中國科學院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

# CEPC-SppC General Status and Perspectives

## -Towards construction through EDR Phase


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On behalf of the CEPC-SppC team

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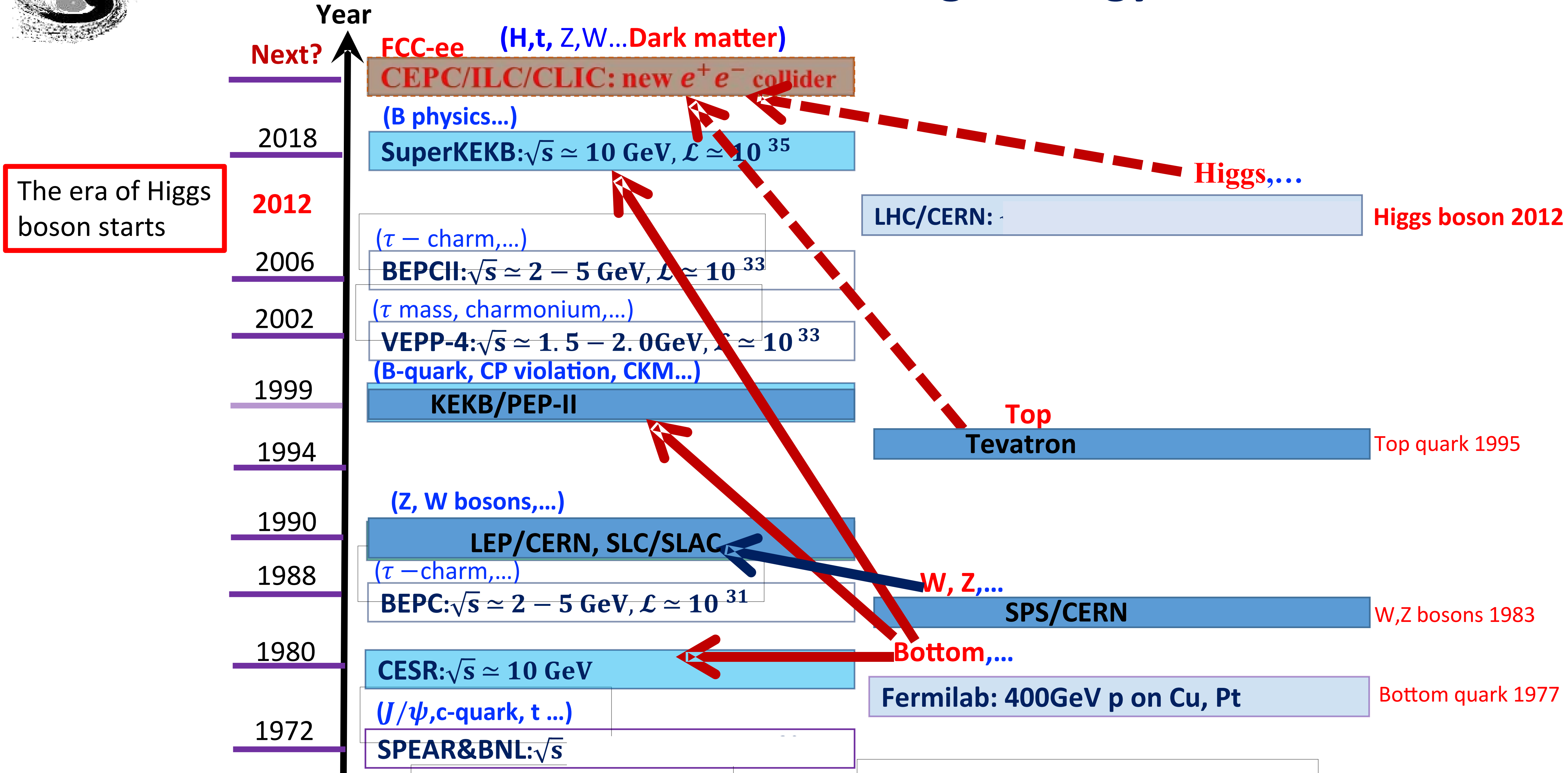
- CEPC Detector R&D status
- CEPC EDR goals, plans and development towards construction
- CEPC industrial preparation and international collaborations
- Summary

# A Brief Historical Recall: High Energy Colliders




($e^+e^-$ colliders) (zoom) (proton accelerators)

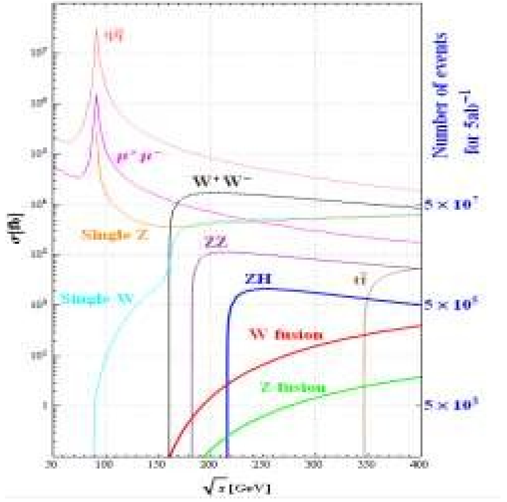
# Physics Goals of CEPC-SppC

- **Circular Electron-Positron Collider (CEPC) as a Higgs Factory (91, 160， 240, 360 GeV)**
  - **Higgs Factory** （>10^6 Higgs）：
    - Precision study of Higgs(mH, JPC, couplings)， **complementary** to Linear colliders
    - Looking for hints of new physics, Dark Matter…
  - Z & W factory （>10^10 Z0）：
    - precision test of SM
    - Rare decays ?
  - Flavor factory: b, c, t and QCD studies
- **Super proton-proton Collider(SppC) (~100 TeV)**
  - Directly search for new physics beyond SM
  - Precision test of SM
    - e.g., h3 & h4 couplings

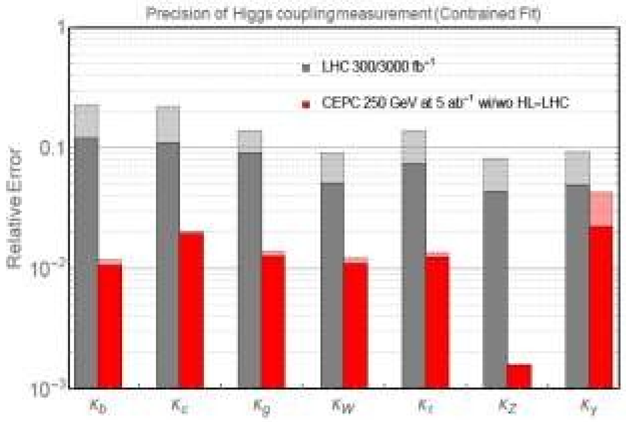
**Precision measurement + Searches for new physics: complementary with each other (lepton and hadron colliders)**

**CEPC-SppC was proposed by Chinese scientists in Sept. 2012 after Higgs Boson was discovered on July 4, 2012 at CERN**

Started from **2012**, Human being entered into the **era of Higgs**.
**A new calendar of Science-Anno Higg** is proposed by J. Gao, i.e. **2012AD=0AH**. Year **2024AD** is also**12AH**




Cross sections for major SM physics processes at the electron positron collider




Anticipated accuracy on Higgs properties at CEPC and at LHC/HL-LHC

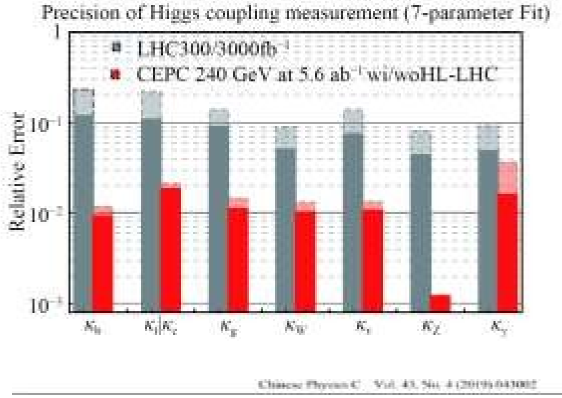
# Scientific Objectives: “Discovery + Precision Measurement”

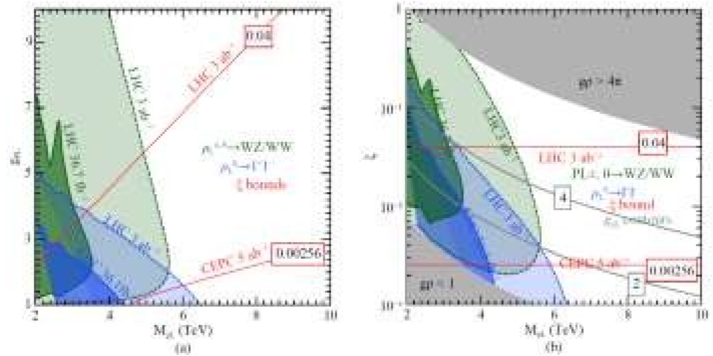


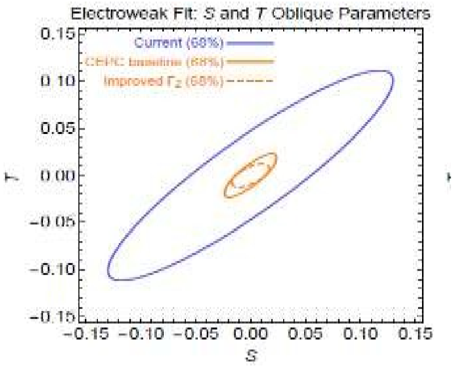
**Higgs coupling measurement can be improved by orders magnititude**

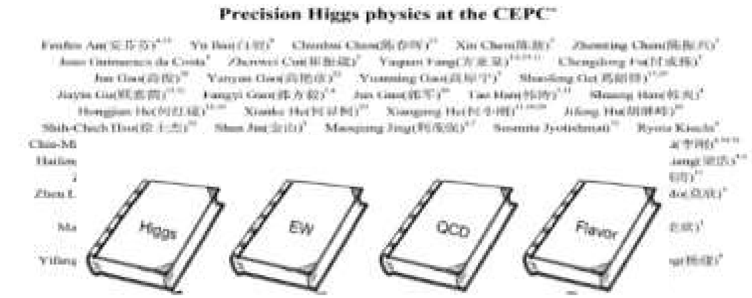
**Direct and indirect probe to new physics up to 10 TeV, an order of magntitude higher than HL-LHC**

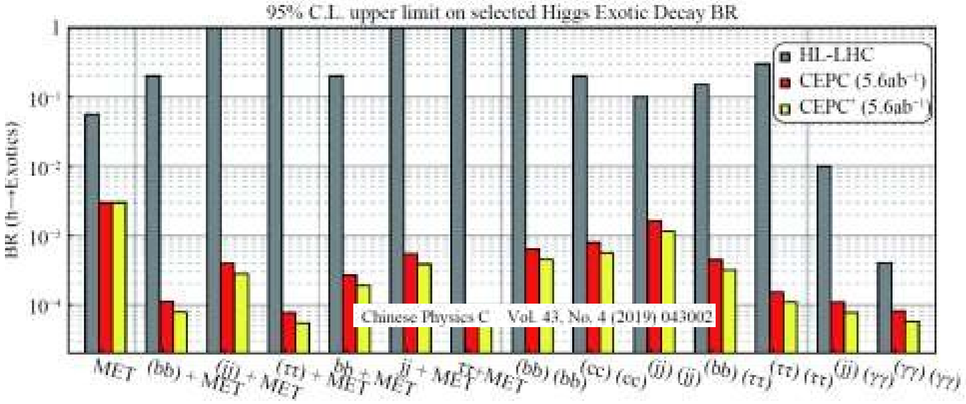
**Electroweak measurement can be improved by a large factor**




**Physics white papers published and to be published**

# Key Scientific Issues and Technological Route

### 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) | $2.5\times10^{12}$ | $1.0\times10^{8}$ | $2.5\times10^{6}$ |
| Event yield (50 MW) | $4.0\times10^{12}$ | $1.6\times10^{8}$ | $4.0\times10^{6}$ |

**Physics ⟹ Detector ⟹ MDI ⟹ Accelerator**

# CEPC Operation Plan and Goals in TDR

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

* 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.

# The Global HEP Consensus on Higgs Factories



The scientific importance and strategical value of an electron positron Higgs factory is clearly identified worldwide

**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**

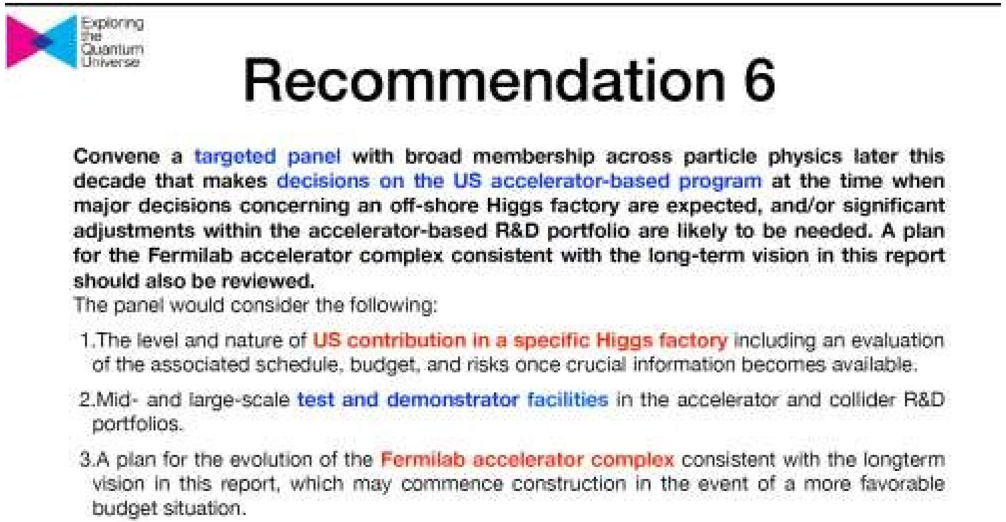
**2017**: Japan Association of High Energy Physicists (JAHEP) proposes to construct a 250 GeV center-of-mass ILC promptly as a Higgs factory.

**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:

**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

Exploring the Quantum Universe

## Recommendation 6

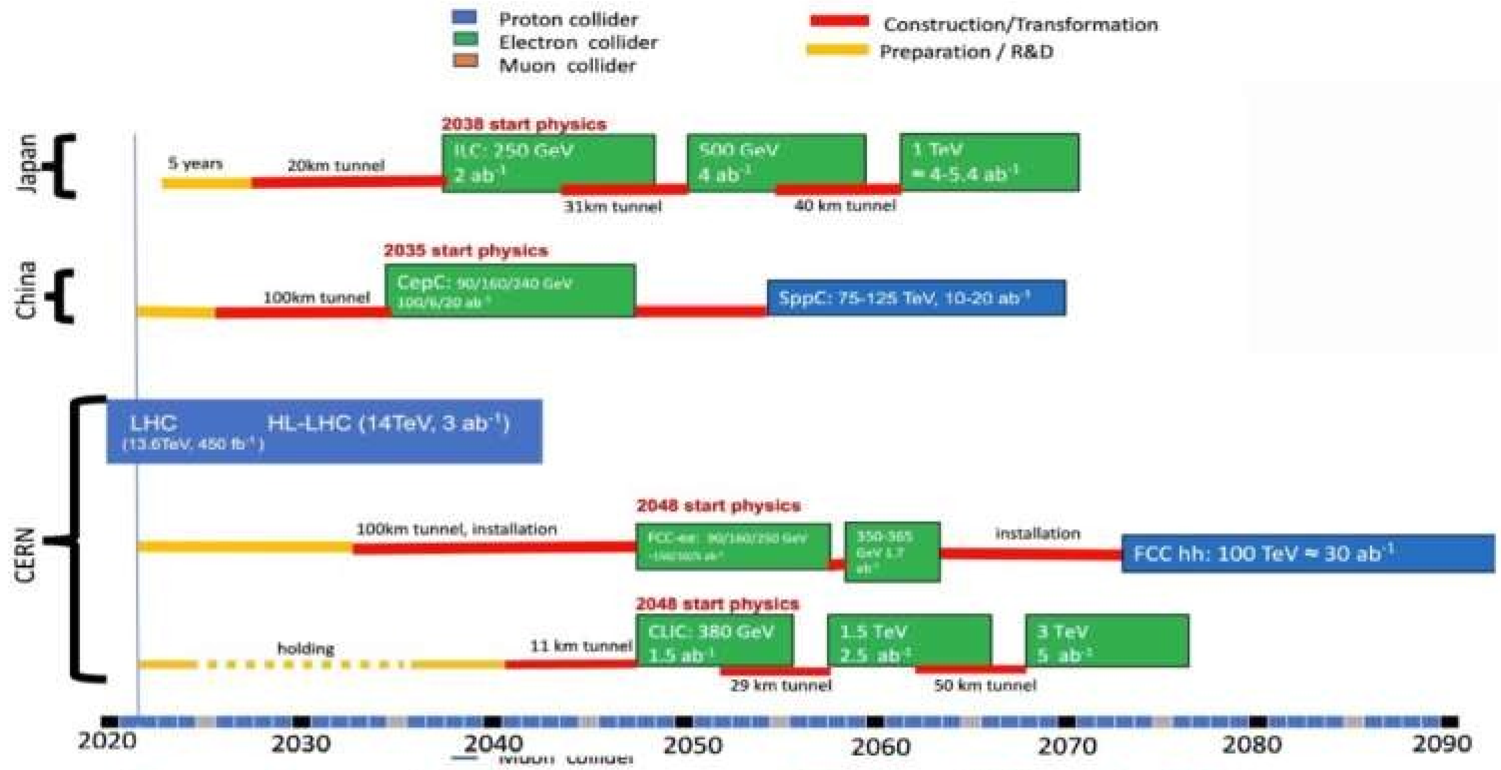
Convene a targeted panel with broad membership across particle physics later this decade that makes decisions on the US accelerator-based program at the time when major decisions concerning an off-shore Higgs factory are expected, and/or significant adjustments within the accelerator-based R&D portfolio 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:

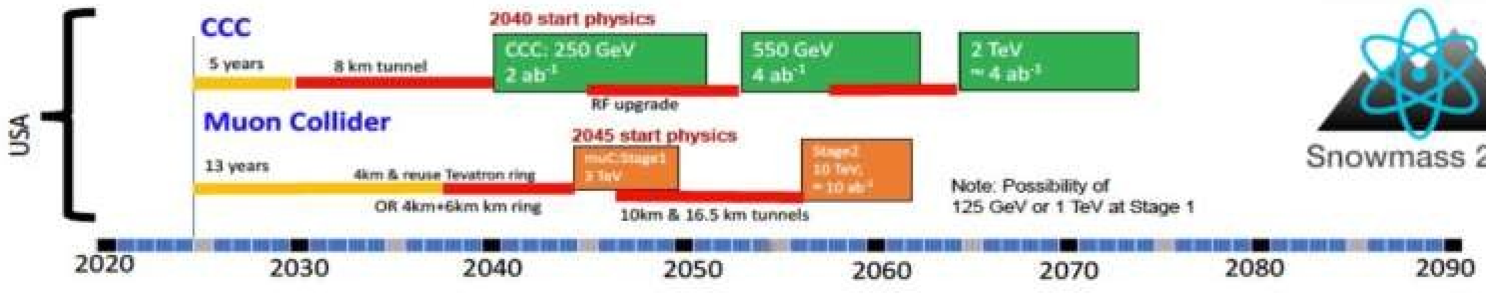
1. The level and nature of US contribution in a specific Higgs factory including an evaluation of the associated schedule, budget, and risks once crucial information becomes available.
2. Mid- and large-scale test and demonstrator facilities in the accelerator and collider R&D portfolios.
3. A plan for 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**

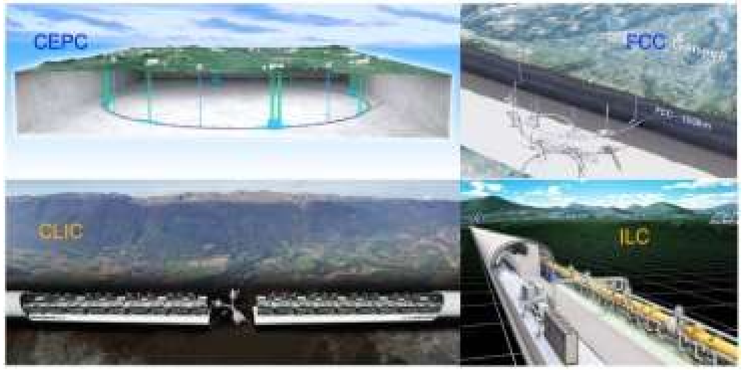
# Timelines in Snowmass Energy Frontier Summary



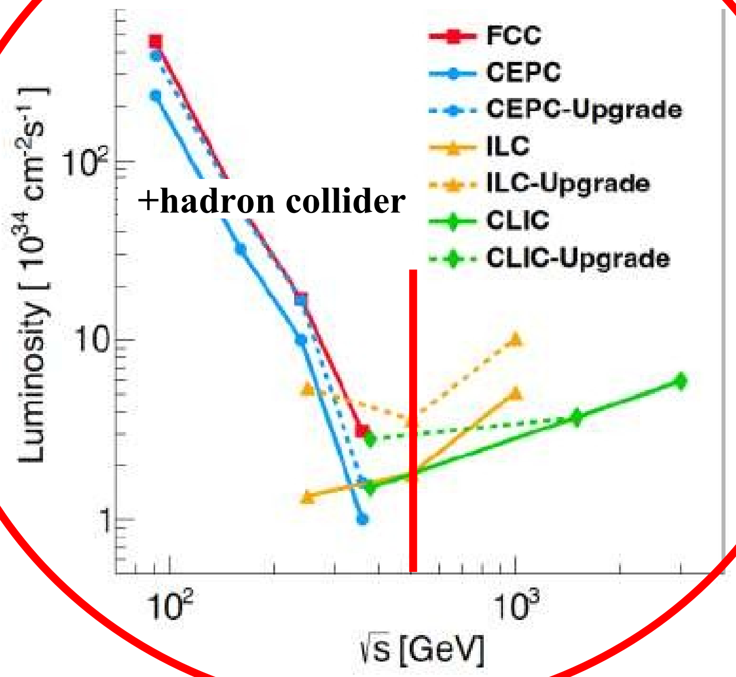

## Proposals emerging from Snowmass 2021 for a US based collider




Snowmass 2021

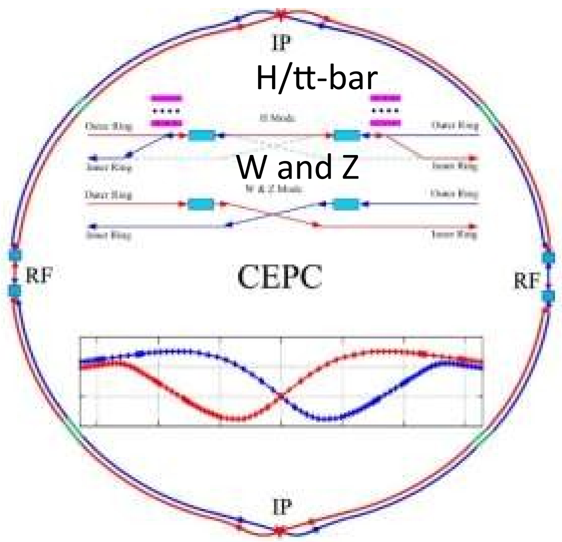



Complementarity between Circular and Linear colliders

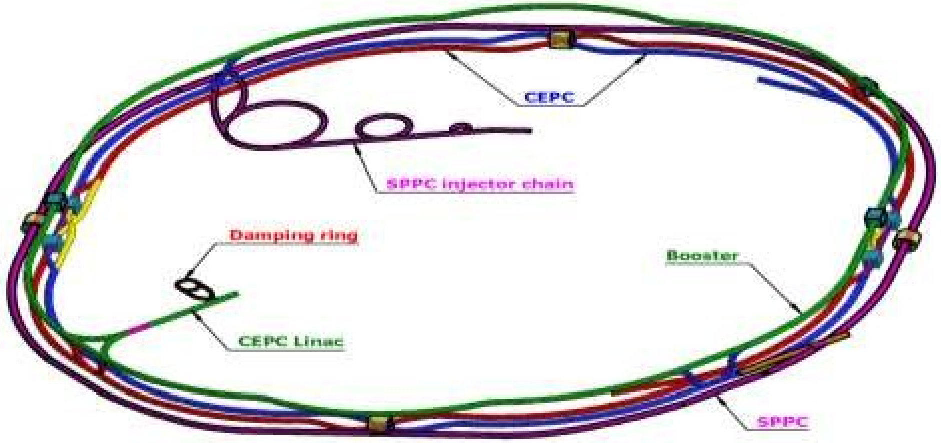


# CEPC Higgs Factory and SppC Layout in TDR

**CEPC as a Higgs Factory: H, W, Z, upgradable to ttbar, followed by a SppC (a Hadron collider) ~125TeV**
**30MW SR power per beam (upgradable to 50MW) , high energy gamma ray 100Kev~100MeV**

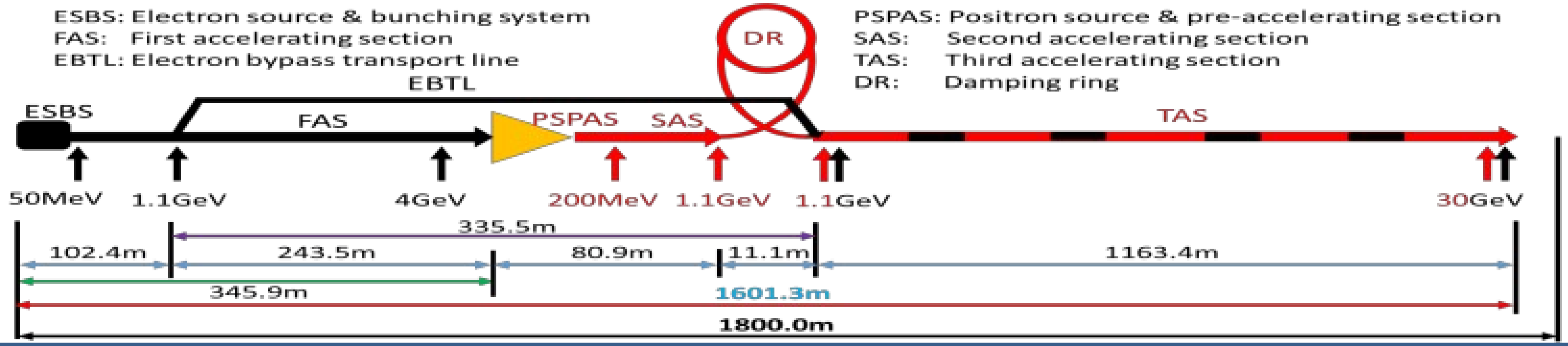


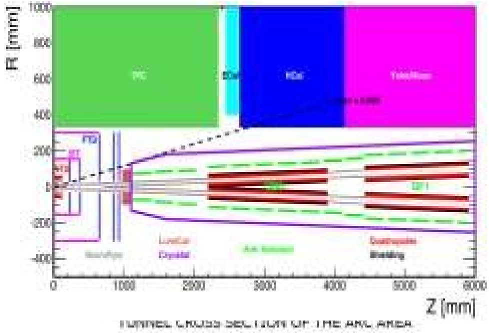

**CEPC collider ring (100km)**

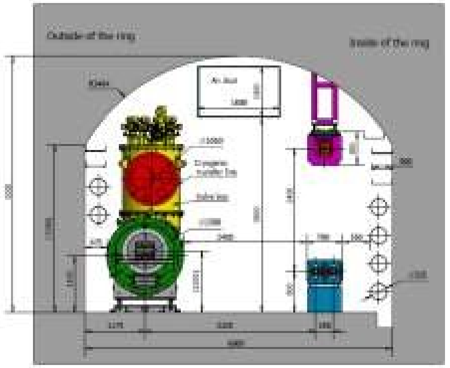



**CEPC booster ring (100km)**

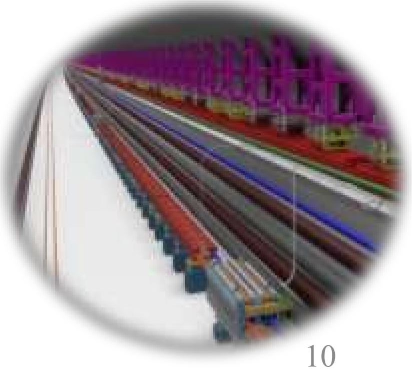
**CEPC TDR S+C-band 30GeV linac injector**



CEPC/SppC in the same tunnel



# CEPC Accelerator System Parameters in TDR

## Linac

| Parameter | Symbol | Unit | Baseline |
|---|---|---|---|
| Energy | $E_{e-}/E_{e+}$ | GeV | **30** |
| Repetition rate | $f_{rep}$ | Hz | 100 |
| Bunch number per pulse | | | 1 or 2 |
| Bunch charge | | nC | 1.5 (3) |
| Energy spread | $\sigma_E$ | | $1.5\times10^{-3}$ |
| Emittance | $\varepsilon_r$ | nm | 6.5 |

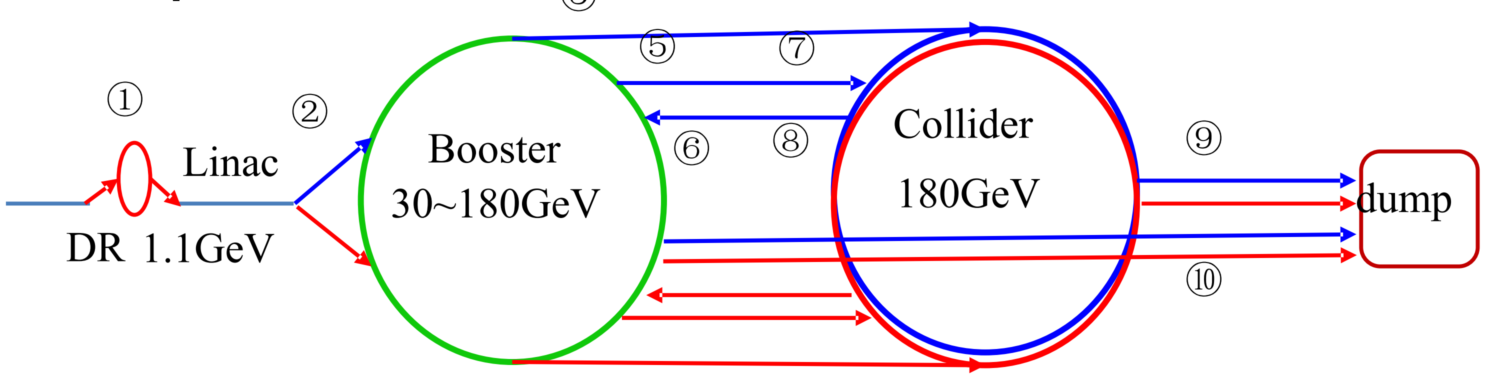
## Booster

| | | *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 | tt |
|---|---|---|---|---|
| **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 $\sigma_x/\sigma_y$ (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 $\xi_x/\xi_y$** | 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** |

## Transport lines




CEPC Technical Design Report (TDR) includes:
1) CEPC Accelerator TDR
2) CEPC Detector TDRrd (rd=reference design)
will be released by June 2025

# Machine Design for all Operation Modes



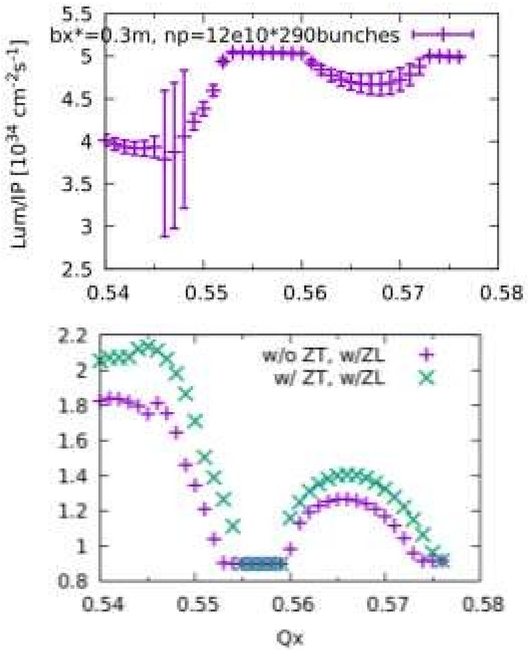
**Goal**

- e+e- circular collider as a high lumi. Higgs factory →
- Compatible operation for Higgs, W, Z and Top →
- Increasing Luminosity →

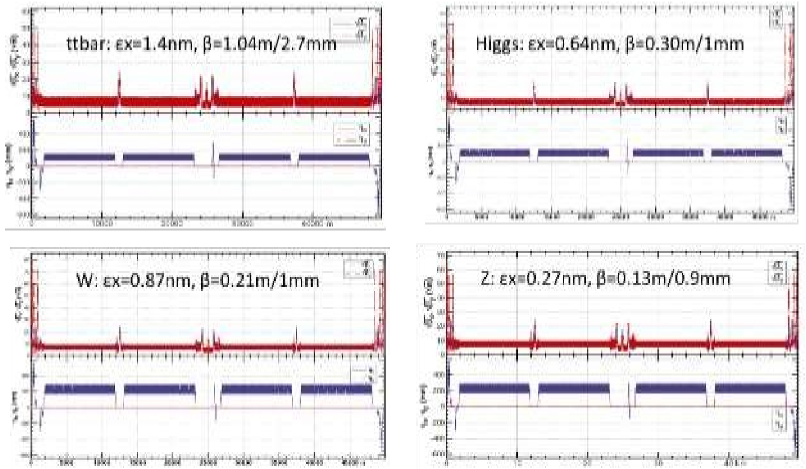
**Design**

- Lattice optimization for all energies
- Sufficient DA for all energies
- Beam-beam & collective instability
- Crab waist scheme with large cross angle and sextuples

**Beam-beam effect study**

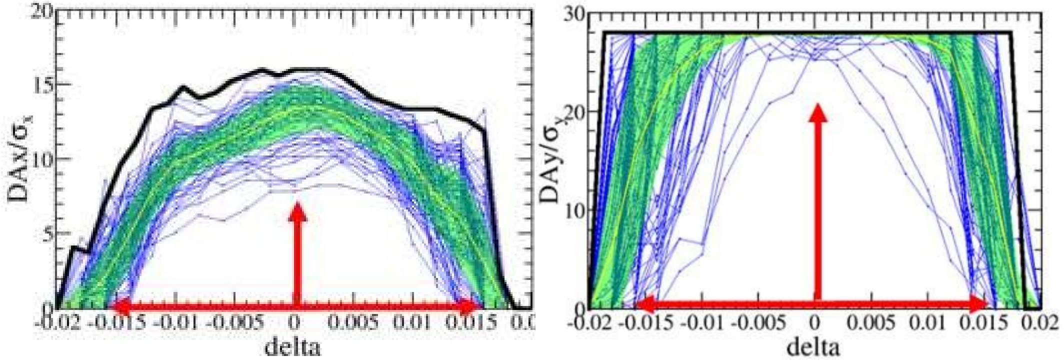



**Lattice for all energies**

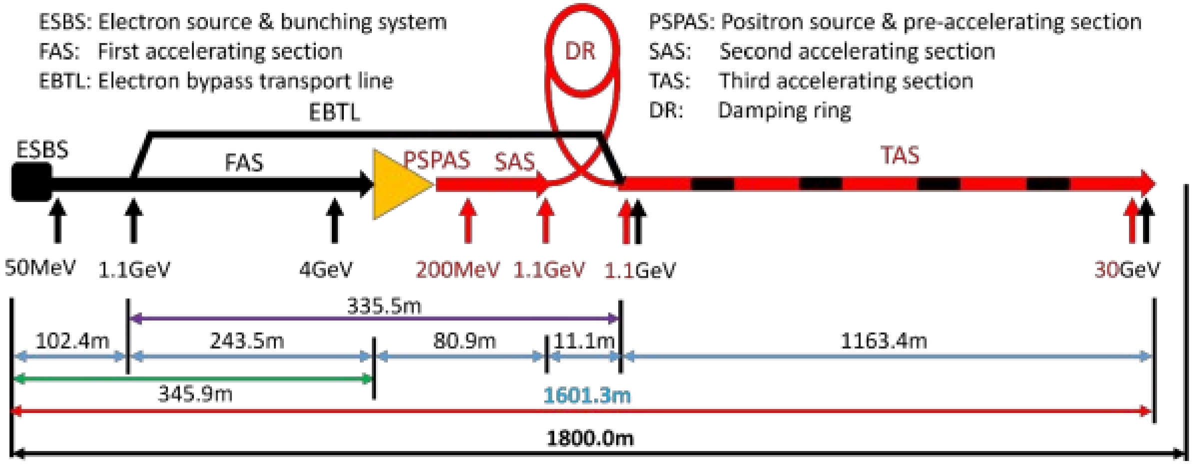



**Dynamic Aperture (DA) optimization**

Requirement met Higgs (w/error):
$7\sigma_x \times 16\sigma_y \times 1.6\%$

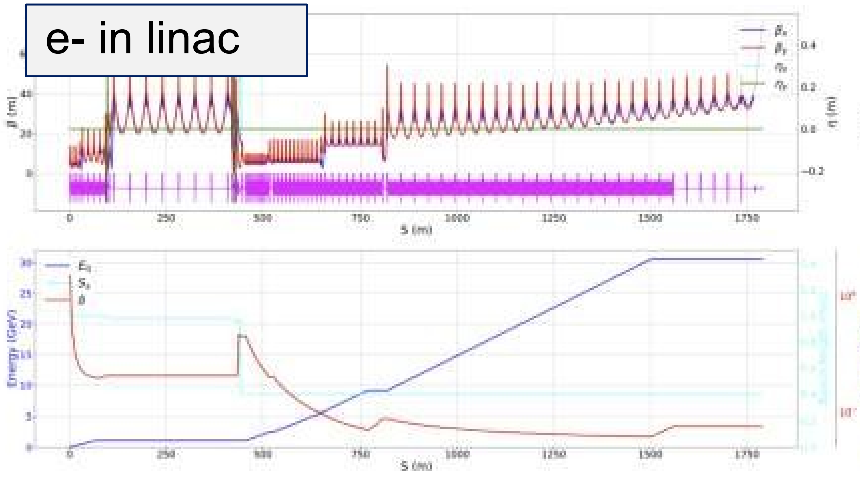


# CEPC e- and e+ Injection Linac Designs in TDR

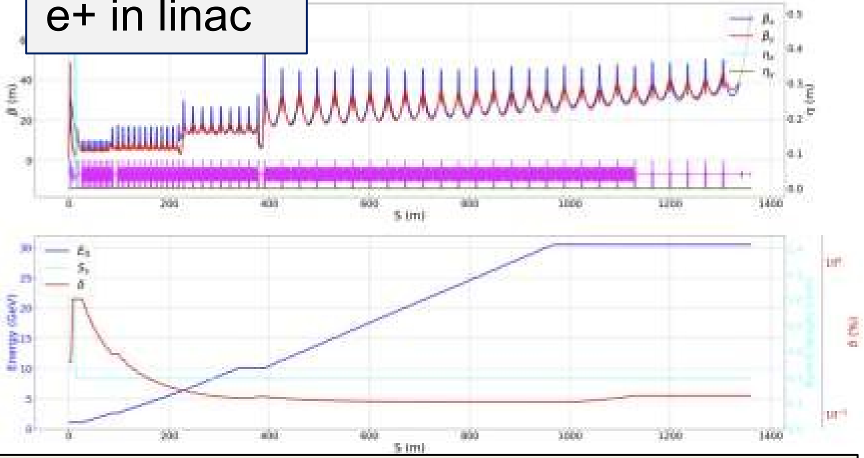



| Parameter | Symbol | Unit | Design value |
|---|---|---|---|
| Energy | $E$ | GeV | 30 |
| Repetition rate | $f_{rep}$ | Hz | 100 |
| Number of bunches per pulse | | | 1 or 2 |
| Bunch charge | | nC | 1.5 |
| Energy spread | $\sigma_E$ | | $1.5\times10^{-3}$ |
| Emittance | $\varepsilon_r$ | nm | 6.5 |
| Electron energy at target | | GeV | 4 |
| Electron bunch charge at target | | nC | 10 |
| Tunnel length | $L$ | m | 1800 |

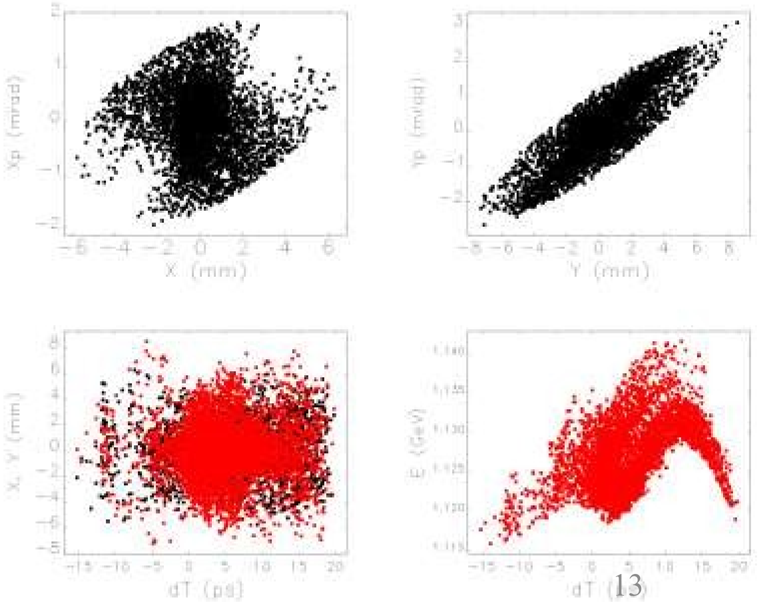
e- in linac



e+ in linac



Phase space @ SAS exit



- Linac energy increases to **30 GeV**, with **S+C band** Accelerator;
- Start-to-end simulations with errors have been conducted for both electron/positron beams, with qualities satisfying design requirements.

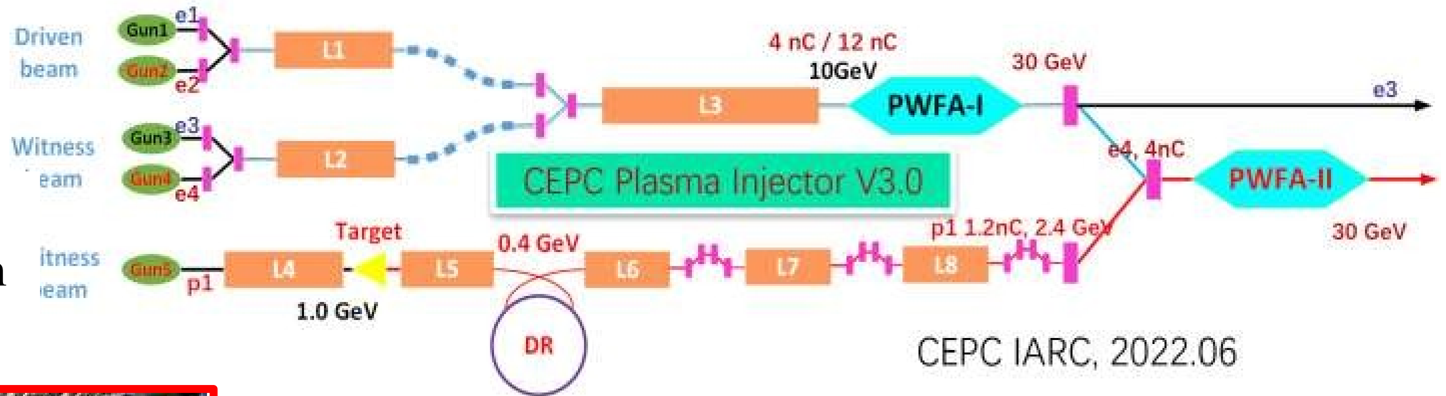
# CEPC Plasma Injector (alternative option) and TF Plan

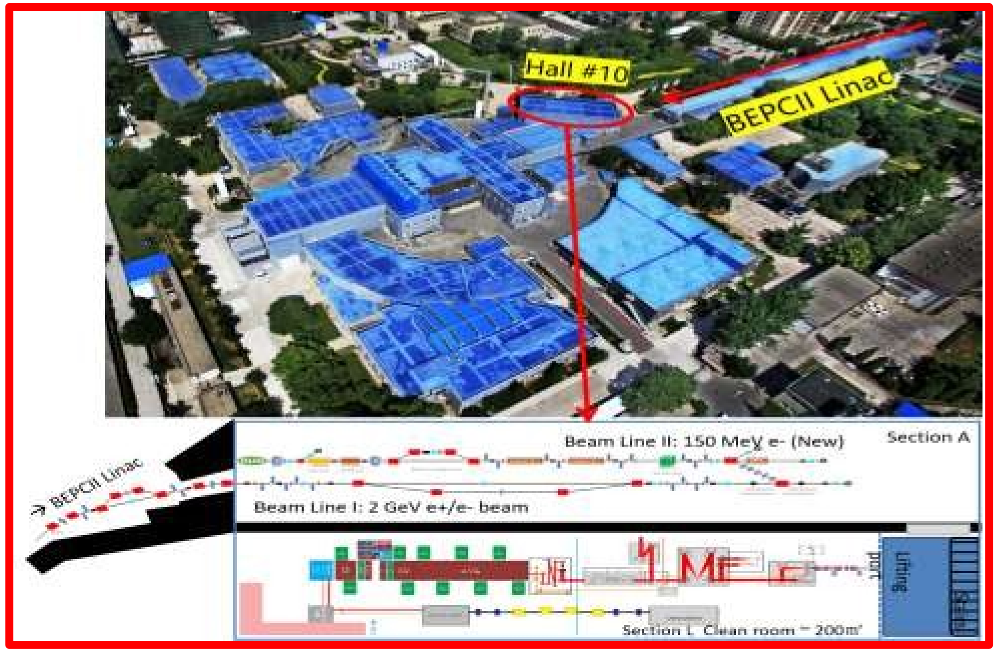


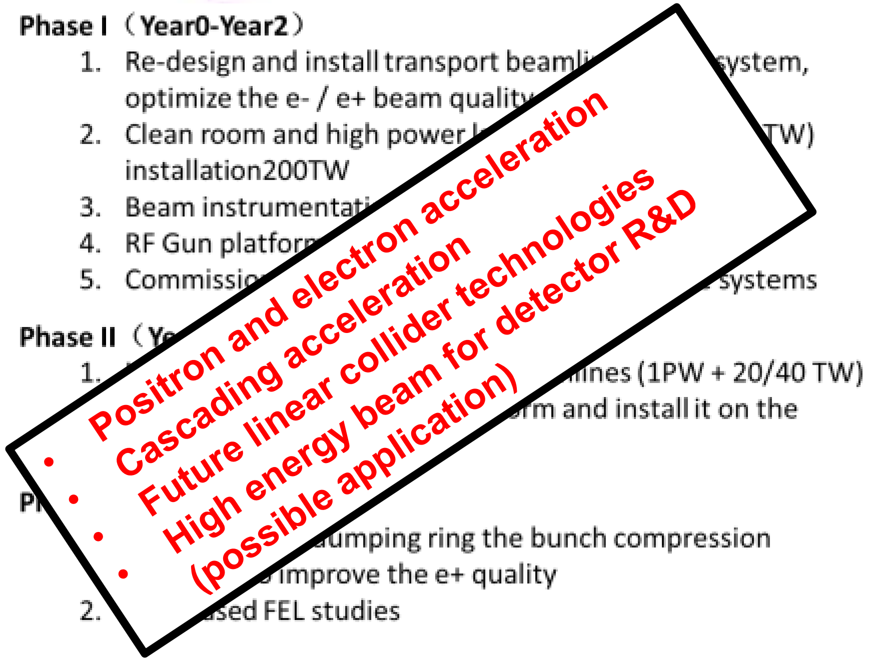
CEPC plasma injector scheme:

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

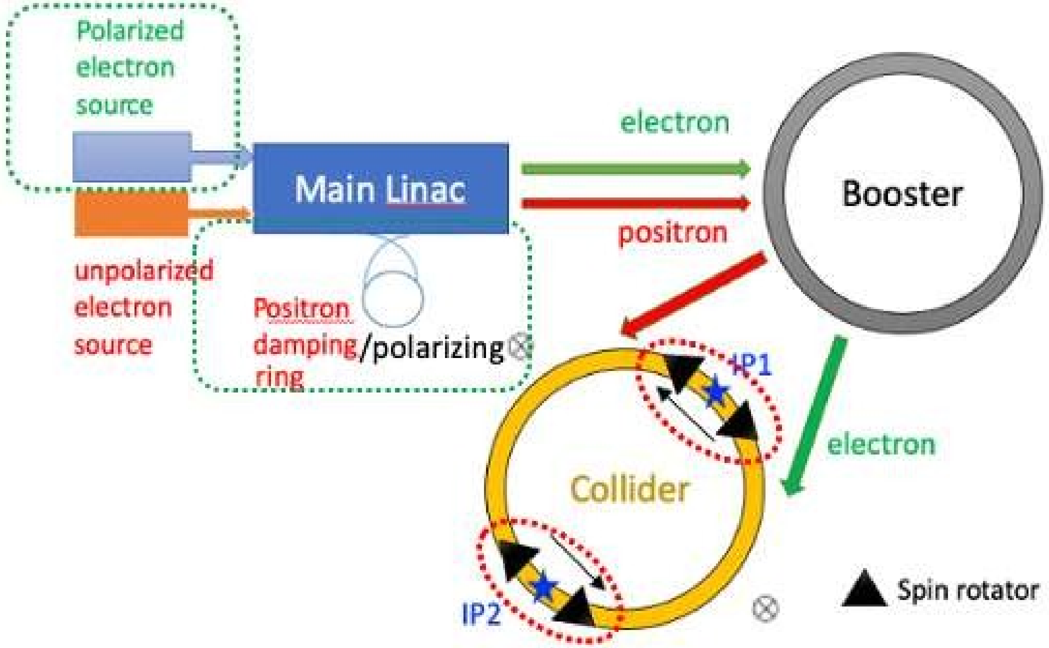


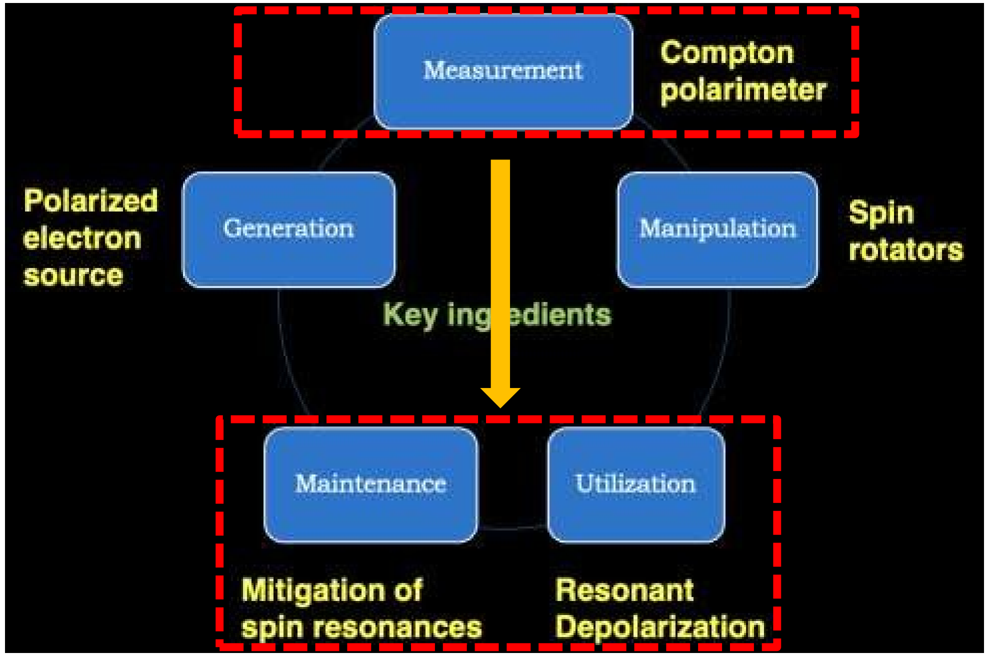




**PWFA/LWFA TF based on BEPC-II Linac and HPL has been founded by CAS 90M RMB in Sept. 2023**

# CEPC Polarization Studies (alternative option)



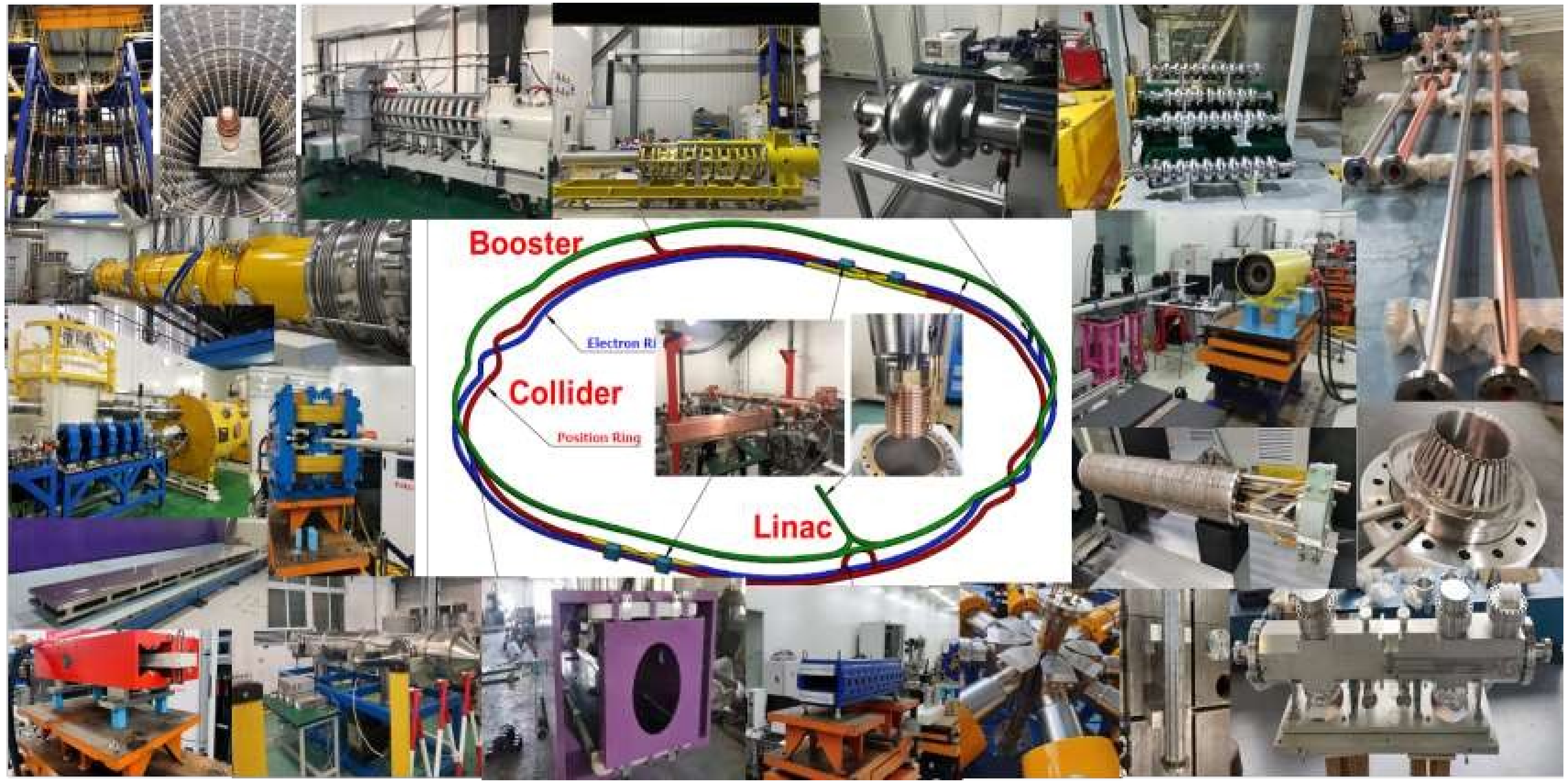

**Both the transverse and longitudinal polarization and Z, W, are feasible (Higgs under study)**

- Implement the lattice design to accommodate polarized beams: spin rotator, wiggler, Compton polarimeters, dumping ring and booster design, etc.
- R&D of Compton polarimeter, polarized electron sources, spin rotator, etc.
- Simulate the process and effects of errors
- Carry out experiments at BEPCII & HEPS booster

# CEPC Key Technology R&D Status in TDR



Specification Met ✓ Prototype Manufactured ✓



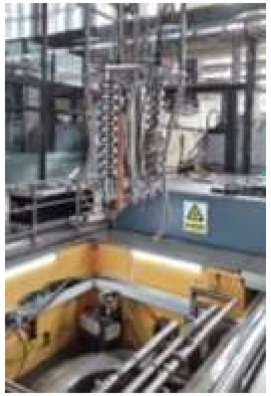

Key technology R&D in TDR spans all component lists in CEPC CDR

| 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 Booster 1.3 GHz 8 x 9-cell High Q Cryomodule

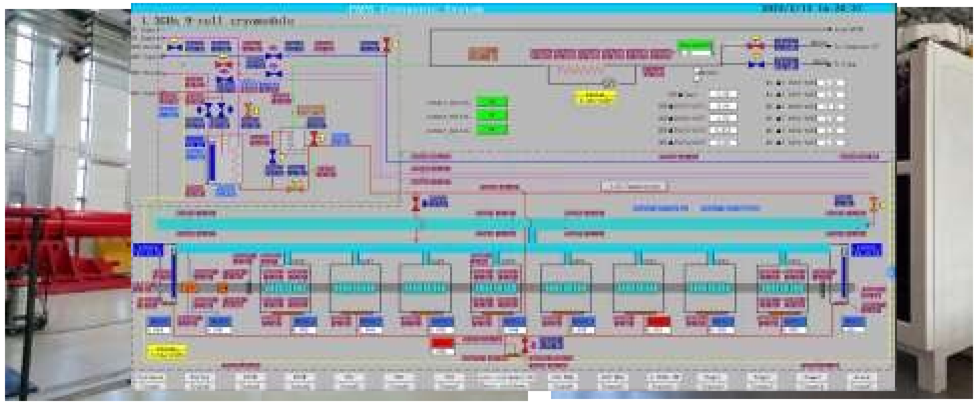
CEPC booster 1.3 GHz SRF R&D and industrialization in synergy with CW FEL projects.

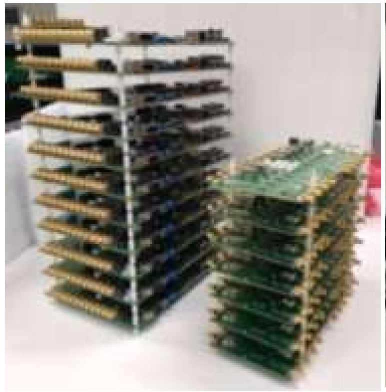
| Parameters | Horizontal test results | CEPC Booster Higgs Spec | LCLS-II, SHINE Spec | LCLS-II-HE Spec |
|---|---|---|---|---|
| Average usable CW $E_{acc}$ (MV/m) | 23.1 | $3.0\times10^{10}$ @ 21.8 MV/m | $2.7\times10^{10}$ @ 16 MV/m | $2.7\times10^{10}$ @ 20.8 MV/m |
| Average $Q_0$ @ 21.8 MV/m | $3.4\times10^{10}$ | | | |









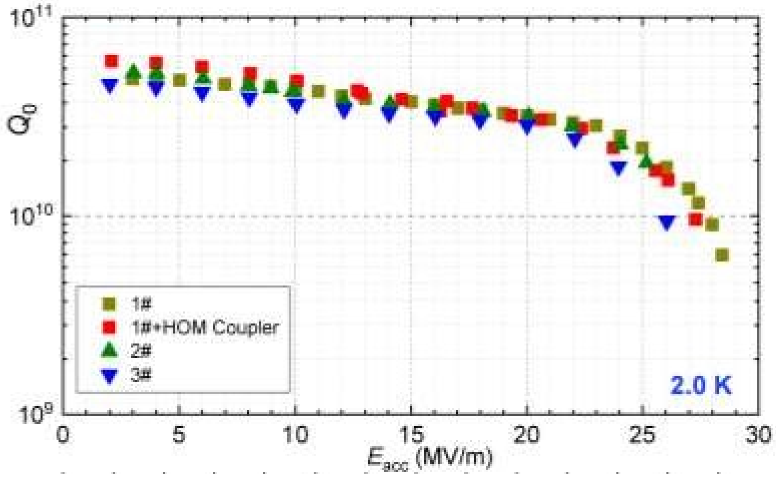


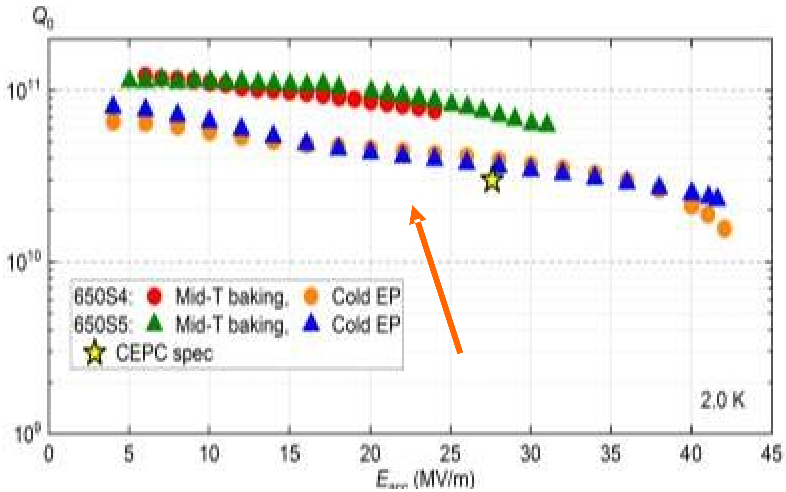

# CEPC R&D: 650 MHz SRF Cavities for collider

- 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 2-cell cavity



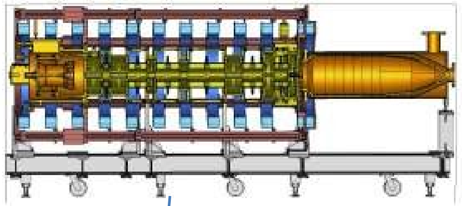




Vertical test of 650 MHz 1-cell cavity

# CEPC High Efficiency High Power Klystron Development and RF Power Distribution System

CEPC klystron R&D

Klystron No. 2
Efficiency 77%
(2021)



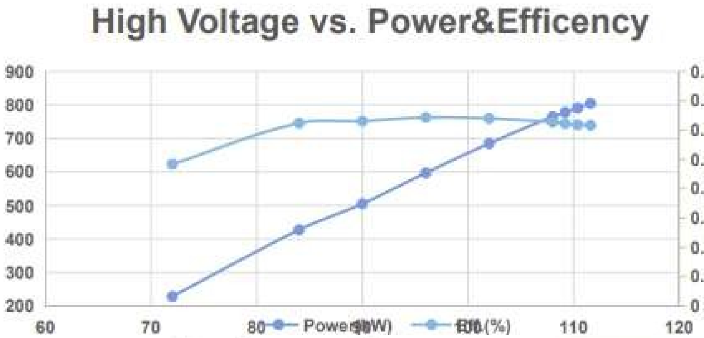
Power Supply Modulator

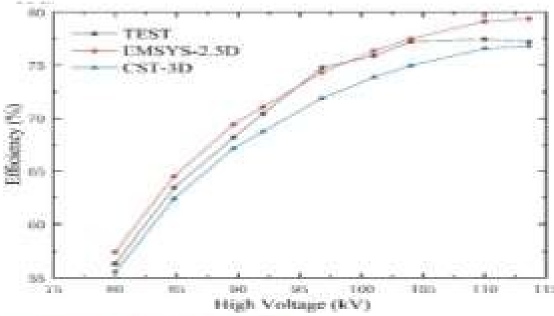
Klystron No. 1
Efficiency 65%
(2020)

Klystron No. 3 （MBK
Efficiency 80.5%
(under fabrication)

Pulsed RF Mode (30% duty factor, 60ms/5Hz) 77.2%@849kW pulsed in 2024

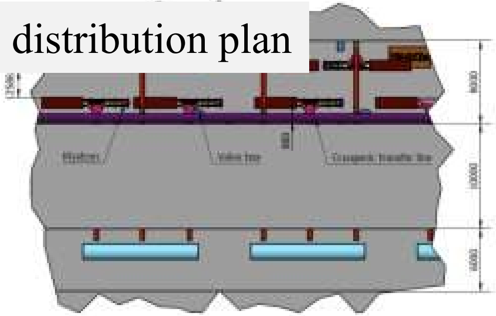
To be tested in 2024

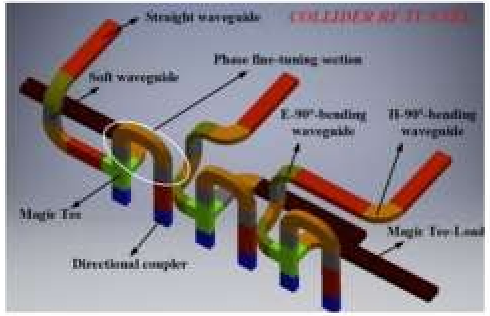




RF distribution plan






- Three prototypes of the **650MHz 800KW CW** klystrons are developed. The efficiency reaches 70%
- PSM is developed with the industrial collaboration
- RF tunnel distribution was planed

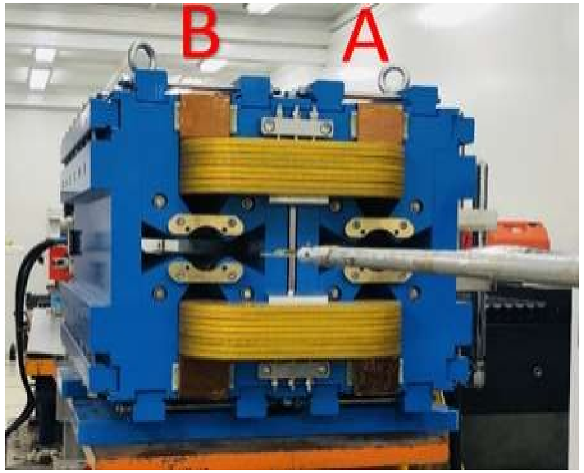
# R&D: Other Prototypes

**Collider dipole magnet**

**booster dipole magnet**


**EM deflector**

**Collider quad magnet**




Vacuum pipes and RF shielding bellows

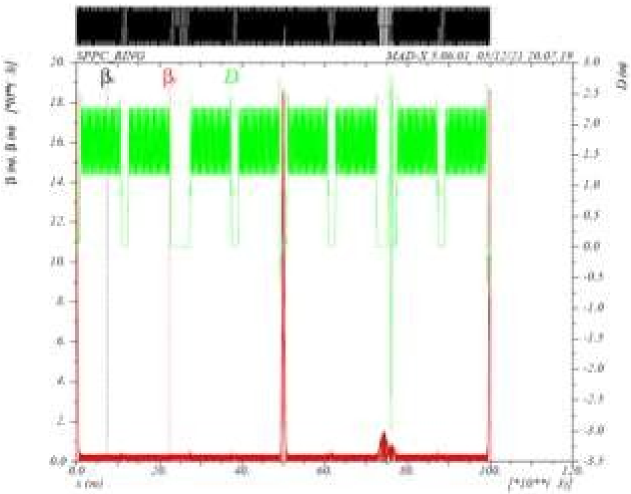
**Lambertson magnets**

# SppC Collider Parameters in TDR

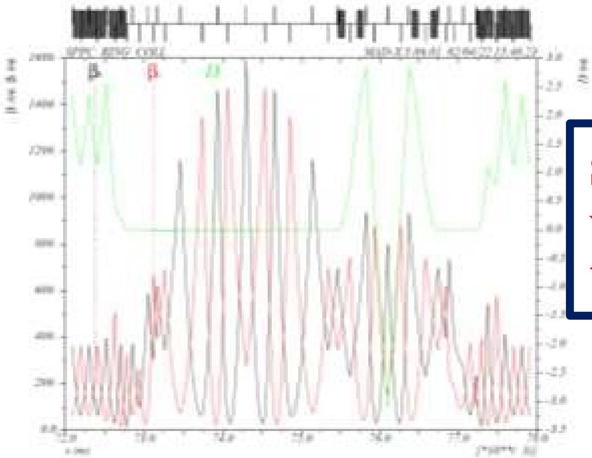
## -Parameter list (updated Feb. 2022)

| | | |
|---|---|---|
| **Main parameters** | | |
| Circumference | 100 | km |
| Beam energy | 62.5 | TeV |
| Lorentz gamma | 66631 | |
| Dipole field | 20.00 | T |
| Dipole curvature radius | 10415.4 | m |
| Arc filling factor | 0.780 | |
| Total dipole magnet length | 65442.0 | m |
| Arc length | 83900 | m |
| Total straight section length | 16100 | m |
| Energy gain factor in collider rings | 19.53 | |
| Injection energy | 3.20 | TeV |
| Number of IPs | 2 | |
| Revolution frequency | 3.00 | kHz |
| Revolution period | 333.3 | µs |
| **Physics performance and beam parameters** | | |
| Initial luminosity per IP | 4.3E+34 | $cm^{-2}s^{-1}$ |
| Beta function at initial collision | 0.5 | m |
| Circulating beam current | 0.19 | A |
| Nominal beam-beam tune shift limit pe | 0.015 | |
| Bunch separation | 25 | ns |
| Bunch filling factor | 0.756 | |
| Number of bunches | 10080 | |
| Bunch population | 4.0E+10 | |
| Accumulated particles per beam | 4.0E+14 | |

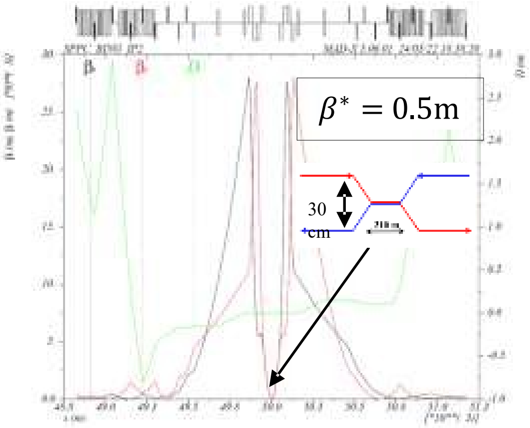
## Lattice of SPPC



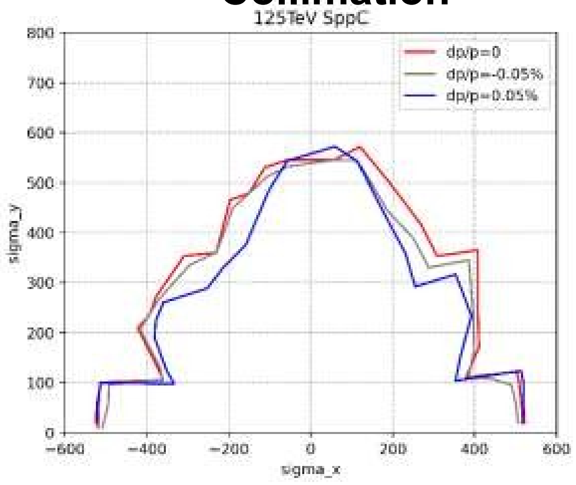

Whole ring



Collimation




IP




Dynamic Aperture

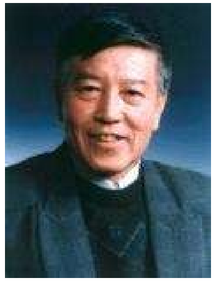
**SppC is compatible with CEPC in the same tunnel**

**Ecm=125TeV with dipole field of 20T**

# IBS Technology for High Field Magnets



**R&D under way**



**Z. Zhao**
IBS ($T_c$ 55K)

**2008.02**

Discovery of IBS

**H. Hosono**
IBS ($T_c$ 26K)

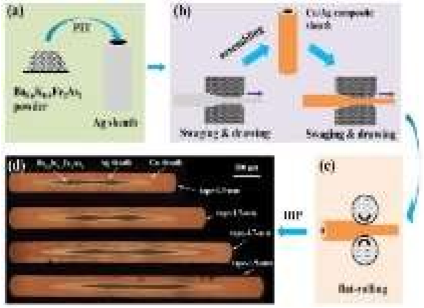
**2008.04**

**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

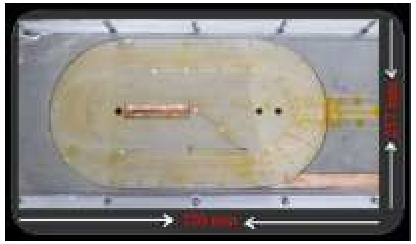
**2016**



**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

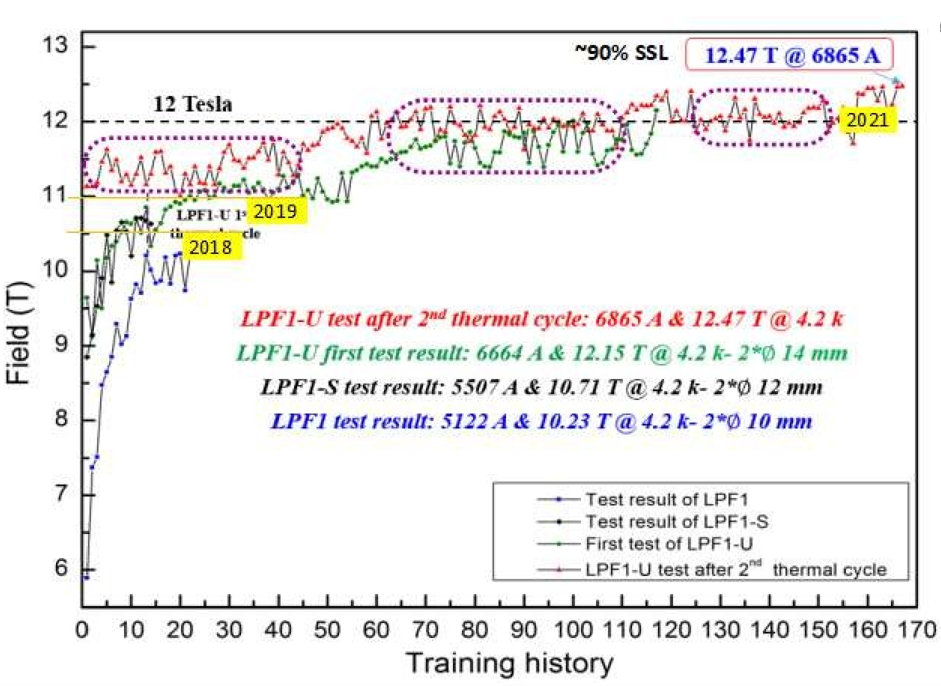
**2022**

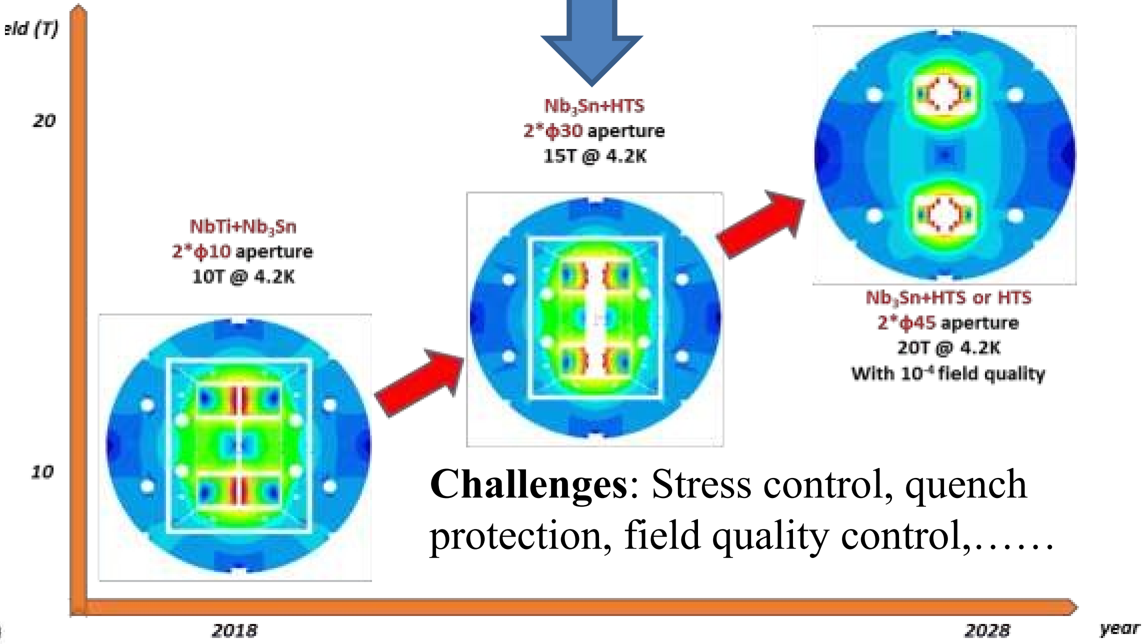
**$J_e$ of IBS expected to be similar as ReBCO in 2020s with better mechanical properties and lower cost, ready for mass applications in ultra high field magnets**

# HF Magnet Development

**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

# CEPC Site Preparations (three candidates in TDR)

# Power Consumption of CEPC @ Higgs

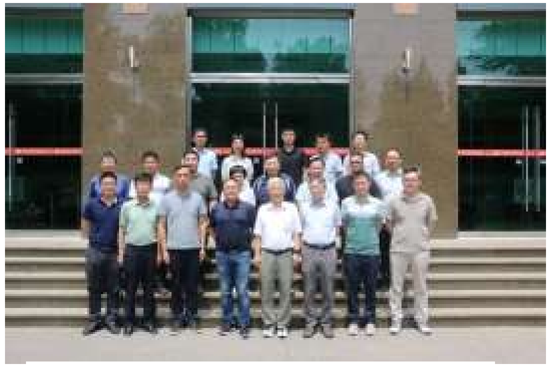
| SN | System | Higgs 30MW | | | | | | | Higgs 50MW | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Collider | Booster | Linac | BTL | IR | Surface building | Total | Collider | Booster | Linac | BTL | IR | Surface building | Total |
| 1 | RF Power Source | 96.90 | 1.40 | 11.10 | | | | 109.40 | 161.60 | 1.73 | 14.10 | | | | 177.40 |
| 2 | Crygenic system | 9.72 | 1.71 | | | 0.14 | | 11.57 | 9.17 | 1.77 | | | 0.14 | | 11.08 |
| 3 | Vacuum System | 5.40 | 4.20 | 0.60 | | | | 10.20 | 5.40 | 4.20 | 0.60 | | | | 10.20 |
| 4 | Magnet Power Supplies | 44.50 | 9.80 | 2.50 | 1.10 | 0.30 | | 58.20 | 44.50 | 9.80 | 2.50 | 1.10 | 0.30 | | 58.20 |
| 5 | Instrumentation | 1.30 | 0.70 | 0.20 | | | | 2.20 | 1.30 | 0.70 | 0.20 | | | | 2.20 |
| 6 | Radiation Protection | 0.30 | | 0.10 | | | | 0.40 | 0.30 | | 0.10 | | | | 0.40 |
| 7 | Control System | 1.00 | 0.60 | 0.20 | | | | 1.80 | 1.00 | 0.60 | 0.20 | | | | 1.00 |
| 8 | Experimental devices | | | | | 4.00 | | 4.00 | | | | | 4.00 | | 4.00 |
| 9 | Utilities | 37.80 | 3.20 | 1.80 | 0.60 | 1.20 | | 44.60 | 46.40 | 3.80 | 2.50 | 0.60 | 1.20 | | 54.50 |
| 10 | General services | 7.20 | | 0.30 | 0.20 | 0.20 | 12.00 | 19.90 | 7.20 | | 0.30 | 0.20 | 0.20 | 12.00 | 19.90 |
| | **Total** | 204.12 | 21.61 | 16.80 | 1.90 | 5.84 | 12.00 | 262.27 | 276.87 | 22.60 | 20.50 | 1.90 | 5.84 | 12.00 | 339.71 |

**Various measures will be studied and implemented towards a green collider, as discussed in the Mini workshop of accelerator, Jan. 18-19, 2024, HKUST-IAS, Hong Kong**
https://indico.cern.ch/event/1335278/timetable/?view=standard

# CEPC Accelerator International TDR Review and Cost Review
# June 12-16, and Sept. 11-15, 2023, in 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

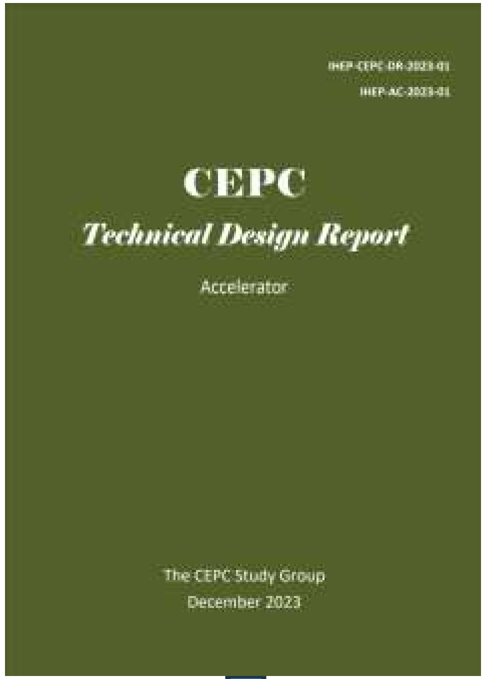
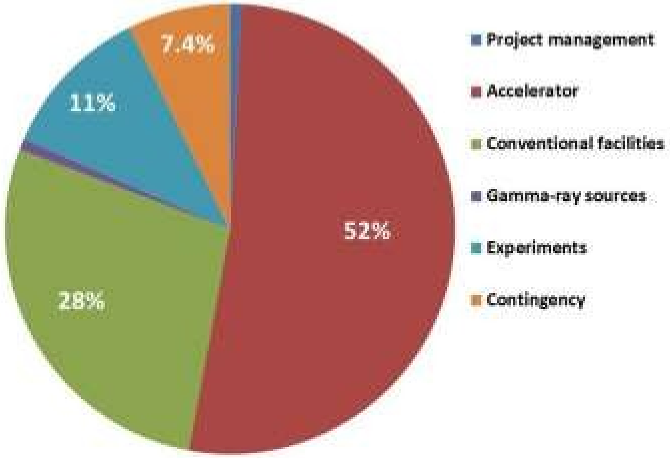



**Table 12.1.2:** CEPC project cost breakdown, (Unit: 100,000,000 yuan)

| 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 International Reviews and CEPC IAC Meeting Endorsement



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**

.

# CEPC Engineering Design Report (EDR) Goal

| 2012.9 | 2015.3 | 2018.11 | 2023.10 | 2025 | 2027 | 15th five year plan |
|---|---|---|---|---|---|---|
| CEPC proposed | Pre-CDR | CDR | TDR | CEPC Proposal<br>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**

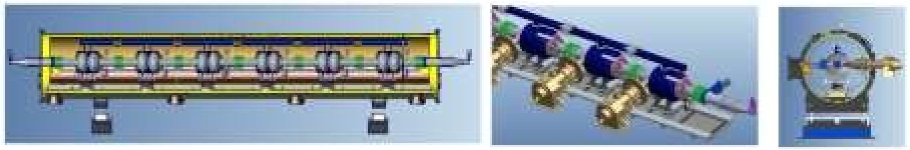
**CEPC Accelerator EDR Phase goals, scope and the working plan (preliminary) of 35 WGs summarized in a documents of 20 pages to be reviewed by IARC in 2024**

# Some Key Issues in EDR (examples)-1



## CEPC Accelerator Main EDR Development: SRF

CEPC collider ring 650MHz 2*cell short test module has been completed in TDR phase



The collider Higgs mode for 30 MW SR power per beam will use 32 units of 11 m-long collider cryomodules will contain six 650 MHz 2-cell cavities, and therefore, a full size 650 MHz cryomodule will be developed in EDR



## CEPC Accelerator Main EDR Development: Klystrons


CEPC collider ring 650MHz klystron development in TDR phase

| Parameters | Value |
|---|---|
| Frequency | 5720 MHz |
| Output Power | 80MW |
| Pulsed width | 2.5us |
| Repetition rate | 100Hz |
| Gain | 54 dB |
| Efficiency | 47% |
| 3dB bandwith | ±5MHz |
| Beam voltage | 420 kV |
| Beam current | 403 A |
| Focusing field | 0.28 T |

C band 5720MHz 80MW Klystron

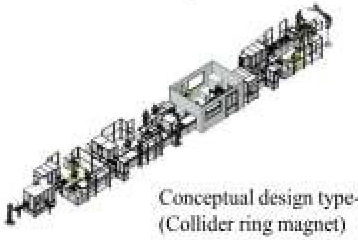

C band 5720MHz 80MW Klystron design progress



## 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)



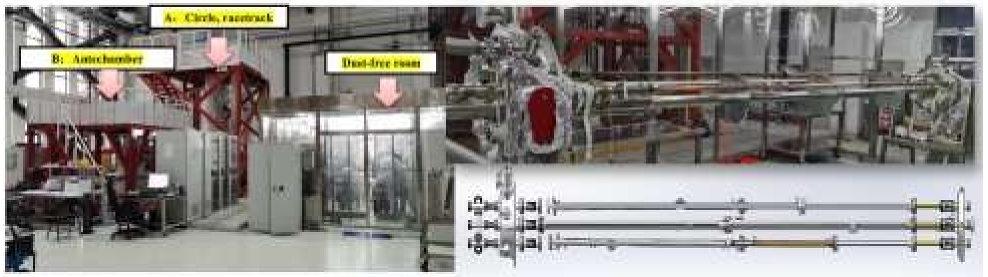
Conceptual design type-II (Collider ring magnet)

Jan.-Sept. 2024： Complete the CEPC booster magnet automatic fabrication facility design.
Oct. 2024-Jun. 2025： Complete the small scale demonstration facility for booster iron core fabrication.

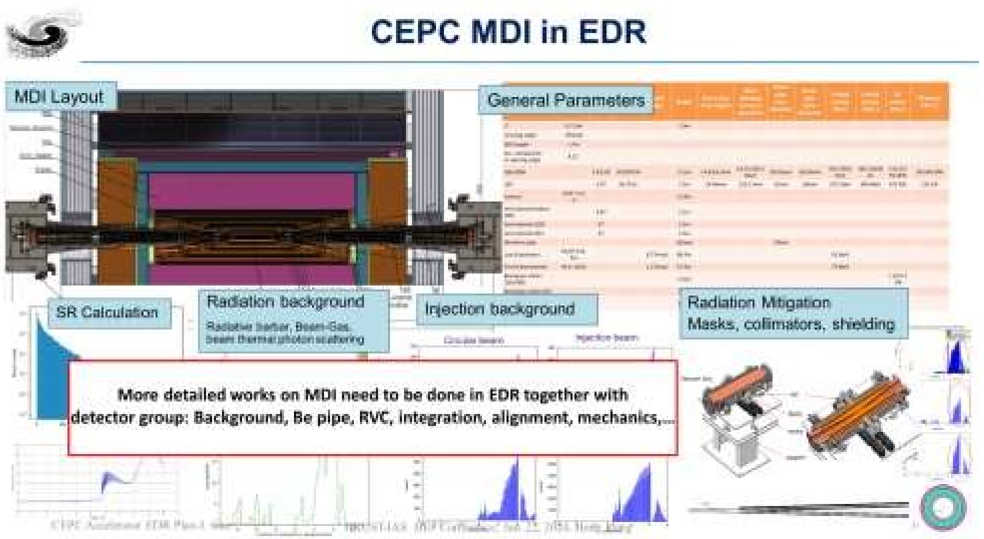


## Massive Production Line of NEG Coating Vacuum Chambers in EDR

- 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**

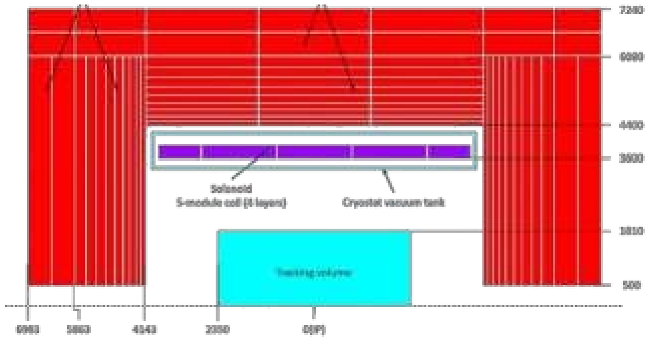


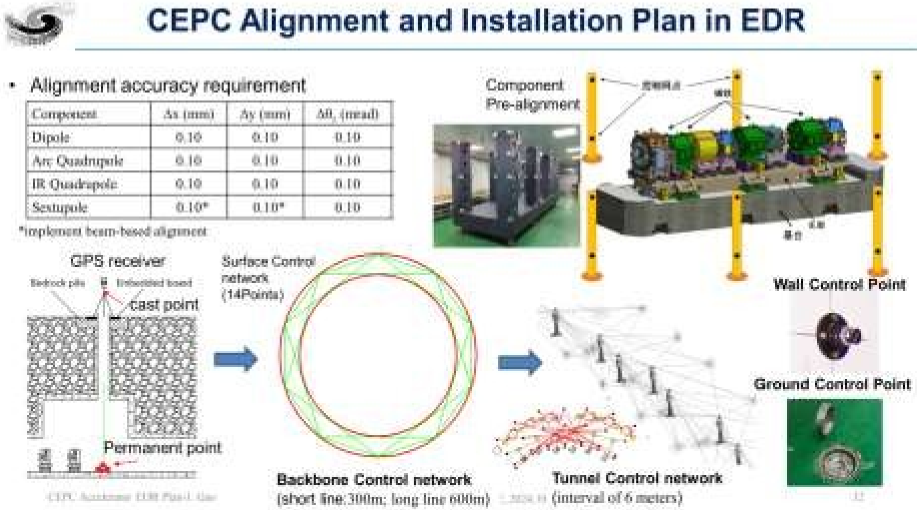
# Some Key Issues in EDR (examples)-2





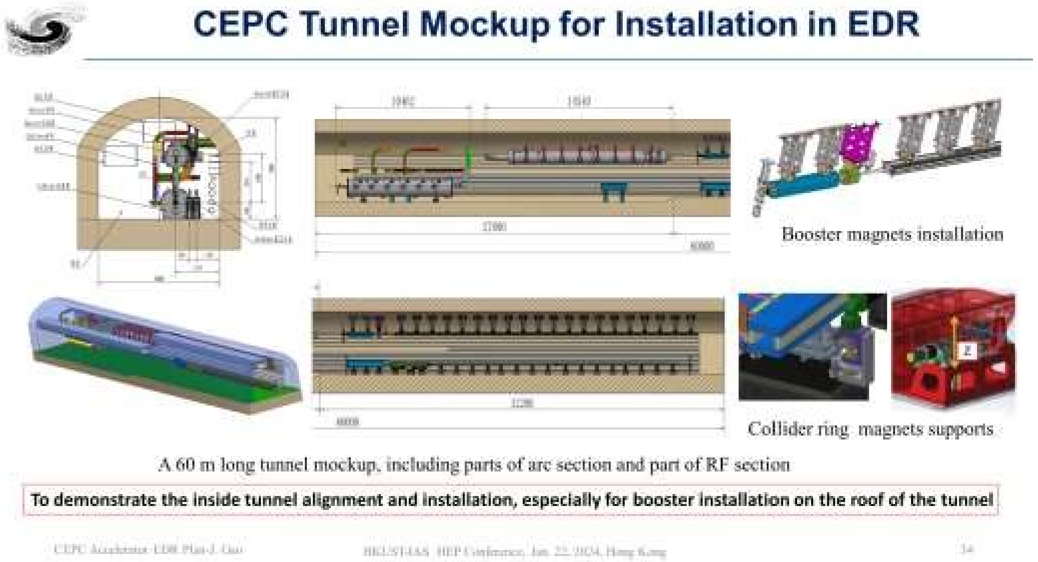
## Detector dummy coil development




| Component | Δx (mm) | Δy (mm) | Δθ_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



# CEPC Accelerator IARC Meetings in TDR and EDR

## International Accelerator Review Committee (IARC) under IAC

The 2019 CEPC International Accelerator Review Committee

Review Report

December 6, 2019

The 2021 CEPC International Accelerator Review Committee

Review Report

May 19, 2021

2021 Second CEPC IARC Meeting

IARC Committee

October 20th, 2021

2022 First CEPC IARC Meeting

IARC Committee

June 17th, 2022

IARC chair: Katsunobu Oide from 2019-2020
IARC chair: Marica Biagini from 2020-now


Nov. 2019: https://indico.ihep.ac.cn/event/9960/
May, 2021: https://indico.ihep.ac.cn/event/14295
October, 2021: https://indico.ihep.ac.cn/event/15177
June, 2022: https://indico.ihep.ac.cn/event/16801/

Jan. 2024: preparation zoom meeting
Sept. 2024: first extended IARC meeting in EDR phase

All IARC reports (**2019-2022**) on IAC2022 Meeting Indico: https://indico.ihep.ac.cn/event/17996/page/1415-materials

**As required by IAC , extended IARC will review the CEPC accelerator progresses on the EDR in September 16-18, 2024**

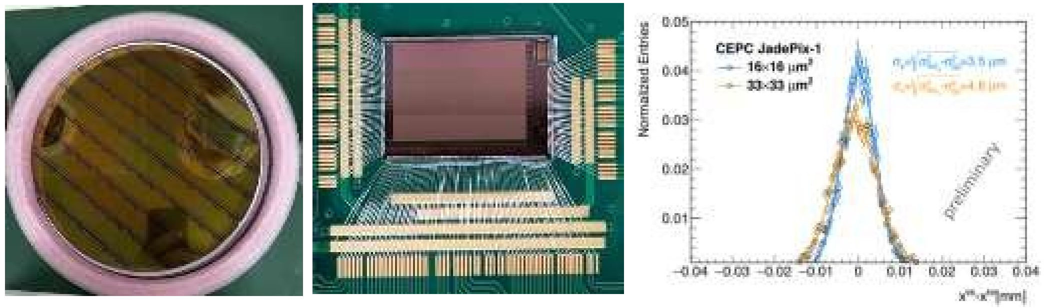
After the completion of CEPC CDR in Nov. 2018, since the first CEPC IARC meeting in **2019**, there has been **totally 4 IARC meetings till 2022**, with each meeting a carefully written IARC report, which are very helpful for CEPC accelerator in TDR phase and beyond.

# CEPC Detector R&D Status

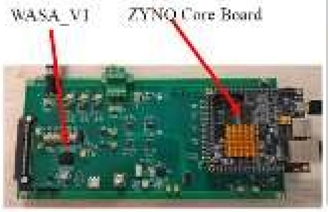
- **Lots of R&D benefitted from past experience**
  - Silicon strip detector: Experience from ATLAS upgrade
  - Drift chamber: Lots of Experience from BESIII
  - Super-conducting magnet: Experience from BESIII
- **New R&D on key technology**
  - Vertex detector
  - TPC drift chamber
  - PFA calorimeter

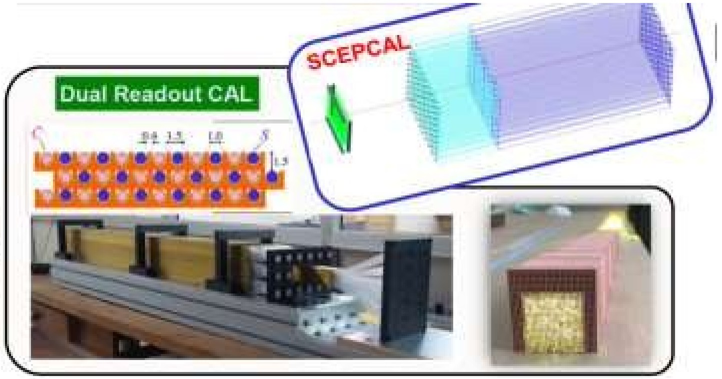
**CEPC Detector TDRrd (rd=reference design) will be released in June, 2025**

Vertex detector R & D ( 3- 5 μm reso.)




TPC prototype (low power electronics)




## Prototype Manufactured

| Sub-detector | Specification | Requirement | World-class level | CEPC prototype |
|---|---|---|---|---|
| Pixel detector | Spatial resolution | $\sim 3\ \mu m$ | $3-5\ \mu m$ [12, 13] | $3-5\ \mu m$ [14–16] |
| TPC/drift chamber | dE/dx (dN/dx) resolution | $\sim 2\%$ | $\sim 4\%$ [17, 18] | $\sim 4\%$ [19–21] |
| Scintillator-W ECal | Energy resolution<br>Granularity | $< 15\%/\sqrt{E(\mathrm{GeV})}$<br>$\sim 2 \times 2\ \mathrm{cm}^2$ | 12.5% [22] | Prototype built to be measured<br>$0.5 \times 0.5\ \mathrm{cm}^2$ |
| 4D crystal ECal | EM energy resolution<br>3D Granularity | $\sim 3\%/\sqrt{E(\mathrm{GeV})}$<br>$\sim 2 \times 2 \times 2\ \mathrm{cm}^3$ | $2\%/\sqrt{E(\mathrm{GeV})}$ [23, 24]<br>N/A | Prototyping [25]<br>$\sim 3\%/\sqrt{E(\mathrm{GeV})}$<br>$\sim 2 \times 2 \times 2\ \mathrm{cm}^3$ |
| Scintillator-Steel HCal | Support PFA,<br>Single hadron $\sigma_E^{had}$ | $< 60\%/\sqrt{E(\mathrm{GeV})}$ | $57.6/\sqrt{E(\mathrm{GeV})}\%$ [26] | Prototyping |
| Scintillating glass HCal | Support PFA<br>Single hadron $\sigma_E^{had}$ | $\sim 40\%/\sqrt{E(\mathrm{GeV})}$ | N/A | Prototyping<br>$\sim 40\%/\sqrt{E(\mathrm{GeV})}$ |
| Low-mass Solenoid magnet | Magnet field strength<br>Thickness | 2 T – 3 T<br>< 150 mm | 1 T – 4 T [27–29]<br>> 270 mm | Prototyping |

# CEPC Detector Technology R&D Breakdown



| Det | Technology | Det | Technology |
|---|---|---|---|
| Pixel Vertex | JadePix | Calorimeter | Crystal ECAL |
| | TaichuPix | | Stereo Crystal ECAL |
| | CPV(SOI) | | Scint+W ECAL |
| | Stitching | | Si+W ECAL |
| | Arcadia | | Scint+Fe AHCAL |
| Tracker & PID | CEPCPix | | ScintGlass AHCAL |
| | Silicon Strip | | RPC SDHCAL |
| | TPC | | MPGD SDHCAL |
| | Drift chamber | | DR Calorimeter |
| | PID drift chamber | Muon | Scintillation Bar |
| | LGAD ToF | | RPC |
| Lumi | SiTrk+Crystal ECAL | | μ-Rwell |
| | SiTrk+SiW ECAL | | HTS / LTS Magnet |
| | CEPC SW | | MDI & Integration |
| | TDAQ | | |

## Large number of detector R&D projects on-going:

Not all at the same level of maturity, some have reach the large-scale prototype level.

**Need to converge soon to a CEPC Detector TDR reference:**

- Start preparation in January of 2024
- A draft version by December, 2024
- **Official release by June 30, 2025.**

## International detector collaborative efforts:

- DRD collaborations
- HL-LHC detector R&D's, help preparing teams for the CEPC detectors.

# The 4th Conceptual Detector towards a Reference Design



Scintillator Glass
PFA HCAL

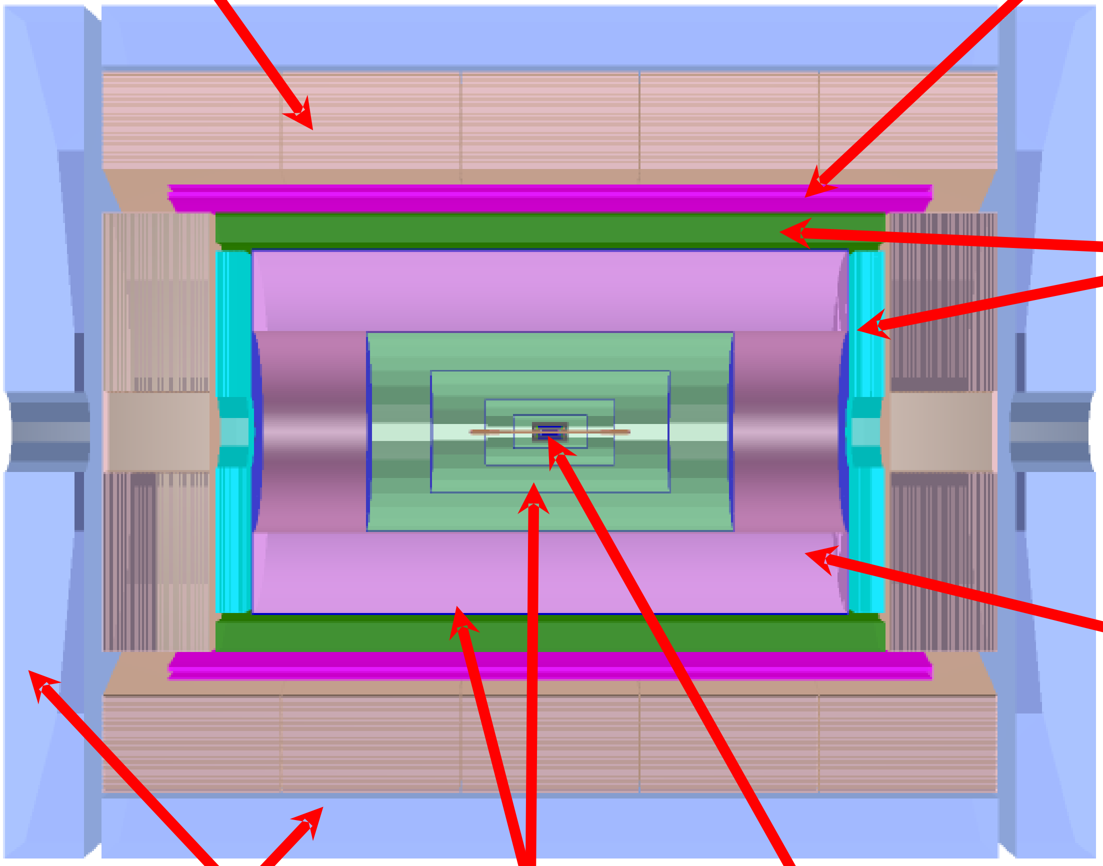
Advantage: Cost efficient, high density

Challenges: Light yield, transparency, radiation hardness, massive production

HTS Solenoid Magnet (3T / 2T )
Between HCAL & ECAL, or inside HCAL

Advantage: HCAL absorbers act as part of the magnet return yoke.

Challenges: Thin enough not to affect the jet resolution; Stability.



Transverse Crystal bar ECAL

Advantage: Better $\pi^0/\gamma$ reconstruction

Challenges: Minimum number of readout channels; Compatible with PFA calorimeter; Maintain good jet resolution.

A Drift chamber
optimized for PID

Advantage: Work at high luminosity Z runs

Challenges: Sufficient PID power; Thin enough not to affect the moment resolution; Need supplementary ToF detector

Muon+Yoke

Si Tracker
w/TOF outer layer

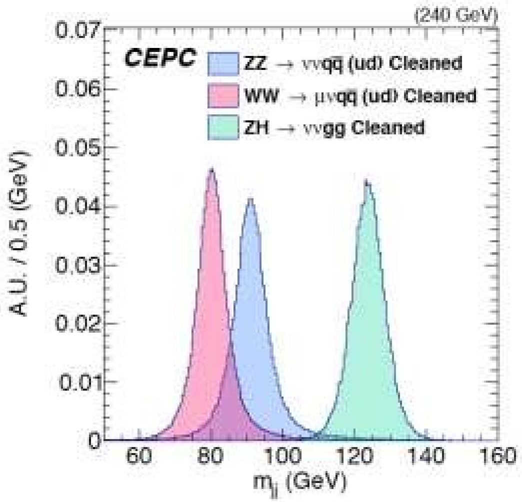
Si Vertex

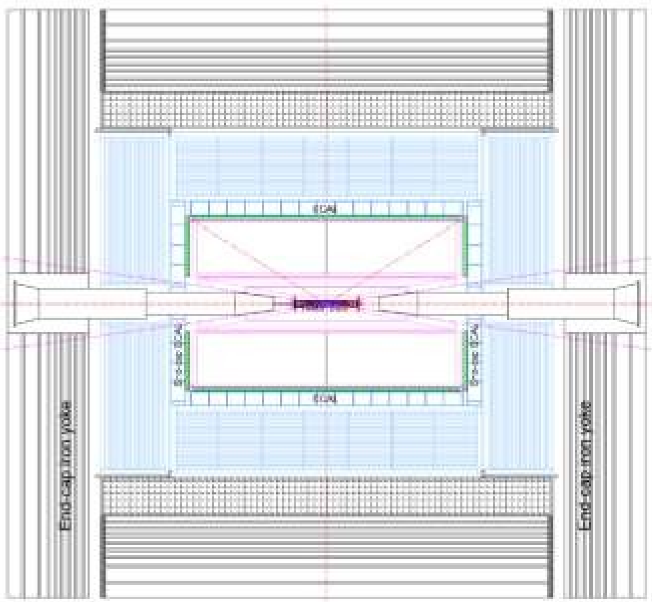
# CEPC Detector: Idea of the "4$^{th}$ Concept"



**Requirements**
boson mass resolution (BMR ~3%)

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



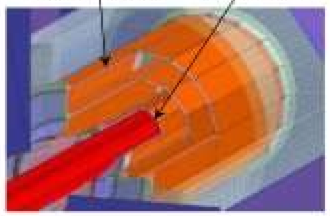




Novel detector design based on PFA calorimeter to improve the BMR from 4% to 3%

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

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

# R&D: Vertex Detector and Tracker




**Goal: σ(IP) ~ 5 μm for high P track**

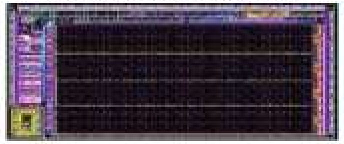
**CDR design specifications**

- 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

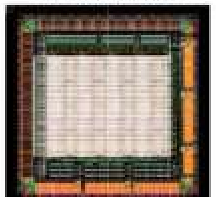
**JadePix**-3 Pixel size ~16×23 μm²



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

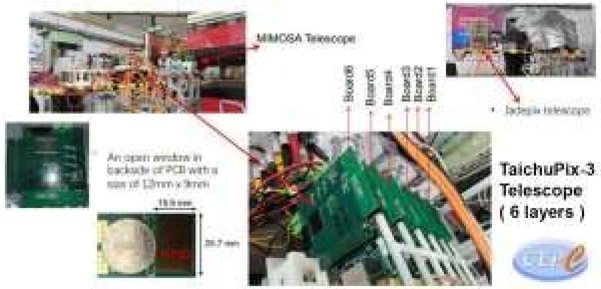
**TaichuPix**-3, FS 2.5x1.5 cm²
25×25 μm² pixel size

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

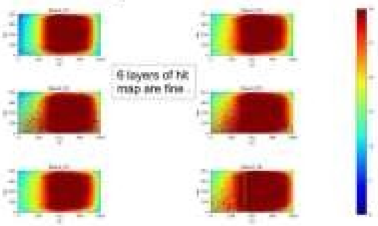


**Arcadia** by Italian groups for IDEA vertex detector
LFoundry 110 nm CMOS

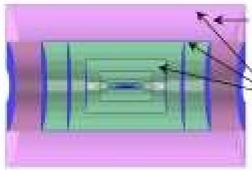
**Full vertex detector prototype (TaichuPix-3, JadePix-3) has TB at DESY in Dec. 2022.**

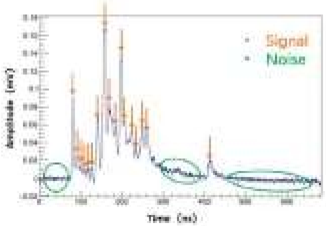



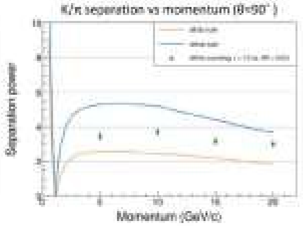

**Hitmap of 4 GeV e⁺/e⁻ beam**



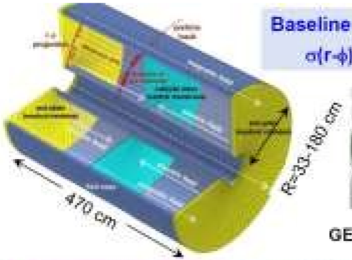

- **Goal: 3σ π/K separation up to ~20 GeV/c.**
- Cluster counting method, or **dN/dx**, measures the number of primary ionization
- **Can be optimized specifically for PID**: larger cell size, no stereo layers, different gas mixture.
- Garfield++ for simulation, realistic electronics, peak finding algorithm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




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

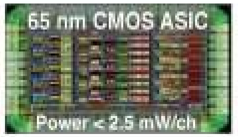



**Baseline main tracker**
**σ(r-ϕ) ~100 μm**

GEM-MM cathode

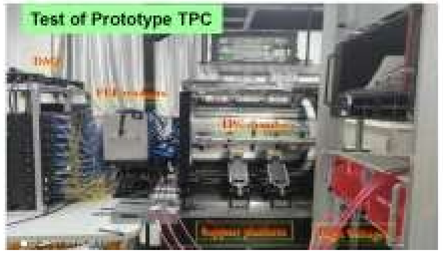
TPC Prototype + UV laser beams

**MOST 1 (IHEP+THU)**

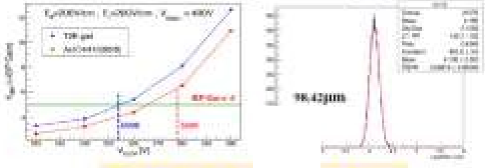



Low power FEE ASIC

**Test of Prototype TPC**



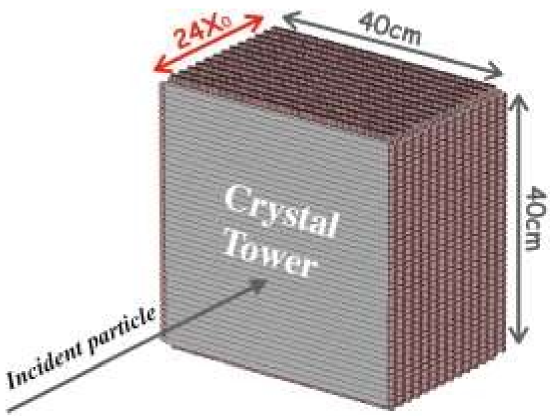
Challenge: Ion backflow (IBF) affects the resolution. It can be corrected by a laser calibration at low luminosity, but difficult at high luminosity Z-pole.



$\sigma_r$ < 100 μm for drift length of 27cm

# R&D: Calorimeters with PFA

## Crystal ECAL




**Energy resolution** $\frac{\sim 3\%}{\sqrt{E}} \oplus \sim 1\%$

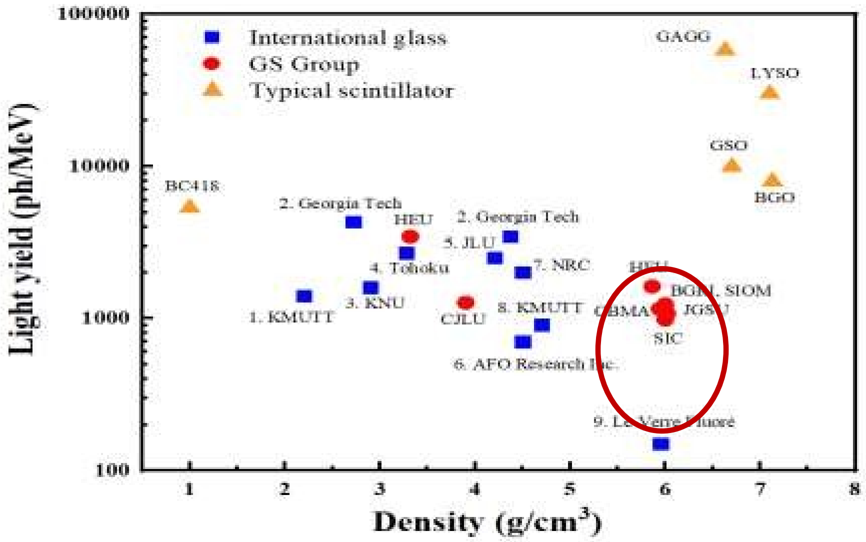
**Features:**

- Good energy resolution
- 3D shower info. with limited readout channel
- Shower separation < 4 cm

**Main issues for R&D**

- Jet reconstruction and PFA algorithm

## Scintillation Glass HCAL



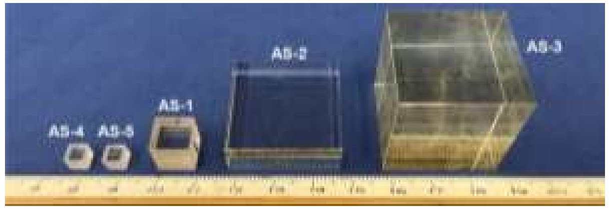

**Energy resolution** $\sim 40\%/\sqrt{E} \pm \sim 2\%$

**Features:**

- Large sampling ratio at low cost

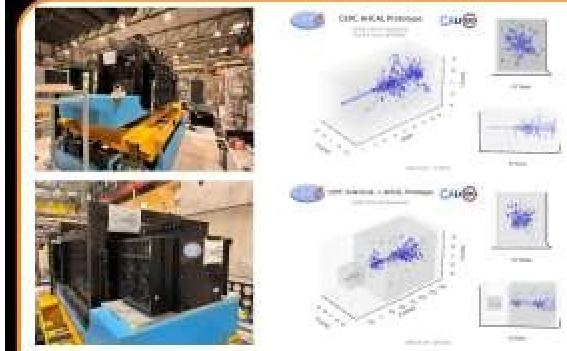
**Main issues for R&D**

- high density, high light yield, radiation hardness, production



# CEPC Sub-detectors with Beam Tests

## CEPC calorimeter prototypes: beamtest in 2022



- Successful beamtest at CERN SPS H8: **Oct-Nov, 2022**
  - High energy particle beams: muons, positrons and hadrons (10 - 160 GeV)
  - Suffered from beam purity issue in pion and positron beams

## Test beam @ DESY

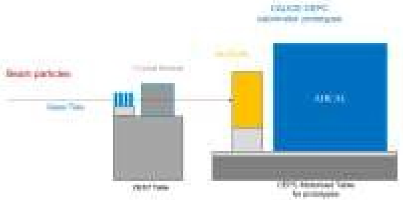
- 2nd testbeam: April 11-23 2023 DESY test beam in Germany (4-6 GeV electron)
  - Vertex detector prototype testbeam
- 1st testbeam: Dec 12-22 2022 DESY test beam in Germany (4-6 GeV electron)
  - TaichuPix Beam Telescope testbeam


Excellent collaboration with DESY testbeam team

## Crystal modules: beamtest at CERN in 2023

- Successful CERN beamtest: parasitic runs at PS-T9 (May 16-23, 2023)

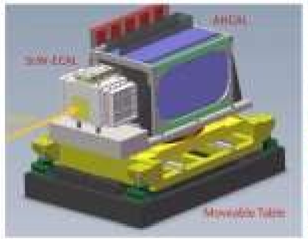





- Achieved major goals
  - Commissioning of the first crystal module
  - Validation of simulation and digitization

## CEPC calorimeter prototypes: beamtests in 2023

- Beamtest campaigns
  - First period (16 days): CERN SPS-H2 in Apr. - May 2023
  - Second period (15 days): CERN PS-T09 in May 2023
- Data sets: significantly improved beam purity than 2022
  - Collected decent statistics, enabling detector performance evaluation, validation of Geant4 simulation, particle-flow studies, etc.




# ECFA DRD Proposals From Chinese Institutes/Universities



- Not all information are available. T**here could be small errors in the table.**

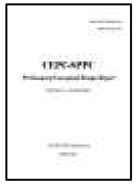
| DRD Themes | Proposals | Institutes | People |
|---|---|---|---|
| 1 Gaseous detectors | 7 (DD) | IHEP, USTC, SJTU, JLU, SIAT, THU, WHU | 46 |
| 2 Liquid detectors | 2 (PA) | IHEP | 7 |
| 3 Solid state detectors | 4 (HJ) | SCNU, SDU, SJTU, THU | 10 |
| 4 PID and photo detectors | 3 (HJ) | IHEP, Henan NU, SDU | 11 |
| 5 Quantum & emerging tech | 2 (HJ) | SDU, THU | 7 |
| 6 Calorimetry | 6 (PA) | IHEP, SDU, SCNU, PKU | 37 |
| 7 Electronics | 3 (HJ) | IHEP, SDU, SJTU | 5 |
| 8 Integration | 3 (HJ) | IHEP | 8 |
| **Total** | **30** | **11 institutes** | **131** |

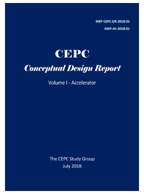
- The total funding, already allocated or wished for, is ~50 MCNY
- Many of the CEPC ongoing R&Ds are in this list. Some may be missing. We will go through all directly related projects and make sure that all necessary ones have proper collaboration.

# CEPC Evolution Milestones

| Year | 2012 | 2013 | 2015 | 2017 | 2018 | 2023 | 2025 | 2027 | 2030 | 2035 |
|---|---|---|---|---|---|---|---|---|---|---|

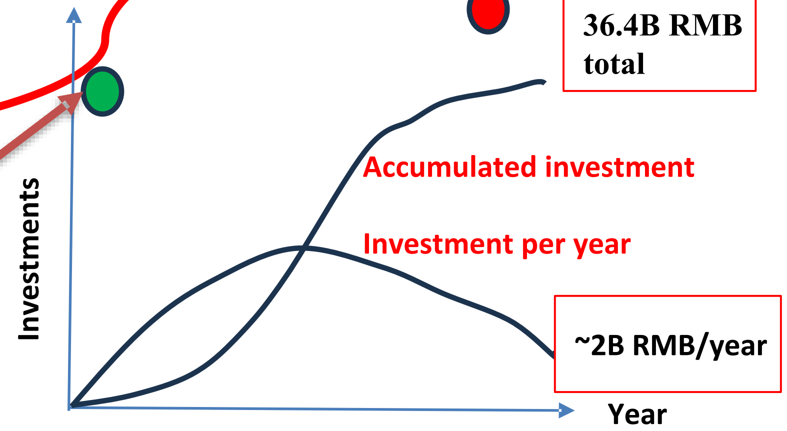
CEPC kickoff meeting in Sept. 2013





Proposal (2025) for CEPC entering 15th five year plan

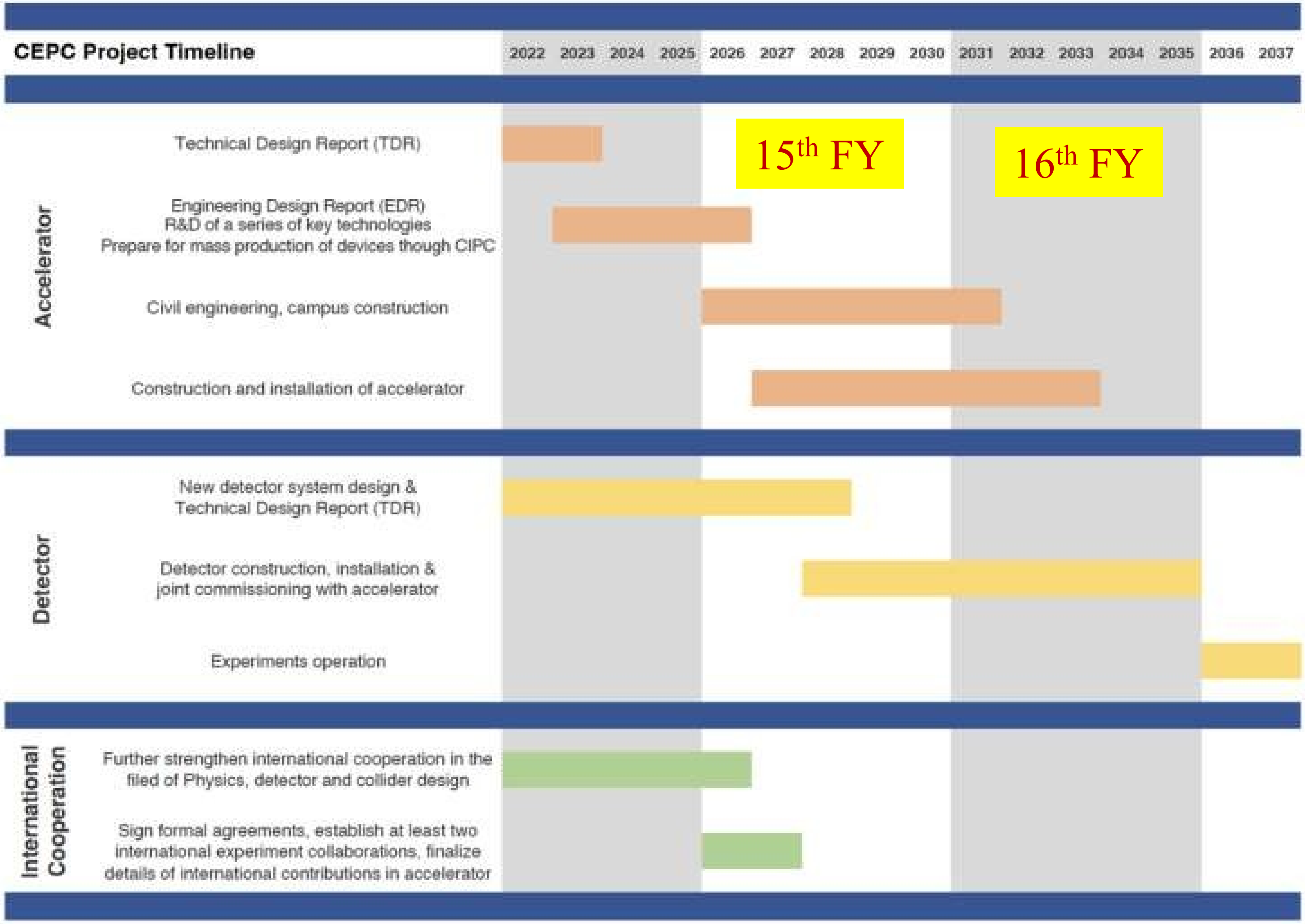
EDR is the critical path towards CEPC construction starting around 2027




| 2012.9 | 2013.9 | 2015.3 | 2017.4 | 2018.11 | 2023.12 | 2024 | ~ | 2027 | | ~2035 |
|---|---|---|---|---|---|---|---|---|---|---|
| CEPC proposed | | Pre-CDR | Progress report | CDR | TDR | | | EDR | start of construction | Completion |

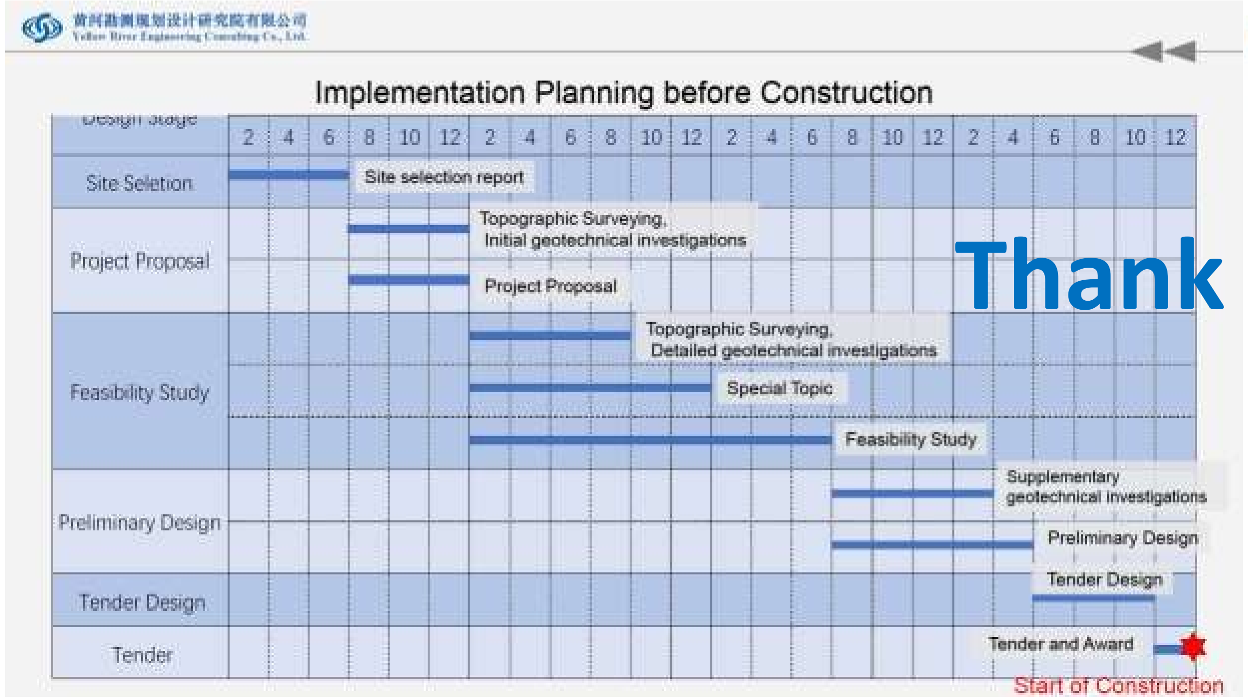
# CEPC Planning and Schedule

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



# CEPC Site Implementation and Construction Plans

## CEPC site implementation plan in EDR

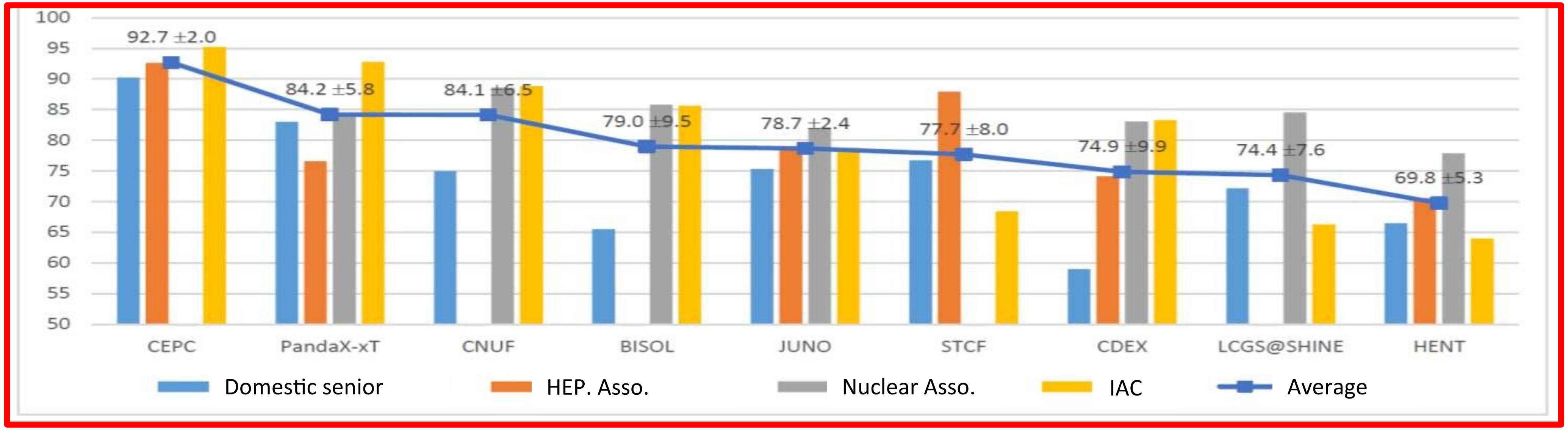



## CEPC construction plan


Thank you

# CEPC Project Development towards construction

- **TDR has been completed** (review + revision) to be **formally released on Dec. 25，2023.**
- **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 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.**



# Participating and Potential Collaborating Companies in China and Worldwide

| | 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


# CEPC International Collaboration-1



## CEPC attracts significant International participation and collaborations

**Accelerator TDR report**: 1114 authors from 278 institutes ( including 159 International Institutes, 38 countries ) arXiv: 2312.14363


- More than 20 MoUs have been signed with international institutions and universities
- CEPC International Workshop since 2014
- EU-US versions of CEPC WS since 2018
- Annual working month at HKUST-IAS (mini workshops and HEP conference) since 2015



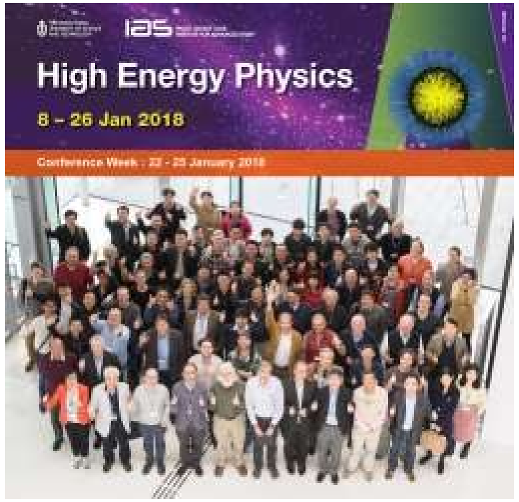
CEPC workshop in Chicago, 2019

# CEPC International Collaboration-2


The first CEPC-SppC international Collaboration Workshop
Nov 6-8, 2017, IHEP, Bejing
http://indico.ihep.ac.cn/event/6618

Workshop on the Circuar Electron Positron Collider-EU edition
May 24-26, 2018, Università degli Studi Roma Tre, Rome, Italy
https://agenda.infn.it/conferenceDisplay.py?ovw=True&confId=14816

3rd CEPC IAC, Nov 8-9, 2017,
IHEP, Beijing




IAS Higgh Energy Physics Workshop
(Since 2015)
http://iasprogram.ust.hk/hep/2018

CEPC Workshop-EU , 2019 Sep 2019, Oxford,UK
https://agenda.infn.it/conferenceDisplay.py?ovw=True&confId=14816

CEPC Workshop, University of Chicago ,
September 16-18, 2019
http://cepc.uchicago.edu/

More than 20 MoUs have been signed with international institutions and universities

CEPC Workshop, he Catholic University of America,
22-23 April 2020, Washingtong, USA (online)
https://indico.cern.ch/event/863751/

# CEPC International Collaboration-3

**HKIAS23 HEP Conference**
**Feb. 14-16, 2023**
https://indico.cern.ch/event/1215937/


**The 2023 International Workshop on Circular Electron Positron Collider, EUEdition,University of Edinburgh, July 3-6, 2023**
https://indico.ph.ed.ac.uk/event/259/overview


**The 2023 international workshop on the high energy Circular Electron Positron Collider (CEPC)**
https://indico.ihep.ac.cn/event/19316/

The 2024 international workshop of CEPC, EU-Edition were held in Marseille, France, April 8-11, 2024.
https://indico.in2p3.fr/event/20053/overview


The 2024 HKUST IAS Mini workshop and conference were held from Jan. 18-19, and Jan. 22-25, 2024, respectively.
https://indico.cern.ch/event/1335278/timetable/?view=standard

**The 2024 international workshop on the high energy Circular Electron Positron Collider (CEPC) will be held from Oct. 23-27, 2024, Hangzhou, China**

Professor Peter Higgs passed away on **April 8, 2024**. We miss him.

# CEPC in Synergy with other Accelerator Projects in China



| Project name | Machine type | Location | Cost (B RMB） | Completion time |
|---|---|---|---|---|
| **CEPC** | Higgs factory<br>Upto ttar energy | Led by IHEP, China | **36.4 (where accelerator 19)** | Around 2035 (starting time around 2027) |
| **BEPCII-U** | e+e-collider 2.8GeV/beam | IHEP (Beijing) | **0.15** | 2025 |
| **HEPS** | $4^{th}$ generation light source of 6GeV | IHEP (Huanrou) | **5** | 2025 |
| **SAPS** | 4th generation light source of 3.5GeV | IHEP (Dongguan) | **3** | 2031 (in R&D, to be approved) |
| **HALF** | 4th generation light source of 2.2GeV | USTC (Hefei) | **2.8** | 2028 |
| **SHINE** | Hard XFEL of 8GeV | Shanghai-Tech Univ., SARI and SIOM of CAS (Shanghai) | **10** | 2027 |
| **S3XFEL** | S3XFEL of 2.5GeV | Shenzhen IASF | **11.4** | 2031 |
| **DALS** | FEL of 1GeV | Dalian DICP | **-** | (in R&D, to be approved, ) |
| **HIAF** | High Intensity heavy ion Accelerator Facility | IMP, Huizhou | **2.8** | 2025 |
| **CIADS** | Nuclear waste transmutation | IMP, Huizhou | **4** | 2027 |
| **CSNS-II** | Spallation Neutron source proton injector of 300MeV | IHEP, Dongguan | **2.9** | 2029 |

**The total cost of the accelerator projects under construction:39B RMB more than CEPC cost of 36.4B RMB**

# Summary

- CEPC addressed most pressing & critical science problems in particle physics
- Accelerator design and technology R&D are reaching maturity, TDR completed in 2023, ready for construction in 3-5 years
- Reference detector TDR under preparation, to be completed by 2025 for the proposal of the 15th 5-year plan
- A strong and experienced team, backed by IHEP and international teams
- Schedule will follow China's 15th 5-year plan, Call for collaboration and proposals once CEPC is (preliminary) approved
- Continue to work with government and funding agencies to get support
- International collaborations are mostly welcome.

# Acknowledgements



Thanks go to CEPC-SppC team's hard works,
international and CIPC collaborations

Special thanks to CEPC IB, SC, IAC, IARC and TDR review (+cost) committee's critical advices, suggestions and encouragement

## Thanks for your attention