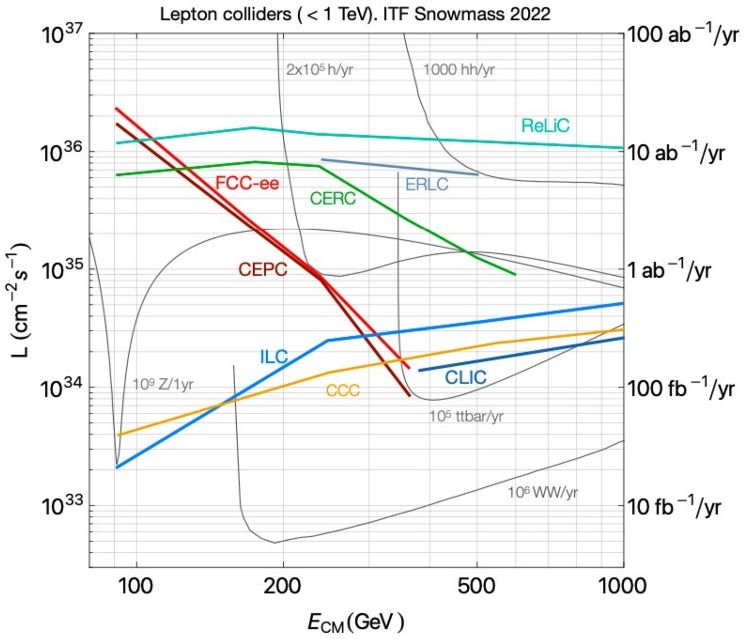
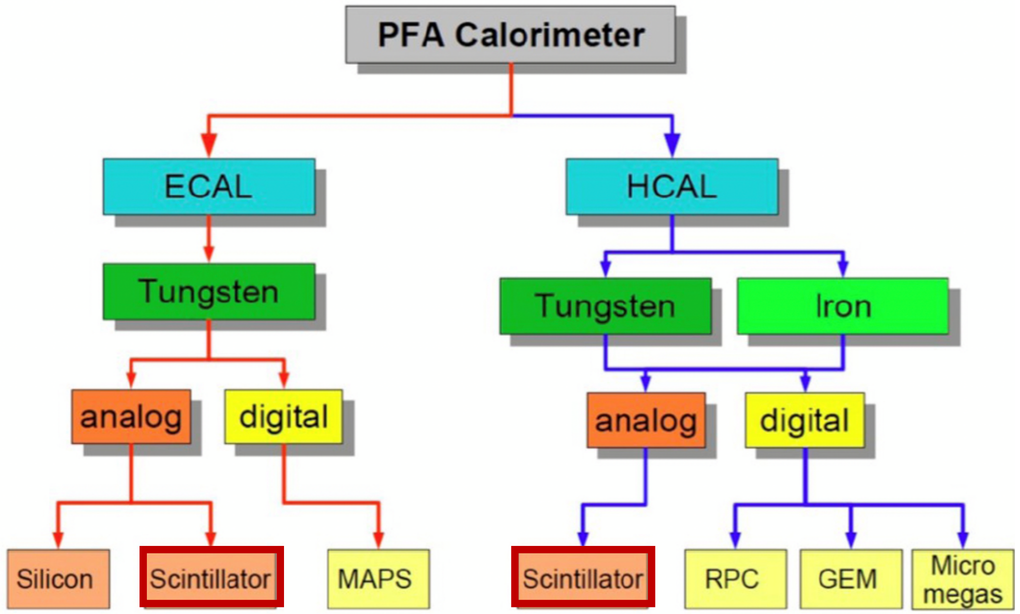
CEPC calorimeters R&D: a brief overview

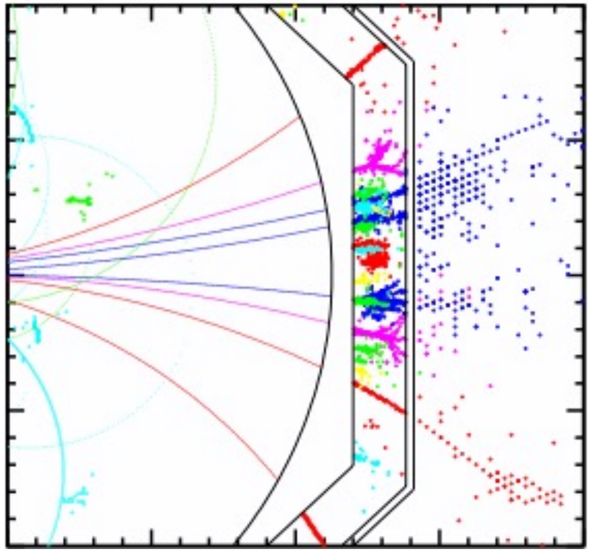
Yong Liu (IHEP), for CALICE and CEPC Calorimeter teams

Apr. 16, 2024

High granularity calorimetry





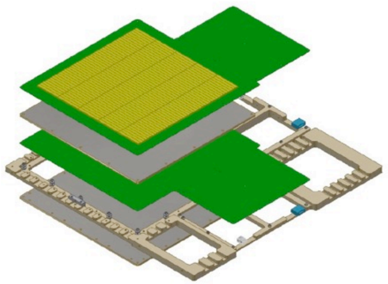


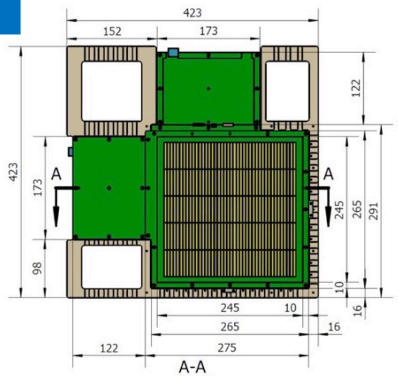
- Future Higgs/EW/top factories
  - Requires unprecedented energy resolution for jet measurements
  - A major calorimetry option: highly granular (imaging) + particle flow algorithms (PFA)
- PFA calorimetry: various options explored in the CALICE collaboration
- Scintillator-SiPM option selected for CEPC calorimeter prototypes

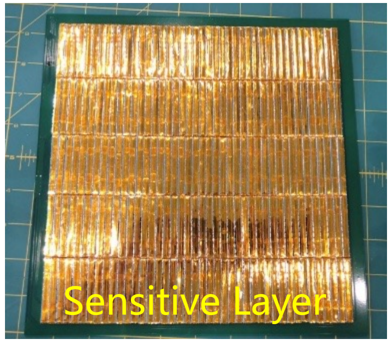
ScW-ECAL technological prototype

ScW-ECAL tech. prototype

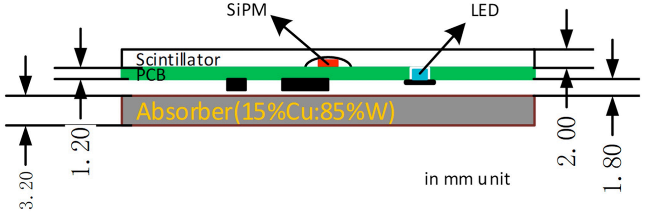
"Super-layer" design



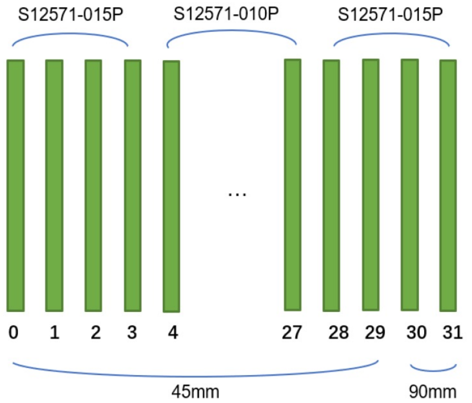




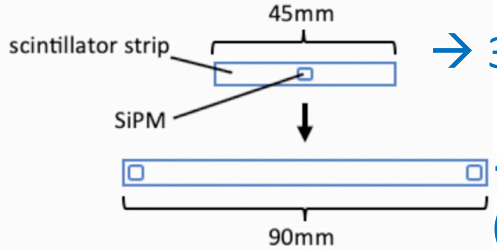
Scintillator-SiPM readout scheme



Sensitive layer arrangements



- ScW-ECAL prototype: developed in 2016-2020
  - Transverse area of ~22x20 cm, 32 longitudinal sampling layers
  - 6,720 channels, ~350 kg, SPIROC2E (192 chips)
- Beamtest campaigns at CERN in 2022-2023
  - Along with AHCAL prototype



→ 30 sampling layers

→ 2 sampling layers (in the rear part)

ScW-ECAL beamtests at CERN

Oct 19 – Nov 2, 2022	Apr 26 – May 10, 2023	May 17 – 31, 2023
SPS H8 beamline	SPS H2 beamline	PS T9 beamline

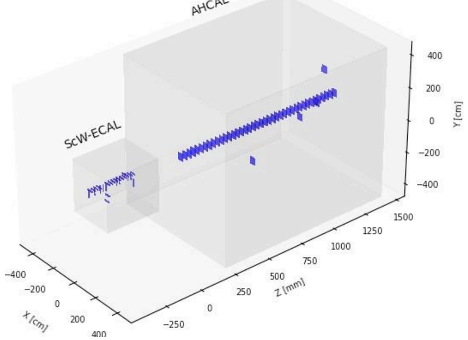
Transportation

Lifting to beam area

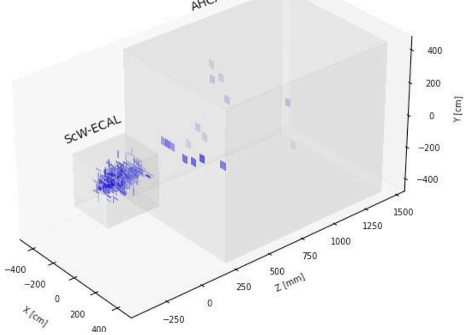
Prototype assembly on site

ScW-ECAL fixed on platform

100GeV muon



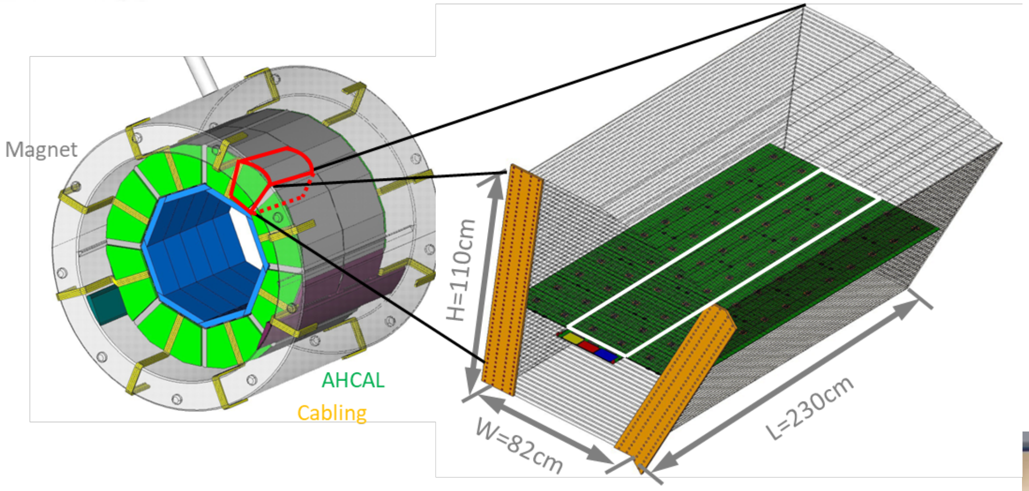
60GeV electron

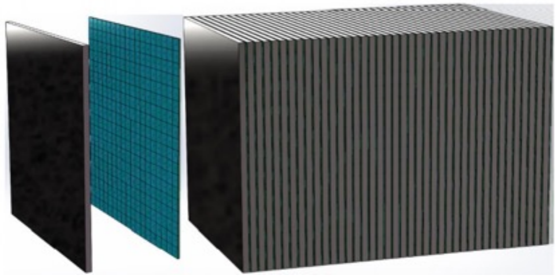


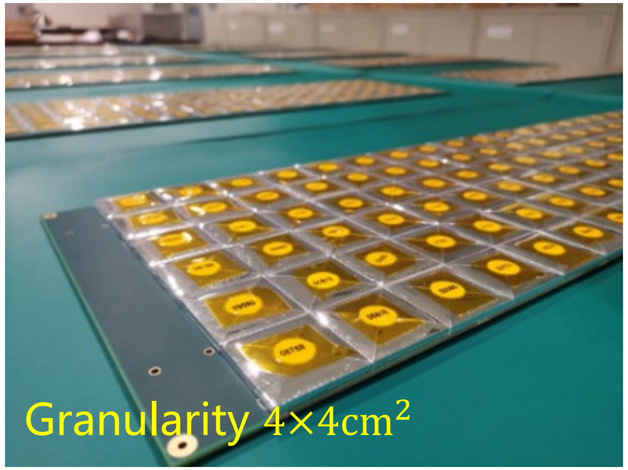
- Decent statistics of testbeam data samples collected
  - Muons: 10 GeV (PS-T9), 108/160 GeV (H8), 120 GeV (H2)
  - Electrons/positrons: 0.5 – 5 GeV at PS; 10 – 120 GeV at SPS
  - Pions: 1 – 15 GeV at PS, 10 – 120 GeV (also 150 – 350 GeV) at SPS

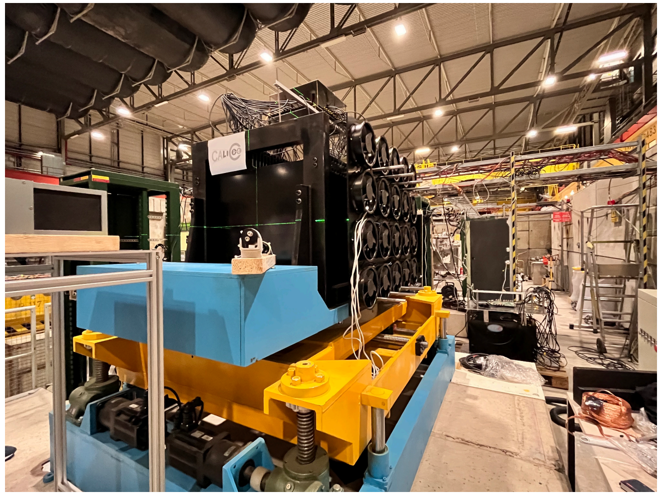
Scintillator-Steel HCAL (AHCAL)

Analogue HCAL prototype：scintillator tile +SiPM, steel









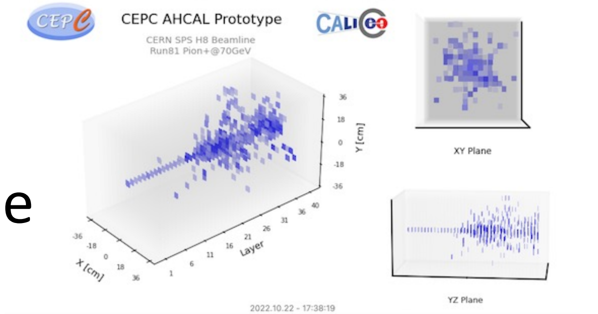
- CEPC-AHCAL prototype: transverse $72\times72\mathrm{cm}^2$, 40 sampling layers
  - 12,960 channels, ~5 tons, SPIROC2E (360 chips), developed in 2018-2022

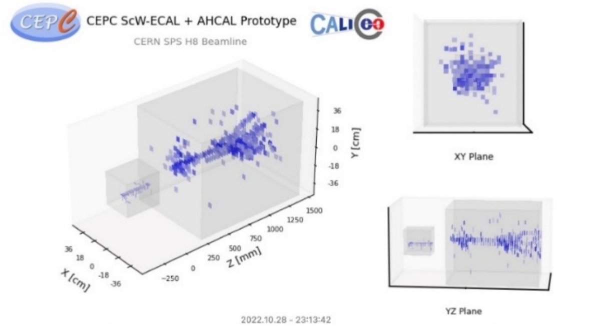
CEPC-AHCAL prototype: CERN beamtests

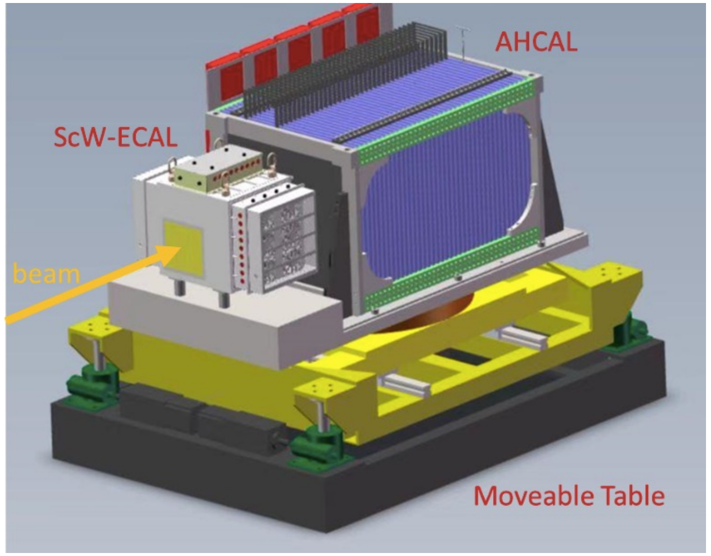
Oct 19 – Nov 2, 2022	Apr 26 – May 10, 2023	May 17 – 31, 2023
SPS H8 beamline	SPS H2 beamline	PS T9 beamline

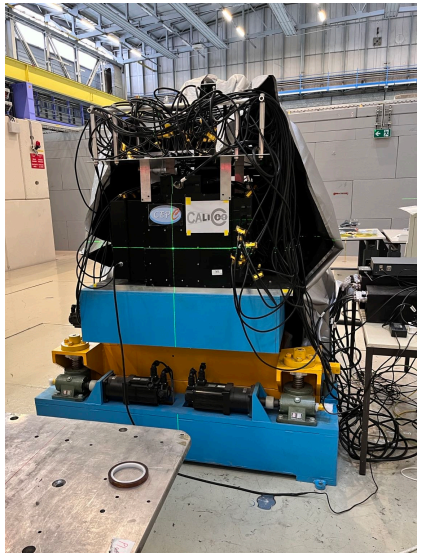
- Decent statistics of testbeam data samples: w/wo ScW-ECAL prototype
  - Muons: 10 GeV (PS-T9), 108/160 GeV (H8), 120 GeV (H2)
  - Electrons/positrons: 0.5 – 5 GeV at PS; 10 – 120 GeV at SPS
  - Pions: 1 – 15 GeV at PS, 10 – 120 GeV (also 150 – 350 GeV) at SPS

→Overlapped energy points (10-15 GeV) at PS and SPS





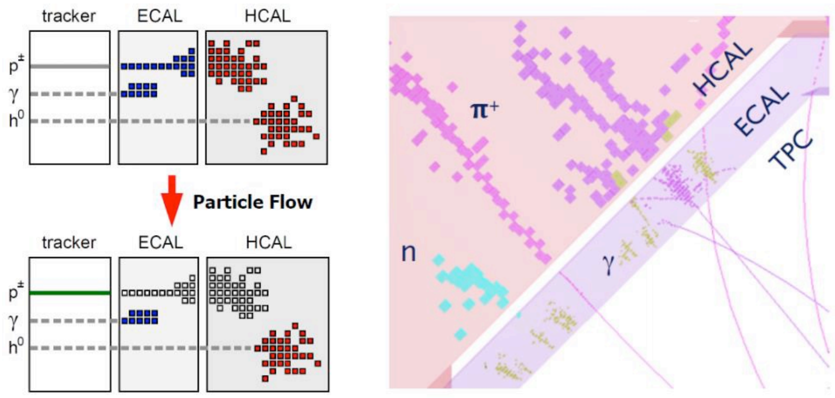




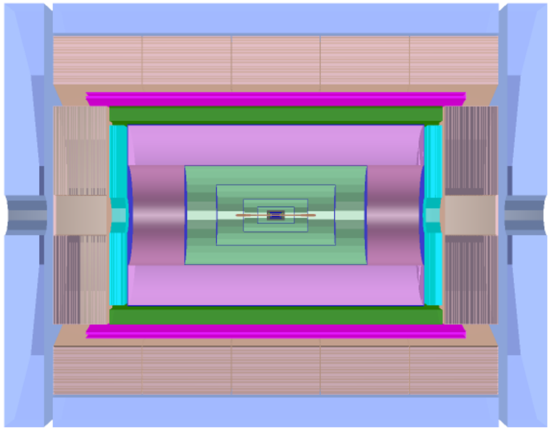
New concepts for CEPC calorimetry

- High-granularity calorimetry with PFA
  - Requires Boson Mass Resolution <4%
- Electromagnetic calorimeter
  - Crystal option: 3D-positioning and timing
  - To improve EM energy resolution from $\sim 16\%/\sqrt{E}$ (CEPC-CDR) to $\sim 3\%/\sqrt{E}$
- Hadron calorimeter
  - Scintillating glass (dense and bright): in the form factor of tiles for high granularity
  - To improve hadron energy resolution from $\sim 60\%/\sqrt{E}$ (CEPC-CDR) to $30\% \sim 40\%/\sqrt{E}$

PFA-oriented Calorimetry



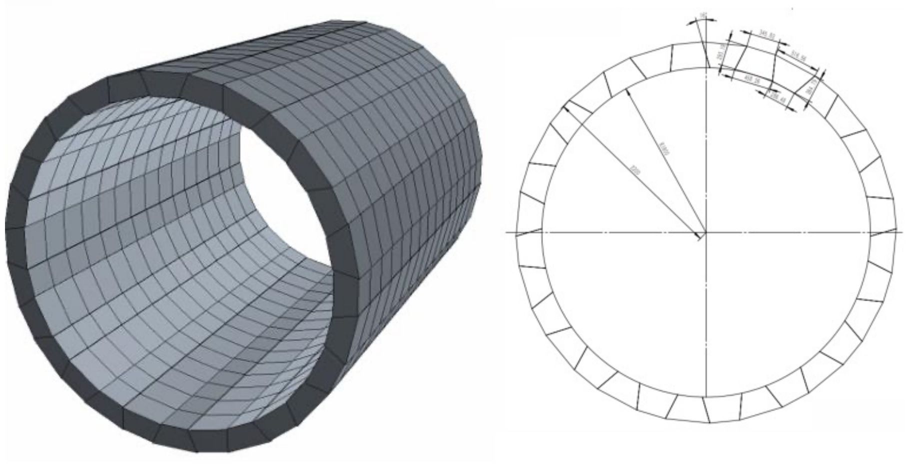
CEPC: the 4th Conceptual Detector Design

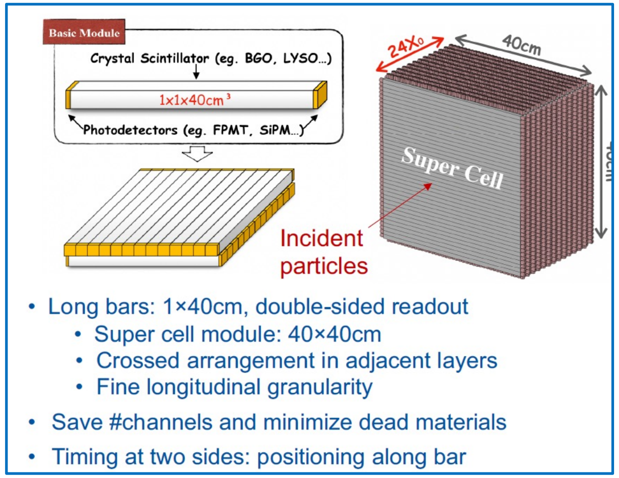


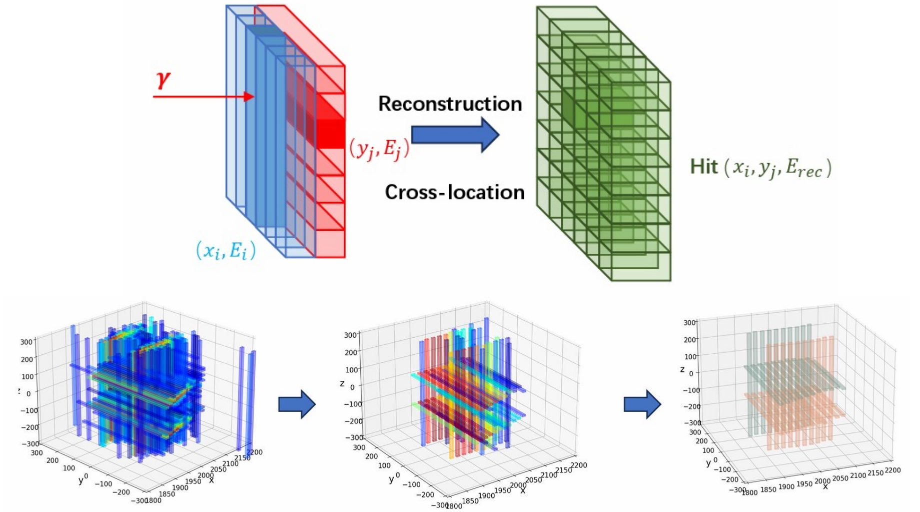
Jianchun Wang, "Status and Perspective of the CEPC" at CLHCP2023

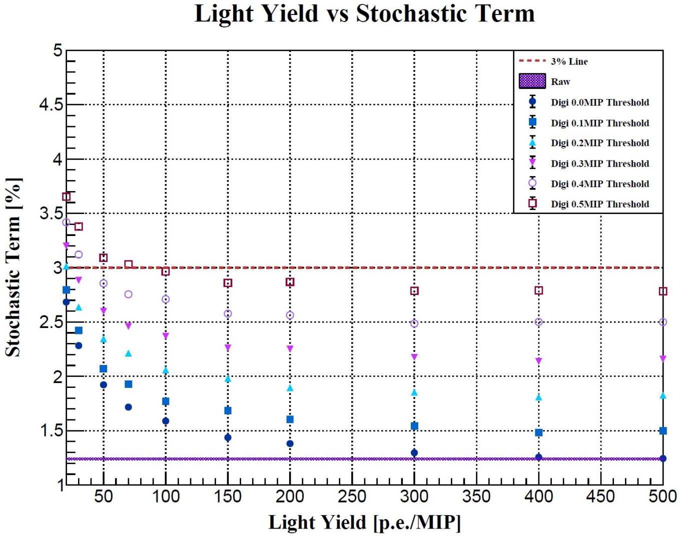
Calorimeters: crystal ECAL and ScintGlass HCAL

High-granularity crystal calorimeter





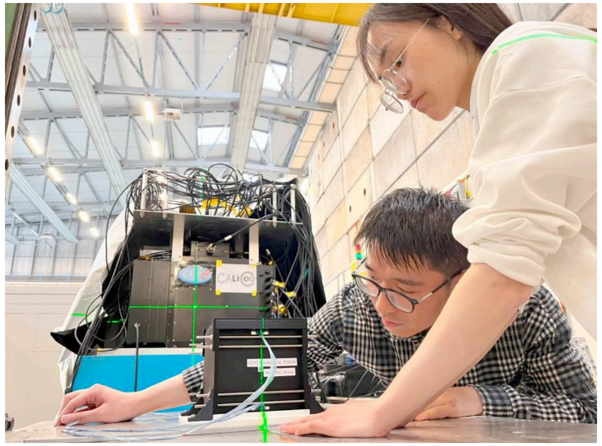


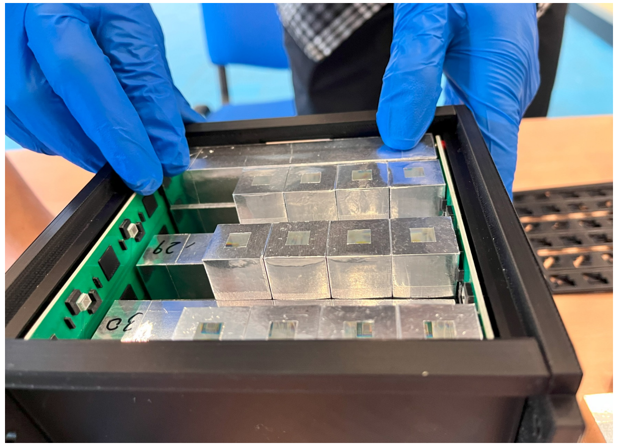


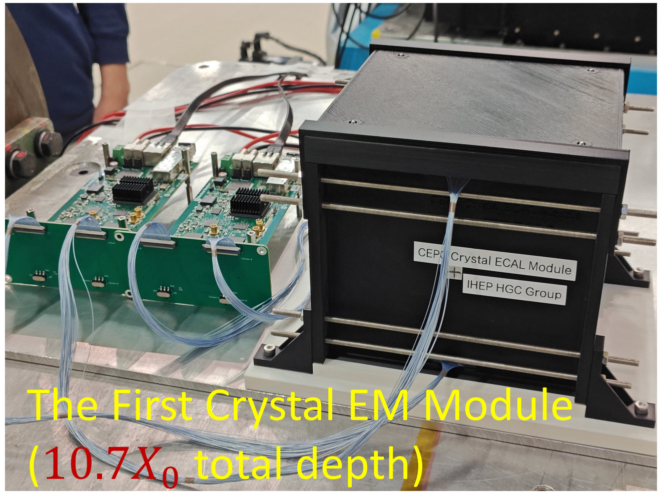
- Major focus on the long-bar configuration
- Simulation studies on design specifications
- Dedicated reconstruction software under development
  - Pattern recognition for particle-flow
- Hardware developments: crystal-SiPM characterizations, crystal modules and beamtests

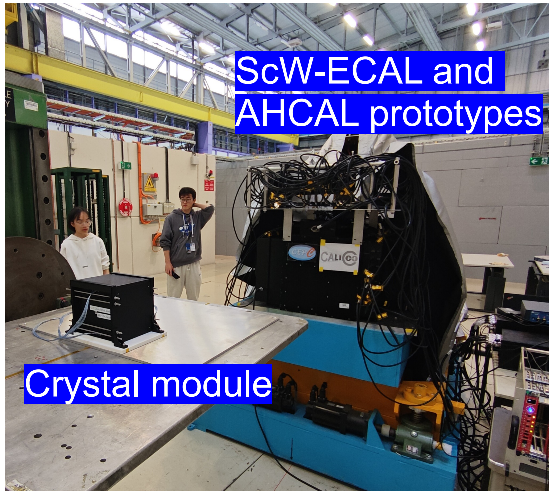
First crystal module: 2023 CERN beamtest

CERN beamtest: parasitic runs at PS-T09 (May 16-23, 2023)

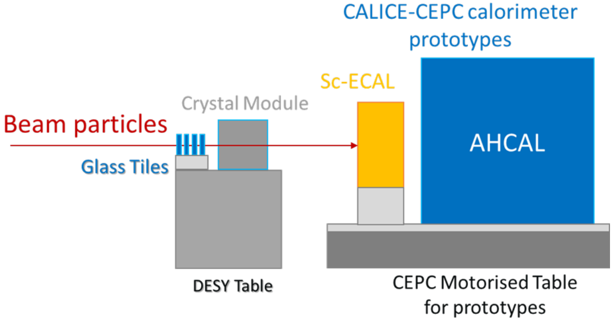




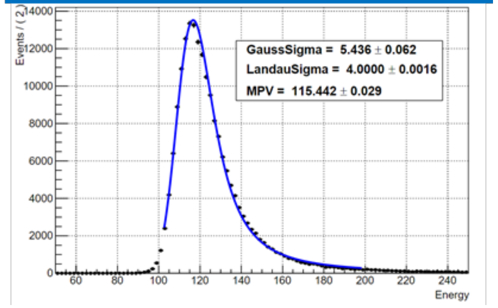




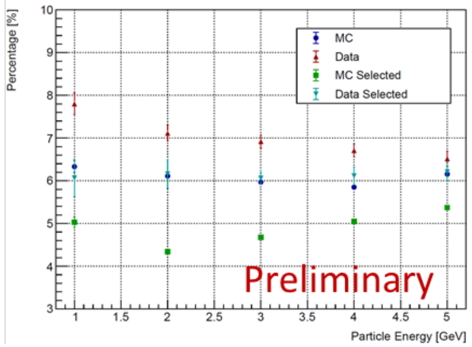
Combined beamtests with CEPC calorimeter prototypes



MIP calibration with muons



EM resolution: MC vs data

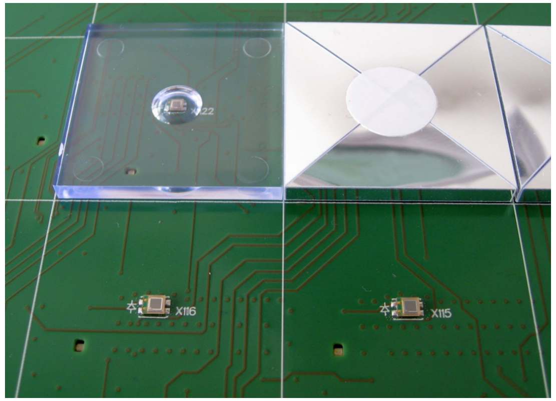


- Beamtest of the first crystal module
  - 15 GeV muons for MIP calibration
  - 1-5 GeV electrons for EM shower studies
  - Data sets for validation of simulation+digitisation

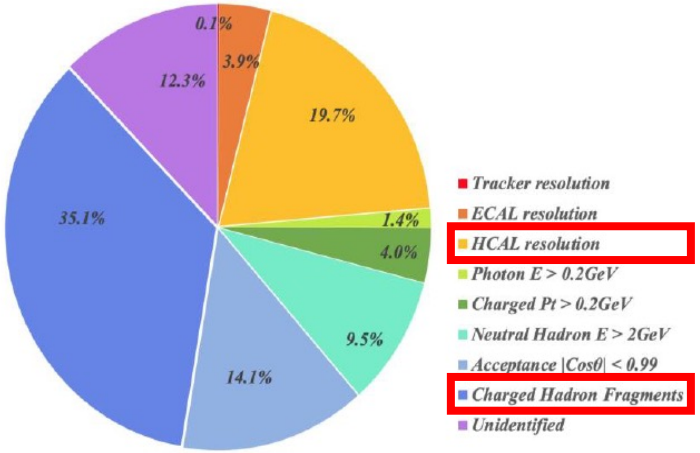
ScintGlassHCAL overview

- ScintGlassHCAL: PFA-oriented sampling hadron calorimeter
  - A variant option of CALICE-AHCAL: scintillator-SiPM, steel
  - Sensitive layer: dense and bright *scintillating glass* tiles
  - Aim to further improve hadron energy resolution, which is a major factor for precision jet energy measurements

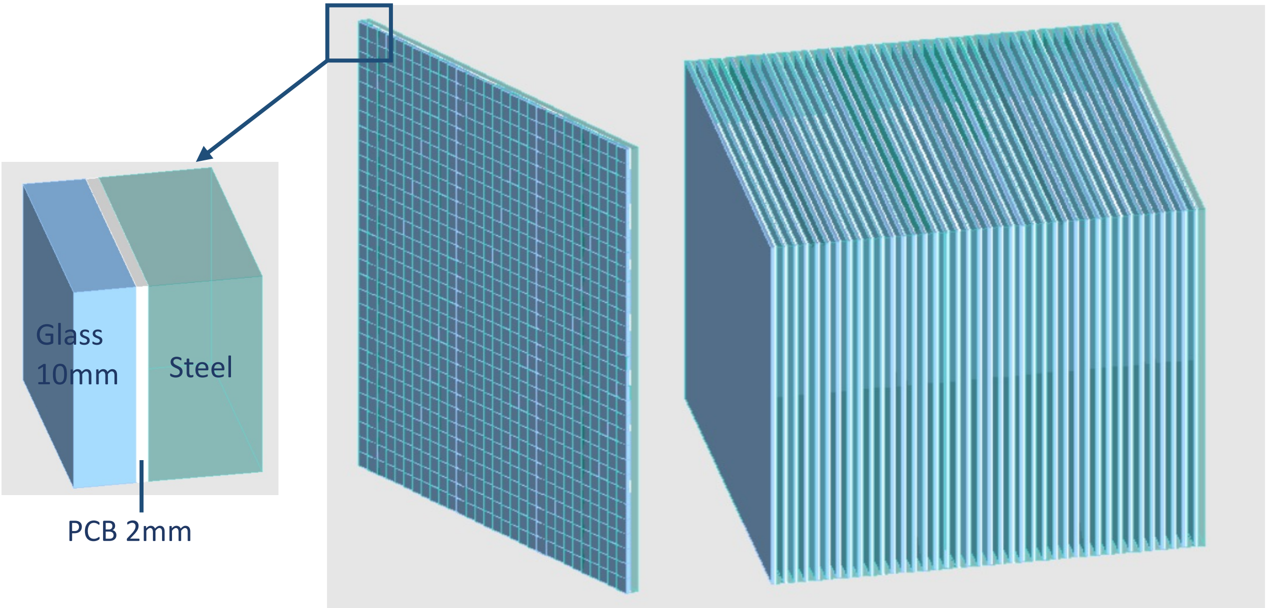
"SiPM-on-Tile" design for CALICE-AHCAL



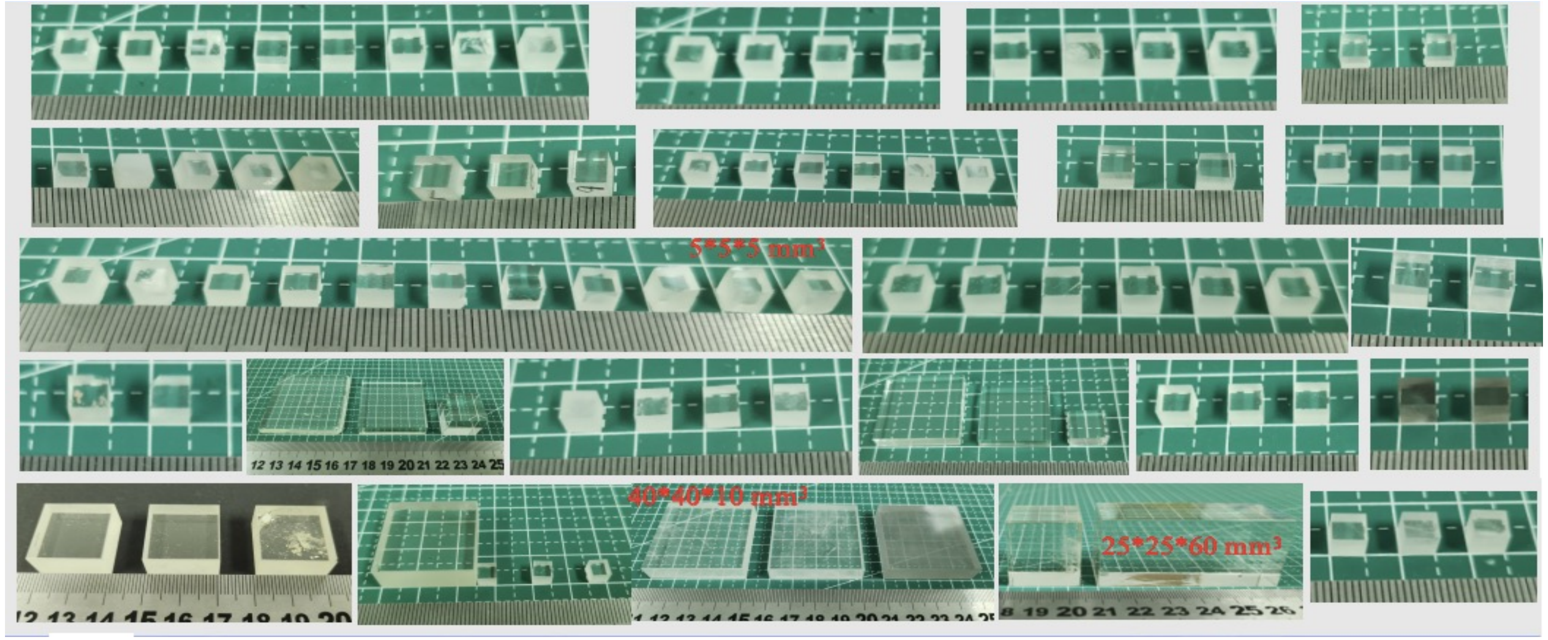
BMR factorization based on PFA

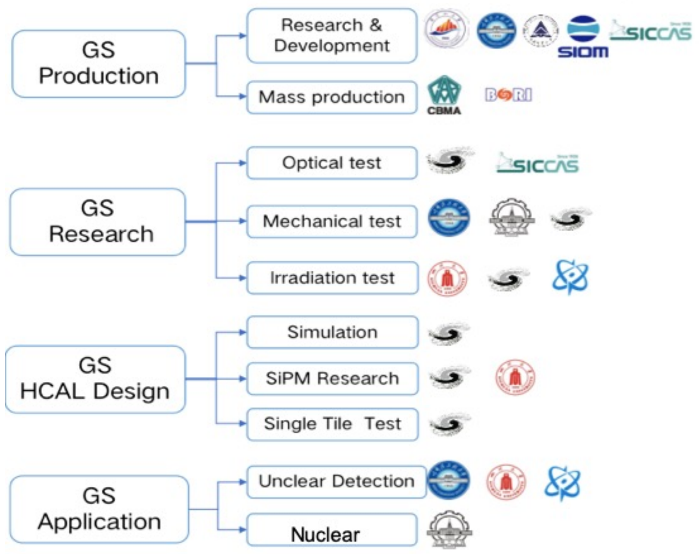


BMR=Boson Mass resolution



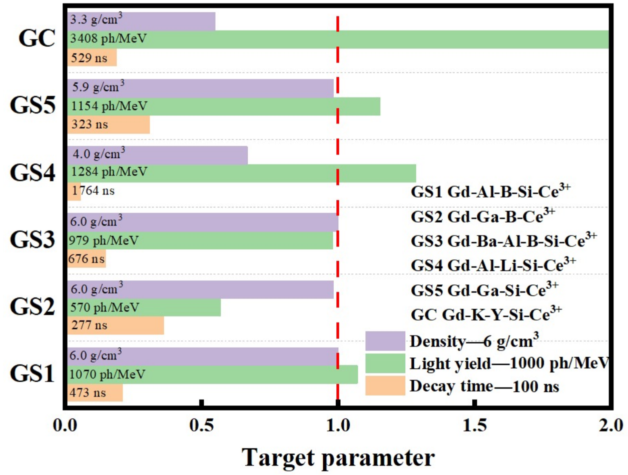
Scintillating glass R&D





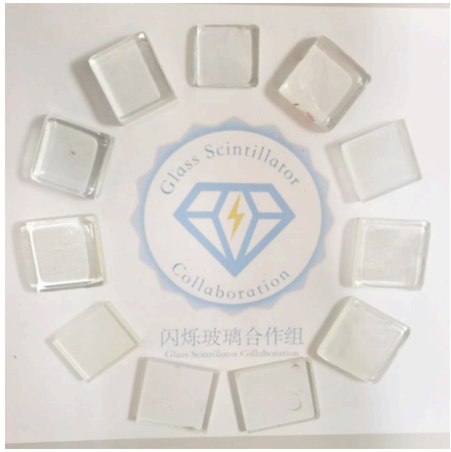
- “Glass Scintillator Collaboration” founded in 2021
  - R&D of large-area, high-performance glass materials
  - For nuclear and particle physics
- Promising performance of best glass samples
  - Close to the goals: i.e. 6 g/cc, 1000 photons/MeV, 100 ns

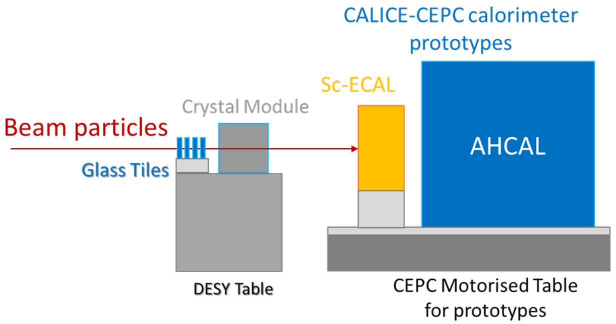
闪烁玻璃合作组
Glass Scintillator Collaboration

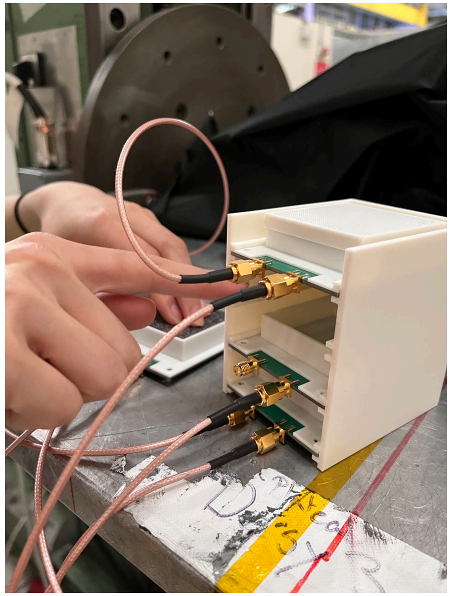


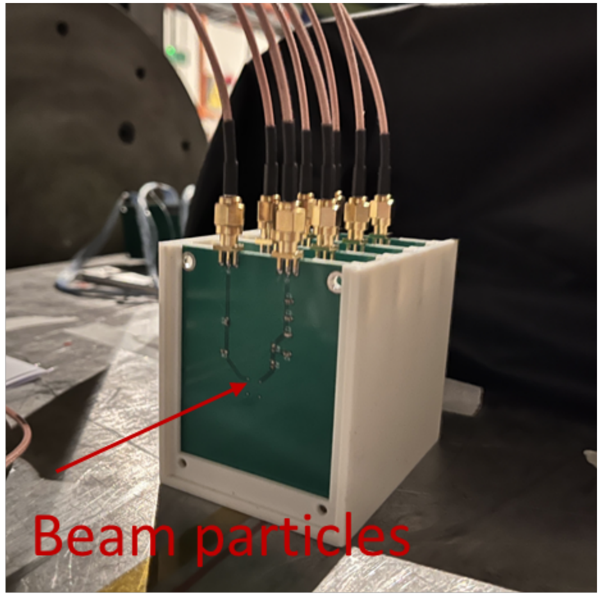
Scintillator glass tiles: CERN beamtest in 2023

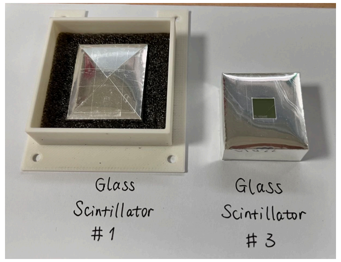
- Successful beamtest with scintillator glass tiles
  - Combined tests with CEPC calorimeter prototypes
  - 11 pieces of large-area glass tiles: the first batch produced by the “Glass Scintillator Collaboration”
  - Clear MIP signals in all 11 glass samples with 15 GeV muons
  - 3 glass tiles showed promising MIP response

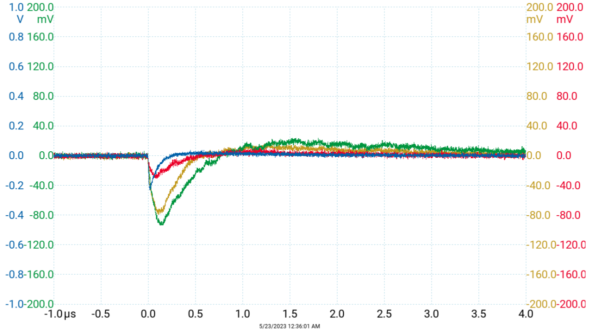


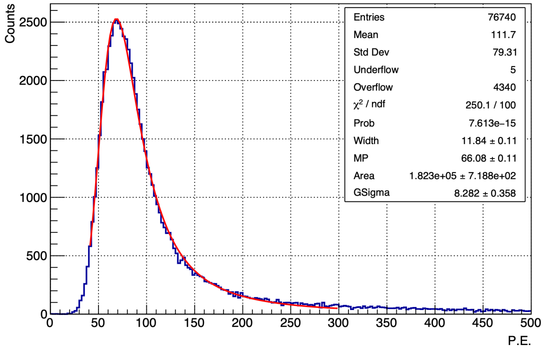










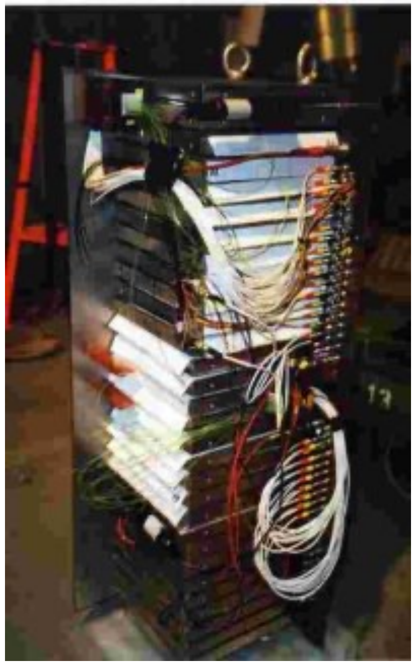


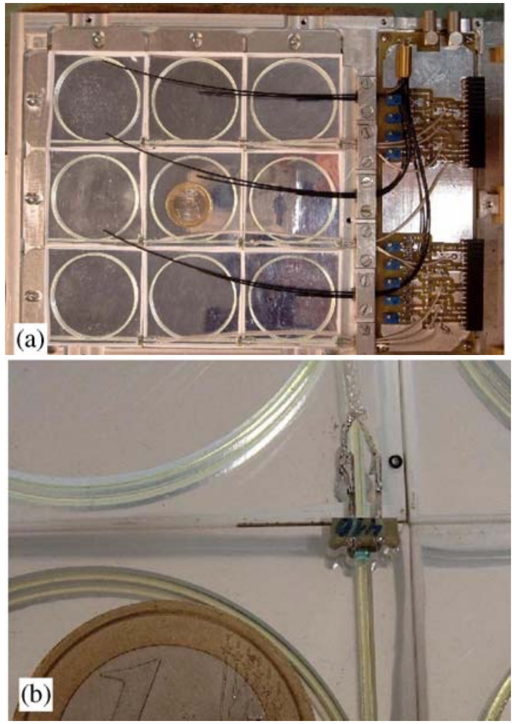
Glass scintillator (#3): 66 p.e./MIP
($29.8 \times 28.1 \times 10.2\ \mathrm{mm}^3$)

CALICE AHCAL technology: R&D in over 20 years

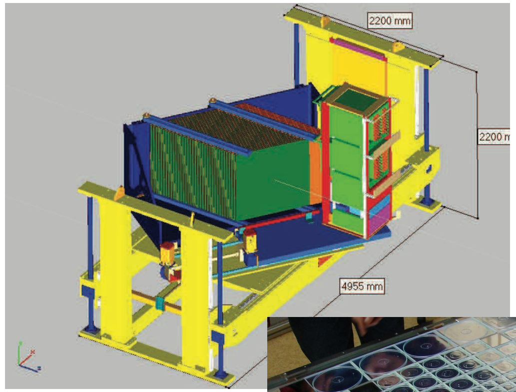
- Significant contributions from Russian institutions
  - CALICE AHCAL prototypes in different stages: scintillator tiles, WLS, SiPMs, etc.
    - MiniCal (2004), Physics prototype (2006-2009), Technological prototype (2017)
  - Detailed hadronic shower studies: software compensation, decomposition, G4 validation

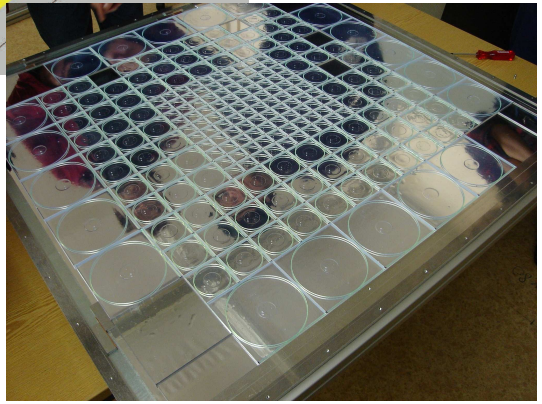
MiniCal: NIM A 540 (2005) 368



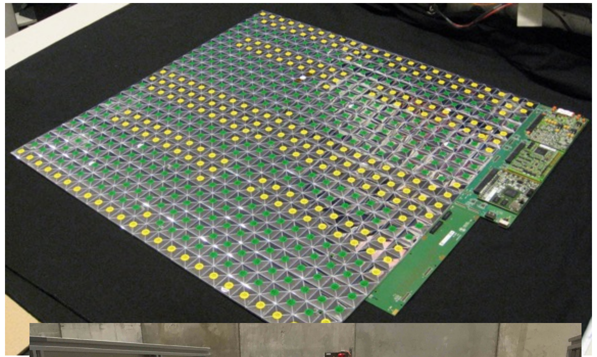


Physics Prototype: 2010 JINST 5 P05004





2023 JINST 18 P11018



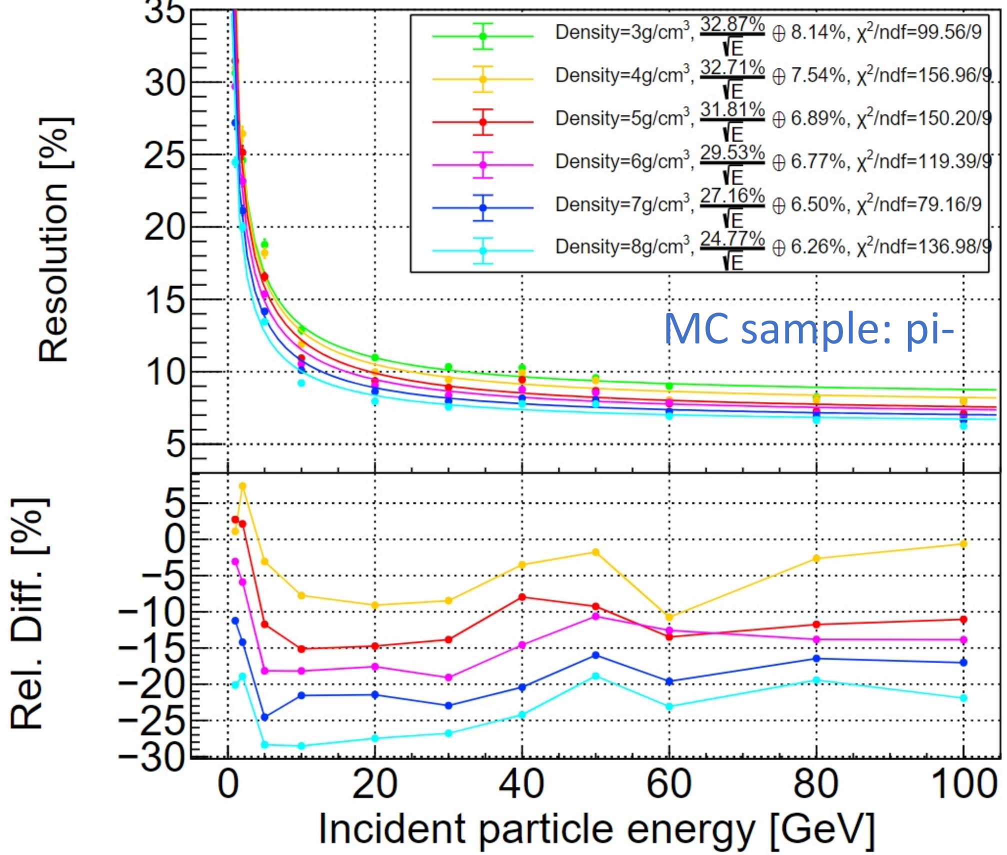
Summary and prospects

- PFA-oriented calorimeters
  - Active R&D area with steady progress made in past years
  - Successful beam test campaigns of scintillator-based prototypes: EM/hadronic performance evaluation and detailed shower studies
  - New concepts with crystal and scintillating glass
- R&D topics for wider collaboration
  - ScECAL and AHCAL prototypes: beamtest data analysis
    - e.g. simulation validation, shower profiles, software compensation, particle flow
  - High-granularity crystal calorimeter R&D
    - e.g. specifications, module beamtests; system integration; reconstruction, …
  - Scintillating glass hadron calorimeter R&D
    - e.g. simulation, module/prototype developments, software compensation, etc.

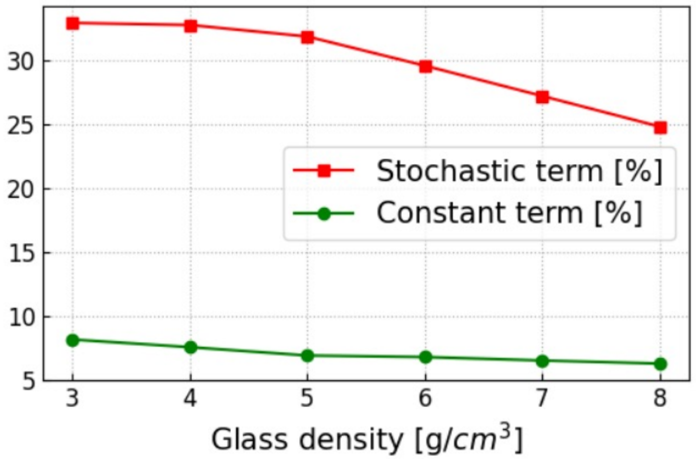
Backup

Simulation studies: hadron performance

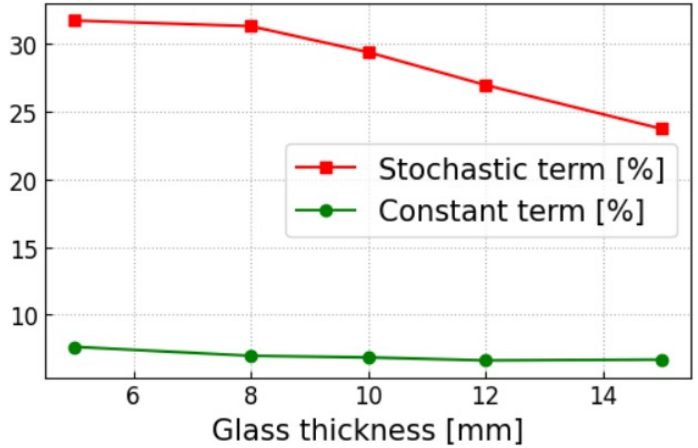
Hadronic energy resolution



Energy resolution vs. glass density



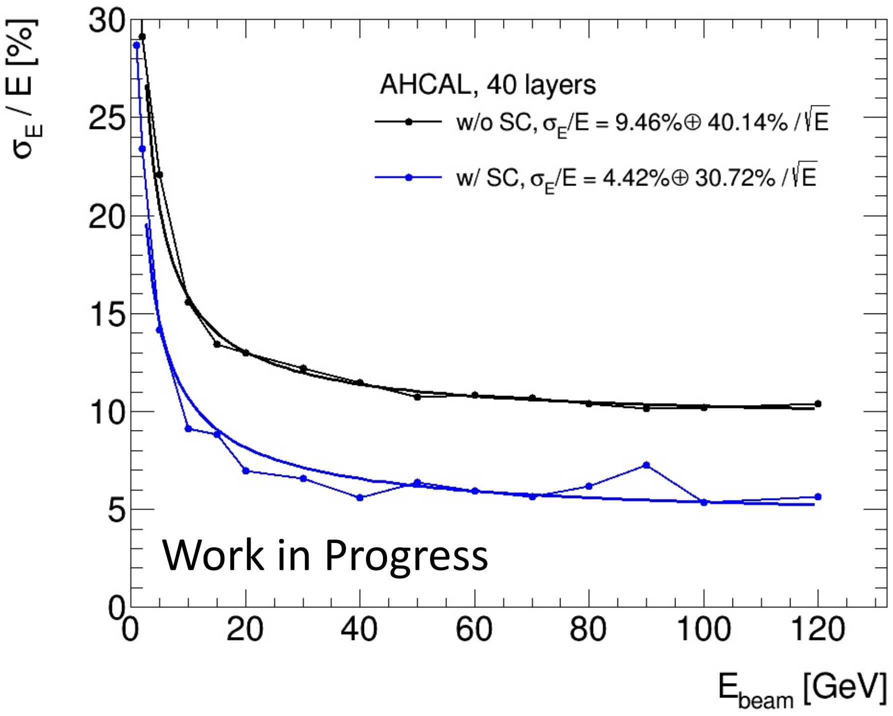
Energy resolution vs. glass thickness



- Improvements of hadronic energy resolution
  - Glass density and thickness, energy threshold
- Targets for scintillating glass R&D
  - Density: 6 g/cc
  - Thickness: 10mm
  - Intrinsic light yield: 1000 photons/MeV

Software compensation for ScintGlass HCAL

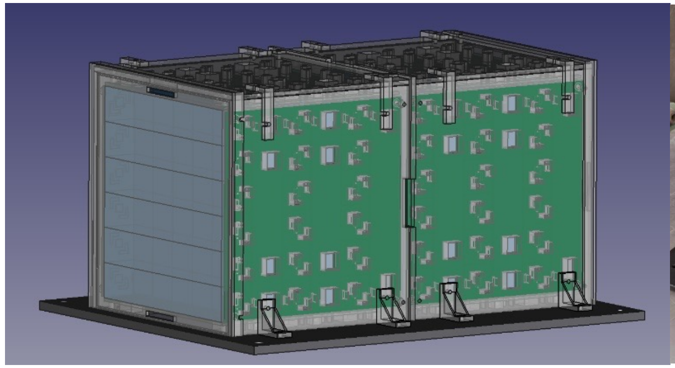
- Further improvements to hadronic energy resolution
  - Hadronic showers: EM core (compact) + purely hadronic component (sparse)
  - Software compensation: determine weights based on energy density for EM/hadronic parts

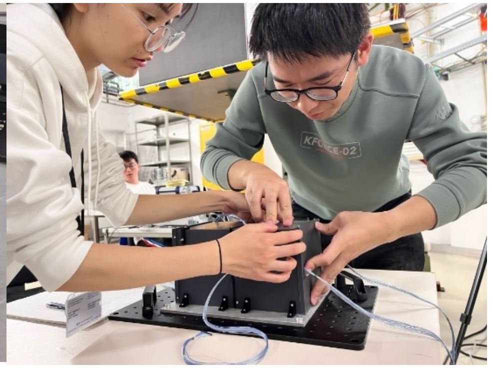


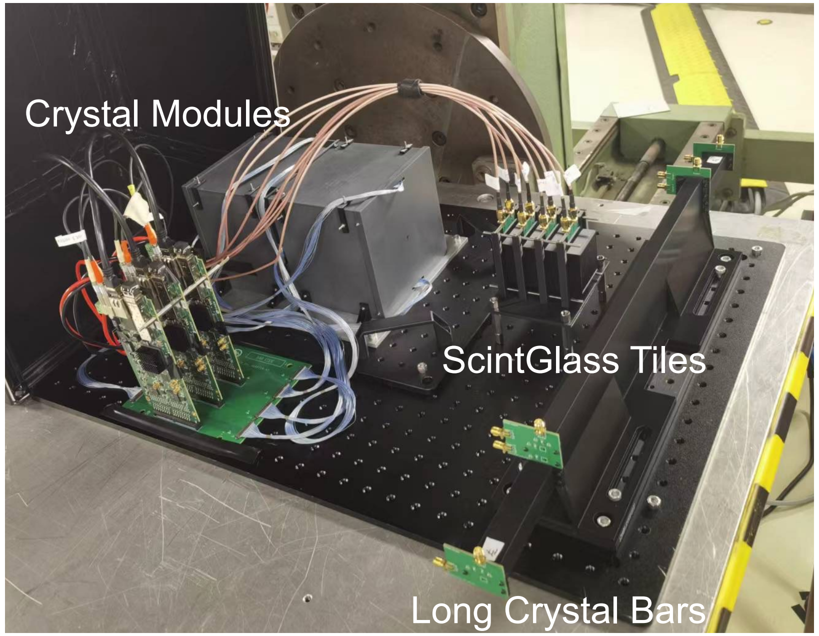
- ScintGlass HCAL option
  - Unequal response to EM/had. (e/h>1)
- Preliminary simulation studies
  - Software compensation shows a significant improvement in energy resolution

SC techniques applied in H1, ATLAS, CALICE-AHCAL, CMS-HGCAL; PandoraPFA

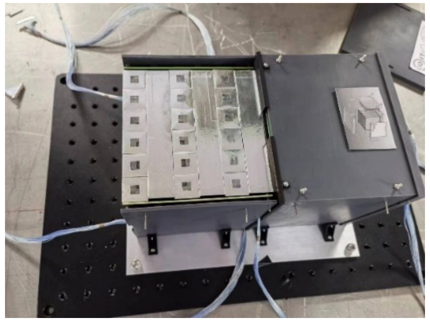
2023 DESY beamtest in October

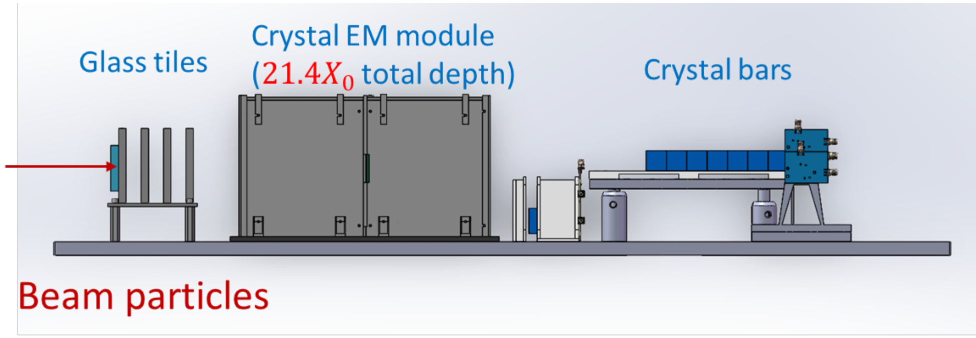






Beamtest at DESY TB22 (Oct. 2-15, 2023)





- DESY TB22 electron beam (1-6 GeV) to study new calorimeters (esp. key components)
  - Physics Prototype of Crystal Calorimeter ($21X_0$): system integration, EM performance
  - Long crystal bars (40/60cm): timing resolution
  - The 2nd batch of tiles from the "Glass Scintillator Collaboration" (4x4x1cm): MIP signals
  - A new SiPM-ASIC (32-ch): single photon spectrum, dynamic range