R&D of Glass Scintillator-HCAL

闪烁玻璃合作组
Glass Scintillator Collaboration

Sen QIAN

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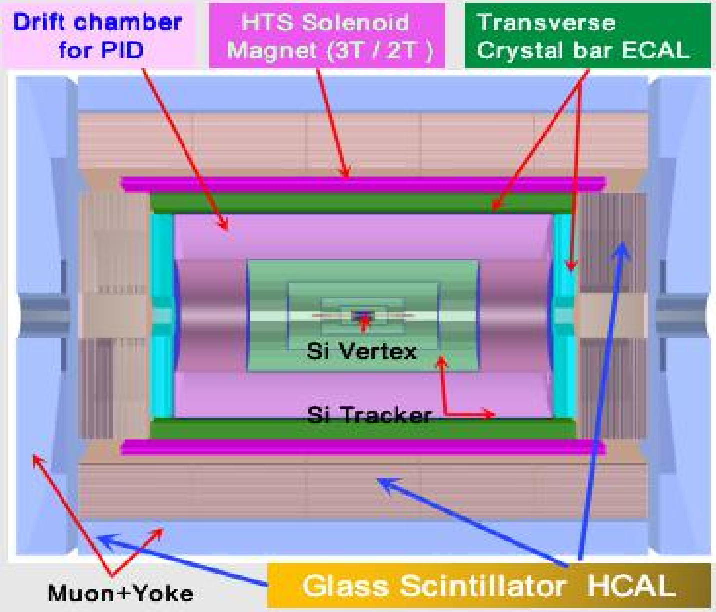
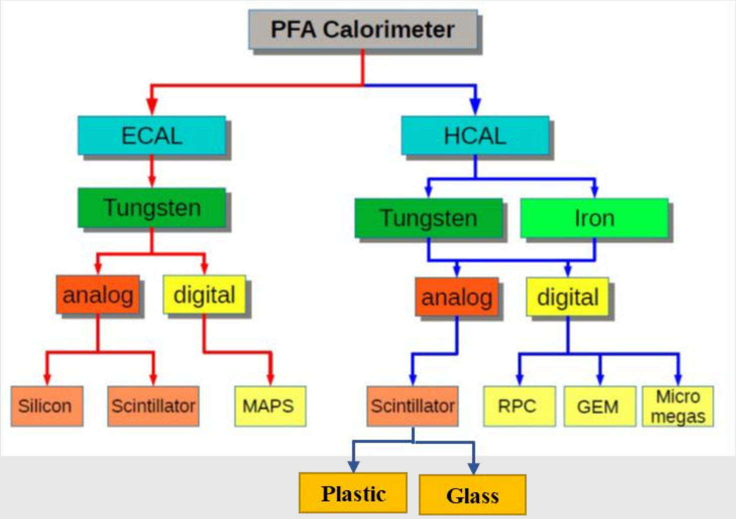
Outline

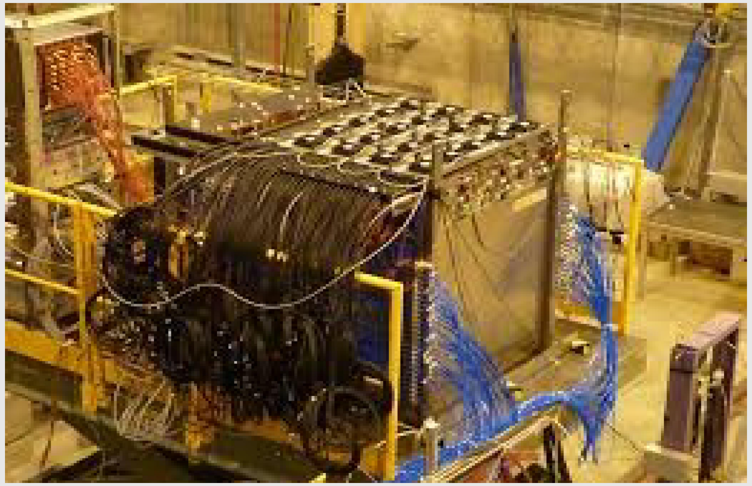
- 1. Motivation for GS-HCAL
- 2. R&D of the GS
- 3. Design of the GS-HCAL in CEPC
- 4. Summary and Next Plan



1.1 HCAL Design Options （The Past）

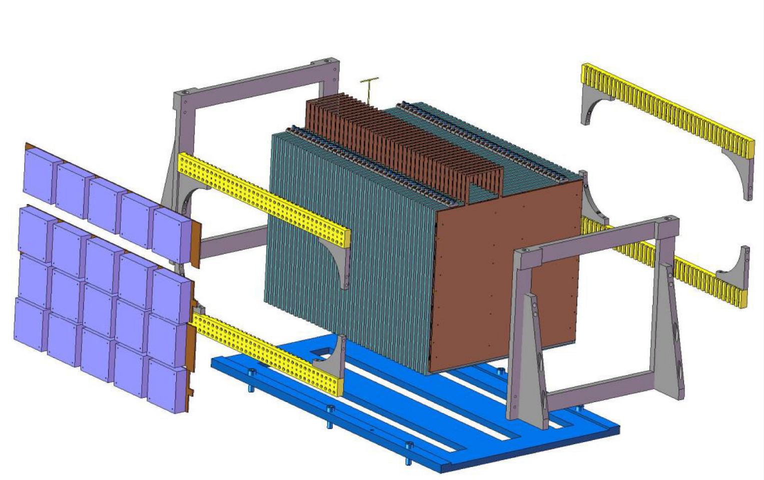
- Several HCAL design options have been proposed
  - Based on Gaseous Detector
    - e.g. CALICE SDHCAL doi:10.1088/1748-0221/11/04/P04001
  - Based on Liquid Argon
    - e.g. ATLAS LAr Endcap HCAL doi:10.1016/j.nuclphysbps.2011.03.150
  - AHCAL: Plastic Scintillator & SiPM readout
    - e.g. CEPC AHCAL doi:10.1088/1748-0221/17/11/P11034





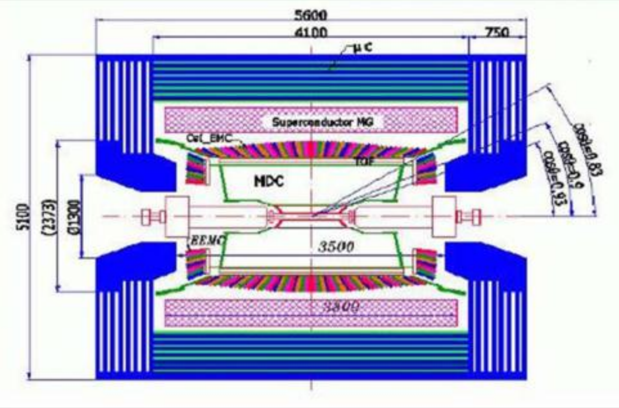
➢ CALICE SDHCAL Prototype

➢ ATLAS LAr Endcap HCAL

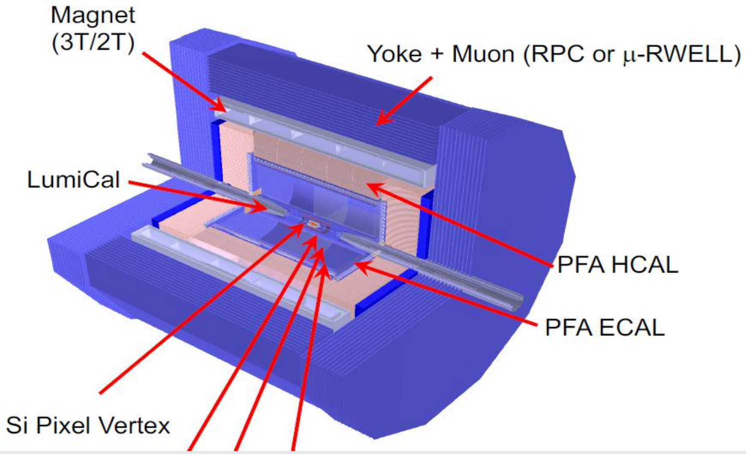


➢ CEPC AHCAL Prototype

Technologies uesd in Calorimeters

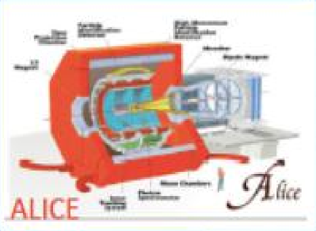


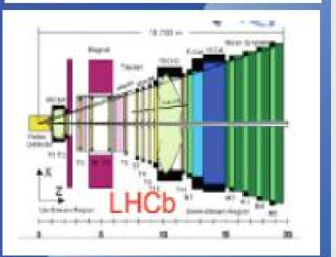
BEPC-BESIII-EMC：CsI + PD

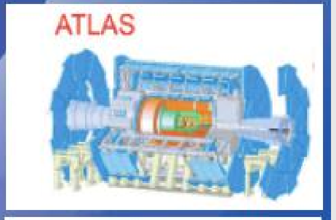


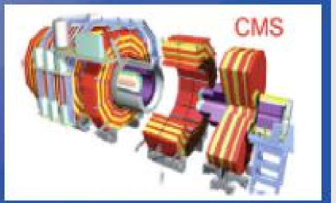
CEPC-CDR-ECAL：Plastic Scintillator tungsten
CEPC-CDR-HCAL：Plastic Scinillator + SiPM

- $PbWO_4$ homogeneous calorimeter:
  - CMS ECAL, ALICE PHOS
- LAr sampling calorimeter:
  - ATLAS EM Barrel and Endcap, Hadronic Endcap, Forward calorimeters
- Scintillator/WLS fiber sampling calorimeters:
  - CMS HCAL Barrel and Endcap, ATLAS TileCal (barrel HCAL), LHCb HCAL
- Shashlik Pb/Scint sampling calorimeters:
  - ALICE EMCal/DCal, LHCb ECAL
- Quartz Fiber/Steel sampling calorimeter:
  - CMS HCAL Forward









Except **$PbWO_4$** or **Plastic Scinillator**, **Crystal can not used for the ECAL or HCAL, too expensive!**

What is the Scintillator？

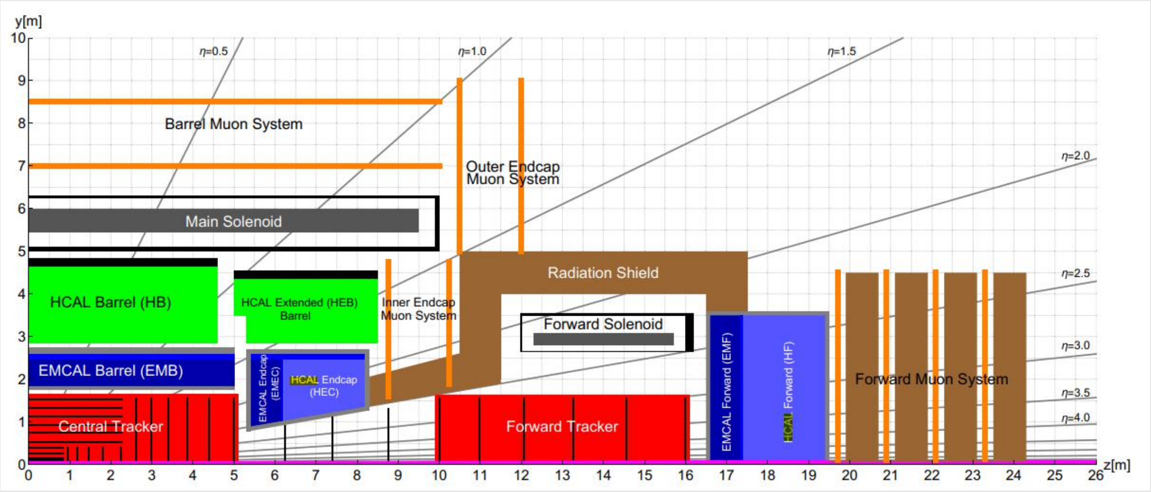
Plastic Scintillator

Glass Scintillator

Crystal Scintillator

Large density	☆	Large density	★★☆	Large density	★★★
High light yield	★★★	High light yield	★	High light yield	★★★
Energy resolution	★	Energy resolution	★★	Energy resolution	★★★
Low cost	★★★	Low cost	★★	Low cost	☆
Fast decay	★★★	Fast decay	★★	Fast decay	★★
Large size	★★★	Large size	★★	Large size	☆

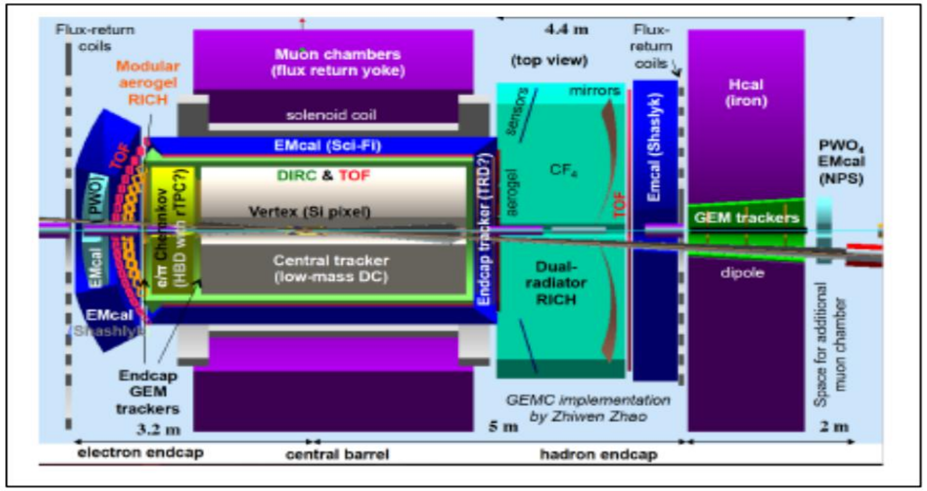
1.2 HCAL Design Options （The Future）



■ Longitudinal cross-section of the FCC-hh reference detector

Task 1.2: Hadronic section with optical tiles	
Subtask 1.2.1: AHCAL	Scintillating plastic tiles/Steel
Subtask 1.2.2: ScintGlassHCAL	Heavy glass tiles/Steel

Task 1.2
- AHCAL: Concept for continous readout
- **ScintGlass HCAL**: cm scale tiles



■ Example layout of the EIC detector base design

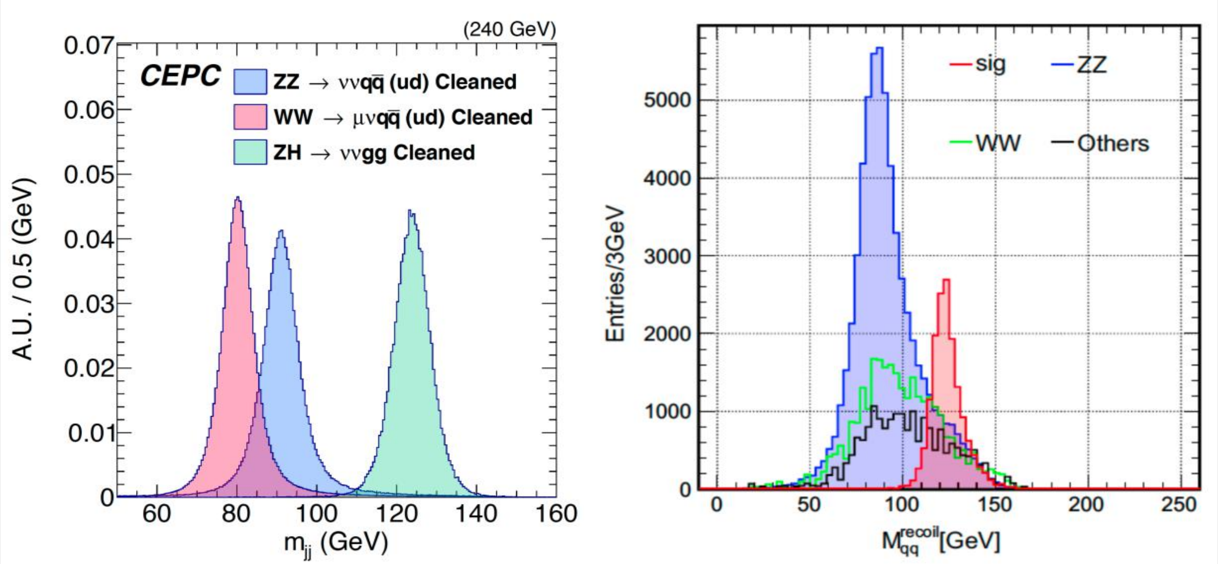
Glass for EIC:
- Sufficient resolution
- Fast response
- Radiation hardness

Task 1 ： build a cost effective glass-ceramic calorimeter for the outer endcaps and central regions

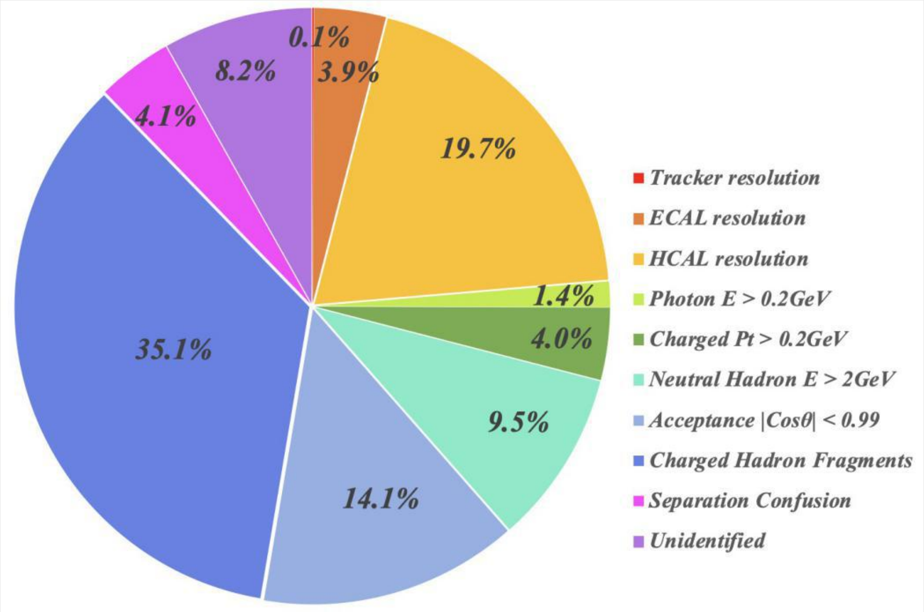
Task 2： Push the performance of **glass ceramics** towards crystals

1.3 Physics Requirements of CEPC-HCAL

- CEPC as Higgs/W/Z factories:
  - **Jet Energy Resolution s/E ~ 5%**
  - **Boson Mass Resolution (BMR) < 4% :** it is strongly motivated by H/W/Z hadronic final states, BSM & Flavor Physics



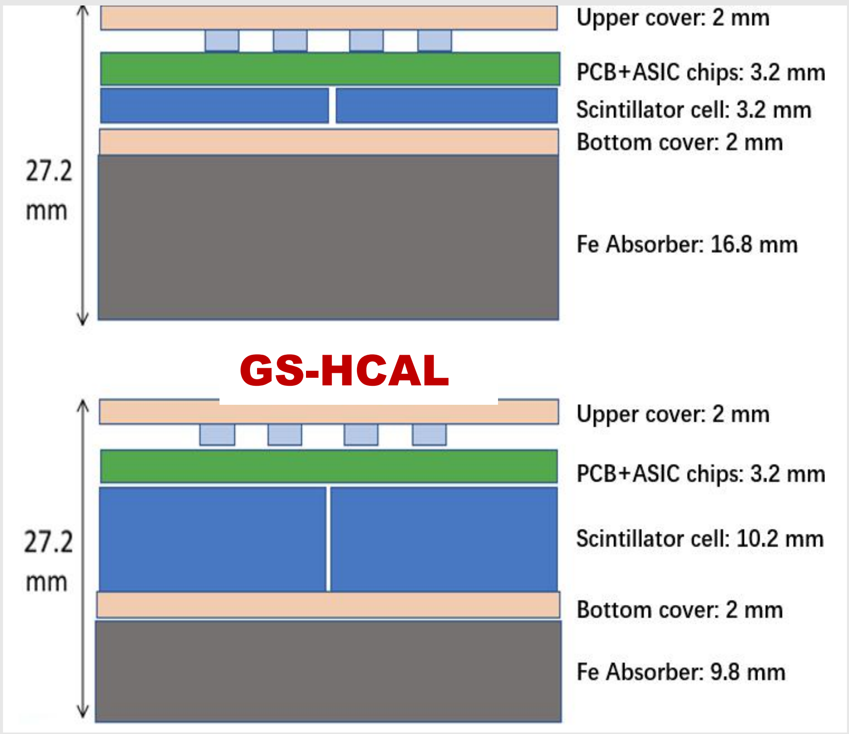
- Leading contributions to BMR:
  - HCAL resolution dominant the uncertainties from intrinsic detector resolution: **~19.7%**
  - **Further improvement of HCAL is needed**



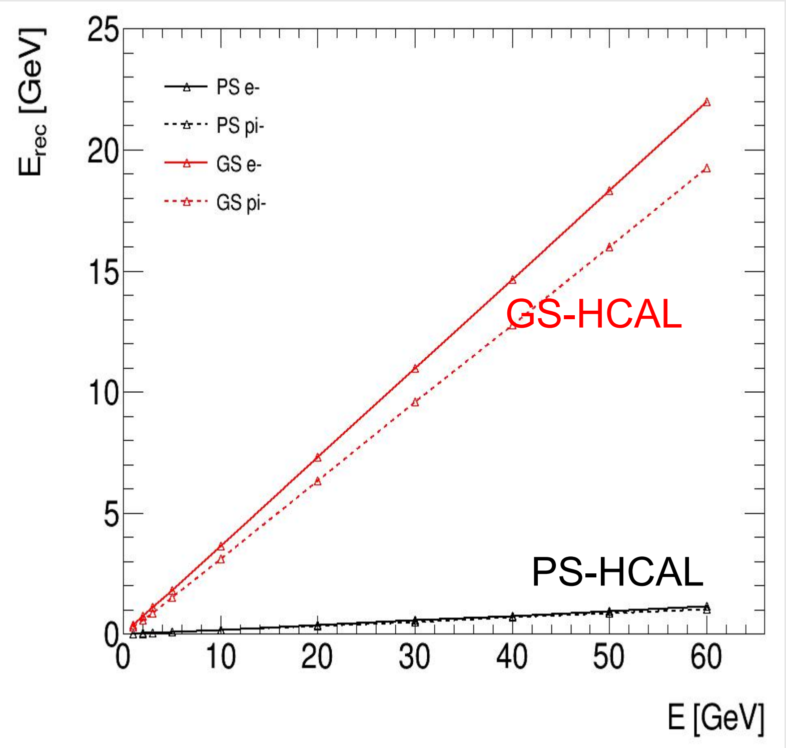
CDR baseline (arXiv:1811.10545): BMR = 3.75%， lots reports were discussed by Manqi Ruan.

Glass Scintillator CEPC-HCAL

- **Basic idea:** to increase sampling fraction for better energy resolution
- With **high density and thick GS cell design,** the sampling fraction of GS-HCAL can be increased by a factor of ~20 compared to that of PS-HCAL.

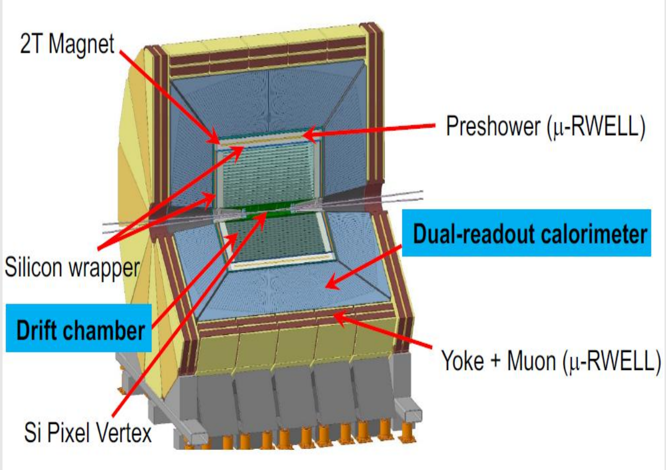


- PS-HCAL
  - Fe: 20.8mm/171.5mm=0.1213 λ_I
  - PS: 3mm/688.7mm=0.0044 λ_I
  - PCB: 1.2mm/492.2mm=0.0024 λ_I
  - Sampling fraction ~ 1.6% (π^- TB, MC)
- GS-HCAL
  - Fe: 13.8mm/171.5mm=0.0805 λ_I
  - GS: 10.2mm/242.8mm=0.0425 λ_I
  - PCB: 1.2mm/492.2mm=0.0024 λ_I
  - Sampling fraction ~ 31% (MC)



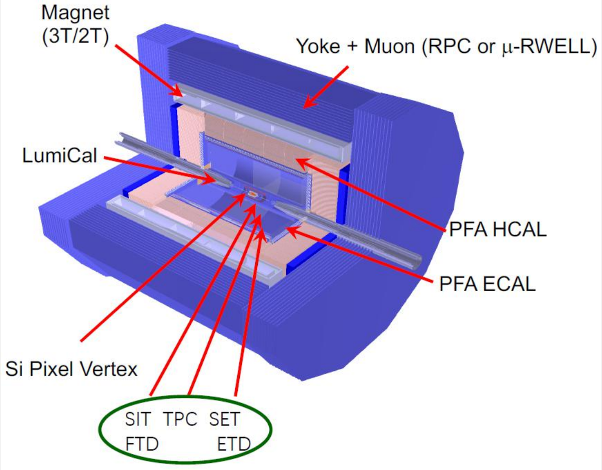
CEPC Conceptual Detector Design （The Future）

1st IDEA Concept (also proposed for FCC-ee)



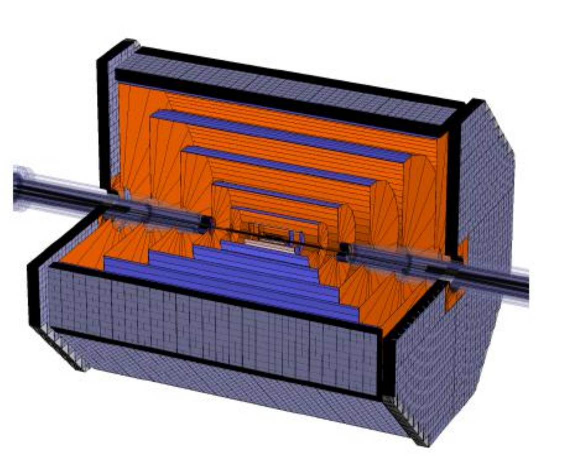
- **Dual-readout calorimeter (Cerenkov-Fiber & Scint-Fiber)**
- both for EM and Hadronic Shower

2nd CDR Baseline Design (Particle Flow Approach)



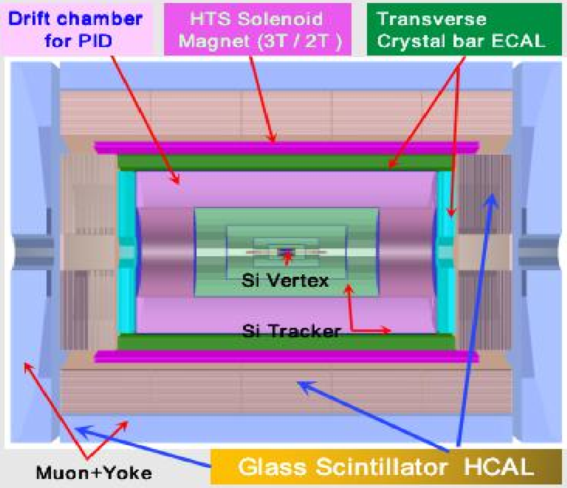
- **AHCAL (PS/Steel) or SDHCAL (Gas/Steel)**
- Si/W ECAL or PS/W ECAL

3rd FST concept (Full Silicon Tracker)



- **AHCAL (PS/Steel) or SDHCAL (Gas/Steel)**
- Si/W ECAL or PS/W ECAL

4th Conceptual Detector



- **GSHCAL (GS/Steel)**
- BGO Crystal ECAL

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2.0 Development of Glass Scintillator

1. Commercialization of glass scintillator

2. High density

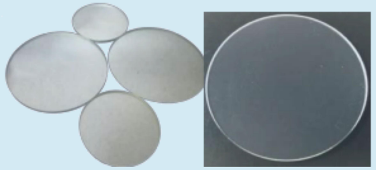
3. High LY

4. High density & LY


Glass Scintillators*

R. J. GINTHER† AND J. H. SCHULMAN†

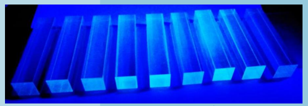
1958, Ce-doped high-silicon glass.
Under γ-ray excitation, the pulse height is 10% of NaI(TI).



1976, commercialized GS series glass scintillator (GS20 ρ=2.5 g/cm³, LY=6000 ph/neutron

2015, DSB glasses for high energy physics experiments,
ρ= 3.8 g/cm³,
LY= 1360 ph/MeV

1996, heavy metal fluoride glass EM calorimeter



2021, GS Group for R&D new glass scintillator
ρ= 6 g/cm³ LY= 1000 ph/MeV

1950 1960 1970 1980 1990 2000 2010 2020 2025

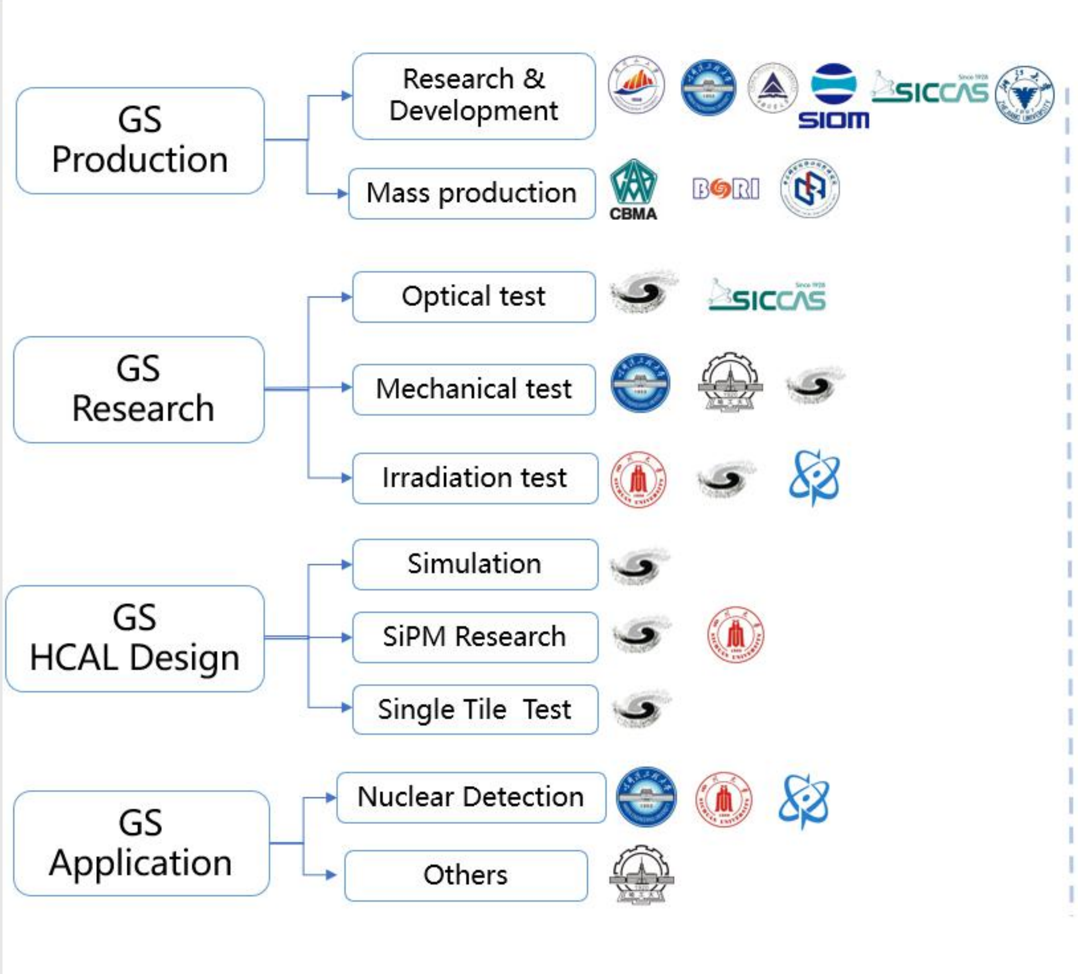
1962, glass for thermal neutron detection

1988, glass scintillator calorimeter design

2000, the concept of energy transfer sensitization

2020, Ce^{3+} doped Gd-based glass

2.1 Large Area Glass Scintillator Collaboration



- 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 Mechanics, 中国科学院上海光学精密机械研究所
- CNNC Beijing Nuclear Instrument Co., 中核（北京）核仪器有限责任公司
- Zhejiang University 浙江大学
- Ganjiang Innovation Academy, CAS 中国科学院赣江创新研究院

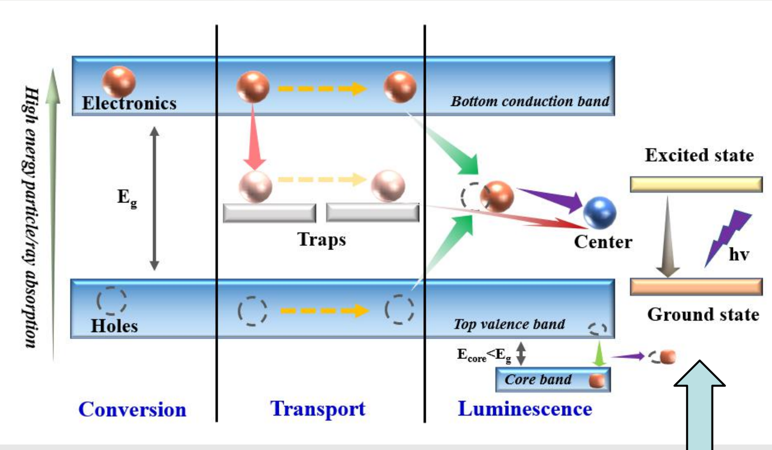
闪烁玻璃合作组
Glass Scintillator Collaboration

Spokesperson：Sen QIAN

-- The Glass Scintillator Collaboration Group established in Oct.2021；

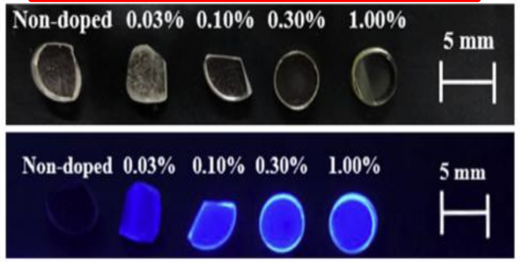
-- There are 4 Institutes from CAS, 6 Universitys, 3 Companies join us for the R&D of GS;

2.2 Design of the GS



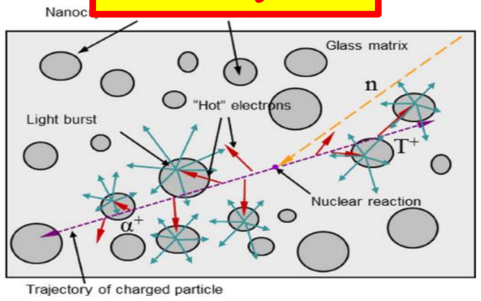
- **Scintillation mechanism----** Luminescence Center
- **Conversion**—photoelectric effect and Compton scattering effect;
- **Transport**—electrons and holes migrate;
- **Luminescence**—captured by the luminescent center ions

Lanthanide elements



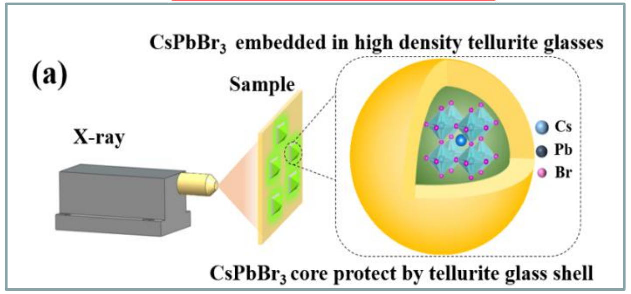
Journal of Alloys and Compounds 782 (2019) 859-864

Nanocrystals



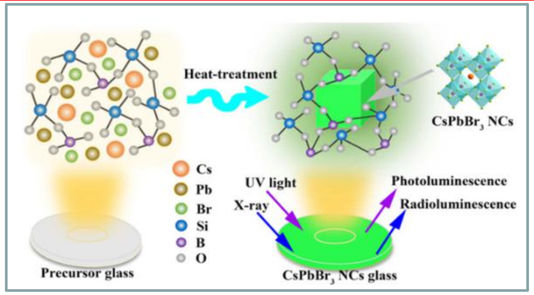
IEEE TNS 60 (2) 2013

Quantum Dots



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

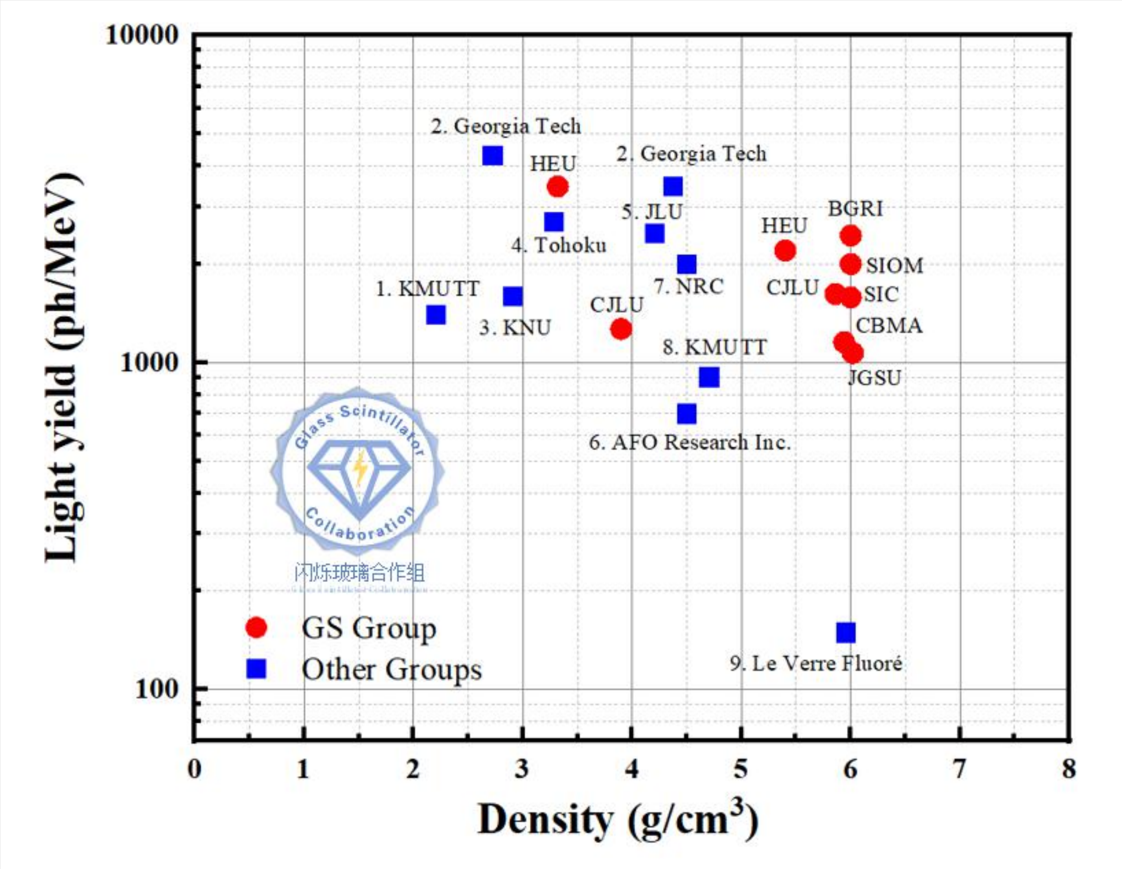
Lanthanide + Quantum Dots

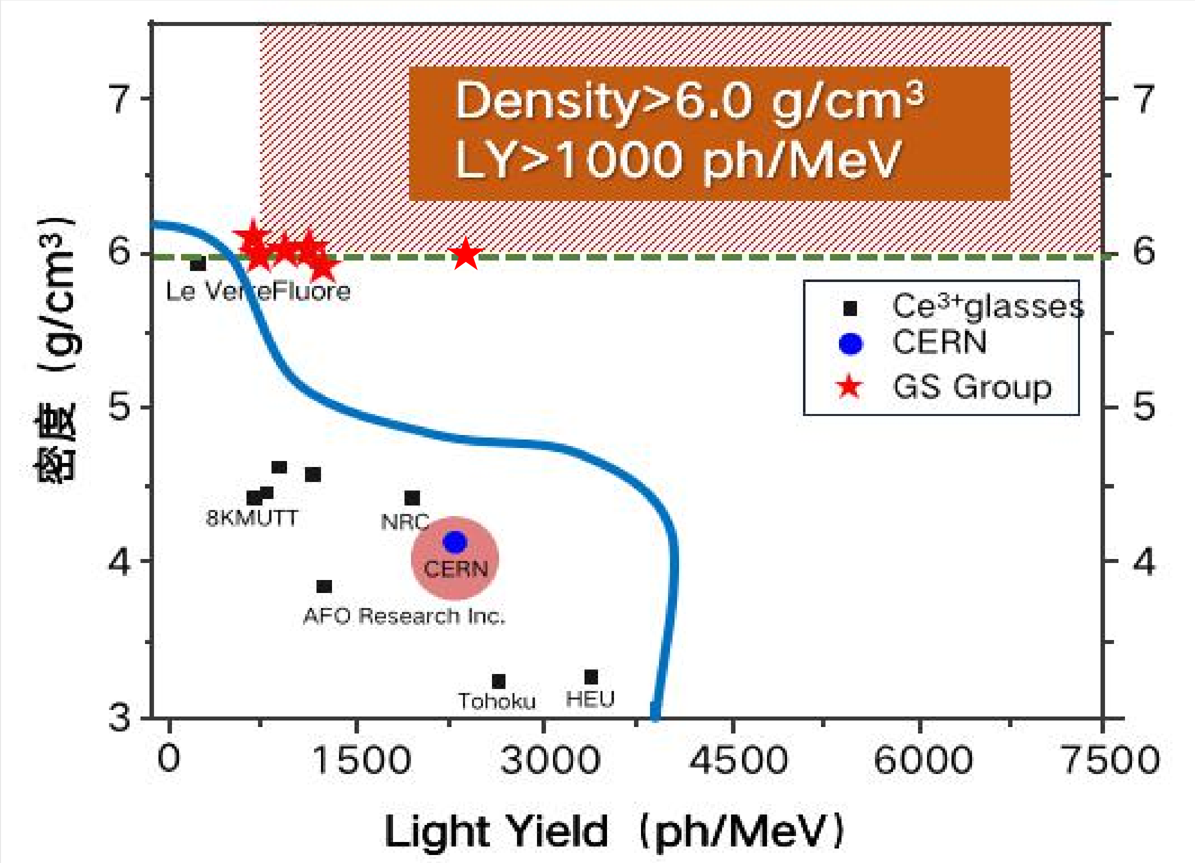


Vol. 9, No. 12 / 2021 / Photonics Research

- 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)~~

2.3 GS Group Samples



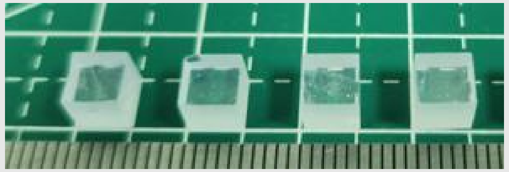


- The GS group has carried out a comprehensive and complete study;
- For high density glass scintillator, the light yield of GS group samples is in the absolute lead.

Small Size Sample

GFO & GFO+ （5mm×5mm×5mm）

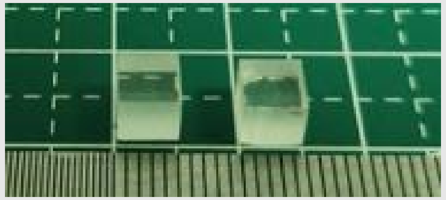
GFO

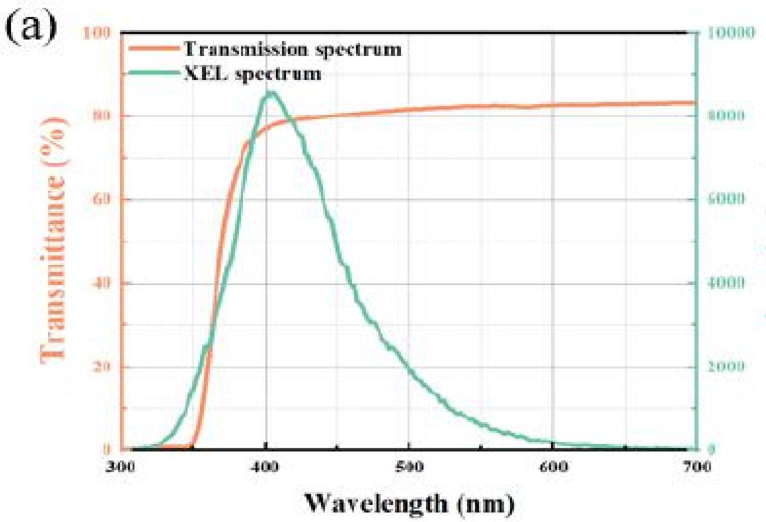


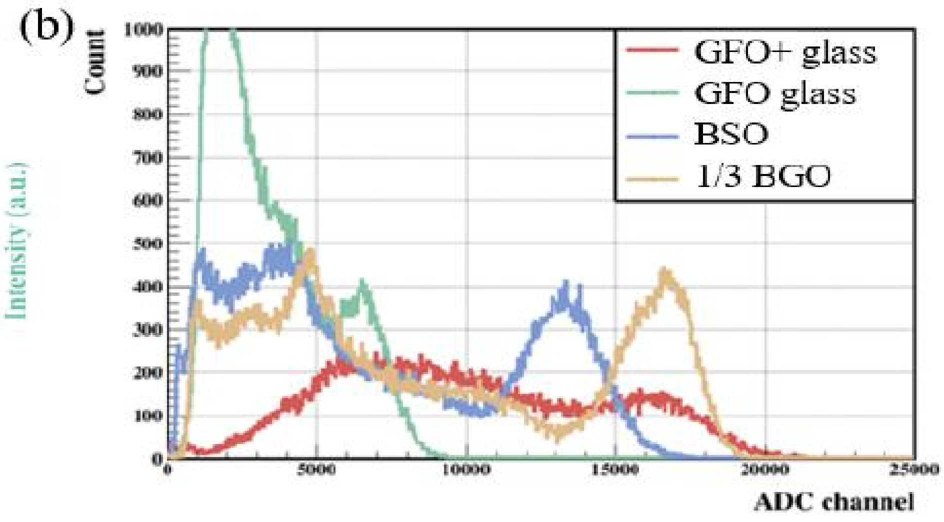
- Density~6.0 g/cm^3
- **LY=985 ph/MeV**
- ER=30.3%
- LO in 1μs=982 (99%)
- Decay=36 (8%), 105 ns

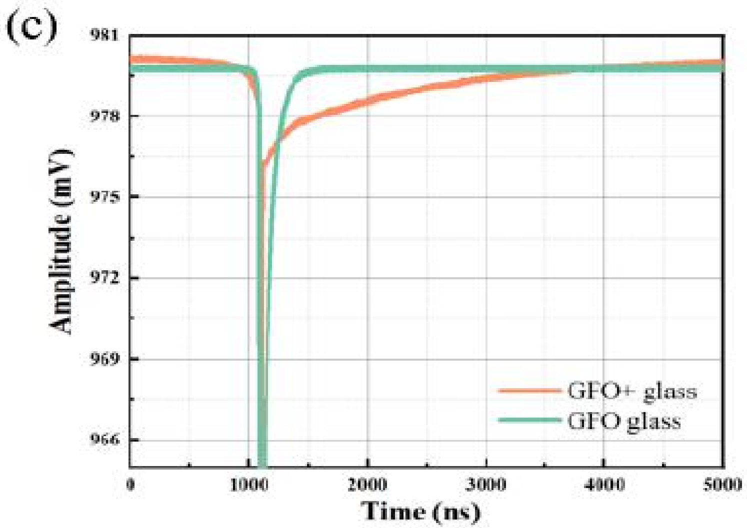
- Density~6.0 g/cm^3
- LY=2445 ph/MeV
- ER=25.8%
- LO in 1μs=1074 (44%)
- Decay=101 (2%), 1456 ns

GFO+







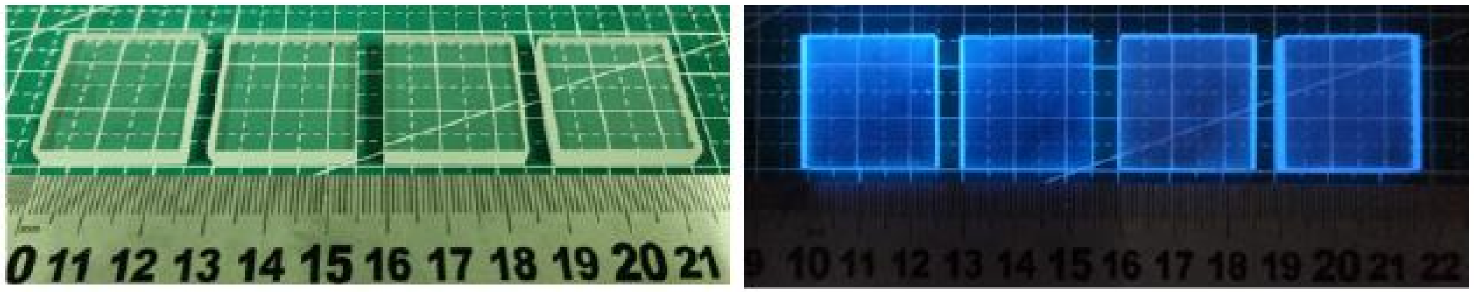


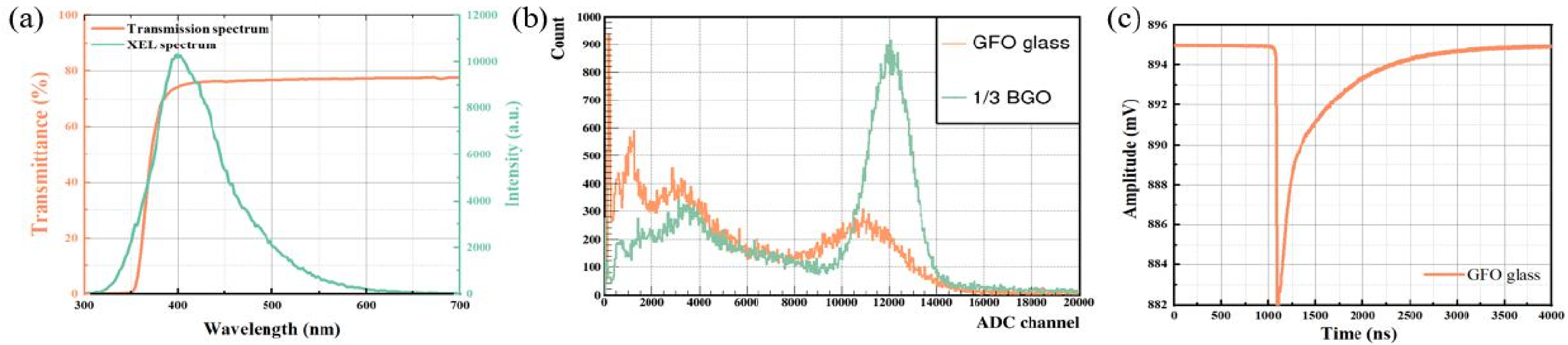
- (a) Transmission and XEL spectra
- (b) Energy spectra
- (c) Scintillation decay curves

Large Size Sample

GFO （40mm×40mm×10mm）

- Density=6.0 g/cm³
- LY=1506 ph/MeV
- ER=41.2%
- LO in 1μs=1129 (75%)
- Decay=53 (3%), 655 ns





- (a) Transmission and XEL spectra
- (b) Energy spectra
- (c) Scintillation decay curves

Published Paper about Glass Scintillator

Ceramics International 49 (2023) 18044–18051

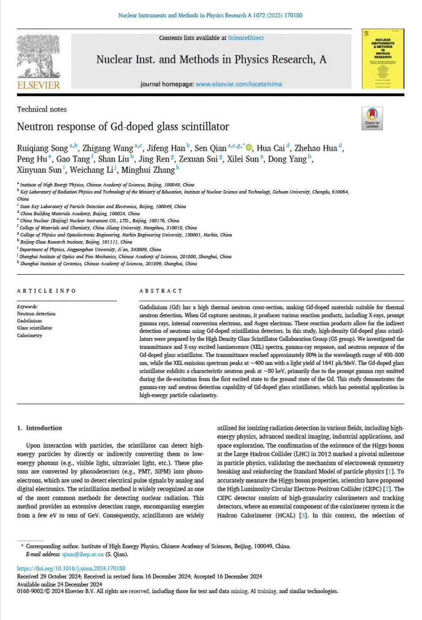
Ceramics International

Effect of B_2O_3 on luminescence and scintillation properties of Ce^{3+}-doped gadolinium aluminium–silicate glass

Radiation Detection Technology and Methods

ORIGINAL PAPER

An evaluation method for nuclear radiation detection performance of glass scintillator



Nuclear Instruments and Methods in Physics Research A 1072 (2025) 170180

Nuclear Inst. and Methods in Physics Research, A

Technical notes

Neutron response of Gd-doped glass scintillator

Nuclear Instruments and Methods in Physics Research A 1072 (2025) 170102

Nuclear Inst. and Methods in Physics Research, A

Light attenuation and loss in Ce^{3+}-doped dense glass scintillator

ARTICLE IN PRESS

Ceramics International

Ce^{3+}-doped glass scintillator with high density and high light yield for imaging application

Nuclear Instruments and Methods in Physics Research A 1081 (2026) 170869

Nuclear Inst. and Methods in Physics Research, A

Technical notes

Radiation resistance study of Gd-Al-B-Si-Ce^{3+} glass scintillators using 80 MeV proton|beam irradiation

- 2022 Cermaics Inter.
  Introduce the GS sample
- 2024 RDTM.
  Performance of GS
- 2025 NIMA.
  Neurton Rsponce of GS
- 2025 NIMA.
  Light attenuation of GS
- 2025 Cermaics Inter.
  X-Ray imaging of GS
- 2026 NIMA.
  Radiation resistance of GS

2026 for the publish plan

- Cosmic Ray test of GS and GS-HCAL mini prototype
- Electron beam test of GS
- Pion beam test of GS and GS-HCAL mini prototype

The Innovation Review Paper

REVIEW

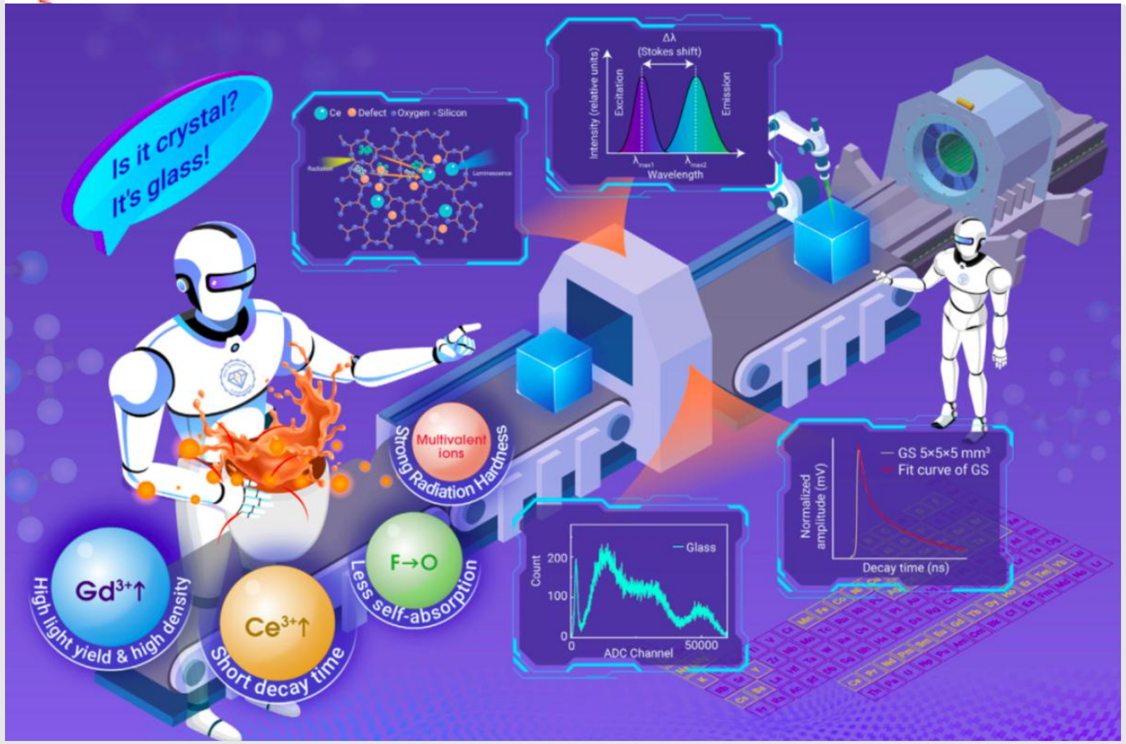
OPEN ACCESS

Glass scintillator: A window to future high-energy radiation detection

Zexuan Sui,[1,2] Sen Qian,[1,2,*] Luyue Niu,[1] Peng Hu,[3] Zhehao Hua,[2] Xiaoxin Zheng,[1] Xinyuan Sun,[4] Gao Tang,[5] Hua Cai,[6] Dong Yang,[7] Weichang Li,[8] Minghui Zhang,[9] Jifeng Han,[10] and Jing Ren[1,*]

*Correspondence: qians@ihep.ac.cn (S.Q.); ren.jing@hrbeu.edu.cn (J.R.)

Received: January 24, 2025; Accepted: March 9, 2025; Published Online: May 5, 2025; https://doi.org/10.1016/j.xinn.2025.100878



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Glass Scintillator Collaboration

DOI:10.1016/j.xinn.2025.100878；

Sui Z., Qian S., Niu L., et al. (2025). Glass scintillator: A window to future high-energy radiation detection. The Innovation 6:100878.

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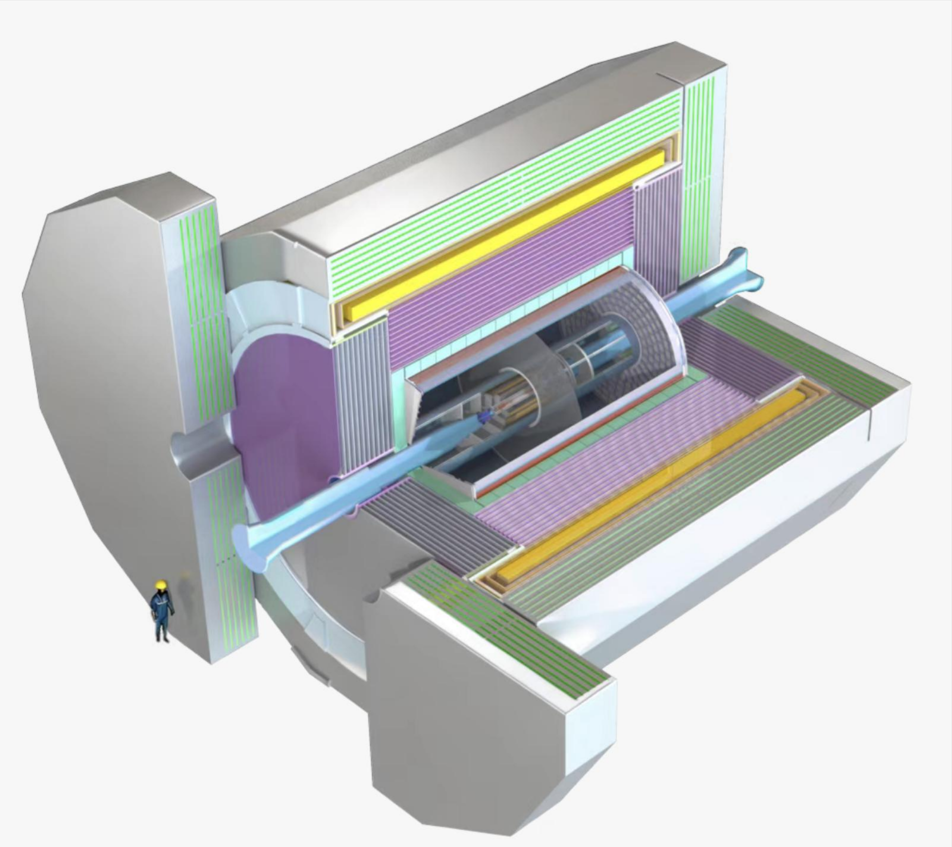
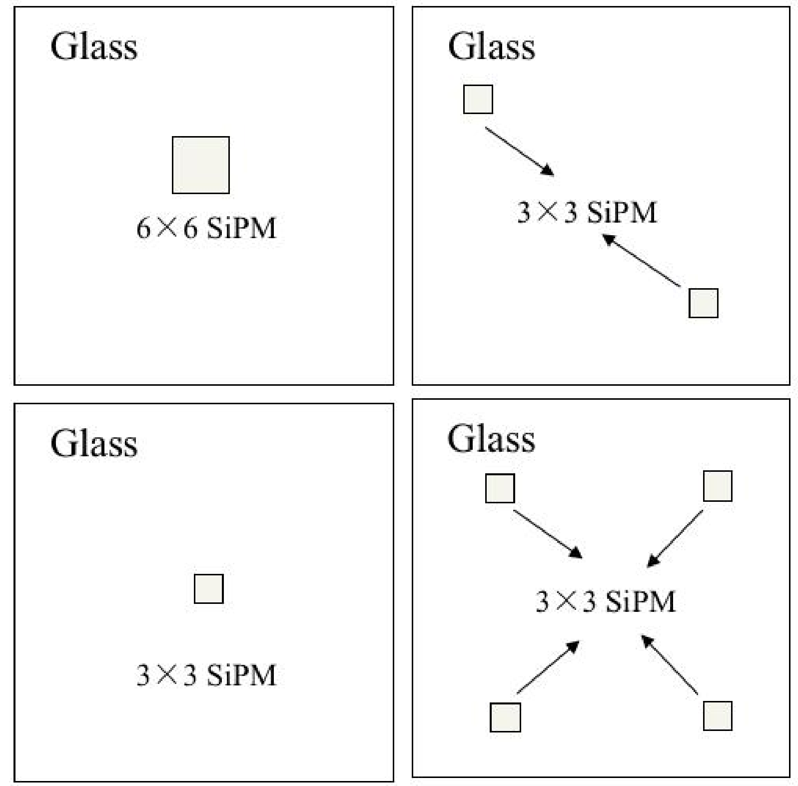
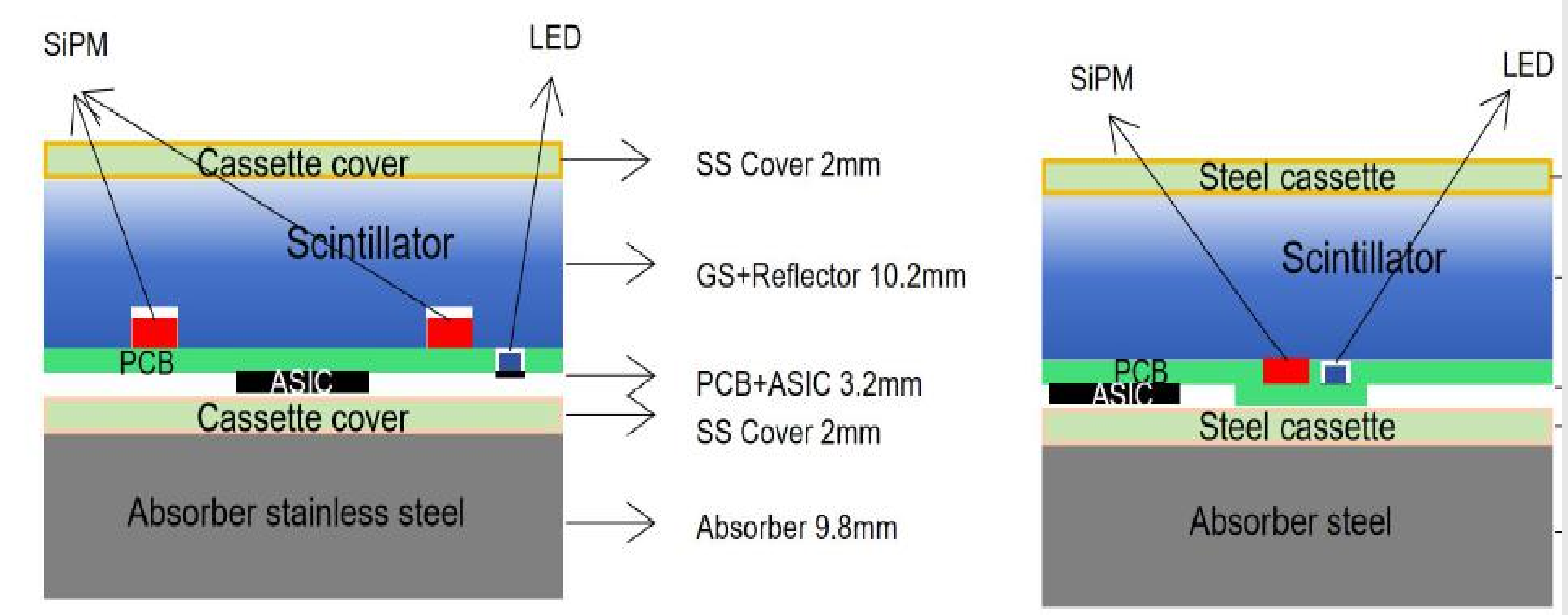


3.1 Detector Cell = GS +SiPM

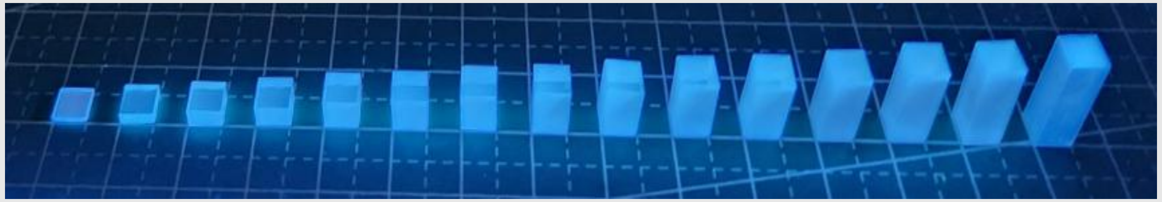


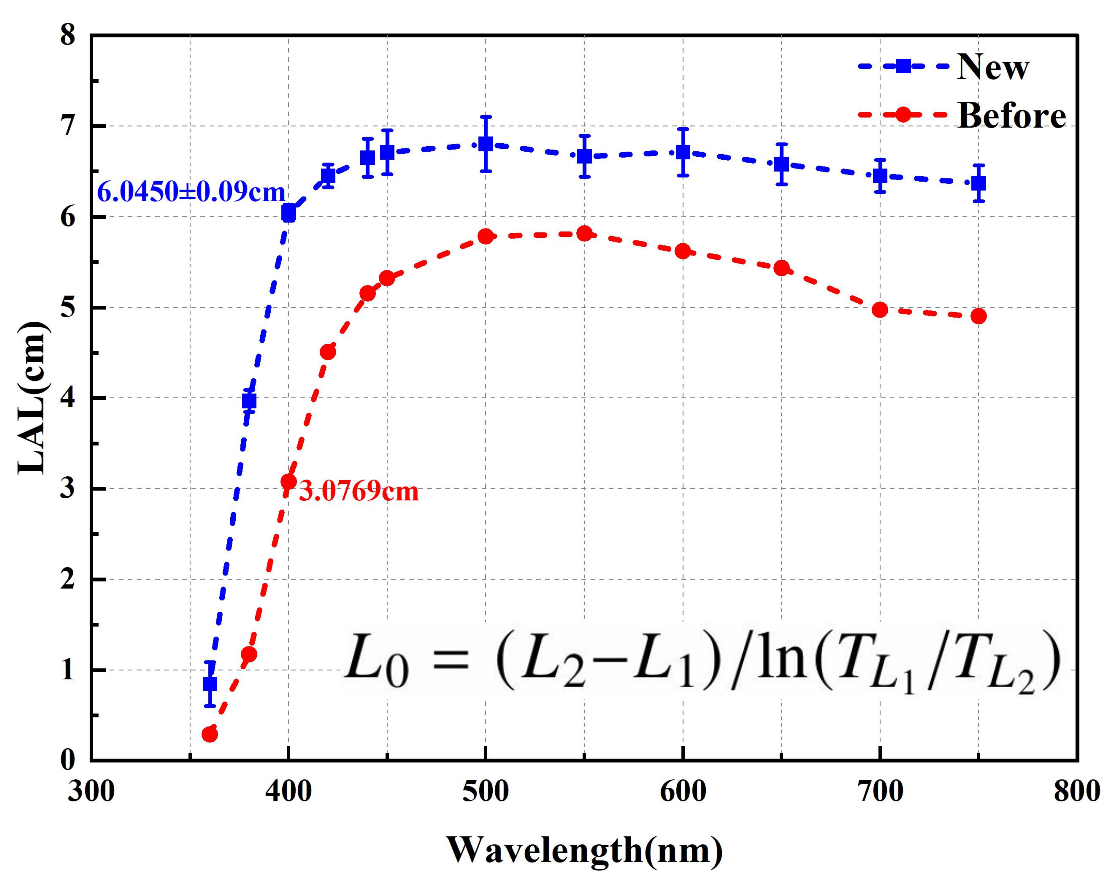


- at the beginning, light attenuation length is only ~23 mm, more SiPMs are needed to collect sufficient light.
- One scintillator is coupled with either 1, 2, or 4 SiPMs (3 mm × 3 mm SiPMs).
- There is a gap to hold the SiPM either in the GS or in the PCB. More tests are needed to determine the optimal position of this gap (in the glass or PCB) and to identify a low-cost and practical method for implementation.

Attenuation Length of new GS

- GS samples before IDRC review
  - attenuation length: 3.1 cm @ 400nm
- NEW GS samples after IDRC review
  - attenuation length: 6.1 cm @ 400nm
- Feasible to use one SiPM per GS tile





Progress of SiPM for Detector

NEWS & BUZZ

The Innovation

A significant breakthrough achieved in the production of high-performance SiPMs with epitaxial quenching resistors

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Recently, a significant breakthrough has been achieved in the production of high-performance silicon photomultipliers (SiPMs) with epitaxial quenching resistors (EQRs).[1] The EQR SiPM packaging production line, developed by CGN Capital Photonics Technology (Tianjin), has been successfully launched with a product yield exceeding 90%. This breakthrough has sparked new growth in China's semiconductor optoelectronic device industry.

The SiPM is a solid-state photon detector known for its high sensitivity and compact structure. It is a silicon chip that is composed of a series of miniature avalanche photodiodes (APDs), each operating in Geiger mode by being reverse biased above the breakdown voltage to realize the avalanche multiplication of photoelectrons. A special resistor is connected with each APD to quench the avalanche multiplication after detection. These micro APDs are operating independently, and their summed outputs are sensitive to injected light intensity, enabling single-photon detection and high gain comparable with traditional photomultiplier tubes (PMTs).

SiPMs are progressively replacing traditional PMTs across diverse fields, including high energy physics (where radiation hardness is a significant constraint), astrophysics, nuclear medical imaging, and autonomous driving, owing to their superior performance characteristics. In addition to their inherent advantages—excellent single-photon resolution, magnetic fields immunity, low operating voltage, compact size, and ease of integration—SiPMs are continually optimized for critical performance parameters such as enhanced photon detection efficiency (PDE), higher photon count rate, broader linear dynamic range, and cost-effectiveness to meet the increasing requirements in these fields and other advanced applications. Due to the compactness, good timing performance and insensitive to magnetic field, SiPMs are currently used for the most commercial clinical TOF-PET scanners, especially in the PET/MRI, PET/CT. Time-of-flight measurement in a PET system can improve the signal/noise ratio of the reconstructed images, reduce the radiation dose, and shorten the scan time. The latest EQR SiPMs (EQR20 series) demonstrate a short pulse width and a sharp rising edge, which could enhance its application in TOF-PET scanners. Besides, EQR SiPMs achieved a high fill factor (more than 40%) and a high microcell density (up to 2,500/mm^2), which could achieve high energy resolution and broad dynamic range.

The quenching resistor is a critical component in SiPMs, enabling their operation in Geiger mode while ensuring stable and reproducible photon detection. Currently, polysilicon quenching resistors are widely used in commercially available SiPMs due to their tunable resistivity and compatibility with standard CMOS fabrication processes. However, the utilization of polysilicon resistors along with connected metal lines leads to the occupation of active area within the devices, diminishing the geometric fill factor and consequently decreasing the PDE, particularly in cases where there is a large number of pixels. To

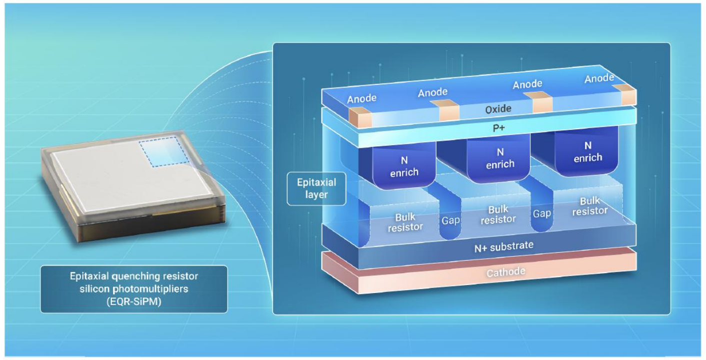


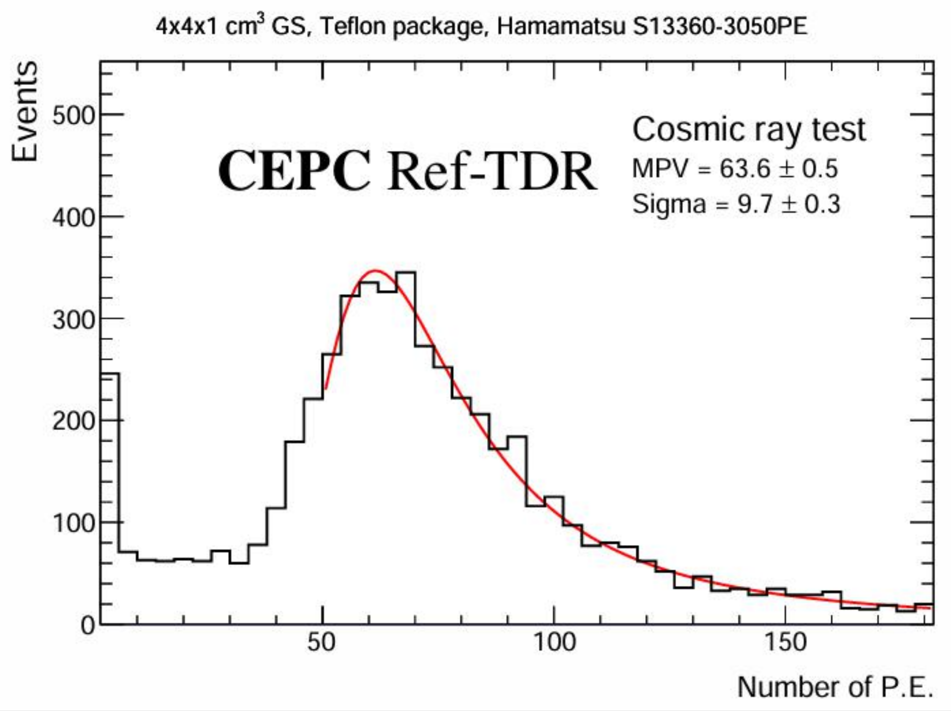
Figure 1. Schematic structure of the SiPM with epitaxial quenching resistor Modified from Zhao et al.[1]

Company	Onsemi	Broadcom	HPK	ZJ （NDL）
Product Mode	J—series 40035[1]	AFBR—S4N44P014M[2]	S14160—4050HS[3]	EQR20—11—4040—NS[4]
Microcell Size	35 μm	40 μm	50 μm	20 μm
Microcell density	816/mm^2	625/mm^2	400/mm^2	2500/mm^2
Gain	6.3×10^6	7.3×10^6	2.5×10^6	8.0×10^5
Dark count	150 kHz/mm^2	125 kHz/mm^2	——	150 kHz/mm^2
Detection Efficiency	50% @420 nm	63% @420 nm	50% @450 nm	47.8% @420 nm
EfficiencyActive area	3.93×3.93 mm^2	3.72×3.62 mm^2	4.00×4.00 mm^2	3.76×3.76 mm^2
Package Area	4.00×4.00 mm^2	4.31×4.18 mm^2	4.40×4.40 mm^2	4.12×4.12 mm^2
Packaging Method	TSV	COB	TSV	CGB
Quenching Resistor	Polycrystalline silicon Resistor	Polycrystalline silicon Resistor	Polycrystalline silicon Resistor	Epitaxial Resistor

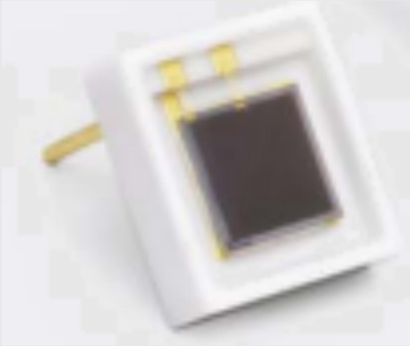
[1]https://www.onsemi.cn/download/data-sheet/pdf/microj-series-d.pdf
[2]https://docs.broadcom.com/doc/AFBR-S4N44P014M-NUV-MT-Silicon-Photomultiplier
[3]https://www.hamamatsu.com/content/dam/hamamatsuphotonics/sites/documents/99_SALES_LIBRARY/ssd/s14160_s14161_series_kapd1064e.pdf
[4] Zhao, T., Preston, R., Jiang, J. et al. (2018). NIMA. 912:252–254. DOI:https://doi.org/10.1016/j.nima.2017. 11.069.

3.2 Performance of GS-SiPM coupling

- Cosmic ray test of GS-SiPM coupling
- Light output is ~ 64 pe/MIP



NDL EQR20

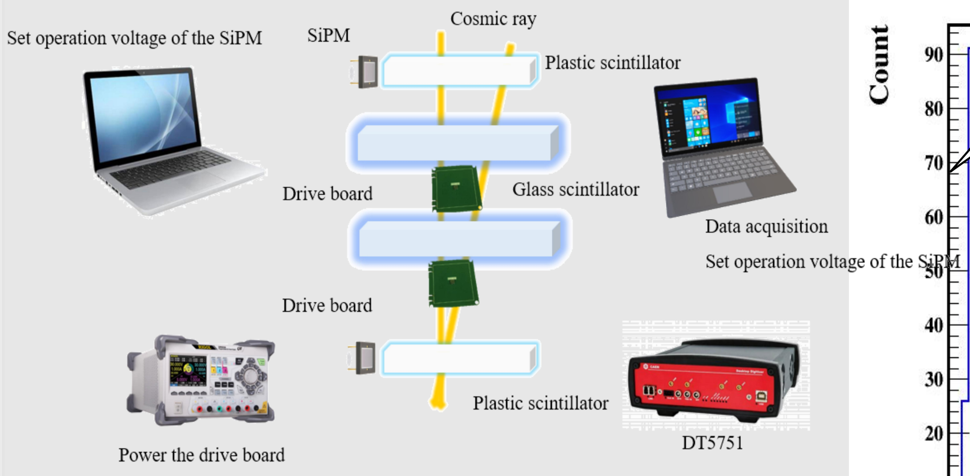


HPK S13360

- Mass production of high quality SiPM;
  - HPK S13360 ~22% PDE ➔ HPK S14160 ~43%
  - NDL EQR20 ~42% PDE ➔ NDL ~50%
- Cost of mass production (~5.3M)
  - GS: ~ 0.5 CHF/cc, SiPM: ~ 1.25 CHF/pcs

- Further Optimization of GS size, thickness, GS-SiPM couplings (air vs optical glue).

3.3 Cosmic Ray test result



1.BGRI-146L 40×40×10 mm³

2.BGRI-4# 40×40×20 mm³

•Detector:

1. NDL EQR20 11-3030 3×3 mm²,

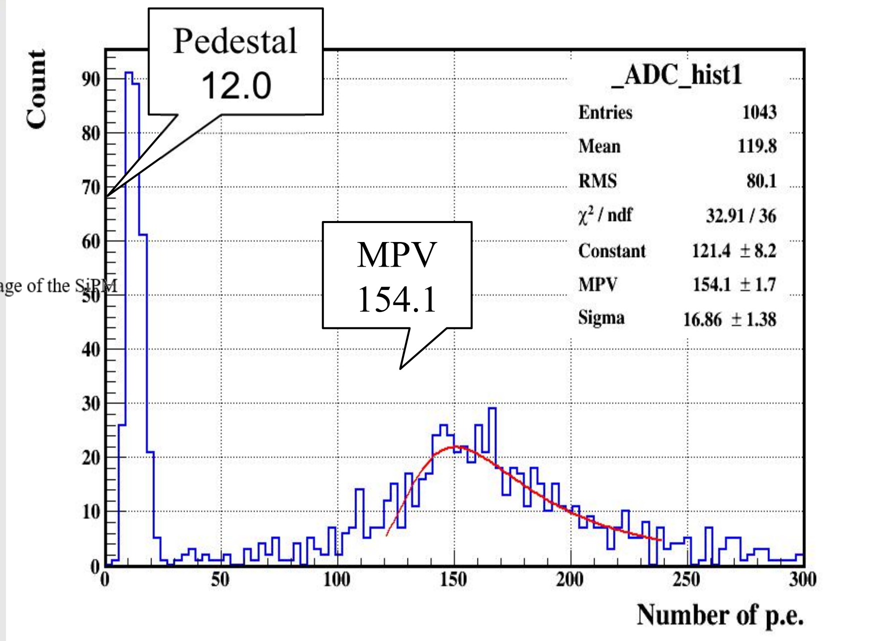
Weighted PDE=42.5%

•Reflector: Teflon

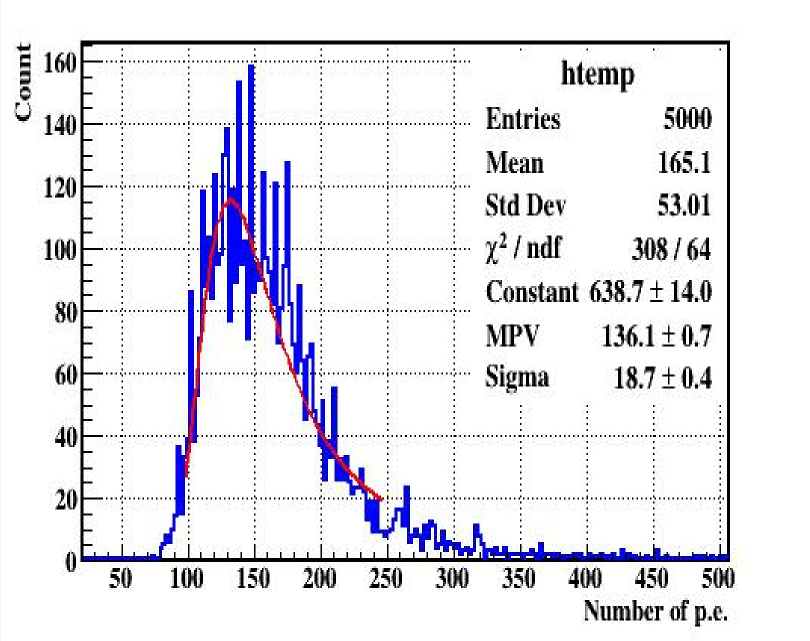
•DAQ: DT5751 Integral time=1000 ns

•Trigger: PS 30*30*10 mm³×2

•Distance: 5 cm



Cosmic ray test (ADC pedestal deducted)



MIP response simulation for Muon

MIP Response (p.e./MIP)	
Cosmic ray experiment	G4 Muon simulation
142.1 ± 1.7	136.1 ± 0.7

3.4 GS Beam Test at KEK

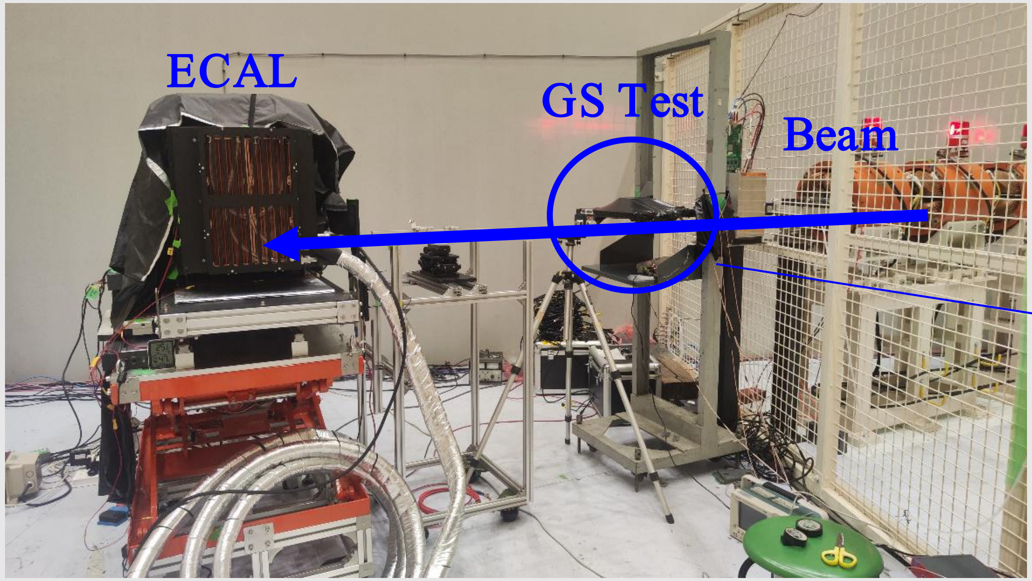
- GS tile size: 4 × 4 × 1 cm^3 & 1 SiPM (3×3 mm2) for each GS tile

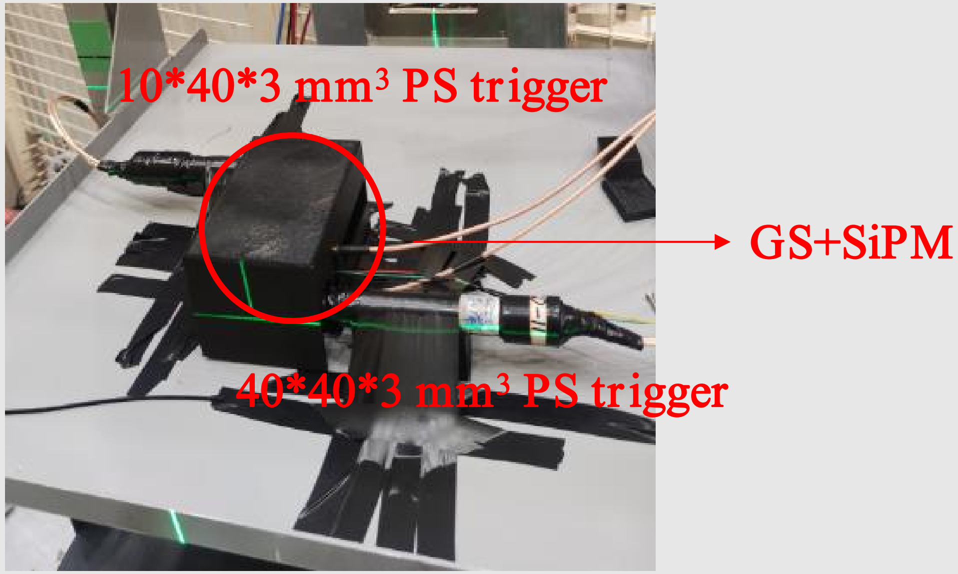
KEK test beam in 2025.6

- 5 GeV electron
- 1.6 kHz (from beam line)

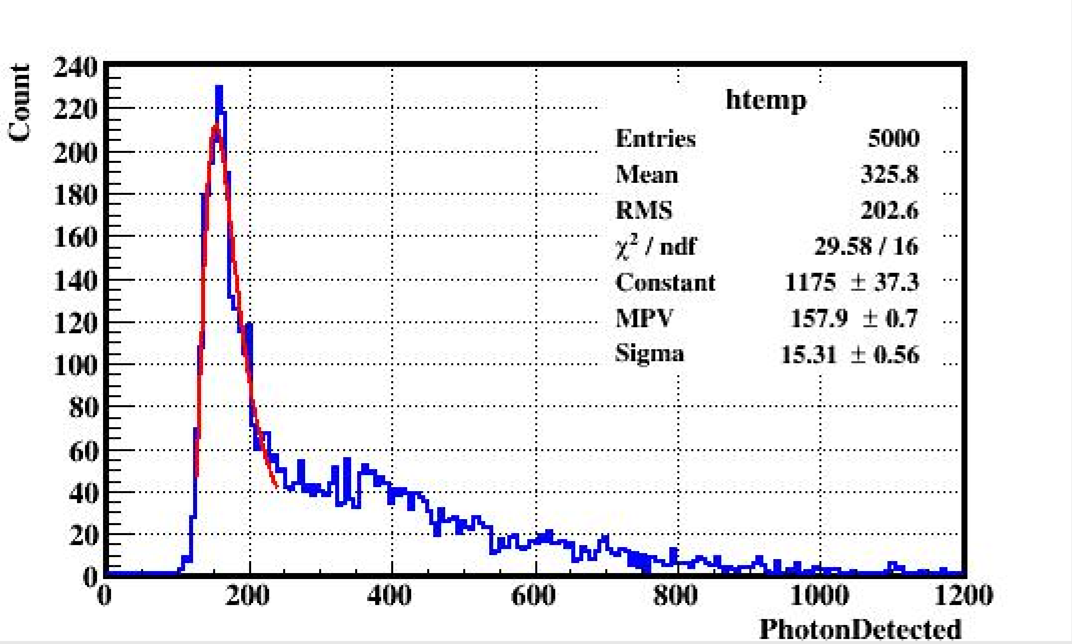
Experimental goals for GS-HCAL

- MIP response calibration with low-energy electron for GFO glass
- Compare light output with previous samples measured by DESY
- Compare wrapping effects of different reflectors (Teflon, Tyvek, TiO2)
- Compare performance of various SiPMs from different manufacturers

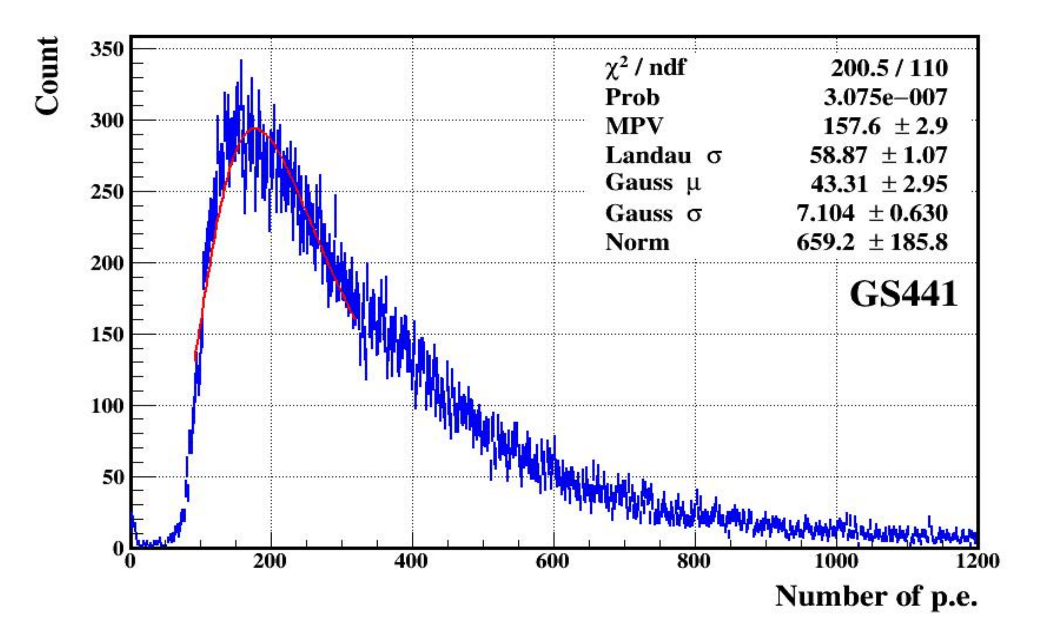




Electron beam test result



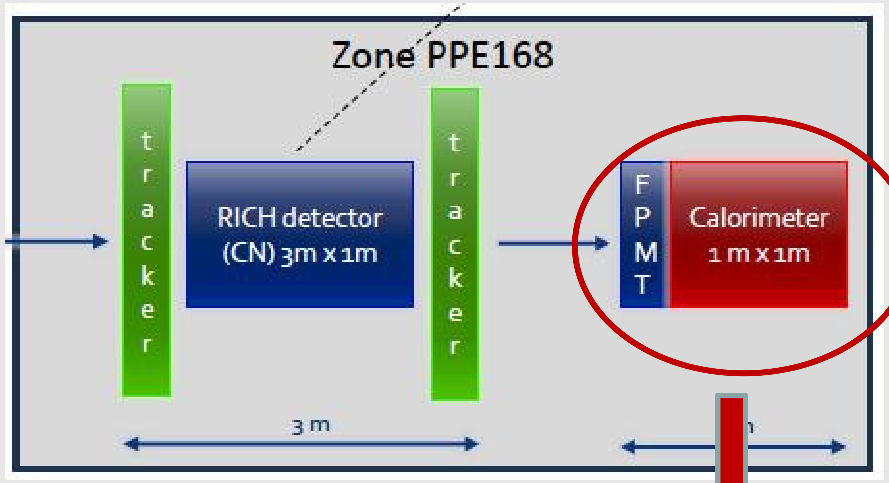
MIP response simulation for electron beam

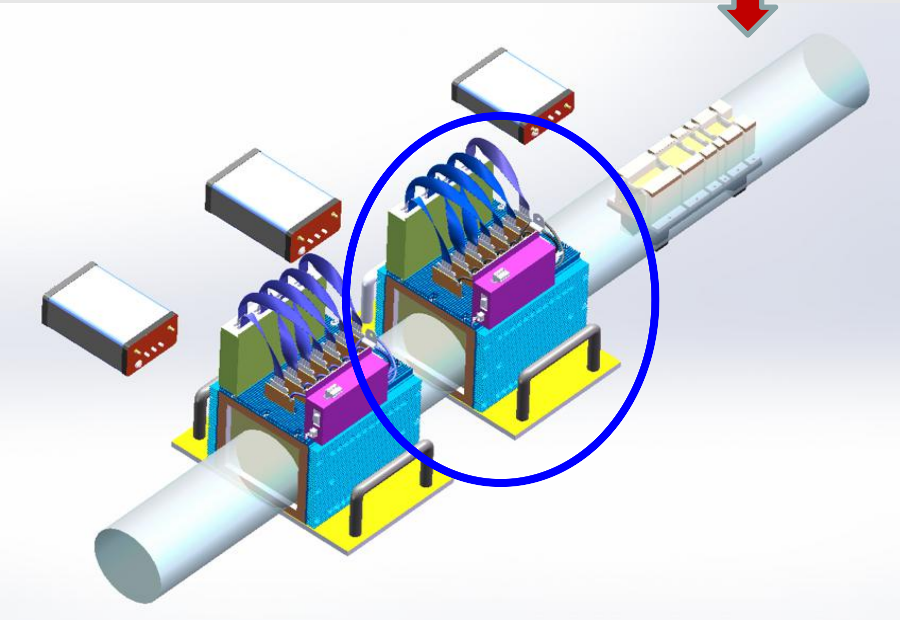


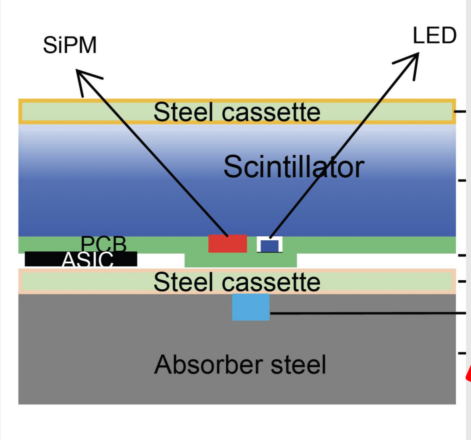
KEK electron beam test

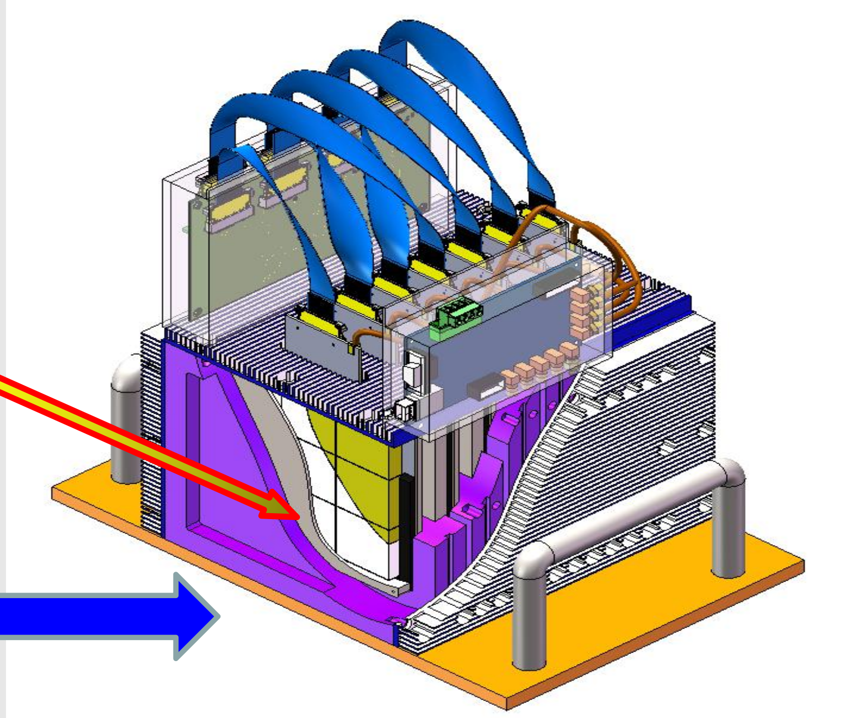
GS	Reflector	MIP Response (p.e./MIP)	
		NDL 3030 (Weighted PDE=42.5%)	
		Simulation for Electron	Electron Beam Test
BGRI-146	Teflon	157.9±0.7	157.6±2.9

3.5 GS-HCAL Mini-prototype in CERN



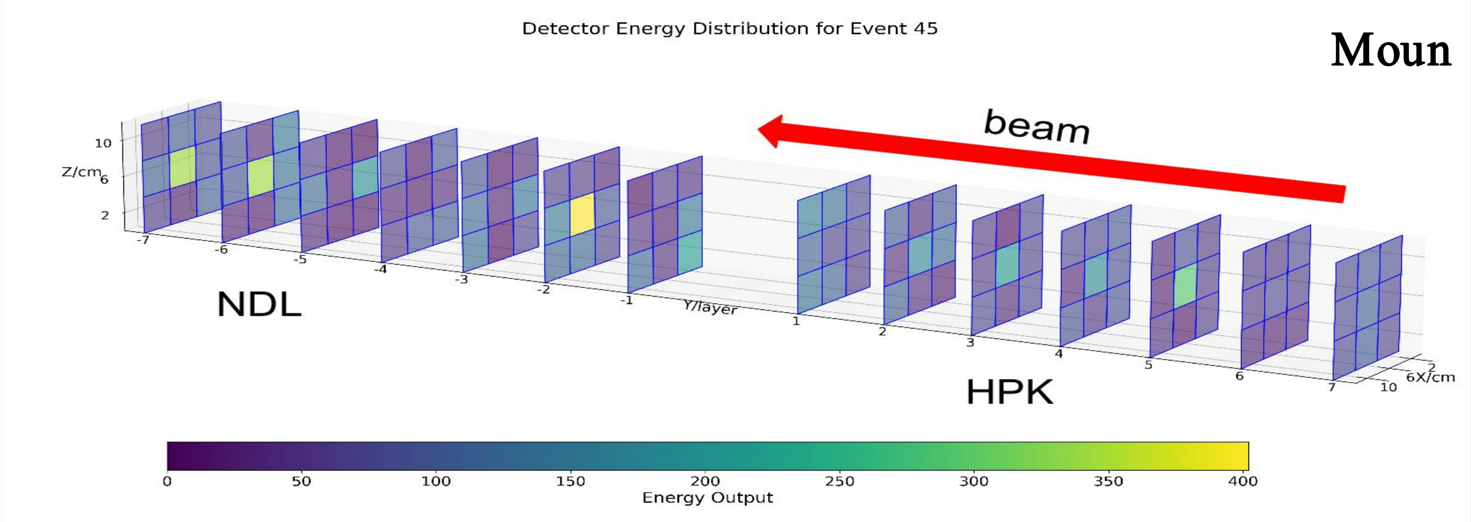


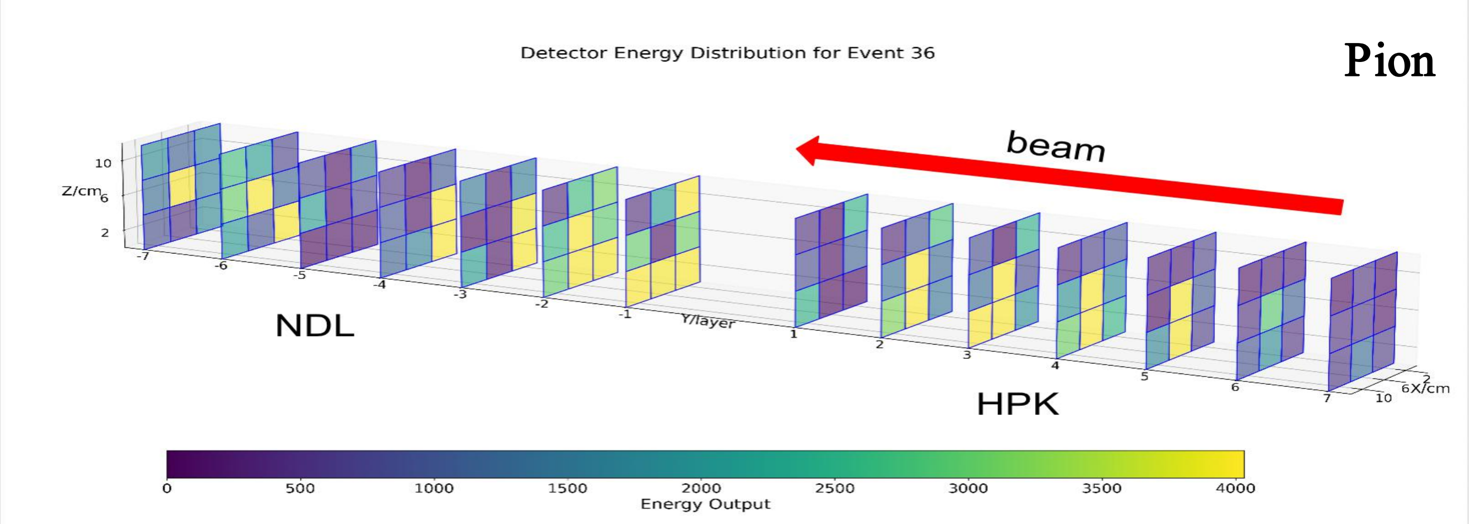




- **Mini-Prototype:** 7 layers, each layer has 3×3=9 GS tiles, 63 GS tiles in total, each GS size of 4×4×1 cm^3
- **Two mini-prototypes** using HPK & NDL, respectively
- **CERN beam tests** (Pion / Muon) **in October 2025**

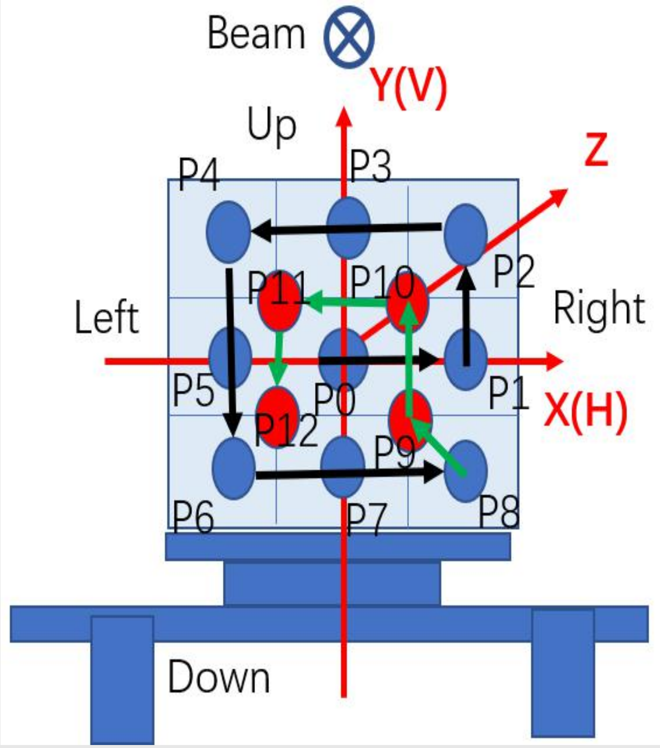
Pion/Muon beam test result-event shown





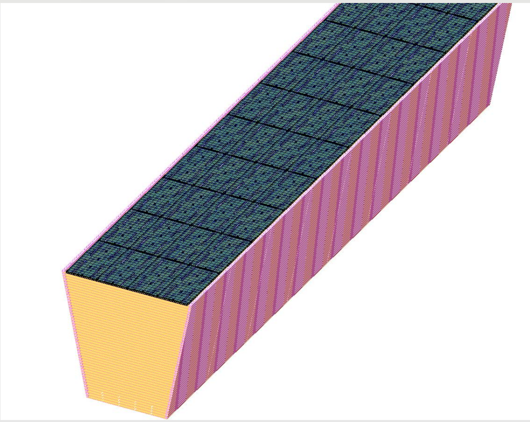
CERN SPS H8 Beamline

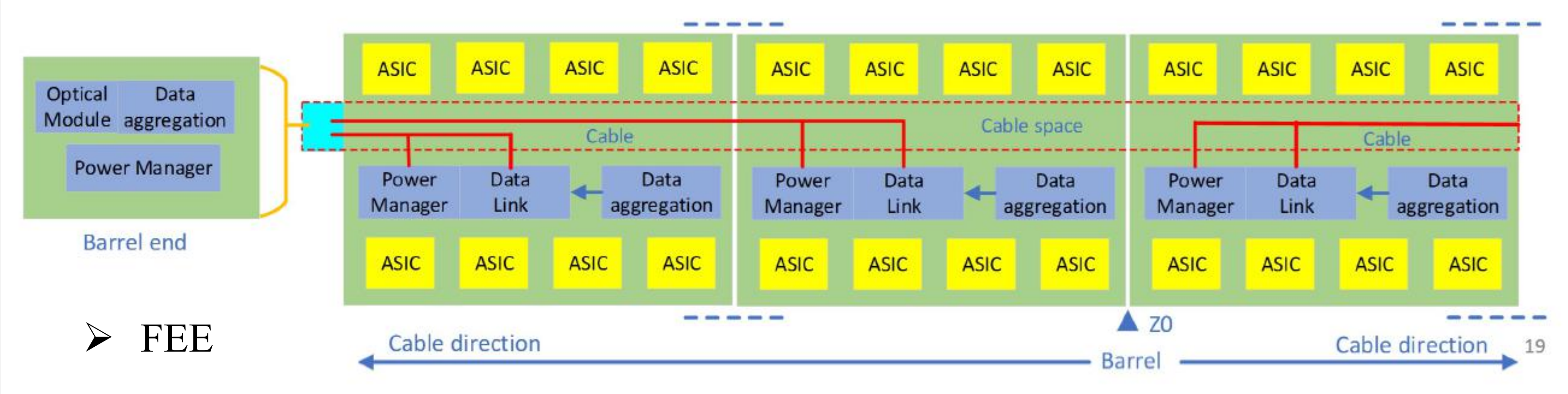
- Particle: Pion and Moun
- Energy: 0-180 GeV
- Beam spot: SigmaX and SigmaY≈ 1 cm



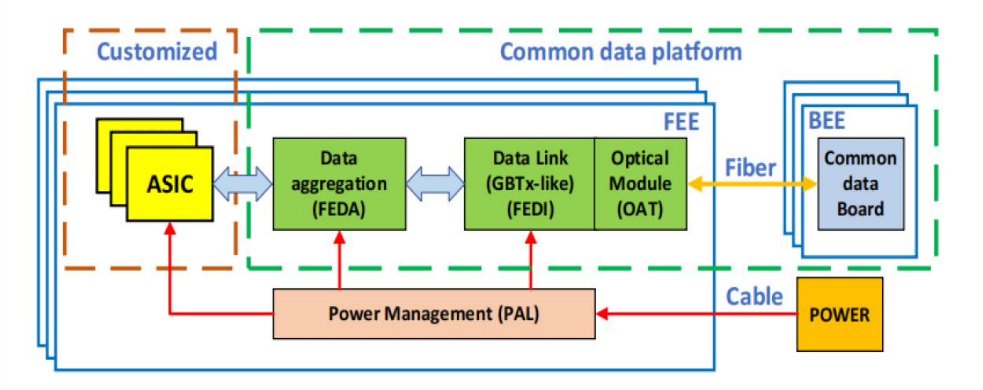
- waiting for the come back of the module from CERN for futther test for the data callaboration.

3.6 Readout Electronics



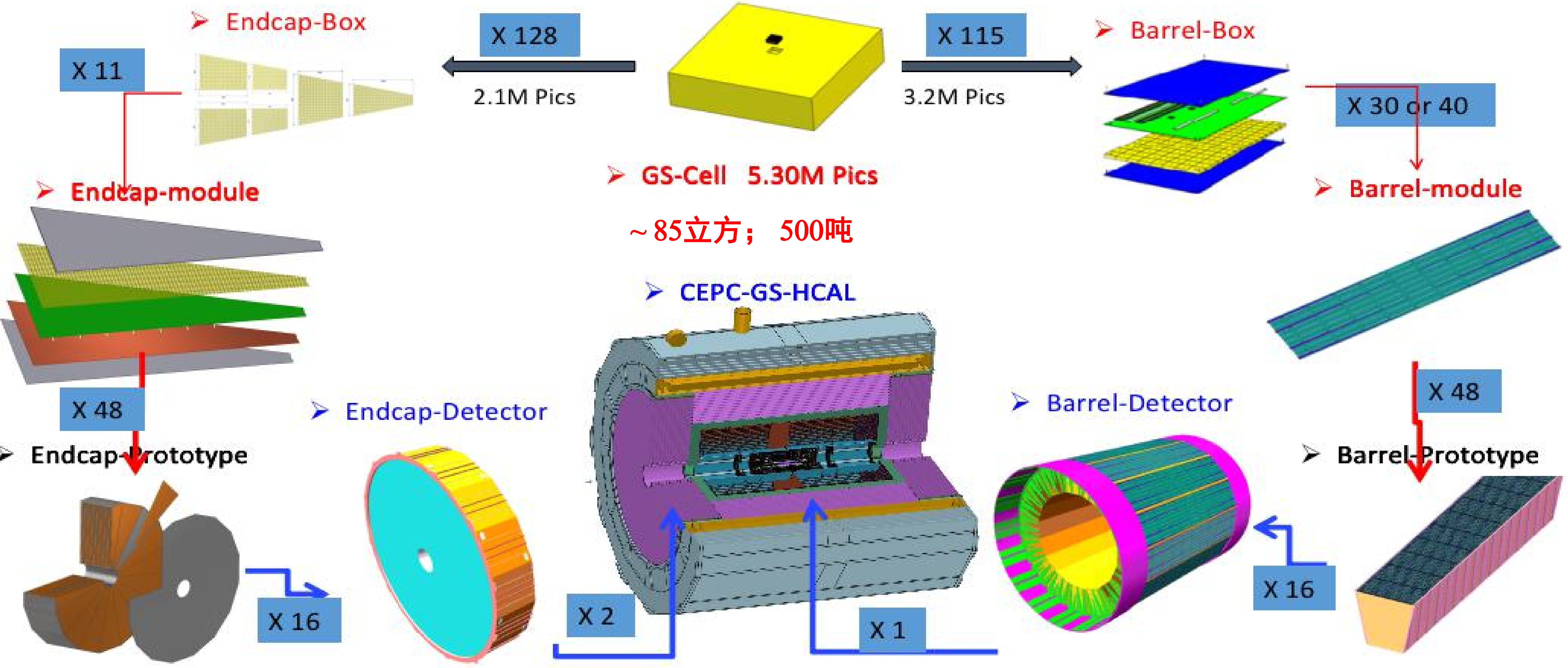


- **Front-End Electronics (FEE) readout boards in HCAL cell Box**
  - Thickness: 3.2mm = PCB 1.2mm + ASIC Chip 2mm
  - SiPMs, ASICs and Data Aggregation
  - PCB dimensions: flexible in different positions
- **SiPM-readout ASIC: under development**
  - Self-developed for CEPC calorimeter system
  - Functionality: energy and time measurements
  - Power consumption: target at 15mW/ch
- **Aggregation board at the end of barrel, cable connection**



- **Energy Measurement:** ASIC for ECAL & HCAL
- **Data transmission:** common data platform
- **Trigger mode:** FEE triggerless readout

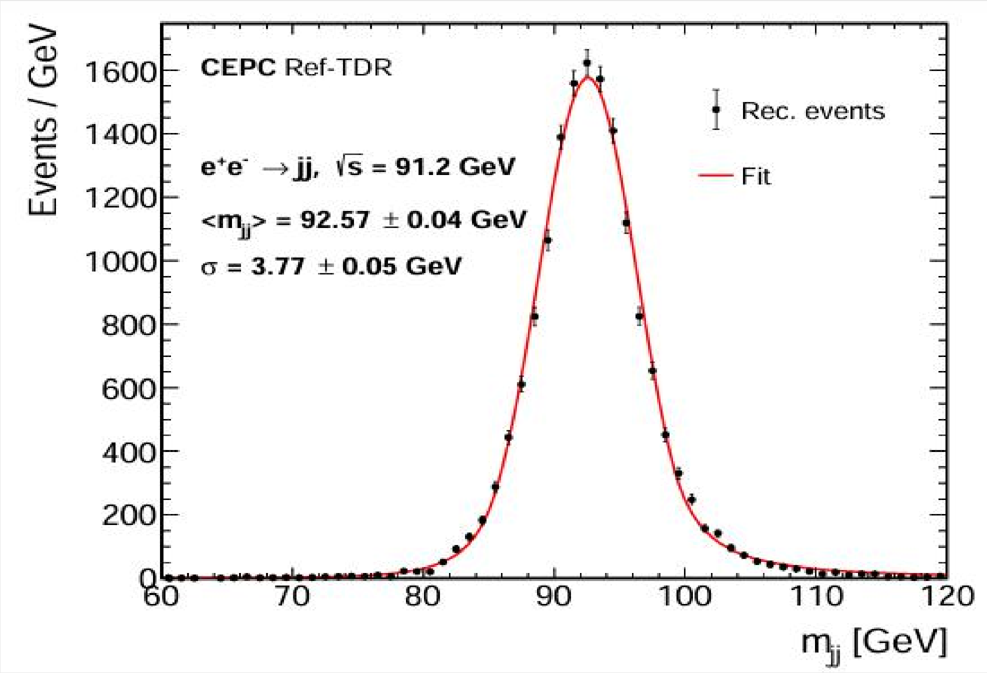
3.7 Overview of the Mechanics



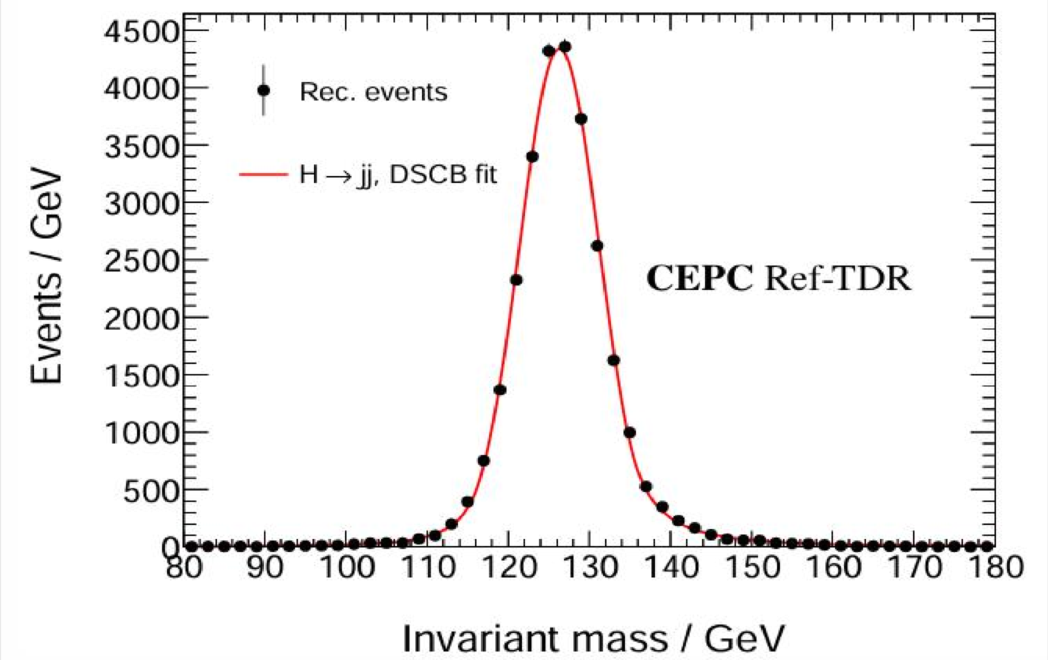
3.8 GS-HCAL Physics Performance simulation

- **Hadron Energy Resolution (full simu. + digitization):**
  - MC Sample: ee→Z→jj @ 91.2 GeV, ee→ZH→ nngg @ 240 GeV
  - Tracker (Si + TPC) + Crystal ECAL + GS-HCAL, Cyber PFA Reconstruction

BMR (Z→jj) = 4.0%



BMR (H→gg) = 3.88%



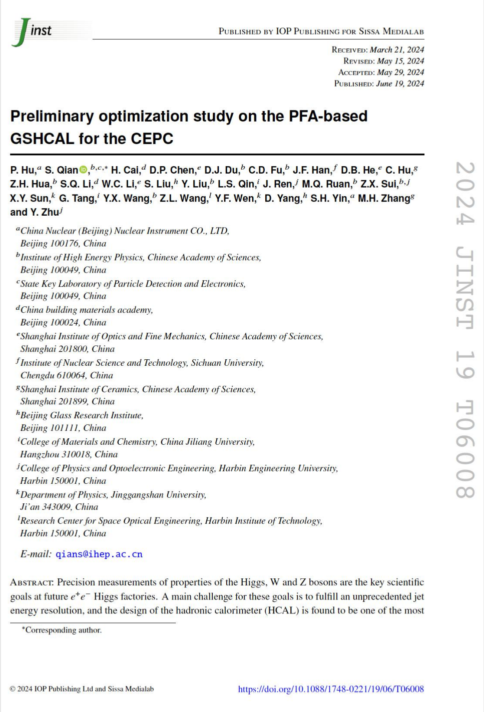
Outline

- 1. Motivation for GS-HCAL
- 2. R&D of the GS
- 3. Design of the GS-HCAL in CEPC
- 4. Summary and Next Plan

4.1 Finished the GS-HCAL design for Ref-TDR

➤ 2022 Instruments 2022, 6, 32.

➤ 2023 NIIMA 1059

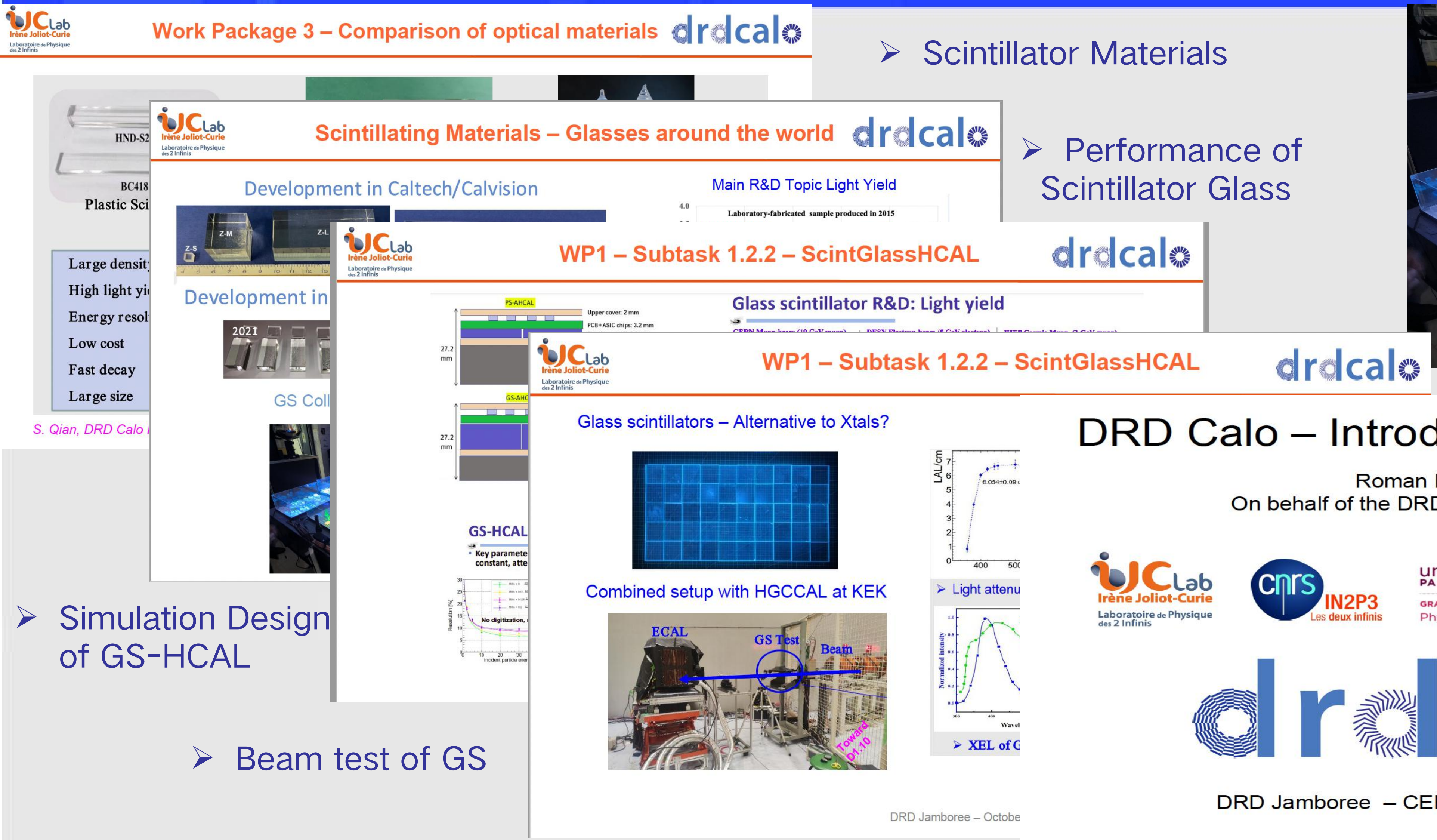


➤ 2024 JINST 19 T06008

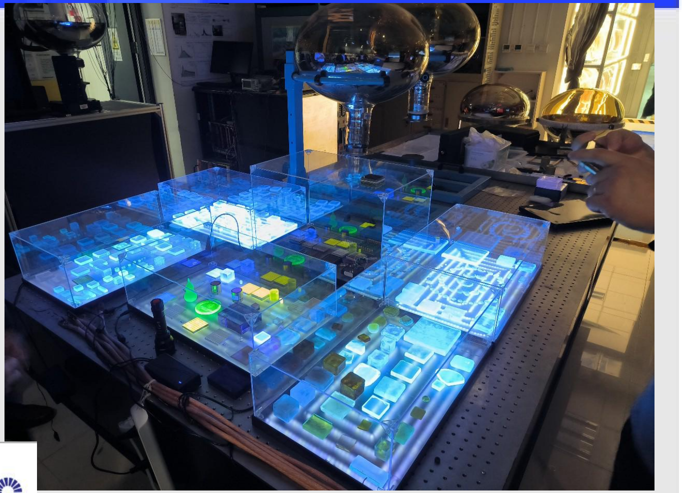
CEPC Reference Detector
Technical Design Report

➤ 2025 RDTM

4.2 Contribute to the DRD6 and DRD review



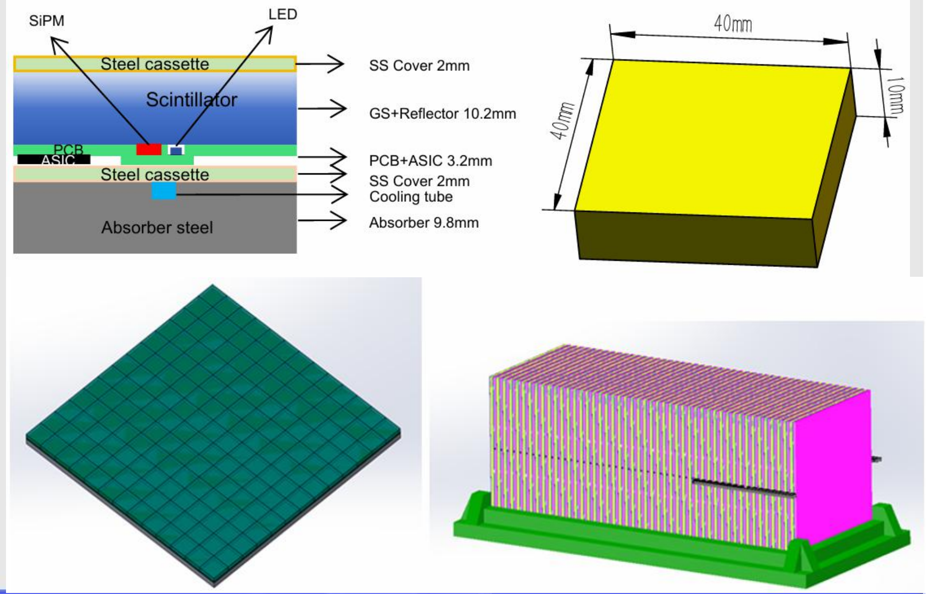
- Scintillator Materials
- Performance of Scintillator Glass



- Simulation Design of GS-HCAL
- Beam test of GS

GS-HCAL Full-size Prototype

- Plan towards a full-scale prototype
  - Step 1: test beam of new GS tiles at KEK (2025.6)
  - Step 2: test beam of mini-prototype at CERN (2025.10)
  - Step 3: batch production & test of ~10k GS (2025-2026)
  - Step 4: build full-scale prototype with ~8k GS tiles (2026)
  - Step 5: test beam of full-scale prototype (2027)
- Full-scale GS-HCAL prototype (2025-2026)
  - Total: 48 layers, Total GS tiles: 13 × 13 × 48 = 8112
  - Each layer: 13 × 13 GS tiles (52 × 52 cm2)
  - GS tile size: 4 × 4 × 1 cm^3
  - 1 SiPMs (3×3 mm2) for each GS tile
  - ASIC Chip with power consumption of 15mW/ch
  - Stainless steel as absorber and covers: 13.8mm
- Test beam plan (2027)
  - CERN: PS or SPS
  - KEK (Japan): 5 GeV electron
  - HEPS (China): 6 GeV electron



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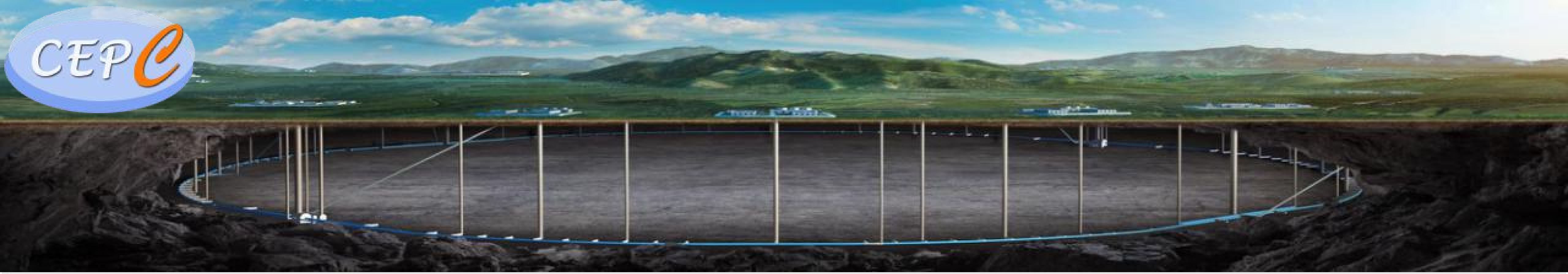
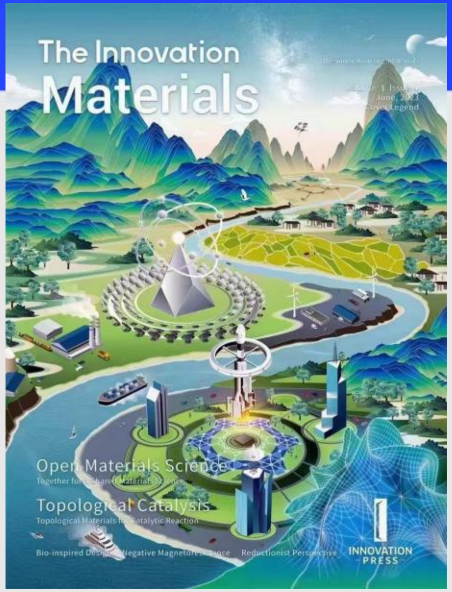
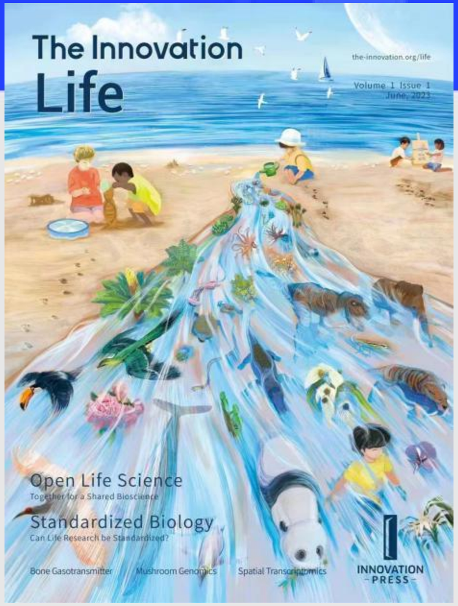


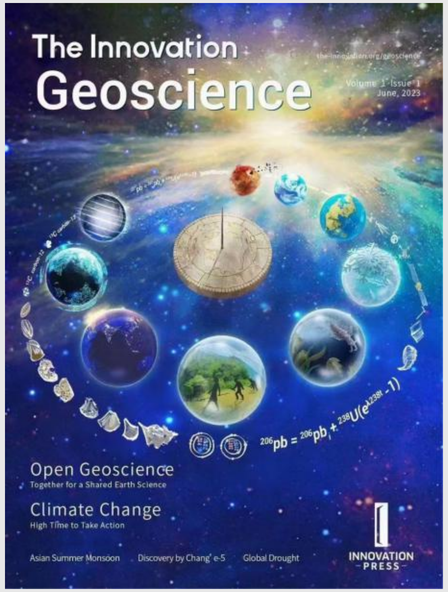
Backup slides

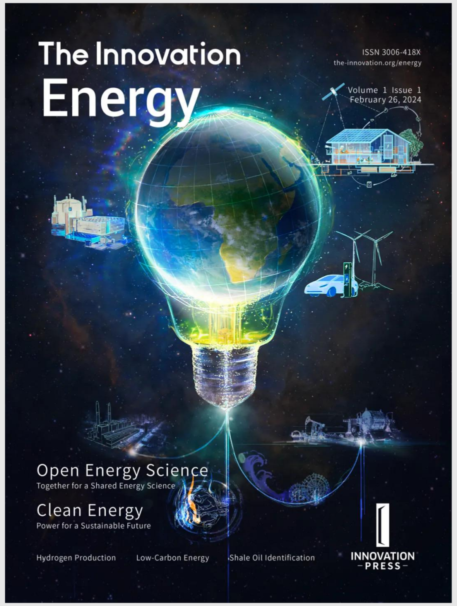
Summary and Future Plans

- **Physics requirement for the design:**
  - Hadron energy resolution < 5 %
  - Boson mass resolution (BMR) < 4%
- **GS-HCAL is selected as baseline based on its promising performance**
  - Intensive R&D on high quality GS (e.g. light yield, decay time, attenuation length)
  - Update design of GS-HCAL mechanics, cooling and readout electronics
  - Preliminary study with CEPCSW shows promising result which is feasible for Ref-TDR
- **Future R&D plans**
  - To further optimize GS size, GS-SiPM coupling, cooling and readout electronics
  - To optimize simulation, digitization, reconstruction and analysis chain
  - To develop techniques for mass production of GS, SiPM with low cost
  - To prepare full-size GS-HCAL prototype with integrated electronics for beam test



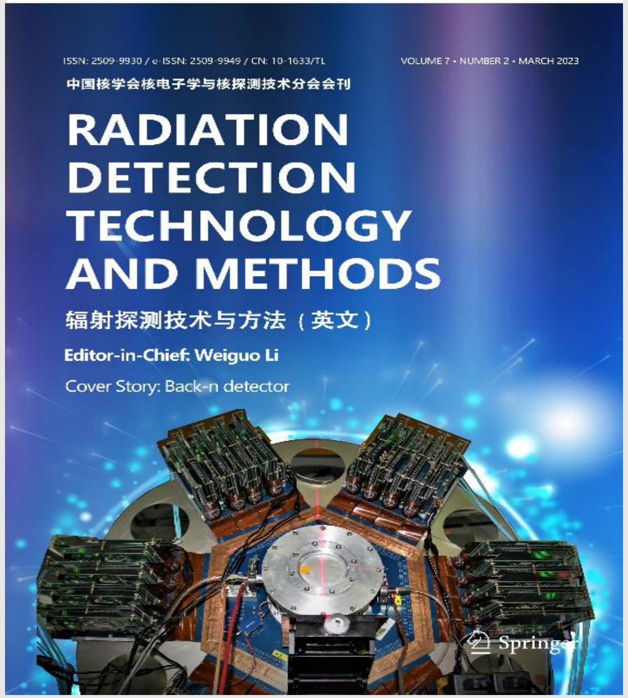


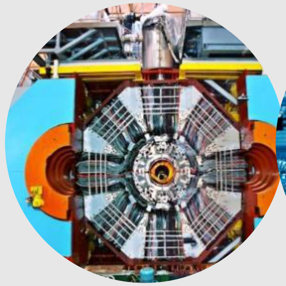




Impact Factor=33.1

核电子学与核探测技术 & Radiation Detection Technology and Methods

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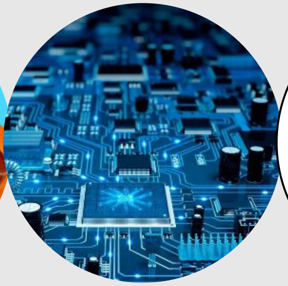
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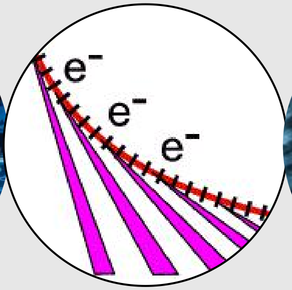


加速器
技术


核医学
技术


同步辐射
技术


计算机
技术


天体粒子
技术

HCAL Research Group

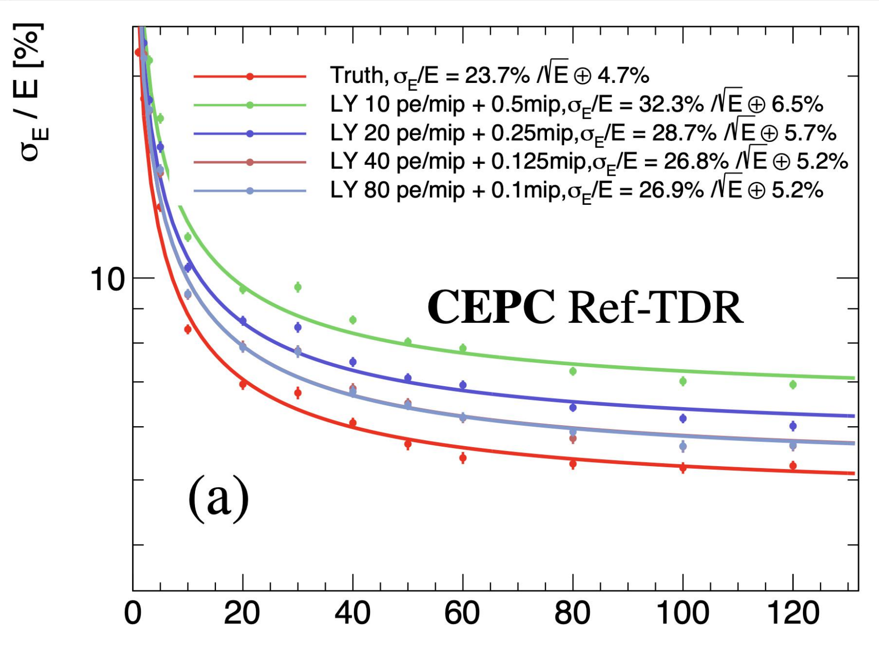
- Actively involve in DRD-Calo Collaboration
- CEPC-HCAL team: IHEP, USTC, SJTU, XJTU, SCNU, SCU, HEU, ZZU
  - Detector for PS/GS-HCAL: Staff(9) + Student(10)
  - Electronics: Staff(5), Mechanics: Staff(3)
  - GS Collaboration: 13 institutes, Staffs (26) + Students (10)

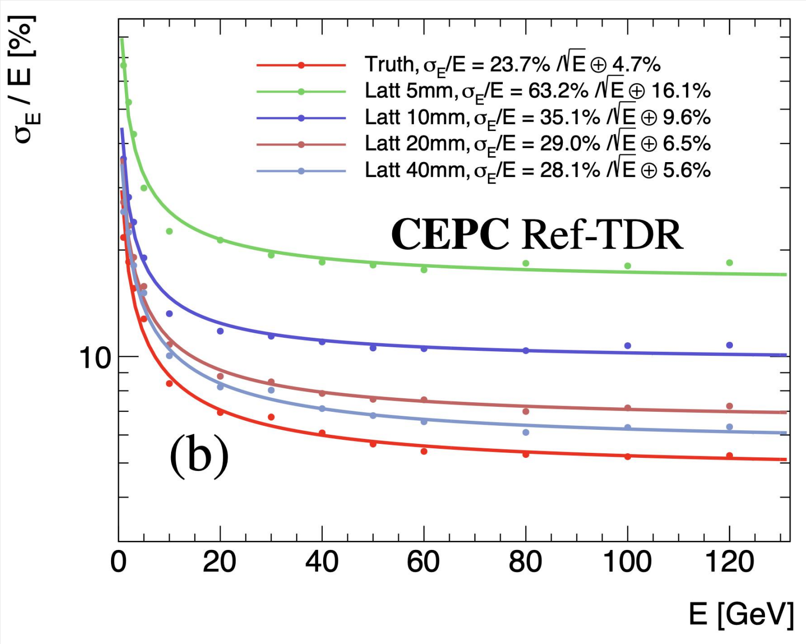
Convener: Sen Qian (IHEP), Jianbei Liu (USTC)
Physics: Manqi Ruan(IHEP), Haijun Yang (SJTU)
Software: Sengsen Sun(IHEP)
Design: Fangyi Guo(IHEP), Hengne Li(SCNU), Qingming Zhang(XJTU), Weizheng Song(IHEP), Peng Hu(261)
Dejing Du(IHEP), Hongbing Diao(USTC), Jiyuan Chen(SJTU), to design the GS-HCAL based on CEPCSW;
Glass Scintillator: Sen Qian(IHEP), Jing Ren(HEU), the GS collaboration (13 institutes, 26 staffs +10 students);
SiPM: Yuguang Xie(IHEP), Jifeng Han(SCU), Guang Luo(SYSU), SiPM and electronics for the GS performance test;
Electronics: Jingfan Chang(IHEP), to design the ASIC and FEE, power supply, cables etc.;
DAQ: Chen Boping(IHEP)
Mechanics and cooling system: Yatian Pei(IHEP), Junsong Zhang(IHEP), Shang Bofeng(ZZU)
Detector: Boxiang Yu(IHEP), Yunlong Zhang (USTC), Yong Liu (IHEP), GS-HCAL module, TB and cosmic test;

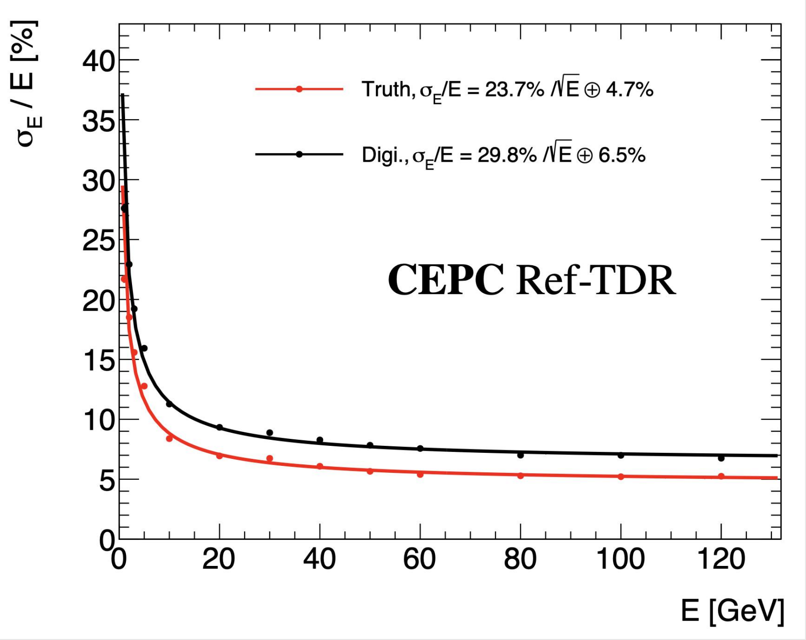
GS-HCAL Energy Resolution

- **A full detector geometry constructed with DD4hep in CEPCSW**
  - GS density 6 g/cm^3, λ_I = 242.8 mm, attenuation length ~ 60 mm
  - GS cell size $4\times4\times1$ cm^3, 48 layers, $6\lambda_I$ in total
  - Geometry: follow the mechanics design with supporting structures.

$$\sigma_E/E = 29.8\%/\sqrt{E} \oplus 6.5\%$$







- GS light output: > 50 p.e/MIP
- Threshold: 0.1 MIP (> 5 p.e)

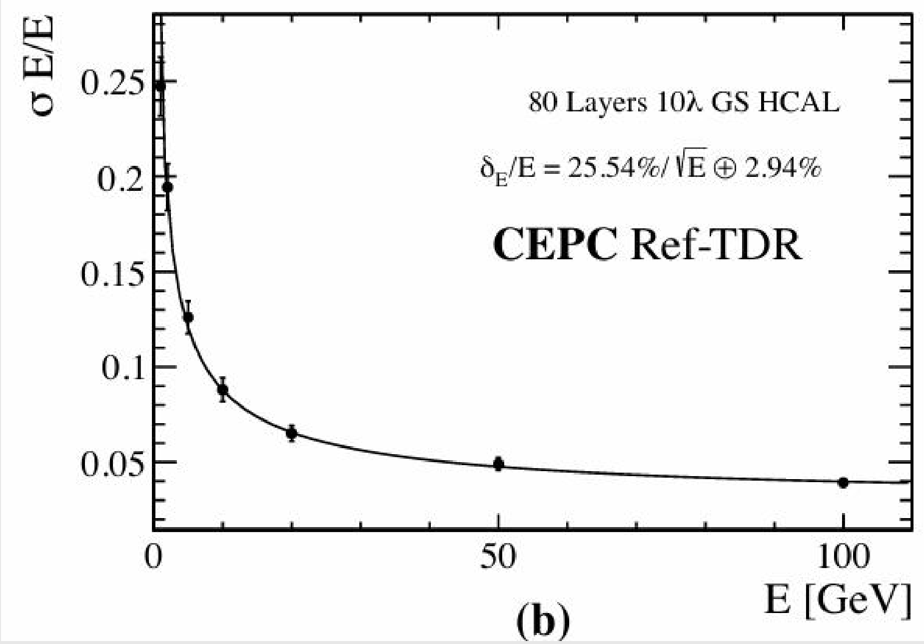
- GS attenuation length

- GS attenuation length: ~60 mm

GS-HCAL Constant Term

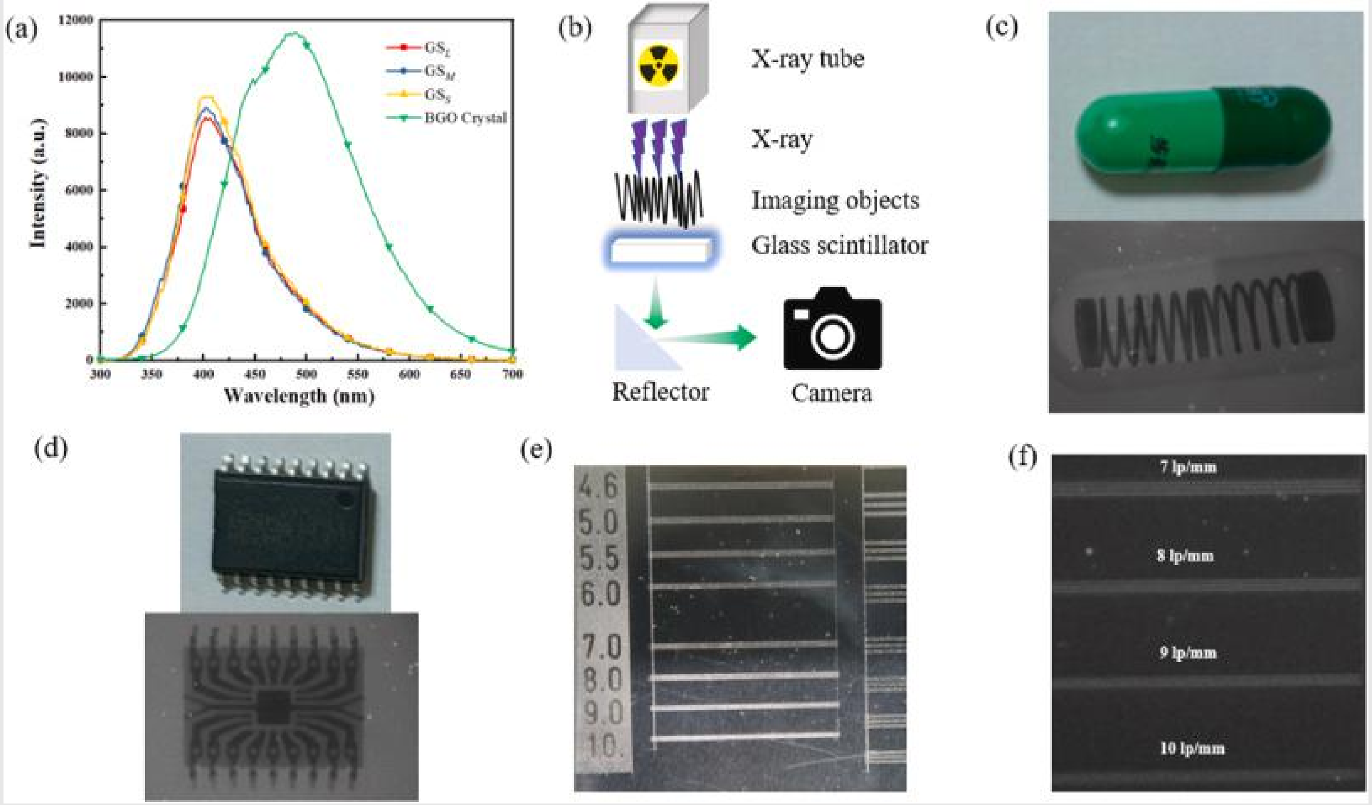
- **GS-HCAL in full simu+digi:** 6λ, $\frac{\sigma_E}{E} = \frac{29.8\%}{\sqrt{E}} \oplus 6.5\%$ (**all events**)
  - Large HCAL (80 layers, 10λ): $\frac{\sigma_E}{E} = \frac{24.7\%}{\sqrt{E}} \oplus 2.9\%$
  - Shower starts at the first 2 layers: $\frac{\sigma_E}{E} = \frac{25.9\%}{\sqrt{E}} \oplus 3.5\%$

80 layers (10λ)

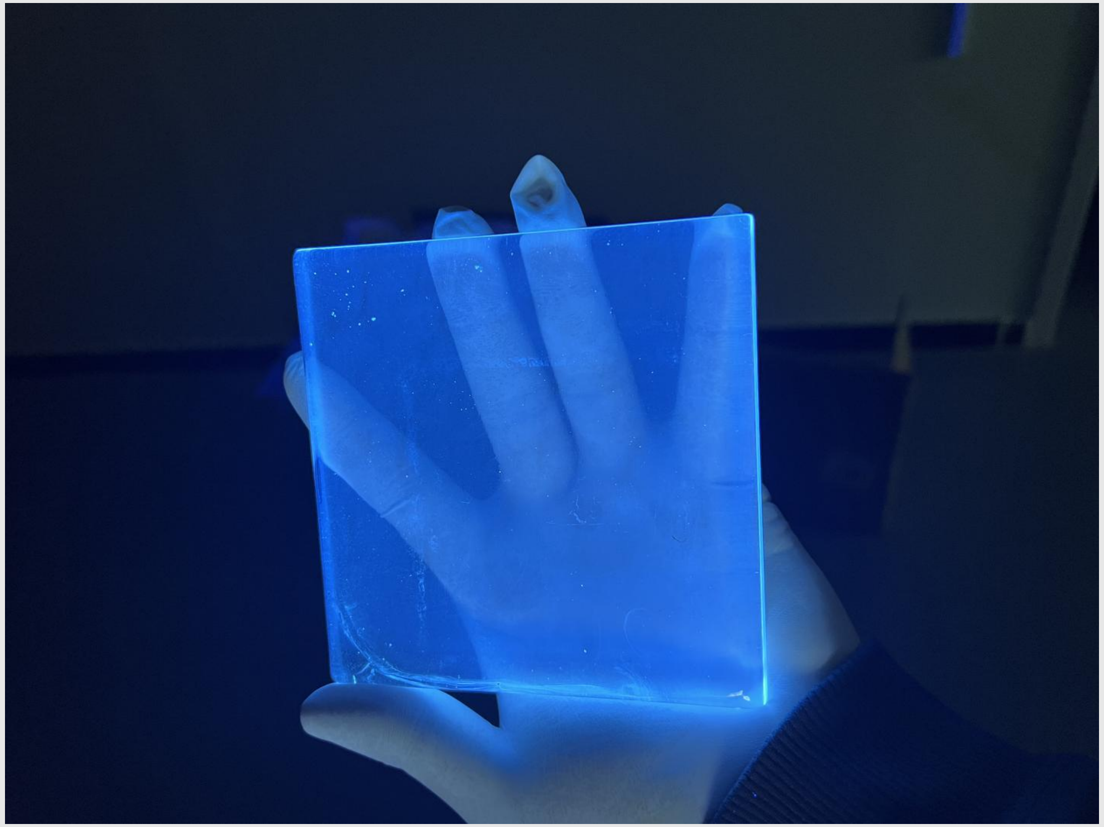


- Large constant term in GS-HCAL is mainly due to longitudinal shower leakage, combining ECAL(1.2 λ_I) and HCAL(6 λ_I) helps to reduce leakage
- Software compensation is expected to reduce constant term

The Application of the Glass Scintillator



Ultra-Large size glass （12.5cm X 122cm）



From: Adv. Opt. Mater. 2025, 2403243

From: Ceram. Int., 50 (2024) 47253–47258

From: Ceram. Int., 2025.02.151