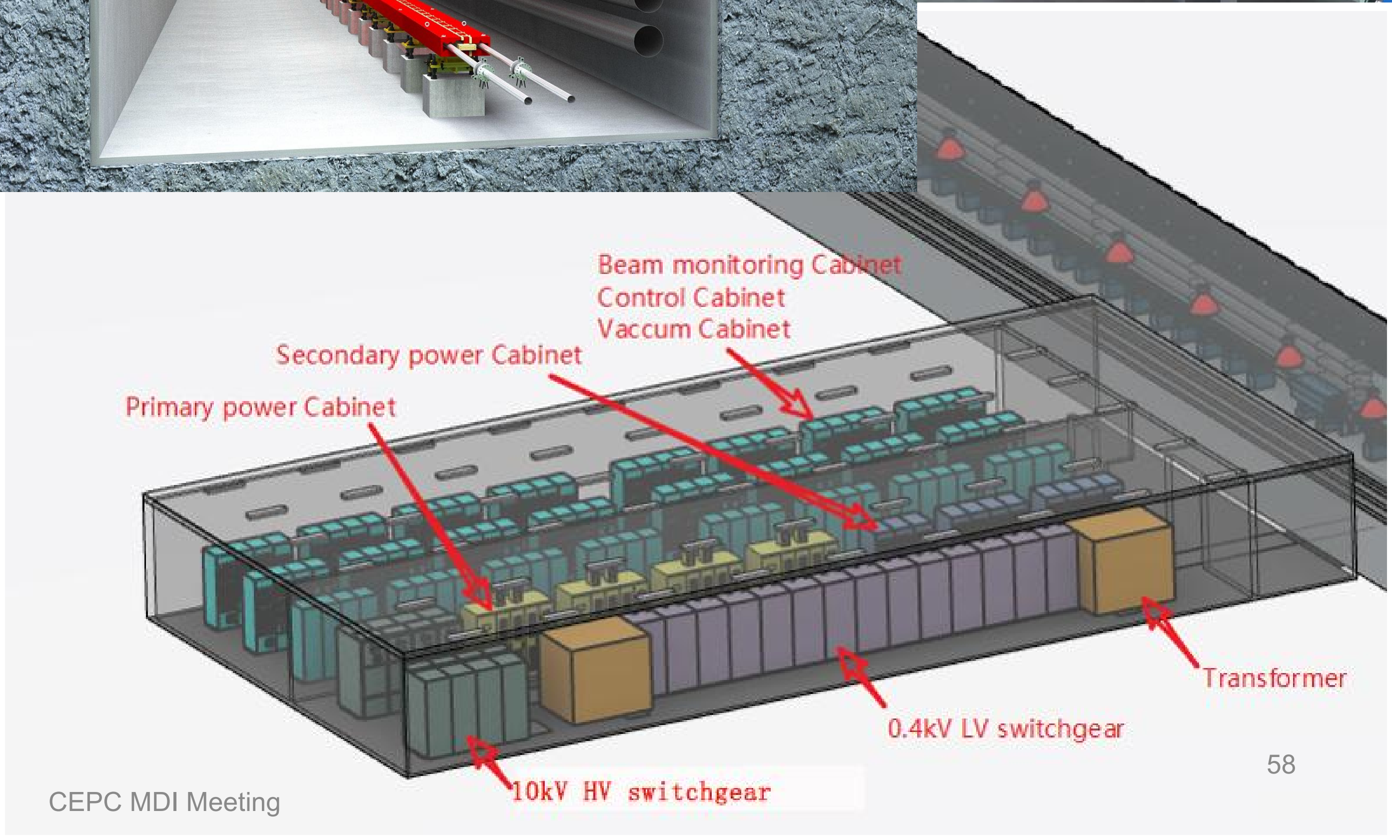
CEPC Conventional Facility and Civil Engineering

Electrical Equipment General Layout in Auxiliary



Cables installed!





CEPC TDR Power Consumption Breakdowns@Higgs with 30GeV injection Linac and 30MW SR/beam

	Location and electrical demand(MW)						
	Ring	Booster	LINAC	BTL	IR	Surface building	TOTAL
RF Power Source	96.9	1.4	11.1				109.5
Cryogenic System	11.6	0.6	-		1.1		13.4
Vacuum System	1.0	3.8	1.8				6.5
Magnet Power Supplies	52.3	7.5	2.4	1.1	0.3		63.5
Instrumentation	1.3	0.7	0.2				2.2
Radiation Protection	0.3		0.1				0.4
Control System	1.0	0.6	0.2	0.0	0.0		1.8
Experimental devices					4.0		4.0
Utilities	31.8	3.5	2.0	0.6	1.2		39.1
General services	7.2		0.3	0.2	0.2	12.0	19.8
RF system			0.8				0.8
TOTAL	203.4	18.2	18.9	1.8	6.8	12.0	261.1

CEPC TDR Power Consumption Breakdowns@Higgs with 30GeV injection Linac and 50MW SR/beam

		Location and electrical demand(MW)						
		Ring	Booster	LINAC	BTL	IR	Surface building	TOTAL
1	RF Power Source	161.5	1.4	11.1				174.1
2	Cryogenic System	15.5	0.6	-		1.7		17.9
3	Vacuum System	1.0	3.8	1.8				6.5
4	Magnet Power Supplies	52.3	7.5	2.4	1.1	0.3		63.5
5	Instrumentation	1.3	0.7	0.2				2.2
6	Radiation Protection	0.3		0.1				0.4
7	Control System	1.0	0.6	0.2	0.0	0.0		1.8
8	Experimental devices					4.0		4.0
9	Utilities	42.4	3.5	2.0	0.6	1.2		49.7
10	General services	7.2		0.3	0.2	0.2	12.0	19.8
11	RF system			0.8				0.8
12	TOTAL	282.4	18.2	18.9	1.8	7.4	12.0	340.7

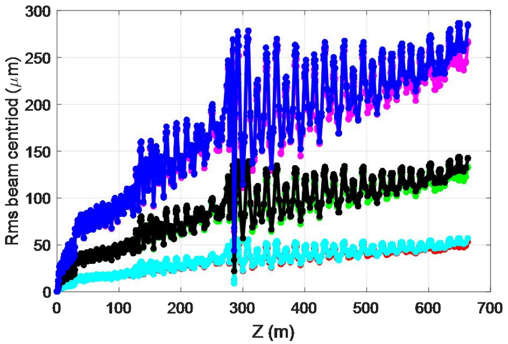
Preliminary Studies on CEPC Ground Motion

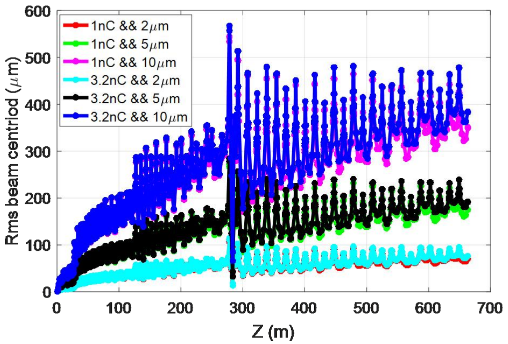
Y.W. Wang, C. Meng

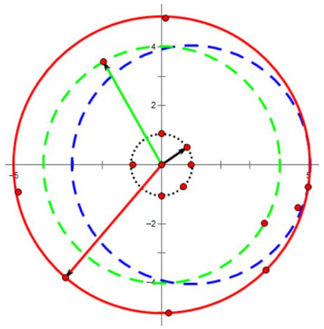
- Ground motion will increase cause beam orbit variation and also beam emittance

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

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

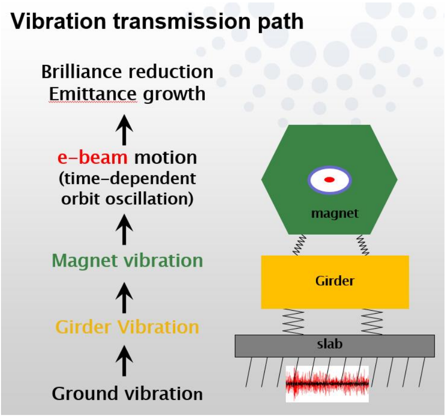




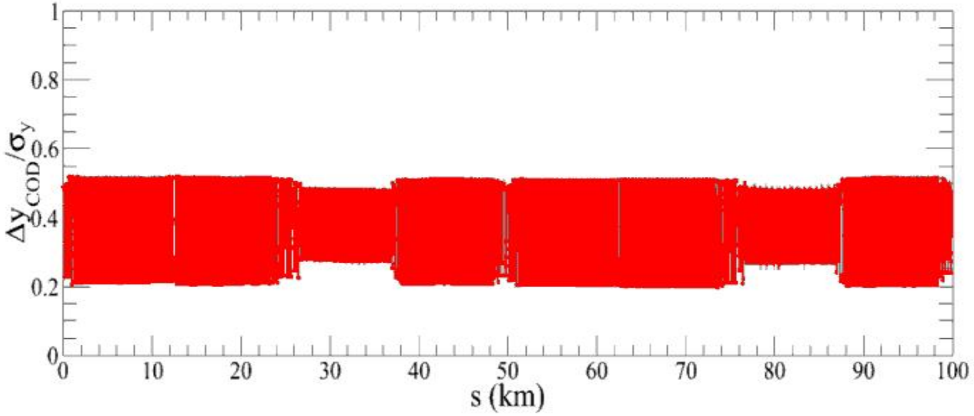


Effective emittance increase due to orbit variation

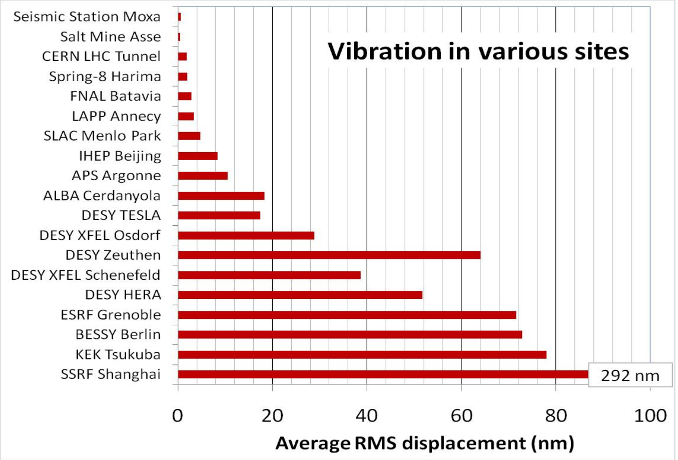
CEPC beam orbit variation in linac due to ground motion
With ground motion amplitude of 100nm, linac effective emittance increse 20%



Ground vibration transmission to colliding beams



CEPC colliding beam orbit variation due to ground motion



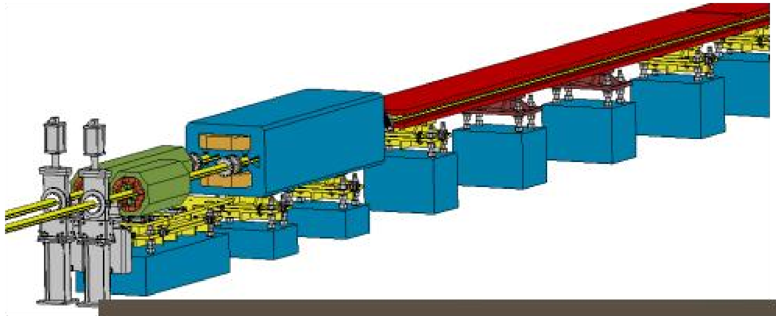
Ground vibration in different sites, LHC site is a good reference~3nm

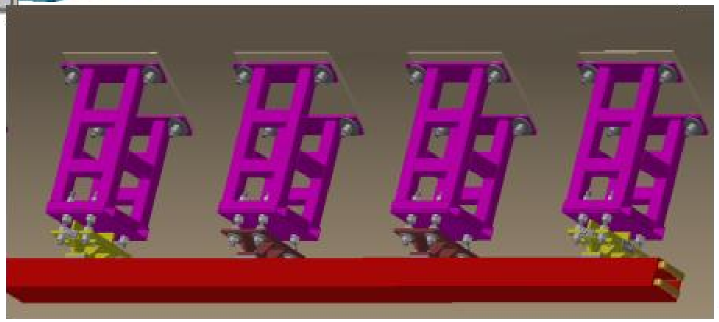
CEPC Accelerator Mechanical Supports and Installation Tools Inside the Tunnel

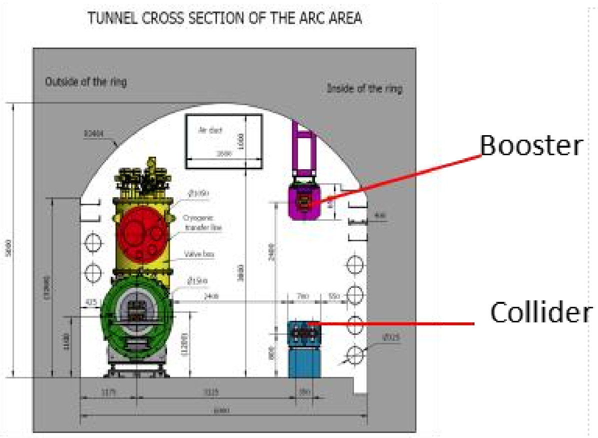
H.J. Wang

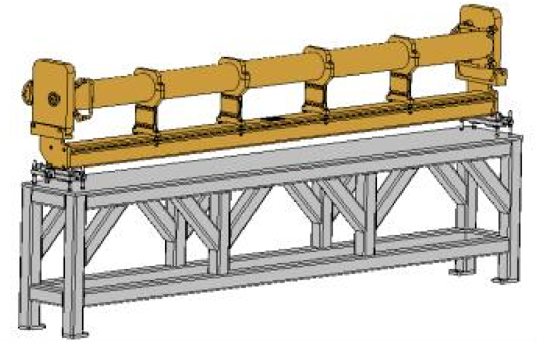
- Over 80% of the length is covered by magnets of about 138 types.

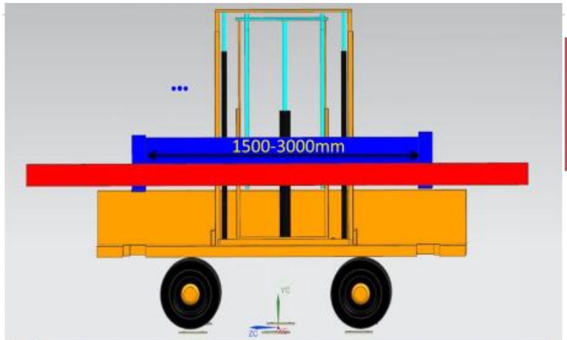
Adjustment Ranges of magnets			
X	≥±20 mm	Δθx	≥±10 mrad
Y	≥±30 mm	Δθy	≥±10 mrad
Z	≥±20 mm	Δθz	≥±10 mrad







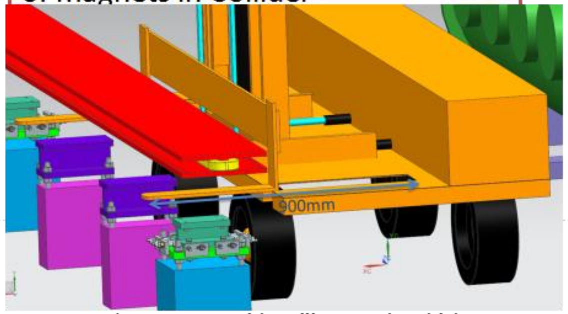


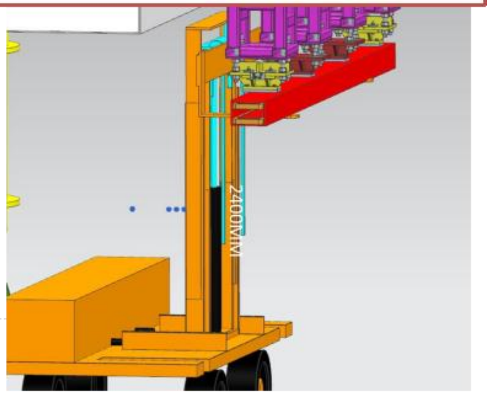


Flexible load support for “long” devices and “short” devices

Transportation and coarse location of magnets in Booster

Transportation and coarse location of magnets in Collider





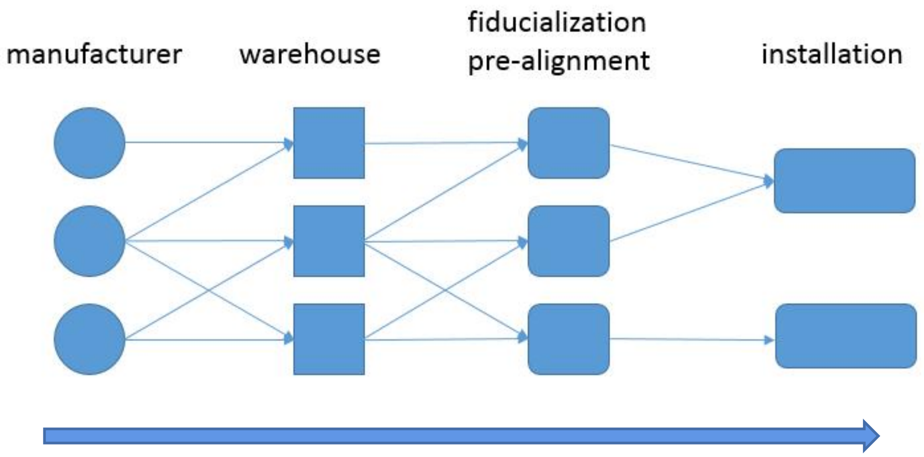
* *Cooperate with Beijing North Vehicle Group Corporation.*

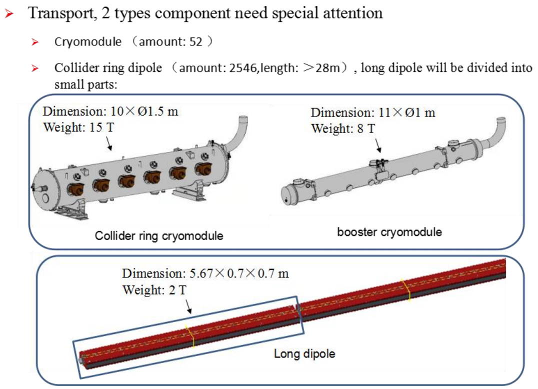
CEPC Installation Strategy-1

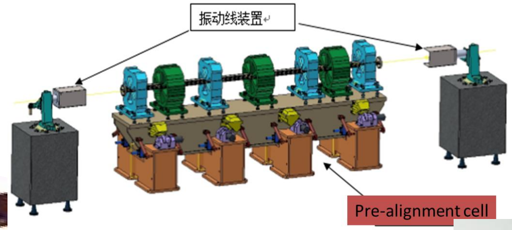
X.L. Wang

Installation and alignment scheme

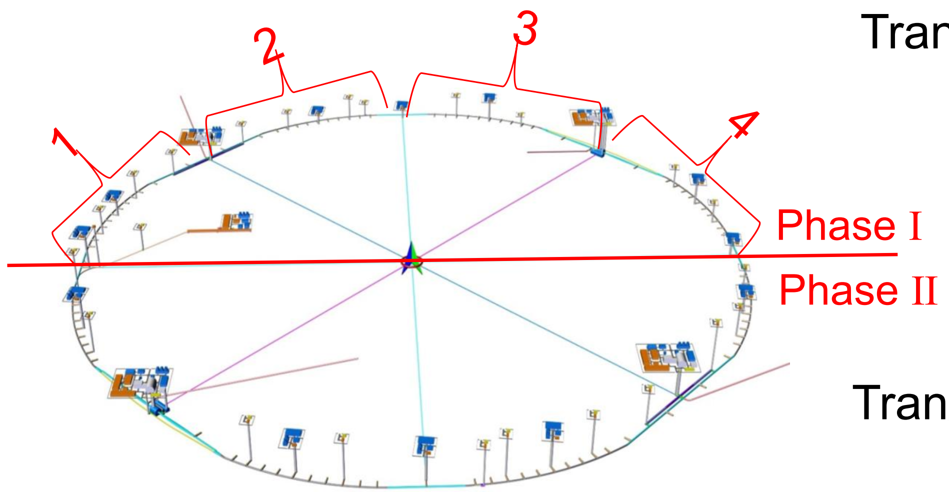
-Ring installation: phase Ⅰ, phase Ⅱ, each phase： half a ring

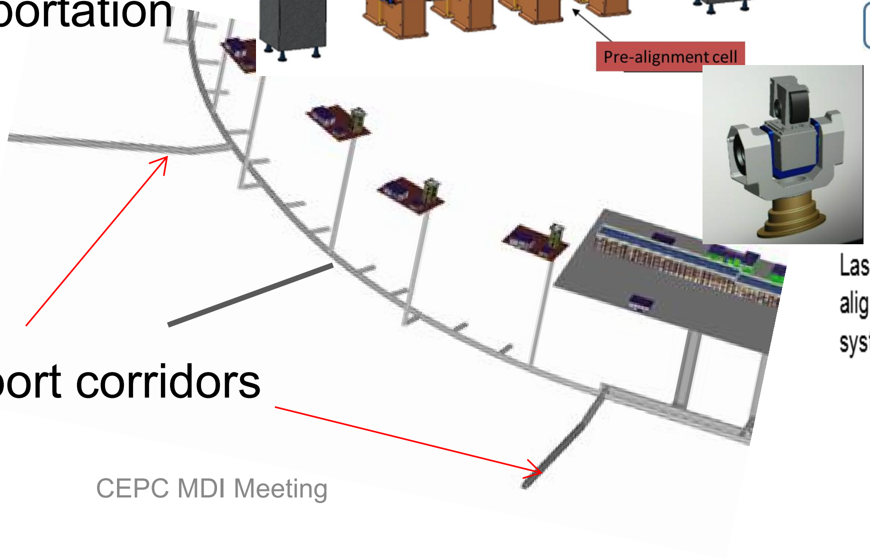




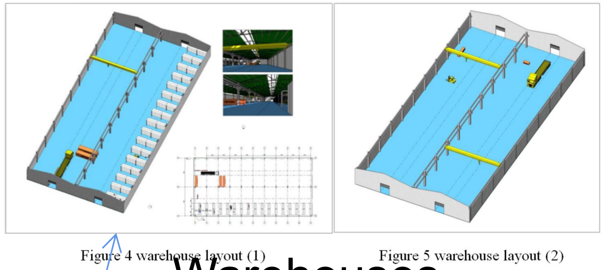


Transportation

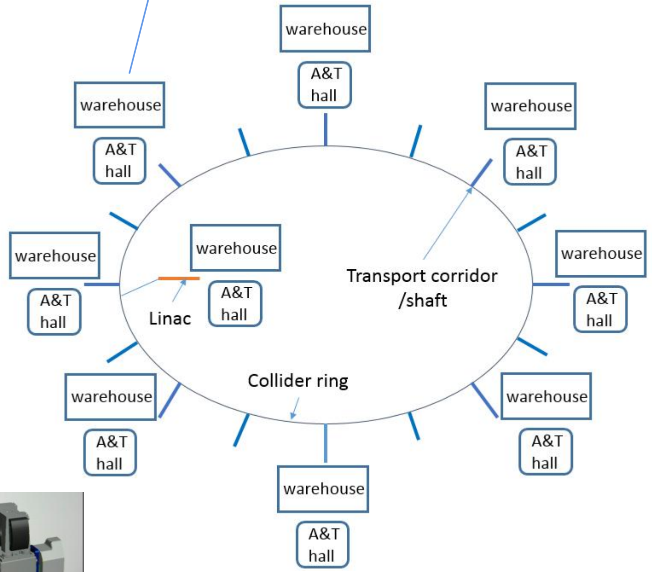


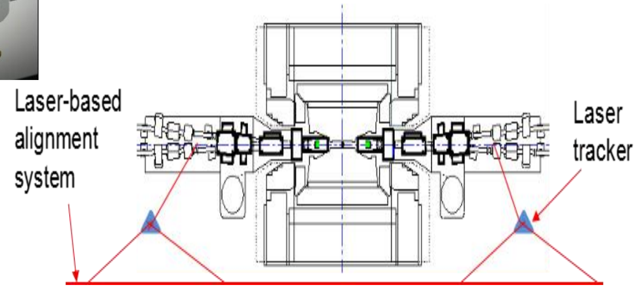


Transport corridors



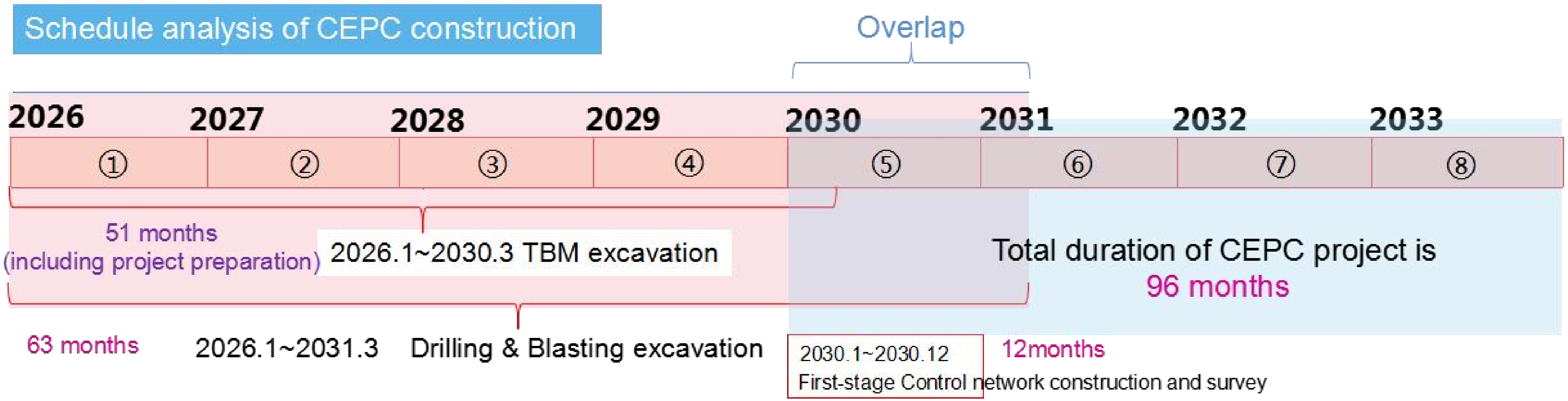
Warehouses





Civil Construction and Installation Timeline

Huadong Company

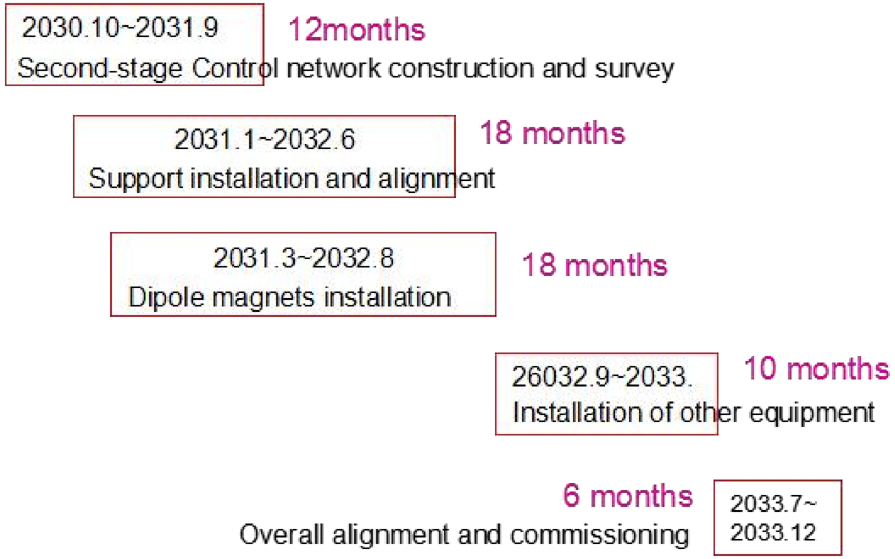


1.CEPC production Including civil works and installation of physical equipment. It will begin in 2026 and end in 2033, The total duration of CEPC project is 96 months.

2.The total civil works period is 63 months.

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

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



Accelerator TDR Documentation Schedule and EDR Plans and Timeline

CEPC Accelerator TDR Content Table

Contents

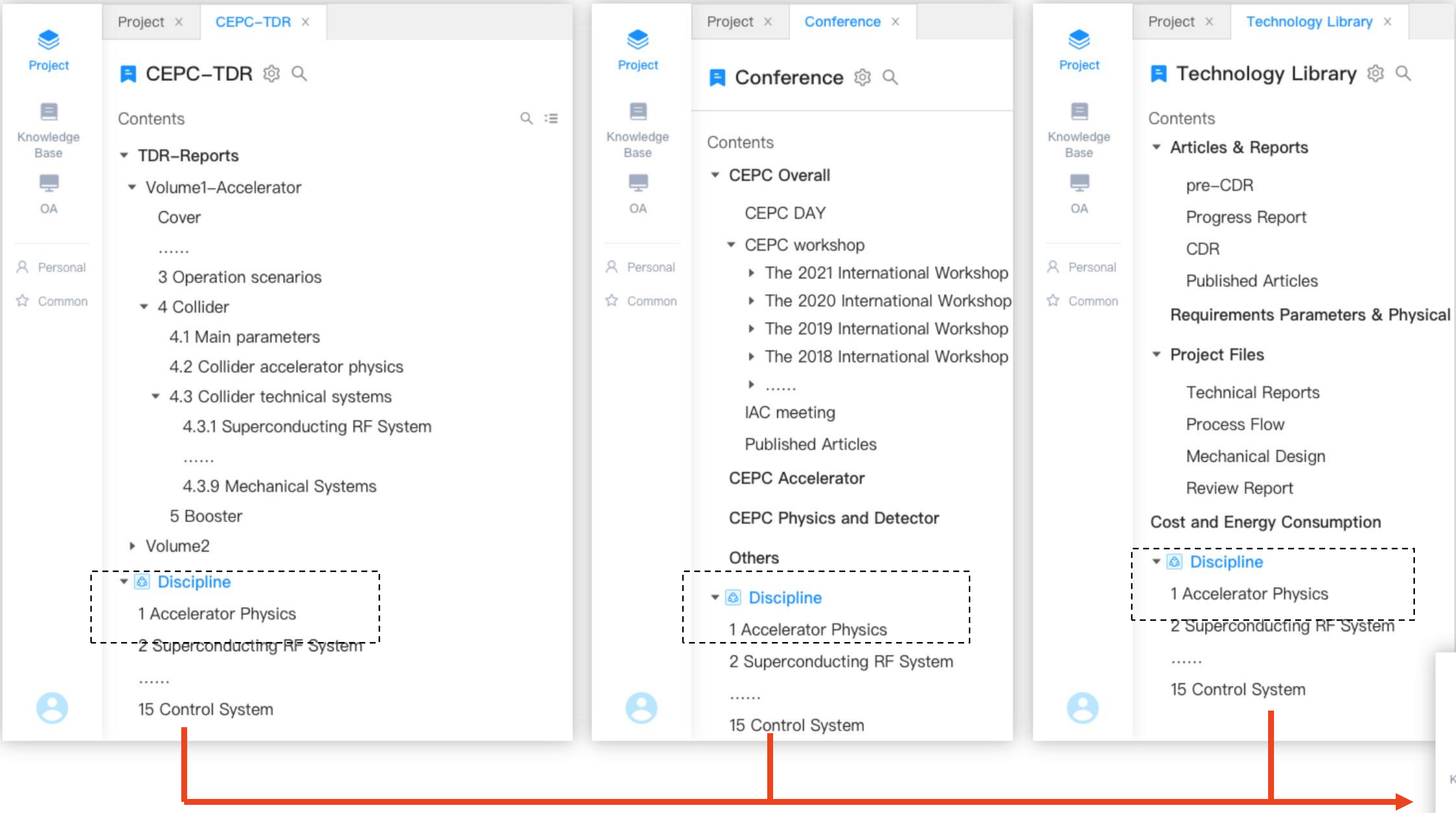
Example of contents

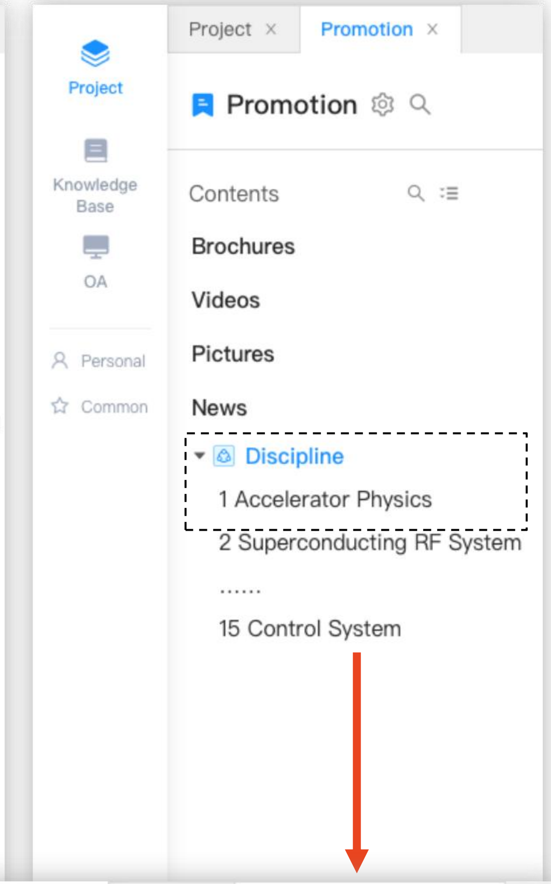
TDR written is underway, and to be finished in April 2023

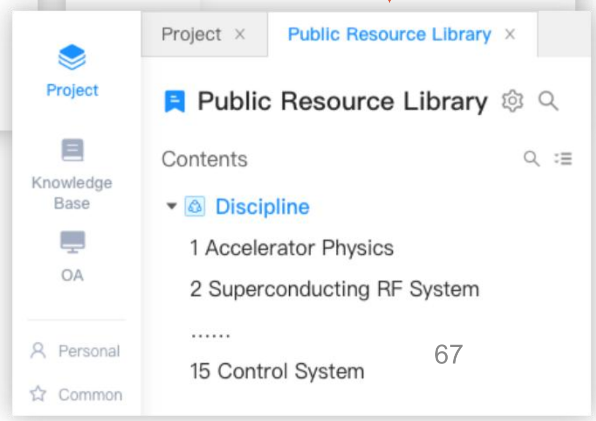
TDR International Review June 12-16, 2023
at HKUST IAS, Hong Kong, China
TDR cost International Review Sept. 11-15, 2023
at HKUST IAS, Hong Kong, China

CEPC Accelerator TDR Electronic Documentation System-DeepC Development

HYDROCHINA Huadong Company with IHEP







Four categories: TDR Preparation; Conference; Technology Library; Promotion

DeepC is a software developed jointly by HYDROCHINA Huadong Company with IHEP will be put to use started in August for CEPC TDR

CEPC Accelerator TDR Documentation Preparation and EDR Plans

TDR timeline:

TDR started to write after the first IARC reveiw in June 2022
TDR completes document writing in April 2023
TDR International Review June 12-16, 2023 at HKUST IAS, Hong Kong, China
TDR cost International Review Sept. 11-15, 2023 at HKUST IAS, Hong Kong, China
TDR released in 2023 after international review

CEPC Accelerator EDR Phase Plan:Jan. 2023-Dec. 2025

-CEPC site study converging to one or two with detailed feasibility studies (tunnel and infrastructures, environment)

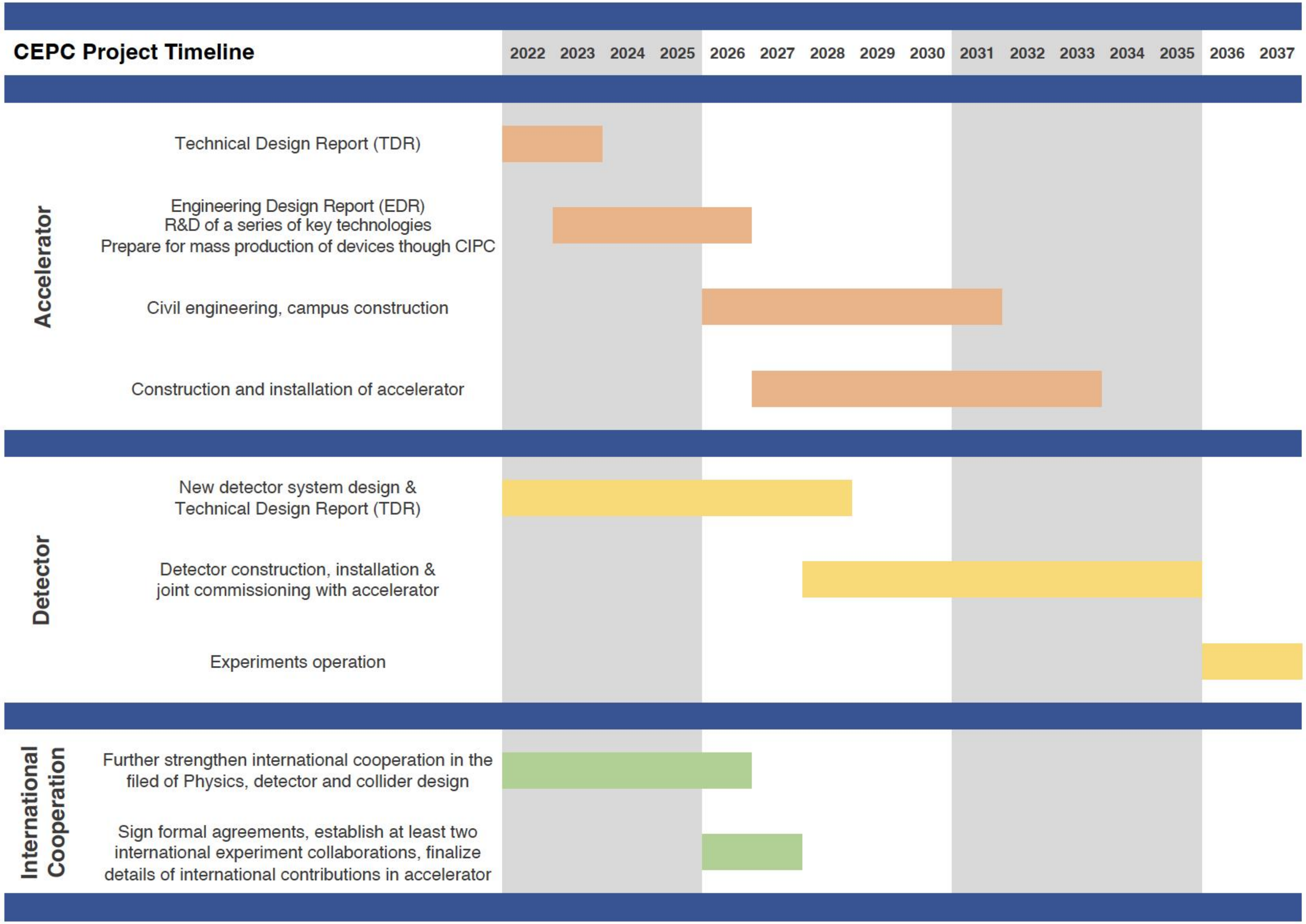
-Engineering design of CEPC accelerator systems and components towards fabrication in an industrial way

-Site dependent civil engineering design implementation preparation

-Work closely with CAS and MOST to prepare CEPC be put in the “15th five year plan” (under way)

-EDR document completed for government’s approval of starting construction around 2026 (the starting of the “15th five year plan”)

CEPC Timeline



CEPC International and Industrial Collaborations, Conferences, Worhshops and Meetings

CEPC Accelerator IARC2022

June 7-10, 2022 (online)

The 2019 CEPC International Accelerator Review Committee

Review Report

December 6, 2019

The review mee Circular Electr Committee (IAR (MDI) sessions

The IARC was p TDR. The quali even if not alre luminosity perfo improving the fo

The IARC is ple would like to th help and hospita

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, curren ergy Physics of the Chinese Academ design of the CEPC accelerator in 20 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.

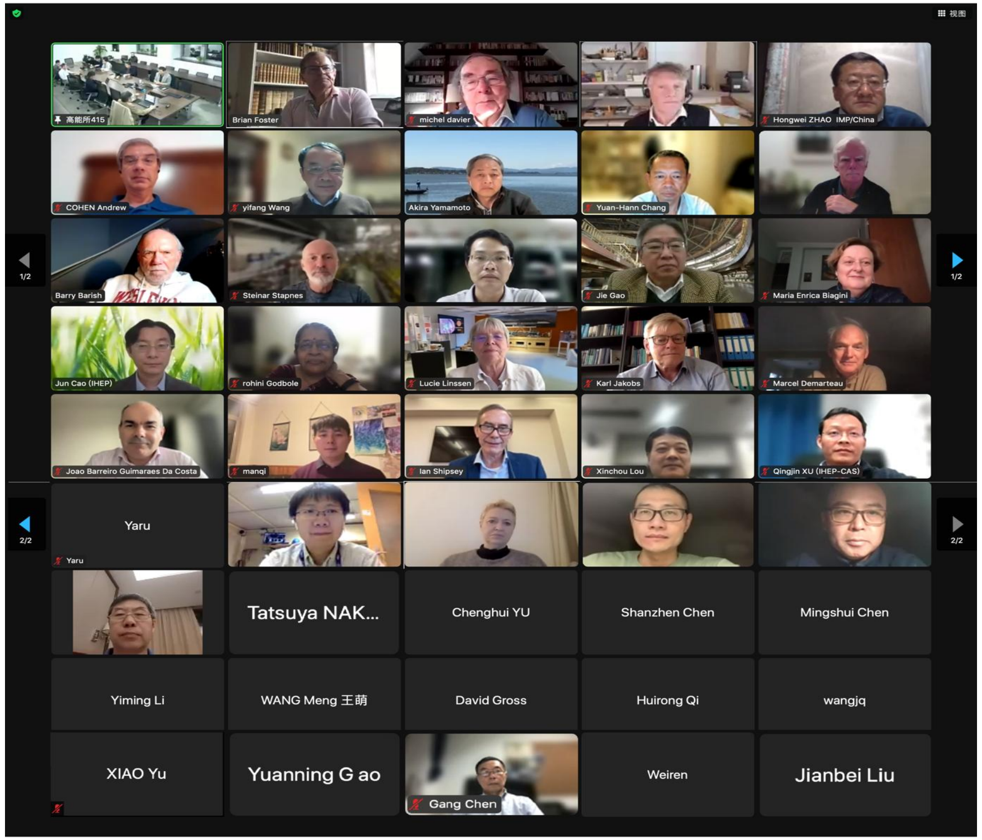
CEPC IAC2022

Oct. 31-Nov. 4, 2022

https://indico.ihep.ac.cn/event/17996/timetable/

8th Meeting of the CEPC-SppC International Advisory Committee

Oct.31-Nov.4, 2022 Beijing, China



The Eighth Meeting of the CEPC-SppC International Advisory Committee

IAC Committee

B. Barish, M. Biagini, Yuan-Hann Chang, A. Cohen, M. Davier, M. Demarteau, B. Foster (Chair), R. Godbole, D. Gross, B. Heinemann, K. Jakobs, L. Linssen, L. Maiani, M. Mangano, T. Nakada, I. Shipsey, S. Stapnes, G. Taylor, A. Yamamoto, Hongwei Zhao

November 4th, 2022

1 Overview

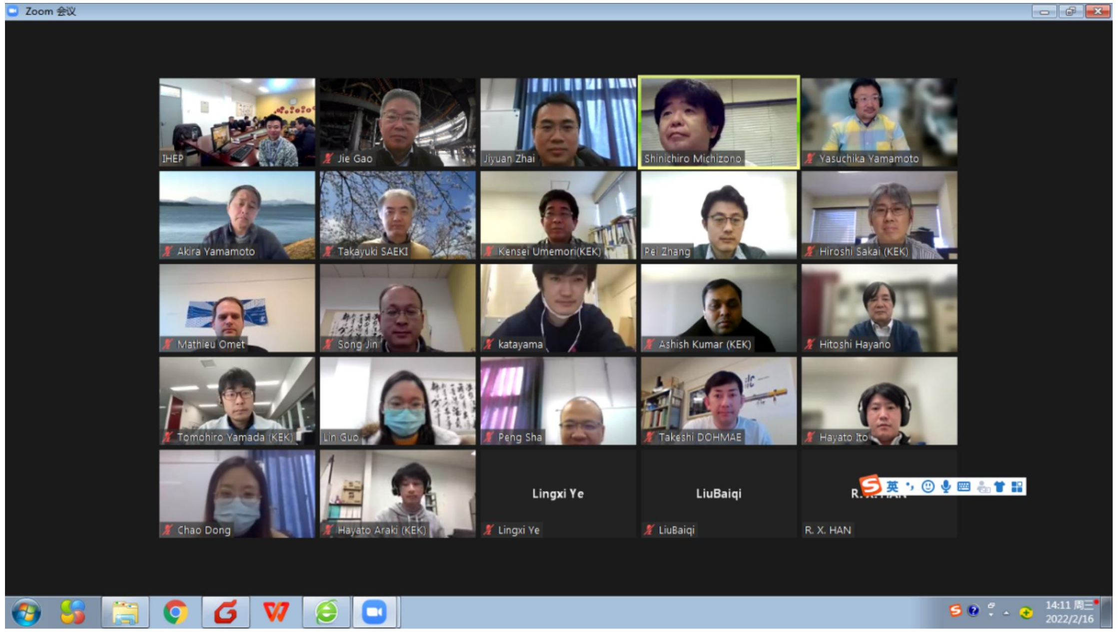
The eighth meeting of the CEPC-SppC International Advisory Committee took place virtually on October 31, November 1,2 and 4, 2022. The appendices to this report contain the charge for the meeting (Appendix A), the members of the IAC (Appendix B), and the agenda of the meeting (Appendix C). Due to different time zones, this meeting was necessarily much shorter than previous in-person meetings and missed informal exchanges of opinions. The IAC considers it essential to have some form of person-to-person meetings with more detailed materials at its next meeting in 2023, even if such a meeting has to take place outside China.

CEPC Collaborations with Industries

- CIPC, established in 2017, composed of ~ 70 high tech. enterprises, covers CIPC actively joins the Key technology R&D and **prepares for the mass production** for the CEPC construction.
- CEPC study group is **surveying main international suppliers.**
- CEPC strongly promote these relevant technology development (cost-benefit).

International Collaboration Meetings and Workshops

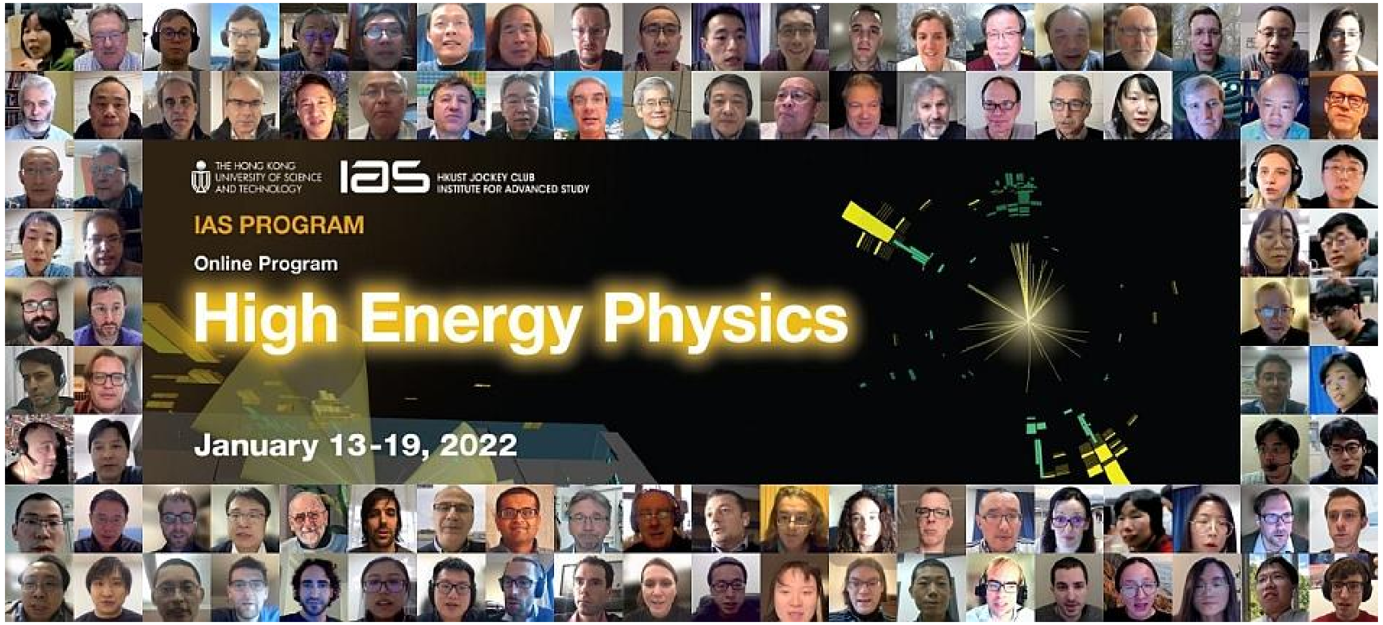
On Feb. 16, 2022, the 10th IHEP-KEK SRF Technology Collaboration Meeting was held online, more than 30 participants joined the meeting. J..Gao and Shinichiro Michizono co-chaired the meeting.



https://conference-indico.kek.jp/event/171/timetable/#20220216

HKIAS Mini workshop, January 13-14, 2022, on : Accelerator Physics — Key Beam Physics and Technologies Issues for Colliders. 41 talks from **Asia, Europe and USA.**

HKIAS 22 HEP Conference (**ILC,CLIC,C3,FCC, CEPC, Muon Collider.**.) **January 17-19, 2022**



https://indico.cern.ch/event/1096427/timetable/#20220113.detailed

International Collaboration Meetings and Workshops

HKIAS Mini-workshops in Theory & Experiment and Detector: February 12-13, 2023
HKIAS HEP Conference: February 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://events.ph.ed.ac.uk/cepceu2023

CEPC 2023 International Workshop
Oct. 23-27, Nanjing, China (in person)

Summary

CEPC accelerator system optimization design based on TDR parameters considering also 50MW SR/beam and ttbar energy upgrade possibilities are completed

CEPC accelerator key hardware R&D made important progresses with the aim of finishing TDR in the beginning of 2023

SppC high field magnet R&D and SppC design progress well

CEPC siting, civil engeering, AC power consumptions, installation planning, international collaborations and CIPC collaborations are progressing well

CEPC TDR and Cost international reviews will be taken places in June 12-16 and Sept. 11-15, 2023, respectively

Preparation for CEPC accelerator EDR phase and beyond (15th five year plan) is underway

Acknowledgements

Thanks go to CEPC-SppC accelerator team's hardworks, international and CIPC collaborations

Special thanks to CEPC SC, IAC and IARC's critical comments, suggestions and encouragement

Thanks

CEPC Key Technology R&D Status-1

Technology	Category	Quantity	Specification	R&D Status
650MHz 1 cell SRF cavity	Collider	240	Q= 3E10 @ 39.3 MV/m	Q= 2.3E10 @ 41.6 MV/m
650MHz 2 cell SRF cavity	Collider	240	Q= 4E10 @ 22 MV/m	Q= 6E10 @ 22 MV/m
1.3GHz SRF cavity	Booster	96	Q=3E10 @ 24 MV/m	Q= 4.3E10 @ 31 MV/m
650MHz high efficiency Klystron	Collider	120	Efficiency:75%; Power:800kW	Efficiency: ~70%; Power: 600kW
Electrostatic deflector	Collider	32	Electro field: 2.0MV/m; stability: 5 x 10-4; good field range: 46mm x 11mm	Prototype fulfill the specification
C-band RF cavity	Linac	292	45MV/m	2-m prototype engineered, waiting for high power test
Cool Copper RF cavity (C-band)	Linac	/	120MV/m	Physical design finished, in the manufacture process
Positron source FLUX concentrator	Linac	1	Center field>6T	Center field: 6.2T
Dual aperture dipole	Collider	2384	Field strength: 140Gs~560Gs, aperture:70mm; length: 28.7m in 5 segments; harmonic component <5×10-4; fields difference <0.5%	All specifications are satisfied in the 1-m prototype; full length prototype in manufacture
Dual aperture qudrupole	Collider	2392	Field gradient: 3.2~12.8T/m; length: 2m, aperture: 76mm; harmonic component <5×10-4; field difference<0.5%。	Preliminary measurement in the prototype shows prominent results, more test in process
Weak field dipole	Booster	16320	Field error <1E-3@60Gs	Prototype fulfills the specifications
Visual alignment device	All	11	Pixel position accuracy 5μm+5μm/m; angular accuracy: (h) 1.8”, (v) 2.2”;	Prototype manufactured, in test
Superconducting high field dipole magnet	SPPC	/	20T	12T

CEPC Key Technology R&D Status-2

Technology	Category	Quantity	Specification	R&D Status
2860MHz klystron	Linac	35	Power: 80MW Efficiency: 55%	Power: 65MW Efficiency: 42%
Advanced S-band cavity	Linac	111	30MV/m	HEPS production fulfill CEPC specifications
Single aperture Mag.	D(160)+Q(960)+S (1864)+Corr.(5808)	/	/	HEPS production fulfill CEPC specifications
BPM & electronics	All	~5000	Spatial resolution: 600nm response frequency:10Hz	Spatial resolution: 100nm response frequency:10Hz
Cryogenic machine	Collider/booster	4	18kW@4.5K	2.5kW@4.5K collaboration with CAS
kicker ceramic vacuum chamber and coating	transport line	/	75x56x5x1200mm	Prototype in manufacture
in-air delay-line dipole kicker & pulser	transport line	/	Trapezoid pulse width=440-2420ns,1kHz	Design completed
in-air delay-line nonlinear kicker & pulser	transport line	/	Trapezoid pulse width=440-2420ns,1kHz	Design completed

CEPC Key Technology R&D Status-3

Technology	Category	Quantity	Specification	R&D Status
strip-line kicker & fast pulser	transport line	/	pulse width<10ns, 20kV into 50Ω	HEPS devices fulfill specifications
slotted-pipe kicker & fast pulser	transport line	/	Trapezoid pulse width≤250ns	HEPS devices fulfill specifications
in-air Lambertson septa	transport line	/	septum thickness≤3.5mm	HEPS devices fulfill specifications
in-vacuum Lambertson septa	transport line	/	septum thickness≤2mm	HEPS devices fulfill specifications
Electric source	All	9294	Stability: 100-1000ppm; accuracy: 0.1%	HEPS devices fulfill specifications
Vacuum chamber &NEG coating	collider	~200km	Length: 6000mm; aperture: D56mm vacuum: 3×10^{-10} Torr NEG film H_2 pumping speed: 0.5 $L/s \cdot cm^2$	Prototype fulfill specifications
Vacuum bellow	collider/booster	24000/12000	Force 125±25 g/finger;	HEPS devices fulfill specifications
Vacuum gate valves	All	1040	Leakage: 1×10^{-9} mbar·L/s @ 5000 times	Life time: 100

The CEPC key technology R$D are carried out with dedicated studies and in synergy with other projects, such as HEPS