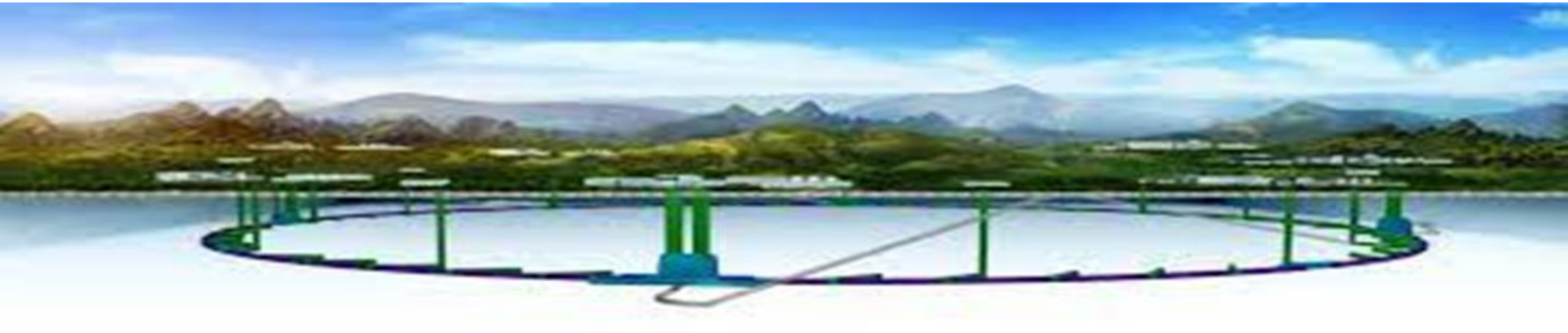
IHEP Review, September 20, 2023

CEPC
The Circular Electron Positron Collider

XinChou LOU

IHEP, Beijing



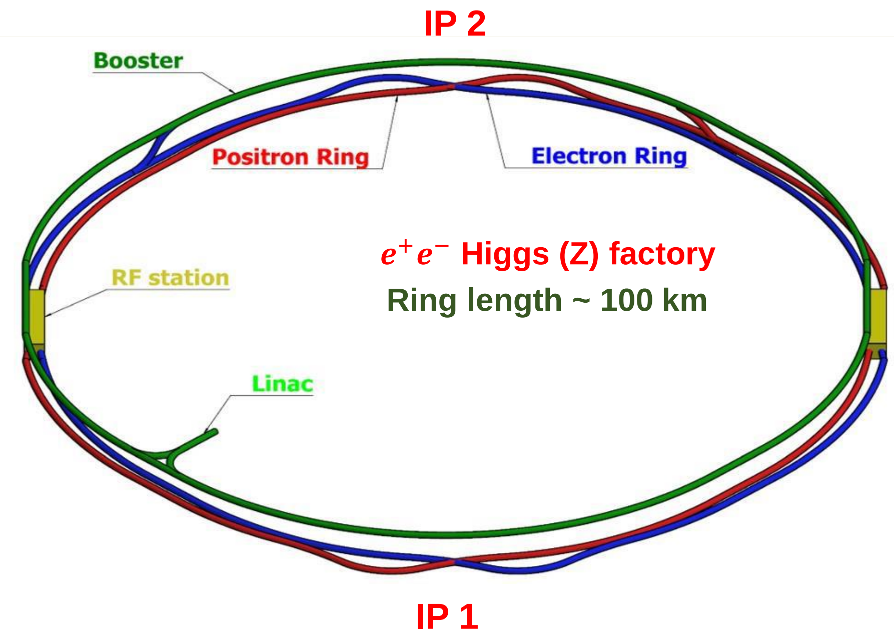
Outline

- Introduction and reminder
- CEPC status and progress
- Project development and schedule
- Summary
- Discussion, Q&A

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.

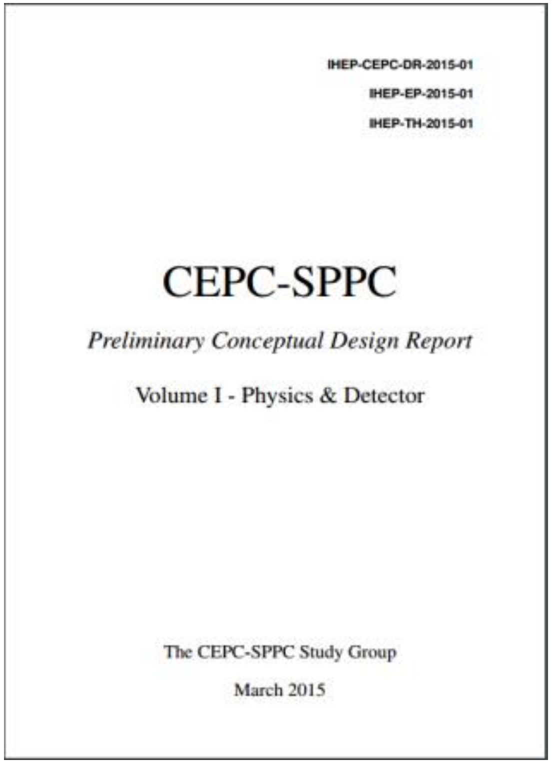
- **Looking for Hints@e^+e^- Collider ➔ If yes, direct search at pp collider**
- **The tunnel can be re-used for pp, AA, ep colliders up to ~ 100 TeV**



- 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 no show stoppers, then decide to proceed


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

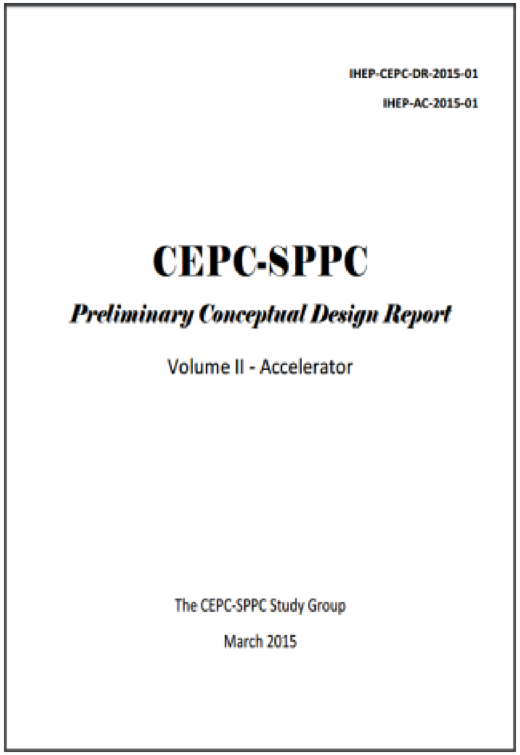
CEPC-SPPC

Preliminary Conceptual Design Report

Volume I - Physics & Detector

The CEPC-SPPC Study Group

March 2015


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

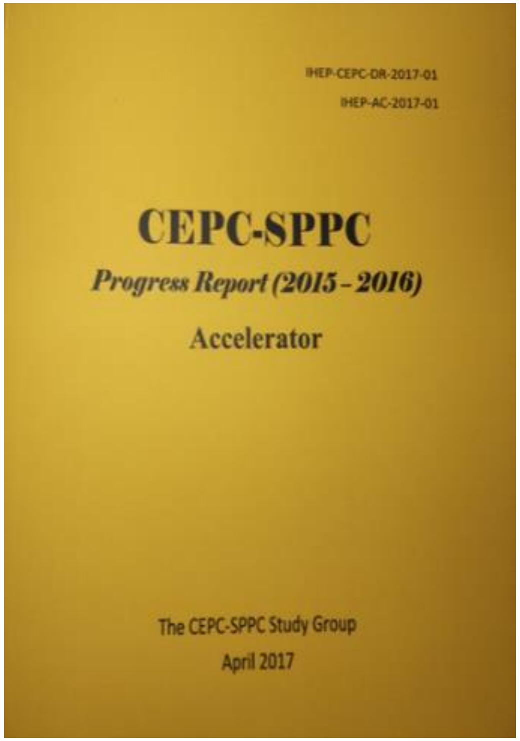
CEPC-SPPC

Preliminary Conceptual Design Report

Volume II - Accelerator

The CEPC-SPPC Study Group

March 2015


IHEP-CEPC-DR-2017-01
IHEP-AC-2017-01

CEPC-SPPC

Progress Report (2015 – 2016)

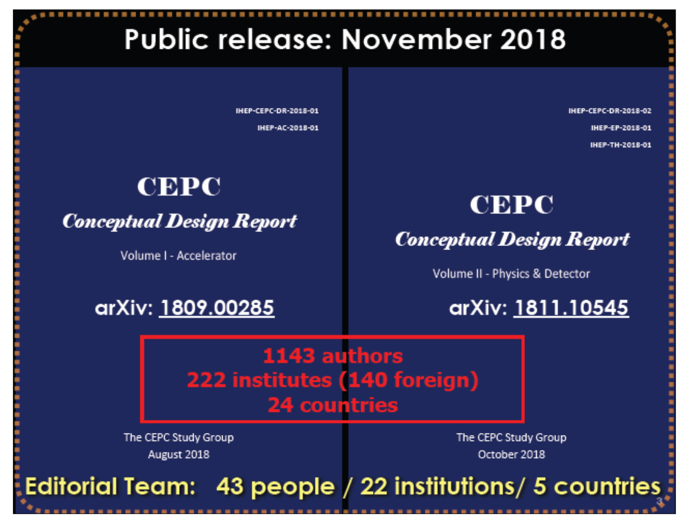
Accelerator

The CEPC-SPPC Study Group

April 2017

Introduction

CEPC team took steps to advance



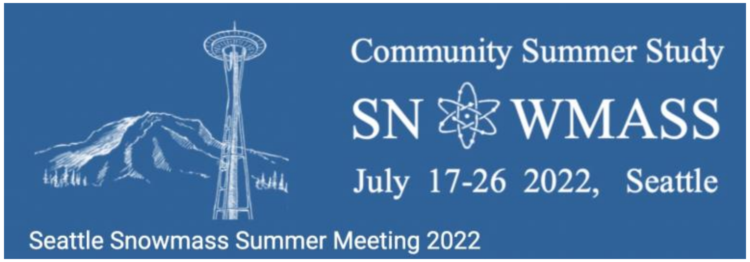
Introduction

Global consensus on Scientific objectives, significance & value

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

2020 European Strategy Update

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:



Conclusion from Executive Summary

Given the **strong motivation** and existence of proven technology to build an e^+e^- **Higgs Factory in the next decade**, the **US should participate** in the construction of **any facility that has firm commitment** to go forward.

Sridhara Dasu (Wisconsin)

ICFA

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. Recently, the United States also proposed a new linear collider concept based on the cool copper collider (C3) technology [31].*

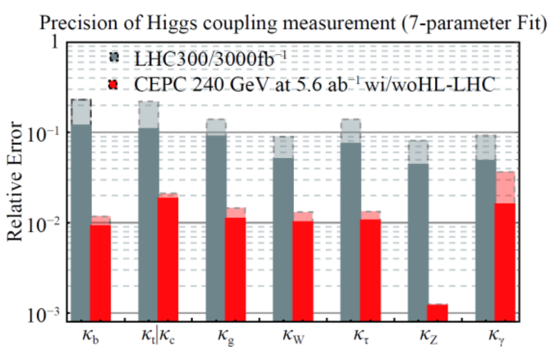
Introduction

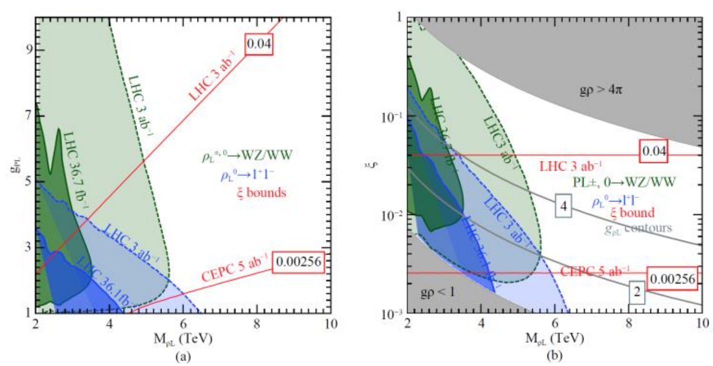
CEPC Scientific objectives： discovery, precision measurement

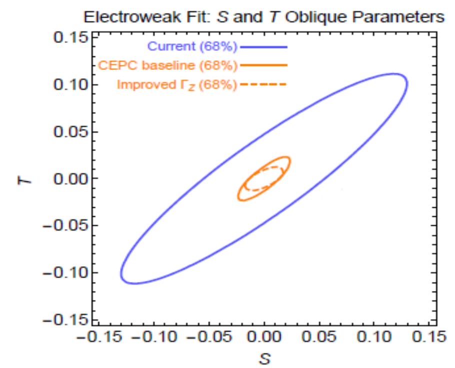
Higgs coupling measurement can be improved by orders magnititude

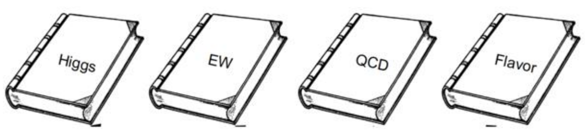
Direct and indirect proble to new physics up to 10 TeV, an order of magntitude higher then HL-LHC

Electroweak measurement can be improved by a large factor

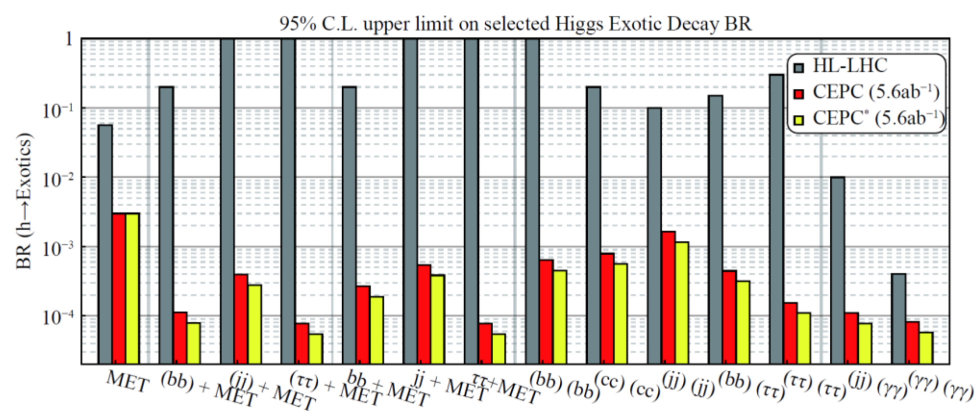








Physics white papers published and to be published



IHEP Review, September 20, 2023

CEPC Status & Progress

CEPC Concepts: physics goals, collider, detector and operation

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
Event yield (50 MW)	4.0×10^{12}	1.6×10^8	4.0×10

CEPC Operation Plan

~20 years of integrated physics program

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.

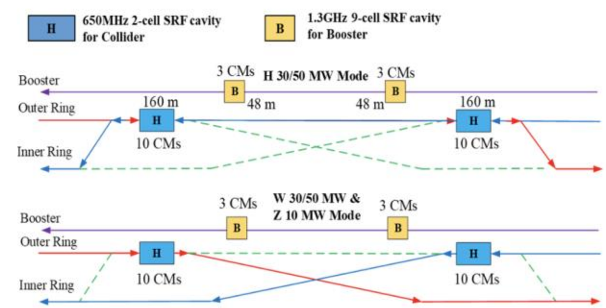
** Detector solenoid field is 2 Tesla during Z operation, 3Tesla for all other energies.

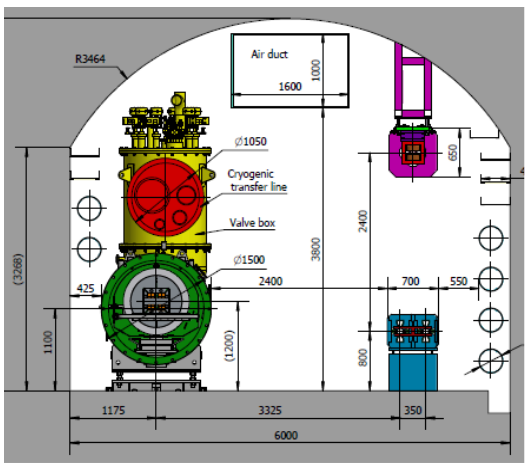
*** Calculated using 3,600 hours per year for data collection.

CEPC Layout and Design Essentials

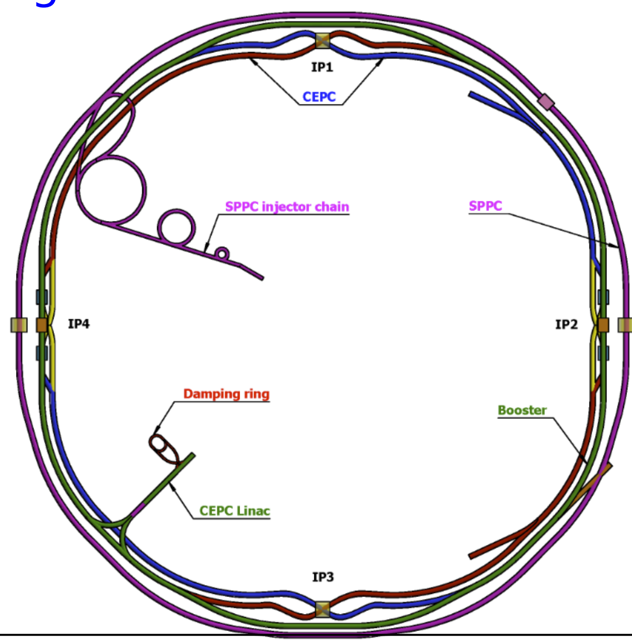
- **Circular collider**: **Higher luminosity than a linear collider**
- **100km circumference**: **Optimal total cost**
- **Shared tunnel**: **Compatible design for CEPC and SppC**
- **Switchable operation**: **Higgs, W/Z, top**
- Accelerator complex comprised of a Linac, a 100 km booster and a collider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

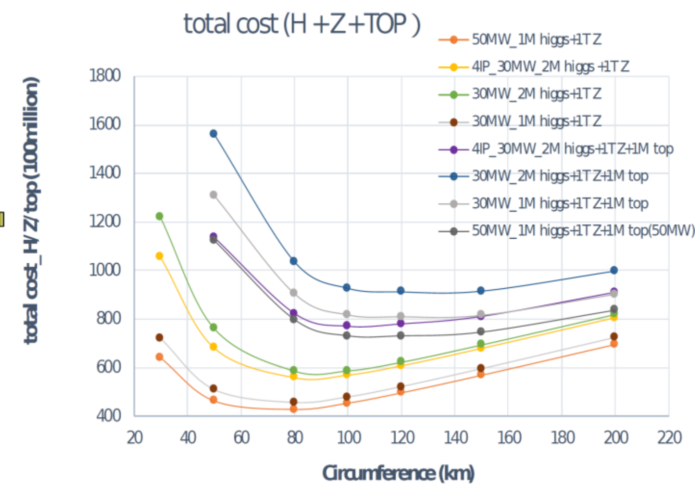
Switchable operation for Higgs W and Z





Common tunnel for booster/collider & SppC



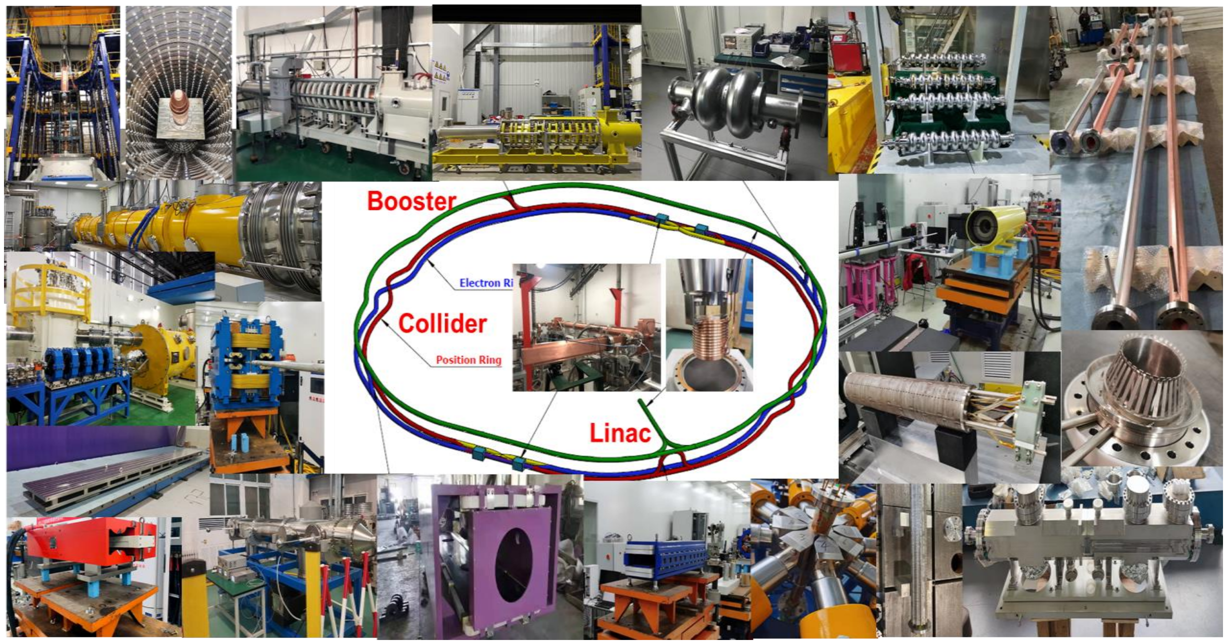


Baseline: 100 km, 30 MW; Upgradable to 50 MW, High Lumi Z, ttbar

CEPC Accelerator will be covered by Professor Jie GAO

Key Accelerator Technology Readiness

Represented Key Technologies for the CEPC



Key technology R&D spans all component list for CEPC

Will be ready for construction by 2026

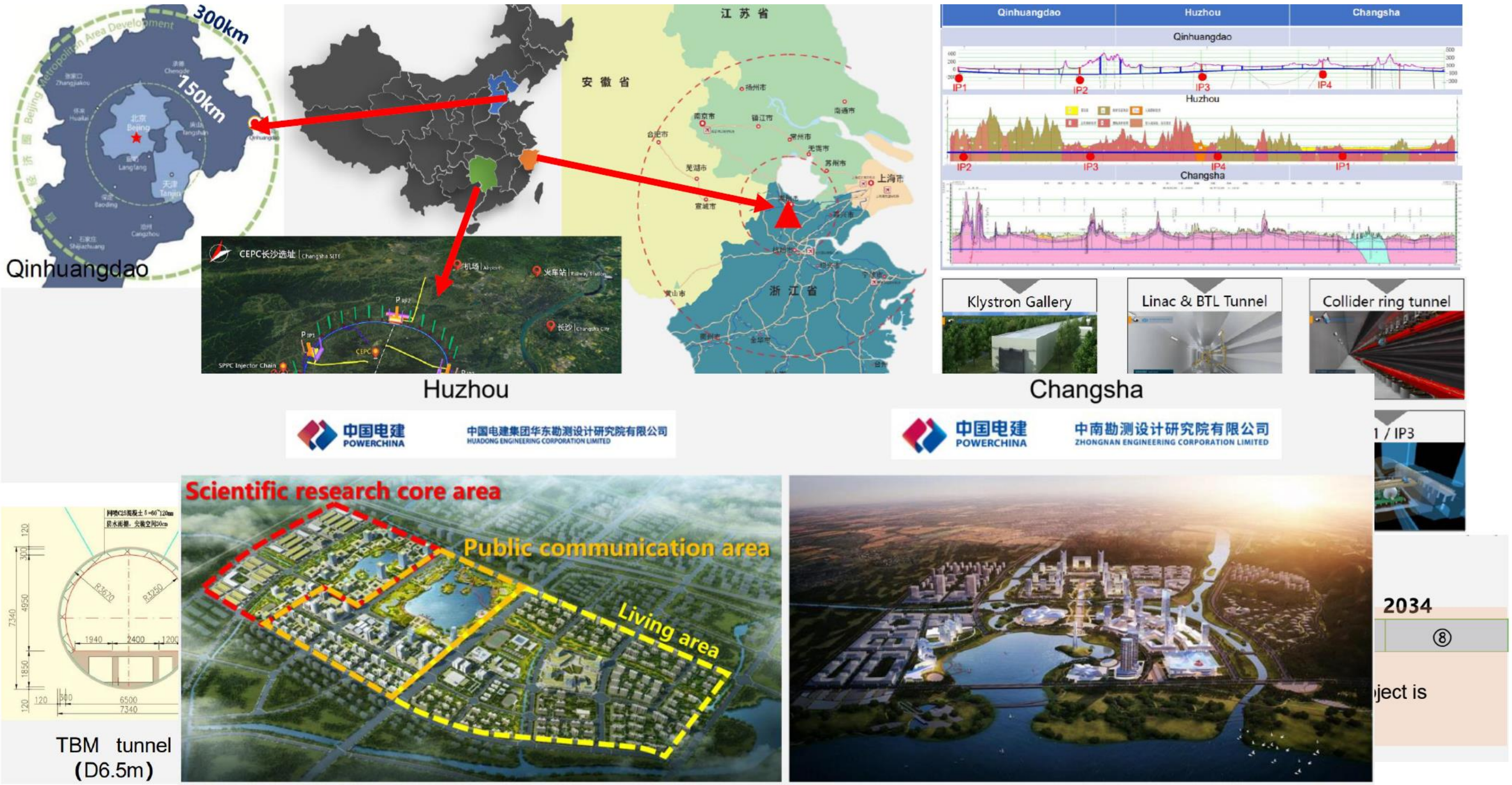
Specification Met

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 Status – site selection

Three suitable sites under study



CEPC Status & Progress

CEPC Accelerator Technical Design Report (TDR) (2023)

The CEPC Accelerator TDR covers

The design and the knowledge and progress gained by the CEPC

The advancement of the technologies the CEPC depends upon, delivered through the comprehensive R&D program, HEPS experience and international contributions and cooperation

New, innovative ideas and future upgrades to make the CEPC start-of-art as times moves forward

The costs

Two phases of reviews conducted

Phase-I: This review on the **technical aspects** of CEPC accelerator June 12-16, HKUST

Phase-II: Review on the **civil cost** aspects by a domestic committee June 26, 2023

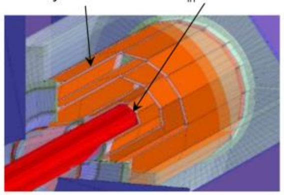
committee report was presented to an international panel July 17, 2023, online

Review on **cost of accelerator technical system** by an international committee September 11-15, 2023, HKUST

TDR to be endorsed by the CEPC IAC committee, published in November 2023

CEPC Detector R&D

Vertex detector



Goal: σ(IP) ~ 5 μm for high P track

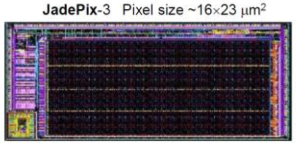
CDR design specifications

- **Single point resolution ~ 3μm**
- **Low material (0.15% X_0 / layer)**
- **Low power (< 50 mW/cm^2)**
- **Radiation hard (1 Mrad/year)**

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

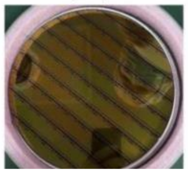
Develop **CEPCPix** for a CEPC tracke
basing on **ATLASPix3** CN/IT/UK/DE
TSI 180 nm HV-CMOS process

JadePix-3 Pixel size ~16×23 μm^2

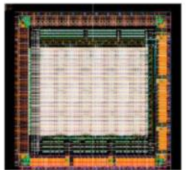


Tower-Jazz 180nm CiS process
Resolution 5 microns, 53mW/cm^2

TaichuPix-3, FS 2.5x1.5 cm^2
25×25 μm^2 pixel size

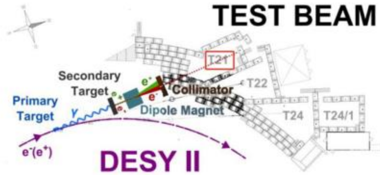


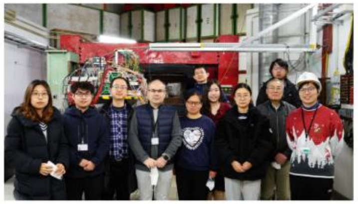
CPV4 (SOI-3D), 64×64 array
~21×17 μm^2 pixel size

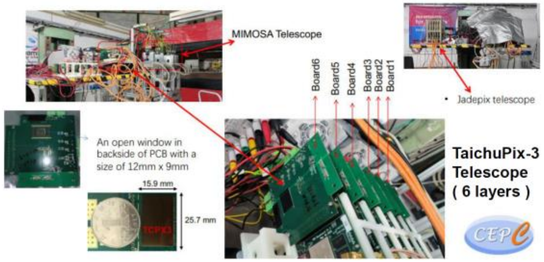


Arcadia by Italian groups
for IDEA vertex detector
LFoundry 110 nm CMOS

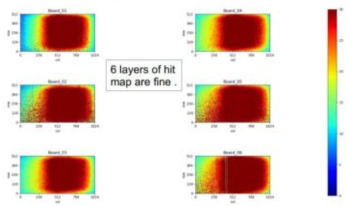
Full vertex detector prototype (TaichuPix-3, JadePix-3) has TB at DESY in Dec. 2022.





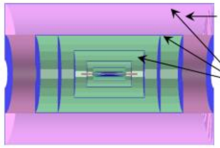


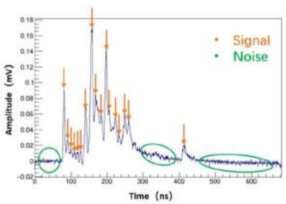
Hitmap of 4 GeV e+/e- beam

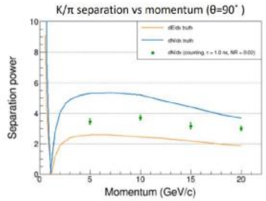


particle ID +main tracker

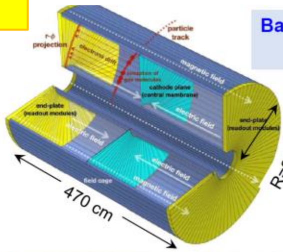
- **Goal: 3σ π/K separation up to ~20 GeV/c.**
- Cluster counting method, or **dN/dx**, measures the number of primary ionization
- **Can be optimized specifically for PID**: larger cell size, no stereo layers, different gas mixture.
- Garfield++ for simulation, realistic electronics, peak finding algorithm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



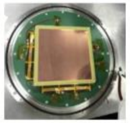




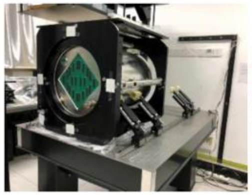
IHEP and Italian INFN groups have close collaboration and regular meetings.
IHEP joined the TB (led by INFN group) in 2021 and 2022



Baseline main tracker
σ(r-ϕ) ~100 μm

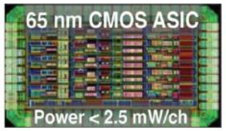


GEM-MM cathode



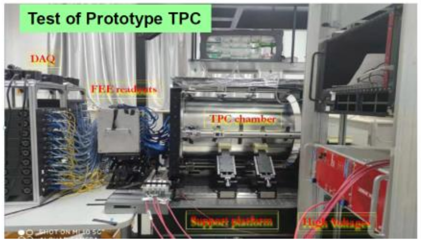
TPC Prototype + UV laser beams

MOST 1 (IHEP+THU)

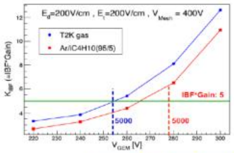


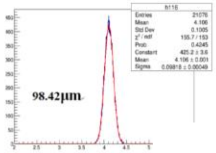
Low power FEE ASIC

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.**



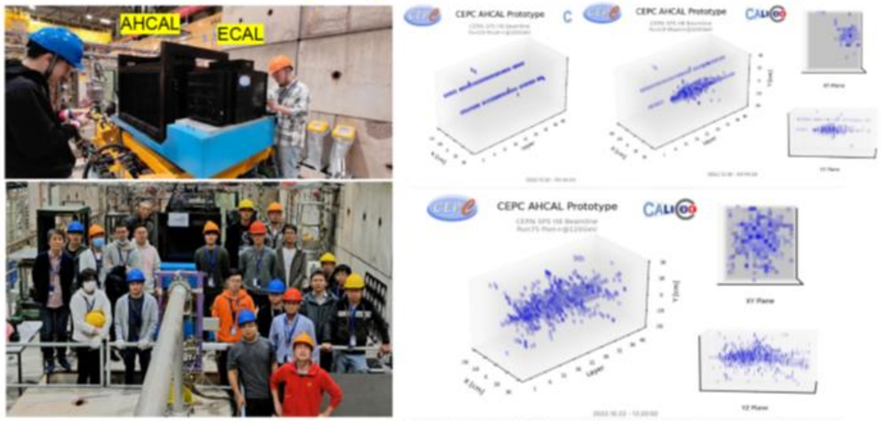


σ_x < 100 μm for drift length of 27cm

CEPC Detector R&D

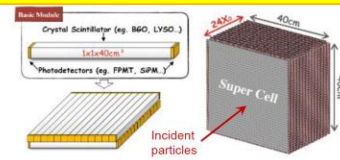
EM + hadron colarimeters： prototypes

➢ **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 32

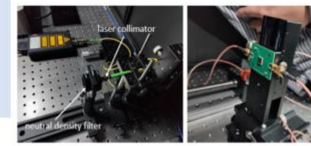
new crystal EM calorimeter for better resolution



Goal

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

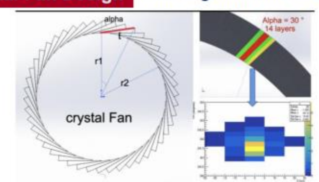
Bench Test



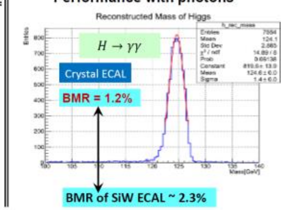
- Long bars: 1 x 40 cm, super-cell: 40x40 cm^2
- Timing at both ends for positioning along bar.
- Significant reduction of number of channels.

Full Simulation Studies + Optimizing PFA for crystals

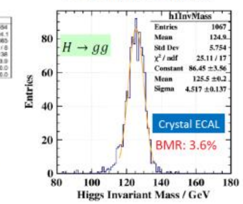
Crystal Fan Design Fine segmentation in Z, ϕ, r



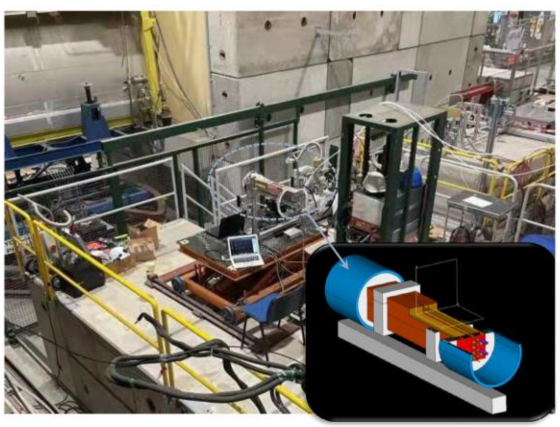
Performance with photons

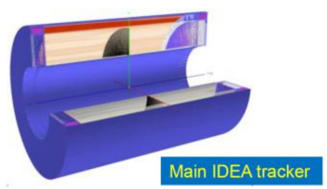


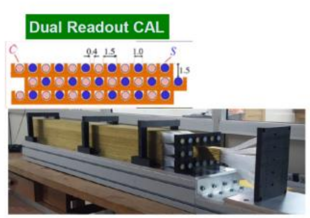
Performance with jets



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

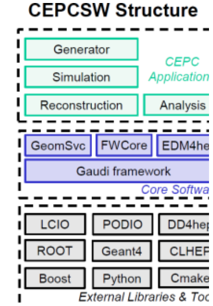
Architecture of CEPCSW

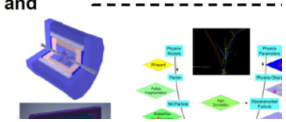
- External libraries
- Core software
- CEPC applications for simulation, reconstruction and analysis

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

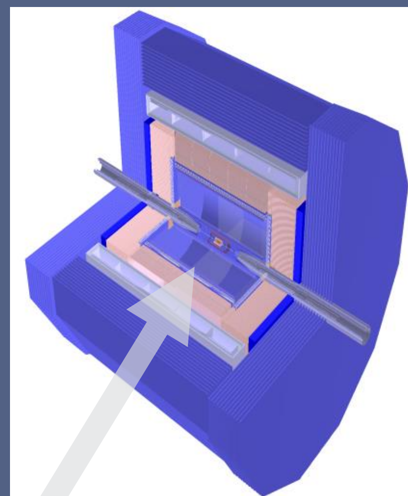




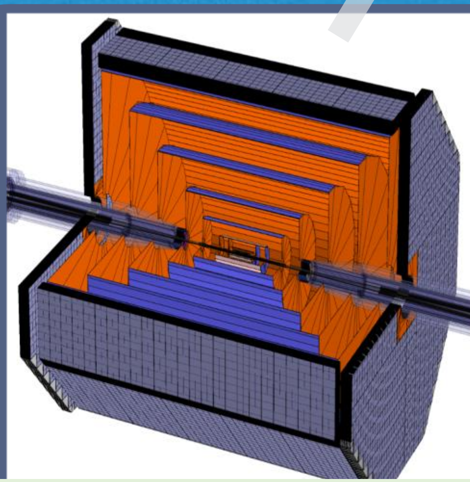
Detector System Concepts Studied

Particle Flow Approach

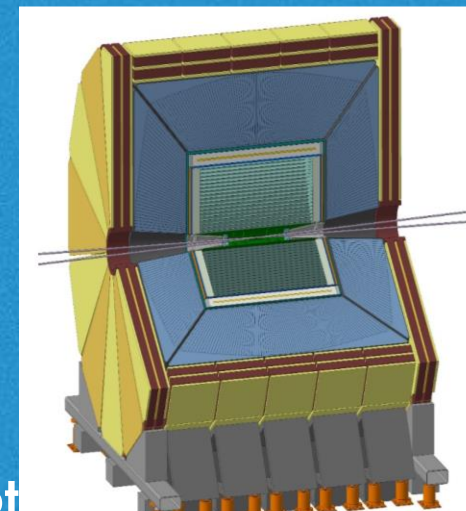
High magnetic field concept (3 Tesla)



Full silicon tracker concept

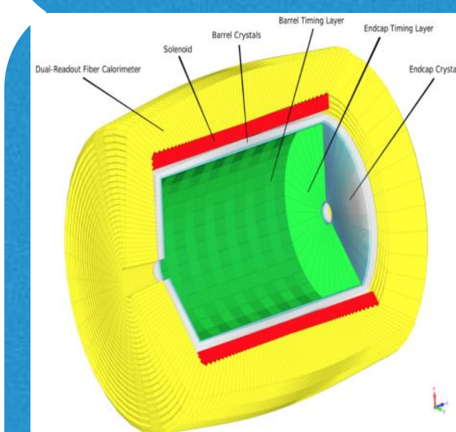


Low magnetic field concept (2 Tesla)



IDEA Concept

also proposed for FCC-ee



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

Final two detectors WILL be a mixture of different options

Funding for CEPC

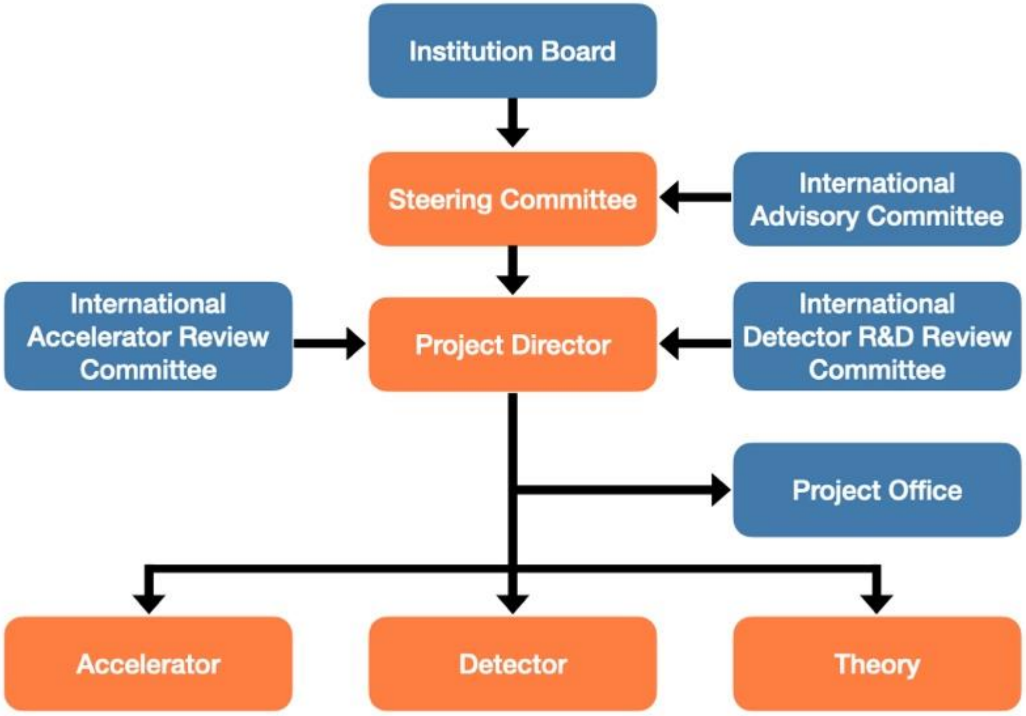
Tasks	Source of Funding	Funding(CNY)
CEPC designs, R&D, performance study conceptual design reports (CDR) accelerator tech. design report (TDR) R&D, prototypes, optimization cost evaluation-reduction, ……	Chinese Academy of Sciences Ministry of Sci. & Technology NSF of China IHEP Innovative Fund ……	~260 Million
Innovative ideas and R&D high efficiency klystron high Q SRF cavities precision weak field dipole dual aperture magnets PWFA Injector innovative PFA detector, detector system, wireless detector, ……		many items are covered by the above funding ~100 Million
R&D for SppC for the very long term HTS superconductors		~300 Million +follow up funding

- R&D expenditures are fully covered; tasks will be completed by 2026
- Funding requests will be made for future Engineering Design Report （EDR）

IHEP Review, September 20, 2023

Team and Organization

- Currently, the core team consists of ~ 400 people mainly from China; ~ 400 more from BEPC/JUNO/HEPS will come once CEPC is approved
- IHEP is currently the host lab with experience managing international collaborations such as BESIII/Daya Bay/JUNO, and projects such as BEPCII/CSNS/HEPS
- The temporary management structure is endorsed by the international advisory committee.
- Once approved, Funding agencies will be added at the top



International Collaboration

- Great international participation to CDR, expect 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 this year


CEPC workshop in Chicago, 2019

CEPC Status & Progress

training scientific/technical staff and recruiting talents

CEPC design and R&D work

- **brought up a large number of young staff members;**
- **trained many graduate students and postdocs. They are playing critical roles.**

IHEP has recruited scientists and experts; CEPC at universities also expanded

Prof. Jianchun WANG
Ph.D. （MIT）
Formerly research professor
Syracuse University, USA

Prof. Yuhui LI
Ph.D. （USTC）
Formerly permanent research staff
DESY, Germany

Prof. Jingbo YE
Ph.D. （ETH-USTC）
Formerly professor
SMU, USA

Prof. Hideki Okawa
Ph.D. (University of Tokyo)
Formerly professor
Fudan University
Shanghai, China

International Collaboration

International cooperation

CEPC Input to the ESPP 2018
- Physics and Detector

CEPC Physics-Detector Study Group

Abstract

ESPPU input

arXiv: 1901.03170
1901.03169

Snowmass2021 White Paper AF3- CEPC

CEPC Accelerator Study Group[1]

1. Design Overview

1.1 Introduction and status

Snowmass input

arXiv: 2203.09451
2205.08553

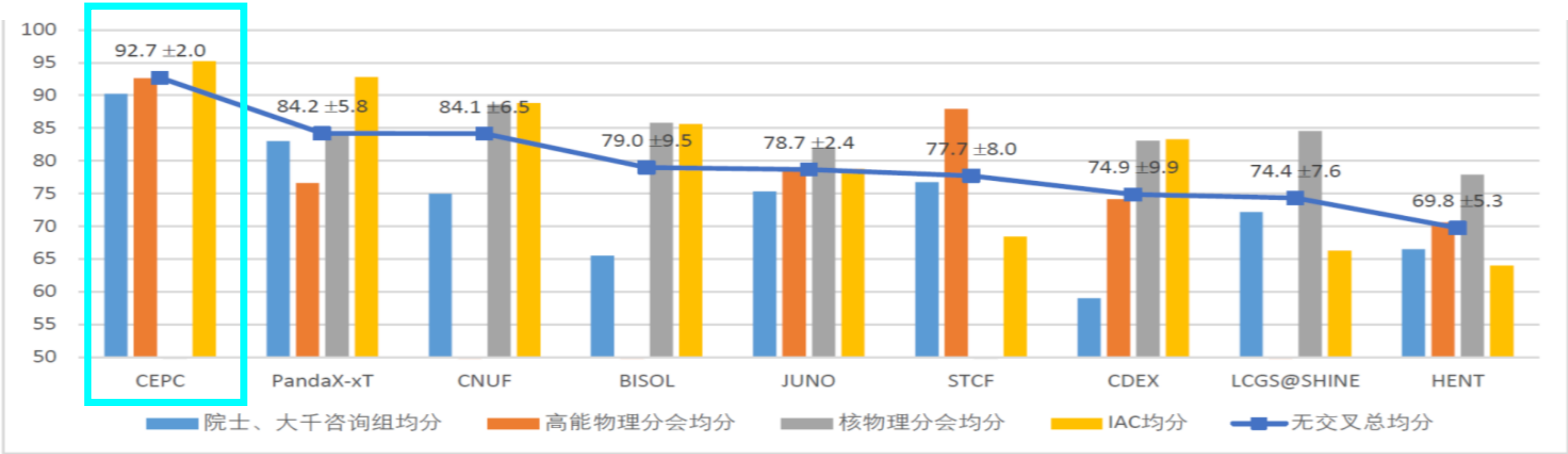
- CEPC provides critical input to ESPPU & Snowmass as a **major player**
- Team member actively participated International study(ESPPU and Snowmass committees) and Panel discussions

"**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.

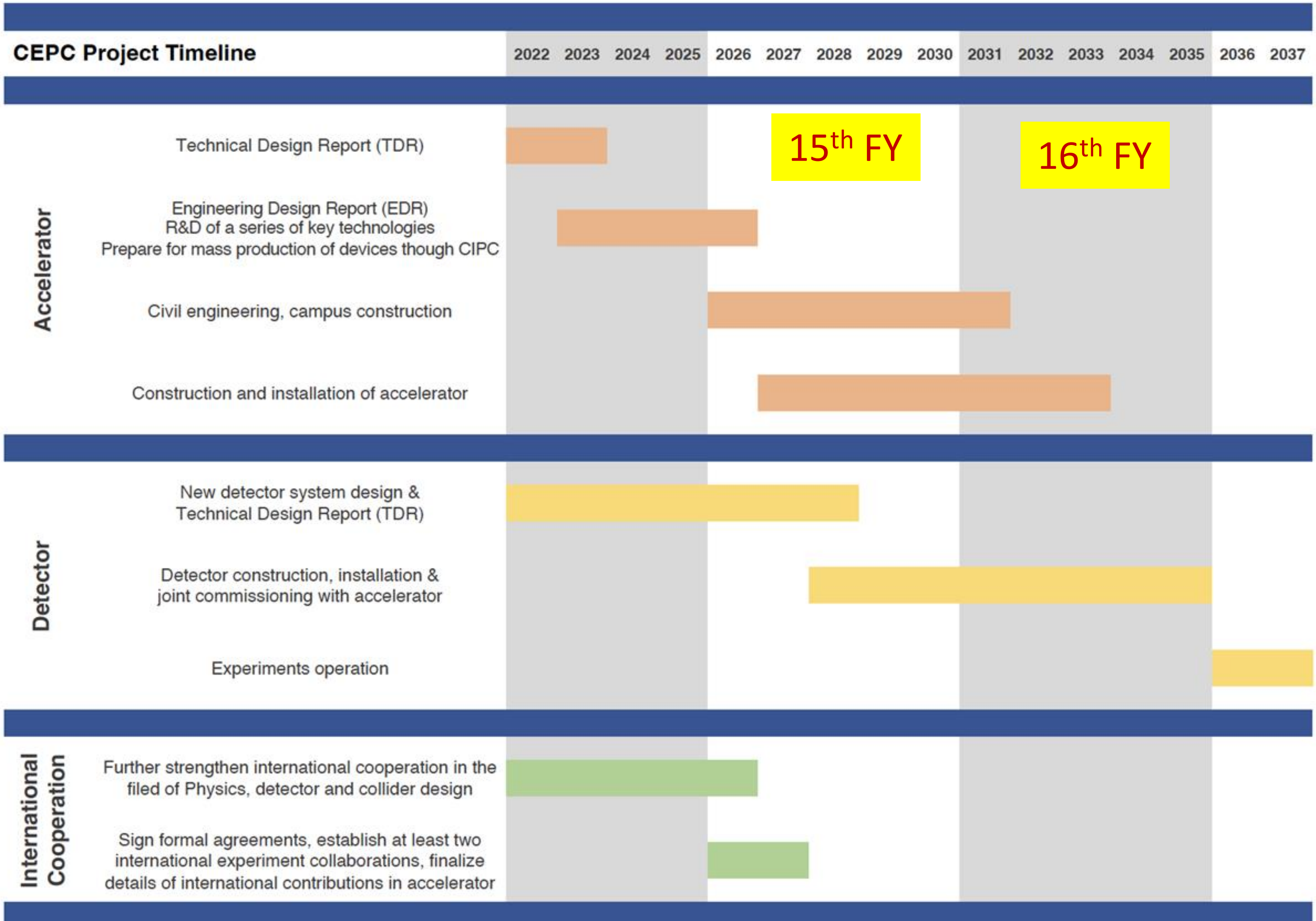
Project Development

- **TDR is being completed** (review + revision) to be released in 2023
- 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, has been working on this for a year:
  - 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 will be submitted to CAS for consideration



Planning & Schedule

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



Summary

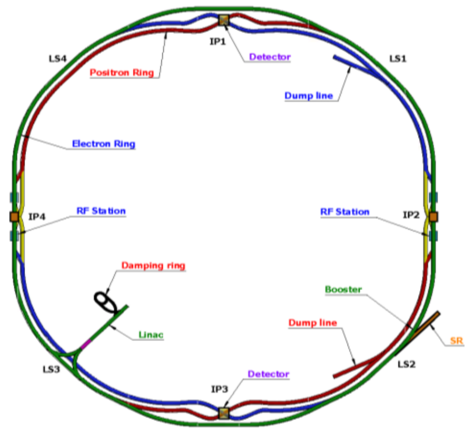
CEPC

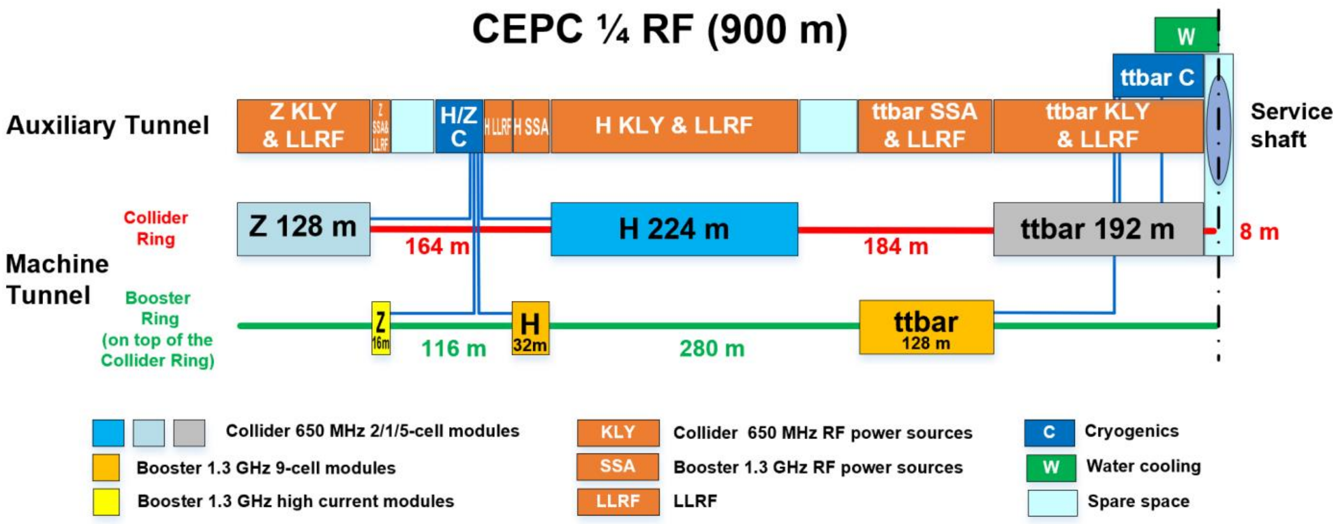
- addresses many most pressing & critical science problems in particle physics
- is part of the worldwide effort to build a leading edge, highly capable next generation accelerator system as a Higgs factory as well as for energy frontier collider
- has made strong and systematic progress; design and technologies are reaching maturity
- is completing the TDR for the e^+e^- accelerator as a boson–top factory (H, Z, W, top) and will enter the EDR phase
- aims at a schedule following China's 5-year planning; expects to complete the R&D and the preparation to build the facility and carry out the science program
- will offer worldwide HEP community an early Higgs factory

Discussion

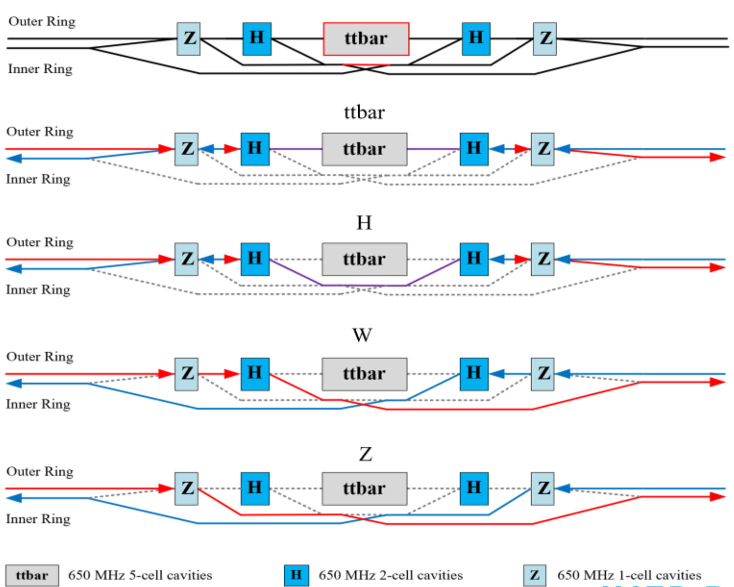
Q & A

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 Status

CEPC: aims at innovative design, key technologies R&D, & to be among leading future colliders.

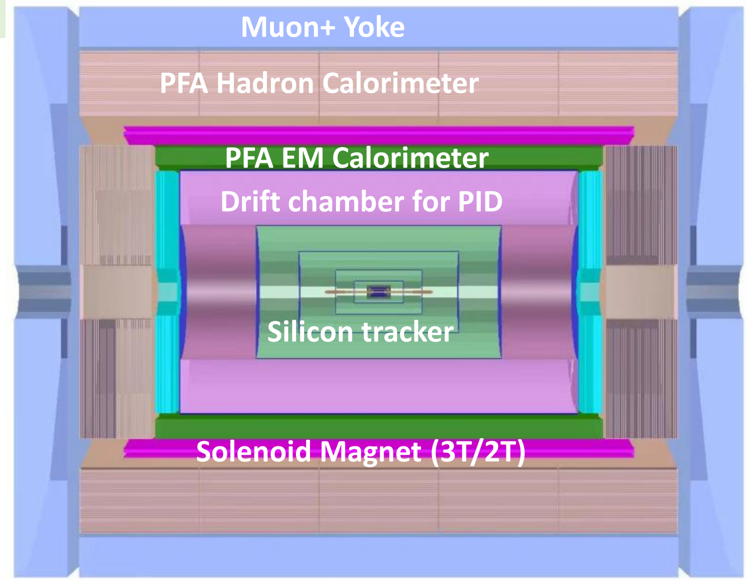
- Conceptual Innovation
- Upgradable Capability
- State-of-the-art Tech.
- Green & Cost Saving
- Revolutionary Principle
- Spillover

- 100km circular collider
- Partial/Full double ring
- Switchable energies H/W/Z
- One tunnel for booster/collider and SppC

- High efficiency Klystron
- SRF cavities
- Weak field dipole
- Dual aperture magnets
- PWFA Injector
- Iron based HTS Mag
- Innovative PFA Detector

CEPC Status

Detector

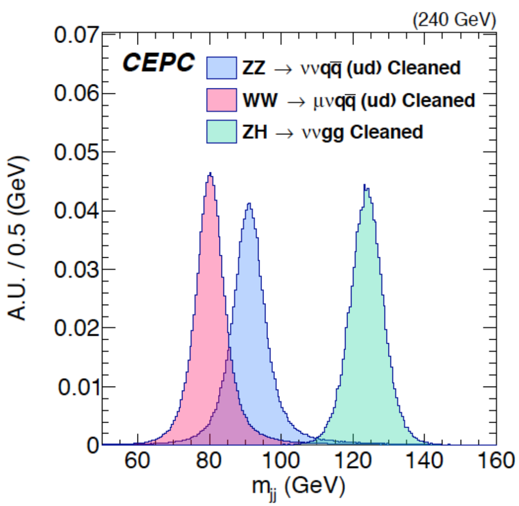


Requirements

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-class level	CEPC design
PFA based EM calorimeter	EM shower E resolution	~20%/√E	<3%/√E
PFA based Hadron calorimeter	Single hadron E resolution	~50%/√E	~40%/√E

CEPC Status

Core team, the host institution and the existing support

- IHEP is one of the few institution in the world that
  - has rich management experience and successful constructed many large scientific facilities
  - has a full coverage of all technical disciplines for accelerators and detectors, **in particular for the design and construction and continuous operation of a circular e+e- collider (BEPCII) and the detector(BESIII)**
  - has all needed infrastructure for the construction of large facilities
  - has successfully hosted international projects such as BESIII, Daya Bay, JUNO, LHAASO, etc.
- **CEPC is committed by IHEP and workplan endorsed by CAS**