The CEPC Studies, R&Ds and Status, and Synergies with the LC Community

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http://cepc.ihep.ac.cn/
Outline

➢ Introduction to the Circular Electron Positron Collider (CEPC)
   ➢ Brief history and the Plan

➢ Studies, R&Ds and Status, and Synergies with the LC Community
   ➢ Physics Programs
   ➢ Accelerator R&Ds
   ➢ Detector R&Ds
   ➢ Synergies with the LC Community

➢ Other Aspects (briefly and if time permits)
   ➢ Synergies in IHEP and industry engagement
   ➢ the CEPC team, committees, international efforts/contributions
   ➢ Project site candidates and timeline

➢ Summary and Prospect
Proposed in 2012 right after the Higgs discovery, CEPC will be an e+e− facility, a Higgs factory producing Higgs, W and Z bosons, and top quarks, for precision measurements and searches of new physics beyond the Standard Model (BSM).

The penciled construction starts in 2026 and operation in 2030s.

Upgrade in mind: Super pp Collider (SppC) of $\sqrt{s} \sim 100$ TeV in the future.

One of the proposed Higgs factories

CEPC Accelerator white paper for Snowmass21, arXiv:2203.09451

CEPC versus FCC-ee
- Collisions expected in 2030s
- Large tunnel cross section (ee & pp coexistence)
- Lower cost: ~½ the construction cost with similar luminosity up to 240 GeV

CEPC versus Linear Colliders
- Higher luminosity for Higgs and Z runs
- Potential upgrade for pp collider
- LCs have higher energy potentials and in principle polarized beams
Reached Major Milestones

CEPC-SPPC Kickoff (2013.9)

CEPC CDR Released (2018.11)

CEPC IAC Meeting (2015.9)
**CEPC CDR: first for a circular $e^+e^-$ Higgs factory**

Since 2019

- CEPC project with many R&Ds towards
  - (1) Accelerator TDR (2023)
  - (2) Detector key technologies R&D and establishment of seeds for International Collaborations

Identify challenges and devise solutions
Studies, R&D and Status, and Synergies with LC

➢ Physics Programs
➢ Accelerator R&D
➢ Detector R&D
➢ Synergies with the LC Community
Physics Programs (in CDR)

- Will perform detailed studies of various physics processes
- Higgs bosons will be detected via recoil mass of the reconstructed Z, allowing for model independent & full investigation of the Higgs and any new physics that Higgs may reveal
- Jets and events with missing neutrinos will be well reconstructed and identified

$e^+e^-$ annihilations at the CEPC

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[O(100) Journal / arXiv papers]
Physics Programs (thrgh workshops + white papers)

Physics similar to FCC-ee, ILC, CLIC
- 2019.7 Workshop@PKU: EW, Flavor, QCD working groups formed
- 2020.1 Workshop@HKUST-IAS: Review progress, EW draft ready
- 2021.4 Workshop@Yangzhou: BSM working group formed
- 2022.5 Workshop of CEPC physics, software and detector
- 2022 Input for Snowmass study  arXiv:2205.08553

<table>
<thead>
<tr>
<th>CEPC Operation mode</th>
<th>ZH</th>
<th>Z</th>
<th>W<em>W</em></th>
<th>ttbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>√s [GeV]</td>
<td>~ 240</td>
<td>~ 91.2</td>
<td>~ 160</td>
<td>~ 360</td>
</tr>
<tr>
<td>Run time [years]</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>L / IP [×10^{34} cm^{-2}s^{-1}]</td>
<td>3</td>
<td>32</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>∫ L dt [ab^{-1}, 2 IPs]</td>
<td>5.6</td>
<td>16</td>
<td>2.6</td>
<td>-</td>
</tr>
<tr>
<td>Event yields [2 IPs]</td>
<td>1×10^6</td>
<td>7×10^{11}</td>
<td>2×10^7</td>
<td>-</td>
</tr>
<tr>
<td>Run time [years]</td>
<td>10</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>L / IP [×10^{34} cm^{-2}s^{-1}]</td>
<td>8.3</td>
<td>191.7</td>
<td>26.6</td>
<td>0.8</td>
</tr>
<tr>
<td>∫ L dt [ab^{-1}, 2 IPs]</td>
<td>20</td>
<td>96</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Event yields [2 IPs]</td>
<td>4×10^6</td>
<td>4×10^{12}</td>
<td>5×10^7</td>
<td>5×10^5</td>
</tr>
</tbody>
</table>
Physics Programs (compare w/ LHC)

- Unprecedented precision measurements on Higgs, EW, flavor physics and QCD
- BSM physics (e.g. dark matter, EW phase transition, SUSY, LLP, …) probed up to ~10 TeV scale

<table>
<thead>
<tr>
<th></th>
<th>240 GeV, 20 ab$^{-1}$</th>
<th>360 GeV, 1 ab$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ZH</td>
<td>vvH</td>
</tr>
<tr>
<td>inclusive</td>
<td>0.26%</td>
<td>1.40%</td>
</tr>
<tr>
<td>H→bb</td>
<td>0.14%</td>
<td>1.59%</td>
</tr>
<tr>
<td>H→cc</td>
<td>2.02%</td>
<td>8.80%</td>
</tr>
<tr>
<td>H→gg</td>
<td>0.81%</td>
<td>3.40%</td>
</tr>
<tr>
<td>H→WW</td>
<td>0.53%</td>
<td>2.80%</td>
</tr>
<tr>
<td>H→ZZ</td>
<td>4.17%</td>
<td>20%</td>
</tr>
<tr>
<td>H → ττ</td>
<td>0.42%</td>
<td>2.10%</td>
</tr>
<tr>
<td>H → γγ</td>
<td>3.02%</td>
<td>11%</td>
</tr>
<tr>
<td>H → μμ</td>
<td>6.36%</td>
<td>41%</td>
</tr>
<tr>
<td>H → Zγ</td>
<td>8.50%</td>
<td>35%</td>
</tr>
<tr>
<td>Br$_{upper}$ (H → inv.)</td>
<td>0.07%</td>
<td></td>
</tr>
<tr>
<td>$\Gamma_H$</td>
<td>1.65%</td>
<td>1.10%</td>
</tr>
</tbody>
</table>

arXiv:2205.08553

CEPC can reveal new physics at energy ~ 10 TeV or higher
Physics Programs: Higgs and EW

• Unprecedented precision measurements on Higgs, EW, flavor physics and QCD
• BSM physics (e.g. dark matter, EW phase transition, SUSY, LLP, …) up to ~10 TeV scale

<table>
<thead>
<tr>
<th>Observable</th>
<th>current precision</th>
<th>CEPC precision (Stat. Unc.)</th>
<th>CEPC runs</th>
<th>main systematic</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta m_Z$</td>
<td>2.1 MeV [37–41]</td>
<td>0.1 MeV (0.005 MeV)</td>
<td>$Z$ threshold</td>
<td>$E_{beam}$</td>
</tr>
<tr>
<td>$\Delta I_Z$</td>
<td>2.3 MeV [37–41]</td>
<td>0.025 MeV (0.005 MeV)</td>
<td>$Z$ threshold</td>
<td>$E_{beam}$</td>
</tr>
<tr>
<td>$\Delta m_W$</td>
<td>9 MeV [42–46]</td>
<td>0.5 MeV (0.35 MeV)</td>
<td>$WW$ threshold</td>
<td>$E_{beam}$</td>
</tr>
<tr>
<td>$\Delta I_W$</td>
<td>49 MeV [46–49]</td>
<td>2.0 MeV (1.8 MeV)</td>
<td>$WW$ threshold</td>
<td>$E_{beam}$</td>
</tr>
<tr>
<td>$\Delta m_t$</td>
<td>0.76 GeV [50]</td>
<td>$\mathcal{O}(10)$ MeV$^a$</td>
<td>$t\bar{t}$ threshold</td>
<td></td>
</tr>
<tr>
<td>$\Delta A_e$</td>
<td>$4.9 \times 10^{-3}$ [37, 51–55]</td>
<td>$1.5 \times 10^{-5}$ ($1.5 \times 10^{-5}$)</td>
<td>$Z$ pole ($Z \rightarrow \tau\tau$)</td>
<td>Stat. Unc.</td>
</tr>
<tr>
<td>$\Delta A_\mu$</td>
<td>0.015 [37, 53]</td>
<td>$3.5 \times 10^{-5}$ ($3 \times 10^{-5}$)</td>
<td>$Z$ pole ($Z \rightarrow \mu\mu$)</td>
<td>point-to-point Unc.</td>
</tr>
<tr>
<td>$\Delta A_\tau$</td>
<td>$4.3 \times 10^{-3}$ [37, 51–55]</td>
<td>$7.0 \times 10^{-5}$ ($1.2 \times 10^{-5}$)</td>
<td>$Z$ pole ($Z \rightarrow \tau\tau$)</td>
<td>tau decay model</td>
</tr>
<tr>
<td>$\Delta A_0$</td>
<td>0.02 [37, 56]</td>
<td>$20 \times 10^{-5}$ ($3 \times 10^{-5}$)</td>
<td>$Z$ pole</td>
<td>QCD effects</td>
</tr>
<tr>
<td>$\Delta A_c$</td>
<td>0.027 [37, 56]</td>
<td>$30 \times 10^{-5}$ ($6 \times 10^{-5}$)</td>
<td>$Z$ pole</td>
<td>QCD effects</td>
</tr>
<tr>
<td>$\Delta \sigma_{had}$</td>
<td>37 pb [37–41]</td>
<td>2 pb (0.05 pb)</td>
<td>$Z$ pole</td>
<td>luminosity</td>
</tr>
<tr>
<td>$\delta R_0^b$</td>
<td>0.003 [37, 57–61]</td>
<td>0.0002 ($5 \times 10^{-6}$)</td>
<td>$Z$ pole</td>
<td>gluon splitting</td>
</tr>
<tr>
<td>$\delta R_0^c$</td>
<td>0.017 [37, 57, 62–65]</td>
<td>0.001 ($2 \times 10^{-5}$)</td>
<td>$Z$ pole</td>
<td>gluon splitting</td>
</tr>
<tr>
<td>$\delta R_0^t$</td>
<td>0.0012 [37–41]</td>
<td>$2 \times 10^{-4}$ ($3 \times 10^{-6}$)</td>
<td>$Z$ pole</td>
<td>$E_{beam}$ and $t$ channel</td>
</tr>
<tr>
<td>$\delta R_\mu^0$</td>
<td>0.002 [37–41]</td>
<td>$1 \times 10^{-4}$ ($3 \times 10^{-6}$)</td>
<td>$Z$ pole</td>
<td>$E_{beam}$</td>
</tr>
<tr>
<td>$\delta R_\tau^0$</td>
<td>0.017 [37–41]</td>
<td>$1 \times 10^{-4}$ ($3 \times 10^{-6}$)</td>
<td>$Z$ pole</td>
<td>$E_{beam}$</td>
</tr>
<tr>
<td>$\delta N_\nu^0$</td>
<td>0.0025 [37, 66]</td>
<td>$2 \times 10^{-4}$ ($3 \times 10^{-5}$)</td>
<td>$ZH$ run ($\nu\nu\gamma$)</td>
<td>Calo energy scale</td>
</tr>
</tbody>
</table>
Physics Program: Discovery Potential (BSM)

Compared with HL-LHC, CEPC has significantly better detection sensitivity for dark matter and selected Higgs exotic decays. The high luminosities that circular machines offer to physics complement the high energy potential of linear colliders.
Studies, R&D and Status, and Synergies with LC

➢ Physics Programs
➢ Accelerator R&D
➢ Detector R&D
➢ Synergies with the LC Community
Design Improvements, from CDR (2018) to TDR (23)

- 100 km double ring design (30 MW SR power, upgradable to 50MW).
- Switchable operation for H & Z, W modes without hardware change.

### Operation mode

<table>
<thead>
<tr>
<th>Operation mode</th>
<th>ZH</th>
<th>Z</th>
<th>W*W^-</th>
<th>tt</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sqrt{s}$ [GeV]</td>
<td>~240</td>
<td>~91.2</td>
<td>158-172</td>
<td>~360</td>
</tr>
<tr>
<td>$L / IP$ [x10^{34} cm^-2s^-1]</td>
<td>CDR (2018)</td>
<td>3</td>
<td>32</td>
<td>10</td>
</tr>
<tr>
<td>TDR (30MW)</td>
<td>5.0</td>
<td>115</td>
<td>16</td>
<td>0.5</td>
</tr>
<tr>
<td>TDR (50MW)</td>
<td>8.3</td>
<td>191.7</td>
<td>26.6</td>
<td>0.8</td>
</tr>
</tbody>
</table>
R&Ds on the Key Technologies

Klystrons
SC cavities
SRF technology
Linac injector
SC Quadrupole
Vacuum
Magnets
Kickers
High Q SCRF Cavities

- 1.3 GHz 9-cell SCRF cavity for booster: \( Q_0 = 3.4 \times 10^9 @ 26.5 \text{ MV/m} \)
- 650 MHz 2-cell SCRF cavity for collider ring: \( Q_0 = 6.0 \times 10^9 @ 22.0 \text{ MV/m} \)
- 650 MHz 1-cell SCRF cavity for collider ring: \( Q_0 = 6.0 \times 10^9 @ 31.0 \text{ MV/m} \)

Medium-temperature (Mid-T) annealing adopted to reach \( Q_0 = 3.4 \times 10^9 @ 26.5 \text{ MV/m} \)

N-infusion adopted to reach \( Q_0 = 6.0 \times 10^9 @ 22.0 \text{ MV/m} \)

All SCRF satisfied CEPC design specifications! The 1.3 GHz SCRF cavity could be used for LCs.
High Efficiency Klystrons

- The 1st Klystron prototype, design 65%, achieved efficiency ~ 63%.
- The 2nd Klystron prototype tested at PAPS in 2022, design eff. is 77%, achieved eff. ~ 70.5% (so far), a window broke, under investigation + repairing
- The 3rd Klystron (MBK) is being fabricated, design eff. is ~ 80.5%.
- High efficiency Klystron helps to reduce electricity consumption.

The 1st Klystron (tested)

The 2nd Klystron (testing)

The 3rd multi-beam Klystron (MBK) under fabrication
**HTS SC Magnet and Iron-Based Superconductor**

- **LPF1-U test after the 2\textsuperscript{nd} thermal cycle**
  - 6865 A & 12.47 T @ 4.2 K
  - Two apertures - 2*∅ 14 mm

**Challenges**
- Fabrication process, stress control, quench protection

**SS Tape**
- Achieved the highest \( J_e \) in 2022
- Significantly reduced the cost and improved mechanical properties of IBS conductor.

**Timeline**
- **2018**
  - NbTi+NbSn
  - Nb\(_3\)Sn+HTS
  - 10T @ 4.2K
  - 15T @ 4.2K

- **2021**
  - Nb\(_3\)Sn+NbSn
  - Nb\(_3\)Sn+HTS
  - 45° aperture
  - 20T @ 4.2K

- **2025**
  - Nb\(_3\)Sn+NbSn
  - Two apertures

**Achievements**
- Stainless-steel stabilized IBS tape achieved the highest \( J_e \) in 2022
- Significantly reduced the cost and improved mechanical properties of IBS conductor.
The Plasma Injector

<table>
<thead>
<tr>
<th>Booster Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (GeV)</td>
<td>45.5</td>
</tr>
<tr>
<td>Bunch Charge (nC)</td>
<td>0.78</td>
</tr>
<tr>
<td>Bunch length (um)</td>
<td>&lt;3000</td>
</tr>
<tr>
<td>Energy Spread (%)</td>
<td>0.2</td>
</tr>
<tr>
<td>$\varepsilon_N$ ($\mu$m·rad)</td>
<td>&lt;800</td>
</tr>
<tr>
<td>Bunch Size (um)</td>
<td>&lt;2000</td>
</tr>
</tbody>
</table>

High eff. uniform wakefield acceleration of a positron beam using stable asymmetric mode in a hollow channel plasma

3D Quasi-static PIC simulations show:
- Energy extraction efficiency ~ 30%
- Energy spread ~ 1%

PRL 127, 174801 (2021)

Plasma dechirper exp at SXFEL

Experiment Goal:
1. Decrease the energy spread from 1% to 0.1%
2. Study Hollow channel impact on beam quality
IHEP’s New SCRF Lab (PAPS) in Operation

CEPC SCRF Test Facility is located at IHEP Huairou Area (4500m$^2$)

New SC Lab Design (4500m$^2$)

SC New Lab (PAPS) has been in operation since June 2021

Cryogenic system hall

Vacuum furnace (doping & annealing) Nb$_3$Sn furnace Nb/Cu sputtering device Cavity inspection camera and grinder 8-cell cavity pre-tuning machine

Temperature & X-ray mapping system Second sound cavity quench detection system Helmholtz coil for cavity vertical test Vertical test dewars Horizontal test cryostat
Studies, R&D and Status, and Synergies with LC

- Physics Programs
- Accelerator R&D
- Detector R&D
- Synergies with the LC Community
Several Conceptual Detector Designs

- Magnet (3T/2T)
- Yoke + Muon (RPC or $\mu$-RWELL)
- LumiCal
- Si Pixel Vertex
- PFA HCAL
- PFA ECAL
- SIT TPC SET
- FTD ETD

- IDEA concept
  (also proposed for FCC-ee)
  - Preshower ($\mu$-RWELL)
  - Dual-readout calorimeter
  - Yoke + Muon ($\mu$-RWELL)

- The 4th Concept
  - PFA HCAL
  - Partially Yoke
  - Magnet (3T/2T)
  - PID (DC+ToF)
  - Crystal ECAL (Transverse bar)

- FST concept
  (Full Silicon Tracker)
Novel Conceptual Detector Design

**Advantage:** Cost efficient, high density
**Challenges:** Light yield, transparency, massive production.

**Solenoid Magnet (3T / 2T) Between HCAL & ECAL**

**Advantage:** the HCAL absorbers act as part of the magnet return yoke.
**Challenges:** thin enough not to affect the jet resolution (e.g. BMR); stability.

**Transverse Crystal bar ECAL**

**Advantage:** better $\pi/\gamma$ reconstruction.
**Challenges:** minimum number of readout channels; compatible with PFA calorimeter; maintain good jet resolution.

A Drift chamber that is optimized for PID

**Advantage:** Work at high luminosity Z runs
**Challenges:** sufficient PID power; thin enough not to affect the moment resolution.

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**Novel detector design based on PFA calorimeter. Aim at improving BMR 4% → 3%**
R&Ds on Silicon Pixel Chips

**Goal:** $\sigma(\text{IP}) \sim 5 \mu m$ for high momentum track

CDR design specifications
- Single point resolution $\sim 3 \mu m$
- 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

- JadePix-3 Pixel size $\sim 16 \times 23 \mu m^2$
- TaichuPix-3, FS 2.5x1.5 cm$^2$ 25x25 $\mu m^2$ pixel size
- CPV4 (SOI-3D), 64x64 array $\sim 21 \times 17 \mu m^2$ pixel size

Develop CEPCPix for a CEPC tracker basing on ATLASpix3 CN/IT/UK/DE TSI 180 nm HV-CMOS process

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

Tower-Jazz 180nm CiS process Resolution 5 microns, 53mW/cm$^2$
R&Ds on Vertex Detector Prototype

Beam tests on the full vertex detector prototype (TaichuPix-3, JadePix-3) in DESY, Dec. 2022 and Apr. 2023:

TEST BEAM

MIMOSA Telescope

An open window in backside of PCB with a size of 12mm x 9mm

25.7 mm

15.9 mm

TaichuPix-3 Telescope (6 layers)

Hitmap of 4 GeV $e^+ / e^-$ beam

6 layers of hit map are fine.
**R&Ds on Drift Chamber for PID**

- **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 beam-tests led by the INFN group in 2021 and 2022
R&Ds on the Time Projection Chamber

Baseline main tracker
\[ \sigma_{(r-\phi)} \sim 100 \ \mu m \]

GEM-MM cathode TPC Prototype + UV laser beams

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.

Low power FEE ASIC

Test of Prototype TPC

\[ \sigma_x < 100 \ \mu m \] for drift length of 27cm

MOST 1 (IHEP+THU)

65 nm CMOS ASIC

Power < 2.5 mW/ch
R&Ds on PFA Calorimeters

Calorimeter options

Chinese institutions have been focusing on Particle Flow calorimeters

R&D supported by MOST, NSFC and IHEP seed funding

Electromagnetic
- ECAL with Silicon and Tungsten (LLR, France)
- ECAL with Scintillator+SiPM and Tungsten (IHEP + USTC)

High Granularity
- SDHCAL with RPC and Stainless Steel (SJTU + IPNL, France)
- SDHCAL with ThGEM/GEM and Stainless Steel (IHEP + UCAS + USTC)
- HCAL with Scintillator+SiPM and Stainless Steel (IHEP + USTC + SJTU)

Hadronic
- Crystal Calorimeter (LYSO:Ce + PbWO)
- Dual readout calorimeters (INFN, Italy + Iowa, USA) — RD52
PFA Calorimeter Prototypes

ScW ECAL Prototype (32-layer, 6720-ch)

Sct + SiPM AHCAL Prototype (40-layer, 12960-ch)

Combined: ScW-ECAL + AHCAL

 Beam-test at CERN SPS for two prototypes in Oct. 2022
PFA Calorimeter Prototypes

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

USTC, IHEP, SJTU, Japanese & Israel groups have close collaboration and regular meetings. The next beam test is April – May (now) at CERN.
R&Ds on SDHCAL

MOST 1: RPC and MPGD (RWELL) R&D, MIP Eff > 95%

R&D Plan: 5-D SDHCAL (X, Y, Z, E, Time)
- MRPC + fast timing PETIROC ASIC (~40 ps)

SDHCAL-GRPC (1.3 m³, IPNL)
JINST 15, P10009 (2020)
JINST 17, P07017 (2022)

R51 GDD trigger + tracker

Tested RPWELL prototypes

MOST 1: RPC and MPGD (RWELL) R&D, MIP Eff > 95%
GRPC 1m x 1m (SJTU)
JINST 16, P12022 (2021)

RWELL 0.5m x 1m (USTC+IHEP)

SJTU
IPNL
IJCLab
OMEGA
CIEMAT

FE Board

JTAG
UART
Ethernet
ZCU102
DIF Card

JINST 15, P10009 (2020)
JINST 17, P07017 (2022)
R&Ds on High Granularity Crystal ECAL

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

Crystal Fan Design
- Fine segmentation in Z, φ, r

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

Full Simulation Studies
- BMR = 1.2%
- BMR of SiW ECAL ~ 2.3%
- Optimizing PFA for crystals

Performance with photons
- Crystal ECAL
- H → γγ

Performance with jets
- Crystal ECAL
- H → gg
- BMR: 3.6%

Dual readout crystal calorimeter also being considered by USA and Italian colleagues
R&Ds on New HCAL with Scintillating Glass Tiles

Goal

- Better hadronic energy resolution
- To further improve BMR

Full simulation studies

Scintillator HCAL: Plastic vs. Glass

Varying glass thickness

Performance study with jets

Scintillating Glass R&D

Testing Scintillating Glass Samples

Tiles for AHCAL (30x30x3mm)

‘SiPM-on-Tile” design for HCAL

ZH(Z → vνH → gg) at 240 GeV

Detected photons at SiPM: 273.8 p.e./MIP
R&Ds on IDEA Tracker and Dual Readout Calorimeter

Italian groups and IHEP colleagues participated the beam test at CERN.
Machine Detector Interface (MDI)

Crossing angle: 33 mrad
Focal length: 2.2 m

Final focusing magnets (QD0, QF1) with Segmented Anti-Solenoidal Magnets

Beam Pipe
\( \phi 28 \rightarrow 20 \text{ mm}, \text{Be thickness: } 0.85 \rightarrow 0.35 \text{ mm} \)

Vertex
LumiCal Tracker
Silicon Tracker

2021 Workshop on CEPC Detector & MDI Mechanical Design, Oct.22-23
https://indico.ihep.ac.cn/event/14392/

22 Workshop on CEPC Detector & MDI Mechanical Design, Mar.30 – Apr. 1, 2023:
https://indico.ihep.ac.cn/event/19071/

Workshop on CEPC Central Beampipe and Beryllium Application May 6, 2022,
https://indico.ihep.ac.cn/event/16173/
CEPC Software Migration to Key4hep

**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
Synergies with LC

- Circular machine’s high luminosities at relatively low energies complement the high energies of linear colliders.
- The R&Ds on 1.3 GHz SCRF cavity and the high efficiency Klystron will benefit the accelerator communities, including the LCs’.
- The studies of machine and detector interface will benefit circular and linear colliders.
- The CPEC detector came from ILC-ILD. Due to different working modes and accelerator energy ranges, a lot of R&Ds and optimizations have been carried out. With the 4th concept CEPC detector, progresses made in PIDs, PFA Calorimeters, the possible use of scintillating glass tiles, and the idea of a SC magnet between the ECAL and HCAL, all will contribute to detector technologies, on circular machines and on linear colliders alike.
Other Aspects of CEPC

- Synergies in IHEP and industry engagement
- the CEPC team, committees, international efforts/contributions
- Project site candidates and timeline
Synergy: IHEP experience with large projects

- IHEP is one of the few institutions in the world that can host a project like the CEPC:
  - It has rich management experience, and has successful constructed many large scientific facilities
  - It has full coverage of all technical disciplines for accelerators and detectors, in particular for the design, construction and operation of the circular e+e- collider (BEPCII) and the detector (BESIII)
  - It has all necessary infrastructures for constructions of large facilities
  - It has successfully hosted international projects such as BESIII, Daya Bay, JUNO, LHAASO, etc.
- IHEP is committed in CEPC, its workplan is endorsed by CAS
Large amount of key technologies validated in other projects: **BEPCII, HEPS, ...**

### CEPC R&D

~ 50% cost of acc. components

- High efficiency klystron
- 650MHz SRF cavities
- Key components to e+ source
- High performance Linac
- Electrostatic Deflector
- Cryogenic system

- Novel magnets: Weak field dipole, dual aperture magnets
- Extremely fast injection/extraction
- Vacuum chamber tech.
- Survey & Alignment for ultra large Acc.
- MDI

### BEPCII / HEPS

~ 40% cost of acc. components

- High precision magnet
- Stable magnet power source
- Vacuum chamber with NEG coating
- Instrumentation, Feedback system
- Traditional RF power source
- SRF cavities

- Electron Source, traditional Linac
- Survey & Alignment
- Ultra stable mechanics
- Radiation protection
- Cryogenic system
- MDI

~ 10% missing items consist of anticipated challenges in the machine integration, commissioning etc. and the corresponding international contribution
CEPC Industrial Promotion Consortium (CIPC)

- CIPC, established in 2017, composed of ~70 high tech. enterprises, covers Superconducting materials, SC cavities, cryomodules, cryogenics, Klystrons, electronics, power source, vacuum, civil engineering, etc. CIPC actively joins the Key technology R&D and prepares for the mass production for the CEPC construction.

- CEPC strongly promote relevant technology development (cost-benefit).

- CEPC study group is surveying main international suppliers.

CCT SC Magnet  Klystron  SC Coil Winding
The CEPC Team so far

- **Institution Board**: 32 institutes, top universities/institutes in China
- **Management team**: comprehensive management experience at construction projects of BEPCII/CSNS/HEPS, and international projects of BESIII/Daya Bay/JUNO/…
- **Accelerator team**: fully over all disciplines with rich experiences at BEPCII, HEPS…
- **Physics and Detector team**: fully over all disciplines with rich experiences at BESIII, Daya Bay, JUNO, ATLAS, CMS, LHCb …

Management team, leading scientists

117 accelerator + ~300 detector staffs currently, + ~ 400 from BEPC/BESIII/JUNO/HEPS/… once CEPC approved
➢ IAC: global renowned scientists and top laboratory or project leaders who have ample experience in project management, planning, and execution of strategies, operating since 2015

➢ IARC & IDRC: leading experts of this field, provide guide to the project director
CEPC International Efforts

CEPC attracts significant International participation

• Conceptual Design Report: 1143 authors from 221 institutes (including 140 Intl. Institutes)
• 20+ MoUs signed and executed
• Intensive collaboration on Physics studies
• Oversea scientists made substantial contributions to the R&D, especially to the detector system
• CEPC International Workshop since 2014
• EU-US versions of CEPC WS: Next one at Marseille
• Annual working month at HKUST-IAS (since 2015)
• The recent CEPC Workshop: Oct. 24-28, 2022 (423 registrants, 285 talks, 38 posters)
• The next CEPC EU Workshop: 3 – 6 July 2023, the Univ. of Edingurgh.

https://events.ph.ed.ac.uk/cepceu2023
CEPC International Efforts

CEPC provides critical input to ESPPU & Snowmass as a major player

Team member actively participated Intl. study (ESPPU and Snowmass committees) and Panel discussions

CEPC attracts intensive international collaboration, ensuring that the CEPC design and technology are among the most advanced in the world.
Candidate Sites and Science Cities

[Diagram showing maps of Qinhuangdao, Huzhou, and Changsha with labeled features such as Klystron Gallery, Linac & BTL Tunnel, and Collider ring tunnel.]

[Image of scientific research core area, public communication area, and living area with TBM tunnel (D6.5m).]
### CEPC Project Timeline

#### Accelerator
- **2023**: Technical Design Report (TDR)
- **2026**: Engineering Design Report (EDR) & R&D of key technologies
- **2026**: Prepare for mass production of devices through CIPC
- **2026**: Civil engineering, campus construction
- **2027**: Construction and installation of accelerator

#### Detector
- **2026**: New detector system design & Technical Design Report (TDR)
- **2028**: Detector construction, installation & joint commissioning with accelerator
- **2036**: Experiments operation

#### International Cooperation
- **2026**: Further strengthen international cooperation in the field of Physics, detector and collider design
- **2026**: Sign formal agreements, establish at least two international experiment collaborations, finalize details of international contributions in accelerator

**2023**: Accelerator TDR; **2026**: EDR; Start construction upon approval
• Since the CDR, lots of progresses have been made in physics program studies, accelerator and detector R&Ds. Contributions in the HEP international community (e.g. Snowmass21). Progresses and breakthroughs from the R&Ds may contribute to common technologies for other proposed Higgs factories.

• The Accelerator TDR is schedule to be in this year.

• The physics driven time-line is very aggressive. Lots of people (young and young at heart) are working hard towards the official start-line.

• Everyone in CEPC extends open arms to collaborations from the HEP community and beyond.
Acknowledgements

Many thanks to the CEPC study group for enormous efforts and achievements!
Thank you!