Study on performance test of glass scintillator

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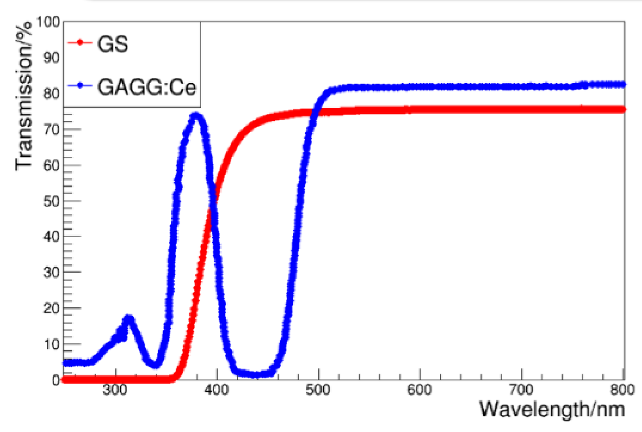
Introduction

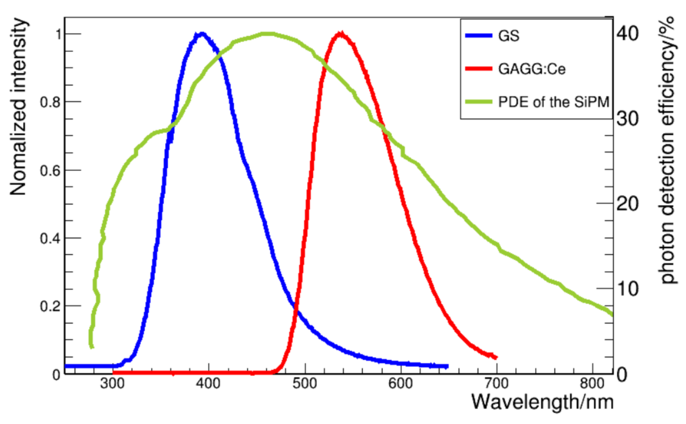
The Circular Electron Positron Collider (CEPC) is a large international scientific facility proposed by the Chinese particle physics community. To achieve accurate measurement of Higgs, W/Z boson properties, CEPC needs to cover a wide range of solid angles, excellent particle identification, accurate measurement of particle energy, and high resolution of the collision vertex. A hadronic calorimeter (HCAL) is an important part of the calorimeter system. Glass scintillators have many advantages, such as a simple preparation process, low cost, and continuously adjustable components. Hence, the proposal to use the glass scintillator coupled with silicon photomultiplier (SiPM) as the active layer is a new solution for the next generation calorimeter.

Scintillating glass (Hafnium Fluoride Glass) has also been considered to apply in calorimeter of the Compact Muon Solenoid (CMS). However, high cost and poor scintillation performance limit its application in high-energy physics. A series of aluminum-borosilicate glasses were prepared by high temperature melt-quenching method, the composition of the scintillating glass is $30B_2O_3$–$25SiO_2$–$10Al_2O_3$–$34Gd_2O_3$–$1Ce_2O_3$ *(GS). The performance test of scintillating glasses requires precise facility. Our leading test targets are the transmittance, emission wavelength, energy resolution, light yield, and decay time of the scintillating glasses. We tested different properties of the GAGG:Ce crystal as a standard and the scintillating glass, such as transmission spectra, X-ray induced emission spectra, energy spectra and scintillation decay time. A new calculation method for the light yield of glass scintillators is proposed.*

1. Transmission spectra and XEL spectra



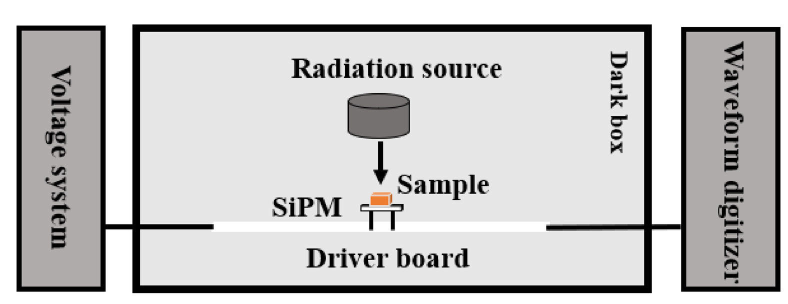
The transmittance curves



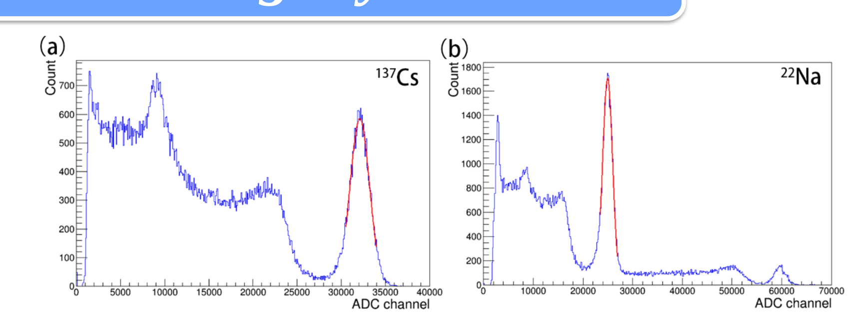
The XEL spectra and PDE of the SiPM

- The absorption bands of the GAGG:Ce are located near 250 nm and 360 nm, corresponding to 4f-5d$_2$ and 4f-5d$_1$ transitions of Ce^{3+}. The absorption band of the glass is located near 360 nm, corresponding to 4f-5d$_1$ transitions of Ce^{3+}. When the wavelength is longer than 500 nm, the transmittance of the GAGG:Ce is higher than 82%. When the wavelength is longer than 450 nm, the transmittance of the glass is higher than 75%.
- The XEL spectra show that glass scintillator has broadband emission in 300-600 nm. In addition, the emission peak of the glass is around 400nm, and the emission peak of GAGG:Ce is approximately 550nm. The glasses exhibited two peaks (400 and 440 nm), obtained by double Gaussian fitting. It can be ascribed to the electron transitions from the 5d level to the two ground-state Ce^{3+} ($^2F_{5/2}$, $^2F_{7/2}$). A weak peak at 315 nm was detected in all samples, due to the 4f-4f transition of Gd^{3+}.

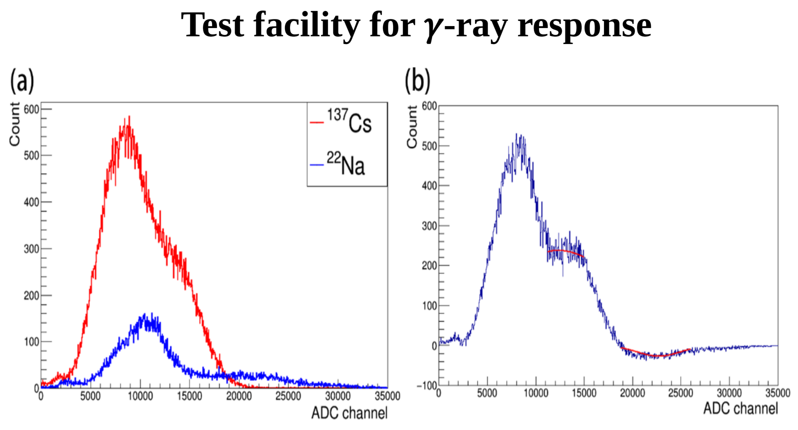
2. Energy resolution and light yield



Test facility for γ-ray response



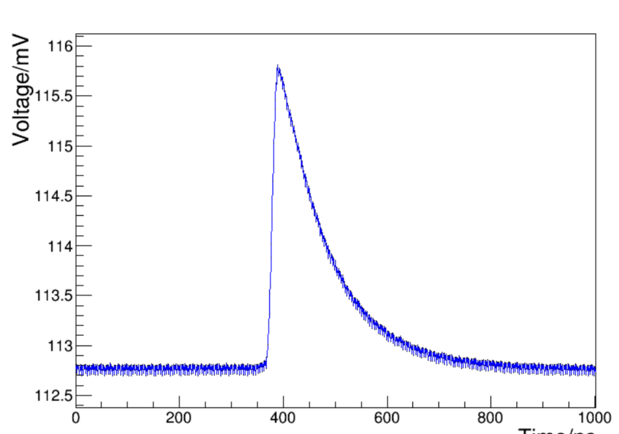
The energy spectra of the GAGG:Ce with γ-ray



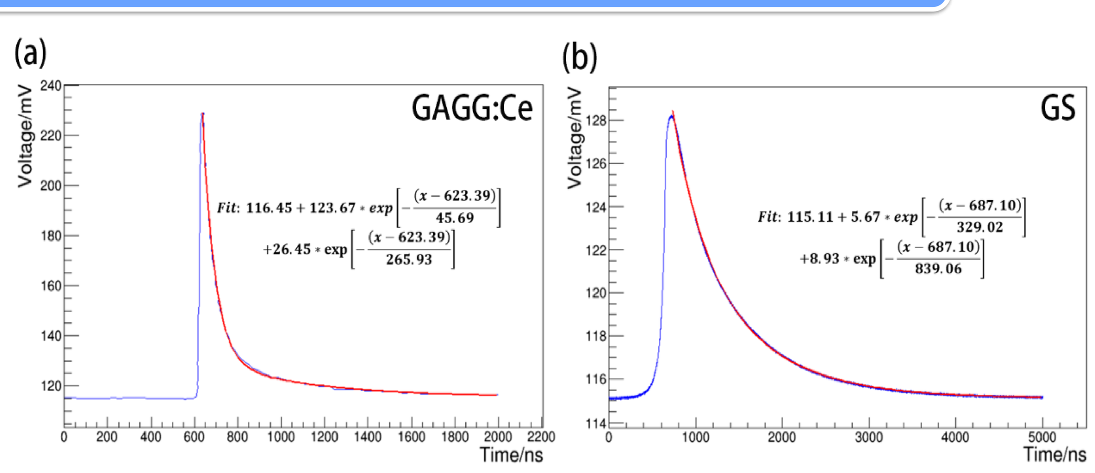
(a) The energy spectra of the glass, (b) the energy spectrum after subtracting the two energy spectra

- The light yield of the GAGG:Ce is 29300±16 ph/MeV. The measured energy resolution of the crystal is 8.09%@662keV.
- The full-energy peak of the radioactive sources cannot be measured in most glasses. Hence, we proposed a new method to measure the light yield. Subtracting the energy spectra of two radioactive sources obtains a new charge integral spectrum. When the ratio of two peak positions is close to the ratio of ^{137}Cs and ^{22}Na full-energy peaks, the light yield can be calculated. The light yield of the glass is 396 ph /MeV.

3. Scintillation decay time



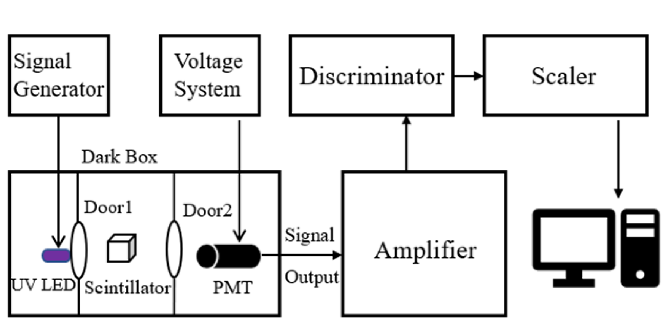
Dark noise of the SiPM



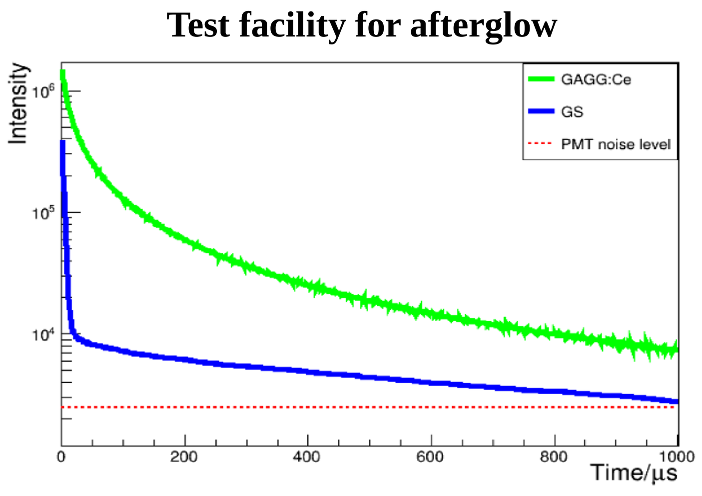
Decay time of (a) GAGG:Ce and (b) GS

- The rise time of SiPM is less than 15 ns and the fall time is about 180 ns. The dark noise amplitude of SiPM is only 3 mV, which hardly affects the test of scintillators. When the size of the SiPM matches that of the scintillators, most photons can be collected. Therefore, SiPM could be used to test the decay time of the scintillators.
- For GAGG:Ce, the decay time of the fast and slow components is 45.69 ns (45%) and 265.93 ns (55%), respectively. For the glass, the decay time of the fast and slow components is 329.02 ns (20%) and 839.06 ns (80%). The fast component is attributed to the 5d-4f transitions of Ce^{3+} in host glass and the energy transport to Ce^{3+} center results in the slow component.

4. Afterglow



Test facility for afterglow



Afterglow of the GAGG:Ce and the glass

- In scintillators, 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.
- After the UV light cut-off, the intensity of GAGG:Ce crystal shows a decrease of more than three orders of magnitude. In addition, the afterglow intensity of GAGG:Ce scintillators shows a steady state after a certain decrease, but it is still higher than the PMT noise level. This is due to the thermoluminescence of GAGG:Ce at room temperature. In fact, the effect of thermoluminescence can be reduced by changing the temperature. However, 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.

5. Conclusions

- **The test facilities for different properties of the scintillators, including transmission spectra, emission spectra, light yield, energy resolution, decay time were developed. The test results have verified our test methods.**
- **The transmittance of the glass at visible wavelengths is higher than 75%. The emission peak of the glass is around 400 nm. And the decay times consist of fast and slow components, are 329.02 ns (20%) and 839.06 ns (80%), respectively. In addition, the afterglow of the scintillating glass decreased faster than GAGG:Ce crystal.**
- **A new calculation method for the light yield of glass scintillators is proposed. The light yield of the glass is 396 ph/MeV by the new calculation method.**

Acknowledgement

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