Development of LYSO Crystals for CMS at SLHC

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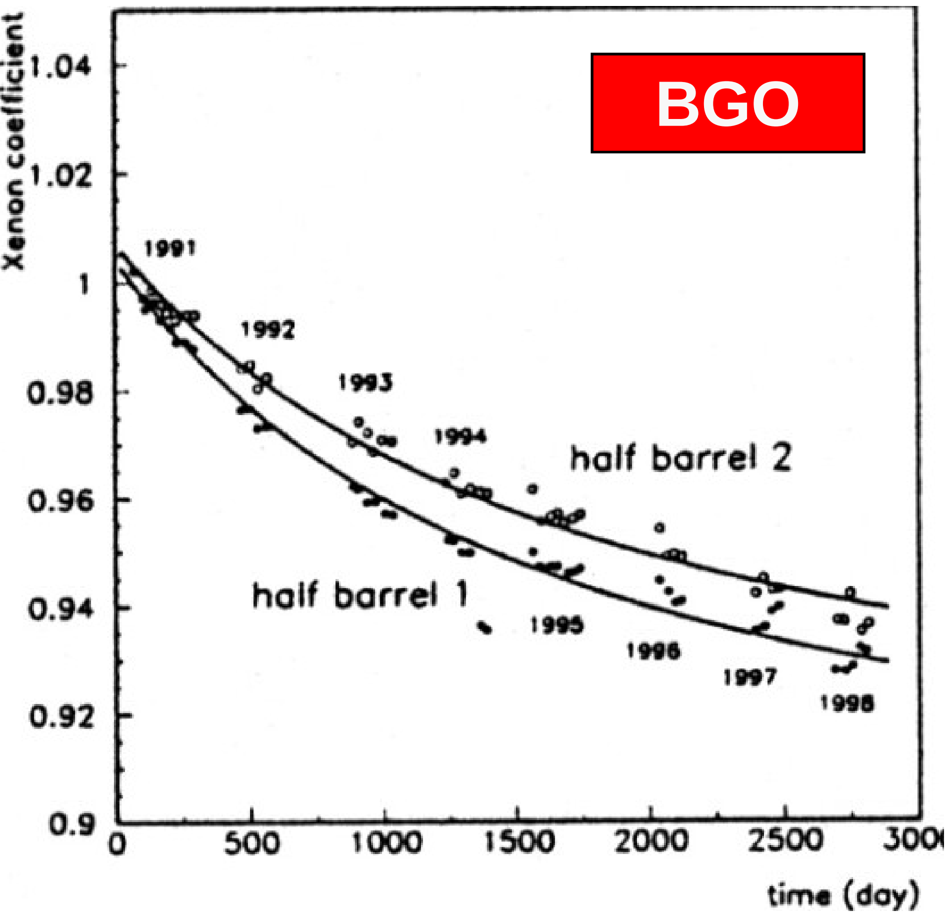
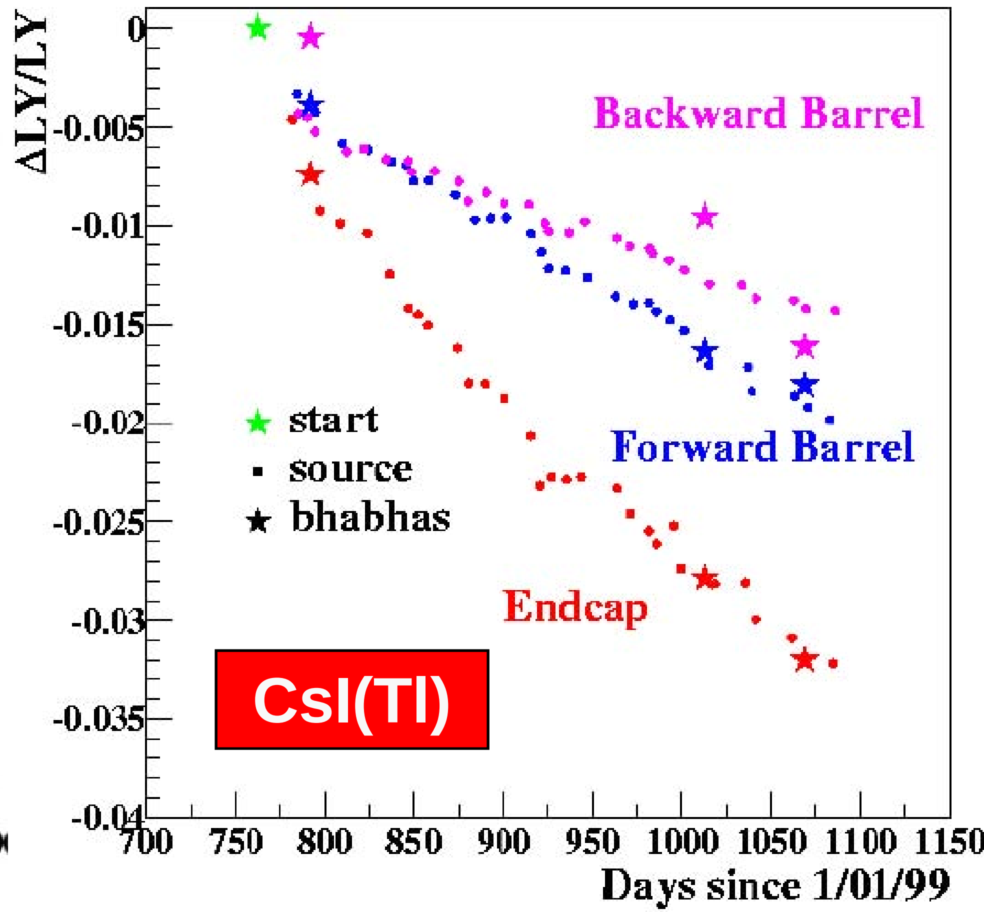
Crystal Degradation *in situ*

L3 BGO: 6 – 7% in 7 years

***BaBar* CsI(Tl): 1 - 3 % per year**

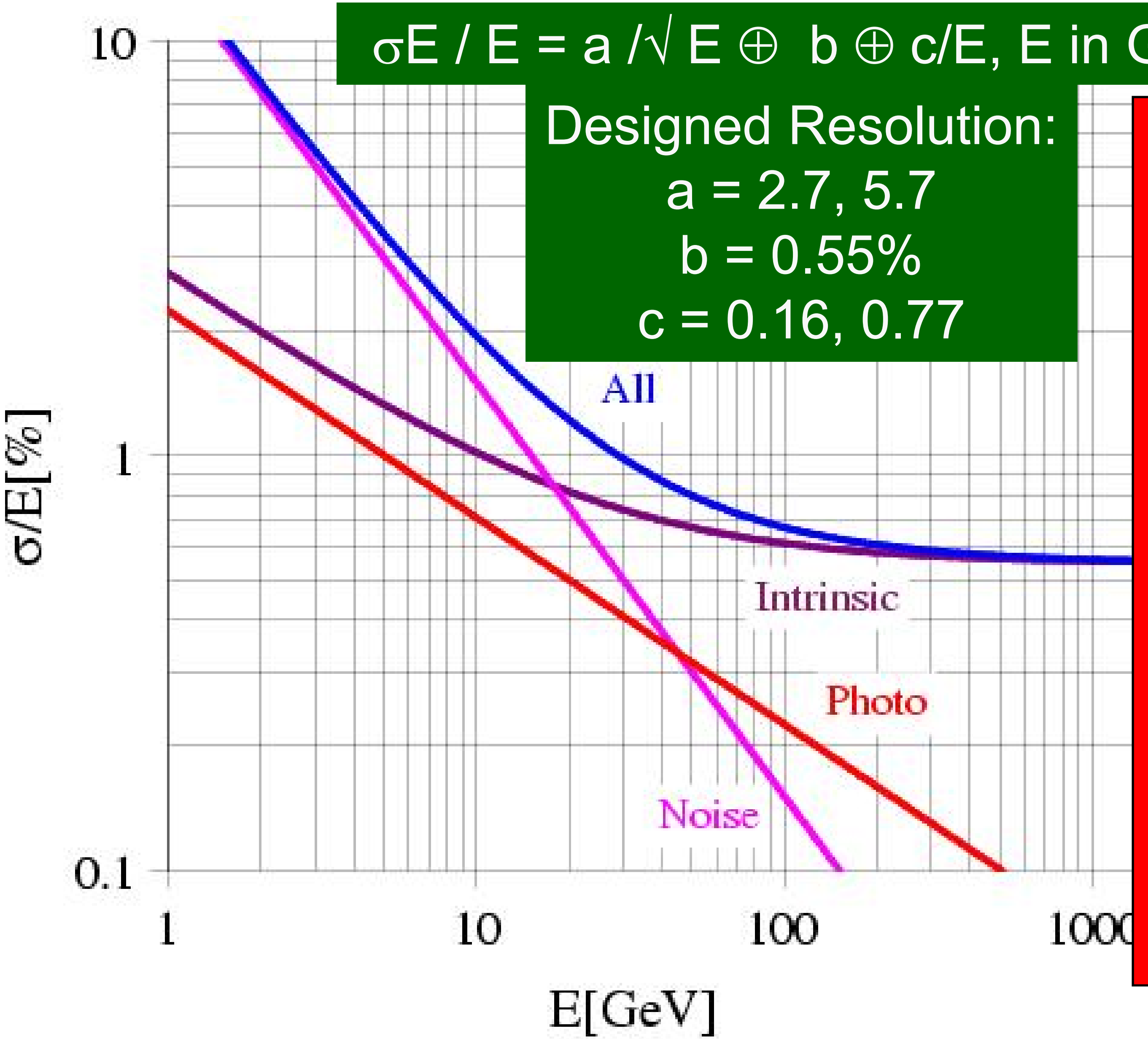




Effect of PWO Damage to E. R.

$\sigma E / E = a / \sqrt{E} \oplus b \oplus c/E$, E in GeV

Designed Resolution:
a = 2.7, 5.7
b = 0.55%
c = 0.16, 0.77

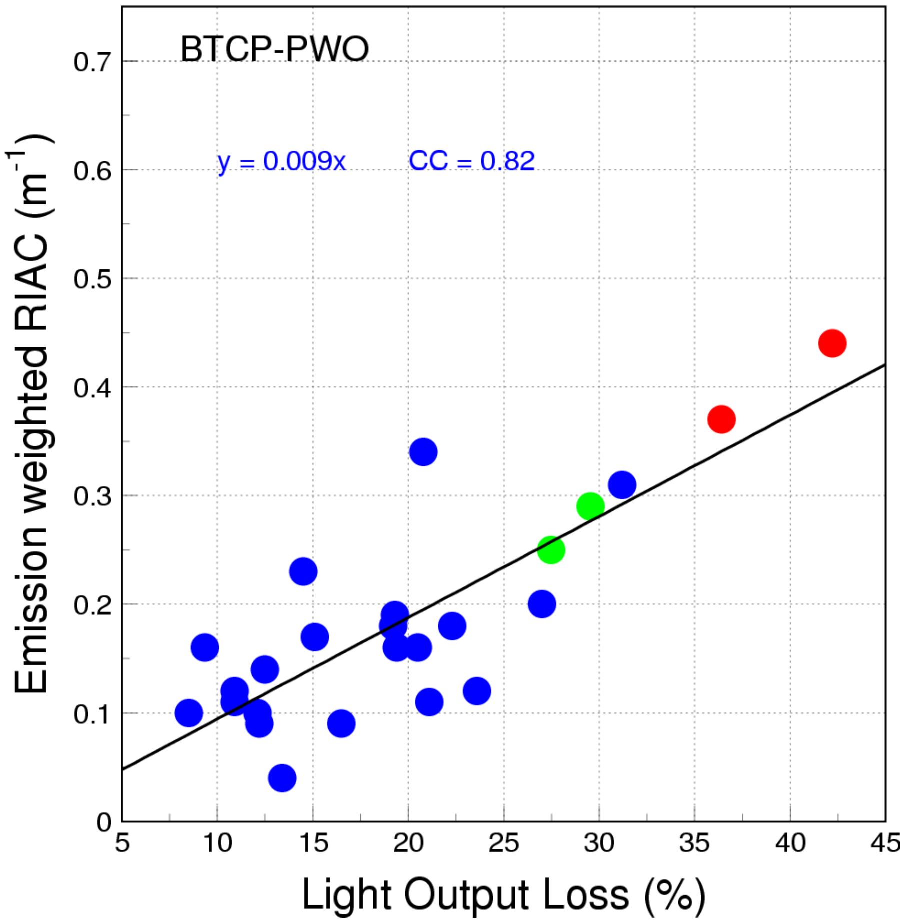


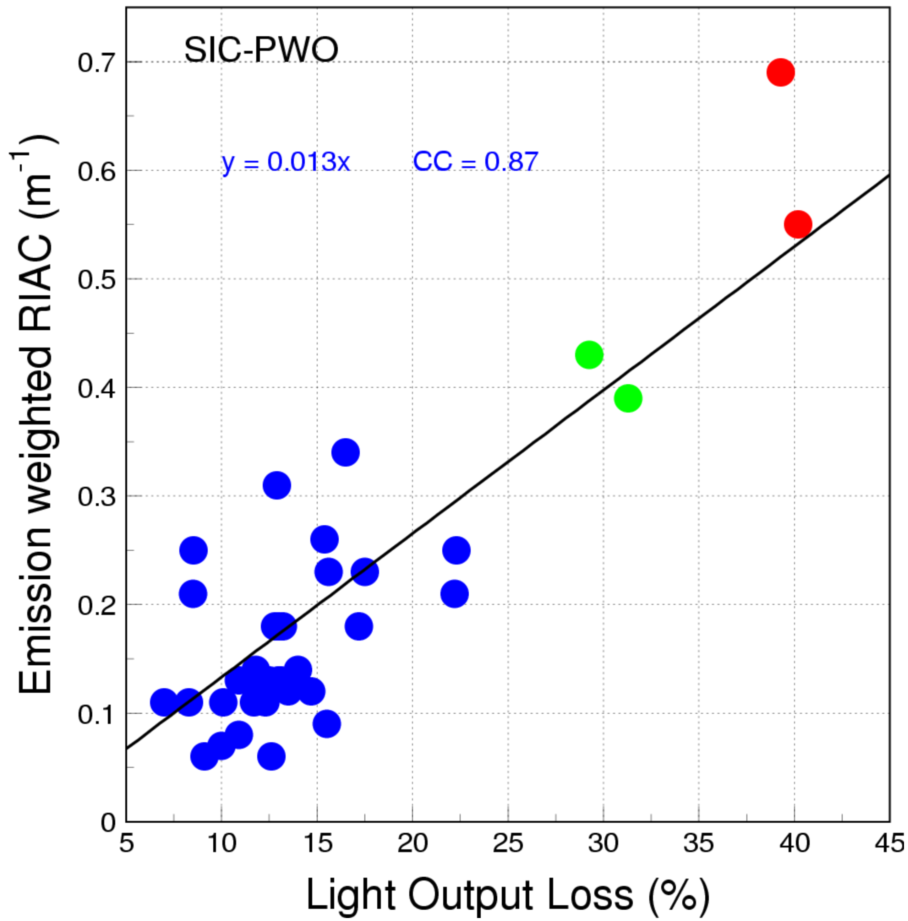
Induced absorption leads to degraded noise term, stochastic term and may be also constant term if light attenuation length is less than 80 cm (induced absorption larger than 1.25 m)

Discuss only γ irradiation
See Francesca talk for hadrons

Correlation: LO Loss versus RIAC

LO Loss = 1.1/0.77 RIAC for BTCP/SIC
for PMT readout with 100% coverage





LAL Affects LO and LRU

Nucl. Instr. And Meth. A413 (1998) 297

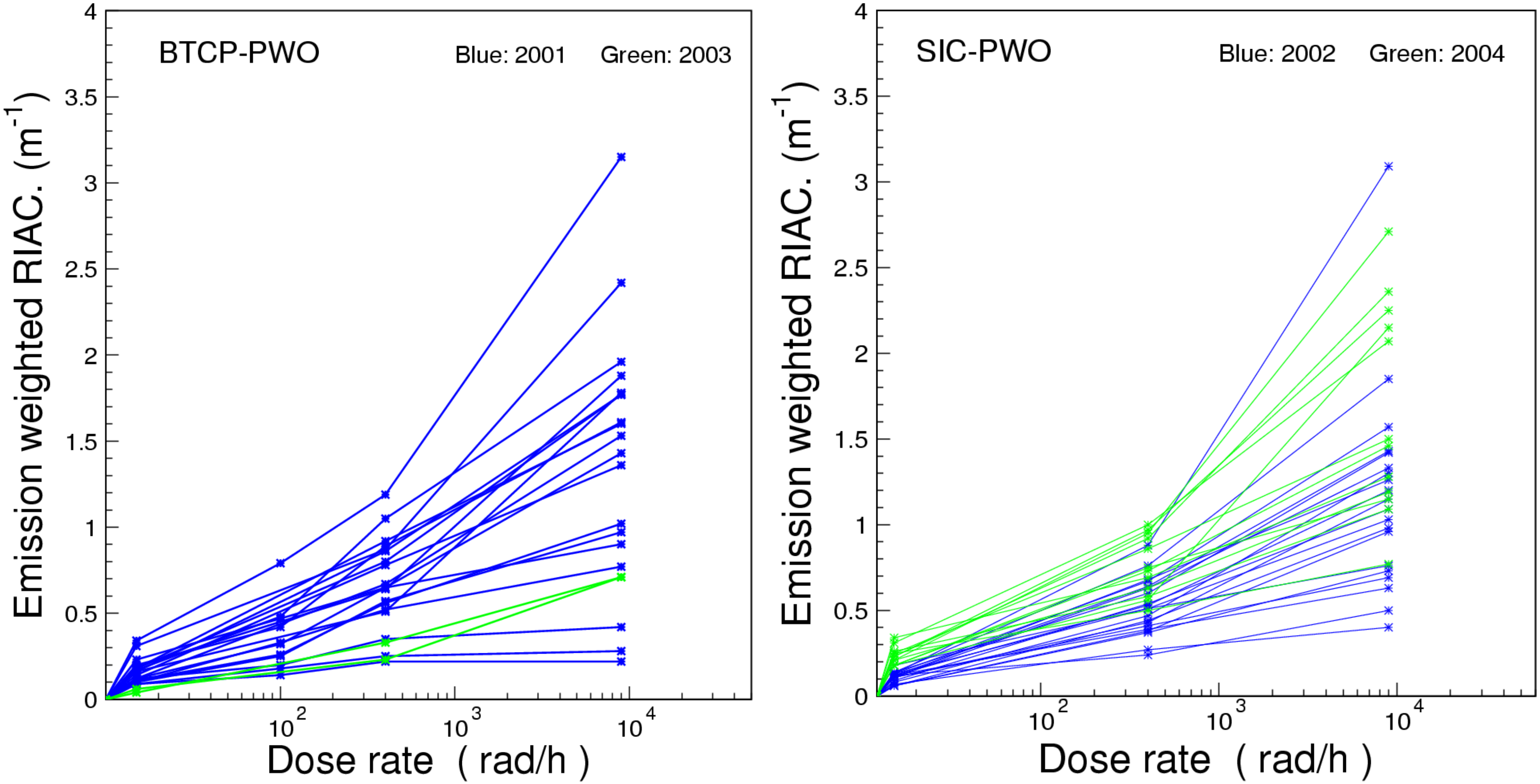
Relation between light collection efficiency (η_m) and light attenuation length (1/RIAC) depends on light path in crystal
LRU would not degrade much if LAL > 80 cm

Light collection efficiency, fit to a linear function of distance to the small end of the crystal, was determined with two parameters: the light collection efficiency at the middle of the crystal and the uniformity.

LAL (cm)	20	40	60	80	200
Large Area Photo Detector, covering 100% back face					
η_m (%)	9.5±.2	15.7±.4	19.2±.5	21.6±.6	26.9±.7
δ (%)	23±1	-4.6±.8	-11±1	-15±1	-15±1
ϕ5 mm Photo Detector, covering 3.7% back face					
η_m (%)	.38±.04	.74±.08	1.1±.1	1.4±.2	3.0±.3
δ (%)	23±4	−3.5±4	-12±4	-16±4	-17±3
$\frac{\eta_m(\phi 5mm)}{\eta_m(Full)}$ (%)	4.0	4.7	5.7	6.5	11

RIAC of Mass Produced Crystals

0.15 (45%) / 0.10 (20%), 0.69 (45%) / 0.51 (32%) and 1.43 (50%) / 1.16 (48%) at 15, 400 and 9,000 rad/h for BTCP/SIC respectively



LSO/LYSO Mass Production

CTI: LSO

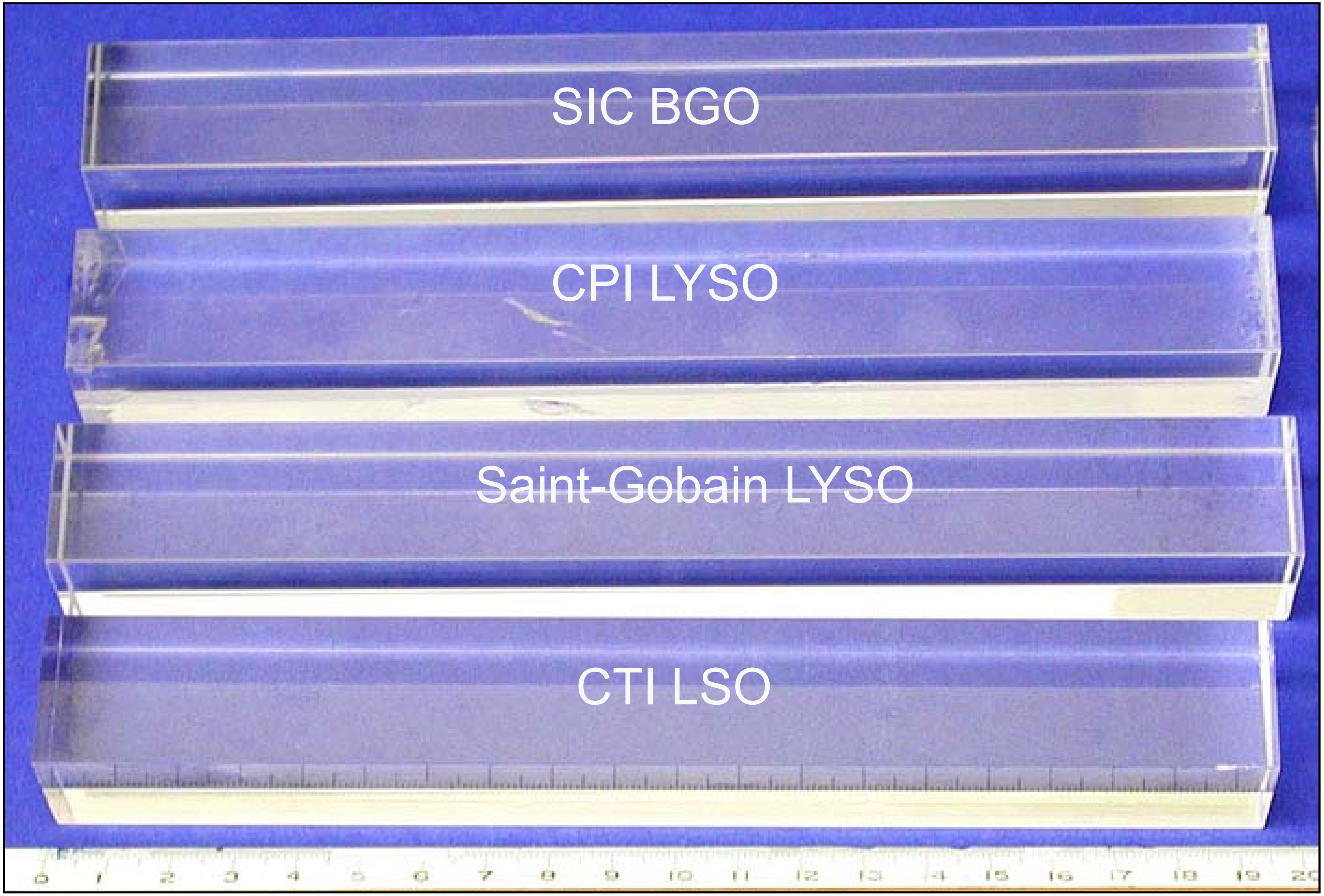
CPI: LYSO

Saint-Gobain LYSO

Additional Capability: SIPAT @ Sichuan, China

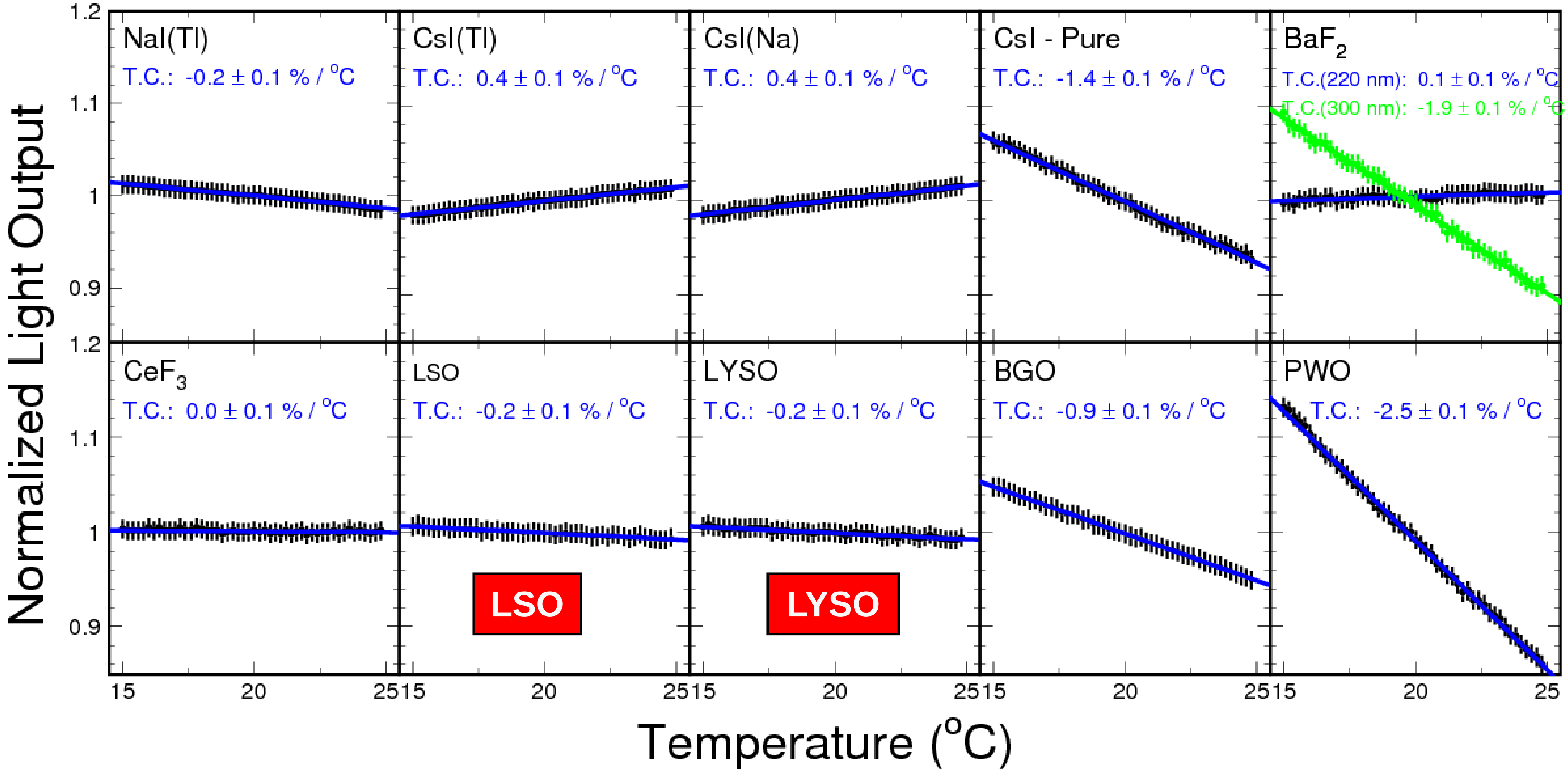
BGO, LSO & LYSO Samples

2.5 x 2.5 x 20 cm (18 X_0)



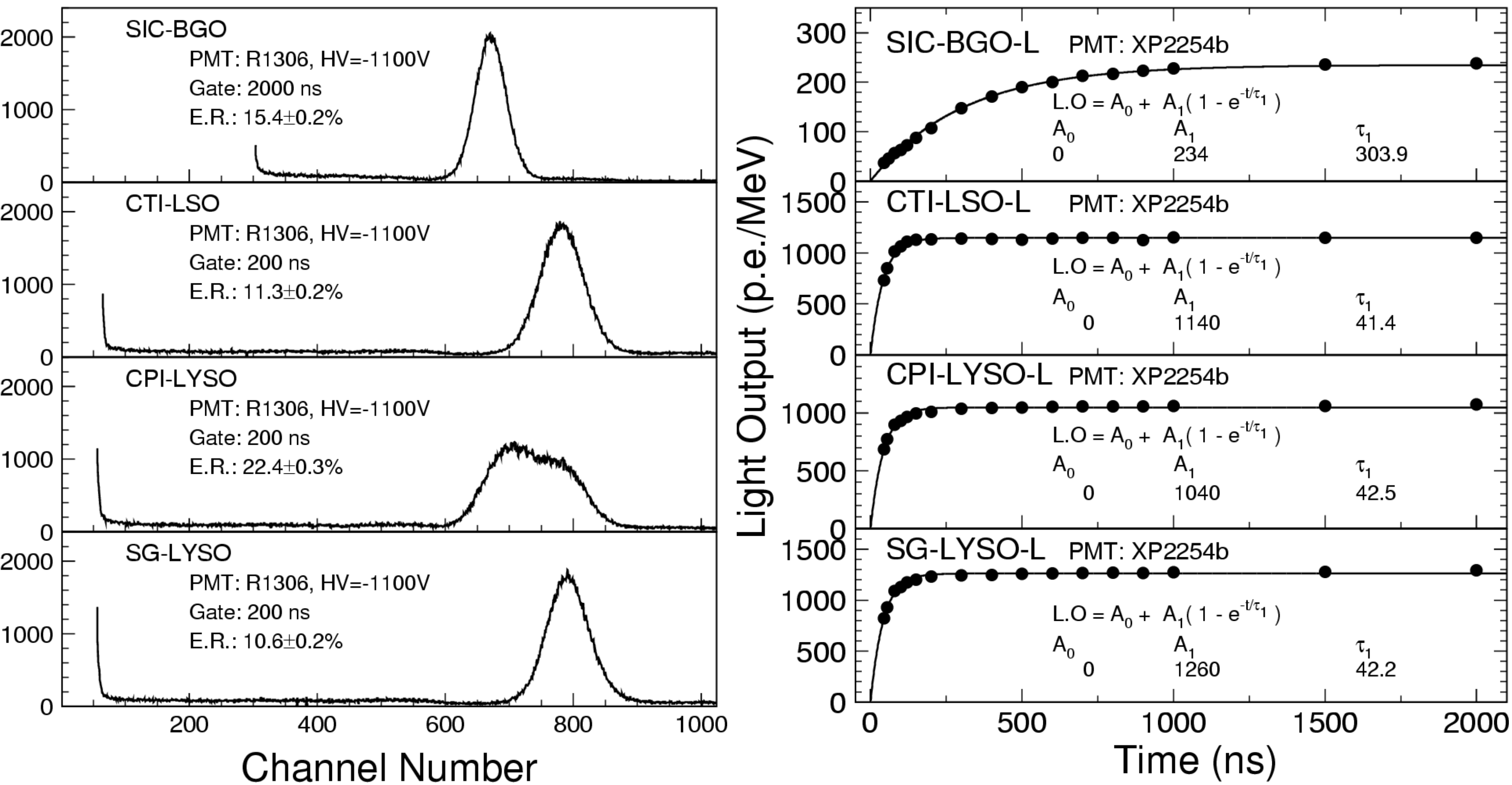
Light Output Temperature Coefficient

Temperature Range: 15ºC ~ 25ºC



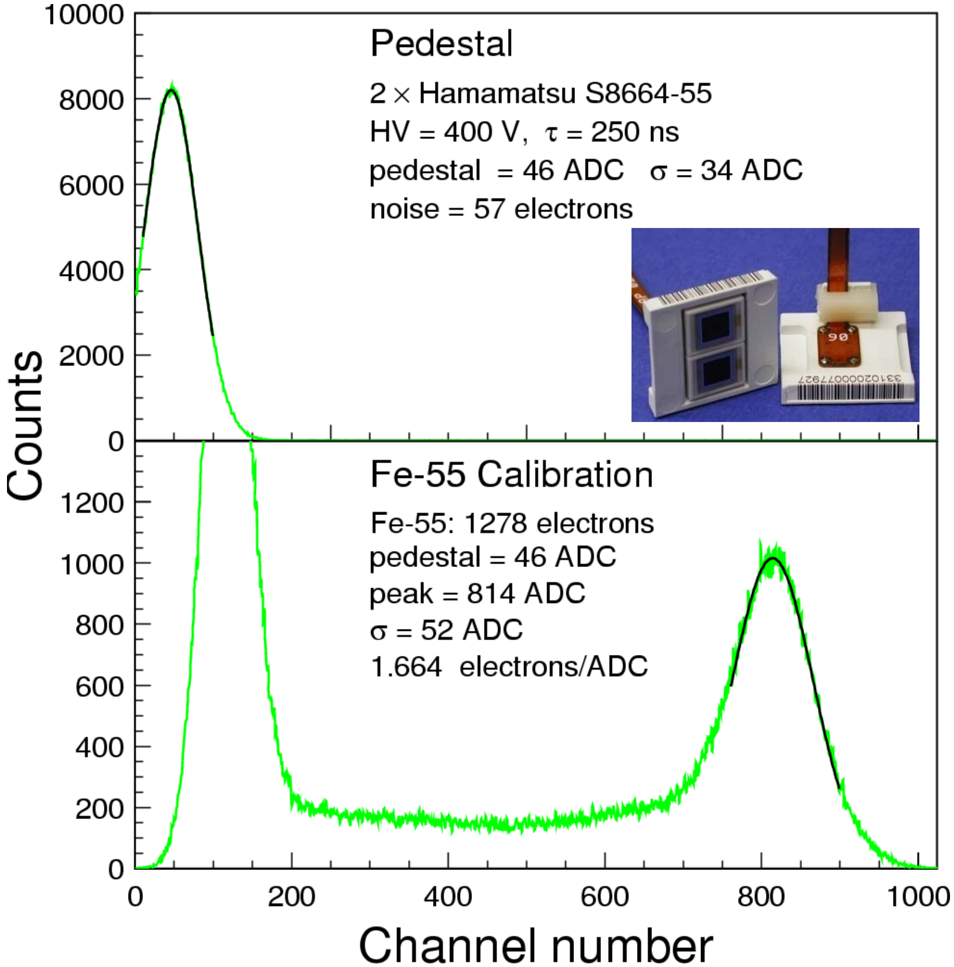
LSO/LYSO with PMT Readout

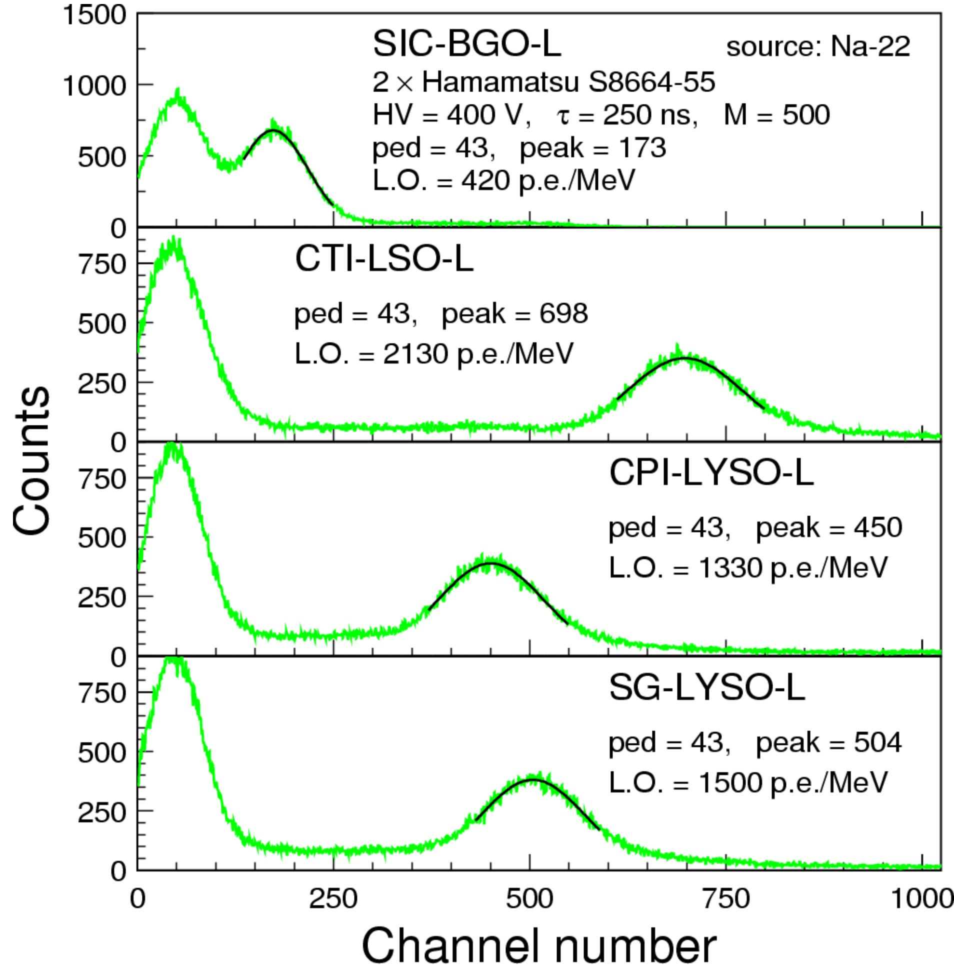
~10% FWHM resolution for ^{22}Na source (0.51 MeV)
1,200 p.e./MeV, 5/230 times of BGO/PWO



LSO/LYSO with APD Readout

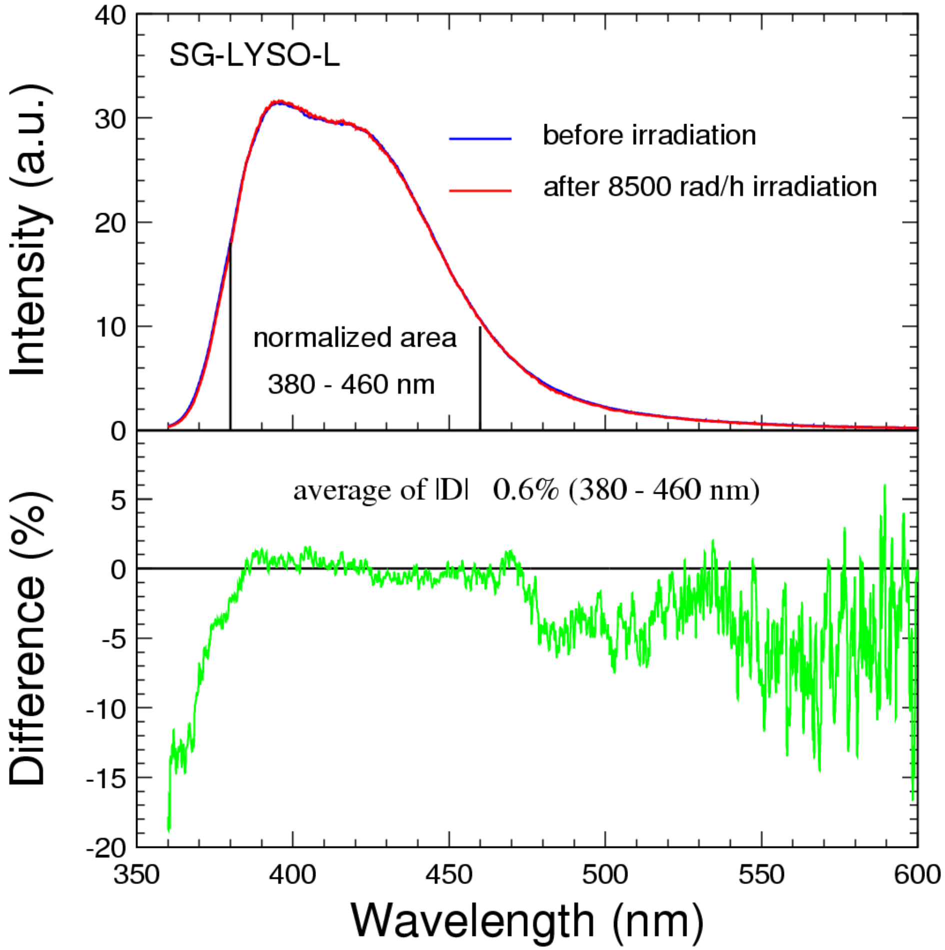
L.O.: 1,500 p.e./MeV, 4/200 times of BGO/PWO
Readout Noise: < 40 keV



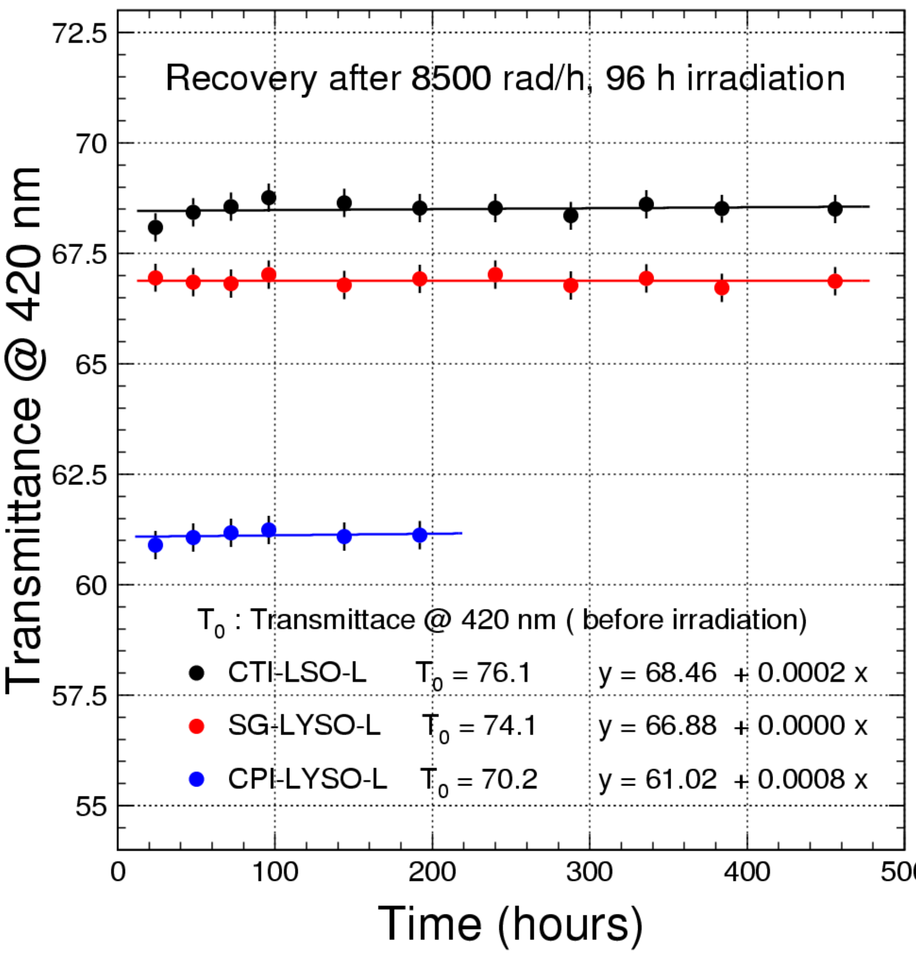


γ-Rays Induced Damage

No damage in Photo-Luminescence



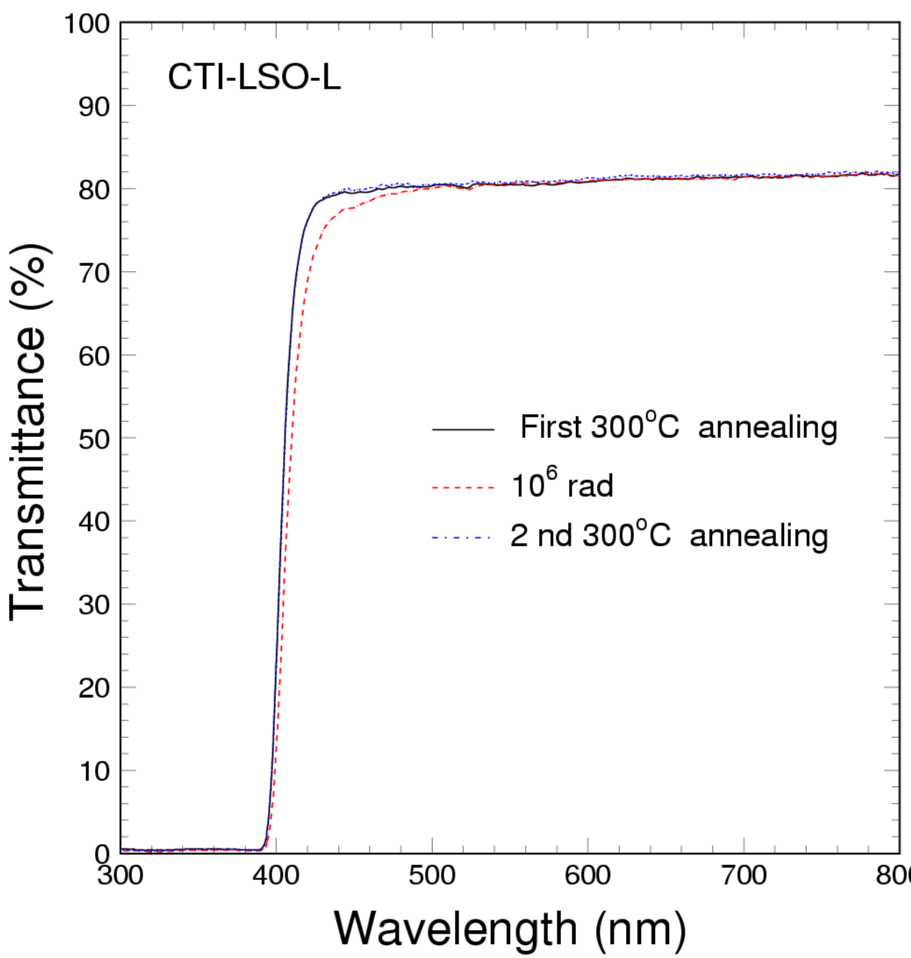
Transmittance recovery slow

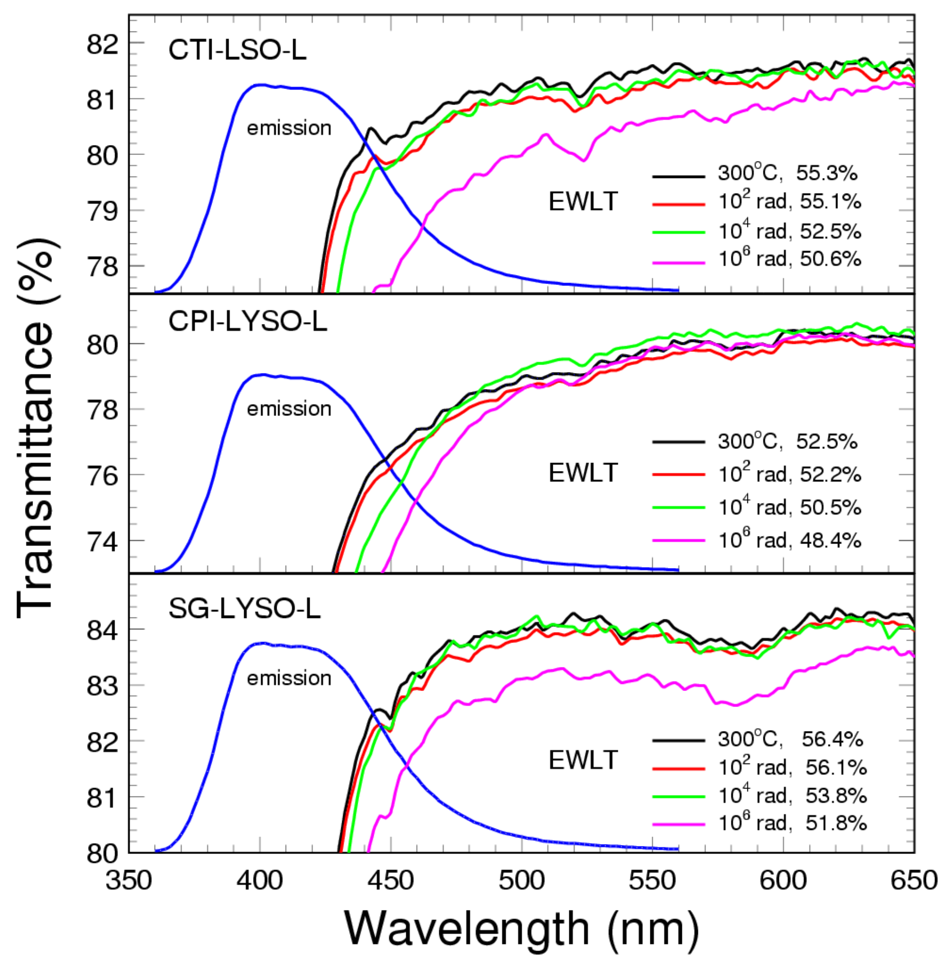


γ-Rays Induced Transmittance Damage

300°C thermal annealing effective

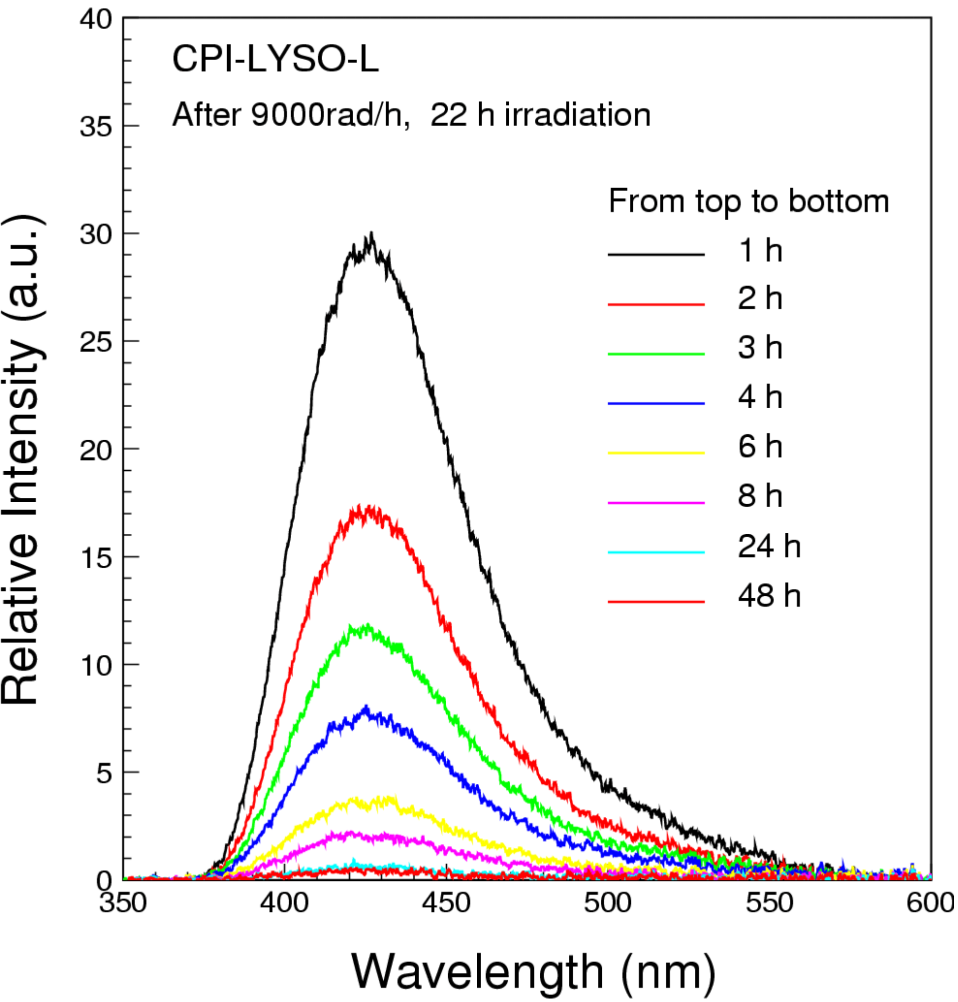
LT damage: 8% @ 1 Mrad

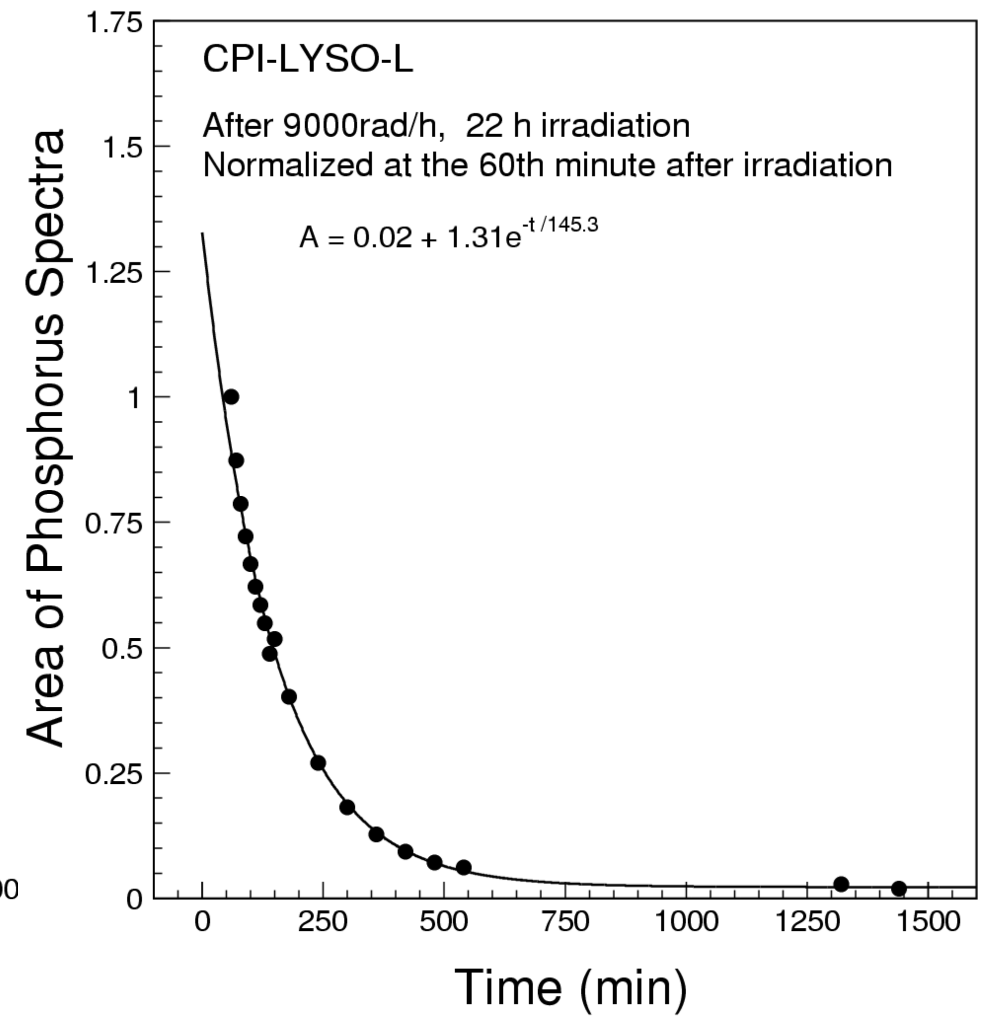




γ–ray Induced Phosphorescence

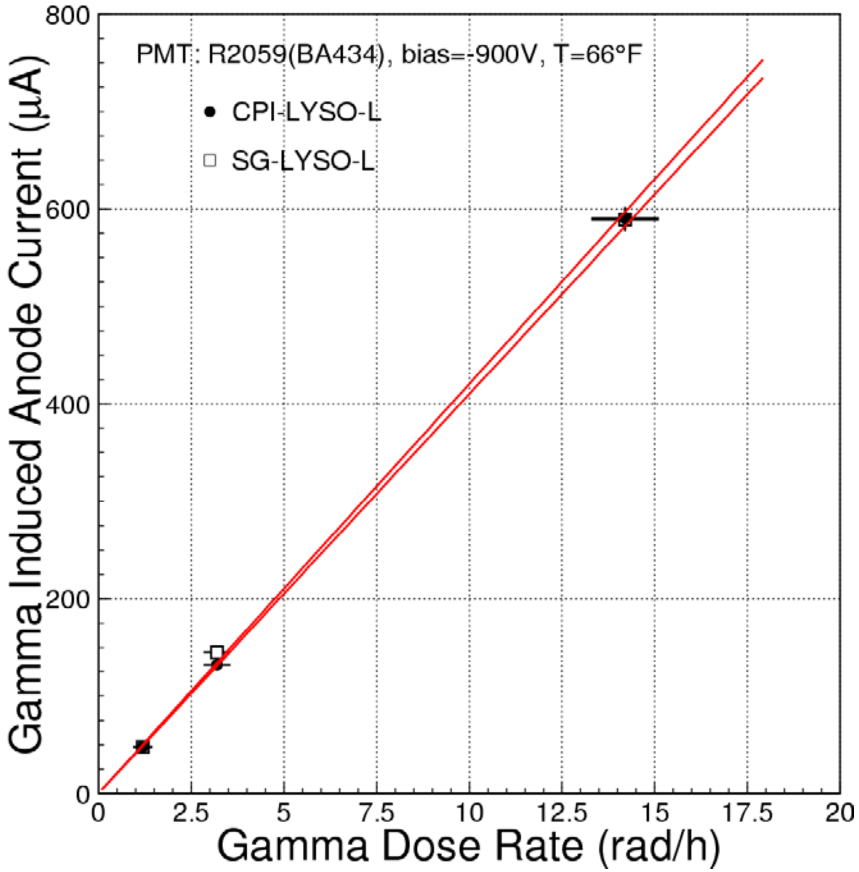
Phosphorescence peaked at 430 nm
with decay time constant of 2.5 h observed





γ–ray Induced Readout Noise

Sample ID	L.Y. p.e./MeV	F μA/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): 0.2 & 1 MeV @ 15 & 500 rad/h.

Six LSO & LYSO Samples

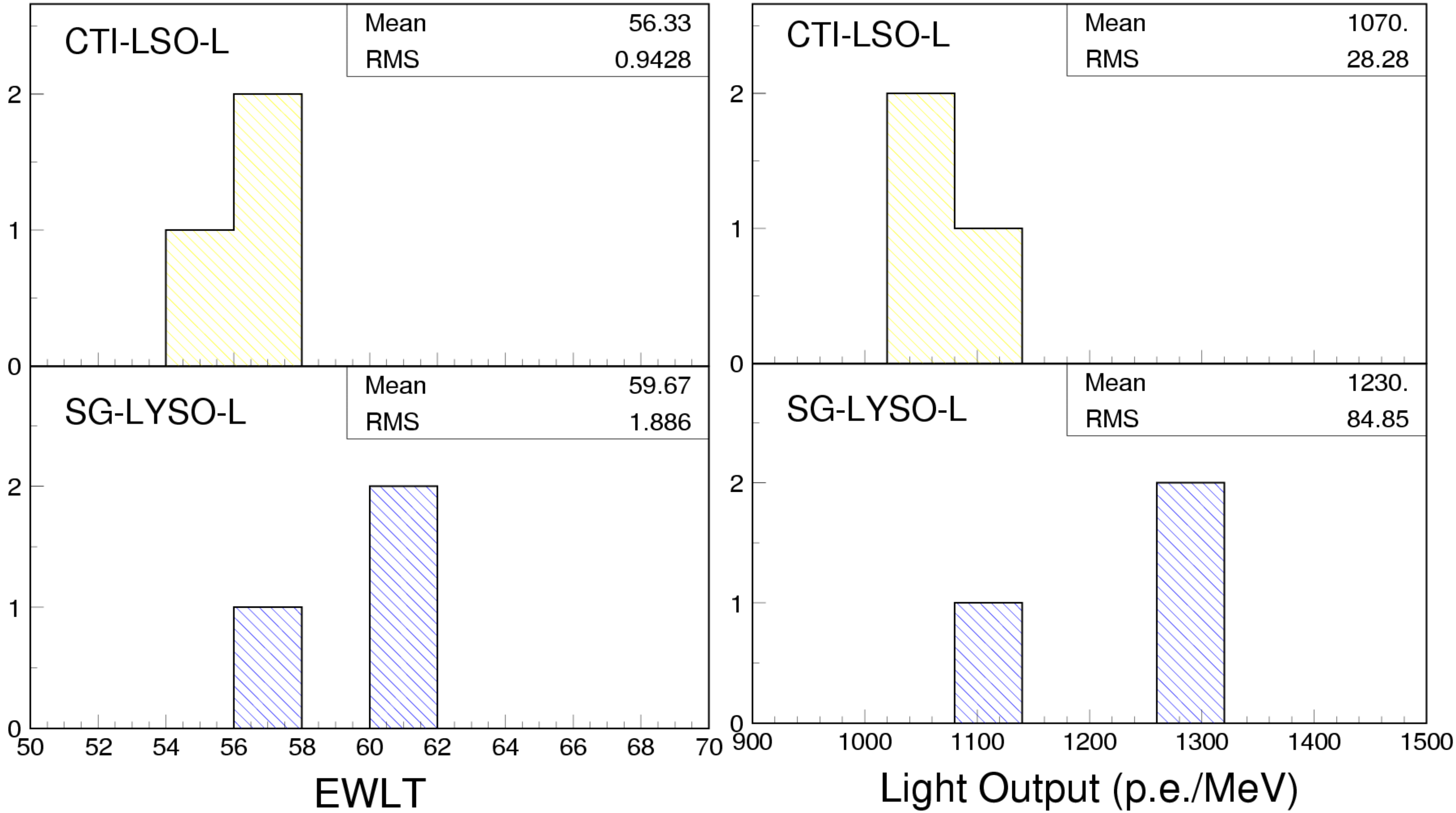
2.5 x 2.5 x 20 cm (18 X_0) Bar

Three CTI LSO samples are provided by Chuck Melcher.

Three LYSO samples are purchased from Saint-Gobain.

Statistical Comparison

Recent LYSO crystals are better than LSO



Sichuan Institute of Piezoelectric and Acousto-optic Technology (SIPAT)

China Electronics Technology Corporation (CETC) No. 26 Research Institute, www.sipat.com

SIPAT: Furnace & R&D Issues

- **Raw material:**

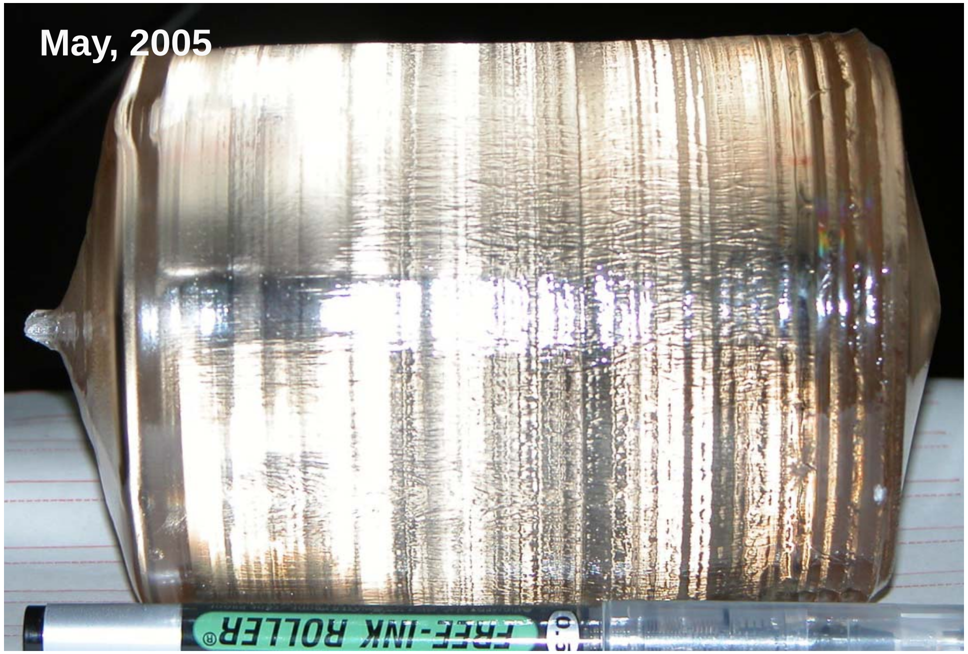
  Lu_2O_3: 99.995%

  SO_2: 99.999%

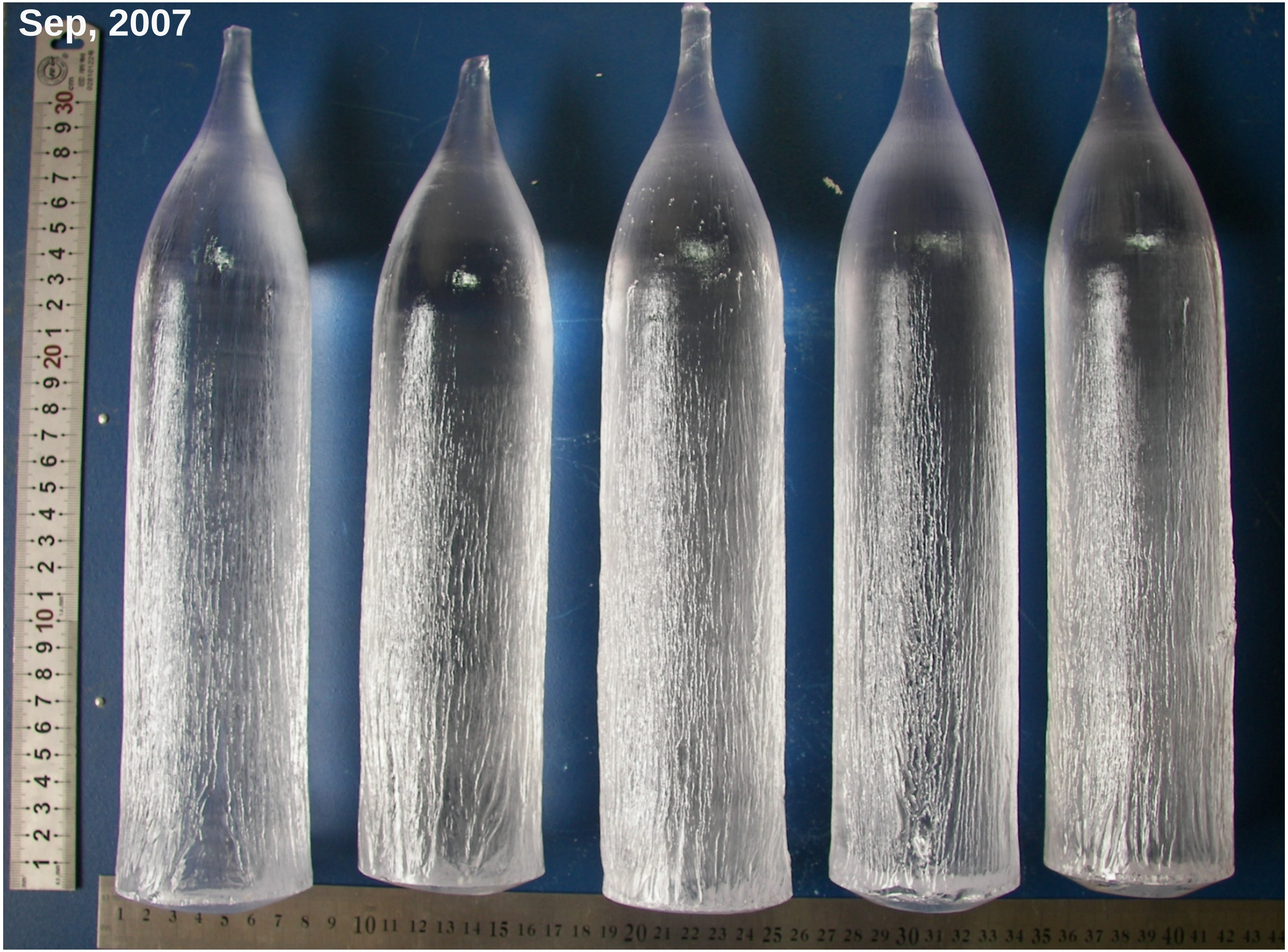
- **Stoichiometry**
- **Temperature Gradient**
- **Growth Parameter Optimization**
- **Thermal Annealing**
- **Iridium Crucible Maintenance**
- **Power Supply Stability**
- **Chilled Water Stability**

LYSO Growth Progress at SIPAT

Started 2001 with Significant Progress in the last year

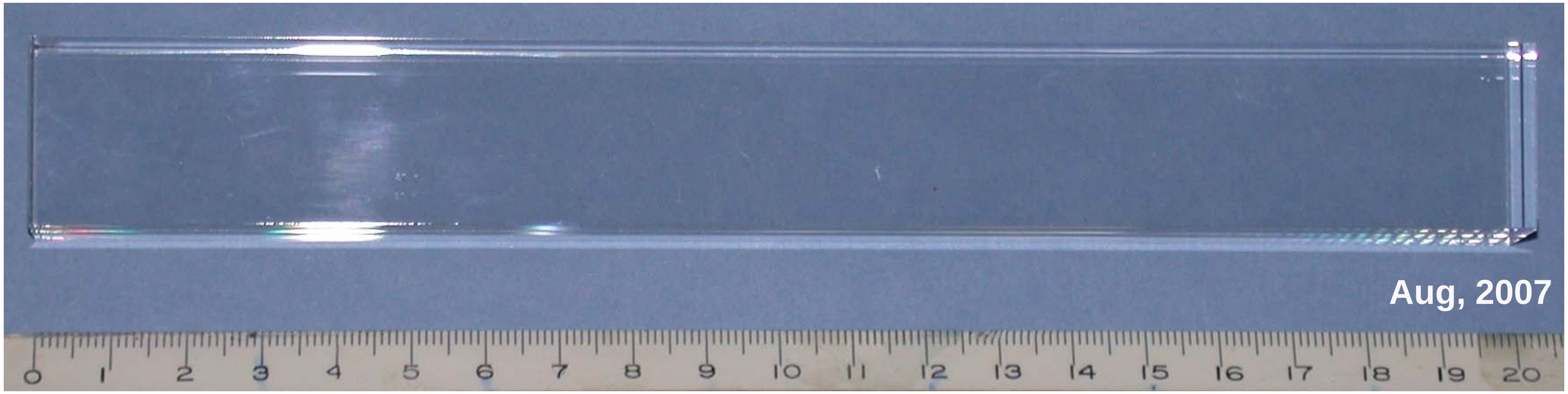


SIPAT Ø 60 x 250 mm LYSO Ingots



SIPAT Czochralski Furnaces

First SIPAT LYSO Sample for HEP

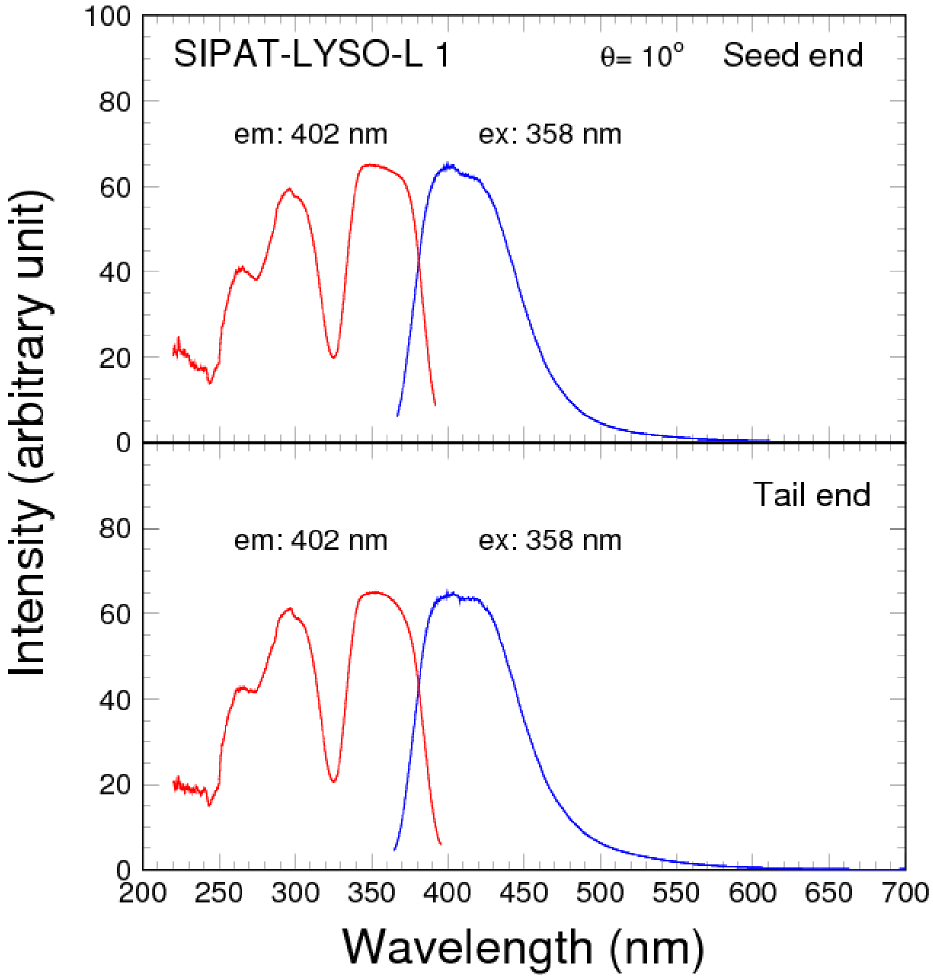


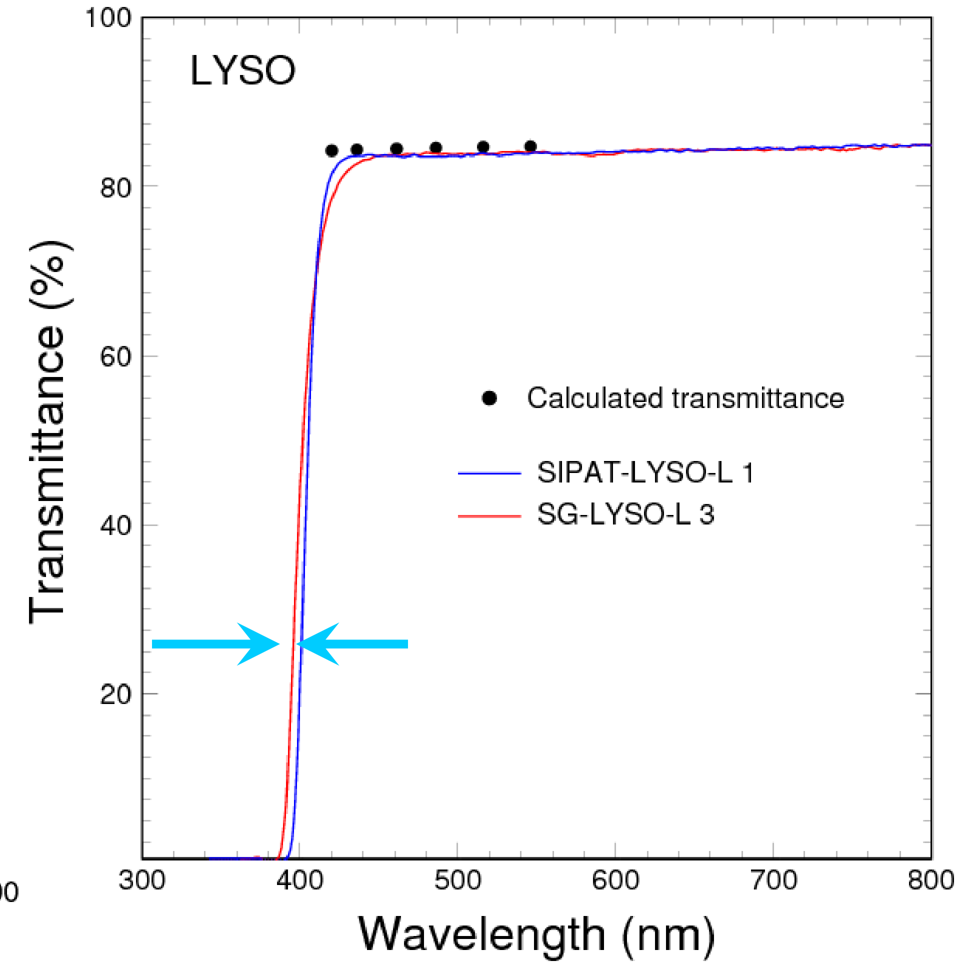
- Received in the middle of August with dimension of 25 x 25 x 200 mm and good visual inspection.
- It was first annealed at 300ºC for 10 hours and with its initial optical and scintillation properties measured.
- Together with SG-L3, two samples were irradiated with integrated doses of 10, 10^2, 10^3, 10^4 10^5 and 10^6.
- Samples were kept in dark after irradiation for 48 hours before optical and scintillation property measurement.
- Damage to transmittance, light output and uniformity are compared with samples from CTI, CPI and Saint-Gobain.

Initial Optical Properties

Excitation: emission @ 402 nm Emission: excitation @ 358 nm

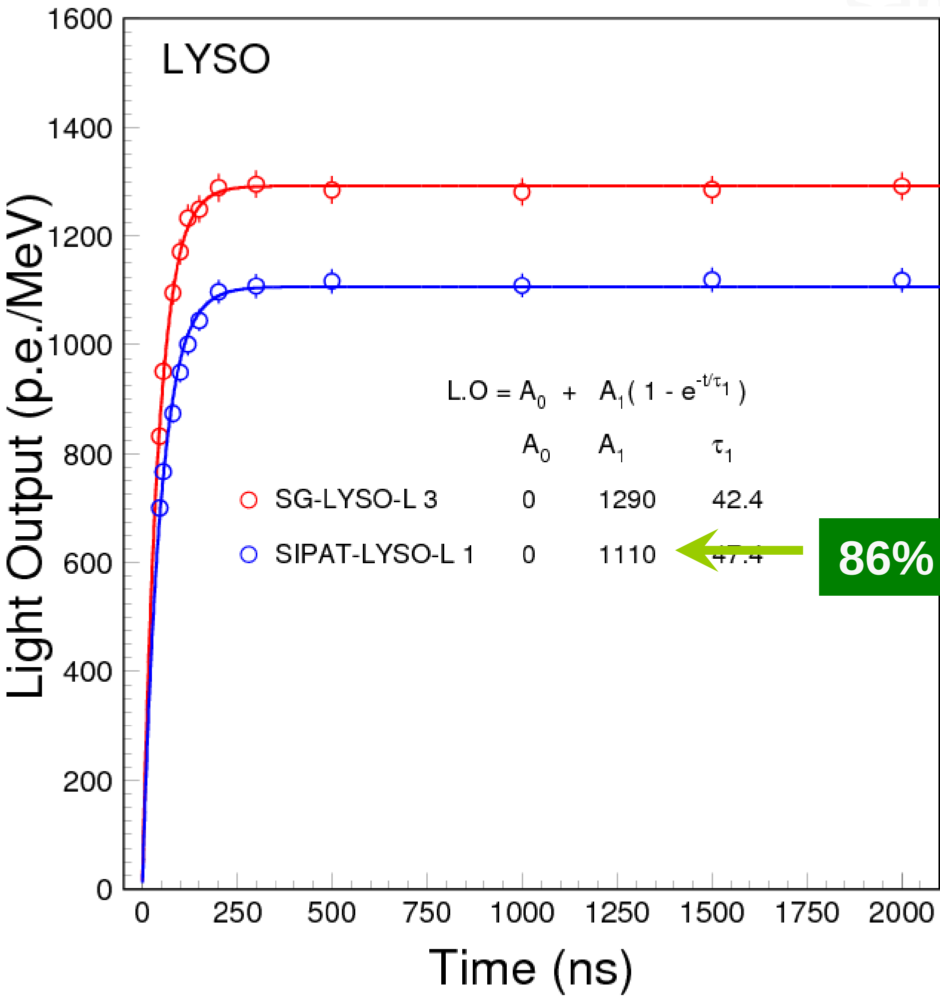
The cutoff of SG-L3 has ~5 nm blue shift compared to SIAPT-L1



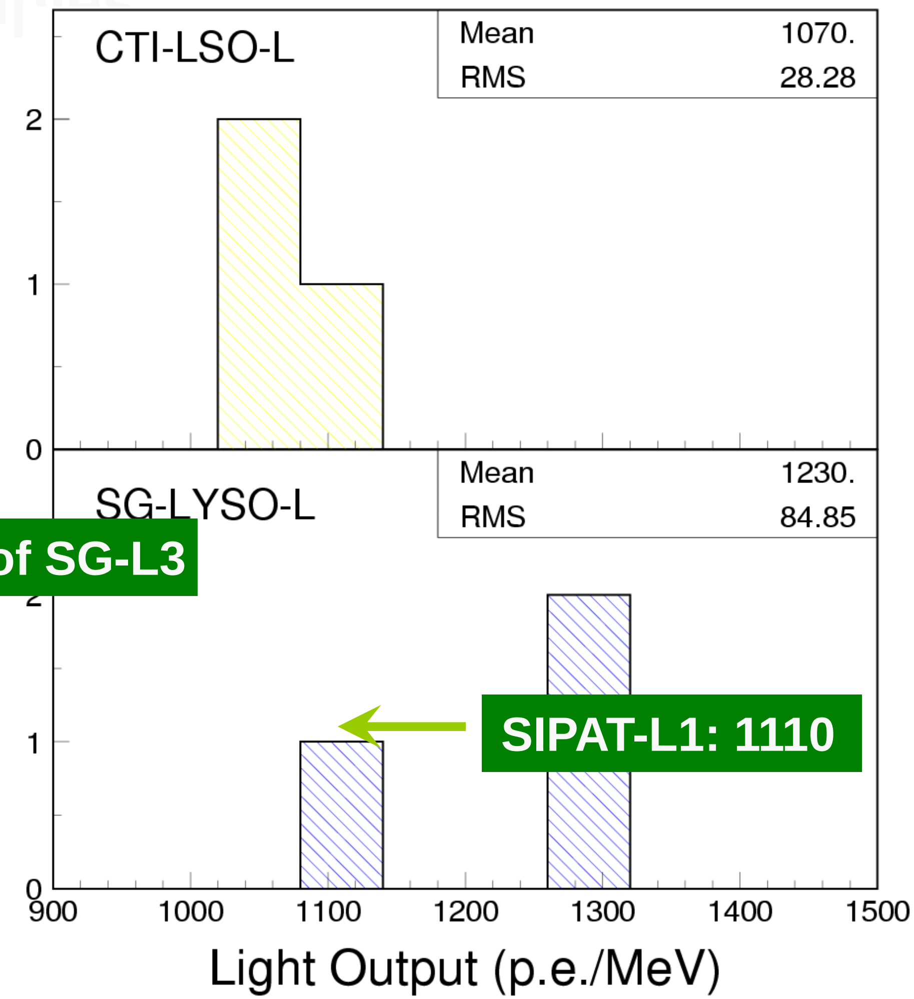


Light Output & Decay Kinetics

Compatible with the first batch large size samples from CTI and Saint-Gobain, and is 86% of the 'best' samples



86% of SG-L3

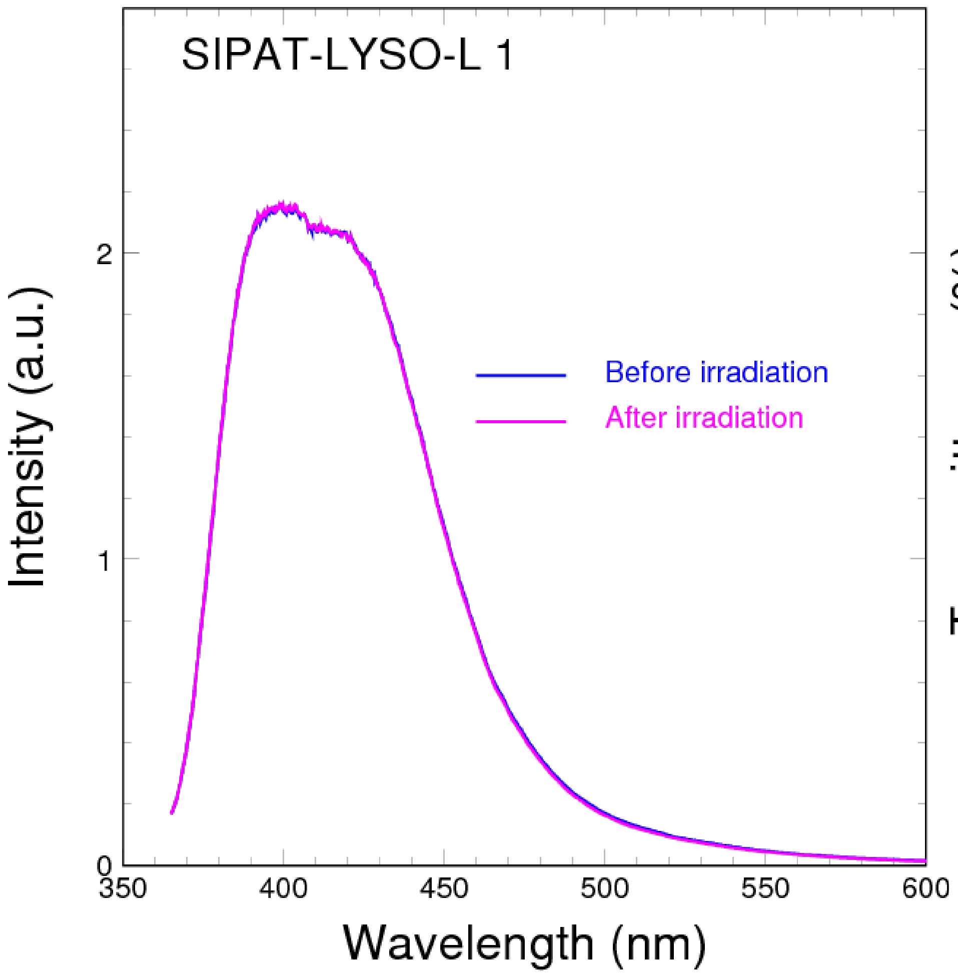


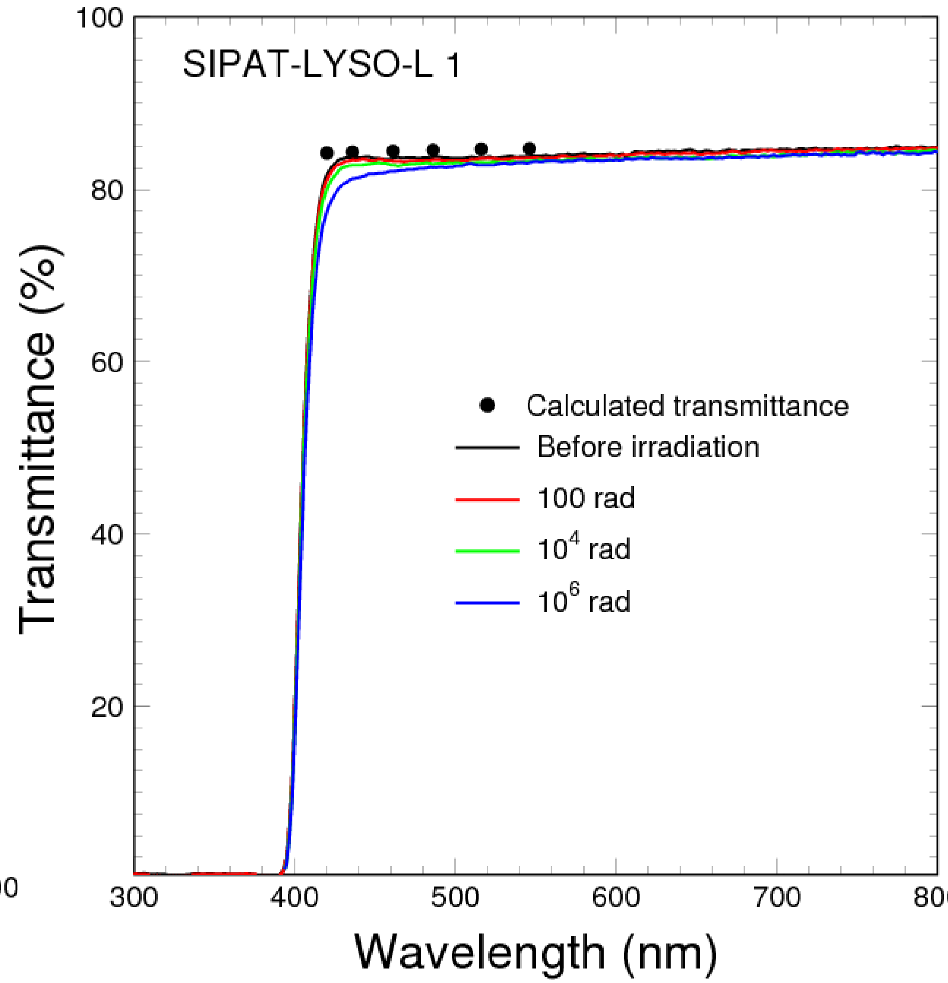
SIPAT-L1: 1110

γ-Ray Induced Radiation Damage

Scintillation spectrum not affected by irradiation

~8% damage @ 420 nm after 1 Mrad irradiation



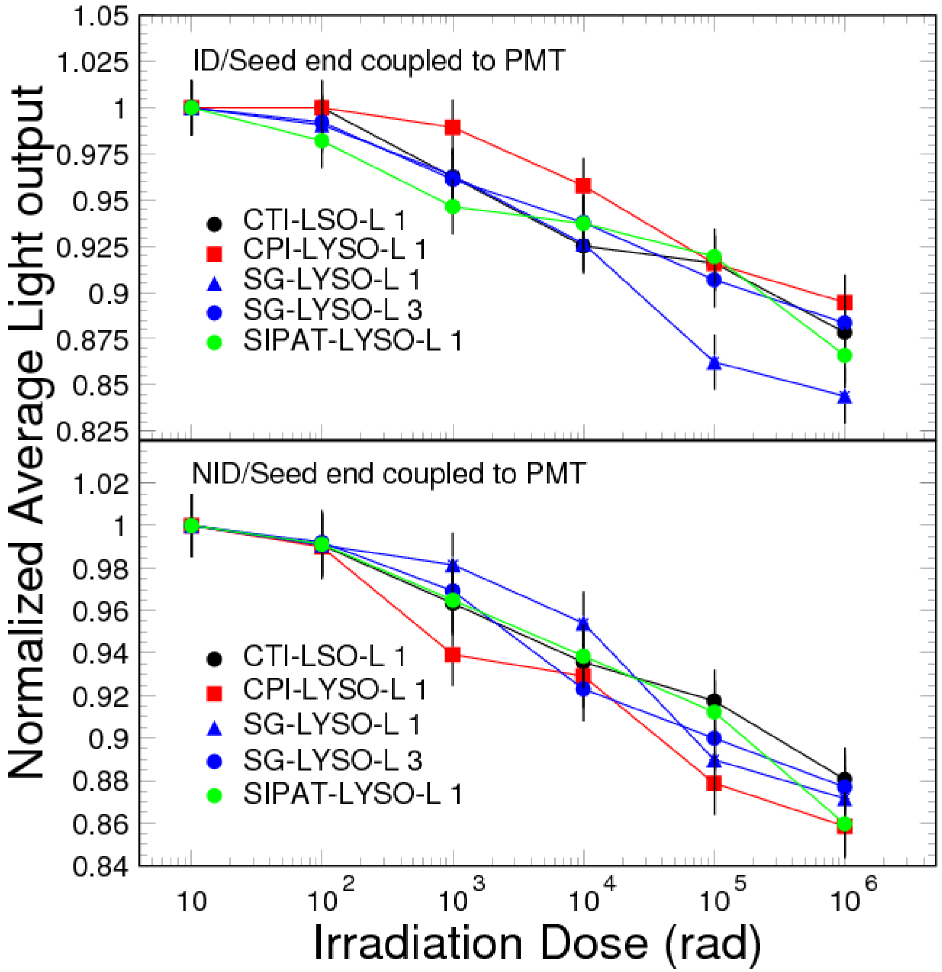


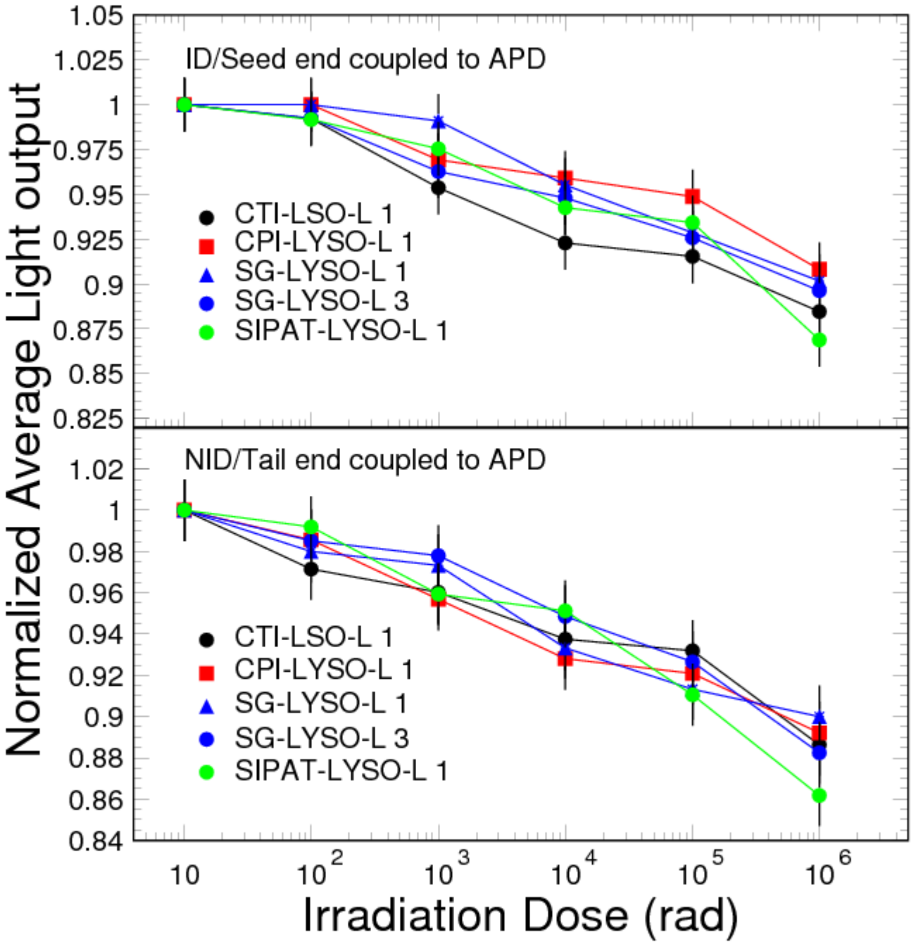
Comparison of L.O. Damage

All samples show consistent radiation resistance

10% - 15% loss by PMT

9% - 14% loss by APD





LSO/LYSO ECAL Performance

- Less demanding to the environment because of small temperature coefficient.
- Radiation damage is less an issue as compared to other crystals.
- A better energy resolution, $\sigma(E)/E$, at low energies than L3 BGO and CMS PWO because of its high light output and low readout noise:

$$2.0\% / \sqrt{E} \oplus 0.5\% \oplus .001/E$$

Summary

- Lead tungstate crystals suffer from radiation damge originated from photons/electrons and hadrons. While the real consequence will only be known after the ECAL is *in situ* at LHC, existing data indicate that significant light output loss and thus energy resolution degradation is expected.
- LYSO crystals with blight, fast scintillation and excellent radiation hardness against γ irradiation seems an excellent candidate for the ECAL endcap upgrade at SLHC.
- While LYSO crystal quality is adequate for SuperB, work is needed to develop LYSO crystals of CMS size and to understand the consequence of damage caused by neutrons and hadrons.