The optical properties of Glass Scintillator for HCAL of CEPC

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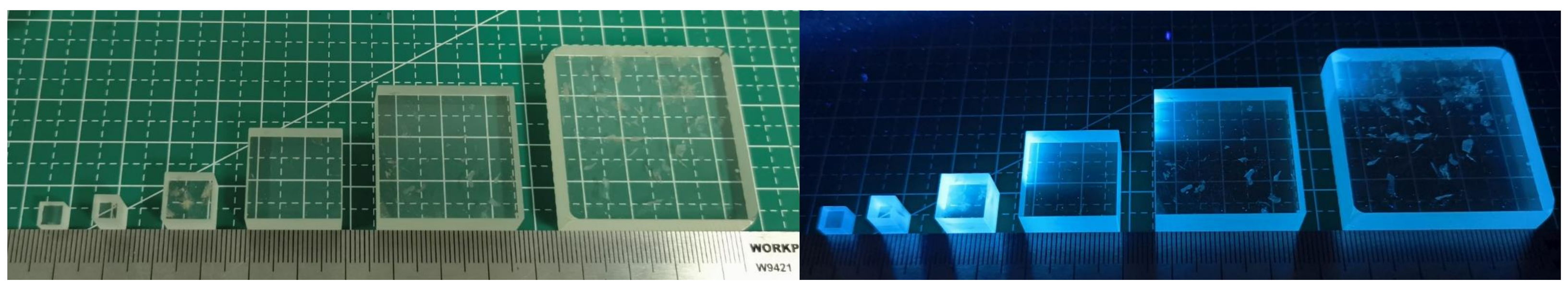
Introduction

Since 2021, the Glass Scintillator Collaboration Group (GS Group) has been developing large-size, high-density(~6 g/cm^3), high-light-yield(>1000 ph/MeV), fast-decay(<300 ns), and radiation-resistant scintillation glass for glass scintillator hadron calorimeter (GSHCAL) of Circular Electron-Positron Collider(CEPC), and has achieved certain results. In order to explore the differences between scintillation crystals and glass scintillator in different sizes and detection methods, we have selected the standard scintillation crystal $Bi_4Ge_3O_{12}$ (BGO) for comparison, hoping to make a contribution to the application of large glass scintillator detectors.

1. Research progress of GS Group

Key parameters	Target
Tile size	~30×30 mm^2
Tile thickness	~10 mm
Density	6-7 g/cm^3
Intrinsic light yield	1000-2000 ph/MeV
Transmittance	~75 %
MIP light yield	~150 p.e./MIP
Energy threshold	~0.1 MIP
Scintillation decay time	~100 ns
Emission spectrum	Typically 350-600 nm

- **Ultra-high density Tellurite Glass —6.6 g/cm^3**
- **High light yield Glass Ceramic —3500 ph/MeV**
- **Fast Decay Time Pr^{3+}-doped Glass —100 ns**
- **Large size Glass —51mm*51mm*10mm**



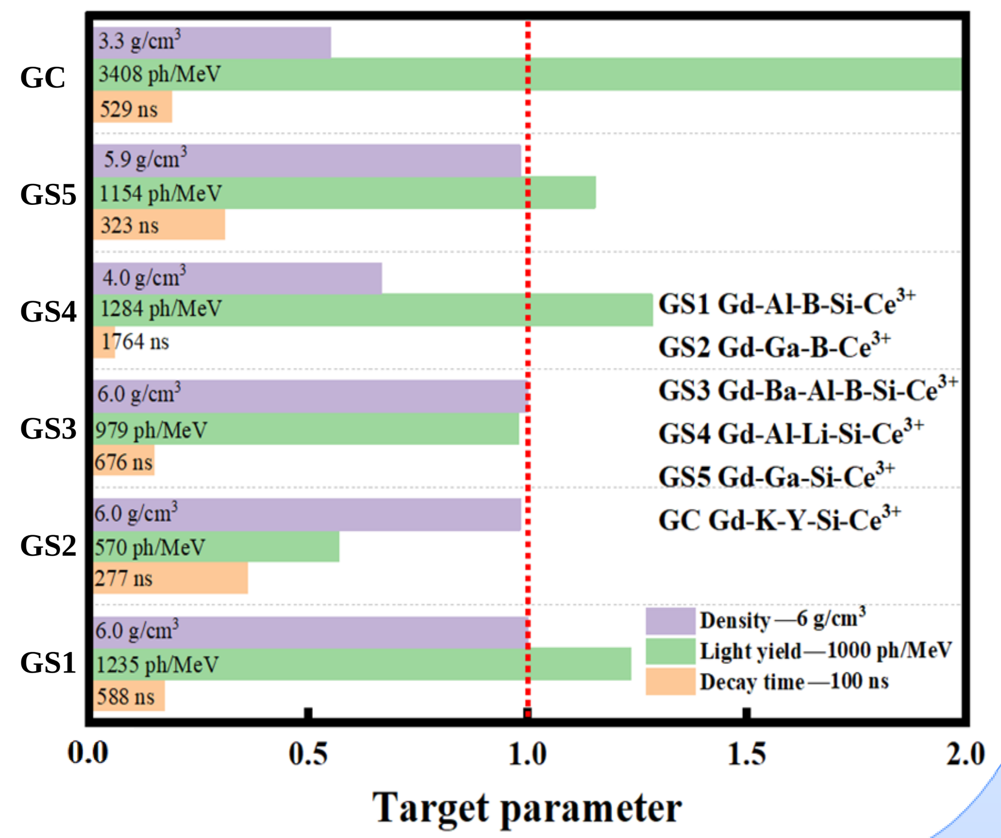
- ***Glass scintillator of high density and light yield***

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

6.0 g/cm^3 & 1235 ph/MeV with 24.0% @662 keV & 588 ns

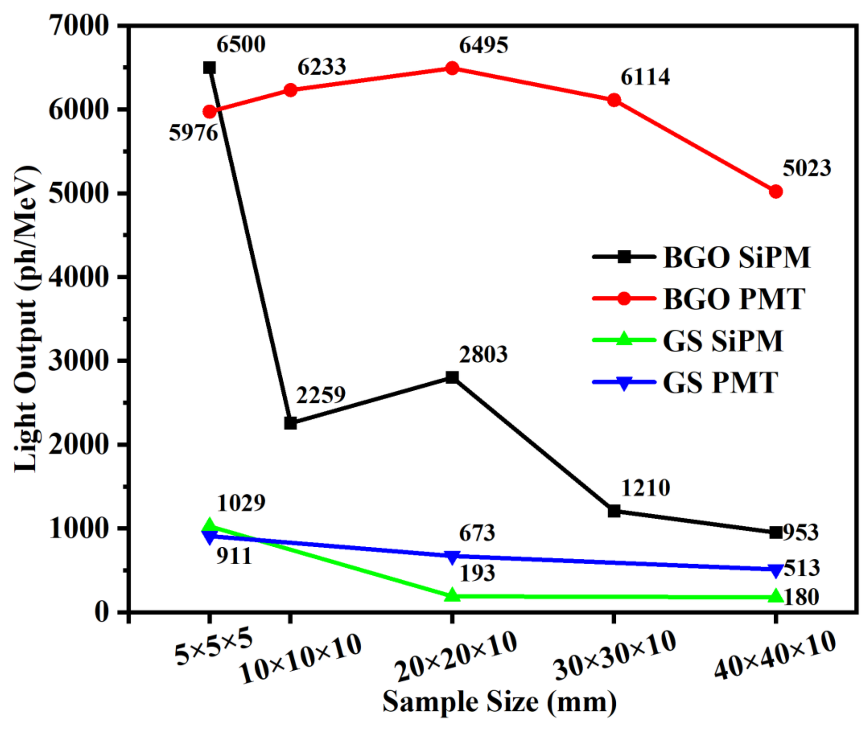
GS5: Gd-Ga-Si-Ce^{3+} glasses: (Silicate glass)

5.9 g/cm^3 & 1154 ph/MeV with 25.4% @662keV & 323 ns



2. Size Effects of Glass Scintillator and BGO

- BGO crystal: As the size increases, the number of photons detected by SiPM gradually decreases (SiPM detection area 6*6mm, with the scintillator body enlarging, the detection area ratio decreases). The number of photons detected by large-size glass remains relatively constant.

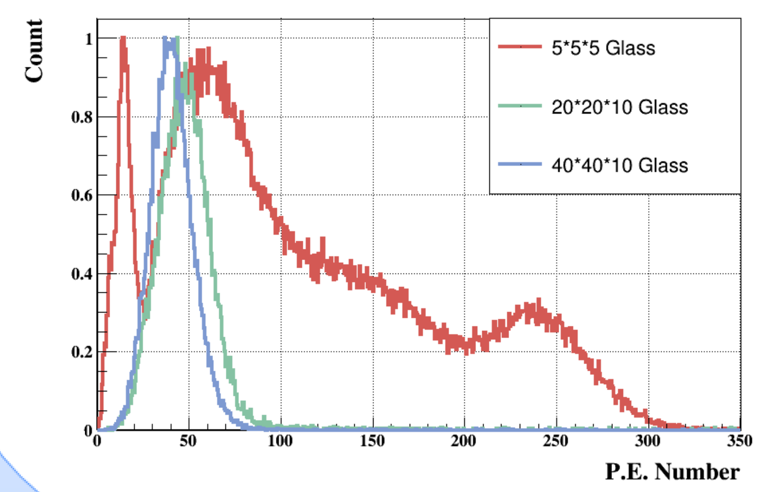


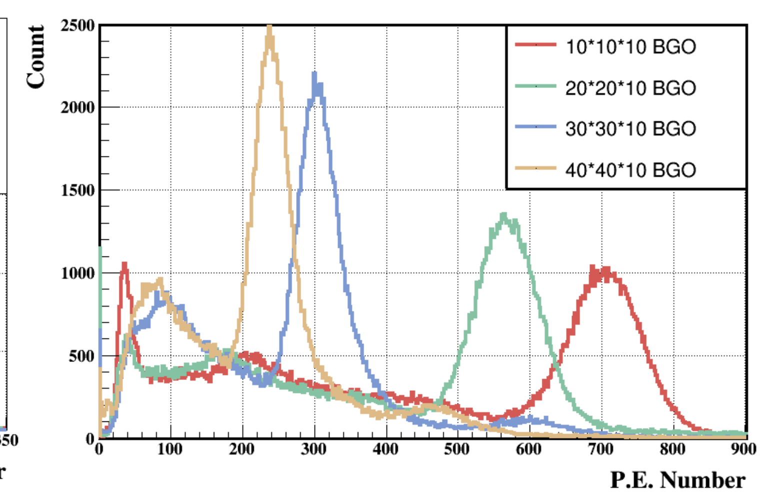
- **Possible reasons:**

The glass has a small attenuation length, and the dispersed scintillation light is absorbed by the glass matrix.

This results in only the scintillation light generated by the glass within a certain area being detected by SiPM, and increasing the glass area has no effect on this.

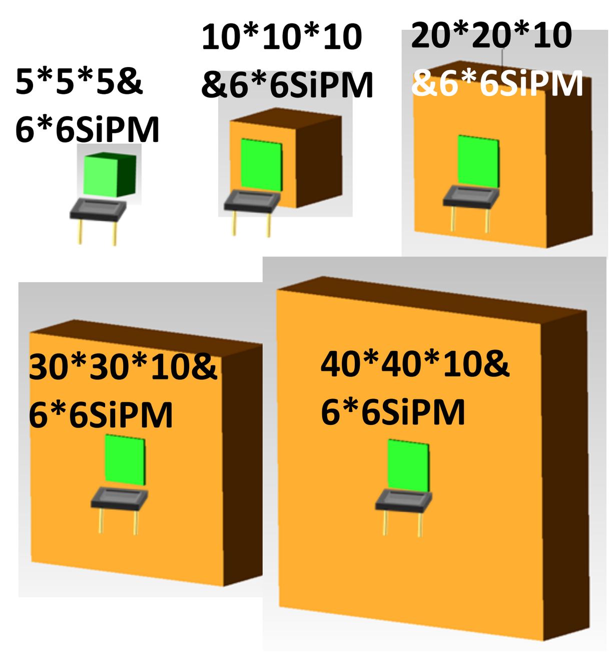
BGRI	T（%）@400nm	LO (ph/MeV)		BGO	T（%）@400nm	LO (ph/MeV)	
5*5*5	74	1029	1	5*5*5	74	6970	1
				10*10*10	75	3238	46.4%
20*20*10	73	193	18.8%	20*20*10	76	2609	37.4%
				30*30*10	76	1398	20%
40*40*10	66	180	17.5%	40*40*10	75	1101	15.8%

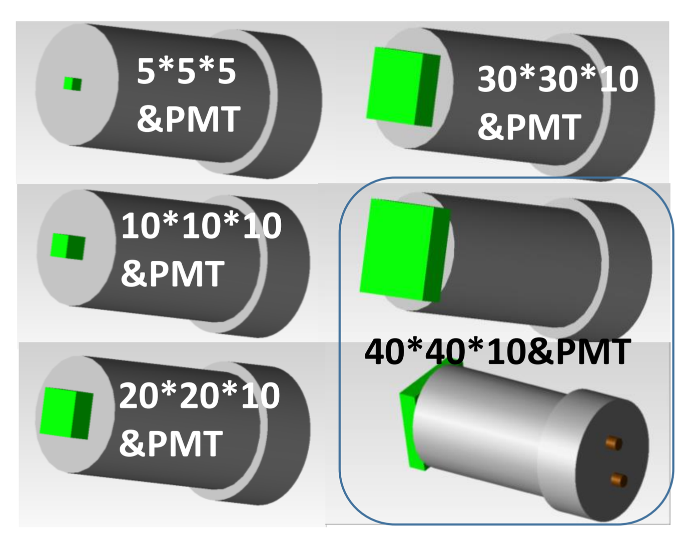




3. The optical properties of Glass Scintillator and BGO

- **Regarding the test results of the large-size samples, GS and BGO exhibit similar but not entirely consistent trends in their variation. Experimental evidence suggests that GS cannot be directly predicted using the empirical results of BGO. The main differences are as follows:**
  - **a)The radiation lengths of the scintillating glass and BGO crystal are different, leading to different energy deposition effects.**
  - **b)The influence of material scattering.**
  - **c)The refractive index of the BGO crystal is 2.1, which is significantly affected by total internal reflection. This can be mitigated by adding anti-reflection coatings.**
  - **d)The scintillating glass exhibits a short attenuation length, leading to substantial loss of scintillation light, with a higher proportion of detected photons being those that have undergone minimal refraction and reflection.**





Conclusion

- **The borosilicate and silicate glass system has the characteristics of high density and high light output, and is expected to be applied in the calorimeter of CEPC. Borosilicate glass remains the focus of future research. In the next step, we aim to:**
  - **a) Shorten the scintillation decay time of the glasses (<300 ns).**
  - **b)Repeatedly prepare and optimize the performance of large-size glass.**
  - **c)Improve raw material purity to enhance scintillation performance.**
  - **d)Further improve the performance of glass through energy band engineering and composition engineering.**
  - **e)Lastly, explore the structure, radiation resistance, and mechanical properties of the glasses.**
- **In addition, the GS team has also prepared other glass scintillators, which can be used in nuclear radiation detection, nuclear medicine, and other fields, such as ultra-high density tellurite glass and fast decay time Pr^{3+}-doped glass.**

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