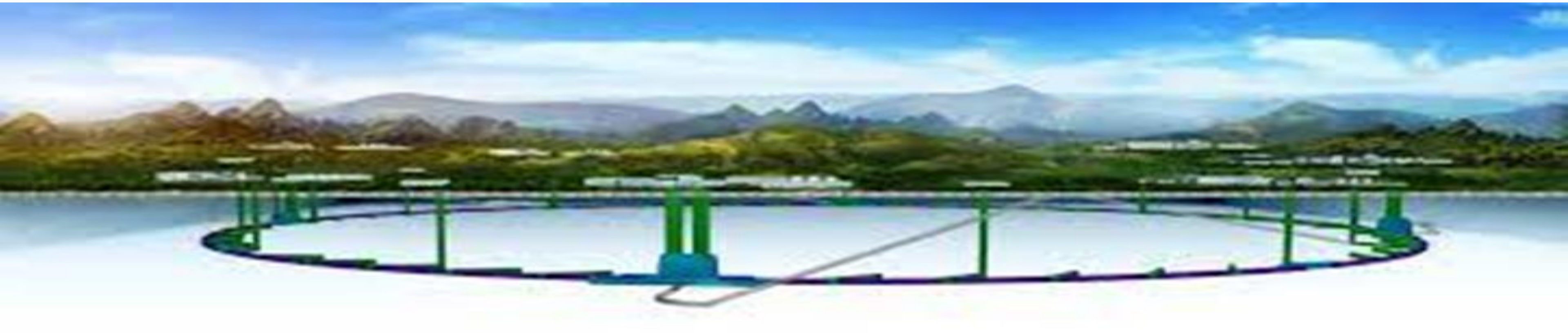
114th Plenary ECFA Meeting, Frascati, July 4-5, 2024

Status and Plan
The Circular Electron Positron Collider

XinChou LOU
IHEP, Beijing



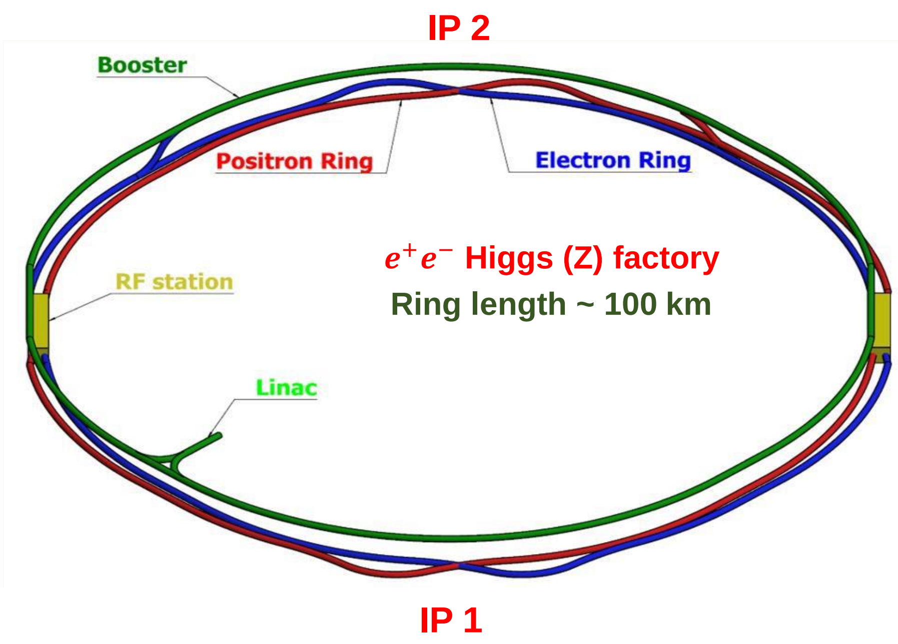
Outline

- Introduction and Reminder
- CEPC Status and Progress
- The SppC
- CEPC Plan
- Summary

Introduction

The idea of CEPC followed by a possible Super proton-proton collider(SppC) was proposed in Sep. 2012, and quickly gained the momentum in IHEP and in the world.

- **Looking for Hints@e^+e^- Collider ➔ If yes, direct search at pp collider**
- **The tunnel can be re-used for pp, AA, ep colliders up to ~ 100 TeV**



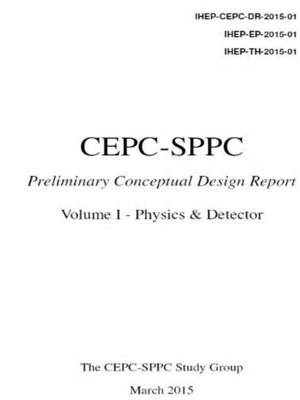
- ❑ A Higgs factory - to run at $\sqrt{s}$ ~ 240 GeV, above the **ZH** production threshold for ≥1 M Higgs; at the **Z** pole for ~Tera Z; at the **W^+W^-** pair and then $t\bar{t}$ pair production thresholds. Probes of physics BSM.
- ❑ The CEPC aims to start operation in 2030's, as a Higgs (Z / W) factory in China.

Introduction

CEPC team took steps to advance

2013

2015



IHEP-CEPC-DR-2015-01
IHEP-EP-2015-01
IHEP-TH-2015-01

CEPC-SPPC

Preliminary Conceptual Design Report

Volume I - Physics & Detector

The CEPC-SPPC Study Group
March 2015

IHEP-CEPC-DR-2015-01
IHEP-AC-2015-01

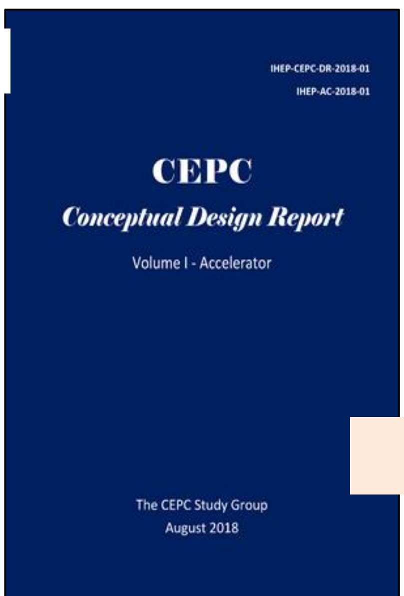
CEPC-SPPC

Preliminary Conceptual Design Report

Volume II - Accelerator

The CEPC-SPPC Study Group
March 2015

2018



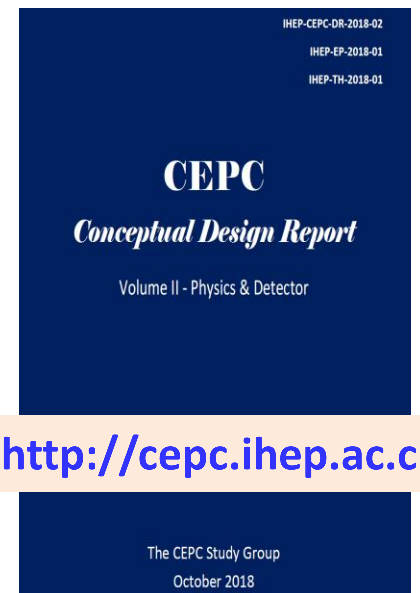
IHEP-CEPC-DR-2018-01
IHEP-AC-2018-01

CEPC

Conceptual Design Report

Volume I - Accelerator

The CEPC Study Group
August 2018



IHEP-CEPC-DR-2018-02
IHEP-EP-2018-01
IHEP-TH-2018-01

CEPC

Conceptual Design Report

Volume II - Physics & Detector

The CEPC Study Group
October 2018

2023

IHEP-CEPC-DR-2023-01
IHEP-AC-2023-01

CEPC

Technical Design Report

Accelerator

The CEPC Study Group
December 2023

http://cepc.ihep.ac.cn

CEPC Status and Progress

CEPCAccelerator TDR Published



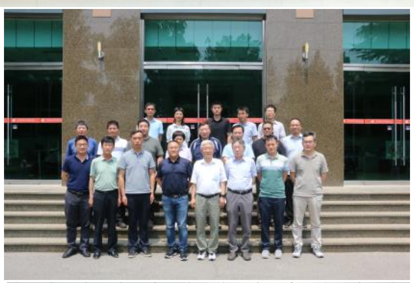
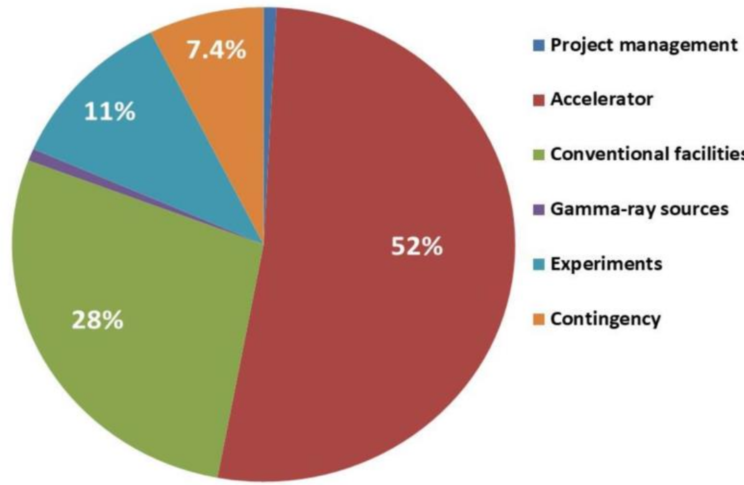



Table 12.1.2: CEPC project cost breakdown, (Unit: 100,000,000 yuan)

Total	**364**	**100%**
Project management	3	0.8%
Accelerator	190	52%
Conventional facilities	101	28%
Gamma-ray beam lines	3	0.8%
Experiments	40	11%
Contingency (8%)	27	7.4%



Distribution of CEPC Project total TDR cost of **36.4B RMB (~ 5B €)**

CEPC accelerator TDR has been completed and formally released on December 25, 2023
CEPC accelerator TDR link: (arXiv: 2312.14363)
CEPC accelerator TDR releasing news:
http://english.ihep.cas.cn/nw/han/y23/202312/t20231229_654555.html

published in
RDTM Vol.8
June 2024

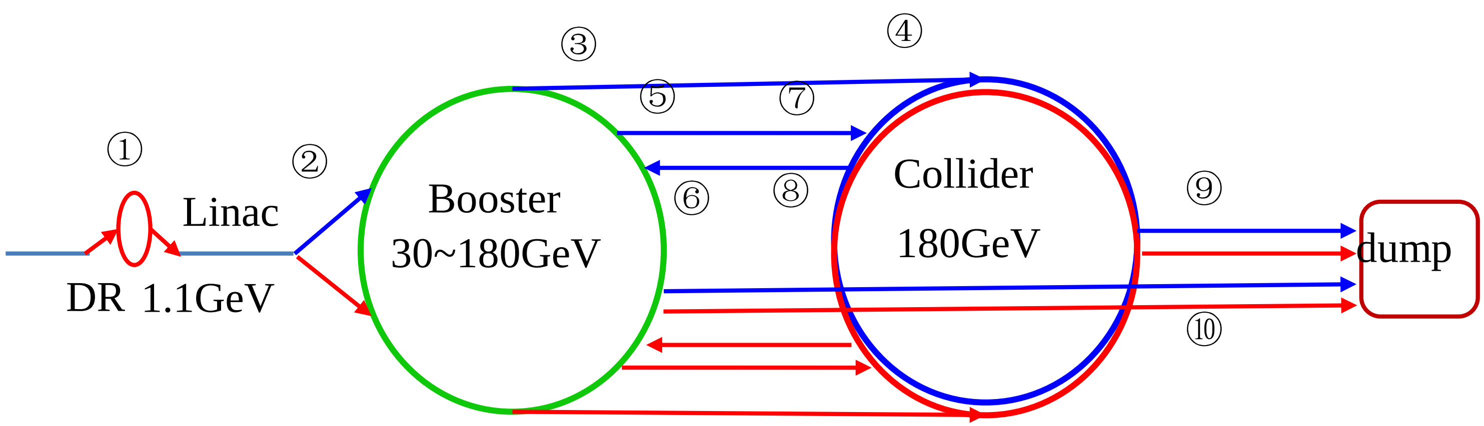
CEPC Parameters and Layout

Booster

		tt	*H*		*W*	*Z*	
		Off axis injection	Off axis injection	On axis injection	Off axis injection	Off axis injection	
Circumfer.	km	**100**					
Injection energy	GeV	**30**					
Extraction energy	GeV	**180**	**120**		**80**	**45.5**	
Bunch number		35	268	261+7	1297	3978	5967
Maximum bunch charge	nC	0.99	0.7	20.3	0.73	0.8	0.81
Beam current	mA	0.11	0.94	0.98	2.85	9.5	14.4
SR power	MW	0.93	0.94	1.66	0.94	0.323	0.49
Emittance	nm	2.83	1.26		0.56	0.19	
RF frequency	GHz	1.3					
RF voltage	GV	9.7	2.17		0.87	0.46	
Full injection from empty	h	0.1	0.14	0.16	0.27	1.8	0.8

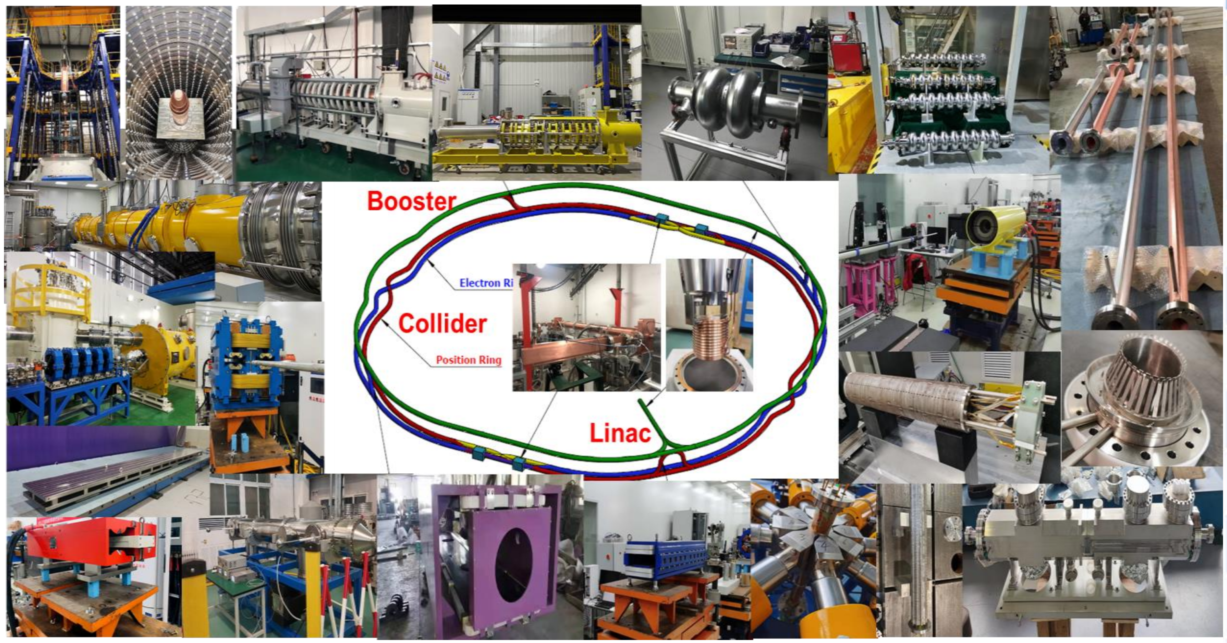
Collider

	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	**100.0**			
SR power per beam (MW)	**30**			
Energy (GeV)	**120**	**45.5**	**80**	**180**
Bunch number	268	11934	1297	35
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Beam size at IP σ_x/σ_y (um/nm)	14/36	6/35	13/42	39/113
Bunch length (natural/total) (mm)	2.3/4.1	2.5/8.7	2.5/4.9	2.2/2.9
Beam-beam parameters ξ_x/ξ_y	0.015/0.11	0.004/0.127	0.012/0.113	0.071/0.1
RF frequency (MHz)	650			
Luminosity per IP (10^{34} cm^{-2} s^{-1})	**5.0**	**115**	**16**	**0.5**



Key Accelerator Technology Readiness

Key Technologies for the CEPC



key technology R&D spans all component for CEPC ready for construction by 2027-8

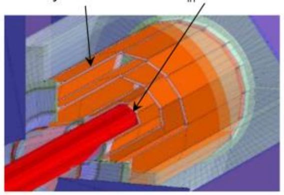
Specification Met ✓ Prototype Manufactured ✓

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

CEPC Detector R&D

Vertex detector

2 layers / ladder R_{in}~16 mm



Goal: σ(IP) ~ 5 μm for high P track

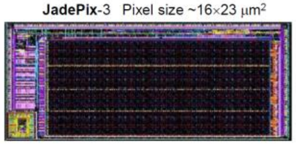
CDR design specifications

- Single point resolution ~ 3μm
- Low material (0.15% X_0 / layer)
- Low power (< 50 mW/cm²)
- Radiation hard (1 Mrad/year)

Silicon pixel sensor develops in 5 series: JadePix, TaichuPix, CPV, Arcadia, CEPCPix

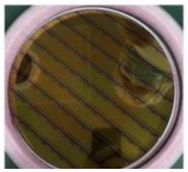
Develop **CEPCPix** for a CEPC tracke basing on **ATLASPix3** CN/IT/UK/DE TSI 180 nm HV-CMOS process

JadePix-3 Pixel size ~16×23 μm²

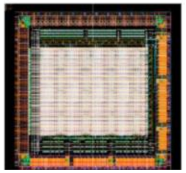


Tower-Jazz 180nm CiS process
Resolution 5 microns, 53mW/cm²

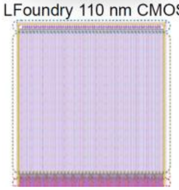
TaichuPix-3, FS 2.5x1.5 cm² 25×25 μm² pixel size



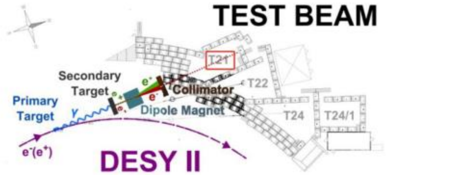
CPV4 (SOI-3D), 64×64 array ~21×17 μm² pixel size

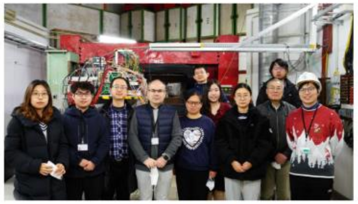


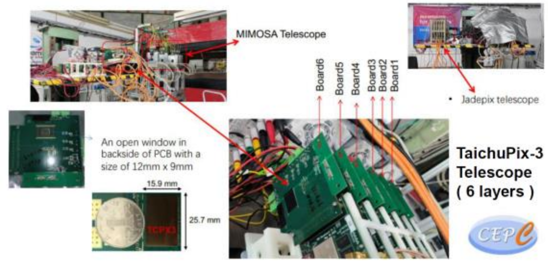
Arcadia by Italian groups for IDEA vertex detector LFoundry 110 nm CMOS



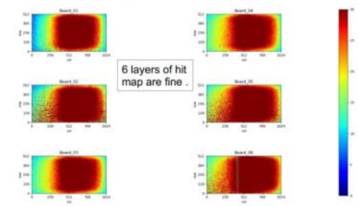
Full vertex detector prototype (TaichuPix-3, JadePix-3) has TB at DESY in Dec. 2022.





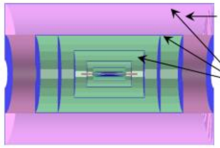


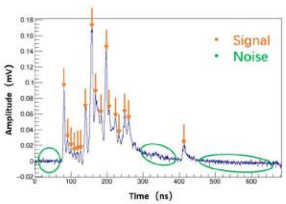
Hitmap of 4 GeV e⁺/e⁻ beam

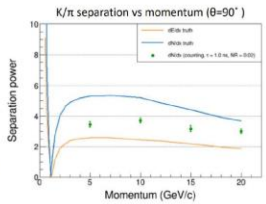


particle ID +main tracker

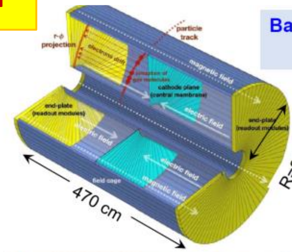
- **Goal: 3σ π/K separation up to ~20 GeV/c.**
- Cluster counting method, or **dN/dx**, measures the number of primary ionization
- **Can be optimized specifically for PID**: larger cell size, no stereo layers, different gas mixture.
- Garfield++ for simulation, realistic electronics, peak finding algorithm development.



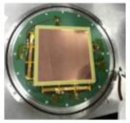




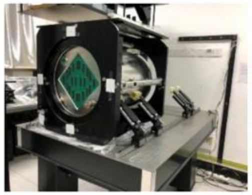
IHEP and Italian INFN groups have close collaboration and regular meetings.
IHEP joined the TB (led by INFN group) in 2021 and 2022



Baseline main tracker $\sigma(r\text{-}\phi)$ ~100 μm

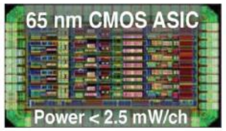


GEM-MM cathode



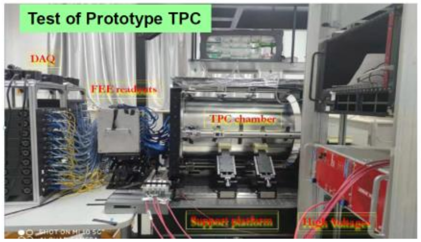
TPC Prototype + UV laser beams

MOST 1 (IHEP+THU)

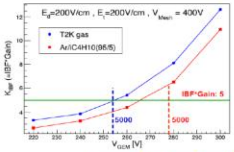


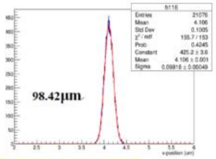
Low power FEE ASIC

Test of Prototype TPC



Challenge: Ion backflow (IBF) affects the resolution. It can be corrected by a laser calibration at low luminosity, but difficult at high luminosity Z-pole.



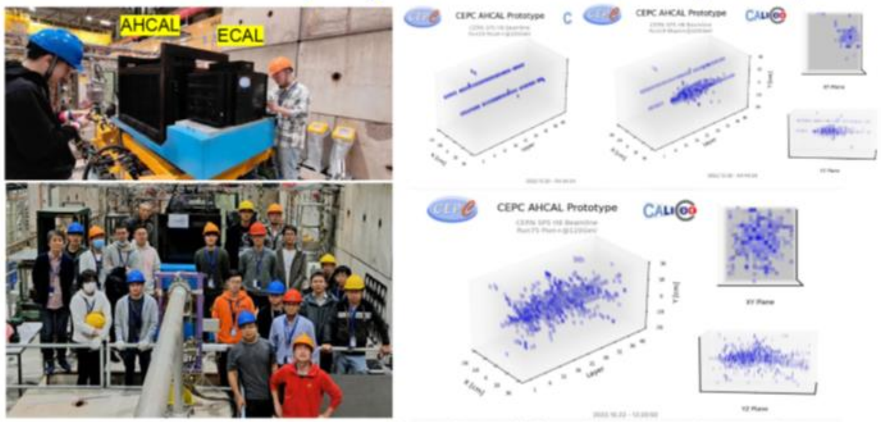


$\sigma_{r\phi}$ < 100 μm for drift length of 27cm

CEPC Detector R&D

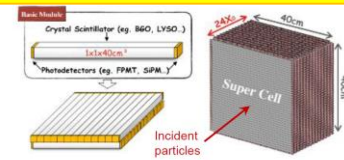
EM + hadron colarimeters： prototypes

➢ PFA ScW-ECAL & AHCAL prototypes: Test Beam at CERN SPS H8 (Oct. 2022)



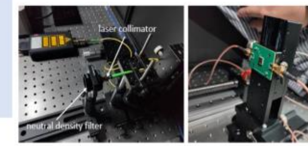
USTC, IHEP, SJTU, Japanese & Israel groups have close collaboration and regular meetings

new crystal EM calorimeter for better resolution



Goal

- Boson Mass Resolution < 4%
- Better BMR than ScW-ECAL
- Much better sensitivity to γ/e, especially at low energy.

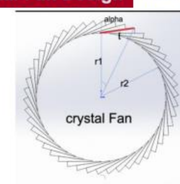


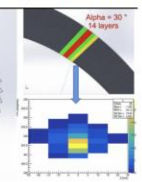
- Long bars: 1 x 40 cm, super-cell: 40x40 cm^2
- Timing at both ends for positioning along bar.
- Significant reduction of number of channels.

Bench Test

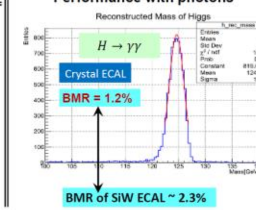
Full Simulation Studies + Optimizing PFA for crystals

Crystal Fan Design Fine segmentation in Z, ϕ, r

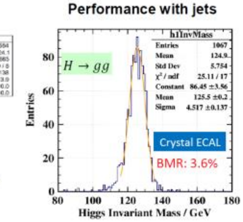




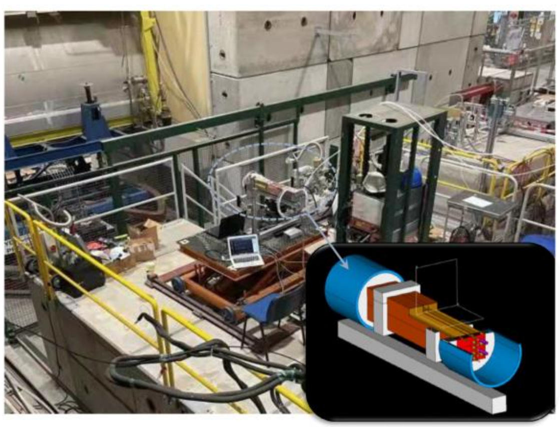
Performance with photons

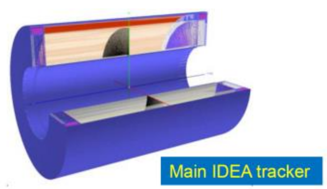


Performance with jets



Dual readout crystal calorimeter also being considered by USA and Italian colleagues





Italian groups and IHEP colleagues participated the test beam at CERN.

software

Key4hep: an international collaboration with CEPC participation
CEPCSW: a first application of Kep4hep – Tracking software
CEPCSW is already included in Key4hep software stack

https://github.com/cepc/CEPCSW

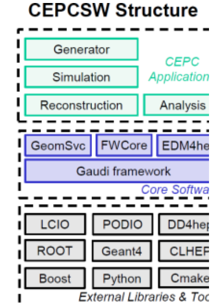
Architecture of CEPCSW

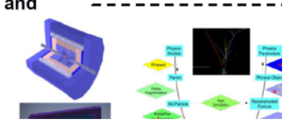
- External libraries
- Core software
- CEPC applications for simulation, reconstruction and analysis

Core Software

- Gaudi framework: defines interfaces of all software components and controls the event loop
- EDM4hep: generic event data model
- FWCore: manages the event data
- GeomSvc: DD4hep-based geometry management service

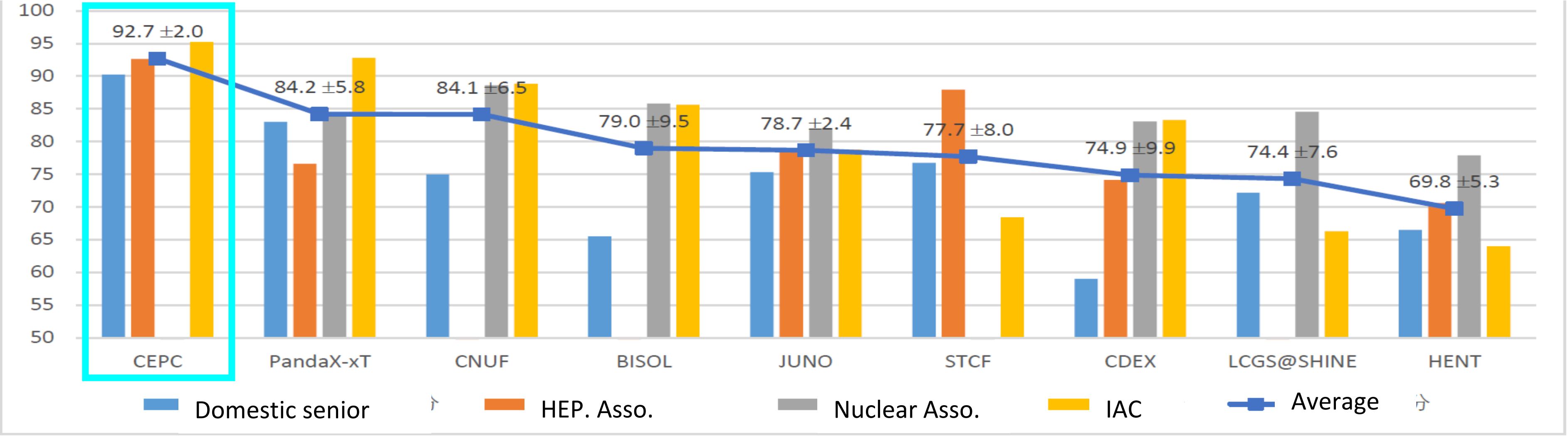
CEPCSW Structure





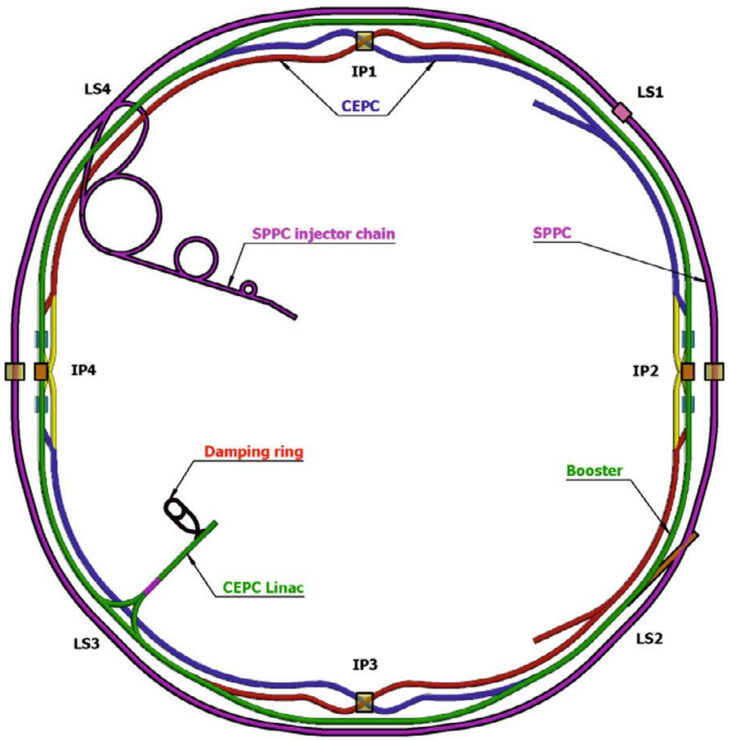
Project Development

- CAS is planning for the 15th 5-years plan for large science projects, and a steering committee has been established, chaired by the president of CAS
- **High energy physics**, as one of the 8 groups, accomplished the following:
  - Setting up rules and the standard(based on scientific and technological merits, strategic value and feasibility, R&D status, team and capabilities, etc.), established domestic and international advisory committees
  - Collected 15 proposals and selected 9, based on the above-mentioned standard
  - Evaluations and ranking by committees after oral presentations by each project
- **CEPC is ranked No. 1, with the smallest uncertainties, by every committee**
- A final report was submitted to CAS for consideration



Super proton-proton Collider

SppC

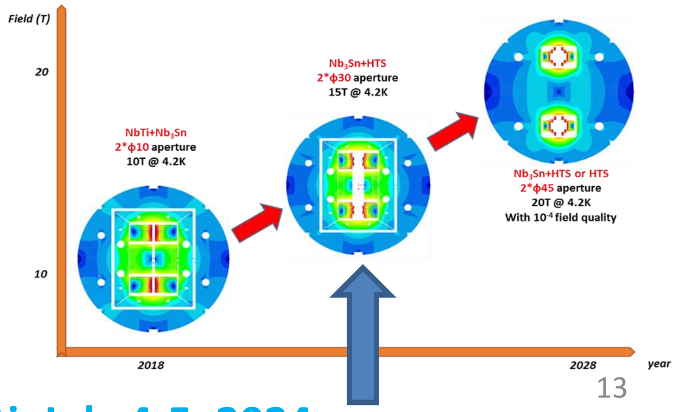


Super proton-proton Collider

- E_{cm} up to 125 TeV with 100 km ring
- 2 IPs, 10^{35} $cm^{-2}s^{-1}$ per IP
- new machine after the CEPC
- can extend to heavy ion collisions
- retaining the CEPC collider
- add possible ep option

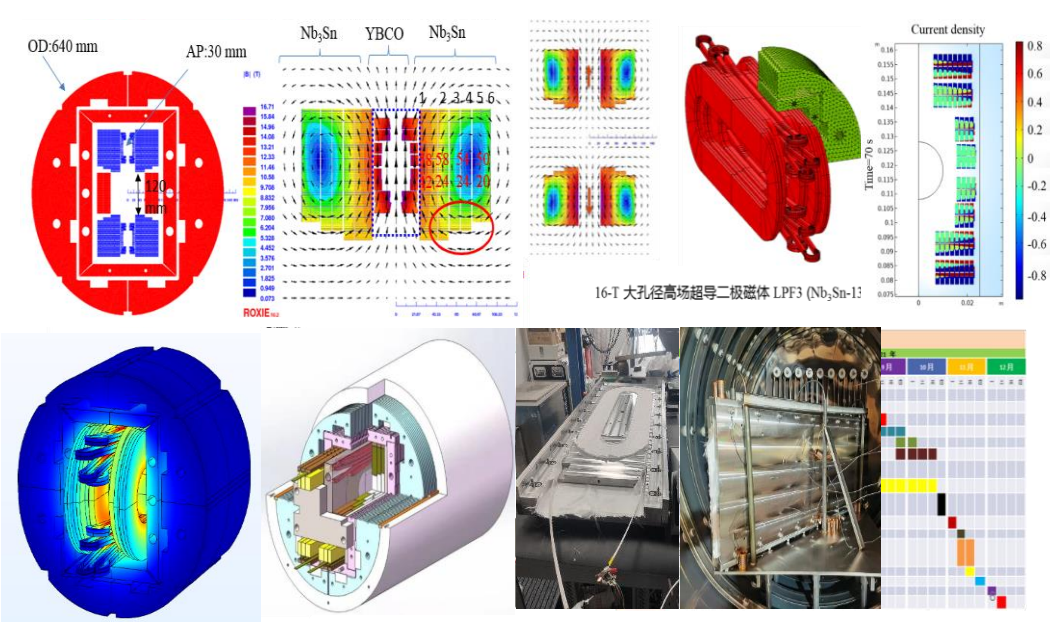
Current consideration for SppC

- design compatible with a future SppC layout
- 20T B field, twin-aperture magnets
- new HTS (even IBS) magnets (in 20-30 years)

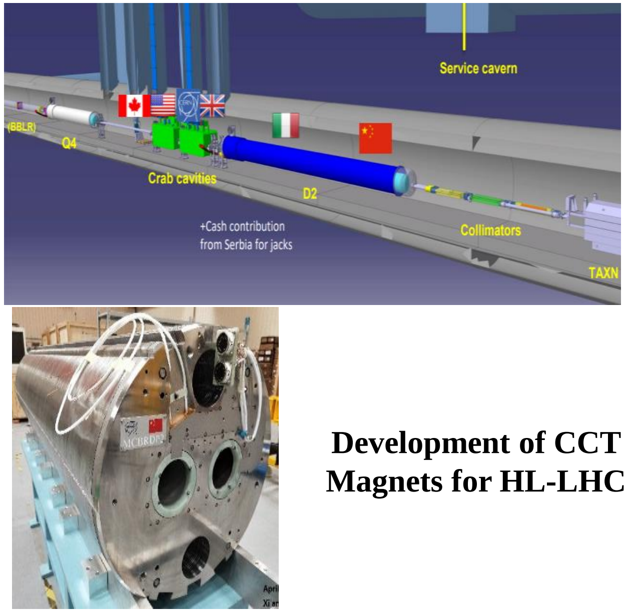


SppC

- **16T model dipole magnet under development:** Nb_3Sn 12~13T + HTS 3~4T. **The highest quench field reached over 14T @4.2K in 2023. 16T @4.2K to be realized in 2024.**
- **Stainless-steel stabilized IBS tape achieved the highest J_e in 2022. Significantly reduced cost and raised mechanical properties. IBS model coils reached 60A @32T.**
- **China & CERN Collaboration on accelerator technology: development of HL-LHC CCT magnets going well. Half of 12+1 magnets have been delivered to CERN**



16T Model Dipole under development



Development of CCT Magnets for HL-LHC

CEPC Plan

- **Engineering Design towards an EDR**
- **A reference design detector for domestic evaluation**
- **15^{th} FYP**

Engineering Design towards an EDR

2012.9	2015.3	2018.11	2023.10	2025	2027	15th five year plan
CEPC proposed	Pre-CDR	CDR	TDR	CEPC Proposal	EDR	Start of construction

CEPC EDR Phase General Goal (2024-2027):

CEPC accelerator will enter the Engineering Design Report (EDR) phase (2024-2027); its also the preparation phase with the aim for CEPC proposal to the Chinese government ~2025 for approval.

CEPC EDR includes accelerator and detector (TDRrd)
CEPC detector TDR reference design (rd) will be released by June 30, 2025

CEPC Accelerator EDR Phase goals, scope and the working plan (preliminary) of 35 WGs summarized in a documents of 20 pages to be reviewed by IARC in 2024

EDR Scope and Plan

Based on the CEPC TDR accelerator design, demonstrate a complete and coherent feasibility EDR design, which will guarantee the construction, commissioning, operation, and upgrade possibilities .

The CEPC EDR accelerator design should guarantee the physics goals with required energies (Higgs, W and Z pole, with ttbar as upgrade possibility) and corresponding required luminosities with 30MW synchrotron radiation power/beam as a baseline, and 50MW as upgrade possibility.

Based on the CEPC TDR accelerator key technology R&D achievement, complete the accelerator engineering design and necessary EDR R&D to be ready for industrial fabrications.

Complete a practical procurement strategy and logistics with both domestic and international suppliers.

In collaboration with local government, CAS and MOST (central government), CEPC sites converge from serval candidates to a EDR construction site satisfying the required geological conditions, electric power and water resources, social and environment conditions, domestic and international transportation network conditions, international science city, and sustainable development , etc.

Complete detailed construction site geological studies and corresponding site dependent civil engineering design and general utility facility design.

Complete the radiation, security, environment assessment studies and necessary documents –so called CEPC PROPOSAL, around 2025ready for the application to the central government to get the formal approval of construction in the “15th five year plan”

Make detailed analysis and preparation for the human resources needed for the completion of CEPC construction.

In the Engineering Design Phase, create and maintain a complete database, such as cost items with information regarding technology maturity (TRL), design completeness, and cost basis, to identify and prioritize areas for R&D, prototyping and industrialization.

Work out a detailed construction time line and plan in relation with industrial fabrications, measurements, transportations, storage warehouses, installation, human resource evolution, etc.

Workout details on 3% installation and 3% commissioning items of the total accelerator cost.

Improve design maturity of several systems (particularly MDI and cryogenics) and develop system integration.

Implement the risk-mitigation plan in the production and procurement plans to eliminate major risk during the mass production, providing multiple vendors and multiple production lines (for example, demonstrate automatic magnets production line and NEG coated vacuum chambers mass production facility)

Consider re-optimizing the technical design of components and systems with large electricity consumption taking into account both capital and operational expenditure

Define unambiguously what constitutes the end of the construction project.

For labour-intensive, high-volume activities, in particular the components of the collider and booster, refine and review the production model to check the availability of in-house resources.

Risk assessment and risk management

Based on TDR cost estimate, make an updated EDR cost estimate.

Carefully consider the recommendations from CEPC accelerator TDR review and TDR cost review committees, IARC and IAC, etc.

Continues efforts in green collider and sustainable development with energy saving technologies, wast heat reuse, energy recovery, and green energy utilization, etc.

Establish more international collaborations, international involvement, and industrial preparations both from domestic and international companies and suppliers.

Refine the CEPC management structure in relation with host lab. Refine the CEPC construction funding modes.

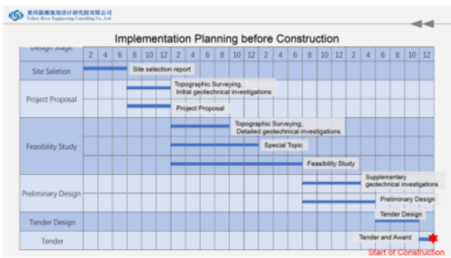
Obtain the necessary EDR plan and scope related fundings.

Complete “CEPC Proposal” around 2025 ready for application of final selection of the 15th 5-year plan, and complete EDR around 2027 before the construction.

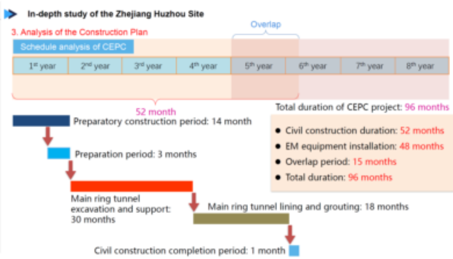
Engineering Design towards an EDR

CEPC Site Implementation and Construction Plans

CEPC site implementation plan in EDR



CEPC construction plan

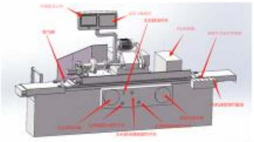


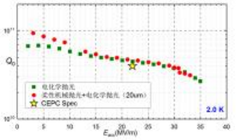
Future Plan for CEPC SRF

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034-2035	2036-2045	2046-2047	2048	2049-2053
EDR																
Civil construction																
Acc. construction & installation																
Commission & operation													H	Z	W	ttbar
SRF system engineering design	Layout, cost, module, beam-cavity, LLRF, interfaces ...															
650 MHz test module (2x2-cell)	Beam operation, replace with high Q cav & variable coupler															
650 MHz H module (6x2-cell)	Design	pCM fabrication		pCM test	Prepare	Production of 32 CM / 192 2-cell CAV for 30 MW H				Installation, Commissioning			Op & +24 CM	Operation		
1.3 GHz H module	High Q module	Mass production of modules with SCM and BPM			pCM fab	pCM test	Production of 12 CM / 96 9-cell CAV			Installation, Commissioning			Operation			
1.3 GHz Z module (high current)		Design and R&D			pCM fabrication		pCM test		Production of 4 CM / 32 9-cell CAV		Installation, Commissioning		Operation			
650 MHz HL-Z module	Conceptual design. 500 MHz high current module production.				Design and R&D							Produce and Install 60+40 1-cell CM		Op		
ttbar cavity and module	Design and R&D of high gradient high Q and new material (Nb3Sn etc.) 650 MHz and 1.3 GHz cavities and module for ttbar								pCM fabrication and test				Production and Installation of 48 CM / 192 650 MHz 5-cell CAV 32 CM / 256 1.3 GHz 9-cell CAV			Op

CEPC SRF Industrial Production Technology

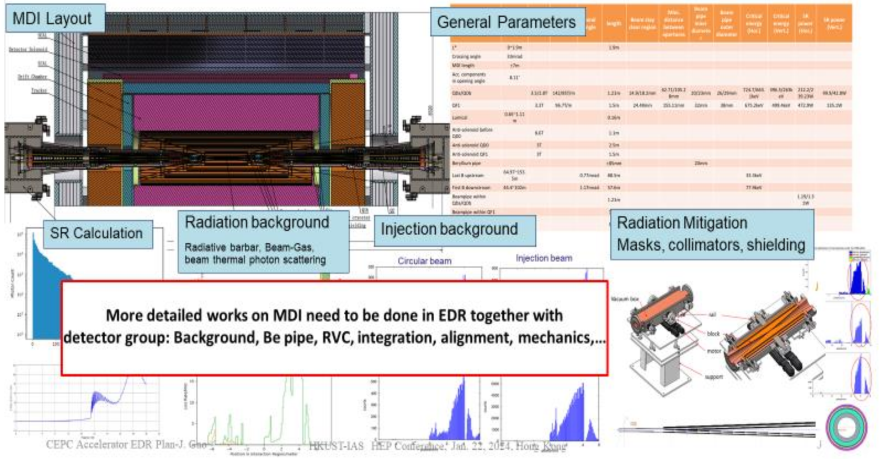
- In 2023, IHEP invented soft SRF cavity polishing equipment has been completed and it will be installed at IHEP soon, and it reached the same surface roughness as EP. CEPC 650 MHz cavity treated by the soft polishing equipment reached the CEPC specification





650 MHz SC measurement result with soft polishing technology

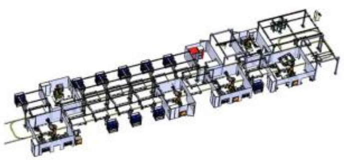
CEPC MDI in EDR



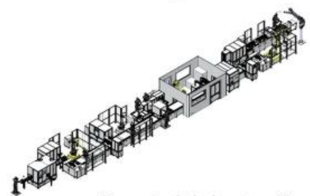
EDR - Examples

CEPC Magnets' Automatic Production Lines in EDR

To reduce the fabrication cost of the magnets of CEPC, automatic magnet production lines will be demonstrated in EDR and used during construction



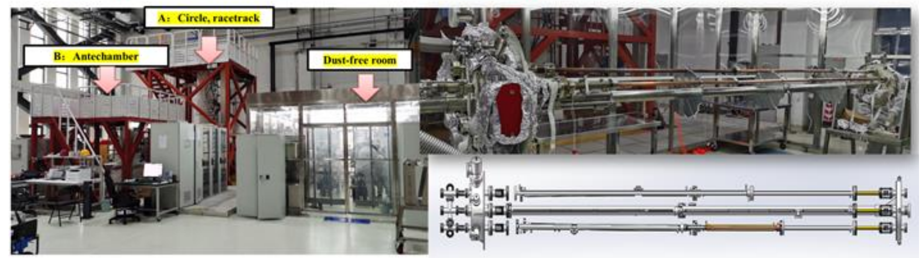
Conceptual design type-I (Booster magnet)



Conceptual design type-II (Collider ring magnet)

Massive Production Line of NEG Coating Vacuum Chambers in EDR

- The coating device A: Vacuum chambers are connected in parallel to 6 groups, each group of vacuum chambers length should be lower than 3.5m, outer diameter is about 0.47m;
- The coating device B: Antechamber are connected in parallel to 4 groups, each group of vacuum chambers length should be lower than 1.5m, due to its discharge difficulty.
- Two setups of NEG coating have been built for vacuum pipes of HEPS at IHEP Lab. And a lot of test vacuum pipes have been coated, which shows that NEG film has good adhesion and thickness distribution.
- **In EDR phase a dedicated CEPC NEG coated vacuum chamber production line is planned**



CEPC Accelerator Control and Timing in EDR

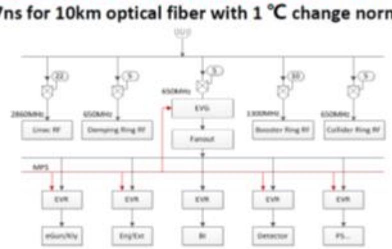
The basic structure of Timing System

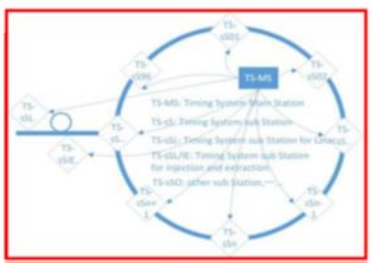
- Event system and RF transmission system
- Event system: Trigger signal and Low frequency clock signal
- RF transmission system: Transmit high stability RF signal

Temperature variation induced drift compensation

0.7ns for 10km optical fiber with 1 ℃ change normally

In EDR phase CEPC high precision timing and control technology will be developed





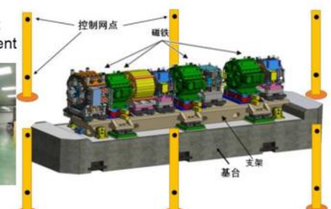
CEPC Alignment and Installation Plan in EDR

- Alignment accuracy requirement

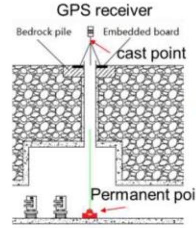
Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)
Dipole	0.10	0.10	0.10
Arc Quadrupole	0.10	0.10	0.10
IR Quadrupole	0.10	0.10	0.10
Sextupole	0.10*	0.10*	0.10

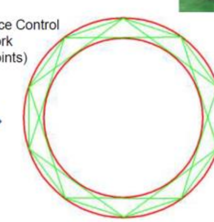
*implement beam-based alignment

Component Pre-alignment



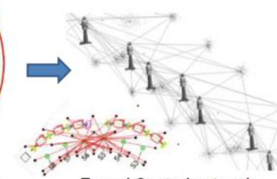
Wall Control Point





Surface Control network (14Points)

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



Tunnel Control network (interval of 6 meters)

Ground Control Point

CEPC Accelerator EDR Plan-J. Gao

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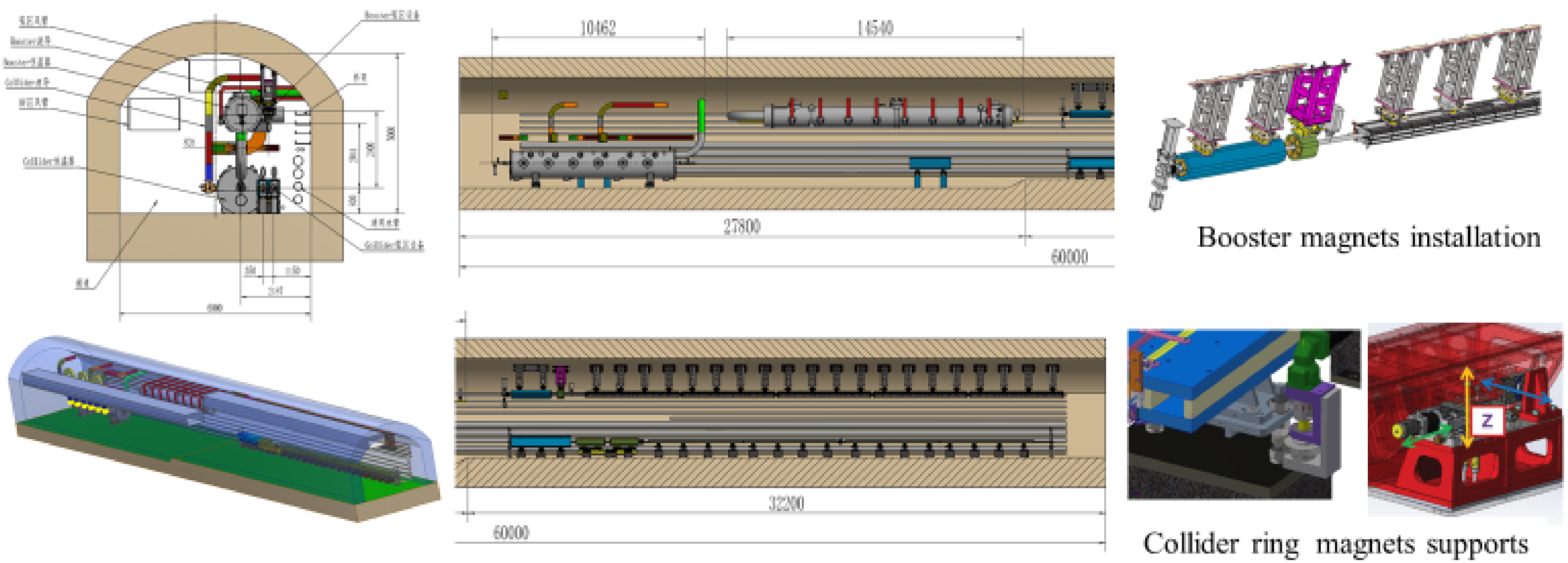
EDR - Examples

CEPC Tunnel Mockup for Installation in EDR



A 60 m long tunnel mockup, including parts of arc section and part of RF section

To demonstrate the inside tunnel alignment and installation, especially for booster installation on the roof of the tunnel

Industrial Partners and Suppliers

	System
1	Magnet
2	Power supplier
3	Vacuum
4	Mechanics
5	RF Power
6	SRF/ RF
7	Cryogenics
8	Instrumentation
9	Control
10	Survey and alignment
11	Radiation protection
12	e-e+Sources

CEPC Industrial Promotion Consortium (CIPC, established in Nov. 2017)

Potential international collaborating suppliers and partners worldwide

TDR of a Reference Detector

- The CEPC study group is in process to produce TDR of a reference detector (ref-TDR) by June 2025, aiming mainly for domestic endorsement
- CEPC will continue to seek for better technologies, and decide the final detectors within the CEPC international collaborations

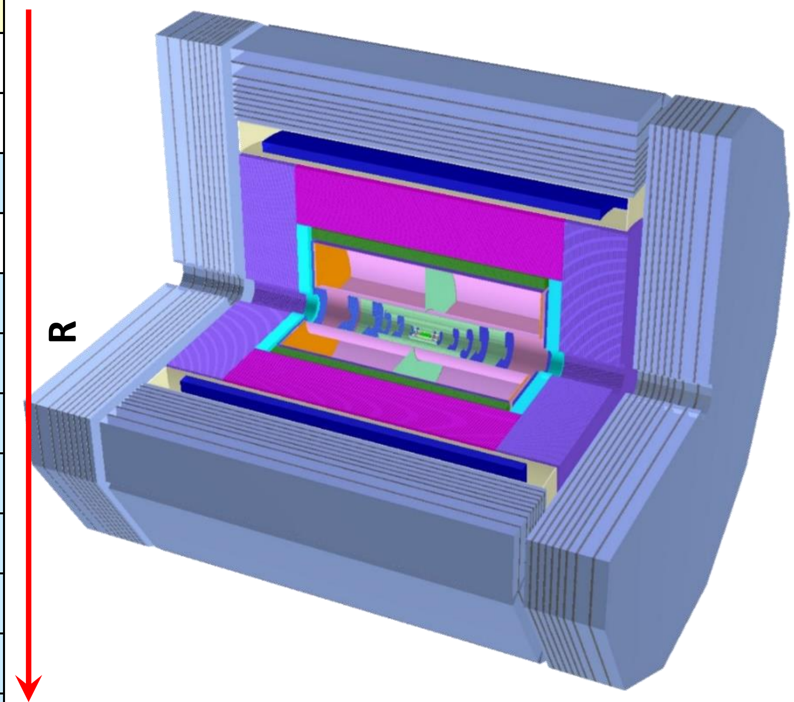
Date	Actions and/or Expectations
Jan 1, 2024	Start the process by comparing different technologies
Jun 30, 2024	Baseline technologies, general geometric configuration and key issues are decided
Oct 31, 2024	Discuss the ref-TDR at the CEPC workshop, report progresses to the CEPC IAC
Dec 31, 2024	The first draft of the ref-TDR is ready for internal reviews
Apr 15, 2025	international review
Jun 30, 2025	The ref-TDR for ready for public reviews
Oct 30, 2025	Submit the ref-TDR for publication

Foundations:
- CEPC Instrument R&D
- LHC detector upgrade projects
- other HEP experiments
- progress in HEP worldwide R&D
- development in industry

Technologies for Ref-TDR

<table>
<tr><th>System</th><th colspan="6">Technologies</th></tr>
<tr><td>Beam pipe</td><td colspan="3">Φ20 mm</td><td colspan="3"></td></tr>
<tr><td>LumiCal</td><td colspan="3">SiTrk+Crystal</td><td colspan="3"></td></tr>
<tr><td>Vertex</td><td colspan="2">CMOS+Stitching</td><td colspan="2">CMOS Pixel</td><td colspan="2">SOI</td></tr>
<tr><td rowspan="4">Tracker</td><td colspan="3">SPD ITrk</td><td colspan="3"></td></tr>
<tr><td colspan="3">Pixelated TPC</td><td colspan="3">PID Drift Chamber</td></tr>
<tr><td colspan="2" rowspan="2">AC-LGAD OTrk</td><td colspan="2">SSD OTrk</td><td colspan="2">SPD OTrk</td></tr>
<tr><td colspan="4">LGAD ToF</td></tr>
<tr><td rowspan="2">ECAL</td><td colspan="3">4D Crystal Bar</td><td colspan="3">Stereo Crystal Bar</td></tr>
<tr><td colspan="2">GS+SiPM</td><td colspan="2">PS+SiPM+W</td><td colspan="2">SiDet+W</td></tr>
<tr><td>HCAL</td><td colspan="2">GS+SiPM+Fe</td><td colspan="2">PS+SiPM+Fe</td><td colspan="2">RPC+Fe</td></tr>
<tr><td>Magnet</td><td colspan="3">LTS</td><td colspan="3">HTS</td></tr>
<tr><td>Muon</td><td colspan="3">PS Bar+SiPM</td><td colspan="3">RPC</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td>TDAQ</td><td colspan="3">Conventional</td><td colspan="3">Software Trigger</td></tr>
<tr><td>BE electr.</td><td colspan="3">Common</td><td colspan="3">Independent</td></tr>
</table>

Baseline | For Comparison



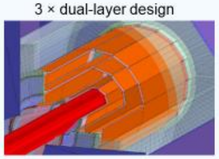
An international review committee has been formed to guide and review the design

Technologies for Ref-TDR

Silicon Pixel Vertex Detector

Looking into stitching technology

3 × dual-layer design

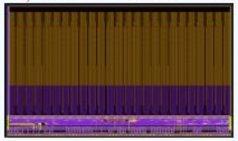


Goal: σ(IP) ~ 5 μm for high P

Key specifications:

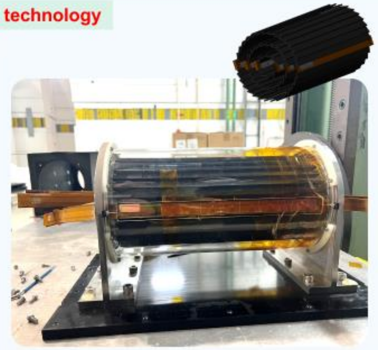
- Single point resolution ~ 3 μm
- Low material (0.15% X_0 / layer)
- Low power (< 50 mW/cm²)
- Radiation hard (1 Mrad/year)

JadePix4
356×498 array of 20×29 μm²
$\sigma_{x/y}$ ~ 3-4 μm, σ_t ~ 1 μs, ~100 mW/cm²



TaichuPix3
1024×512 array of 25×25 μm²

TowerJazz 180nm CIS process

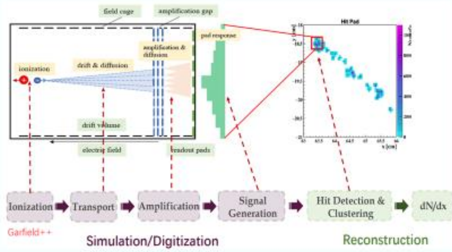


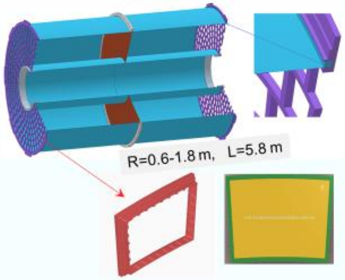
A TaichuPix-based prototype detector was tested at DESY in April 2023

Spatial resolution ~ 4.9 μm

Pixelated TPC

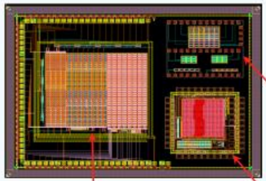
- Initial TPC design has difficulty at high luminosity Z pole due to IBF
- A pixelated TPC of (500 μm)² readout pads reduces IBF×Gain ~1 at G=2000, and achieves σ(r-Φ) ~100 μm
- Full simulation study also shows 3σ K/π separation at 20GeV
- Preliminary mechanical design ⇒ RL = 15% X_0 for endcap and 0.55% X_0 for barrel part
- Plan to have a test beam this fall to characterize the performance and validate the design





Silicon Pixel Inner Tracker

- ❑ Focus on HV-CMOS pixel inner tracker of ~15-20 m².
- ❑ Ladder design for barrel and disc for endcap
- ❑ Given what happened with the TSI 180nm production line, it is better to have backup foundries
- ❑ Exploring SMIC 55 nm and TPSCo 65 nm processes

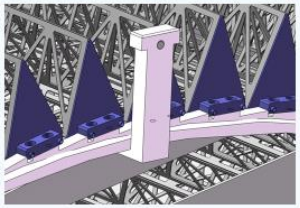


COFFEE2 chip with SMIC 55 nm process

Zone 1
6×9 pixels, 80×40μm²
Diodes of different charge collection

Zone 2
20×32 pixels, 72×36μm²
Designs of charge collection & cell electronics

Zone 3
26×26 pixels, 25×25μm²
Peripheral digital processing and communication

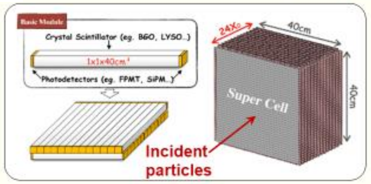


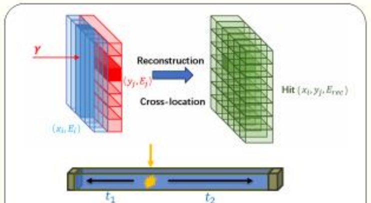
CFRP truss structure: ~0.18% X_0
Outer layer may be attached to TPC

COFFEE2 Test Board

5

4D Long Crystal Bar Calorimeter

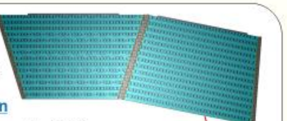




Achieve high granularity with adjacent layers

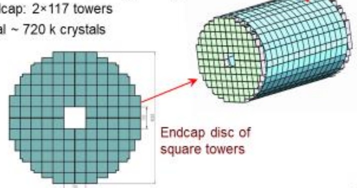
- ❑ Double-end readout, potential positioning with timing
- ❑ Save readout channels, minimize dead materials
- ❑ Challenging in pattern recognitions with multiple particles

Cylindrical barrel with alternately arranged trapezoidal supercells



Preliminary design

- 27 layers of BGO crystal, ~ 24 X_0
- Barrel: 32 towers per ring, 15 rings
- Endcap: 2×117 towers
- Total ~ 720 k crystals



Endcap disc of square towers

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Technologies for Ref-TDR

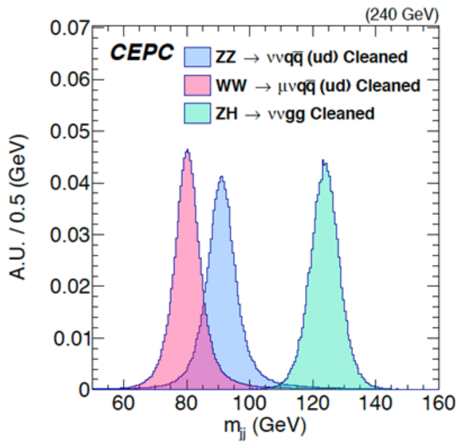
Requirements

boson mass resolution (BMR ~3%)

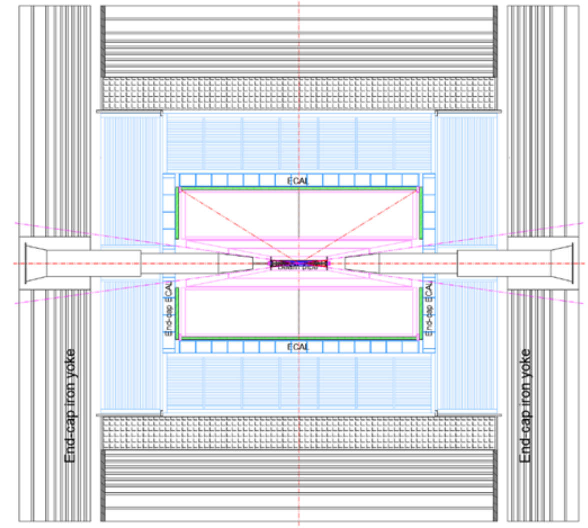
→

Challenges

- Support Particle flow with
  - High granularity
  - High precision



Novel detector design based on PFA calorimeter to improve the BMR from 4% to 3%



Detector	Key parameter	World level	4^{th} concept
PFA based EM calorimeter	EM shower E resolution	$\sim 20\%/\sqrt{E}$	$<3\%/\sqrt{E}$
PFA based Hadron calorimeter	Single hadron E resolution	$\sim 50\%/\sqrt{E}$	$\sim 40\%/\sqrt{E}$

- Silicon combined with gaseous chamber as the tracker and PID
- ECAL based on crystals with timing for 3D shower profile for PFA and EM energy
- Scintillation glass HCAL for better hadron sampling and energy resolution

CEPC Plan – 15^{th} FYP

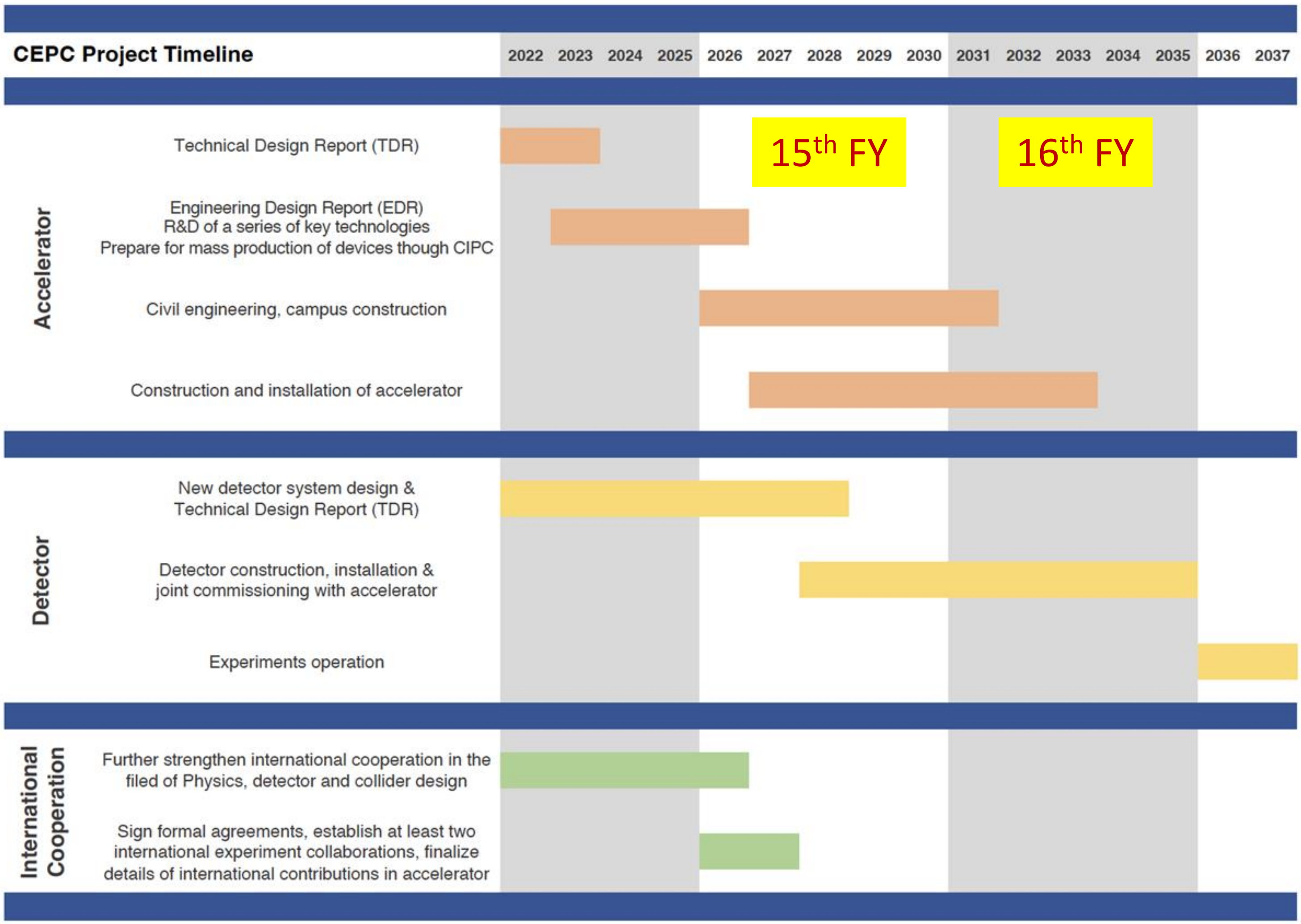
Preparation for China's 15^{th} Five Year Plan (2026-30)

- **Preparation is beginning….**
- **Procedure not clear**
- **The overall funding not known yet**
- **Coordination among IHEP, CAS, local-national governments expected**
- **CEPC aims at a start date in 2027-8, in the middle of the 15^{th} FYP**

CEPC team will complete the detector TDR_rd, well into the EDR, and make ready the necessary documents for the proposal

Ideal Schedule

TDR (2023), EDR(2026), start of construction (2027-8)



Summary

CEPC

- is on the path to converge into a complete package
- EDR process will reduce the cost and benefit the community
- is committed to strive to maximize international collaboration
- great help from international scientists and labs which are essential for CEPC
- is making strong effort to complete a proposal to the government for approval
- will offer the HEP community an early Higgs factory if successful

Acknowledgements

- CEPC team’s hard work, very fruitful international and CIPC collaborations have been critical to the CEPC program
- Special thanks to CEPC IB, SC, IAC, IARC and TDR review (+cost) Committee for their critical advices, suggestions and supports
- Funding agencies, CAS and IHEP for their financial supports

Introduction

Overall CEPC Concepts and Requirements

New Physics
~10 TeV

- ✓ Dark Matter
- ✓ Extended Higgs
- ✓ Composite Higgs
- ✓ Supersymmetry
- ……

High Precision
~1%

- ✓ Higgs: 1%-0.1%
- ✓ EW : $O(10^2-10^3)$ vs current
- ✓ Flavor
- ……

Detector
Particle Flow

- ✓ High Granularity
- ✓ Good Resolution
- ✓ Reliable PID
- ……

Design & Implementation
Detector & Accelerator

- ✓ Multi-purposed Acc.
- ✓ New concept Detector
- ✓ Cost, added values
- ✓ Spill-over
- ……

- ✓ Management
- ✓ Collaboration
- ……

High Lumi.
$\sim 10^{34-36} cm^{-2}s^{-1}$

- ✓ Higgs: 20 ab^{-1}
- ✓ Z: 100 ab^{-1}
- ✓ W: 6 ab^{-1}
- ✓ Top: 1 ab^{-1}

Accelerator
2 IPs/100 km

- ✓ Switchable Operations
- ✓ Upgradability
- ✓ Large Piwinski angle with Crab-waist
- ……

Operation mode	Z	W	Higgs
Center-of-mass energy (GeV)	91	160	240
Operation time (year)	2	1	10
Instantaneous luminosity/IP ($10^{34}cm^{-2}s^{-1}$)	115	16.0	5.0
Integrated luminosity (ab^{-1}, 2 IPs)	60	3.6	12
Event yield (30 MW)	2.5×10^{12}	1.0×10^{8}	2.5×10^{6}
Event yield (50 MW)	4.0×10^{12}	1.6×10^{8}	4.0×10^{6}

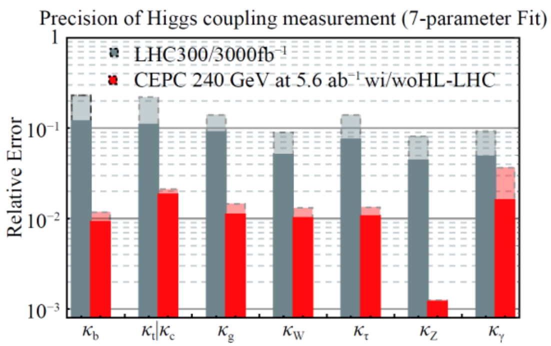
Introduction

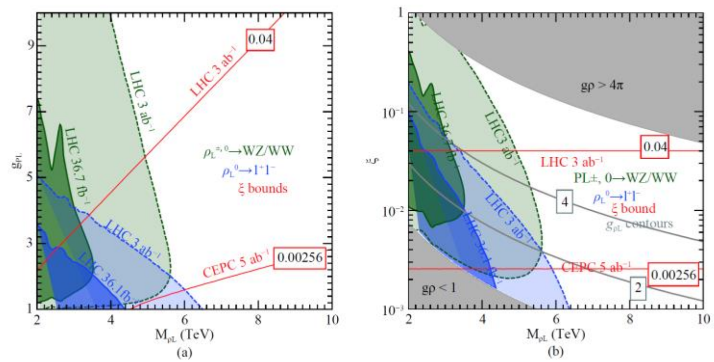
Scientific objectives: discovery + precision measurement

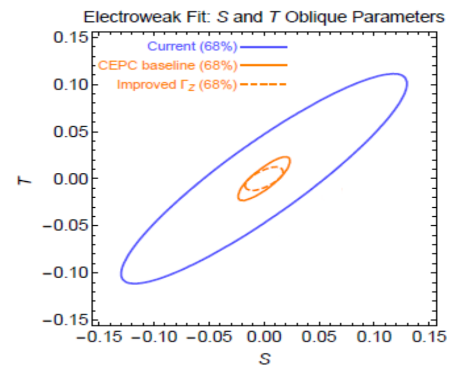
Higgs coupling measurement can be improved by orders magnititude

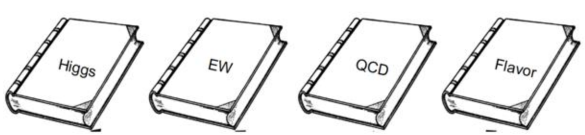
Direct and indirect proble to new physics up to 10 TeV, an order of magntitude higher then HL-LHC

Electroweak measurement can be improved by a large factor

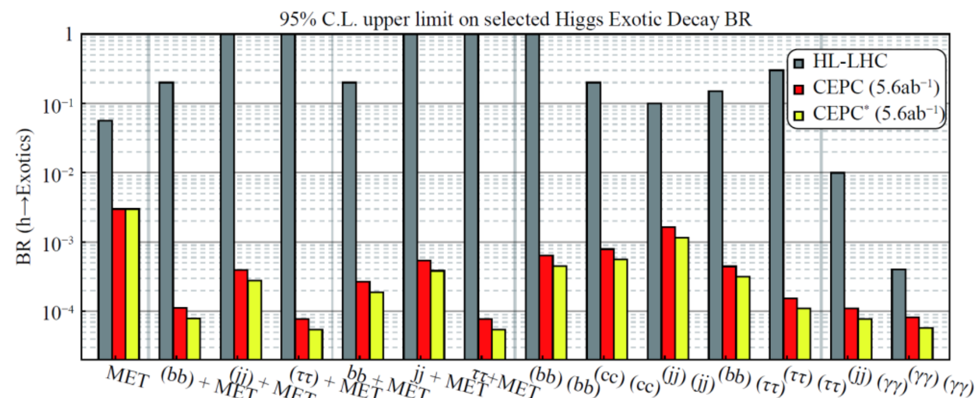








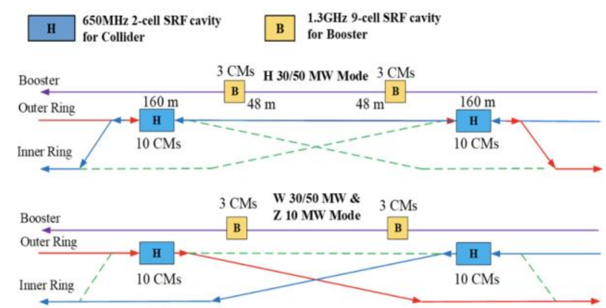
Physics white papers published and to be published

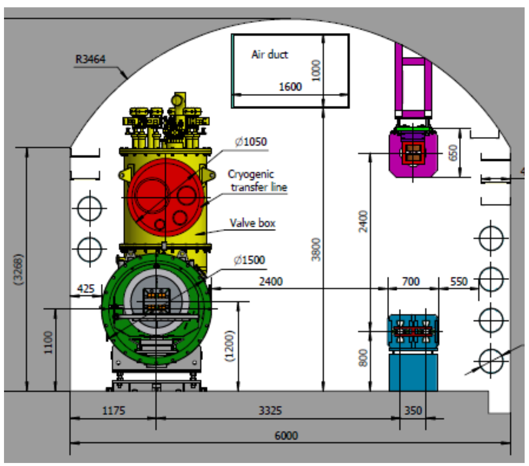


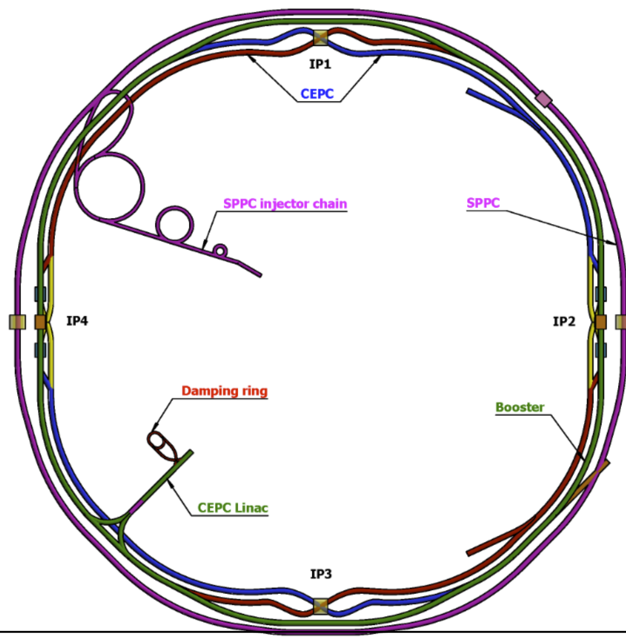
CEPC TDR Layout & Design Essentials

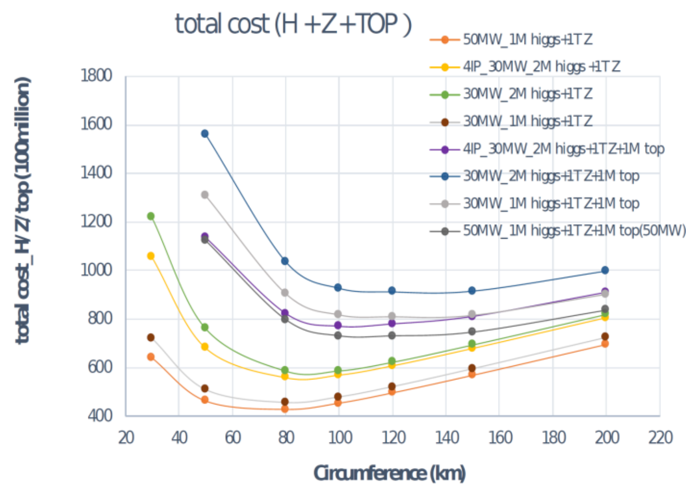
- **Circular collider**: Higher luminosity than a linear collider
- **100km circumference**: Optimal total cost
- **Shared tunnel**: Compatible design for CEPC and SppC
- **Switchable operation**: Higgs, W/Z, top

Switchable operation for Higgs W and Z









Common tunnel for booster/collider & SppC

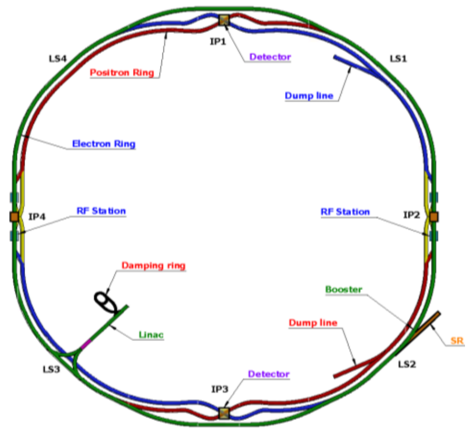
Baseline: 100 km, 30 MW; Upgradable to 50 MW, High Lumi Z, ttbar

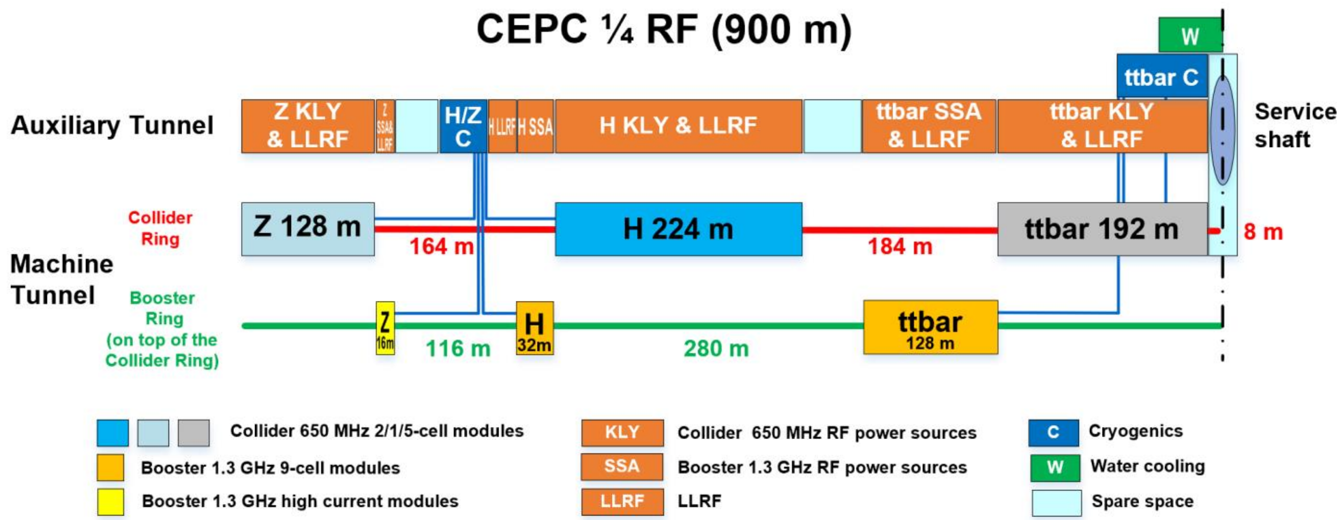
CEPC TDR Operation Plan

Particle	$E_{c.m.}$ (GeV)	Years	SR Power (MW)	Lumi. /IP ($10^{34}cm^{-2}s^{-1}$)	Integrated Lumi. /yr (ab^{-1}, 2 IPs)	Total Integrated L (ab^{-1}, 2 IPs)	Total no. of events
H*	240	10	50	8.3	2.2	21.6	4.3×10^6
			30	5	1.3	13	2.6×10^6
Z	91	2	50	192**	50	100	4.1×10^{12}
			30	115**	30	60	2.5×10^{12}
W	160	1	50	26.7	6.9	6.9	2.1×10^8
			30	16	4.2	4.2	1.3×10^8
$t\bar{t}$	360	5	50	0.8	0.2	1.0	0.6×10^6
			30	0.5	0.13	0.65	0.4×10^6

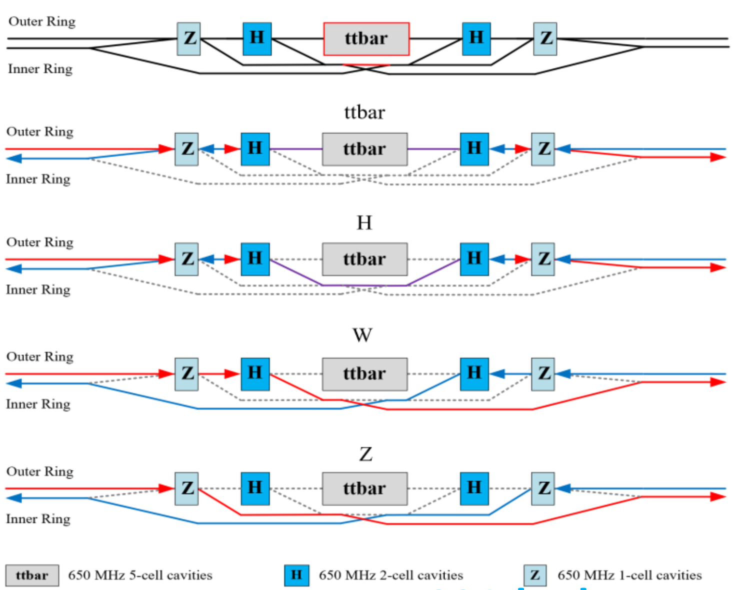
* Higgs is the top priority. The CEPC will commence its operation with a focus on Higgs.
** Detector solenoid field is 2 Tesla during Z operation, 3Tesla for all other energies.
*** Calculated using 3,600 hours per year for data collection.

SRF System Design and Upgrade Plan





H/W/Z/ttbar bypass scheme

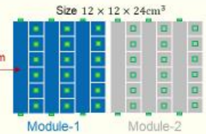


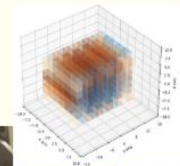
- SRF layout and parameters are designed to meet physics requirements;
- Starting from Higgs, H/W/Z/ttbar can be switchable
- RF system design optimized for Higgs 30/50 MW. Power and energy can be upgraded by adding cavities, RF power sources, cryogenic plants and other systems
- Use dedicated high current 1-cell cavity for 10-50 MW Z. Solve the FM & HOM CBI problems.

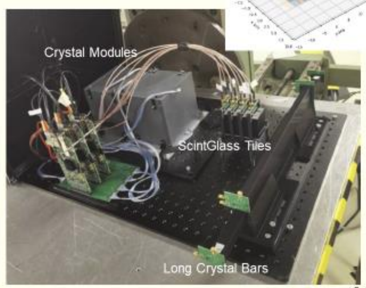
Technologies for Ref-TDR

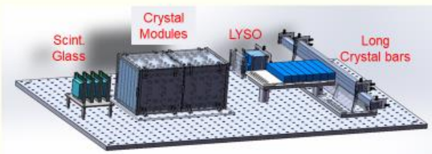
Testbeam of Prototype 4D Crystal ECAL

- A successful testbeam @ DESY, Oct 2023
- To address critical issues at system level
  - Validation: design of crystal-SiPM, light-weight mechanical structure
  - EM shower performance
- Module development
  - BGO crystal bars from SIC-CAS
  - SiPM: 3×3 mm² sensitve area, 10μm pixel pitch
  - Front-end electronics with CITIROC, by CNRS OMEGA. An ASIC with a large dynamic range would be more desirable









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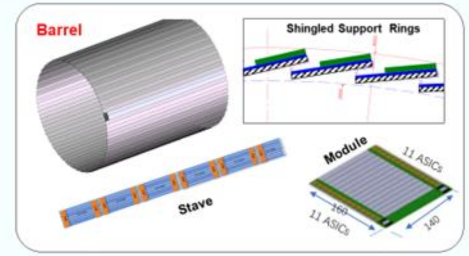
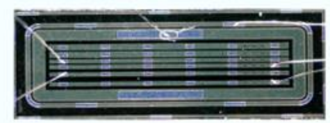
AC-LGAD Outer Tracker (Time Tracker)

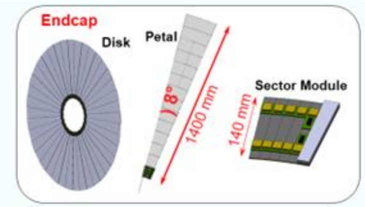
- The outer silicon tracker ~ 85 m², the Z precision is not crucial ⇒ cost-effective Si strip detector
- Need a supplemental PID to TPC at low energy ⇒ LGAD ToF
- AC-LGAD Time Tracker combines the two needs in one detector, and expect σ_t ~30 ps, $\sigma_{R\Phi}$ ~10 μm



Strip AC-LGAD by IHEP / IME

Strip size 5.6 mm × 100 μm
Pitch: 150, 200, 250 μm





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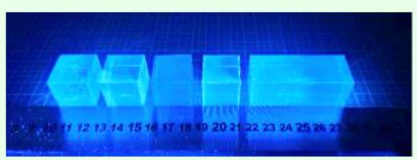
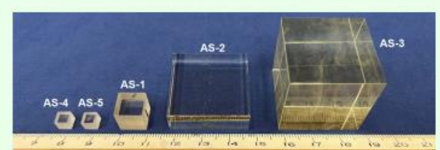
Glass Scintillator HCAL

- To replace plastic scintillator with high density, low cost glass scintillator, for better hadronic energy resolution and BMR
- Key specifications:
  - Light yield: 1000~2000 ph / MeV
  - Density: 5~7 g/cm³
  - Scintillation time: ~100 ns
- The Scintillation Glass collaboration continues to progress on the quest for better GS
- The GS1 / GS5 measurements are from (5mm)³ small size samples. Tiles of 40×40×10 mm³ are needed for GS-HCAL

Parameters	Unit	BGO	LYSO	GAGG	GS1	GS5
Density	g/cm³	7.13	7.5	6.6	6.0	5.9
Hygroscopicity	--	No	No	No	No	No
Rad. Length, X_0	cm	1.12	1.14	1.63	1.59	1.61
Transmittance	%	82	83	80	80	80
Refractive Index	--	2.1	1.82	1.91	1.74	1.75
Emission peak	nm	480	420	520	390	390
Light yield, LY	ph/MeV	8000	3000	54000	1347	1154
Energy resol., ER	%	9.5	7.5	5.0	25.3	25.4
Decay time	ns	60, 300	40	100	80,600	90,300





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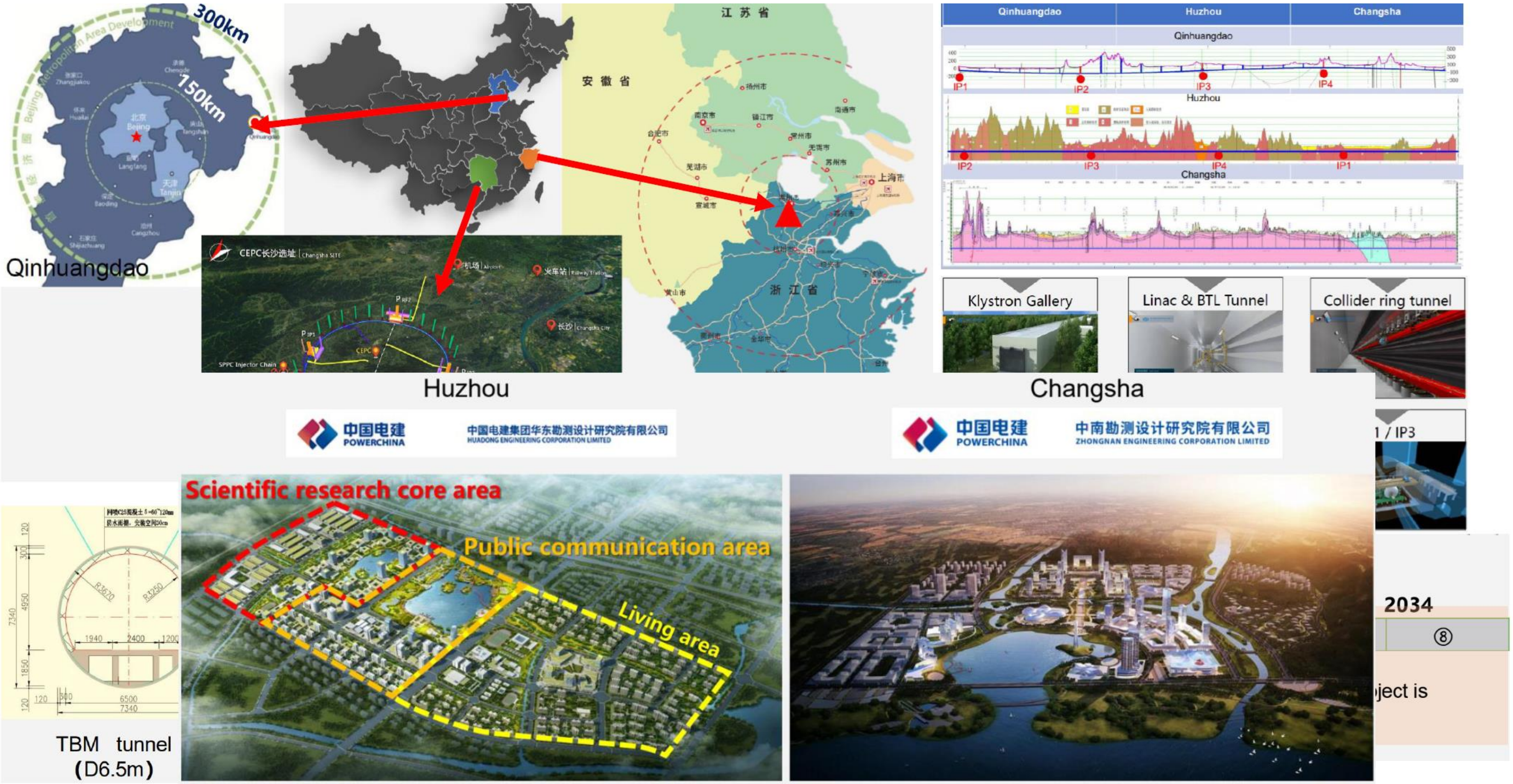
CEPC Status – site selection



CEPC Status & Progress

Making efforts towards a green accelerator

- Experience at HEPS
  - Solar panel: 10 MW ➔ 10% saving
  - Permanent magnet: 5.6 GWh saving/yr
  - Hot water(13 MW@42°C) for heating: more than what HEPS needs
- R&D for CEPC
  - High eff. Klystron, energy recovery Klystron, Solid State Transformer, permanent magnet, …
  - Design and R&D of a “cooling-compressor + heating-pump system” to recover hot water in winter and cooling water in summer for use at HEPS
  - Continue to investigate power generator using low-T hot water