Monitoring LYSO Crystal Based Shashlik Matrix for Fermilab BT

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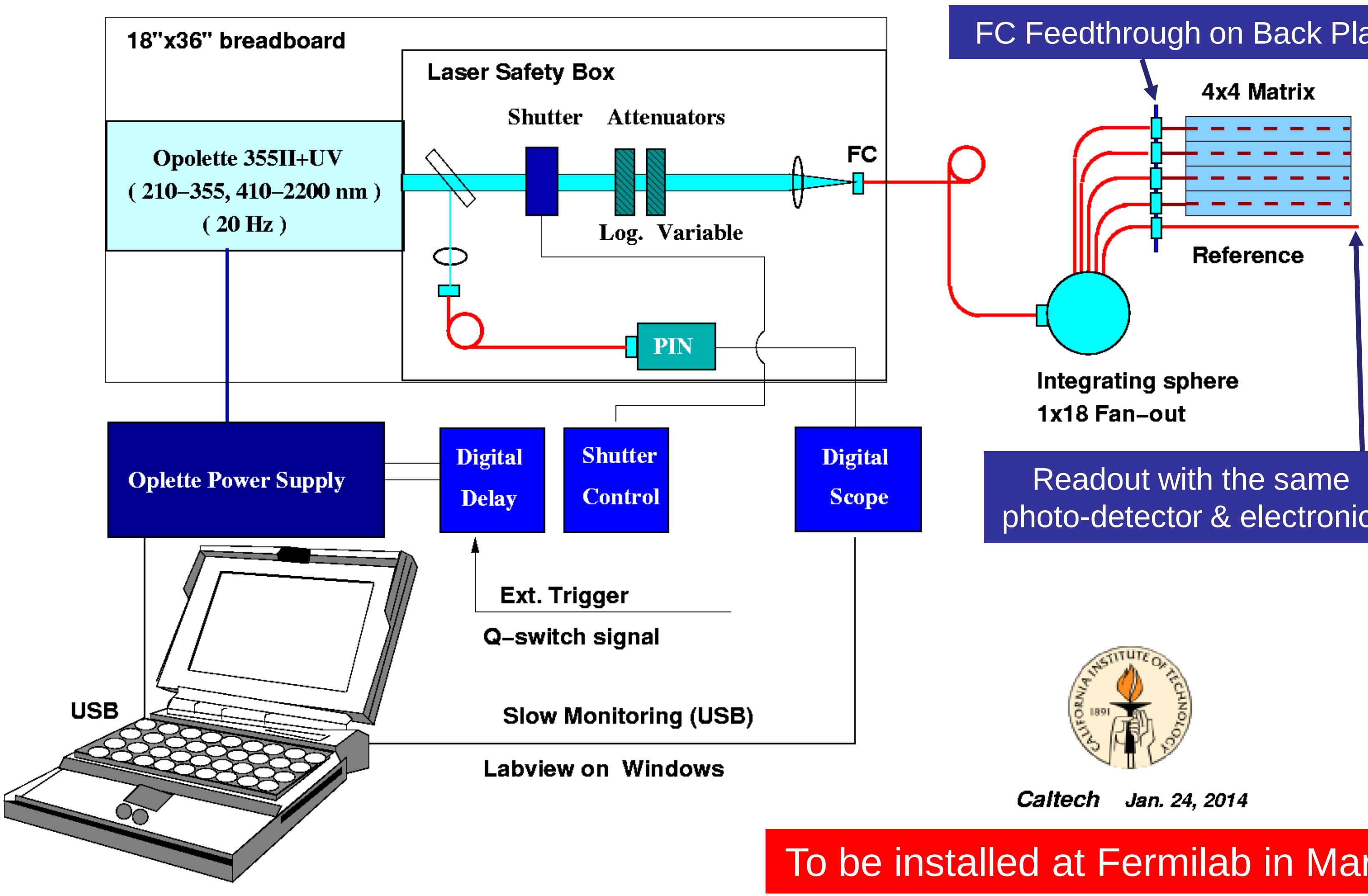
A Tunable Laser Based Monitoring System

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



FC Feedthrough on Back Plane

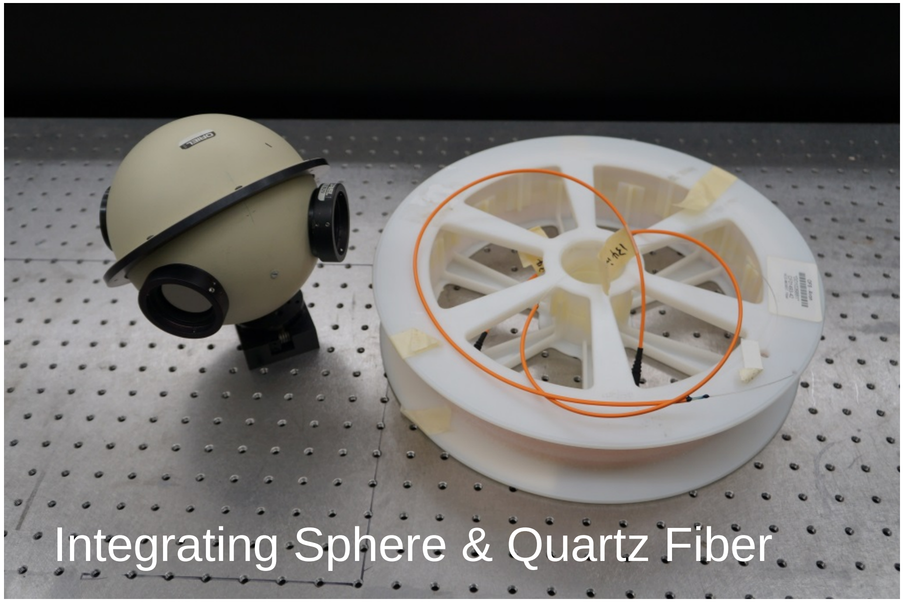
Readout with the same photo-detector & electronics

To be installed at Fermilab in March

Existing Hardware

Laser Power

Laser Head & Safety Box



Integrating Sphere & Quartz Fiber

Introduction

- Because of their excellent radiation hardness variations of transparency in LYSO plates is very small. 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 2nd approach 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

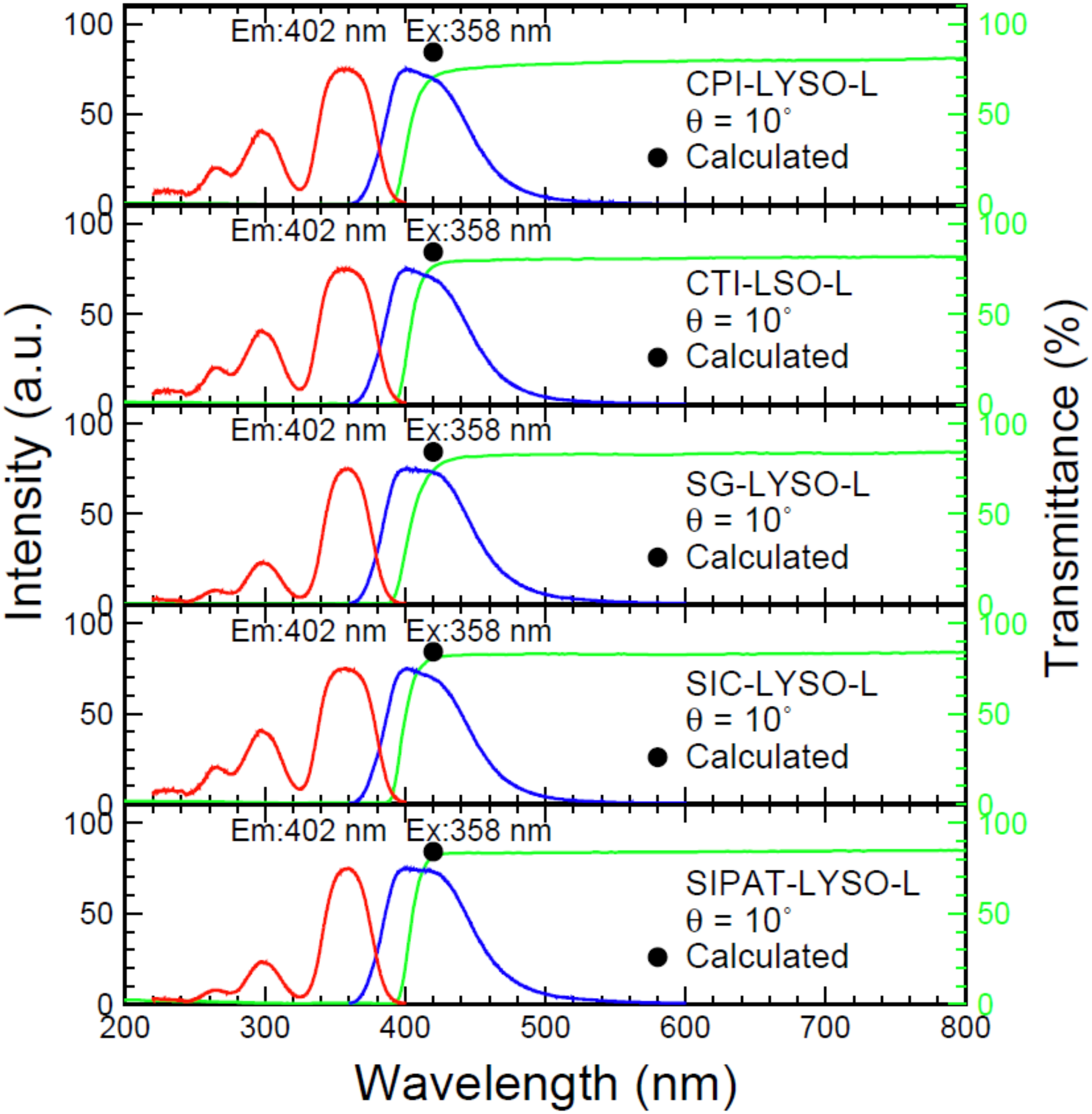


Photo-luminescence spectra for 20 cm samples with peaks:

Excitation: 358 nm

Emission: 402 nm

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

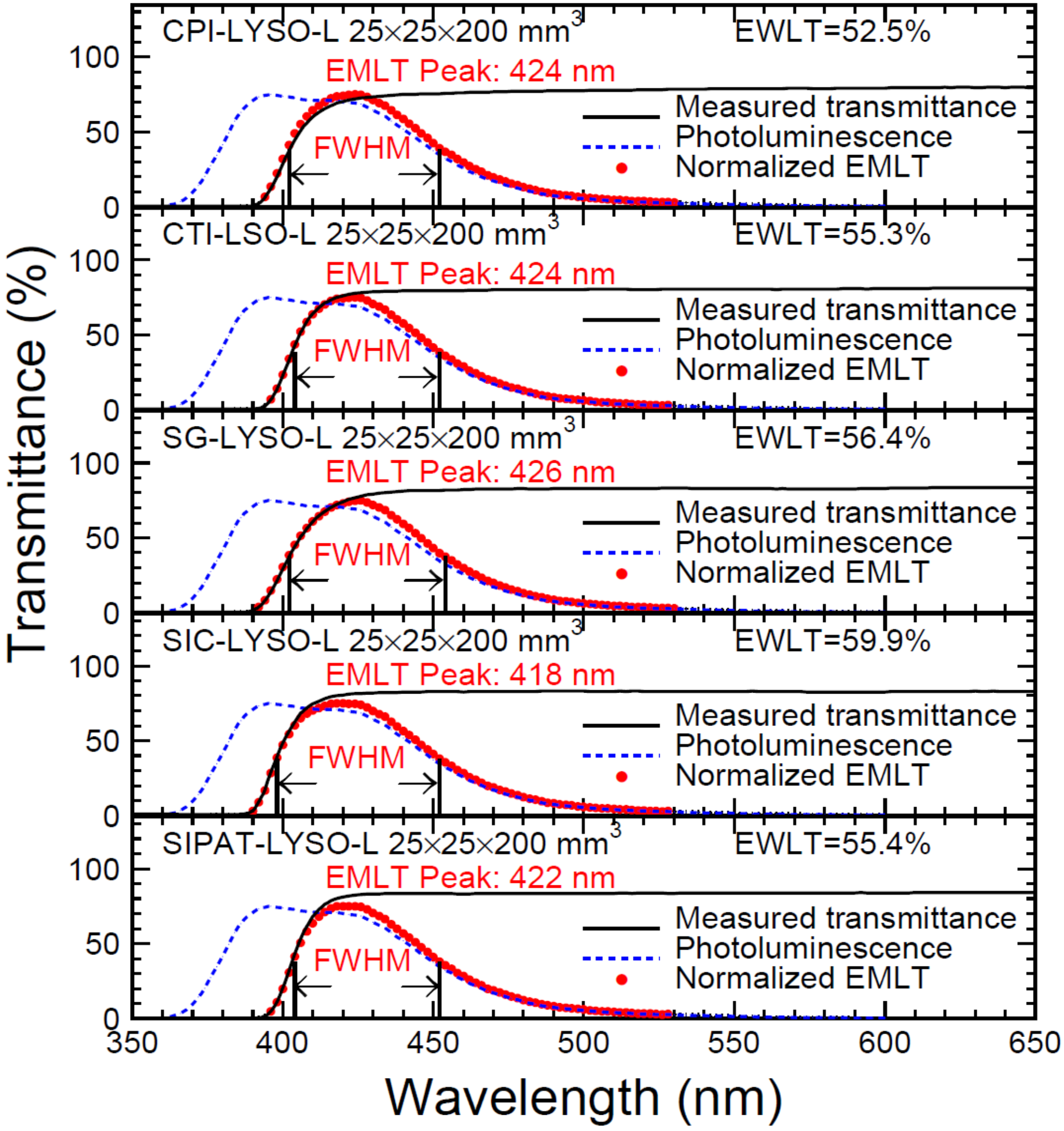
Emission (PL), LT and EMLT

EMLT (Emission Multiplied Longitudinal Transmittance): $EMLT(\lambda) = Em(\lambda) \times LT(\lambda)$.

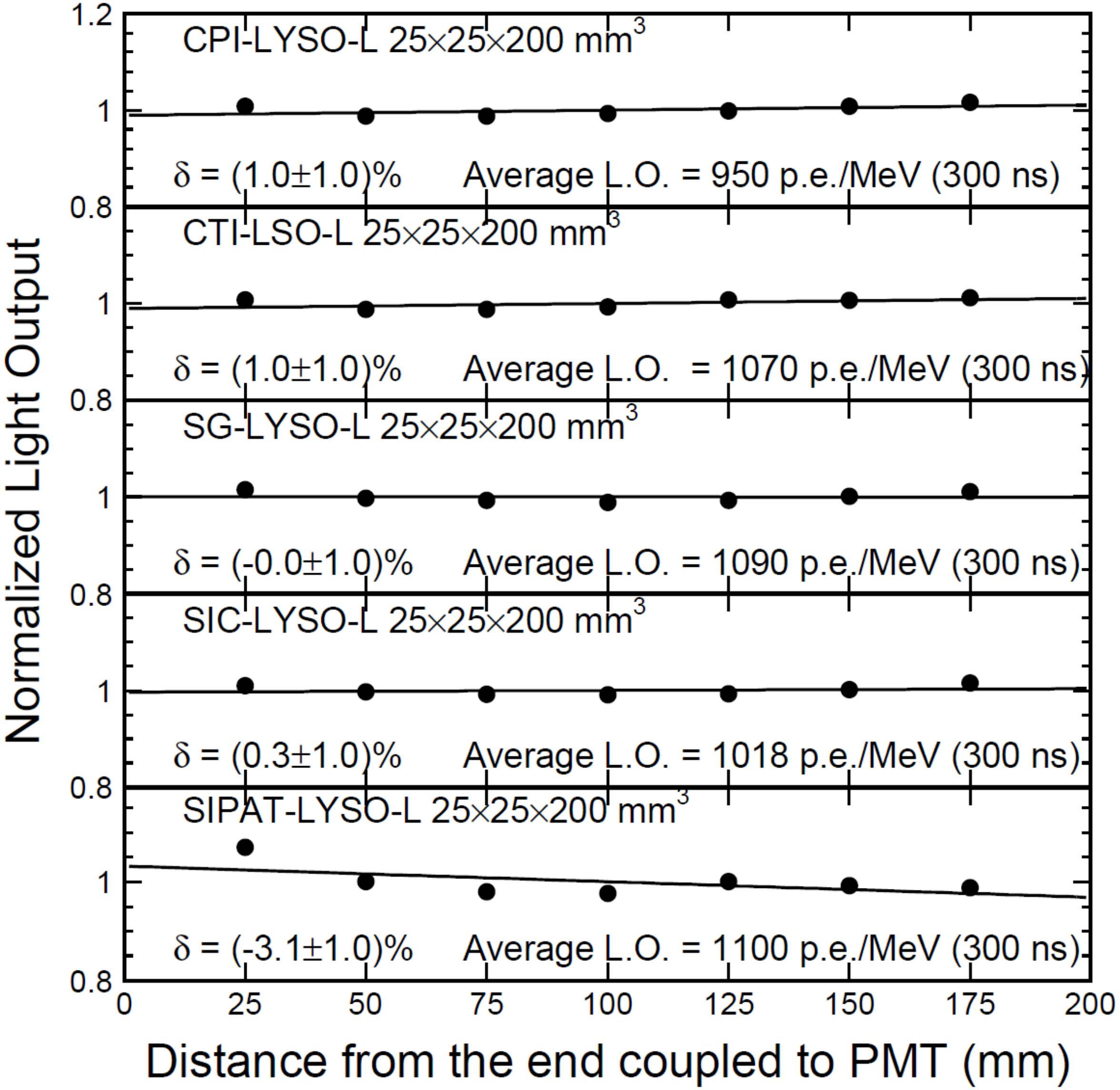
The average peak position of EMLT is at 423 nm.

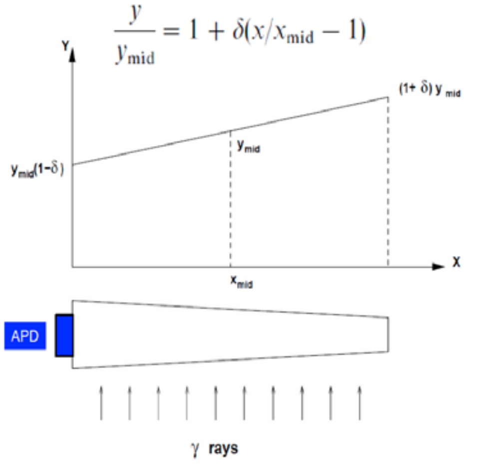
The average FWHM of EMLT is 48 nm:
from 404 nm to 452 nm.

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



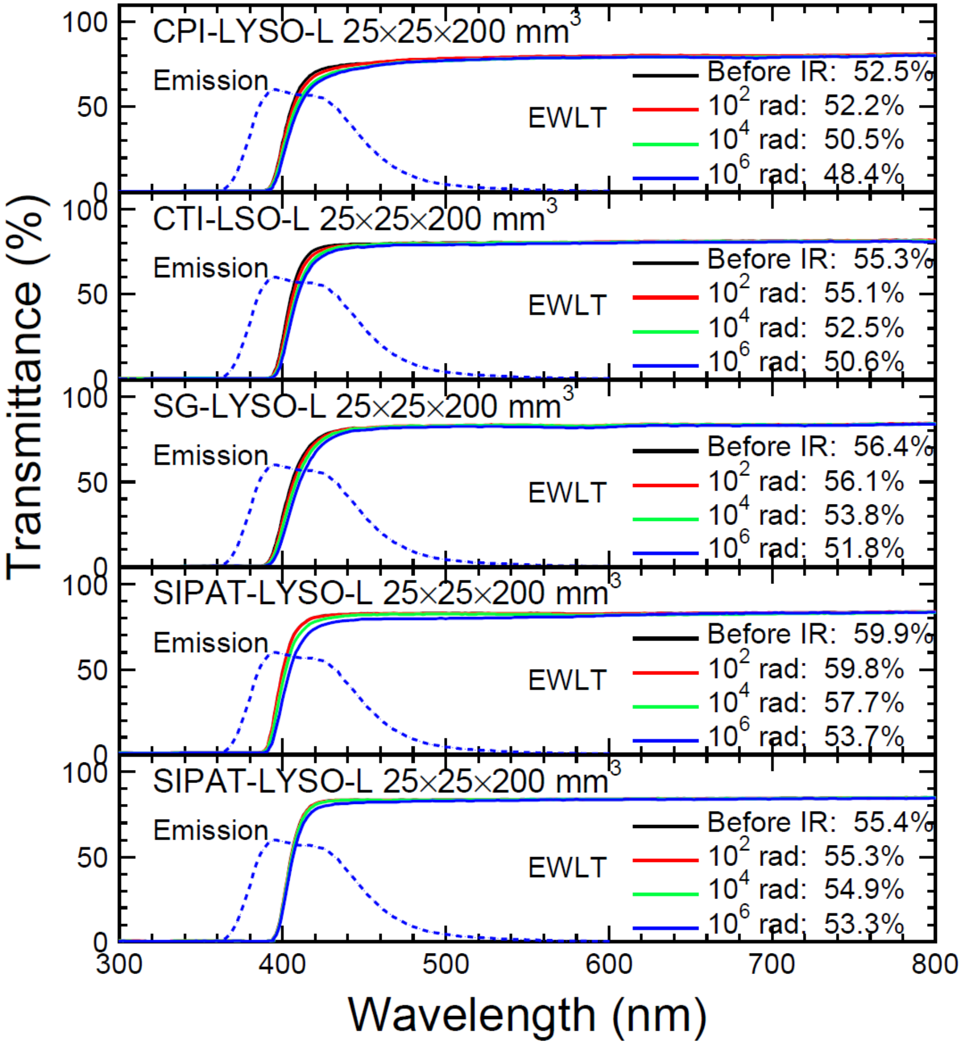


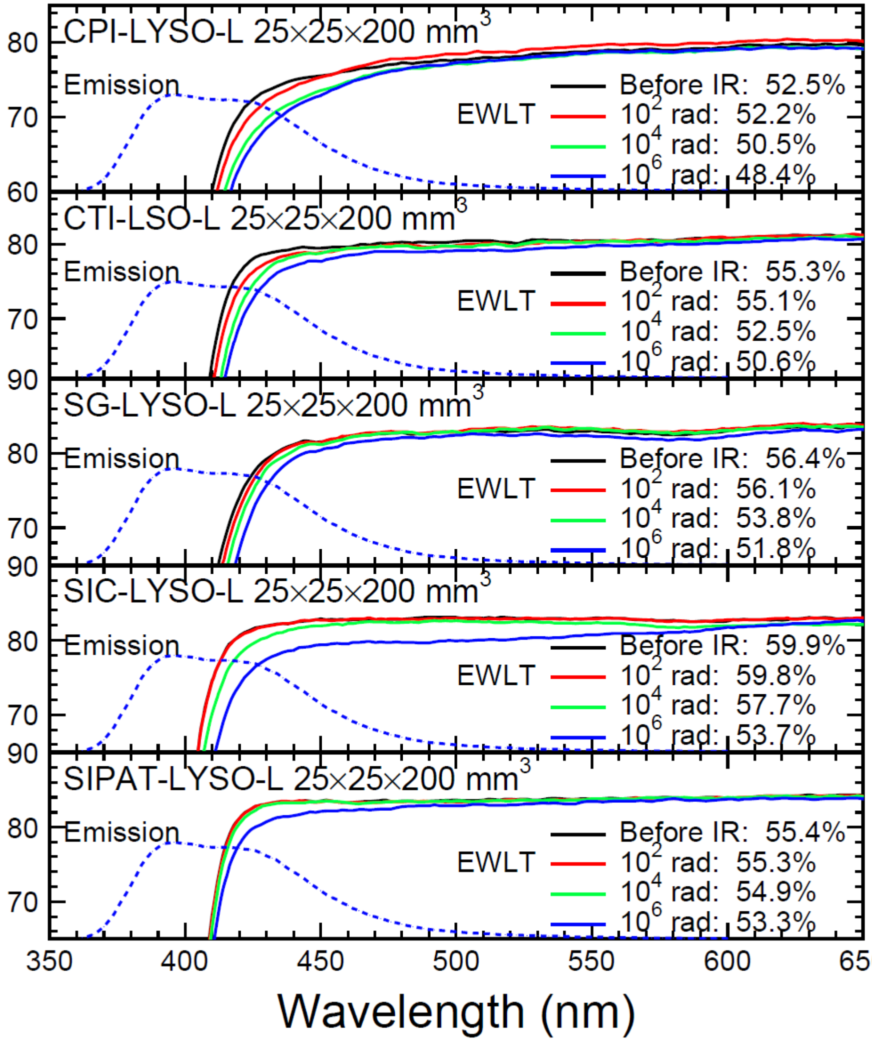
Light output (LO) is defined as the average of seven measurements uniformly distributed along the sample.

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

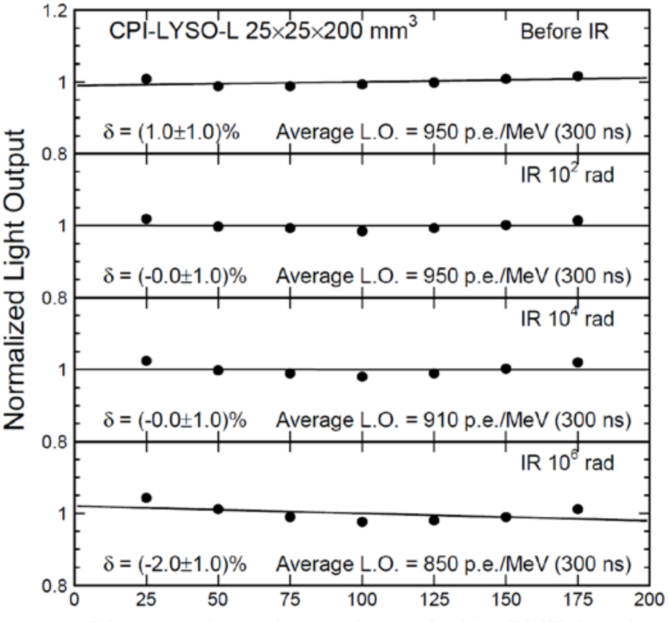
Excellent Radiation Hardness in LT

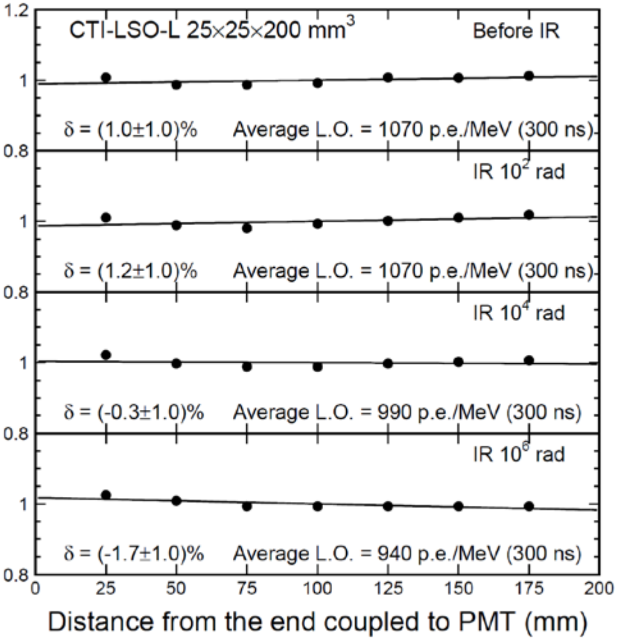
Consistent & Small Damage in LT → Larger variation @ shorter λ

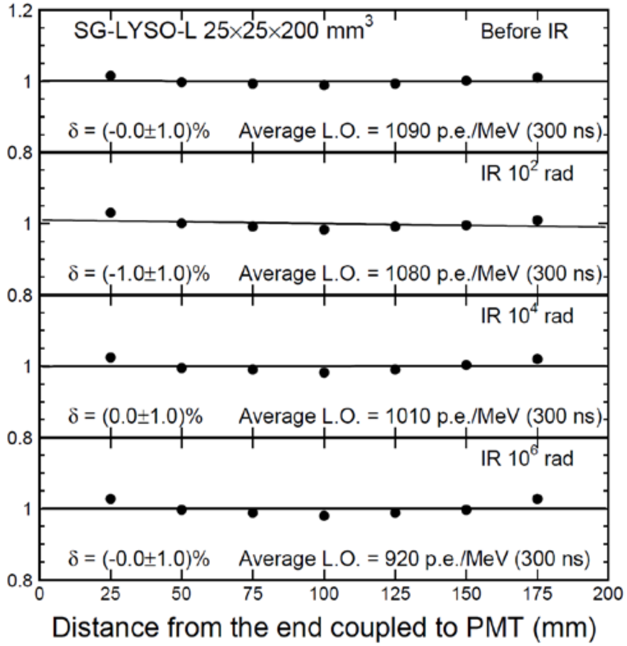


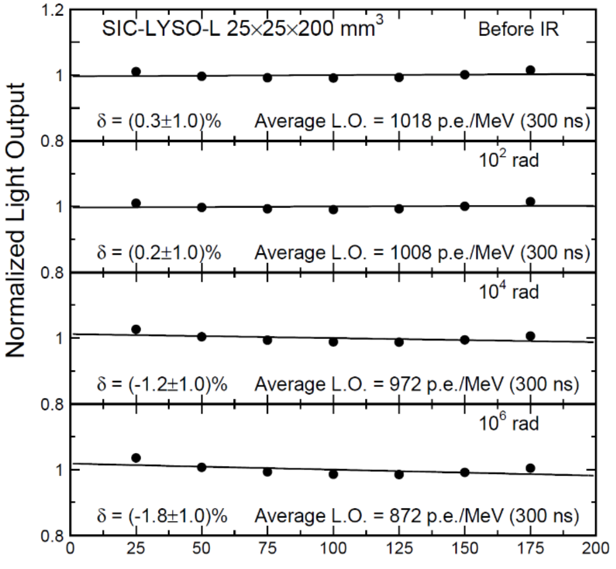


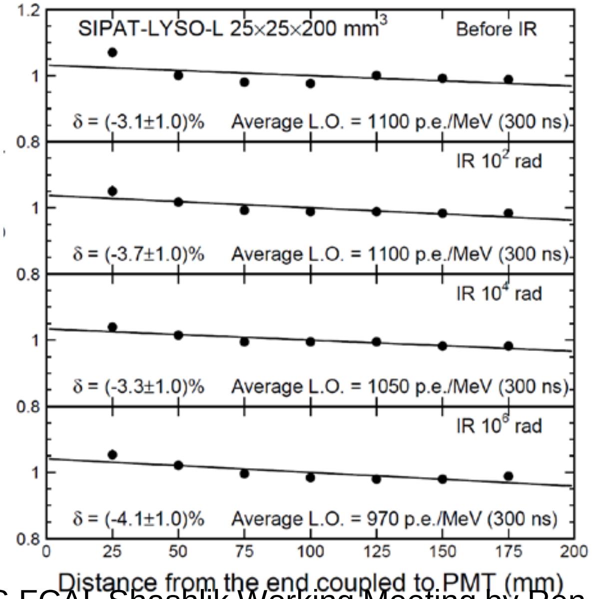
Excellent Radiation Hardness in LO





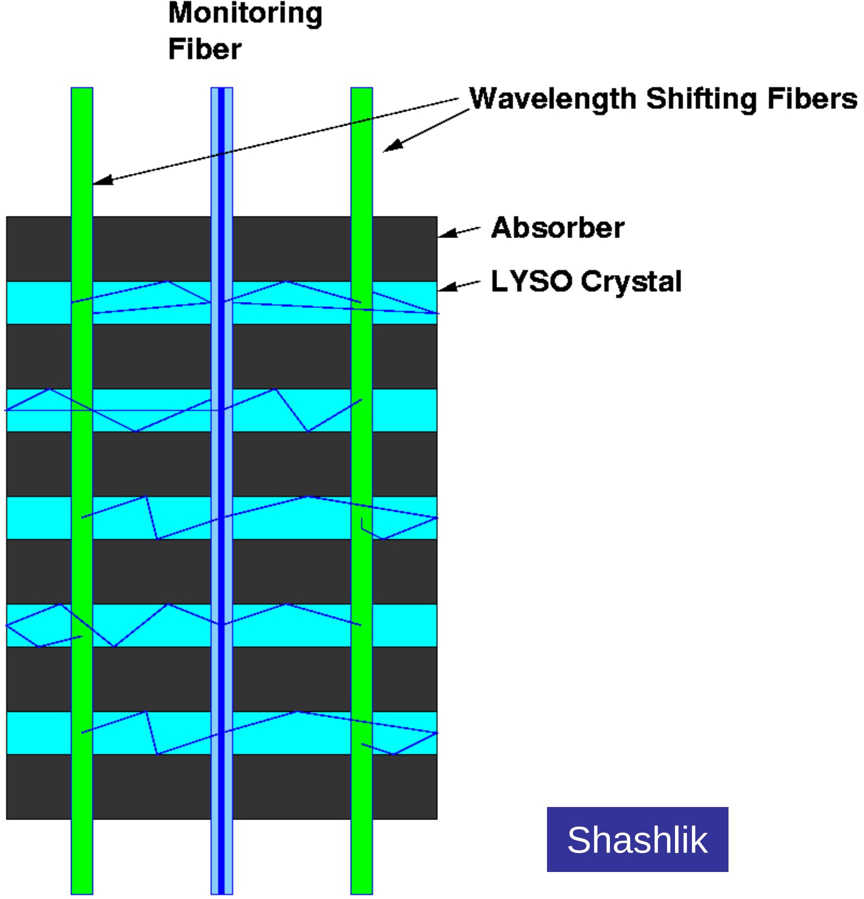




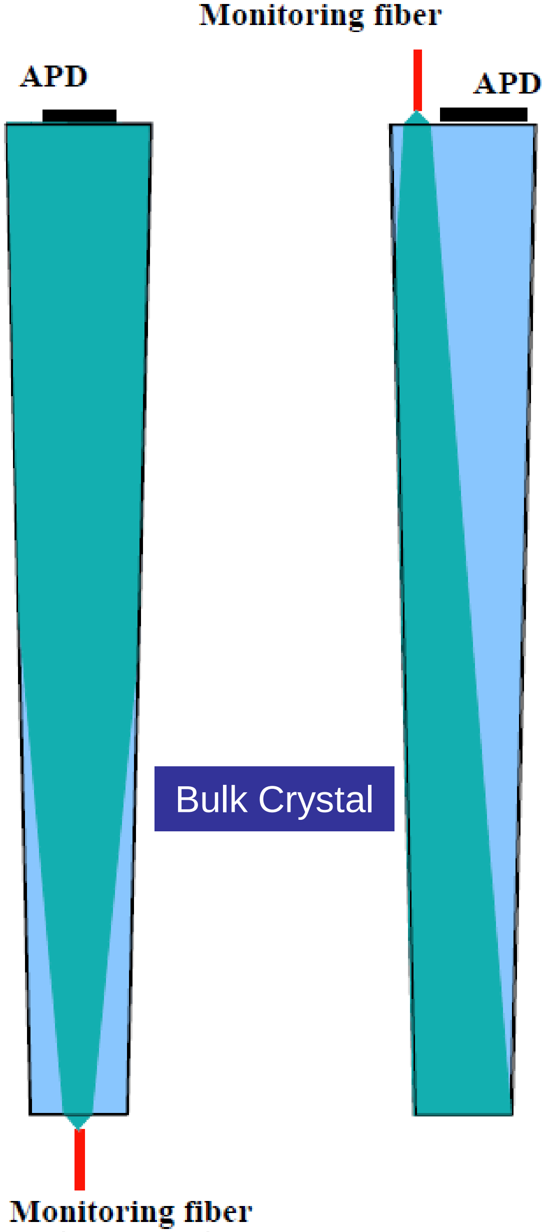


About 12% LO loss observed after 1 Mrad irradiation in all samples with LRU maintained. It can be corrected by light monitoring.

Monitoring with Scintillation Light



Shashlik



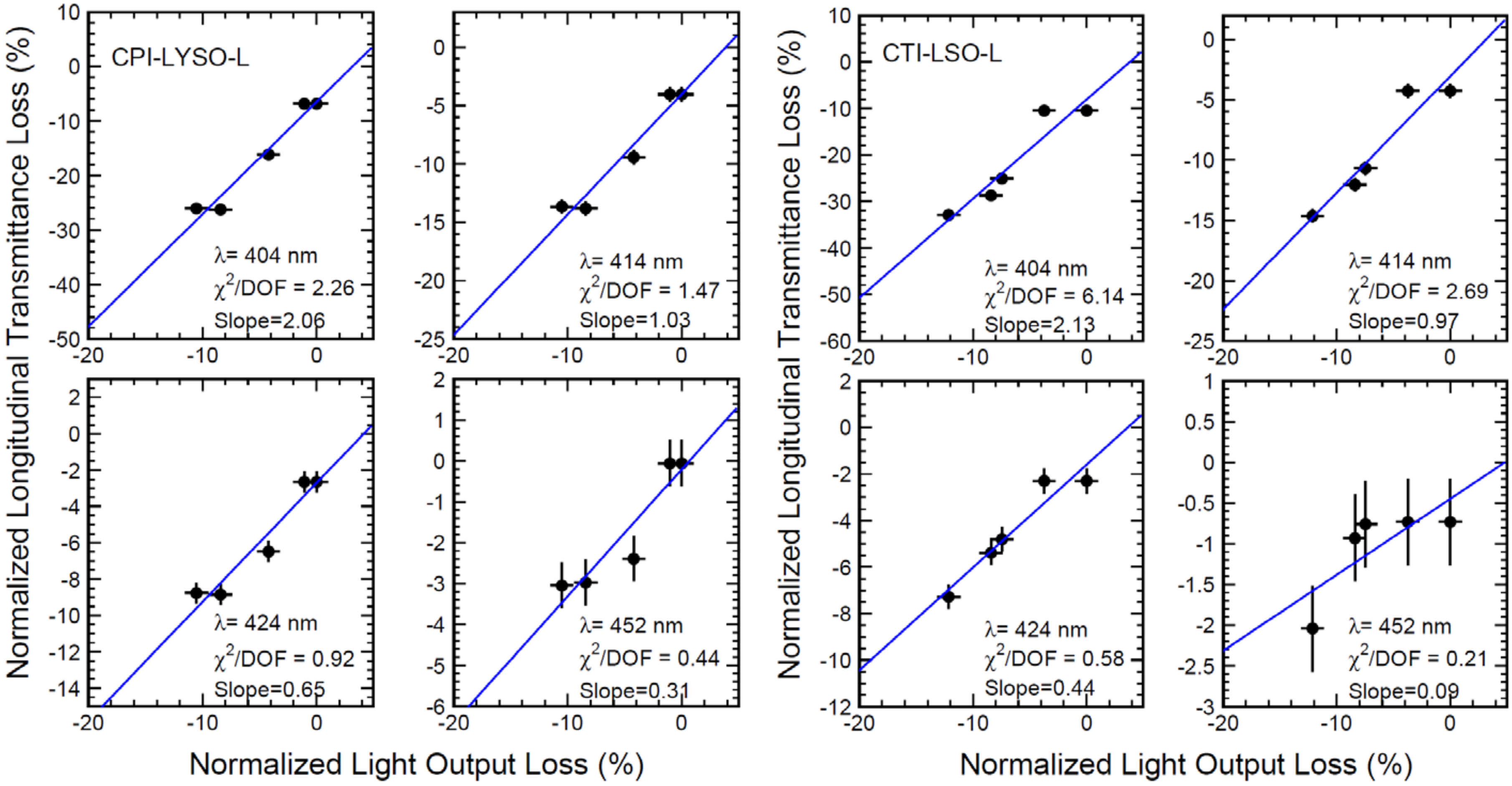
Bulk Crystal

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

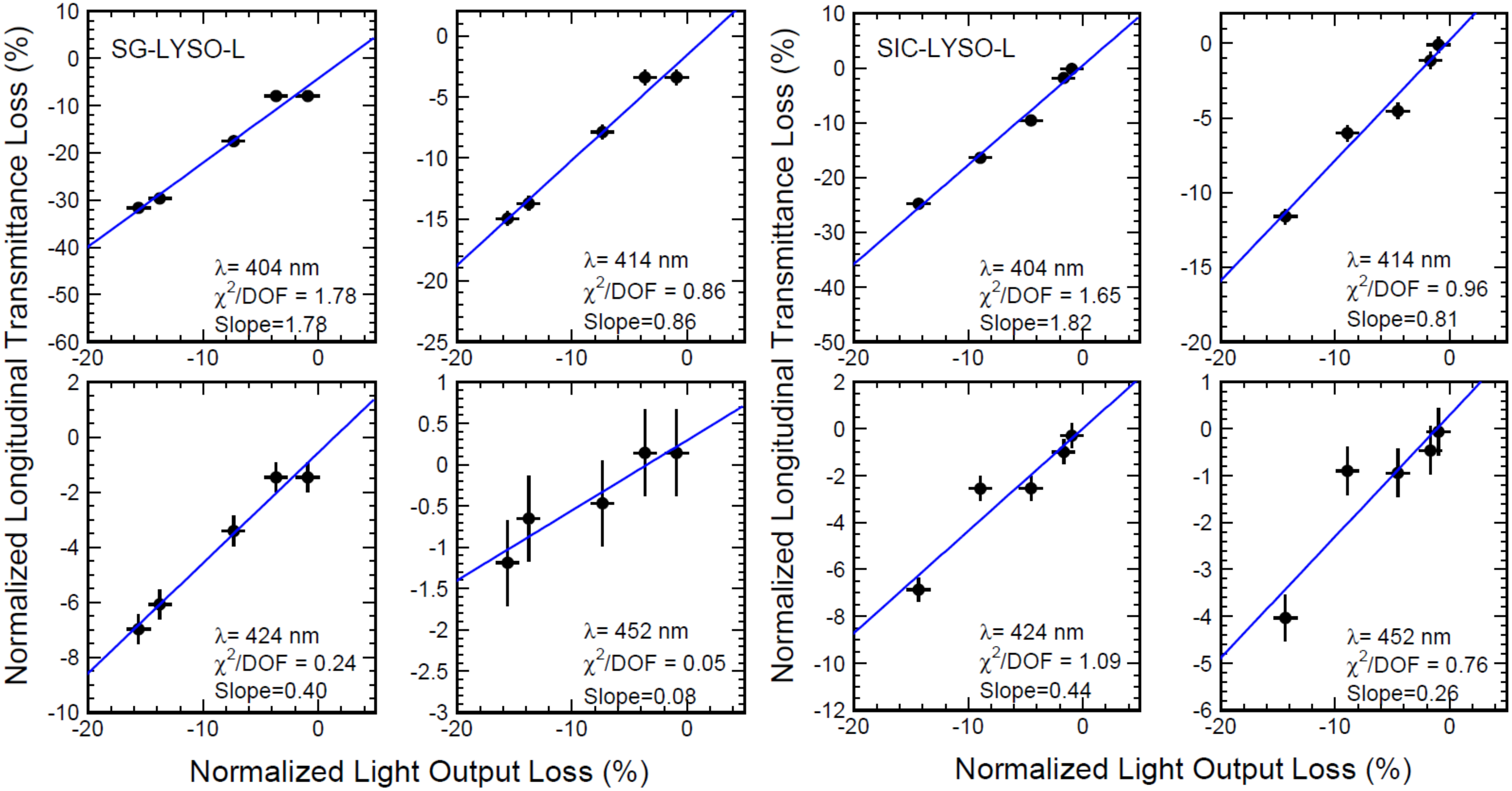
LT Loss vs. LO Loss after Irradiation

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

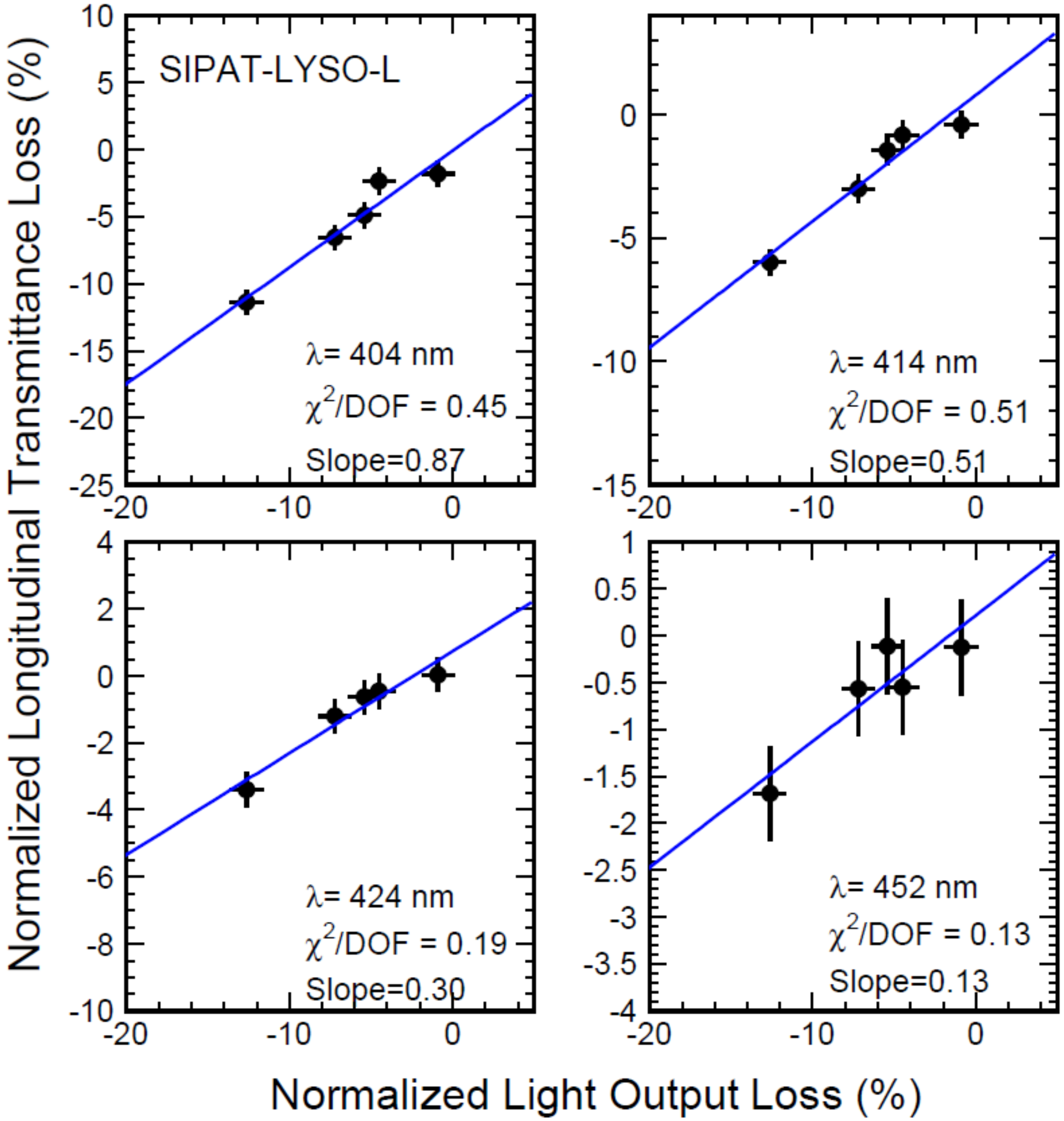


The slope represents the monitoring sensitivity at a particular wavelength

LT Loss vs. LO Loss after Irradiation



LT Loss vs. LO Loss after Irradiation

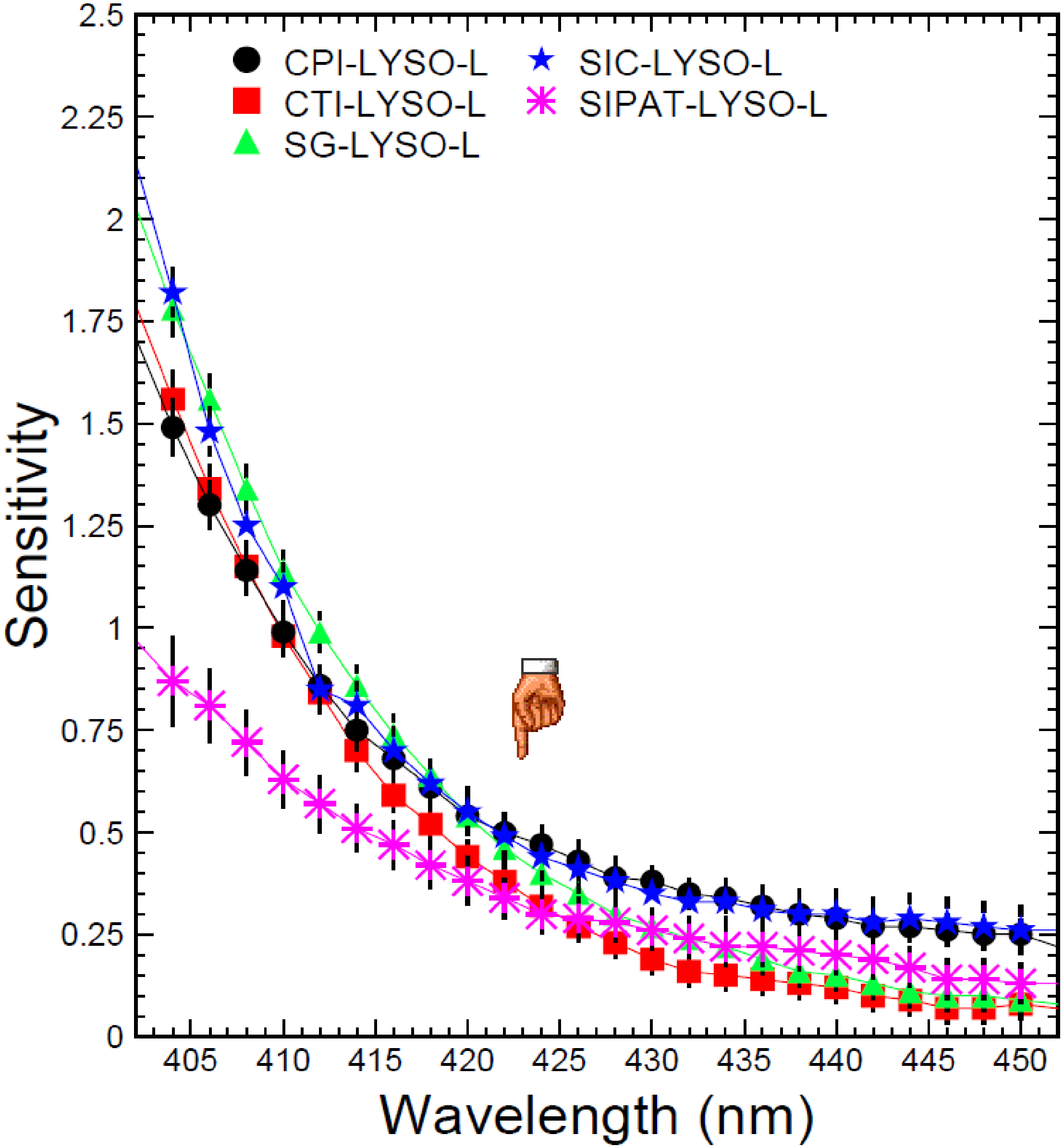


Monitoring Sensitivity vs. Wavelength

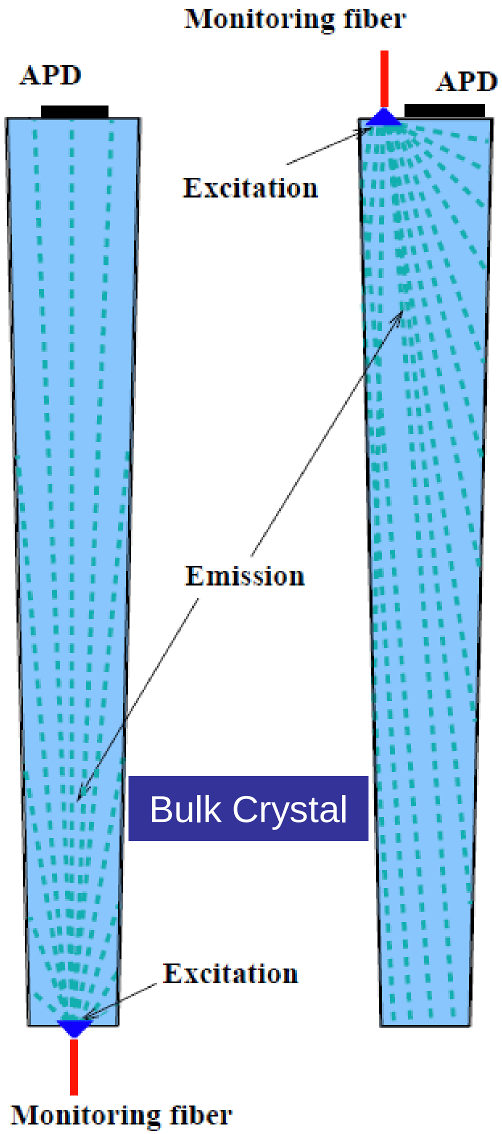
The monitoring sensitivity increases at shorter wavelengths because of larger variation in transparency.

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

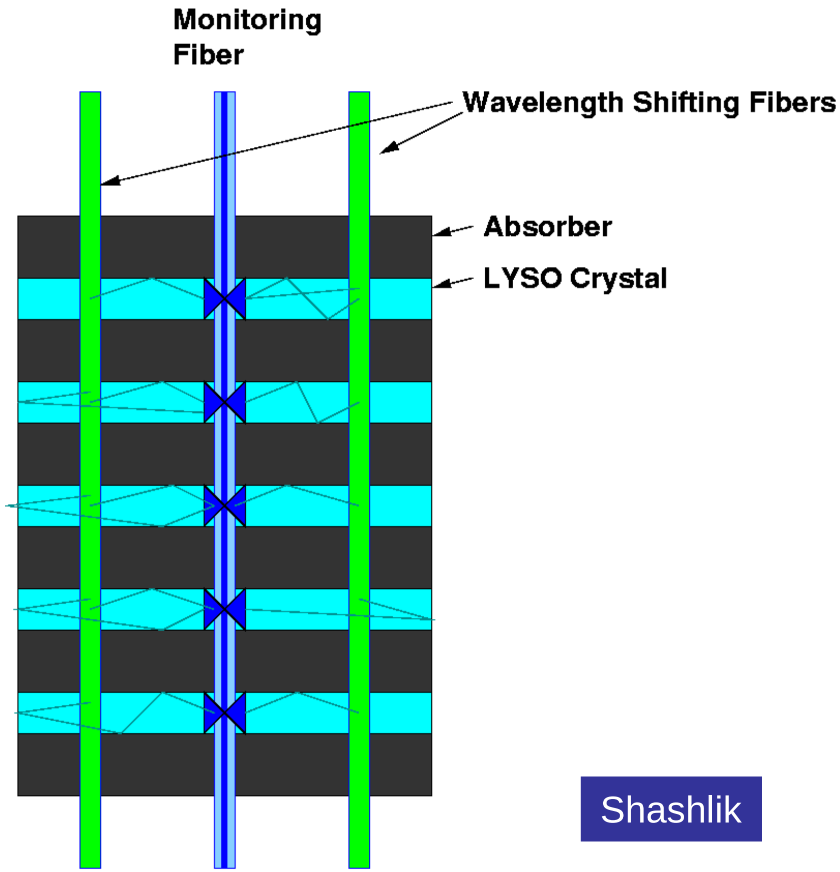
The EMLT peak position at ~423 nm would be the choice. Blue DPSS lasers, however, are expensive.



Monitoring with Excitation Light



Bulk Crystal

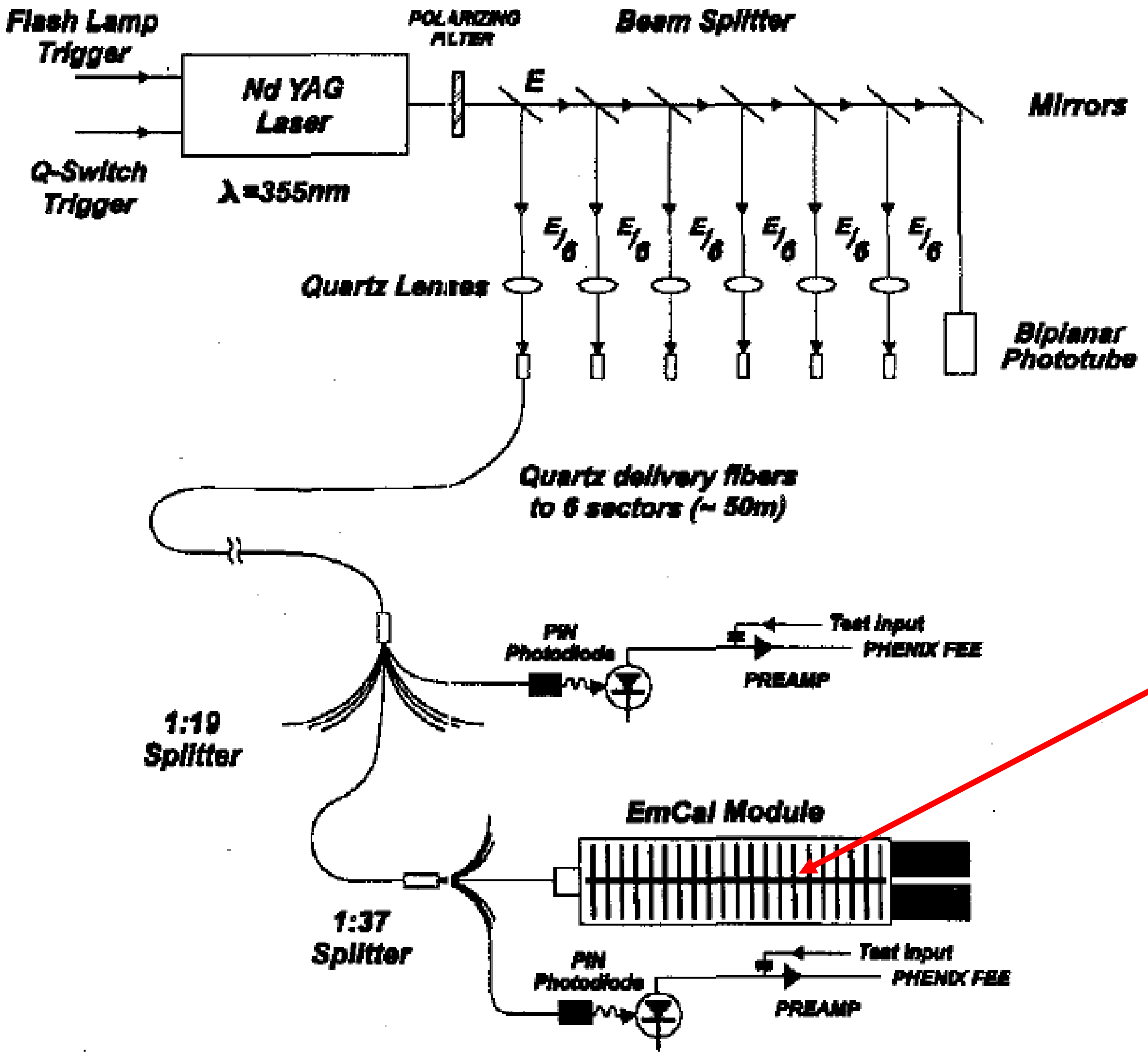


Shashlik

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.

PHENIX Laser Monitoring System

G. David *et al.*, IEEE TNS VOL. 45, NO. 3, JUNE (1998) 705-709

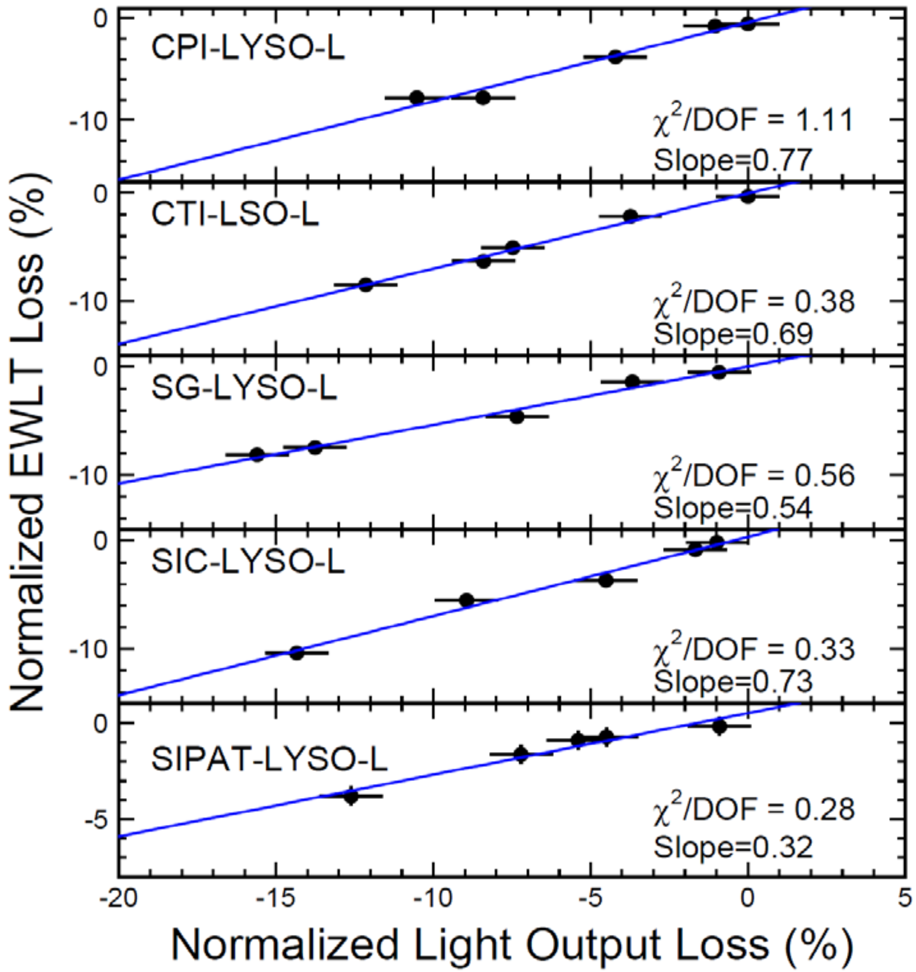


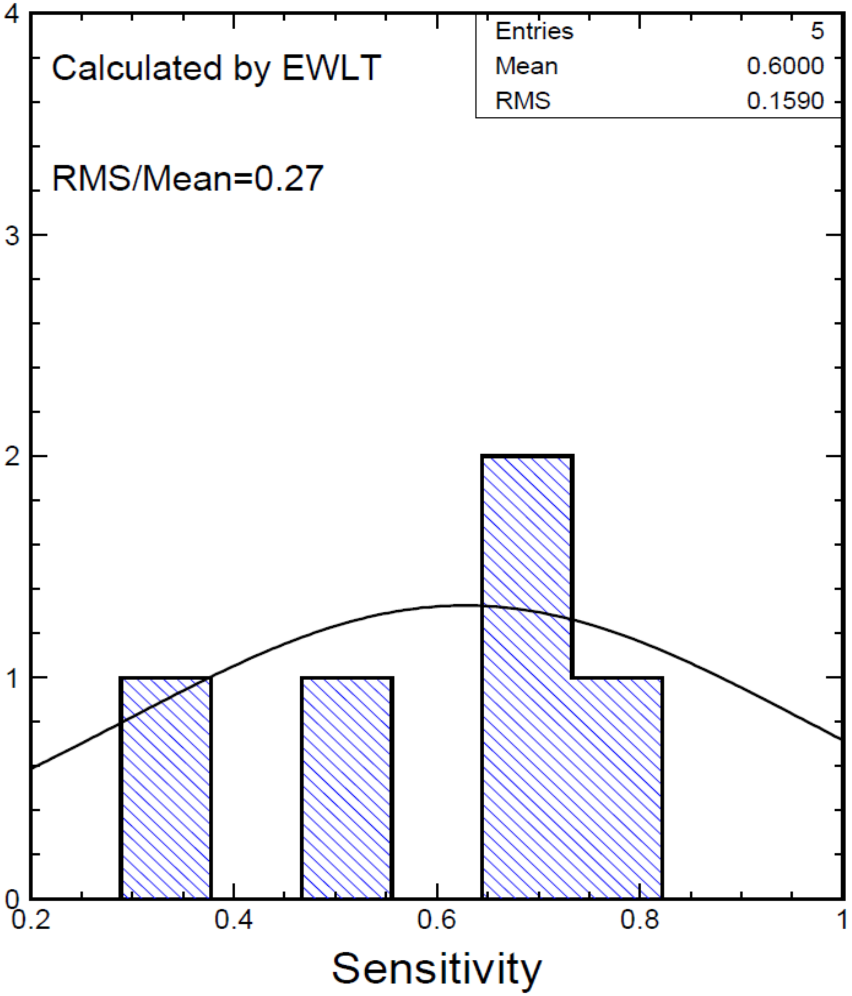
Excitation light at 355 nm from a frequency tripled Nd:YAG laser is used.

Light pulses sent to Shashlik modules through leaky fibers with groove density carved according to EM shower profile.

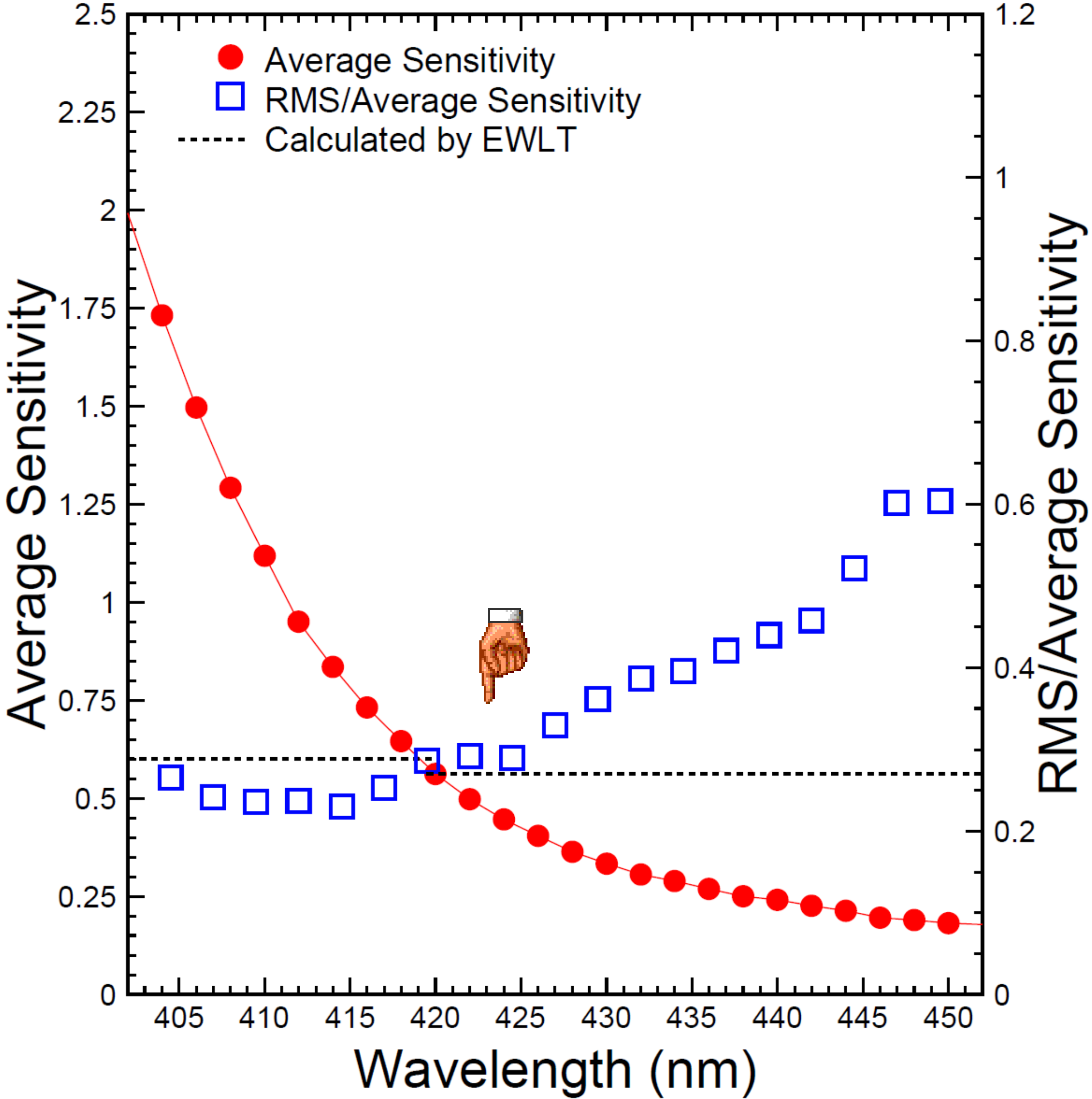
Monitoring Sensitivity with EWLT

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.

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 2nd 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. This approach, however, requires large monitoring pulse intensity because of the conversion of excitation to emission and the higher loss in quartz fiber at 355 nm as compared to 420 nm.

Cost-Effective UV Lasers at 355 nm

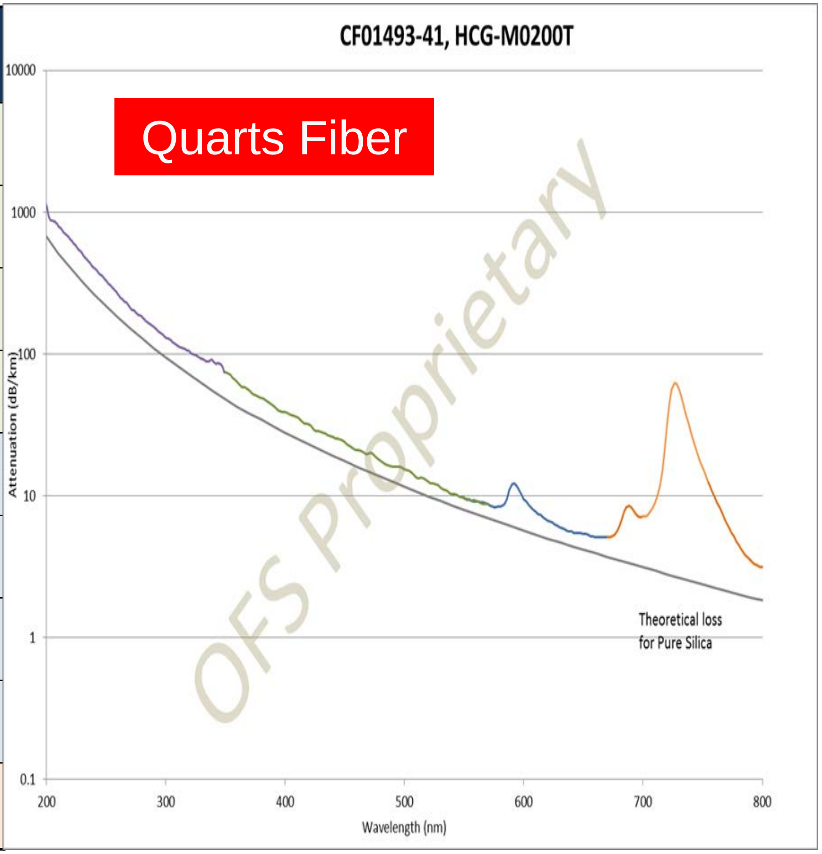
Frequency tripled DPSS YAG laser at 355 nm: @ $50k
http://rpmclasers.com/product/XHE%20355%20datasheet.pdf

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

Required Monitoring Pulse Energies

Two level fanout, 100 m quartz fiber, 1,000 channels & 1GeV

Parameter	Emission	Excitation
Monitoring wavelength (nm)	423	355
LYSO light output (γ/MeV)	30,000	30,000
Dynamic range (GeV)	1	1
Channel Number	1,000	1,000
2-Level fanout extra loss (dB)	24	24
100 m optical fiber loss (dB)	3	7
Ex-Em conversion loss	0	3
Total loss (dB)	27	34
Laser pulse energy (μJ)	7	42



Quarts Fiber

Six times monitoring pulse intensity requirement for the excitation approach