中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Research Progress of The Glass Scintillator for CEPC

Qian Sen

On behalf of the Glass Scintillators R&D Group

2022.04.22

Outline

- **Motivation**
- **Simulation of Glass Scintillators**
  - Cosmic-ray test and simulation
  - Optical simulation for a single glass scintillator tile
- **Measurements of Glass Scintillator samples**
  - Energy spectra and light yield
  - Preparation of glass scintillator array
- **Summary**
- **Next plan**

1.0 Motivation

- **Glass Scintillators:** have simple preparation process, low cost, continuously adjustable composition and performance, excellent shaping and processing performance, and easy mass production and large-scale production.
- **Glass Scintillators are good candidate for the next generation HCAL.**
  - 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)
- **Geant4 simulation for the target parameters of glass scintillator.**
- **Adjusting the composition of glass scintillators to improve the properties.**

- Ma Lishuang，Study of scintillation glass，CEPC Physics and Detector Plenary Meeting (December 8, 2021) (ihep.ac.cn)
- Qian Sen，Status of the Glass Scintillator，CEPC DAY(December 22, 2021)(ihep.ac.cn)

1.1 Glass Scintillators R&D Group (Before)

- **Glass Scintillators Production**
  - Development
  - Mass production
  - Application Development
- **Glass Scintillators Research** — Institute of High Energy Physics, Chinese Academy of Sciences: **Q**
  - Optical test — **H, M**
  - Mechanical test — **X**
  - Irradiation test — **S, W**
- **HCAL design** — Institute of High Energy Physics, Chinese Academy of Sciences: **Q, L**
  - Simulation — **M, D**
  - Single Tile Test — **M, B,**

中國科學院高能物理研究所
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Qian Sen, **L**iu Yong, **S**un Xilei, Qian **X**iaohui, **W**ang Zhigang, **M**a Lishuang, **H**ua Zhehao, **D**u Deijing, Qi **B**aohua

Jinggangshan University

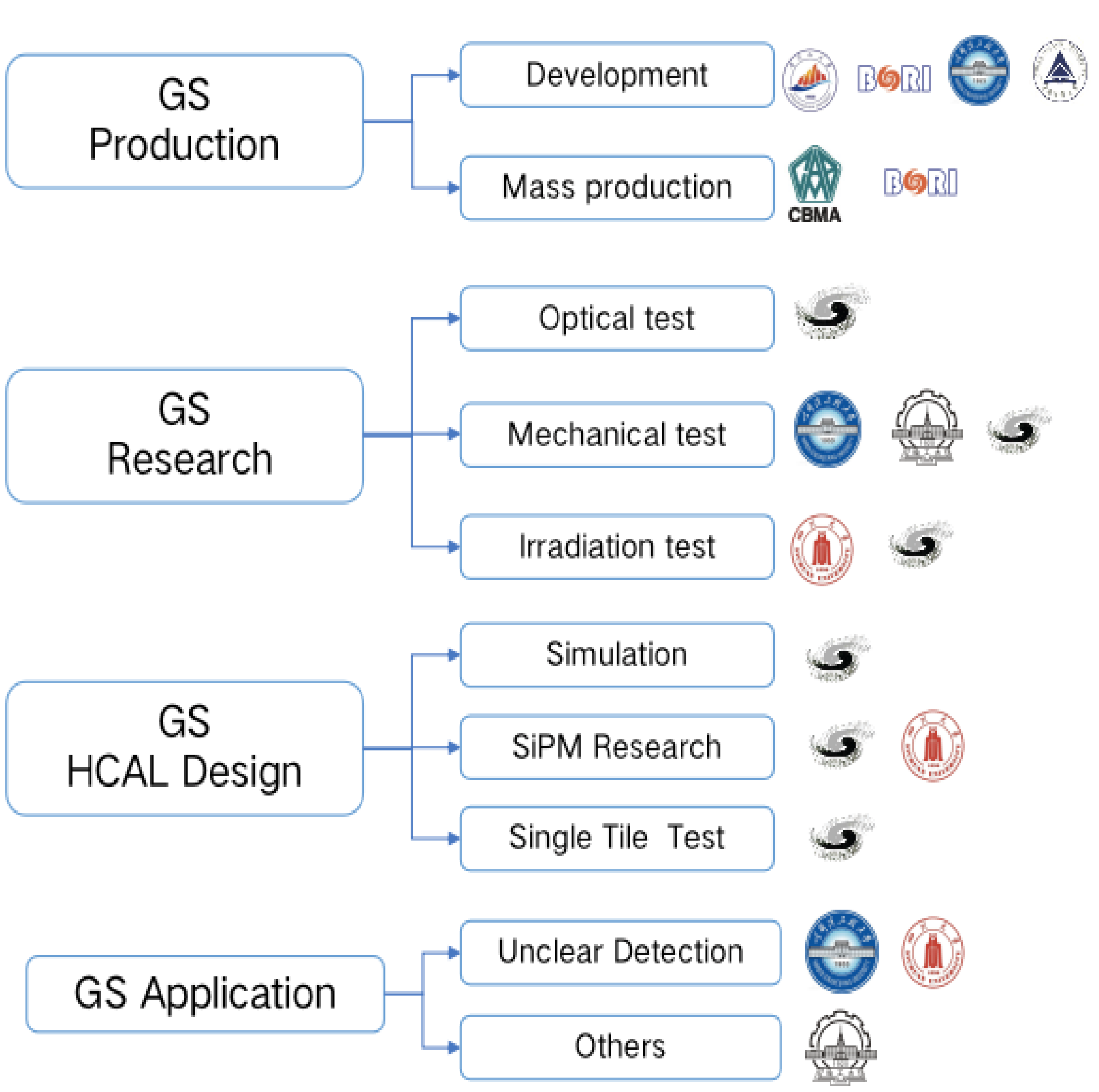
Beijing Glass Research Institute

China Building Materials Academy

China Jiliang University

Harbin Engineering University

1.1 Glass Scintillators R&D Group (Now)



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Beijing Glass Research Institute
北京玻璃研究院

China Building Materials Academy
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China Jiliang University
中国计量大学

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四川大学

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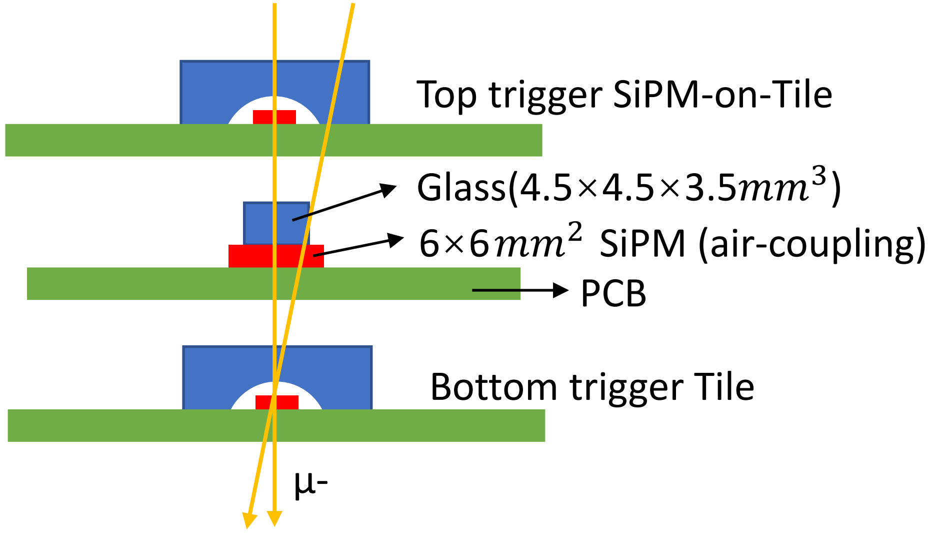
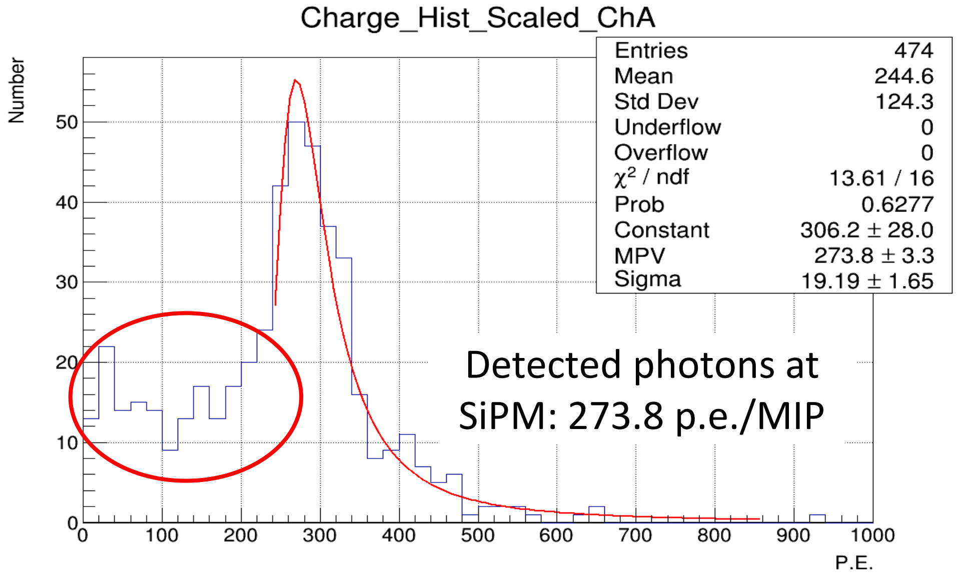
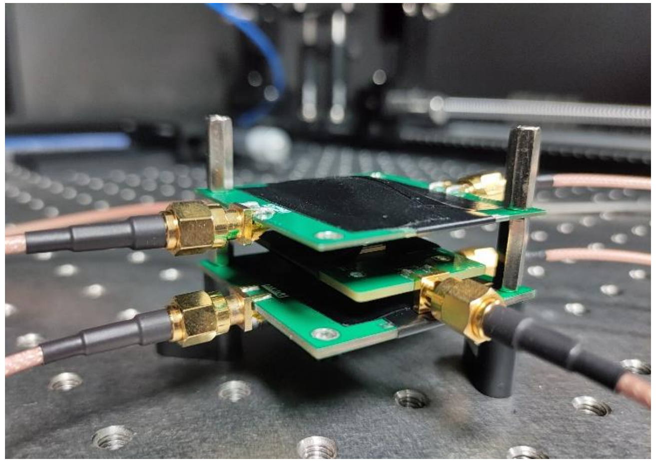
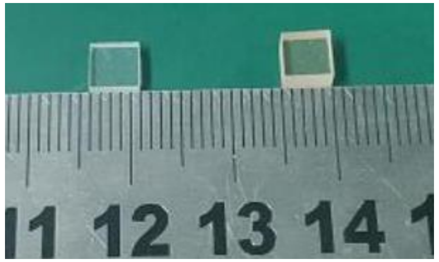
2.1 MIP response: cosmic-ray test setup and result

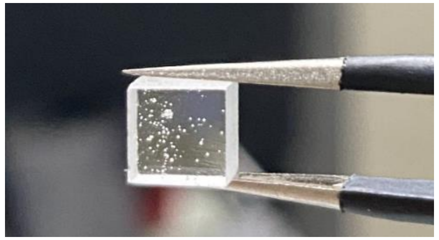
By Du Dejing









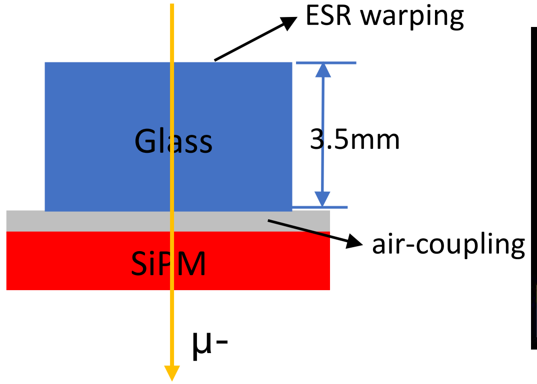


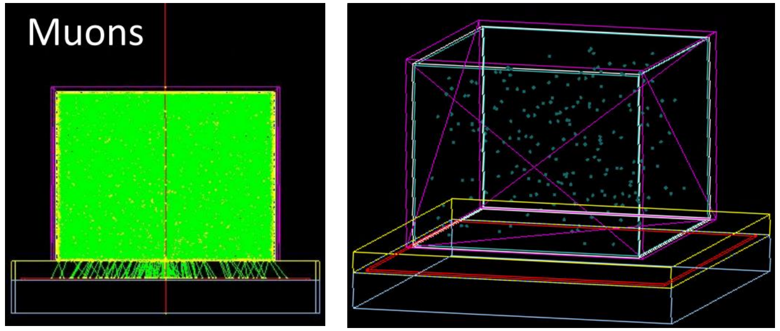
- MIP response: 274 p.e./MIP
- Plastic scintillator triggers cover larger area than sample does, some comic rays cross part of the sample

2.2 MIP response: optical simulation setup and result

By Du Dejing

- Simulation setup
  - Scintillating glass ($4.5\times4.5\times3.5mm^3$)
  - $6\times6\ mm^2$ SiPM , air-coupling
  - Small air bubbles are included
- 1 GeV mu- (regard as MIP particle)
- Vertical incidence in tile center

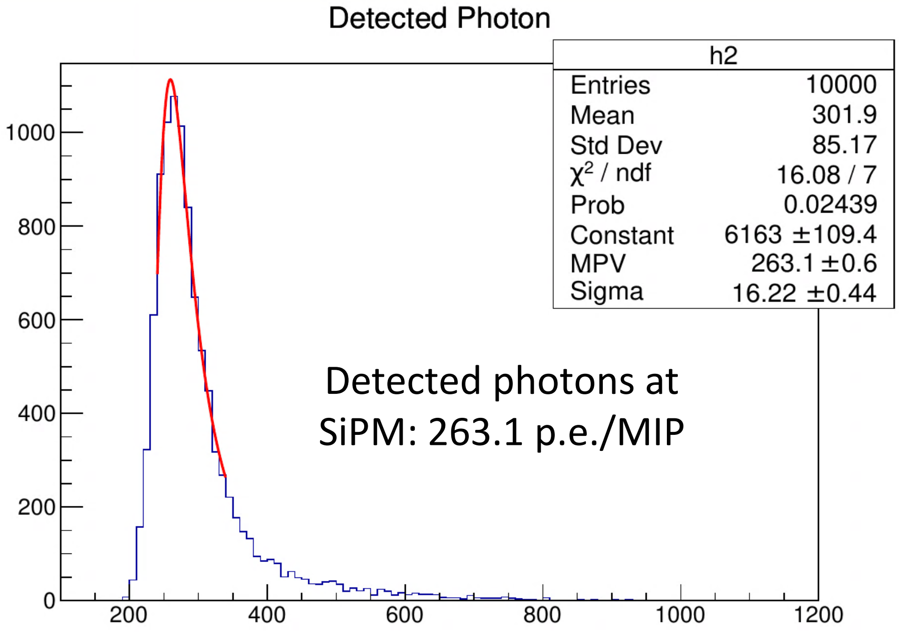




Properties of scintillating glass

- Component: $B_2O_3-SiO_2-Al_2O_3-Gd_2O_3-Ce_2O_3$
- Density: 4.94 g/cm^3
- Refractive index: 1.67
- Transmission: 63%
- Emission peak: 394 nm
- Light yield: 705 ph/MeV

(All data based on measurements)

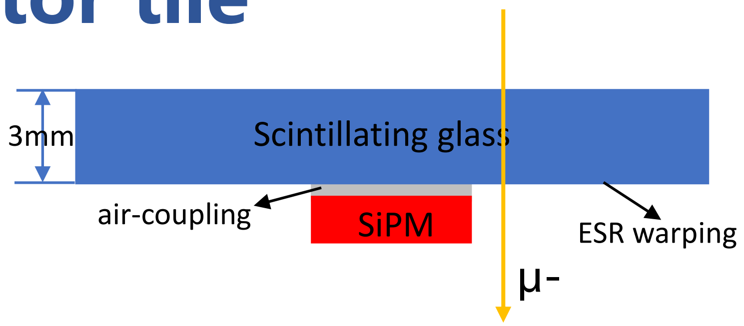


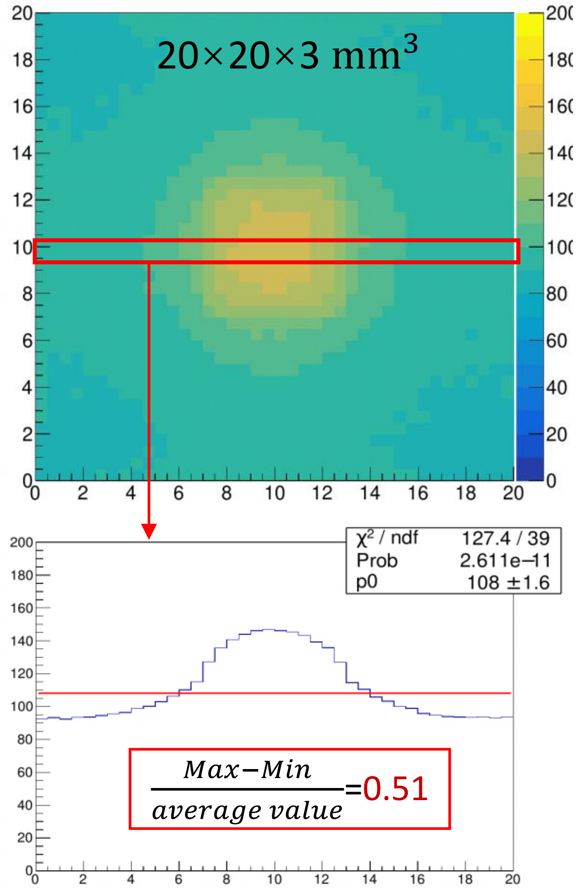
- MIP response
  - Energy deposition: 2.0 MeV/MIP
  - Detected photons: 263 p.e./MIP
- The difference between simulation and test result: ~4%

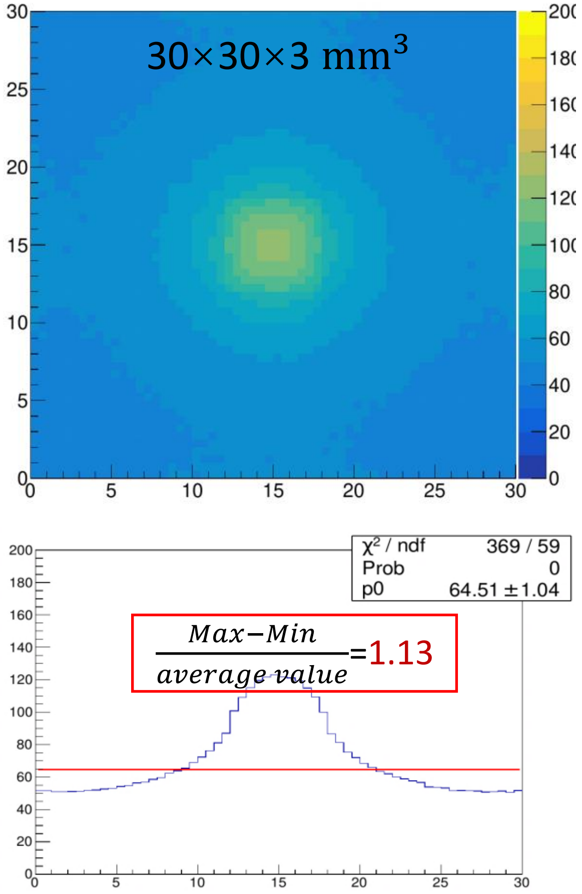
2.3 Simulation of uniformity for glass scintillator tile

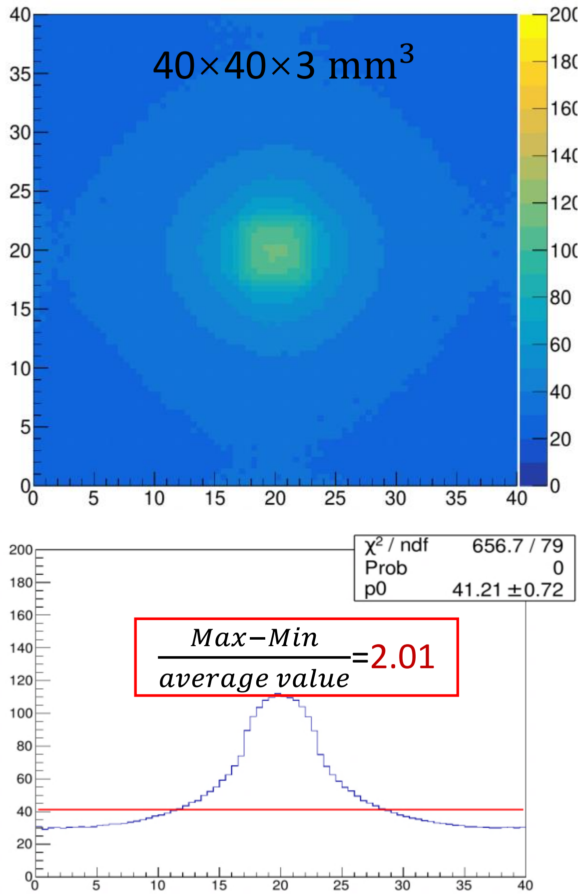
By Du Dejing

- Assuming change glass size does not affect its properties
- Uniformity scan: 1 GeV mu-, change hit positions
- Larger tile size leads to fewer detected photons and worse uniformity









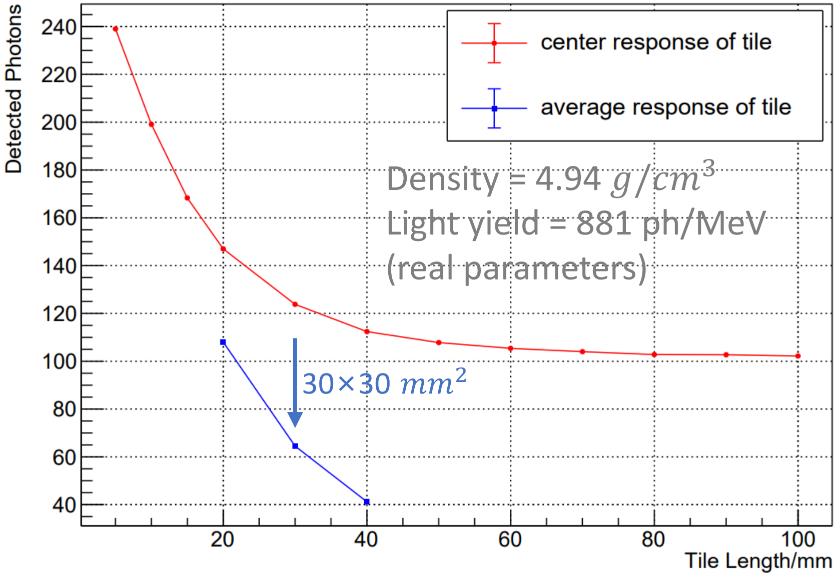
2.4 Simulation of size for glass scintillator tile

By Du Dejing

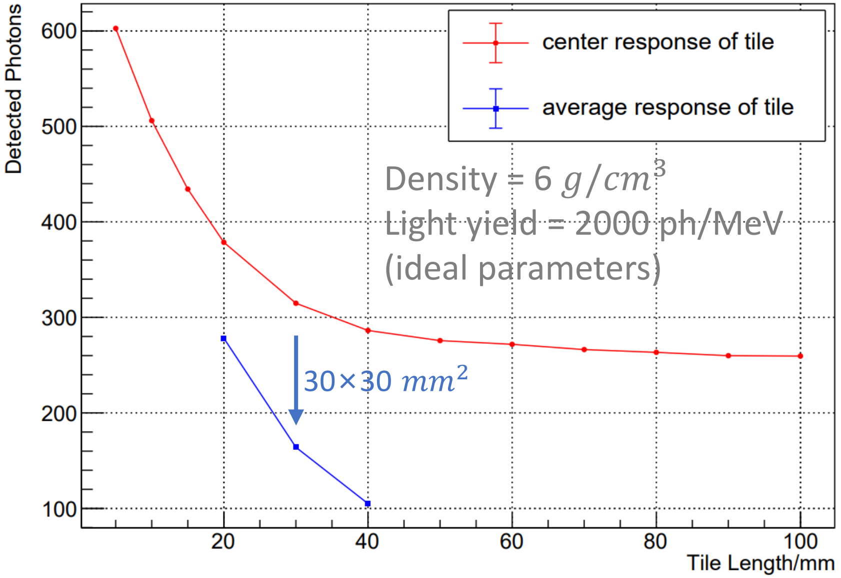
- Assuming change tile size does not affect its properties
- Incident particle: 1 GeV mu-, center position

Vary transverse size, fixed tile thickness at 3 mm (AHCAL baseline design)

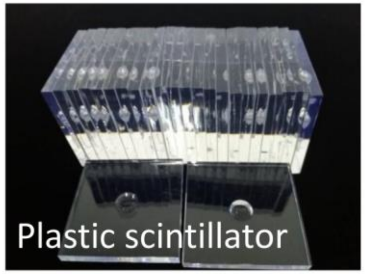
Detected photons vs. tile size



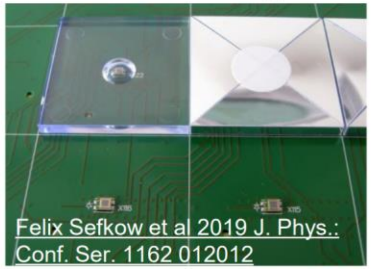
Detected photons vs. tile size



Tiles for AHCAL (30x30x3mm)



"SiPM-on-Tile" design for HCAL



- Realistic parameters: ~65 p.e./MIP not enough (using large size 6×6 mm^2 SiPM)
- Ideal parameters: ~160 p.e./MIP → smaller size SiPM
- Next plans:
  - The impact of SiPM size
  - Improve uniformity through tile-designs: "SiPM-on-Tile" is a feasible option
  - Scintillating glass R&D: improve density and light yield

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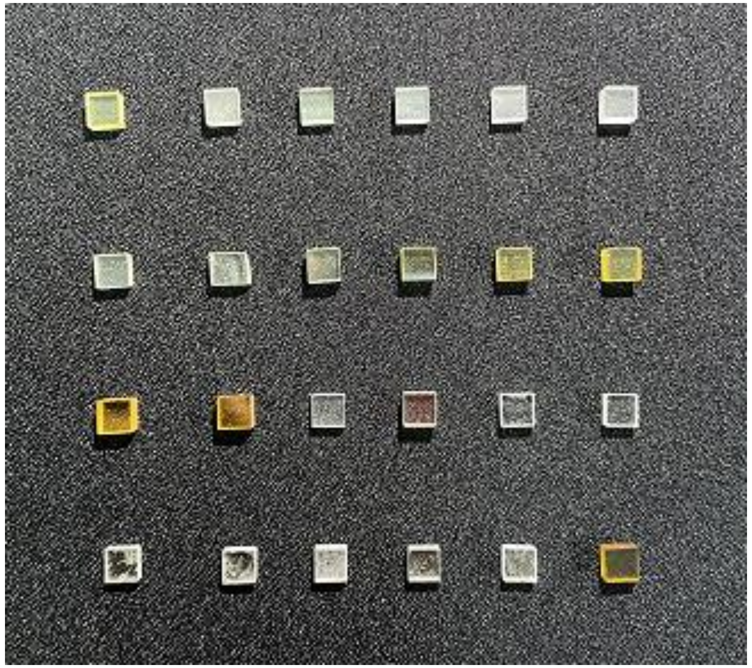
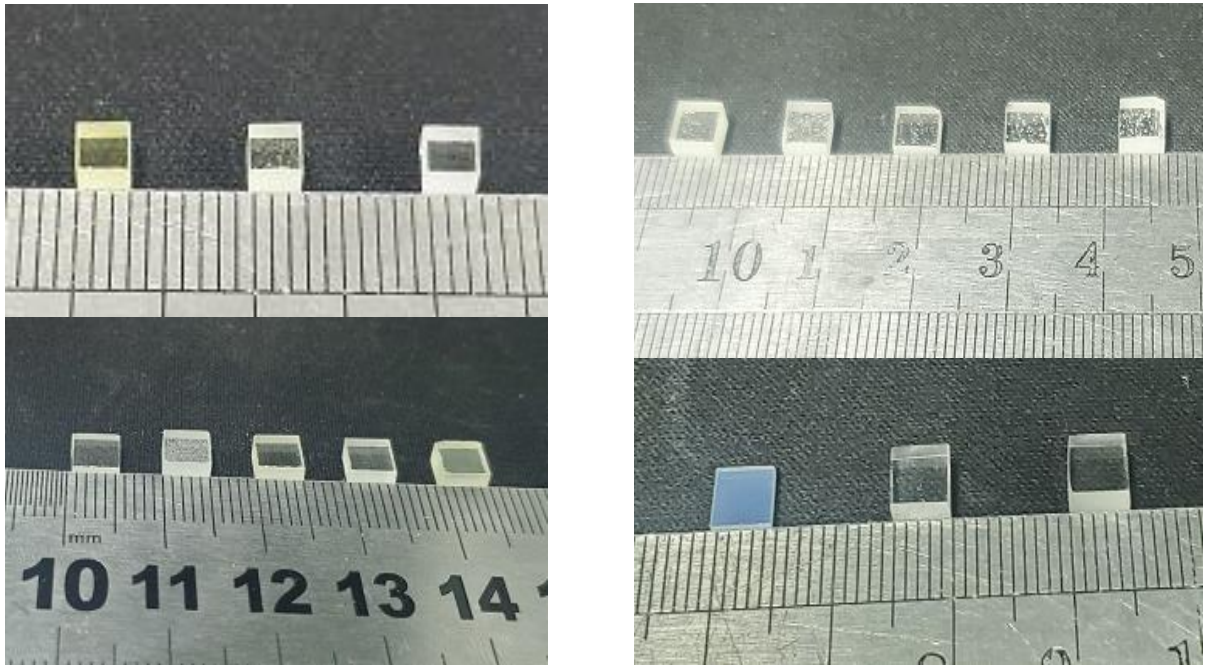
3.1 Laboratory glass scintillator samples



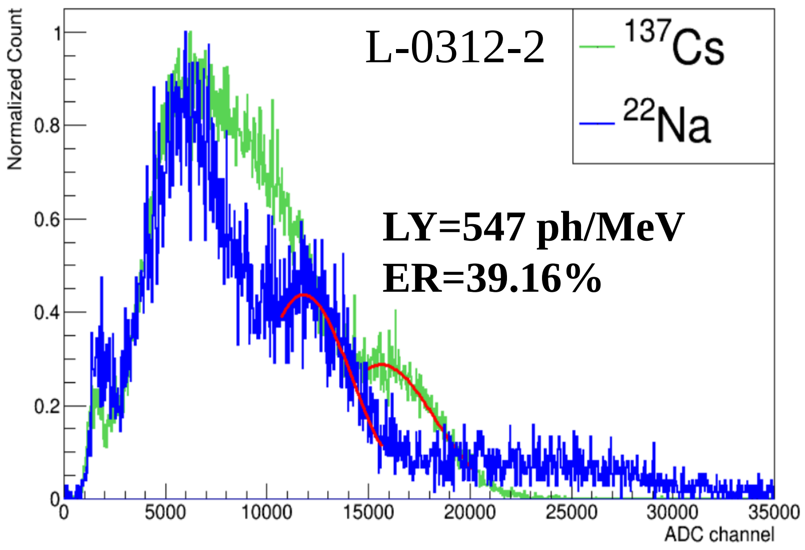
First stage glass scintillator samples
(2021.11-2022.02)

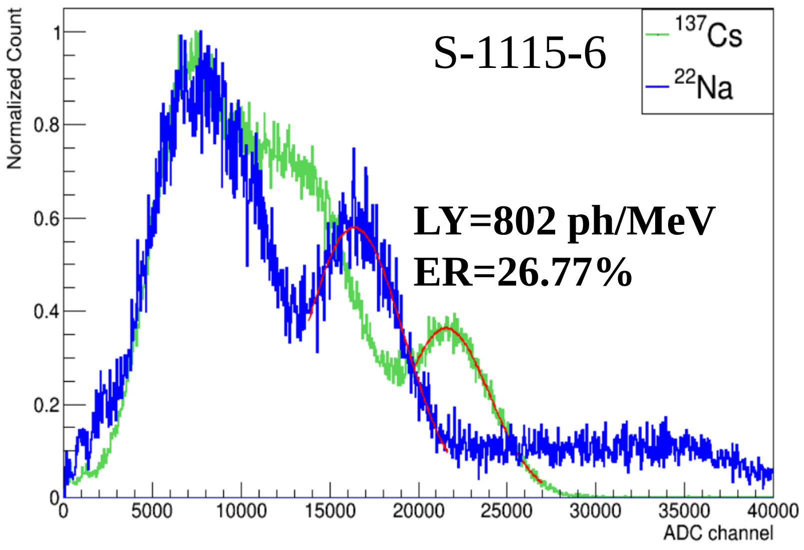


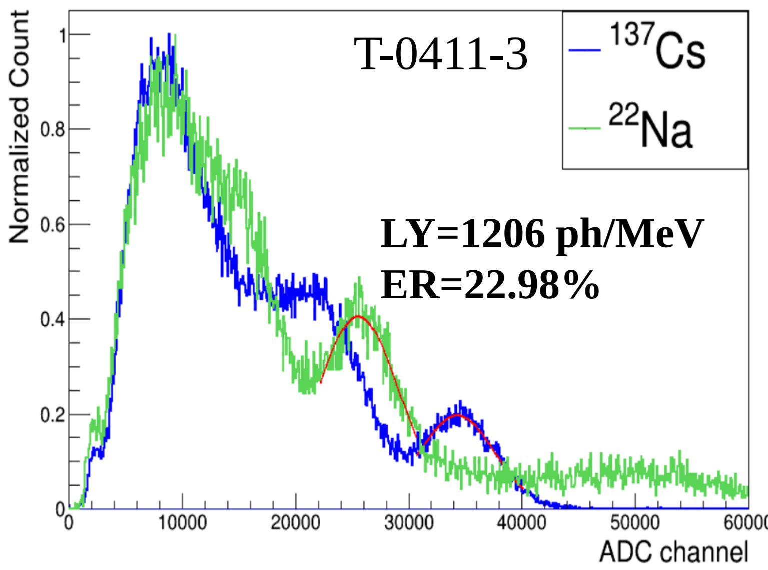
Second stage glass scintillator samples
(2022.02-2022.04)

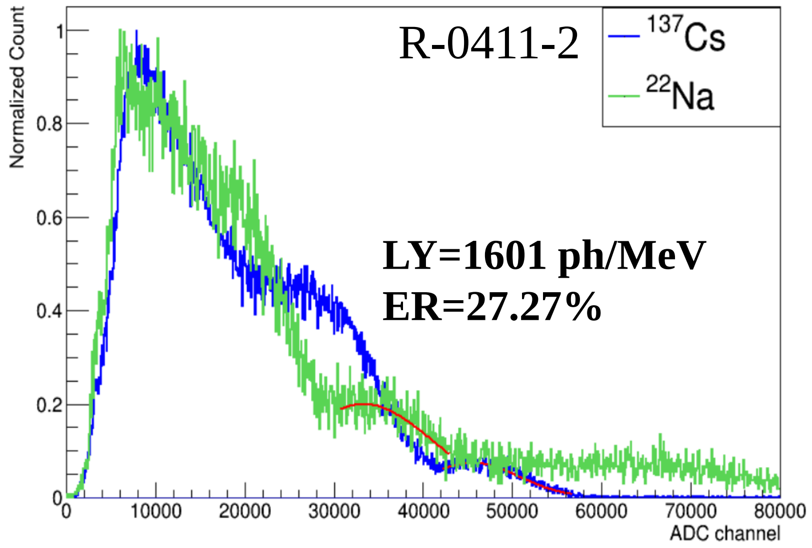
- We have tested over 30 pieces of glass in the first stage. The scintillating performance of most glasses is poor.
- In the second stage, we focused on the research of glass scintillators with better performance.
- In addition to high light yield aluminosilicate glasses, glass ceramics also exhibit very good scintillation properties.

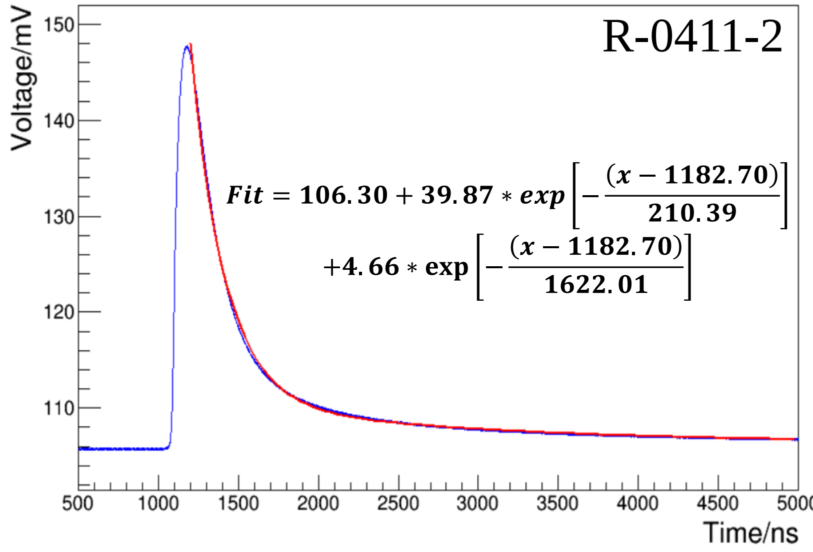
3.2 Scintillation properties of glass scintillators







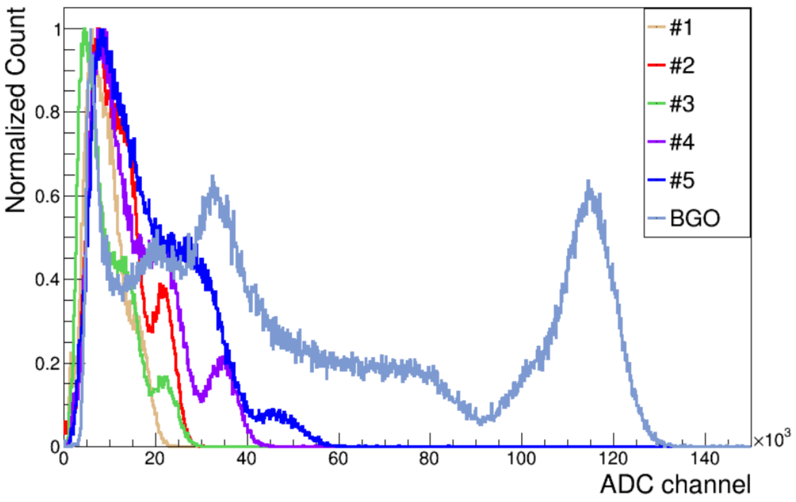




- The highest light yield of the glass has exceeded 1600 ph/MeV.
- The decay is 210.39 ns (52.6%), 1622.01 (47.4%), and the fast component accounts for more than 50%;
- The best energy resolution has reached 23% @662keV.

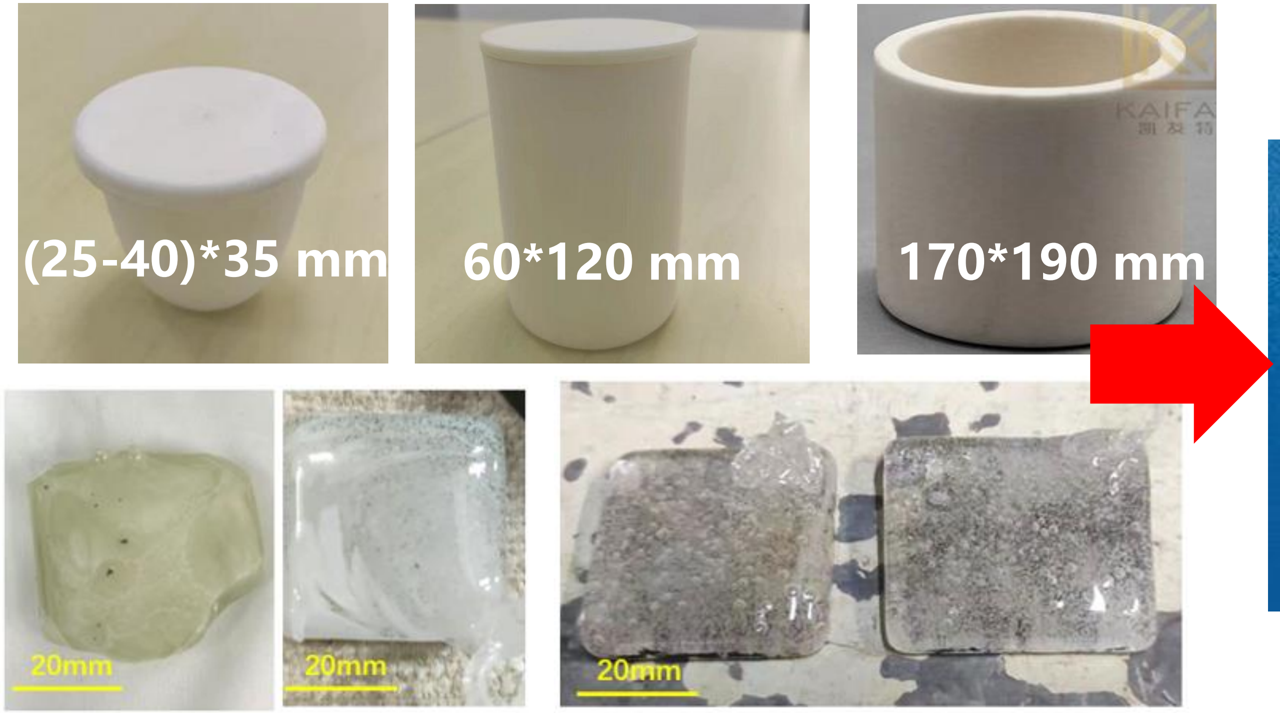
3.2 Summary of Laboratory glasses

	Composition	Density (g/cm³)	Transmittance (%)	Light yield (ph/MeV)	Energy Resolution (%)	Decay time (ns)	Emission peak (nm)
BGRI	**Gd-B-Si-Ce^{3+}**	**4.6**	70	547	39.16	**127,659**	400
JGSU	**Gd-Al-B-Si-Ce^{3+}**	4.5	67	802	26.77	318,1380	393
CJLU	**Gd-Al-Li-B-Si-Ce^{3+}**	4.1	60	807	29.29	267,1237	430
CJLU	**Gd-Al-Si-Ce^{3+}**	4.2	65	1206	**22.98**	346,1740	430
HEU	**K-Y-Gd-Si-Ce^{3+}**	3.3	**80**	**1601**	27.27	210,1622	380
	?	~6	>75	~2000	<20	<100	350-500

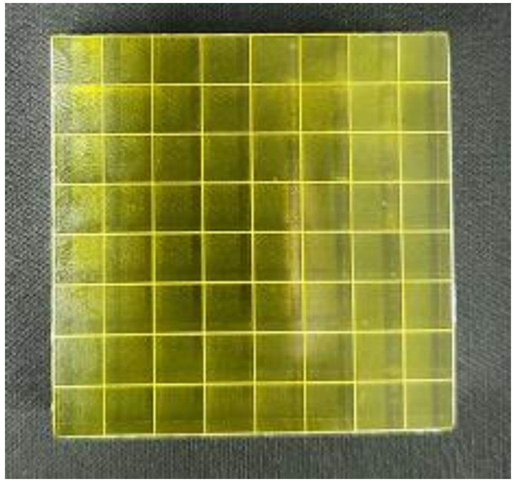


- Under the same conditions, the number of photons detected by the glass scintillator is 1/3 of that of the BGO crystal.
- However, the density of the glasses is still low, and the composition of the scintillation glass needs to be adjusted to increase its density while keeping the light yield.

3.3 Preparation of glass scintillator array



Glass array



GAGG array

- Since 2022.2.21, 41 single melting of 100-200 g glasses has been carried out for 6 kinds of glass compositions;
- However, there are several problems such as 1. increase of glass defects, 2. the Ce are converted into Ce^{4+} ions in the preparation of large size glass scintillators;
- On 2022.3.24, with the joint efforts of the Glass Scintillators R&D Group, a glass scintillator array was finally obtained. The glass preparation process still needs to be improved.

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4. 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	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
Scintillator Glass for CEPC (preliminaryl target)	?	>7	>1000	50	350-500	< 0.1$/c.c
Scintillator Glass for CEPC	?	**>6**	**>2000**	?	350-500	< 0.1$/c.c
Scintillator 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.

5. Next plan

（1）Glass Scintillator Research Program：

1.Millimeter-scale samples, improve the density, 5->6;

2.Centimeter-scale samples, performance research；

3.Raw material replacement, cost control；

（2） Related research work on SiPM：

1.Development of NDL-SiPM Electronic Driver Board；

2.Test evaluation of large area, low price NDL-SiPM ；

Thank you!