

# Progress on Radiation Damage Investigation for LYSO Crystals and Sealed Capillaries

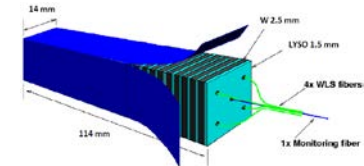
**Ren-Yuan Zhu**

California Institute of Technology

March 11, 2015



# Introduction

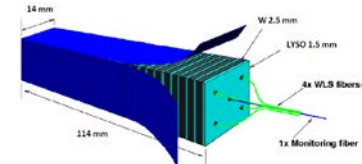


- One LFS crystal of 25 x 25 x 180 mm was irradiated by  $\gamma$ -rays. Data up to 180 Mrad are available for six vendors.
- In addition to 623 SIC LYSO plates for beam tests 231 LFS plates from BOET/Zecotek/Hamamatsu were measured. 30 were used for a LYSO/W Shashlik cell irradiated to 90 Mrad.
- **LYSO crystals were irradiated at CERN, Davis and Los Alamos.**
- Randy arranged to have six sealed capillaries of 6 cm long (3 each of J2 and DSB) sent to Caltech last December.
  - The 1<sup>st</sup> batch of four was irradiated by 800 MeV protons to  $2.7 \times 10^{14}$  p/cm<sup>2</sup> on Dec 20, 2014, at the WNR facility of LANSCE [1]. They were shipped back to Caltech around the end of February. Unfortunately, the measurement setup was not ready before irradiation.
  - The 2<sup>nd</sup> batch of two is not irradiated and used as reference.

[1] <https://indico.cern.ch/event/368990/contribution/2/material/slides/0.pdf>

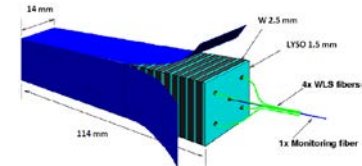


# Long Crystals from Six Vendors

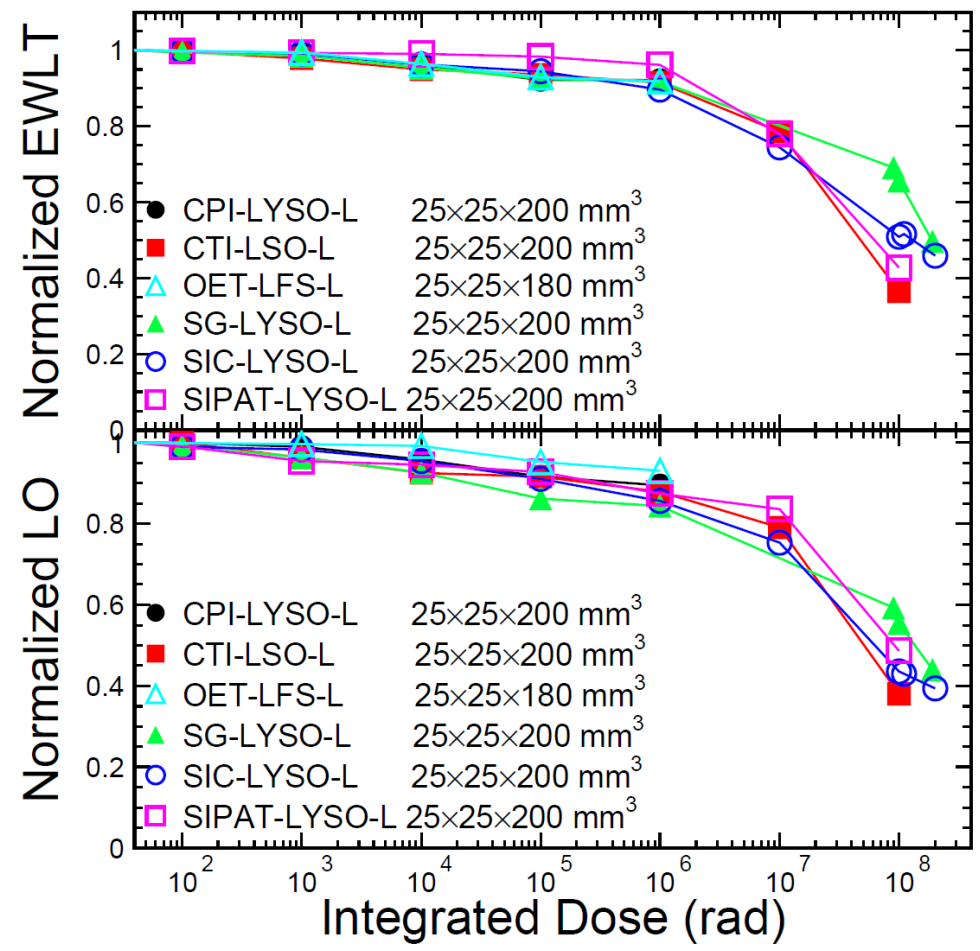
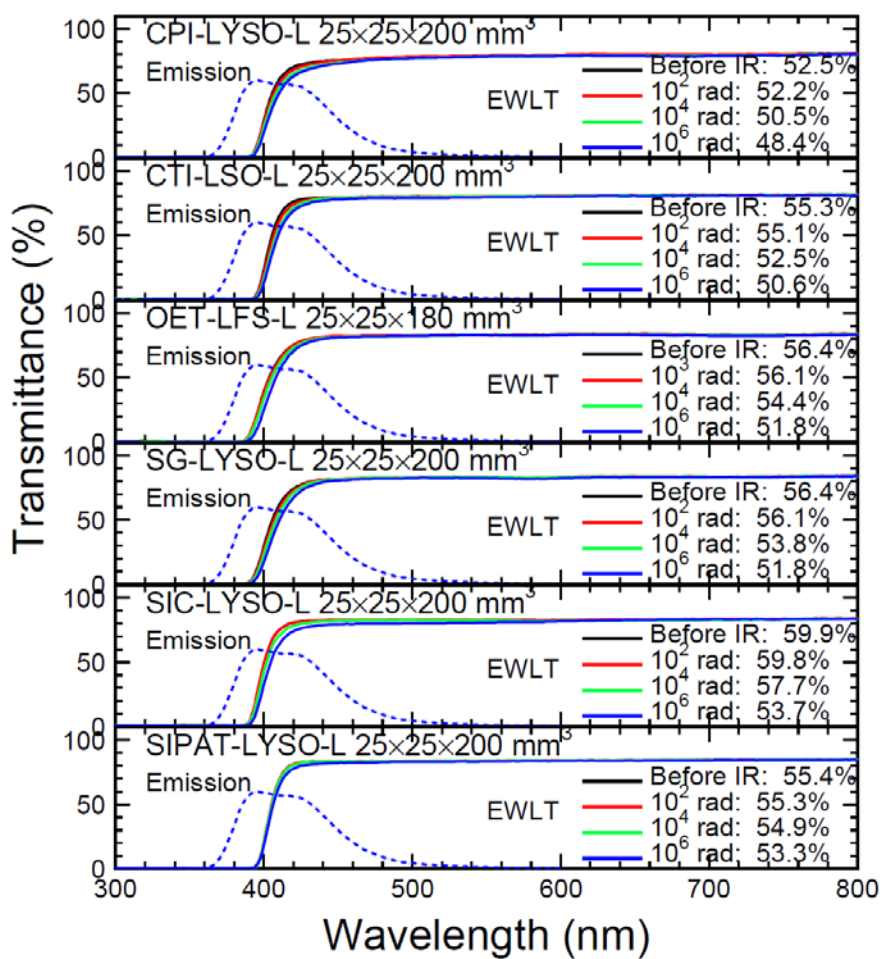




# Radiation Damage in Long LYSO

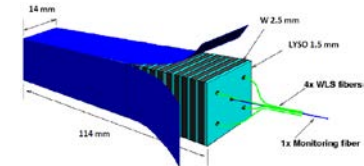


Consistent damage in LT and LO up to 180 Mrad for LYSO crystals from six vendors

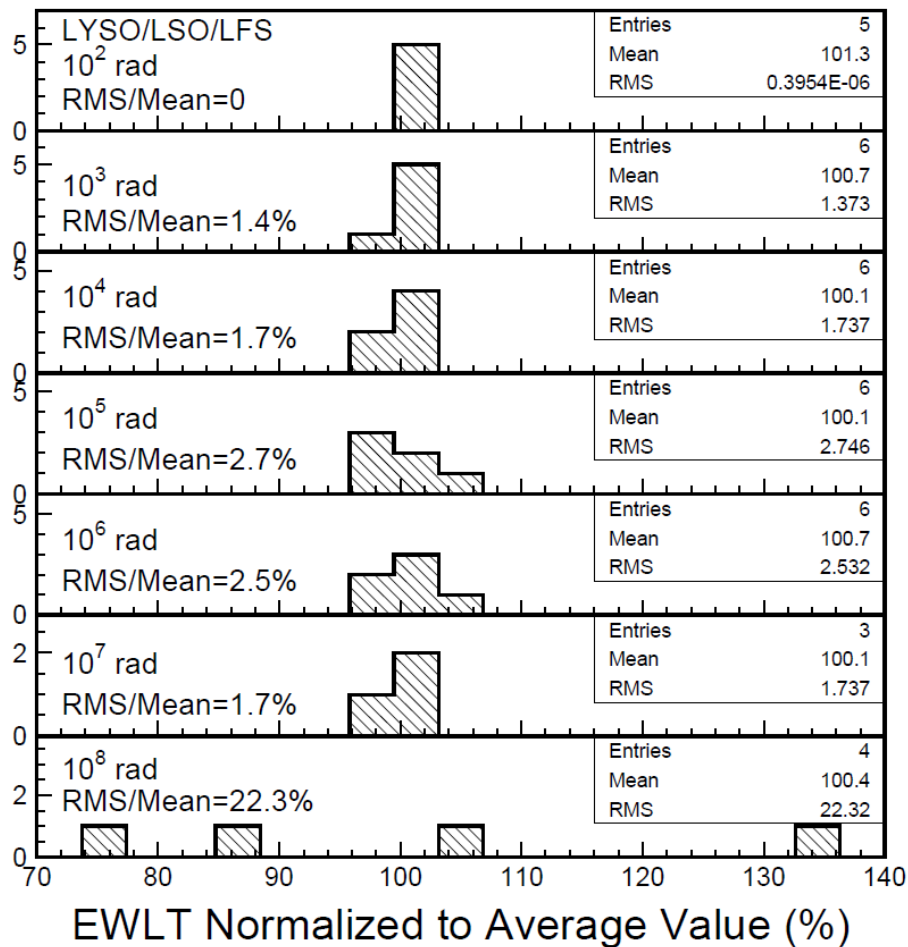




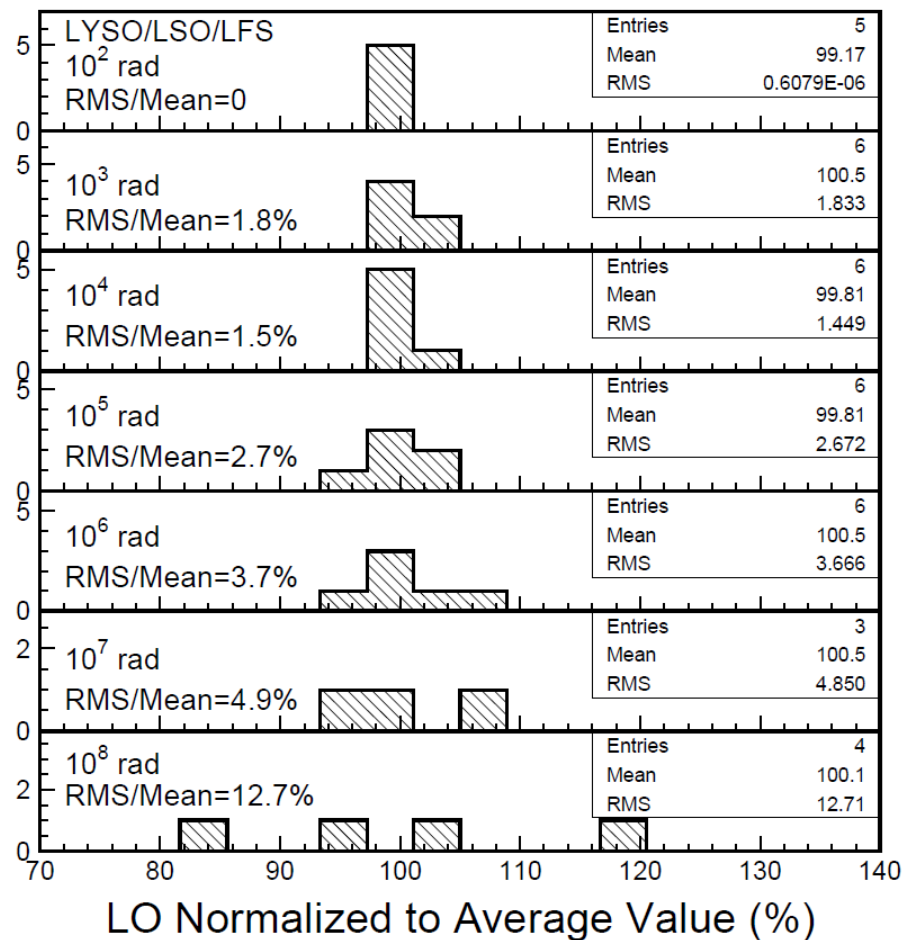
# Consistent Radiation Damage in Long LYSO crystals from Six Vendors



## Longitudinal Transmittance



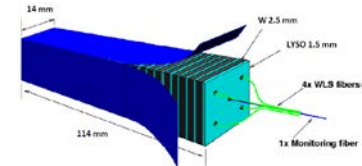
## Light Output



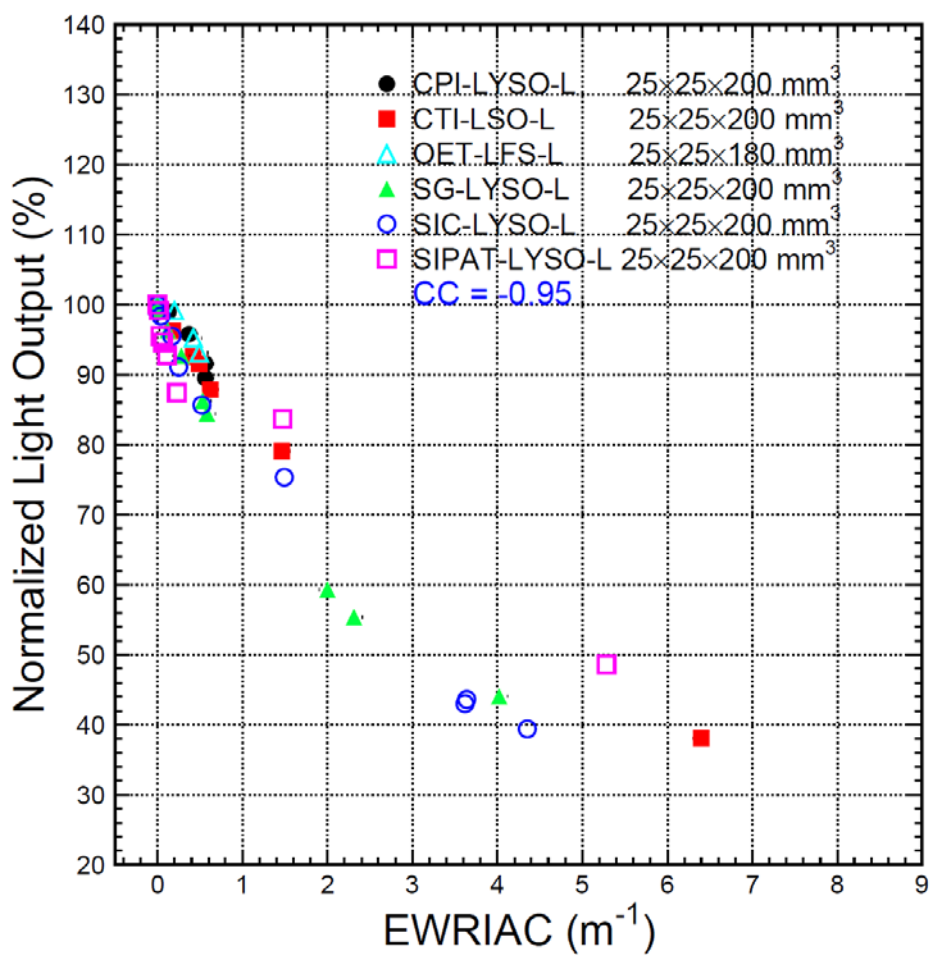
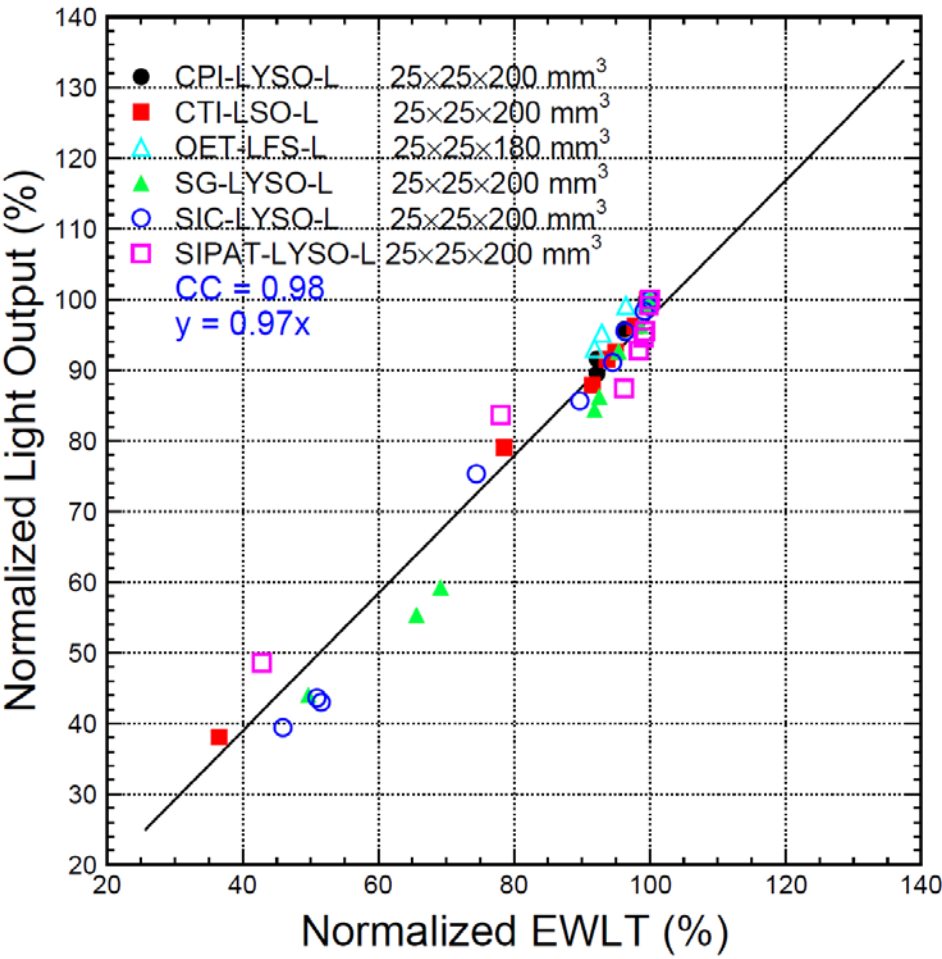
Better than 5% up to 10 Mrad with a larger divergence after 100 Mrad



# Relation between Normalized LO, LT and RIAC for Long LYSO

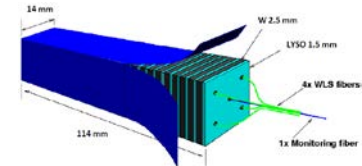


Good correlation between LO and LT and Consistent LO loss versus RIAC





# 14 x 14 x 1.5 mm Plates

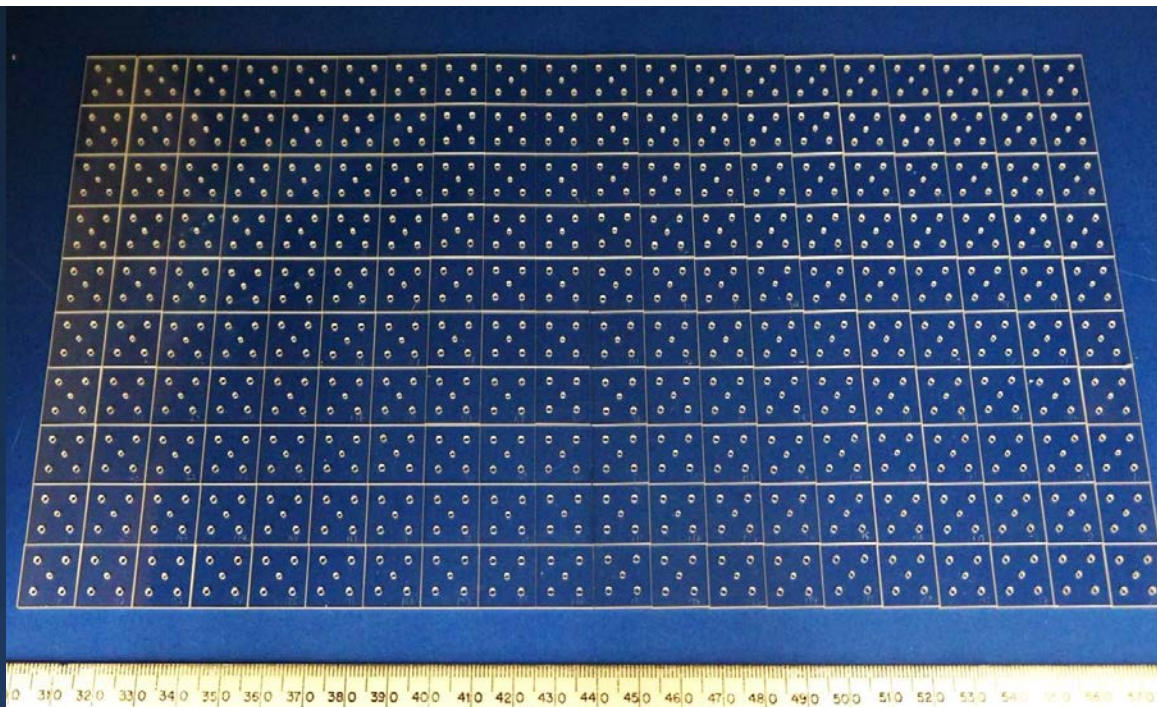
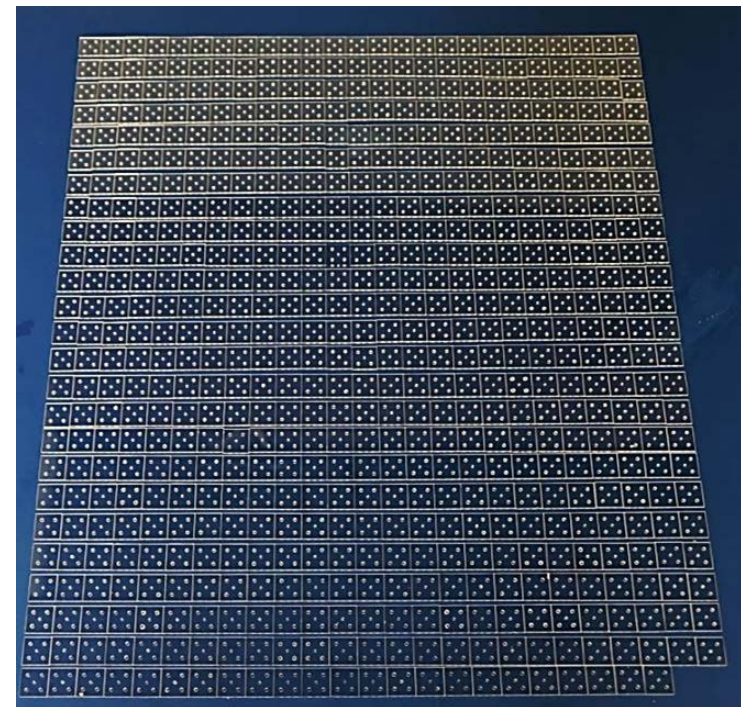


BOET-LFS-L

SIC/BOET plates with five holes were measured

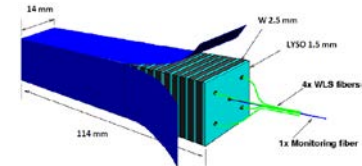
623 SIC LYSO Plates

200 BOET LFS Plates

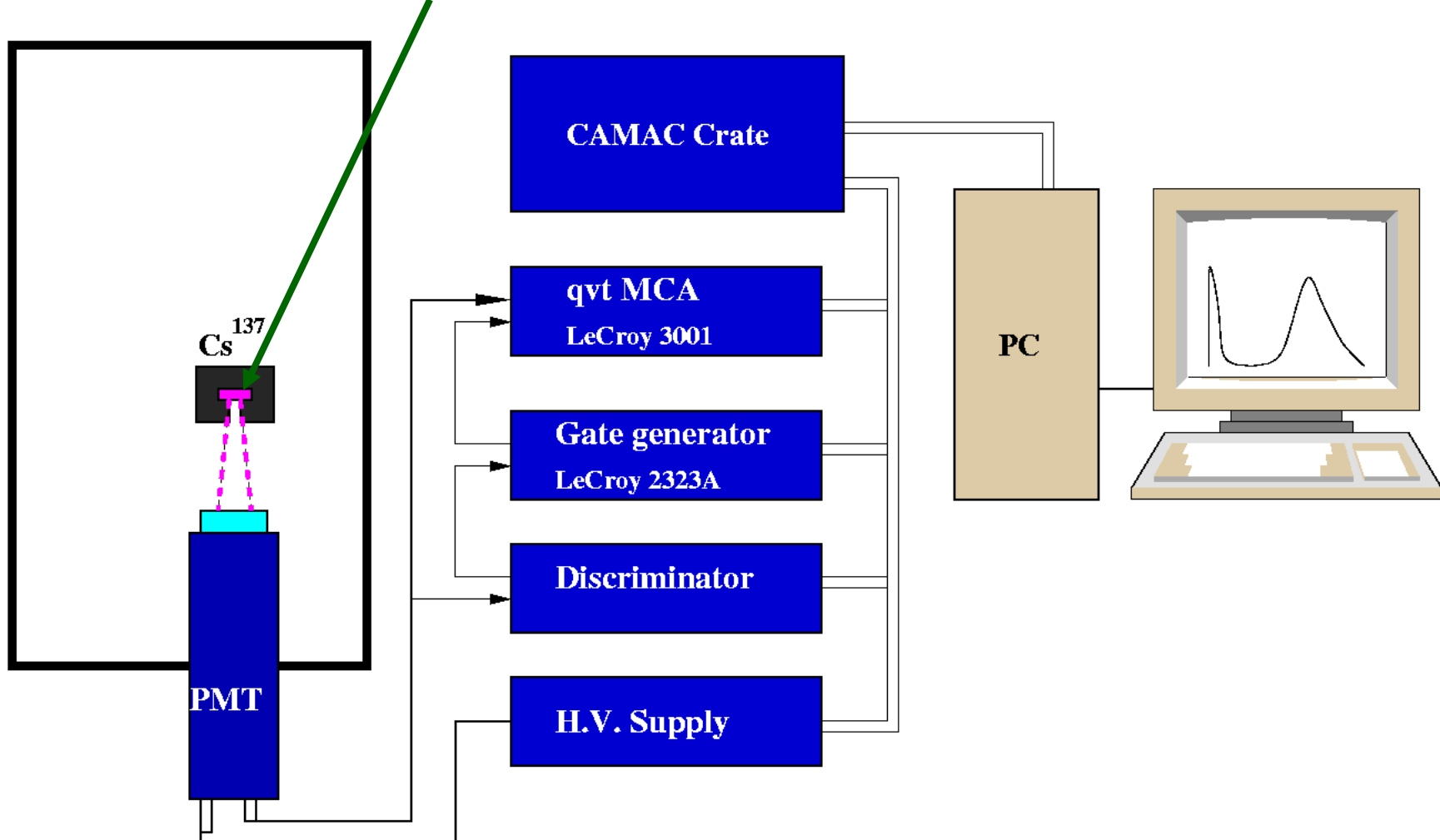




# LO Measurement for LYSO Plates



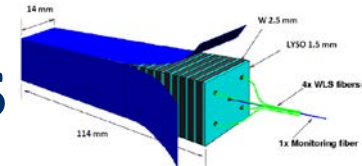
14 x 14 mm LYSO plates with Tyvek wrapping are measured by a R1306 PMT with an air gap





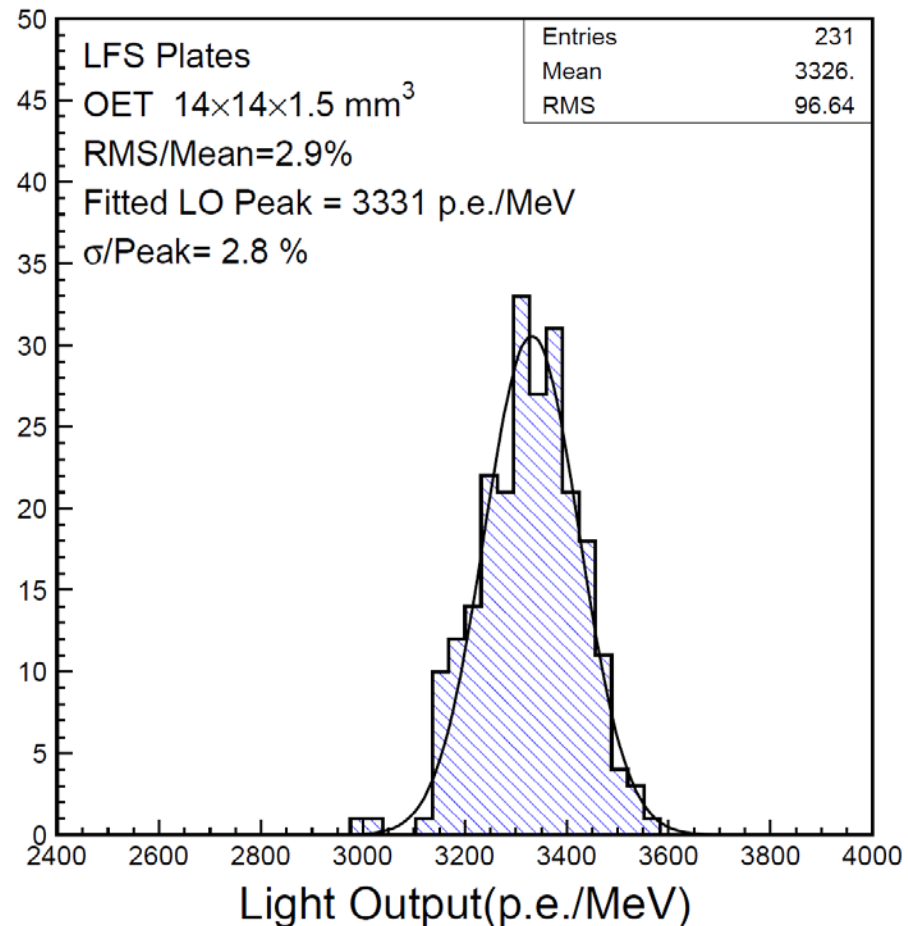
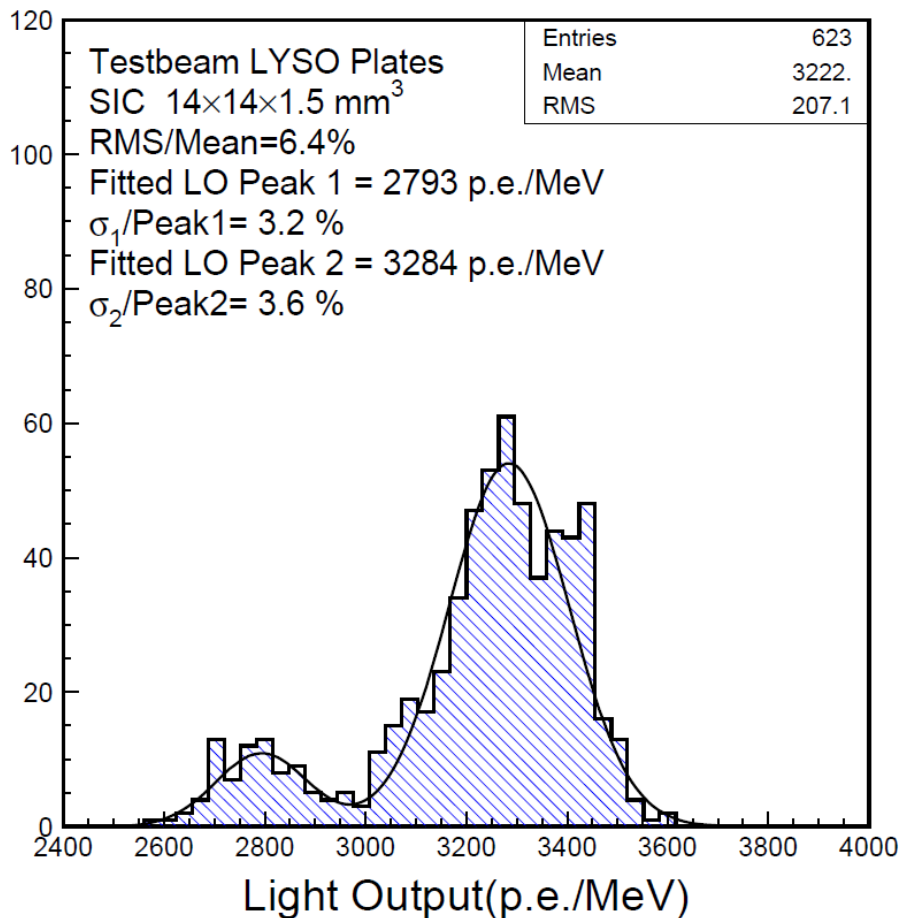


# LO Distribution of LYSO/LFS Plates



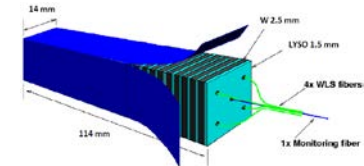
623 SIC LYSO: 6.4%

231 BOET LFS: 2.9%

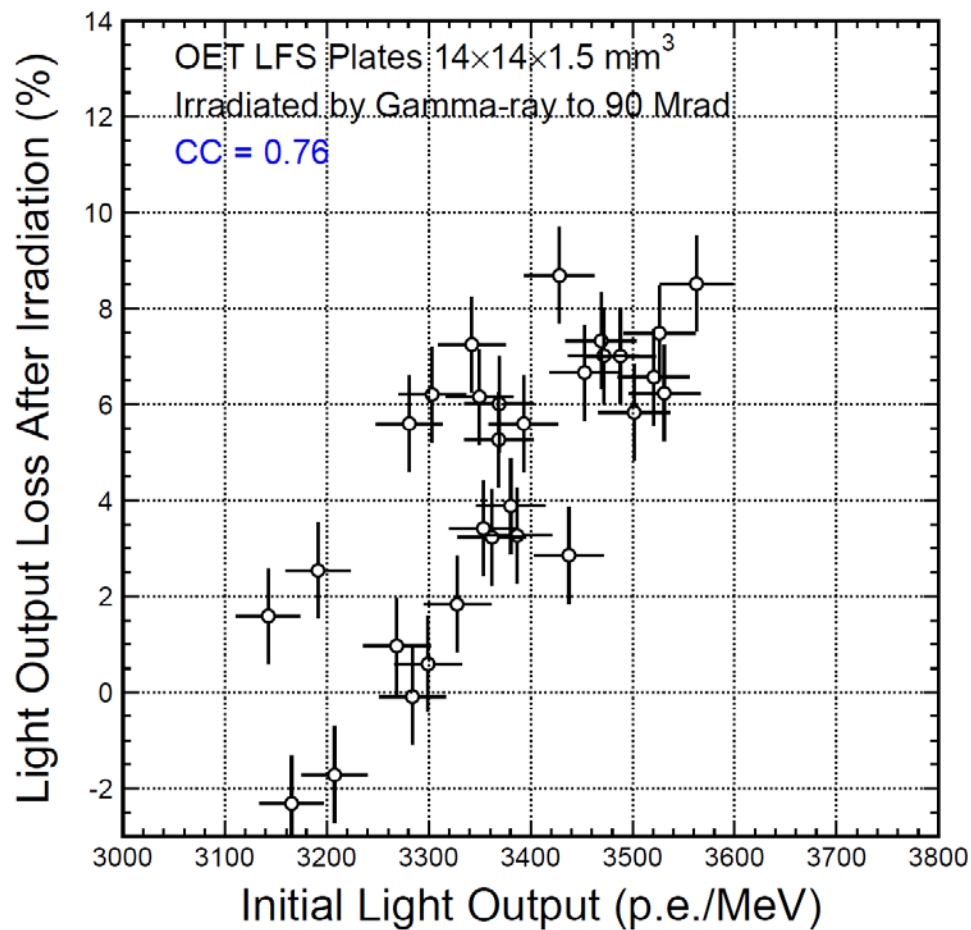
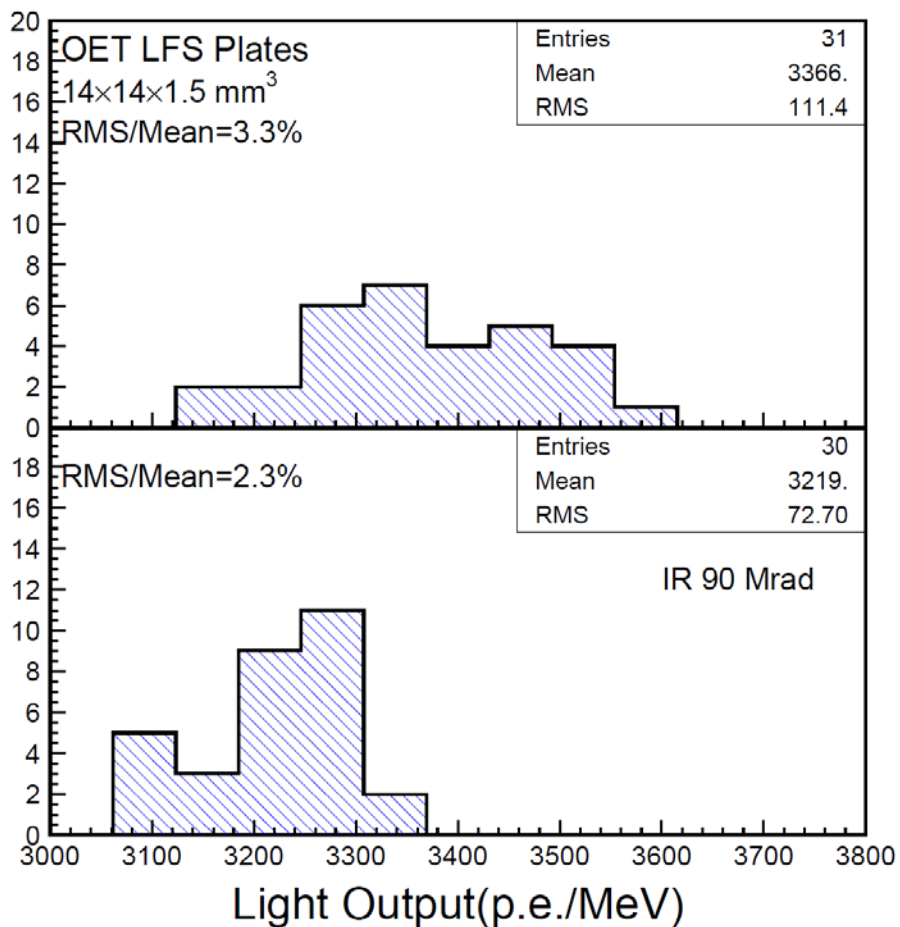




# 31 BOET LFS Plates

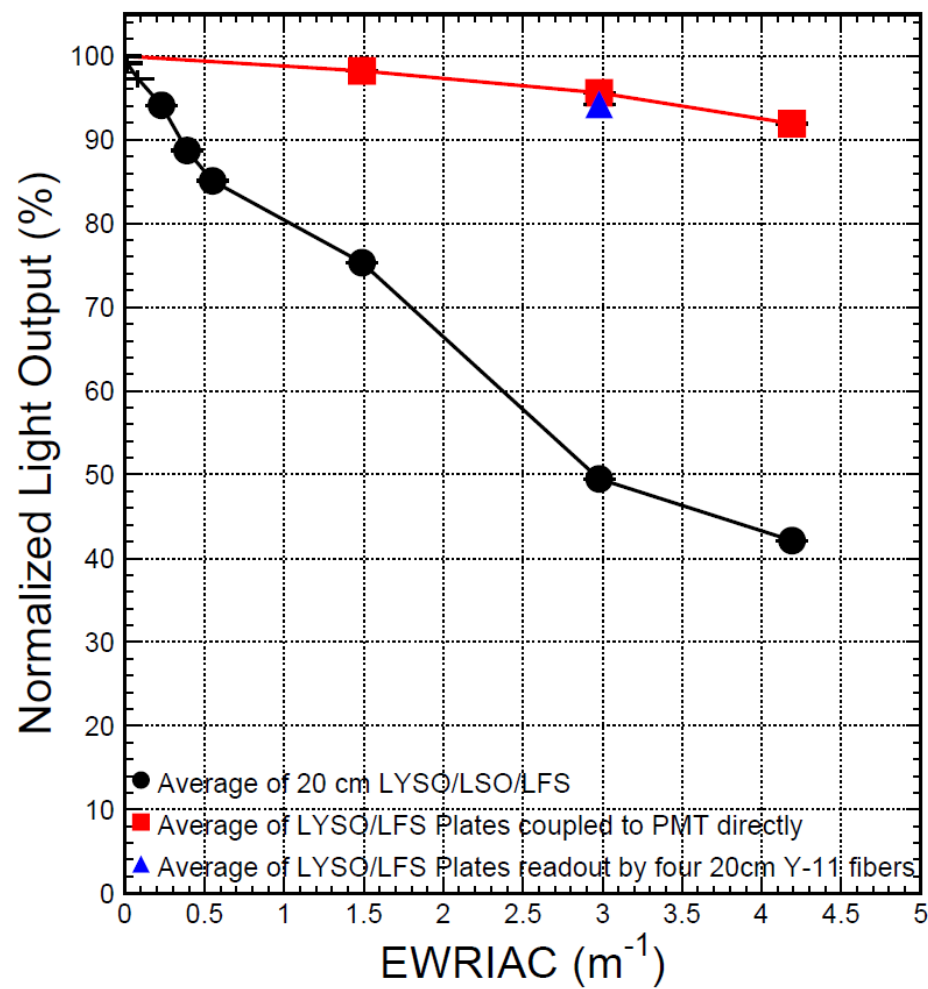
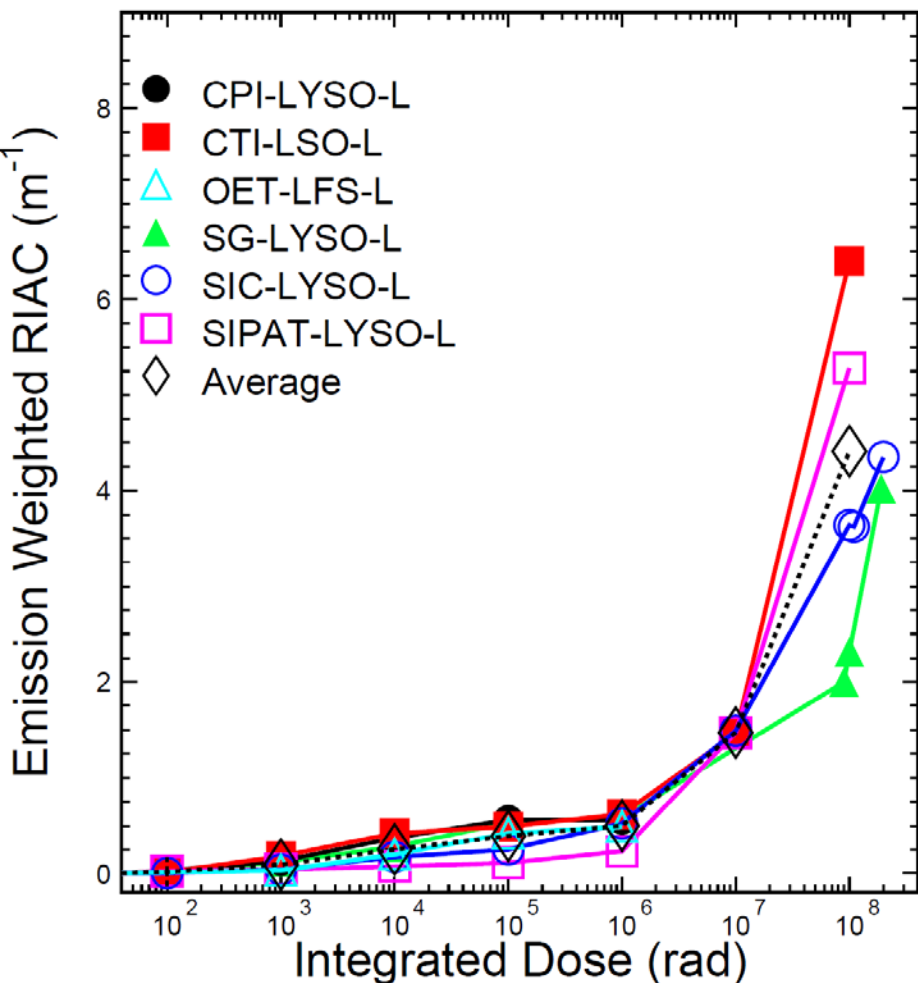
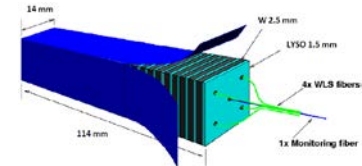


Consistency of light output is 3.3%/2.3% before/after 90 Mrad irradiation  
Better consistency after irradiation shows consistent RIAC



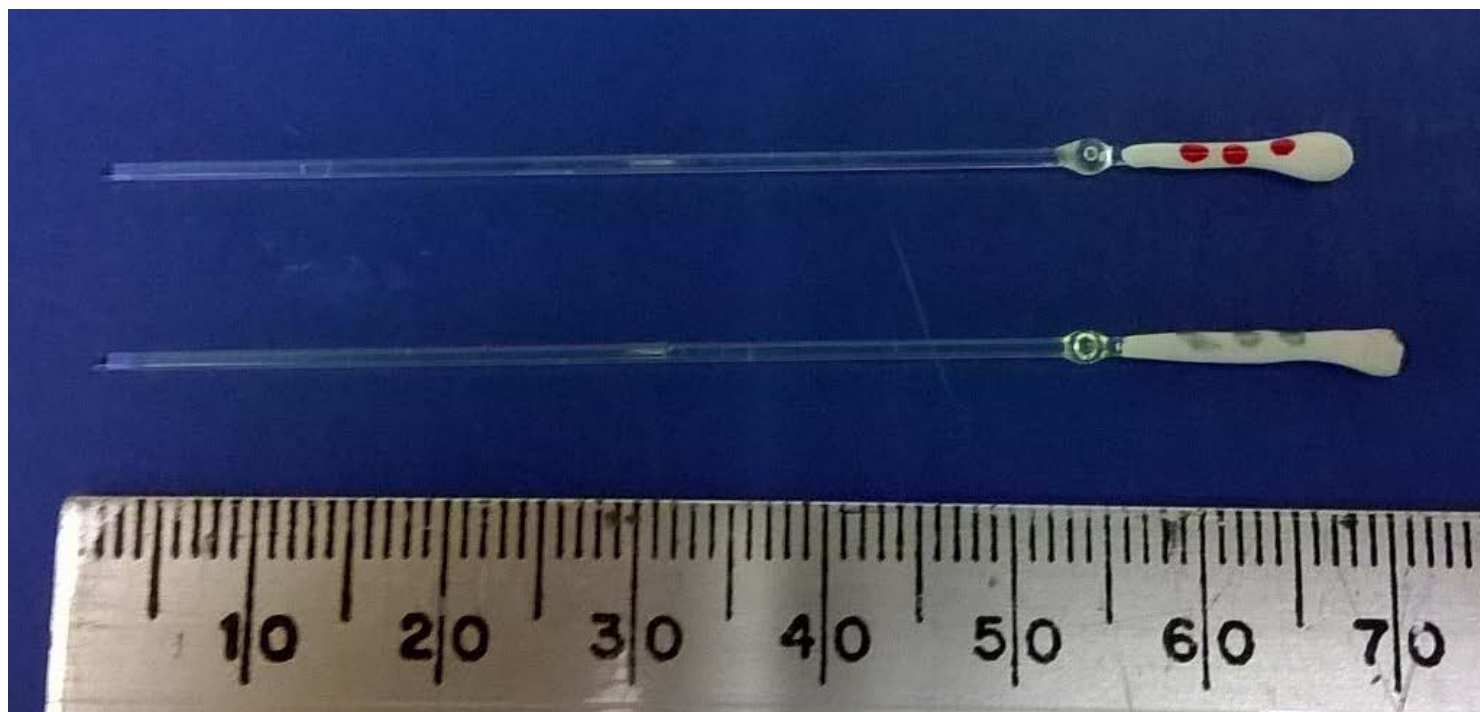
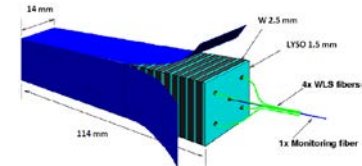


# RIAC as a Function of Integrated Dose and Normalized LO versus RIAC





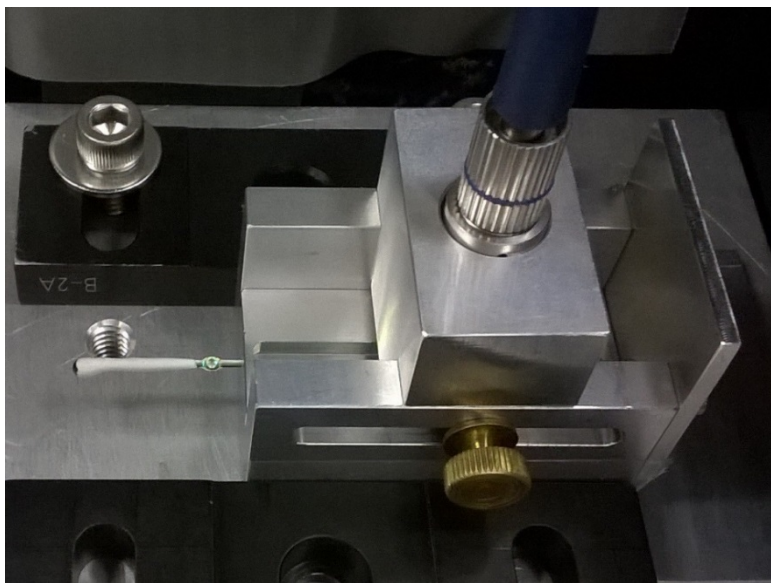
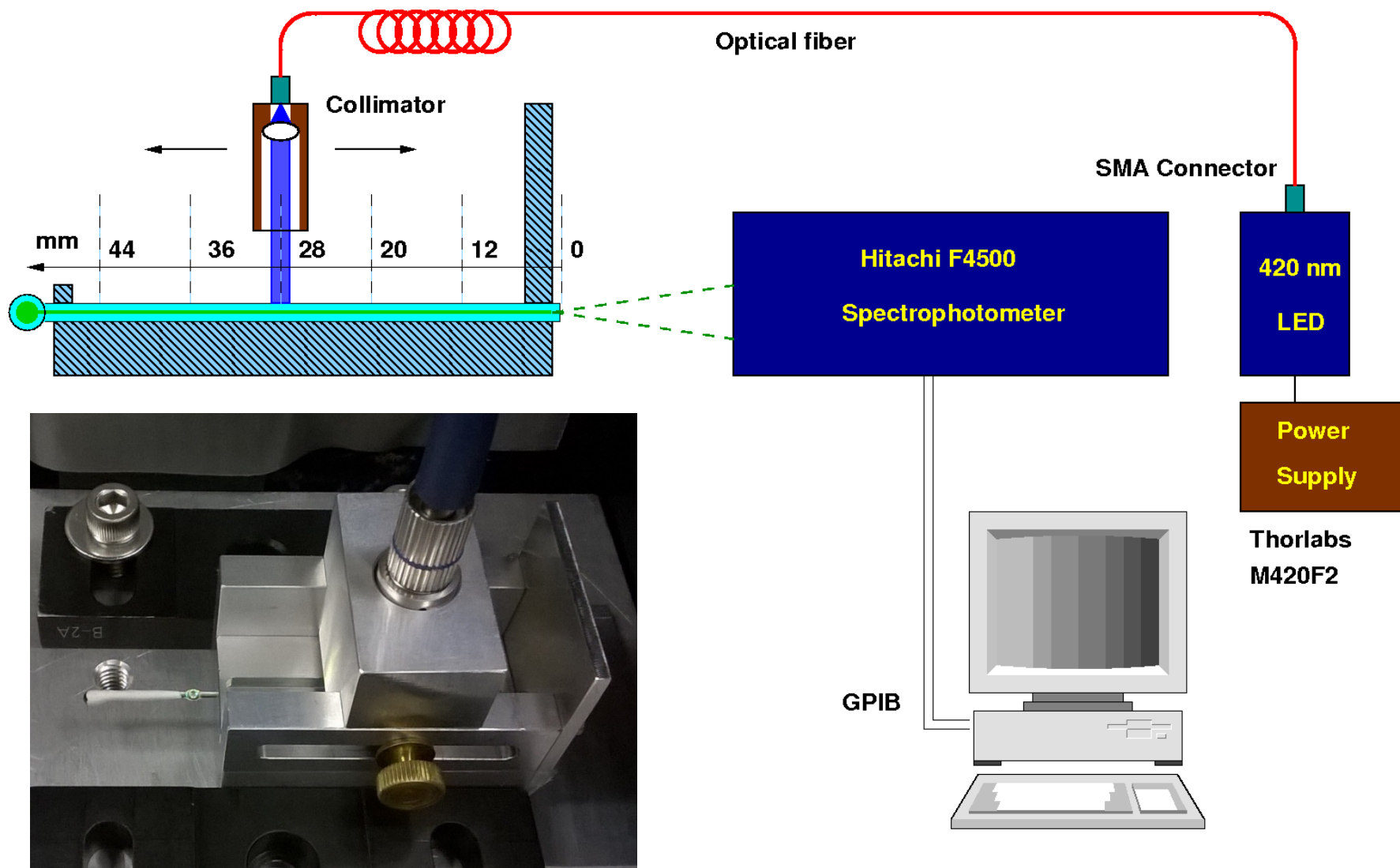
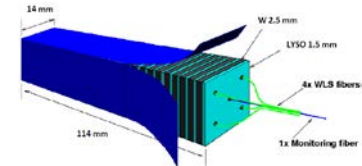
# Two Type Sealed Capillaries



- 10A J2-1 and 2, and 11A DSB1-1 and 2 were irradiated by protons at Los Alamos.
- 10A 3 and 11A 3 are used as references.

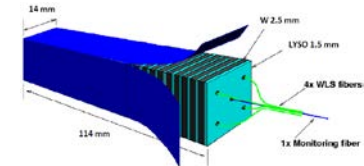


# Capillary Measurement Setup

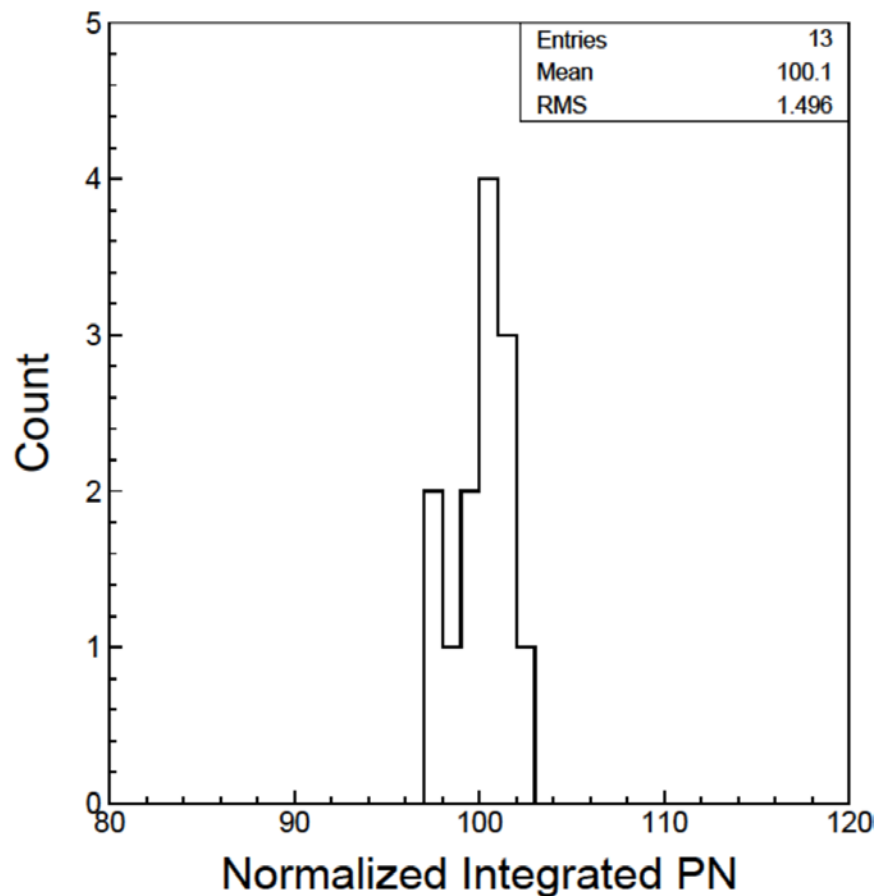
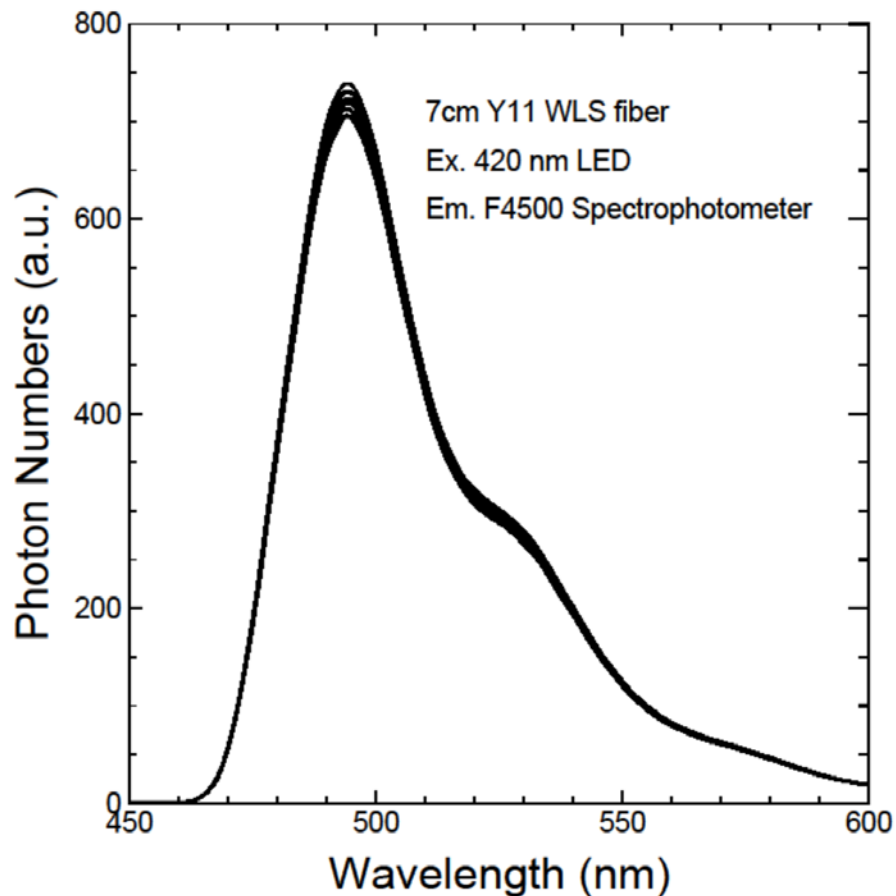




# Systematic Uncertainties

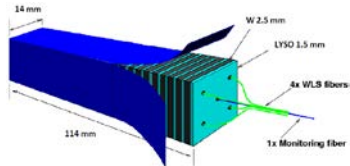


Checked with a Y-11 WLS fiber of 6 cm, the systematic uncertainty is 1.5%

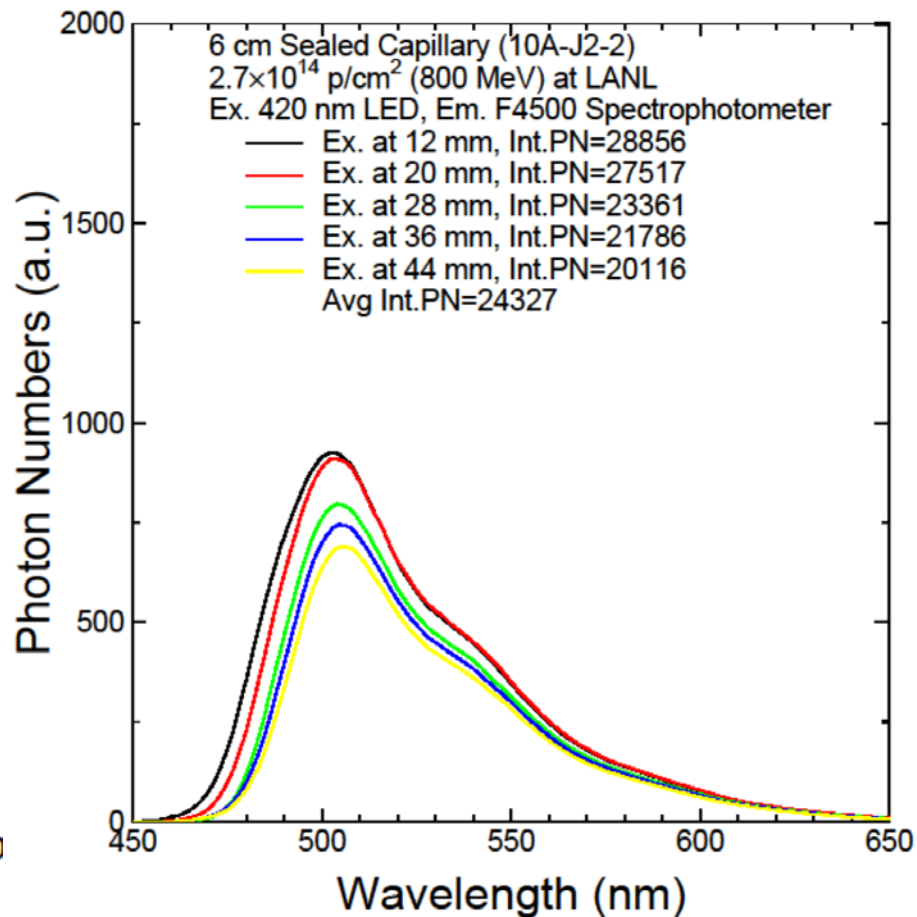
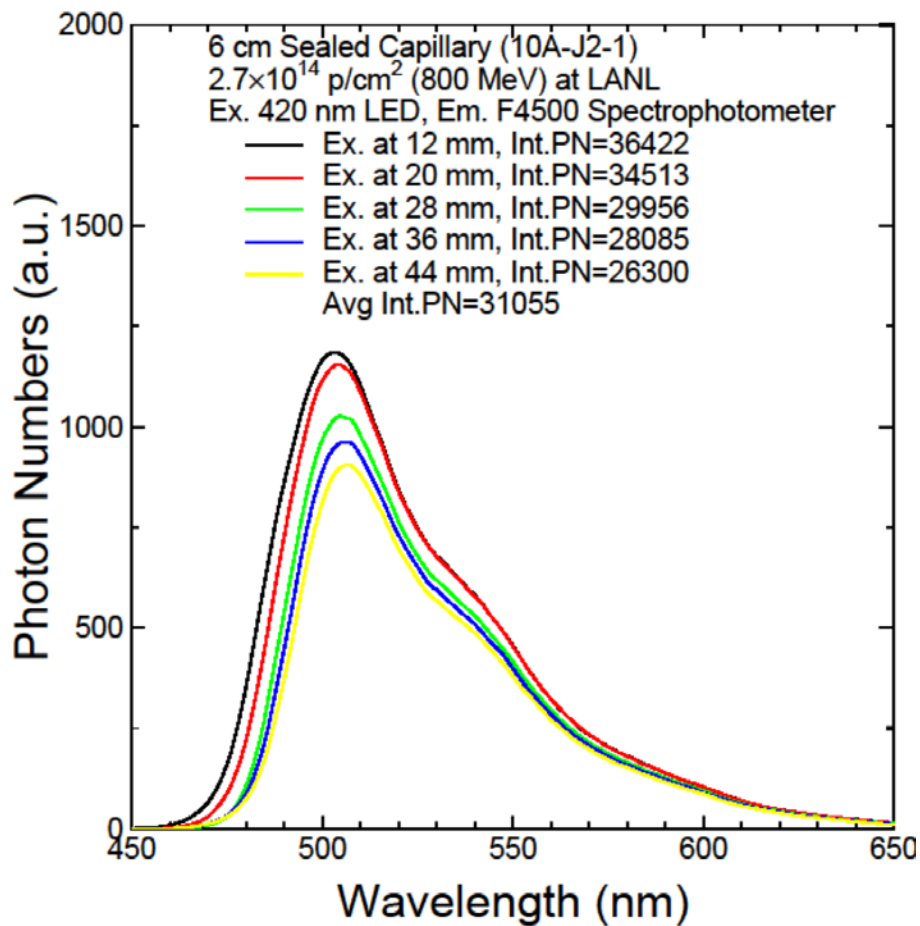




# J2 Capillaries after $2.7 \times 10^{14} \text{ p/cm}^2$

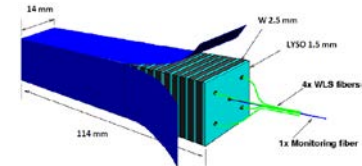


## Emission intensity as function of the distance to the coupling end

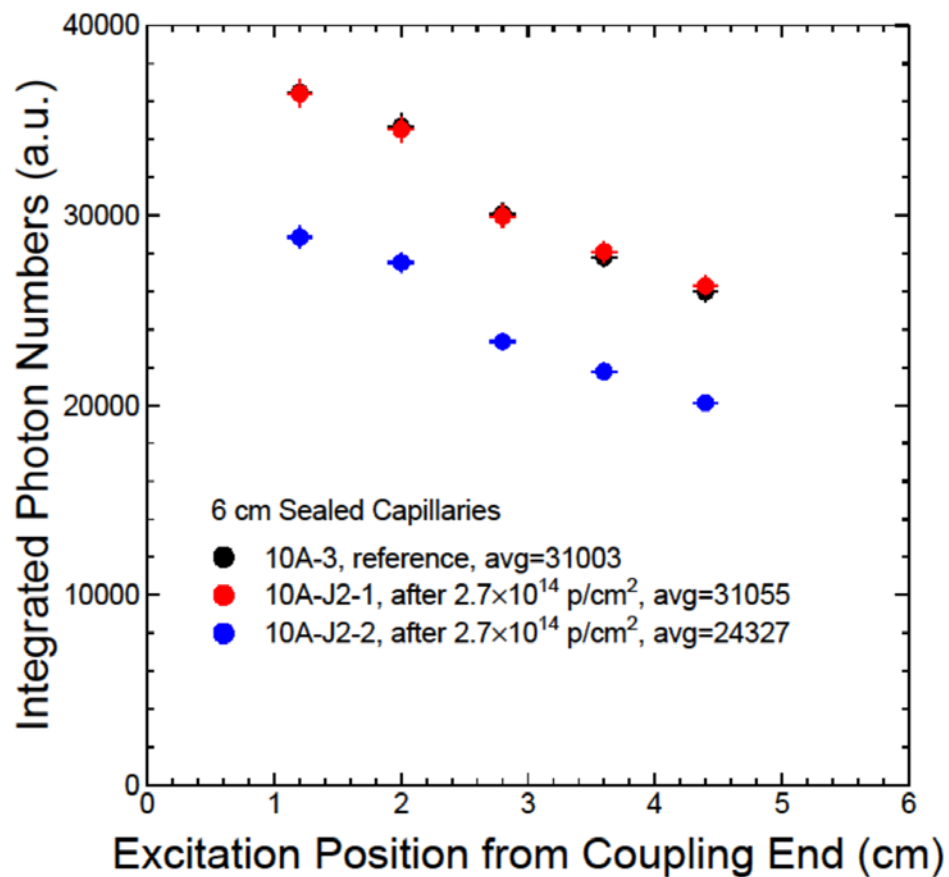
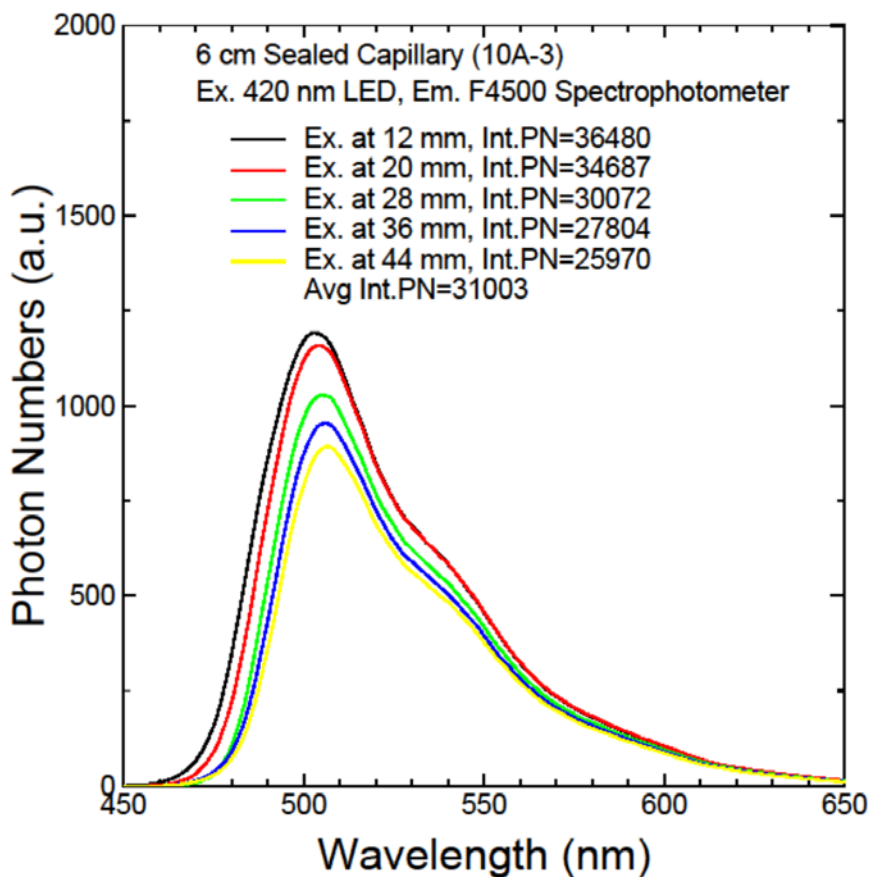




# Comparison with Un-irradiated J2



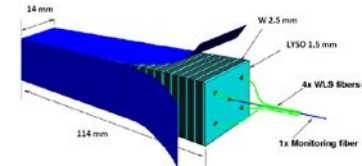
All three 10A-J2 capillaries show consistent emission spectrum  
Consistent photon intensity between 10A-J2-1 and 10A-3 is observed  
10A-J2-2 is 22% lower than the other two, requiring further investigation



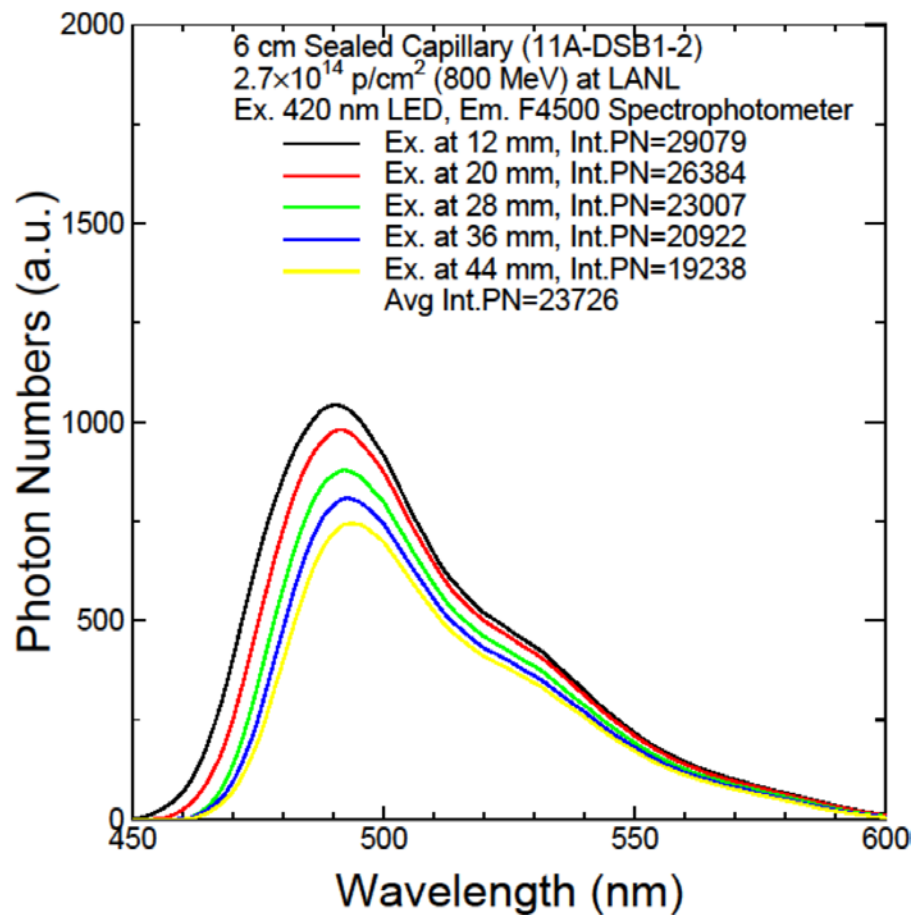
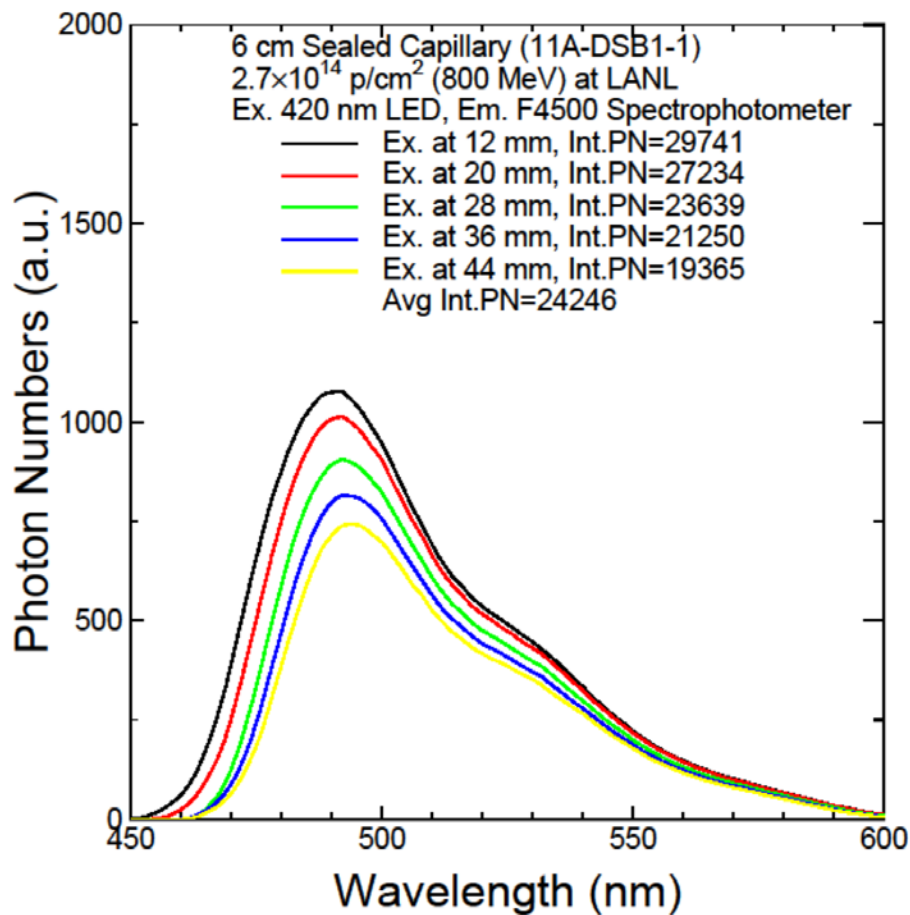




# DSB Capillaries after $2.7 \times 10^{14}$ p/cm<sup>2</sup>

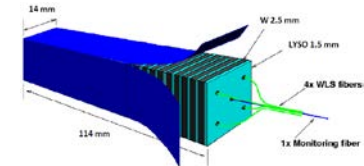


Emission intensity as function of the distance to the coupling end

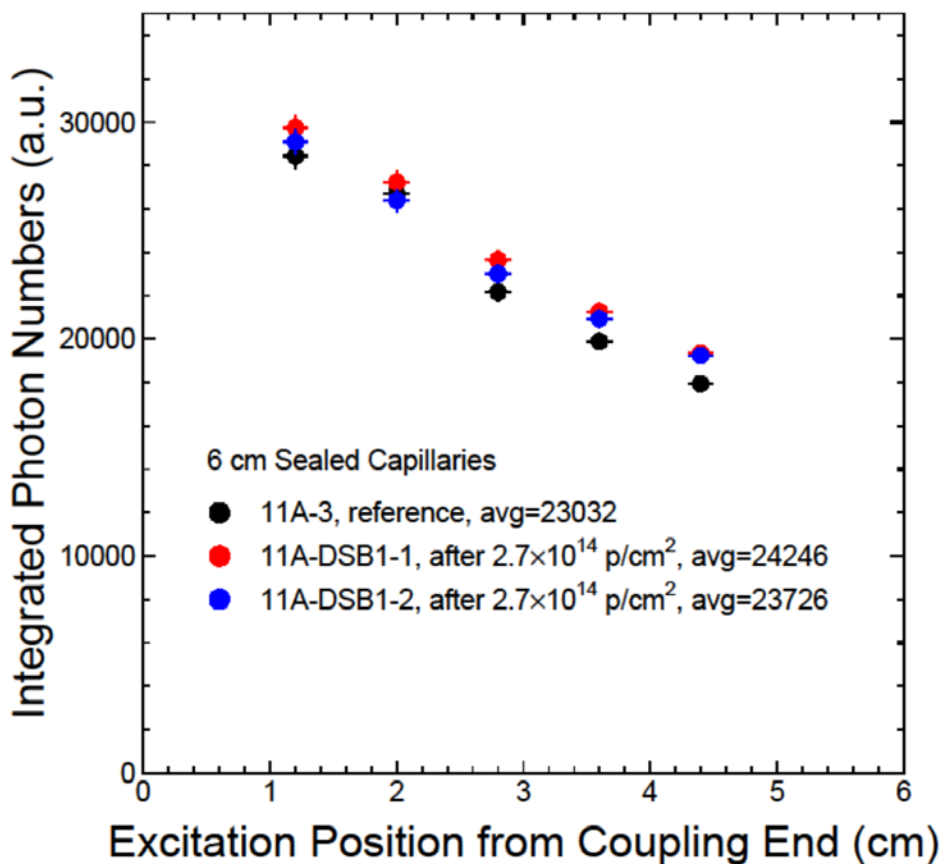
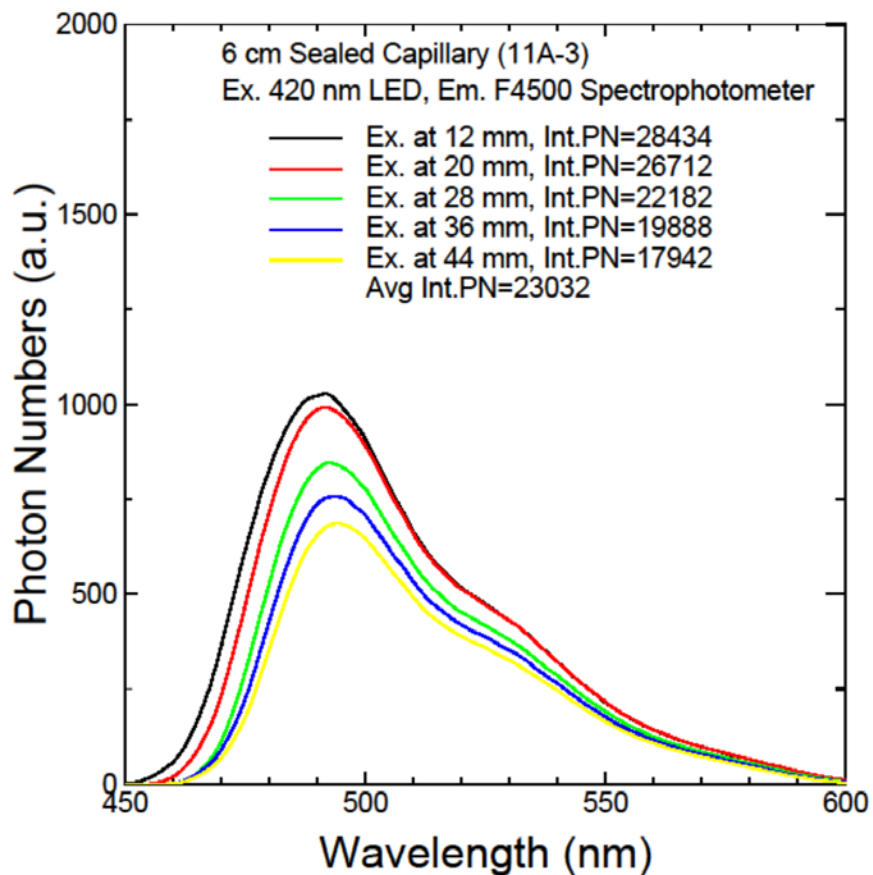




# Comparison with Un-irradiated DSB

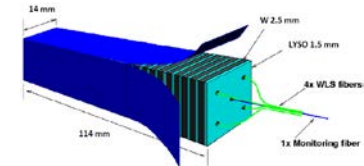


All three DSB capillaries show consistent emission spectrum  
11A-DSB-1 and 11A-DSB-2 show 5% and 3% higher photon intensity as compared to the un-irradiated 11A-3





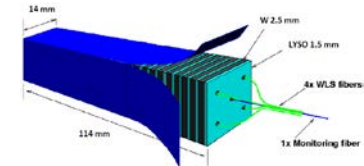
# Summary



- Long LYSO/LSO/LFS crystals from six vendors were irradiated by  $\gamma$ -rays up to 180 Mrad. Consistent degradation is observed in transmittance and light output.
- LYSO/LFS plates of 14 x 14 x 1.5 mm with five holes were irradiated by  $\gamma$ -rays up to 90 Mrad. Consistent degradation in light output is observed.
- Four sealed capillaries of 6 cm long were measured 76 days after irradiation by 800 MeV protons to  $2.7 \times 10^{14}$  p/cm<sup>2</sup> at Los Alamos. Consistent light emission spectra were observed. The result of sealed capillaries is very encouraging. Further investigation is needed for long capillaries.



# LYSO Testing Plan



- Four LYSO plates irradiated at CERN by 24 GeV protons were shipped back to Caltech. They were irradiated to  $7.4 \times 10^{13}$ , two  $2.3 \times 10^{15}$  and  $6.9 \times 10^{15}$  p/cm<sup>2</sup>.
- Five LYSO plates irradiated at UC Davis by 67 MeV protons will be shipped back to Caltech. They were irradiated to two  $1.2 \times 10^{12}$ ,  $1.2 \times 10^{13}$ ,  $2.2 \times 10^{13}$  and  $9.5 \times 10^{13}$  p/cm<sup>2</sup>.
- Samples irradiated at LANL by 800 MeV protons were shipped back to Caltech:
  - Four 6 cm long sealed capillaries:  $2.7 \times 10^{14}$  p/cm<sup>2</sup>;
  - Three 20 cm long Y-11 WLS fibers:  $2.7 \times 10^{14}$  p/cm<sup>2</sup>;
  - One 2.5 x 2.5 x 20 cm LYSO crystal:  $3.3 \times 10^{14}$  p/cm<sup>2</sup>; and
  - One 2.2 x 15 x 2.6 cm CeF<sub>3</sub> crystal:  $1.4 \times 10^{14}$  p/cm<sup>2</sup>.
- Characterization of above samples is on-going.