«Colliders of Tomorrow » at Fermi Lab

The Circular Electron-Positron Collider
Status and Progress

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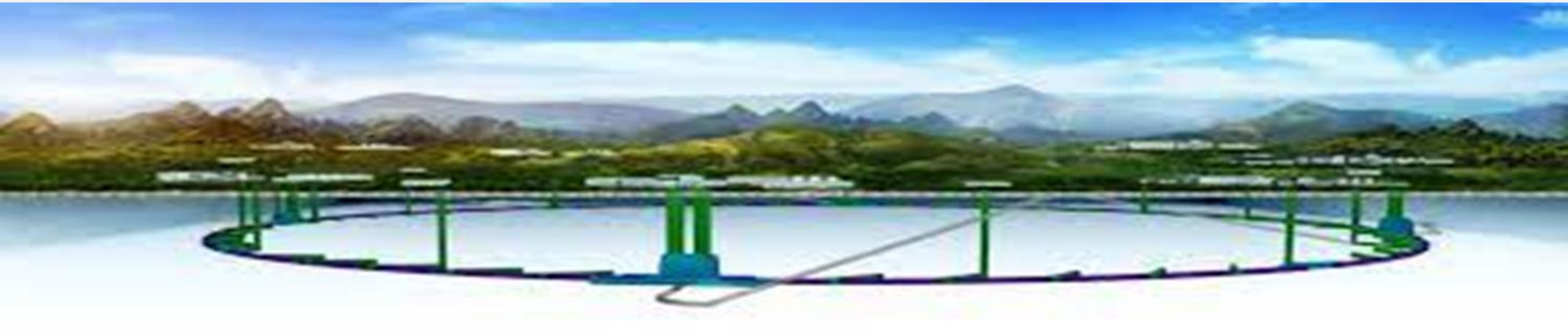
Outline

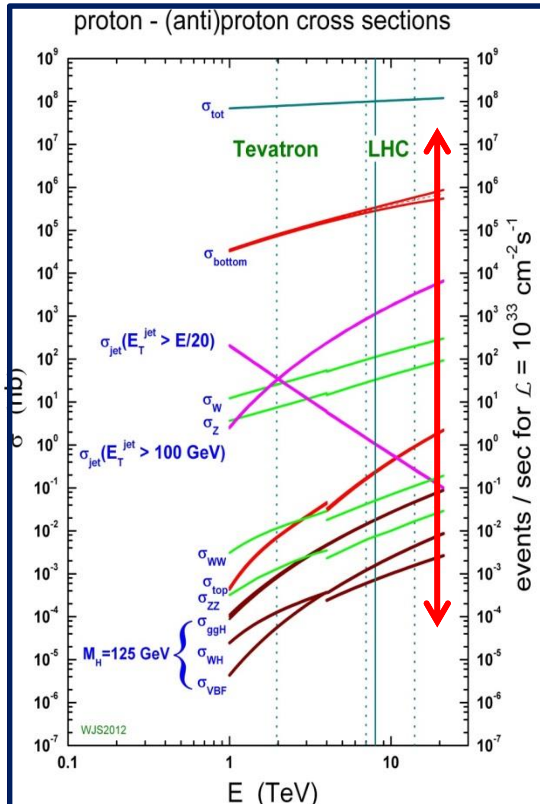
- Introduction and Reminder
- Physics at CEPC (Fcc-ee, ILC)
- CEPC Status and Progress
- Project Development
- Summary



Introduction and Reminder

- The discovery of the Higgs boson solidifies the Standard Model
- The Higgs boson provides rare opportunities to probe new physics
- The e^+e^- Higgs factory is called for
- Such a Higgs factory can also be a factory for top, Z and W
- CEPC covers the Higgs, Z, W and the top
- CEPC can be upgraded to a ~100 TeV pp collider in future
- The CEPC Study Group – design + R&D since Sept. 2013

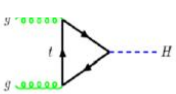
The cases for high energy e^+e^- colliders



LHC –

- large Higgs cross section
- 150M Higgs per exp.
- dominated by QCD events
- **S**(H)/**B**(All) 10^{-10}
- Pile-up and jet overlap
- Not knowing

$$(\overrightarrow{P_H}, E_H)_{\text{initial}}$$

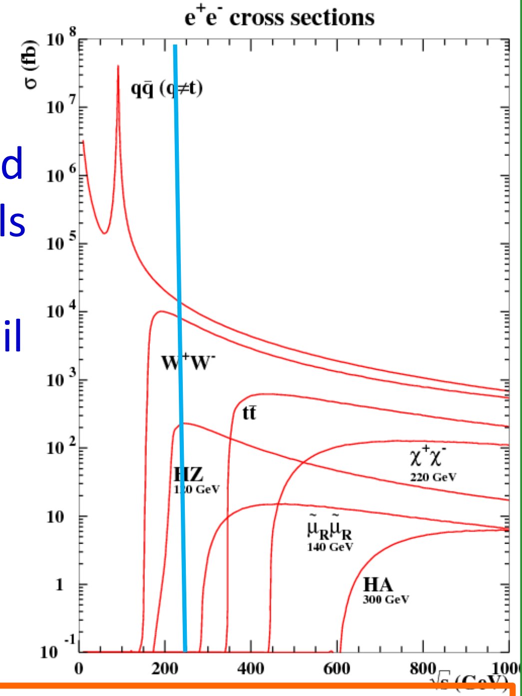


Precisions on H couplings

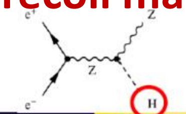
~(5-10)% expected

e^+e^- collider –

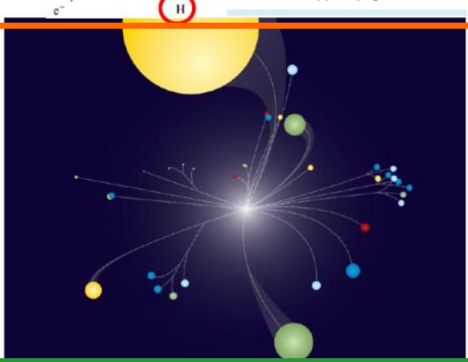
- Higgs cross section, predicted with (sub)% levels
- Know $(\overrightarrow{P_H}, E_H)_{\text{initial}}$ allowing for recoil mass reconst.
- Clean events
- low Higgs cross section



unbiased H sample can be selected by way of recoil mass against the Z boson



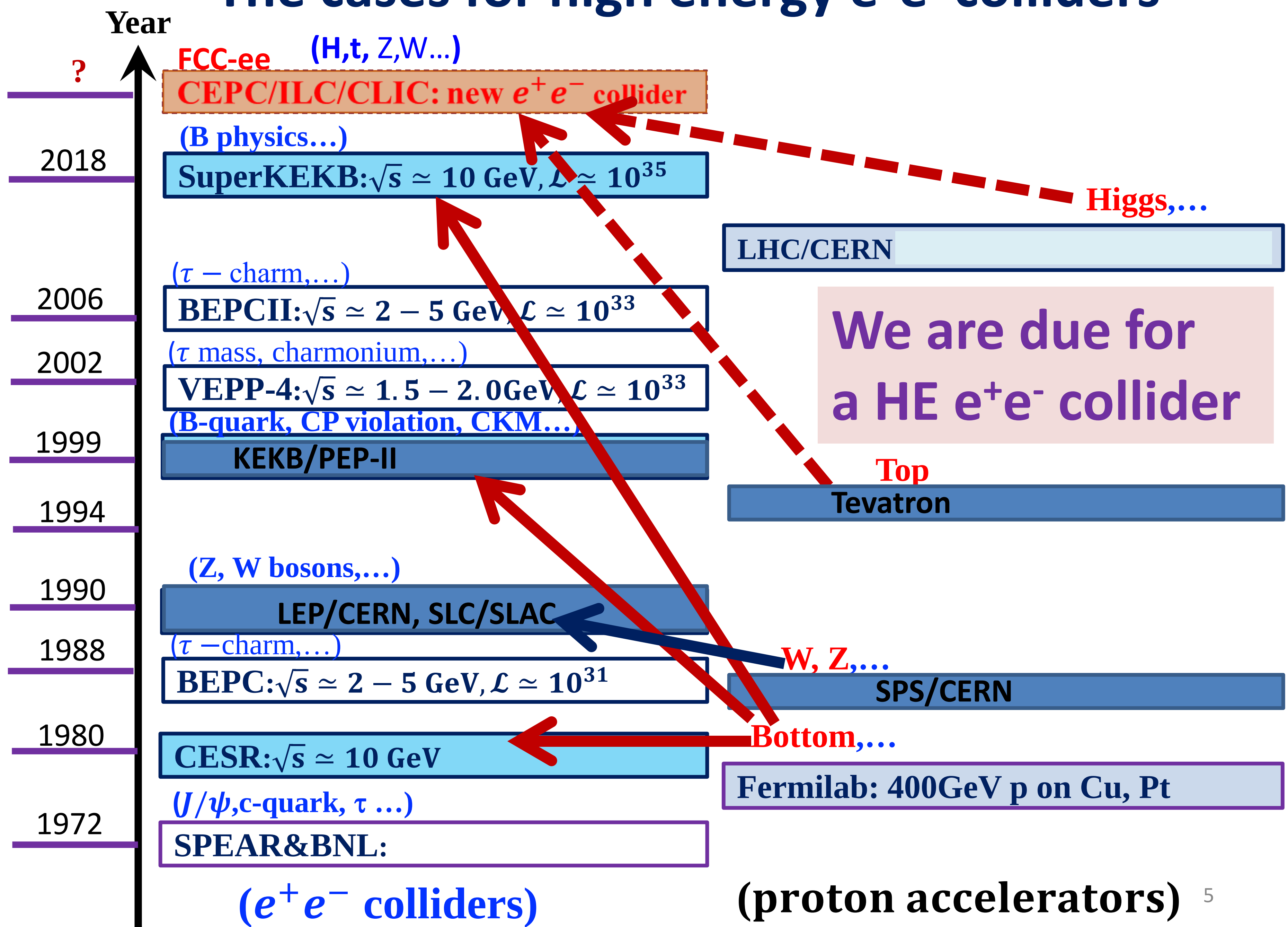
$$M^2_{H\to FS} = (\sqrt{S} - E_Z)^2 - |\vec{P}_Z|^2$$



Precisions on H couplings

~1% or less expected

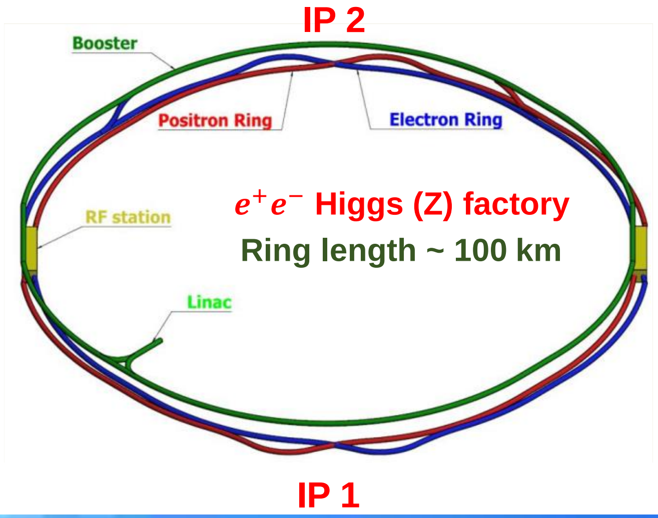
The cases for high energy e^+e^- colliders

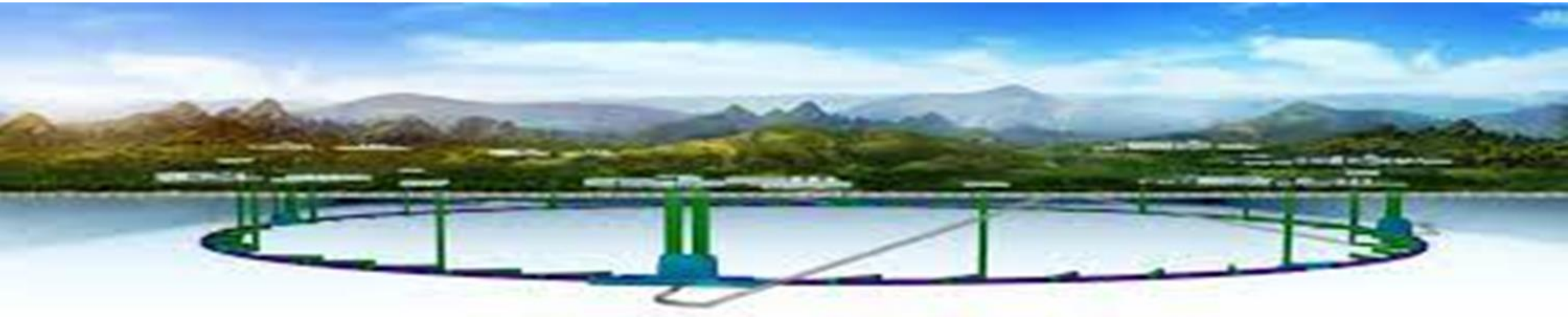


The Concept of CEPC

The idea of CEPC followed by a possible Super proton-proton Collider (SppC) was proposed in Sep. 2012.

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





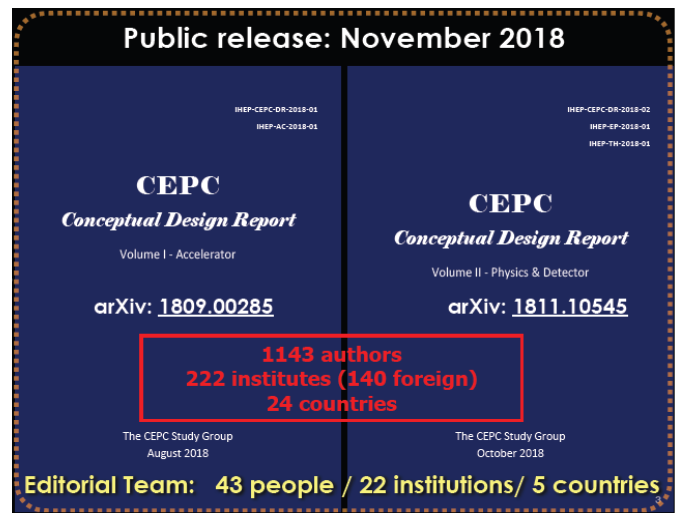
Introduction

CEPC team took steps to advance

CEPC-SPPC Kickoff (2013.9)

First CEPC IAC Meeting (2015.9)

CEPC CDR Released (2018.11)



Global HEP Consensus on Higgs Factories

China

2013, 2016: Xiangshan Science Conferences concluded that the CEPC is the best approach and a major historical opportunity for the national development of accelerator-based high-energy physics program.

JAHEP Japan

2017: Japan Association of High Energy Physicists (JAHEP) proposes to construct a 250 GeV center-of-mass ILC promptly as a Higgs factory.

Europe

2020: An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

In April **2022**, the International Committee for Future Accelerators (ICFA) "reconfirmed the international consensus on the importance of a Higgs factory as the highest priority for realizing the scientific goals of particle physics", and expressed support for the above-mentioned Higgs factory proposals

Exploring the Quantum Universe

Pathways to Innovation and Discovery in Particle Physics

Report of the Particle Physics Project Prioritization Panel 2023

Exploring the Quantum Universe

Recommendation 6

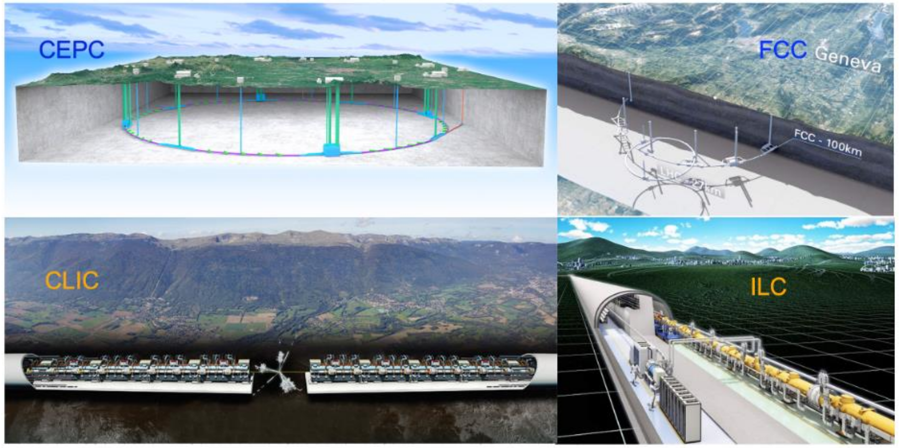
Convene a targeted panel with broad membership across particle physics later this decade that makes decisions on the US accelerator-based program at the time when major decisions concerning an off-shore Higgs factory are expected, and/or significant adjustments within the accelerator-based R&D portfolio are likely to be needed. A plan for the Fermilab accelerator complex consistent with the long-term vision in this report should also be reviewed.

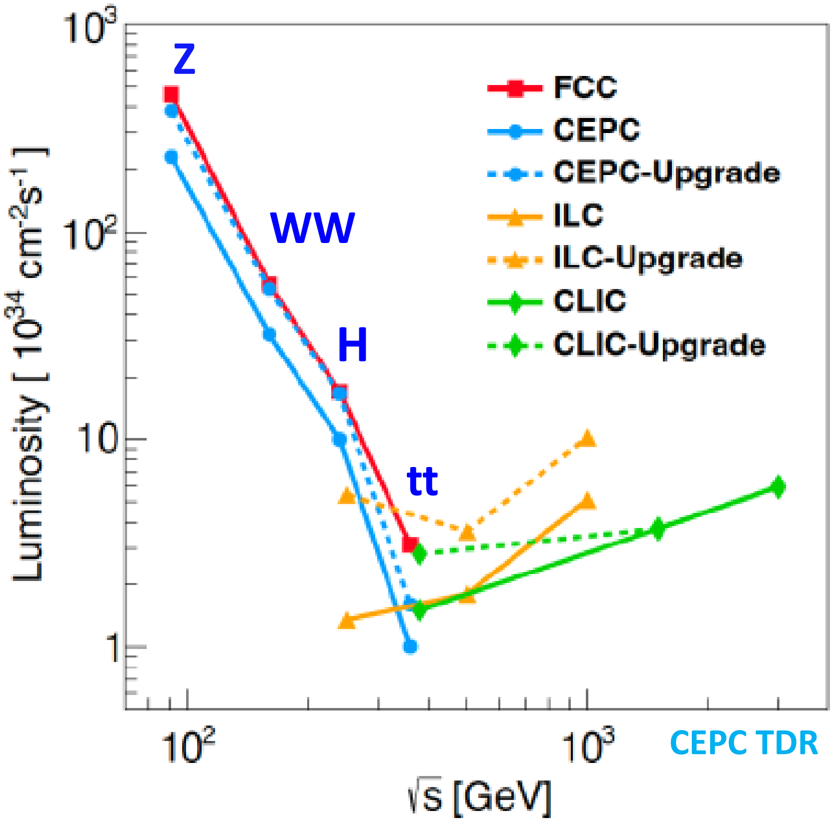
The panel would consider the following:

1. The level and nature of US contribution in a specific Higgs factory including an evaluation of the associated schedule, budget, and risks once crucial information becomes available.
2. Mid- and large-scale test and demonstrator facilities in the accelerator and collider R&D portfolios.
3. A plan for the evolution of the Fermilab accelerator complex consistent with the longterm vision in this report, which may commence construction in the event of a more favorable budget situation.

P5 report, USA, 2023

Circular or Linear?





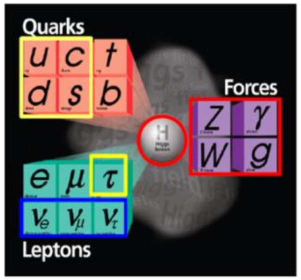
- Electron-positron Higgs factories identified as top priority for future collider (ESPPU).
- CEPC has strong advantages among mature electron-positron Higgs factories (design report delivered),
  - **Earlier data**: collision expected in 2030s (vs. FCC-ee ~ 2040s), **larger tunnel cross section**（ee, pp coexistence)
  - **Higher precision** vs. linear colliders with more Higgs & Z; potential for **proton collider upgrade**.

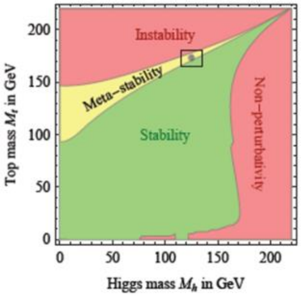
Physics at CEPC

- Probing new physics to 10 TeV (direct-indirect)
- Unprecedented precision on EW and QCD
- Rich flavor physics
- With a future 100 TeV pp collider, fully testing SM and extending search for NP to the limit
- Theoretical developments crucial and exciting

Higgs Factory – Great Scientific Value

- We have a very successful Standard Model
- But we still have a lot of issues and questions:
  - Anything fundamentals behind the flavor symmetry ?
  - Mass hierarchy of elementary particles normal ?
  - Fine tuning of Higgs mass natural ?
  - Why a meta-stable vacuum ?
  - What are dark matter particles ?
  - No CP in the SM to explain Matter-antimatter asymmetry
  - Dirac or Majorana Neutrino mass ?
  - Unification of interactions at a high energy ?
- We are at a turning point:
  - a new, much deeper theory ?
  - Choices of experimental approaches ?
    - e^+e^-, pp, ep, $\mu^+\mu^-$ or no machine ?





- "Small cost" to look for hints. If yes, go for direct searches

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{M^2}\mathcal{O}_{6,i} \qquad \delta \sim c_i \frac{v^2}{M^2}$$

No signal at LHC:

Direct searches: M ~ 1 TeV

10% precision: M ~ 1 TeV

Look for signals at CEPC/FCC-ee:

Precisions exceed HL-LHC ~ 1 order of magnitude (1% precision) ➔ M ~10 TeV

CEPC CDR

Naturalness will be at $\sim 10^{-4}$ up to 10 TeV
If no New Physics up to 10 TeV, there will be no naturalness ➔ even bigger discovery ?

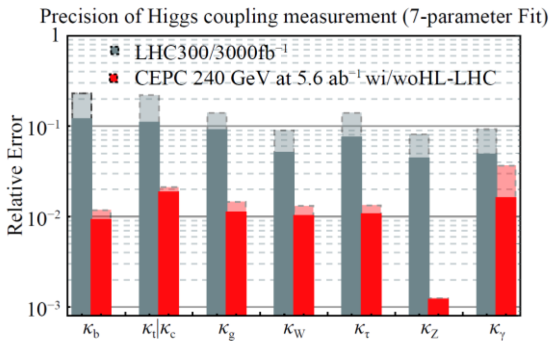
Pressing science questions, best addressed by an e^+e^- Higgs factory (~1% precision or better)

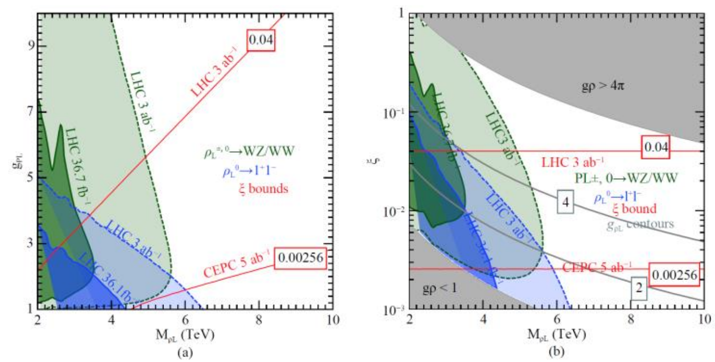
Physics at CEPC

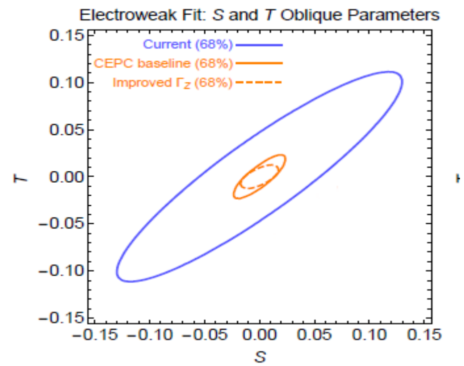
Higgs coupling measurement can be improved by orders magnititude

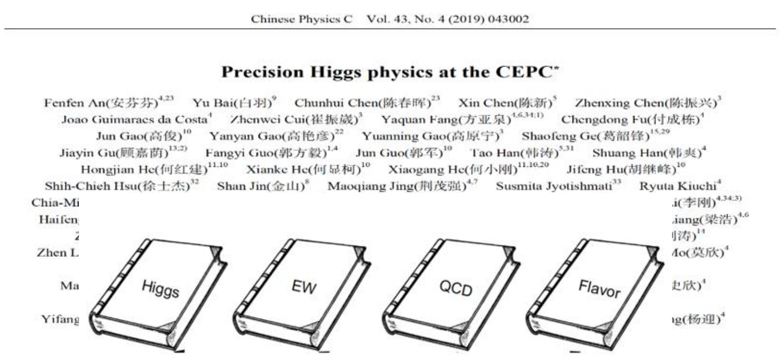
Direct and indirect proble to new physics up to 10 TeV, an order of magntitude higher then HL-LHC

Electroweak measurement can be improved by a large factor

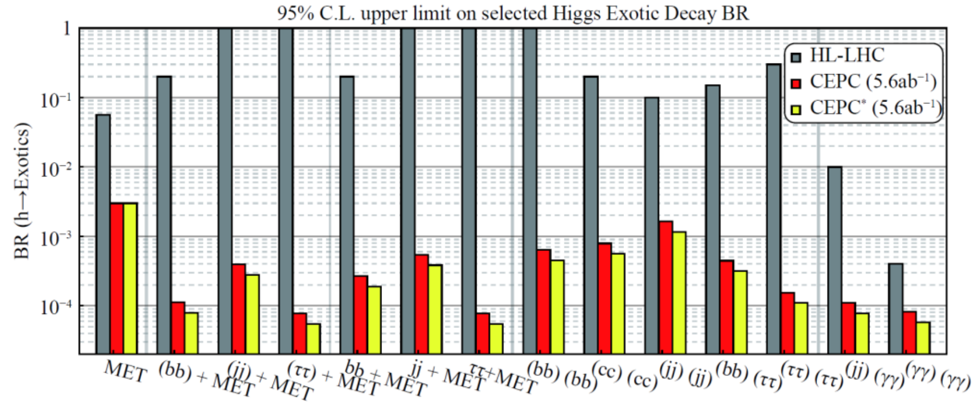




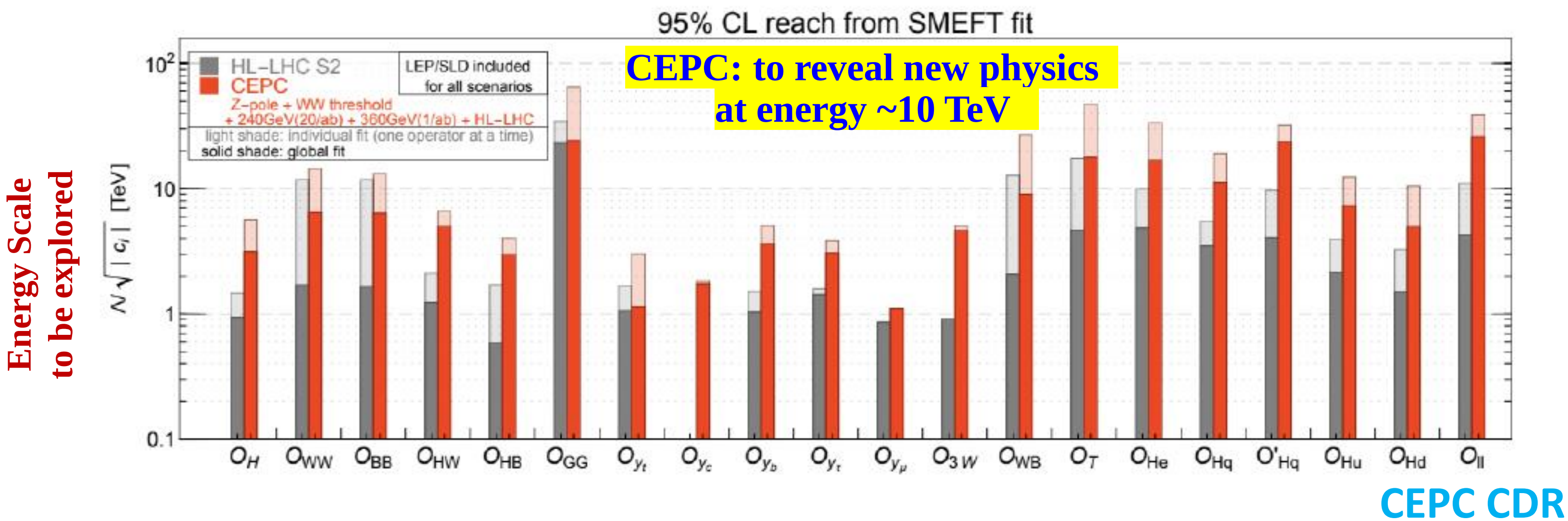




Physics white papers published and to be published



Physics at CEPC



Covered energy scales of new physics from CPEC and HL-LHC, based on measurements of operators in the framework of the Standard Model Effective Field Theory (SMEFT).

CEPC Status and Progress

- CEPC CDR released in 2018, outlining the R&D program
- Design improvement, R&D continuously pursued since
- Benefitted from constructing an advanced light source, operation experience of the BEPCII
- Majority of R&D completed
- Accelerator TDR released in December 2023
- CEPC is for the worldwide HEP community, and the CEPC Study Group actively engages in international collaboration

CEPC Concepts

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.
~$10^{34\text{-}36}$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

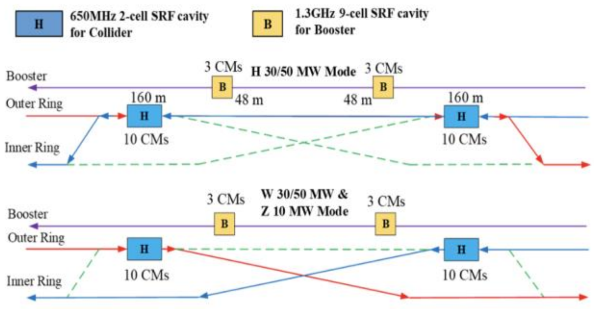
- ✓ Switchable Operations
- ✓ Upgradability
- ✓ Large Piwinski angle with Crab-waist
- ……

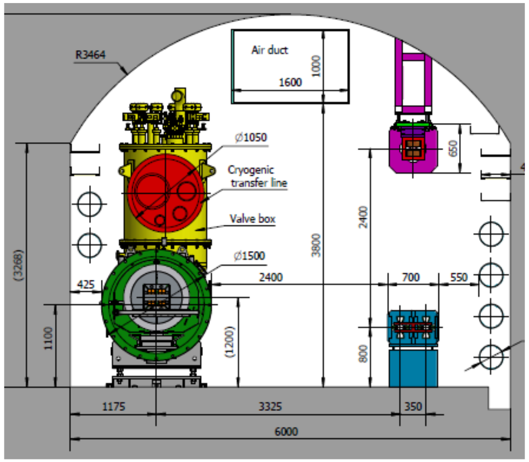
Operation mode	Z	W	Higgs
Center-of-mass energy (GeV)	91	160	240
Operation time (year)	2	1	10
Instantaneous luminosity/IP (10^{34}cm$^{-2}s^{-1}$)	115	16.0	5.0
Integrated luminosity (ab^{-1}, 2 IPs)	60	3.6	12
Event yield (30 MW)	2.5×10^{12}	1.0×10^8	2.5×10^6
Event yield (50 MW)	4.0×10^{12}	1.6×10^8	4.0×10^6

CEPC Layout and Design Essentials

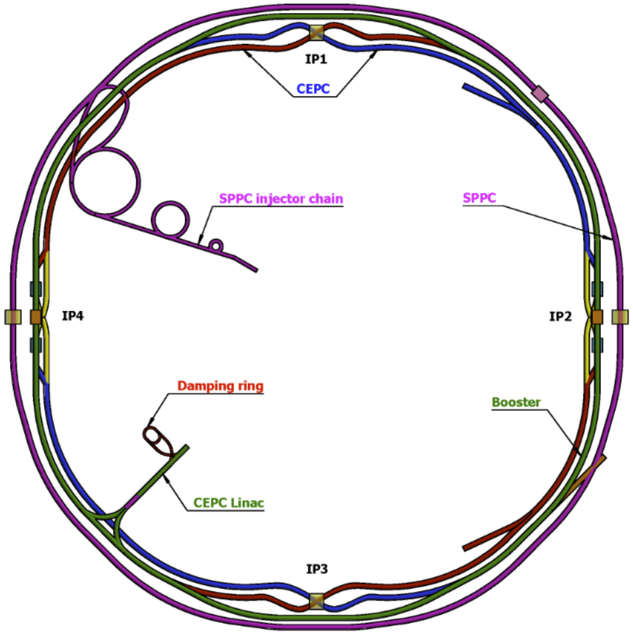
- **Circular collider: Higher luminosity than a linear collider**
- **100km circumference: Optimal total cost**
- **Shared tunnel: Compatible design for CEPC and SppC**
- **Switchable operation: Higgs, W/Z, top**
- Accelerator complex comprised of a Linac, a 100 km booster and a collider ring

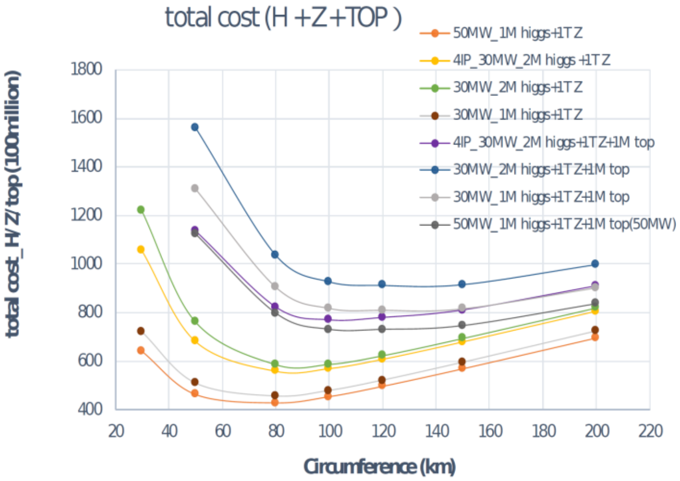
Switchable operation for Higgs W and Z





Common tunnel for booster/collider & SppC





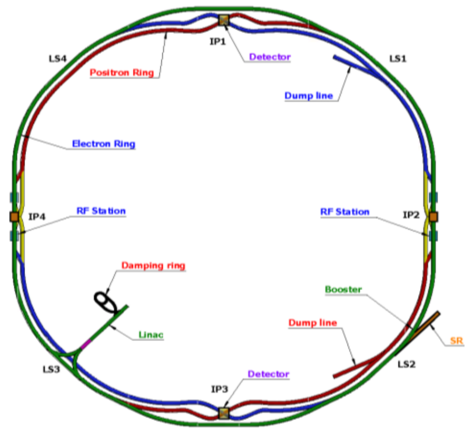
Baseline: 100 km, 30 MW; Upgradable to 50 MW, High Lumi Z, ttbar

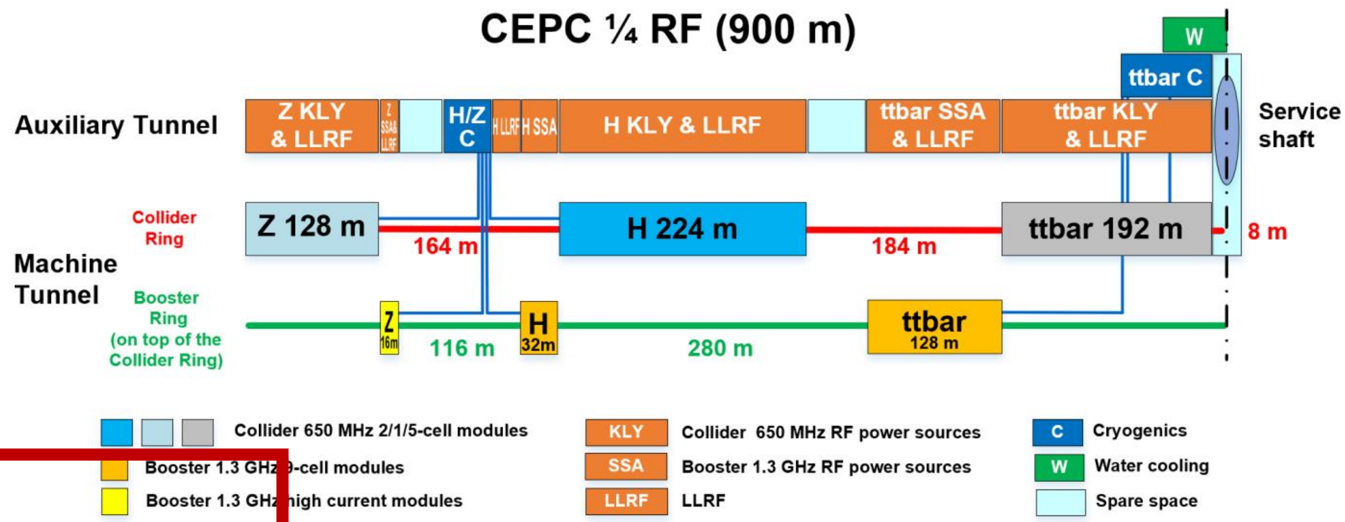
CEPC Operation Plan

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}

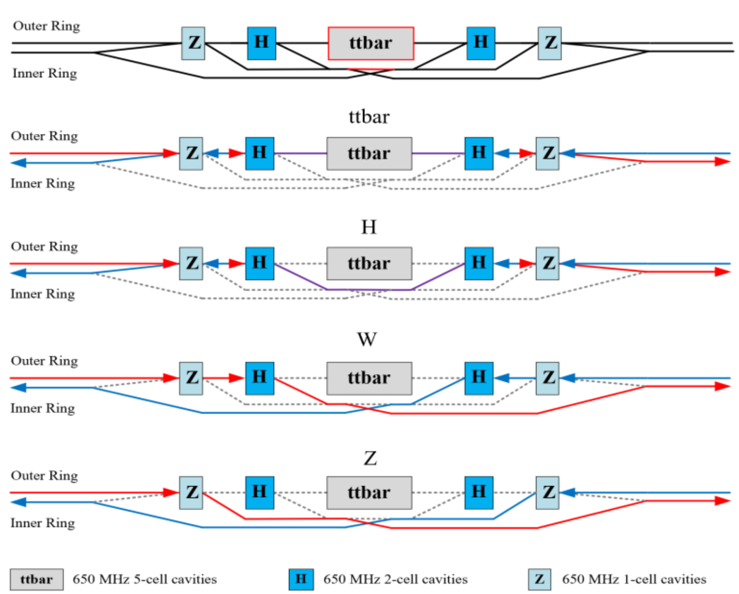
* Higgs is the top priority. The CEPC will commence its operation with a focus on Higgs.
** Detector solenoid field is 2 Tesla during Z operation, 3Tesla for all other energies.
*** Calculated using 3,600 hours per year for data collection.

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.

CEPC R&D Program

- **Polarized electron gun**
  - ⇨ Super-laIce GaAs photocathode DC-Gun
- **High current positron source**
  - ⇨ bunch charge of ~3nC,
  - ⇨ 6Tesla Flux Concentrator peak magnetic field
- **SCRF system**
  - ⇨ High Q cavity - Max operation Q_0 = 2E10 @ 2 K
  - ⇨ High power coupler - 300kW（Variable）
- **High efficiency CW klystron**
  - ⇨ Efficiency goal > 80%
- **Low field dipole magnet（booster）**
  - ⇨ Lmag=5m, Bmin=30Gs, Errors <5E-4
- **Vacuum system**
  - ⇨ 6m long cooper chamber
  - ⇨ RF shielding bellows
- **Electro-static separator**
  - ⇨ Maximum operating field strength: 20kV/cm
  - ⇨ Maximum deflection: 145 urad
- **Large scale cryogenics**
  - ⇨ 12 kW @4.5K refrigerator, Oversized,
  - ⇨ Custom-made, Site integration
- **HTS magnet**
  - ⇨ Advanced HTS Cable R&D: > 10kA
  - ⇨ Advanced High Field HTS Magnet R&D: main field 12~12T

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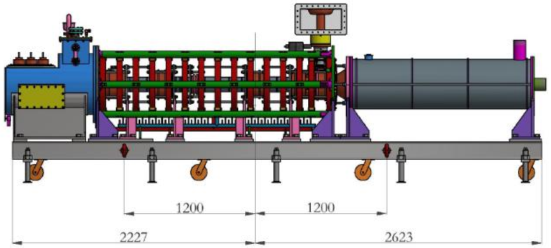
N-doping of 650MHz 1-cell cavities

Vertical test of 650MHz 1-cell cavity

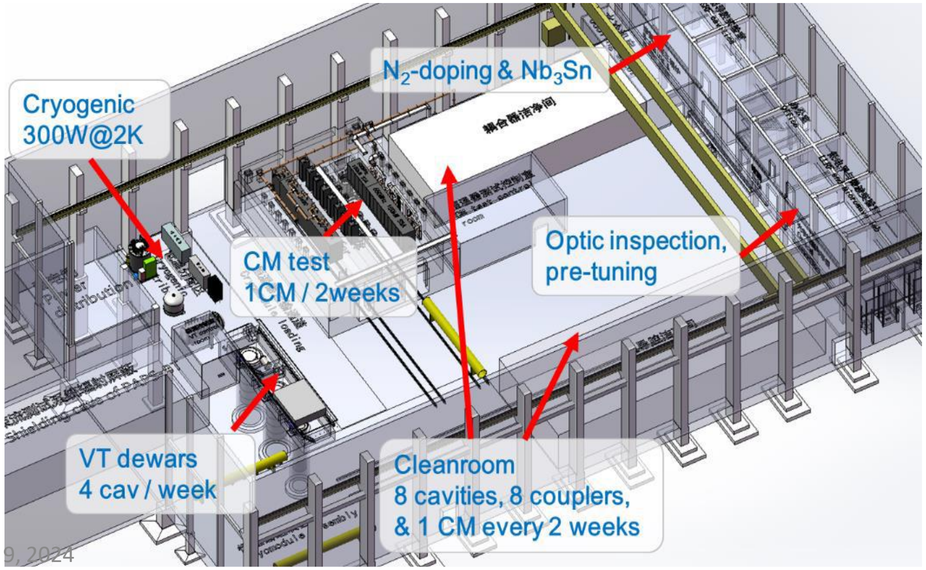
High voltage DC Gun



Mechanical design of conventional klystron

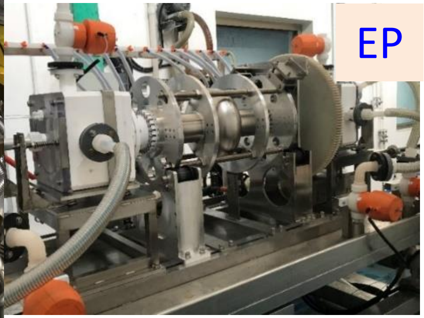
A New Lab at IHEP for SRF system(PAPS)

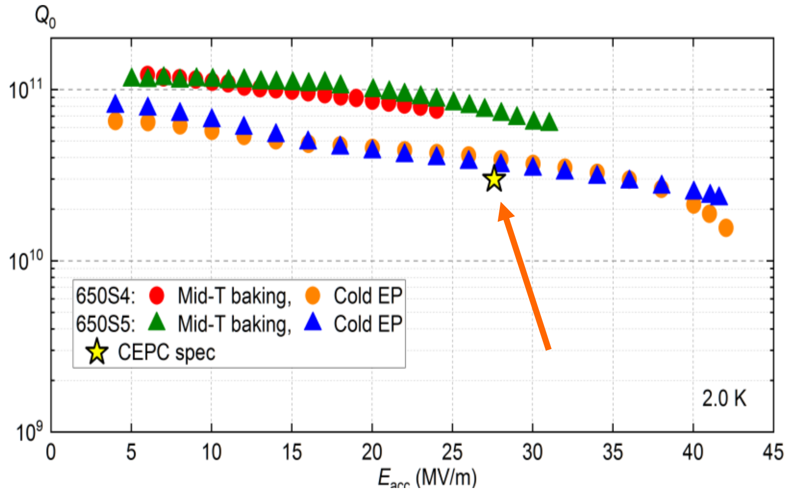
- A gift by the city of Beijing, next to HEPS
- A cryogenic system with 2.5KW@4.5K or 300W@2K
- Ovens and clean rooms for cavity production
- 2 horizontal and 3 vertical SRF test stand
- ~200 SRF cavities/year
- Testing of klystrons, electron guns, magnets, etc., and NEG coating of vacuum pipes
- ATF in the future



CEPC R&D: 650 MHz SRF Cavities for collider

- First three 2-cell cavities based mainly on BCP shows reasonable performance
- Recent 1-cell cavity based on cold-EP and Mid-temperature baking achieved the world best results, exceeding CEPC spec.
- Continue to develop multi-cell cavities

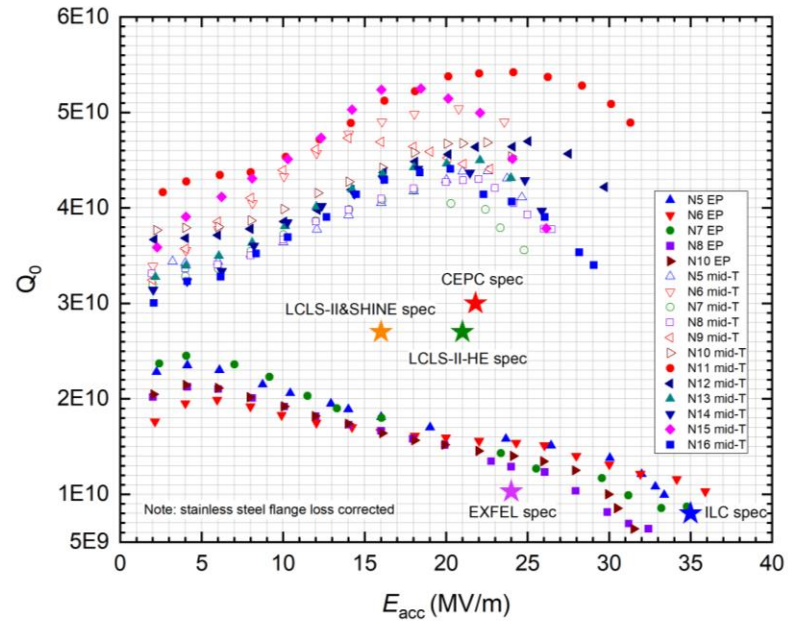


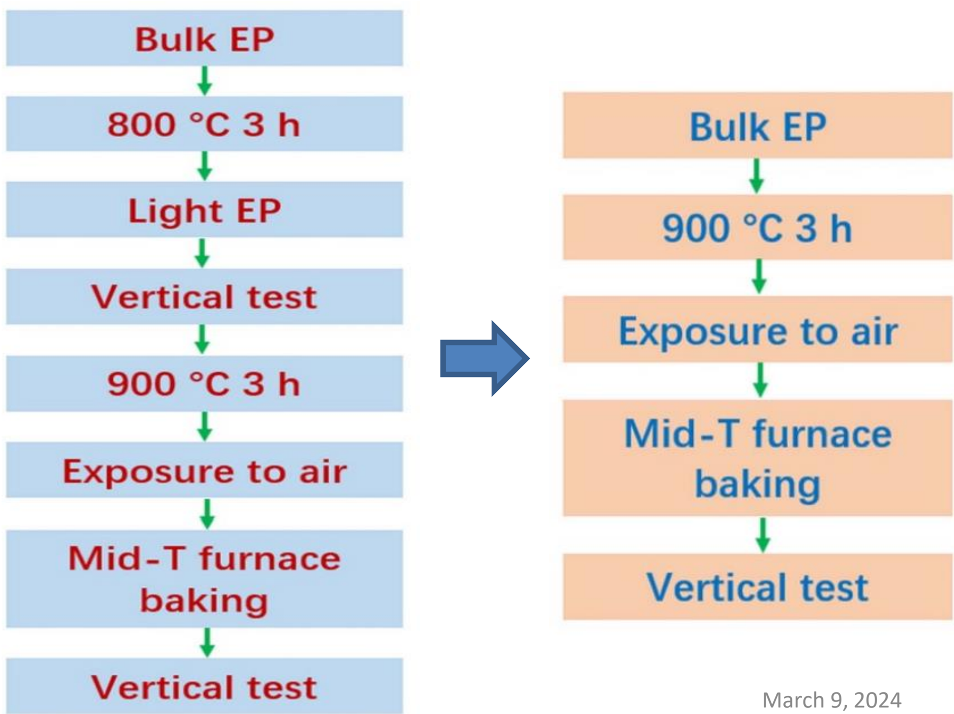


Vertical test of 650 MHz 1-cell cavity

CEPC R&D: 1.3 GHz SRF Cavities for booster

- Mid-T baking (O-doping) VS N-doping: higher E_{acc} & Q, simple process, less EP.
- Excellent results obtained, exceeding requirements by CEPC, SHINE, LCLS-II, etc.
- ILC type of cavity with higher E_{acc} is also under development

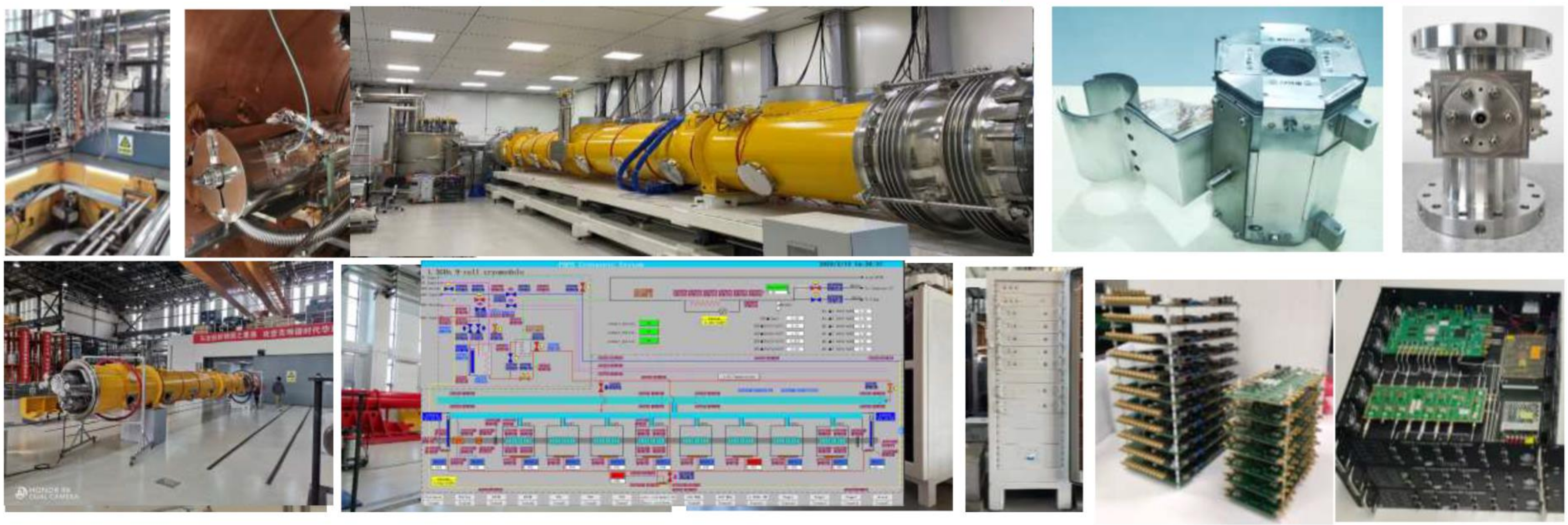




CEPC R&D: 8×9 Cell High Q Cryomodule

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

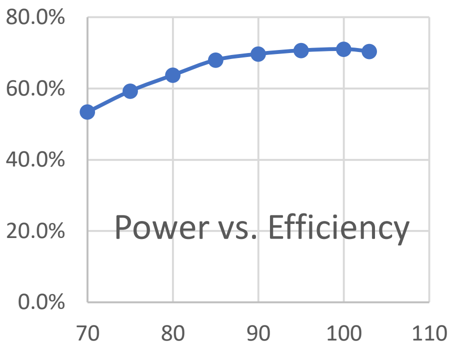
Parameters	Horizontal test results	CEPC Booster Higgs Spec	LCLS-II, SHINE Spec	LCLS-II-HE Spec
Average usable CW E_{acc} (MV/m)	23.1	3.0×10^{10} @ 21.8 MV/m	2.7×10^{10} @ 16 MV/m	2.7×10^{10} @ 20.8 MV/m
Average Q_0 @ 21.8 MV/m	3.4×10^{10}			



Exceeds the CEPC specifications

CEPC R&D: High Eff. Klystrons

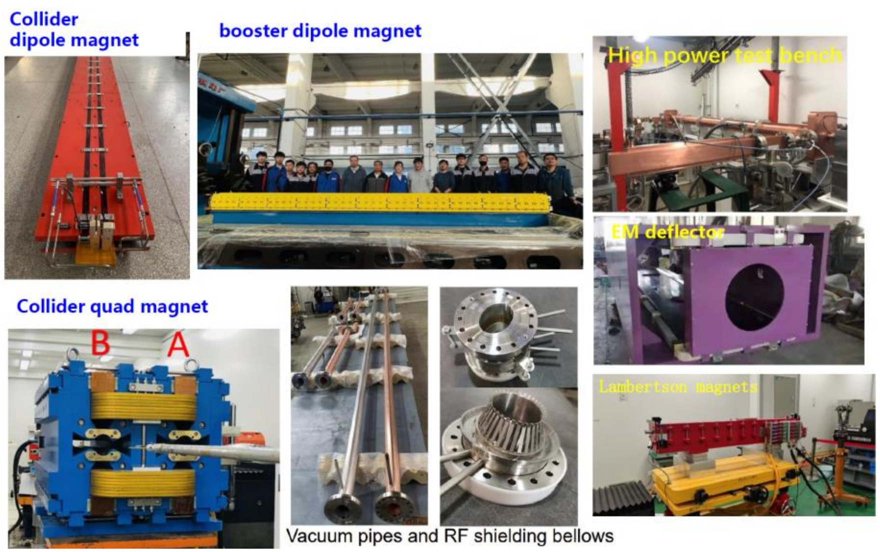
- 1st prototype: normal eff.
  - Single-beam with 70 kV
  - output power reached design value of 800 kW
  - efficiency ~ 62%
- 2nd prototype: High eff.
  - Single-beam with 110 kV
  - Designed eff. ~77%, test result 70%
  - Issues understood, to be re-tested soon
- 3rd prototype: High eff.
  - Multi-beam Klystron(MBK) with a designed eff. of 80%
  - Manufacture underway



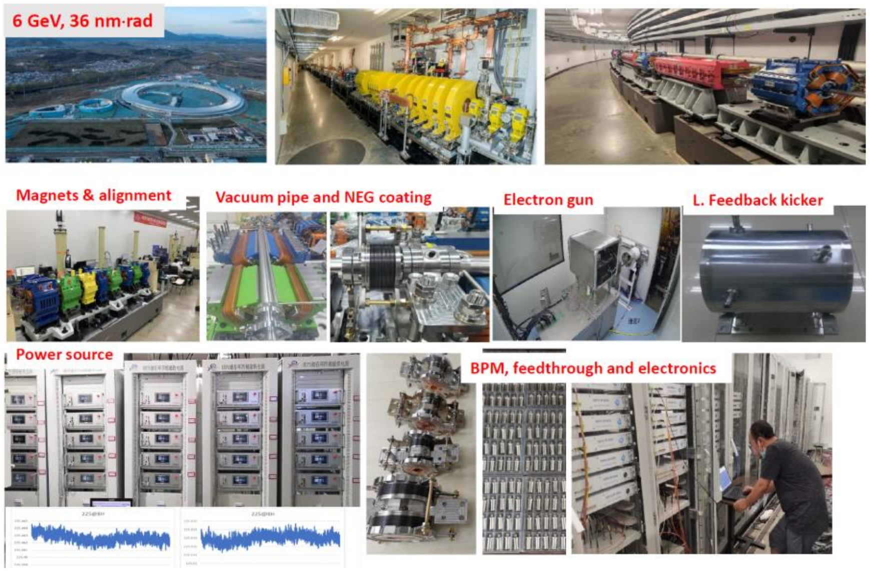
Window processing

CEPC R&D and Prototypes

R&D: Other Prototypes



Experience at HEPS & BEPCII



Summary of Key Technology R&D

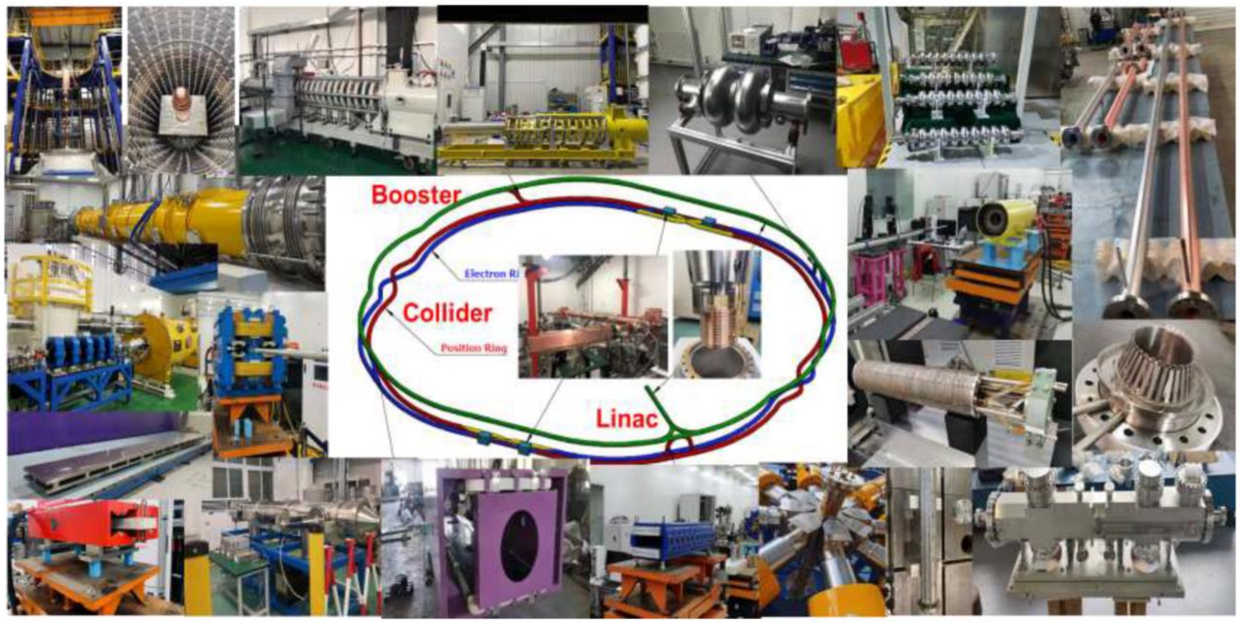
- CEPC received ~ 260 Million CNY from MOST, CAS, NSFC for key technology R&D
- Large amount of key technology validated in other project by IHEP: BEPCII, HEPS, …

CEPC R&D ~ 40% cost of acc. components	➢ High efficiency klystron ➢ SRF cavities ➢ Positron source ➢ High performance accelerator	➢ Novel magnets: Weak field dipole, dual aperture magnets ➢ Extremely fast injection/extraction ➢ Electrostatic deflector ➢ MDI
BEPCII / HEPS ~ 50% cost of acc. components	➢ High precision magnet ➢ Stable magnet power source ➢ Vacuum chamber with NEG coating ➢ Instrumentation, Feedback	➢ Survey & Alignment ➢ Ultra stable mechanics ➢ Radiation protection ➢ Cryogenic system ➢ MDI

- **~10% remaining (the machine integration, commissioning etc.) to be completed by 2026.**
- **International contribution/collaboration important**

Key Accelerator Technology Readiness

Specification Met ✓ Prototype Manufactured ✓

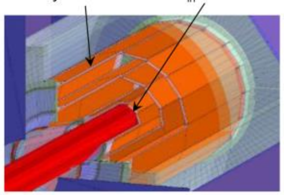


Key technology R&D in TDR spans all component lists in CEPC CDR

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 covering all sub-detector technologies

2 layers / ladder R_{in}~16 mm



Goal: σ(IP) ~ 5 μm for high P track

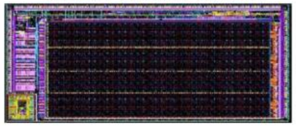
CDR design specifications

- 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

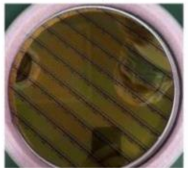
Develop **CEPCPix** for a CEPC tracke basing on **ATLASPix3** CN/IT/UK/DE TSI 180 nm HV-CMOS process

JadePix-3 Pixel size ~16×23 μm²

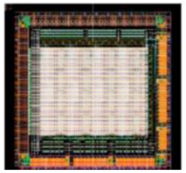


Tower-Jazz 180nm CiS process
Resolution 5 microns, 53mW/cm²

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

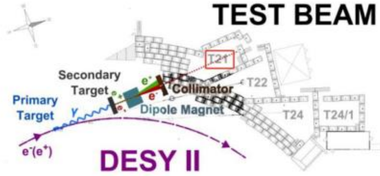


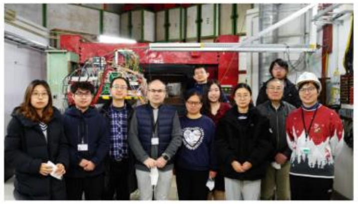
CPV4 (SOI-3D), 64×64 array ~21×17 μm² pixel size

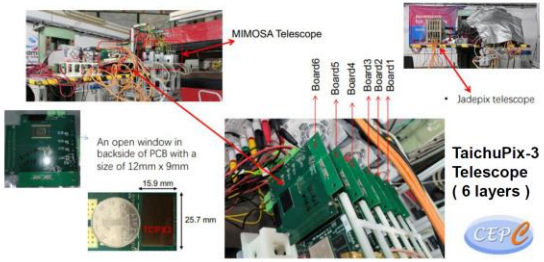


Arcadia by Italian groups for IDEA vertex detector LFoundry 110 nm CMOS

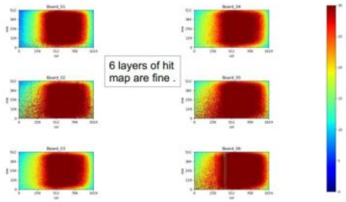
Full vertex detector prototype (TaichuPix-3, JadePix-3) has TB at DESY in Dec. 2022.



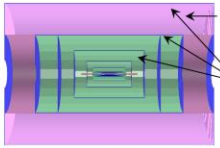


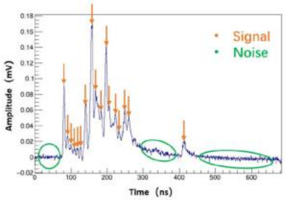


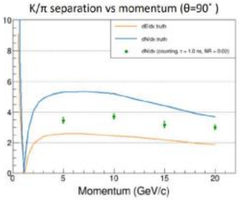
Hitmap of 4 GeV e⁺/e⁻ beam



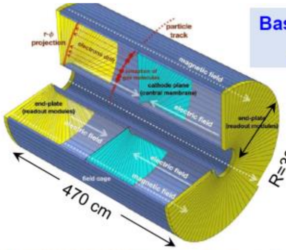
- **Goal: 3σ π/K separation up to ~20 GeV/c.**
- Cluster counting method, or **dN/dx**, measures the number of primary ionization
- **Can be optimized specifically for PID**: larger cell size, no stereo layers, different gas mixture.
- Garfield++ for simulation, realistic electronics, peak finding algorithm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



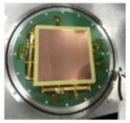




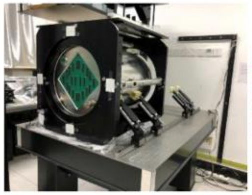
IHEP and Italian INFN groups have close collaboration and regular meetings.
IHEP joined the TB (led by INFN group) in 2021 and 2022



Baseline main tracker σ(r-ϕ) ~100 μm



GEM-MM cathode

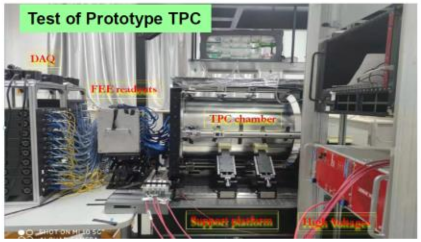


TPC Prototype + UV laser beams

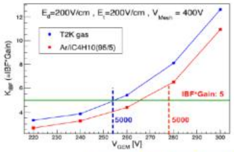
MOST 1 (IHEP+THU)

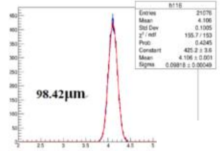
Low power FEE ASIC

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.

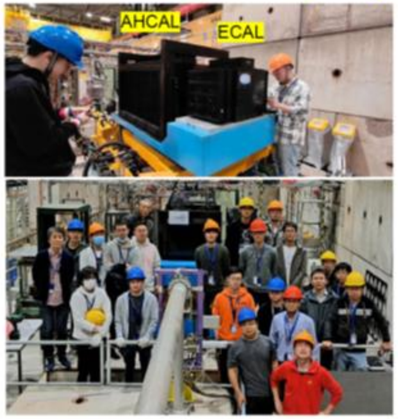


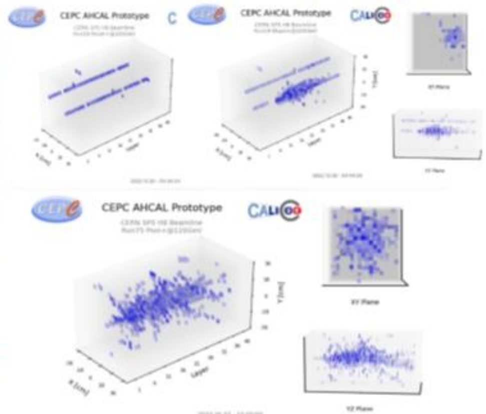


σ_x < 100 μm for drift length of 27cm

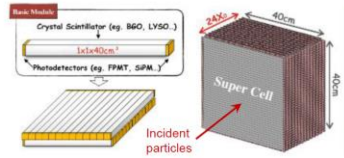
CEPC Detector R&D covering all sub-detector technologies

➢ 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

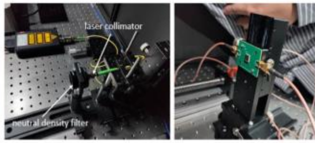


- Long bars: 1 x 40 cm, super-cell: 40x40 cm²
- Timing at both ends for positioning along bar.
- Significant reduction of number of channels.

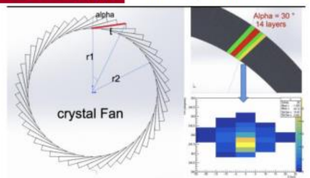
Goal

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

Bench Test

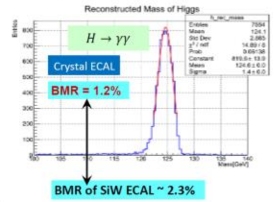


Crystal Fan Design Fine segmentation in Z, ϕ, r

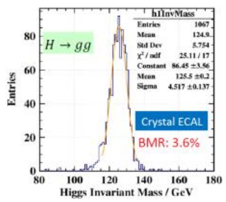


Full Simulation Studies + Optimizing PFA for crystals

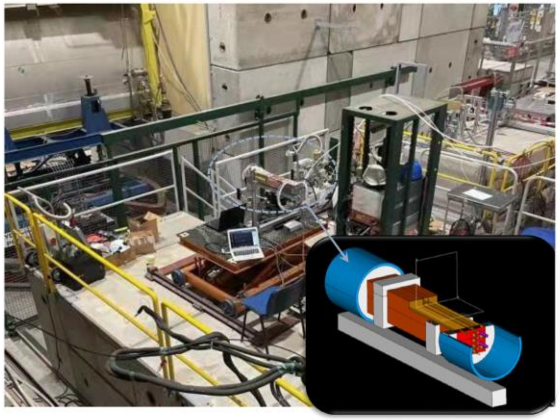
Performance with photons

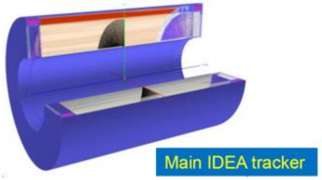


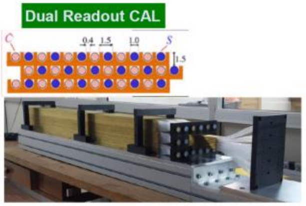
Performance with jets



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







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

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

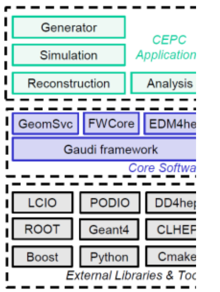
Architecture of CEPCSW

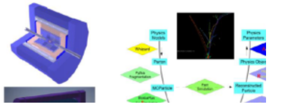
- External libraries
- Core software
- CEPC applications for simulation, reconstruction and analysis

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

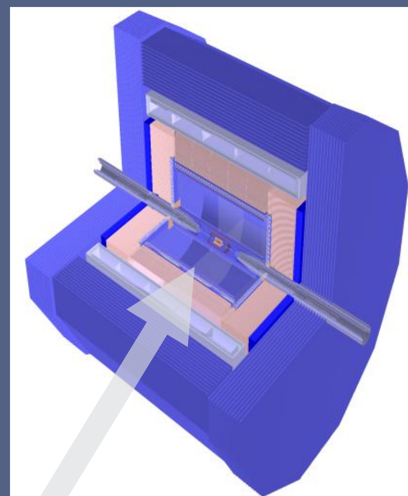




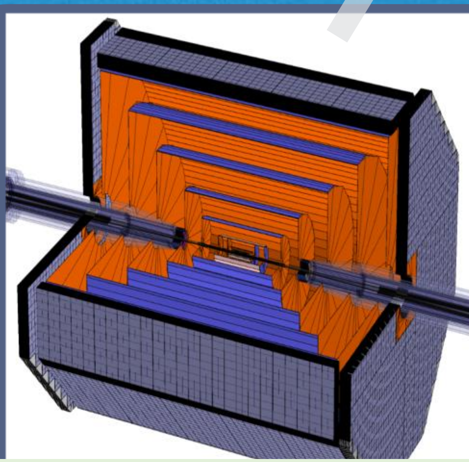
Detector System Concepts Studied

Particle Flow Approach

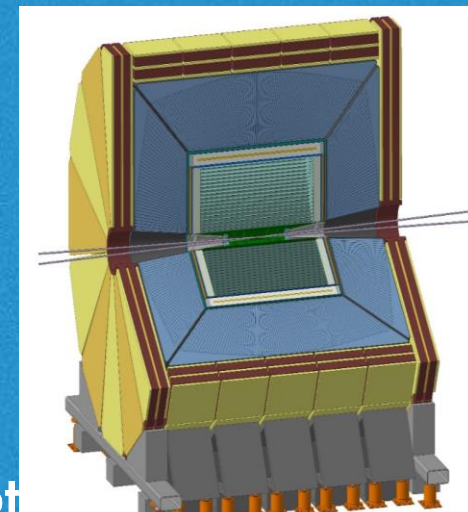
High magnetic field concept (3 Tesla)



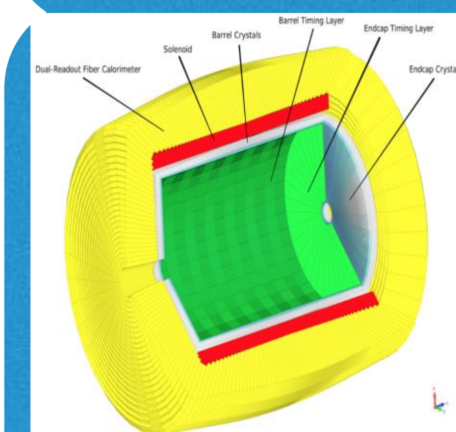
Full silicon tracker concept



Low magnetic field concept (2 Tesla)



IDEA Concept
also proposed for FCC-ee



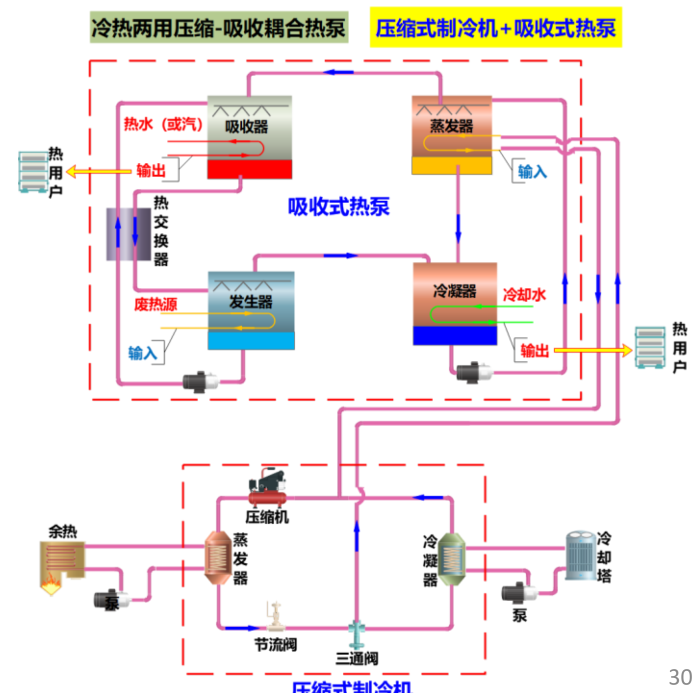
"Fourth concept": Crystal Calorimeter based detector (2-3 Tesla)

Final two detectors will likely be a mixture of different options

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, …
  - 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

Solar panel on the roof of HEPS



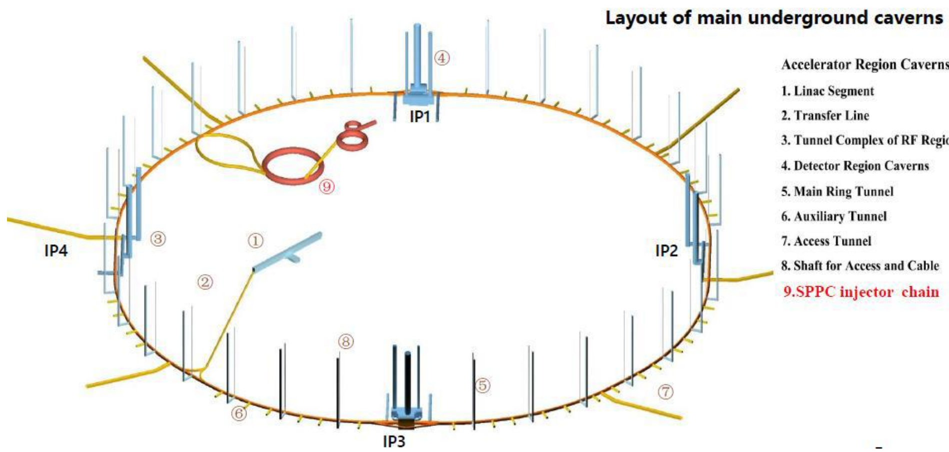
3030
30

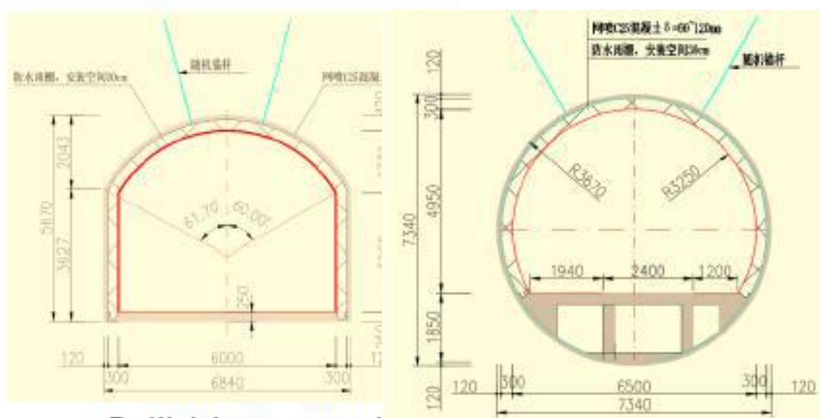
CEPC Site Selection

Three sites documented in the Accelerator TDR

Civil Design and Planning

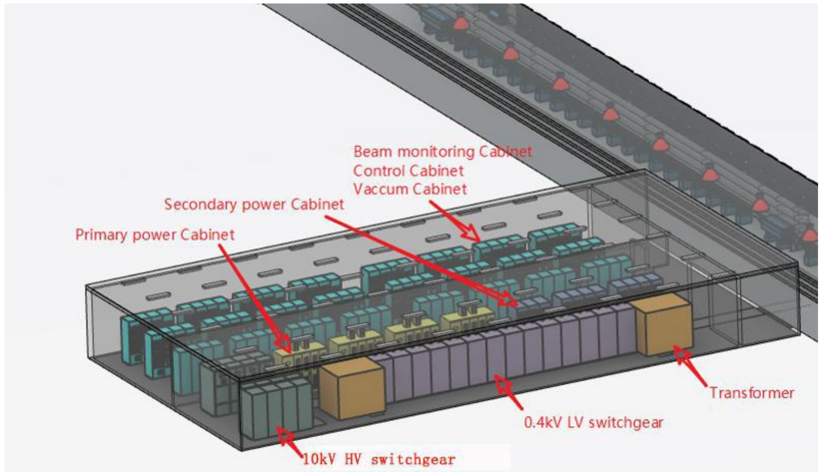
- 3 companies working on the design, one for each site. Review in progress
- Most of the tunnel(75-95%) in granite, greatly impact the cost
- Construction method yet to be determined
- Time for construction is ~5 years

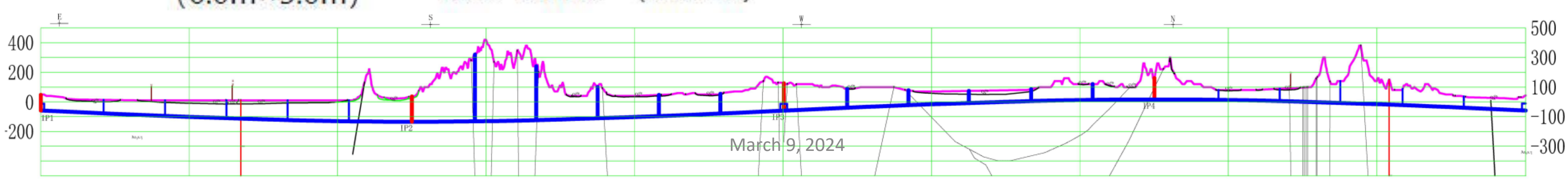




Drill-blast tunnel (6.0m×5.0m)

TBM tunnel (D6.5m)





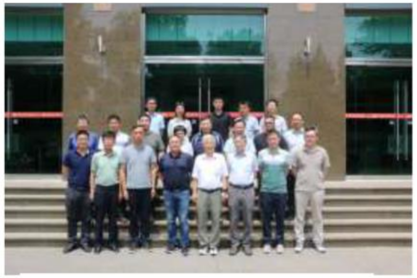
CEPC Accelerator TDR Released

Positive review outcomes and endorsement by the CEPC IAC

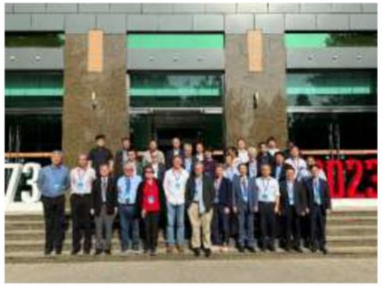
International Reviews of the CEPC Accelerator TDR, HKUST-IAS, Hong Kong

CEPC Accelerator TDR Review
June 12-16, 2023, Hong Kong

CEPC Accelerator TDR Cost Review
Sept. 11-15, 2023, Hong Kong



Domestic Civil Engineering
Cost Review, June 26, 2023, IHEP



9th CEPC IAC 2023 Meeting
Oct. 30-31, 2023, IHEP

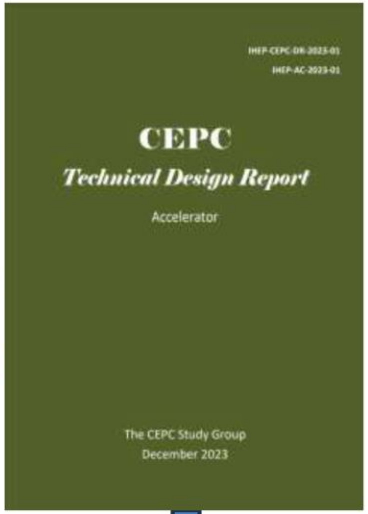
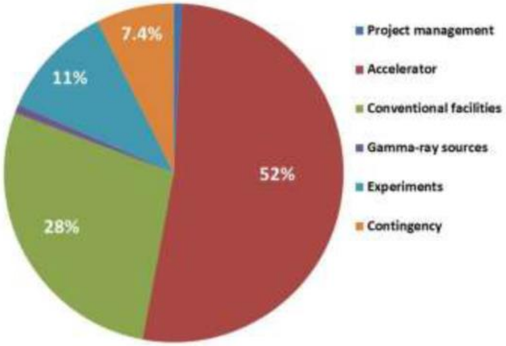


Table 12.1.2: CEPC project cost breakdown, (Unit: 100,000,000 yuan)

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**

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

CEPC Accelerator TDR

Positive review outcomes and endorsement by the CEPC IAC

June 12-16, 2023, in HKUST-IAS, Hong Kong

Chaired by Frank Zimmermann

Phase 1 CEPC TDR Review Report

CEPC TDR Technical Review Committee

15 July 2023

The CEPC Study Group, hosted by the Institute of High Energy Physics (IHEP), has been working on the design and development of a forefront e^+e^- collider as a Higgs factory that can extend to energies corresponding to the Z, WW and the top-quark pairs, with the upgrade potential to a high-energy pp collider. The CEPC represents a "grand plan" proposed, studied, and to be constructed by Chinese scientists in close collaboration with international partners. Since the release of the CEPC Conceptual Design Report in 2018, the CEPC Study Group has devoted significant effort to the design optimisation, the R&D of key technologies and the study of the technical systems of the CEPC.

The CEPC Study Group has produced a draft Technical Design Report (TDR). The International Review Committee, chaired by Dr. Frank Zimmermann (CERN), was asked to conduct a first phase review of this TDR draft. This first phase review shall cover all but the cost and site aspects of the CEPC.

The Phase 1 CEPC TDR Review Committee meeting was held in person at HKUST from 12 to 16 June 2023.

https://indico.ihep.ac.cn/event/19262/timetable/

Sept. 11-15, 2023, in HKUST-IAS, Hong Kong

Chaired by Loinid Rivkin

CEPC Accelerator TDR Cost Review

The CEPC Accelerator TDR Cost Review committee examined the cost estimate of the TDR of accelerator systems for the first stage of the CEPC project operated as a Higgs factory with synchrotron radiation power up to 30 MW per beam (including all infrastructure that is not easily upgradeable and is already designed to operate up to the ttbar energy and at 50 MW). The cost estimate under review does not include the civil engineering, the detectors at the IPs with their technical services, and the central computing services.

In the opinion of the committee the cost estimate presented is sufficiently complete to form a proper basis for the next iteration that will be done during the EDR stage.

https://indico.ihep.ac.cn/event/19262/timetable/

Oct. 30-31, 2023, in IHEP

Chaired by Brian Foster

The Ninth Meeting of the CEPC-SppC International Advisory Committee

IAC Committee
M. E. Biagini, Y.-H. Chang, A. Cohen,
M. Davier, M. Demarteau, B. Foster (Chair),
B. Heinemann, K. Jakobs, L. Linssen,
L. Maiani, M.L. Mangano, T. Nakada, S. Stapnes,
G. N. Taylor, A. Yamamoto, H. Zhao

November 14th, 2023

https://indico.ihep.ac.cn/event/20107

The IAC also supports another key conclusion in the TDR Review Report, that the accelerator team is well prepared to enter the EDR phase.

-The IAC also support another conclusion in the TDR Review Report that the accelerator team is well prepared to **enter the EDR phase**

Project Development

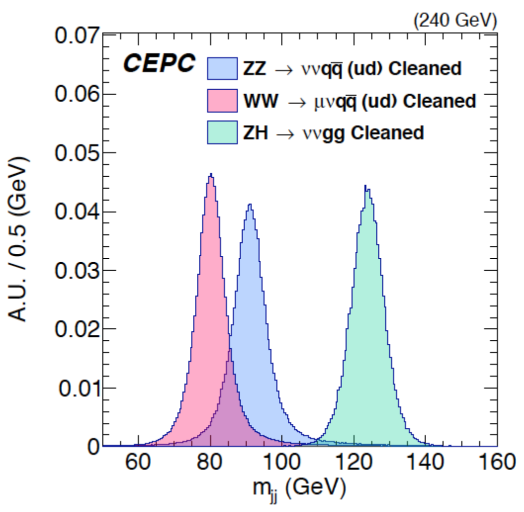
- The detector reference technical design (TDR) is ongoing
- The Engineering Design towards a EDR has begun
- Remaining R&D work to be completed
- Automatic mass production systems being designed
- Site specific development/construction plan will go forward
- Advanced studies being pursued
- Positioning for construction starting in 2027-8

TDR – a New ‘Concept Detector System’

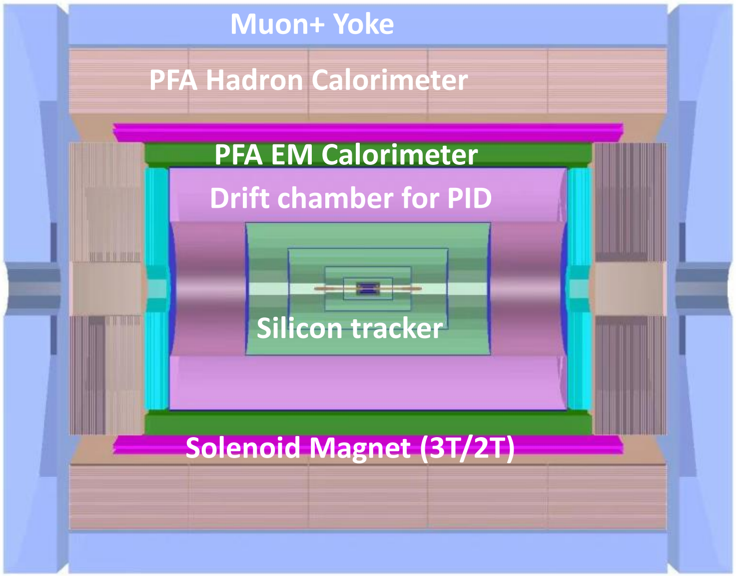
Requirements
boson mass resolution (BMR ~3%)

→

Challenges
- Support Particle flow with
  - High granularity
  - High precision



Novel detector design based on PFA calorimeter. Aim at improving 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 TPC or drift chamber for better tracking 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

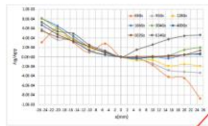
Outcomes of the R&D provide important inputs to this detector system design

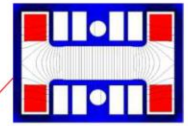
Major EDR Tasks

CEPC Accelerator Main EDR Development: booster magnet

Magnet name	BST-63B-Arc	BST-63B-Arc-SF	BST-63B-Arc-SD	BST-63B-IR
Quantity	10192	2017	2017	640
Aperture [mm]	63	63	63	63
Dipole Field [Gs] @180 GeV	564	564	564	549
Dipole Field [Gs] @120 GeV	376	376	376	366
Dipole Field [Gs] @30 GeV	95	95	95	93
Sextupole Field [T/m²] @180 GeV	0	16.0388	19.1423	0
Sextupole Field [T/m²] @120 GeV	0	10.6925	12.7615	0
Sextupole Field [T/m²] @30 GeV	0	2.67315	3.19035	0
Magnetic length [mm]	4700	4700	4700	2350
GFR [mm]	±22.5	±22.5	±22.5	±22.5
Field errors	$\pm1\times10^{-3}$	$\pm1\times10^{-3}$	$\pm1\times10^{-3}$	$\pm1\times10^{-3}$

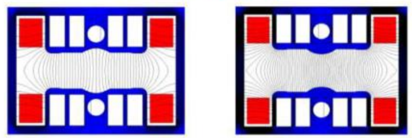
- Booster requires ~19k pieces of magnets (68km);
- Booster dipoles are required to work at the low field of 95 Gs (30GeV) with an error smaller than 1×10^{-3} ;
- Full length (4.7m) dipole was developed, and it meets the field specification;





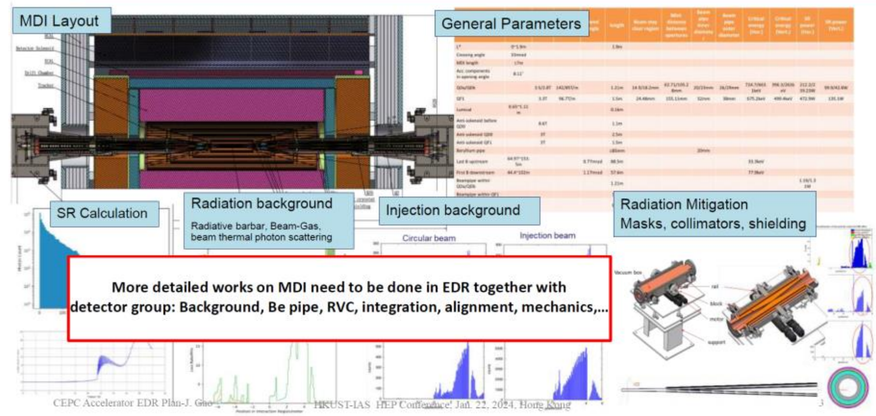
TDR booster dipole magnets: type I

In the TDR stage, the dipole magnets are grouped into three families. One family is the pure dipoles, while the other two families are the dipole sextupole combined magnets with the sextupole field of 10.69 T/m² and -12.76 T/m² at 120GeV.



EDR booster dipole magnets with sextupoles: type II and III

CEPC MDI in EDR



CEPC Accelerator Control and Timing in EDR

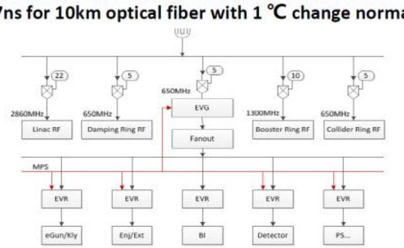
The basic structure of Timing System

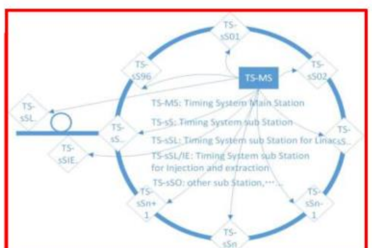
- Event system and RF transmission system
- Event system: Trigger signal and Low frequency clock signal
- RF transmission system: Transmit high stability RF signal

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





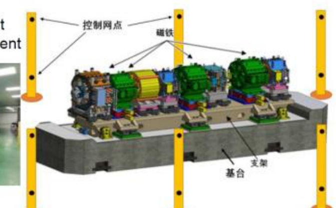
CEPC Alignment and Installation Plan in EDR

- 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

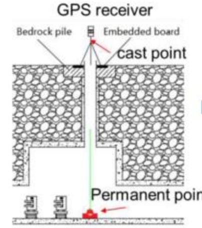
*implement beam-based alignment

Component Pre-alignment

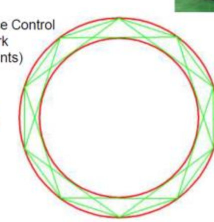


Wall Control Point

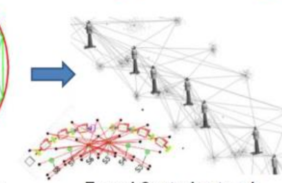
GPS receiver



Surface Control network (14Points)



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



Tunnel Control network (interval of 6 meters)

Ground Control Point

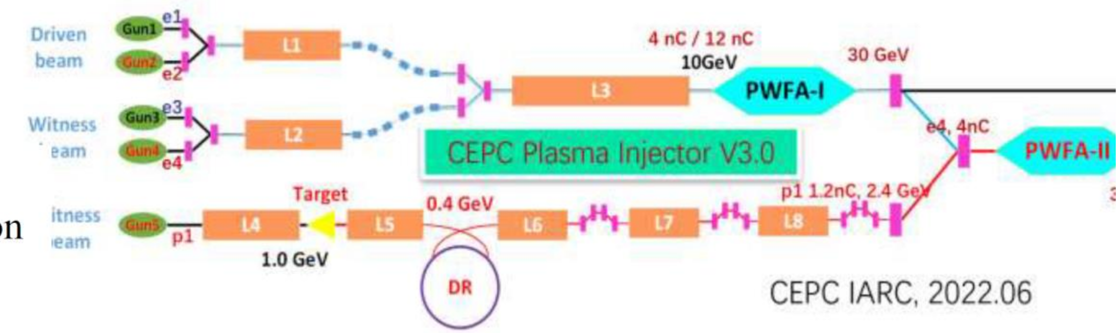
CEPC Accelerator EDR Plan-J. Gao

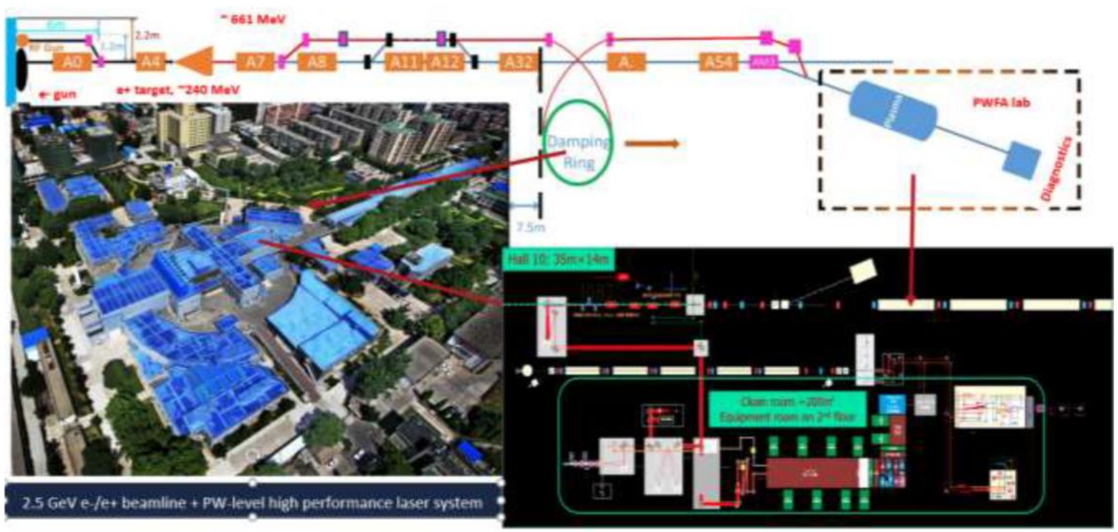
CEPC Plasma Injector (alt. option) and TF Plan

CEPC plasma injector scheme:

From 10 GeV → 30 GeV → **TR ≥ 2**

Simulation results show that it works on paper with reasonable error tolerances for both electron and positron beams injected to the booster





Phase I（**Year0-Year2**）
1. Re-design and install transport beamlin… ystem, optimize the e- / e+ beam quality
2. Clean room and high power las… TW) installation200TW
3. Beam instrumentatio…
4. RF Gun platform…
5. Commissioni… ystems

Phase II（**Yea**…
1. U… es (1PW + 20/40 TW)
… and install it on the

Phase II…
1. A… mping ring the bunch compression bea… mprove the e+ quality
2. PBA-… d FEL studies

- Positron and electron acceleration
- Cascading acceleration
- Future linear collider technologies
- High energy beam for detector R&D (possible application)

PWFA/LWFA TF based on BEPC-II Linac and HPL has been founded by CAS 120M RMB in Sept. 2023

Advanced Studies for ‘State of Art” CEPC

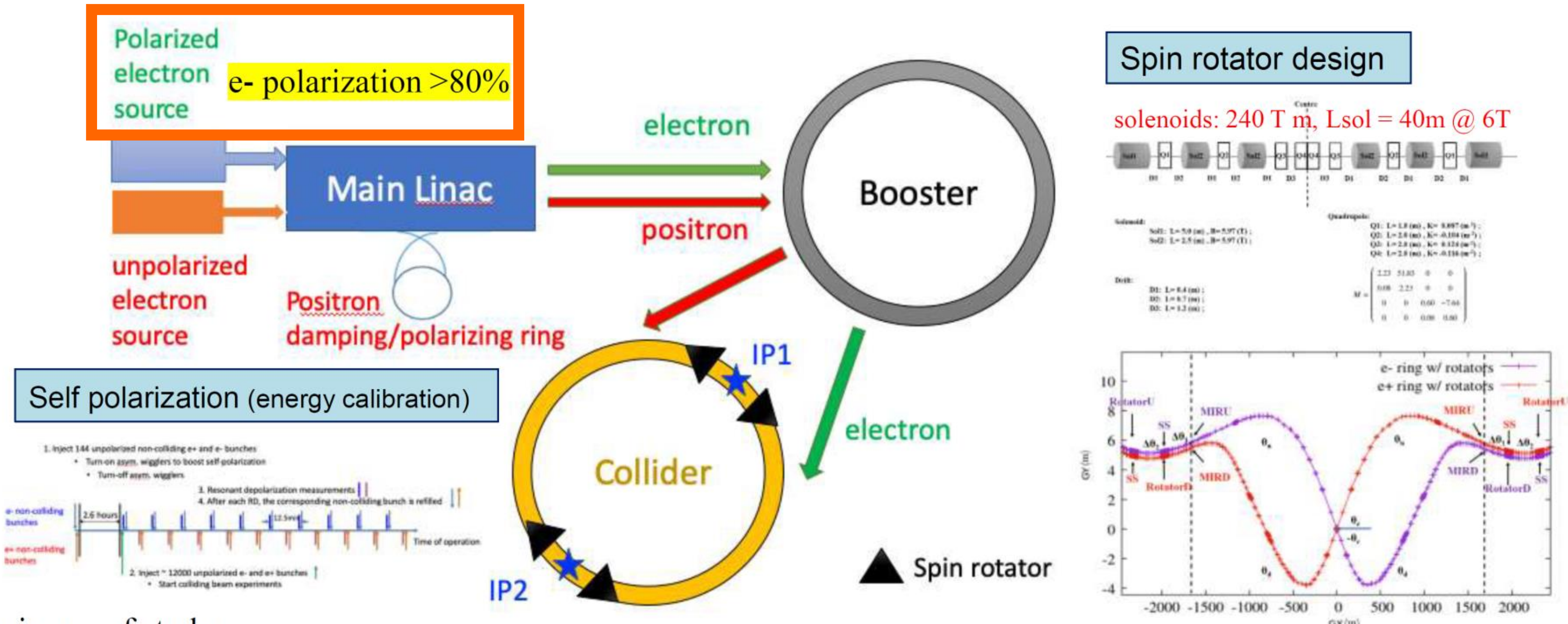
Feb. 2, 2024

CEPC 650 MHz/800 KW high efficiency klystron

tested efficiency 77.2%

Advanced Studies for ‘State of Art” CEPC

- LEP successfully applied spin rotator to the beam to produce polarized beam;
- CEPC attempts to inject polarized beam at the source to rid of deadtime, and to achieve high/fast polarization for the Higgs run



Key issues of study:

- Energy calibration in collider ring with transverse polarization (self polarization & inj. polarization)
- Longitudinal polarization for collision
- Polarization beam injection, positron polarization and ramping in booster

Critical for energy calibration, important EW measurements

Advanced Studies for 'State of Art" SppC

R&D under way

Z. Zhao
IBS (T_c 55K)

2008.02
Discovery of IBS

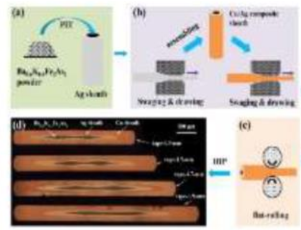
H. Hosono
IBS (T_c 26K)

2008.04

2008.09
Discovery of 122 phase IBS

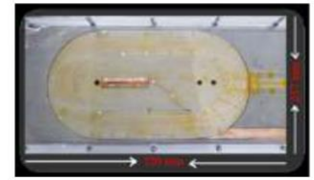
100-m 7-core IBS tape fabricated
J_e= 100 A/mm^2
@ 10 T, 4.2 K

2016



2018

- IBS solenoid at 24 T
Racetrack at 8 T
J_e= 300 A/mm^2
@ 10 T, 4.2 K

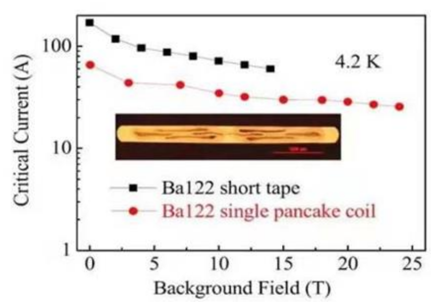


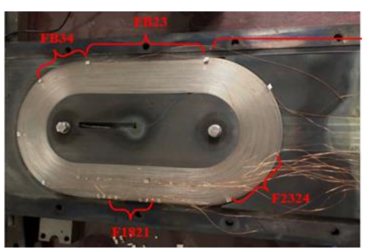
2020

IBS solenoid at 32 T
Racetrack at 10 T
1.3 kA transposed cable
J_e > 450 A/mm^2
@ 10 T, 4.2 K

2022

- A collaboration formed in 2016 by IHEP, IOP, IOEE, SJTU, etc., and supported by CAS
- World first: 1000m IBS cable, IBS coil



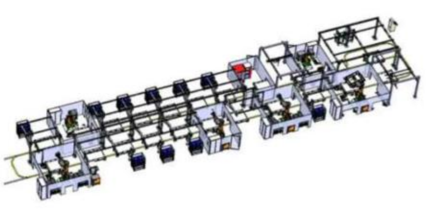


1st Iron-based Superconducting solenoid Coil at 24T

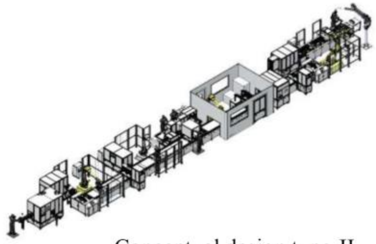
Getting Ready for Mass Production & Installation

Automatic magnet production lines

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



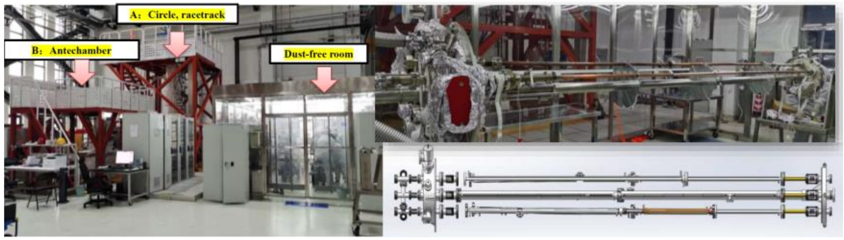
Conceptual design type-I (Booster magnet)



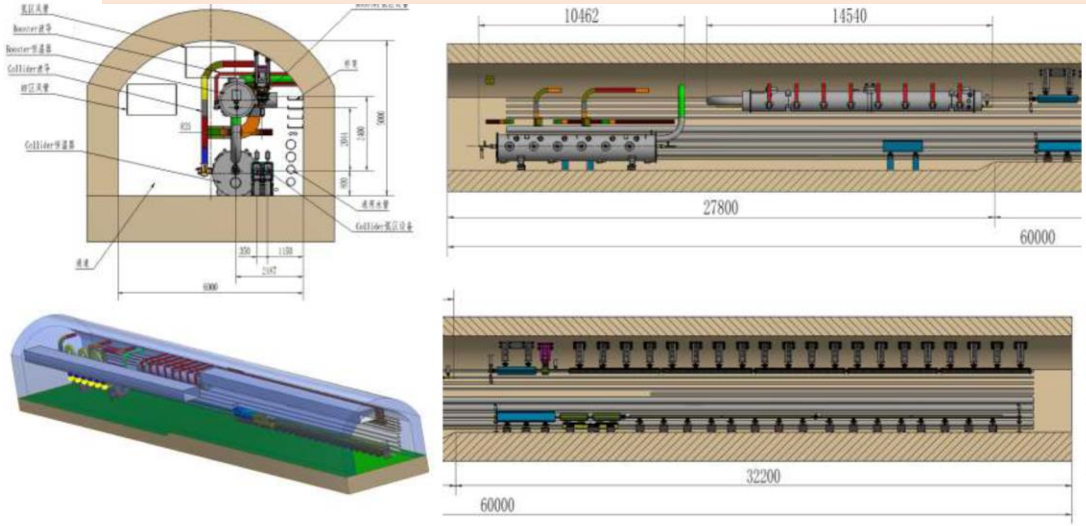
Conceptual design type-II (Collider ring magnet)

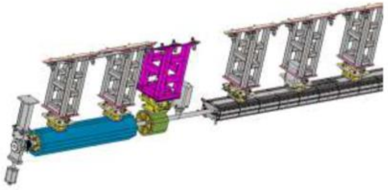
Production line for NEG Coating (vacuum chambers)

- 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**

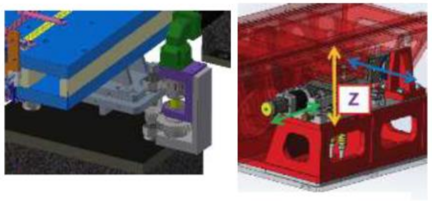


Mockup CEPC Tunnel for Optimizing Installation, Alignment, …





Booster magnets installation



Collider ring magnets supports

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

Industrial Partners and Suppliers

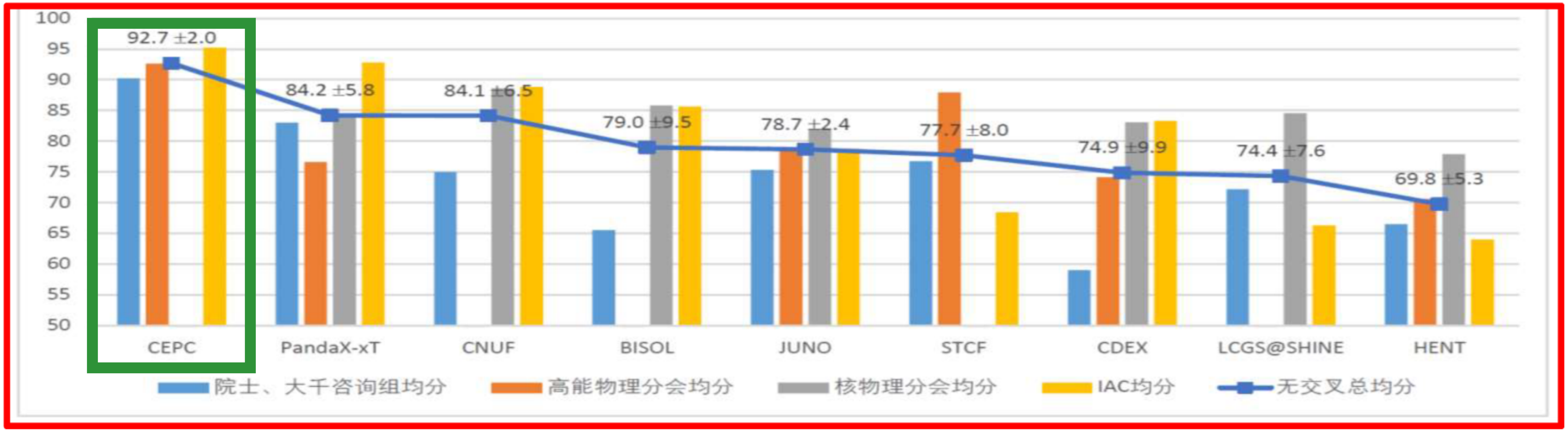
	System
1	Magnet
2	Power supplier
3	Vacuum
4	Mechanics
5	RF Power
6	SRF/ RF
7	Cryogenics
8	Instrumentation
9	Control
10	Survey and alignment
11	Radiation protection
12	e-e+Sources

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

Potential international collaborating suppliers and partners worldwide

Project Planning and 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 and nuclear physics**, is one of the 8 groups (fields).
- **CEPC is ranked No. 1, with the smallest uncertainties, by every evaluation committee both domestic and international one** among all the collected proposals.
- **A final report has been submitted to CAS for consideration.**
- **The above mentioned actual process is within CAS and the following national selection process will be decisive.**



Planning & Schedule

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

CEPC EDR Phase General Goal: 2024-2027

After completion CEPC accelerator TDR in 2023, CEPC accelerator will enter into the Engineering Design Report (EDR) phase (2024-2027), which is also the preparation phase with the aim for CEPC proposal to be presented to and selected by Chinese government around 2025 for the construction start during the "15th five year plan (2026-2030)" (for example, around 2027) and completion around 2035 (the end of the 16th five year plan).

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

Summary

- CEPC addresses many most pressing & critical science problems in particle physics.
- The CEPC design and technologies are reaching maturity with the accelerator TDR as a (H, Z, W, top) factory.
- CEPC is working on a reference design of the detector TDR.
- Both the accelerator and the detector have entered a EDR phase to complete the remaining R&D, the site-construction plan and the engineering design.
- CEPC schedule follows China's 5-year planning; expects to complete the R&D and the preparation to build the facility and carry out the science program.
- CEPC will offer the worldwide HEP community an early Higgs factory.

Backup Slides

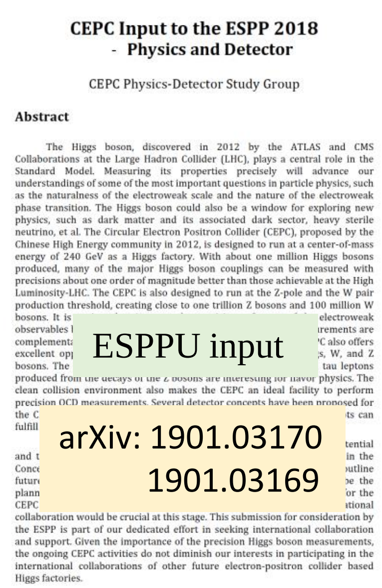
International Collaboration

- Great international participation to CDR, similar for TDR
- Many MoUs signed and executed
- Substantial collaboration on Physics studies and detector R&D, fewer on accelerator
- Substantial International advice through many committees and conferences, particular to accelerator
- Joined CALICE, ILD TPC, and RD collab.s, in addition to LHC exp. and many others
- Actively involved in the European Strategy update and the Snowmass process
- Annual CEPC International Workshop in China and EU/US-edition since 2014
- Annual working month at HKIAS (since 2015), resumed in 2023


CEPC workshop in Chicago, 2019

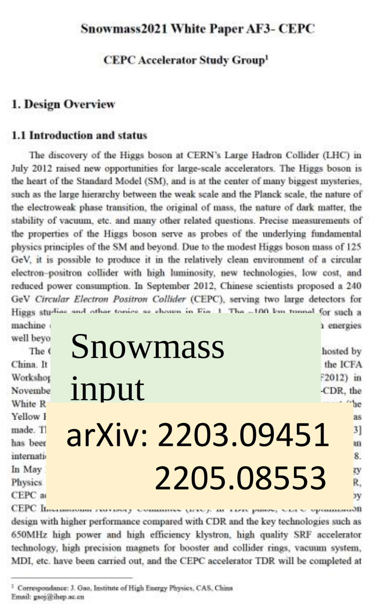
International Collaboration

International cooperation



ESPPU input

arXiv: 1901.03170
1901.03169



Snowmass input

arXiv: 2203.09451
2205.08553

ICHEP 2022

ICHEP 2022

EPPSU 2019

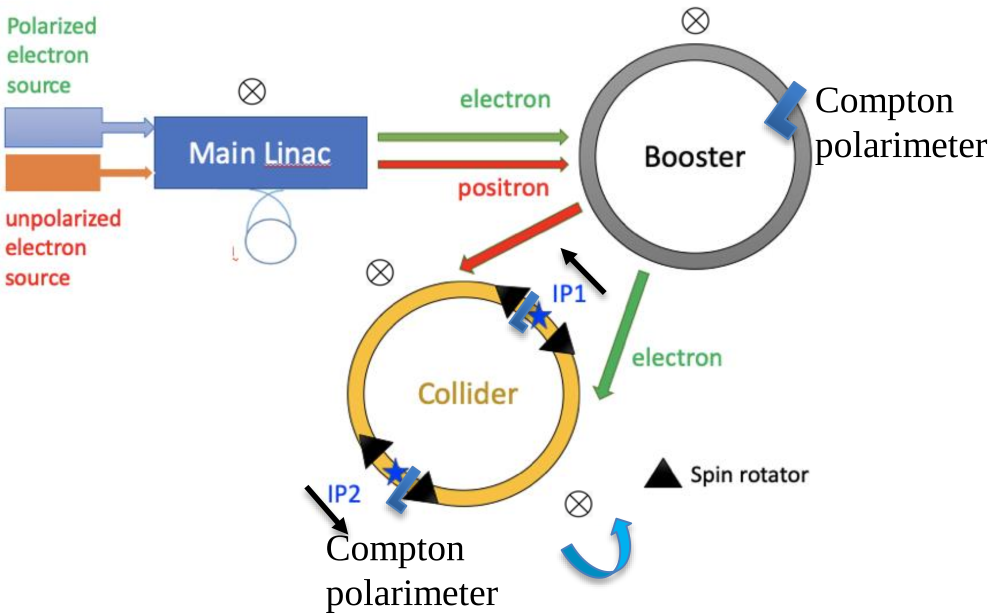
ICHEP 2018

- CEPC provides critical input to ESPPU & Snowmass as a **major player**
- Team member actively participated International study(ESPPU and Snowmass committees) and Panel discussions

"**Circular Electron Positron Collider - status & possible synergies on circular collider developments**"
Xinchou LOU, FCC Week, May 30, 2022, Paris, France.

"**Circular Electron Positron Collider** "
Xinchou LOU, Snowmass Community Meeting, July 24, 2022, Seattle, USA.

Polarization



Longitudinal polarization

Polarized e- source
- Polarization >85%
- Ref: ILC, EIC

Linac & transport lines
- Polarization loss < 10%
- Ref: SLC, ILC

Booster
- Polarization loss < 5% for Z/W based on simulation

Collider
- P_{inj} > 70% in most cases

Future

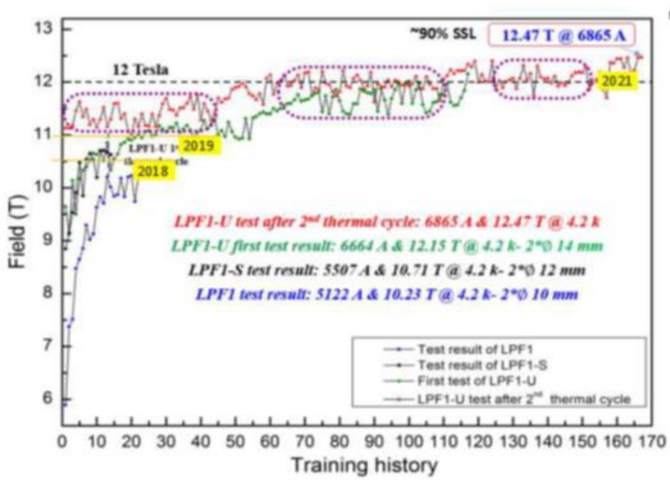
- Implement the spin rotator into CEPC lattice, including errors
- Extend the spin rotator to cover HE
- Simulate the RD process and the analysis of the errors in beam energy calibration.
- Carry out RD experiments at BEPCII & HEPS booster

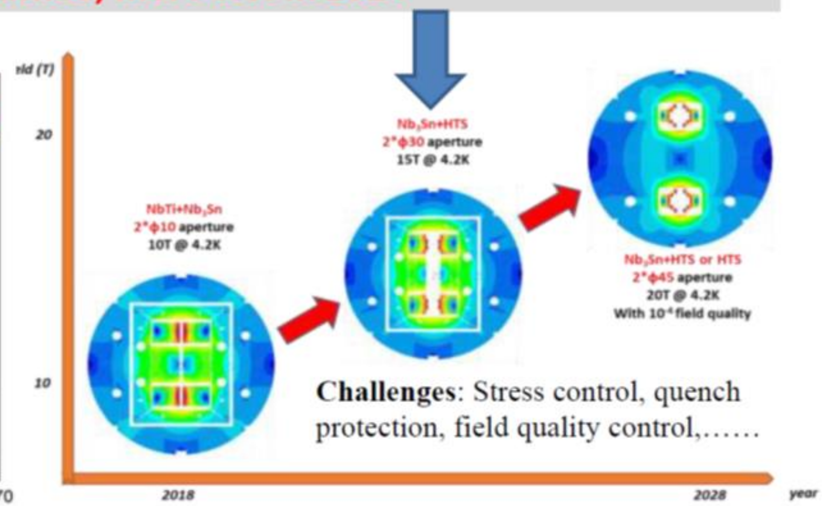
Advanced Studies for ‘State of Art” SppC

SppC HF Magnet Development

SppC 16 T Model Dipole: Nb_3Sn 12~13 T + HTS 3~4 T;
14T has been reached, more test in 2024

Picture of LPF1-U





Challenges: Stress control, quench protection, field quality control,……

Dual aperture superconducting dipoles achieve 12T@4.2 K and 14T@4.2K entirely fabricated in China. The next step is reaching 16-20T