An Overview of The CEPC Accelerator and Detector

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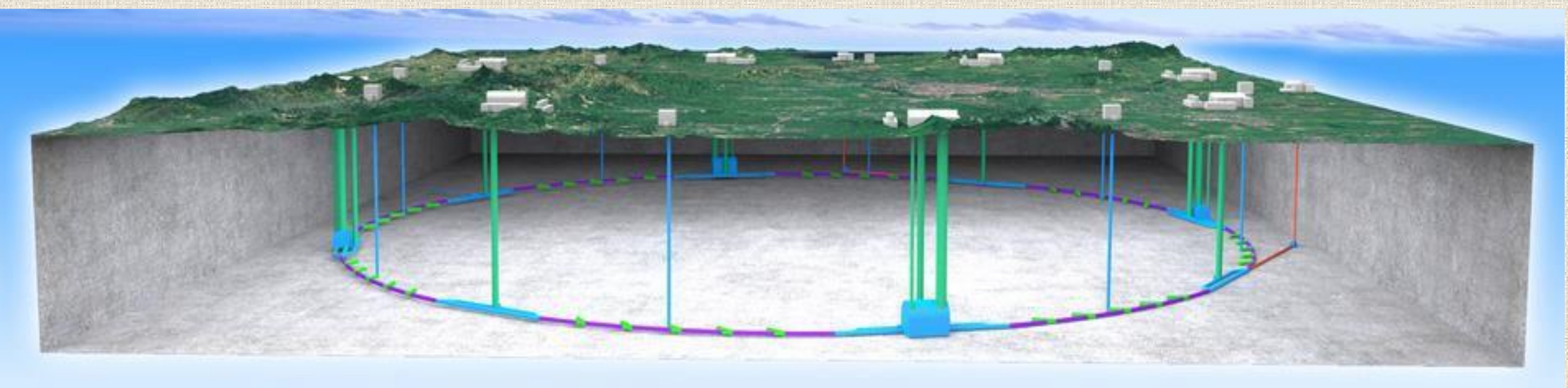
For the CEPC Study Group

US FCC Workshop, Apr 24-26, 2023
Brookhaven National Laboratory

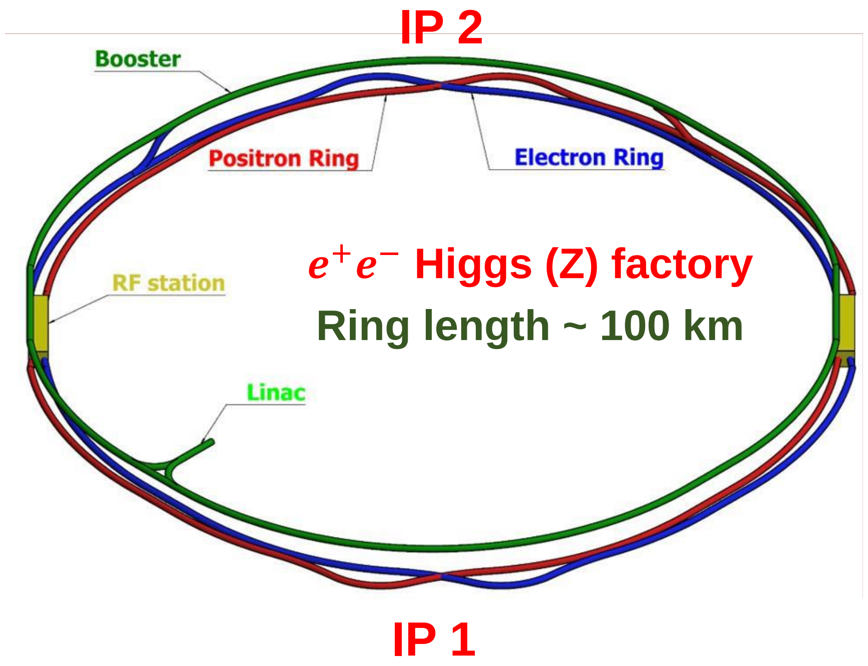


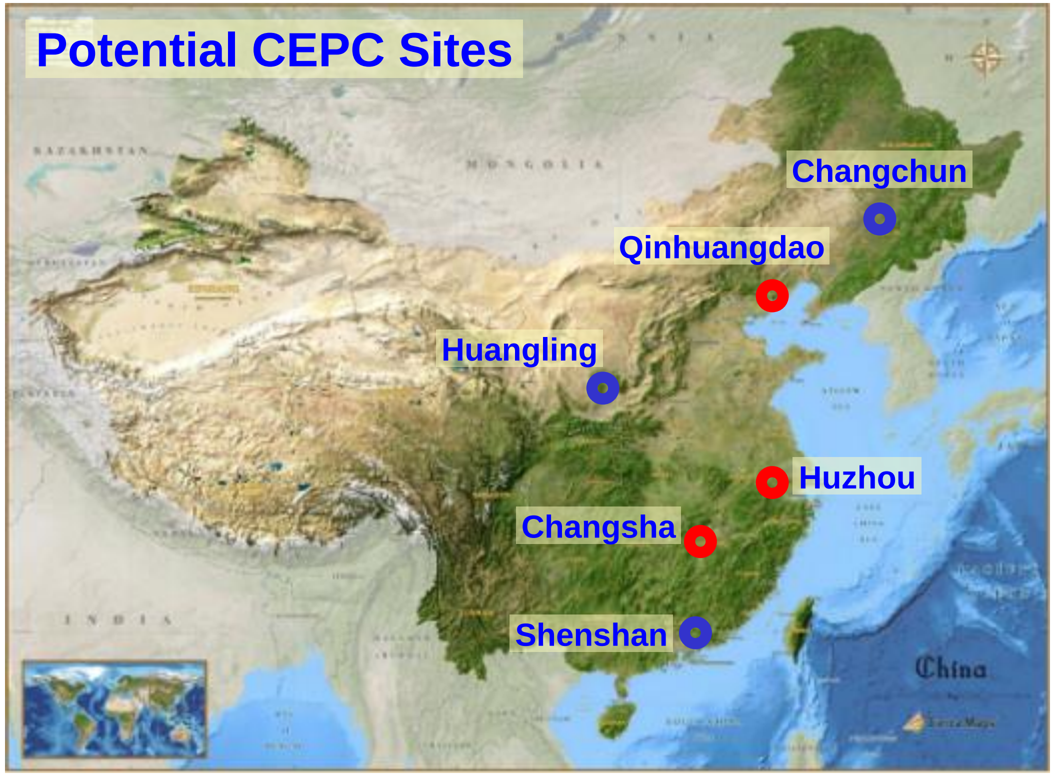
Recent Progresses of The CEPC Accelerator and Detector

- Brief introduction of the CEPC
- The accelerator R&D towards TDR
- Highlights of the detector R&D
- International efforts and connection with industry

The Circular Electron Positron Collider (CEPC)

- The CEPC was proposed in 2012 right after the Higgs discovery. It aims to start operation in 2030s, as an e^+e^- Higgs / Z factory.
- To produce Higgs / W / Z / top for high precision Higgs, EW measurements, studies of flavor physics & QCD, and probes of physics BSM.
- It is possible to upgrade to a *pp* collider (SppC) of $\sqrt{s}$ ~ 100 TeV in the future.



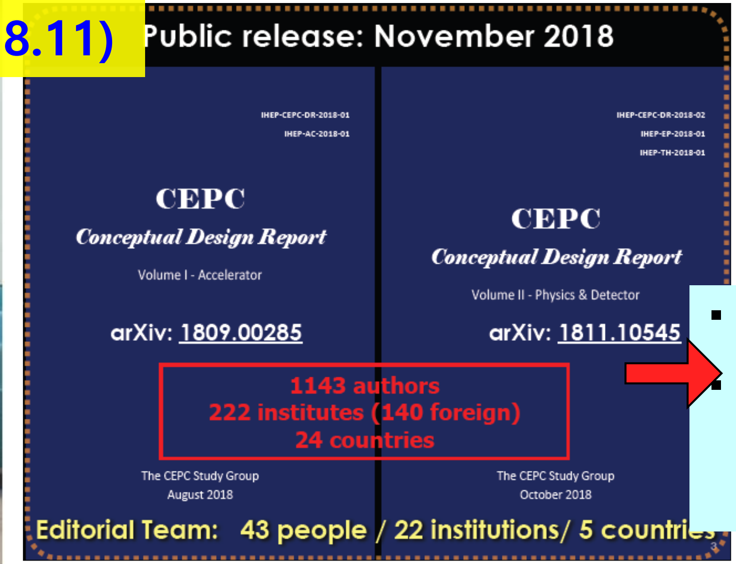


Major Milestones

CEPC-SPPC Kickoff (2013.9)

CEPC IAC Meeting (2015.9)

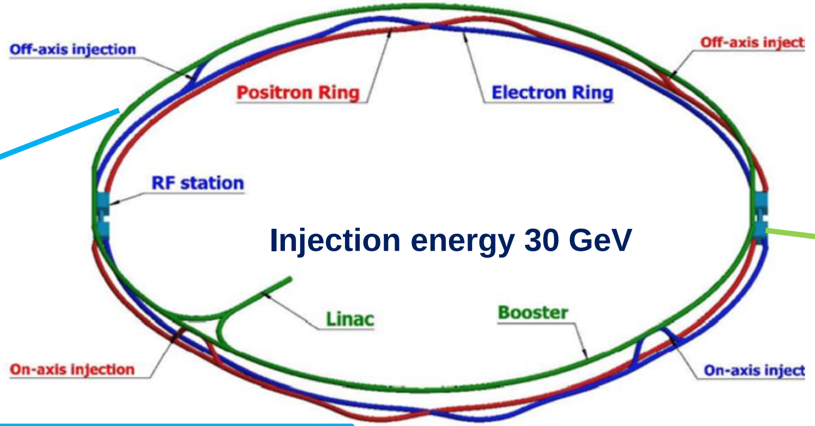
CEPC CDR Released (2018.11)

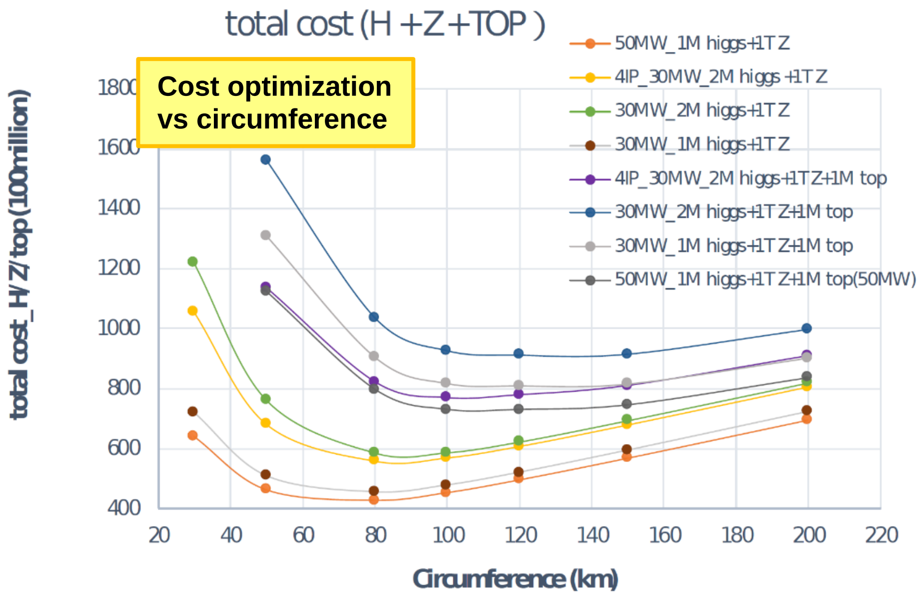


- Accelerator TDR (2023)
- Key detector technology R&D and establishment of seeds for international collaborations

High Luminosity TDR Layout

- 100 km double-ring design (30 MW, upgradable to 50 MW)
- Shared tunnel for booster, collider and SppC
- Switchable between Higgs, W/Z, and top modes





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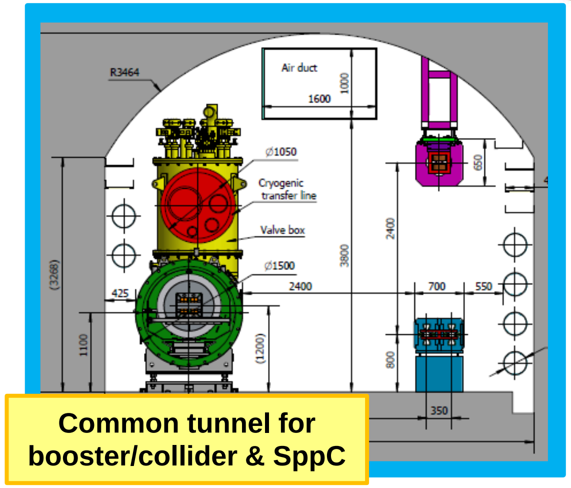
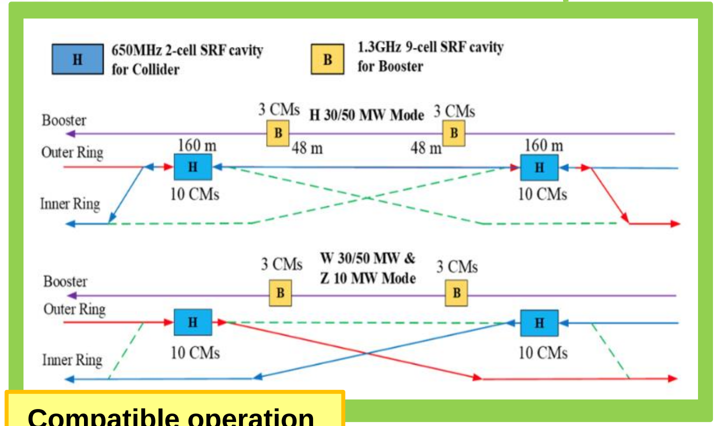


Common tunnel for booster/collider & SppC



Compatible operation for Higgs W and Z

Main Parameters	Higgs	W	Z	ttbar
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	**30**	**30**	**30**	**30**
Energy [GeV]	**120**	**80**	**45.5**	**180**
Bunch number	249	1297	11951	35
Emittance (εx/εy) [nm/pm]	0.64 / 1.3	0.87 / 1.7	0.27 / 1.4	1.4 / 4.7
Beam size at IP (σx/σy) [um/nm]	15 / 36	13 / 42	6 / 35	39 / 113
Bunch length (SR/total) [mm]	2.3 / 3.9	2.5 / 4.9	2.5 / 8.7	2.2 / 2.9
Beam-beam parameters (ξx/ξy)	0.015/0.11	0.012/0.113	0.004/0.127	0.071/0.1
RF frequency [MHz]	650			
Lumin / IP[10^{34}/cm²/s]	**5.0**	**16**	**115**	**0.5**

5

Design and Technical Requirements

Goal

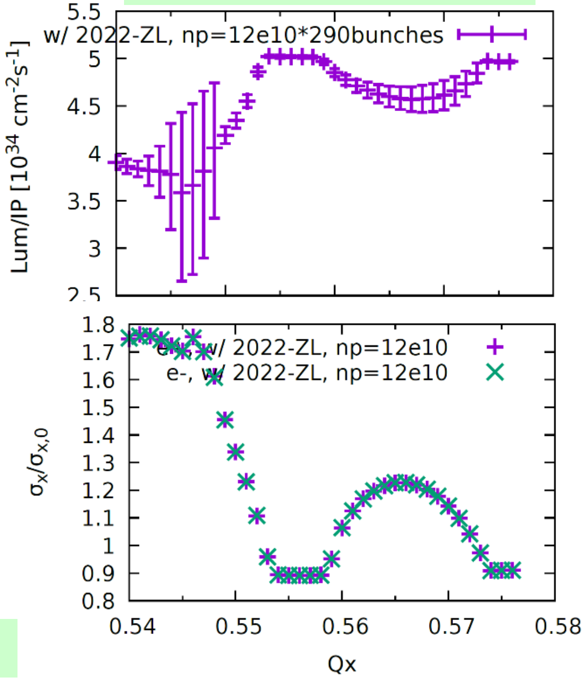
- e^+e^- circular collider as a high lumin. Higgs / Z factory
- Switchable operation for Higgs, W, Z and top modes
- A green machine with a maximum luminosity

Design

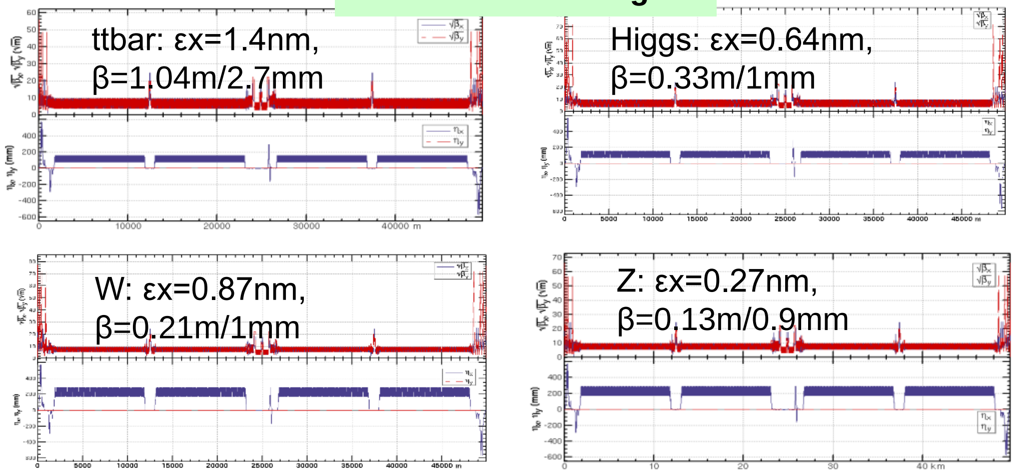
- Accelerator design with the latest ideas completed.
- Lattice optimization for all energies
- Sufficient DA for all energies
- Beam-beam & collective instability

……

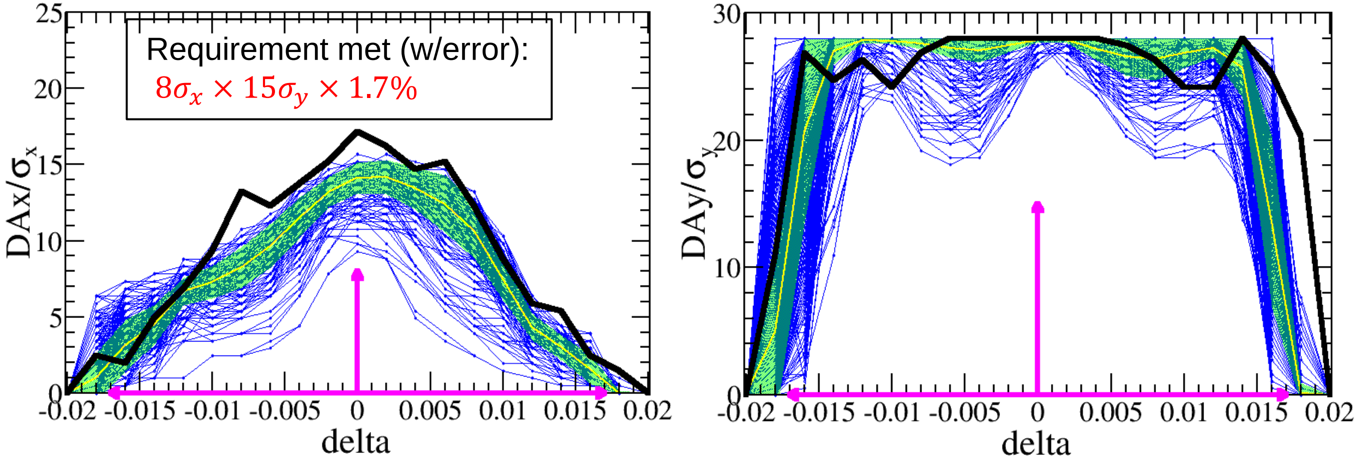
Beam-beam effect study



Lattice for all energies



Dynamic Aperture (DA) optimization



Key Technology Readiness

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

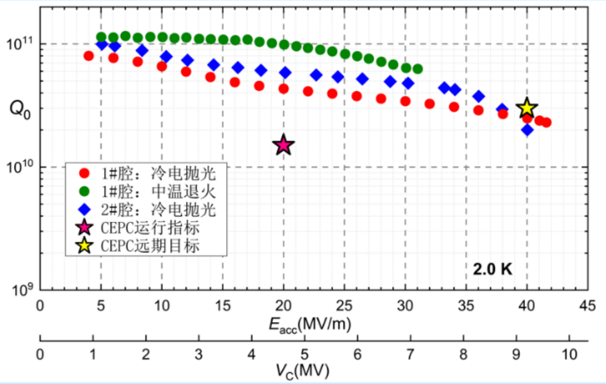
CEPC R&D ~ 30% cost of acc. components	▪ High efficiency klystron ▪ 650MHz SRF cavities ▪ Key components to e+ source ▪ High performance Linac ▪ Electrostatic Deflector ▪ Cryogenic system	▪ Novel magnets: Weak field dipole, dual aperture magnets ▪ Extremely fast injection/extraction ▪ Vacuum chamber tech. ▪ Survey & Alignment for ultra large Acc. ▪ MDI
BEPCII / HEPS ~ 60% 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 contributions.

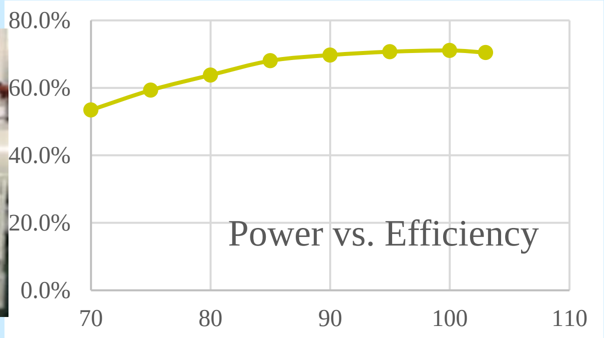
Highlights of Key Technology R&D

Key Components

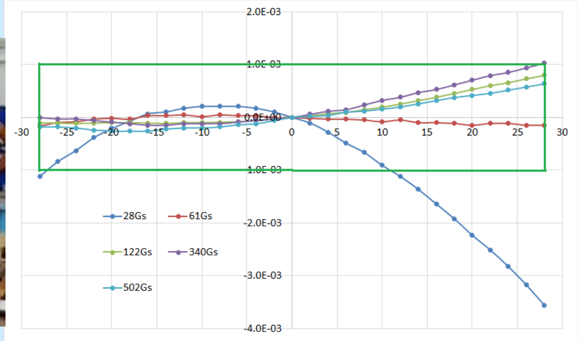
650MHz SRF cavity



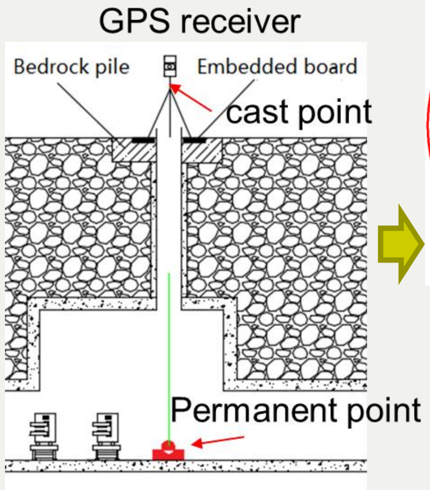
High efficiency klystron



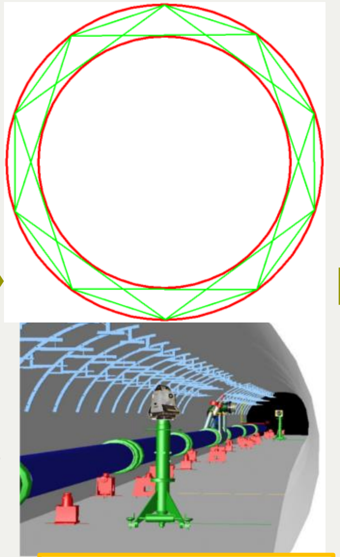
Weak field dipole



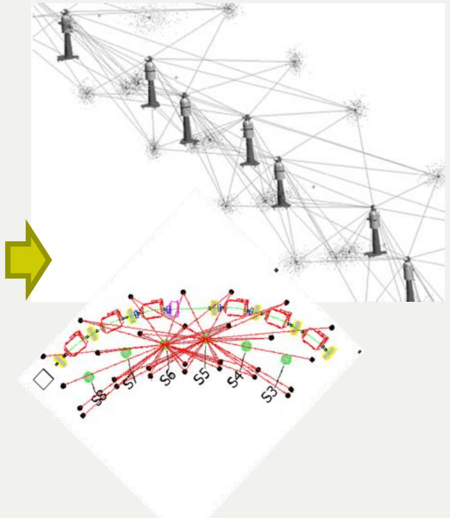
100km Accelerator Alignment & Installation R&D



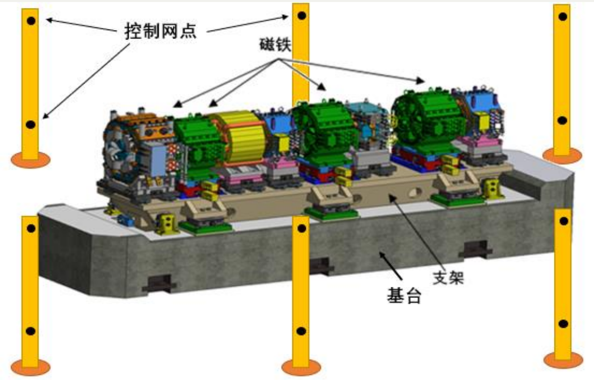
Control Point



Backbone Network



Tunnel Control Network



Acc. Unit Pre-alignment

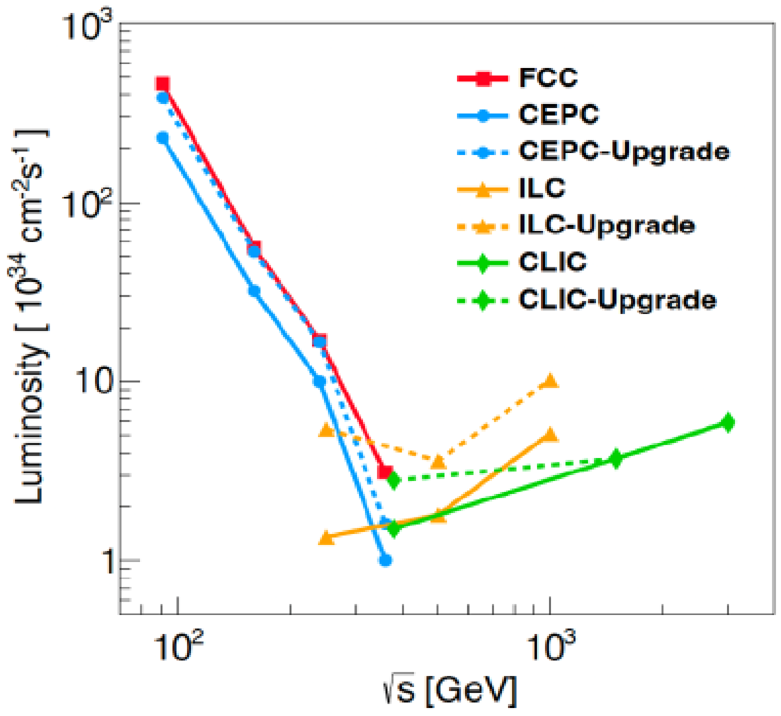
Multi Functional Alignment Instrument

Towards CEPC Accelerator TDR

Operation mode			ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]			~240	~91.2	~160	~360
Run time [years]			7	2	1	-
CDR (30 MW)		L / IP [$\times10^{34}$ $cm^{-2}s^{-1}$]	**3**	**32**	**10**	-
		$\int L\,dt$ [ab^{-1}, 2 IPs]	5.6	16	2.6	-
		Event yields [2 IPs]	1×10^6	7×10^{11}	2×10^7	-
Run Time [years]			10	2	1	~5
Latest	30 MW	L / IP [$\times10^{34}$ $cm^{-2}s^{-1}$]	**5.0**	**115**	**16**	**0.5**
	50 MW	L / IP [$\times10^{34}$ $cm^{-2}s^{-1}$]	**8.3**	**191.7**	**26.6**	**0.8**
		$\int L\,dt$ [ab^{-1}, 2 IPs]	20	96	7	1
		Event yields [2 IPs]	4×10^6	4×10^{12}	2×10^7	5×10^5

Both 50 MW and $t\bar{t}$ modes are currently considered as upgrades.

CEPC Accelerator white paper for Snowmass21, arXiv:2203.09451



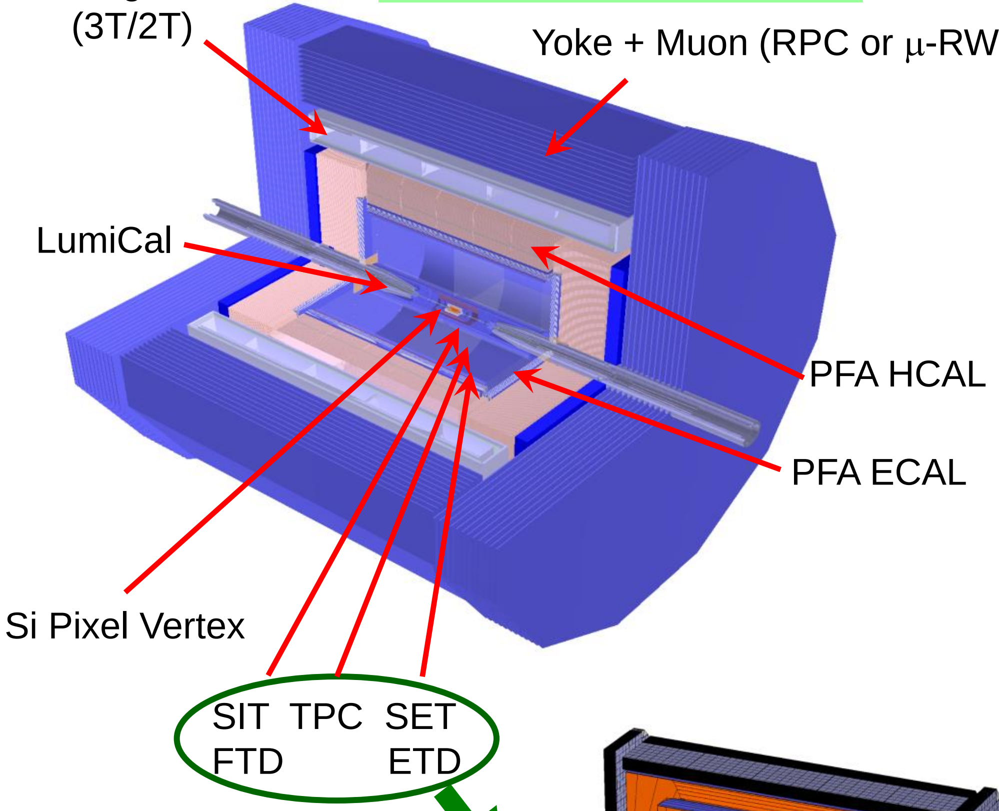
- **The CEPC Accelerator TDR International Review, June 12-16, 2023 at HKUST**
- **Release of the TDR by the end of 2023**

Requirements of Detector and Key Technologies

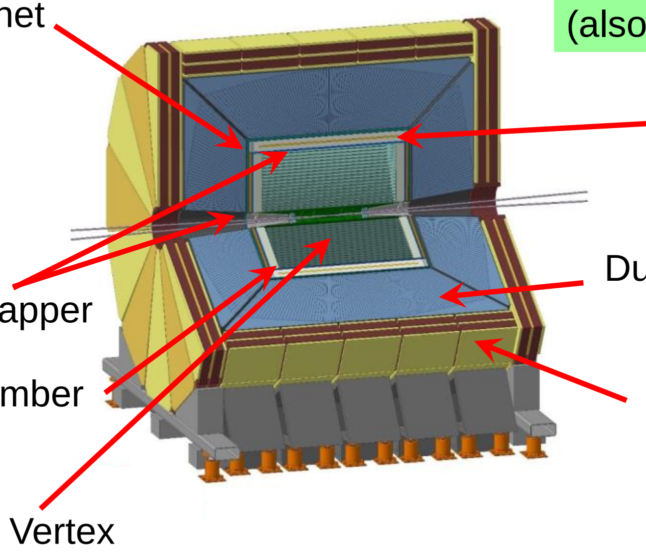
Sub-detector	Key technology	Key Specifications
Silicon vertex detector	Spatial resolution and materials	$\sigma_{r\phi} \sim 3\ \mu\text{m}$, $X/X_0 < 0.15\%$ (per layer)
Silicon tracker	Large-area silicon detector	$\sigma(\frac{1}{p_T}) \sim 2 \times 10^{-5} \oplus \frac{1\times10^{-3}}{p\times\sin^{3/2}\theta}(\text{GeV}^{-1})$
TPC/Drift Chamber	Precise dE/dx (dN/dx) measurement	Relative uncertainty 2%
Time of Flight detector	Large-area silicon timing detector	$\sigma(t) \sim 30$ ps
Electromagnetic Calorimeter	High granularity 4D crystal calorimeter	EM energy resolution $\sim 3\%/\sqrt{E(\text{GeV})}$ Granularity $\sim 2 \times 2 \times 2\ \text{cm}^3$
Magnet system	Ultra-thin High temperature Superconducting magnet	Magnet field $2 - 3$ T Material budget $< 1.5 X_0$ Thickness < 150 mm
Hadron calorimeter	Scintillating glass Hadron calorimeter	Support PFA jet reconstruction Single hadron $\sigma_E^{had} \sim 40\%/\sqrt{E(\text{GeV})}$ Jet $\sigma_E^{jet} \sim 30\%/\sqrt{E(\text{GeV})}$

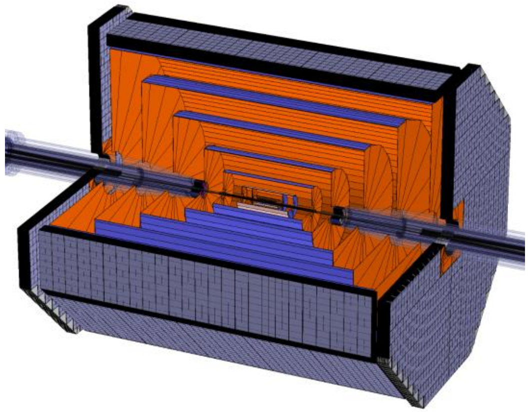
Conceptual Detector Designs

(Baseline Design, ILD-like)
Particle Flow Approach



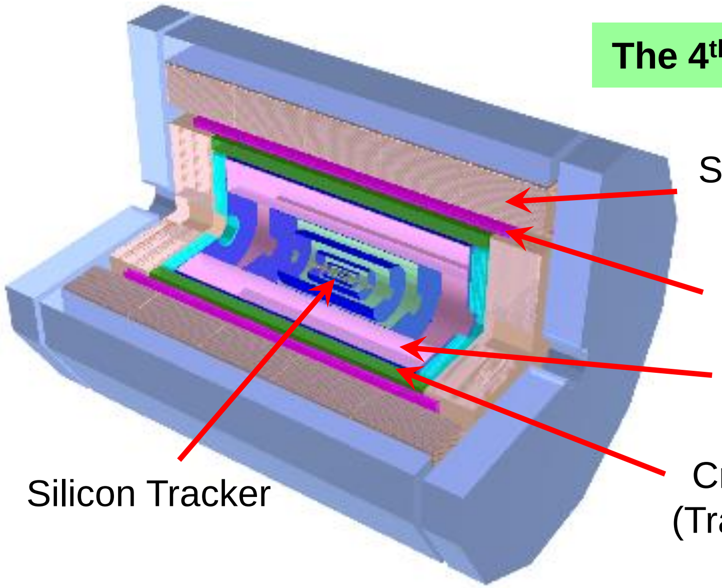
IDEA concept
(also proposed for FCC-ee)



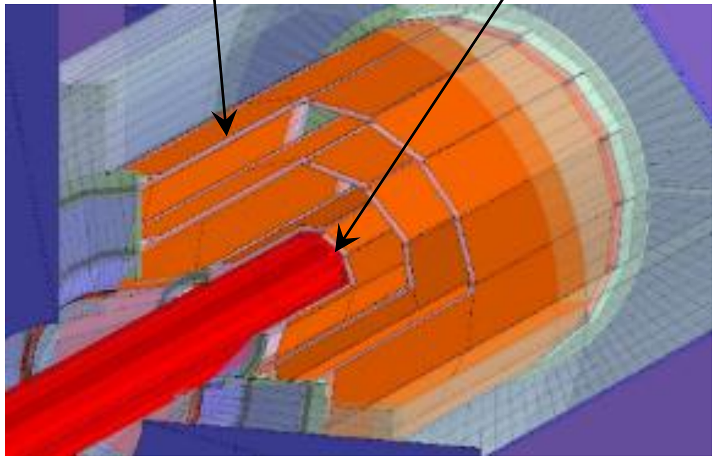


FST concept
(Full Silicon Tracker)

The 4th Concept



Silicon Vertex Detector



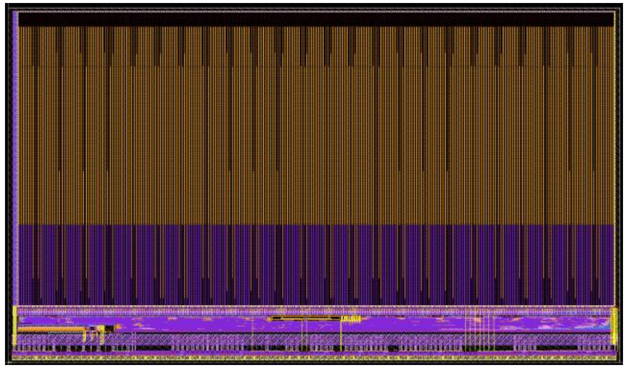
Goal: σ(IP) ~ 5 μm for high P track.

CDR design spec:

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

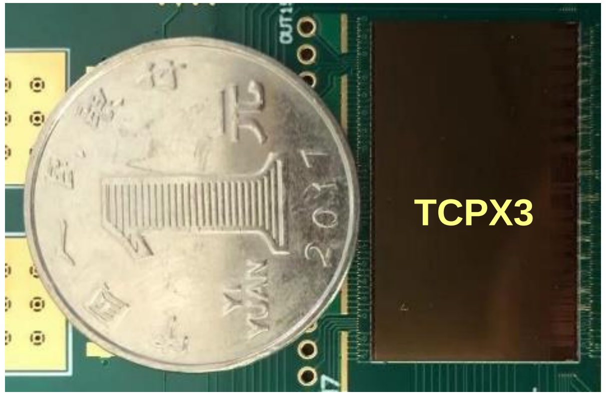
Silicon pixel sensor develops in 3 series:
JadePix / MIC, **TaichuPix**, **CPV**

JadePix4 356×498 array of 20×29 μm^2



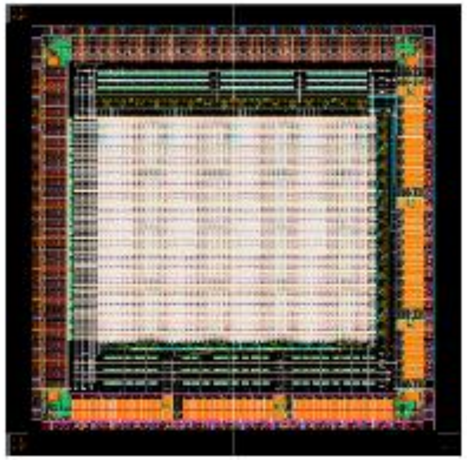
TowerJazz 180nm CIS process
$\sigma_{x/y}$ ~ 3-4 μm, σ_t ~ 1 μs, ~100 mW/cm^2

TaichuPix3 1024×512 array of 25×25 μm^2

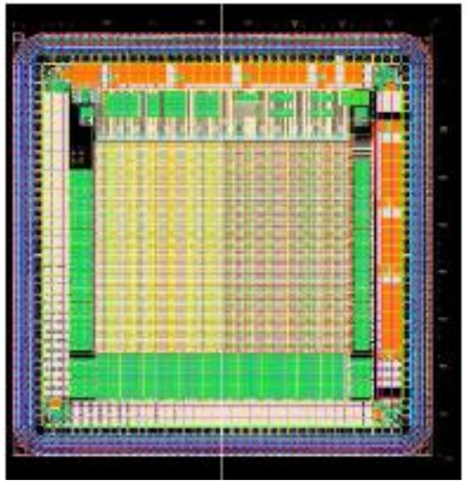


CPV4 (SOI-3D), 64×64 array
~21×17 μm^2 pixel size

Upper chip



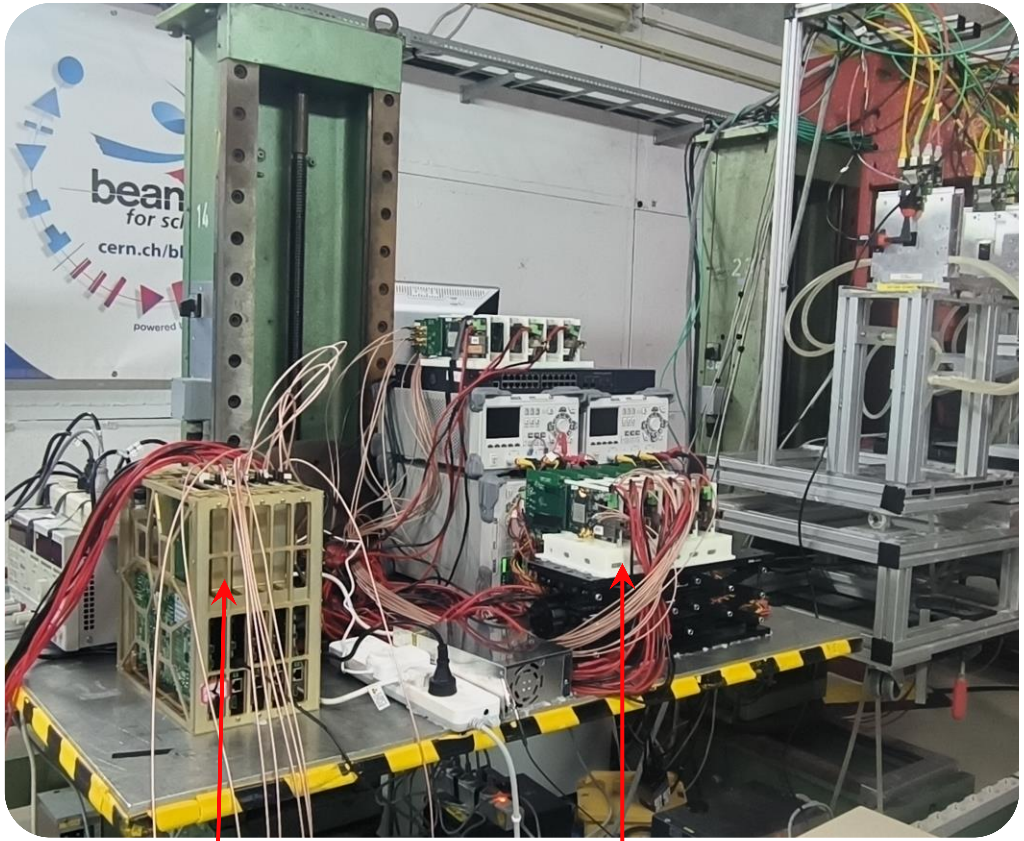
Lower chip



LAPIS 200nm SOI process

Prototyping Vertex Detector

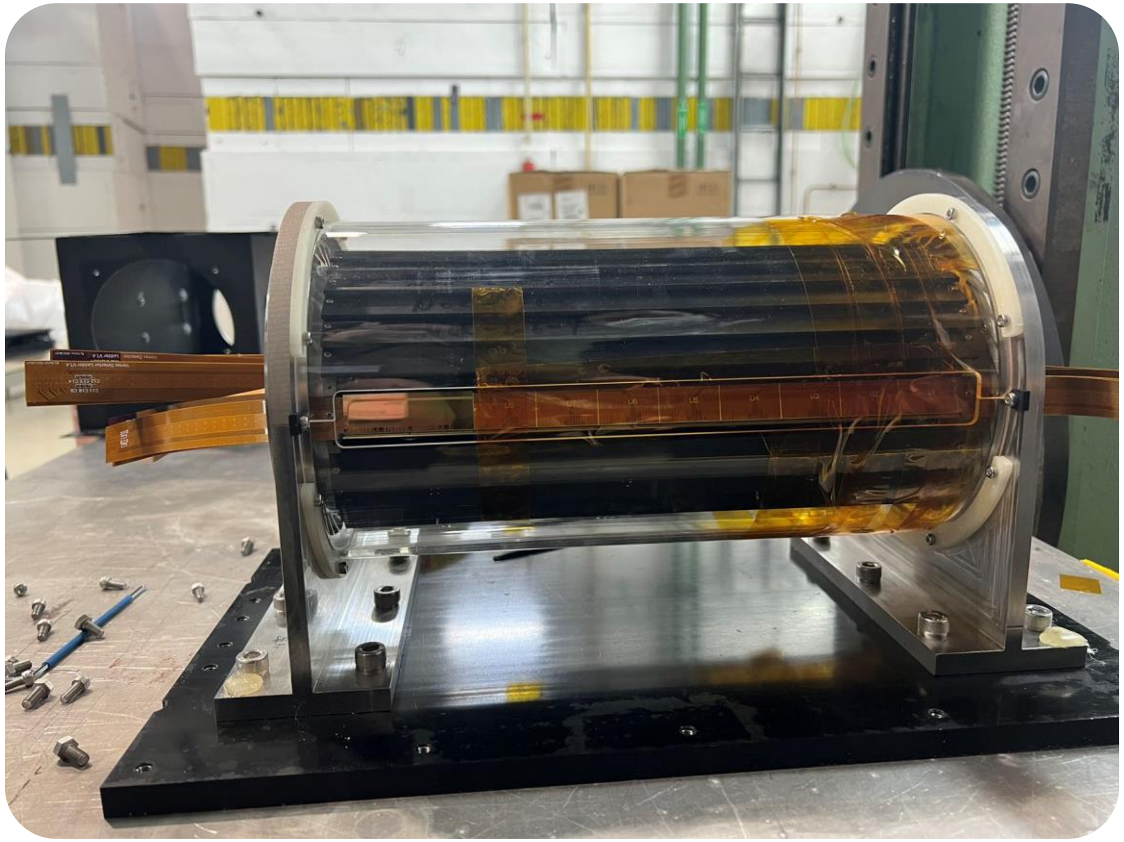
Testbeam of single chip boards
at DESY in Dec 2022



JadePix telescope TaichuPix telescope

Two independent telescopes

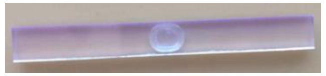
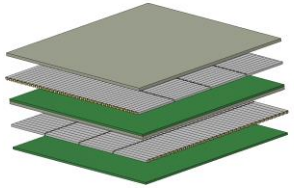
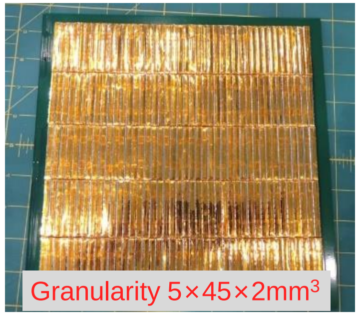
Testbeam of a prototyping detector
at DESY in April 2023

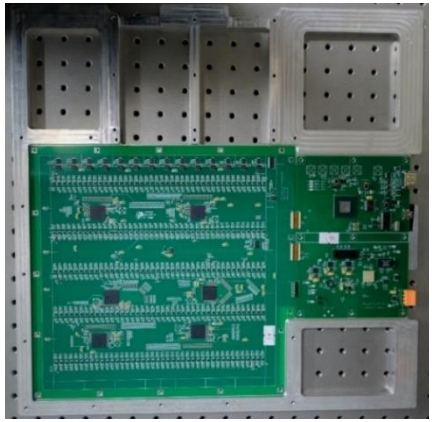


Populated with 3 double-layer ladders

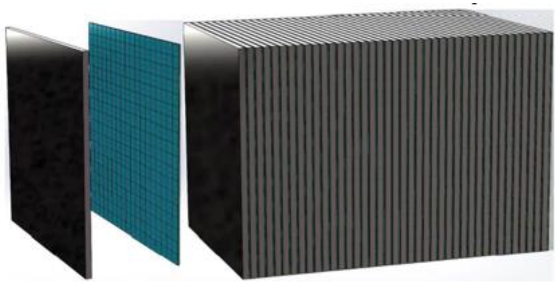
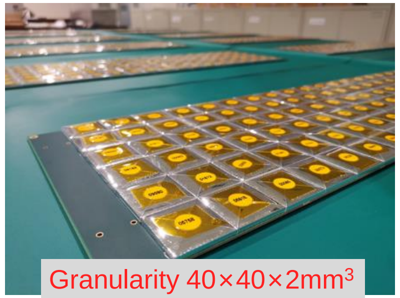
Prototype PFA Calorimeters

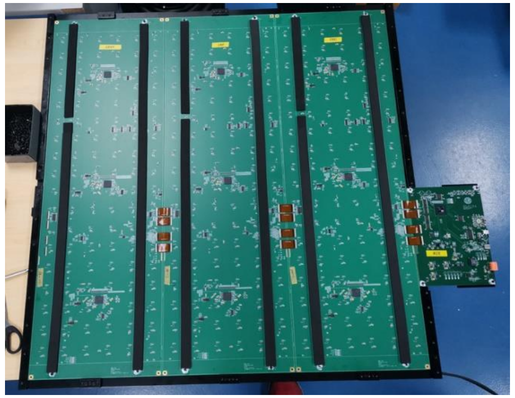
ECAL: scintillator(strip)+SiPM, CuW




HCAL: scintillator (tile)+SiPM, steel

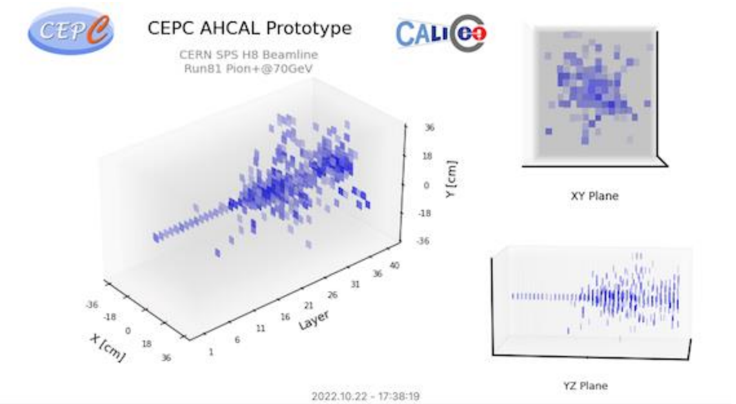


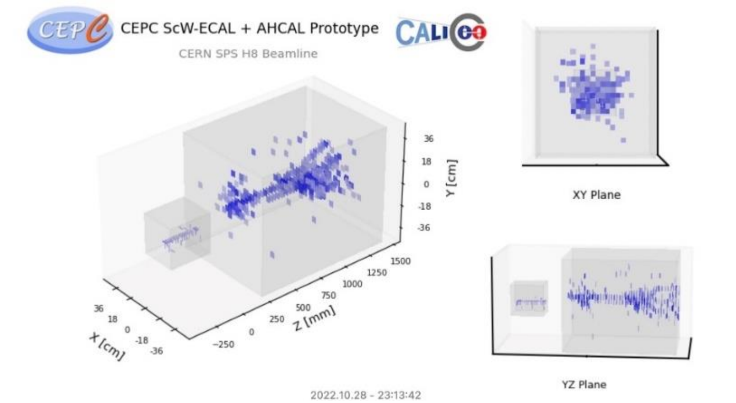

- ScW-ECAL: transverse ~20×20 cm, 32 sampling layers
  - ~6,700 channels, SPIROC2E (192 chips)
- AHCAL: transverse 72×72 cm, 40 sampling layers
  - ~13k channels, SPIROC2E (360 chips)

Prototypes developed within **CALICE**

- China: IHEP, SJTU, USTC
- Japan: U. Shinshu, U. Tokyo
- France: CNRS Omega
- Israel: Weizmann

Testbeam of Prototype PFA Calorimeters

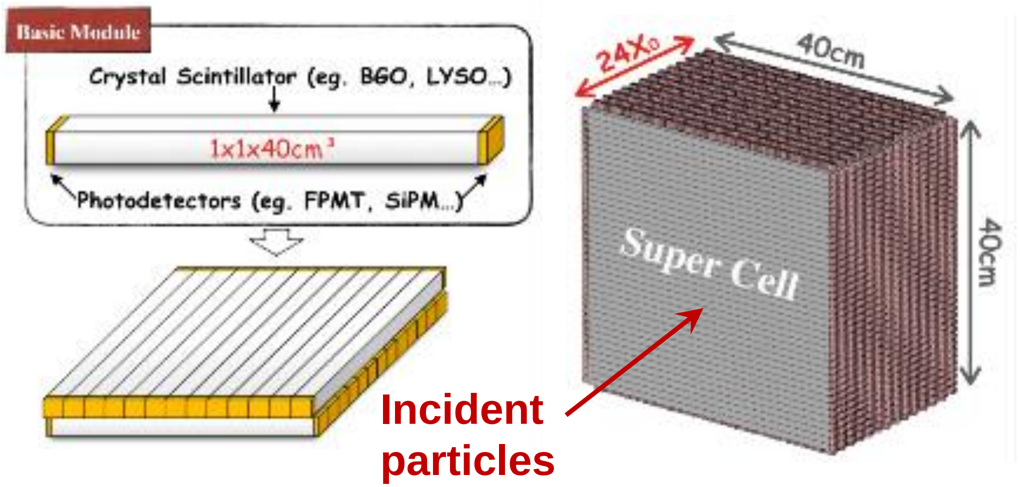


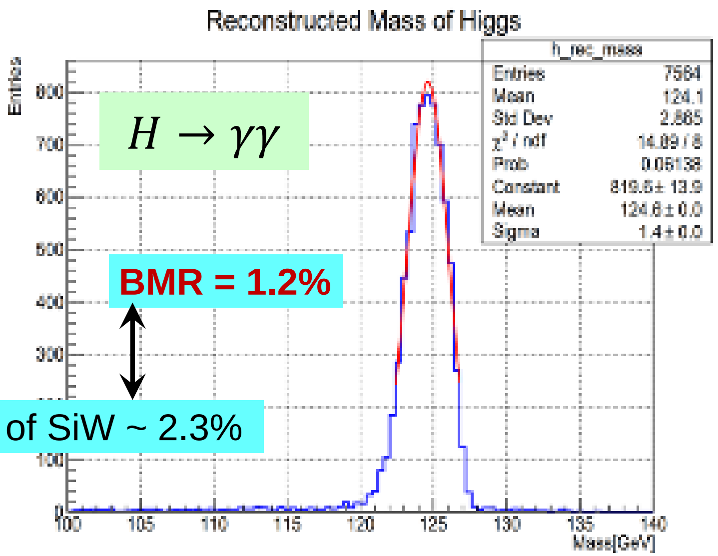


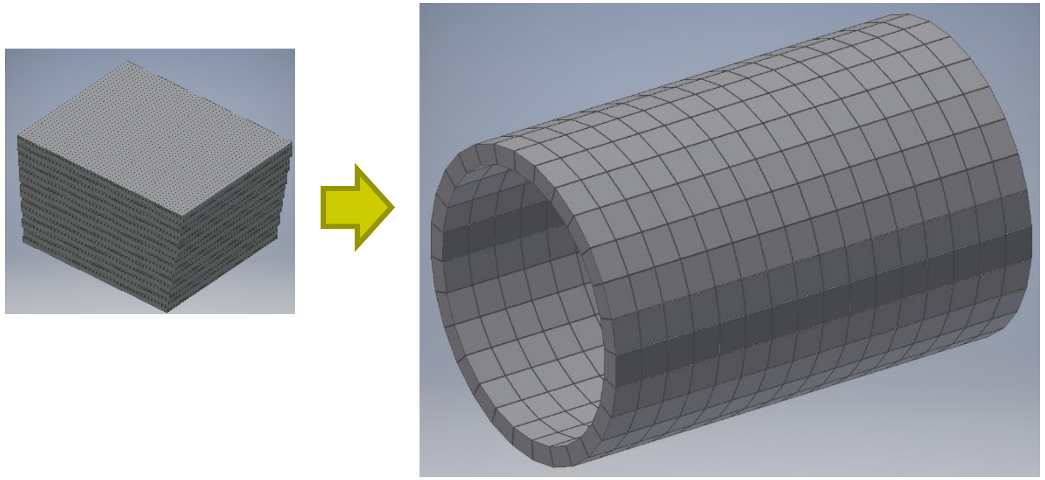
- Successful testbeam at CERN SPS H8: Oct-Nov, 2022
  - High energy particles: muon, positron and hadrons (10 - 160 GeV)
  - Decent statistics for detector performance evaluation, validation of Geant4 simulation, particle-flow studies, etc.
- Preparing for testbeams at PS & SPS with better beam purity.

4D Orthogonal Crystal Calorimeter

- Goal
  - Comparable BMR resolution as with the Si+W ECAL.
  - Much better sensitivity to γ/e, EM resolution $\leq 3\%/\sqrt{E(GeV)}$
- Features:
  - Timing at two ends for positioning along the bar.
  - Crossed arrangement in adjacent layers.
  - High granularity with reduced readout channels
- Key issues:
  - Ambiguity caused by 2D measurements (**ghost hit**).
  - Identification of energy deposits from particles (**confusion**).

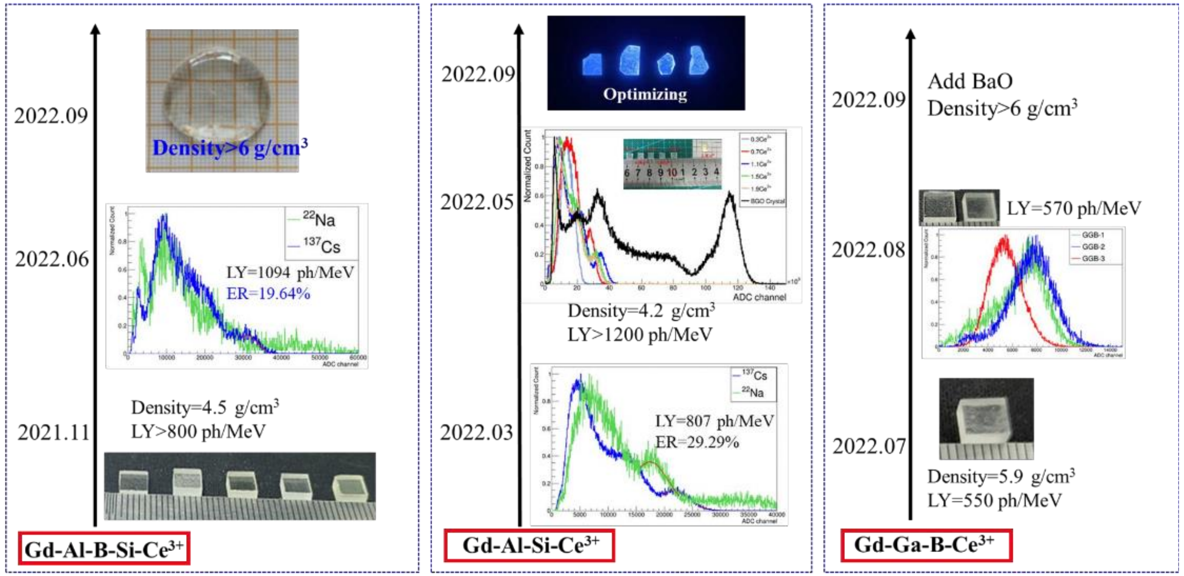




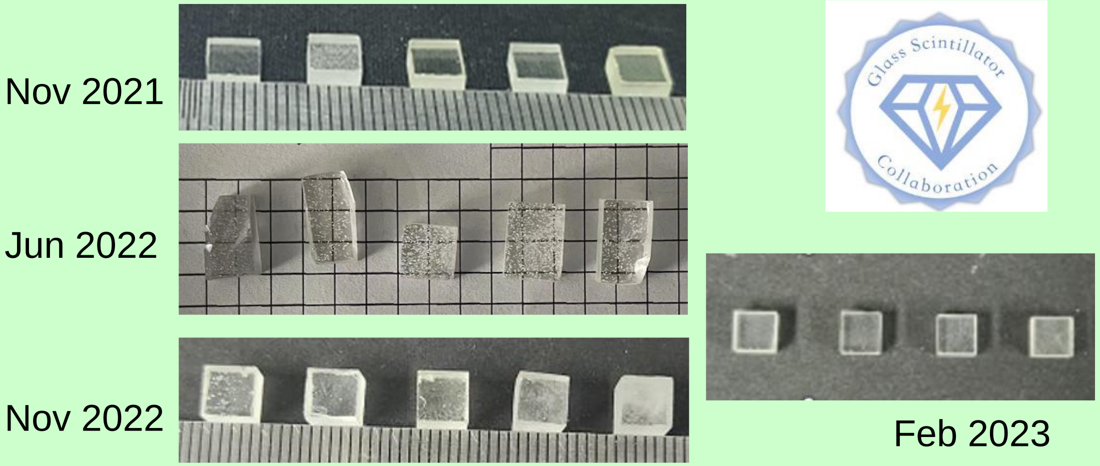


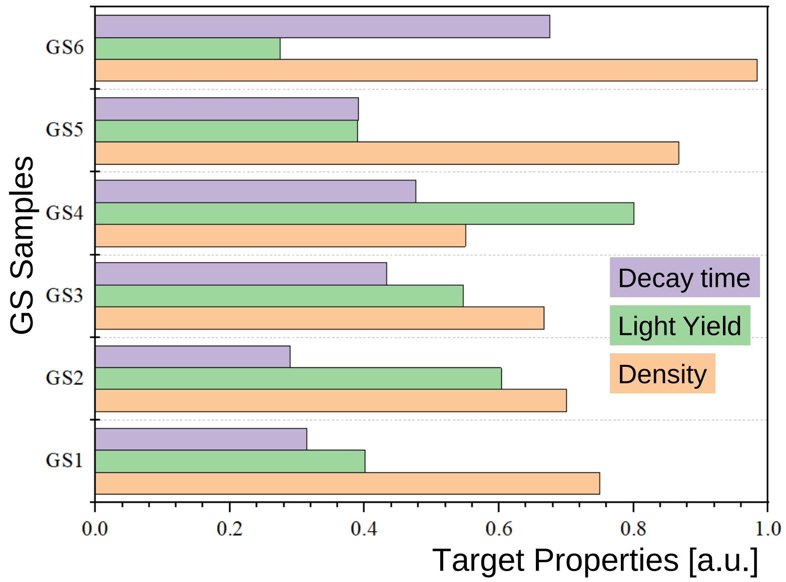
Scintillation Glass R&D Activities

- Replacing plastic scintillator in the PFA HCAL with high light yield, high density, low cost scintillating glass.
- Efforts on finding a proper material
  - Light yield: 1000 ~2000 photons/MeV
  - Density: 5~7 g/cm^3
  - Scintillation time: ~100 ns
  - Tiles in cm scale for PFA HCAL
- Proposal input to the ECFA DRD6



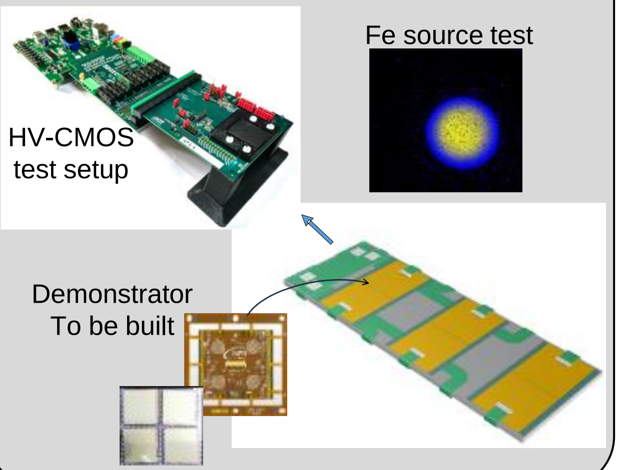
Aims: high density, high light yield, low cost ScintiGlass





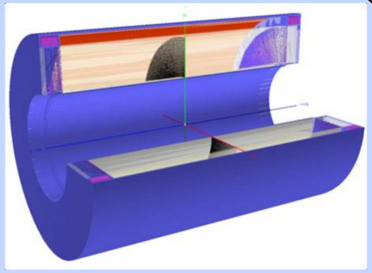
Many Other CEPC Detector R&Ds

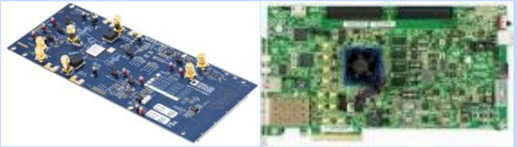
HV-CMOS Tracker



LGAD ToF

Drift Chamber

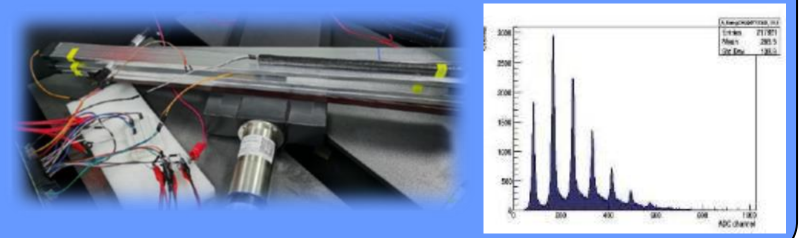


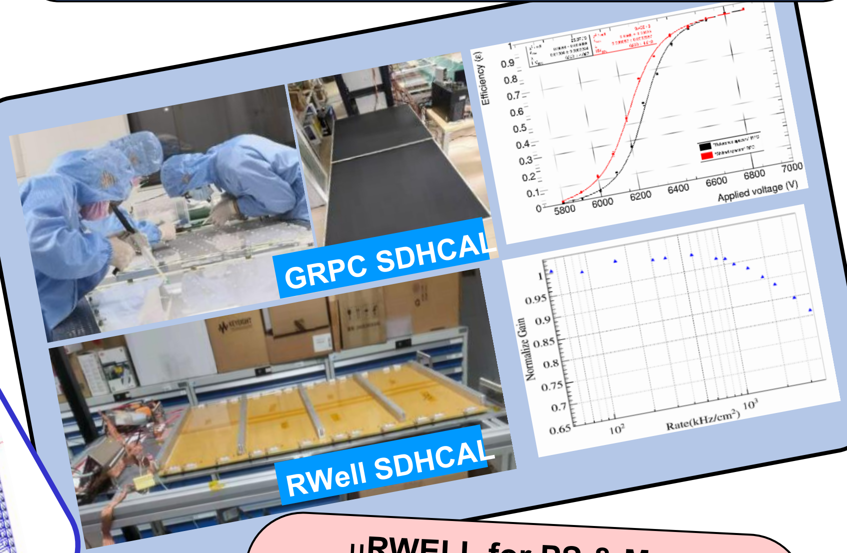


AD9689 – 2000 EBZ

Xilinx KCU105

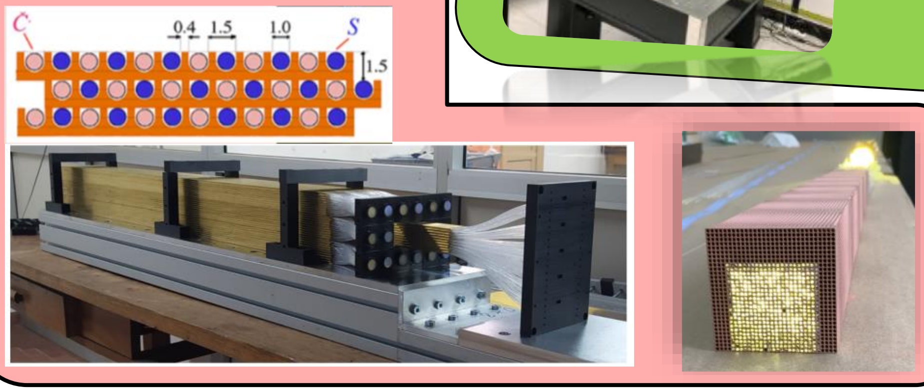
Scintillator Bar Muon

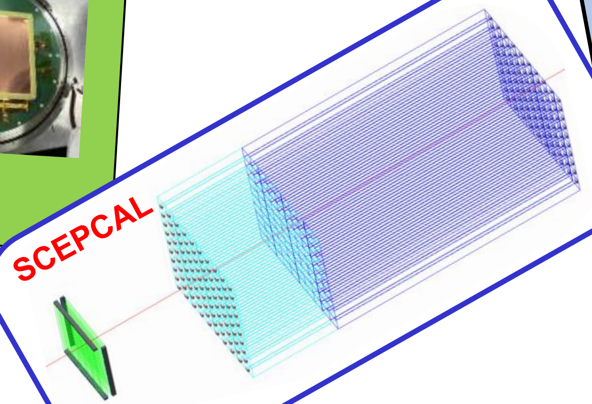




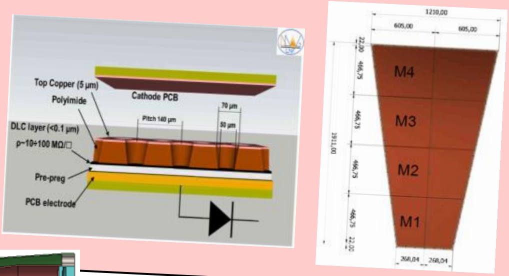
TPC Prototype

Dual Readout CAL

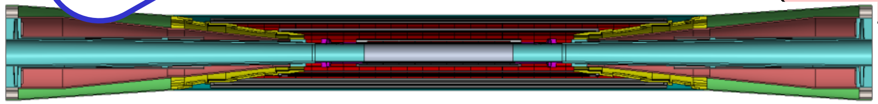




μRWELL for PS & Muon



Beampipe Design



Collaboration With Industry

CEPC 650MHz Klystron at Kunshan Co.

CERN HL-LHC CCT SC magnet

CEPC SC QD0 coil winding at KEYE Co.

CIPC (CEPC Industrial Promotion Consortium) was established in Nov 2017. So far 70+ companies have joined.

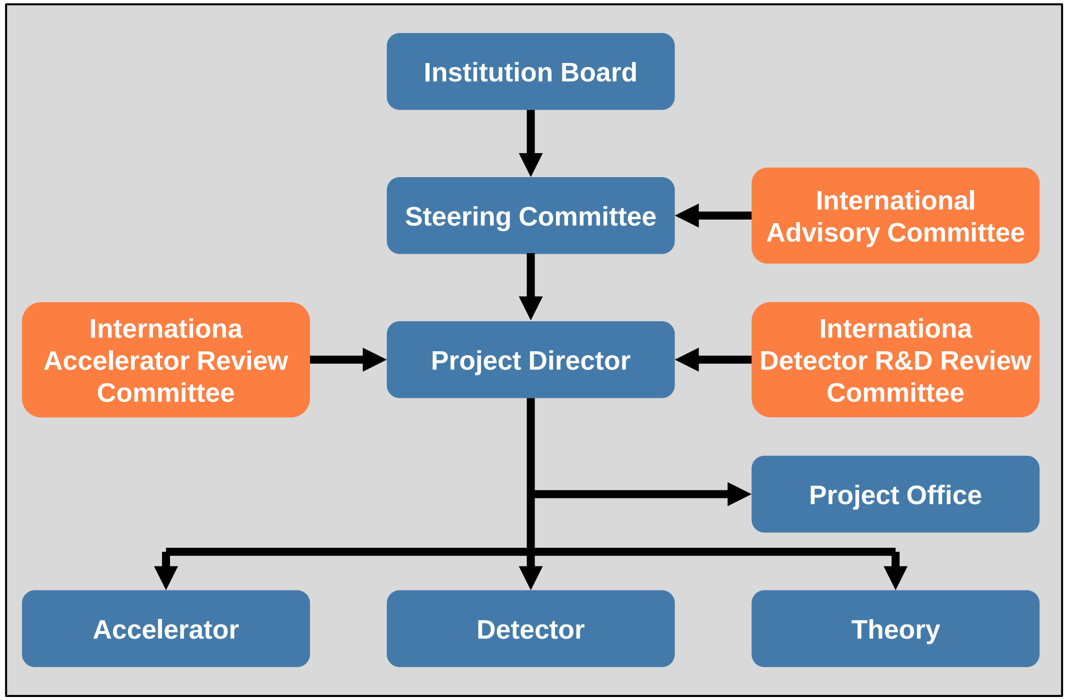
CEPC Detector SC coil winding tools at KEYE Company (Diameter ~7m)

CEPC long magnet measurement coil

1) Superconduting materials (for cavity and for magnets)
2) Superconducting cavities
3) Cryomodules
4) Cryogenics
5) Klystrons
6) Magnet technology
7)Vacuum technologies
8) Mechanical technologies
9)Electronics
10) SRF
11) Power sources
12) Civil engineering
13) Precise machinery
.....

More than 40 companies joined in first phase of CIPC,
and 70 companies now.

International Efforts



- The International Advisory Committee (IAC) started in 2015, and held meeting yearly.
- Two international review committees for accelerator and detector R&D: (IARC, IDRC) started operating since 2019.
- Currently the CEPC study group consists of ~1/4 international members. We hope to boost up international participation.
- Collaborative R&D through various channels, including CALICE, LPTPC, RD*, DRD*, …

- International workshops (with emphasis on the CEPC):
  - In China: Beijing (2017.11, 2018.11, 2019.11), Shanghai (2020.10 / hybrid), Nanjing (2021.11 / online, 2022.11 / online, **2023.10.23-27**)
  - In Europe: Rome (2018.05), Oxford (2019.04), Edinburgh (**2023.07.03-07**)
  - In USA: Chicago (2019.09), DC (2020.04 / online)
  - Annual IAS program on HEP (HKUST) since 2015 (a conference + small workshops)
- Various topic-specific workshops every year (Flavor+PID @ Shanghai, 2023.08)

Closing Remarks

Completion of Accelerator TDR

Continue R&D on key technologies
System-level validations
……

Form
International Collaborations

Decide on technologies and complete TDR