Progress of the Glass Scintillator Calorimeter

Sen QIAN

qians@ihep.ac.cn; On Behalf of the GS R&D Group

The Institute of High Energy Physics, CAS

2023. May. 30th CEPC DAY

Outline

- 1. The status of the GS Group;
- 2. The Simulation for GS Detector
- 3. The Test Facilities for GS;
- 4. The Progress of the GS Production;
- 5. Summary and Next Plan

1.1 The 4th GS Collaboration Meeting

1.2 Large Area Glass Scintillator Collaboration

- **GS Production**
  - Research & Development
  - Mass production
- **GS Research**
  - Optical test
  - Mechanical test
  - Irradiation test
- **GS HCAL Design**
  - Simulation
  - SiPM Research
  - Single Tile Test
- **GS Application**
  - Unclear Detection
  - Others

Institute of High Energy Physics，CAS
中国科学院高能物理研究所

Jinggangshan University
井冈山大学

Beijing Glass Research Institute
北京玻璃研究院

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

Shanghai Institute of Ceramics，CAS
中国科学院上海硅酸盐研究所

Shanghai Institute of Optics and Fine Mechanics，
中国科学院上海光学精密机械研究所

CNNC Beijing Unclear Instrument Factory
中核（北京）核仪器有限责任公司

New Partners！

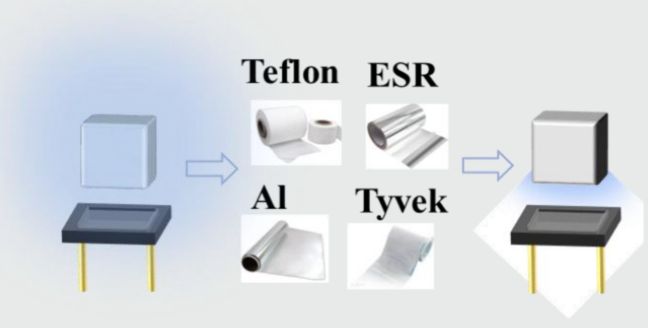
闪烁玻璃合作组
Glass Scintillator Collaboration

Outline

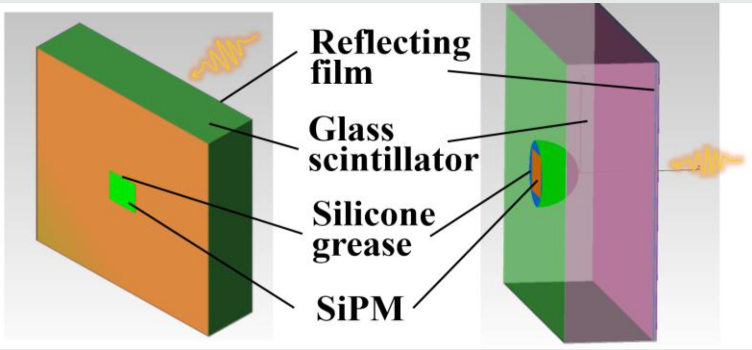
- 1. The status of the GS group;
- 2. The Simulation for GS Detector
- 2.1. The Optical Simulation for the Cell;--by Zexuan SUI;
- 2.2. The Simulation for the Standalone; --by Dejing DU;
- 2.3. The FPA of the GS-HCAL; --by HU Peng; Yuexin WANG;

2.1 The Optical Simulation for the Cell

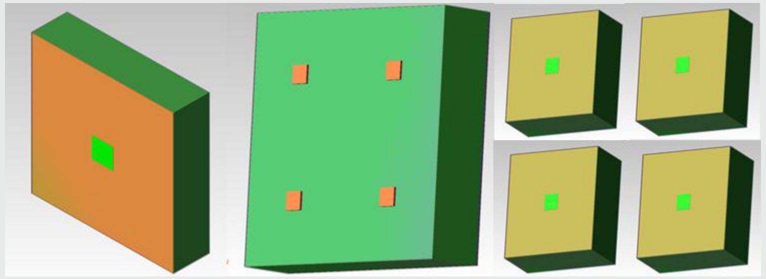
Reflective coating



Glass structure

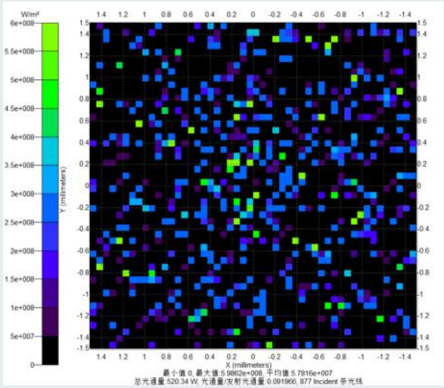


Detection position

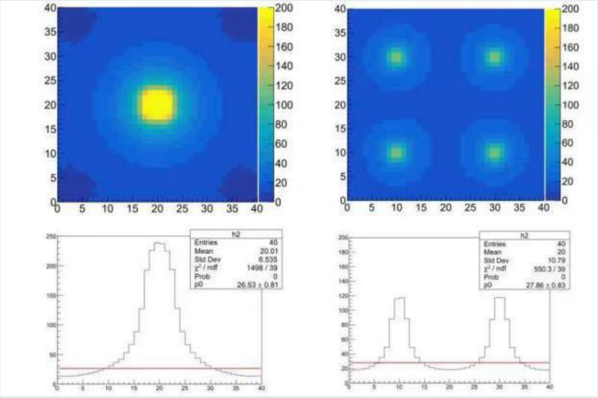


40*40 / 6*6 40*40 / 3*3 20*20 / 3*3

Collection efficiency



Uniformity



2.1 Module (1) The Reflection Film

Aluminum / ESR film

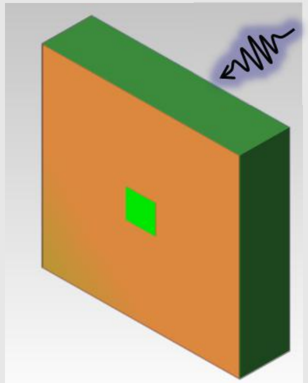
(specular reflection)

ref.ratio = 80% / 99%

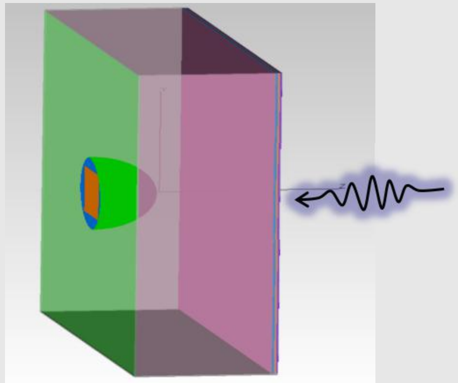
Teflon/

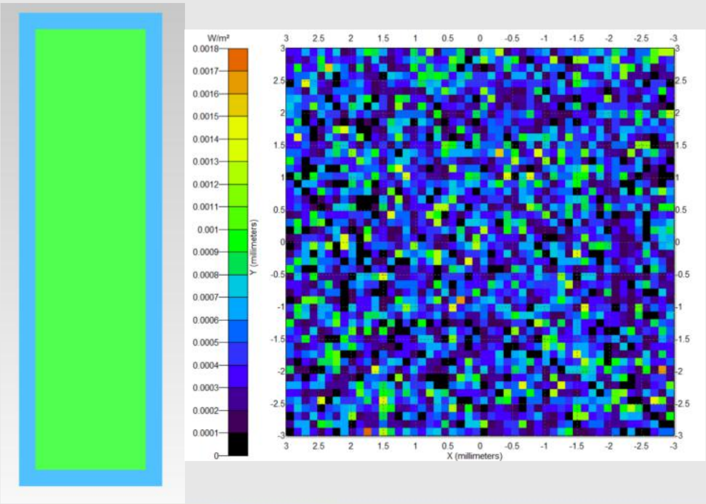
(diffuse reflection)

ref.ratio =98%

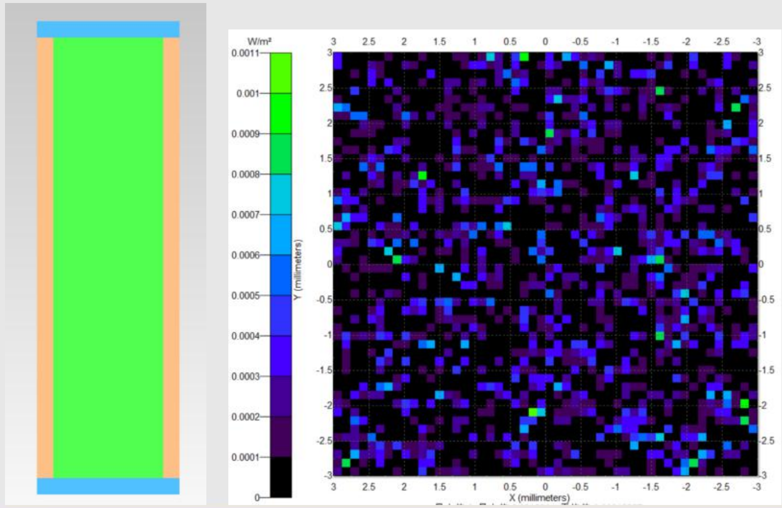


VS

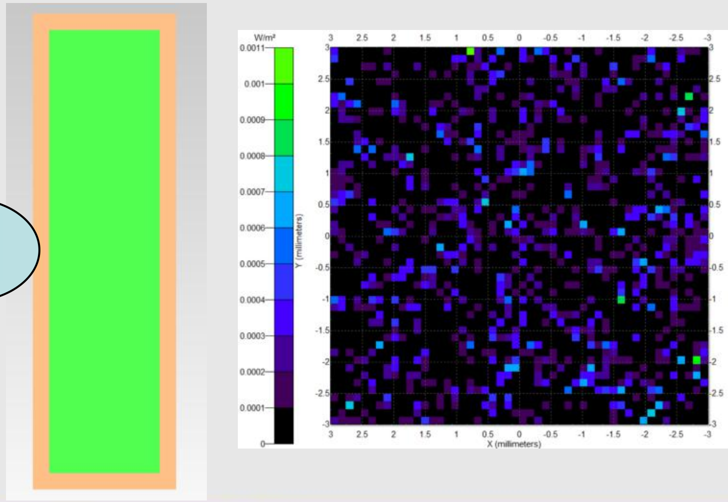




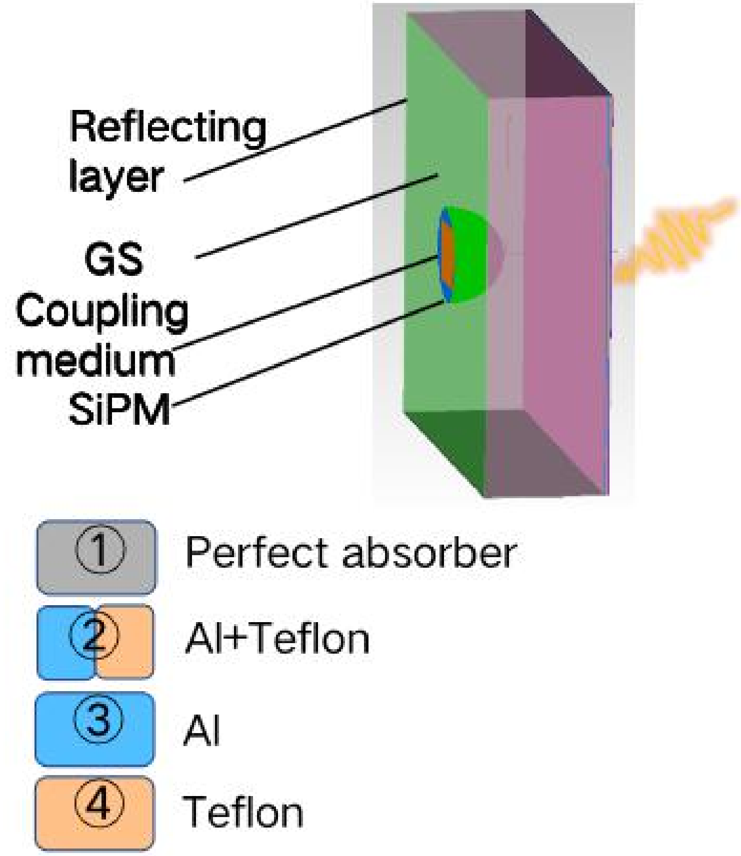
VS

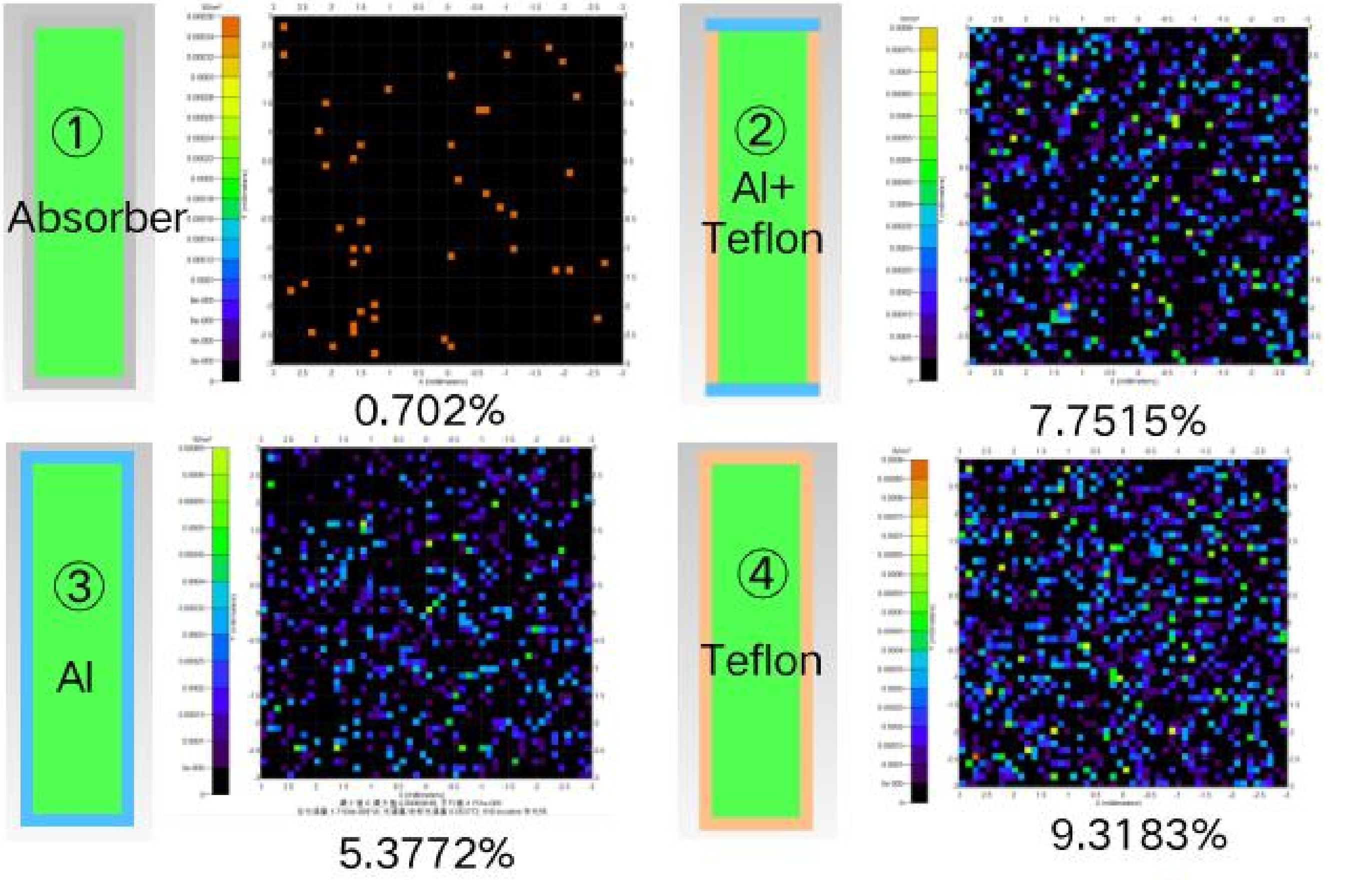


VS

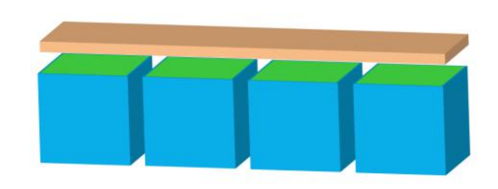


2.1 Result（1） Reflective coating（40*40*10mm³）





Fully wrapped Teflon has the highest light collection efficiency, but considering the actual difficulty and effect of wrapping, the combination film is the best choice



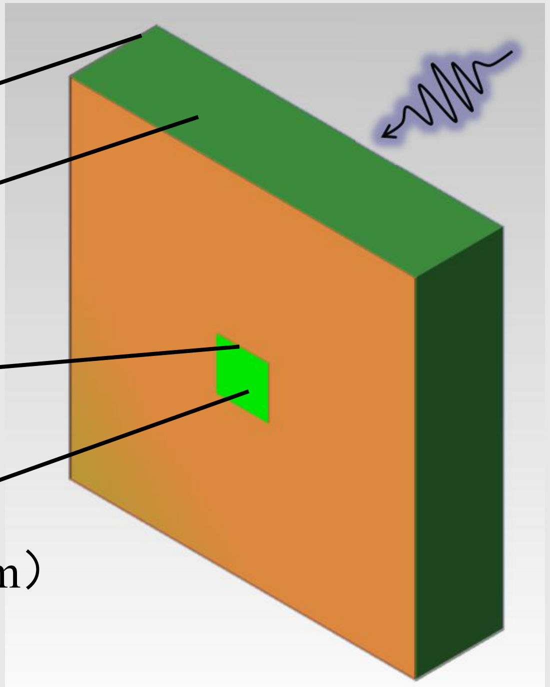
2.1 Module (2) Coupling mode of GS and SiPM

Reflecting layer

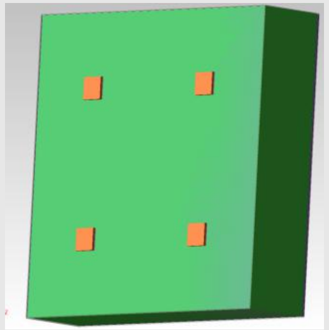
Glass scintillator

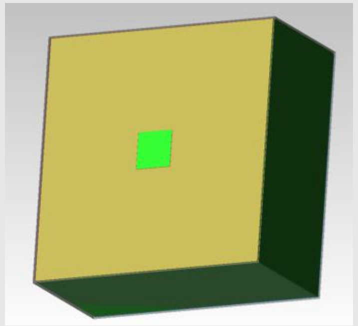
Coupling medium

SiPM
（6*6mm or 3*3mm）



- **Direct detection**



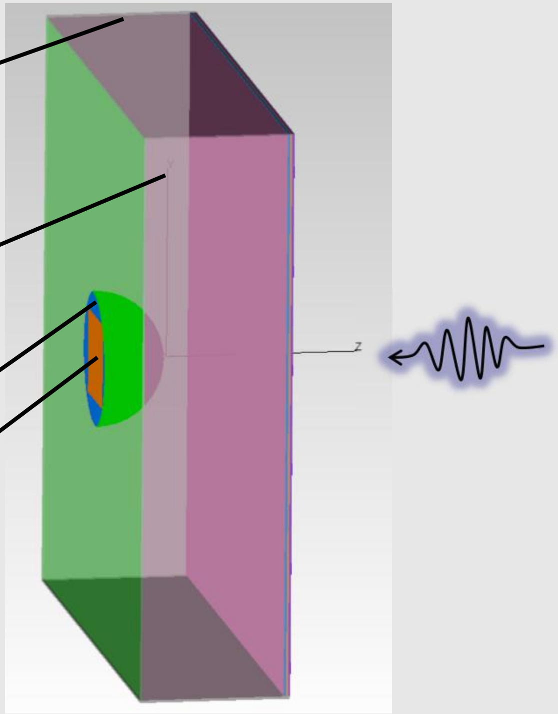


Reflecting layer

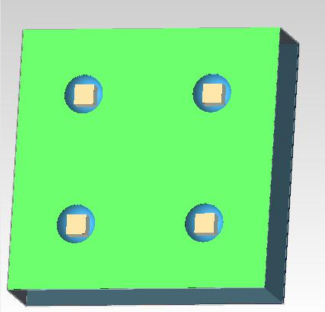
Glass scintillator

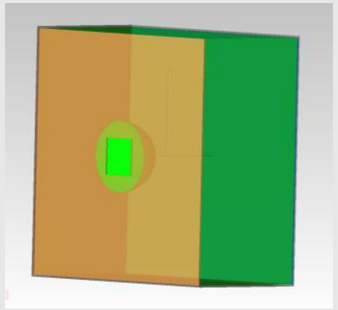
Coupling medium

SiPM
（6*6mm or 3*3mm）

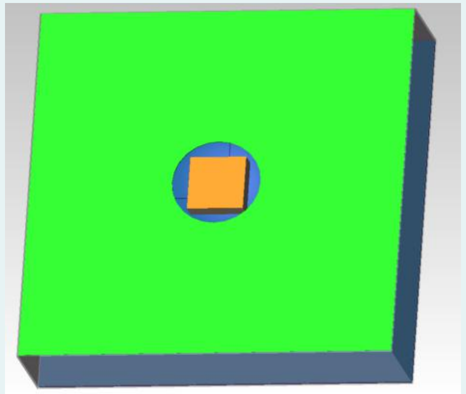
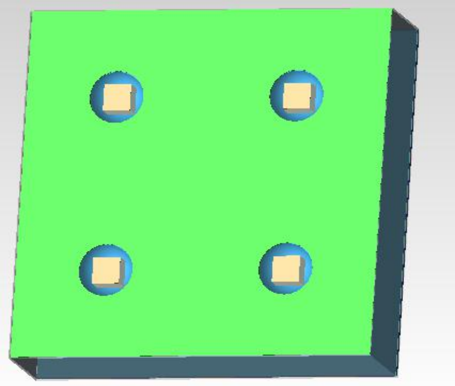
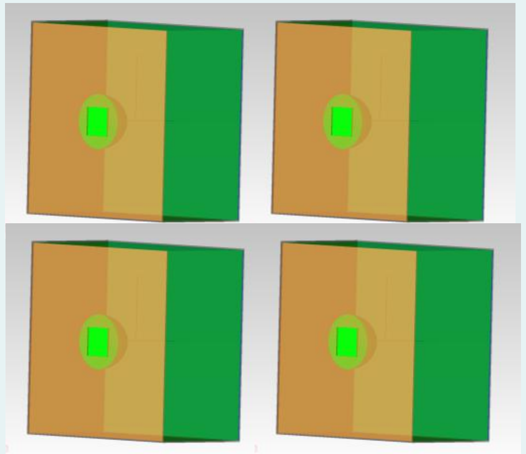
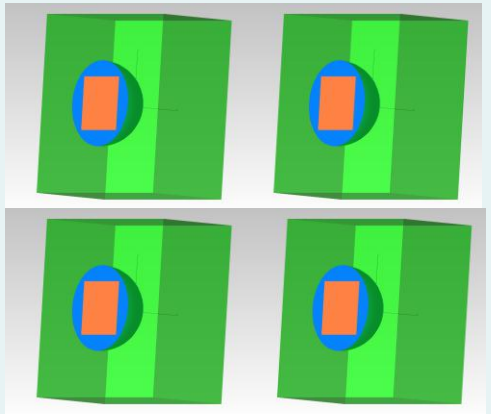


- **Hemisphere detection**

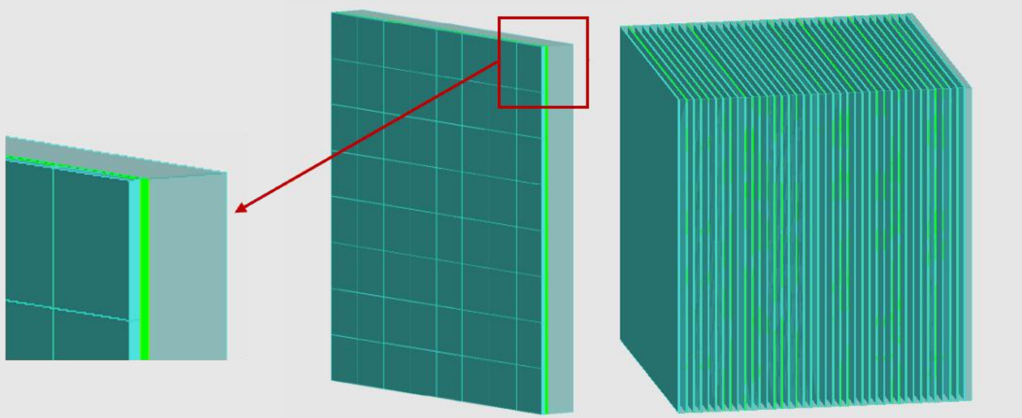




2.1 Result (2) Coupling mode of GS and SiPM

	GS=40mm*40mm SIPM= 6mm*6mm	GS=40mm*40mm SIPM= 3mm*3mm*4	GS=20mm*20mm* 4 SIPM= 3mm*3mm * 4	GS=20mm*20mm* 4 SIPM= 6mm*6mm * 4
				
Al	5.3772%	5.0695%	4.2392%	13.224%
Teflon	9.3183%	8.8004%	6.9315%	20.492%
Teflon+Al	7.7515%	7.1944%	5.3354%	18.294%

2.2 The Simulation for the Standalone



CEPC AHCAL prototype schematics

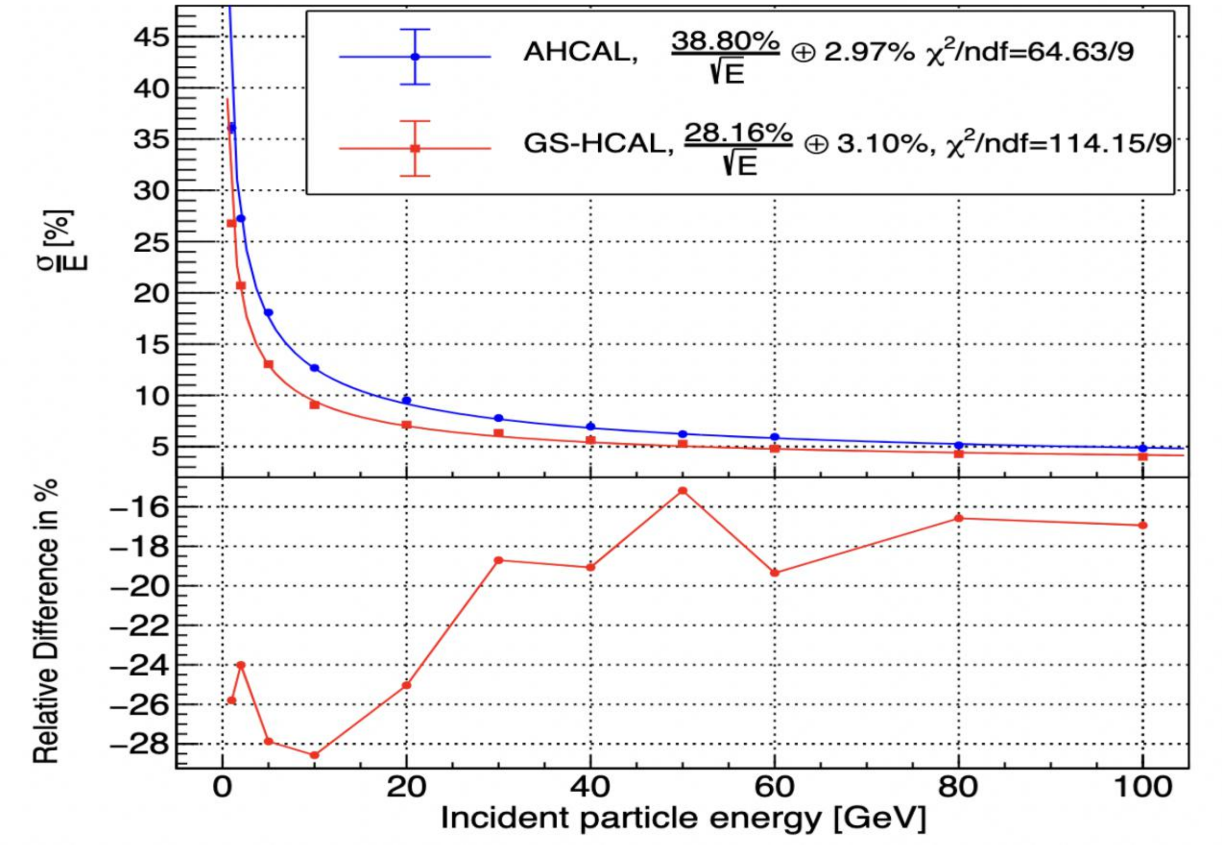
Geometry： Similar to PS AHCAL protype;

Tile size: 30mm*30mm*10mm

Steel absorber： 13mm;

Density of the GS: 6g/c.c

ENR: AHCAL vs. GSHCAL

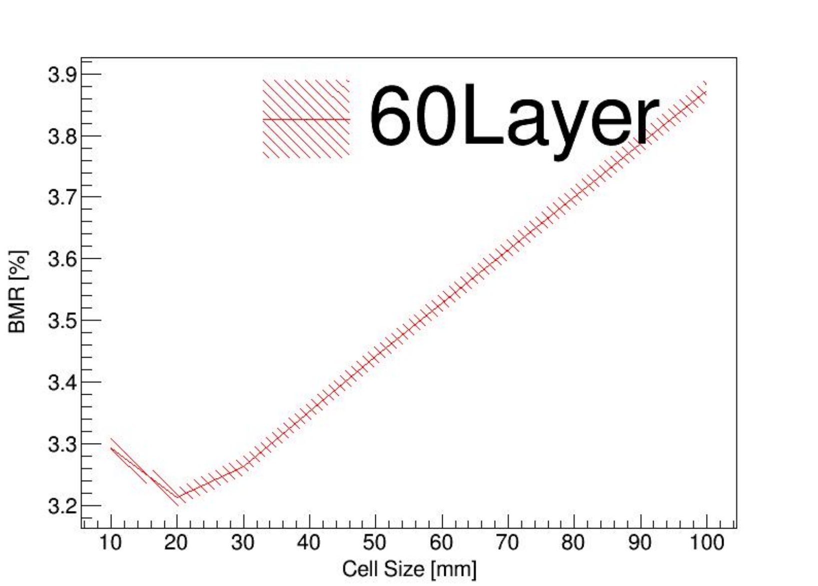


The energy resolution has significant improvement by GS-HCAL!

2.3 The Simulation for GS-HCAL

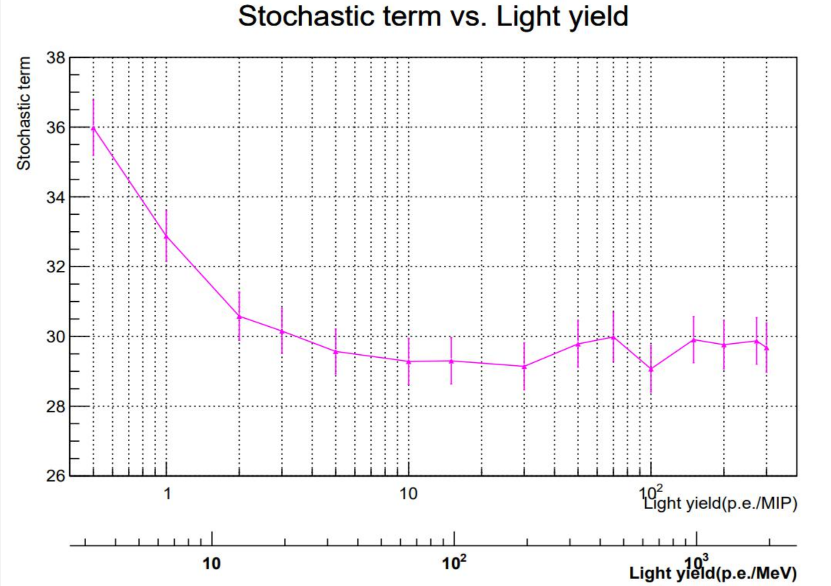
How to achieve the optimized energy resolution (Boson Mass Resolution, BMR)

➢ Impact of Transverse Size



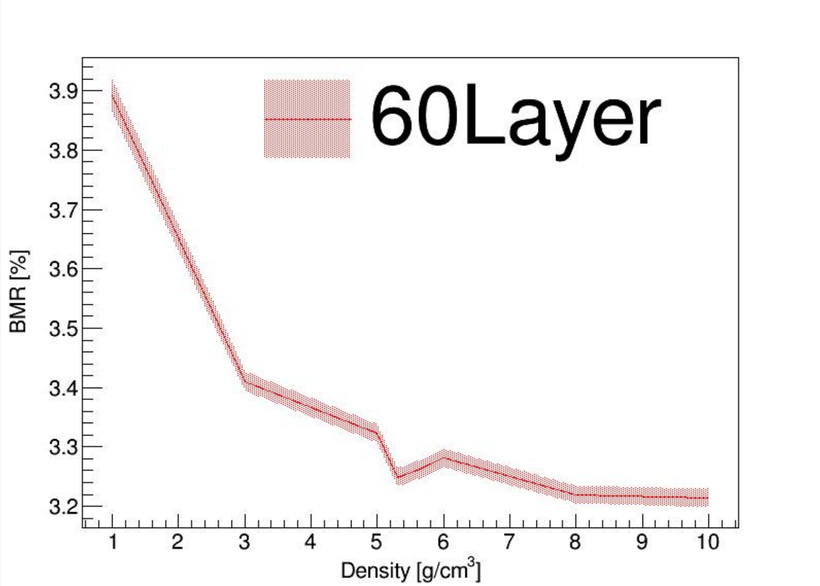
A smaller cell size is beneficial to a better BMR, though the behavior for cell size lower than **20 mm** needs a further study

➢ Impact of Light Yield

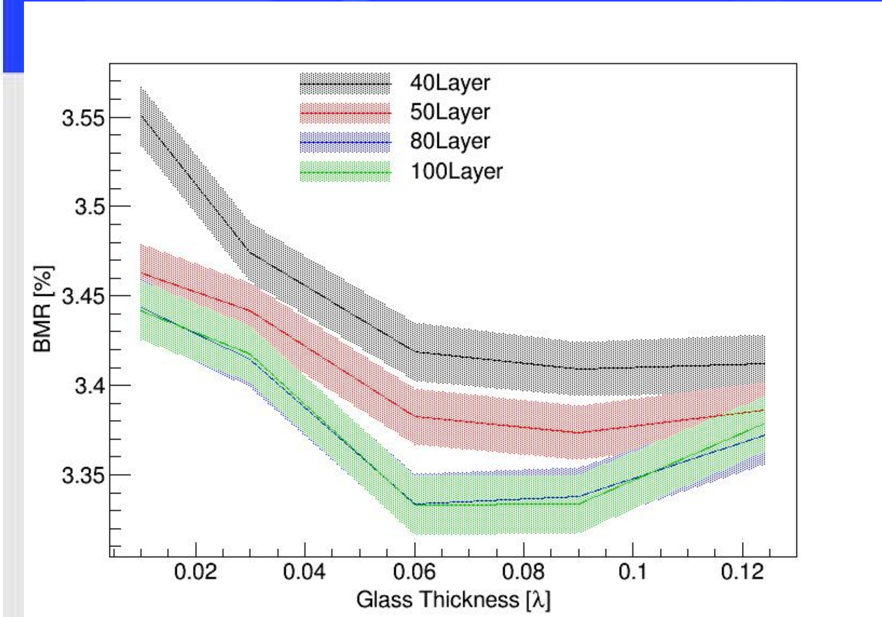


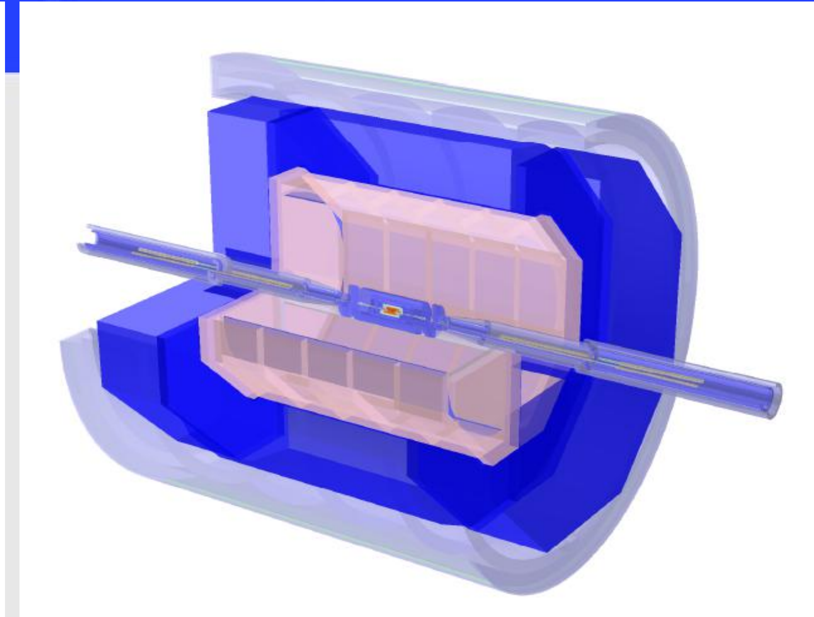
A light yield of 100 p.e./MIP or **1000p.e./MeV** seems to be good enough for better BMR;

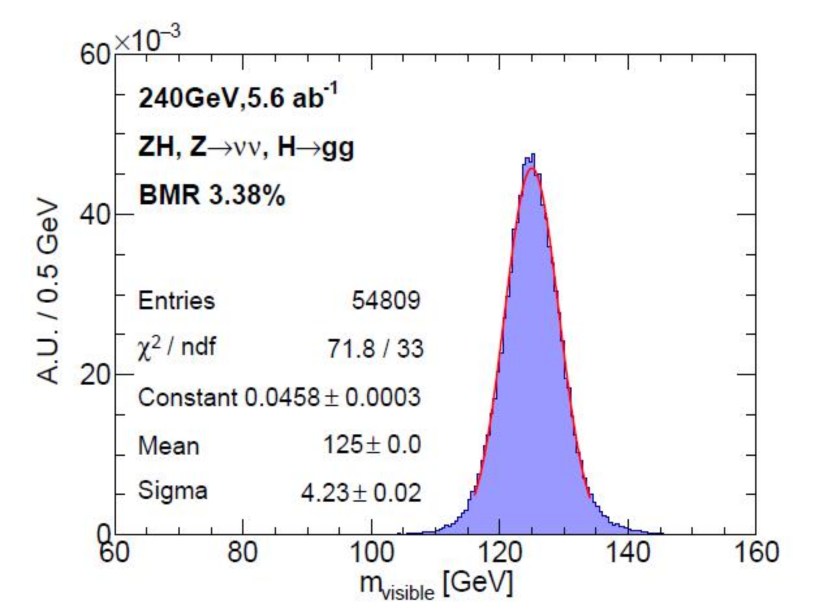
➢ Impact of Density



The BMR improves as the glass density increases, but the improvement is not significant when the density is above **6 g/cm^3**





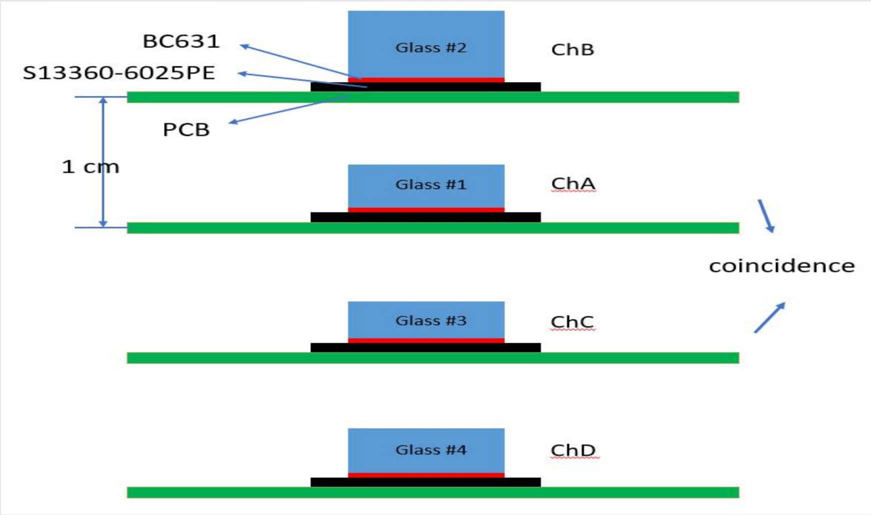


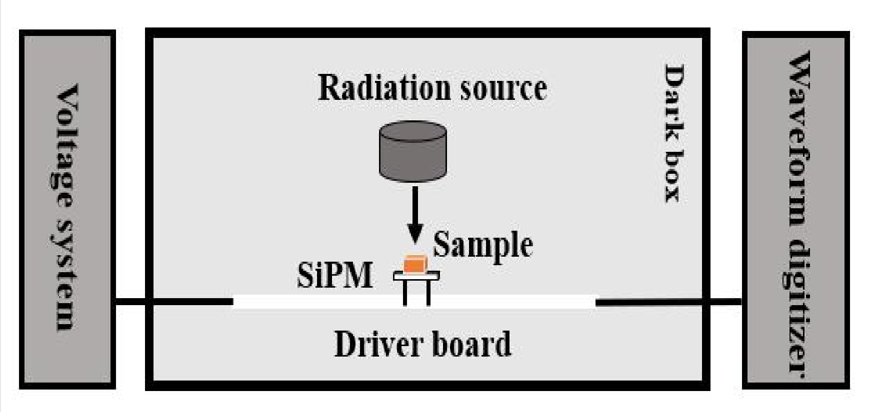
- GS-HCAL: 50 layers,; Density of the GS: 6g/c.c; Tile size: 30mm*30mm*14.3mm
- Under the CEPC_v4 and Arbor PFA framework, the BMR with GS-HCAL can reach ~3.38% after preliminary optimization;GS-HCAL show ~10% improvement compare to the AHCAL baseline design (3.8%).
- The preliminary optimization reveals some problems in the parameter setup of the ArborPFA, which was previously optimized for AHCAL and should be further tuned for GSHCAL

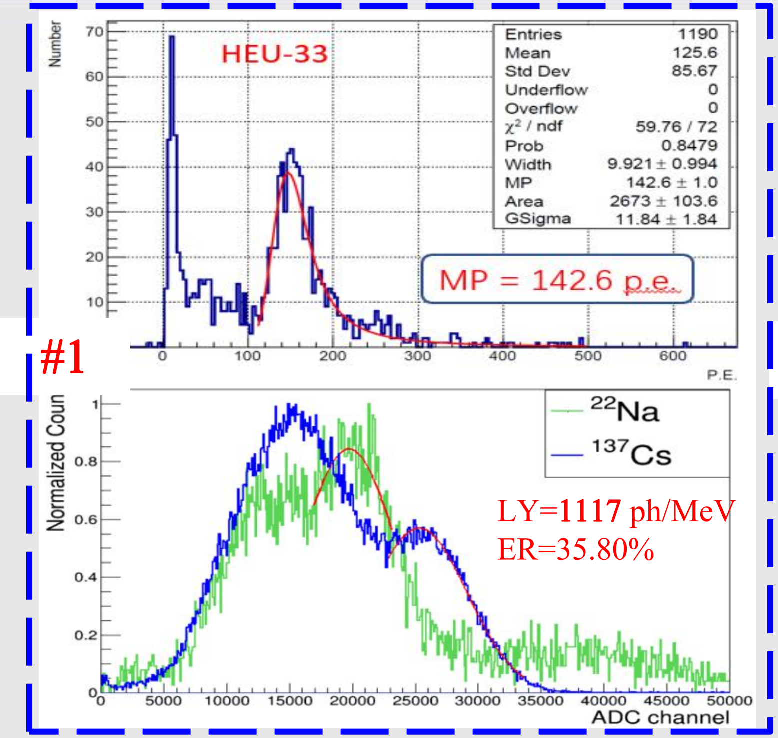
Outline

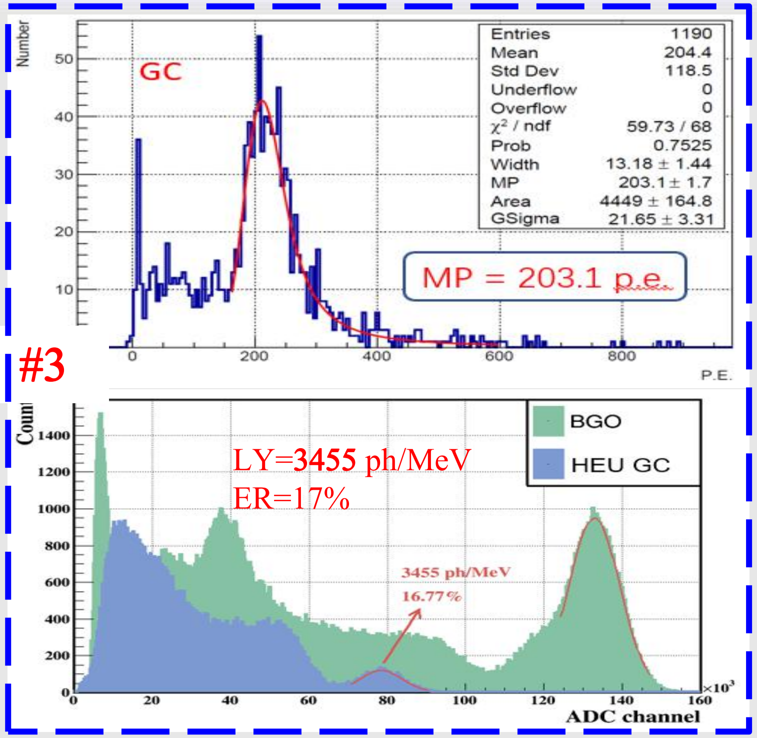
- 1. The status of the GS group;
- 2. The Simulation for GS Detector
- **3. The Test Facilities for GS Test;**
- 4. The Progress of the GS Production;
- 5. Summary and Next Plan

3.1 The Light Yield--Cosmic Ray VS Gamma Ray





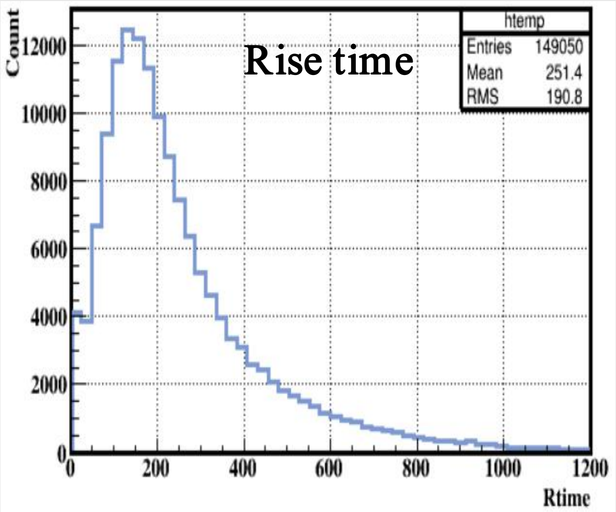


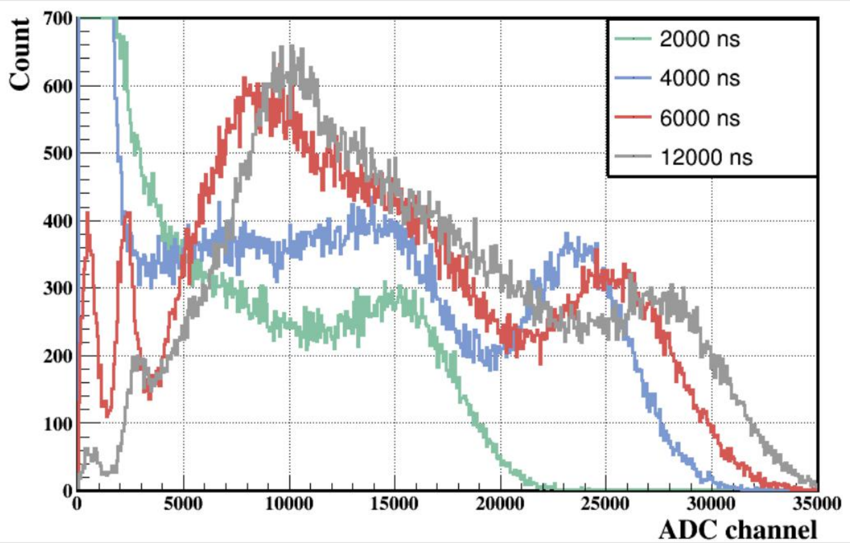


- Considering the density and thickness of the glasses, the MIP response by the cosmic ray is consistent with the light yield of the glass scintillator by gamma ray.

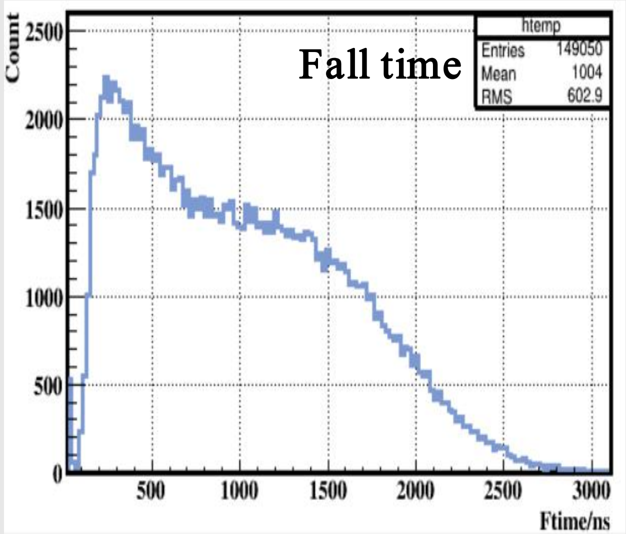
	MIP（p.e.）	LY（ph/MeV）	Thicknes（mm）	Density（g/cm³）	mip/(Thi*Den)	LY/MIP
#1	143	1117	2.6	5.4	10.2	**110**
#3（GC）	203	3455	2	3.3	30.6	**113**

3.2 Effect of integral time on glass scintillator





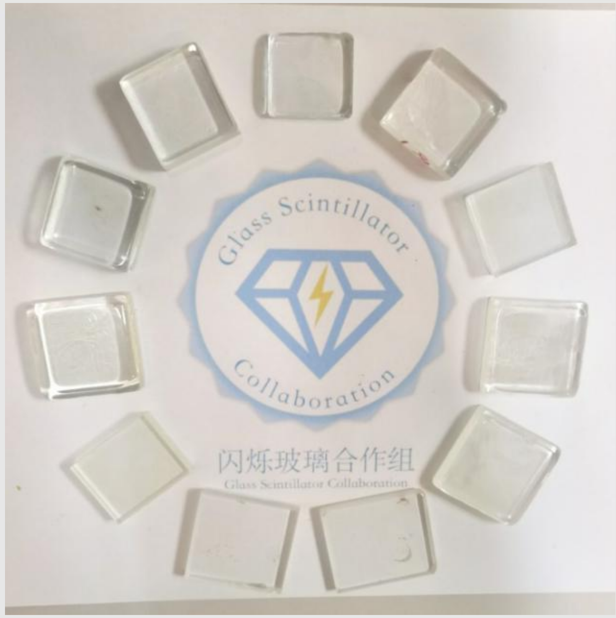
Integral time (ns)	LY (ph/MeV)	ER (%)	Decay time (ns)
1000	/	/	619.9
2000	708	44.2	279.4 (0.3%), 3594.7
4000	1126	26.4	198.7 (0.9%), 1708.0
6000	1204	28.6	165.8 (0.6%), 1652.2
8000	1247	28.8	152.2 (0.5%), 1653.5
10000	1278	28.6	167.5 (0.6%), 1649.0
12000	1296	30.0	166.0 (1.0%), 1642.4

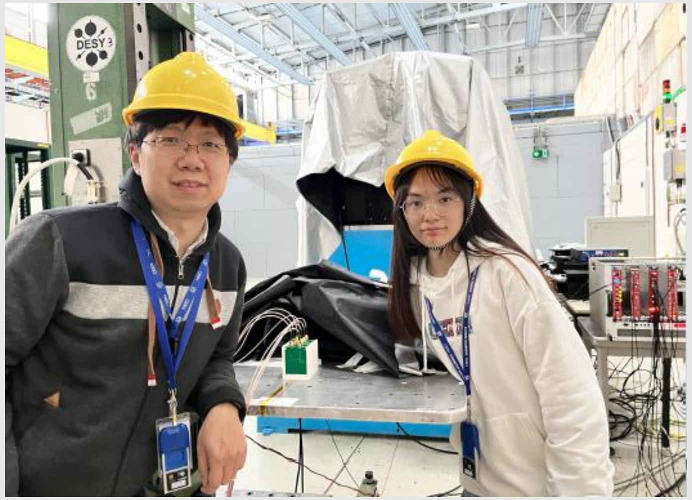


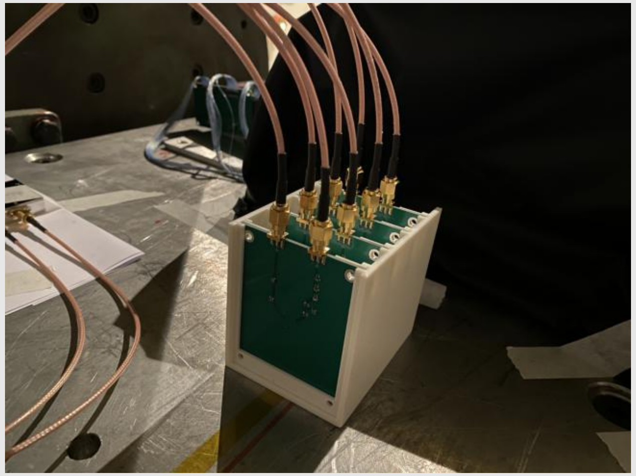
- According to RT+FT, the integral time should be set to more than 4000 ns.
- Taking **0.5 mol% Ce^{3+}-doped glass** as an example, the calculated light yield increases with the increase of the integral time due to large slow component decay time, and the longer the integral time, the worse the energy resolution.
- Therefore, the appropriate integral time should be set up according to different decay of the glasses.

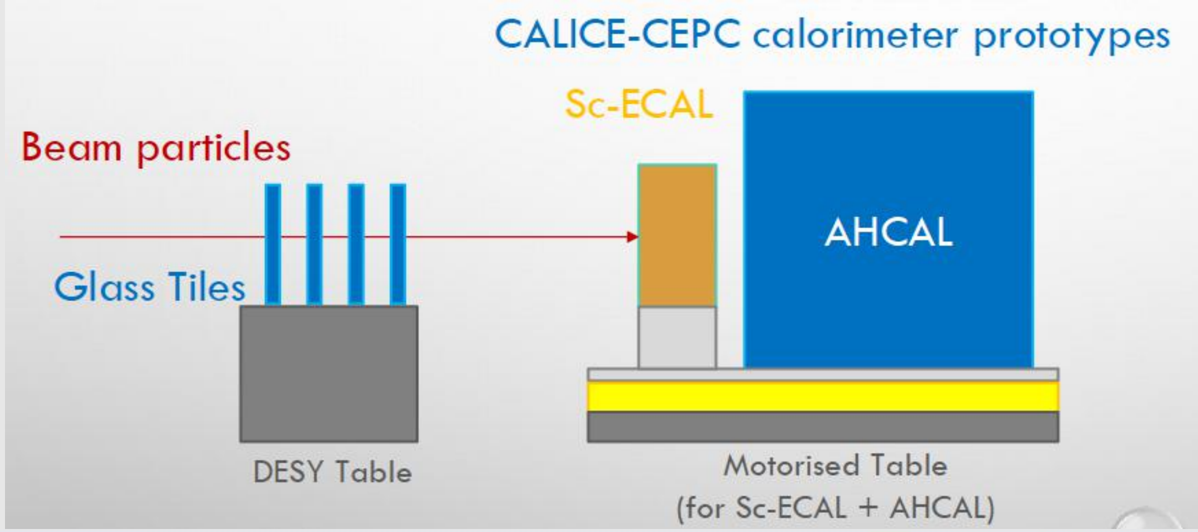
3.3 CERN Muon beam test

With Prof. Liu Yong & Du Dejing





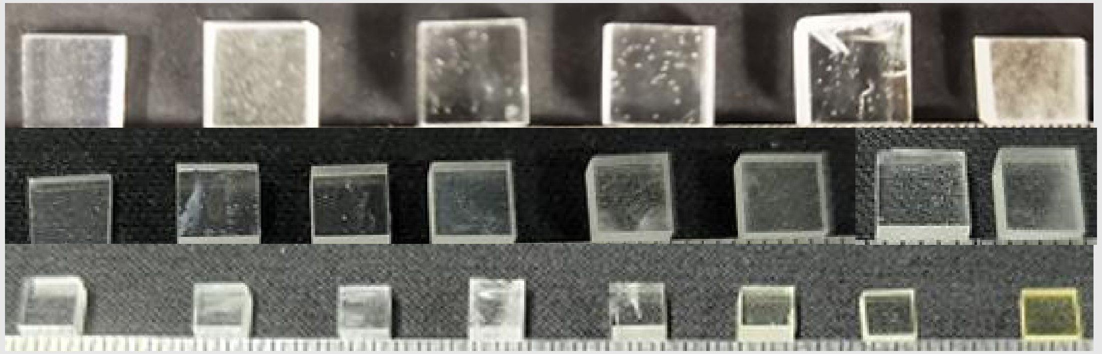




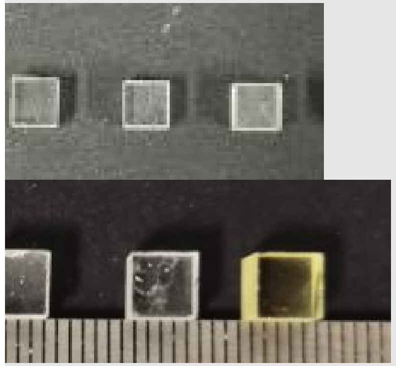
Outline

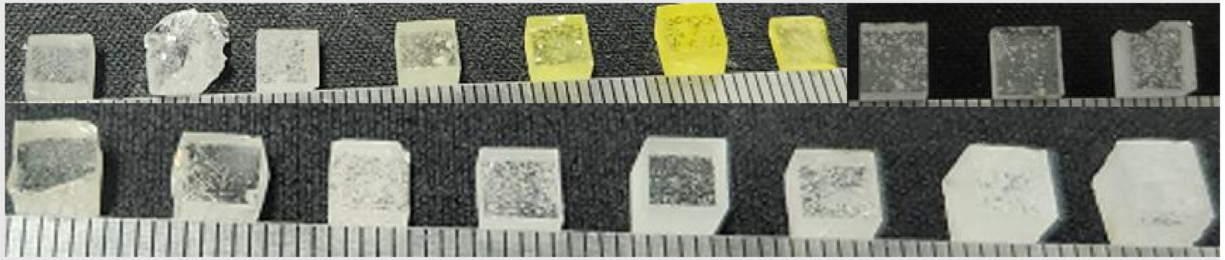
- **1. The status of the GS group;**
- 2. The Simulation for GS Detector
- 3. The Test Facilities for GS Test;
- **4. The Progress of the GS Production;**
- 5. Summary and Next Plan

4.0 The GS Samples produced （>315）



Gd-Ga-B-Ce^{3+} glass
20mm*20mm*12mm





HEU: 50+12 (20230406)

CJLU: 61+7 (20221018)

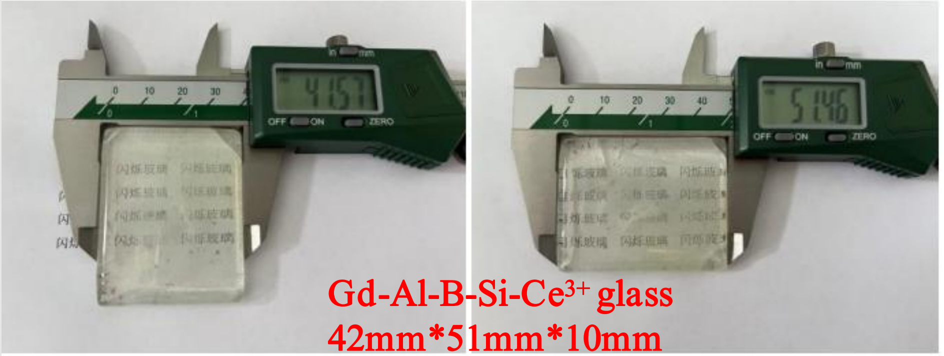
JGSU: 70+4 (20230315)

BGRI: 40+13 (20230419)

CBMA: 39+3(20230328)

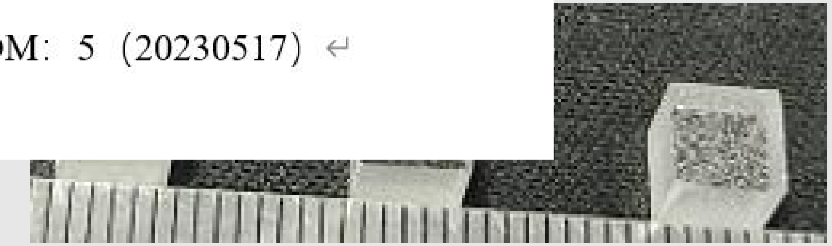
SIC: 6+5 (20230521)

SIOM: 5 (20230517)



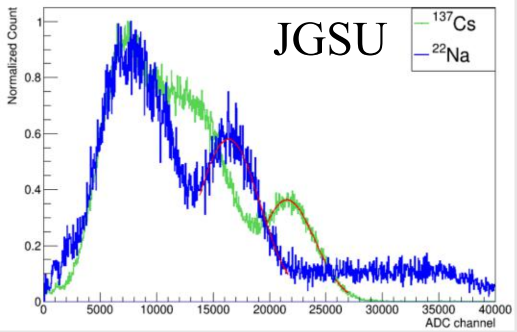
Gd-Al-B-Si-Ce^{3+} glass
42mm*51mm*10mm

Gd-Al-B-Si-Ce^{3+} glass
37mm*30mm*9mm

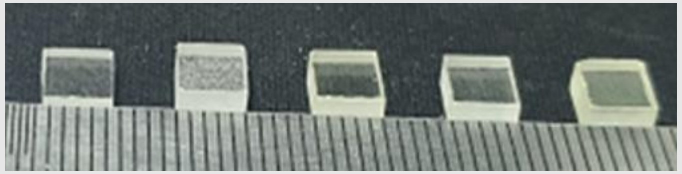


4.1 Borosilicate Glass（Gd-Al-B-Si-Ce^{3+}）--GS1

- Density~4.5 g/cm³
- LY=802 ph/MeV
- ER=26.8%
- Decay=262 ns (18%), 1235 ns

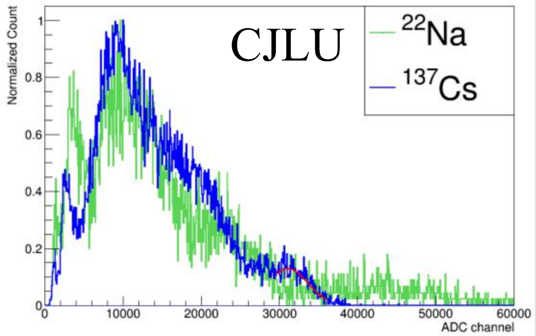


2021.11

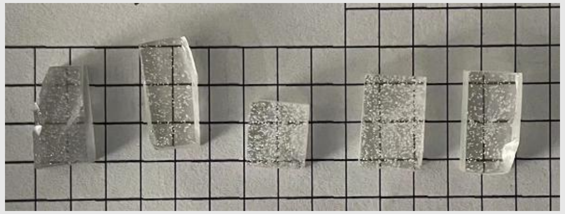


(2022.05)Opt. Mater. 2022(130): 112585

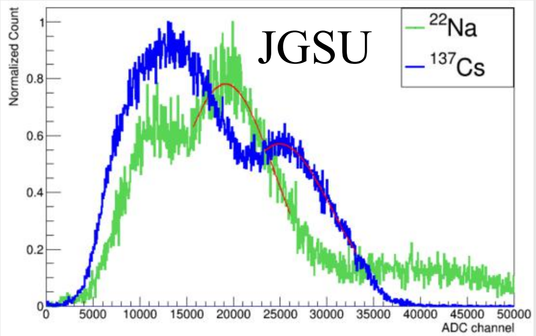
- Density~4.0 g/cm³
- LY>1200 ph/MeV
- ER=23.2%
- Decay=231 ns (10%), 1897 ns



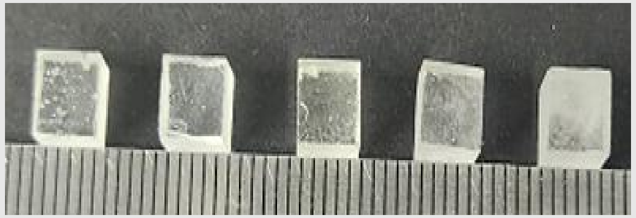
2022.06



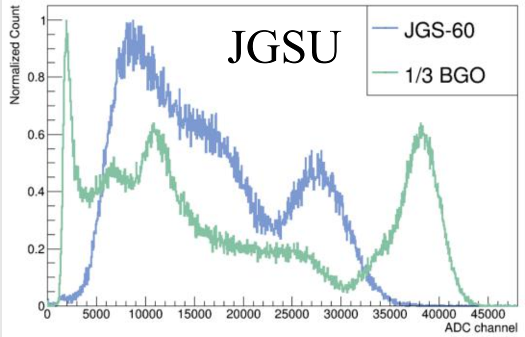
- Density~6.0 g/cm³
- LY>1000 ph/MeV
- ER=49.6%
- Decay=847 ns



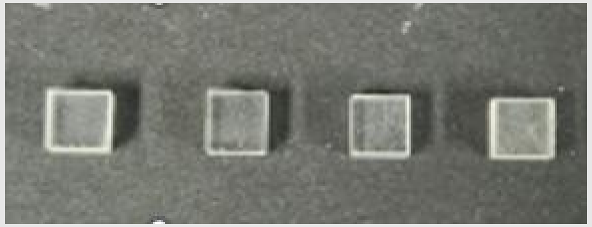
2022.11



- **Density~6.0 g/cm³**
- **LY>1100 ph/MeV**
- **ER=24.4%**
- **Decay=460 ns**

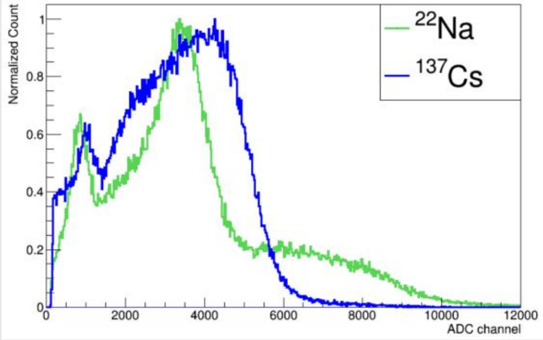


2023.02



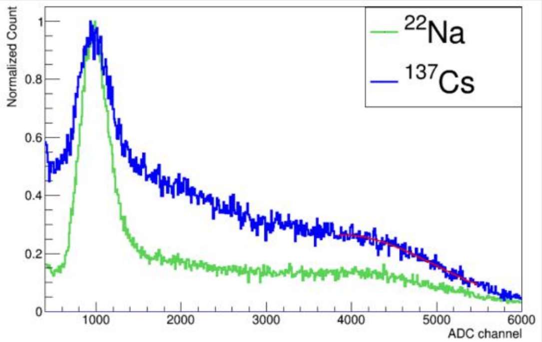
4.2 Large Size Glass（Gd-Al-B-Si-Ce^{3+}）--GS1

- Size=30*27.5*9 mm^3
- Density=5.1 g/cm^3
- LY=466 ph/MeV
- ER=None

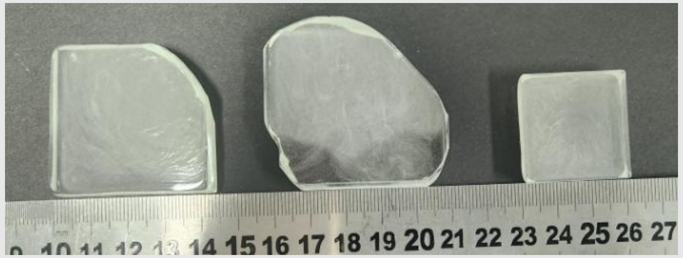


2022.10

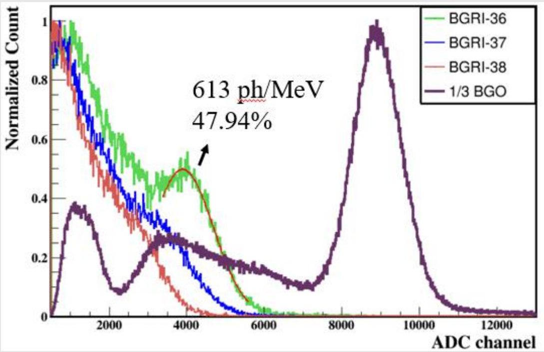
- Size=30*30*10 mm^3
- Density=5.2 g/cm^3
- LY~600 ph/MeV
- ER=None



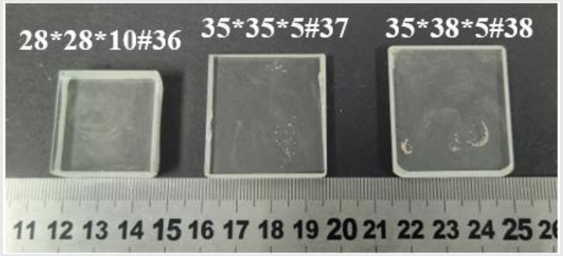
2022.12



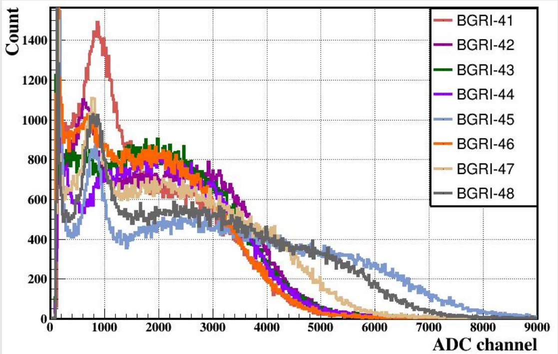
- Size=28*28*10 mm^3
- Density=5.2 g/cm^3
- LY=613 ph/MeV
- ER=47.9%



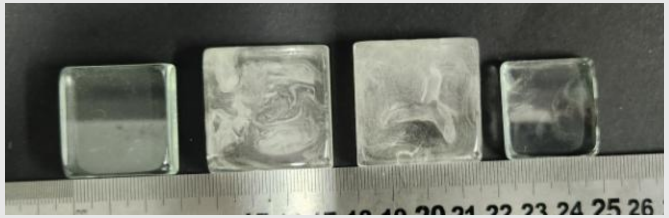
2023.01



- Size=28*26*5 mm^3
- Density=5.1 g/cm^3
- LY=840 ph/MeV
- ER=None



2023.04



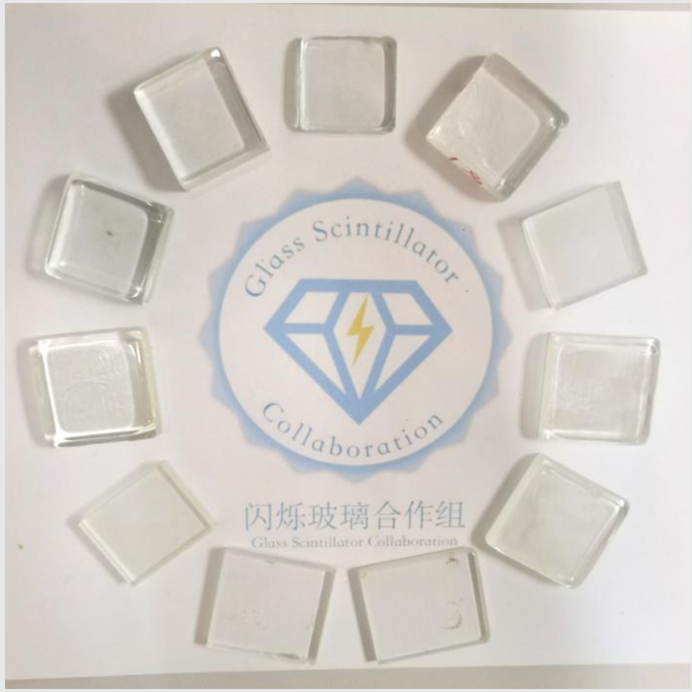
21

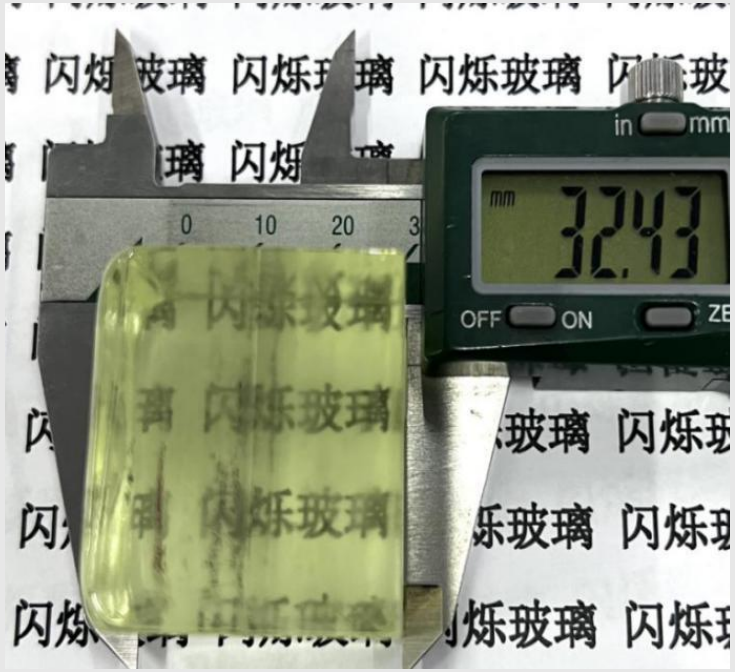
4.2 Large Size Glass（Gd-Al-B-Si-Ce^{3+}）--GS1

- Size=30*30*10 mm^3
- Density=5.1 g/cm^3
- LY=600 ph/MeV

- Size=50*50*12 mm^3
- Density=5.6 g/cm^3
- LY=？ ph/MeV

- Size=35*35*33 mm^3
- Density=5.4 g/cm^3
- LY=？ ph/MeV





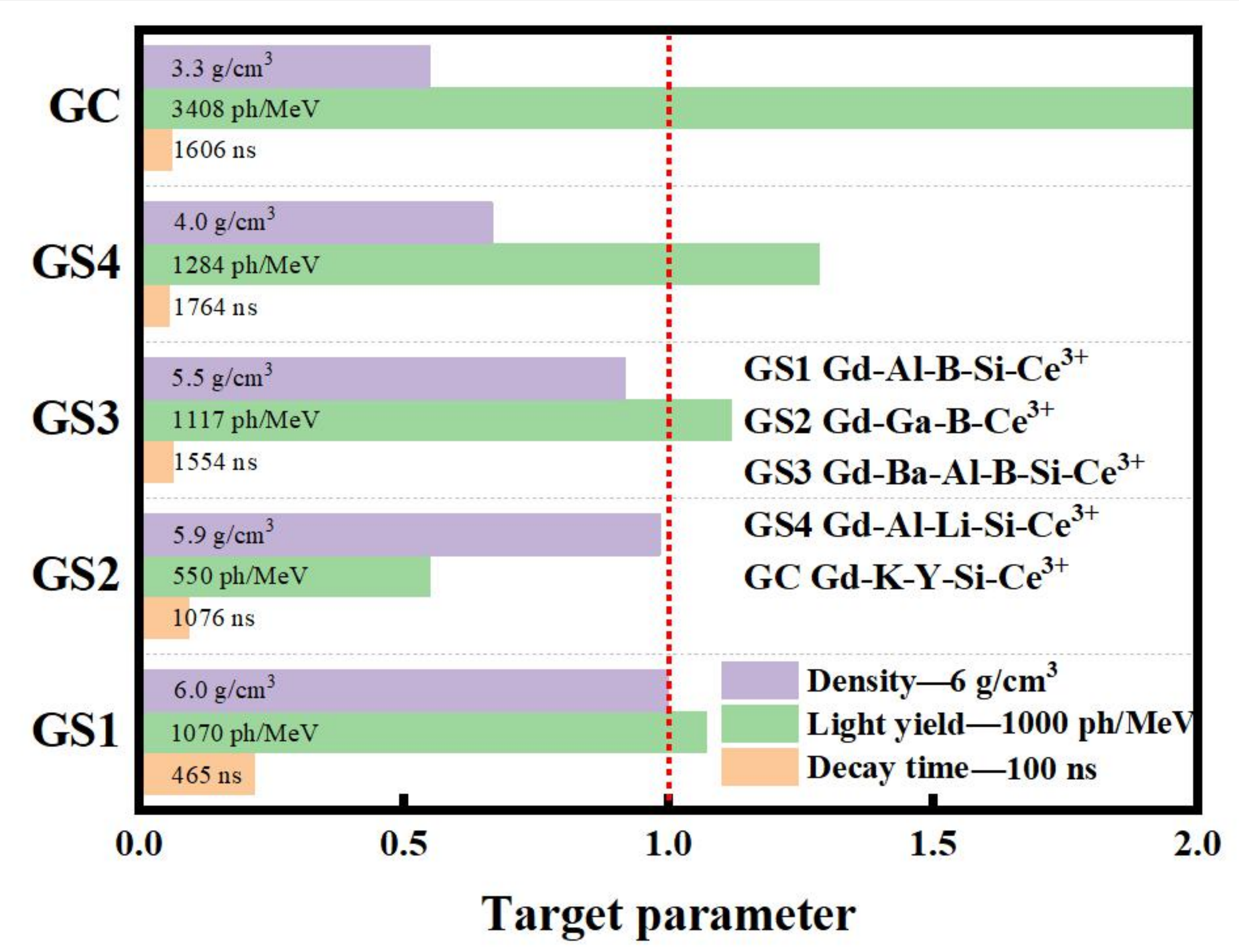
2023.04

2023.05

Outline

- 1. The status of the GS group;
- 2. The Simulation for GS Detector
- 3. The Test Facilities for GS Test;
- 4. The Progress of the GS Production;
- 5. Summary and Next Plan;

5.1 Summary



Glass scintillator of good energy resolution, fast decay, high density and light yield

- **6.0 g/cm³ & 1070 ph/MeV with 23.8% @662keV & 465 ns —Gd-Al-B-Si-Ce^{3+} glass**

  - Ultra-high density **Tellurite Glass**—6.6 g/cm³
  - High light yield **Glass Ceramic**—3400 ph/MeV
  - Fast scintillating Decay Time—100 ns
  - Large size Glass—42mm*51mm*10mm

5.2. Target of Glass Scintillator

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	5-7 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-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

5.3 The Scintillator data

Typy	Composition	Density (g/cm³)	Light yield (ph/MeV)	Decay time (ns)	Emission peak(nm)	Price/1 c.c (RMB)
Glass Scintillator in Paper	Ce-doped high Gadolinium glass[1]	4.37	3460	522	431	~10
	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	560	2400
	LYSO:Ce[5]	7.1	30000	40	420	1200
	BGO[6]	7.3	8000	300	480	800
Glass Scintillator for CEPC (preliminaryl target)	?	>7	>1000	< 100	350-500	~1
Stuaus of Glass Scintillator	?	>6	>1000	< 200	350-500	~?

[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. [6]Akapong Phunpueok, et al. Applied Mechanics and Materials, 2020,901:89-94.

See the unseen
change the unchanged

The Innovation

THANKS