Large Size LSO:Ce and LYSO:Ce Crystal Scintillators for Future High Energy Physics and Nuclear Physics Experiments

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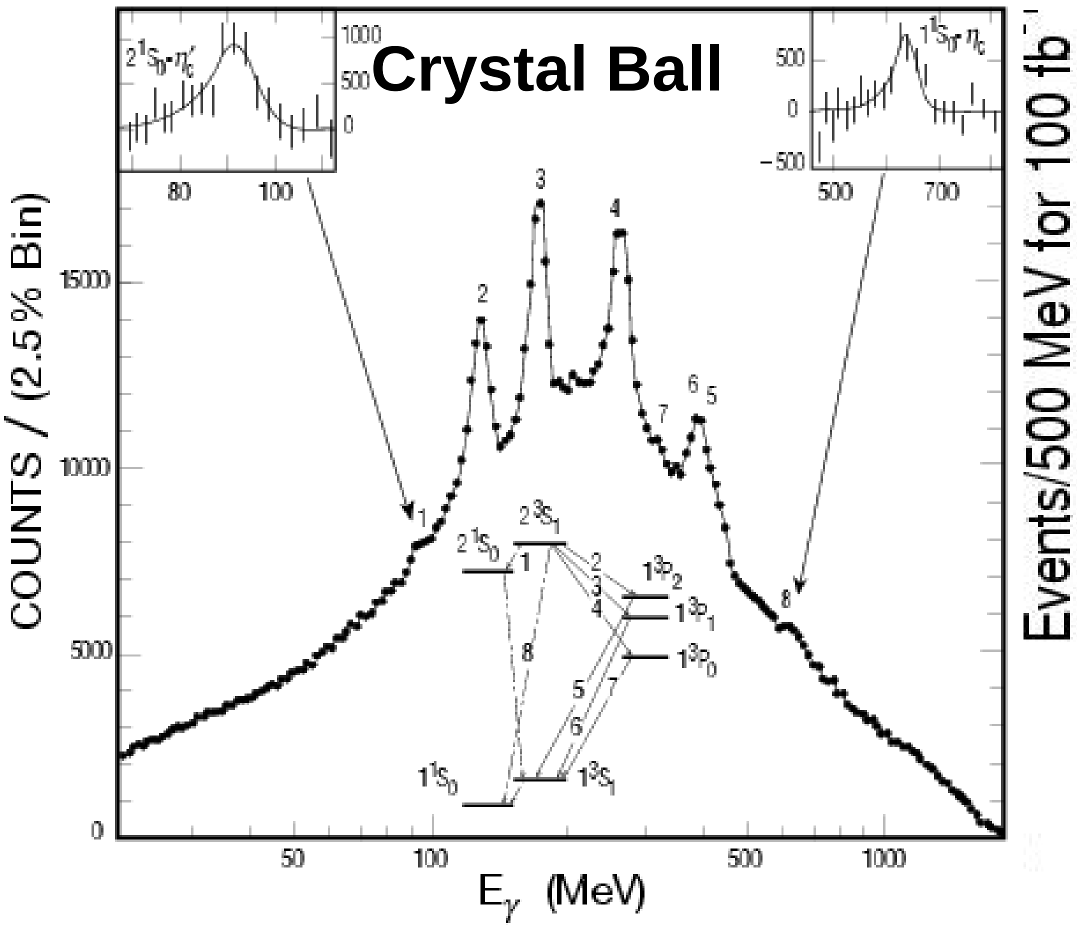
Why a Crystal Calorimeter

- Photons and electrons are fundamental particles for the SM and new physics.
- Performance of a crystal calorimeter is well understood:
  - The best possible energy resolution, good position and photon angular resolution;
  - Good e/photon identification and reconstruction efficiency;
  - Good missing energy resolutions;
  - Good jet energy resolution.
- Enhance the physics discovery potential.

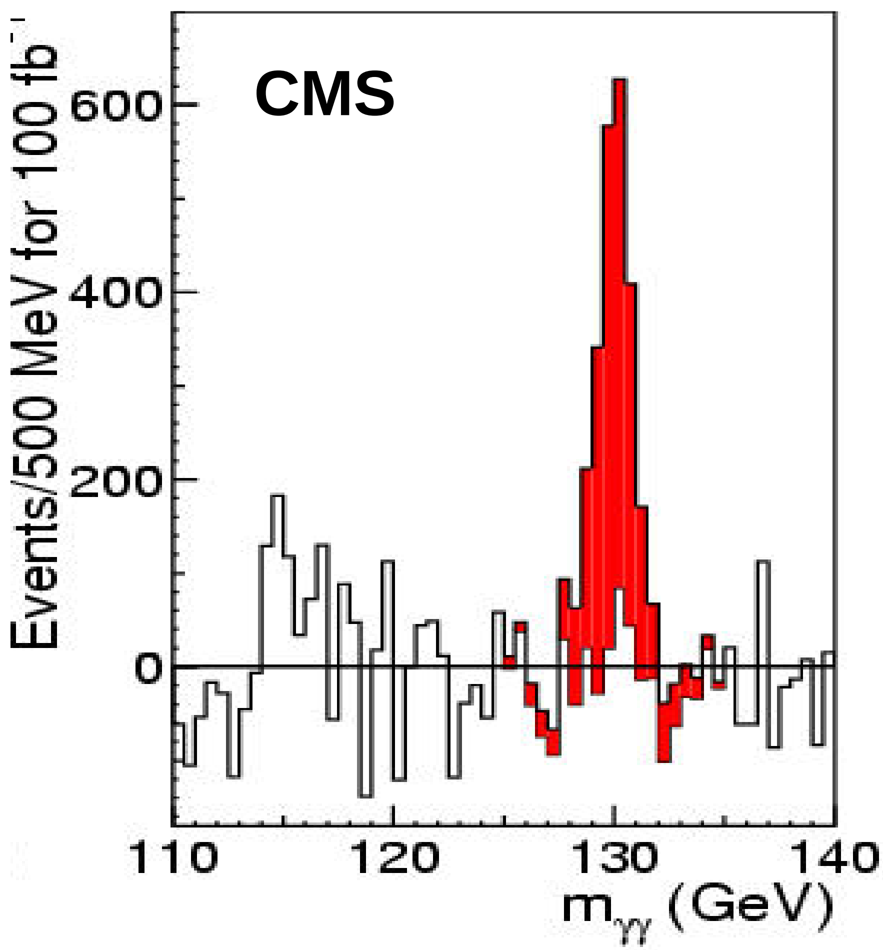
Physics in Crystal Calorimeters

Charmonium System Observed Through Inclusive Photons



Higgs Searches at LHC

$$H \to \gamma\gamma$$



Mass Produced Crystal Scintillators

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
Refracti								.85
Hygrosc								No
Lumine (at peak								40
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)…	-	-

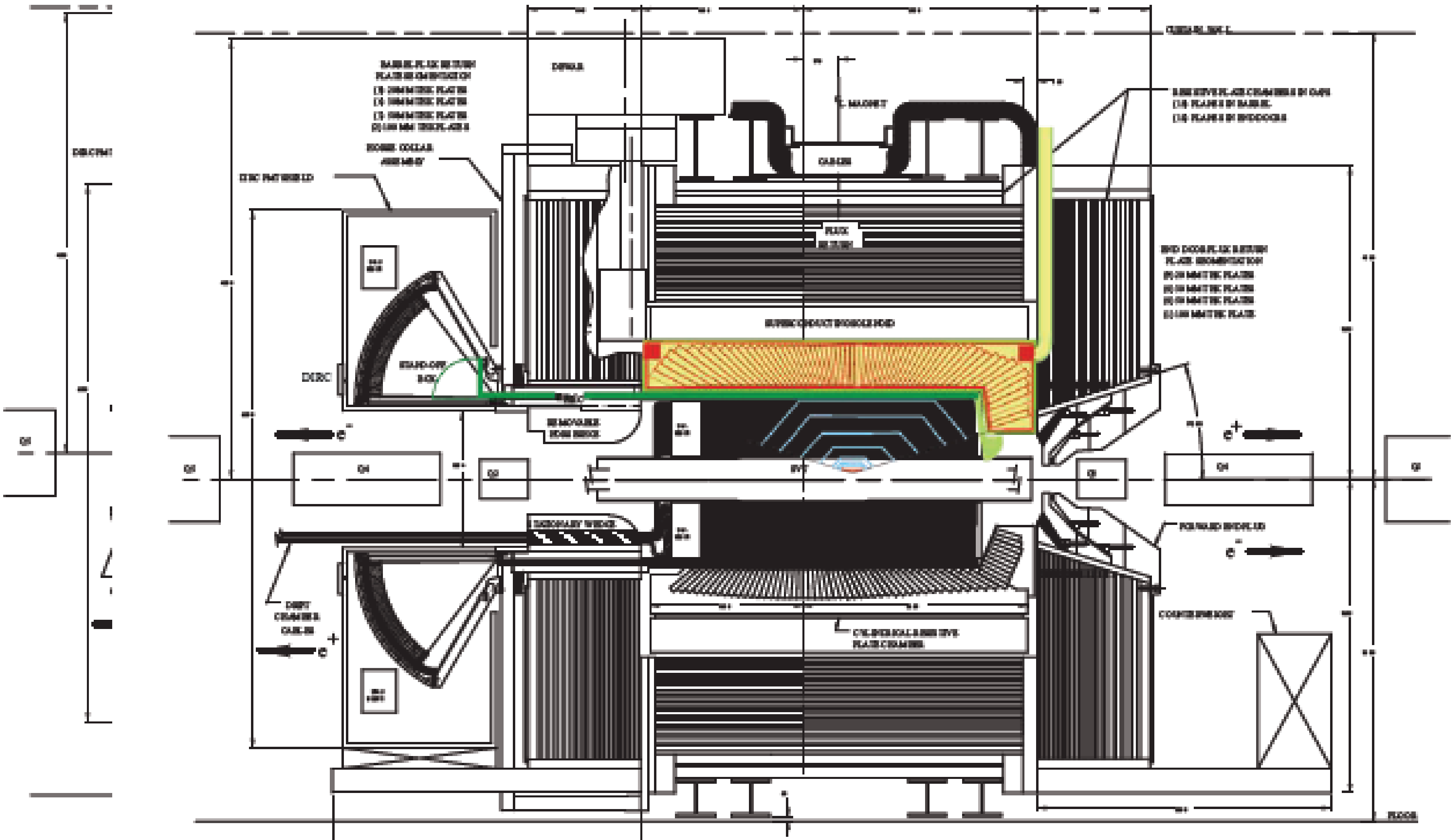
LSO/LYSO is a unique crystal with high light output & fast decay time

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

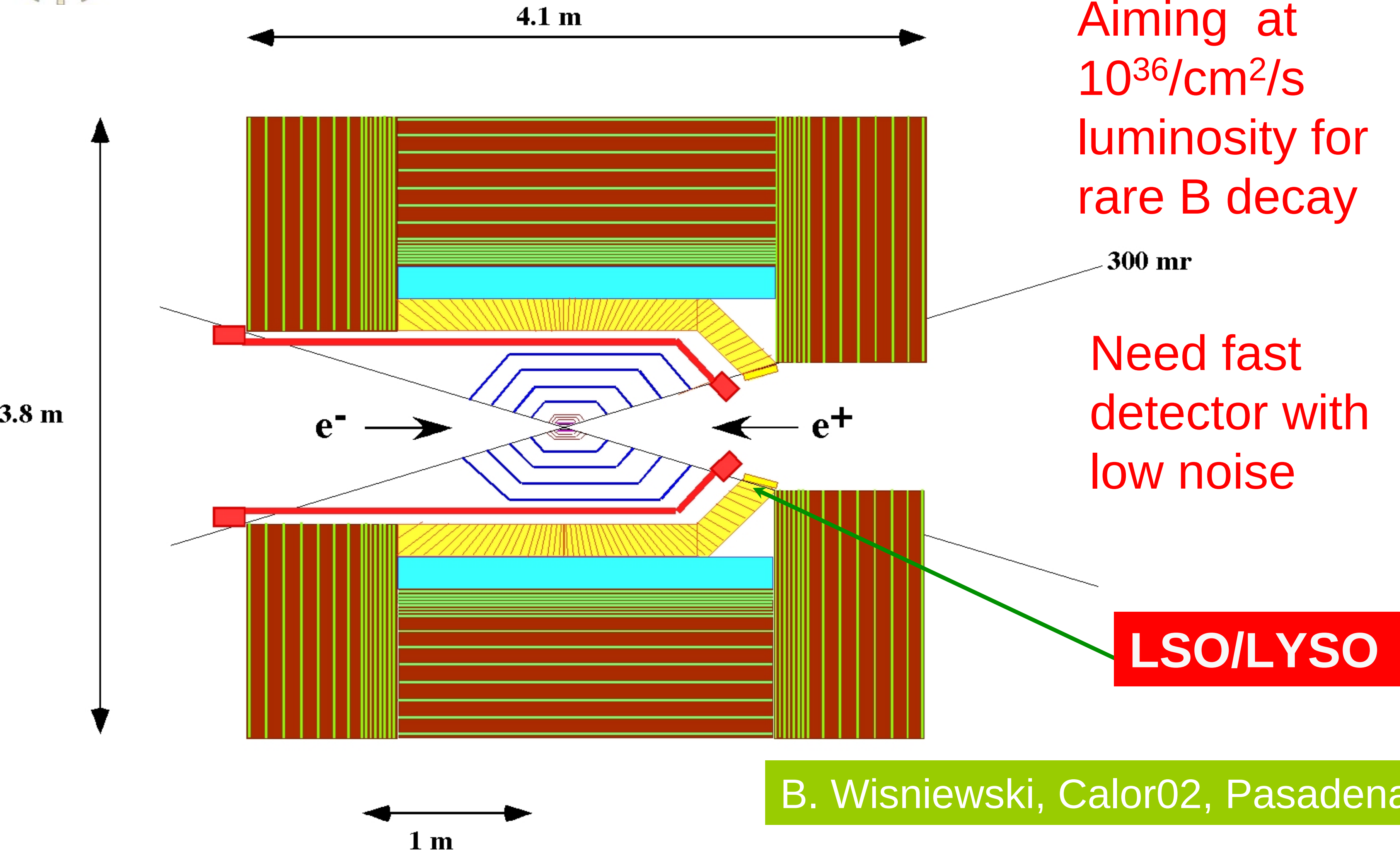
From *BaBar* to Super *BaBar*

A Super *B* detector needs a new endcap, maybe also barrel

Super *B* Factory Workshop – Honolulu April, 2005



An LSO/LYSO Based Super B Detector



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

Need fast detector with low noise

B. Wisniewski, Calor02, Pasadena

The LSO (Molière r., cost) barrel require smaller radius tracker. A new detector would be smaller than *BABAR*/Belle; can, of course, fit into existing detectors

LSO/LYSO Mass Production

CTI: LSO

CPI: LYSO

Saint-Gobain LYSO

BGO, LSO & LYSO Samples

0.3--1% Ce, 5--10% yttrium fraction

Cube: 1.7 X1.7 x 1.7 cm (1.5 X_0)

Bar: 2.5 x 2.5 x 20 cm (18 X_0)

Experiment

- Without any thermal treatment, all samples went through initial measurement for optical and scintillation properties.
- Properties measured: transmittance, emission and excitation spectra, light output, decay kinetics and light response uniformity.
- Two LYSO long samples went through a series of γ–ray irradiations in steps under 2, 100 and 9k rad/h for 19/24, 19/24 and 22 hours respectively, followed by recovery.
- Light output was measured again for two long LYSO samples two days after ending γ–ray irradiations.

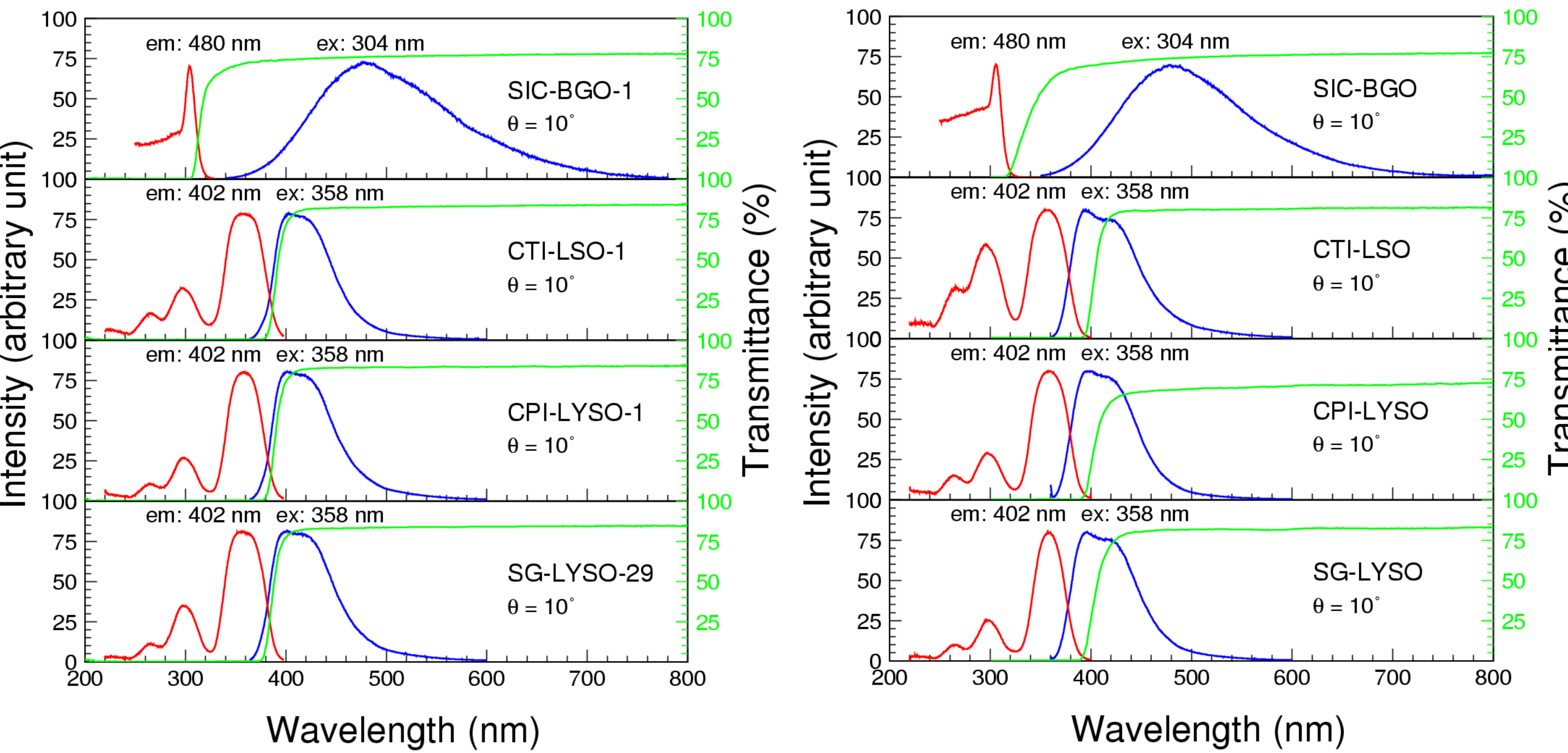
Excitation, Emission & Transmittance

Identical transmittance, emission & excitation spectra

Part of emitted light may be self-absorbed in long samples

1.7 cm Cube

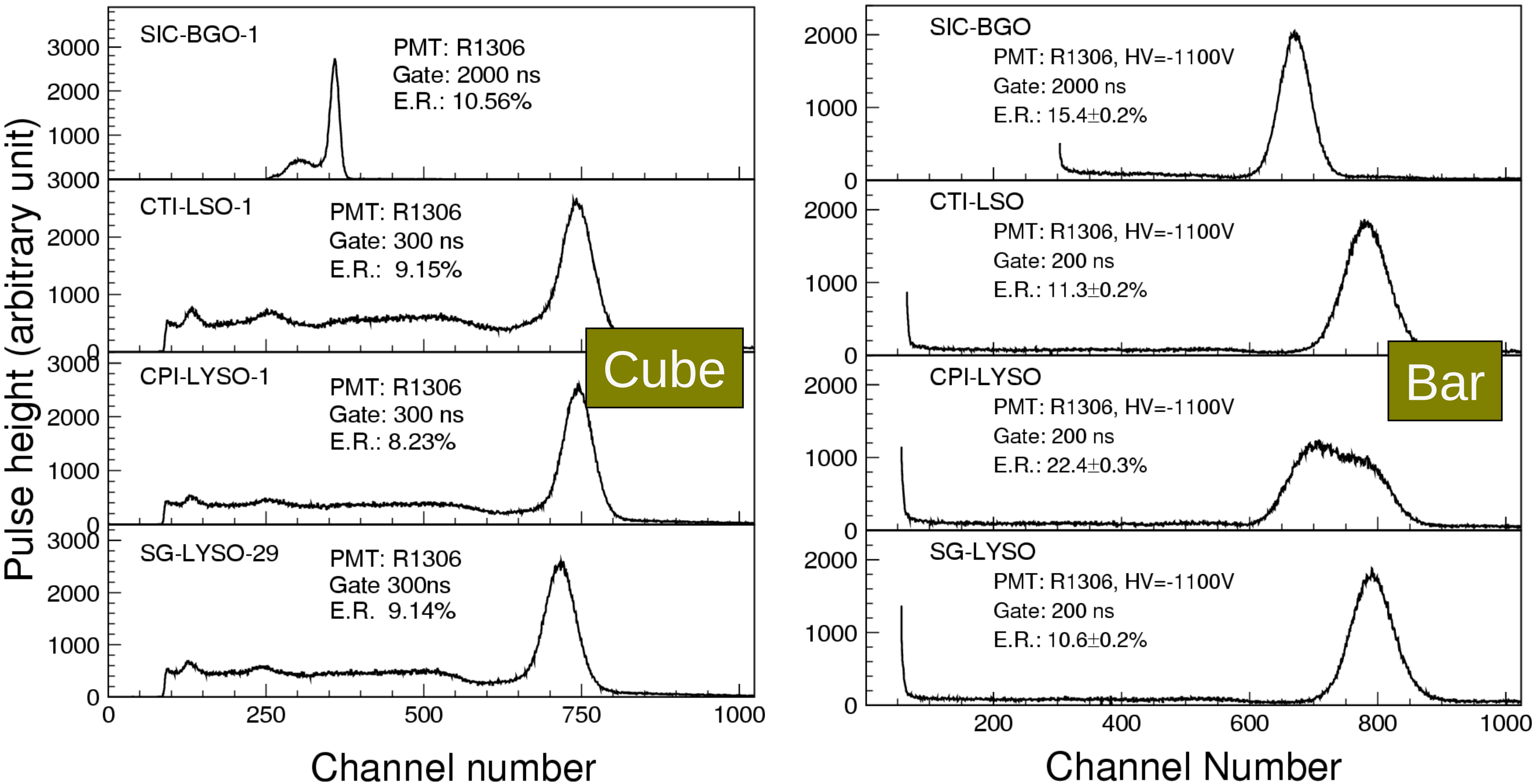
2.5 x 2.5 x 20 cm Bar



^{137}Cs & ^{22}Na Pulse Height Spectra

Cube and bar samples have 8% and 10% FWHM resolution respectively for ^{137}Cs (0.66 MeV) and ^{22}Na source (0.51 MeV)

CPI LYSO bar has double peak because of poor annealing

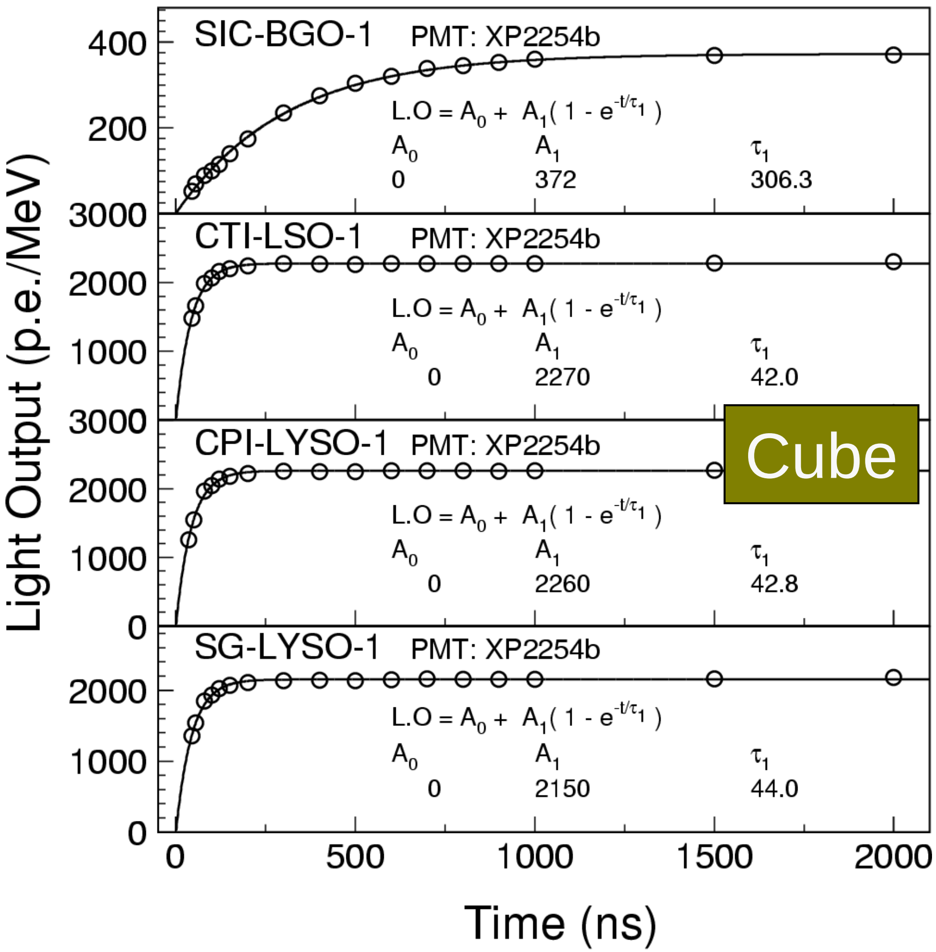


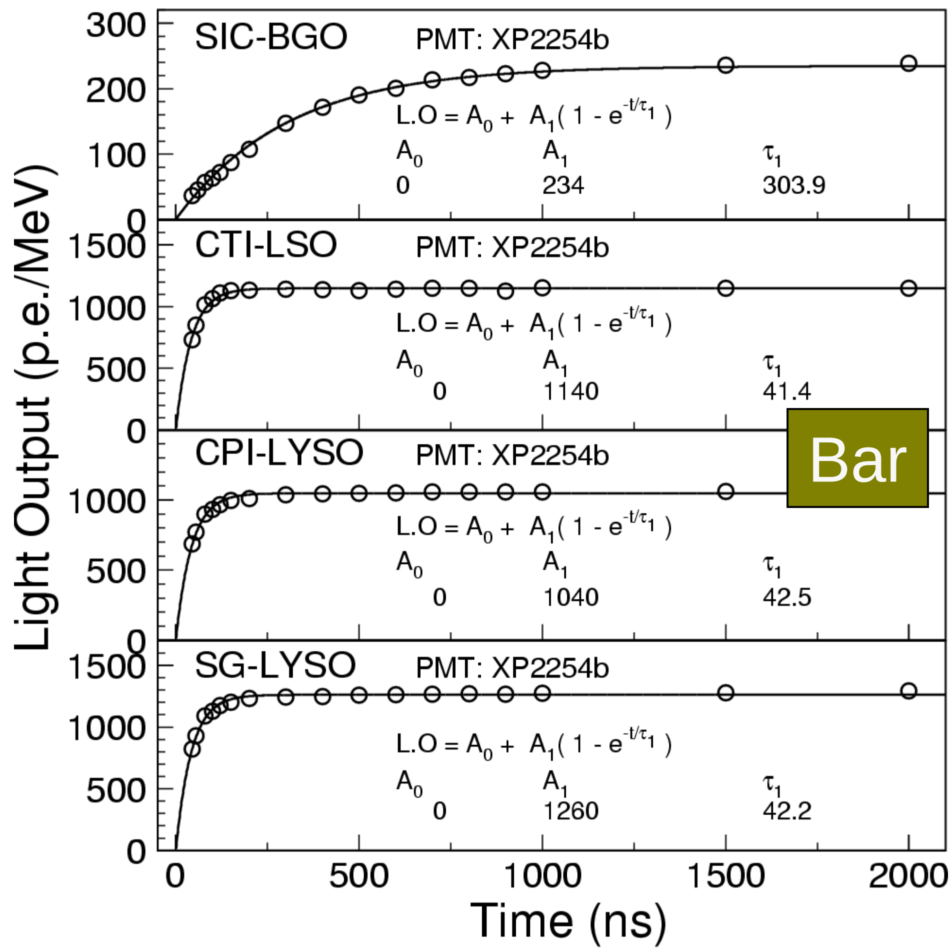
Light Output & Decay Time

LSO/LYSO Light yield: a factor of 6/100 of BGO/PWO

Bar sample has ~50% of light of cube sample

LSO/LYSO decay time: 42 ns compared to 300 ns of BGO

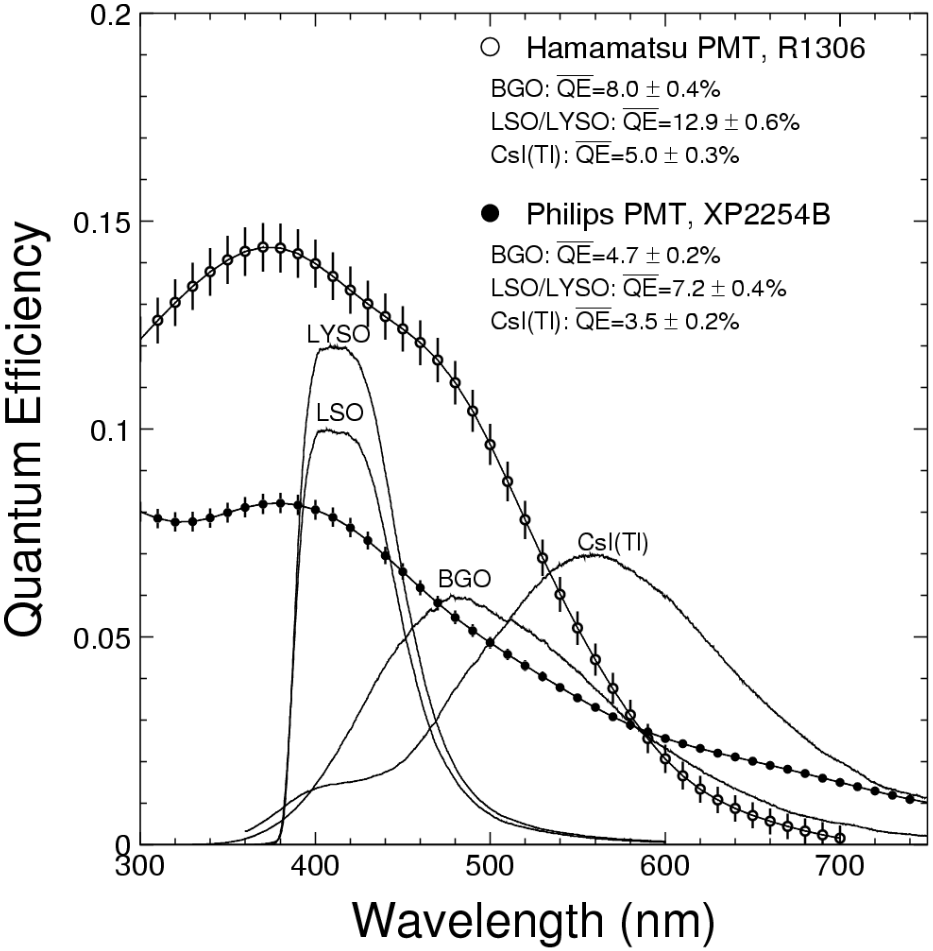


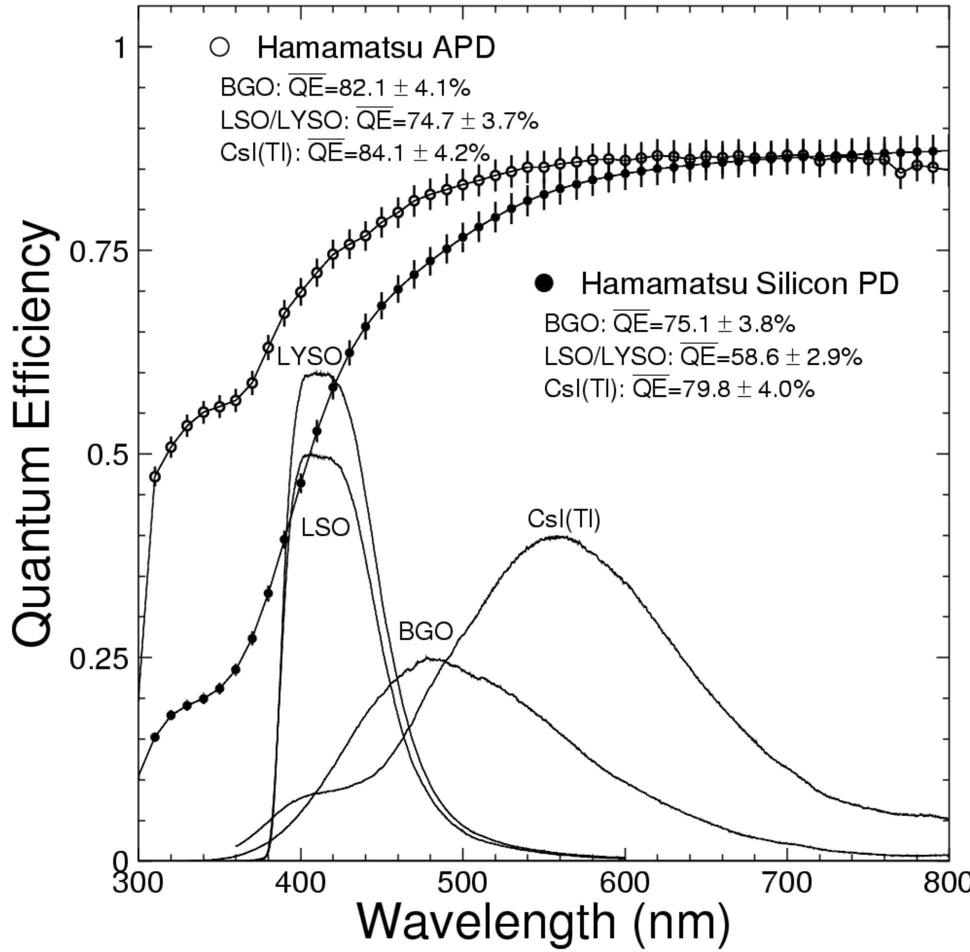


Emission Weighted Q.E.

Taking out PMT QE, LO of LSO/LYSO is 4 times BGO

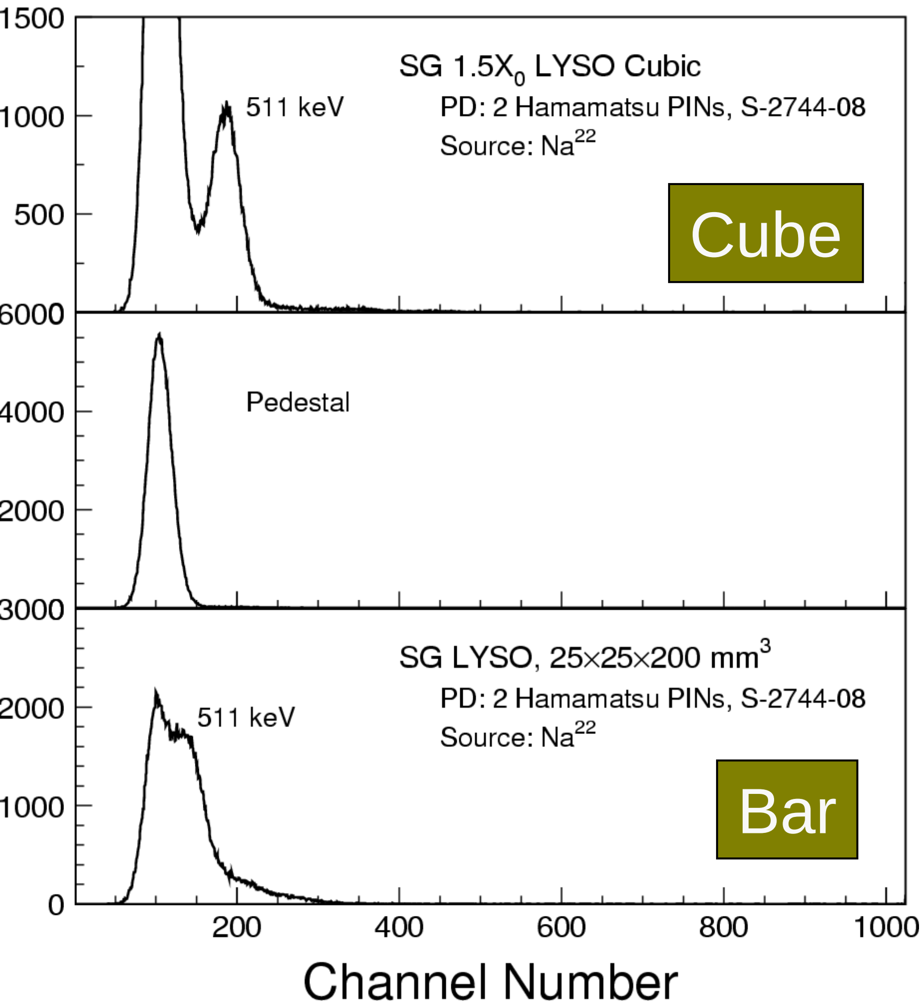
For Si PD and APD, QE is 59% and 75% respectively

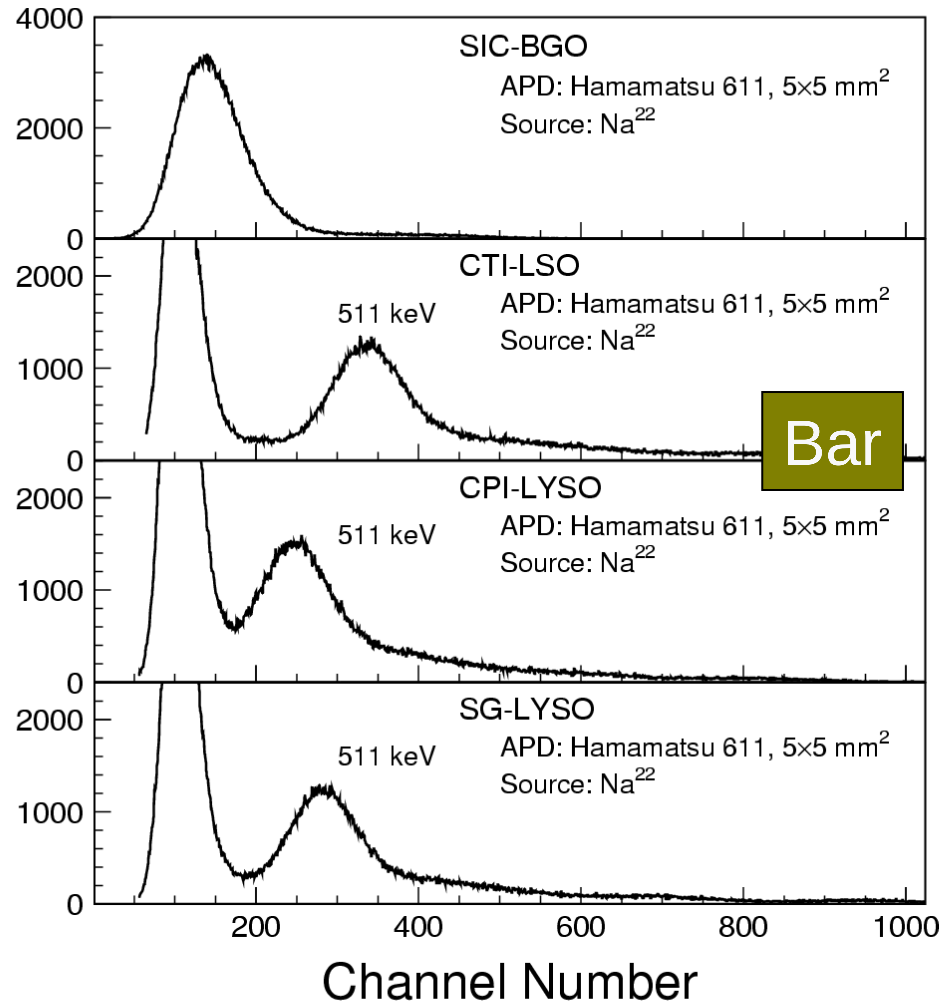




LSO/LYSO with Si Readout

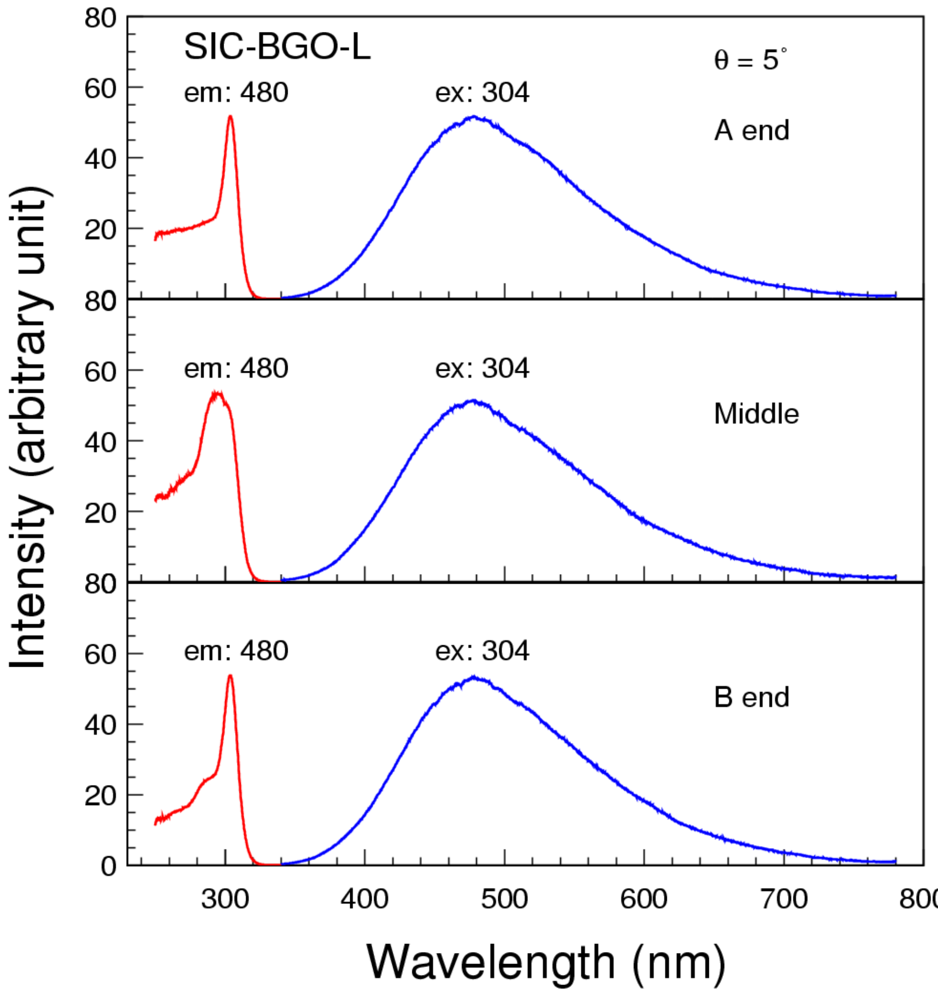
LSO/LYSO (not BGO) bars can be read in lab by using a single APD of 25 mm^2 (not Si PD) and 0.51 MeV ^{22}Na source

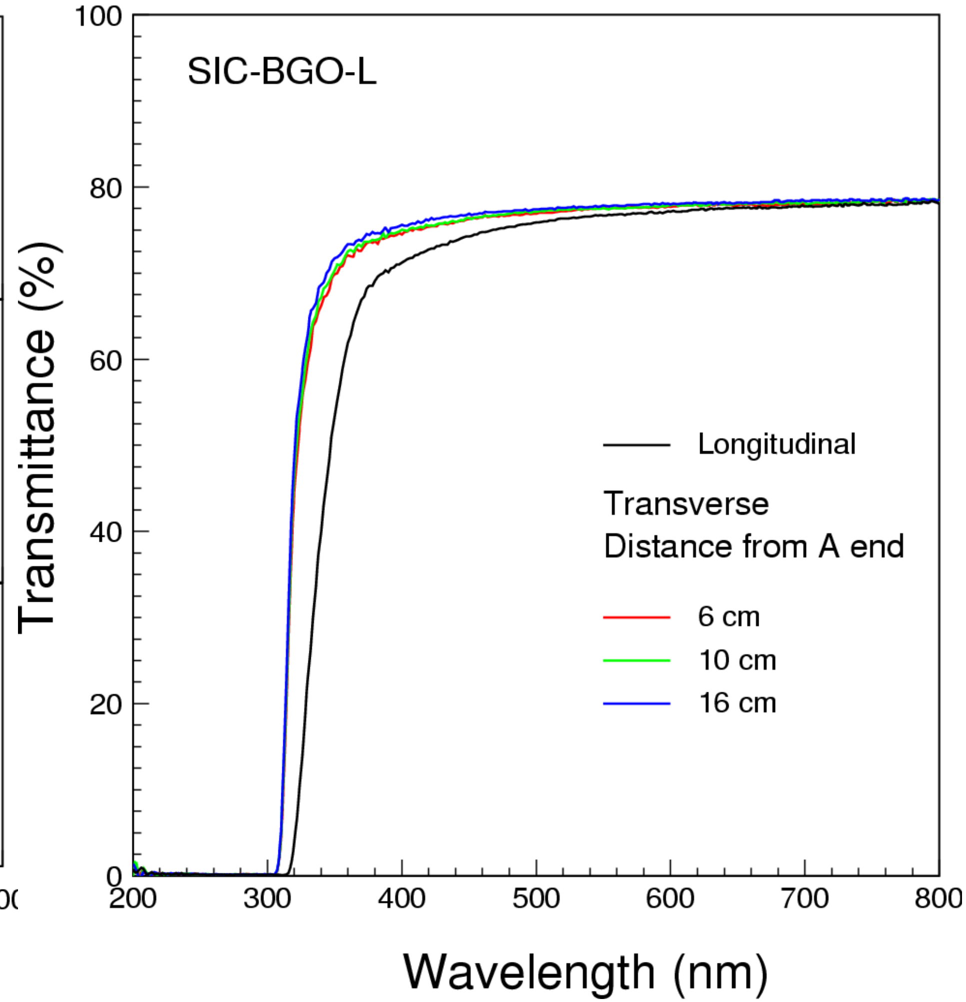




SIC BGO: longitudinal optical uniformity

No longitudinal variation in optical properties

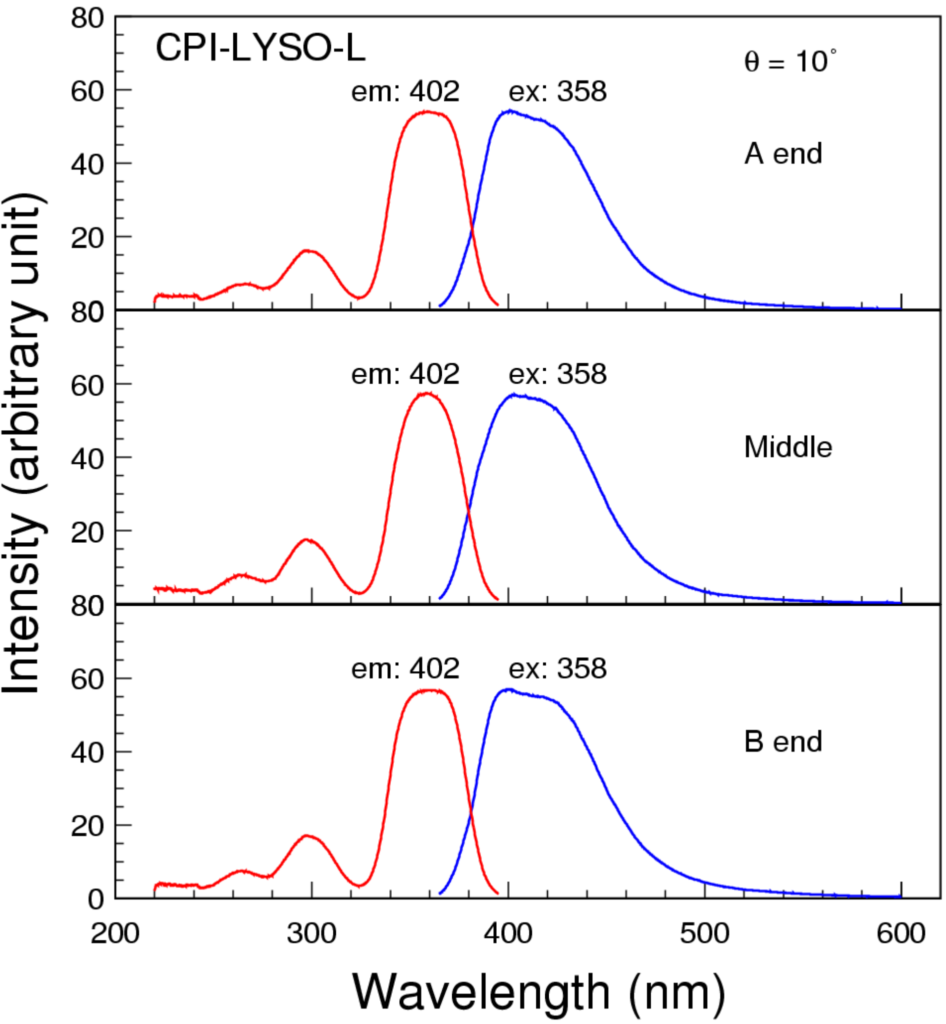


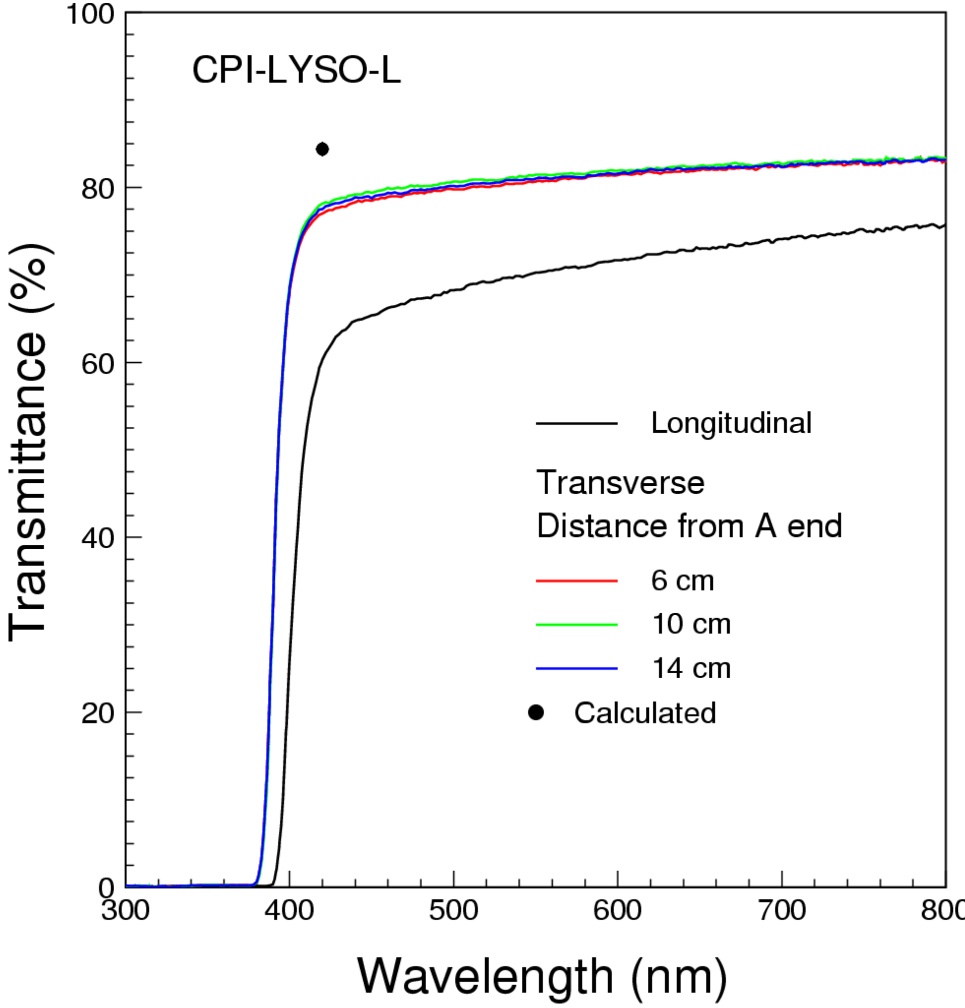


CPI LYSO: longitudinal optical uniformity

No longitudinal variation in optical properties

Poor LT and TT may be caused by poor surface polishing

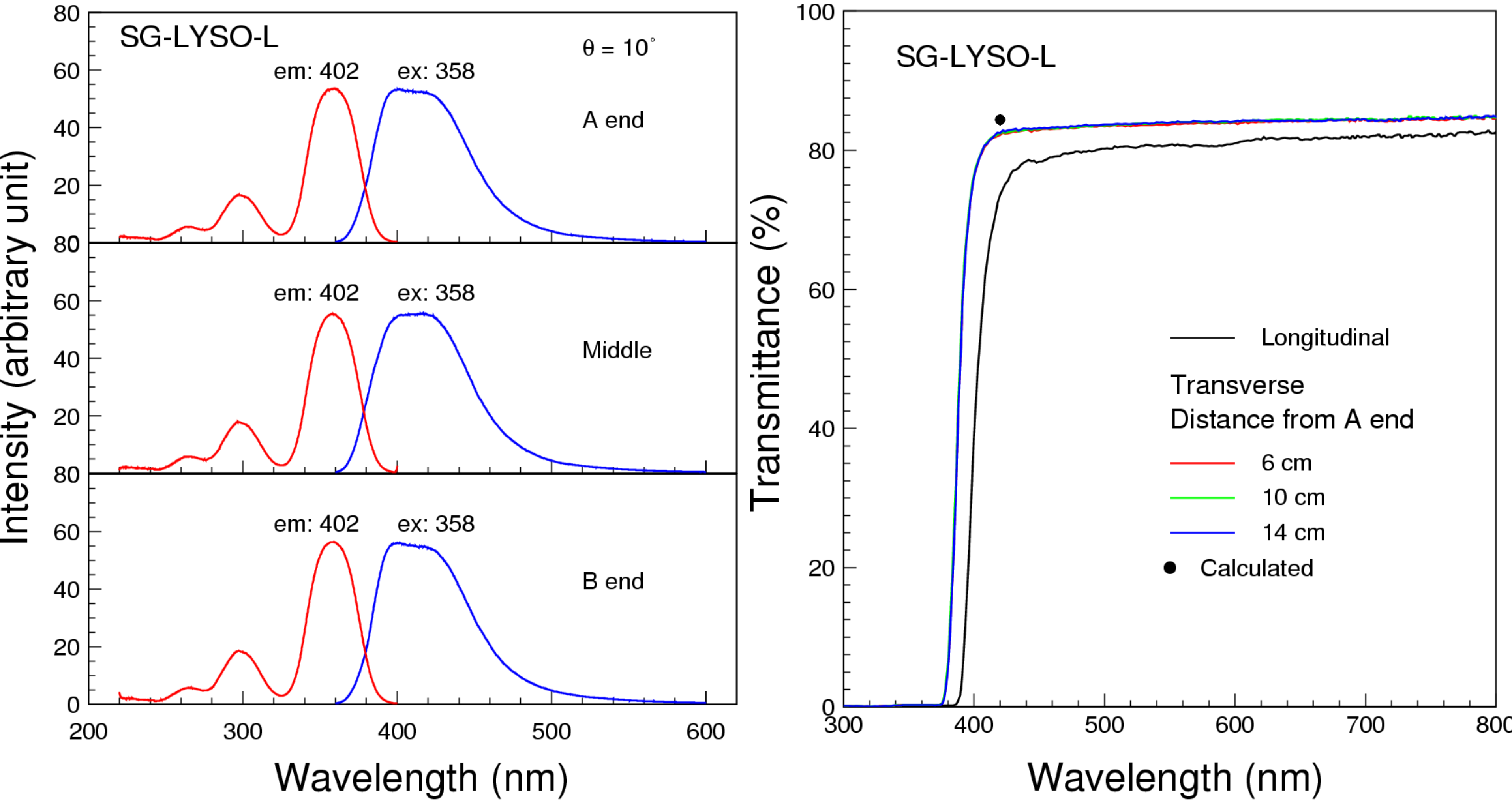




SG LYSO: longitudinal optical uniformity

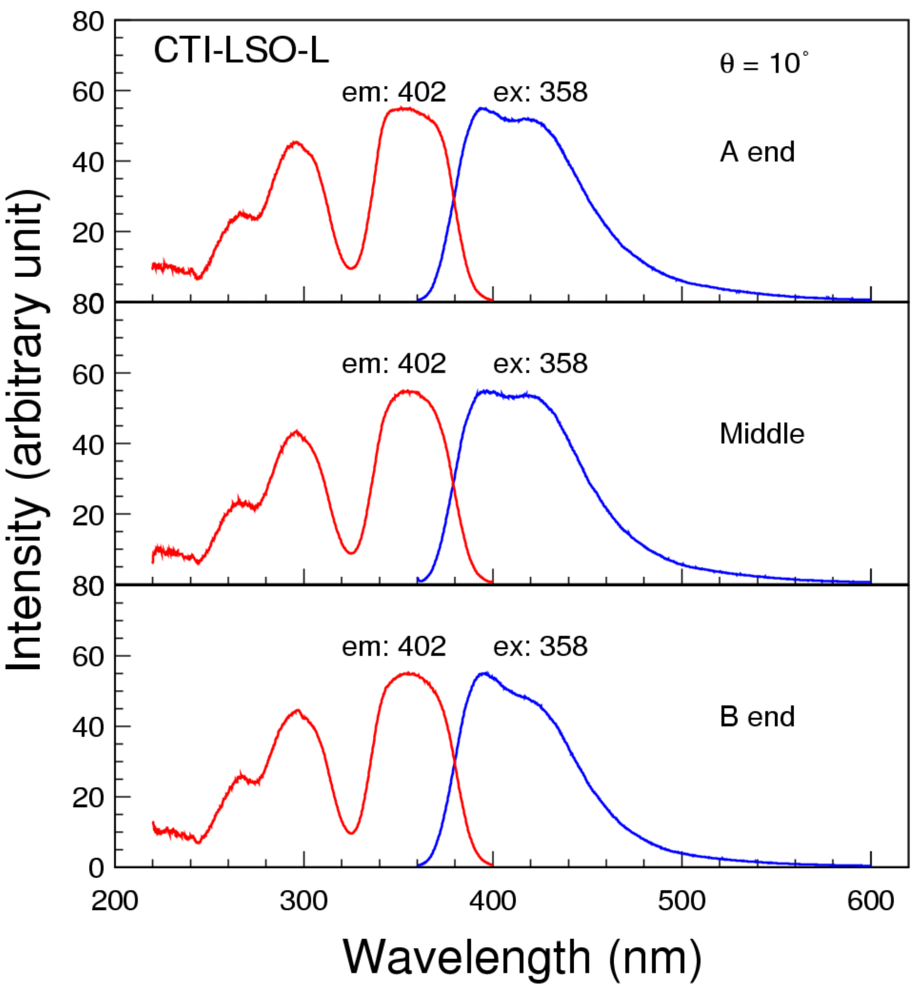
No longitudinal variation in optical properties.

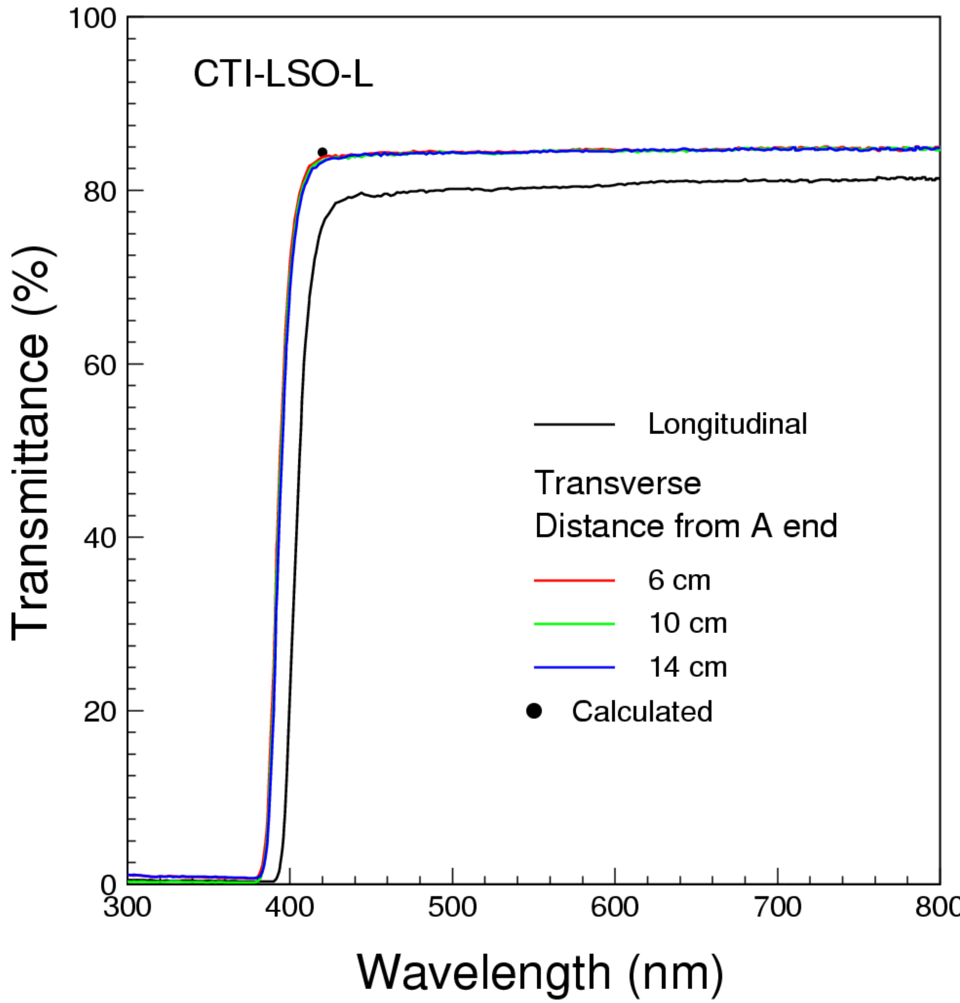
TT approaches theoretical limit, LT shows an absorption band peaked at 580 nm: no effect on emission



CTI LSO: longitudinal optical uniformity

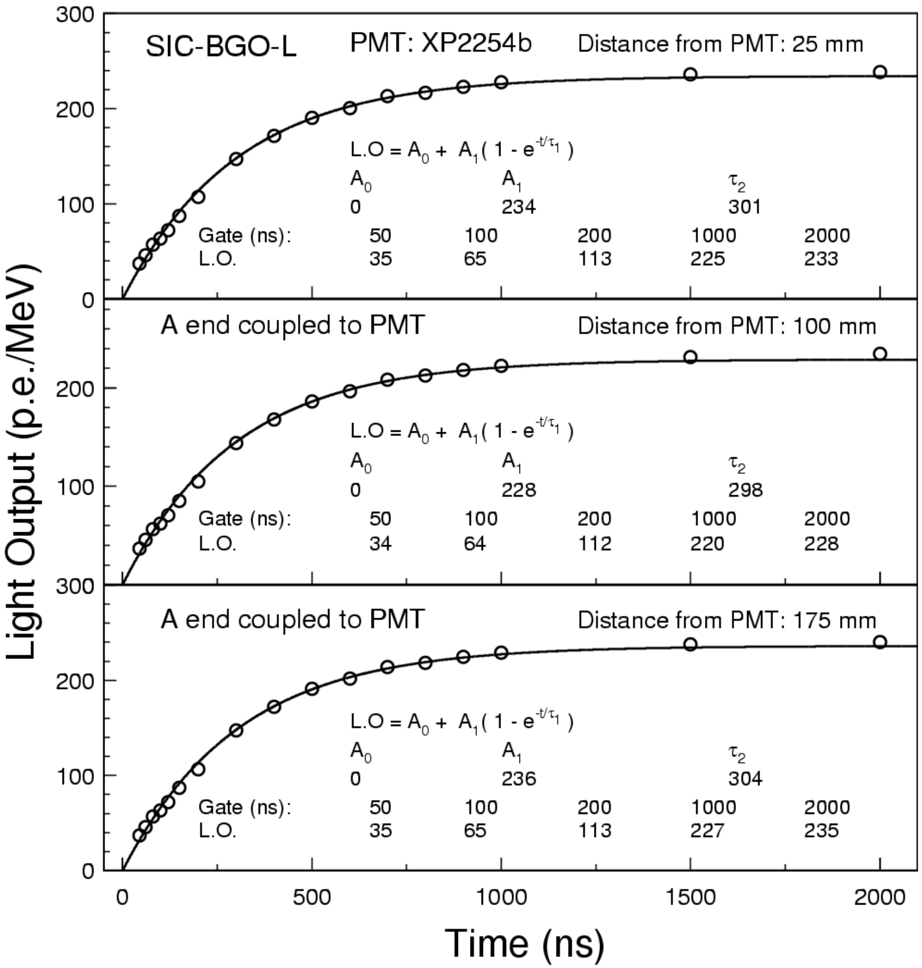
No longitudinal variation in optical properties
Transverse transmittance approaches theoretical limit

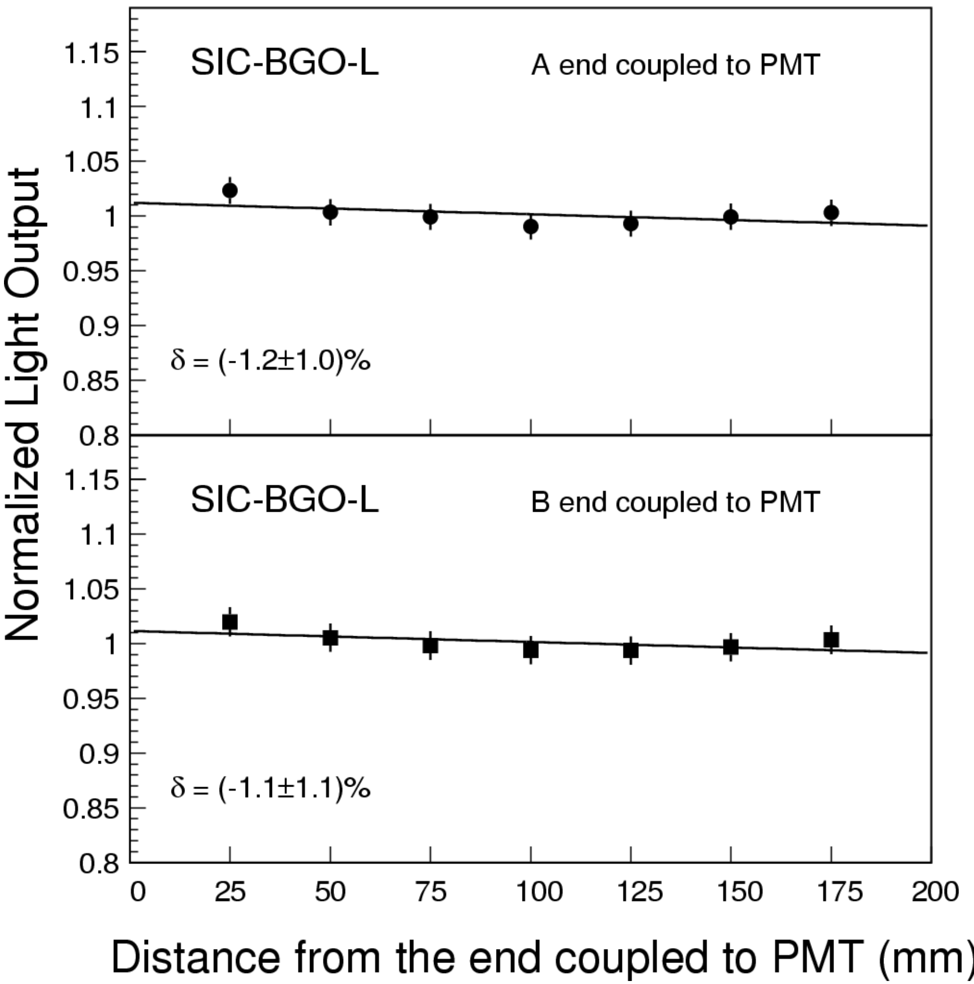




BGO Light Response Uniformity

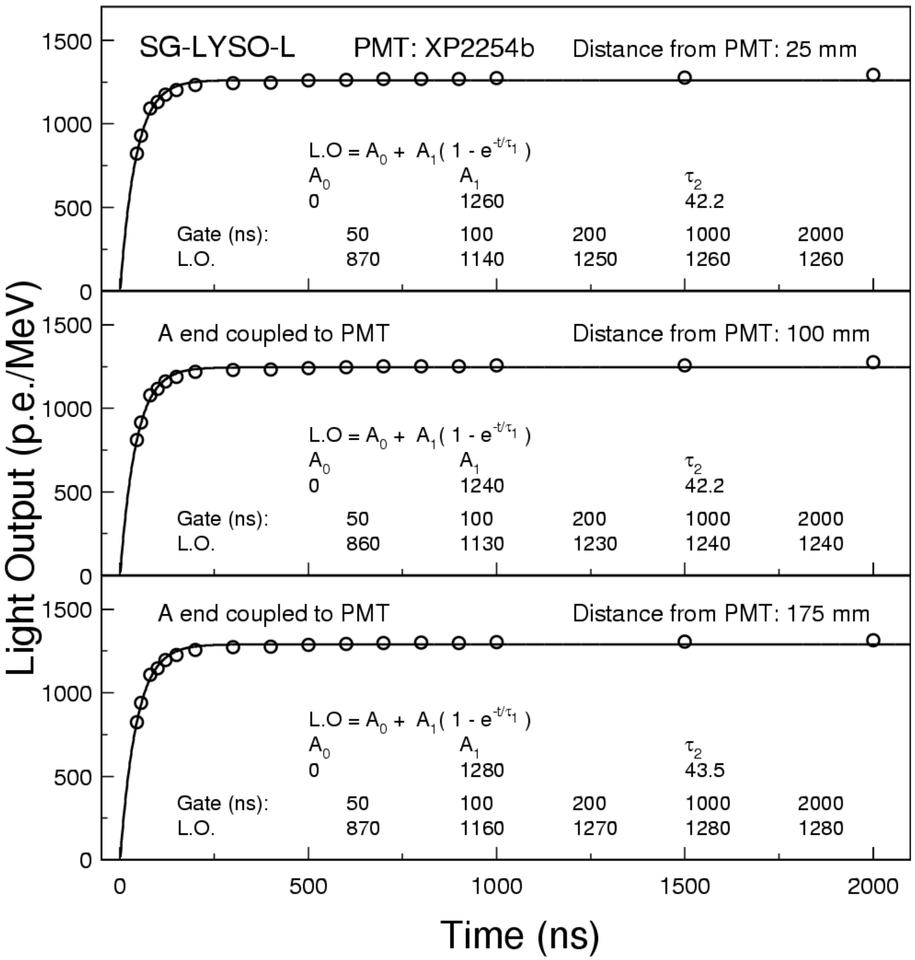
A slight negative slope for both end coupled to the PMT indicating a good longitudinal uniformity

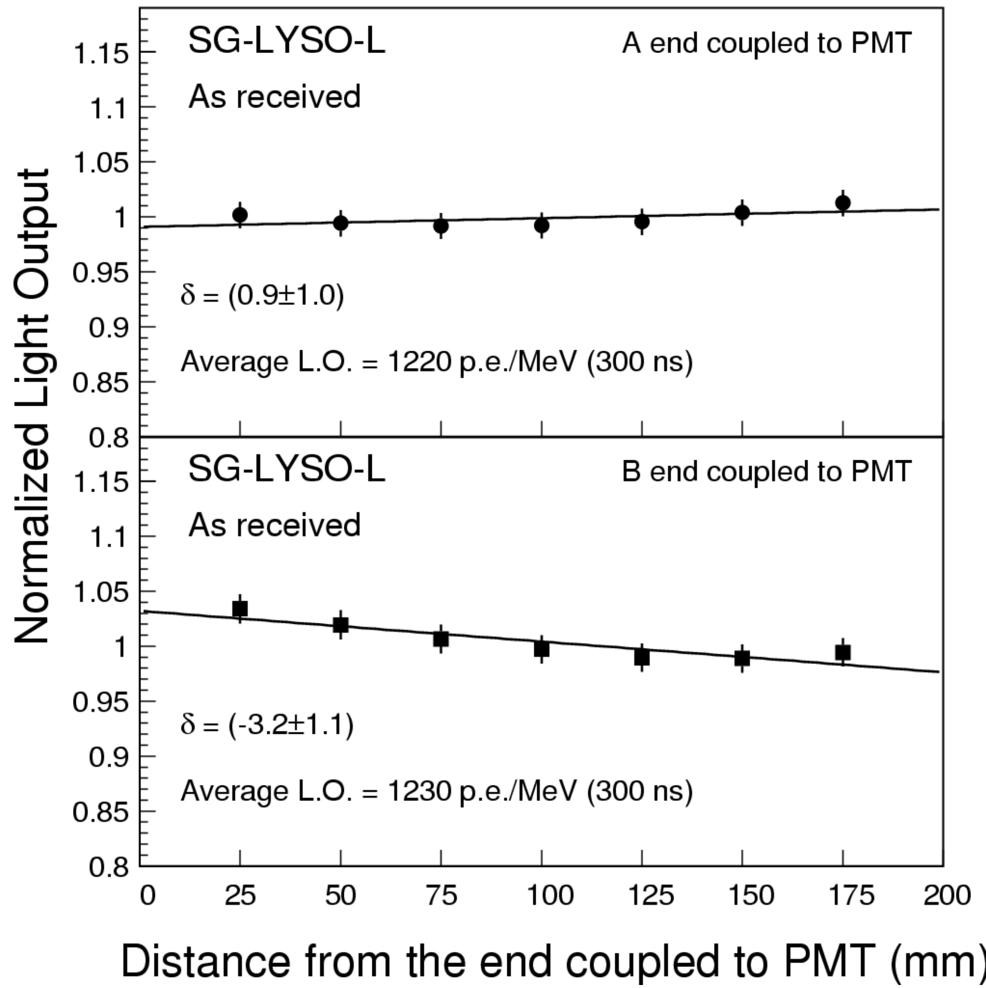




LYSO Light Response Uniformity

Uniformity depends on which end coupled to the PMT, indicating a not uniform light yield along crystal





LYSO Light Response Uniformity

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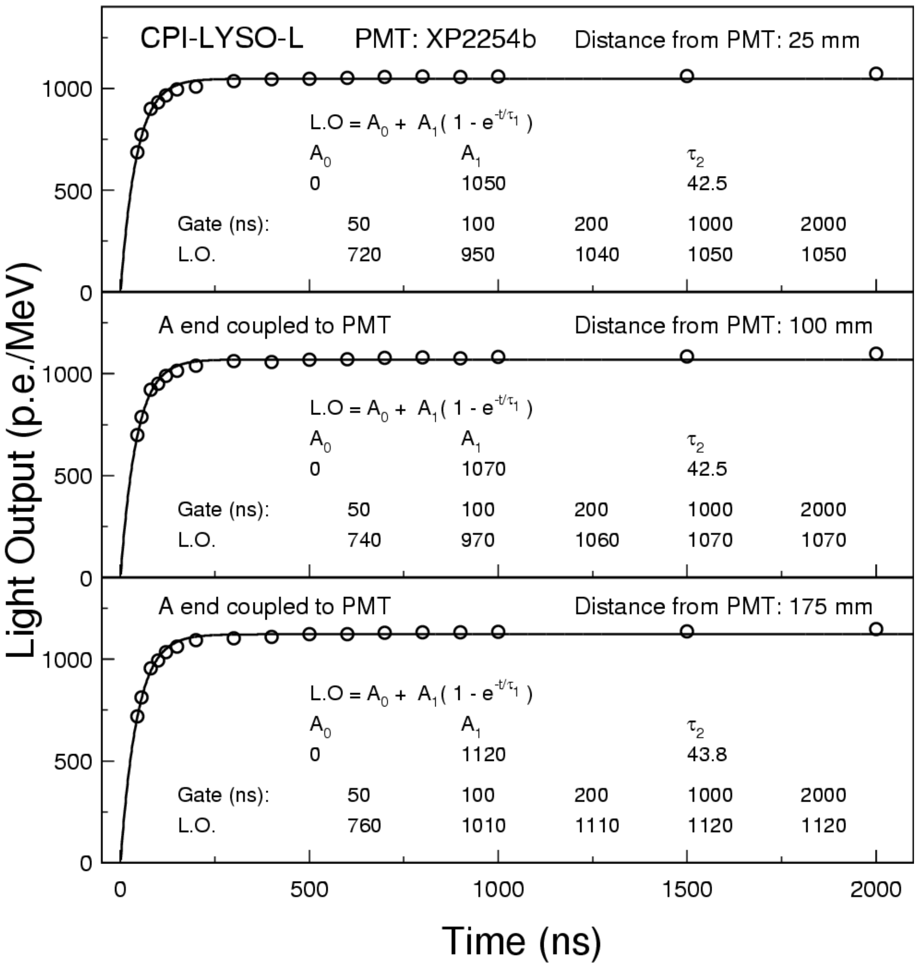
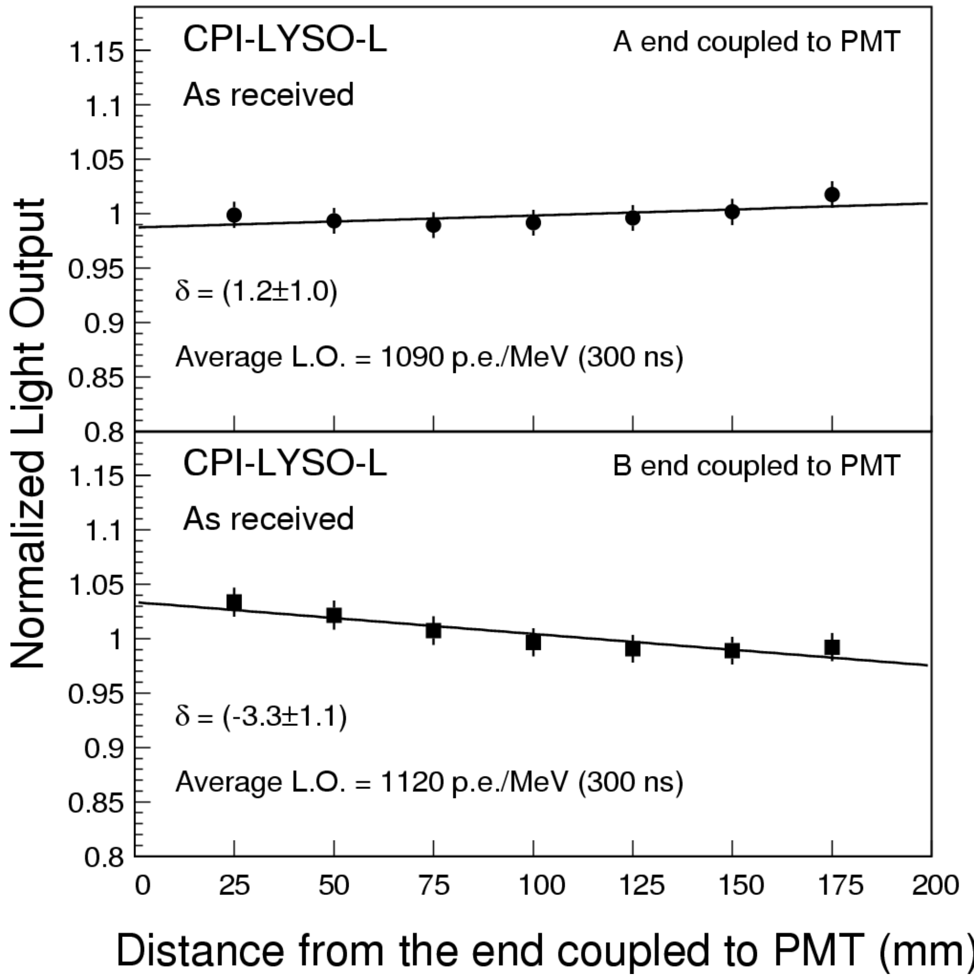
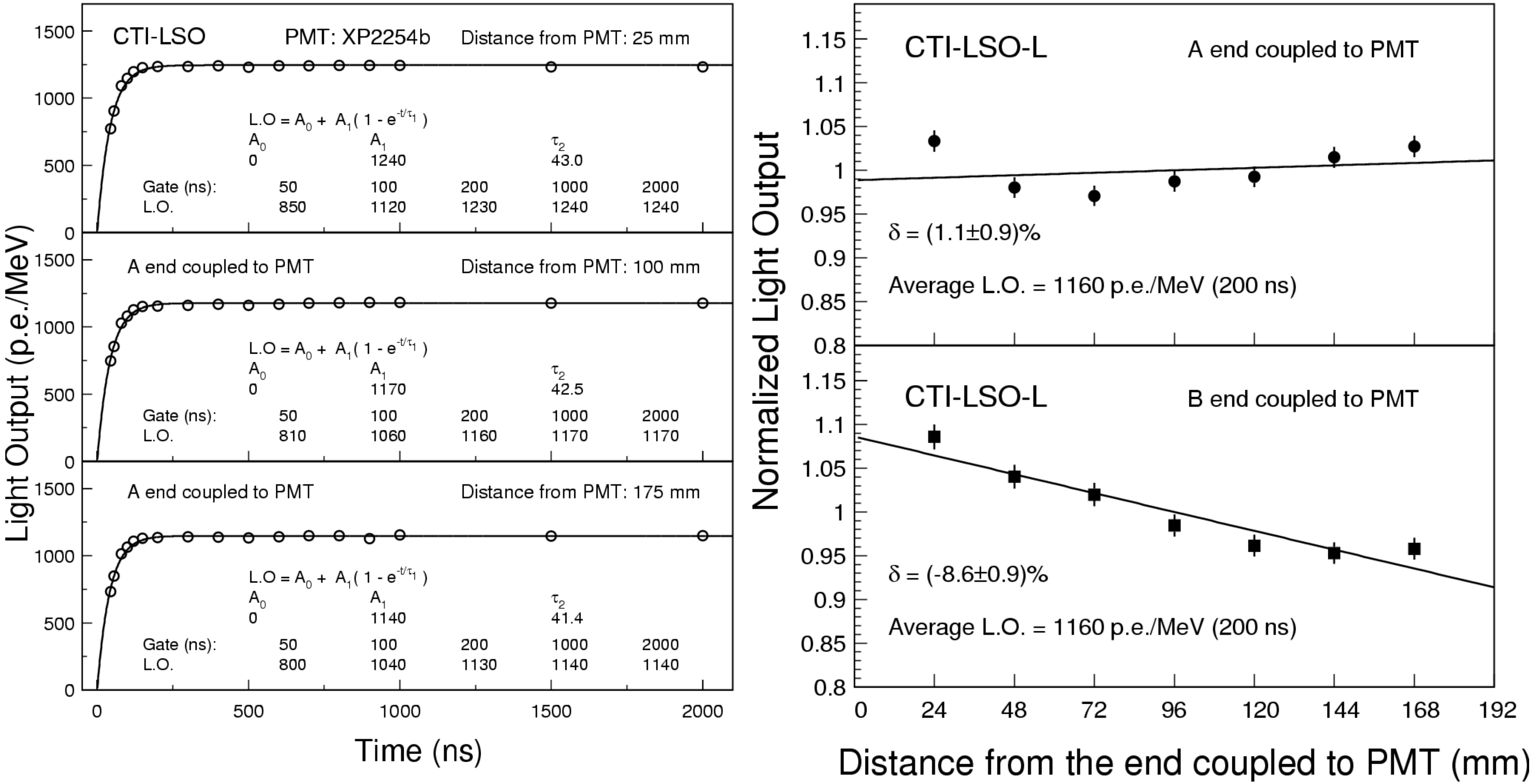




LSO Light Response Uniformity

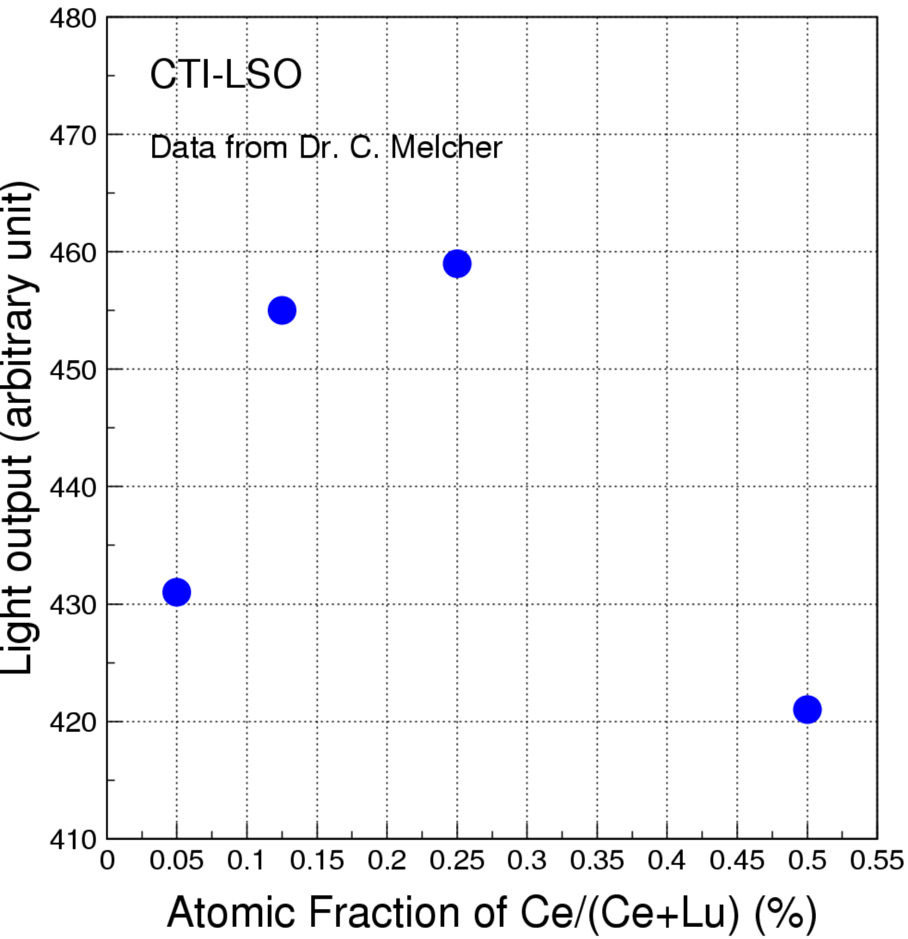
Uniformity depends on which end coupled to the PMT, indicating a not uniform light yield along crystal

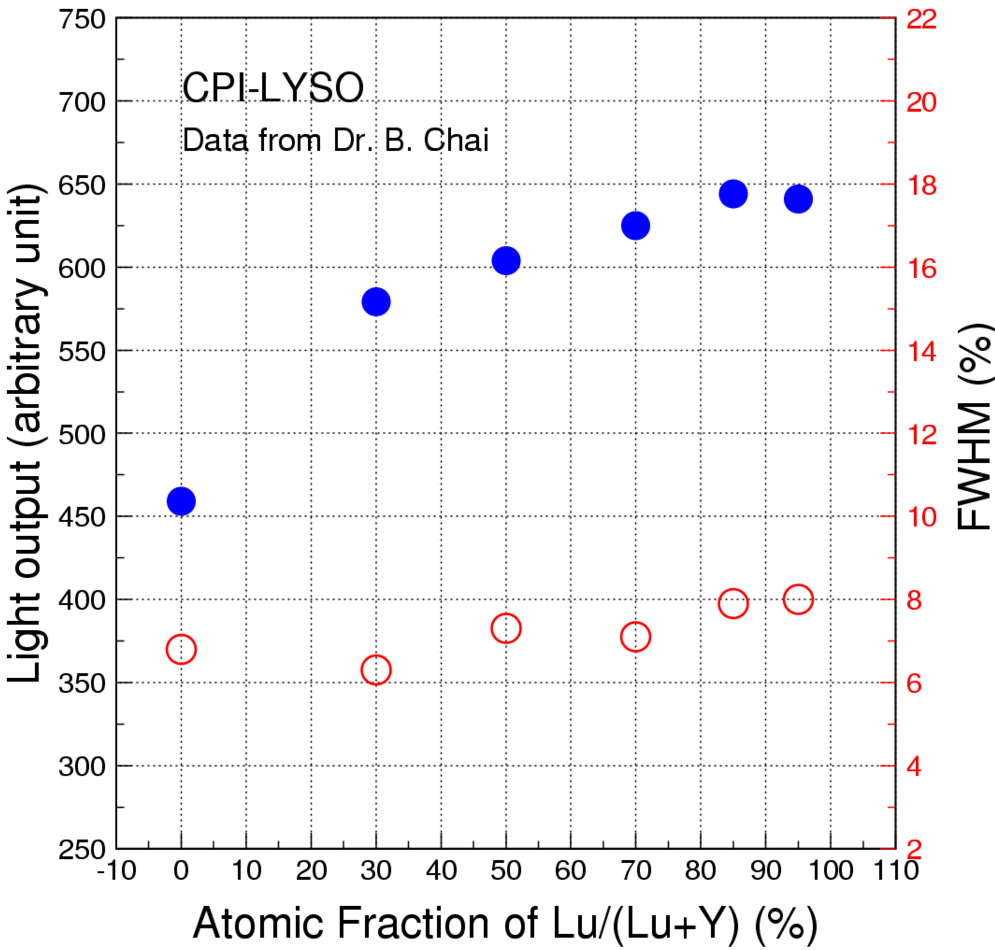


Possible Origin of Non Uniformity

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

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

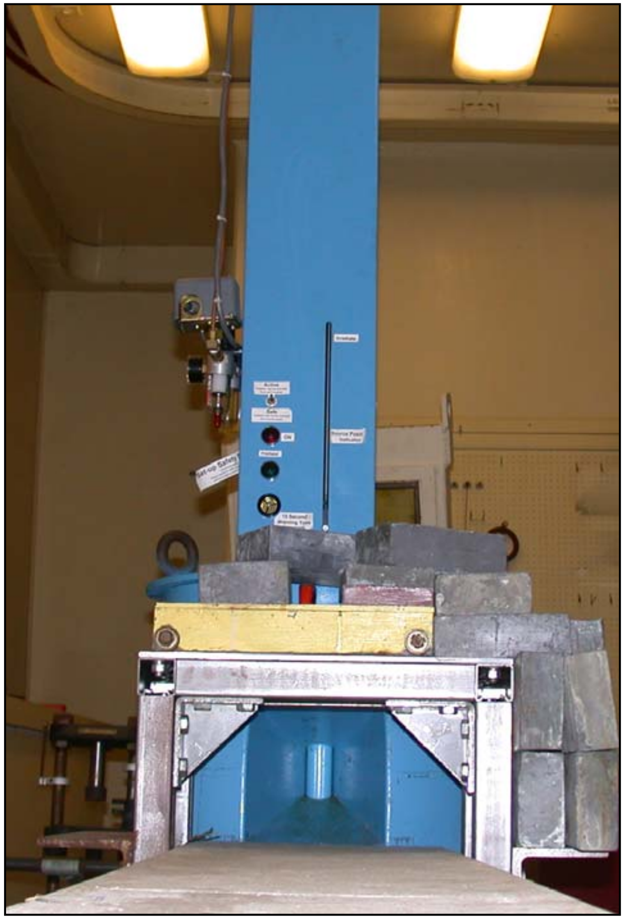




Caltech γ–ray Irradiation Facilities

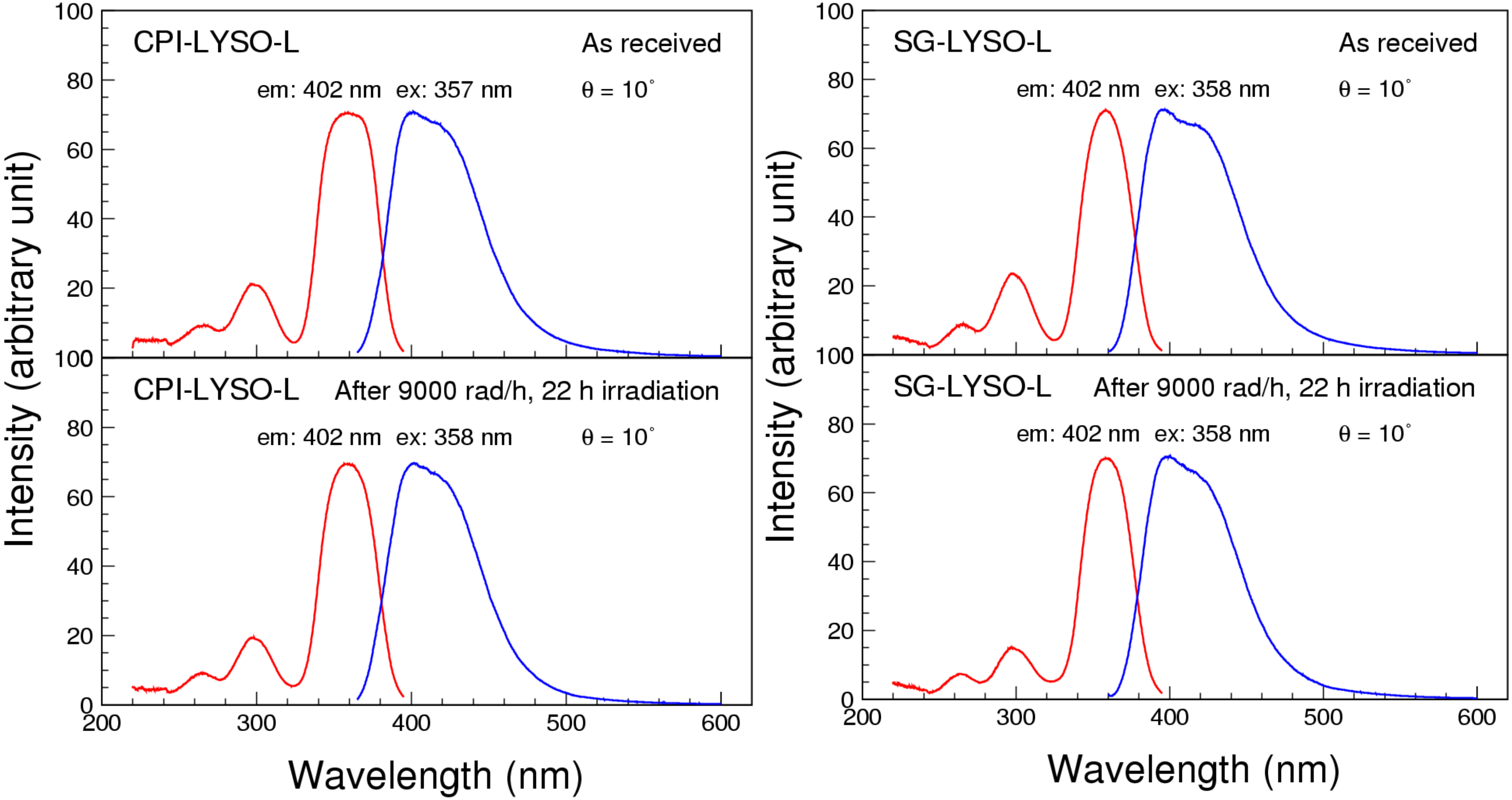
Open 50 curie Co-60 provides 2 & 100 rad/h

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



LYSO Excitation/Emission

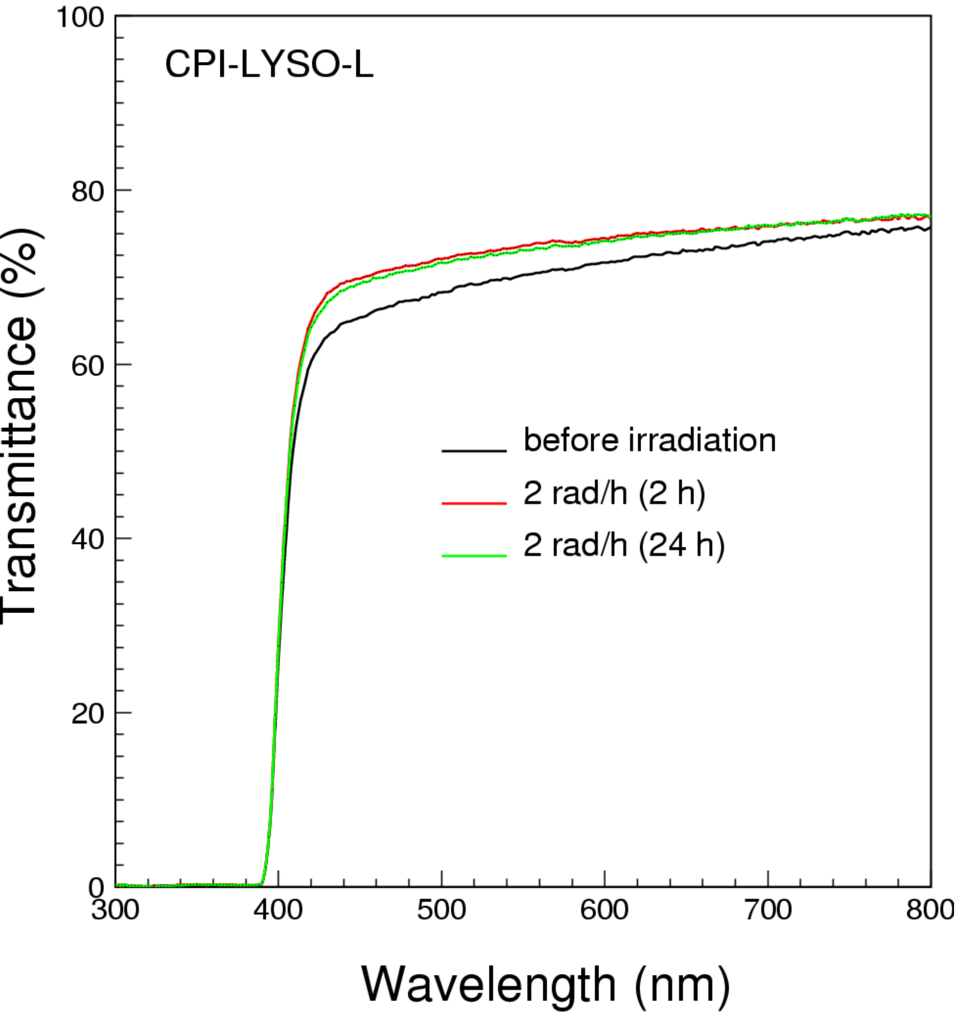
No variation in emission & excitation

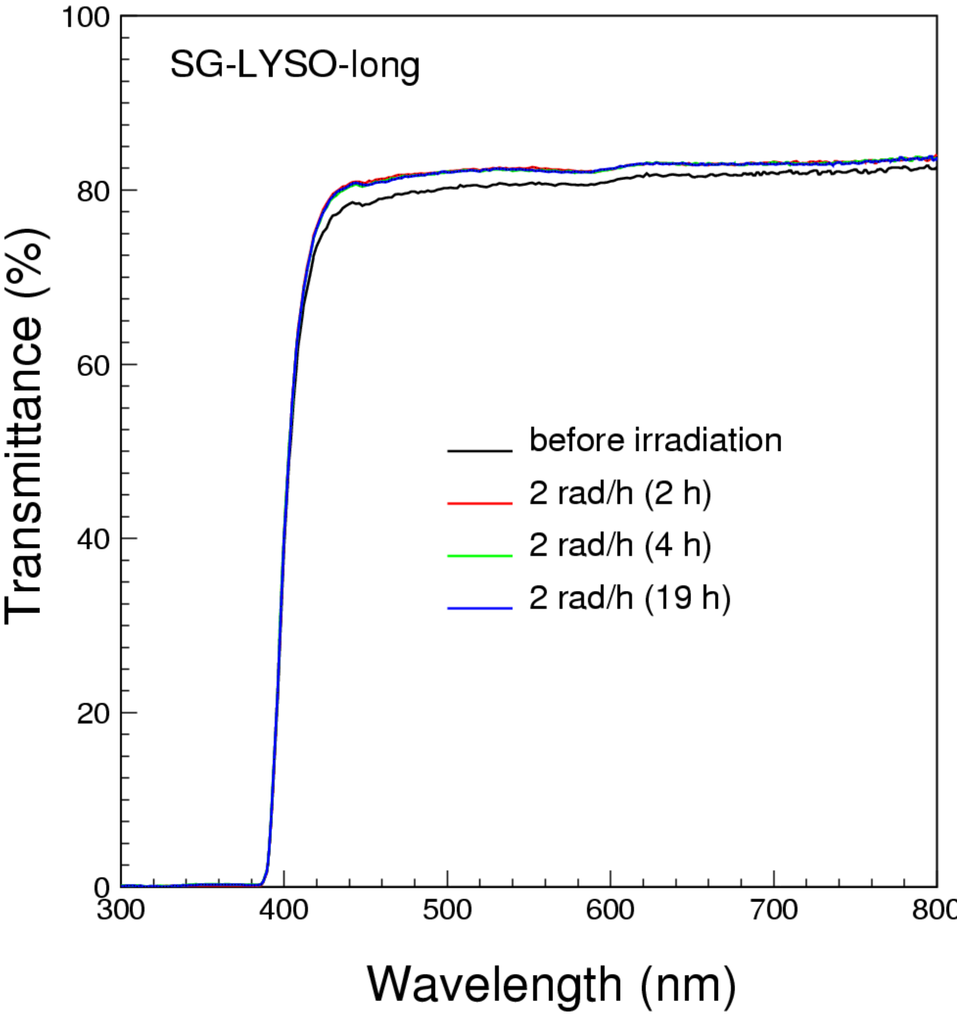


Transmittance under 2 rad/h

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

No further variation observed under 2 rad/h

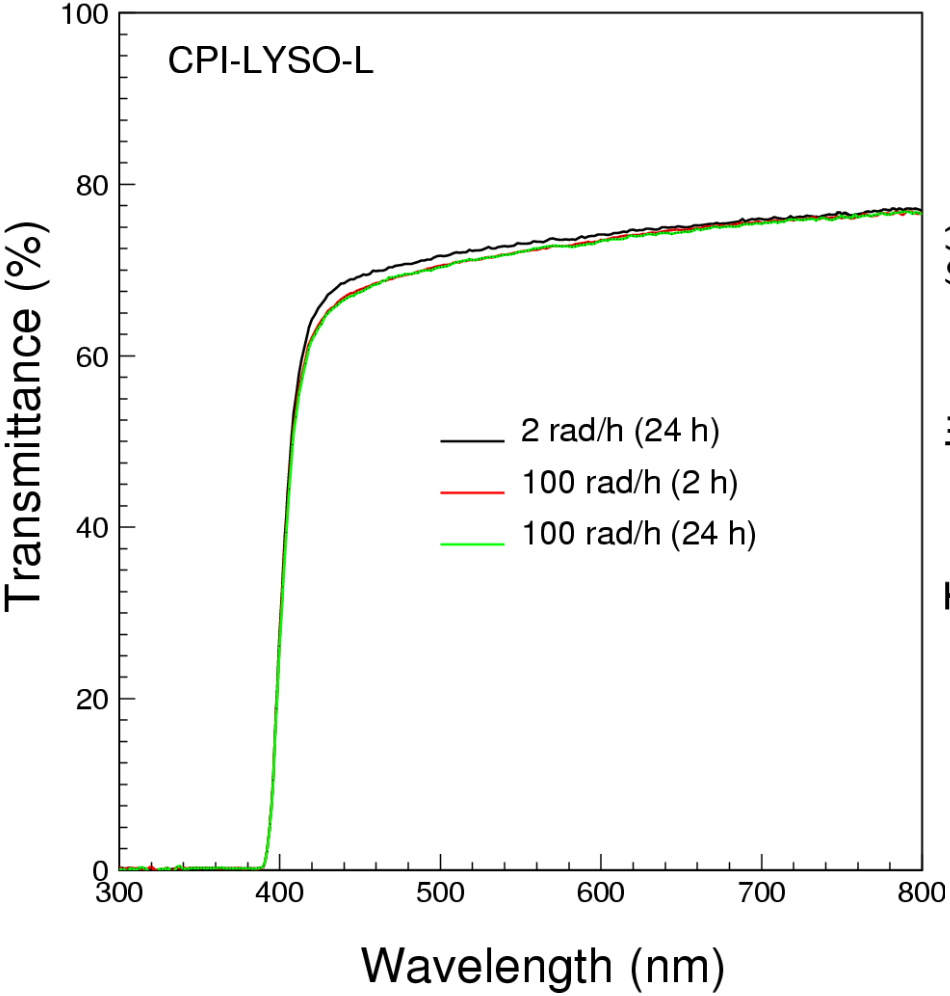


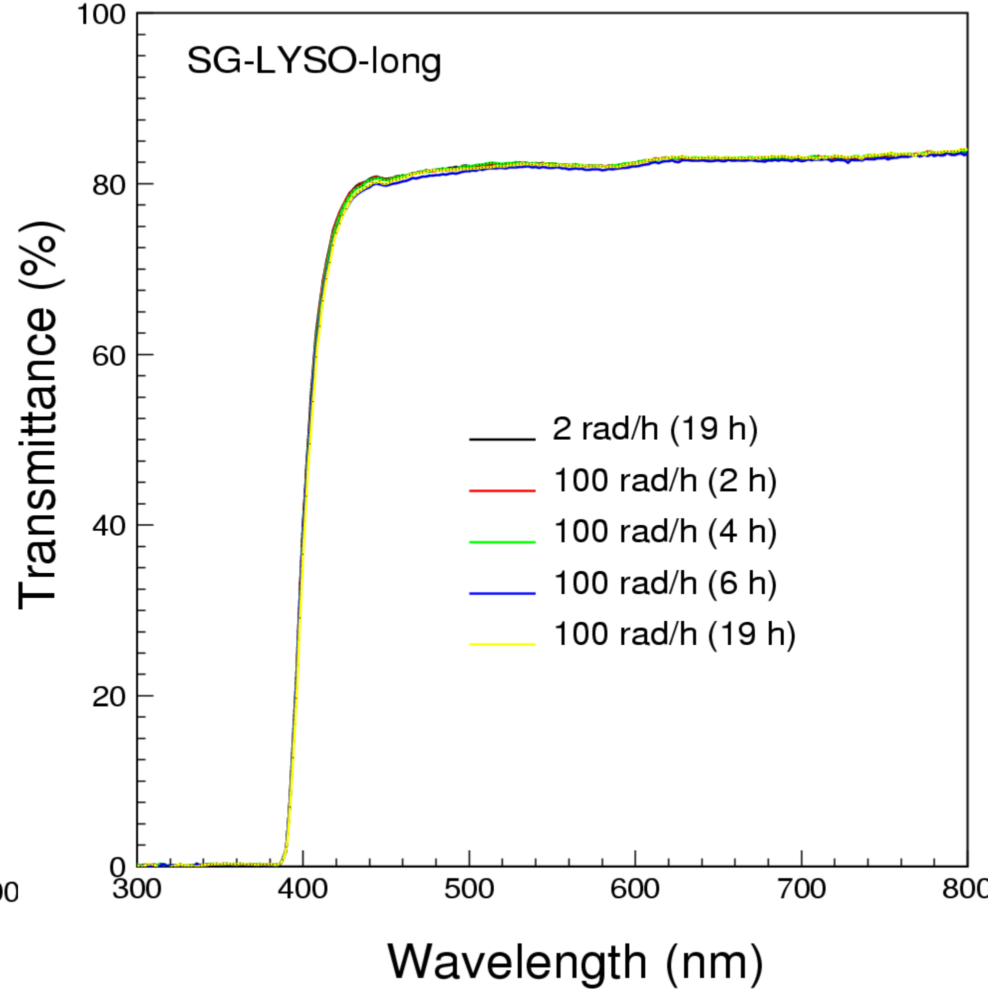


Transmittance under 100 rad/h

Some indication on initial decrease under 100 rad/h

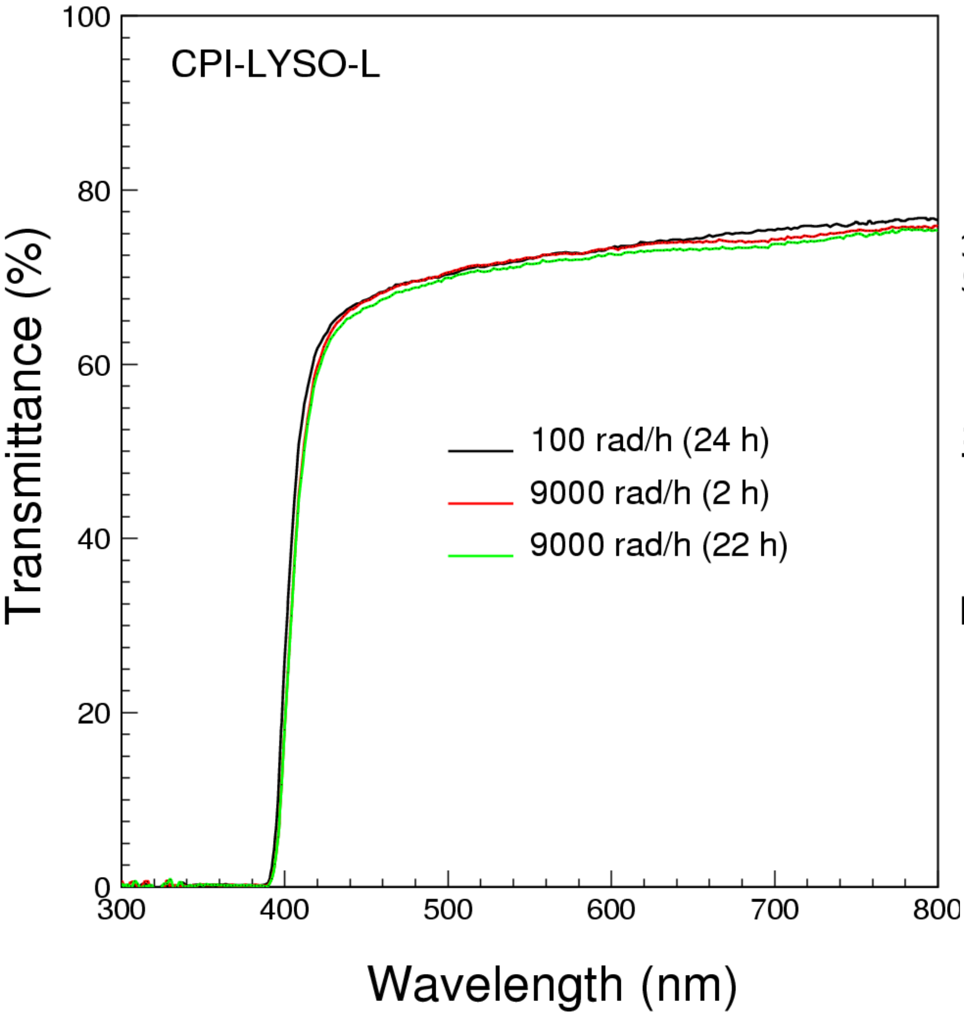
No further variation observed under 100 rad/h

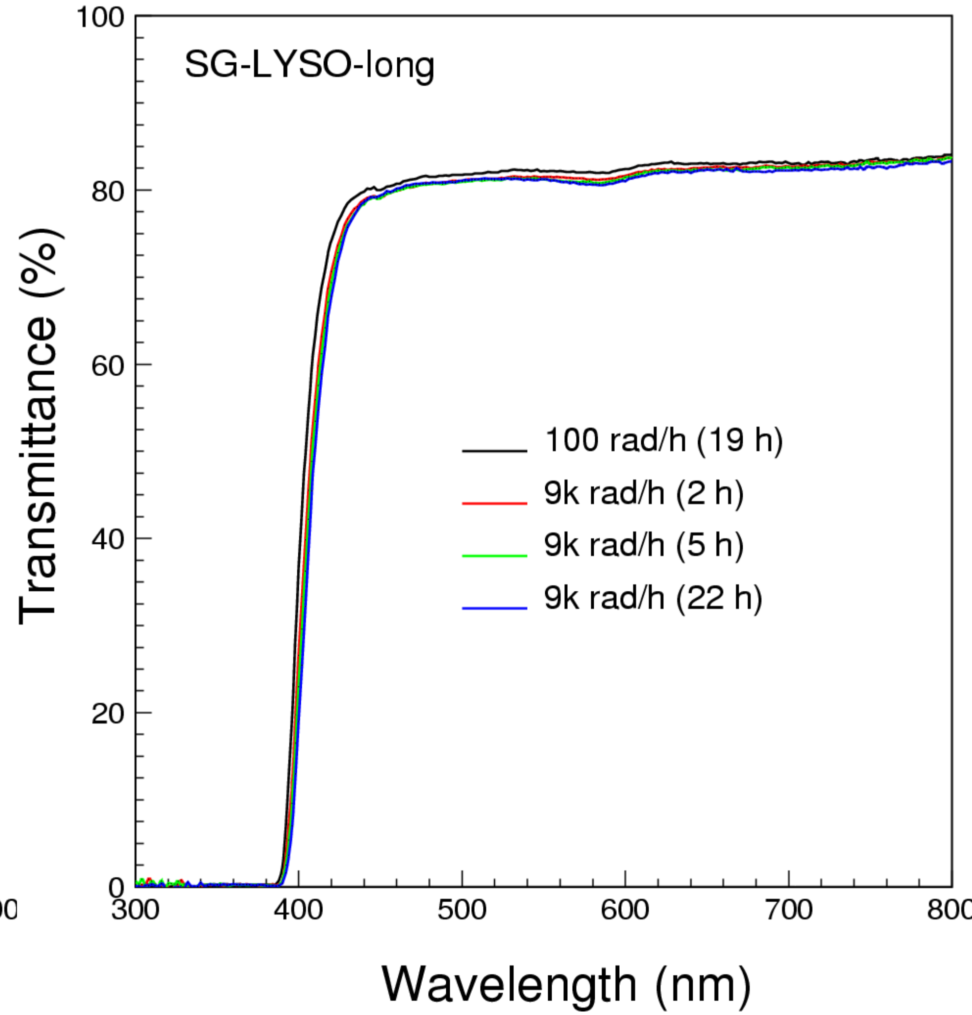




Transmittance under 9 krad/h

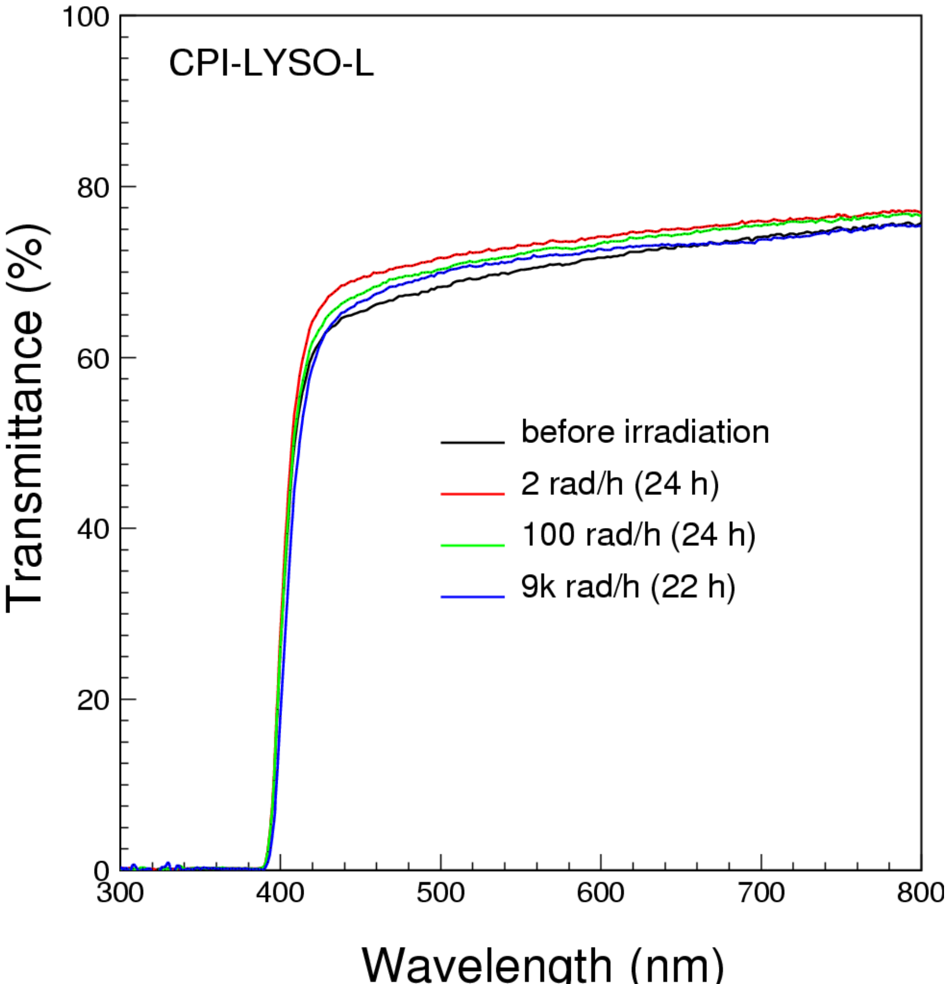
Small variation observed under 9 krad/h

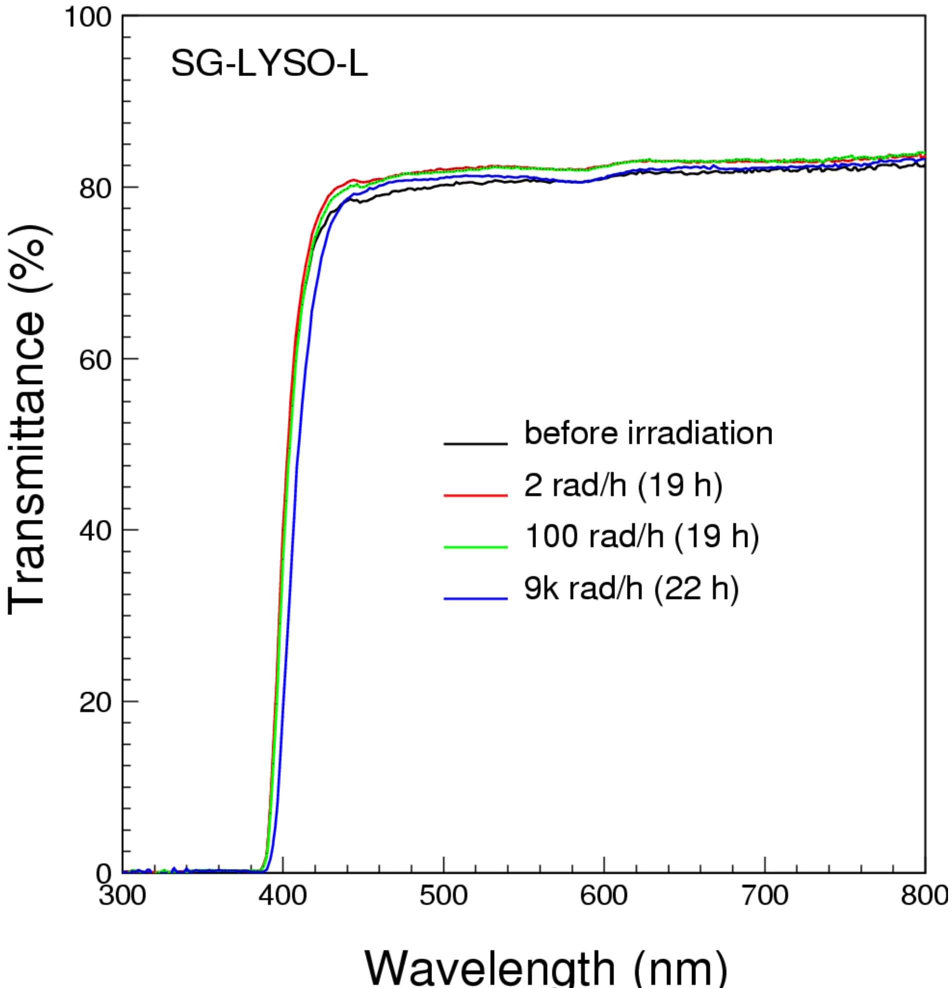




LYSO Longitudinal Transmittance

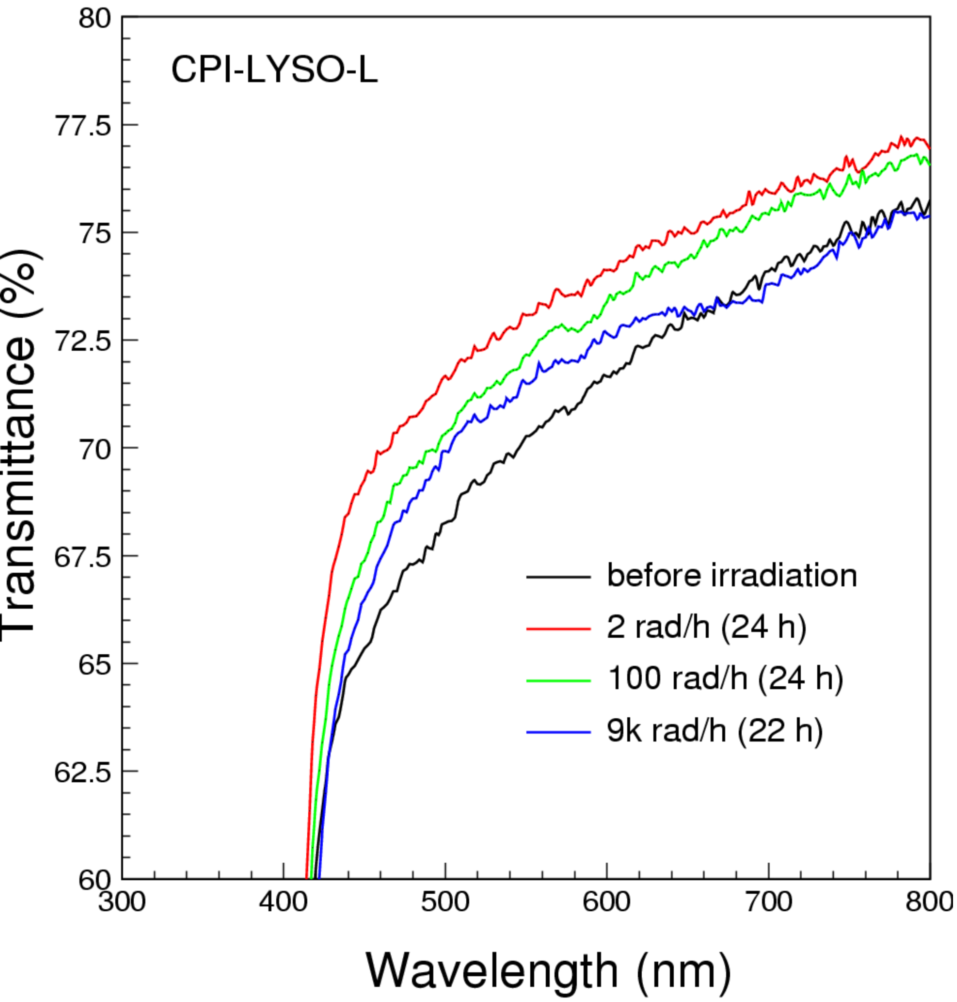
LT@430 nm	Initial	2 rad/h	100 rad/h	9 krad/h
CPI	63.2%	67.1%	64.9%	63.3%
SG	77.1%	79.3%	78.5%	75.7%

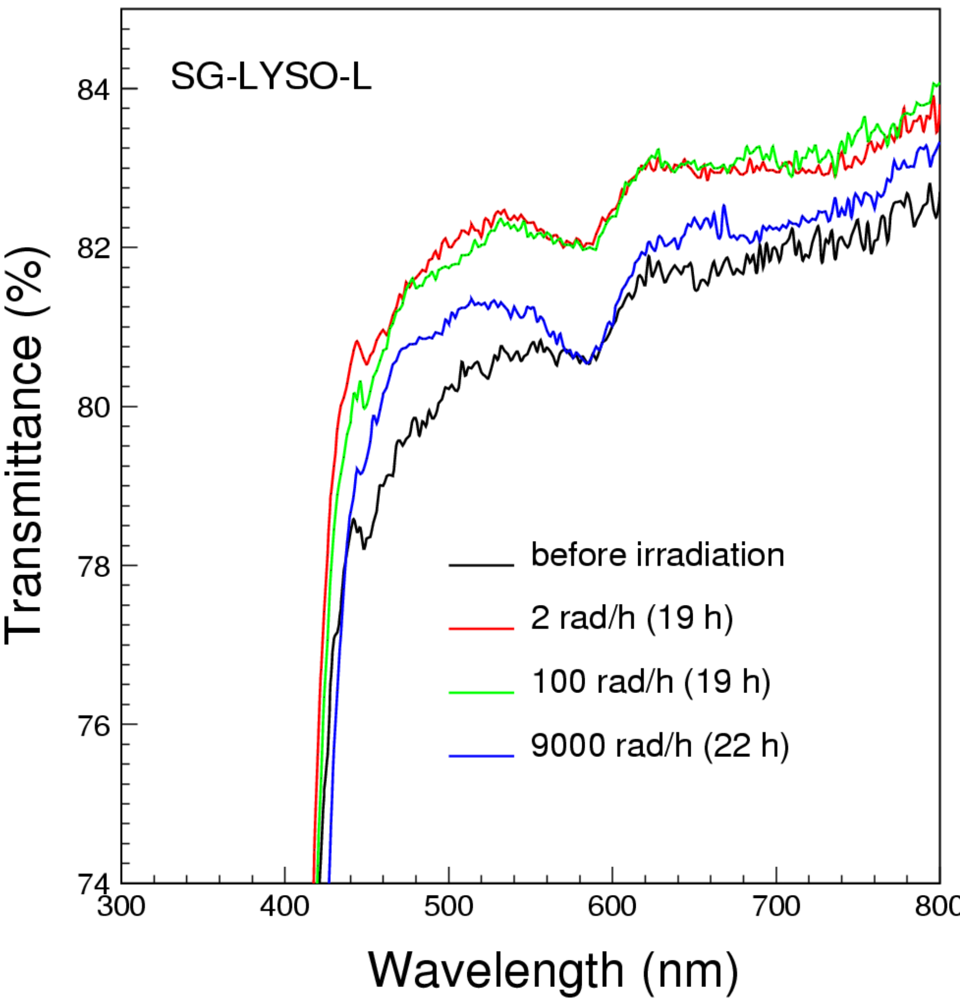




LYSO Transmittance Damage

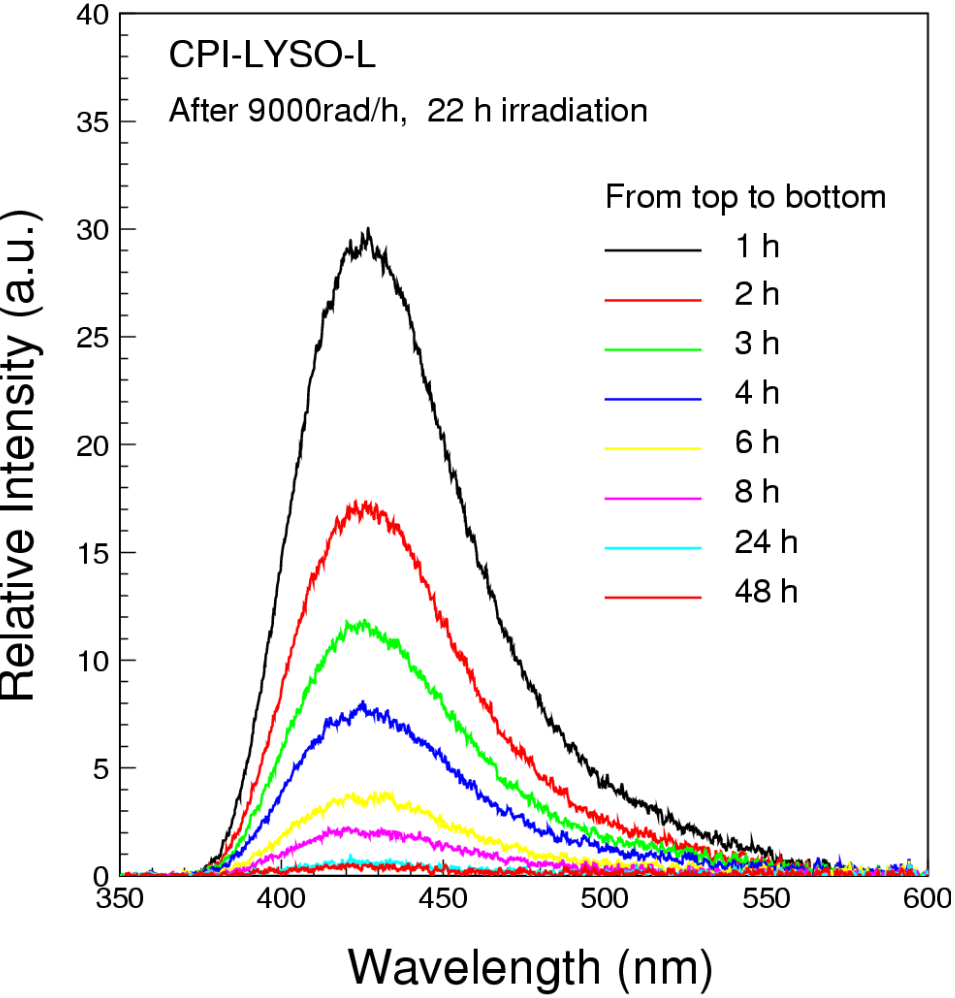
LT @ 430 nm shows 6 and 3% increase under 2 rad/h, followed by 6 and 5% degradation under 9 krad/h for CPI and SG samples respectively

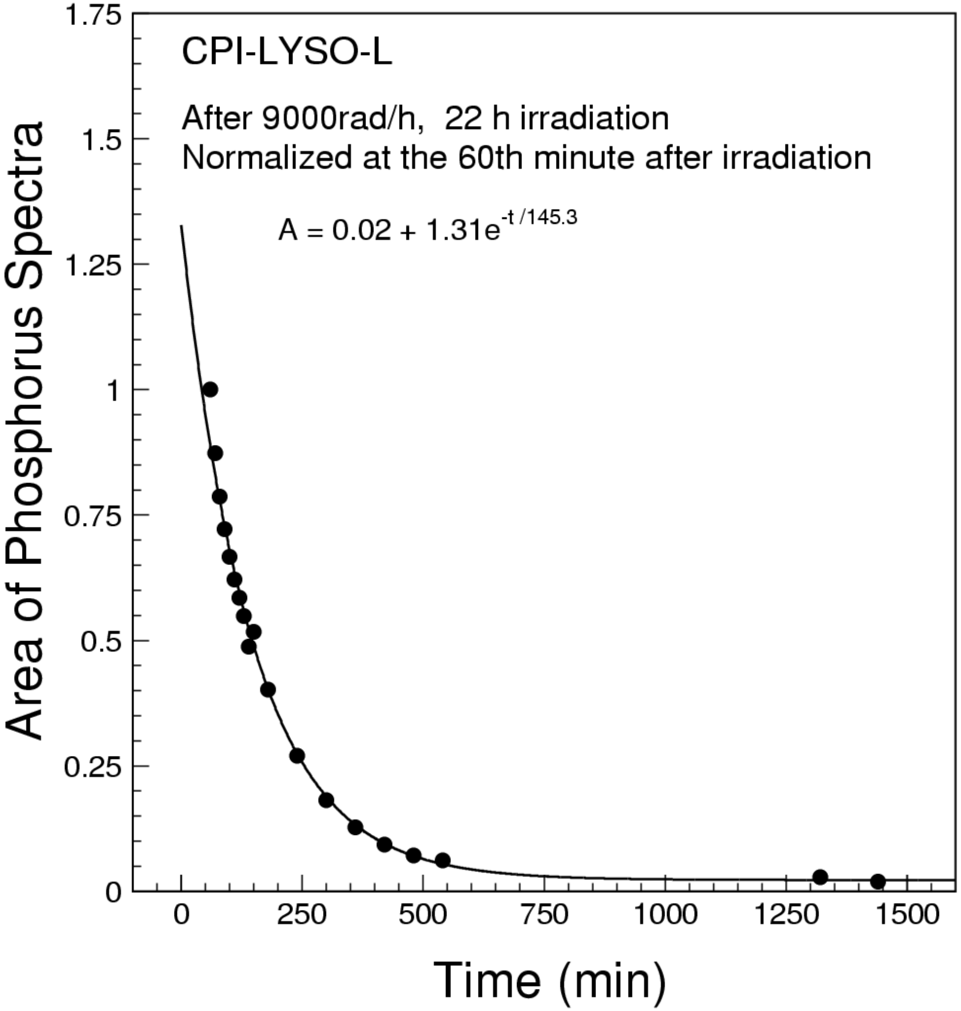




Radiation Induced Phosphorescence

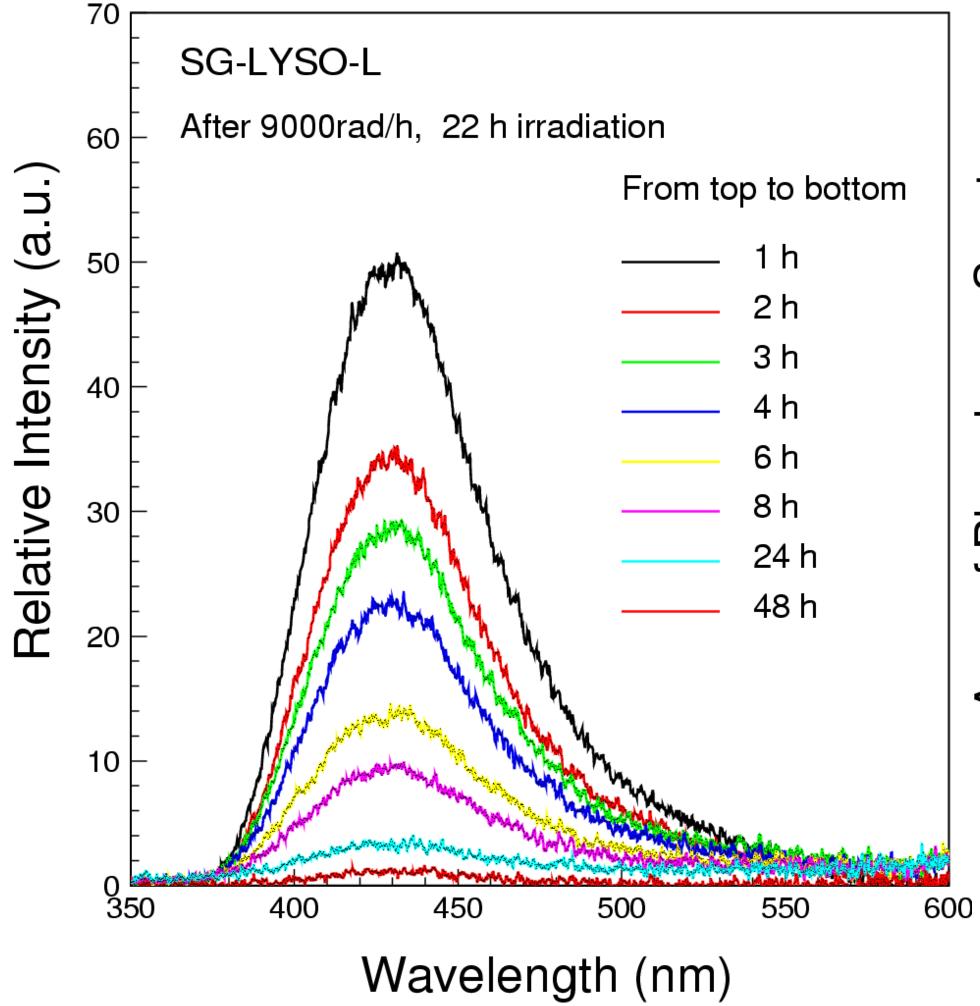
Phosphorescence peaked at 430 nm with decay time constant of 2.5 h observed

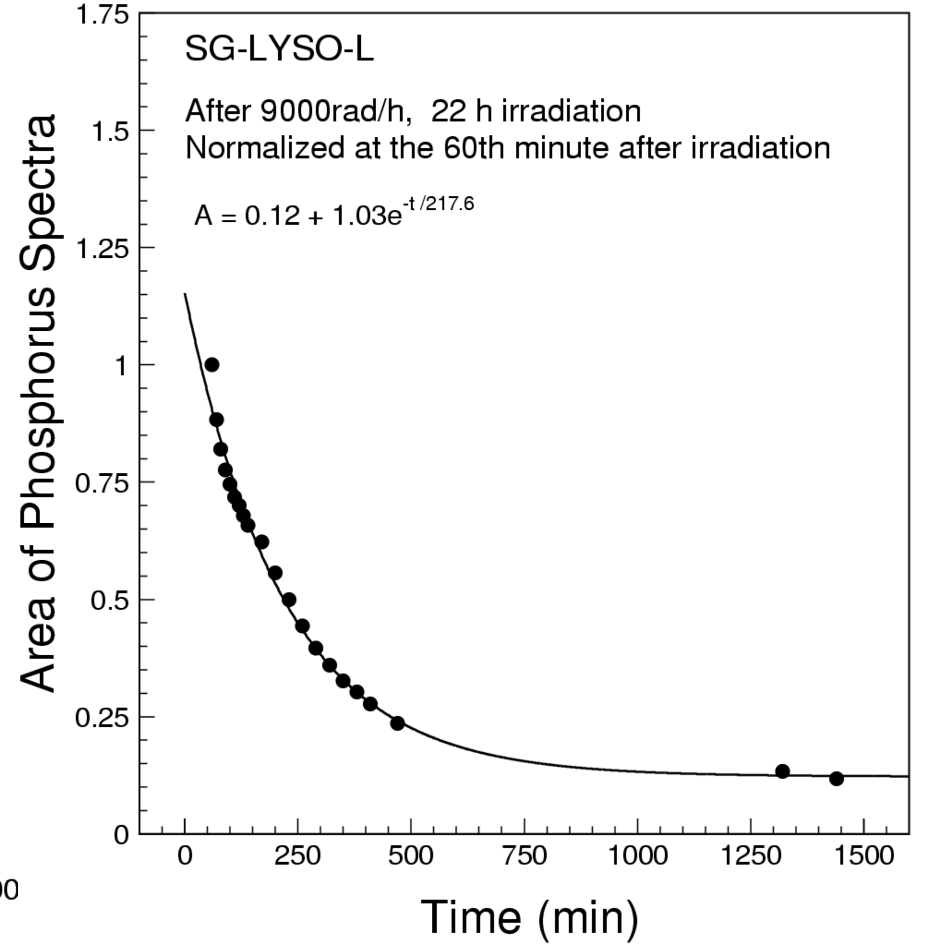




Radiation Induced Phosphorescence

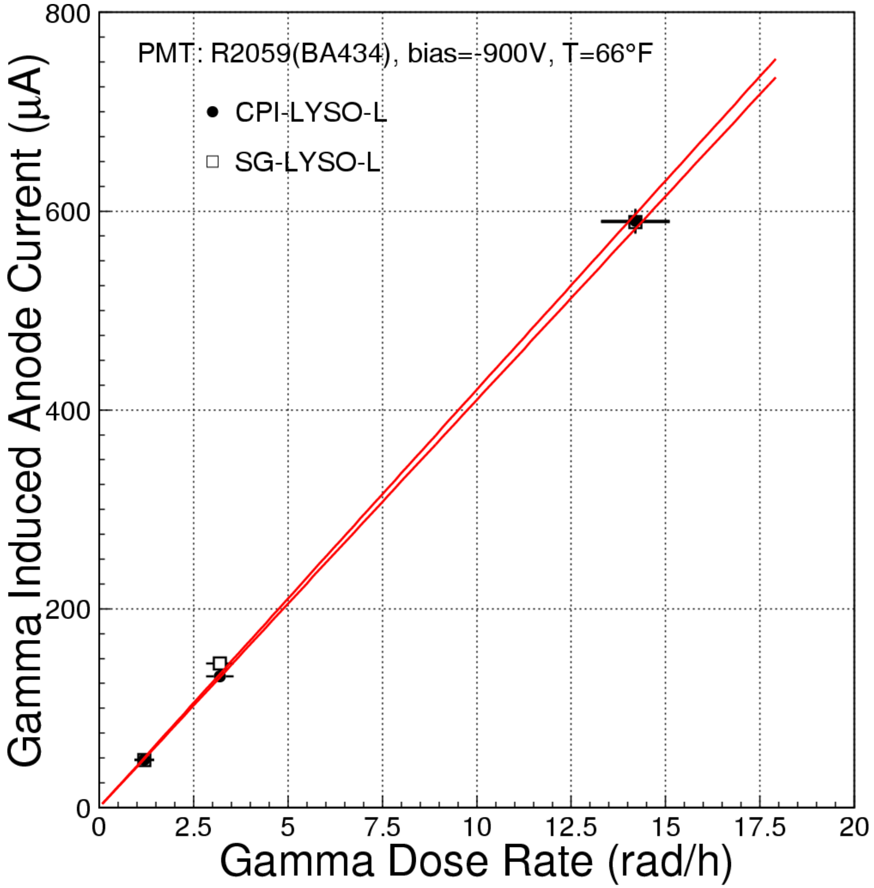
Phosphorescence peaked at 430 nm was observed





γ–ray Induced Readout Noise

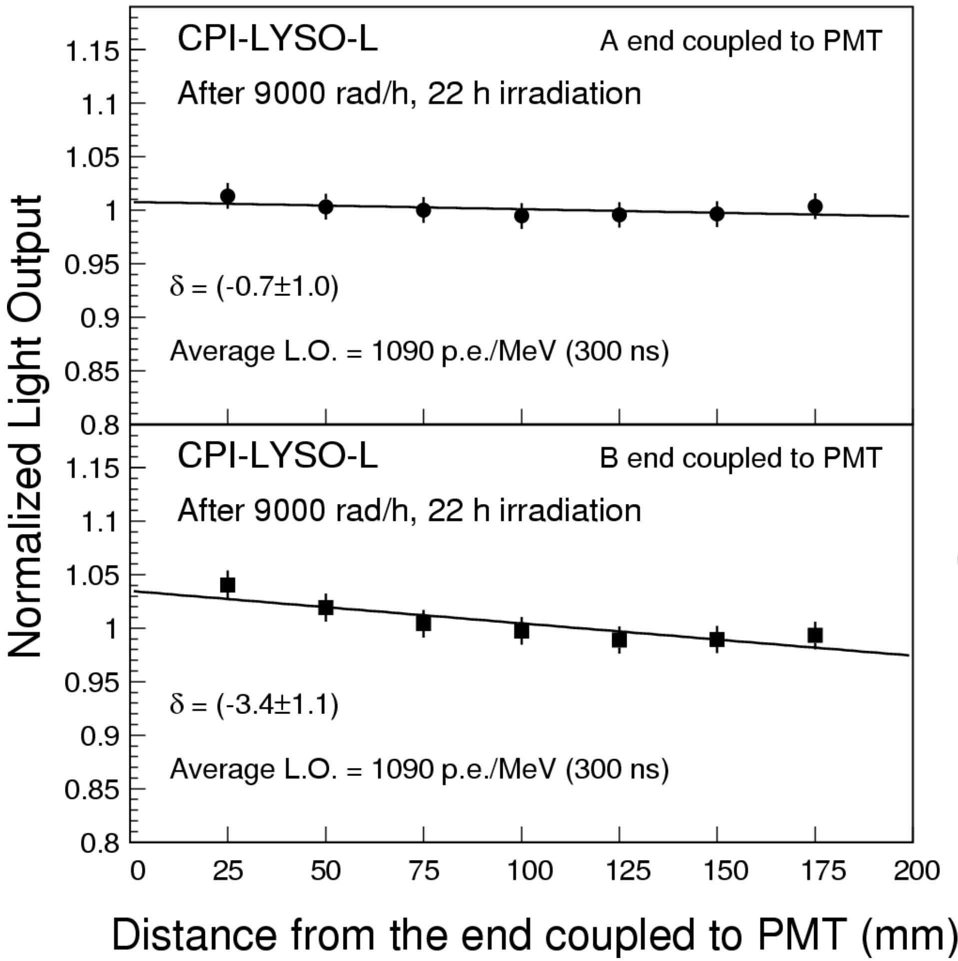
Sample ID	L.Y. p.e./MeV	F μ A/rad/h	$Q_{15\ rad/h}$ p.e.	$Q_{500\ rad/h}$ p.e.	$\sigma_{15\ rad/h}$ MeV	$\sigma_{500\ rad/h}$ MeV
CPI	1,480	41	6.98×10^4	2.33×10^6	0.18	1.03
SG	1,580	42	7.15×10^4	2.38×10^6	0.17	0.97

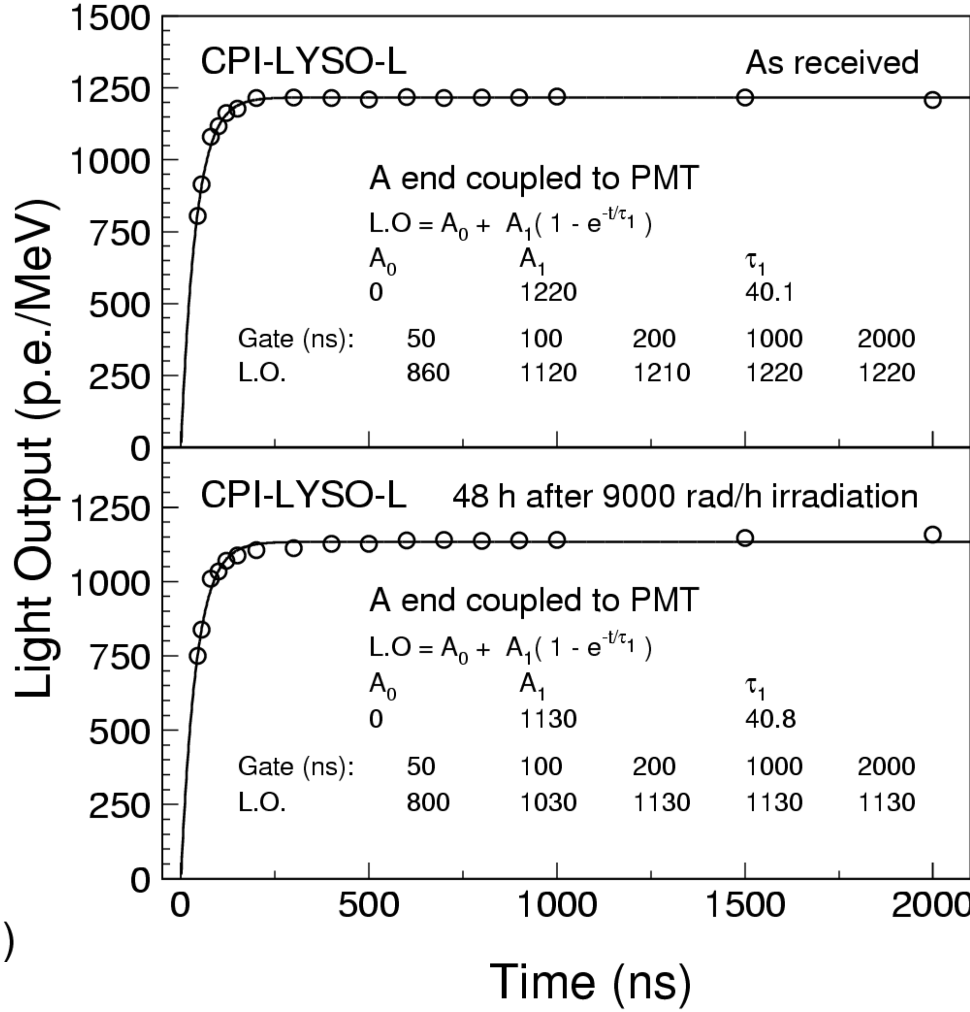


γ–ray induced PMT anode current can be converted to the photoelectron numbers (Q) integrated in 100 ns gate. Its statistical fluctuation contributes to the readout noise (σ).

Light Output Degradation

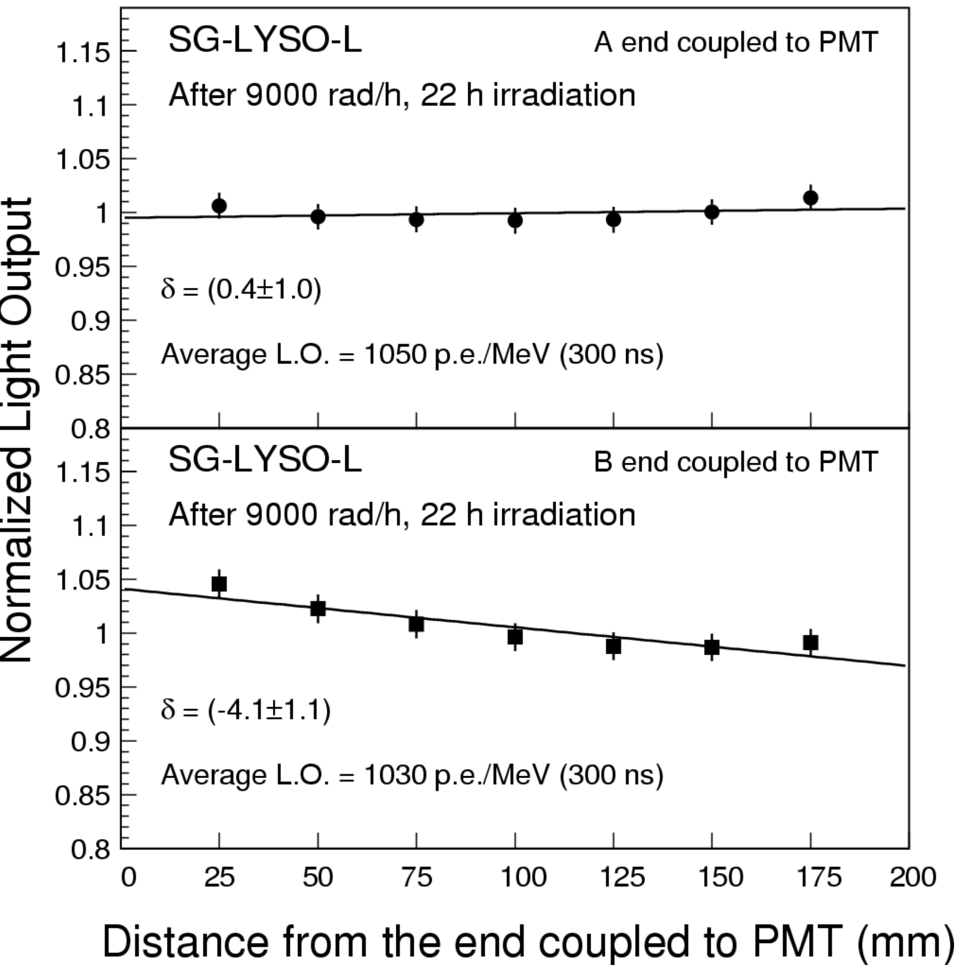
Damages in LRU and LO is small after γ–ray irradiations of 22 h at 9,000 rad/h

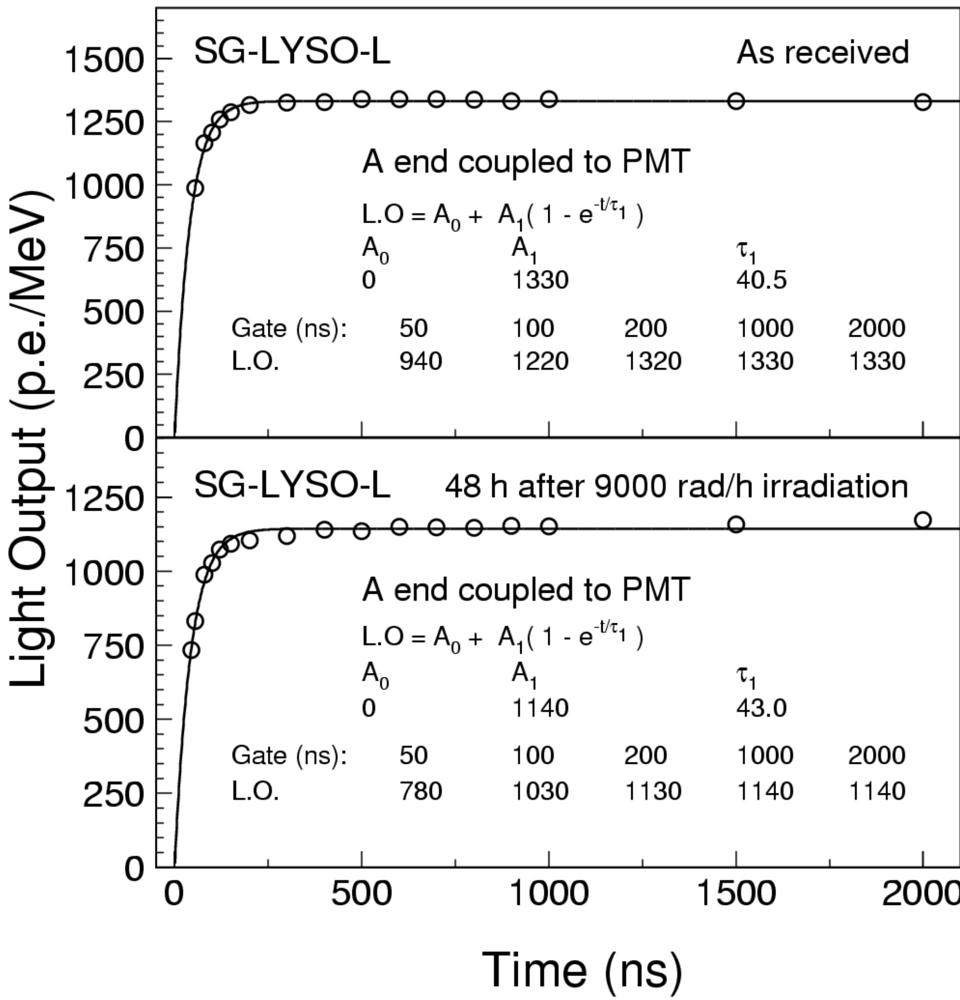




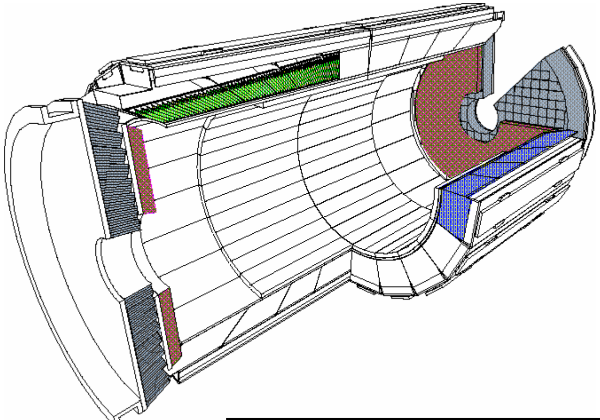
Radiation Damage in LYSO

Damage effect in LRU and LO is small after 22 h γ–ray irradiations at 9,000 rad/h: better than PWO



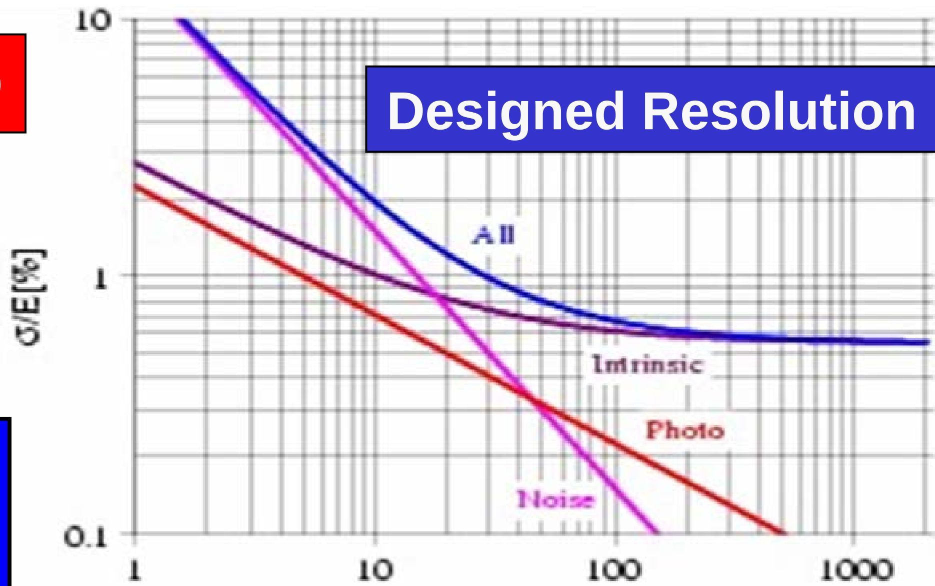


CMS PWO Resolution



77k PWO

Designed Resolution

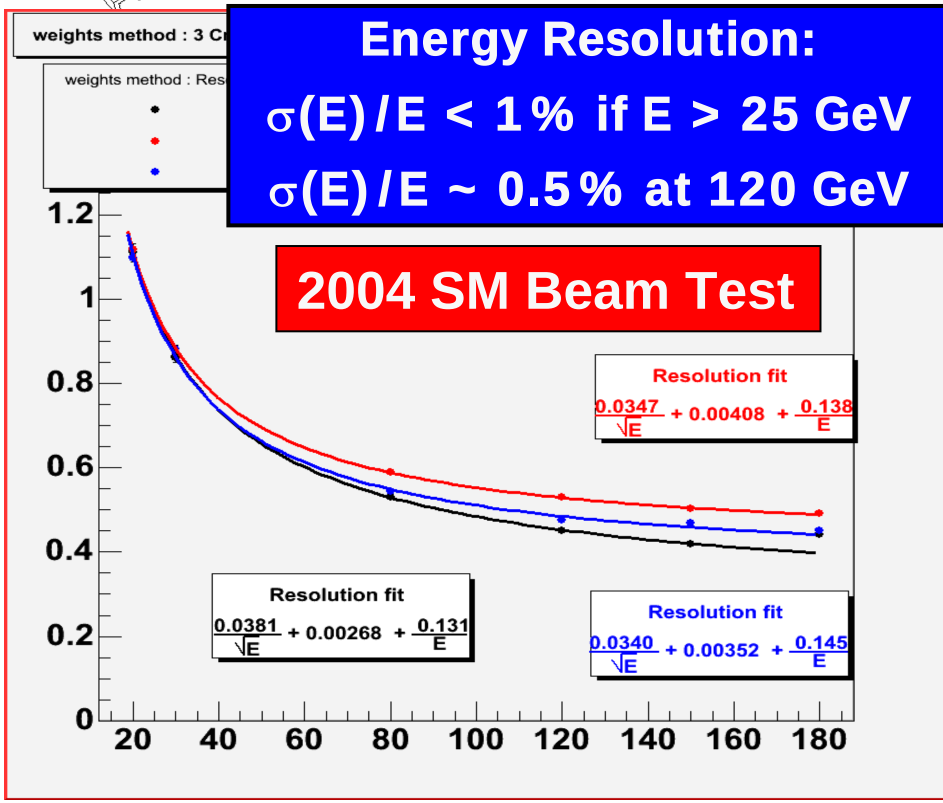


Energy Resolution:

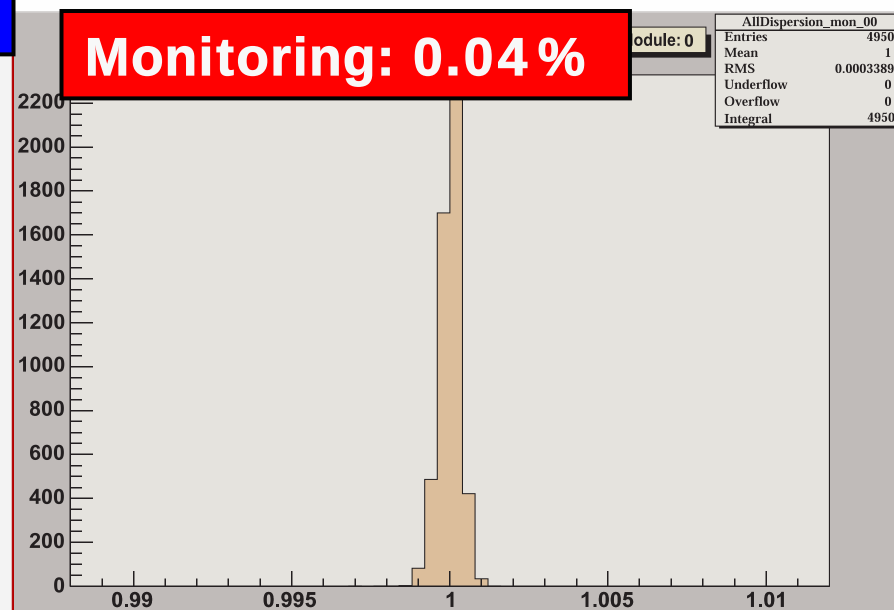
$\sigma(E)/E < 1\%$ if $E > 25$ GeV

$\sigma(E)/E \sim 0.5\%$ at 120 GeV

2004 SM Beam Test



Monitoring: 0.04%



LSO/LYSO ECAL Performance

- Energy resolution, σ(E)/E, better than L3 BGO and CMS PWO because of its high light output and thus low readout noise contribution:

$$2.0\% / \sqrt{E} \oplus 0.5\% \oplus .002/E$$

- Less demanding to the environment because of small temperature coefficient.
- Radiation damage is less an issue as compared to the PWO crystals.

Summary

- Ce doped LSO & LYSO crystals have fast (42 ns) and high (4 X BGO) light output. The light output of 2.5 x 2.5 x 20 cm LSO and LYSO samples, excited by 0.51 MeV γ–ray, can be readout by single APD of 25 mm^2.
- LSO/LYSO has good radiation hardness. The radiation induced phosphorescence in 2.5 x 2.5 x 20 cm LYSO causes ~0.2 MeV noise @ 15 rad/h.
- An LSO/LYSO crystal calorimeter will provide the best possible energy resolution for future experiments, and will produce rich physics with precision electrons and photons