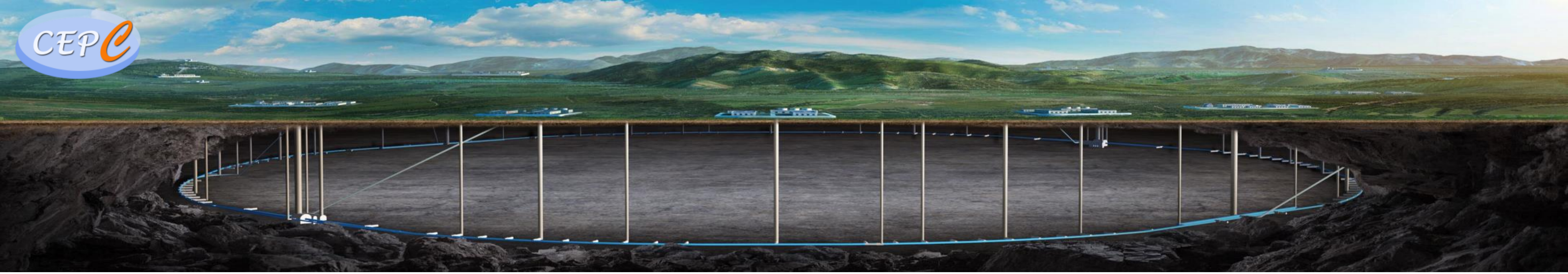

CEPC Accelerator Status Overview

Yuhui Li

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

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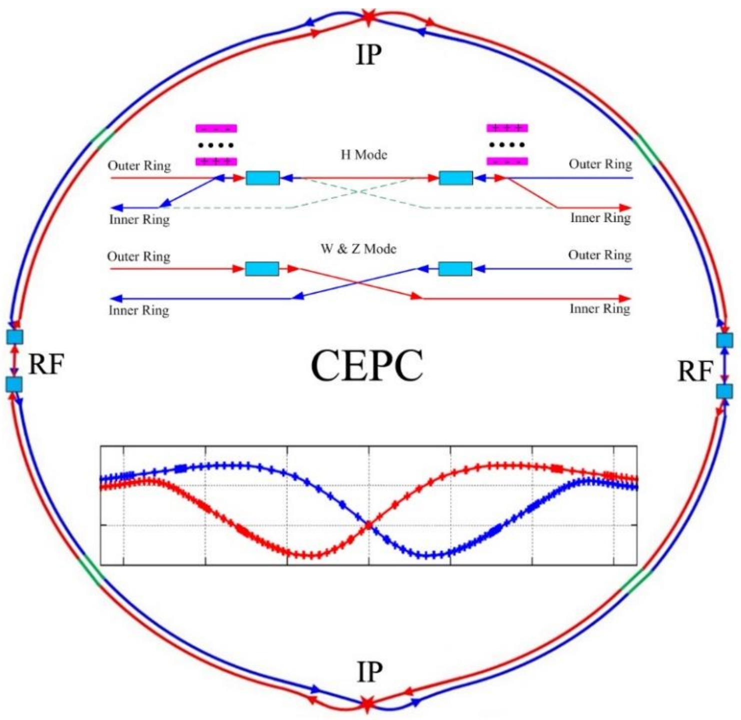
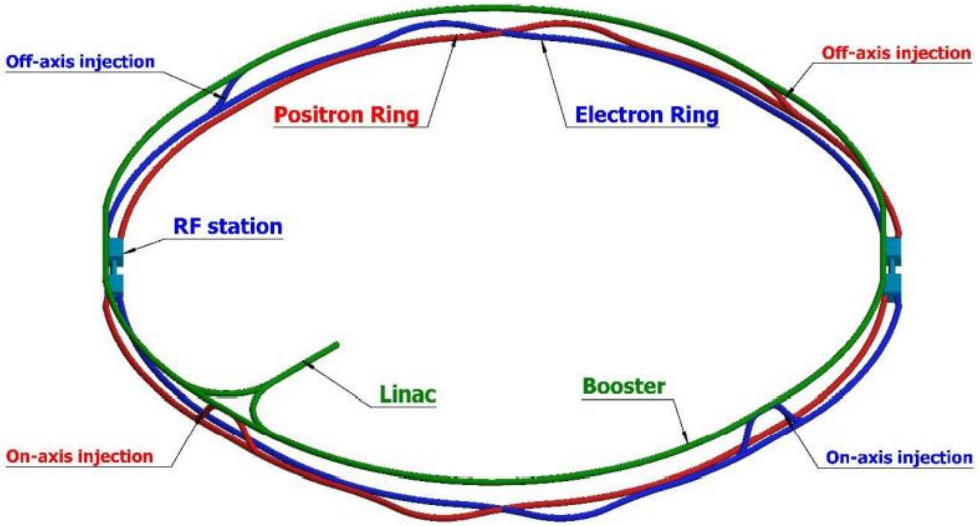
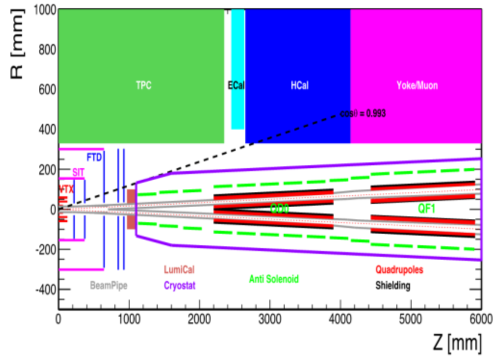
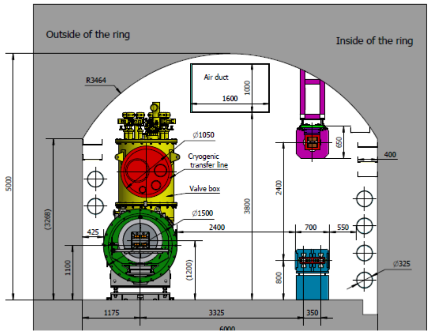
CEPC High TDR Layout

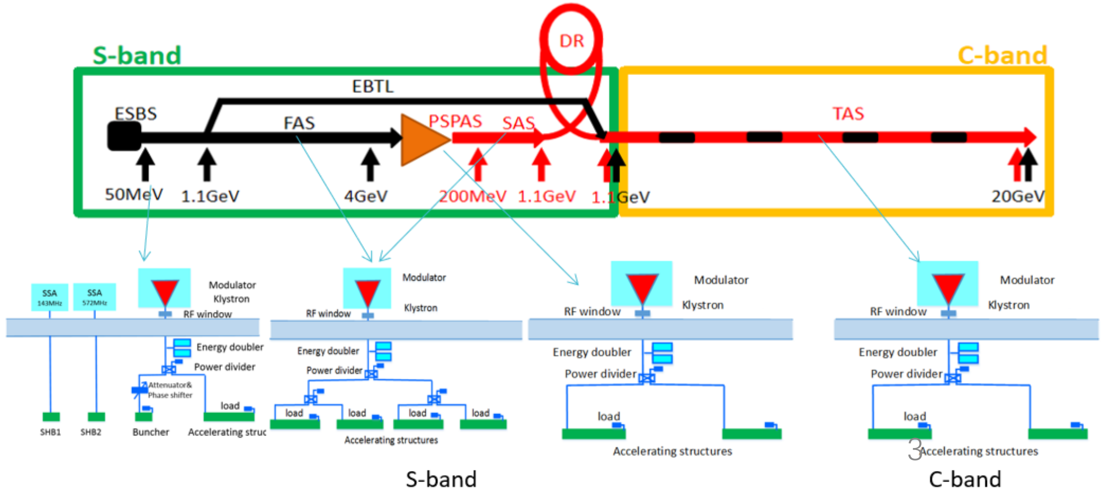






TUNNEL CROSS SECTION OF THE ARC AREA





- CEPC as a Higgs Factory： ttbar, H, W, Z, followed by a SppC ~100TeV
- 100 km collider and booster ring
- Maximum energy of 180GeV for ttbar
- 20GeV extraction energy by Linac

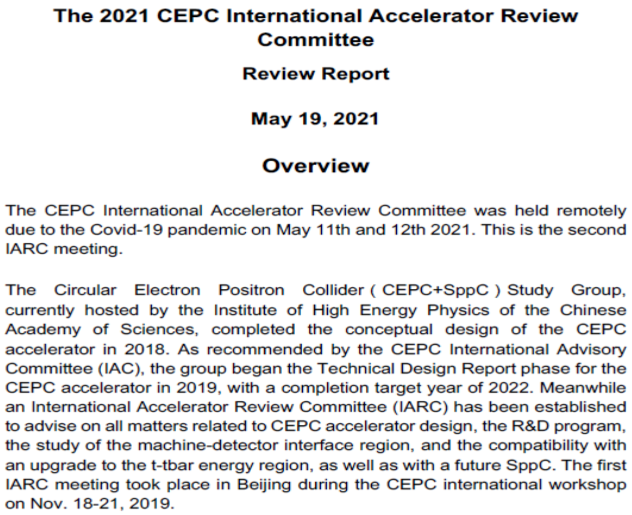
Accelerator Review by IARC

Two International Accelerator Review Committee (IARC) meeting organized each year to review the progress of CEPC accelerator preparation

- 11 talks were presented in May. 2021
- 22 talks were given in Oct. 2021

IARC report is written by IARC for every meeting. CEPC accelerator team answers it by careful study

- The accelerator progress, including physical design and hardware key technology R&D is congratulated by the committee
- Weak points are pointed out which are essentially import to guide the study.



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.

The 2019 CEPC International Accelerator Review Committee

Review Report

December 6, 2019

Overview

The review meeting overlapped with the 2019 International Workshop on High Energy Circular Electron Positron Collider (CEPC). The International Accelerator Review Committee (IARC) reviewed the talks in the accelerator and machine-detector interface (MDI) sessions of the workshop. Talks not specific to CEPC have been omitted.

The IARC was pleased to see the progress on the work performed up to now toward the TDR. The quality of the work performed, how most important issues were addressed, even if not already solved, and how there is still design work on-going to increase the luminosity performances at Higgs and Z were highly appreciated. Some suggestions for improving the format of the review are summarised in the final section.

The IARC is pleased to see efforts for several improvements over the CDR. The IARC would like to thank Jie Gao, Dou Wang, Zhaoru Zhang, and the CEPC team for their help and hospitality during the meeting.

Collider ring parameters in CDR and High Luminosity

- ttbar energy is reached
- Luminosity is increased significantly

	Higgs	*W*	*Z* （3T）	*Z* （2T）
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Half Crossing angle at IP (mrad)	16.5			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
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	
Bending radius (km)	10.7			
Momentum compact (10^{-5})	1.11			
β function at IP β_x^* / β_y^* (m)	0.36/0.0015	0.36/0.0015	0.2/0.0015	0.2/0.001
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016
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**

	ttbar	Higgs	W	Z
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	30			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	180	120	80	45.5
Energy loss per turn [GeV]	9.1	1.8	0.357	0.037
Piwinski angle	1.21	5.94	6.08	24.68
Bunch number	35	249	1297	11951
Bunch population [10^10]	20	14	13.5	14
Beam current [mA]	3.3	16.7	84.1	803.5
Momentum compaction [10^-5]	0.71	0.71	1.43	1.43
Beta functions at IP (bx/by) [m/mm]	1.04/2.7	0.33/1	0.21/1	0.13/0.9
Emittance (ex/ey) [nm/pm]	1.4/4.7	0.64/1.3	0.87/1.7	0.27/1.4
Beam size at IP (sigx/sigy) [um/nm]	39/113	15/36	13/42	6/35
Bunch length (SR/total) [mm]	2.2/2.9	2.3/3.9	2.5/4.9	2.5/8.7
Energy spread (SR/total) [%]	0.15/0.20	0.10/0.17	0.07/0.14	0.04/0.13
Energy acceptance (DA/RF) [%]	2.3/2.6	1.7/2.2	1.2/2.5	1.3/1.7
Beam-beam parameters (ksix/ksiy)	0.071/0.1	0.015/0.11	0.012/0.113	0.004/0.127
RF voltage [GV]	10	2.2	0.7	0.12
RF frequency [MHz]	650	650	650	650
HOM power per cavity (5/2/1cell)[kw]	0.4/0.2/0.1	1/0.4/0.2	-/1.8/0.9	-/-/5.8
Longitudinal tune Qs	0.078	0.049	0.062	0.035
Beam lifetime (bhabha/beamstrahlung)[min]	81/23	39/40	60/700	80/18000
Beam lifetime total [min]	18	20	55	80
Hour glass Factor	0.89	0.9	0.9	0.97
Luminosity per IP[1e34/cm^2/s]	0.5	5.0	16	115

Key parameters of high luminosity scheme

C. Yu, Y. W. Wang, Y. Zhang, S. Bai, Y. Zhu, D. Wang, J. Gao et al

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**

- To make the lattice robust and provide good start point for DA

ARC region for all modes

Y. W. Wang

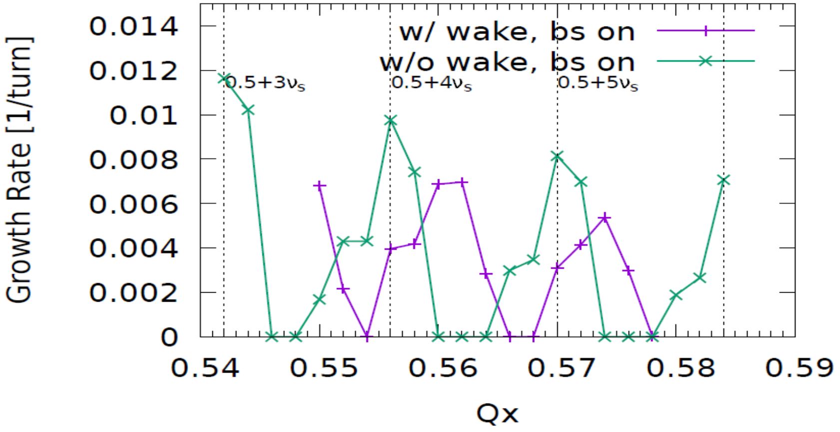
- Z and W modes need larger momentum compaction factor αp and thus larger emittance εx, Qs
  - To suppress the impedance induced instability at Z mode
  - To increase stable tune area if considering beam-beam effect and impedance consistently at W and Z modes

Microwave instability

Na Wang,
CEPC Day, March 2020

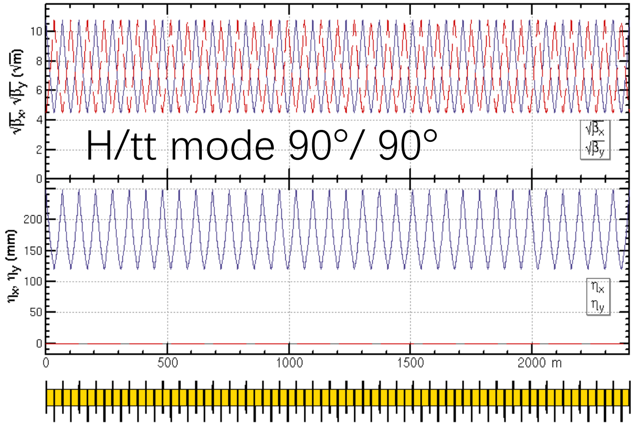
$$I_{th} = \frac{\sqrt{2\pi}\alpha_p \frac{E}{e}\sigma_{e0}^2\sigma_l}{R\left|\frac{Z_\parallel}{n}\right|_{eff}}$$

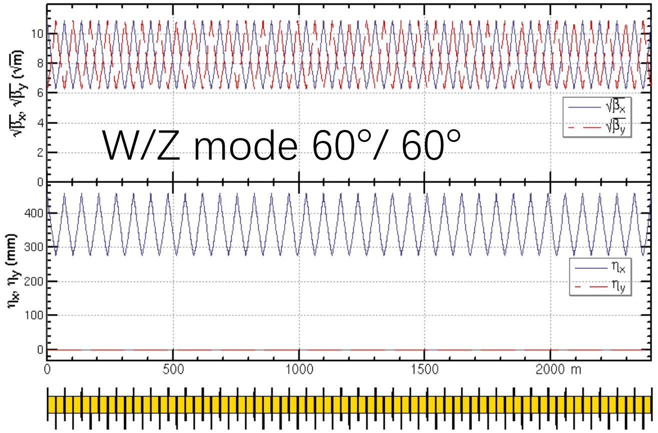
stable tune area with both beam-beam and impedance (Z mode 90/90)



Yuan Zhang

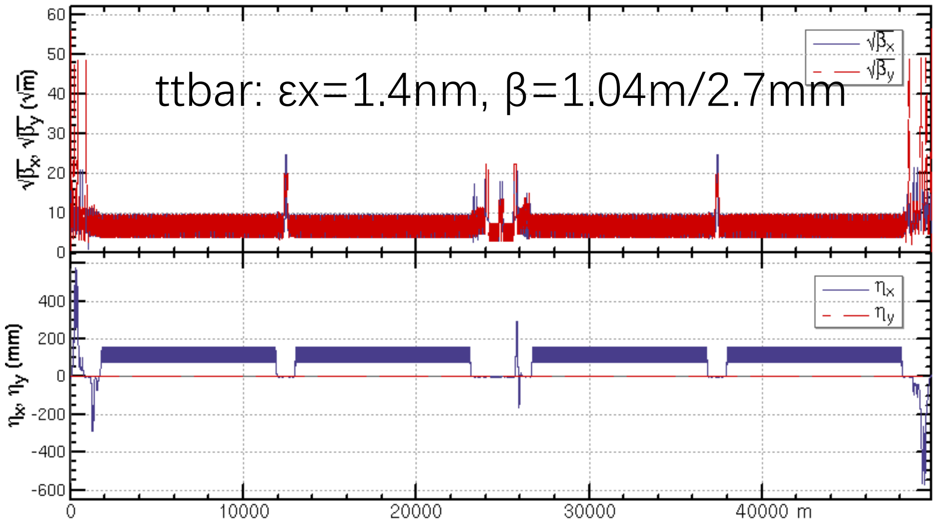
- **Phase advance for H/tt: 90° for W&Z: 60°**

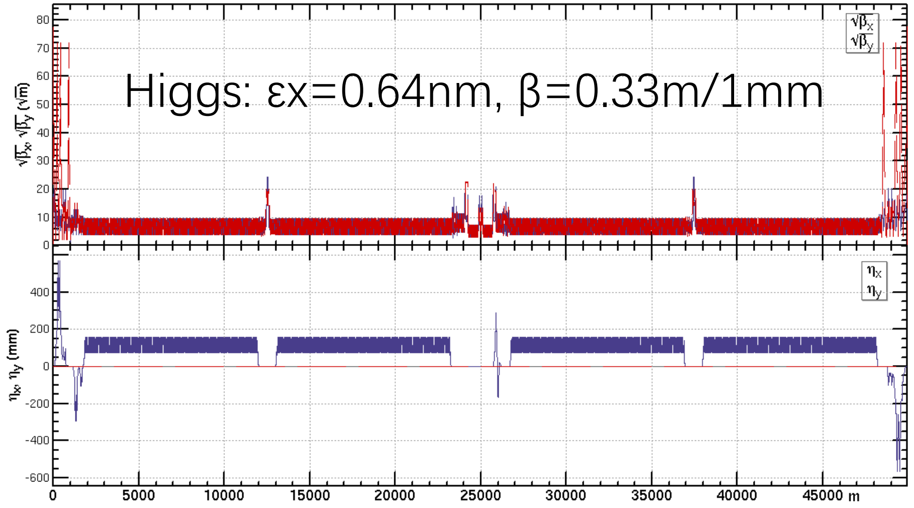


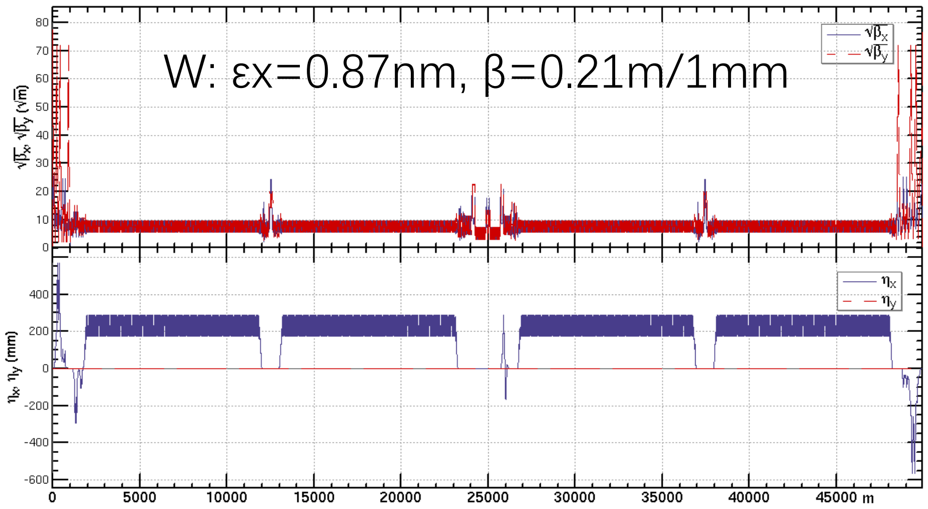


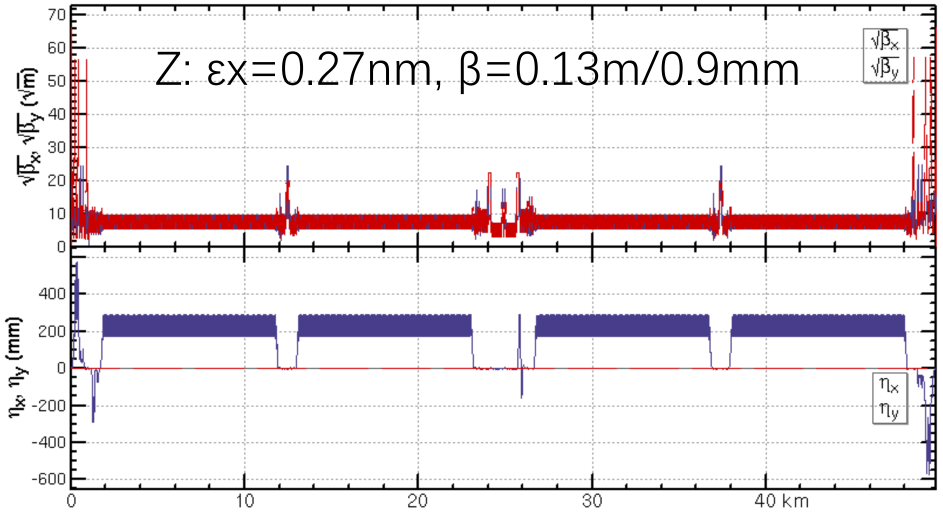
Lattice of Half Ring

Y. W. Wang









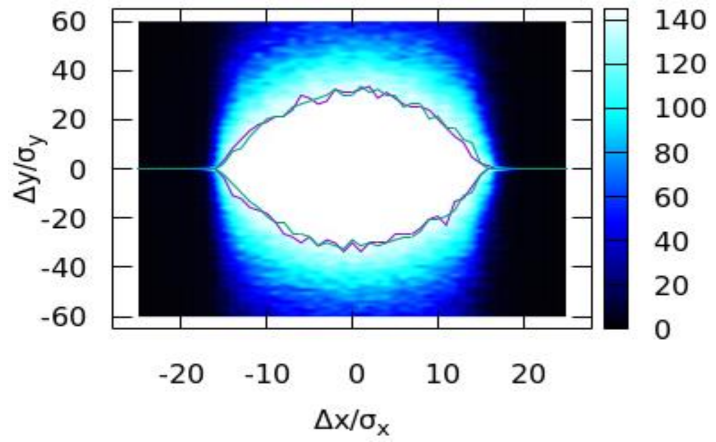
The new RF layout has not been implemented in these lattices.

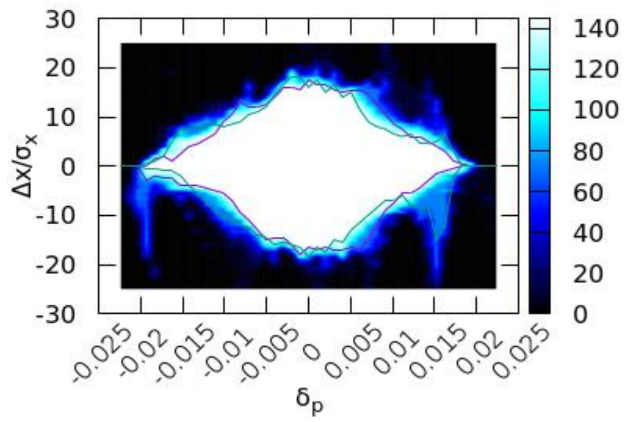
Dynamic Aperture for ttbar&Higgs

Y. W. Wang

- Higgs DA achieved 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
  - will be further optimized with other variables
- Totally 256 families of arc sextupoles.

Higgs



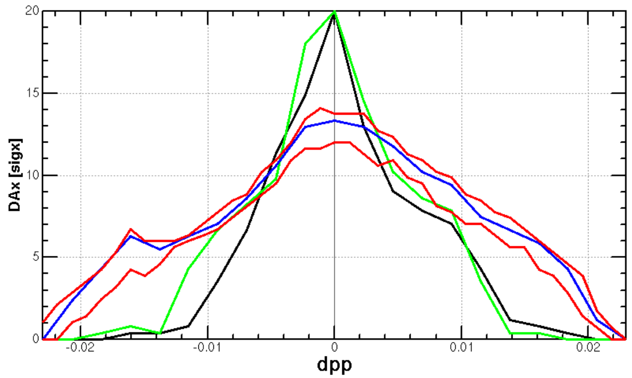


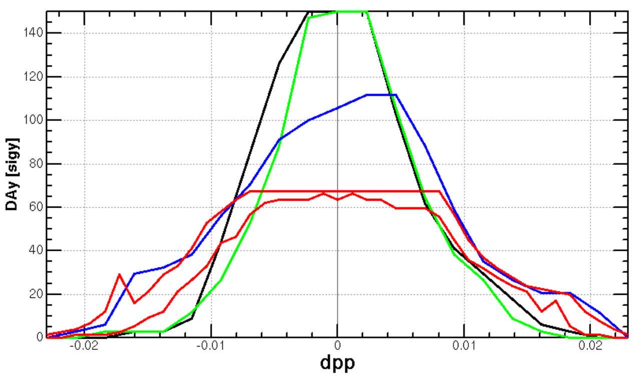
Achieved (w/o error): $16\sigma_x \times 32\sigma_y \times 1.9\%$

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

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

ttbar



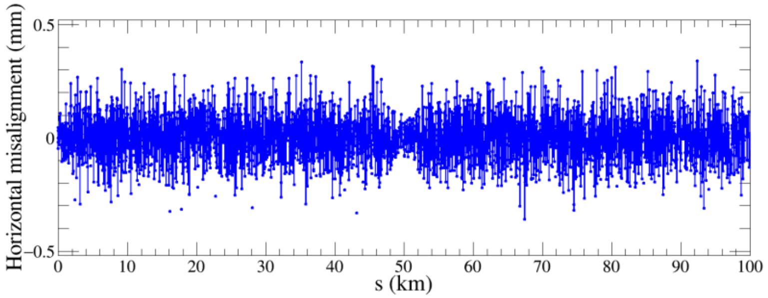


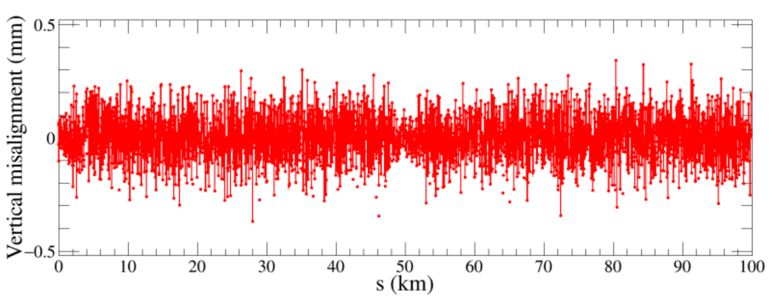
w/o RF
w/o rad
w/ damp
w/ damp+fluc (max, min)
turns for one transvers damping time
Initial phase=0

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	





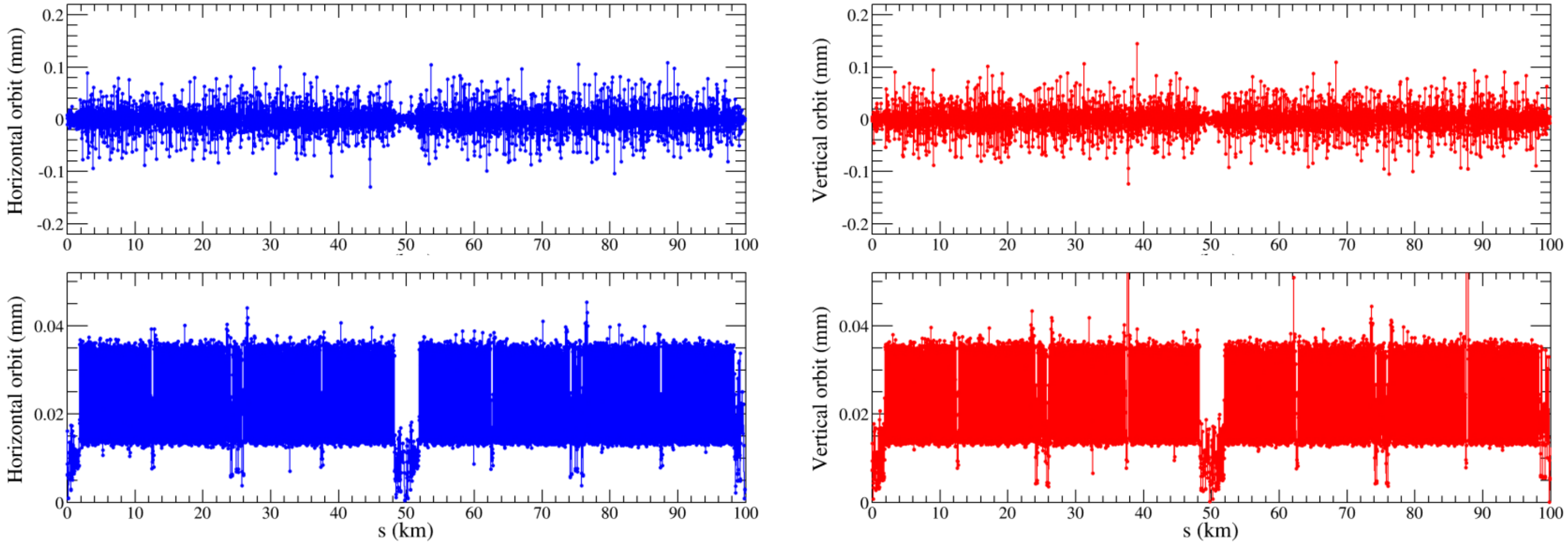
- The high luminosity lattice is much more sensitive to imperfections
- 1000 lattice seeds are generated for further correction.

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）



$RMS_{COD} < 0.05\ mm$

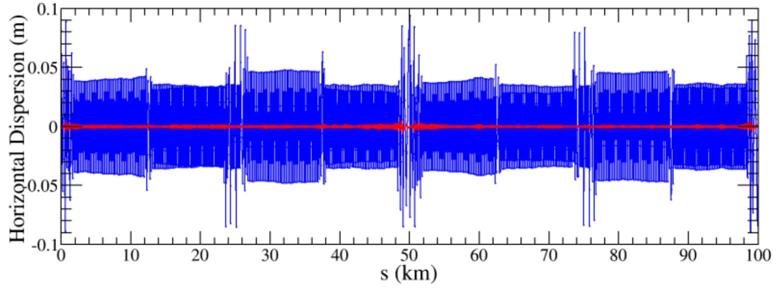
Dispersion Correction

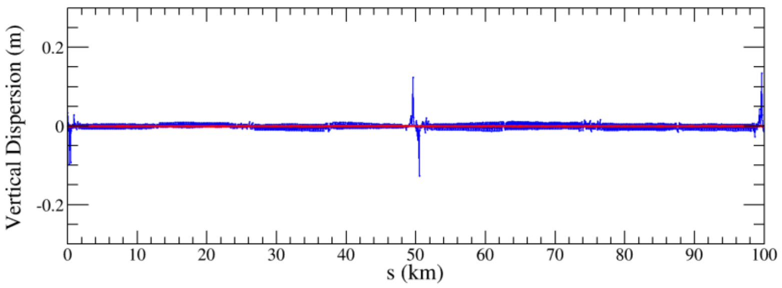
B. Wang

Dispersion free steering principle (DFS): θ_c

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

Result of one seed





$\vec{u}$: Orbit vector

$\vec{D}_u$: Dispersion vector

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

α: Weight factor

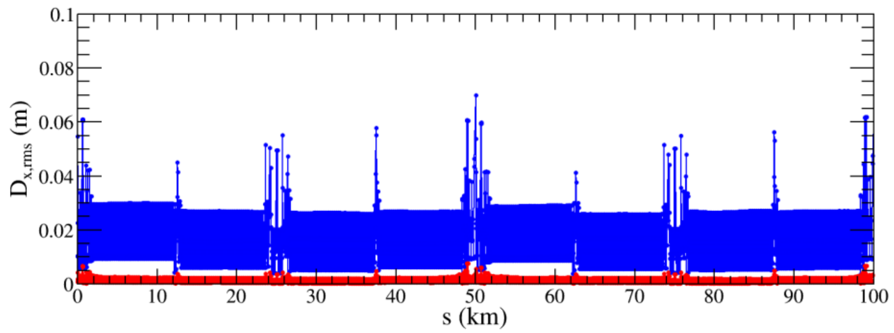
A: Orbit response matrix

B: Dispersion response matrix

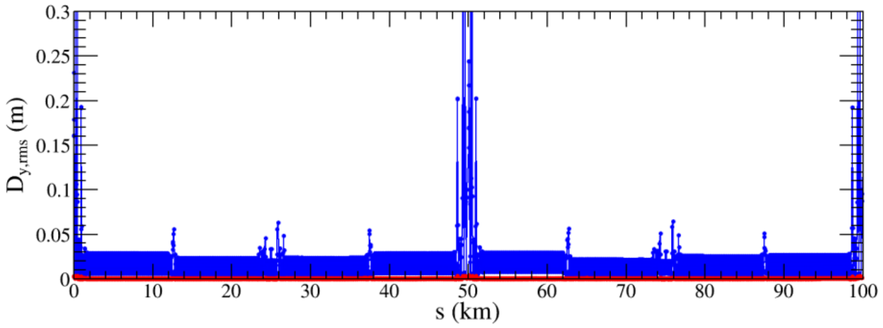
Before DISP correction

After DISP correction

674 seeds converged



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



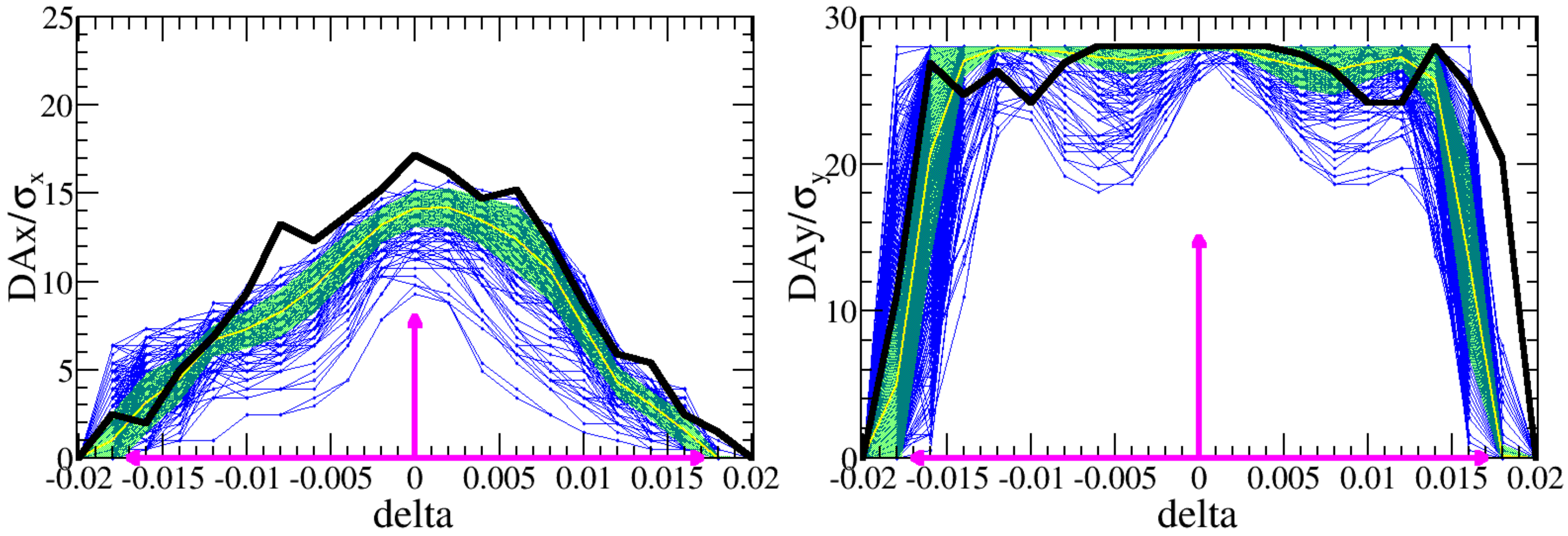
$\Delta D_{x,rms}$ decreased from 18.4mm to 0.4mm
Factor 46 improvement

- 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 $\mathbf{8}\boldsymbol{\sigma}_{\boldsymbol{x}} \times \mathbf{15}\boldsymbol{\sigma}_{\boldsymbol{y}}$ & $\mathbf{0.017}$, after error correction

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

Booster TDR Parameters

- Injection energy: 10GeV → 20GeV
- Max energy: 120GeV → 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				

Extraction

D. Wang

		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	
RF energy acceptance	%	1.34	1.31		1.6	2.6	
Damping time	ms	14.2	47.6		160.8	879	
Natural bunch length	mm	2.0	2.0		1.7	0.96	
Full injection from empty ring	h	0.1	0.14	0.16	0.27	1.8	0.8

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

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:

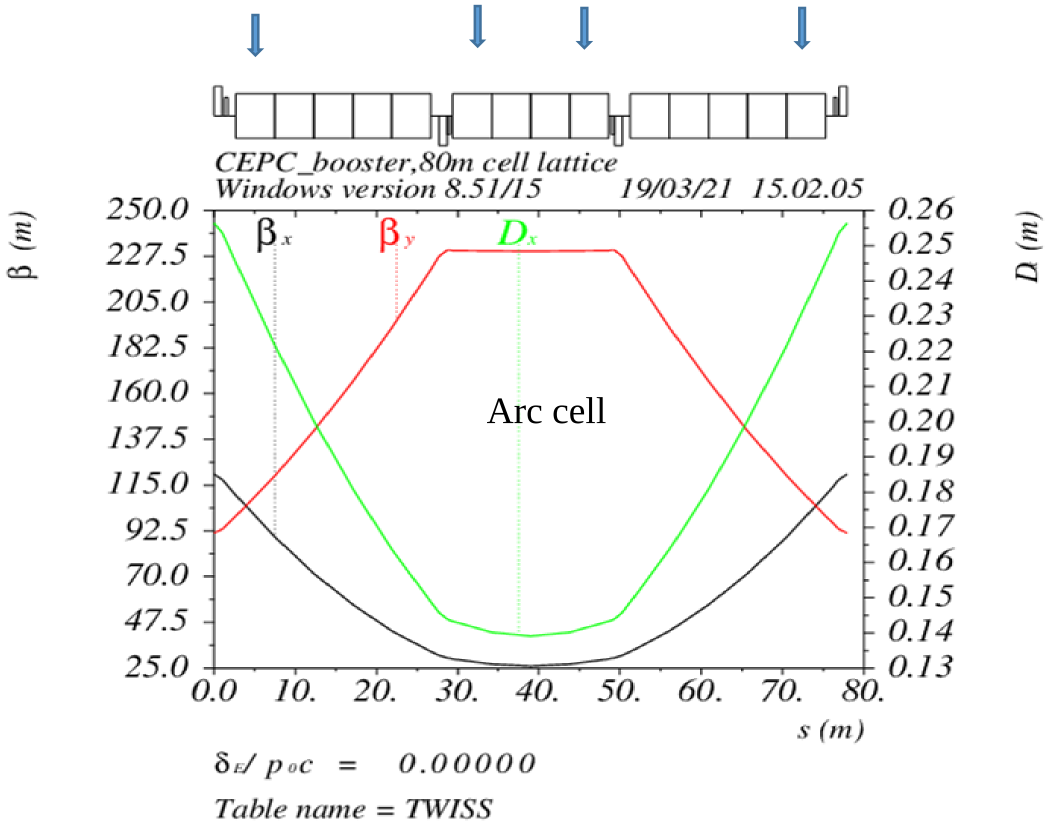
- No independent sextupole for TME
- Quadrupole strength of TME is lower

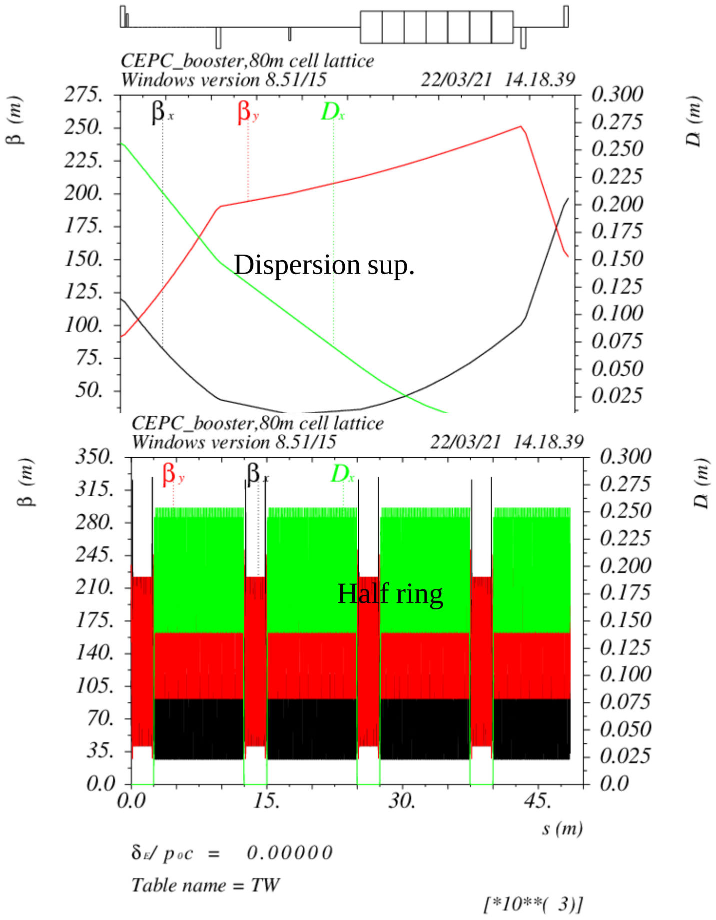
Booster TDR Optics

D. Wang, C. H. Yu, Y. M. Peng…

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

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





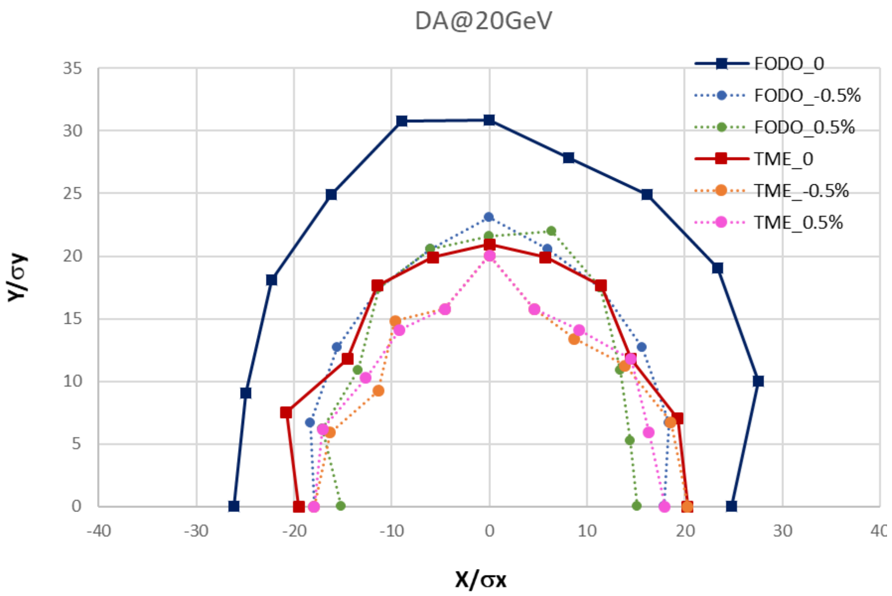
Dynamic Aperture results

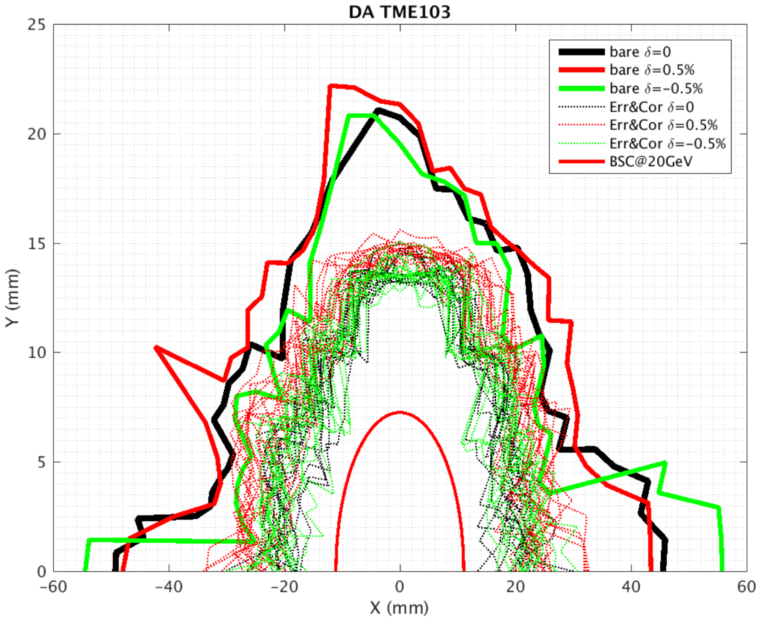
- Booster energy: 20GeV~180GeV
- Inj. emittance from Linac:10nm
- Energy spread from Linac: 0.16%

	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



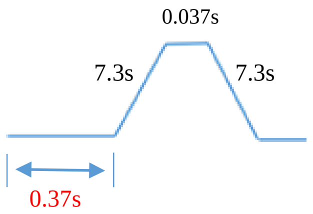


- ➢ Almost impossible to obtain the initial closed orbit naturally
  - Start from sextupole off
- ➢ Orbit correction (COD)(100 Seeds)
  - Response matrix method(RM)
  - SVD method
- ➢ Optics correction(96 Seeds)
  - Response matrix method
  - LOCO code
  - Dispersion corrected

Booster Ramping Scheme

Dou Wang, Xiaohao Cui

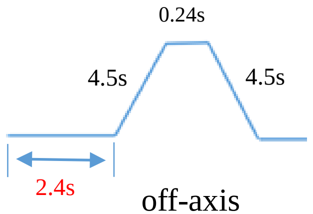
tt



1 cycles/beam

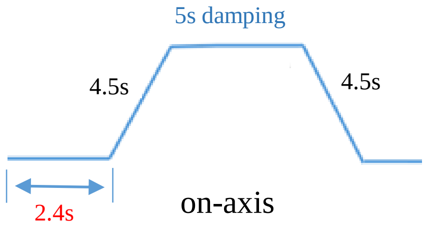
0.37s+7.3s+0.037s+7.3s=15.0s

Higgs



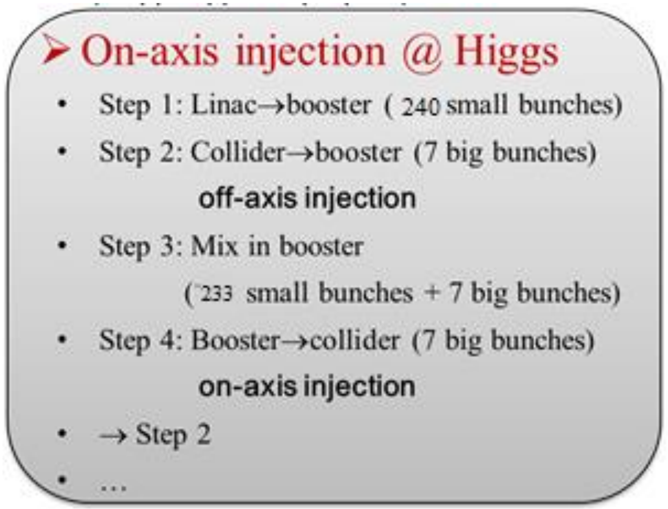
off-axis

1 cycles/beam



on-axis

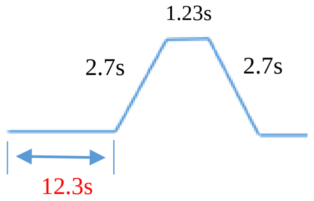
2.4s+4.5s+5.0s+4.5s=16.4s



➢ 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
- …

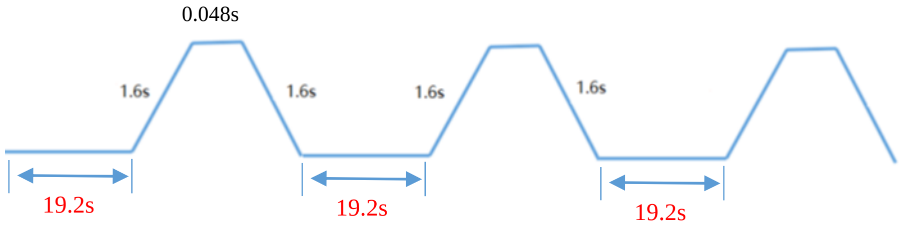
W



1 cycles/beam

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

Z



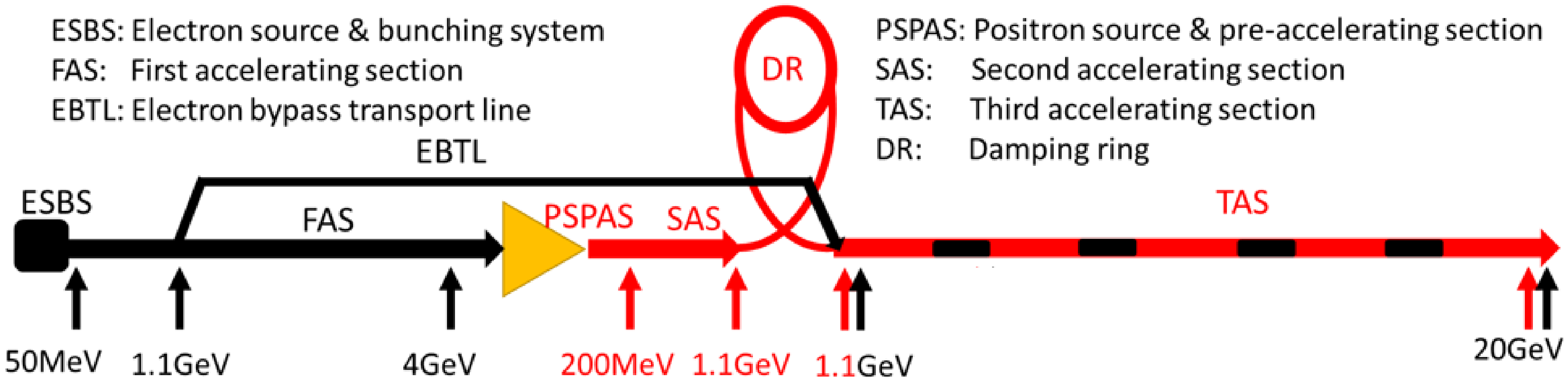
(19.2s+1.6s+0.048s+1.6s)*3=67.34s

3 cycles/beam

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

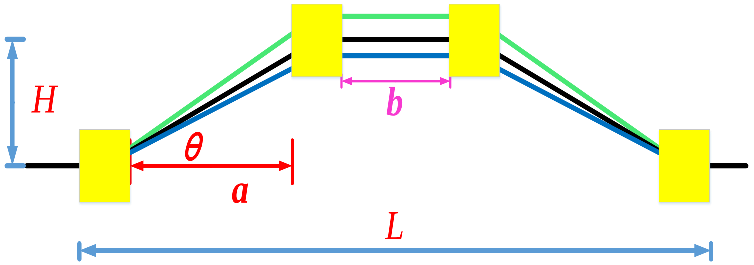
Parameter	Unit	S-band	C-band
Frequency	MHz	2860	5720
Length	m	3.1	1.8
Cavity mode		2π/3	3π/4
Aperture diameter	mm	20~24	11.8~16
Gradient	MV/m	21	**45**

Parameter	Symbol	Unit	Baseline
e^- /e^+ beam energy	E_{e-}/E_{e+}	GeV	20
Repetition rate	f_{rep}	Hz	100
e^- /e^+ bunch population	$Ne-$ /$Ne+$	$\times 10^{10}$	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

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

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

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

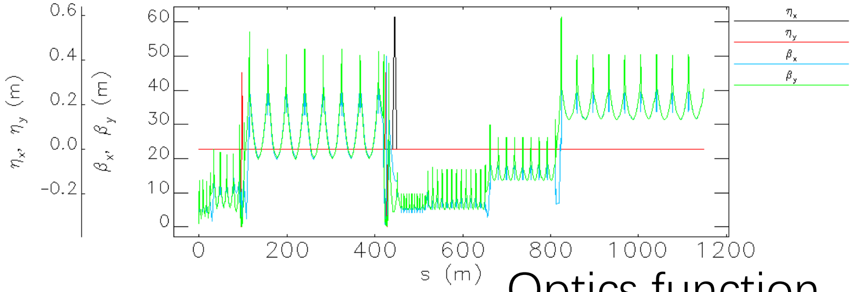
$$R_{56} = 4\rho\left[\theta - \tan\theta\right] - 2a\frac{\sin^2\theta}{\cos^3\theta} = -0.196\text{m}$$

Start to End Simulations for e- Beam

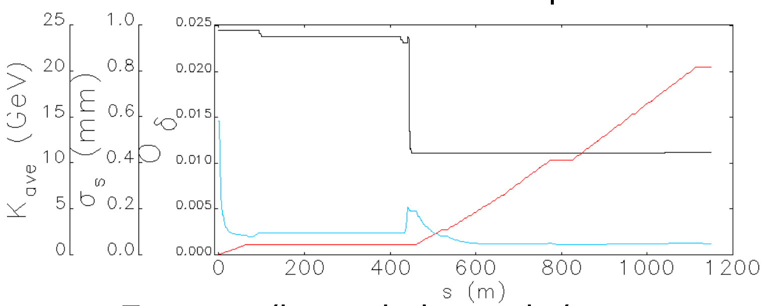
C. Meng

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

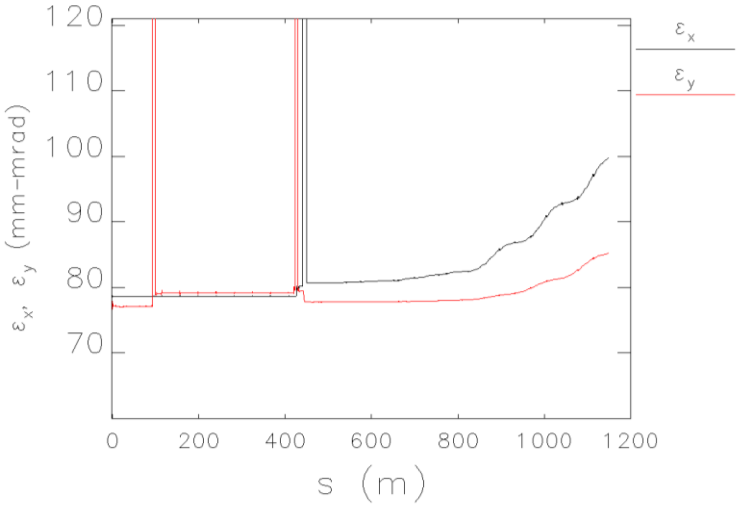
Parameter	Unit	Baseline	Electron
e^-/e^+ beam energy	GeV	20	20.38
Repetition rate	Hz	100	100
e^-/e^+ bunch population	$\times 10^{10}$	0.94(1.88)	1.88
	nC	1.5 (3)	**3**
Energy spread (e^-/e^+)		1.5×10^{-3}	1.3×10^{-3}
Emittance (e^-/e^+)	nm	10	**2.5**



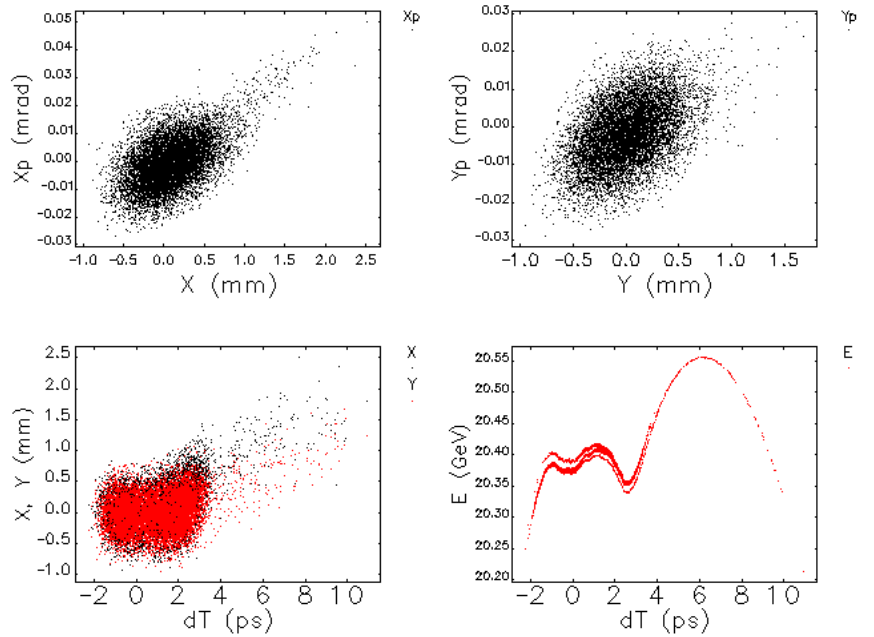
Optics function



Energy/bunch length/energy spread



Emittance



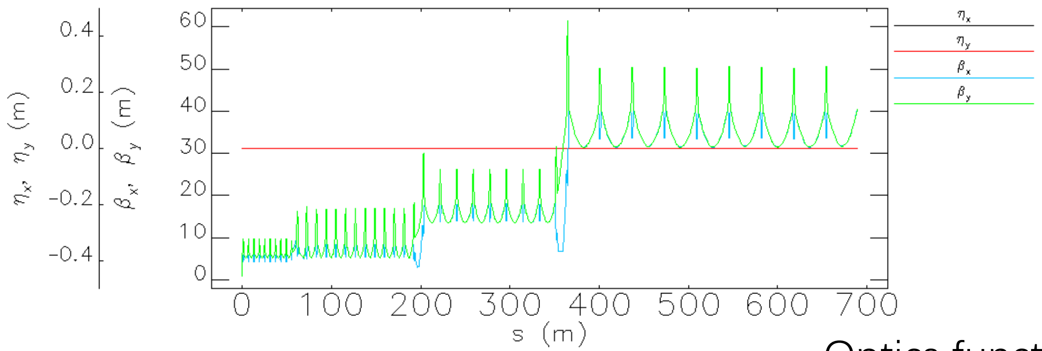
Distribution @ 20GeV

Simulations for Positron

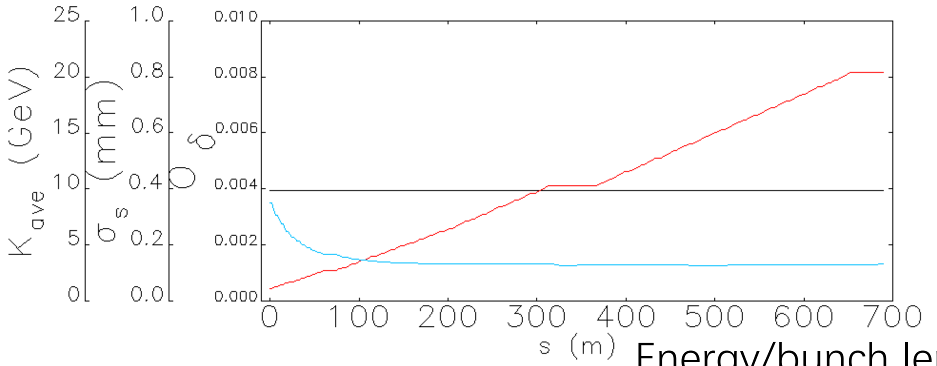
- Positron Linac
  - Wakefield & CSR
  - Emittance(w/o error)
    - Growth: 5%
    - 5.2nm@20GeV

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

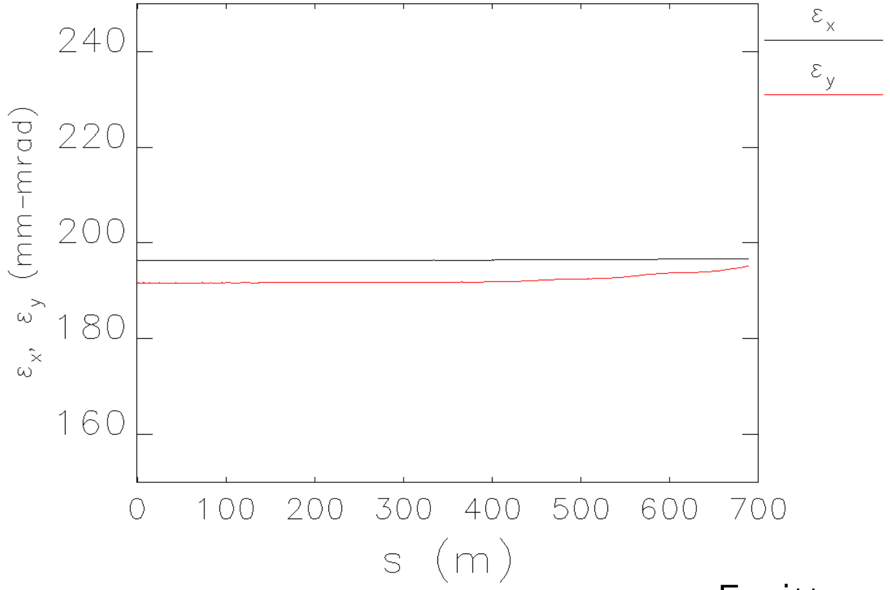
C. Meng



Optics function



Energy/bunch length/energy spread



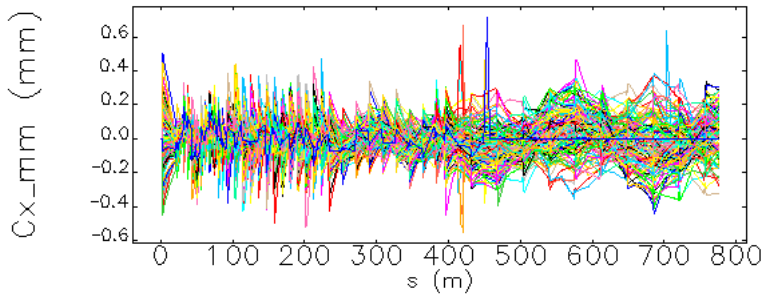
Emittance

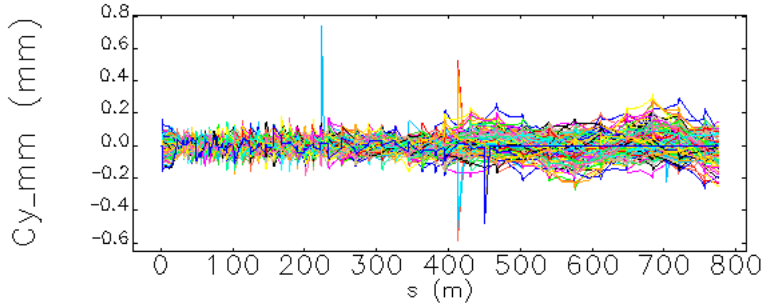
Error Simulations for Positron

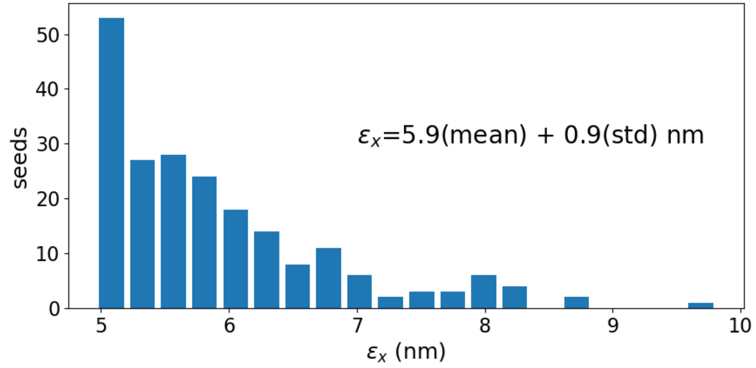
C. Meng

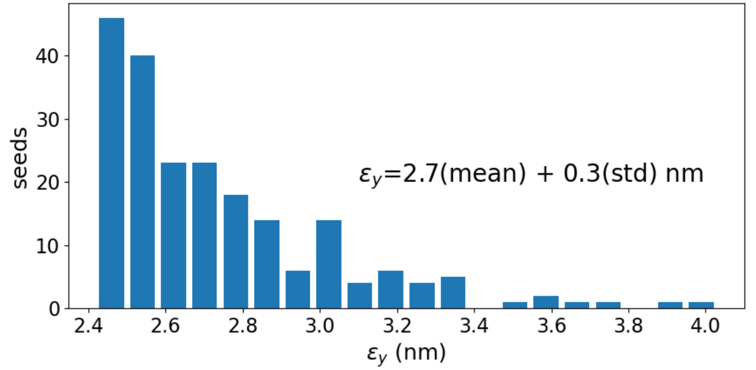
- Positron Linac
  - errors: Magnets/Accelerating structure/BPM
  - Trajectory correction: beam center<0.5mm
  - Emittance growth: meet the requirement
    - X: 18%(mean)+18%(std)
    - Y: 10%(mean)+12%(std)

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





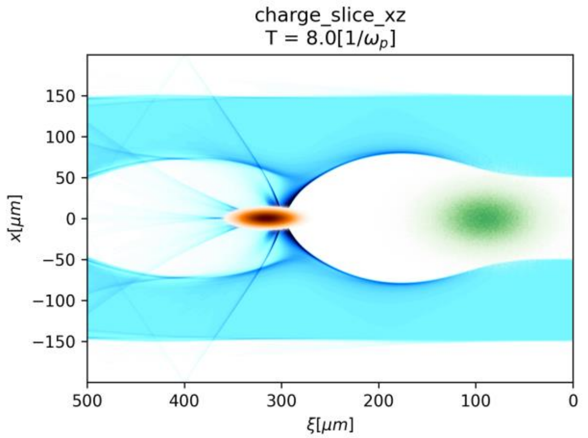




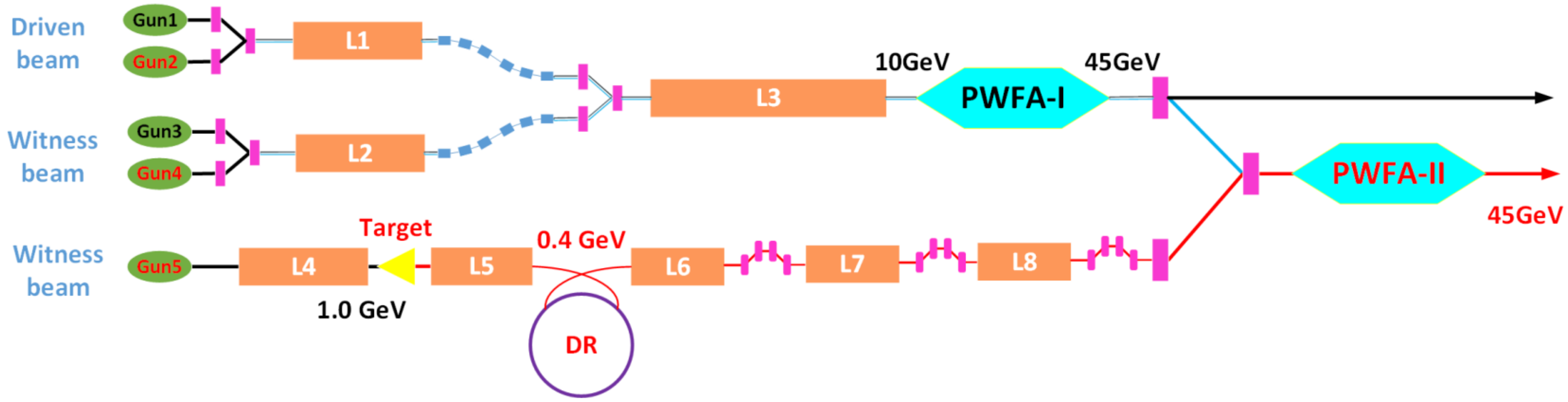
Plasma Acceleration Investigation

W. Lu, D.Z. Li

Booster Requirement	
Energy（GeV)	45.5 (0.2%)
Bunch Charge（nC)	0.78
Bunch length(um)	<3000
Energy Spread(%)	0.2
ε_N(μm·rad)	<800
Bunch Size(um)	<2000



Positron acceleration scheme



Dazhang Li, CPS, September 2019

HTR e- acceleration

- Start-to-end simulation performed, CPI requirement to linac updated
- Without extra damping mechanism, the growth of hosing instability from statistical noise is acceptable when transformer ratio is 1-1.5
- There are other powerful damping mechanisms. HTR is still possible

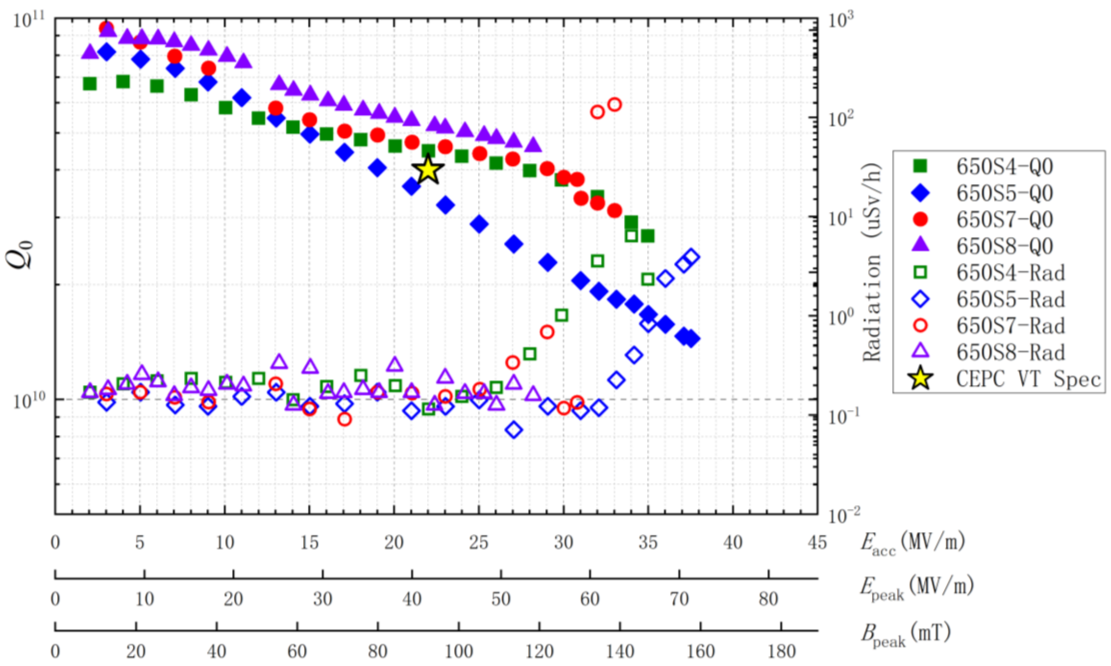
e+ acceleration

- Asymmetry beam scheme is well accepted by PRL reviewers
- More schemes are under consideration

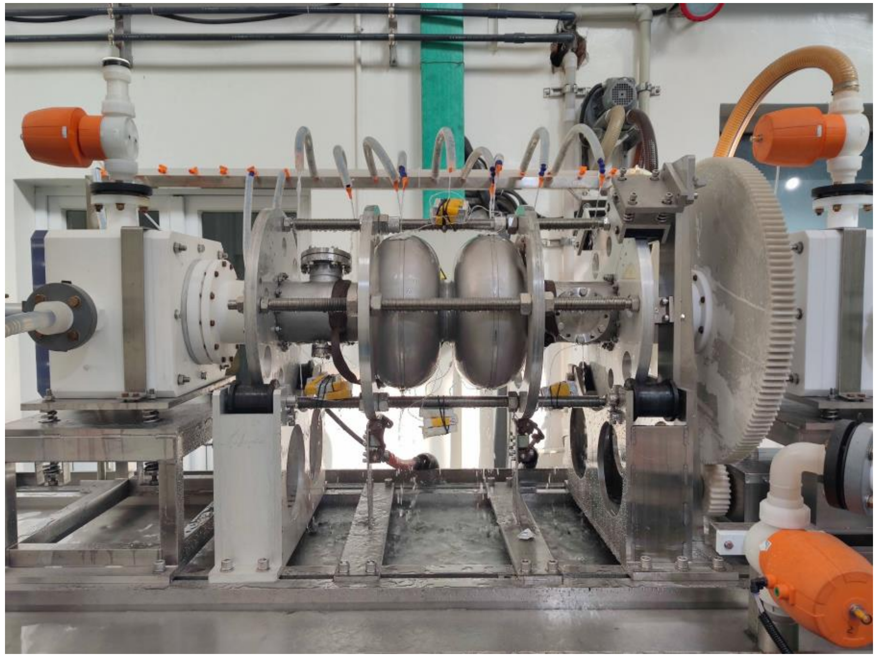
Experiments Plasma dechirper experiment got good results.

- Experiment on SXFEL is still ongoing. Dedicated TF for PWFA is crucial and under consideration

650MHz 1&2 -cell Cavities



Y. Ji, P. Sha



Cavity	Processing	Result
650S4 (FG)	Bulk BCP 200 um + light EP 20 um + 950C 3h + light EP 20 um + 120C 48h	2.7E10@ 35.0MV/m
650S7 (LG)	Bulk FP 200 um + 950C 3h + light EP 20 um + 900C 3h + light EP 20 um + 120C 48h	3.1E10@ 33.0MV/m
650S5 (FG)	Bulk EP 200 um + 120C 48h	1.5E10@ 37.5MV/m
650S8 (LG)	Bulk BCP 200 um + light EP 20 um + 950C 3h + light EP 20 um + 120C 48h	4.6E10@ 28.2MV/m

- Studies on EP process for 650 MHz 2-cell cavities were carried on.
- New jigs and cathodes special for the EP on 650 MHz 2-cell cavities was made.
- Parameters were scanned and optimized for the process like voltage, temperatures, flow rates and so on.
- Some technological processes like on-site DI water cleaning were re-developed.
- The new-treated cavities will be ready soon.

CEPC 650MHz Beam Test System

Y. Ji, P. Sha

- Cavity string and module assembly in March to May 2021.
- Modul installation in beamline, 2 K cool down test and RT coupler conditioning in May to July. Horizontal and beam test soon.
- IR laser output to 116 W. Photo-cathode QE to 5 %. DC gun vacuum to 1.5E-10 Pa, voltage to 350 kV. Buncher cavity high power tested.

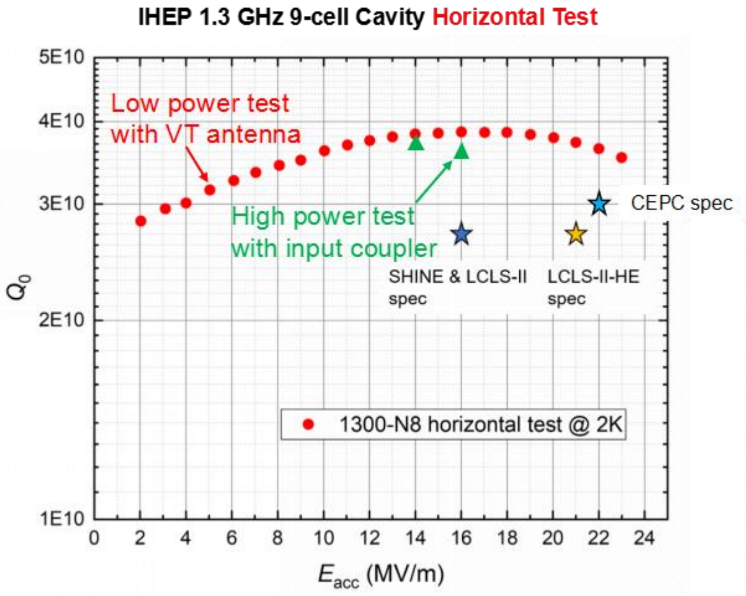
CEPC SRF Facilities and Components

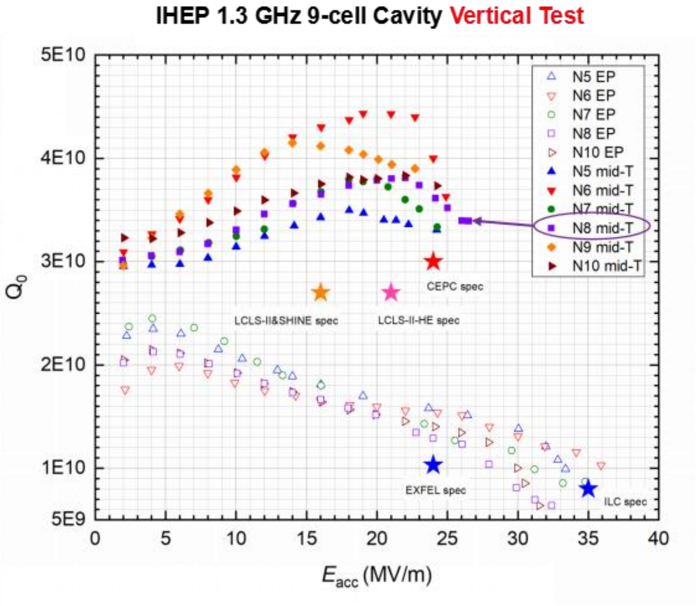
J.Y. Zhai, P. Sha



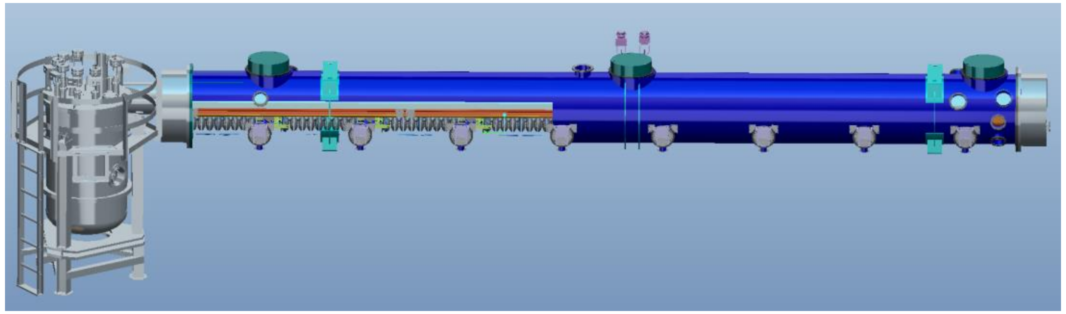


IHEP PAPS established in July 2021   Horizontal test stand, 1.3GHz 9cell cavities, and couplers...





1.3 GHz High Q Mid-T Cavity Horizontal Test



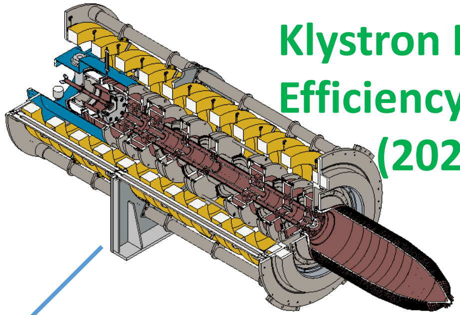
- 1.3 GHz 8x9-cell high Q cryomodule prototype
- Component fabrication in 2021 to mid 2022
- Assemble and horizontal test in 2022
- Ship to Dalian in 2023

CEPC 650MHz High Efficiency Klystron

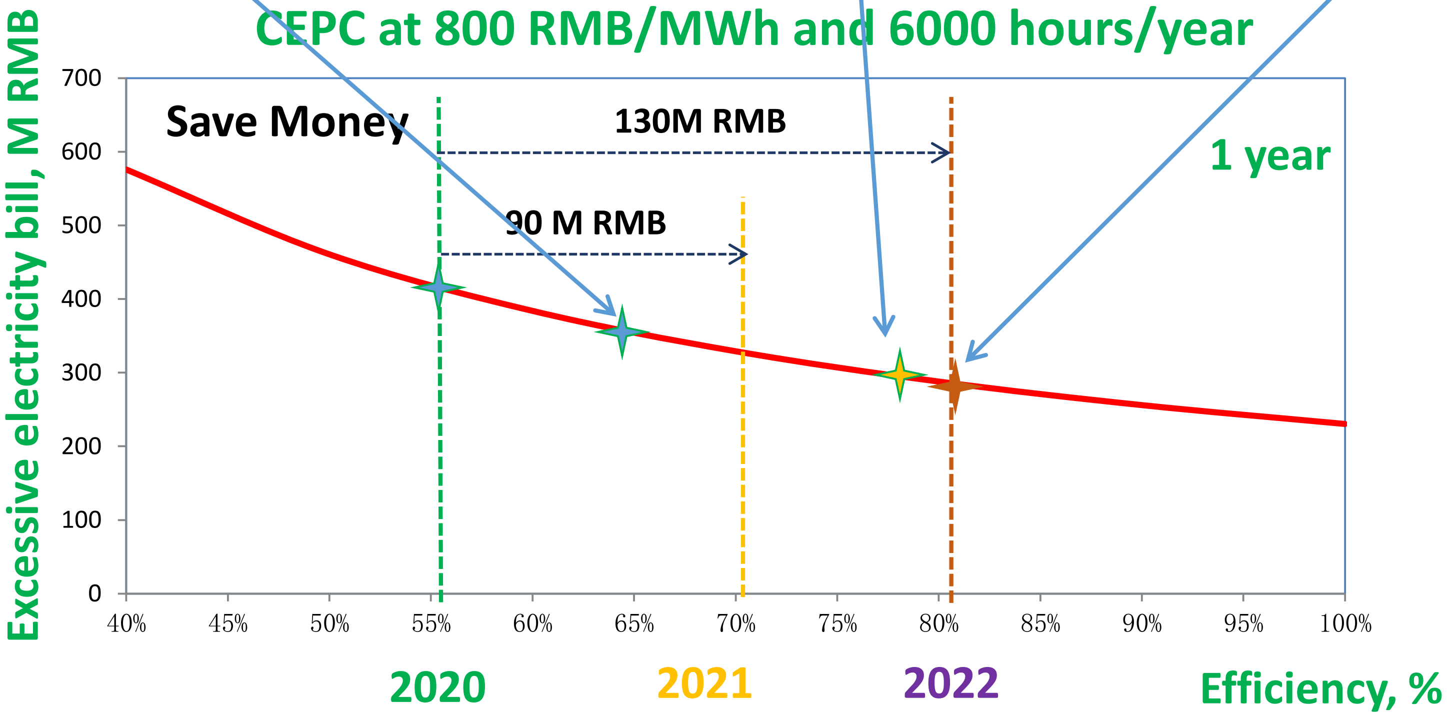
Z.S.Zhou

Klystron No. 1
Efficiency 65%
(2020)

Klystron No. 2
Efficiency 77%
(2021)



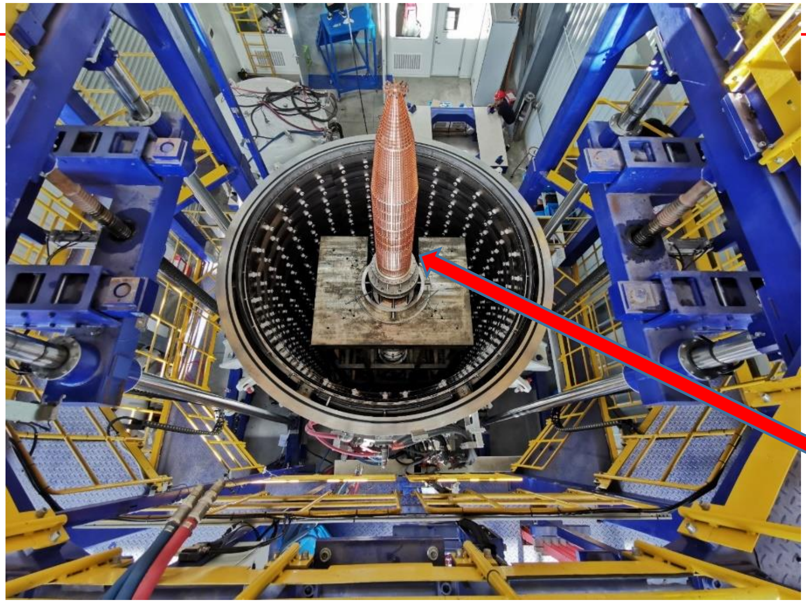
Klystron No. 3
Efficiency 80.5%
(2022)



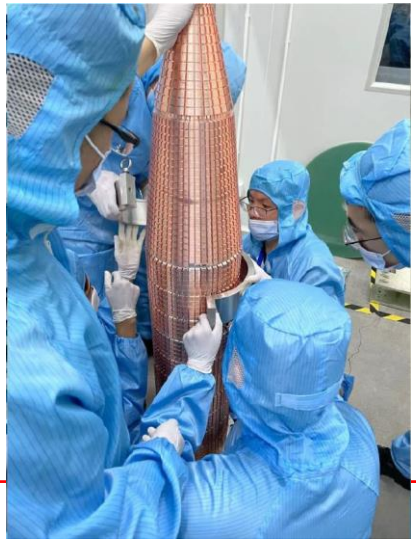
Efficiency impact on operation cost (Only considering operation efficiency of 650MHz klystrons)

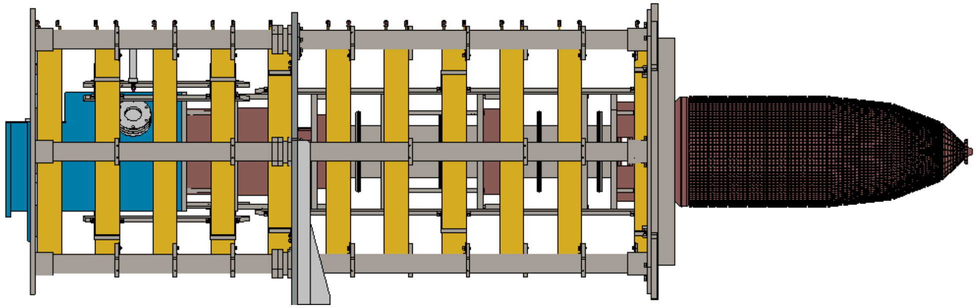
CEPC 650MHz High Efficiency Klystron Fabrication

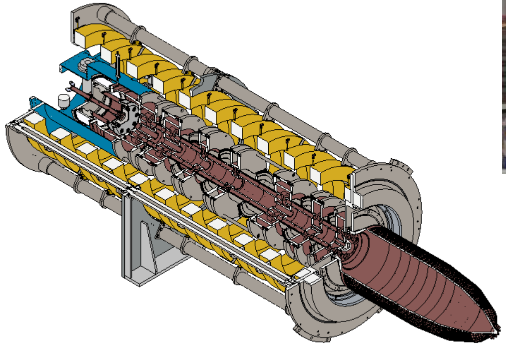
Z.S.Zhou



The 650MHz high voltage single beam klystron is fabricated under baking (**77% efficiency**) and test will start soon in PAPS



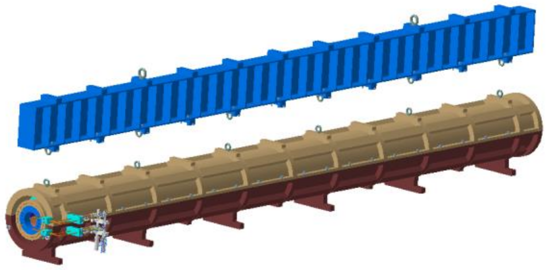


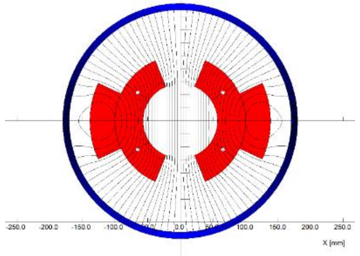


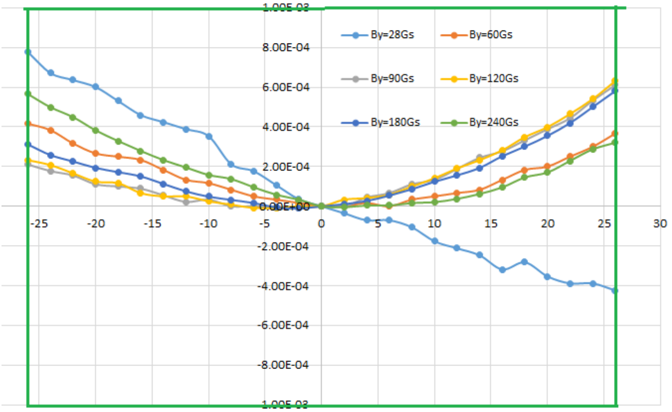
The preliminary 3d mechanical drawing of 650MHz multi beam klystron is finished (**80% efficiency**)

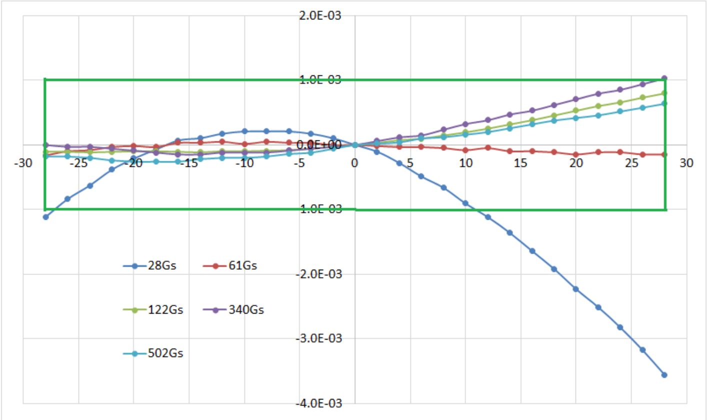
Booster Dipoles Full Scaled Prototypes Plan

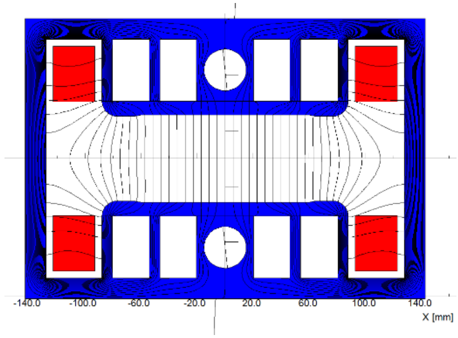
W. Kang

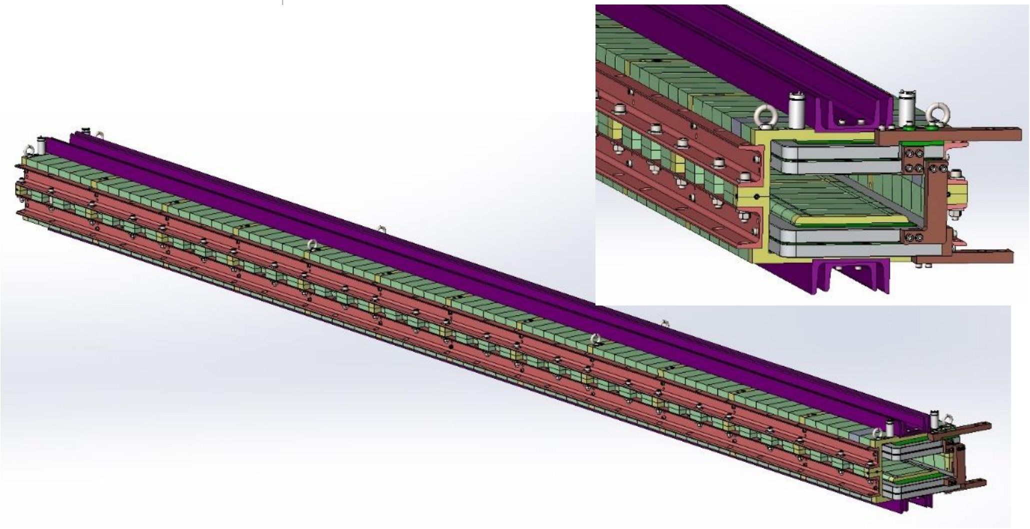












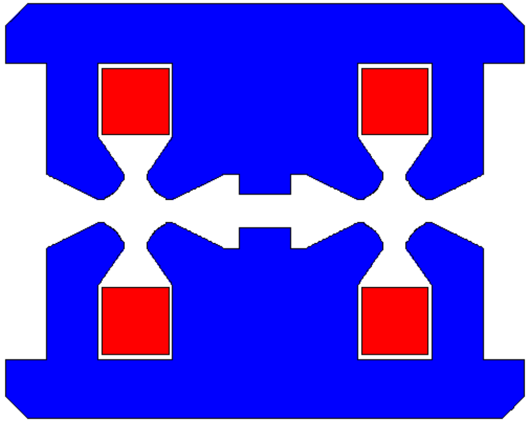
- Two kinds of the subscale prototype magnet w/wo iron cores have been developed.
- As for the CDR parameters with 10 GeV injection energy the low field performance of the magnet without iron cores meets the requirements whereas the magnet with iron cores not
- With the new baseline of 20GeV injection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

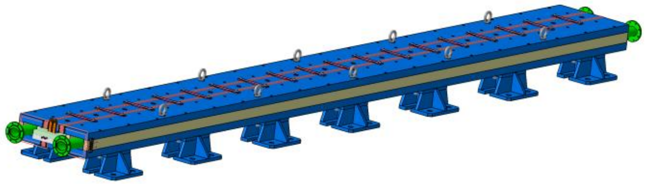
Dual Aperture Magnets for Collider

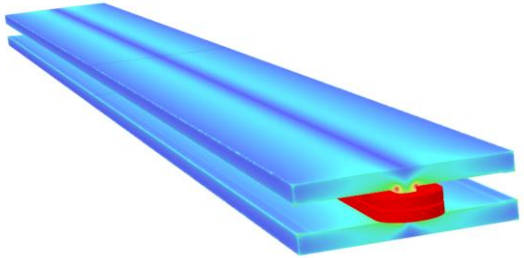
Item	Value
Center field (Gs)	141.6@45.5GeV，373@120GeV, 568@182.5GeV
Gap (mm)	66
Magnetic Length (m)	5.737
Good field region (mm)	±13.5
Field harmonics	<0.05%
Field adjustability	±1.5%
Field difference between two apertures	<0.5%

harmonic variations are accepted at different energies.

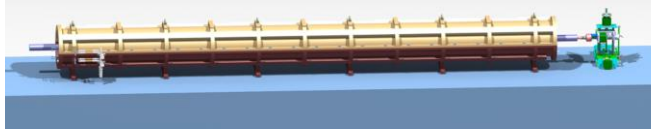
M. Yang

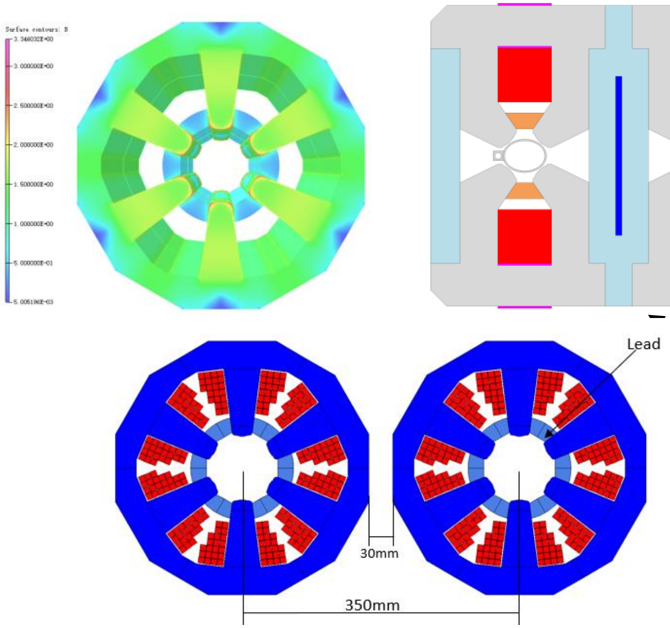


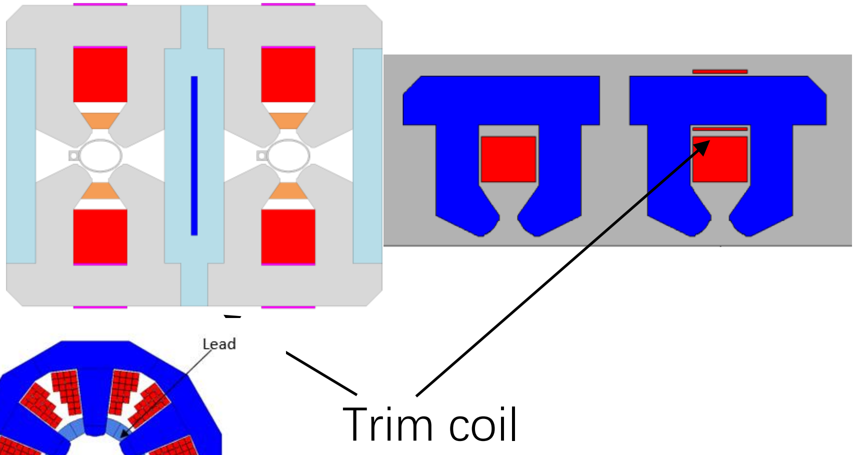




Full size dual aperture dipole



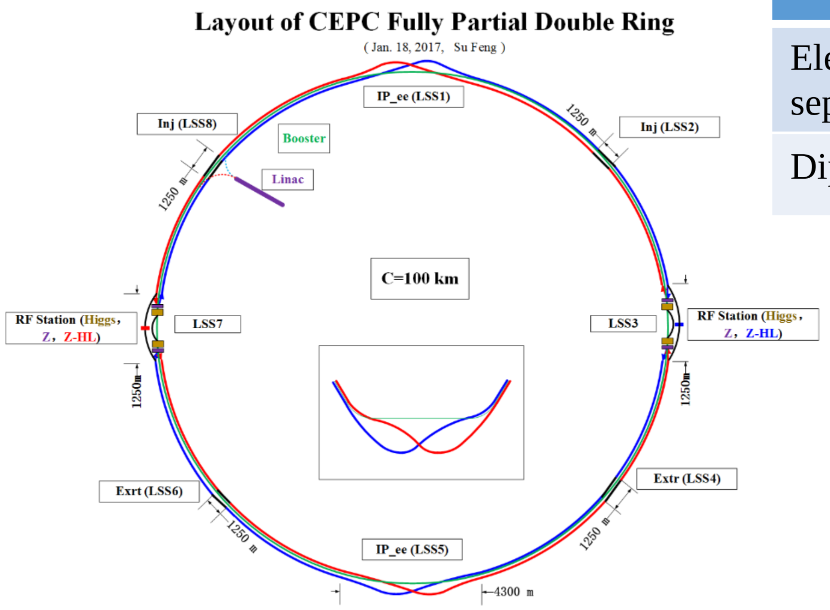


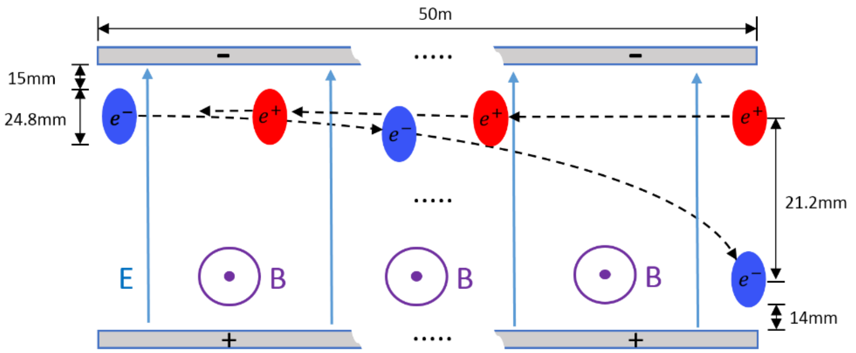


Electrostatic-Magnetic Deflector for Higgs

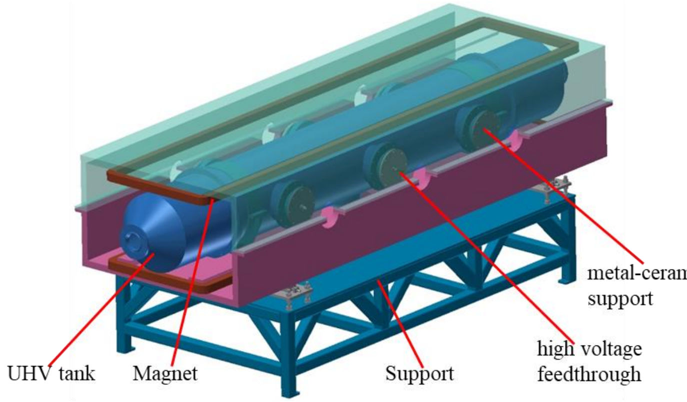
B. Chen

	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}

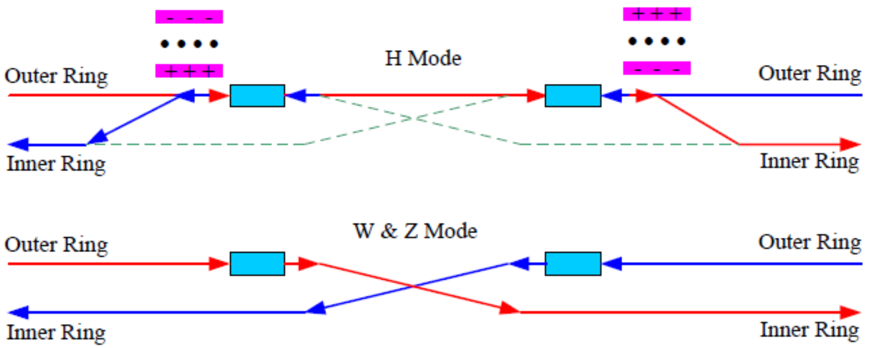




Schematic of Electrostatic-Magnetic separator

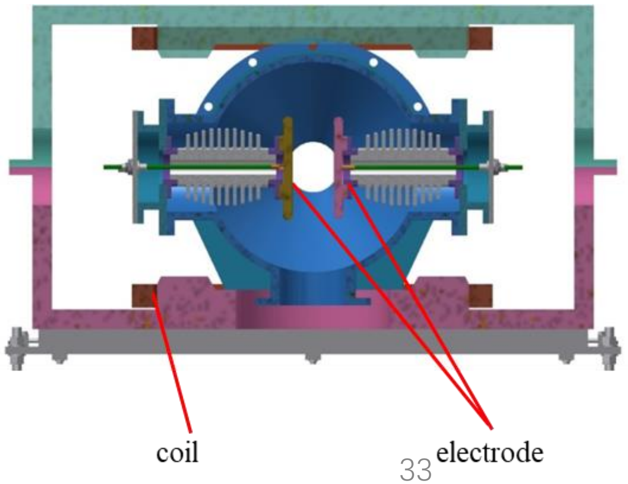


structure drawing of Electro-Magnetic Separator



Layout of RF region

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

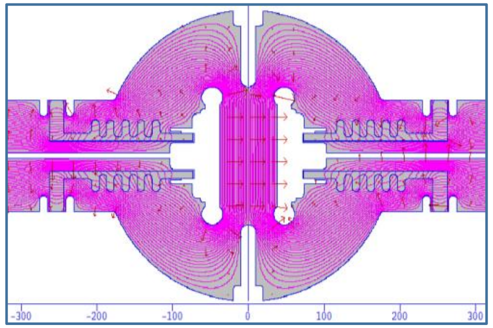
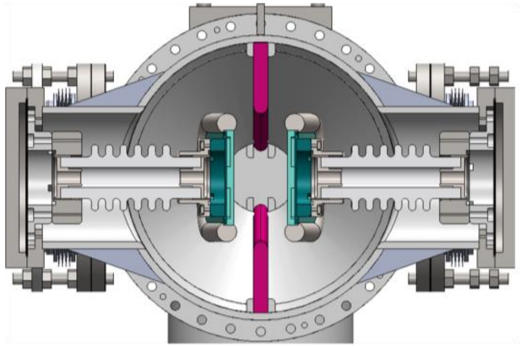
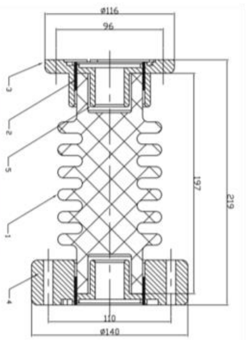


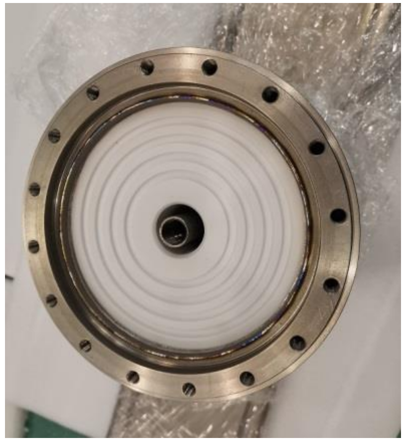
Electrostatic-Magnetic Deflector Manufacture & Test

B. Chen

Index	indicators	Factory test	Test results
Vacuum leakage rate		≤1x10-10Pa.m3/s	**2×10-13Pa m3/s**
Vacuum pressure	$\le 2.0\times10^{-10}$Torr	$\le 4.0\times10^{-10}$Torr	**$\le 1.0\times10^{-10}$Torr**
Maximum conditioning voltage		±135KV, 8 hours non-stop operation, Vacuum ≤ 4.0×10^{-10}Torr	**－108KV ＋97.6KV**

- 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, two power supplies failed to be used.
- 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.



CPEC Injection & Extraction Hardware Types

J. Chen

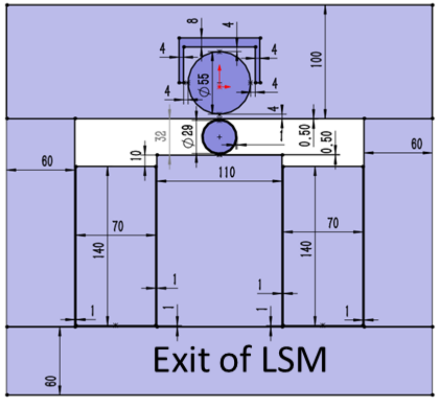
	Sub-system	Kicker Type	Kicker waveform	Septa Type	Thickness of septum
1	Damping ring inj./ext.	Slotted-pipe kicker	Half-sine/250ns	Horizontal LMS	ϕ22/3.5mm
2	Booster LE inj.	Strip-line kicker	Half-sine/50ns	Horizontal LMS	ϕ55/5.5mm
3	Booster ext. for CR off-axis inj.	Delay-line dipole kicker	Trapezoid /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

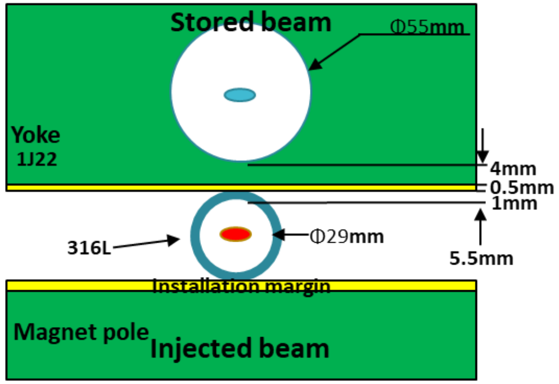
- **The same team is in charge of both HEPS and CEPC inj. & ext. system**
- **Experience gained in HEPS applies for CEPC**

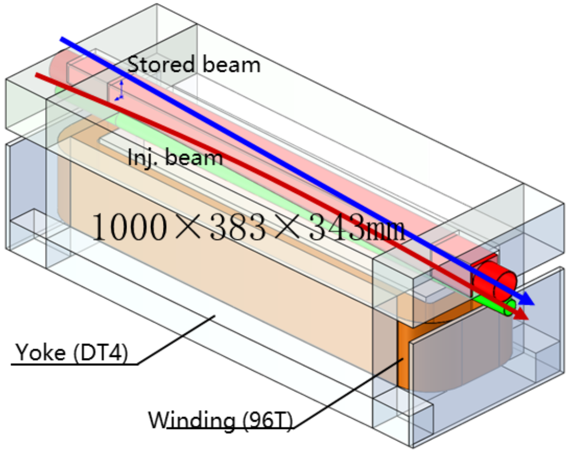
Lambertson Septum Prototype for HEPS BST

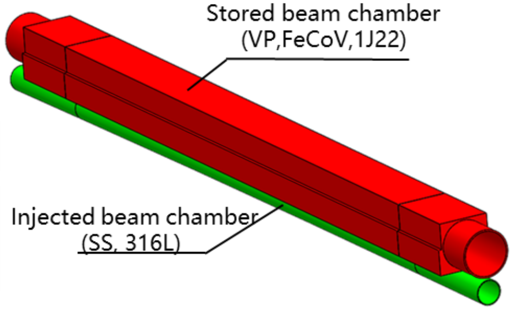
J. Chen

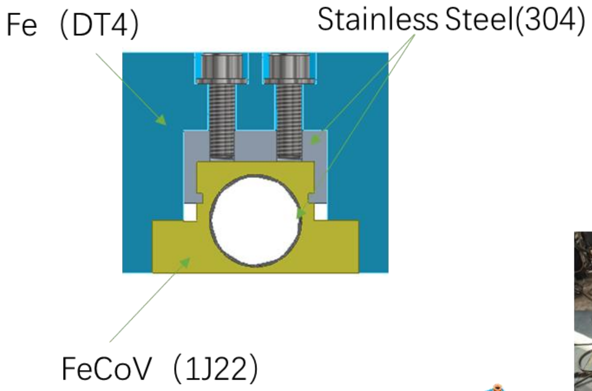
- Stored beam pipe(VP) inner diameter= ø55mm, Thickness=4mm
- Injected beam pipe (SS):   inner diameter=ø29mm, Thickness=1mm
- Septum thickness=4+1+0.5=5.5mm
- Magnet gap: 32mm
- Winding: W=70mm,H=140mm,T=128
- Exciting current=188A
- Inductance=0.0682H

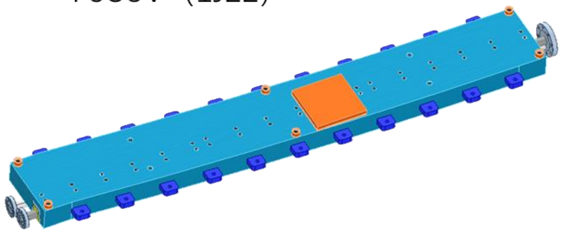


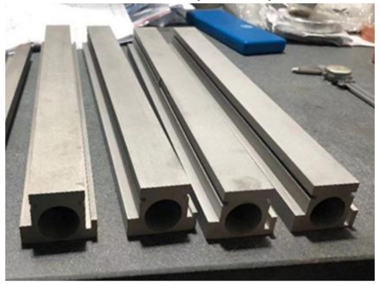






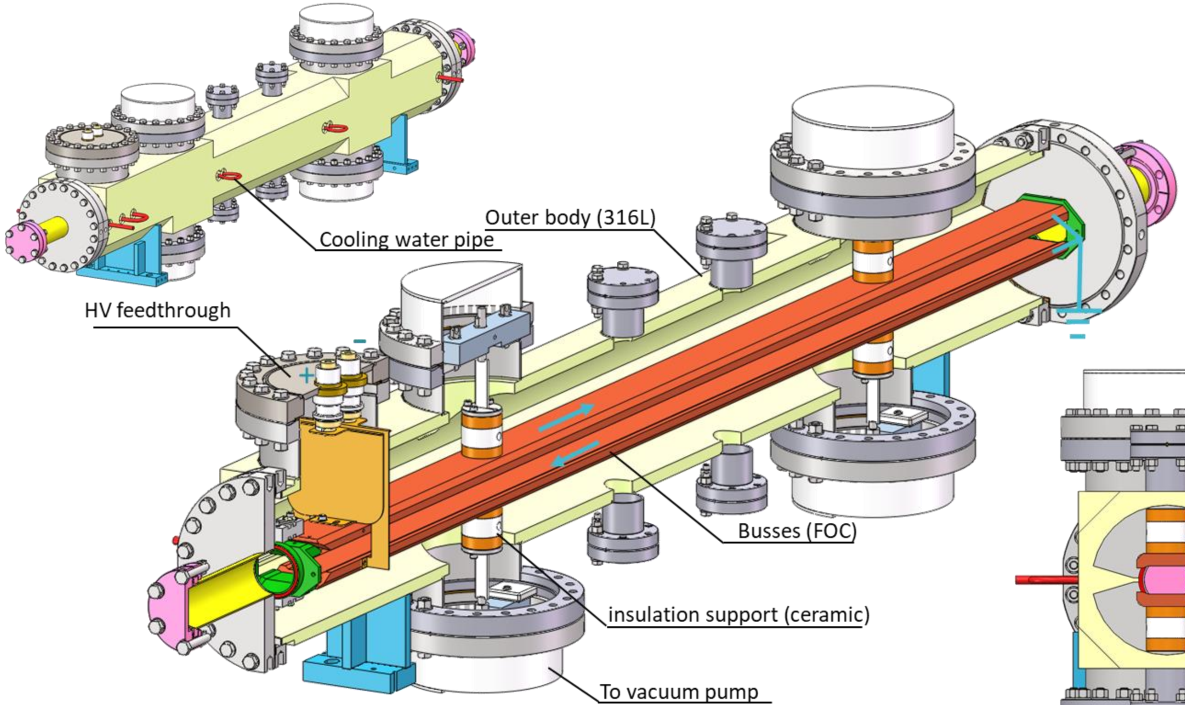


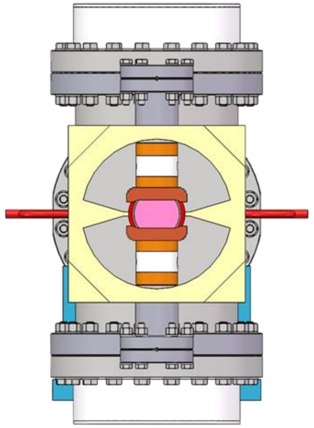




Slotted-pipe Kicker Prototype Design & Fabrication

J. Chen

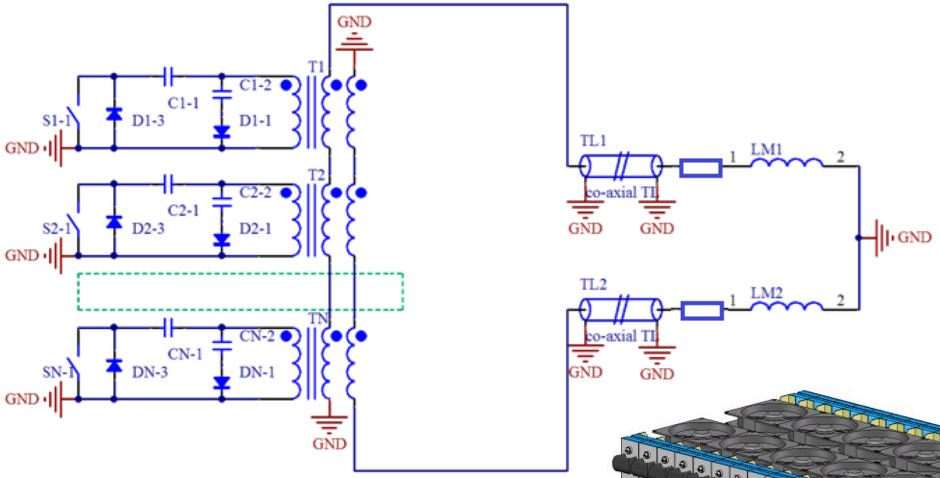


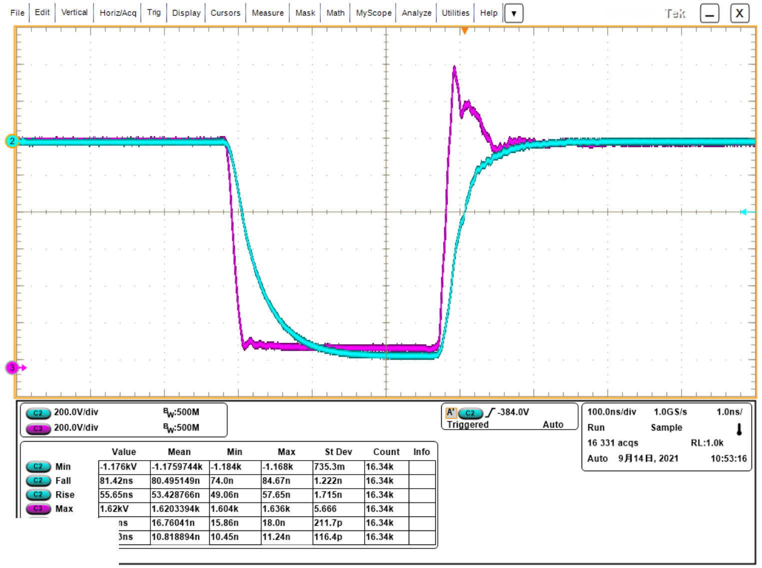


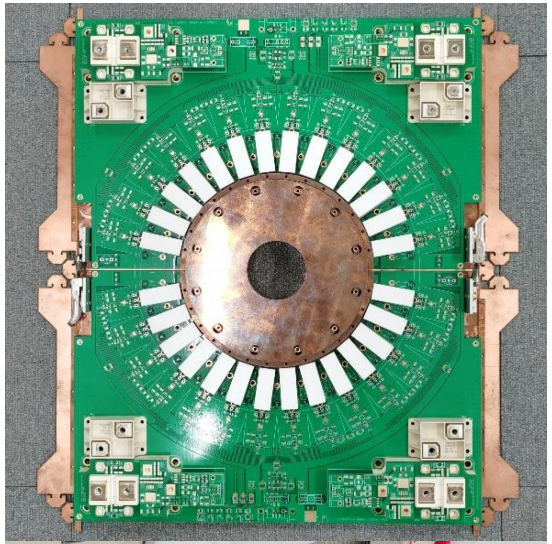
250ns Fast Kicker Pulser

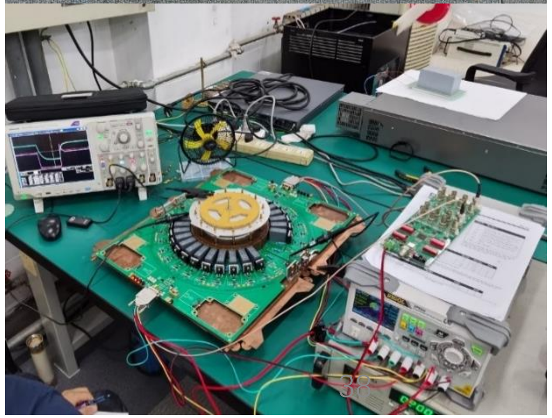
J. Chen

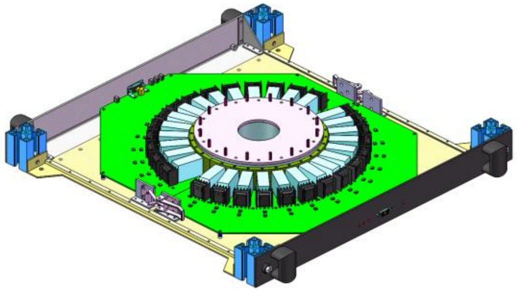
- Scheme: 20-stage inductive adder based on SiC-MOSFETs.
- The co-axial transformer is configured as bipolar output.
- The pulser is located outside tunnel and ten 50 Ω cables with length more than 30m are applied to connect with kicker.
- Matching terminal resistor is 10Ω.

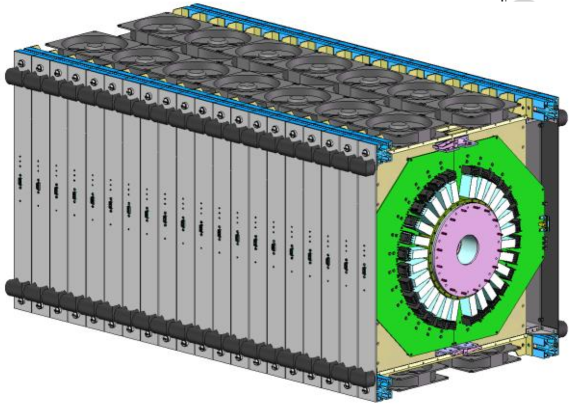








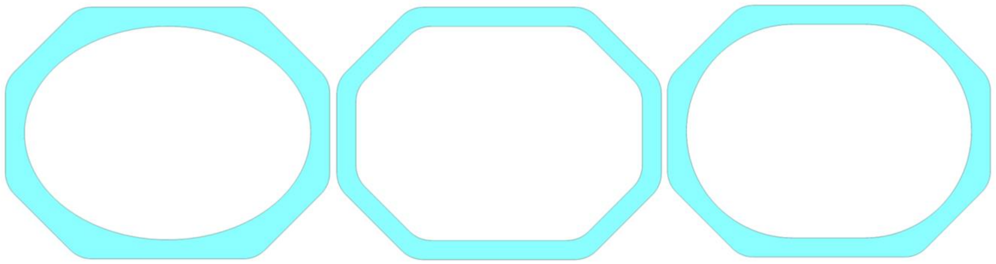




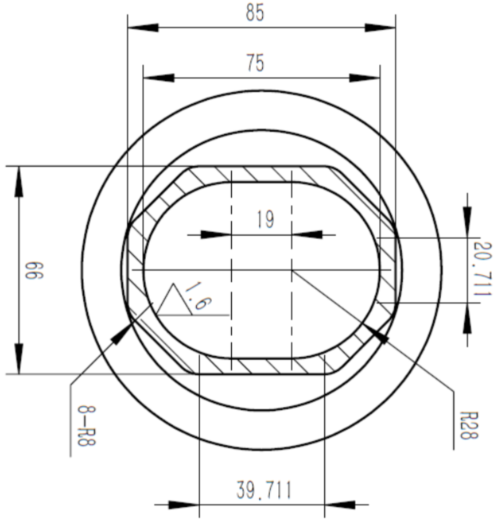
Ceramic Vacuum Chamber

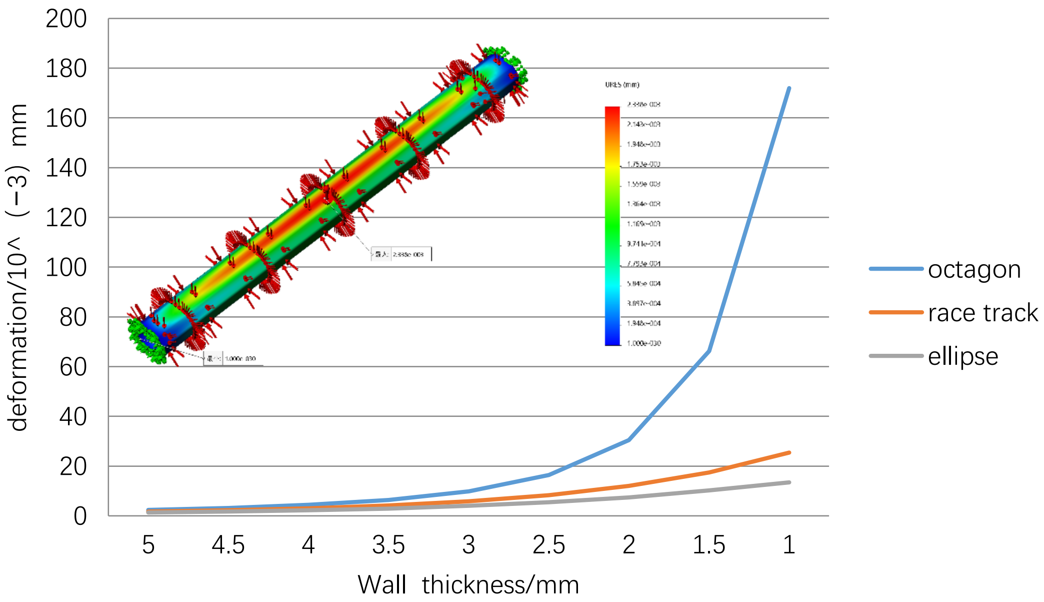
J. Chen

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



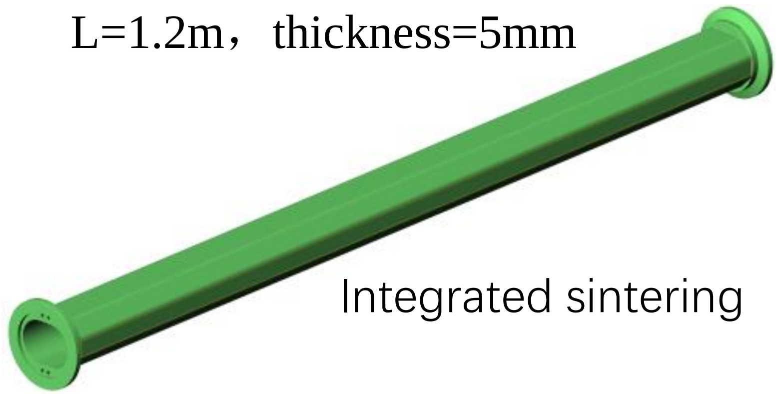
ellipse octagon Race track √





Ceramic material: 99% AL_2O_3

L=1.2m，thickness=5mm

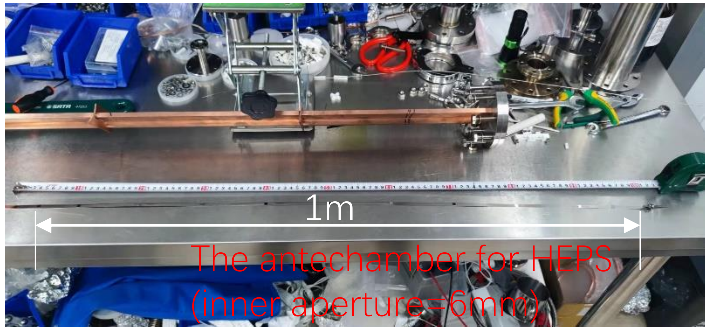


Integrated sintering

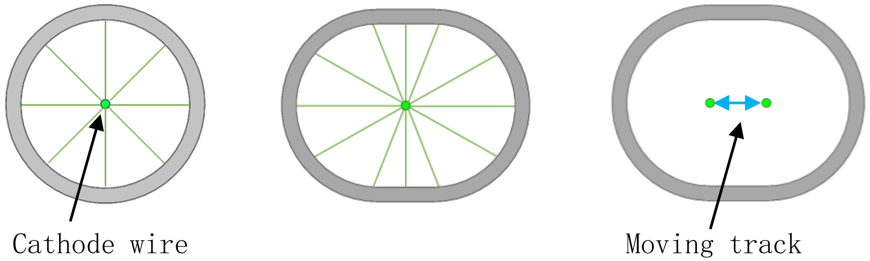
Magnetron Sputtering Coating Prepare

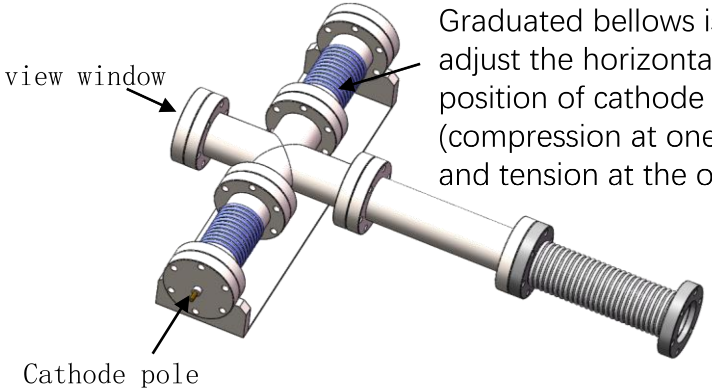
J. Chen

- 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.





Graduated bellows is used to adjust the horizontal position of cathode wire (compression at one end and tension at the other end)

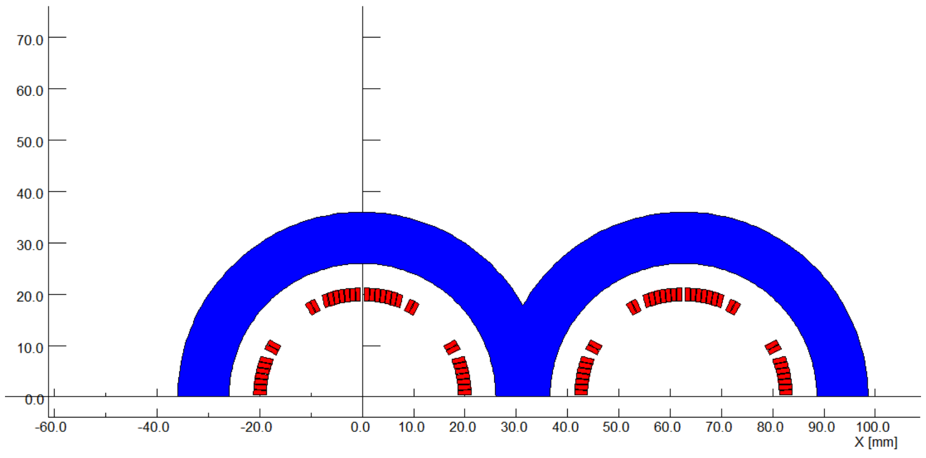
Weight Reduction for the MDI SC Quadrupole

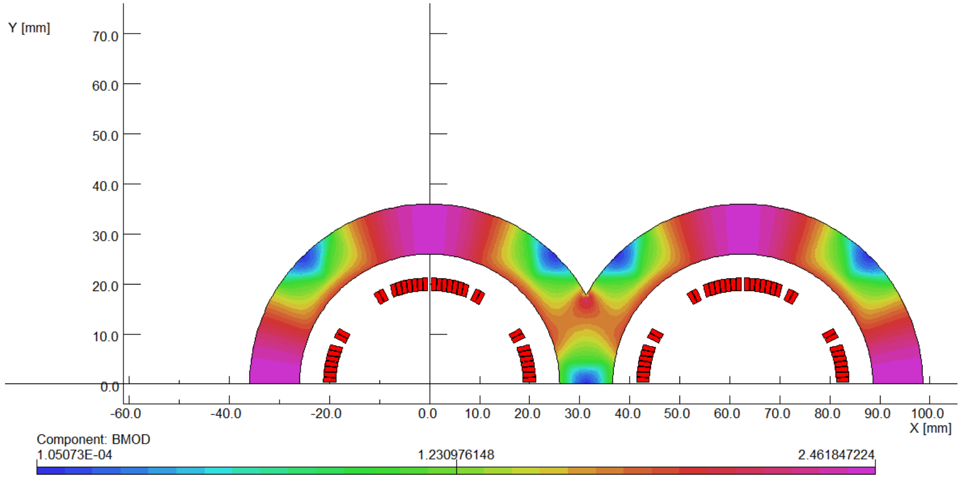
Y.S. Zhu

- 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



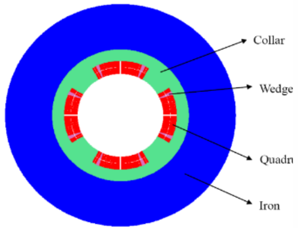


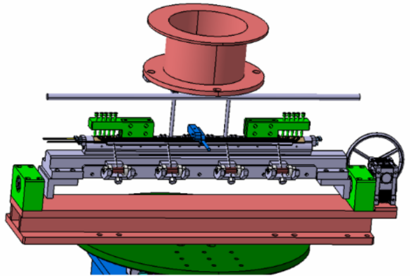
CEPC QD0 SC Magnet R&D (0.5 m short model)

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

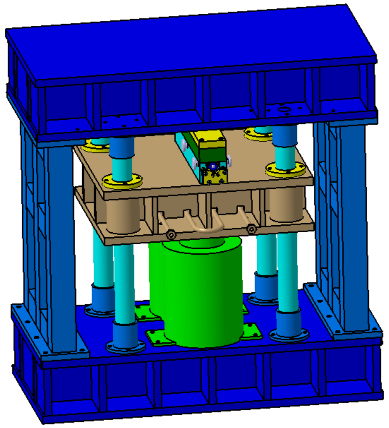
Y.S. Zhu

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





Fabrication of QD0 short model magnet is in progress



High Field Dipoles with HTS for SppC

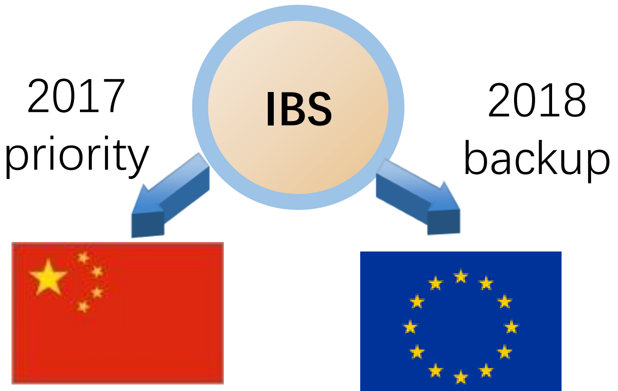
Q. Xu

Scientific merit

-Even high collision energy is expected with the CEPC tunnel: **SPPC**
-Energy is proportional to the dipole field

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

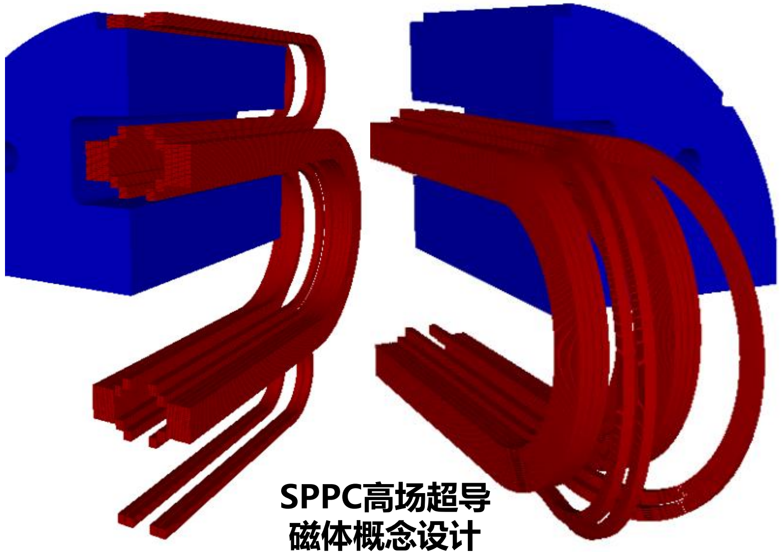
HTS Magnet is the only measure for ultra high field (12～24 T) 、IBS has a bright prospect。



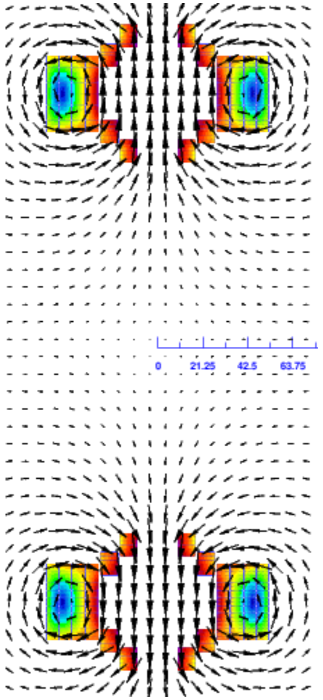
CEPC
SPPC

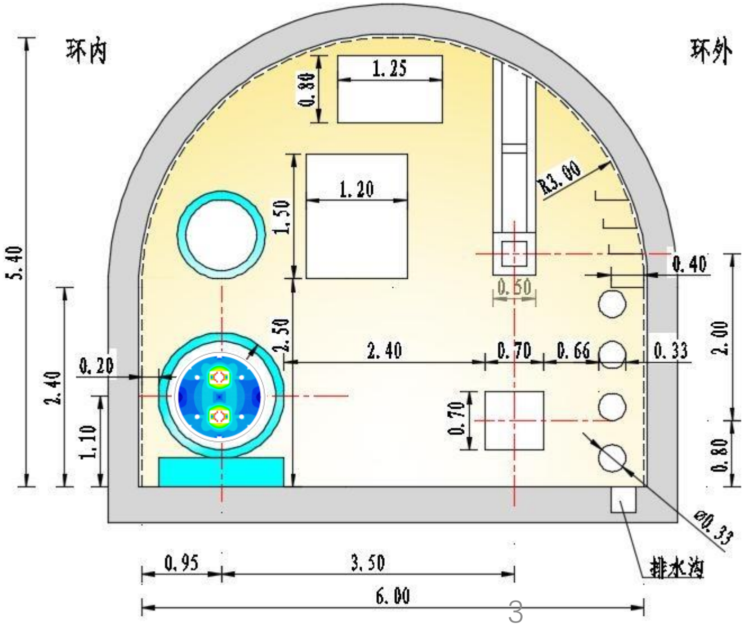
FCC

Thousands of HTS magnet are needed for SPPC or FCC



SPPC高场超导磁体概念设计





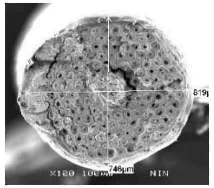
SPPC隧道截面布局

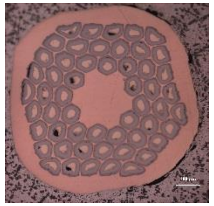
HTS Magnet Fabrication Procedure

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

J_c, RRR, Cu ratio,
Filament size,

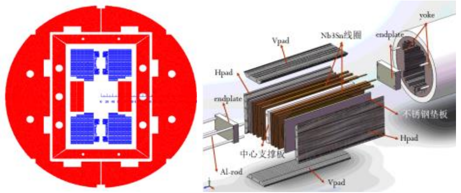


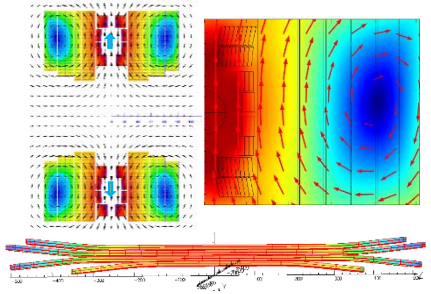


Material,
Cross section,
Processing,⋯

超导线材 →

Magnetic field strength,
EM force, quench protection,⋯

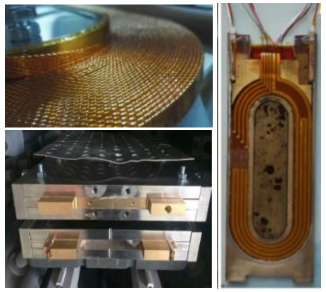




Magnetic field quality,
Persistent current effect,
Coil stress,⋯

磁体设计 →

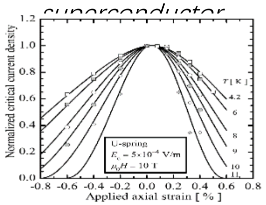
J_c and RRR degradation
Stress and dimension control



Impregnation quality control
Thermal stress control
Mechanical strength and stability

线圈制作 →

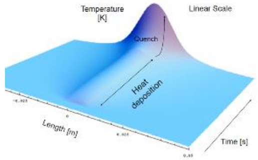
J_c & strain curve of the superconductor



Pre-stress control
Dimension control,
Mechanical Stability

磁体组装 →

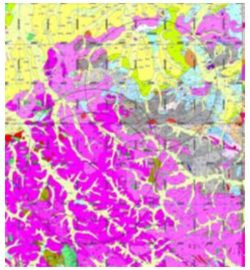
Quench protection
Hot spot, voltage,⋯

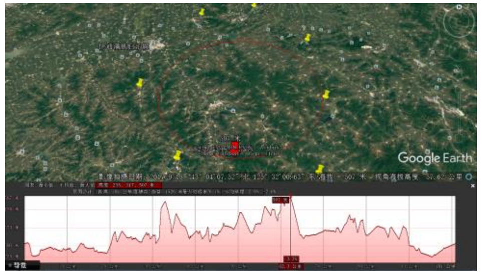


Training, Thermal-magnetic instability,
Thermal cycle,⋯

性能测试

CEPC Site Selection Status

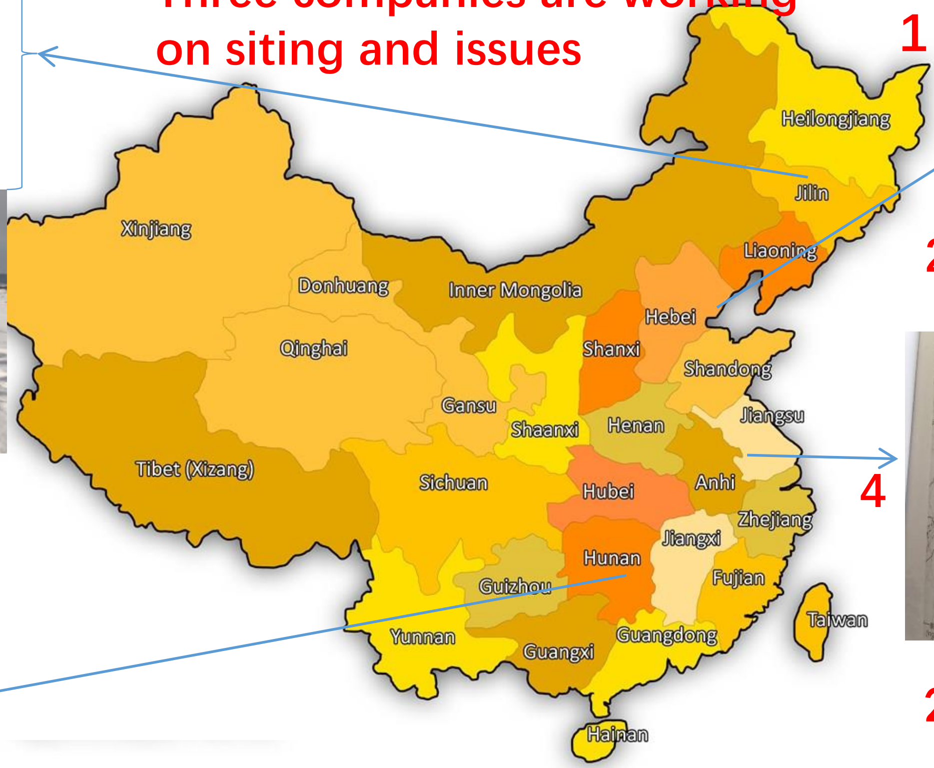


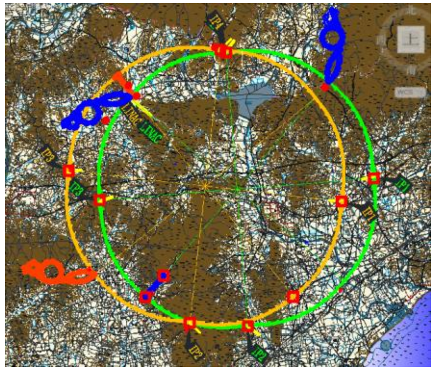


5

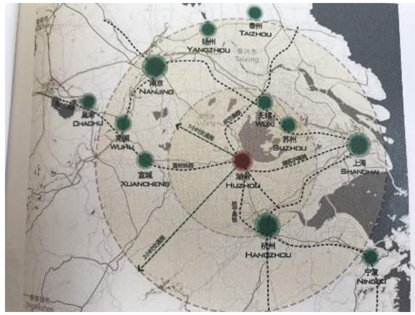
Three companies are working on siting and issues

2019.12月8-11 and 2020.1.8-10 Chuangchun sitings update

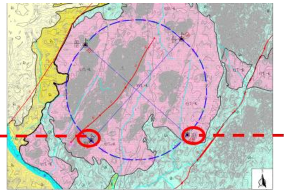




2020.9.14-18 Qinhuangdao updated

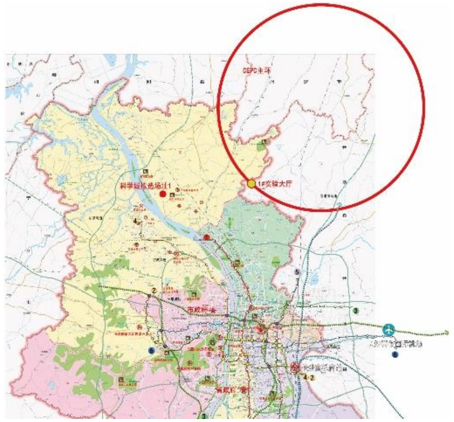


2019.12.16-17 Huzhou siting update



6

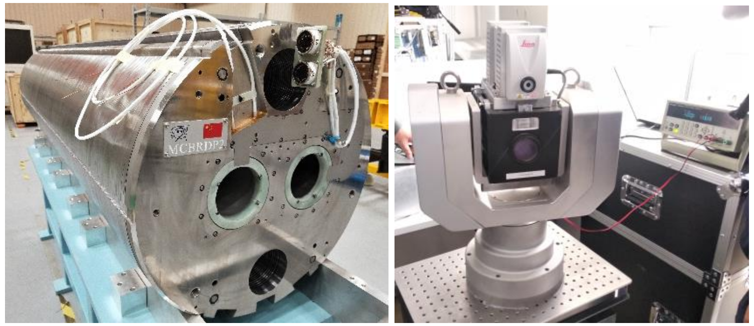
2019.08.19-20 Changsha siting update



1) Qinhuangdao, Hebei Province（Completed in 2014)
2) Huangling, Shanxi Province（Completed in 2017)
3) Shenshan, Guangdong Province(Completed in 2016)
4) Huzhou, Zhejiang Province (Started in March 2018)
5) Chuangchun, Jilin Province (Started in May 2018)
6) Changsha, Hunan Province (Started in Dec. 2018)

CEPC-CIPC Collaboration (part of CIPC members' logo)

CEPC 650MHz klystron at Kunshan Company



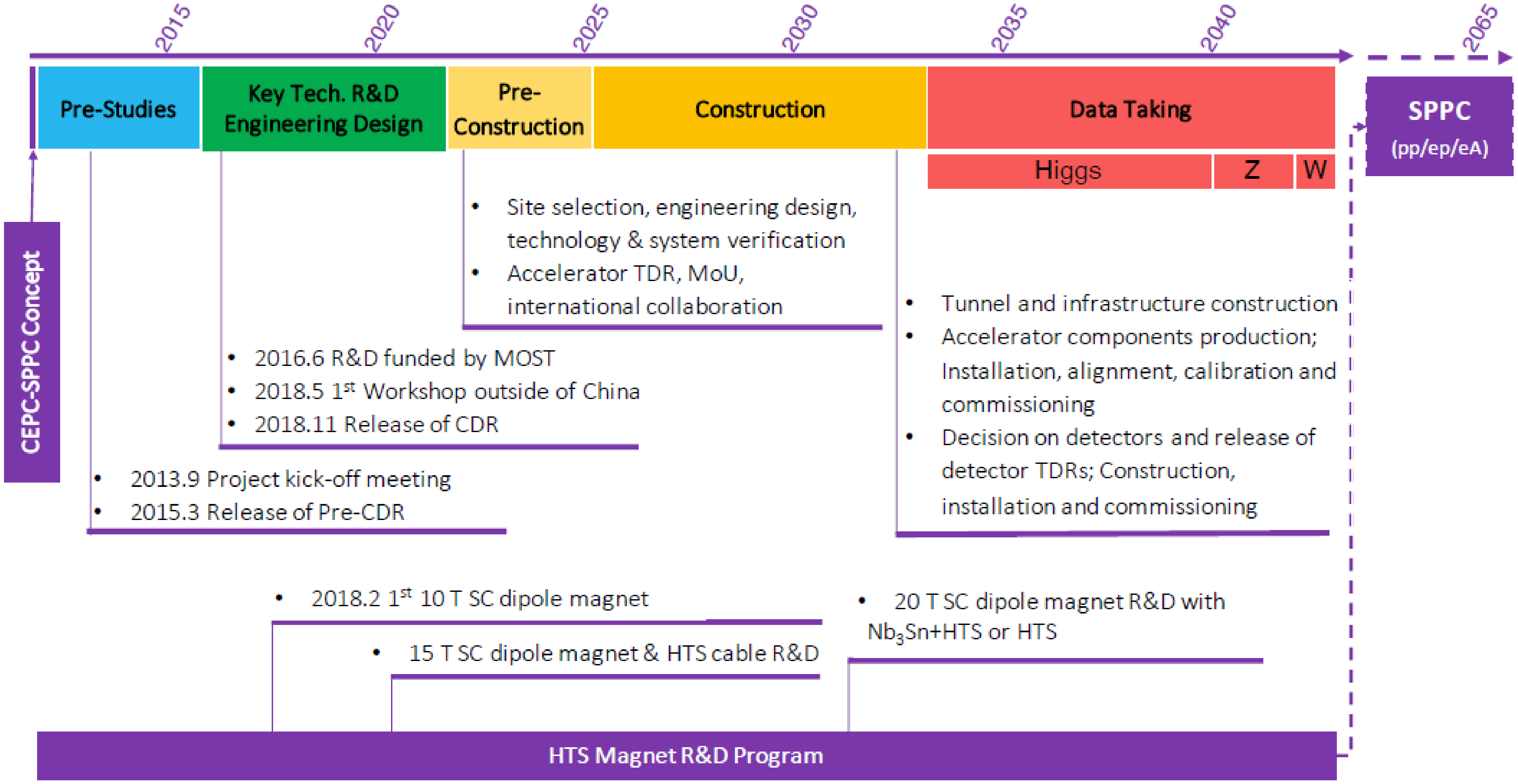
CERN LHC-HL CCT SC magnet

CEPC SC QD0 coil winding at KEYE Company

CEPC Detector SC coil winding tools at KEYE Company (Diameter ~7m)

CEPC long magnet measurement coil

CEPC Project Timeline



Summary

- CEPC accelerator system is optimized for the high luminosity operation including ttbar energy.
- CEPC key technology hardware R&D is progressing with the aim of TDR accomplishment by the end of 2022
- More efforts are needed to the TDR completion and EDR preparation

Acknowledgement

- Materials of this presentation are from various talks in the recent IARC meeting, especially from Prof. Gao's
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