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Research Progress of The Glass Scintillator of HCAL

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On behalf of the Glass Scintillators R&D Group

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Outline

1. Motivation and target
2. Simulation of HCAL
3. Research and preparation progress
4. Summary and plan

1.1 Motivation

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

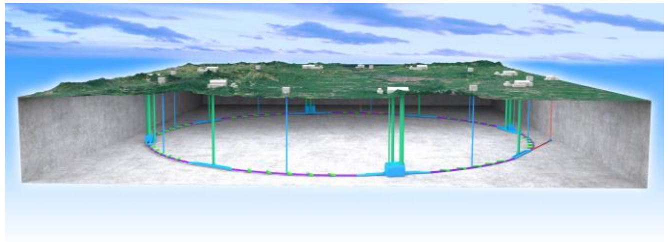
- Main physical goal: precision measurements of the Higgs and Z/W bosons
- Challenge: unprecedented jet energy resolution $\sim 30\%/\sqrt{E(GeV)}$

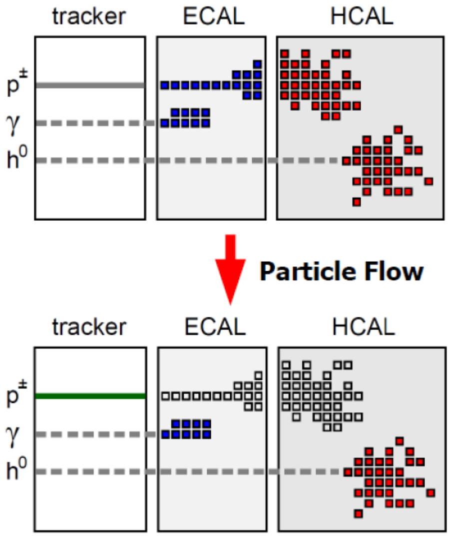
CEPC detector: crystal ECAL + glass scintillator HCAL

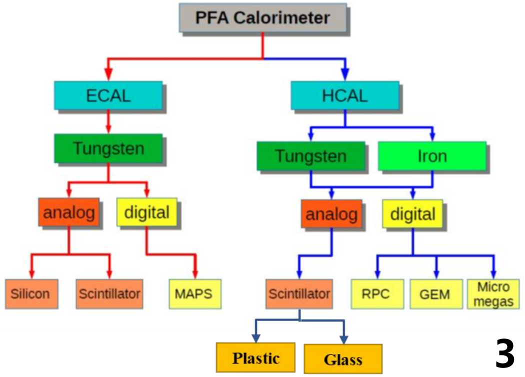
- A leap in terms of sampling fractions
- Aim to improve the energy resolution: esp. the hadronic resolution
- Physics performance goal: Boson Mass Resolution(BMR) 4%→3%

Next generation HCAL: Glass Scintillators

- 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)







1.2 Target

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	**6-7 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 type, 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

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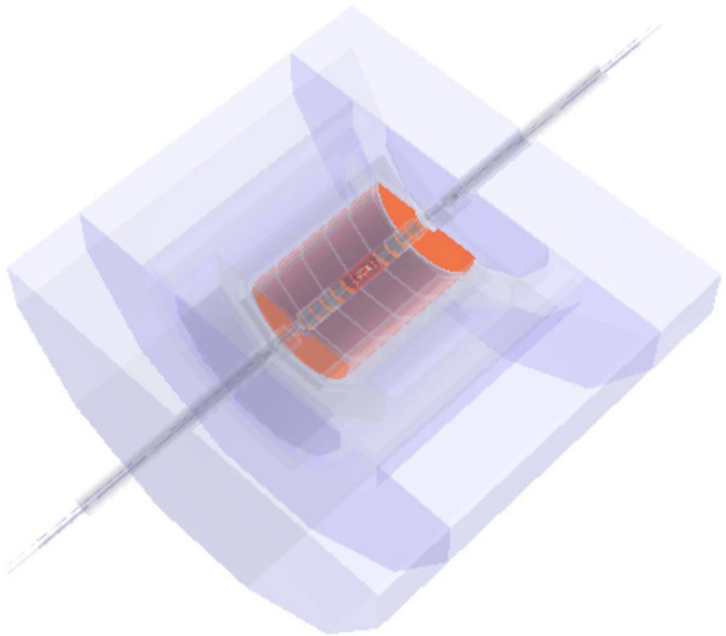
2.1 Simulation of glass of different density

□ Setup

- A specific HCAL based on glass scintillator was implemented in the CEPC_v4
- Primaries input: 240 GeV e+e- → ZH (Z → υυ, H → gg)
- Glass composition: GS1, GS2, GS4, GS6, GS9, GS10
- Cell size: 3x3x1 cm^3
- Lambda of each layer: 0.124 (3mm PS+ 2cm Steel)
- Total Layers: 40



theoretical value

	Composition	Density（g/cm³）
GS-Simu1	Gd-Al-Si-Ce^{3+}	5.10
GS-Simu2	Gd-B-Si-Ce^{3+}	5.35
GS-Simu3	Gd-B-Si-Ce^{3+}	5.49
GS-Simu4	Gd-B-Si-Ge-Ce^{3+}	5.51
GS-Simu5	Gd-Ga-Si-B-Ce^{3+}	5.64
GS-Simu6	Gd-Ge-B-Ce^{3+}	5.68
GS-Simu7	Gd-Ga-B-Ce^{3+}	5.77
GS-Simu8	Gd-Ga-Ba-B-Ce^{3+}	5.78
GS-Simu9	**Gd-Ga-Ba-B-Si-Ce^{3+}**	**5.81**
GS-Simu10	Gd-Ga-Ge-B-Si-Ce^{3+}	6.03

2.2 BMR Analysis with Marlin

◻ Setup

- Edep threshold in HCAL cell was set to 0.3 MIP
- Edep in each sampling layer of HCAL was based on sampling fraction ***f*** and calibration coefficient ***k*** (i.e. $Edep_{digi}=\boldsymbol{k}\times Edep_{raw}/\boldsymbol{f}$)
- BMR Cut： Pt_ISR<1 GeV && Pt_neutrino<1 GeV && |Cos(Theta_Jet)|<0.8

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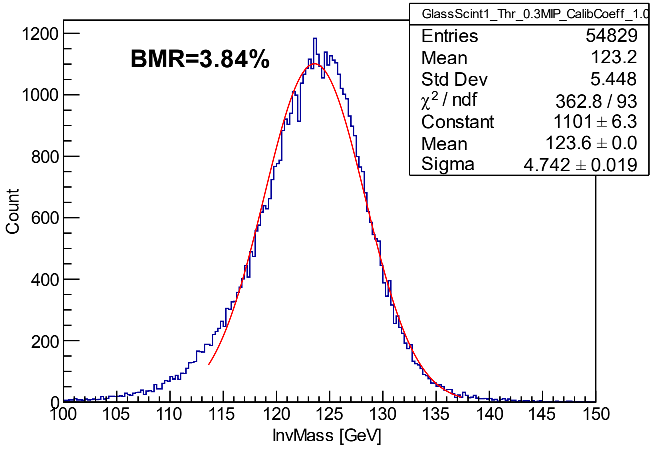
- Track digitization and reconstruction
- CaloHit digitization
- CaloHit clustering, cluster and track linking, PID

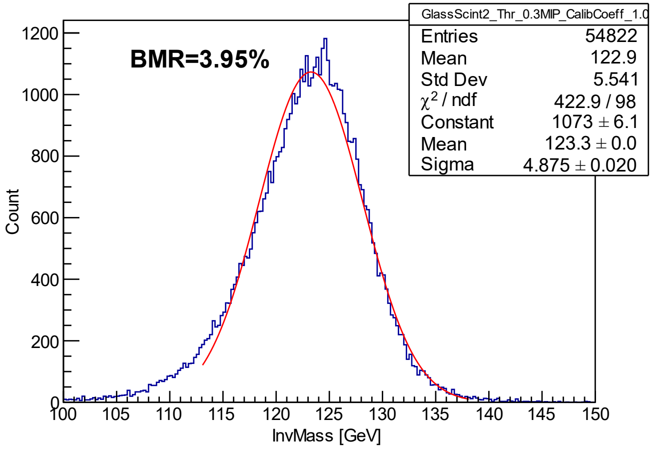
2.3 BMR vs. glass density

Preliminary

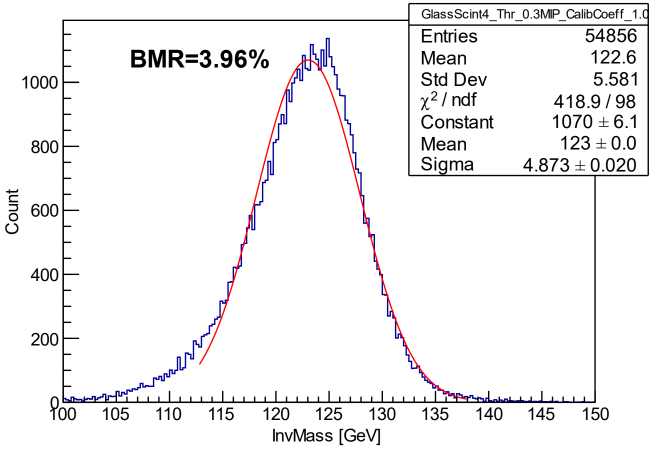
- Density: 5.10 g/cm^3



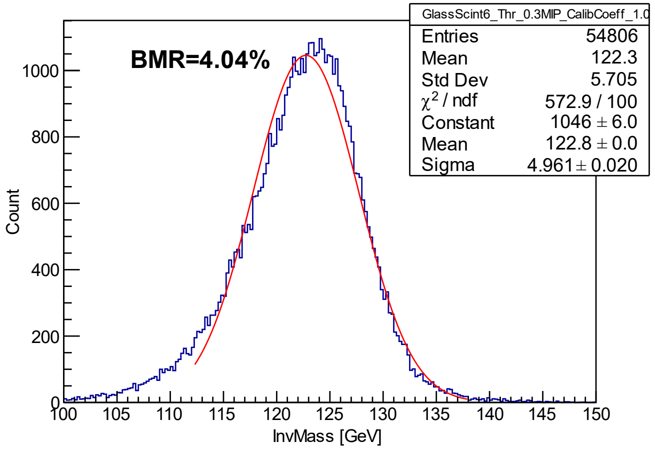
- Density: 5.35 g/cm^3



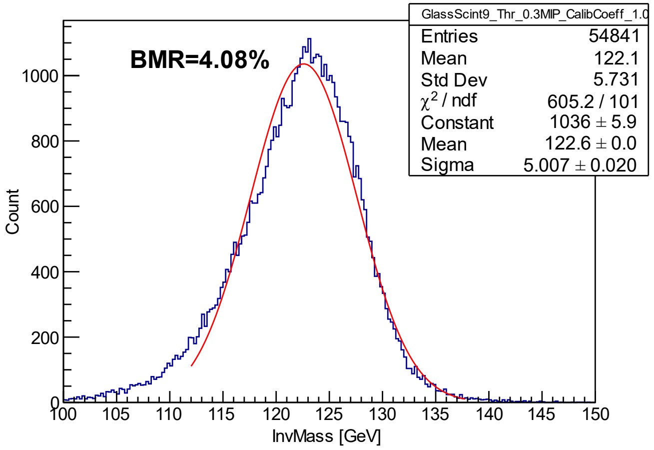
- Density: 5.51 g/cm^3



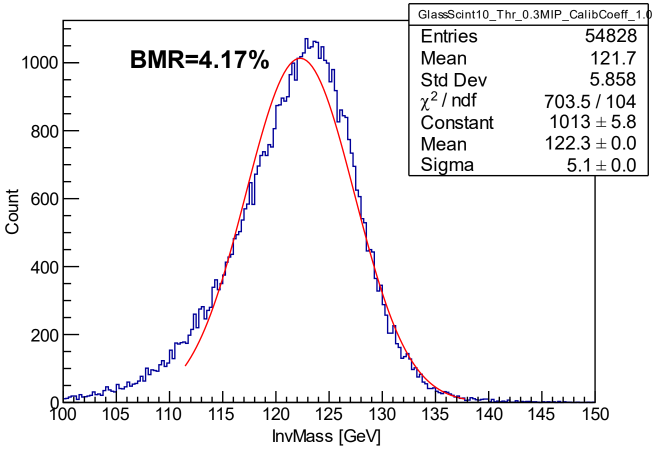
- Density: 5.68 g/cm^3



- Density: 5.81 g/cm^3



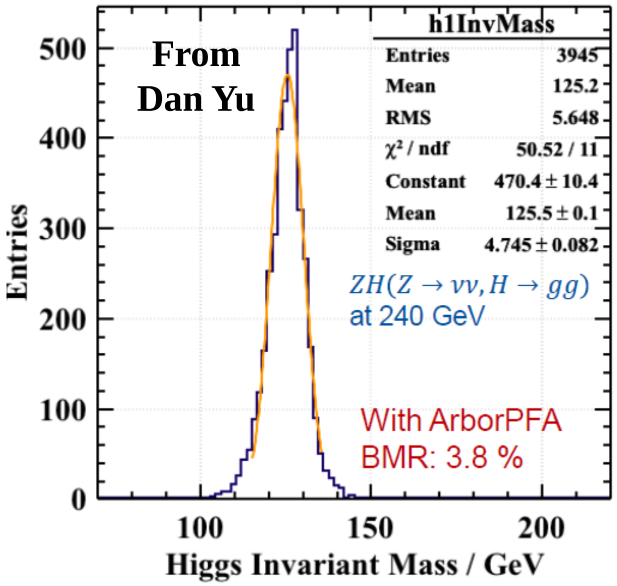
- Density: 6.03 g/cm^3



2.4 More optimization required in reconstruction

- Further work
  - Non-gaussian distribution and deviation from expected invariant mass should be checked
    - The calibration coefficient of HCAL needs to be optimized
    - The parameter used in Arbor PFA may need to be tuned in the case of glass scintillator HCAL
  - Understanding the contribution of glass scintillator to the Arbor PFA and BMR

PS+Steel AHCAL



Glass Scintillator AHCAL

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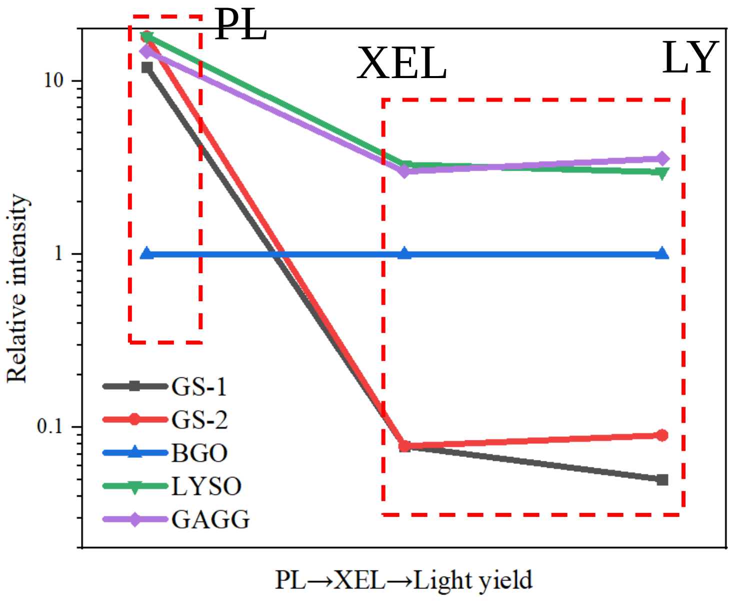
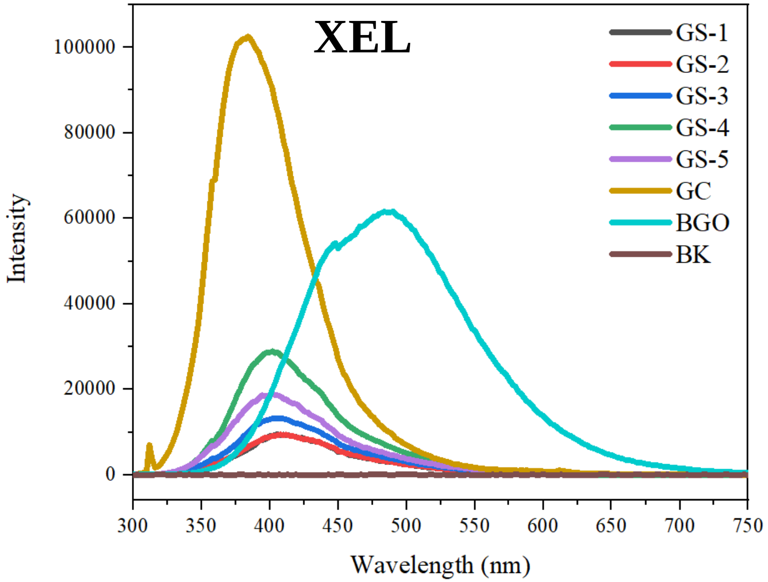
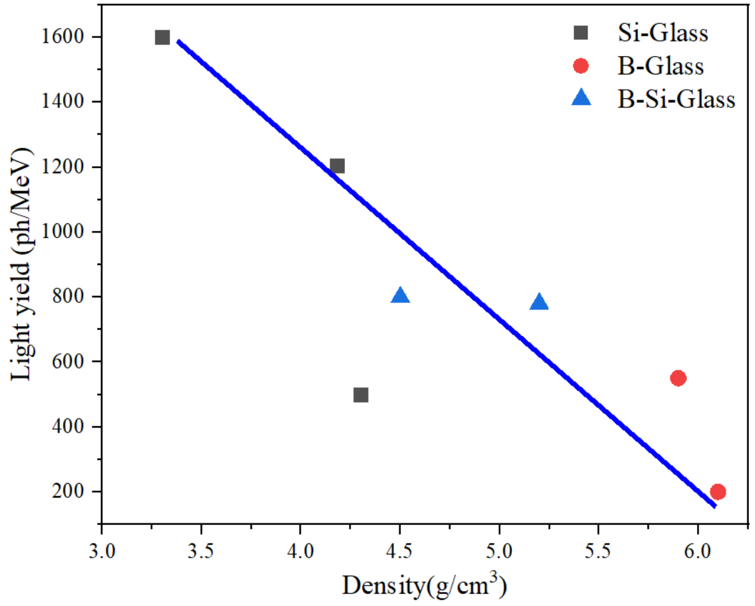
3.1 PL vs XEL vs LY



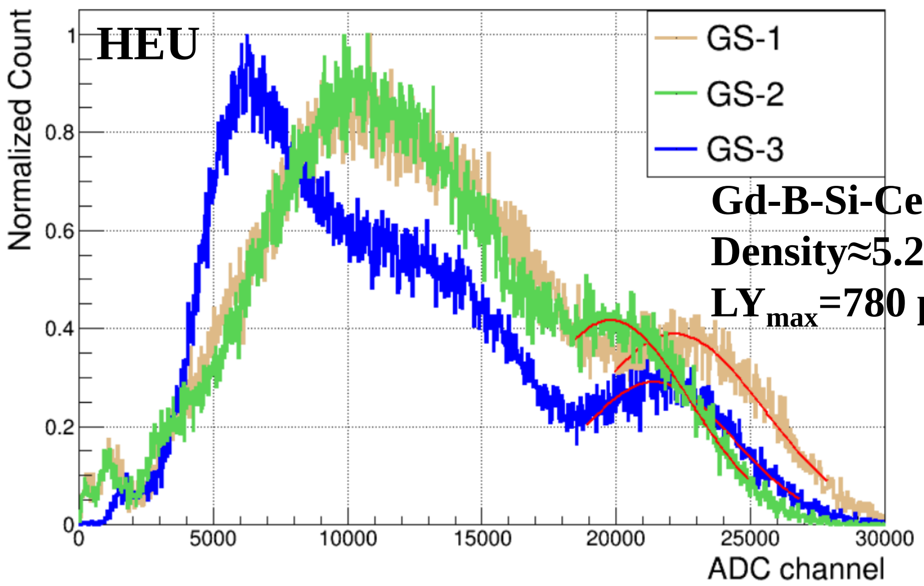




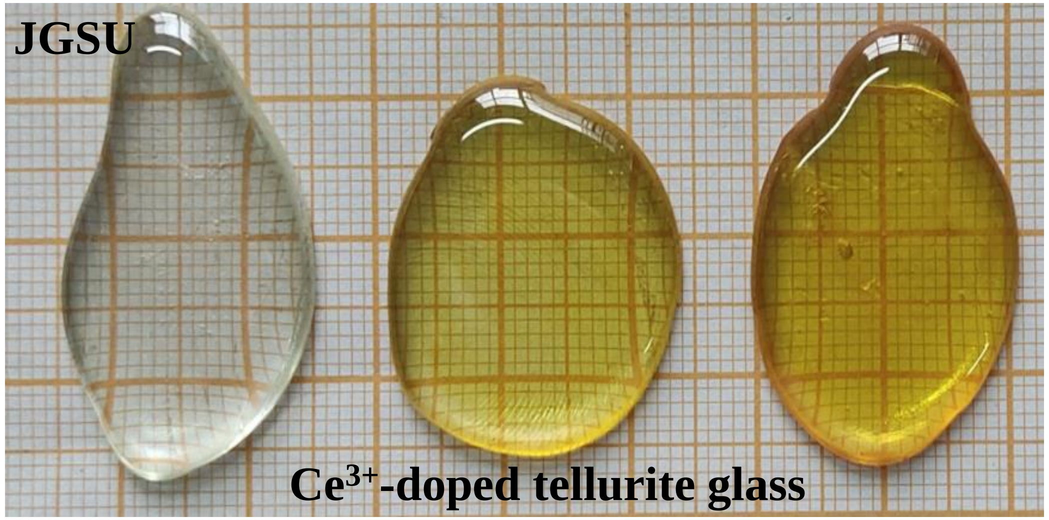
	Density (g/cm^3)	XEL	Light yield
GS-1	4.67	0.103	0.050
GS-2	4.50	0.105	0.091
GS-3	4.53	0.144	0.077
GS-4	4.20	0.289	0.091
GS-5	4.18	0.203	0.136
GC	3.30	0.949	0.181
BGO	7.13	1	1

- Photoluminescence is not related to its scintillation properties；
- X-rays and gamma rays interact with scintillation materials in different processes;
- When the composition of glass scintillator is similar, the lower the glass density, the higher the light yield;

3.2 Research progress

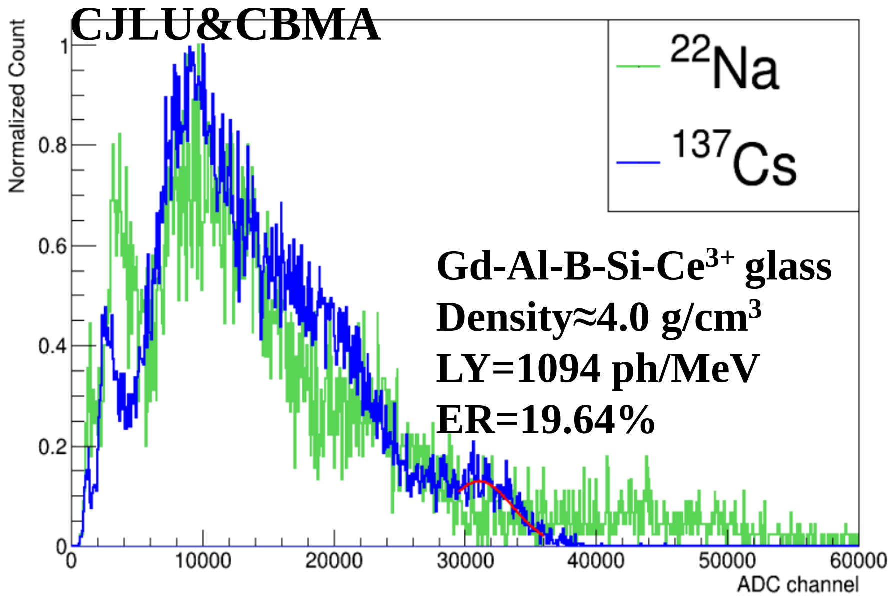


Gd-B-Si-Ce^{3+} glasses
Density≈5.2 g/cm^3
LY_{max}=780 ph/MeV

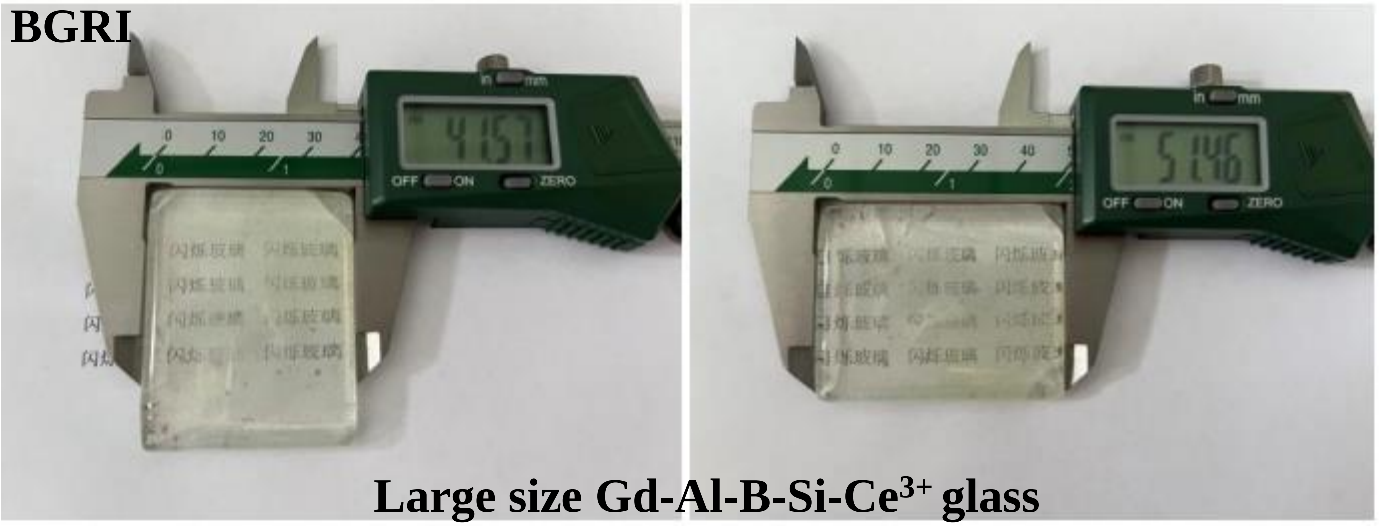


Ce^{3+}-doped tellurite glass

Density≈6.5 g/cm^3

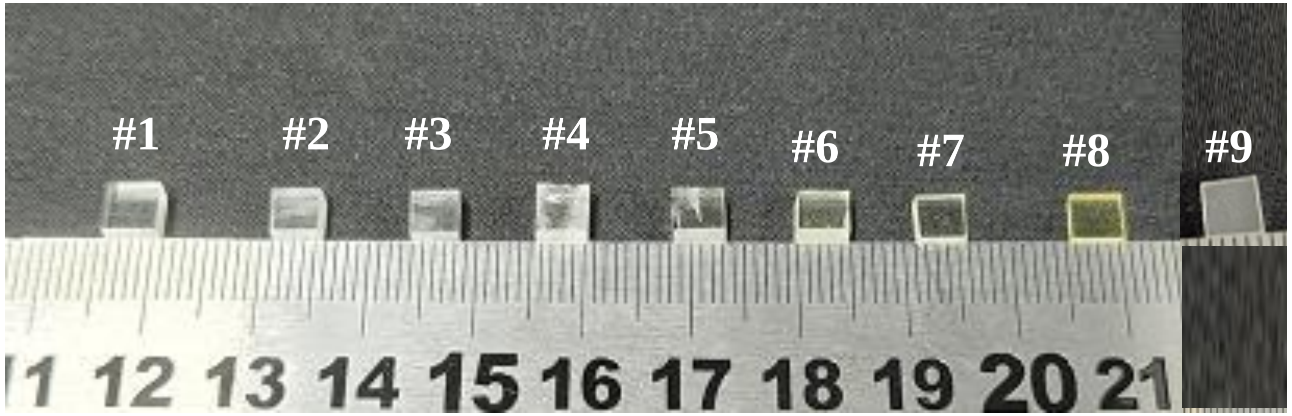


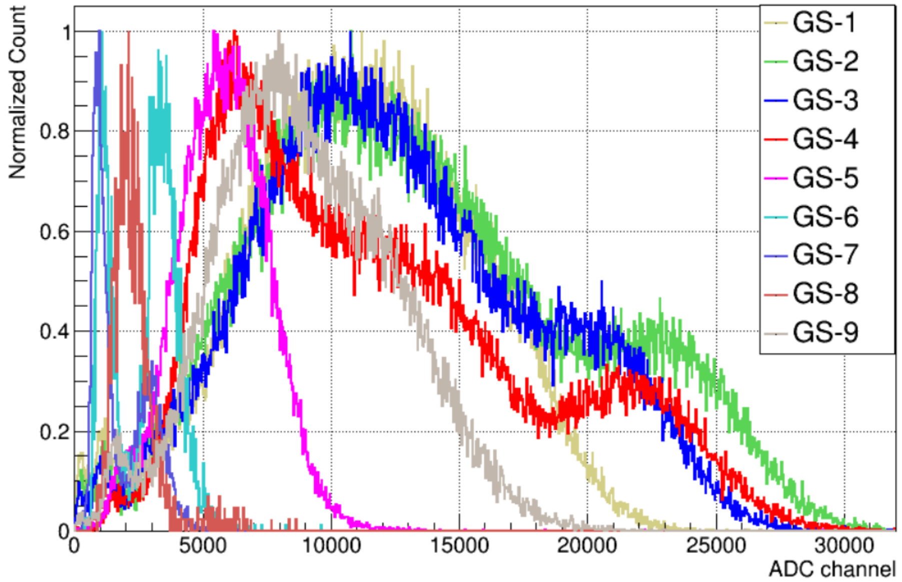
Gd-Al-B-Si-Ce^{3+} glass
Density≈4.0 g/cm^3
LY=1094 ph/MeV
ER=19.64%



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

3.3 Gd-B-Si-Ce^{3+} glass

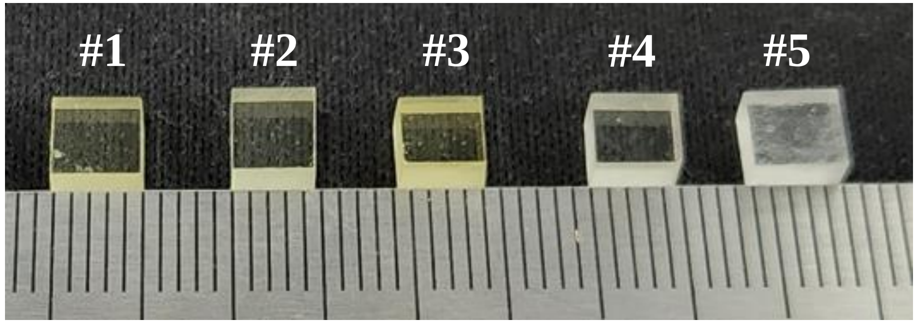




	Composition	Density（g/cm³）	Light yield（ph/MeV）	Energy Resolution （%）	Decay time（ns）
GS-Si-1#	Gd-B-Si-Ce^{3+}	4.963	568	35.59	/
GS-Si-2#	**Gd-B-Si-Ce^{3+}**	**5.161**	**782**	**33.19**	**256 (15%), 1641**
GS-Si-3#	**Gd-B-Si-Ce^{3+}**	**5.152**	**694**	**35.26**	**268 (16%), 2099**
GS-Si-4#	**Gd-B-Si-Ce^{3+}**	**5.161**	**756**	**31.42**	**294 (22%), 925**
GS-Si-5#	Gd-Ge-B-Si-Ce^{3+}	5.309	418	/	/
GS-Si-6#	Gd-Te-B-Si-Ce^{3+}	5.838	246	/	/
GS-Si-7#	Gd-Te-B-Si-Ce^{3+}	6.038	212	/	/
GS-Si-8#	Gd-Pb-B-Si-Ce^{3+}	6.111	151	/	/
GS-Si-9#	Gd-B-Si-Ce^{3+}	5.299	375	67.10	/

- **The density of Gd-B-Si-Ce^{3+} glass is about 5.0-6.1 g/cm³, maximum light yield is 782 ph/MeV.**

3.4 Gd-Ga-B-Ce^{3+} glass

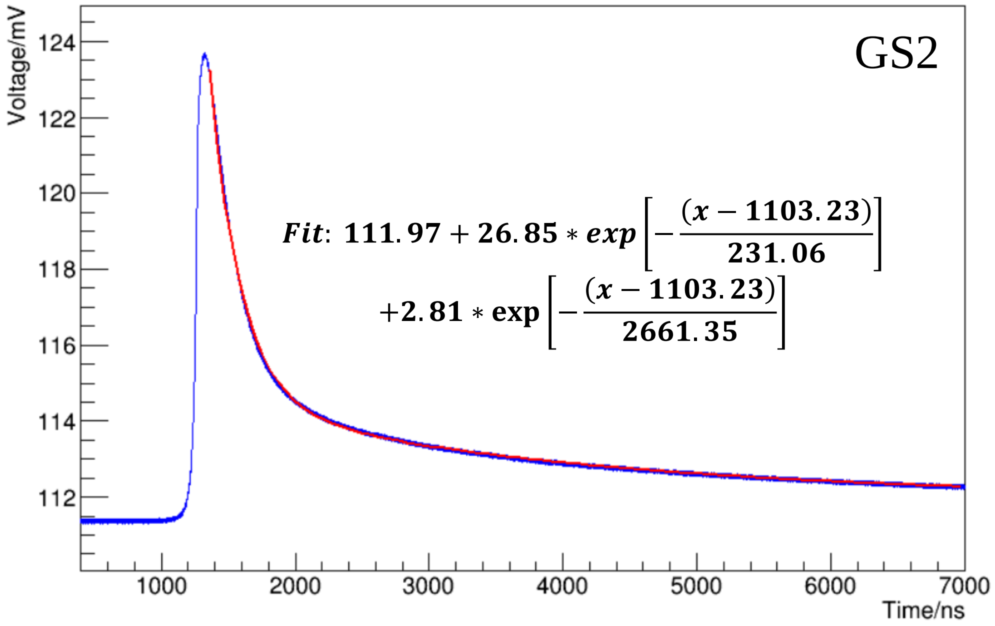


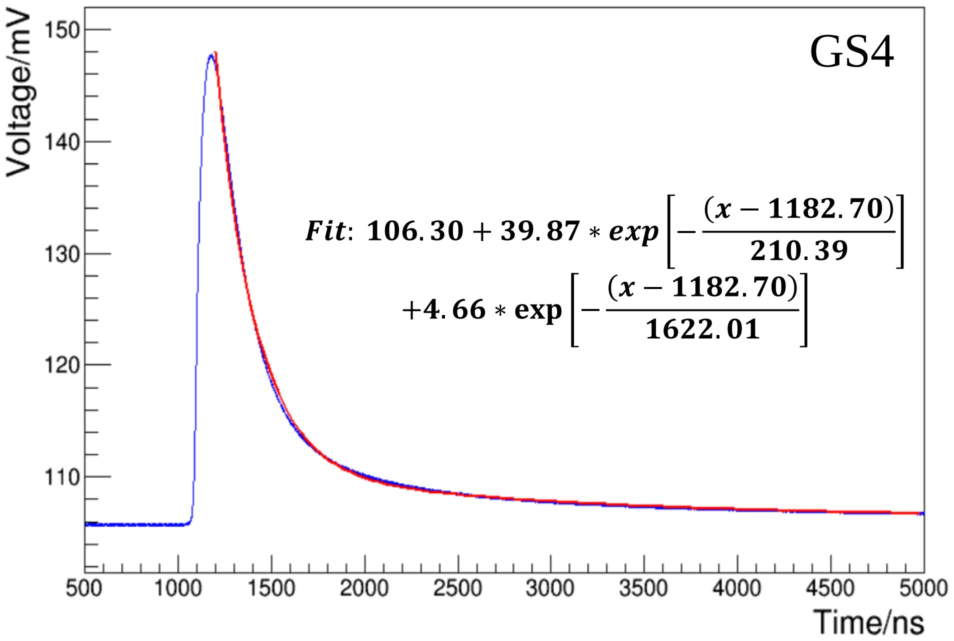
	Composition	Density（g/cm³）	Light yield（ph/MeV）	Decay time（ns）
GS-Ge-1#	Gd-Ge-B-Ce^{3+}	6.0	225	/
GS-Ge-2#	Gd-Y-Ge-B-Ce^{3+}	5.57	209	/
GS-Ge-3#	Gd-Mg-Ge-B-Ce^{3+}	6.1	110	/
GS-Ge-4#	Gd-Ge-B-Ce^{3+}	6.0	370	/
GS-Ga-5#	**Gd-Ga-B-Ce^{3+}**	**5.91**	**550**	148(24%), 1954

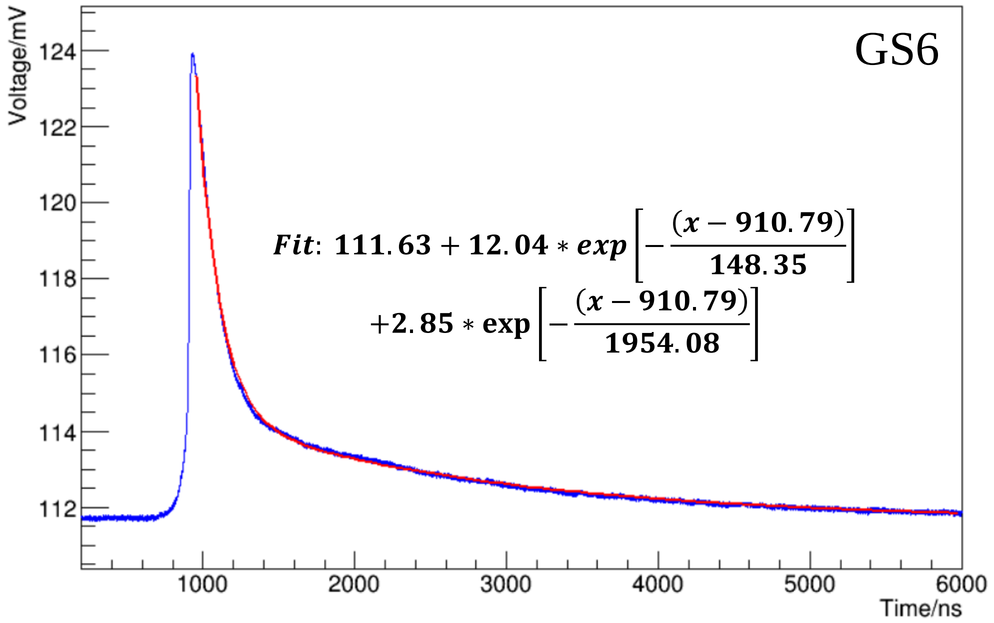
- The density of Gd-Ga-B-Ce^{3+} glass is about 5.6-6.1 g/cm^3, maximum light yield is 550 ph/MeV.
- It is the main research direction of high-density and high light yield glass scintillator:

1. **Add SiO_2 to the glass—Gd-Ga-B-Si-Ce^{3+} glass;**
2. **Efficient reduction of Ce^{3+} ions in high-density glass.**

3.5 Scintillation decay time







- The scintillating decay time of the glasses usually has two components and is longer than that of crystal. The decay time of glass scintillator can reach about 150 ns (24%).
- The fast component originate from trapping processes during the transport stage, and slow component originate from **re-trapping processes.**

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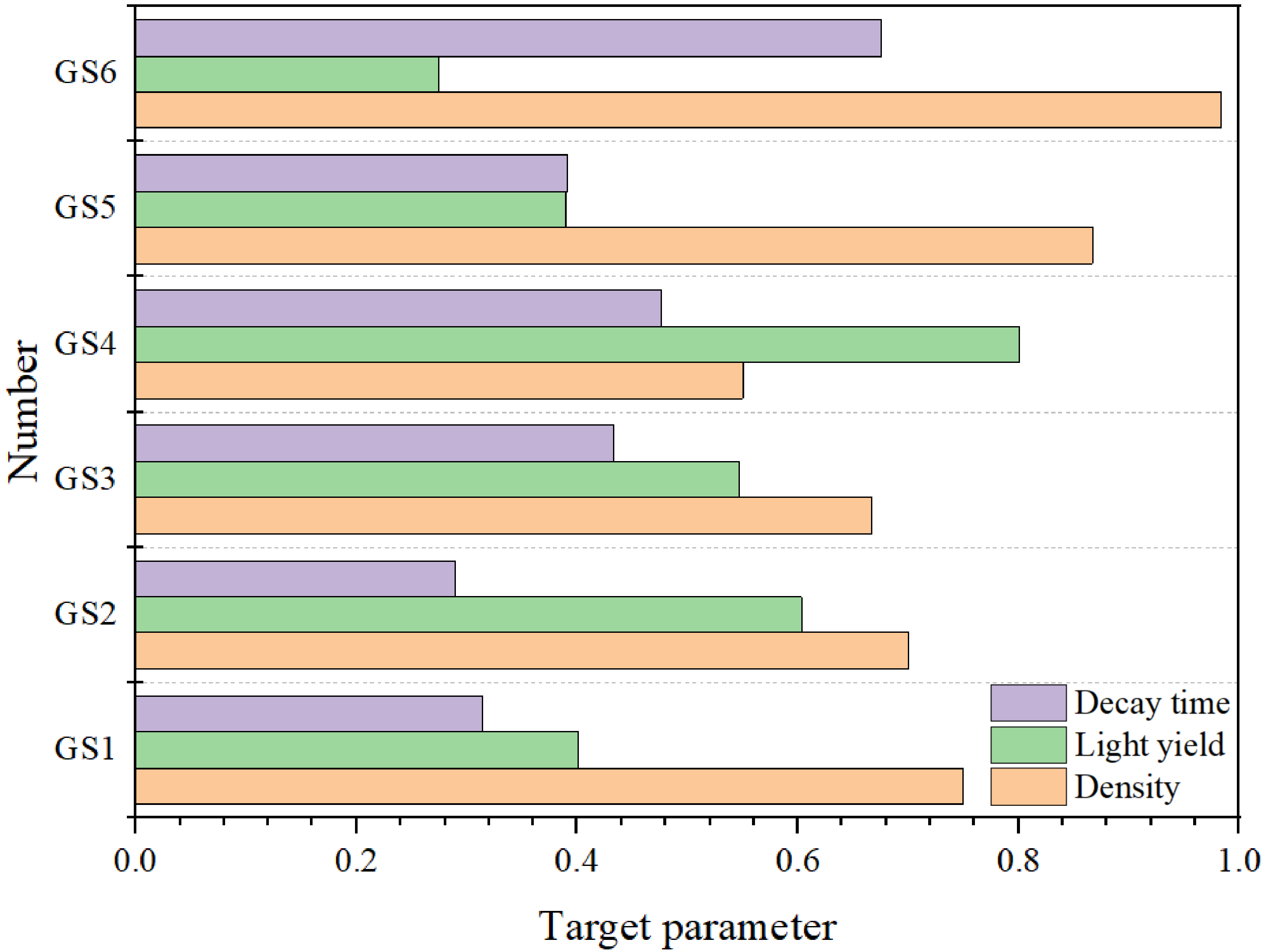
4.1 Summary



- Ultra-high density tellurite glass—6.6 g/cm^3
- High light yield glass ceramic—1600 ph/MeV
- Fast scintillating decay time— 100 ns

Glass scintillator of high density and light yield

- **5.2 g/cm^3 & 800 ph/MeV—Gd-B-Si-Ce^{3+} glass**
- **5.9 g/cm^3 & 550 ph/MeV—Gd-Ga-B-Ce^{3+} glass**

4.2 Plan

Number	Composition	Density (g/cm³)	Transmittance (%)	Light yield (ph/MeV)	Energy Resolution (%)	Decay time (ns)	Emission peak (nm)
GS1	Gd-Al-B-Si-Ce^{3+}	4.5	67	802	26.77	318,1380	393
GS2	Gd-Al-Si-Ce^{3+}	4.2	65	**1206**	**22.98**	346,1740	430
GS3	Gd-Al-B-Si-Ce^{3+}	4.0	70	1094	**19.64**	231,1897	440
GS4	Gd-K-Y-Si-Ce^{3+}	3.3	**80**	**1601**	27.27	**210**,1622	380
GS5	**Gd-B-Si-Ce^{3+}**	**5.2**	**80**	**780**	**33.09**	**256,1640**	**390**
GS6	**Gd-Ga-B-Ce^{3+}**	**5.9**	**70**	**550**	**/**	**148,1954**	**390**
	?	~6	>75	~2000	<20	<100	350-500

- **Gd-Ga-B-Si glass** will be the focus of future research.
- This glass can balance the targets of high density and high light yield.
- Next, the properties of the glass will be further improved through raw material purification and vacuum preparation.

Thank you!