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# Radiation Damage in Crystals and a LFS/W/Capillary Shashlik Cell Induced by 800 MeV Protons

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# Introduction

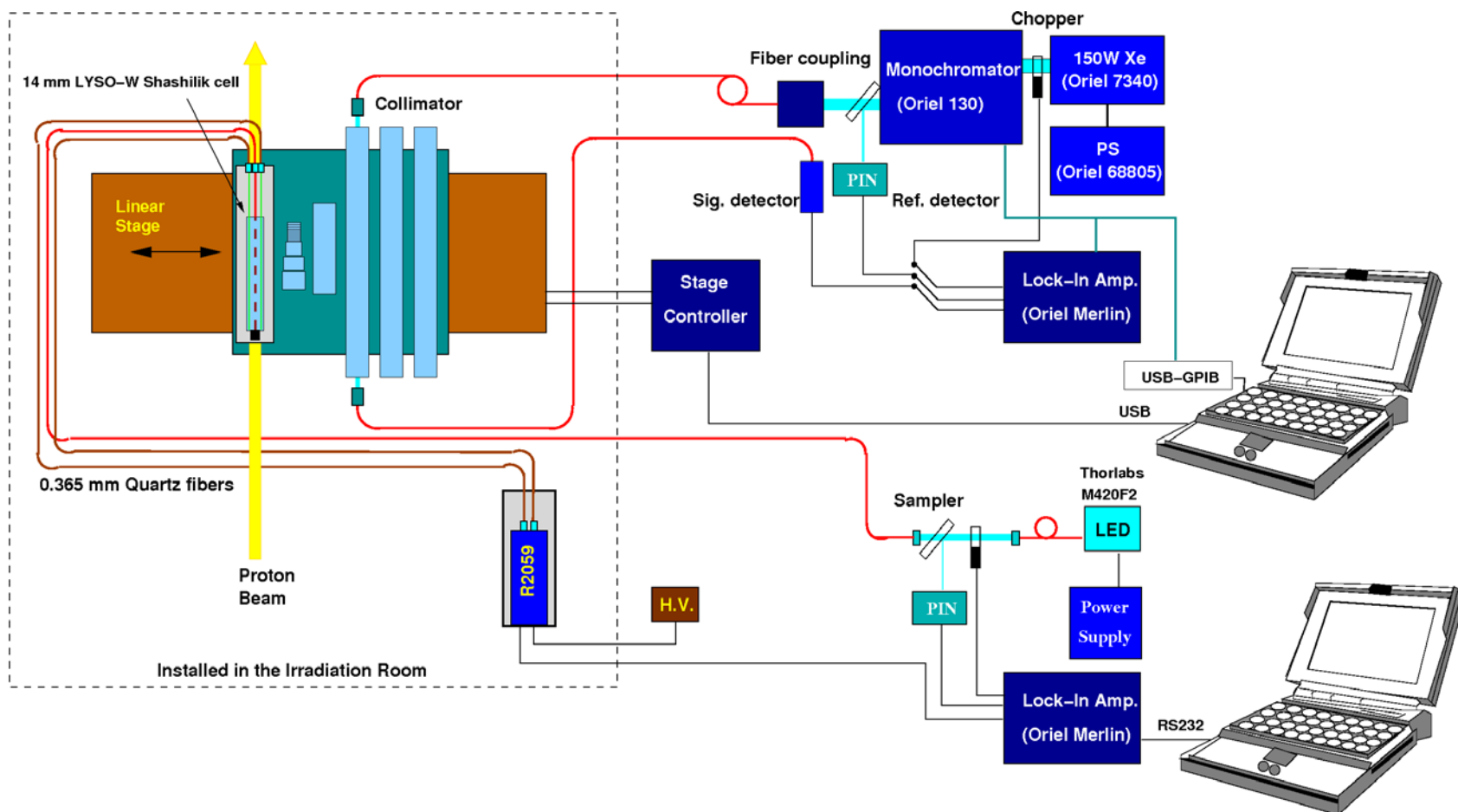
- Following proton irradiations at CERN and LANL in 2014, irradiations were carried out at CERN/LANL in 2015/2016. While samples irradiated at CERN are being cooled down, we report results for three long crystals and a LFS/W/Capillary Shashlik cell irradiated at LANL.
- The 800 MeV protons at the Weapons Neutron Research facility of Los Alamos Neutron Science Center (WNR of LANSCE) provide an ideal facility for investigations of charged hadron induced radiation damage.
- With excellent beam conditions a total of 14 runs were carried out for the experiment 6990 in 29 hours between 7 PM, 2/5, to 2 AM, 2/7:
  - One LFS/W/Capillary Shashlik cell with LED based monitoring;
  - Several crystal and ceramic samples of small size;
  - Quartz capillaries and Y-11 WLS;
  - Three 20 cm long crystals: LFS, PWO and BGO.
- Measurements were carried out before, during and after irradiations *in situ* for long crystals and the Shashlik cell with preliminary results presented in this report. Final results will be reported after samples are back to Caltech.

# Plan: Six Samples Irradiated to $3 \times 10^{14}$ p/cm<sup>2</sup> in the Blue Room at LANL in 2016

Samples		Dimensions (mm <sup>3</sup> )	In-situ Measurement
Shashlik Cell		34x34x215	<b>420 LED Monitoring</b> / Al
Small Samples	BaF <sub>2</sub>	30x30x20	Al foil activation
	LuAG Ceramic	25x25x0.4	
	10 PWOs	25x25x10	
	BGO	17x17x17	
	20 LFS Plates	14x14x1.5	
2 Capillaries + 2 Y11s		Φ1x200	Al foil activation
PWO		28.5 <sup>2</sup> x30 <sup>2</sup> x220	<b>LT (350-700 nm)</b>
LFS		25x25x180	<b>LT (350-700 nm)</b>
BGO		25x25x200	<b>LT (350-700 nm)</b>

# Setups for On-line Monitoring

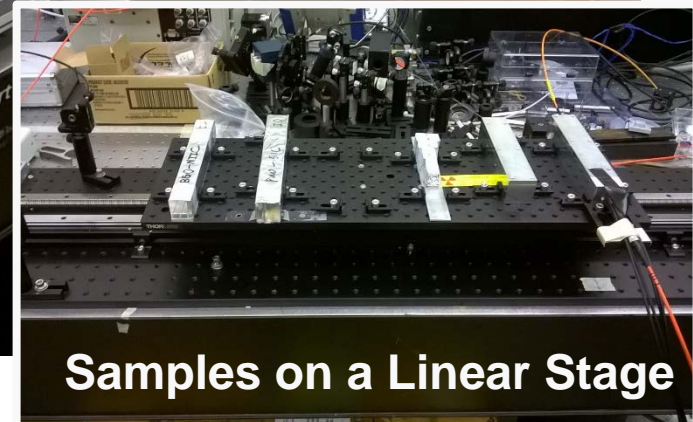
A LYSO-W-Capillary Shashlik cell and three long crystals were monitored by a 420 nm LED and a fiber based spectrophotometer (300 – 800 nm) respectively before, during and after irradiation



# Instruments for On-line Monitoring

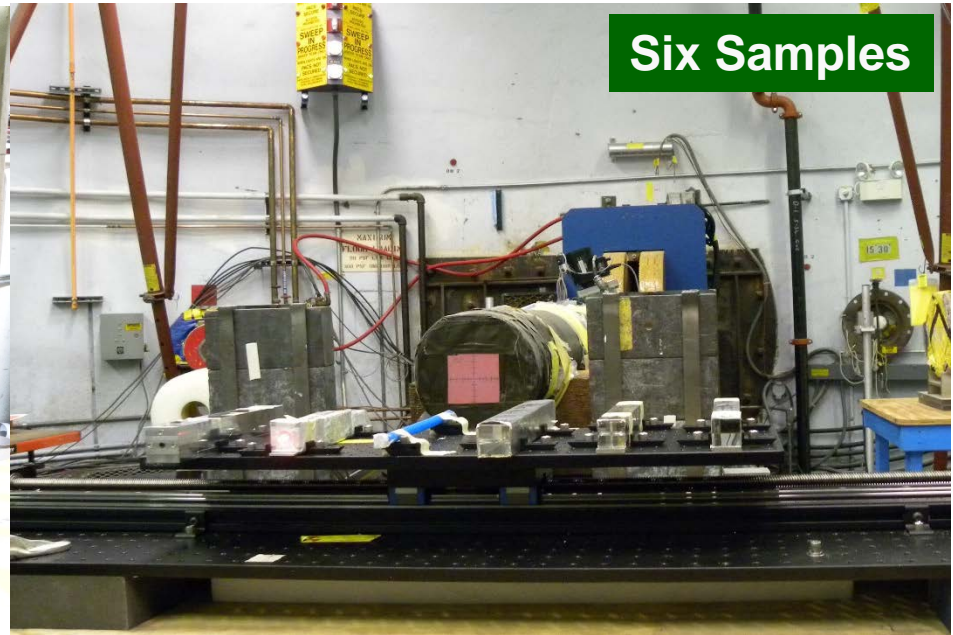
Most were shipped to Los Alamos on 12/8/2015. The LYSO/W/Capillary Shashlik cell and its LED based monitoring system was shipped on 1/29/2016

## Instruments for Los Alamos Irradiation



Samples on a Linear Stage

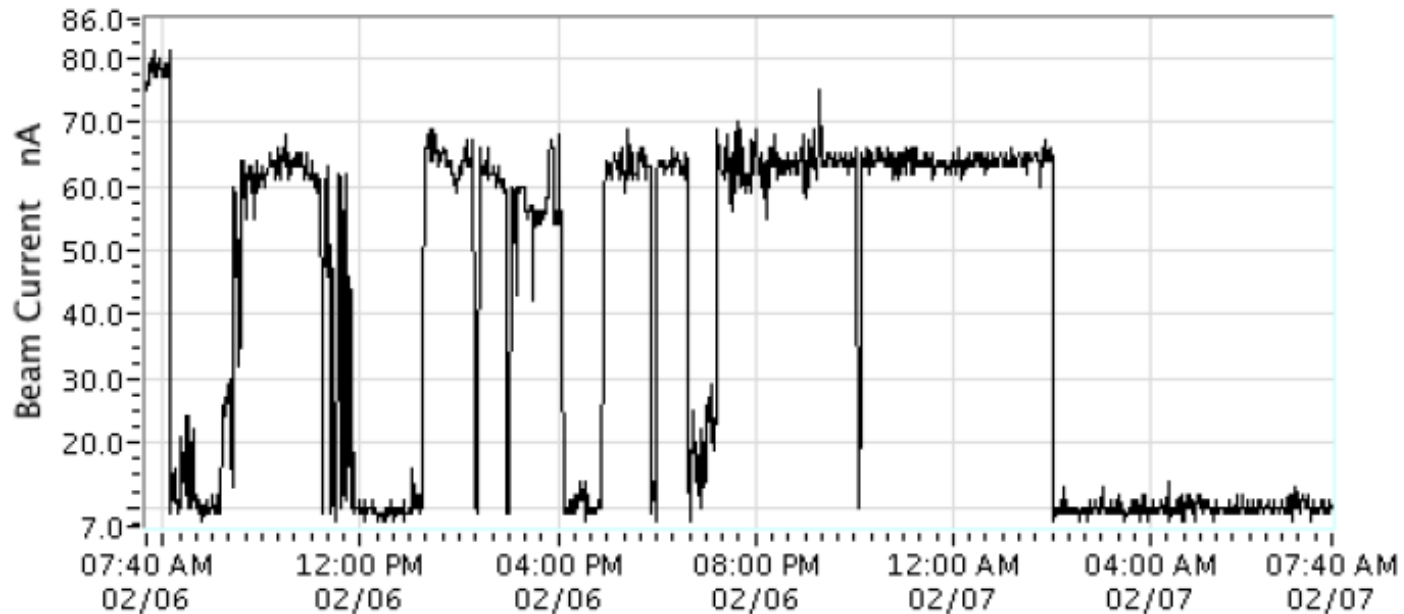
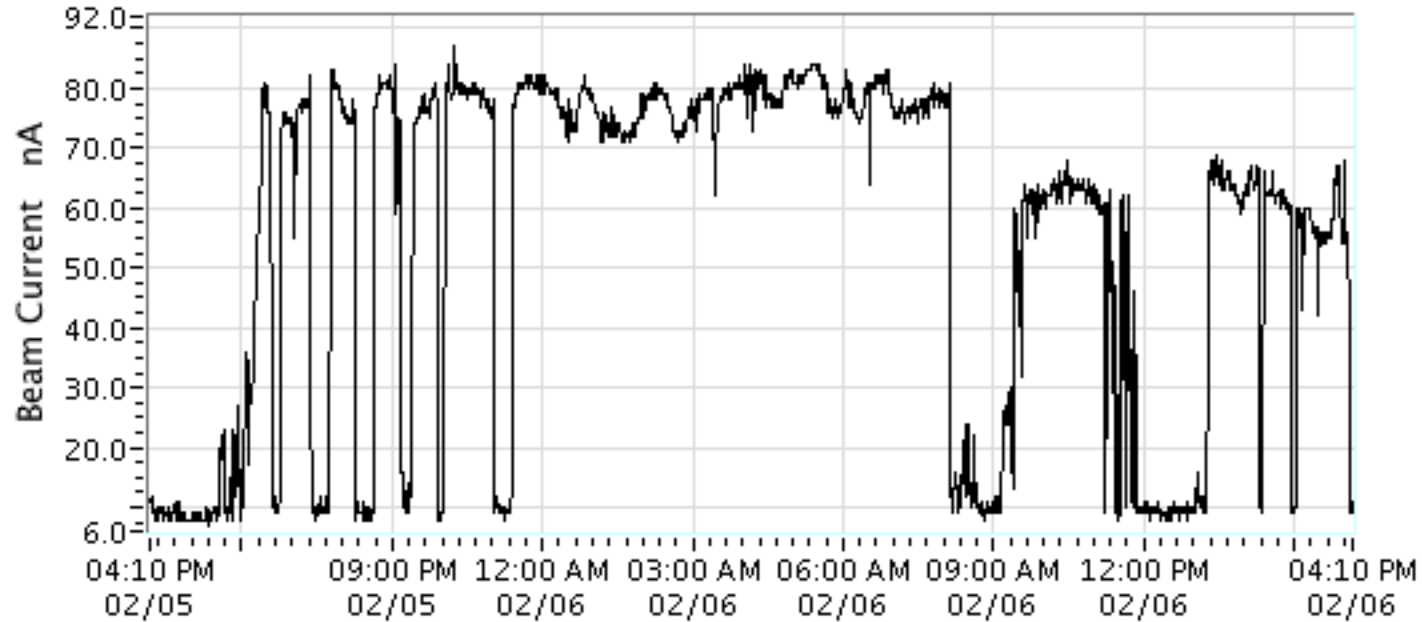
# A Few Photos at Los Alamos



# The Proton Fluence

Samples	Dimensions (mm <sup>3</sup> )	In-situ Measurement	Fluence (p/cm <sup>2</sup> )
Shashlik Cell	34x34x215	420 LED Monitoring / Al	$1.24 \times 10^{15}$
BaF <sub>2</sub>	30x30x20	Al foil activation	$2.94 \times 10^{14}$
LuAG Ceramic	25x25x0.4		
10 PWOs	25x25x10		
BGO	17x17x17		
20 LFS Plates	14x14x1.5		
2 Capillaries + 2 Y11s	Φ1x200	Al foil activation	$3.05 \times 10^{15}$
PWO	28.5 <sup>2</sup> x30 <sup>2</sup> x220	LT (350-700 nm)	$1.80 \times 10^{14}$
LFS	25x25x180	LT (350-700 nm)	$2.87 \times 10^{15}$
BGO	25x25x200	LT (350-700 nm)	$1.77 \times 10^{14}$

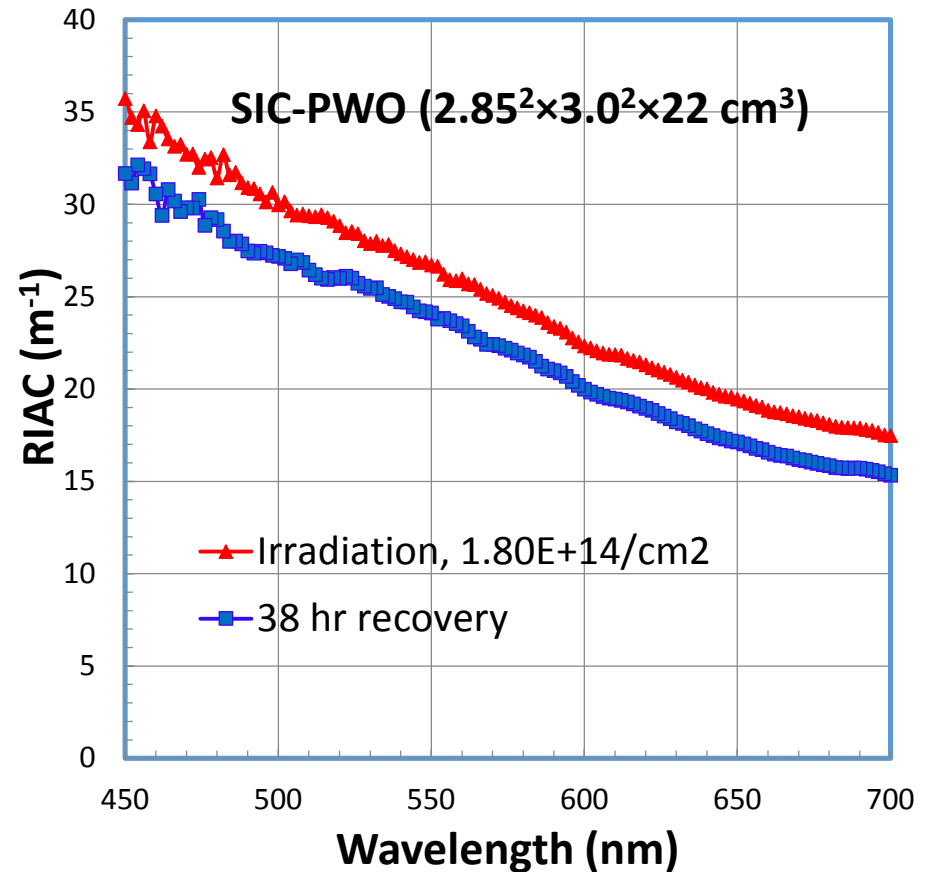
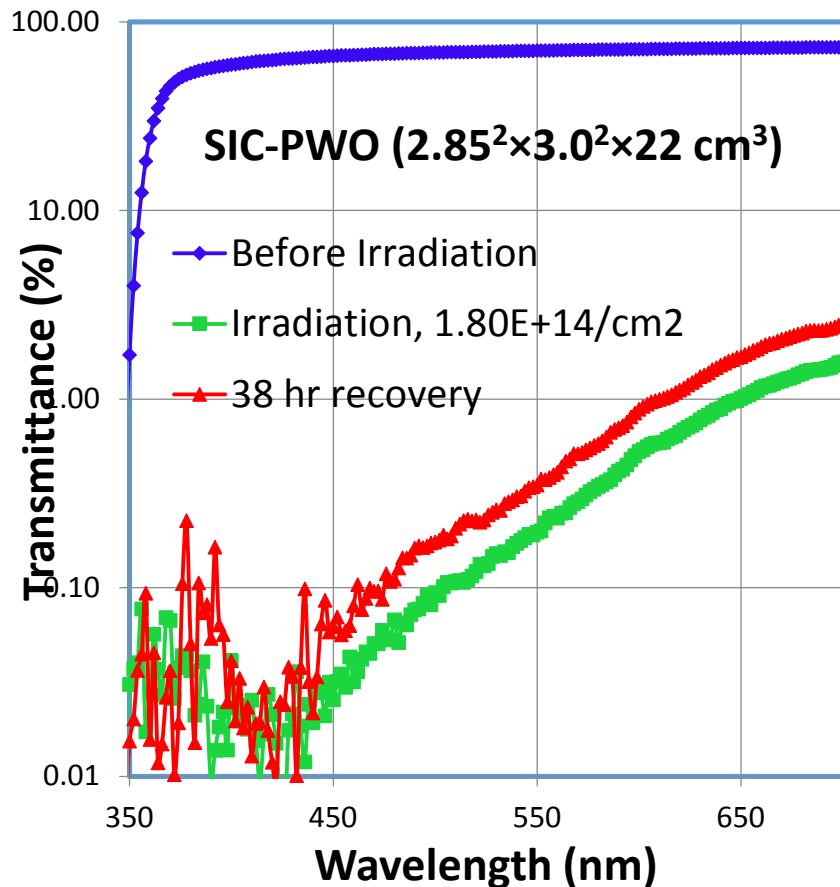
# Proton Beam History





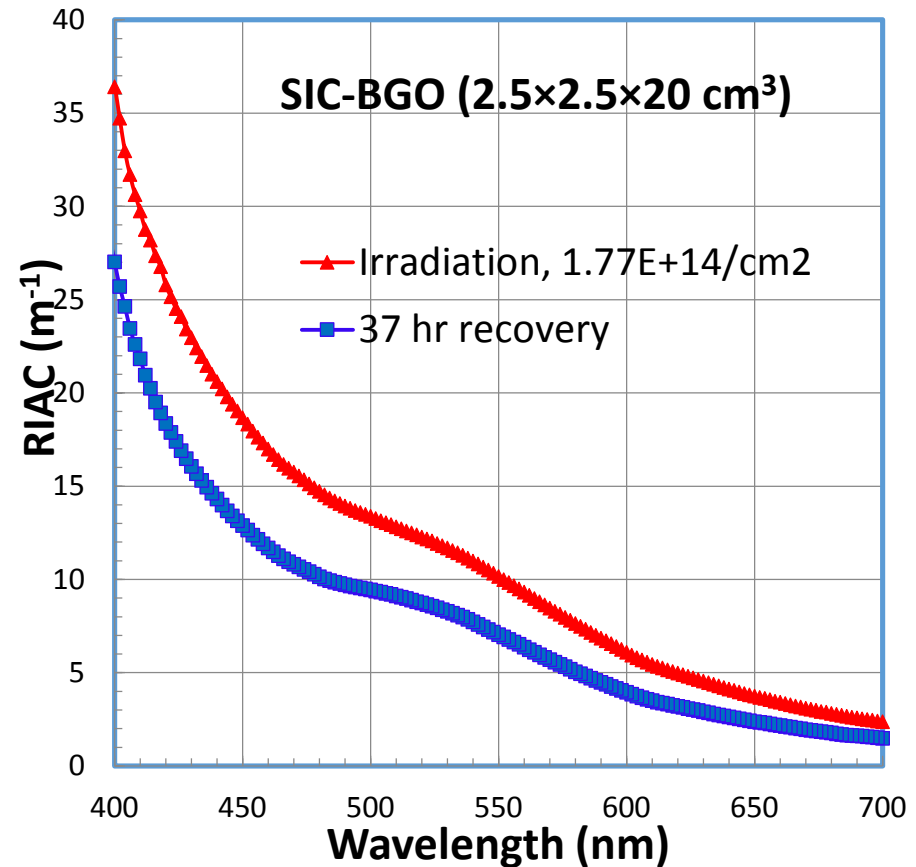
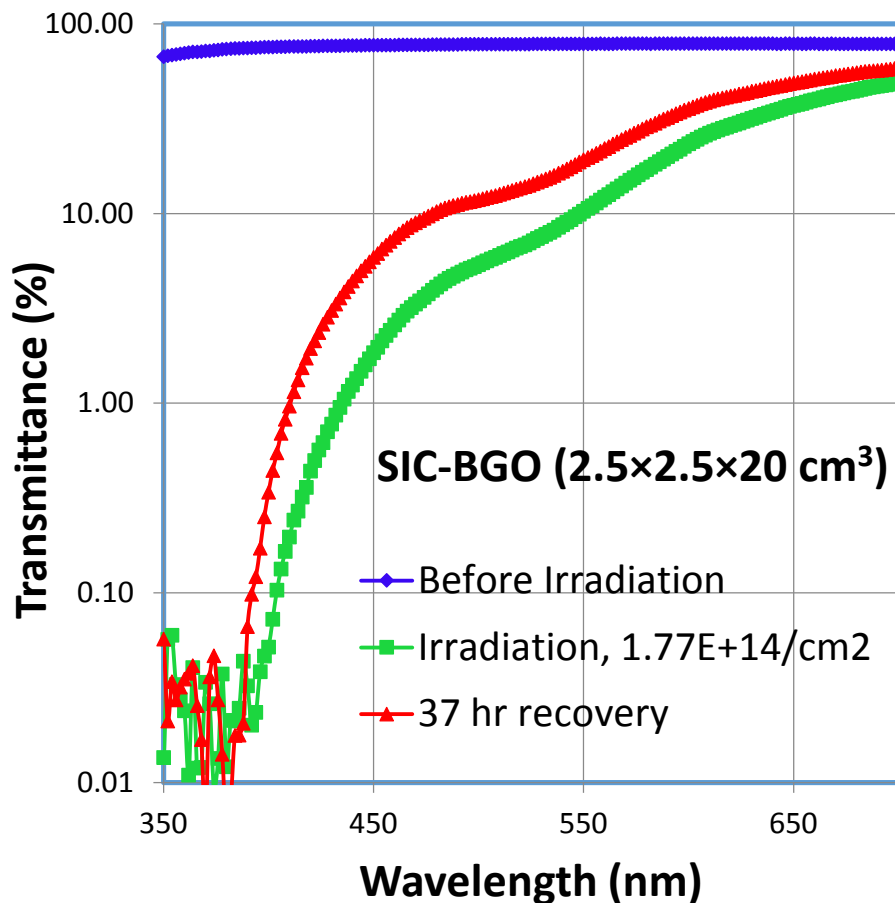
# PWO: LT Damage and RIAC

The 22 cm PWO sample irradiated to  $1.8 \times 10^{14}$  p/cm<sup>2</sup> with a flux of  $3.1 \times 10^{14}$  p/cm<sup>2</sup>/hr is completely black below 450 nm with recovery observed after 38 hr



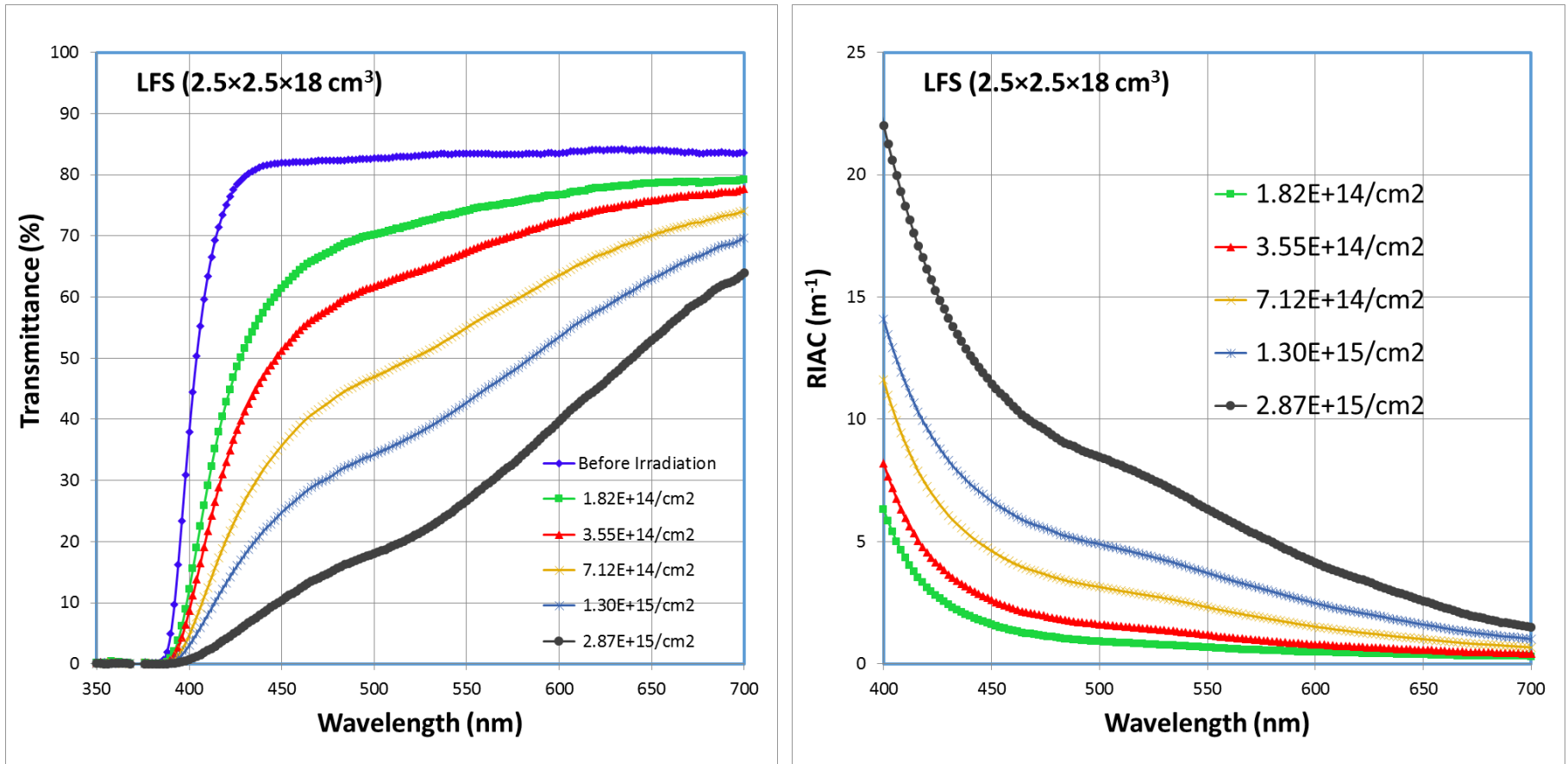
# BGO: LT Damage and RIAC

The 20 cm BGO sample irradiated to  $1.8 \times 10^{14}$  p/cm<sup>2</sup> with a flux of about  $3.1 \times 10^{14}$  p/cm<sup>2</sup>/hr is completely black below 400 nm with recovery recorded from 15 to 10 m<sup>-1</sup> at its emission peak after 37 hr



# LFS: LT Damage and RIAC

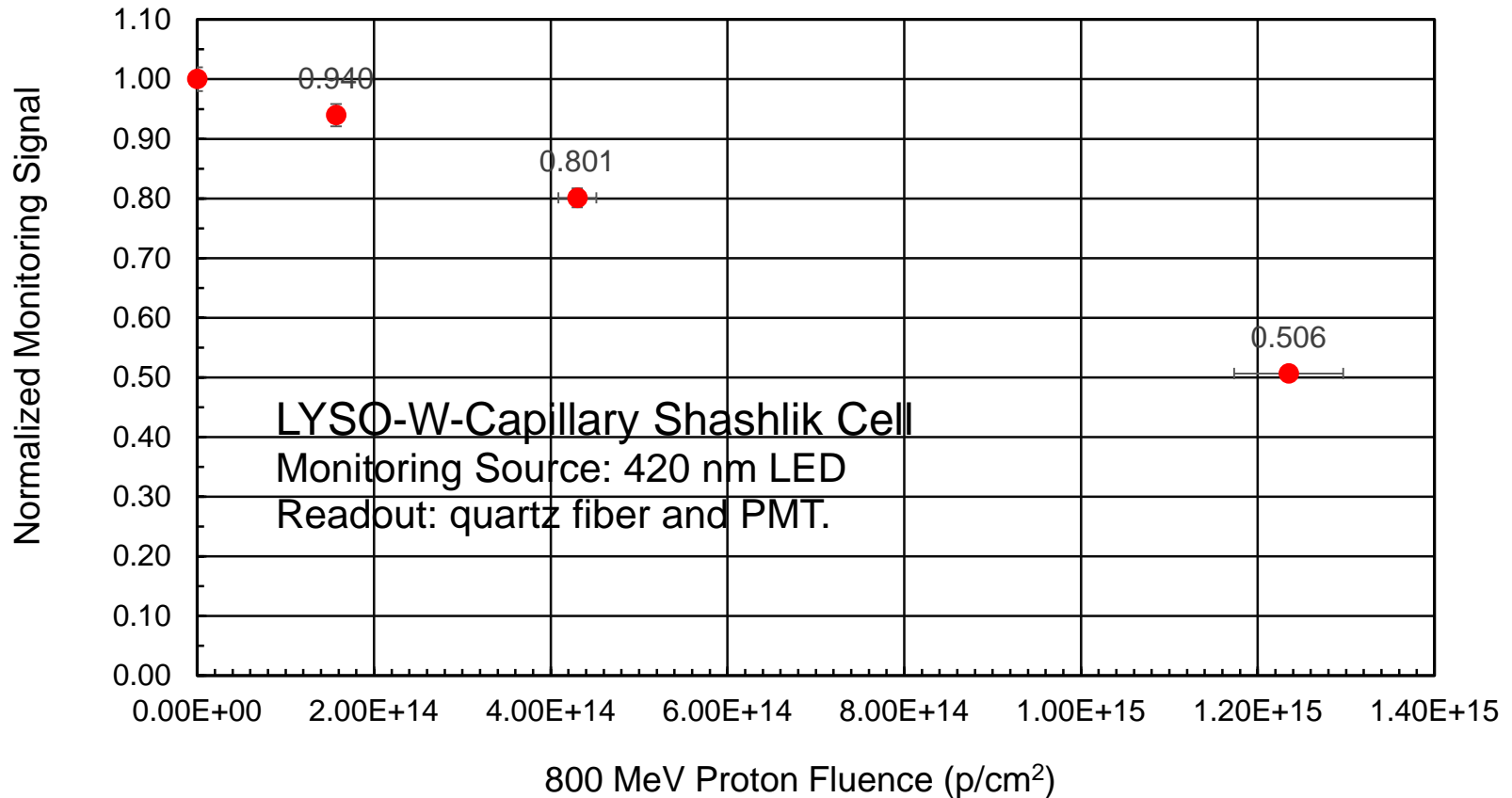
The 18 cm LFS crystal irradiated to  $2.9 \times 10^{15}$  p/cm<sup>2</sup> in five steps with the RIAC at 430 nm of 3.7 / 14.1 m<sup>-1</sup> after  $3.6 \times 10^{14}$  /  $2.9 \times 10^{15}$  p/cm<sup>2</sup> respectively



Result consistent with 2014 irradiations, published in <http://dx.doi.org/10.1016/j.nima.2015.11.100>

# LFS/W/Capillary Shashlik Cell

The Shashlik cell irradiated to  $1.2 \times 10^{15}$  p/cm<sup>2</sup> in 3 steps with degradation of 20%/50% after  $4.3 \times 10^{14}$  /  $1.24 \times 10^{15}$  p/cm<sup>2</sup>



The LYSO/capillary based Shashlik is radiation hard against charged hadrons

# Summary

- Experiment 6900 measures crystal's transmittance and Shashlik response during proton irradiation at Los Alamos.
- Irradiation was carried out up to  $3 \times 10^{15}$  p/cm<sup>2</sup>.
- After  $1.8 \times 10^{14}$  p/cm<sup>2</sup> PWO is black at its emission peak, BGO has a RIAC value of  $10 \text{ m}^{-1}$  at its emission peak. An 18 cm long LFS crystal shows good radiation hardness, similar to LYSO crystals irradiated in 2014.
- A LFS/W/Capillary Shashlik cell was irradiated to  $1.24 \times 10^{15}$  p/cm<sup>2</sup> in 3 steps with degradation of 20%/50% after  $4.3 \times 10^{14}$  /  $1.24 \times 10^{15}$  p/cm<sup>2</sup>, indicating that the proposed LYSO and quartz capillary based Shashlik calorimeter is radiation hard against charged hadrons.
- Investigations are planned to further understand hadron induced radiation damage in crystals and their monitoring.
- Acknowledgements: US Department of Energy Grants DE-SC0011925 and DE-AC52-06NA25396.