Novel Scintillating Glass for Future HEP Calorimetry

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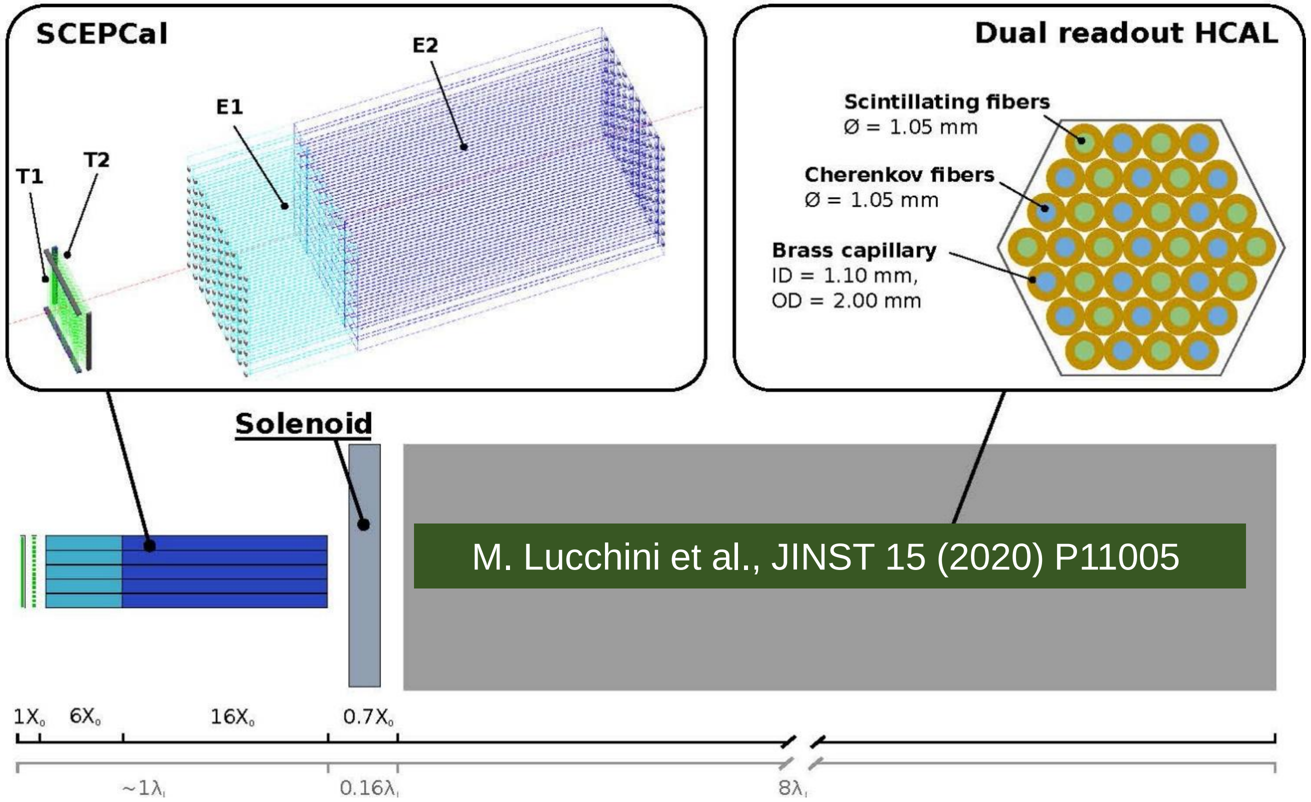
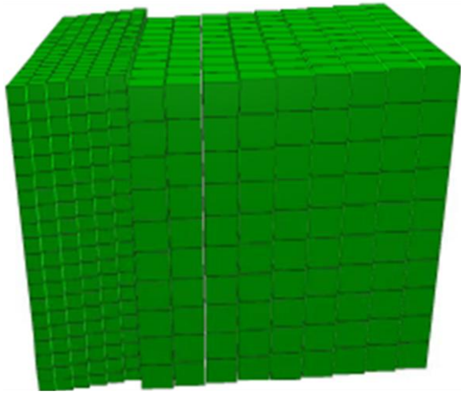
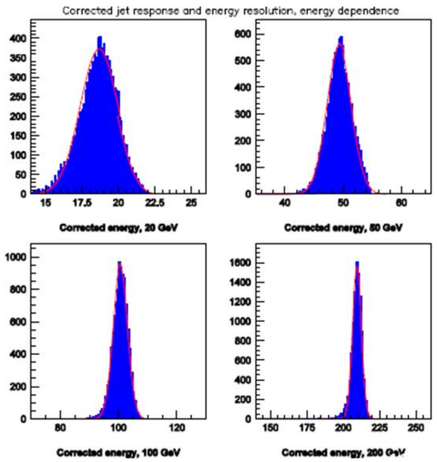
Introduction

A longitudinally segmented electromagnetic calorimeter with multiple readout is being pursued by the CalVision collaboration. Novel dense, UV-transparent and cost-effective inorganic scintillators are under development. New material may also be used for a homogeneous hadronic calorimeter concept with a volume of up to 100 m^3. We report an investigation on cerium-doped ABS (aluminoborosilicate) and DSB ($BaO \cdot 2SiO_2$) glass samples.



M. Lucchini et al., JINST 15 (2020) P11005





A. Para, H. Wenzel and S. McGill in Callor2012 Proceedings and
A. Benaglia *et al.*, IEEE TNS **63** (2016) 574-579: a jet energy resolution at a level of 20%/√E by HHCAL with dual readout of S/C or dual gate.
M. Demarteau, 2021 CPAD Workshop

Nuclear Properties

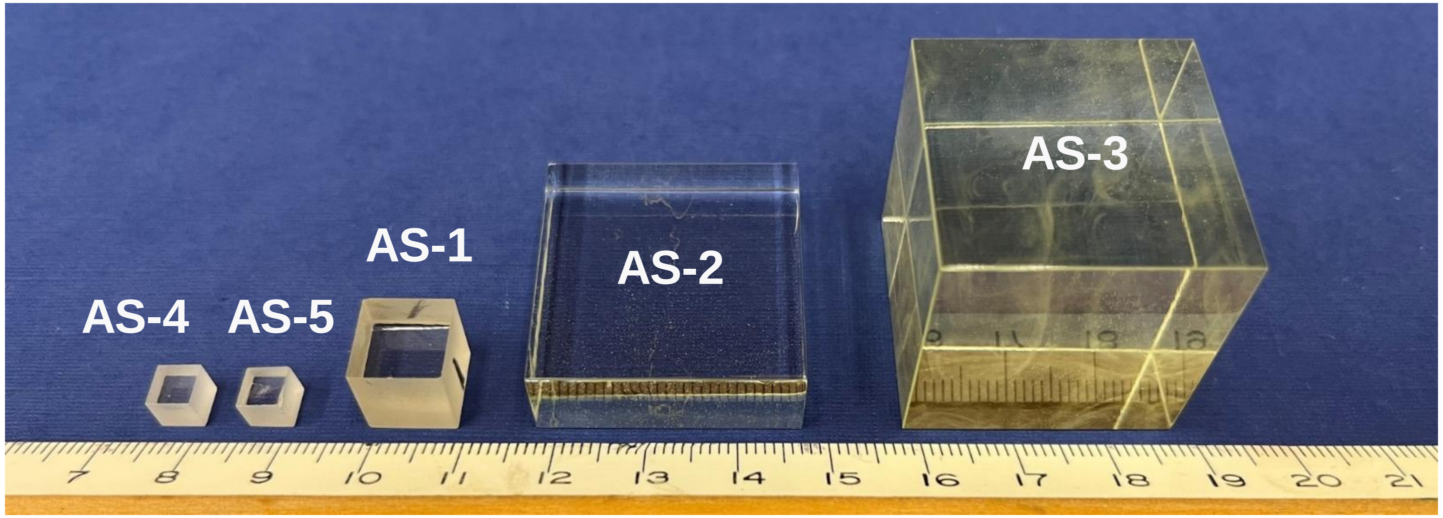
ABS: 1.55 cm X_0 and 24.7 cm λ_I DSB: 2.58 cm X_0 and 30.9 cm λ_I

Crystal and Glass	BGO	BSO	PWO	Gd-ABS		Gd-DSB	
				ABS**	Z-S, M, L	BGS*	DSB-1,2,3
Density (g/cm^3)	7.1	6.8	8.3	4.5	6.0	4.2	4.3
X_0 (cm)	1.12	1.15	0.89	2.41	**1.55**	2.62	**2.58**
R_M (cm)	2.23	2.33	2.00	3.09	2.50	3.33	3.24
λ_I (cm)	22.7	23.4	20.7	28.8	**24.7**	31.8	**30.9**
Z_{eff}	71.5	73.8	73.6	51.9	56.9	49.7	49.5
dE/dX (MeV/cm)	9.0	8.6	10.1	6.4	8.0	5.9	6.1

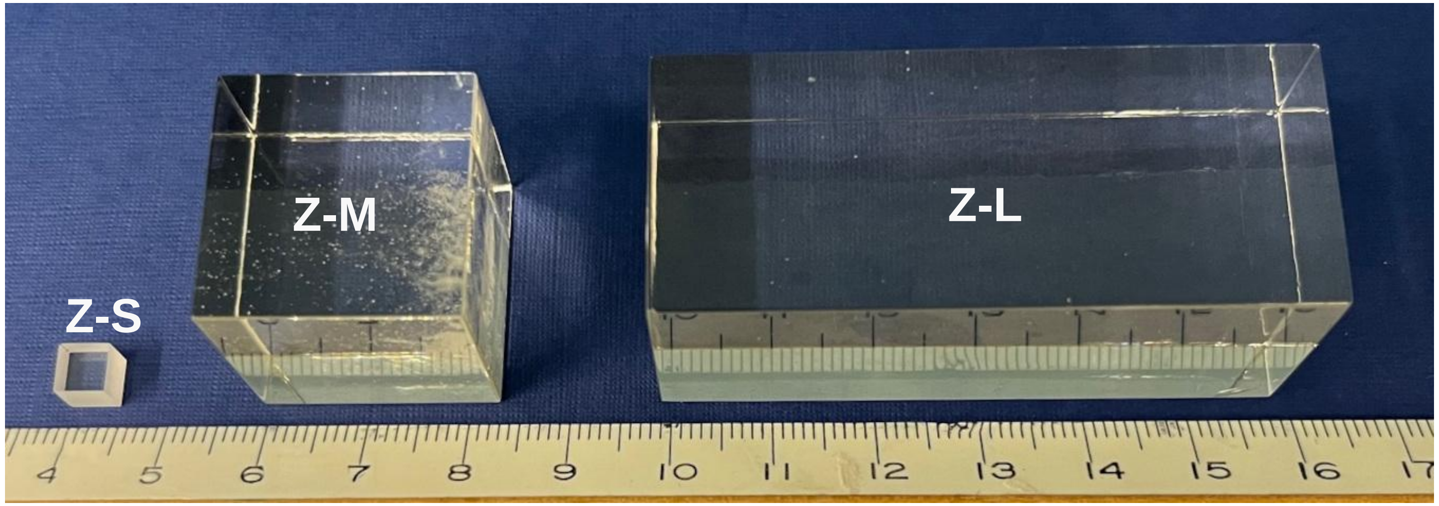
Aluminoborosilicate (ABS) Glass Samples

ABS samples provided by the Institute of High Energy Physics (IHEP), Beijing

The 1st batch samples were received on June 15, 2023.



The 2nd batch samples were received on Nov.22, 2023.



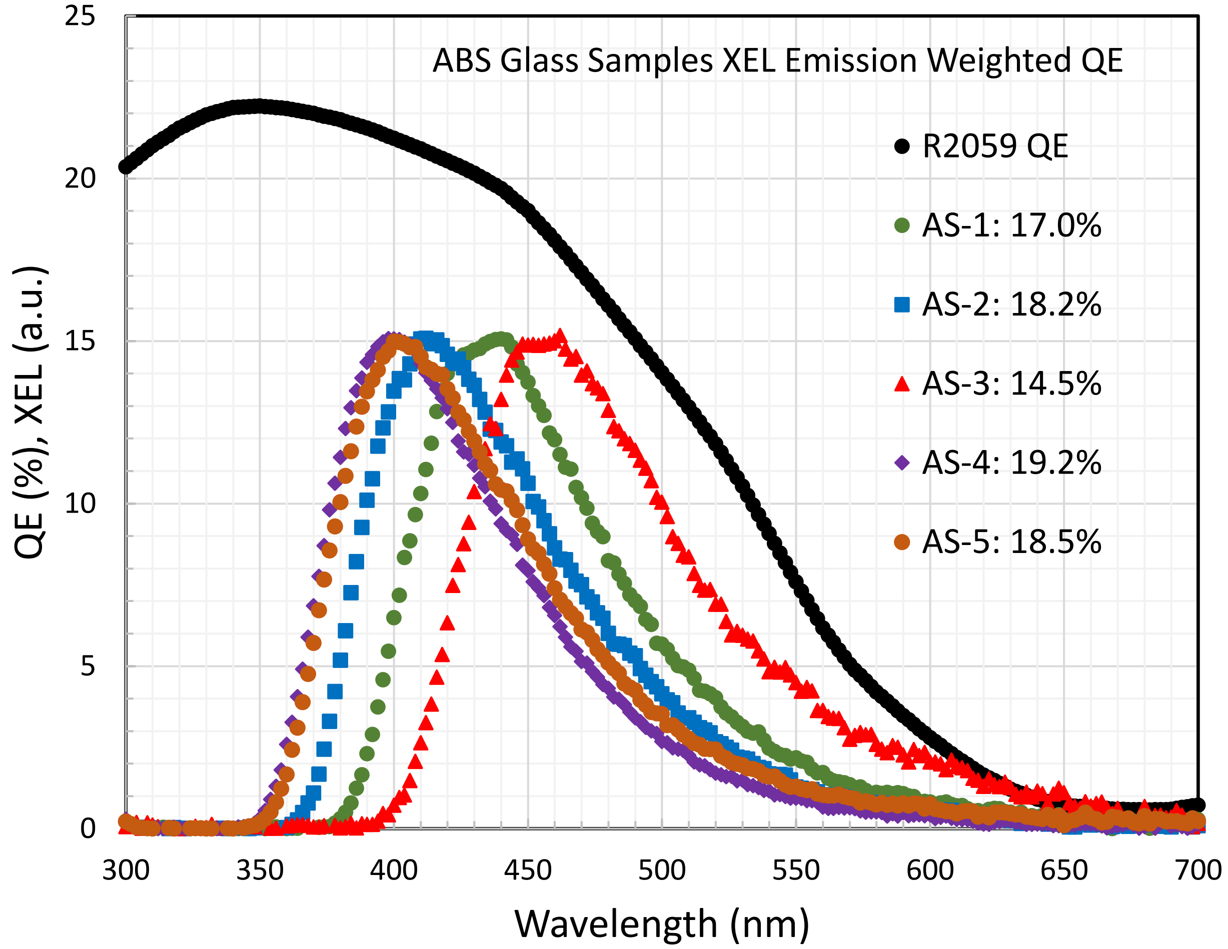
No.	ID	Doping	Dimensions (mm^3)	Lot info.
1	AS-1		10×10×10	NB, low LY
2	AS-2		30×30×10	NB, low LY
3	AS-3		30×30×30	NB, low LY
4	AS-4	$1Ce^{3+}$	5×5×5	OB, high LO.
5	AS-5	$1.5Ce^{3+}$	5×5×5	OB, high LO
6	Z-S	Ce^{3+}	5×5×5	Gd-loaded
7	Z-M	Ce^{3+}	24×24×24	Gd-loaded
8	Z-L	Ce^{3+}	25×25×60	Gd-loaded

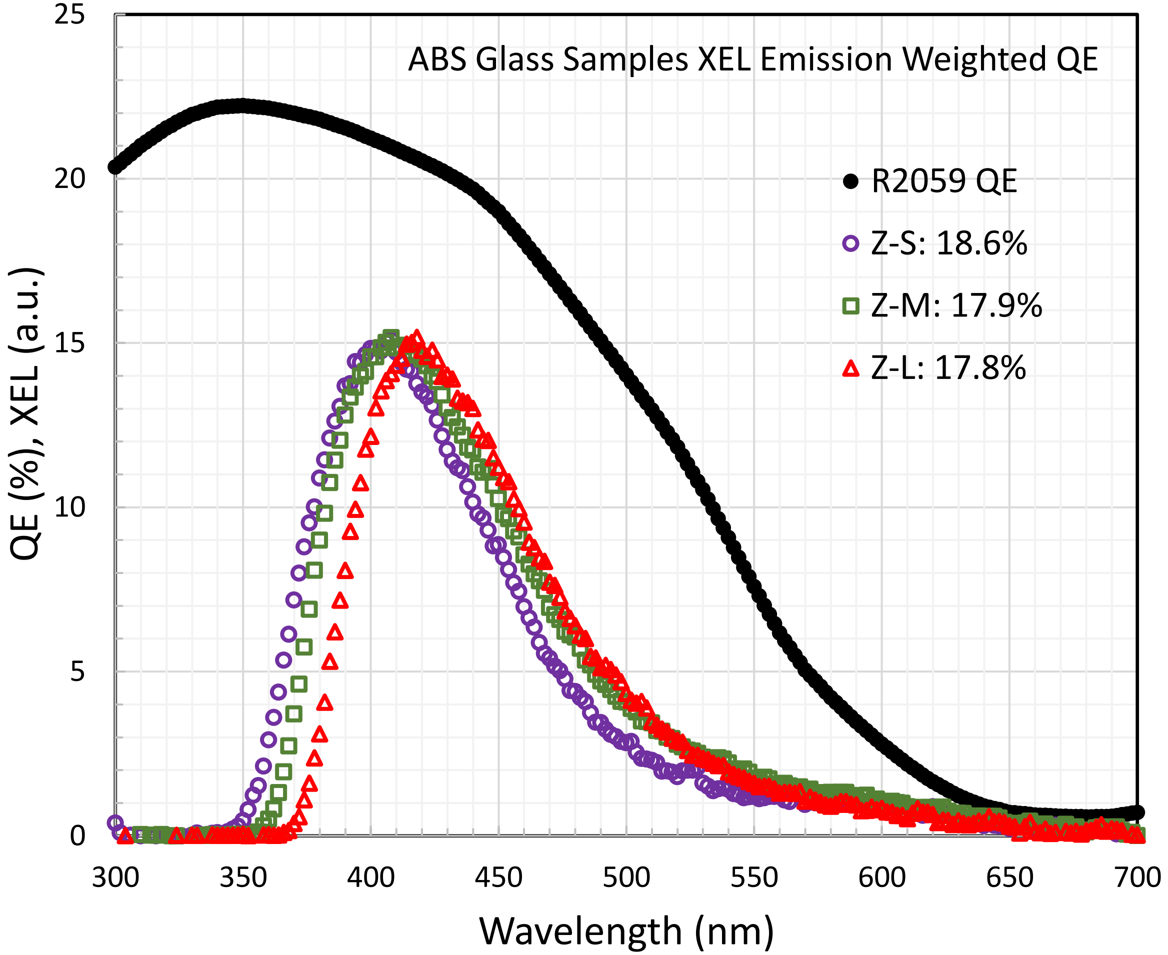
Measurements at room temperature:

- X-ray excited emission and EWQE,
- Transmittance and EWLT,
- Pulse Height Spectra (PHS),
- Light Output (LO) vs. integration time and Decay Time (τ).

ABS XEL and EWQE

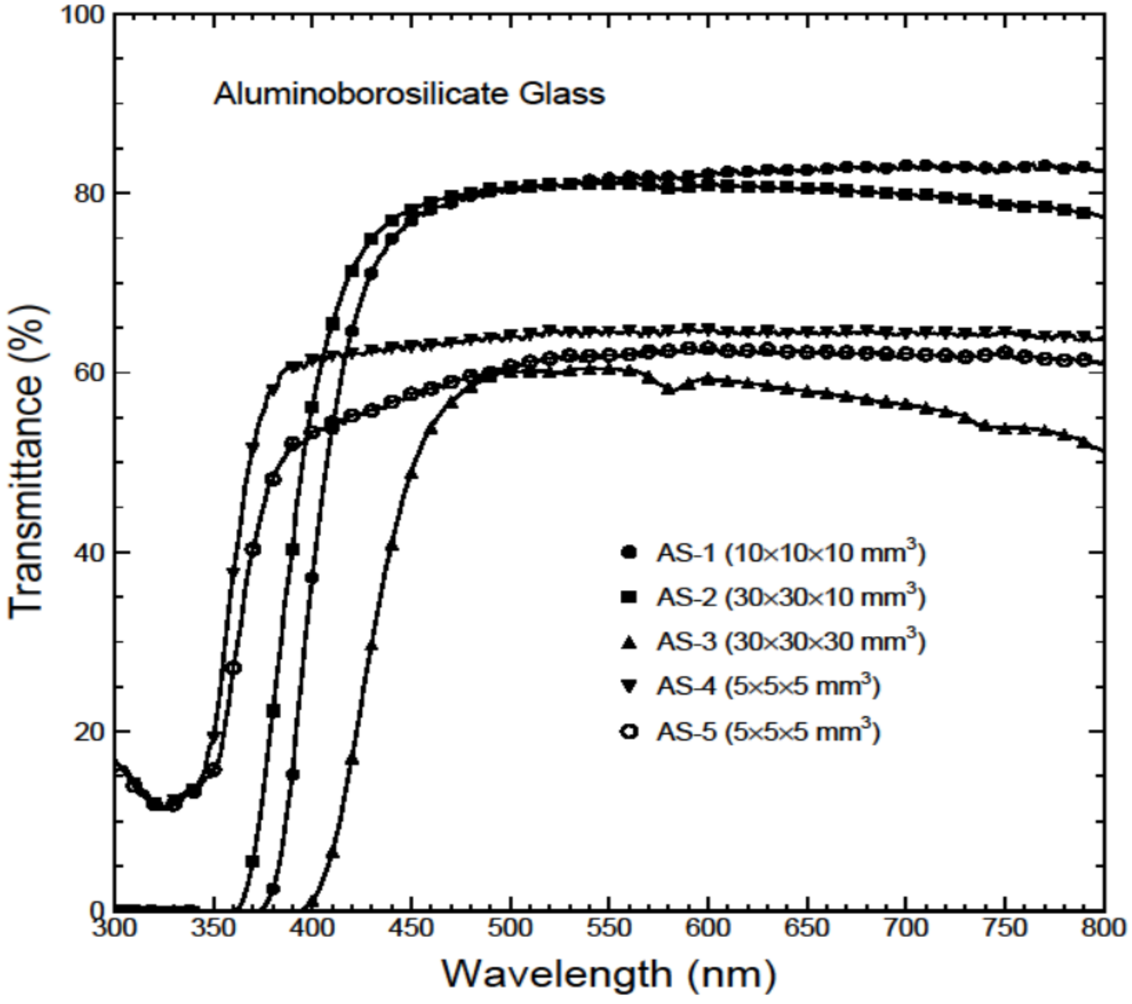
XEL (420 nm) and EWQE (18%) affected by light path length and chemical composition

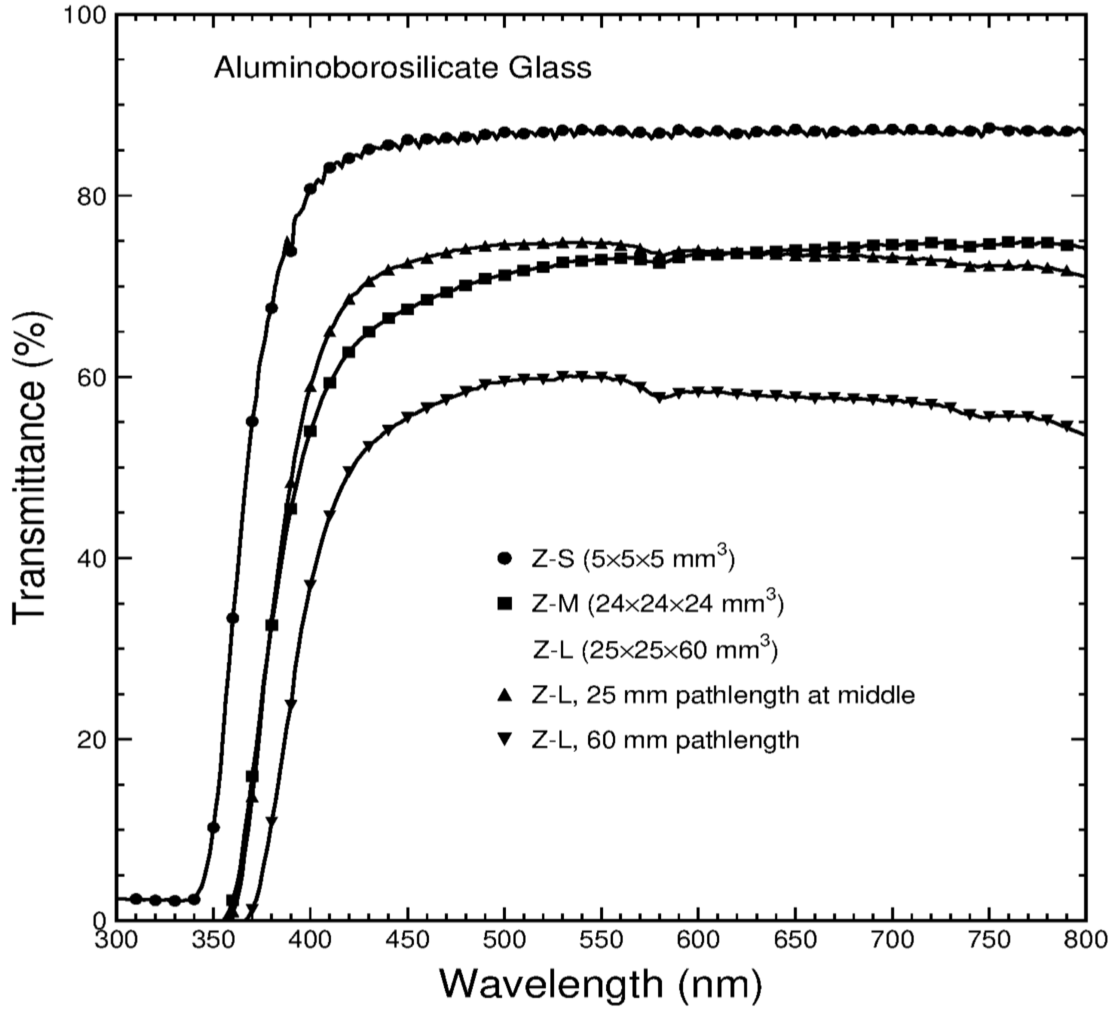




ABS Transmittance

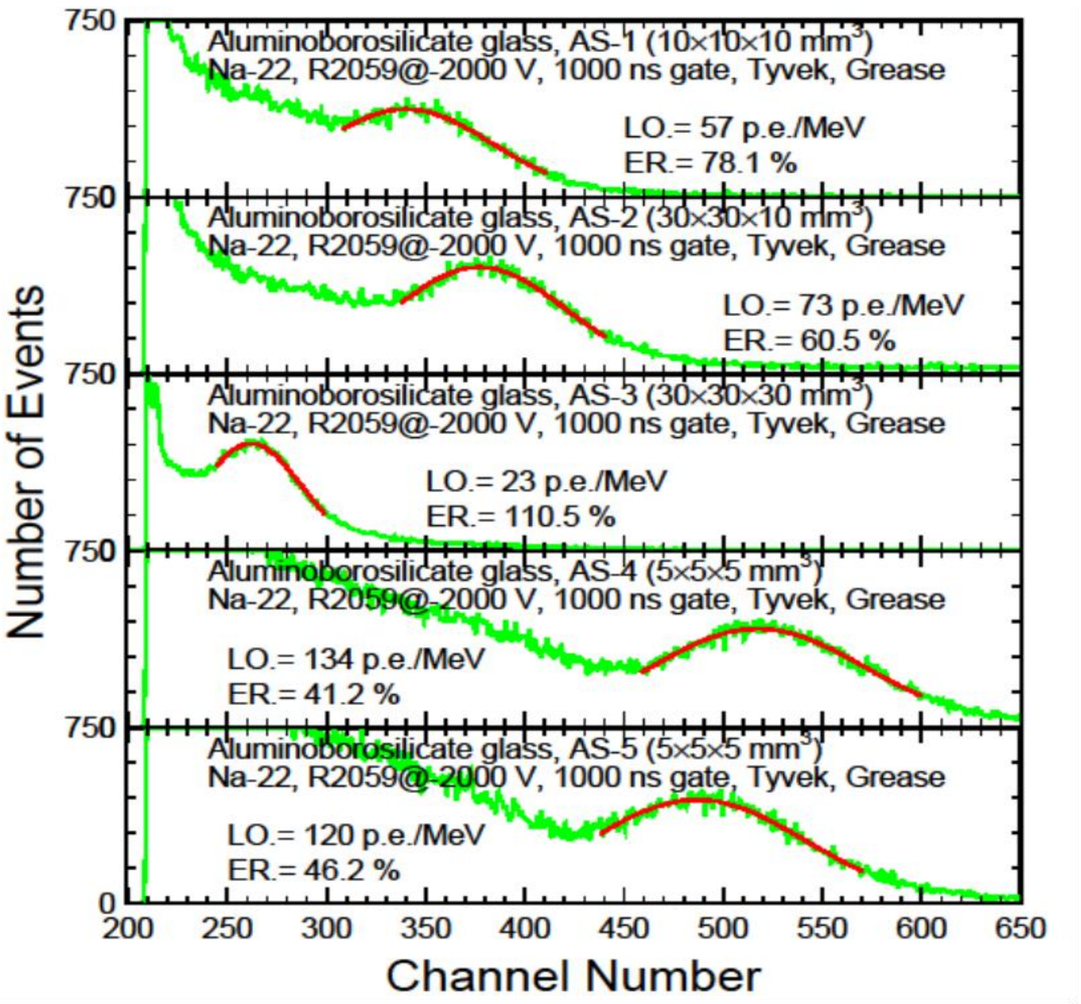
Transmittance affected by light path length, chemical composition and production techniques

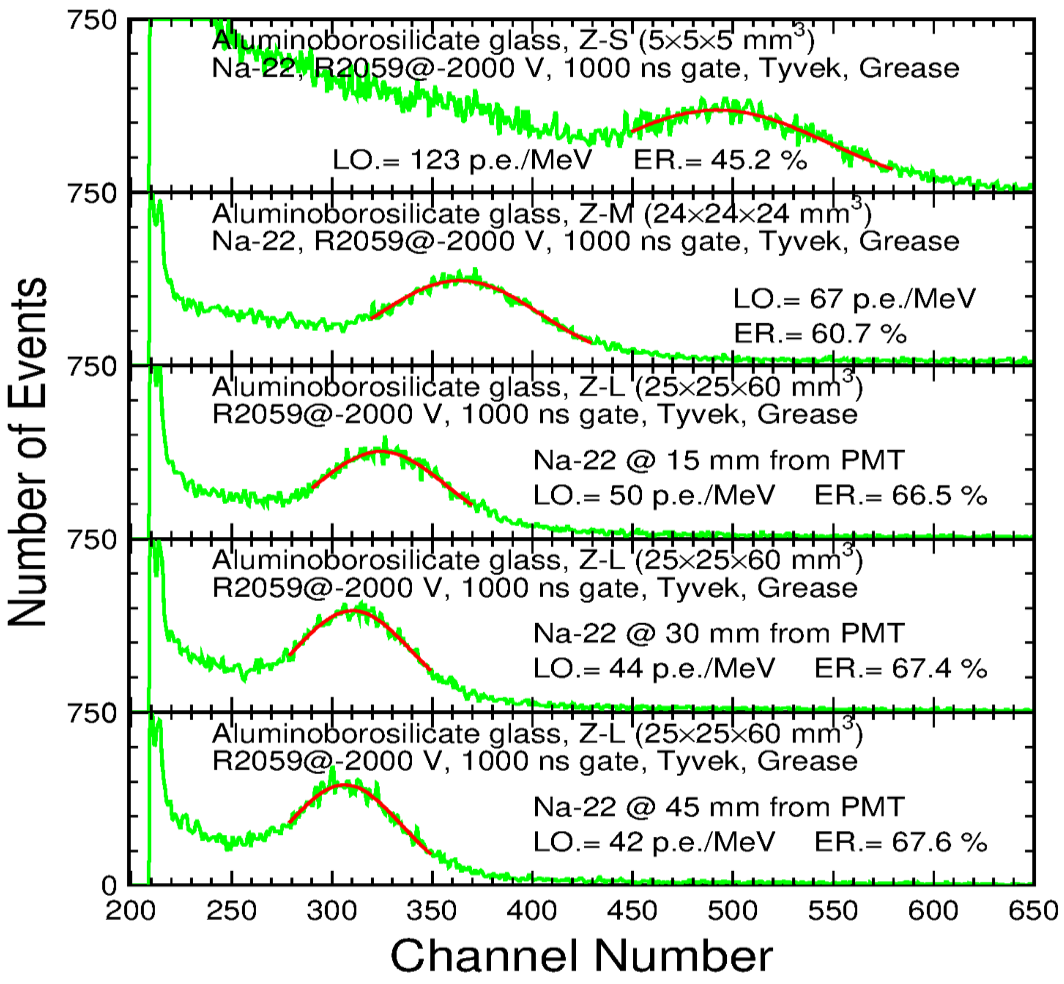




ABS Pulse Height Spectra

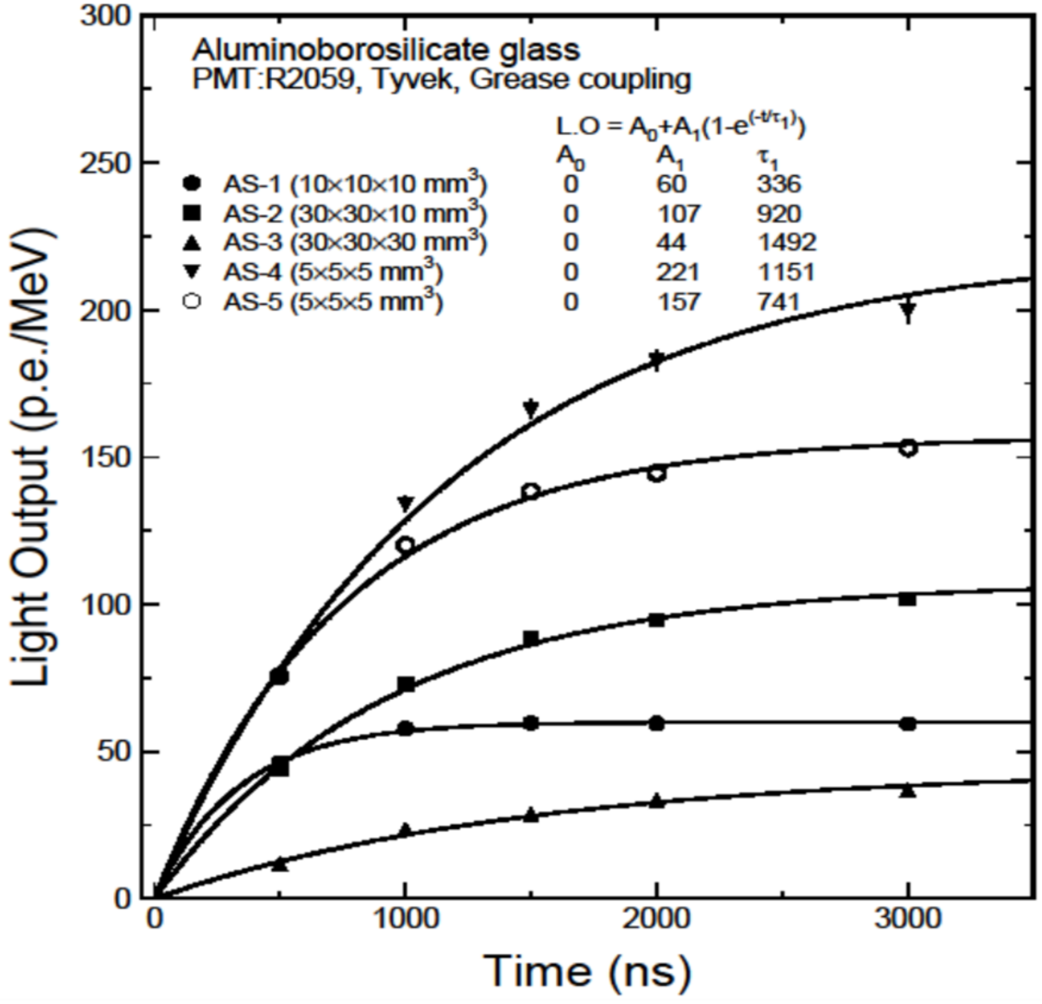
LO: 40-123 p.e./MeV, ER: 45%-70% affected by light path length and chemical composition

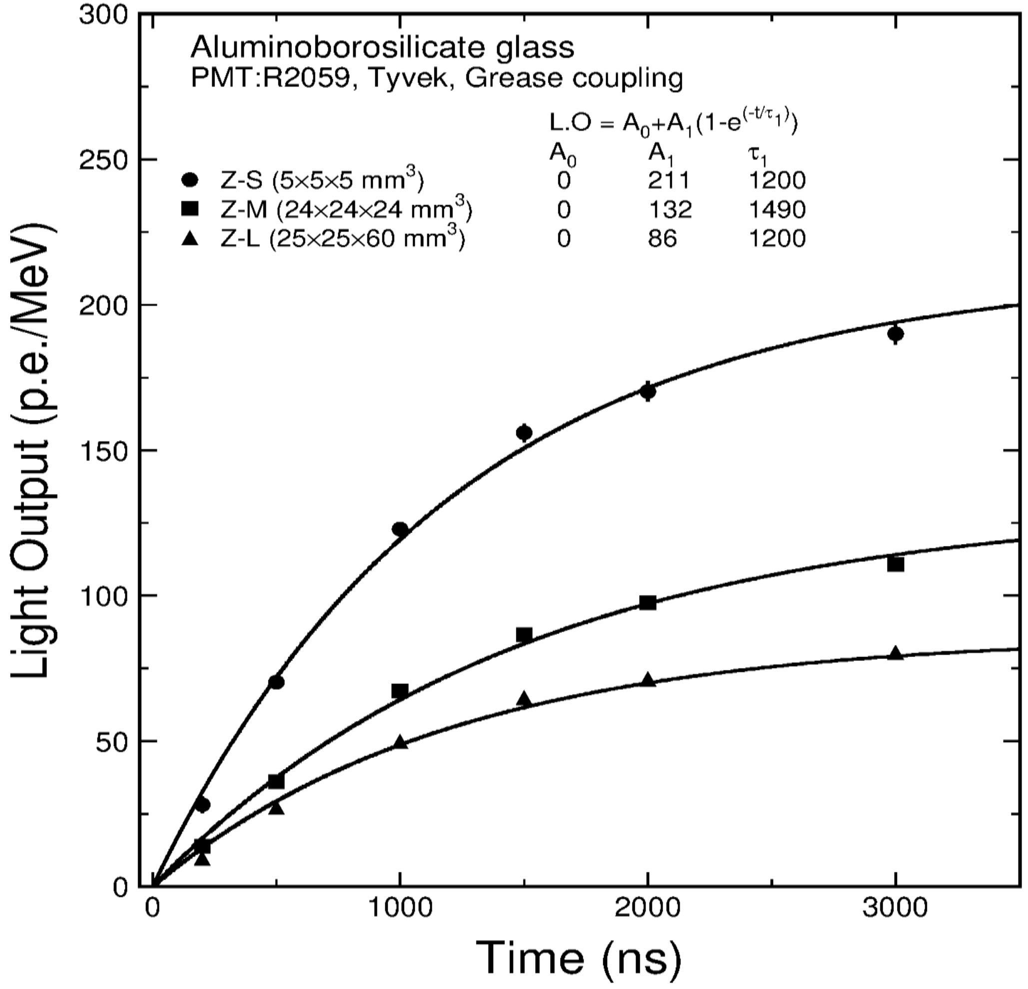




ABS Light Output and Decay

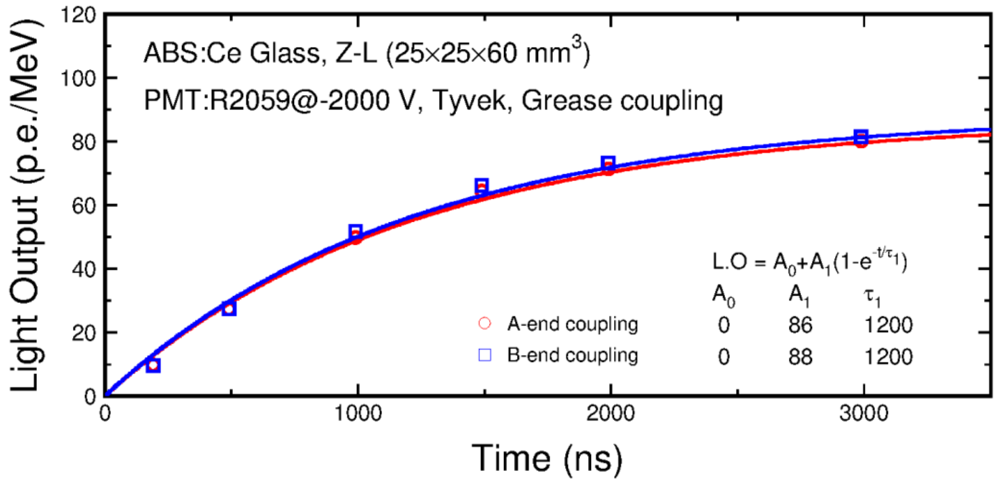
LO: 211 p.e./MeV, taking out EWQE LY: >1,136 ph/MeV, decay time: 1,200 ns

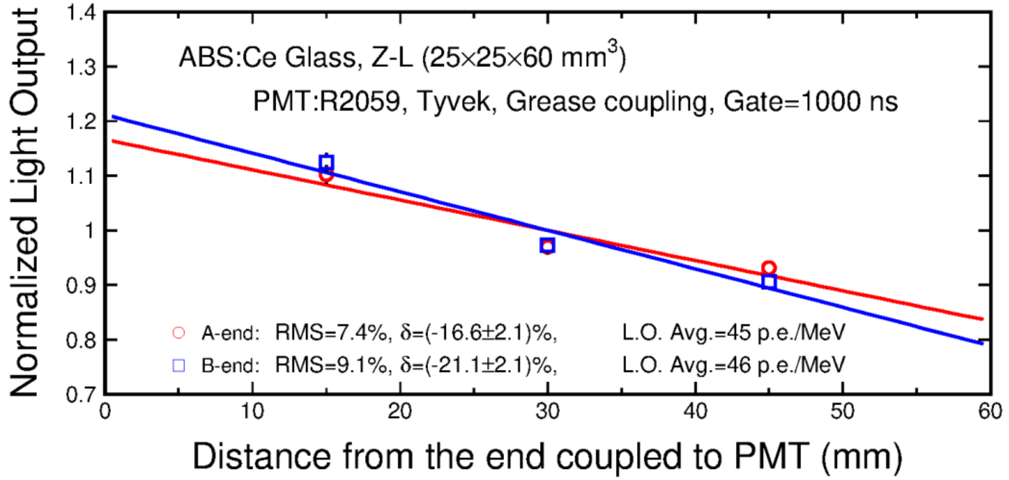


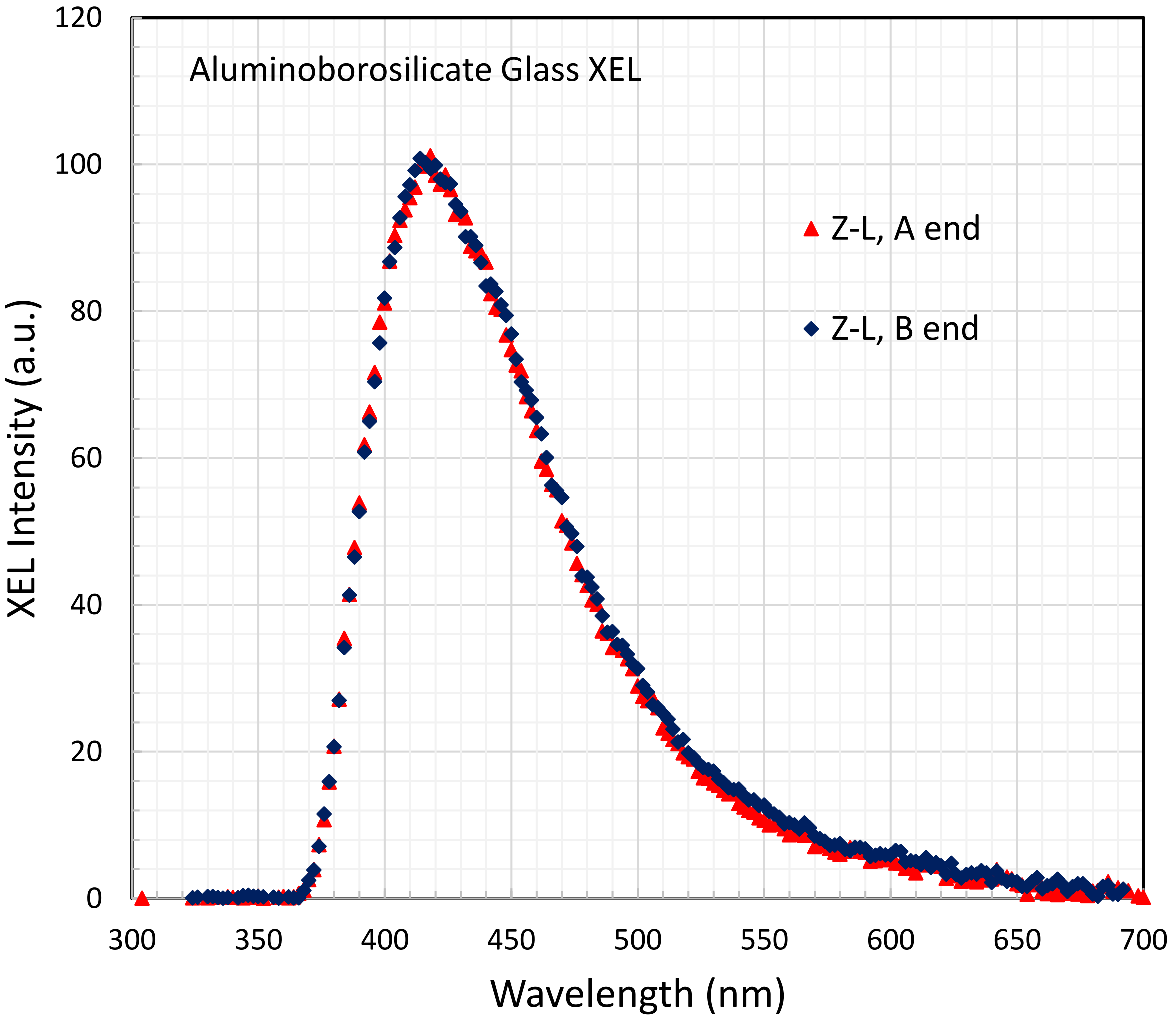


ABS Z-L (6 cm long) Uniformity

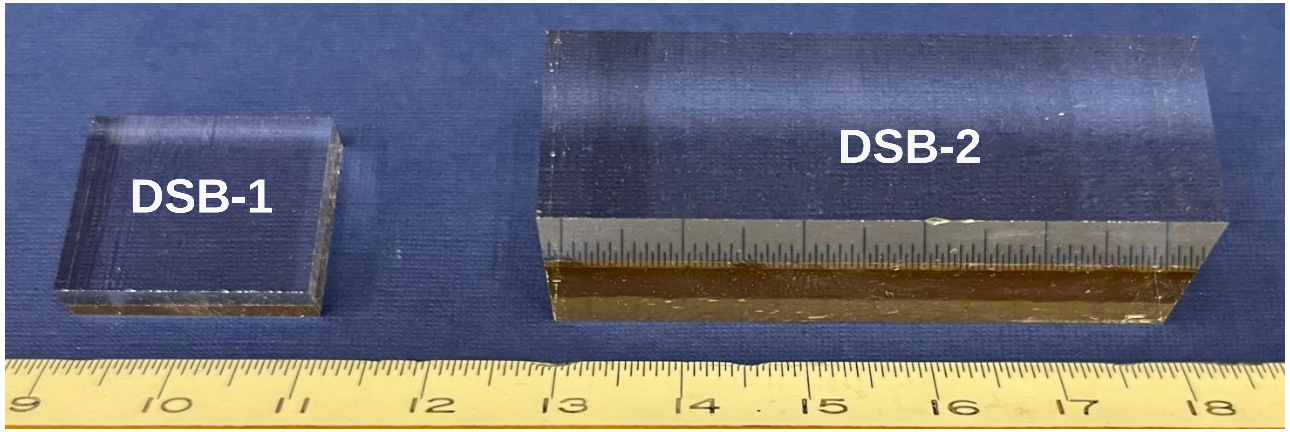
Light response non-uniformity: 7-9%

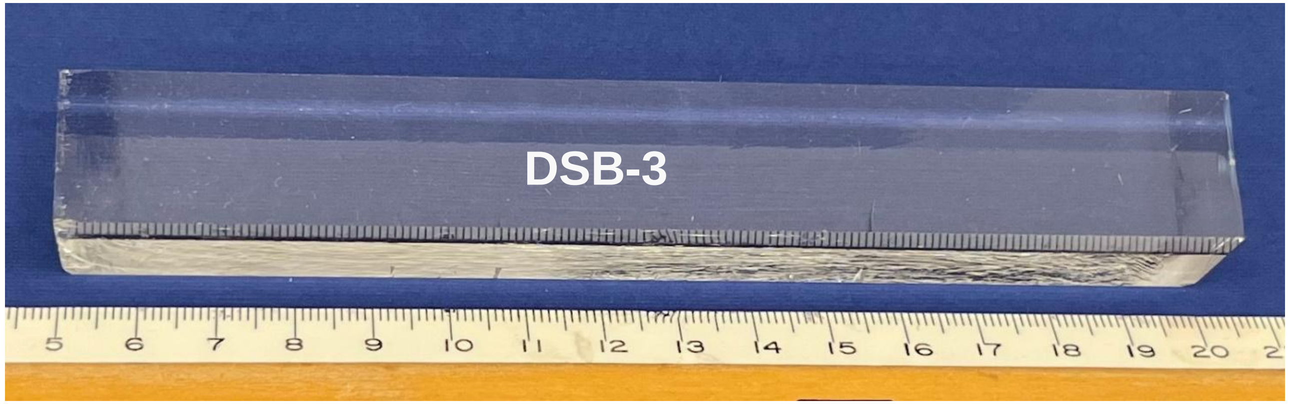






DSB:Ce Glass Samples





DSB samples provided by the 2nd Physics institute of Justus-Liebig University Giessen, Germany

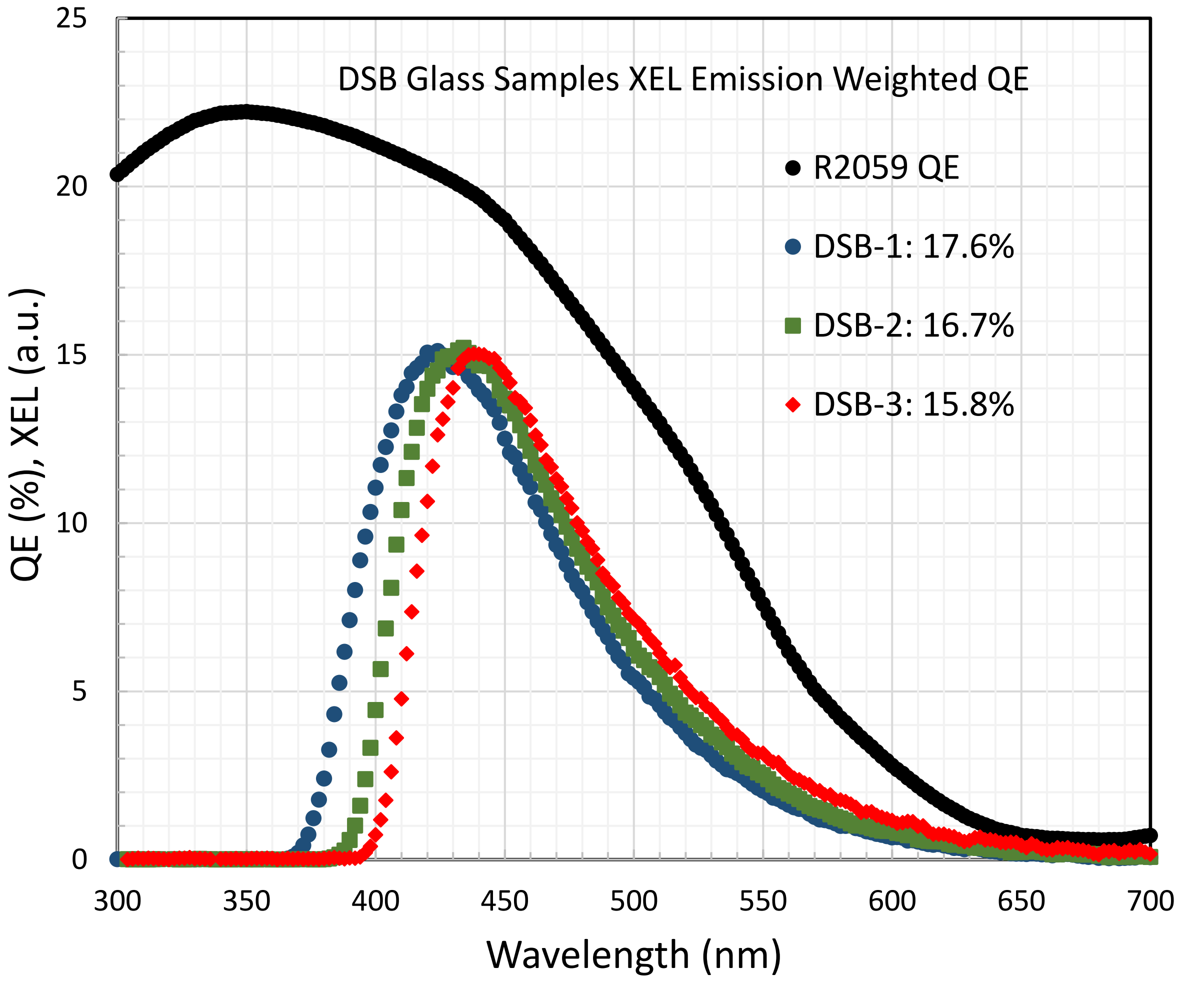
Measurements at room temperature:

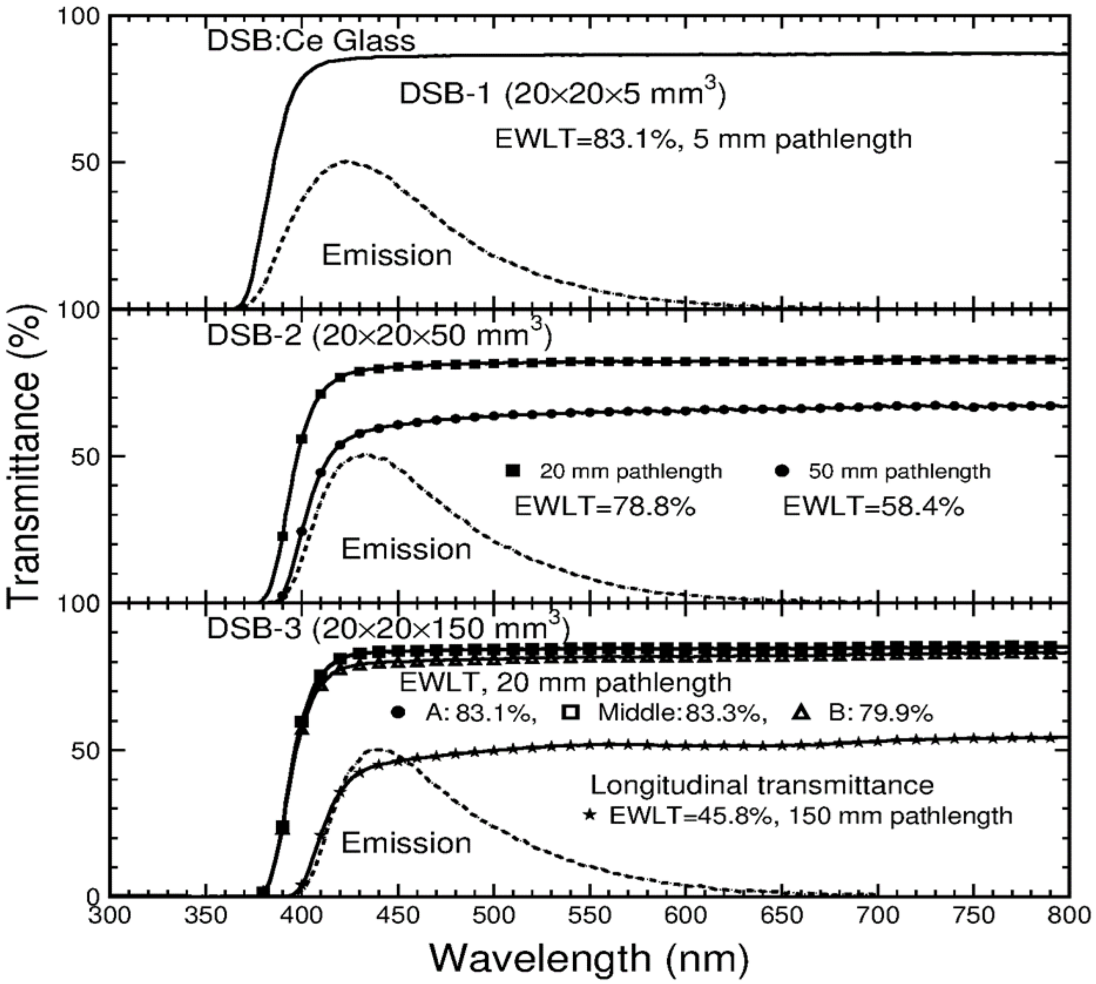
- X-ray excited emission and EWQE,
- Transmittance and EWLT,
- Pulse Height Spectra (PHS),
- Light Output (LO) vs. integration time and decay time (τ).

No.	ID	Doping	Dimensions (mm^3)	Lot info.	Received date
1	DSB-1	Ce	20×20×5	new batch, low LY	Aug. 2, 2023
2	DSB-2	Ce	20×20×50	new batch, low LY	Aug. 2, 2023
3	DSB-3	Ce	20×20×150	new batch, low LY	Nov. 3, 2023

DSB XEL, EWQE and Transmittance

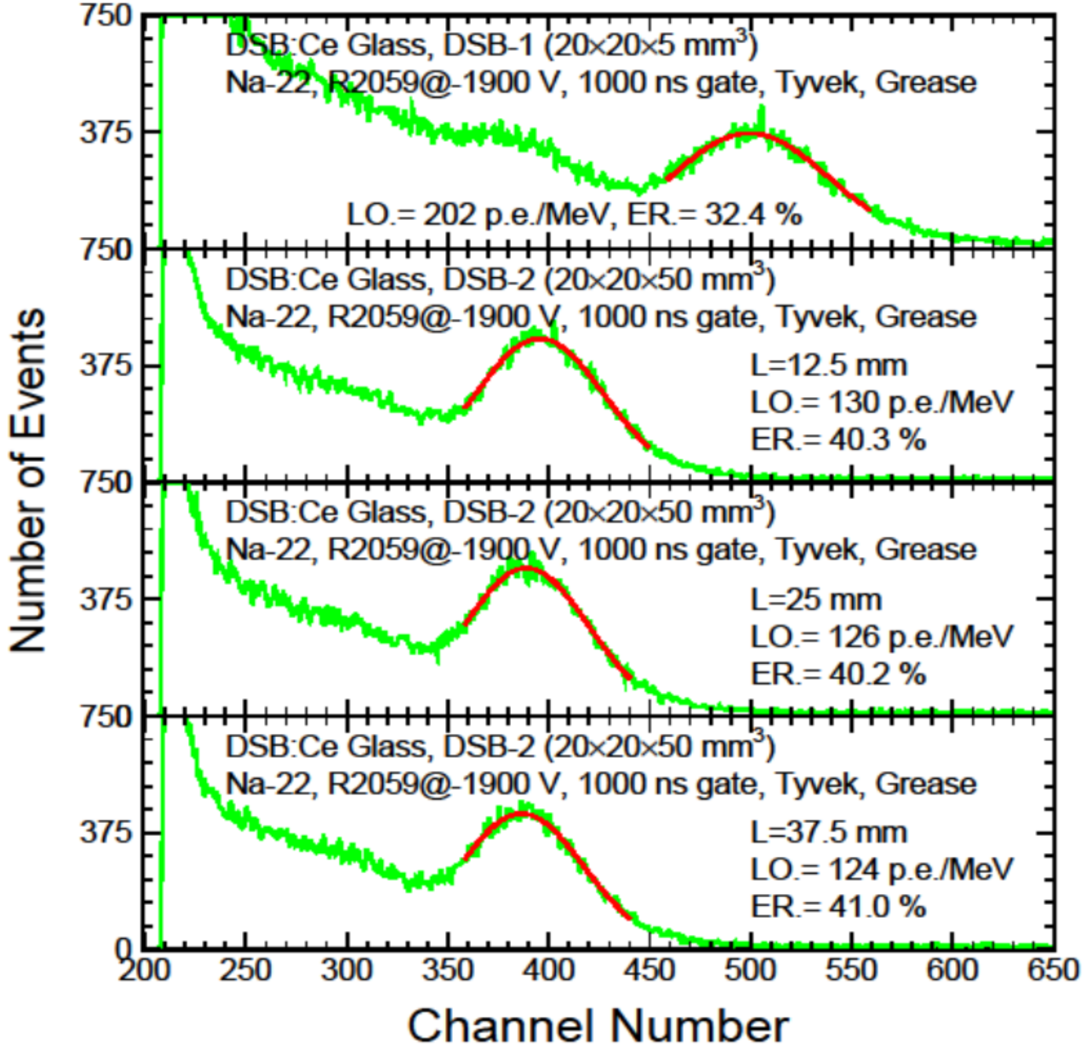
XEL (440 nm), EWQE (16%, R2059) and EWLT (46%)
All affected by light path length for the same chemical composition

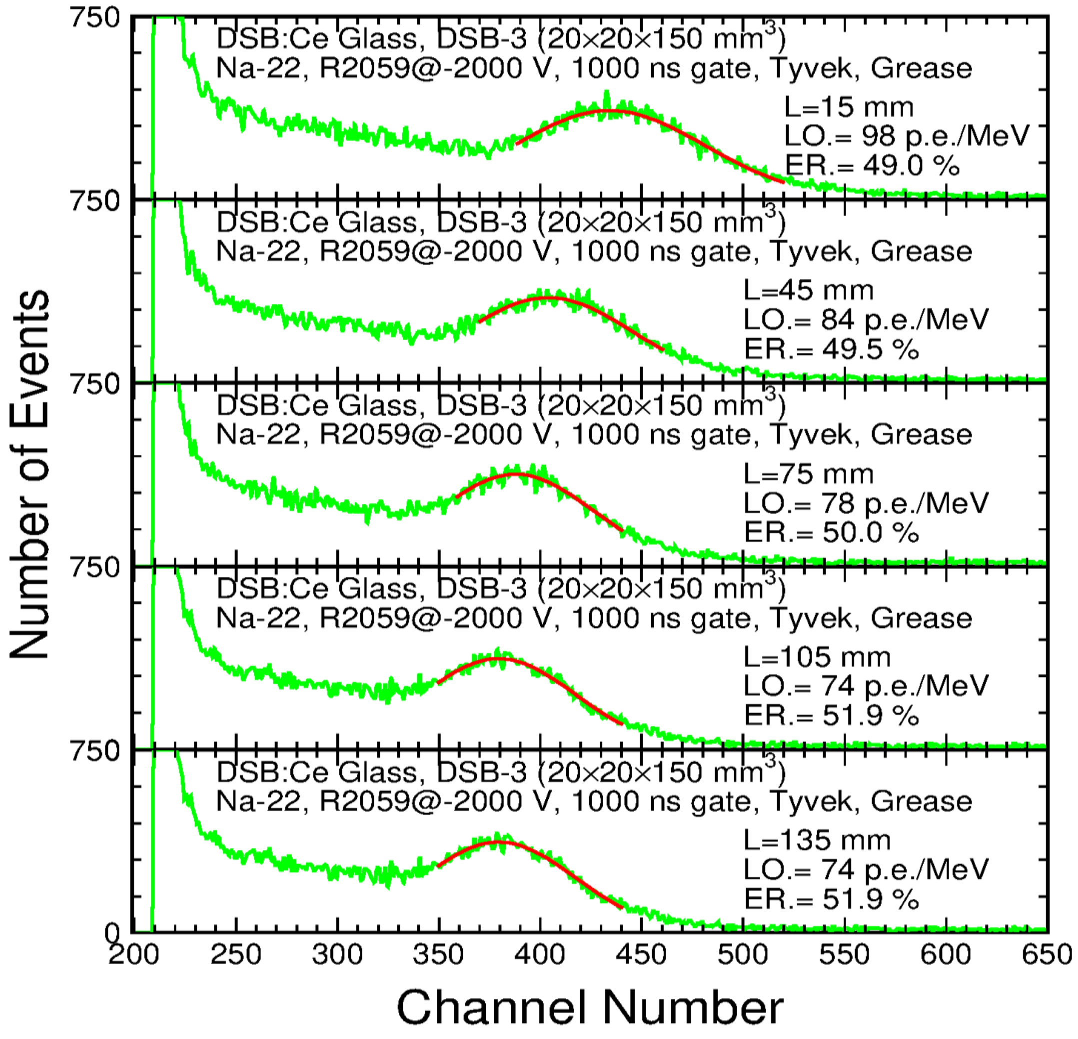




DSB Pulse Height Spectra

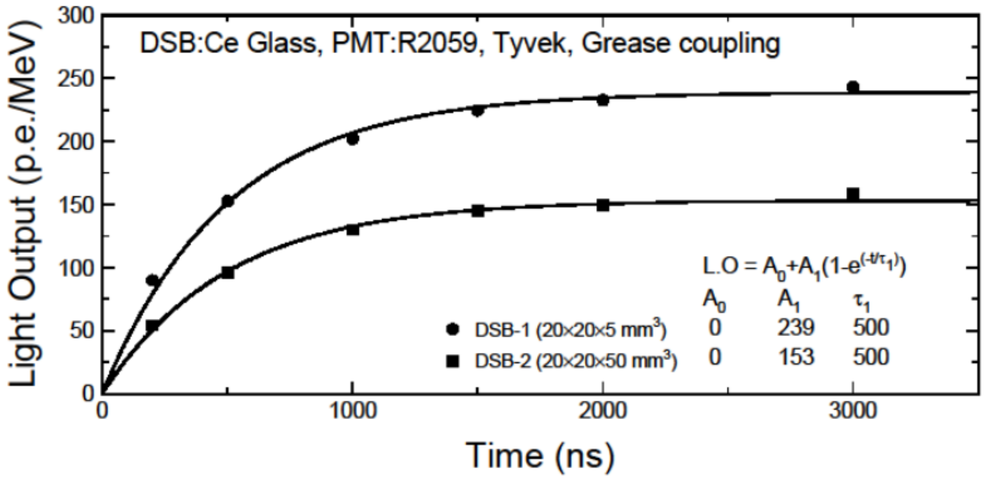
LO: 70-202 p.e./MeV, ER: 30%-50% affected by light path length and chemical composition

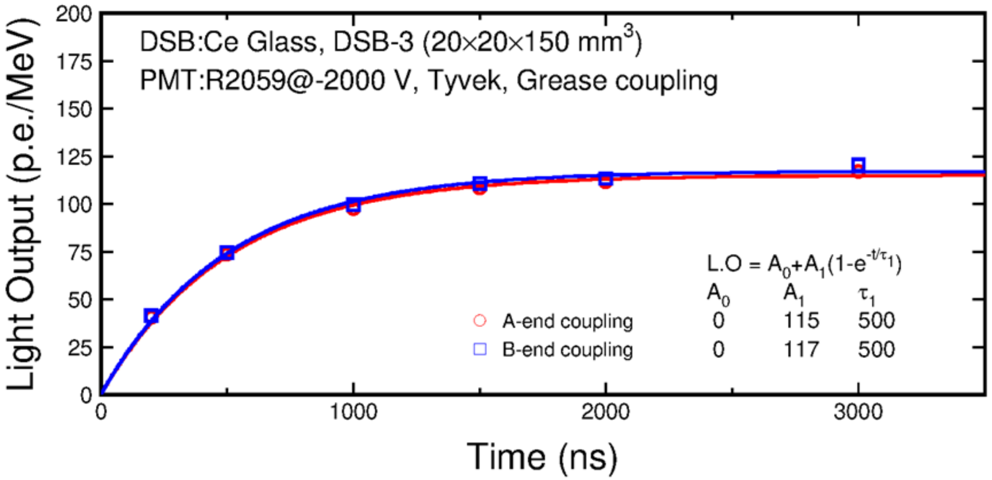


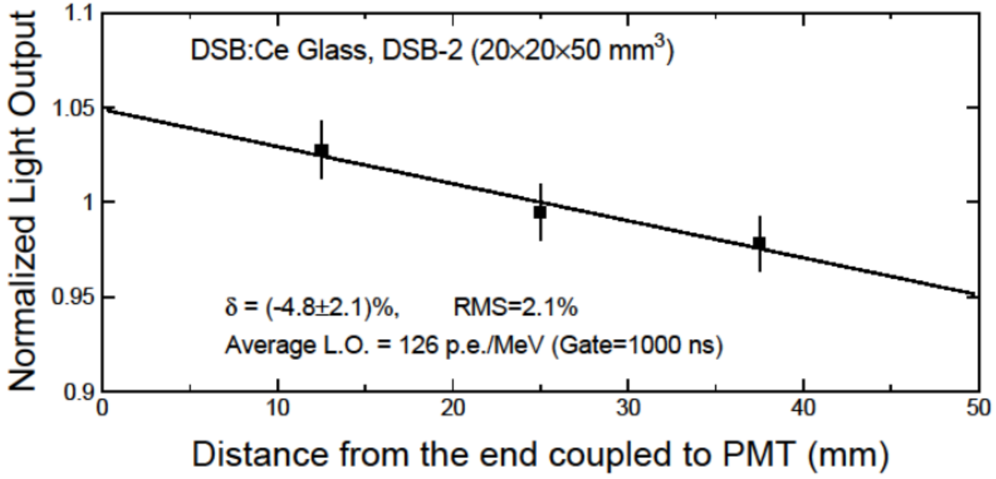


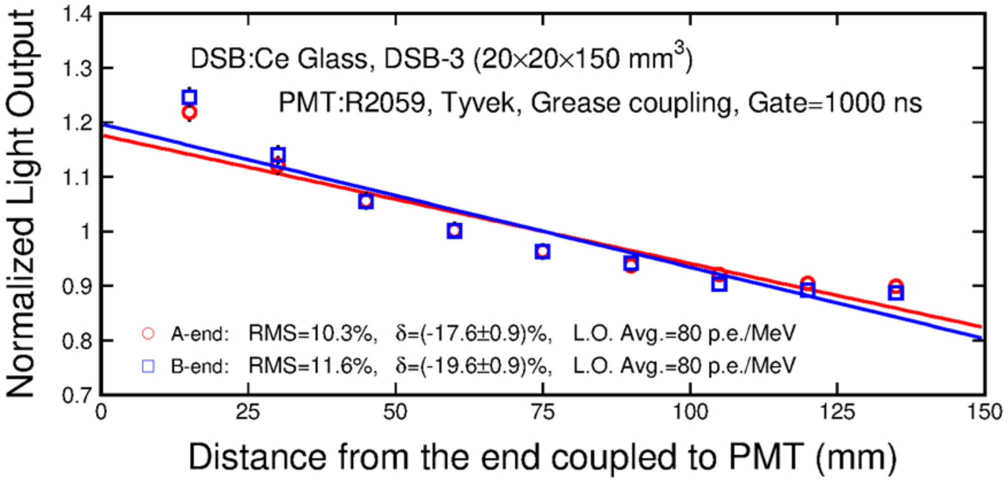
DSB LO, Decay and LRU

LO: 240 p.e./MeV Taking out EWQE LY: >1,360 ph/MeV, Decay time: 500 ns, uniformity: 10-12%



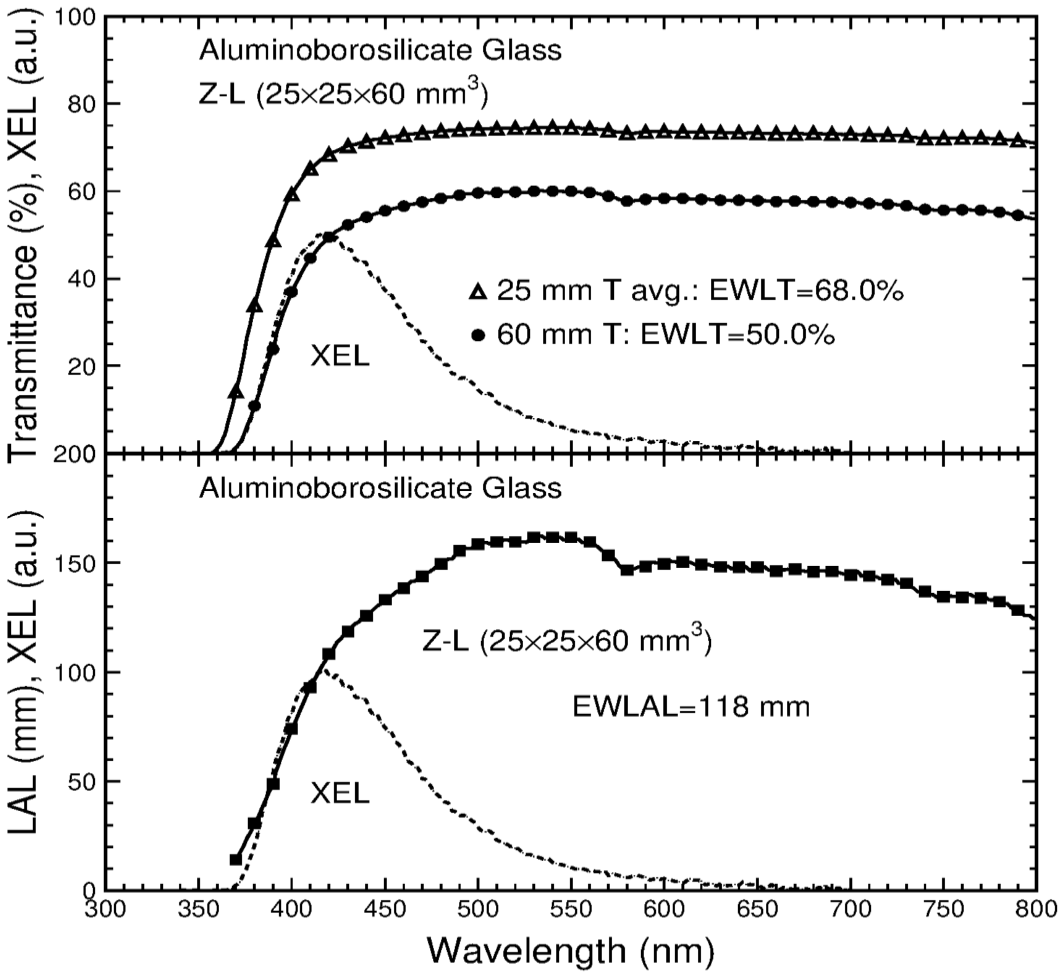


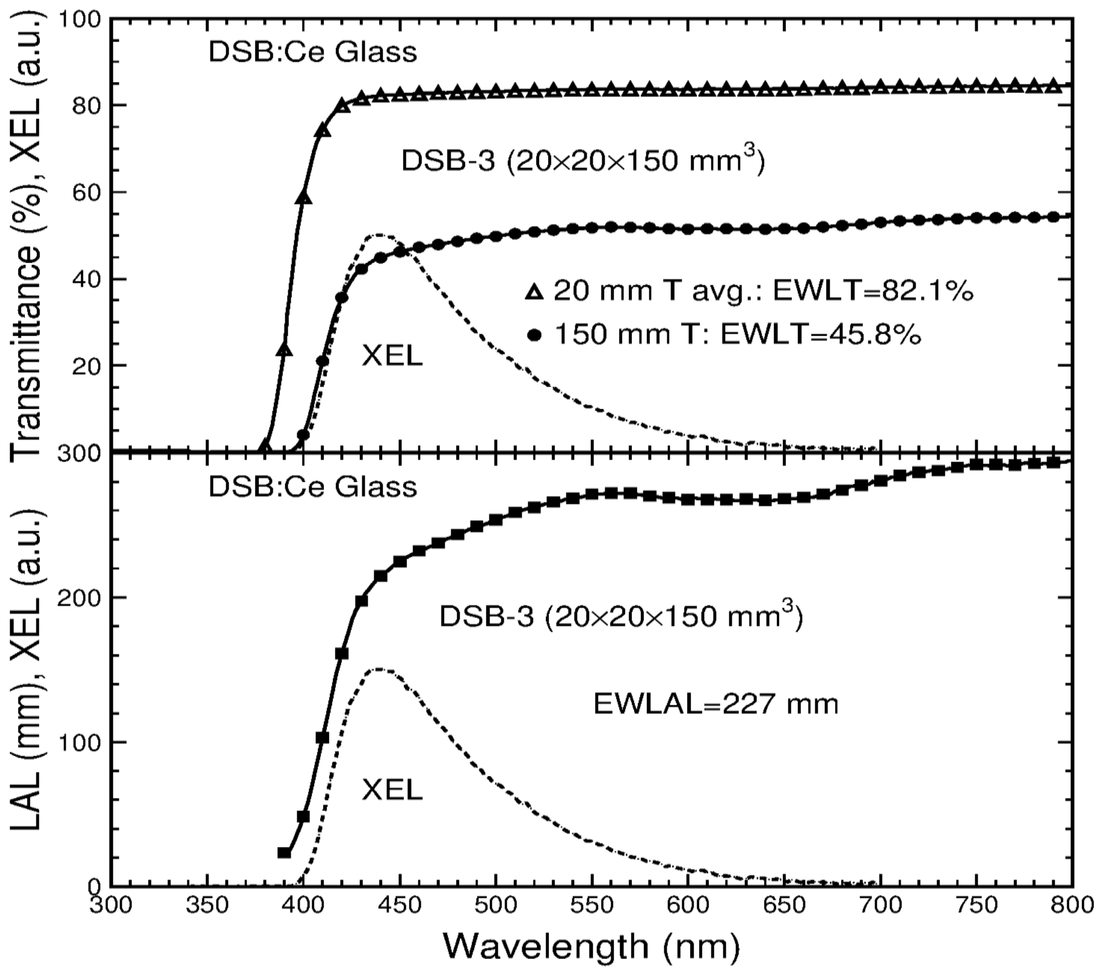




Light Attenuation Length (LAL)

Calculated by using the ratio of transverse and longitudinal transmittance
EWLAL: 118 mm and 227 mm for 6 cm ABS Z-L and 15 cm DSB-3





Performance Comparison with Crystals

Glass has lower light output and longer decay time

Parameters	1.5X_0 Cubes			Gd-ABS			Gd-DSB		
	BGO	BSO	PWO	Z-S	Z-M	Z-L	DSB-1	DSB-2	DSB-3
Dimensions (mm^3)	17×17×17	17×17×17	13×13×13	5×5×5	24×24×24	25×25×60	20×20×5	20×20×50	20×20×150
XEM Peak (nm)	480	480	428	406	410	416	426	432	438
Decay time (ns)	312	94	30	1200	1490	1200	500	500	500
EWQE (R2059, %)	13.0	13.0	18.5	18.6	17.9	17.8	17.6	16.7	15.8
E.R for 511 keV (R2059, %)	16.7	34.9	86.5	45.2	60.7	66.2	32.4	40.2	50.5
Fitted LO (R2059, p.e./MeV)	760	152	23	211	132	87	239	153	116
Fitted LO/QE (R2059, ph/MeV)	5846	1169	124	1136	738	490	1361	915	735
EWPDE (s14160-3015ps, %)	31.8	31.8	28.6	26.5	27.8	29.0	29.7	31.1	31.9

An Approach for LY Improvement

Congruent crystallization in an alkali earth metal silicate glass system by high temperature annealing may improve LY

Fig. 1 (b)

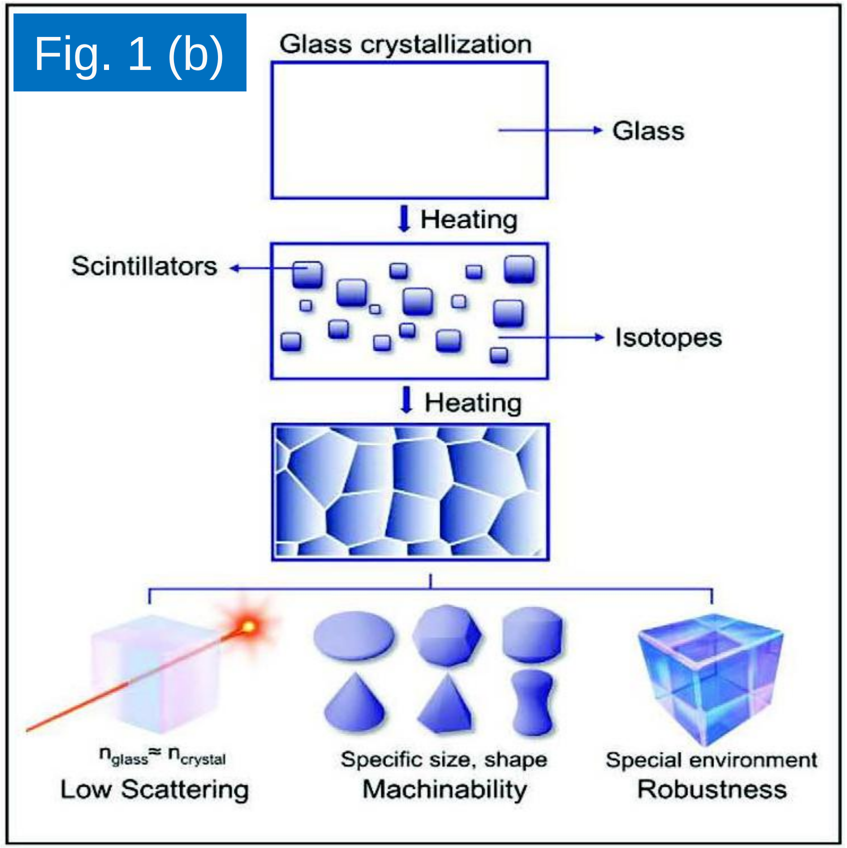
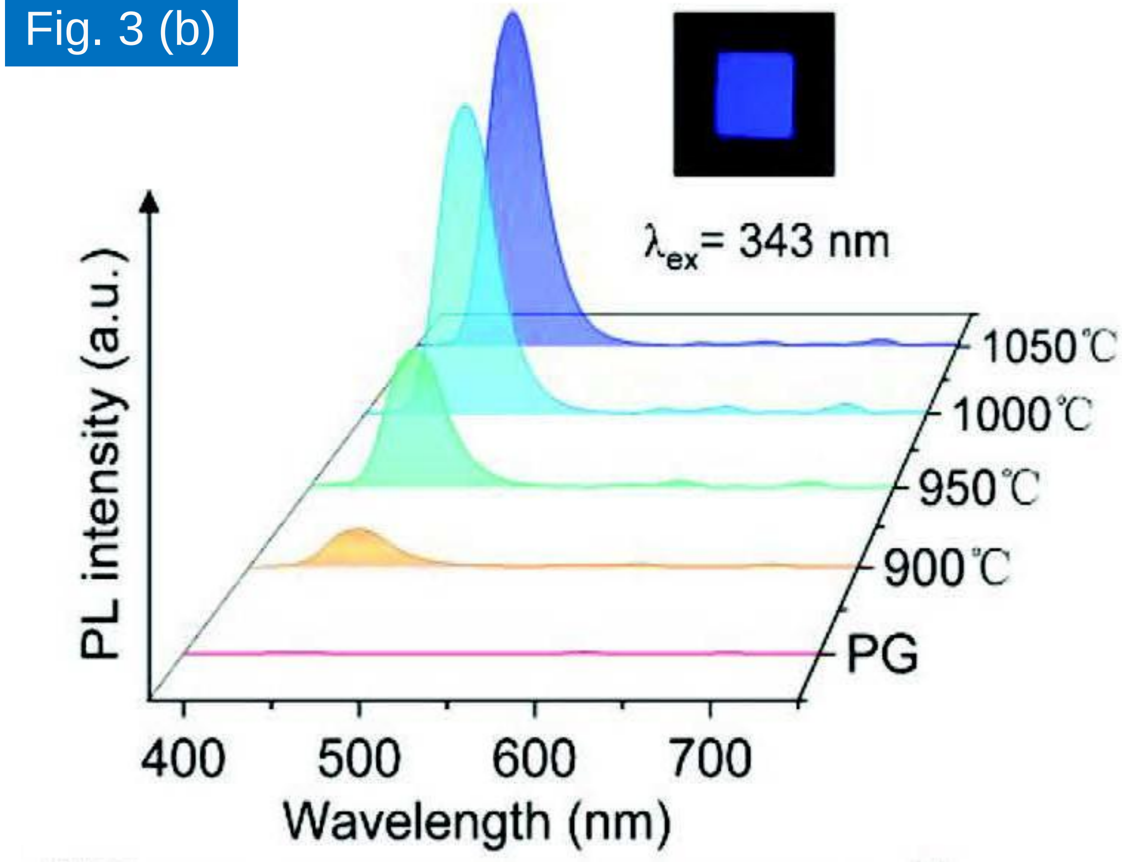


Fig. 3 (b)



D. Wang *et. al.*, Transparent Glass Composite Scintillator with High Crystallinity for Efficient Thermal Neutron Detection *Advanced Functional Materials, **34**,* 2401992 (2024).

Summary

Novel cost-effective heavy scintillating glass is under development for a longitudinally segmented Calvision crystal ECAL with multiple readout. Combined the IDEA HCAL, it promises excellent EM and Hadronic resolutions for the proposed Higgs factory.

ABS and DSB glass samples of up to 6 and 15 cm long were measured at Caltech. Both show adequate light output and response uniformity. The DSB sample is faster, brighter and more uniform than the ABS sample.

ABS, however, appears more promising for the HHCAL detector concept because of its high density of 6 g/cm^3.

R&D will continue to investigate bright, fast and cost-effective heavy inorganic scintillators in crystal and glass form for CalVision.

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