Scintillating Glass Calorimetry for AGORA

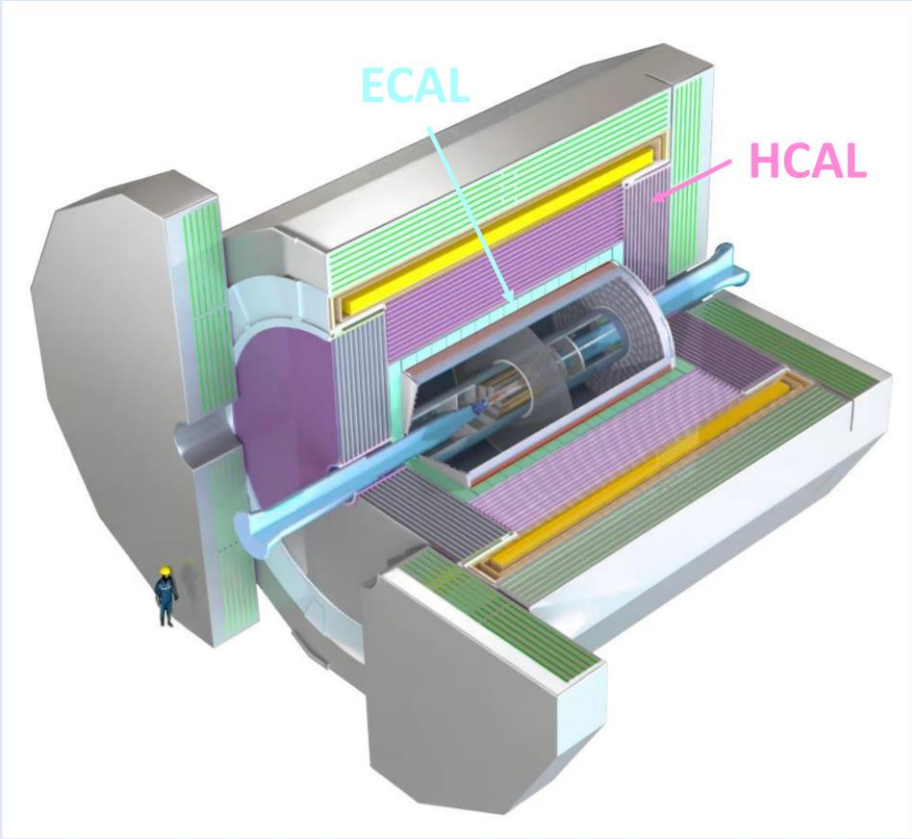
Design, Simulation and Single-Cell Tests

CEPC Workshop 2026

Weizheng Song (speaker), Yang Zhang, Yushan Liu,
Yong Liu, Sen Qian, Shengsen Sun, Yuekun Heng, Yifang Wang

CEPC Reference Detector: Calorimeter Overview

- Precision Higgs/Z/W measurements target ~30%/√(E/GeV) jet energy resolution.
- A calorimeter system based on the particle-flow approach: high granularity and high energy resolution.

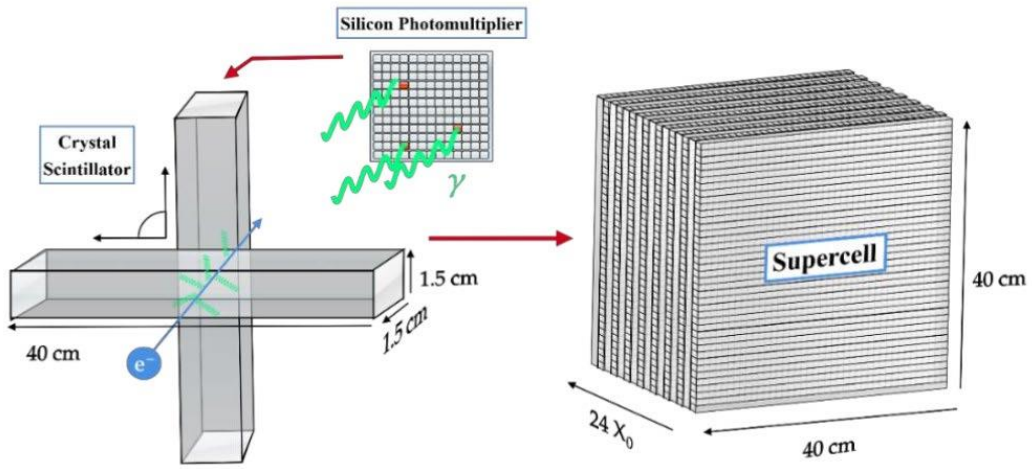


Section	Performance requirement	Technology
ECAL	EM energy resolution < 3%/√E ⊕ 1%	Long crystal bars Orthogonal bars in adjacent layers
HCAL	Hadron energy resolution ~30%/√E	Scintillating glass tiles (high density and high light yield) High sampling ratio

CEPC Reference Detector: Crystal ECAL

- BGO bars (1.5 × 1.5 × ~40 cm³) alternate in x and y, with a 3 × 3 mm² SiPM at each end.

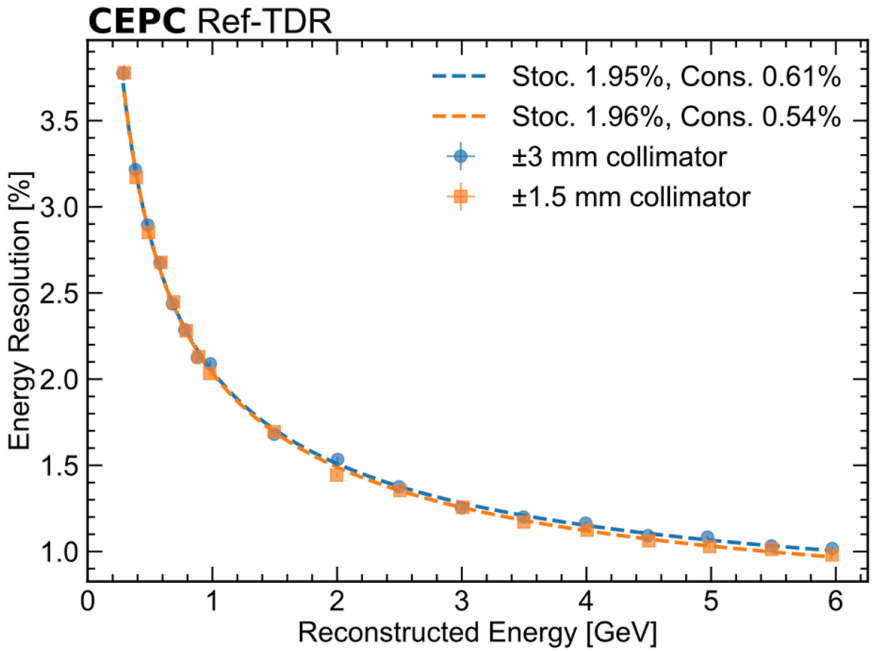
Crystal bar structure



Reference design: 18 layers, 24 X_0

Simulation: 1.20%/√E ⊕ 0.44%

BGO prototype beam test

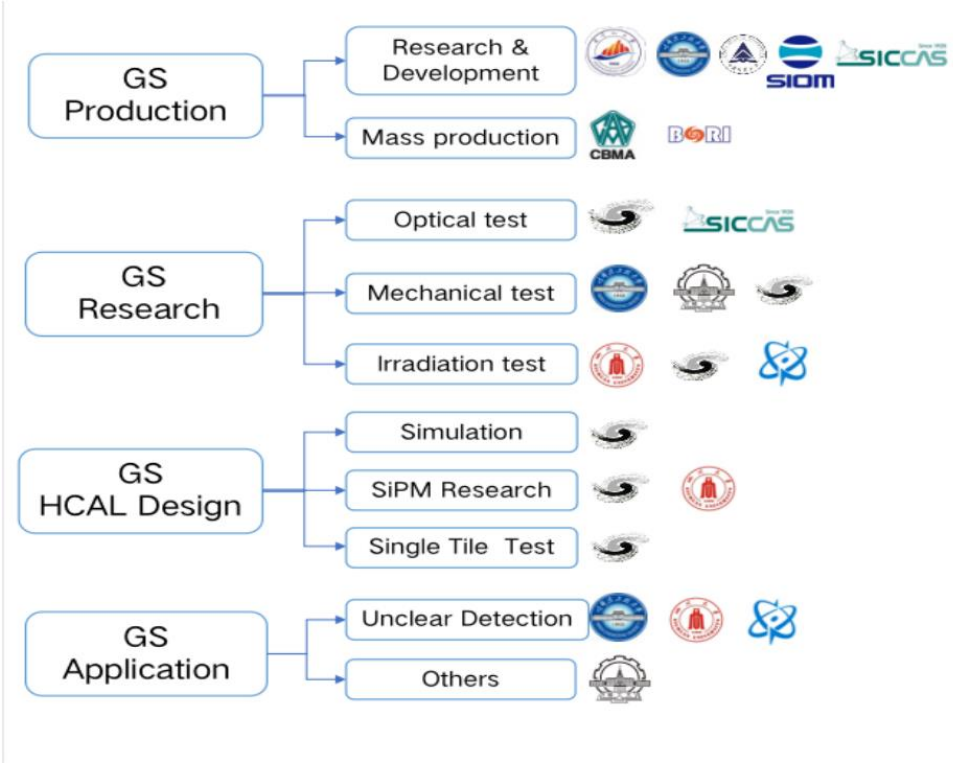


Beam test: 1.95%/√E ⊕ 0.6%

Prototype: 2 × 2 cm² cross section, 12 cm bars.

Scintillating Glass: History and Collaboration

- The history of glass scintillators began in 1958.
- **Achieving high density and high light yield simultaneously has long been a key challenge.**



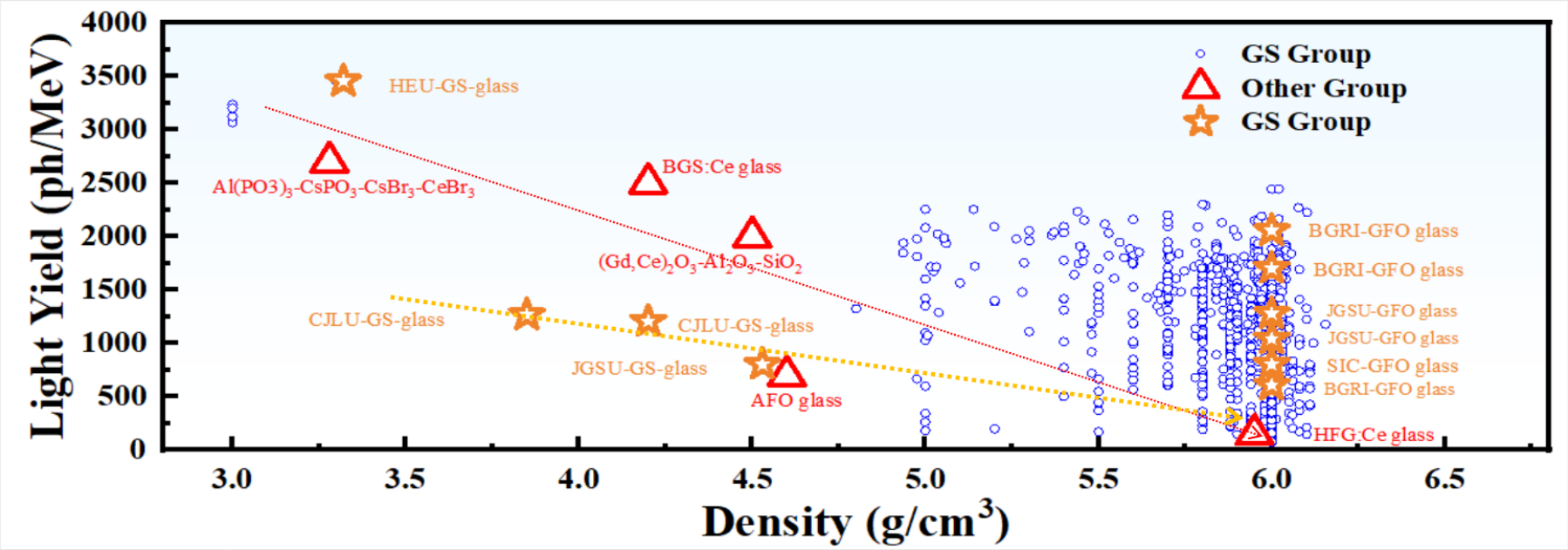
- The GS collaboration brings together universities, research institutes and industry for glass development.
- Optical tests, SiPM studies and single-cell tests connect material R&D to calorimeter applications.

13 groups in 2024.
>2000 glass samples reported.

GFO Glass Development

- Increasing the Gd content raised the density of GFO glass to ~6 g/cm³.
- Ce^{3+} doping, defect control and co-doping with other elements increased the light yield to ~2000 ph/MeV.

Light yield versus density (GS and other groups)



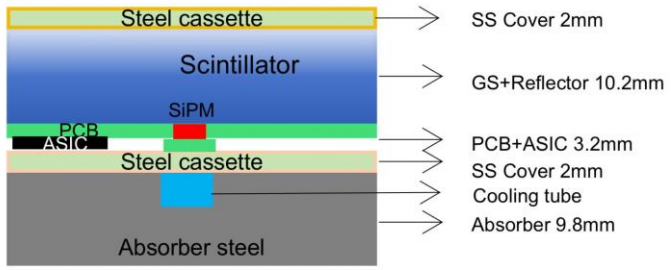
- **Gadolinium Fluoro-Oxide (GFO) with Ce^{3+} doping becomes a clear winner for high density and high light yield.**

Glass Parameters for Simulation

Property	Simulation input
Glass tile dimensions (mm^3)	**40 × 40 × 10**
Density (g/cm^3)	**6.0**
Transmittance at 400 nm (%)	76
Emission peak (nm)	**390**
Light yield (ph/MeV)	**1000**
Energy resolution (%) at 662 keV	30
Scintillation decay time (ns)	72.4 (10.5%), 547.8
Attenuation length (cm) at 400 nm	**6**

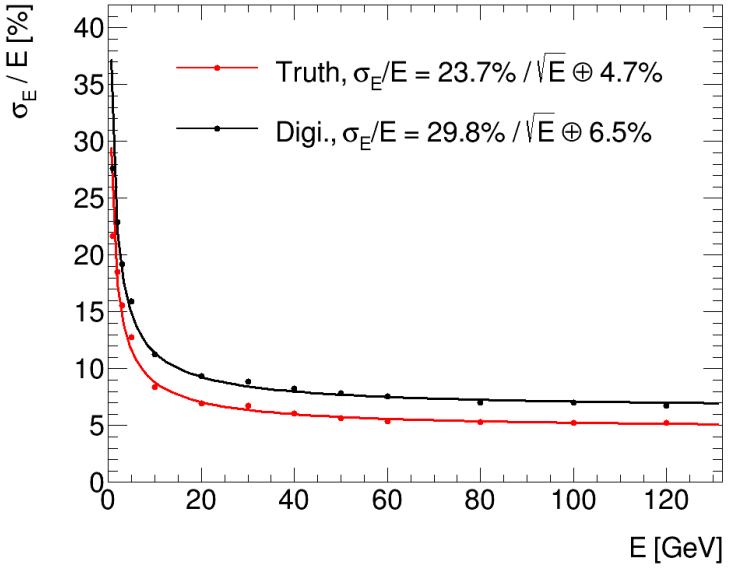
Scintillating Glass HCAL Performance

Glass + steel HCAL



4 × 4 × 1 cm³ tiles
48 layers per module
Sampling ratio ~30%

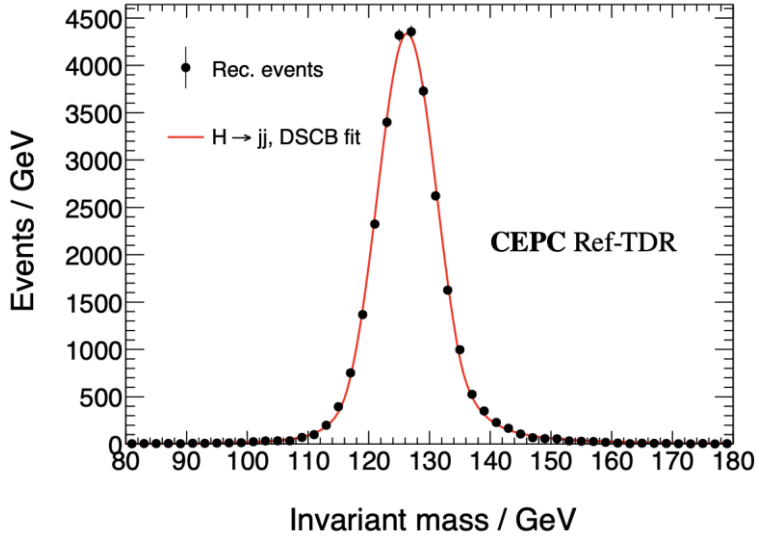
Hadronic energy resolution



~30%/√E ⊕ 6.5%

Geometry + digitization

Full detector PFA



H → gg: BMR = 3.88%

Tracker + ECAL + HCAL

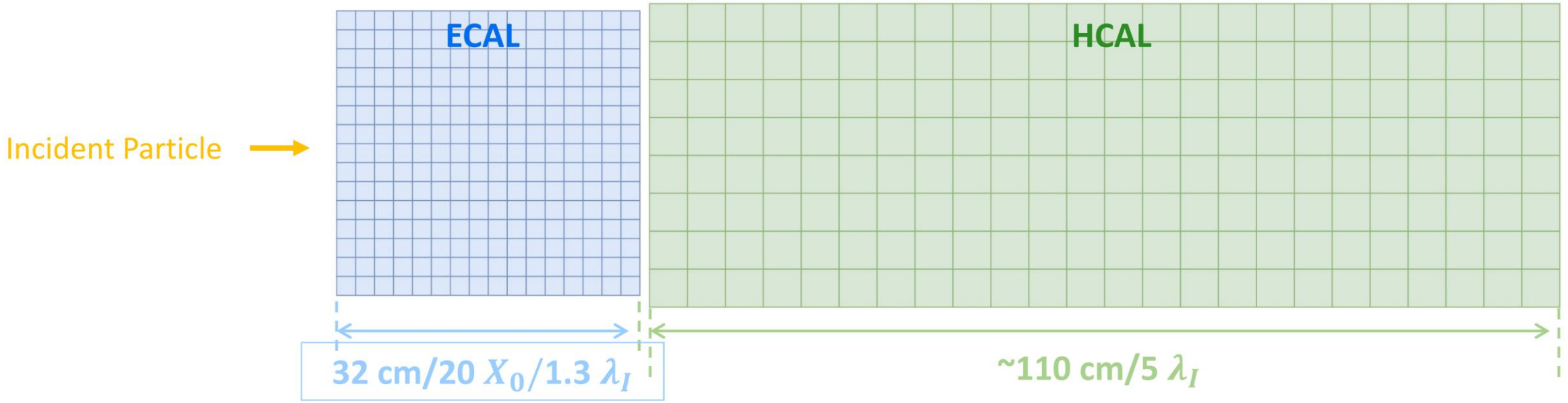
Full-Absorption Glass Calorimetry for AGORA

- AGORA (Advanced Glass Optimized Research Apparatus) is one of the proposed FCC-ee detector concepts.
- TDR-stage calorimetry uses a long crystal-bar ECAL and a scintillating-glass HCAL. BGO is expensive.
- Improved GFO glass motivates a high-granularity, full-absorption glass ECAL.
- Lower ECAL material cost could support a higher HCAL sampling ratio (>70%).

Subsystem	TDR-stage design		New full-absorption concept	
	Design	Resolution	Design	Target
ECAL	Long BGO crystal bars	**1.95%/√E ⊕ 0.6%**	GFO glass cells with 3D high granularity	**< 3%/√E ⊕ 1%**
HCAL	Glass + steel sampling ~30% sampling ratio	**~30%/√E ⊕ 6.5%**	Glass replaces steel absorber Higher sampling ratio (>70%)	**~ 15%/√E ⊕ 4%**

Full-Absorption Glass ECAL and HCAL

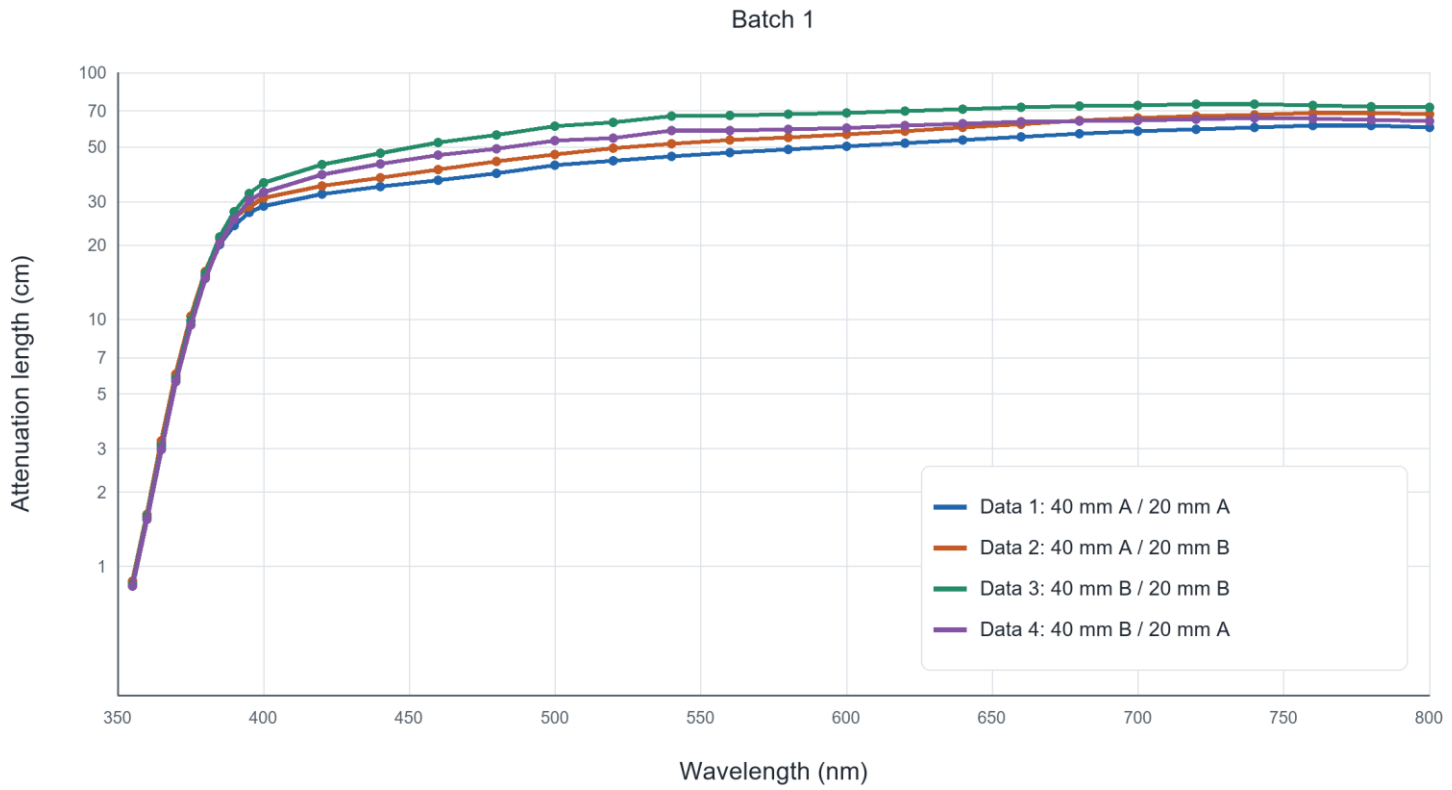
Design goals: 3D high granularity and the maximum possible HCAL sampling ratio.



Subsystem	Typical glass cell	Conceptual depth
ECAL	~2 × 2 × 2 cm³	32 cm ≈ 20 X_0 ≈ 1.3 λI
HCAL	4 × 4 cm², 3–4 cm thick	~110 cm ≈ 5 λI

Preliminary Attenuation-Length Measurement

- Batch 1 glass (40 × 40 × 20 mm³): transmittance measured along 20 mm and 40 mm paths.



Near 400 nm

30–40 cm (prelim.)

Earlier TDR input: ~6 cm

Transmittance ratio

$AL(\lambda) = 2\ \text{cm} / \ln[T_{20}(\lambda)/T_{40}(\lambda)]$

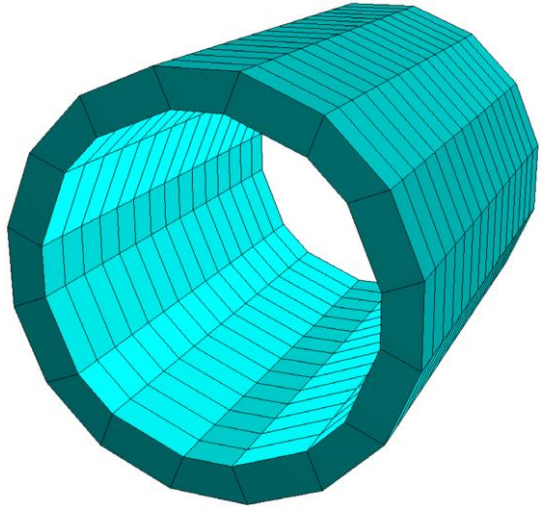
- Uncertainties and repeatability remain under study.

- **Preliminary data motivate an AL sensitivity scan beyond the TDR input (~6 cm).**

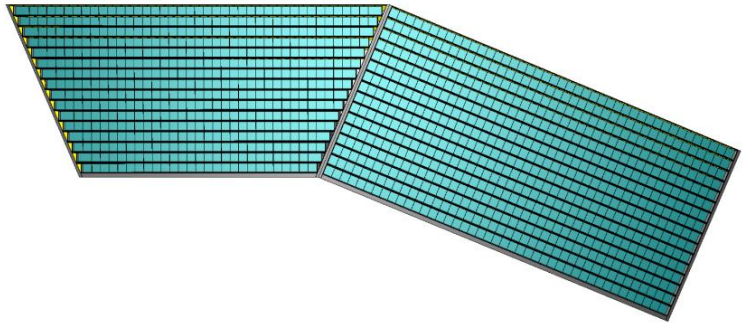
Detailed Parameters

	2025.09 (9th Meeting)	2026	
	Realization	Target (ECAL)	Target (HCAL)
Dimension (mm^3)	**40 × 40 × 10**	**20 × 20 × 20**	**40 × 40 × (30–40)**
Density (g/cm^3)	**>6.0**	**6.0**	
Transmittance (% @ 400 nm)	76	>80	
Emission peak (nm)	**390**	**~400**	
Light yield (ph/MeV)	**1408**	**~1500**	**1000**
Energy resolution (% @ 662 keV)	28.7	<25	
Decay time (ns)	72.4 (10.5%), 547.8	<500	
Attenuation length (cm @ 400 nm)	**6.05**	**10–110**	

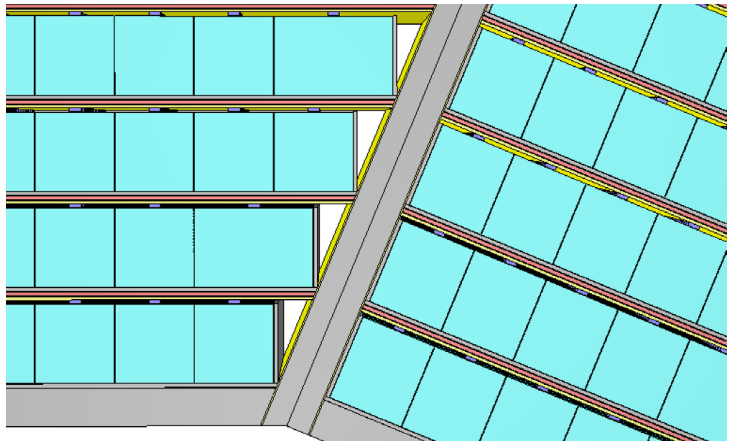
Glass ECAL Geometry and Cell Design



Barrel ECAL



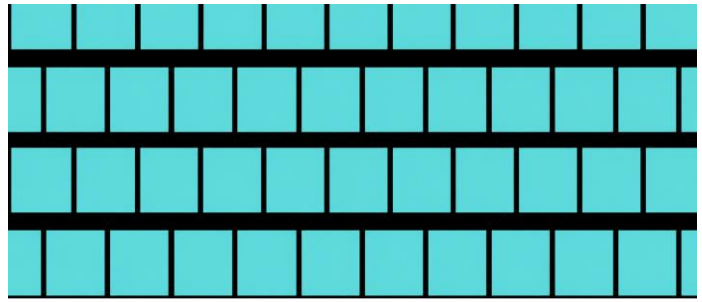
Layered module



Cells at module edges

- The barrel ECAL has 16 layers of approximately 2 × 2 × 2 cm^3 glass cells.
- Critical issue: intra-cell light collection non-uniformity due to finite attenuation length.
- Readout studies: one central 3 × 3 mm^2 SiPM, with or without a dome cavity.

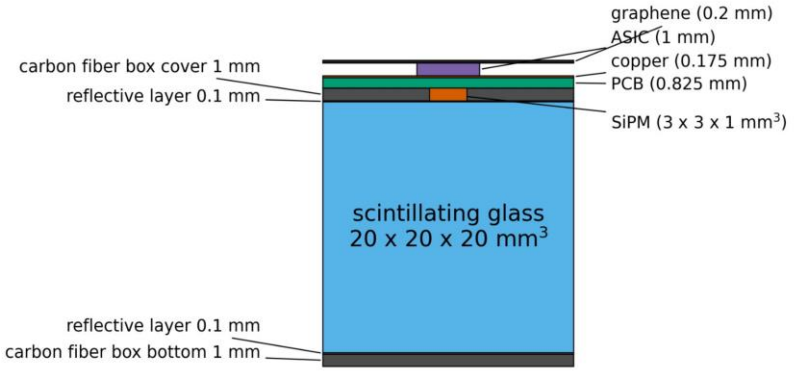
Staggered Cell Arrangement



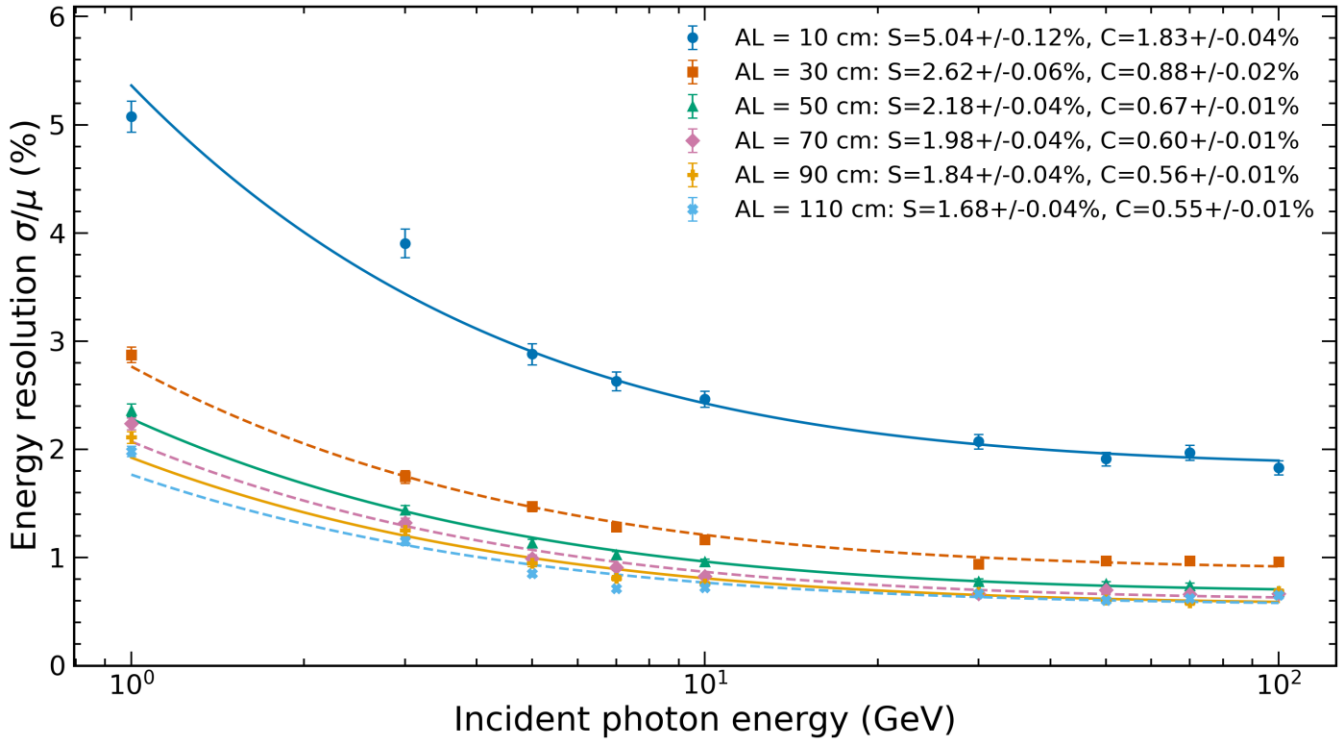
Cell Readout Option 1: External SiPM

One central external 3 × 3 mm² SiPM

External SiPM (no cavity)



Digitization includes light collection efficiency (**absorption length, scattering effect will be included in the near future**)



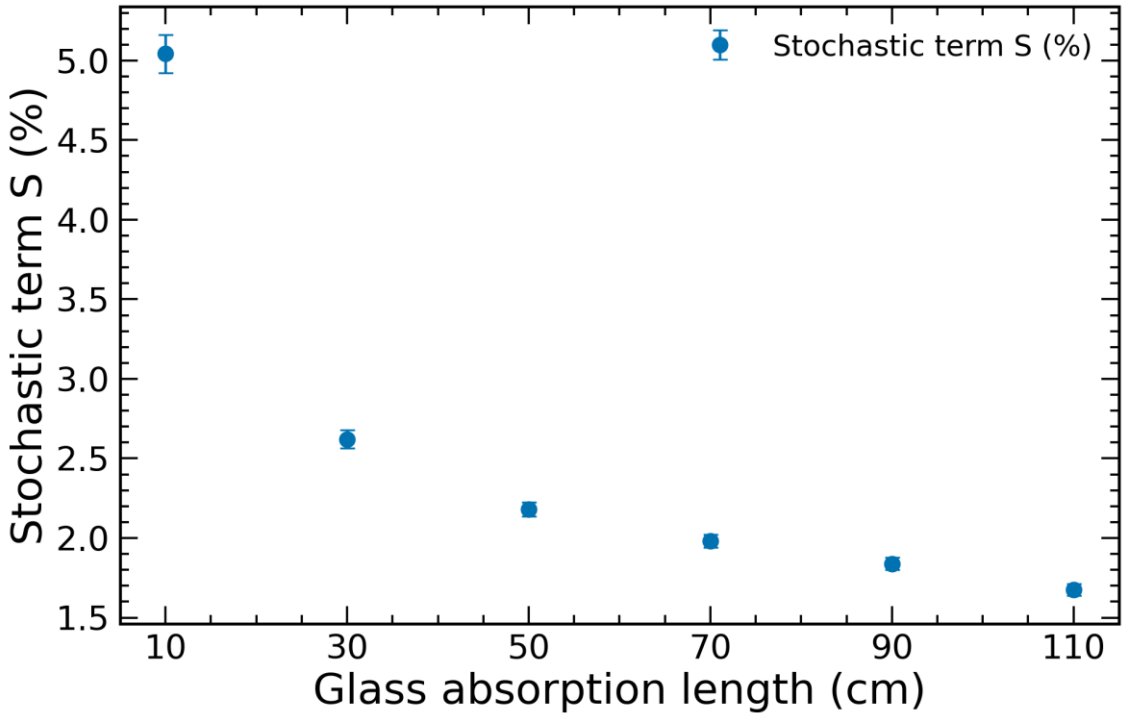
At AL = 30 cm:

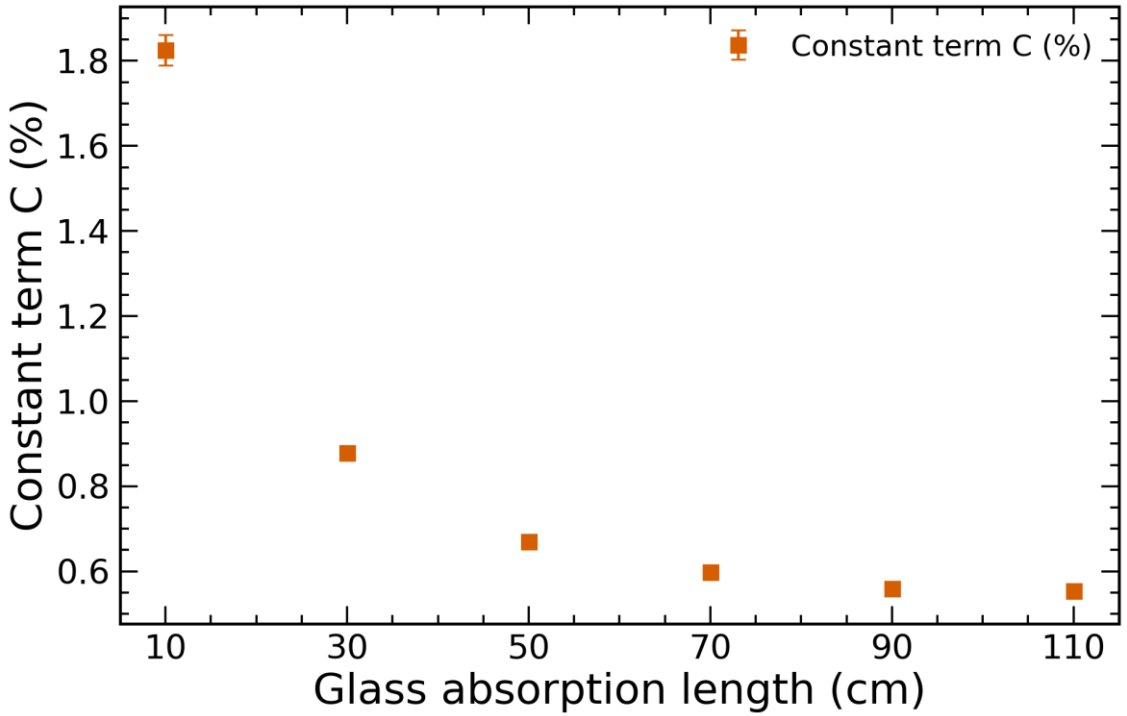
σ/μ = 2.62%/√E ⊕ 0.88%

Ref.: Yang Zhang et al. (oral): Simulation and Reconstruction for the Highly Granular Scintillating-Glass Calorimeter in the AGORA Detector

External SiPM: Absorption-Length Scan

At AL = 30 cm: σ/μ = 2.62%/√E ⊕ 0.88%

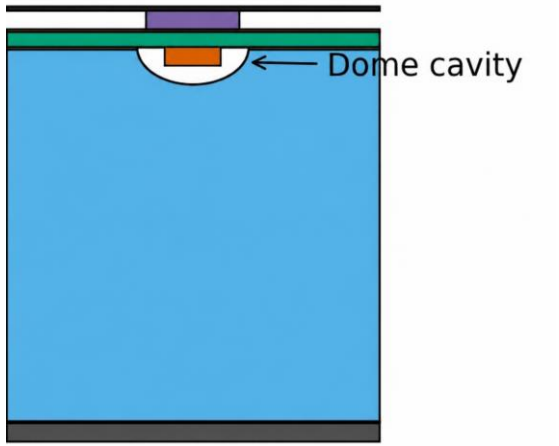


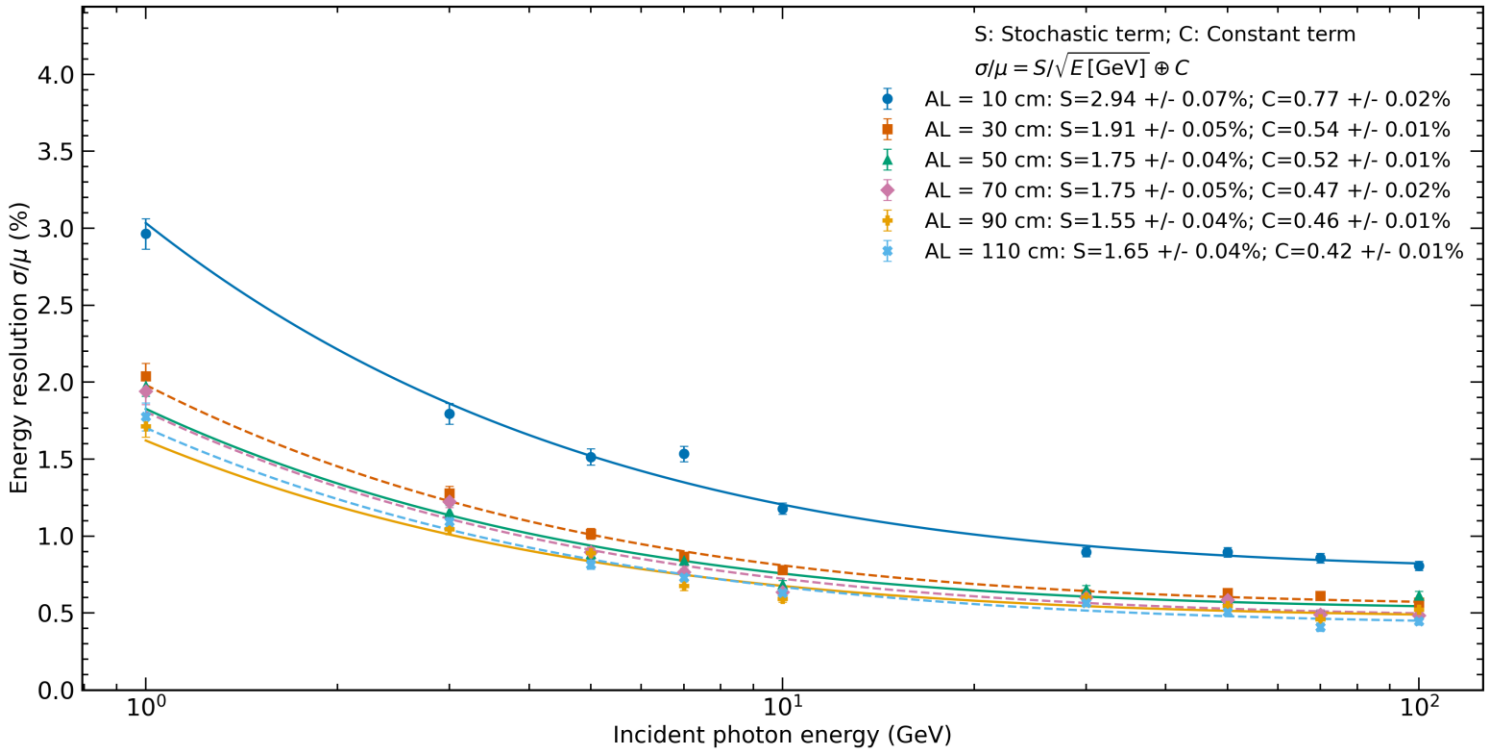


Cell Readout Option 2: Dome-Shaped Cavity

One central 3 × 3 mm² SiPM in a dome cavity (R = H = 3.6 mm)

SiPM inside a dome cavity



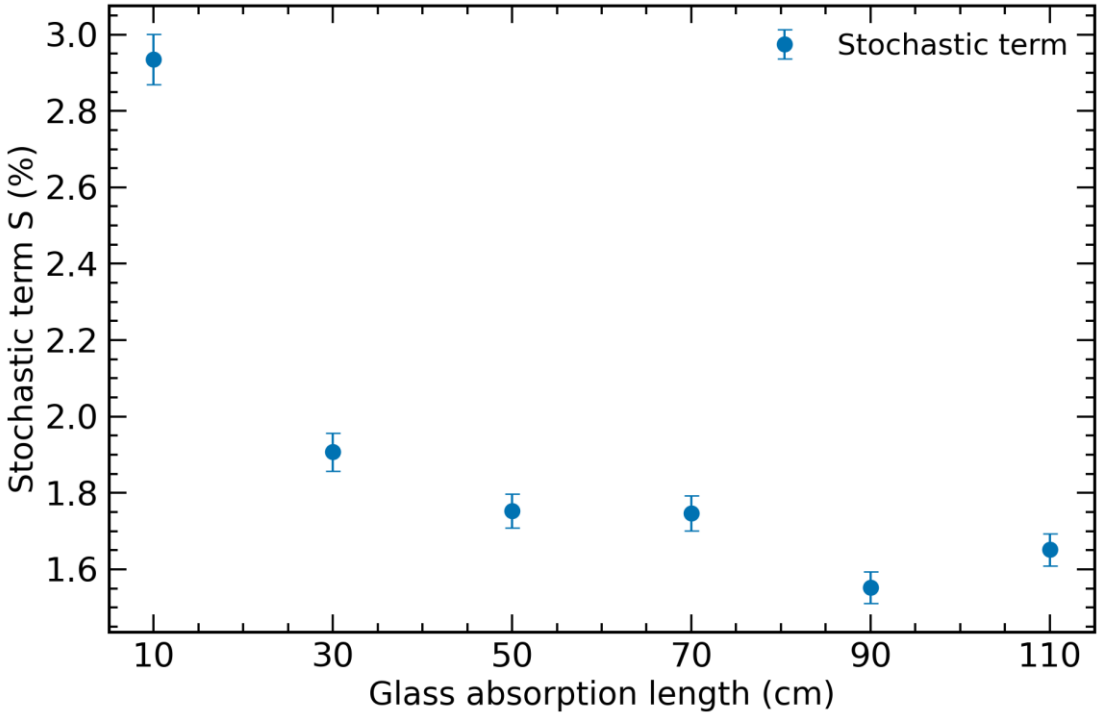


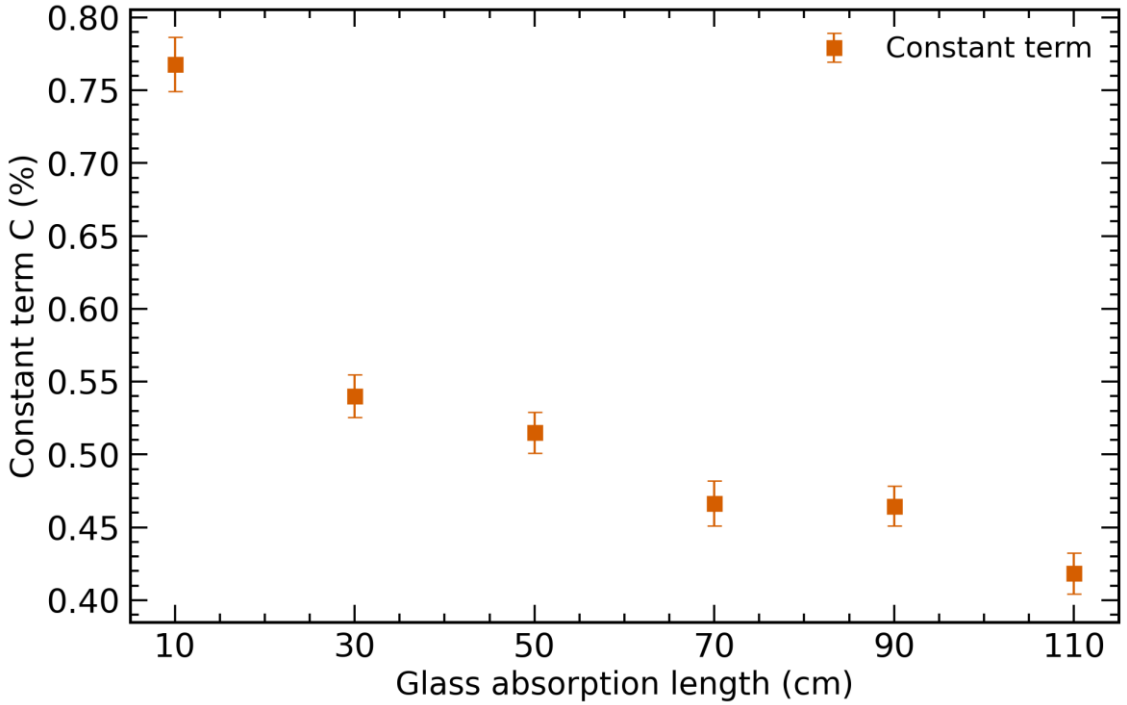
At AL = 30 cm:

σ/μ = 1.91%/√E ⊕ 0.54%

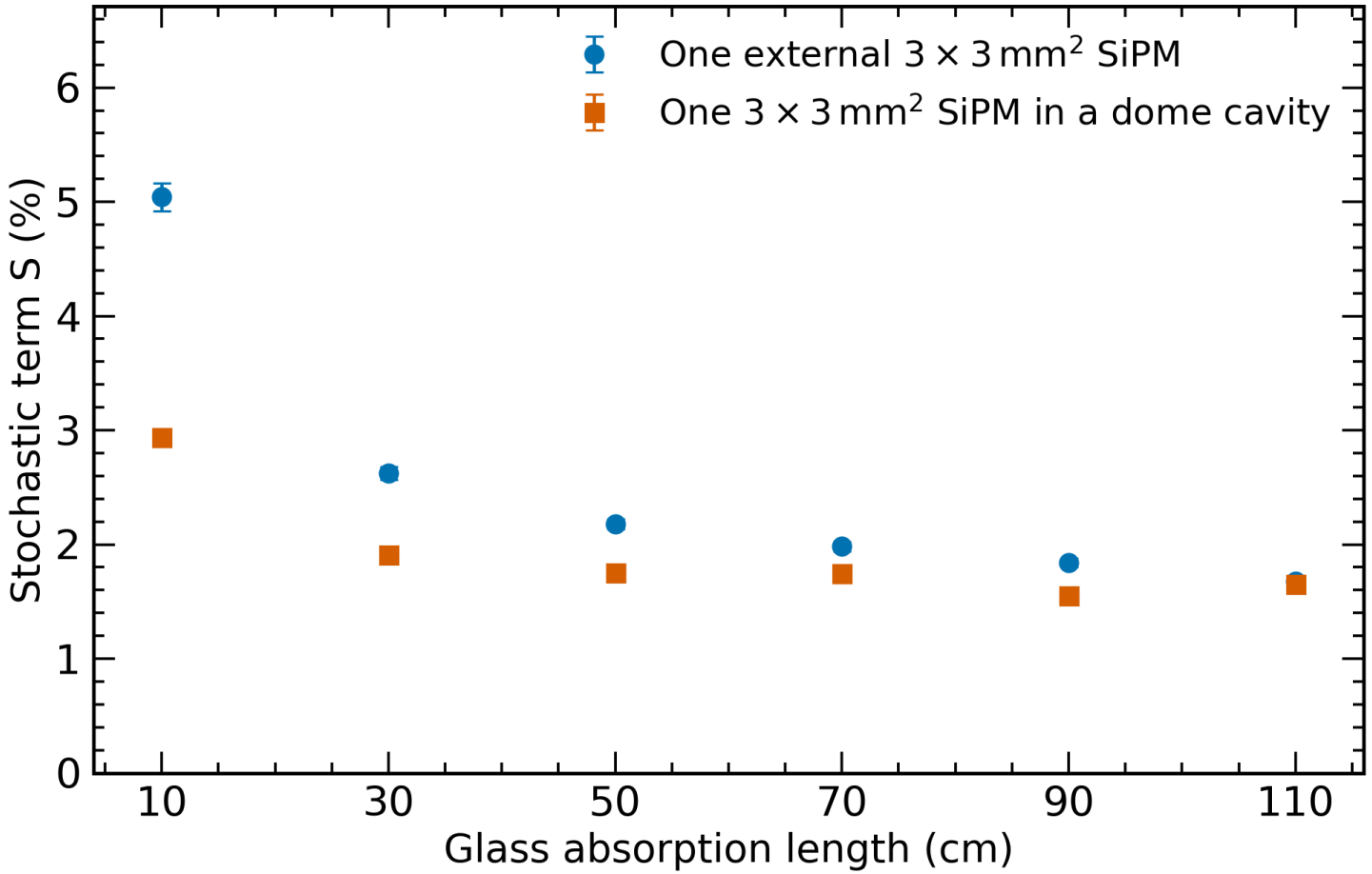
Dome Cavity: Absorption-Length Scan

At AL = 30 cm: σ/μ = 1.91%/√E ⊕ 0.54%





Cell Readout: Baseline Selection



At AL = 30 cm

External SiPM: S = 2.62%

Dome cavity: S = 1.91%

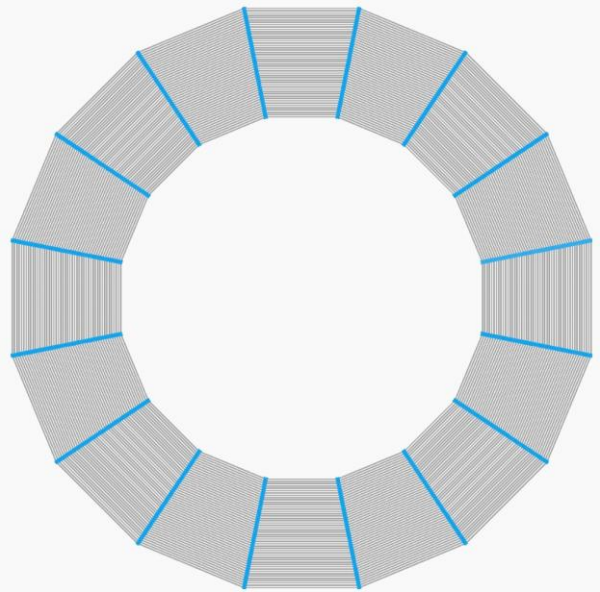
- **Lower stochastic term with the dome cavity.**
- To improve cell-response uniformity and enable SMD-SiPM coupling.

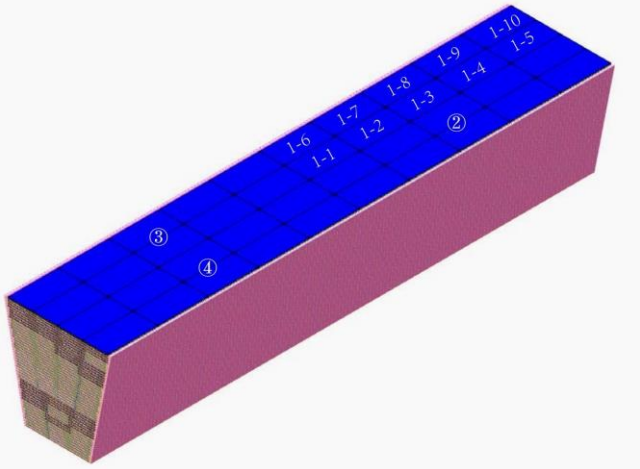
- **Baseline: one 3 × 3 mm² SiPM inside a dome-shaped cavity.**

Glass HCAL Structure

- Glass replaces the steel absorber, with steel retained for mechanical support.

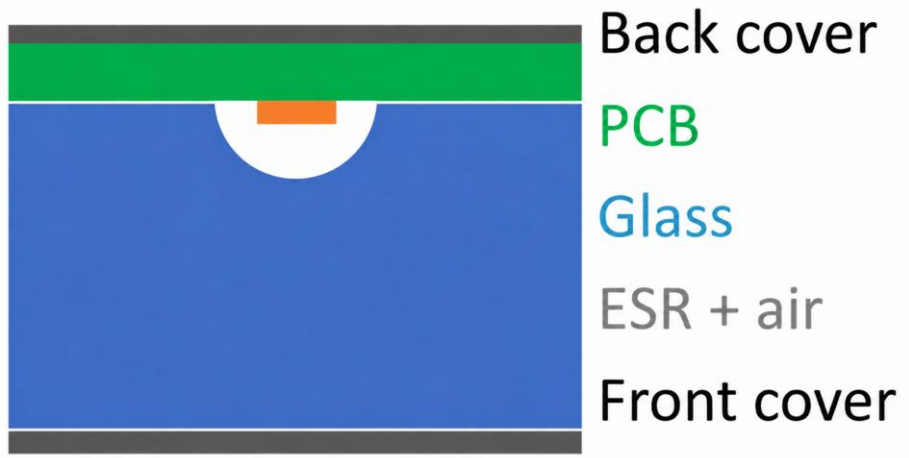
Barrel: 16 sectors





Barrel and longitudinal sector

Layer structure



Glass, reflector, PCB and steel covers

Hadronic Performance in Simulation

$4 \times 4 \times 3$ cm³ glass cells
with dome-shaped cavities

90% sampling ratio
33 layers (~4.6 λI)

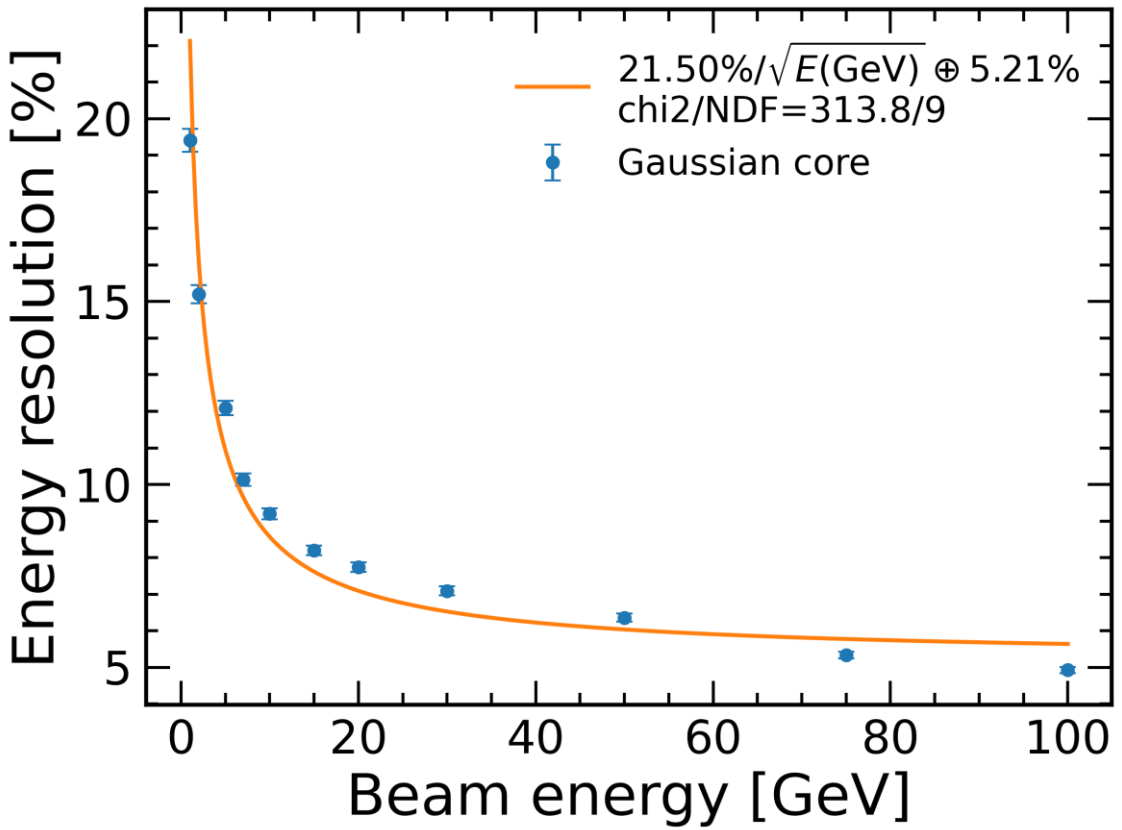
Digitization:
light-collection non-uniformity
and a 0.1 MIP threshold

Single charged pions (1–100 GeV)
in the full-absorption glass ECAL + HCAL

$21.50\%/\sqrt{E} \oplus 5.21\%$

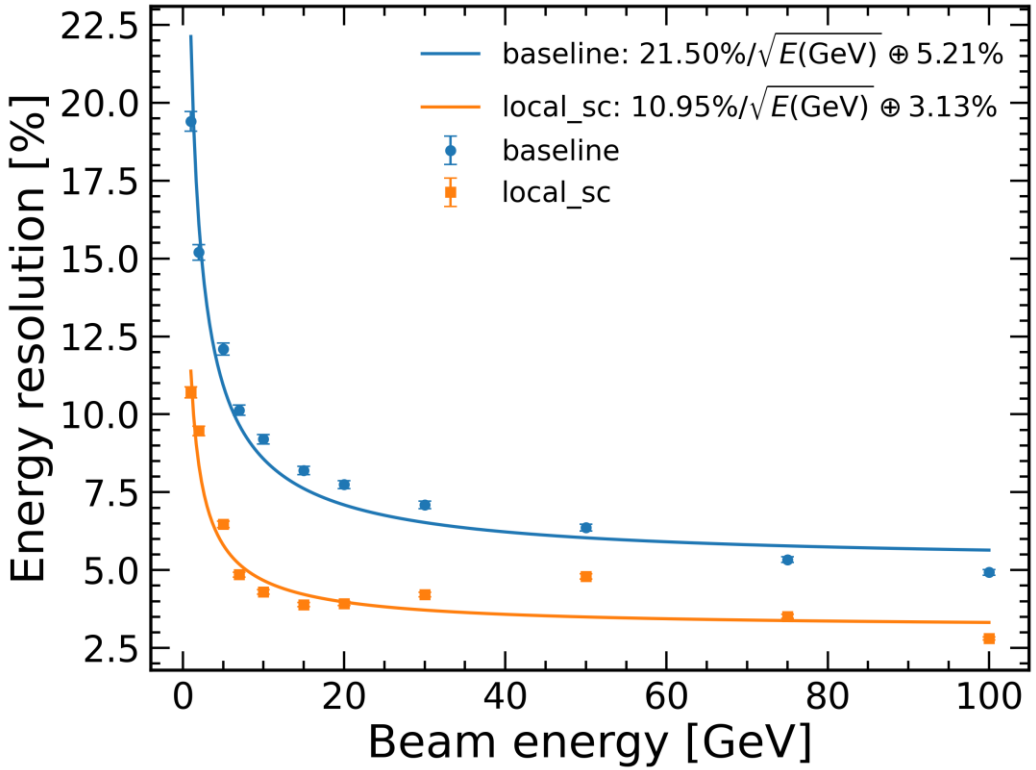
1. Hadronic shower fluctuations
2. Energy threshold
3. **$e/h \neq 1$ → software compensation**

Digitized response



HCAL: Software Compensation

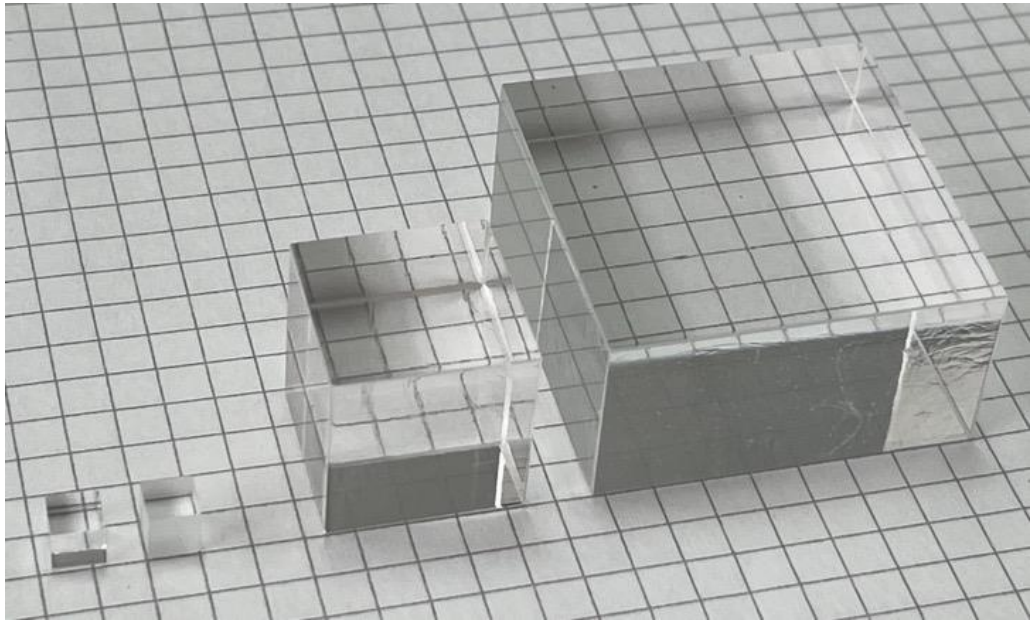
- SC technique applied in many detectors or experiments: WA1/CDHS, H1, ATLAS, CALICE, CMS-HGCAL, etc. (different naming in literature)
- Local SC: to assign weights based on measured energy density (enabled by high granularity) to hits corresponding to EM and purely hadronic components for e/h~1



10.95%/√E ⊕ 3.13%

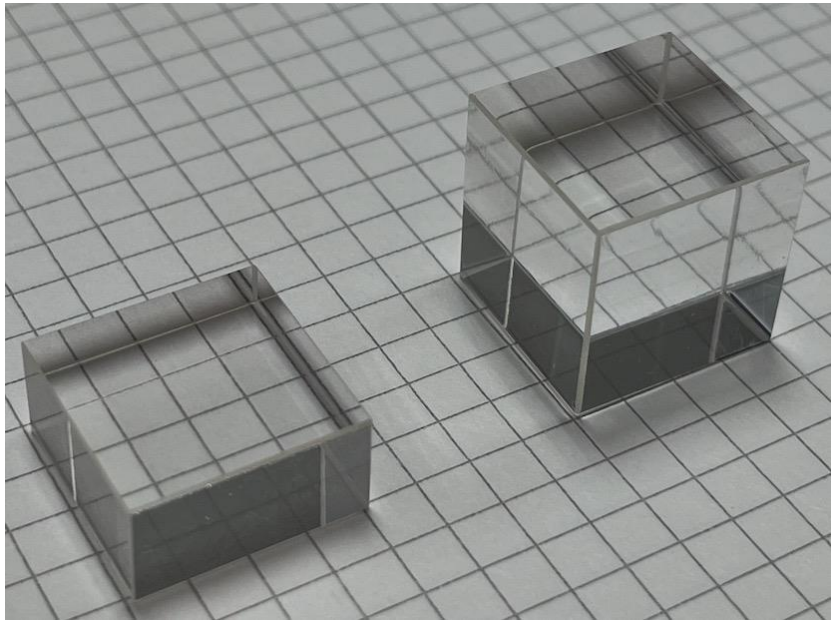
Glass Samples and Cosmic-Muon Tests

Batch 1



5 × 5 × 5 mm³ cubes (×2)
20 × 20 × 20 mm³ cube (×1)
40 × 40 × 20 mm³ tile (×1)

Batch 2



20 × 20 × 20 mm³ cube (×1)
20 × 20 × 10 mm³ tile (×1)

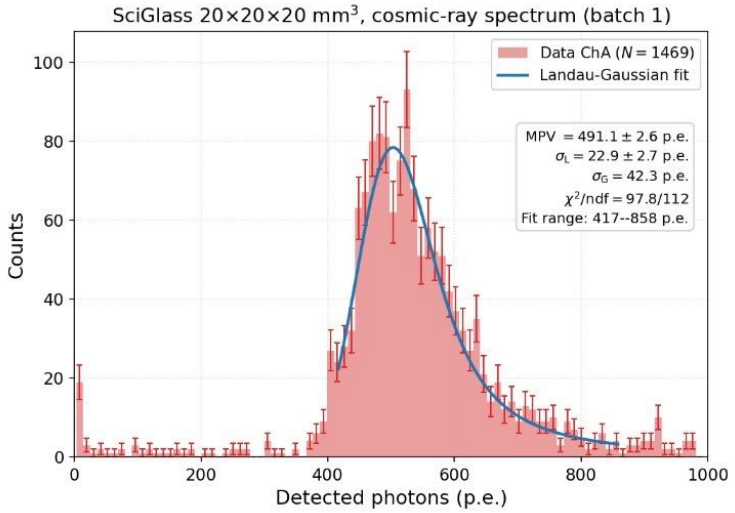
MIP Response of Different Glass Samples

- Cosmic-muon tests with one **6 × 6 mm²** SiPM per glass sample

Ref.: Yong Liu & Yushan Liu (poster C08)
Experimental Characterization and Optical Simulation of Scintillating Glass for the AGORA Calorimeter

20 × 20 × 20 mm³

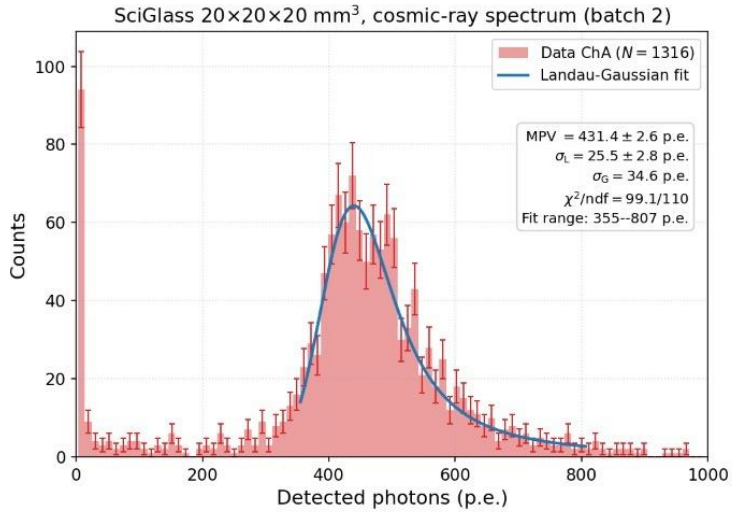
Batch 1



MPV: 491.1 ± 2.6 p.e.

20 × 20 × 20 mm³

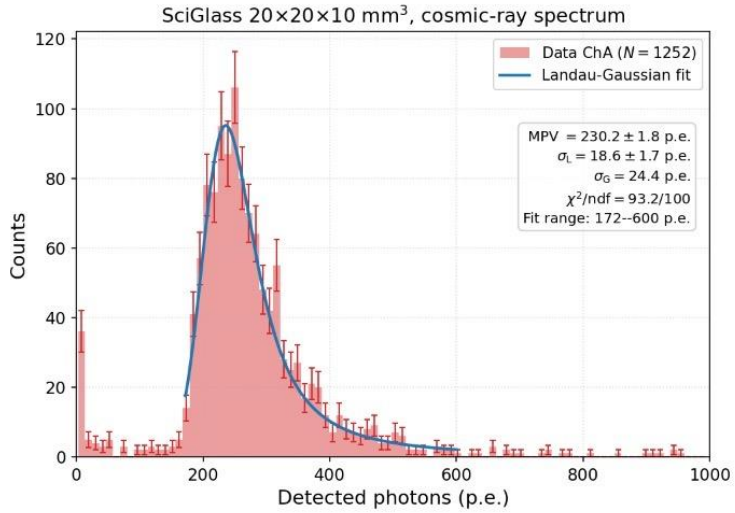
Batch 2



MPV: 431.4 ± 2.6 p.e.

20 × 20 × 10 mm³

Batch 2



MPV: 230.2 ± 1.8 p.e.

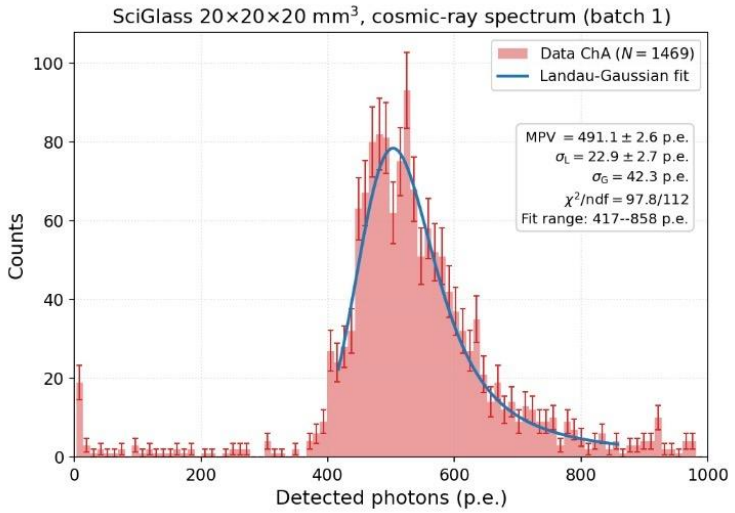
- **MIP tests suggest a bulk attenuation length significantly longer than 6 cm.**

MIP Response with Different SiPMs

Same 20 × 20 × 20 mm³ glass cube, Batch 1

6 × 6 mm² SiPM

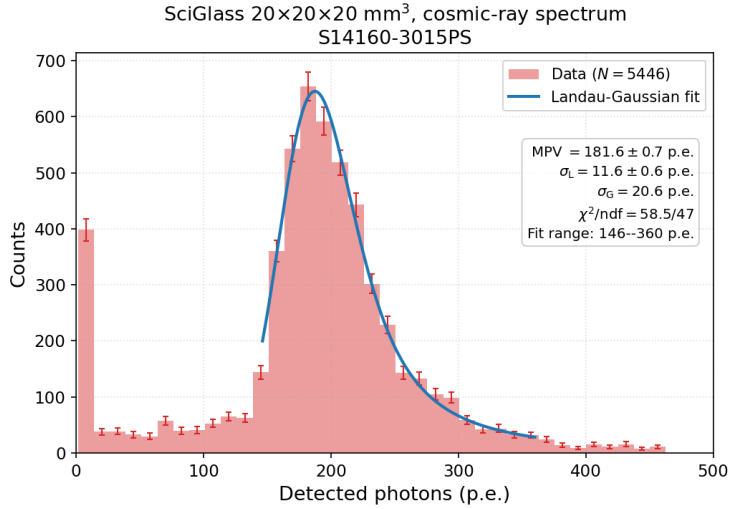
S13360-6025PE, PDE (400nm) ≈ 23%



MPV: 491.1 ± 2.6 p.e.

3 × 3 mm² SiPM

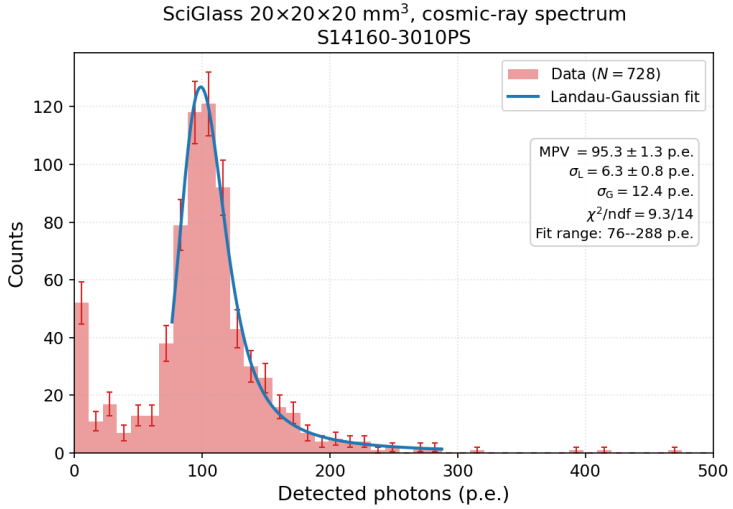
S14160-3015PS , **PDE (400nm) ≈ 27%**



MPV: 181.6 ± 0.7 p.e.

3 × 3 mm² SiPM

S14160-3010PS , **PDE (400nm) ≈ 15%**

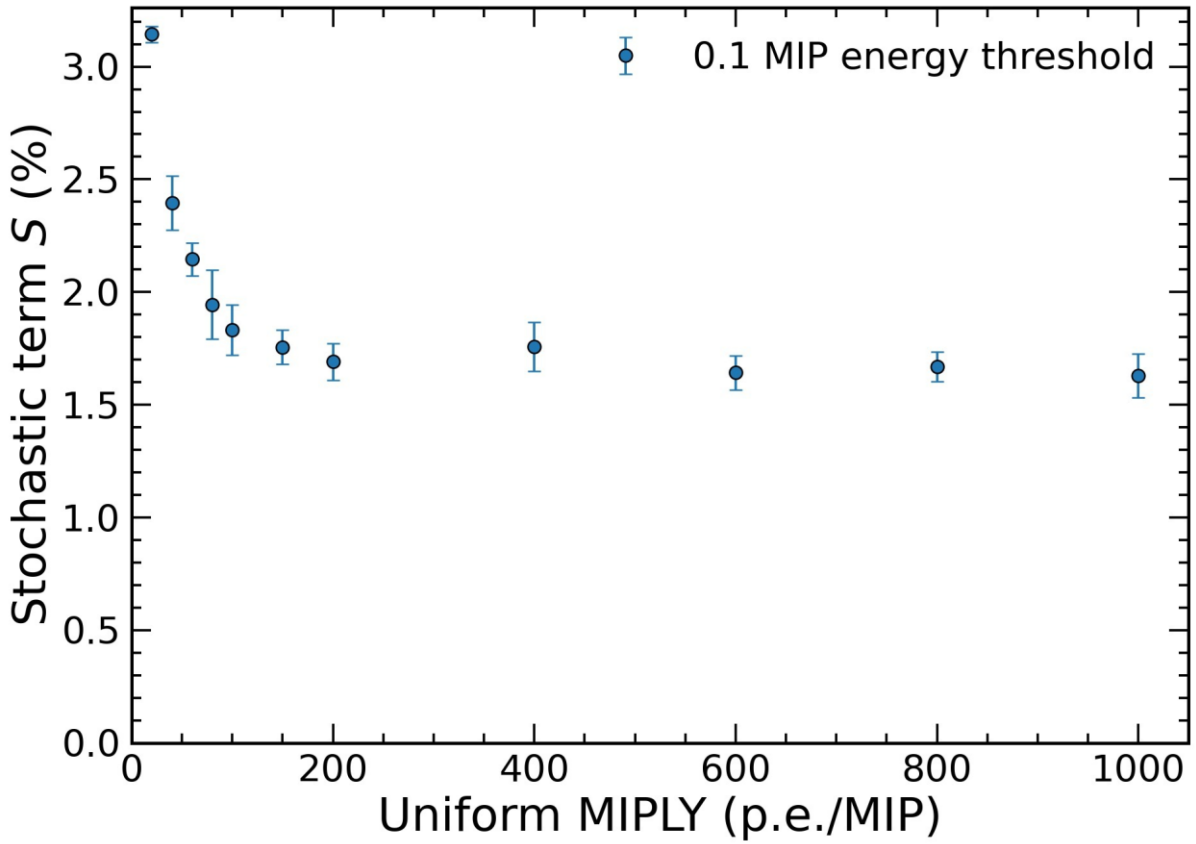


MPV: 95.3 ± 1.3 p.e.

- **promising to meet the glass requirement for photon statistics.**

MIP Response and ECAL Resolution

Effect of detected p.e./MIP on the ECAL stochastic term



Uniform-response simulation
0.1 MIP energy threshold

- Photon statistics limit resolution most strongly at low MIP response. Gains diminish at higher response.

Measured response:
3 × 3 mm² SiPM, 15 µm pitch
181.6 ± 0.7 p.e./MIP

- **Meets the ECAL stochastic-term requirement.**

Summary and Planning

New design: full-absorption glass ECAL and HCAL

- Builds on the scintillating-glass HCAL in the CEPC Ref-TDR.
- High sampling ratio and 3D high granularity.

Simulation studies and single-cell tests

- **one 3 × 3 mm² SiPM inside a dome-shaped cavity**
  - **ECAL (AL = 30 cm): 1.91%/√E ⊕ 0.54%**
  - **Hadronic energy resolution (with software compensation): 10.95%/√E ⊕ 3.13%**
- Tests with the latest glass samples.

Preliminary conclusions

- **one 3 × 3 mm² SiPM: 181.6 ± 0.7 p.e. with cosmic muons.**
- Tests indicate a bulk attenuation length significantly longer than 6 cm.
- Promising to meet the photon-statistics requirement.

Next steps

- Optimise cell uniformity and EM/hadronic performance.
- Continue cosmic-muon uniformity studies (limited by the low rate).
- Prototype design and integration: mechanics, cooling, FEA and cabling.

Prospects

2026: design optimisation and definition of specifications

- Full-absorption design of ECAL–HCAL based on ScintGlass.
  - SiPM candidates, readout electronics and system integration (mechanics and cooling).
- Longitudinal/transverse granularity: HCAL sampling ratio, separation power and cost estimates.
- **Critical issue: intra-cube/tile response uniformity.**
- Requirements for scintillating glass materials.

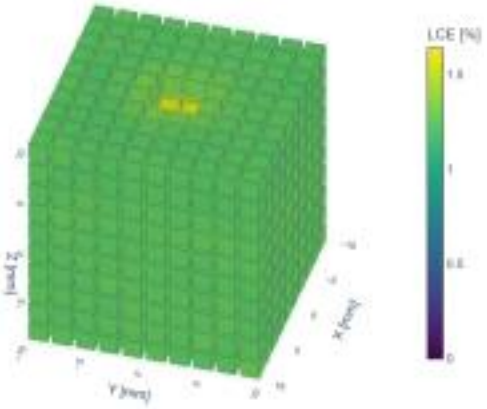
2026–2028: development from detector units to modules/prototypes

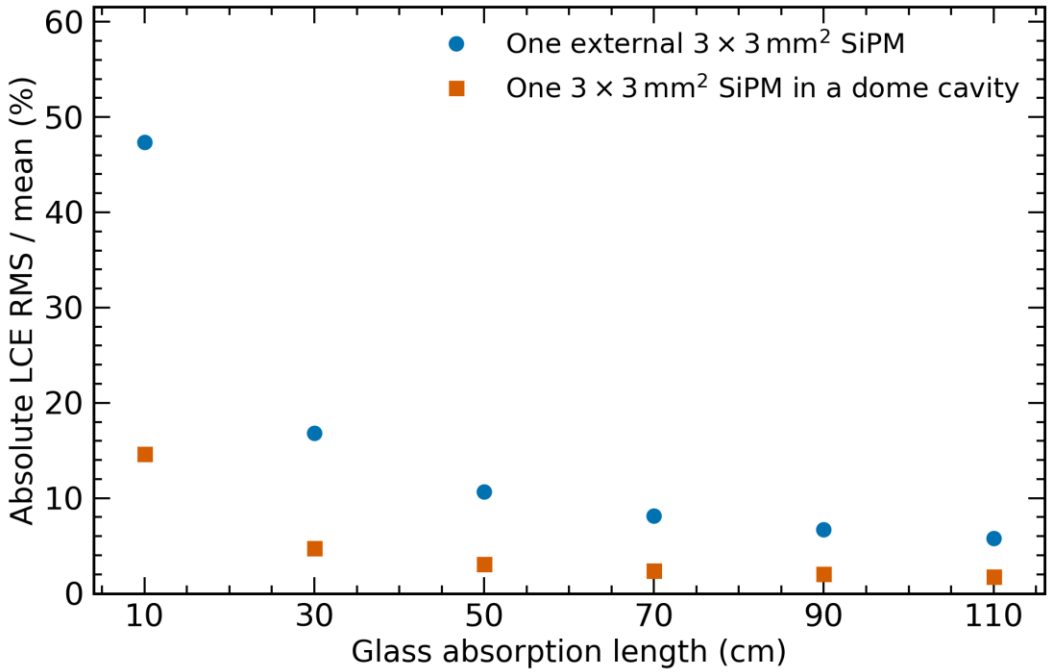
- 2026–2027: testing of glass samples, QA/QC protocols and specifications.
- 2027–2028: ECAL prototype.
- 2027–2029: HCAL prototype.

2028–2029: beam tests of ECAL and HCAL prototypes for performance evaluation

Thanks!

Backup: LCE Uniformity in Simulation





At AL = 30 cm

LCE RMS/mean

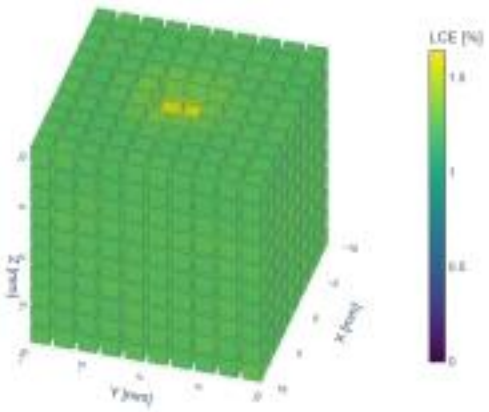
External SiPM: 16.81%

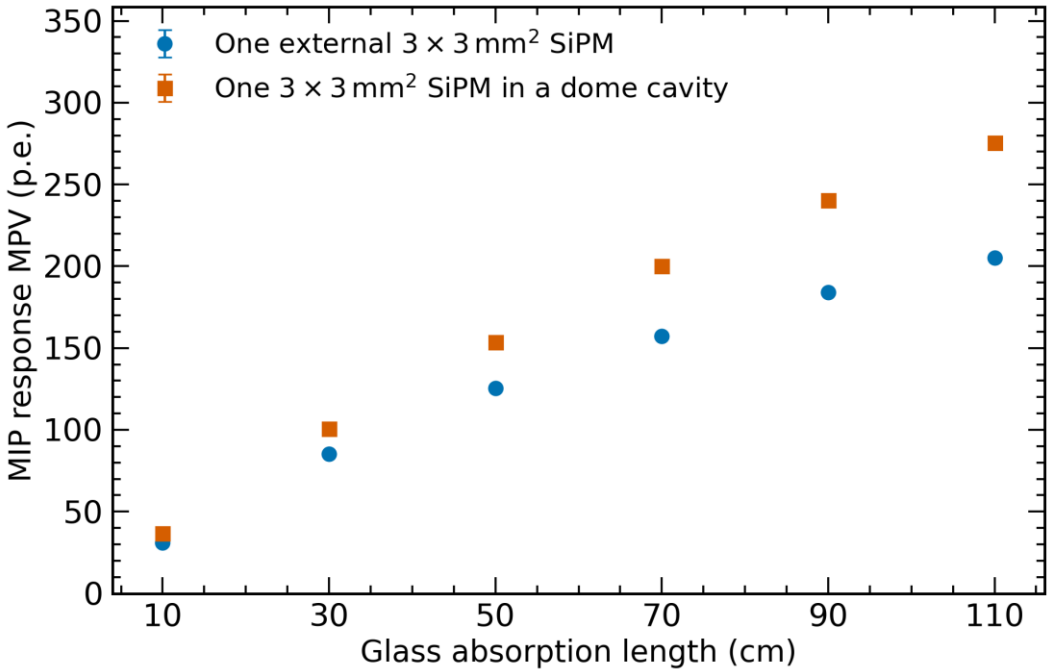
Dome cavity: 4.75%

- Lower RMS/mean indicates more uniform light collection.

- **The dome cavity improves light collection uniformity within the cell.**

Backup: MIP Response in Simulation





At AL = 30 cm

MIP response (MPV)

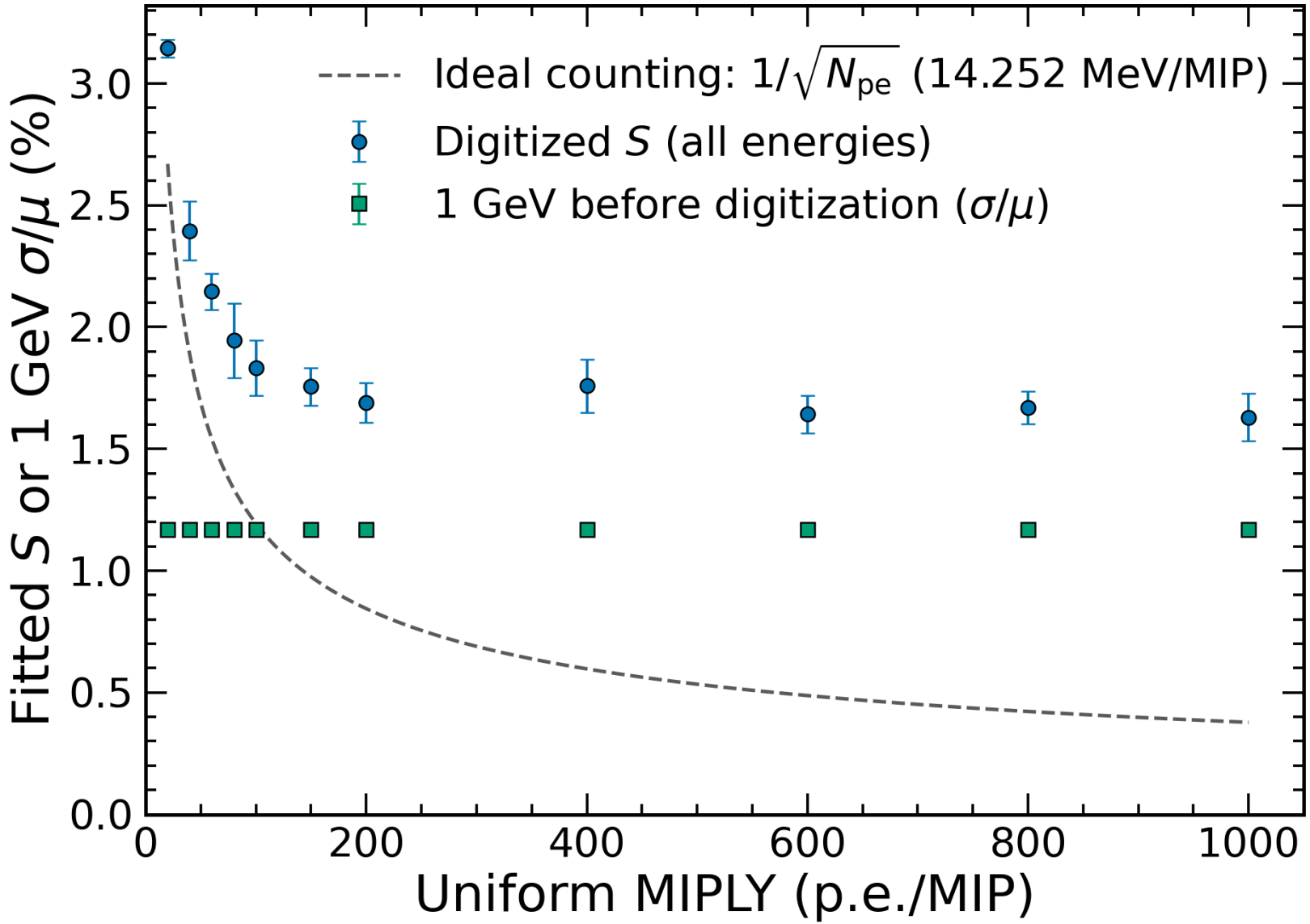
External SiPM

85.2 ± 0.2 p.e.

Dome cavity

100.5 ± 0.2 p.e.

- **The dome cavity gives ~18% higher MIP response.**


Ideal counting: $1/\sqrt{N_{pe}}$ (14.252 MeV/MIP)
Digitized S (all energies)
1 GeV before digitization (σ/μ)
Fitted S or 1 GeV σ/μ (%)
Uniform MIPLY (p.e./MIP)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
200
400
600
800
1000