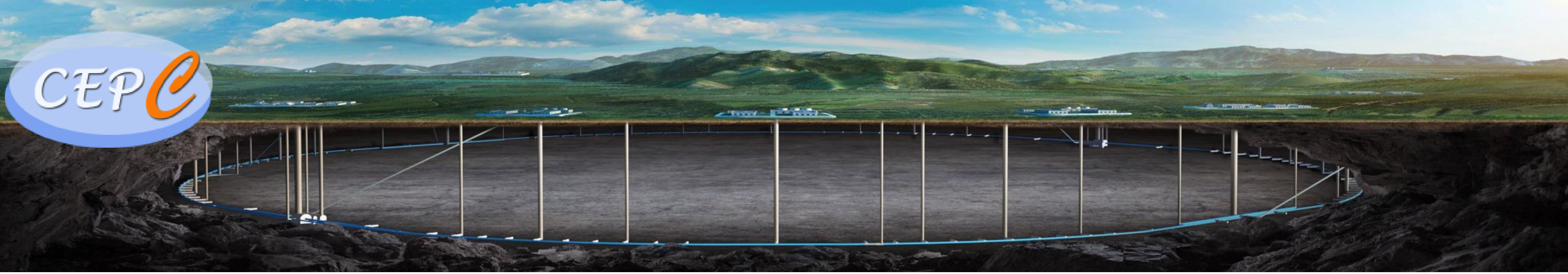


CEPC Accelerator TDR Status Overview

Yuhui Li

September 12, 2022

On behalf of CEPC accelerator team

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

65th ICF Advanced Beam Dynamics Workshop on High Luminosity Circular e+e- Colliders (eeFACT2022)
September 12-15 2022

Contents

I. Introduction

II. Collider

III. Booster

IV. Linac

- Physical design
- Key technologies

V. Injection & Extraction

VI. Other issues

- High Energy Gamma Source
- Superconducting High Field Magnets
- Plasma Acceleration
- Installation & Alignment strategy
- CIPC

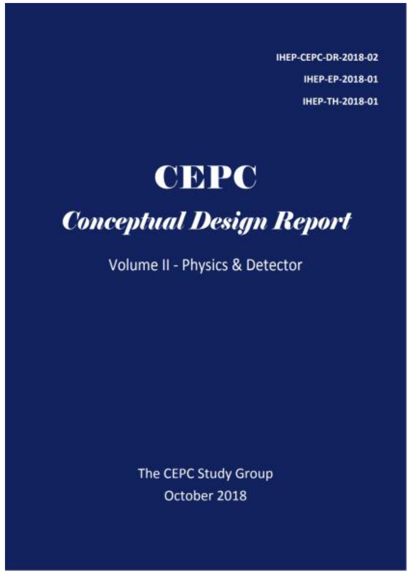
VII. Summary

Milestones


CEPC Kickoff, 2013

1st IAC meeting, 2013


CDR released, 2018



International Collaborations: IAC, HKIAS, Inter. Workshops

2^{nd} IAC meeting, 2016

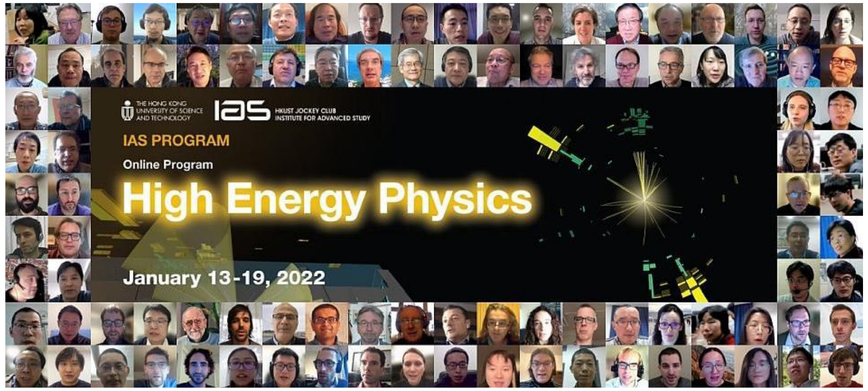
3^{rd} IAC meeting, 2017

4^{th} IAC meeting, 2018

5^{th} IAC meeting, 2019

6^{th} IAC meeting, 2020

7^{th} IAC meeting, 2021



CEPC workshop in Roma, 2017

CEPC workshop in Oxford, 2019

CEPC workshop in Chicago, 2019

International Collaborations: IARC meetings

Chair:
Biagini Maria Enrica (INFN-LNF, Italy)

Members:

Bambade Philip	(IJCLab, France)
Foster Brian	(Oxford-DESY, England-GER)
Ko In Soo	(Postech, Korea)
Levichev Eugene	(BINP, Russia)
Ohuchi Norihito	(KEK, Japan)
Oide Katsunobu	(KEK/CERN, Japan/Swiss)
Pagani Carlo	(Univ. Milan, Italy)
Sidorin Anatoly	(JINR, Russia)
Stapnes Steinar	(CERN, Swiss)
Tobiyama Makoto	(KEK, Japan)
Zhao Zhentang	(SINAP, China)

The 2021 CEPC International Accelerator Review Committee

Review Report

May 19, 2021

Overview

The CEPC International Accelerator Review Committee was held remotely due to the Covid-19 pandemic on May 11th and 12th 2021. This is the second IARC meeting.

The Circular Electron Positron Collider (CEPC+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 phase for the CEPC accelerator in 2019, with a completion target year of 2022. Meanwhile an International Accelerator Review Committee (IARC) has been established to advise on all matters related to CEPC accelerator design, the R&D program, the study of the machine-detector interface region, and the compatibility with an upgrade to the t-tbar energy region, as well as with a future SppC. The first IARC meeting took place in Beijing during the CEPC international workshop on Nov. 18-21, 2019.

2021 Second CEPC IARC Meeting

IARC Committee

October 20th, 2021

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 target year of 2022. Meanwhile an International Accelerator Review Committee (IARC) has been established to advise on all matters related to CEPC accelerator design, the R&D program, the study of the machine-detector interface region, and the compatibility with an upgrade to the t-tbar energy region, as well as with a future SppC.

The second 2021 CEPC International Accelerator Review Committee was held remotely due to the Covid-19 pandemic on October 11th to 14th 2021.

A total of 22 talks were presented on a variety of topics.

1 General comments

The Committee congratulates the CEPC team for the work performed in the last months and presented at this meeting. In particular, the progress on the R&D of the hardware components looks very promising. The team has updated the table of parameters for the high-luminosity running, as well as the lattices and components for all accelerator systems: sources, Linac, Booster and Collider.

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 target year of 2022. Meanwhile an International Accelerator Review Committee (IARC) has been established to advise on all matters related to CEPC accelerator design, the R&D program, the study of the machine-detector interface region, and the compatibility with an upgrade to the t-tbar energy region, as well as with a future SppC.

The 2022 CEPC International Accelerator Review Committee was held remotely due to the Covid-19 pandemic on June 7th to 10th 2022.

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?

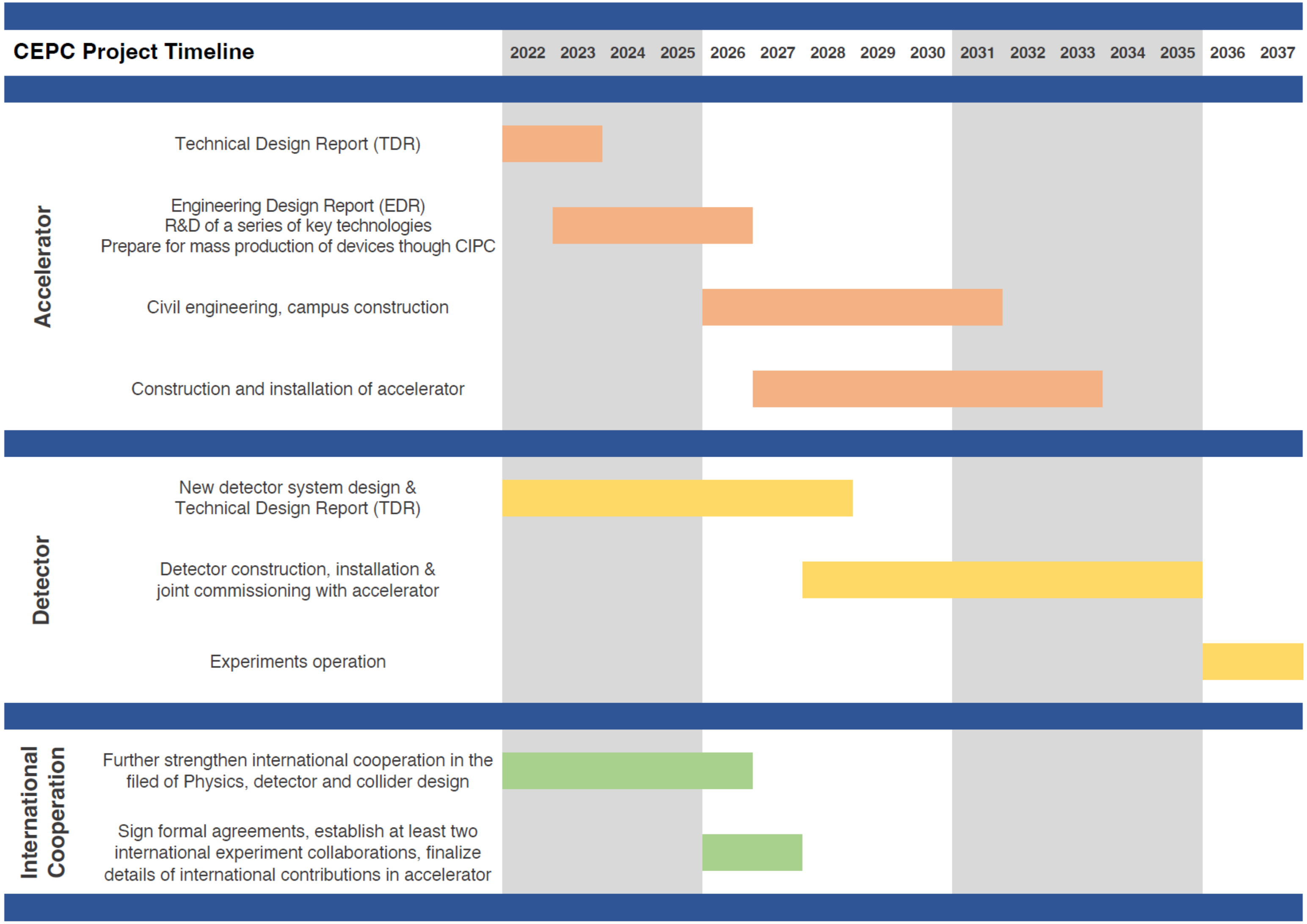
May, 2021: https://indico.ihep.ac.cn/event/14295

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

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

- As requested by CEPC-IAC, three times International Accelerator Review Committee meetings were organized on line, in 2021/2022
- In each IARC meeting, a carefully written report was delivered

CEPC Project Timeline



- CEPC TDR was released in 2018. Since then, a series of key technology R&D was carried out, as well as luminosity optimization
- CEPC-TDR is planed to be finished in early 2023
- A three-year EDR phase is planned after TDR
- Acc. construction is scheduled to be started in the 15th five-year-plan
- The CEPC aims to start operation in 2030's, as a Higgs (Z / W) factory in China

TDR Content Table

CEPC key technology R&D

Technology	Category	Quantity	Specification	R&D Status
650MHz 1 cell SRF cavity	Collider	240	Q= 3E10 @ 39.3 MV/m	Q= 6.3E10 @ 31 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

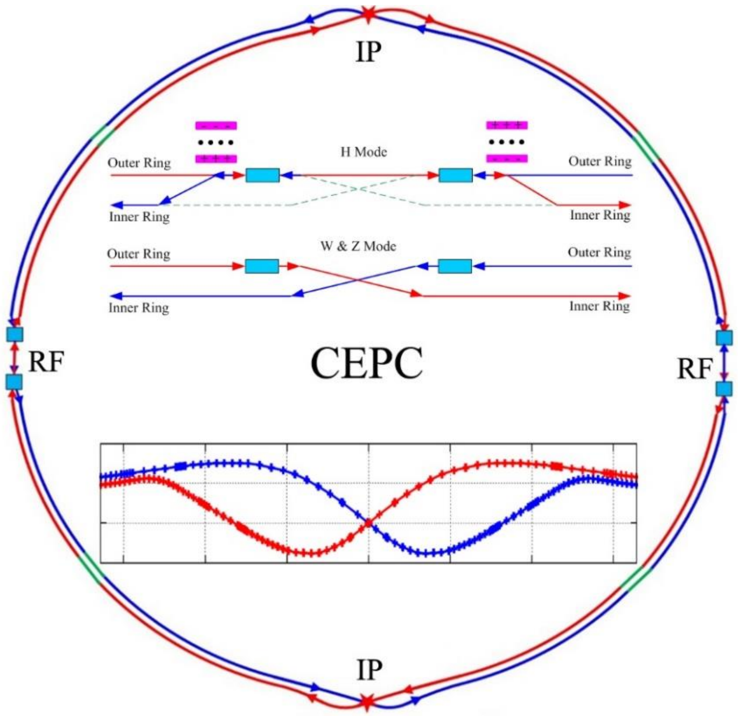
key technologies developed in other projects

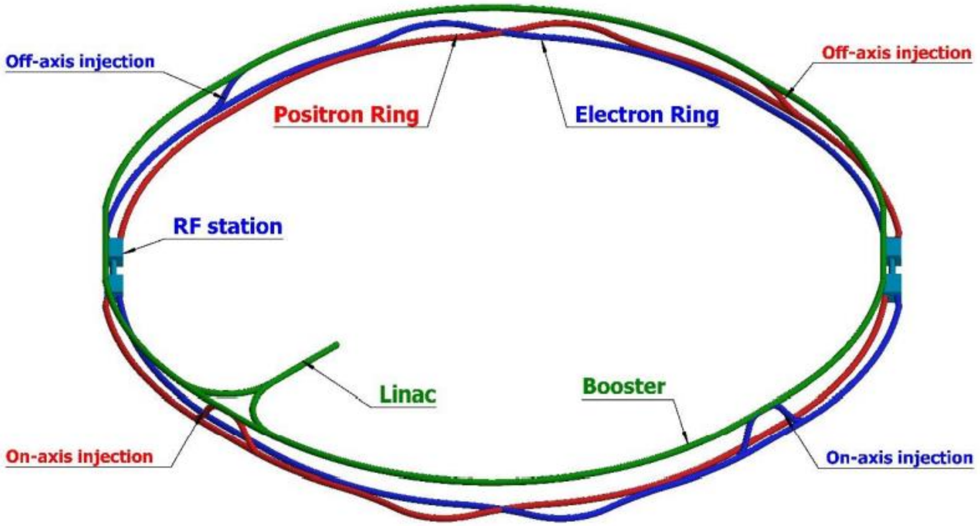
Technology	Category	Quantity	Specification	R&D Status
2860MHz klystron	Linac	35	Power: 80MW Efficiency: 55%	Power: 65MW Efficiency: 42%
Advanced S-band cavity	Linac	111	30MV/m	HEPS production fulfill CEPC specifications
Single aperture Mag.	D(160)+Q(960)+S(1864)+Corr.(5808)	/	/	HEPS production fulfill 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

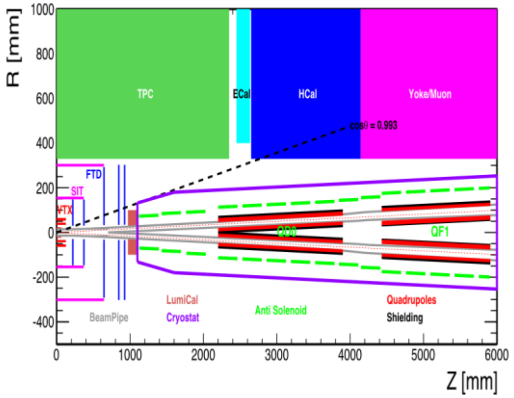
key technologies developed in other projects (conti.)

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

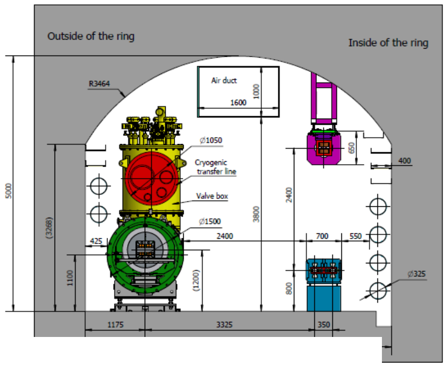
CEPC Accelerator Layout



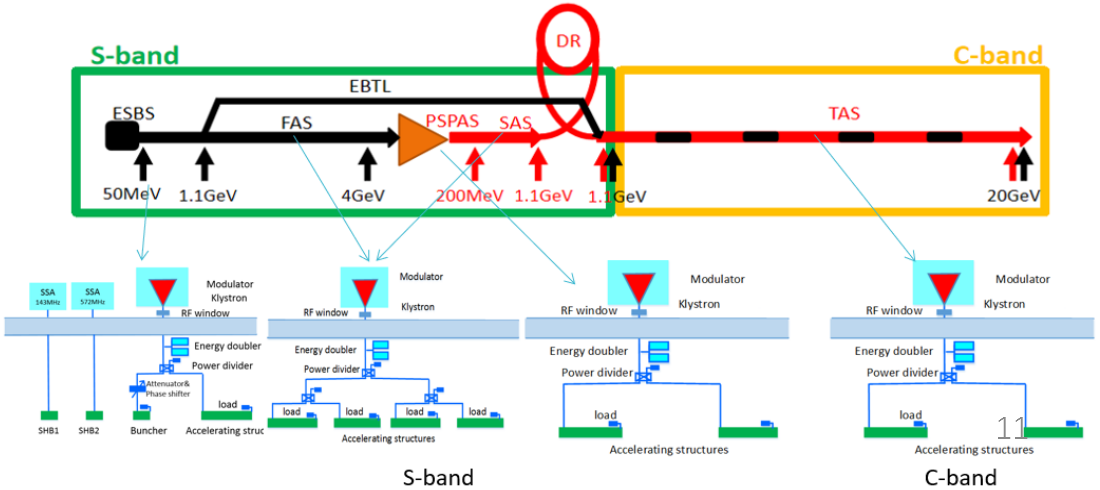




TUNNEL CROSS SECTION OF THE ARC AREA



- CEPC as a Higgs Factory
- Upgradable to 50 MW
- Upgradable to High Lumi. Z & ttbar
- Compatible to SPPC



Major parameters in CDR and High Luminosity

- Four energies operation based on solid design
- Luminosity is increased significantly

CDR

	Higgs	*W*	*Z (3T)*	*Z (2T)*
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Bunch number (bunch spacing)	242 (0.68μs)	1524 (0.21μs)	12000 (25ns+10%gap)	
Beam current (mA)	17.4	87.9	461.0	
SR power /beam (MW)	30	30	16.5	
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
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_y	0.031/0.109	0.013/0.106	0.0041/0.056	0.0041/0.072
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Natural bunch length σ_z (mm)	2.72	2.98	2.42	
Bunch length σ_z (mm)	3.26	5.9	8.5	
Natural energy spread (%)	0.1	0.066	0.038	
Energy acceptance requirement (%)	1.35	0.4	0.23	
Energy acceptance by RF (%)	2.06	1.47	1.7	
Lifetime (hour)	0.67	1.4	4.0	2.1
Luminosity/IP L (10^{34}cm^{-2}s^{-1})	**2.93**	**10.1**	**16.6**	**32.1**

TDR, High luminosity (30MW)

	Higgs	**W**	**Z**	**ttbar**
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	30	30	30	30
Energy [GeV]	120	80	45.5	180
Bunch number	**249**	**1297**	**11951**	**35**
Beam current [mA]	16.7	84.1	803.5	3.3
Beta functions at IP (βx/βy) [m/mm]	**0.33/1**	**0.21/1**	**0.13/0.9**	**1.04/2.7**
Emittance (εx/εy) [nm/pm]	**0.64/1.3**	**0.87/1.7**	**0.27/1.4**	**1.4/4.7**
Beam size at IP (σx/σy) [um/nm]	15/36	13/42	6/35	39/113
Bunch length (SR/total) [mm]	2.3/3.9	2.5/4.9	2.5/8.7	2.2/2.9
Energy spread (SR/total) [%]	0.10/0.17	0.07/0.14	0.04/0.13	0.15/0.20
Energy acceptance (DA/RF) [%]	1.7/2.2	1.2/2.5	1.3/1.7	2.3/2.6
Beam-beam parameters (ξx/ξy)	0.015/0.11	0.012/0.113	0.004/0.127	0.071/0.1
RF voltage [GV]	2.2 (2cell)	0.7 (2cell)	0.12 (1cell)	10 (5cell)
RF frequency [MHz]	650			
Beam lifetime [min]	20	55	80	18
Luminosity per IP[10^{34}/cm^2/s]	**5.0**	**16**	**115**	**0.5**

Major parameters meet the scientific goals

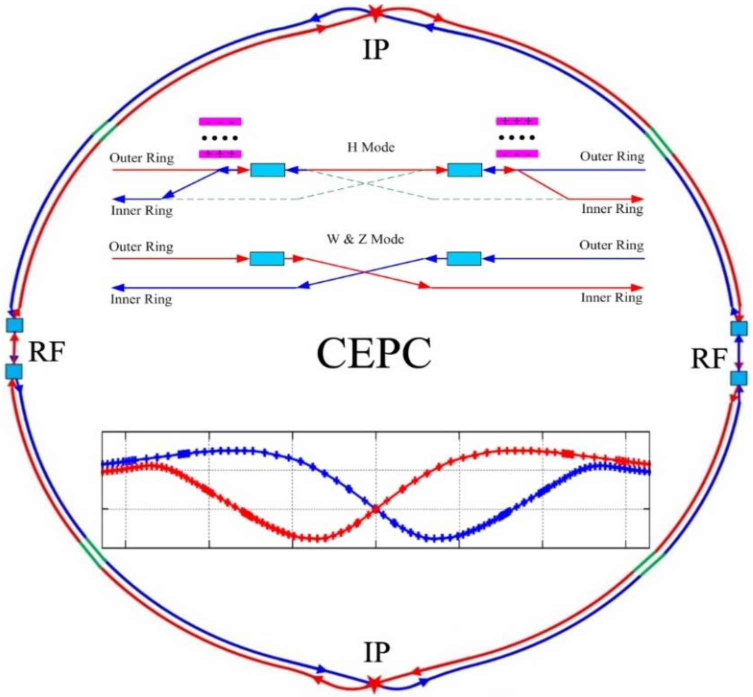
Collider Ring

Physical Design

- IP parameters in CDR & High Lumi.
- Lattice
- Error study and DA
- Beam-beam effect
- Impedance & collective instability
- MDI

Key technologies

- Power source & high efficient klystron
- 650 MHz superconducting cavity and modules
- Dual-aperture magnets
- MDI components: mechanics, cold mass, final focus magnets,……
- Vacuum system
- Feedback and Instrumentation
- Alignment technology



MDI key parameters

Y. W. Wang

Key parameters of CDR scheme for Higgs

L*=2.2m, θc=33mrad, βx*=0.36m, βy*=1.5mm, Emittance=1.2nm

- Strength requirements of anti-solenoids B_z~7.2T
- Two-in-one type SC quadrupole coils (Peak field 3.8T & 136T/m)

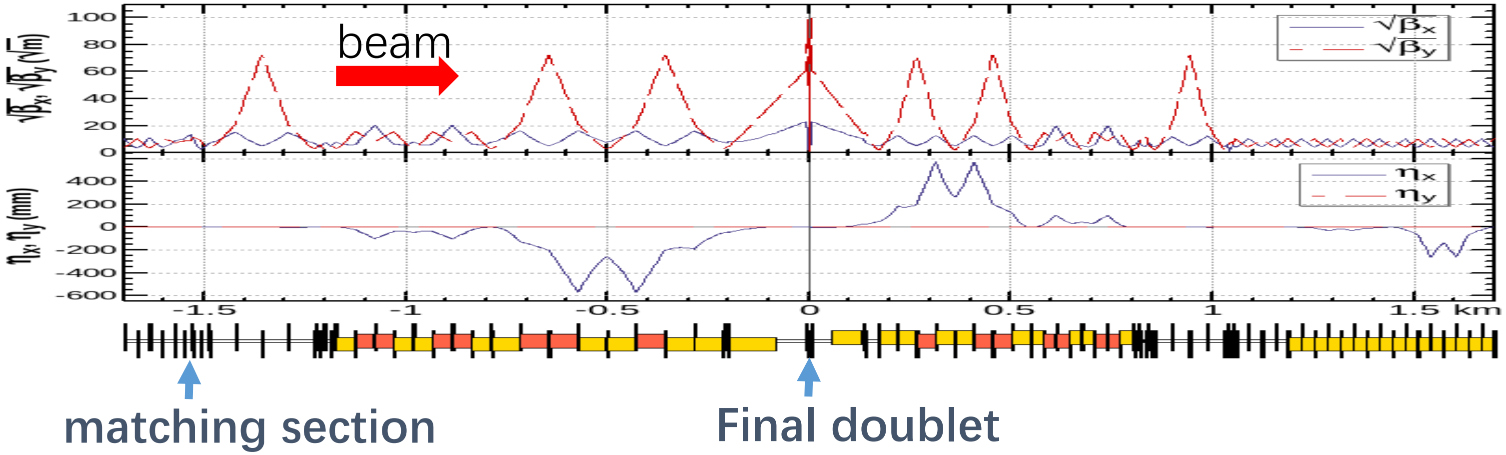
Key parameters of high luminosity scheme for Higgs

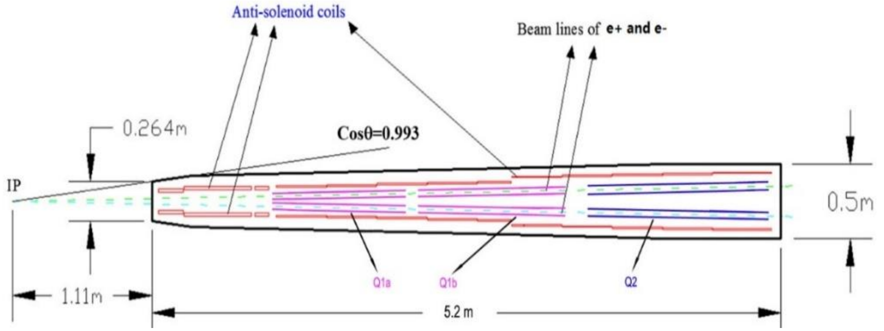
L*=1.9m, θc=33mrad, βx*=0.33m, βy*=1.0mm, Emittance=0.64nm

- Strength requirements of anti-solenoids B_z~7.2T (6.8T with a shorter solenoid)
- Two-in-one type SC quadrupole coils (Peak field 3.8T & 141T/m) with room temperature vacuum chamber & Iron yoke

Reduction of the length from IP to 1st quadrupole **without changing the front-end position of the FD cryo-module**

Z	Q1a	Q1b+Q2
W/H	Q1a+Q1b	Q2
ttbar	Q1a+Q1b+Q1c	add quads

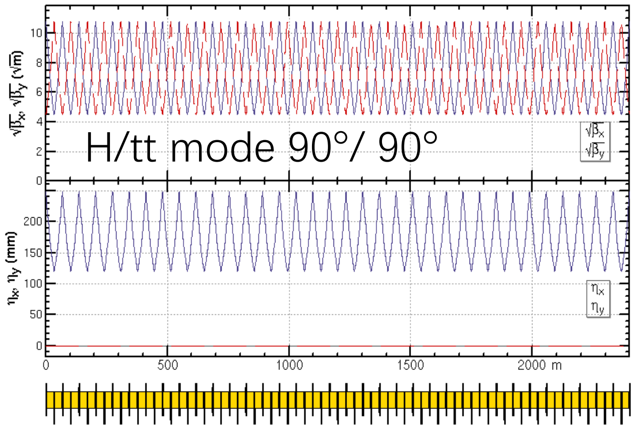


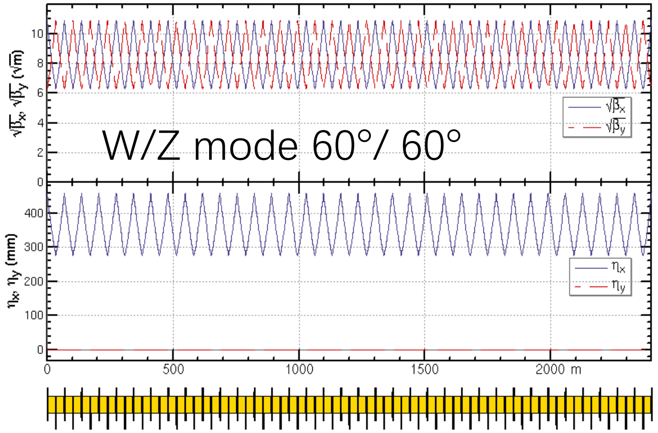


Optics for all modes

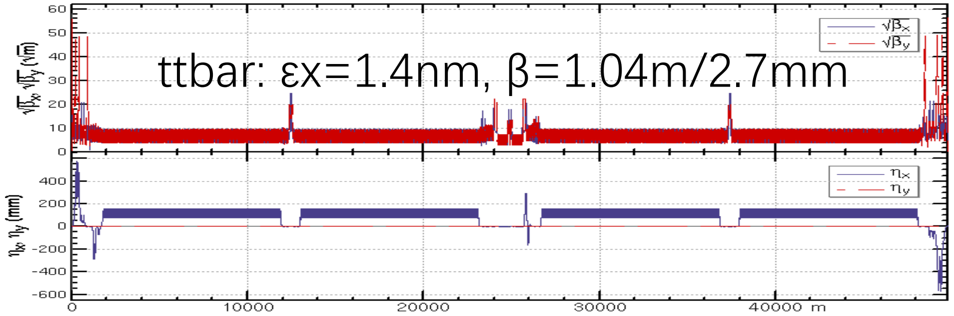
- **Phase advance for H/tt: 90° for W&Z: 60°**

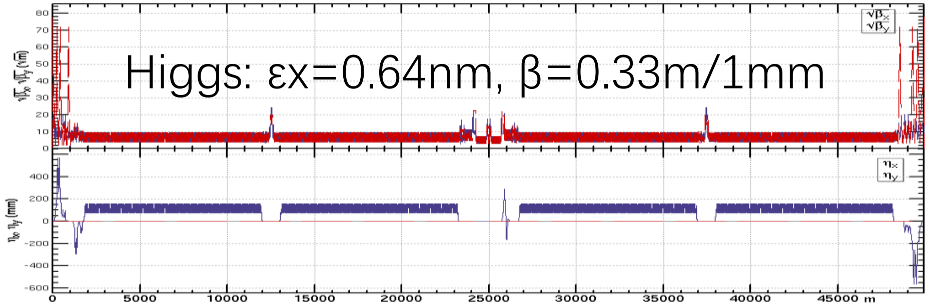
Y. W. Wang

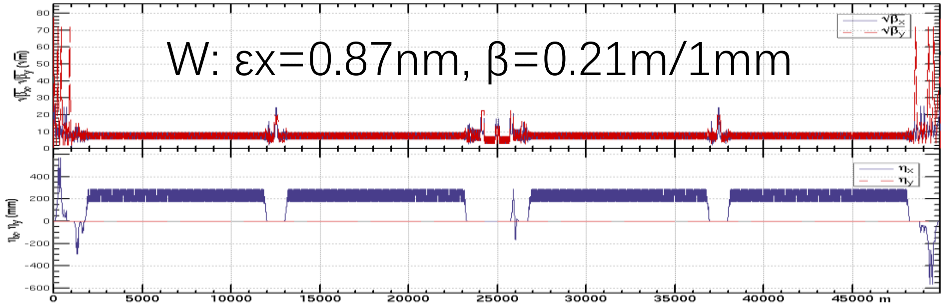


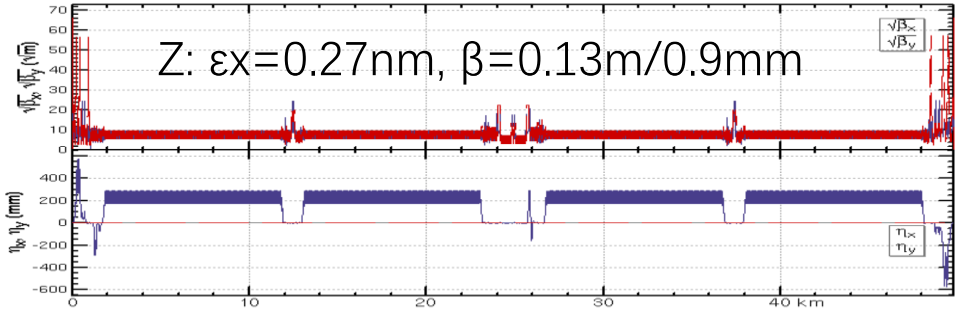


- **Lattice of half ring**









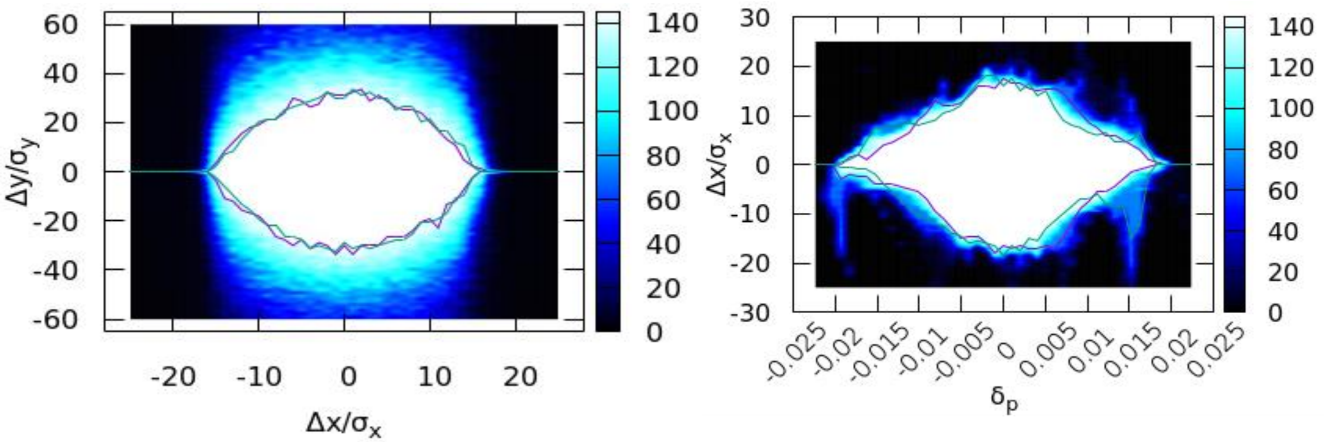
Dynamic Aperture for Higgs

Y. W. Wang

- Higgs Dynamic Aperture (DA) achieves its requirement with 52variables (32 arc sextupoles + 8 IR sextupoles + 4 multipoles + 8 phase advance)
- ttbar DA achieved energy acceptance of 2.0% with 32 arc sextupoles
- Totally 256 families of arc sextupoles.

Higgs

w/ synchrotron motion, radiation damping and fluctuation
w/o error effects



Achieved (w/o error): $16\sigma_x \times 32\sigma_y \times 1.9\%$

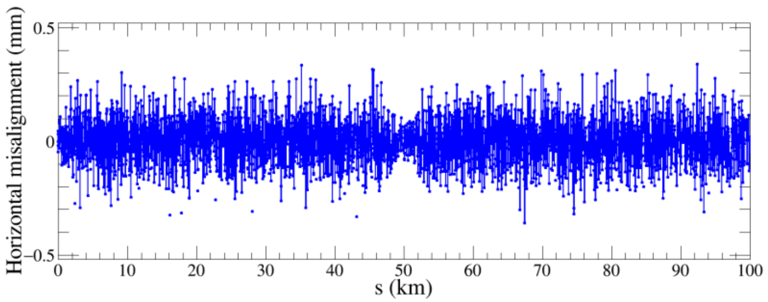
Goal (w/ error): $8\sigma_x \times 15\sigma_y \times 1.7\%$

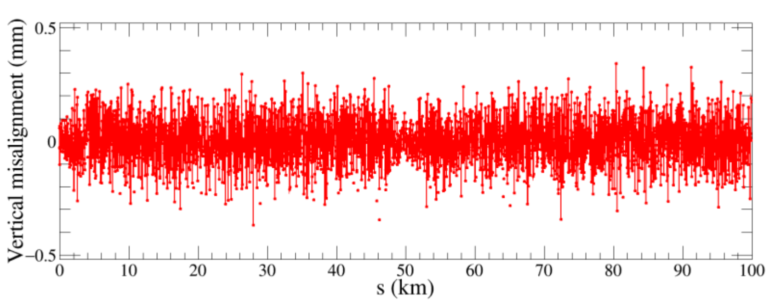
DA for other energies, tt W Z, were studied as well

Error Types and Correction Challenges

B. Wang

Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
Dipole	0.10	0.10	0.1	0.01%
Arc Quadrupole	0.10	0.10	0.1	0.02%
IR Quadrupole	**0.05**	**0.05**	**0.05**	
Sextupole	0.10	0.10	0.1	





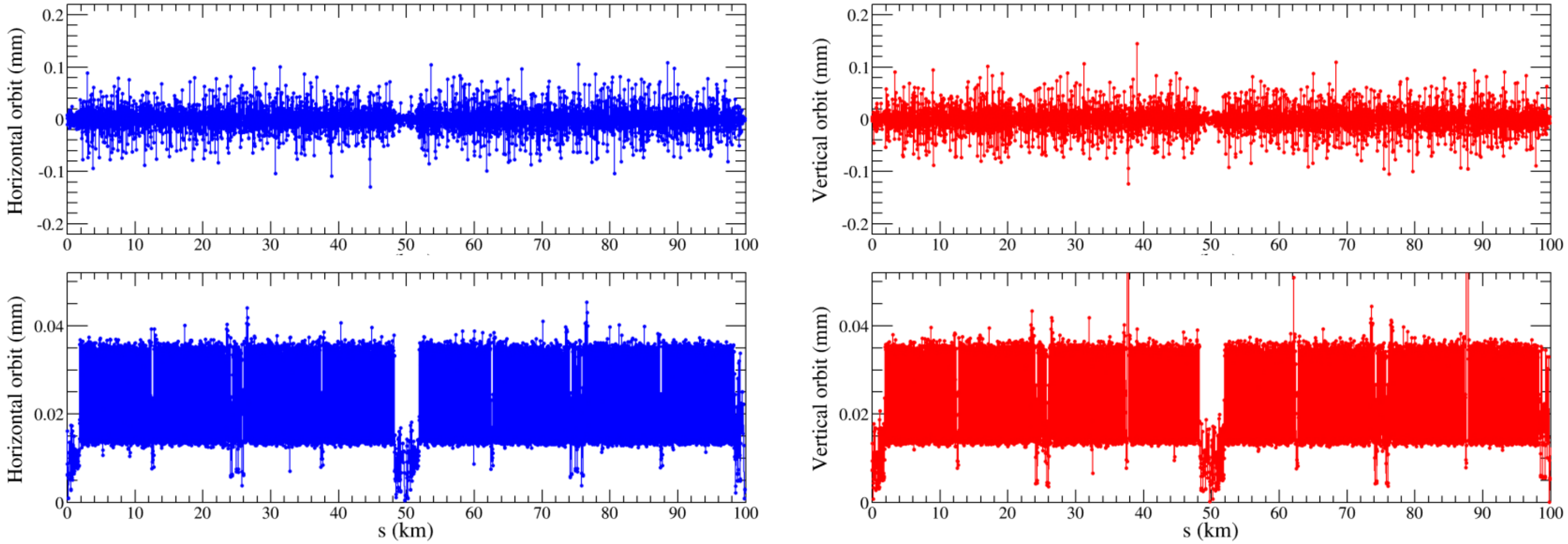
- The high luminosity lattice is much more sensitive to imperfections
- 1000 lattice seeds are generated for further correction.

Closed Orbit Distortion (COD) Correction

B. Wang

Orbit correction is applied using orbit response matrix and SVD method.

- BPMs placed at quadrupoles (~1800, 4 per betatron wave)
- Horizontal correctors placed beside focusing quadrupoles （~1800）
- Vertical correctors placed beside defocusing quadrupoles （~1800）



$$\boxed{RMS_{COD} < 0.05\ mm}$$

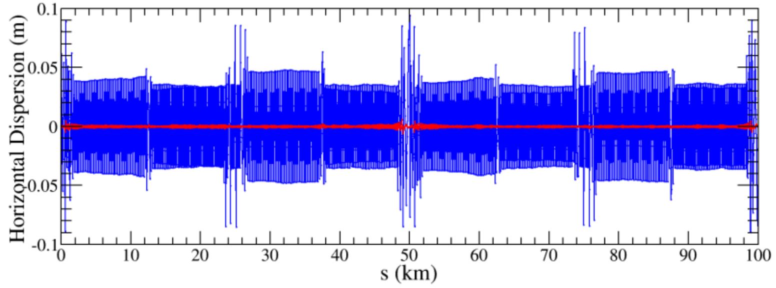
Dispersion Correction

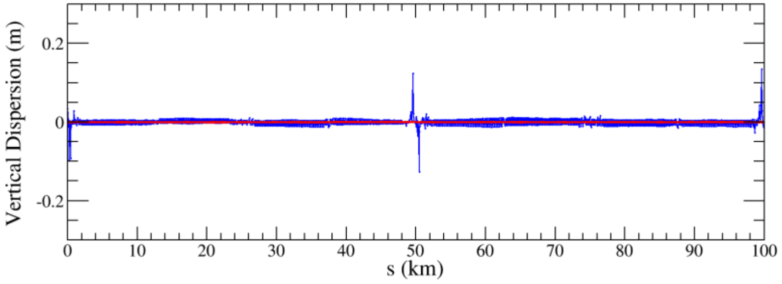
B. Wang

Dispersion free steering principle (DFS): θ_c

$$\vec{d} = \begin{pmatrix} (1-\alpha)\vec{u} \\ \alpha \vec{D}_u \end{pmatrix} \quad M = \begin{pmatrix} (1-\alpha)A \\ \alpha B \end{pmatrix} \quad \vec{d} + M\vec{\theta} = 0$$

Result of one seed





$\vec{u}$: Orbit vector

$\vec{D}_u$: Dispersion vector

$\vec{\theta}$: Corrector strengths vector

α: Weight factor

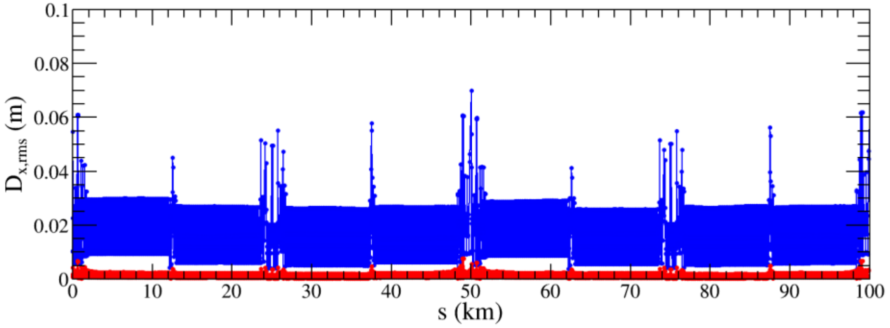
A: Orbit response matrix

B: Dispersion response matrix

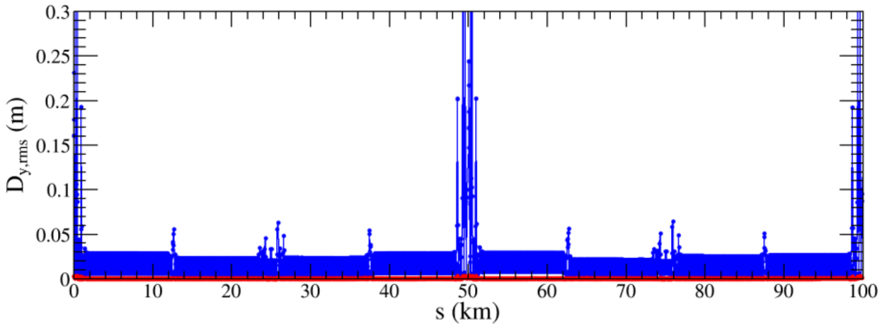
Before DISP correction

After DISP correction

674 seeds converged



$\Delta D_{x,rms}$ decreased from 15.5mm to 1.0mm



$\Delta D_{y,rms}$ decreased from 18.4mm to 0.4mm

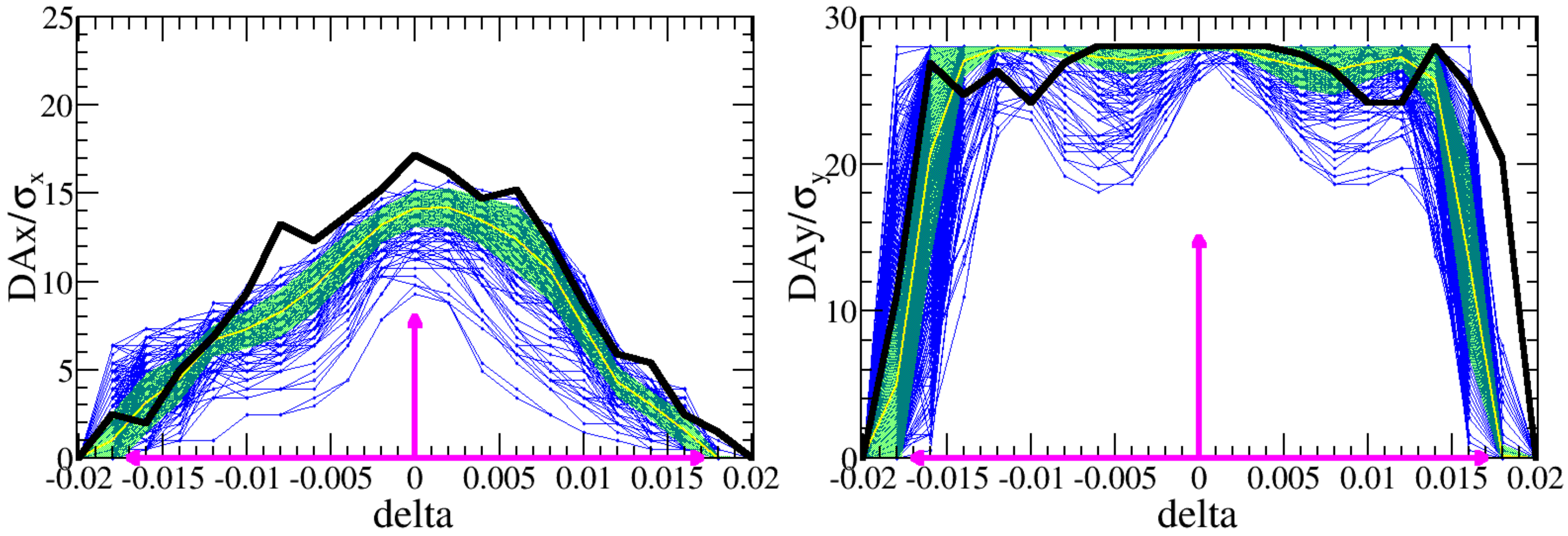
Factor 46 improvement

- The dispersion correction is performed for all selected seeds, 674 seeds are converged.
- The correction effect is better than that of CDR lattice.

Dynamic Aperture with error for Higgs

Lattice version cepc.lat.diff.8713.346.2p used
εx=0.64nm, β=0.33m/1mm, L*=1.9m

Y. Wang, B. Wang



- The blue lines are the DA of each seed, the yellow lines and green bands are the mean value and its corresponding statistics errors, the black line is the DA of bare lattice.

- The DA of 418 error seeds with errors satisfy the on-axis injection requirements, which is $\mathbf{8\sigma_x \times 15\sigma_y}$ & $\mathbf{0.017}$, after error correction

Goal (w/ error): $8\sigma_x \times 15\sigma_y \times 1.7\%$

Impedance budget for H-Lumi. Z

N. Wang

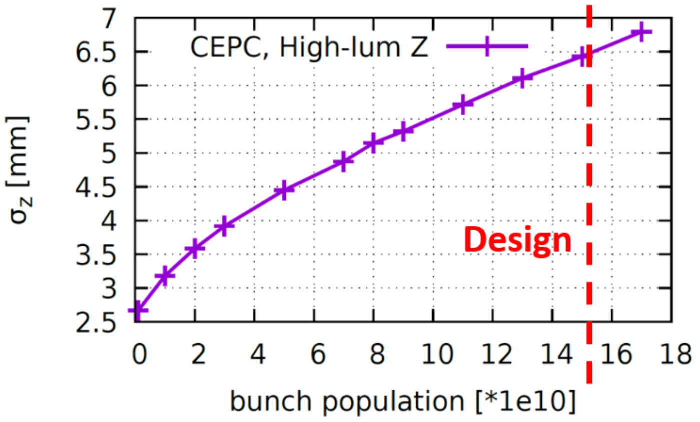
- H-Lumi. Z mode introduces the strongest instability
- No apparent show stoppers to Higgs, W/Z and ttbar from the collective instability issus

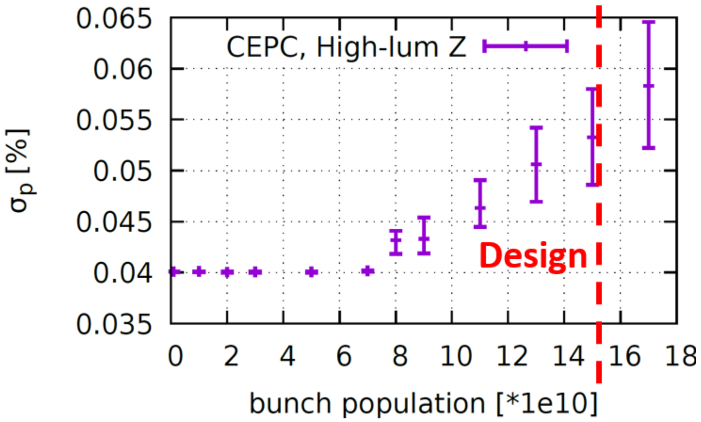
Components	Number	$Z_{\|\|}/n$, mΩ	k_{loss}, V/pC	ky, kV/pC/m
Resistive wall	-	6.2	363.7	11.3
RF cavities	60	0.5	101.2	0.5
Flanges	37714	5.2	37.3	5.2
BPMs	1808	0.04	9.5	0.2
Bellows	15949	2.9	87.4	3.9
Gate Valves	500	0.2	14.5	0.4
Pumping ports	5316	0.3	2.3	0.2
Collimators	8	0.02	11.7	0.3
IP chambers	2	0.004	0.3	0.05
Electro-separators	20	-0.1	34.5	0.1
Taper transitions	48	0.04	2.5	0.09
Total		**15.3**	**664.9**	**22.2**
CDR Total		**11.4**	**786.8**	**20.2**

- Longitudinal and transverse broadband impedances are dominated by the RW, flanges and bellows.
- The loss factor is mainly contributed by the resistive wall, RF cavities and bellows.
- Compare to the CDR budget, we have larger Z/n and k_y, but smaller k_{loss}.

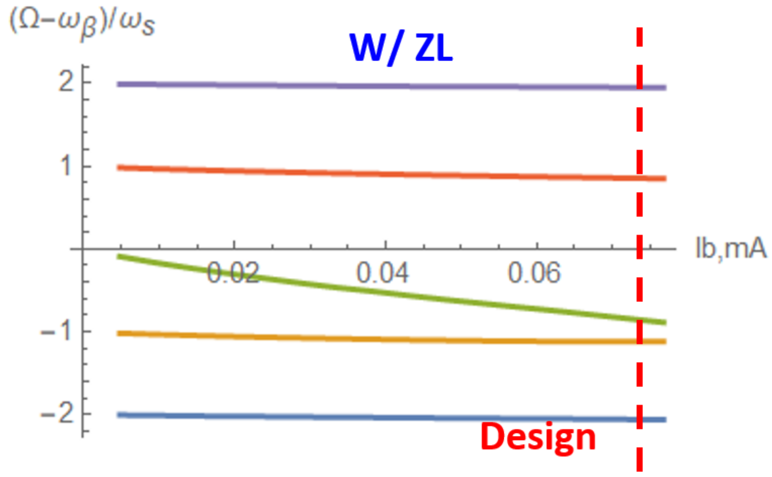
Various Impedance Effects

- High lumi. Z operation meets the most serious collective instability
- Instabilities: MWI & bunch lengthening; Transverse mode coupling; Trans. Resistive wall;





MWI & bunch lengthening, energy spread

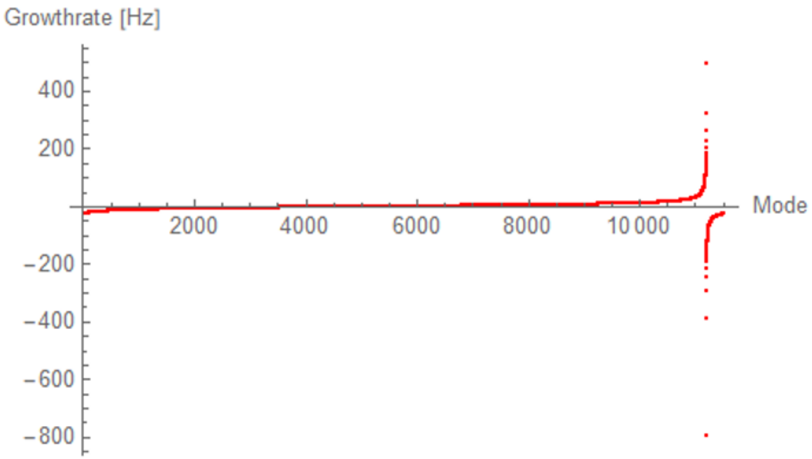


Transverse mode coupling

Transverse resistive wall & dangerous mode

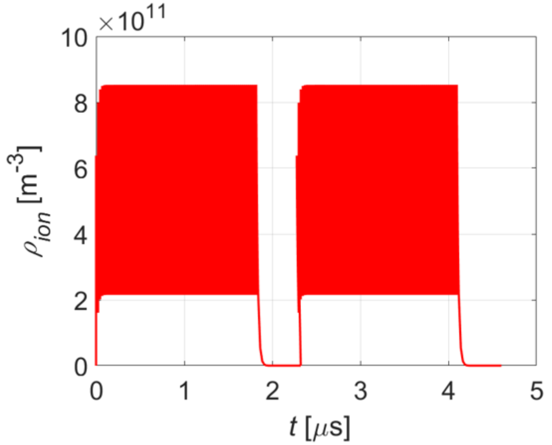
	Z-High Lumi
Instability growth time [ms]	2.0 (~6 turns)
Radiation damping [ms]	840
Bunch by bunch feedback [ms]	1.0 (~3 turns)

Growth time of the most dangerous mode vs. damping factors



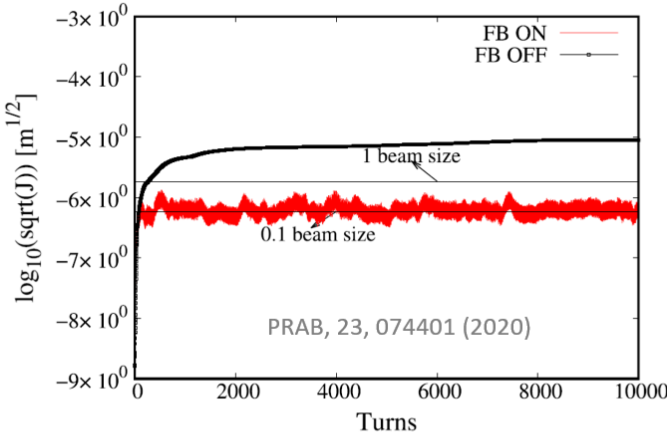
Instabilities by Other Effects

- Instabilities: beam ion; electron cloud;

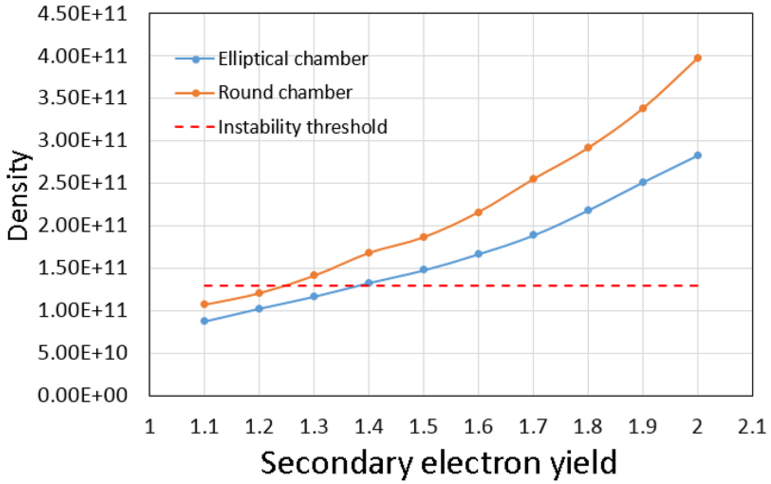


Build-up of ions along the bunch train

Parameters	Z-30MW
$L_{sep}\omega_{ion}/c_0$	0.8
$\rho_{ion,ave}[m^{-3}]$	4.3E11
τ_e [ms]	0.1
τ_H [ms]	4.0
$\Delta\nu_y$	0.016

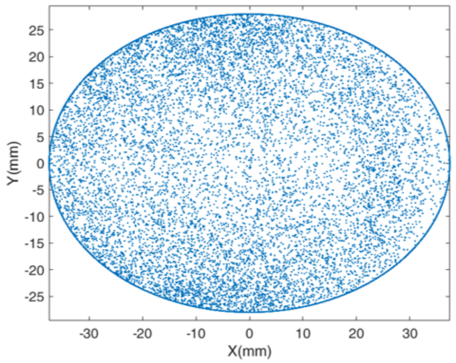


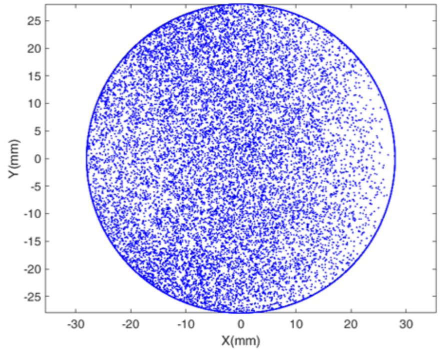
Bunch by bunch feedback can be effective on damping this effect



Elliptical chamber: SEY<1.3

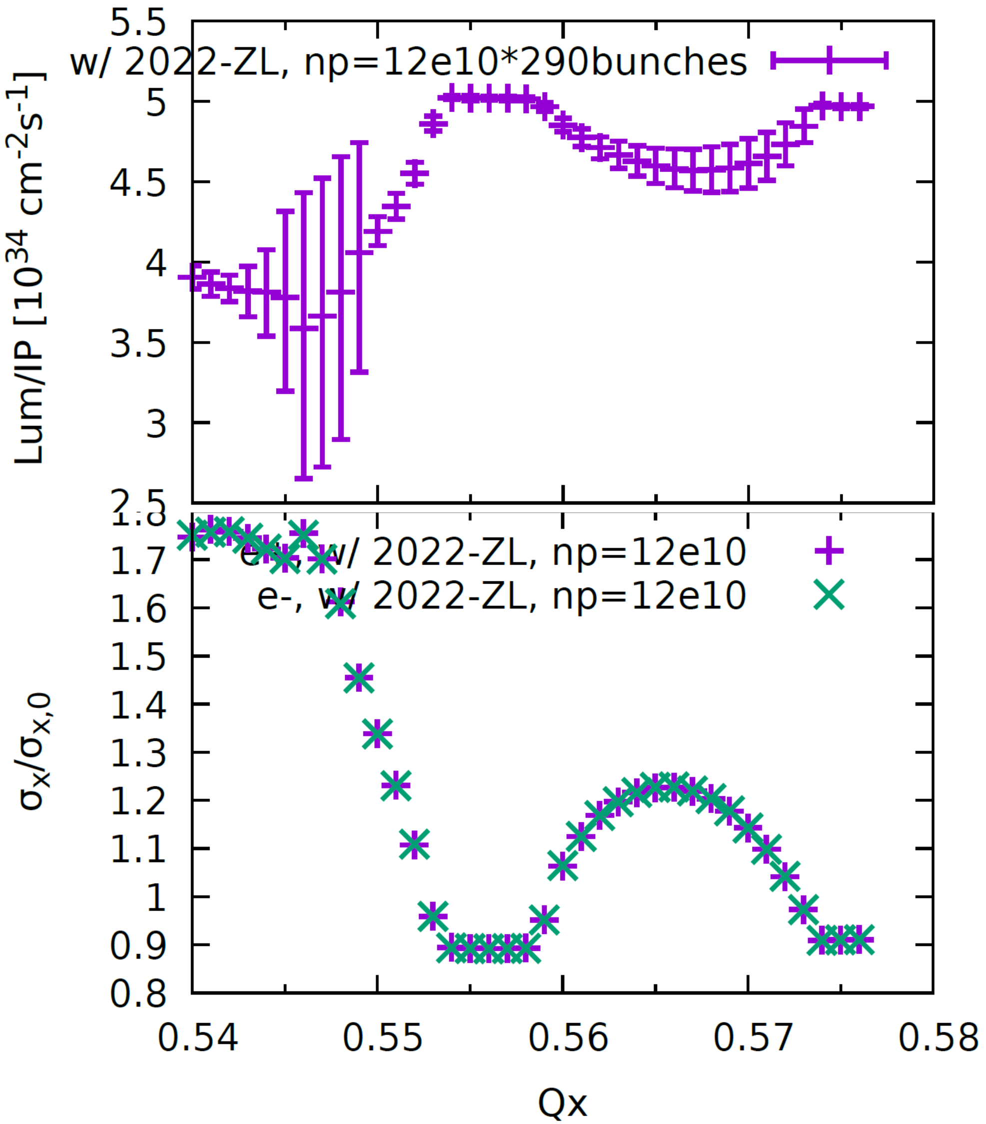
Round chamber: SEY<1.2



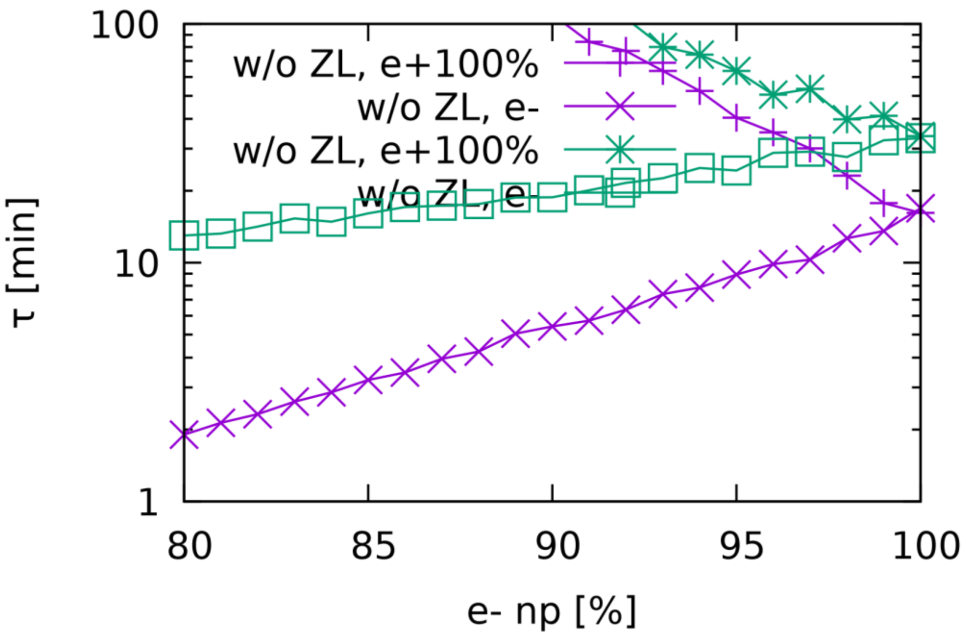


Beam-beam effects study for Higgs

- Design Lum=5e34
- Stable width of Qx~0.004 considering ZL



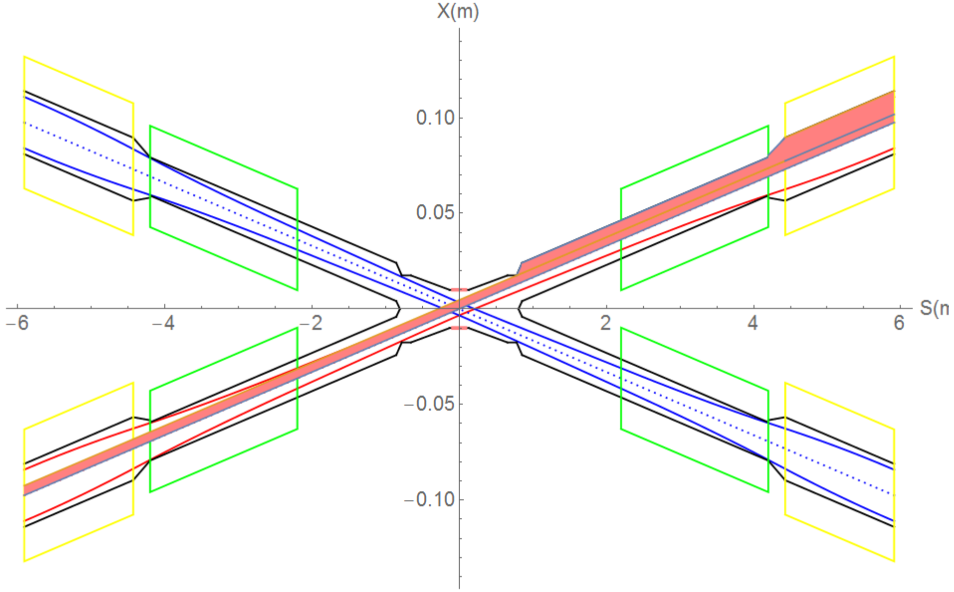
- Beam lifetime is increased due to longitudinal impedance
- 10% asymmetry of bunch population could be accepted.



- Large Piwinski Angle~6 (CW=0.8)
- Beamstrahlung Lifetime
- X-Z instability

MDI: SR heat & Beam loss

- SR heat load in normal & extreme conditions



Normal Condition

Region	SR heat load	SR average power density
0~780mm	0	0
780mm~855mm	48.3W	178.9W/cm^2
855mm~1.11m	0.454W	0.49W/cm^2
1.11m~2.2m(QD0 entrance)	1.49W	0.38W/cm^2
QD0	2.89W	0.39W/cm^2
QD0~QF1	47.9W	57.6W/cm^2
QF1	3.42W	0.64W/cm^2

Extreme Condition

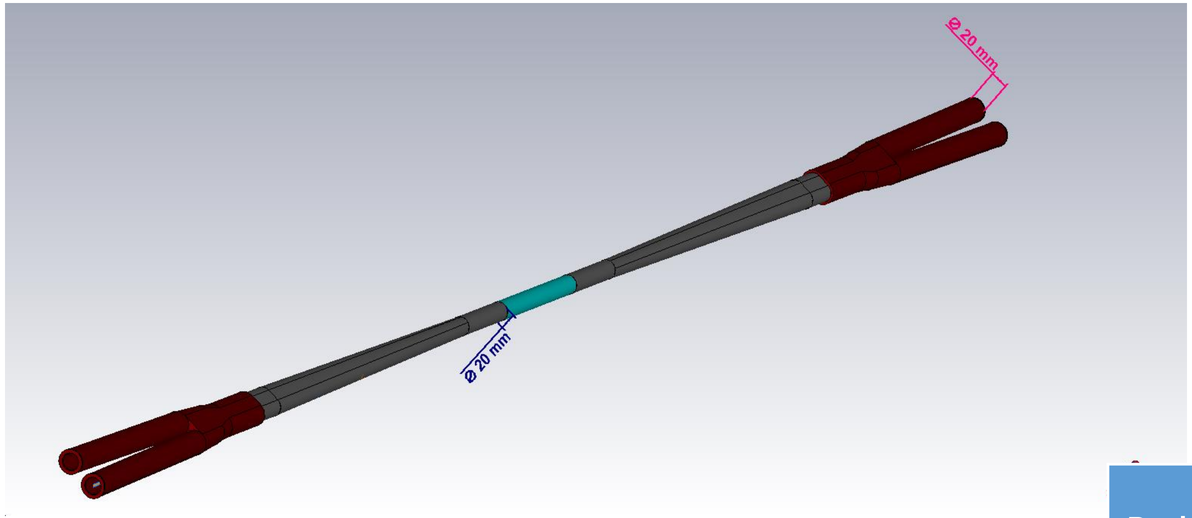
Region	Material	SR heat load	SR average power density
-85mm ~ 11.4mm	Be	13.74W	41W/cm^2
-130mm ~ -85mm	Al	6.66W	41.1W/cm^2
-780mm ~ -655m	Al	18.3W	40.7W/cm^2

- Extreme condition, eg, if a magnet power is lost, a large distortion will appear immediately for the whole ring orbit.
- In extreme cases ~ at least 10 times per day. The beam will be stopped within 0.5ms when abnormal.

- Beam loss effects due to Radiative BhaBha, Beam gas inelastic scattering, Beam thermal photon scattering, taking into account multipole & beambeam effects

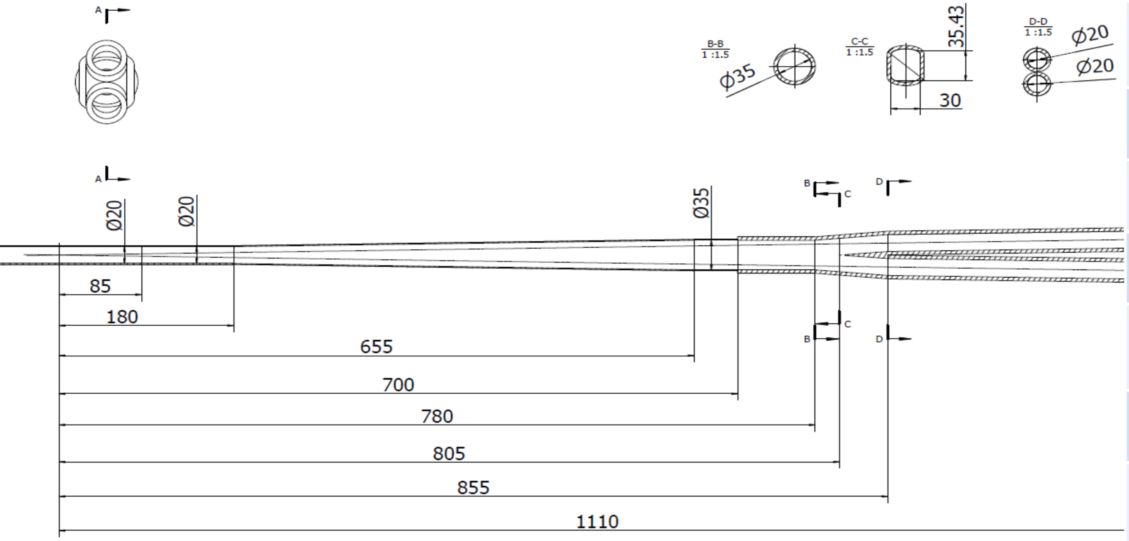
Region	SR heat load from RBB	SR heat load from BS	SR heat load from BG	SR heat load from BTH
Berryllium pipe	6.7mW	0	0	0
Detector beam pipe	0.024W	0	4.8uW	1.2uW
Accelerator beam pipe before QDa	0.17W	0	4.2uW	1.2uW
QDa~QDb	2.13W	3.8uW	5.9uW	1.8uW
QDb~QF1	0.01W	3.8uW	0.5uW	0.6uW
QF1	0.26mW	0	3.7uW	0.66uW

MDI: HOM (20mm Be tube)



- ✓ results for MDI 20mm-20mm
- ✓ Transition region: Racetrack (including materials)
- ✓ σ_z=5mm: Two beam in the IR
- ✓ Loss factor Trap in IR @k_trap: 0.032v/pc

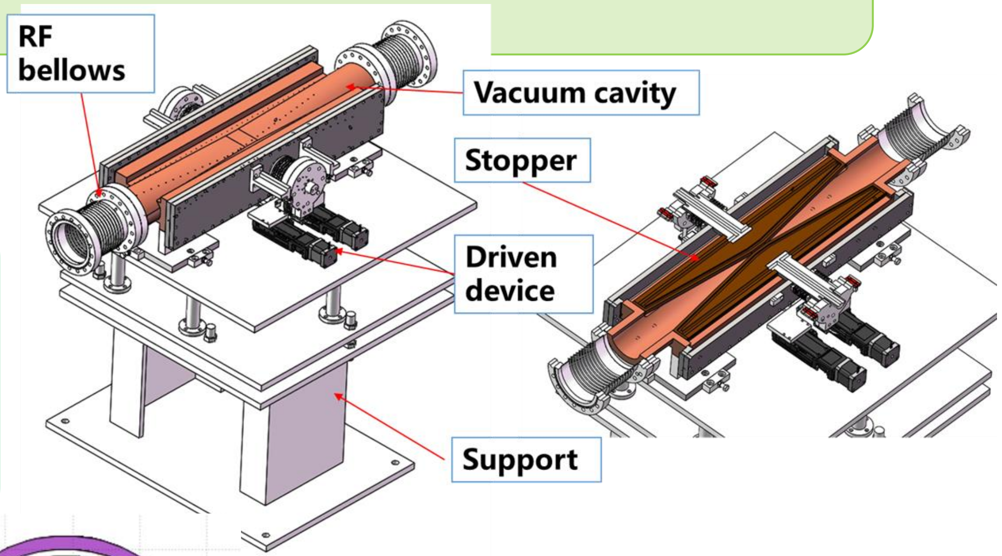
P_{trap}: H/W/Z/tt: 24.0w/117.1w/1160.8w/6.67w



Position	Position Start-end (mm)	material	Length (mm)	Higgs(w) & (w/cm²)	W (w) & (w/cm²)	Z(w) & (w/cm²)	ttbar (w) & (w/cm²)
Be pipe (w)	0-85	Be	85	1.13 & 0.021	5.587 & 0.105	**55.295 & 1.35**	0.31 & 0.005
Be pipe transition(w)	85-180	Al	95	0.61 & 0.01	2.950 & 0.049	**29.280 & 0.491**	0.172 & 0.007
Transition pipe (w)	180-655	Al	475	6.99 & 0.017	34.48 & 0.085	**341.562 & 0.83**	1.958 & 0.005
Transition (w)	655-700	Al	45	0.62 & 0.015	2.95 & 0.071	**29.28 & 0.701**	0.172 & 0.004
RVC bellow (w)	700-780	Cu	80	0.52 & 0.007	2.532 & 0.034	**25.002 & 0.337**	0.14 & 0.002
Transition on Y-crotch	780-805	Cu	25	0.16 & 0.007	0.785 & 0.032	**7.822 & 0.316**	0.05 & 0.002
Y- crotch (w)	805-855	Cu	50	0.33 & 0.005	1.572 & 0.024	**15.626 & 0.241**	0.091 & 0.002
Quadrupole pipe(w)	855-1100	Cu	245	1.58 & 0.005	7.735 & 0.024	**75.594& 0.24**	0.434 & 0.002
Total	0-1100	-	1100	12.0 &0.011	58.594 &0.056	**580.46 & 0.56**	3.331 & 0.003

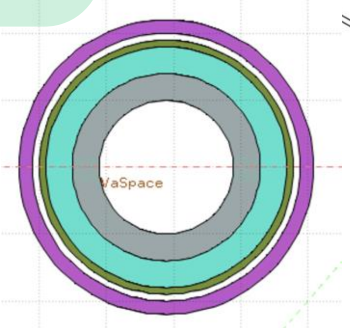
MDI: Collimator & Shield

➢ **Two pairs of vertical collimators** added for one IP in one ring, with which the beam loss background with multipole errors and beam-beam effects reduced **20%.**



- ➢ Beam loss in the downstream IR with a large amount, due to the process of radiative bhabha scattering, beamstrahlung, beam-gas scattering, beam thermal photon scattering.
- ➢ Radiation dose may damage the SC magnet coil and the detector.

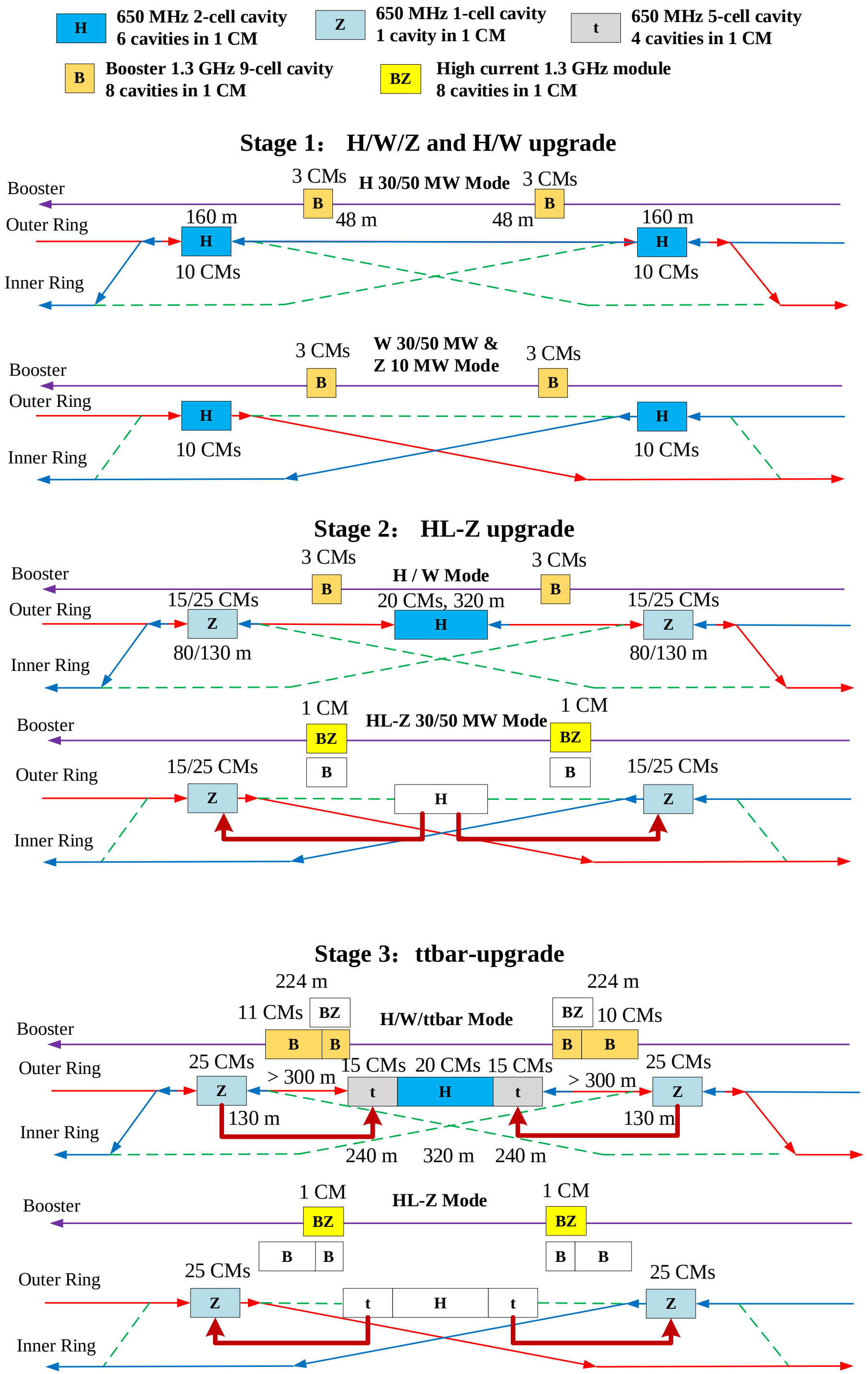
1. Tungsten IR beam pipe,
2. Combined iron and tungsten yoke of SC magnet



White: Vacuum
Gray: Tungsten Pipe
Light Green: Helium
Heavy Green: Stainless Steel Vassel
Pink: Coil

- ➢ Pure tungsten IR beam pipe with 4mm thickness without cooling taken into account, simulate the Absorbed Dose on Coil (Region)
- ➢ Only Beam-Gas beam loss is taken into account until now
- ➢ Take the loss rate calculated by SAD into account:
  - ➢ ~0.00166 Gy/s(0.166rad/s)
  - ➢ ~14.35 Gy/day
  - ➢ ~36662.49 Gy/lifetime(Higgs plans to run 7 years)
  - ➢ Limit is 100000 Gy/lifetime

RF Staging & By-pass Scheme



- **Stage 1 (H/W run for 8 years):** Keep CDR RF layout for H(HL-H)/W and 50 MW upgrade. Common cavities for H. Separate cavities for W/Z. Z initial operation for energy calibration and could reach CDR luminosity. **Minimize phase 1 cost and hold Higgs priority**.

- **Stage 2 (HL-Z upgrade)**: Move Higgs cavities to center and add high current Z cavities. **By-pass low current H cavities**. International sharing (modules and RF sources): Collider + 130 MV 650 MHz high current cryomodules.

- **Stage 3 (ttbar upgrade):** add ttbar Collider and Booster cavities. International sharing (modules and RF sources): Collider + 7 GV 650 MHz 5-cell cavity. Booster + 6 GV 1.3 GHz 9-cell cavity. Both low current, high gradient and high Q, Nb_3Sn etc. 4.2 K?

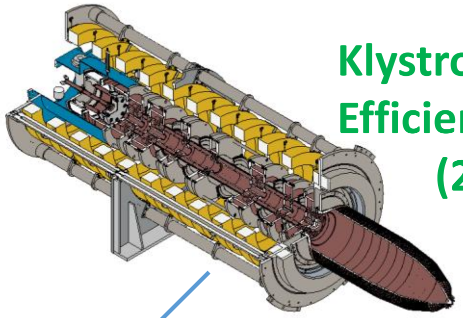
Unleash full potential of CEPC with flexible operation
Seamless mode switching with unrestricted performance at each energy until AC power limit.
Stepwise cost, technology and international involvement with low risk.

CEPC 650MHz High Efficiency Klystron

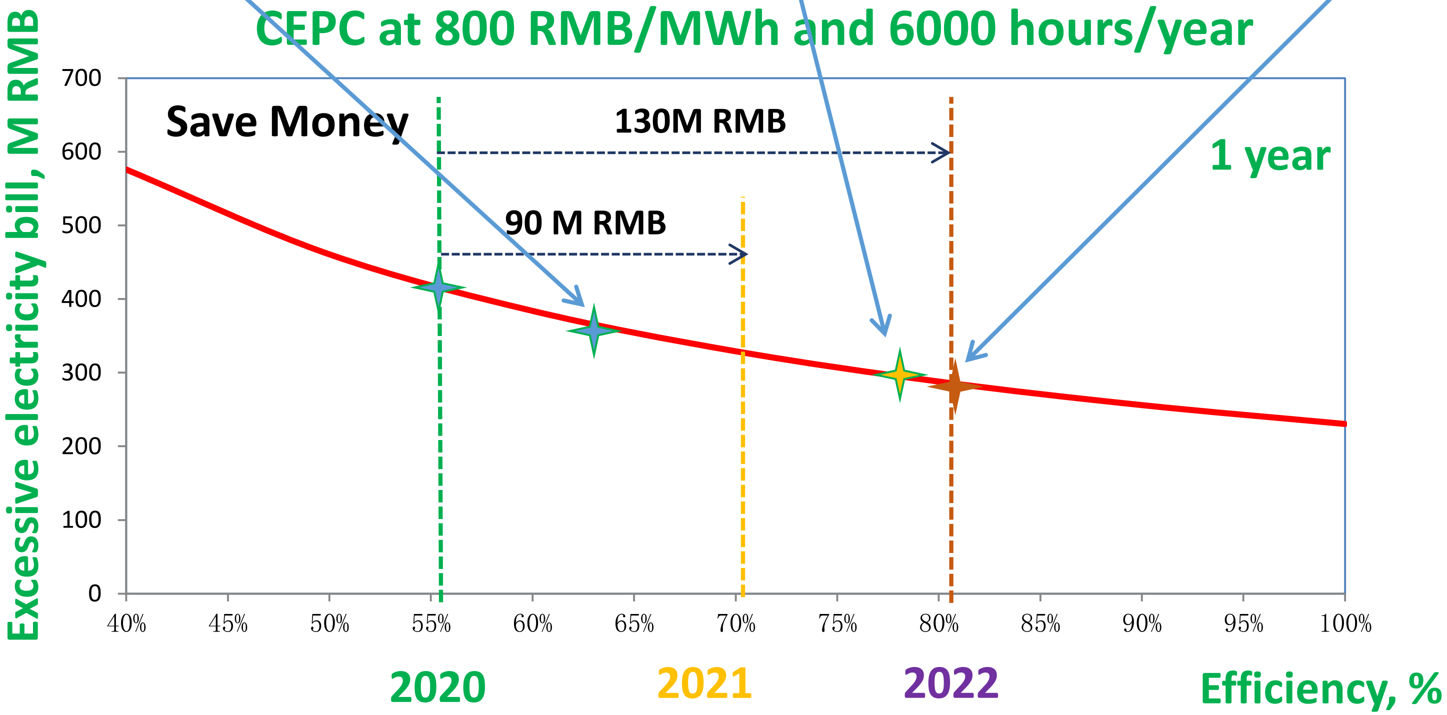
Z.S.Zhou

Klystron No. 1
Efficiency 62%
(2020)

Klystron No. 2
expected
efficiency 77%
(2022)



Klystron No. 3
Efficiency 80.5%
(2023)



Efficiency impact on operation cost (Only considering operation efficiency of 650MHz klystrons)

1st 650MHz Klystron for CEPC

Z.S.Zhou

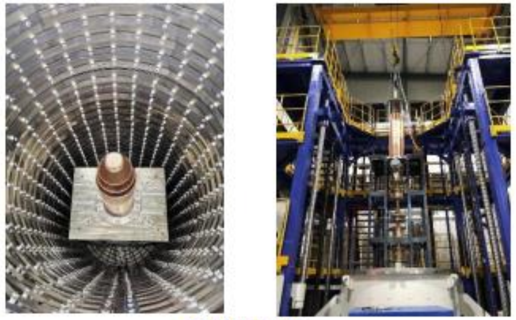
- 2017. 10: Design Report
- 2018. 05: Mechanical Design Review
- 2019. 10: Parts Processing
- 2019. 11: Baking out
- 2020. 03: High Power test (400kW CW & 800kW Pulsed)
- 2021. 03: High Power test (700kW CW)

Parameters	Conventional efficiency
Centre frequency (MHz)	650+/-0.5
Output power (kW)	800
Beam voltage (kV)	80
Beam current (A)	16
Efficiency (%)	~ 62

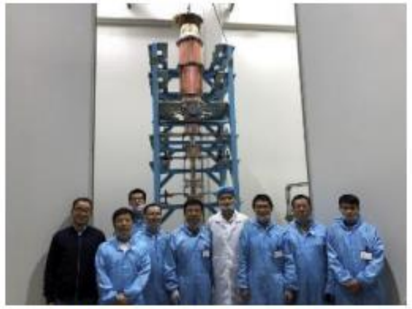
- ◆ First P-band Chinese Klystron;
- ◆ Satisfies the least requirement of CEPC as the RF power source;


Cavity cold


Collector brazing


Baking out

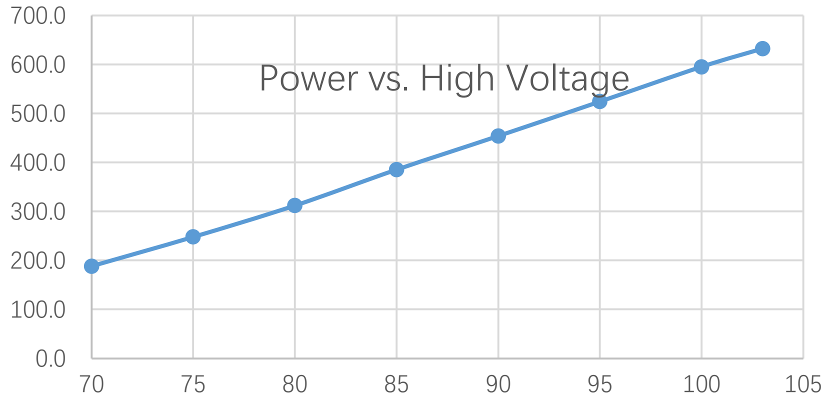

Gun processing

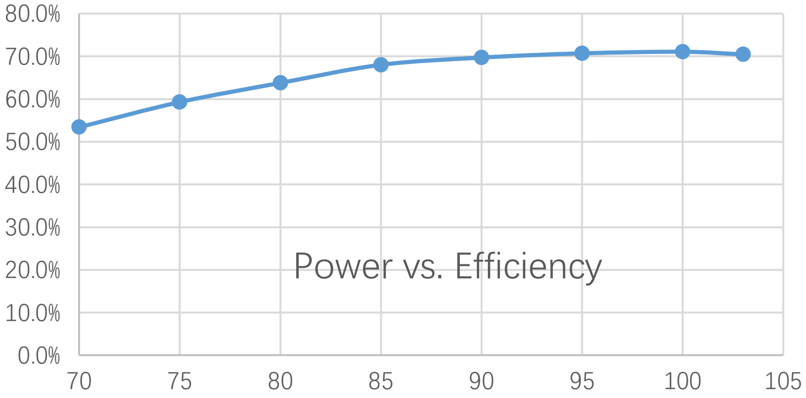

Vacuum Assy assembly


Before delivery

2nd 650MHz Klystron – High Efficiency

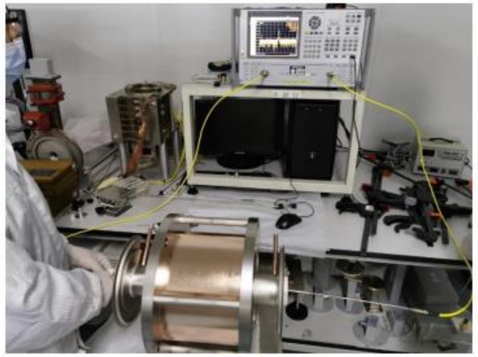
- 2021. 03: First cavity completed fabrication
- 2021. 07: Collector Braze, while leakage happened
- 2021. 11: Klystron baking out
- 2021. 12: Delivery to IHEP @ PAPS



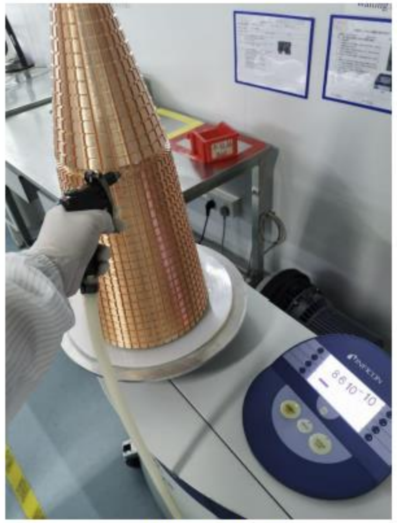


70.5% @ 630kW efficiency in the present status

Electron gun



Cold test



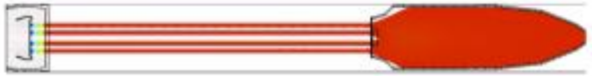
Collector body

3rd 650MHz Klystron – MBK Technology

Physical design is completed and reviewed by foreign and domestic experts.

Z.S.Zhou

Parameters	Value
Freq.	650 MHz
Output power	800 kW
Efficiency	80.5%
1dB band width	± 0.75 MHz
Cathode Voltage	54 kV
Cathode beam	2.51*8 A
Beam Number	8



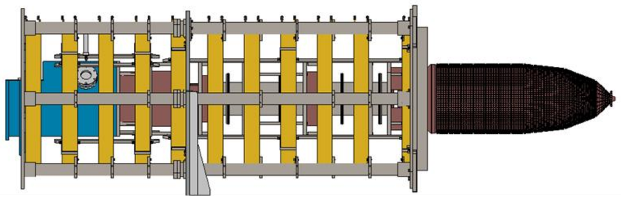

ELSEVIER

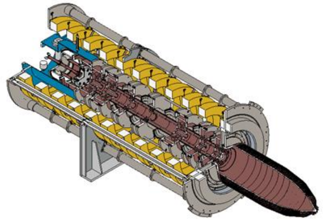
Nuclear Inst. and Methods in Physics Research, A

Design study and modeling of multi-beam Klystron for Circular Electron Positron Collider

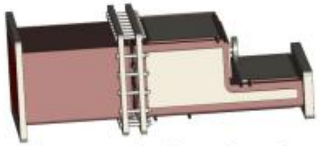
Shengchang Wang, Shigeki Fukuda, Zhijun Lu, Zaib un N

Ouzheng Xiao, Guoxi Pei



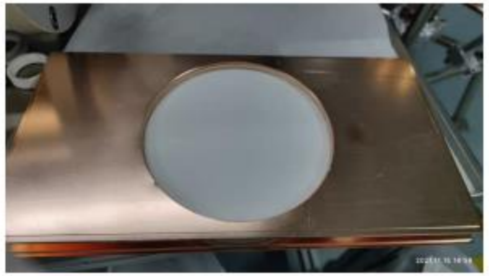


Key components, experiment cavities and output window, start their fabrication



Output window drawing

High power test scheme of output window

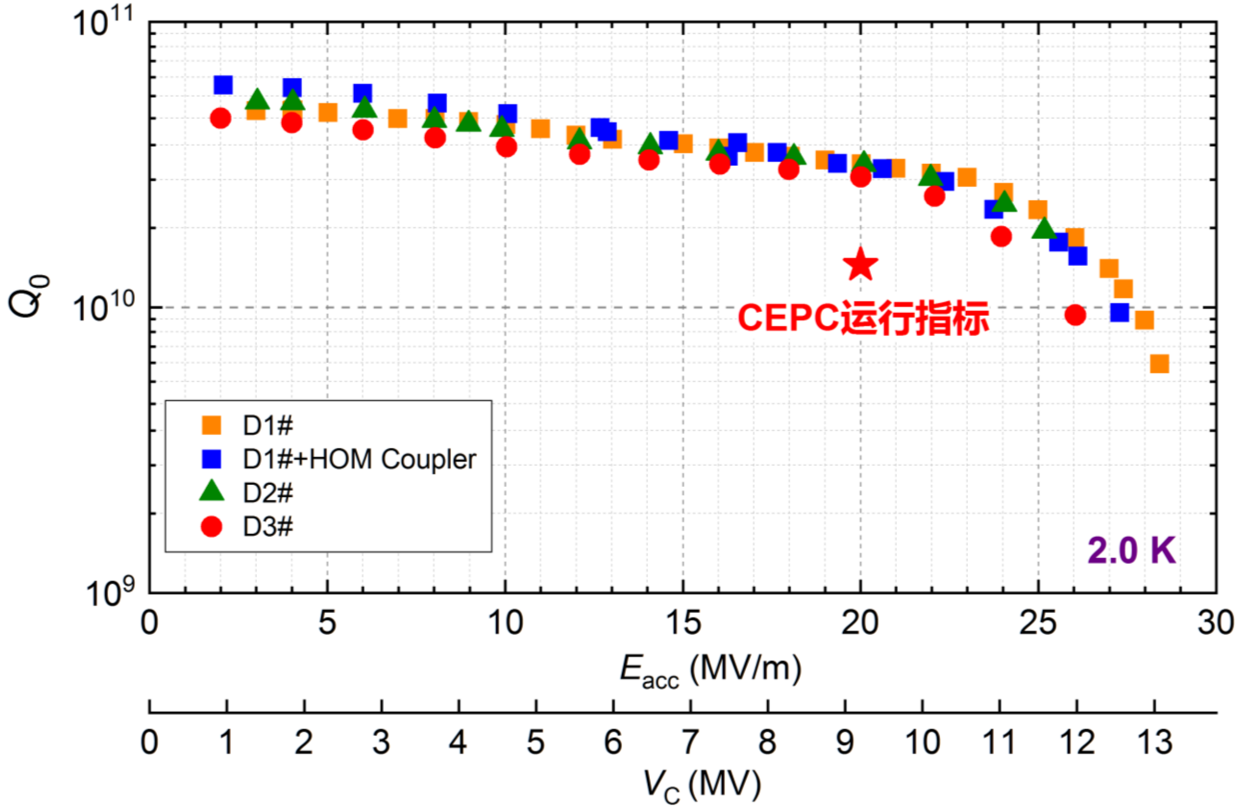


Window processing

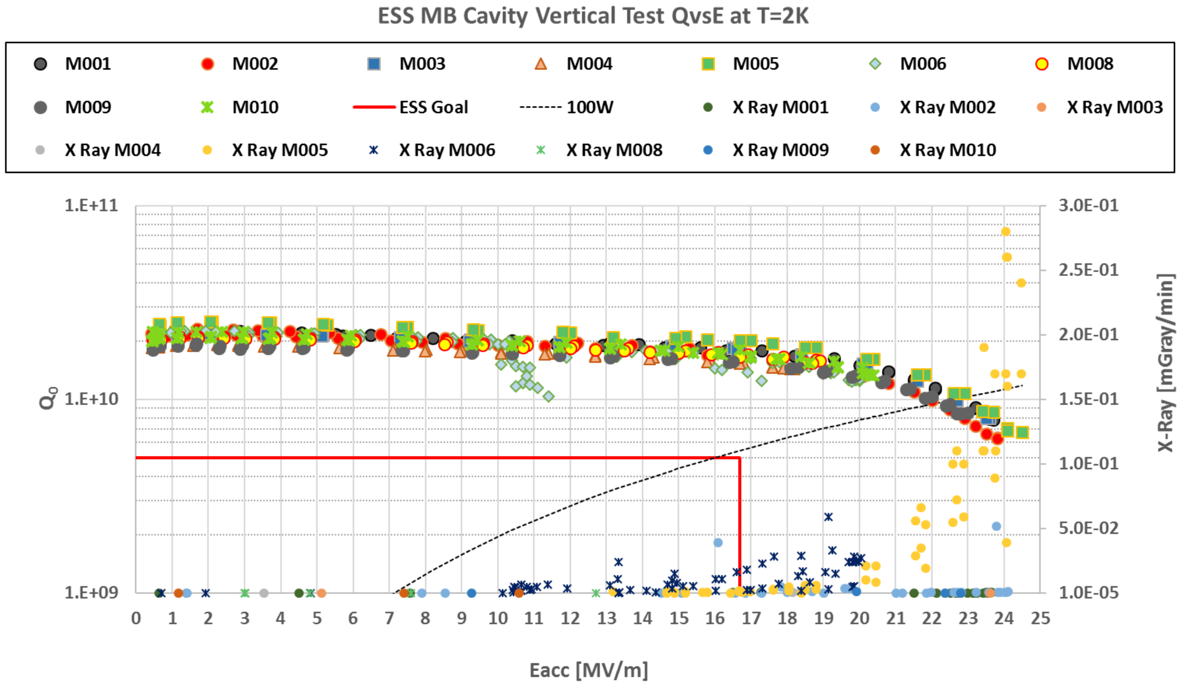
- With the new technology of MBK, the efficiency is expected higher than 80%

Two Cells 650MHz SC Cavity for Collider

- 650 MHz two-cell SRF cavity uses chemical polishing technology to achieve satisfactory results
- Comparable results with **ESS 704 MHz MB Cavity** (β=0.67, 3~4E10@17MV/m)



650 MHz test crymodule at PAPS

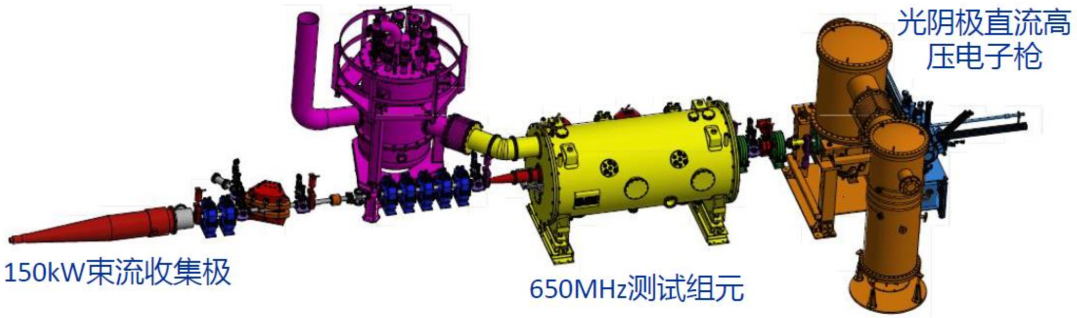


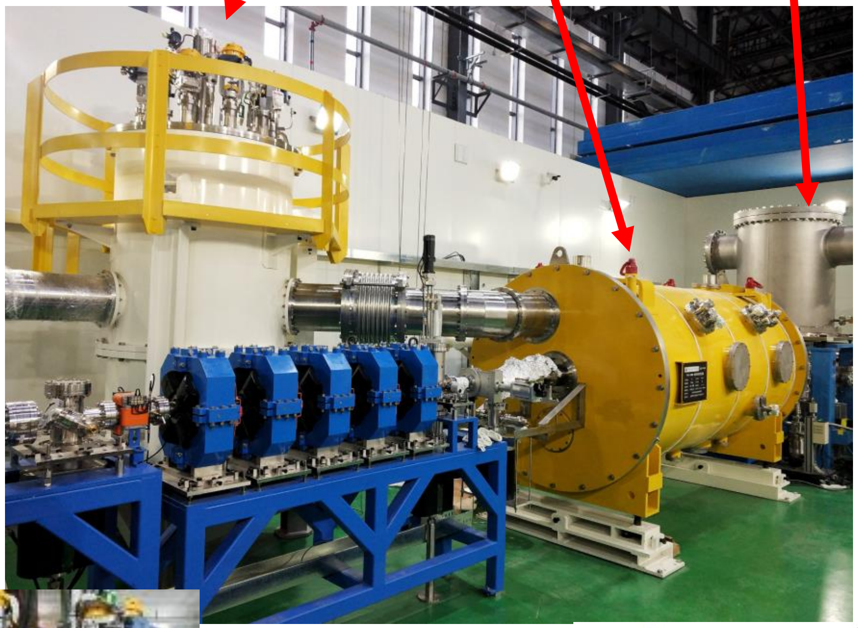
Scaling R/Q and frequency to CEPC 650 MHz @ β=1: Q=3-4E10@17MV/m

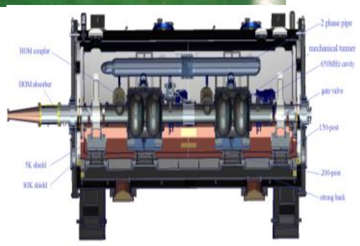
Carlo Pagani, CEPCWS 2019

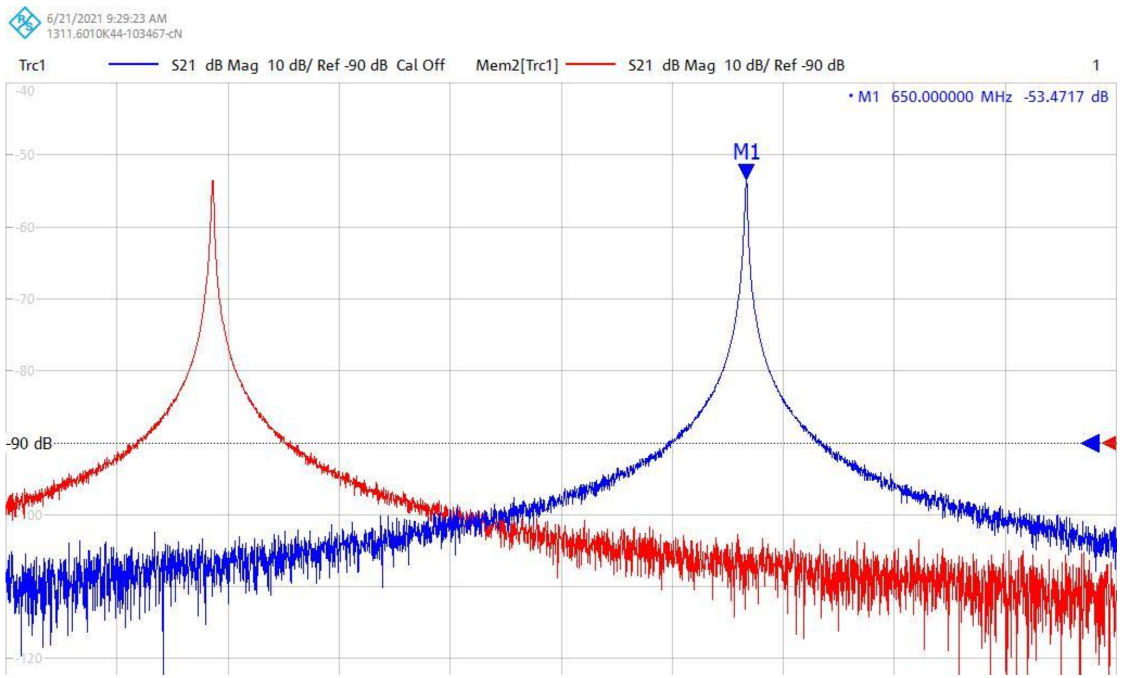
650MHz SRF Module

650 MHz test crymodule at PAPS





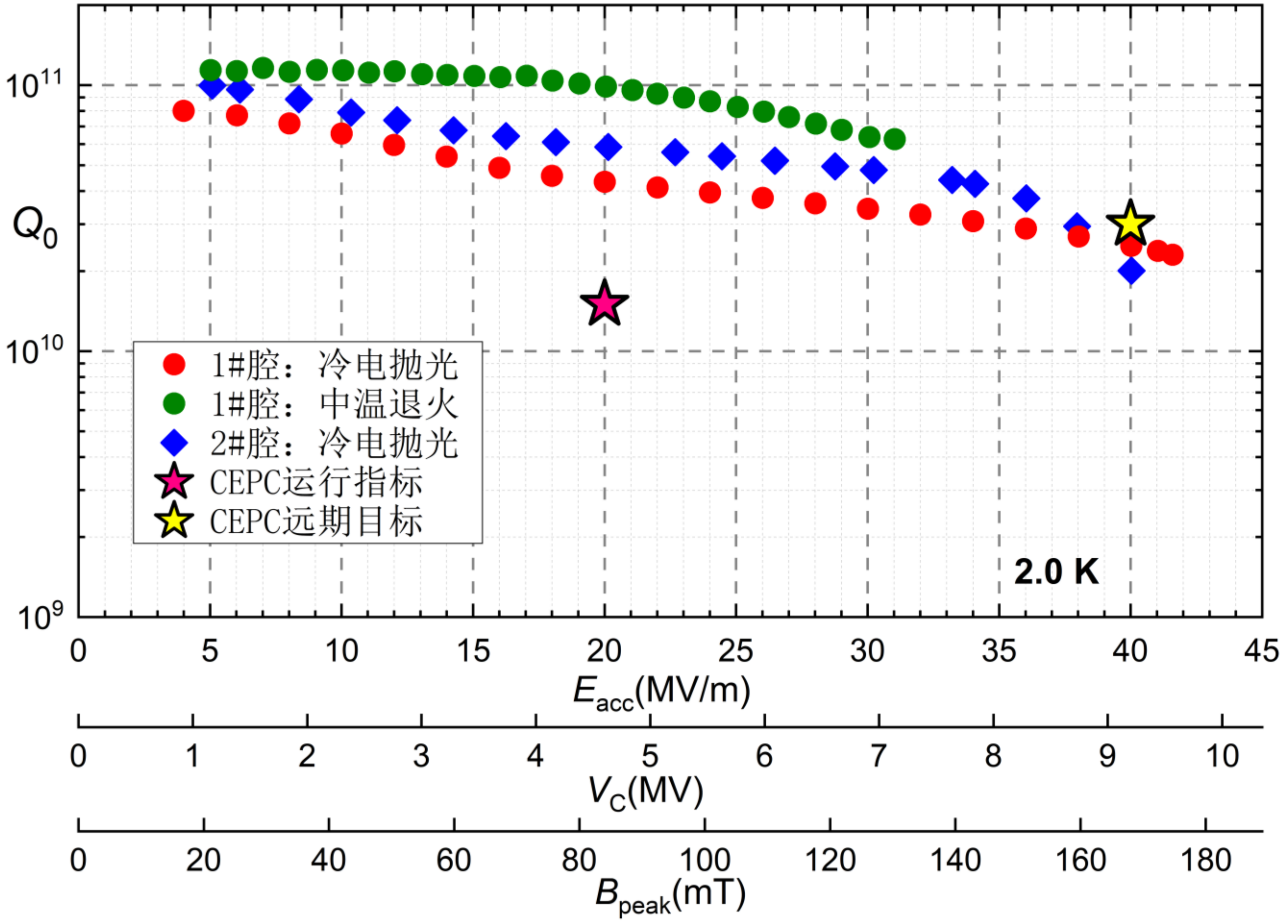




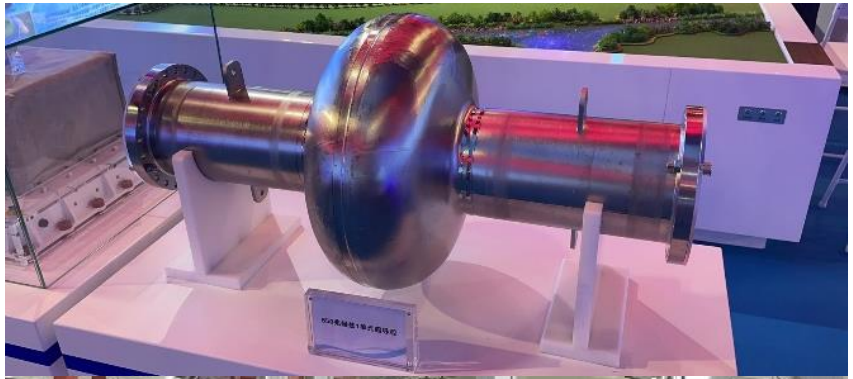
- Cryomodule test：
  - Cavity vaccum @2 K: 6E-7 Pa, no leakage, satisfying the specification of 1E-6Pa
  - Qe of fundamental mode of 3 couplers：6.8E13, 1.9E13, 2.1E12, better than the requirement of 4E11
  - Remanence: < 3 mG， meeting the specification of 10 mG

650MHz Single Cell Cavity for Z mode

- 650 MHz single-cell tried advanved techniques of EP, Annealing, Nitrogen Doping, large grain, feasible polishing, test results is 6.4E10@30MV/m, stat of the art in SRF cavity

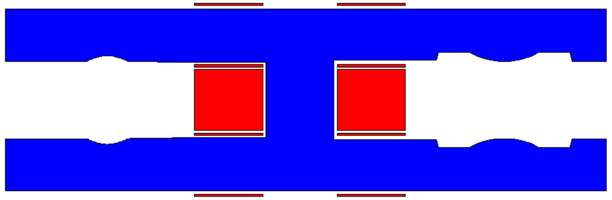


650 MHz single-cell SRF cavity test results

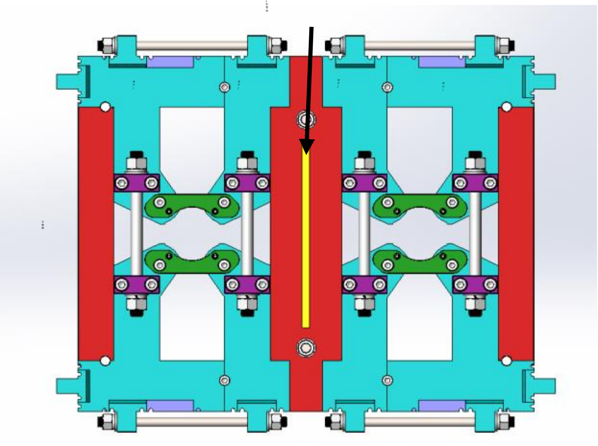


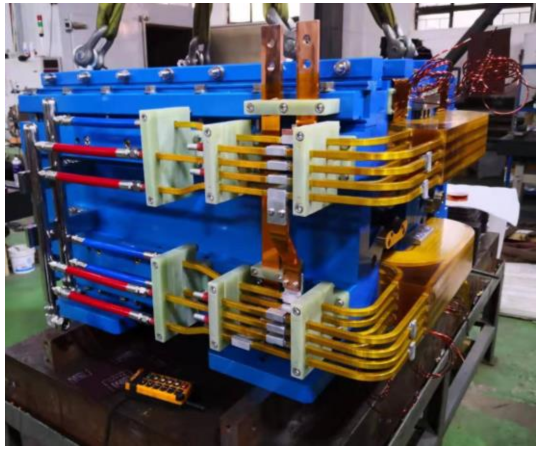
Continuous development for even higher single cell Gradient until able to support Higgs operation?

Collider Magnets



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

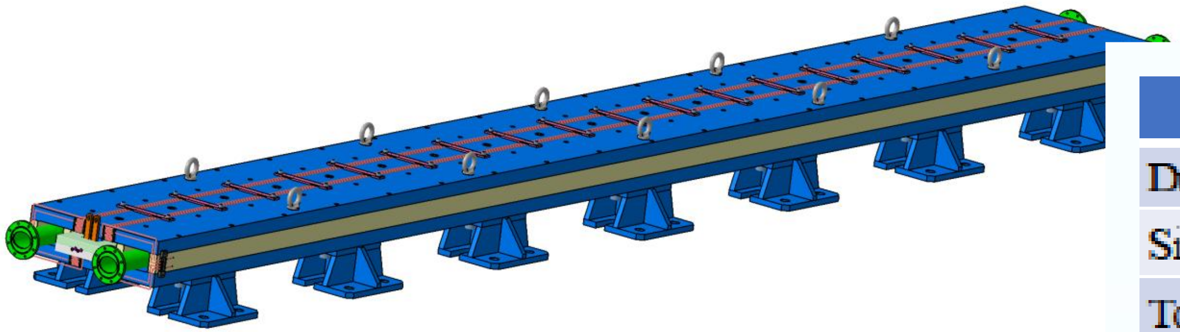




First dual aperture quadrupole magnet has been fnished in Nov, 2019

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

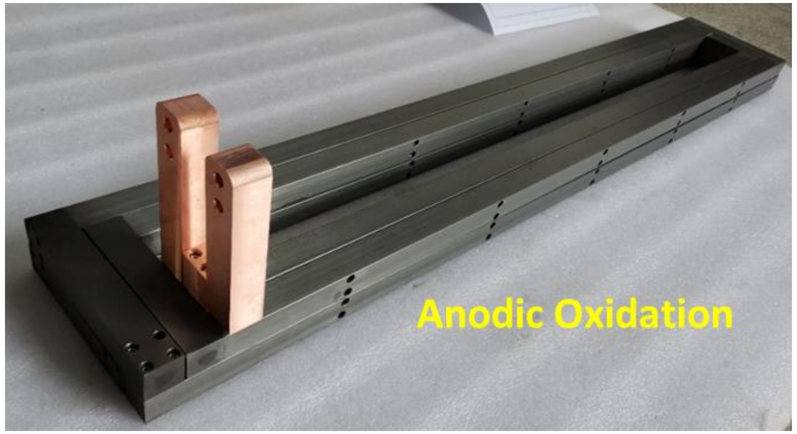
Facility: CEPC magnet test facility (lab) is located in IHEP Dongguan CSNS

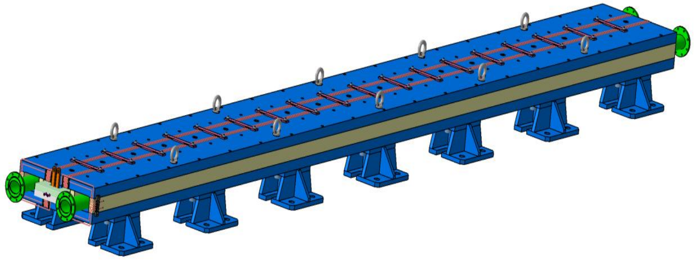


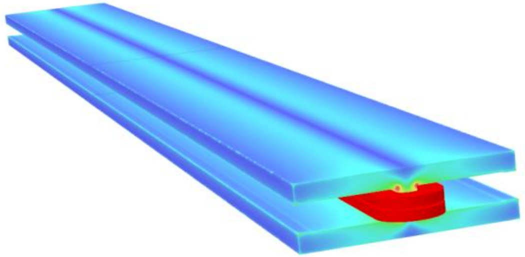
	Dipole	Quad.	Sext.	Corrector	Total
Dual aperture	2384	2392	-	-	13742
Single aperture	80*2+2	480*2+172	932*2	2904*2	
Total length [km]	71.5	5.9	1.0	2.5	80.8
Power [MW]	7.0	20.2	4.6	2.2	34

Dual Aperture Dipoles Development

Item	Value
Center field (Gs)	141.6@45.5GeV, 373@120GeV, 568@182.5GeV
Gap (mm)	66
Magnetic Length (m)	5.737
Good field region (mm)	±13.5
Field harmonics	<0.05%
Field adjustability	±1.5%
Field difference between two apertures	<0.5%







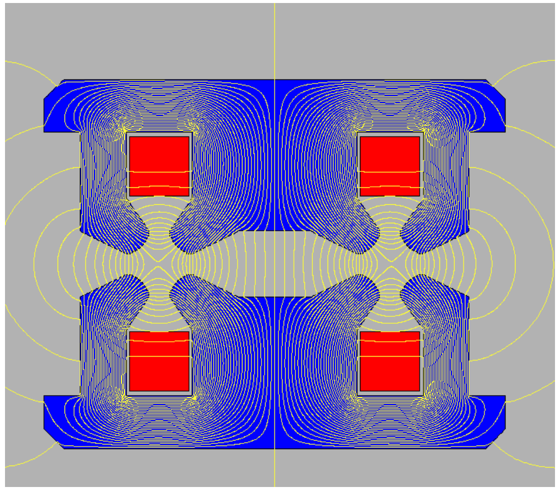
- The dual aperture dipole was optimized by Opera, which fulfils the requirement of CEPC;
- Short prototype (1m) were developed and tested. Results satisfy the CEPC requirement;
- **The 5.7m full length prototype is in fabrication process；**

Dual Aperture QUAD Development

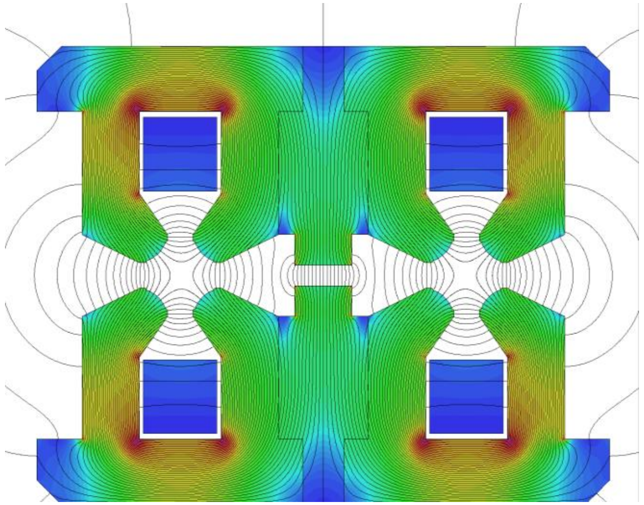
- The first 1m prototype was fabricated and tested.
- The field quality heavily improved by center shim. Modification applied, test will be done soon.

E=120GeV	origin		center shim	
n	Bn/B2-L	Bn/B2-R	Bn/B2-L	Bn/B2-R
1	1557.30	-1557.27	-13.51	13.53
2	10000	10000	10000	10000
3	126.14	-126.18	-1.11	1.06
4	0.52	0.52	0.51	0.53
5	1.70	-1.71	-0.02	0.01
6	-0.04	-0.03	-0.04	-0.03
B1(T)	-0.01622	-0.0162197	0.00014	0.00014
B2(T)	-0.1041546	0.1041547	-0.10411	0.10411
B3(T)	-1.31E-03	-0.0013143	0.00001	0.00001
G(T/m)	-8.537	8.537	-8.534	8.534
S(T/m2)	-17.654	-17.660	0.155	0.149

Original design



Centre Shim

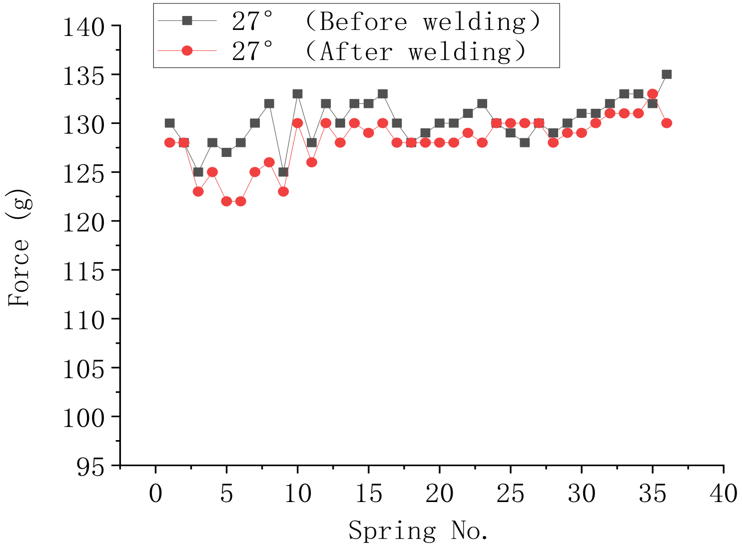


Center shim is an effective method to

- **Reduce the crosstalk of the dual QUADs;**
- **Improve the field stability with respect to current, making QUAD works for all energies.**

Vacuum System---RF shielding bellows and chamber

- RF shielding bellows



Contact force is identical in different fingers and meets the requirement of 125±25g.

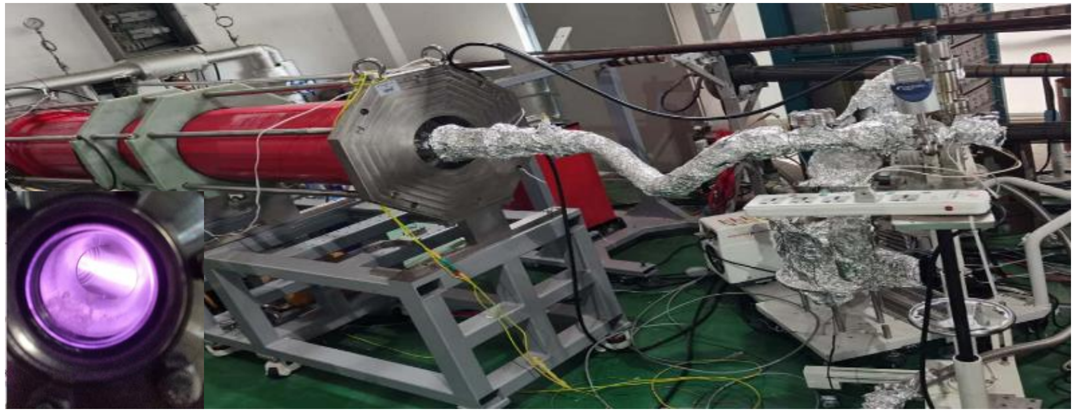
- Cu & Al prototypes been made

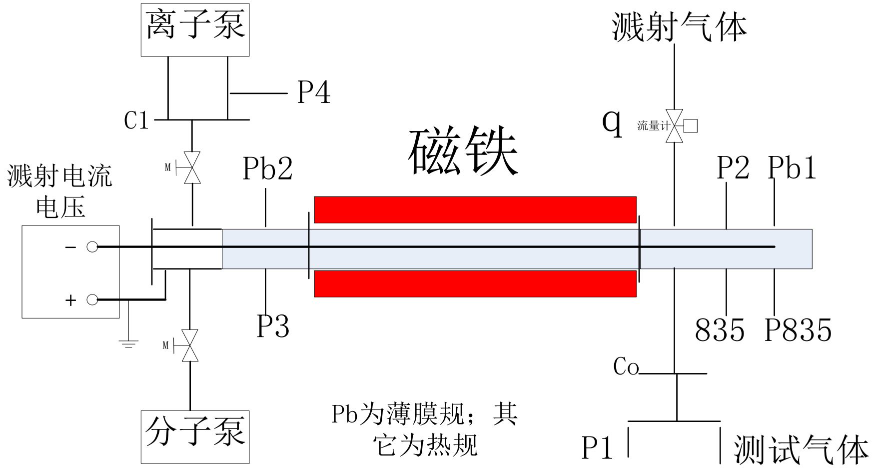
Elliptical and round vacuum chambers have been made

Vacuum System---Components and coating test

Coating allows vacuum meet the requirements for all energies, including High Lumi. Z operation

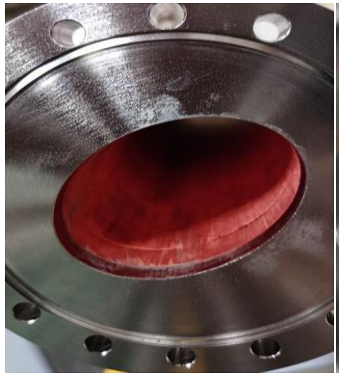
- Coating Procedures

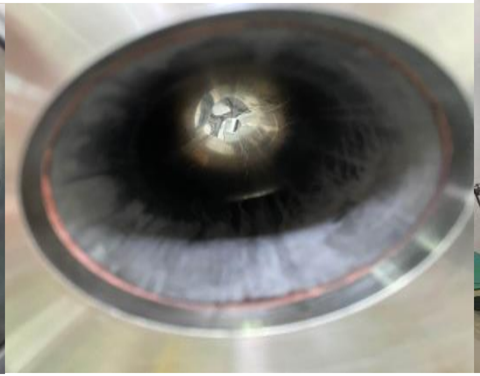




- 56×75×1500 NEG coating pipe:

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





NEG Coating Facility @ PAPS

☐ NEG coating of vacuum pipe

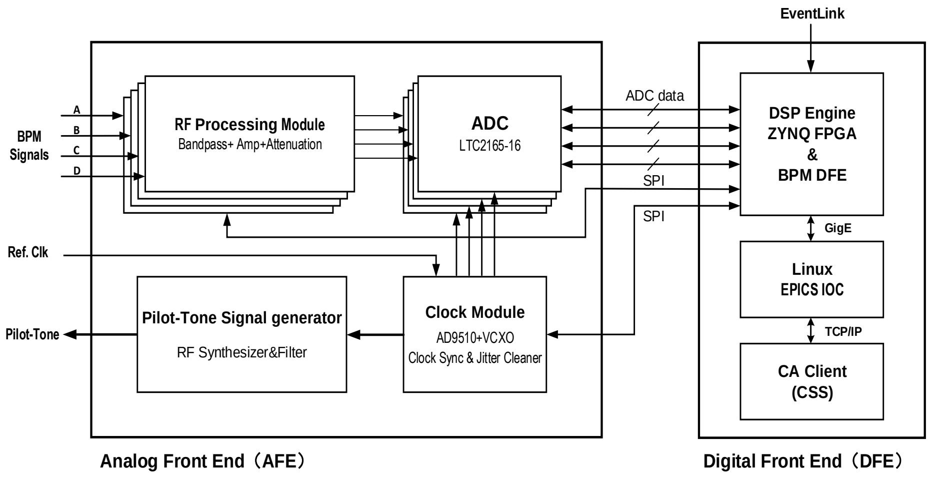
A setup of NEG coating which has ability to coat 4 meters long pipe has been built for vacuum pipes of HEPS at location of PAPS. And one test vacuum pipe of 4 meters long, φ22 mm of inner diameter have been coated, which shows that NEG film has good adhesion and thickness distribution. Theoretically, It is easier to be coated of CEPC vacuum pipe, because of the ratio of diameter to length is 56/6000 which is bigger then 22/4000.

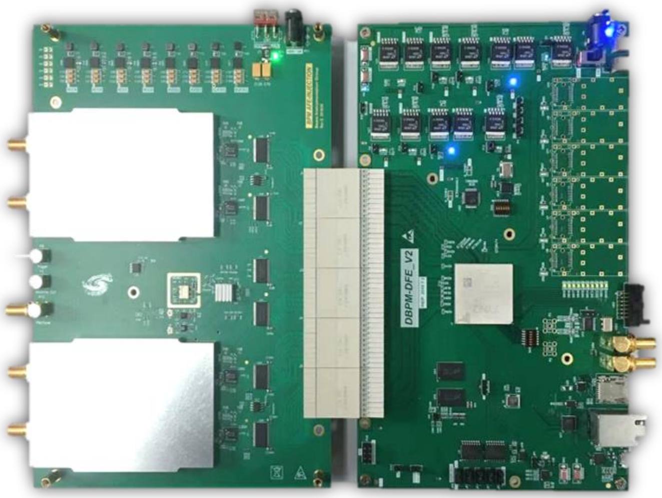
NEG Coating Facility @ Dongguan

- A setup of NEG coating which has ability to coat 6 meters long pipe by moves solenoid is being built for vacuum pipes at location of Dongguan of Guangdong province.

Instrumentation --- BPM electronics

- BPM electronics development





- Application to BEPC-II

- ADF interface is not suitable for RF signal transmission, IHEP developed new hardware, ADC&CLK in AFE board.
- AFE board： RF Processing+ ADCs + Clock + Pilot tone;
- DFE board： FPGA(ZYNQ) + DDR3 memory + SFPs + Ethernets;
- EPICS IOC： In ZYNQ FPGA, Increase the convenience of the BPM system;

Instrumentation --- Feedthrough & Feedback

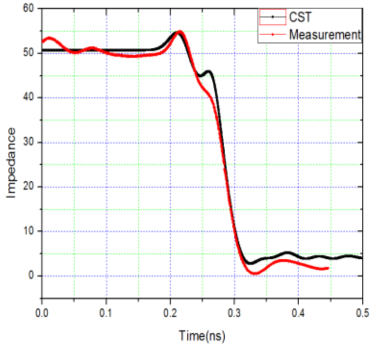
Feedthrough

- The study of feed-through in beam instrumentation was accomplished.
- Two versions of feed-through have been made
- The test results show that the feedthrough can meet the demands of the CEPC BPM

BPM feed-through V1.0

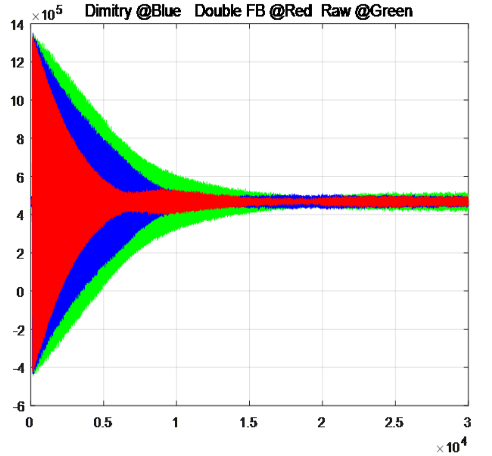
BPM feed-through V2.0

Kicker feed-through

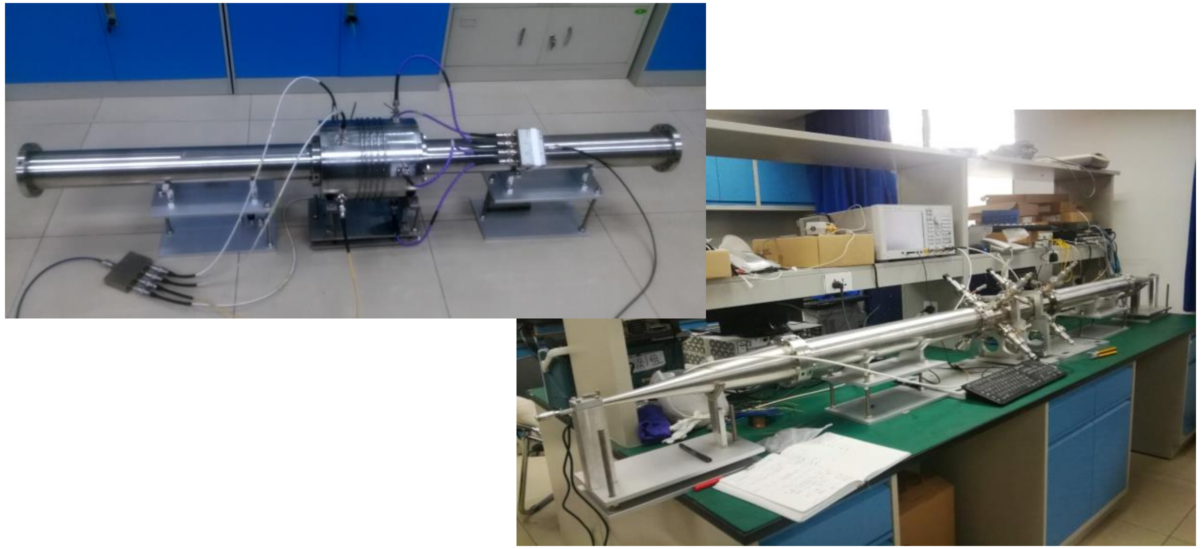


Feedback system

FB electronics R&D based commercial product



The damping time of two TFBs



The kicker design and test in the lab

Status of CEPC Instrumentation R&D

System	R&D Work supported by			Work to be done
	BEPCII	HEPS/HEPS TF	CEPC Funding	
BPM electronics	√	√	√	Radiation hardness Industrialization
Beam position monitor fabrication		√	√	Feed through product and detection; BPM pick-up design,
Longitudinal feedback system	√	√		Electronics development
Transverse feedback system	√	√		Electronics development Longer kicker design
Synchrotron radiation monitor				Cooling of SR extraction mirror; X-ray interferometer; Gas jet scanner
BI at the interaction point			√	Special beam monitor design at IP
Bunch current monitor		√		BBB electronics R&D based home-developed and company
Beam loss monitor			√	beam loss detector R&D Industrialization

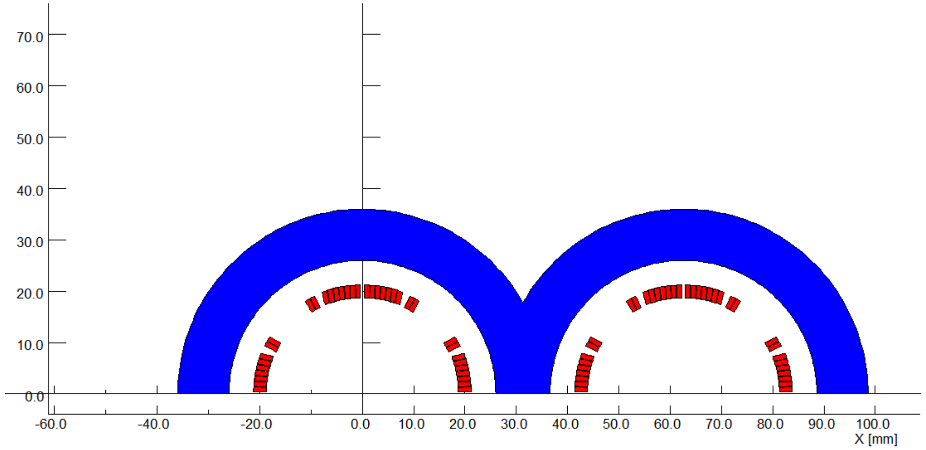
Weight Reduction for the MDI SC Quadrupole

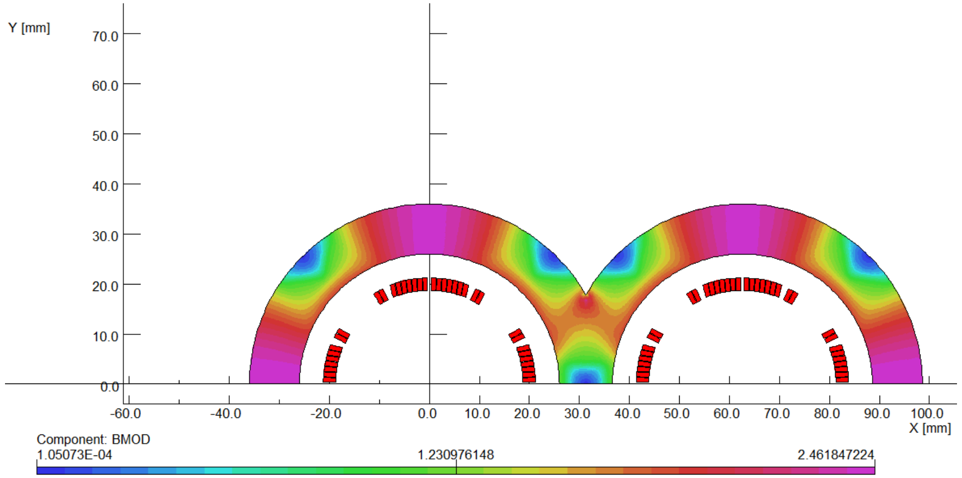
Y.S. Zhu

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

High luminosity requirements

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



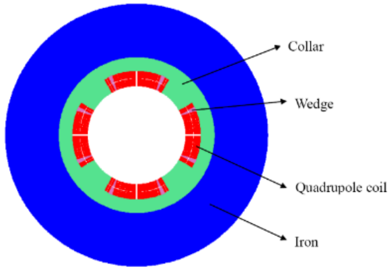


CEPC QD0 SC Magnet R&D (0.5 m short model)

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

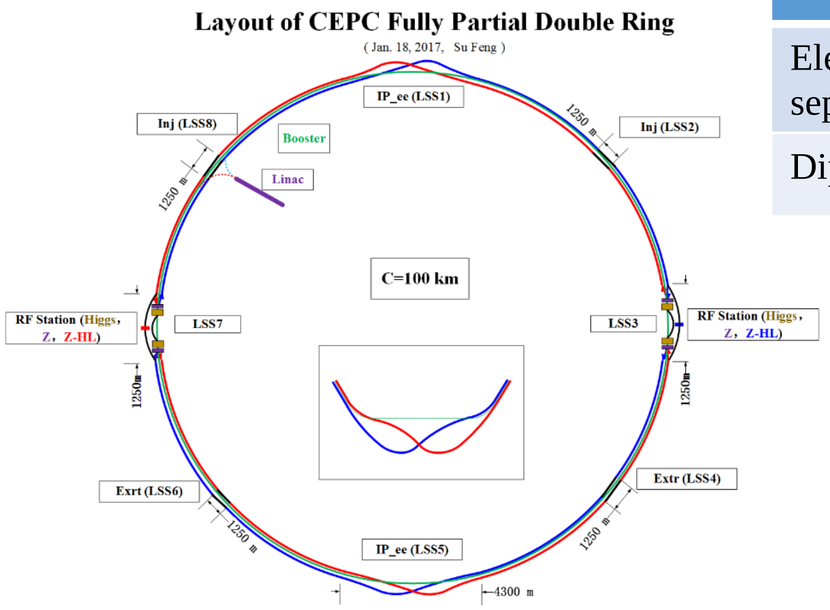
Fabrication of NbTi Rutherford cable is finished (12 strands). SC quadrupole coil winding machine, coil heating and curing system has been finished.

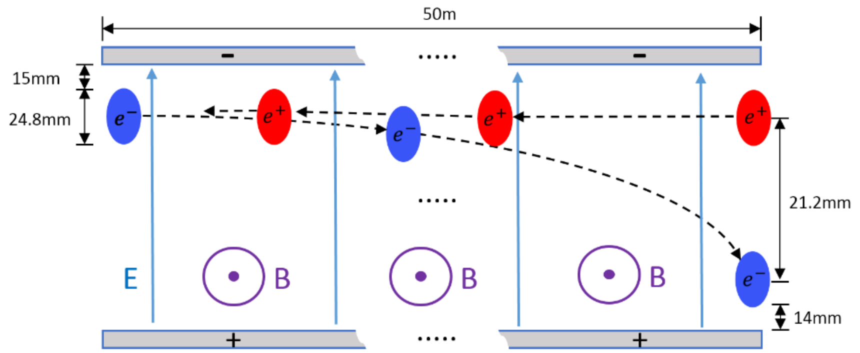


Electrostatic-Magnetic Deflector for Higgs

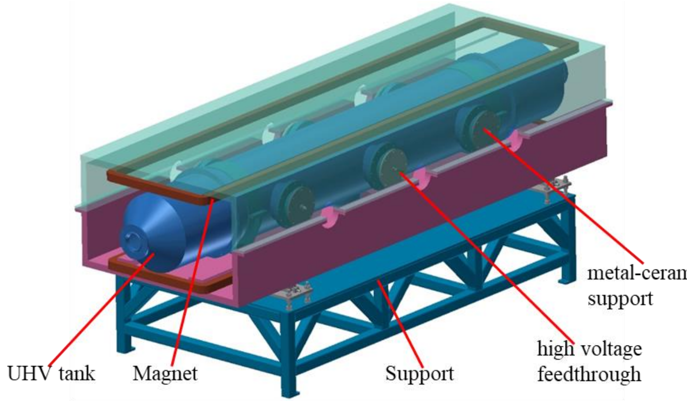
B. Chen

	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}

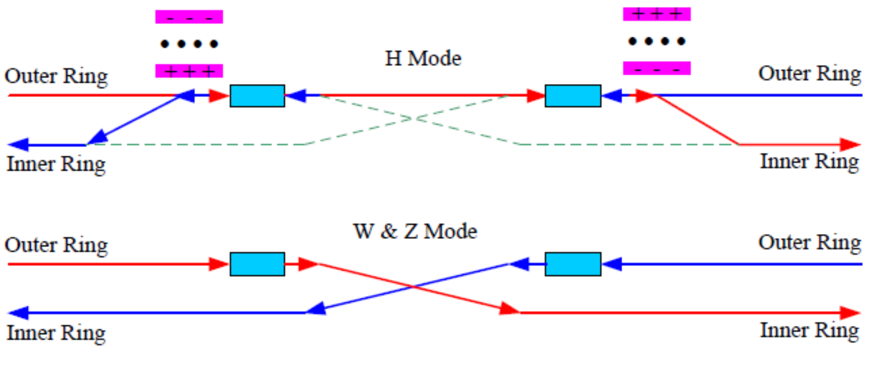




Schematic of Electrostatic-Magnetic separator

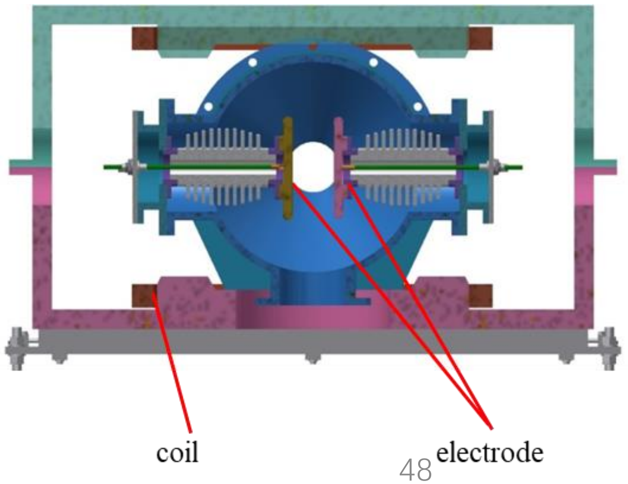


structure drawing of Electro-Magnetic Separator



Layout of RF region

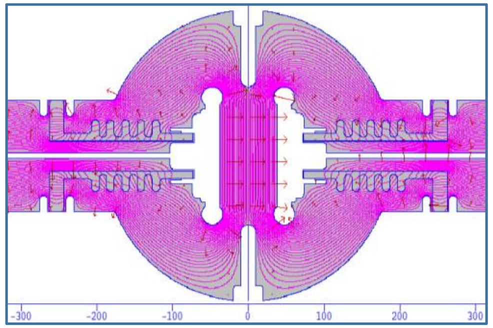
- Higgs Energy requires the acceleration of e- & +by both RF stations
- Electro-Magnetic Separator are installed to deflect e-/e+ to inner/outer rings

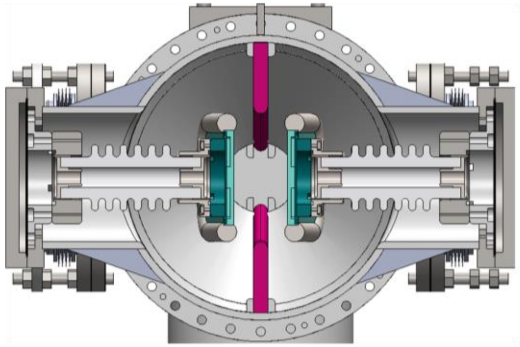


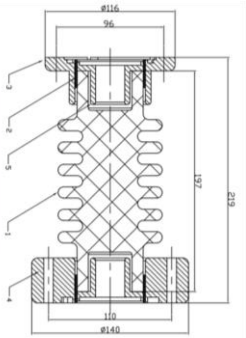
Electrostatic-Magnetic Deflector Manufacture & Test

B. Chen

Index	indicators	Factory test	Test results
Vacuum leakage rate		≤1x10-10Pa.m3/s	**2×10-13Pa m3/s**
Vacuum pressure	≤2.0×10^{-10}Torr	≤4.0×10^{-10}Torr	**≤1.0×10^{-10}Torr**
Maximum conditioning voltage		8 hours non-stop operation , Vacuum ≤ 4.0×10^{-10}Torr	Arc occurs at ±90kV





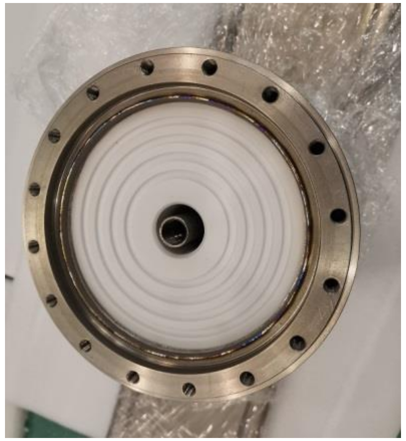


- The mechanical design of electrostatic separator was completed. The prototype of the separator was fabricated in factory and the factory test had been done.

- The factory test showed that the vacuum reached the target. However, due to the arc of the high voltage test, the maximum voltage is ±90kV satisfying the H- operation (±75kV).

- The magnet yoke is H-type. The prototype is being fabricated. It is planned to complete production in next month.

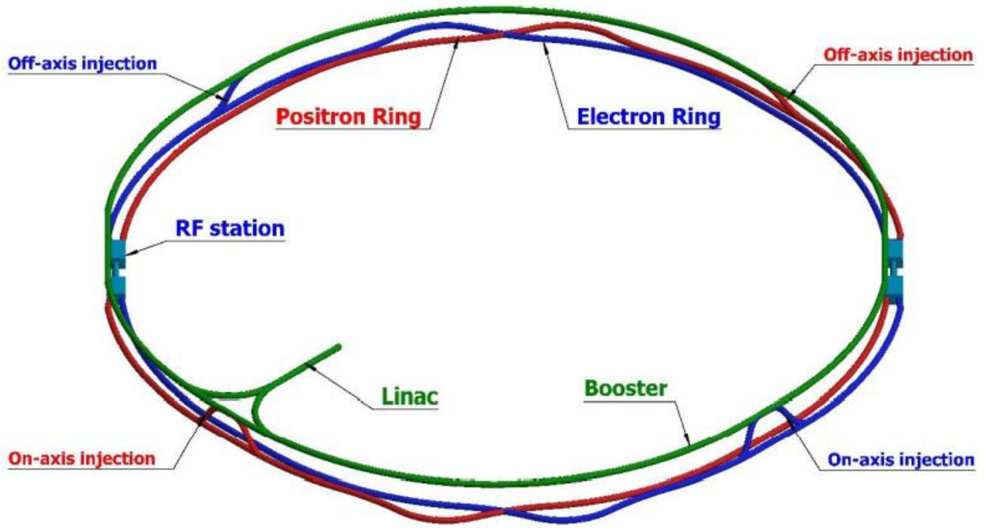
- Prototypes for Booster power supply and Correctors with Multi-unit combination structure has been fabricated and finished the test.



Booster

Physical Design

- Parameters
- Lattice
- Error study and DA
- Ramping Scheme



Key technologies

- 1.3GHz Superconducting Cavity
- Weak field Dipole

Booster TDR Parameters

D. Wang

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

Injection

		tt	*H*	*W*	*Z*	
Beam energy	GeV	20				
Bunch number		37	240	1230	3840	5760
Threshold of single bunch current	µA	7.18	4.58	3.8		
Threshold of beam current (limited by coupled bunch instability)	mA	27				
Bunch charge	nC	1.07	0.78	0.81	0.89	0.92
Single bunch current	µA	3.2	2.3	2.4	2.7	2.78
Beam current	mA	0.12	0.56	2.99	10.3	16.0
Energy spread	%	0.016				
Synchrotron radiation loss/turn	MeV	1.3				
Momentum compaction factor	10^{-5}	1.12				
Emittance	nm	0.035				
Natural chromaticity	H/V	-372/-269				
RF voltage	MV	438.0	197.1	122.4		
Betatron tune ν_x/ν_y		321.23/117.18				
Longitudinal tune		0.13	0.087	0.069		
RF energy acceptance	%	5.4	3.6	2.8		
Damping time	s	10.4				
Bunch length of linac beam	mm	0.5				
Energy spread of linac beam	%	0.16				
Emittance of linac beam	nm	10				

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

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		37	240	233+7	1230	3840	5760
Maximum bunch charge	nC	0.96	0.7	23.2	0.73	0.8	0.83
Maximum single bunch current	µA	2.9	2.1	69.7	2.2	2.4	2.5
Threshold of single bunch current	µA	95	79				
Threshold of beam current (limited by RF system)	mA	0.3	1		4	10	16
Beam current	mA	0.11	0.51	0.99	2.69	9.2	14.4
Bunches per pulse of Linac		1	1		1	2	
Time for ramping up	s	7.3	4.5		2.7	1.6	
Injection duration for top-up (Both beams)	s	30.0	23.3	32.8	39.3	134.7	128.2
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	9.3	2.05		0.59	0.284	
Longitudinal tune		0.13	0.087		0.069	0.069	

30GeV injection energy under the consideration for the cost saving

Optics Parameters Comparison

D. H. Ji, W. Kang

Lattice	FODO 0 (CDR)	FODO	TME (combine magnets)
Emittance X (nm) @120GeV	3.57	1.29	1.26
Momentum compaction ($\times 10^{-5}$)	2.44	1.18	1.12
Tunes	[263.201/261.219]	[353.180/353.280]	[321.271/117.193]
Quad amount	2110	2816	3458
Quad Strength (K1L rms)	0.0383	0.0407	0.0259
Sext amount	512	896	0
Sexts Strength (K2L rms)	0.179	0.4091	0.0492
H Corrector	1053	1408	1218
V Corrector	1054	1408	2240
BPM	2108	2816	3458

Magnets' cost of TME is lower than FODO:

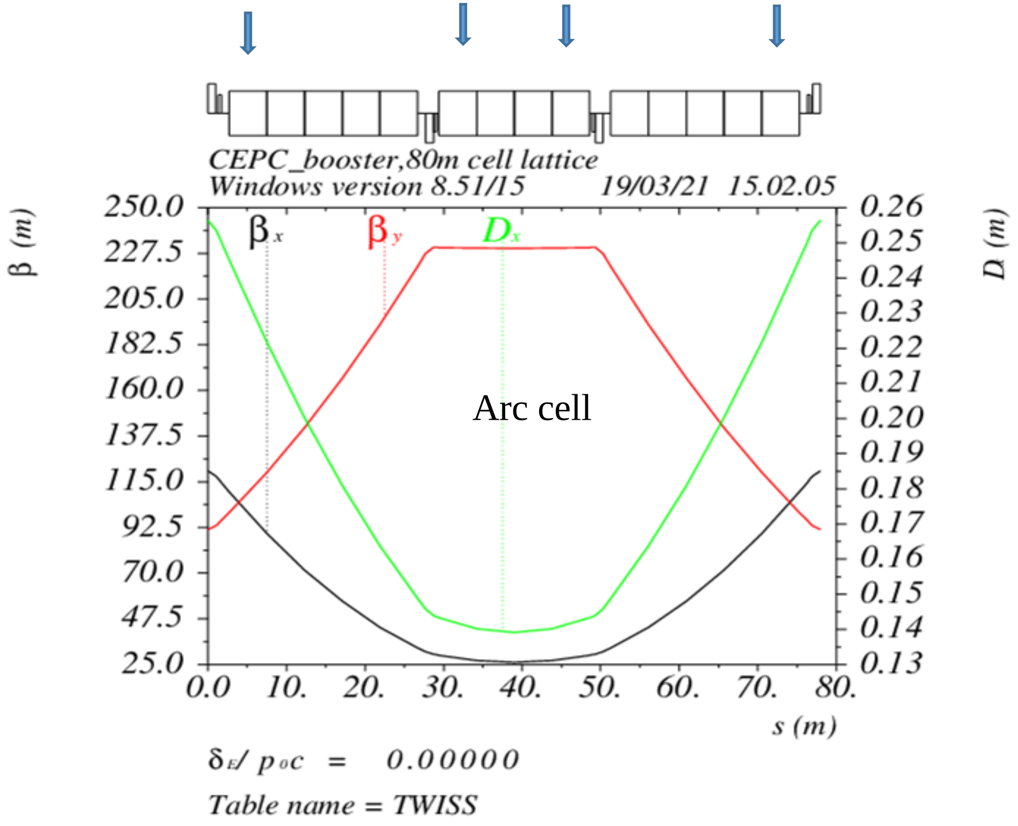
- No independent sextupole for TME
- Quadrupole strength of TME is lower

Booster TDR Optics

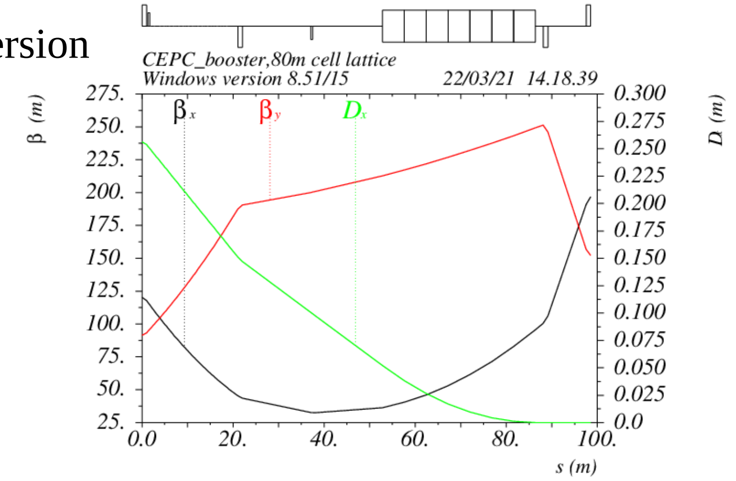
D. Wang, C. H. Yu, Y. M. Peng...

- Overall idea: uniform distribution for the Q
- Combined magnet (B+S) scheme possible

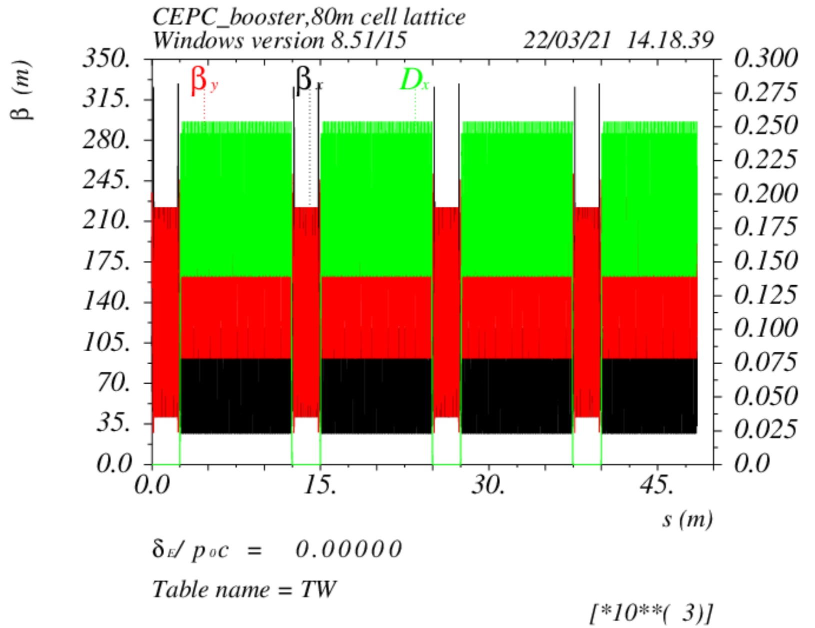
- TME like structure (cell length=80m)
- Interleave sextupole scheme
- Emittance@120GeV=1.26nm



Dispersion sup.



Half ring optics



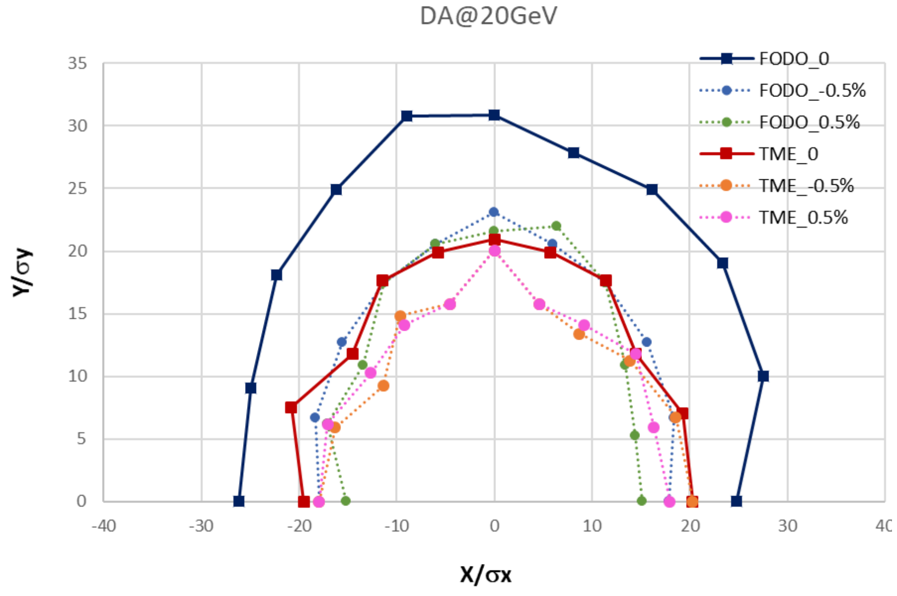
Dynamic Aperture results

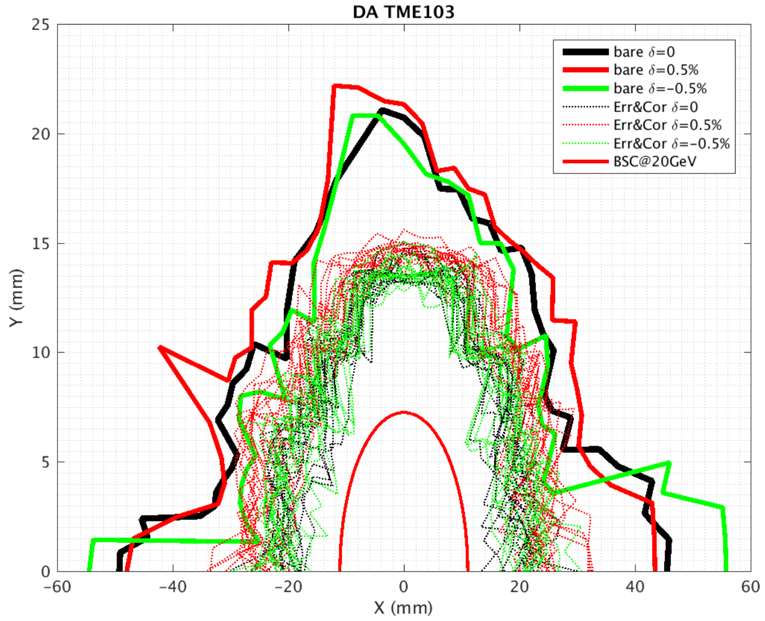
- Booster energy: 20GeV~180GeV
- Inj. emittance from Linac:10nm
- Energy spread from Linac: 0.16%

	Accuracy (m)	Tilt (mrad)	Gain	Offset w/ BBA(mm)
BPM(10Hz)	1e-7	10	5%	30e-3

	Dipole	Quadrupole	Sextupole
Transverse shift X/Y (μm)	100	100	-
Longitudinal shift Z (μm)	100	150	-
Tilt about X/Y (mrad)	0.2	0.2	-
Tilt about Z (mrad)	0.1	0.2	-
Nominal field	1e-3	2e-4	3e-4

D. Wang
D. Ji





- Almost impossible to obtain the initial closed orbit naturally
  - Start from sextupole off
- Orbit correction (COD)(100 Seeds)
  - Response matrix method(RM)
  - SVD method
- Optics correction(96 Seeds)
  - Response matrix method
  - LOCO code
  - Dispersion corrected

Booster Ramping Scheme

Dou Wang, Xiaohao Cui

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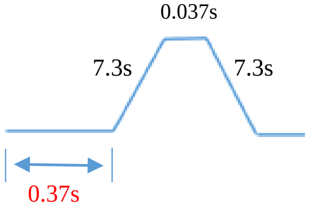
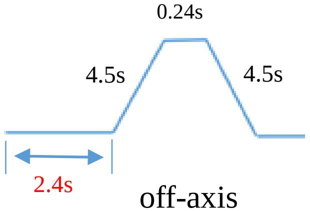


1 cycles/beam

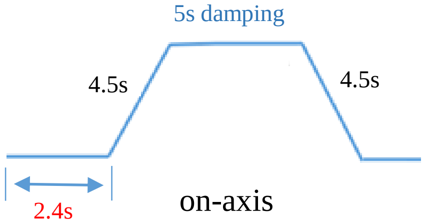
0.37s+7.3s+0.037s+7.3s=15.0s

Higgs



off-axis

1 cycles/beam

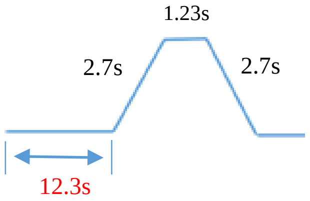


on-axis

2.4s+4.5s+5.0s+4.5s=16.4s

➢ 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
- …

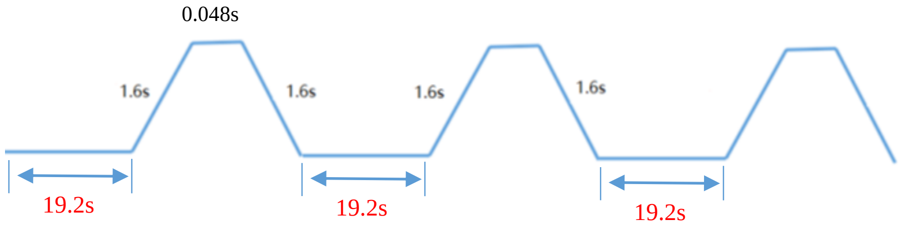
W



1 cycles/beam

12.3s+2.7s+1.23s+2.7s=18.9s

Z



(19.2s+1.6s+0.048s+1.6s)*3=67.34s

3 cycles/beam

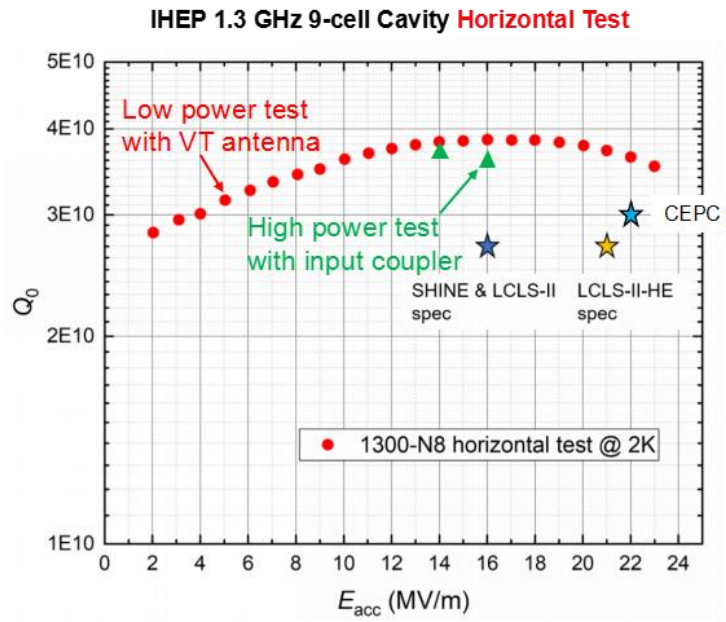
SRF Facilities and 1.3GHz Cavity

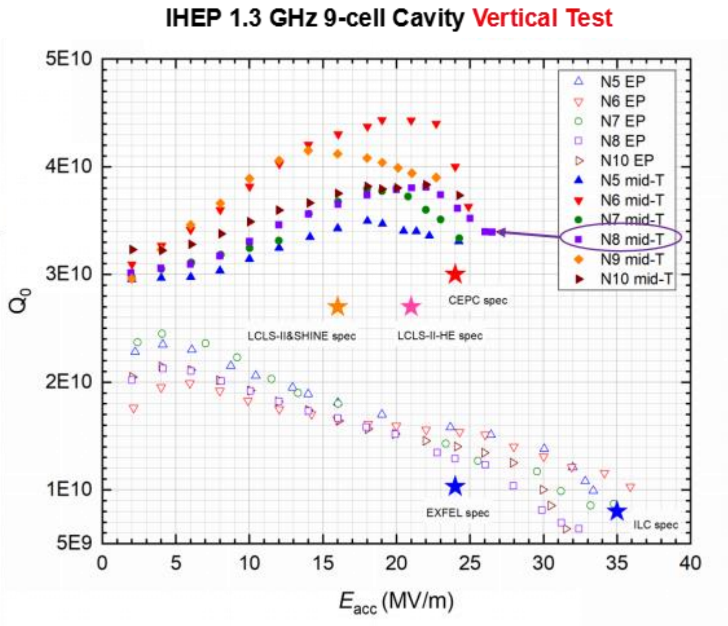
J.Y. Zhai, P. Sha





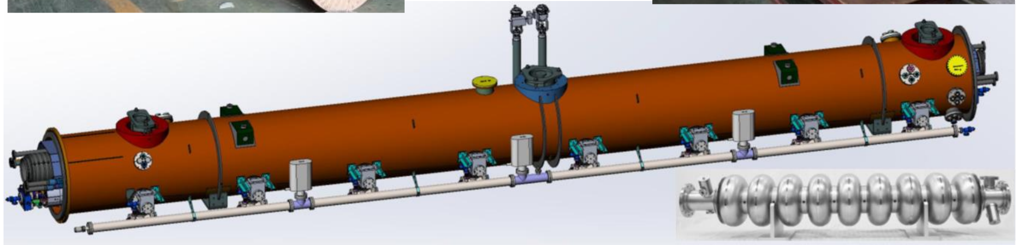
IHEP PAPS established in July 2021 Horizontal test stand, 1.3GHz 9cell cavities, and couplers...





1.3 GHz High Q Mid-T Cavity Horizontal Test

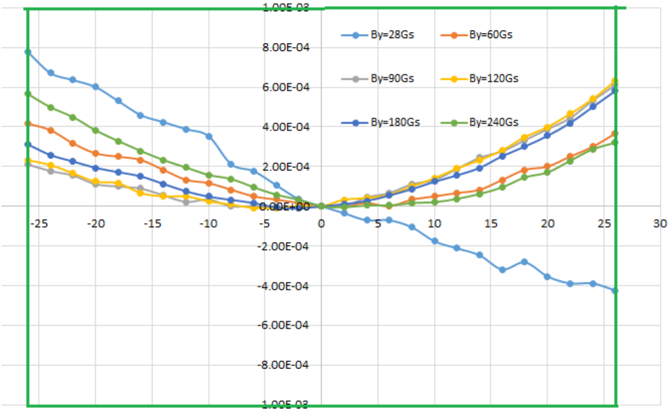


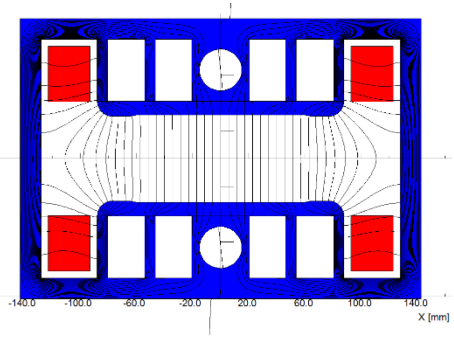


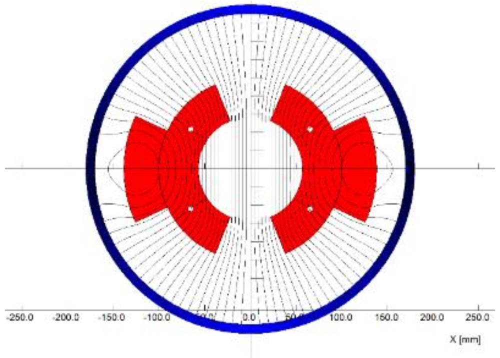
- 1.3 GHz 8x9-cell high Q cryomodule prototype
- Component fabrication in 2021 to mid 2022
- Assemble and horizontal test in 2022
- Ship to Dalian in 2023

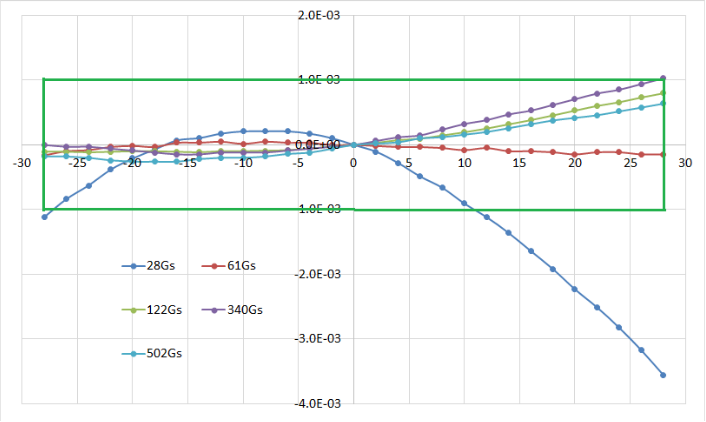
Weak Field Dipole

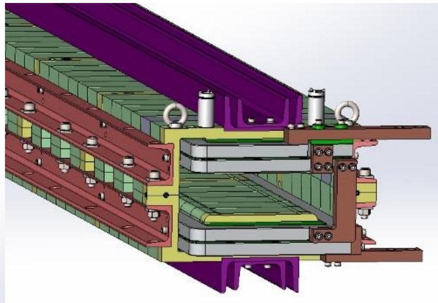
W. Kang

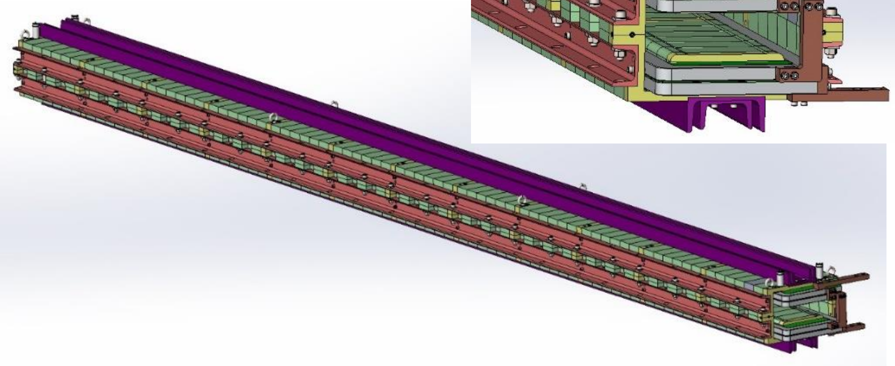










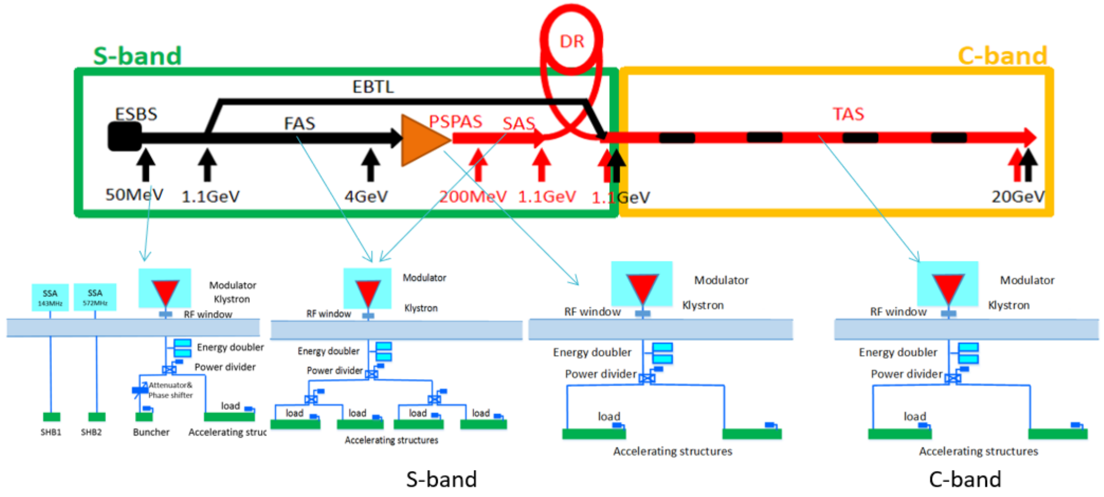


- Two kinds of the subscale prototype magnet w/wo iron cores have been developed.
- As for the CDR parameters with 10 GeV injection energy the low field performance of the magnet without iron cores meets the requirements whereas the magnet with iron cores not
- With the new baseline of 20GeV injection both prototypes full fill the requirement
- The full scale prototypes are under the development. Results are expected in June 2022

Linac

Physical Design

- New Base line
- Parameters
- Start to End Simulations
- Study for Positron
- Error simulations



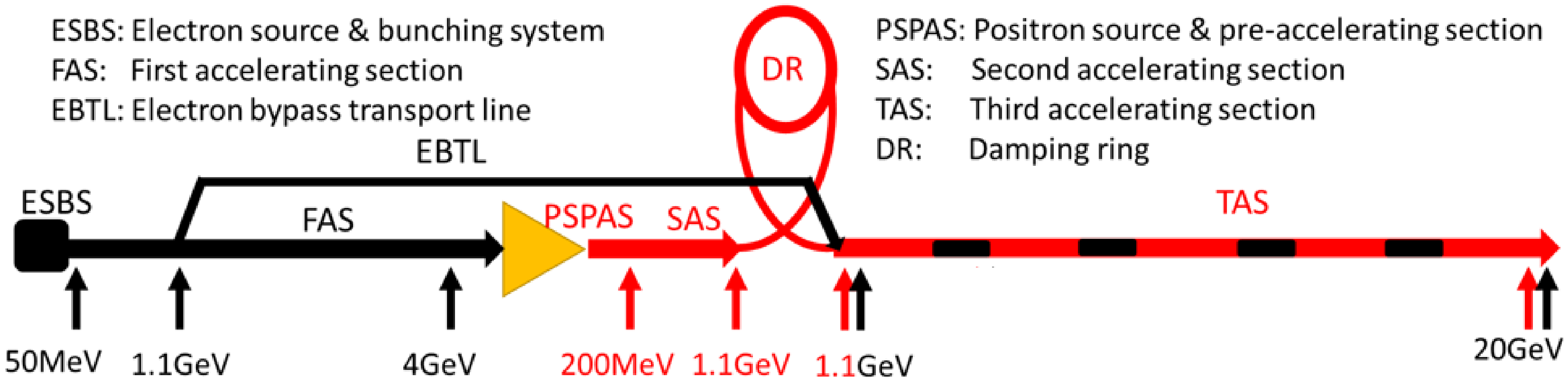
Key technologies

- High performance S-band accelerator structure
- C-band accelerator cavities
- Pulse compressor
- Positron source

LINAC New Baseline Layout

J. Zhang, C. Meng

- Layout
  - Vertical electron by-pass transport line (EBTL): 1.2 m separation
- S-band Linac
  - **FAS**: 4GeV + **PSPAS**: 200MeV + **SAS**: 1.1GeV
- C-band Linac
  - TAS： 1.1GeV→20GeV
  - Because the emittance of damping ring is decreased, the C-band accelerating structure could be used from 1.1 GeV



LINAC New Baseline Parameters

J. Zhang, C. Meng

- Increase the energy of the Linac from 10 GeV to 20GeV
  - **Booster magnet**: Low magnetic field & large magnetic field range
  - Linac： C-band accelerating structure: Higher gradient; Smaller aperture
- Decrease the emittance of the Linac from 40nm to 10nm
  - Low emittance damping ring
    - Nor. RMS. Emittance: 200mm-mrad

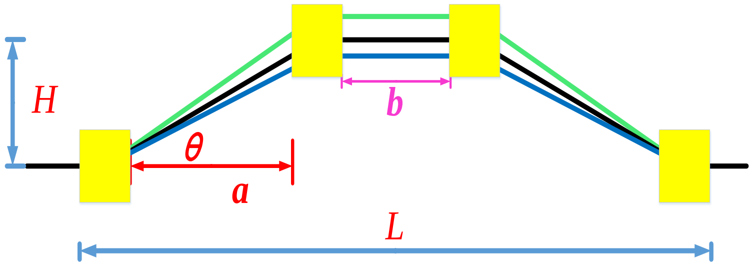
Parameter	Unit	S-band	C-band
Frequency	MHz	2860	5720
Length	m	3.1	1.8
Cavity mode		2π/3	3π/4
Aperture diameter	mm	20~24	11.8~16
Gradient	MV/m	21	**45**

Parameter	Symbol	Unit	Baseline
e^- /e^+ beam energy	E_{e-}/E_{e+}	GeV	20
Repetition rate	f_{rep}	Hz	100
e^- /e^+ bunch population	$Ne-/Ne+$	$\times10^{10}$	0.94(1.88)
		nC	1.5 (3)
Energy spread (e^- /e^+)	σ_E		1.5×10^{-3}
Emittance (e^- /e^+)	ε_r	nm	10

Bunch Compressor for LINAC

J. Zhang, C. Meng

- Bunch compressor is needed before C-band accelerating structure
  - Bunch length is from 1mm to 0.5mm
  - Chicane type
    - Angle: 10°
  - Accelerating structure
    - Voltage:100MV



		Value	Units
Initial rms bunch length	$\sqrt{\langle z_0^2\rangle}$	0.923	mm
Initial rms energy spread	$\sqrt{\langle \delta_0^2\rangle}$	0.235%	
Final rms bunch length	$\sqrt{\langle z_1^2\rangle}$	$\frac{\sqrt{\langle z_0^2\rangle}}{2}$	mm
Initial energy	E_0	1.1	GeV

$$\langle z_1^2\rangle / \langle z_0^2\rangle = \left(1 + R_{56}^{ch} R_{65}^{rf}\right)$$

$$R_{56}^{ch} T_{655}^{rf} + R_{65}^{rf\,2} T_{566}^{ch} = 0$$

$$R_{56}^{ch} = -\frac{1}{R_{66}^{rf}} \frac{\sqrt{\langle z_1^2\rangle}}{\sqrt{\langle \delta_0^2\rangle}} \sqrt{1 - \frac{\langle z_1^2\rangle}{\langle z_0^2\rangle}} = -0.196 \text{ m}$$

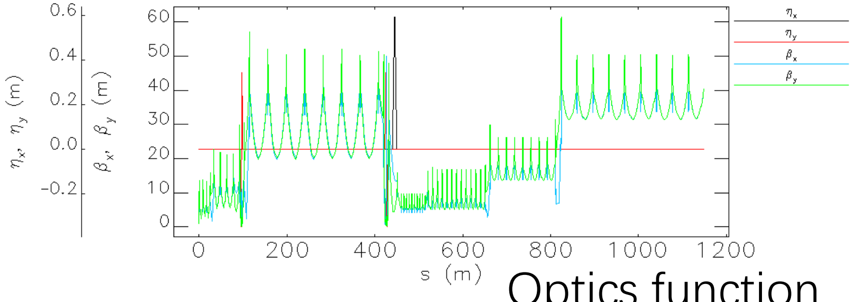
$$R_{56} = 4\rho\left[\theta - \tan\theta\right] - 2a\frac{\sin^2\theta}{\cos^3\theta} = -0.196\text{m}$$

Start to End Simulations for e- Beam

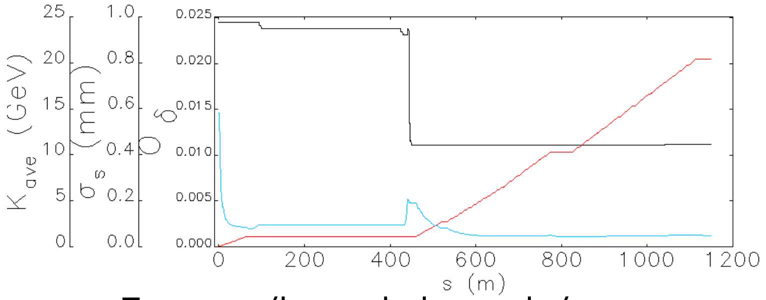
C. Meng

- Electron Linac
  - Wakefield & CSR
  - Emittance(w/o error)
    - Growth: 25%
    - 2.5nm@20GeV

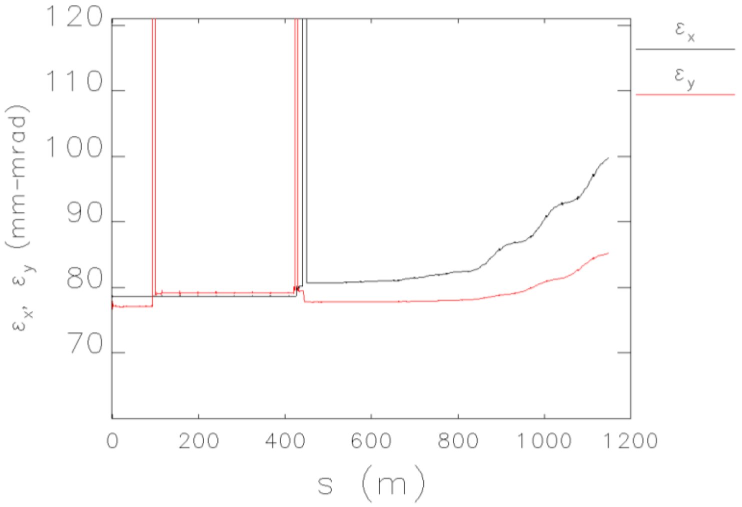
Parameter	Unit	Baseline	Electron
e^-/e^+ beam energy	GeV	20	20.38
Repetition rate	Hz	100	100
e^-/e^+ bunch population	$\times10^{10}$	0.94(1.88)	1.88
	nC	1.5 (3)	**3**
Energy spread (e^-/e^+)		1.5×10^{-3}	1.3×10^{-3}
Emittance (e^-/e^+)	nm	10	**2.5**



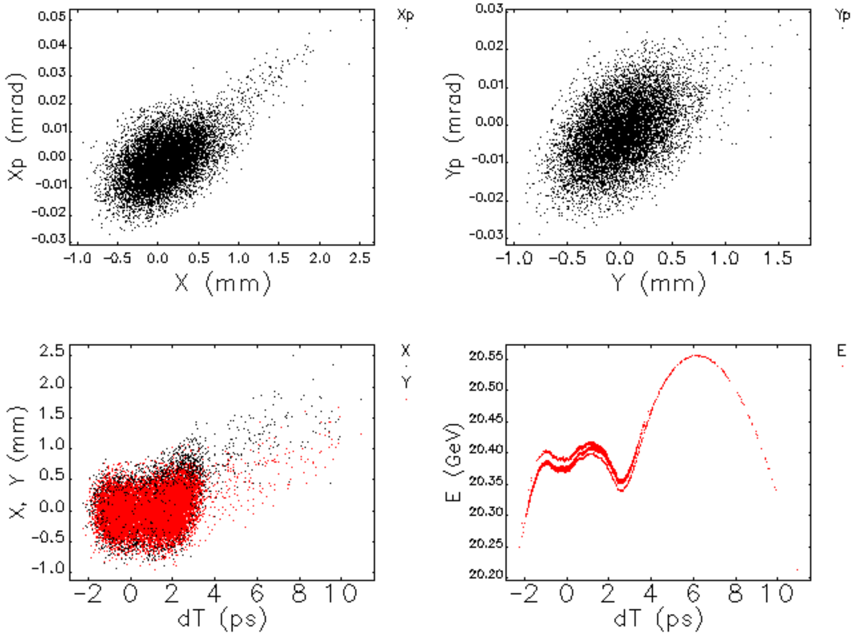
Optics function



Energy/bunch length/energy spread



Emittance



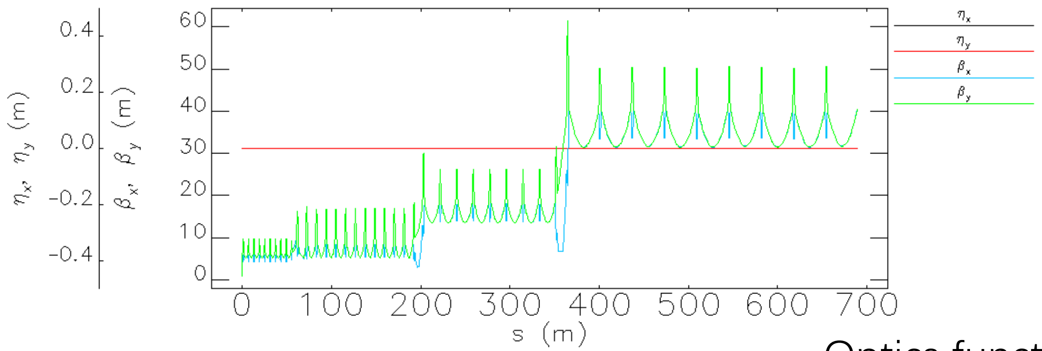
Distribution @ 20GeV

Simulations for Positron

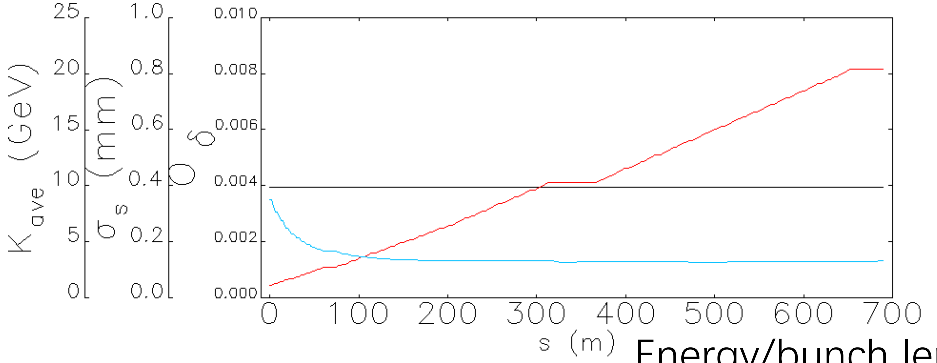
- Positron Linac
  - Wakefield & CSR
  - Emittance(w/o error)
    - Growth: 5%
    - 5.2nm@20GeV

Parameter	Unit	Baseline	Electron	Positron
e^-/e^+ beam energy	GeV	20	20.38	20.37
Repetition rate	Hz	100	100	100
e^-/e^+ bunch population	$\times10^{10}$	0.94(1.88)	1.88	1.88
	nC	1.5 (3)	3	3
Energy spread (e^-/e^+)		1.5×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
Emittance (e^-/e^+)	nm	10	2.5	5.2

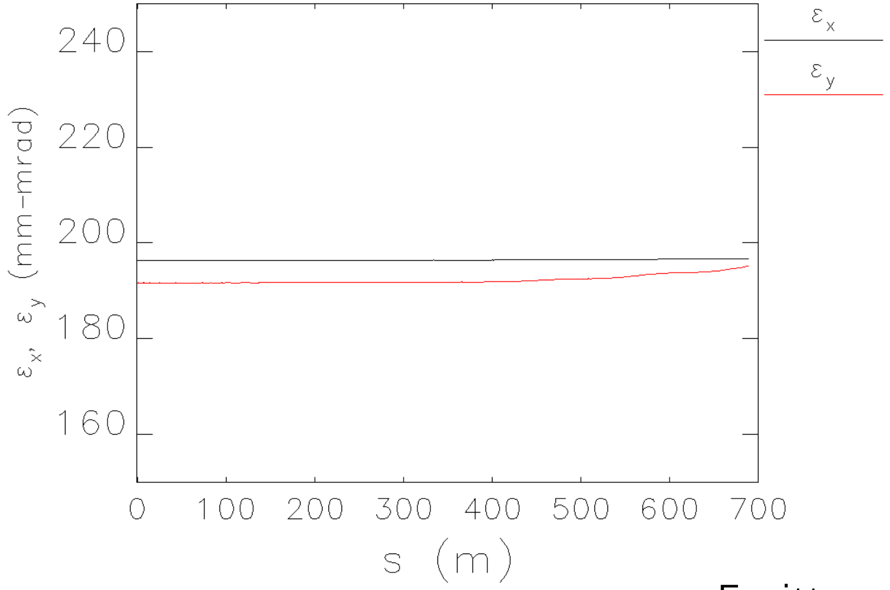
C. Meng



Optics function



Energy/bunch length/energy spread



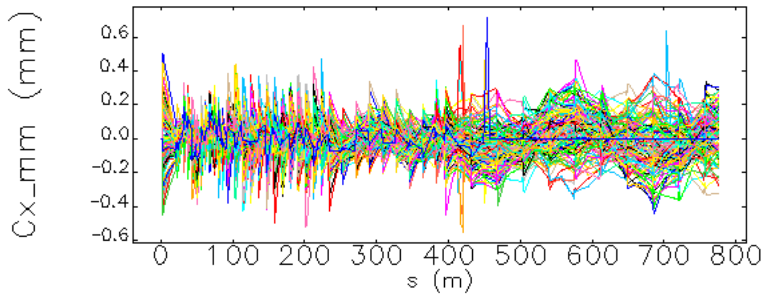
Emittance

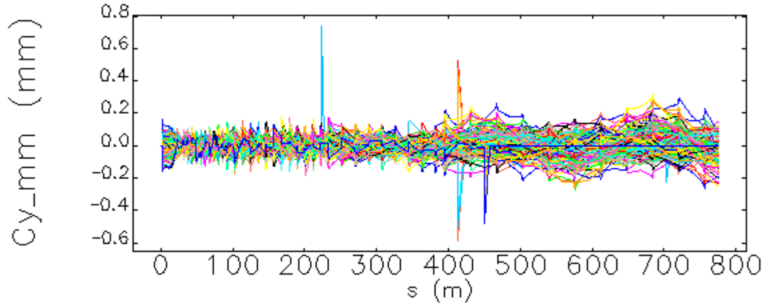
Error Simulations for Positron

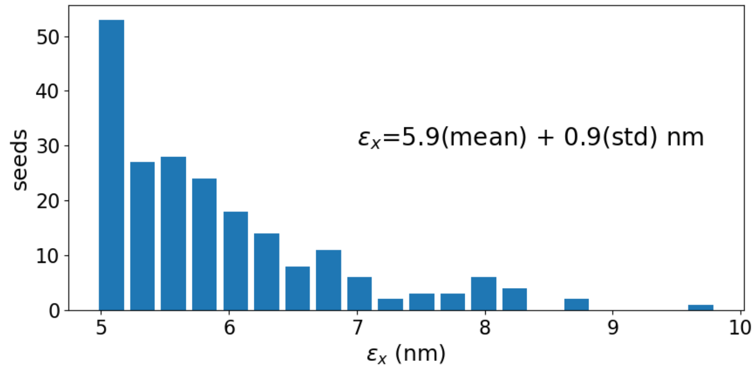
C. Meng

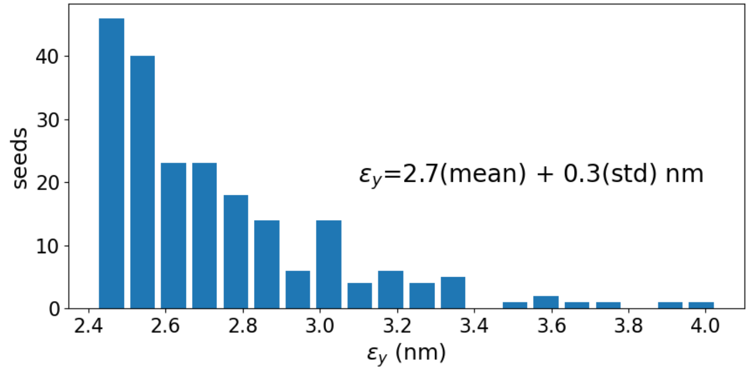
- Positron Linac
  - errors: Magnets/Accelerating structure/BPM
  - Trajectory correction: beam center<0.5mm
  - Emittance growth: meet the requirement
    - X: 18%(mean)+18%(std)
    - Y: 10%(mean)+12%(std)

Error description	Unit	Value
Misalignment error	mm	0.1
Rotation error	mrad	0.2
Magnetic element field error	%	0.1
BPM uncertainty	μm	30



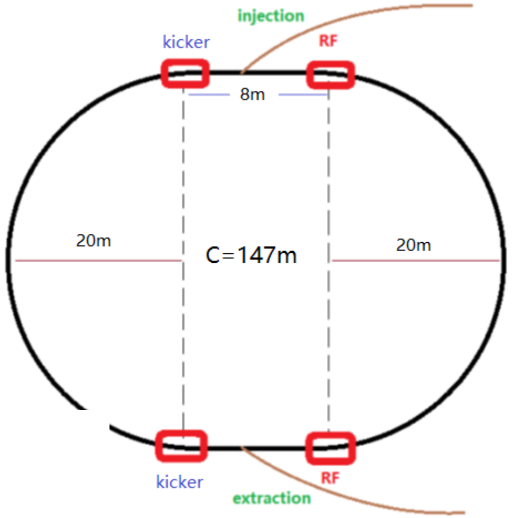




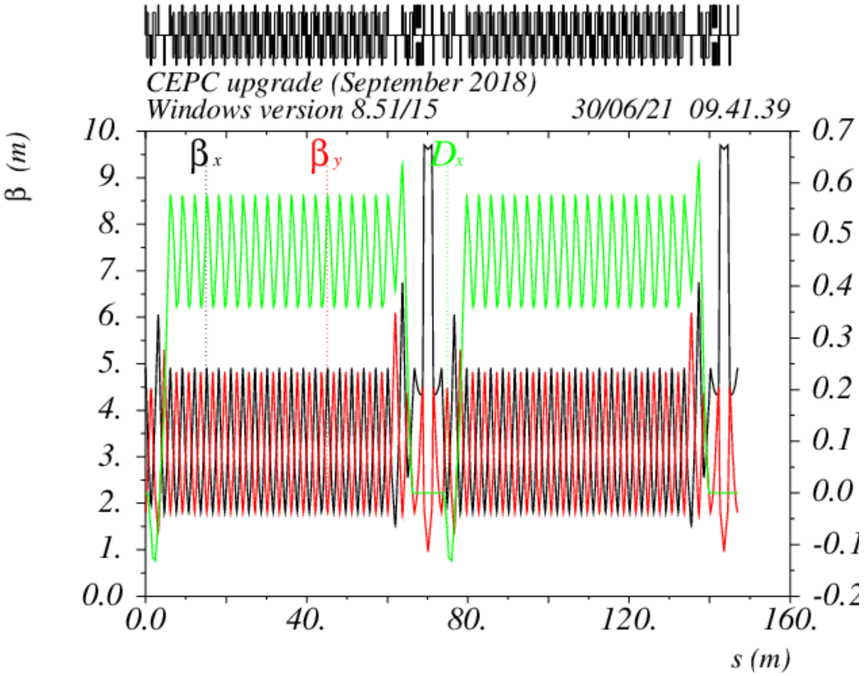


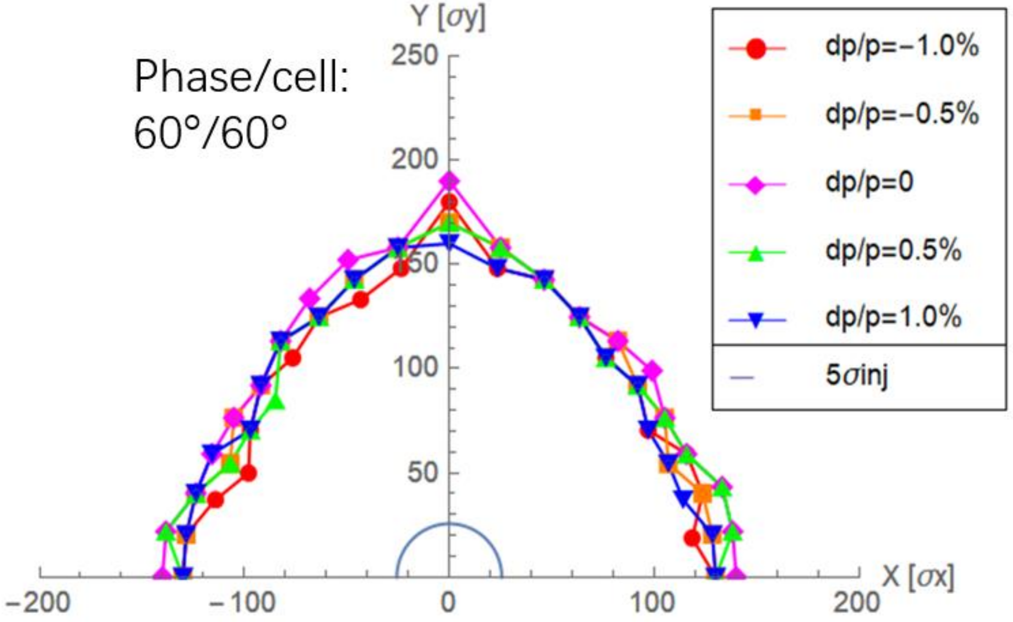
Damping Ring Design & Optimization

- Layout, basic comparison
- Lattice design (60°~90° FODO)
- Preliminary DA studies (>5 injection beam size)

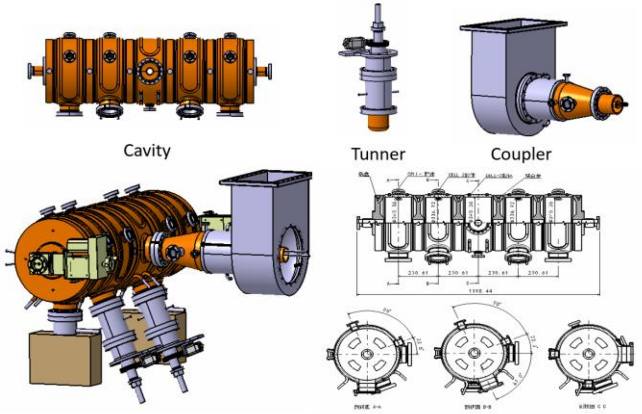


	CDR	TDR
Energy (GeV)	1.1	1.1
Inj. Emittance (mm·mrad)	2500	2500
Ext. emittance (mm·mrad)	530	<200
Storage time (ms)	20	20
Damping time (ms)	15	<13
Circumference (m)	75	~150





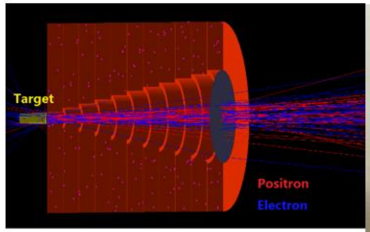
- RF Cavity Design

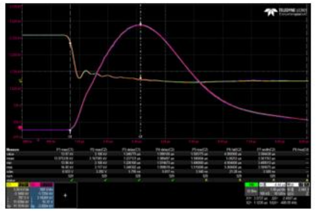


CPEC Linac Key Technologies

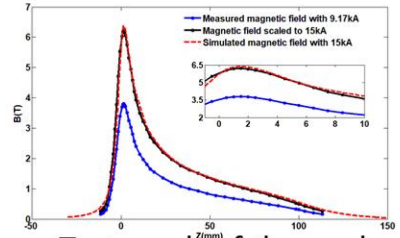
J. Zhang

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

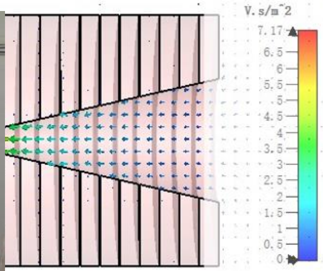




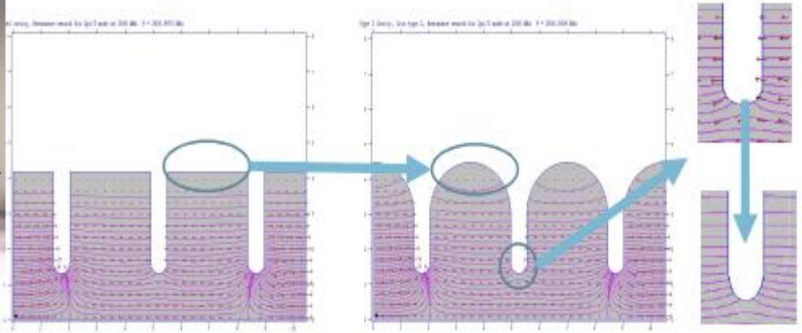
R&D of the solid state

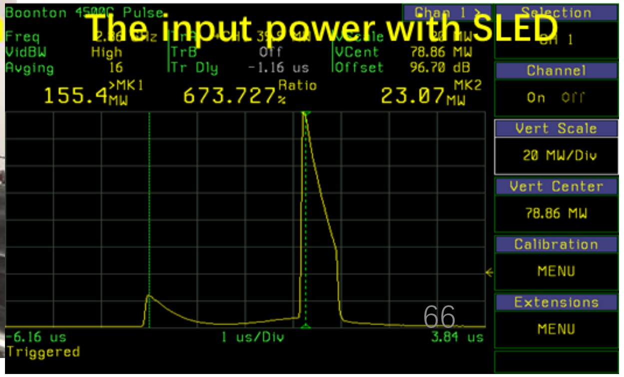


Test result of the peak



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





Injection & Extraction System

Physical Design

- Timing and bunch pattern (common frequency)

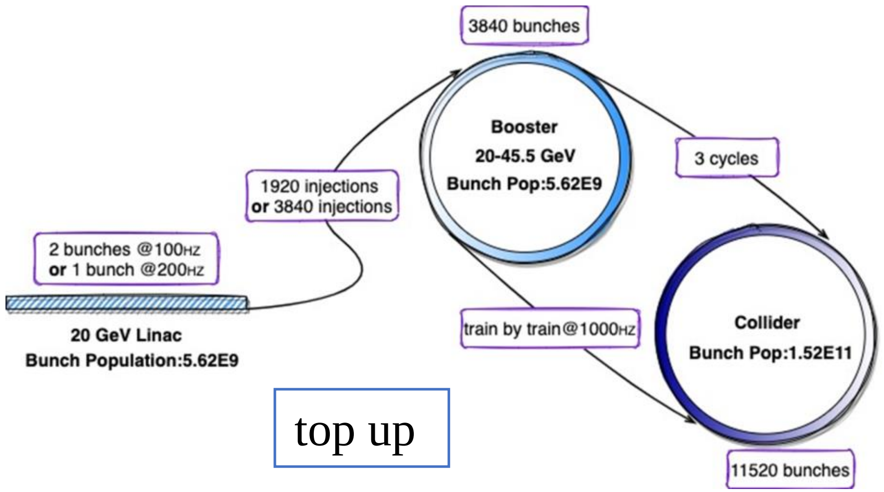
- Transporting line design

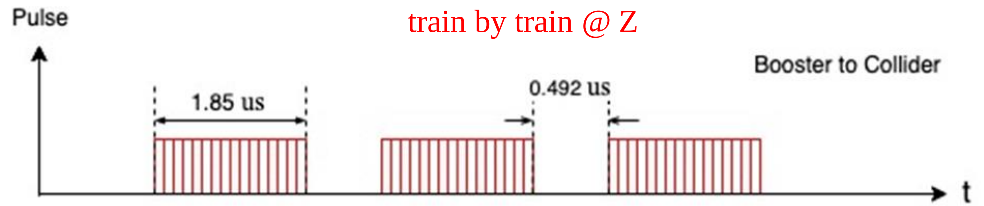
Key technologies

- Fast kicker pulser
- Fast kicker
- Lambertson septum

Timing and Bunch Pattern

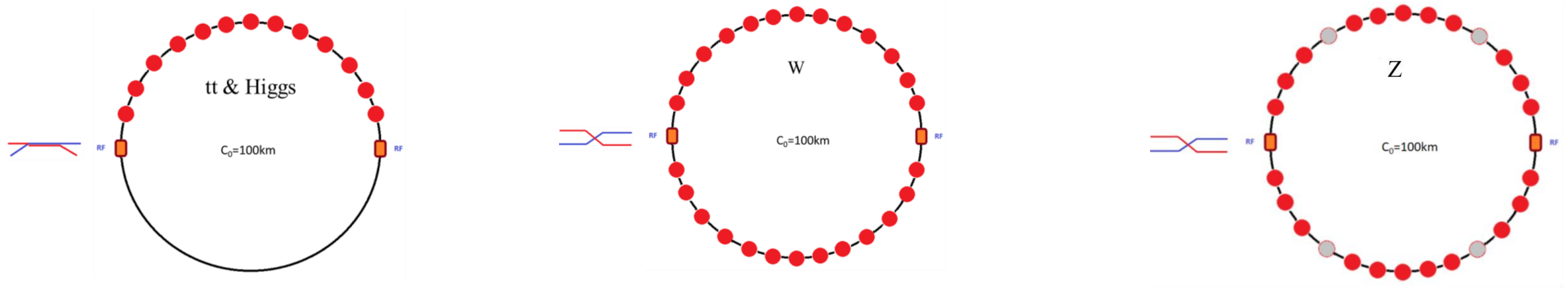
- Both top-up and empty-to-full injection for the collider ring are required.
- Injection & extraction hardware should be compatible for four energy modes.
- Bunches are in the half ring for tt and Higgs, while they are in the whole ring for W and Z.
- Z-mode is the most challenging operation in terms of charge flux delivered by the injectors.





f (MHz)	SHB1	SHB2	Linac	DR	Pre-booster	booster	collider
CEPC	143	572	2860	650	—	1300	650
FCC	—	—	2855.98	400	400	400	400

- Common frequency:130MHz, minimum time separation: 7.69ns.
- Bunch separation @ Z: 23ns



Common Frequency for the Timing System

Cai Meng, Dou Wang, Ge Lei

- Choose 130MHz as clock beat $\rightarrow$ minimum time separation=7.69ns (FPGA clock &EVG/EVR transmission can be realized)

- Circumference of damping ring:
  $(L*1000*10^9/(3*10^8))/(1000/650)$=integer

- Length of transfer line between DR and Linac:
  （（N*150+75+104*2-8.3）$10^9/(3*10^8))/(1000/2860)$=integer

  104m $\rightarrow$101.65m

- Circumference of collider/booster:
  $(L*1000*10^9/(3*10^8))/(1000/650)$=integer

- Length of transfer line between booster and collider:
  $(L*10^9/(3*10^8))/(1000/650)$=integer

  252m or 246m

CPEC Injection & Extraction Hardware Types

J. Chen

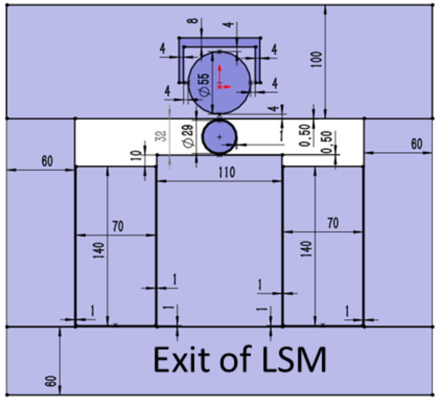
	Sub-system	Kicker Type	Kicker waveform	Septa Type	Thickness of septum
1	Damping ring inj./ext.	Slotted-pipe kicker	Half-sine/250ns	Horizontal LMS	ϕ22/3.5mm
2	Booster LE inj.	Strip-line kicker	Half-sine/50ns	Horizontal LMS	ϕ55/5.5mm
3	Booster ext. for CR off-axis inj.	Delay-line dipole kicker	Trapezoid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

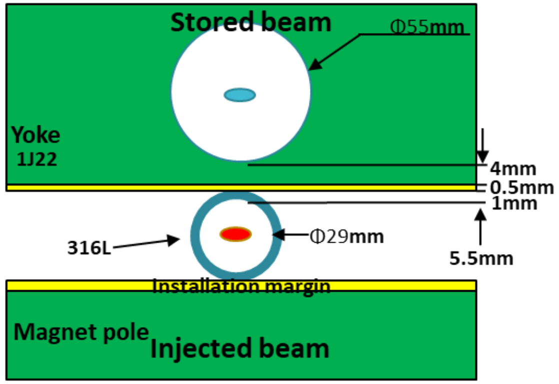
- **The same team is in charge of both HEPS and CEPC inj. & ext. system**
- **Experience gained in HEPS applies for CEPC**

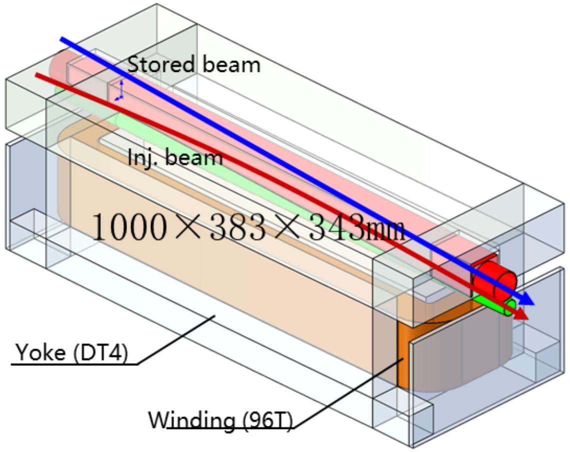
Lambertson Septum Prototype for HEPS

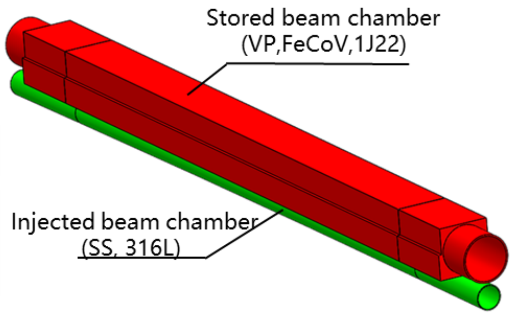
J. Chen

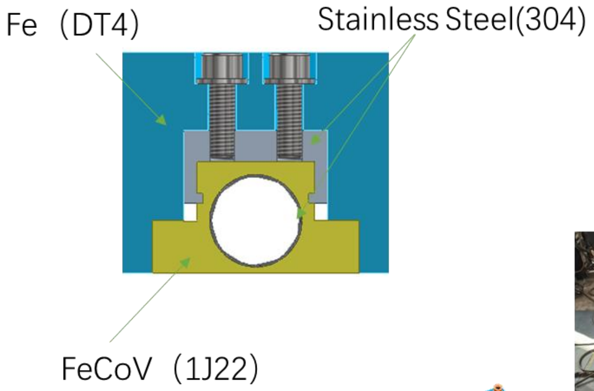
- Stored beam pipe(VP) inner diameter= ø55mm, Thickness=4mm
- Injected beam pipe (SS):   inner diameter=ø29mm, Thickness=1mm
- Septum thickness=4+1+0.5=5.5mm
- Magnet gap: 32mm
- Winding: W=70mm,H=140mm,T=128
- Exciting current=188A
- Inductance=0.0682H

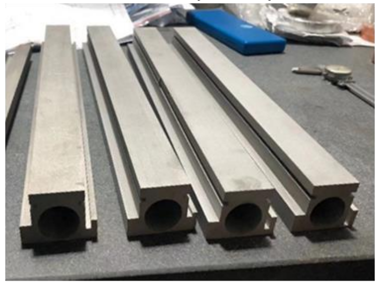




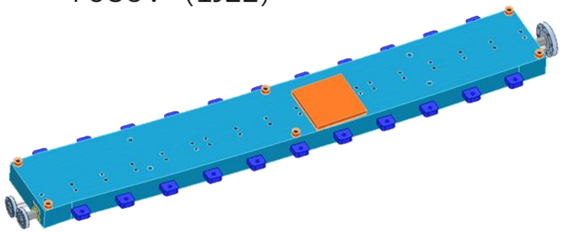








FeCoV（1J22)

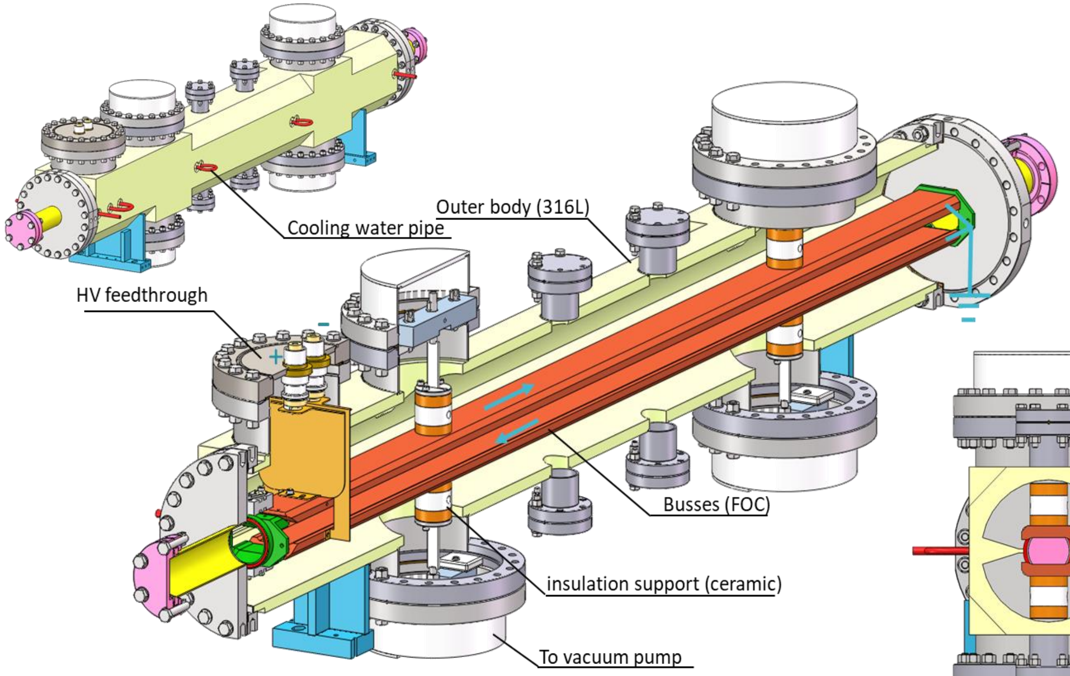


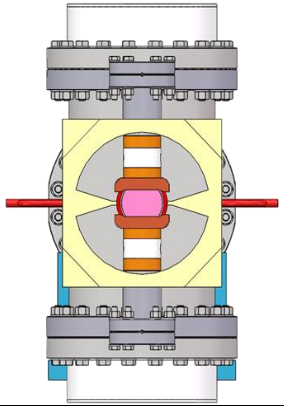
Fe（DT4)

Stainless Steel(304)

Slotted-pipe Kicker Prototype Design & Fabrication

J. Chen



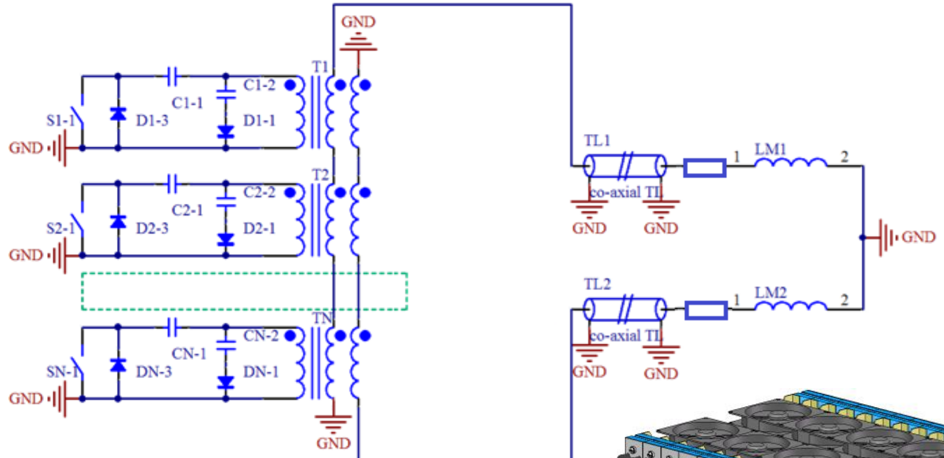


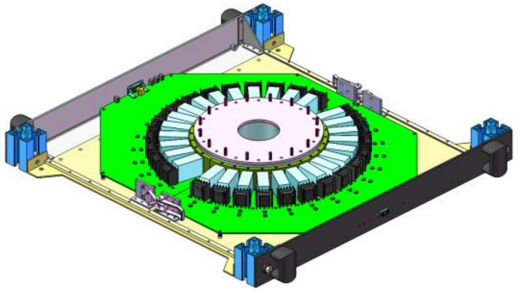
parameter	Unit	DR-kicker
Deflect direction	-	Vertical
Beam Energy	GeV	1.1
Magnetic effective length	m	1.4
Magnetic strength	T	0.0281
Repetition rate	Hz	100
Amplitude repeatability	-	±0.5%
Pulse jitter	ns	⩽5
Bottom width of half sine pulse(5%-5%)	ns	< 250

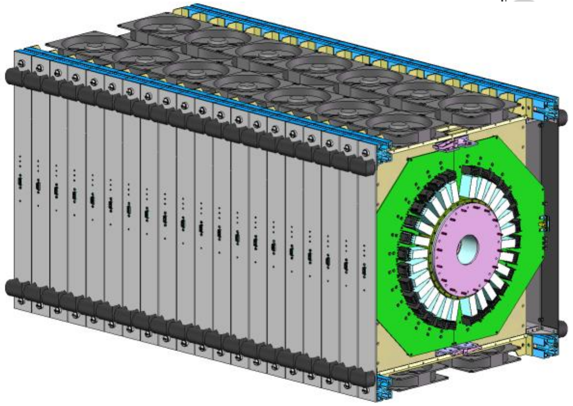
250ns Fast Kicker Pulser

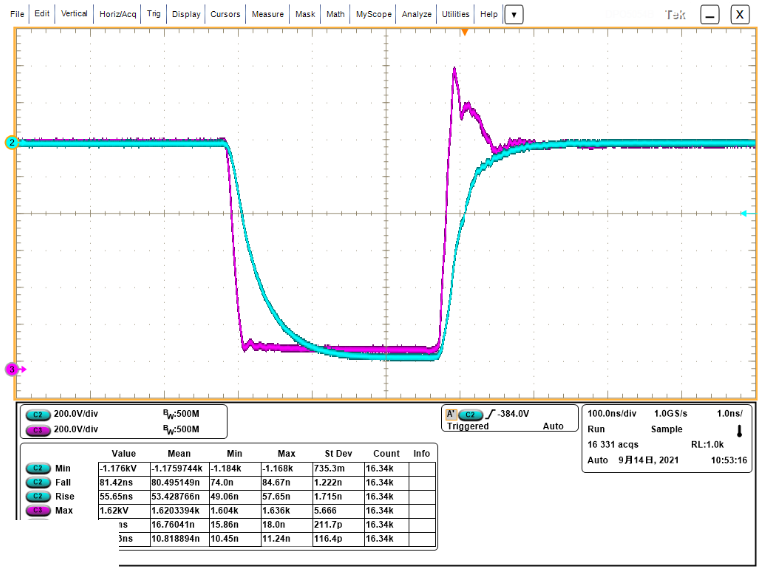
- Scheme: 20-stage inductive adder based on SiC-MOSFETs.
- The co-axial transformer is configured as bipolar output.
- The pulser is located outside tunnel and ten 50 Ω cables with length more than 30m are applied to connect with kicker.
- Matching terminal resistor is 10Ω.

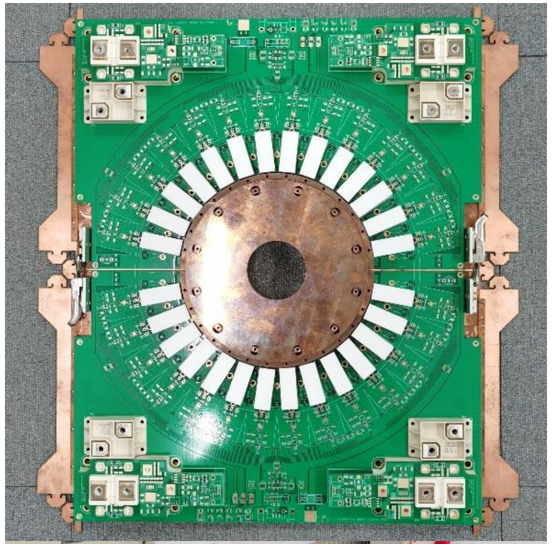
J. Chen

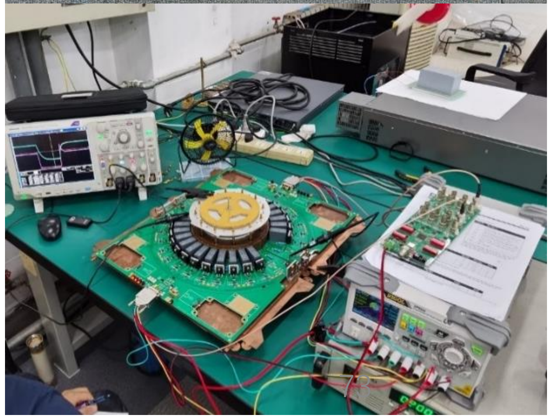








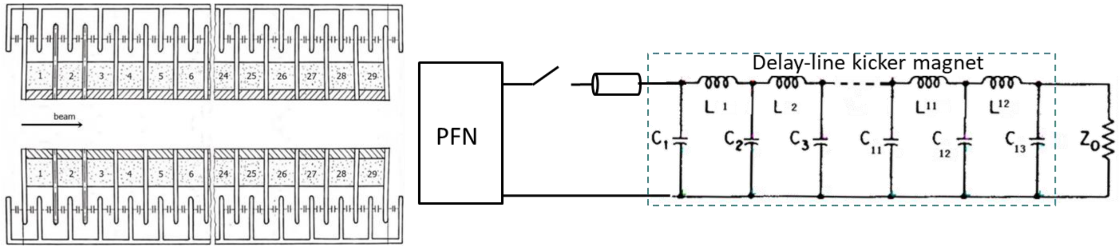


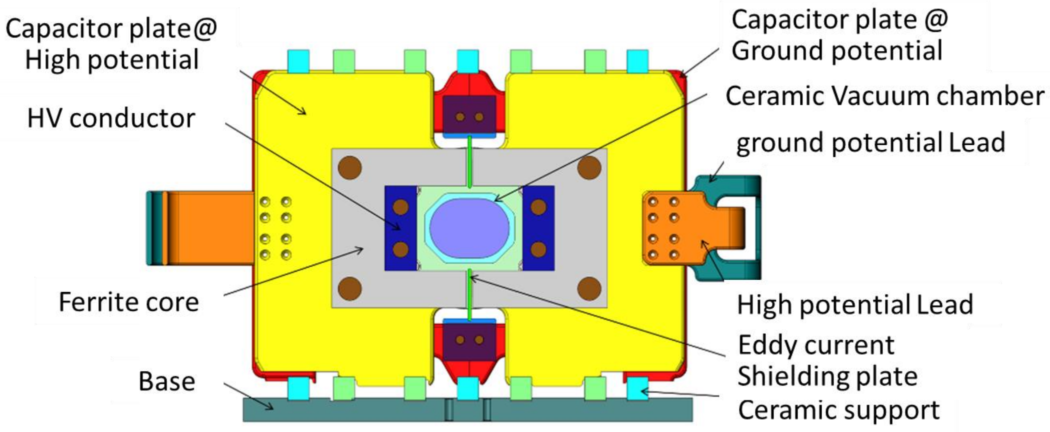


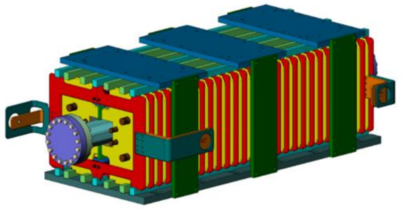
Ferrite core kicker & Ceramic Vacuum Chamber

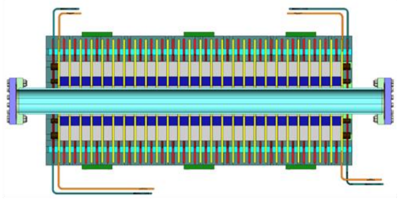
Delay-line dipole kicker system & dual-C type kicker

J. Chen



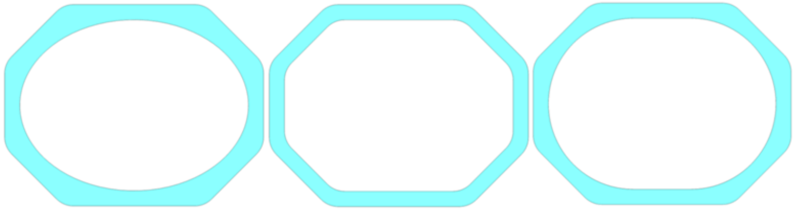




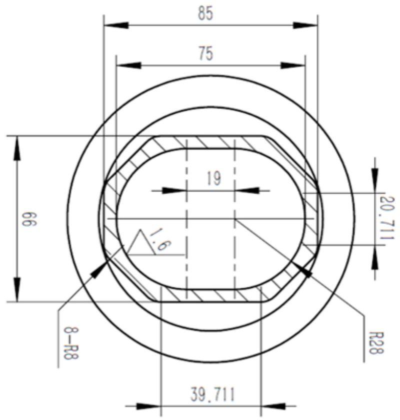


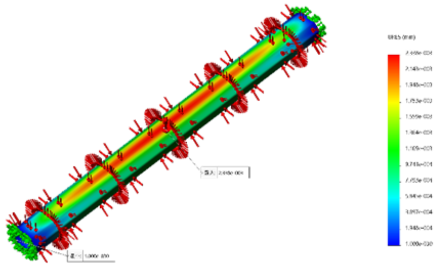
Ceramic Vacuum Chamber

- ceramic vacuum chamber with special pattern metallic coating is key component for outside-vacuum kicker magnet.
- Prototype is in fabrication phase



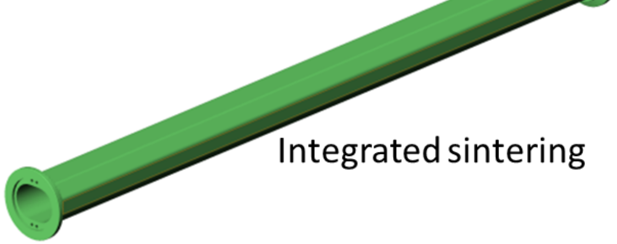
ellipse octagon Race track √





Ceramic material: 99% AL_2O_3

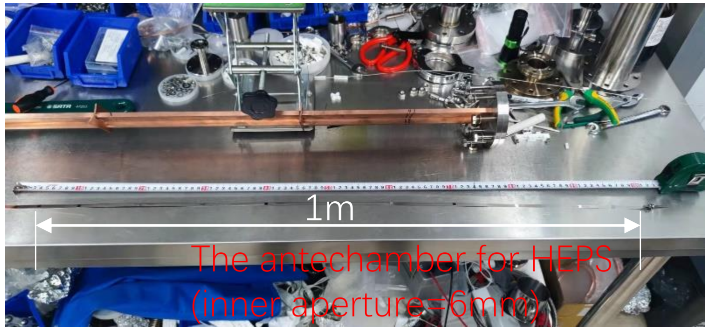
L=1.2m, thickness=5mm



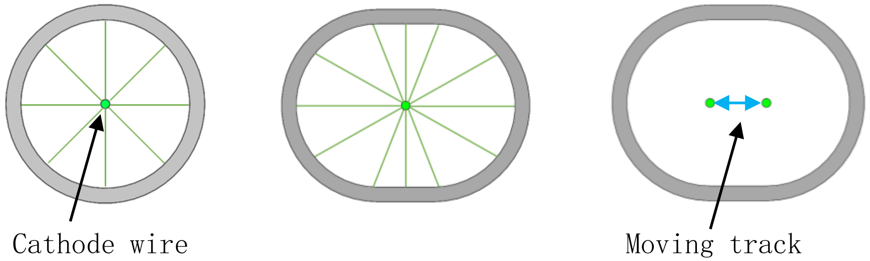
Magnetron Sputtering Coating Prepare

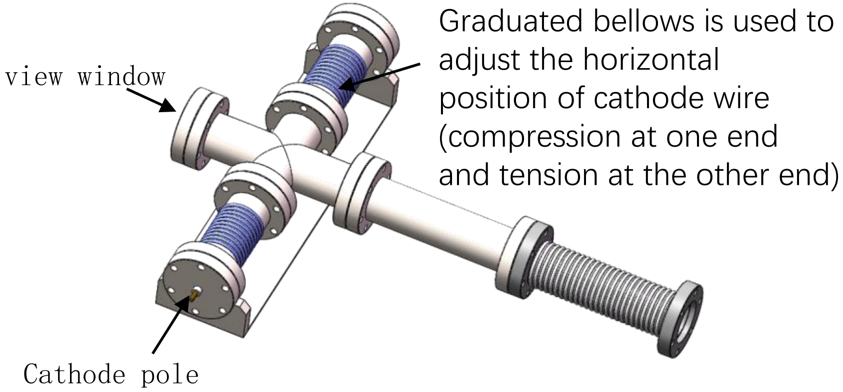
J. Chen

- According to the experience of coating, the cathode target discharge is unstable for long vacuum chamber more than 600mm and it is easy to cause ignition or local film formation failure.
- Sectional coating method by a movable solenoid is proposed for our 1.2m ceramic vacuum chamber. The coating experiment shows uniform coating achieved in one antechamber of 1m.



- In order to obtain uniform coating inner racing track shape vacuum chamber, a horizontal movable cathode wire target solution is proposed.

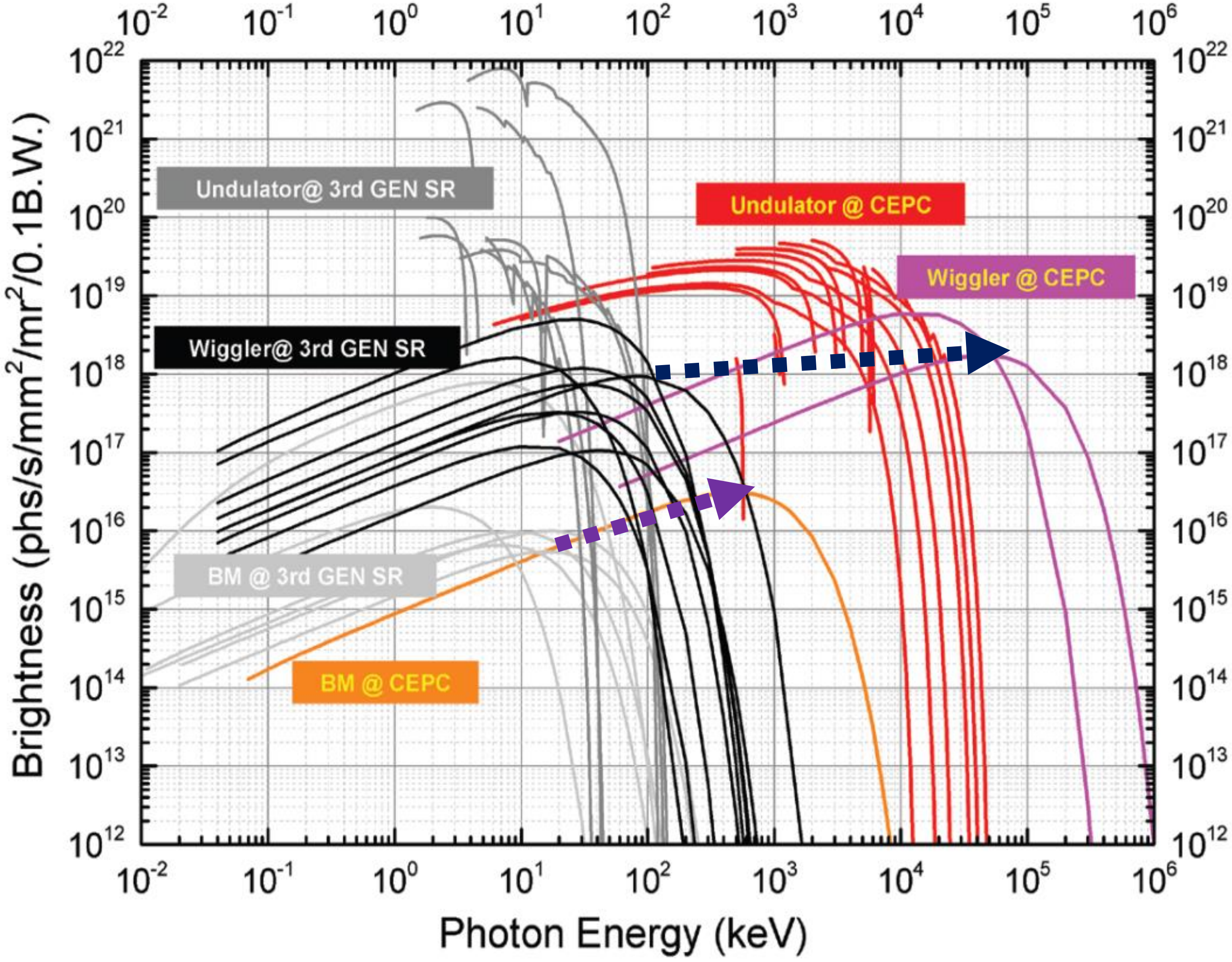




CEPC Extension

- High Energy Gamma Source
- Superconducting High Field Magnets
- Plasma Acceleration
- Installation & Alignment strategy
- CIPC

High Energy Gamma Source



$$\rho[\mathrm{m}] = 3.3\, E_e\,[\mathrm{GeV}]/B[\mathrm{T}]$$

$$\omega_c = \frac{3}{2}\gamma^3\omega_\rho = \frac{3\gamma^3 c}{2\rho}$$

$$\frac{d\dot{\mathscr{F}}}{d\varphi} = 2.46 \times 10^{13}\, E_e\,[\mathrm{GeV}]\, I[\mathrm{A}]\, G_1(\omega/\omega_c)$$

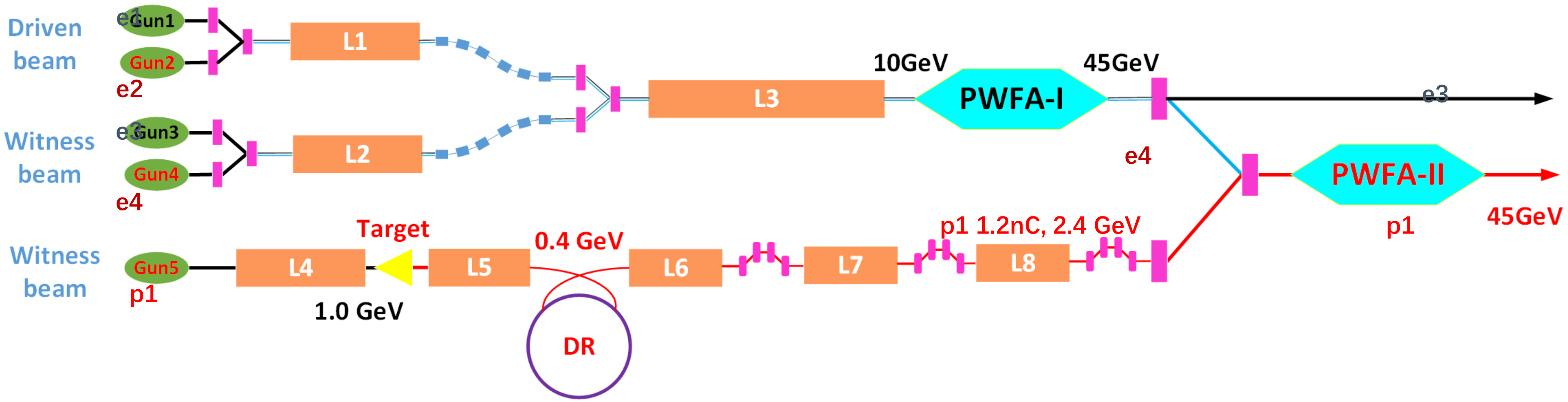
$$G_1(y) = y\int_y^\infty K_{5/3}(y')\,dy'$$

$$G_1(\omega/\omega_c) \approx \begin{cases} (\omega/\omega_c)^{1/3} & (\omega \ll \omega_c) \\ \exp\left(-\dfrac{\omega}{\omega_c}\right) & (\omega \gg \omega_c) \end{cases}$$

- **SR crucial energy proportional to beam energy square**
- **SR flux proportional to beam energy**
- **120GeV electron energy will generate higher than 100 MeV SR photons with sufficient brightness**

CEPC Plasma Injector Option

Conceptual Design and parameters:



	e1/e3 Before PWFA-I	e3 After PWFA-I	e2/e4 Before PWFA-I	e4 After PWFA-I	p1 Before PWFA-II	p1 After PWFA-II	Booster Requirement
Energy (GeV)	10/10	45.5	10/10	45.5	2.4	45.5	45.5
Bunch Charge (nC)	5.8/0.84	1	15/4.5	>3	1.2	1	0.78
Bunch length (ps)	2/0.257	<1	3/0.7	<1	0.07	<1	<10
Energy Spread	~/0.2%	~1%	~/0.2%	1%	0.2%	~1%	0.2%
E_{normal} (μm·rad)	<20*/<100	~100	<50*/<100	~100	<50	~100	<800
Bunch Size (μm)	3.87/8.65	<20	30/20	<20	20	<20	<2000

PWFA type plasma accelerator technology:

- Positron acceleration
- Cascaded accelerating for super high energy
- High bunch charge ~10nC

High Field Dipoles with HTS for SppC

Q. Xu

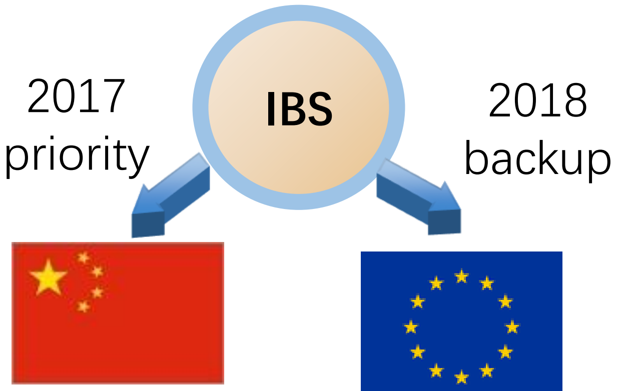
Scientific merit

-Even high collision energy is expected with the CEPC tunnel: **SPPC**

-Energy is proportional to the dipole field

$$E[GeV] = 0.3 \times B[T] \times \rho[m]$$

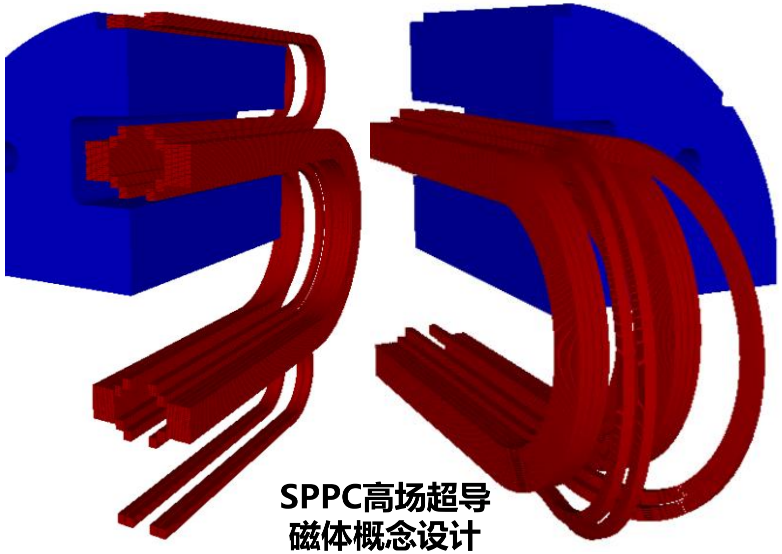
HTS Magnet is the only measure for ultra high field (12～24 T)、IBS has a bright prospect。



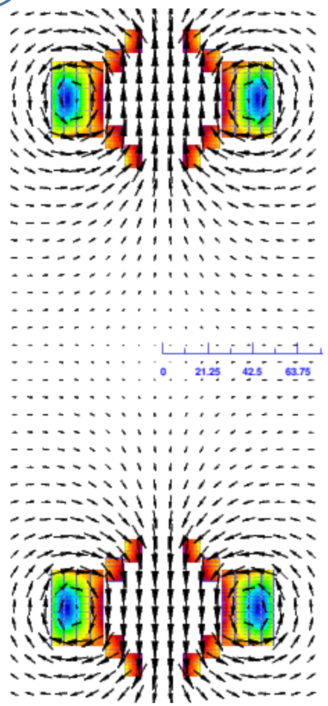
CEPC
SPPC

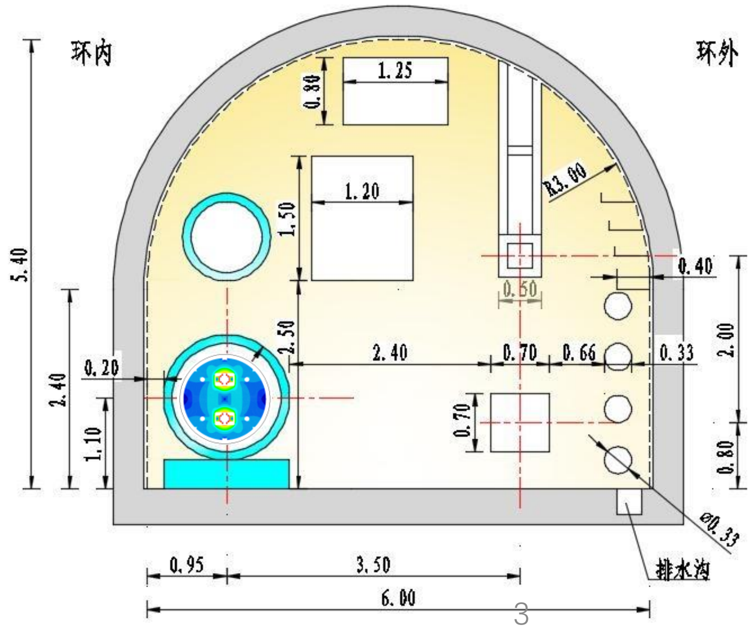
FCC

Thousands of HTS magnet are needed for SPPC or FCC



SPPC高场超导磁体概念设计



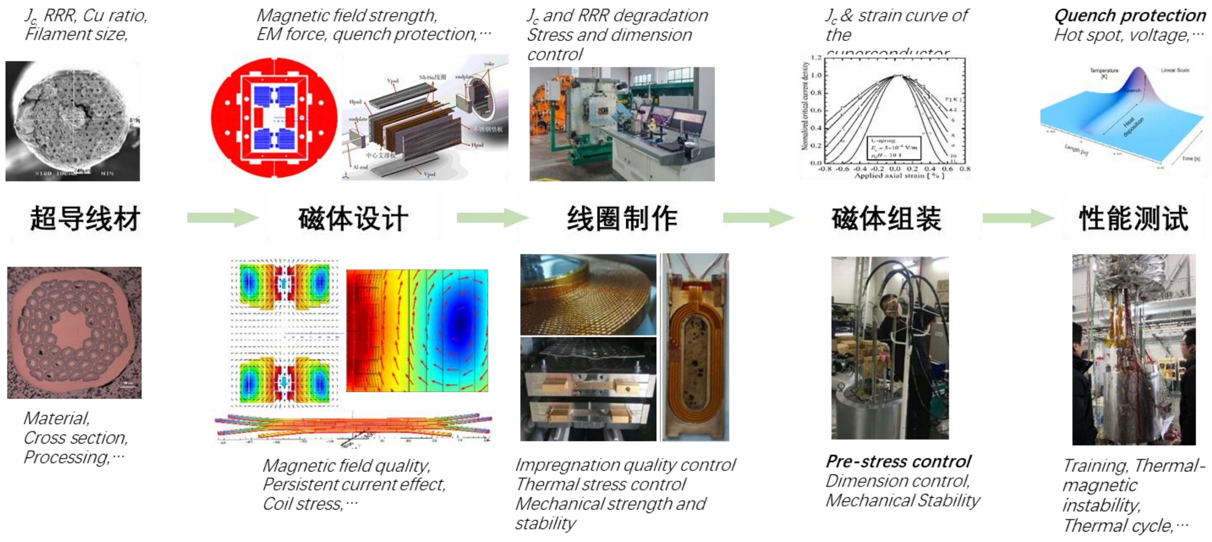


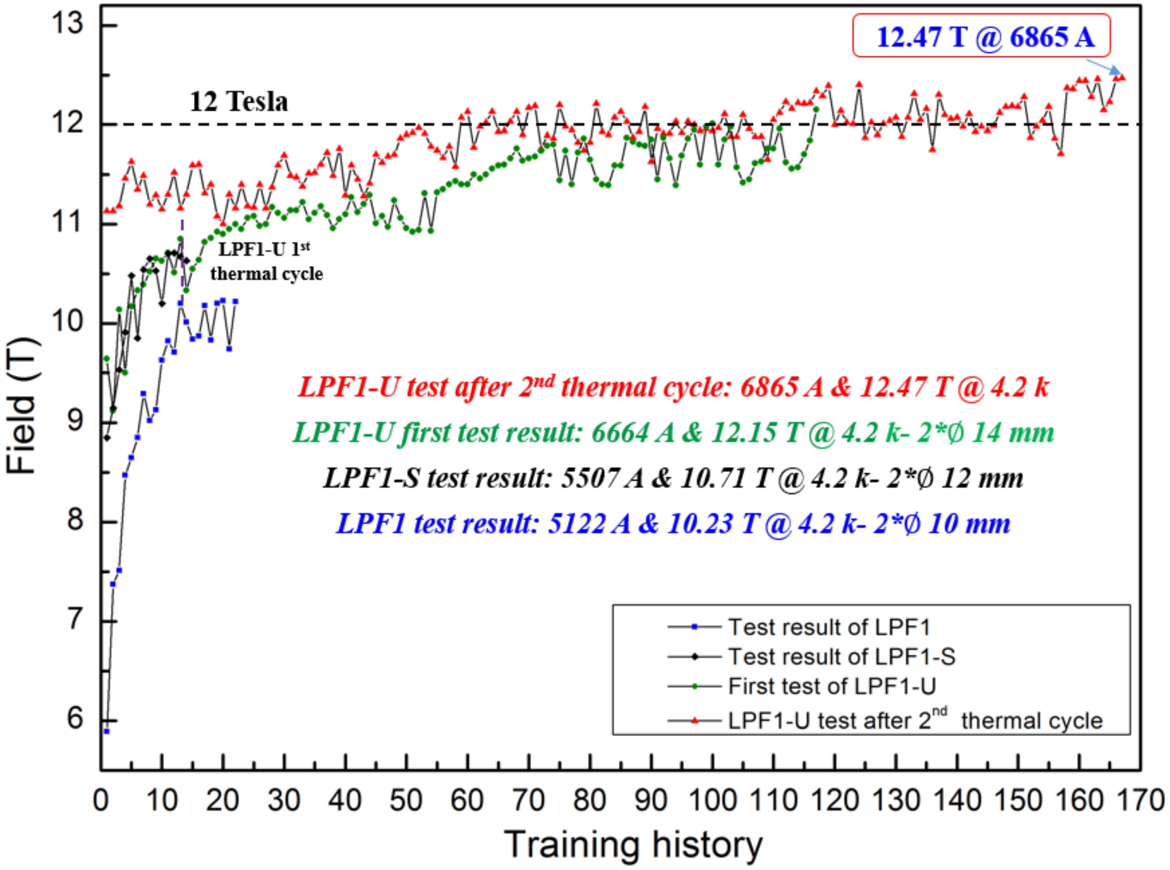
SPPC隧道截面布局

HTS Magnet Fabrication Procedure

Q. Xu

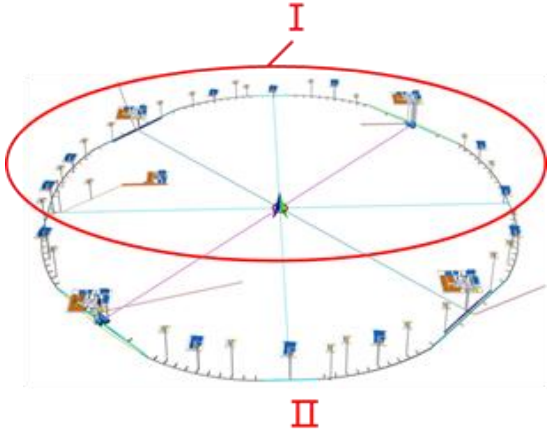
- Dual aperture superconducting dipole achieves 12.47 T at 4.2 K
- Entire self-fabrication in China
- The next step is reaching 16-19T field, aiming at breaking the world record of 16 T by CERN



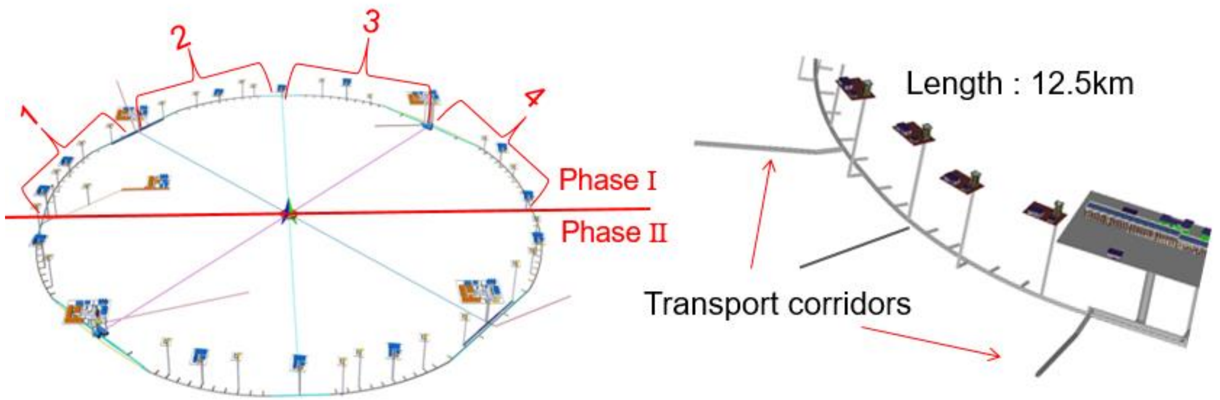


Installation Strategy

X. Wang



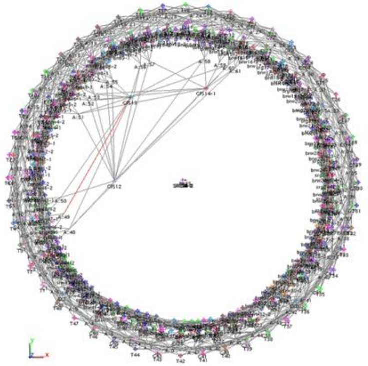
2 phases civil construction scheme => 2 phases installation

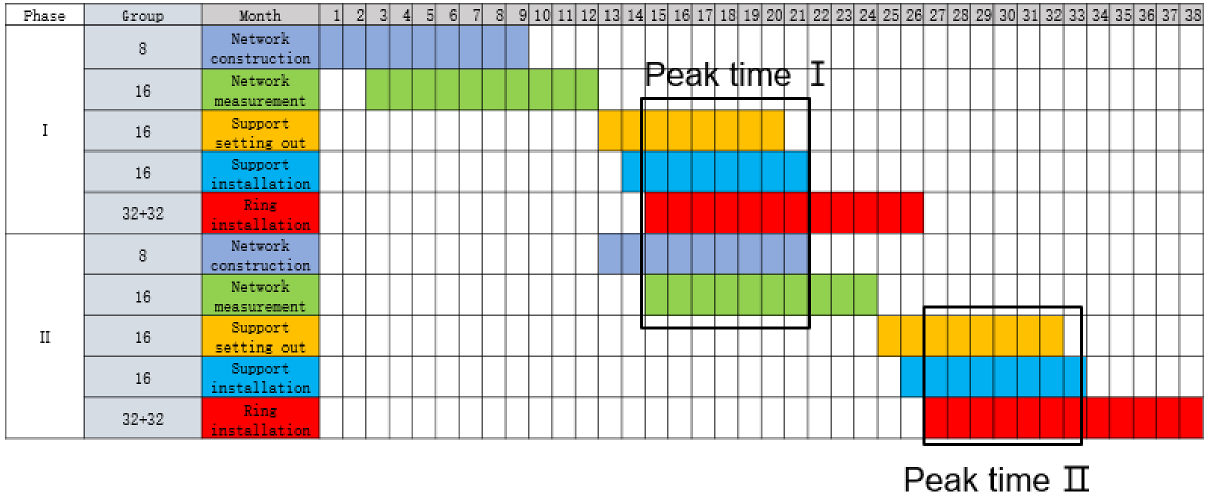


- Each phase: installation parallel process in four sections
- Peak time Ⅰ, 64 alignment and 56 installation groups
- Peak time Ⅱ, 48 alignment and 48 installation groups

- **Procedure:**

1. Control network construction.
2. Control network measurement
3. Support setting out and installation
4. Component fiducialization
5. Component installation and alignment.
6. Smooth alignment





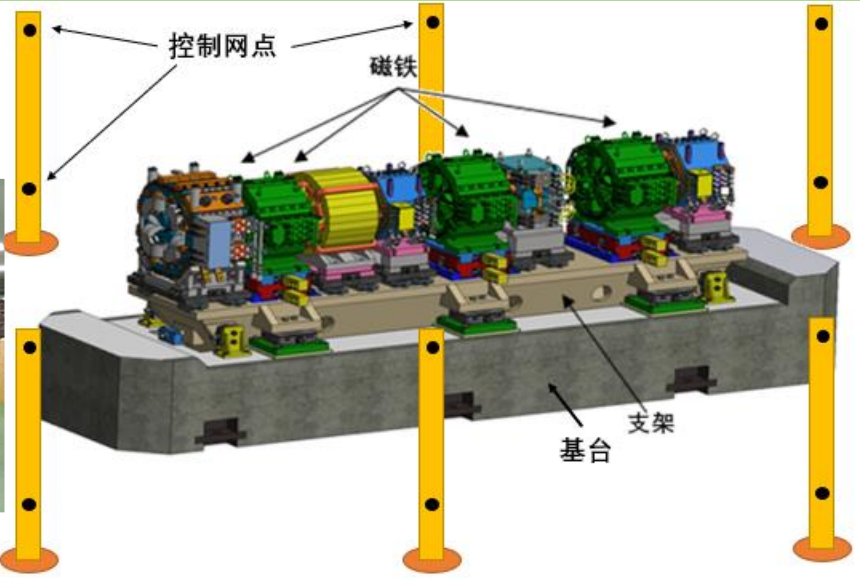
Alignment Strategy

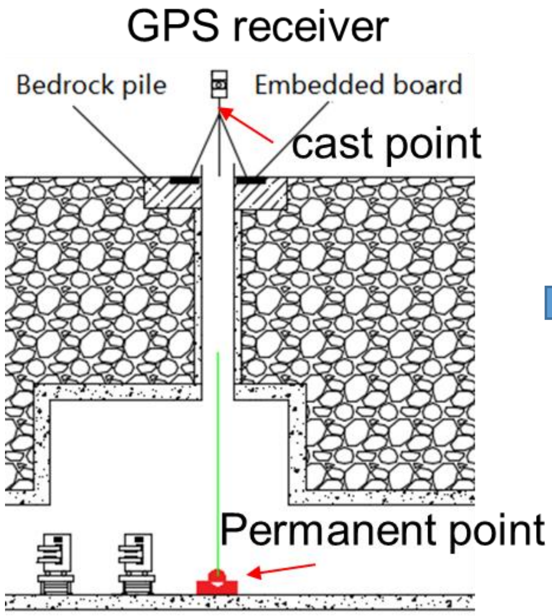
X. Wang

- Clear Alignment accuracy requirement

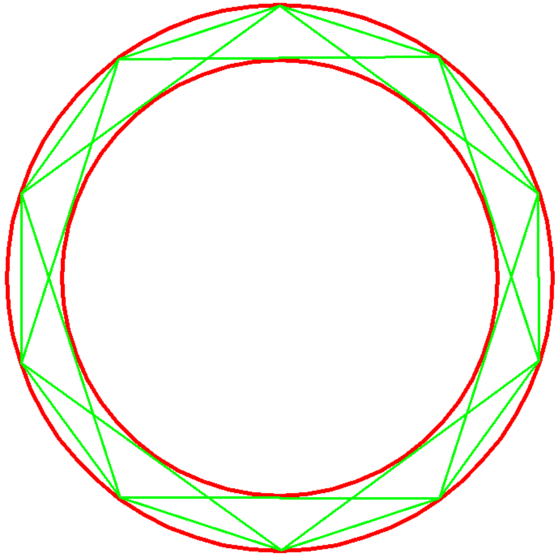
Component	Transversal/mm	Vertical /mm	Longitudinal/mm	Pitch /mrad	Yaw /mrad	Roll /mrad
Arc Dipole	0.1	0.1	0.1	0.1	0.1	0.1
Arc Quadrupole	0.1	0.1	0.1	0.1	0.1	0.1
Arc Sextupole	0.1	0.1	0.1	0.1	0.1	0.1
IR Quadrupole	0.05	0.05	0.05	0.05	0.05	0.05
IR SCQ	0.05	0.05	0.05	0.05	0.05	0.05
IR Sextupole	0.05	0.05	0.05	0.05	0.05	0.05

Component Pre-alignment

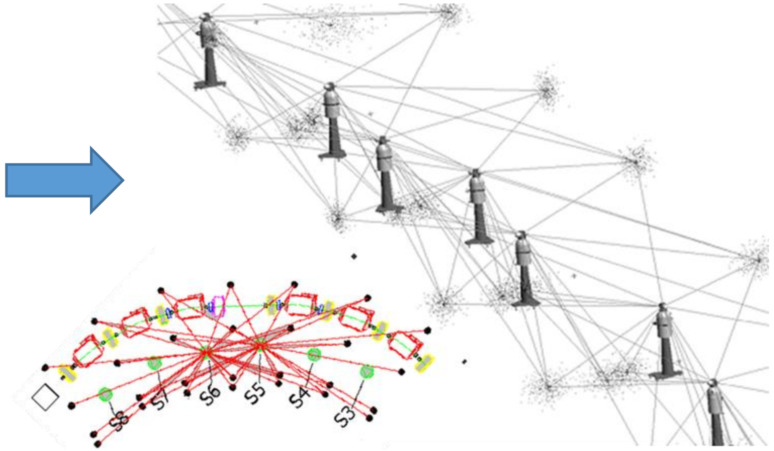




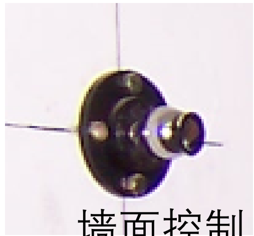
Surface Control network (14Points)



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



Tunnel Control network
(interval of 6 meters)



墙面控制点

地面控制点

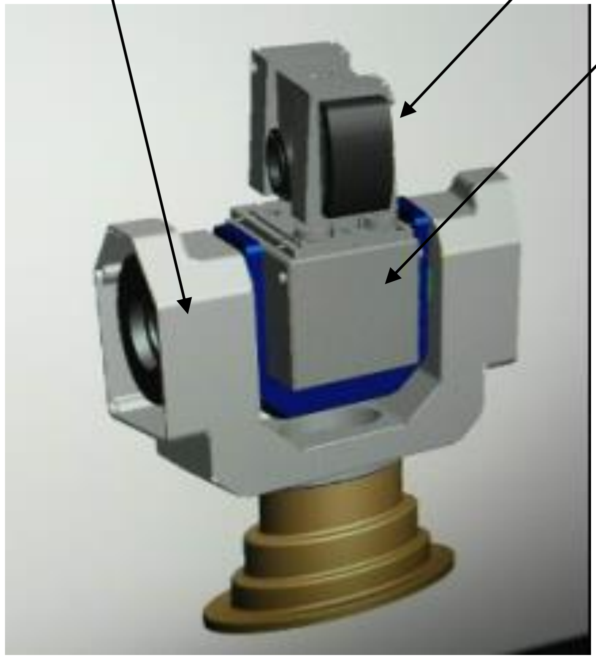
Fast Alignment Device --- Visual Instrument

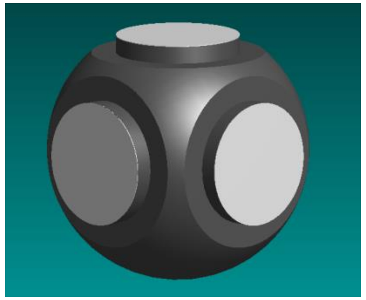
● Visual alignment device

- ➢ Novel concept combining multi-functions
- ➢ Fast alignment

Necessary Development:

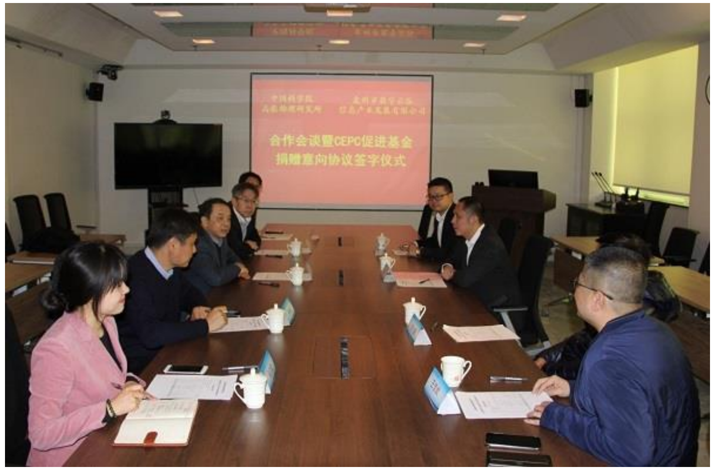
1. Device hardware
2. Alignment strategy
3. Data post procedure





Fiducial target

CEPC Industrial Promotion Consortium (CIPC) Collaboration Status



Established in Nov. 7 , 2017

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

Now:

-Huanghe Company, Huadong Engineering Cooperation Company, and Zhongnan Company on CEPC civil engineering design, site selection, implementation...

-Shenyang Huiyu Company on CEPC MDIRVC design

-Keye Compant on CEPC magntes desgins and SC Quadupole, DR cavity, detector hall...

-. Wuhan University: Alignmnent,

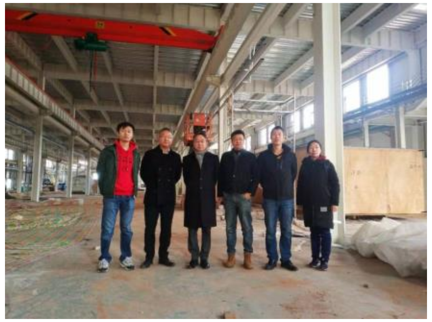
-Kuanshan Guoli on CEPC 650MHz high efficiency klystron

-Huadong Engineering Cooperation Company, on CEPC alignement and installation logistics...

-Beijing Pudaditai company: on Alignment and instatation

2020. 1. 2

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

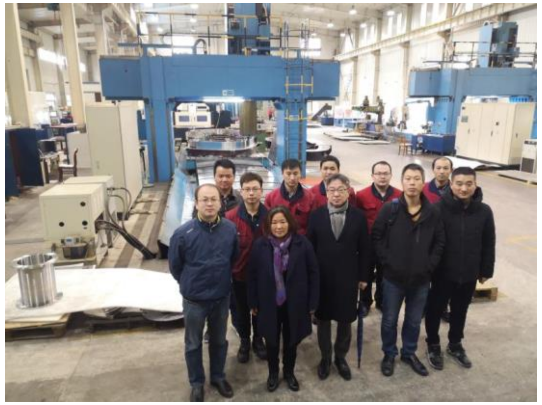


2019. 12. 25-26, Nanchong,

Sichuan Jiutian Vacuum company

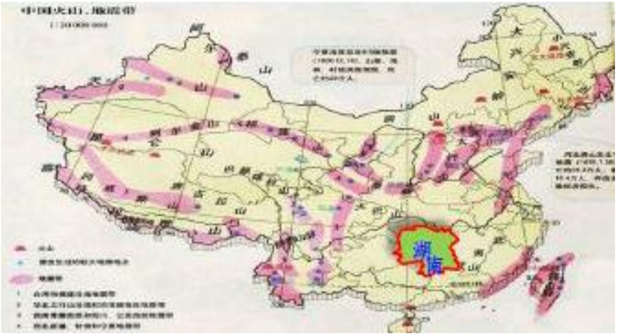
2020. 6. 5

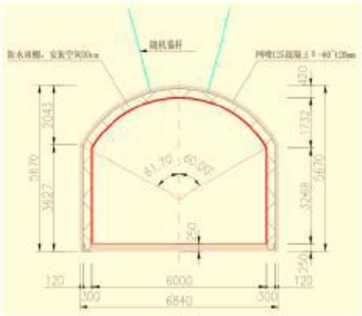
Hefei Keye and Beijing Puda Ditai Company signed CEPC Propmotion Fund Contribution with IHEP



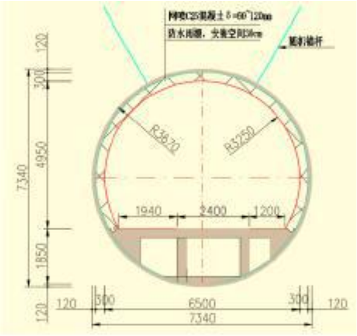
2019. 1218-19 visit Keye Company

CEPC Siting (Changsha as the example)



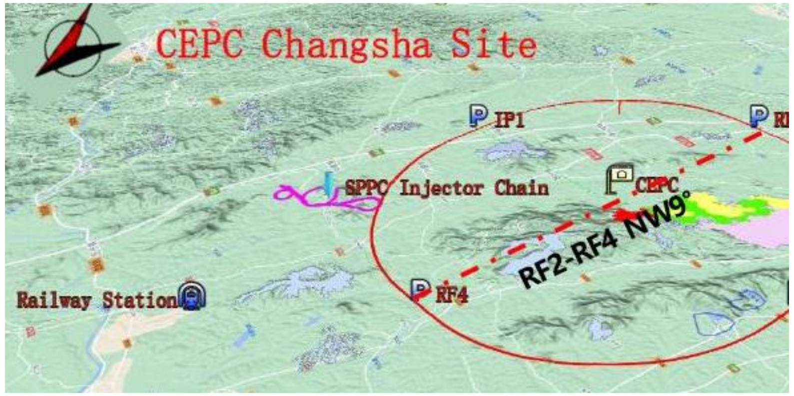


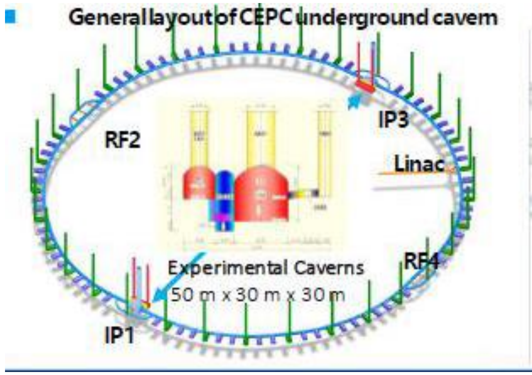
Drill-blast tunnel (6.0m×5.0m)

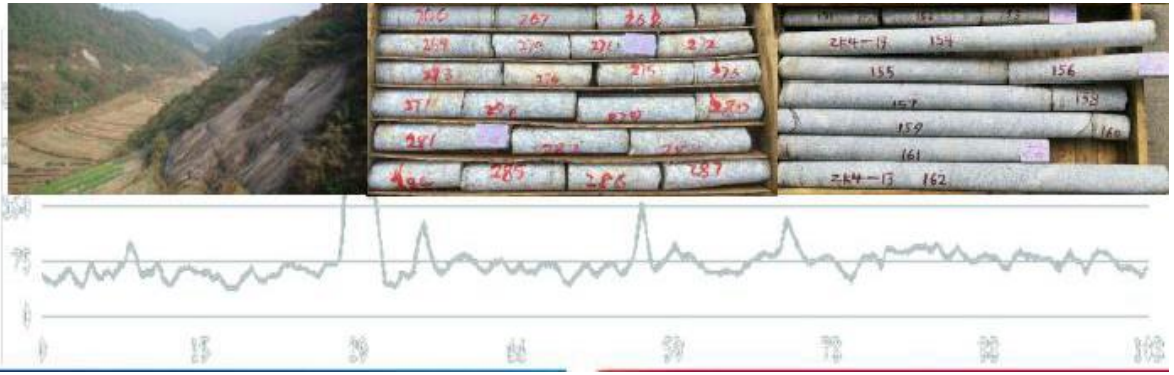


TBM tunnel (D6.5m)

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

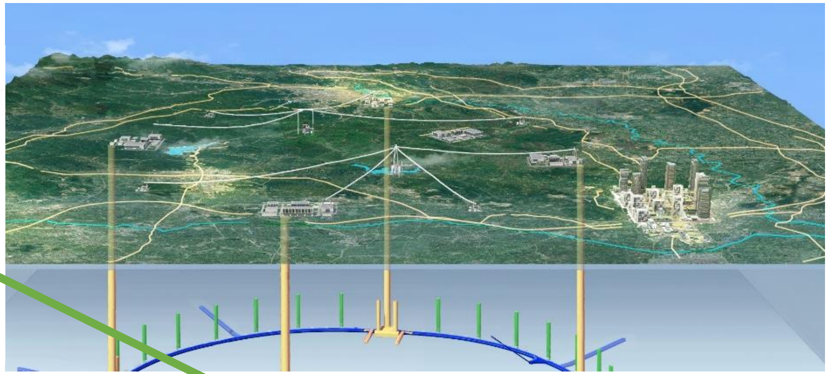


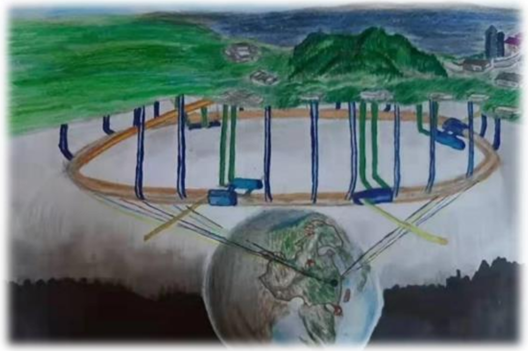




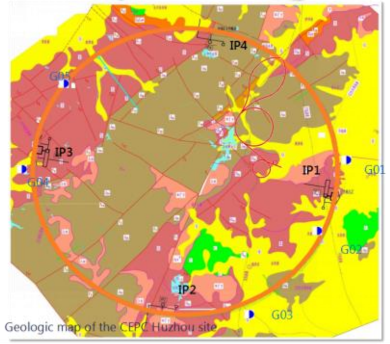
Very good geological condition

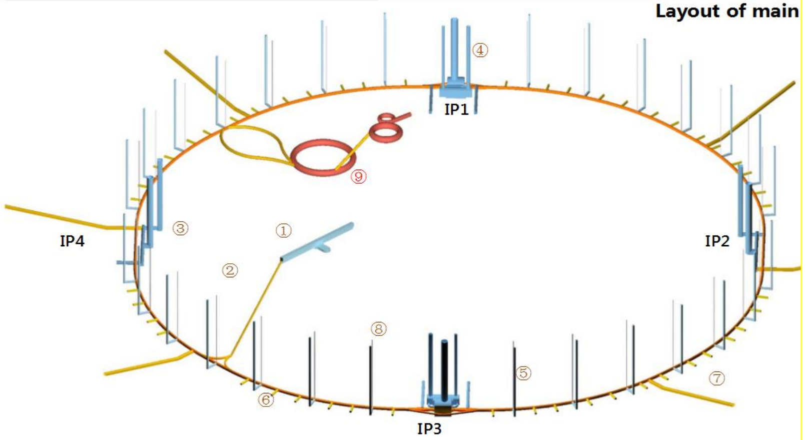
CEPC Siting (Huzhou as the example)





Huadong Company K. Huang





Huzhou site （example）

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

The work that has been done is as follows

- **CEPC report on site selection (Zhejiang Huzhou)**

Answer the questions-Why did CEPC choose huzhou

- **CEPC report on socio-economic assessment**

Answer the questions-Why did huzhou choose CEPC

- **CEPC Technology Design Report on Civil engineering of the first stage**

- **CEPC report on science city concept plan**

Find a comfortable home for scientists

Summary

- The CEPC accelerator parameters optimization, compatible to 50 MW and ttbar energy upgrade, are converging
- Important progress for the key hardware R&D was made, based on which the TDR aims to be finished at the end/beginning of 2022/2023
- CEPC siting, civil engineering, installation strategy and CIPC collaboration are under progress
- CEPC international collaboration progresses well
- Preparation for EDR is underway

Acknowledgements

- Thanks to the CEPC-SppC accelerator team’s hardworks
- Special thanks to the CEPC IAC and IARC’s critical comments and warmth encouragement