中国科学院高能物理研究所
Institute of High Energy Physics
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Research Progress of The Glass Scintillator

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On behalf of the Glass Scintillators R&D Group

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Outline

1. Motivation

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

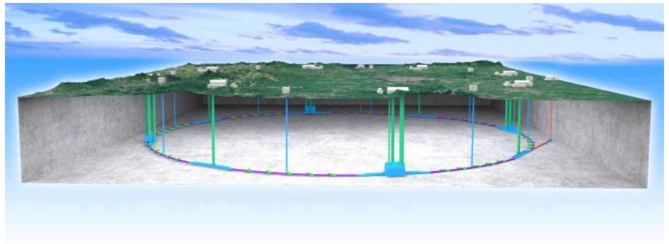
- Main physical goal: precision measurements of the Higgs and Z/W bosons
- Challenge: unprecedented jet energy resolution $\sim 30\%/\sqrt{E(GeV)}$

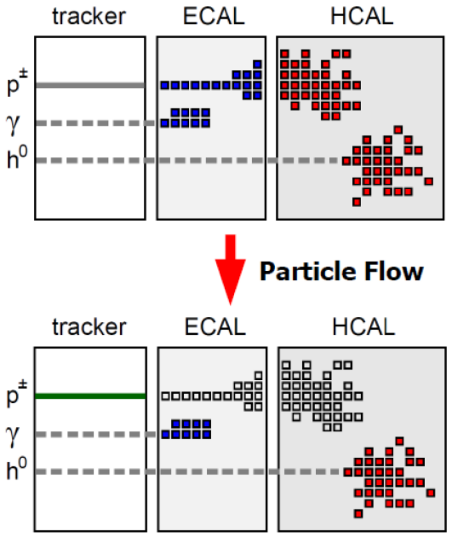
CEPC detector: crystal ECAL + scintillating glass HCAL

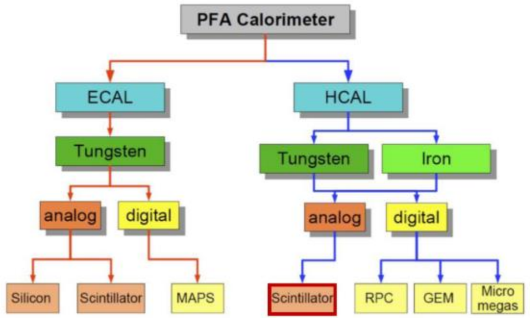
- A leap in terms of sampling fractions
- Aim to improve the energy resolution: esp. the hadronic resolution
- Physics performance goal: Boson Mass Resolution(BMR) 4%→3%

Next generation HCAL: Glass Scintillators

- Higher density provides higher energy sampling fraction
- Certain doping to enhance neutron capture: improve hadronic response (Gd)
- More compact HCAL layout (given 4~5 nuclear interaction lengths in depth)







Outline

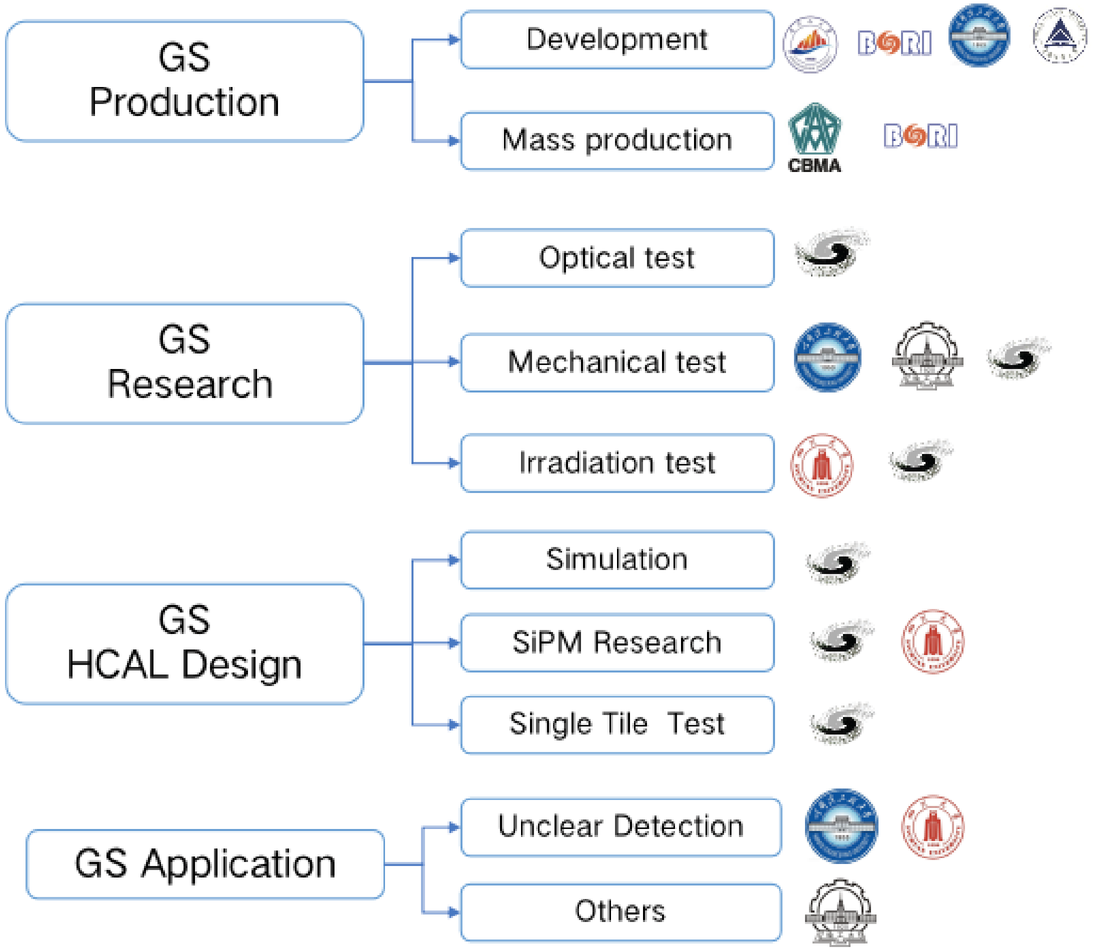
2. Research objective

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	6-7 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 type, 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

Outline

1. Motivation
2. Research objective
3. **Research foundation**
   - 3.1 Glass Scintillators R&D Group
   - 3.2 Test facility
4. Research progress
   - 4.1 Density
   - 4.2 Light yield and energy resolution
   - 4.3 Decay time
   - 4.4 Neutron detection
5. Summary

3.1. Glass Scintillators R&D Group



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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

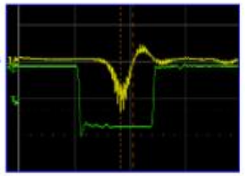
Sichuan University
四川大学

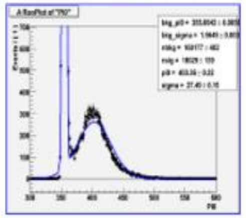
-- The Glass Scintillator Collaboration Group established in Oct.2021；

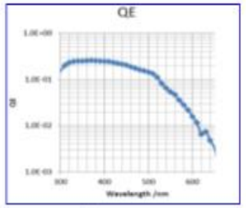
-- The Experts of the GS in the University and Industry are still welcomed to join us.

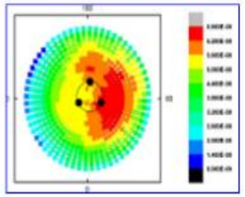
3.2. Test facility

➢ PMT性能标定平台









Others

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- 阳极信号上升时间-- Anode Pulse Rise Time;
- 前/后脉冲信息--Pre/Late/After Pulse;
- 暗计数率-- Dark Count

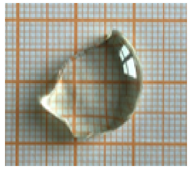
- 单光电子谱--The Single Photoelectron Spectrum;
- 分压器设计--The voltage distribution (BASE) ;
- 最佳工作高压--The Supply voltage;
- 典型高压增益曲线--Typical Gain Caracteristic;
- 阳极暗电流--Anode Dark Current

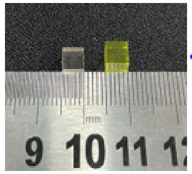
- 光谱响应曲线--Spectral Response;
- 峰值波长曲线--Wavelength of Maximum Response;
- 阴极灵敏度--Cathode Sensitivity: Luminous(2856K);
- 光阴极量子效率--Quantum efficiency with λ

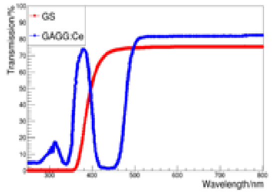
- 光阴极有效面积--Photocathode efficiency Area;
- 光阴极均匀性--Photocathode efficiency Uniform;
- 碱源安装布局--The position of the Sb, K, Cs;

- 线性--The linearity of the PMT
- 抗磁场性能--Magnetic characteristics;
- 时间性能--Transit Time Spread (FWHM)

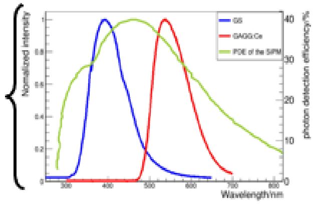
➢ 闪烁材料性能标定平台（晶体，玻璃，光纤……）



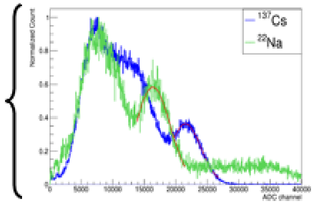




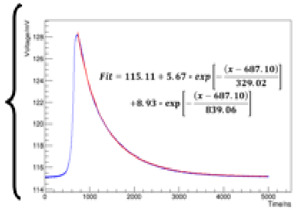
- Density;
- Elastic Modulus;
- Refractive Index;
- Transmission Spectrum



- Absorbance;
- Excitation Spectrum;
- Emission Spectrum;
- PL QY



- Light Yield;
- Energy Resolution;
- Decay time;
- Afterglow



- Coincidence Time Resolution;
- Neutron/Gamma Discrimination;
- Irradiation Damage

Others

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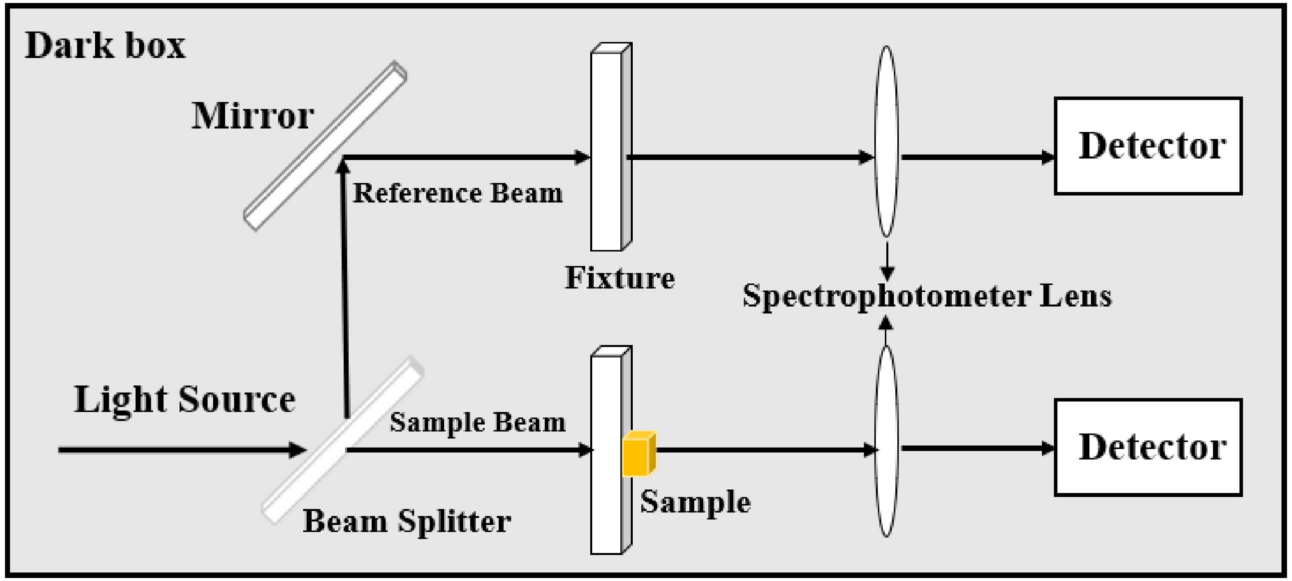
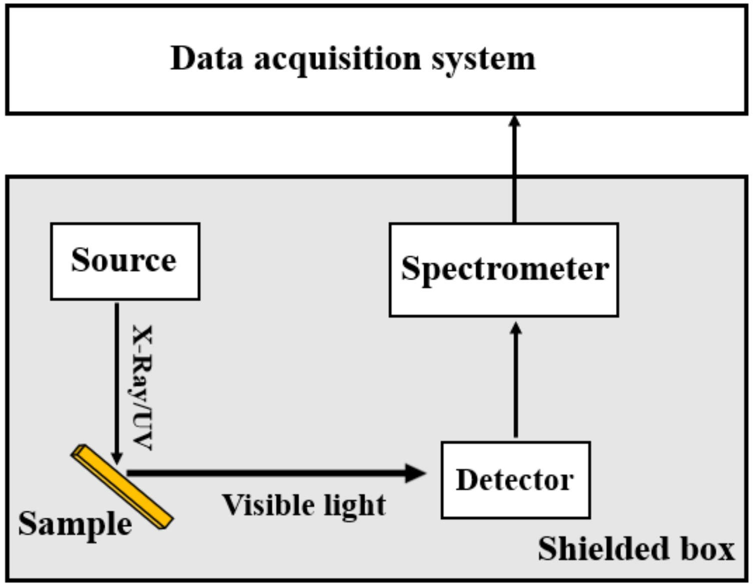
- XPS
- XRD

3.2. Test facility--(1) optical properties



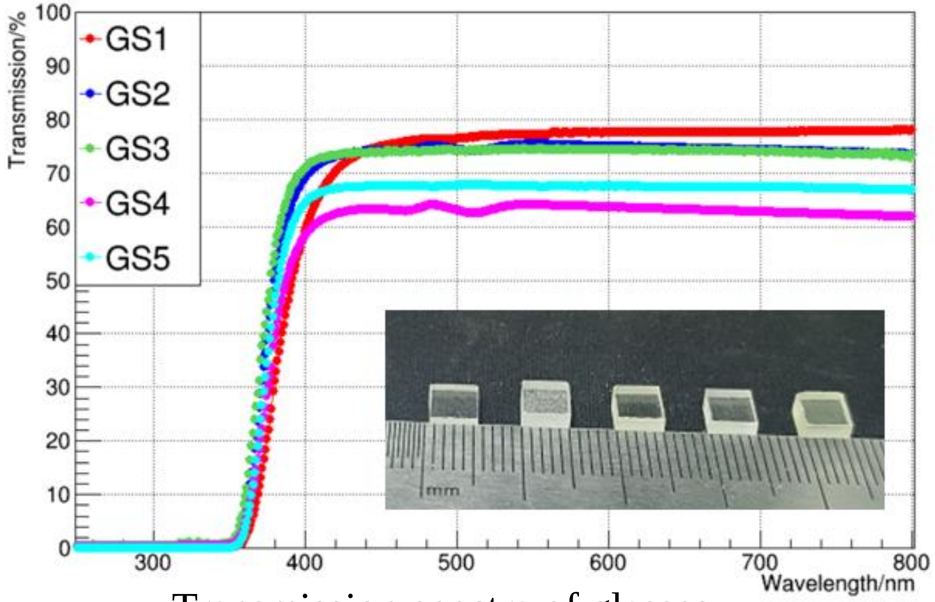
Transmittance



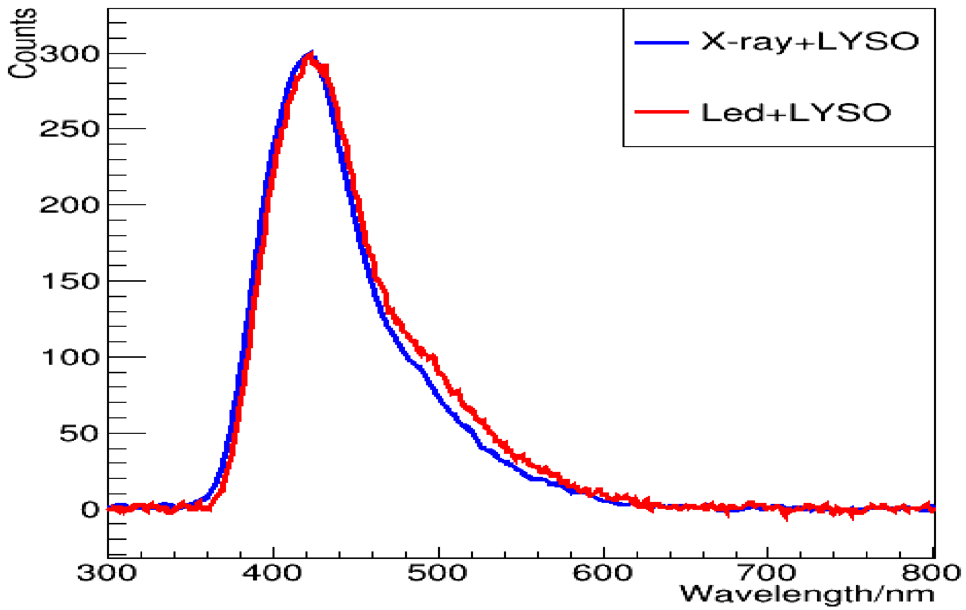
Emission spectrum

- Transmittance—The ratio of the light passing through to the light incident on the specimens. The transmittance of the scintillator affects its light output.
- The photon detection efficiency of SiPM and PMT is closely related to the emission range of the scintillator.

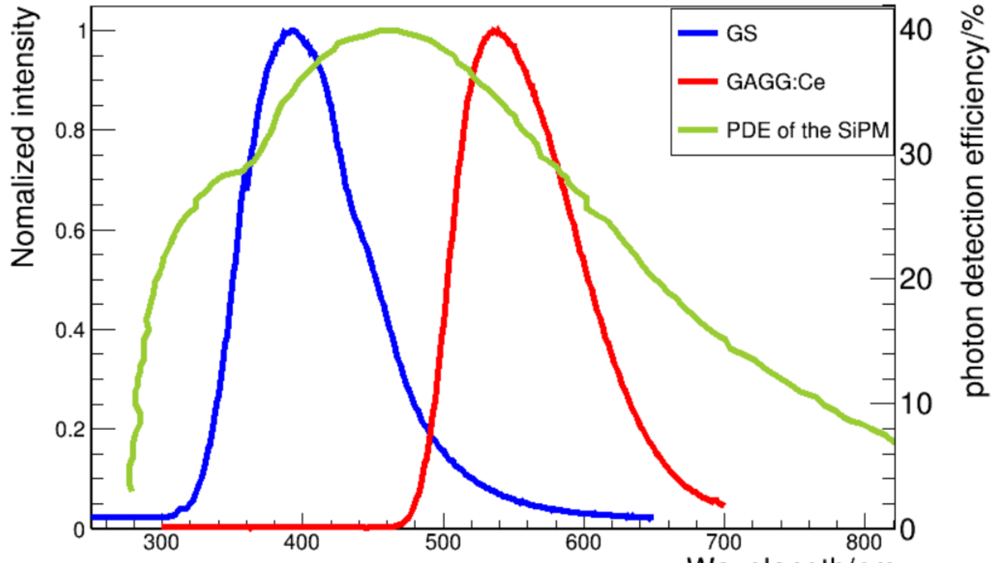
3.2. Test result-crystal and glass



Transmission spectra of glasses



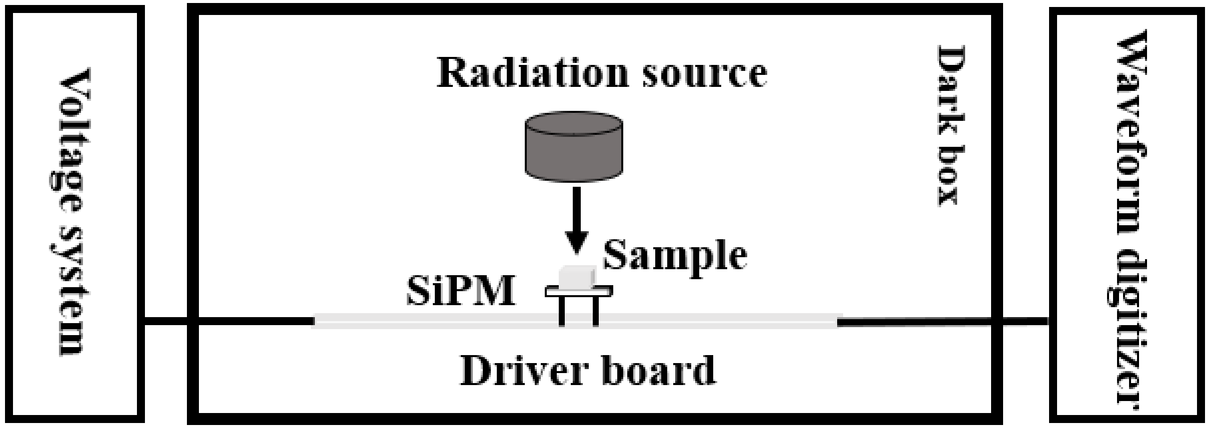
PL and XEL Spectra of LYSO crystal



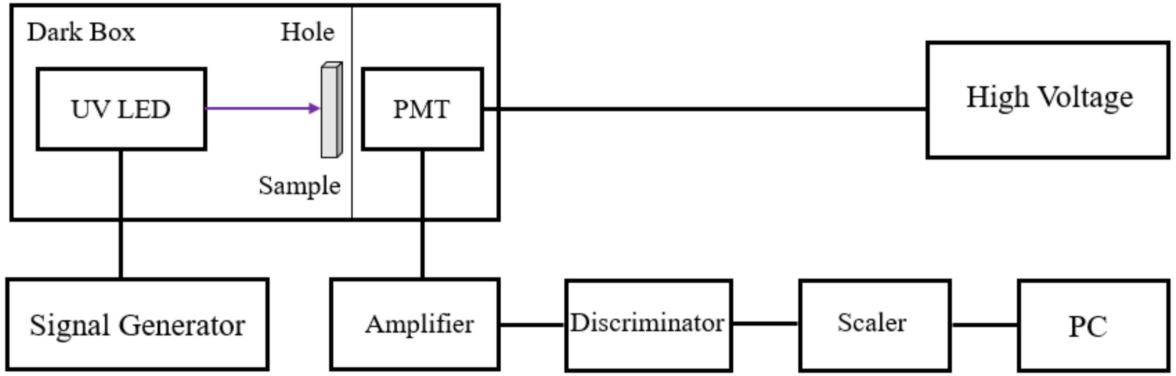
Emission spectra of GAGG and glass

- The transmittance of the scintillating glasses is between 50-80%. (Air bubbles, heavy metal ratio will affect its transmittance)
- The peak wavelength of the emission spectra is around 400 nm, which can be matched with the detector band by adjusting the composition.

3.2. Test facility--(2) scintillation and time properties



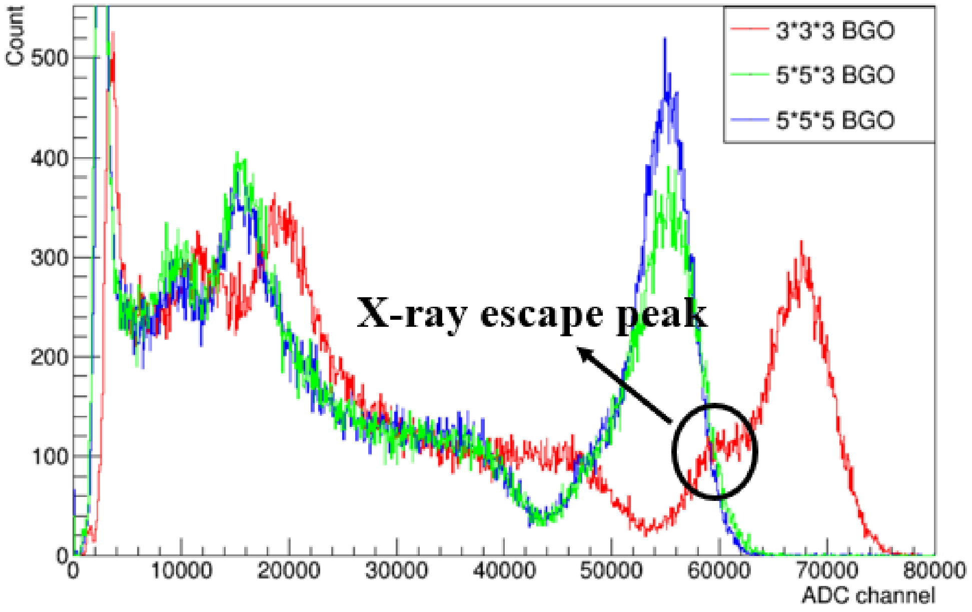
Energy spectrum



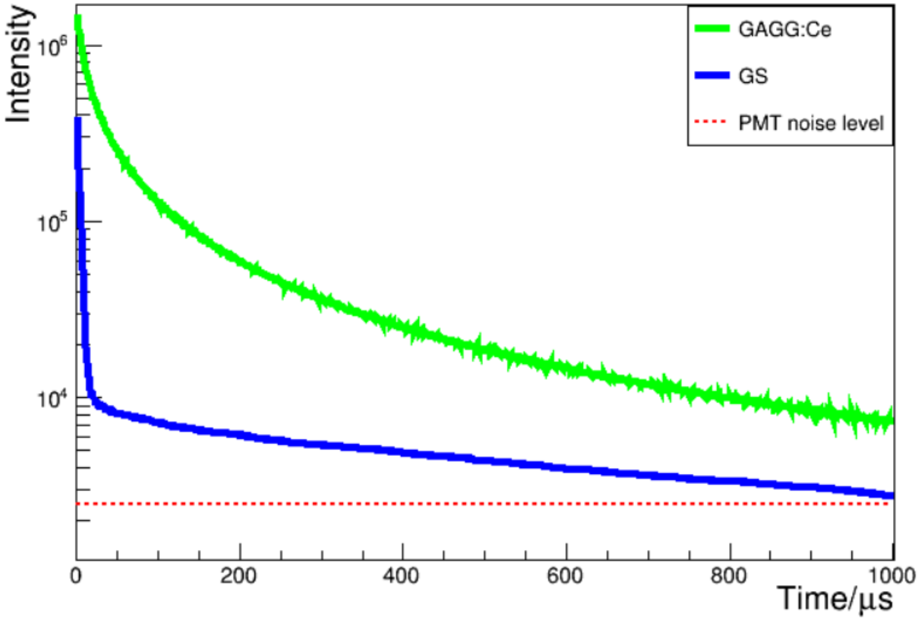
Afterglow

- Through the waveform sampling data acquisition system, we can obtain light yield, energy resolution and scintillation decay time of the scintillator.
- The higher the light yield of the scintillator, the more photons that can be detected, the smaller the statistical error of the system, and the higher the test accuracy obtained.
- When the light generating free electron or hole free fall into the trap and store it, stop excitation thermal disturbance release captured trap an electron or hole traps, it would composite with luminescence center then generate afterglow.
- Test system of afterglow has microsecond accuracy.

3.2. Test result-crystal and glass



Energy spectra of BGO crystals



Afterglow of GAGG and glass

- The light yield of 5*5*3 and 5*5*5 mm^3 BGO standard crystal is about **8000 ph/MeV**. The energy resolution is about 10%@662keV.
- The afterglow of the scintillating glass decreased faster. It indicates that most of the electrons and holes are captured by the traps in the glass, which prevents the photons from escaping from the glass.

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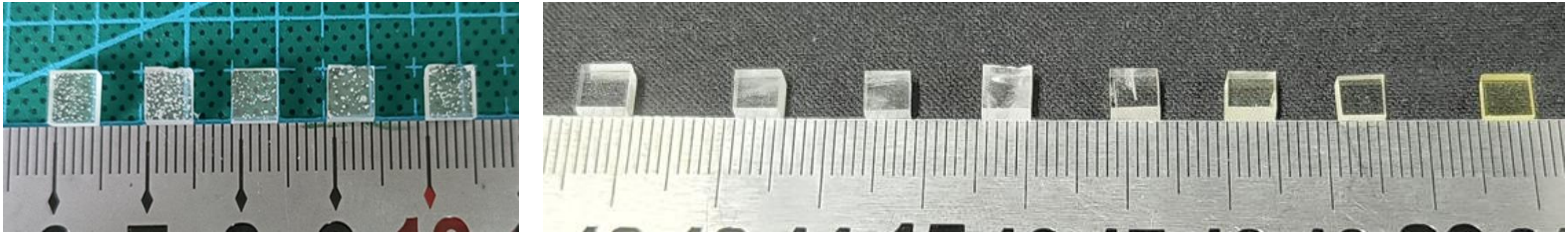
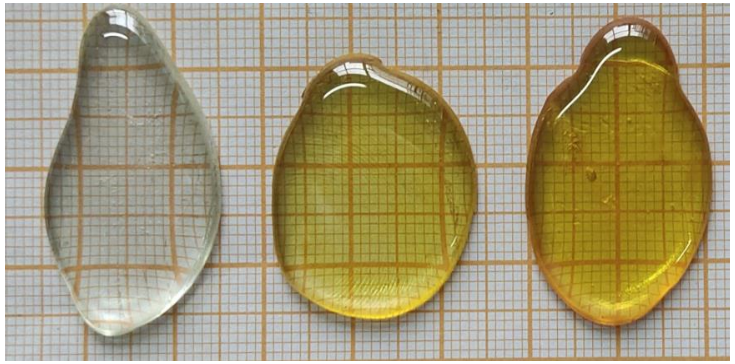
4.1. Density

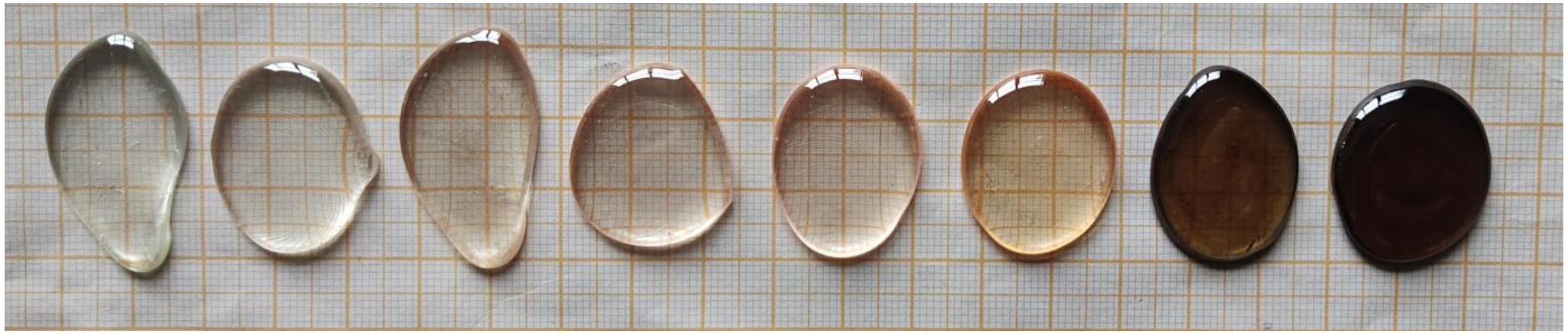


Ce^{3+}-doped aluminoborosilicate glass

- The density of aluminoborosilicate glass is about 4.5 g/cm^3.
- By increasing the Gd_2O_3 content and adding other heavy metals, the density of the glass can reach 6.1 g/cm^3.



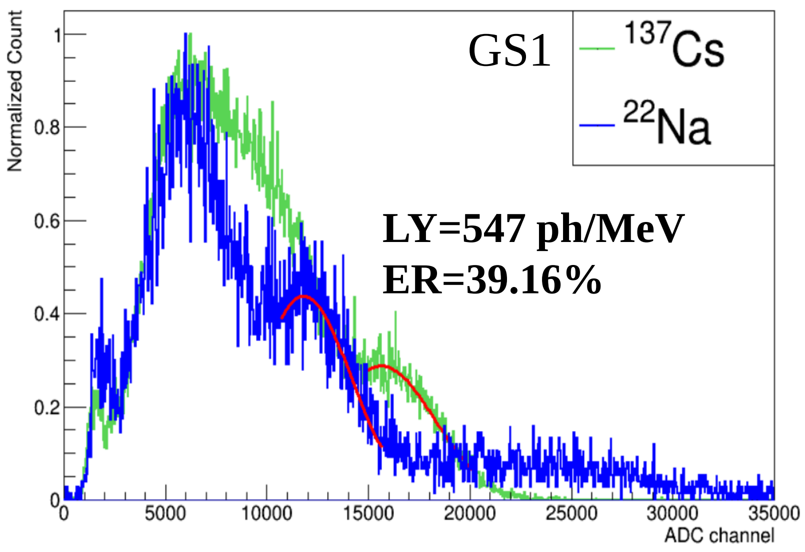
Ce^{3+}-doped tellurite glass

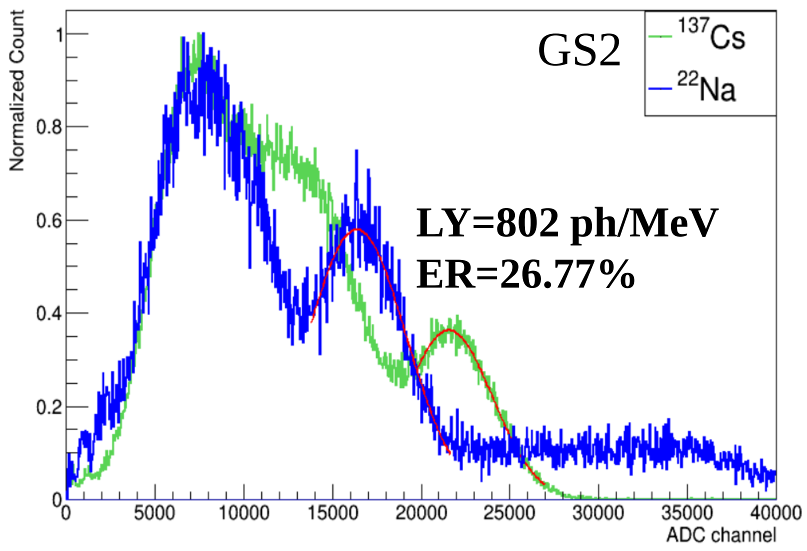


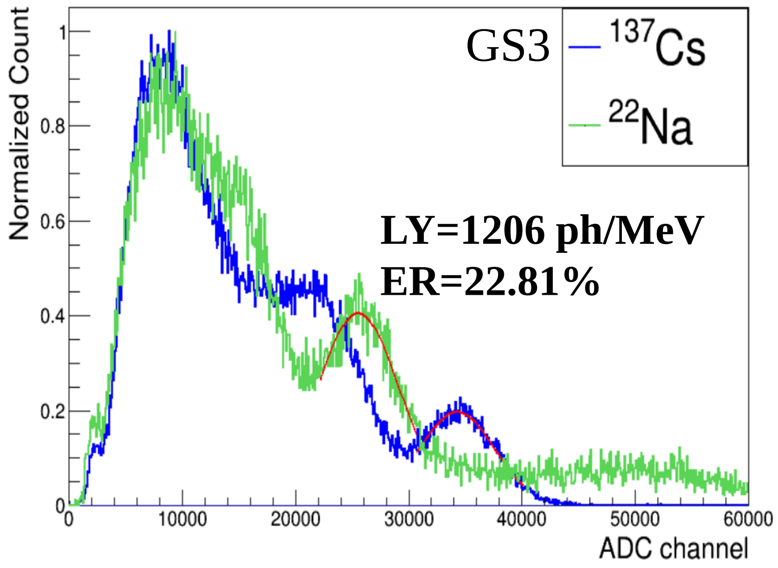
Eu^{3+}-doped tellurite glass

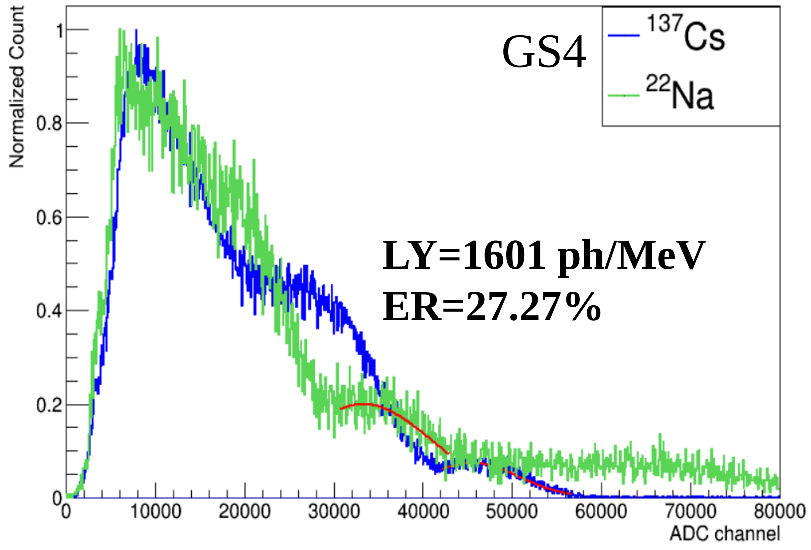
- Tellurite glass has a high density in the range of 6.2-6.5 g/cm^3.

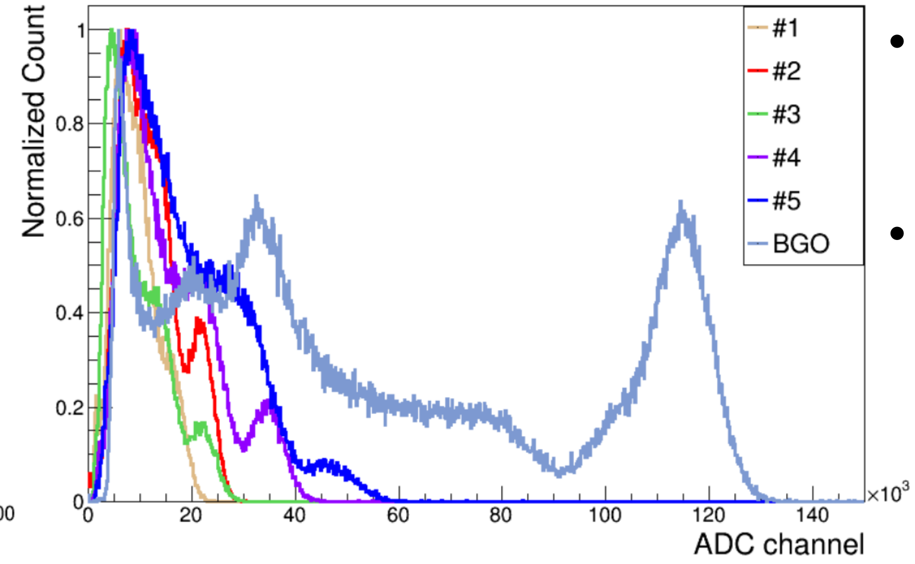
4.2. Light yield and energy resolution





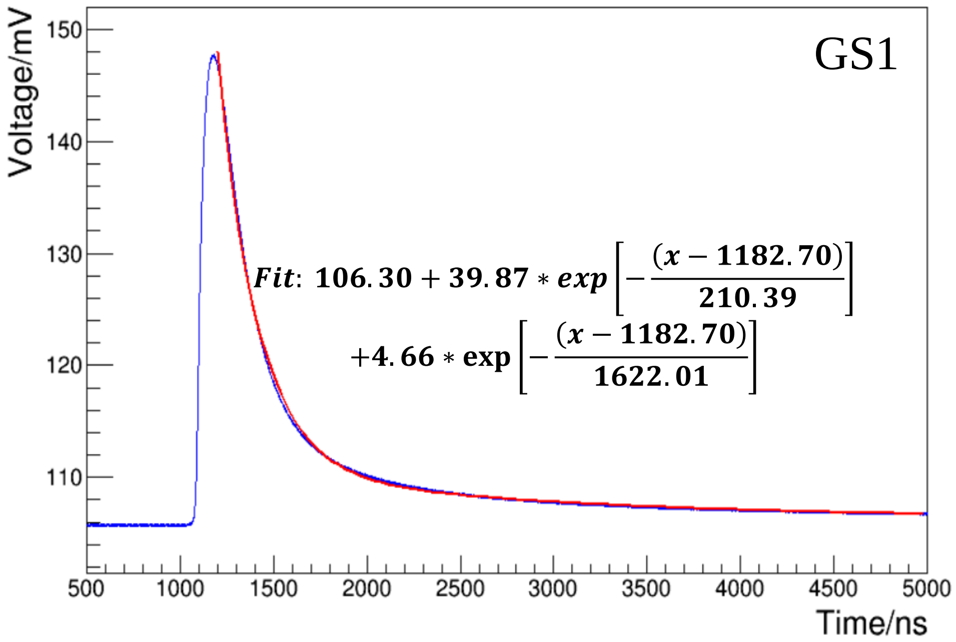


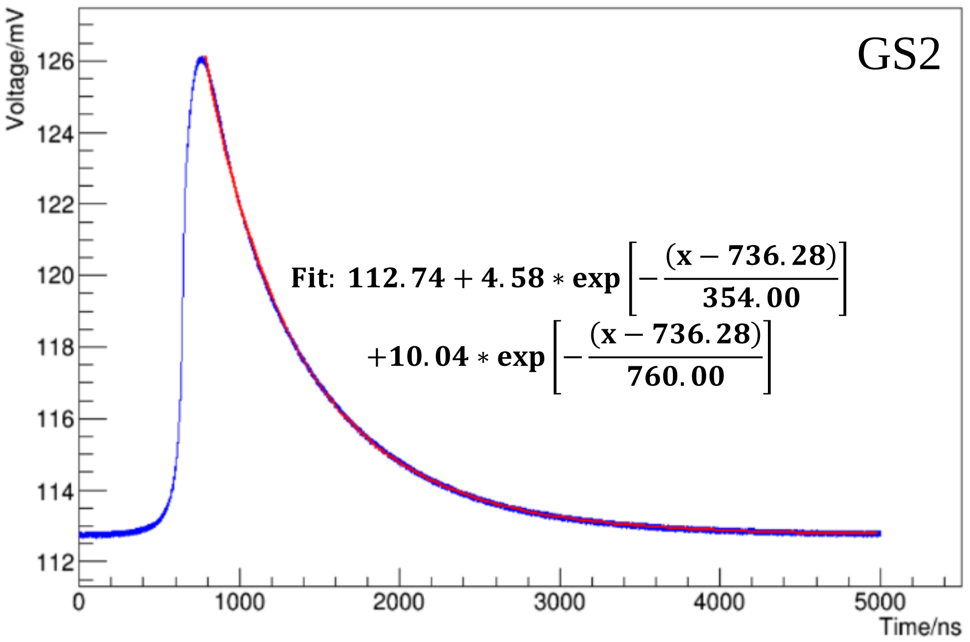


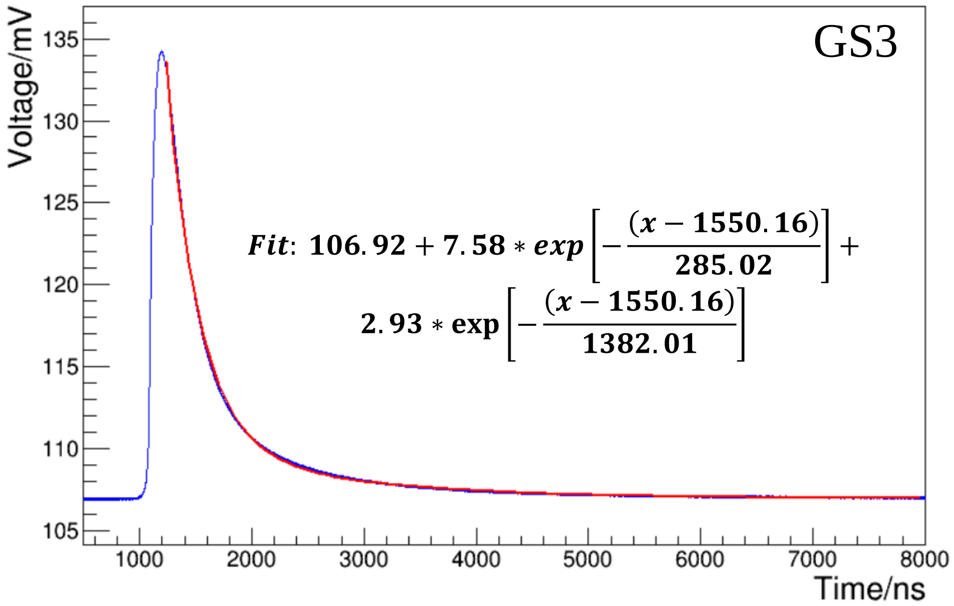


- The highest light yield of the glass has exceeded **1600 ph/MeV**.
- Under the same conditions, the number of photons detected by the glass scintillator is **1/3 of BGO crystal**.

4.3. Decay time

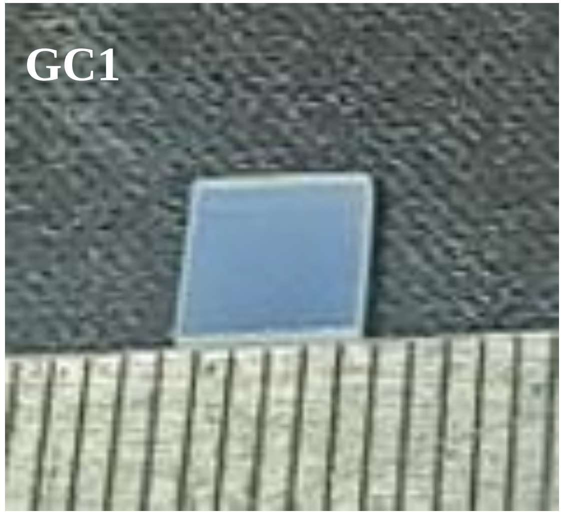


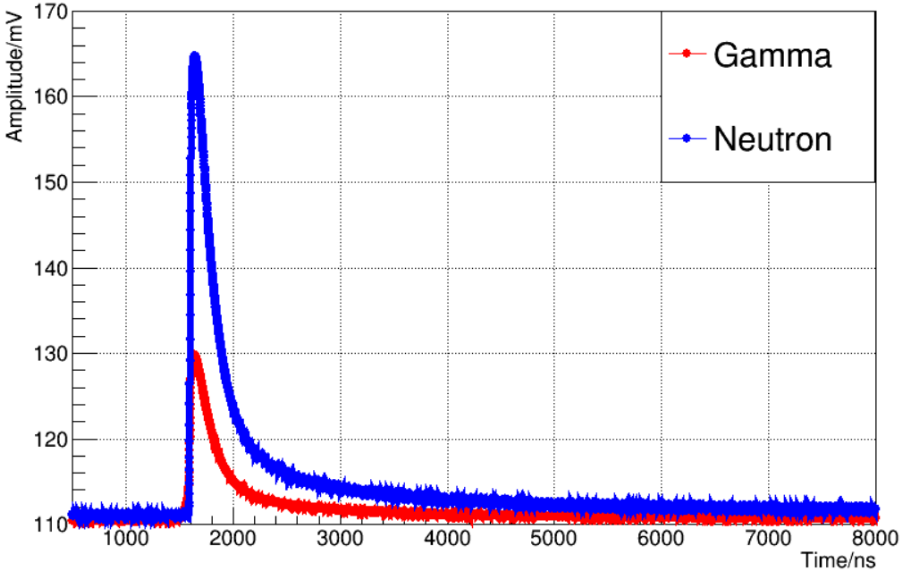


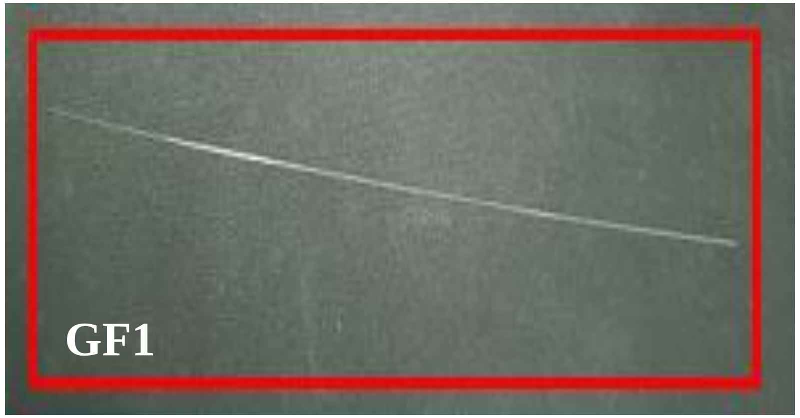


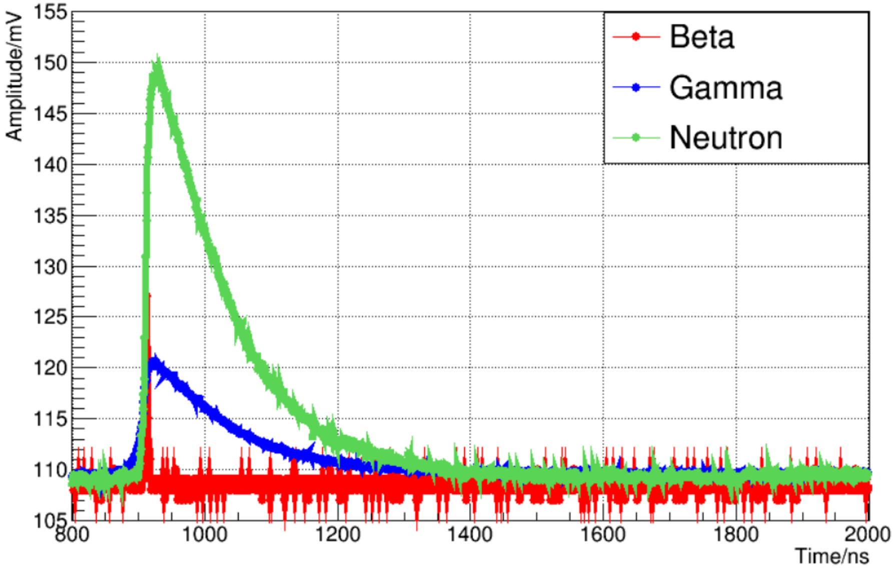
- The scintillating decay time of the glasses usually has two components and is longer than that of crystal.
- The fast component originate from trapping processes during the transport stage, and slow component originate from **re-trapping processes.**

4.4. Neutron detection









- For the glass, the neutron and gamma signals can be distinguished by their amplitudes.
- For the glass fiber, the decay time is very fast under β source.
- The neutron and gamma signals can be distinguished by their amplitudes.

Outline

5. Summary

Number	Density（g/cm^3）	Transmittance（%）	Light yield（ph/MeV）	Energy Resolution（%）	Decay time（ns）	Emission peak（nm）
#1	4.5	67	802	26.77	318,1380	393
#2	**6.5**	80	--	--	--	--
#3	4.2	65	**1206**	**22.98**	346,1740	430
#4	4.0	70	1094	**19.64**	231,1897	440
#5	3.3	**80**	**1601**	27.27	**210**,1622	380
#6	**5.2**	**80**	780	33.09	256,1640	390
?	~6	>75	~2000	<20	<100	350-500

- Ultra-high density tellurite glass—6.5 g/cm^3
- High light yield glass ceramic—1600 ph/MeV
- Scintillating glass for high density and light yield—5.2 g/cm^3 & 800 ph/MeV
- Large size glass—42mm*51mm*10mm

5. Summary

Typy	Composition	Density (g/cm^3)	Light yield (ph/MeV)	Decay time (ns)	Emission peak(nm)	Price/1 cm^3 (RMB)
Scintillating Glass in Paper	Ce-doped high Gadolinium glass[1]	4.37	3460	522	431	8
	Ce-doped fluoride hafnium glass[2]	6.0	2400	23.4	348	150
Plastic Scintillator	BC408[3]	~1.0	5120	2.1	425	60
	BC418[3]	~1.0	5360	1.4	391	80
Crystal	GAGG:Ce[4]	6.6	50000	50.1	560	400
	LYSO:Ce[5]	7.3	30000	40	420	1200
Scintillating Glass for CEPC (preliminaryl target)	?	>7	>1000	50	350-500	< 0.1$/c.c
Scintillating Glass for CEPC	?	**>6**	**>2000**	?	350-500	< 0.1$/c.c
Scintillating Glass in Lab	Ce-doped-Si-Gd-glass	3.3	~1600	200； 1600	380	--

Refs *[1] Struebing, C . Journal of the American Ceramic Society, 101(3). [2] Zou, W. Journal of Non-Crystalline Solids, 184(1), 84-92 .*
[3] Plastic Scintillators | Saint-Gobain Crystals. [4] Zhu, Y. Qian, S. Optical Materials, 105, 109964. [5] Ioannis, G. Nuclear Instruments & Methods in Physics Research.

Thank you!