# Monitoring LSO/LYSO Crystal Based Calorimeters

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O5-02, Calor2014, April 11, 2014, Giessen, Germany

# Introduction

- Variations of transparency in thin LYSO plates is small because of their superb radiation hardness. Long crystals were studied to understand LYSO monitoring.
- In general monitoring can be carried out by taking two approaches:
  - Monitoring variations of crystal transparency only by injecting light pulses at the wavelength close to its emission peak, e.g. CMS at LHC;
  - Monitoring both photo-luminescence production and crystal transparency by injecting light pulses at the wavelength close to its excitation peak, e.g. PHENIX at RHIC.
- The $2^{nd}$ approach requires high pulse intensity but may have some advantages for LYSO monitoring.

# LYSO Samples Investigated


| Sample ID | Dimension ($mm^3$) | Polish |
|---|---|---|
| CPI-LYSO-L | 25 × 25 × 200 | Six faces polished |
| CTI-LSO-L | 25 × 25 × 200 | Six faces polished |
| SG-LYSO-L | 25 × 25 × 200 | Six faces polished |
| SIC-LYSO-L | 25 × 25 × 200 | Six faces polished |
| SIPAT-LYSO-L | 25 × 25 × 200 | Six faces polished |

## Experiments

- Properties measured at room temperature before after irradiation: longitudinal transmittance (LT) & light output (LO).
- Step by step irradiations by γ-rays: 100, 1K, 10K, 100K and 1M rad.

# Excitation, Emission & Transmittance

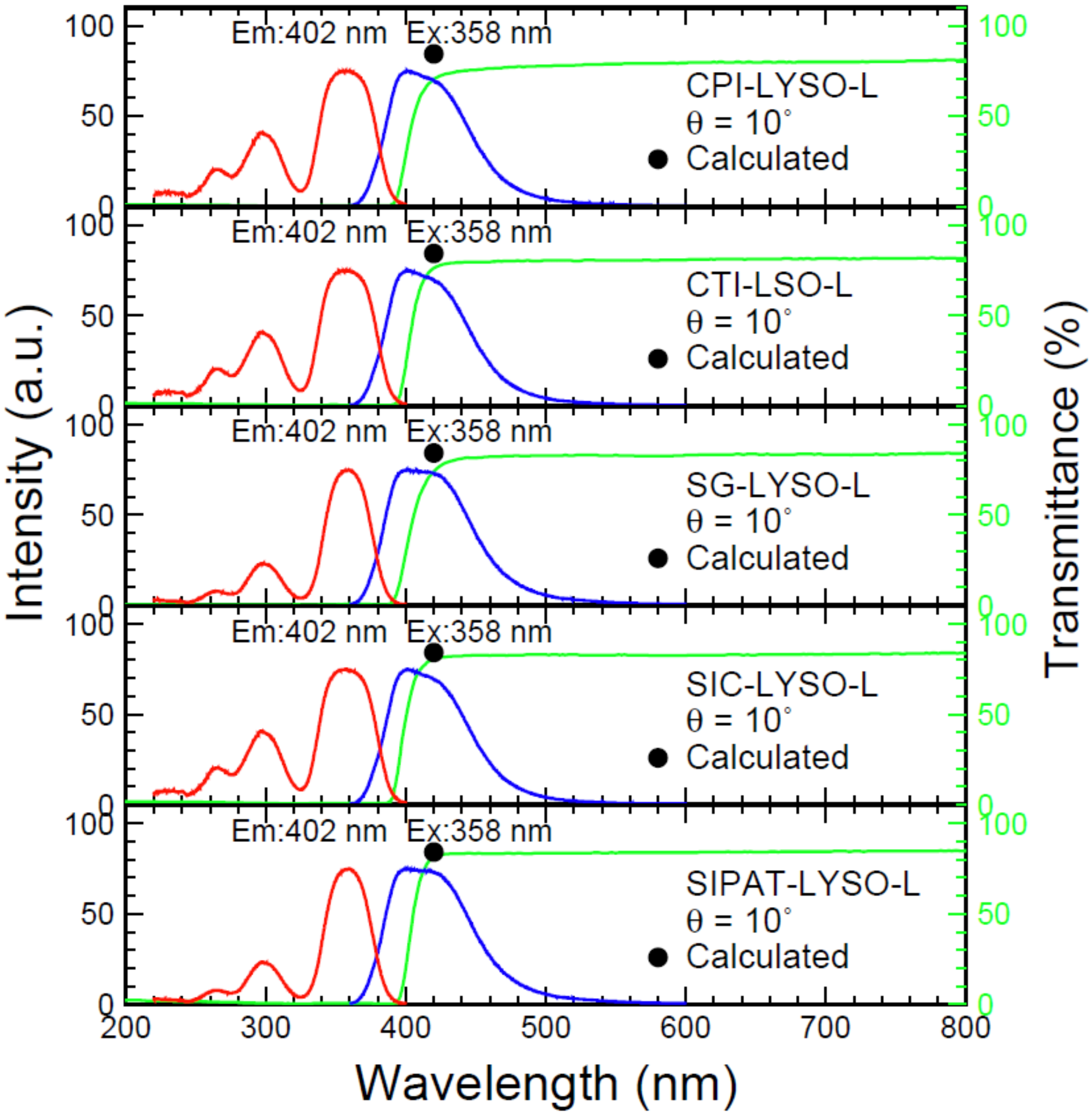



Photo-luminescence spectra for 20 cm samples with peaks:

Excitation: 358 nm

Emission: 402 nm

The cut-off wavelength of the transmittance is red-shifted because of self-absorption.

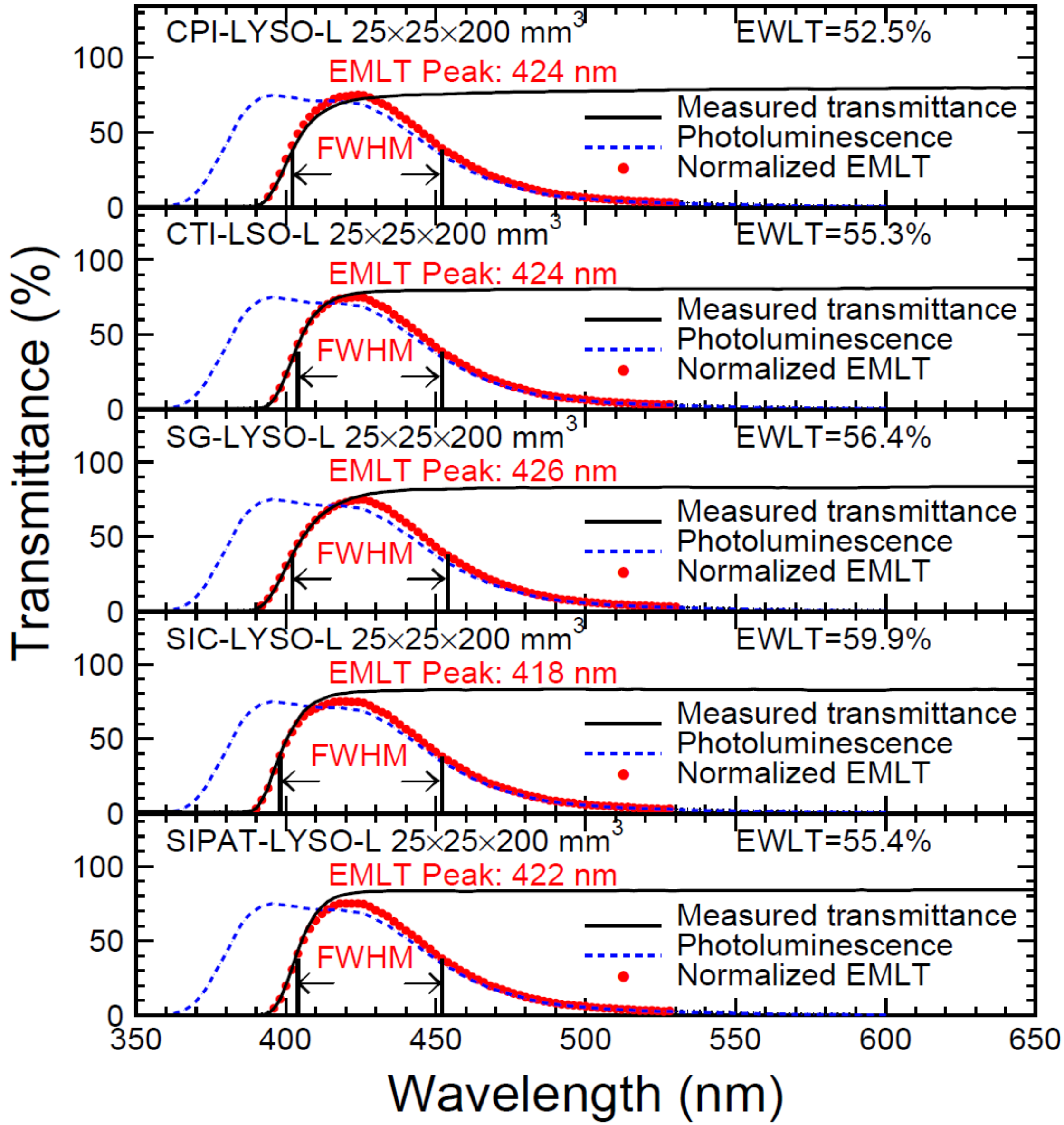
# Emission (PL), LT and EMLT

EMLT (Emission Multiplied Longitudinal Transmittance):
*EMLT(λ) = Em(λ) × LT(λ).*

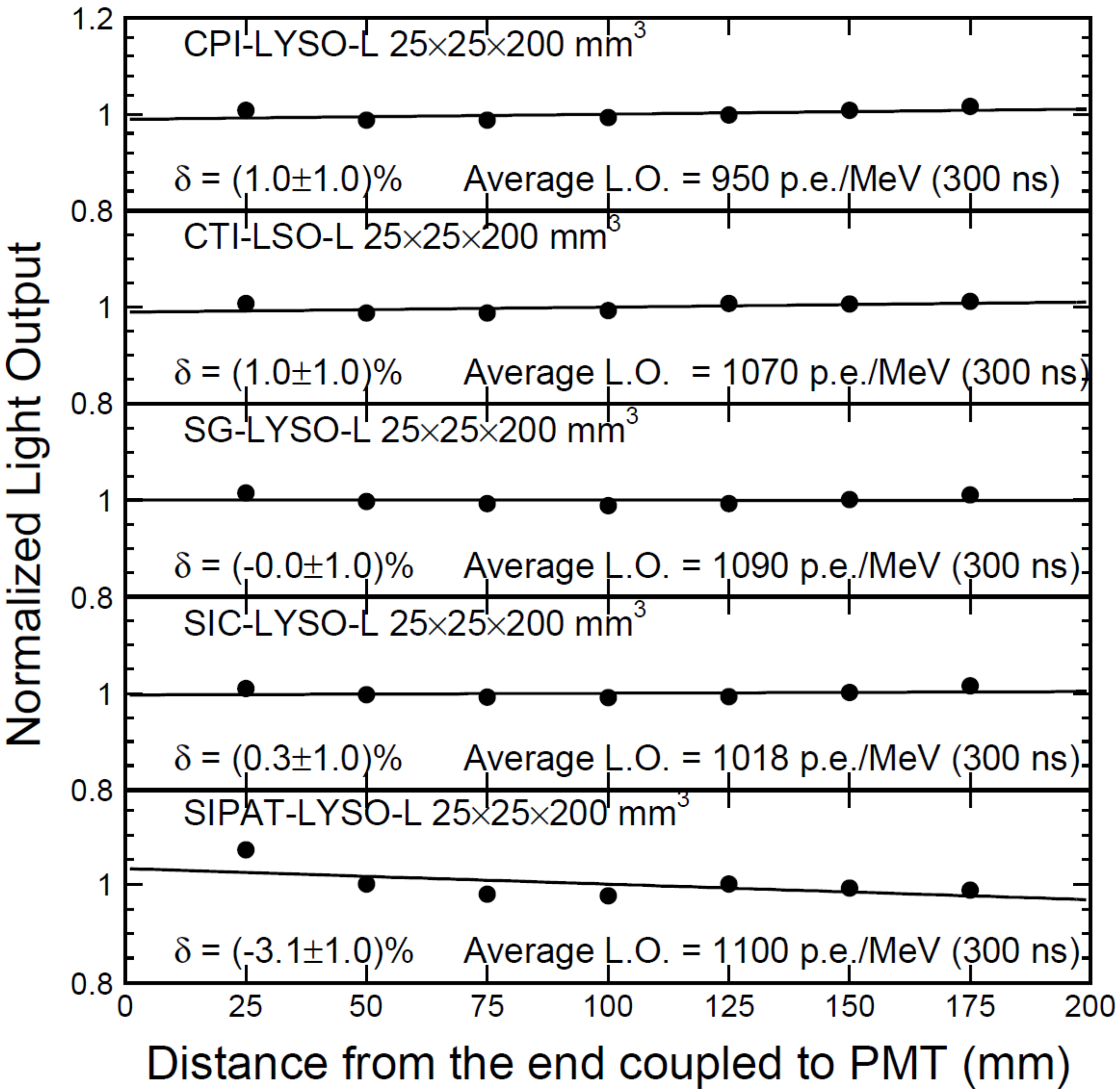
The average peak position of EMLT is at 423 nm.

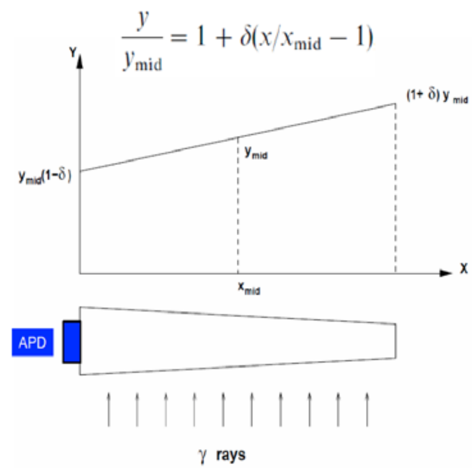
The average FWHM of EMLT is 48 nm:
from 404 nm to 452 nm.

EWLT (Emission Weighted Longitudinal Transmittance), $EWLT = \int Em(\lambda)LT(\lambda)d\lambda$, represents the transparency for the entire emission spectrum.



# Initial LO and LRU



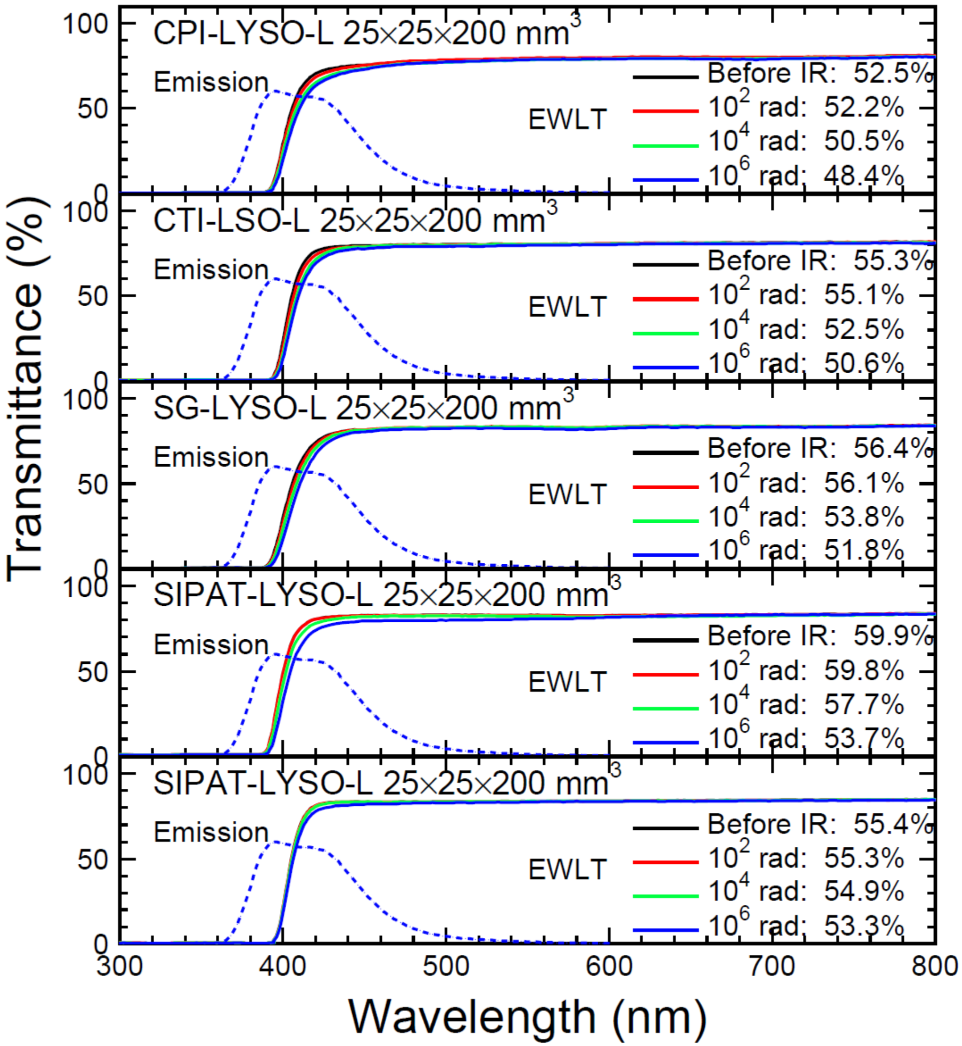



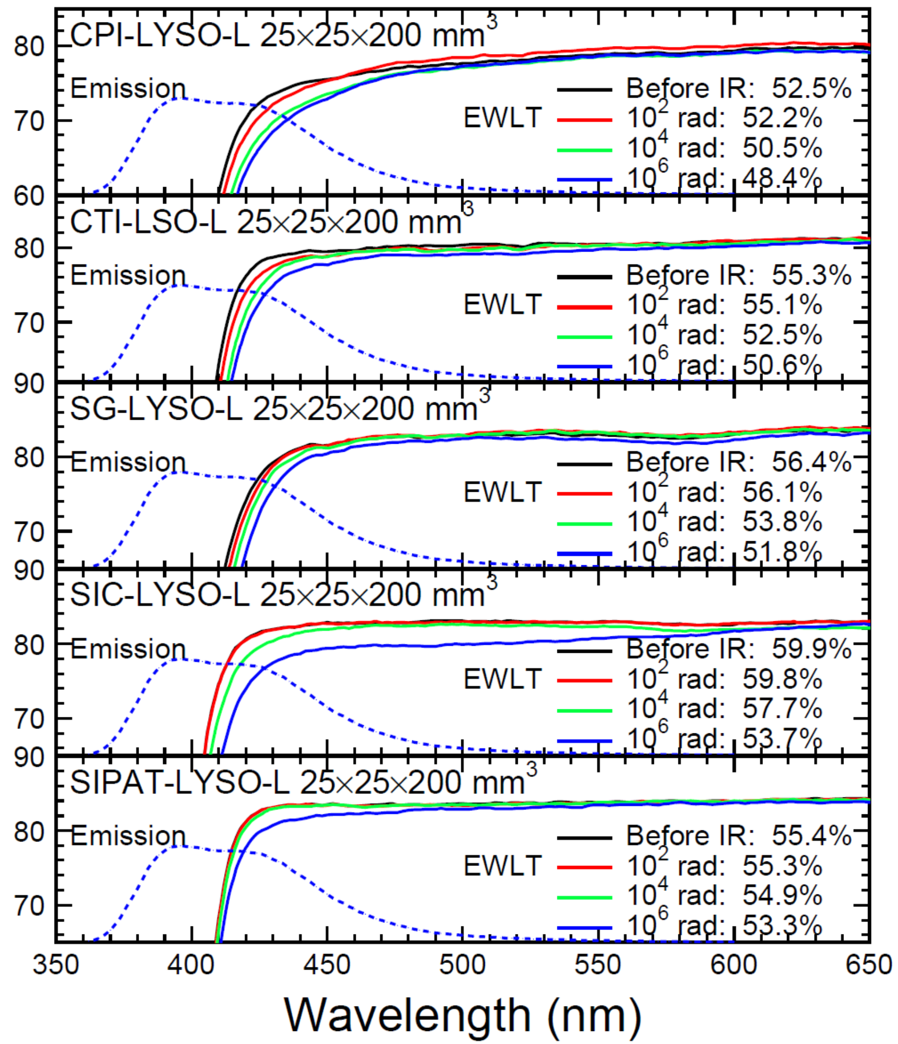

Light output (LO) is defined as the average of seven measurements uniformly distributed along the sample.

All samples have good LO with light response uniformity (LRU) of better than 3%: the self-absorption effect is compensated by [Ce].

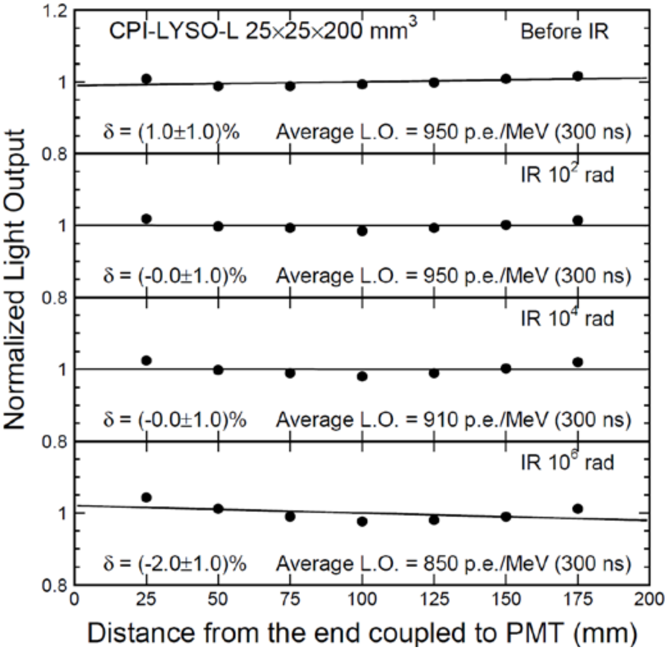
# Excellent Radiation Hardness in LT

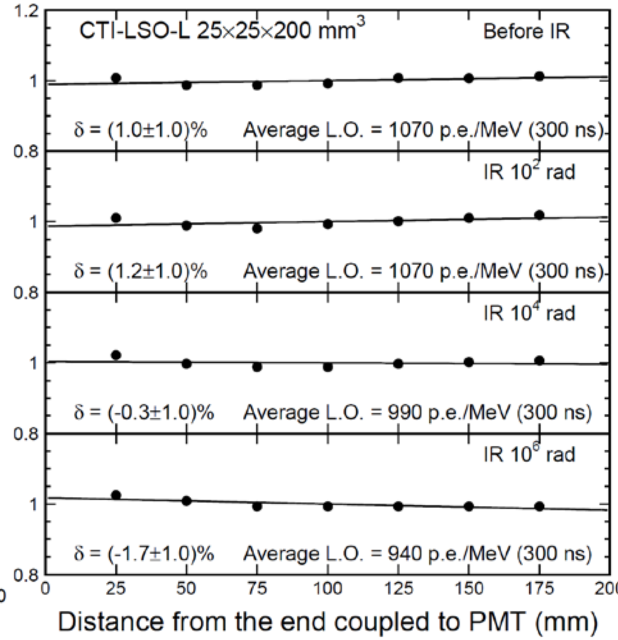
Consistent & Small Damage in LT → Larger variation @ shorter $\lambda$

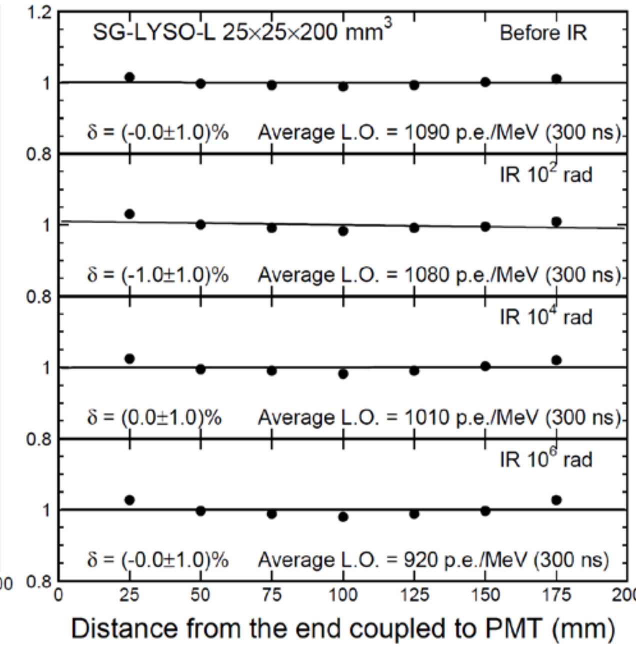


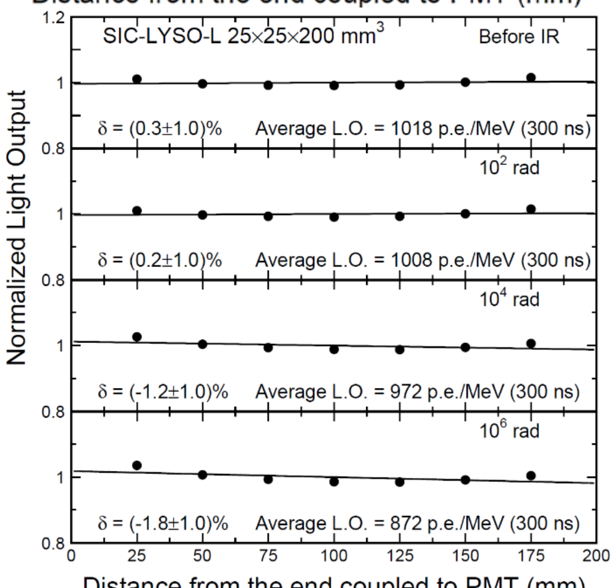



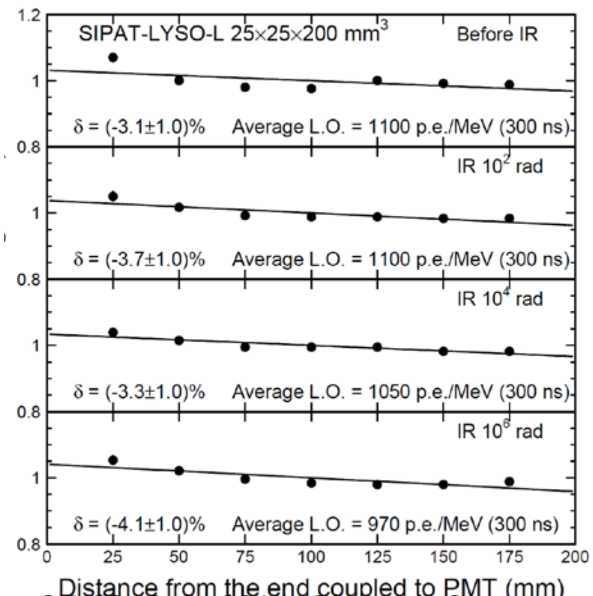
# Excellent Radiation Hardness in LO



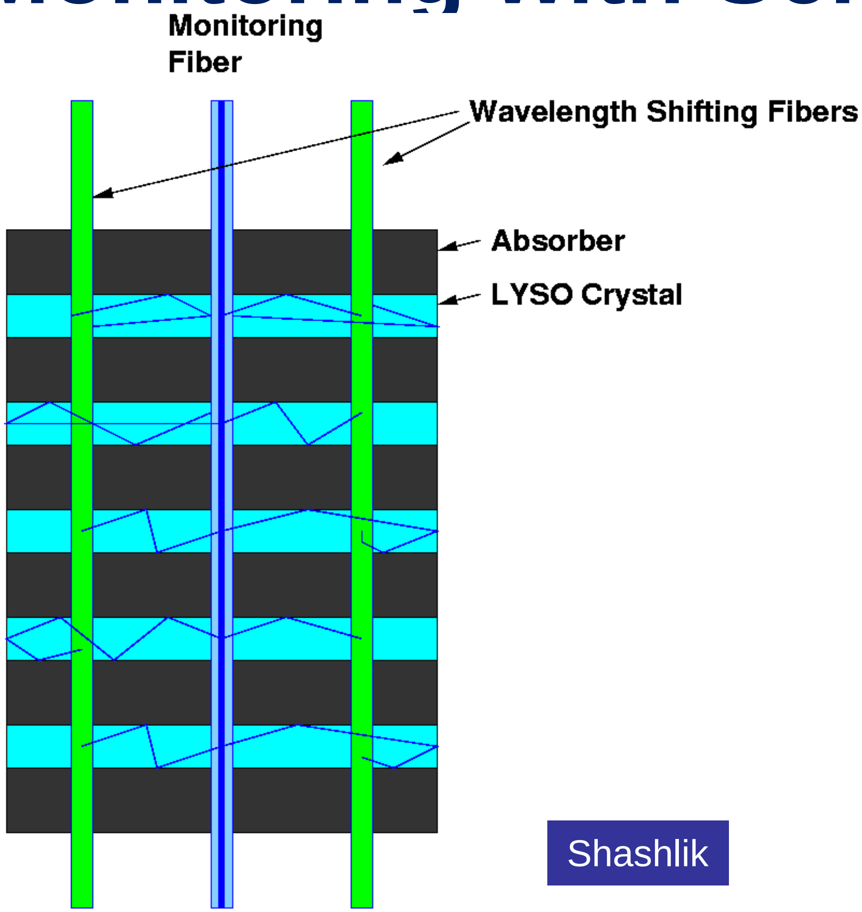



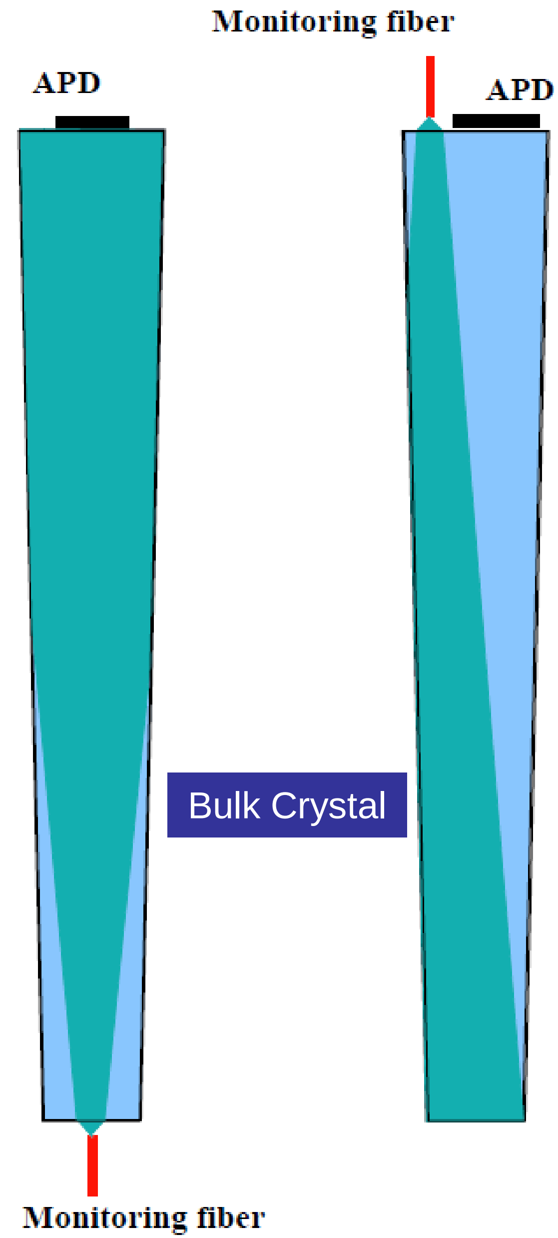




About 12% LO loss observed after 1 Mrad irradiation in all samples with LRU maintained. It can be corrected by light monitoring.

# Monitoring with Scintillation Light



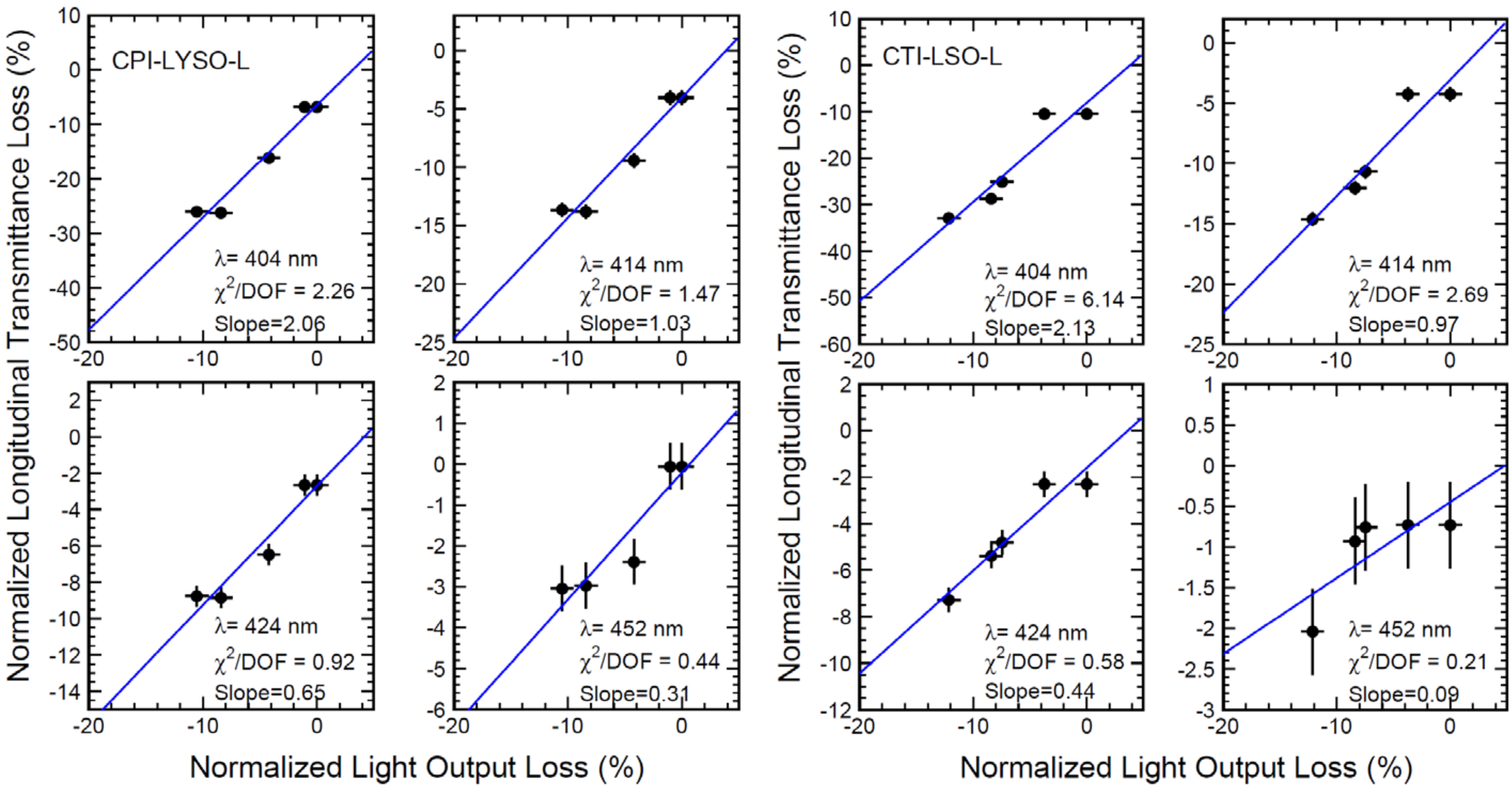




If scintillation mechanism is not damaged, light pulses with a wavelength close to the emission peak would be effective to monitor variations of crystal transparency. CMS at LHC, for example, selects ~440 nm for PWO crystal monitoring.

X.D. Qu *et al*., IEEE TNS VOL. 47, NO. *6,* DECEMBER (2000) 1741-1747

# LT Loss vs. LO Loss after Irradiation

Fitting function: $\frac{LT_{IR}-LT_0}{LT_0} = Slope \times \frac{LO_{IR}-LO_0}{LO_0}$



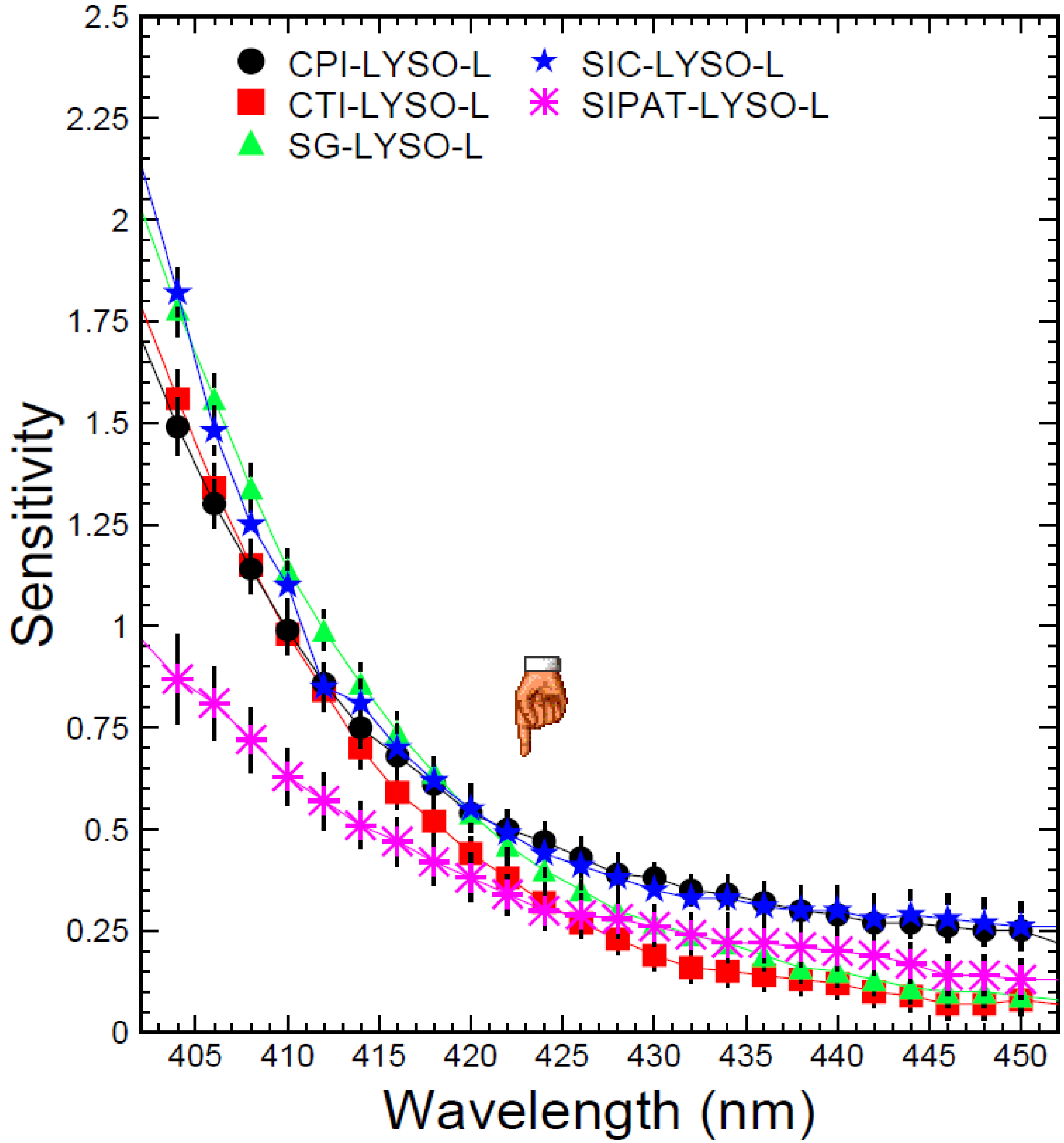

The slope represents the monitoring sensitivity at a particular wavelength

# Monitoring Sensitivity vs. Wavelength

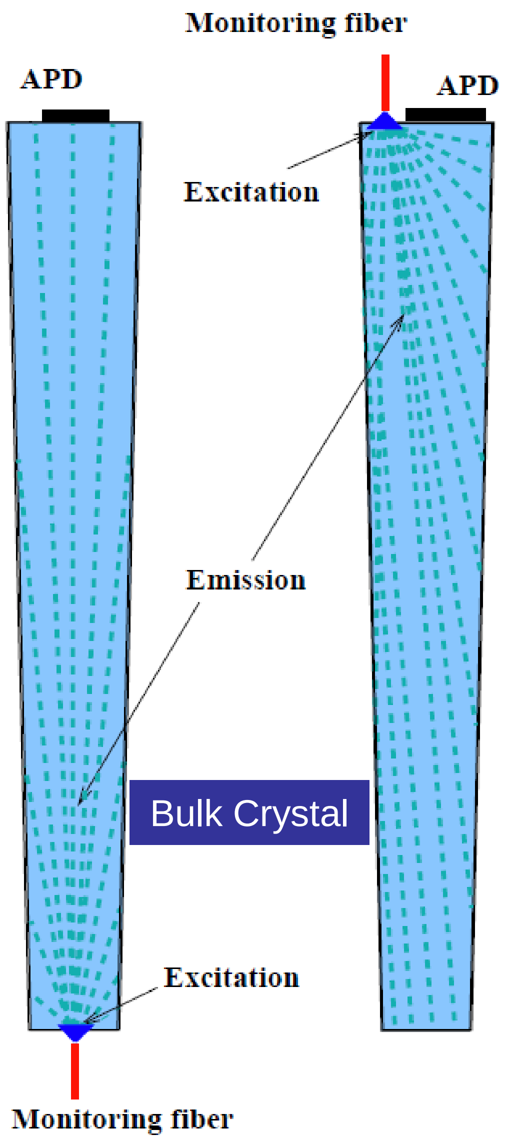
The monitoring sensitivity increases at shorter wavelengths because of larger variation in transparency.

A shorter wavelength is preferred for a better sensitivity. A longer wavelength is preferred for a larger monitoring light signal.

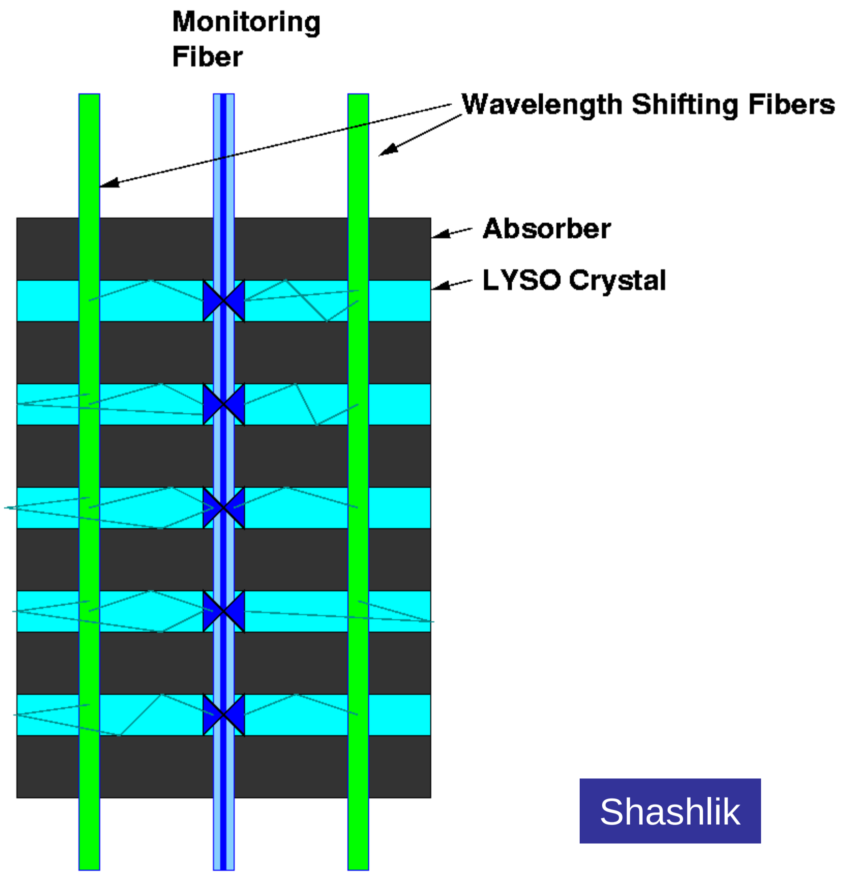
The EMLT peak position at ~423 nm would be the choice. Blue DPSS lasers, however, are expensive.



# Monitoring with Excitation Light




Bulk Crystal

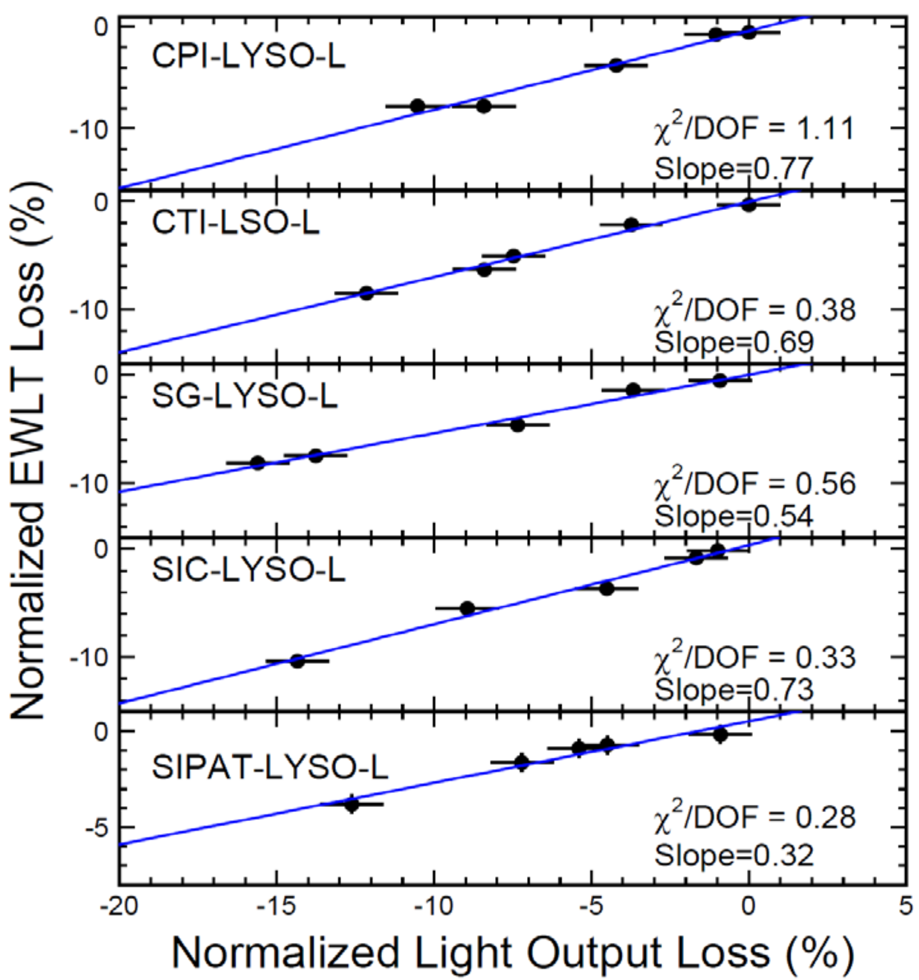


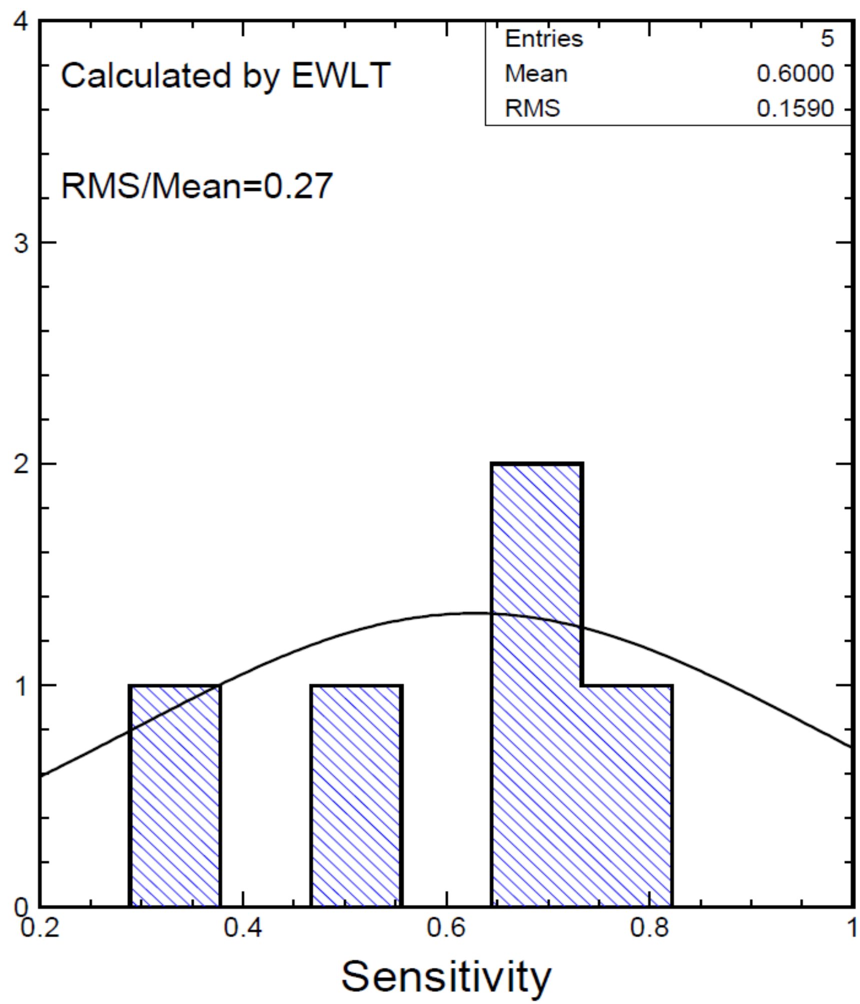

Shashlik

Light pulses with a wavelength at an excitation peak, e.g. 358 nm for LYSO, monitor crystal transparency and photo-luminescence production. PHENIX at RHIC selects 355 nm from an Nd:YAG laser for plastic scintillators.

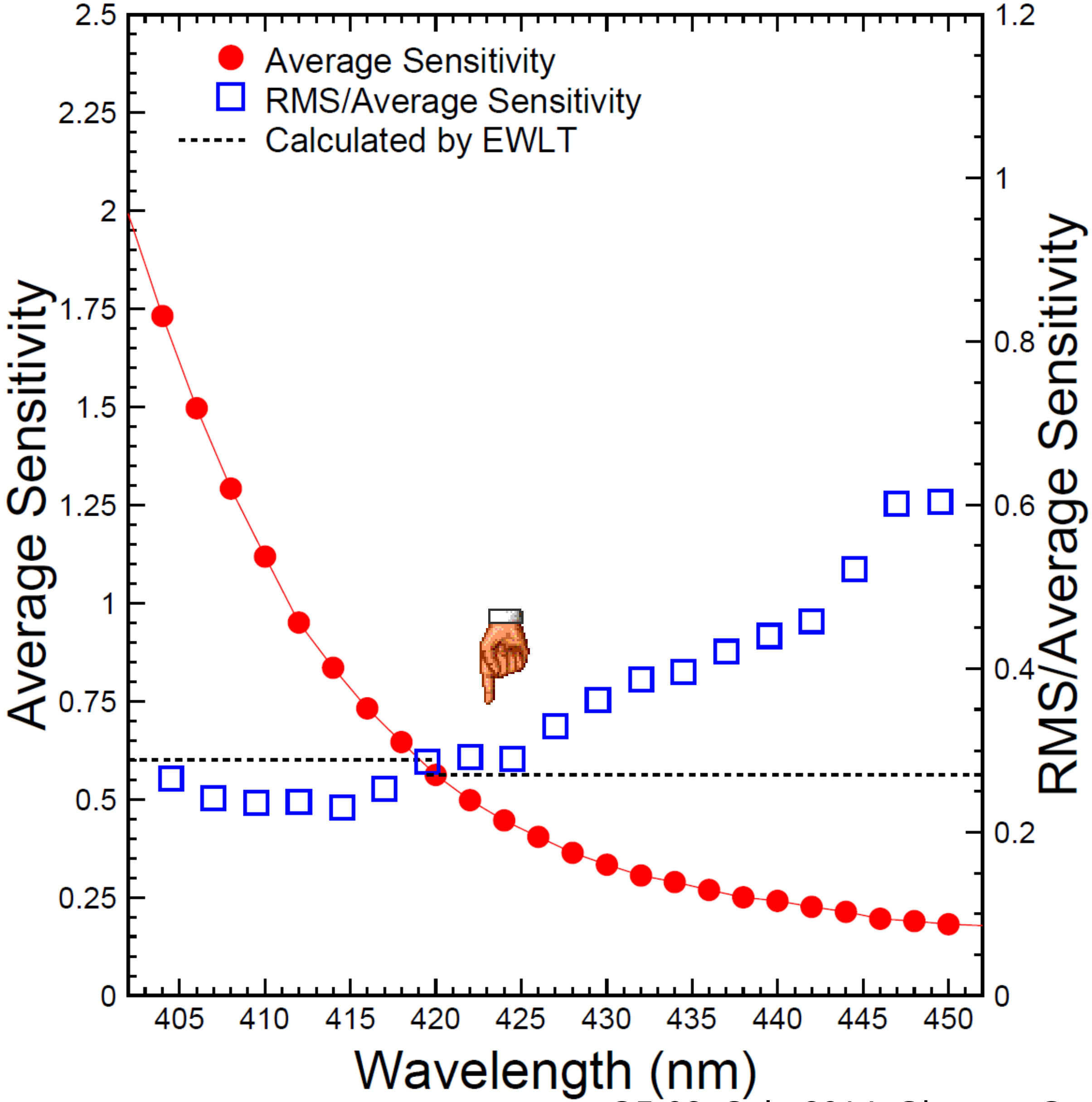
# Monitoring Sensitivity with EWLT

RMS/Mean represents the divergence between 5 vendors



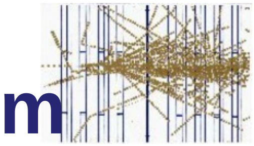
# Choice of Monitoring Wavelength



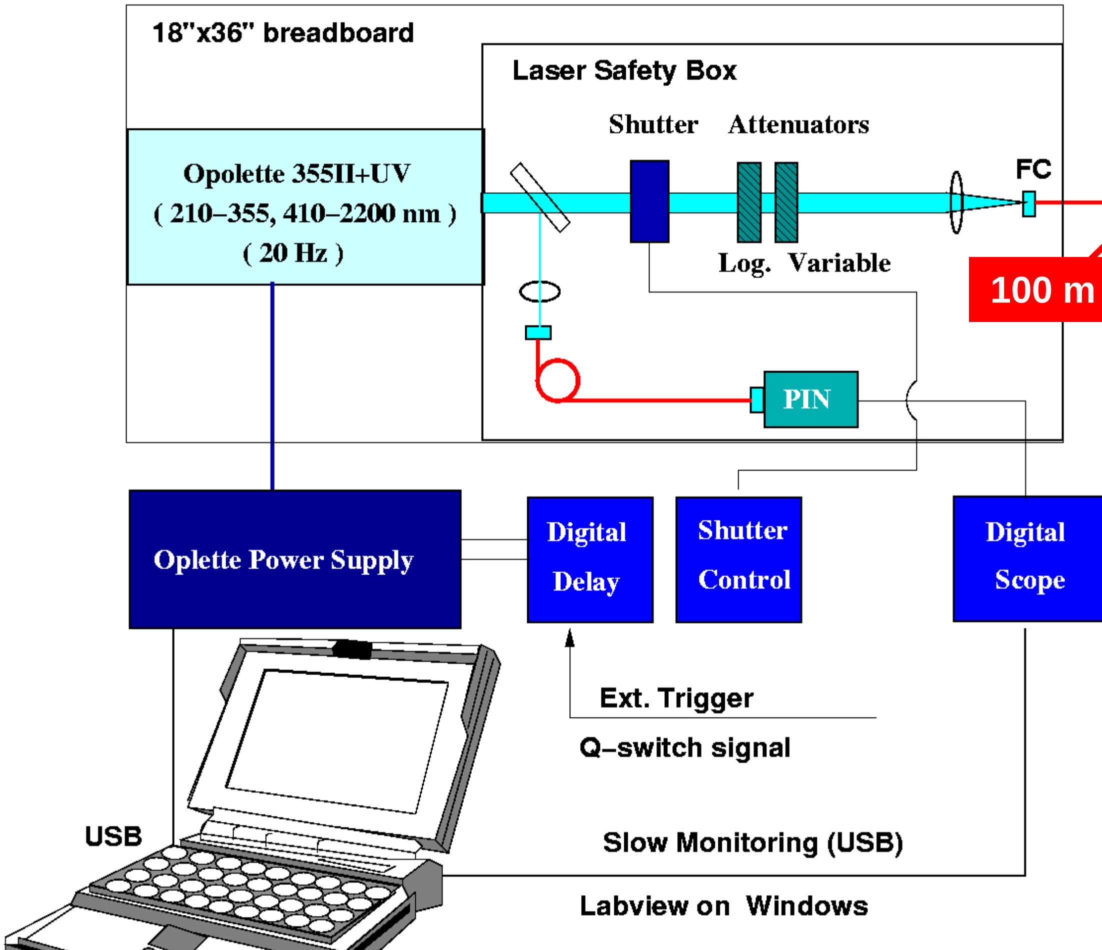

Consistent monitoring sensitivity is observed for both the EWLT for the entire emission spectrum and the wavelength close to the emission peak: 423 nm.

A divergence at 25% level for crystals from five different vendors is observed for both the EWLT and the wavelength close or shorter than the emission peak, which will be improved in mass-production.

# A Tunable Laser Based Monitoring System

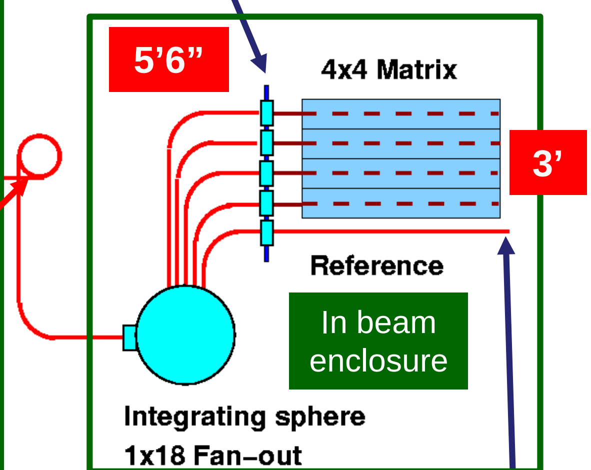


Plan to run at two wavelengths: 425 nm and 355 nm




In laser barracks/room

FC Feedthrough on Back Plane

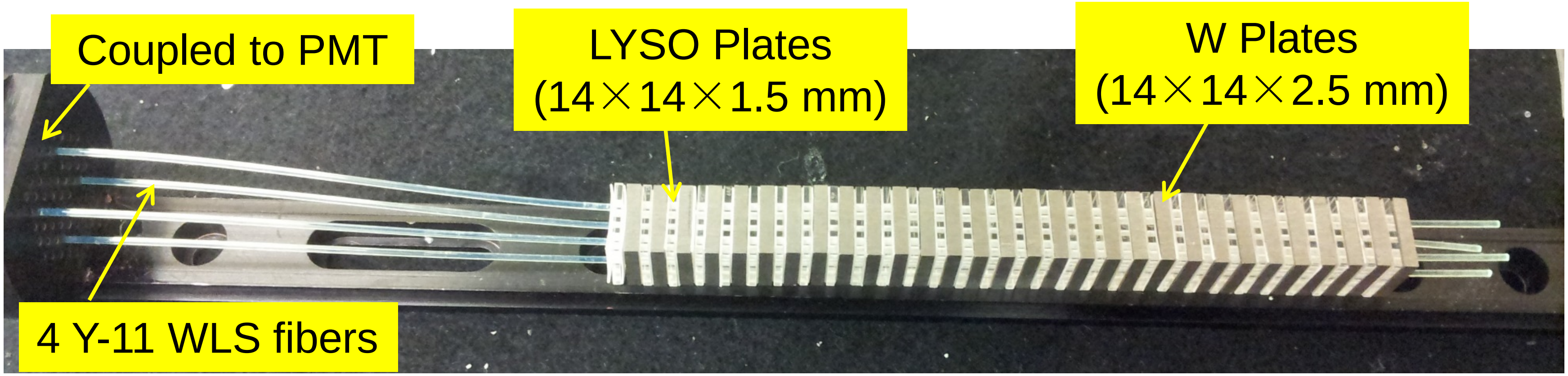


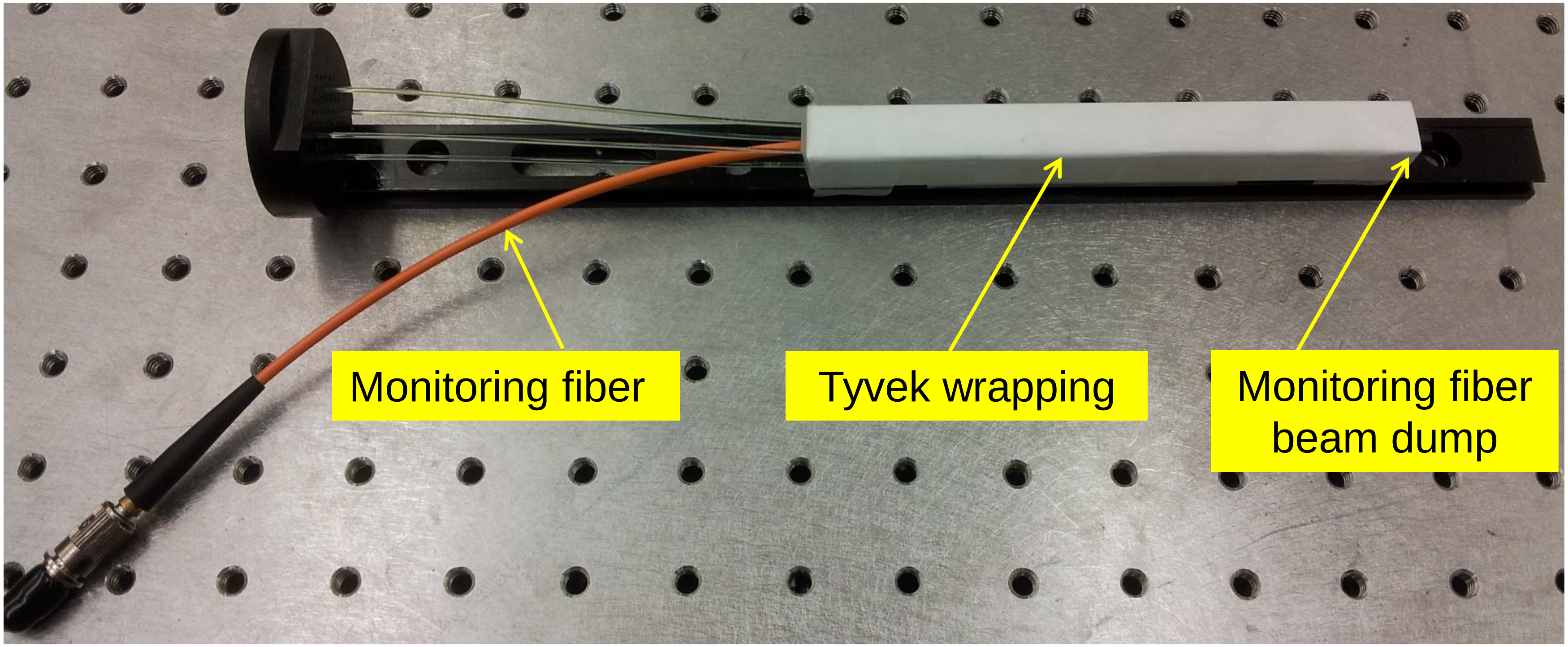

Readout with the same photo-detector & electronics

*Caltech* *Jan. 24, 2014*

To be installed at Fermilab next week

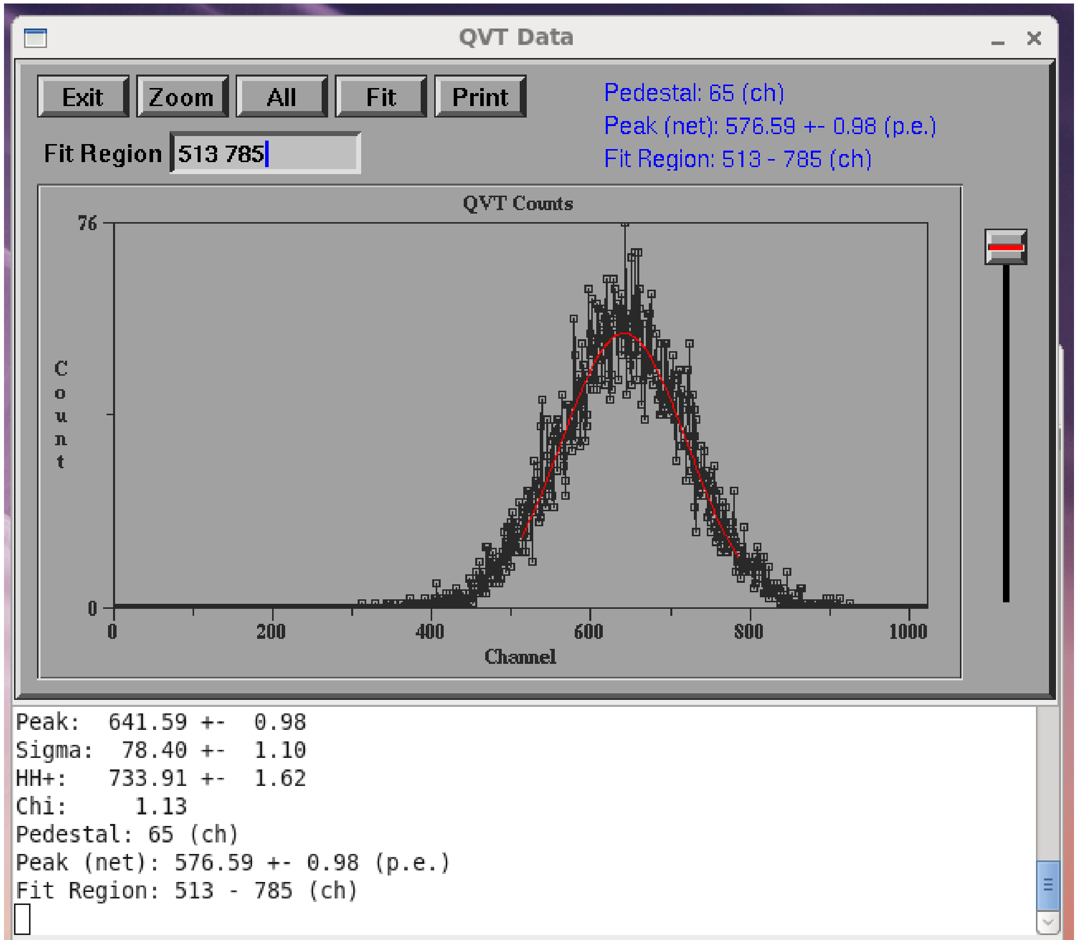
# LYSO-W Cell for Monitoring Test



# Monitoring Insertion Test

Monitoring signal through WLS fiber coupled to PMT is 20,000 p.e. with σ/E~14% from 0.7 mJ laser pulses, indicating a total attenuation of about 110 dB. Up to 80,000 p.e. is achievable with 3 mJ pulse.




80,000 p.e. corresponds a dynamic range of 4 GeV in LYSO, or 20 GeV in Shashlik tower when laser is running at 3 mJ.

Another factor of 5 is needed to reach 100 GeV, requiring R&D on leaky fiber.

110 dB can be compared to 106/72 dB of PHENIX/CMS monitoring.

# Summary

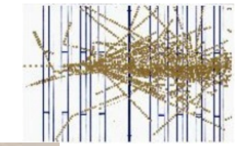
- LSO/LYSO crystals suffer from transparency loss, leading to light output loss. Variations of light output can be corrected by using variations of crystal response to monitoring light pulses.

- Two approaches may be used for LYSO monitoring. One uses a wavelength around the emission peak, which is adapted by CMS for monitoring PWO crystals at LHC. The other uses a wavelength at the excitation peak, which is adapted by PHENIX for monitoring plastic scintillators in a Shashlik ECAL at RHIC.

- The 2$^{nd}$ approach has three advantages: (1) crystal transparency is monitored with the entire emission spectrum; (2) crystal photo-luminescence production is also monitored and (3) cost-effective frequency tripled DPSS YAG laser at 355 nm is commercially available.

- The two approaches will be tested in the Shashlik Beam Test at Fermilab.

# Cost-Effective UV Lasers at 355 nm



Frequency tripled DPSS YAG laser at 355 nm: @ $50k
http://rpmclasers.com/product/XHE%20355%20datasheet.pdf

| Parameters | XHE11903 | Opolette 355 II+UV |
|---|---|---|
| Pulse energy (mJ) at 355 nm | 2 | 0.06 |
| Repetition rate (Hz) | 1 - 100 | 20 |
| Pulse width (ns) | 3 | 5 |
| Pulse Stability (rms, %) | < 5 | ~20 |
| Divergency (full angle, mrad) | 2 | 6 |
| Beam diameter (1/e2) | 4 | 3 |
| Jitter (ns) | N/A | ~ 1 |
| TEM quality (M2) | 5 | N/A |
| Polarization | Random | Linear |
| Pump source | Diodes | Pulsed lamp |
| Cooling | Air | Internal water loop |
| Dimensions (cm) | 18×9×8 | 36×14×44 |

# Efficiencies in CMS and PHENIX Monitoring Systems

| CMS ECAL Monitoring at 440/447 nm | | | | PHENIX ECAL (Lead Scintillator) Monitoring at 355 nm | | | |
|---|---|---|---|---|---|---|---|
| | Fanout | Extra | Total | | Fanout | Extra | Total |
| LSDS | 0 | 13 | 13 | LSDS | 7.8 | 0.1 | 7.9 |
| Optical Fiber (150M) | 0 | 3 | 3 | Optical Fiber (50M) | 0 | 3 | 3 |
| Level 2 (1:7) | 8.5 | 8.5 | 17 | Level 1 (1:21) | 13.3 | 12.2 | 25.5 |
| Level 1 (1:240) | 24 | 15 | 39 | Level 2 (1:38) | 15.8 | 10.8 | 26.6 |
| | | | | Module Conv. Eff. (UV-VIS) | 0 | 31.2 | 31.2 |
| | | | | Connections and extra | 0 | 11.5 | 11.5 |
| Total | 32.5 | 39.5 | 72 | | 36.9 | 68.8 | 105.7 |