ScintGlassHCAL: heavy glass tiles and steel hadronic section

Yong Liu (IHEP) for the ScintGlassHCAL team

DRD6 Collaboration Meeting at CERN

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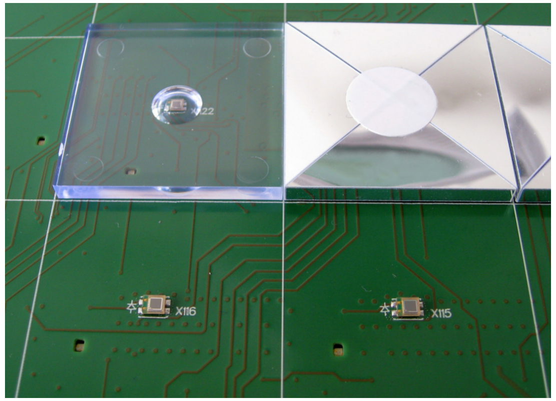
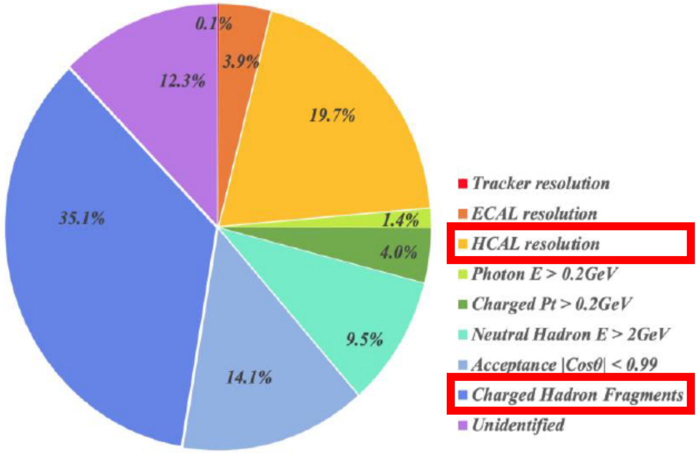
ScintGlassHCAL overview

- 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 precison jet energy measurements

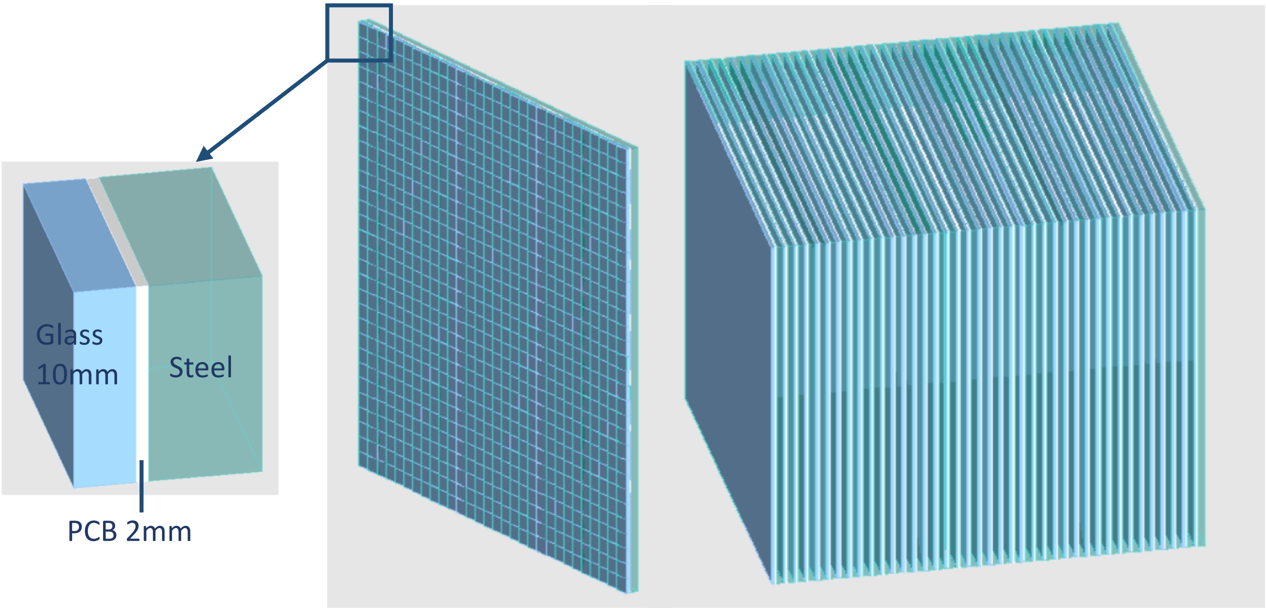
"SiPM-on-Tile" design for CALICE-AHCAL



BMR factorization based on PFA



BMR=Boson Mass resolution

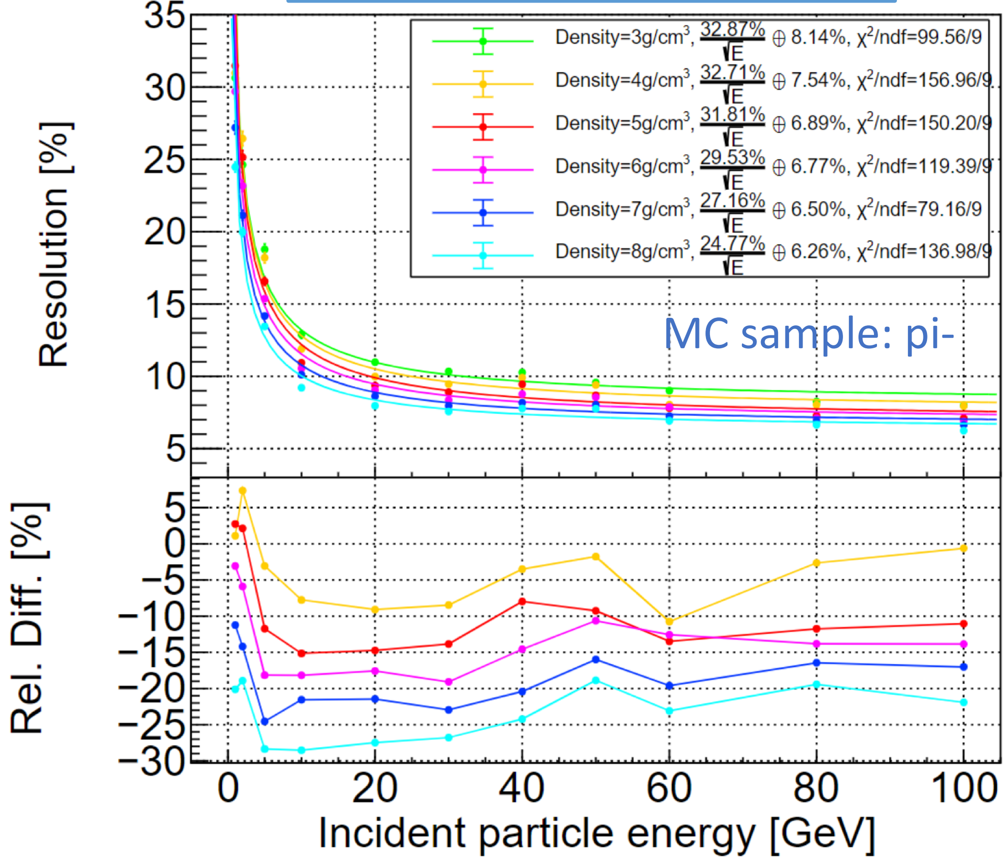


ScintGlassHCAL overview

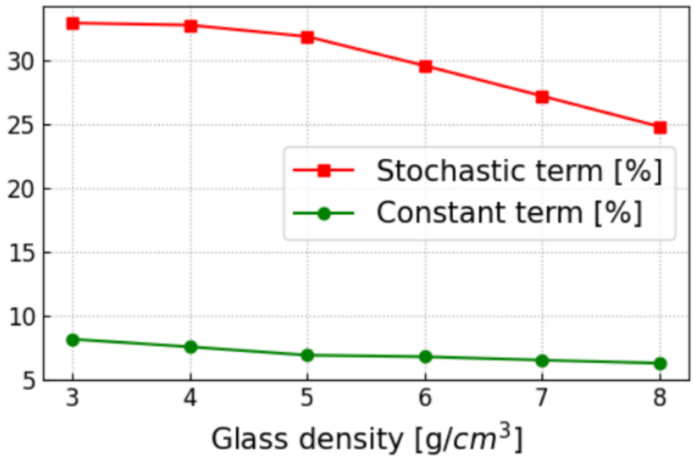
- ScintGlassHCAL: PFA-oriented sampling hadron calorimeter
  - A variant option of CALICE-AHCAL: scintillator-SiPM, steel
  - Sensitive layer: dense and bright *scintillating glass* tiles (cost effective)
  - Aim to further improve hadron energy resolution (high sampling ratio, low threshold)
- Simulation: to understand potentials and to formulate design specifications
  - Performance with single hadrons
  - PFA performance with jets
  - Optical photon simulation: response uniformity across tile area
- Hardware activities: glass production and measurements
  - Synthesizing scintillating glass samples: aim to meet specs
  - Measurements of small-scale glass samples: density, light yield, transmission, …
  - Cosmic and beam tests of large glass tiles: MIP response

Simulation studies: hadron performance

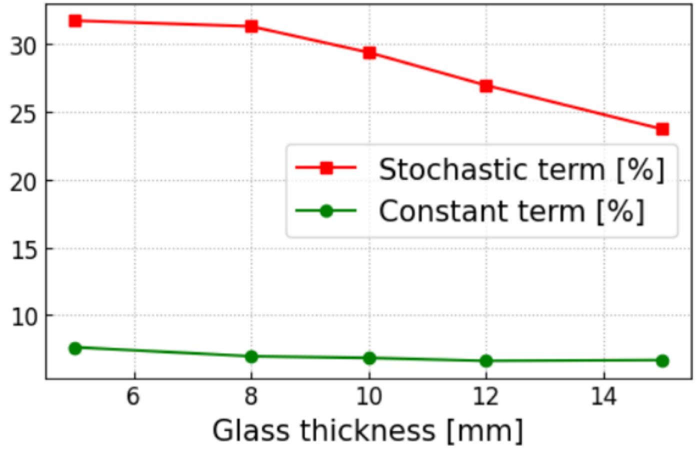
Hadronic energy resolution



Energy resolution vs. glass density



Energy resolution vs. glass thickness

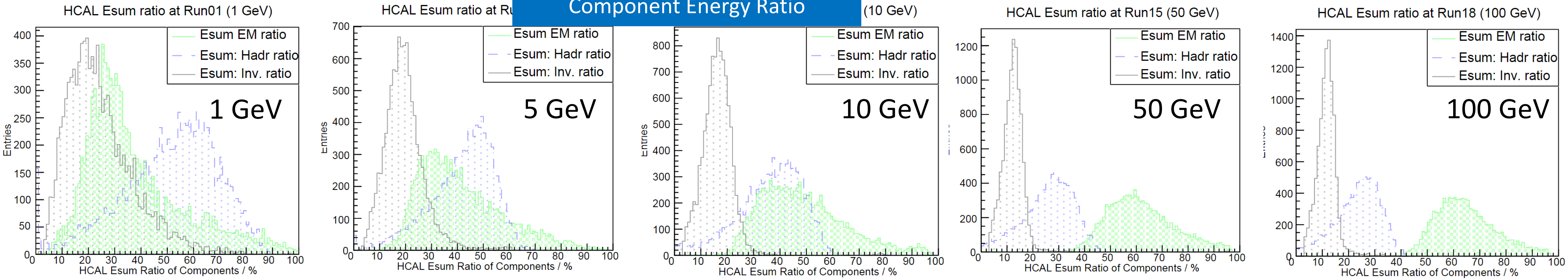


- Improvements of hadronic energy resolution
  - Glass density and thickness, energy threshold
- Targets for scintillating glass R&D
  - Density: 6 g/cc
  - Thickness: 10mm
  - Intrinsic light yield: 1000 photons/MeV

Simulation studies: hadron performance

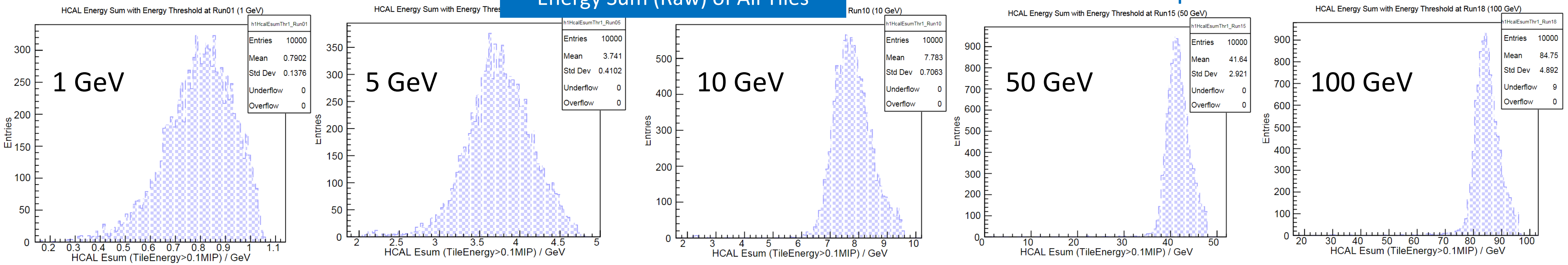
- Categorize components of hadronic showers: “non-compensation”
  - Total energy deposition: non-Gaussian distributions → Dominate the large constant term (>5%)

Component Energy Ratio



Energy Sum (Raw) of All Tiles

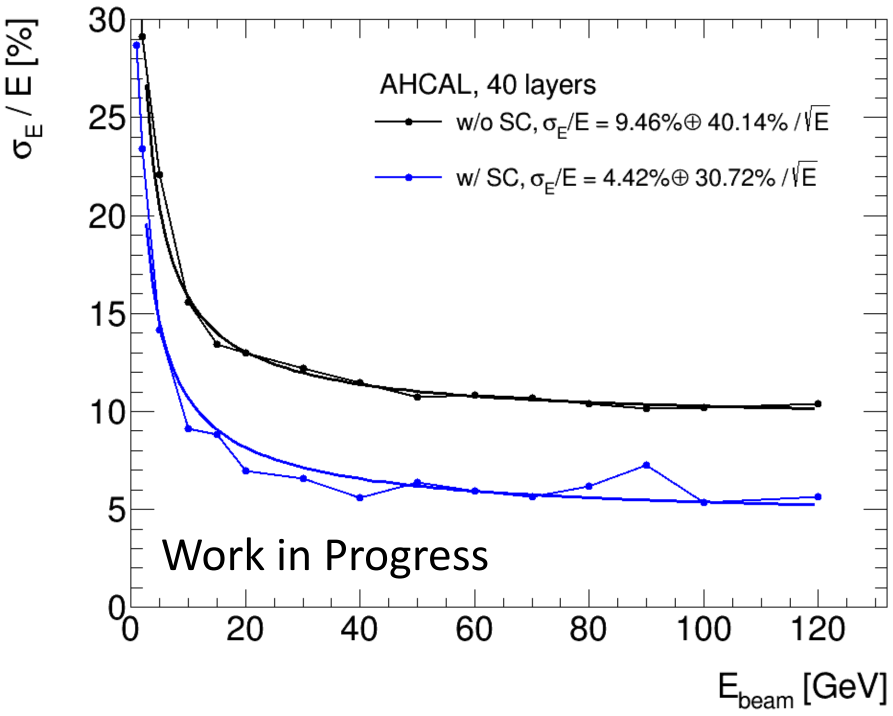
MC samples with π^-



Software compensation for ScintGlass HCAL

Fangyi Guo (IHEP)

- 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

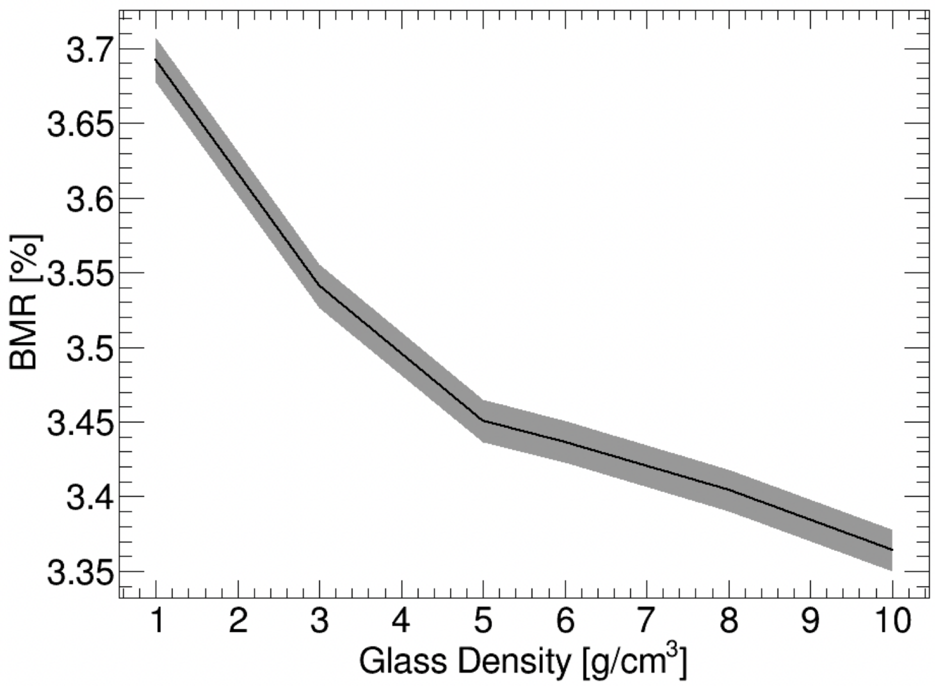


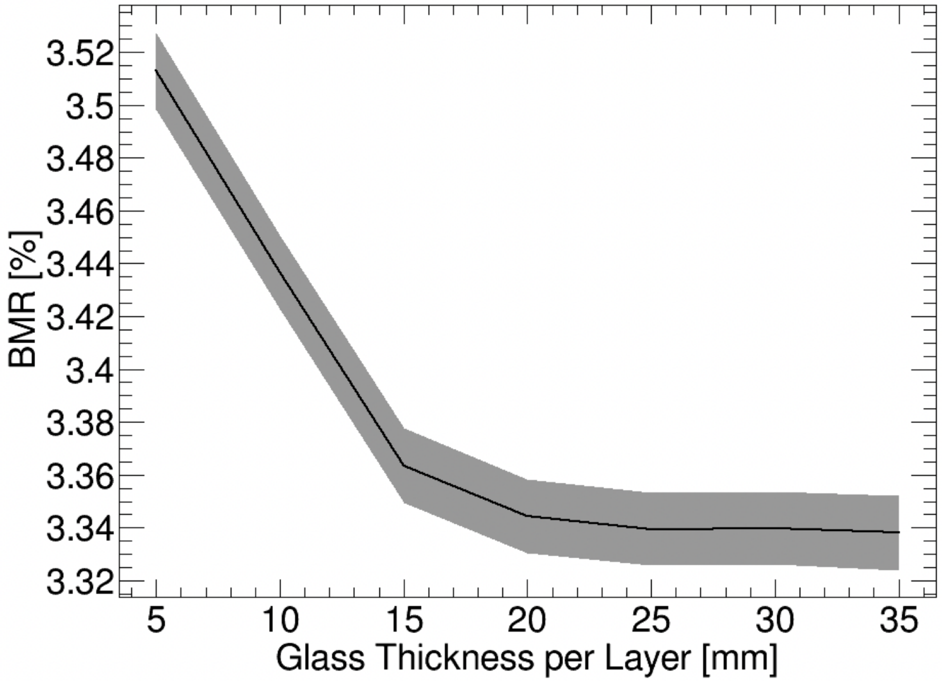
- ScintGlass HCAL option
  - Unequal response to EM/had. (e/h>1)
- Preliminary simulation studies
  - Software compensation shows a significant improvement in energy resolution

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

Jet performance: BMR vs. glass density/thickness

Peng Hu (IHEP)

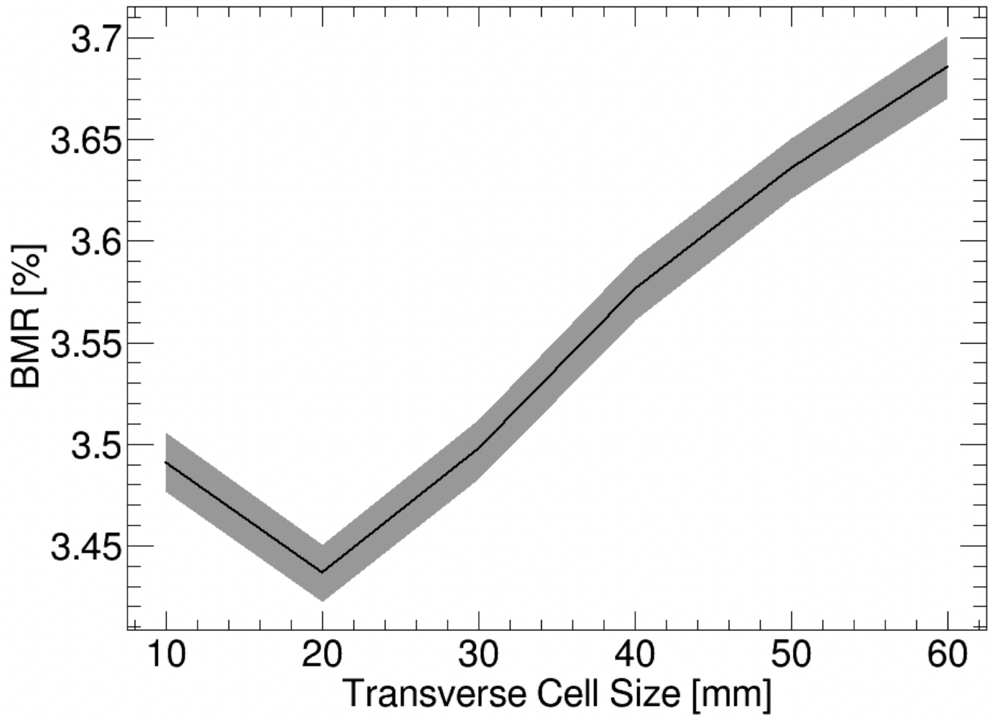


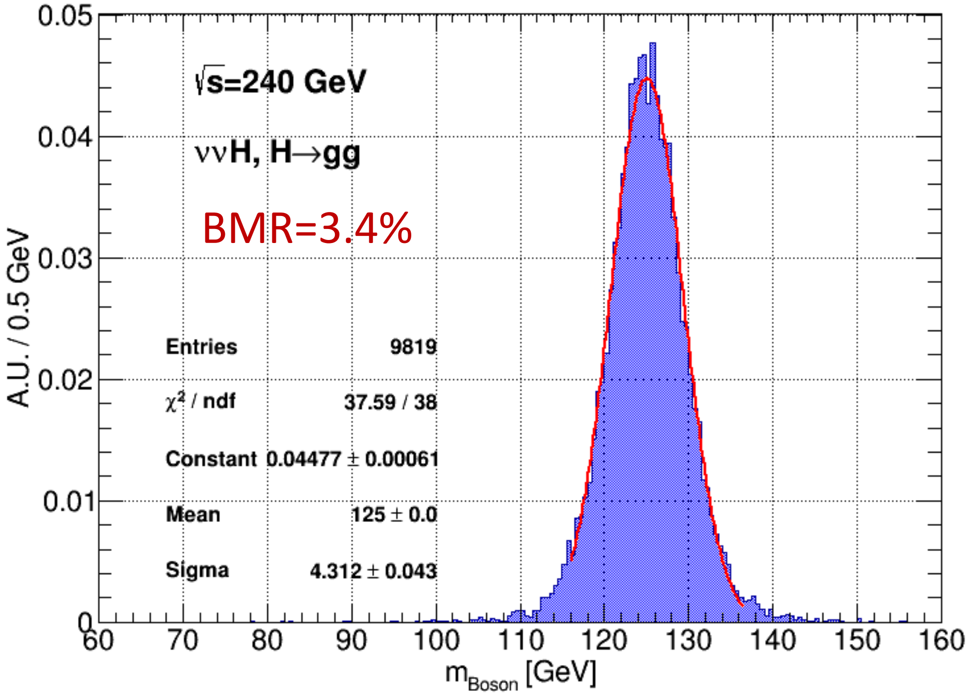


- BMR will be improved with higher density and thicker tiles
  - Guidance for the design glass tile: plateau regions ($\geq 5g/cm^3$, ~15 mm)
- Technical limitations from glass production
  - Generally thicker or more dense tiles → lower light yield

Jet performance: BMR vs. transverse granularity

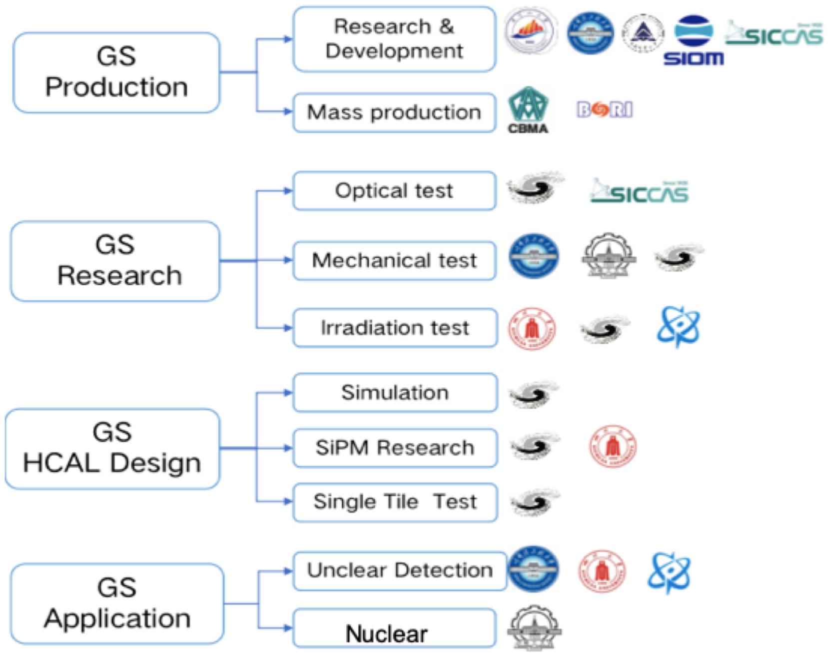
Peng Hu (IHEP)





- BMR improved with finer transverse granularity
  - Granularity of ~10x10mm: pattern recognition issue with dramatically more #hits
- Optimal BMR has reached 3.4%
  - Could be further improved by optimization of PFA parameters (goal: BMR ~3%)

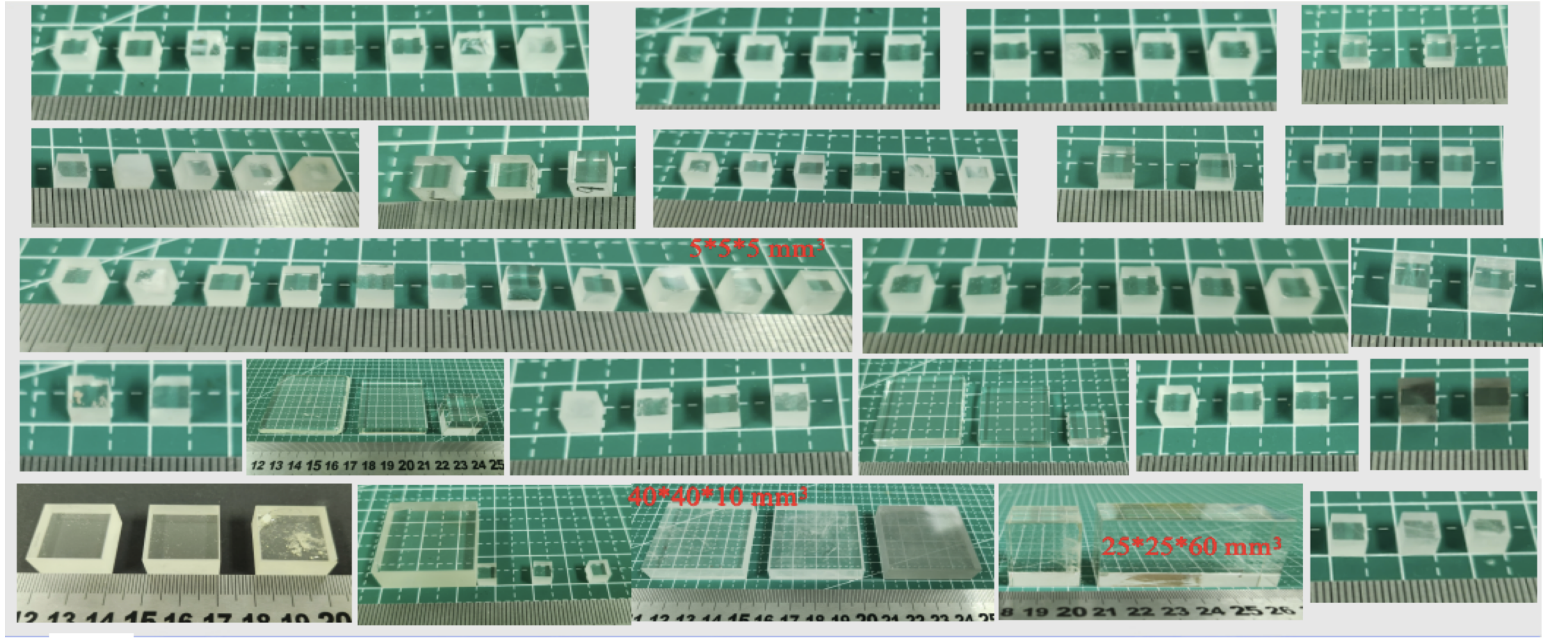
Glass materials R&D: Glass Scintillator Collaboration

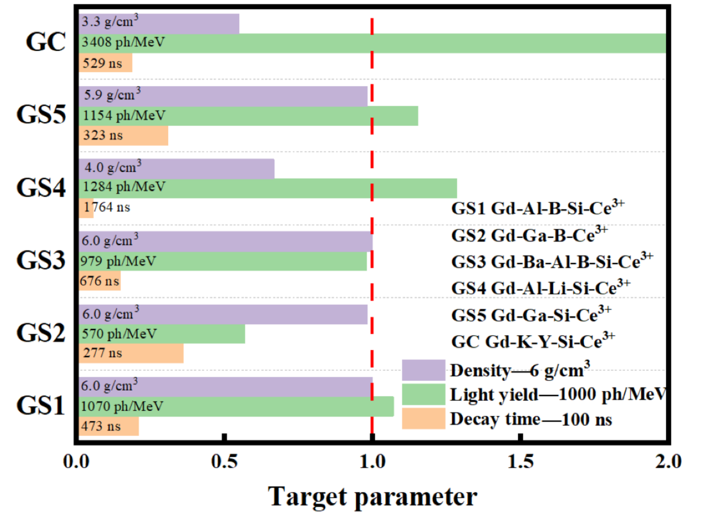


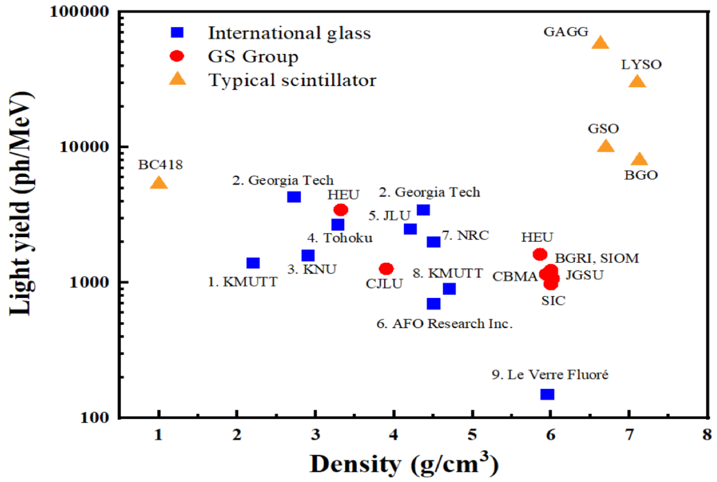
闪烁玻璃合作组
Glass Scintillator Collaboration

- GS collaboration (since 2021): R&D of large-area, high-performance glass materials
  - For nuclear and particle physics
  - IHEP as the leading institution, with 11 members (3 institutes in CAS, 5 universities, 3 corporations)
- Welcome wider collaboration from academia and industry: Sen Qian (qians@ihep.ac.cn)

Brief summary of glass R&D





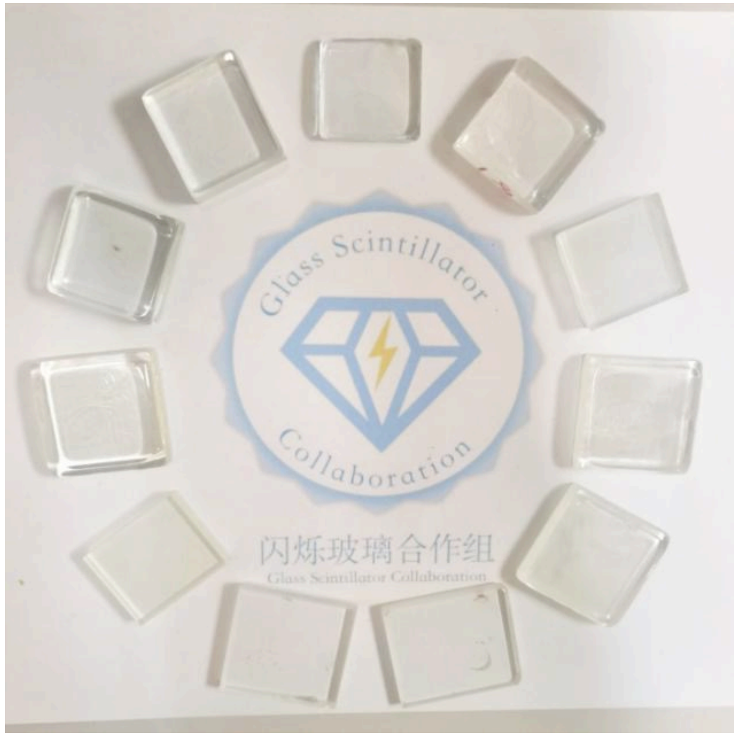


- Steady progress made: R&D based on five glass systems
- Promising performance of best glass samples
  - Close to the goals: i.e. 6 g/cc, 1000 photons/MeV, 100 ns
- For high-density scintillating glass, samples from GS collaboration currently take the lead in light yield

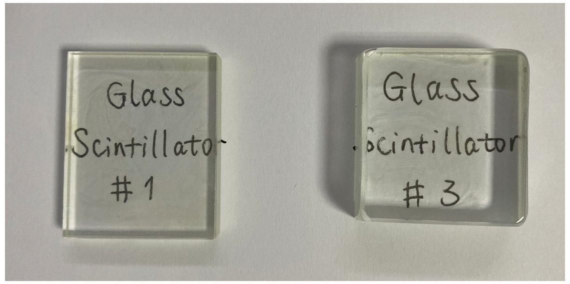
2023 CERN beam test in 2023

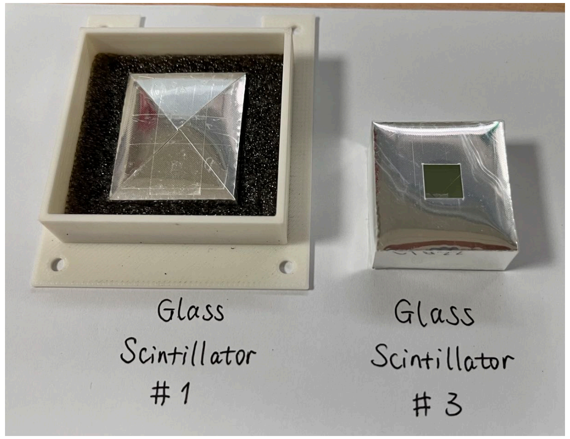
- 11 scintillator glass tiles (first batch in large scale) successfully tested
    - Parasitic runs with CALICE scintillator-calorimeter prototypes at PS-T09 in May 2023
- **Motivation**: use muon beam to measure MIP response of each glass tile

Glass tiles (cm-scale) before wrapping



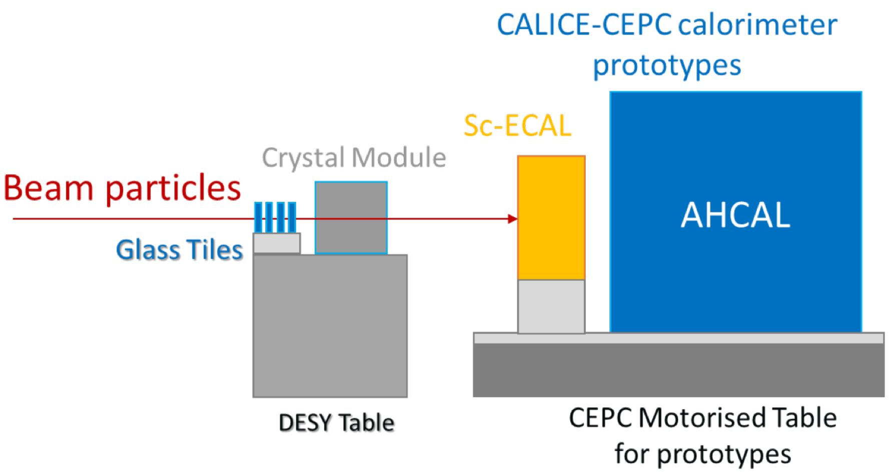
Glass tiles wrapped with Teflon and black tapes

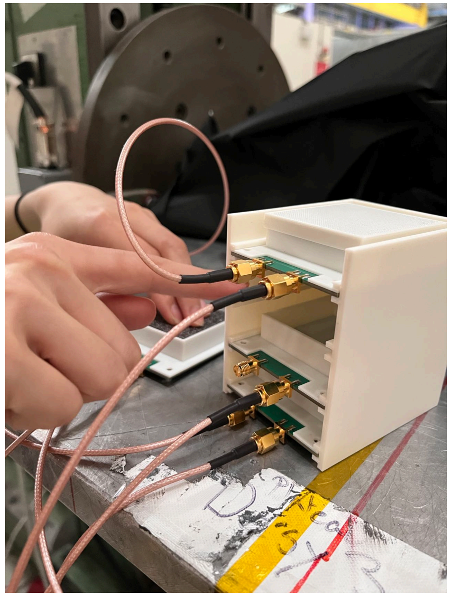


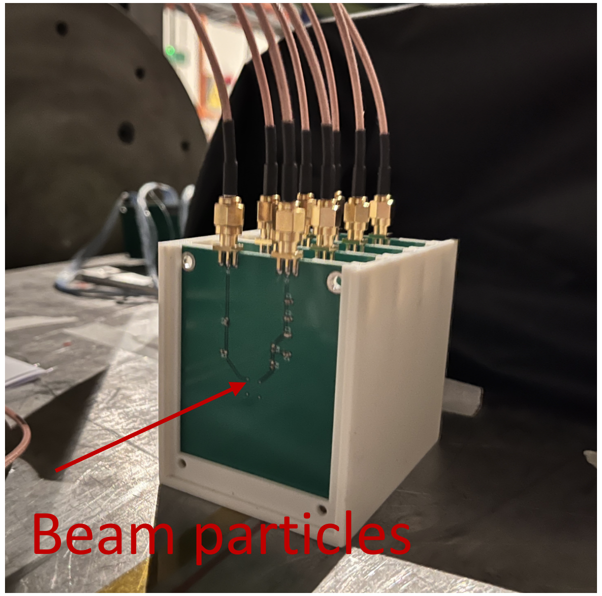


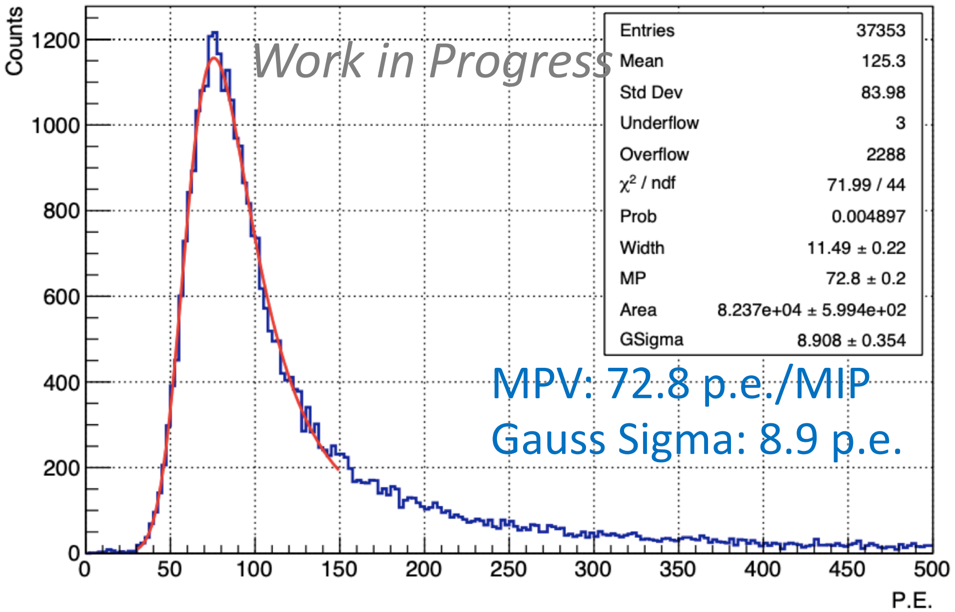
Two glass tiles re-wrapped with ESR

2023 CERN beam test in 2023









Glass scintillator tile #11: $30.5\times30.0\times8.7\ \mathrm{mm}^3$

Summary and prospects

- ScintGlassHCAL
  - Steady progress made in simulation studies, glass production and characterisations
  - Preliminary results are promising, yet still more to be better understood and explored
  - Synergies expected with other subtasks and transverse work areas

Task/Subtask	Sensitive Material/ Absorber	DRDTs	Target Application	Current Status
Task 1.2: Hadronic section with optical tiles				
Subtask 1.2.1: AHCAL	Scintillating plastic tiles/ Steel	6.2	e^+e^- collider central detector	Prototype for finalising R&D for LC, Specification for CC and of timing for PFA needed
Subtask 1.2.2: ScintGlassHCAL	Heavy glass tiles/ Steel	6.2	e^+e^- collider central detector	Material studies and specifications for prototypes

	Milestone	Deliverable	Description	Due date
Task 1.2: Hadronic section with optical tiles				
Subtask 1.2.1: AHCAL	M1.7		Concept for continuous readout	2024
	M1.8		First layer with continuous readout	2025
		D1.7	EM prototype demonstrating system aspects	2026
		D1.8	Full-size layer and multi-layer demonstrator	>2026
		D1.9	Engineering prototype	>2026
Subtask 1.2.2: ScintGlassHCAL	M1.9		cm-scale tiles	2024
		D1.10	15-layer EM module	2025
		D1.11	40-layer prototype	>2026

Planning

- ScintGlassHCAL: “uncharted territory for dense glass + imaging calorimetry”
- Major items for future R&D in next years
  - In-depth simulation studies
    - Performance, HCAL specifications, PFA optimisations
  - HCAL unit design optimisations
    - Response uniformity, readout scheme, photo-sensors
  - Readout electronics
    - e.g. multi-channel front-end chip (analog + digital) for SiPM readout
  - Glass mass production
    - scalable, cost effective, quality assurance & control
  - Developments of prototypes from small to large scale at several stages
    - To evaluate performance and validate simulation; to address challenges in system integration
  - And try to identify “additional, still unknown, R&D challenges”

Thank you!

Backup

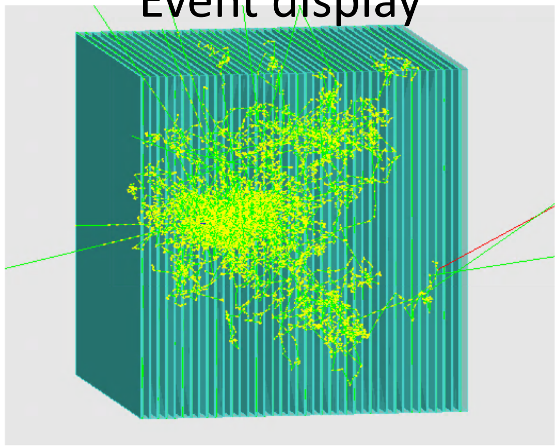
GS-HCAL simulation setup

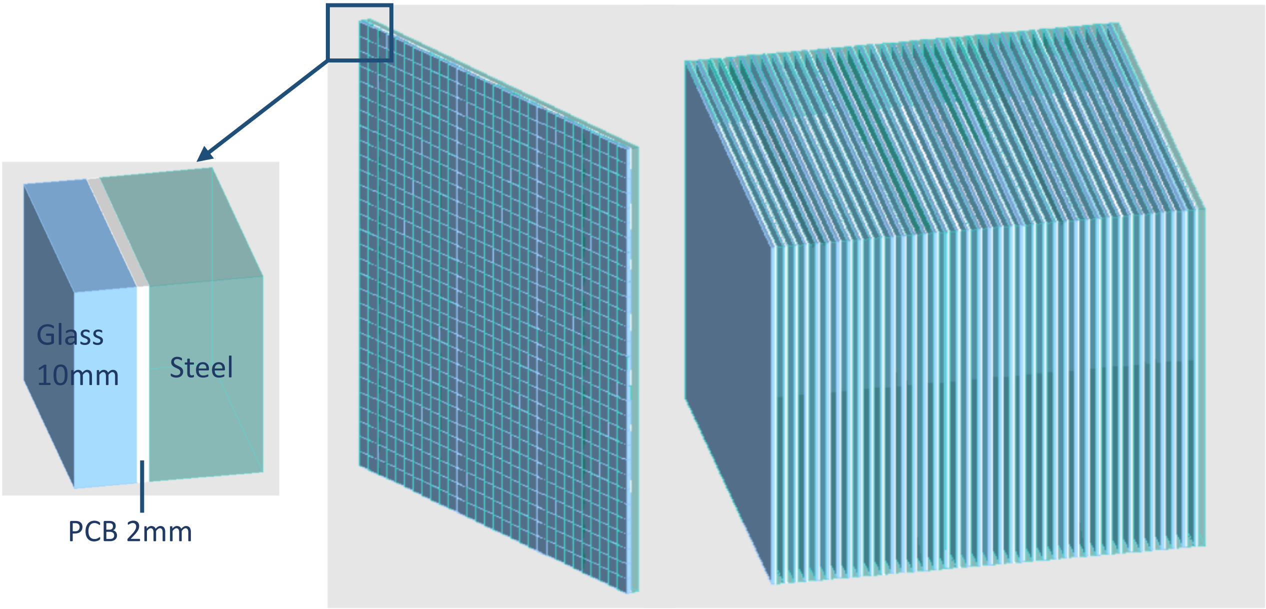
Dejing Du (IHEP)

- GS-HCAL geometry
  - Refer to Scintillator-Steel AHCAL (CEPC CDR baseline)
  - Replace plastic scintillator with glass scintillator
- Glass scintillator material
  - Composition: Gd-B-Si-Ge-F-Ce^{3+}
  - Nuclear interaction length: 23.83 cm
  - MIP response: 7 MeV/cm
- GS-HCAL nominal parameters

Total number of layers	**40**
Total nuclear interaction length	**5 λ**
Glass tile size	**40×40×10 mm³**
Glass density	**6 g/cm³**
Readout threshold	**0.1 MIP**

Event display





Optimisation based on PFA studies

Peng Hu (IHEP)

- Adapted from CEPC baseline detector
  - ScintGlass-Steel HCAL + Si-W ECAL
- Higgs benchmark with two gluon jets (at 240 GeV)
- Physics performance evaluation
  - Boson Mass Resolution (BMR): resolution of the Higgs invariant mass
  - Full simulation + PFA reconstruction by Arbor

Total number of layers	**40**
Total nuclear interaction length	**6 λ**
Glass density	**6 g/cm^3**
Energy threshold	**0.1 MIP**