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Simulation and Measurements of Scintillating Glass for HCAL

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On behalf of the Glass Scintillators R&D Group

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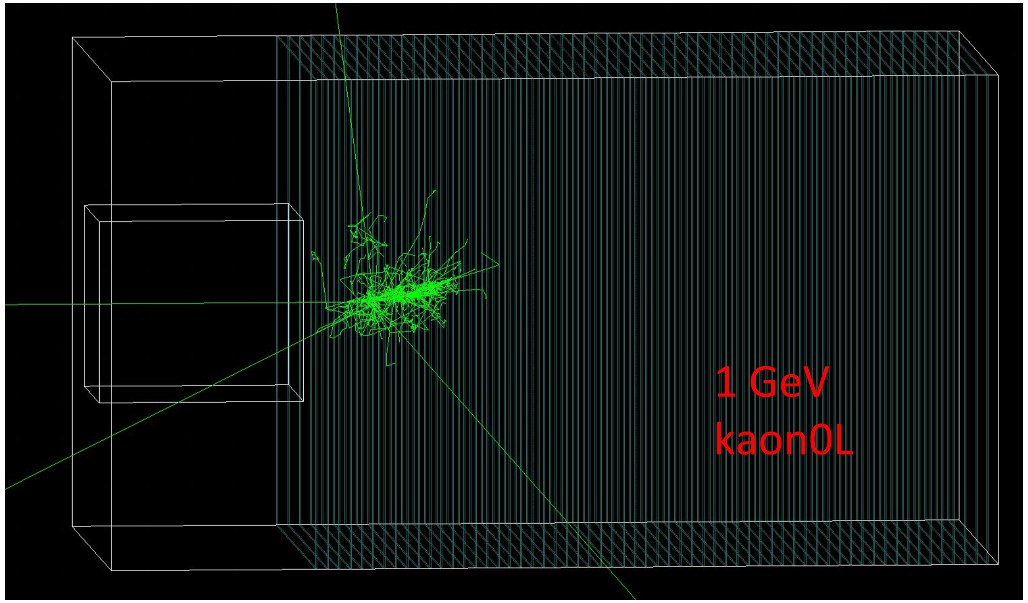
Simulation Construction of HCAL with Glass Scintillator

HCAL geometry

- Transverse plane: $108 \times 108cm^2$
- 60 longitudinal layers, each with
  - Scintillator: 3mm
  - PCB: 2.1mm
  - Absorber (steel): 20mm



Scintillator materials

- Scintillating glass: $42SiO_2$-$5Al_2O_3$-$22BaF_2$-$9NaF$-$3CaF_2$-$3Gd_2O_3$-$9GdF_3$-$7TbF_3$

References: https://doi.org/10.1016/j.jeurceramsoc.2021.05.064

Note: HCAL with 40 layers in CEPC CDR as baseline.
Hereby use 60 layers to evaluate leakage effects

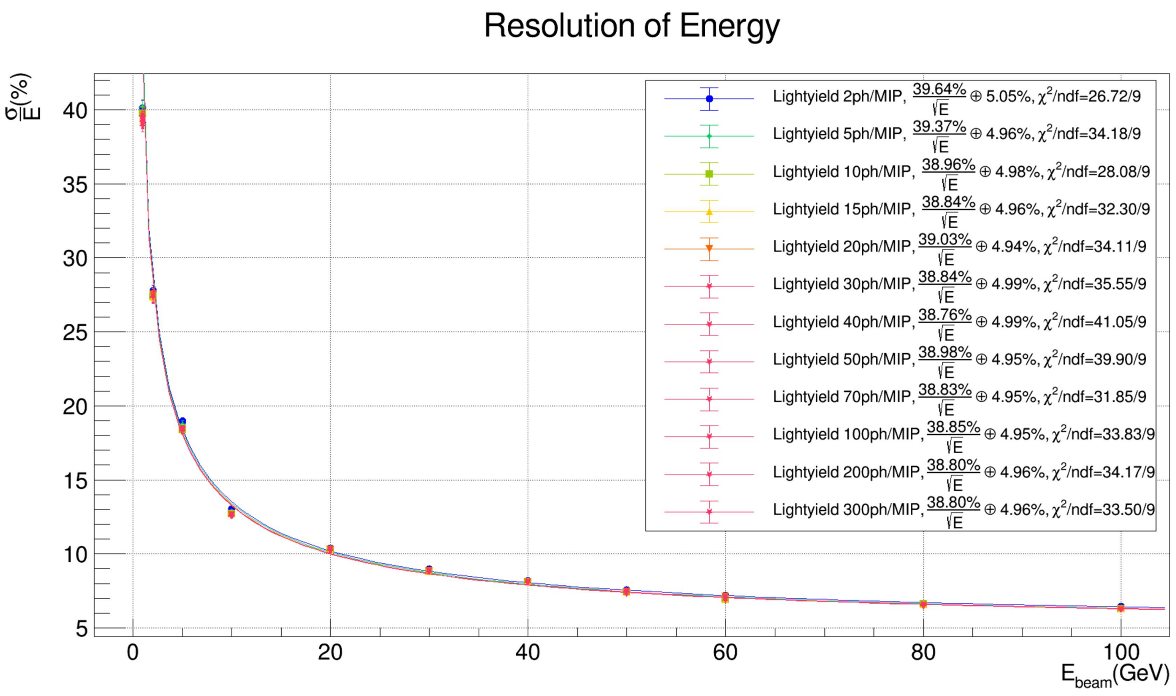
By Dejing DU

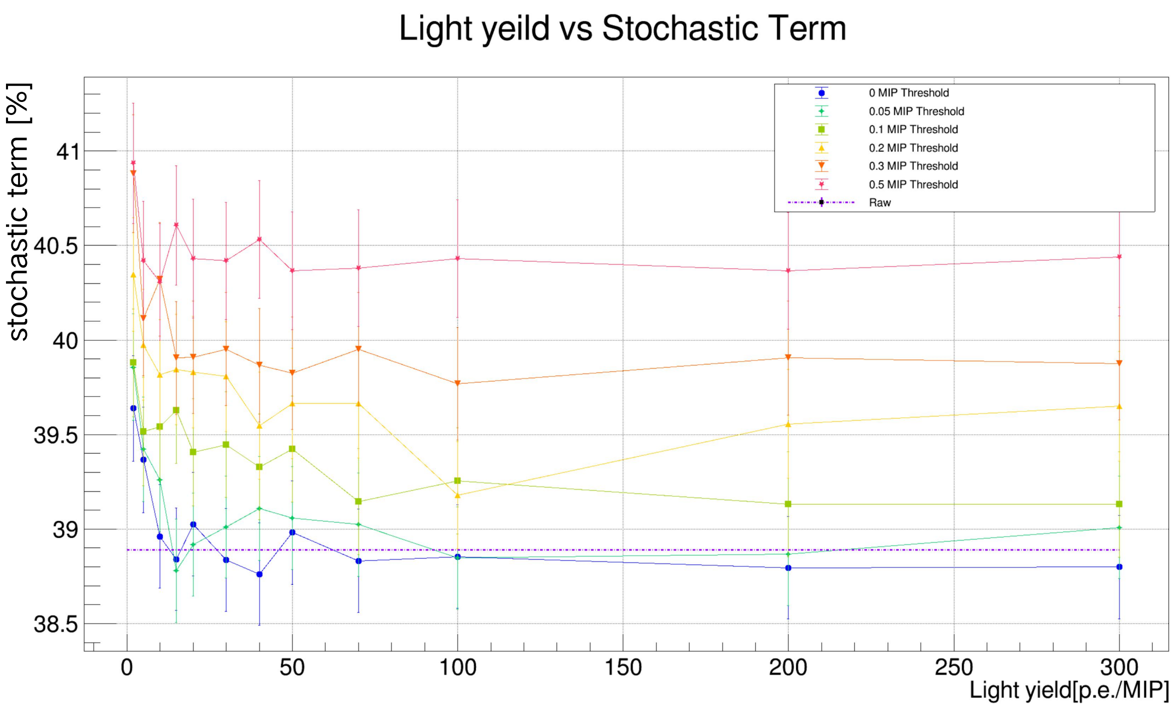
Light yield vs Energy Resolution

Impact of light yield to hadronic energy resolution

- Energy threshold: 0 MIP.
- Incident particle: kaon0L (1-100 GeV)
- Scintillating glass density: **4.3** g/cm^3

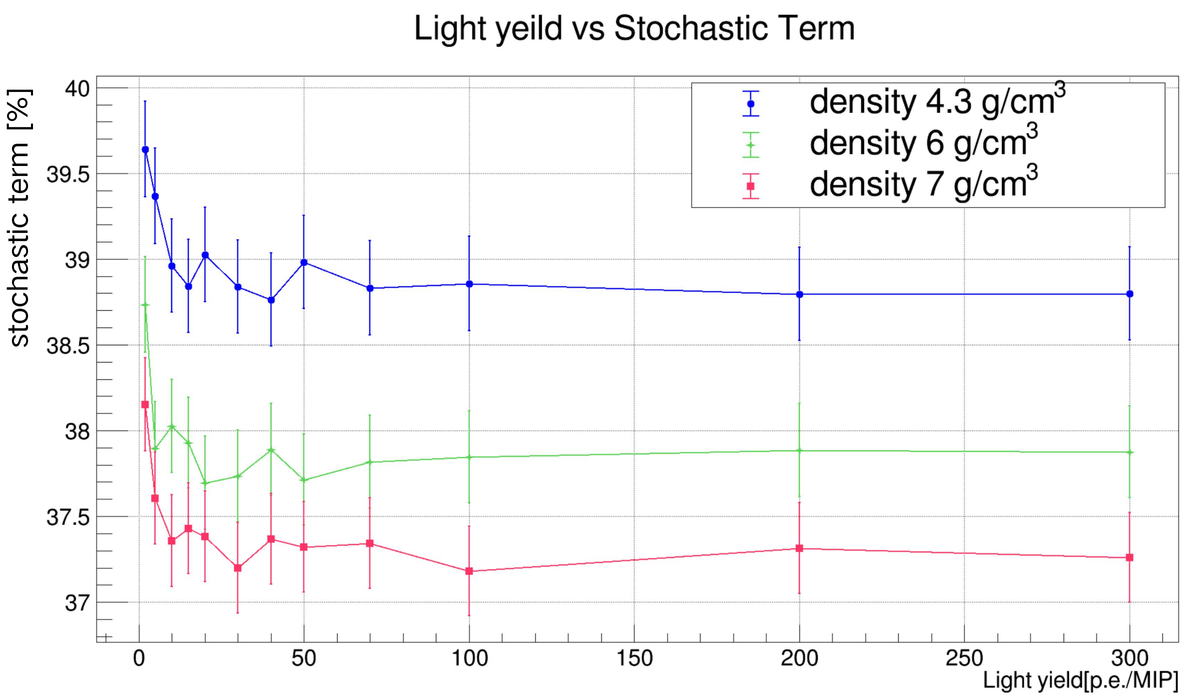
$$\frac{\sigma_E}{E_{beam}} = \frac{p_0}{\sqrt{E_{beam}}} \oplus p_1$$



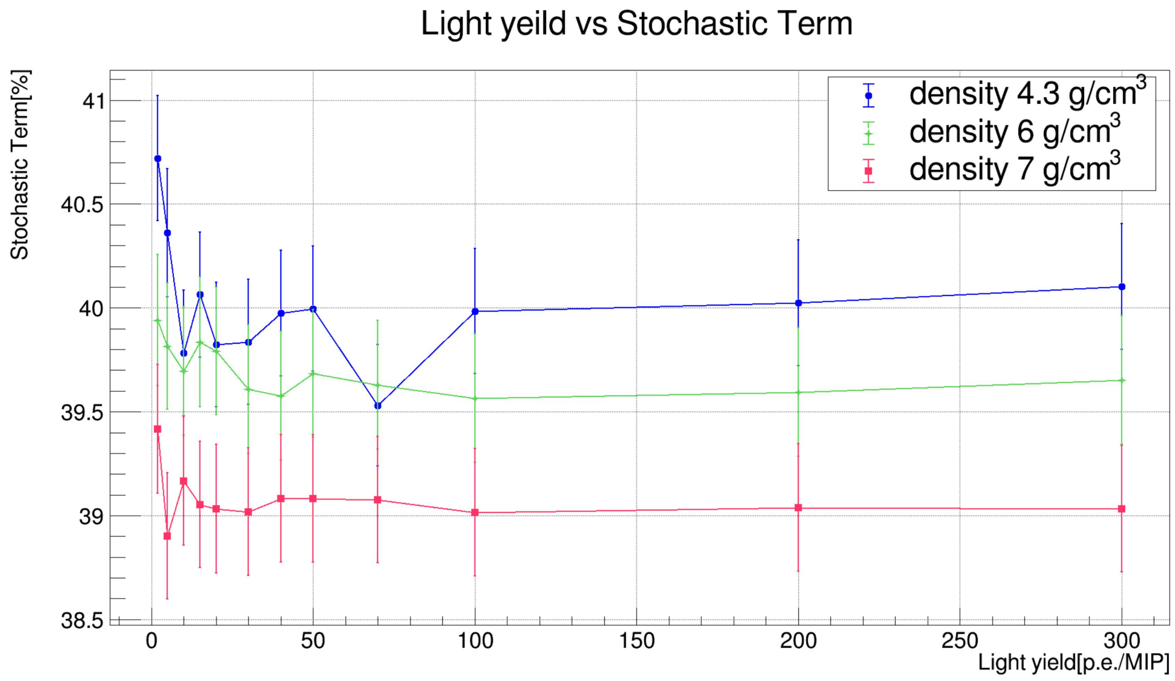


Light yield vs Density

- Incident particle: kaon0L (1-100 GeV)



Threshold 0 MIP



Threshold 0.3 MIP

- When the density of scintillating glass was 7, the Stochastic term only dropped by no more than 1.5%.
- Considering the complexity of glass development, we initially set the target density as 6 g/cm^3.

Relationship between Np.e. and Light Yield

$$N_{p.e.} = E_{\text{dep}} \times LY \times \text{PCE} \times PDE$$

Photon detection efficiency

Detected photons

Light yield of scintillators

Photon collection efficiency

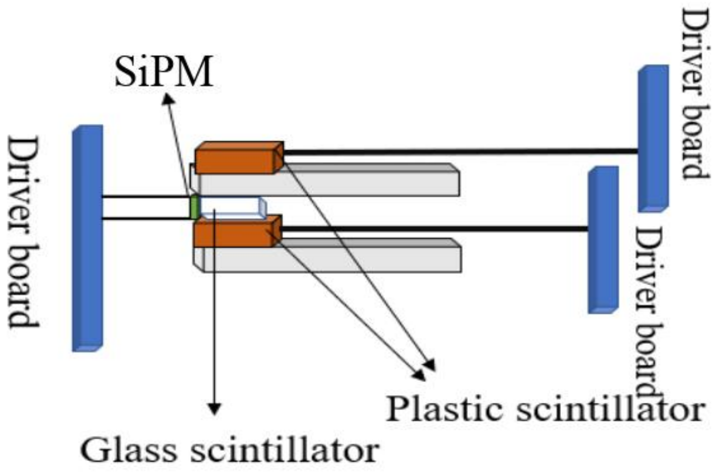
Simulated by G4 or Tested

Related to : tile size, surface, foil, SiPM coupling

Can be tested directly: MIP response by muon

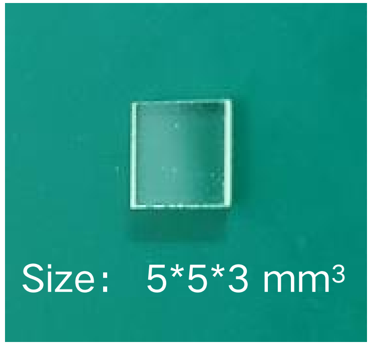
MIP Response: the light yield of 1MIP

MIP Response



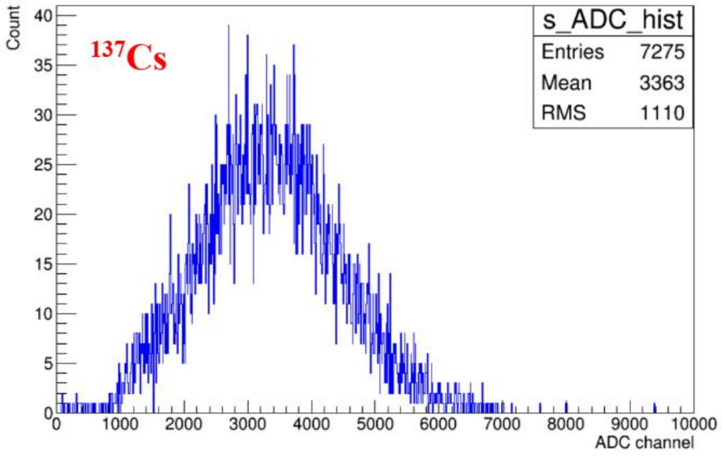
实验装置示意图

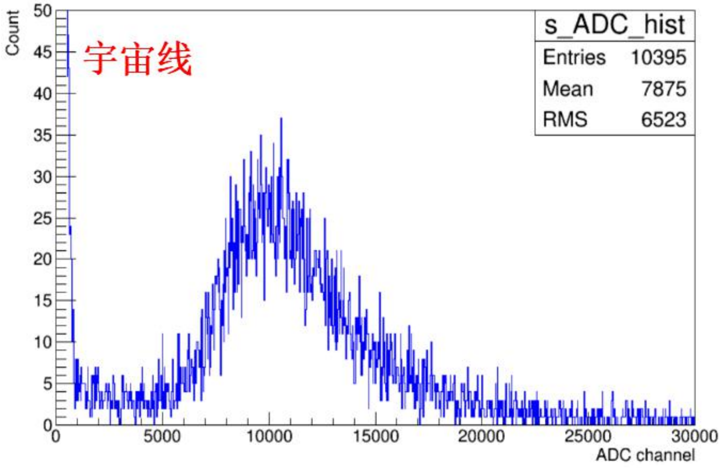
Before cut



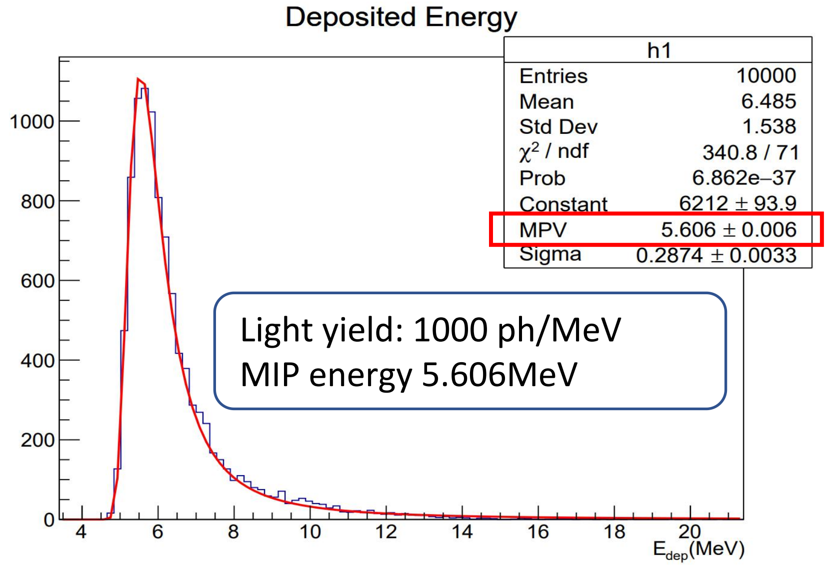
after cut

- The result was conducted before cut
- The glass sample is too small to achieve compliance after cut.
- Only 4 counts in 12 hours





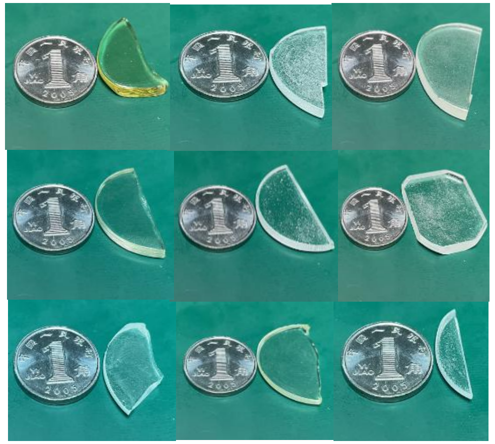
Test results before cut By Zhehao Hua



Simulation results By Dejing Du

The samples

By Zhehao Hua



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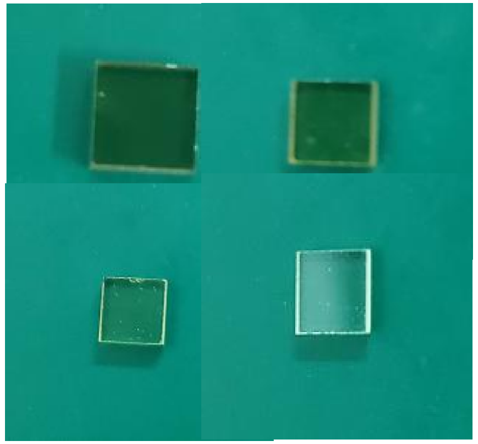

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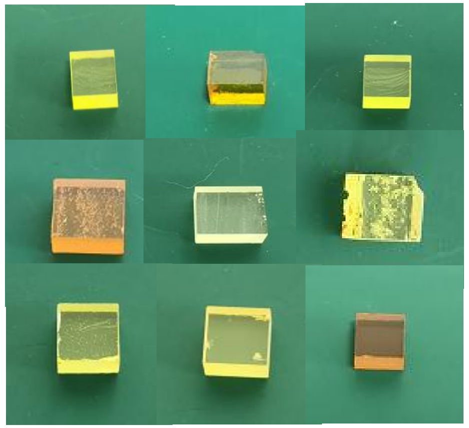

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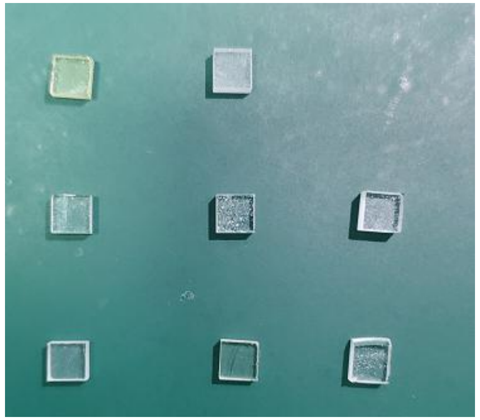

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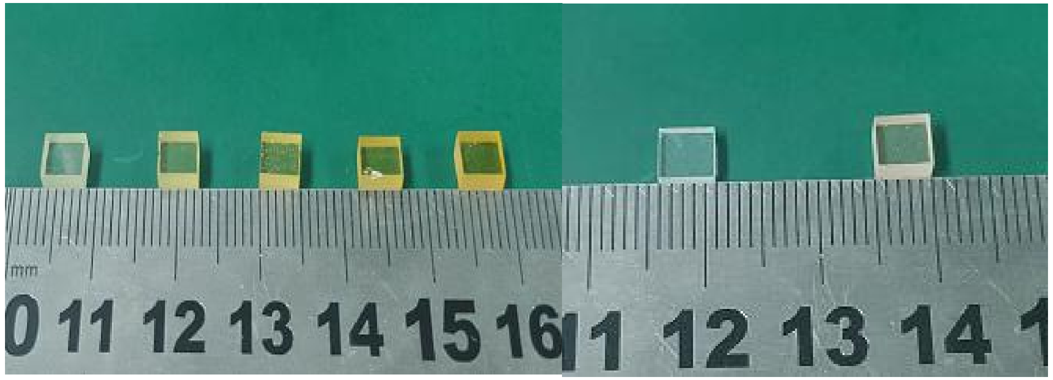

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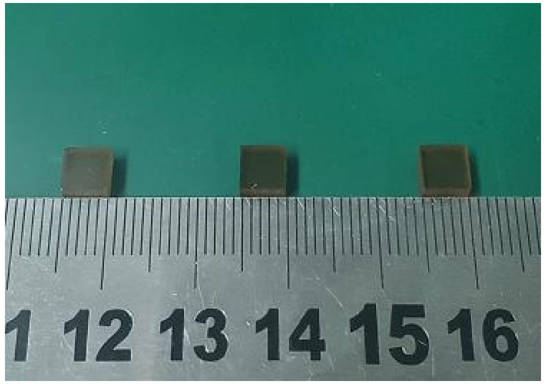

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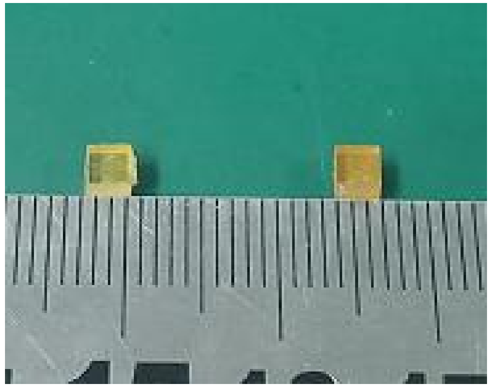

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- We have tested over 30 pieces of glass in the past two months. The scintillating performance of most glasses is poor.
- The transmission spectra, X-ray induced emission spectra, light yield, energy resolution and decay time of these glasses were measured.
- The best performing glass is aluminoborosilicate scintillating glass with the composition of

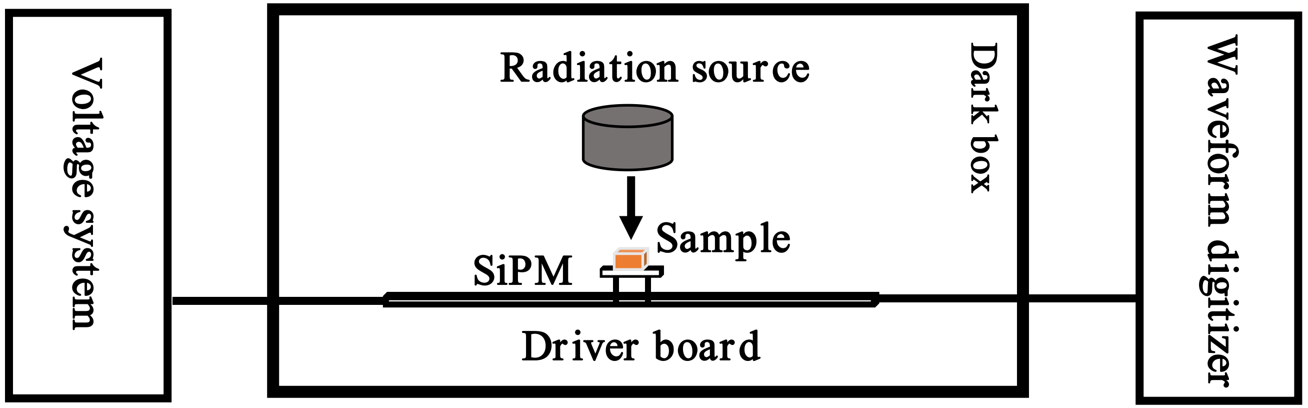
Calculation of light yield

By Zhehao Hua

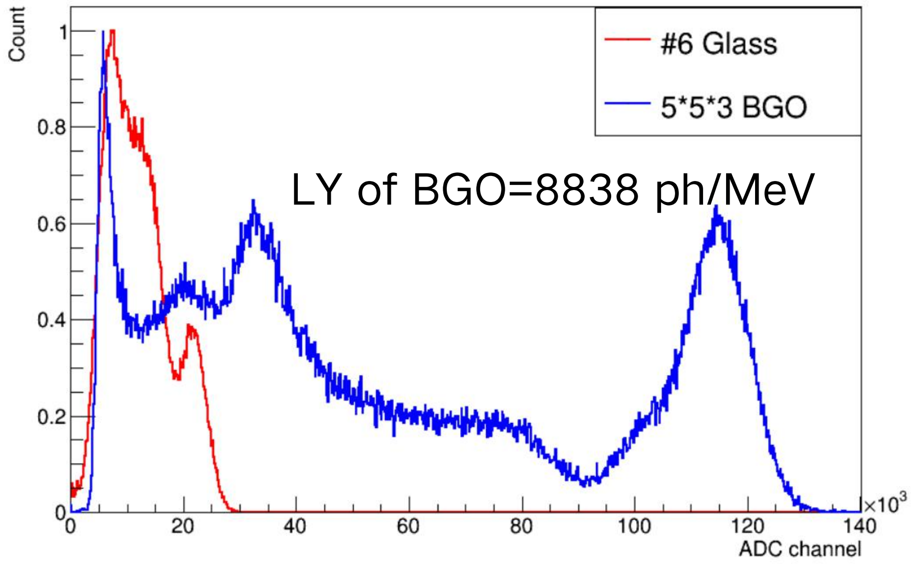
- **Light yield** of scintillator is the luminous ability of the scintillator, which refers to the efficiency of the loss of energy of particles into scintillating photons, and its unit is ph/MeV. It represents the number of photons excited by the energy deposition of 1MeV energy in the scintillator.

- **The formula of the light yield**: $LY_s = \frac{Mean_{energy} * 1000\text{keV}}{Mean_s * PDE_w * PCE * Energy}$

where LY is the light yield of the glass scintillator; $Mean_{energy}$ is the channel number corresponding to the energy peak of the ADC spectrum; $Mean_s$ is the single photoelectron channel number of the SiPM; PDE_w is determined by the emission spectrum of scintillator and the photo detection efficiency (PDE) of SiPM.; PCE is collection efficiency of SiPM.



Test facility for γ-ray response



Result of some glasses

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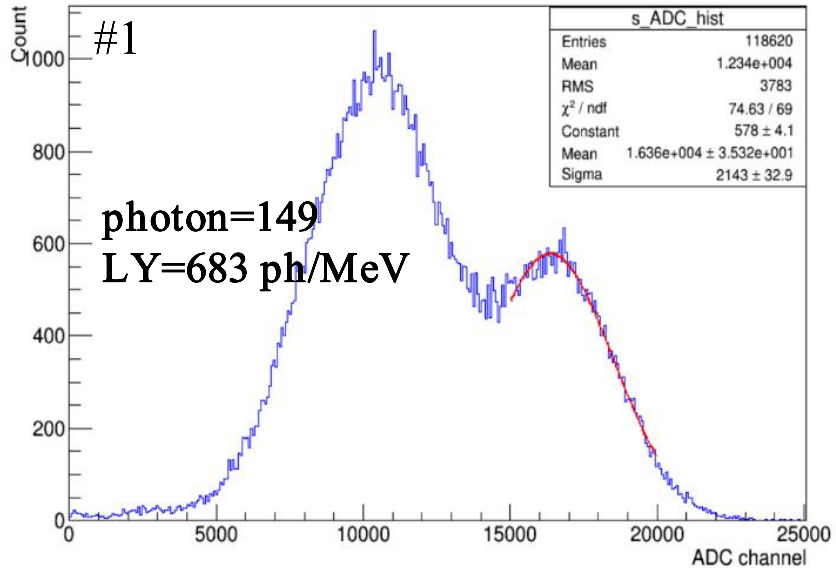

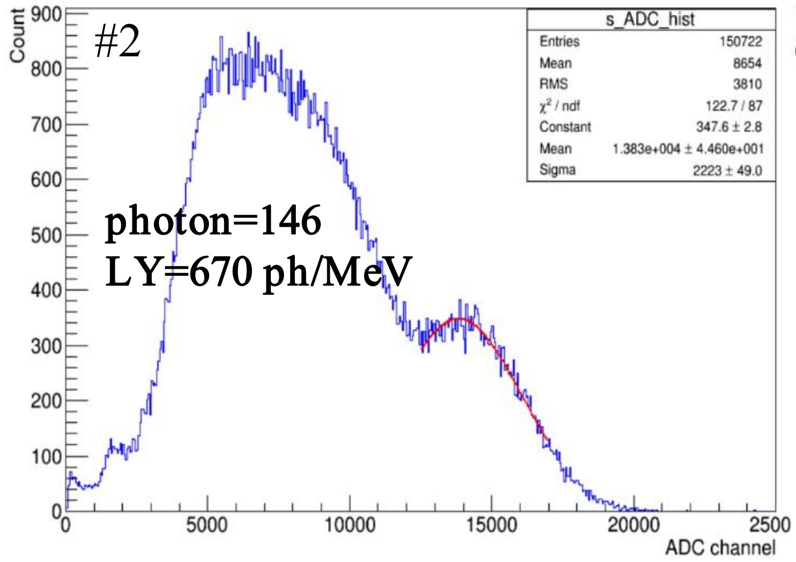

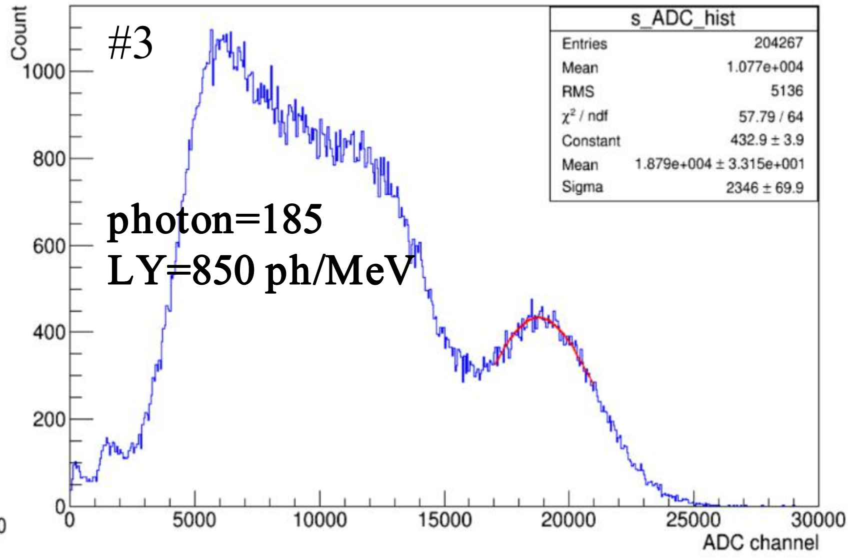

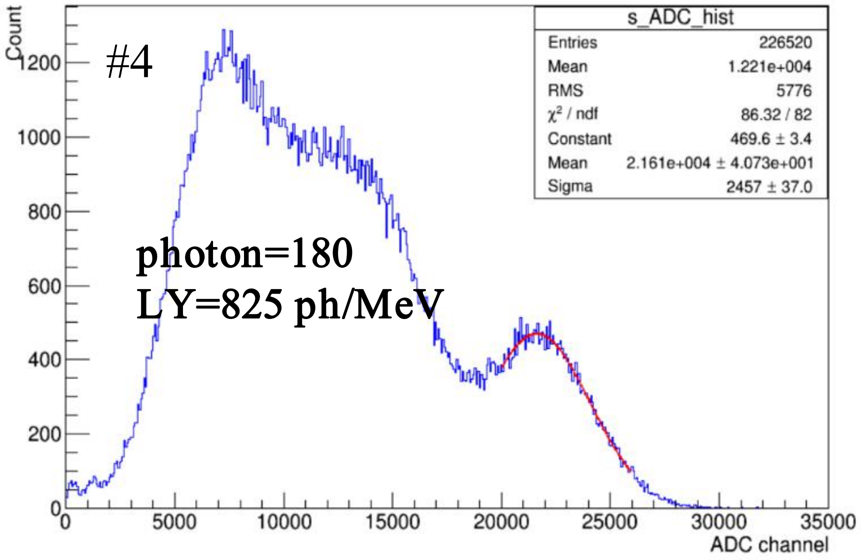

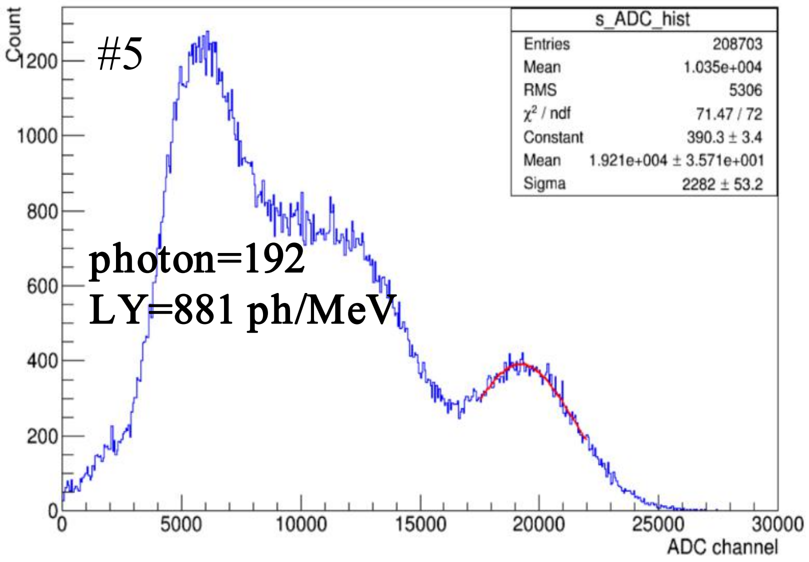

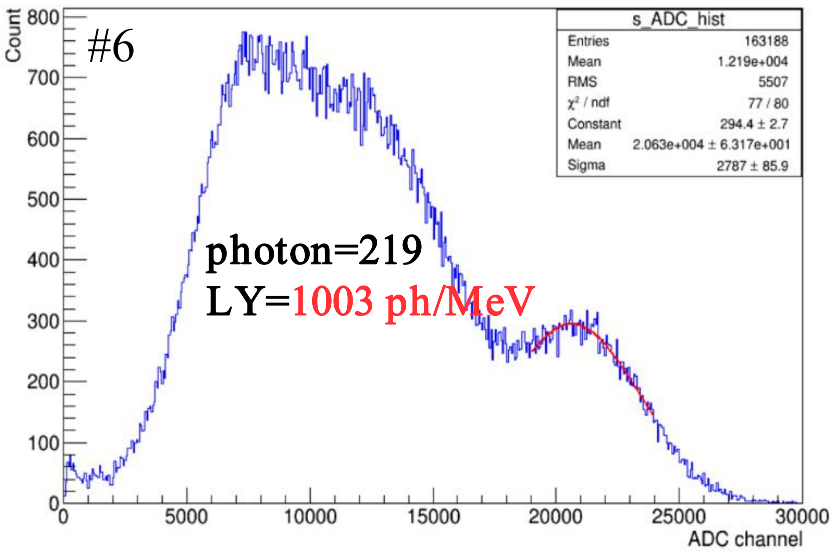

Summary

By Zhehao Hua

Number	Density（g/cm³）	Transmittance（%）	Light yield（ph/MeV）	Energy Resolution（%）	Decay time（ns）	Emission peak（nm）
#1	~4.5	50	683	30.84	273,1004	394
#2	~4.5	76	670	37.87	334,939	392
#3	~4.5	75	850	29.41	351,1123	393
#4	4.65	74	825	31.82	308,1363	396
#5	**4.94**	64	881	27.97	**354,760**	392
#6	4.53	67	1003	26.77	318,1380	393

◆ The light yield of Ce^{3+}-actived aluminoborosilicate scintillating glass could reach more than 1000 ph/MeV；

Plan：

① improve the Light Yield

② improve the density

Summary

Typy	Composition	Density (g/cm^3)	Light yield (ph/MeV)	Decay time (ns)	Emission peak(nm)	Price/1 cm^3 (RMB)
Scintillator Glass in Paper	$33.4SiO_2$-$33.3LiF$-$32.0GdBr_3$-$1.3CeBr_3$ (Ce-doped high Gadolinium glass[1])	4.37	3460	522	431	8
	$63SiO_2$-$21.75BaO$-$1.4AlF_3$-$13.09Gd_2O_3$-$0.76Ce_2O_3$ (Ce-doped high silica glass [2])	4.2	2500	90,400	430	3
	$20HfF_4$-$24YF_3$-$32ZnF_2$-$24BaF_2$-$2CeF_3$ (Ce-doped fluoride glass[3])	6.0	2400	23.4	348	150
Plastic Scintillator	BC408[4]	~1.0	5120	2.1	425	60
	BC418[4]	~1.0	5360	1.4	391	80
Crystal	GAGG:Ce[5]	6.6	50000	50.1	560	400
	LYSO:Ce[6]	7.3	30000	40	420	1200
Scintillator Glass for CEPC	Ce-doped+ ?	**7 --> 6**	**1000 -- > 2000**	50	350-500	
Scintillator Glass in Lab	Ce-doped-Gd-glass	~4.5	~1000	300；1000	400	3

In the future, we will continue to optimize simulation and testing methods to give more detailed indicators.

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