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Status and Perspectives of The CEPC

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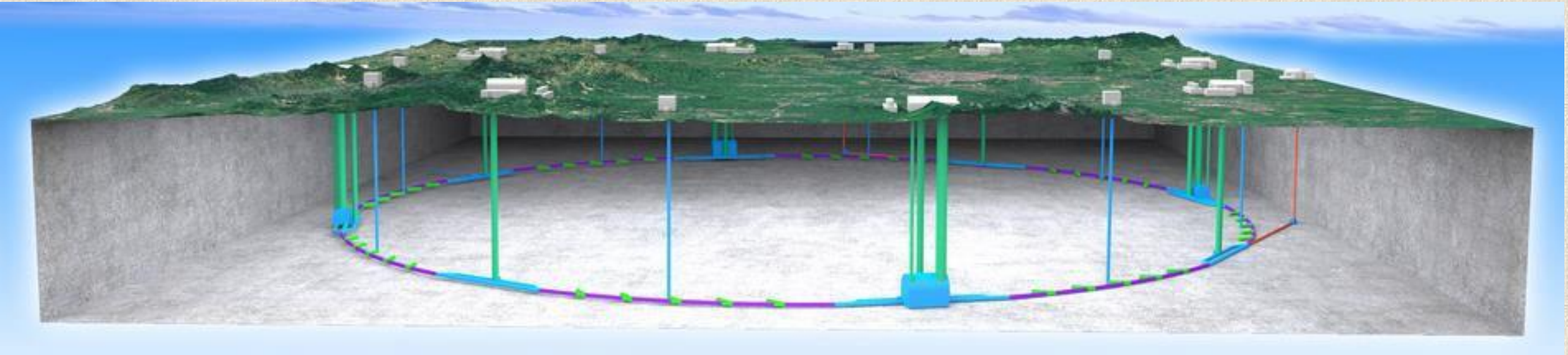
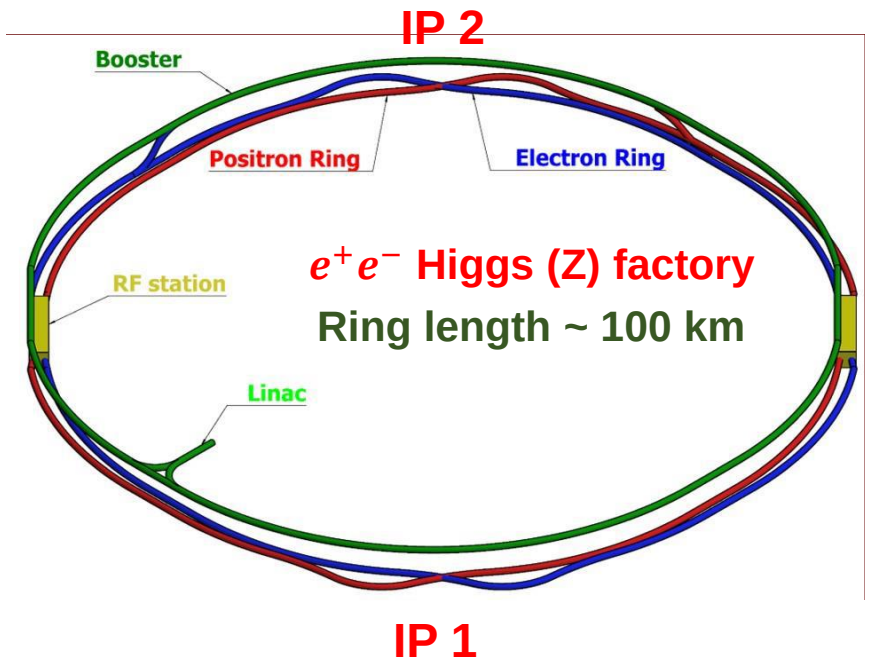
IHEP, CAS

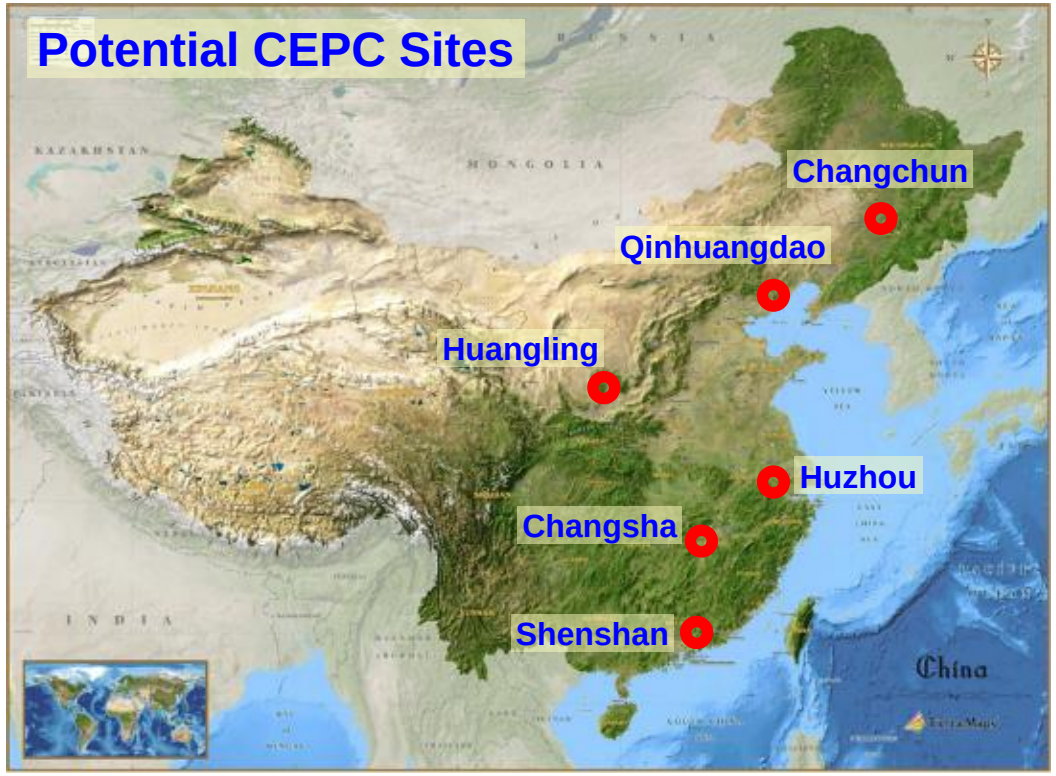
For the CEPC working group



The Circular Electron Positron Collider

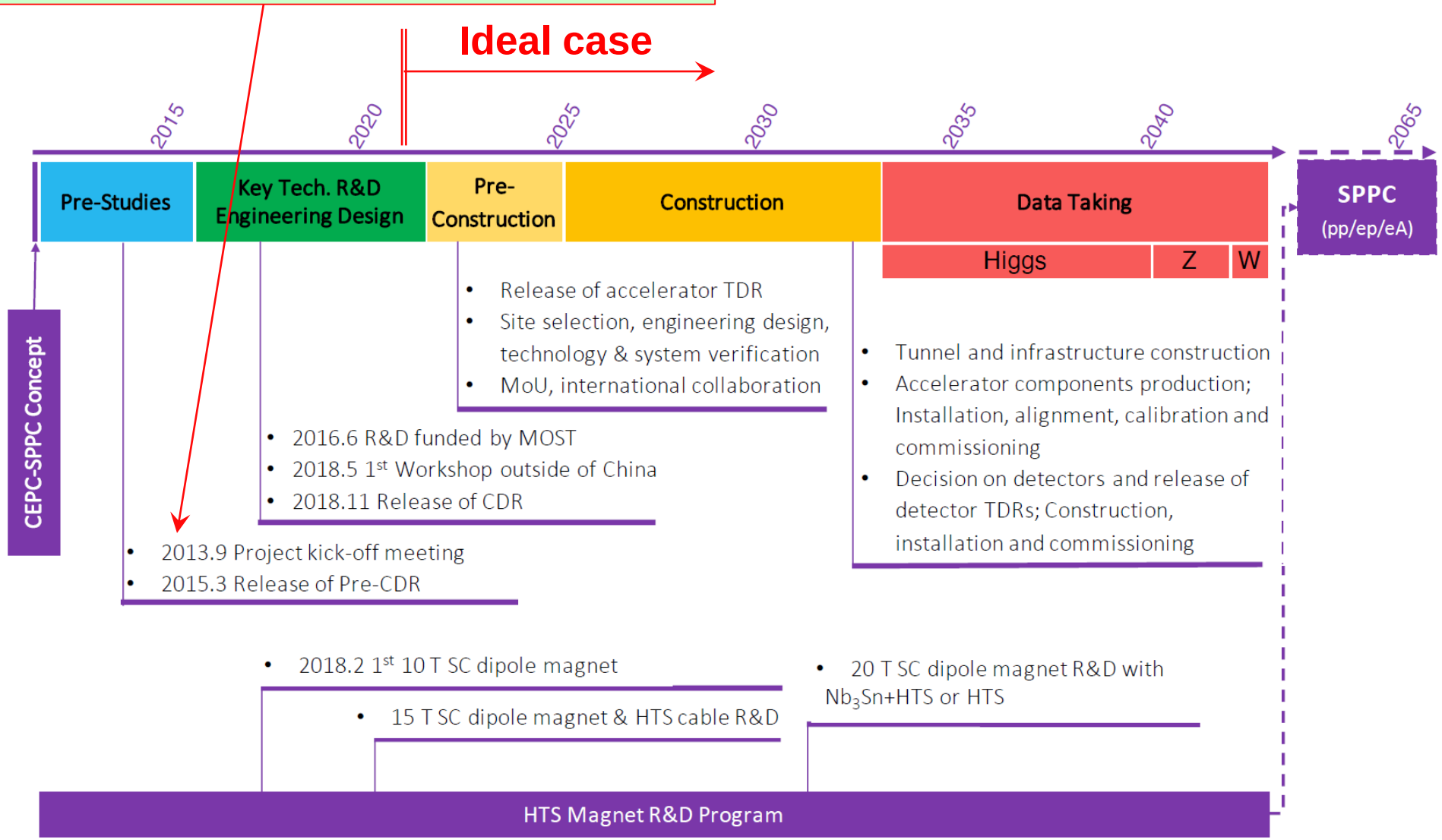
- The CEPC aims to start operation in 2030's, as a Higgs (Z) factory in China.
- To run at $\sqrt{s}$ ~ 240 GeV, above the **ZH** production threshold for ~1M Higgs; at the **Z** pole for ~Tera Z, at the **W^+W^-** pair (possible $t\bar{t}$ pair) production threshold.
- High precision Higgs, EW measurements,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



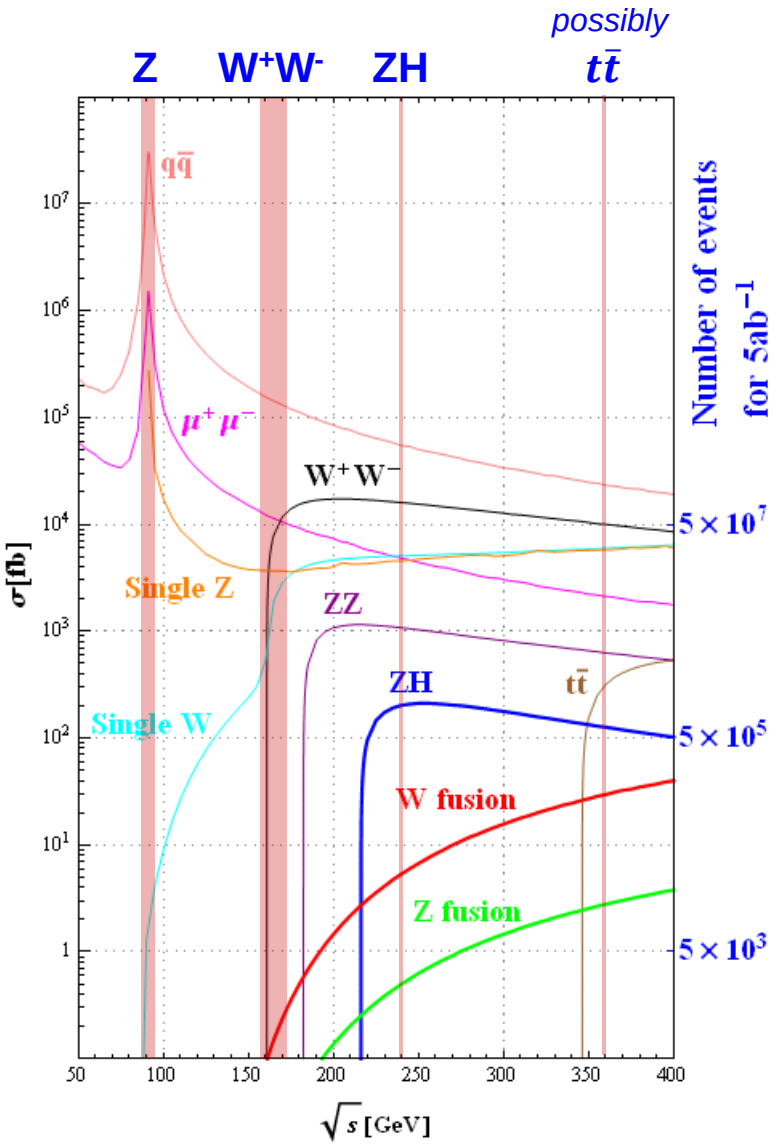


CEPC Roadmap (Proposed)

Inspired by the discovery of the Higgs boson at the LHC



The CEPC Operation Plan



Operation mode		ZH	Z	W^+W^-
$\sqrt{s}$ [GeV]		~240	~91.2	158-172
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**	**105.5**	**15.4**

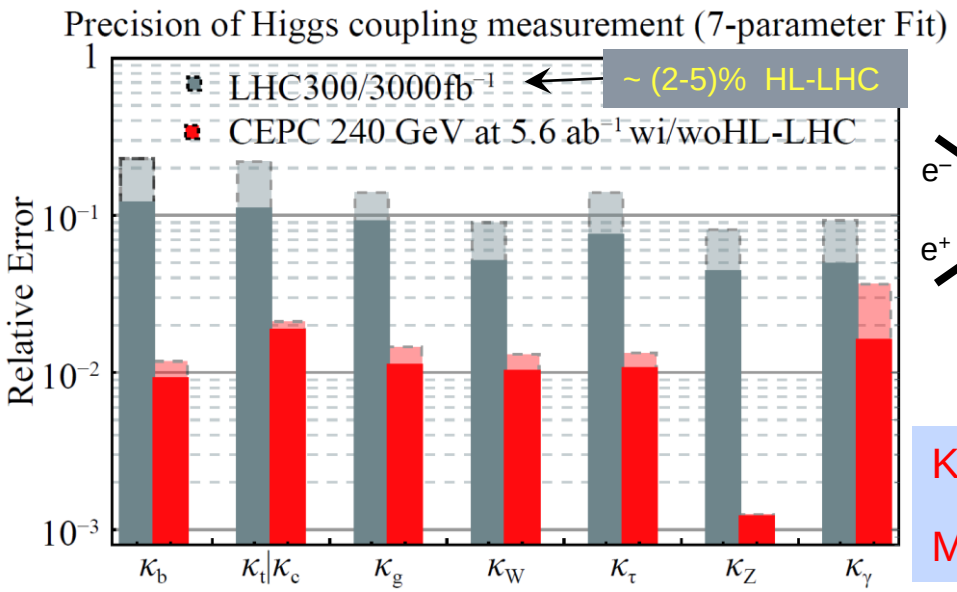
The large samples from 2 IPs: ~**10^6** Higgs, ~**10^{12}** Z, and ~**10^8** W bosons,

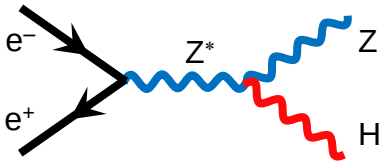
- CEPC Conceptual Design Report: Volume 1 – Accelerator, arXiv:1809.00285
- CEPC Conceptual Design Report: Volume 2 – Physics & Detector, arXiv:1811.10545

Physics Reach of The CEPC

The large samples of H, Z &W bosons from the CEPC provide a unique opportunity

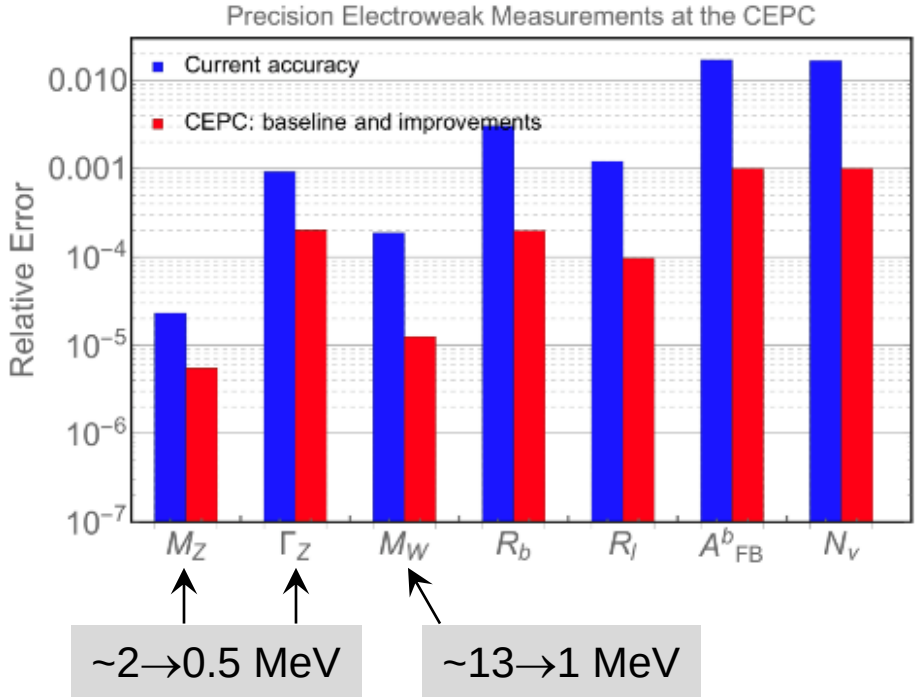
- Higgs physics white paper, arXiv:1810.09037
- Model independent measurement of Higgs boson width.
- Delivers ≤ **1%** precision in some key measurements of Higgs properties, some are not accessible @ LHC.
- Sensitive to invisible decay modes of Br ~0.3%, and exotic decay channels.





K_Z uncert. ~ 0.13%

Most others ~ 1%

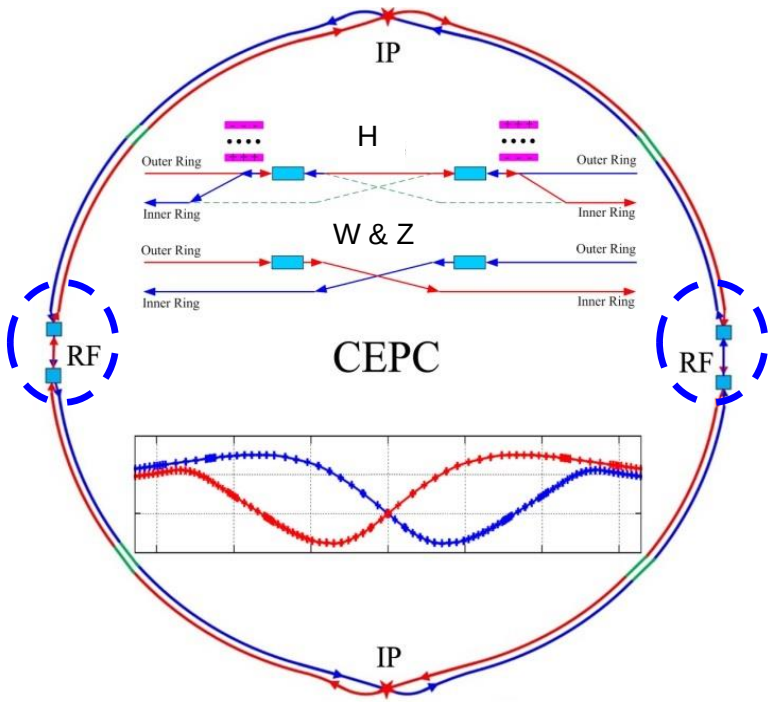


- Precision EW measurements,
- Flavor physics (b, c, tau),
- Study of QCD,
- Probe physics BSM.

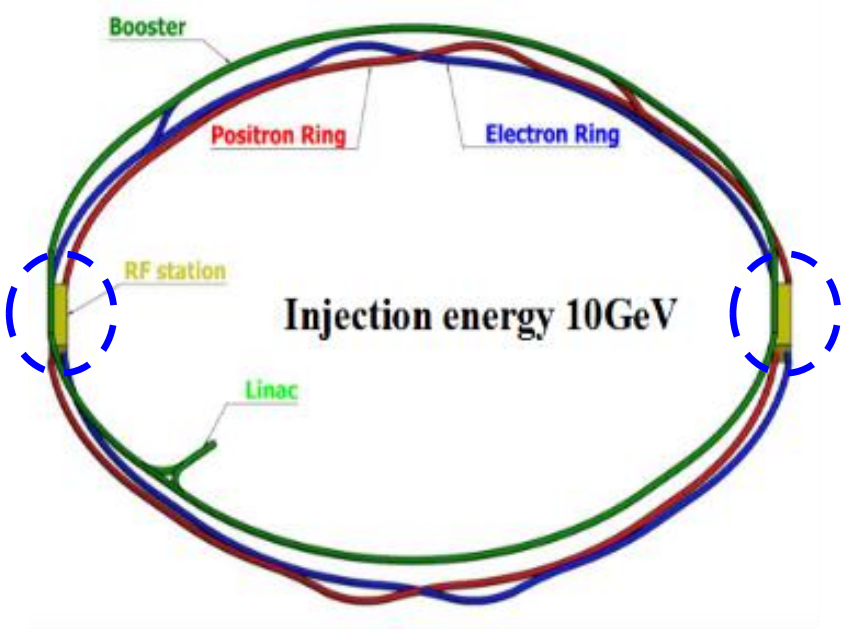
The CEPC Collider

- Double ring baseline design (30 MW/beam, upgradable to 50)
- Switchable between H & Z, W modes without hardware change (magnet switch).

A very active **accelerator** R&D program towards a **TDR ~** the end of 2022

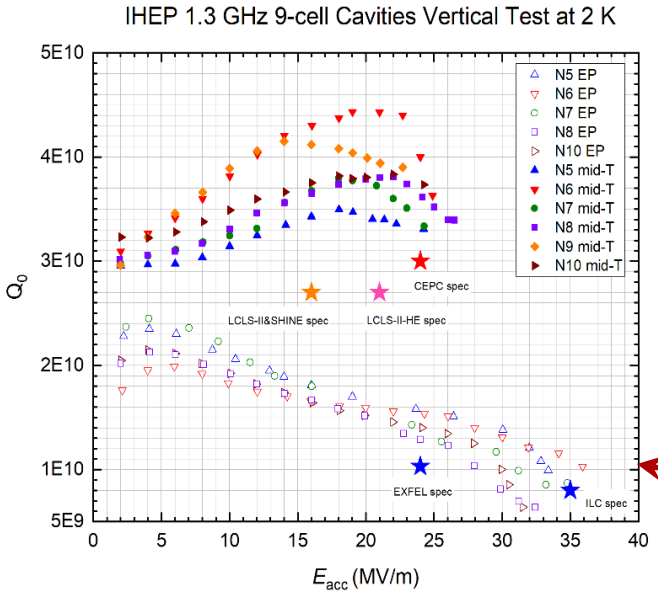


650 MHz SRF system
for the collider ring (100 km)



1.3 GHz SRF system
for the booster ring (100 km),
which is above the collider ring

Accelerator R&D: High Q SRF Cavities



Both exceeded the CEPC spec, a milestone towards the TDR

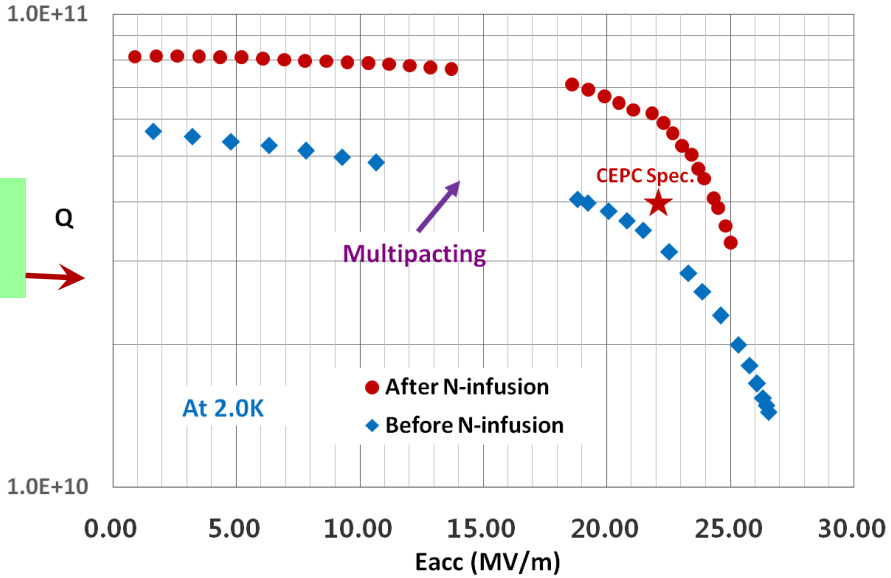
Collider ring 650MHz 2-cell cavity

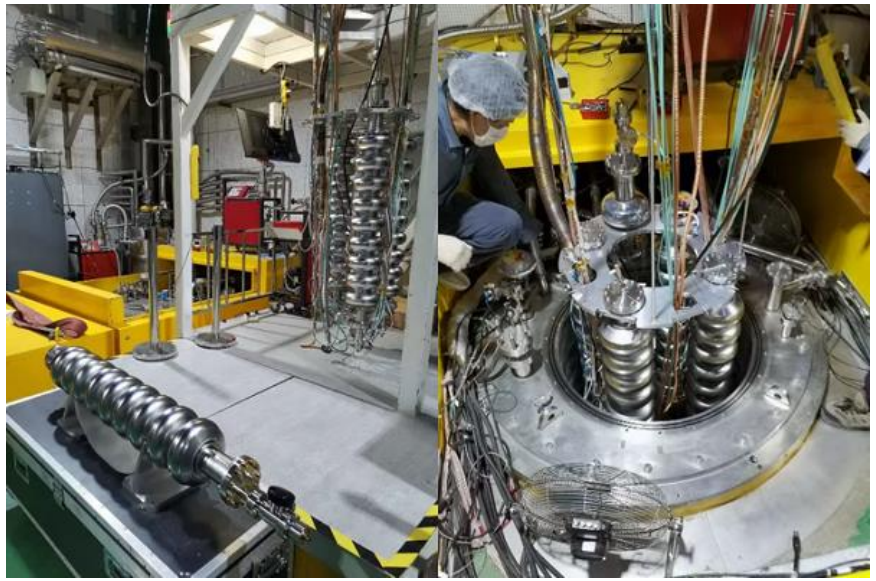
N-infusion adopted, Q = 6.0E10@22MV/m

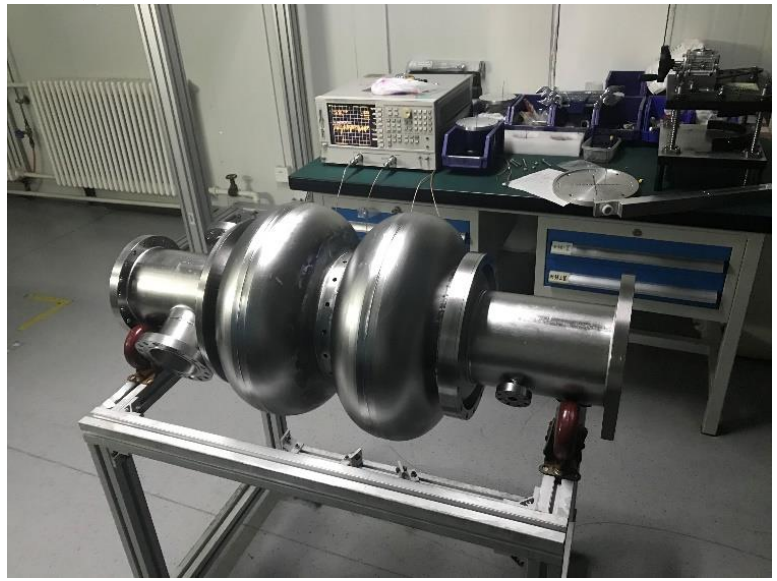
Booster 1.3GHz 9-cell cavity

> 30 MV/m, max 36 MV/m.

Q= 3.4~4.5E10@16~22MV/m







Accelerator R&D: High Efficiency Klystrons

- The 1st prototype finished its fabrication and passed the maximum power test.
- Output power reaches 700 kW in CW mode and 800 kW in pulsed mode. Power transfer rate ~ 62%.
- one of the key technology and breakthrough for CEPC

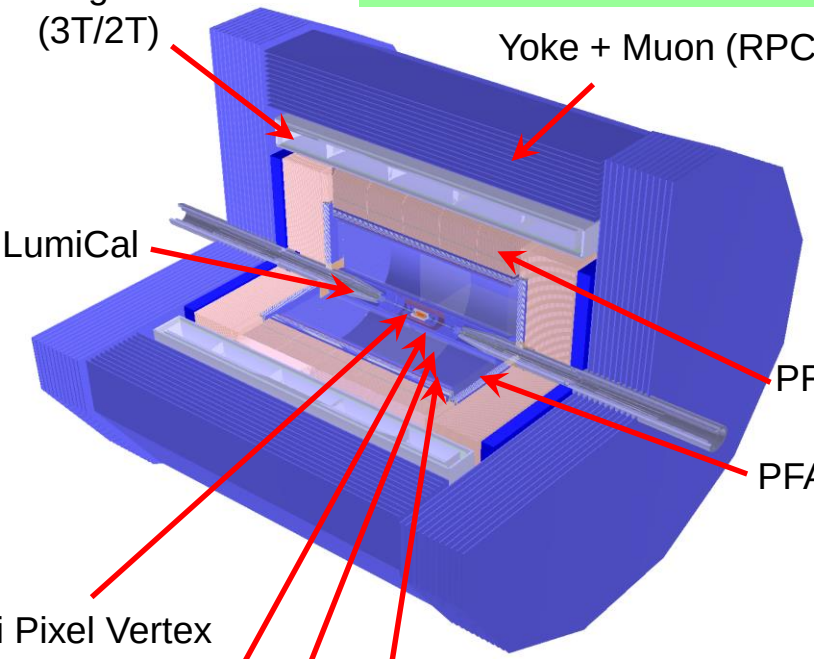
Bake out

Cold test

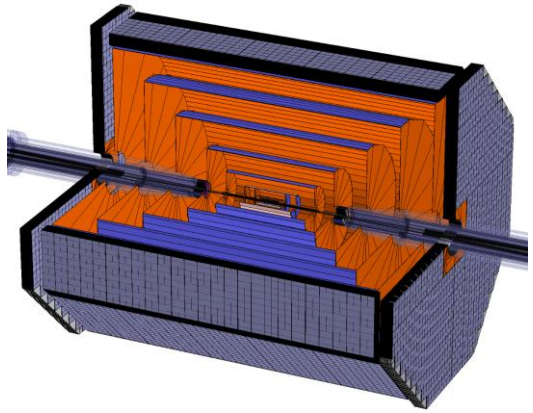
High power test

Conceptual Detector Designs

(Baseline Design)
Particle Flow Approach

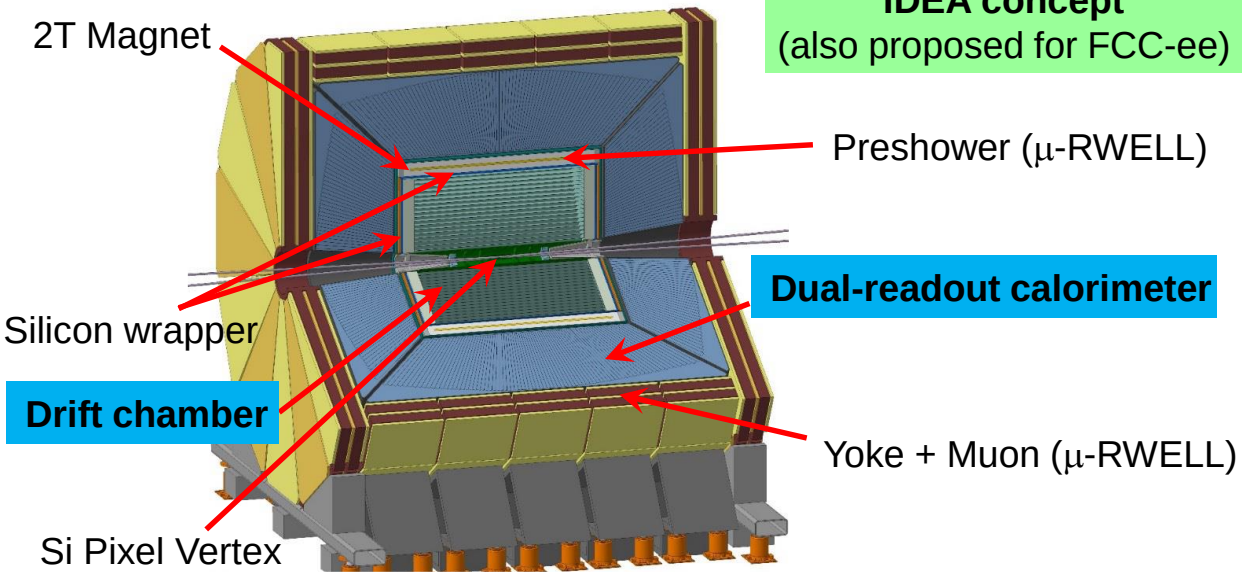


SIT TPC SET
FTD ETD

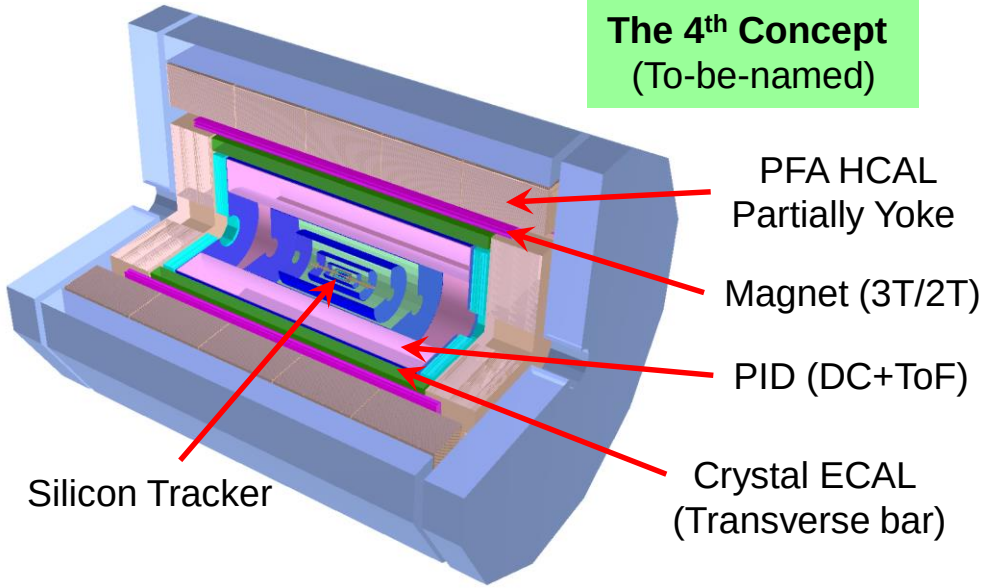


FST concept
(Full Silicon Tracker)

IDEA concept
(also proposed for FCC-ee)



The 4th Concept
(To-be-named)



Requirements of The CEPC Detector

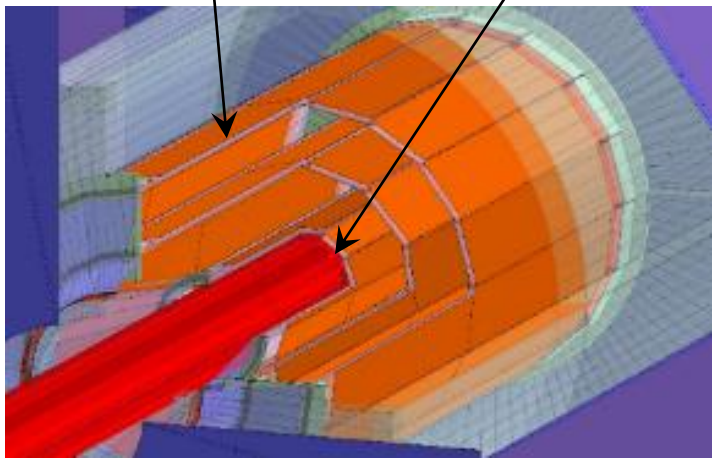
The physics motivations dictate our selection of detector technologies

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) =$ $2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV})\sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} =$ $5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta}(\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E =$ $3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E =$ $\frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

- Flavor physics $\Rightarrow$ Excellent PID, better than 2σ separation of π/K at momentum up to ~20 GeV.
- EW measurements $\Rightarrow$ High precision luminosity measurement, $\delta L / L \sim 10^{-4}$.

Silicon Vertex Detector

2 layers / ladder R_{in}~16 mm



Goal: σ(IP) ~ 5 μm for high P track.

CDR design spec:

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

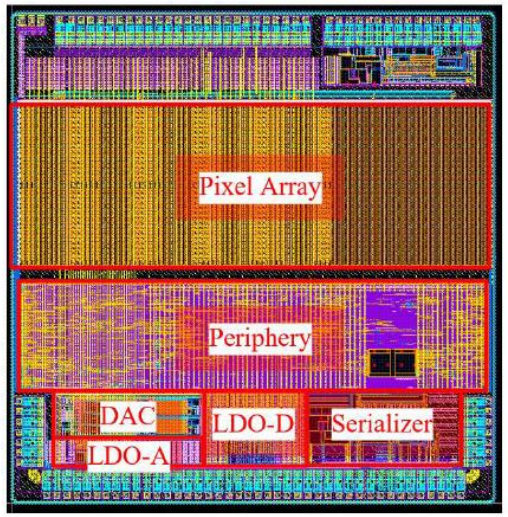
Silicon pixel sensor develops in 3 series:
JadePix / MIC, **TaichuPix**, **CPV**

JadePix-3 Pixel size ~16×23 μm^2

Tower-Jazz CiS process

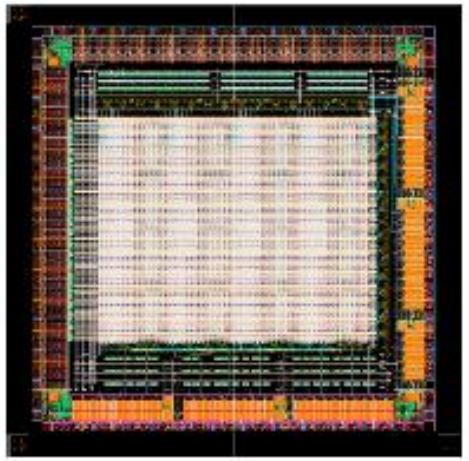
Full size TaichuPix-3 to be used for prototyping ladder

TaichuPix-2, 64×192 array
25×24 μm^2 pixel size

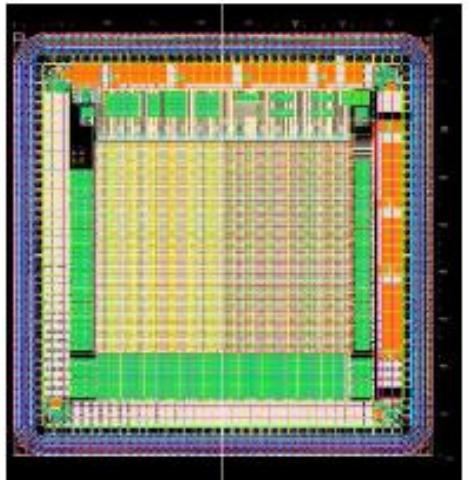


CPV4 (SOI-3D), 64×64 array
~21×17 μm^2 pixel size

Upper chip



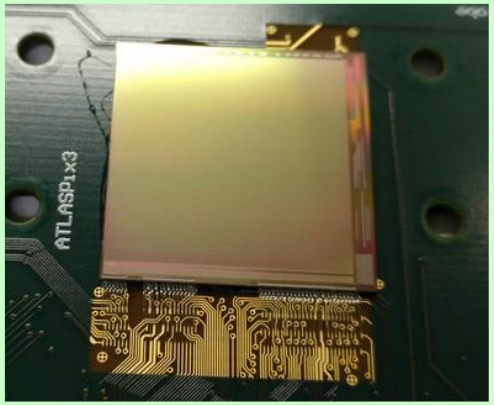
Lower chip

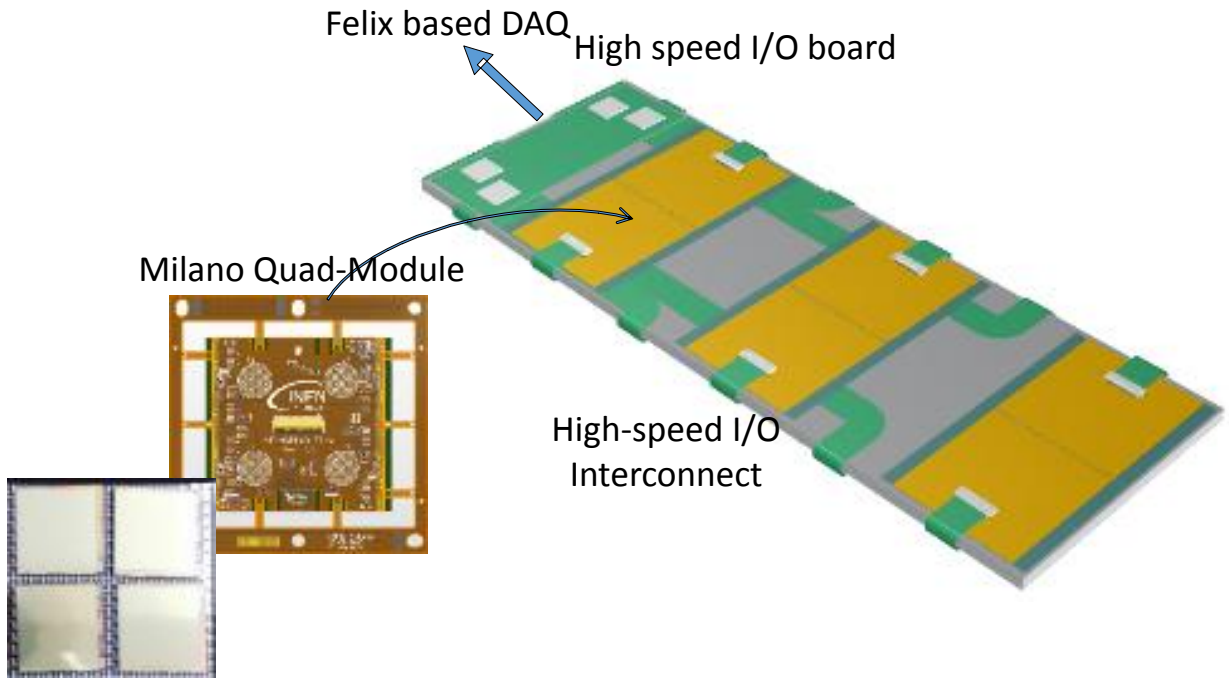


Silicon Tracker

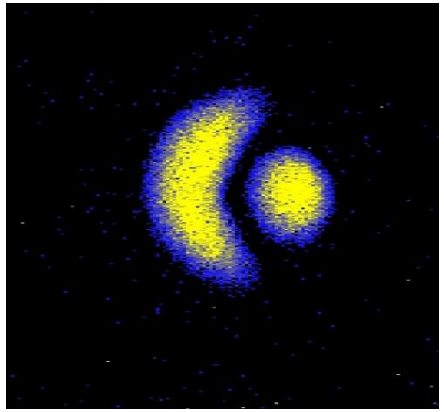
- Area of the silicon tracker is very big: ~70 m^2 in SiTrk+TPC, or ~140 m^2 in FST plans. R&D focuses on cost effective and high performance.
- A HV-CMOS solution based on the ATLASPix3 designed by KIT.
- Study ATLASPix3 with radioactive source, cosmic ray, & particle beam.
- A short stave demonstrator will be constructed.
- A CEPC-version of pixel size 25×150 μm^2 is to be fabricated with the HLMC 55nm technology.

ATLASPix3
132×372 pixels
150×50 μm^2 pixel size.
Time resolution: O(10ns)





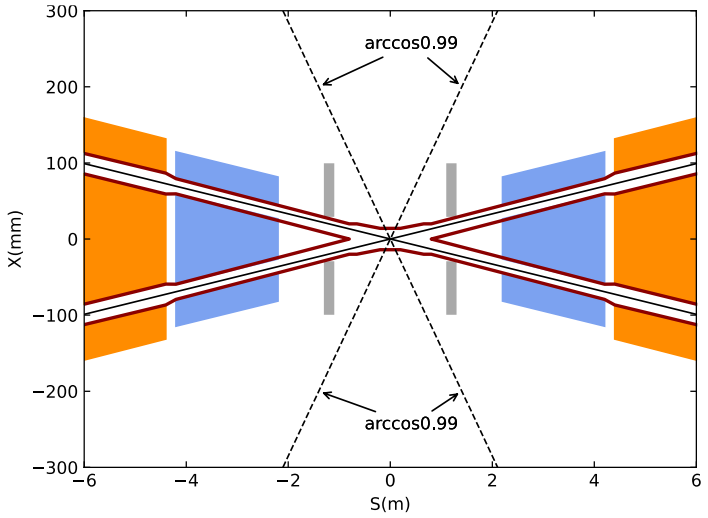
Fe-55 with collimator



Interaction Region Design

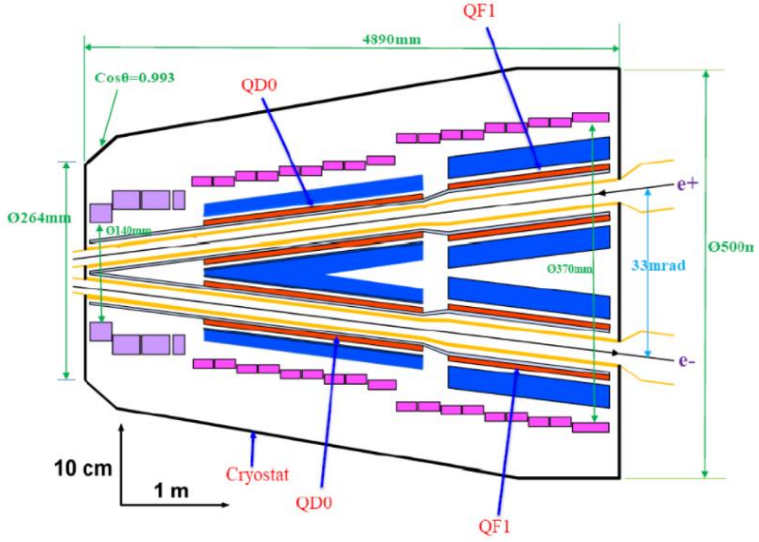
Crossing angle: 33 mrad,

Focal length: 2.2 m



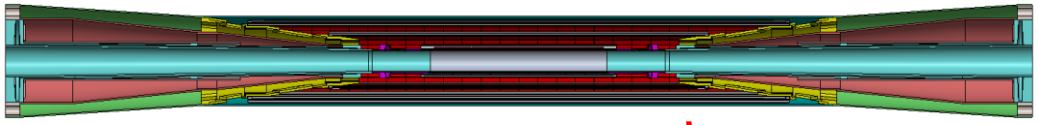
Final focusing magnets (QD0, QF1) with

Segmented Anti-Solenoidal Magnets



Beam Pipe

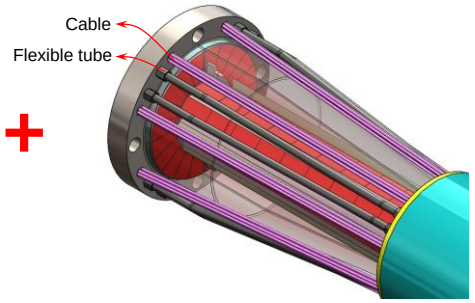
ϕ 28→20 mm, Be thickness: 0.85→0.35 mm

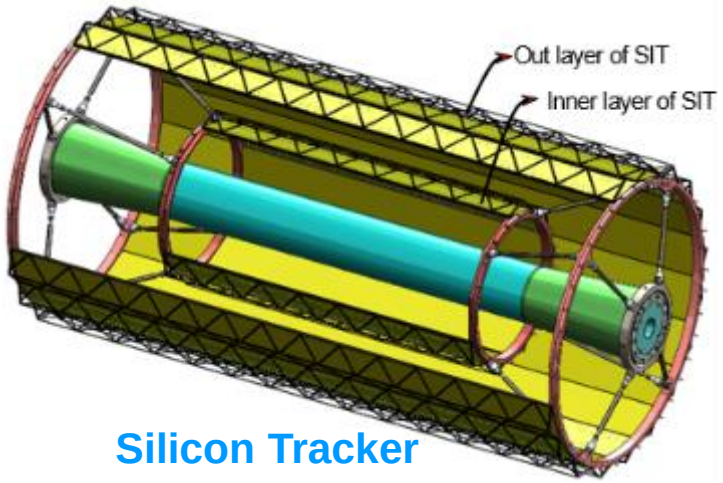


Vertex

+

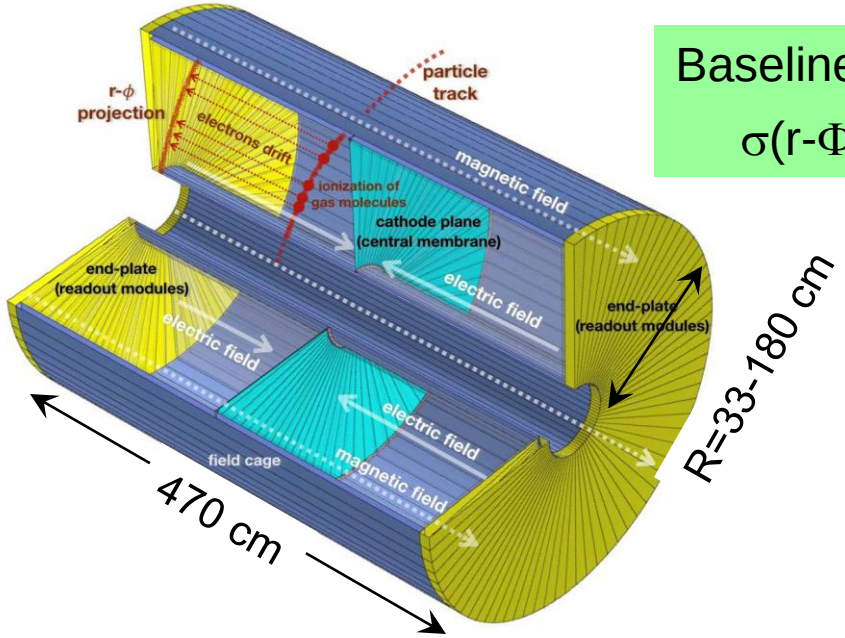
LumiCal Tracker





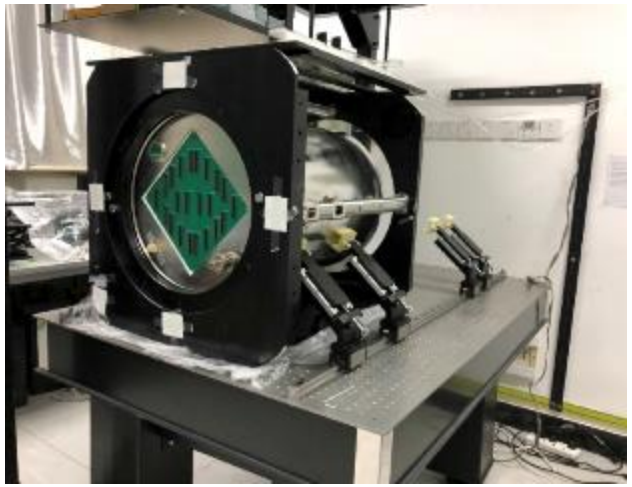
Silicon Tracker

Time Projection Chamber

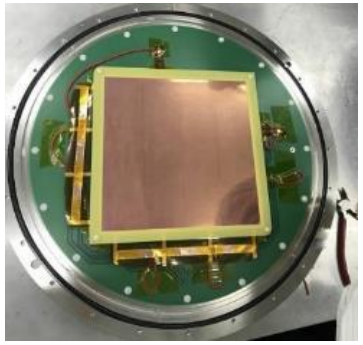


Baseline main tracker

$\sigma(r\text{-}\Phi)$ ~100 μm

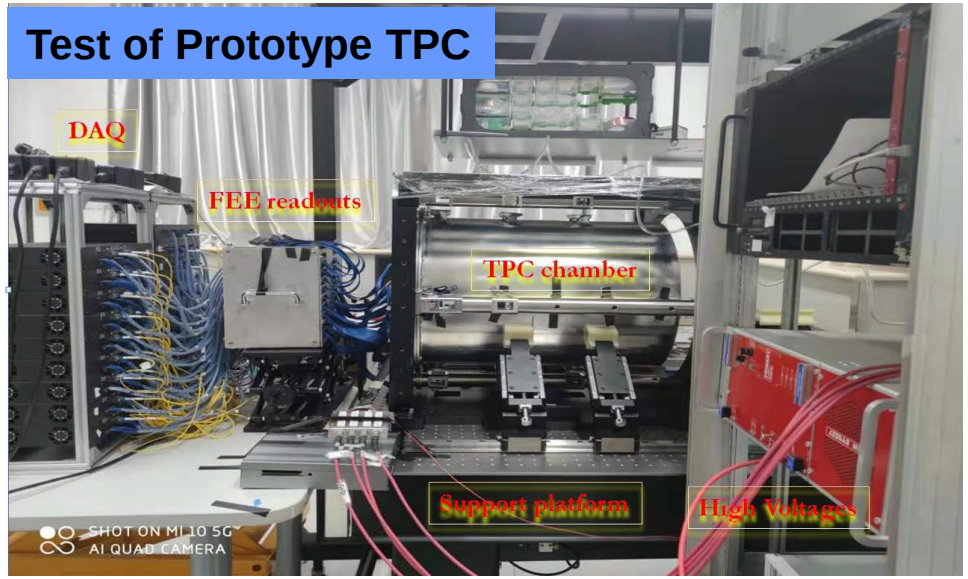


TPC Prototype + UV laser beams



GEM-MM cathode

Test of Prototype TPC

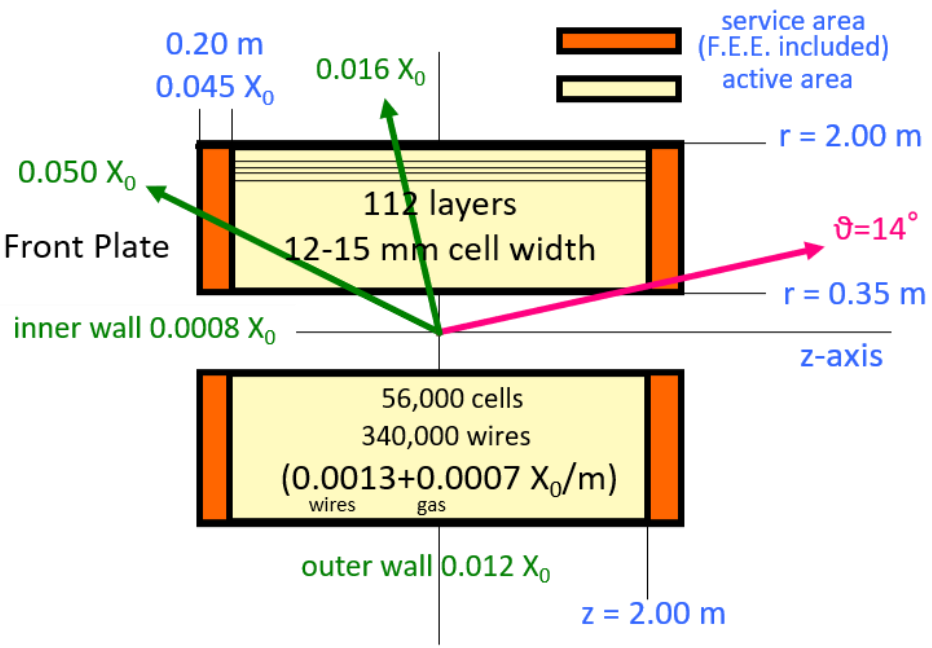


- Challenge: Ion backflow (IBF) affects the resolution. It can be corrected by a laser calibration at low luminosity, but difficult at high luminosity Z-pole.
- Exploring potential solutions, e.g. Pixel TPC with double meshes, or micromegas.
- When Gain×IBF=1, distortion <16 μm @ L= 32 $\times 10^{34}$ $cm^{-2}s^{-1}$, <49 μm @10^{36} $cm^{-2}s^{-1}$.

IDEA Drift Chamber

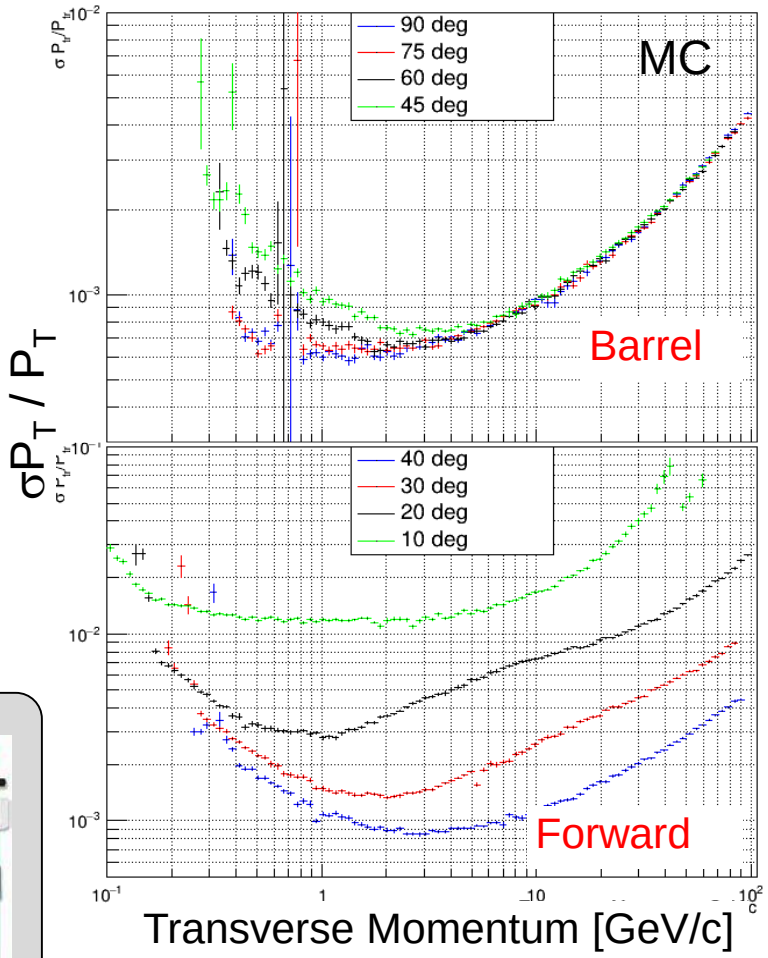
tracking efficiency $\varepsilon \approx 1$
for $\vartheta > 14^\circ$ (260 mrad)
97% solid angle

0.016 X_0 to barrel calorimeter
0.050 X_0 to end-cap calorimeter



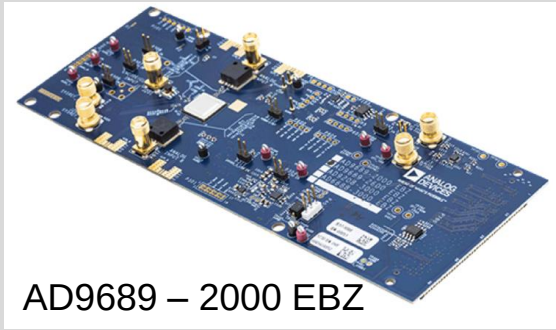
The main tracker in IDEA design

Gas: He/iC_4H_{10} (90:10)%
Spatial resolution: <100 μm
Max drift time: ~ 350 ns



DAQ for prototype drift tube to study front end data compression.

Cluster counting for PID


AD9689 – 2000 EBZ


Xilinx KCU105

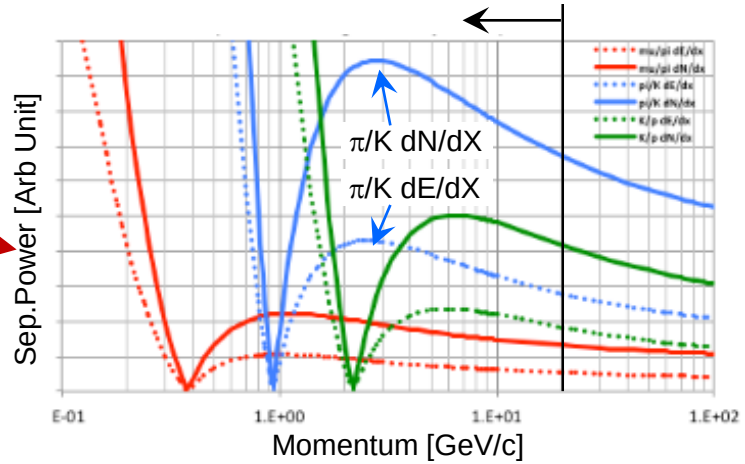
Particle ID Possibilities

- Both TPC & DC in the two designs have good PID, with dE/dX or dN/dX (cluster counting).
- The FST solution needs a supplement PID. A combination of different PID detectors is also possible.
- Aim is to for have 2σ π/K separation for P<~20 GeV/c.

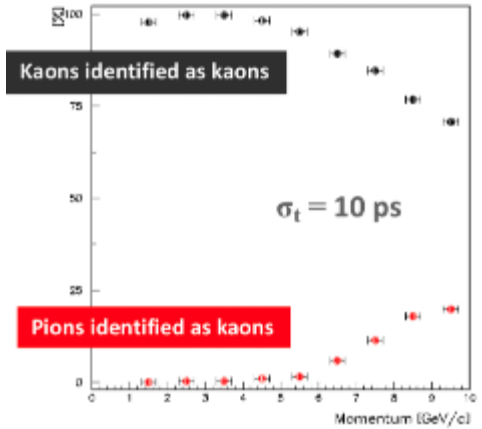
① **Drift chamber** between the outer layers of FST. The dN/dX method is more efficient. It is a joint R&D effort with the IDEA DC. But the DC can be optimized for PID only, not its tracking capability.

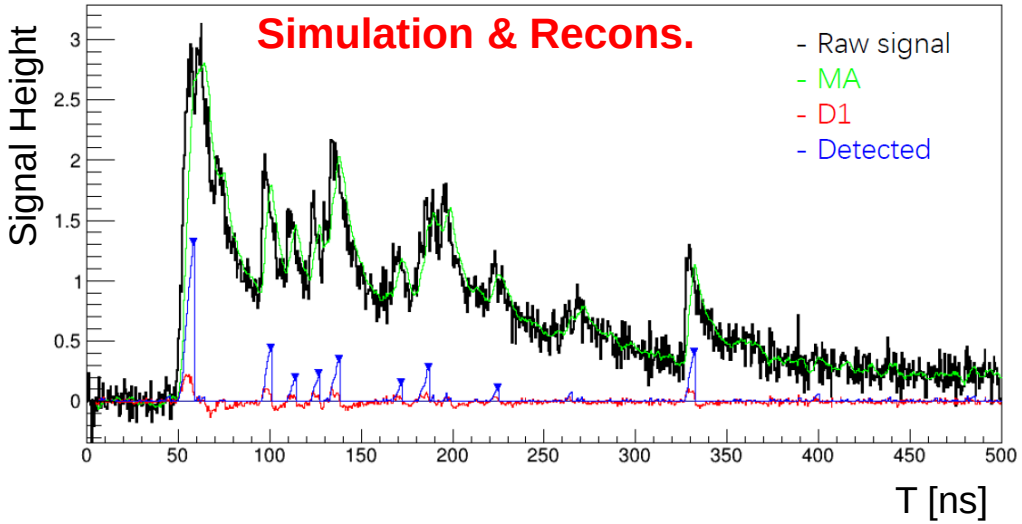
② **Time of flight** detector, e.g. LGAD. The time resolution ~20-30 ps today. Resolution of 10 ps is possible by the time of CEPC.

- Other options, e.g. an aerogel **RICH**, will also be considered.



IHEP-NDL LGAD-V2
Pixel size 1.3×1.3 mm²

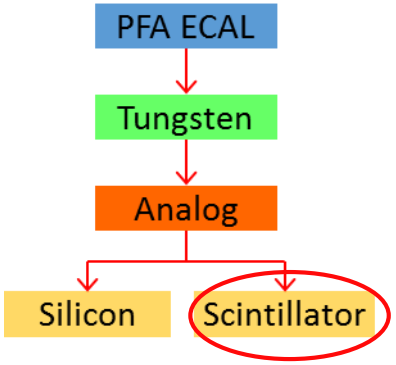




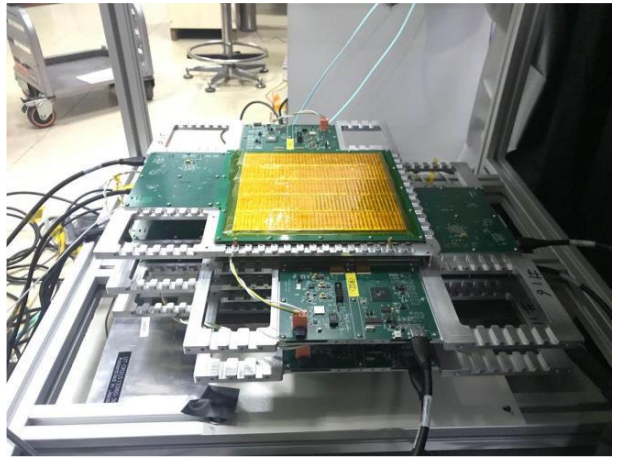
PFA ECAL

Goal of ECAL+HCAL+…

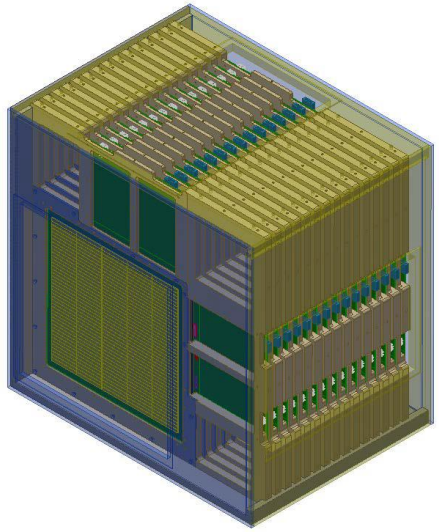
4% BMR, e.g. in ($Z\rightarrow\nu\nu$) ($H\rightarrow gg$)



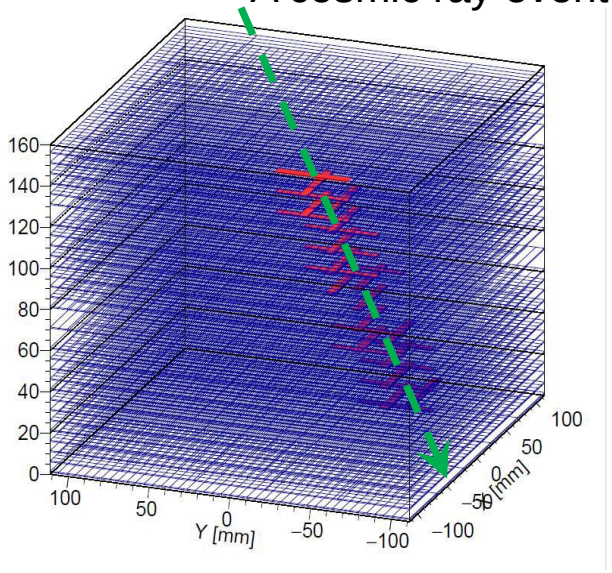
Super-layer bench test



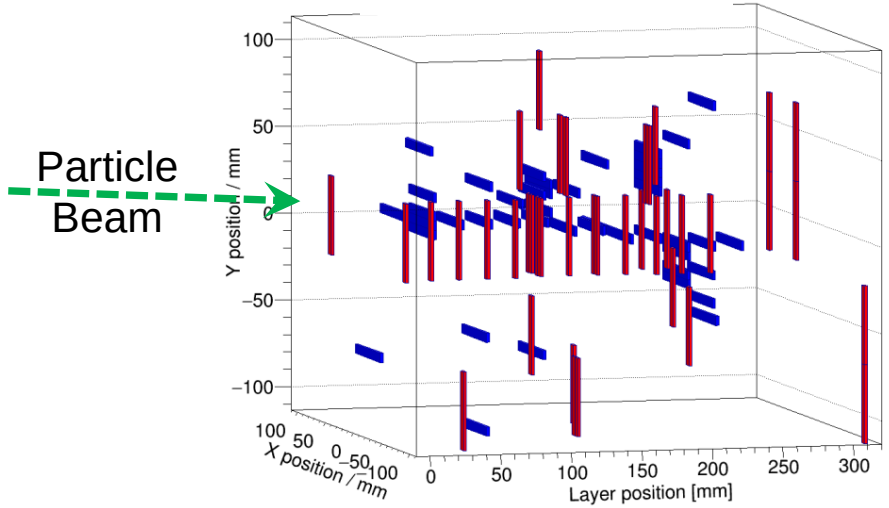
Prototype ScECAL



A cosmic ray event

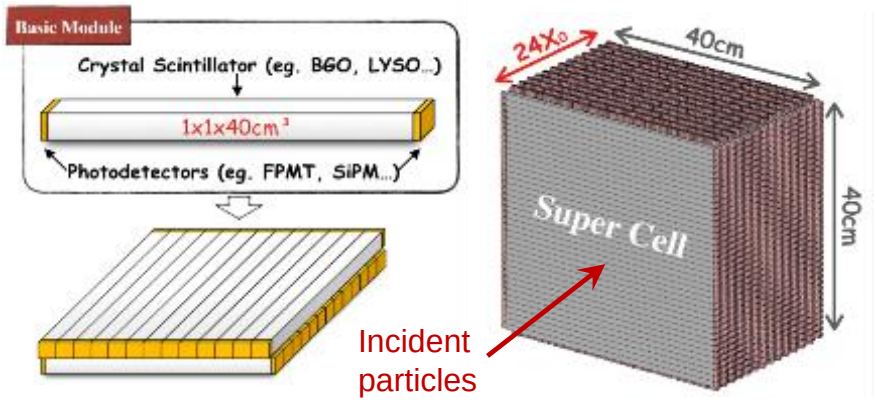


A testbeam event



- An alternative PFA ECAL in CDR: scintillator + SiPM as sensitive detector, tungsten as absorber, totals $24X_0$ radiation length.
- A 32-layer prototype: 3.2 mm thick W-Cu plate, scintillator bar size 5×45 mm^2, 1 SiPM/bar.
- It has been tested with cosmic rays, and an electron beam at IHEP (Nov 2020). When possible it will be tested in a higher intensity electron beam at DESY.

High Granularity Crystal ECAL



- Timing at two ends for positioning along bar.
- Significant reduction of number of channels.

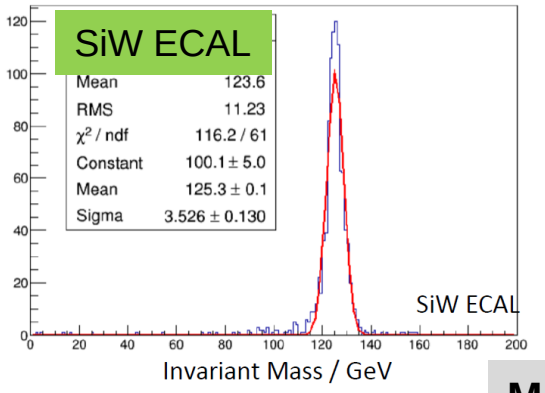
Design Idea

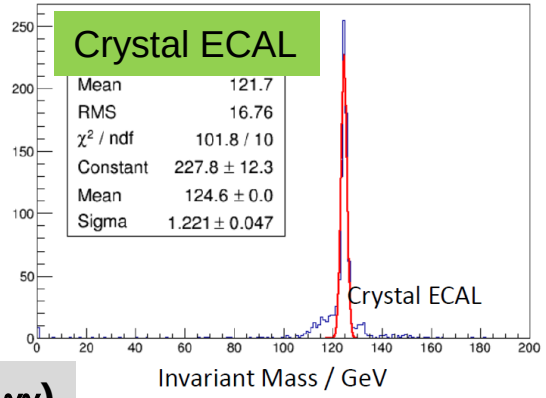
Goal

- Comparable BMR resolution as with the Sci+W ECAL.
- Much better sensitivity to γ/e, especially at low energy.

Bench Test

MC Simulation

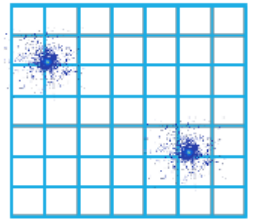


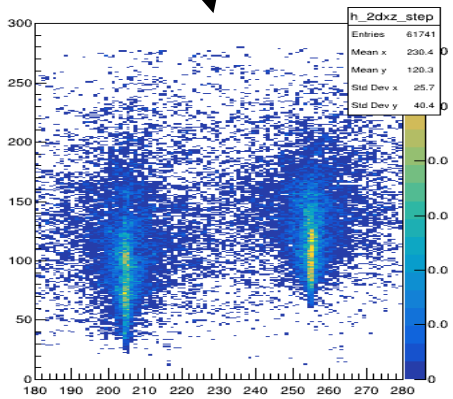


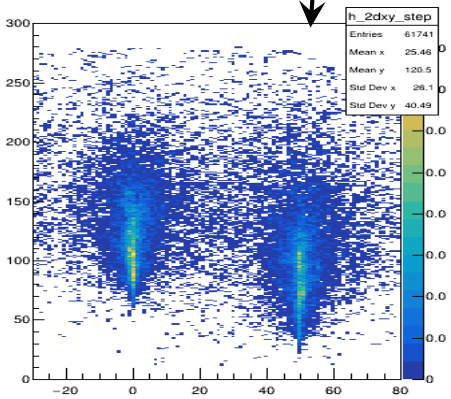
M(H→γγ)

Recon. Algorithm

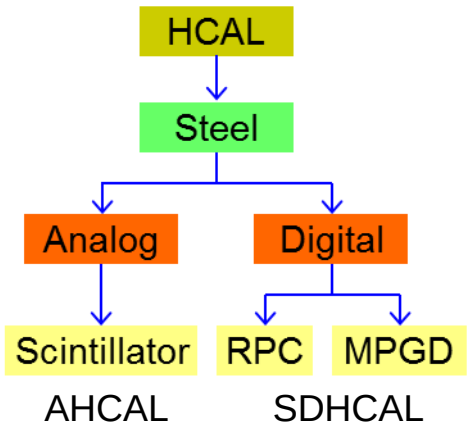
Energy & time matching solves ambiguity

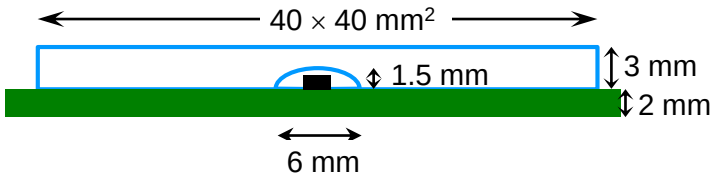


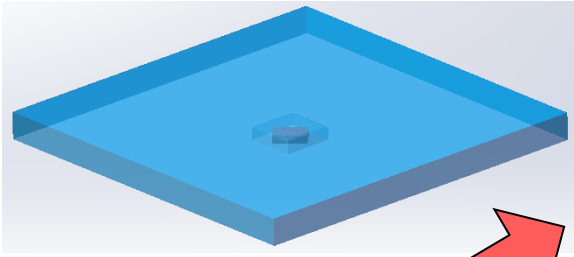


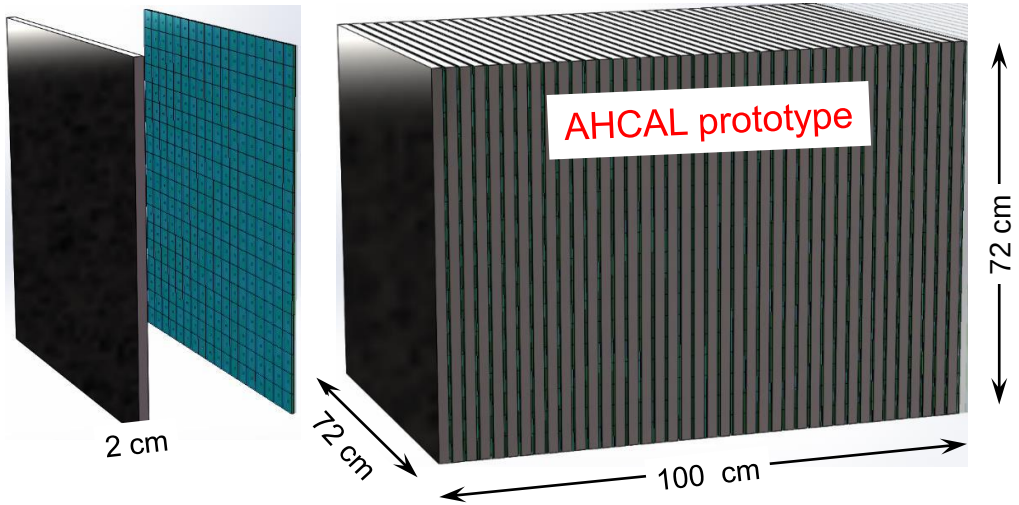


PFA HCAL







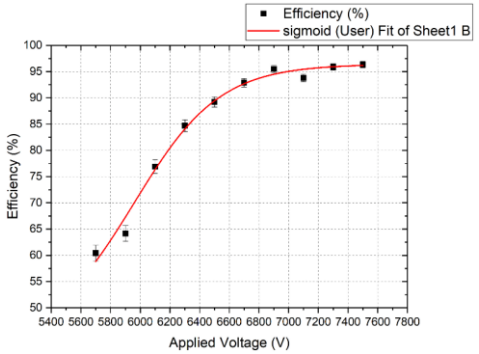


- AHCAL of Steel, Plastic scintillator, SiPM+SPIROC

  Prototype in production, size 72×72×100 cm³, 40 layers, Steel+Scint+PCB=20+3+2=25mm, cell size 40×40 mm²

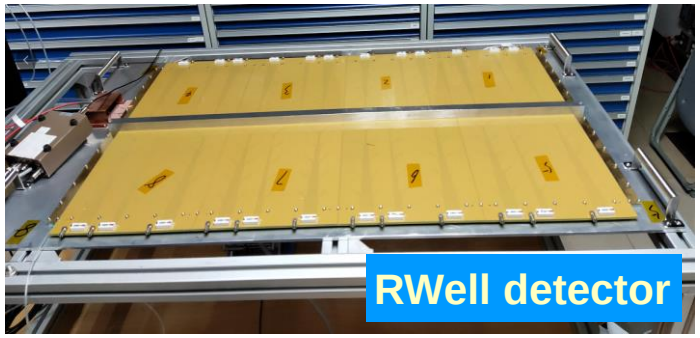
- SDHCAL based on GRPC:

  Prototype size 1×1×1.3 m³, 48 layers, 1×1 cm² detector cell, 2 cm steel absorber.



- SDHCAL based on MPGD

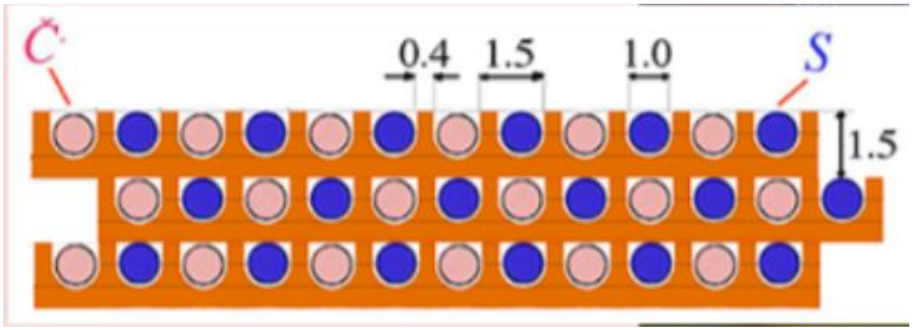
  Constructed a 100×50 cm² RWell detector.

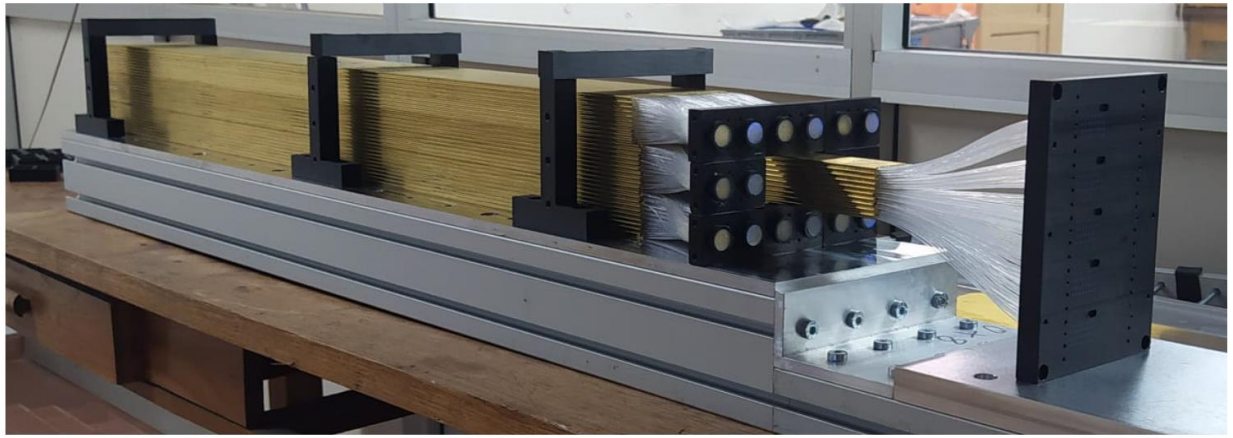


DR Calorimeter & SCEPCAL

A 3×3 towers ECal-size prototype has been built, waiting for testbeam.

Dual Readout calorimeter in the IDEA design





160 scint. fibers 160 Cherenkov fibers

Tower: 20 rows × 16 cols

Combining Crystal ECal and DR Calorimeter

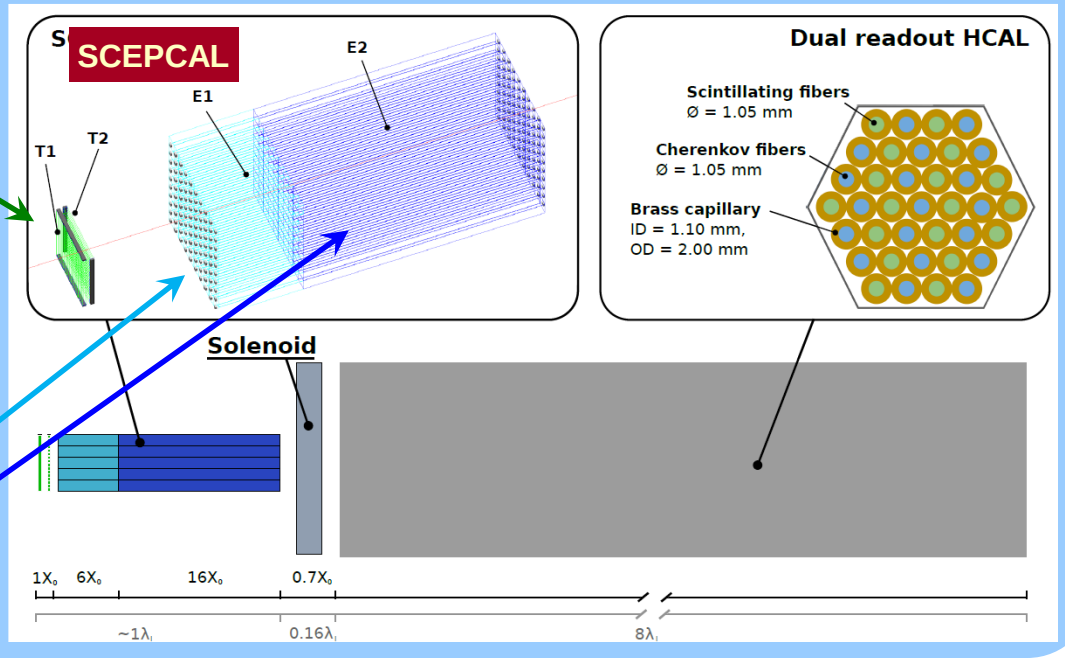
by Eno, Lucchini, and Tully et al. (arXiv:2008.00338)

Timing layer σ_t ~ 20 ps

- LYSO Ce crystal (~1X_0)
- 3×3×54 mm^3 active cell
- 3×3 mm^2 SiPMs (15-20 μm)

ECAL layer $\sigma_E/E \sim 3\%/\sqrt{E}$

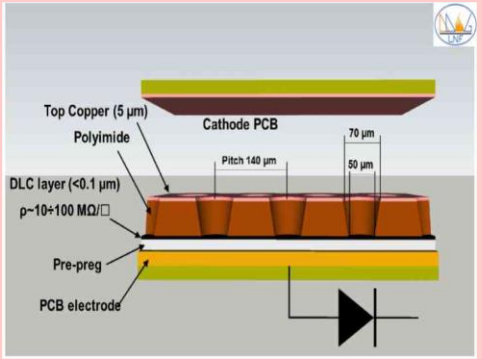
- PbWO crystals
- Front segment (~6 X_0)
- Read segment (~16 X_0)
- 10×10×200 mm^3 Crystals
- 5×5 mm^2 SiPMs (10-15 μm)

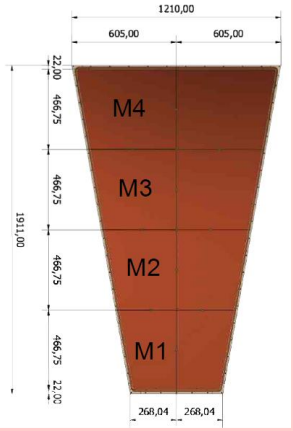


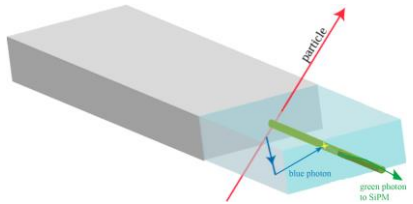
Muon Detector

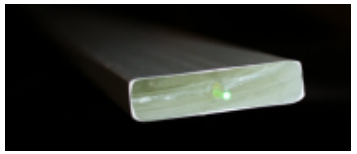
- **RPC** R&D applies to both SDHCAL & Muon.
- An alternative is **μ-RWELL** technology. The concept was proved. Currently focus mainly on industrialization and cost reduction.
- **Scintillator** Muon detector. R&D overlaps with Belle II KLM.
  - Building a prototype detector
  - Scintillator strips, improving quality & cost-reduction.
  - WLS fiber: purchased Kuraray, focusing on optical couplings.
  - SiPM Hamamatsu S13360-13**CS, and MPPC option.

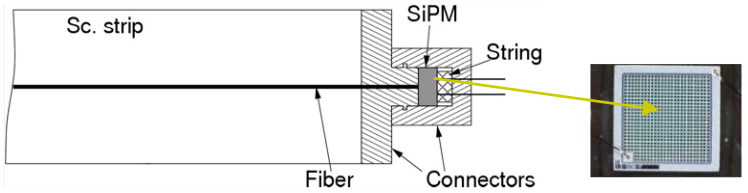
μRWELL for PS & Muon

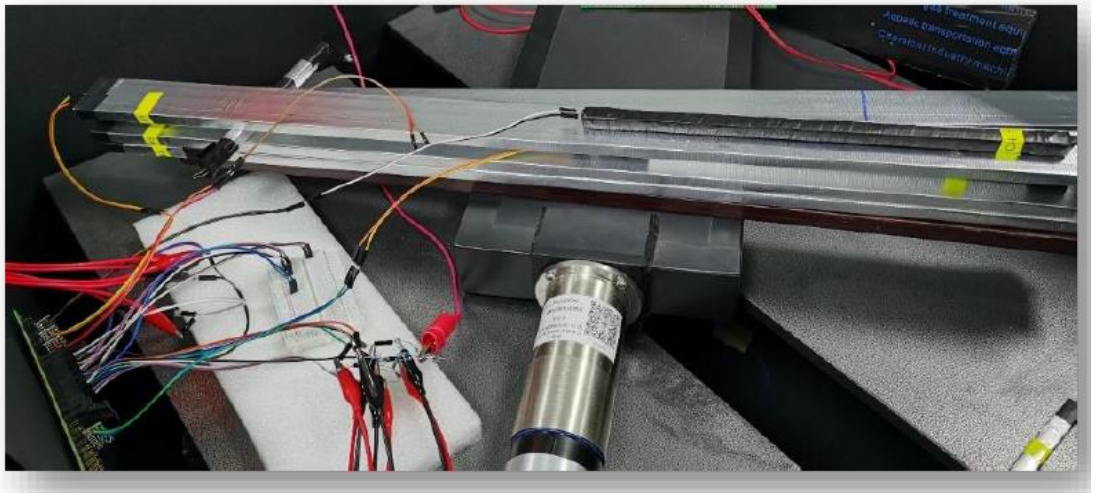












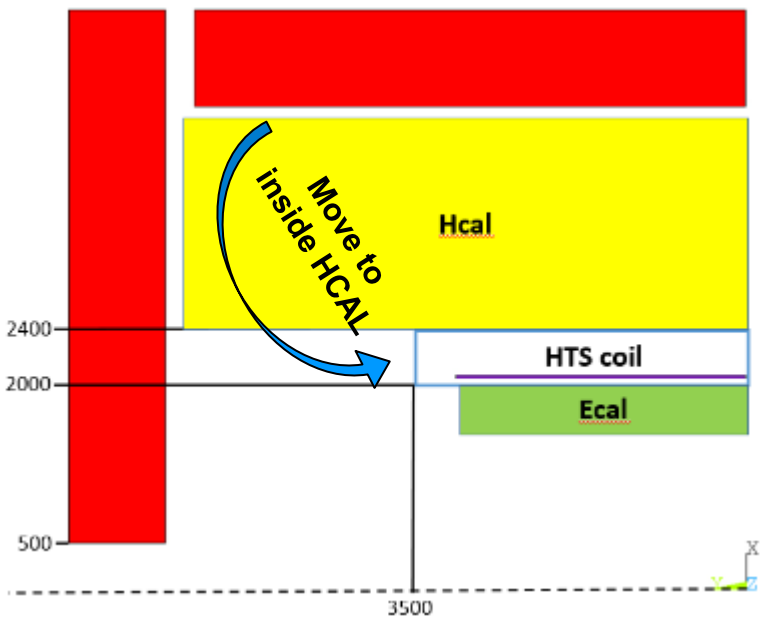
Achieved σ_t~2ns,
Aim for 100-200 ps.

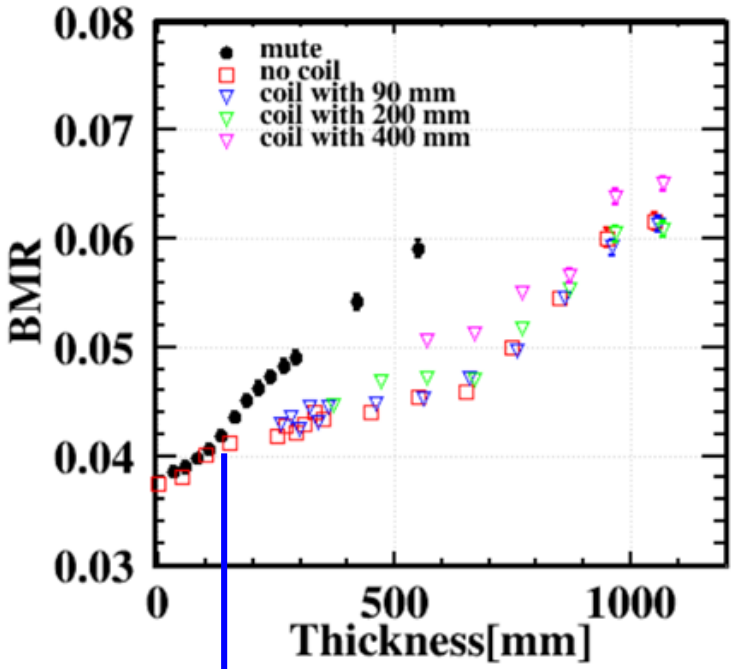
Closing Remarks

- The CEPC aims to explore Higgs, EW, QCD, flavor physics and BSM at Higgs (Z) factory.
- The International Advisory Committee operates since 2015. International Accelerator Review Committee, and International Detector R&D Review Committee started in 2019.
- International workshops (with emphasis on CEPC):
  - In China: Beijing (2017.11, 2018.11, 2019.11), Shanghai (2020.10), Nanjing (2021.11)
  - In Europe: Rome (2018.05), Oxford (2019.04), Marseille (2022.05 ?)
  - In USA: Chicago (2019.09), DC (2020.04, remote)
- Annual IAS HEP program (HKUST) since 2015; Various topic specific workshops every year.
- Actively participated in the European Strategy Update and the Snowmass Process for particle physics, and international detector R&D collaborations: CALICE, LPTPC, RD*, …
- Aim for the accelerator TDR ~ the end of 2022.
- The detector R&D progresses towards TDR. Two international experiment collaborations will be formed before that time. The current working group consists of ~1/3 international members.
- Supported by various funding sources in China: MOST, NSFC, CAS, institutes, local governments…

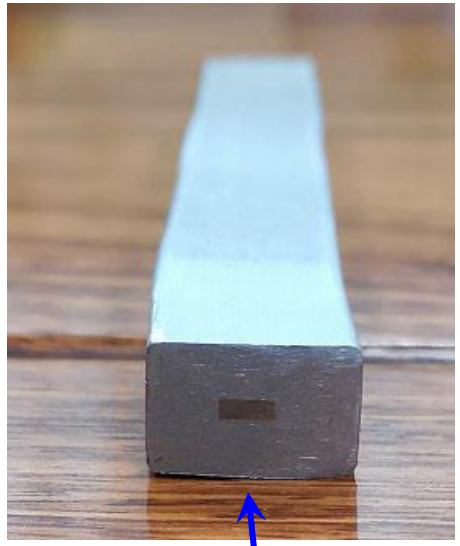
Backup Slides

Solenoid Magnet



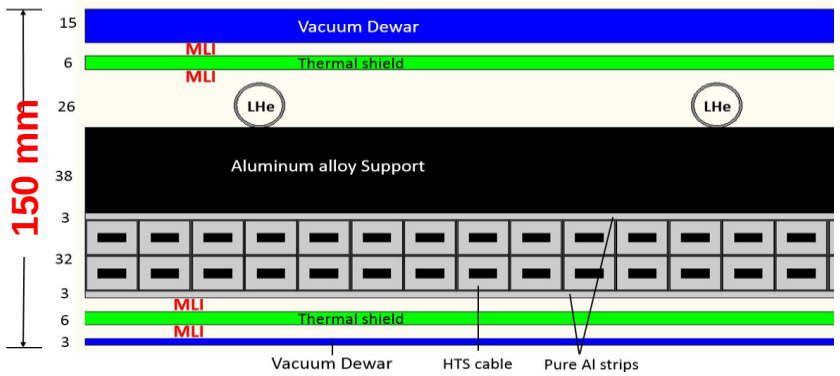


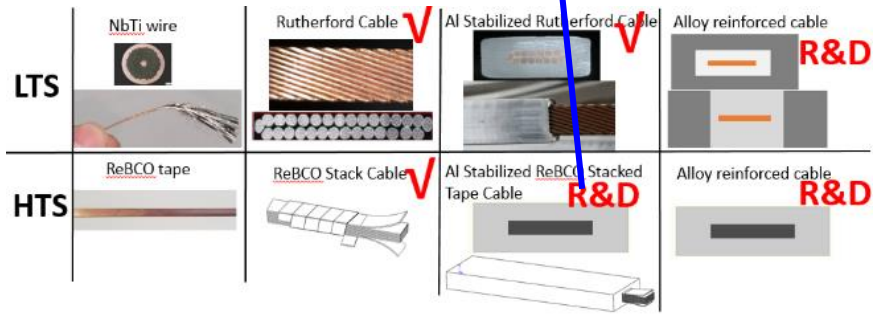
Al stabilized ReBCO stacked tape cable



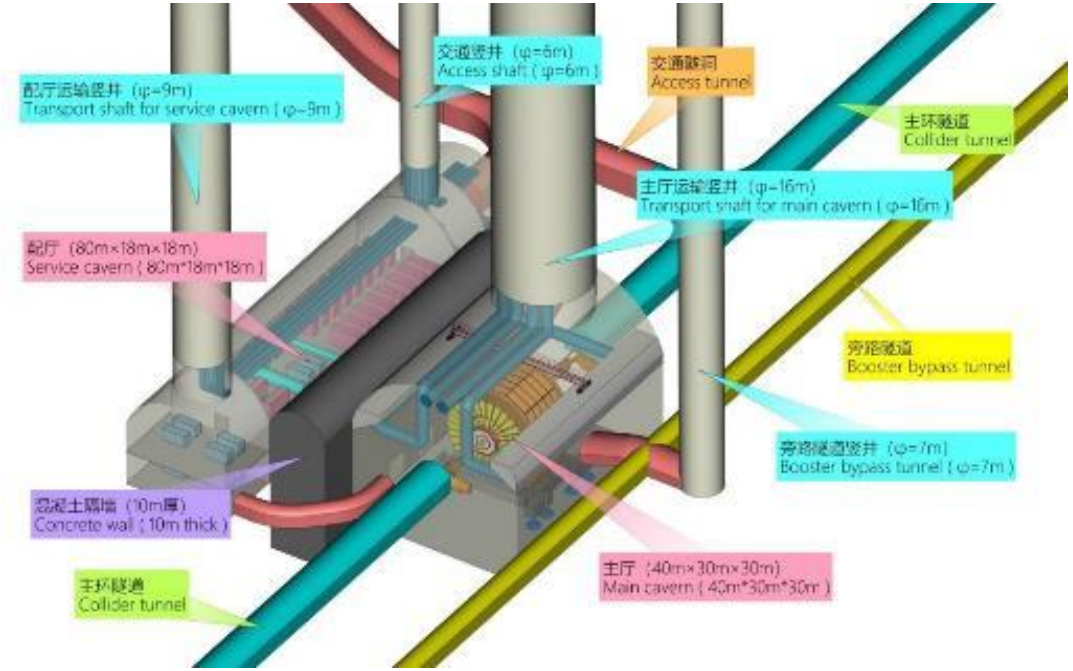
Challenges

Low mass, ultra-thin, high strength cable





The Experimental Area



Main cavern to host the detector

- 40*30*30 m^3 (L*H*W)
- One main access shaft, Ø16 m
- An 1K-ton gantry crane for large heavy objects

Auxiliary cavern for peripheral equipment and devices

- 80*18*18 m^3 (L*H*W)
- One service shaft of Ø9 m
- One personnel access shaft Ø6 m

Ground level buildings

CEPC Software

- Core software, external libraries & tools are the base of the CEPCSW. More packages and components will be added when available.
- CEPC applications are created for CDR design. With new type of detectors introduced, corresponding codes are being developed.
- Recent added CEPC applications:
  - Software for SiTrk + DC design, detector description and track fitting.
  - Cluster counting method of DC
  - Simulation and simplified digitization of the crystal bar ECal.
- Work to be done
  - Further development of simulation & reconstruction for SiTrk+DC and Crystal bar ECal.
  - Non-uniform magnetic field & piling-up of beam backgrounds in simulation
  - Algorithms for building reconstructed particles
  - Continue to check the consistence of software, with benchmark performance studies.

CEPCSW structure