The R&D of the New Glass Scintillator for HCAL of CEPC

闪烁玻璃合作组
Glass Scintillator Collaboration

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2023. Aug. 16th

Outline

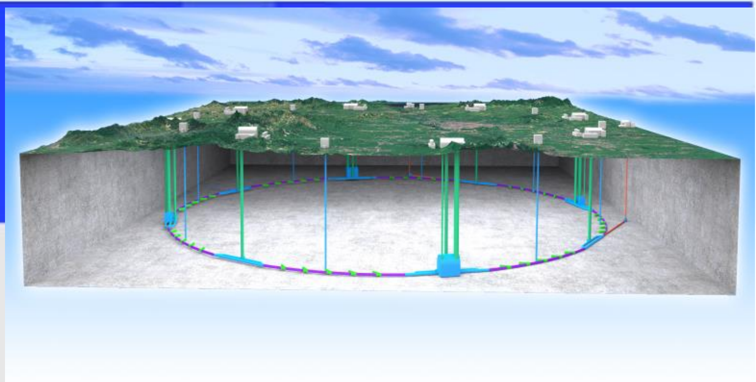
1. The Motivation and Design

2. Experiment of Scintillation Properties

3. Progress in glass preparation

4. Summary and Next Plan

1.1 The GS-HCAL of CEPC

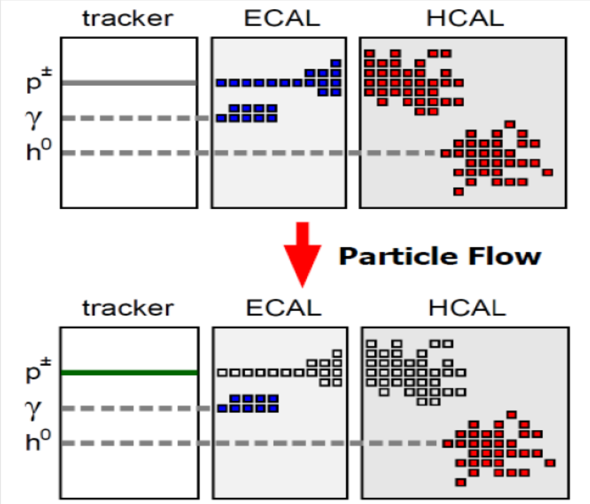


Future electron-position colliders (e.g. CEPC)

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

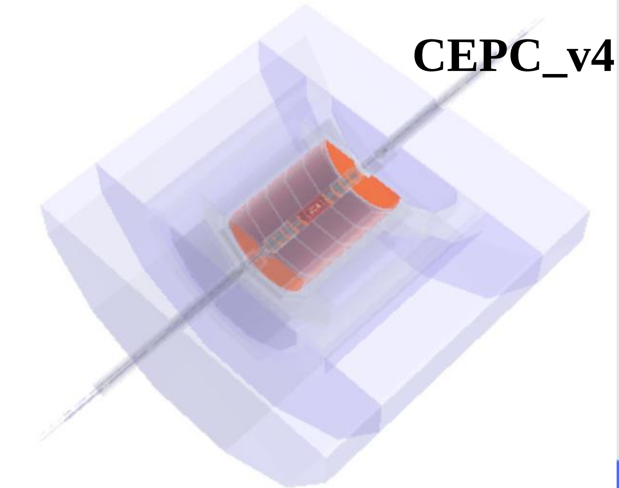
CEPC detector: highly granular calorimeter + tracker

- Boson Mass Resolution (BMR) ~4% has been realized in this baseline design
- Further performance goal: BMR 4%→3%
- Dominant factors in BMR: charged hadron fragments & HCAL resolution



New Option: Glass Scintillator HCAL (GS-HCAL)

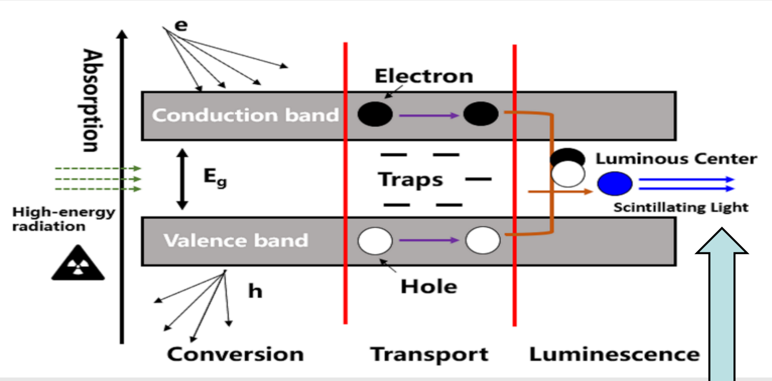
- Higher density provides higher energy sampling fraction
- Doping with neutron-sensitive elements: improve hadronic response (Gd)
- More compact HCAL layout (given 4~5 nuclear interaction lengths in depth)



1.2 Target of Glass Scintillator

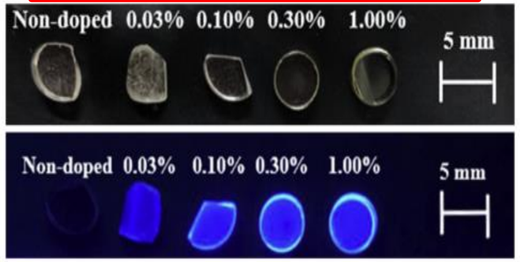
Key parameters	Value	Remarks
➢ Tile size	~30×30 mm^2	Reference CALICE-AHCAL, granularity, number of channels
➢ Tile thickness	~10 mm	Energy resolution, Uniformity and MIP response
➢ **Density**	**5-7 g/cm^3**	More compact HCAL structure with higher density
➢ **Intrinsic light yield**	**1000-2000 ph/MeV**	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

1.3 The Design of the Glass Scintillator



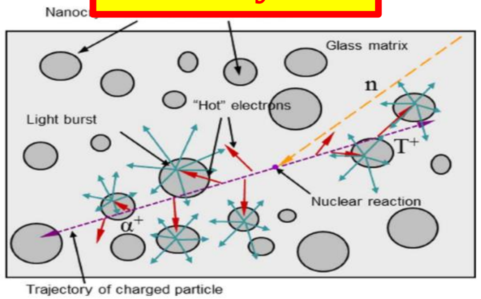
- **Scintillation mechanism----** **Luminescence Center**
- **Conversion**—photoelectric effect and Compton scattering effect;
- **Transport**—electrons and holes migrate;
- **Luminescence**—captured by the luminescent center ions

Lanthanide elements



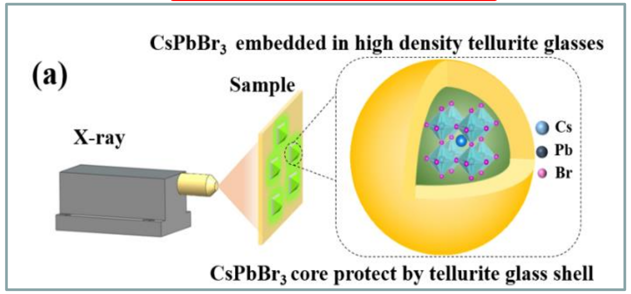
Journal of Alloys and Compounds 782 (2019) 859-864

Nanocrystals



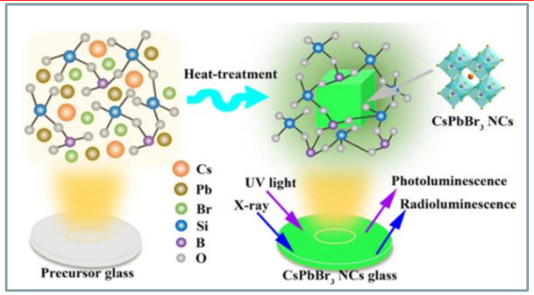
IEEE TNS 60 (2) 2013

Quantum Dots



Optics Letters 46(14) 3448-3451 (2021)

Lanthanide + Quantum Dots



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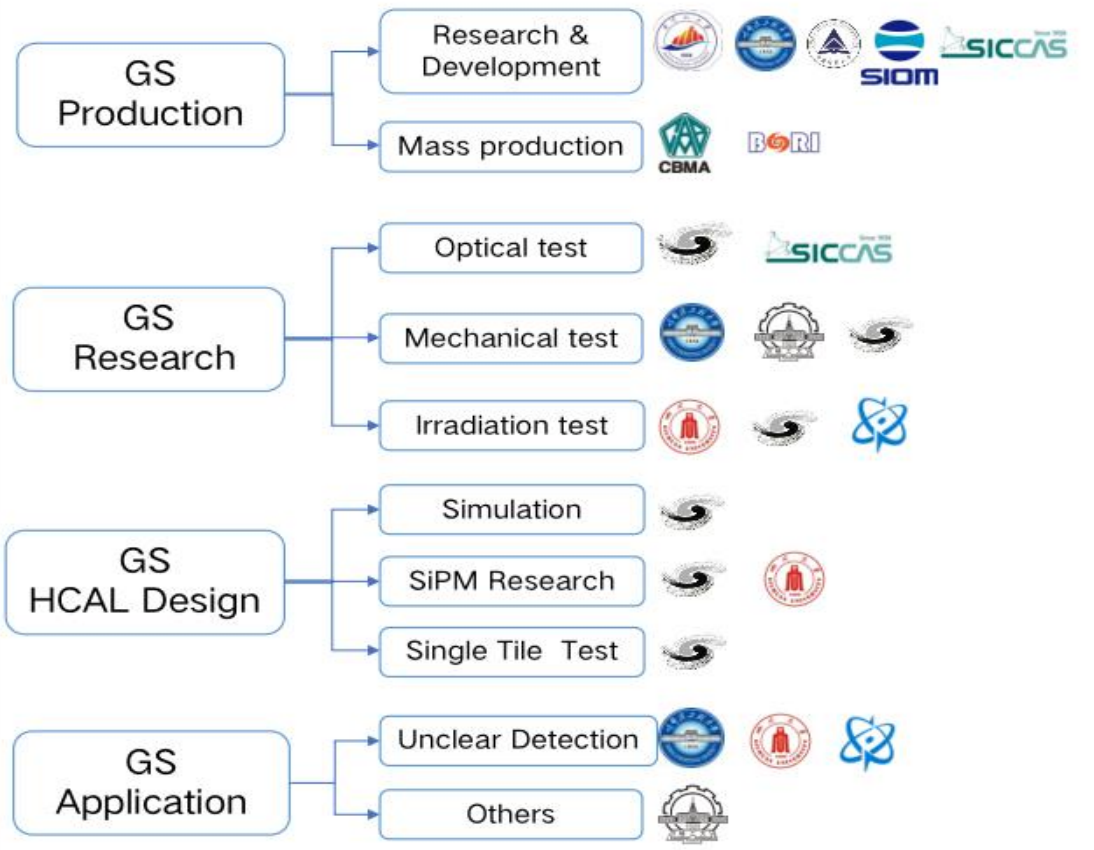
- **High Light Yield： Lanthanide for the Luminescence Center：Cerium（Ce）；**
- **High Density and Low radioactivity background：Gadolinium（Gd）；**

1.4 Large Area Glass Scintillator Collaboration



- 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

闪烁玻璃合作组
Glass Scintillator Collaboration

-- The Glass Scintillator Collaboration Group established in Oct.2021, only 5 groups join together;

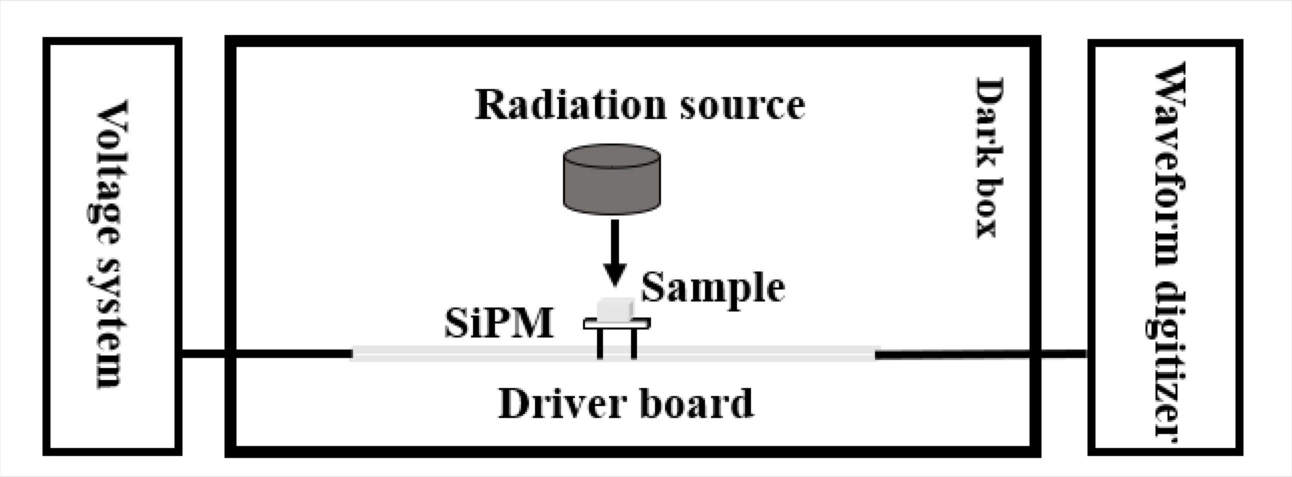
-- There are 3 Institutes of CAS, 5 Universitys, 3 Factorys join us for the R&D of GS;

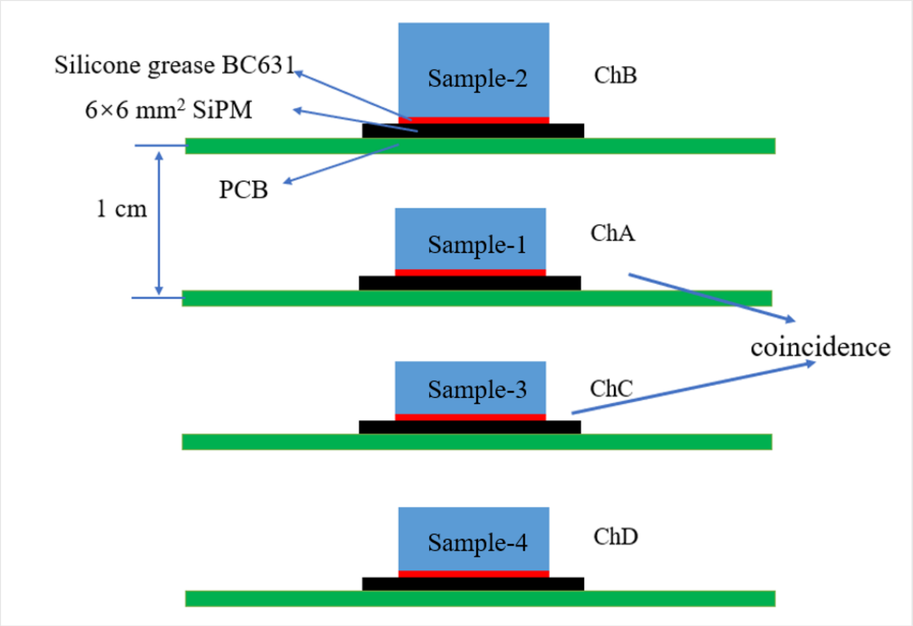
-- The Experts of the GS in the University, Institute and Industry are still welcomed to join us **(qians@ihep.ac.cn)**.

Outline

2.1 Test facility of Energy spectrum

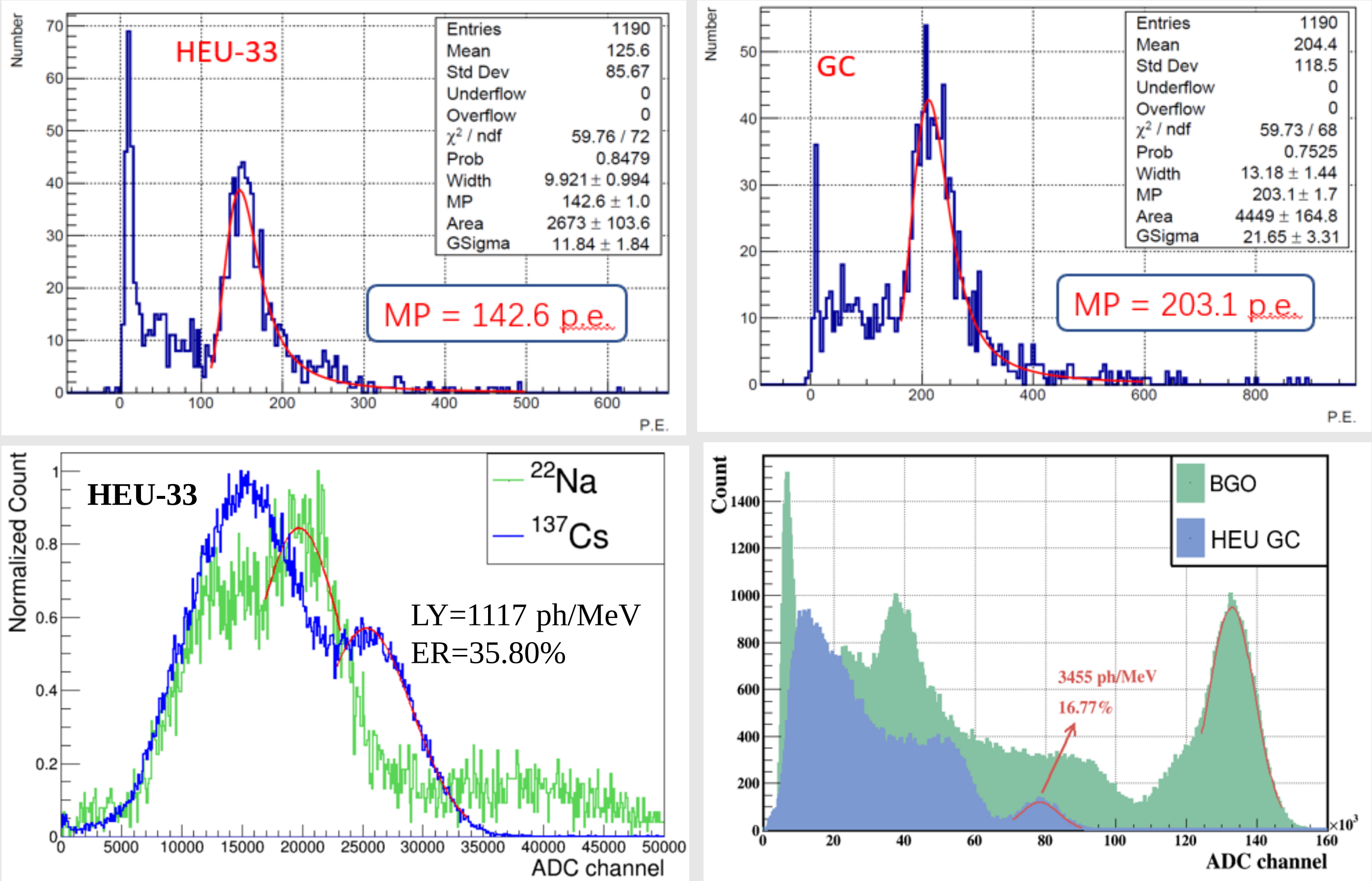
With Du Dejing





- **Absolute light yield (LY):** $LY = \frac{Mean_{energy} * 1000\text{keV}}{Mean_{s} * PDE_{w} * Energy}$
- **Energy resolution (ER):** $\varepsilon = \frac{\Delta p}{p} = \frac{\Delta E}{E}$
- **Scintillation decay time :** $I = I_0 + I_i * \exp\left(-\frac{t}{\tau_i}\right), i = 1, 2, 3 \ldots$
- **Minimum ionizing particle (MIP) response**—Cosmic ray experiment facility

2.2 MIP response & Light yield



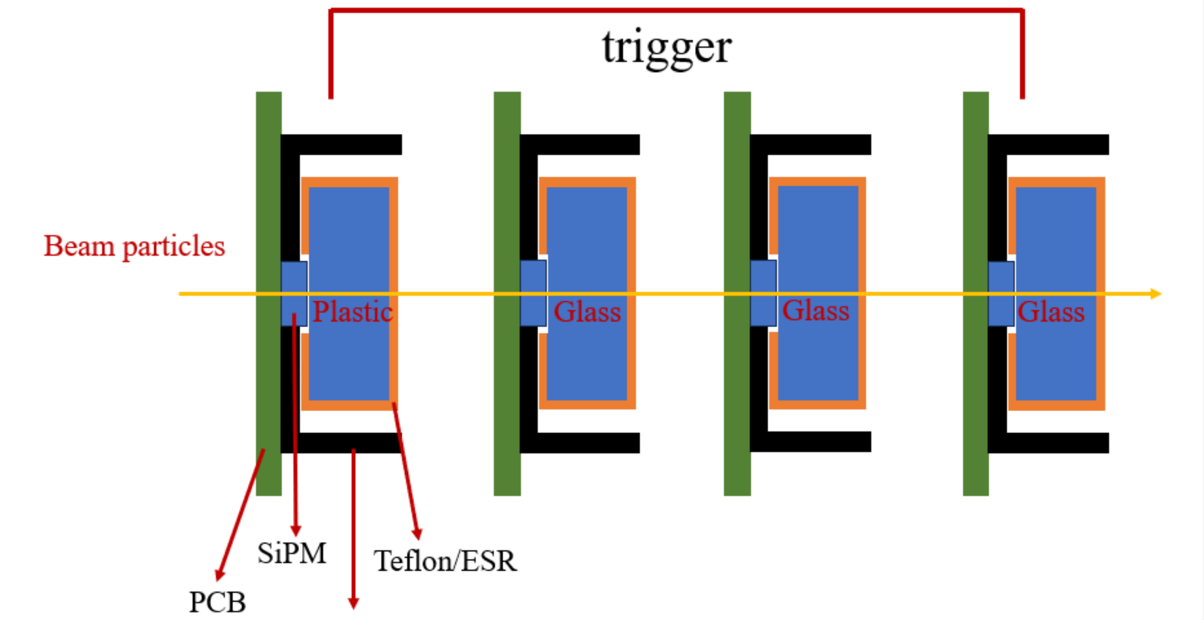
	#1	#3（GC）
MIP（p.e.）	**143**	**203**
LY（ph/MeV）	**1117**	**3408**
Thickness（mm）	**2.6**	**2**
Density（g/cm^3）	**5.4**	**3.3**
MIP/(Thi*Den)	**10.2**	**30.6**
LY/[MIP/(Thi*Den)]	**110**	**111**

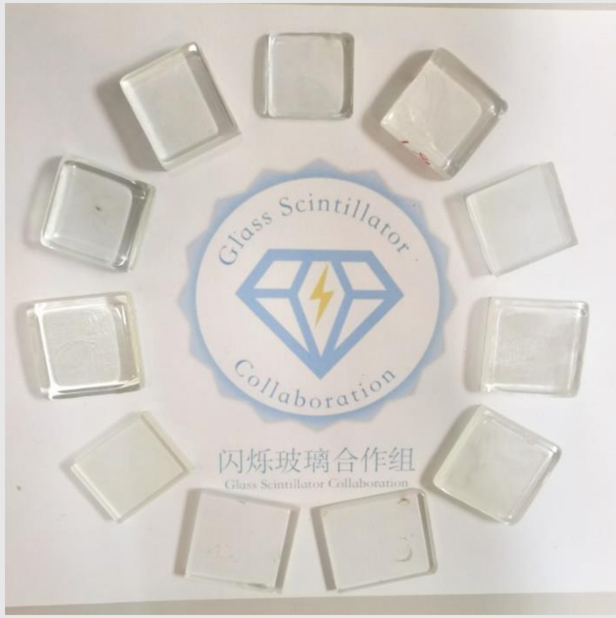
- Considering the density and thickness of the glasses, the MIP response of the cosmic rays is consistent with the light yield of the glass scintillator.

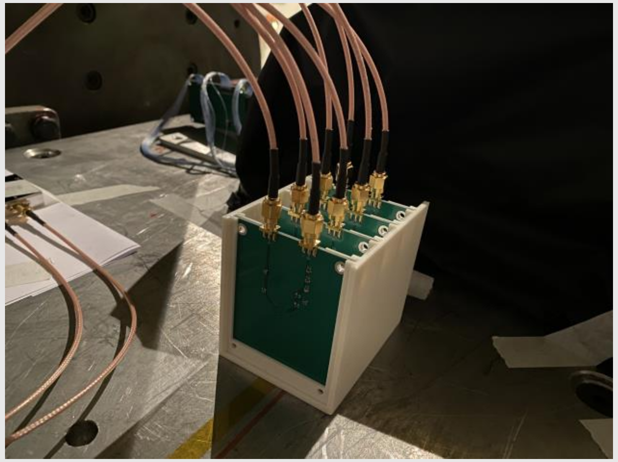
2.3 CERN beam experiment

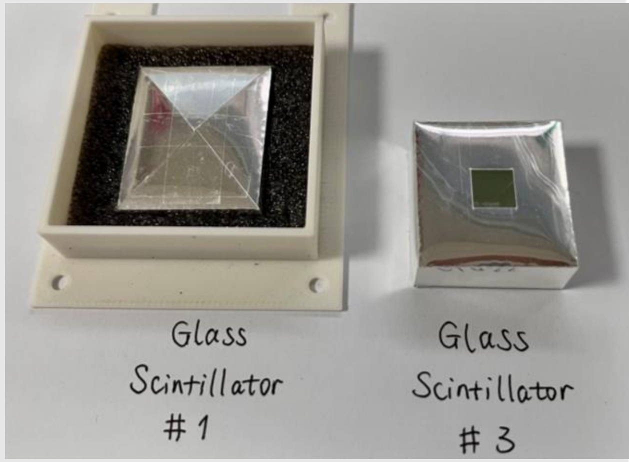
With Du Dejing

- 11 glass scintillator tiles successfully delivered from IHEP to CERN (May 16)
- Beam test facility: CERN Proton Synchrotron (primary 24GeV protons)
- Major motivation: to measure the MIP response of each glass tile



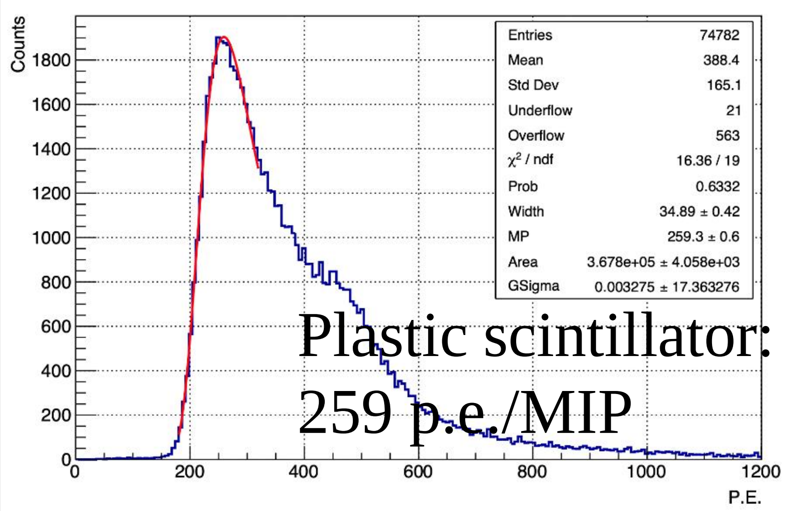


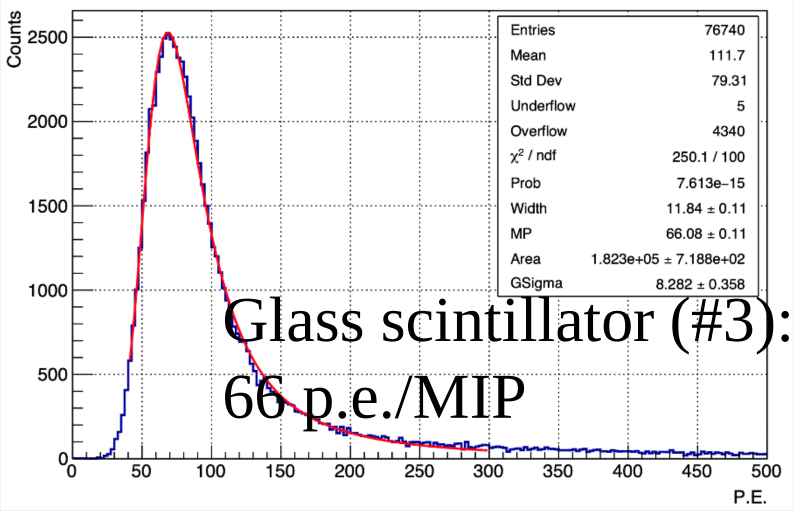


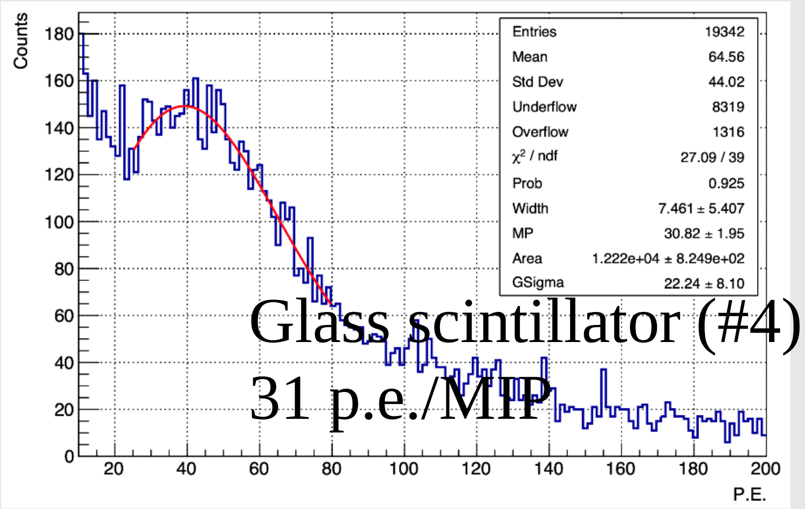


2.3 CERN beam experiment

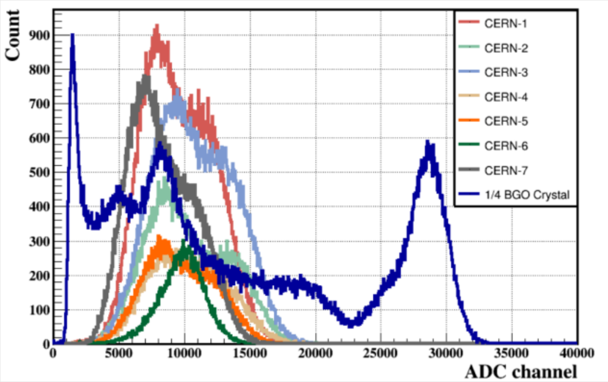
With Du Dejing







	Size (mm³)	Light yield (ph/MeV)	MIP_LY (p.e./MIP)	MIP/(Thi*Den)	LY/[MIP/(Thi*Den)]
#3	29.9×28.1×10.2	617	66	1.27	486
#4	37.2×35.1×5.3	571	31	1.15	497



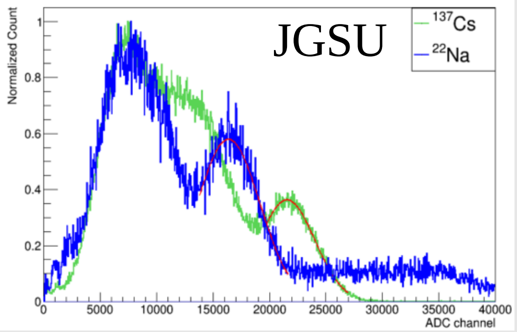
- Normalized through density and thickness, the MIP response of some glasses is consistent with the light yield.
- All results need to be further analysis according to the waveform of the glasses.

Outline

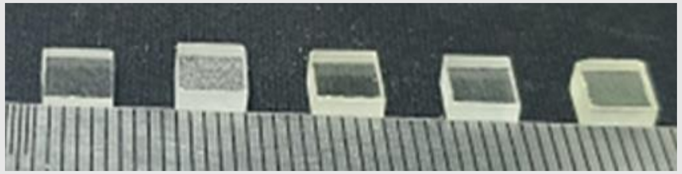
3.1 The glass samples （>400）

3.2 Gd-Al-B-Si-Ce^{3+} glass

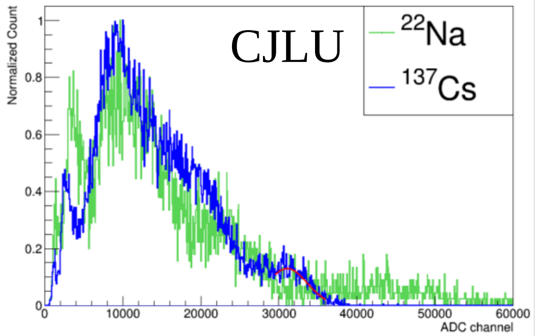
- Density~4.5 g/cm^3
- LY=802 ph/MeV
- ER=26.8%
- Decay=262 ns (18%), 1235 ns



2021.11



- Density~4.0 g/cm^3
- LY>1200 ph/MeV
- ER=23.2%
- Decay=231 ns (10%), 1897 ns



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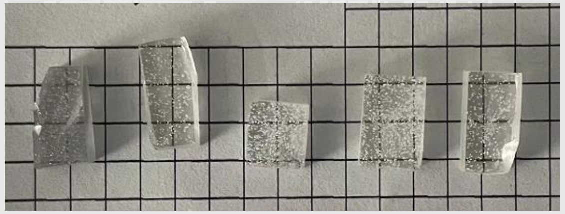
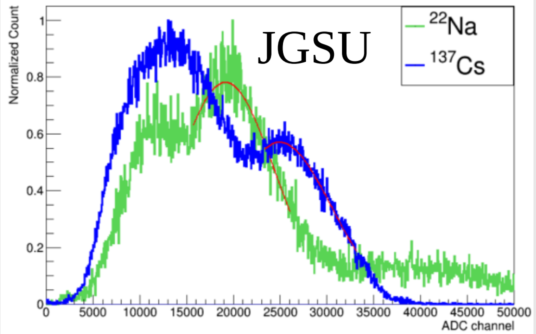
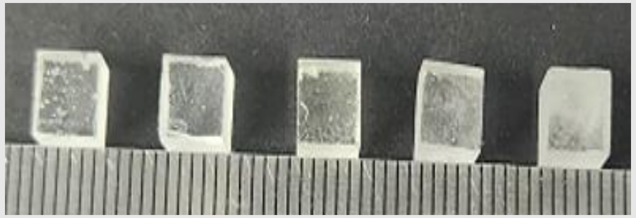


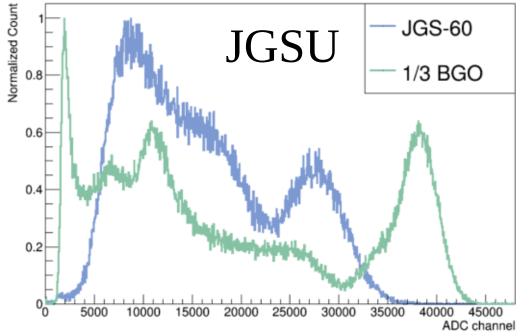
- Density~6.0 g/cm^3
- LY>1000 ph/MeV
- ER=49.6%
- Decay=847 ns



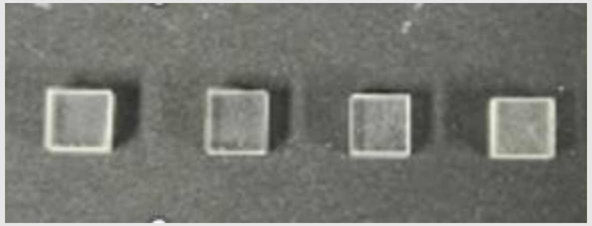
2022.11



- **Density~6.0 g/cm^3**
- **LY~1100 ph/MeV**
- **ER=24.4%**
- **Decay=460 ns**



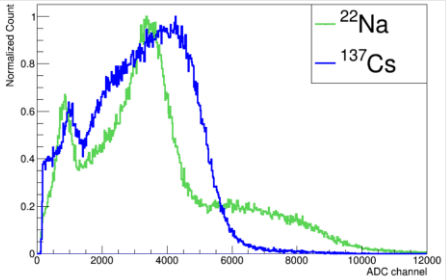
2023.02



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

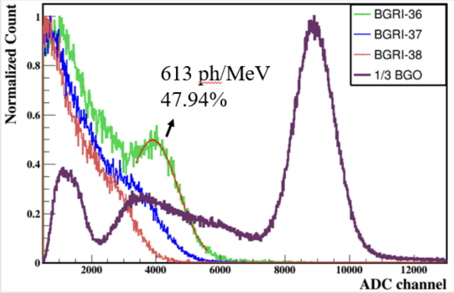
3.3 Large size glass (Gd-Ba-Al-B-Si-Ce^{3+})

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

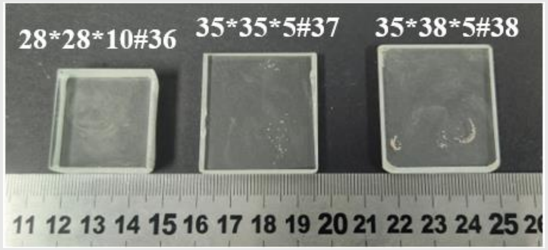


2022.10

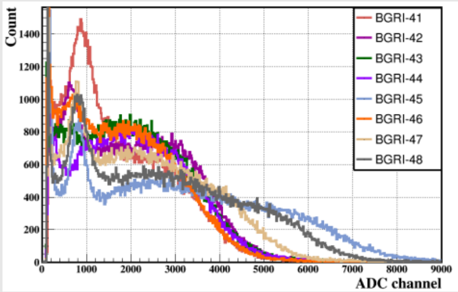
- Size=28*28*10 mm^3
- Density=5.2 g/cm^3
- LY=613 ph/MeV
- ER=47.9%



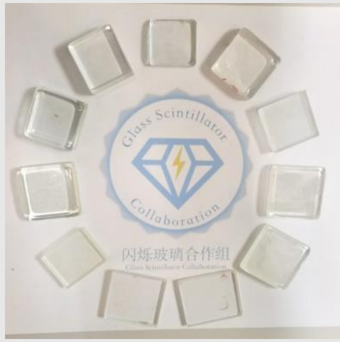
2023.01



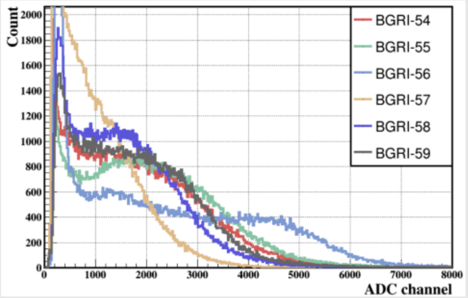
- Size=30*30*9 mm^3
- Density=5.1 g/cm^3
- LY=767 ph/MeV
- ER=None



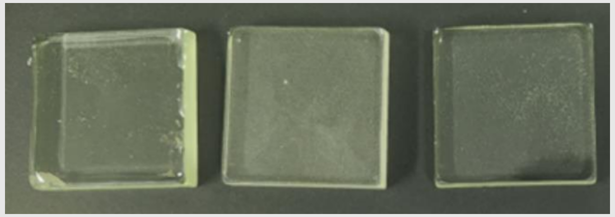
2023.04



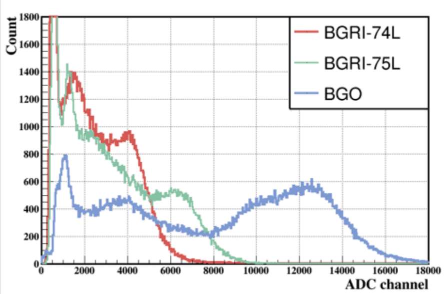
- Size=50*50*10 mm^3
- Density=5.8 g/cm^3
- LY=172 ph/MeV
- ER=None



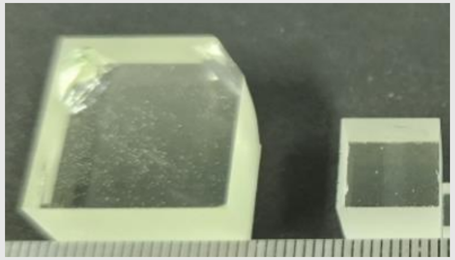
2023.05



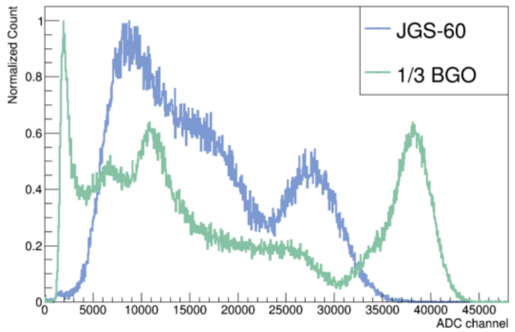
- Size=20*20*10 mm^3
- Density=5.8 g/cm^3
- LY=506 ph/MeV
- ER=50%



2023.08



3.4 Bottleneck of glass scintillator



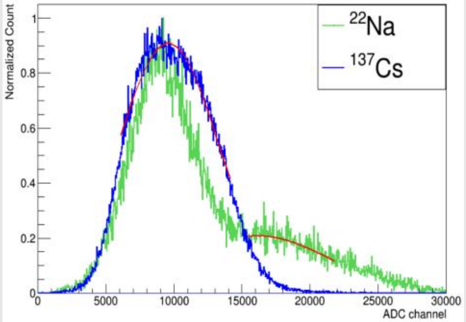
- Density~6.0 g/cm^3
- LY~1100 ph/MeV

to be faster: Decay time

- Optimize preparation process
- Optimize glass composition

to be more: The Uniformity ?

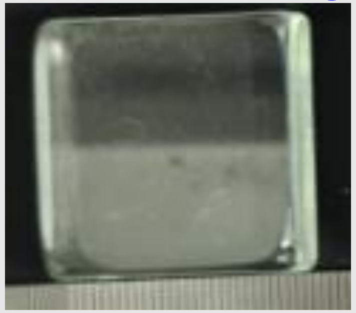
➢ **Sample Array in Factory**

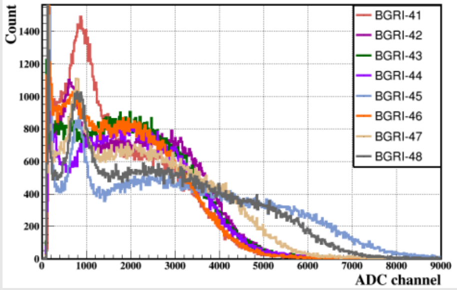


LY=**346** ph/MeV

to be Large: The Repeatability ?

➢ **Large Sample in Factory**

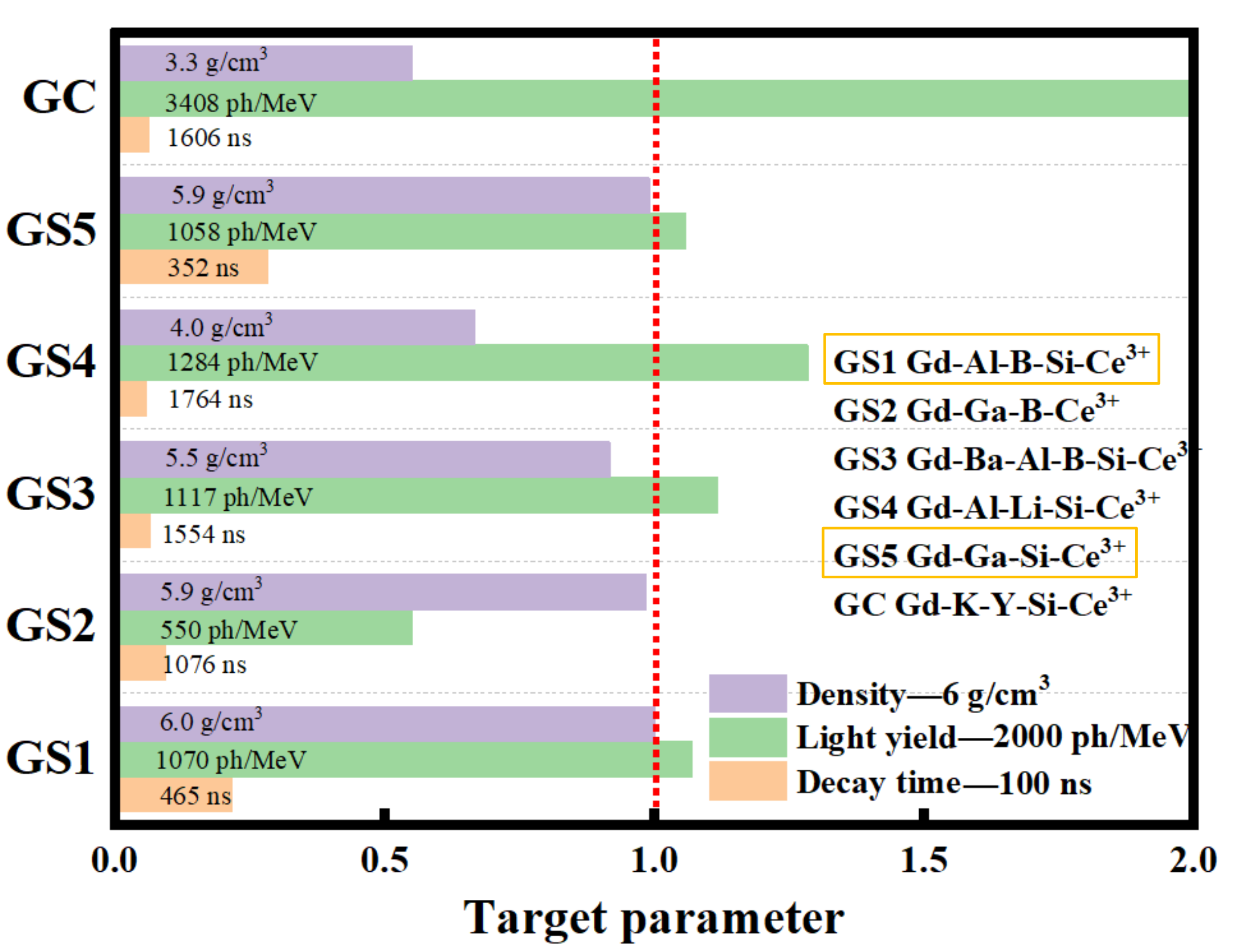




LY=**767** ph/MeV

Outline

4.1 Summary



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

- **6.0 g/cm^3 & >1000 ph/MeV with ~24%@662keV & <500 ns —Gd-Al-B-Si-Ce^{3+} & Gd-Ga-Si-Ce^{3+} glasses**

- Ultra-high density **Tellurite Glass**—6.6 g/cm^3
- High light yield **Glass Ceramic**—3400 ph/MeV
- Pr^{3+}-doped glass for fast decay—100 ns
- Large size glass—50mm*50mm*10mm

4.2 Research status of scintillator

Typy	Composition	Density (g/cm^3)	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.

4.3 Conclusion and plan

- **The results of MIP response by beam experiment, cosmic ray experiment and light yield by radioactive source experiment are unified.**

- **Gd-R-(B)-Si -Ce^{3+} (R=Al, Ba, Ga) glass will be the focus of future research.** The R&D of large-size glass tiles featuring **high density, high light yield and fast decay time** is the main focus of next stage for the Glass Scintillator R&D collaboration;

- More detailed studies like **SiPM performances**, coupling designs with the glass cell and the photon collection efficiency will be done to give advice for glass tile design;

Glass Scintillator Collaboration
闪烁玻璃合作组
Glass Scintillator Collaboration

See the unseen
change the unchanged

The Innovation

THANKS