# Status of LSO/LYSO Crystals for HEP Experiments


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# Introduction

LSO/LYSO is a bright (200 times of PWO) and fast (40 ns) crystal scintillator. It has been widely used in medical industry for the PET application with mass production capability exits in the world.

The Caltech group has been investigating this material for HEP applications since 2005. It was found that its radiation hardness is excellent against $\gamma$–ray and neutrons. Work by the ETH group also found that it is radiation hard against protons. It thus is an excellent material for HEP & NP experiments in a severe radiation environment, e.g. SLHC.

**References**: *IEEE Trans. Nucl. Sci.* NS-52 (2005) 3133-3140, *Nucl. Instrum. Meth.* A572 (2007) 218-224, *IEEE Trans. Nucl. Sci.* NS-54 (2007) 718-724, *IEEE Trans. Nucl. Sci.* NS-54 (2007) 1319-1326, *IEEE Trans. Nucl. Sci.* NS-55 (2008) 1759-1766 and *IEEE Trans. Nucl. Sci.* NS-55 (2008) 2425-2341, paper N69-8 @ NSS08, Dresden, paper N32-3, N32-4 and N32-5 @NSS09, Orlando.

# Existing Producers

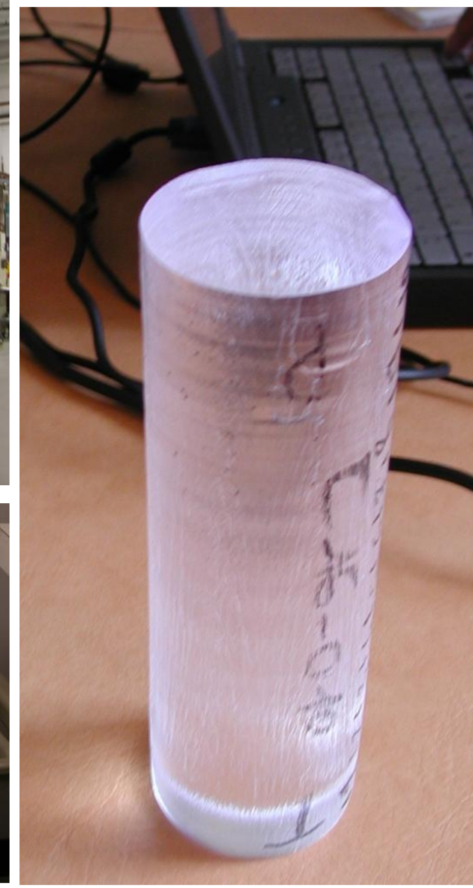
- CTI Molecular Imaging (**CTI**), USA
- Crystal Photonics, Inc. (**CPI**), USA
- Saint-Gobain Ceramics & Plastics, Inc. (**Saint-Gobain**), France
- Shanghai Institute of Ceramics (**SIC**), China
- Sichuan Institute of Piezoelectric and Acousto-optic Technology (**SIPAT**), China
- Crystalux Inc. **(Crystalux),** Taiwan

# LSO/LYSO Mass Production

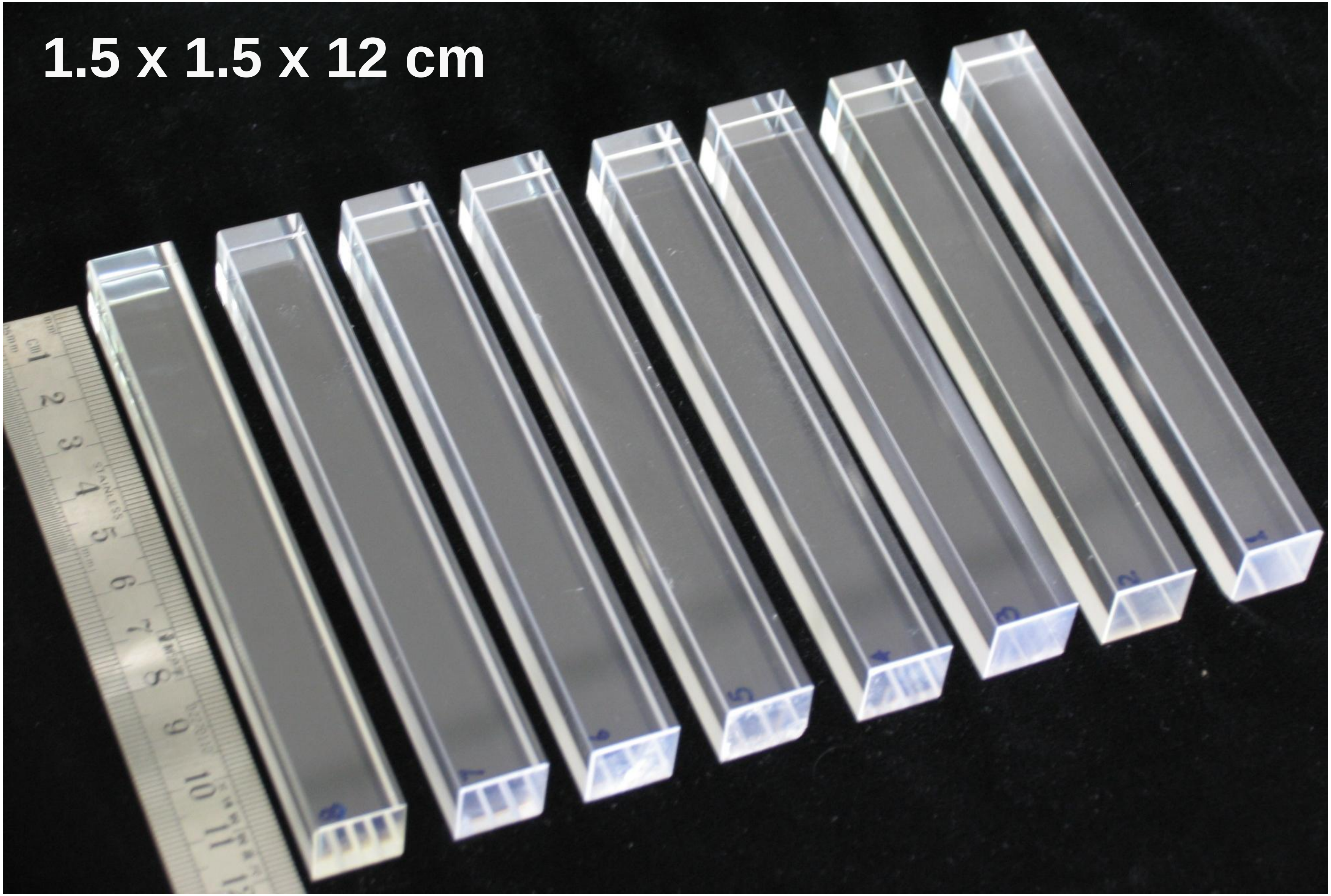
**CTI: LSO**

**CPI: LYSO**

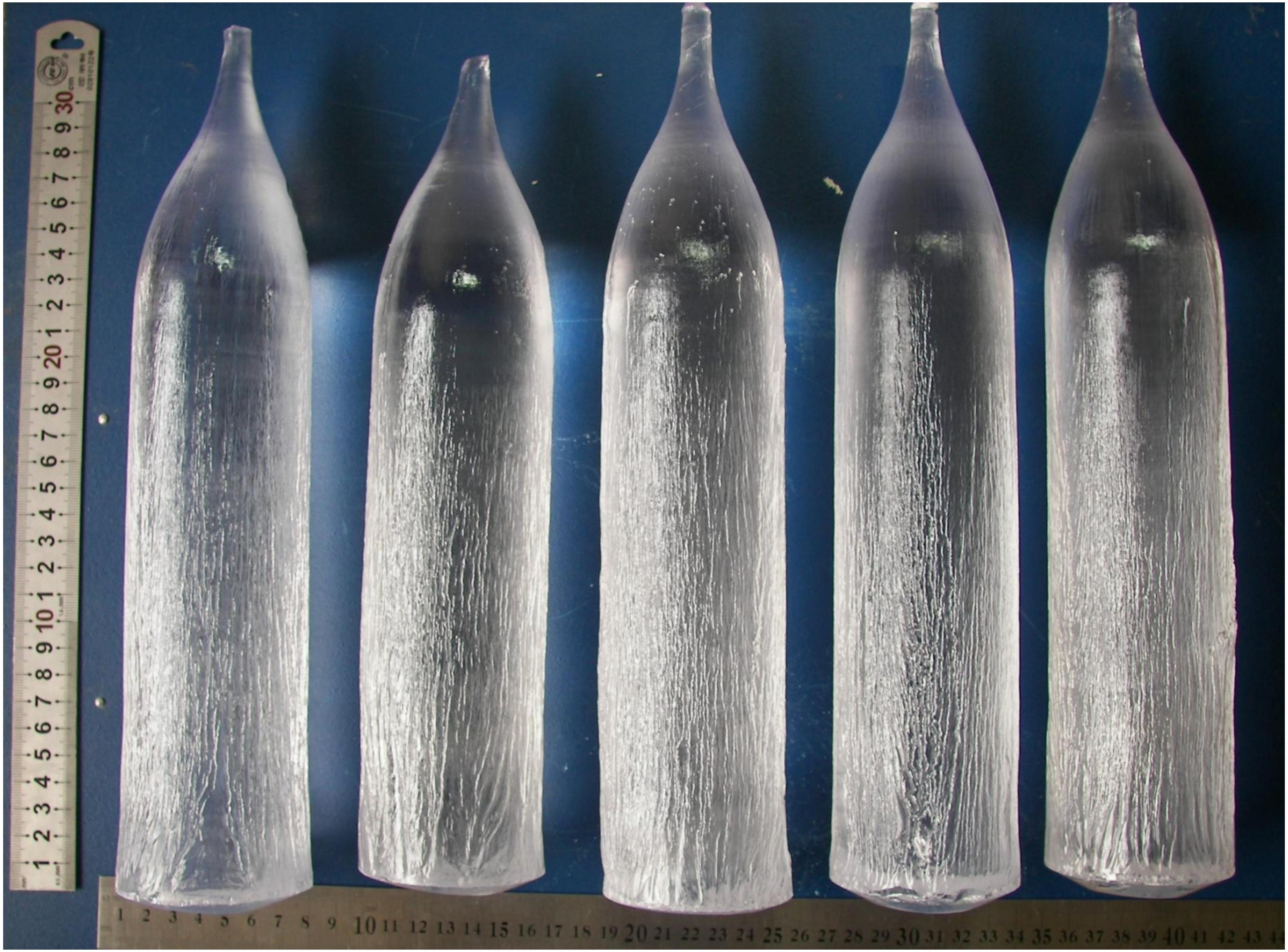
**Saint-Gobain LYSO**



# SIC LYSO Crystals

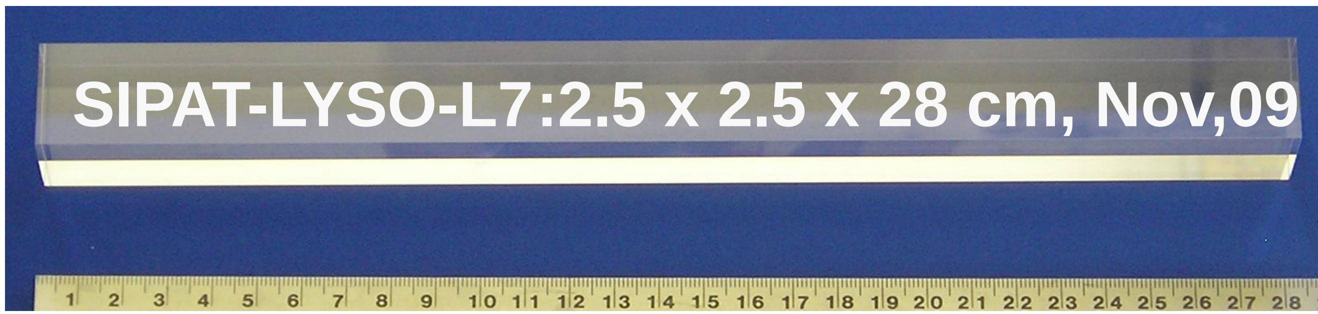


# SIPAT Ø60 x 250 mm LYSO Ingots



# 1$^{st}$ 25 $X_0$ LYSO from SIPAT

**Talk on Dec 8, 2009, in ECAL Upgrade Meeting.**


1. Photo-luminescence, transmission, light output and light response uniformity;
2. [Ce] from the Cut-off and the growth parameters;
3. FWHM resolutions of long LSO/LYSO crystals measured by an R1306 PMT for 0.511 MeV γ-rays from a Na-22 source with a coincidence triggers.

# Crystals for HEP Calorimeters

| Crystal | NaI(Tl) | CsI(Tl) | CsI | $BaF_2$ | BGO | LYSO(Ce) | PWO | $PbF_2$ |
|---|---|---|---|---|---|---|---|---|
| Density $(g/cm^3)$ | 3.67 | 4.51 | 4.51 | 4.89 | 7.13 | 7.40 | 8.3 | 7.77 |
| Melting Point (°C) | 651 | 621 | 621 | 1280 | 1050 | 2050 | 1123 | 824 |
| Radiation Length (cm) | 2.59 | 1.86 | 1.86 | 2.03 | 1.12 | 1.14 | 0.89 | 0.93 |
| Molière Radius (cm) | 4.13 | 3.57 | 3.57 | 3.10 | 2.23 | 2.07 | 2.00 | 2.21 |
| Interaction Length (cm) | 42.9 | 39.3 | 39.3 | 30.7 | 22.8 | 20.9 | 20.7 | 21.0 |
| Refractive Index [a] | 1.85 | 1.79 | 1.95 | 1.50 | 2.15 | 1.82 | 2.20 | 1.82 |
| Hygroscopicity | Yes | Slight | Slight | No | No | No | No | No |
| Luminescence [b] (nm) (at peak) | 410 | 550 | 420<br>310 | 300<br>220 | 480 | 402 | 425<br>420 | ? |
| Decay Time [b] (ns) | 245 | 1220 | 30<br>6 | 650<br>0.9 | 300 | 40 | 30<br>10 | ? |
| Light Yield [b,c] (%) | 100 | 165 | 3.6<br>1.1 | 36<br>4.1 | 21 | 85 | 0.3<br>0.1 | ? |
| d(LY)/dT [b] (%/ °C) | -0.2 | 0.4 | -1.4 | -1.9<br>0.1 | -0.9 | -0.2 | -2.5 | ? |
| Experiment | Crystal Ball | BaBar<br>BELLE<br>BES III | KTeV | (L*)<br>(GEM)<br>TAPS | L3<br>BELLE | KLOE-2<br>SuperB<br>SLHC? | CMS<br>ALICE<br>PANDA | HHCAL? |

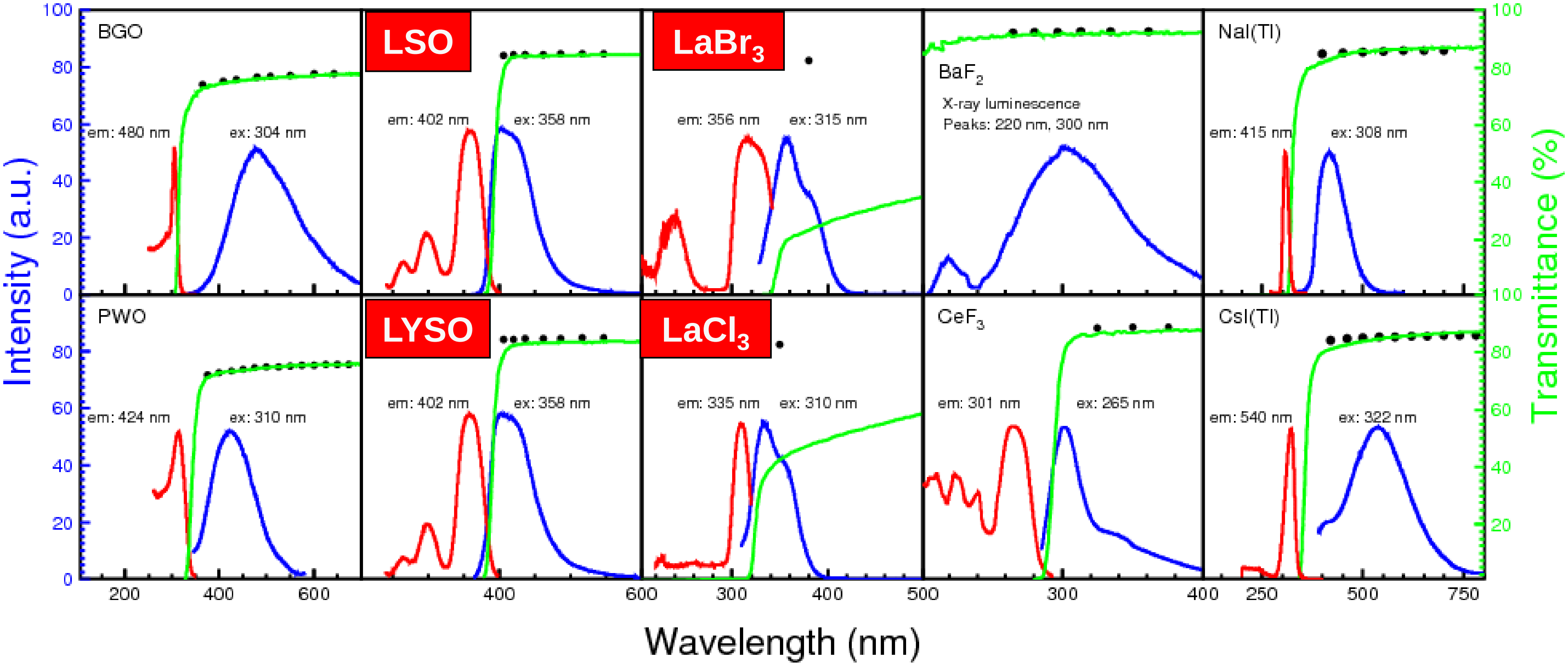
a. at peak of emission; b. up/low row: slow/fast component; c. QE of readout device taken out.

# Excitation, Emission, Transmission

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

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

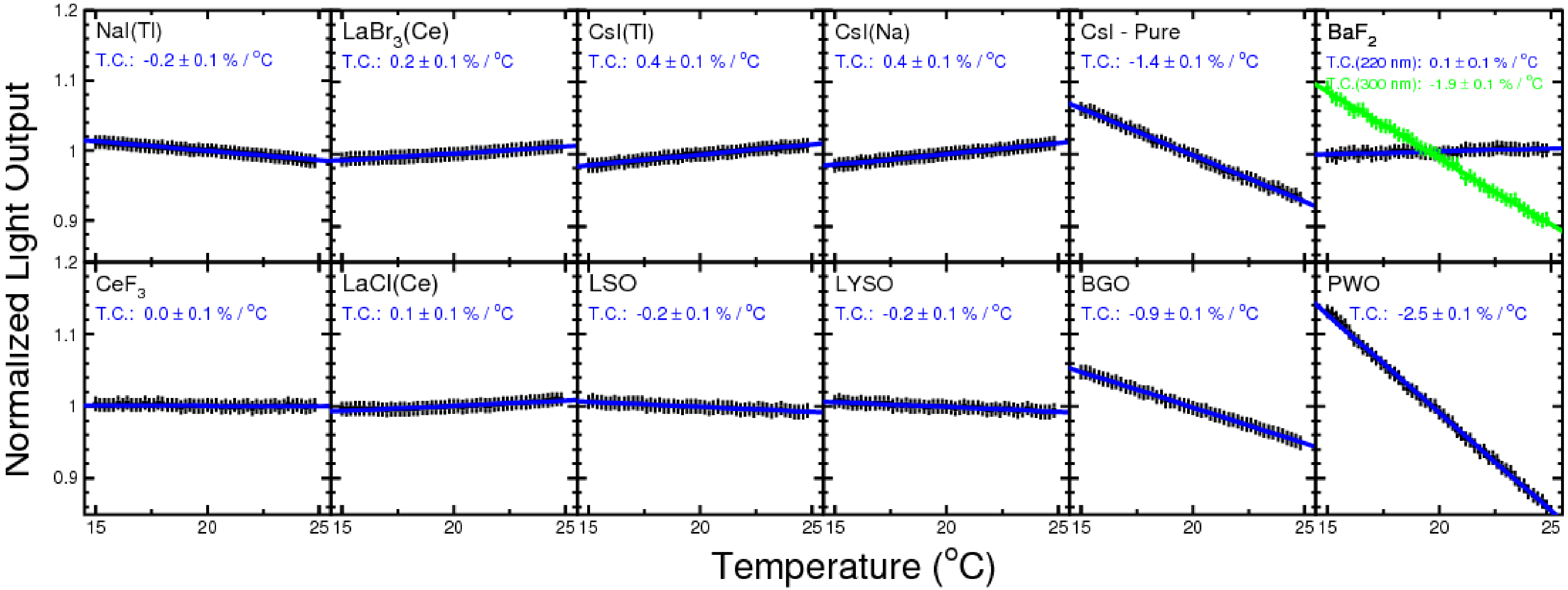
**Black Dots: Theoretical limit of transmittance: NIM A333 (1993) 422**




**LSO/LYSO has Self-absorption, so are $LaBr_3$ and $LaCl_3$**

# L.O. Temperature Coefficient

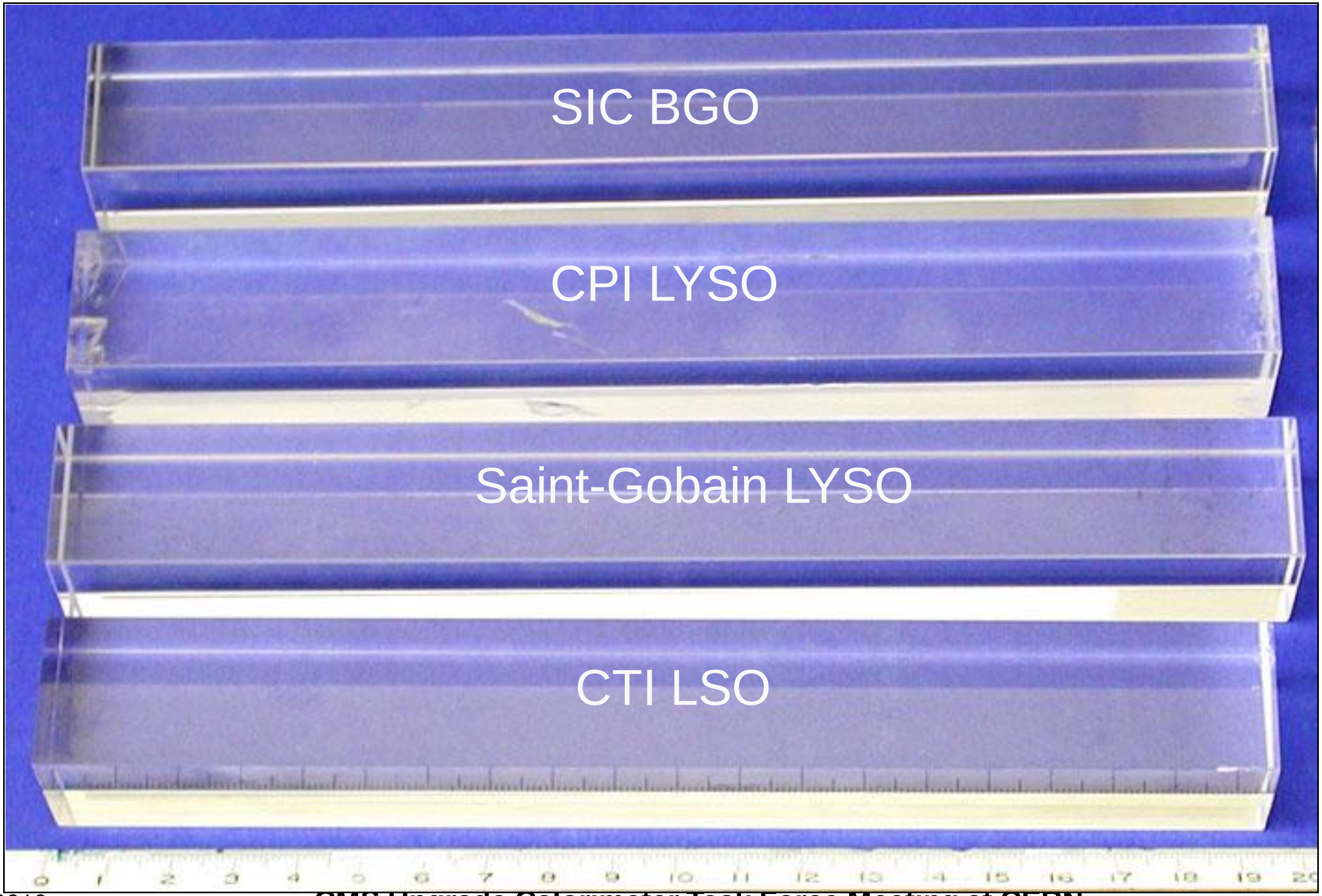
**Temperature Range: 15 - 25ºC**




**LSO/LYSO: -0.2%/ºC temperature coefficient**

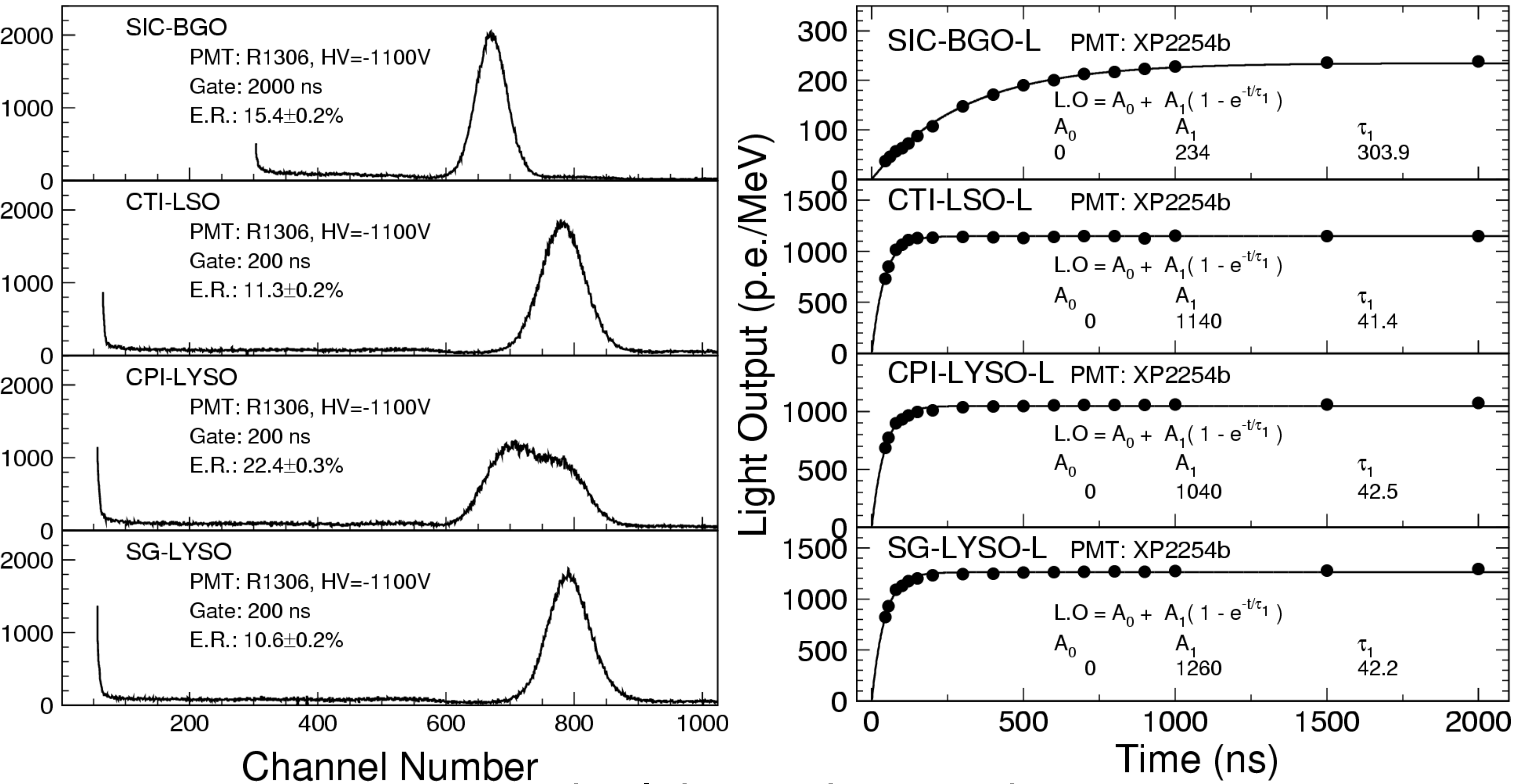
# BGO, LSO & LYSO Samples

2.5 x 2.5 x 20 cm (18 $X_0$)



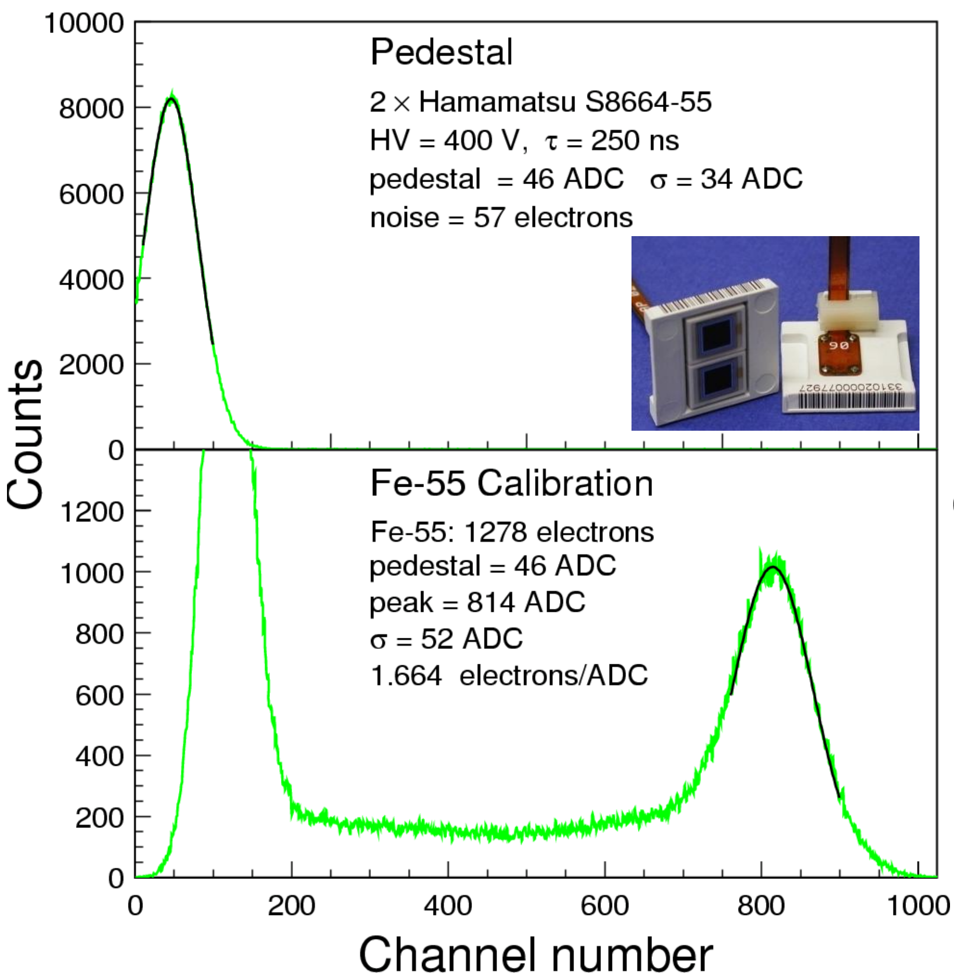
# LSO/LYSO with PMT Readout

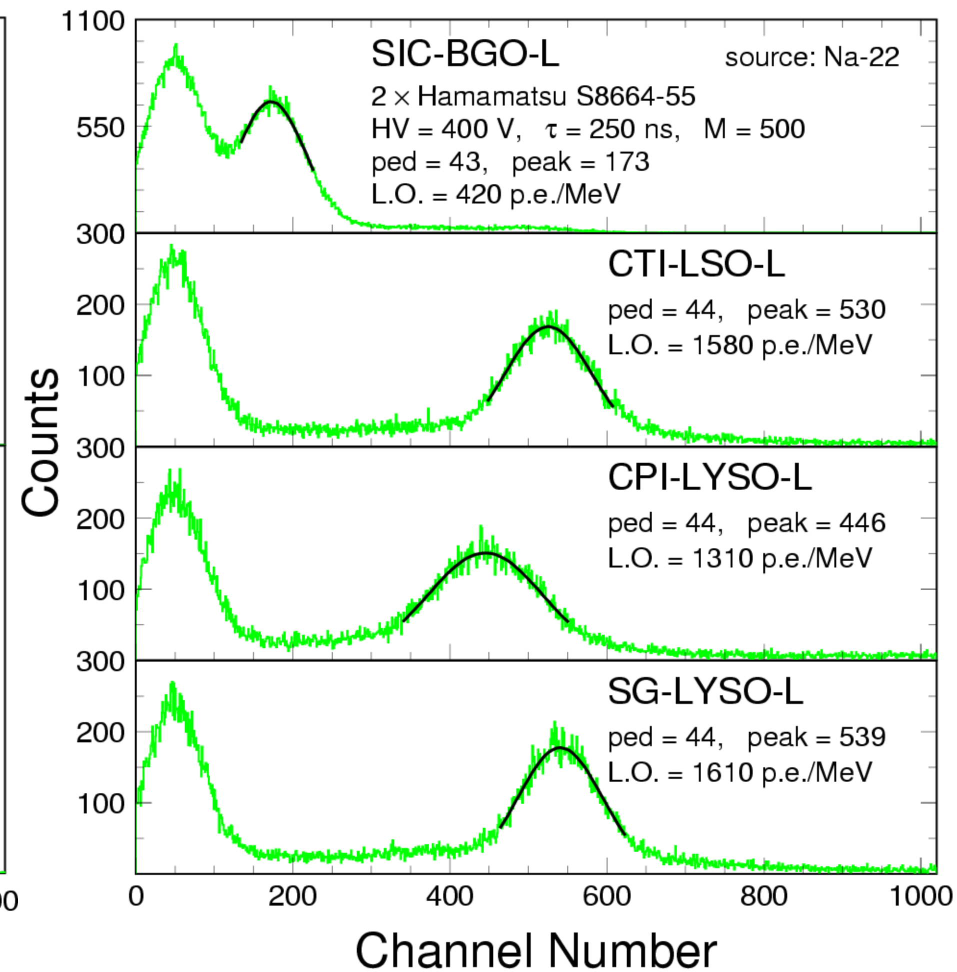
11% FWHM resolution for $^{22}$Na source (0.511 MeV)
40 ns decay, 5/230 times light yield of BGO/PWO



# LSO/LYSO with APD Readout

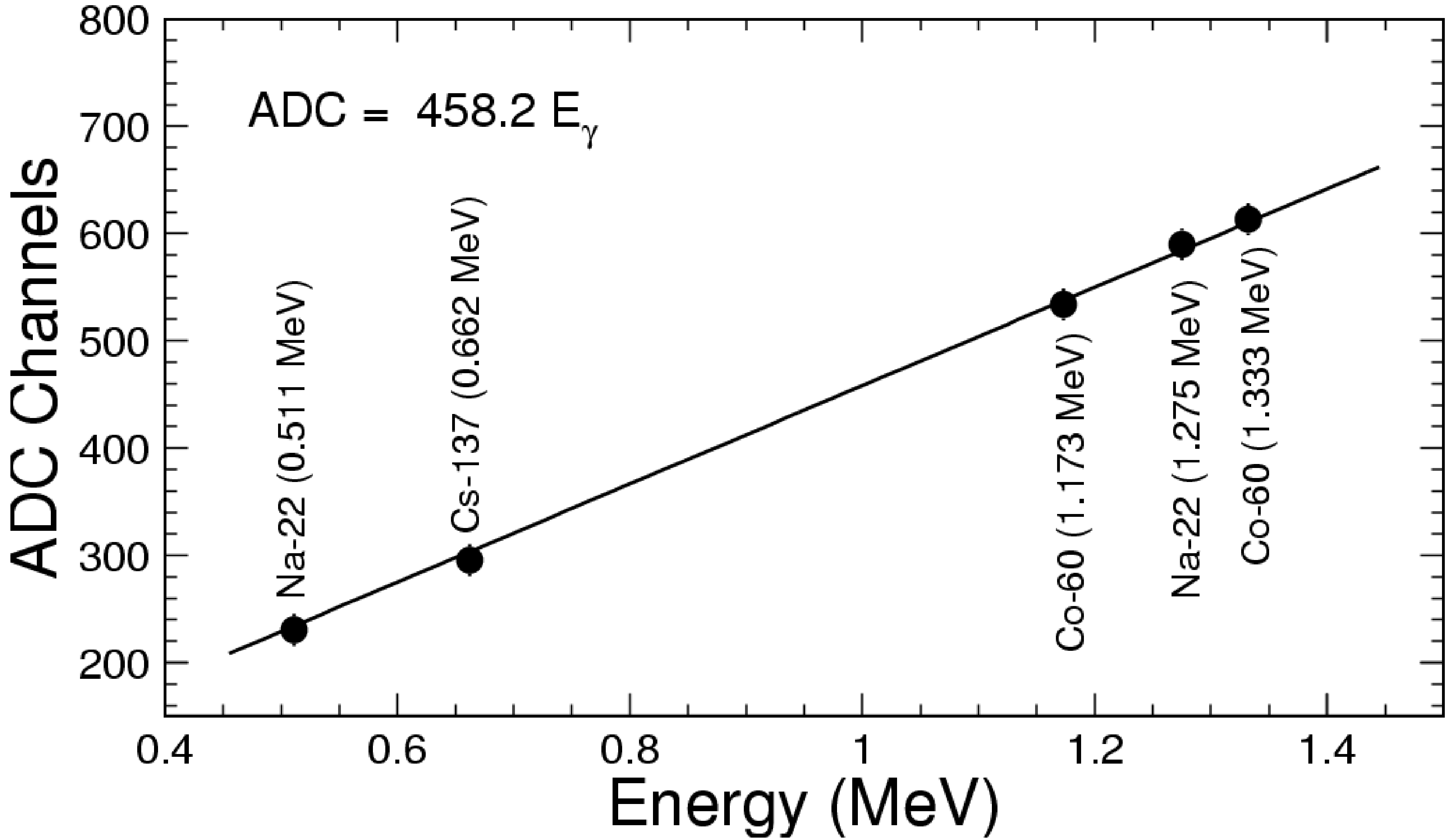
4/230 times light yield of BGO/PWO
Readout Noise: < 40 keV



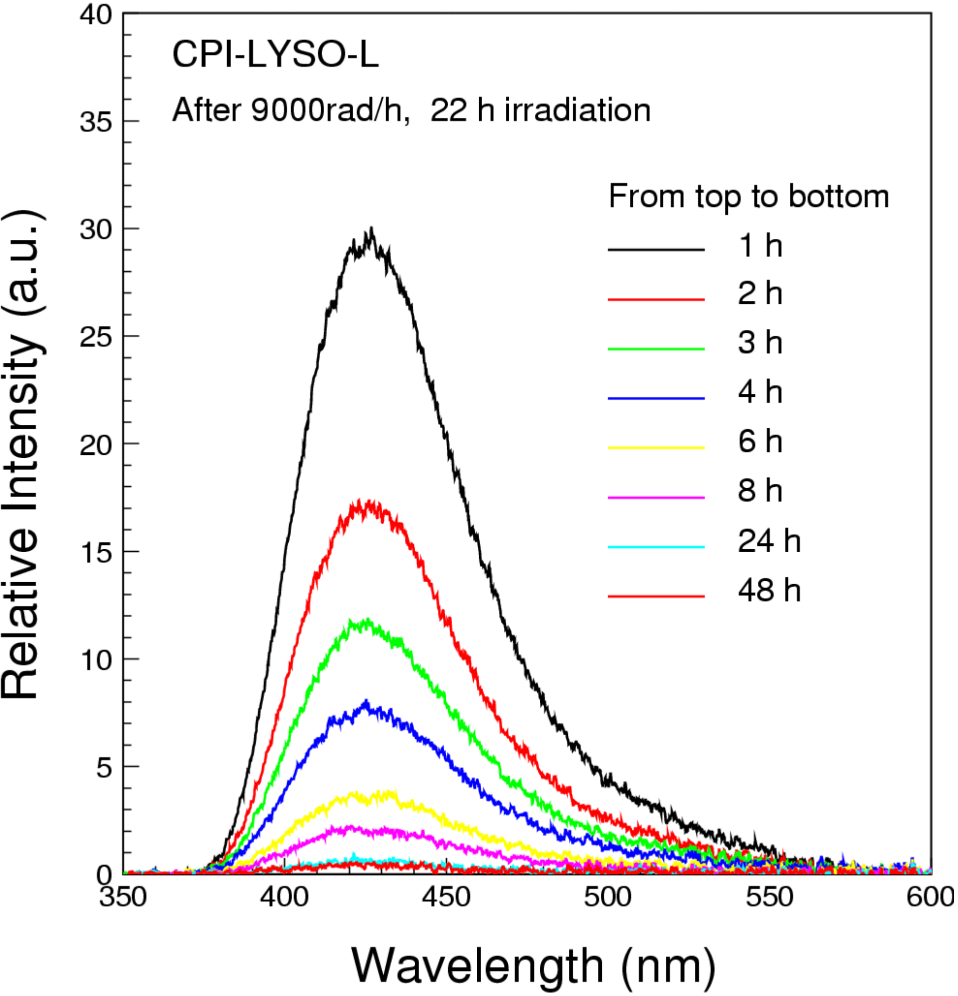
# Excellent Linearity: > 0.511 MeV

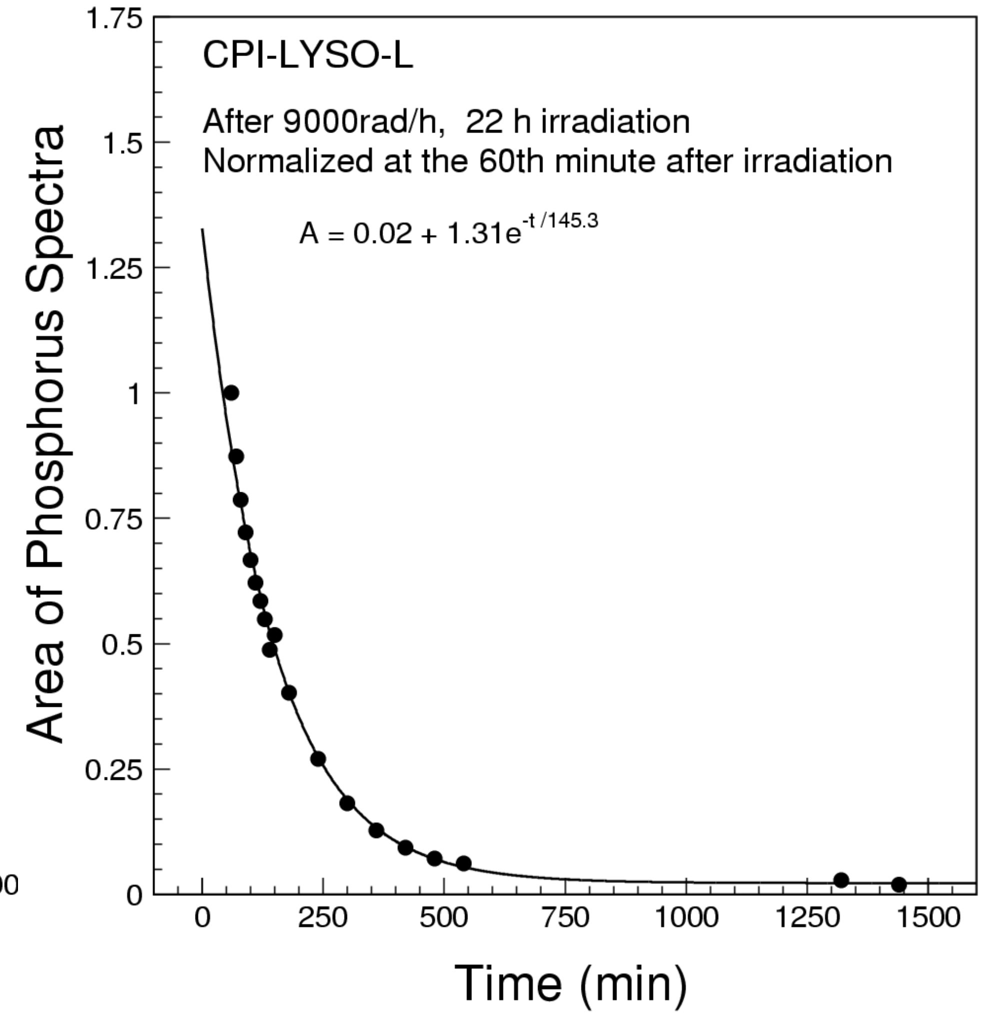
Observed with APD readout



# γ–Ray Induced Phosphorescence

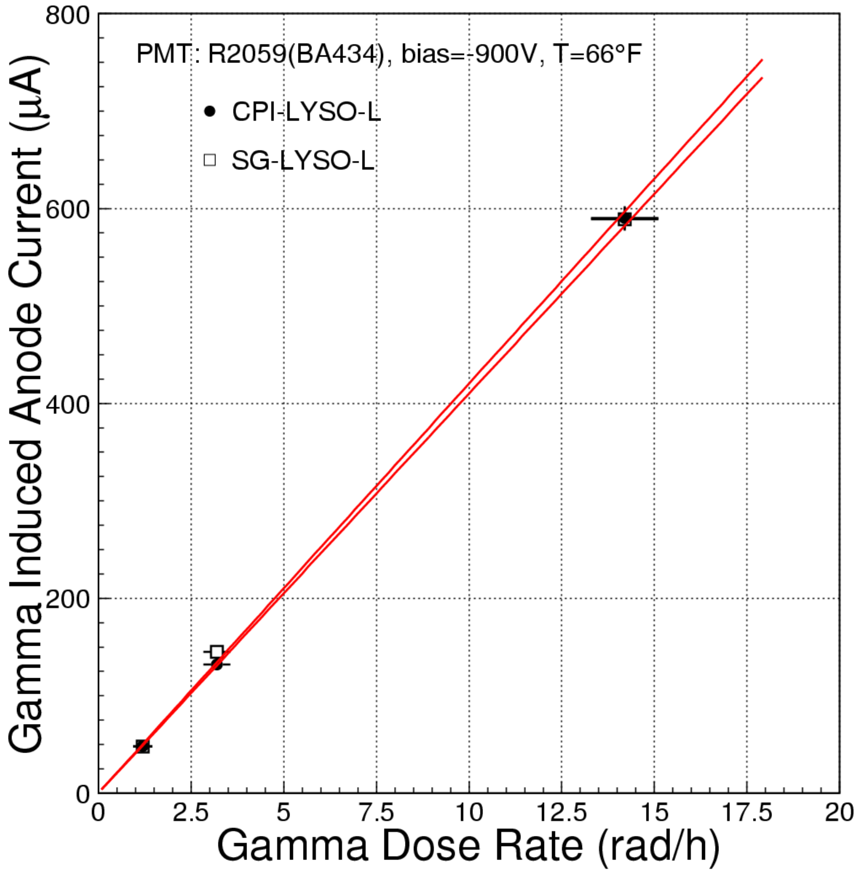
Phosphorescence peaked at 430 nm with decay time constant of 2.5 h observed



# $\gamma$–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 | $6.98\times10^4$ | $2.33\times10^6$ | 0.18 | 1.03 |
| SG | 1,580 | 42 | $7.15\times10^4$ | $2.38\times10^6$ | 0.17 | 0.97 |

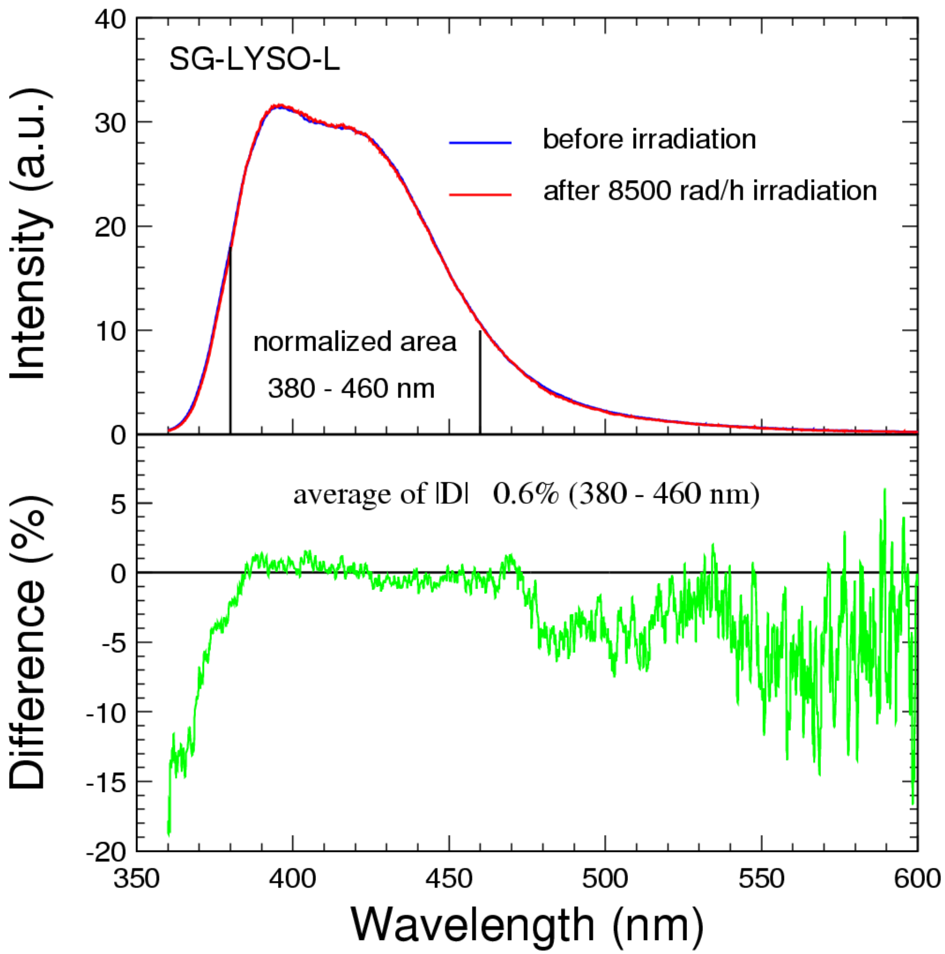


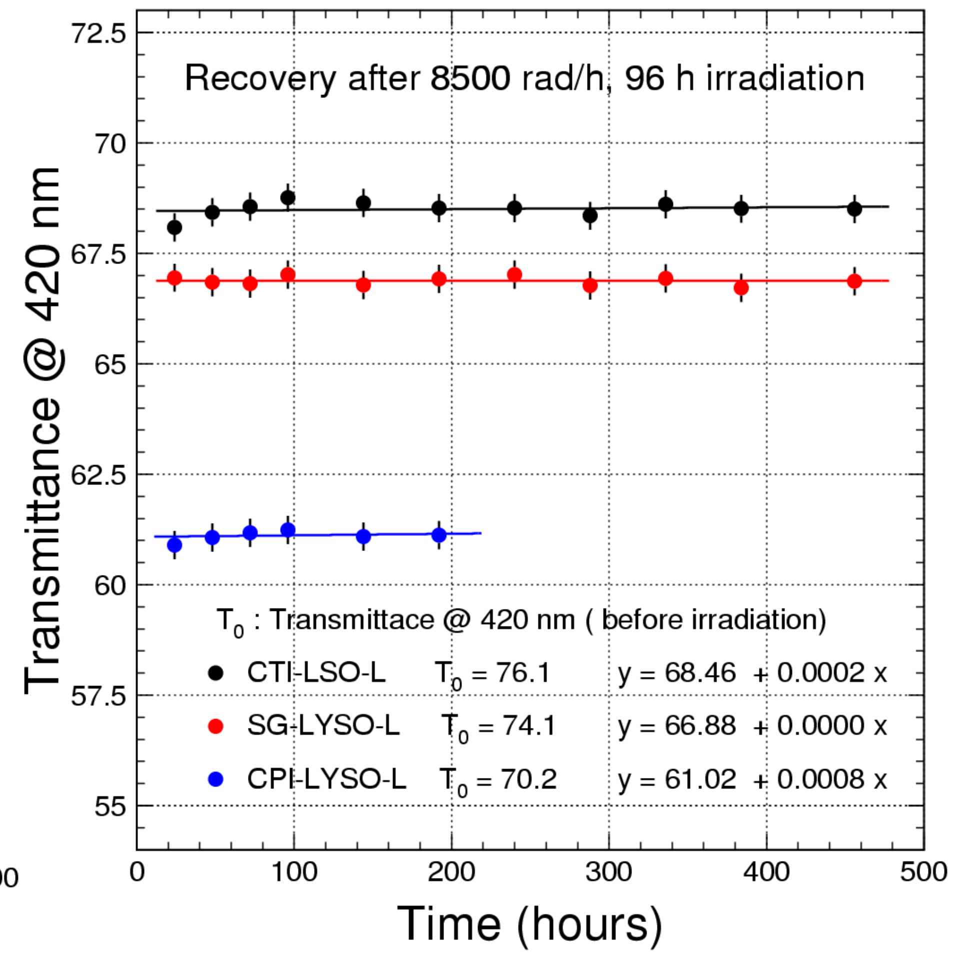

$\gamma$–ray induced PMT anode current can be converted to the photoelectron numbers (Q) integrated in 100 ns gate. Its statistical fluctuation contributes to the readout noise ($\sigma$): 0.2 & 1 MeV @ 15 & 500 rad/h.

# γ-Ray Induced Damage

**No damage in photo-luminescence**

**Transmittance recovery slow**

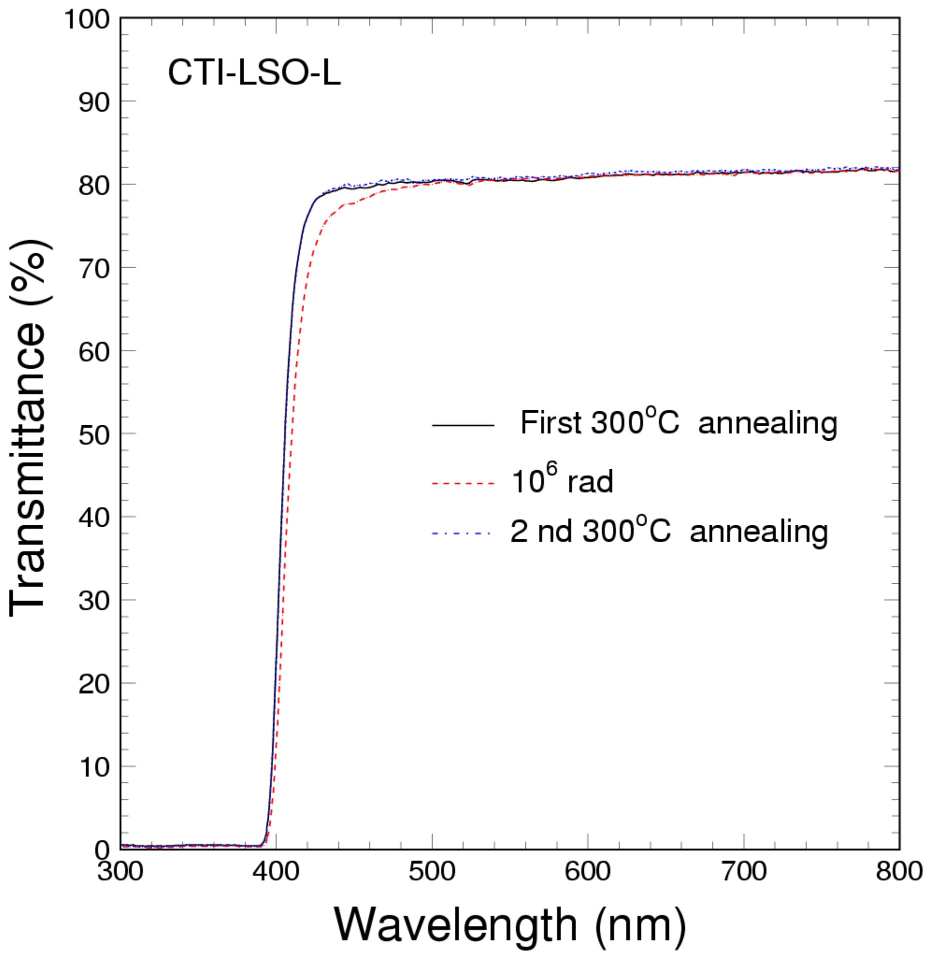


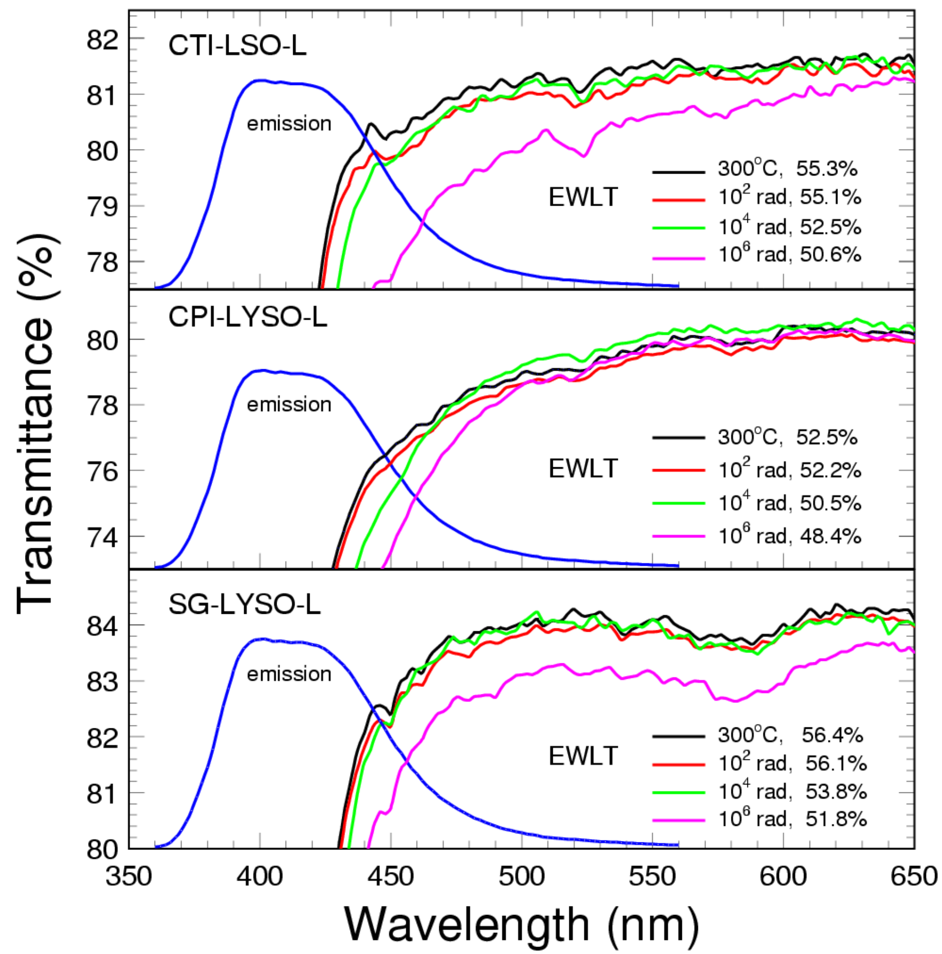



# γ-Ray Induced Transmittance Damage

300ºC thermal annealing effective

LT damage: 8% @ 1 Mrad



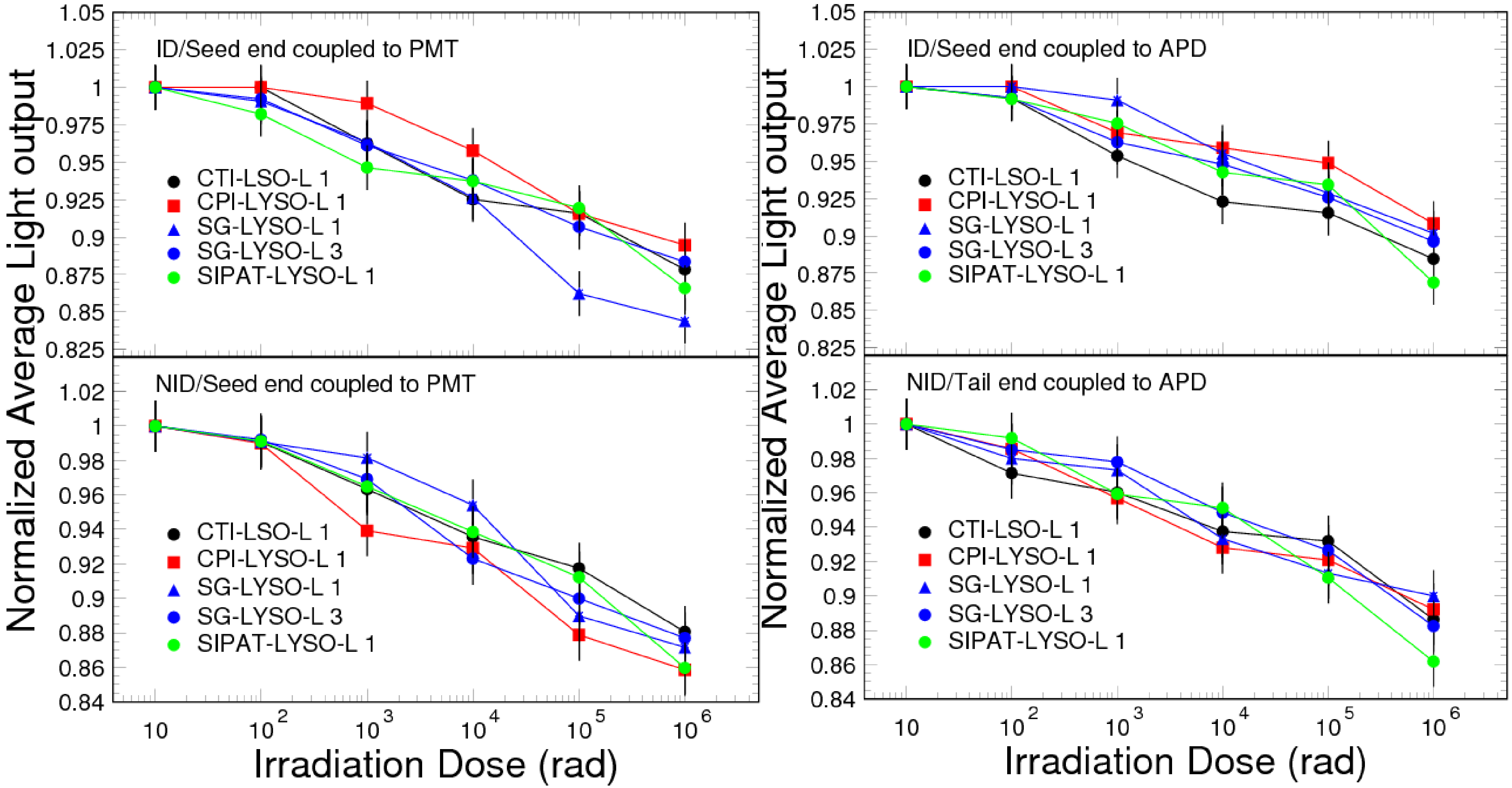



# About 10% L.O. Loss after 1 Mrad

All samples show consistent radiation resistance

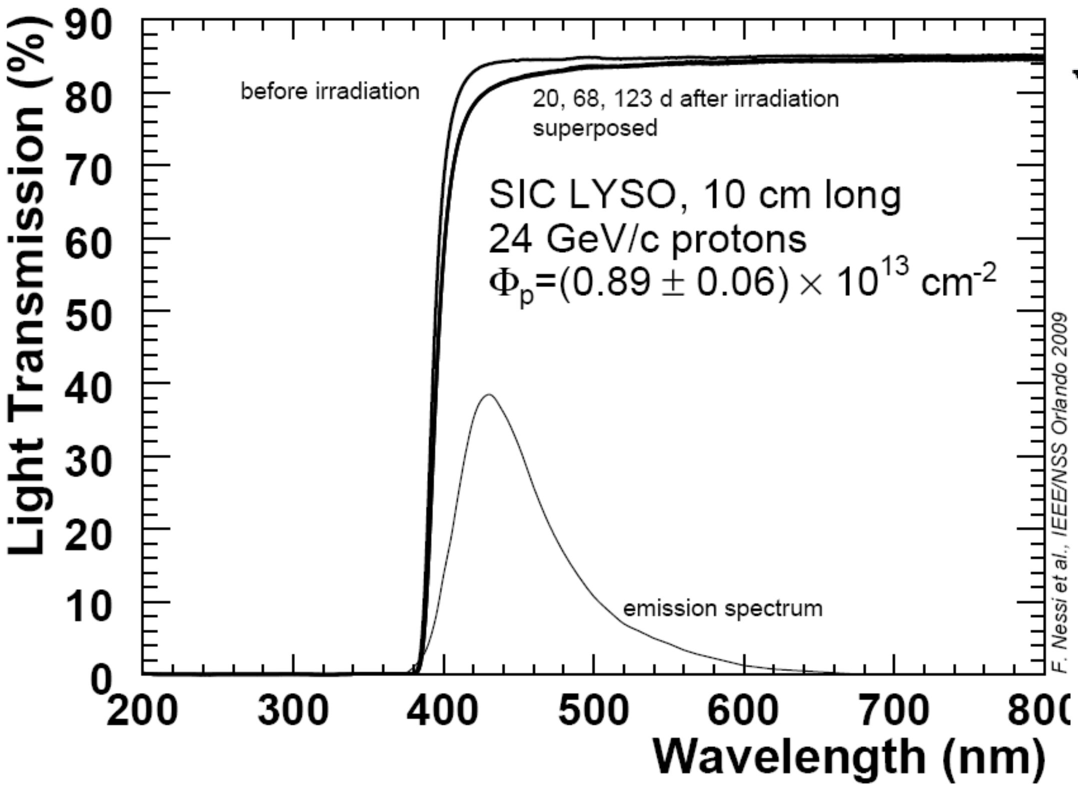
10% - 15% loss by PMT

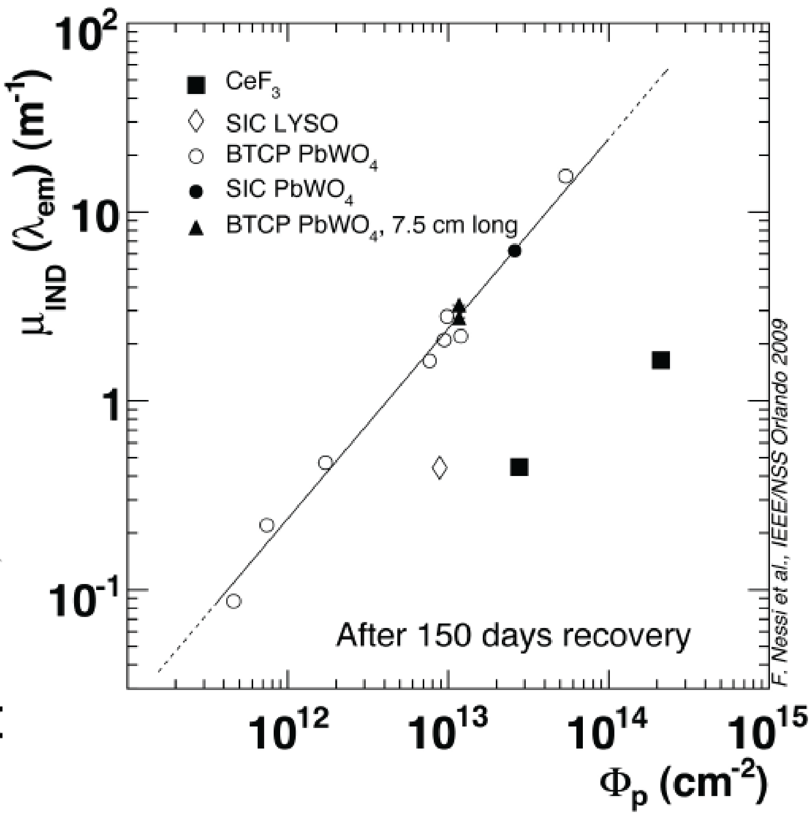
9% - 14% loss by APD



# News on Hadron Damage from ETH

G. Dissertori, D. Luckey, P. Lecomte, Francesca Nessi-Tedaldi, F. Pauss, Paper N32-3@NSS09, Orlando.




After $10^{13}$ neutrons/cm$^2$ the induced absorption of LYSO is five times less than that of PWO.

# LSO/LYSO ECAL Performance

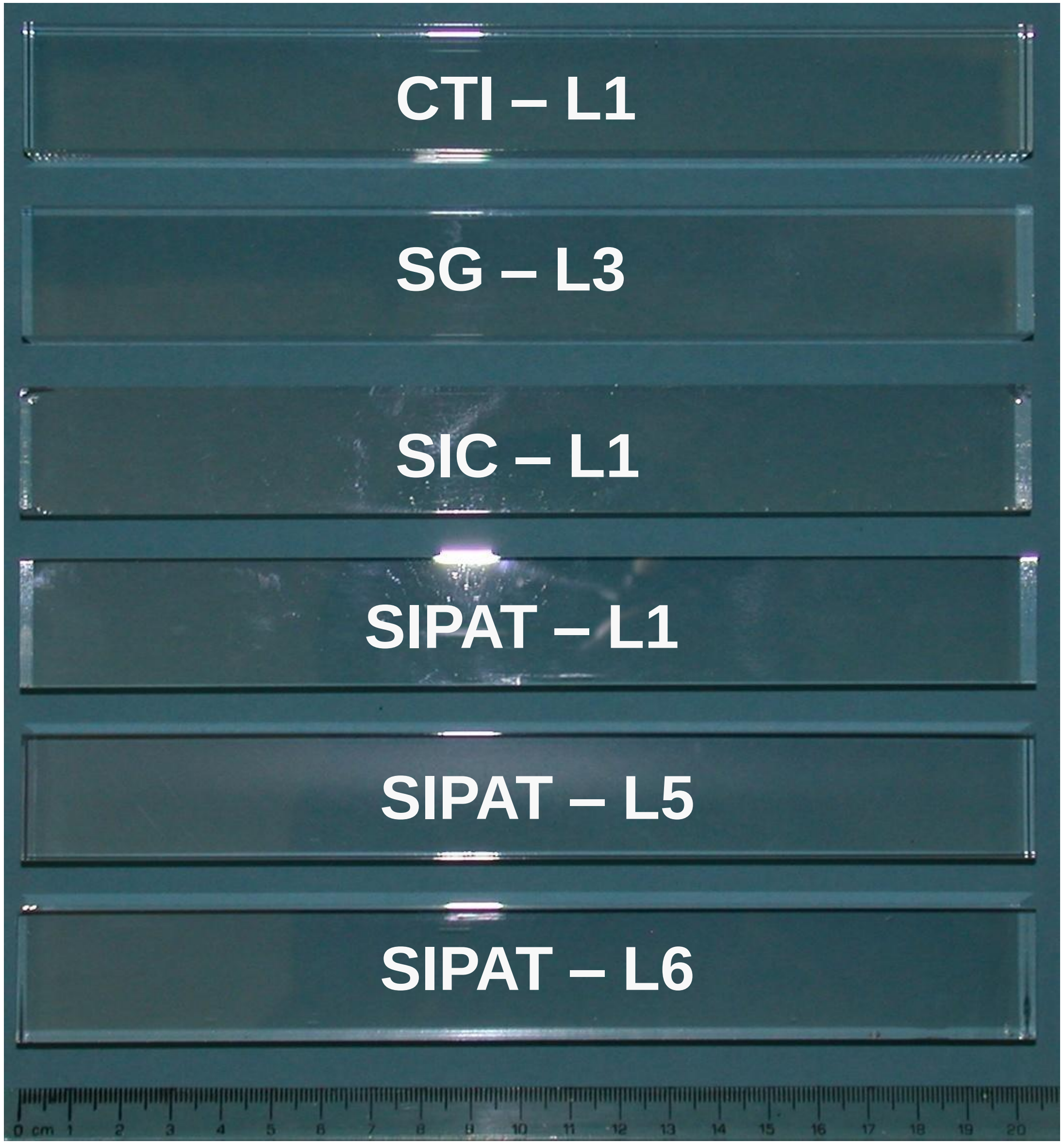
- Less demanding to the environment because of -0.2%/$^{o}$C T coefficient.
- This material seems the best in terms of radiation hardness among all crystals.
- A better energy resolution, $\sigma(E)/E$, at low energies than L3 BGO and CMS PWO may be achieved because of its high light output and low readout noise:

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

# Summary

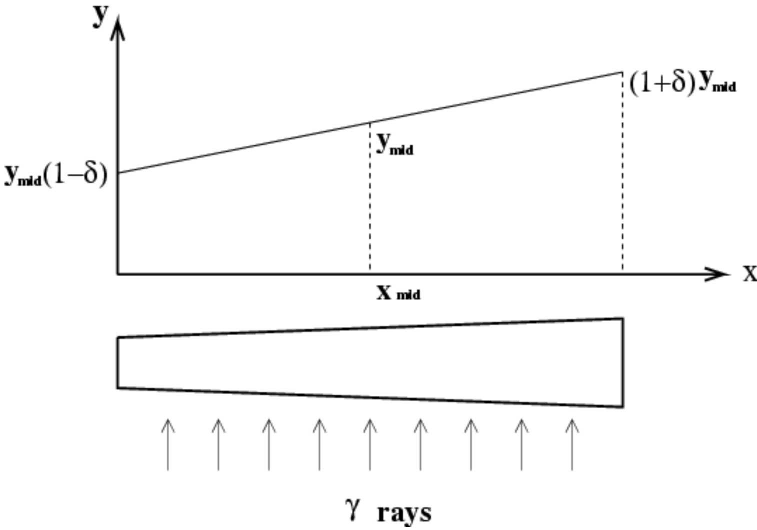
- LSO/LYSO crystals with blight, fast scintillation and excellent radiation hardness is a good candidate material for calorimeter at the SLHC.
- The quality of LYSO crystals is adequate for low energy applications, such as KLOE-2 and SuperB. R&D work is needed to further develop crystals for a severe radiation environment, such as SLHC.
- R&D issues include growth of crystals of adequate length/size cost-effectively and improving the longitudinal light response uniformity (Ce concentration & self-absorption etc.) and radiation hardness.

# Light Response Uniformity



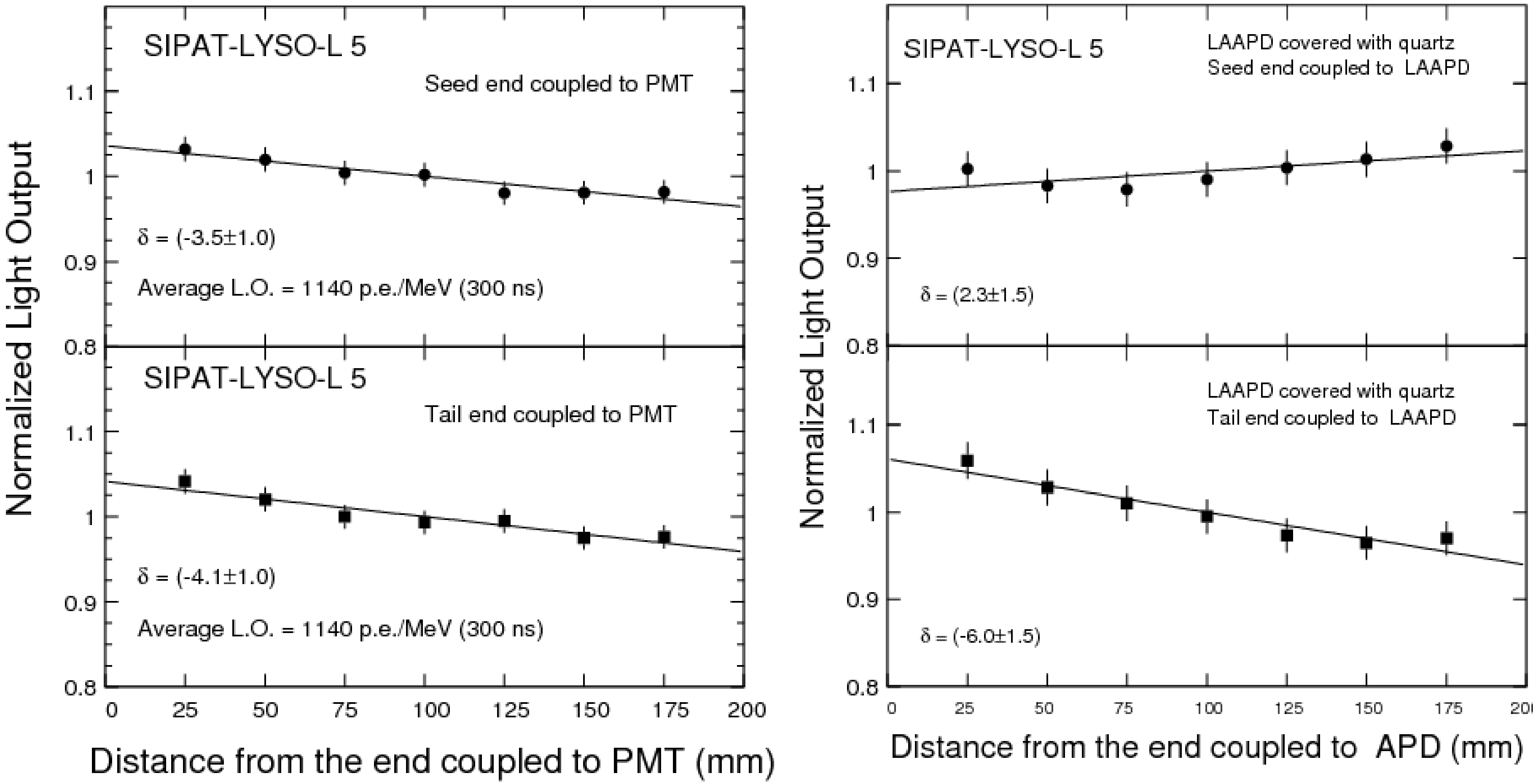

25 x 25 x 200 mm samples measured for their L.R.U. and fit to a linear function

$$Y = Y_{mid}\left[1 + \delta(x/x_{mid} - 1)\right]$$



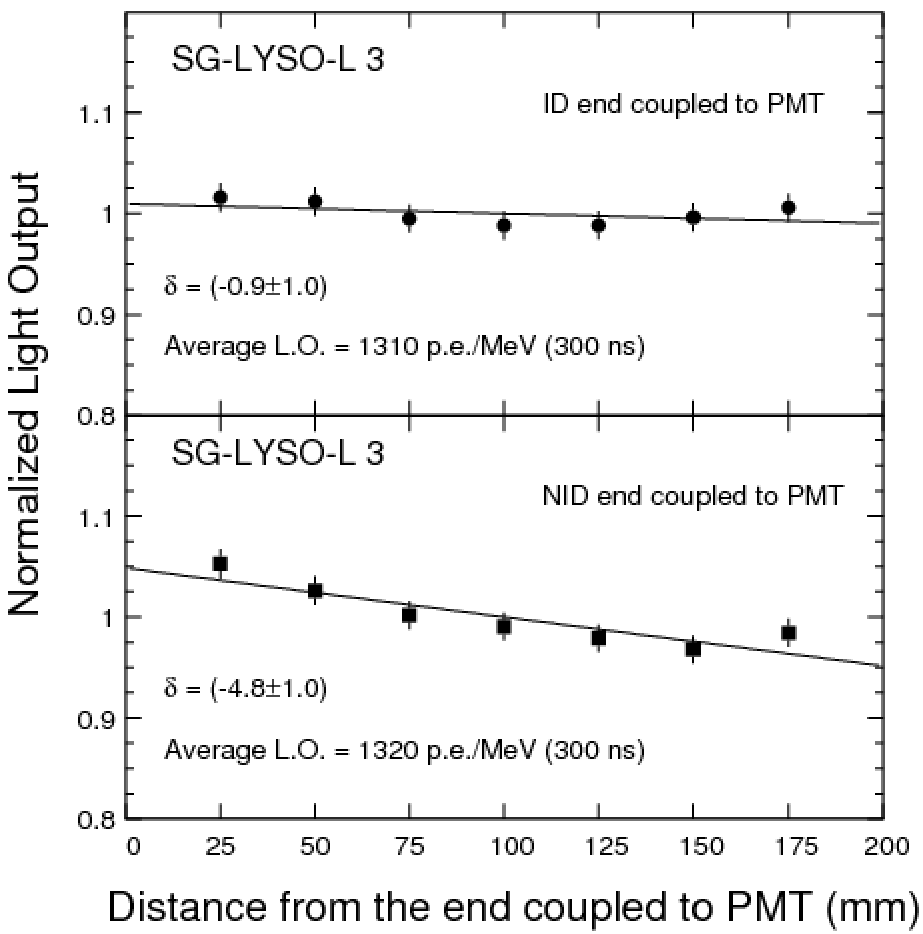
# L.R.U. by PMT & LAAPD: SIPAT-LYSO-L5

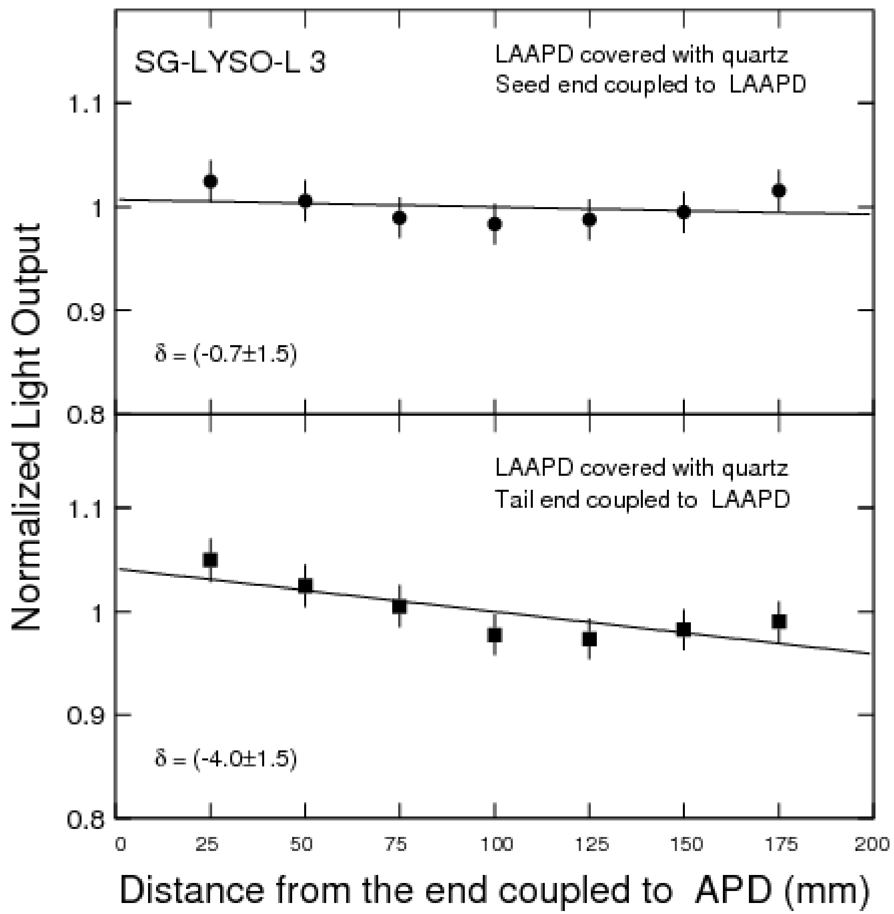
Issue: Ce doping was optimized for the uniformities measured by PMT with two end-couplings, but a large difference observed between the PMT & APD readouts.



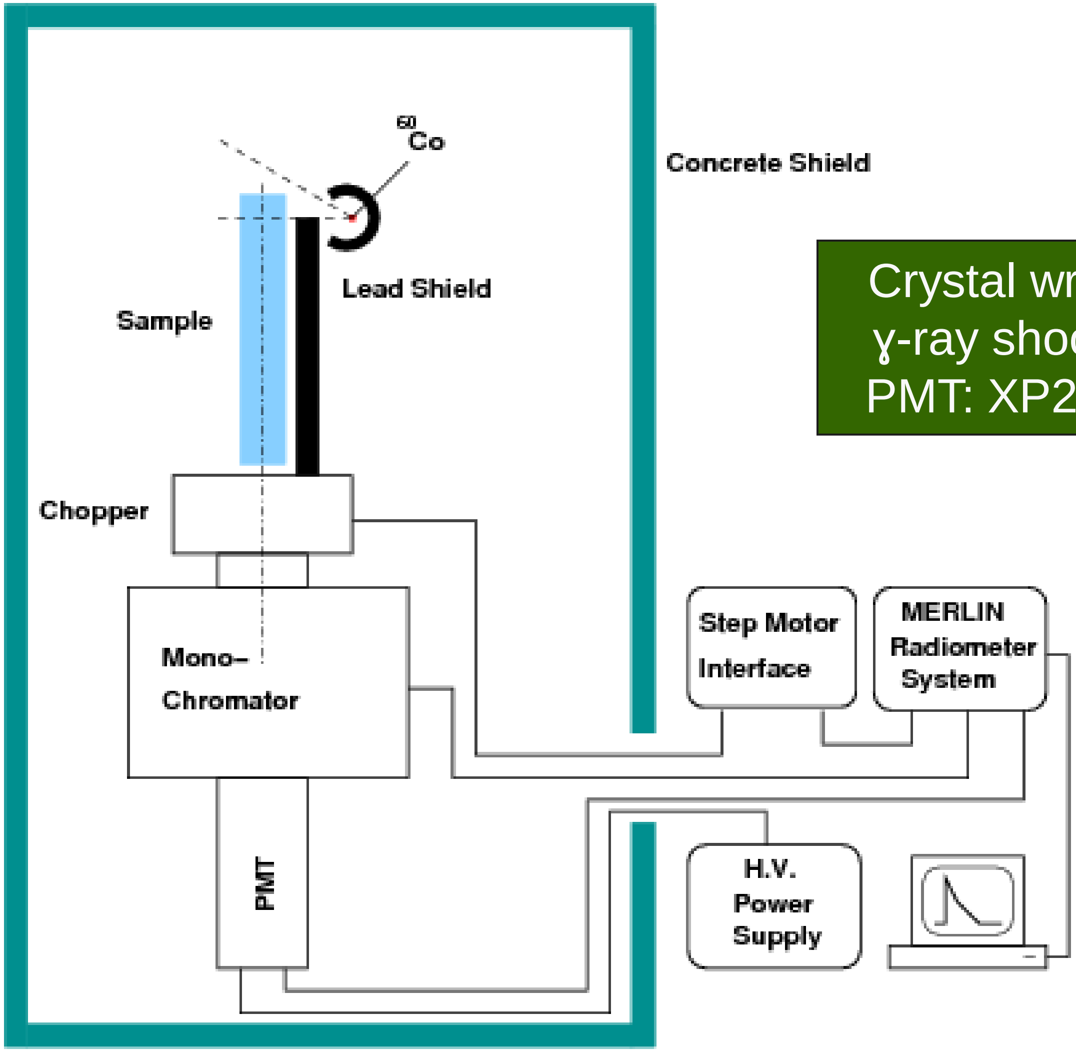
# L.R.U. by PMT & LAAPD: SG-LYSO-L3

Consistent uniformities between PMT and APD
Some difference between two end-couplings



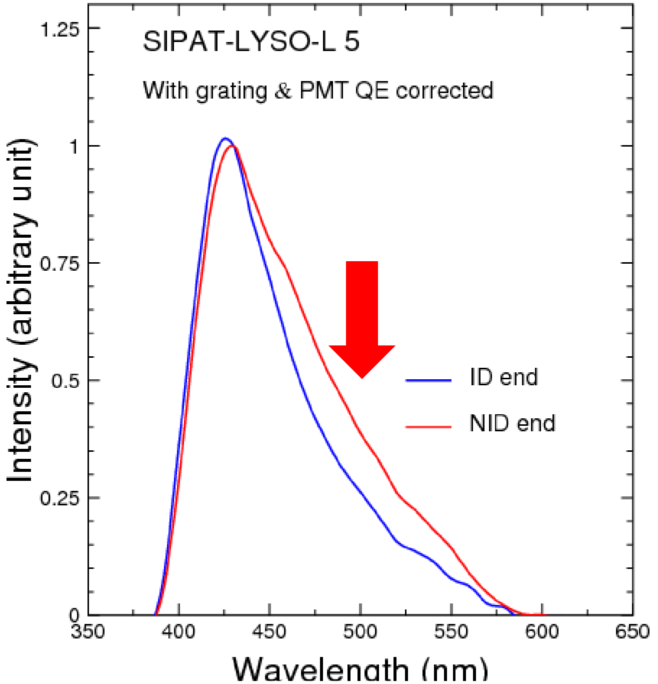
# Radio-luminescence for LSO/LYSO

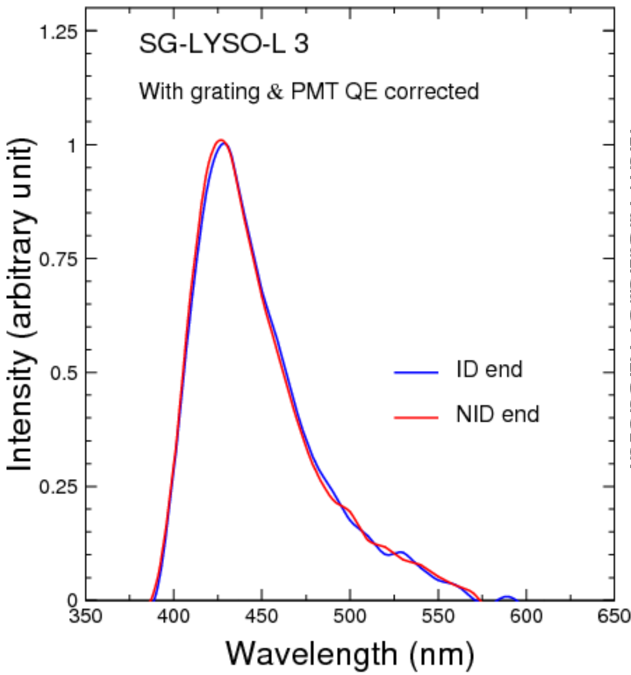


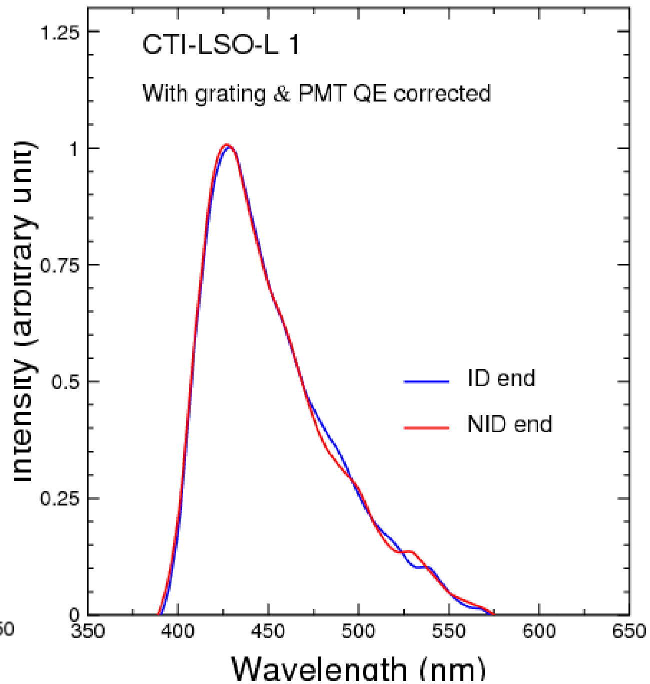

Crystal wrapped with Tyvek paper;
ɣ-ray shooting at two ends (1 cm);
PMT: XP2254B running @ -1800V.

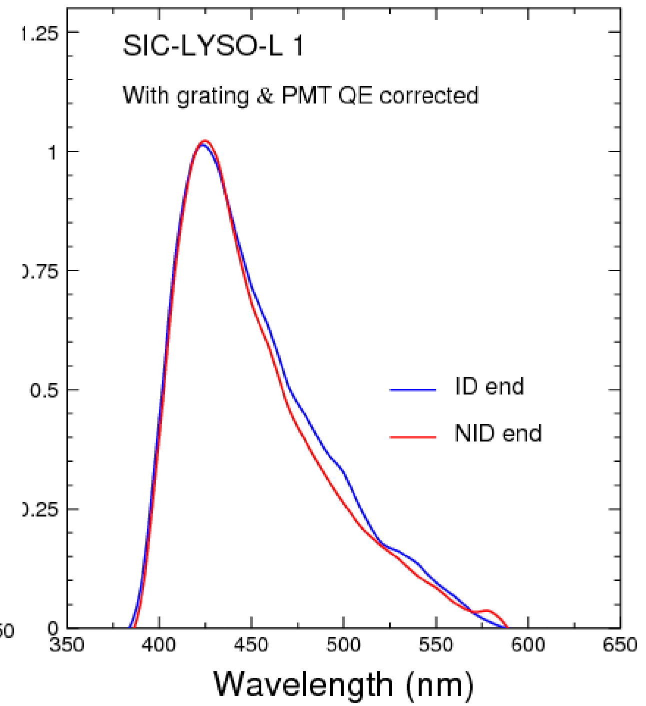
# Radio-luminescence

Found: SIPAT-LYSO-L5 has an extra green emission component at the tail end, which does not show in other samples. This may explain the large difference observed in uniformities measured by PMT and APD.



# SIPAT-L6: Consistent Emission at two ends

Extra green component at the tail end eliminated