Research progress of glass scintillator of HCAL

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Outline

1. Motivation and Target

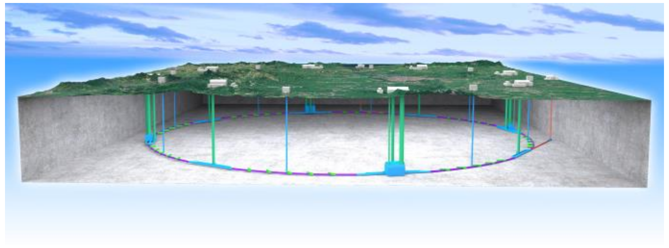
2. Standalone Simulation of GS-HCAL

3. PFA Performance with GS-HCAL

4. Research Progress of GS

5. Summary

1.1 Motivation



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

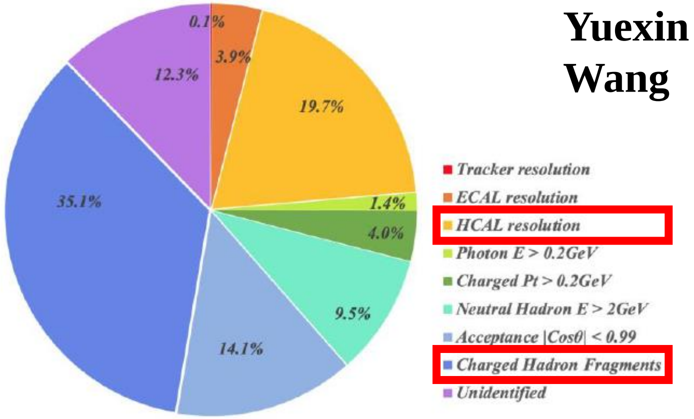
- Main physical goals: precision measurements of the Higgs and Z/W bosons
- Challenge: unprecedented jet energy resolution $\sim 30\%/\sqrt{E(GeV)}$

CEPC detector: highly granular calorimeter + tracker

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

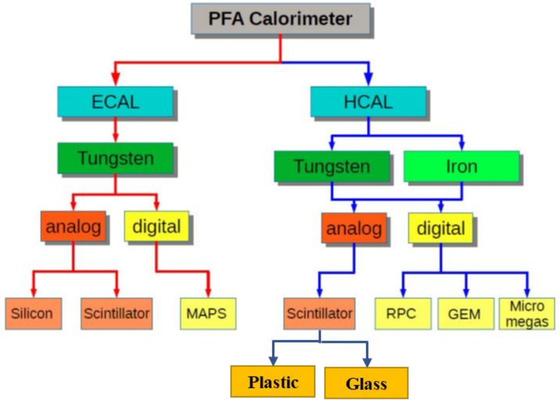
All Factors in BMR based on PFA

Yuexin Wang



New Option: Glass Scintillator HCAL (GS-HCAL)

- Higher density provides higher 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

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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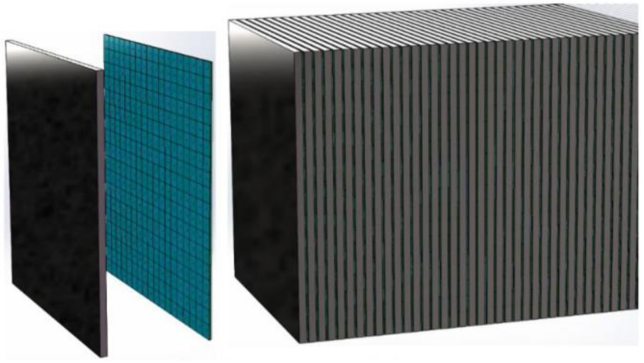
2.1 HCAL Setup of Standalone Simulation

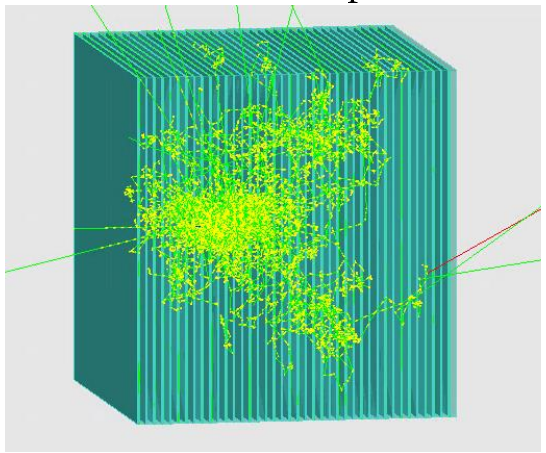
From Dejing Du
More details in Poster C03

- Geometry: similar to CEPC AHCAL prototype (baseline)
  - Transverse plane: 108×108 cm^2
    - Tile size: 3×3 cm^2
  - 40 longitudinal layers, each with
    - Scintillator (sensitive): 3 mm
    - Steel (absorber): 20 mm
    - PCB: 2 mm

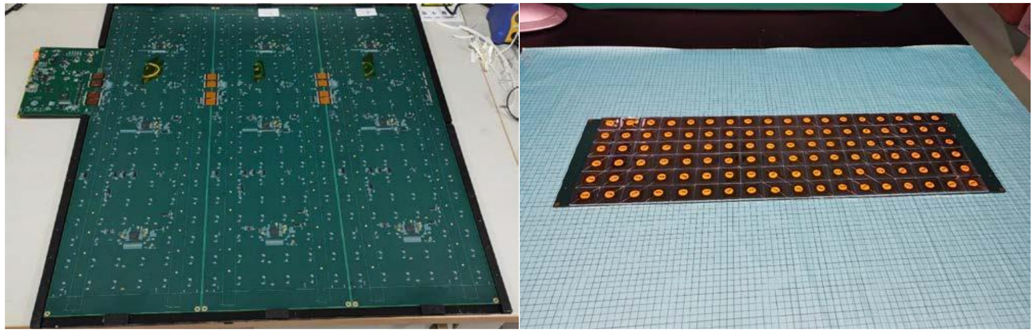
CEPC AHCAL prototype schematics



Shower development



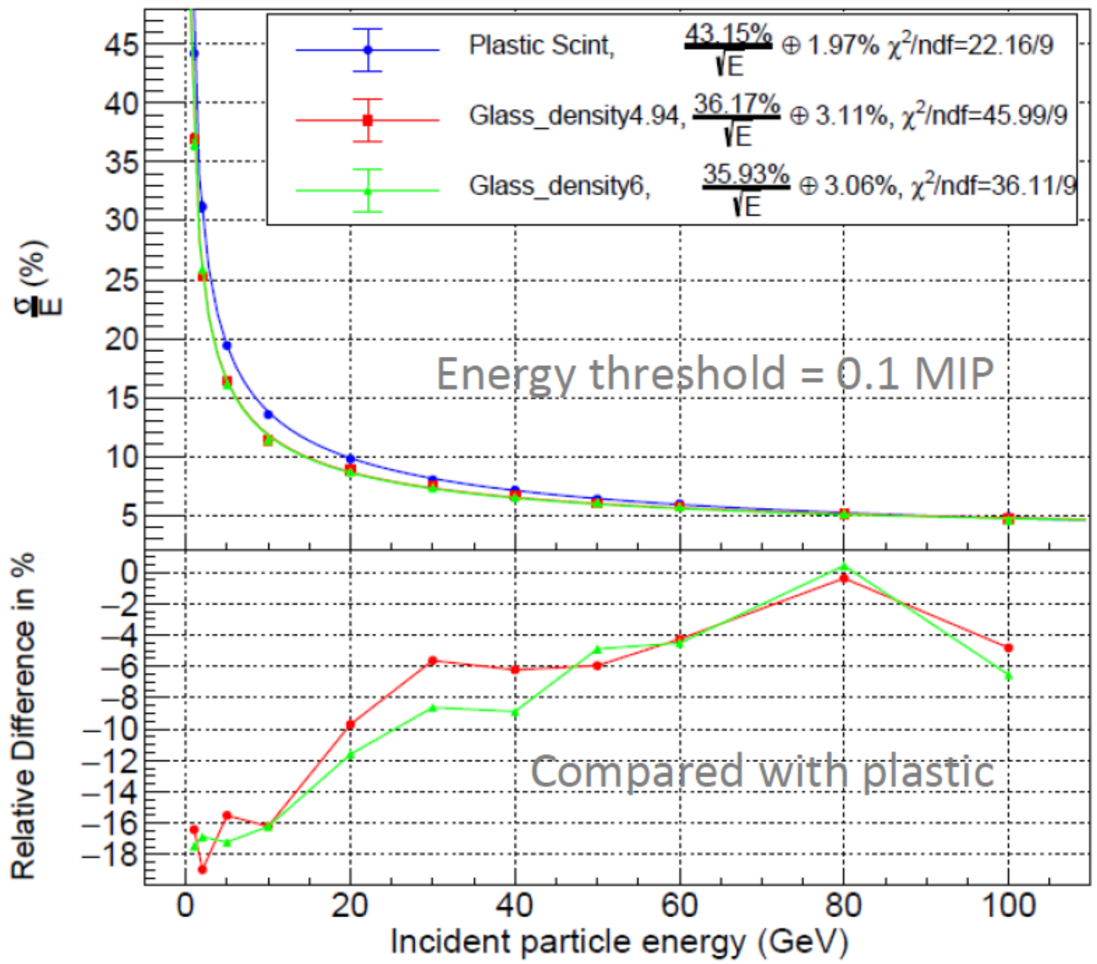
- GS-HCAL
  - Replace plastic scintillator with glass scintillator
    - Component: B_2O_3-SiO_2-Al_2O_3-Gd_2O_3-Ce_2O_3
  - Glass tile design: ongoing optimization



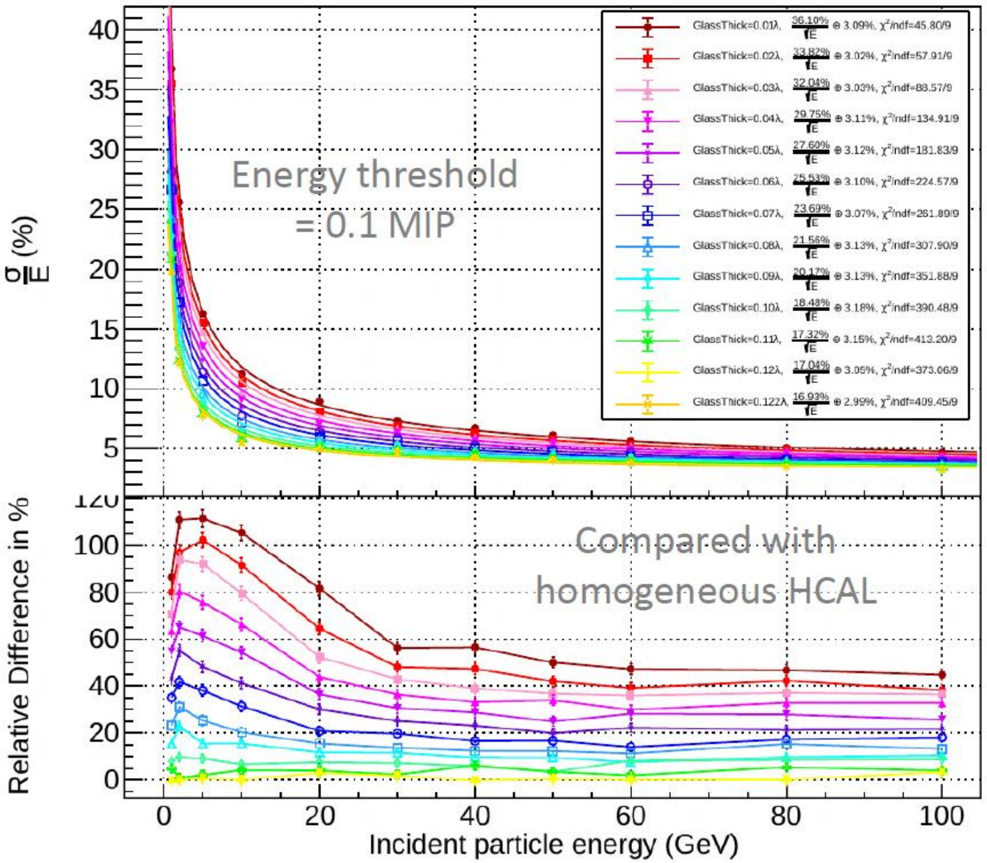
Single layer of CEPC AHCAL prototype

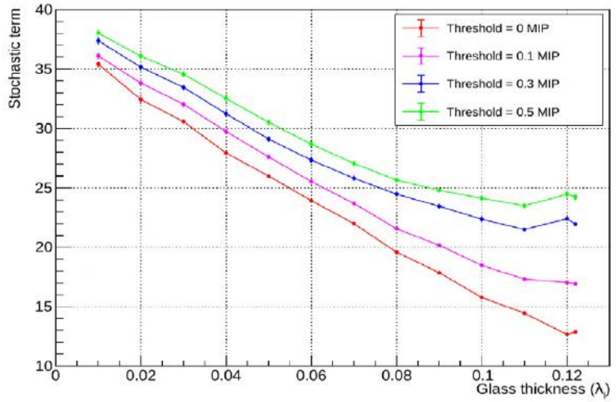
2.2 Plastic Scintillator vs Glass Scintillator

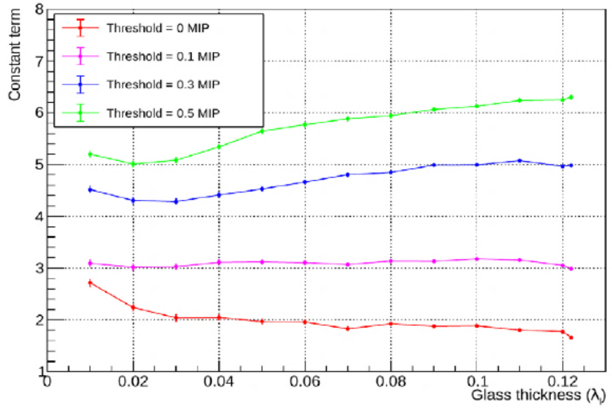
- Incident particle: K_L^0
- Performance comparison
  - Same thickness of sensitive materials: 3mm
- Glass scintillator: better hadronic energy resolution in low energy region (<30GeV)
  - Majority of hadrons in jets at CEPC are below 10 GeV



2.3 Hadronic Energy Resolution vs Glass Thickness







➢ Each layer was fixed to ~ 0.12 λ

- Better stochastic term with thicker glass scintillator, whereas the constant term is hardly affected
- The hadronic energy resolution can improve by a factor 2 when increasing the glass thickness from 0.01 λ to 0.12 λ (sampling → homogeneous) below 10 GeV

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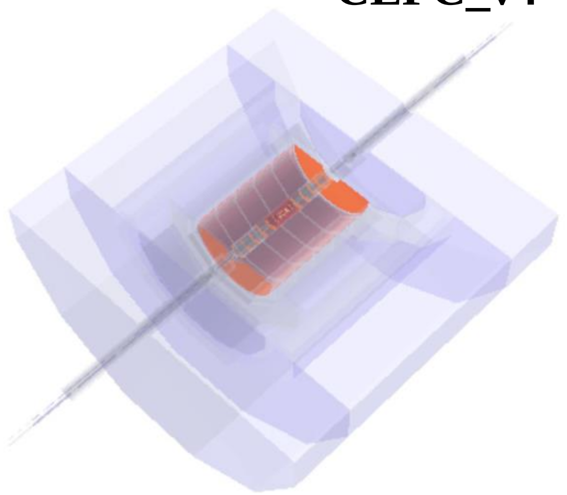
3.1 PFA Performance Simulation for GS

□ Setup

- CEPCSoft Framework: CEPC_v4, glass scintillator/steel HCAL + Si/W ECAL
- Primaries input: 240 GeV e+e- → $\upsilon\bar{\upsilon}$H (H → gg)
- Glass candidates: from Simu1-GS1 to GS10, most of them have been synthesized by the Glass Scintillator Collaboration
- Glass cell area: 3x3 cm^2 (fixed)
- Each sampling layer was fixed 0.124 λ (3mm PS+ 2cm steel)
- Total layers, thickness of glass and steel vary accordingly with different setup

CEPC_v4



theoretical value

	Composition	Density (g/cm³)	MIP Edep (MeV/mm)	NIL (mm)
Simu1-GS1	Gd-Al-Si-Ce^{3+}	5.10	0.596	274.8
Simu1-GS2	Gd-B-Si-Ce^{3+}	5.35	0.617	267.8
Simu1-GS3	Gd-B-Si-Ce^{3+}	5.49		261.9
Simu1-GS4	Gd-B-Si-Ge-Ce^{3+}	5.51	0.636	259.5
Simu1-GS5	Gd-Ga-Si-B-Ce^{3+}	5.64		254.1
Simu1-GS6	Gd-Ge-B-Ce^{3+}	5.68	0.656	251.3
Simu1-GS7	Gd-Ga-B-Ce^{3+}	5.77		247.3
Simu1-GS8	Gd-Ga-Ba-B-Ce^{3+}	5.78		249.6
Simu1-**GS9**	**Gd-Ga-Ba-B-Si-Ce^{3+}**	**5.81**	**0.670**	**250.5**
Simu1-GS10	Gd-Ga-Ge-B-Si-Ce^{3+}	6.03	0.699	241.0

3.2 BMR Analysis with Marlin

Setup

- Edep threshold in glass cell was set to 0.1 MIP and 0.3 MIP
- Edep in each sampling layer of HCAL was based on sampling fraction $\boldsymbol{f}$ and calibration coefficient $\boldsymbol{k}$ (i.e. $Edep_{layer}=\boldsymbol{k}\times Edep_{GS}/\boldsymbol{f}$), **an optimized BMR was obtained by scanning the calibration coefficient *k***
- BMR Cut： Pt_ISR<1 GeV && Pt_neutrino<1 GeV && |Cos(Theta_Jet)|<0.8 (~60% selection efficiency)

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    <!-- ========== Calorimeter digitization  === -->
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    <processor name="MySimpleMuonDigi"/>

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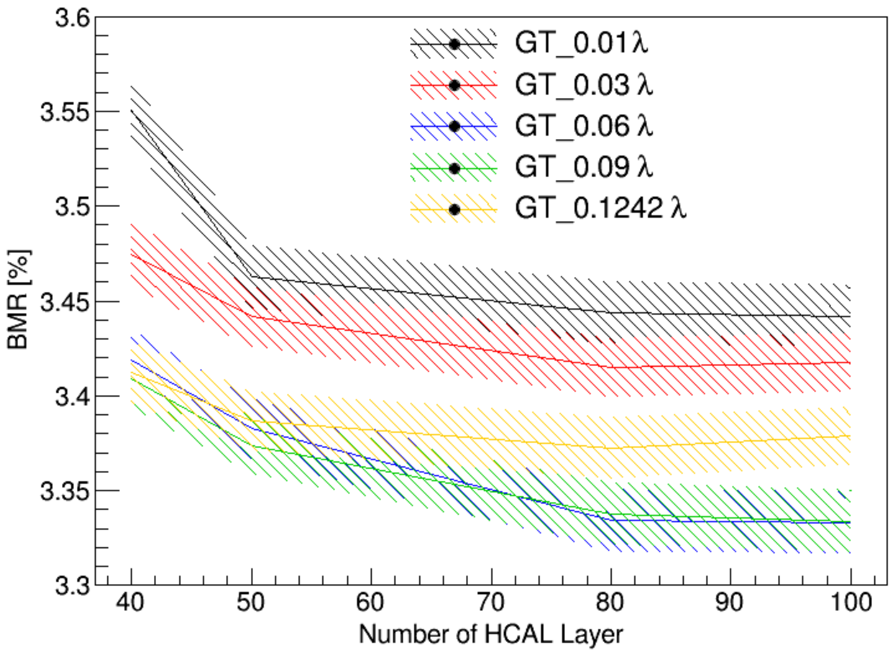
- Track digitization and reconstruction
- CaloHit digitization (only Edep threshold is applied, while the scintillation process and electronics were not considered yet
- CaloHit clustering, cluster and track linking, PID

3.3 Optimized BMR for Glass Thickness

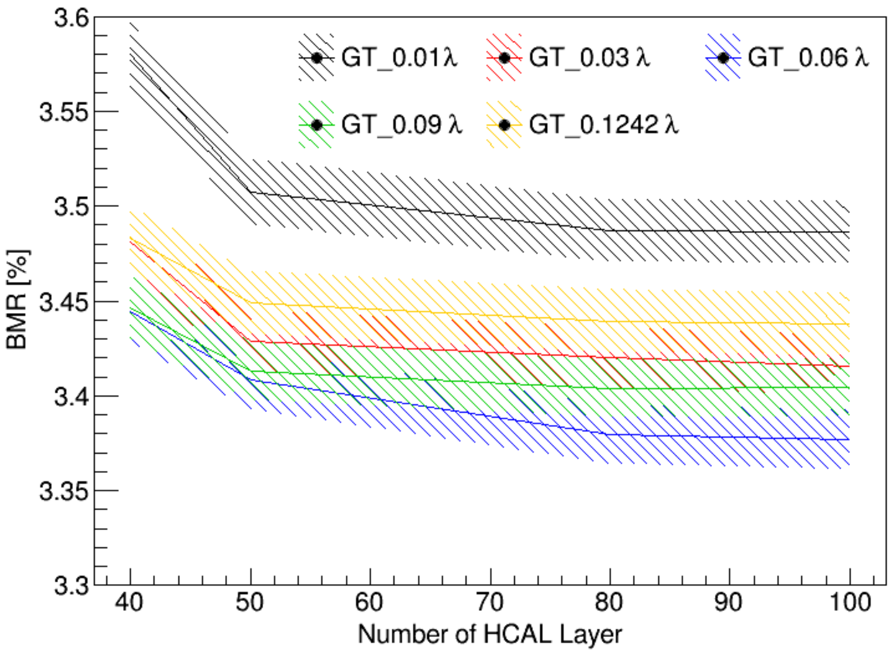
Preliminary

- In the case of different glass thickness and threshold

Optimized BMR @ **0.1** MIP Thr.



Optimized BMR @ **0.3** MIP Thr.



- Simu1-GS4
- ~90k simu events

- Optimized BMR is around 3.34% when the glass thickness of each layer is around 0.06 λ (each layer is fixed to 0.124 λ)

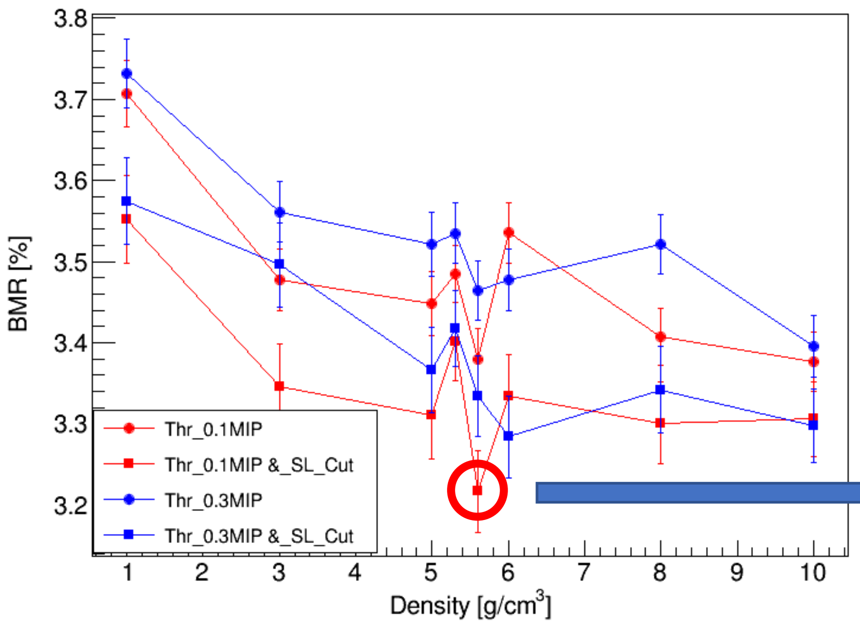
- The effect of shower leakage leads to ~3% degradation in BMR for 40-layer & 0.06 λ setup (compared with 100-layer)

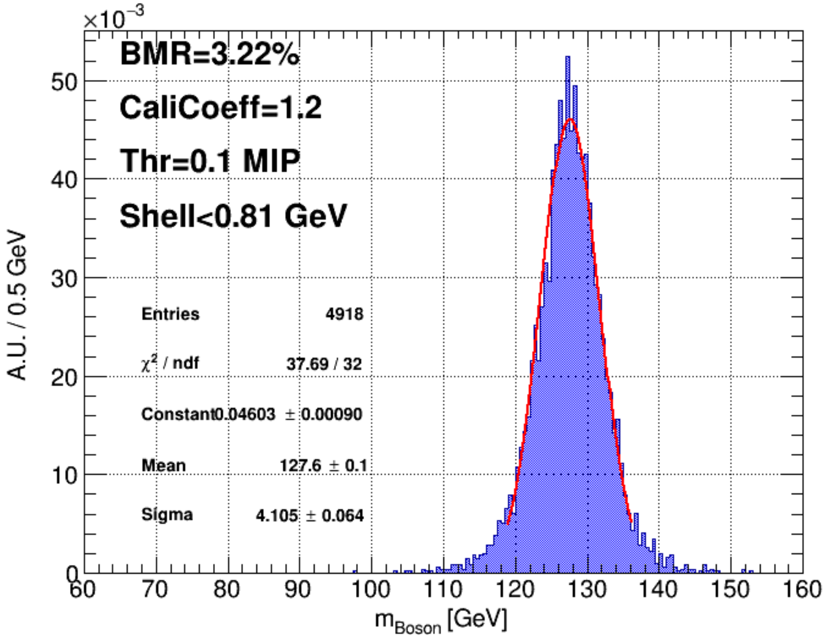
3.4 Optimized BMR for Glass Density

Preliminary

- In the case of different density and threshold

Optimized BMR for each glass sample





- 40 layers
- Glass Thickness 10 mm
- Simu1-GS4 with modified density
- ~16k simu events

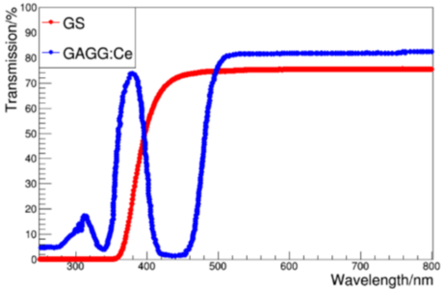
- Events with lower energy deposition (50% total events) in outer layer of HCAL (10% HCAL thickness) were used to evaluate the influence of shower leakage (denoted as SL_Cut)
- The preliminary result shows the optimized BRM can reach up to 3.22% when the glass density is around 5.5 g/cm^3
- More statistics and further check are needed to verify this result

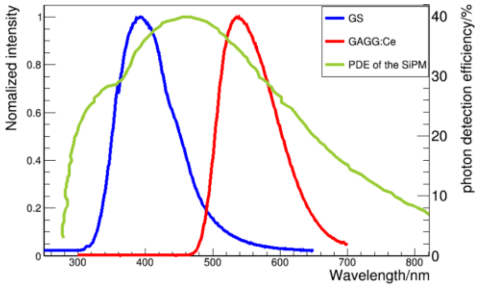
Outline

4.1 Performance Test of GS

From Zhehao Hua
More details in Poster C11

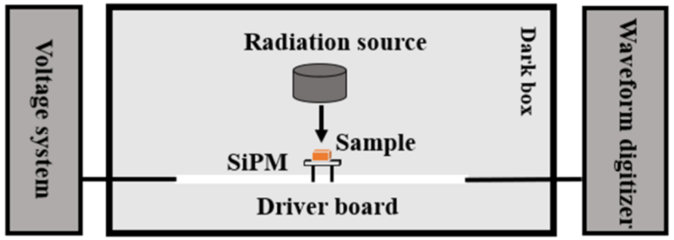
Transmission and XEL spectra

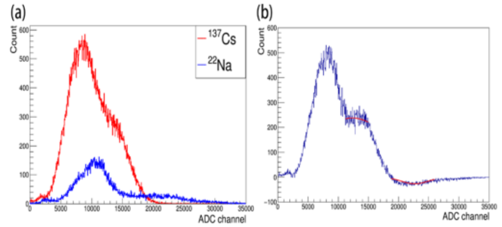




- Absorption band is near 360 nm and transmittance can reach above 75% when wavelength is longer than 450 nm
- Emission spectrum ranges from 300-600 nm with peak position around 400 nm

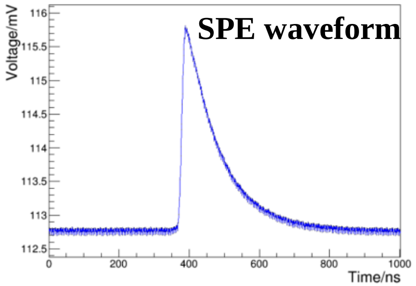
Energy resolution and light yield

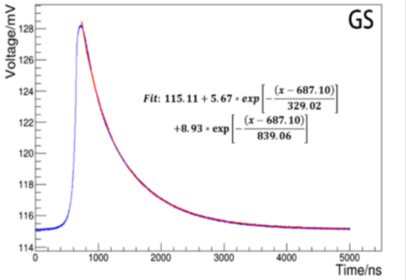




- Measurement system of energy resolution and light yield have been developed
- Full-energy peak is not visible due to low light yield, thus subtraction of energy spectra is used to get the light yield

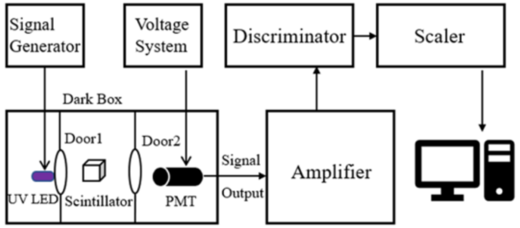
Scintillation decay time

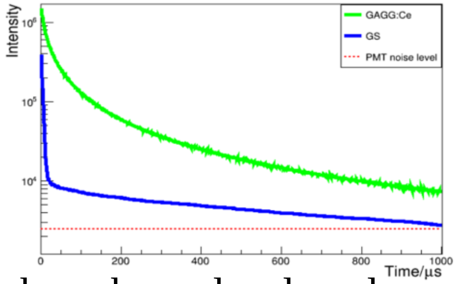




- Rise time and fall time of SPE waveform are around 15 ns and 180 ns, respectively
- The decay time of fast and slow component of glass scintillator are 45.69 ns (45%) and 265.93 ns (55%), respectively

Afterglow

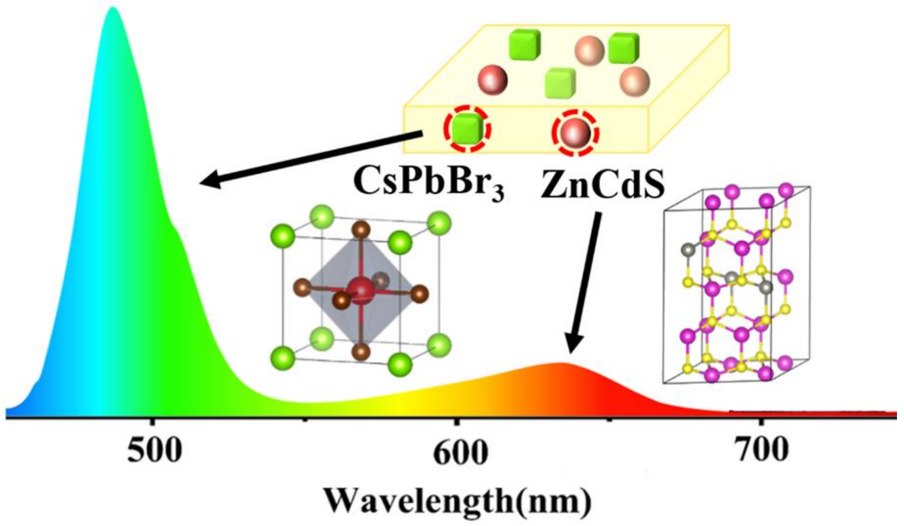




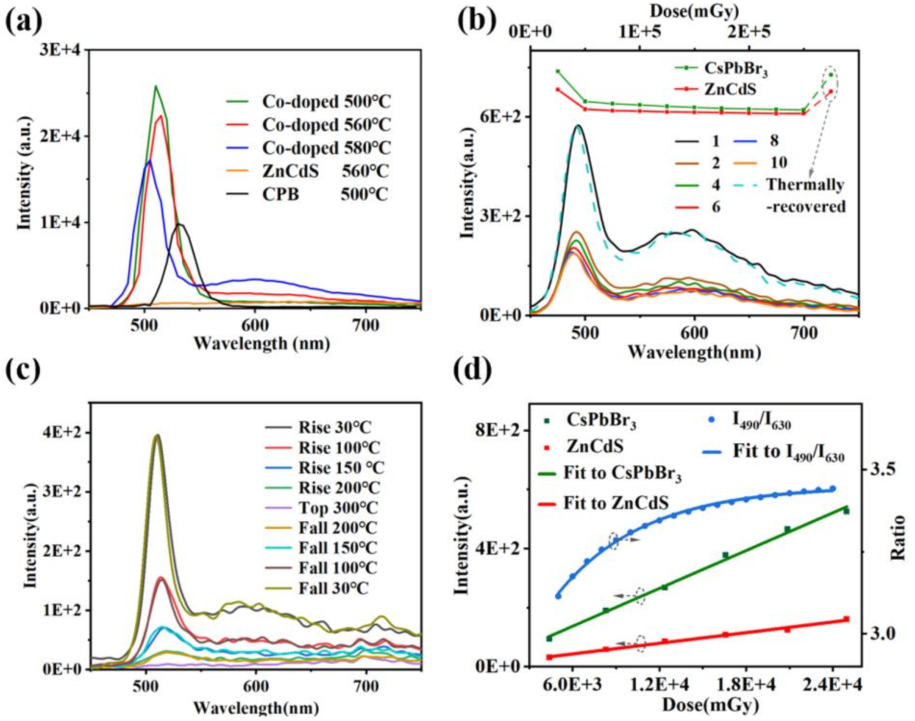
- Measurement system of afterglow have been developed
- Afterglow of glass scintillator decrease much faster than that of GAGG:Ce

4.2 Quantum Dots Co-doped Nano-glass

From Zhexuan Sui
More details in Poster C01



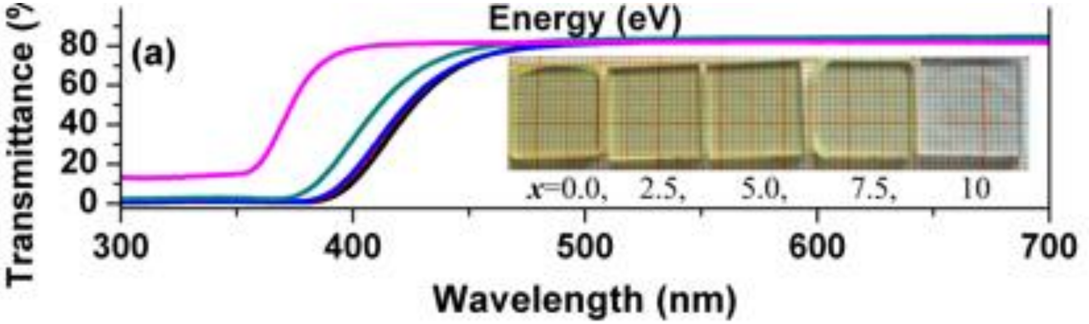
- Semiconductor quantum dots (QDs) possess the advantages of continuously adjustable emission colors and high photoluminescence quantum yields (PLQYs)
- The CsPbBr3 and Zn-Cd-S QDs can be simultaneously grown in borosilicate glass as a result of the diffusion-limited crystallization of the glass
- The tunable dual-band emissions can be also achieved under the X-rays excitation

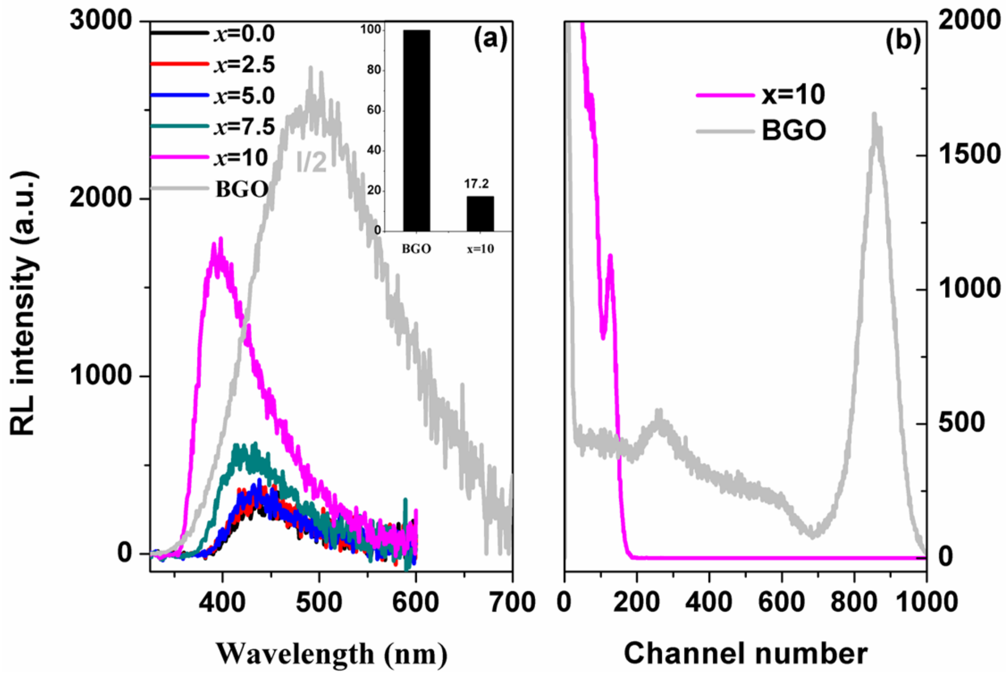


(a) XEL spectra; (b) XEL spectra under repeated X-ray irradiation; (c) Variation of XEL spectra during a heating and cooling cycle; (d) Changes of the dual-band emissions curves excited by different power of X-ray tube without thermal reduction.

4.3 Borosilicate Glass Scintillatior

From Zhehao Hua
More details in Poster C12





- colorless Ce^{3+}-activated borosilicate scintillating glass was successfully synthesized in air atmosphere
- Its integral XEL intensity is about 17.2% BGO, with a light yield of ~800 ph/MeV estimated by gamma ray spectroscopy. And the scintillating decay times of the glass are 262.10 ns (18%) and 1234.83 ns (82%), respectively. And the light decreased faster than GAGG crystal
- It would be a potential possibility for the proposal of GS-HCAL of CEPC

4.4 Aluminium-silicate Glass Scintillator

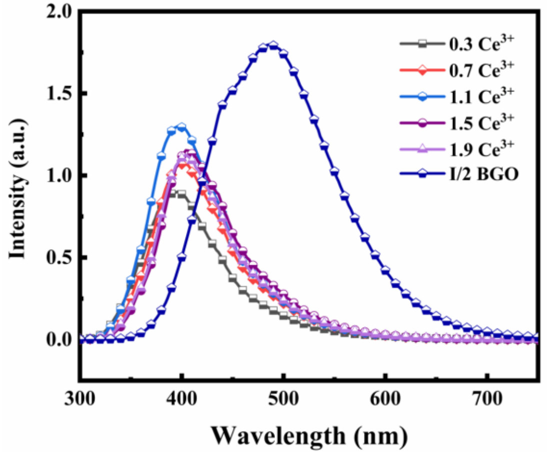
From Tao Wu
More details in Poster C02

- Ce^{3+}-doped $20Gd_2O_3$-$20Al_2O_3$-$60SiO_2$ (GAS: xCe3+) glasses (x = 0.3, 0.7, 1.1, 1.5, 1.9 mol%) with Si3N4 as a reducing agent were prepared

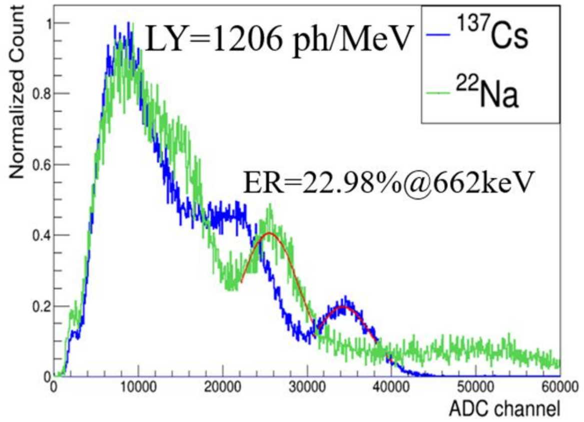
- With 1.1 mol% of Ce^{3+} concentration, the light yield is approximately 1200 ph/MeV with an energy resolution of 22.98% at 662 keV, which is also the optimal value

- The scintillating decay time of the glasses ranged from 285-395 ns (fast components) and 1382-2332 ns (slow components) ,

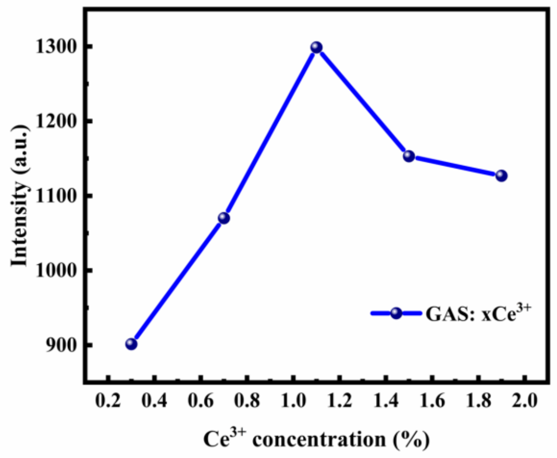
X-ray excited luminescence (XEL) of GAS: xCe3+ glasses



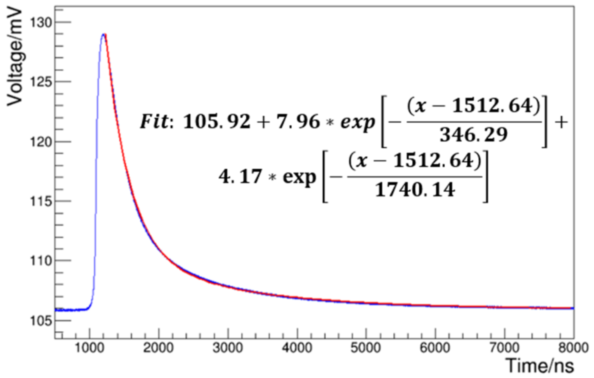
Measured spectra of ^{22}Na and ^{137}Cs in GAS: $1.1Ce^{3+}$ glass



XEL intensity change of GAS: xCe3+ glasses



Scintillating decay time of GAS: $1.1Ce^{3+}$ glasses

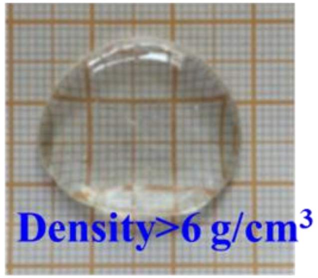


4.5 Overview of GS Research Progress

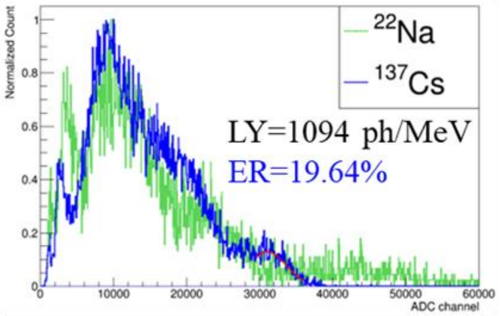
Three glass systems are being investigated simultaneously

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

2022.09

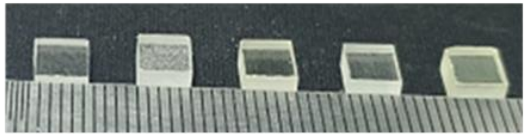


2022.06



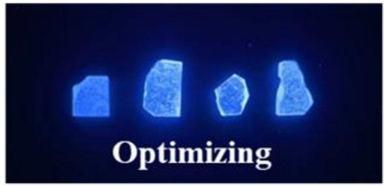
2021.11

Density=4.5 g/cm^3
LY>800 ph/MeV

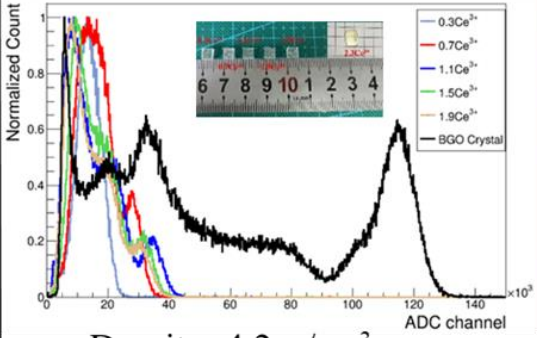


Gd-Al-Si-Ce^{3+}

2022.09

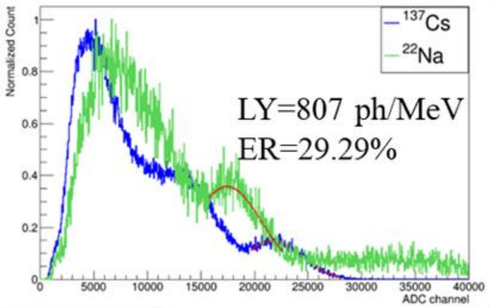


2022.05



Density=4.2 g/cm^3
LY>1200 ph/MeV

2022.03



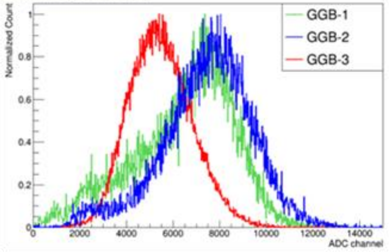
Gd-Ga-B-Ce^{3+}

2022.09

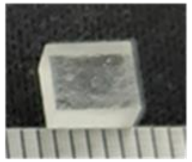
Add BaO
Density>6 g/cm^3

2022.08

LY=570 ph/MeV

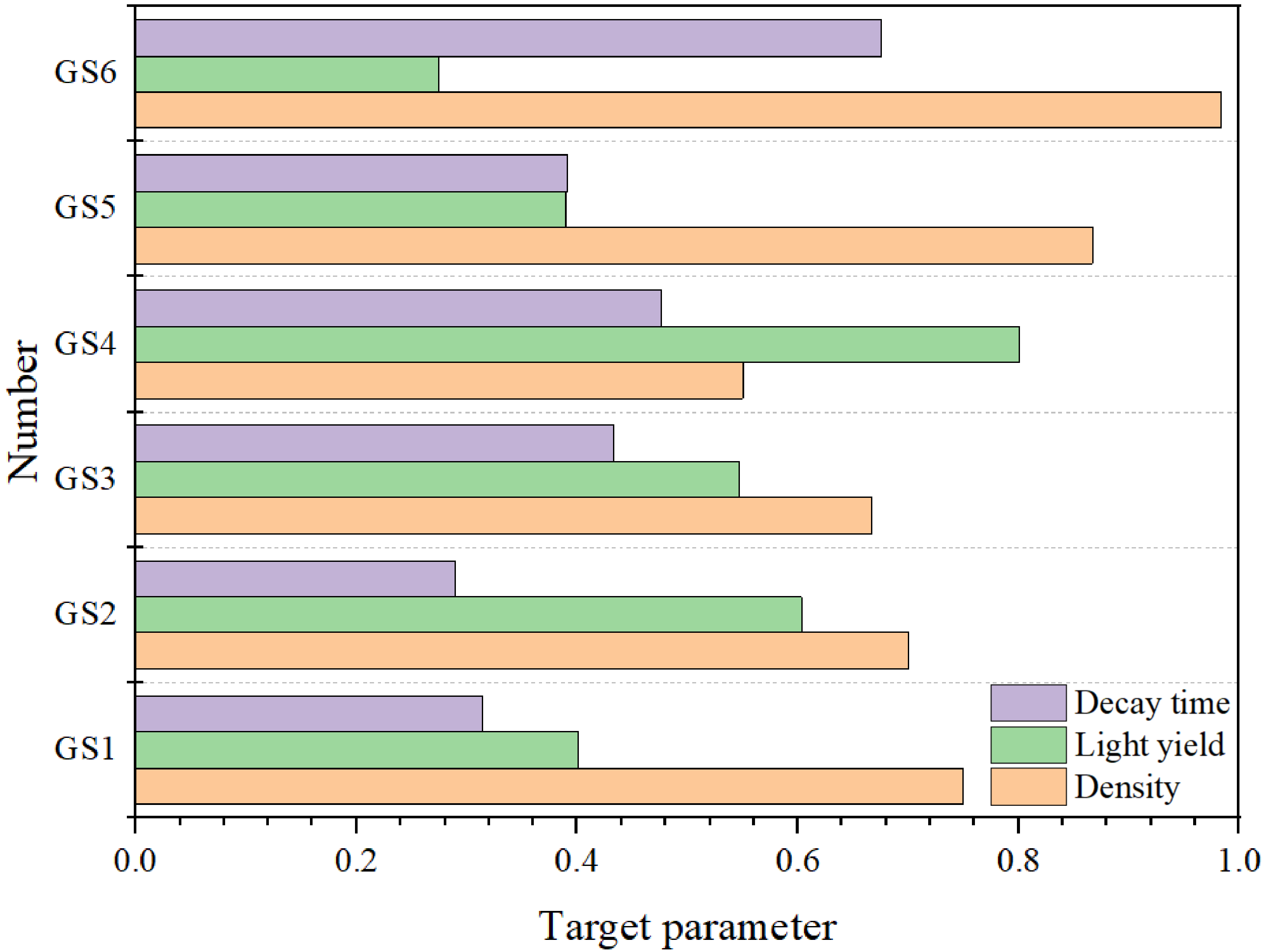


2022.07



Density=5.9 g/cm^3
LY=550 ph/MeV

4.6 Summary of the Latest R&D progress of GS



- Ultra-high density tellurite glass—6.6 g/cm^3
- High light yield glass ceramic—1600 ph/MeV
- Fast scintillating decay time— 100 ns
- Large size glass—42mm*51mm*10mm

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**

Outline

5 Summary

- The better hadronic energy resolution can obtained with GS-HCAL below 30 GeV (cover major jet components), and can be improved by a factor of 2 between low sampling fraction and homogeneous structure

- Under the CEPC_v4 and Arbor PFA framework, the BMR with GS-HCAL can reach ~3.3% and show ~10% improvement w.r.t. the baseline design (3.8%), which is also the best result we can obtain at present

- Three glass systems are being investigated simultaneously by the collaboration, and the best glass we can obtain currently are **Gd-B-Si-Ce^{3+}** glass (5.2 g/cm^3 & 800 ph/MeV) and **Gd-Ga-B-Ce^{3+}** glass **(**5.9 g/cm^3 & 550 ph/MeV)

Thank you!