Update on LYSO Studies

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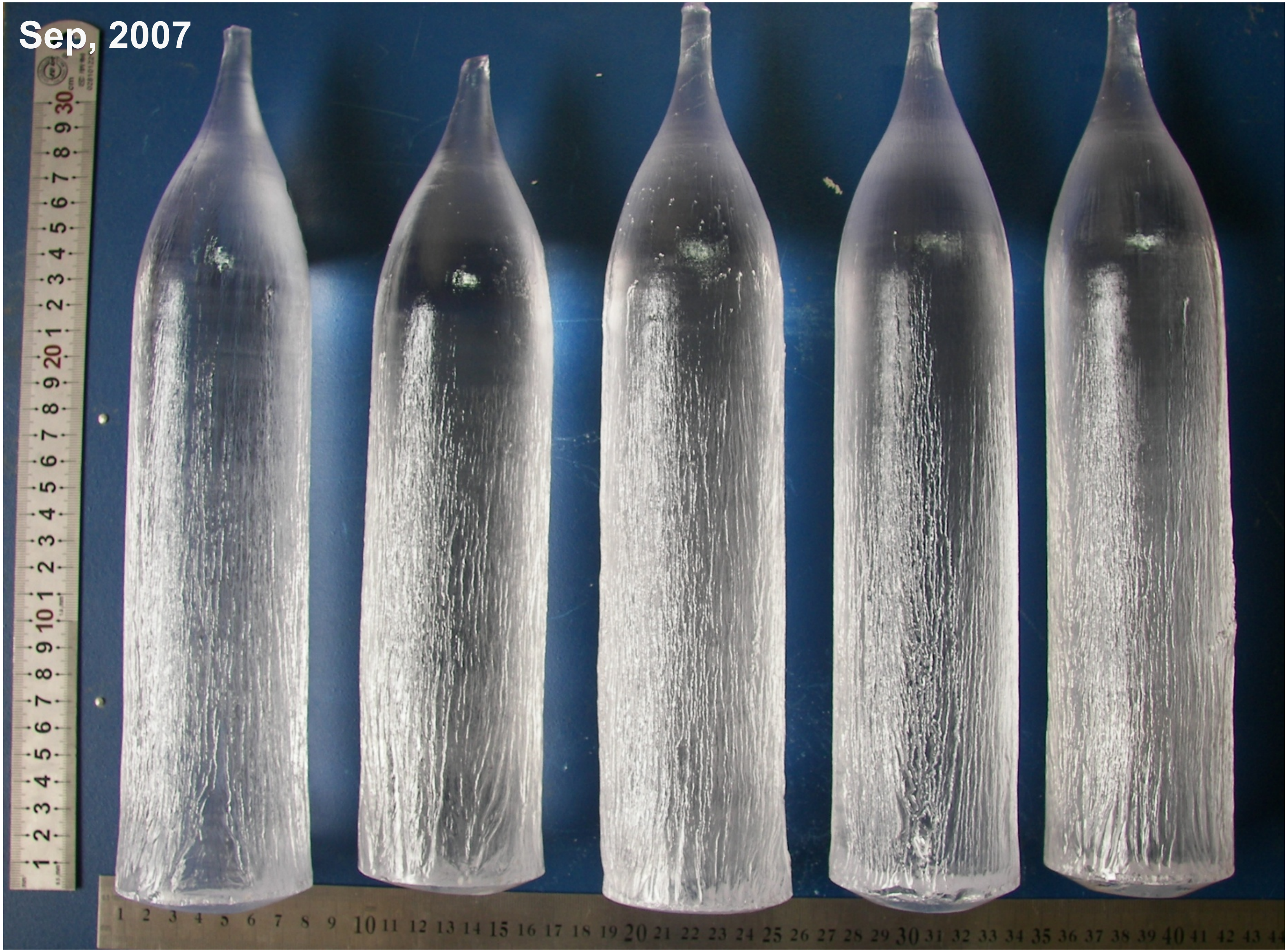
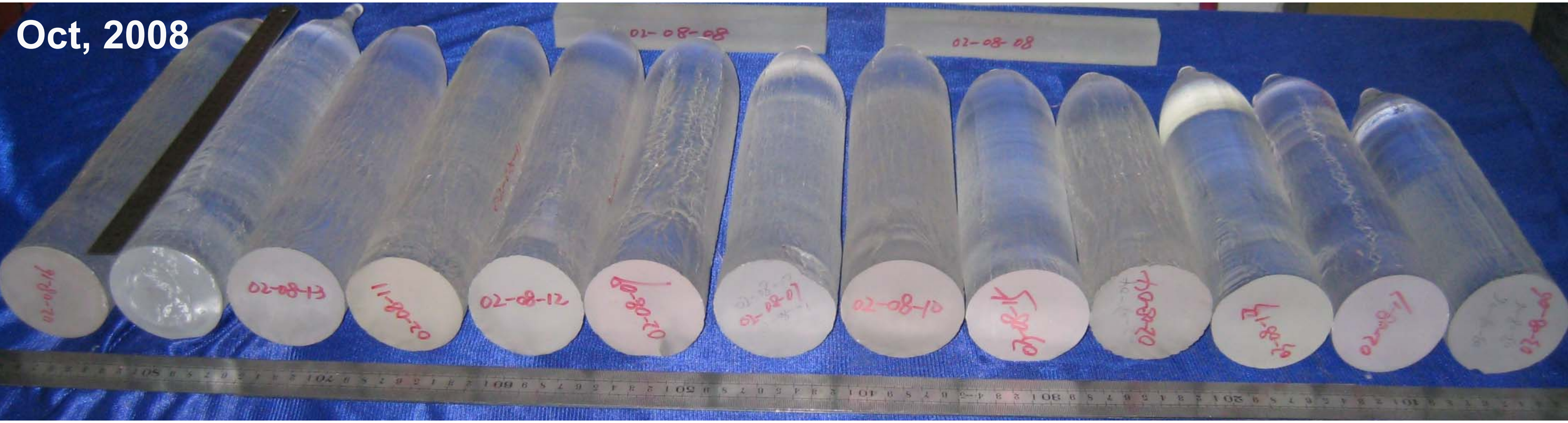
SIPAT Ø60 x 250 mm LYSO Ingots



Production of LYSO at SIPAT

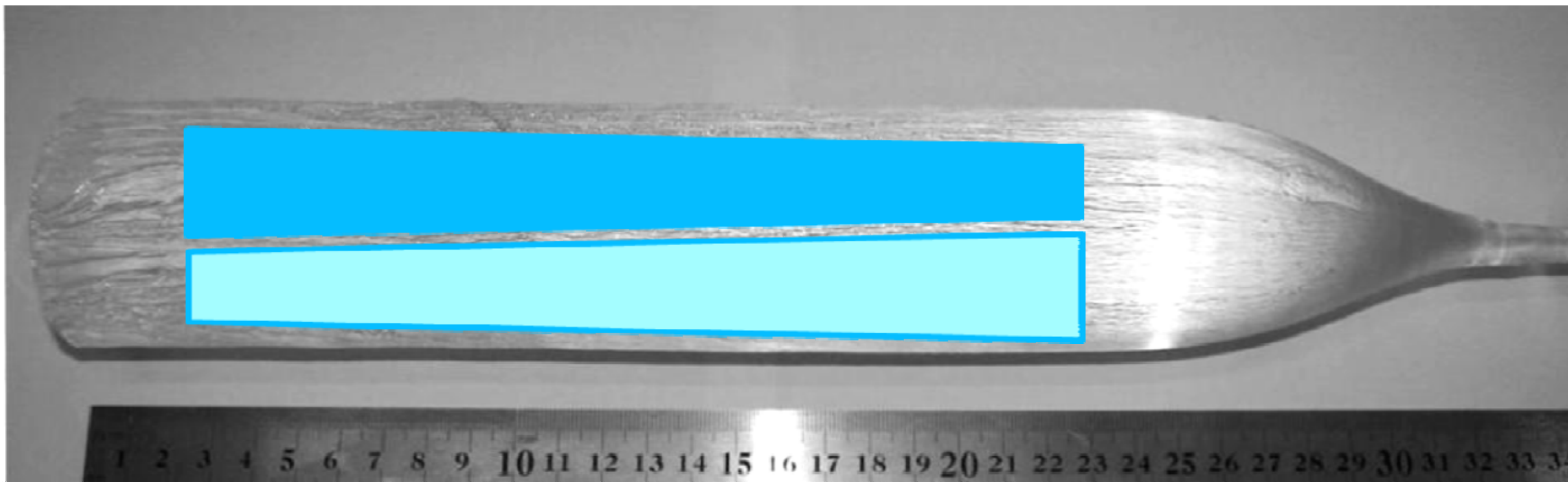


Growth is mature. R&D on following Issues:

- Optimization of Cerium doping;
- Light response uniformity.

LYSO Longitudinal Uniformity

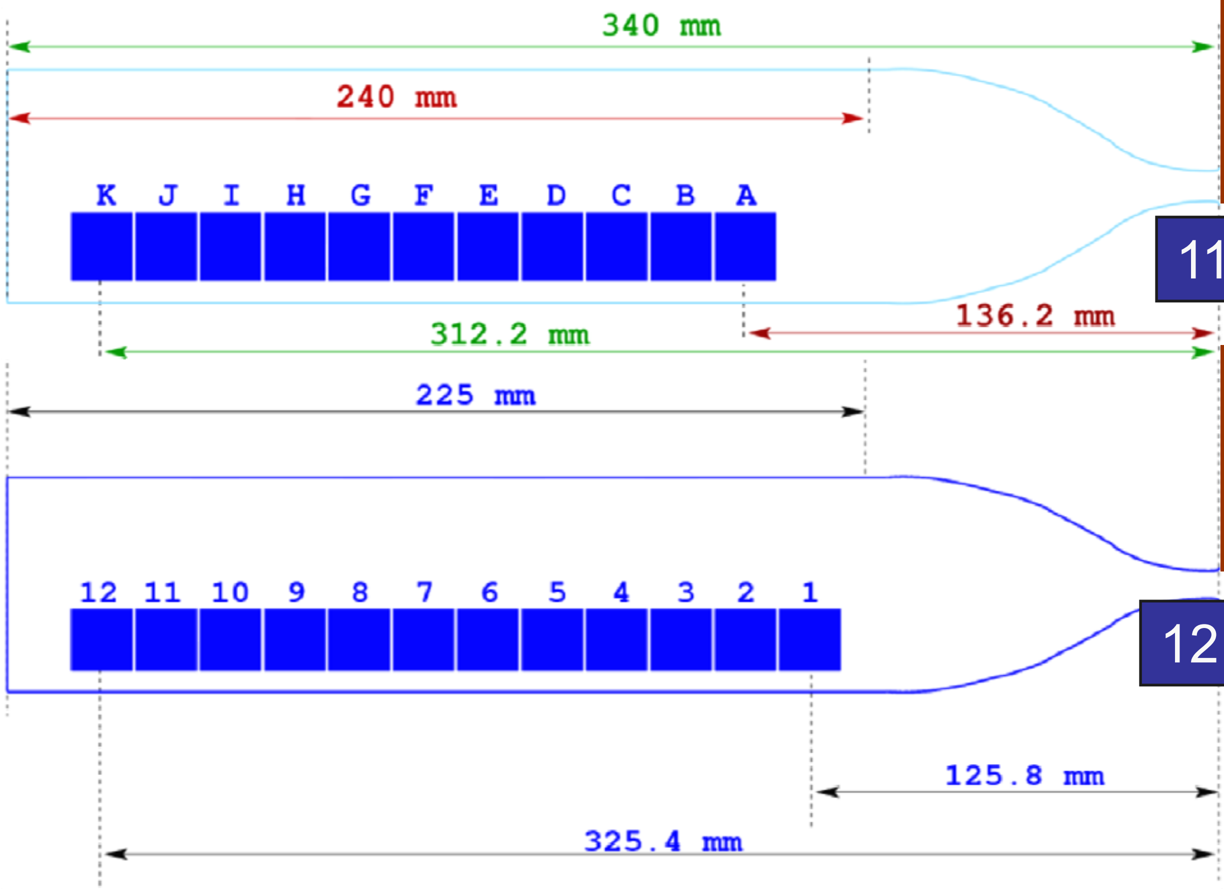
Good light response uniformity is crucial for a crystal calorimeter to achieve its designed energy resolution at high energies. The distribution of the cerium activator, however, is not uniform along the crystal.



Sipat's Φ60 x 250 mm ingot may be cut to two SuperB crystals, significantly increasing the ingot usage. The key issue: longitudinally uniformity.

Cube Samples from SIPAT

Two ingots grown by Czochralski method at SIPAT were cut to 11 & 12 cubes of 1.7 cm.



1st ingot with high cerium

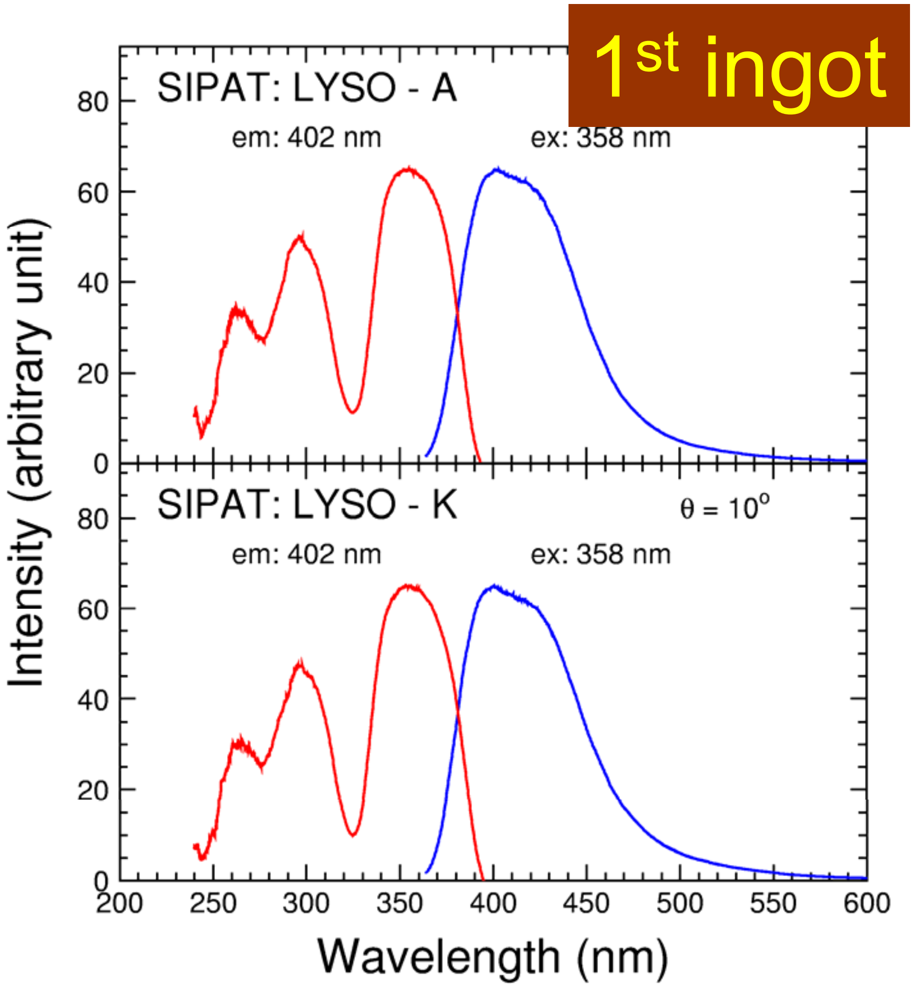
11 cubes of 17 (1.5 X_0) mm^3

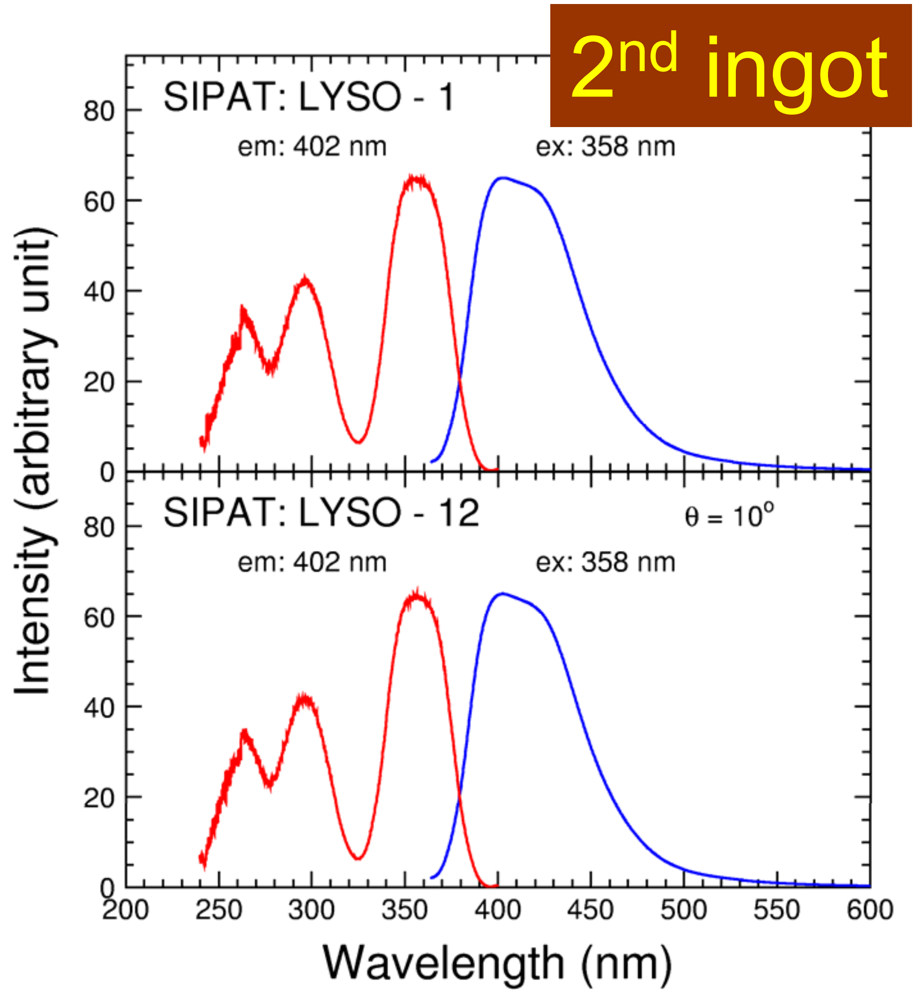
2nd ingot with low cerium

12 cubes of 17 (1.5 X_0) mm^3

UV Excitation & Emission Spectra

Consistent excitation (red) and emission (blue) spectra observed from seed to tail for both ingots.

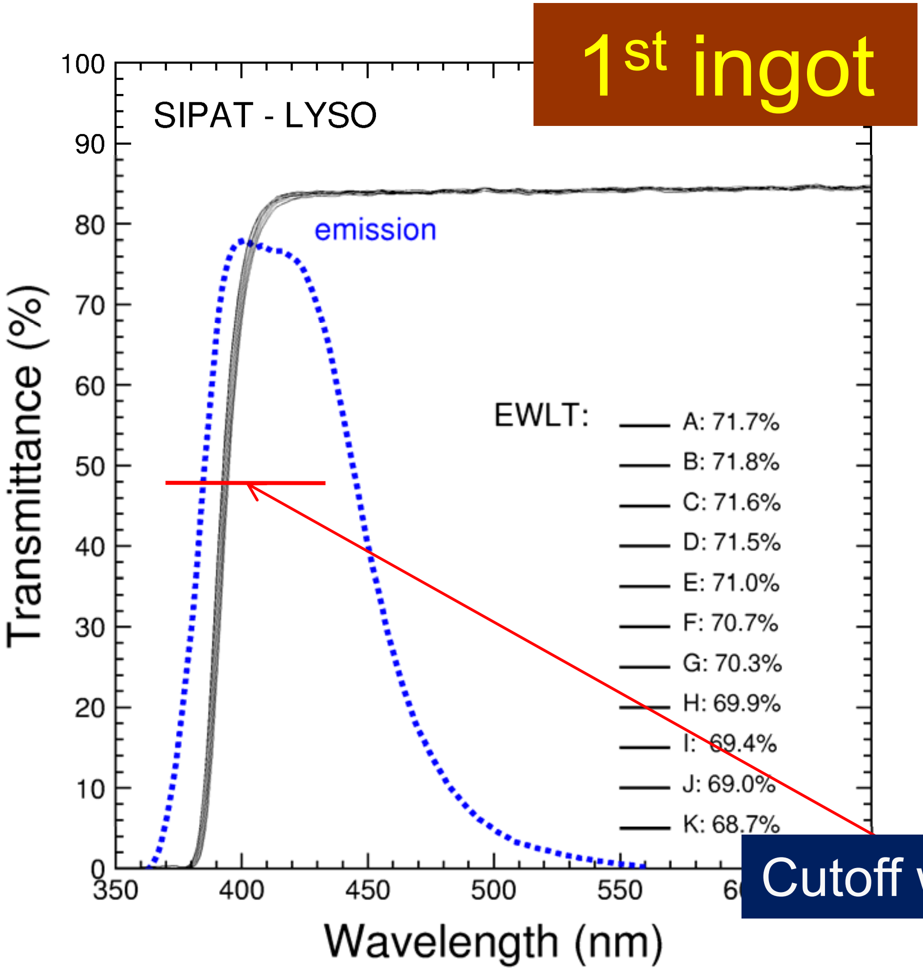


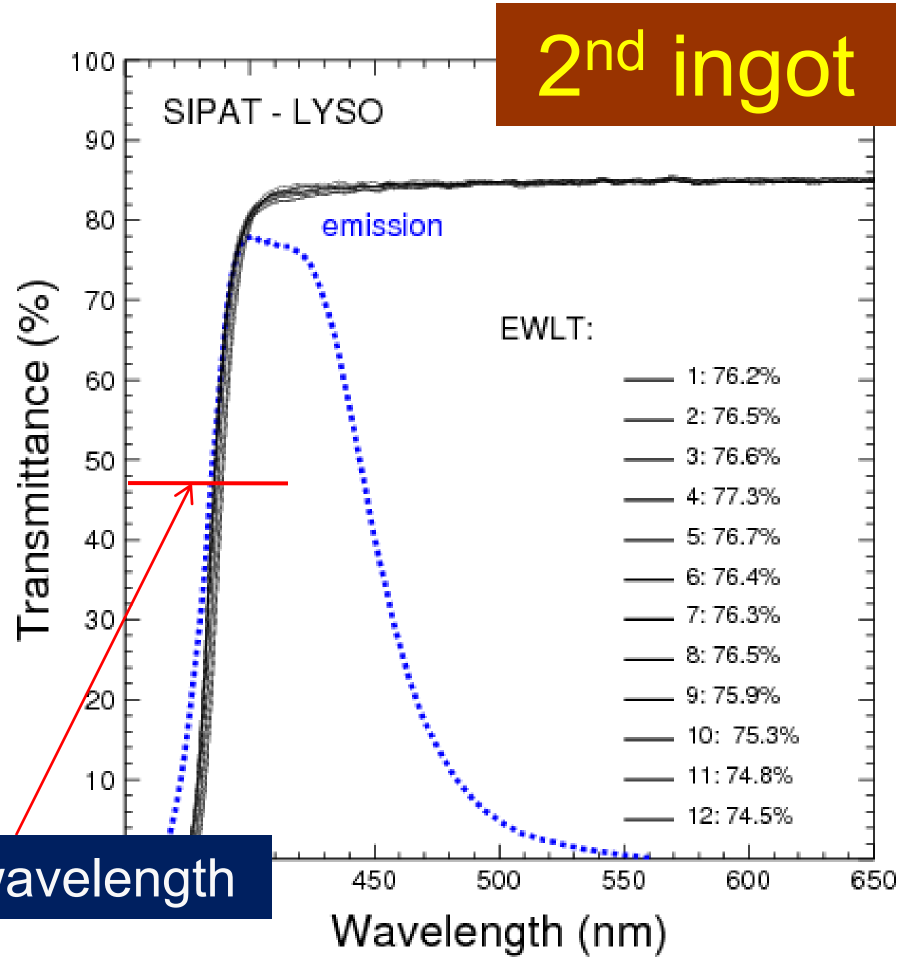


Transmission Spectra

Transmissions are position dependent:

$$EWLT = \frac{\int LT(\lambda)Em(\lambda)d\lambda}{\int Em(\lambda)d\lambda}$$



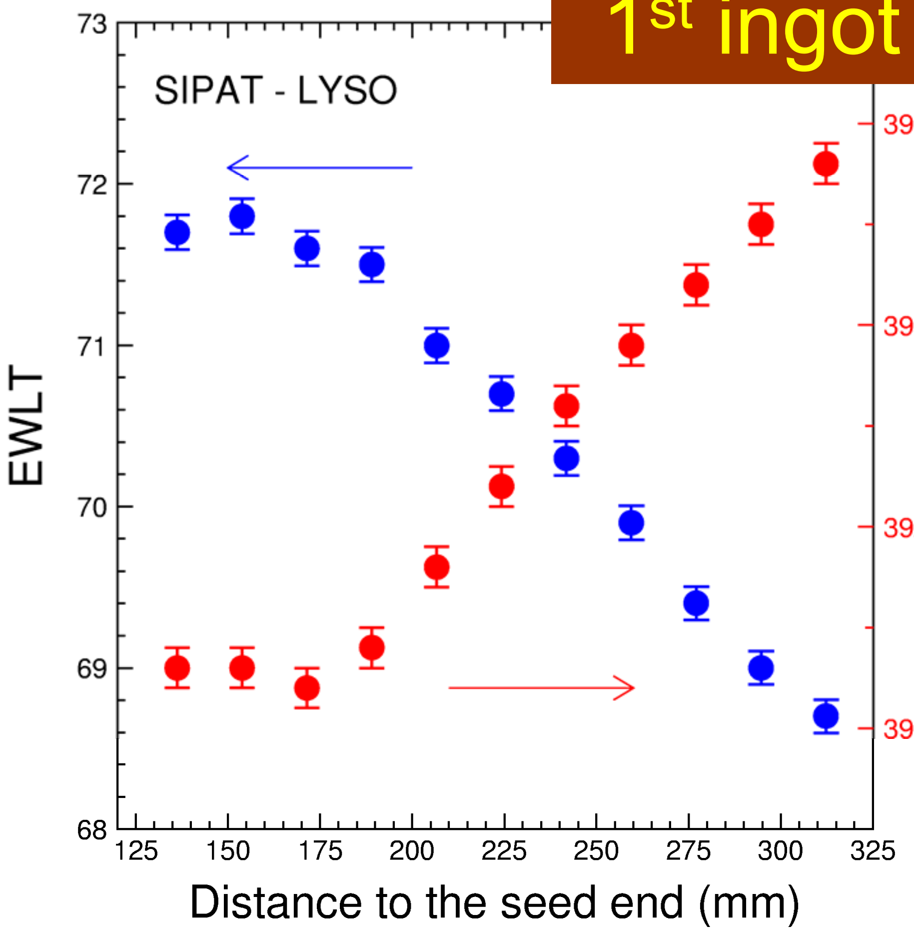


Cutoff wavelength

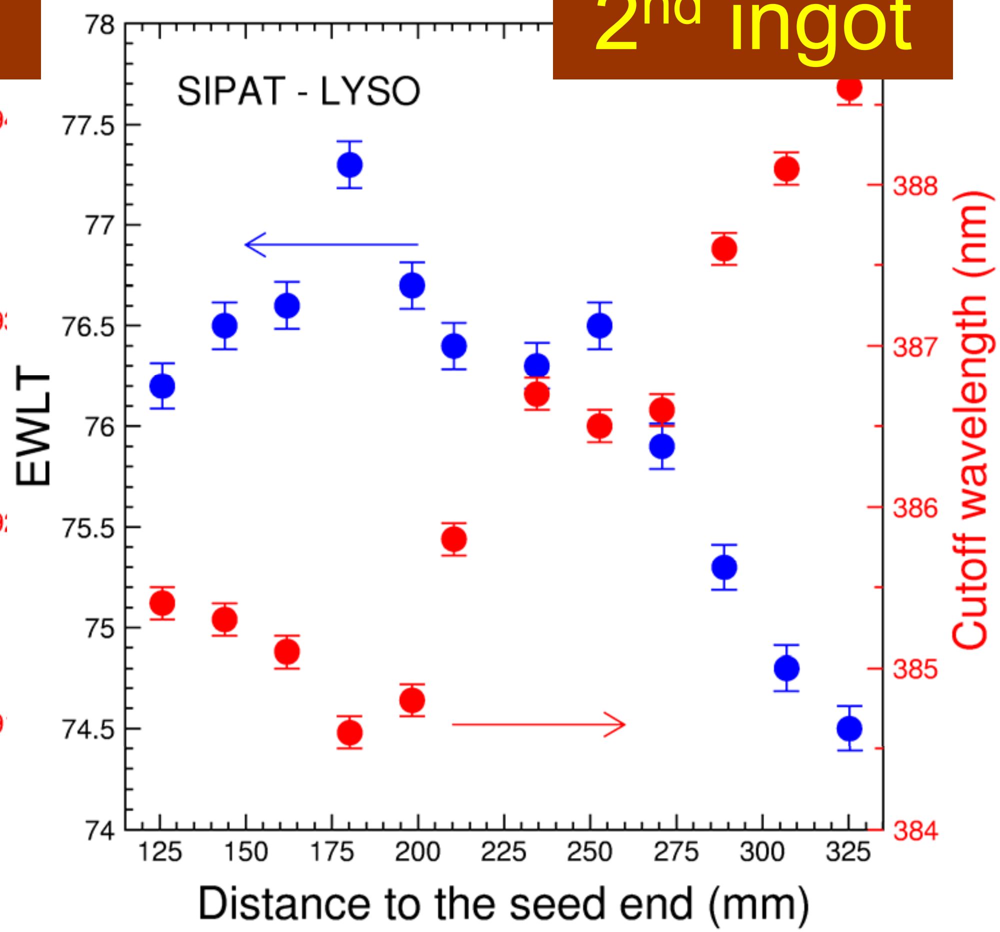
EWLT and Cut-off versus Position

Correlations exist between EWLT/cut-off and cube position, indicating possible correlation with the cerium concentration.

1st ingot



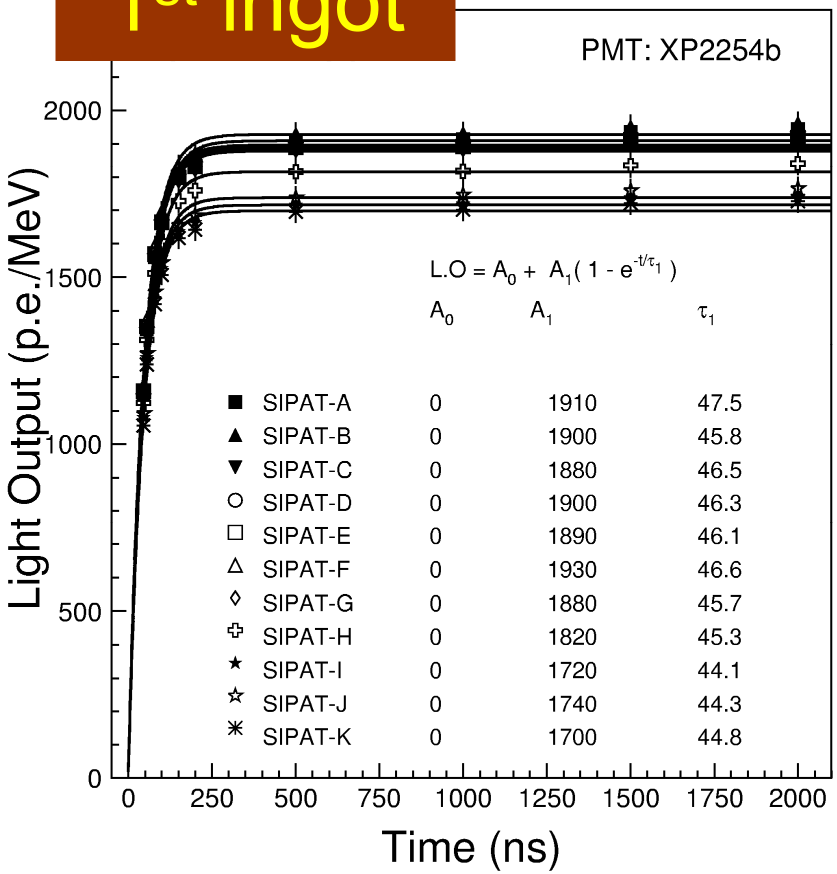
2nd ingot



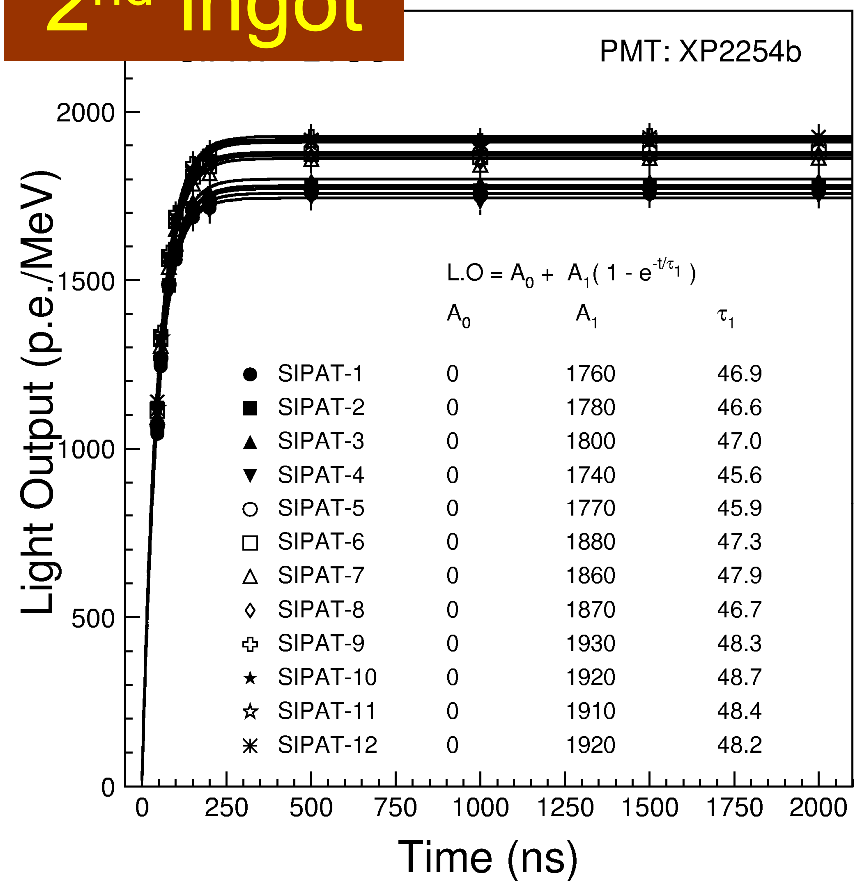
Light Output

Light Outputs are position dependent, indicating possible correlation with the cerium concentration.

1st ingot

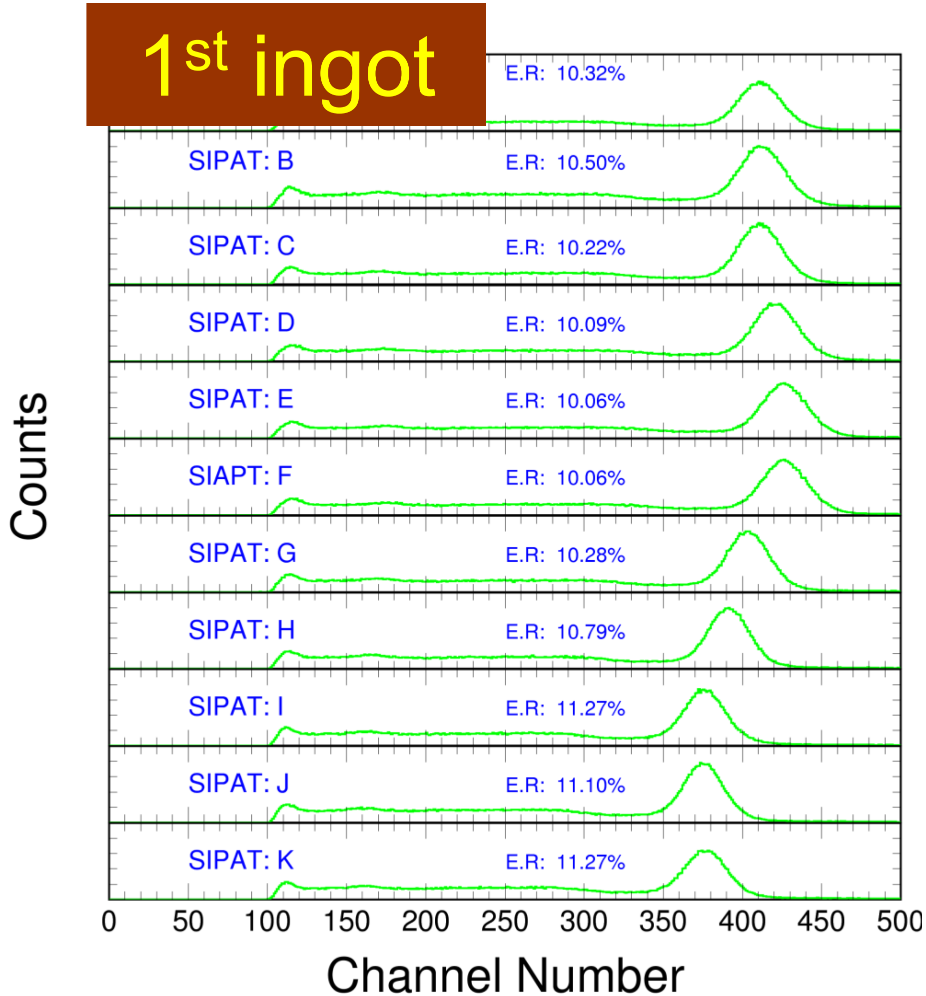


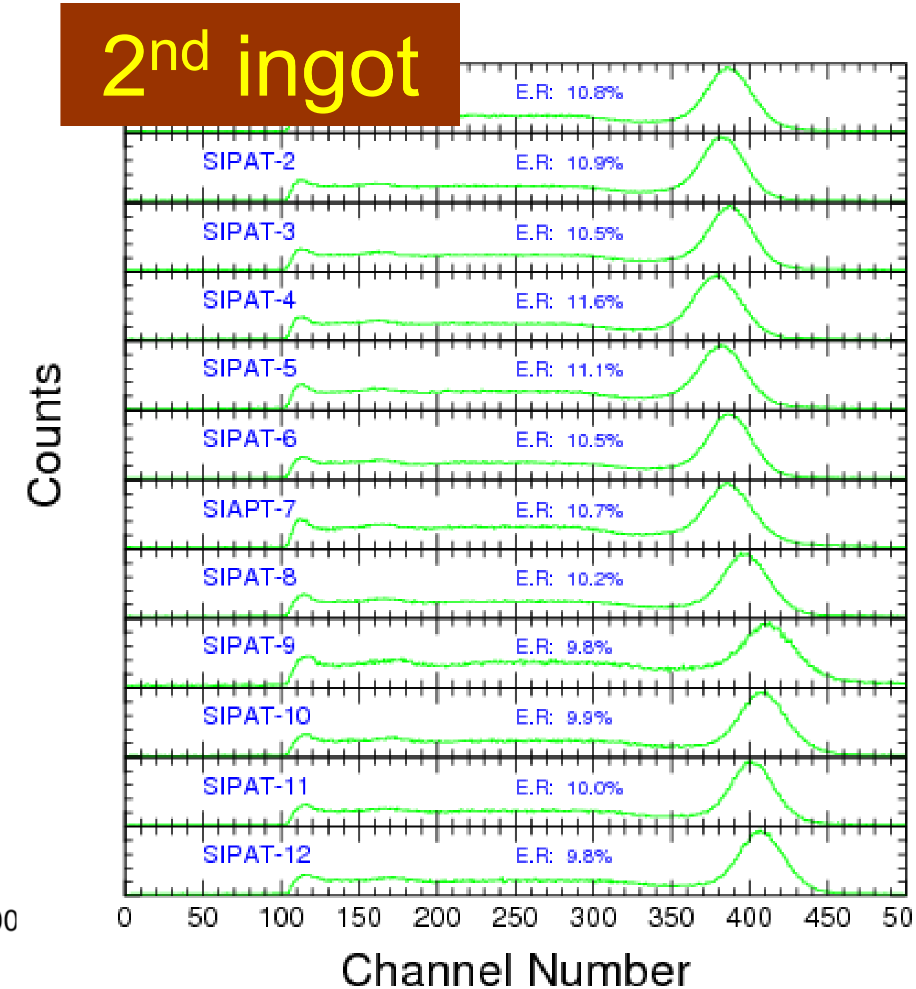
2nd ingot



FWHM Energy Resolution

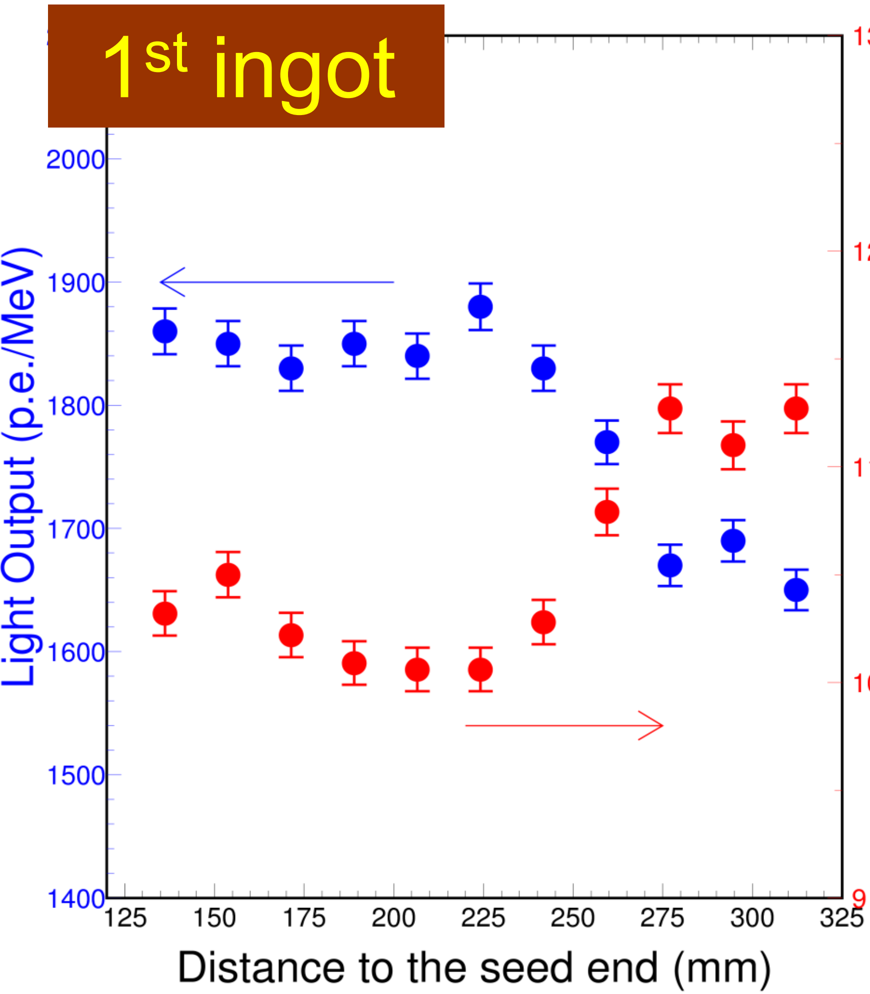
Energy resolutions are position dependent, indicating possible correlation with the cerium concentration.

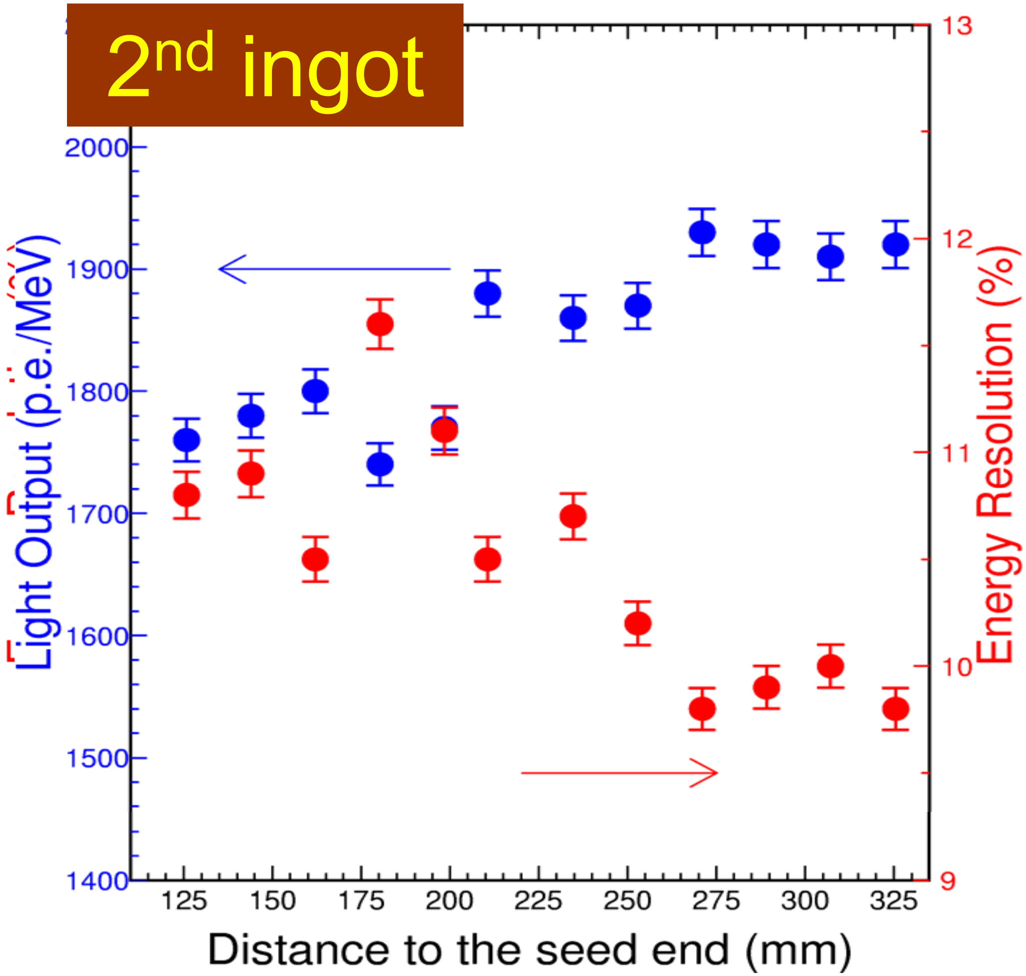




L.O. and E.R. versus Position

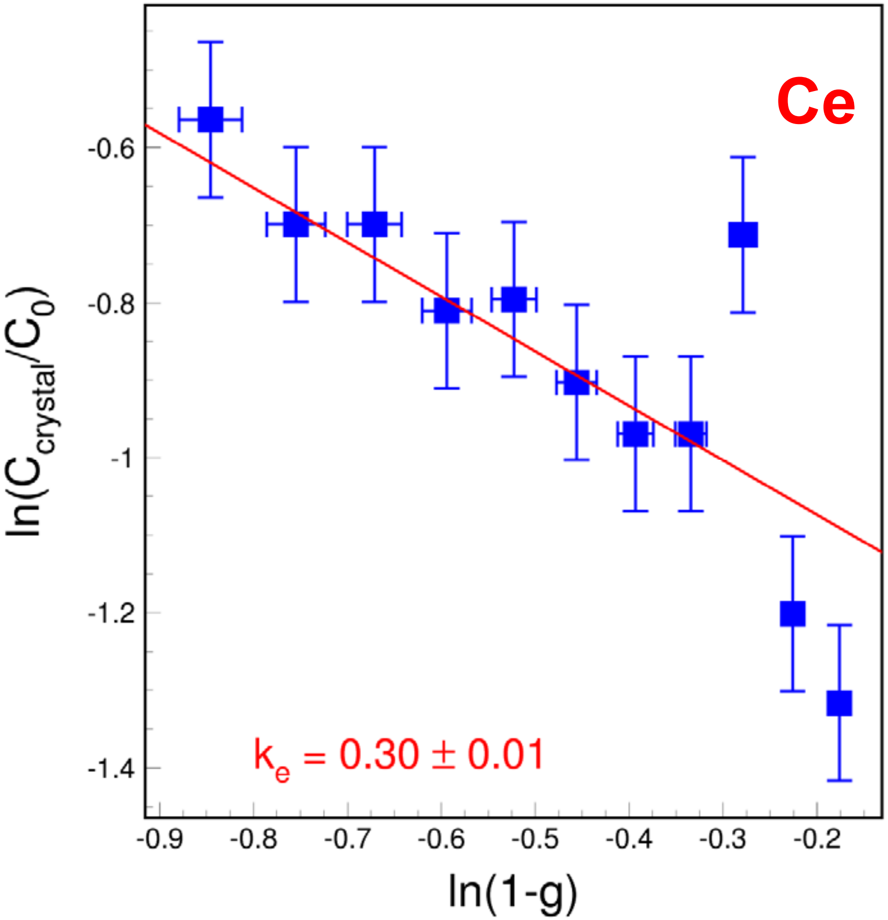
Correlations exist between L.O./E.R. and cube position.

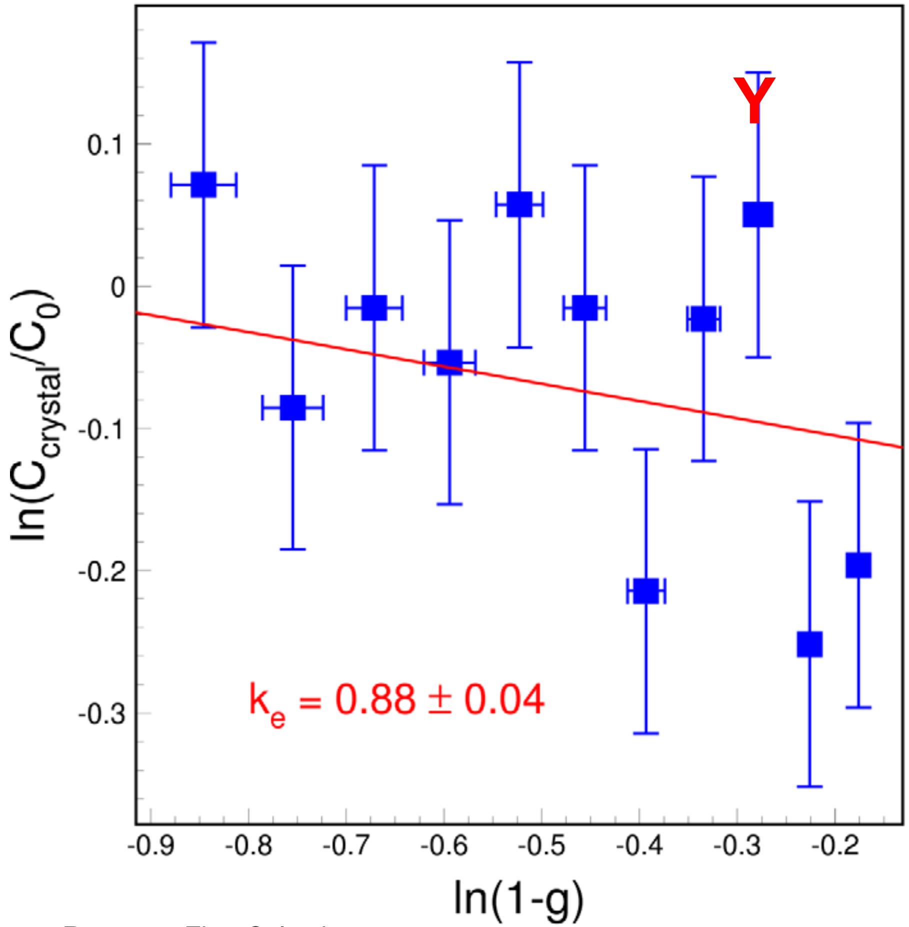




Cerium & Yttrium Segregation

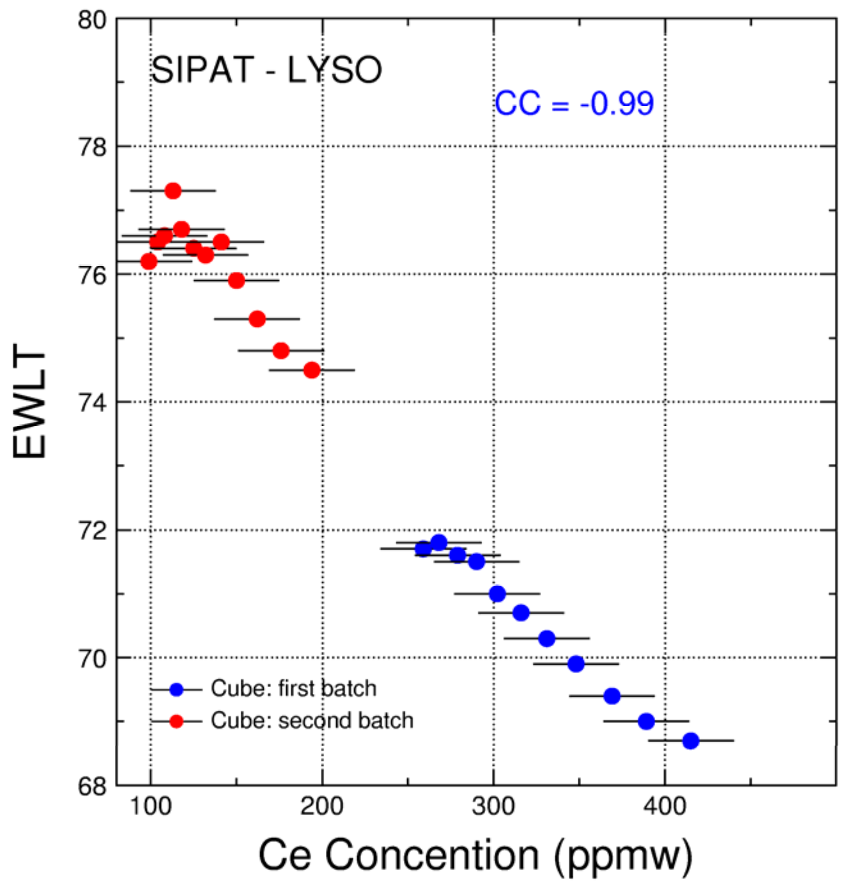
- Concentrations of cerium and yttrium were measured by using Glow Discharge Mass Spectrometry (GDMS) analysis.
- Segregation coefficients of cerium and yttrium in LSO were fitted to be 0.30 and 0.88 respectively: $ln\frac{C_{Crystal}}{C_0} = lnk_e + (k_e - 1)\ln(1-g)$

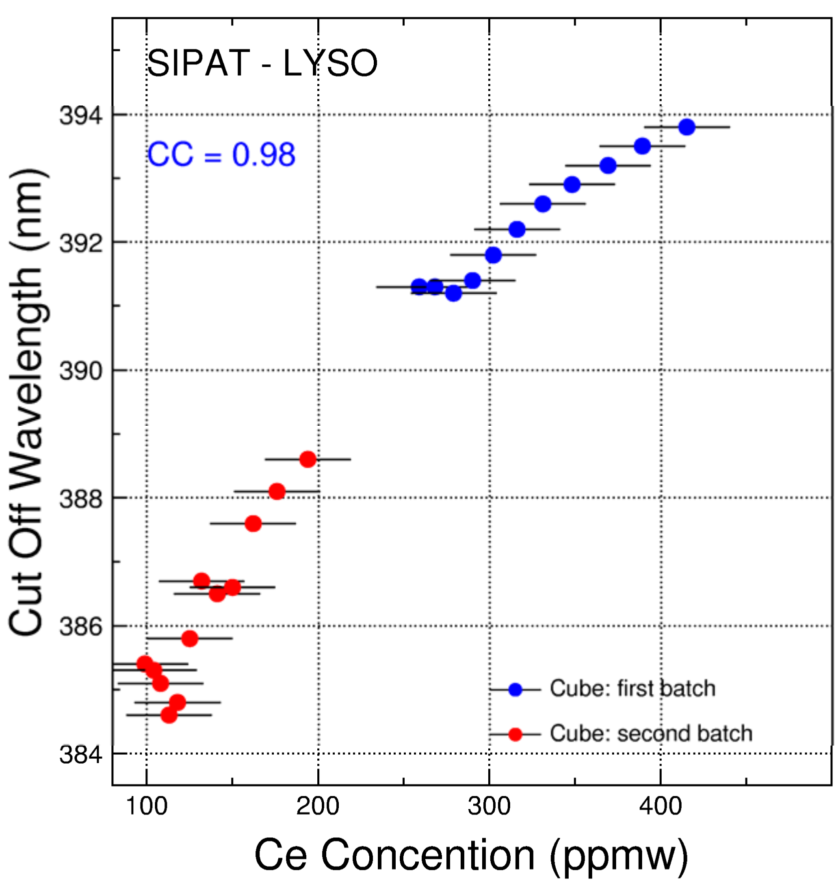




EWLT & Cut-off vs. Ce Concentration

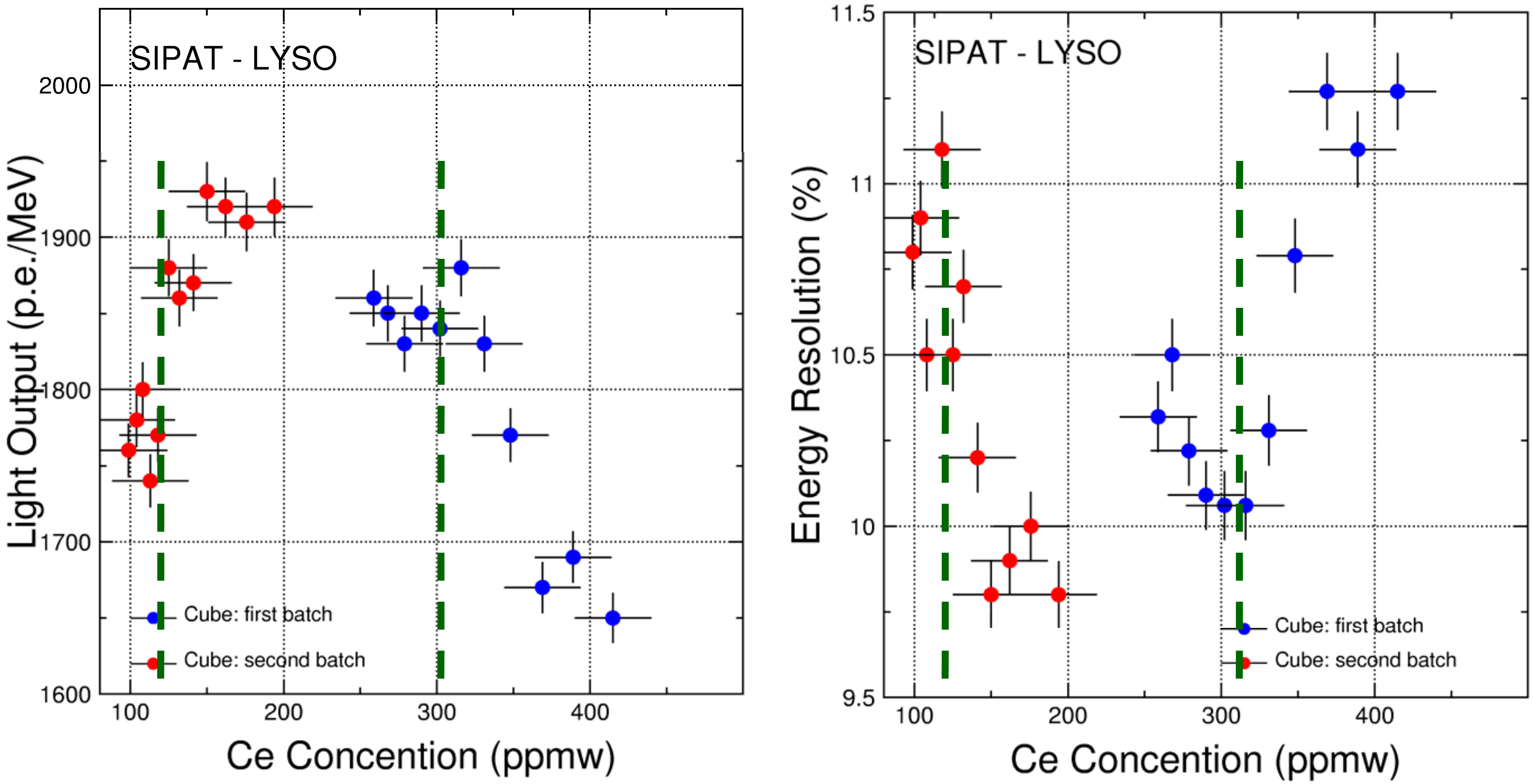
Strong correlations observed between EWLT and the cut-off wavelength versus the Ce concentration.





L.O. and E.R. versus Ce Concentration

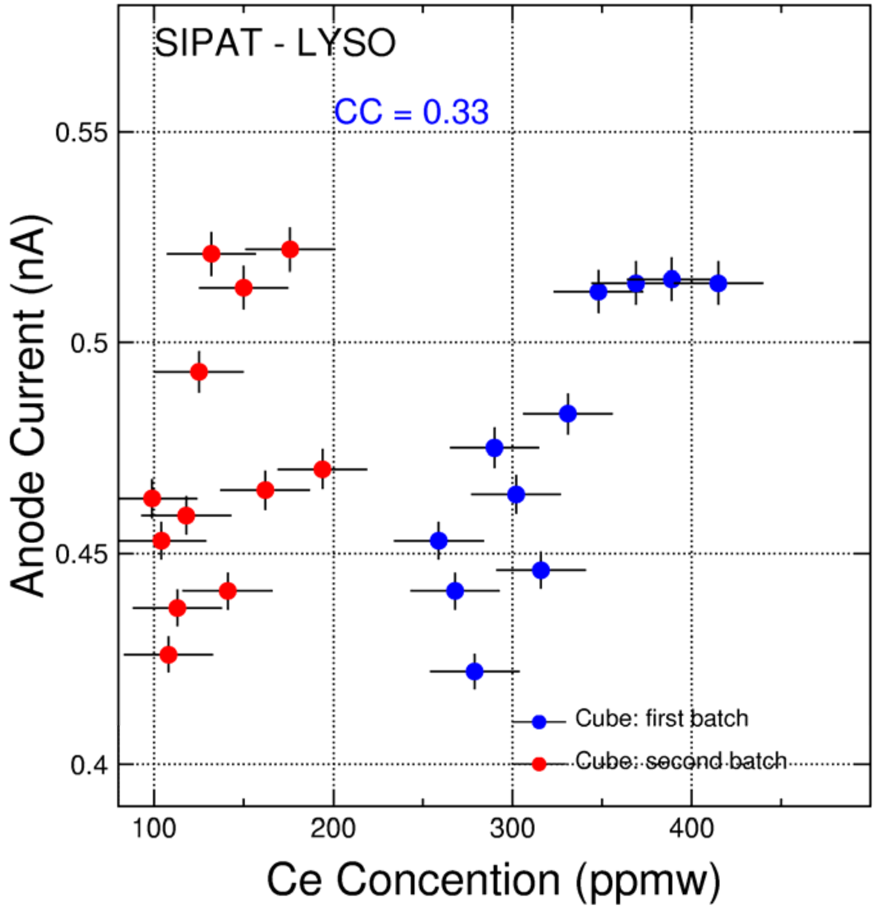
A ‘plateau’ observed between 125 ~ 325 ppm, indicating a possibility to grow uniform crystal with optimized Ce doping. This observation consists with private data from C. Melcher.



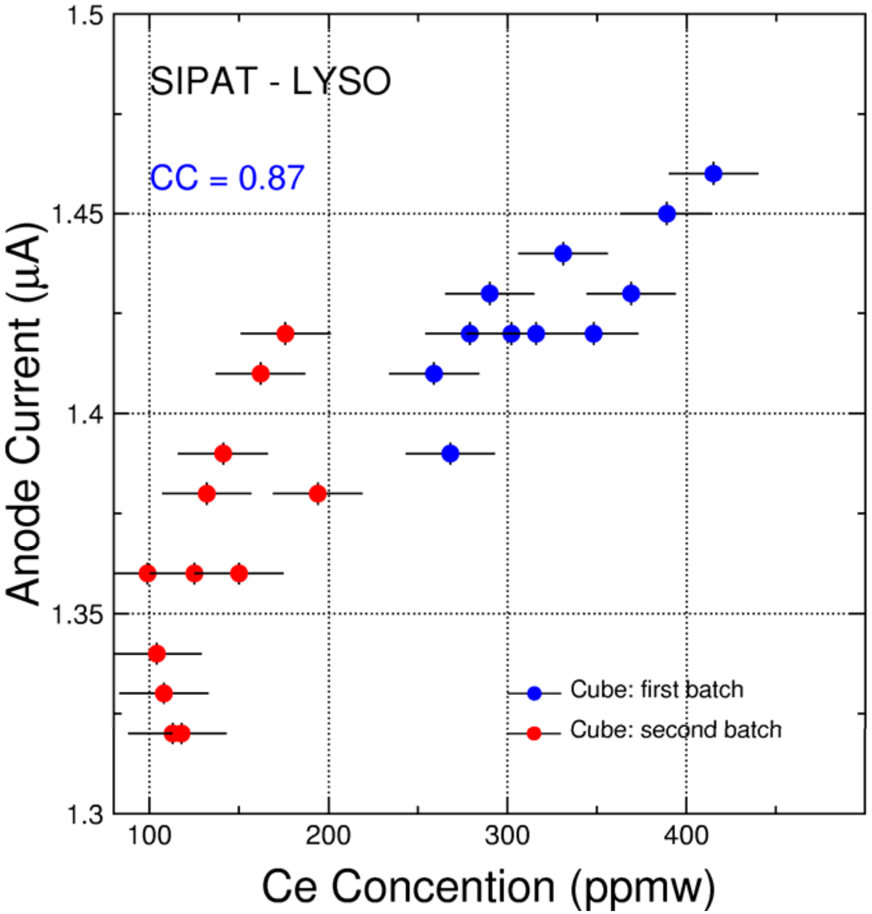
Phosphorescence vs. Ce Concentration

Correlation observed between radiation induced phosphorescence and the Ce concentration, but not before gamma-ray irradiation.

Before irradiation

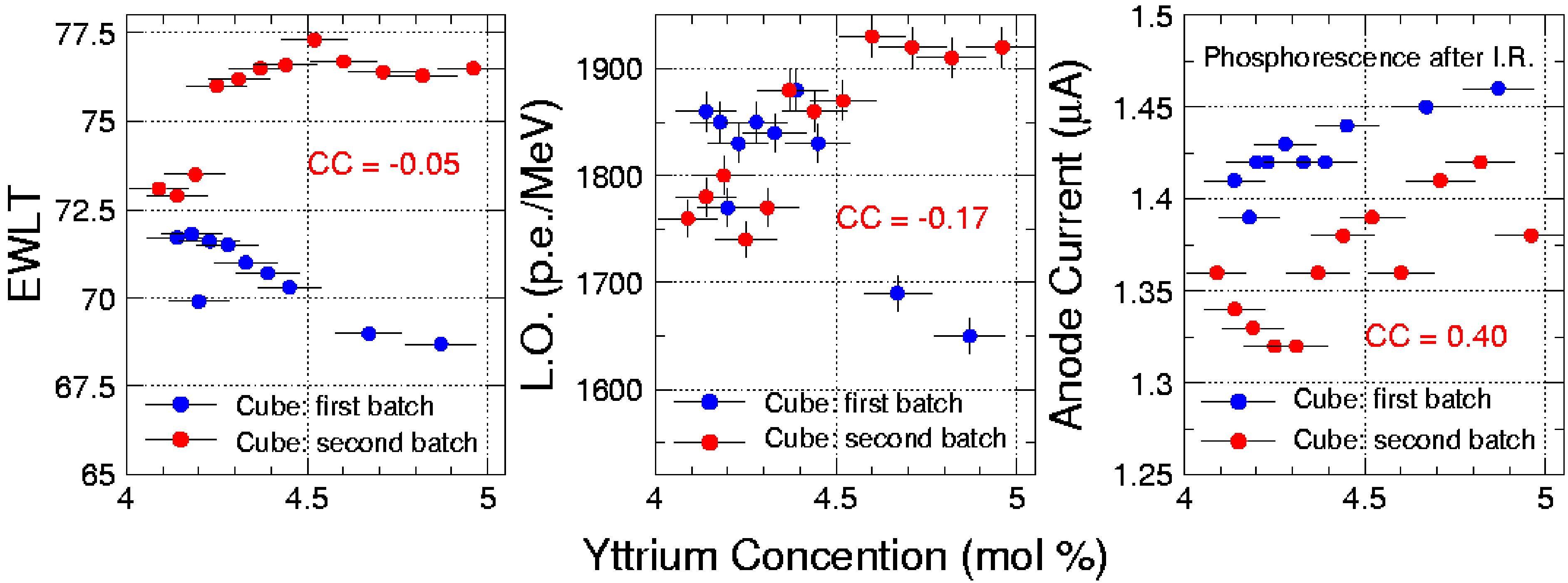


After irradiation

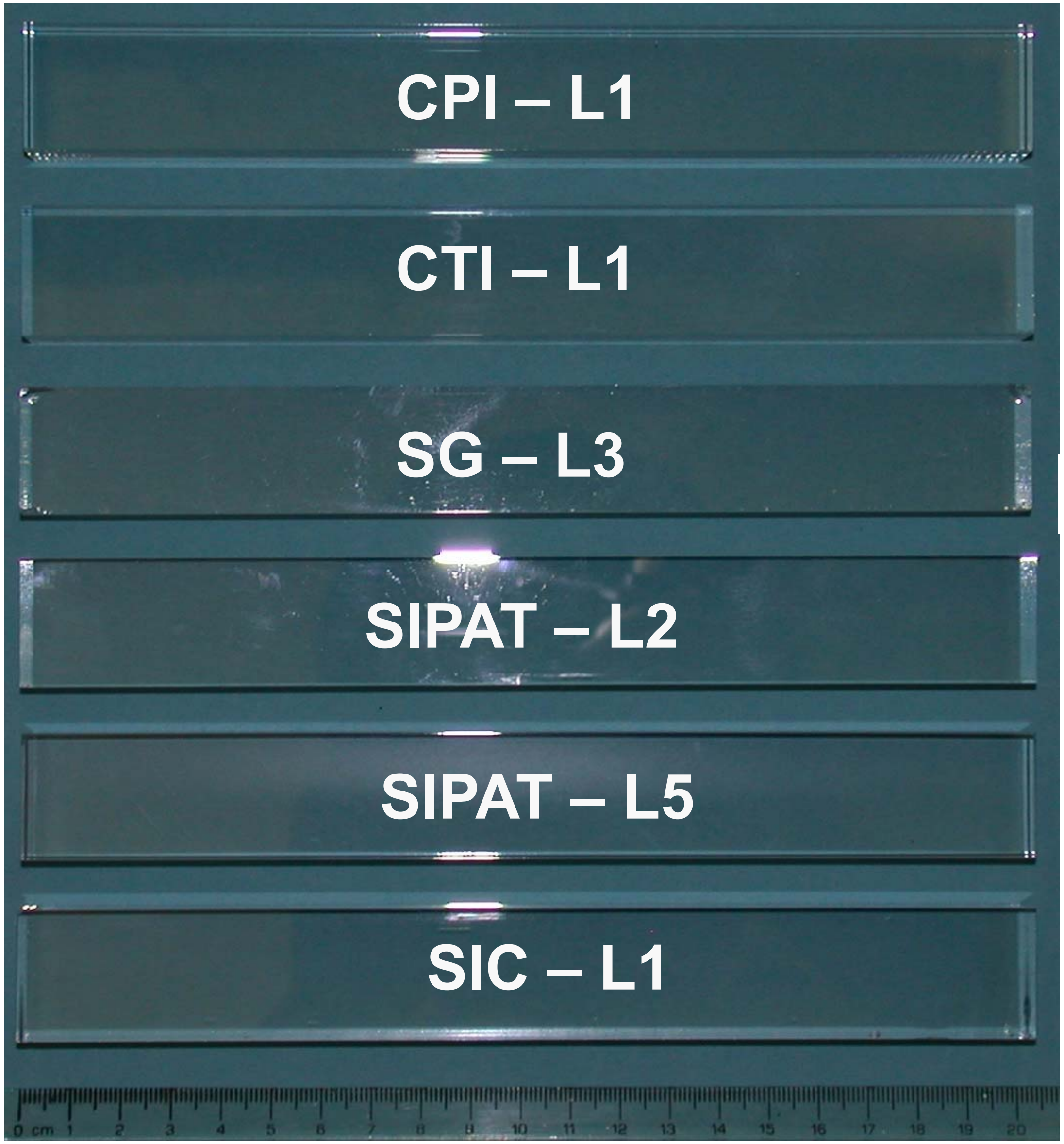


EWLT, L.O. and Phosphorescence after irradiation vs. the Yttrium Concentration

No correlations were observed between the yttrium concentrations and EWLT, the light output and the intensity of phosphorescence after gamma-ray irradiations.

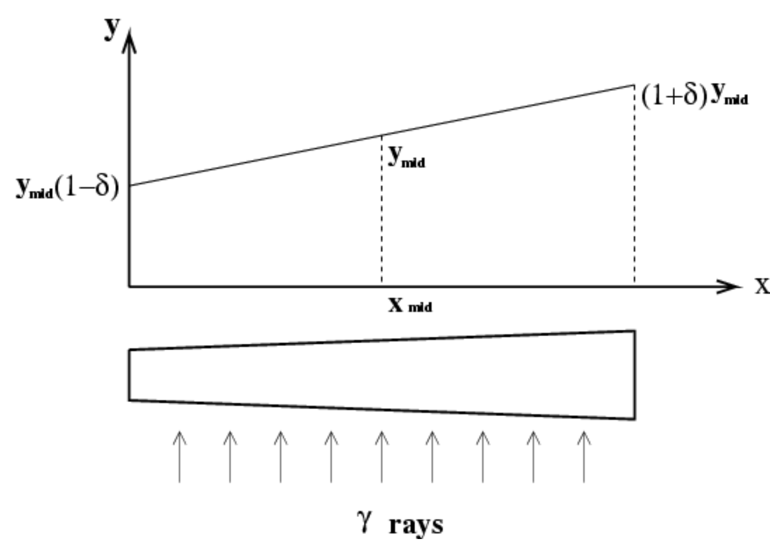


Light Response Uniformity



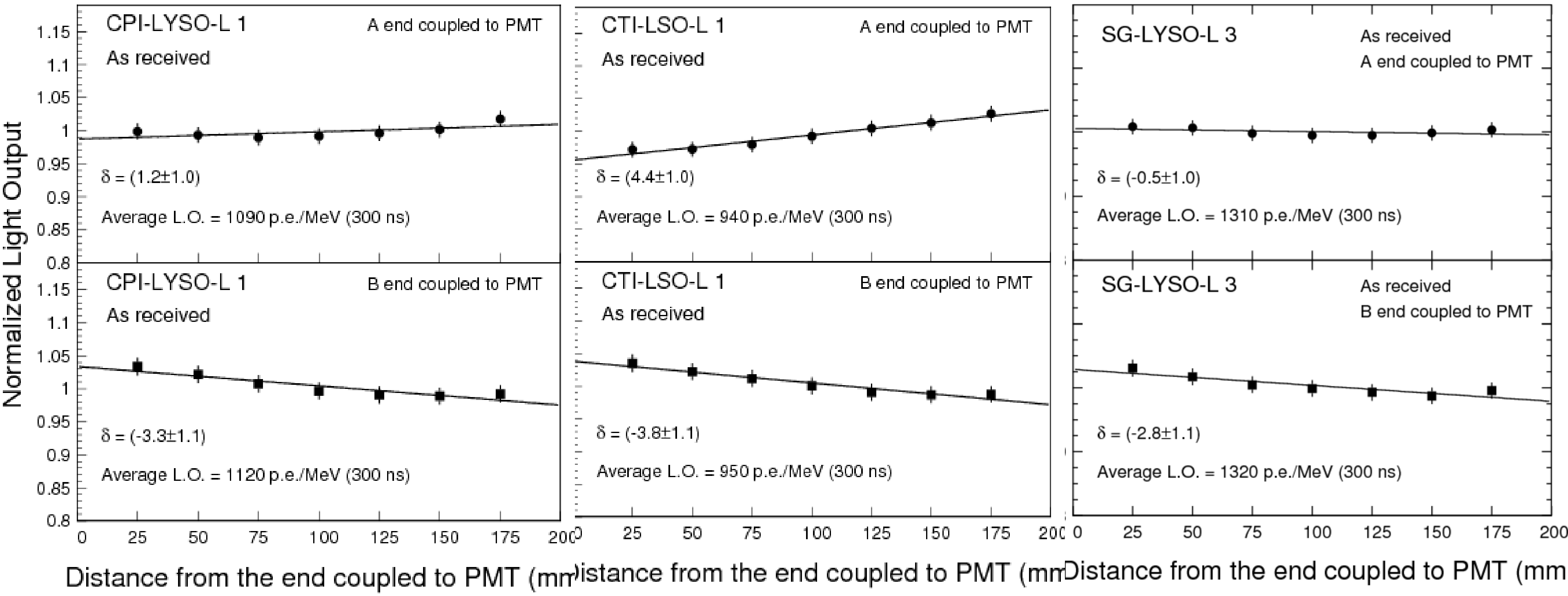
2.5 x 2.5 x 20 cm
Samples tested for their light response uniformity

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



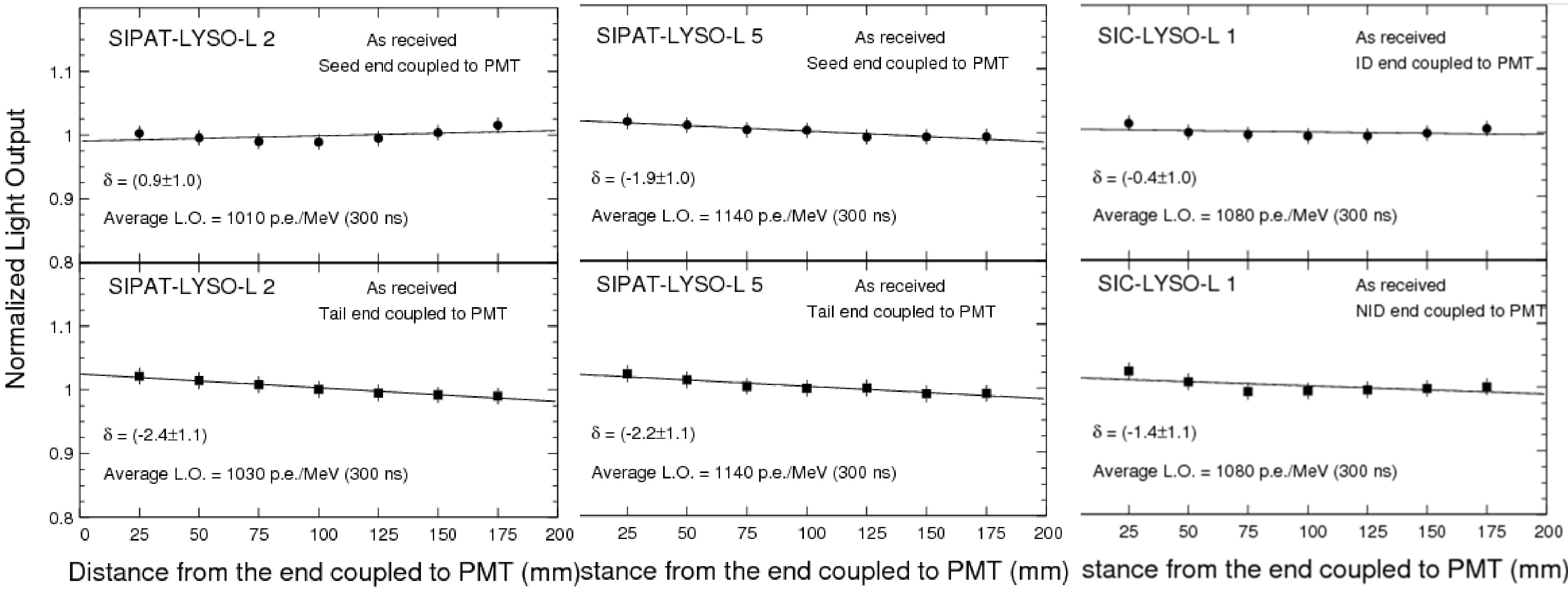
L.R.U. of 20 cm Long LYSO

Diverse light response uniformities observed with δ = 1.2/-3.3, 4.4/-3.9, -0.5/-2.8 for CPI, CTI & SG respectively



Progress Achieved in L.R.U.

The L.R.U. of SIPAT samples is improved from 0.9/-2.4 to -1.9/-2.2, opening a possibility to cut two crystals from one ingot. 1st SIC sample shows good L.R.U.: -0.4/-1.4



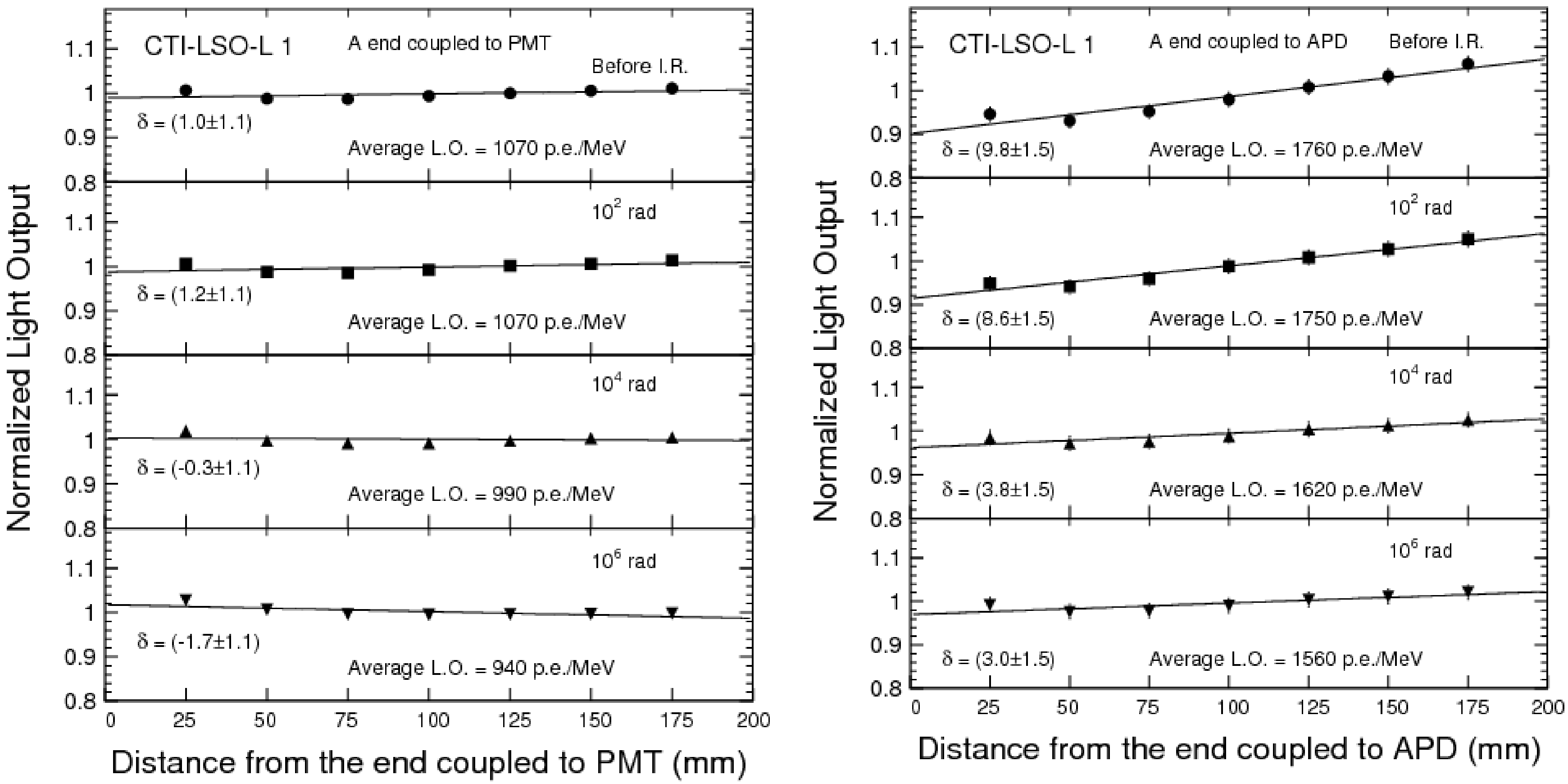
Before Optimization

After Optimization

1st SIC Sample

Radiation Effect on L.R.U.: CTI-LSO-L1

Consistent uniformity before and after irradiations.
Different slopes between PMT & APD readout.



Radiation Effect on L.R.U.: CTI-LSO-L1

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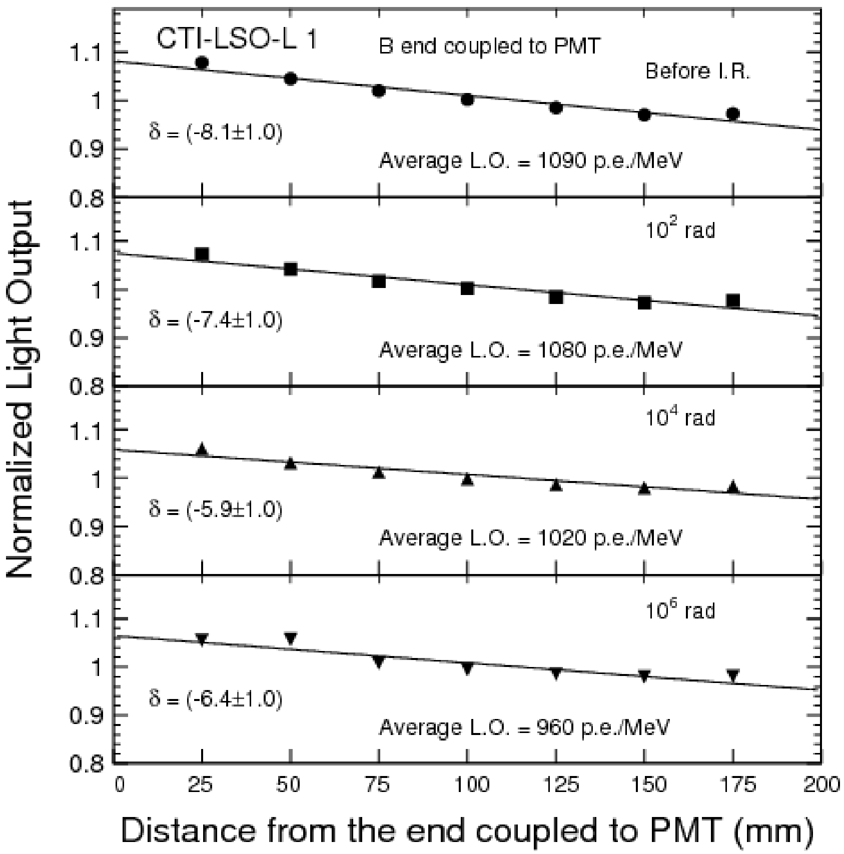
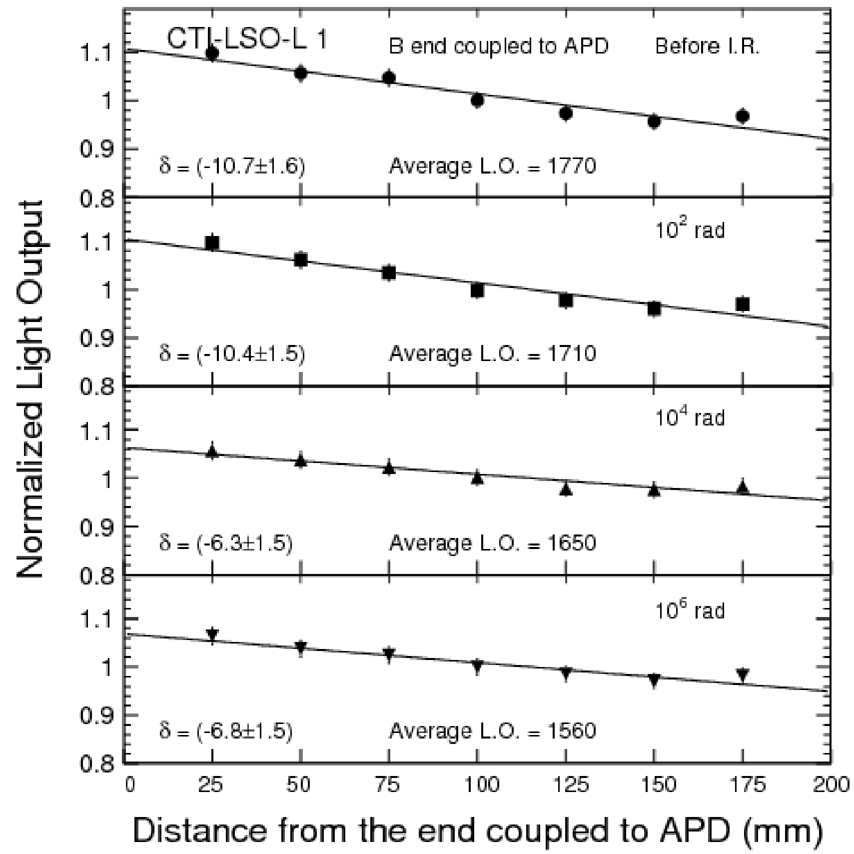
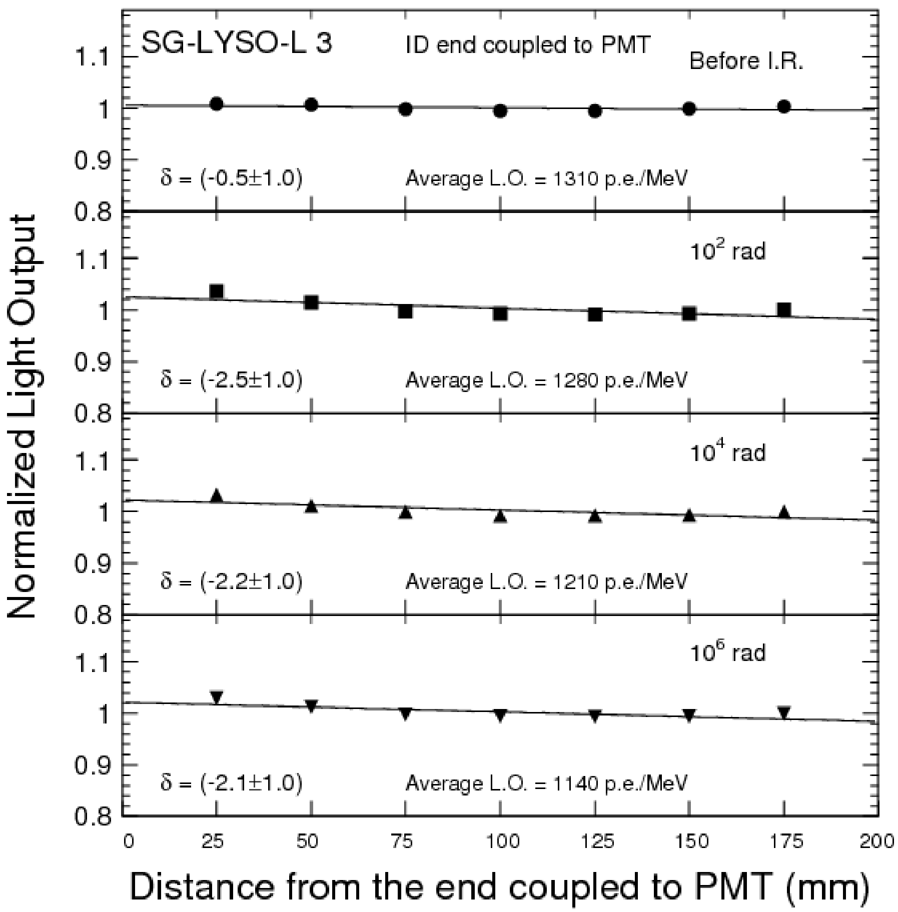
Different slopes between PMT & APD readout.

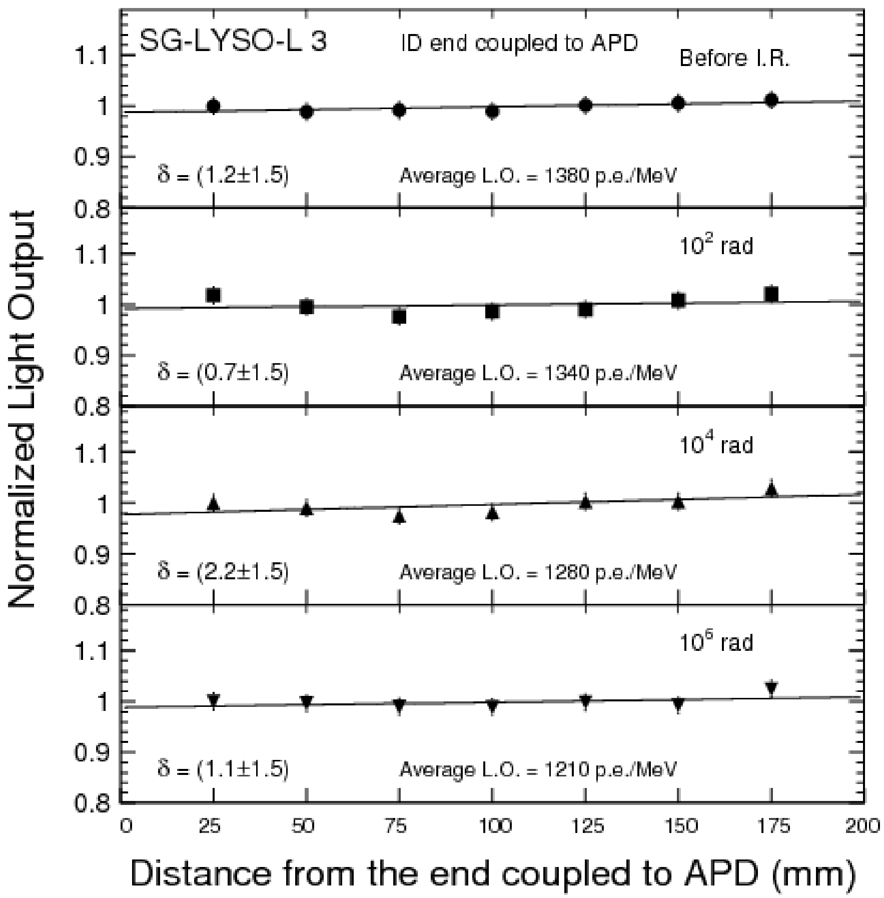




Radiation Effect on L.R.U.: SG-LYSO-L3

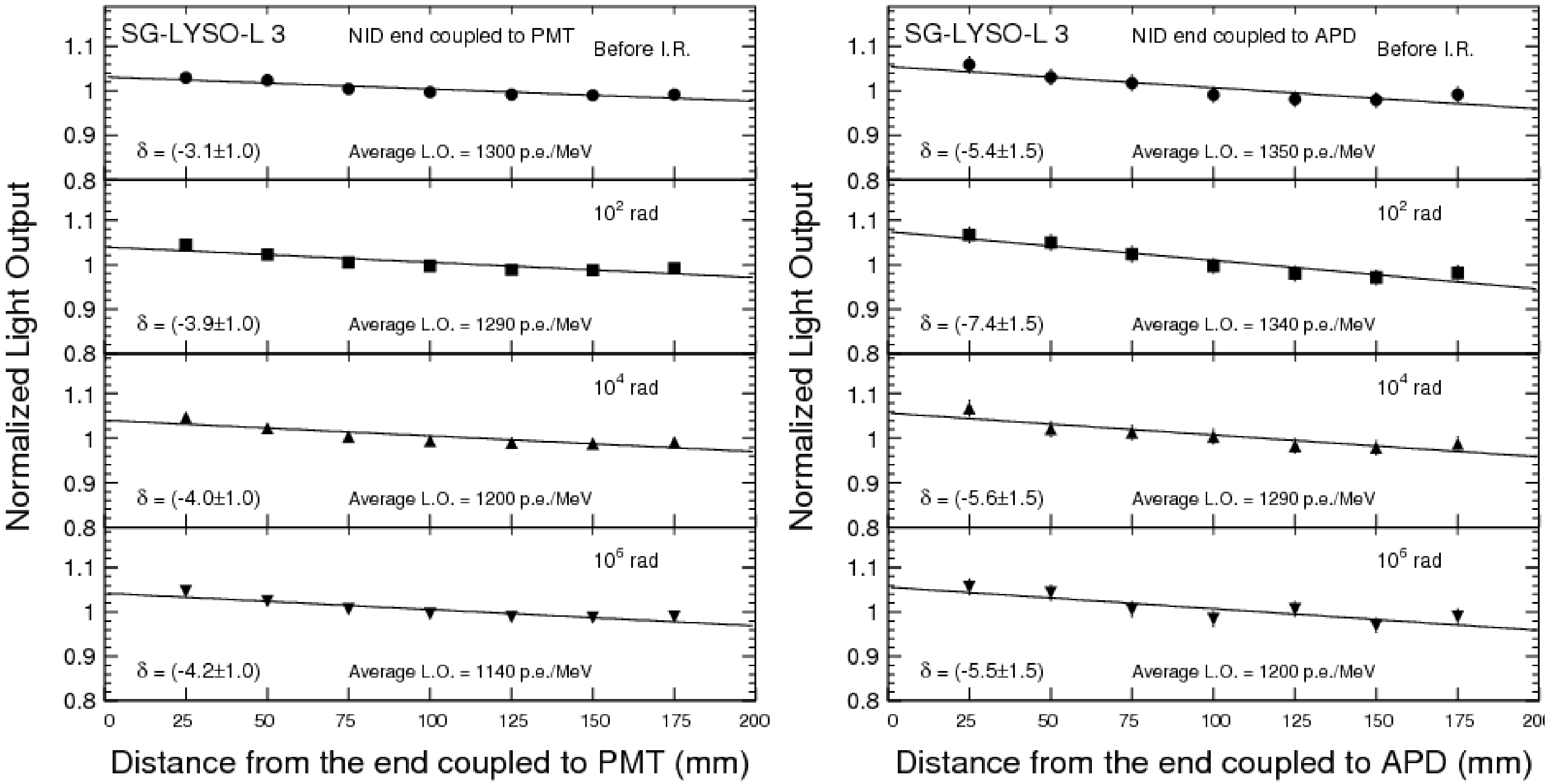
Consistent uniformity before and after irradiations.
Difference slopes between PMT & APD readout.





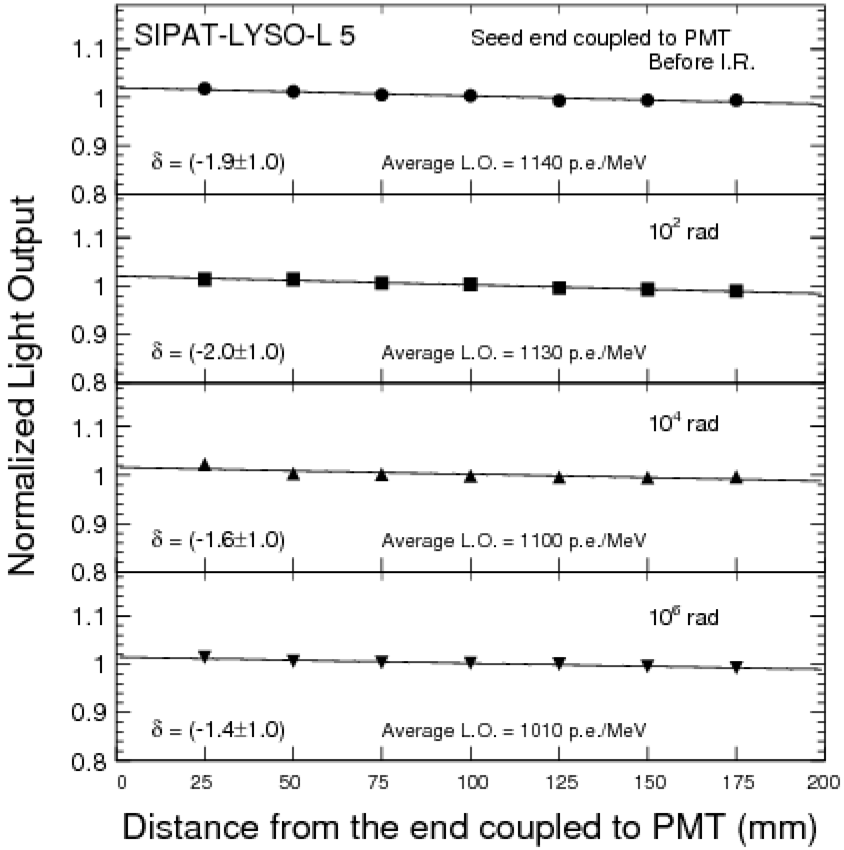
Radiation Effect on L.R.U.: SG-LYSO-L3

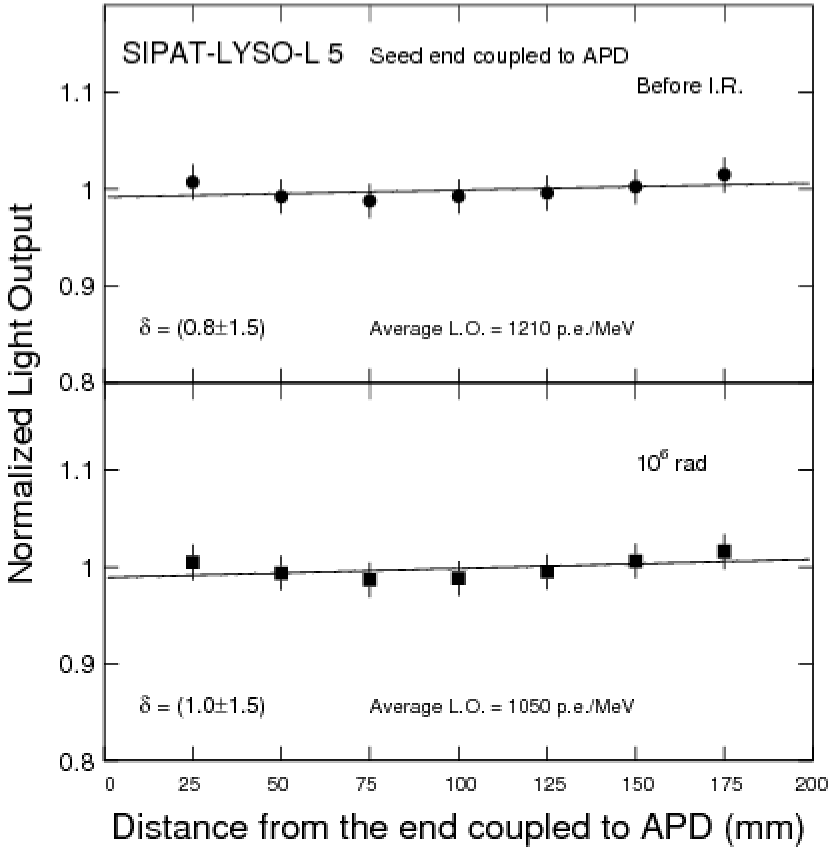
Consistent uniformity before and after irradiations
Difference slopes between PMT & APD readout.



Radiation Effect on L.R.U.: SIPAT-L5

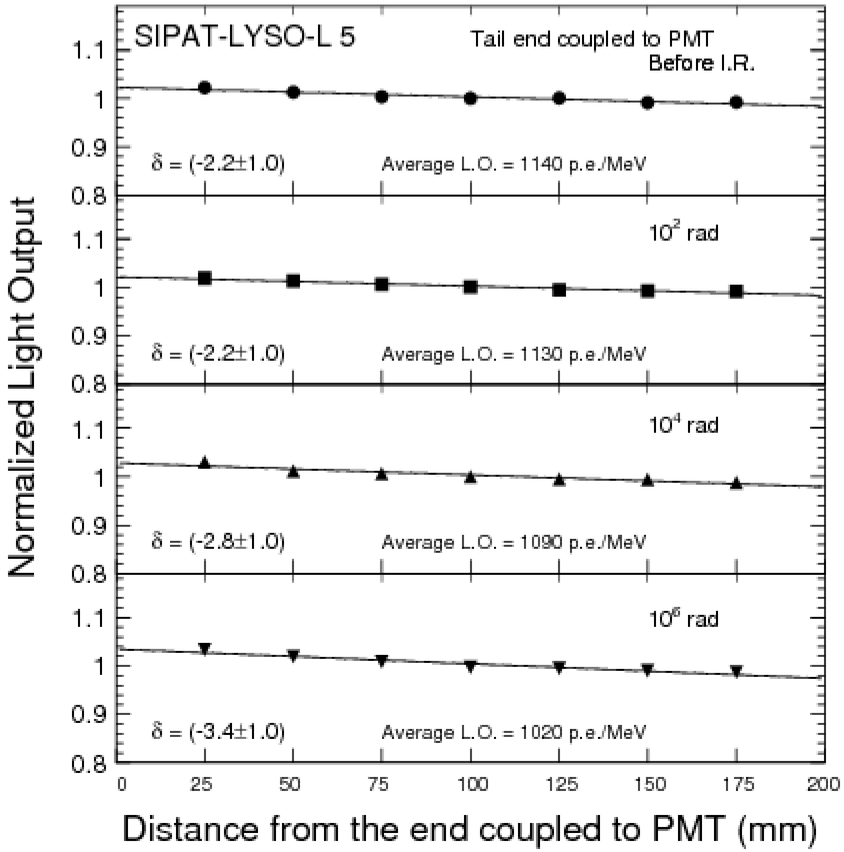
Consistent uniformity before and after irradiations
Difference slopes between PMT & APD readout.

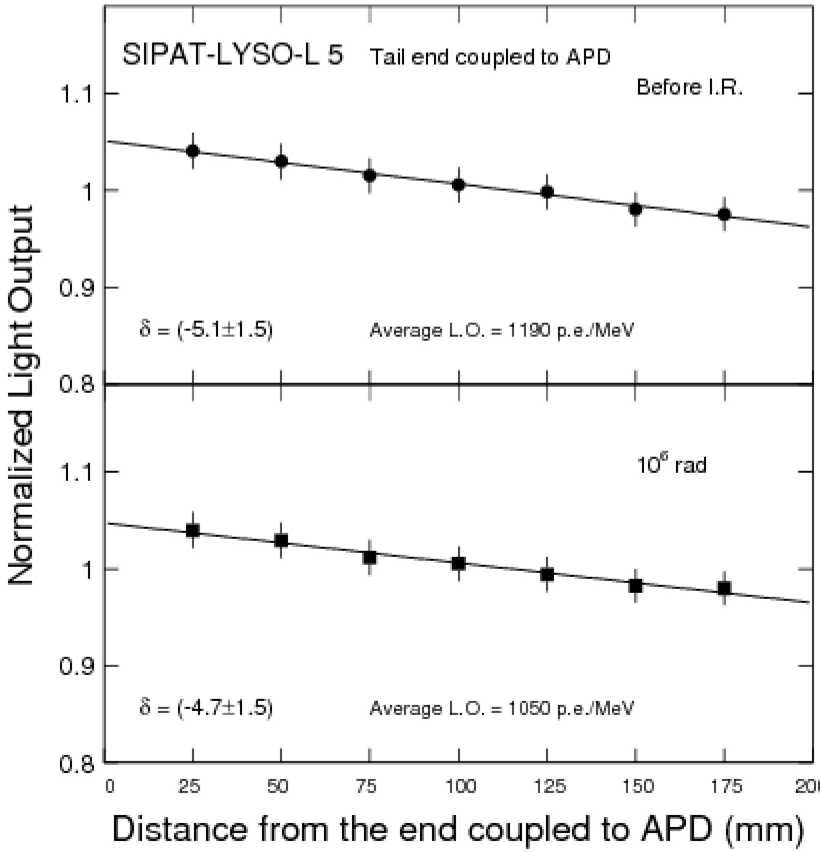




Radiation Effect on L.R.U.: SIPAT-L5

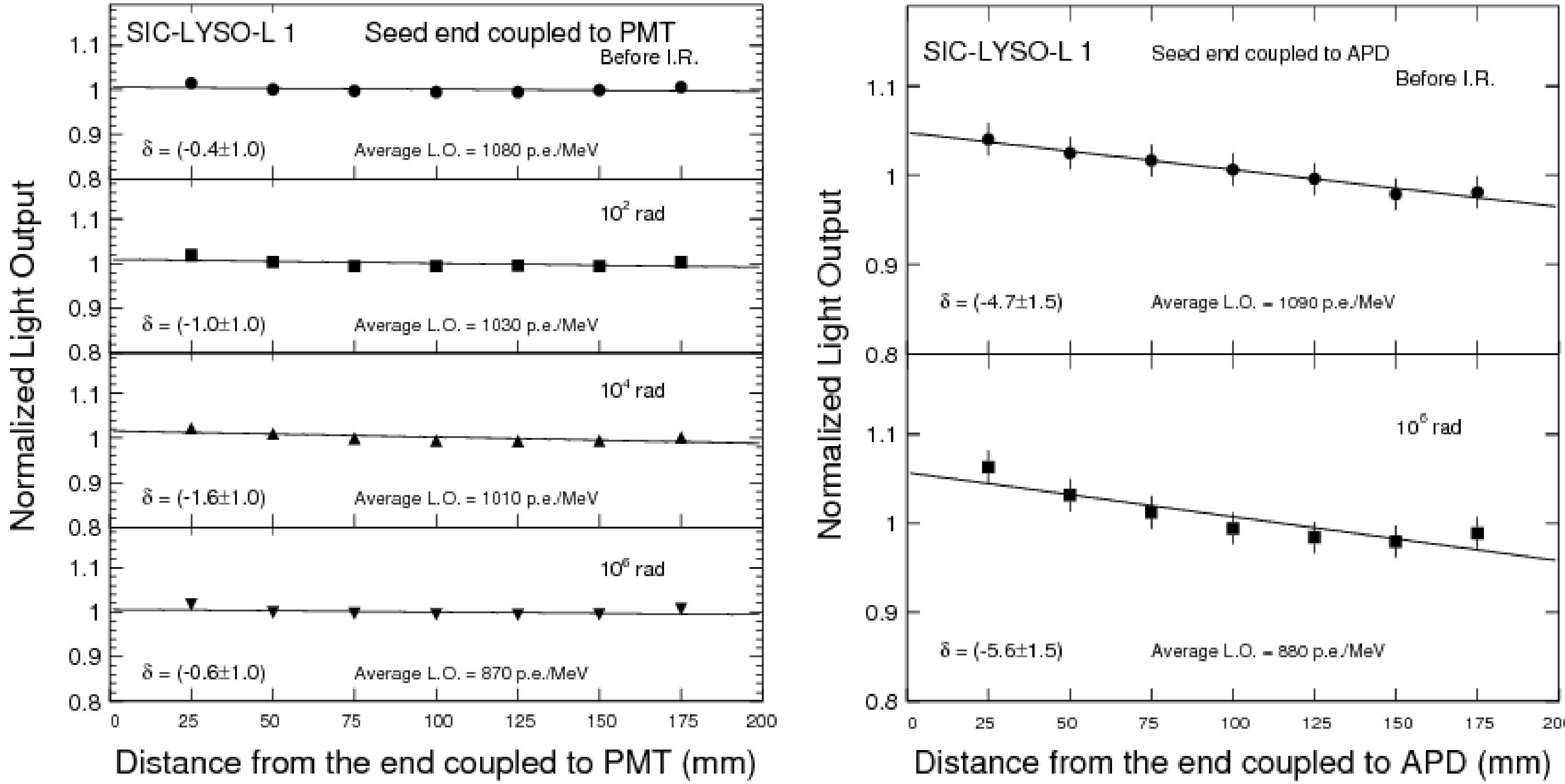
Consistent uniformity before and after irradiations
Difference slopes between PMT & APD readout.





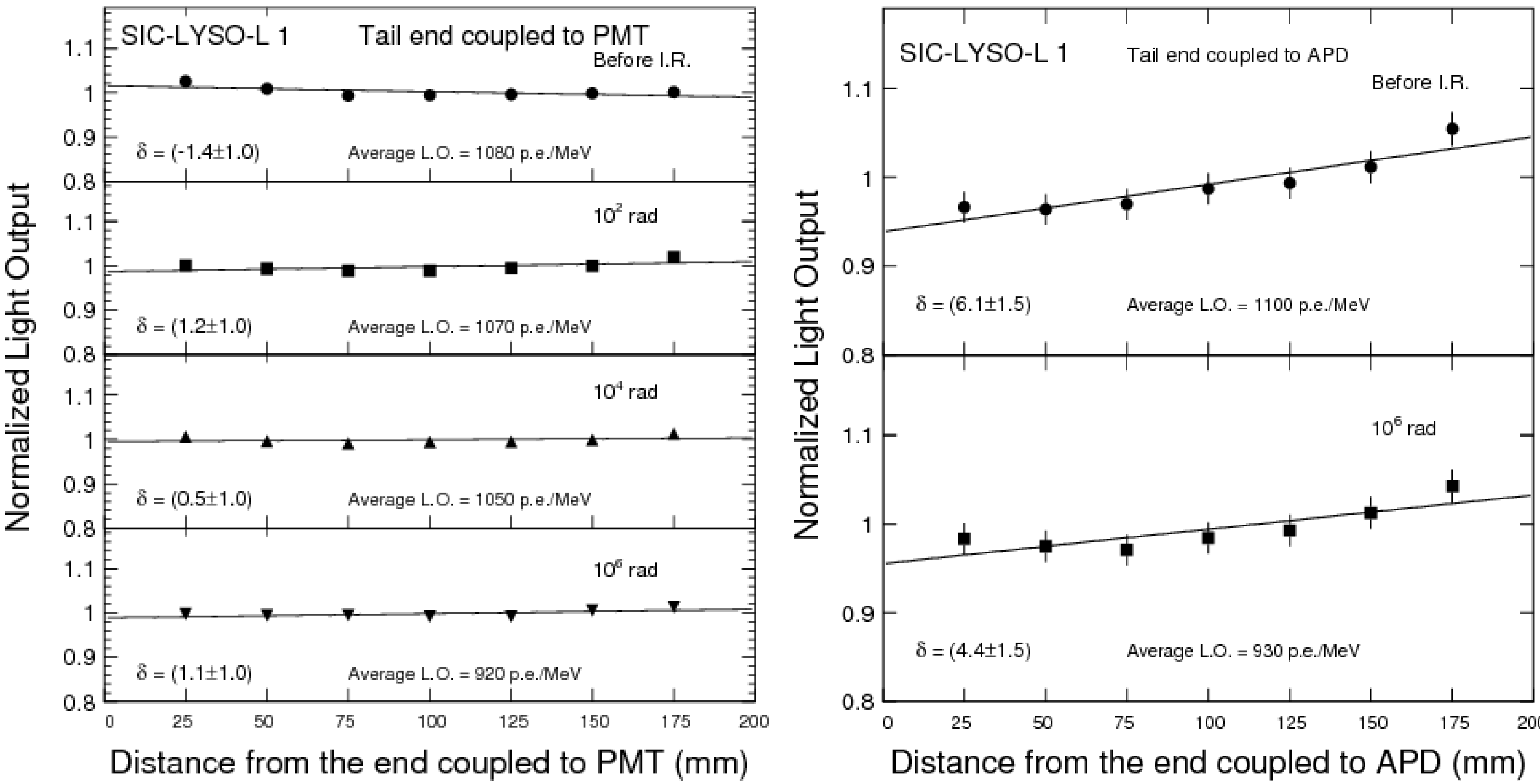
Radiation Effect on L.R.U.: SIC-L1

Consistent uniformity before and after irradiations
Difference slopes between PMT & APD readout.



Radiation Effect on L.R.U.: SIC-L1

Consistent uniformity before and after irradiations.
Difference slopes between PMT & APD readout.

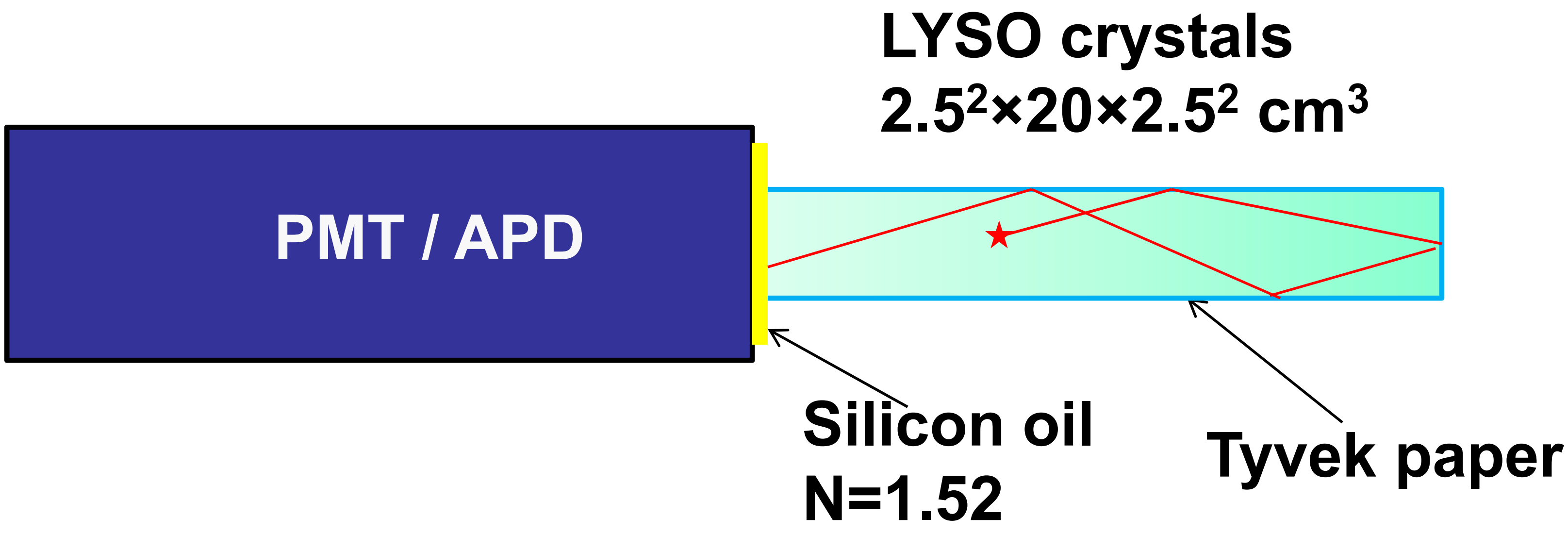


LSO/LYSO L.R.U. Summary

Consistent L.R.U. before & after irradiations.
Different slopes between PMT & APD readout.
Investigations are under way.

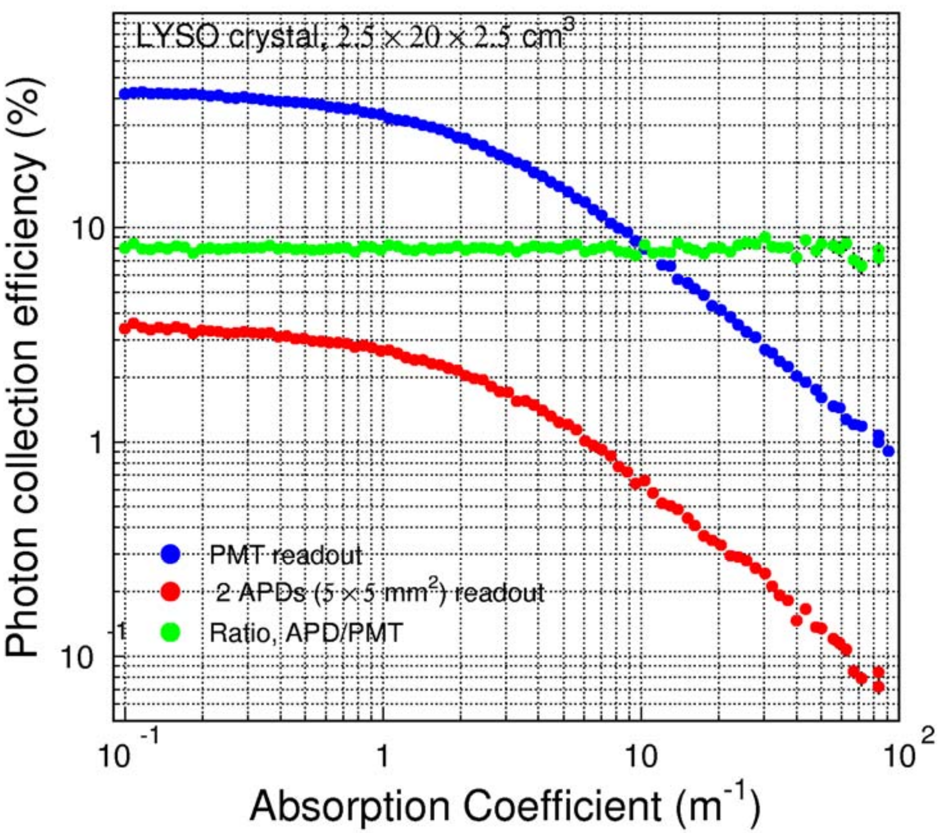
ID	Integrated dose (rad)	δ % (A or Seed end coupling)		δ (B or Tail end coupling)	
		PMT (± 1)	**APD (± 1.5)**	**PMT (± 1)**	**APD (± 1.5)**
CTI-LSO-1	0	**1**	**10**	**-8**	**-11**
	10^6	**-2**	**3**	**-6**	**-7**
SG-LYSO-3	0	**-0.5**	**1.2**	**-3.1**	**-5.4**
	10^6	**-2.1**	**1.1**	**-4.2**	**-5.5**
SIPAT-LYSO-5	0	**-1.9**	**0.8**	**-2.2**	**-5.1**
	10^6	**-1.4**	**1.0**	**-3.4**	**-4.7**
SIC-LYSO-1	0	**-0.4**	**-4.7**	**-1.4**	**6.1**
	10^6	**-0.6**	**-5.6**	**1.1**	**4.4**

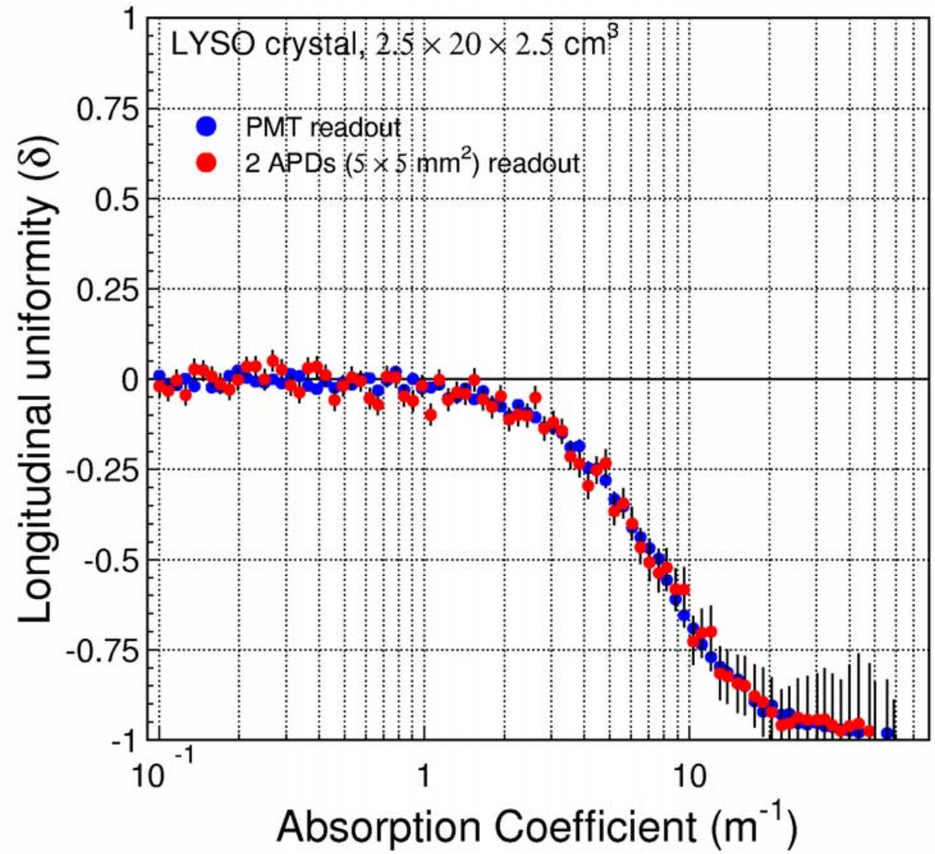
Ray-Tracing Simulation



Area Coverage Effect for PMT and APD

Different area coverage of PMT (2.5 ×2.5 cm^2) and APD (2×0.5×0.5 cm^2) determines the different light collection efficiencies, but has no effect on the L.R.U.

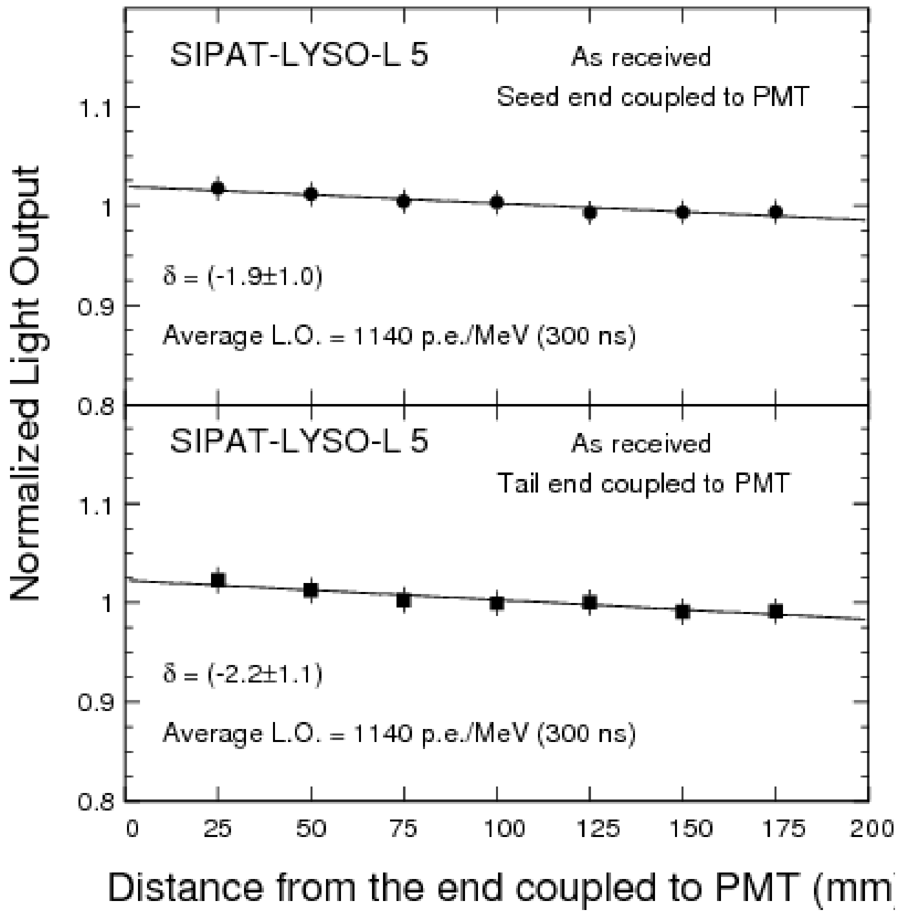




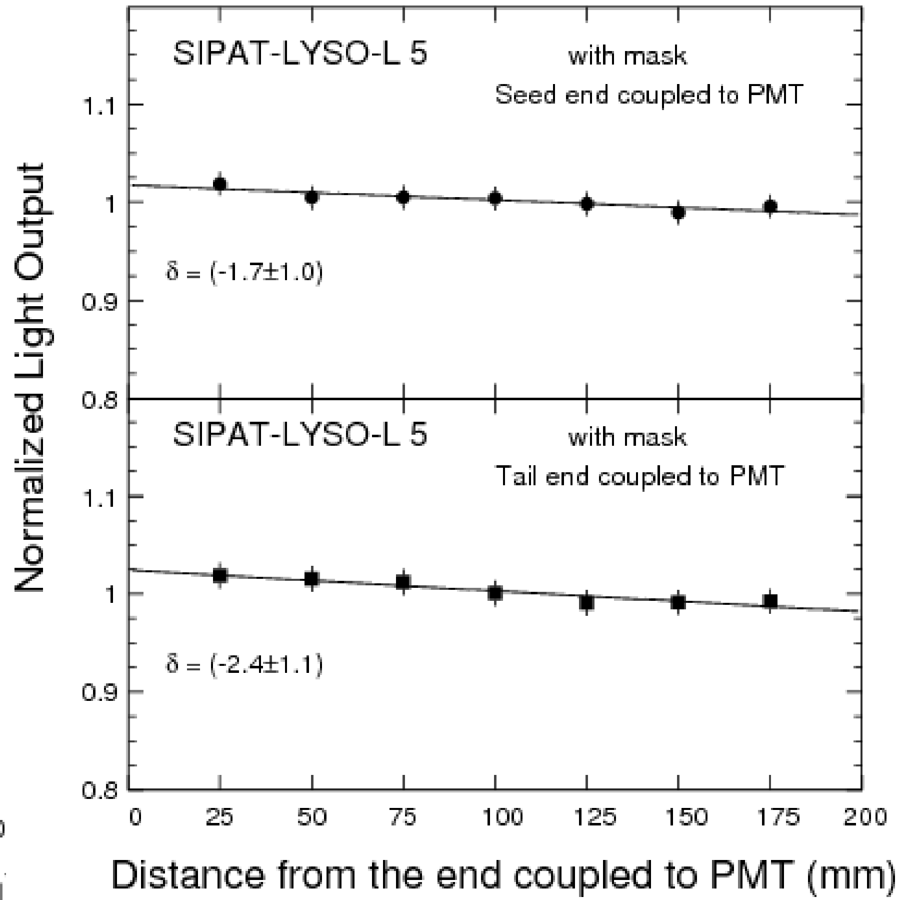
Consistent L.R.U. by PMT & Mask

Data confirm simulation: no geometry effect.

PMT without Mask

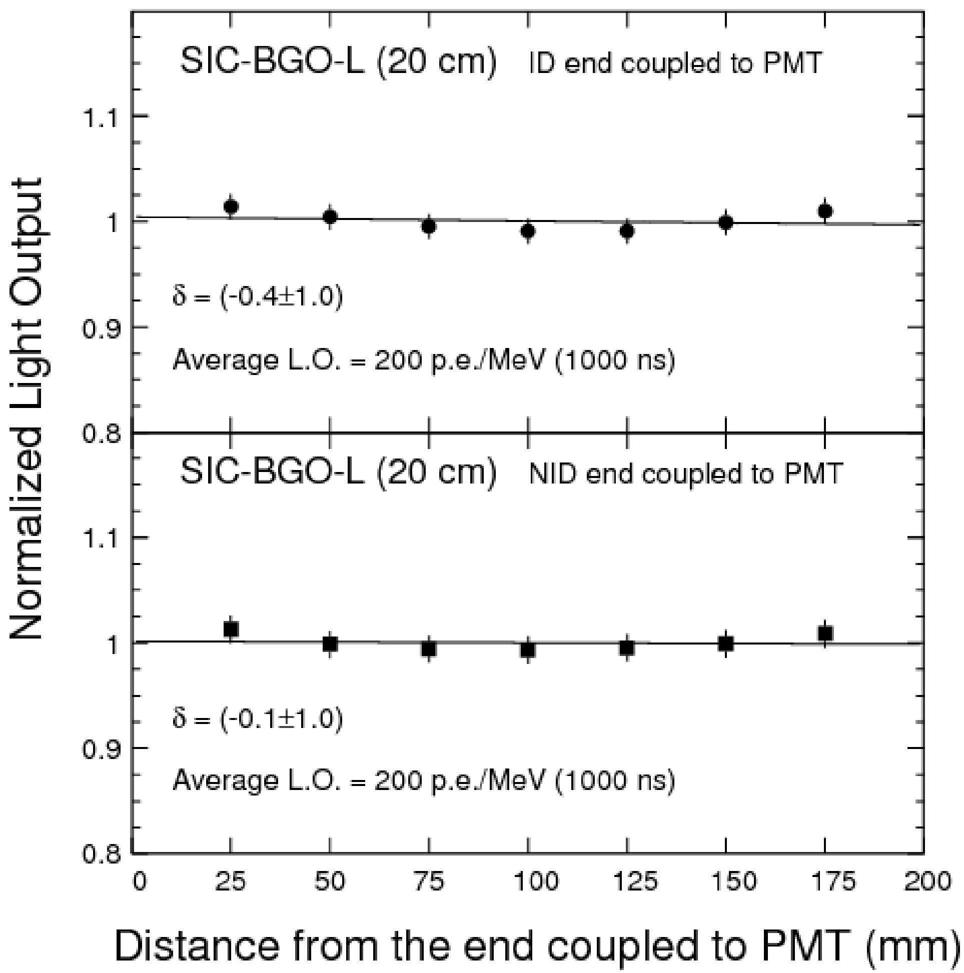


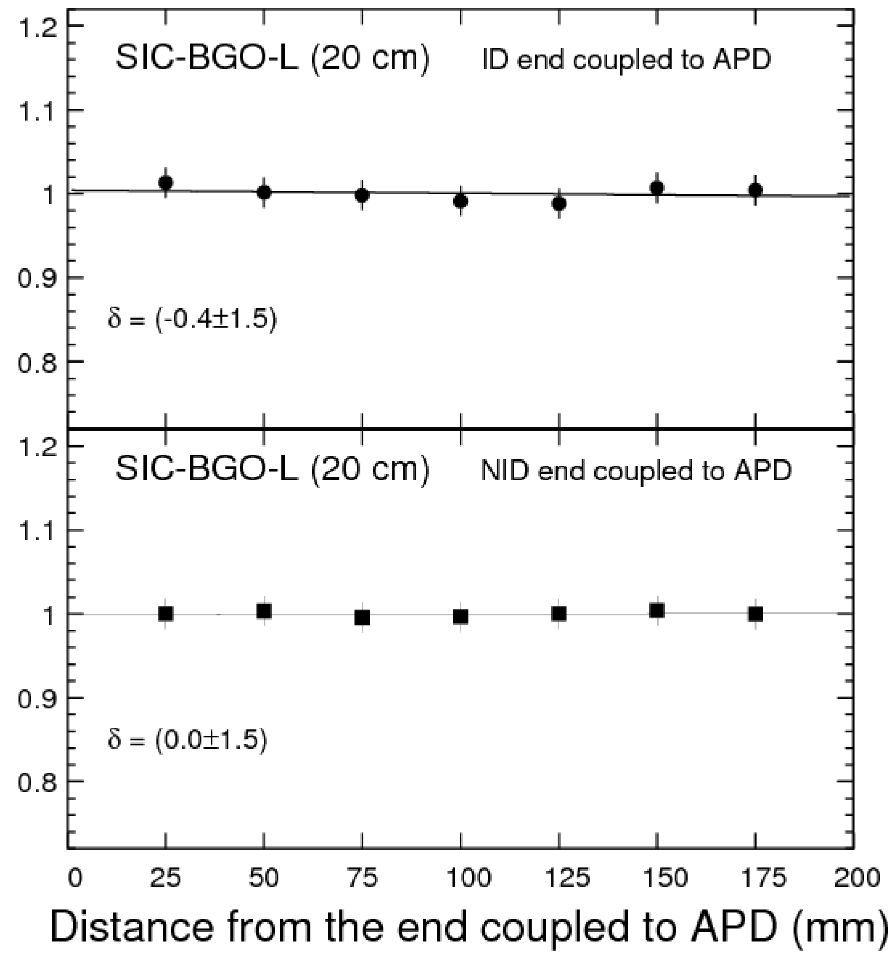
PMT with Mask (APD coverage)



L.R.U. by PMT and APD for BGO

No difference between PMT & APD readout. This seems a particular issue for LYSO.





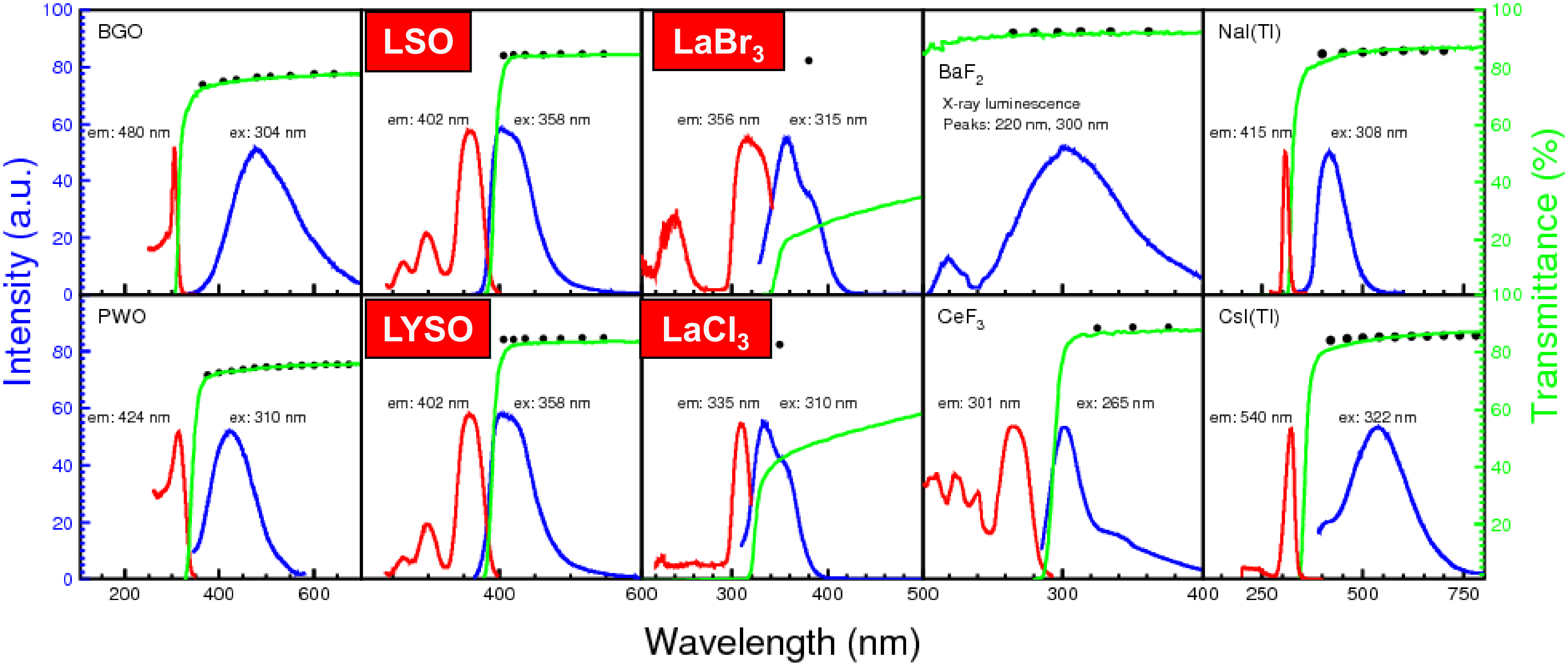
Excitation, Emission, Transmission

It seems not caused by self-absorption

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

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

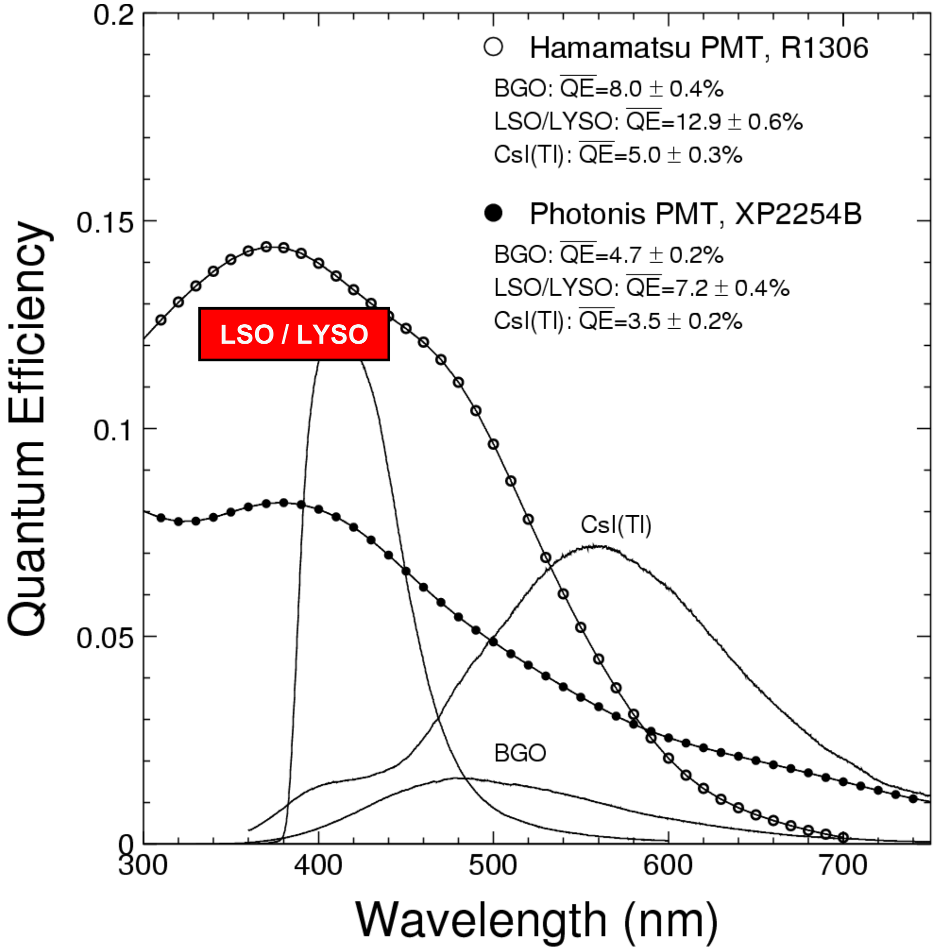
Black Dots: Theoretical limit of transmittance: NIM A333 (1993) 422

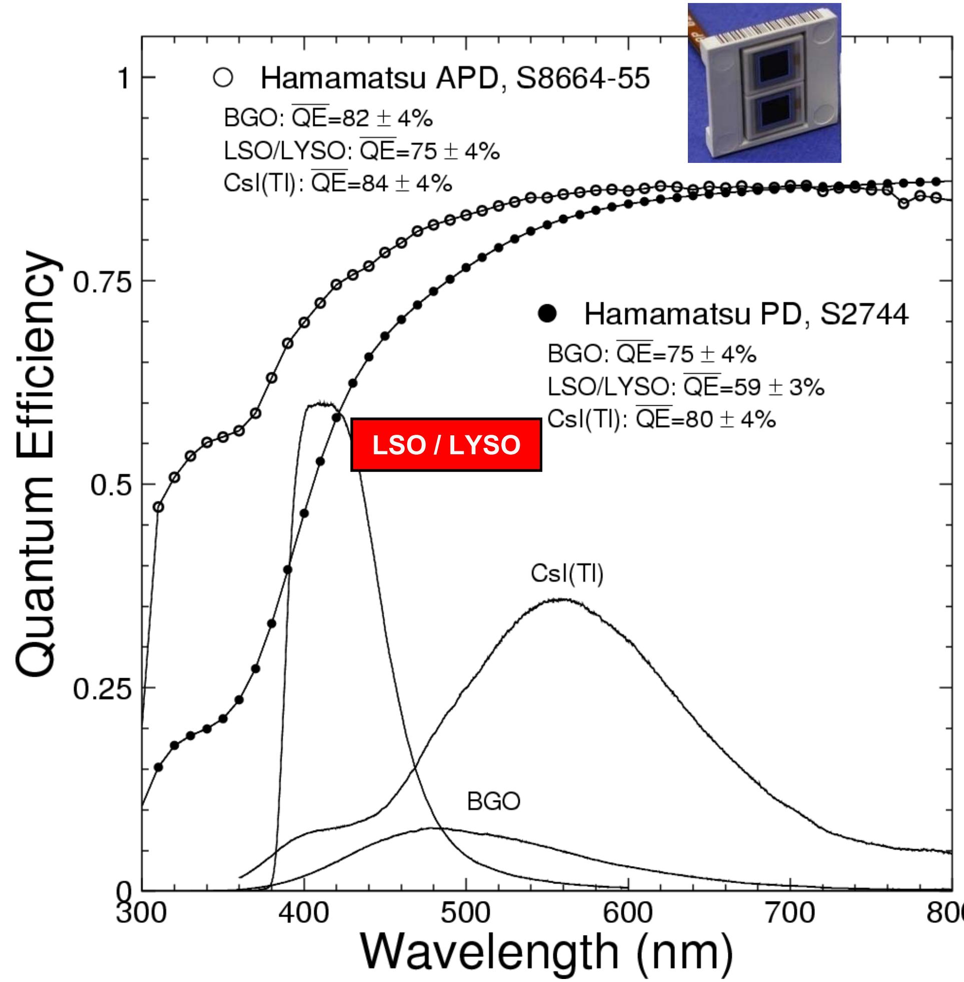


No Self-absorption: BGO, PWO, BaF_2, NaI(Tl) and CsI(Tl)

Emission Weighted QE

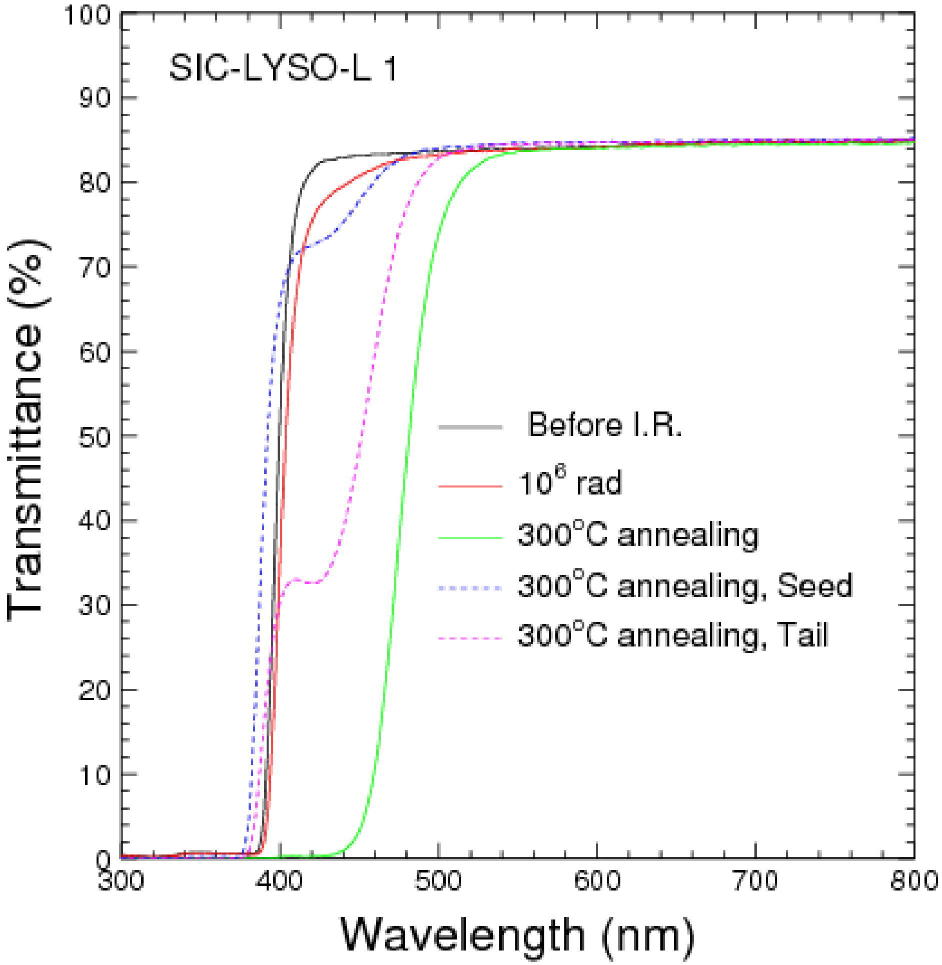
It may be due to the QE difference between PMT & APD.
Investigation is under way with optical filters.





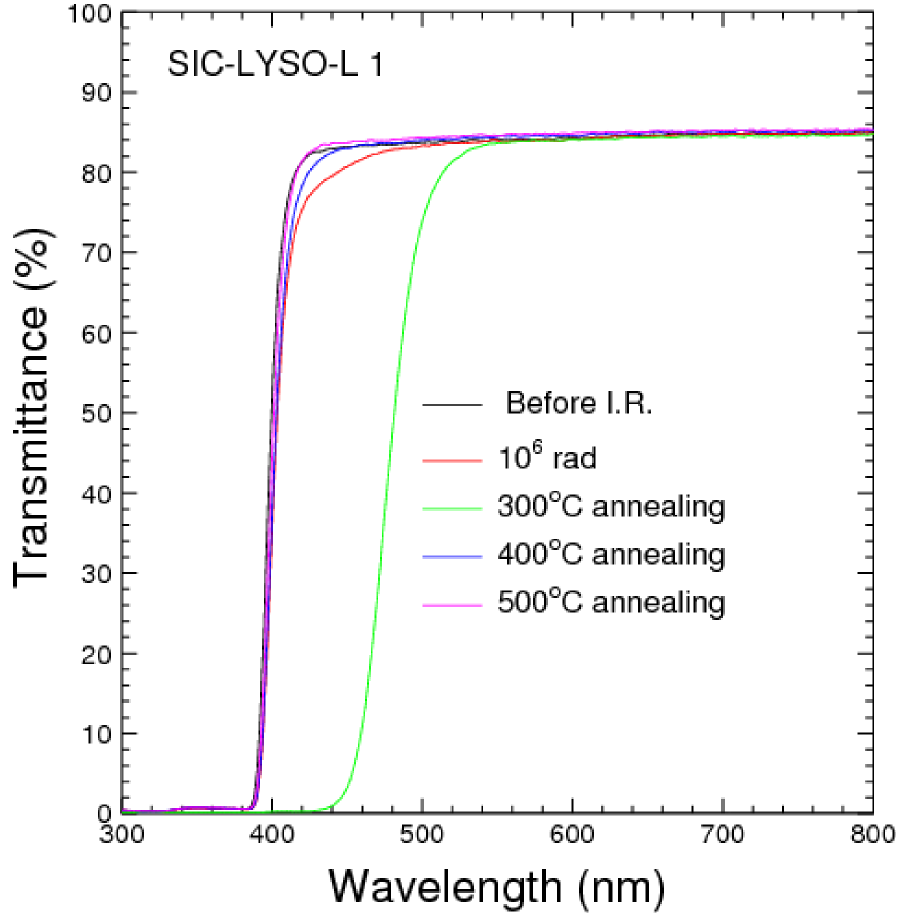
300°C Annealing: Absorption in SIC-L1

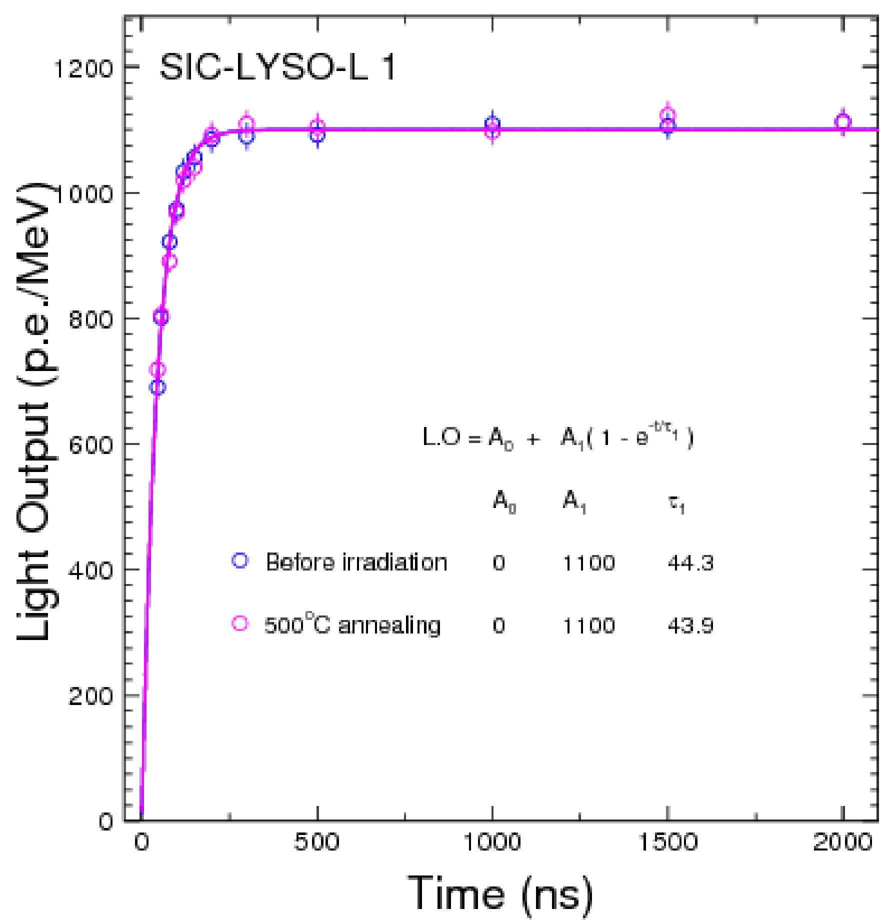
Transverse transmittance indicates color centers (impurities?) at the tail end after 300°C annealing



500°C Annealing eliminated Absorption

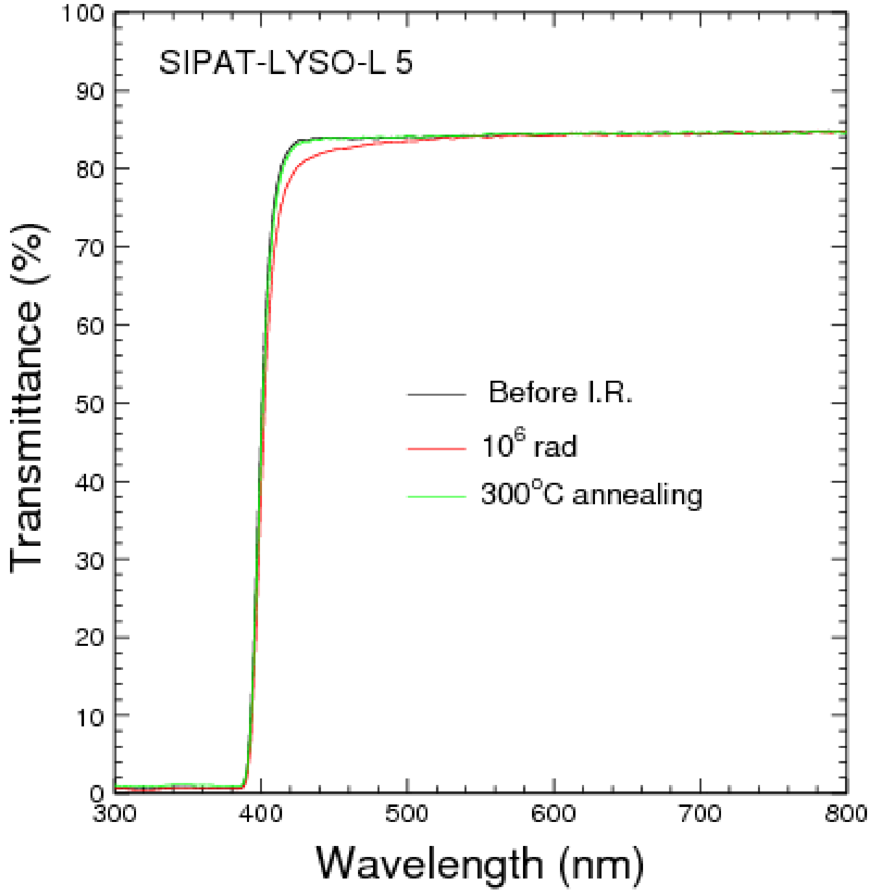
Fully recovered after 500°C thermal annealing

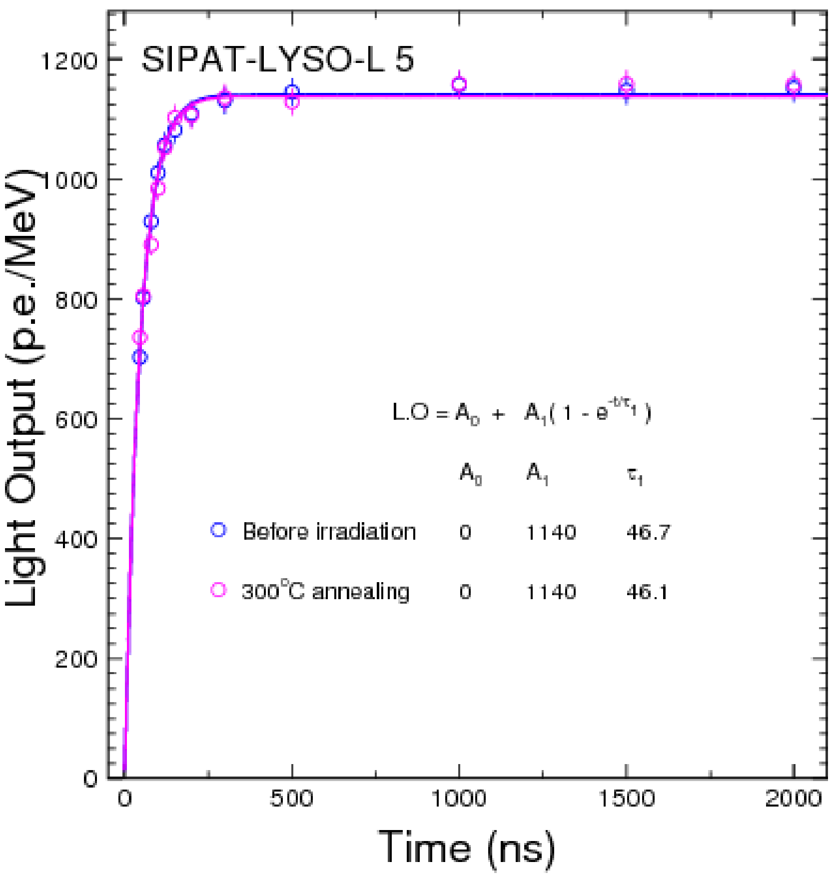




300°C Sufficient for SIPAT-LYSO-L5

Fully recovered after 300°C annealing





Summary

- LYSO crystals with blight, fast scintillation and good radiation resistance is an excellent material for SuperB ECAL endcap.
- The optimized cerium concentration in LYSO was found to be between 125 and 325 ppmw. An optimized SIPAT sample shows a possibility of cutting one ingot into two tapered crystals.
- Different L.R.U. was found between the PMT and APD readout, which can not be explained by detector geometry. Investigation is under way to understand the nature of this difference.
- The 1st SIC sample shows adequate L.R.U.. Its thermal annealing induced absorption is suspected to be caused by contamination.