Electromagnetic Calorimetry for SuperB

David Hitlin

Super$B$ Factory Workshop
Frascati

November 12, 2005

An EMC for Super$B$

- With the likely time structure of SuperB, backgrounds and radiation damage to the EMC should be reduced from those at a 10^{36} conventional collider
- In the endcap region, at least, there will be multi-Bhabhas within the decay/integration time of the CsI(Tl)
  - A faster scintillator may be needed
- We have an excellent candidate in LSO or LYSO, which is under active study by Ren-Yuan Zhu at Caltech
- We are also developing a liquid Xe scintillation counter, although this is more difficult to integrate into an existing detector

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 (°C)	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	42	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] (%/ °C)	~0	0.3	-0.6	-2 ~0	-1.6	-1.9	-0.3	-0.1
Experiment	Crystal Ball	CLEO *BABAR* Belle BES III	KTeV, E787	TAPS (L*) (GEM)	L3 BELLE PANDA?	CMS ALICE PANDA? (BTeV)	Super*B*?	-

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

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)

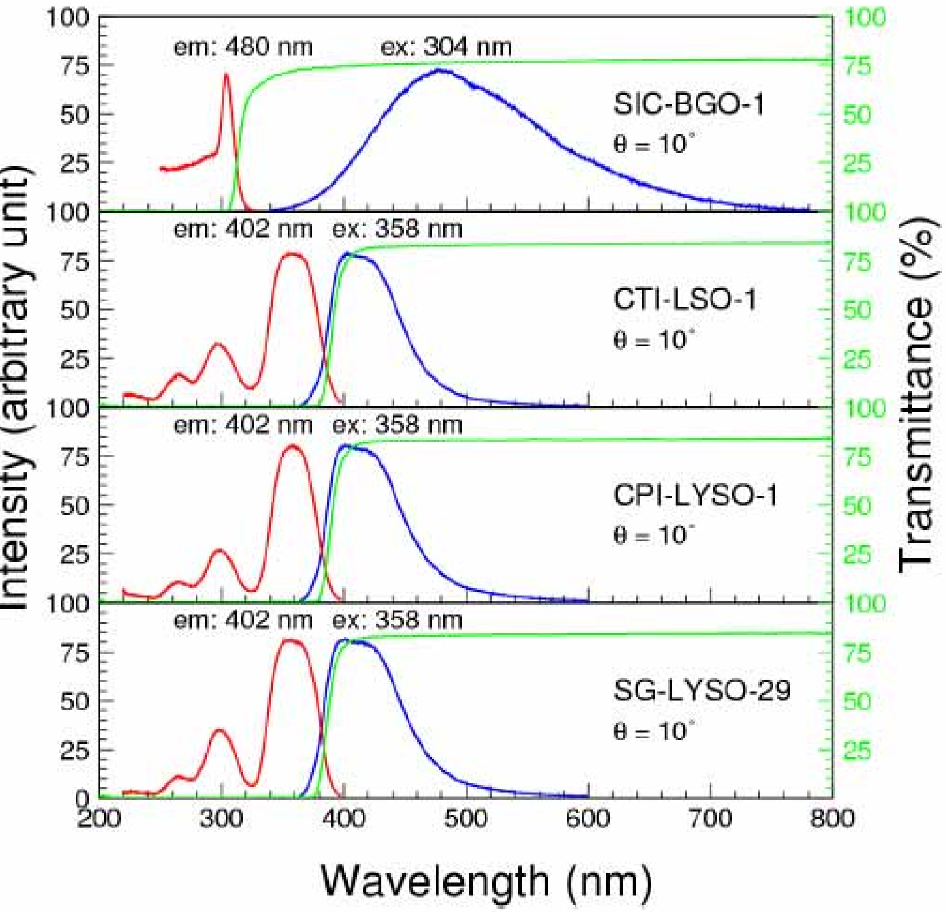
Bar: 2.5 x 2.5 x 20 cm (18 X_0)

Excitation, Emission & Transmittance

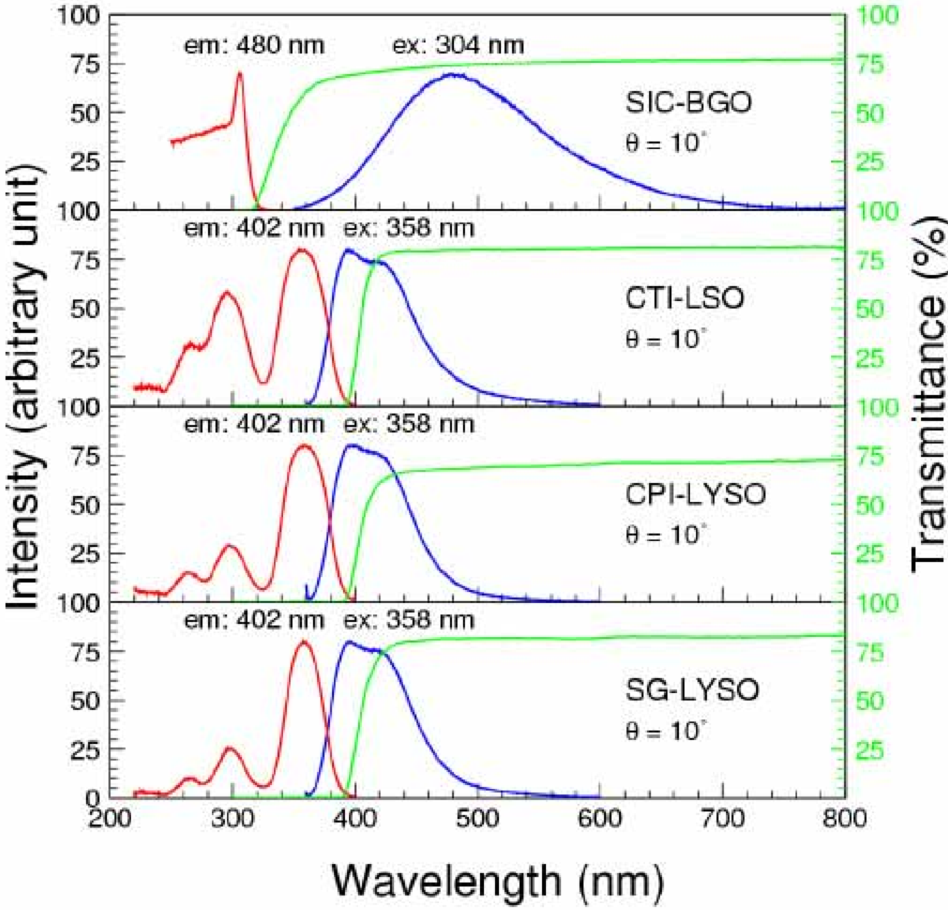
Identical transmittance, emission & excitation spectra

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

1.7 cm Cube



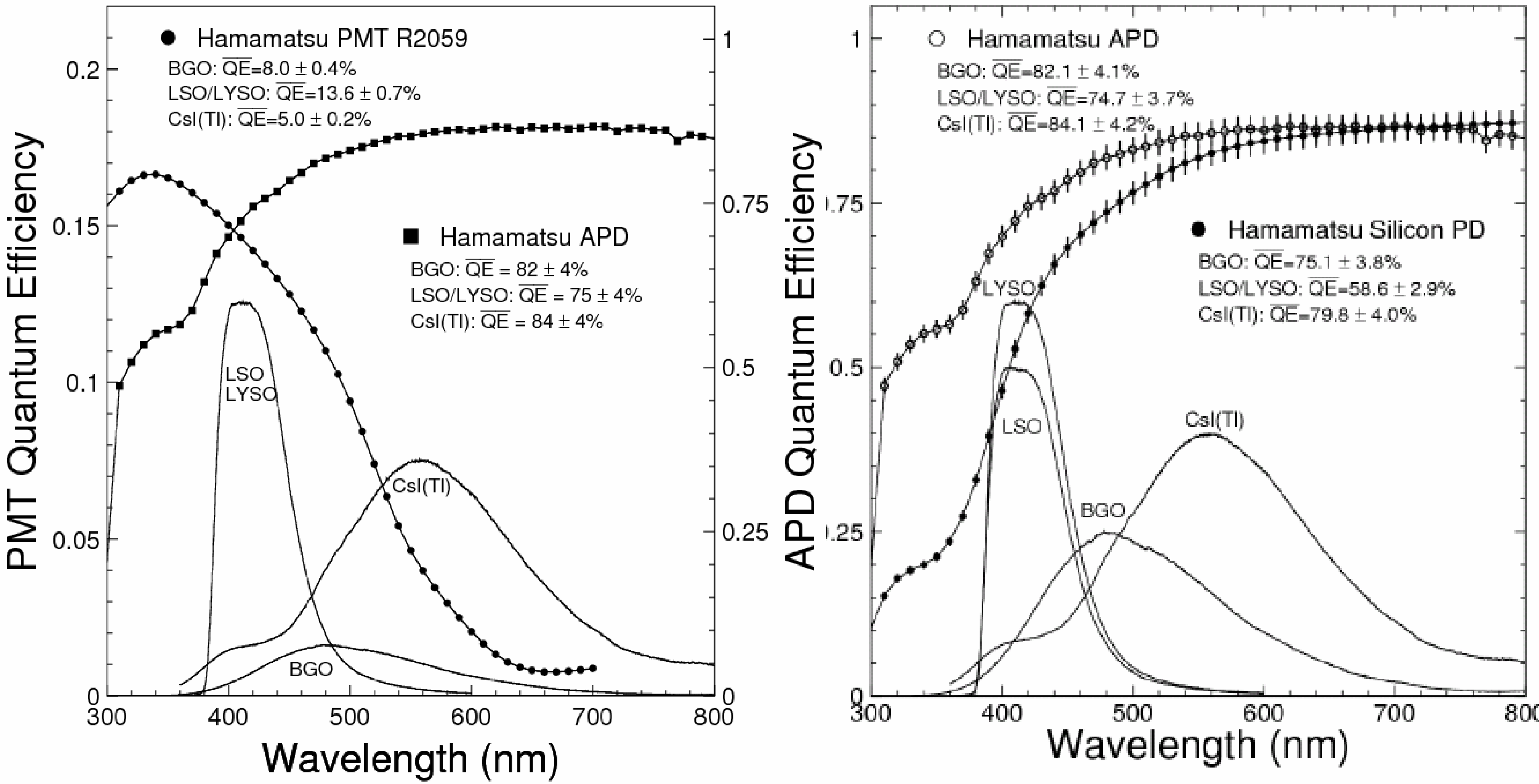
2.5 x 2.5 x 20 cm Bar



Emission Weighted Q.E.

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

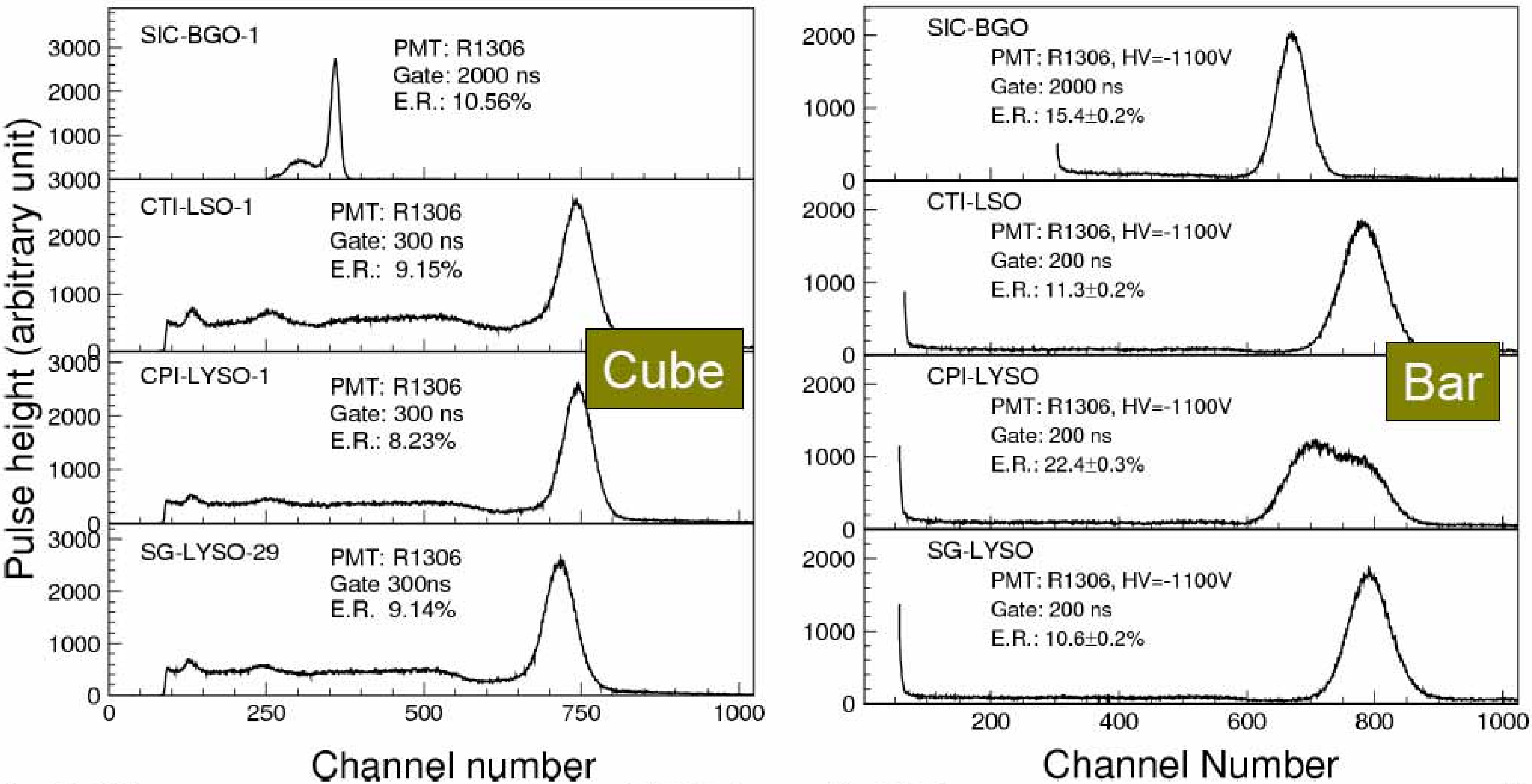
For Si PD and APD, QE is 59% and 75% respectively



^{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

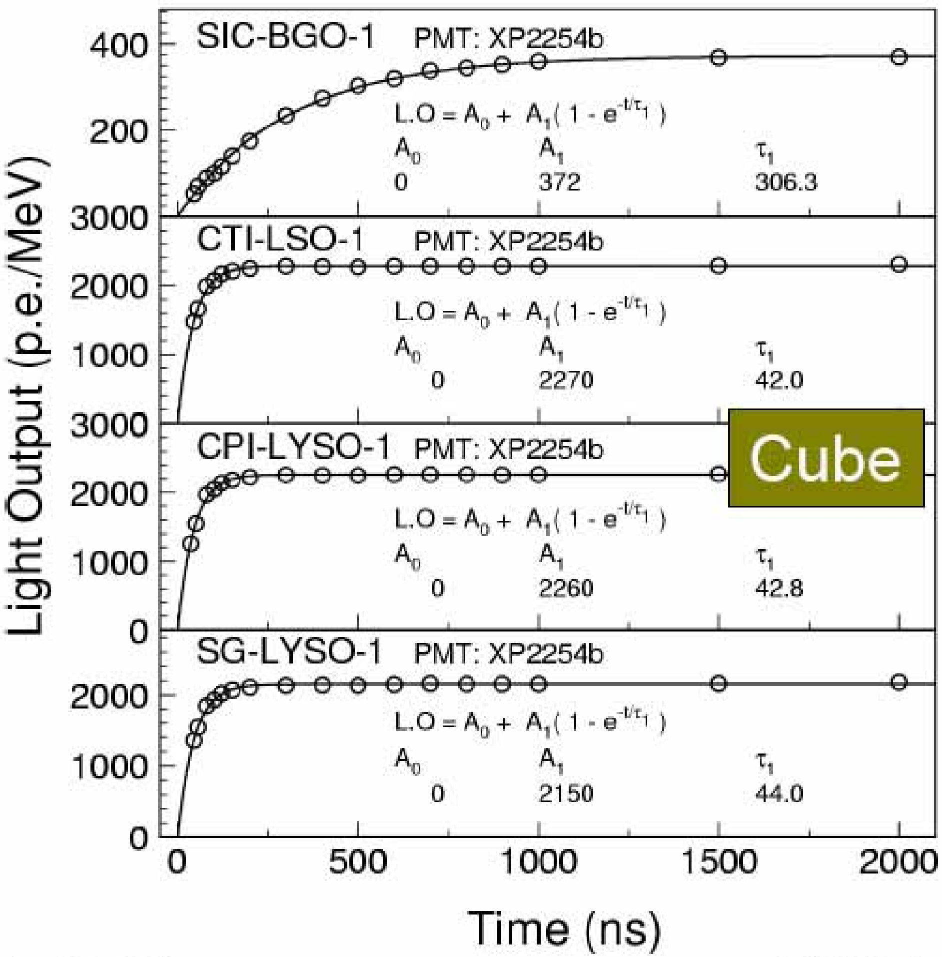


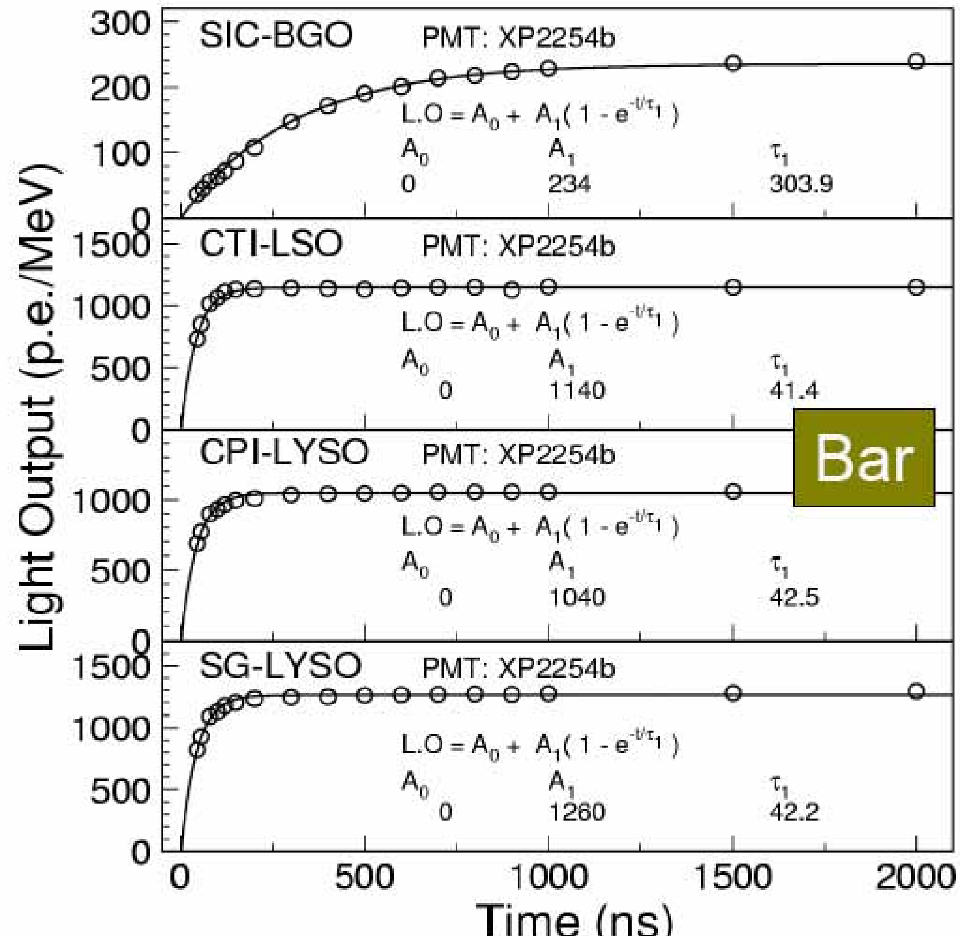
Light Output & Decay Time

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

Bar sample has ~50% of light of cube sample

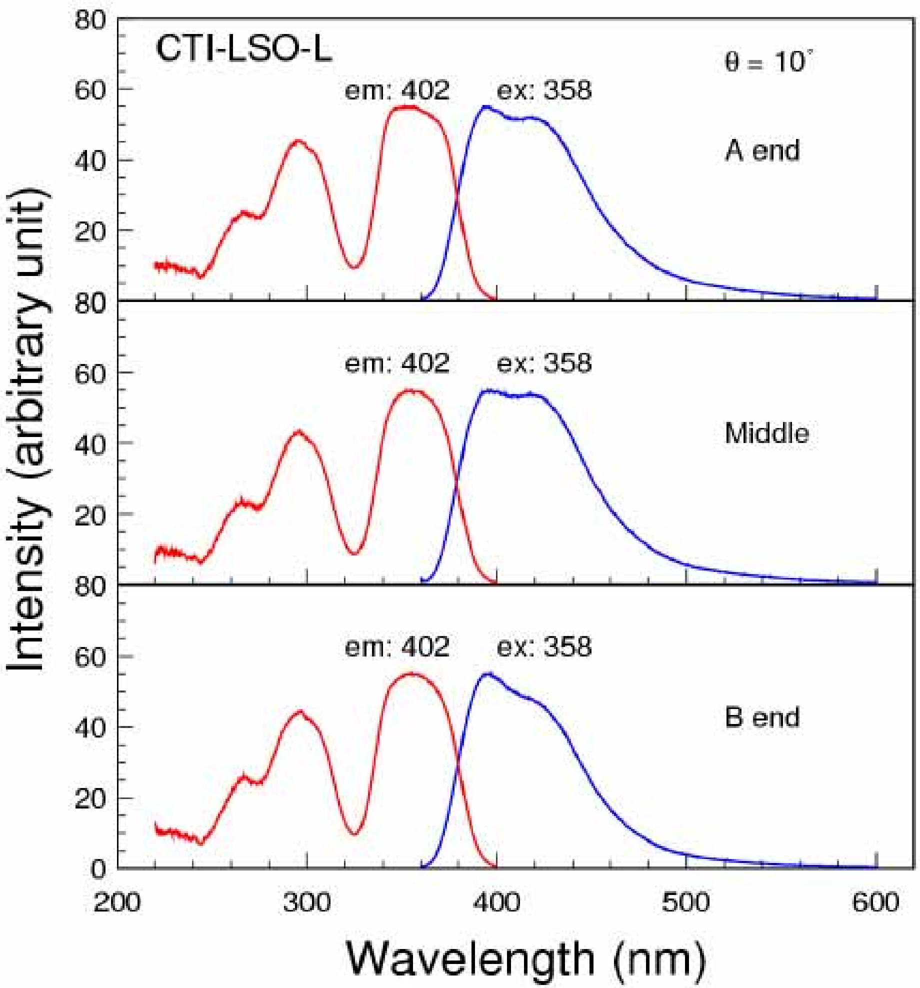
LSO/LYSO decay time: 42 ns compared to 300 ns of BGO

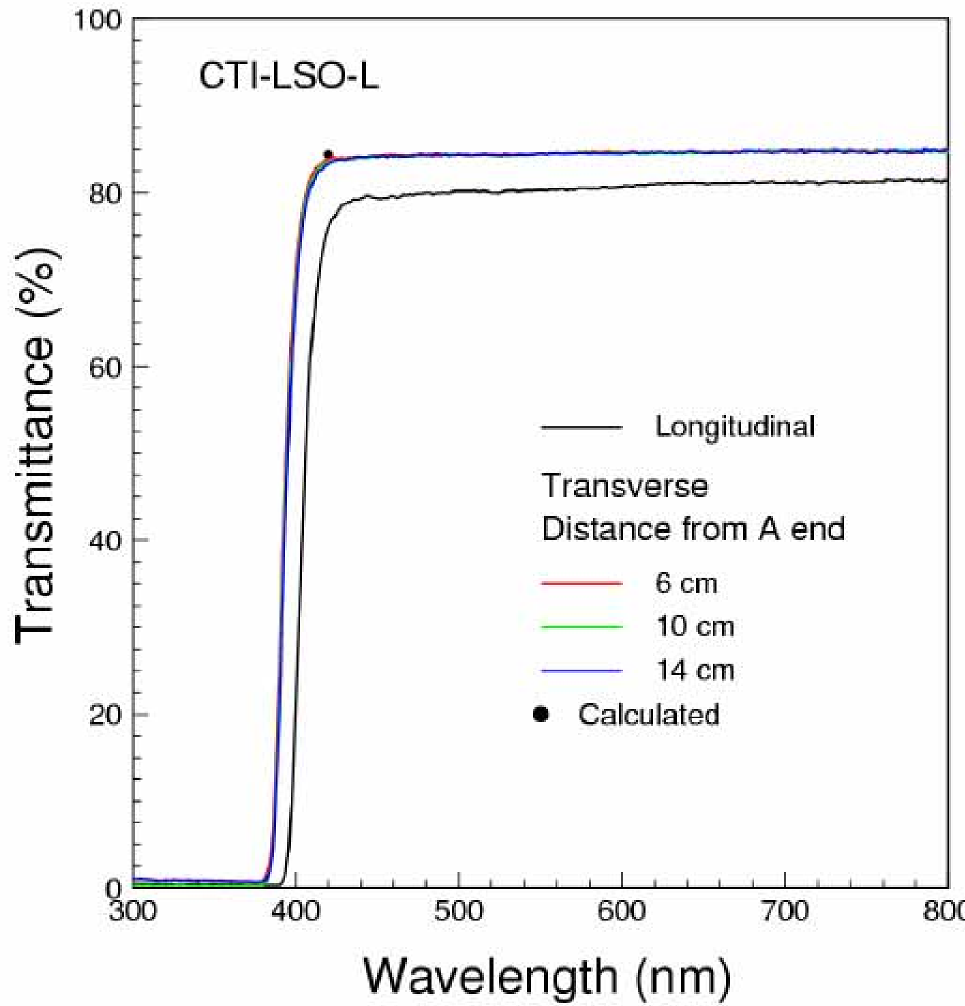




CTI LSO: longitudinal optical uniformity

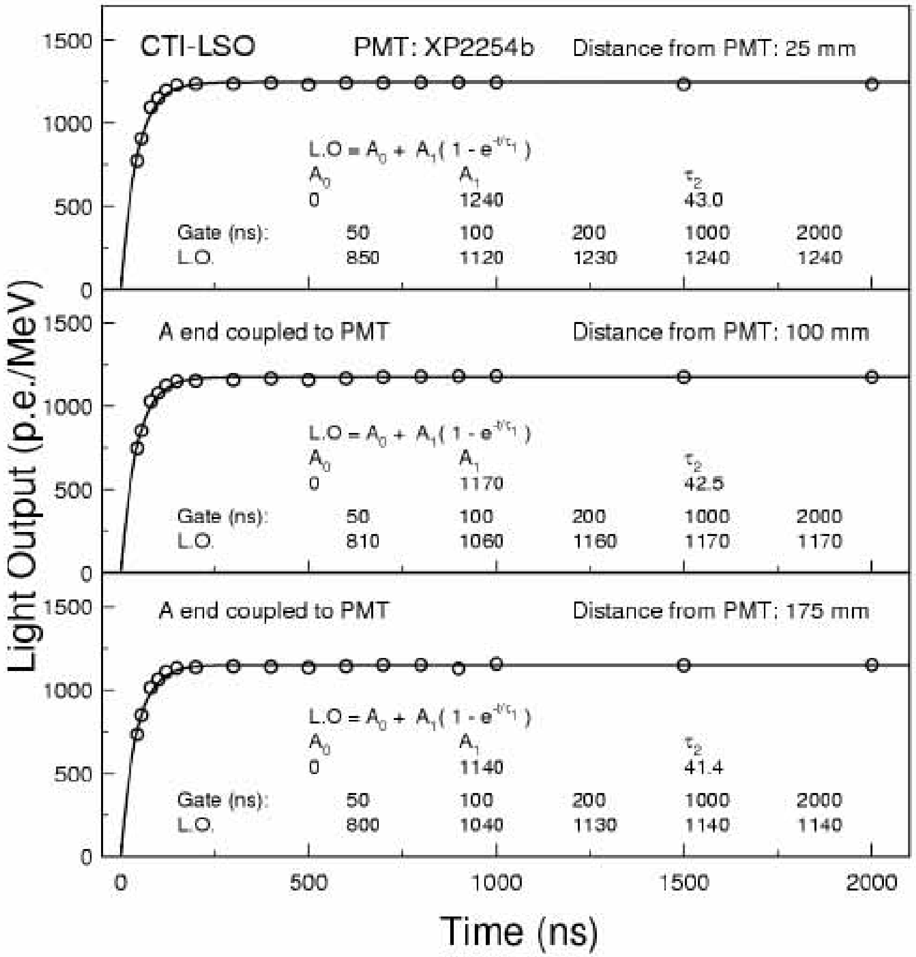
No longitudinal variation in optical properties
Transverse transmittance approaches theoretical limit

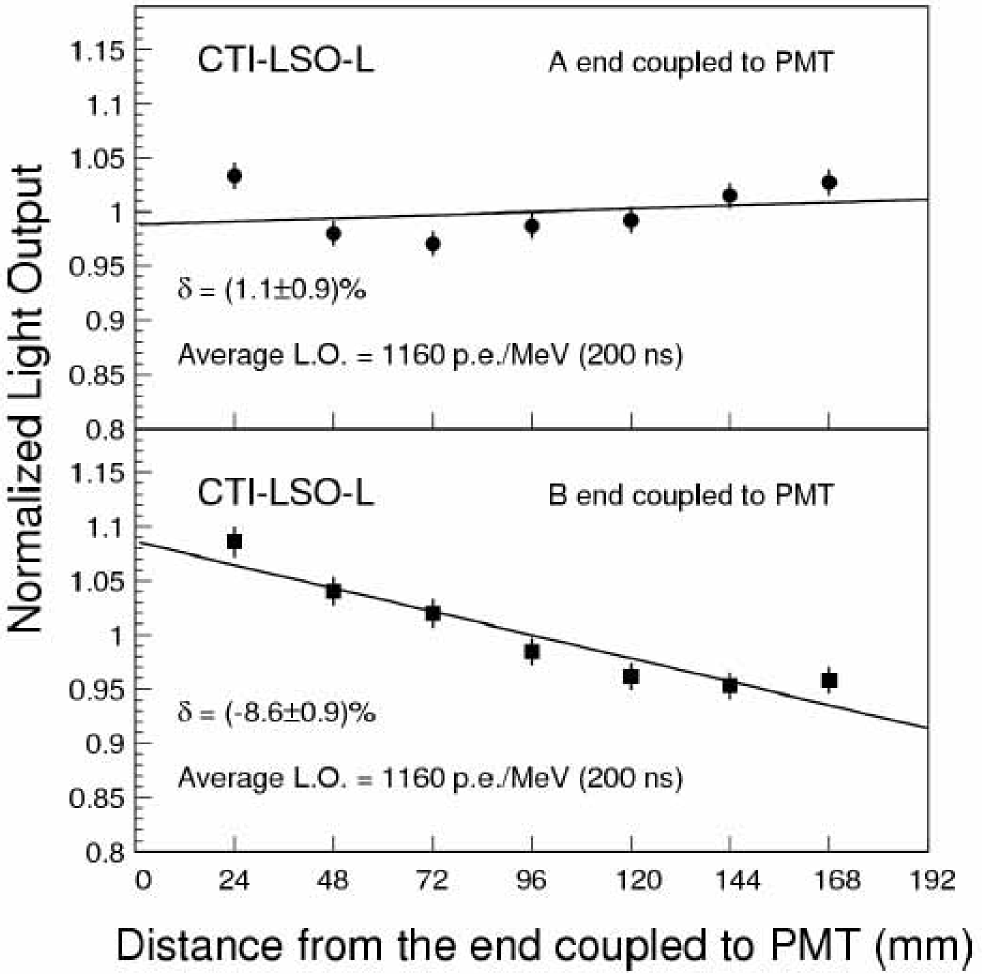




LSO Light Response Uniformity

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

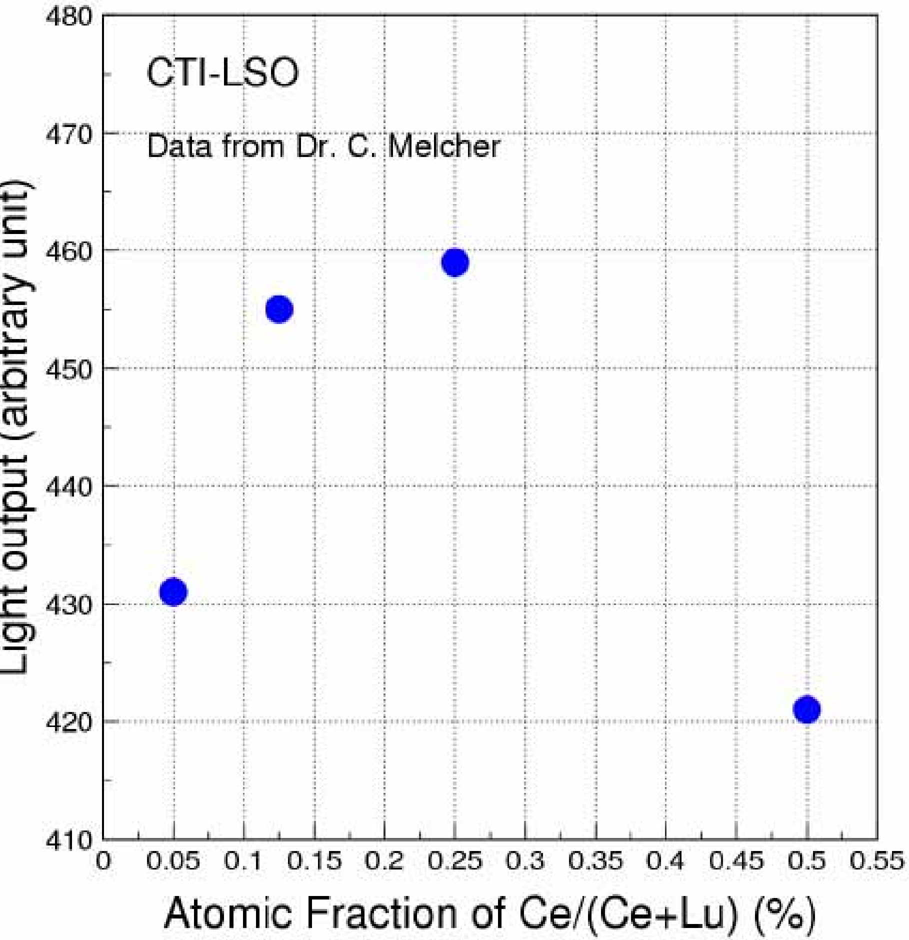


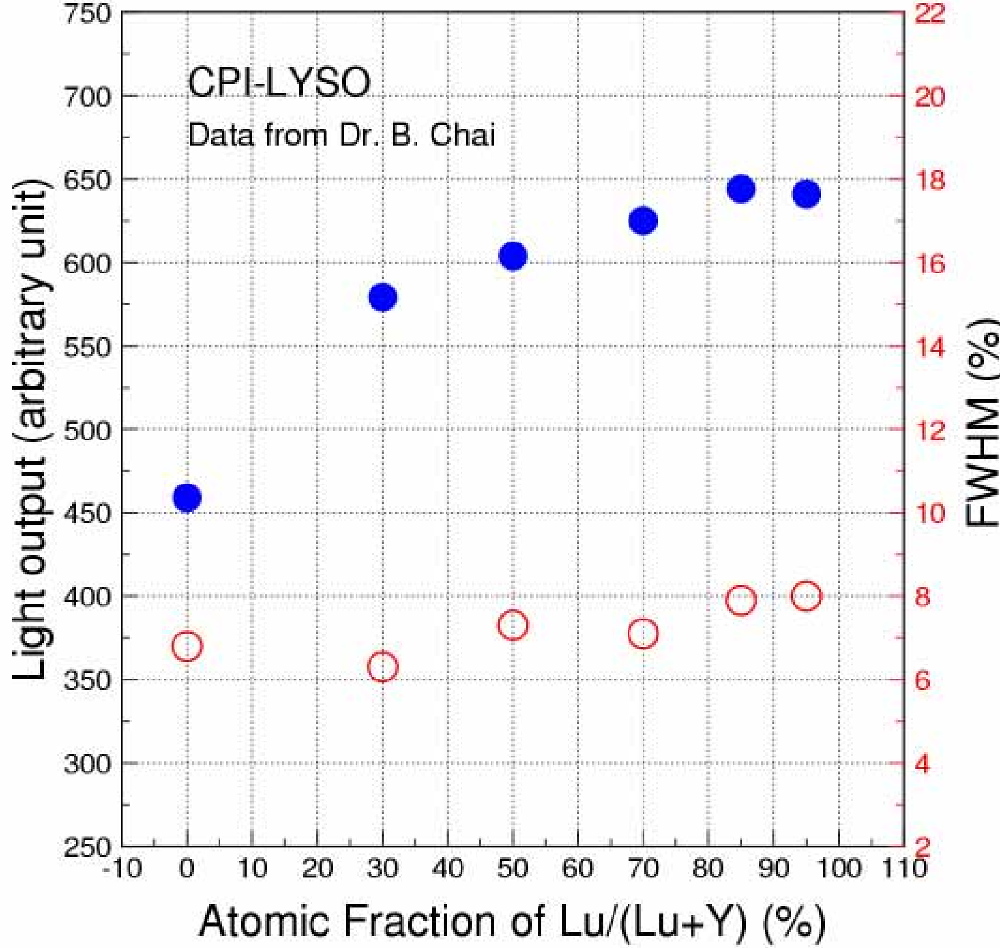


Possible Origin of Non Uniformity

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

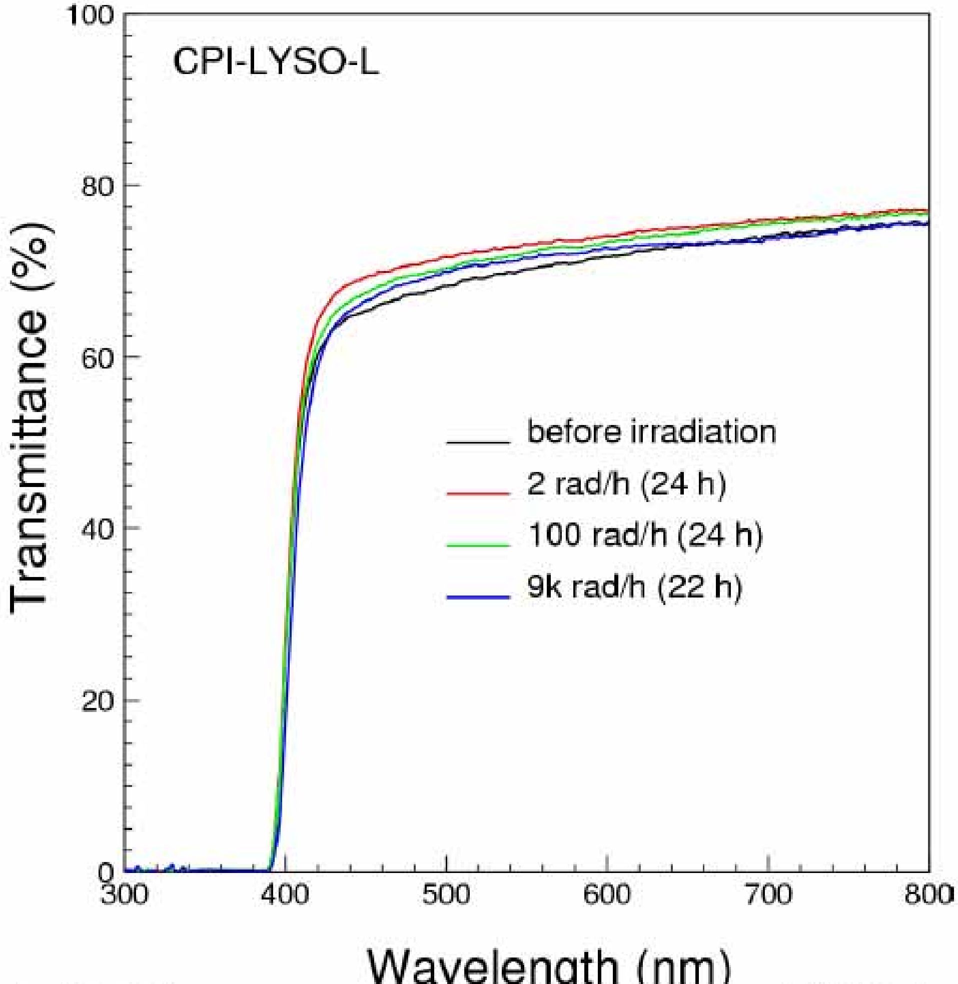
B. Chai: LO in LYSO is a function of atomic fraction of Yttrium

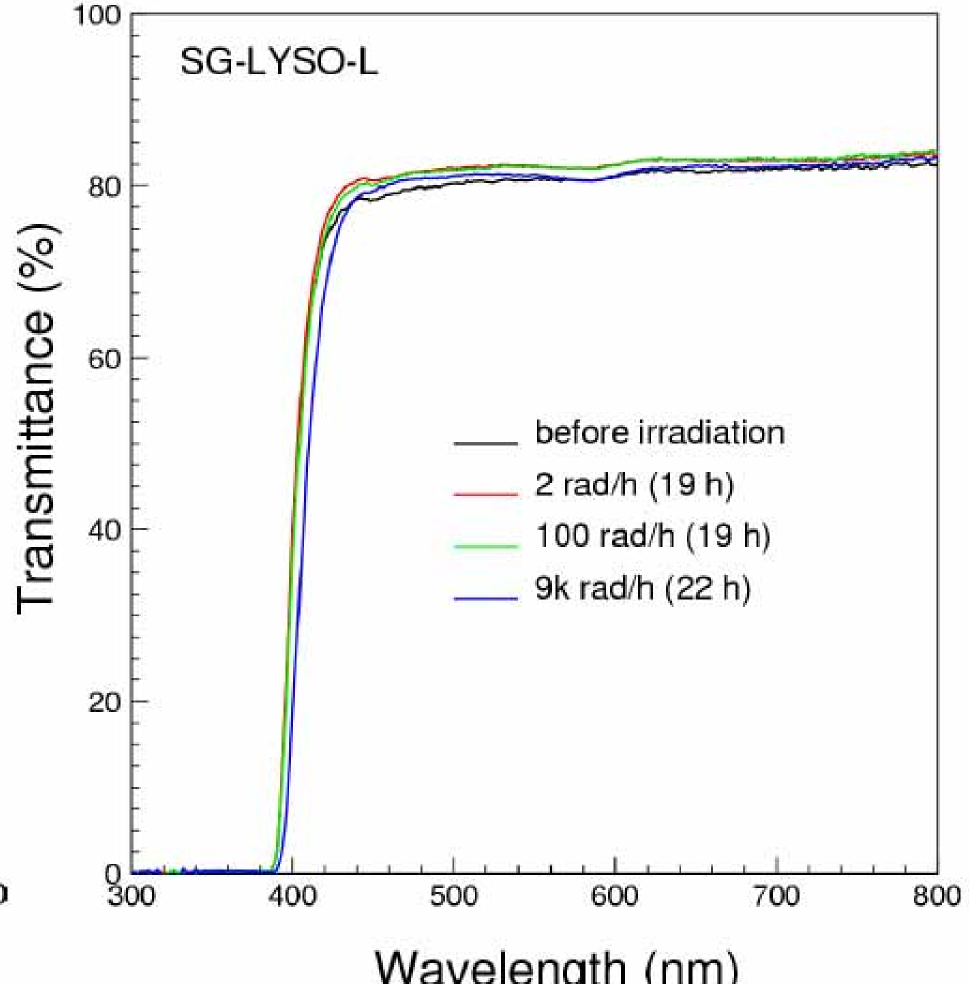




LYSO Longitudinal Transmittance

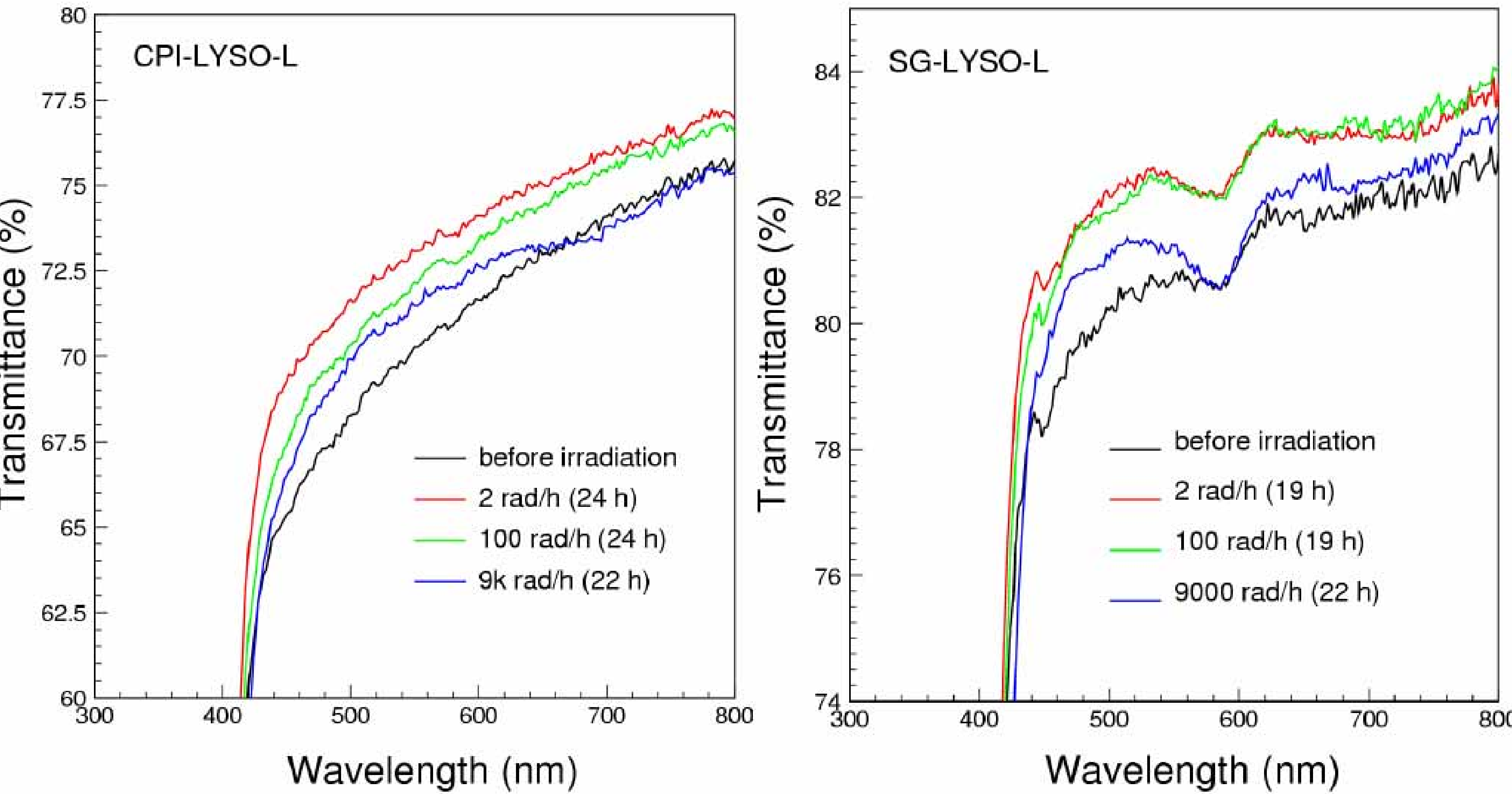
LT@430 nm	Initial	2 rad/h	100 rad/h	9 krad/h
CPI	63.2%	67.1%	64.9%	63.3%
SG	77.1%	79.3%	78.5%	75.7%





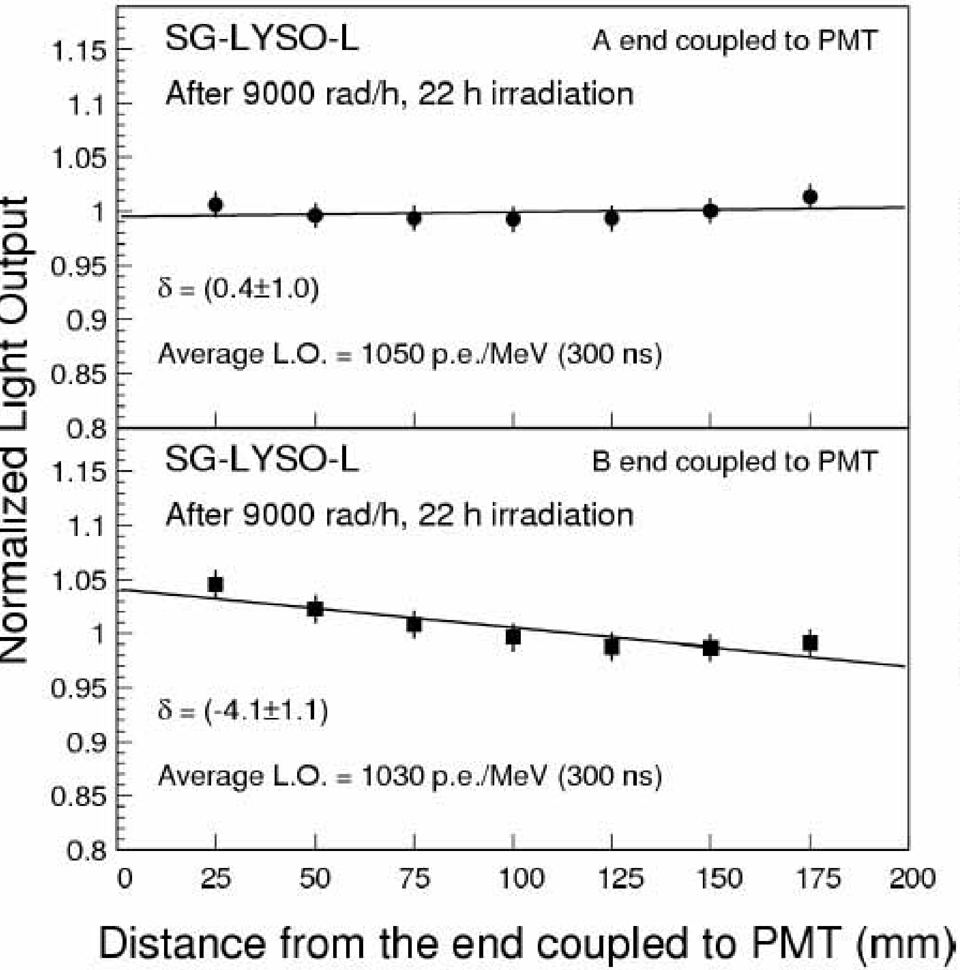
LYSO Transmittance Damage

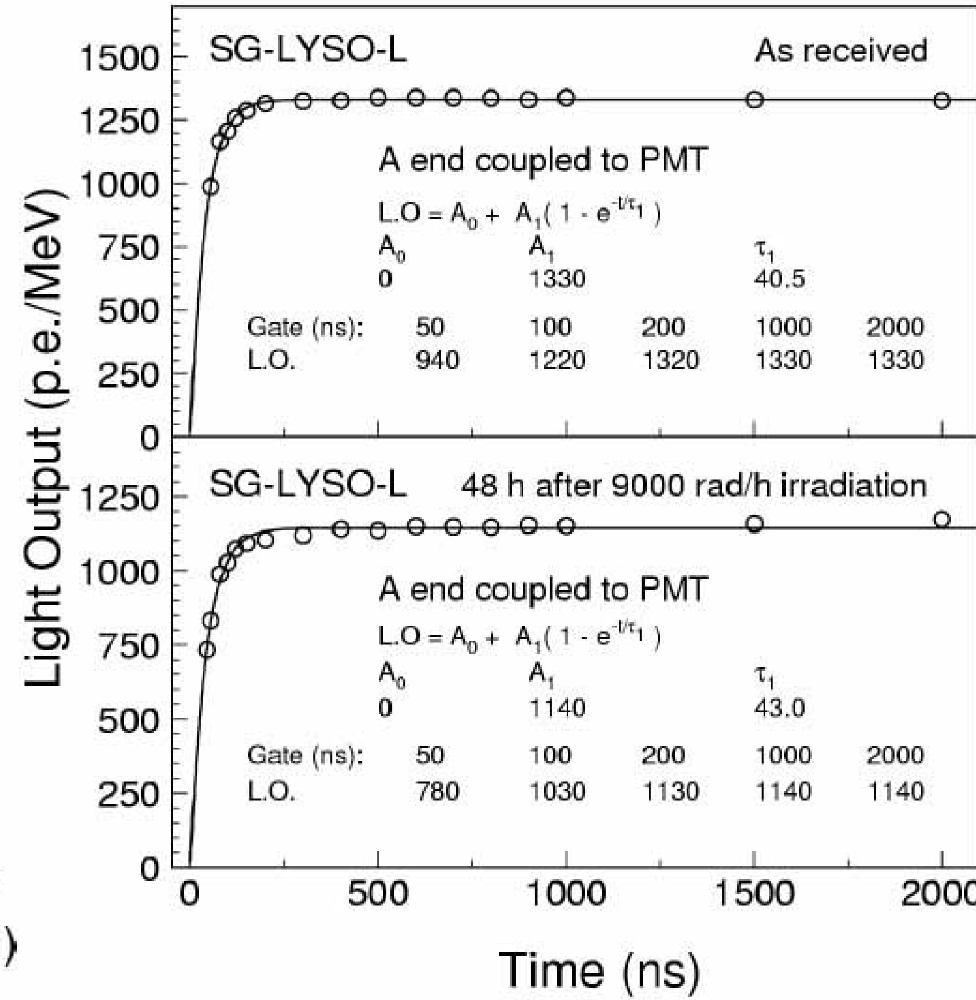
LT @ 430 nm shows 6 and 3% increase under 2 rad/h, followed by 6 and 5% degradation under 9 krad/h for CPI and SG samples respectively



Radiation Damage in LYSO

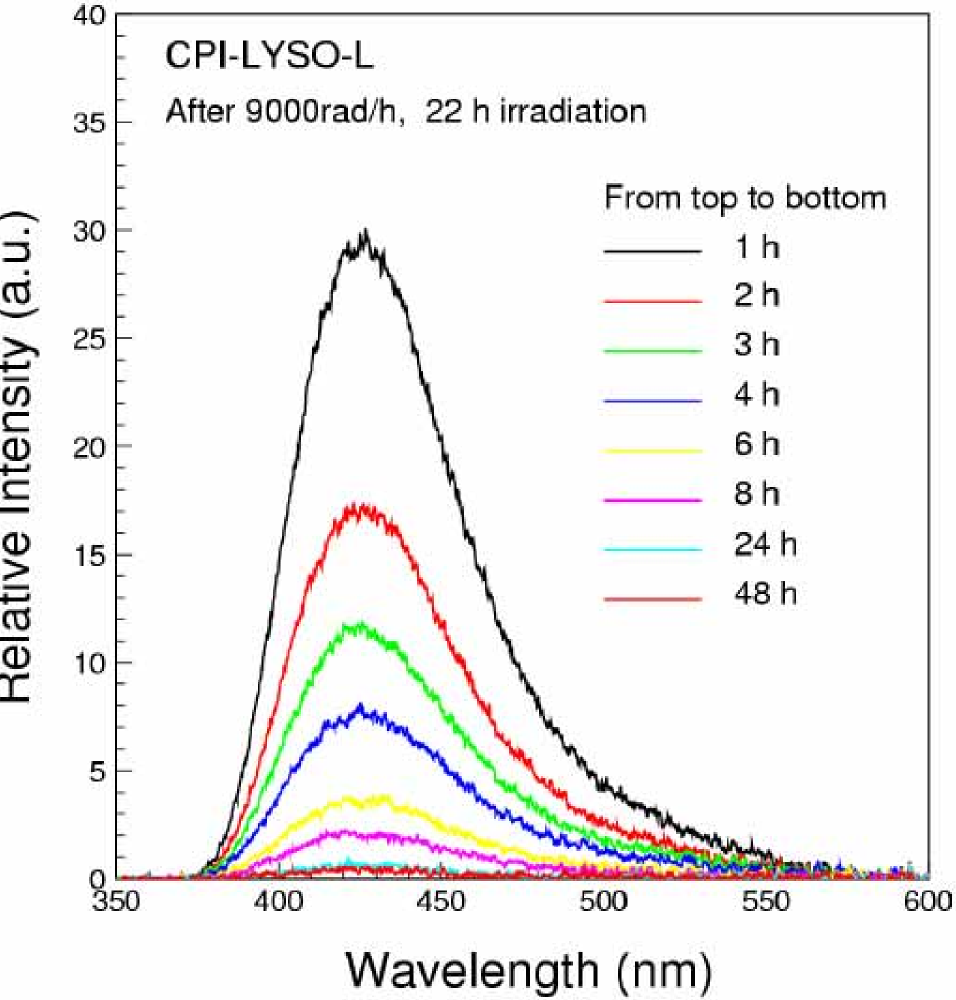
Damage effect in LRU and LO is small after 22 h γ–ray irradiations at 9,000 rad/h: better than PWO

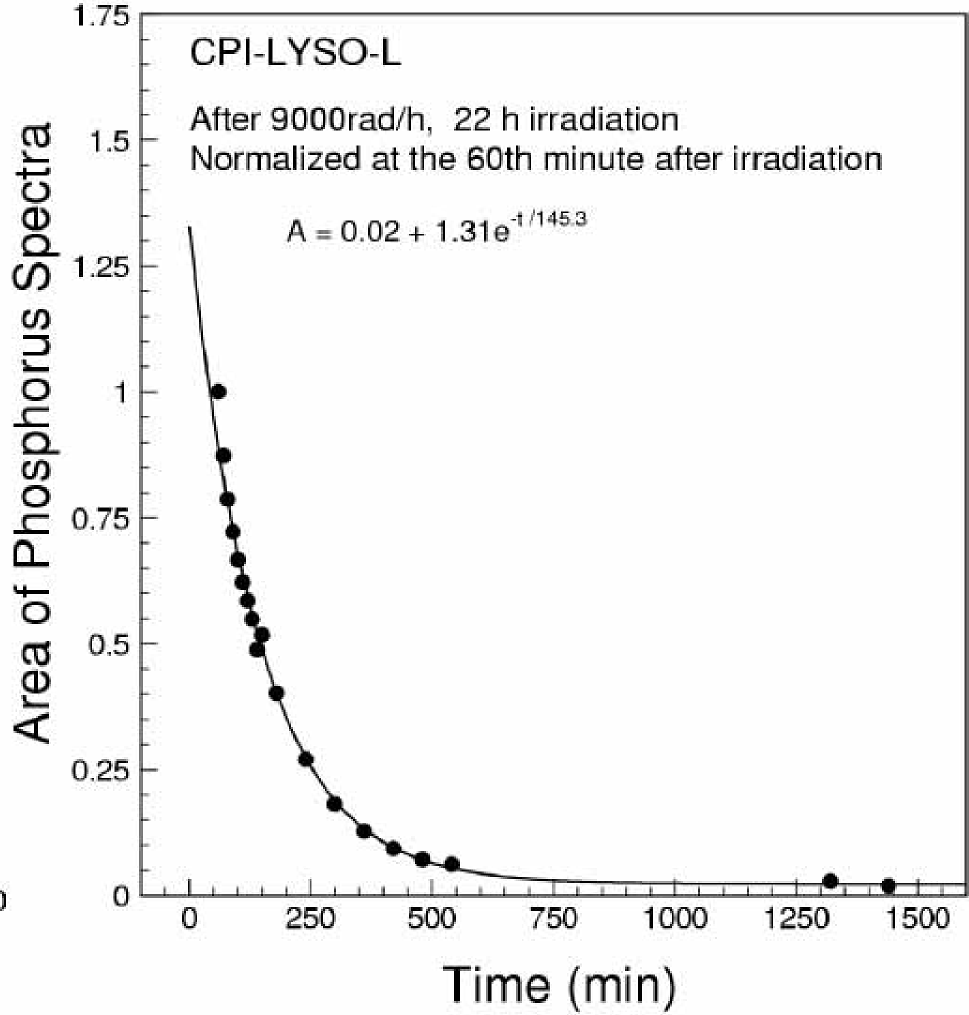




Radiation Induced Phosphorescence

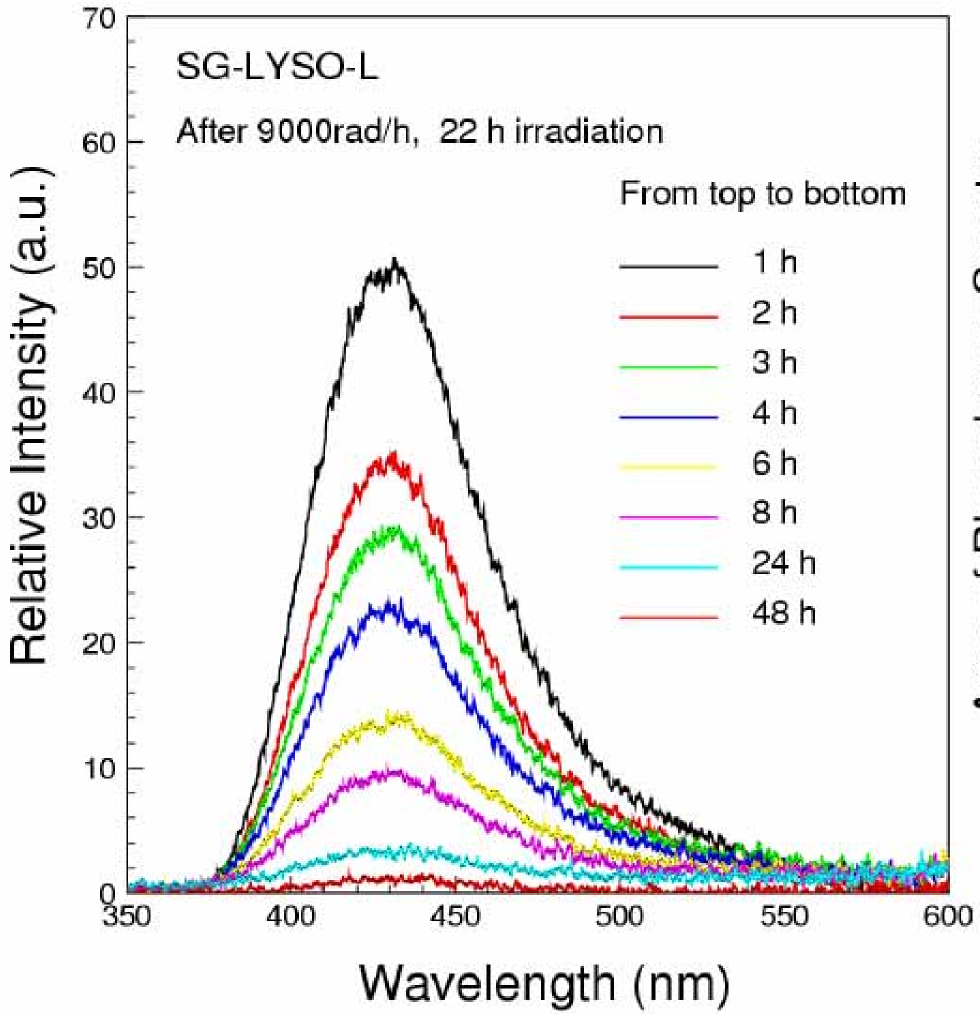
Phosphorescence peaked at 430 nm with decay time constant of 2.5 h observed

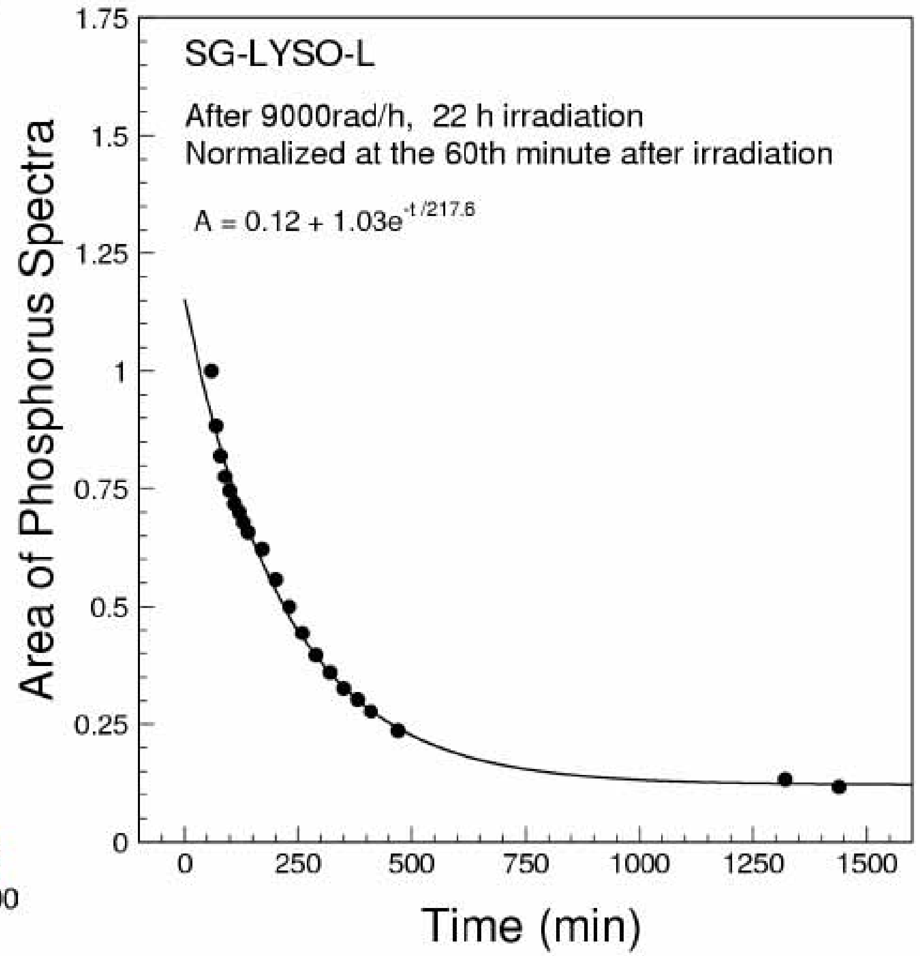




Radiation Induced Phosphorescence

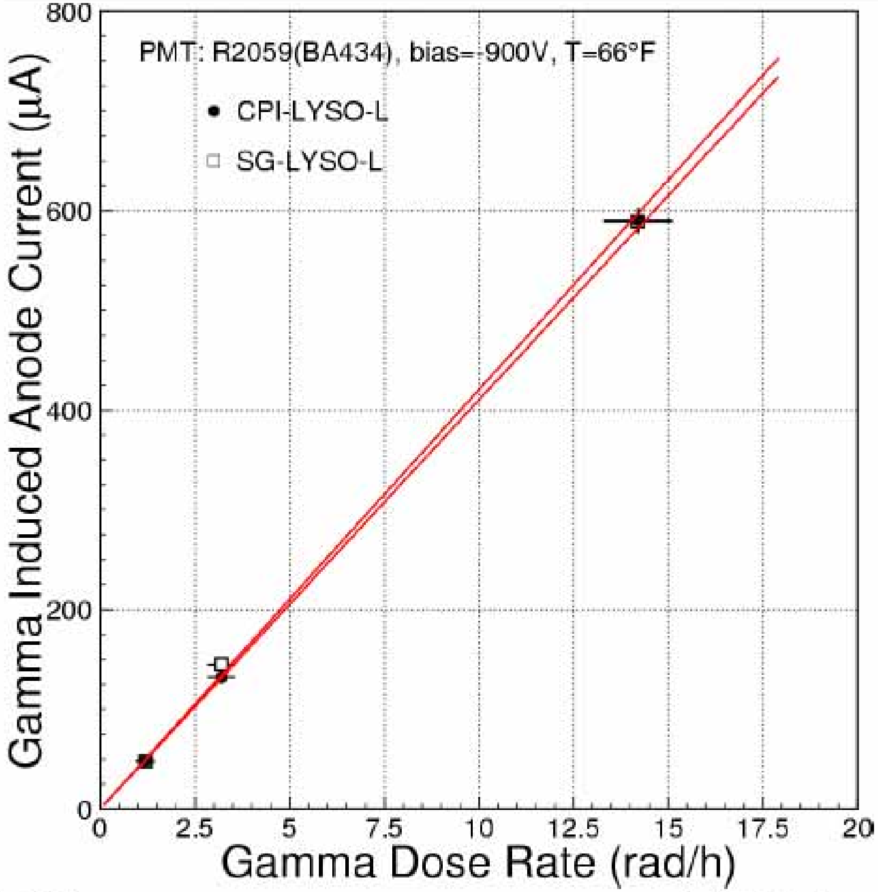
Phosphorescence peaked at 430 nm was observed





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).

LSO/LYSO ECAL Performance

- Energy resolution, $\sigma(E)/E$, 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

Summary

- Ce doped LSO & LYSO crystals potentially useful if we have to upgrade the EMC for SuperB due to new time structure of events
  - LSO, LYSO have essentially identical scintillation properties
    - LYSO is easier to grow
  - Light output is larger than CsI(Tl). Suitable for solid state readout with APD or PD
    - Overlap of emission/absorption spectra affects light output of long samples
  - Decay time of 42 ns is much faster than CsI(Tl)
  - Samples appear to be radiation hard on the SuperB scale
- 2.5 x 2.5 x 20 cm long LSO and LYSO samples have consistent optical properties
  - Light response uniformity may be affected by the distribution of Ce concentration
- Samples of LYSO show phosphorescence under intense irradiation
  - Time constant of 2.5 to 3 hours and would cause <1 MeV noise @ 500 rad/h
    - Impurity related: early CsI(Tl) samples had a similar problem
- Full size crystals are readily obtainable
  - Mass production capabilities exist
  - Cost is still high, but there may be adequate flexibility with large orders