LYSO: A Radiation Hard Material for the SLHC

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(M. Gataullin for R.-Y. Zhu)

Introduction

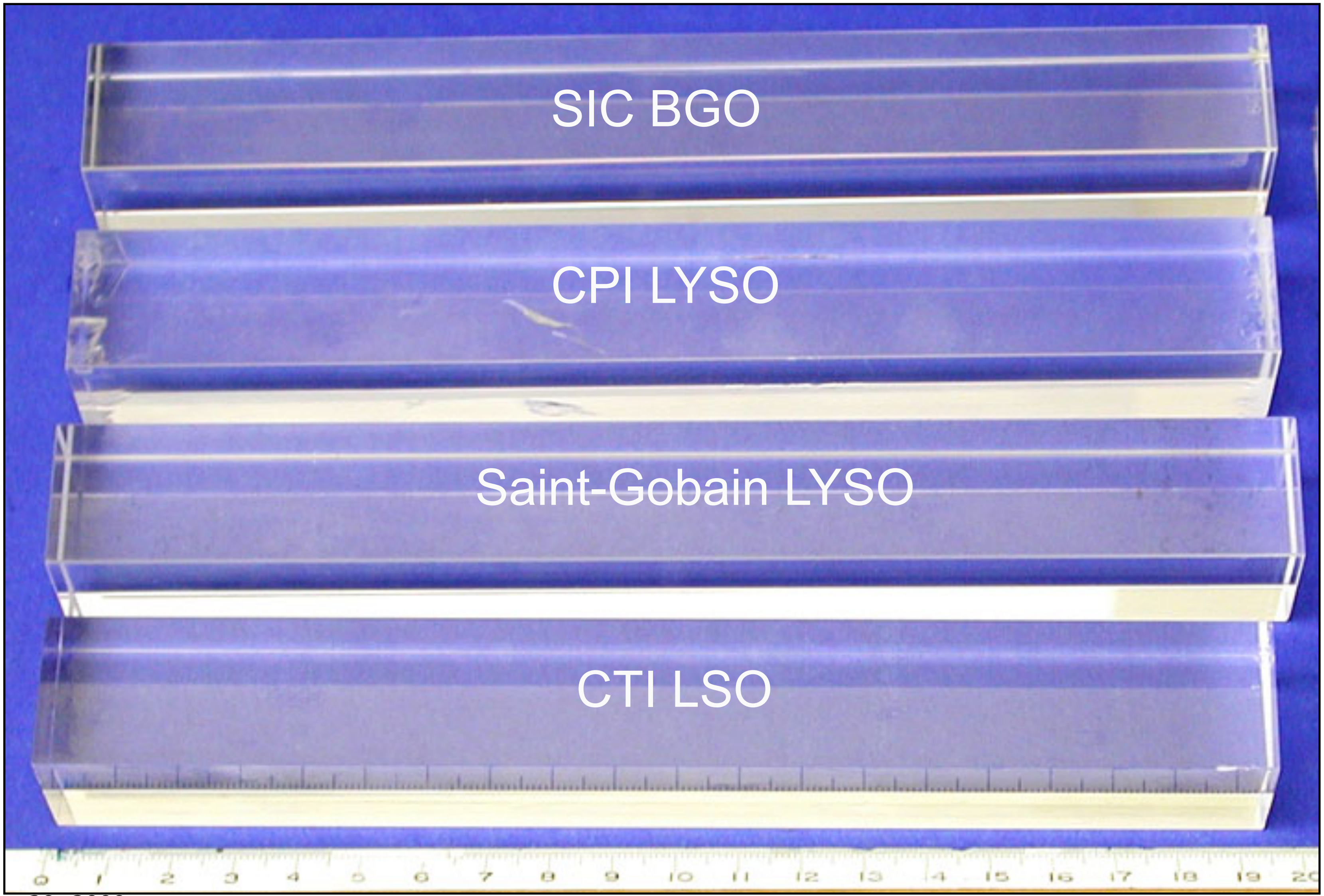
LSO/LYSO is a bright (200 times of PWO) and fast (40 ns) crystal scintillator. It has been widely used in medical industry for the PET application with mass production capability exits in the world.

The Caltech crystal laboratory has been investigating this material for applications in HEP experiment since FY06. It was found that its radiation hardness is excellent against γ–ray and neutron irradiations. The light output loss after 1 Mrad γ–ray irradiation is about 10% for 20 cm long samples. This work is supported by the DOE Advanced Detector R&D program from FY06 to FY08, and also by the US CMS Upgrade R&D Program in FY09.

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, and paper N69-8 @ NSS08, Dresden.

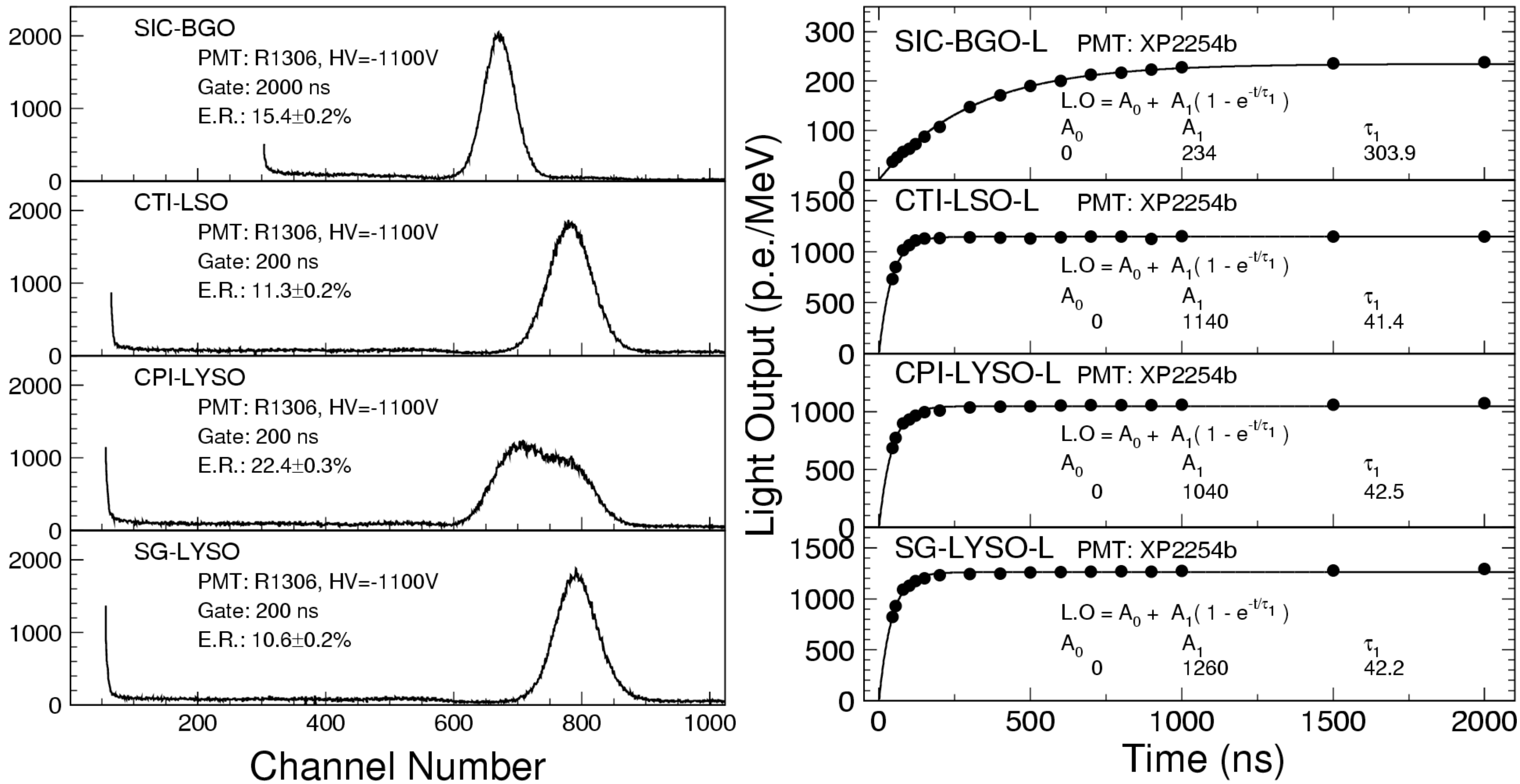
BGO, LSO & LYSO Samples

2.5 x 2.5 x 20 cm (18 X_0)



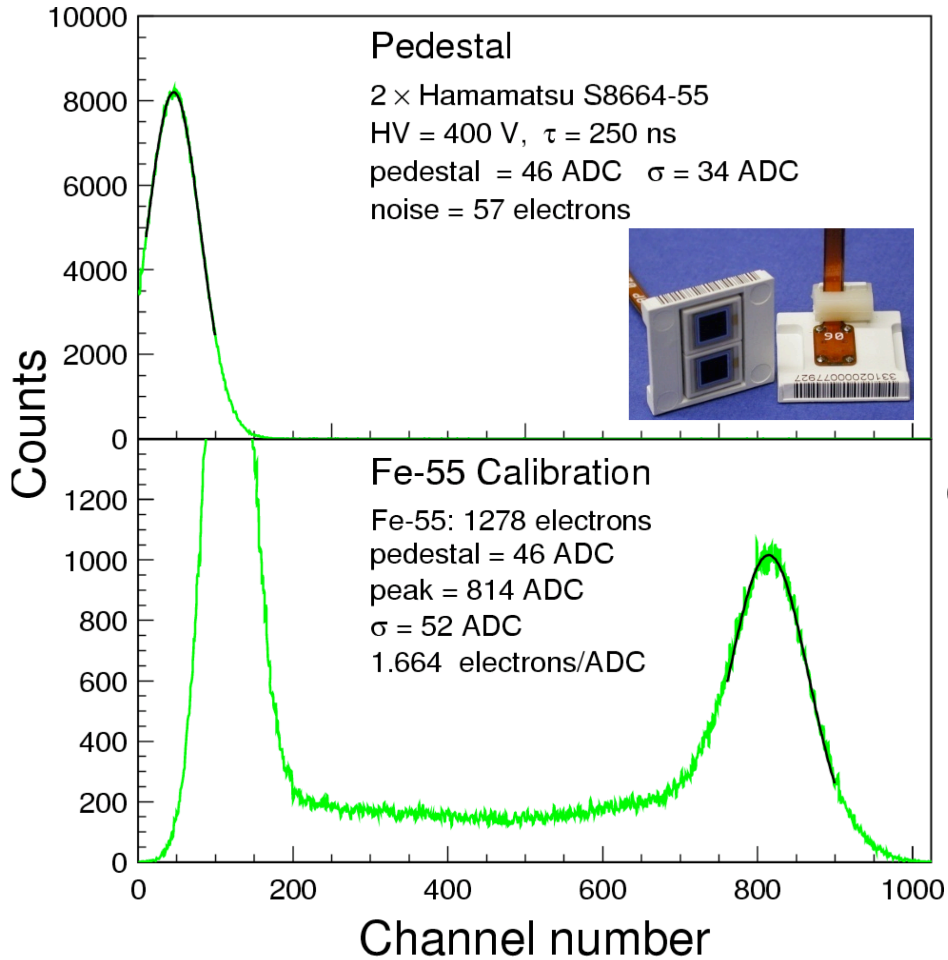
LSO/LYSO with PMT Readout

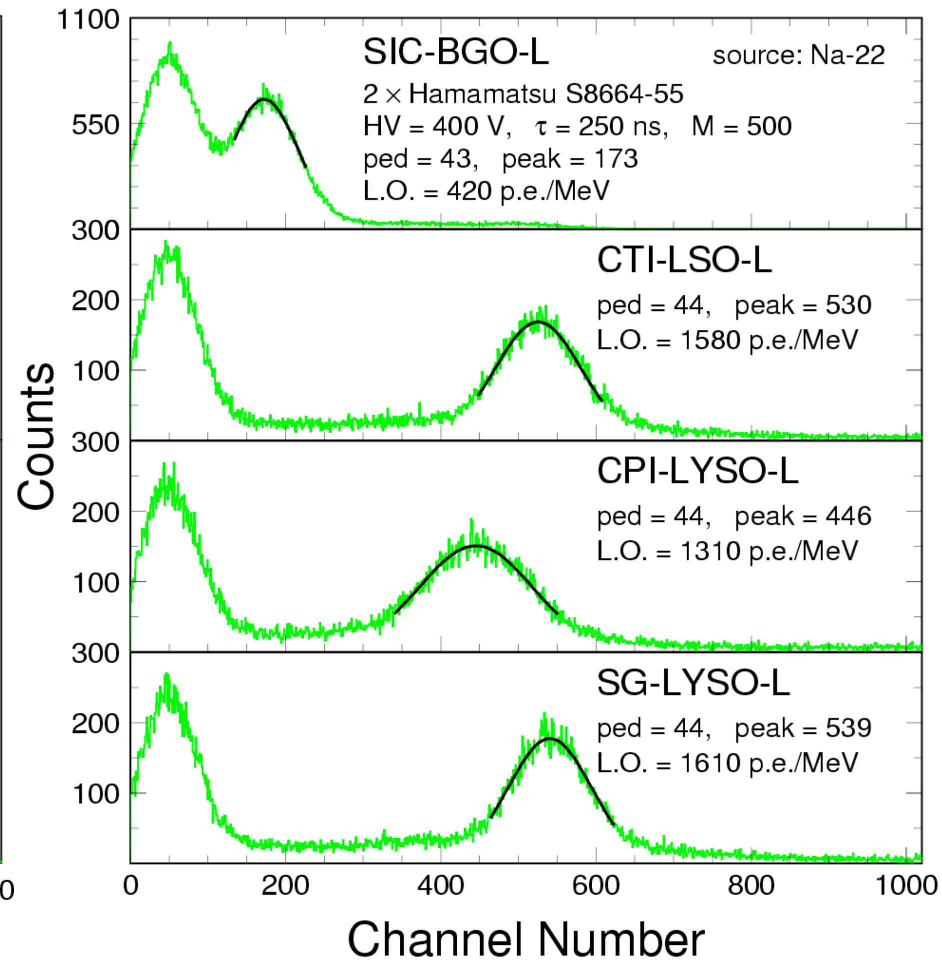
11% FWHM resolution for ^{22}Na source (0.511 MeV)
40 ns, 1,200 p.e./MeV, 5/230 times of BGO/PWO



LSO/LYSO with APD Readout

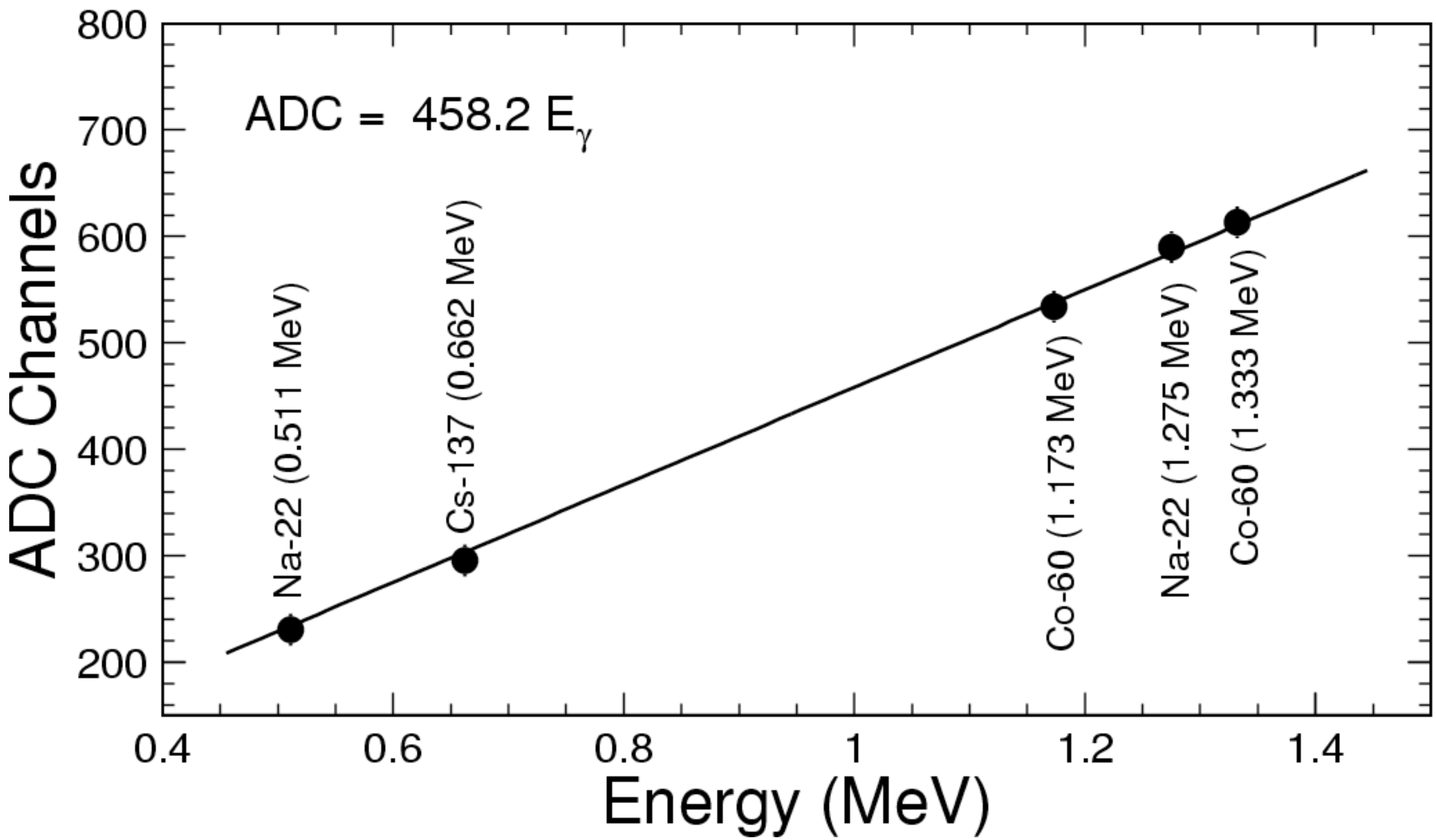
L.O.: 1,500 p.e./MeV, 4/200 times of BGO/PWO
Readout Noise: < 40 keV





Excellent Linearity: > 0.511 MeV

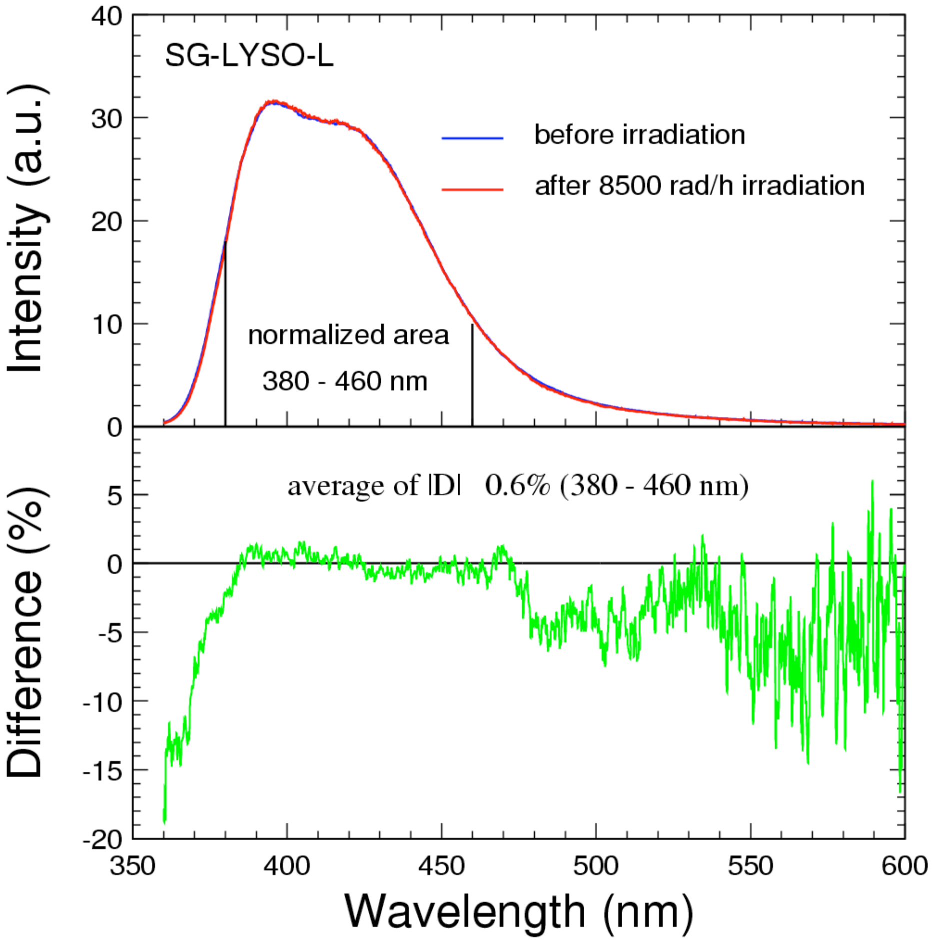
Observed with APD readout

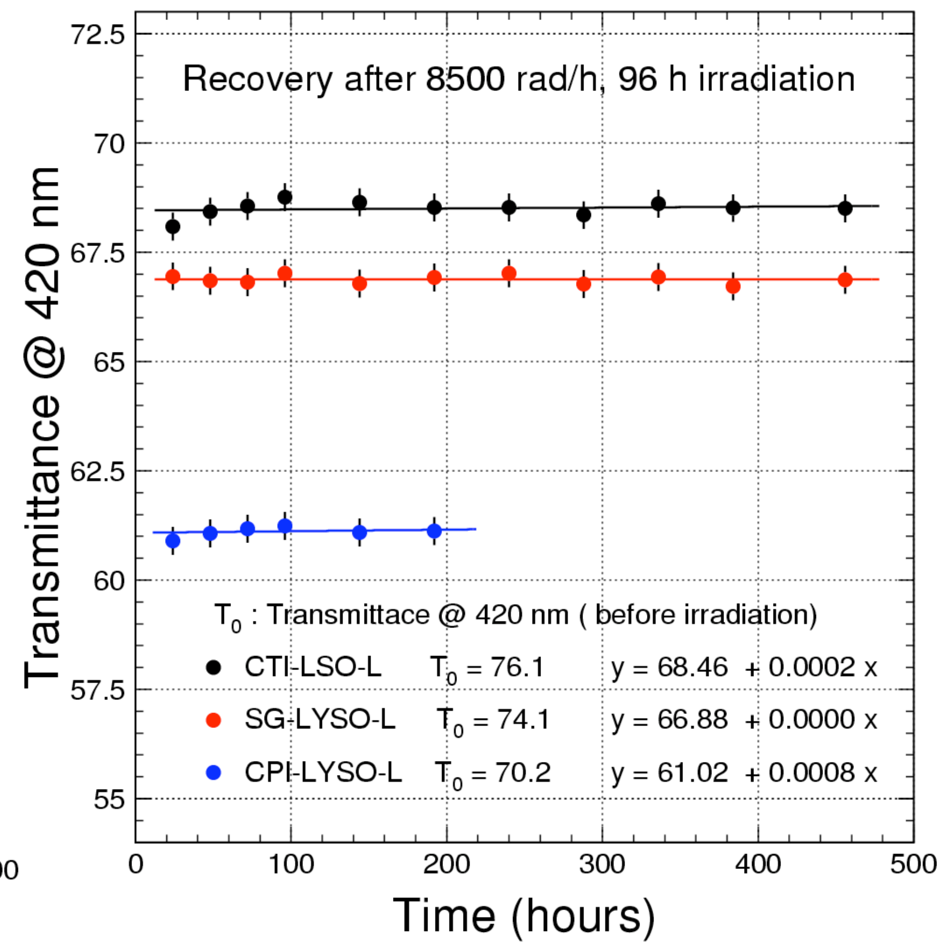


γ-Ray Induced Damage

No damage in photo-luminescence

Transmittance recovery slow

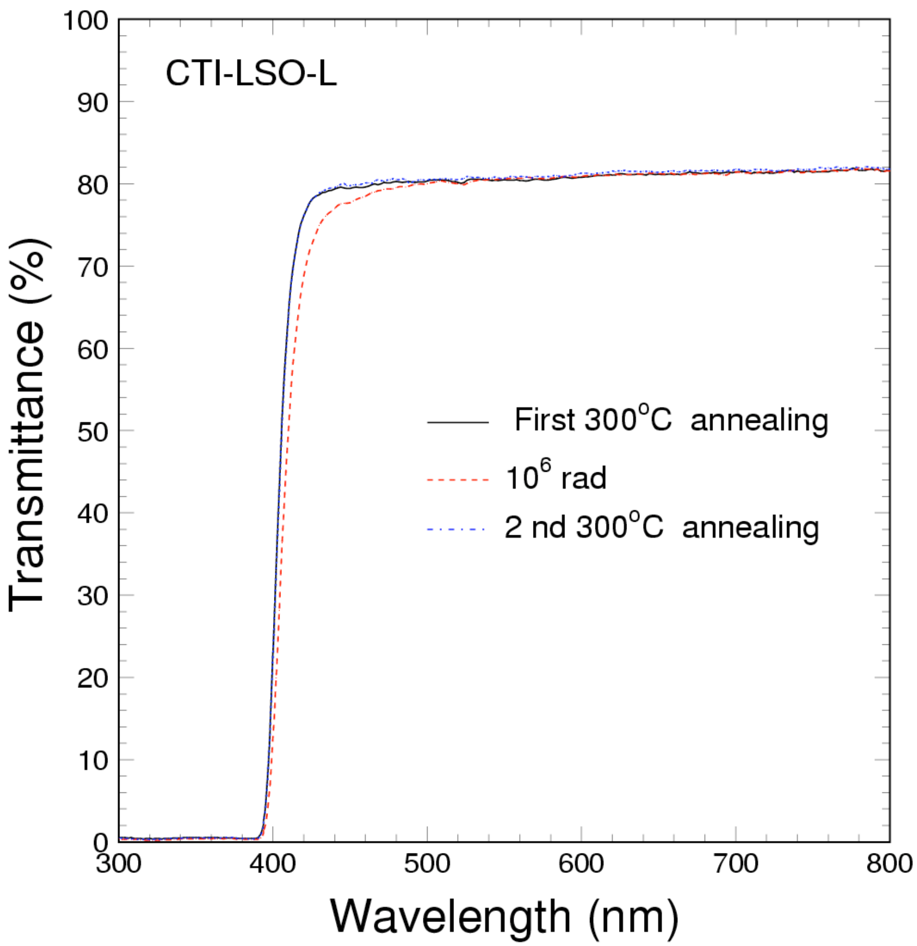


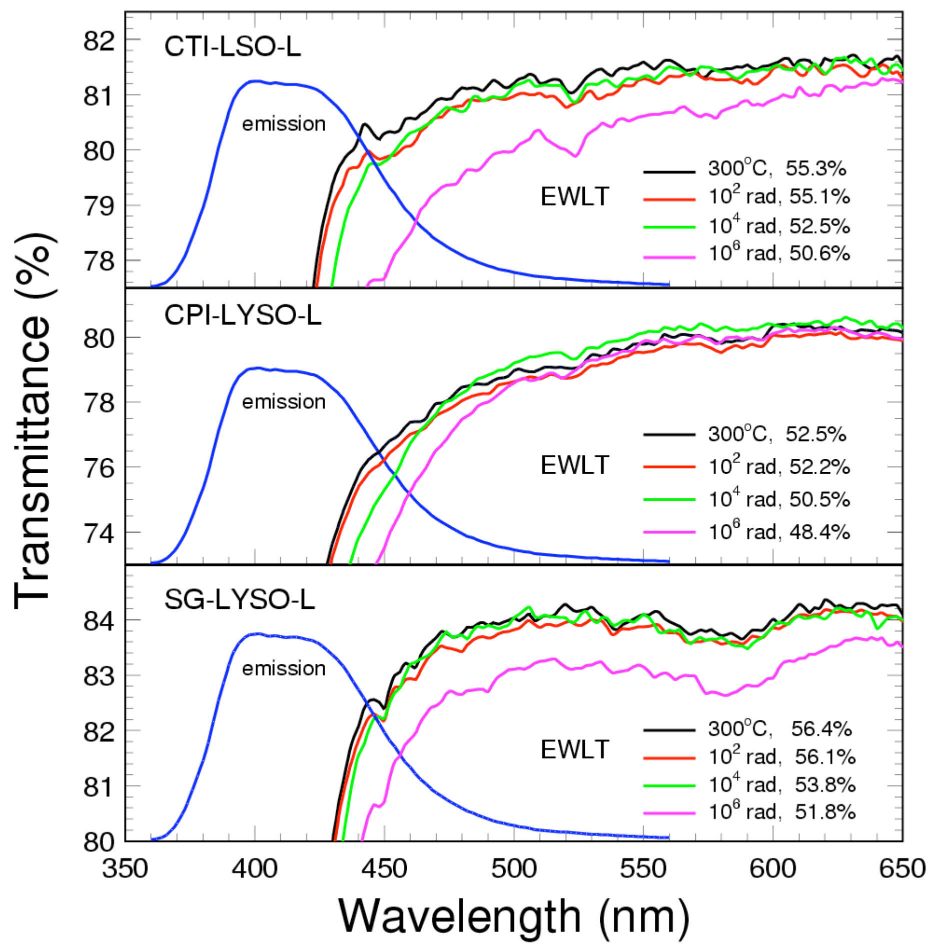


γ-Ray Induced Transmittance Damage

300°C thermal annealing effective

LT damage: 8% @ 1 Mrad



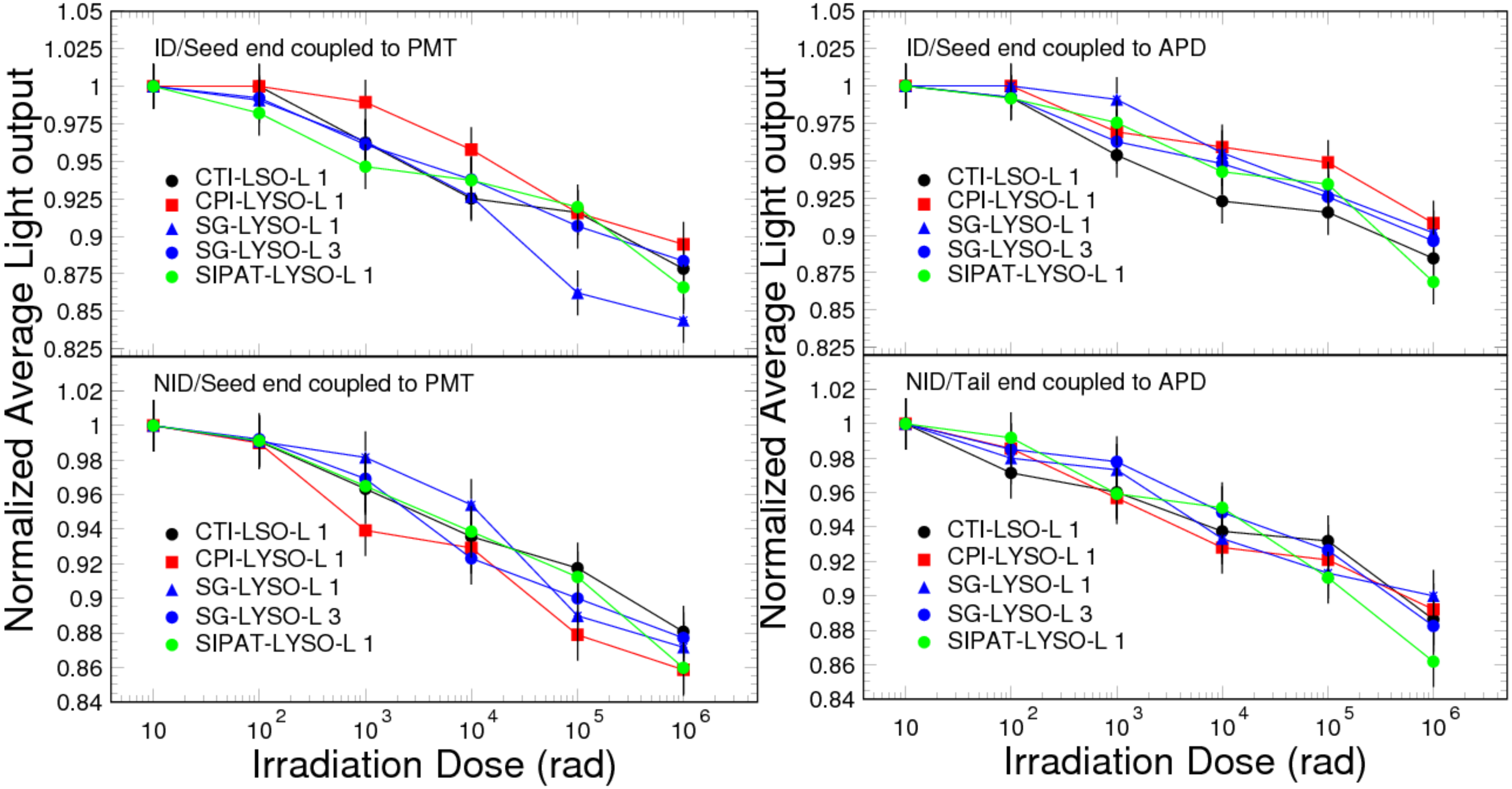


About 10% L.O. Loss after 1 Mrad

All samples show consistent radiation resistance

10% - 15% loss by PMT

9% - 14% loss by APD



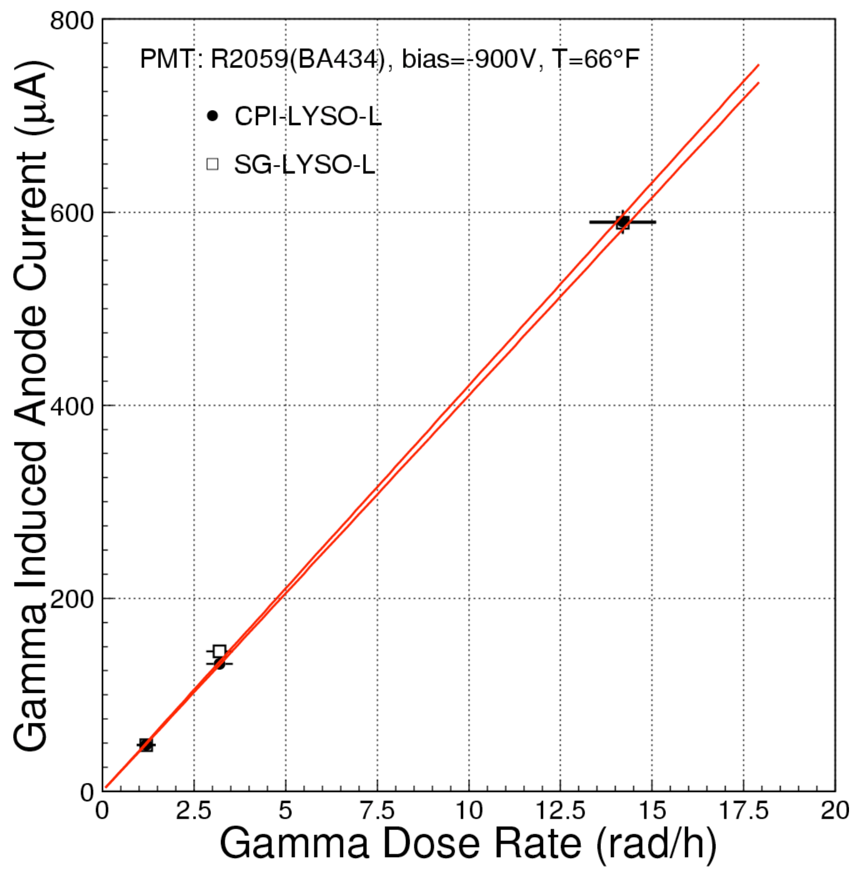
LSO/LYSO ECAL Performance

- Less demanding to the environment because of -0.2%/^{o}C T coefficient.
- This material is expected to survive better the SLHC radiation environment.
- A better energy resolution, σ(E)/E, at low energies than L3 BGO and CMS PWO may be achieved because of its high light output and low readout noise:

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

γ–Ray Induced Readout Noise

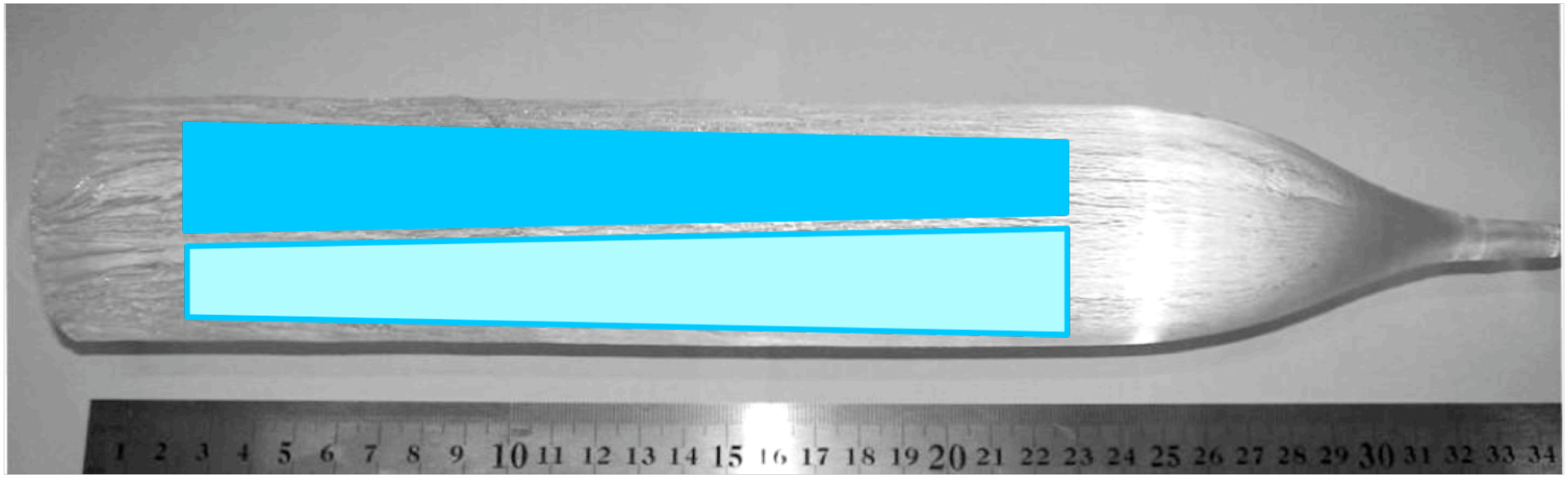
Sample ID	L.Y. p.e./MeV	F μA/rad/h	$Q_{15\ rad/h}$ p.e.	$Q_{500\ rad/h}$ p.e.	$\sigma_{15\ rad/h}$ MeV	$\sigma_{500\ rad/h}$ MeV
CPI	1,480	41	6.98×10^4	2.33×10^6	0.18	1.03
SG	1,580	42	7.15×10^4	2.38×10^6	0.17	0.97



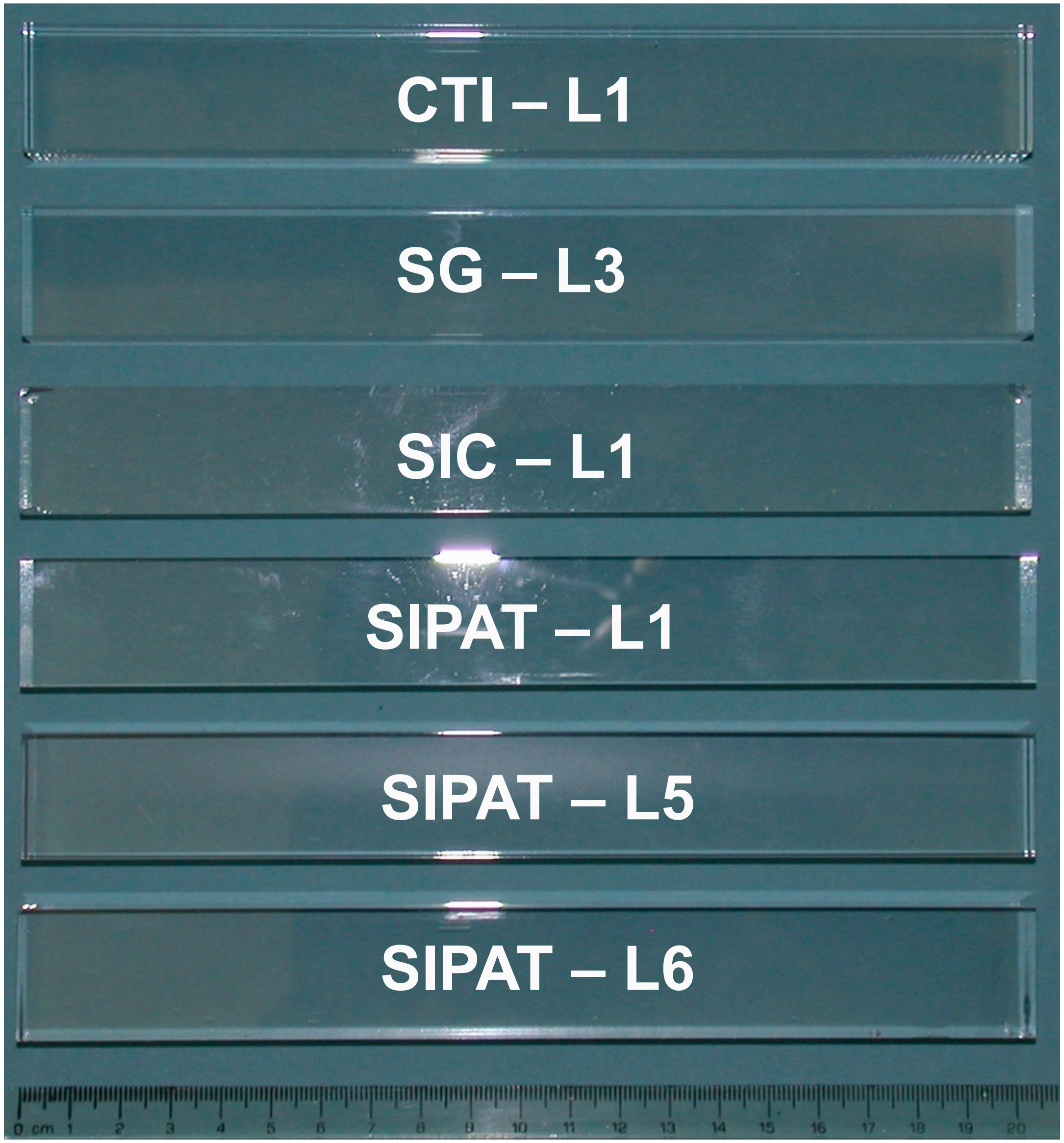
γ–ray induced PMT anode current can be converted to the photoelectron numbers (Q) integrated in 100 ns gate. Its statistical fluctuation contributes to the readout noise (σ): 0.2 & 1 MeV @ 15 & 500 rad/h.

Issues to be addressed

Φ60 ingot may be cut to two crystals, significantly increasing the usage of ingot. A key issue is the light response uniformity, which is crucial to achieve crystal resolution. The distribution of the cerium activator with 0.15 segregation, however, is not uniform along the crystal. Work is needed to achieve designed uniformity.

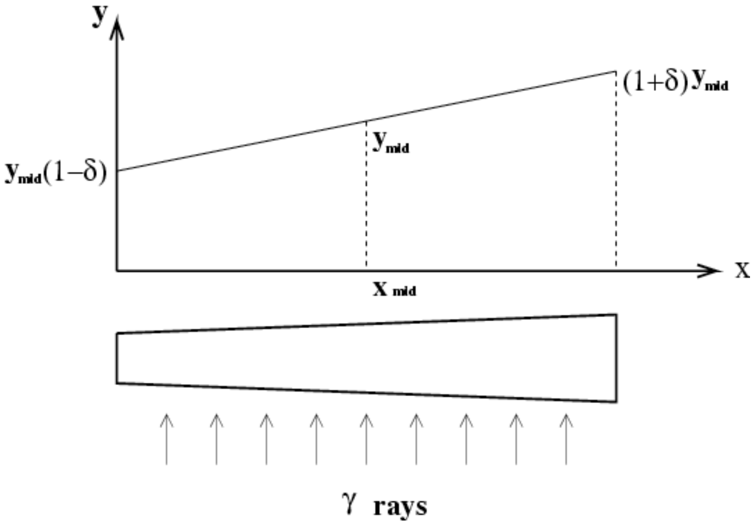


Light Response Uniformity



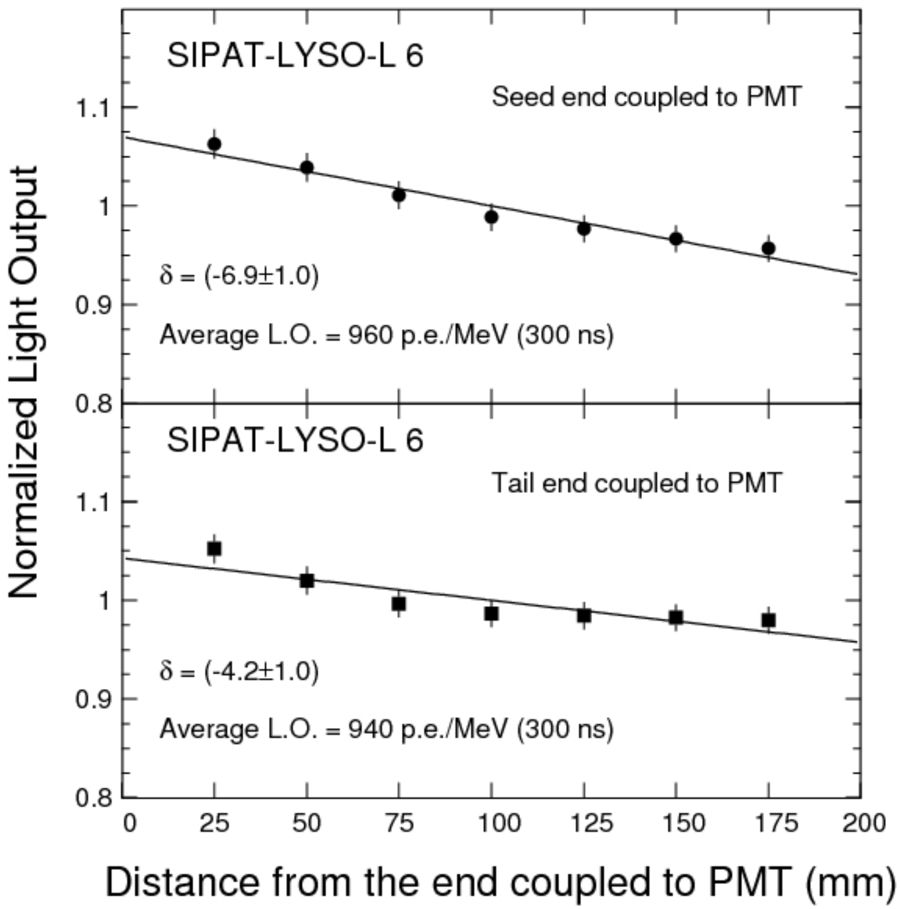
25 x 25 x 200 mm samples measured for their L.R.U. and fit to a linear function

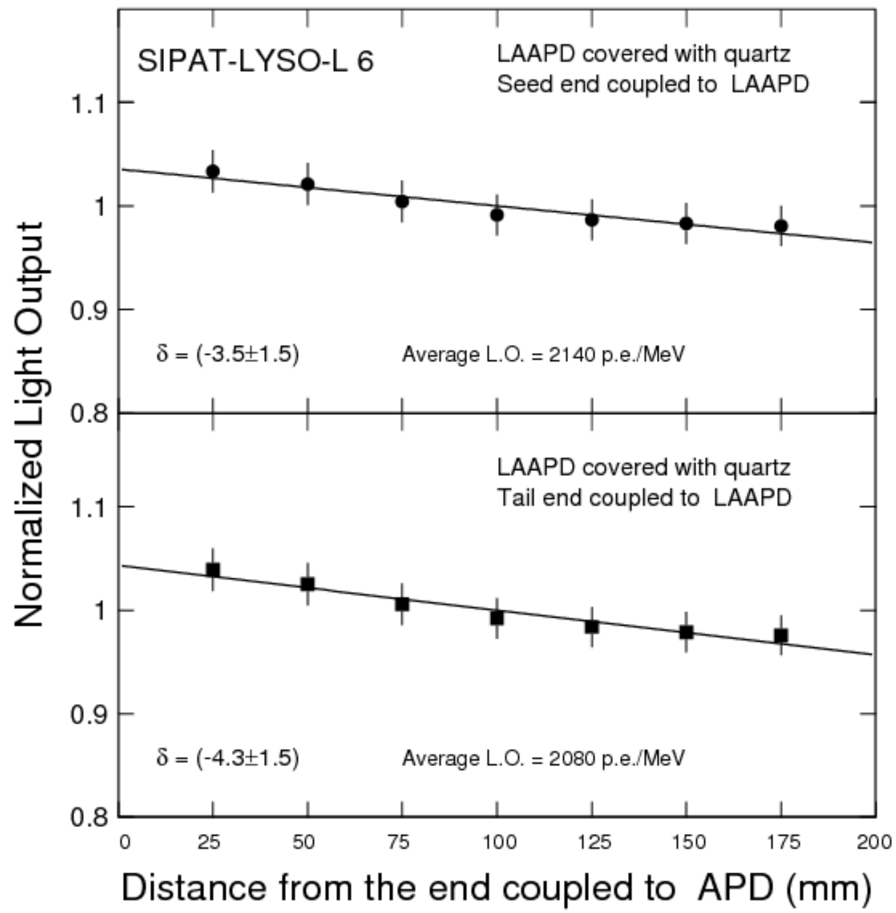
$$Y = Y_{mid}\left[1 + \delta(x/x_{mid} - 1)\right]$$



Progress in 2009 (I)

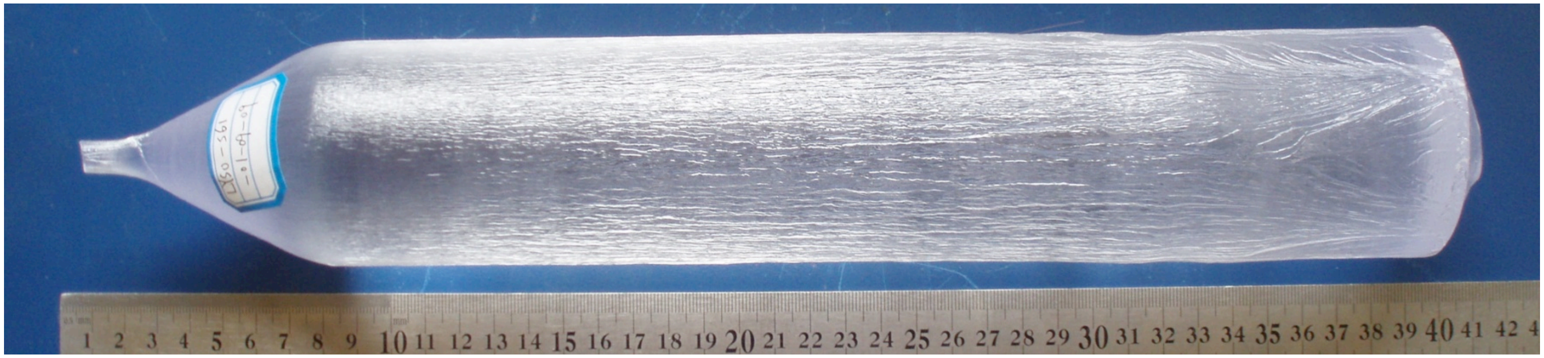
SIPAT-LYSO-L6: Consistent slopes for PMT and APD readout. They may be compensated by the optical focusing effect.





Progress in 2009 (II)

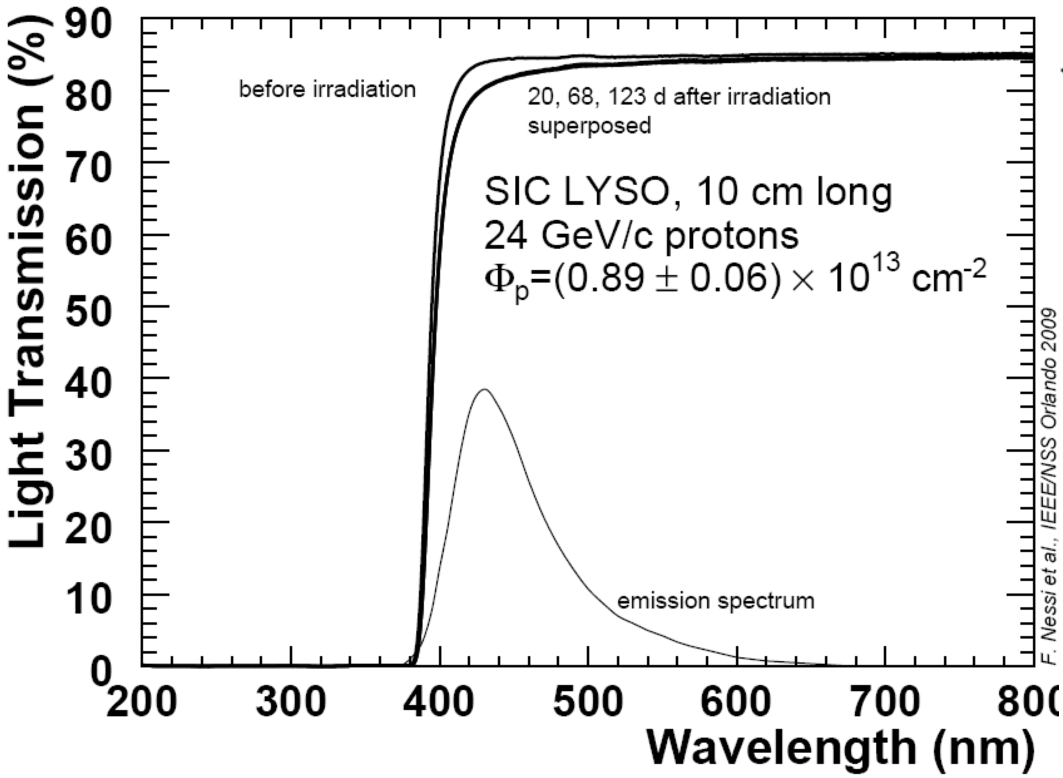
The 1st Φ61x 310 mm LYSO ingot was successfully grown recently at SIPAT, which may be cut into two 28 cm (25 X_0) crystals.

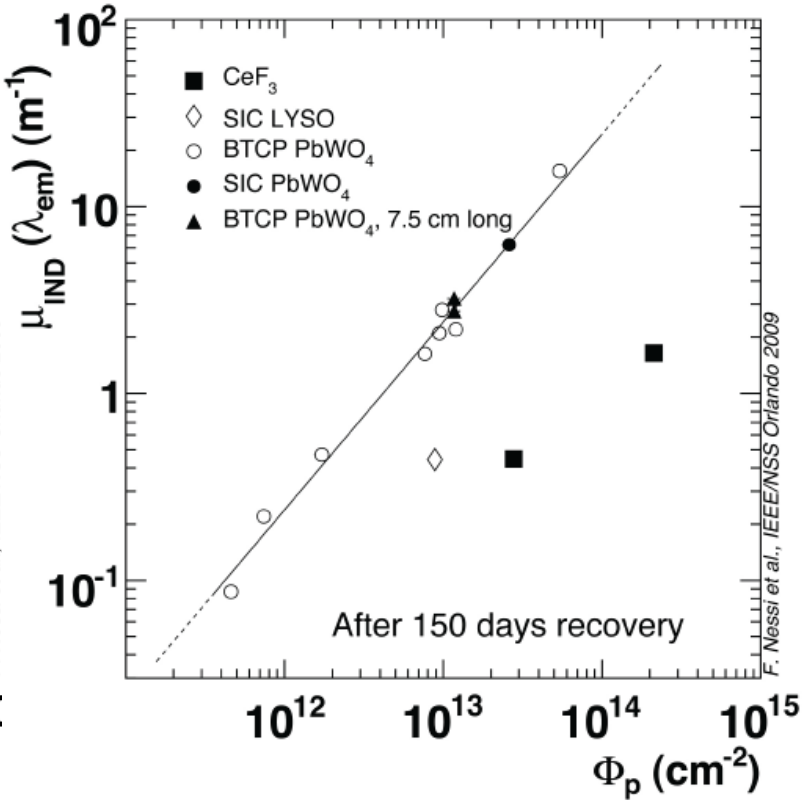


The Caltech crystal laboratory is looking forward to test the 1st 2.5 x 2.5 x 28 cm sample.

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. See talk by Guenther Dissertori in this workshop (30 mins ago).

Summary

- LYSO crystals with bright, fast scintillation and excellent radiation hardness are a good candidate material for the forward calorimeter at the SLHC.
- While the quality of LYSO crystals is adequate for low energy applications, such as KLOE-2 and SuperB, work is needed to further develop crystals for the SLHC. A upgrade R&D proposal for CMS is underway. Support from the US CMS upgrade program is crucial for this effort.

LSO/LYSO Mass Production

CTI: LSO	CPI: LYSO	Saint-Gobain LYSO
 	 	

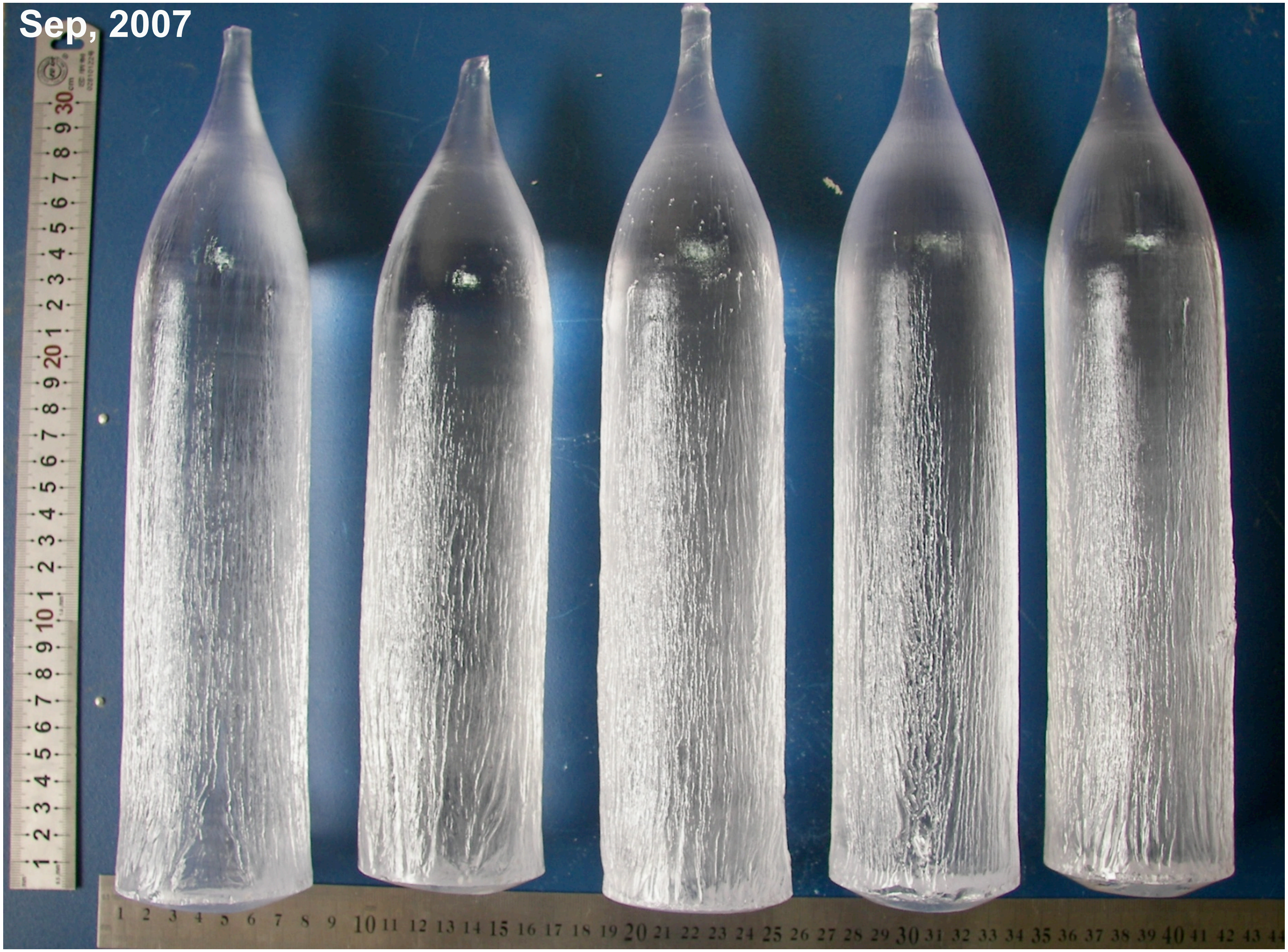
Additional Capability: SIPAT @ Sichuan and SICCAS @ Shanghai, China

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

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

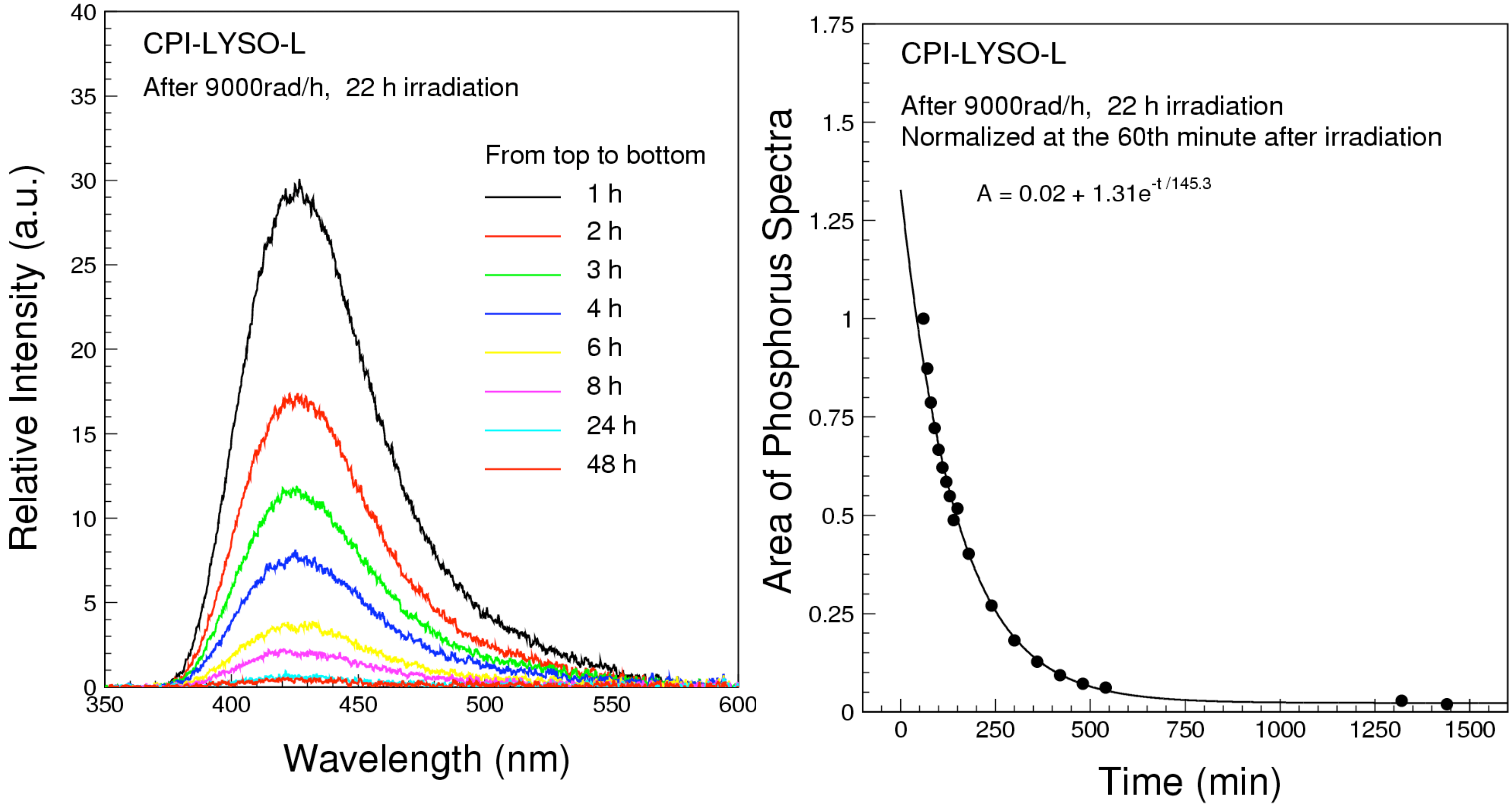
SIPAT Czochralski Furnaces

SIPAT Ø60 x 250 mm LYSO Ingots



γ–Ray Induced Phosphorescence

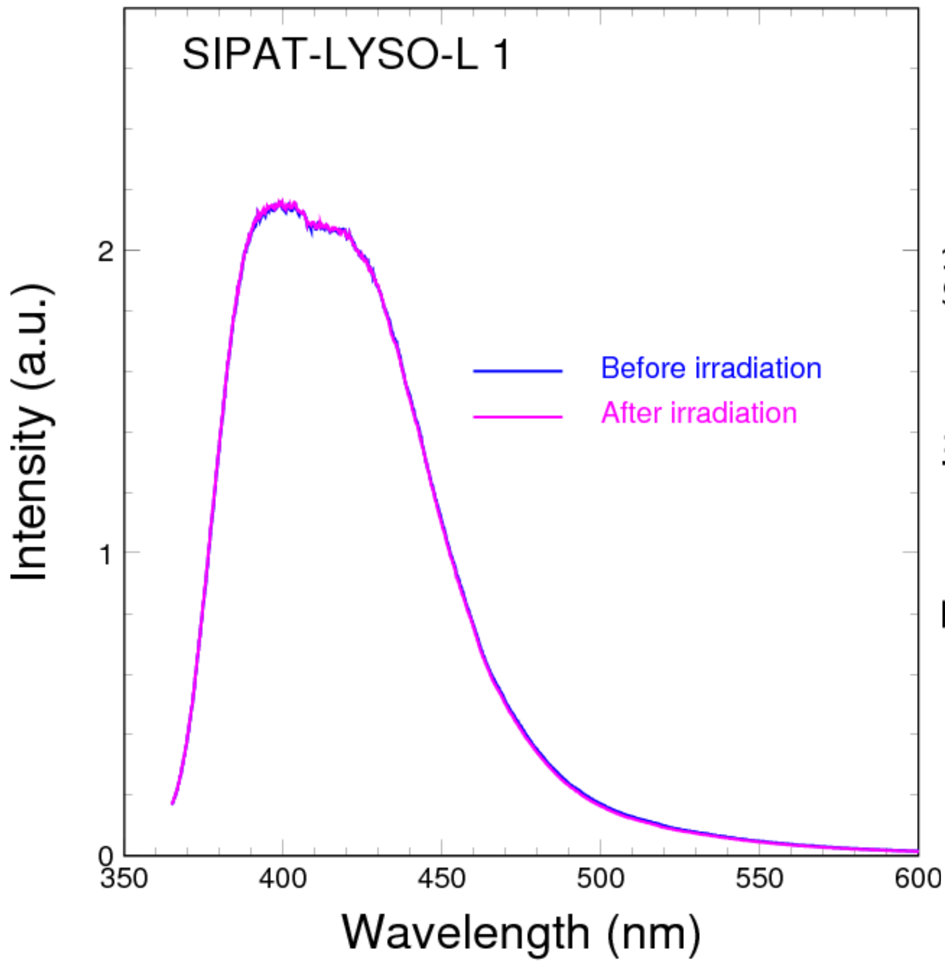
Phosphorescence peaked at 430 nm
with decay time constant of 2.5 h observed

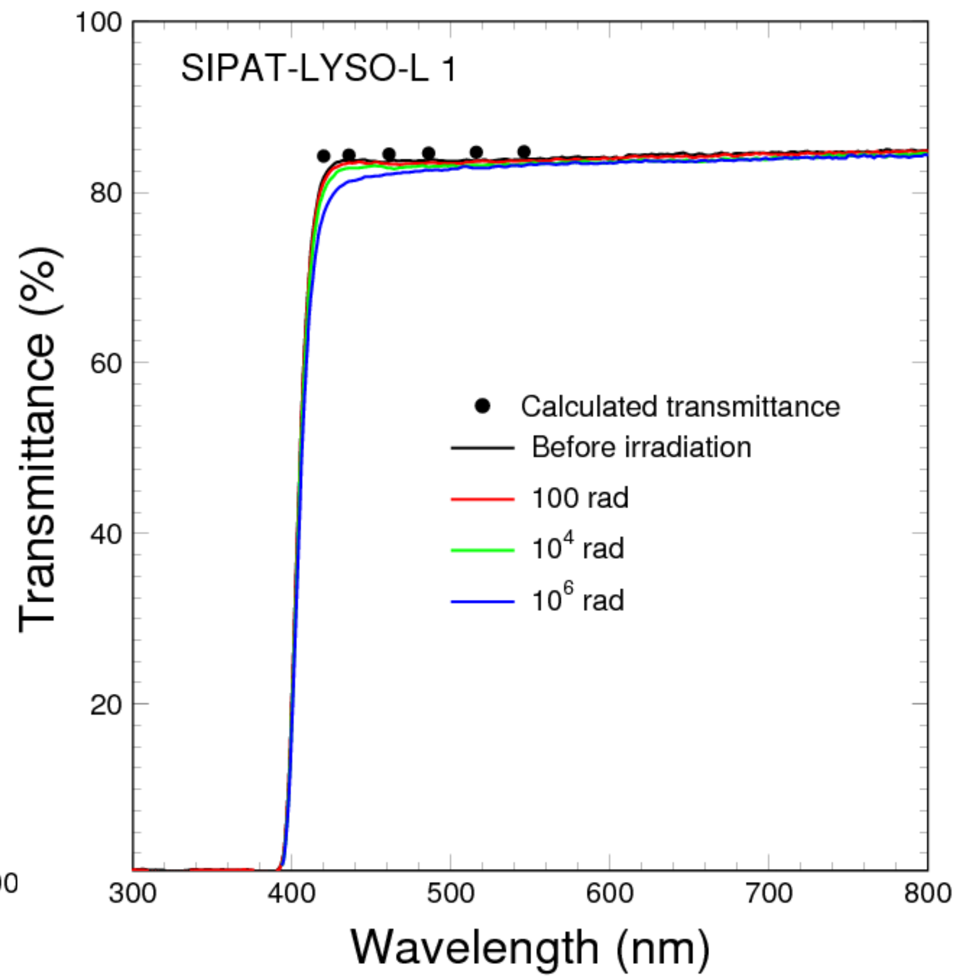


Similar γ-Ray Damage in SIPAT LYSO

Scintillation spectrum not affected by irradiation

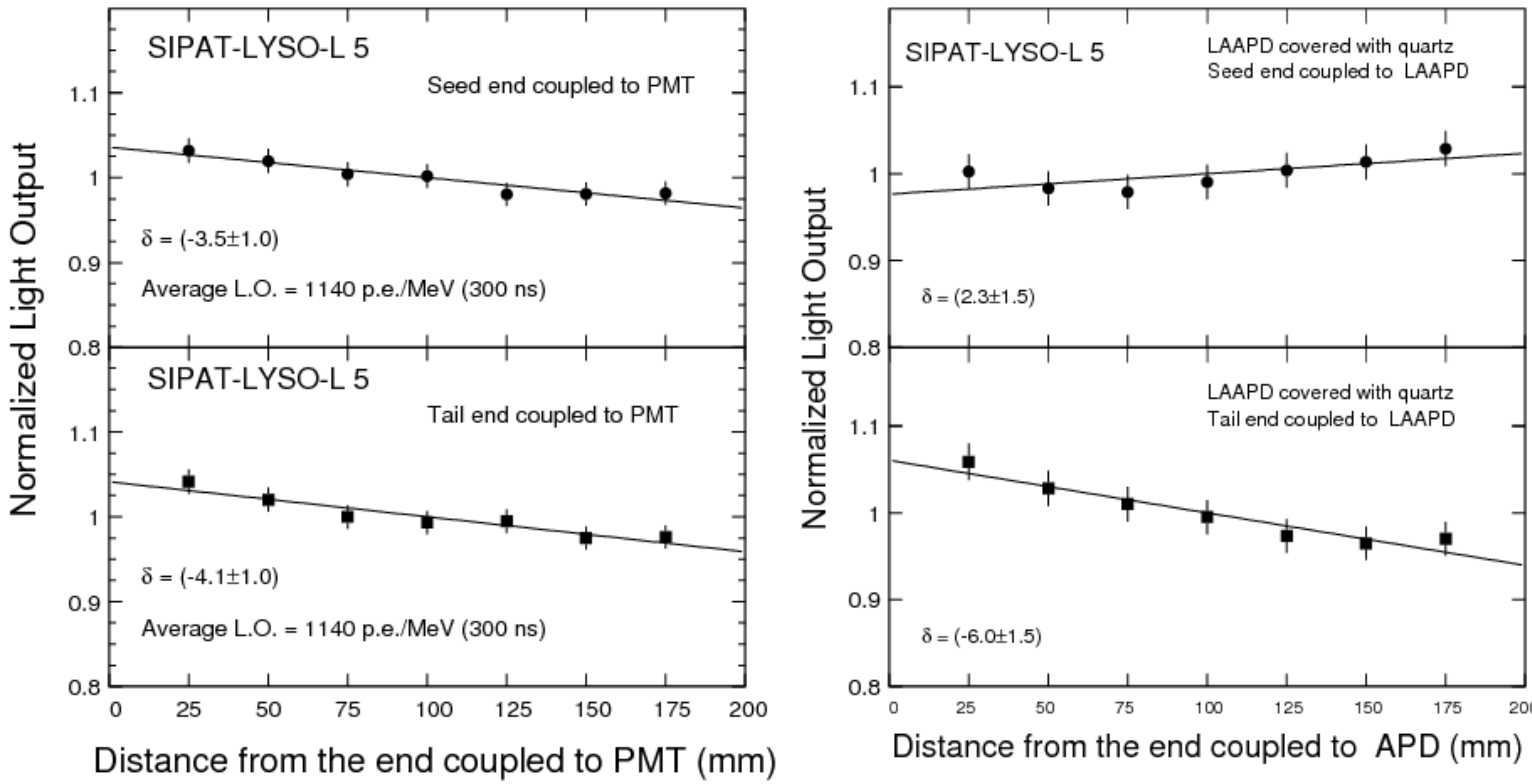
~8% damage @ 420 nm after 1 Mrad irradiation





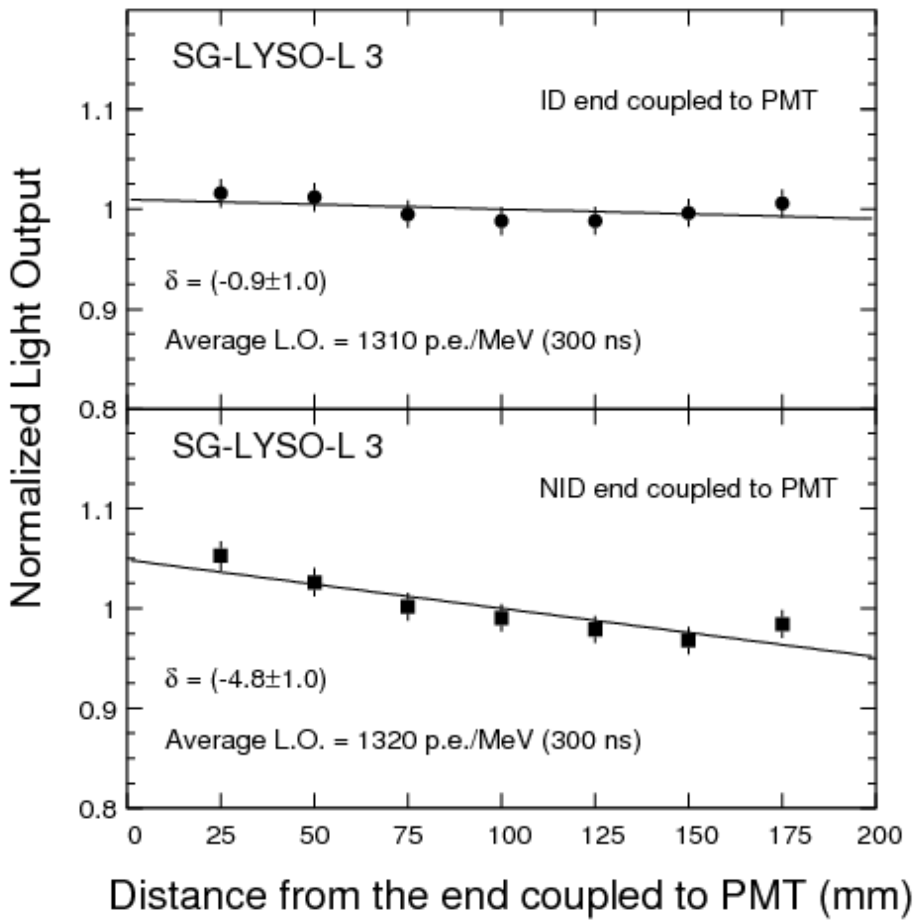
L.R.U. by PMT & LAAPD: SIPAT-LYSO-L5

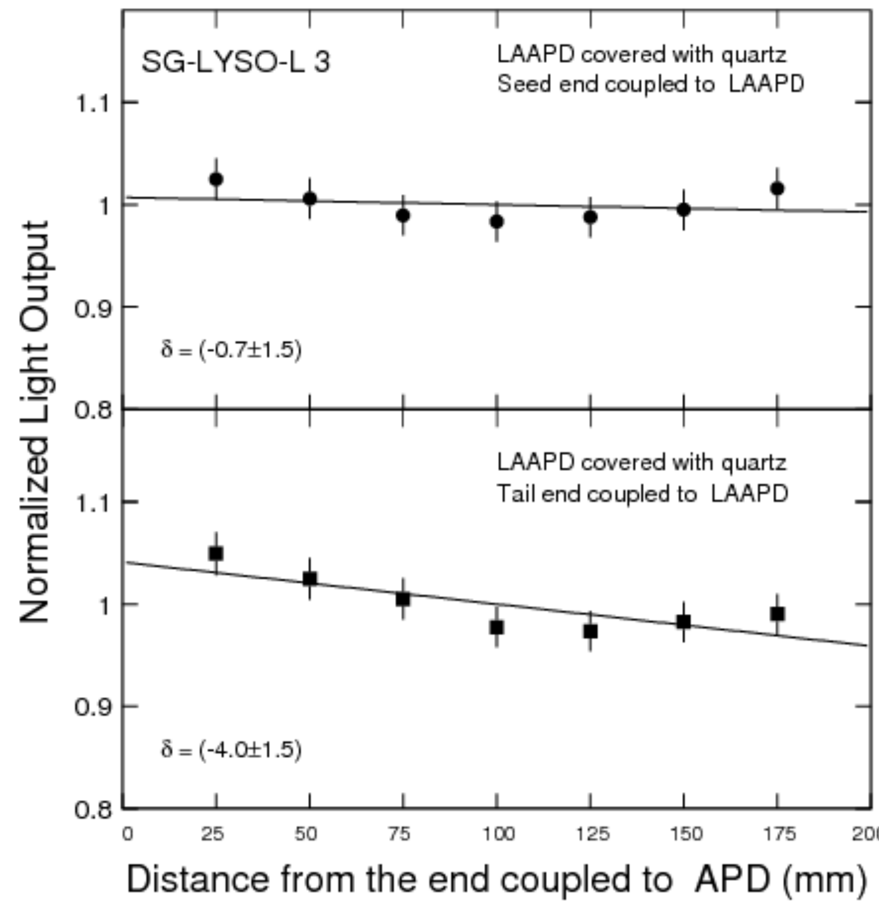
Issue: Ce doping was optimized for the uniformities measured by PMT with two end-couplings, but a large difference observed between the PMT & APD readouts.



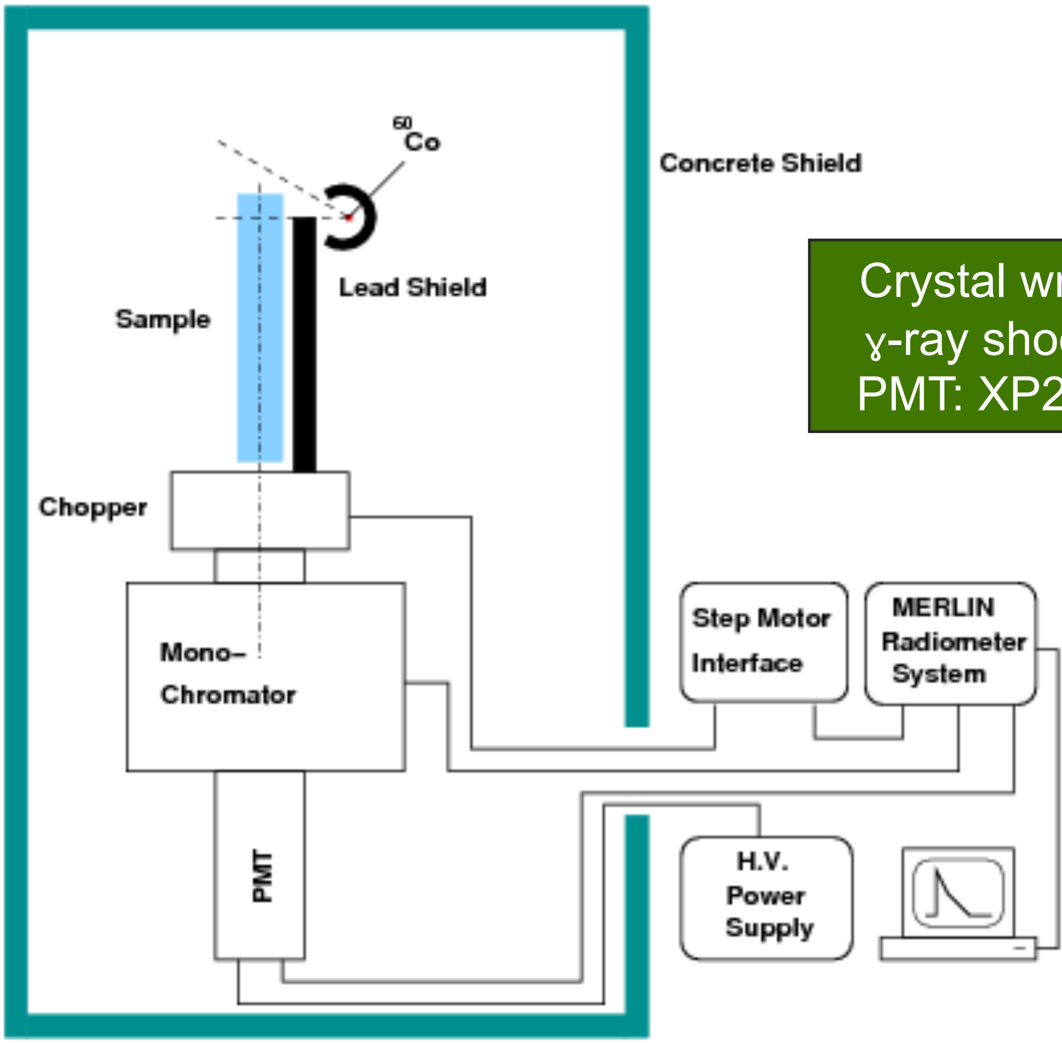
L.R.U. by PMT & LAAPD: SG-LYSO-L3

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





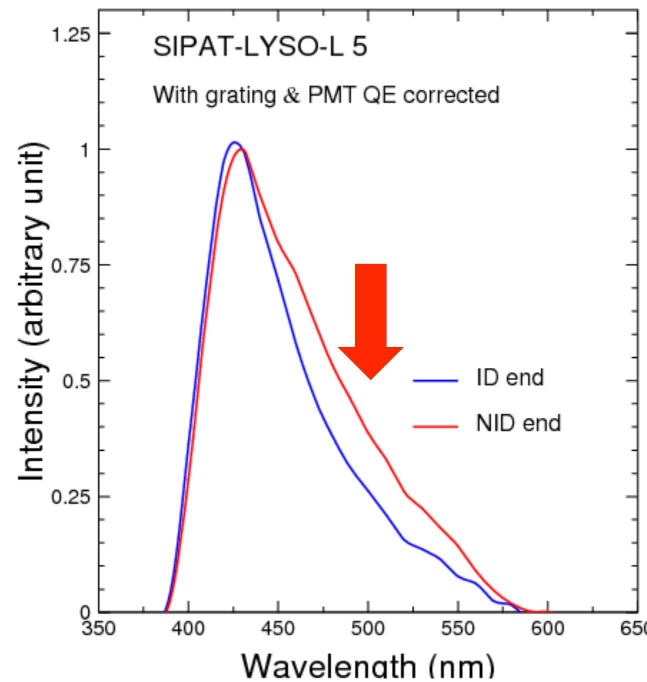
Radio-luminescence for LSO/LYSO

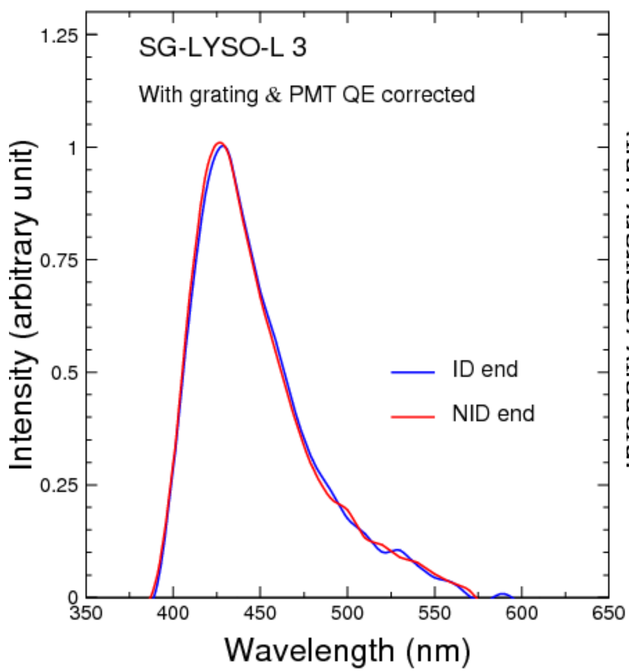


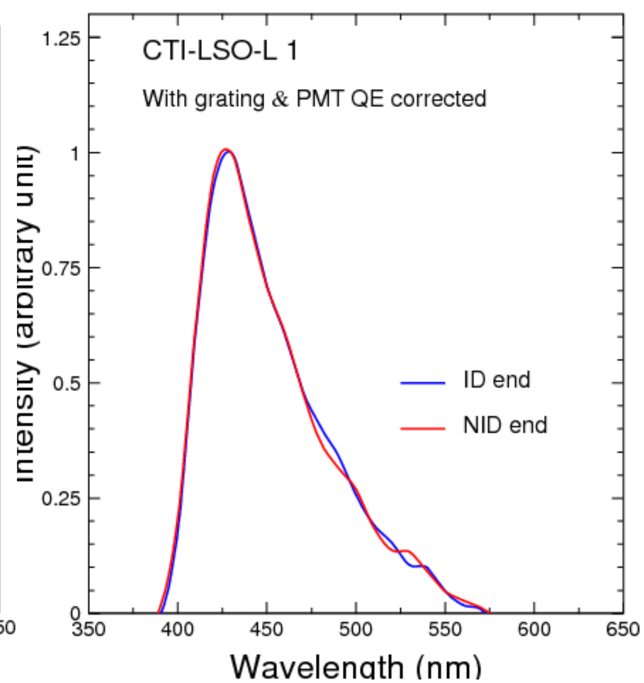
Crystal wrapped with Tyvek paper;
ɣ-ray shooting at two ends (1 cm);
PMT: XP2254B running @ -1800V.

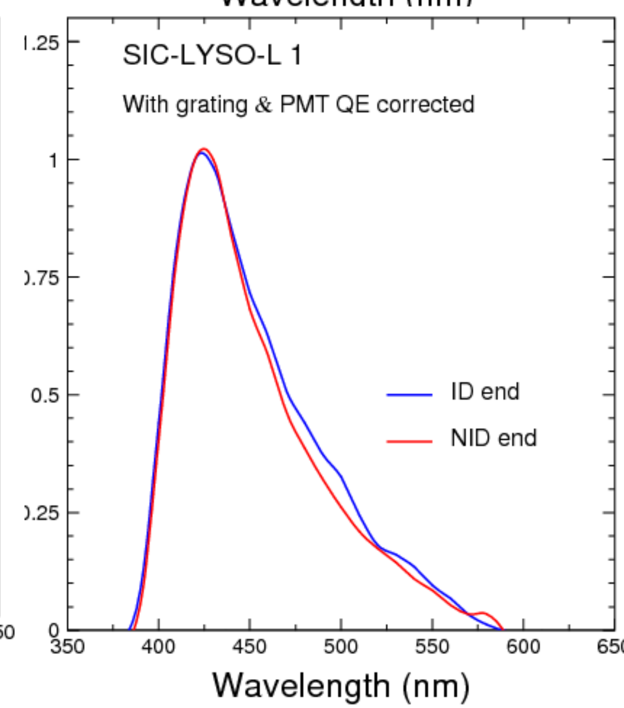
Radio-luminescence

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