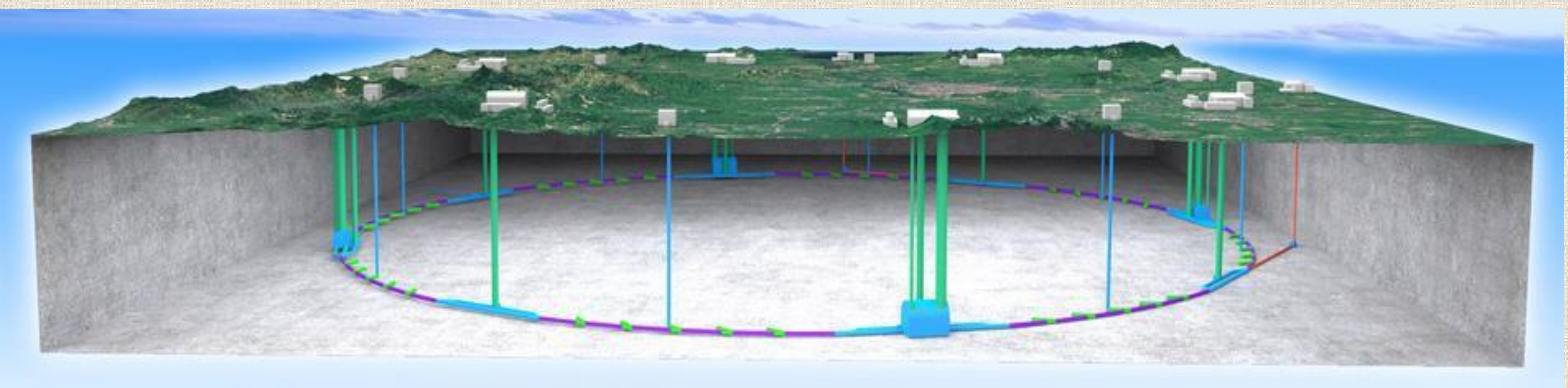
Status of The CEPC

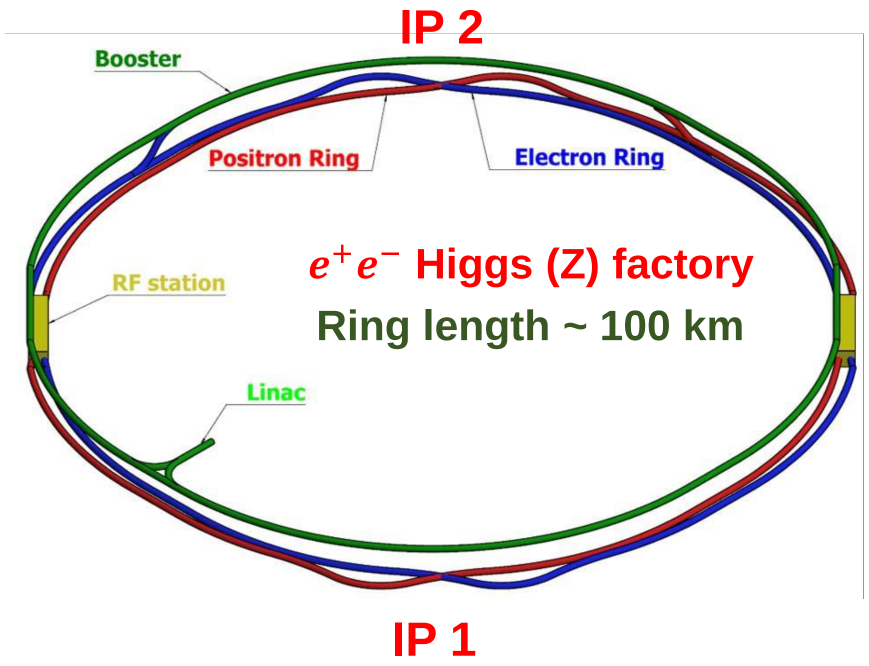
Jianchun Wang (IHEP, CAS)
For the CEPC Study Group

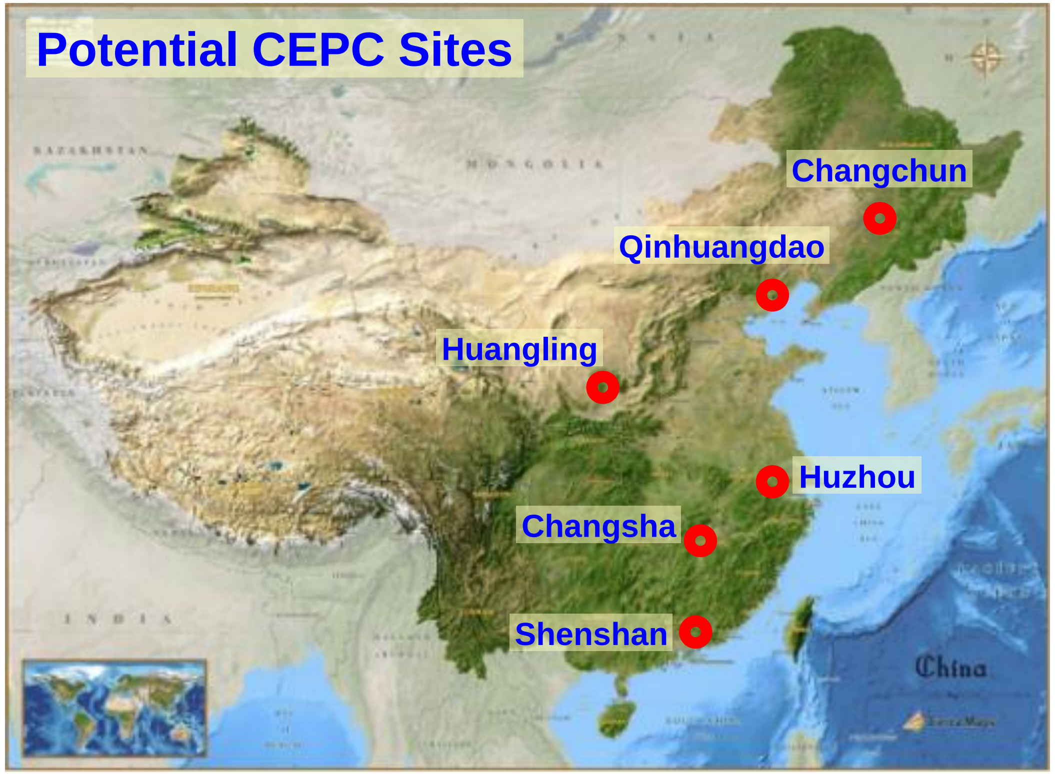
109th Plenary ECFA meeting, Nov 18-19, 2021



The Circular Electron Positron Collider

- The CEPC aims to start operation in 2030's, as a Higgs (Z / W) factory in China.
- To run at $\sqrt{s}$ ~ 240 GeV, above the **ZH** production threshold for ~1 M Higgs; at the **Z** pole for ~Tera Z; at the **W^+W^-** pair and possible $t\bar{t}$ pair production thresholds.
- Higgs, EW, flavor physics & QCD, probes of physics BSM.
- Possible *pp* collider (SppC) of $\sqrt{s}$ ~ 50–100 TeV in the future.



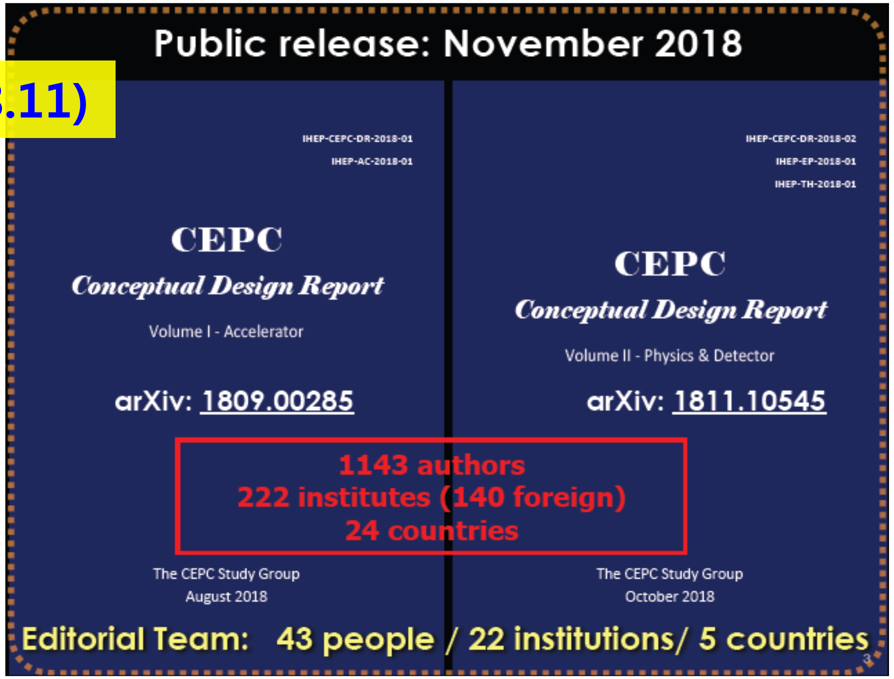


Major Milestones

CEPC-SPPC Kickoff (2013.9)

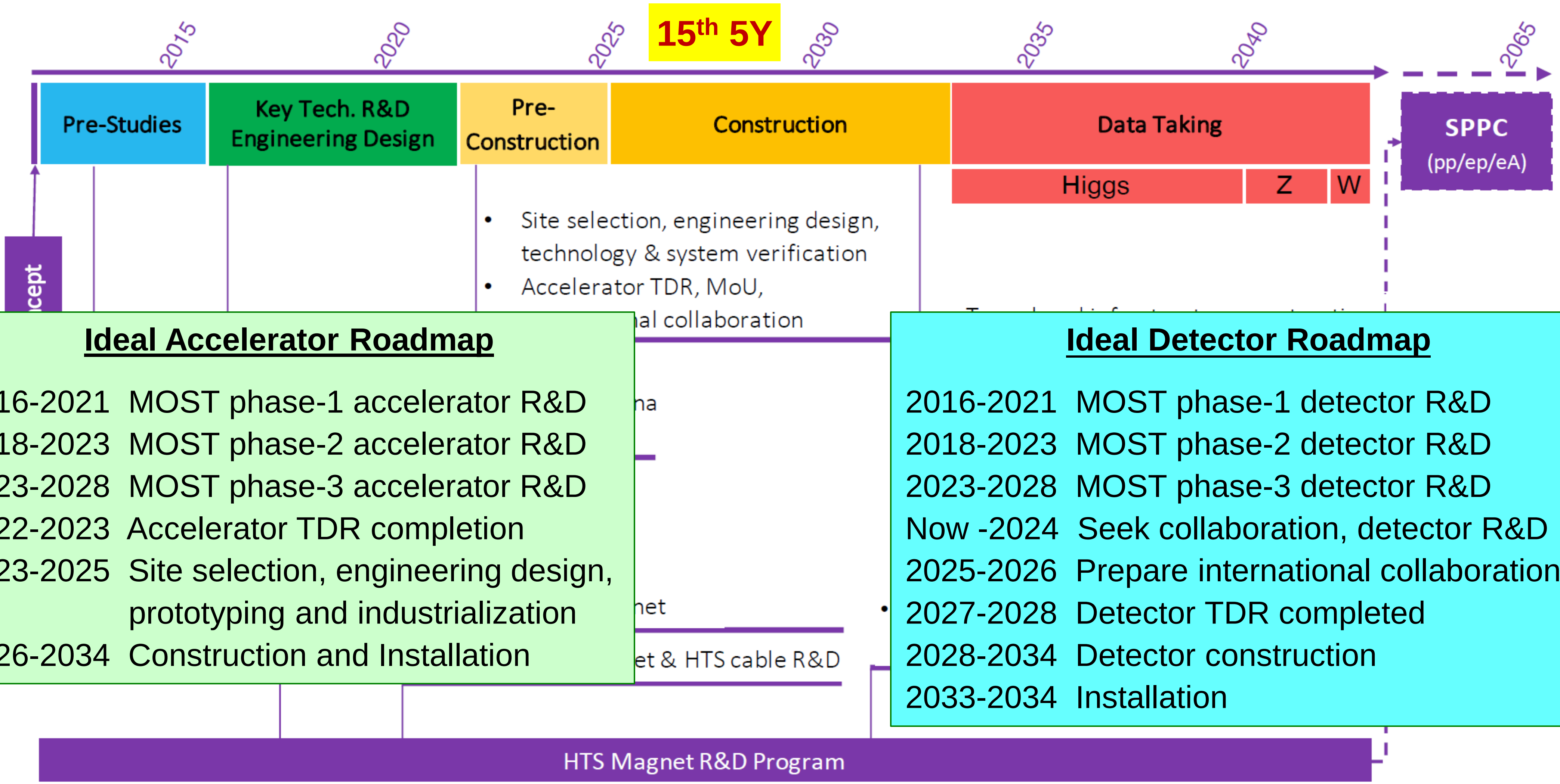
CEPC IAC Meeting (2015.9)

CEPC CDR Released (2018.11)



CEPC Roadmap and Schedule (Ideal)

- 2013-2025: Key technology R&D, from CDR to TDR, site selection, international collaboration etc.
- Ideal case: Approval in the 15th Five-Year Plan, and start construction (~8 years)



Ideal Accelerator Roadmap

2016-2021 MOST phase-1 accelerator R&D
2018-2023 MOST phase-2 accelerator R&D
2023-2028 MOST phase-3 accelerator R&D
2022-2023 Accelerator TDR completion
2023-2025 Site selection, engineering design, prototyping and industrialization
2026-2034 Construction and Installation

Ideal Detector Roadmap

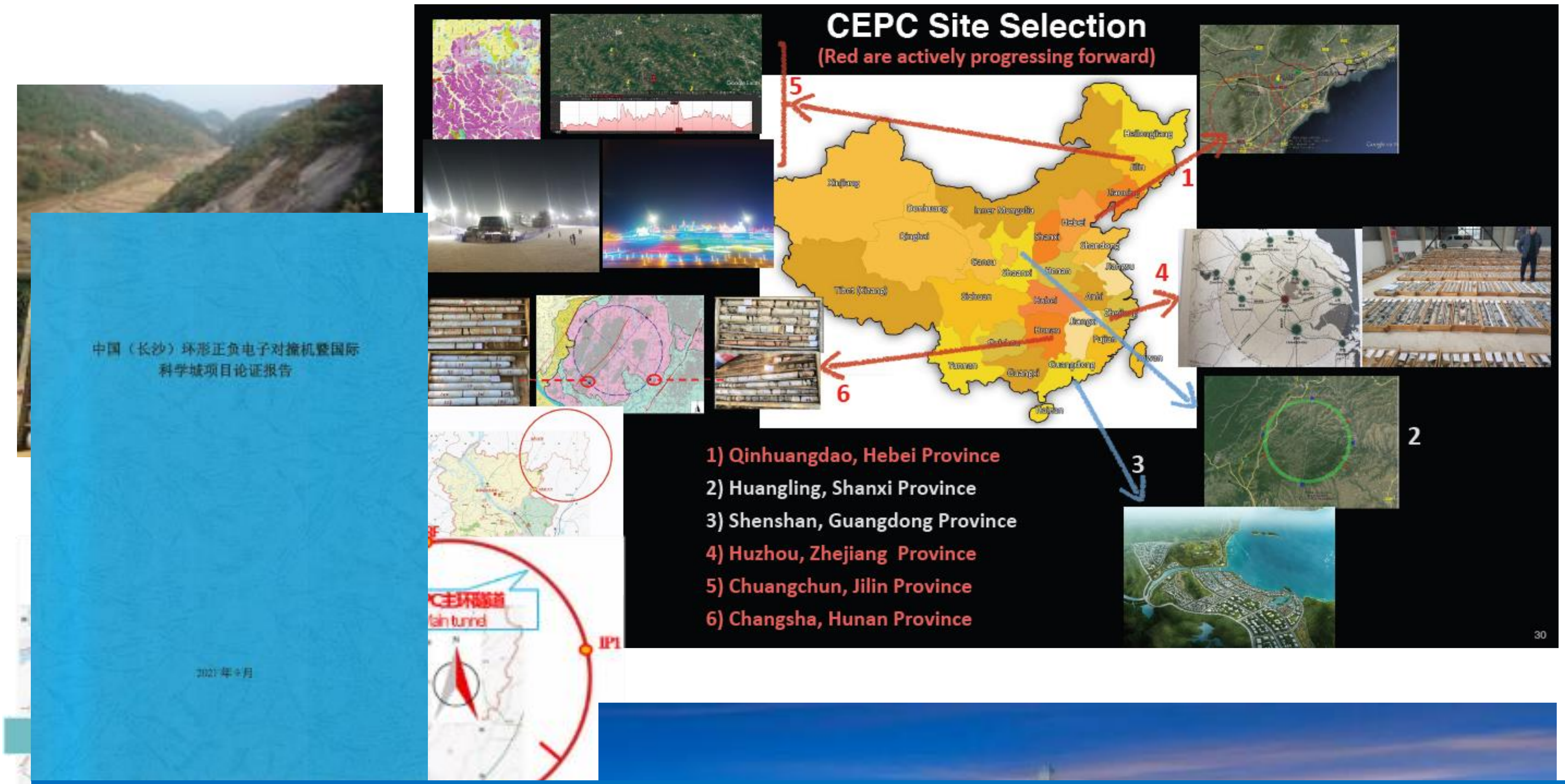
2016-2021 MOST phase-1 detector R&D
2018-2023 MOST phase-2 detector R&D
2023-2028 MOST phase-3 detector R&D
Now -2024 Seek collaboration, detector R&D
2025-2026 Prepare international collaborations
2027-2028 Detector TDR completed
2028-2034 Detector construction
2033-2034 Installation

International Efforts

- The International Advisory Committee (IAC) started in 2015. The 7th annual IAC meeting was held between Nov 1-5, 2021.
- International Accelerator Review Committee (IARC), and International Detector R&D Review Committee (IDRRC) started operating in 2019.
- Currently the CEPC study group consists of ~1/3 international members. By year 2025-26, two international experiment collaborations should be formed.
- Domestic R&D are supported by MOST, NSFC, CAS, institutes, local governments, …
- International collaborative R&D through various channels, including CALICE, LPTPC, RD*, …
- 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**)
  - In Europe: Rome (2018.05), Oxford (2019.04), Marseille (~**2022.05**)
  - 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 at different locations every year.

CEPC Site Selection

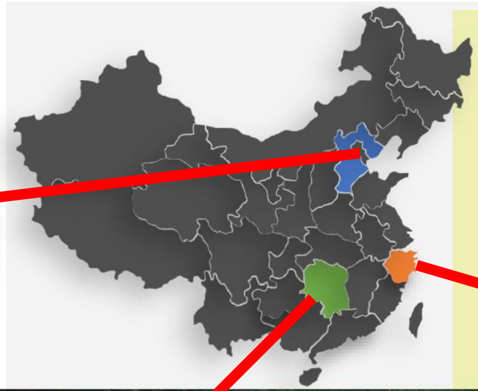
Factors: geology, electricity supply, transportation, international-friendly, local supports …

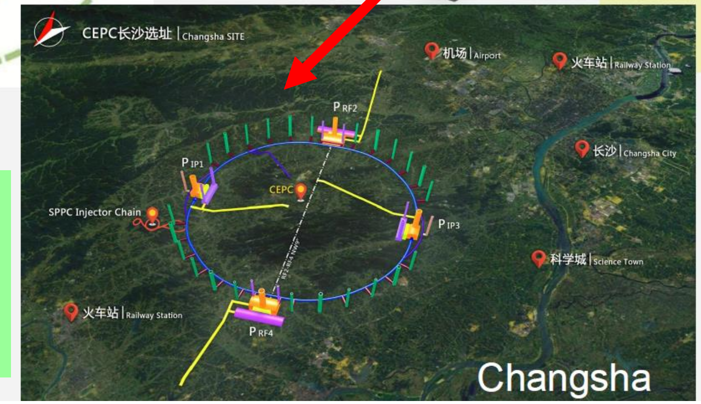


July 5, 2021: Changsha Bureau of S&T entrusted Hunan U. to conduct a feasibility study.

Sept 4, 2021: Hunan U. organized a review by a committee of experts from multiple disciplines. The committee evaluated scientific potential of CEPC, feasibility of a new science city based on CEPC, and overall impact on Changsha. The overall conclusion is very positive. The local government is interested and very supportive to the CEPC project.

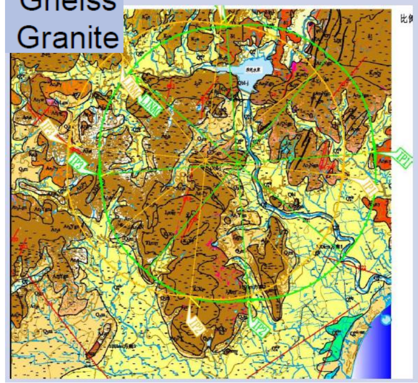
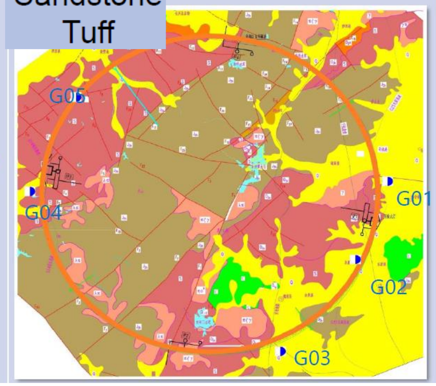
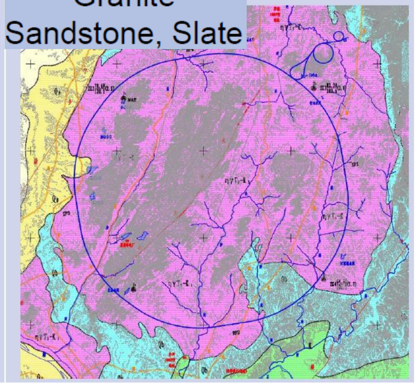
Geology of Candidate Sites and Science Cities

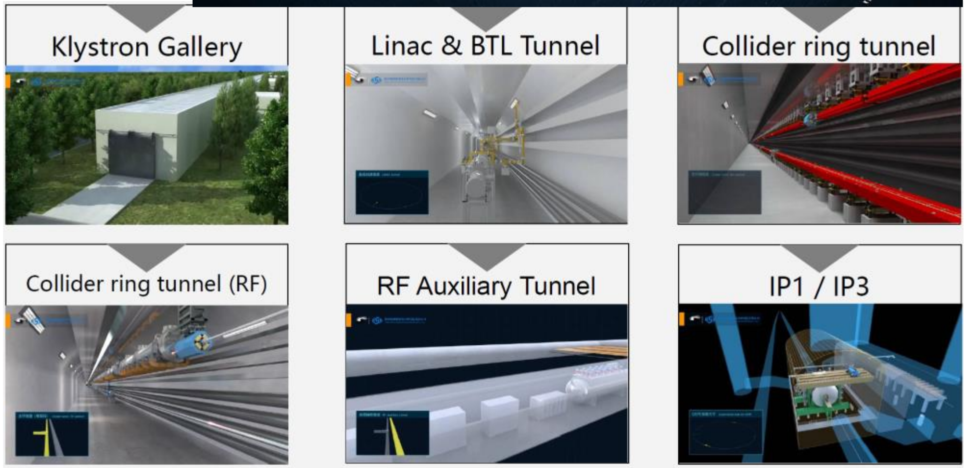




Three sites were presented at the CEPC2021 workshop
https://indico.ihep.ac.cn/event/14938/

Science City

Qinhuangdao	Huzhou	Changsha
Gneiss Granite	Sandstone Tuff	Granite Sandstone, Slate
		



CEPC Financial Model

Funding Sources	Model #1 (CNY)	Model #2 (CNY)
Central Government	30B	6-10B
Local Government	Land, Infrastructure	25-18B Land, Infrastructure
International Partners	1-5B	1-5B
Companies & Donations	0-3B	0-3B
Total Budget	**36B**	**36B**

In Oct 2021: Institute of Science and Technology Strategic Consulting, CAS started an independent assessment of Social Cost Benefit Analysis for the CEPC project, the report will be available in August, 2022.

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)

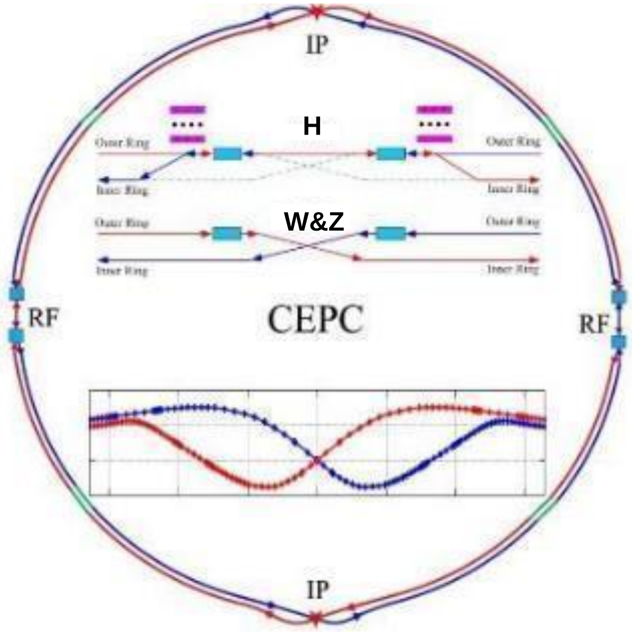
CEPC long magnet measurement coil

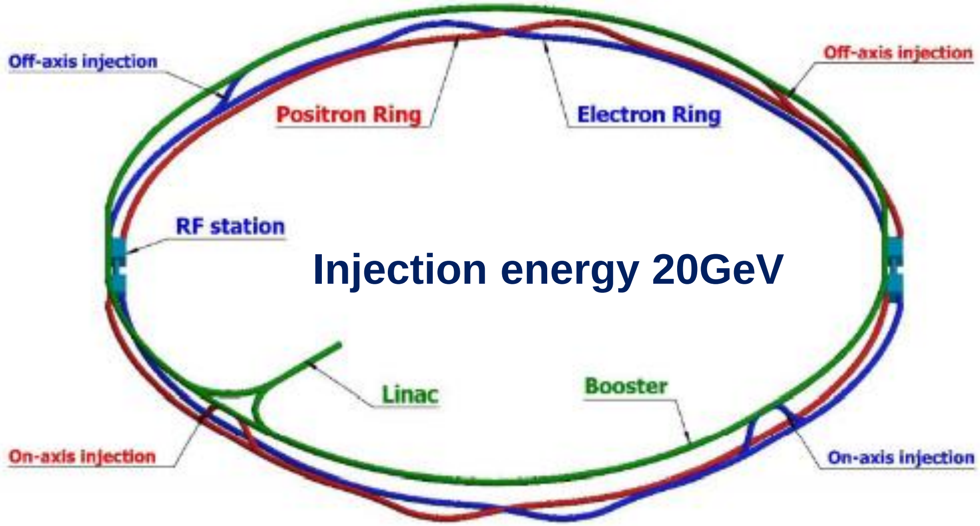
1) Superconduting materials (for cavity and for magnets)
2) Superconducting cavities
3) Cryomodules
4) Cryogenics
5) Klystrons
6) Magnet technology
7)Vacuum technologies
8) Mechanical technologies
9)Electronics
10) SRF
11) Power sources
12) Civil engineering
13) Precise machinery
.....

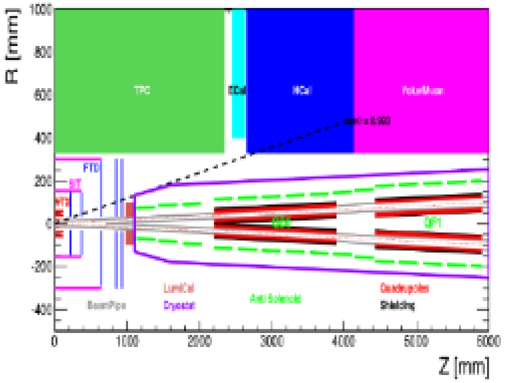
More than 40 companies joined in first phase of CIPC,
and 70 companies now.

CEPC High Luminosity TDR Layout

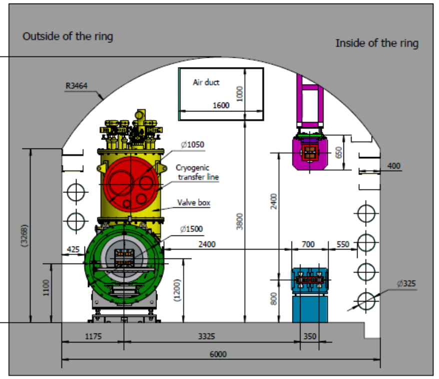
- 100 km double-ring design (30 MW/beam, upgradable to 50).
- New baseline for Linac (C-band, 20GeV) after the CDR.

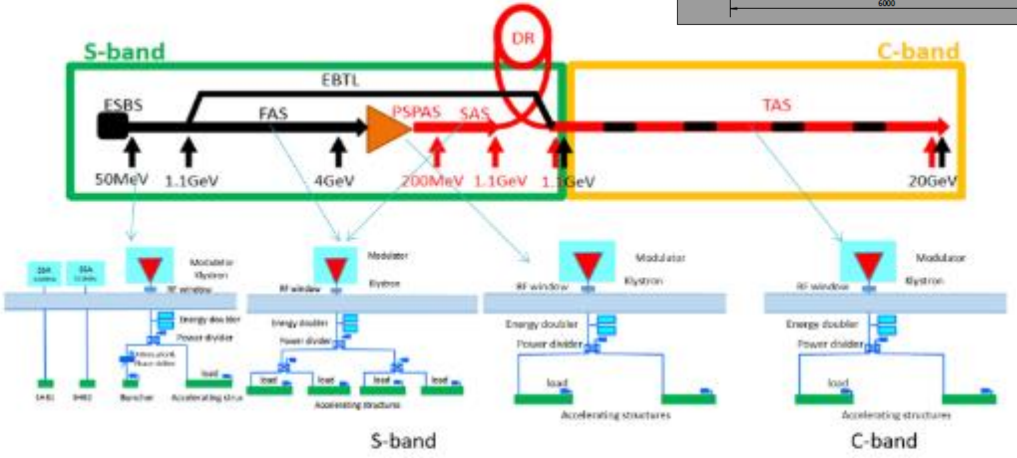






TUNNEL CROSS SECTION OF THE ARC AREA

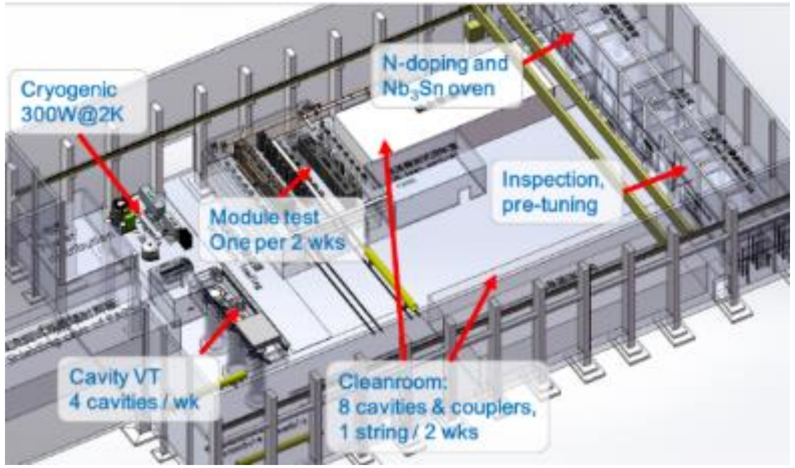




Operation mode		ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]		~240	~91.2	158-172	360
L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	CDR (2018)	3	32	10	
	Latest	5.0	115	16	0.5

CEPC SCRF Test Facility

New SC Lab Design (4500m²)



SC New Lab is available in 2021

Cryogenic system hall in 2020

Vacuum furnace (doping & annealing)

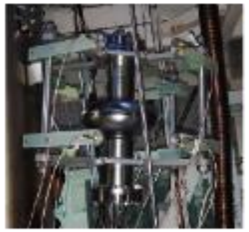
Nb3Sn furnace

Nb/Cu sputtering device

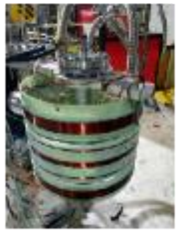
Cavity inspection camera and grinder

9-cell cavity pre-tuning machine

Temperature & X-ray mapping system



Second sound cavity quench detection system

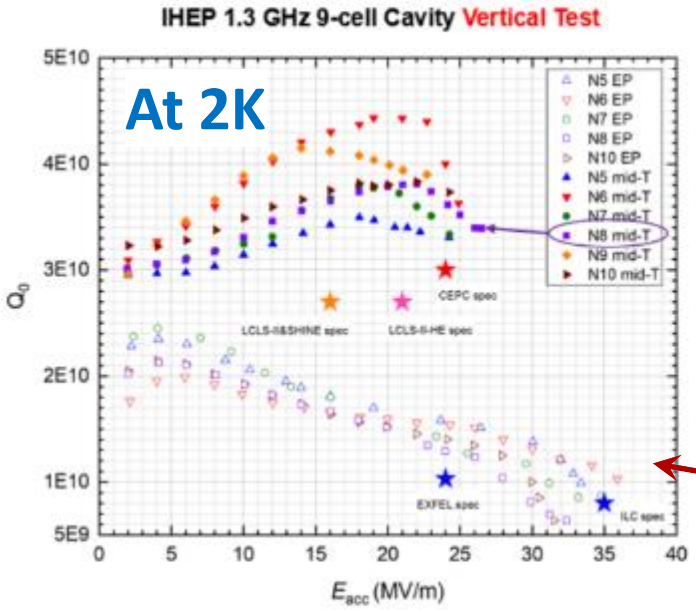


Helmholtz coil for cavity vertical test

Vertical test dewars

Horizontal test cryostat

High Q SCRF Cavities



Both exceeded the CEPC spec, a milestone towards the TDR

<u>Collider ring 650MHz 2-cell cavity</u>

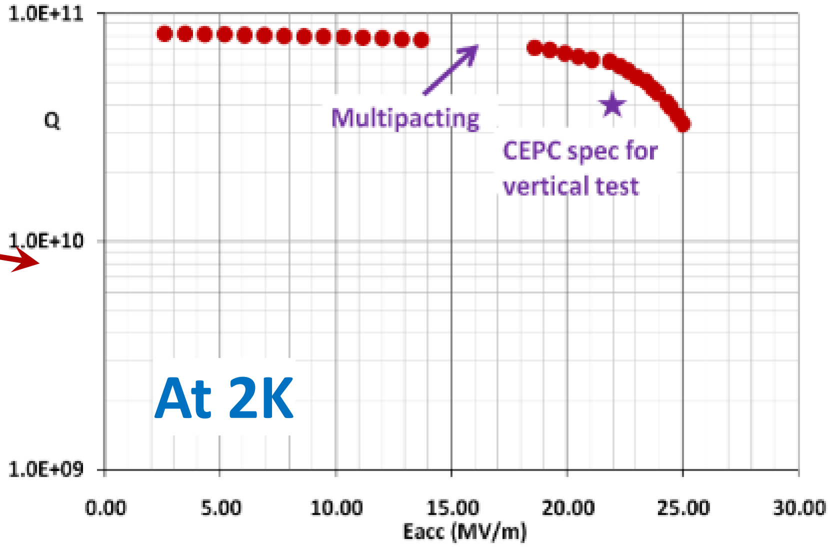
Q = 6.0E10@22MV/m

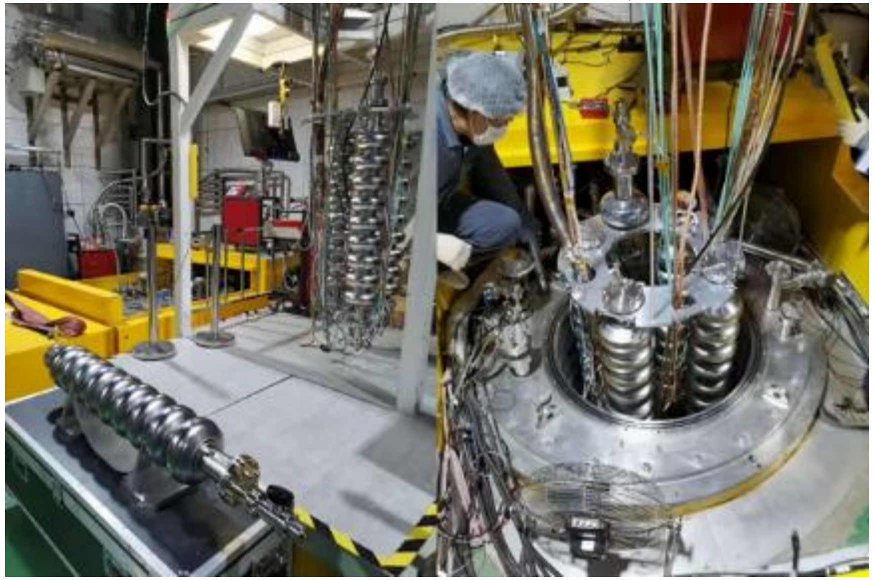
N-infusion adopted

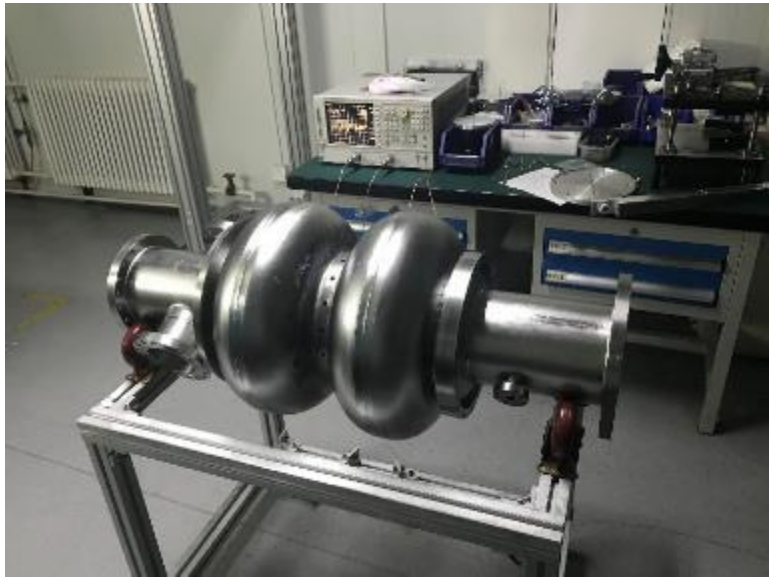
<u>Booster 1.3GHz 9-cell cavity</u>

Q_0 = 3.4E10@26.5 MV/m

Mid-T annealing adopted

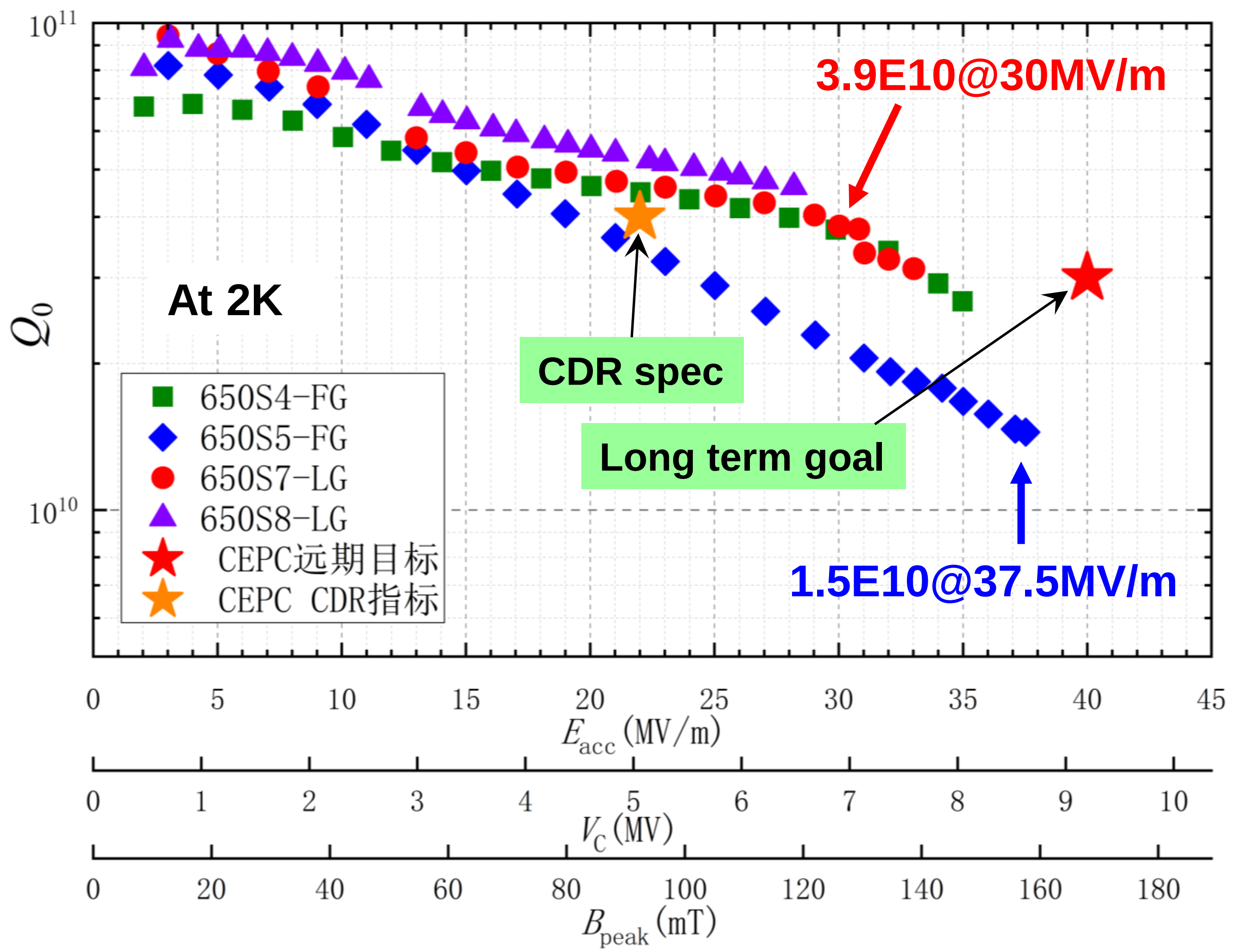






High Q SCRF 650 MHz 1-Cell Cavity

IHEP achieved Q_0=3.9E10@30 MV/m (650MHz 1-cell SCRF Cavity)



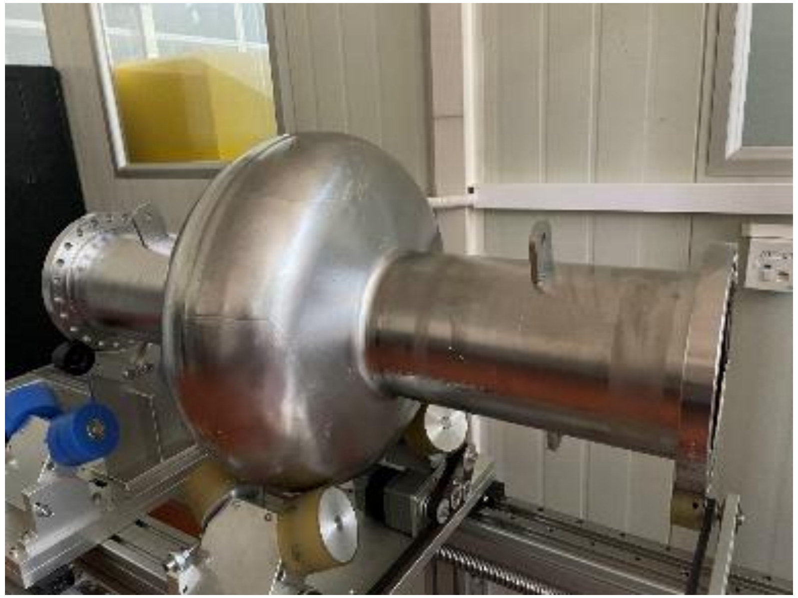
CEPC CDR Goal：

Q_0 = 3.0E10 @ 22 MV/m

Test Results：

Q_0 = 3.9E10 @ 30 MV/m

Q_0 = 1.5E10 @ 37.5 MV/m

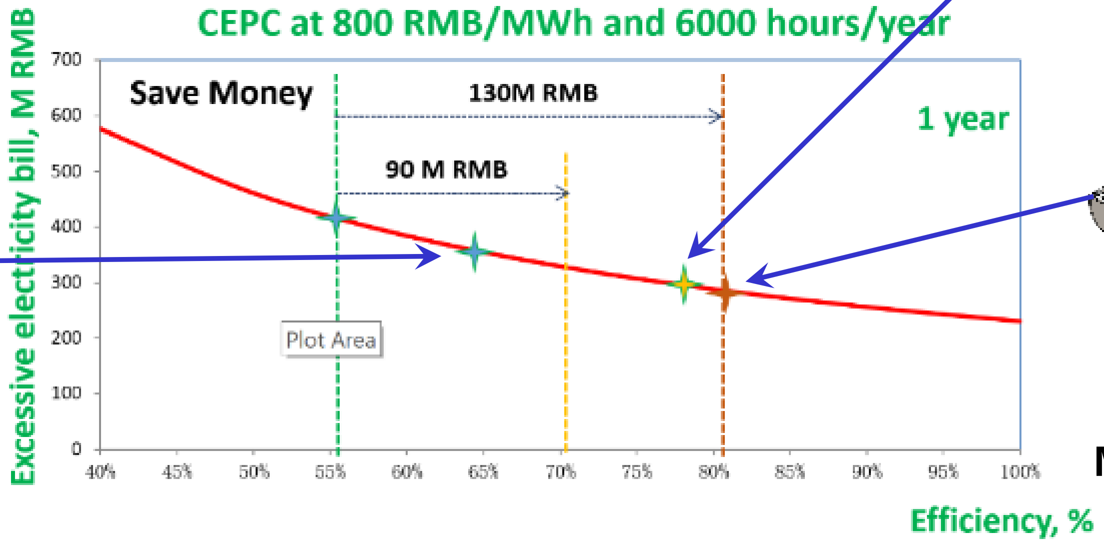


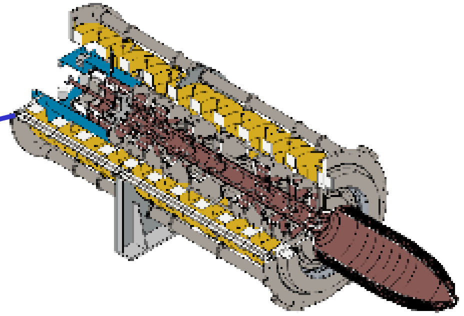
High Efficiency Klystrons

- The 1st prototype finished fabrication & passed the max. power test. Output power reaches 700 kW in CW mode, 800 kW in pulsed mode. Design efficiency is 65%, achieved efficiency ~ 62%.
- The 2nd klystron prototype is manufactured and being baked out, to be tested at PAPS in 2021, design efficiency is ~ 77%.
- Multi-beam Klystron design is finished, design efficiency is ~ 80.5%.
- High efficiency Klystron helps to reduce electricity consumption.

The 2nd Klystron (assembly)

The 1st Klystron (tested)

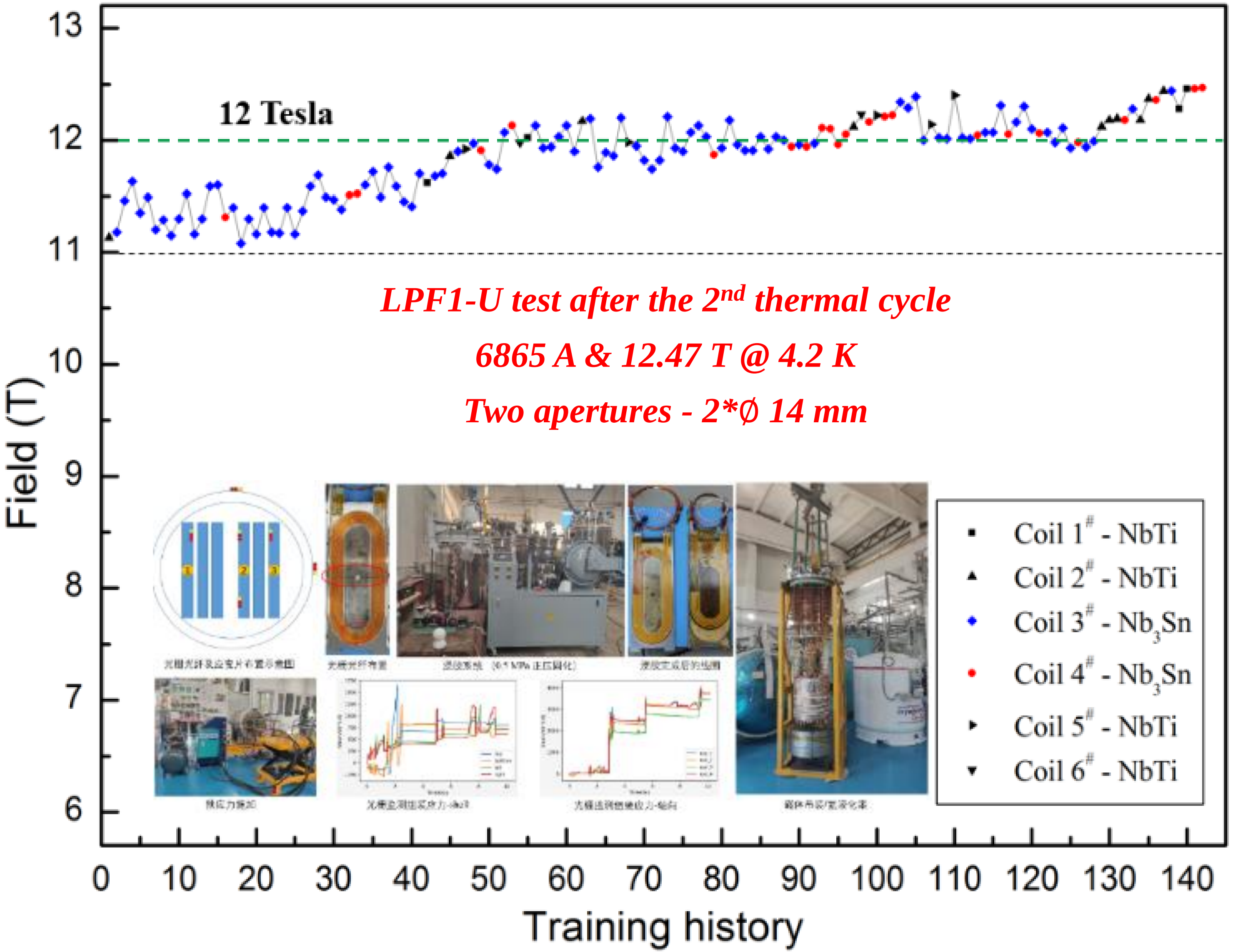


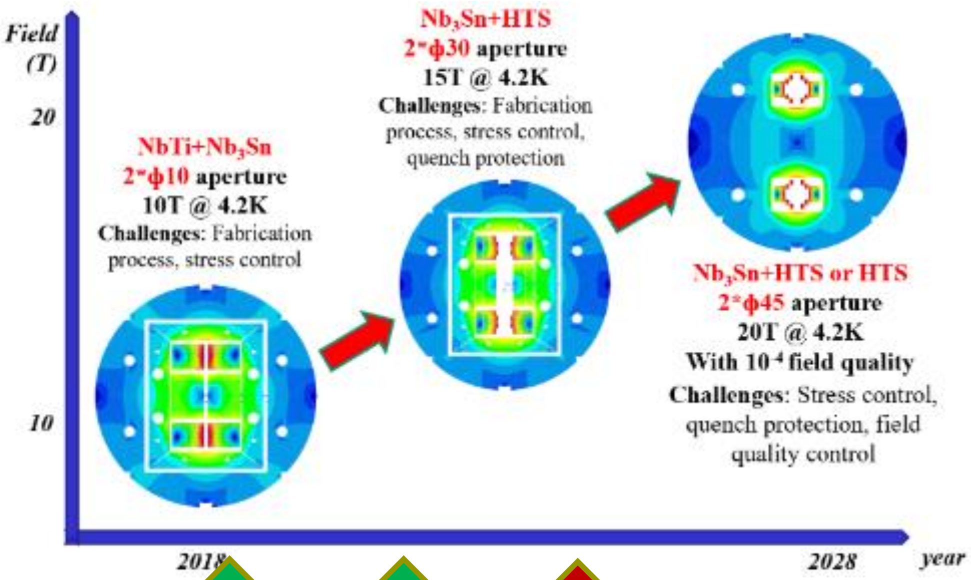


Multi-beam Klystron

HTS Super Conducting Magnet

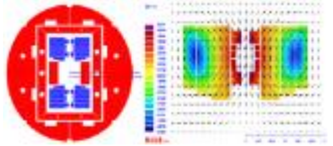
Domestic SC dipole magnet exceeded 12T (IHEP, June, 2021)

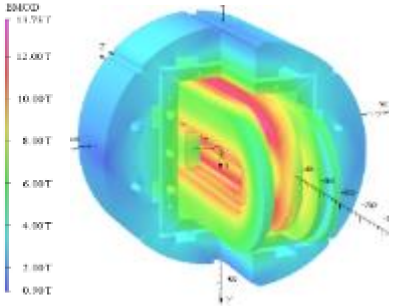




10.2T (2018) | **12.47T (2021)** | **16T (2025)**

LPF3 16T Dipole Magnet:
Nb_3Sn 12~13 T + HTS 3~4 T





CEPC Physics White Papers

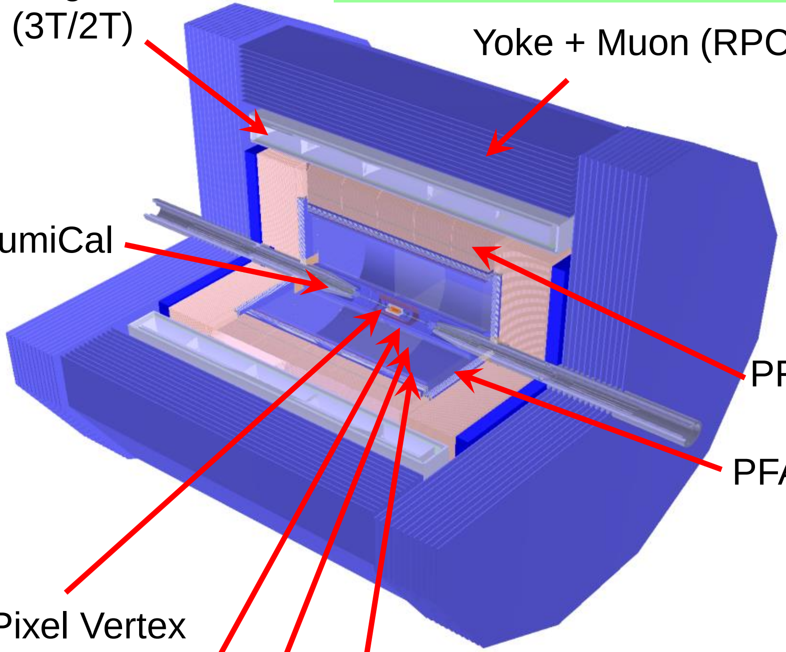
Operation mode		ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]		~240	~91.2	158-172	360
Run time [years]		**7**	**2**	**1**	**?**
CDR	L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	**3**	**32**	**10**	
	$\int L\,dt$ [ab^{-1}, 2 IPs]	5.6	16	2.6	
	Event yields [2 IPs]	1×10^6	7×10^{11}	2×10^7	
Latest	L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	**5.0**	**115**	**16**	**0.5**

The large samples: ~**10^6** Higgs, ~**10^{12}** Z, and ~**10^8** W bosons

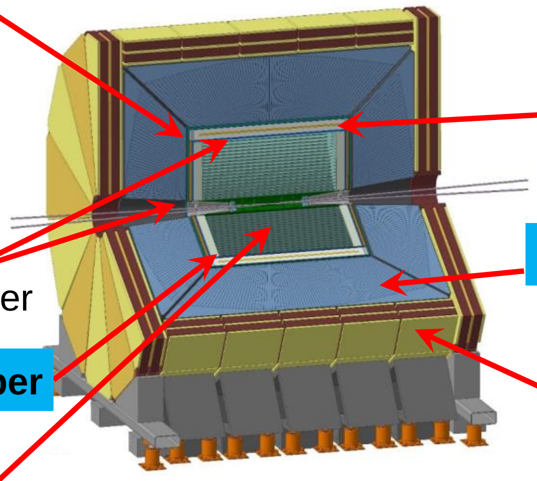
- **Physics goals are similar to FCC-ee, ILC, CLIC.**
- 2019.3 **Higgs** White Paper published *(CPC V43, No. 4 (2019) 043002)*
- 2019.7 Workshop@PKU: **EW, Flavor, QCD** working groups formed
- 2020.1 Workshop@HKUST-IAS: Review progress, EW draft ready
- 2021.4 Workshop@Yangzhou: **BSM** working group formed

Conceptual Detector Designs

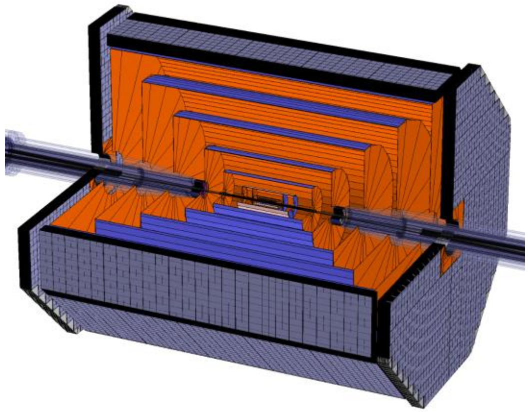
(Baseline Design)
Particle Flow Approach



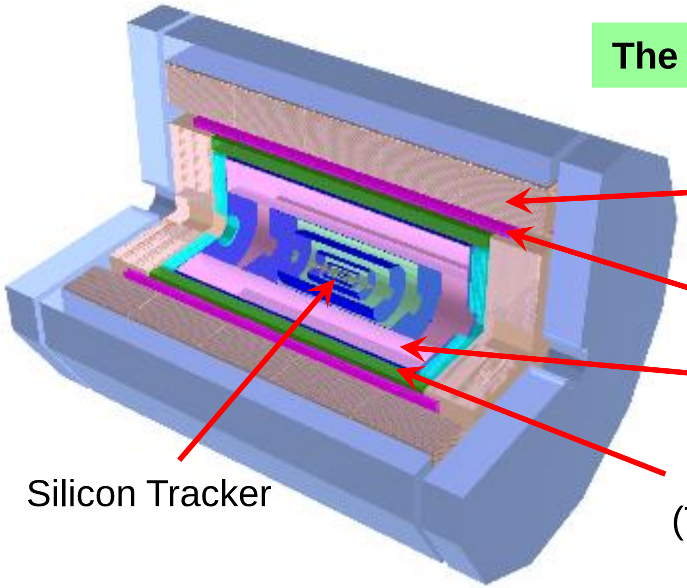
IDEA concept
(also proposed for FCC-ee)



FST concept
(Full Silicon Tracker)

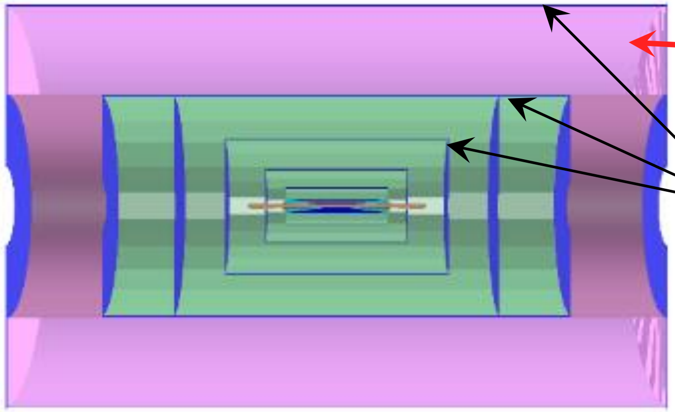


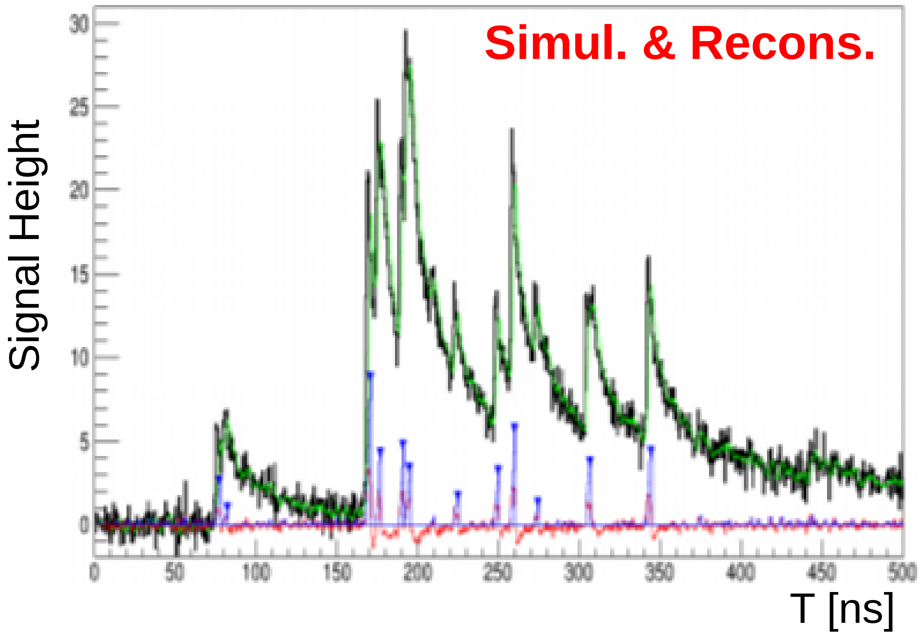
The 4th Concept

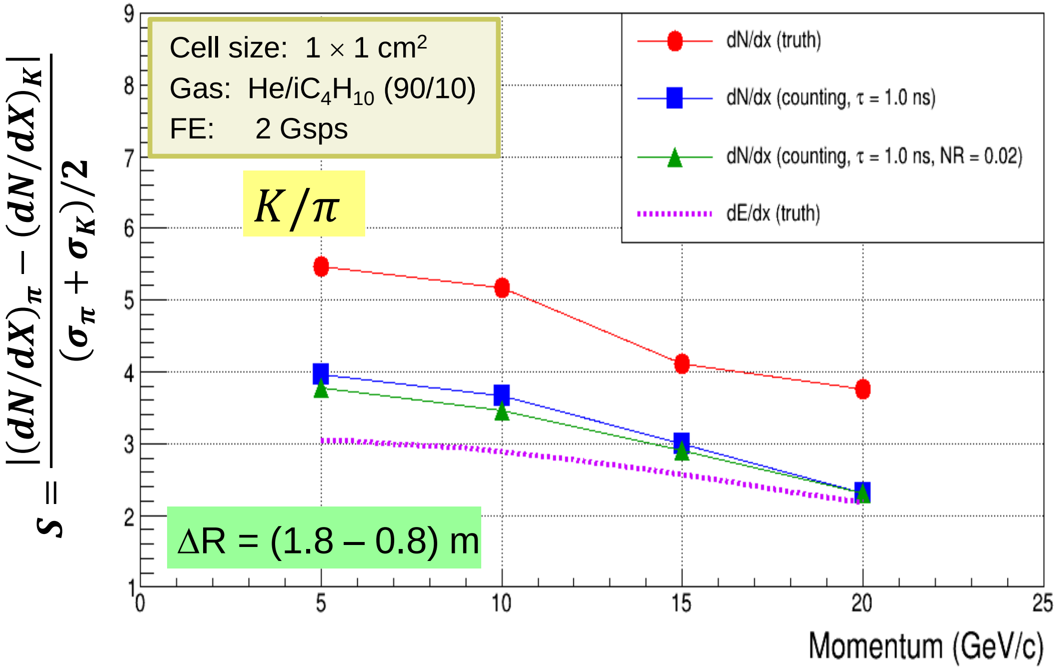


A Drift Chamber Optimized for PID

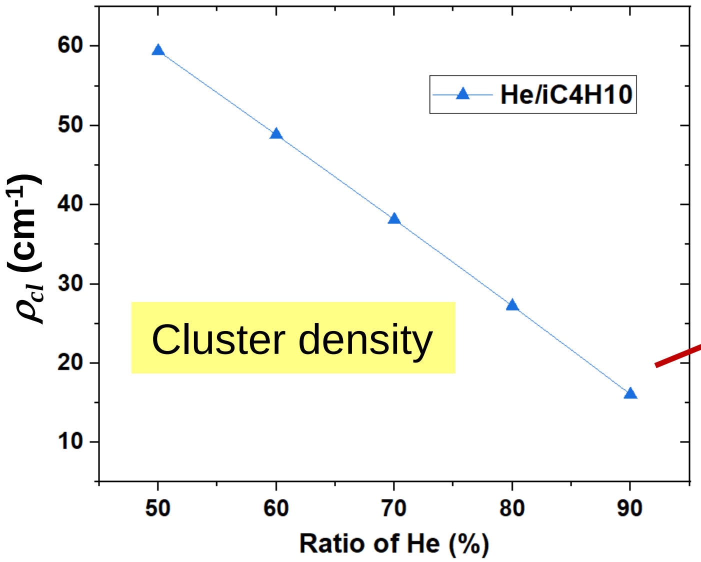
- Goal: 2σ π/K separation at P < ~ 20 GeV/c.
- Use the cluster counting method, or **dN/dx**, by measuring the number of primary ionizations.
- **It can be optimized specifically for PID**: larger cell size, no stereo layers, different gas mixture, …
- Garfield++ for simulation, realistic electronics, peak finding algorithm development.





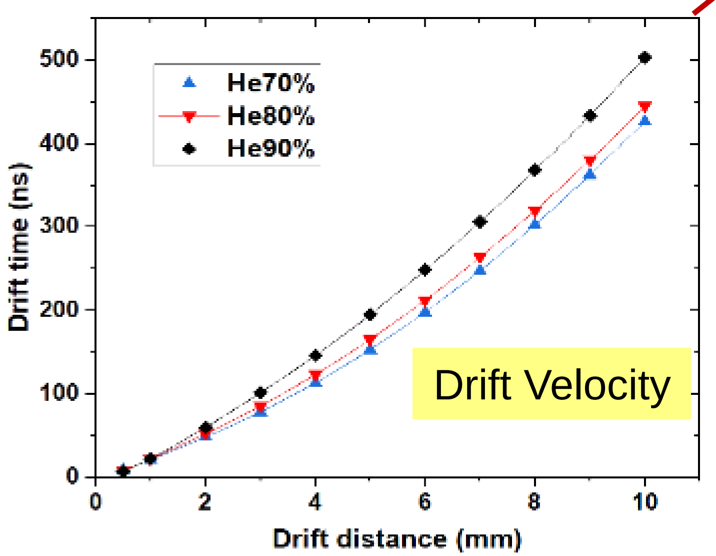


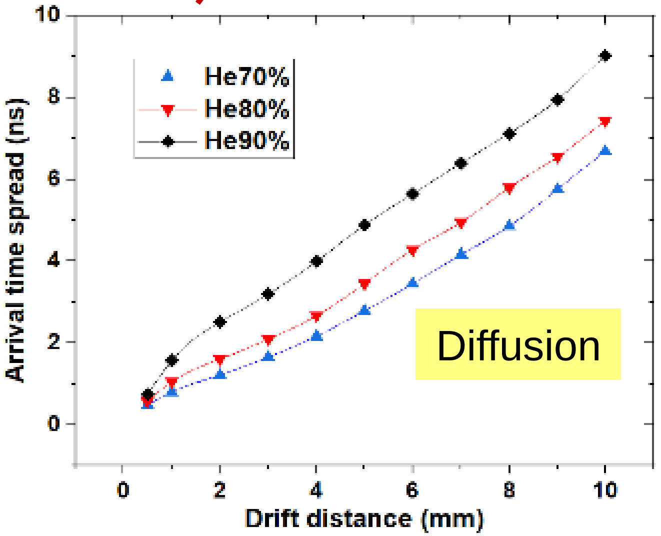
Attempts to Optimize A PID Drift Chamber



$$\frac{\sigma_{dN/dx}}{dN/dx} \propto \frac{1}{\sqrt{L \cdot \rho_{cl} \cdot \varepsilon}}$$

Electronic Performance



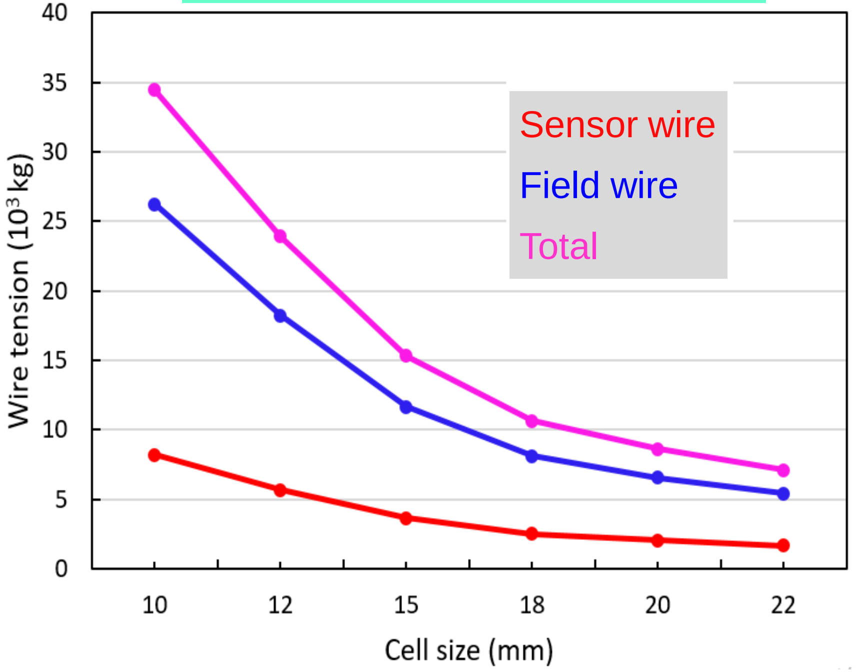


Reducing the number of cells

- Has small effect on dN/dX.
- Reduce material of support structure
- Reduce construction difficulty

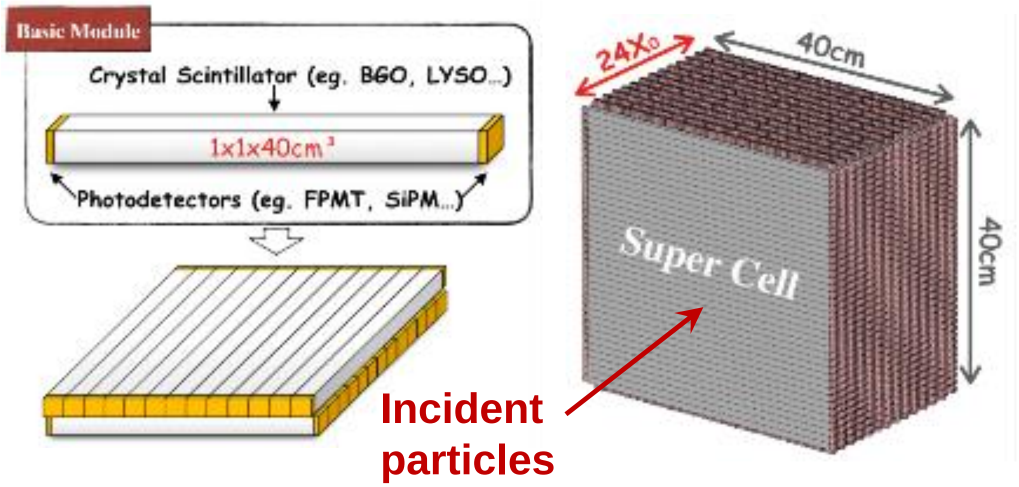
L~5.4 m, Sag ~ 240 μm

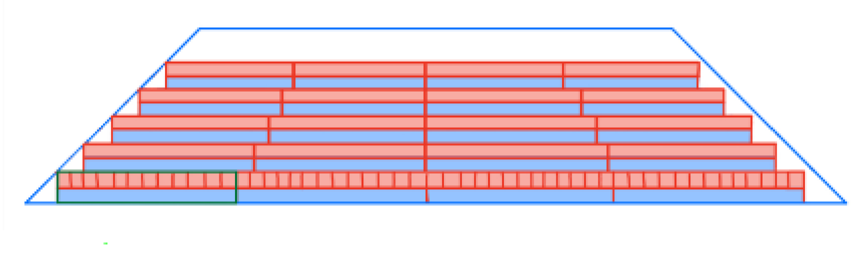
ΔR = (1.8 – 0.6) m, S:F ~ 1:3

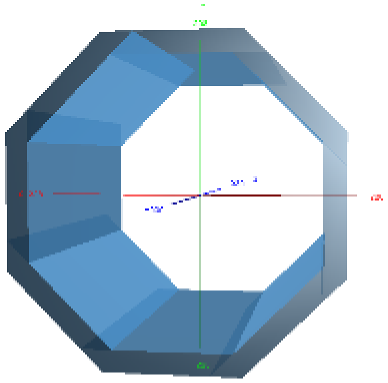


Transverse Crystal Bar ECAL

- A crystal bar ECAL
  - Homogeneous BGO crystal.
  - Bar size ~40×1×1 cm^3, time measurements at two ends for positioning along the bar.
  - Crossed arrangement in adjacent layers. Two layers form a super cell module: ~40×40×2 cm^3.
  - Reduce readout channels, minimize dead materials.
- Key issues:
  - Ambiguity caused by 2D measurements (**ghost hit**).
  - Identification of energy deposits from individual particles (**confusion**).
- Ongoing work:
  - Use ArborPFA software & crystal cubes of 1 cm^3 in size to study PFA performance, compare with SiW ECAL.
  - Develop a proto-PFA new software that has separation capability of multiple incident particles.
  - Bench test of crystal bars.



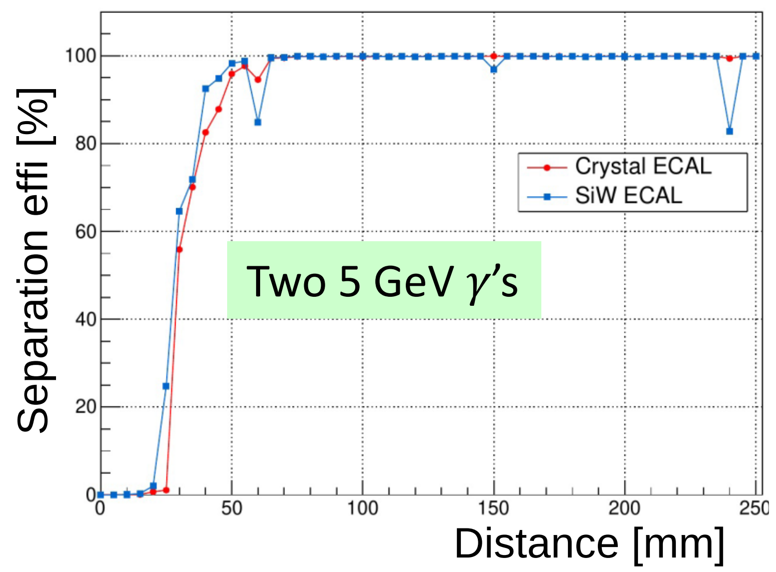


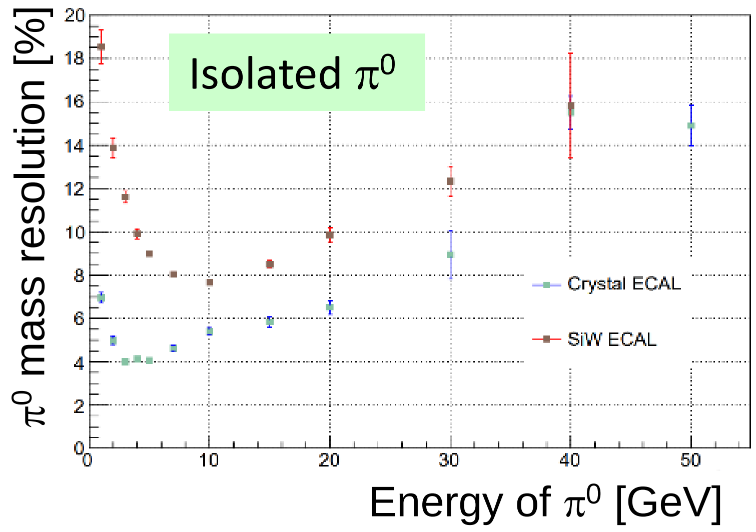


8 trapezoidal staves

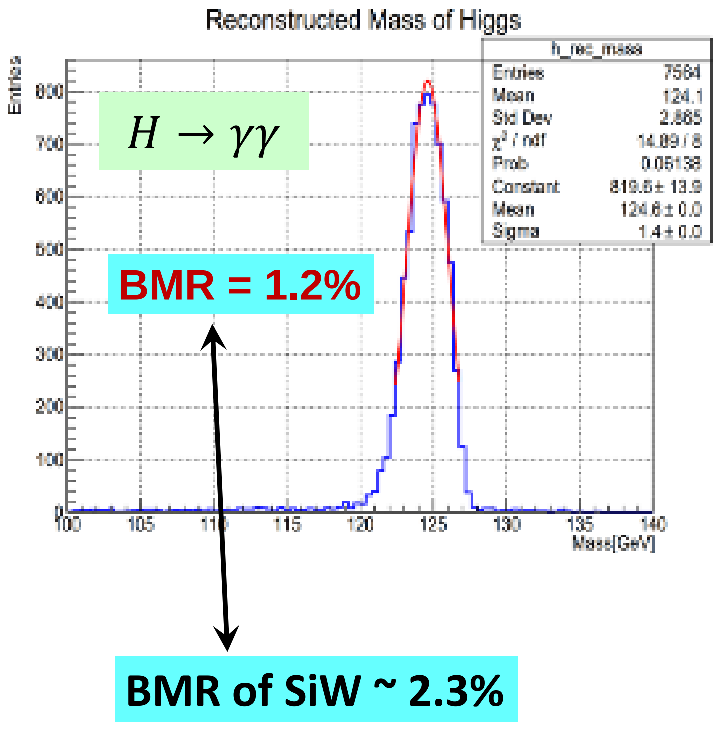
R=1.8m, L=4.6m, H=28cm

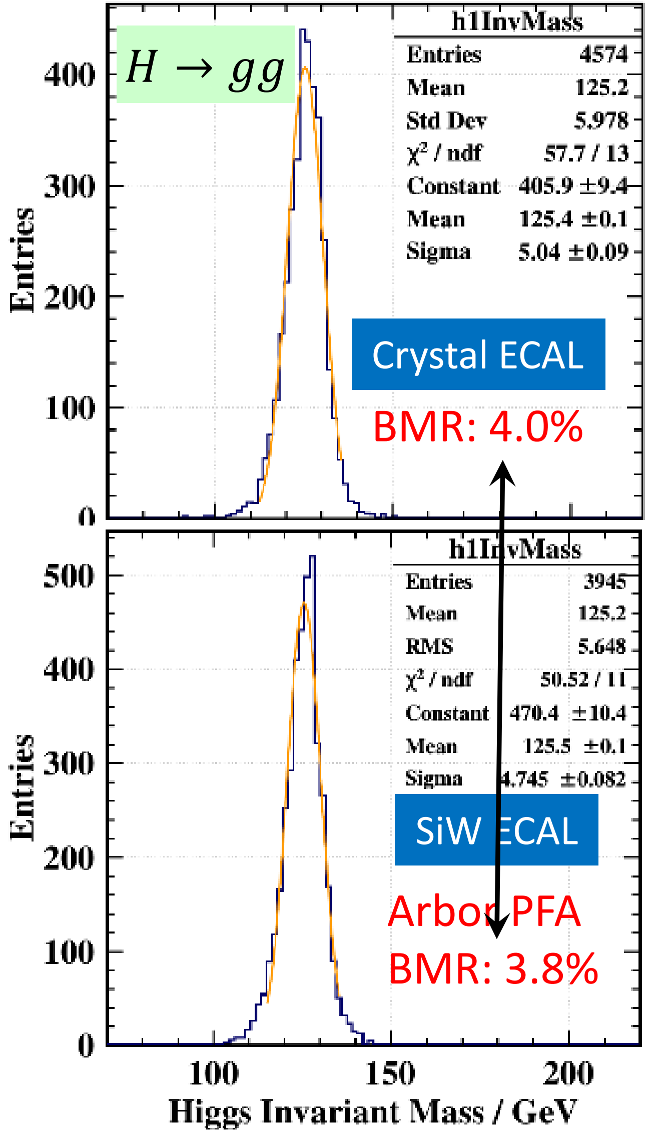
Crystal ECAL vs SiW ECAL



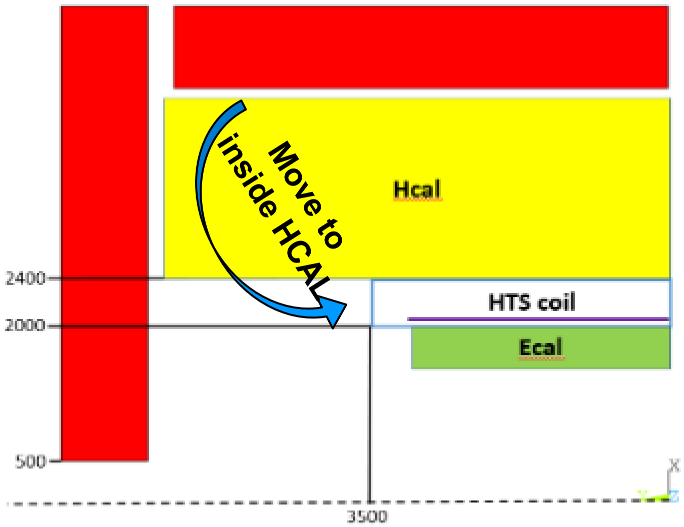


Shower profile & timing info can further improve the Crystal ECAL.





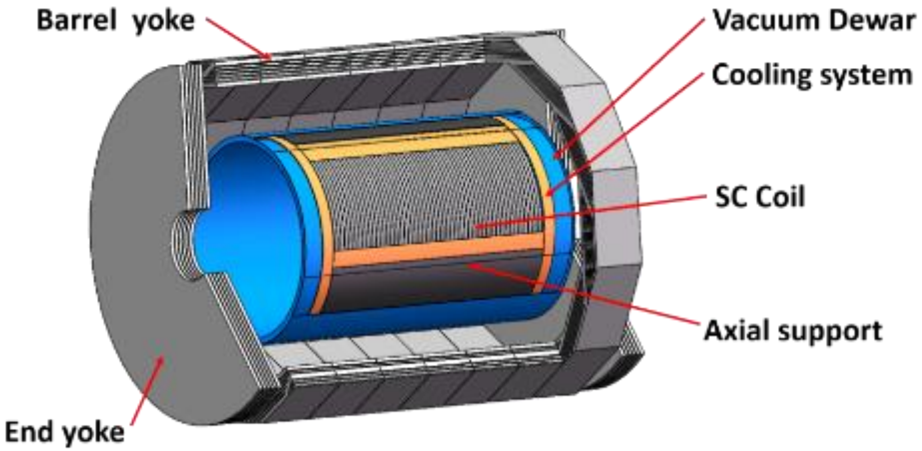
Solenoid Magnet Inside HCAL



Challenges

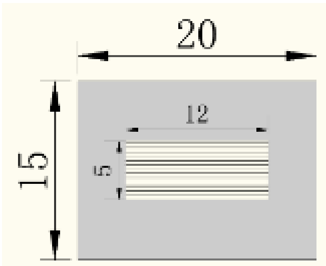
Low mass, ultra-thin, high strength cable

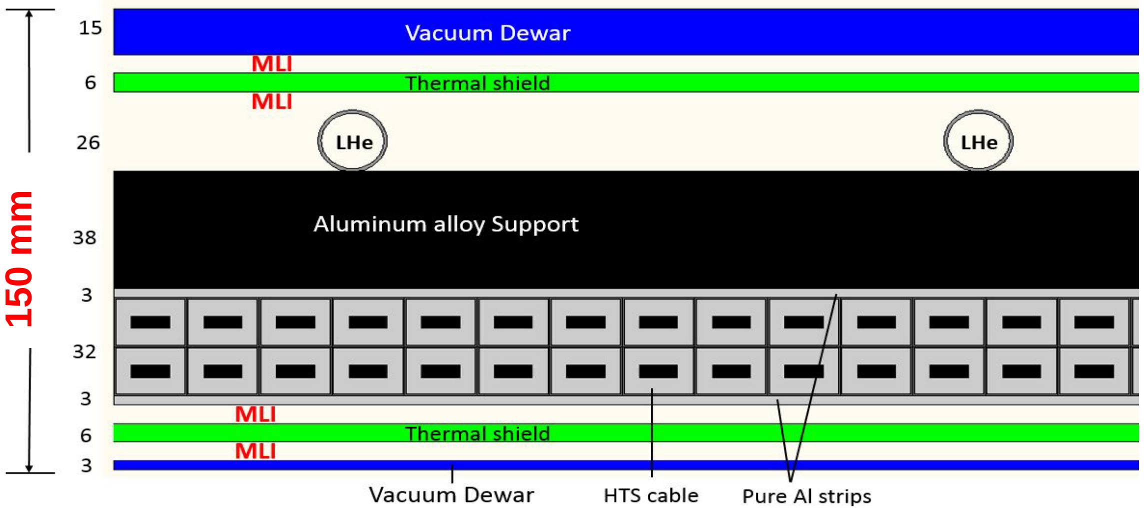
- Inner radius = 2.33m, length < 8m, central magnetic field: 3 T
- Magnet radial thickness < 150 mm
- Mass of magnet < 1.5X_0



R&D: high strength HTS cable, ultra-thin cryostat.

Al stabilized ReBCO stacked tape cable

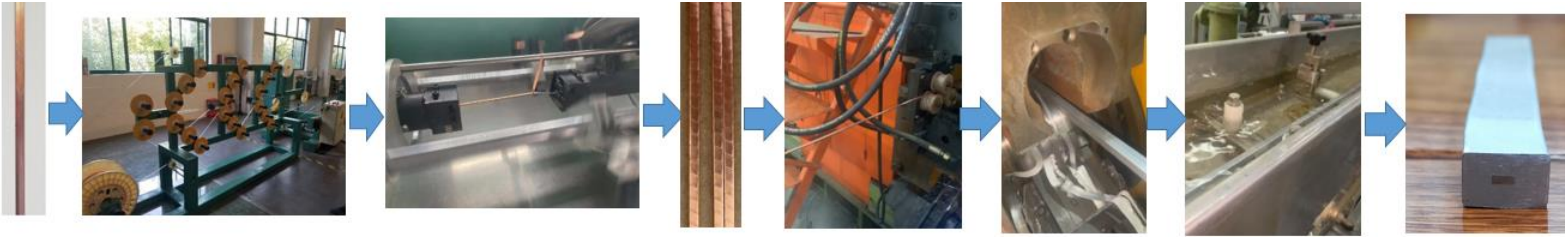




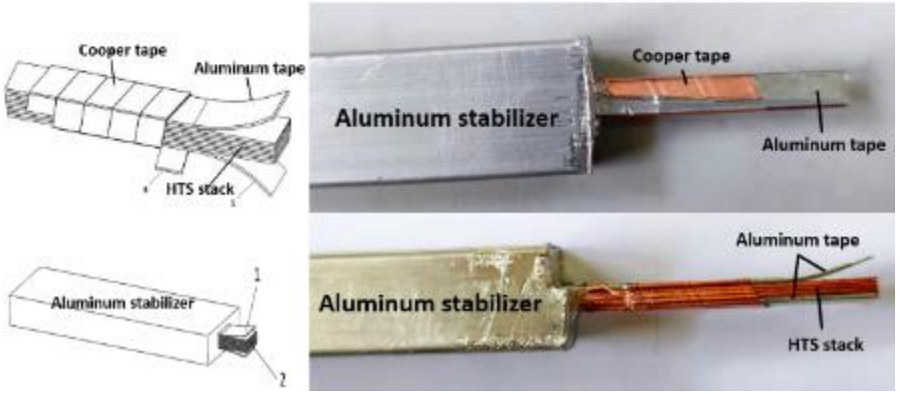
HTS cable length (km)	9
ASTC weight(ton)	9
Operating current(A)	29700
Cold mass weight (ton)	20
Total weight (ton)	35

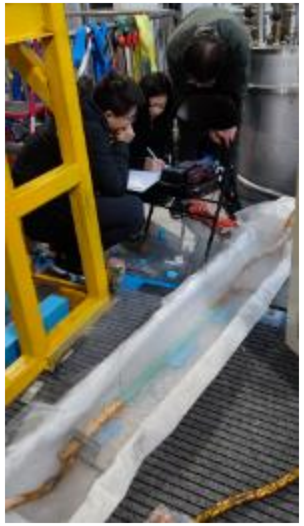
HTS Prototype Cable Development

Prototype cable: 15×20 mm^2, tape width: 4 mm, thickness: 80 μm; tape layer: 20, expected operating current: 6000 A@5K



Big Progress: 10 m ASTC prototype cable is ready. Cable test is ongoing.





Selection of Detector R&D's

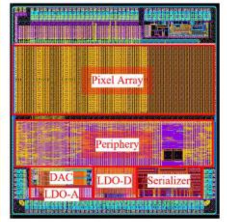
Pixel Vertex

JadePix

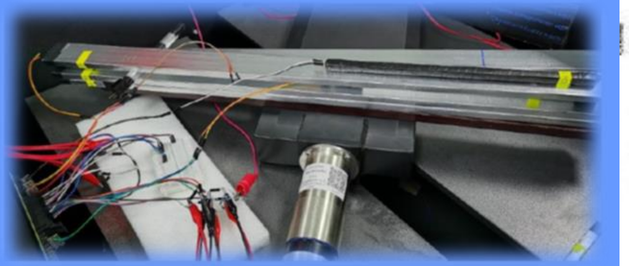
Arcadia

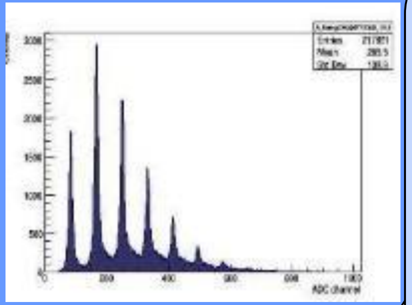
CPV test

TaichuPix

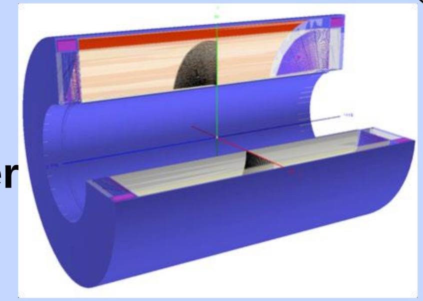


Scintillator Bar Muon





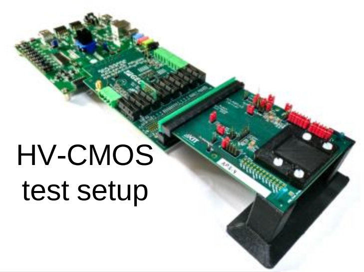
Drift Chamber



AD9689 – 2000 EBZ

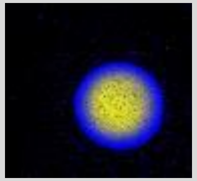
Xilinx KCU105

HV-CMOS Tracker

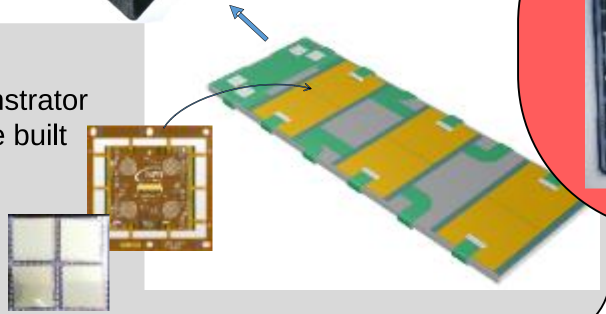


HV-CMOS test setup

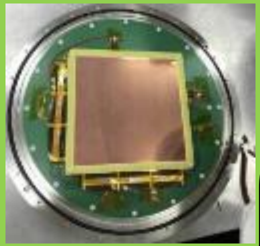
Fe source test



Demonstrator
To be built

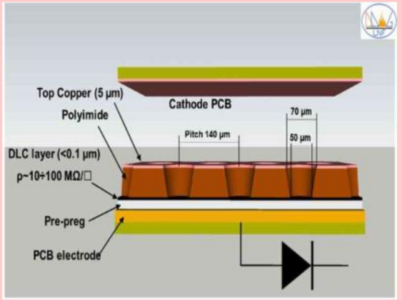


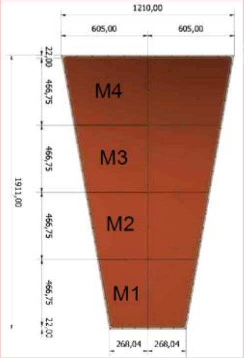
TPC Prototype



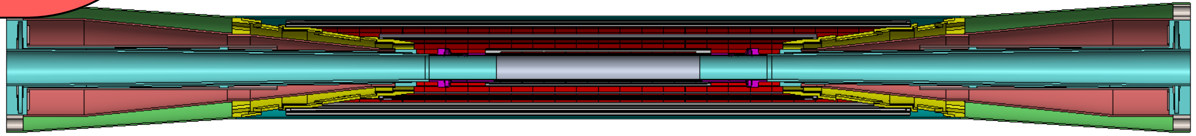
LGAD ToF

μRWELL for PS & Muon



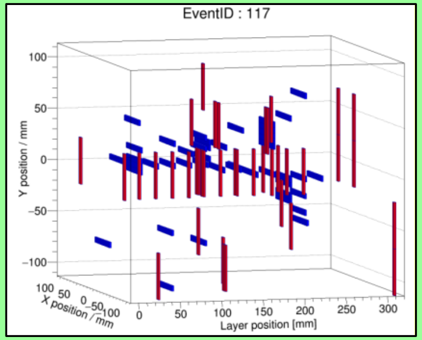


Beampipe Design

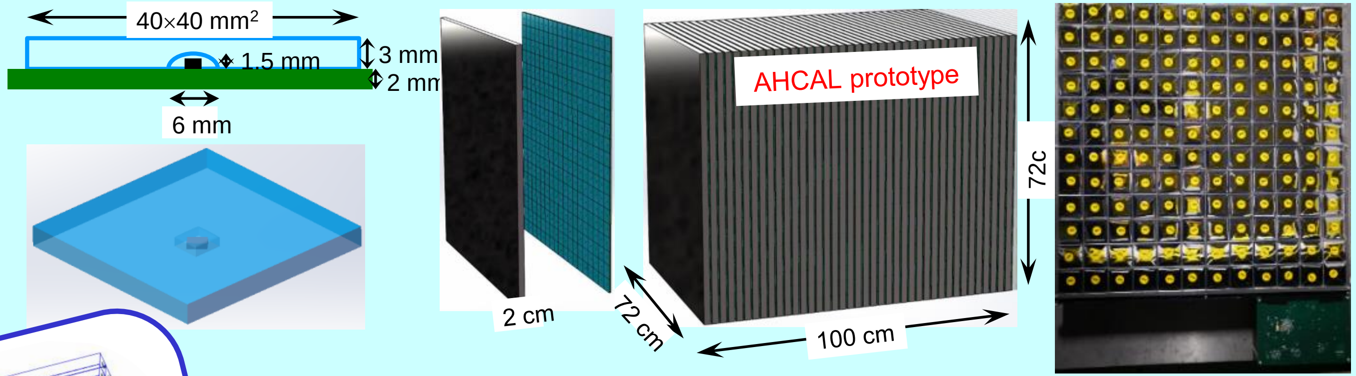


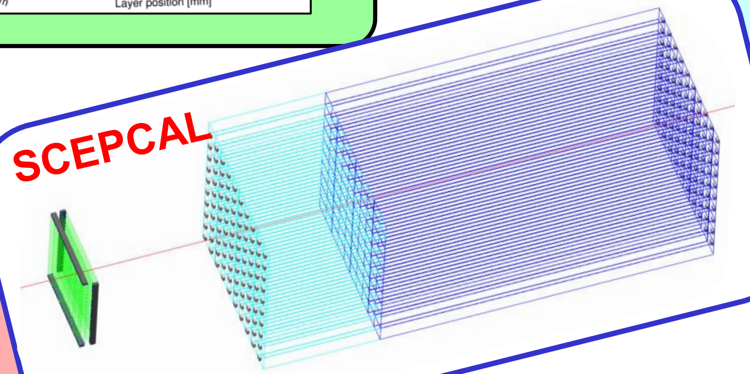
Selection of Detector R&D's

Prototype ScECAL

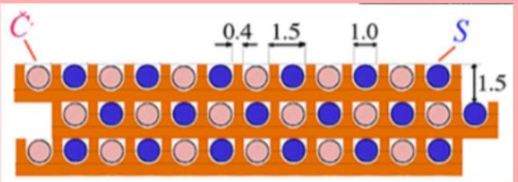


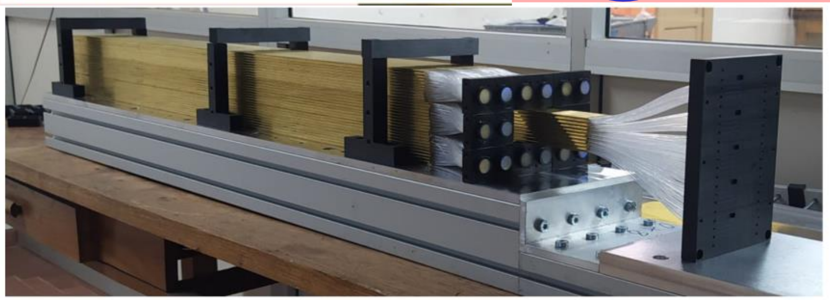
Scint-Steel HCAL

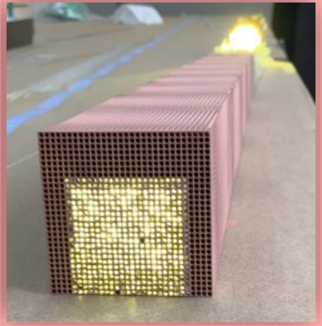




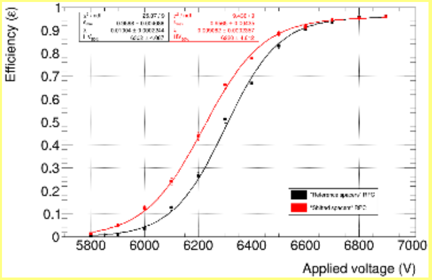
Dual Readout CAL

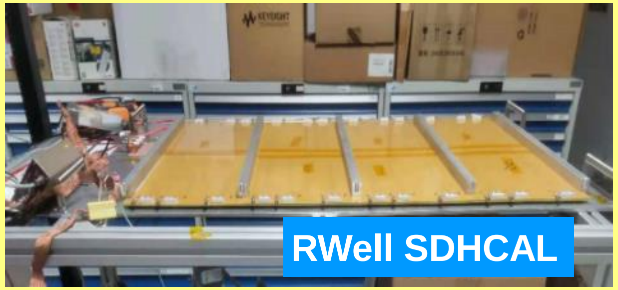




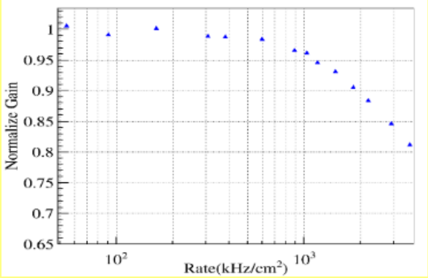


GRPC SDHCAL





RWell SDHCAL



Summary

- The CEPC study group continues its efforts to
  - Conduct R&D's on key technologies of accelerator & detector; has made pre-proposals recently to the MOST for more funding support.
  - Explore physics potentials of the CEPC and complete the physics whitepapers.
  - Investigate further the candidate sites; win support from local government and industry.
  - Work hard to be approved by the government in the 15th five-year plan.
  - Form international experiment collaborations, and proceed on TDR, construction, …, eventually real experiments. We welcome new members to join.
- Further strengthen the international efforts towards our common goal.
  - More collaborations in detector & accelerator R&D, among the potential Higgs factories,
  - Joint research laboratories and shared workshops.
  - …