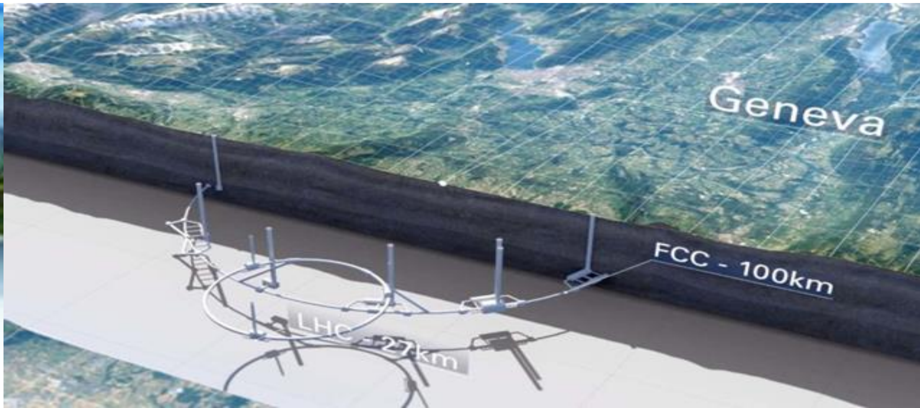
FCC Week, Paris

Circular Electron Positron Collider

Status & possible synergies on circular collider Developments

XinChou Lou

IHEP, Beijing



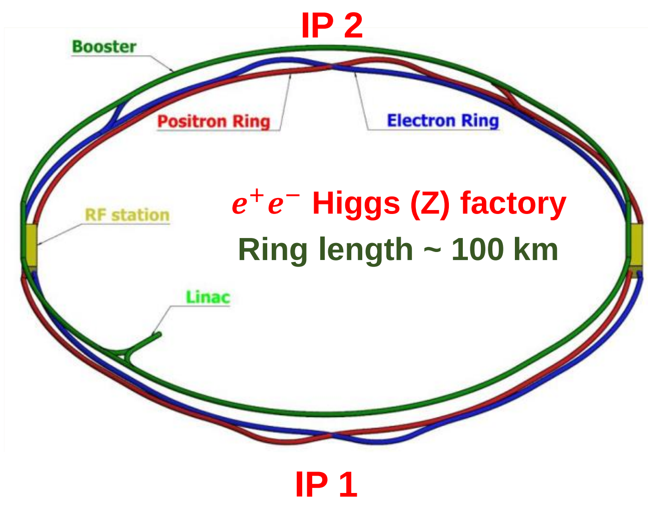
Outline

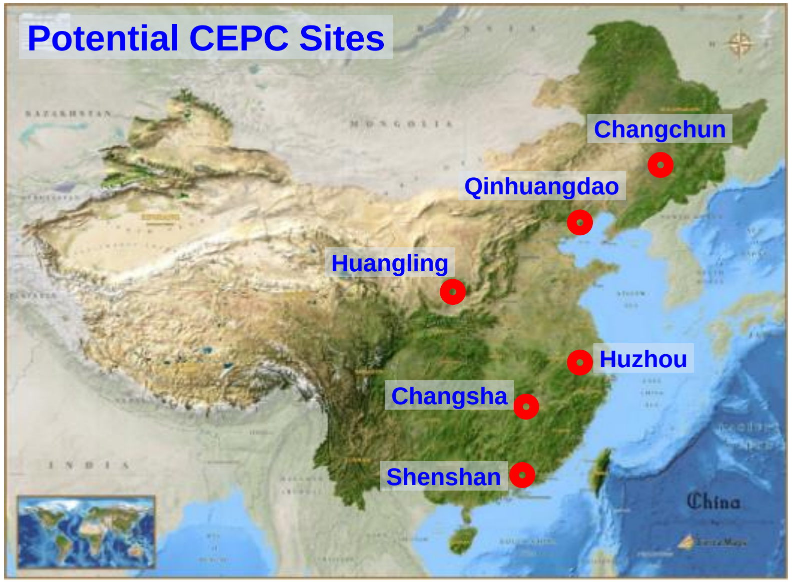
- Status of CEPC
  - introduction-reminder
  - status and plan
- Possible Synergies with FCC-ee
- Discussion

CEPC Status

FCC Week, Paris

- The CEPC aims to start operation in 2030's, as a Higgs (Z / W) factory in China.
- To run at $\sqrt{s}$ ~ 240 GeV, above the **ZH** production threshold for ≥1 M Higgs; at the **Z** pole for ~Tera Z; at the **W^+W^-** pair and possible $t\bar{t}$ pair production thresholds.
- Higgs, EW, flavor physics & QCD, probes of physics BSM.
- Possible *pp* collider (SppC) of $\sqrt{s}$ ~ 50–100 TeV in the far future.





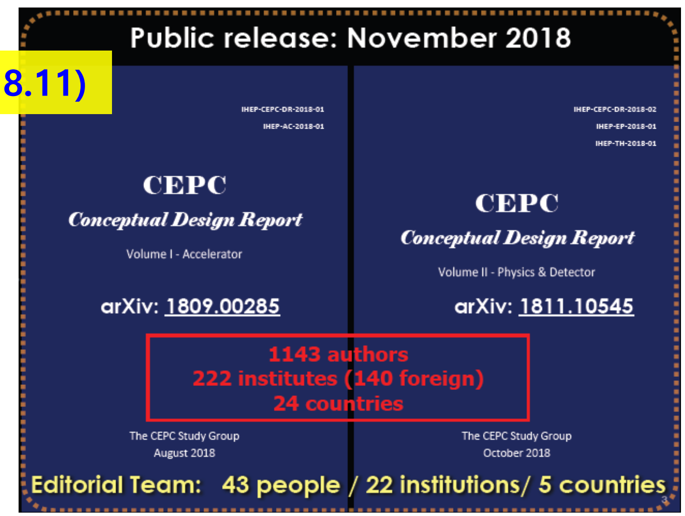
CEPC Status

FCC Week, Paris

CEPC-SPPC Kickoff (2013.9)

CEPC IAC Meeting (2015.9)

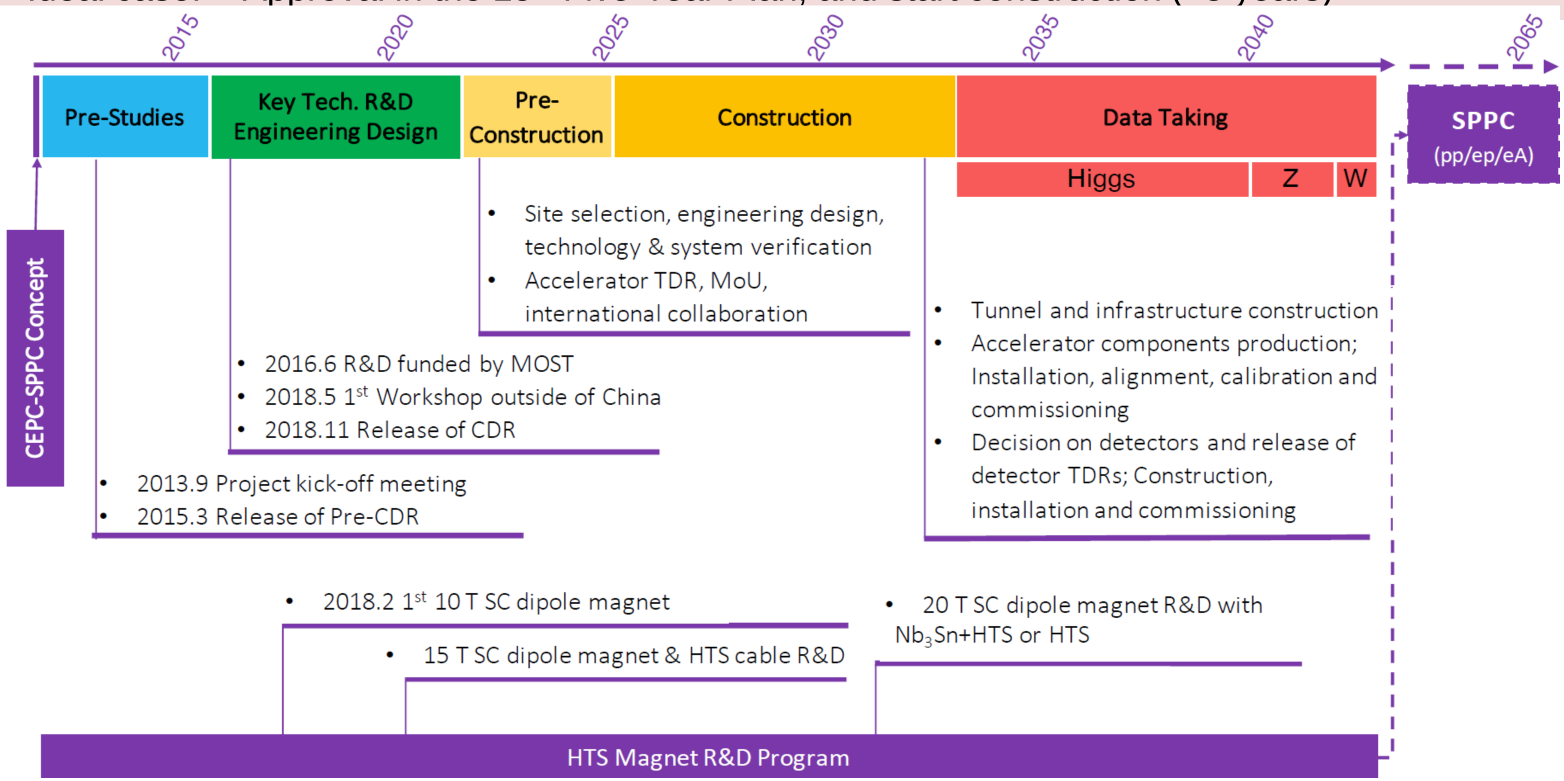
CEPC CDR Released (2018.11)



CEPC Status

FCC Week, Paris

- 2013-2025: Key technology R&D, from CDR to TDR, site selection, international collaboration etc.
- Ideal case: Approval in the 15th Five-Year Plan, and start construction (~8 years)



CEPC Status

FCC Week, Paris

- ❑ 2013-2025: Key technology R&D, from CDR to TDR, site selection, international collaboration etc.
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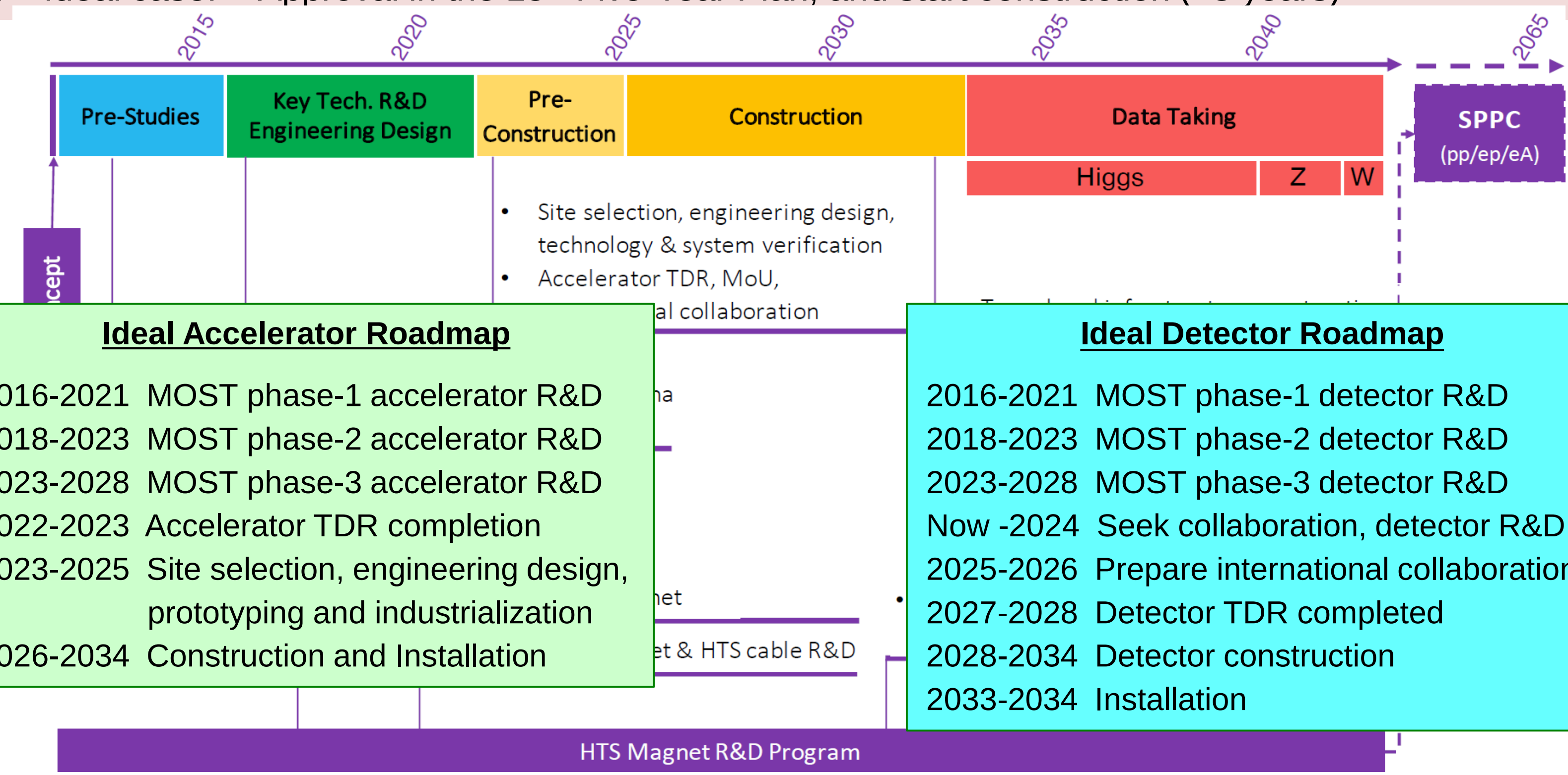


Ideal Accelerator Roadmap

2016-2021 MOST phase-1 accelerator R&D
2018-2023 MOST phase-2 accelerator R&D
2023-2028 MOST phase-3 accelerator R&D
2022-2023 Accelerator TDR completion
2023-2025 Site selection, engineering design, prototyping and industrialization
2026-2034 Construction and Installation

Ideal Detector Roadmap

2016-2021 MOST phase-1 detector R&D
2018-2023 MOST phase-2 detector R&D
2023-2028 MOST phase-3 detector R&D
Now -2024 Seek collaboration, detector R&D
2025-2026 Prepare international collaborations
2027-2028 Detector TDR completed
2028-2034 Detector construction
2033-2034 Installation

CEPC Status

CEPC Accelerator TDR

- **Consistent TDR high luminosity parameter design as a Higgs factory**
- **Key components with prototyping, technical feasibility demonstrated, no technical show stopper**
- **Design and R&D technical documentation (data, drawings, etc.)**
- **CEPC accelerator TDR document release planned for 2023**

CEPC Accelerator EDR Plan; ~Jan. 2023-Dec. 2025 preliminary

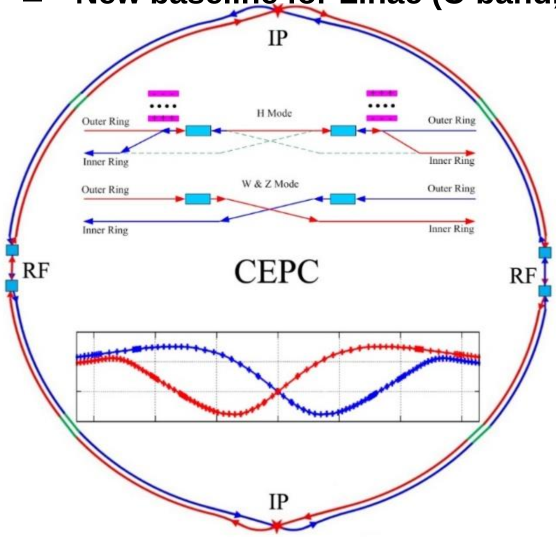
- CEPC site study will converge to one or two with feasibility studies (tunnel and infrastructures, environment)
- Engineering design of CEPC accelerator systems and components
- Site dependent civil engineering design implementation preparation
- EDR document completed for government's approval of starting construction in 2026 (the starting of the "15th five year plan")
- There will be more discussions on the planning

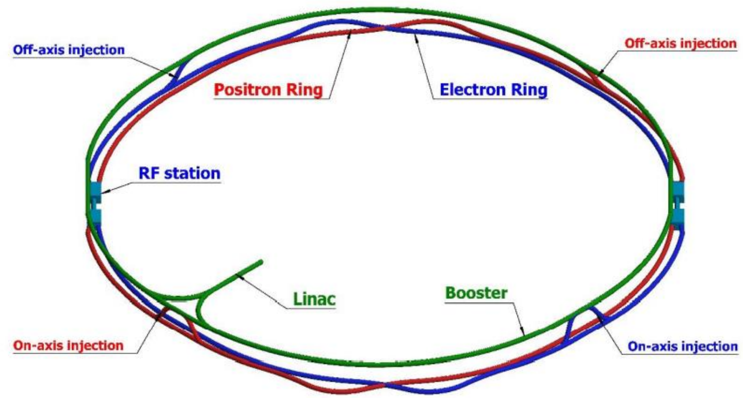
CEPC Status

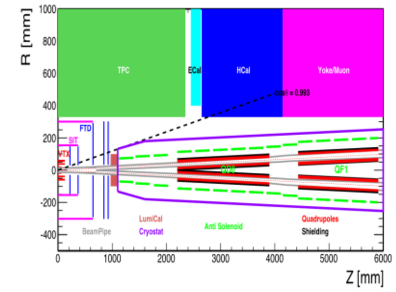
FCC Week, Paris

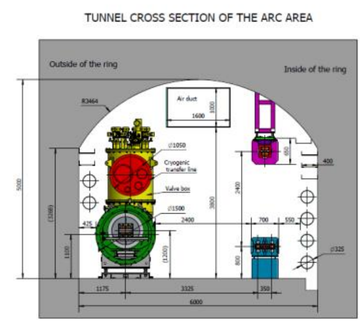
Design improvement and TDR

- 100 km double ring design (30 MW SR power, upgradable to 50MW).
- Switchable between H & Z, W modes without hardware change (magnet switch).
- New baseline for Linac (C-band, 20GeV) .

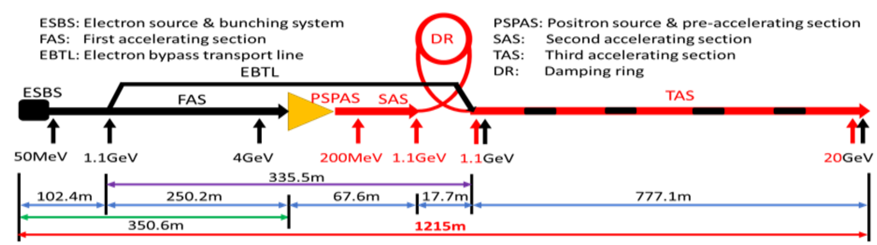








Operation mode		ZH	Z	W^+W^-	tt
$\sqrt{s}$ [GeV]		~240	~91.2	158-172	~360
L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	CDR (2018)	3	32	10	
	Latest	5.0	115	16	0.5



- Injection energy: 10GeV → 20GeV
- Max energy: 120GeV → 180GeV

Future Linac considered: plasma WF, C3

CEPC TDR Parameters

	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 spacing [ns]	4524	636	257	25 (10% gap)
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 [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

Y.W. Wang, D. Wang, Y. Zhang, J. Y. zhai, S.Bai, Y.D. Liu, N. Wang, C. X. Cui, C.H. Yu, J. Gao et al

CEPC Accelerator white paper to Snowss21 arXiv:2203.09451

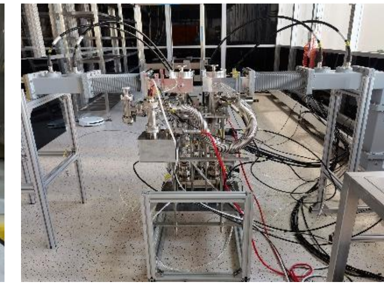
The AC power is 270MW

CEPC SCRF Facility & Components

Beijing Huairou (4500m²)

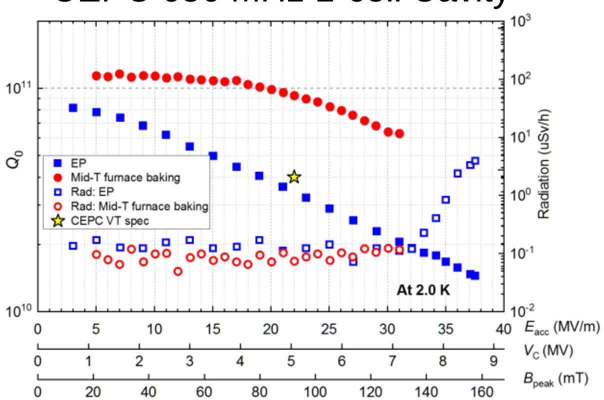

IHEP PAPS established in July 2021





Horizontal test stand, 1.3GHz 9cell cavities, and couplers...

CEPC 650 MHz 1-cell Cavity

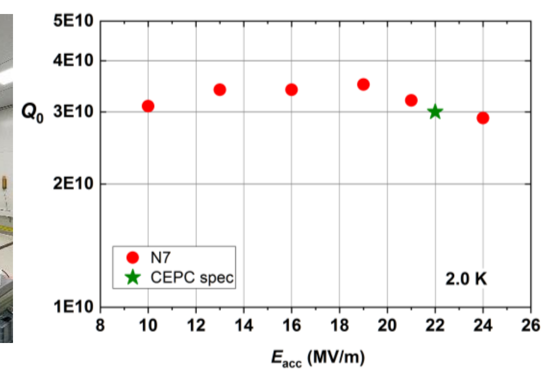


P. Sha et al., *Applied Sciences*. 2022; 12(2):546.

The 650Mhz 1-cell cavity's results (6.4E10@30MV/m, 1.5E10@37.5MV/m) have broken China's gradient record of low-frequency (<1 GHz) elliptical cavities.

World record Q of 650 MHz cavity at 30 MV/m.

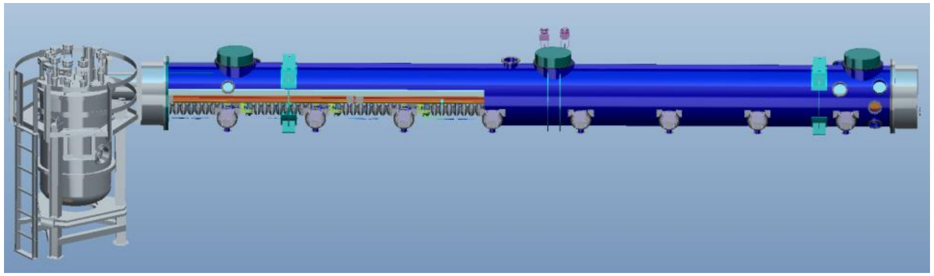
1.3 GHz High Q Mid-T Cavity Horizontal Test

CEPC SCRF Test Facility & Conponents

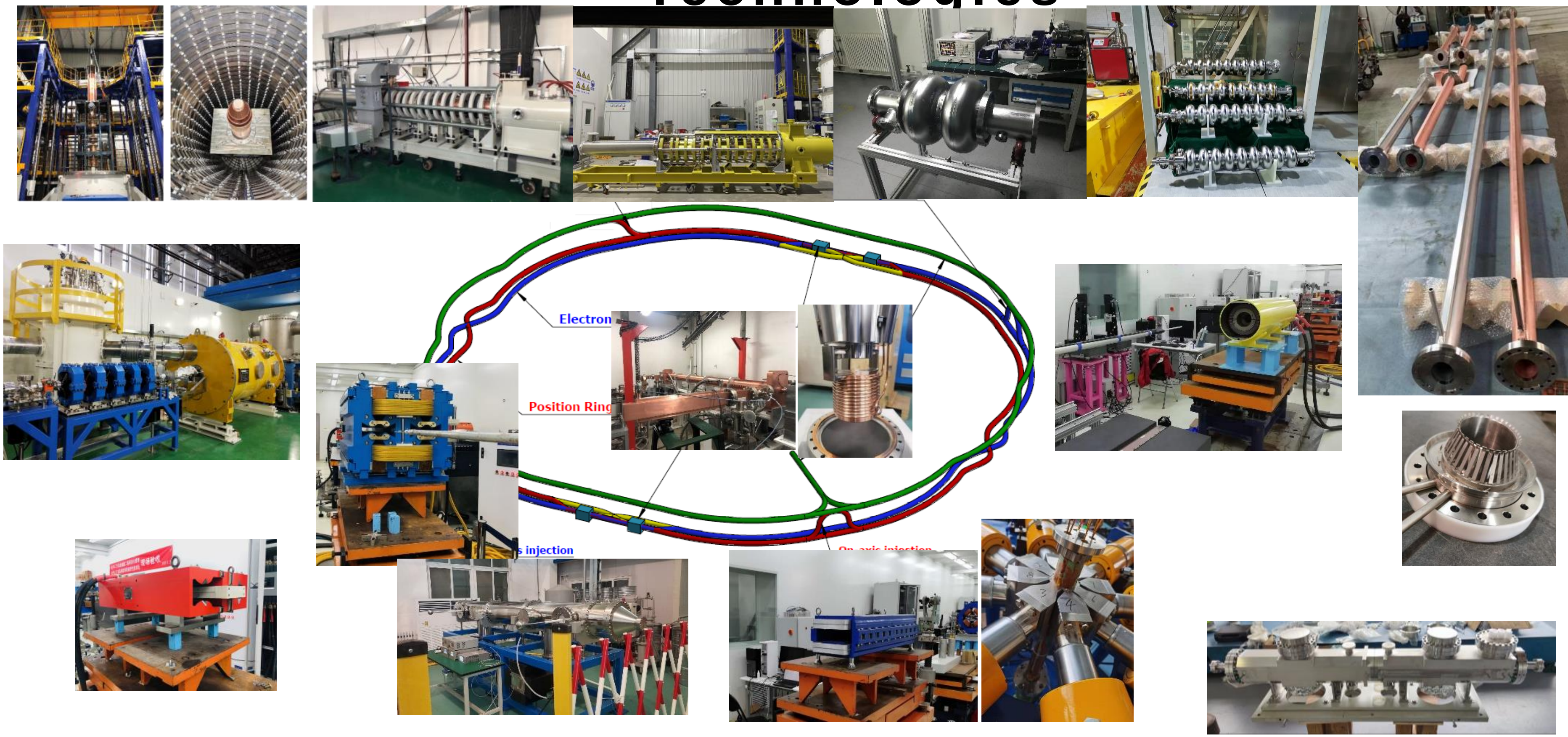
CEPC 650 MHz Test Cryomodule with Beam/
1.3GHz High Q Cryomodule (8X9cell)

- 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.
- 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.

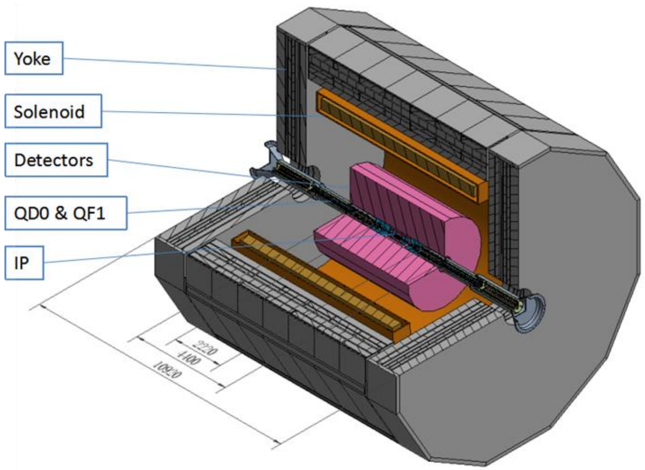


- 1.3 GHz 8x9-cell high Q cryomodule prototype
- Component fabrication in 2021 to mid 2022
- Assemble and horizontal test in 2022

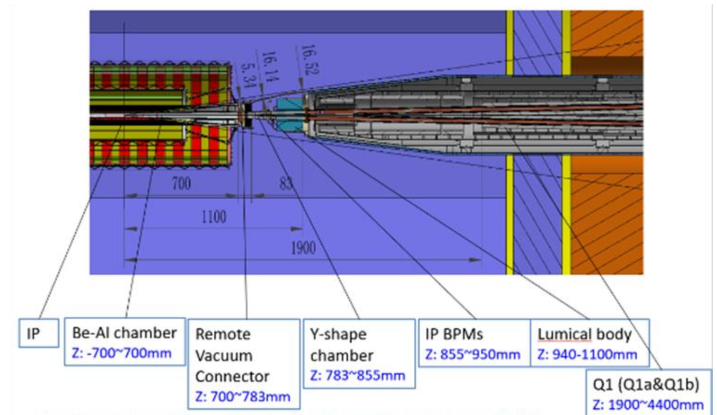
CEPC TDR R&D Status of Key Technologies



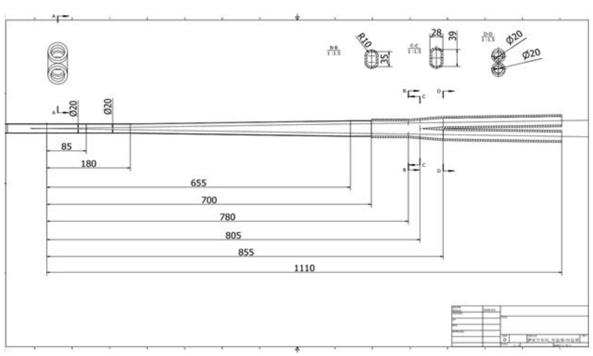
CEPC MDI Study Progresses



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



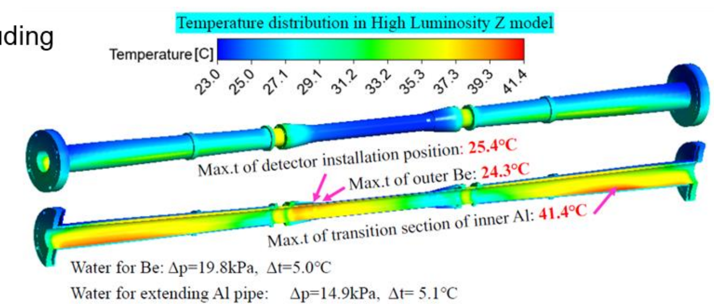
All the devices are within the detective angle, acos0.99.



- ✓ HOM in IR region
- ✓ 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

Temperature studies in IR beam pipe



High Energy Light Source under construction

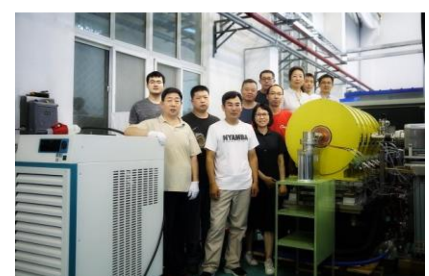
beam energy 6 GeV, 1.36KM, ≤ 0.06nm·rad, 14 beam lines

Carried out by IHEP, to be completed in 2025, great training and preparation for CEPC



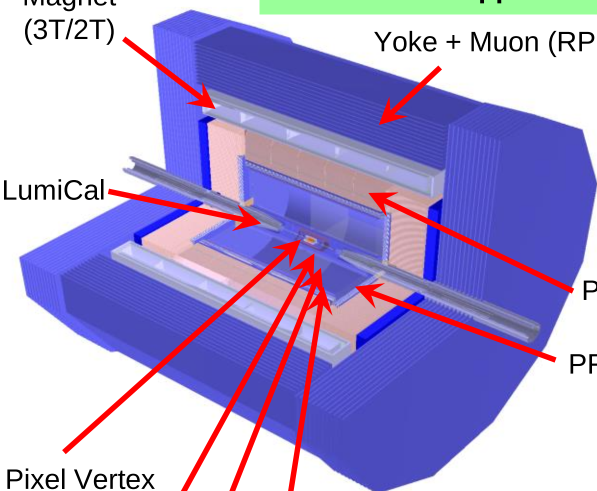




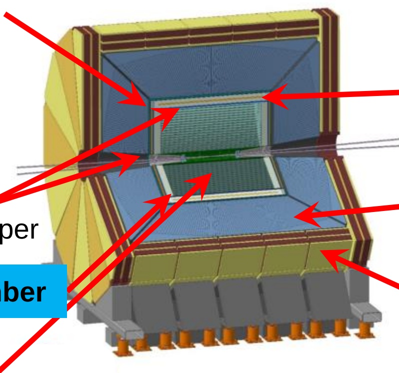


Conceptual Detector Designs

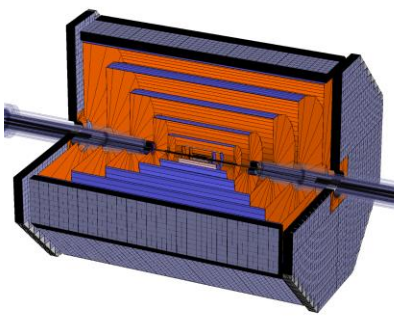
(Baseline Design)
Particle Flow Approach



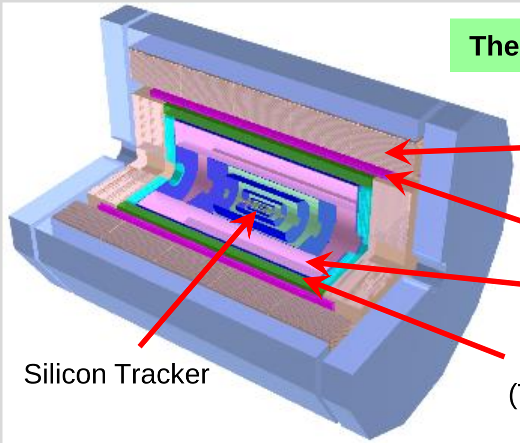
IDEA concept
(also proposed for FCC-ee)



FST concept
(Full Silicon Tracker)

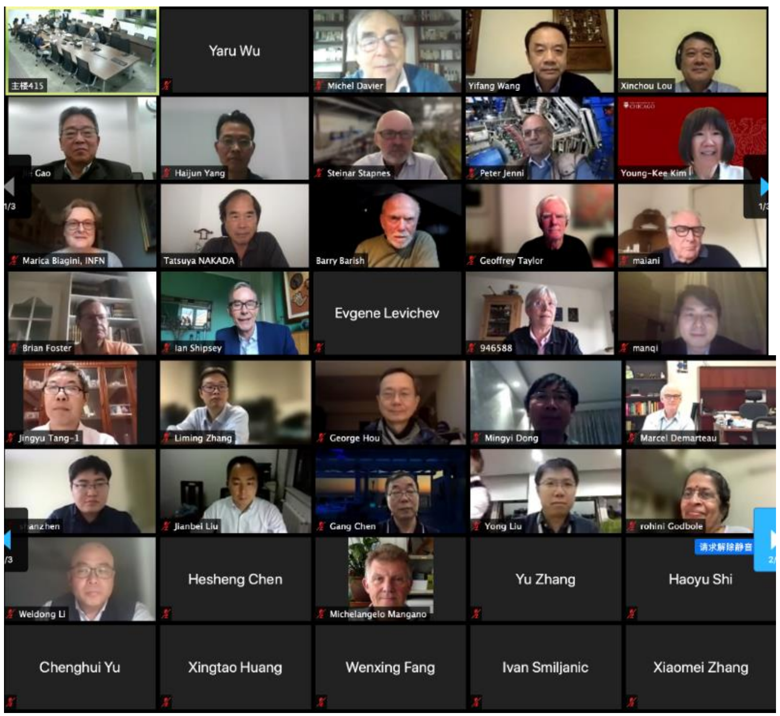


The 4th Concept



CEPC Status

- **The 7th CEPC IAC meeting (online) was held in November, 2021**
- **The IAC presented an advisory report with many recommendations。**



- **In 2021, two online International Accelerator Review Committee (IARC) meetings took place,**
  - **May (11 talks)**
  - **October (22 talks)**
- **IARC delivered two dedicated review reports**

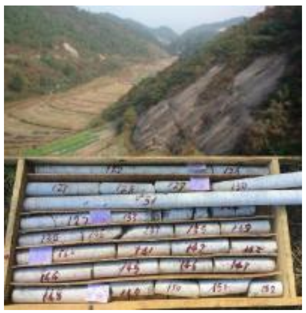
great help and guidance

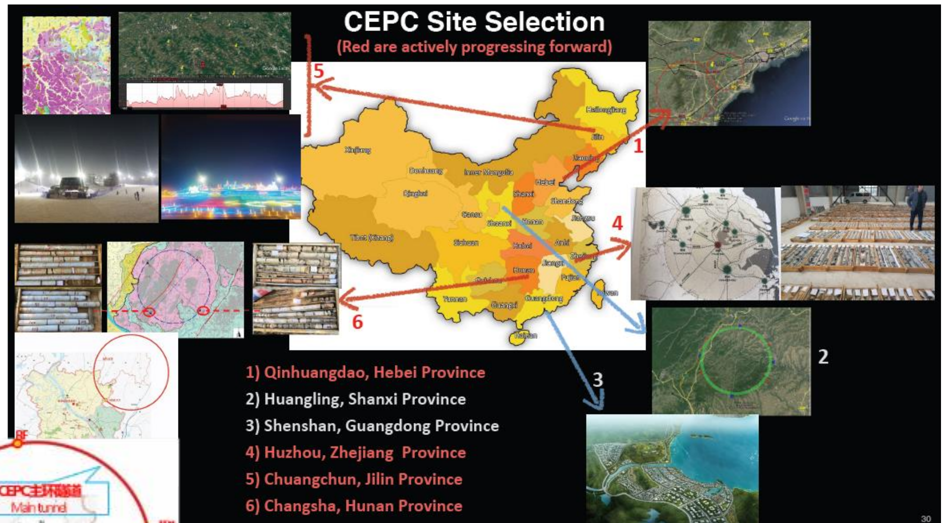
CEPC Status

FCC Week, Paris

Site Investigation

Factors: geology, electricity supply, transportation, international-friendly, local supports …





CEPC Status

FCC Week, Paris

Site Investigation

Factors: geology, electricity supply, transportation, international-friendly, local supports …

July 5, 2021: Changsha Bureau of S&T entrusted Hunan U. to conduct a feasibility study.

Sept 4, 2021: Hunan U. organized a review by a committee of experts from multiple disciplines. The committee evaluated scientific potential of CEPC, feasibility of a new science city based on CEPC, and overall impact on Changsha. The overall conclusion is very positive. The local government is interested and very supportive to the CEPC project.

Possible Synergies

Ideally

- Areas critical to circular ee colliders
- Difficult areas for circular ee colliders to achieve the design performance
- New and innovative approaches that may bring the circular collider to the next level
- Instrumentation enabling physicists to collect & analyze data to reach the limit of the collider data
- Cross-checks and mutual support

Possible Synergies

Areas critical to circular ee colliders

design optimization
design reviews
key beam physics studies

large volume components: design, quality, cost
(magnets, SRF, installation, ….)

……

Possible Synergies

Difficult areas for circular ee colliders to achieve the design performance

machine-detector interface

control system, safety

(environment, operation)

management software

……

Possible Synergies

New and innovative approaches that may bring the circular collider to the next level

new linac and injection (plasma WF, C3, …)
upgradability (luminosity, easy to operate, energy)

HT superconductor development, lower the cost for the pp collider
high energy gamma synchrotron light and app.

……

Possible Synergies

Instrumentation

detector design beyond those of ILC, LEP
6G wireless detector control, data transmission
upgradability (luminosity, easy to operate, energy)

ECFA detector program

……

Possible Synergies

Cross-checks and mutual support

circular ee collider eco-system
strengthen China's collaboration with CERN

outreach and science education about HEP

……

Discussion

Status of CEPC

Possible Synergies

Ideally

- Areas critical to circular ee colliders
- Difficult areas for circular ee colliders to achieve the design performance
- New and innovative approaches that may bring the circular collider to the next level
- Instrumentation enabling physicists to collect & analyze data to reach the limit of the collider data
- Cross-checks and mutual support

Additional Slides

CEPC Plasma Injector 10 GeV → 25 GeV Pratically Feasible

D.Z. Li

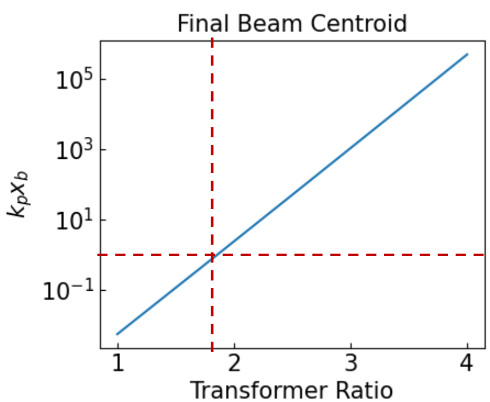
Theoretical analysis:

$$x_b \sim \frac{1.27\sigma_r}{\sqrt{1+1.67R}} \times 10^{-5} \times e^{1.3\left(\frac{\gamma_0}{2}\right)^{\frac{1}{6}} c^{\frac{1}{3}} c_b^{\frac{1}{3}} R^{\frac{1}{3}} \left(\sqrt{2}R+\frac{1}{\sqrt{2}}\right)^{\frac{2}{3}}}$$

The driver should be stable enough, if the beam centroid x_b is no more than $k_p{}^{-1}$. For a 10 GeV driver, let the beam size $k_p\sigma_r = 0.2$, c $= 0.7$, $c_b = 0.8$

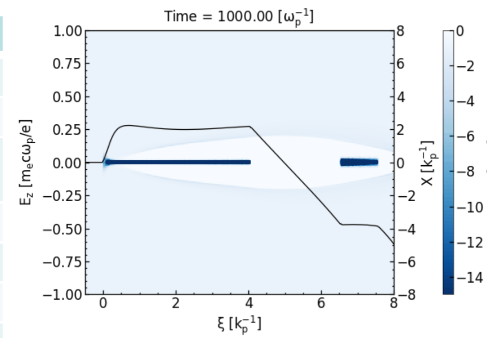
The transformer ratio R should be less than 1.8, which means:

10 GeV → 25 GeV CPI scheme ($R \sim 1.5$) should be safe.



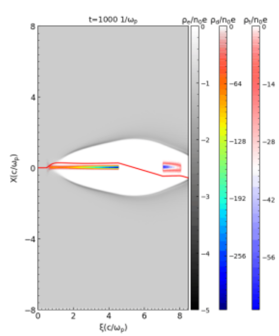
Simulation analysis for 10 GeV → 25 GeV CPI scheme

beam	Driver	Trailer
plasma density n_p	$0.5 \times 10^{16} cm^{-3}$	
Driver energy $E(GeV)$	10	10
Normalized emittance $\epsilon_n(mm\ mrad)$	20	100
Length(um)	300	77
(matched)Spot size(um)	3.87	8.65
Charge(nC)	4	1.24
Energy spread $\delta_E(\%)$	0	0
Beam distance(um)	184	

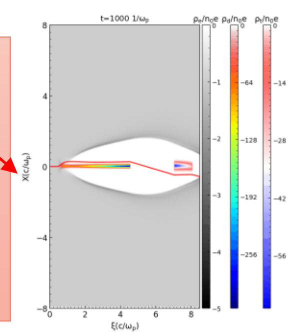


Acceleration process for idea case

Symmetry Ratio	Energy	Emittance (mm·mrad)	Bunch charge	rms Energy spread
100 (Ideal case)	25.02 GeV	100 / 100	1.36 nC	0.4%
97.5% (real case)	24.89 GeV	431 / 294	1.33 nC	0.62%



Error tolerance analysis shows the transverse and longitudinal offset thresholds is (-6μm, 6μm) and (-1.2μm, 1.35μm), which is acceptable to conventional linac accelerators.



CEPC dedicative key technology R&D

Key Devices	Quantity	R&D status
Dual aperture dipole @Collider	2384	1m prototype fulfil the specifications. 5m long full length prototype in progress
Dual aperture QUAD @ collider	2392	Crosstalk interfere between two apertures were reduced by the special yoke shape. Preliminary measurement confirms the design.
Weak field dipole @ booster	16320	1m prototype fulfill the specifications, 5.7 m long full length prototype in progress. Long measurement system in fabrication.
650MHz SRF cavity @ collider	240	Both 1/2-cell cavity show premium quality. State-of-the-art technology for CEPC
650MHz cryogenic stat module	40	Cool test shows good results satisfying the specifications
1.3 GHz 9-cell Nb cavities @ booster	96	Quality better than CEPC requirement. State of the art in the XFEL manufacture
1.3 GHz cryomodule	12	In progress for XFEL project, principle demonstration for CEPC
650MHz klystron/power source @ collider	120	The 1st prototype realize 62% efficiency and 800/700 kW @ pulse/CW mode; 2nd prototype in commissioning, the efficiency reaches 67.1% and the maximum power is 780kW; the 3rd prototype with MBK technology in fabrication.
Visual device for installation & alignment		>40000 instruments for installation, a novel multi-function combined alignment device R&D for high efficient work. Realizing the synchronous diverse targets measurement

Relevant key technologies developed in other projects

Devices	Quantity	R&D status
Single aperture magnets @ collider	D(160)+Q(960)+S(1864) +Corr.(5808)	High specification magnets mass production for HEPS,
Instrumentations & BPM	2900/1808	Mass production for BEPC-II & HEPS, quality meets CEPC requirement
Vacuum tube and system @ collider/booster	34000/17000	NEG coating technology to narrow vacuum tubes developed for HEPS, satisfying CEPC requirements.
RF bellows @ collider/booster	24000/12000	R&D and mass production done for HEPS, satisfying CEPC specifications
Vacuum bump @ collider/booster	35200/8400	Maturely technology
Cryogenic transporting elements	4000	Large size cryogenic system develop by BEPC-II and CEPC
Magnet power source (100-500ppm)	8196	Magnet power source production matures
Normal conducting C-band accelerating cavity		Mass production completion for Soft XFEL project
Fast pulse generator, kicker, septum		HEPS development fulfills CEPC requirements

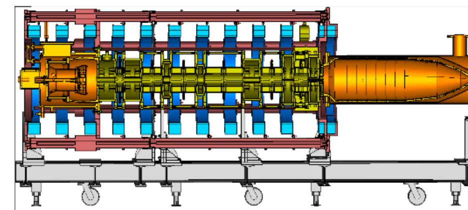
CEPC 650MHz High Efficiency Klystrons

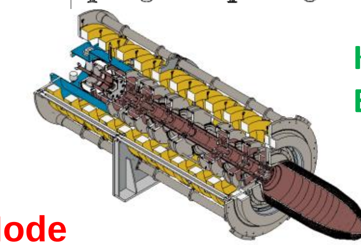
Z.S.Zhou

Klystron No. 1
Efficiency 65%
(2020)

Under test

Klystron No. 2
Efficiency 77%
(2021)

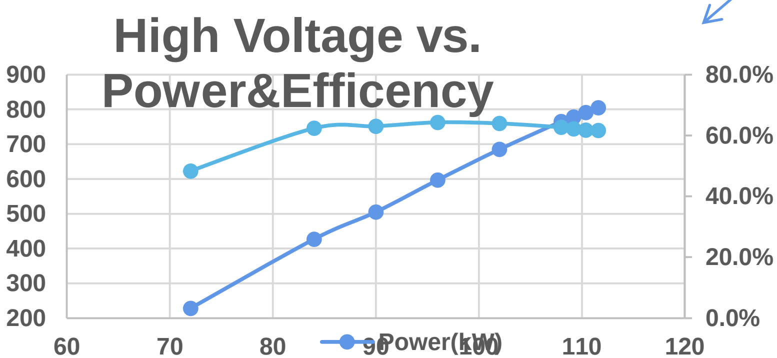




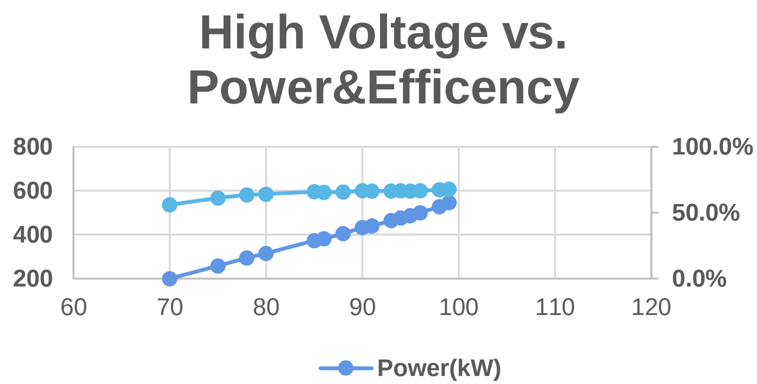
Klystron No. 3
Efficiency 80.5%
(2022)

2022年5月19日

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



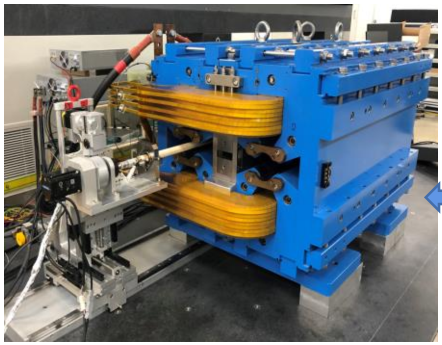
CW RF Mode

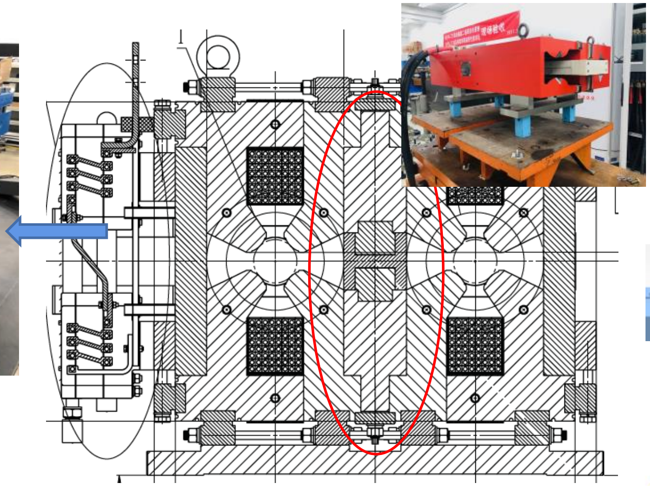


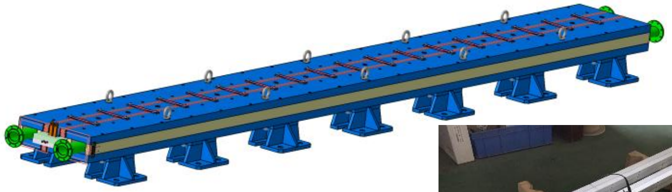
CEPC Collider Ring Magnets

M. Yang

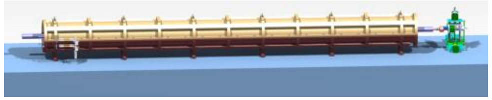
- Modification of the dual aperture quadrupole magnet



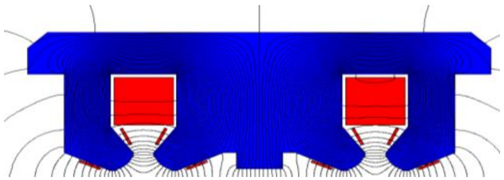




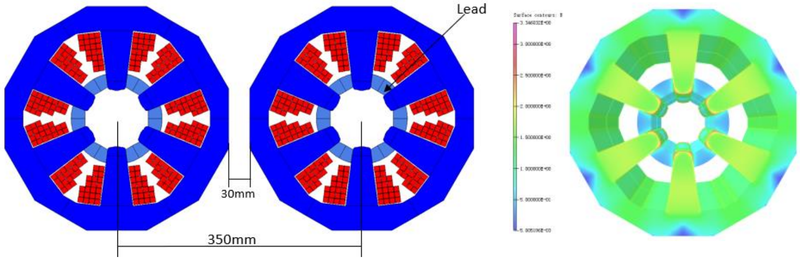
Full size dural aperture dipole



After iron modification with center shim, X0 shifts is lower, which is agreed with the simulation results.



Dural aperture F/D qudrupole design with trim coils

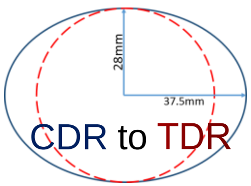


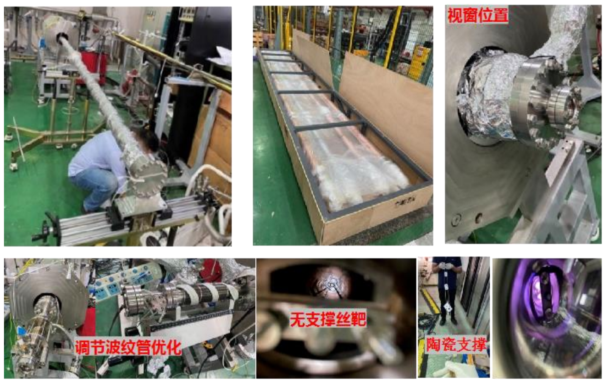
Sextupole design

CEPC Vacuum System R&D

Y.S. Ma

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



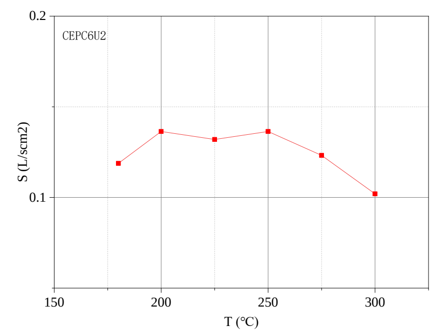


6 m vacuum pipe have been installed on the NEG coating setup

All metal gate valve different from VTA

Vacuum pipes and RF shielding bellows

Facility of pumping speed test have been finished in Dongguan



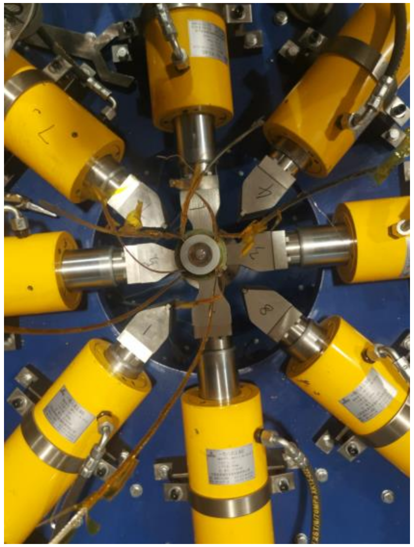
Pumping speed test of 2 meters long CEPC Cu pipe of NEG coating in IHEP

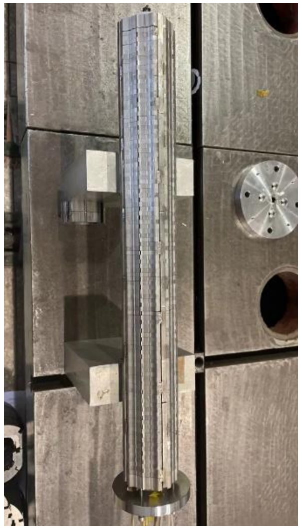
CEPC QD0 SC Magnet R&D (0.5m short model)

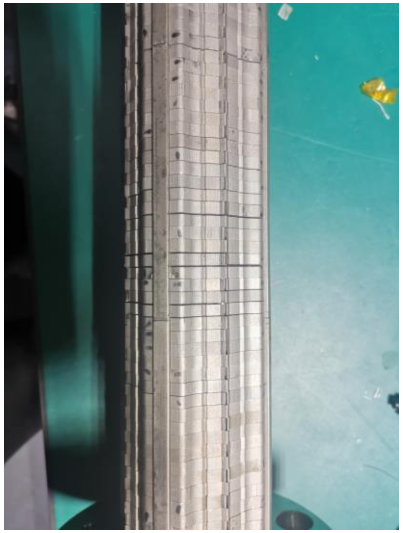
Magnet name	0.5m QD0 model magnet
Field gradient (T/m)	136
Magnetic length (m)	0.5
Coil turns per pole	21
Excitation current (A)	2070
Coil layers	2
Conductor	Rutherford Cable, width 3 mm, mid thickness 0.93 mm, keystone angle 1.9 deg, Cu:Sc=1.3, 12 strands
Stored energy (KJ) (Single aperture)	2.6
Inductance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

Y.S. Zhu

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

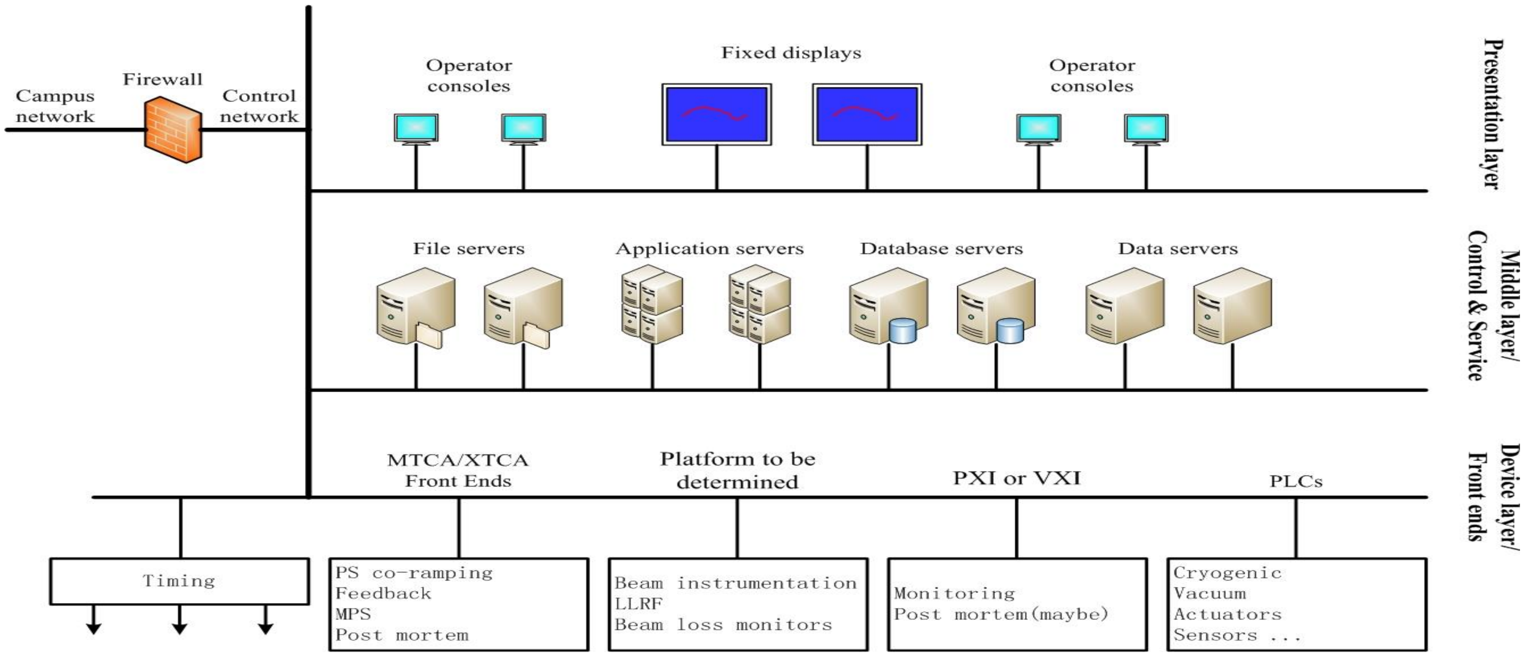






Fabrication of QD0 single aperture short model magnet (NbTi, 136T/m) will be completed in June, 2022, and a dual aperture SC quadrupole will be the next step

CEPC Control System and Sub-system

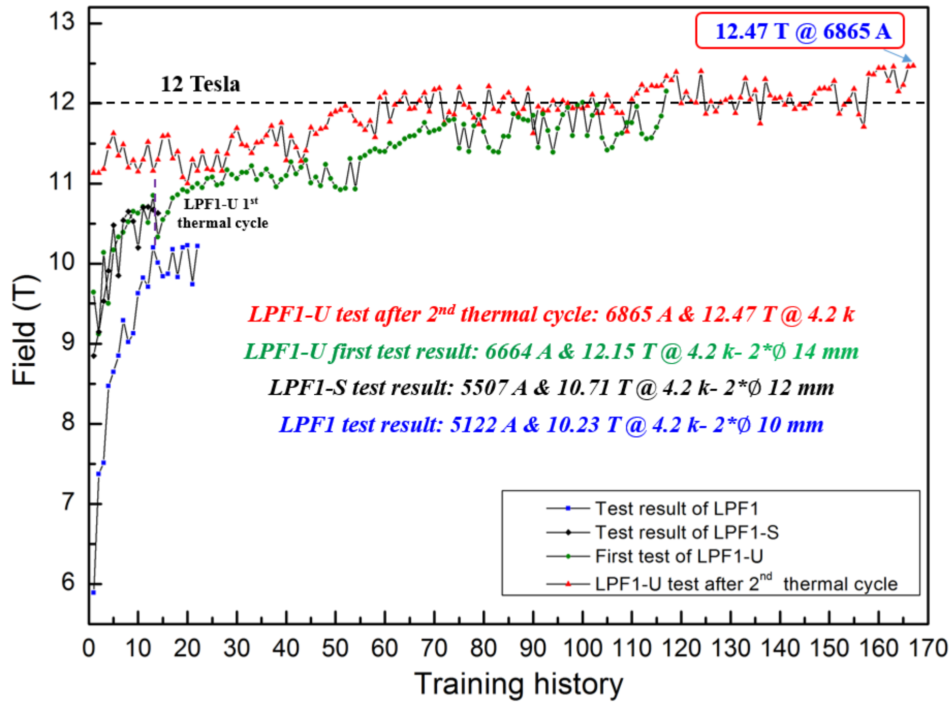


Overall hardware architecture of the control system

Latest performance of LPF1-U (SppC)

Qingjin Xu

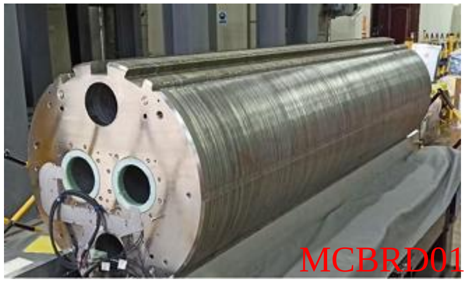
Picture of LPF1-U

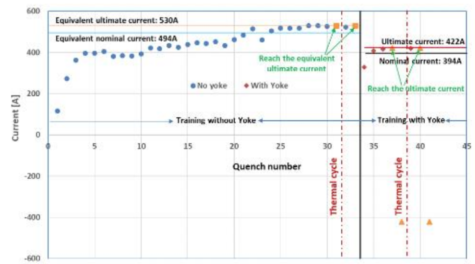


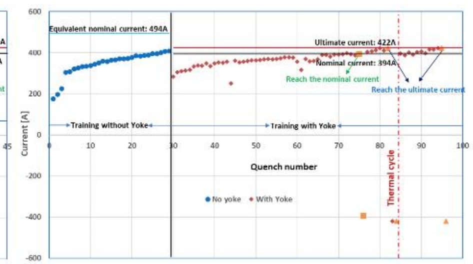
Dual aperture superconducting dipole achieves 12.47 T at 4.2 K
Entirely fabricated in China. The next step is reaching 16-19T field

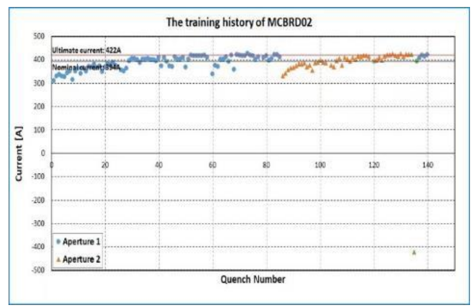
Development of CCT dipole magnets for HL-LHC by IHEP

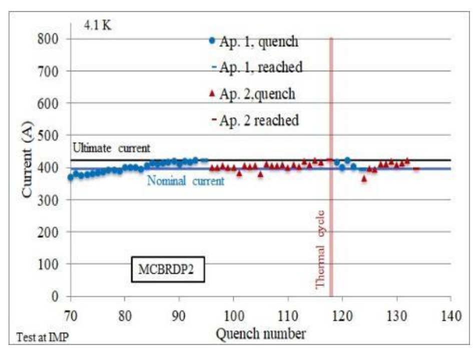
Qingjin Xu











- The first set of CCT superconducting magnets MCBRD01 with satisfactory field strength and field quality, has been shipped to Europe in October, 2021.
- The assembly of the 2nd set of HL-LHC CCT superconducting magnets has been finished in Jan, 2022, and now the magnet is tested at IMP
- Fabrication of a full size prototype magnet MCBRDP2 was completed in May, 2020. Both apertures reached the ultimate current.

CEPC Cost Model Study in relation with Collider Circumference

D. Wang, et al.

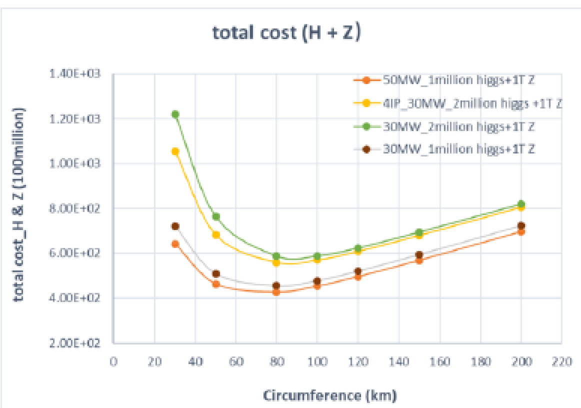
CEPC Cost Model Study and Circumference Optimization*

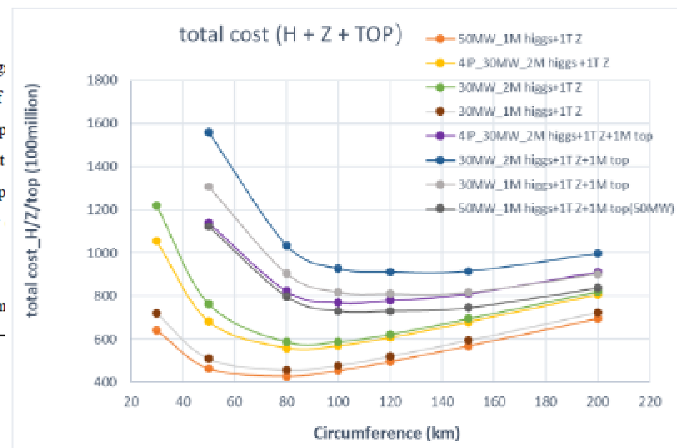
Dou Wang#, Jie Gao, Manqi Ruan, Yuhui Li, Haocheng Xu, Yudong Liu, Meng Li, Yuan Zhang, Yiwei Wang, Jiyuan Zhai, Zusheng Zhou

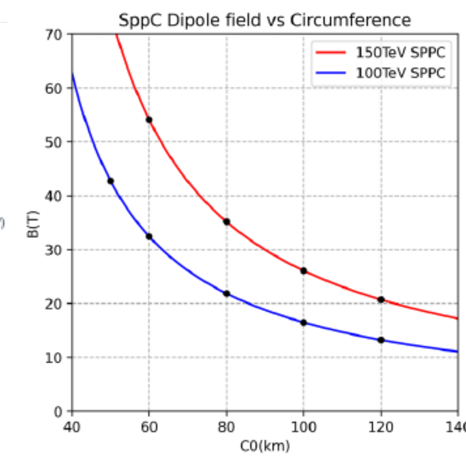
IHEP, Beijing, China

Abstract

An article has been submitted to NIM-A in 2022







Global scientific goals (particle numers)/construction and operation costs shows that around 100km seems a very good choice

CEPC CDR-Higgs

Peak Luminosity = $3\times 10^{34} cm^{-2}s^{-1}$

Ingetrated Luminosity = 5.6 ab^{-1}

Higgs annual luminosity =0.8 ab^{-1}

CEPC TDR-Higgs

Peak Luminosity = $5\times 10^{34} cm^{-2}s^{-1}$

Ingetrated Luminosity = 9.3 ab^{-1}

Higgs annual luminosity =1.3 ab^{-1}

CEPC TDR-Higgs (upgrade)

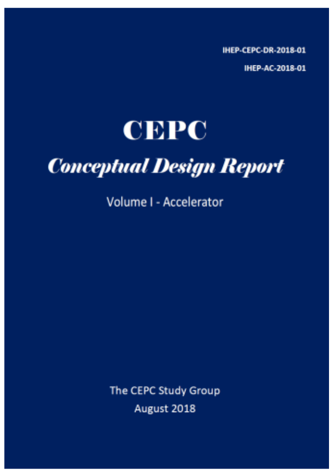
Peak Luminosity = $8.3\times 10^{34} cm^{-2}s^{-1}$

Ingetrated Luminosity = 15.4 ab^{-1}

Higgs annual luminosity =2.2 ab^{-1}

These parameters are used for Snowmass21

CEPC CDR Vol. I, Accelerator



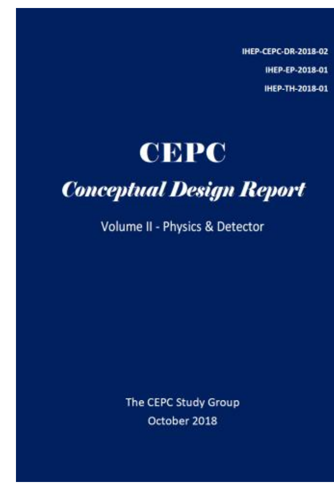
CEPC Accelerator Snowmass 21 AF White Paper

1) CEPC Accelerator white paper to Snowmass21, arXiv:2203.09451

2) CEPC CDR Vol. I, Accelerator ,http://cepc.ihep.ac.cn/CEPC_CDR_Vol1_Accelerator.pdf

3) CEPC CDR Vol. II, Physics and Detector, http://cepc.ihep.ac.cn/CEPC_CDR_Vol2_Physics-Detector.pdf

CEPC CDR Vol. II, Physics/Detector



CEPC Collaboration with Industry (CIPC)

CEPC 650MHz Klystron at Kunshan Co.

CERN HL-LHC CCT SC magnet

CEPC SC QD0 coil winding at KEYE Co.

CIPC was established in Nov. 2017, there are 70+ companies join the CIPC so far.

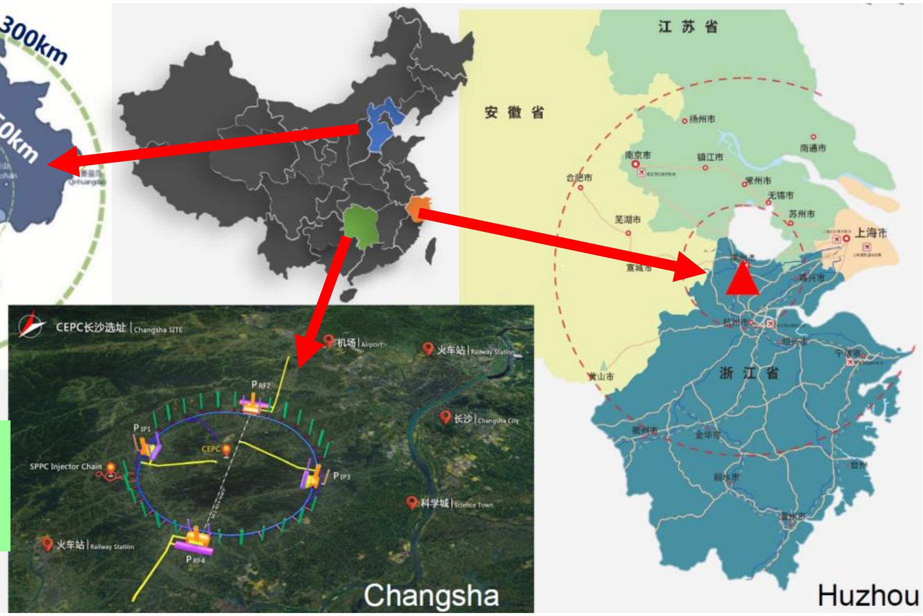
CEPC Detector SC coil winding tools at KEYE Company (Diameter ~7m)

CEPC long magnet measurement coil

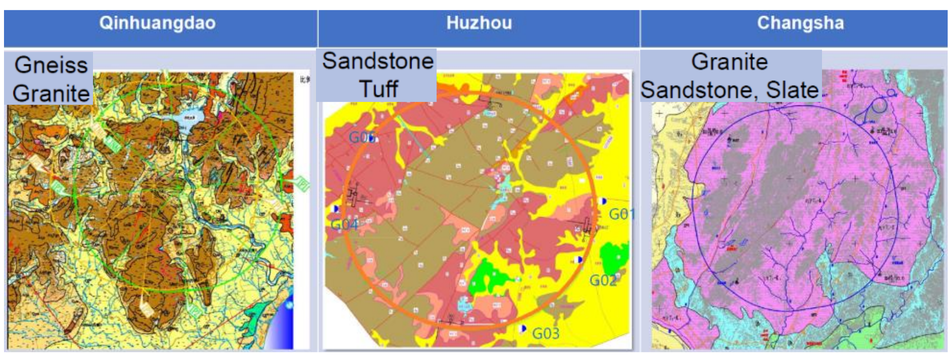
1) Superconduting materials (for cavity and for magnets)
2) Superconductiong cavities
3) Cryomodules
4) Cryogenics
5) Klystrons
6) Magnet technology
7)Vacuum technologies
8) Mechanical technologies
9)Electronics
10) SRF
11) Power sources
12) Civil engineering
13) Precise machinery
.....

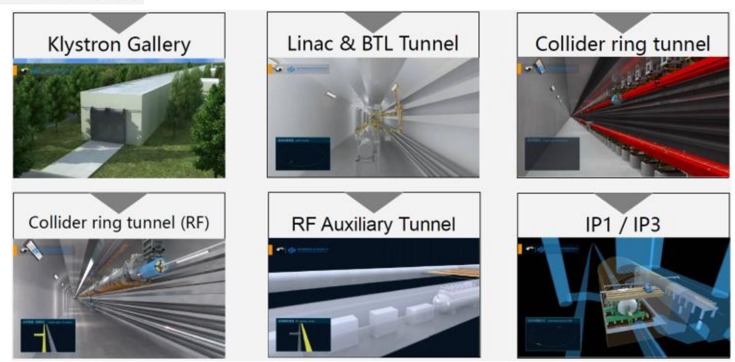
More than 40 companies joined in first phase of CIPC,
and 70 companies now.

Geology of Candidate Sites and Science Cities



Three sites were presented at the CEPC2021 workshop





CEPC Financial Model

Funding Sources	Financial Model #1（RMB）	Financial Model #2 (RMB)
Central Government	30B	6-10B
Local Government	Land, Infrastructure	25-18B Land, Infrastructure
International Partners	1-5B	1-5B
Companies & Donations	0-3B	0-3B
Total Budget	**36B**	**36B**

In Oct., 2021: Institute of Science and Technology Strategic Consulting, CAS is carrying out an independent assessment of Social Cost Benefit Analysis for the CEPC project, the report will be available in August, 2022.