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# Large Size ABS and DSB Scintillating Glass Samples

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January 18, 2024

# Introduction

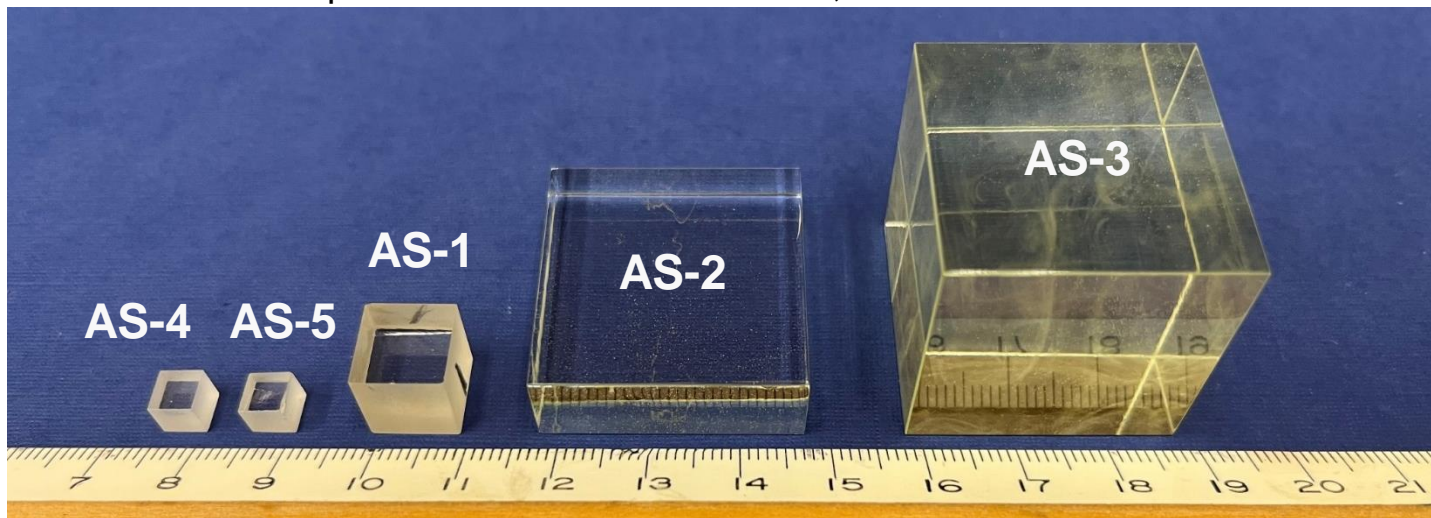
Crystals for the CalVision beam test characterized at Caltech: BGO, BSO,  $\text{PbF}_2$ , PWO and  $\text{LYSO:Ce}$ .

Three additional aluminoborosilicate glass ( $\text{B}_2\text{O}_3\text{-SiO}_2\text{-Al}_2\text{O}_3\text{-Gd}_2\text{O}_3\text{-Ce}_2\text{O}_3$ , ABS) samples from IHEP, including one of  $25\times 25\times 60\text{ mm}^3$ , and one additional barium di-silicate ( $\text{BaO-2SiO}_2$ , DSB) glass sample of  $20\times 20\times 150\text{ mm}^3$  from Giessen were characterized with results reported today. They may be used in the 2024 beam test.

Novel heavy glass scintillators from RMD Inc. are expected in 2024.

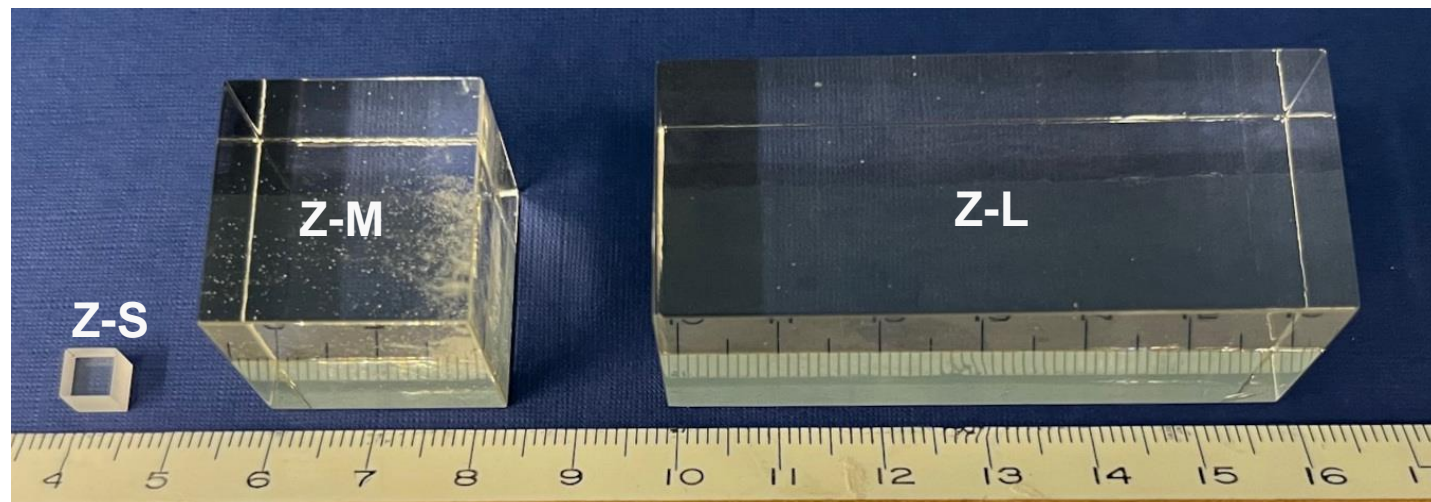
# Aluminoborosilicate Glass Samples

The 1<sup>st</sup> batch samples were received on June 15, 2023.



No.	ID	Doping	Dimensions (mm <sup>3</sup> )	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 <sup>3+</sup>	5×5×5	OB, high LO.
5	AS-5	1.5Ce <sup>3+</sup>	5×5×5	OB, high LO
6	Z-S	Ce <sup>3+</sup>	5×5×5	Gd-based
7	Z-M	Ce <sup>3+</sup>	24×24×24	Gd-based
8	Z-L	Ce <sup>3+</sup>	<b>25×25×60</b>	Gd-based

The 2<sup>nd</sup> batch samples were received on Nov 22, 2023.

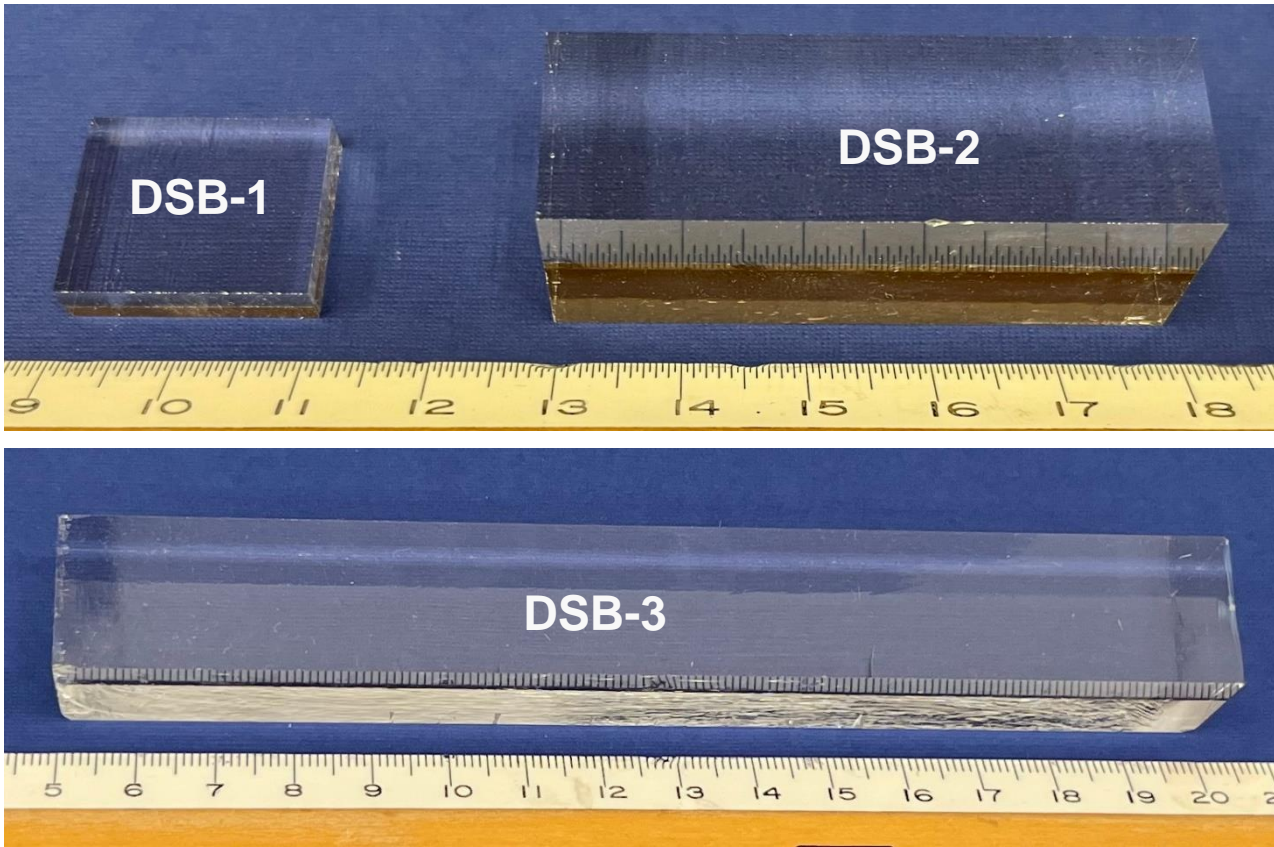


Measurements at room temperature:

- X-ray excited emission,
- Emission weighted QE/PDE,
- Transmittance,
- Pulse Height Spectra (PHS),
- Light Output (LO) vs. Integration Time and Decay Time ( $\tau$ ),
- Longitudinal Uniformity.



# DSB:Ce Glass Samples



Measurements at room temperature:

- X-ray excited emission,
- Emission weighted QE/PDE,
- Transmittance,
- Pulse Height Spectra (PHS),
- Light Output (LO) vs. Integration Time and Decay Time ( $\tau$ ),
- Longitudinal Uniformity.

No.	ID	Doping	Dimensions (mm <sup>3</sup> )	Lot info.	Received date
1	DSB-1	Ce	20x20x5	new batch, low LY	Aug. 2, 2023
2	DSB-2	Ce	20x20x50	new batch, low LY	Aug. 2, 2023
3	DSB-3	Ce	<b>20x20x150</b>	new batch, low LY	Nov. 3, 2023

# Glass Sample Density

Density affected by chemical composition ABS: 6 g/cm<sup>3</sup>, DSB: 4.3 g/cm<sup>3</sup>

Glass Sample	Dimension	Measurement (mm)			Volume (cm <sup>3</sup> )	Weight (g)	$\rho$ (g/cm <sup>3</sup> )
	(mm <sup>3</sup> )	L	W	H			
DSB-1	20×20×5	20.015	19.964	5.029	2.010	8.6	4.3
DSB-2	20×20×50	20.015	19.939	50.013	19.959	85.9	4.3
<b>DSB-3</b>	<b>20×20×150</b>	<b>20.142</b>	<b>20.117</b>	<b>150.114</b>	<b>60.826</b>	<b>259.50</b>	<b>4.3</b>
AS-1	10×10×10	9.982	10.084	10.109	1.018	5.1	5.0
AS-2	30×30×10	29.997	29.972	10.008	8.998	48.0	5.3
AS-3	30×30×30	29.997	30.023	28.499	25.666	137.5	5.4
AS-4	5×5×5	4.953	4.953	4.801	0.118	0.705	6.0
AS-5	5×5×5	4.953	4.953	4.648	0.114	0.675	5.9
Z-S	5×5×5	4.953	5.004	5.055	0.125	0.754	6.0
Z-M	24×24×24	23.978	24.003	24.130	13.888	82.8	6.0
<b>Z-L</b>	<b>25×25×60</b>	<b>24.917</b>	<b>24.943</b>	<b>59.944</b>	<b>37.256</b>	<b>222.7</b>	<b>6.0</b>

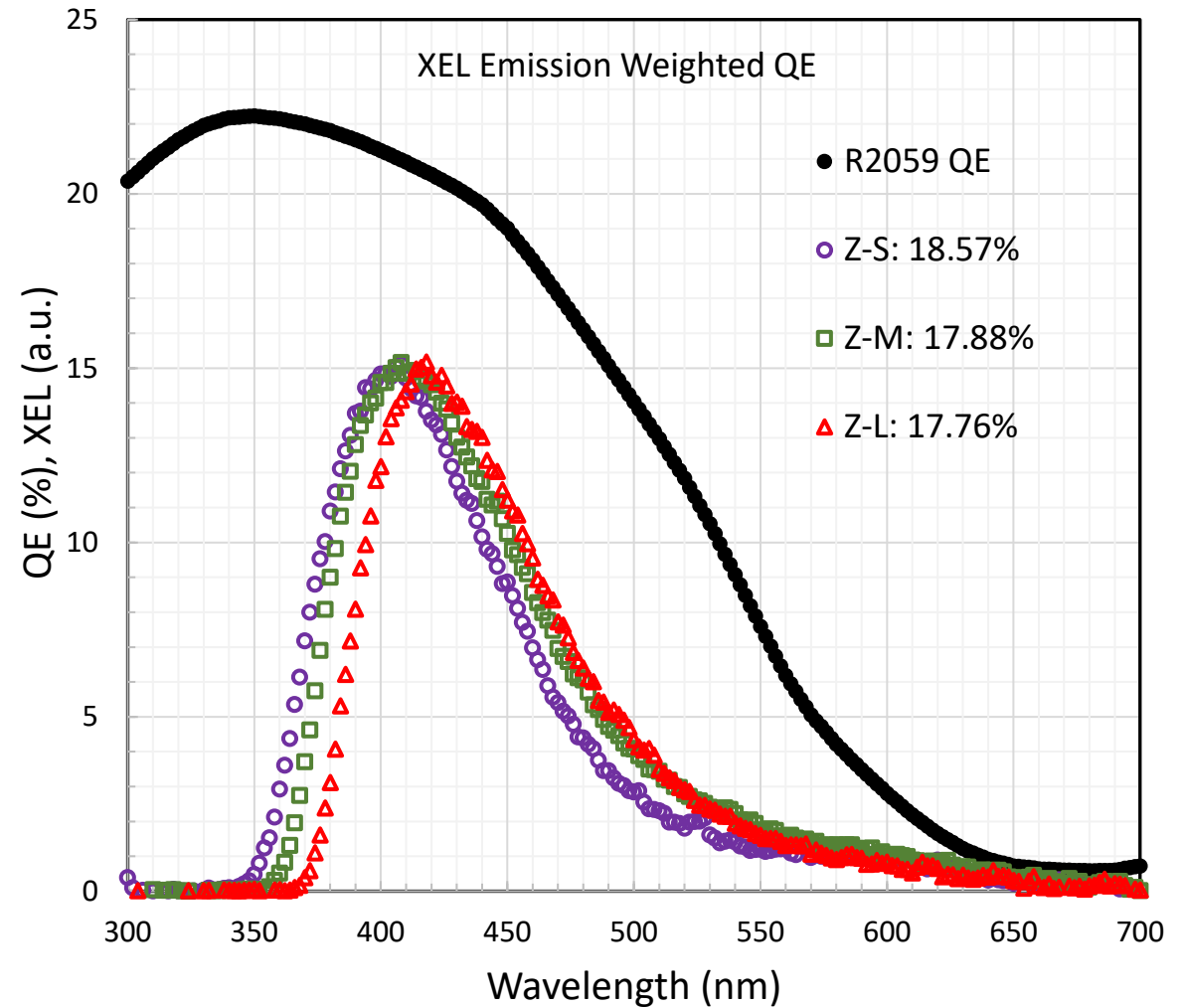
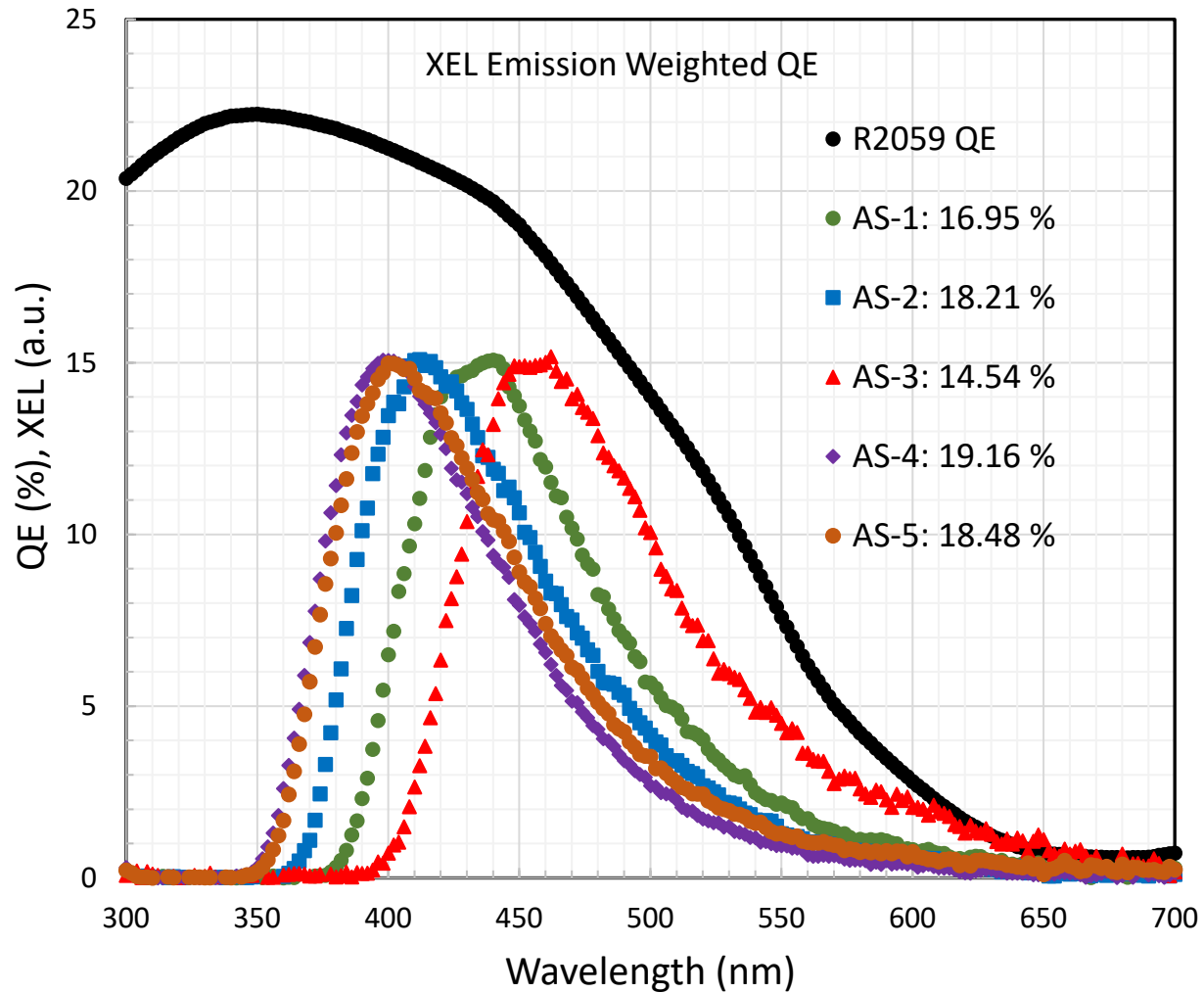
# Nuclear Properties

Affected by chemical composition ABS: 1.55 cm  $\chi_0$  and 24.7 cm  $\lambda_1$  DSB: 2.58 cm  $\chi_0$  and 30.9 cm  $\lambda_1$

Crystal and Glass	BGO	BSO	PWO	Gd-ABS						Gd-DSB	
				ABS**	AS-1	AS-2	AS-3	AS-4,5	Z-S, M, L	BGS*	DSB-1,2,3
Density (g/cm <sup>3</sup> )	7.1	6.8	8.3	4.5	5.0	5.3	5.4	6.0	<b>6.0</b>	4.2	<b>4.3</b>
$\chi_0$ (cm)	1.12	1.15	0.89	2.41	1.89	1.88	1.79	1.56	<b>1.55</b>	2.62	<b>2.58</b>
$R_M$ (cm)	2.23	2.33	2.00	3.09	2.97	2.74	2.73	2.49	<b>2.50</b>	3.33	<b>3.24</b>
$\lambda_1$ (cm)	22.7	23.4	20.7	28.8	29.3	26.5	26.6	24.2	<b>24.7</b>	31.8	<b>30.9</b>
$Z_{\text{eff}}$	71.5	73.8	73.6	51.9	56.0	54.3	55.3	56.6	<b>56.9</b>	49.7	<b>49.5</b>
dE/dX (MeV/cm)	9.0	8.6	10.1	6.4	6.7	7.2	7.3	8.0	<b>8.0</b>	5.9	<b>6.1</b>

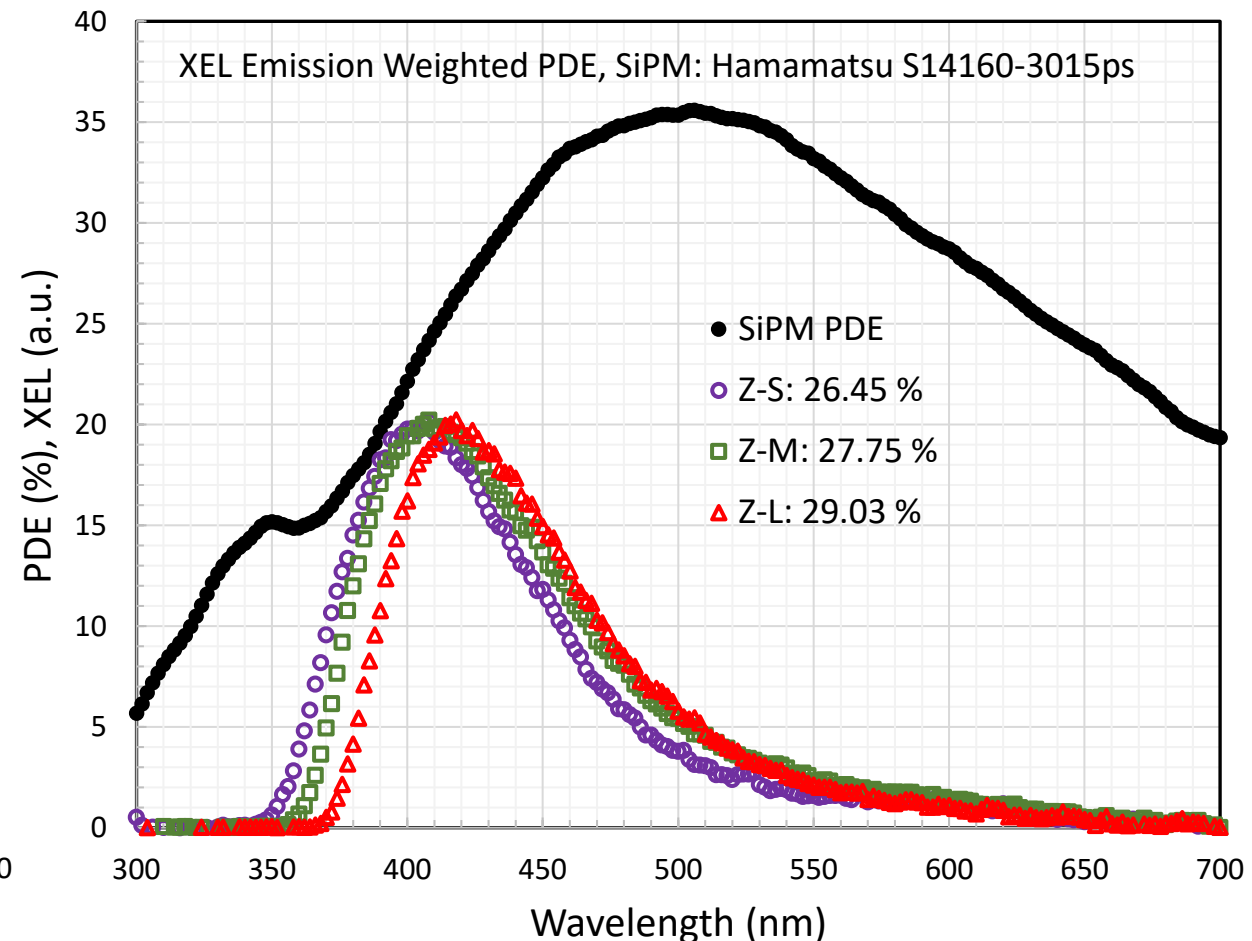
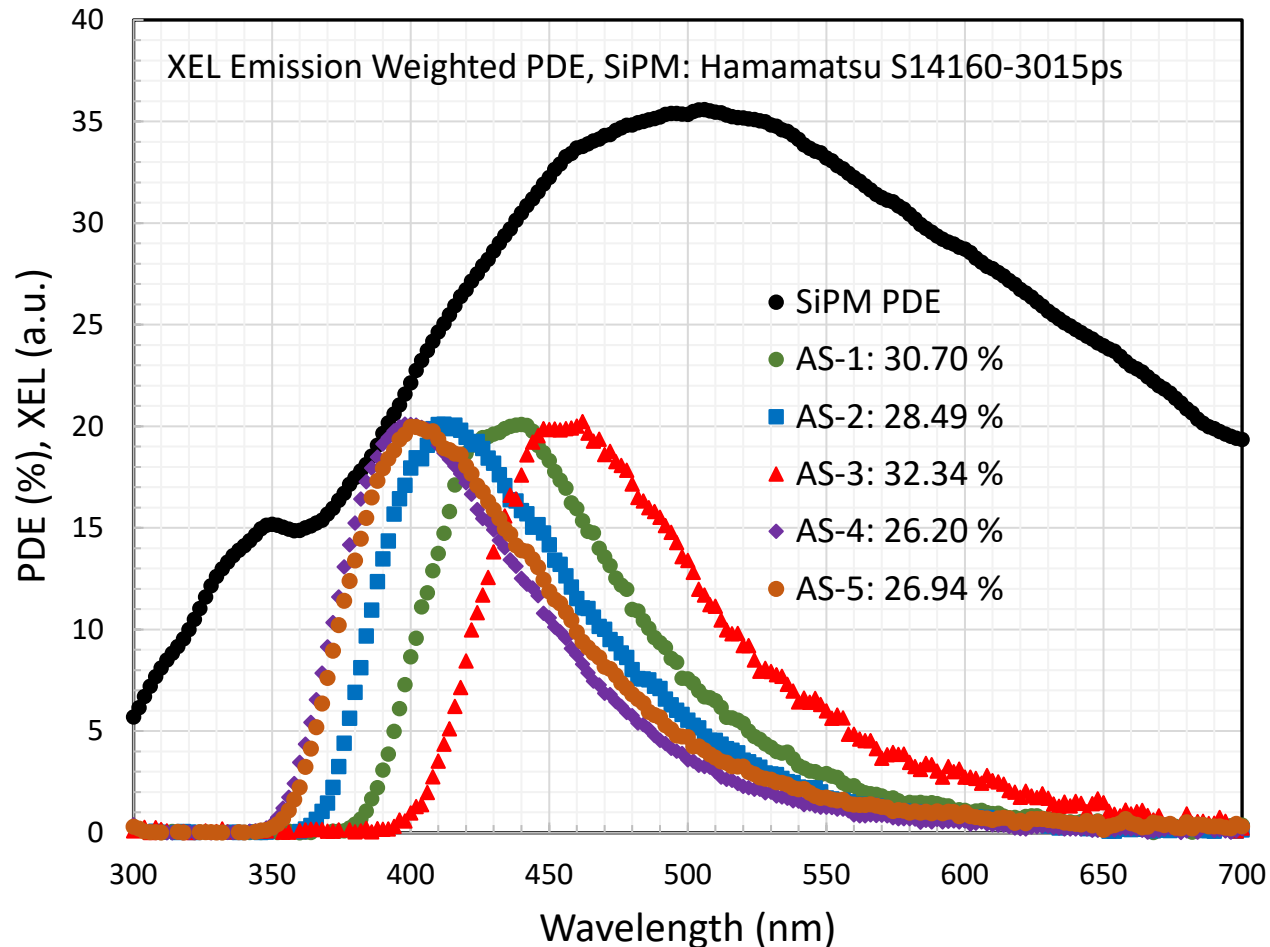
# ABS: XEL and EWQE for Hamamatsu R2059

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



# ABS: XEL and EWPDE for Hamamatsu S14160-3015ps at 43 V

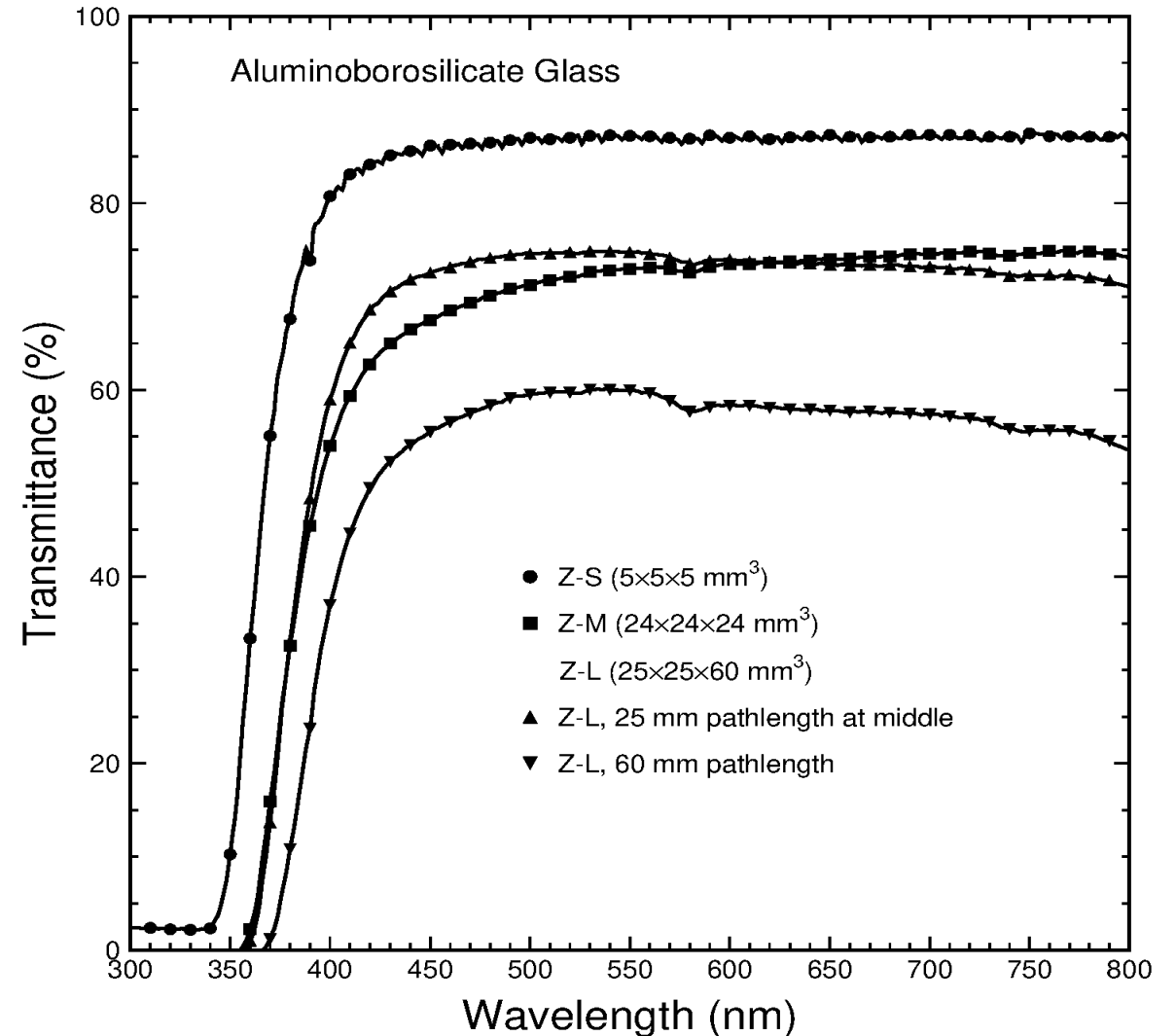
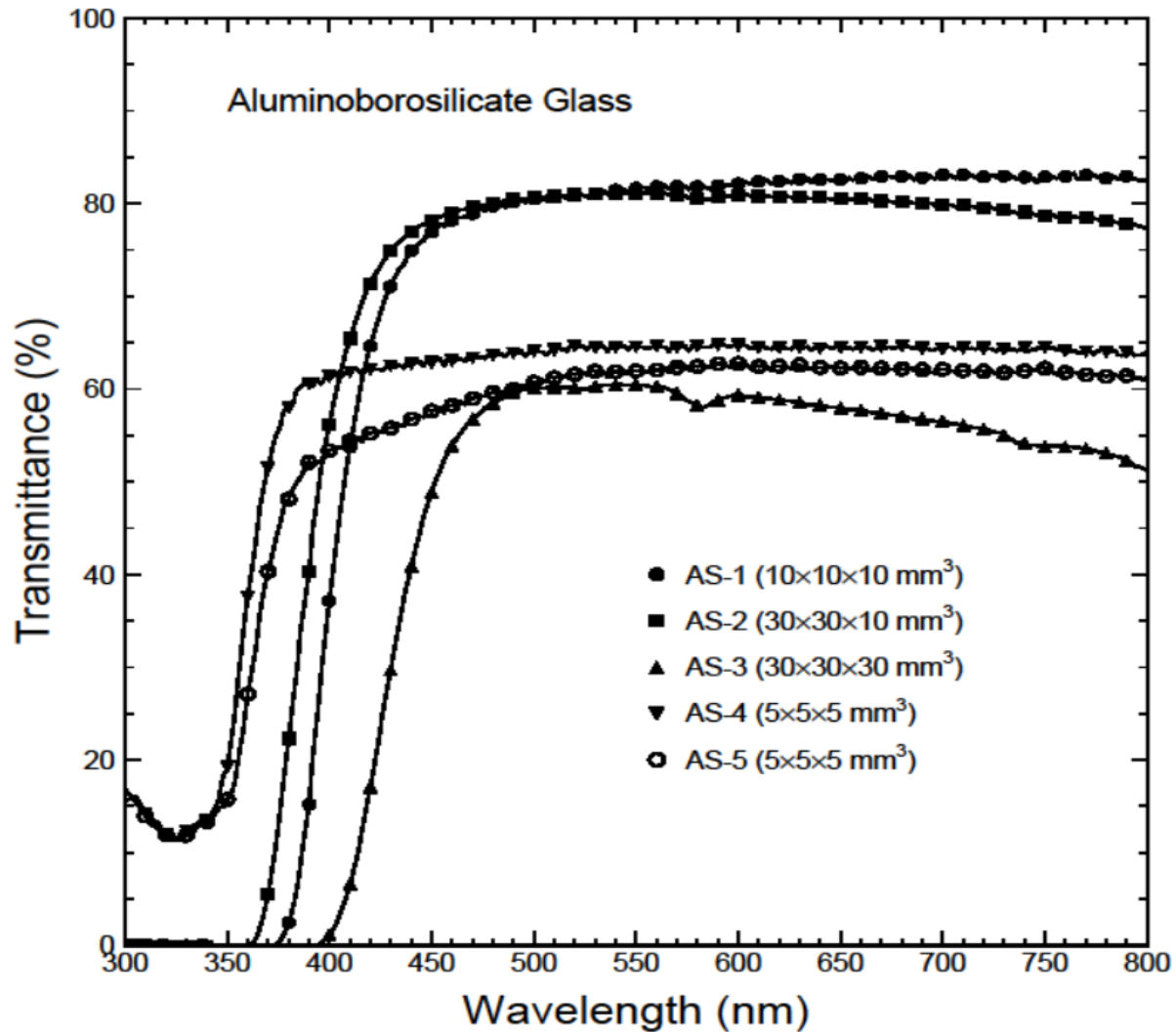
XEL (420 nm) and EWPDE (29%) affected by light path length and chemical composition





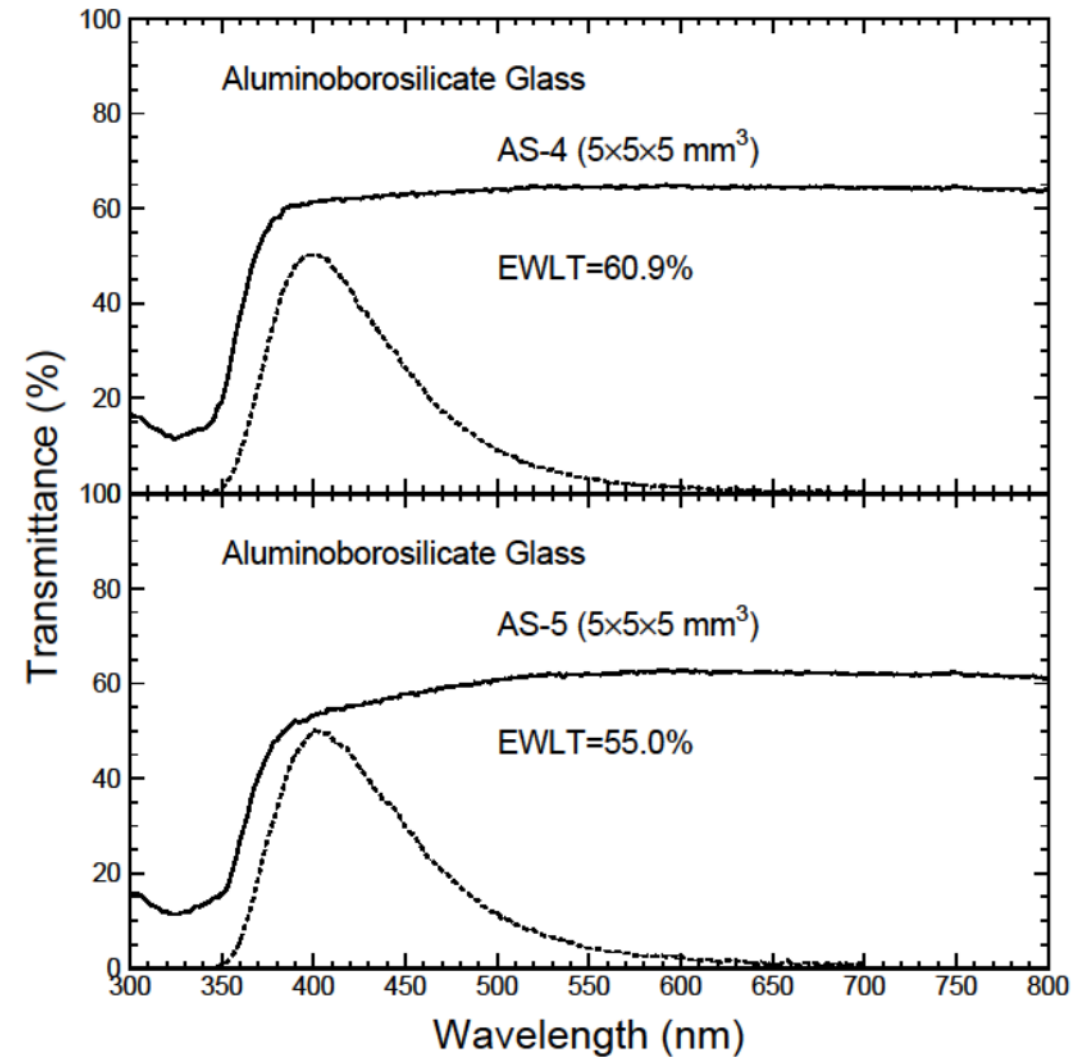
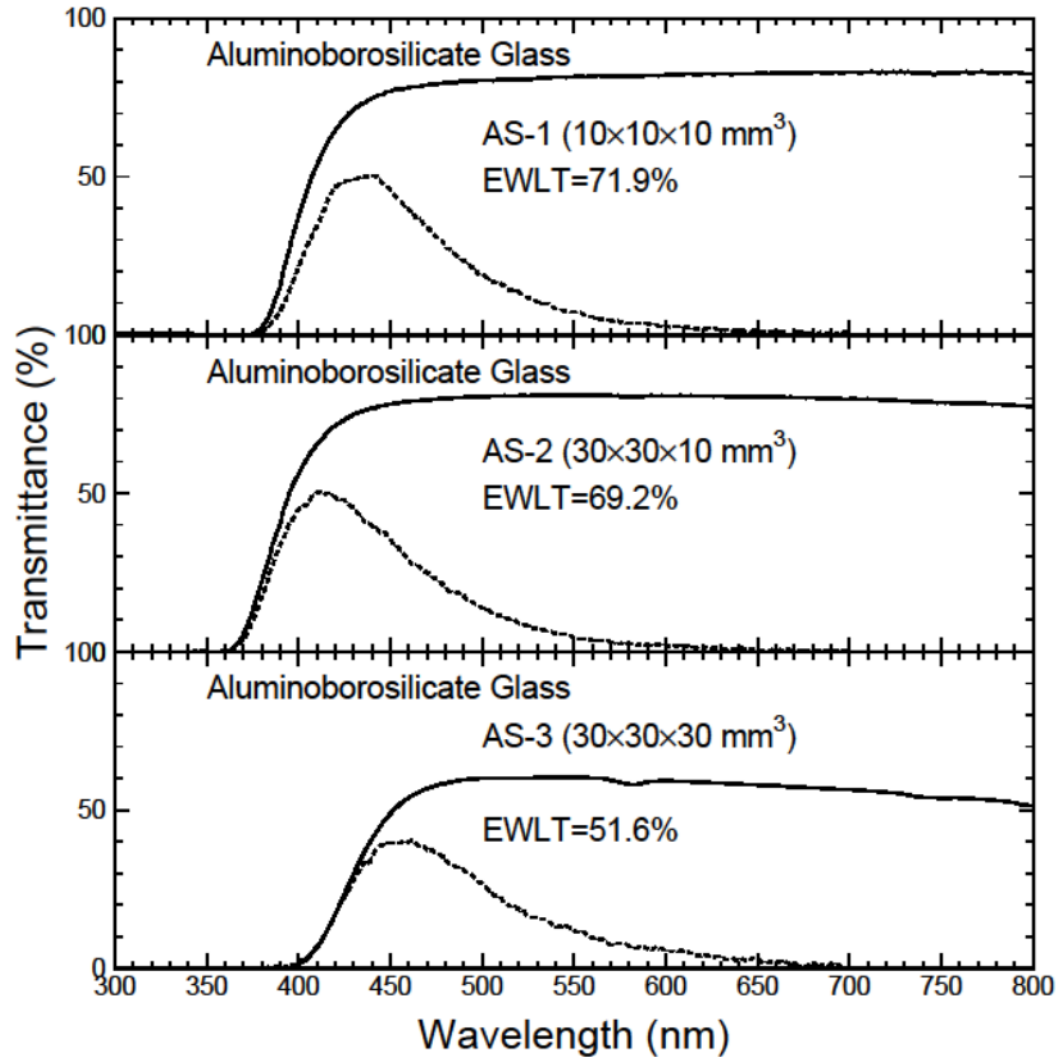
# ABS: Transmittance

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



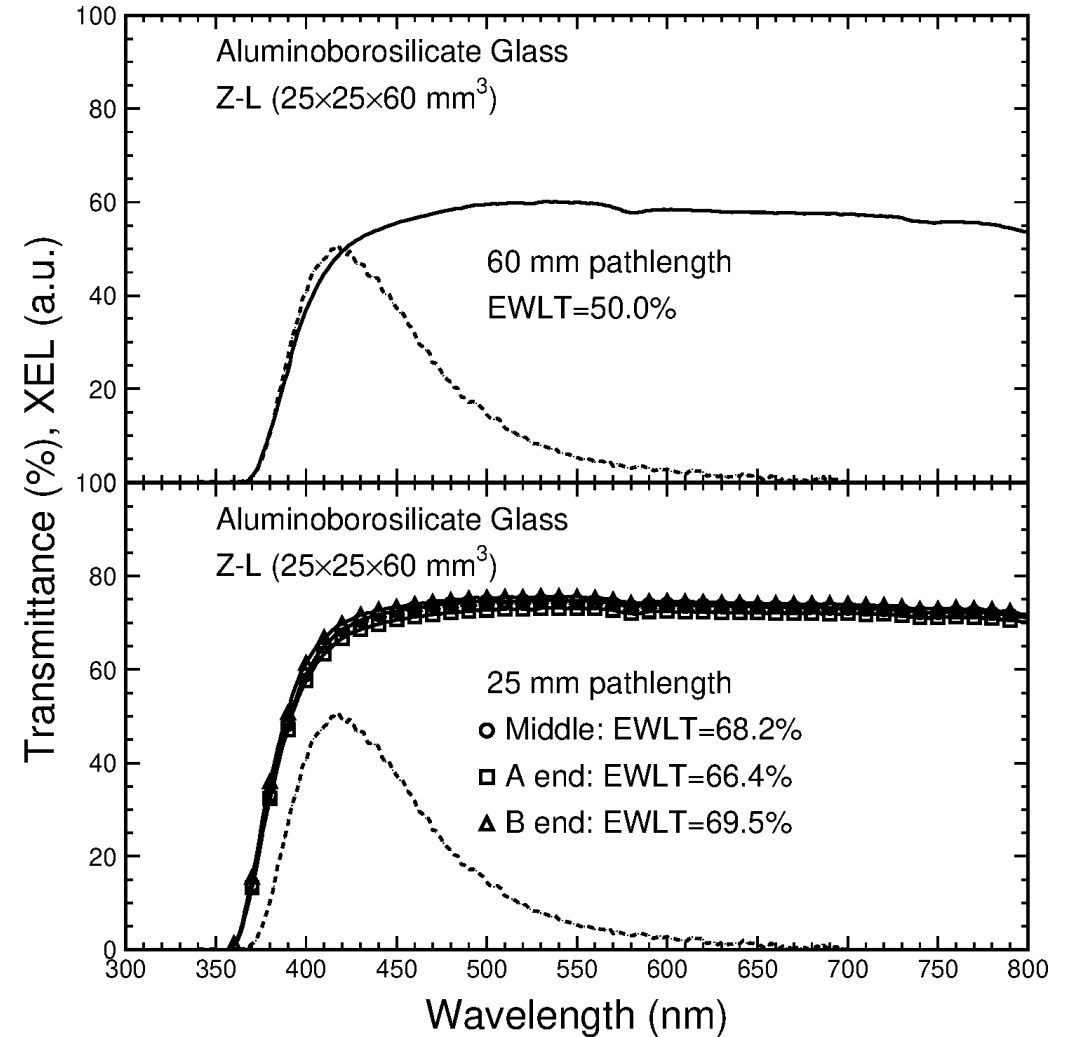
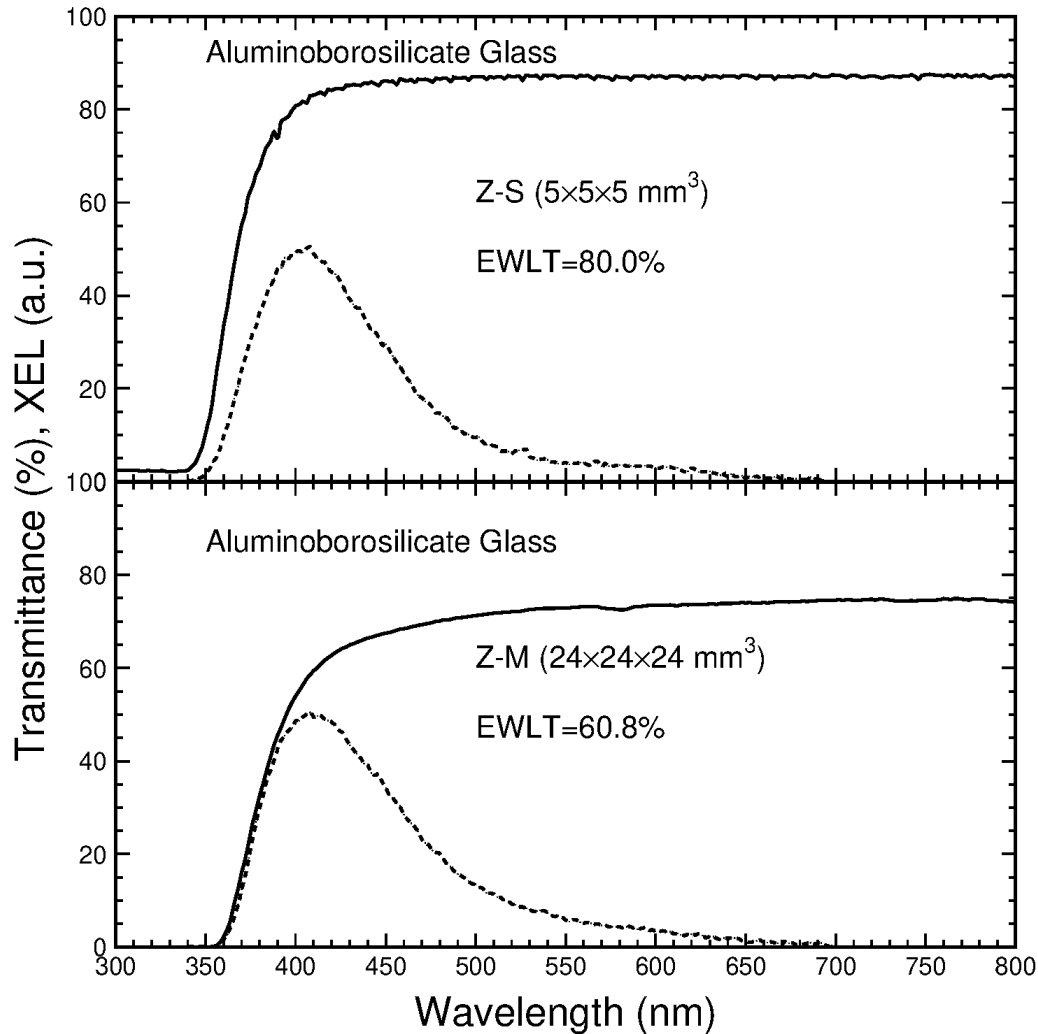
# ABS: Emission Weighted Transmittance

EWLT: 50%-72% affected by light path length and chemical composition



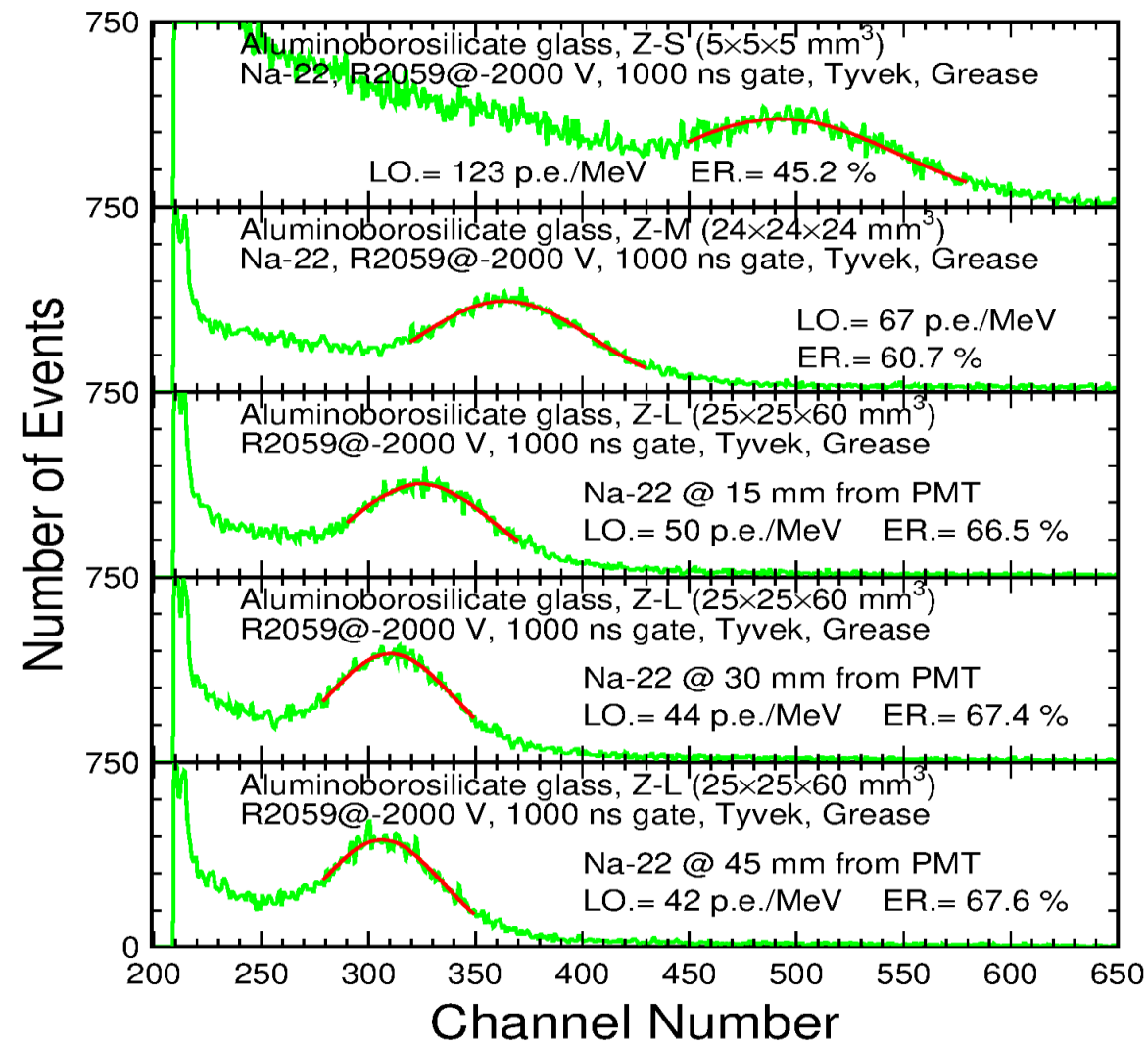
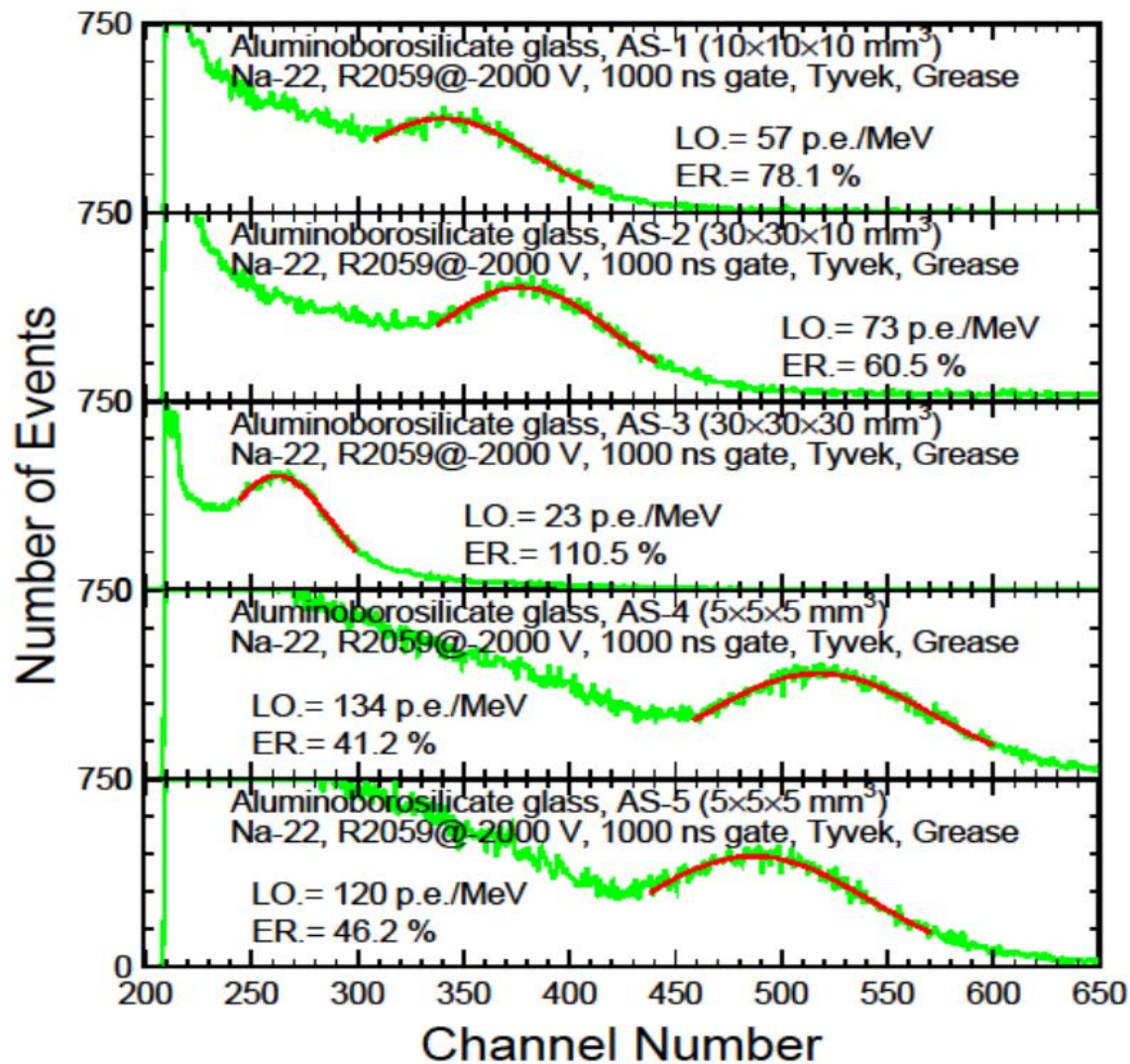
# ABS: Emission Weighted Transmittance

EWLT: 50%-80%, depending on light path length



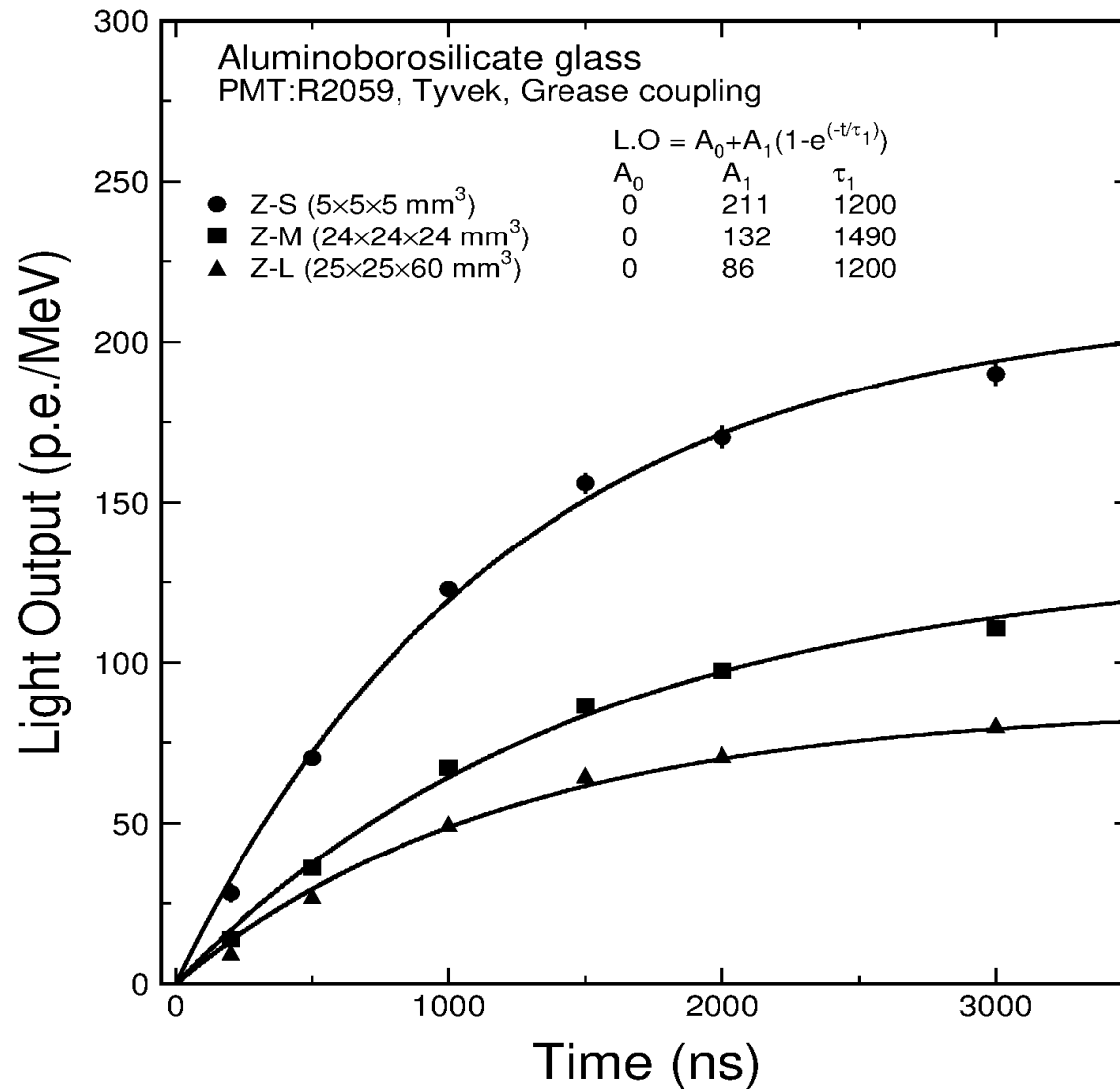
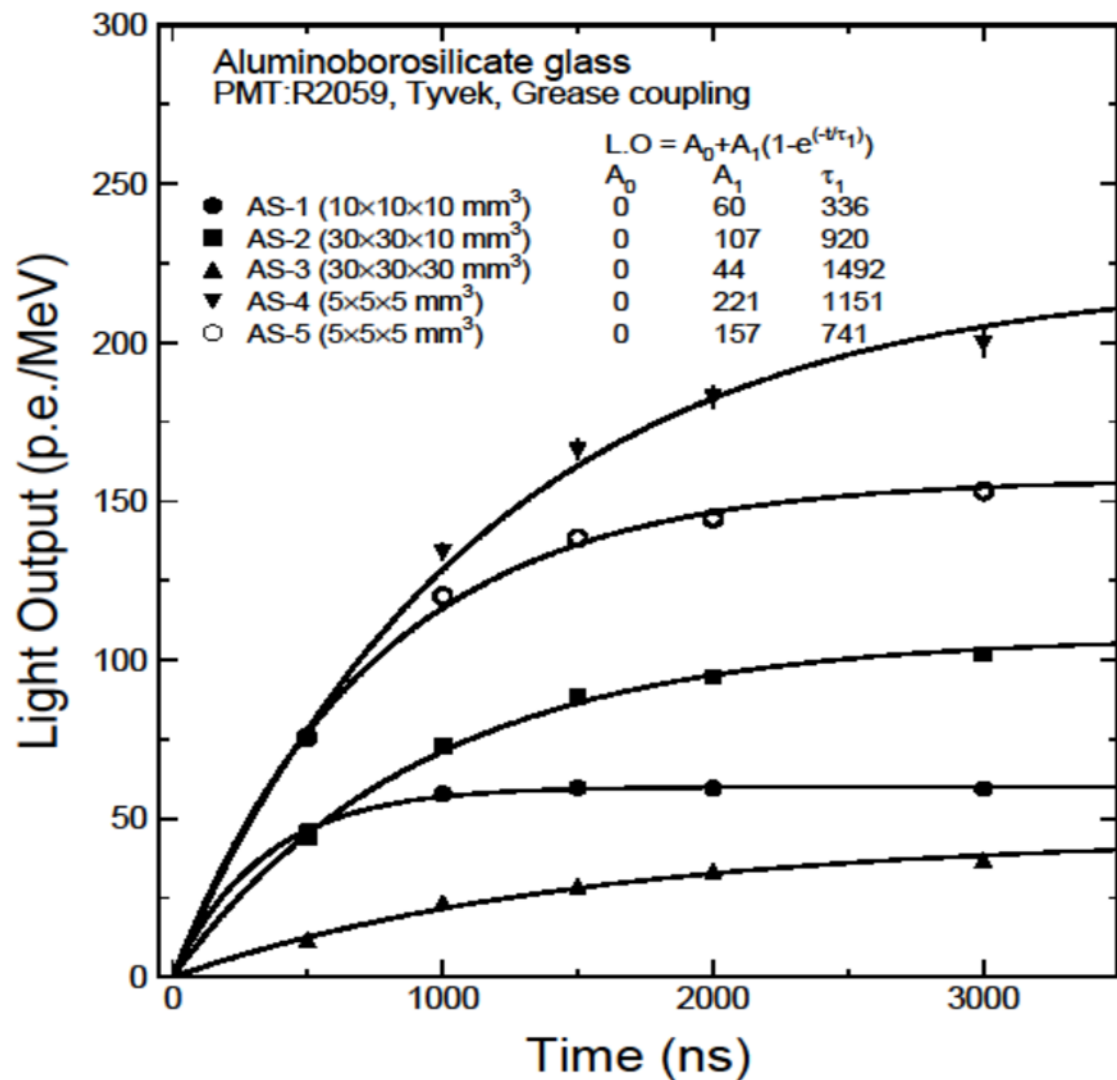
# ABS: Pulse Height Spectra

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



# ABS: Light Output and Decay

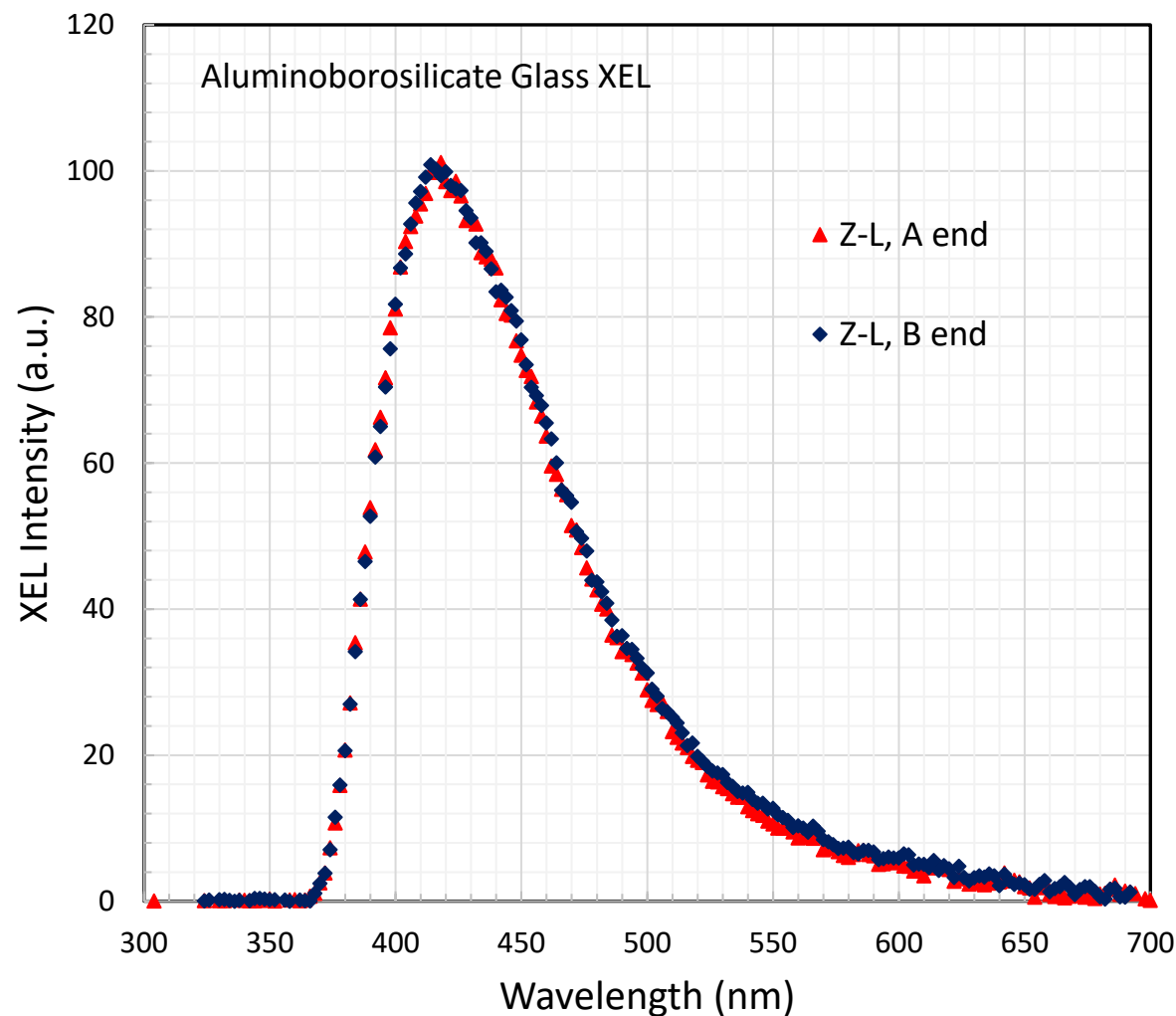
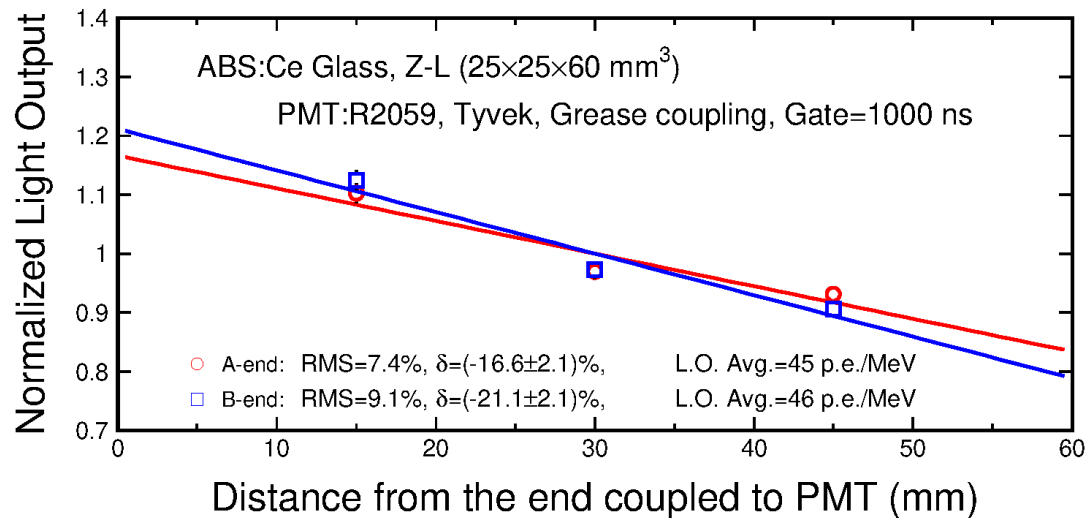
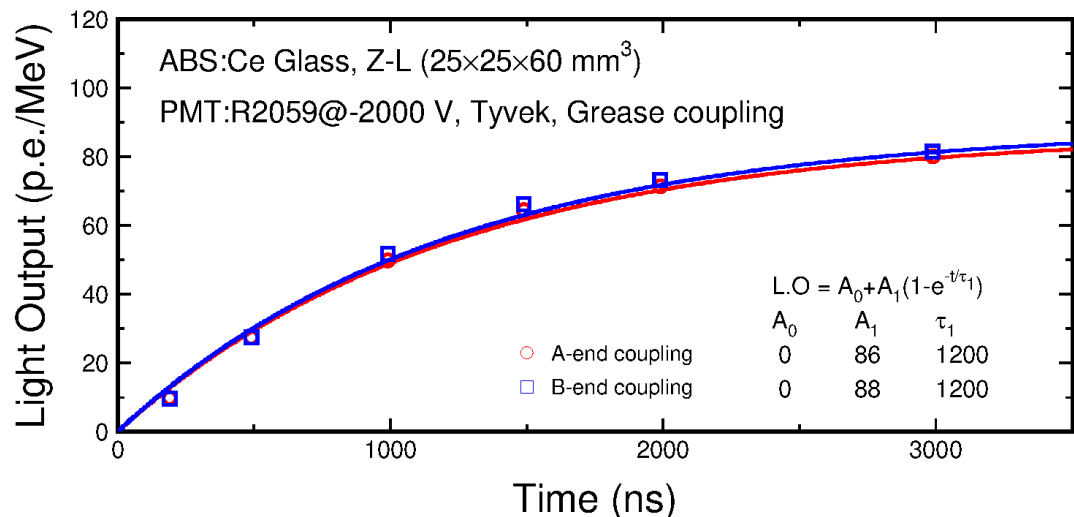
LO: 211 p.e./MeV Taking out EWQE LY: >1,136 ph/MeV, Decay time: 1,200 ns





# Longitudinal Uniformity of Z-L

Longitudinal non-uniformity: 7-9% observed in 6 cm long sample



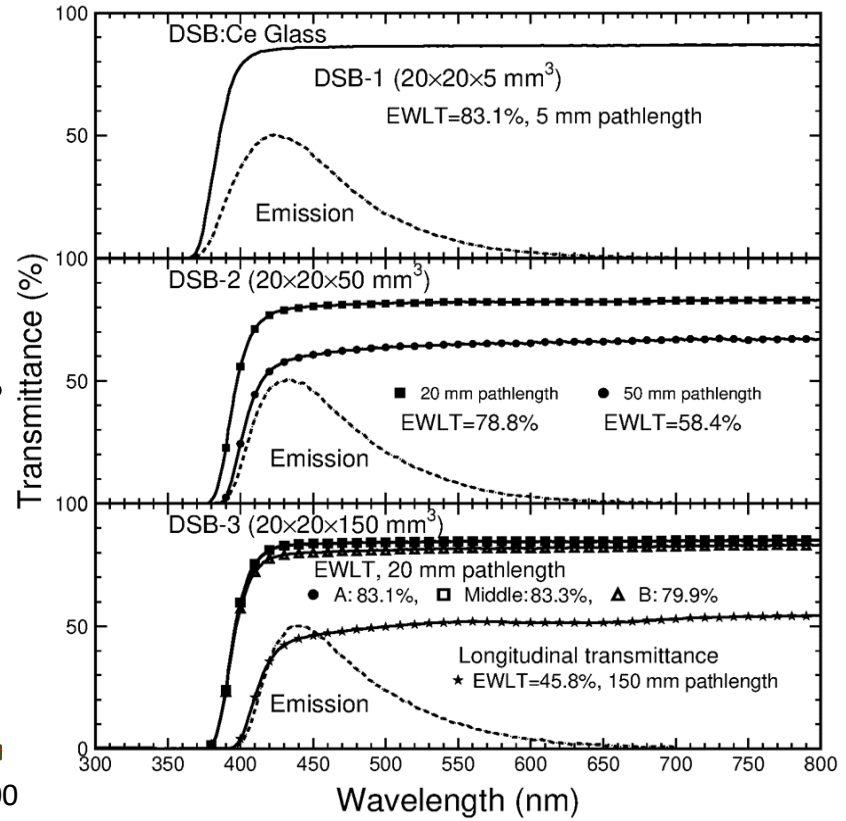
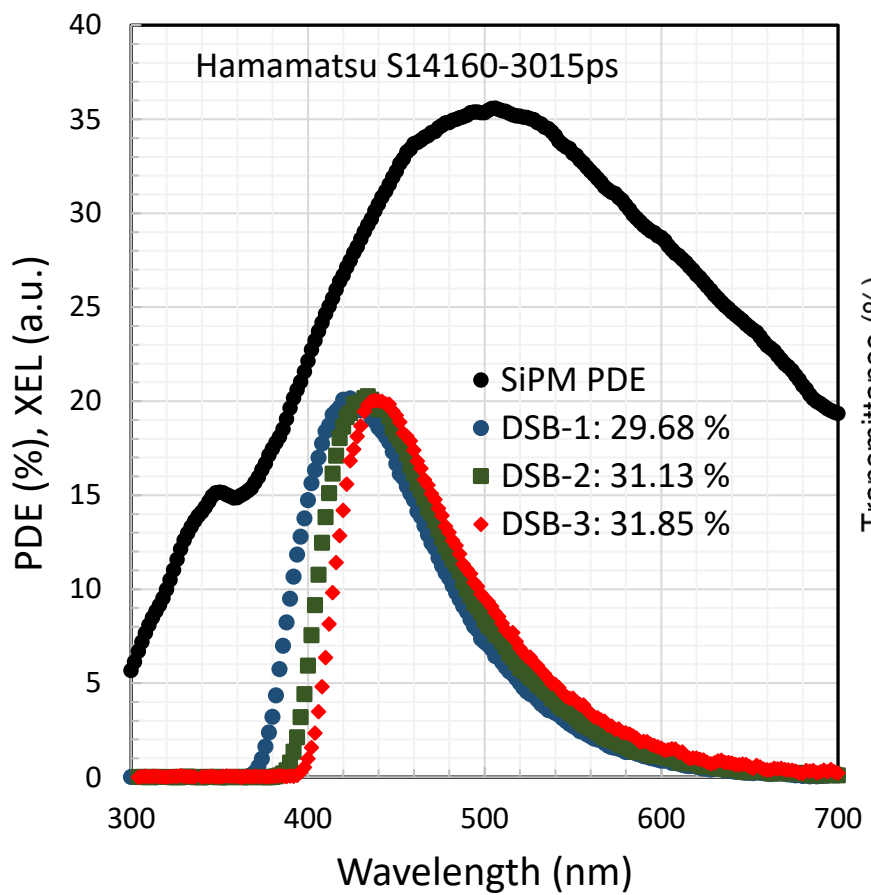
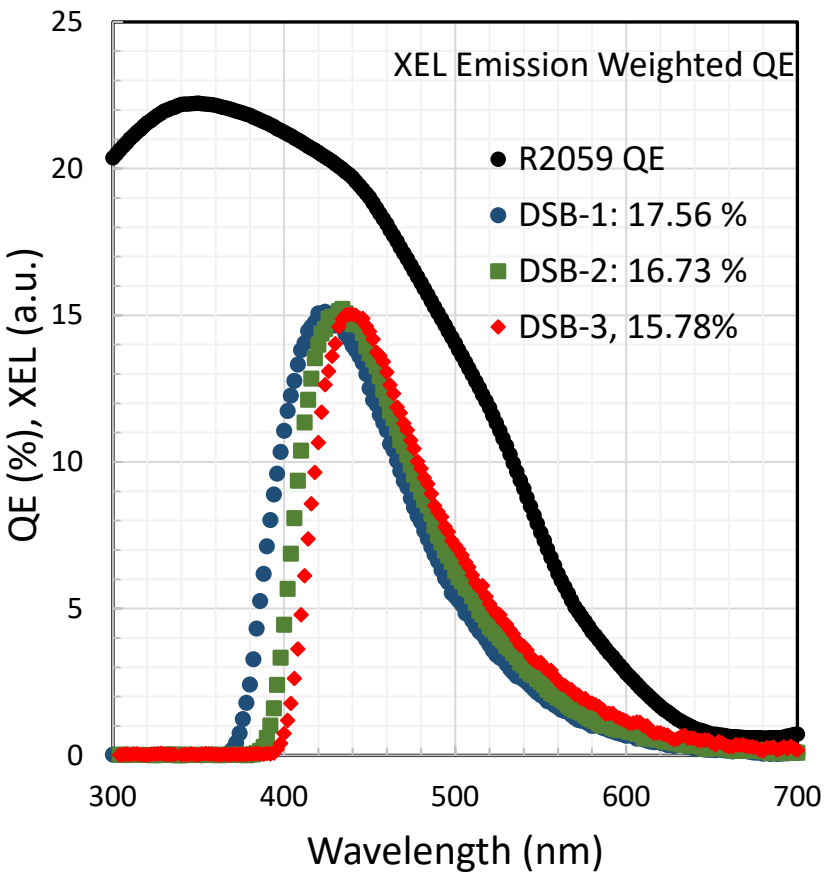
# ABS: Summary

LY: >1,136 ph/MeV, Decay time: 1,200 ns, uniformity: 7-9% for Z-L

Parameters	1.5X <sub>0</sub> Cubes			Gd-ABS							
	BGO	BSO	PWO	AS-1	AS-2	AS-3	AS-4	AS-5	Z-S	Z-M	Z-L
Dimensions (mm <sup>3</sup> )	17×17×17	17×17×17	13×13×13	10×10×10	30×30×10	30×30×30	5×5×5	5×5×5	5×5×5	24×24×24	<b>25×25×60</b>
XEM Peak (nm)	480	480	428	436	410	456	400	404	406	410	<b>416</b>
Decay time (ns)	312	94	30	336	920	1492	1151	741	1200	1490	<b>1200</b>
EWQE (R2059, %)	13.0	13.0	18.5	16.95	18.21	14.54	19.16	18.48	18.57	17.88	<b>17.76</b>
E.R for 511 keV (R2059, %)	16.7	34.9	86.5	78.1	60.5	110.5	41.2	46.2	45.2	60.7	<b>66.2</b>
Fitted LO (R2059, p.e./MeV)	760	152	23	60	107	44	221	157	211	132	<b>87</b>
Fitted LO/EWQE (R2059, ph/MeV)	5846	1169	124	354	588	303	1153	850	<b>1136</b>	738	<b>490</b>
EWPDE (s14160-3015ps, %)	31.8	31.8	28.6	30.7	28.5	32.3	26.2	26.9	26.5	27.8	<b>29.0</b>

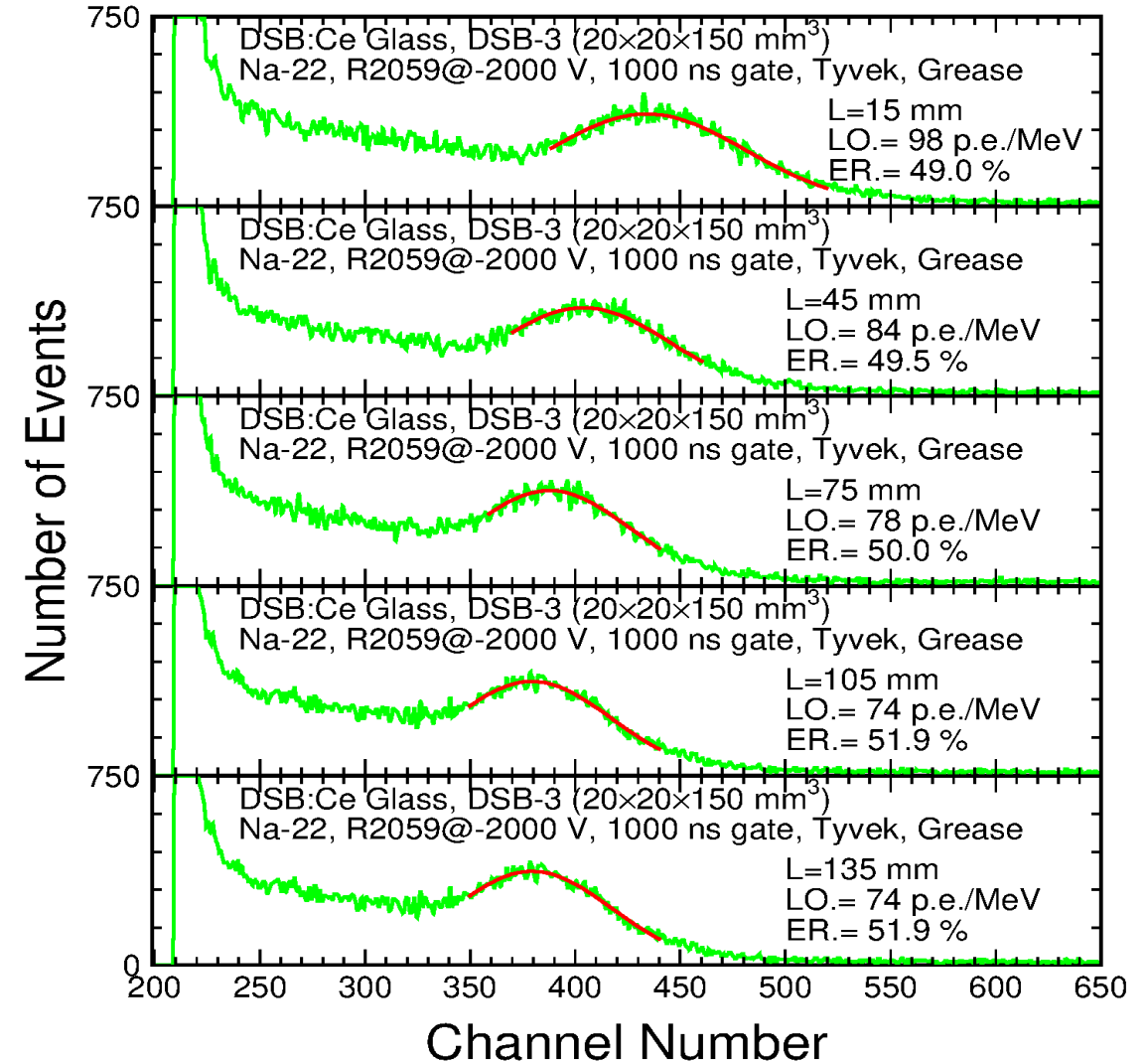
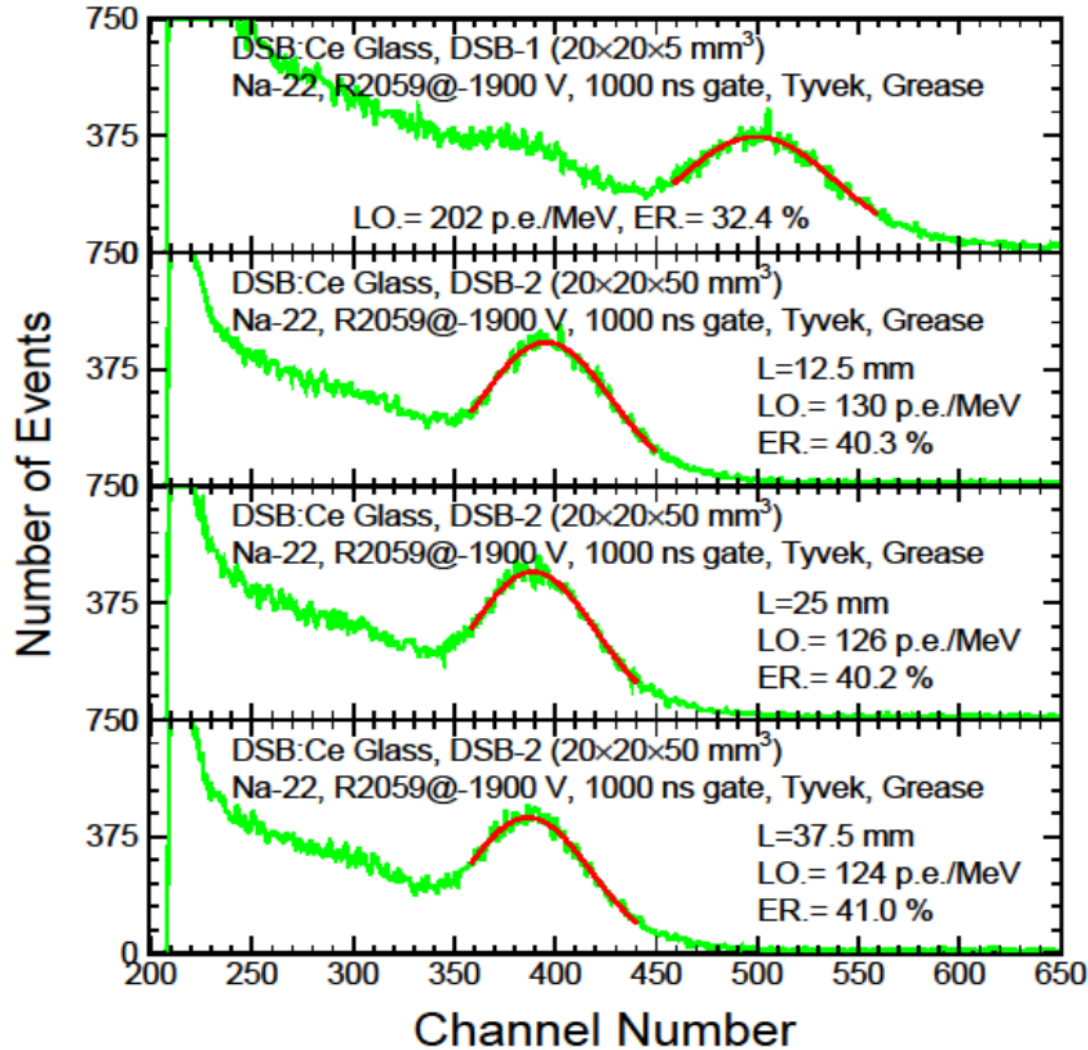
# DSB: XEL, EWQE, EWPDE and Transmittance

XEL (440 nm), EWQE (16%, R2059), EWPDE (32%, S14160-3015ps) and EWLT (46%)  
 All affected by light path length for the same chemical composition



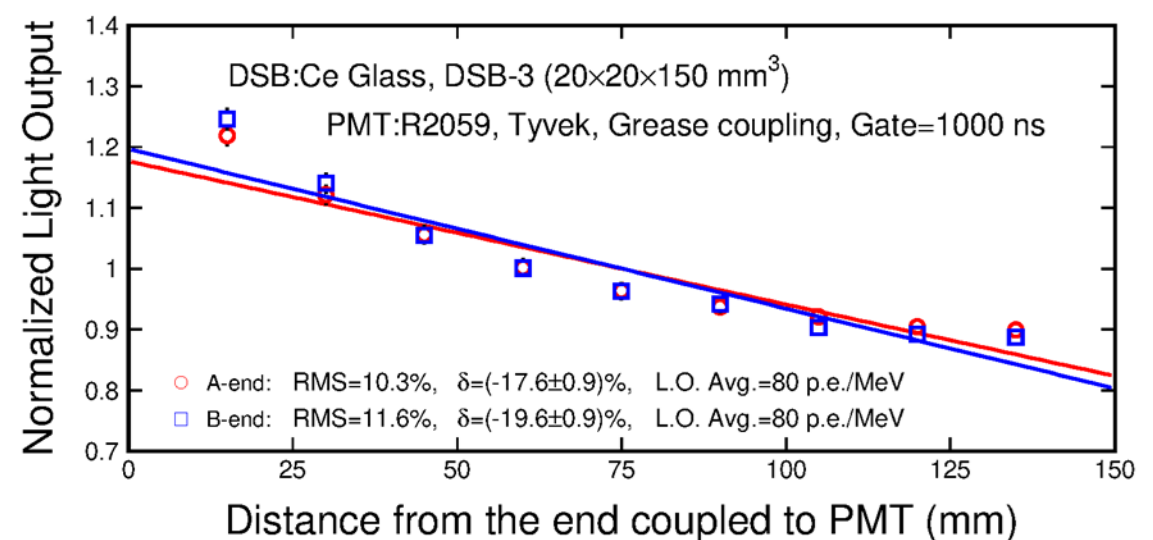
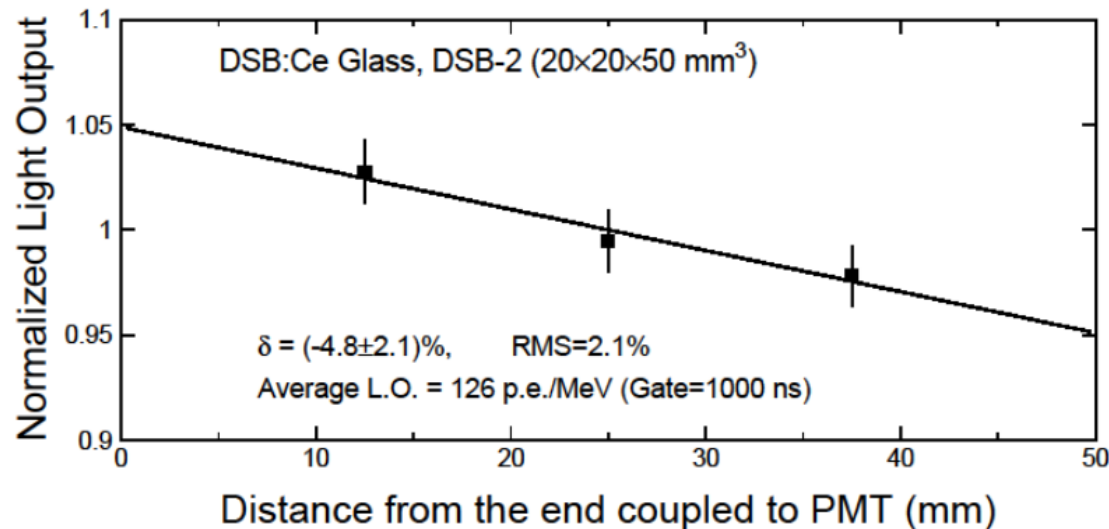
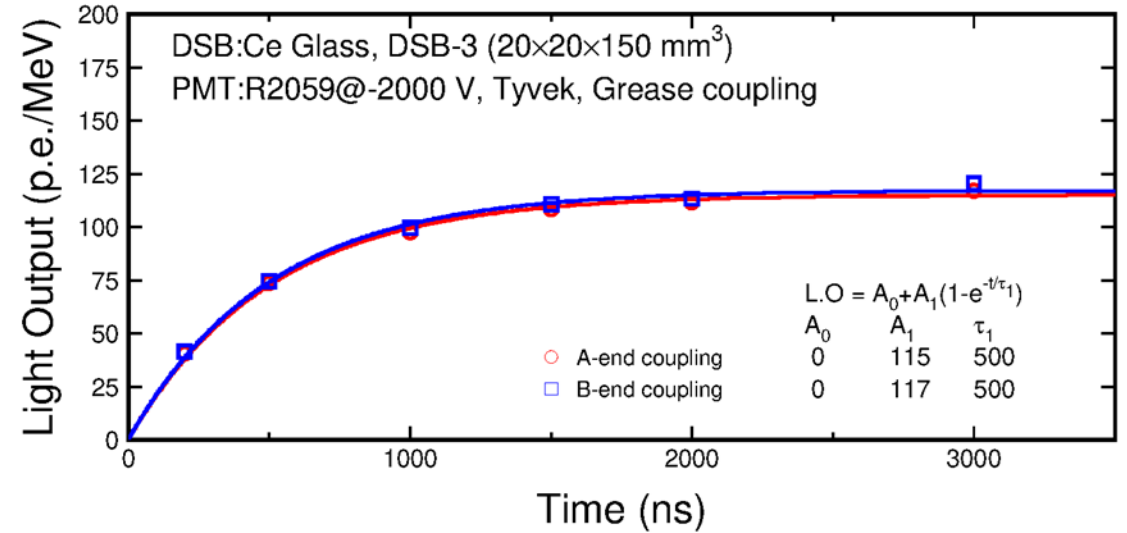
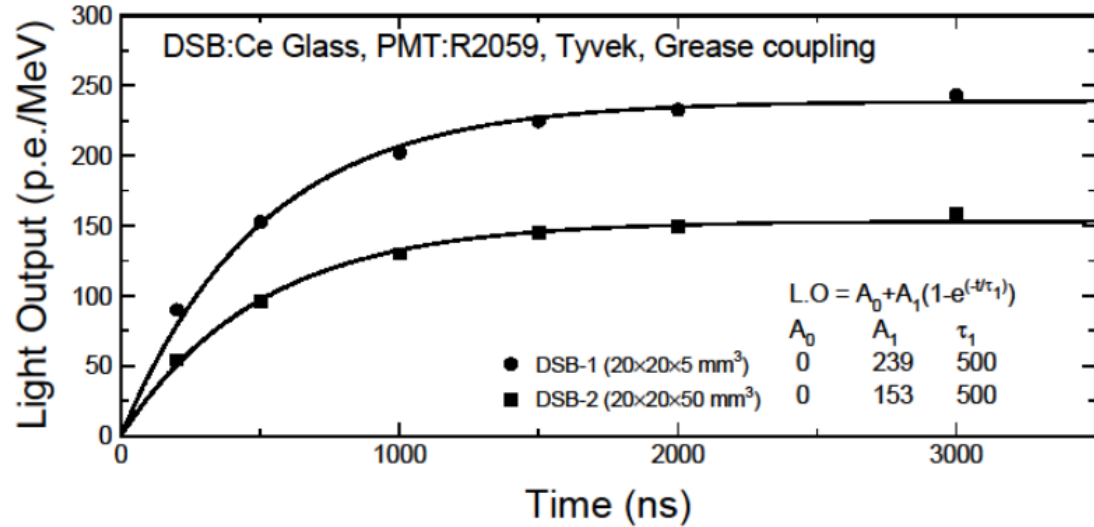
# DSB: Pulse Height Spectra

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%





# DSB: Summary

LY: >1,360 ph/MeV, Decay time: 500 ns, uniformity: 10-12% for DSB-3

Parameters	1.5X <sub>0</sub> Cubes			Gd-DSB		
	BGO	BSO	PWO	DSB-1	DSB-2	DSB-3
Dimensions (mm <sup>3</sup> )	17×17×17	17×17×17	13×13×13	20×20×5	20×20×50	<b>20×20×150</b>
XEM Peak (nm)	480	480	428	426	432	<b>438</b>
Decay time (ns)	312	94	30	500	500	<b>500</b>
EWQE (R2059, %)	13.0	13.0	18.5	17.56	16.73	<b>15.78</b>
E.R for 511 keV (R2059, %)	16.7	34.9	86.5	32.4	40.2	<b>50.5</b>
Fitted LO (R2059, p.e./MeV)	760	152	23	239	153	<b>116</b>
Fitted LO/EWQE (R2059, ph/MeV)	5846	1169	124	<b>1361</b>	915	<b>735</b>
EWPDE (s14160-3015ps, %)	31.8	31.8	28.6	29.7	31.1	<b>31.9</b>

# Inorganic Scintillators for HHCAL

All samples measured at Caltech HEP Crystal Lab

	BGO	BSO	PWO	PbF <sub>2</sub>	PbFCI	Sapphire:Ti	AFO Glass	DSB:Ce Glass	ABS:Ce Glass
Density (g/cm <sup>3</sup> )	7.13	6.8	8.3	7.77	7.11	3.98	4.6	4.3	6.0
Melting point (°C)	1050	1030	1123	824	608	2040	980 <sup>7</sup>	1550	?
X <sub>0</sub> (cm)	1.12	1.15	0.89	0.94	1.05	7.02	2.96	2.58	1.55
R <sub>M</sub> (cm)	2.23	2.33	2.00	2.18	2.33	2.88	2.90	3.24	2.50
λ <sub>l</sub> (cm)	22.7	23.4	20.7	22.4	24.3	24.2	26.4	30.9	24.7
Z <sub>eff</sub> value	71.5	73.8	73.6	76.7	74.7	11.1	41.4	49.5	56.9
dE/dX (MeV/cm)	8.99	8.59	10.1	9.42	8.68	6.75	6.84	6.1	8.0
Emission Peak <sup>a</sup> (nm)	480	470	425 420	\	420	300 750	365	420	400
Refractive Index <sup>b</sup>	2.15	2.68	2.20	1.82	2.15	1.76	?	?	?
LY (ph/MeV) <sup>c</sup>	7,500	1,500	130	\	150	7,900	450	>1,360	>1,140
Decay Time <sup>a</sup> (ns)	300	100	30 10	\	3	300 3200	40	500	1,200
d(LY)/dT (%/°C) <sup>c</sup>	-0.9	?	-2.5	\	?	?	?	0.3	?
Cost (\$/cc)	6.0	7.0	7.5	6.0	?	0.6	2.0	2.0	<1

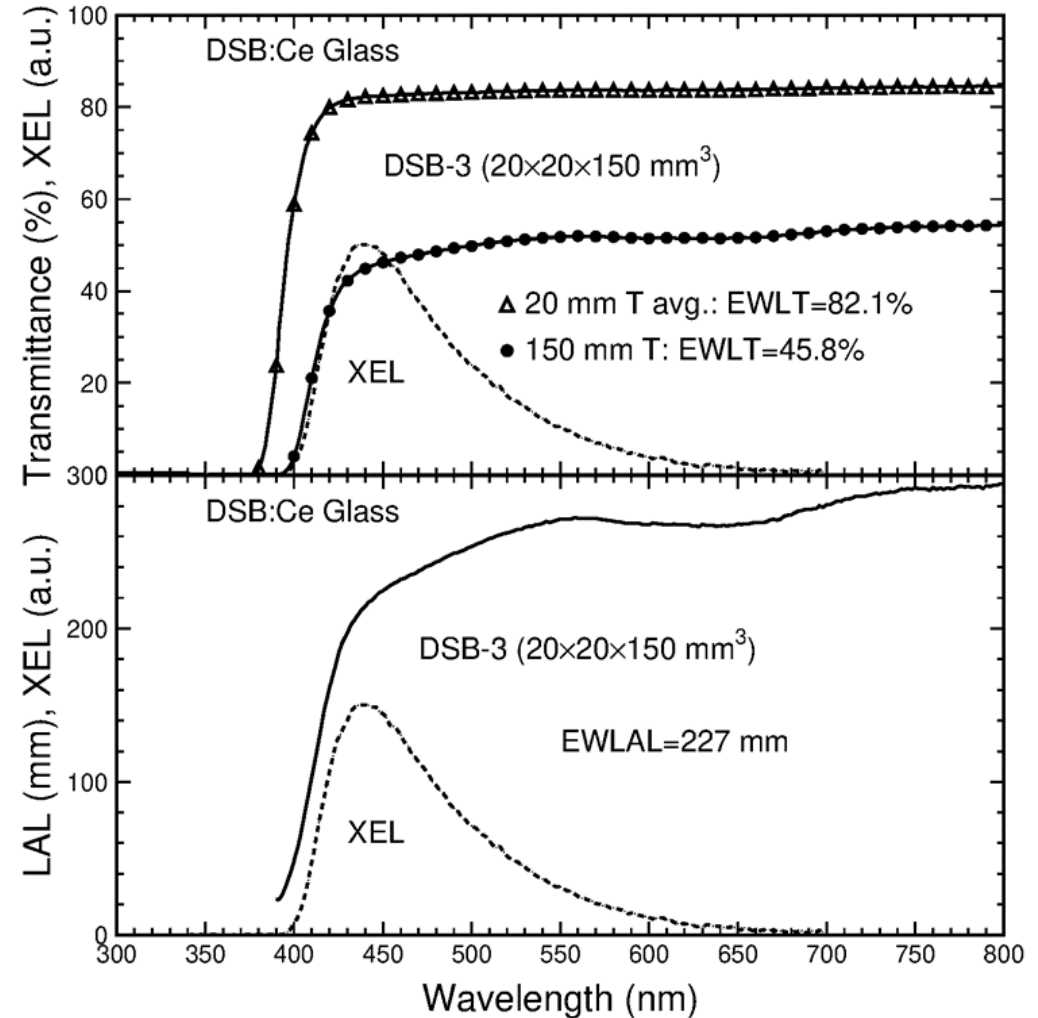
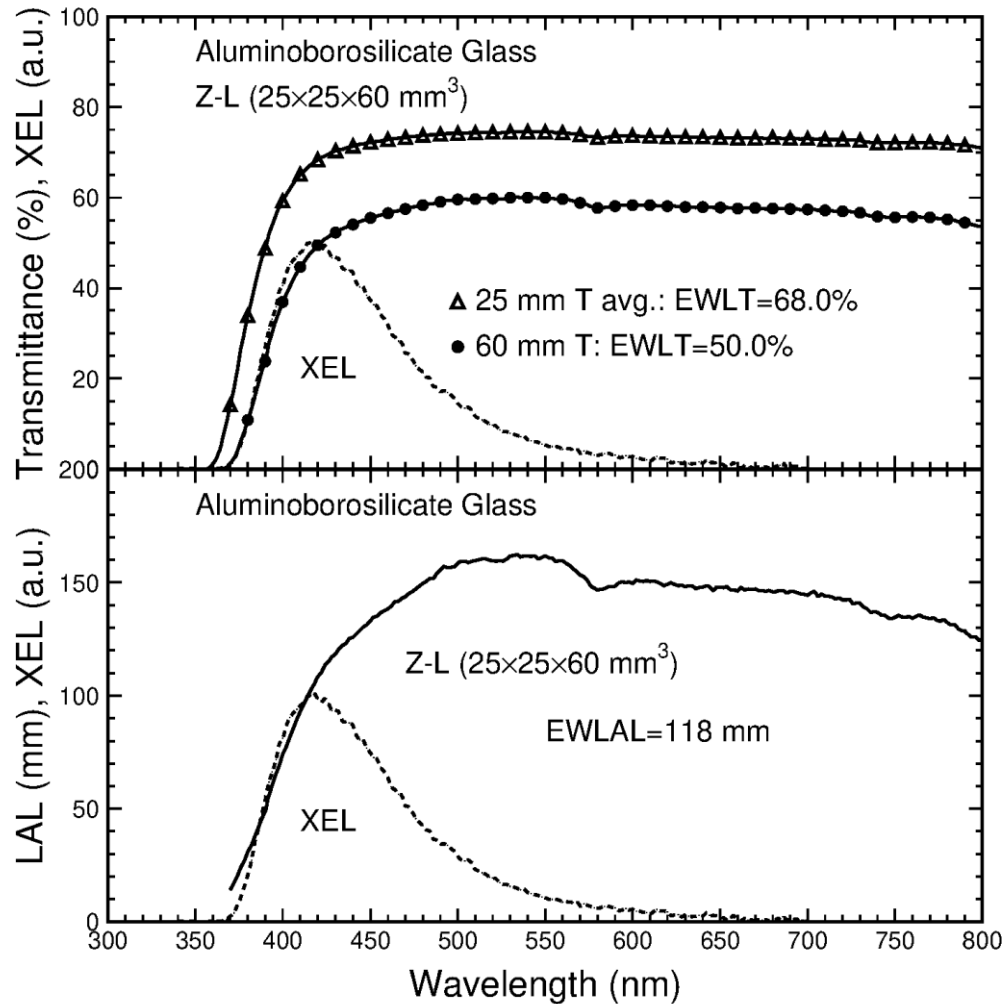
<sup>a</sup>. Top line: slow component, bottom line: fast component.

<sup>b</sup>. At the wavelength of the emission maximum.

<sup>c</sup>. At room temperature (20°C) with PMT QE taken out.

# EWLAL of ABS and DSB Glass Samples

Ignoring scattering LAL is calculated by using the ratio of transverse and longitudinal transmittance  
EWLAL: 118 mm for the 6 cm long ABS glass Z-L, and 227 mm for the 15 cm long glass DSB-3



# Summary

A 6 cm long ABS glass sample shows 6 g/cc,  $X_0$ :1.55 cm,  $\lambda_1$ :24.7 cm, LY: >1,140 ph/MeV, decay time: 1.2  $\mu$ s, uniformity: 7-9% and LAL: 118 mm. It is promising for the HHCAL concept.

A 15 cm long DSB glass sample shows 4.3 g/cc,  $X_0$ :2.58 cm,  $\lambda_1$ :30.9 cm, LY: >1,360 ph/MeV, decay time: 0.5  $\mu$ s, uniformity: 10-12%. And LAL: 227 mm. It is faster and more bright than ABS, but less dense.

While optical property is not as good as crystal samples, these two glass samples may be used in the CalVision beam test.

Plan to characterize glass samples developed under DOE SBIR program at RMD.

Acknowledgements: DOE HEP Award DE-SC0011925

Presented by Ren-Yuan Zhu of Caltech in CalVision Monthly Meeting