# AGORA and its Calorimeter

Yifang Wang
IJCLab, Sep. 14, 2026

# From Ideas to Reference Detector TDR

2015

IHEP-CEPC-DR-2015-01
IHEP-EP-2015-01
IHEP-TH-2015-01

CEPC-SPPC

*Preliminary Conceptual Design Report*

Volume I - Physics & Detector

**Preliminary CDR**

The CEPC-SPPC Study Group

March 2015

2018

IHEP-CEPC-DR-2018-02
IHEP-EP-2018-01
IHEP-TH-2018-01

**CEPC**

***Conceptual Design Report***

Volume II - Physics & Detector

**CDR**

The CEPC Study Group

October 2018

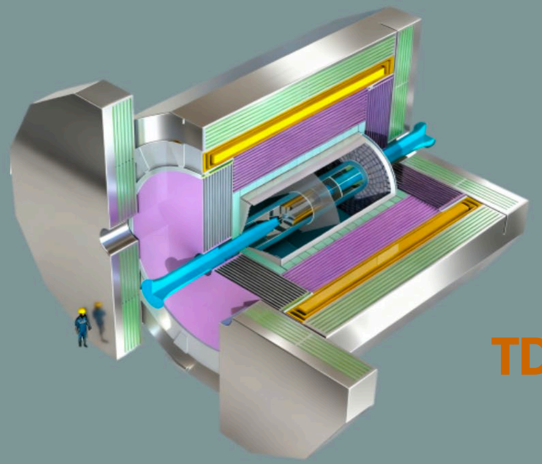
2025

IHEP-CEPC-DR-2025-01
IHEP-EP-2025-01

**CEPC Reference Detector**

**Technical Design Report**

**Version:** v1.0.1 build: 2025-11-02 11:13:11+08:00

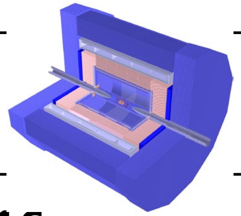
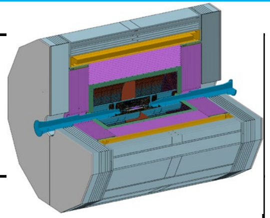


**TDR**

https://arxiv.org/abs/2510.05260

***The CEPC Study Group***
***October, 2025***

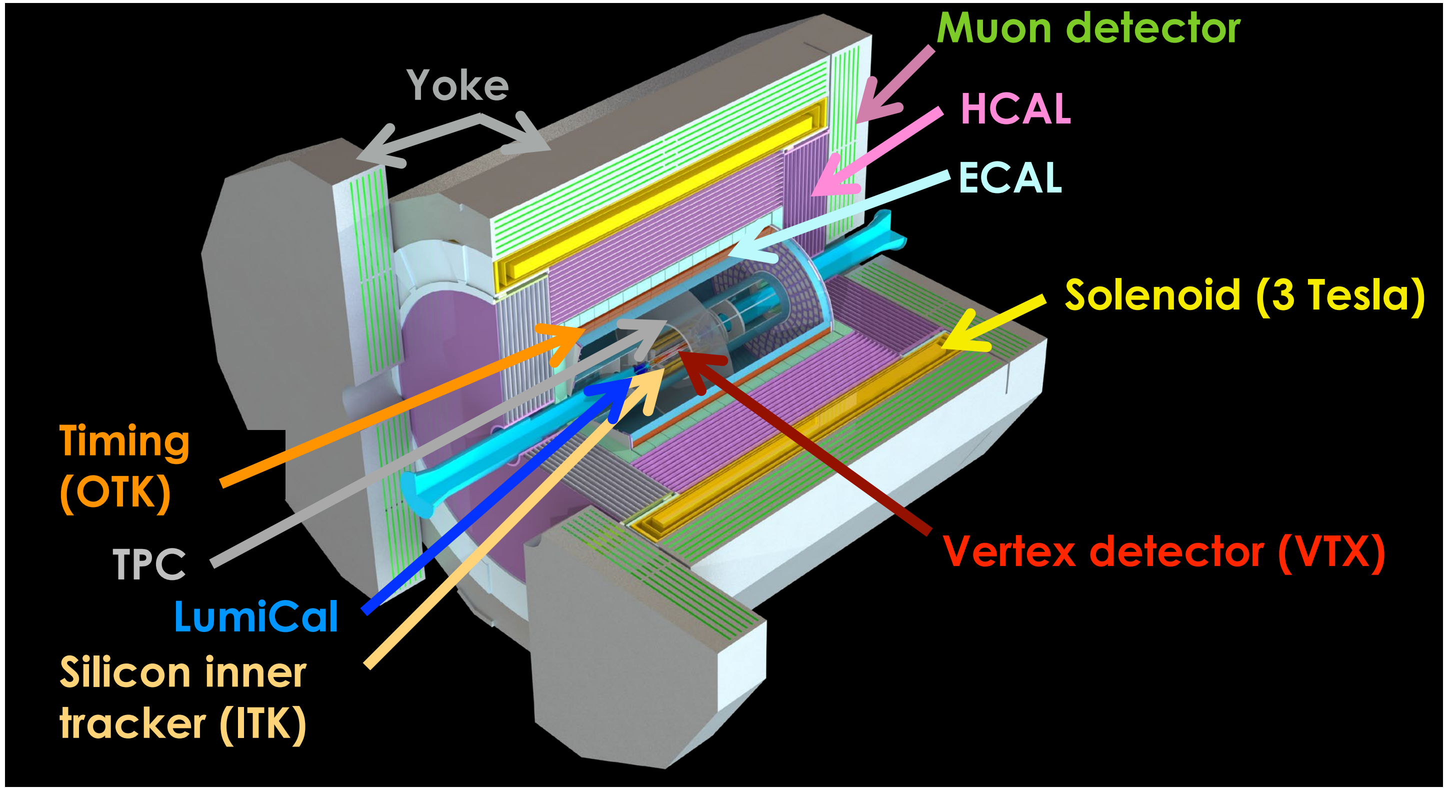
# from CDR to Ref-detector TDR

| | ILD-like CDR  | New concept RefDet-TDR  |
|---|---|---|
| VTX | Inner radius of **16 mm** | Inner radius of **11 mm** |
| | Material Budget: 0.15%*6+0.14%(beampipe)= **1.05% X0** | Material Budget: 0.06%*4(inner)+0.165%*2(outer)+0.2%(beampipe)= **0.77% X0** |
| Gaseous Tracker | TPC with **1 mm* 6 mm** readout, tracking 100 um, **dE/dx ~ 6%** | TPC with **0.5 mm* 0.5 mm** readout tracking 100 um, **dN/dx ~ 3%** |
| Inner tracker | Monolithic HV-CMOS pixel, 10 um | |
| ToF & Outer tracker | - | AC-LGAD, with **50 ps** per MIP, 10 um |
| ECAL | Si-W-ECAL: **17%**/√E ⊕ 1% | Crystal Bar-ECAL: **1.3%**/√E ⊕ 0.7% |
| HCAL | RPC-Iron: **60%**/√E ⊕ 2% | Glass-Steel: **30%**/√E ⊕ 6.5% |

# CEPC was not put into the $15^{th}$ 5-yrs（2026-2030） plan

- A sad news but we will not stop pursueing HEP
- An IB meeting at the last annual CEPC workshop held in Guangzhou concluded the following:
  - Continue CEPC while looking forward to be a major partner of FCC
    - Identify common interests and technologies, find a new way of collaboration
      - In contact with CERN/FCC
      - AGORA listed as one of the FCC detector concept
      - already in DRD
    - If FCC construction is not officially approved before 2030, we will propose again to the Chinese government
  - Continue to explore the pp collider (~100 TeV) by working on Iron-based HTC superconducting materials (IBS) and magnet
    - Only IBS has potential to contribute significantly to the society: new, metal, cheap
  - Working for the high energy linear e+e- collider (1-10 TeV) and applications
    - Established a PWFA test facility based on BEPCII
    - Start to work on technologies, and applications for table-top light sources, injectors, FEL, etc.

# AGORA: Advanced Glass Optimized Research Apparatus




AGORA
ADVANCED GLASS OPTIMIZED RESEARCH APPARATUS

- The name AGORA emphasizes the glass calorimeter at the heart of the detector.
- The acronym AGORA derives from ancient Greek, referring to a central public square in city-states as the heart of the city's political, commercial, and social life.
- It now means "gathering place" or "assembly", symbolize here the international collaboration that we expect to flourish.

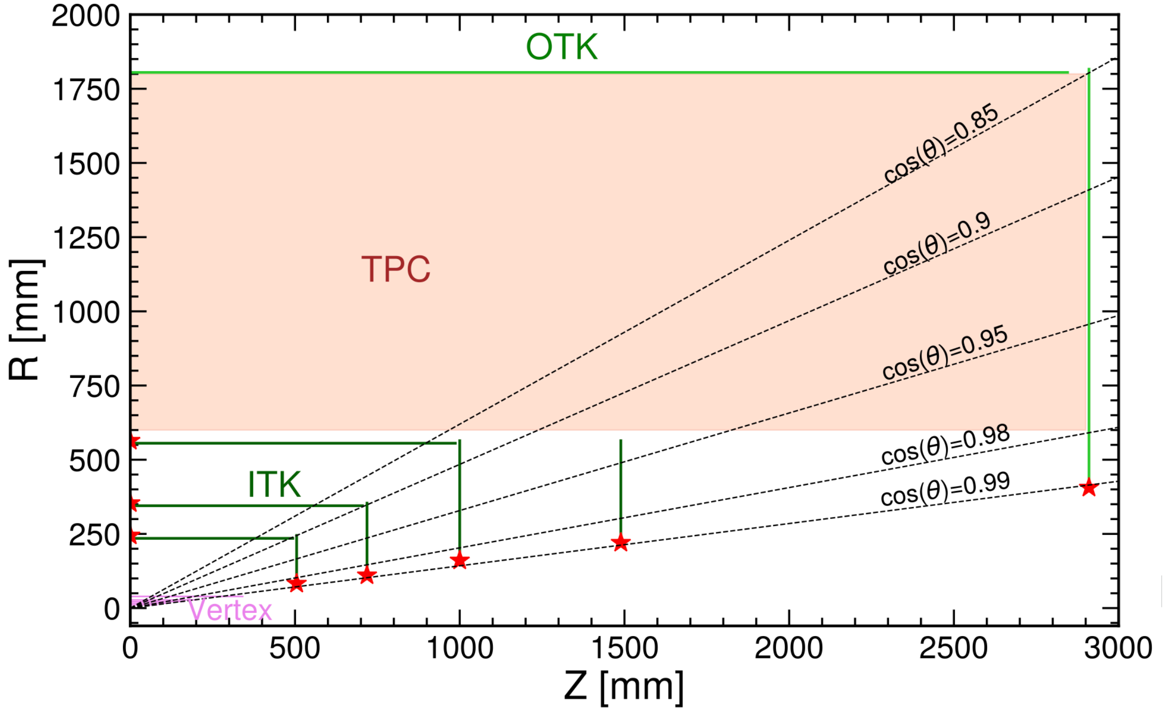

5

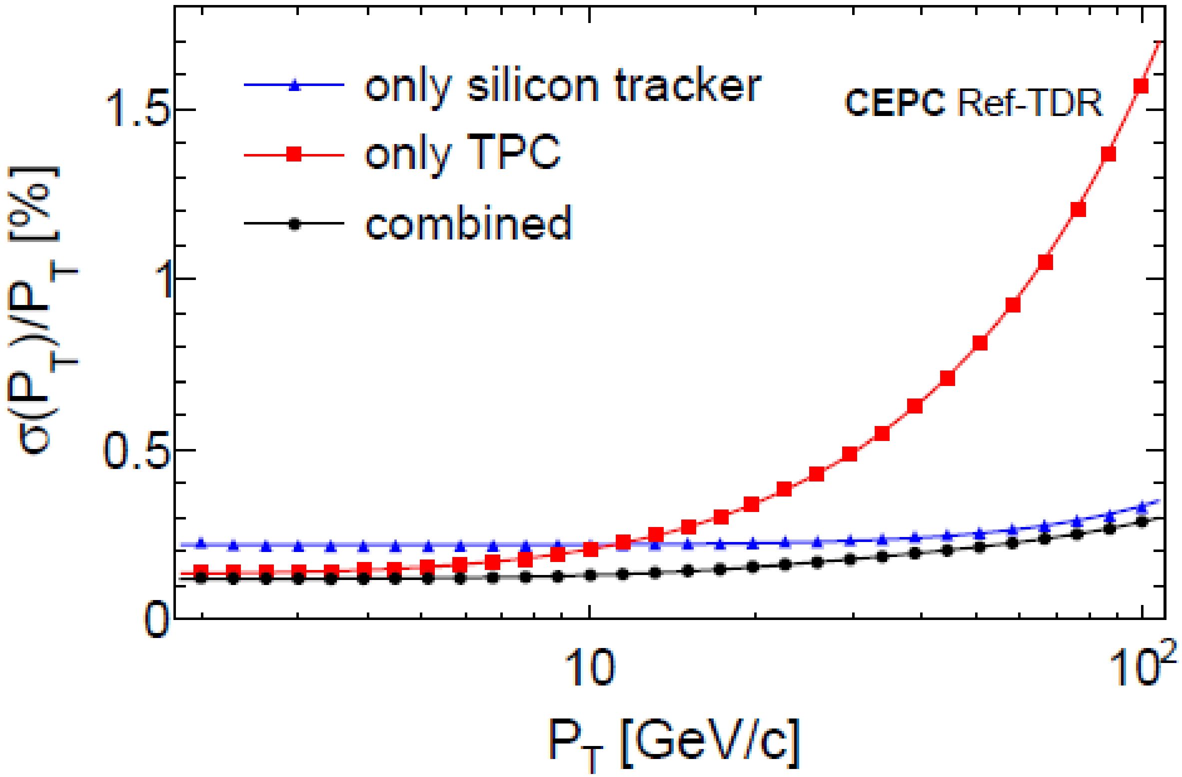
# CDR → Ref-detector TDR → AGORA

| | ILD-like **CDR** | New concept **RefDet-TDR** | Newer concept **AGORA** |
|---|---|---|---|
| VTX | Inner radius of **16 mm** | Inner radius of **11 mm** | |
| | Material: 0.15%*6+ 0.14%(beampipe)=**1.05% X0** | Material: 0.06%*4(inner)+ 0.165%*2(outer)+0.2%(beampipe)=**0.77% X0** | |
| ITK | Monolithic HV-CMOS pixel, 10 um | | |
| Gaseous Tracker | TPC with **1 mm* 6 mm** readout, tracking 100 um, **dE/dx ~ 6%** | TPC with **0.5 mm* 0.5 mm** readout, tracking 100 um, **dN/dx ~ 3%** | |
| ToF & OTK | - | AC-LGAD, **50 ps** per MIP, 10 um | |
| Cerenkov | - | - | Aerogel + SiPM |
| ECAL | Si-W-ECAL: $\mathbf{17\%}/\sqrt{E} \oplus 1\%$ | BGO Crystal: $\mathbf{1.3\%/\sqrt{E} \oplus 0.7\%}$ | Glass cubic: $\mathbf{3\%/\sqrt{E} \oplus 1\%}$ |
| HCAL | RPC-Iron: $\mathbf{60\%}/\sqrt{E} \oplus 2\%$ | Glass-Steel: $\mathbf{30\%/\sqrt{E} \oplus 6.5\%}$ | Glass cubic: $\mathbf{<15\%/\sqrt{E} \oplus 4\%}$ |

# The Vertex and Tracking System

## Silicon tracker inside a Time Projection Chamber (TPC) with a timing layer outside



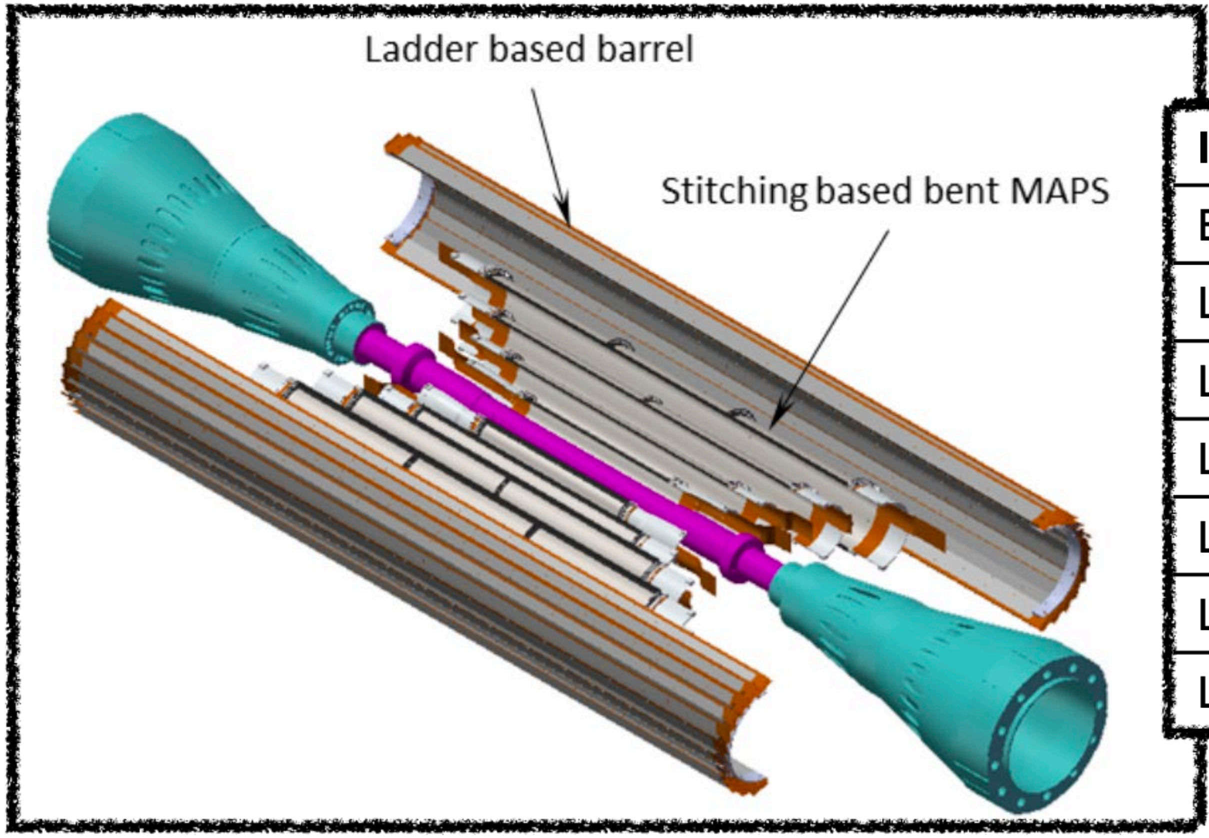

| Measurands | Performance requirement |
|---|---|
| Coverage | $\lvert\cos\theta\rvert \leq 0.99$ |
| Recon. efficiency | $\geq 99\%$ ($p_T > 1$ GeV/$c$) |
| Resolution in barrel | $\sigma_{p_T}/p_T < 0.3\%$ ($\lvert\cos\theta\rvert \leq 0.85$ ) |
| Resolution in endcap | $\sigma_{p_T}/p_T < 3\%$ ($\lvert\cos\theta\rvert > 0.85$ ) |

# The Vertex Detector

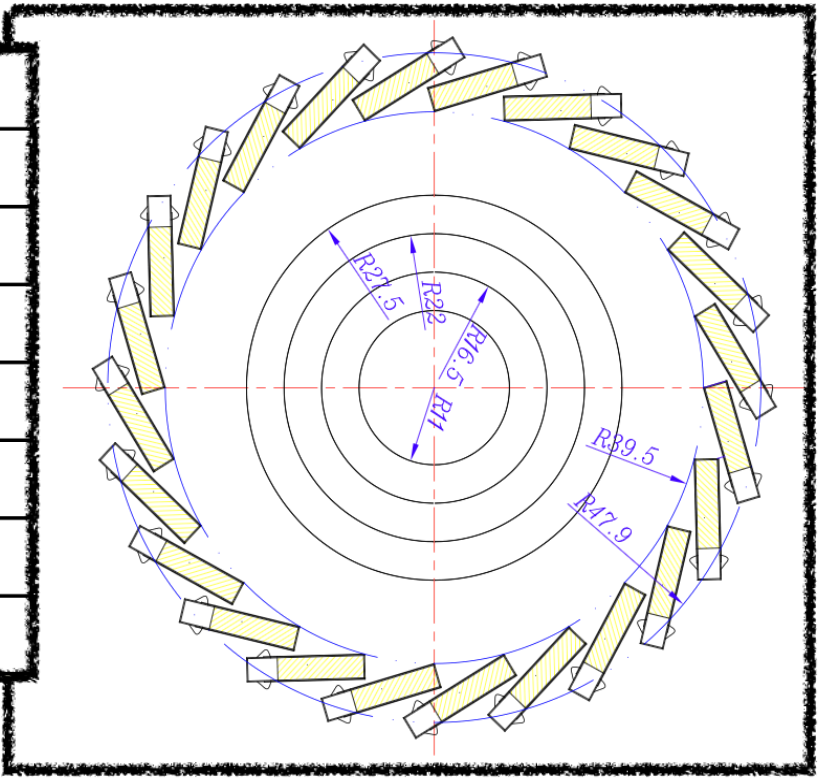
Four single layers of bent MAPS stitched sensors
+
Two double-sided conventional ladders

Sitting on top of beam pipe: inner layer radius 11.1 mm

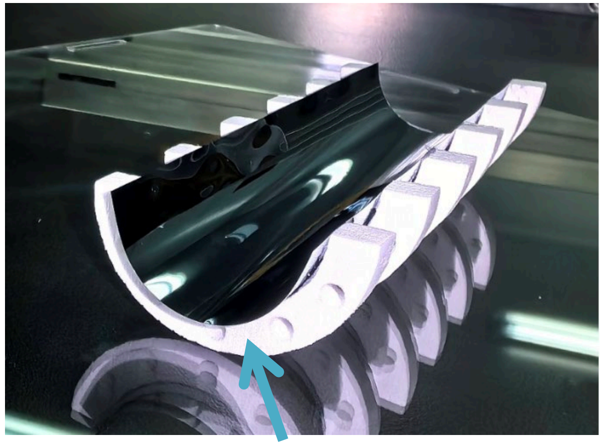
| | |
|---|---|
| Spatial resolution | ~5 µm / layer |
| Material budget | ~0.8% $X_0$ / layer |
| Power consumption | < 40 mW/cm² (air cooled) |
| Angular coverage | $\|\cos\theta\| < 0.99$ |



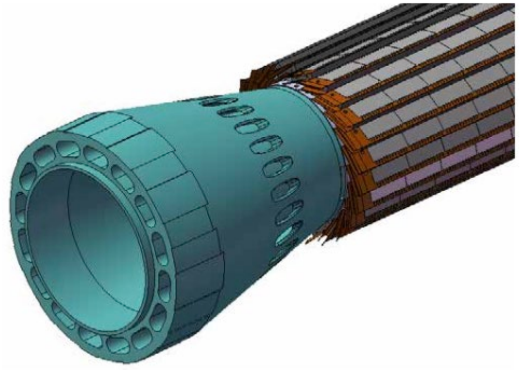

| Items | R.L. (X0) |
|---|---|
| Beam pipe | 0.454 % |
| Layer 1 | 0.067 % |
| Layer 2 | 0.059 % |
| Layer 3 | 0.058 % |
| Layer 4 | 0.061 % |
| Layer 5 | 0.280 % |
| Layer 6 | 0.280 % |



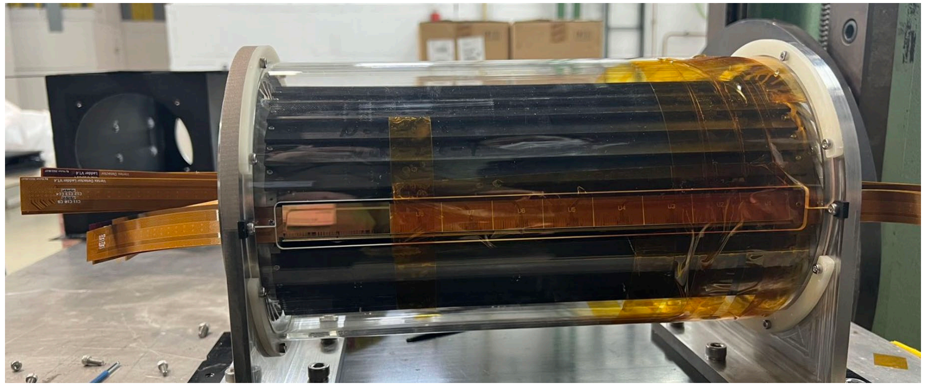
# Vertex Detector R&D

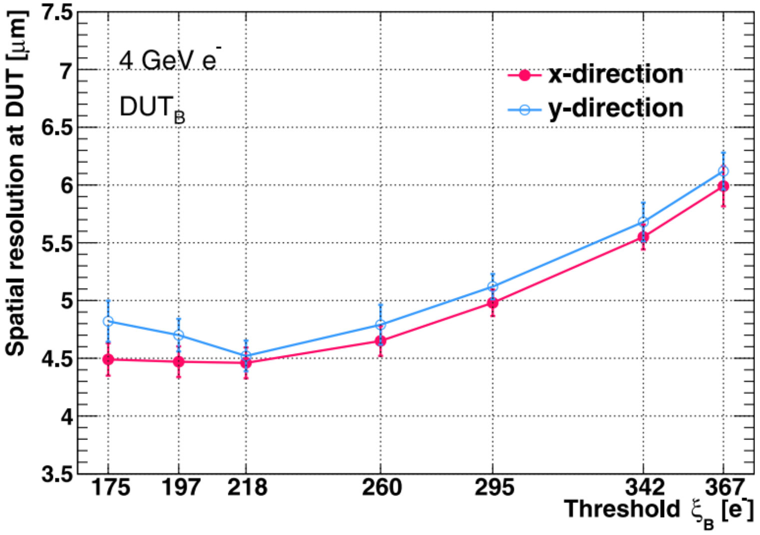


12-mm curvature reached



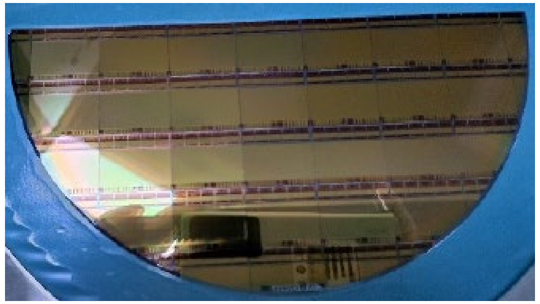
6 double-layer Prototype (no bent layers yet)





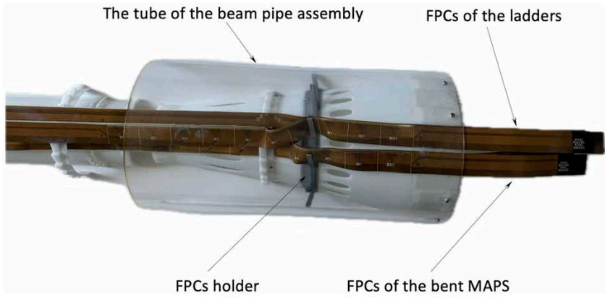

TaichuPix-3 test beam results

| | Status | CEPC final goal |
|---|---|---|
| CMOS chip technology | Full-size chip with TJ 180 nm CIS | Baseline: TPSCo 65 nm MAPS<br>Exploring: HC90L 90/55 nm MAPS |



TaichuPix-3 ASIC on wafer (15.9 × 25.7 mm)

**Thermal mockup**: air cooling & vibration studies underway

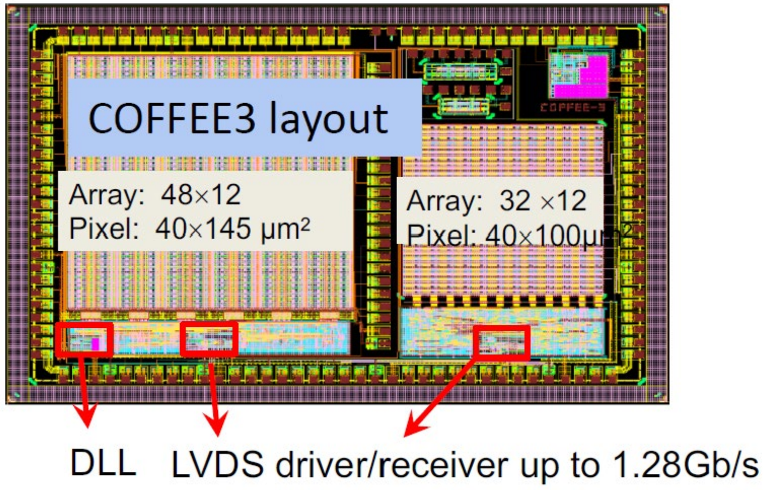


# The Inner Silicon Tracker (ITK)

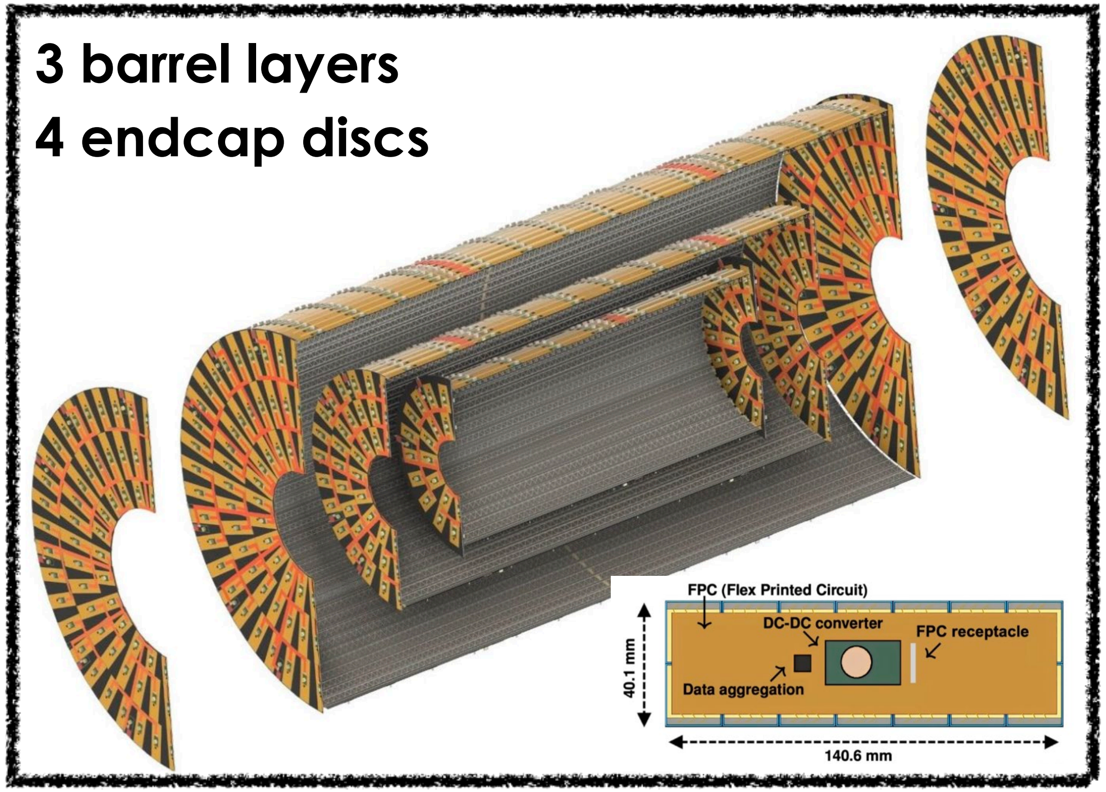
## Monolithic HV-CMOS pixel sensors fabricated using a 55 nm CMOS process

### Sensor R&D

- COFFEE: SMIC 55-nm
  - Low-resistivity wafer
  - Within DRD3: irradiation at FNAL, test beam at CERN




- CHiR:
  - New foundry
  - High-resistivity wafer
  - First MPW available this month
  - Full size sensor around 2027



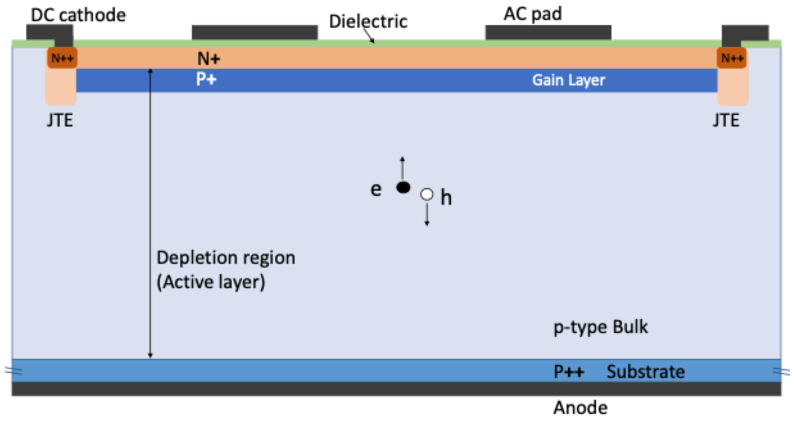

### Lightweight design R&D

- Serial powering
- Module demonstrator being built with DRD3
- Wireless transmission

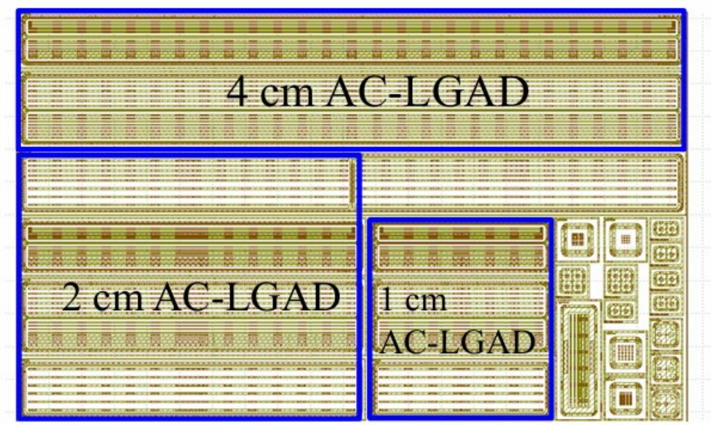
# The Outer Tracker (OTK) - Timing Layer

## Building on top of R&D for HGTD -- the ATLAS Timing Detector

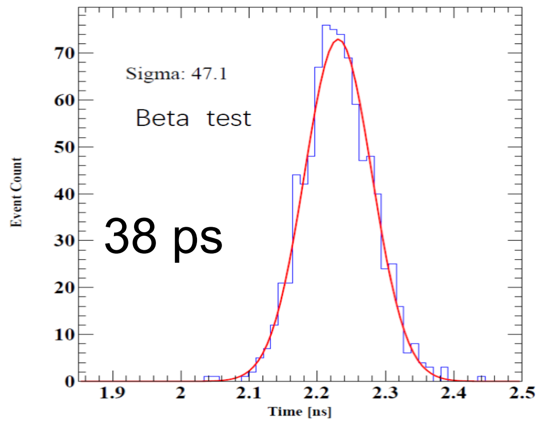
### AC-LGAD sensor development:



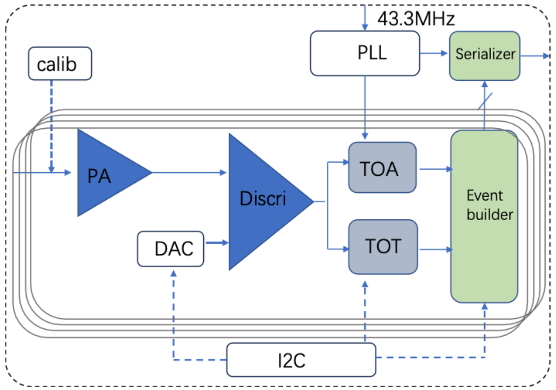

### LGAD v1 tape-out available

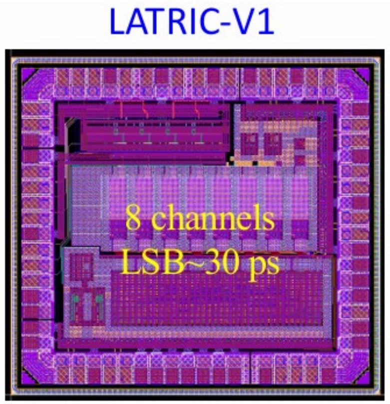



### AC-LGAD test results

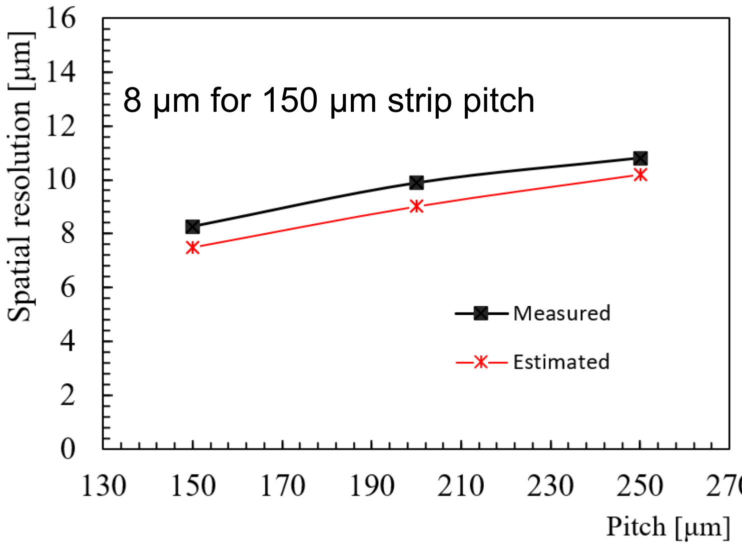



### LATRIC: LGAD Readout Chip



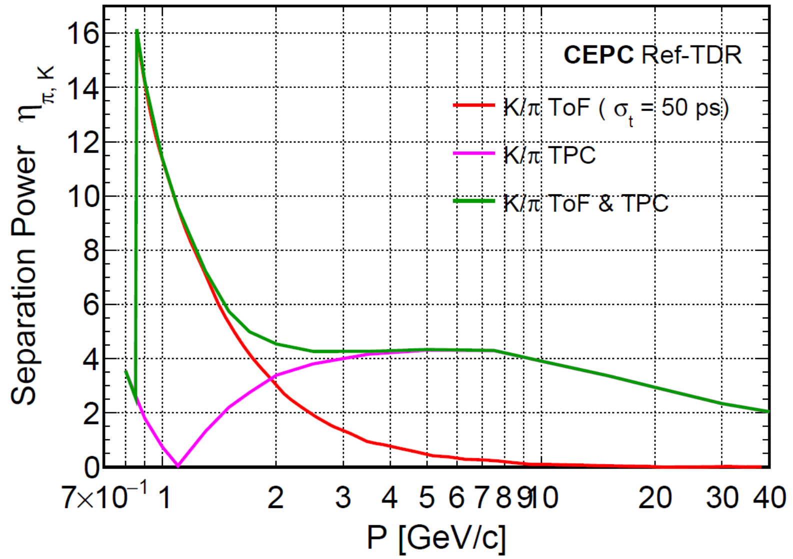




New 8-channel LATRIC-V1 submitted for tape-out



# The Time Projection Chamber (TPC)

## For Particle Identification and improvement of tracking




**Detailed design:**

**Length: 5.8 meter**

**Inner radius: 600 mm**

**Cathode potential: 63 kV**

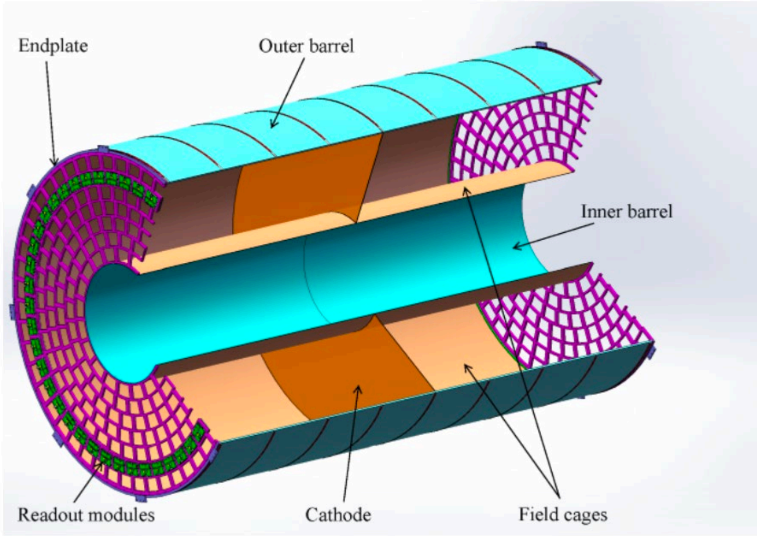
Material budget of the barrel

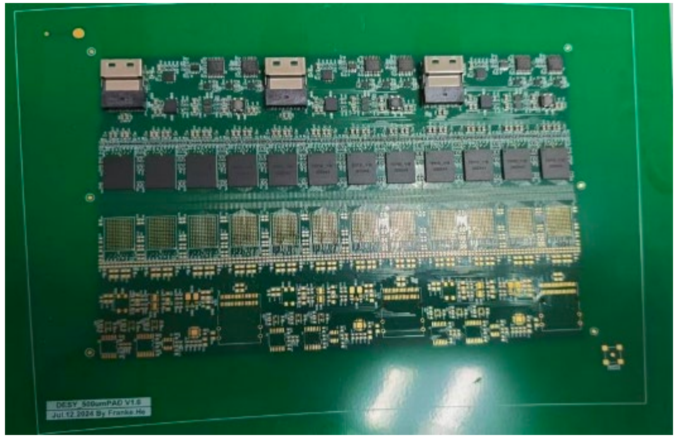
TPC outer wall: 0.69%

TPC inner wall: 0.45%

High granularity readout

Pad size: 500 μm × 500 μm



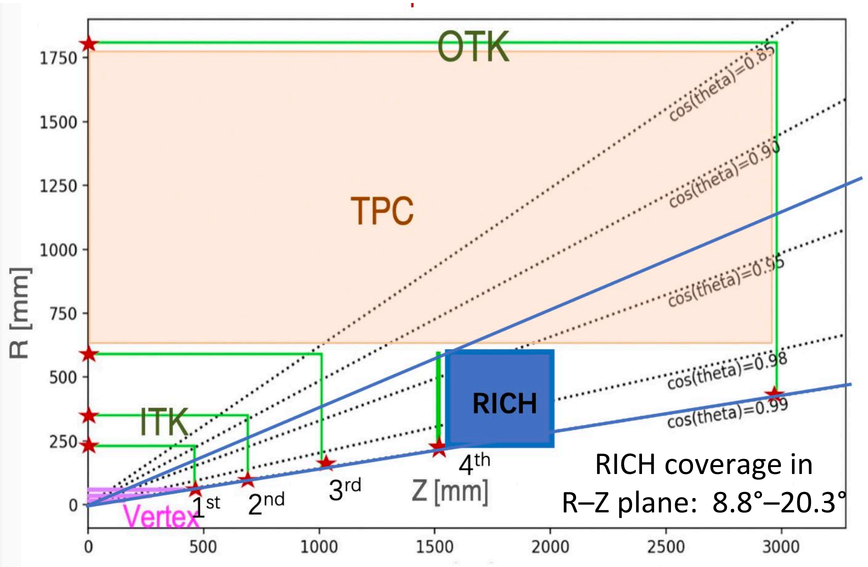



**TEPIX:**
**Low-power readout ASIC ($<100$ mW/cm$^2$)**

- **Continuous** studies on space-charge distortions, IBF suppression, effects of high-luminosity Z mode and beam-induced backgrounds
- **Optimization** of the readout granularity, and the design of readout ASIC
- Various prototypes for design goal of **tracking (σ~100μm) and PID (dN/dx ~3%)**

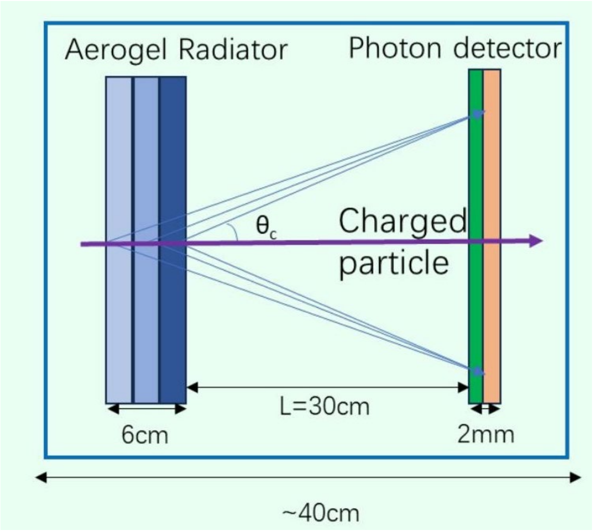
# The Cherenkov Detector (RICH) - a new addition

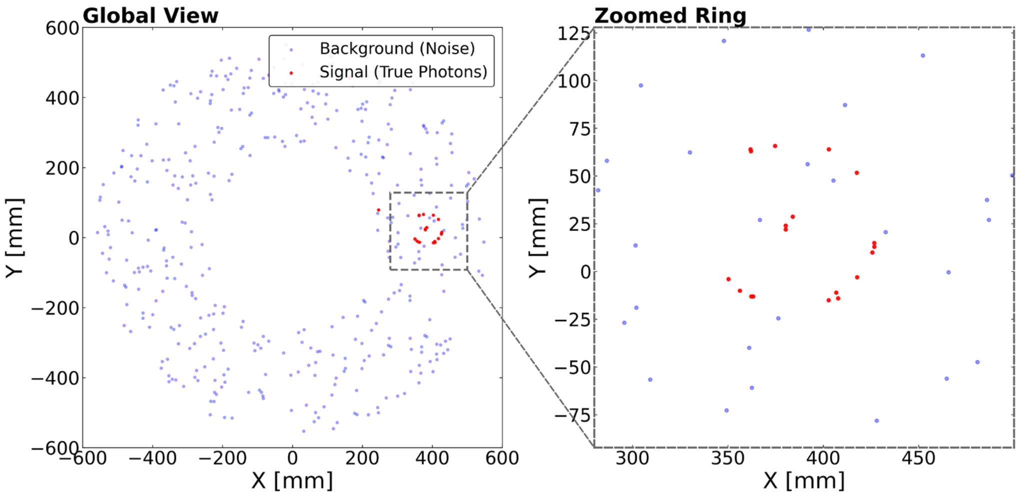
## Ring-Imaging Cherenkov (RICH) in the forward region

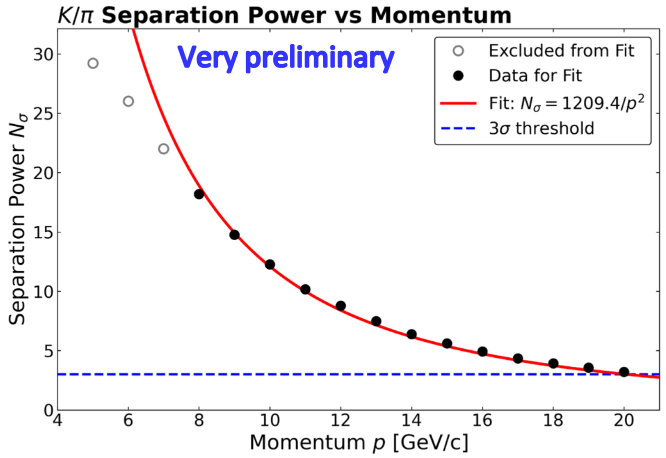



### Design Concept

- Proximity-focusing design with silica aerogel radiator
- SiPM as photo-sensor (active R&D)
- L = 30 cm, radiator 6 cm



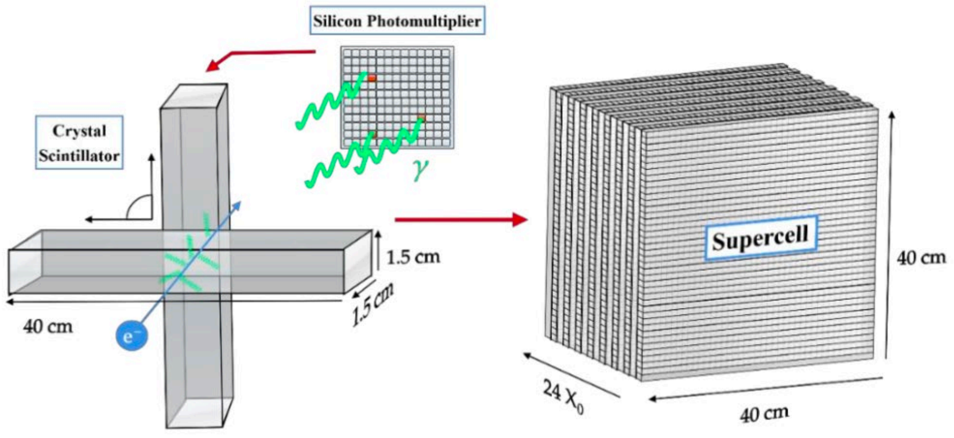



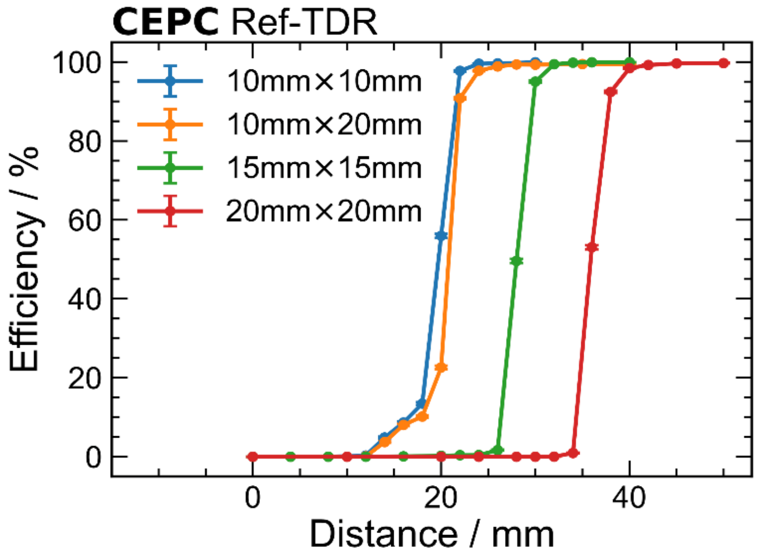




- Further optimization and studies are needed for the noise and cross talk of SiPM, partial or full reflection on the cylinder, beam backgrounds. etc.

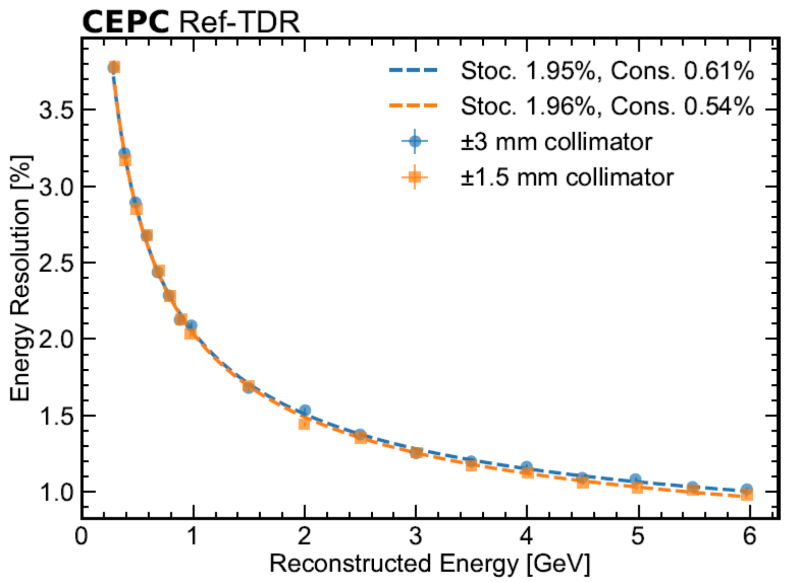
# Electromagnetic Calorimeter: the Concept

- Crystal bars are arranged in x-y direction alternatively, read by a 3×3 mm² SiPM at each end
- Good 3D shower reconstructed for PFA
- From simulation: shower separation ~ 2× crystal cross section, energy resolution 1.2%/√E⊕0.5%
- Beam test at CERN with BGO bars: 2 × 2cm² cross section, 12cm long, Energy resolution: 1.95%/√E⊕0.6%

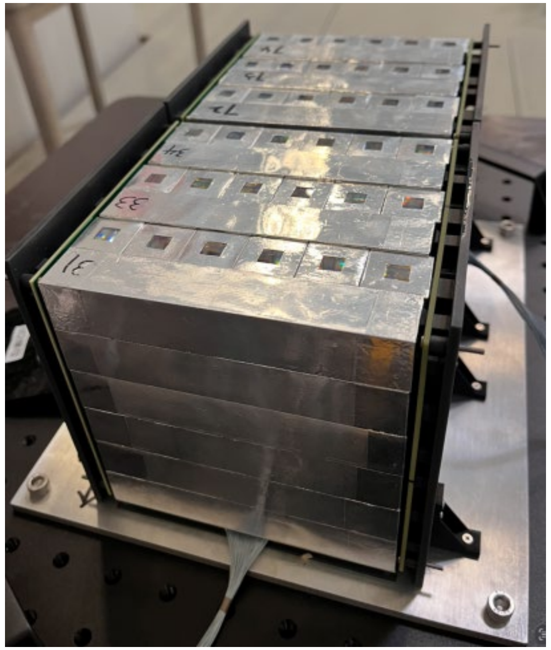



15×15mm² selected

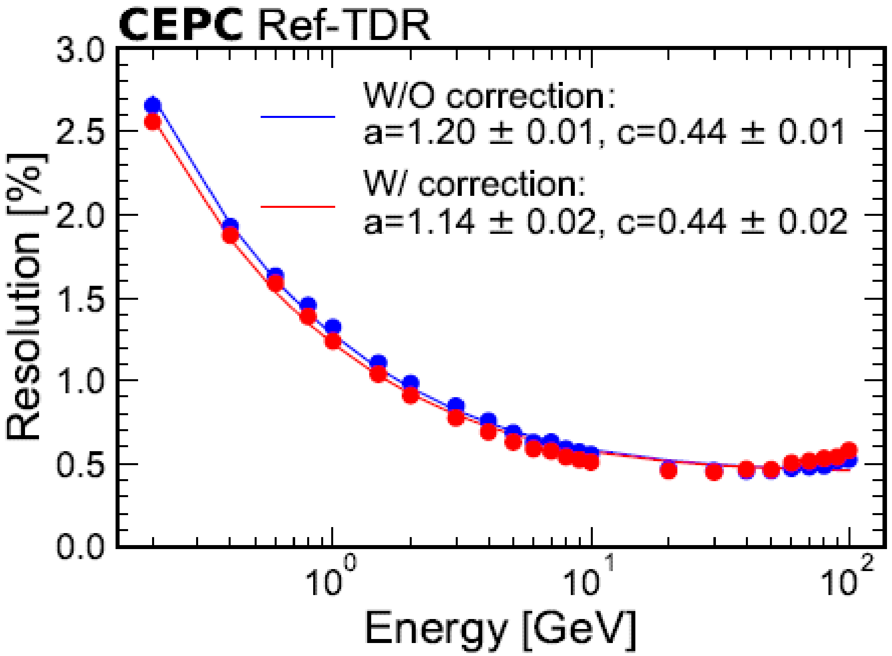


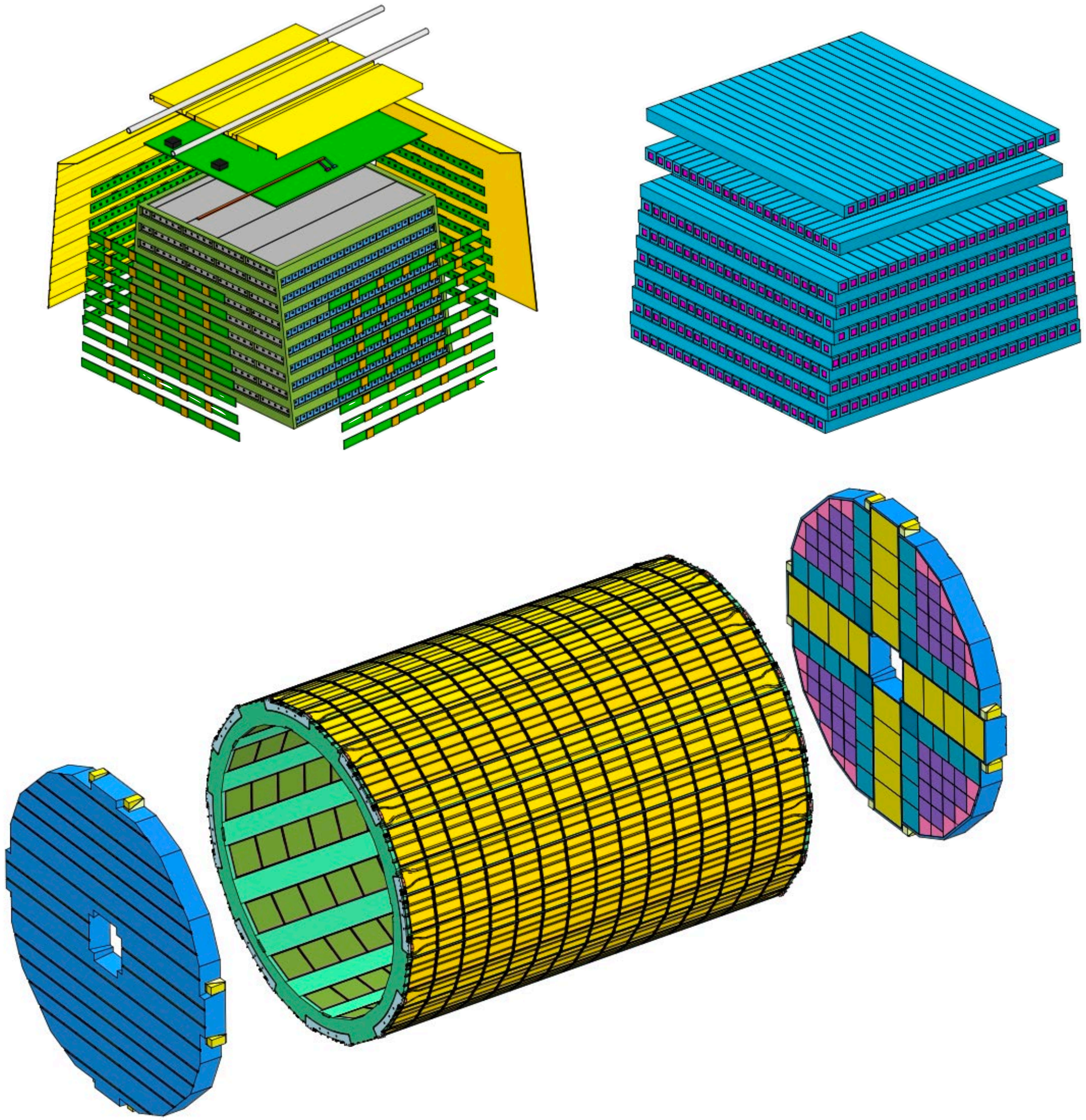

Test beam results



# Electromagnetic Calorimeter: the Design

- 18 layers of crystals (24 $X_0$)
- Barrel: 32 towers per ring, 15 rings
- Endcap: 224 modules
- Total: 24$m^3$ BGO, 571k channels

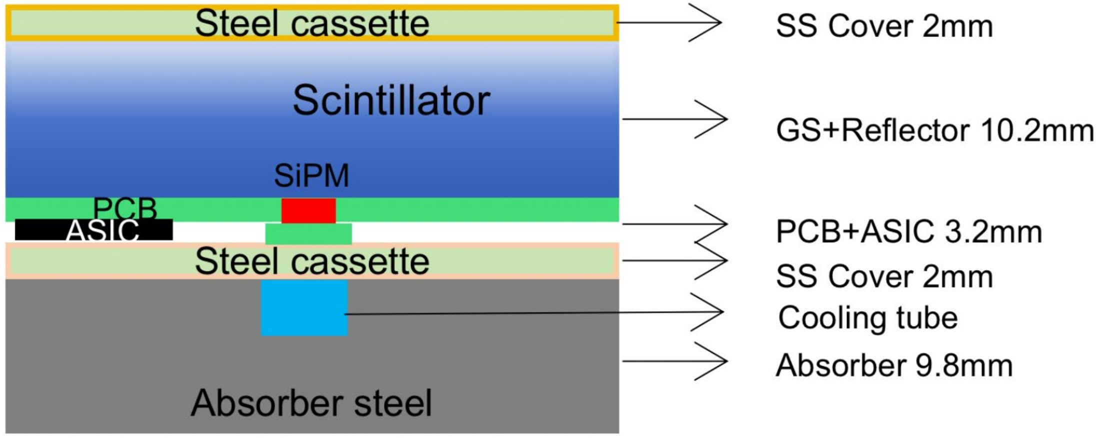


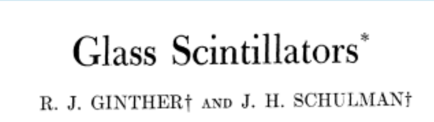
# Using Glass Scintillator as Hadron Calorimeter？

- Using glass scintillator (GS) to replace crystals had been a dream for many decades
- ~20 years ago, we worked with Fermilab and Caltech hoping to produce glass scintillator (>20cm, >6 g/cm$^3$) for hadron calorimeter (total absorption, dual readout) but failed：
  - Too much defects, not even transparent
  - Light yield and density not high enough
- A new idea ~5 years ago:
  - Small cubic(2-4 cm) instead of a bar, to relax transparency requirement: good for 3D shower profile as needed by PFA
  - Similar to that of plastic scintillator HCAL but with much more active materials
  - Feasible now because of SiPM and ASIC

➢ GS can have a much better energy resolution but the key is：
  - ➢ Density ~ similar to that of Iron
  - ➢ Light yield > 1000 ph/MeV



# History of Glass Scintillators


Glass Scintillators*

R. J. GINTHER† AND J. H. SCHULMAN†

**1958, Ce-doped high-silicon glass.**
Under γ-ray excitation, the pulse height is 10% of NaI(TI).

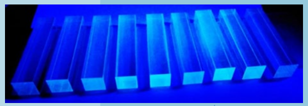
1976, commercialized GS series glass scintillator (**GS20**,ρ=2.5g/cm$^3$), with calorimeter prototypes

**1996**, heavy metal fluoride glass EM calorimeter

2.
High density

3.
High LY

**2015**, **DSB glasses** for high energy physics experiments,
ρ= 3.8 g/cm$^3$,
LY= 1360 ph/MeV



1950 1960 1970 1980 1990 2000 2010 2020 2025

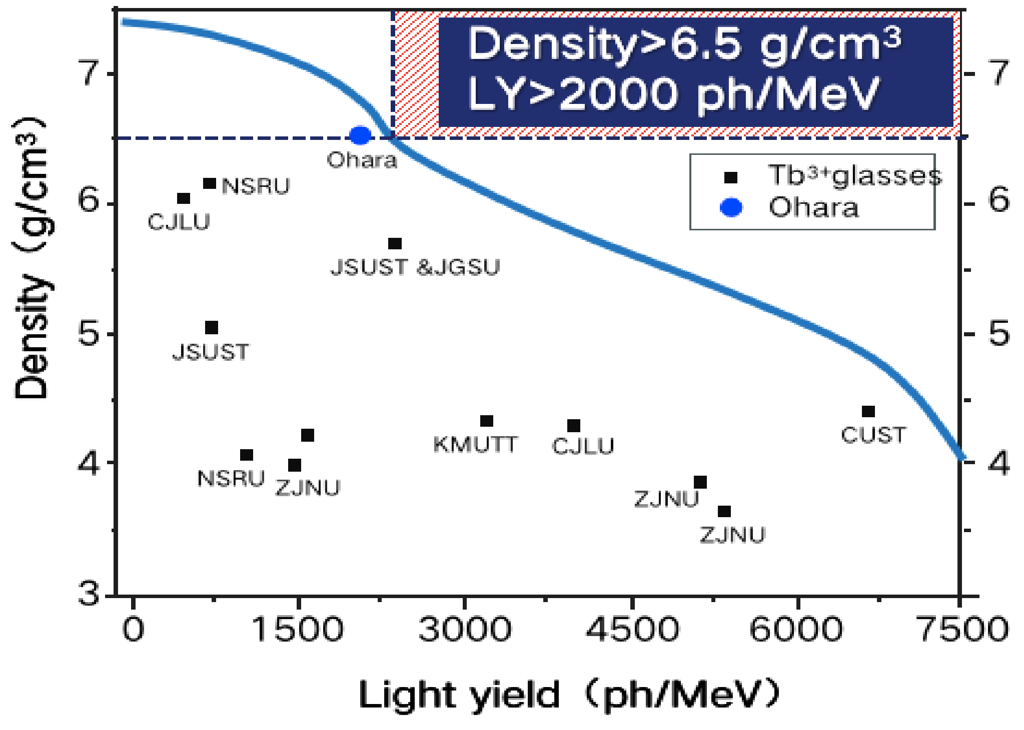
1962, glass for thermal neutron detection

**1988, glass scintillator calorimeter design**

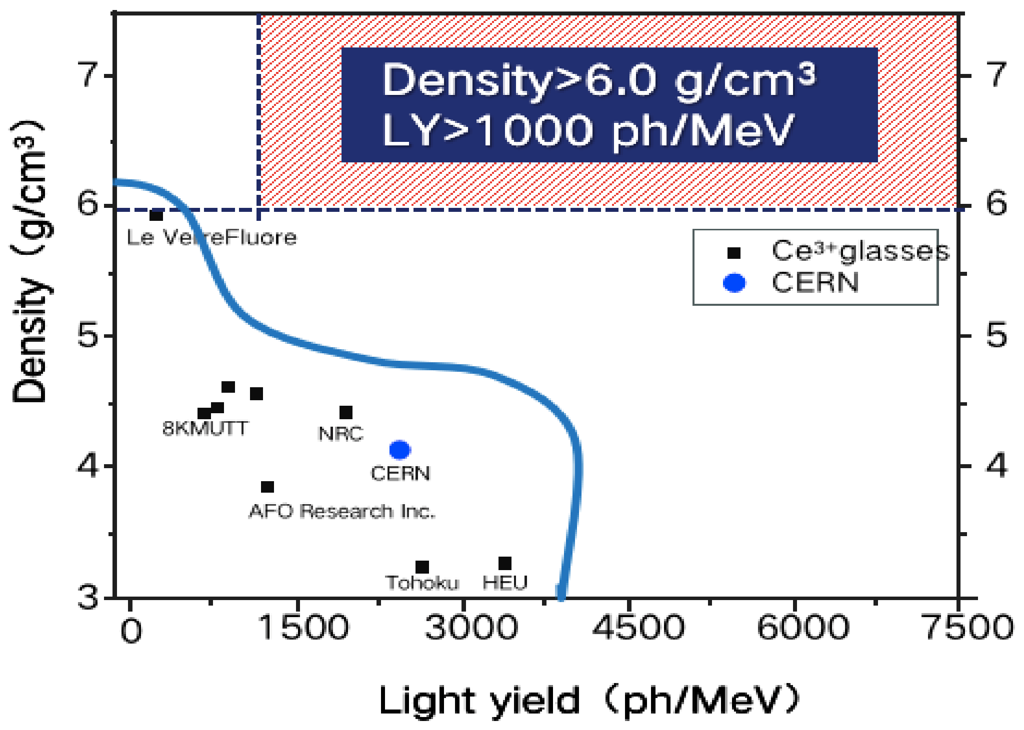
**2000, the concept of energy transfer sensitization**

# History of Heavy Glass Scintillators

- Before 2000, the high-density GS is mainly based on Pb or Bi, with poor scintillation light;
- After 2000, GS with rare-earth elements（Tb, Ce） becomes more popular for improved LY
- However, **it is hard to have high density and high light yield at the same time**




$Tb^{3+}$ doped glass with high light yield




$Ce^{3+}$ doped glass with short decay time

# Glass Scintillator Collaboration

- **GS Production**
  - Research & Development
  - Mass production
- **GS Research**
  - Optical test
  - Mechanical test
  - Irradiation test
- **GS HCAL Design**
  - Simulation
  - SiPM Research
  - Single Tile Test
- **GS Application**
  - Unclear Detection
  - Others

Institute of High Energy Physics，CAS
中国科学院高能物理研究所

Jinggangshan University
井冈山大学

Beijing Glass Research Institute
北京玻璃研究院

China Building Materials Academy
中国建筑材料研究院

China Jiliang University
中国计量大学

Harbin Engineering University
哈尔滨工程大学

Harbin Institute of Technology
哈尔滨工业大学

Sichuan University
四川大学

Shanghai Institute of Ceramics，CAS
中国科学院上海硅酸盐研究所

Shanghai Institute of Optics and Fine I
中国科学院上海光学精密机械研究所

CNNC Beijing Unclear Instrument Factory
中核（北京）核仪器有限责任公司

闪烁玻璃合作组
Glass Scintillator Collaboration

- New receipes, samples, theory: universities, research institutions, industry labs
- Testing and user applications

Oct. 2021, 6 groups
Mar. 2022, 8 groups
Mar. 2023, 11 groups
Oct. 2024, 13 groups

# Collaboration meetings

- 2021-05-14:
- IHEP, Beijing

- 2021-10-14:
- IHEP, Beijing

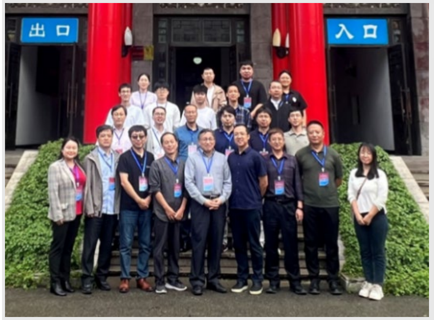
闪烁玻璃合作组
Glass Scintillator Collaboration

- 2022-06-30:
- IHEP+Online

- 2022-11-09:
- IHEP Beijing

- 2023-05-28:
- Jinggangshan Uni., JiAn


- 2023-08-30:
- Harbin

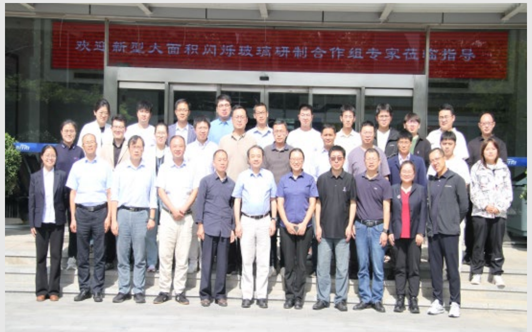



- 2023-12-20:
- ZhaoZhuang


- 2024-05-25:
- Hangzhou

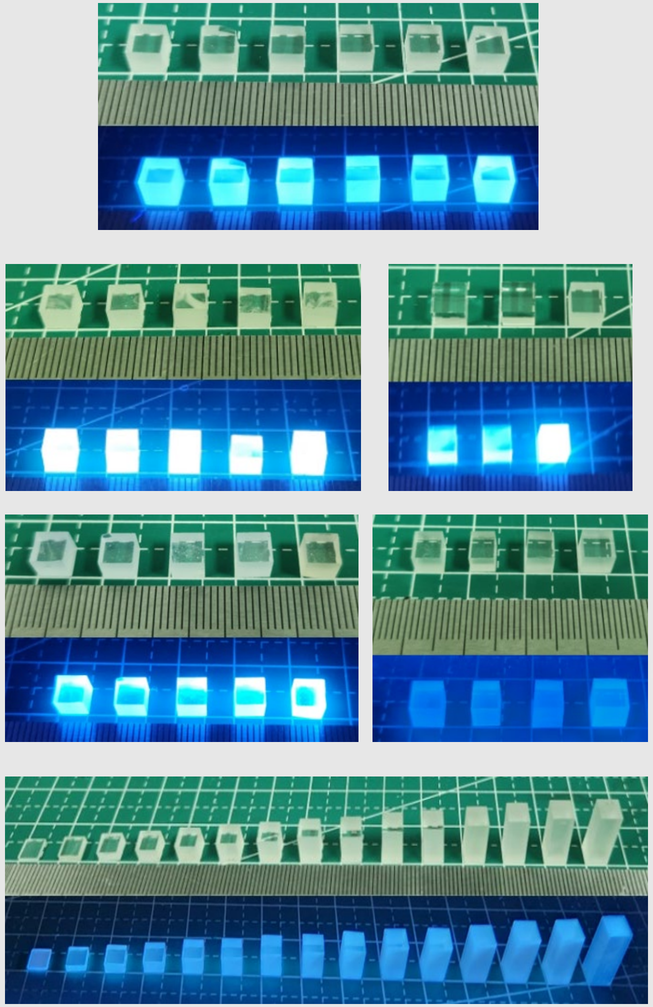

- 2024-10-12:
- JiangMen


- 2025-09-26:
- Beijing

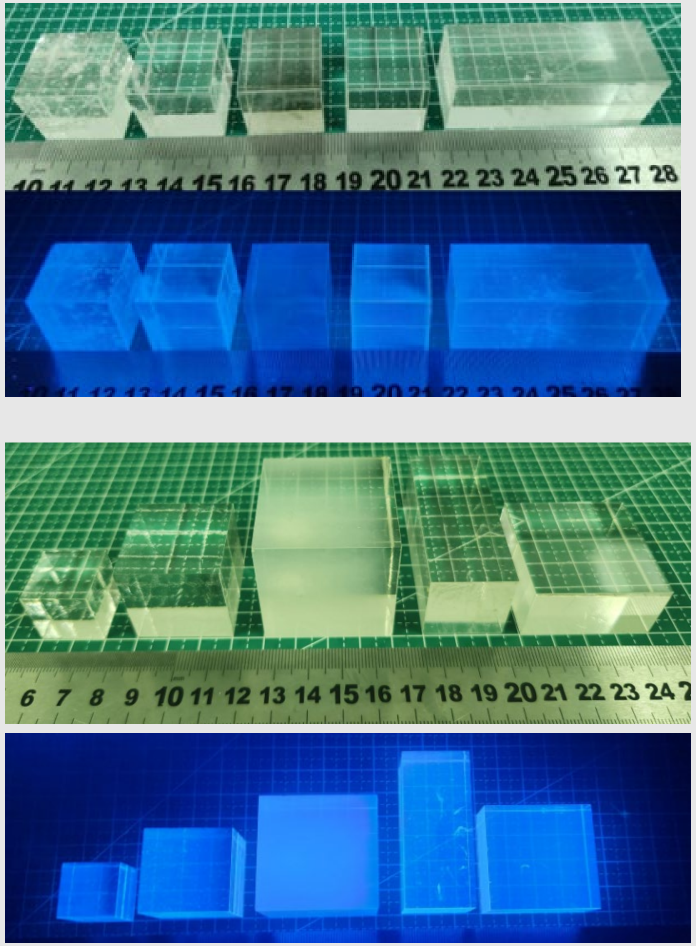


# Large Number of Samples (>2000 pics)

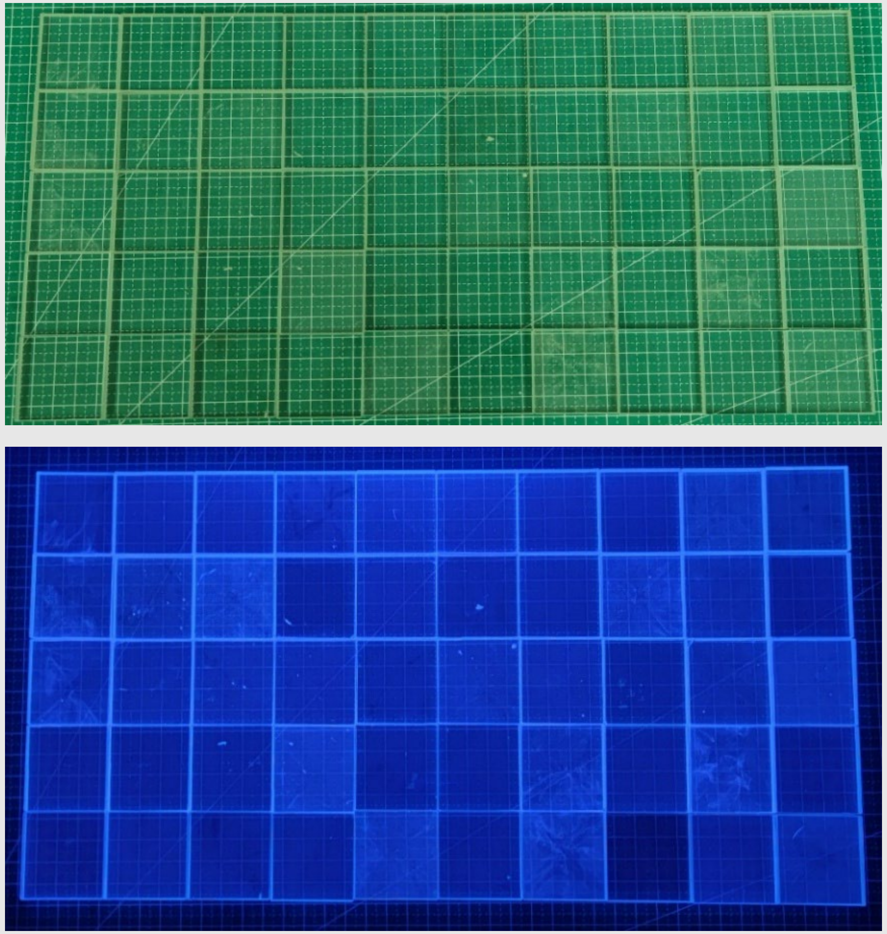
- 5mm X 5mm X 5mm



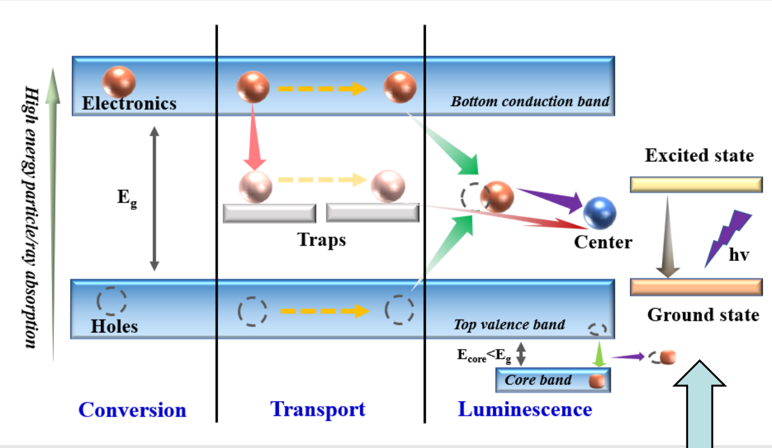
- 20mm ~ 60mm




- 40mm X 40mm X 10mm

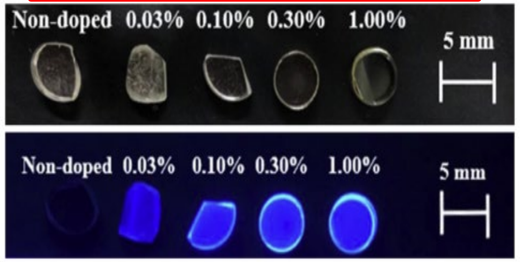


# Design of the New Heavy GS



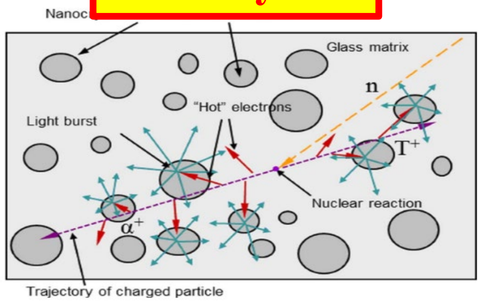

- **Scintillation mechanism----** **Luminescence Center**
- **Conversion**—photoelectric effect and Compton scattering effect;
- **Transport**—electrons and holes migrate;
- **Luminescence**—captured by the luminescent center ions

**Lanthanide elements**



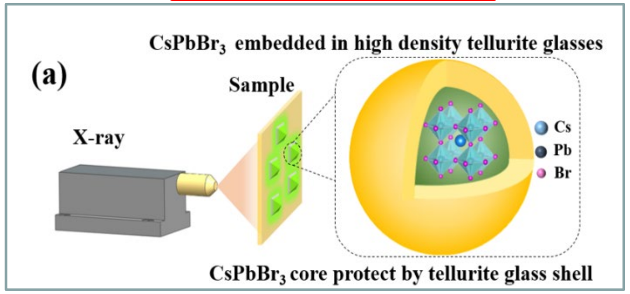

*Journal of Alloys and Compounds 782 (2019) 859-864*

**Nanocrystals**



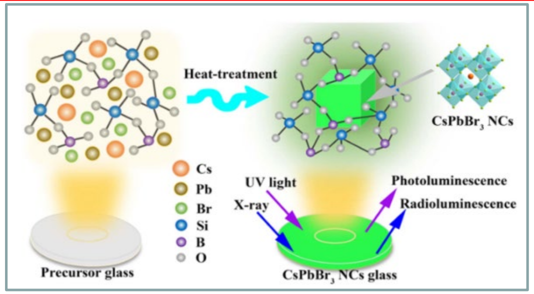

*IEEE TNS 60 (2) 2013*

**Quantum Dots**




*Optics Letters 46(14) 3448-3451 (2021)*

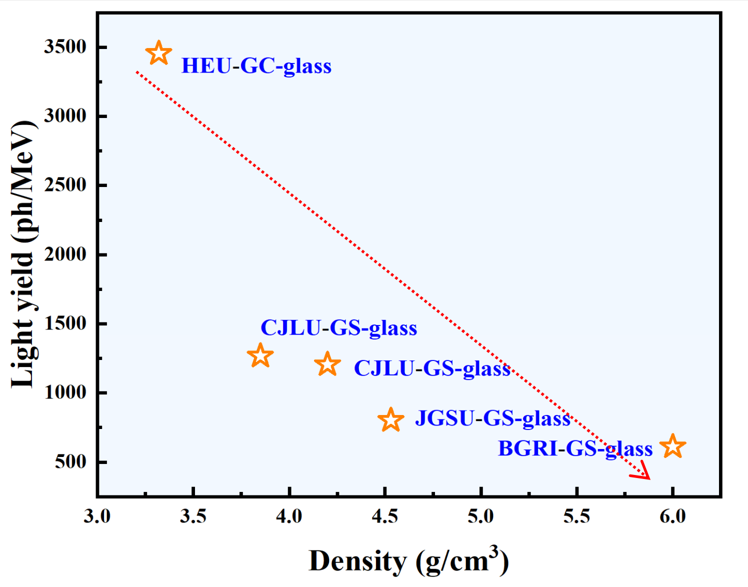
**Lanthanide + Quantum Dots**

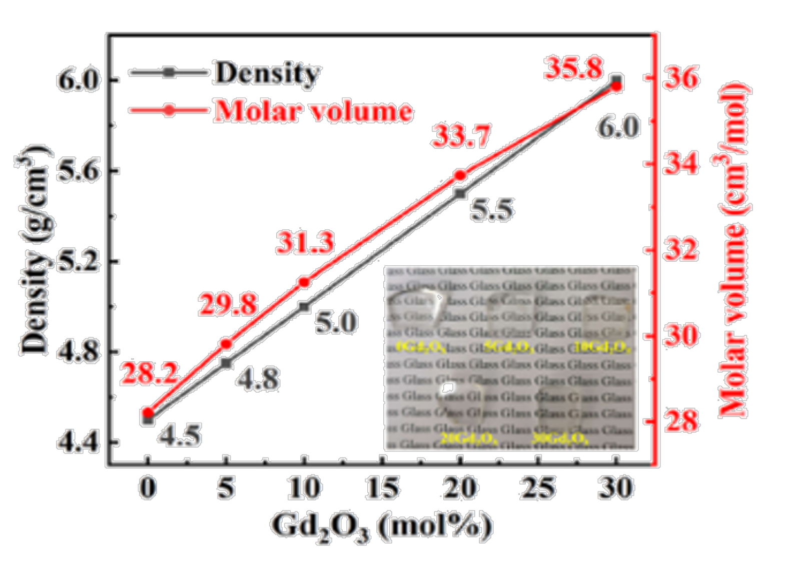



*Vol. 9, No. 12 / 2021 / Photonics Research*

- **High Light Yield (> 2000 ph/MeV): Lanthanide for the Luminescence Center: Cerium (Ce);**
- **High Density (> 6 g/cm$^3$) and Low radioactivity background: Gadolinium (Gd); ~~lutetium (Lu)~~**

# Gd was Chosen for Density



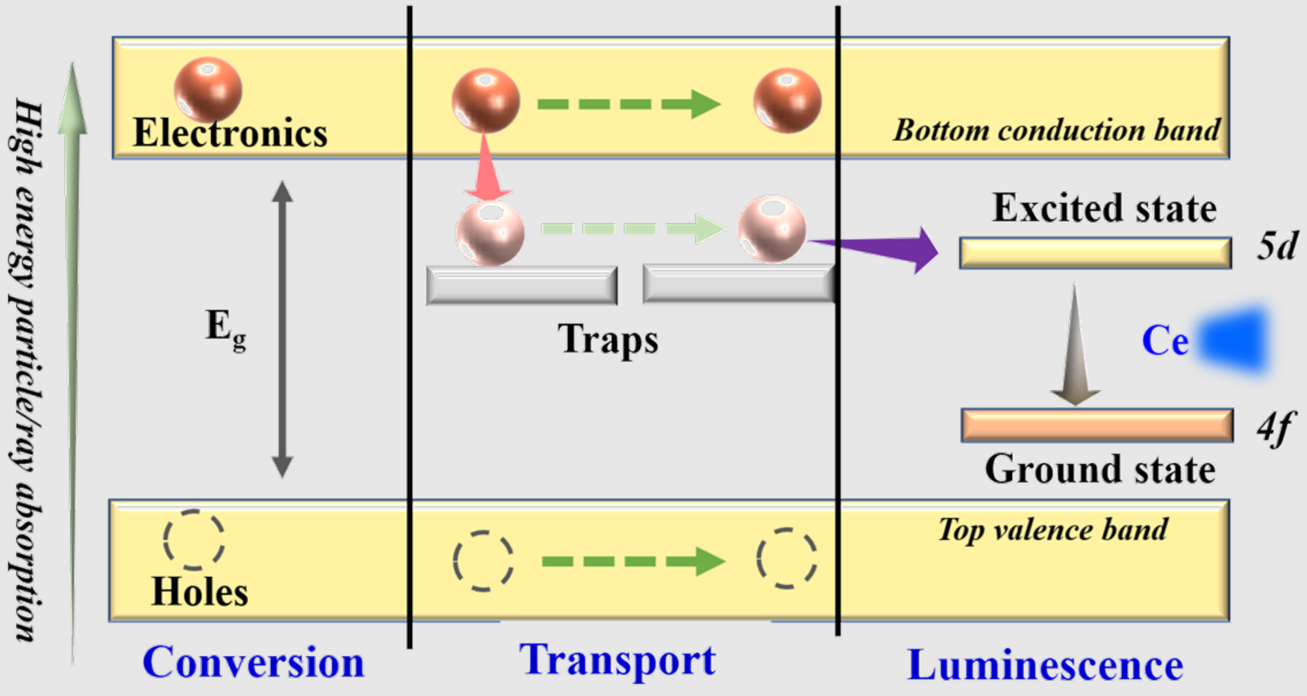




## Gd-F-O (GFO) glass: $Gd_2O_3$-GdF-$Al_2O_3$-$B_2O_3$-$SiO_2$

| Scintillator | Density ($g/cm^3$) | Light yield (ph/MeV) | Mean decay (ns) | Year |
|---|---|---|---|---|
| HEU-GC-glass<br>[7] C.X. Luo, et al., ACS AMI, 2023, 15, 46226-46235. | 3.32 | 3455 | 275.4 | 2023 |
| CJLU-GS-glass<br>[8] Z.H. Hua, et al., Ceram. Int., 2023, 49, 18844-18851. | 3.85 | 1267 | 1730.4 | 2023 |
| CJLU-GS-glass<br>[9] T. Wu, et al., J. Am. Ceram., 2023, 106, 476-487. | 4.20 | 1206 | 1363.6 | 2022 |
| JGSU-GS-glass<br>[10] G. Tang, et al., Opt. Mater., 2022, 130, 112585. | 4.53 | 802 | 1059.9 | 2022 |
| BGRI-GS-glass<br>[11] Z.H. Hua, et al., PoS(ICRC 2023), 2023, 565. | 6.0 | 611 | 1501.4 | 2023 |

- As Gd increases, the glass density gradually rises from 3.3 to 6.0 $g/cm^3$.
- Self-absorption effect decreased the light yield to ~600 Ph/MeV
- Incorporating a high concentration of heavy ions for light yield—inevitably introduces structural defects and energy quenching, resulting a slower decay time.

# Improve the Light Yield by $Ce^{3+}$ Doping




## $Ce^{3+}$ Doped Glass

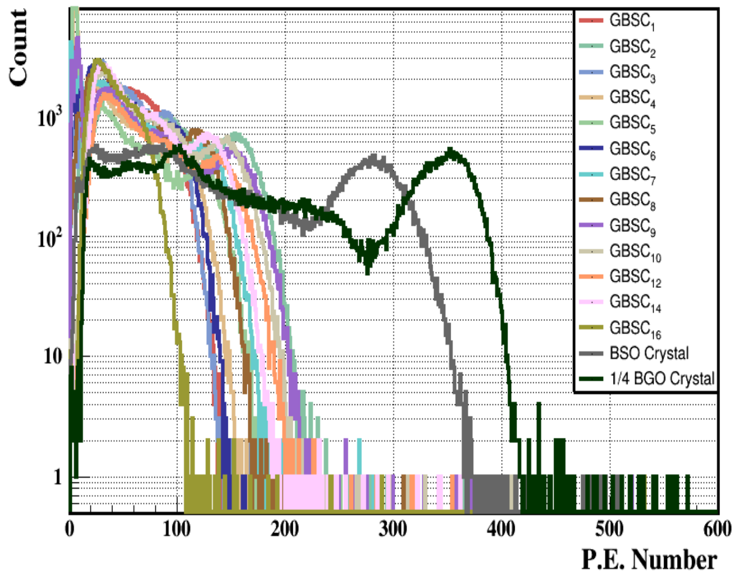
- ✓ **5d–4f electric-dipole-allowed transition:** high transition probability, ns-scale decay time
- ✓ **Tunable emission wavelength:** better spectral matching with photodetectors.
- ✓ **Suitable for high-energy particle detection:** incorporated into a high density/atom number host

## Breakthrough:

- ➢ **Defect Control:** use high-purity raw materials to reduce harmful defects, such as Fe(Ferric).
- ➢ **Co-Doping:** tune energy transfer and luminescence process using **$Mg^{2+}$**, **$Mn^{2+}$**, **$Yb^{3+}$**, **$Li^{+}$**, etc.

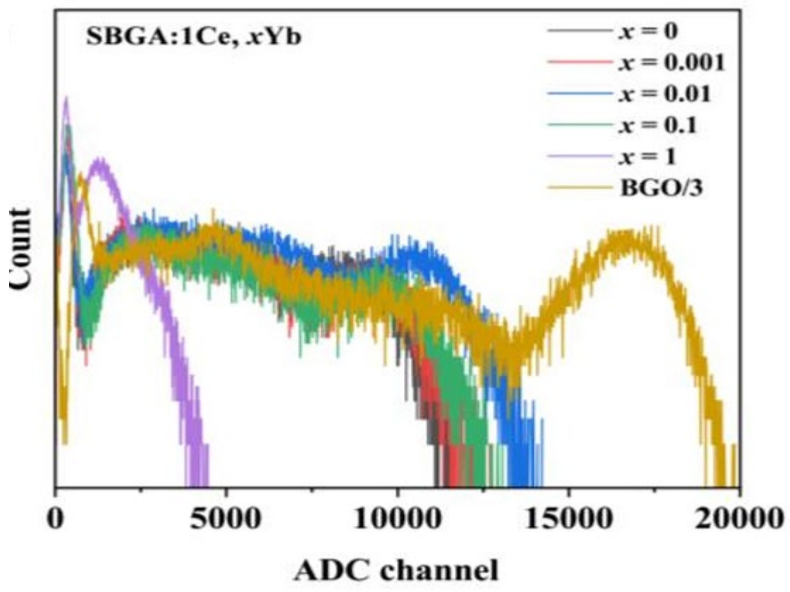
# Light yield Enhancement—Doping & Co-Doping

- Effect of $Ce^{3+}$ concentration on GFO



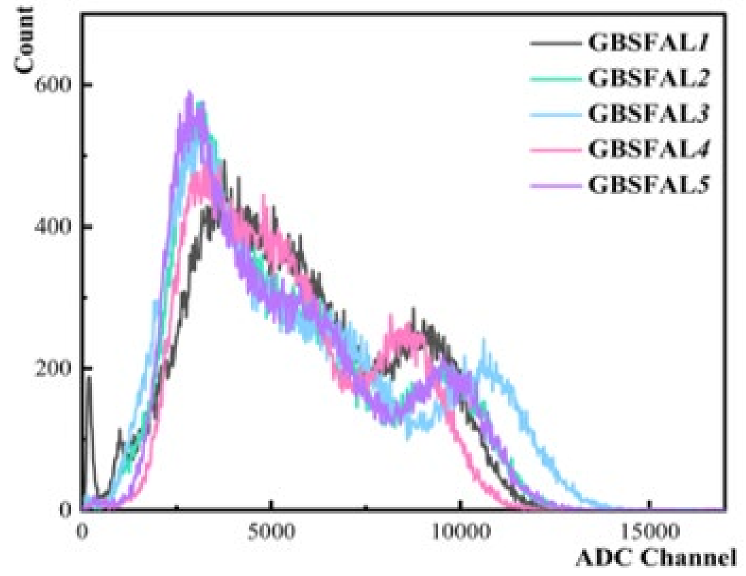

Ref. 2025 Chin. Opt. Lett, 23(12), 121602

- Effect of $Yb^{3+}$ co-doping on GFO




Ref. Ceram. Int., 2026, 52, 26985–26993

- Effect of $Li^{+}$ incorporation on GFO



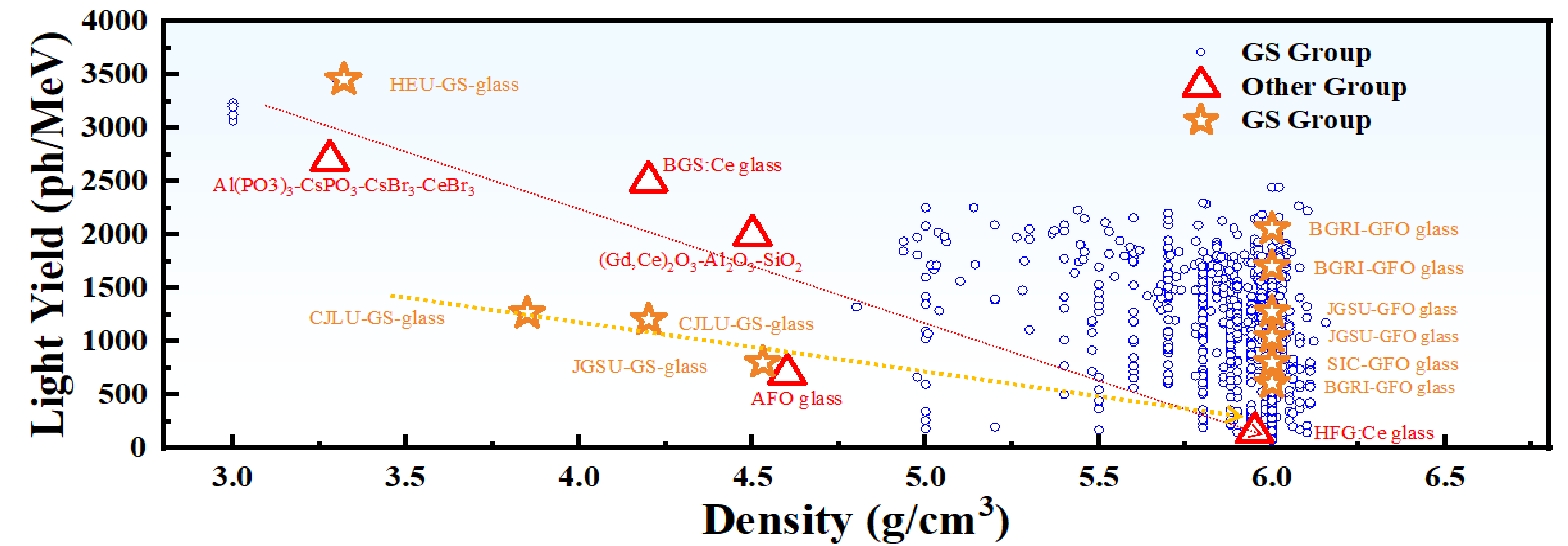

Ref. Ceram. Int., 2025, 51, 35463–35471

- $Ce^{3+}$ concentration regulates scintillation light yield and decay time.
- Optimized doping **enables intense luminescence with faster decay.**

- $Yb^{3+}$ reduces defect-related non-radiative energy loss.
- The light yield improves from ~1200 **to ~1500 ph/MeV.**

- $Li^{+}$ tunes the local coordination environment around $Ce^{3+}$.
- **The emission peak shifts toward the optimal SiPM PDE region.**

# Light Yield vs Density



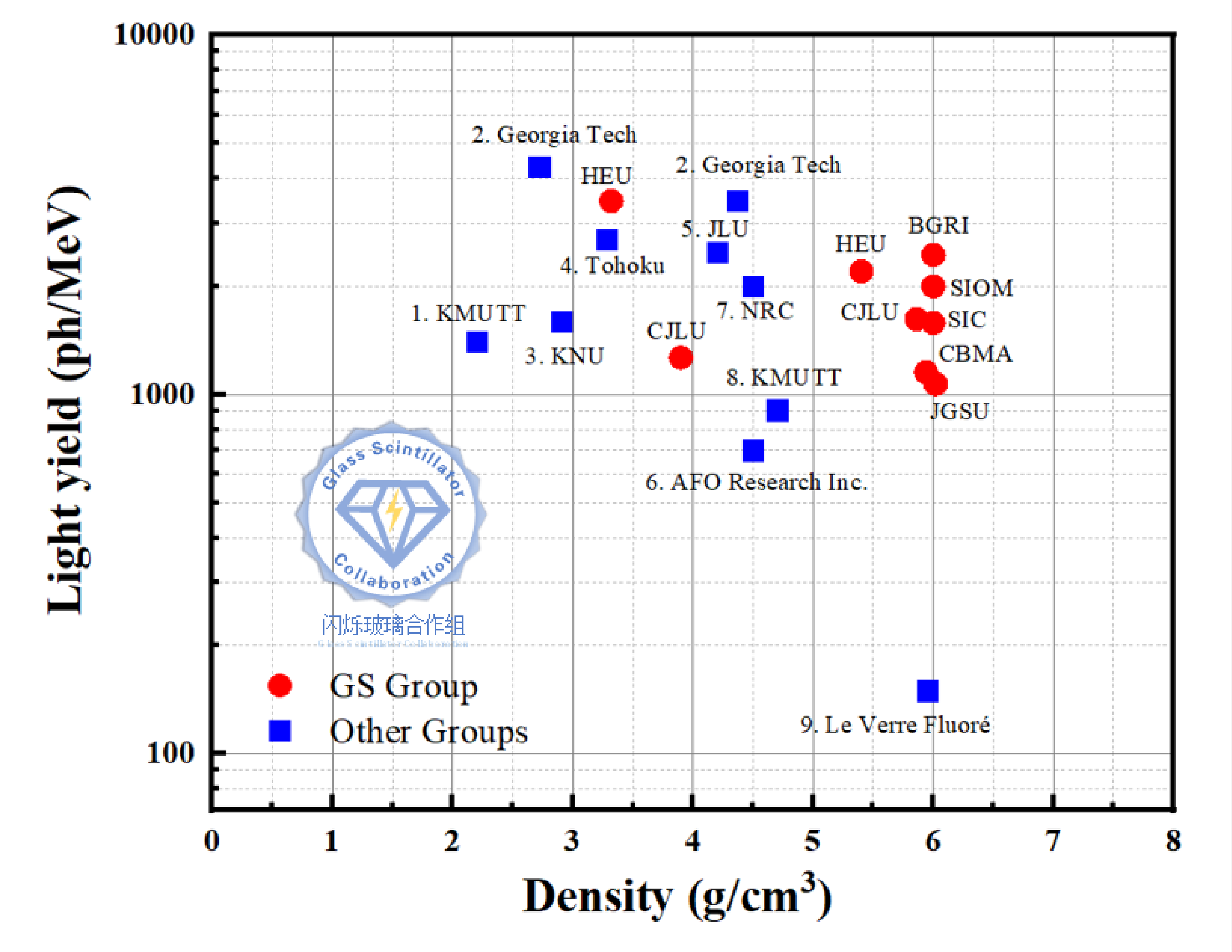

With the increase of Gd, the density of GFO glass gradually increased to 6g/cc;

Doping of $Ce^{3+}$ and co-doping of other elements increased the light yield to ~2000 ph/MeV.

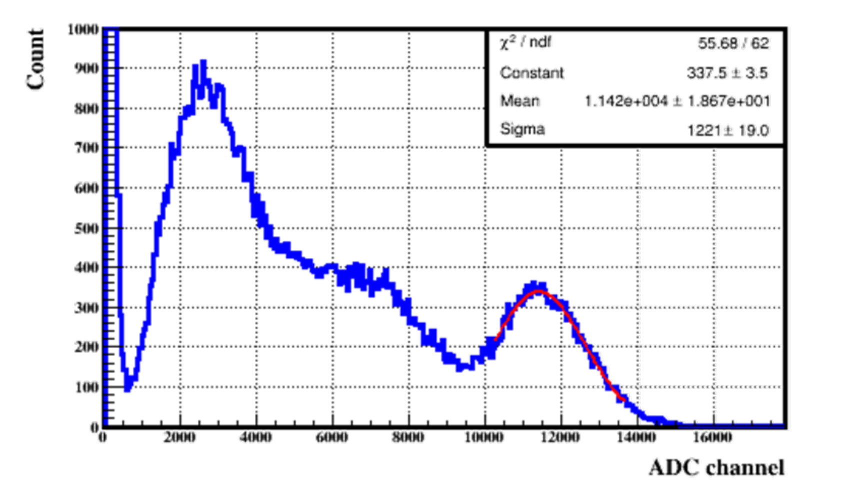
# Final Choice: GFO Glass

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

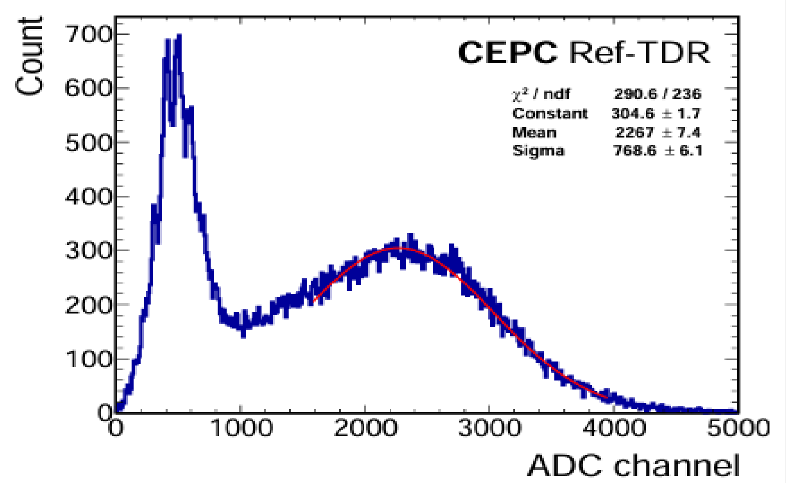
| Key parameters | GFO glass | BGO | DSB Glass |
|---|---|---|---|
| Density (g/cm$^3$) | 6.0 | 7.13 | 4.2 |
| Melting point (℃) | 1250 | 1050 | 1550 |
| Radiation length (cm) | 1.59 | 1.12 | 2.62 |
| Molière radius (cm) | 2.49 | 2.23 | 3.33 |
| Nuclear interaction length (cm) | 24.2 | 22.7 | 31.8 |
| $Z_{eff}$ | 56.6 | 71.5 | 49.7 |
| $dE/dx$ (MeV/cm) | 8.0 | 8.99 | 5.9 |
| Emission peak (nm) | 400 | 480 | 430 |
| Refractive index | 1.74 | 2.15 | |
| Light yield (ph/MeV) | ~ 1500 | 7500 | 2500 |
| Energy resolution (% at 662 keV) | ~ 23 | 9.5 | |
| Scintillation decay time (ns) | ~ 60, 500 | 60, 300 | 90, 400 |



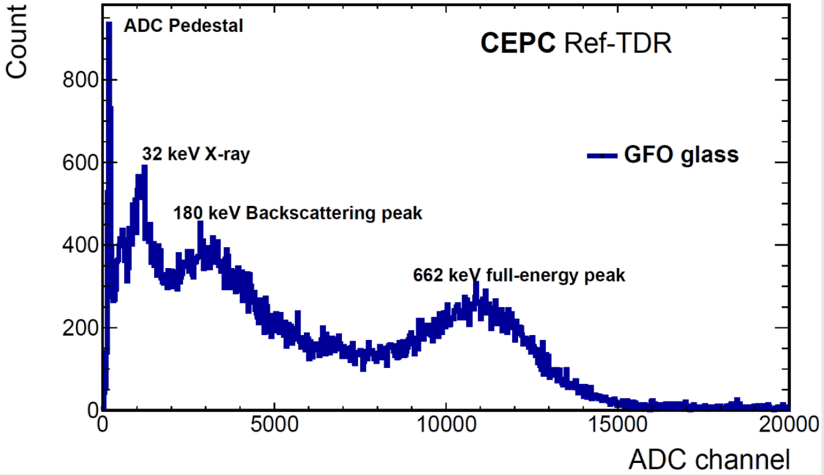
# Measured Energy Spectrum using $^{137}$Cs



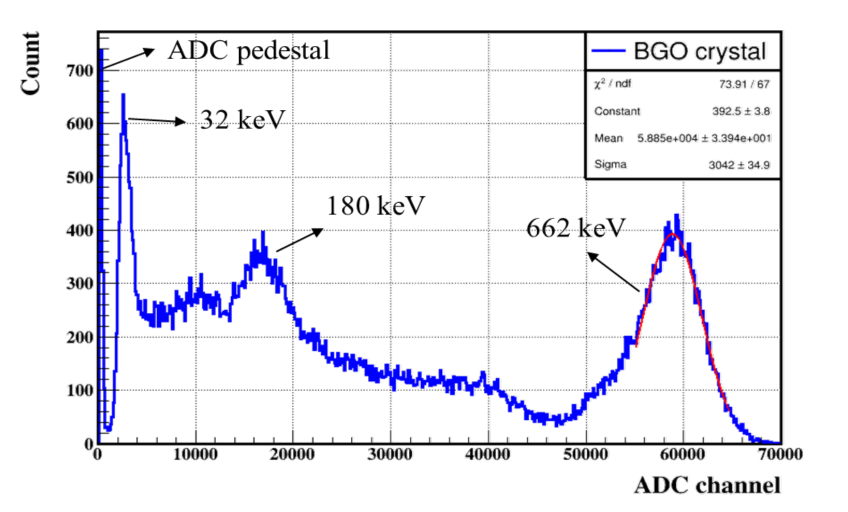

➢ 5×5mm **GFO** + 6×6mm **SiPM（HPK）**



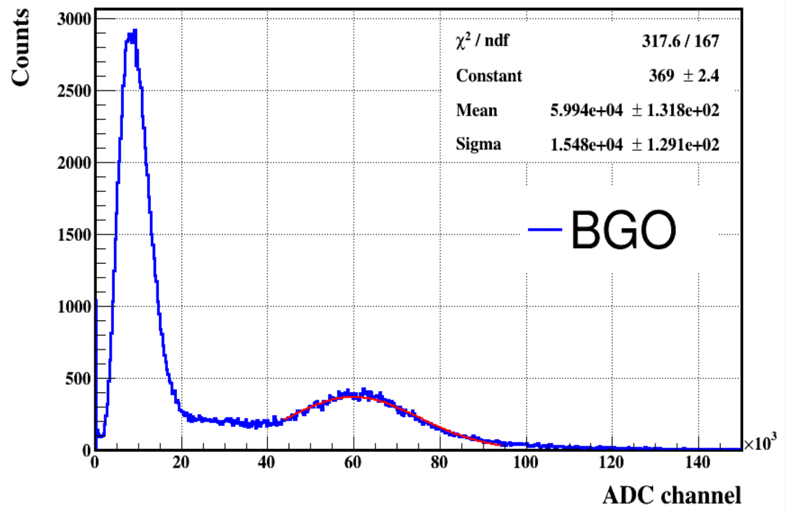

➢ 40×40mm **GFO + 3**×3mm **SiPM(HPK)**



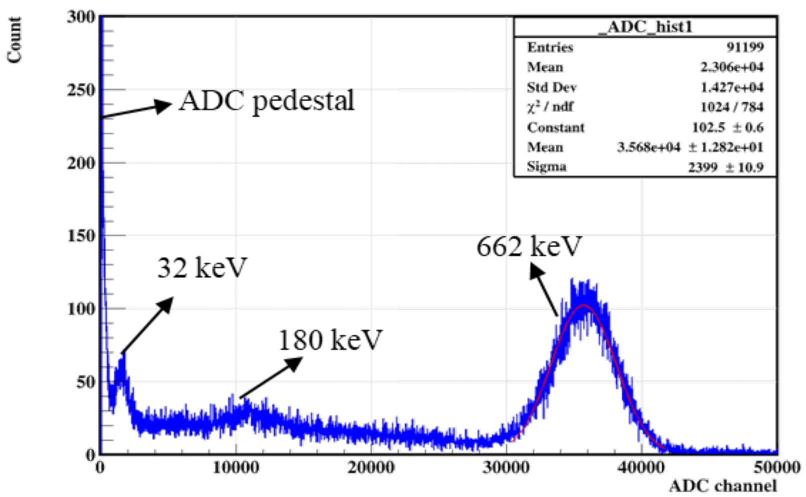

➢ 40mm×40mm **GFO** + 2 inch **PMT**




➢ 5×5mm **BGO** + 6×6mm **SiPM（HPK）**

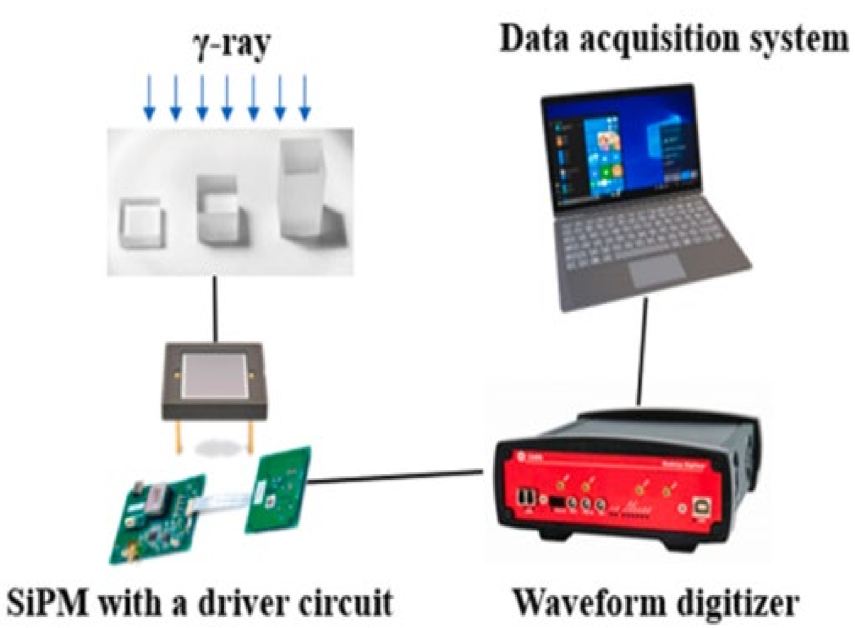



➢ 40×40mm **BGO + 3**×3mm **SiPM(NDL)**

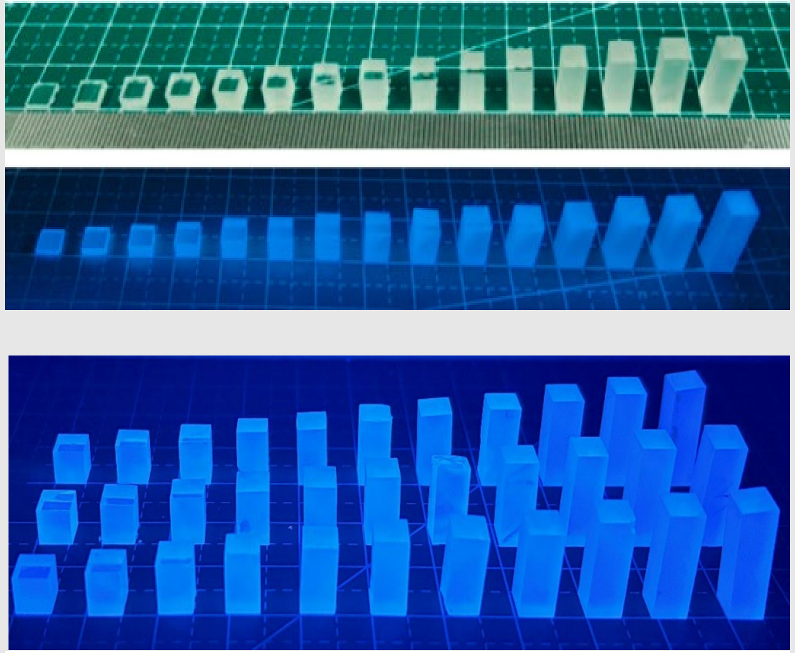



➢ 40mm×40mm **BGO** + 2 inch **PMT**

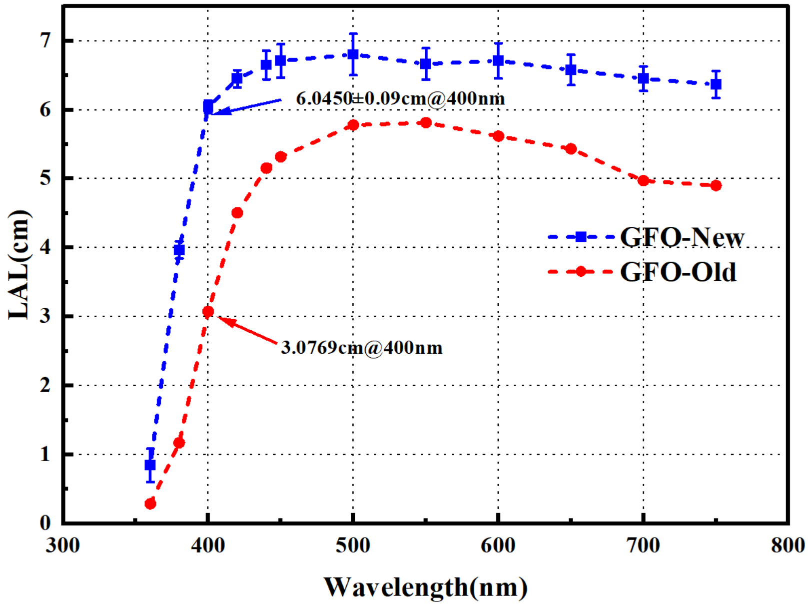
# Light Attenuation Length




➢ Schematic diagram of the testing system.



➢ the samples under UV light




➢ The light attenuation length of CFO glass under different wavelengths.

| Scintillator | Light output (ph/MeV) |
|---|---|
| GL1 glass | 1502±7 |
| GL9 glass | 1058±4 |
| GL15 glass | 728±2 |

- The attenuation length was evaluated using GFO with different thicknesses under $^{137}Cs$

✓ Light output decreased as thickness increased

✓ Composition optimization improved the attenuation length: 3.1cm → 6.0cm@400nm;

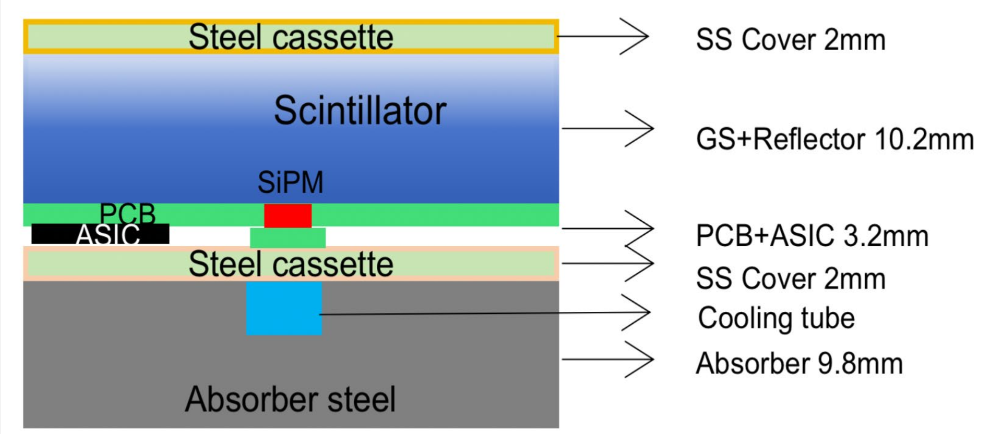
✓ Aim for a better attenuation length of > 10-20 cm.

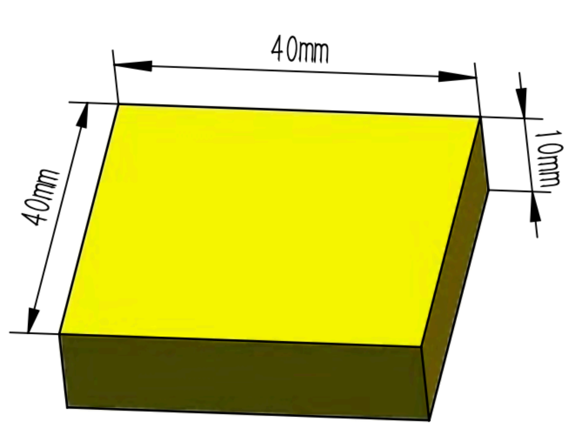
# Parameters used for Simulation and Design

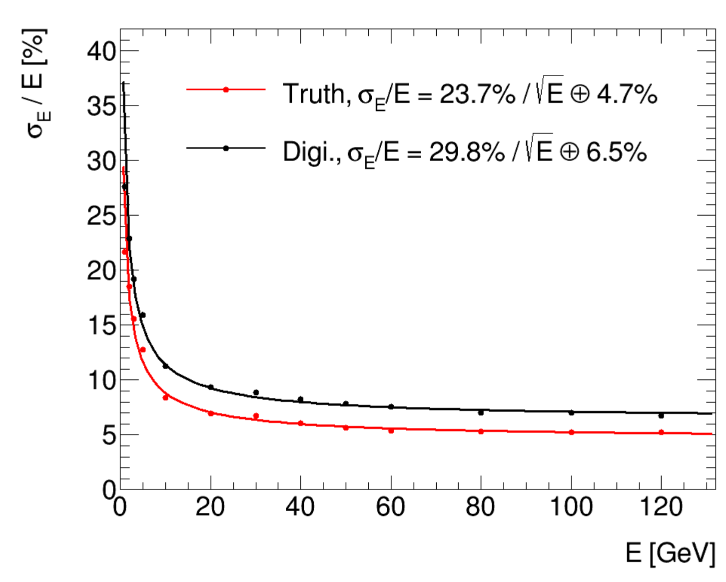
| | Parameters used in simulation | 2025.09（$9^{th}$ Meeting） Measured |
|---|---|---|
| Dimension ($mm^3$) | 40×40×10 | 40×40×10 |
| Density ($g/cm^3$) | 6.0 | >6.0 |
| Transmittance (%@400 nm) | 76 | 76 |
| Emission peak (nm) | 390 | 390 |
| Light yield (ph/MeV) | 1000 | 1408 |
| Energy resolution (%@662keV) | 30 | 28.7 |
| Decay time (ns) | 72.4 (10.5%),547.8 | 72.4 (10.5%),547.8 |
| Attenuation length (cm@400nm) | 6 | 6.05 |

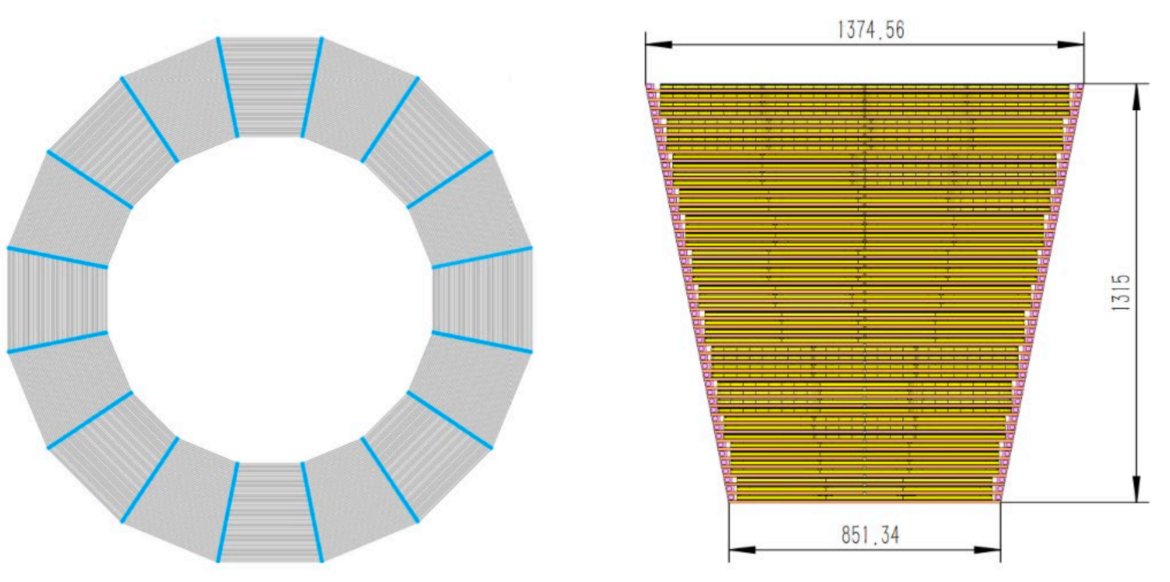
# Hadron Calorimeter in Ref-TDR

30% active materials



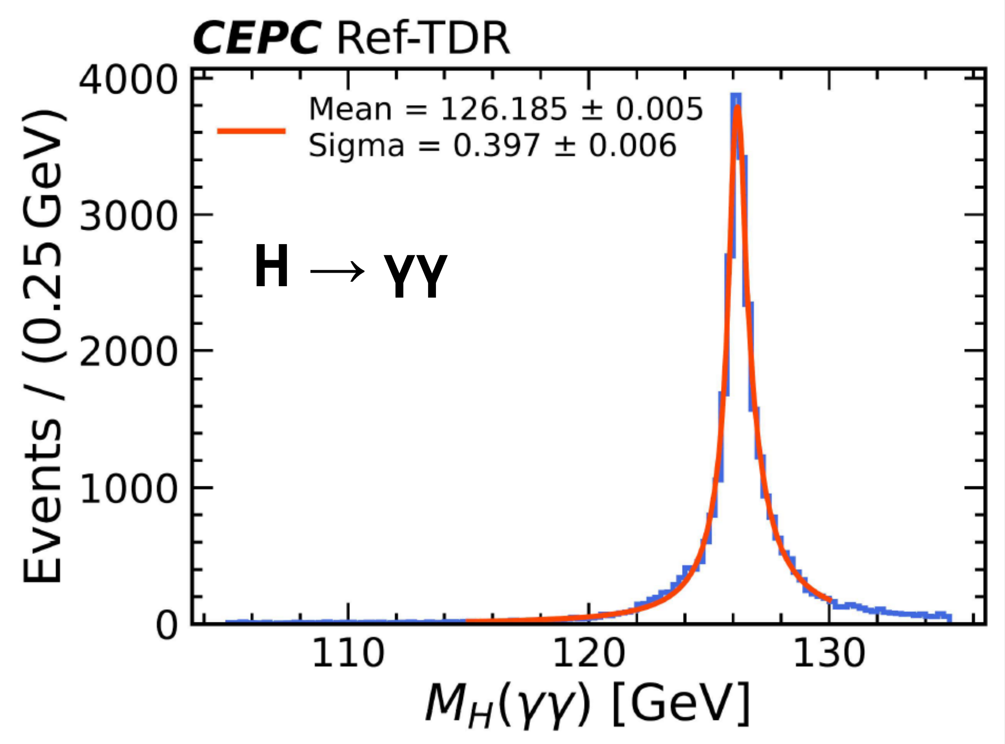



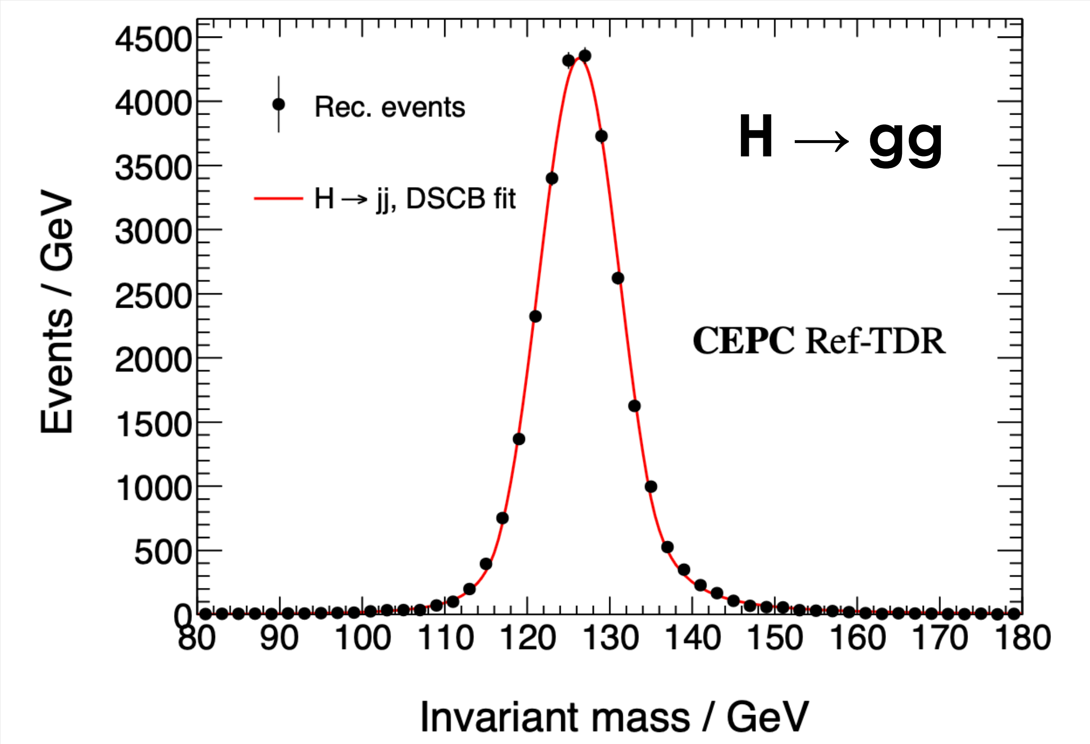

- Including all geometric and digitization effects, energy resolution is ~30%/√E ⊕ 6.5%
- Constant term can be reduced by correcting the shower starting point and the E/H ratio
  - With pulse width measurement, EM energy deposition can be distinguished from that of hadrons

# The Calorimeter Performance on Higgs

**PFA detector performance on simulation events (includes tracker, ECAL, HCAL)**



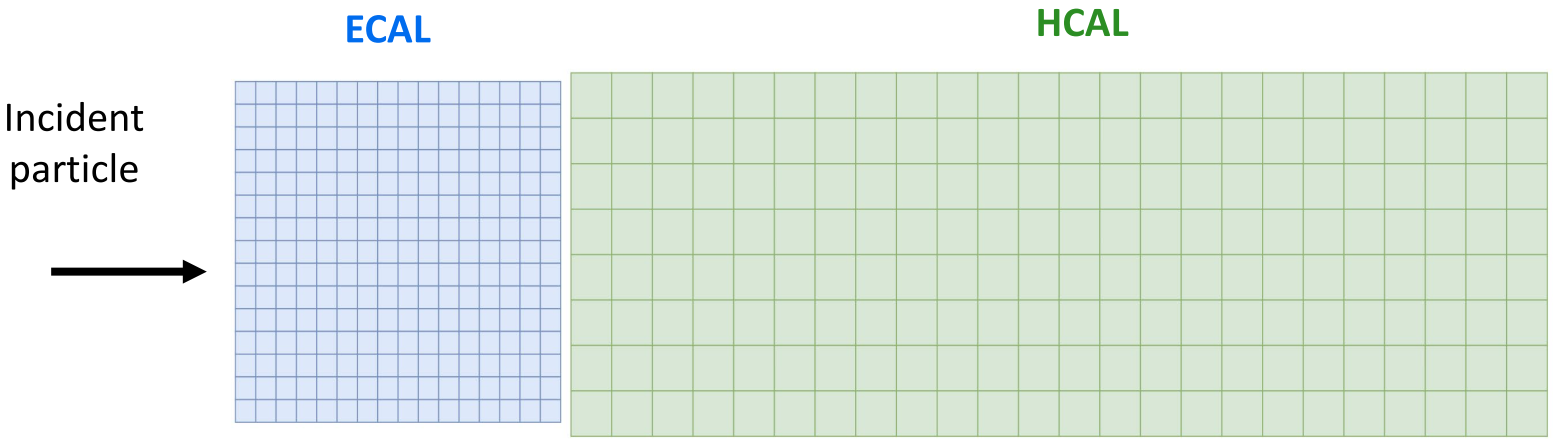

**Higgs boson invariant mass resolution (BMR) = 0.31%**

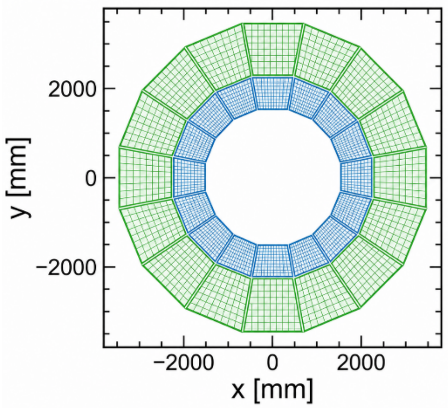



**Higgs boson invariant mass resolution (BMR) = 3.88%**

# Next Step Beyond TDR: Full Absorption EM+H Calorimeter ?

- Best possible EM calorimeter is crystals, but too expensive
- Because of the success of GFO glass, we may use it for EM calorimeter
  - Light Yield >2000 ph/MeV
  - Density ~6 g/cm$^3$
  - Decay time < 500 ns
  - Attenuation length > 10-20 cm
- Money saved will allow us to build a total absorption HCAL



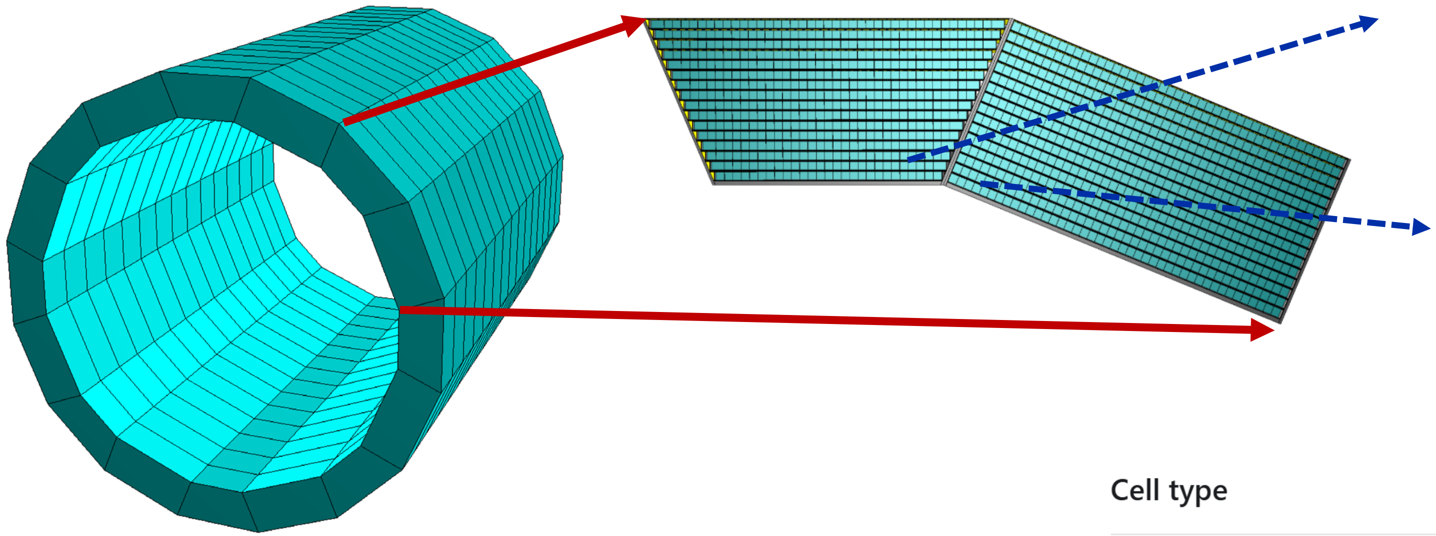

**Goal: EM energy resolution: ~3%/√E， HCAL energy resolution ~10%/√E**

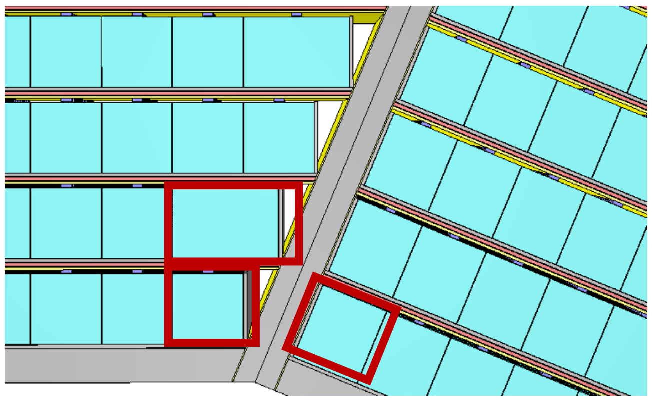
# Detailed Parameters

<table>
<tr><th rowspan="2"></th><th>2025.09（9th Meeting）</th><th colspan="2">2026</th></tr>
<tr><th>Realization</th><th>Target (ECAL)</th><th>Target (HCAL)</th></tr>
<tr><td>Dimension (mm³)</td><td>40×40×10</td><td>20×20×20</td><td>40×40×40</td></tr>
<tr><td>Density (g/cm³)</td><td>>6.0</td><td colspan="2">6.0</td></tr>
<tr><td>Transmittance (%@400 nm)</td><td>76</td><td colspan="2">>80</td></tr>
<tr><td>Emission peak (nm)</td><td>390</td><td colspan="2">~400</td></tr>
<tr><td>Light yield (ph/MeV)</td><td>1408</td><td>2000</td><td>1000</td></tr>
<tr><td>Energy resolution (%@662keV)</td><td>28.7</td><td colspan="2">< 25</td></tr>
<tr><td>Decay time (ns)</td><td>72.4 (10.5%),547.8</td><td colspan="2">< 500</td></tr>
<tr><td>Attenuation length (cm@400nm)</td><td>6.05</td><td colspan="2">> 10-20</td></tr>
</table>

# Scintillating-Glass ECAL Barrel Design

- 16 layers, each cubic is approximately $20 \times 20 \times 20\ mm^3$, $\sim 20\ X_0$, ~1.4 λ
- three glass-cell dimensions: normal and edge cells in trapezoidal module, and one cell type in rectangular module

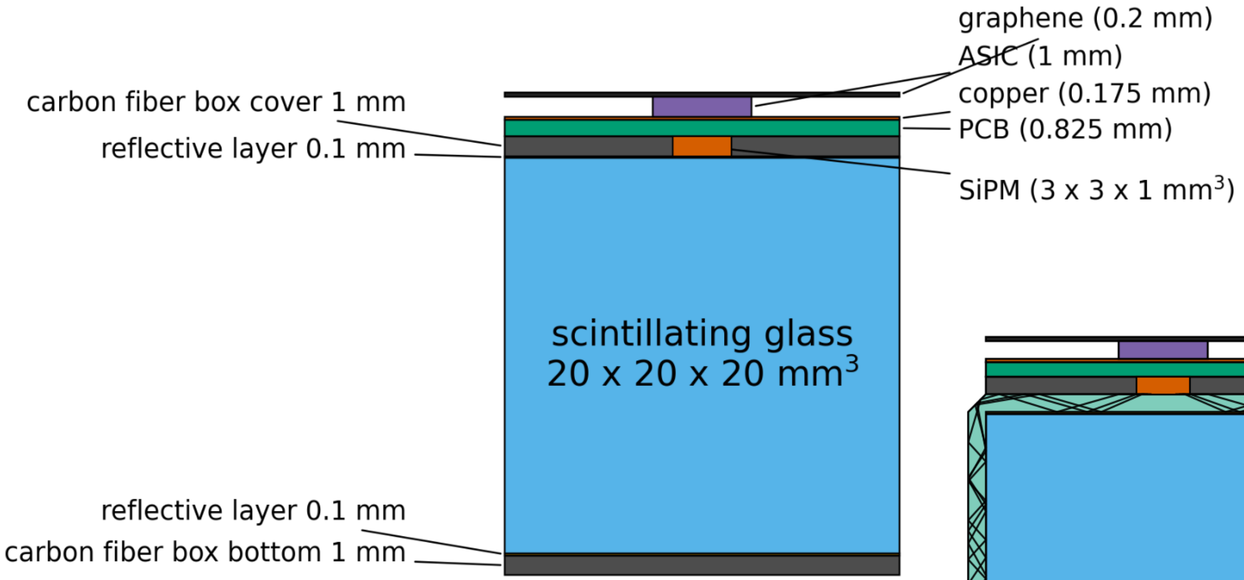


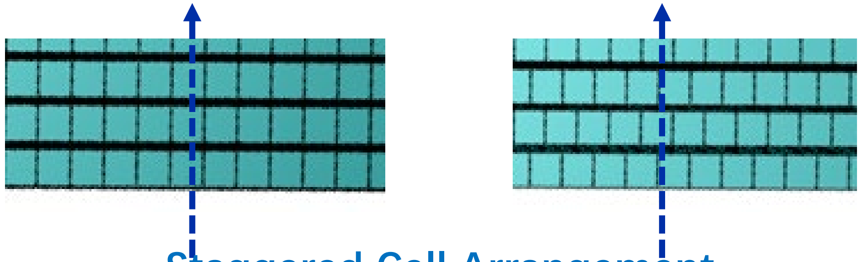


| Cell type | Glass size $(\phi \times z \times r)$ |
|---|---|
| Trapezoidal-module normal cell | $20.5 \times 19.9 \times 20.6\ \mathrm{mm}^3$ |
| Trapezoidal-module edge cell | $30.8 \times 19.9 \times 20.6\ \mathrm{mm}^3$ |
| Rectangular-module cell | $20.0 \times 19.9 \times 22.7\ \mathrm{mm}^3$ |

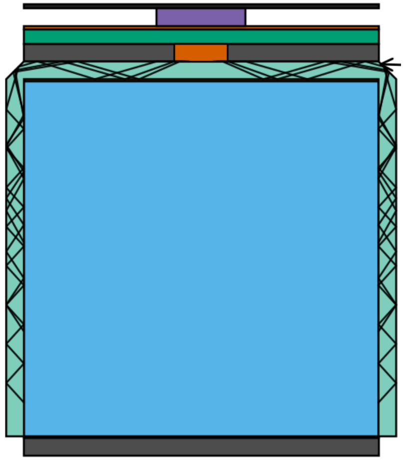
# Scintillating-Glass Cell

- Light collection uniformity across the cell seems a major problem for energy resolution due to the too short attenuation length of the glass
- Solutions: add light guide, staggered cell, add more SiPM/cell

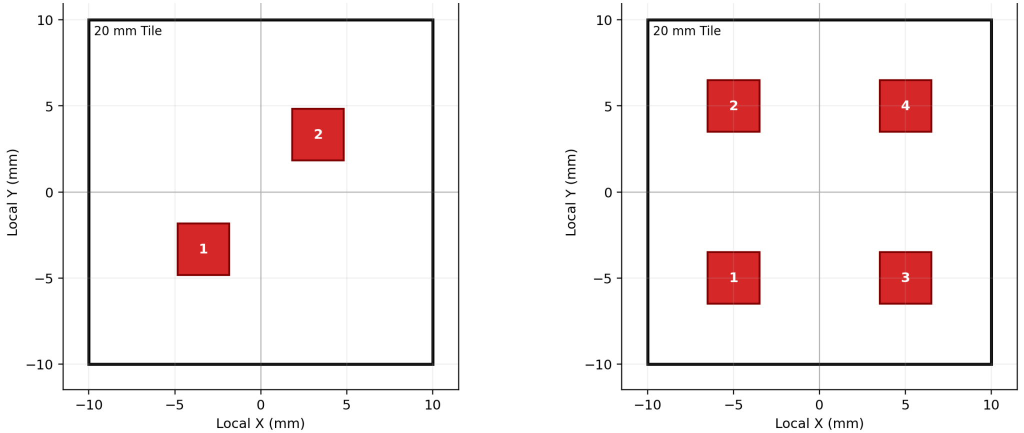


Staggered Cell Arrangement



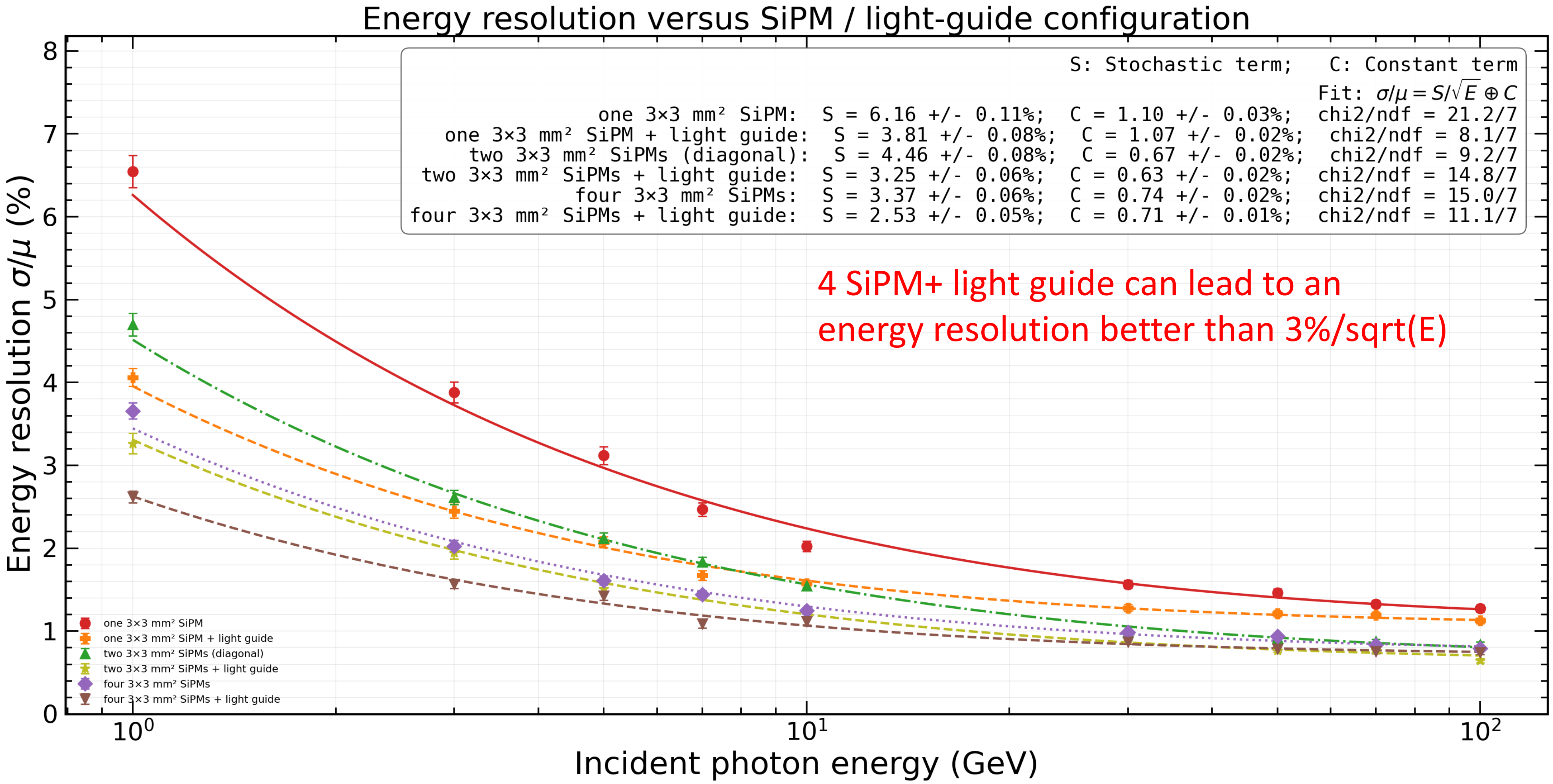
Add the light guide



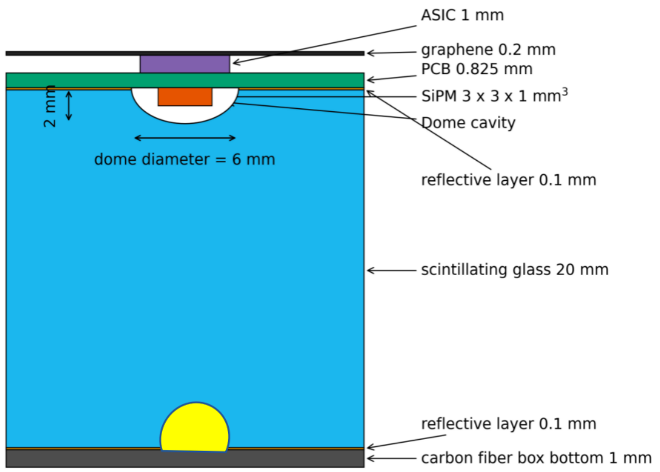

Add more SiPM

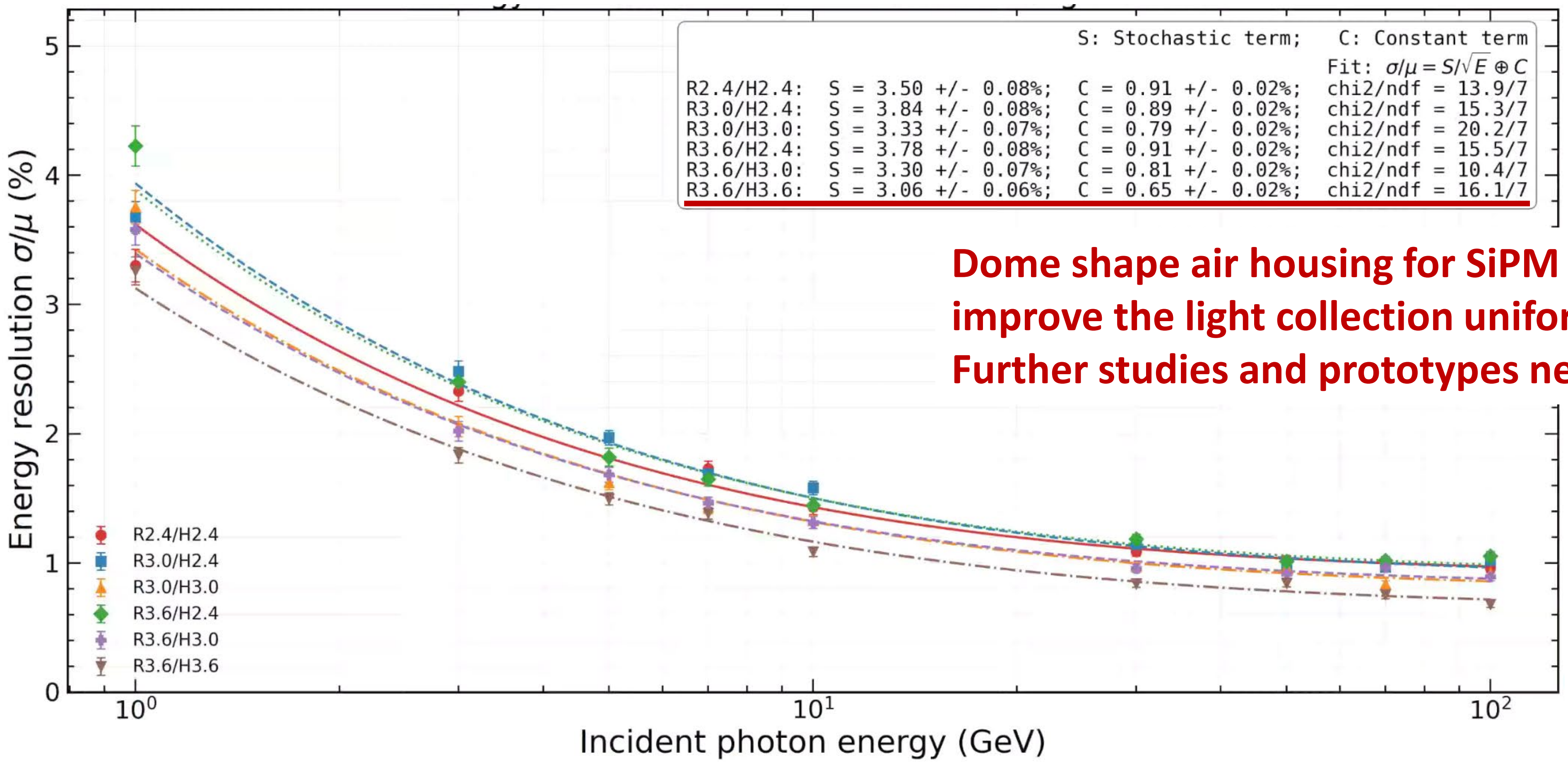
# Performance from Simulation

- 1-100 GeV photons, entering near the centre of one module: $86.9^\circ < \theta < 93.1^\circ, 17.5^\circ < \phi < 27.5^\circ$
- Sum of digitized cell energies



# Another Cell Design: only one 3×3 mm² SiPM



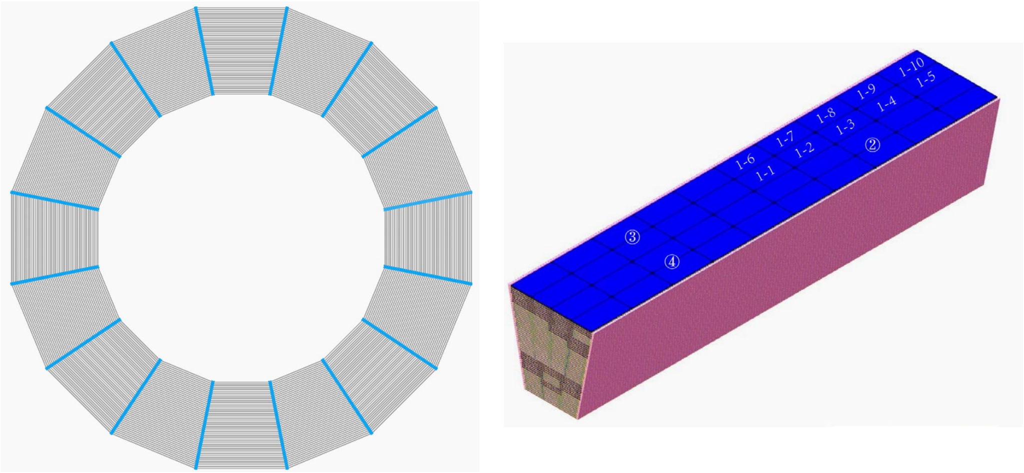




**Dome shape air housing for SiPM can substantially improve the light collection uniformity**

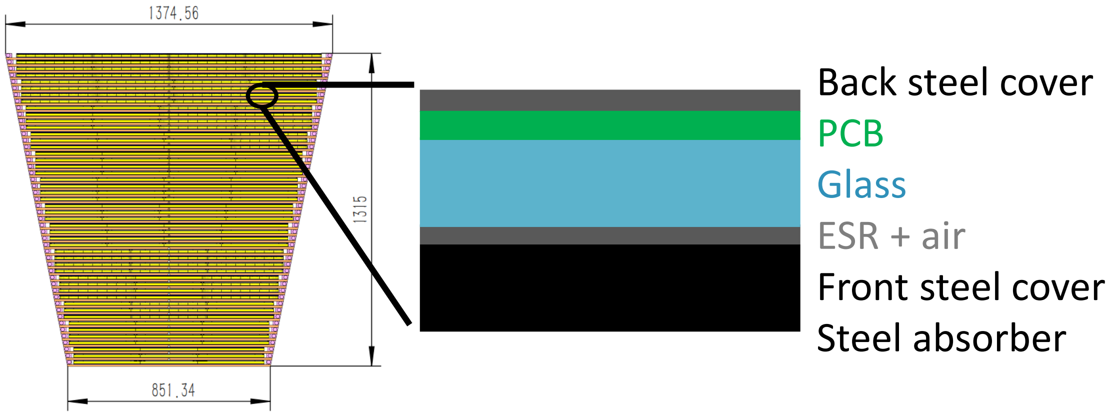
**Further studies and prototypes needed**

# Homogeneous GS-HCAL Design

- Retain the steel for mechanical structure
- Replace the steel absorber by Glass
- Barrel:
  - 16 sectors, supported by steel framework
  - Each layer composed of GS cells (~$4 \times 4 \times 4\ \mathrm{cm}^3$), ESR, PCB and steel covers
  - A total of ~5 $\lambda$



Barrel part of GS-HCAL in AGORA



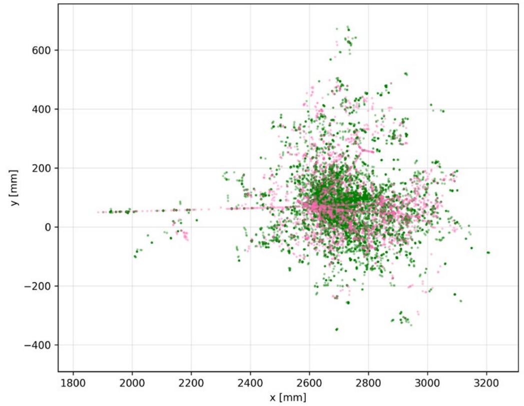

sampling structure (30% sampling fraction )


Homogeneous structure

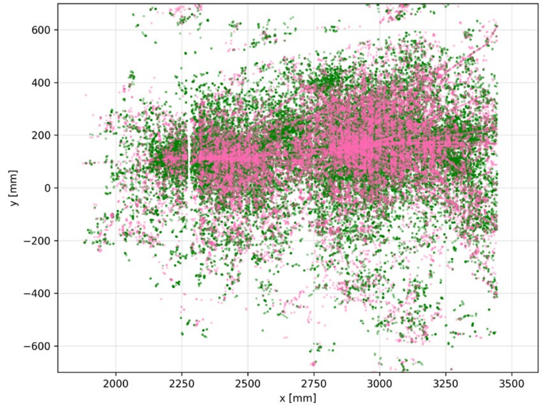
# Performance from Simulation

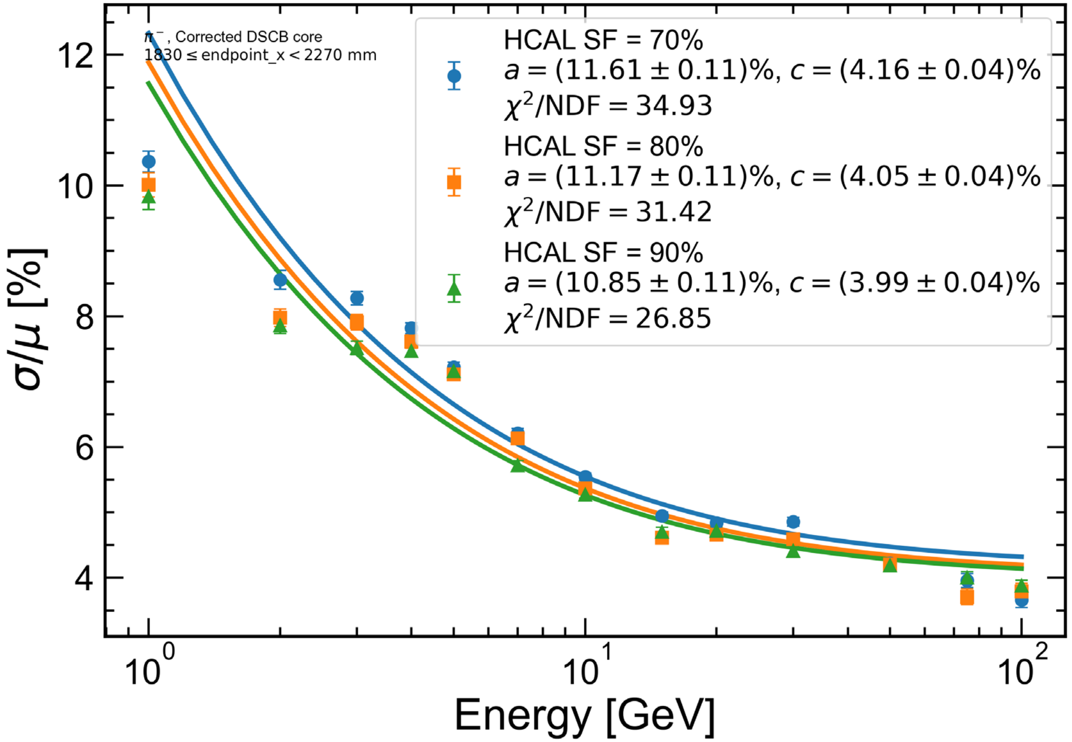
- Simulation settings
  - Geometry
    - GS ECAL + HCAL
    - Three HCAL sampling fractions: 70%, 80%, 90%
    - No B field
  - Particles
    - $\pi^-, E = 1, 2, \ldots, 100$ GeV, $\phi = -3°\sim3°, \theta = 87°\sim93°$
- Preliminary Results
  - For sampling ratio (active materials) more than 70%, energy resolution is ~ $11\%/\sqrt{E} \oplus 4\%$
  - Further studies still needed: Light collection uniformity, PSD for E/H correction, optical wrapping, cubic size optimization, SiPM optimization, readout electronics, calibration, …

a 10 GeV $\pi^-$




an 100 GeV $\pi^-$



# Future Plan for Glass Calorimeter

- Optimize structure design: mechanics, modules, cells, SiPM, electronics, cables, cooling, etc.
- Optimize Glass cells: size, shape, wrapping, glueing, …
- Glass R&D: attenuation length, uniformity, light yield, decay time, production yield, cost
- Performance study: readout electronics, PSD for E/H correction, calibration, …
- Prototyping: ECAL 2027, HCAL 2028

# Summary

- Despite difficulties, we will continue to pursue High Energy Physics: road map is clear for us
- As an innovative concept, AGORA has been listed as a concept for FCC_ee
- Glass scintillator is a very promising material, although a lot more R&D are needed
- Looking forward to (more) collaborations !

# AGORA - FCC-ee/CEPC Detector Concept

- **Website**: https://agora.web.cern.ch
- **Email list**: fcc-ped-detectorconcepts-agora@cern.ch
  - Subscribe at: https://groups-portal.web.cern.ch/group/fcc-ped-detectorconcepts-agora/details
- The AGORA seed: CEPC Reference Detector **TDR**:
  - https://arxiv.org/abs/2510.05260
- AGORA Weekly **Plenary Meeting**:
  - Wednesday at 9 am, CERN time
  - https://indico.cern.ch/category/21753/
- CEPC Yearly **Workshops**:
  - International Workshop, Shanghai, 22-26 October 2026: https://indico.ihep.ac.cn/event/28911/
  - European Edition Workshop, Belgrade, Serbia, June 8-11, 2027
    - (Last year's workshop, Lisbon, Portugal, April 2026: https://indico.cern.ch/event/1598929/)
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AGORA

ADVANCED GLASS OPTIMIZED RESEARCH APPARATUS