The R&D of the New Glass Scintillator for HCAL of CEPC

闪烁玻璃合作组
Glass Scintillator Collaboration

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CalVision general meeting 2023. 10. 12th

Outline

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

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1.1. The GS-HCAL of CEPC

Future electron-position colliders (e.g. CEPC)

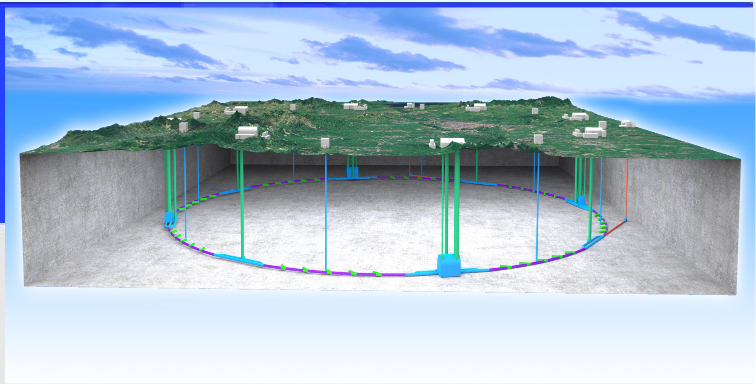
- Main physical goals: precision measurements of the Higgs and Z/W bosons
- Challenge: unprecedented jet energy resolution $\sim 30\%/\sqrt{E(GeV)}$

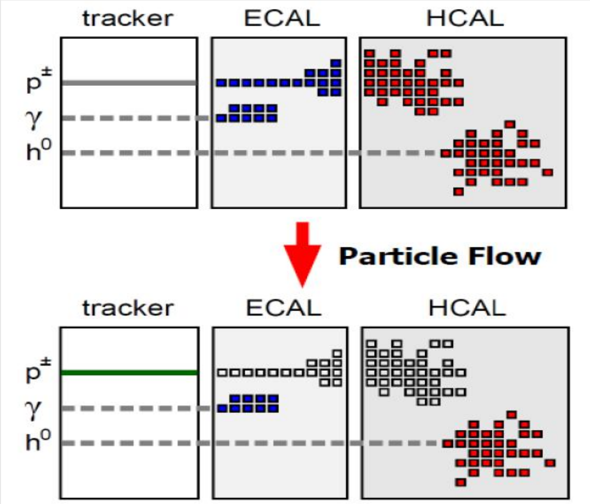
CEPC detector: highly granular calorimeter + tracker

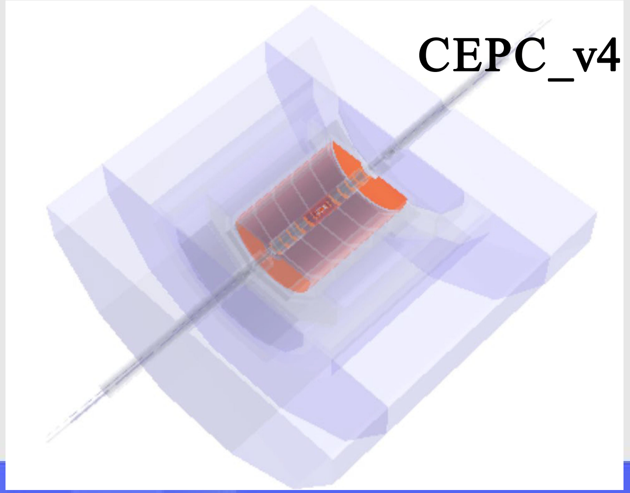
- Boson Mass Resolution (BMR) ~4% has been realized in this baseline design
- Further performance goal: BMR 4%→3%
- Dominant factors in BMR: charged hadron fragments & HCAL resolution

New Option: Glass Scintillator HCAL (GS-HCAL)

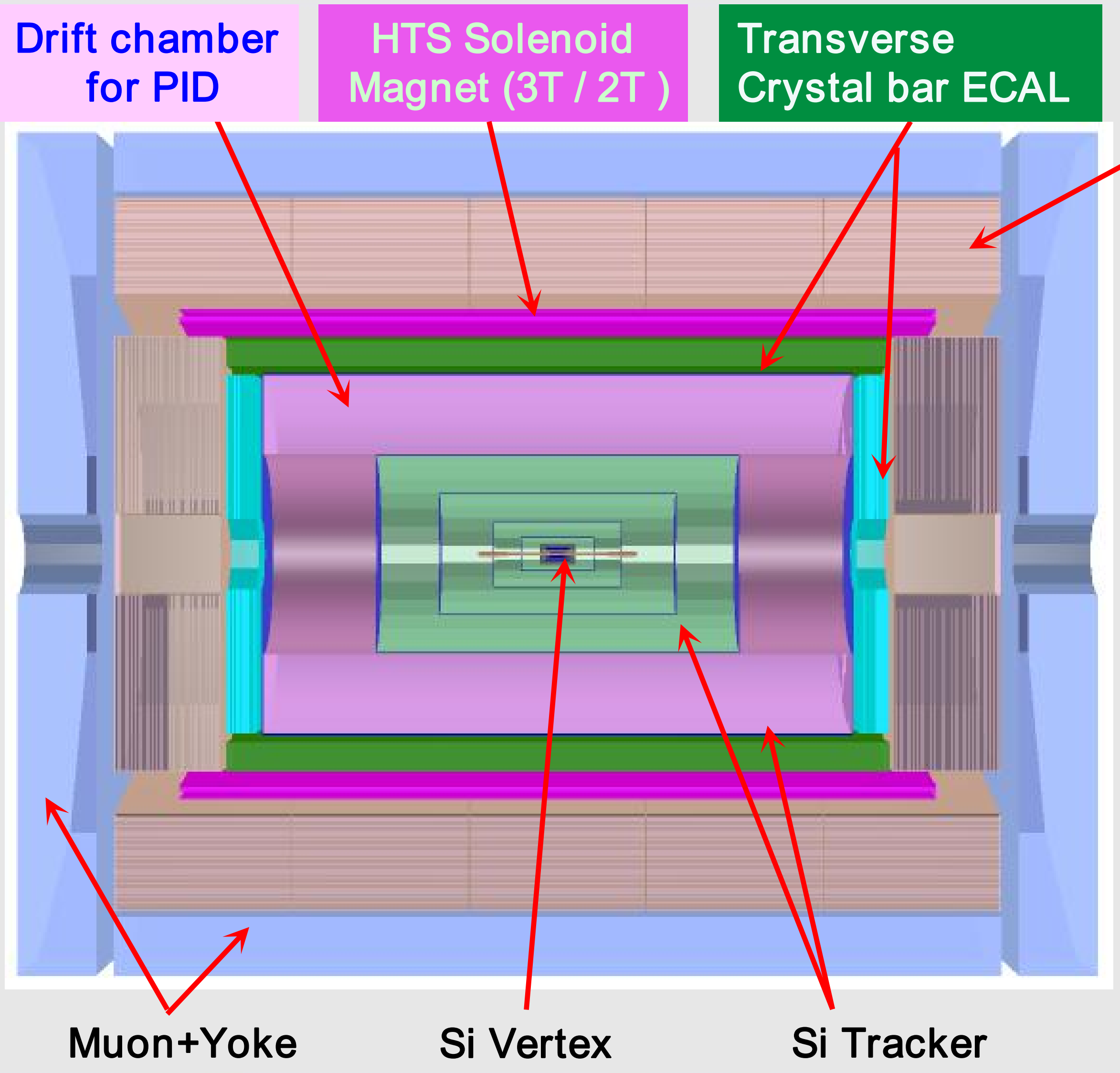
- Higher density provides higher energy sampling fraction
- Doping with neutron-sensitive elements: improve hadronic response (Gd)
- More compact HCAL layout (given 4~5 nuclear interaction lengths in depth)







The 4th Conceptual Detector Design



Scint Glass PFA HCAL

Advantage: Cost efficient, high density

Challenges: Light yield, transparency, massive production.

- Further performance goal: BMR 4%→3%
- Dominant factors in **BMR**: charged hadron fragments & HCAL resolution
  - Higher density provides higher energy sampling fraction
  - Doping with neutron-sensitive elements: improve hadronic response (Gd)
  - More compact HCAL layout (given 4~7 nuclear interaction lengths in depth)

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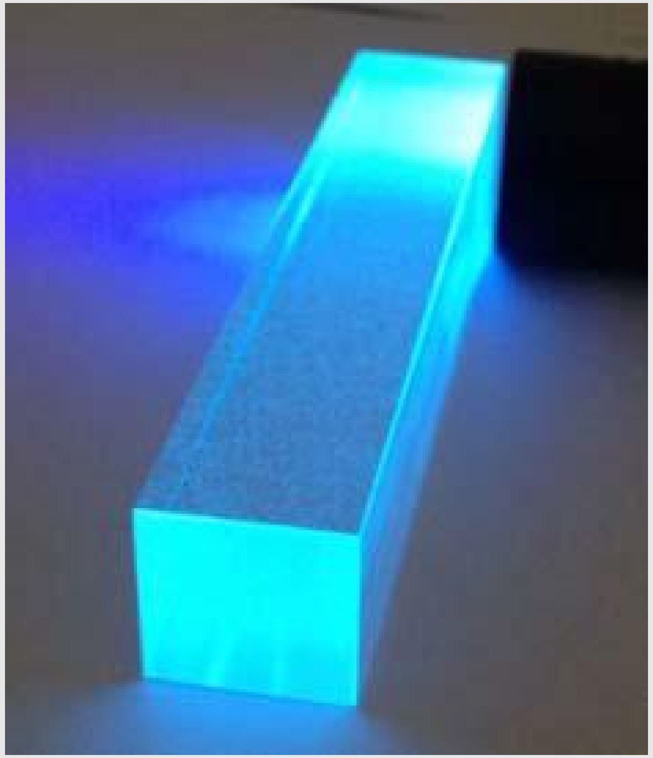
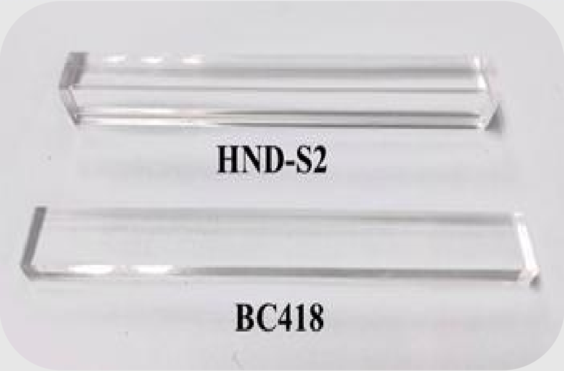
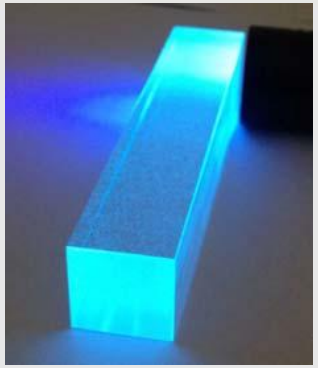


2.0 What is the Glass Scintillator？



Plastic Scintillator



Glass Scintillator

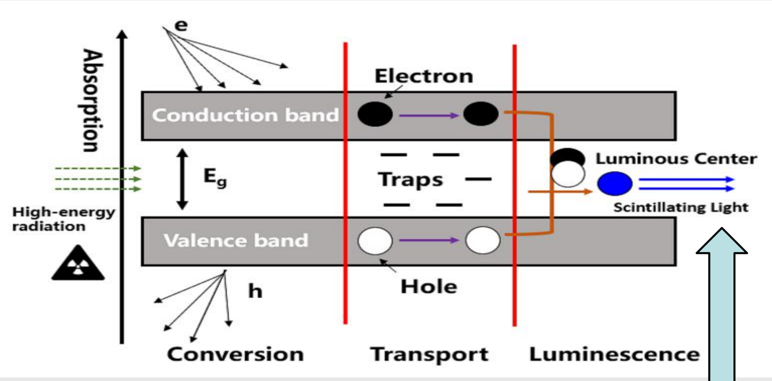
Crystal Scintillator

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

2.1 Target of Glass Scintillator

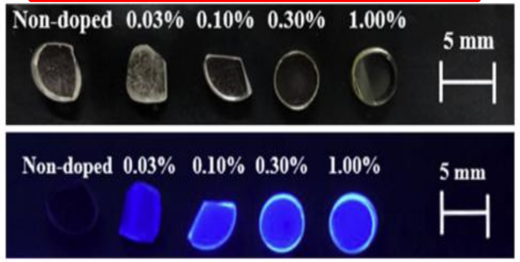
Key parameters	Value	Remarks
➢ Tile size	~30×30 mm^2	Reference CALICE-AHCAL, granularity, number of channels
➢ Tile thickness	~10 mm	Energy resolution, Uniformity and MIP response
➢ **Density**	**5-7 g/cm^3**	More compact HCAL structure with higher density
➢ **Intrinsic light yield**	**1000-2000 ph/MeV**	Higher intrinsic LY can tolerate lower transmittance
➢ Transmittance	~75%	
➢ MIP light yield	~150 p.e./MIP	Needs further optimizations: e.g. SiPM-glass coupling
➢ Energy threshold	~0.1 MIP	Higher light yield would help to achieve a lower threshold
➢ Scintillation decay time	~100 ns	Mitigation pile-up effects at CEPC Z-pole (91 GeV)
➢ Emission spectrum	Typically 350-600 nm	To match SiPM PDE and transmittance spectra

2.2 The Design of the Glass Scintillator



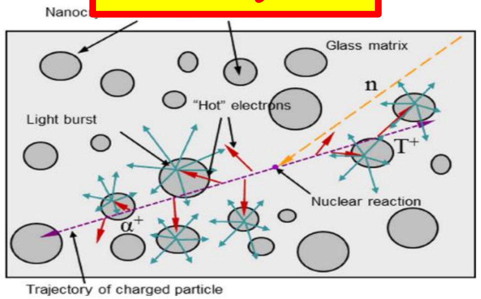
- Scintillation mechanism---- **Luminescence Center**
- **Conversion**—photoelectric effect and Compton scattering effect;
- **Transport**—electrons and holes migrate;
- **Luminescence**—captured by the luminescent center ions

Lanthanide elements



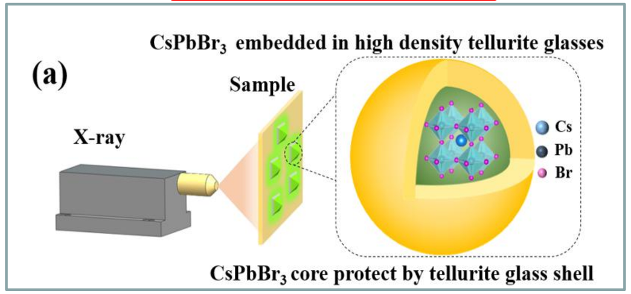
Journal of Alloys and Compounds 782 (2019) 859-864

Nanocrystals



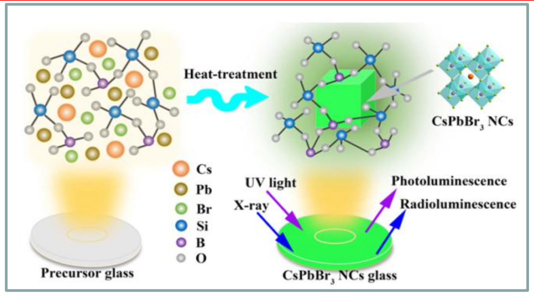
IEEE TNS 60 (2) 2013

Quantum Dots



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

Lanthanide + Quantum Dots



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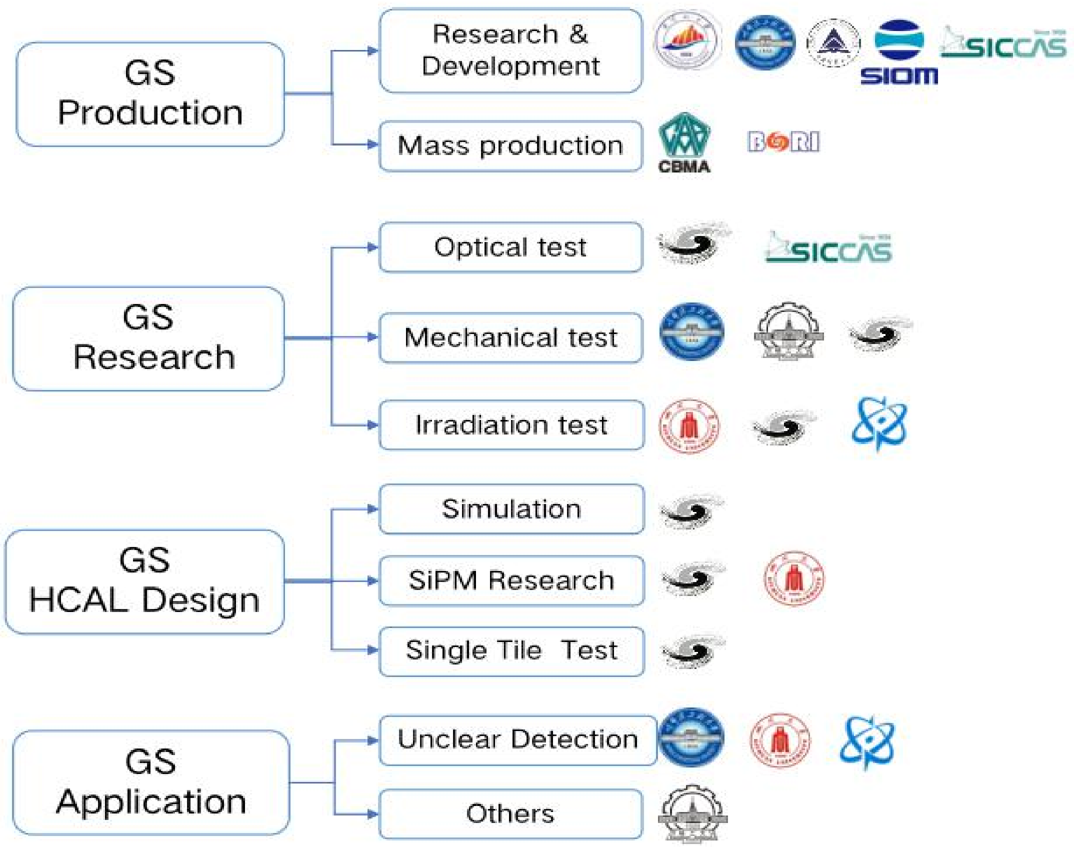
- **High Light Yield： Lanthanide for the Luminescence Center：Cerium（Ce）；**
- **High Density and Low radioactivity background：Gadolinium（Gd）；**

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

闪烁玻璃合作组
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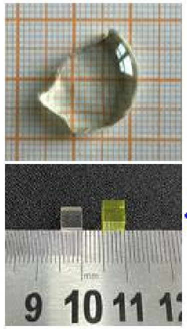
-- The Glass Scintillator Collaboration Group established in Oct.2021, only 5 groups join together；

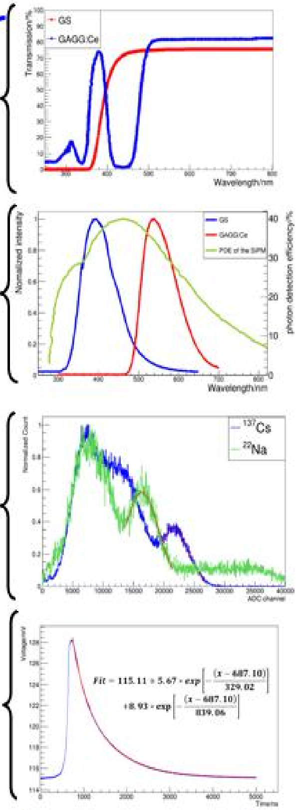
-- There are 3 Institutes of CAS, 5 Universitys, 3 Factorys join us for the R&D of GS;

-- The Experts of the GS in the University, Institute and Industry are still welcomed to join us (qians@ihep.ac.cn).

2.4 The Scintillator Test Facilities

➢ **The Scintillator Test System**





- Density;
- Elastic Modulus;
- Refractive Index;
- Transmission Spectrum
- Absorbance;
- Excitation Spectrum;
- Emission Spectrum;
- PL QY
- Light Yield;
- Energy Resolution;
- Decay time;
- Afterglow
- Coincidence Time Resolution;
- Neutron/Gamma Discrimination;
- Irradiation Damage

Others

……

- XPS
- XRD

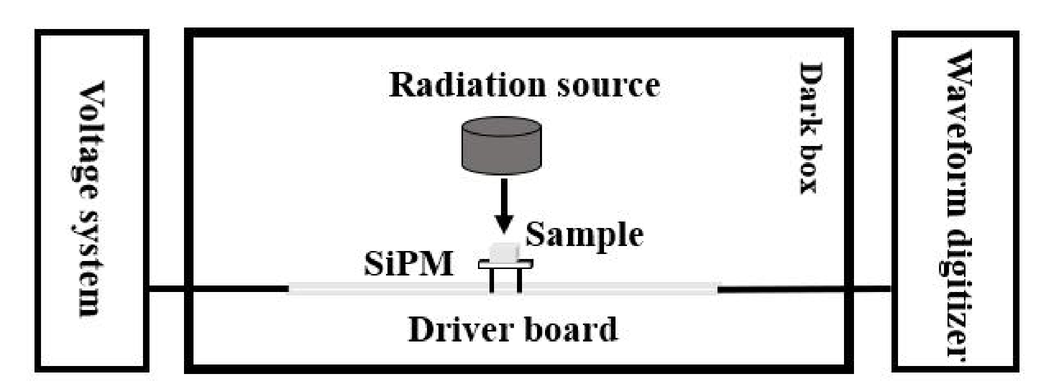
- **Spectroscopy:** Transmission/Absorption、PL-PLE、XEL
- **Nuclear radiation detection:** Light yield、Energy resolution、MIP response、n/γ Discrimination
- **Time characteristics:** Rise time、Decay time、Afterglow、Coincidence time resolution
- **Reliability:** Aging test、Radiation resistance characteristics

The published papers of different Scintillator sampls tested in Lab

1.Optical Materials; 105 109964; 2020; GAGG
2.Optical Materials; 125 112102; 2022; Sn-doped glass
3.Optical Materials; 130 112585; 2022; Aluminoborosilicate glass
4.Journal of Instrumentation; 17 T08001; 2022; CLLB
5.Journal of Instrumentation; 17 T09010; 2022; LYSO

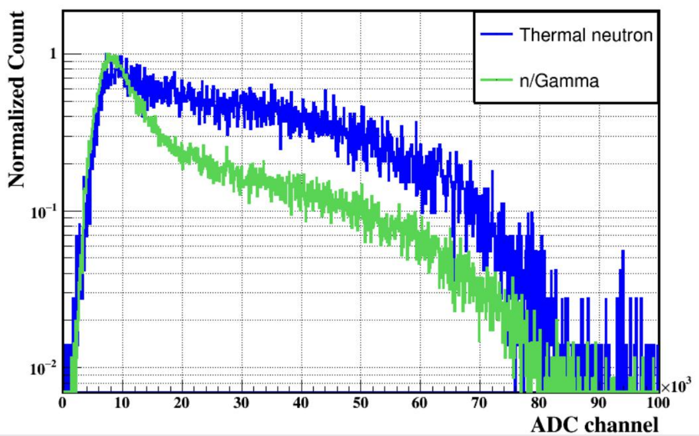
Radioactive Sources Test -- Energy Spectrum --Light Yield

- In IHEP Radioactive Sources Station；
- gamma： 137Cs， 60Co， 133Ba,
- neutron： 252Cf， Am-Be
- electron：90Sr， 22Na

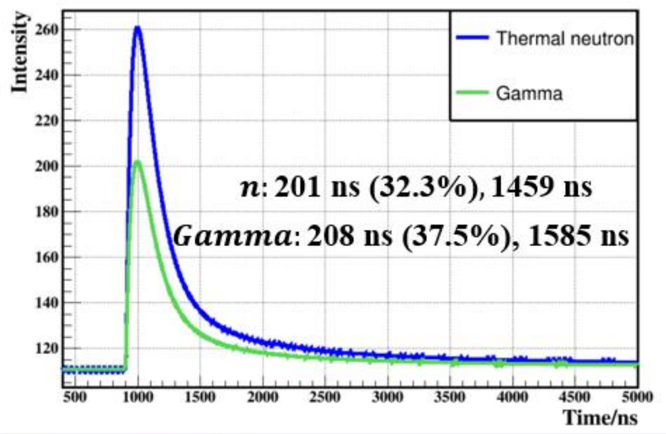


Through the waveform sampling data acquisition system, we can obtain **Light Yield, Energy Resolution and Decay Time** of the scintillator.

➢ γ/n Energy Spectra

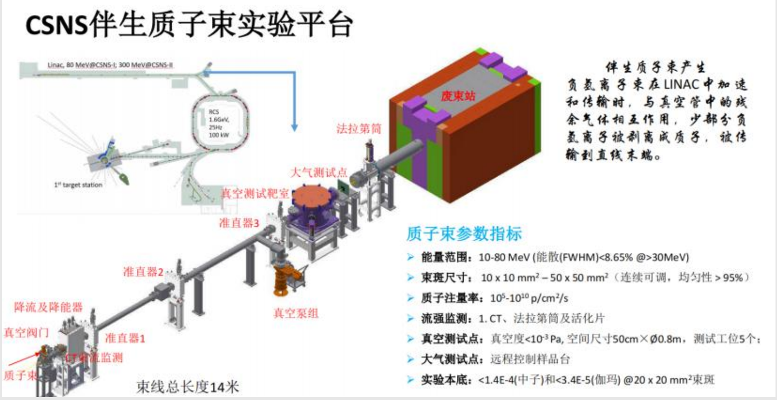


➢ γ/n Decay Time



Special Condition TEST Platform

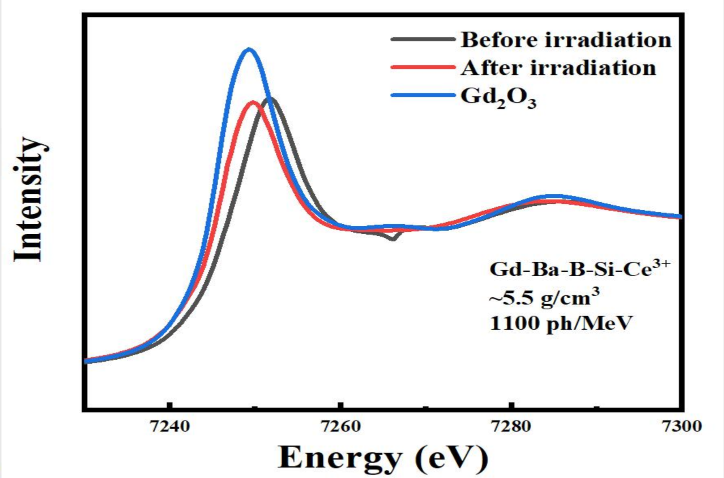
- IHEP--XAFS
- IHEP-CSN-- P Beam
- CERN-MUON beam

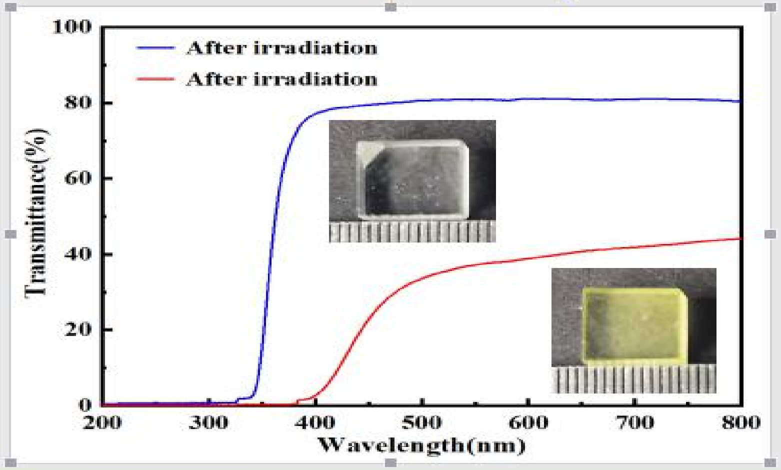


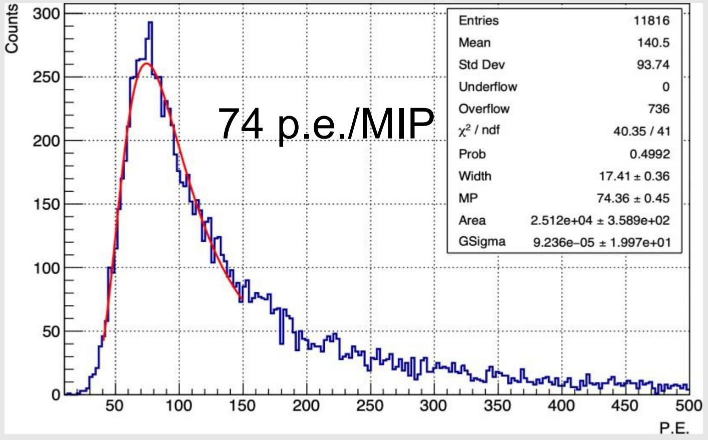
Study the elements influence of GS sample

Study the anti-irradiation characteristics of samples;

Study the particle interaction in GS sample with MUON







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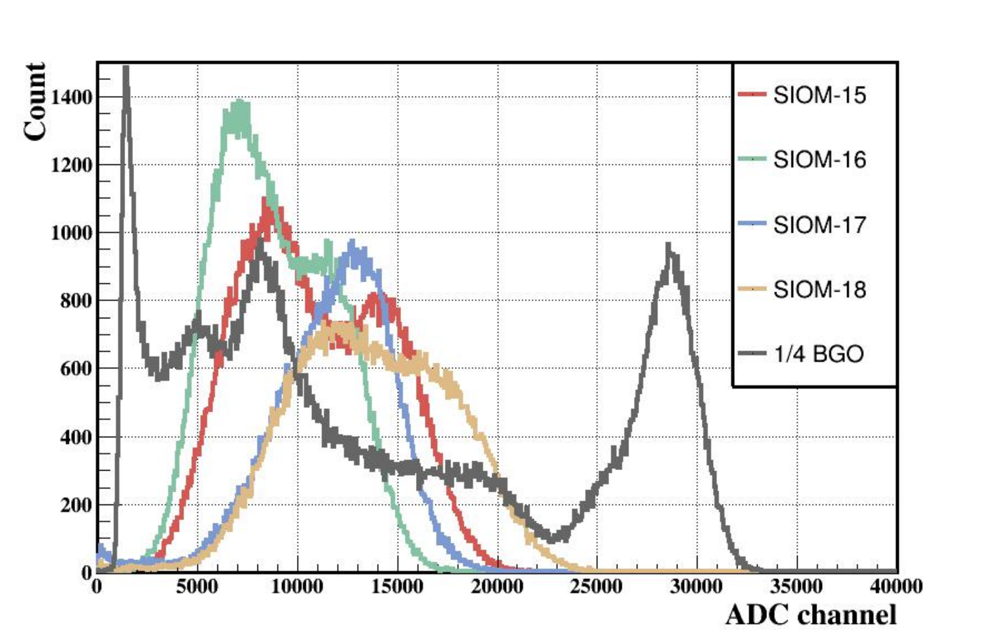
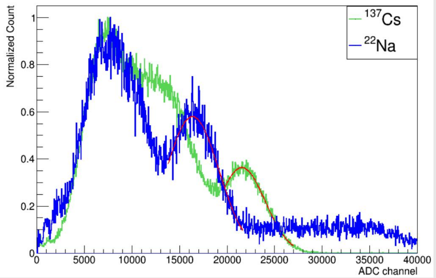


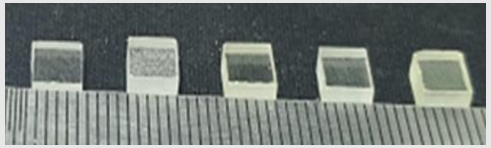
3.0 The GS Samples produced （>400）

3.1 Borosilicate Glass（Gd-Al-B-Si-Ce^{3+}）--GS1

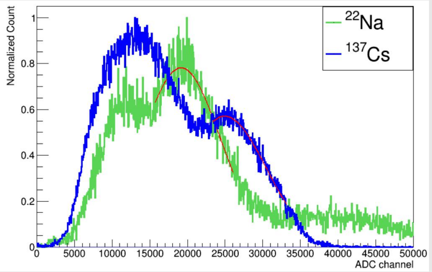
- Density~4.5 g/cm³
- LY=802 ph/MeV
- ER=26.8%
- Decay=262 (18%) 1235 ns



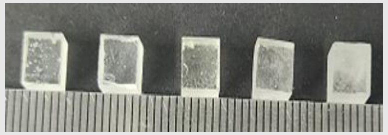
2021.11



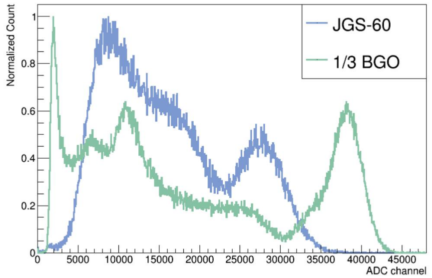
- Density~6.0 g/cm³
- LY>1000 ph/MeV
- ER=49.6%
- Decay=847 ns



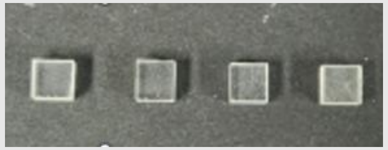
2022.11



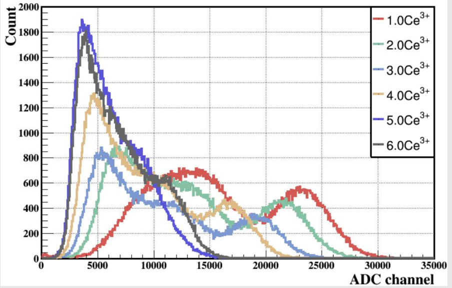
- **Density~6.0 g/cm³**
- **LY~1100 ph/MeV**
- **ER=24.4%**
- **Decay=460 ns**



2023.02

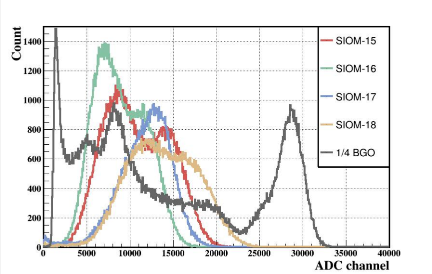


- Density~5.8 g/cm³
- LY~1000 ph/MeV
- ER=26.8%
- Decay=1091 ns

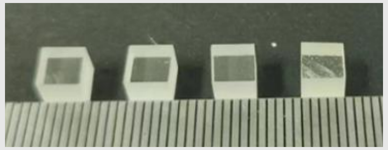


2023.04

- Density~6.0 g/cm³
- LY~700 ph/MeV
- ER=32.3%
- Decay=382 ns



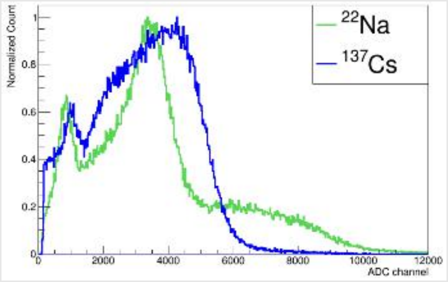
2023.07



- There are 5 types of SG for the study, and focous on the GS1, the Borosilicate Glass for better performance;
- Finally, the **Density~6.0 g/cm³，LY>1100 ph/MeV, ER=24.4%, could be accept to be the candidate for GS-HCAL**
- But the Decay time =460 ns, still need to improve.

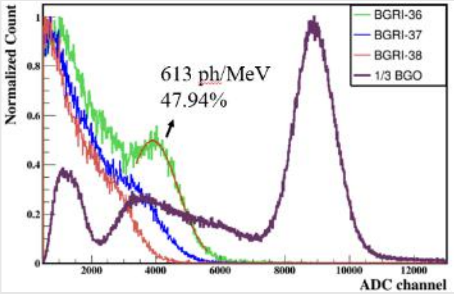
3.2 Large size glass（Gd-Al-B-Si-Ce^{3+}）--GS1

- Size=30*27.5*9 mm^3
- Density=5.1 g/cm^3
- LY=466 ph/MeV
- ER=None

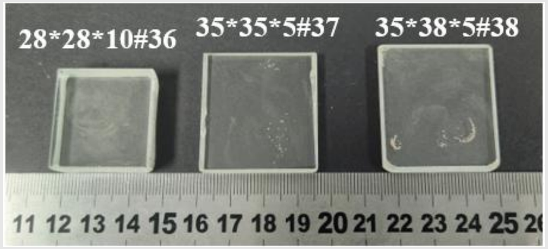


2022.10

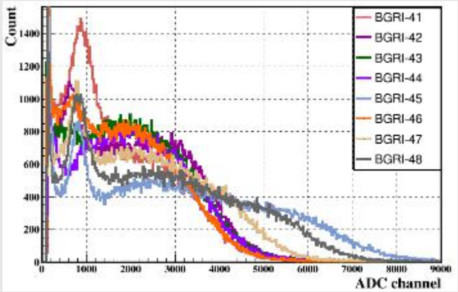
- Size=28*28*10 mm^3
- Density=5.2 g/cm^3
- LY=613 ph/MeV
- ER=47.9%



2023.01



- Size=30*30*9 mm^3
- Density=5.1 g/cm^3
- LY=767 ph/MeV
- ER=None



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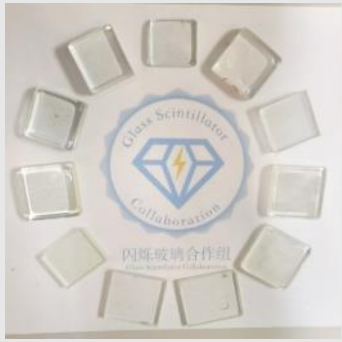
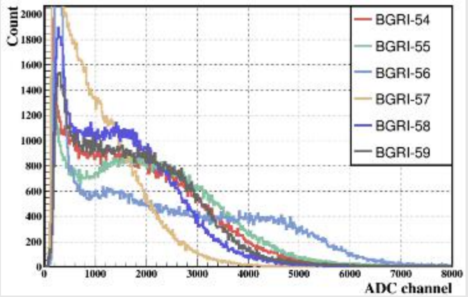
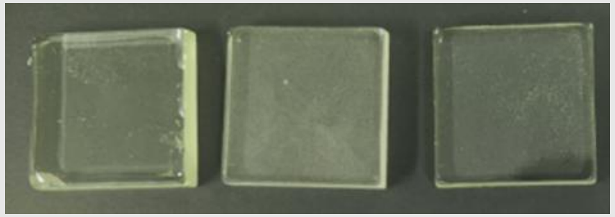


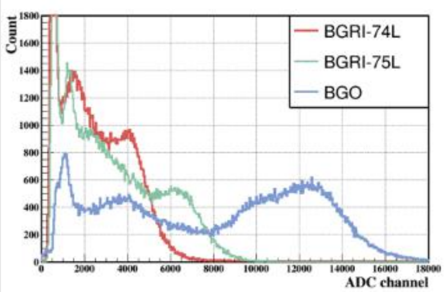
- Size=50*50*10 mm^3
- Density=5.8 g/cm^3
- LY=172 ph/MeV
- ER=None



2023.05



- Size=20*20*10 mm^3
- Density=5.8 g/cm^3
- LY=506 ph/MeV
- ER=50%



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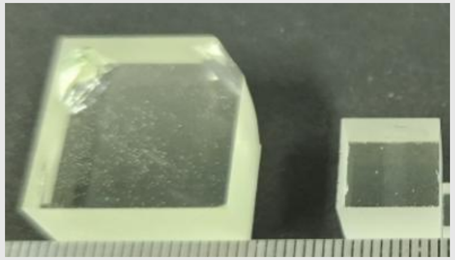
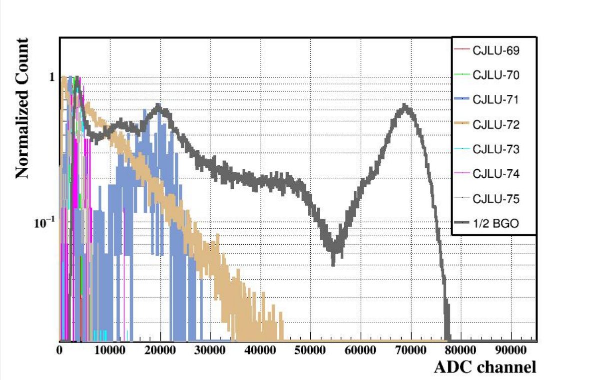


The Bottleneck：

1. How to produce the large size sample in factory, with the same performance of small size in the university Lab.
2. How to increase the denisty and light yield in large siza sample?

3.3 Silicate glass（Gd-Ga-Si-Ce^{3+} glass）—GS5

- Density~5.0 g/cm^3
- LY>2000 ph/MeV?
- ER=None
- Decay=287 ns



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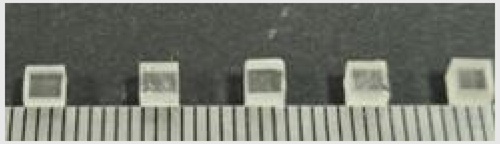
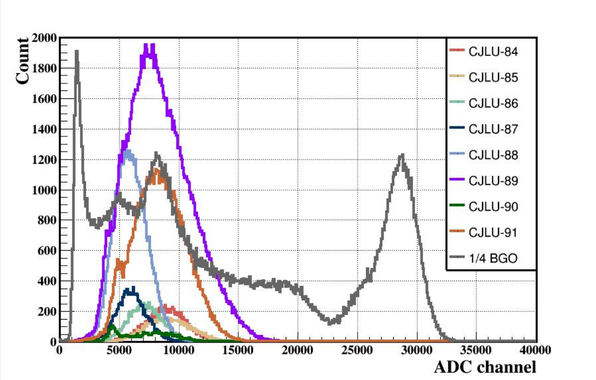


- Density~6.0 g/cm^3
- LY=402 ph/MeV
- ER=None
- Decay=None



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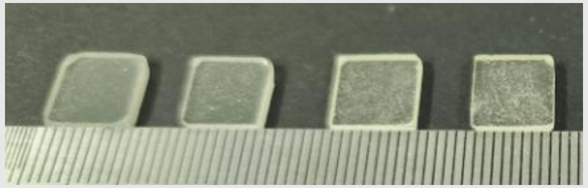
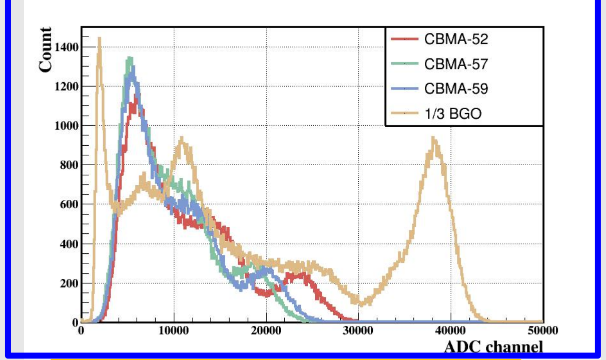


- Density~6.0 g/cm^3
- LY=1058 ph/MeV
- ER=23.7%
- Decay=97 ns (44%), 352 ns



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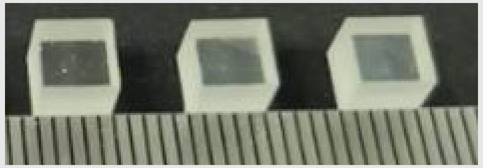
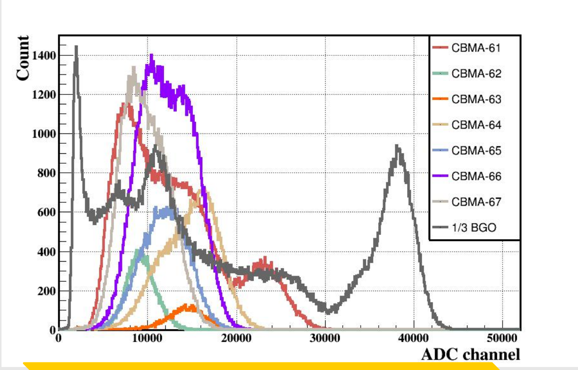
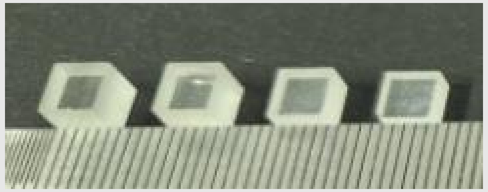


- Density~6.0 g/cm^3
- LY=1040 ph/MeV
- ER=25.8%
- Decay=107 (43%), 450 ns



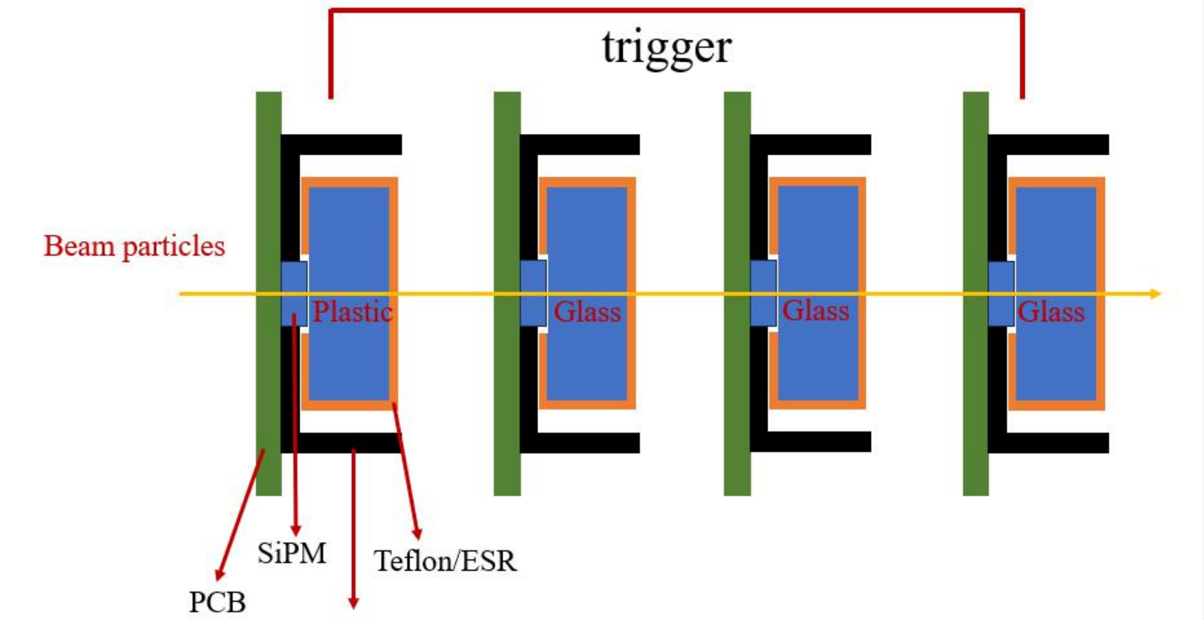
2023.08

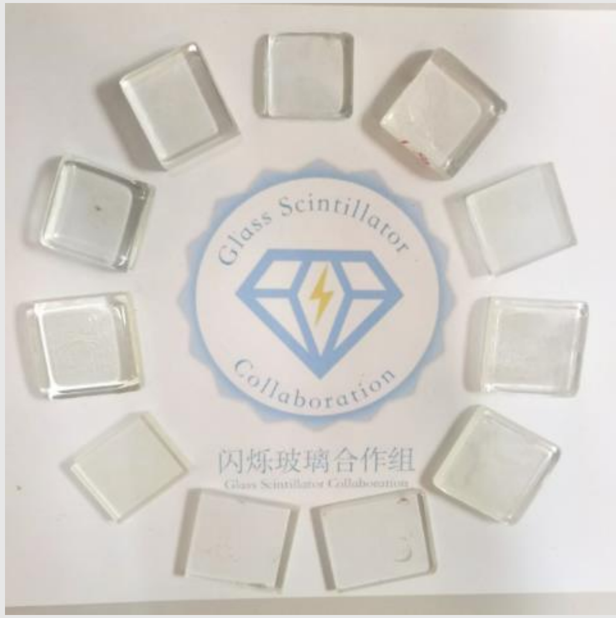


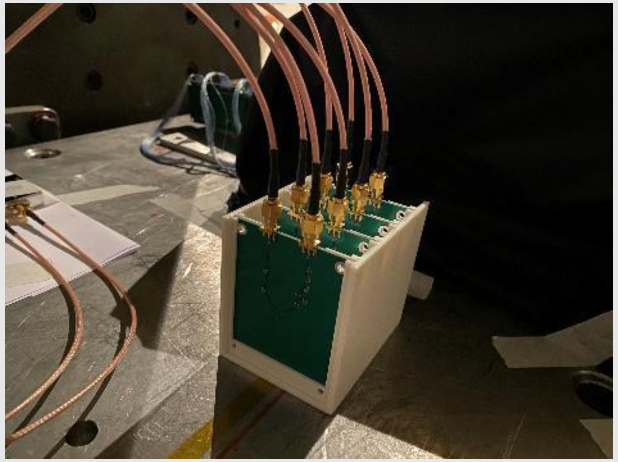
- There are 5 types of SG for the study, and the GS5, the Silicate Glass is to be the other option for us.
- Finally, the **Density~6.0 g/cm^3，LY>1000 ph/MeV, ER=23.7%, could be accept to be the candidate for GS-HCAL**
- But the Decay time =352 ns, still need to improve.

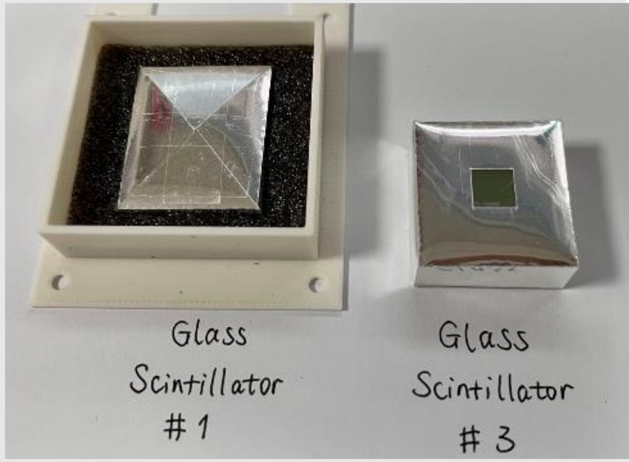
3.4 CERN muon-beam experiment

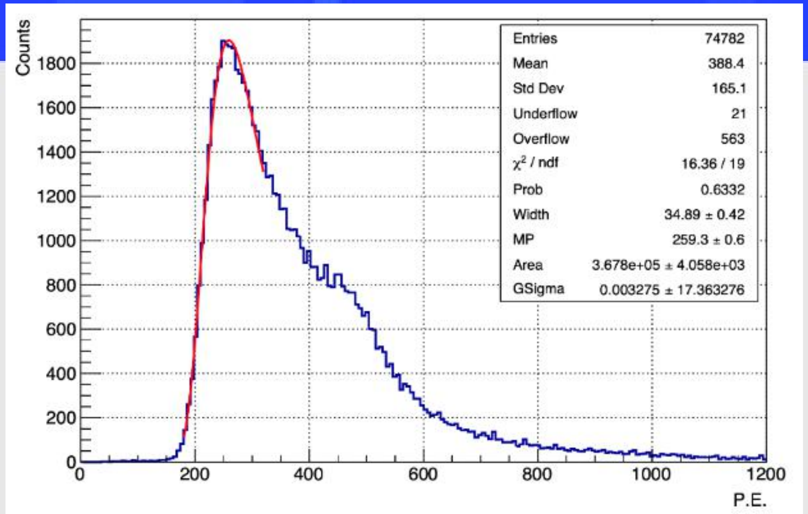
- 11 glass scintillator tiles successfully delivered from IHEP to CERN (May 16)
- Beam test facility: CERN Proton Synchrotron (primary 24GeV protons)
- Major motivation: to measure the MIP response of each glass tile

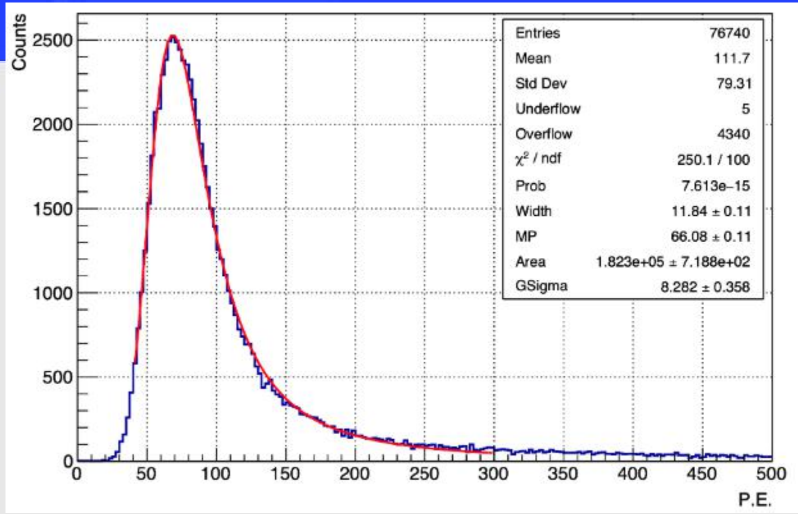


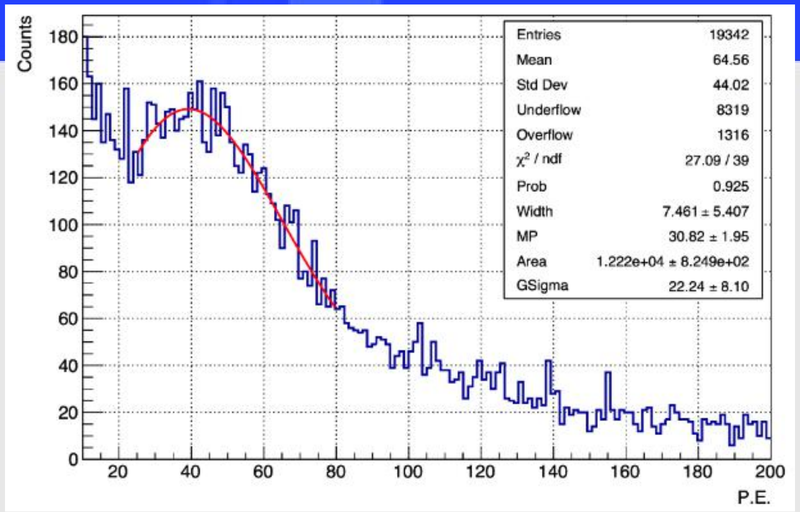












Plastic scintillator:
259 p.e./MIP

Glass scintillator (#3):
66 p.e./MIP

Glass scintillator (#4):
31 p.e./MIP

	Size (mm^3)	Light yield (ph/MeV)	MIP_LY (p.e./MIP)	MIP/(Thi*Den)	LY/[MIP/(Thi*Den)]	MIP_LY_10cm (p.e./MIP)
#3	29.9×28.1×10.2	617	66	1.27	486	**65**
#4	37.2×35.1×5.3	571	31	1.15	497	**59**

- Normalized through density and thickness, the MIP response of some glasses is consistent with the light yield.
- All results need to be further analysis according to the waveform of the glasses.

Outline

- 1. The GS-HCAL of CEPC;
- 2. The Motivation and Design of GS ;
- 3. The progress of the R&D of GS;
- **4. Summary and Next Plan;**

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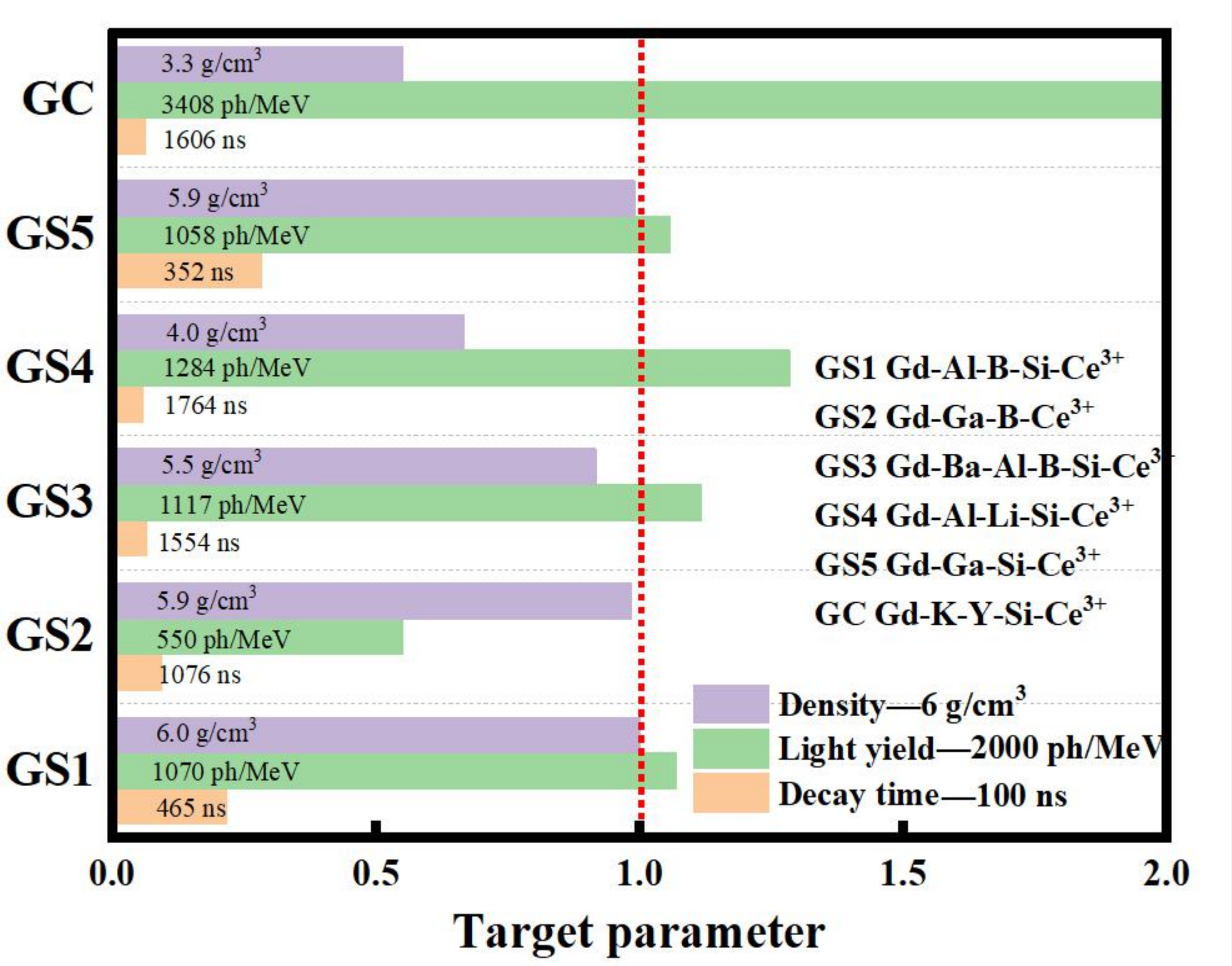
4.1 Summary of GS



Glass scintillator of high density and light yield

◆ GS1: Gd-Al-B-Si-Ce^{3+} glasses: (Borosilicate Glass)

6.0 g/cm³ & 1070 ph/MeV with 24.4% @662keV & 460 ns

◆ GS5: Gd-Ga-Si-Ce^{3+} glasses: (Silicate glass)

5.9 g/cm³ & 1060 ph/MeV with 23.7% @662keV & 352 ns

- Ultra-high density **Tellurite Glass**—6.6 g/cm³
- High light yield **Glass Ceramic**—3500 ph/MeV
- Fast scintillating Decay Time—100 ns
- Large size Glass—42mm*51mm*10mm

4.2 Next Plan for GS-HCAL

- By replacing the CEPC_v4 baseline HCAL with the GSHCAL , **the BMR can reach ~3.4%** in the nominal setup and show ~10% improvement with. the AHCAL baseline design (~3.8%);
- The R&D of large-size glass tiles featuring **high density, high light yield and short decay time** is the main focus of next stage for the Glass Scintillator R&D collaboration;
- More detailed studies like **SiPM performances**, coupling designs with the glass cell and the photon collection efficiency will be done to give advice for glass tile design;
- The mechanical and **modular design** of the GSHCAL will be studied later;

Glass Scintillator Collaboration

See the unseen
change the unchanged

The Innovation

THANKS