Large Size LYSO Crystals for Future High Energy Physics Experiments

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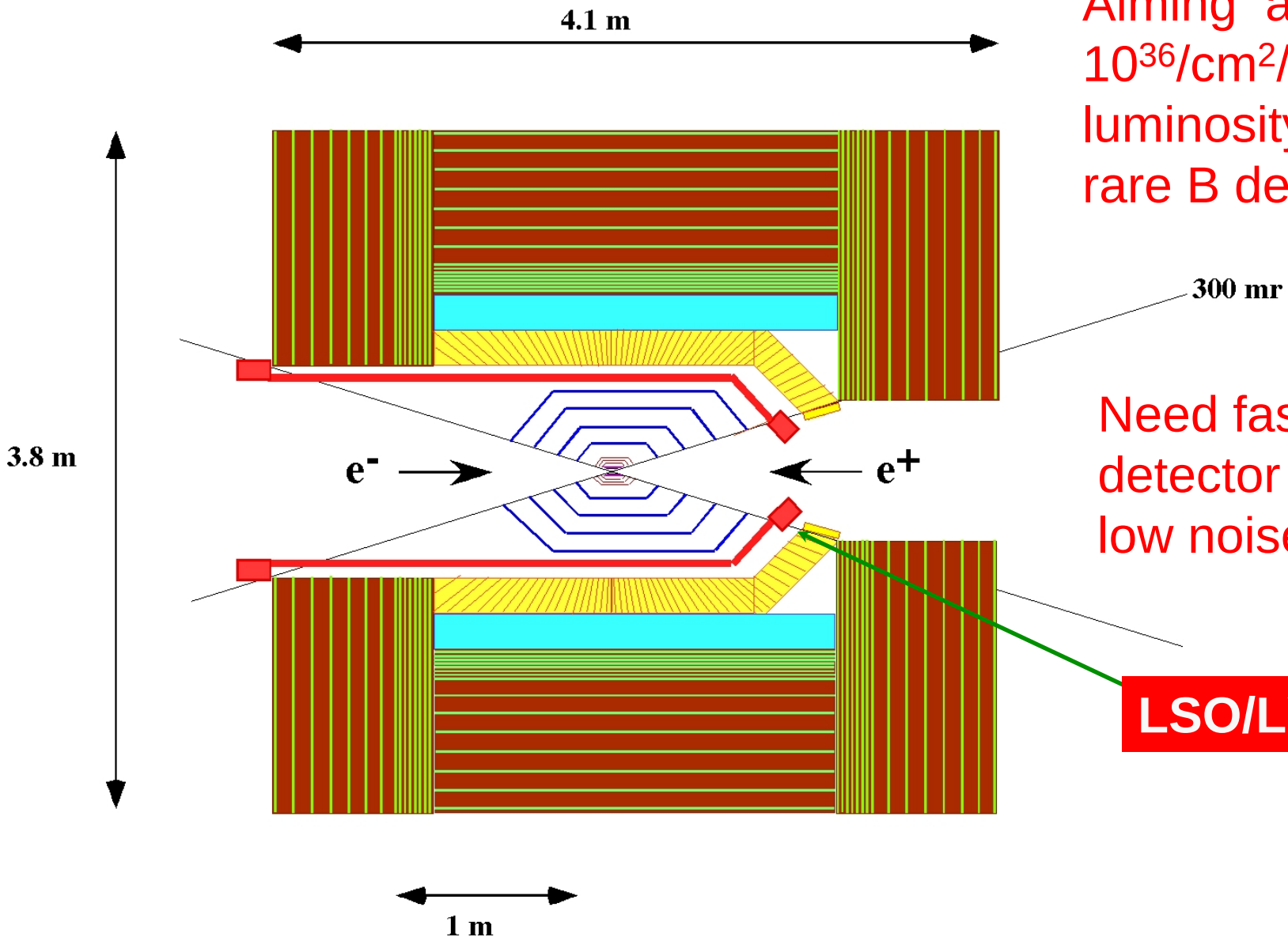
Scintillating Crystals for HEP

Crystal	NaI(Tl)	CsI(Tl)	CsI	BaF_2	BGO	$PbWO_4$	LSO(Ce)	GSO(Ce)
Density (g/cm^3)	3.67	4.51	4.51	4.89	7.13	8.3	7.40	6.71
Melting Point (ºC)	651	621	621	1280	1050	1123	2050	1950
Radiation Length (cm)	2.59	1.85	1.85	2.06	1.12	0.9	1.14	1.37
Molière Radius (cm)	4.8	3.5	3.5	3.4	2.3	2.0	2.3	2.37
Interaction Length (cm)	41.4	37.0	37.0	29.9	21.8	18	21	22
Refractive Index [a]	1.85	1.79	1.95	1.50	2.15	2.2	1.82	1.85
Hygroscopicity	Yes	Slight	Slight	No	No	No	No	No
Luminescence [b] (nm) (at peak)	410	560	420 310	300 220	480	560 420	420	440
Decay Time [b] (ns)	230	1300	35 6	630 0.9	300	50 10	40	60
Light Yield [b,c] (%)	100	45	5.6 2.3	21 2.7	13	0.1 0.6	75	30
d(LY)/dT [b] (%/ ºC)	~0	0.3	-0.6	-2 ~0	-1.6	-1.9	-0.3	-0.1
Experiment	Crystal Ball	CLEO BaBar BELLE BES III	KTeV	TAPS (L*) (GEM)	L3 BELLE PANDA?	CMS ALICE PANDA? BTeV…	-	-

a. at peak of emission; b. up/low row: slow/fast component; c. measured by PMT of bi-alkali cathode.

A Strawman Detector for Super *BaBar*

B. Wisniewski, Calor02, Pasadena



Aiming at $10^{36}/cm^2/s$ luminosity for rare B decay

Need fast detector with low noise

LSO/LYSO?

LSO/LYSO Mass Production Capability

CTI: LSO

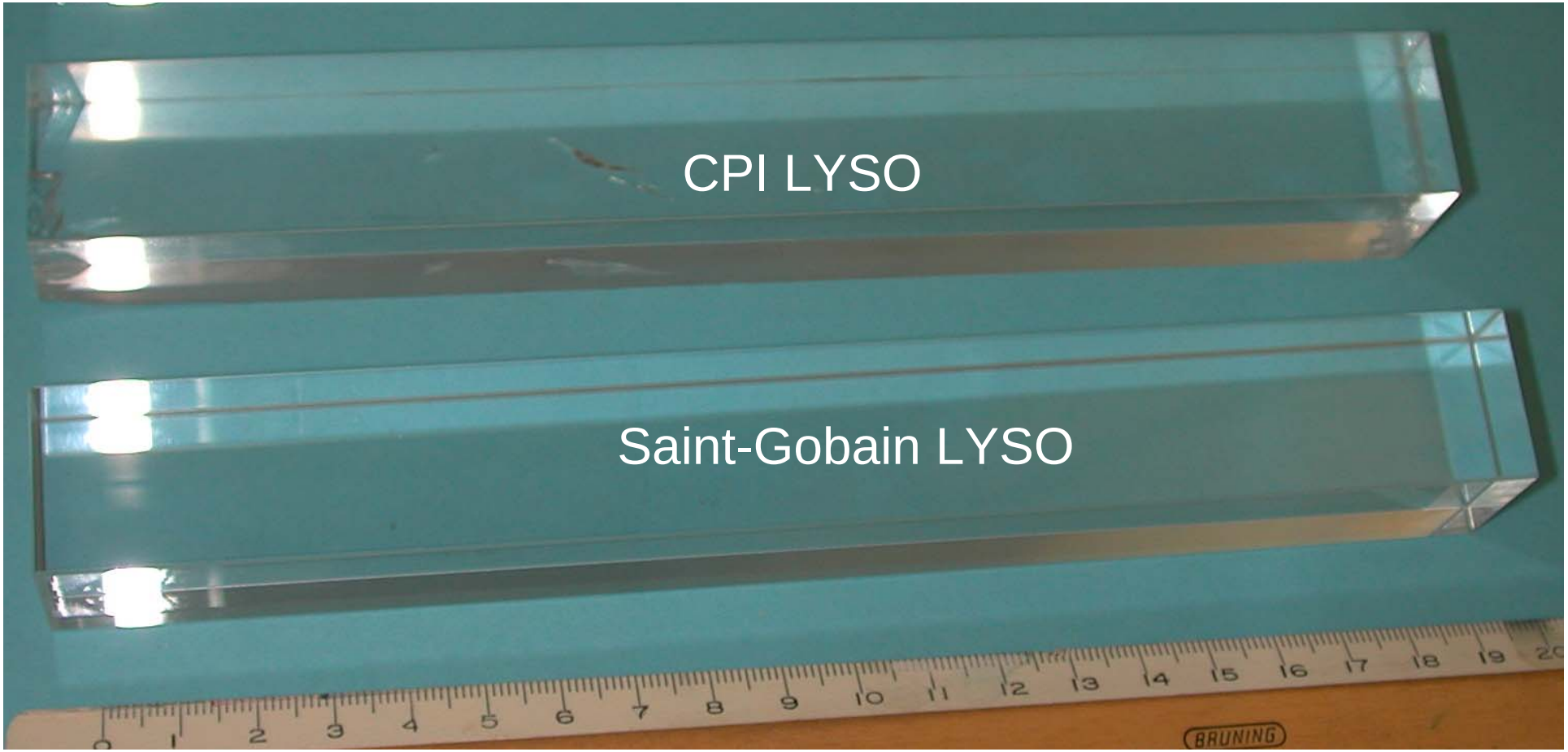
CPI: LYSO

Saint-Gobain LYSO

2.5 x 2.5 x 20 cm LYSO Samples

Saint-Gobain LYSO has perfect geometry & surface polishing

CPI LYSO has chips at corners/surface because of lacking adequate polishing & treatment facilities for large size crystals

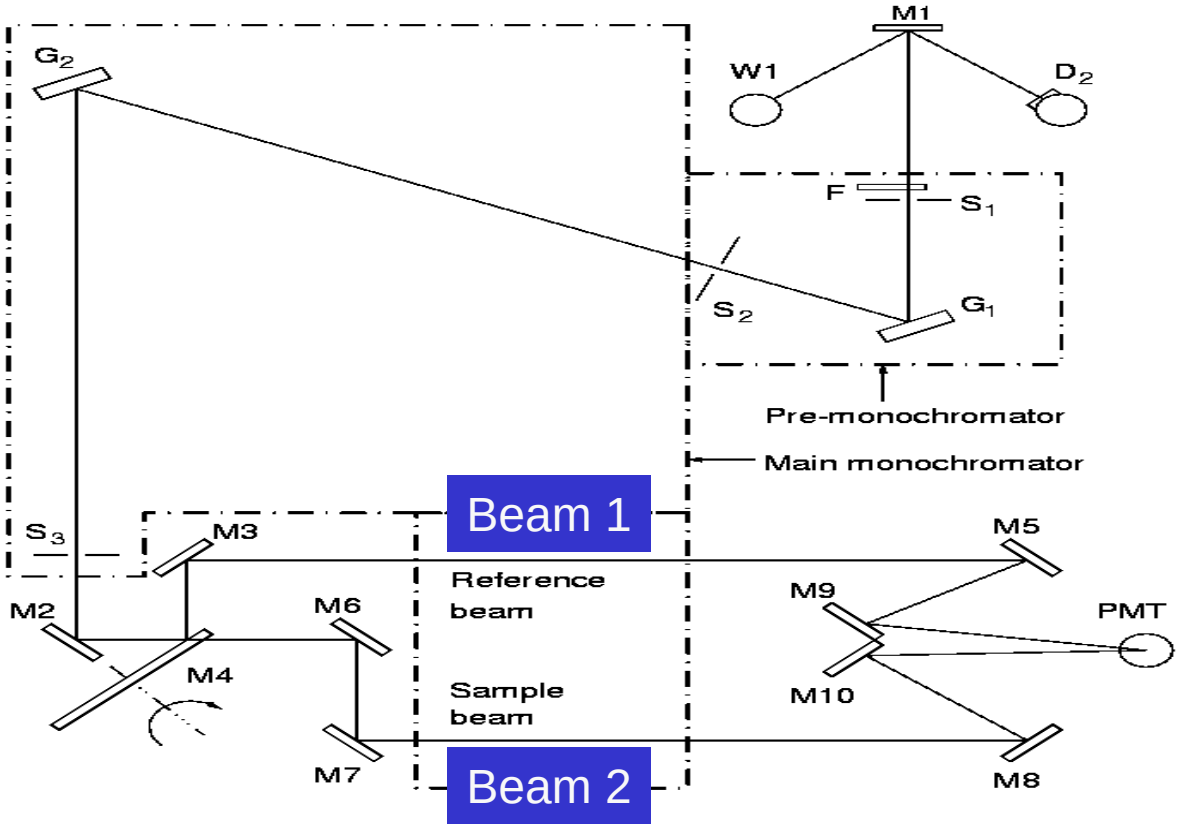


Experiment

- Without any thermal treatment, all samples went through (1) initial measurement of optical and scintillation properties, (2) irradiations by γ–ray for ~20 h each under 2, 100 and 9k rad/h, and (3) recovery.
- Properties measured: transmittance, emission and excitation spectra, light output, decay kinetics and light response uniformity, as well as their degradation under irradiation, and radiation induced phosphorescence.
- Because of serious phosphorescence, light output was measured two days after the ending of irradiation under 9 krad/h.

Transmittance Measurement

HITACHI U-3210 UV/VIS spectrophotometer with a large sample compartment



A simple way for looking absorption bands. No controversy.

Precision of 0.3% can be reached.

$$T_s = (1-R)^2 + R^2(1-R)^2 + \ldots = (1-R)/(1+R), \text{ with}$$

$$R = \frac{(n_{crystal}-n_{air})^2}{(n_{crystal}+n_{air})^2}.$$

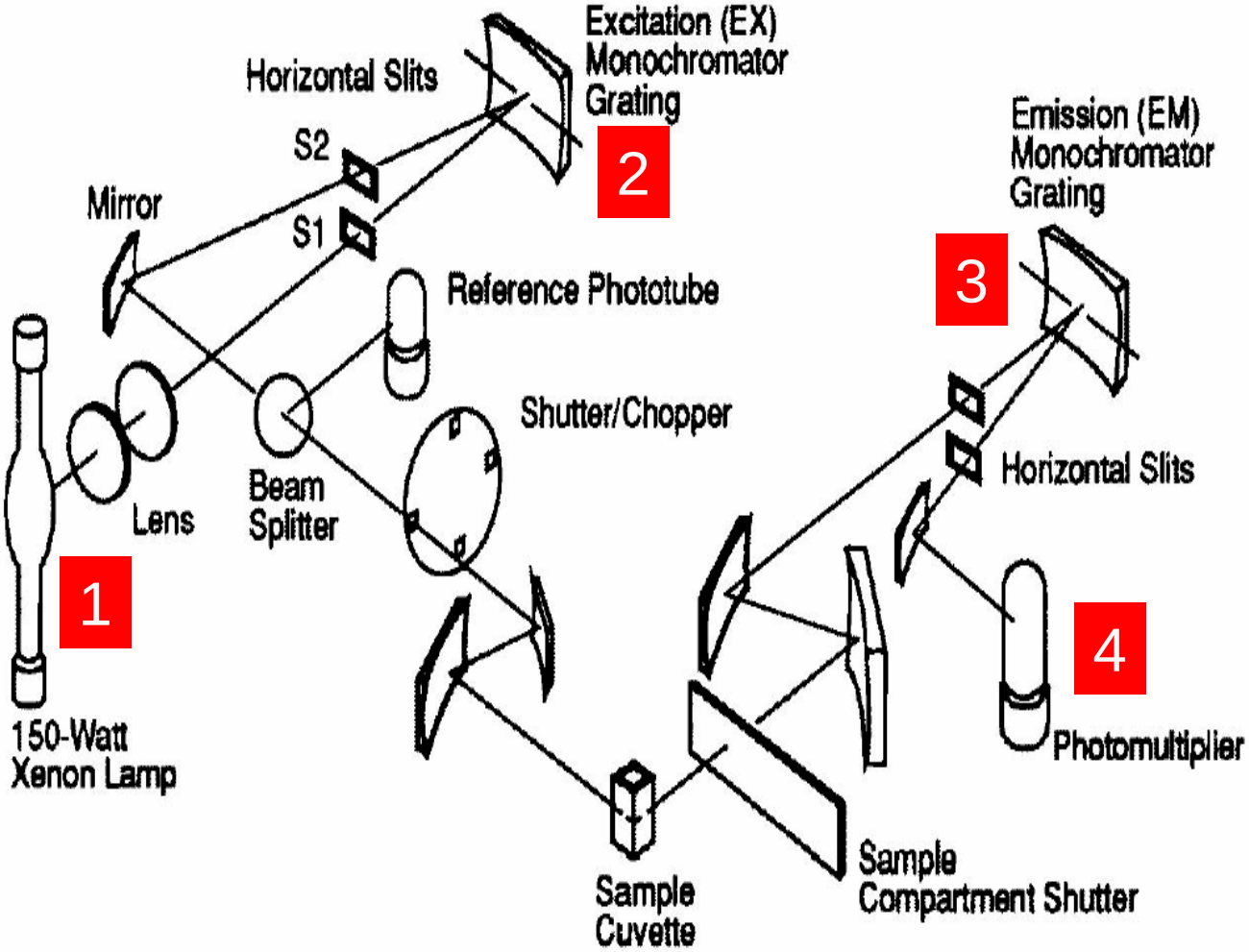
Theoretical limit of transmittance: NIM **A333** (1993) 422

Photo Luminescence Measurement

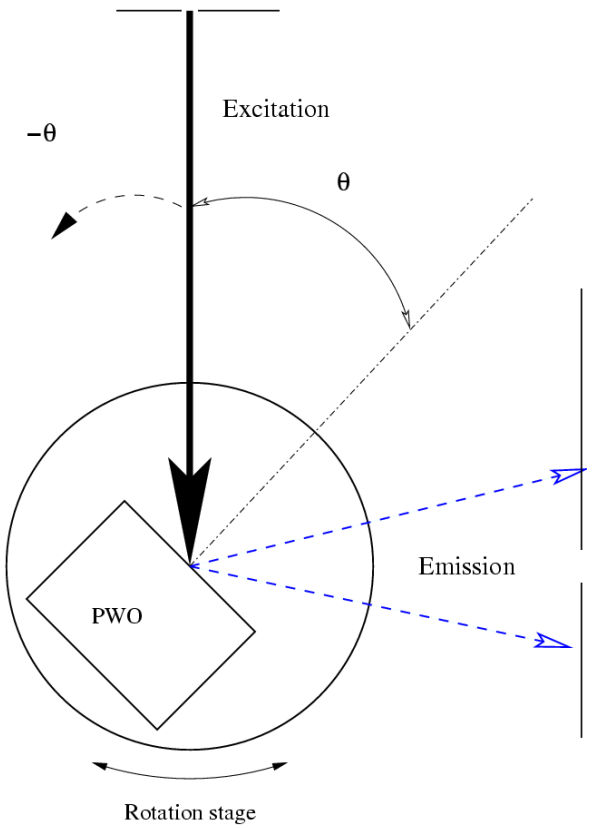
HITACHI F4500 Fluorescence Spectrophotometer

Light Source (1), Gratings Efficiencies (2 & 3) & PMT QE (4)

Red-Extended Hamamatsu R928 PMT(4): 185 to 900 nm



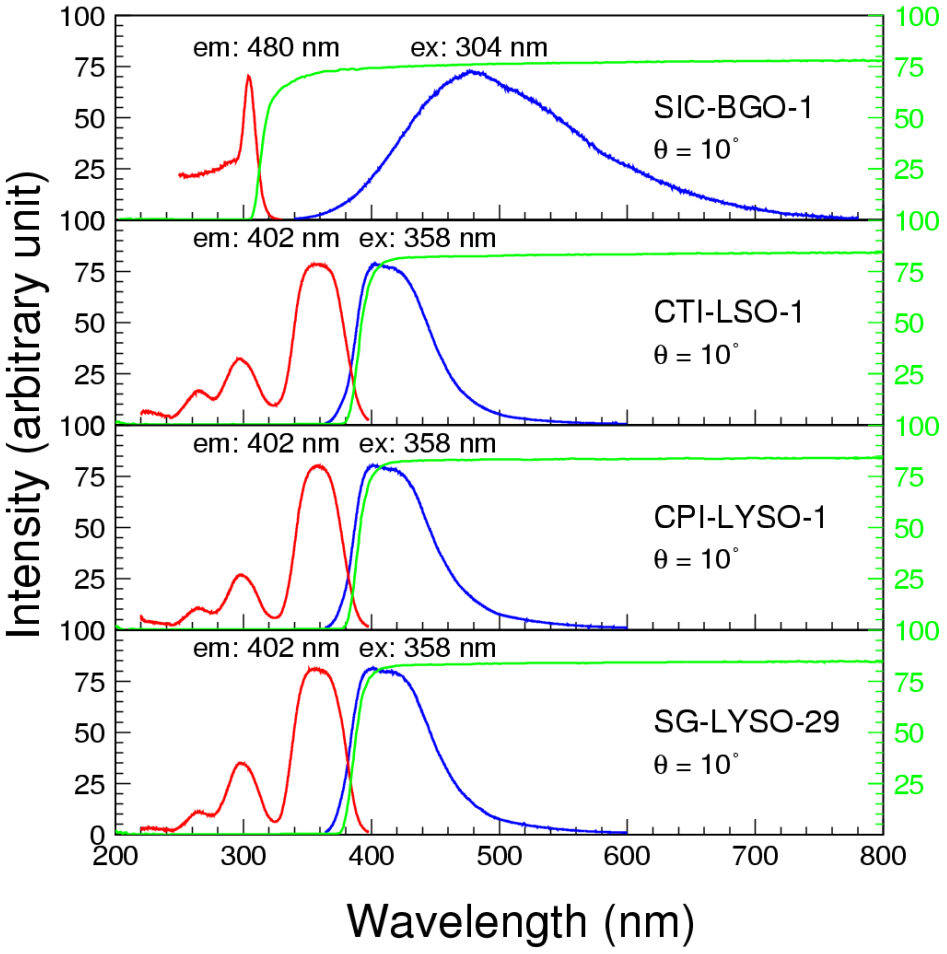
Sample Orientation

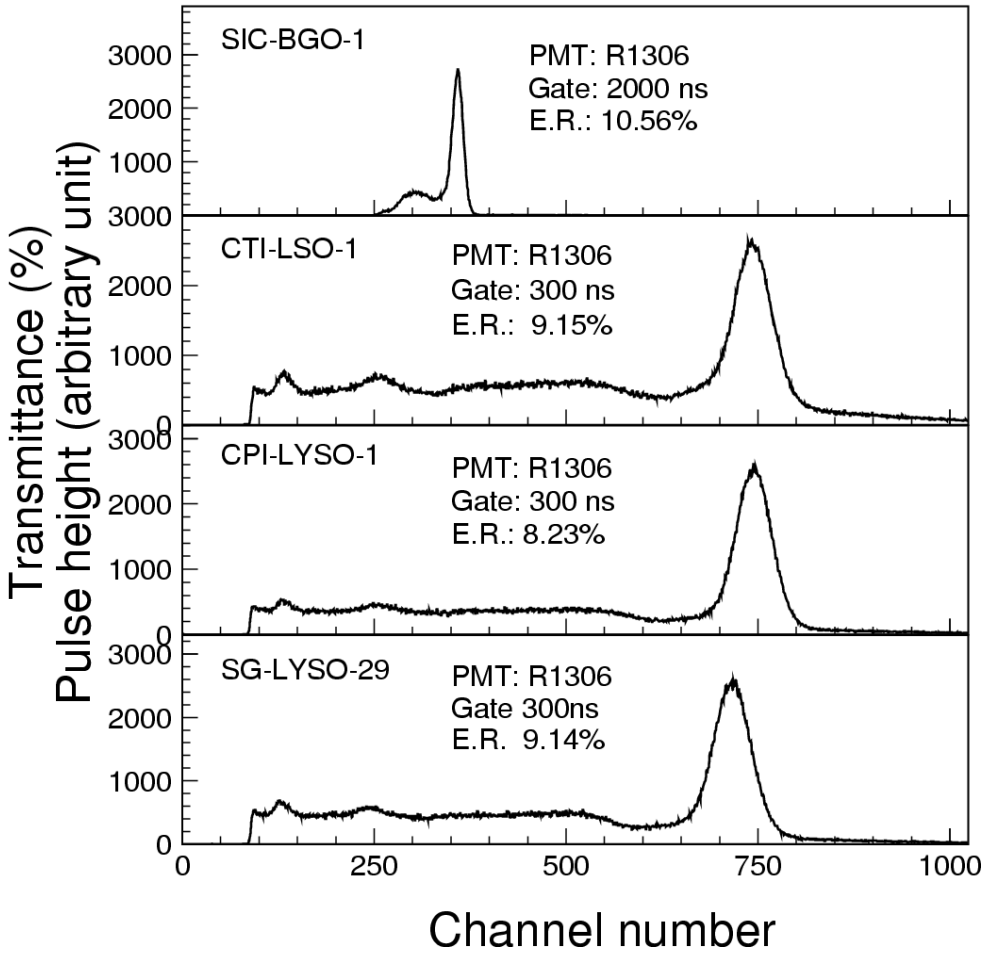


Comparison of 1.5 X_0 Cubic Samples

LSO/LYSO samples have identical transmittance, emission & excitation spectra and a Cs peak FWHM resolution at 8 to 9%

Part of LSO/LYSO emission is cut by their transmittance

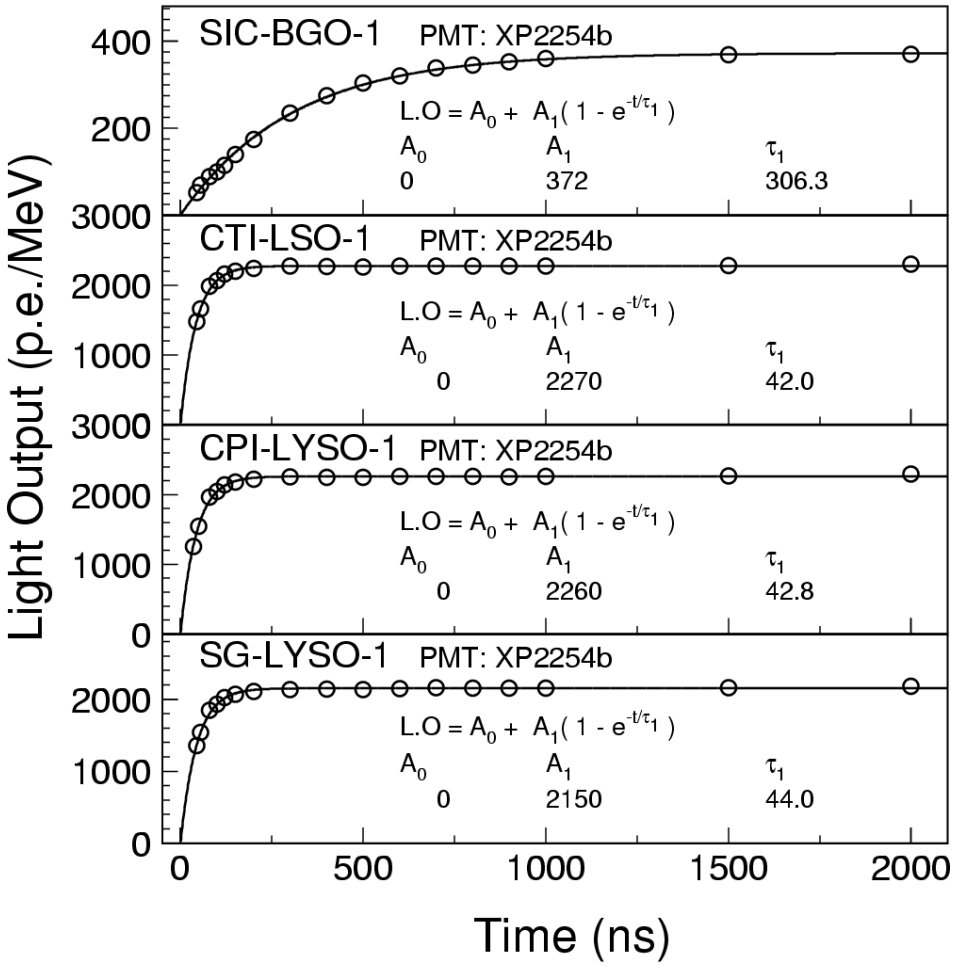


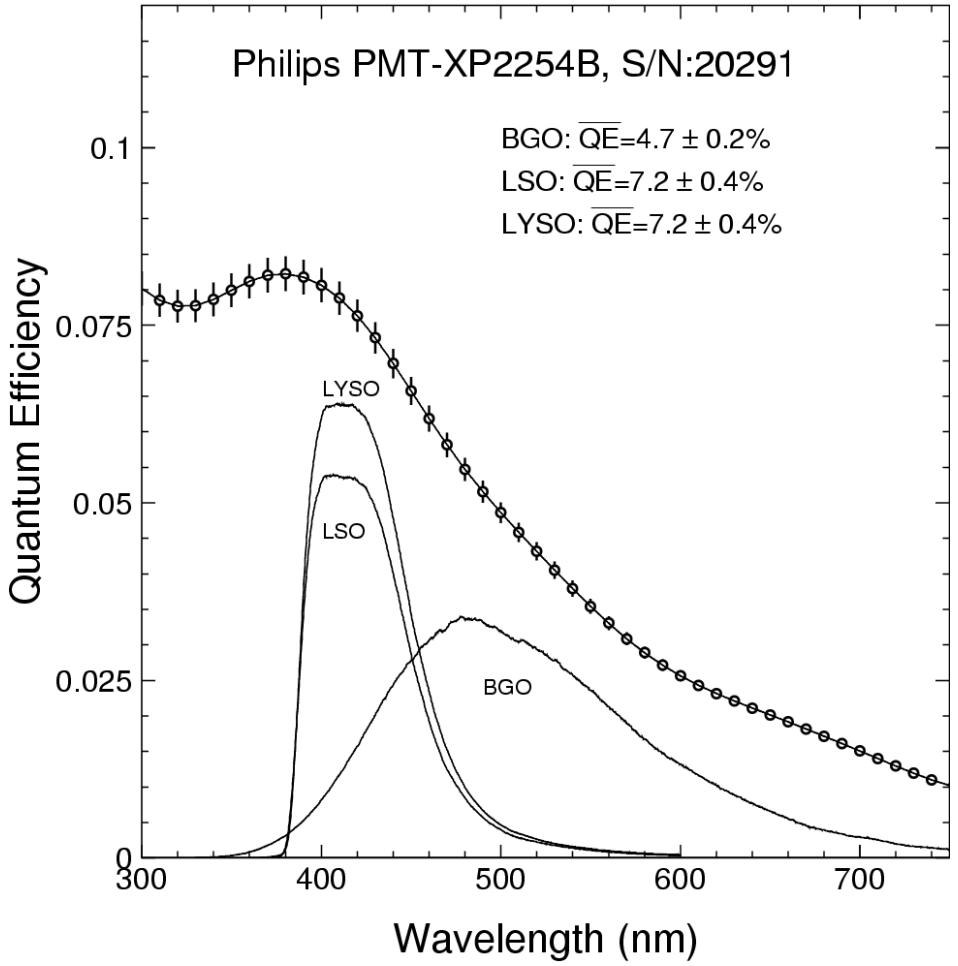


1.5 X_0 Cubic Sample Light Output

LSO/LYSO samples have compatible light output,
which is a factor of 4 of BGO taking into account PMT response

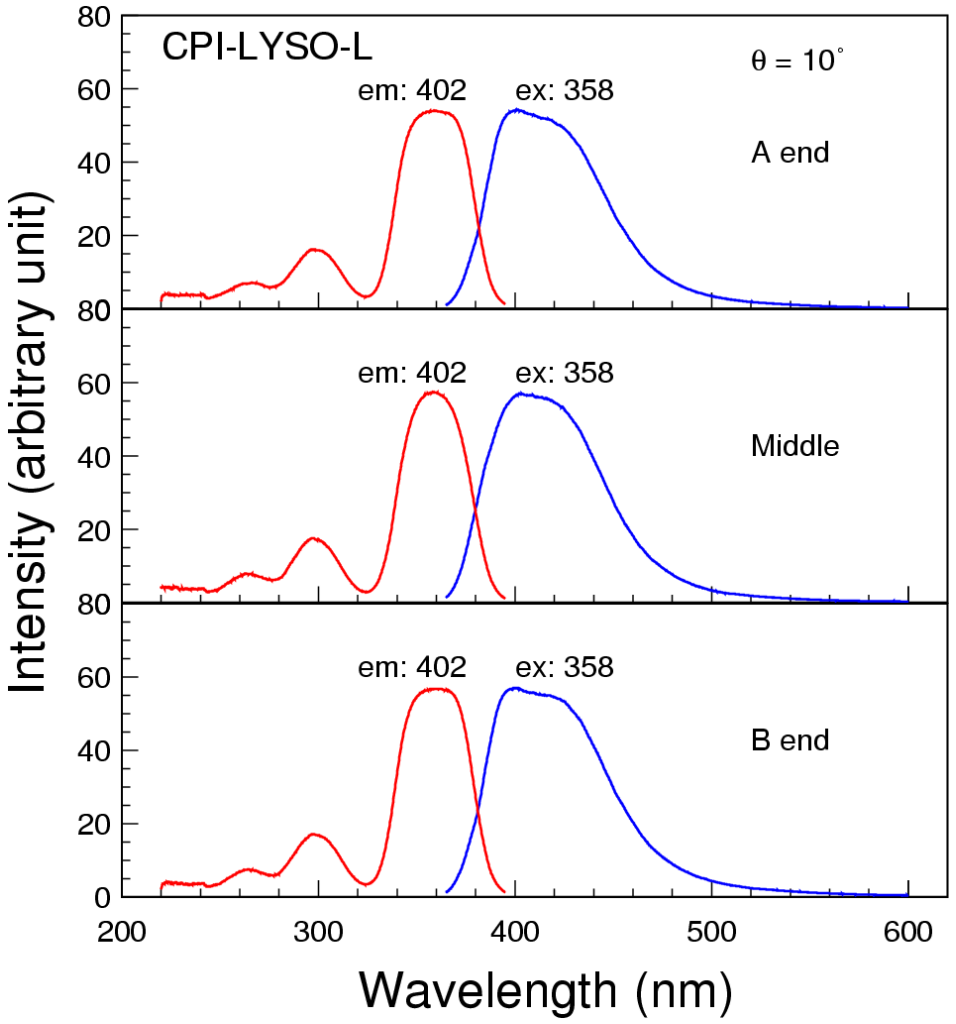
Decay time: 300 ns for BGO and 42 ns for LSO/LYSO

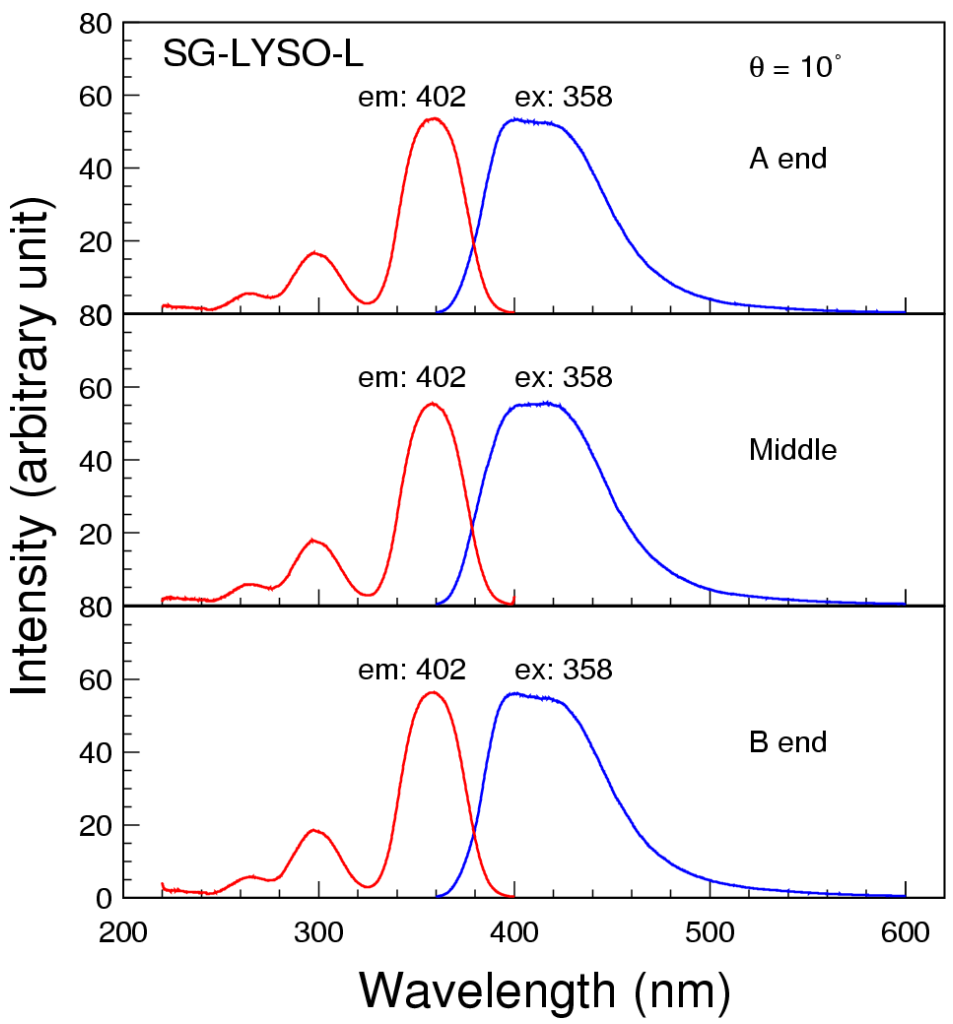




Long LYSO Excitation/Emission

No longitudinal variation in emission & excitation

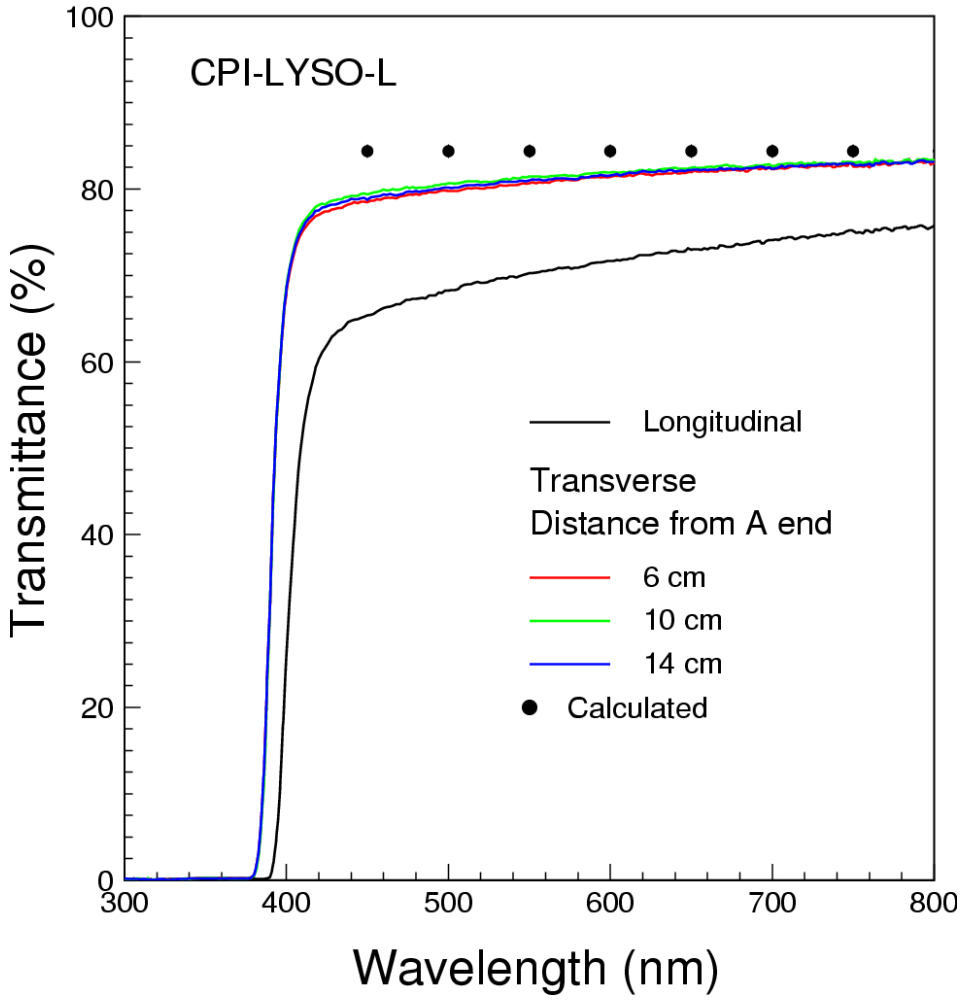


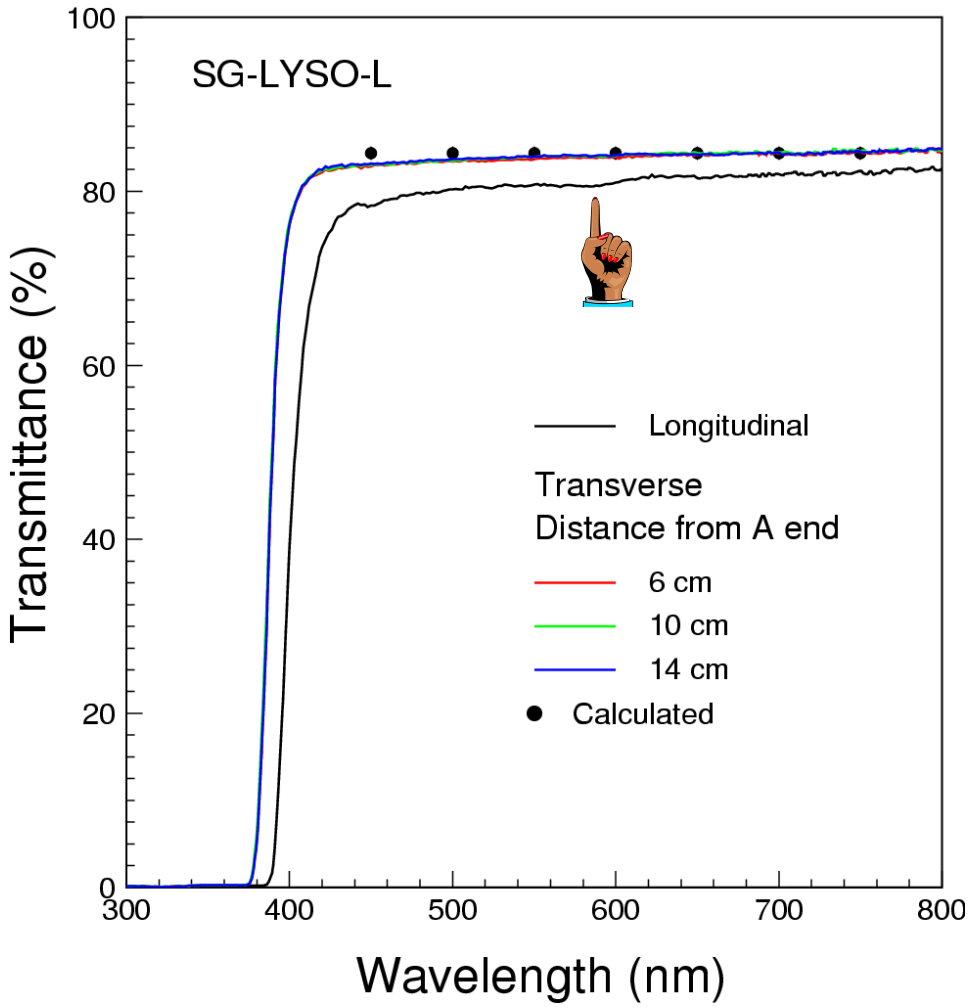


Long LYSO Transmittance

CPI sample has a poor transmittance (surface polishing?)

SG TT approaches theoretical limit, its LT shows an absorption band peaked at 580 nm: no effect on emission

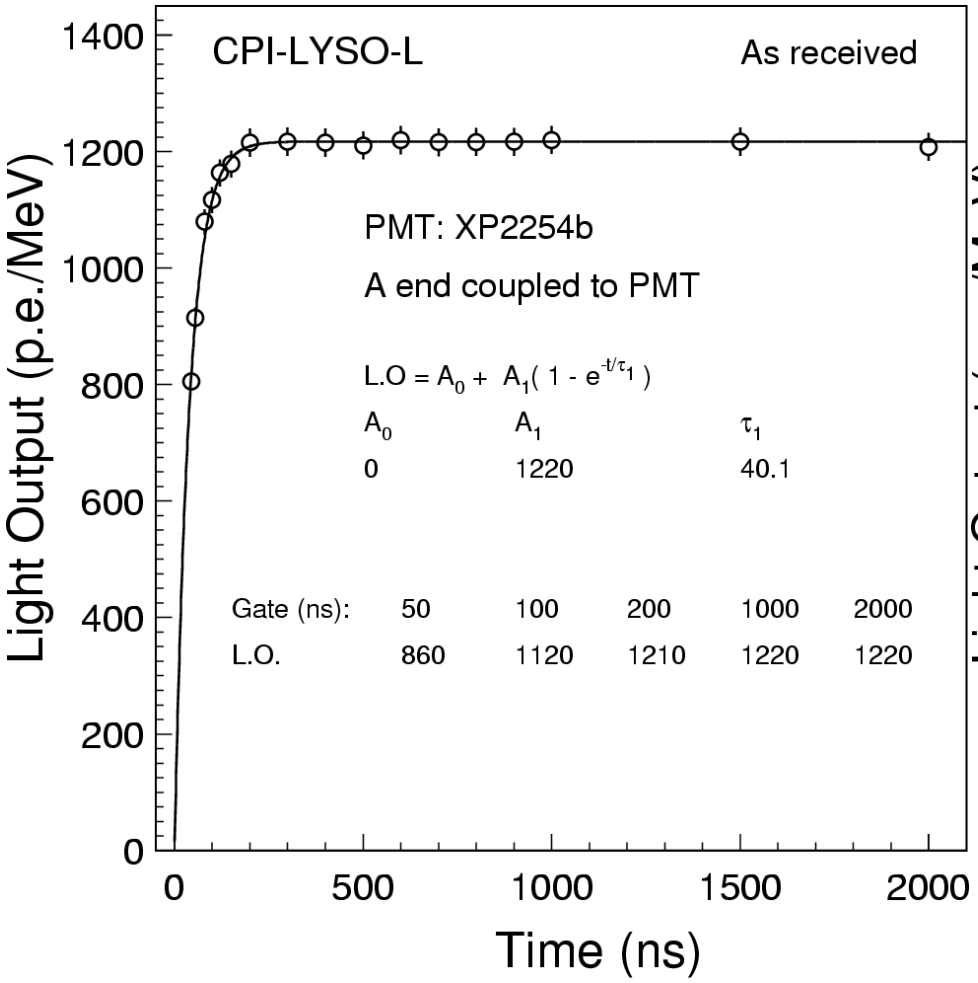


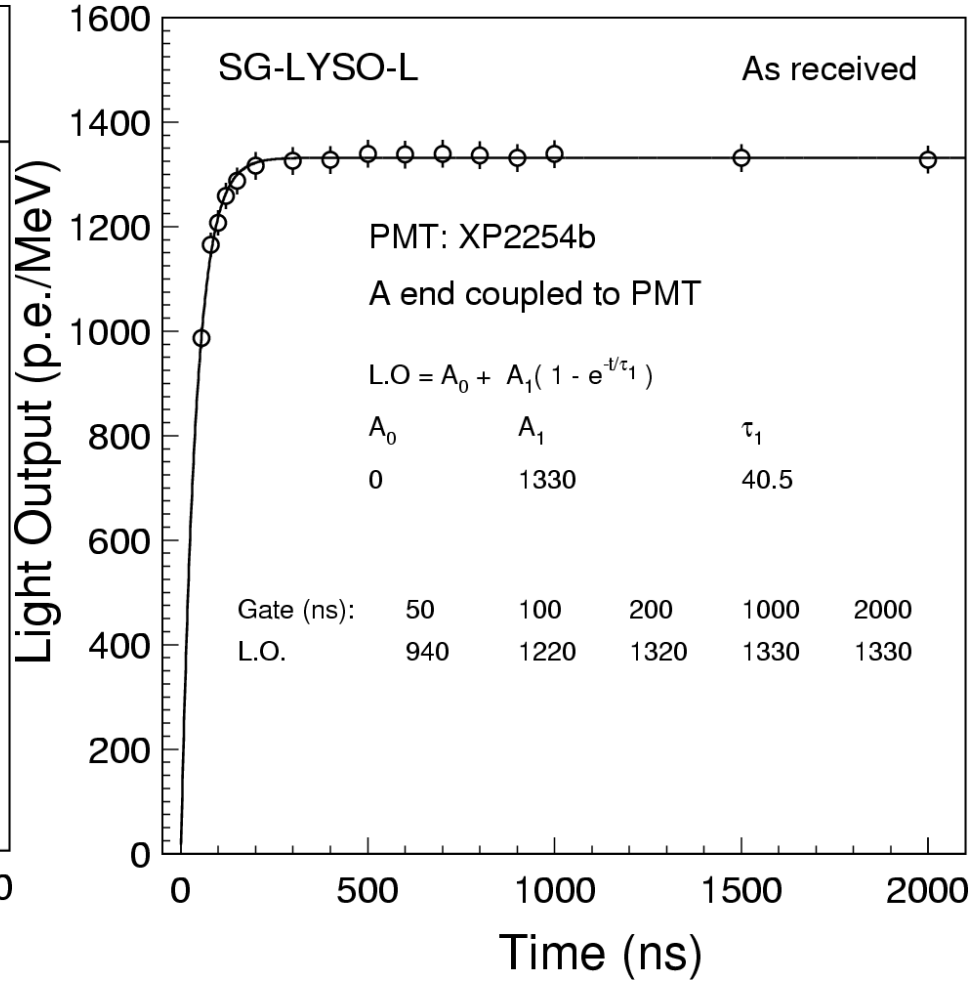


Long LYSO Decay Kinetics

Both samples have no longitudinal variation in decay kinetics

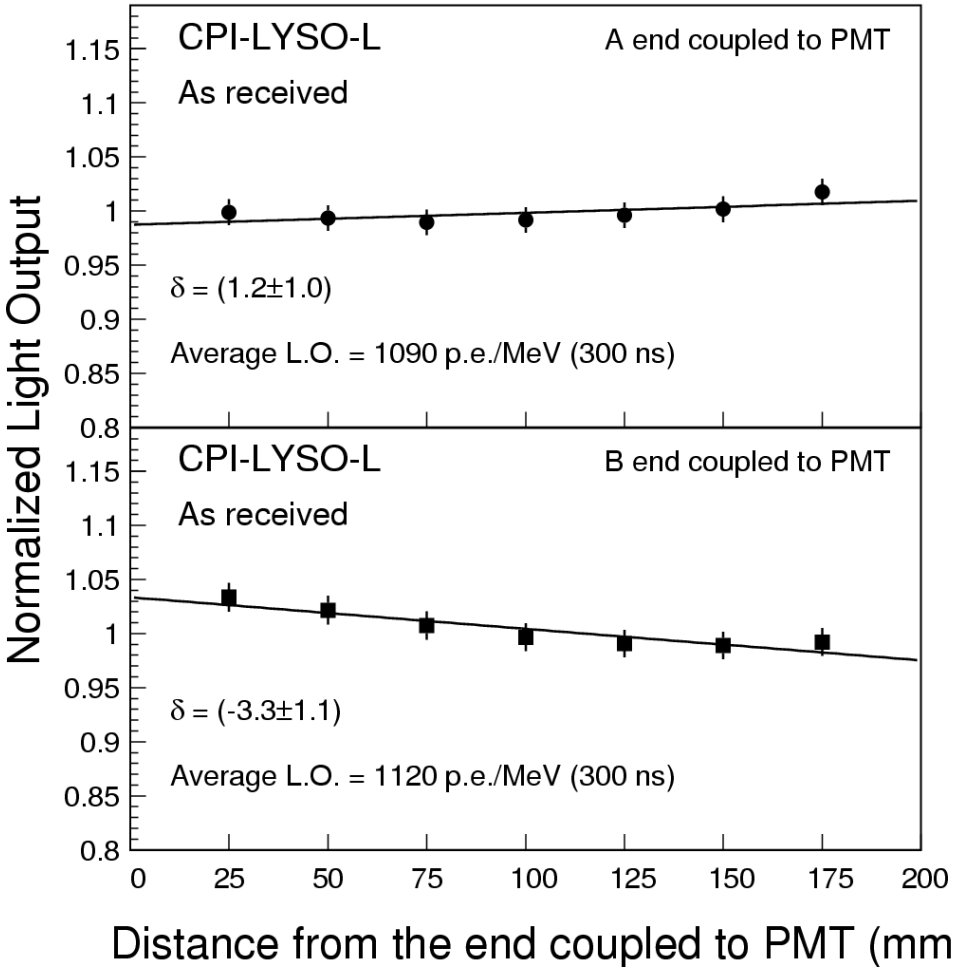
CPI sample has lower light output because of poor surface

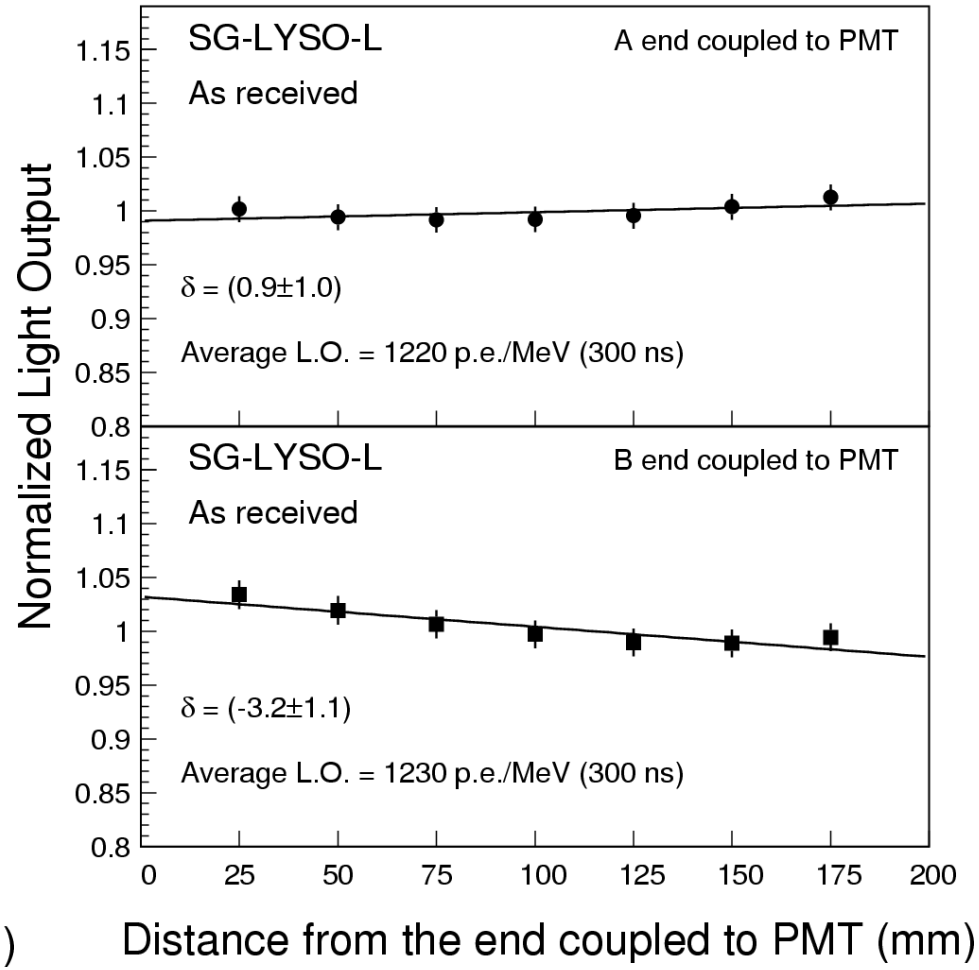




Long LYSO Light Response Uniformity

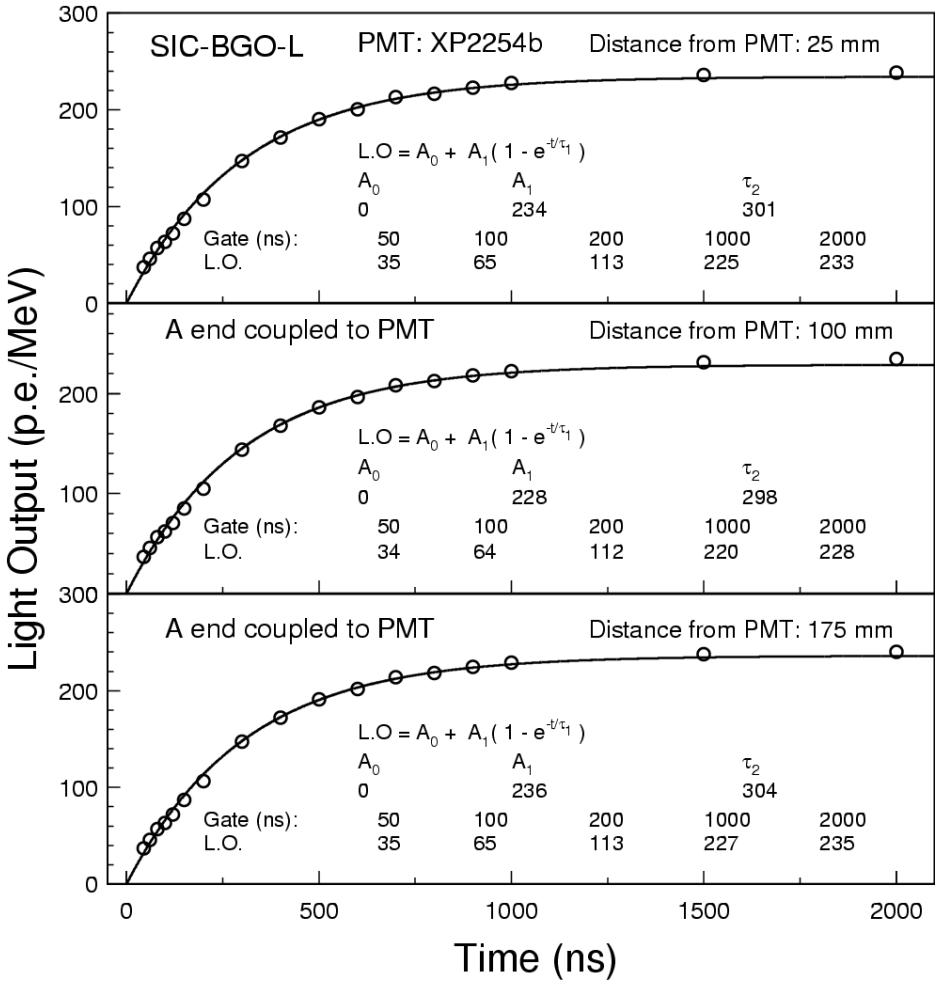
LRU has a minor dependence on the end coupled to the PMT, indicating a slightly not uniform light yield along crystal

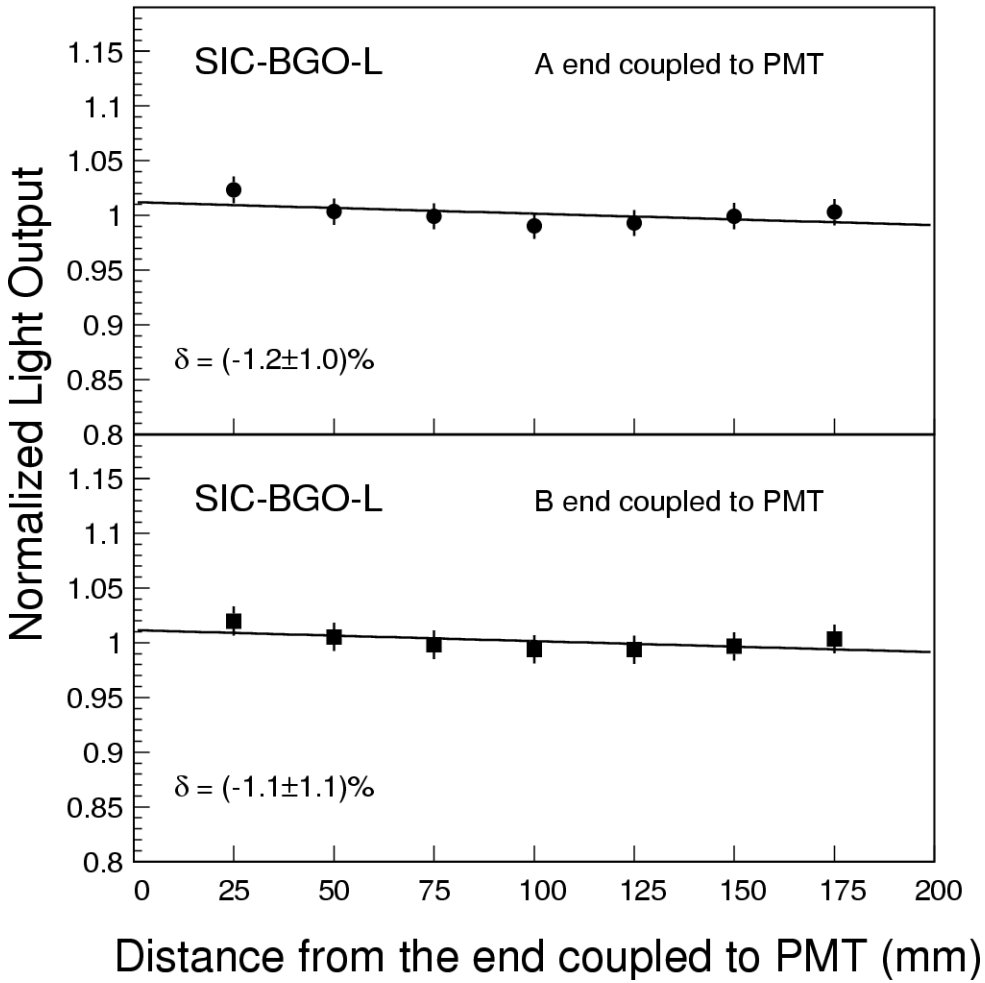




Long (2.5 x 2.5 x 20 cm) BGO Sample

A slight negative slope for both end coupled to the PMT indicating a good longitudinal uniformity

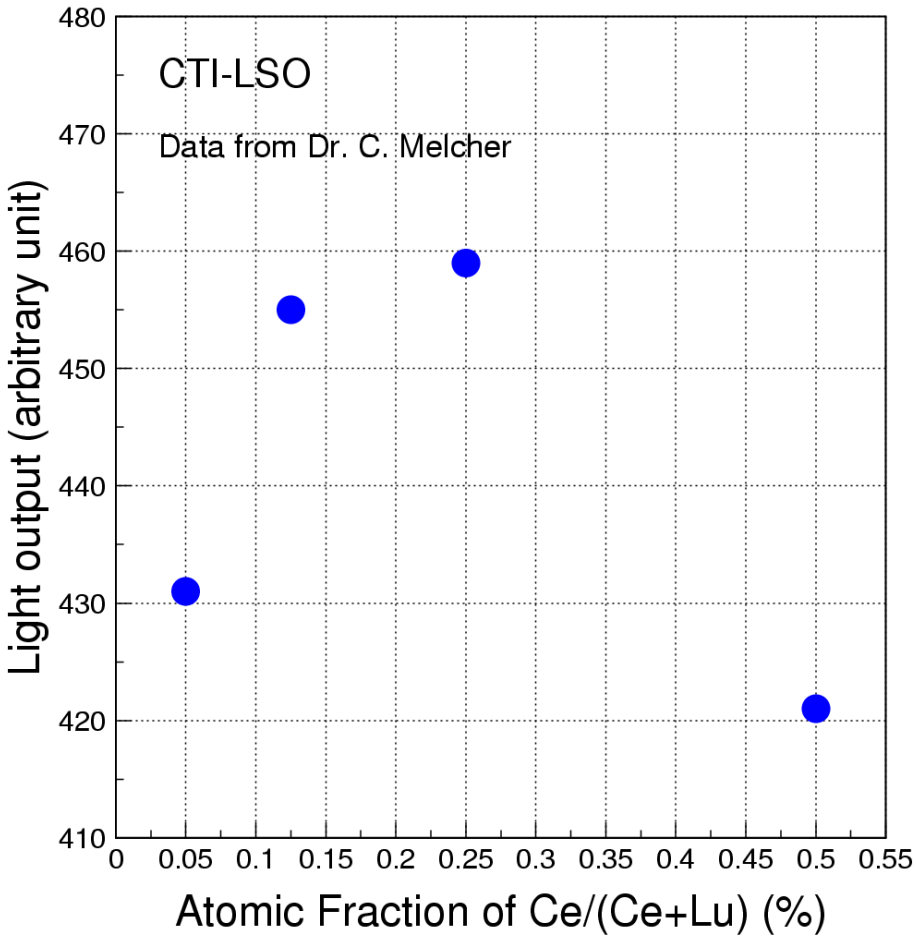


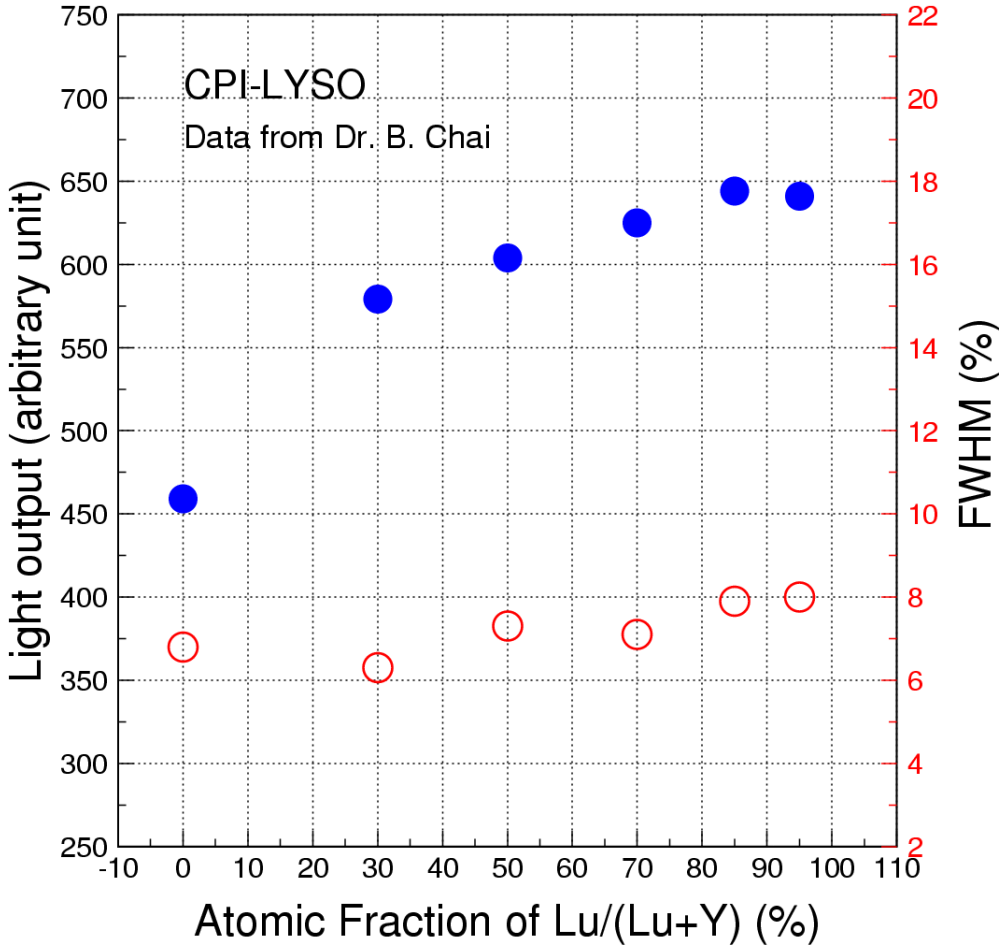


Possible Origin of Non Uniformity

C. Melcher: LO in LSO is a function of Ce concentration

B. Chai: LO in LYSO is a function of atomic fraction of Yttrium

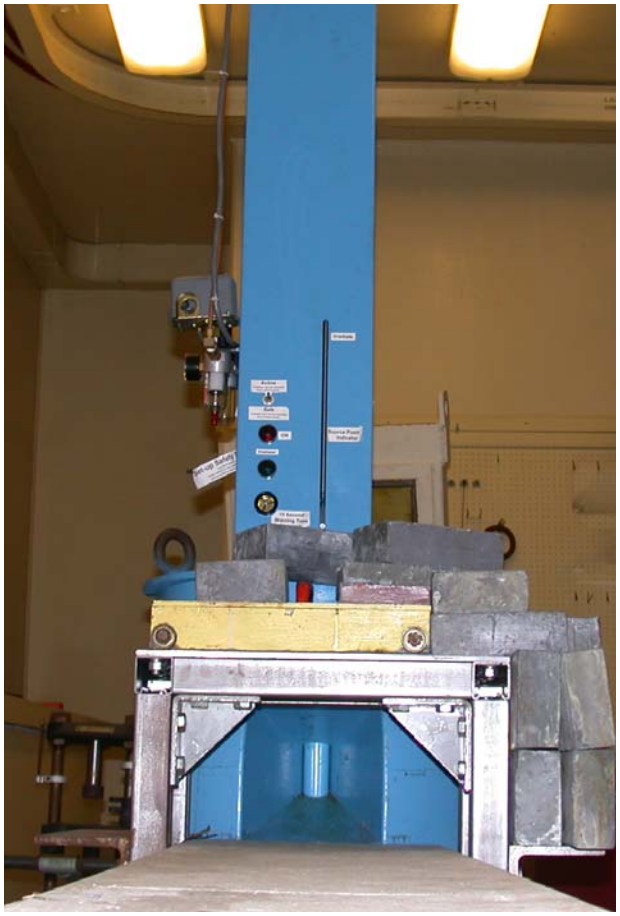




Caltech γ–ray Irradiation Facilities

Open 50 curie Co-60 provides 2 & 100 rad/h

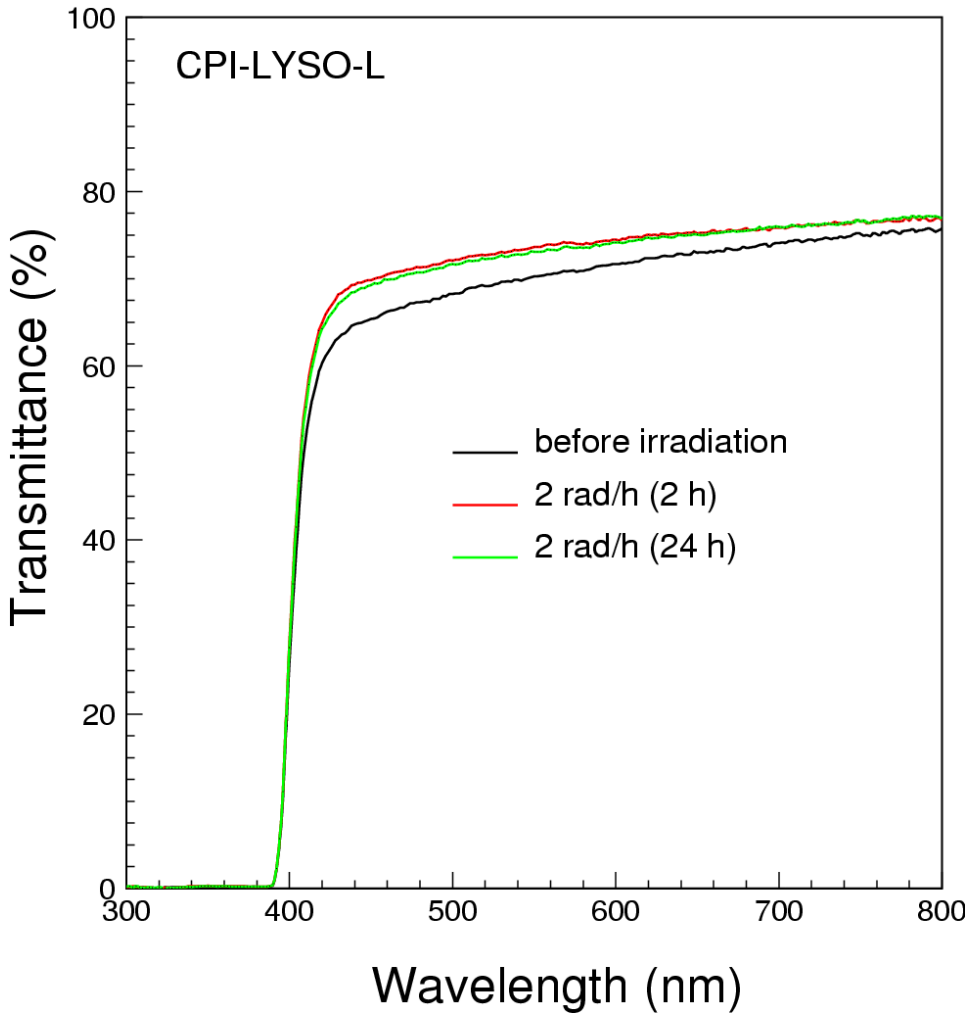
Closed 2,000 curie Cs-137 provides 9k rad/h with 5% uniformity

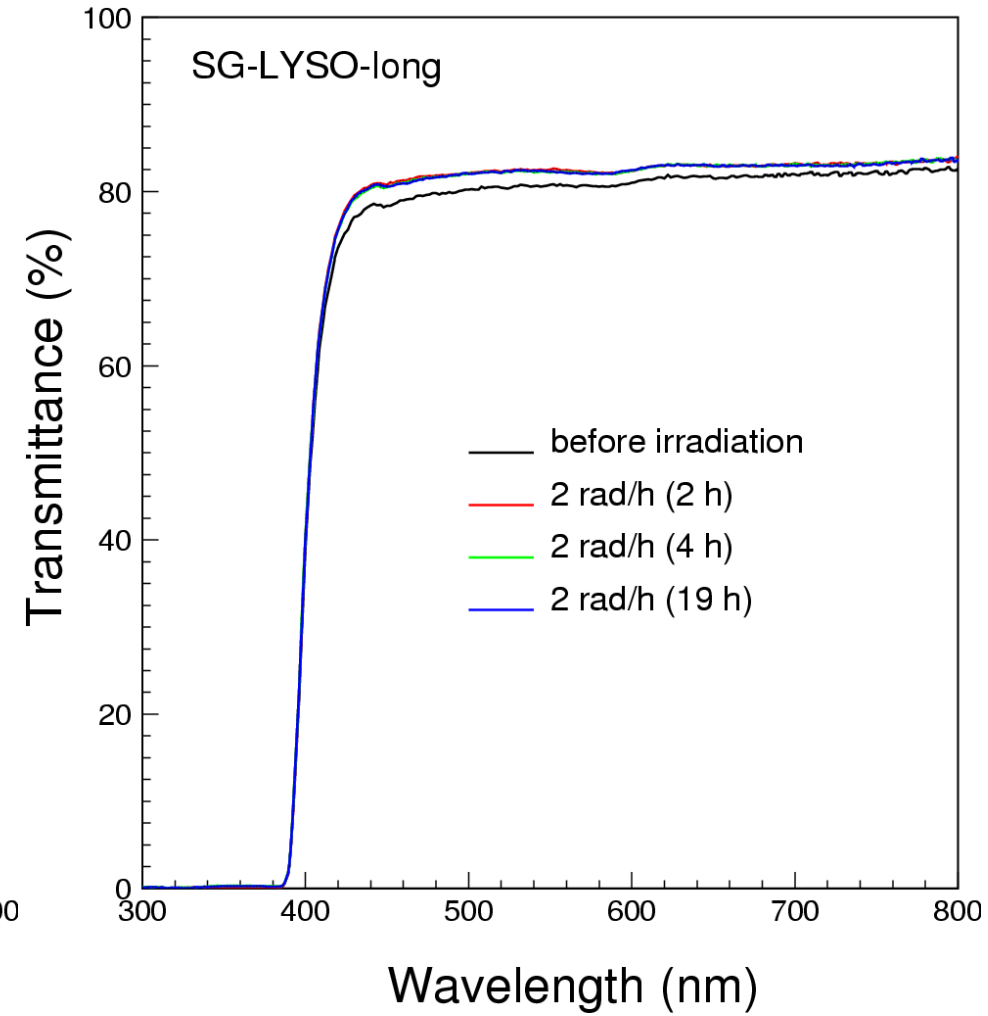


Transmittance under 2 rad/h

An initial increase under 2 rad/h (need thermal annealing?)

No further variation observed under 2 rad/h

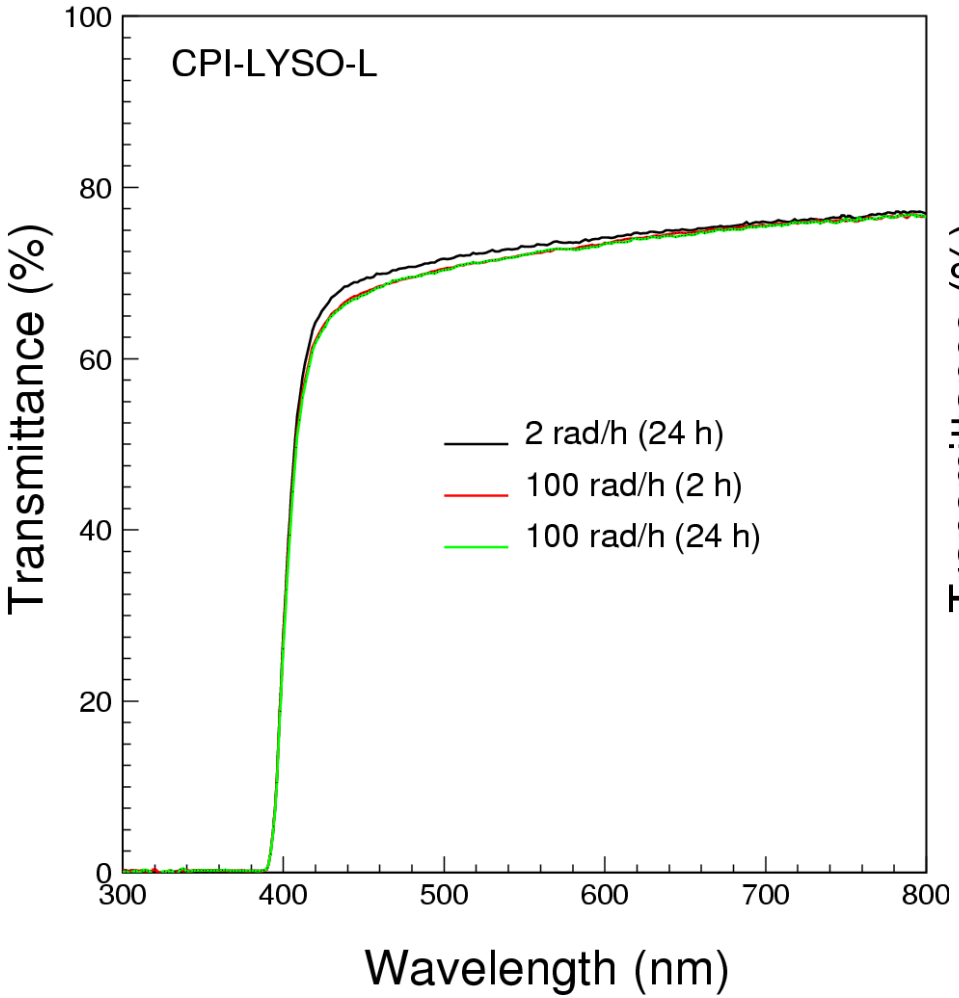


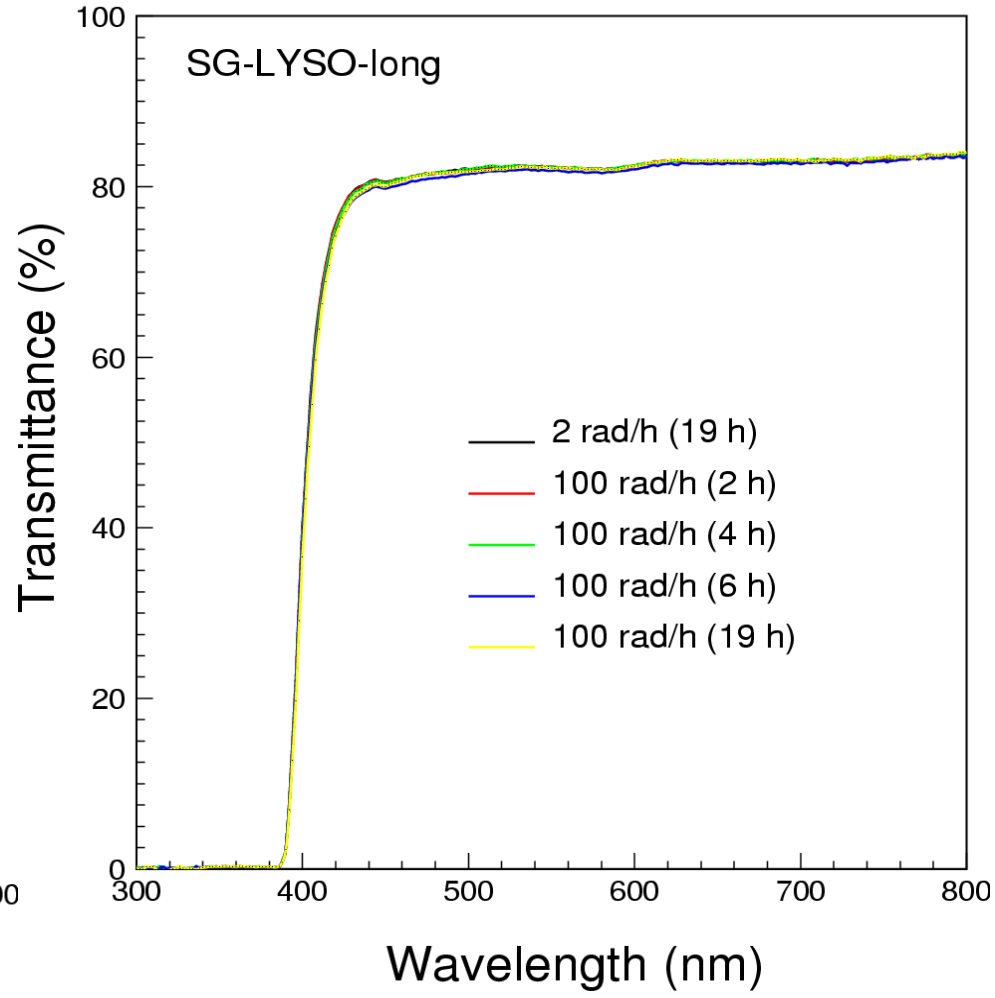


Transmittance under 100 rad/h

Some indication on initial decrease under 100 rad/h

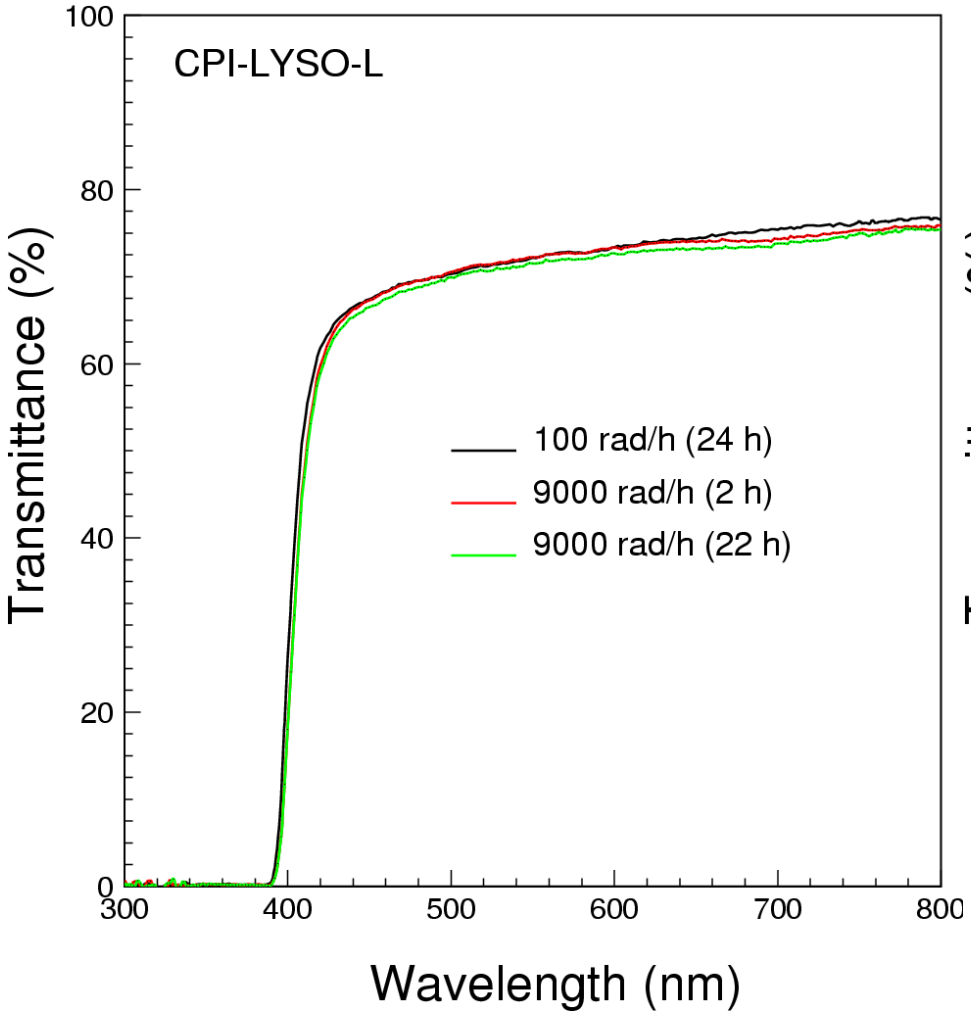
No further variation observed under 100 rad/h

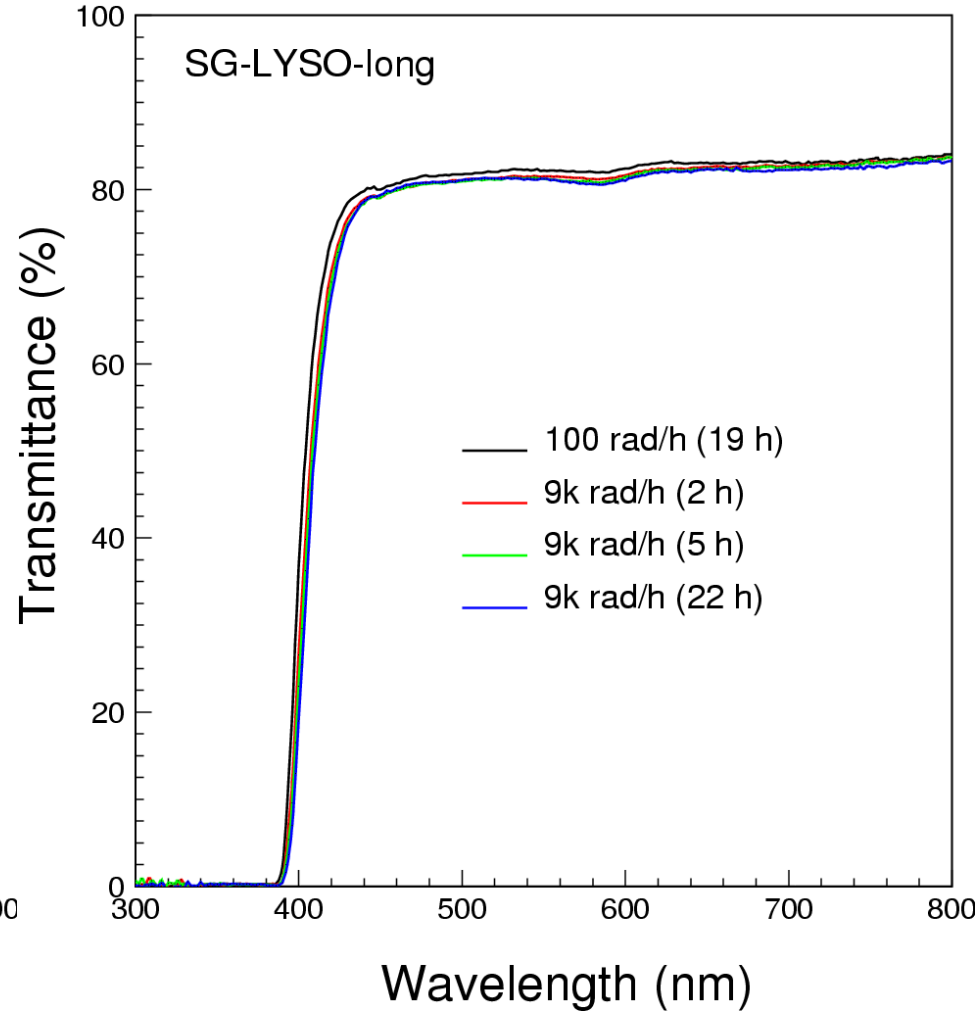




Transmittance under 9 krad/h

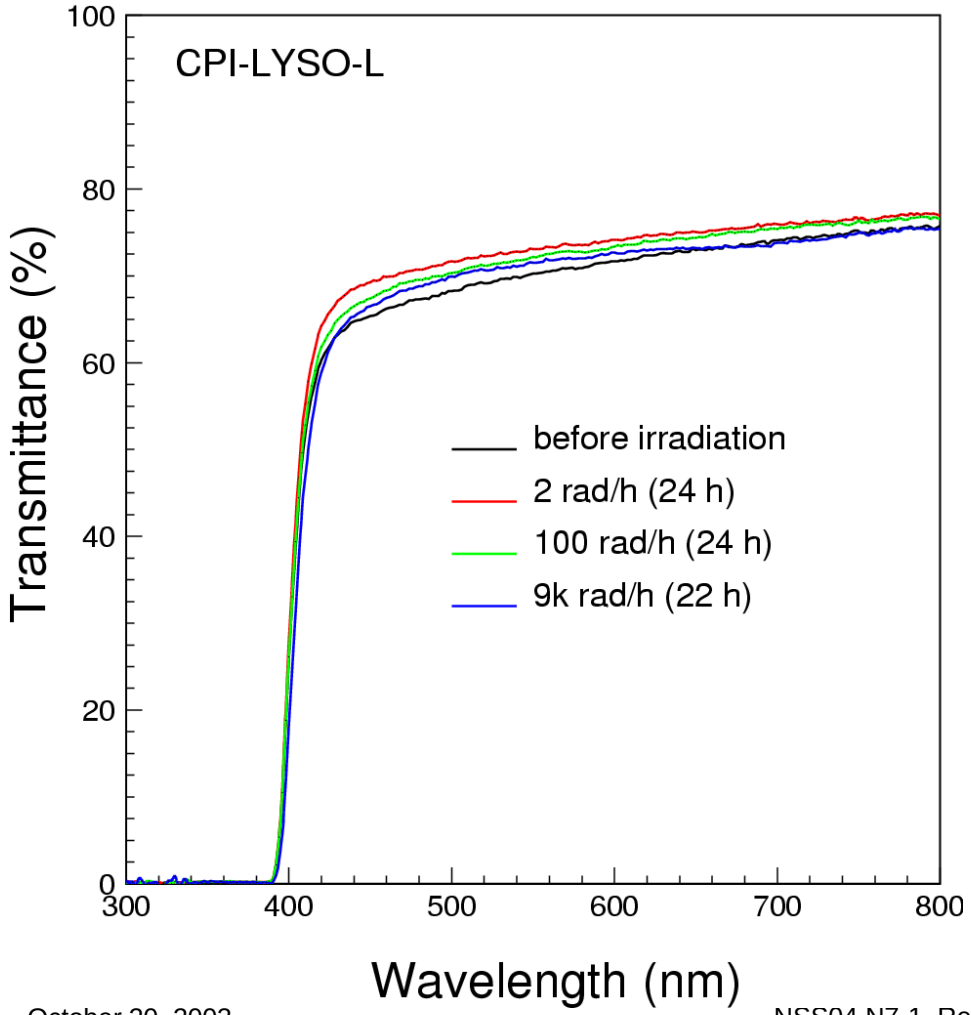
Small variation observed under 9 krad/h

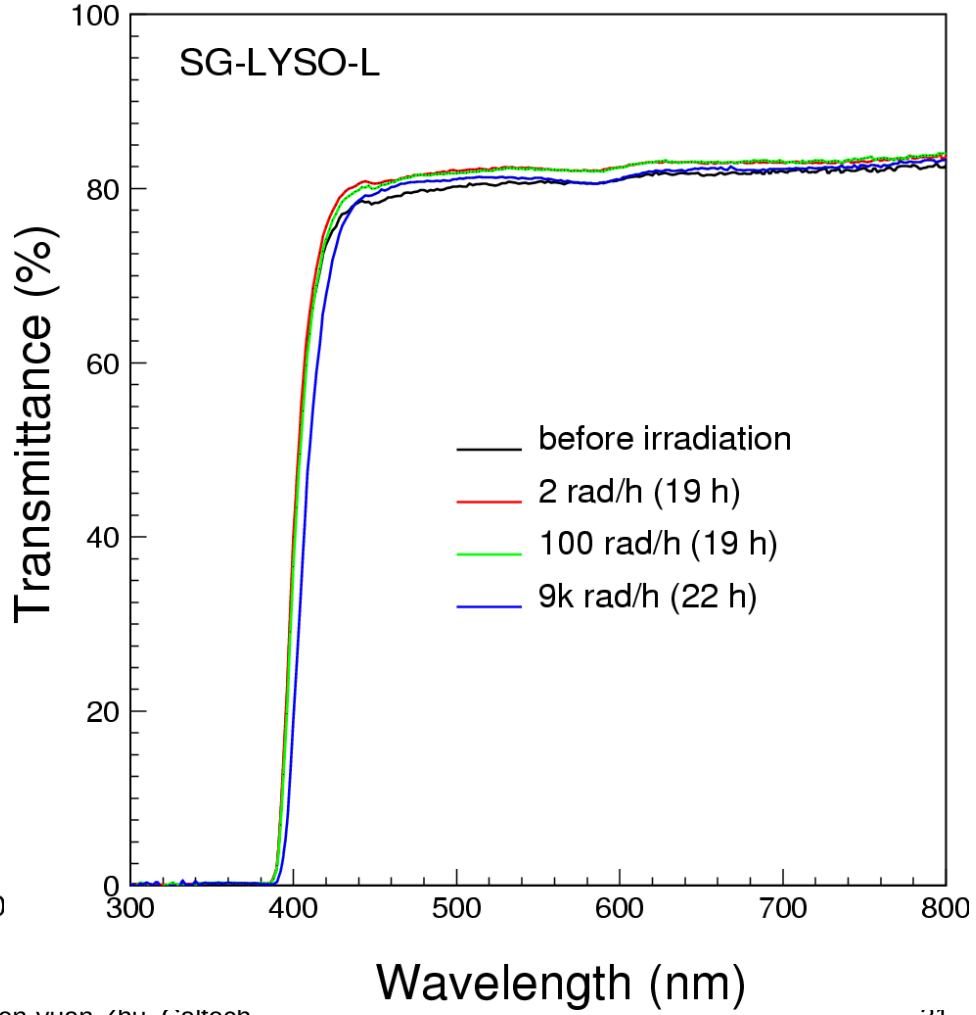




LYSO Longitudinal Transmittance

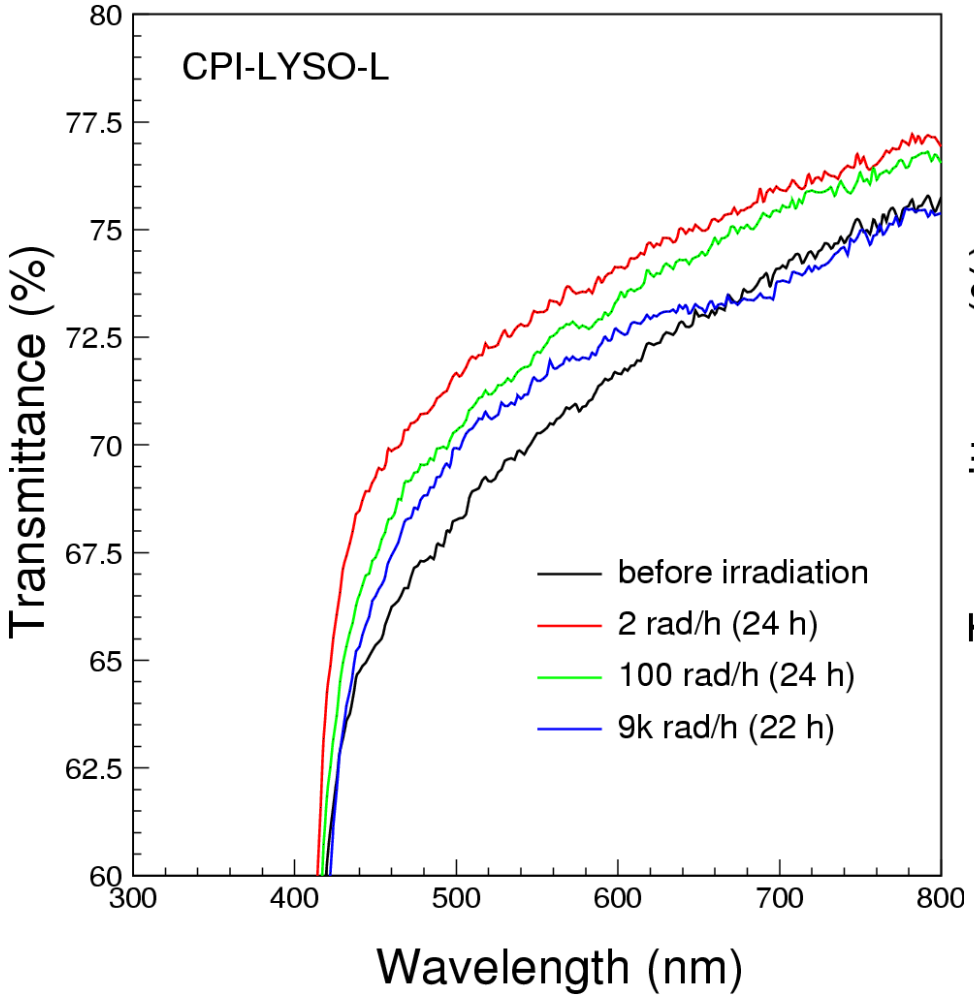
LT@430 nm	Initial	2 rad/h	100 rad/h	9 krad/h
CPI	63.2%	67.1%	64.9%	63.3%
SG	77.1%	79.3%	78.5%	75.7%

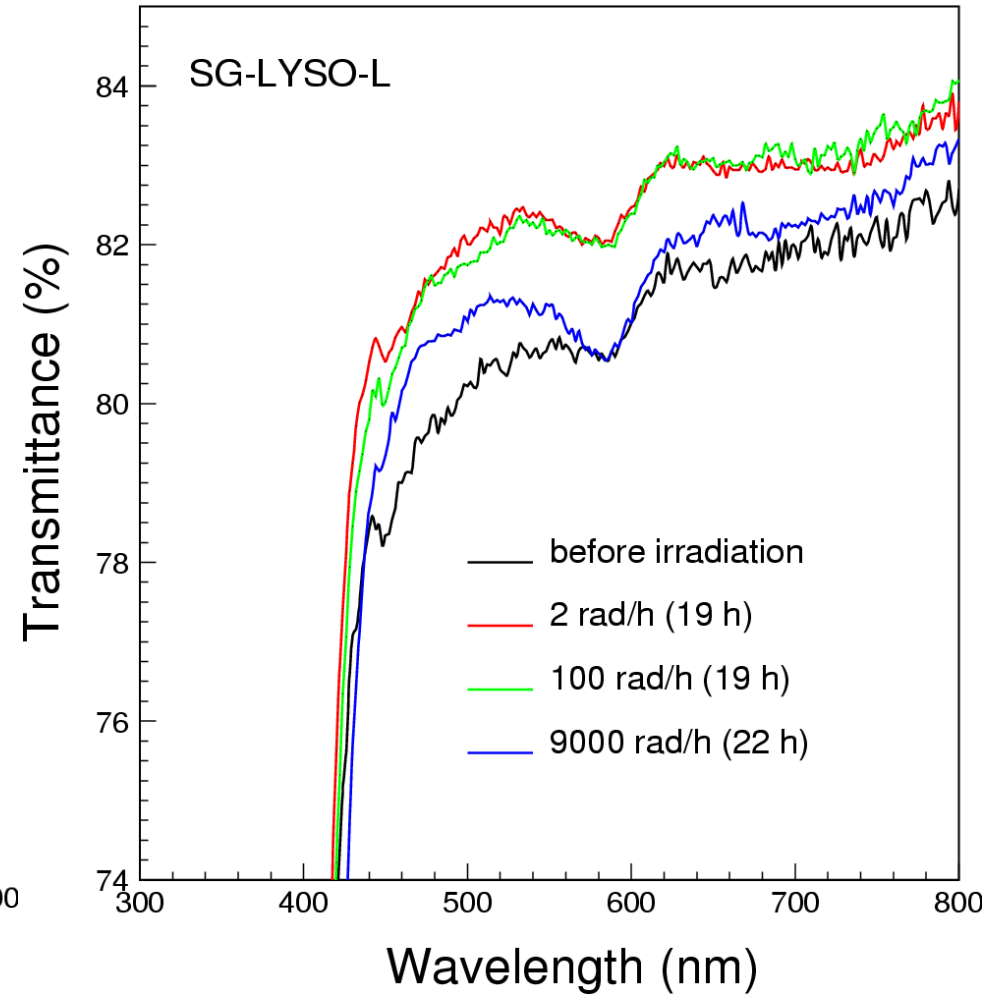




LYSO Transmittance Damage

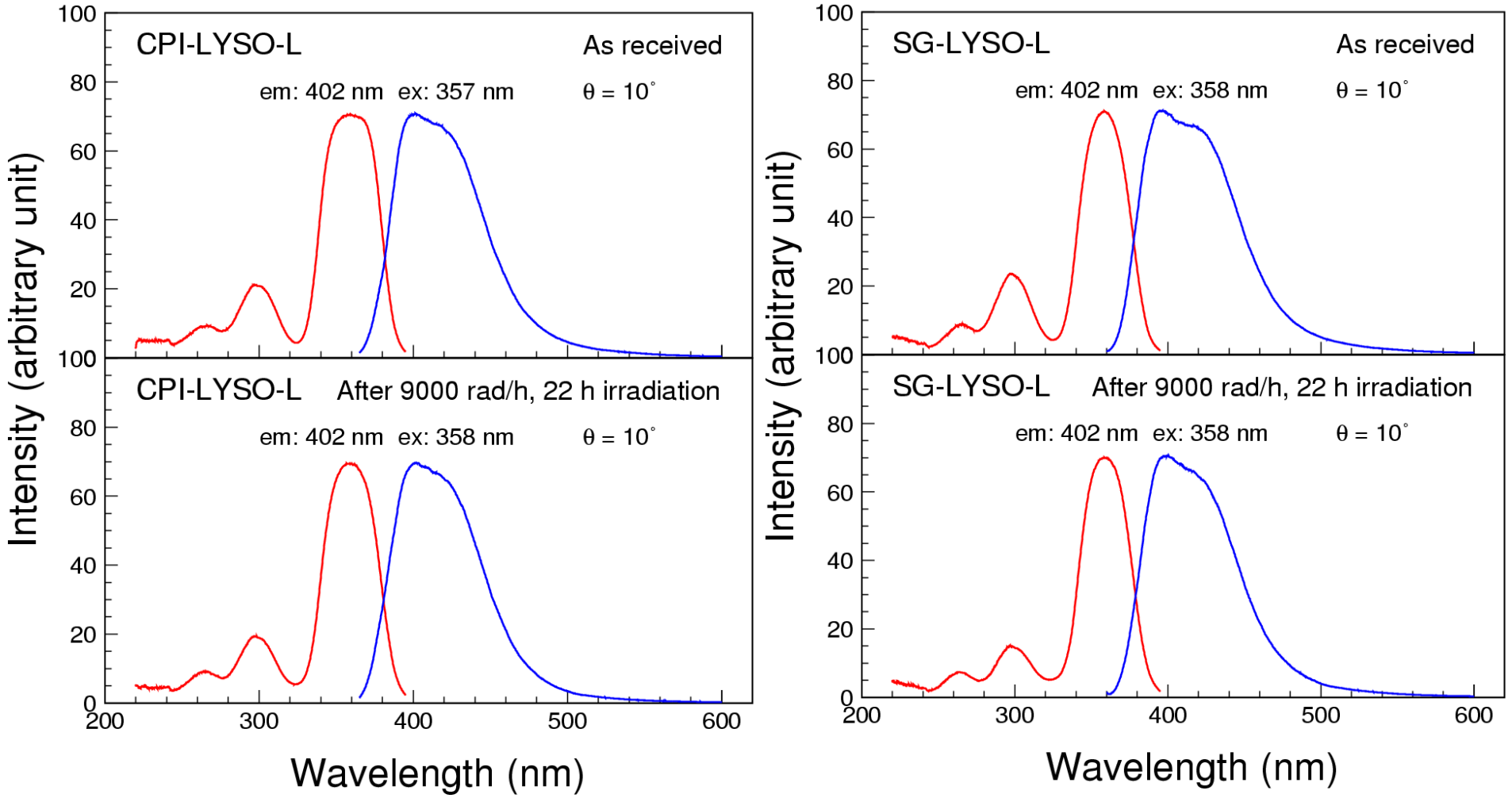
LT @ 430 nm shows 6 and 3% increase under 2 rad/h, followed by 6 and 5% degradation under 9 krad/h for CPI and SG samples respectively





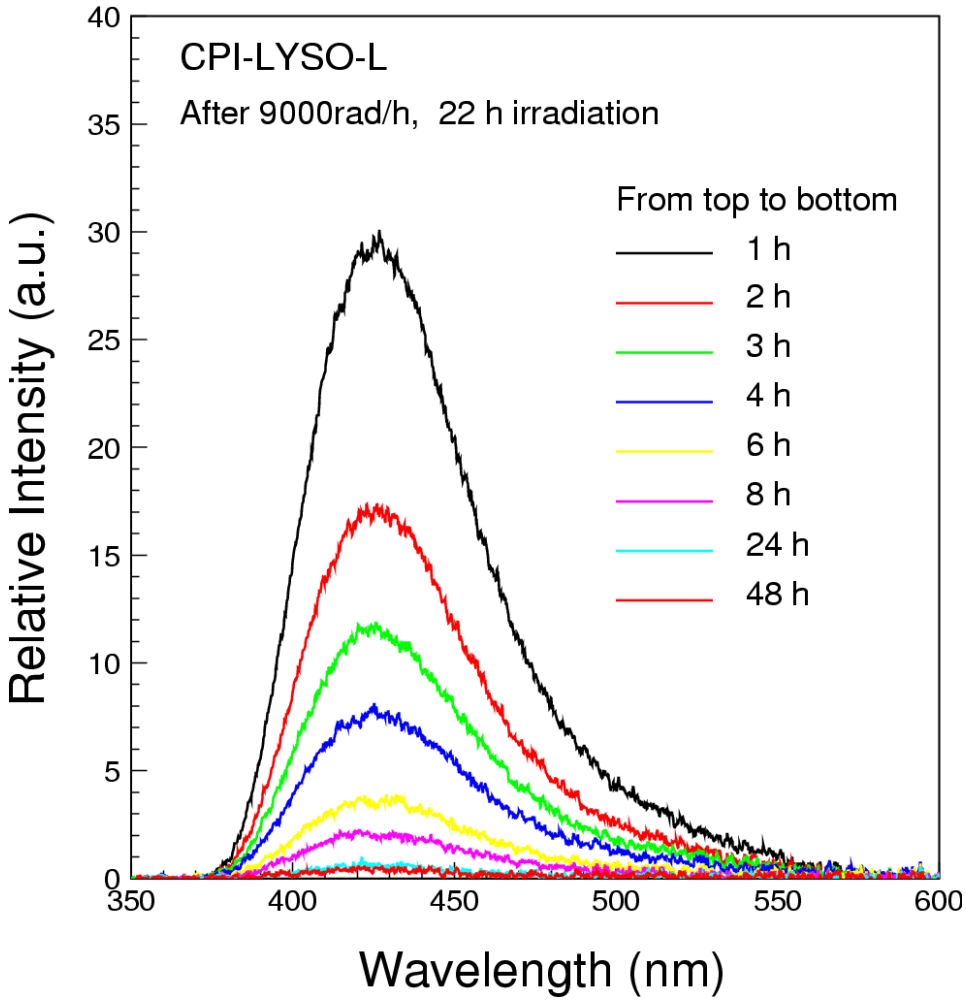
LYSO Excitation/Emission

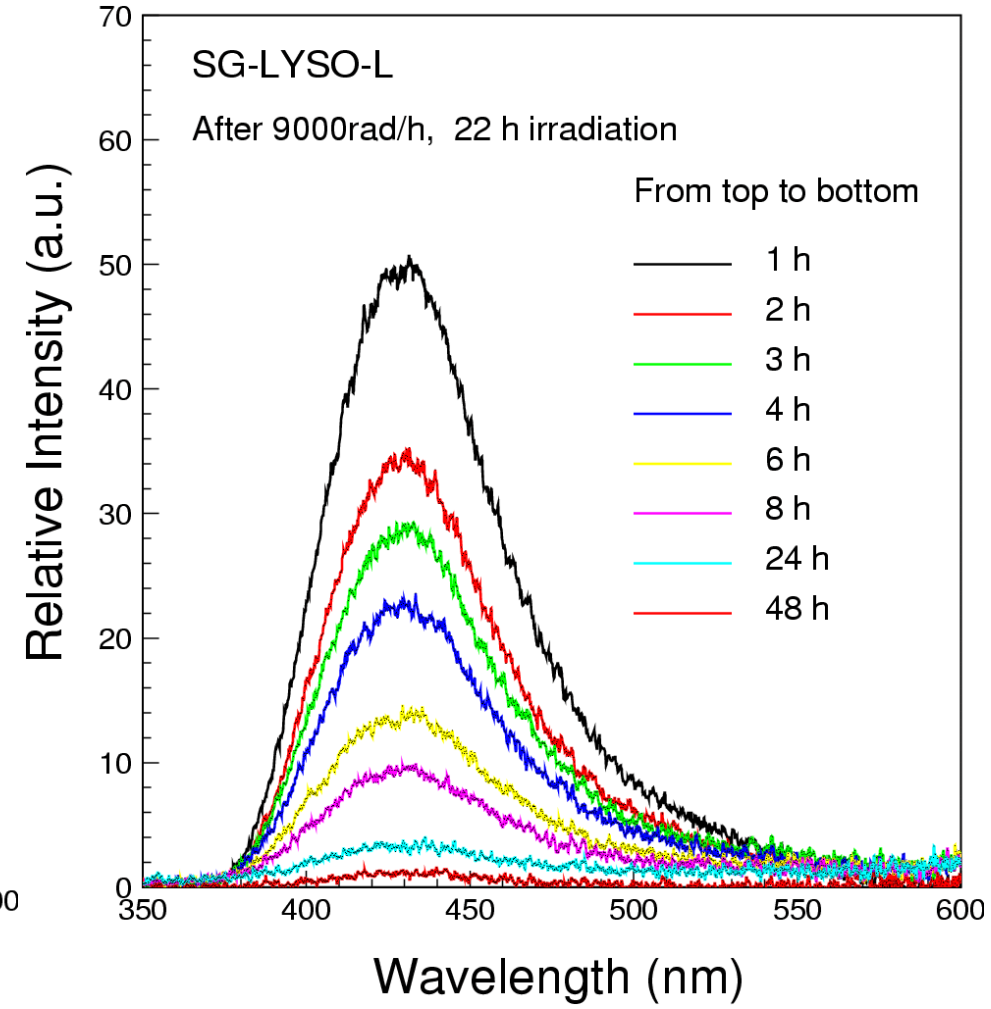
No variation in emission & excitation



Radiation Induced Phosphorescence

Phosphorescence peaked at 430 nm was observed

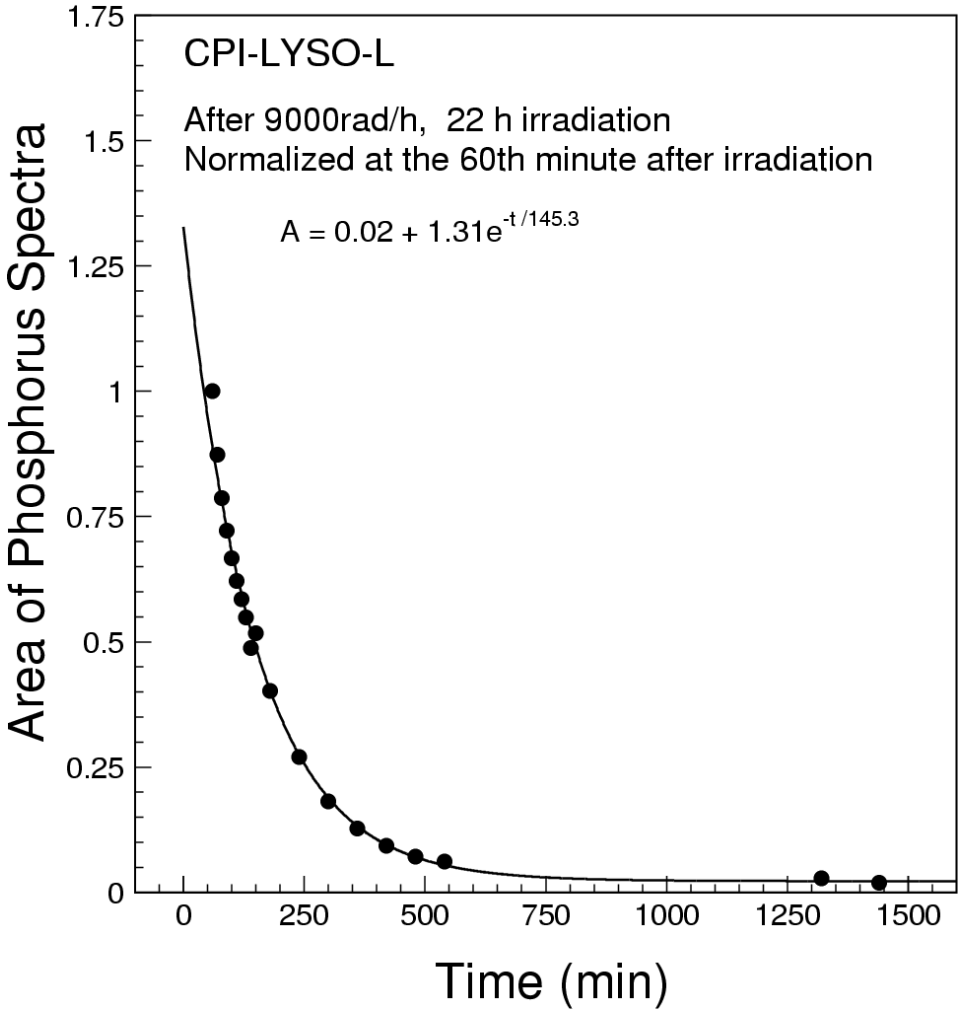


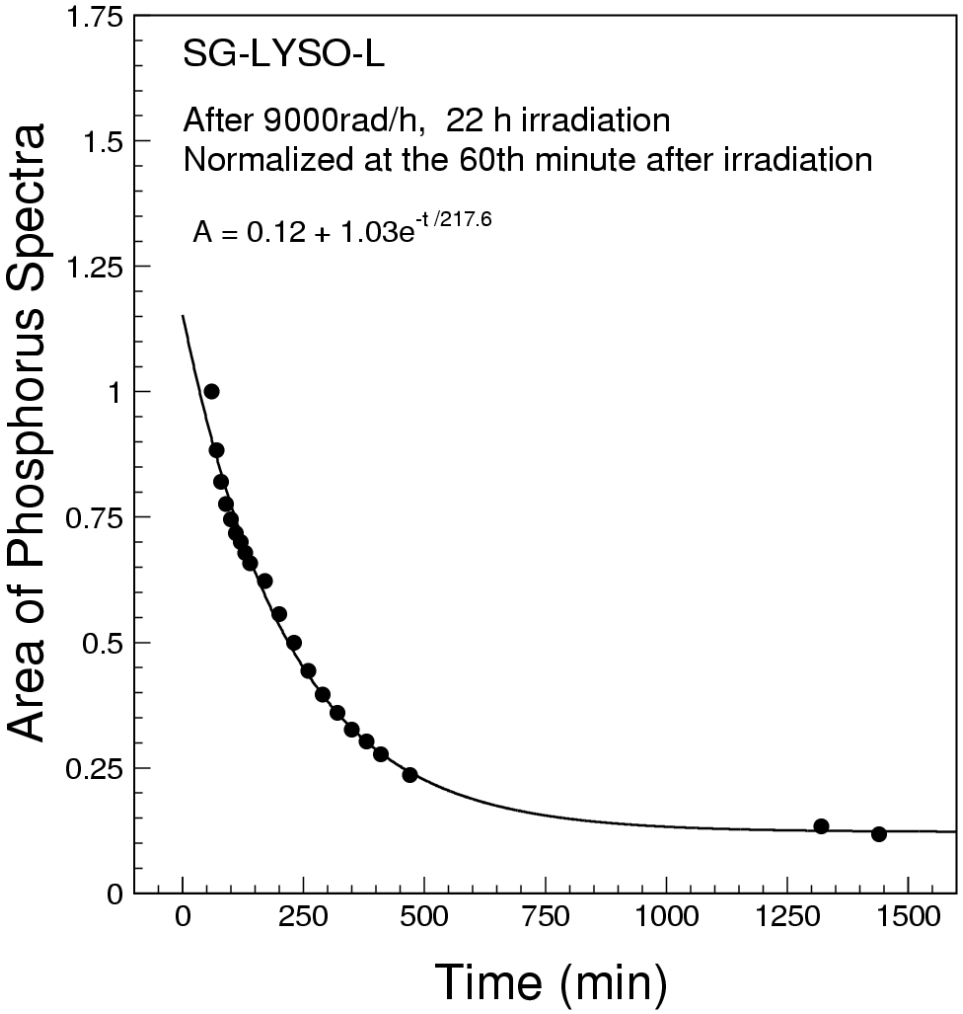


Phosphorescence Decay Time

Decay time constant: 2.5 to 3 h

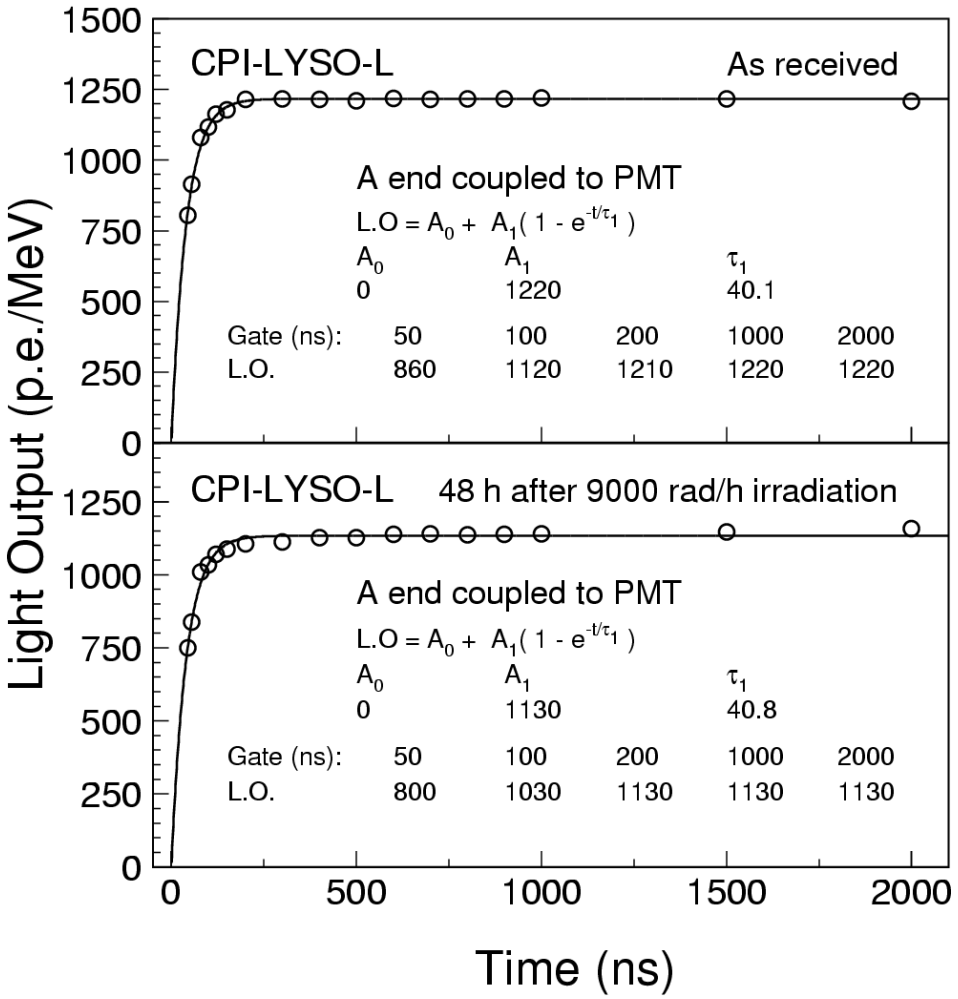
SG sample has a higher residual phosphorescence

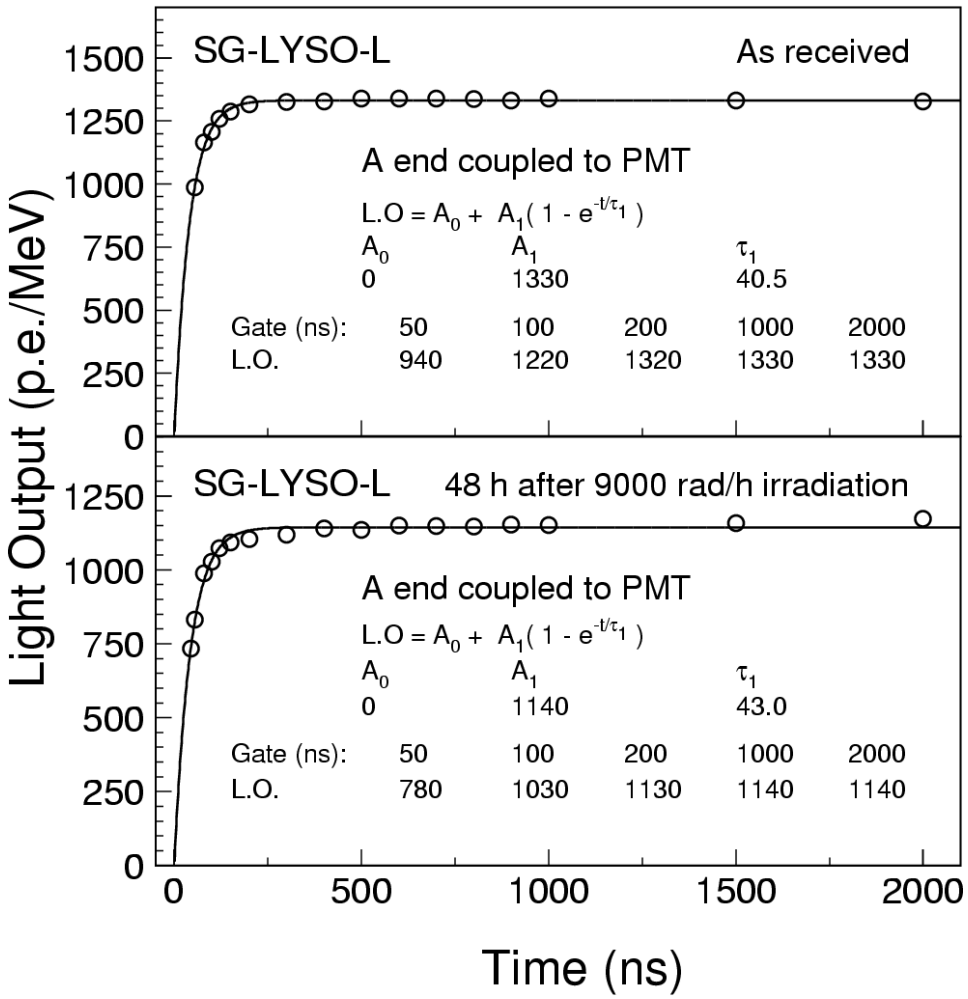




Light Output Degradation

LO may have some degradation after irradiation, which is to be confirmed by further measurement

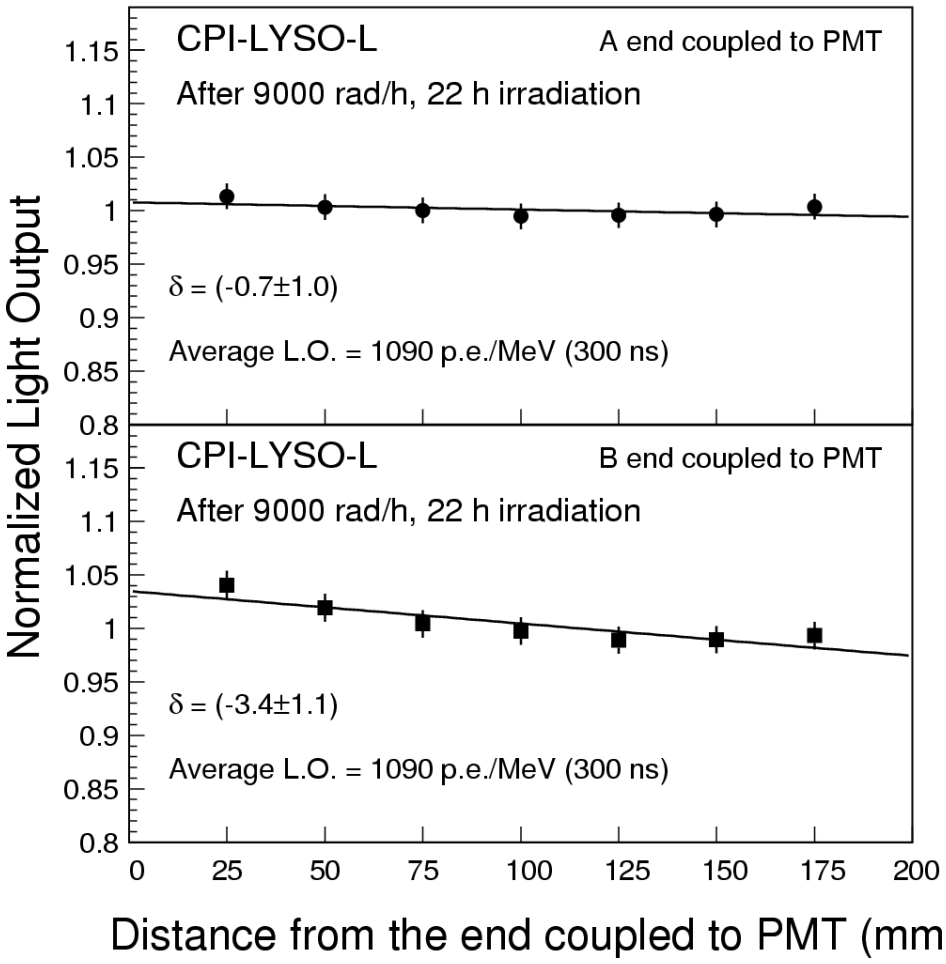


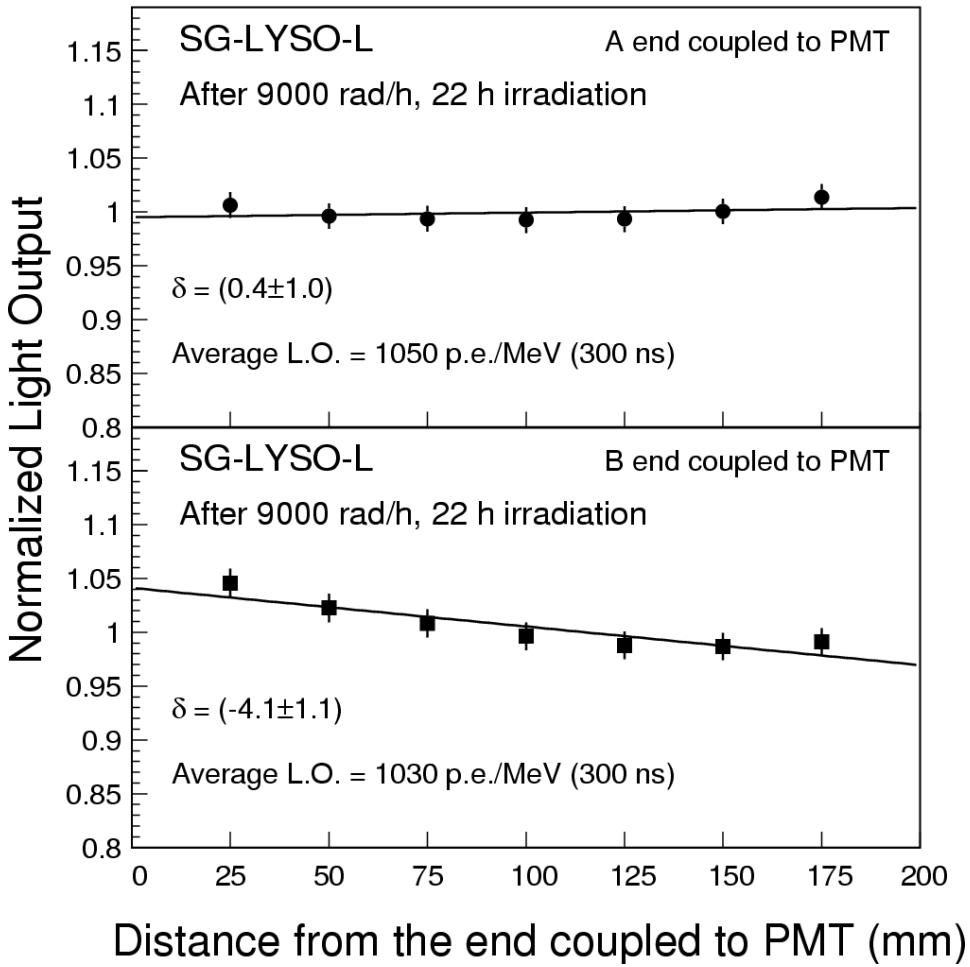


Long LYSO Light Response Uniformity

Small visible variation in light response uniformity

LO degradation is to be confirmed by further measurement





Summary

- Ce doped LSO & LYSO crystals have identical emission, excitation and transmittance spectra. Their fast light output of 42 ns decay time is 4 times of BGO. Their absorption edge in transmittance affects light output.
- 2.5 x 2.5 x 20 cm LYSO samples from CPI and Saint-Gobain have good longitudinal uniformity. Their light response uniformity may be slightly affected by the distribution of the Ce concentration.
- One of the main consequence of radiation damage in LYSO under γ–ray irradiation is radiation induced phosphorescence, which has a time constant of 2.5 to 3 h. Radiation effect on transmittance, emission and excitation spectra and light output is small as compared to other commonly used crystals. Detailed study with solid state (PD or APD) readout in under way.
- With existing mass production capabilities, LSO & LYSO crystals are a good candidate for future crystal calorimeter in high energy physics.