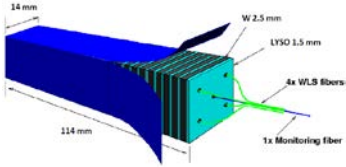

First Report on Radiation Damage Induced by 800 MeV Protons in Scintillating Crystals

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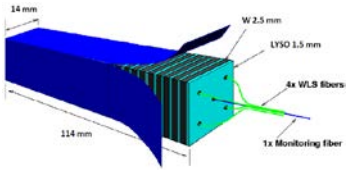
California Institute of Technology

Jon Kapustinsky, Ron Nelson and Zhehui Wang

Los Alamos National Laboratory

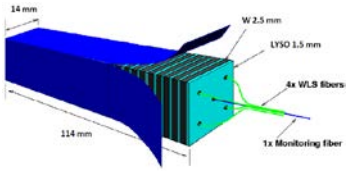
January 28, 2015

Introduction

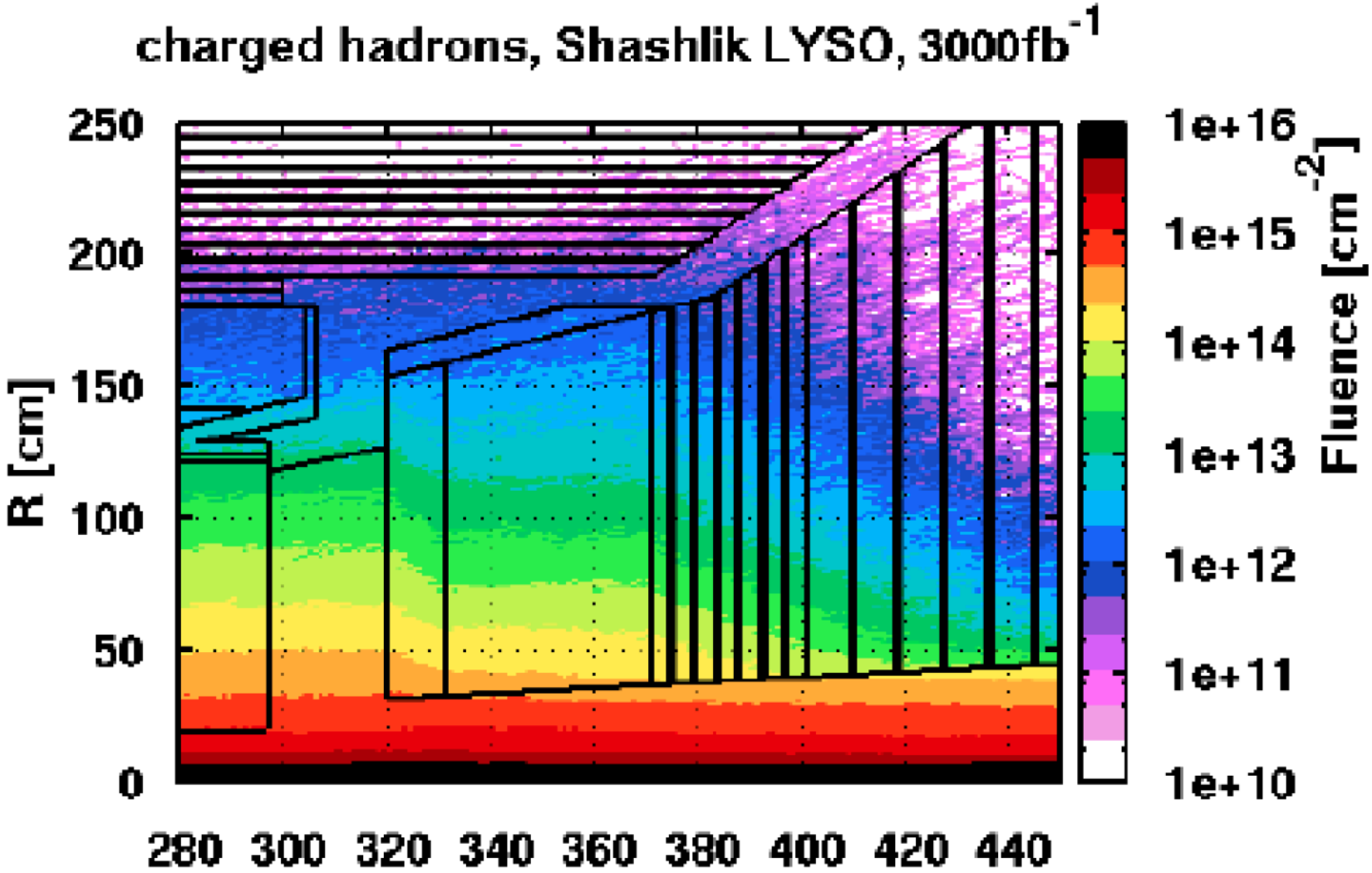


- Because of the severe radiation environment expected at the HL-LHC radiation hardness of LYSO crystals against ɣ-rays and hadrons is a crucial issue for the proposed LYSO/W Shashlik calorimeter.
- As discussed in December Jamboree, the ɣ-ray induced damage in LYSO plates up to 200 Mrad @ 1 Mrad/h is less than 1%/year.
- The 800 MeV proton beam at the Weapons Neutron Research facility of Los Alamos National Lab Neutron Research Center (WNR of LANSCE) is ideal to investigate charged hadron induced radiation damage in crystal scintillators.
- Experiment 6501 was carried out at LANSCE between Dec 18 and 21, 2014. Because of a power black out during the allocated beam time, only 4.5 hour beam time was available to irradiate samples:
  - Four 6 cm long sealed capillaries: 2.7 x 10^{14} p/cm^2;
  - One 2.5 x 2.5 x 20 cm LYSO crystal: 3.3 x 10^{14} p/cm^2; and
  - One 2.2 x 15 x 2.6 cm CeF_3 crystal: 1.4 x 10^{14} p/cm^2.
- While waiting for the irradiated samples be shipped back from Los Alamos after cooled down, this is the 1st report based on the on-line data only.

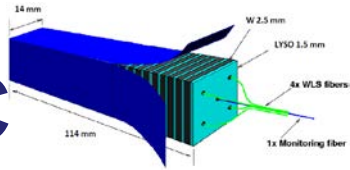
Charged Hadron Fluence @ 3,000 fb^{-1}



Expected charged hadron fluence is 3 x 10^{14}/cm^2 for the proposed Shashlik endcap at |η| = 3



Expected Radiation at HL-LHC



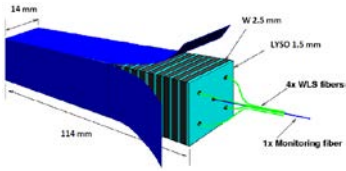
CMS Radiation	LHC (10^{34} $cm^{-2}s^{-1}$, 500 fb^{-1})		HL-LHC (5×10^{34} $cm^{-2}s^{-1}$, 3000 fb^{-1})	
	Barrel (max)	Endcap (max)	Barrel (max)	Endcap (max)
Absorbed dose (rad)	**3.50E+05**	**2.10E+07**	2.10E+06	1.26E+08
Dose rate (rad/h)	25	1512	126	7560
Fast neutrons fluence (E>100KeV, cm^{-2})	**3.00E+13**	**8.00E+14**	1.80E+14	4.80E+15
Fast neutrons flux (E>100KeV, $cm^{-2}s^{-1}$)	6.00E+05	1.60E+07	3.00E+06	8.00E+07
Charged hadrons fluence (cm^{-2})	**4.00E+11**	**5.00E+13**	2.40E+12	3.00E+14
Charged hadrons flux ($cm^{-2}s^{-1}$)	8.00E+03	1.00E+06	4.00E+04	5.00E+06

γ-rays: Up to 130 Mrad at 7.6 krad/h;

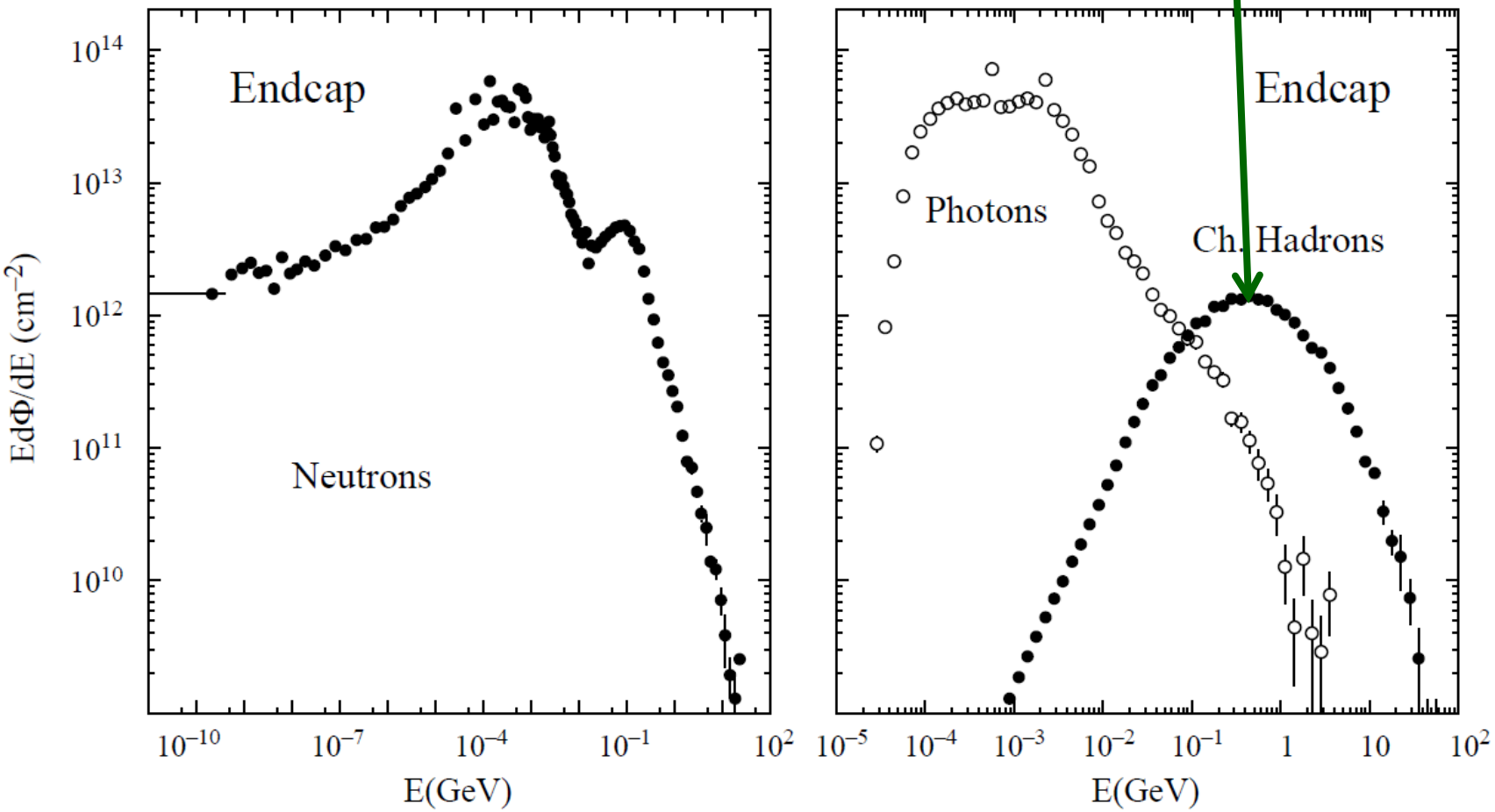
Fast Neutrons: Up to 5 x 10^{15} n/cm^2 at 8 x 10^7 n/cm^2/s;

Charged hadrons: Up to 3 x 10^{14} p/cm^2 at 5 x 10^6 p/cm^2/s.

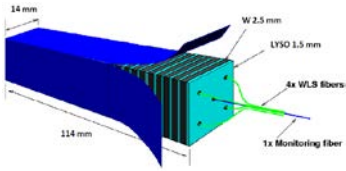
Energy Spectrum: ɣ, n & Charged Hadrons



The peak energy of charged hadron at CMS endcap is hundreds MeV. The 800 MeV proton beam at the WNR of LANSCE is ideal for the investigation of charged hadron induced radiation damage in crystals.



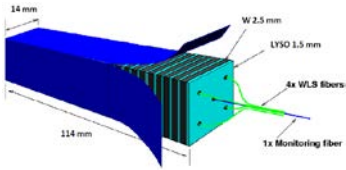
Proton Fluence on Crystals

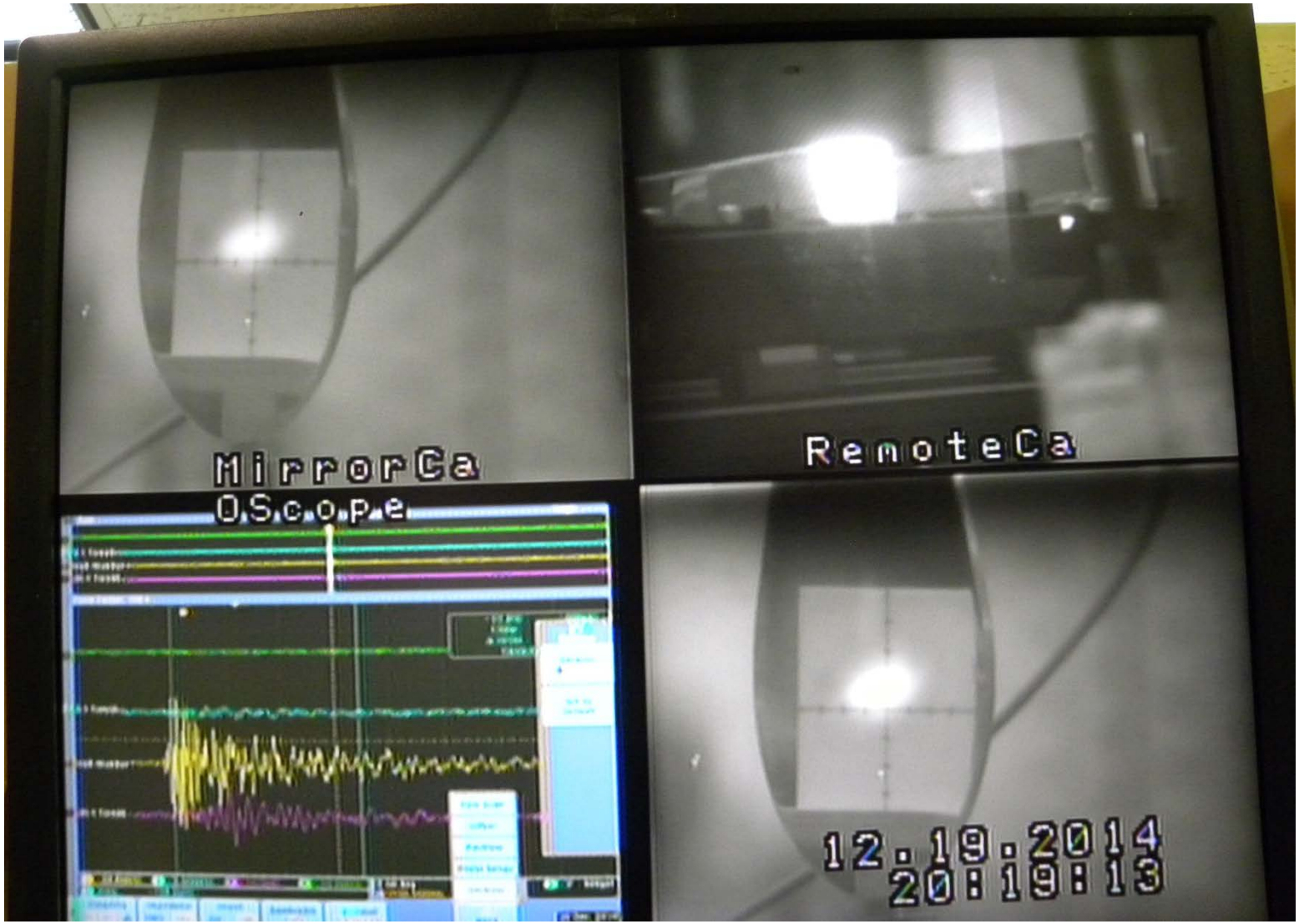


Environment/Source	Flux on Crystal ($p\ s^{-1}\ cm^{-2}$)	Fluence on Crystal ($p\ cm^{-2}$)
CMS FCAL (η=1.4) at HL-LHC	4.0×10^{4}	2.4×10^{12} / 3000 fb^{-1}
CMS FCAL (η=3.0) at HL-LHC	5.0×10^{6}	3.0×10^{14} / 3000 fb^{-1}
WNR facility of LANSCE	**Up to 2×10^{10}**	**Up to 3×10^{14}**

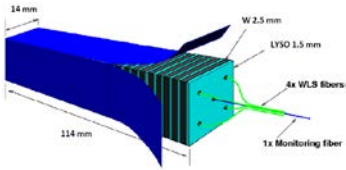
One end of a long crystal is irradiated by 800 MeV protons of a Gaussian shape with FWHM of about one inch

On-Line Beam Monitoring





Samples To Be Irradiated

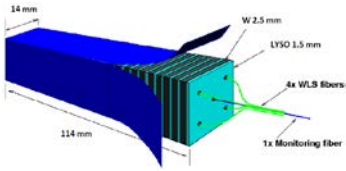


Sample	ID	Dimension (cm^3)
LYSO/W/Y-11 Shashlik Cell	Y-11	1.4×1.4×15
Four Sealed Capillaries and Three Y-11 Fibers	Capillaries	1.4×1.4×15
LYSO	SG	2.5×2.5×20
LFS	OET	2.5×2.5×18
BGO	SIC BGO	2.5×2.5×20
CeF_3	SIC CeF_3	$2.2^2 \times 2.6^2 \times 15$

Because of a power black out only three samples were irradiated. The LYSO/CeF_3 crystals are 20/10 year old. Need optimized CeF_3 crystal.

- Four 6 cm long sealed capillaries and three 20 cm long Y-11: 2.7×10^{14} p/cm^2;
- One 2.5 x 2.5 x 20 cm LYSO crystal: 3.3×10^{14} p/cm^2; and
- One 2.2 x 15 x 2.6 cm CeF_3 crystal: 1.4×10^{14} p/cm^2.

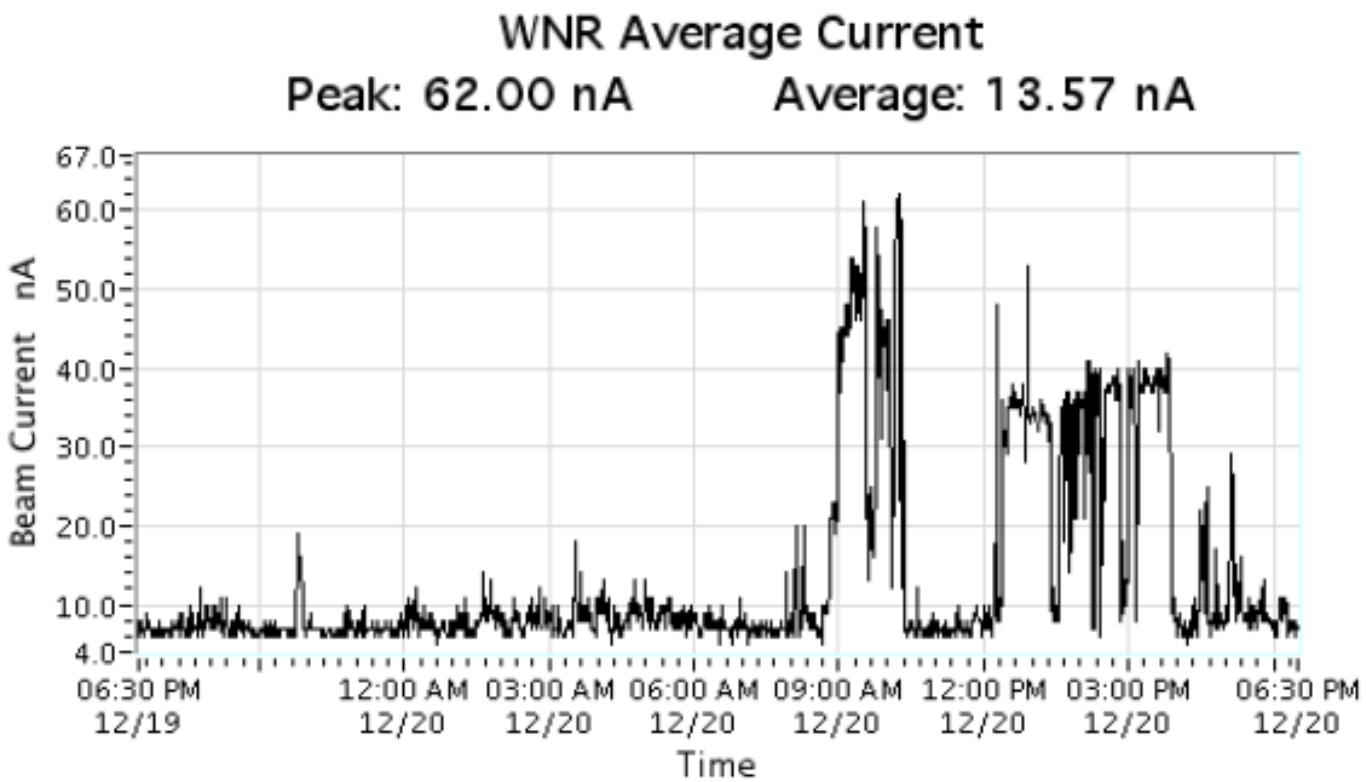
Beam Time at Los Alamos



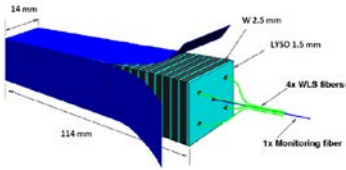
Because of a power black out available beam time is only 4.5 hours

LANSCE
Los Alamos Neutron Science Center

Weapons Neutron Research 24-Hour Beam History

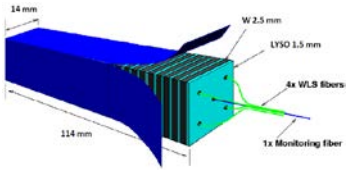


The Experimental Setup



Up to six crystals are hosted on a linear stage. Each crystal can be irradiated by 800 MeV protons in steps with its longitudinal transmittance measured *in situ.*

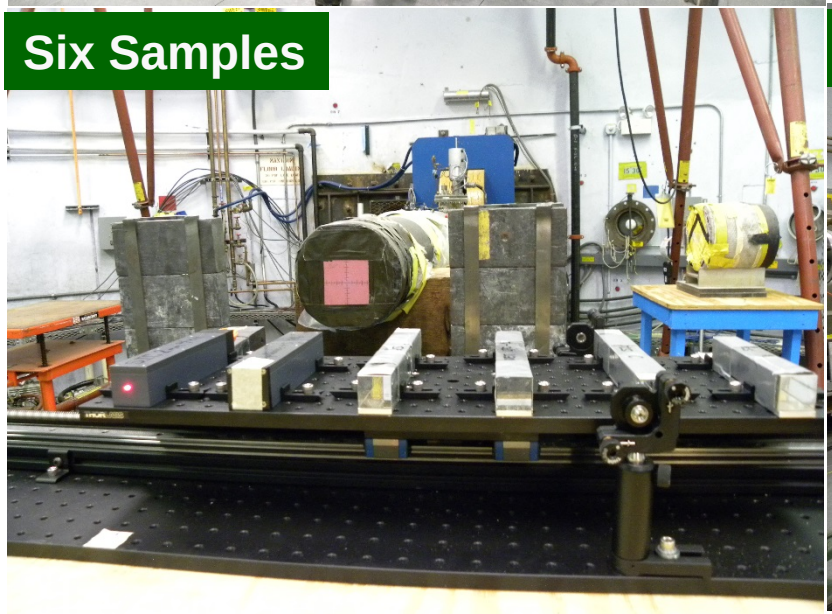
A Few Photos at Los Alamos



Liyuan & Ron

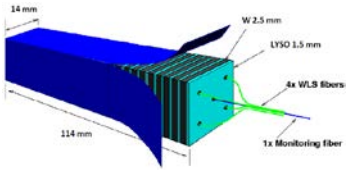
Liyuan & Jeff

Six Samples

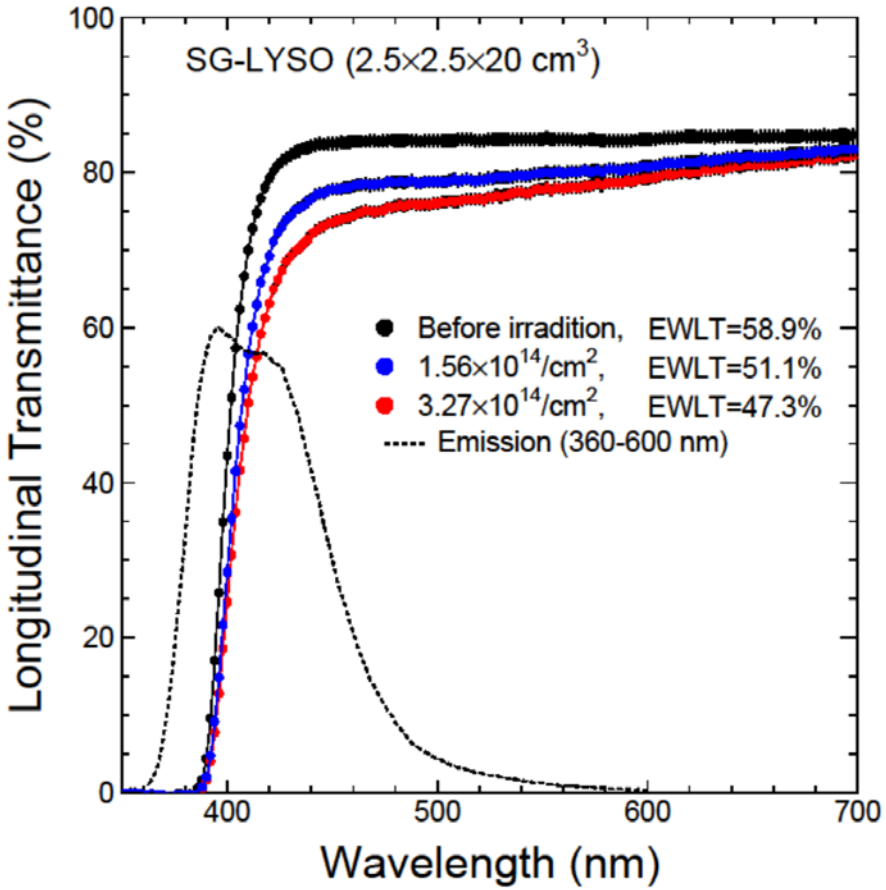


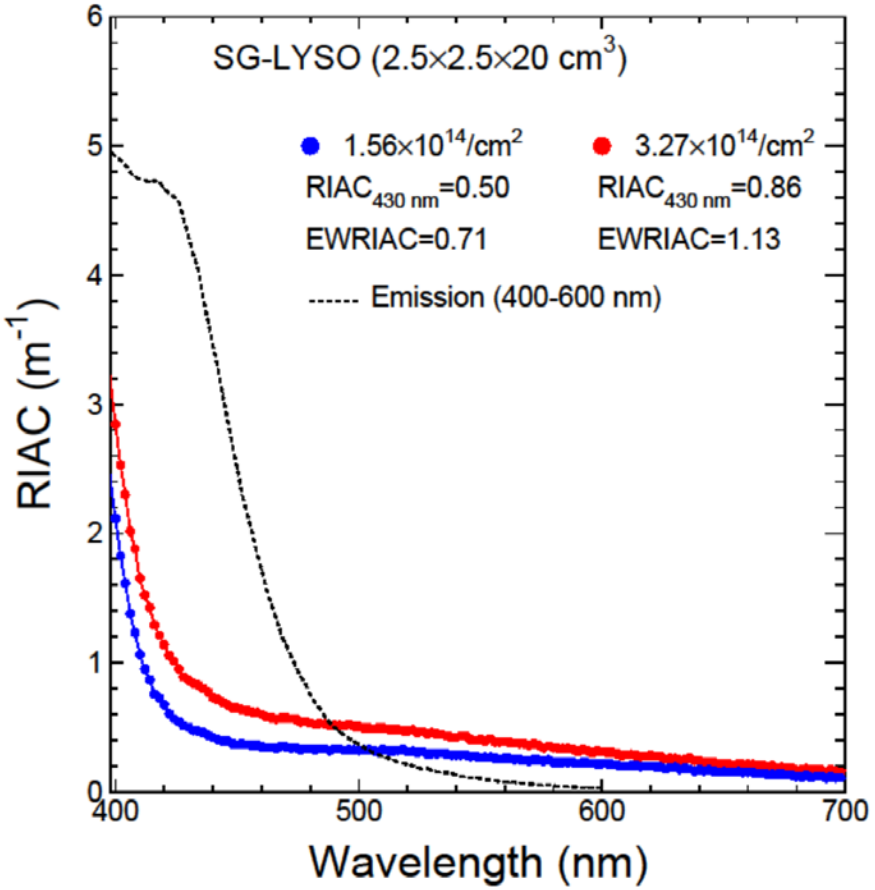
Well Protected

LYSO: LT Damage and RIAC



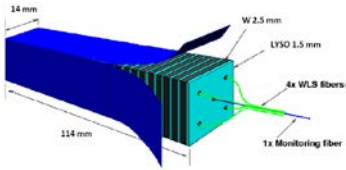
Emission weighted longitudinal transmittance (EWLT)
Emission weighted radiation induced absorption coefficient (EWRIAC)



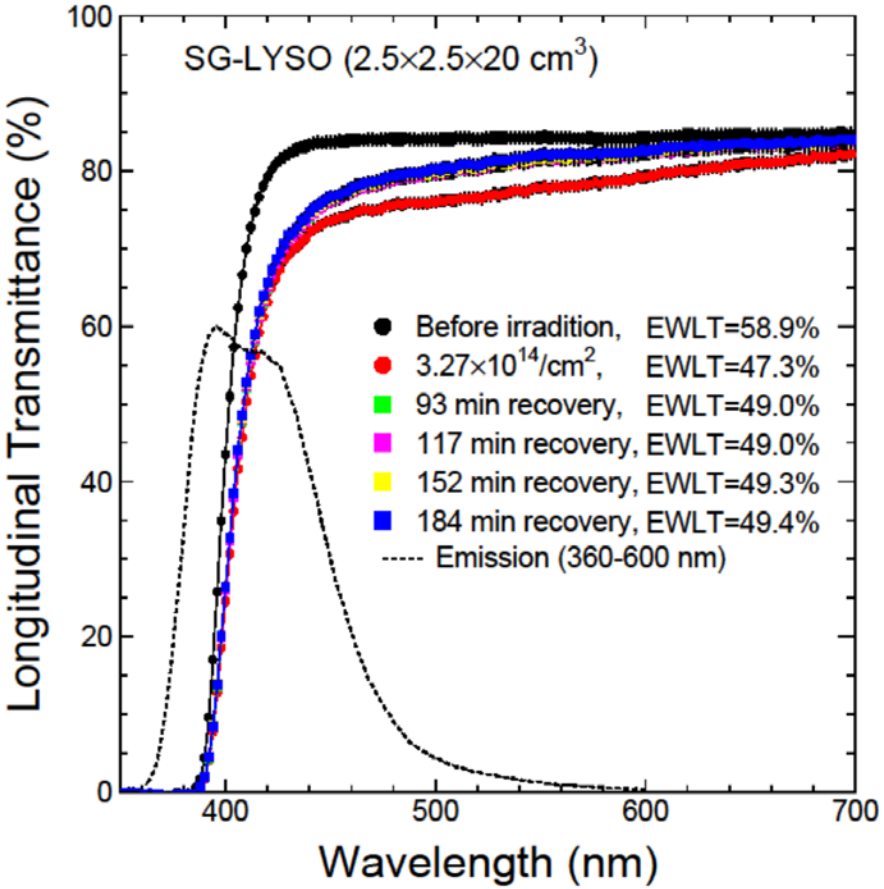


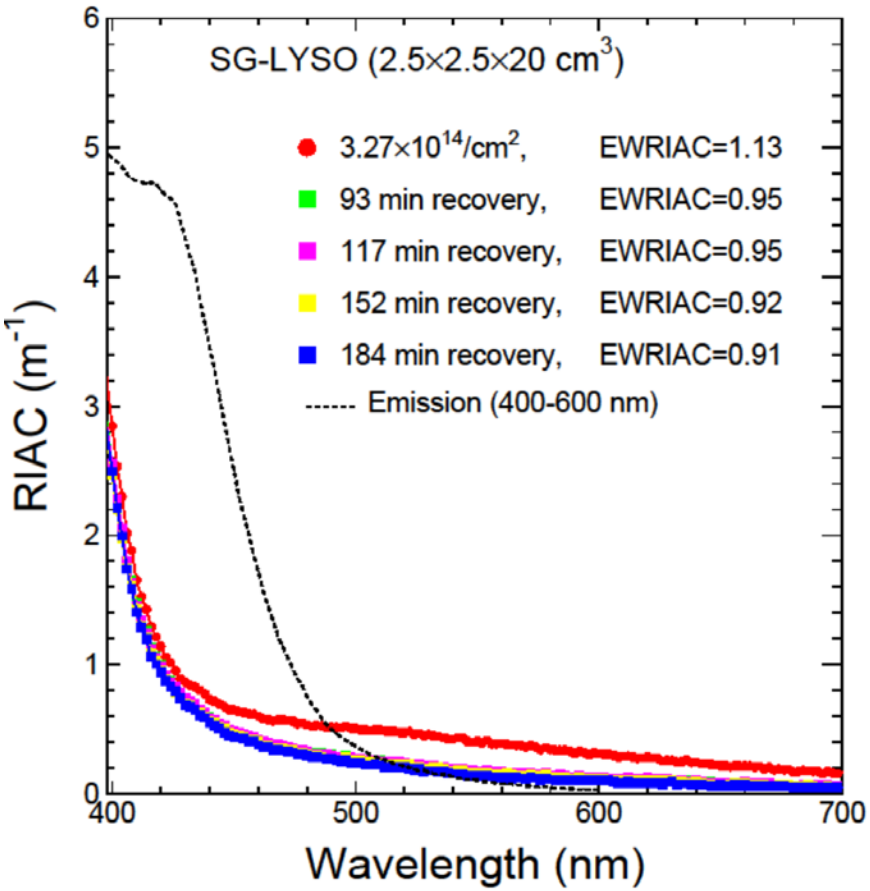
Use EWLT and EWRIAC is important for crystals with self-absorption

LYSO: Recovery of LT & RIAC

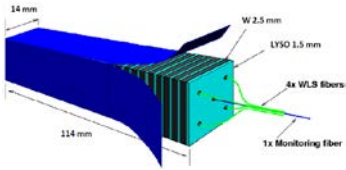


Transmittance spectra were measured after the CeF_3 irradiation





CeF_3: Recovery of LT & RIAC



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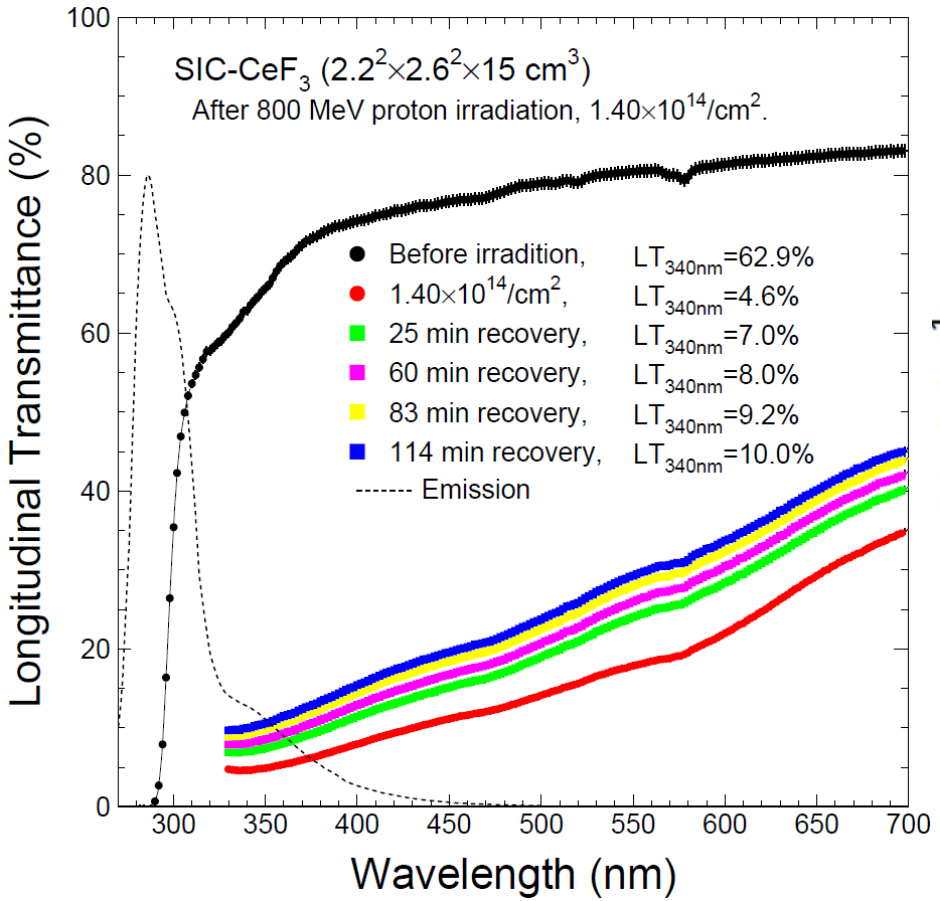
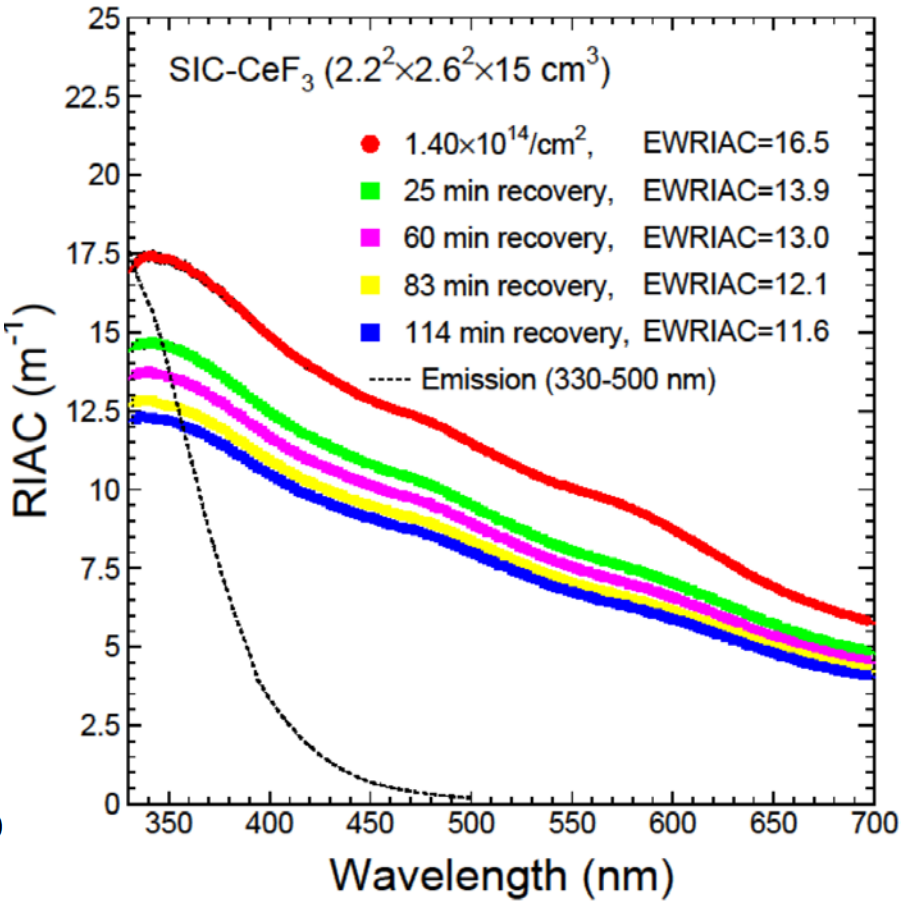
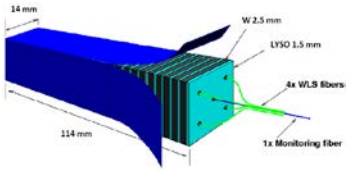


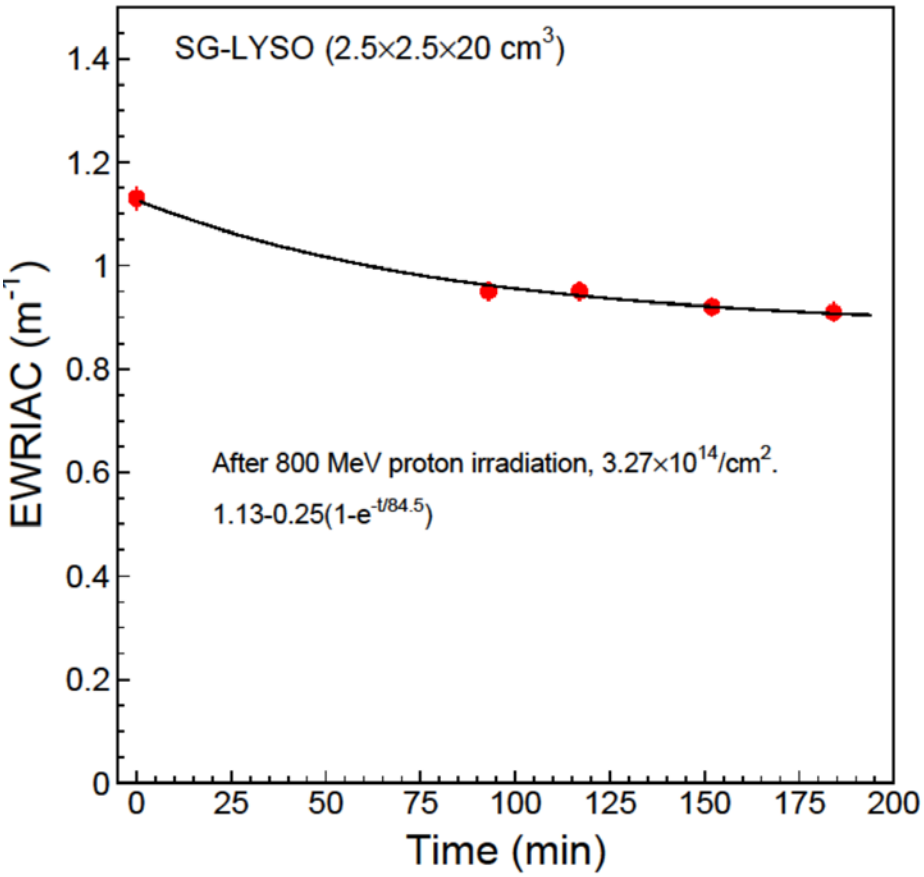


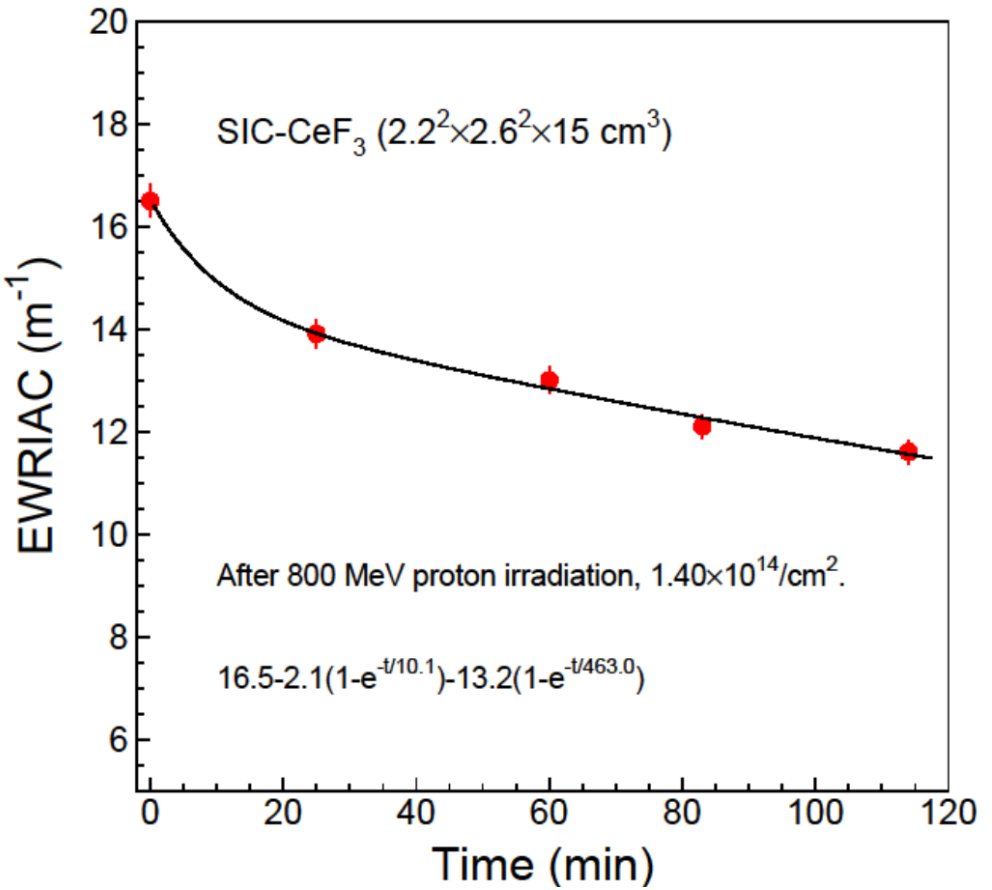
This CeF_3 sample is twenty years old. Need to test optimized crystal.

Recovery: LYSO and CeF_3

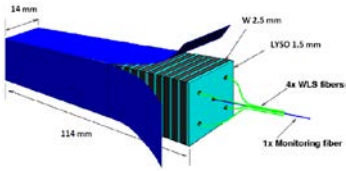


Small/large recovery observed for LYSO/CeF_3 respectively, caused by thermal relaxation and recovery of CeF_3.

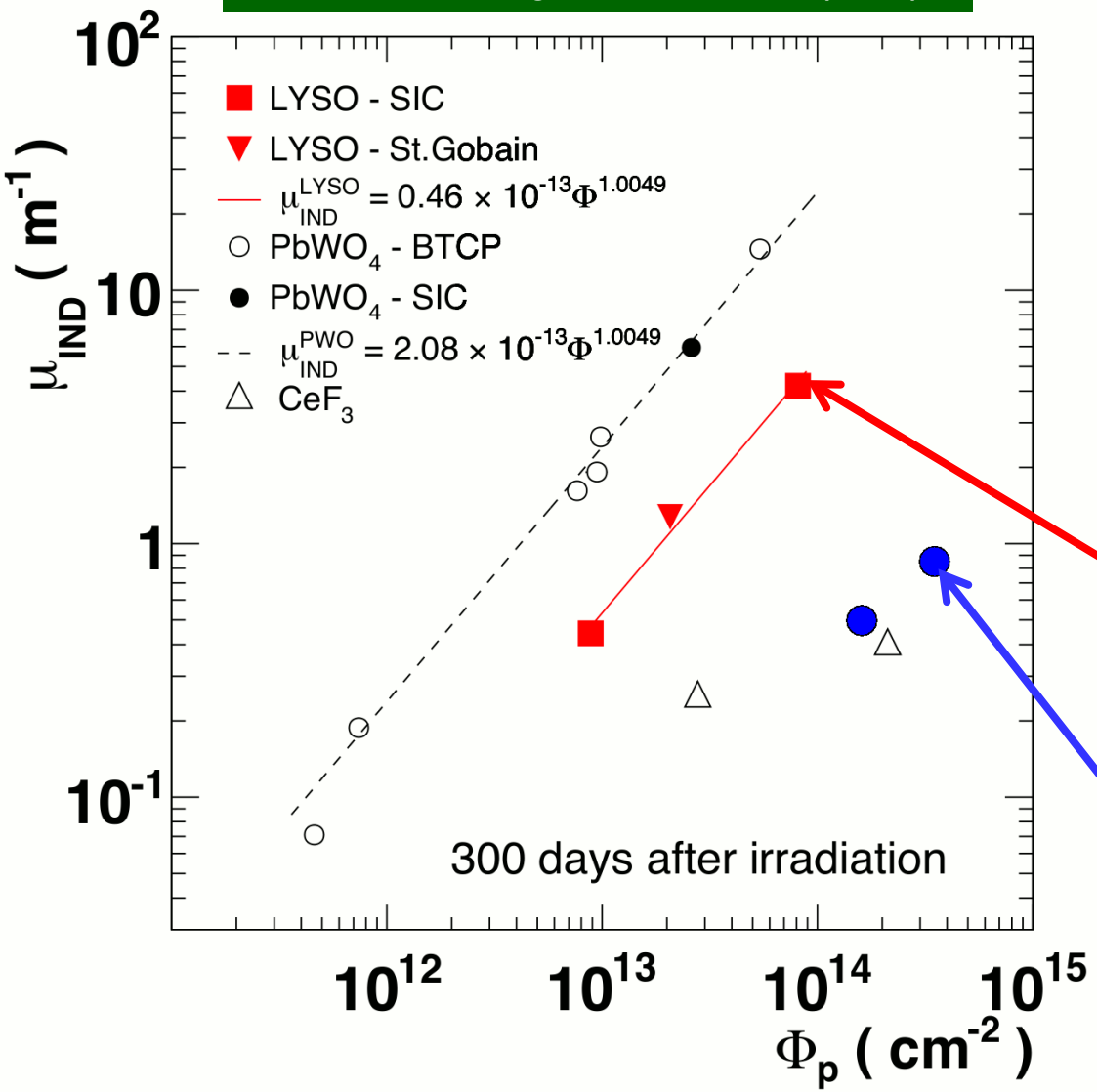




LYSO: A Comparison between Protons of 800 MeV and 24 GeV



Plot taken from Fig. 6 of NIM A 745 (2014) 1

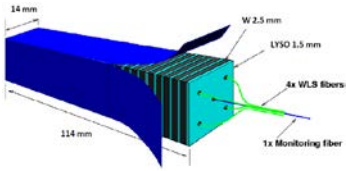


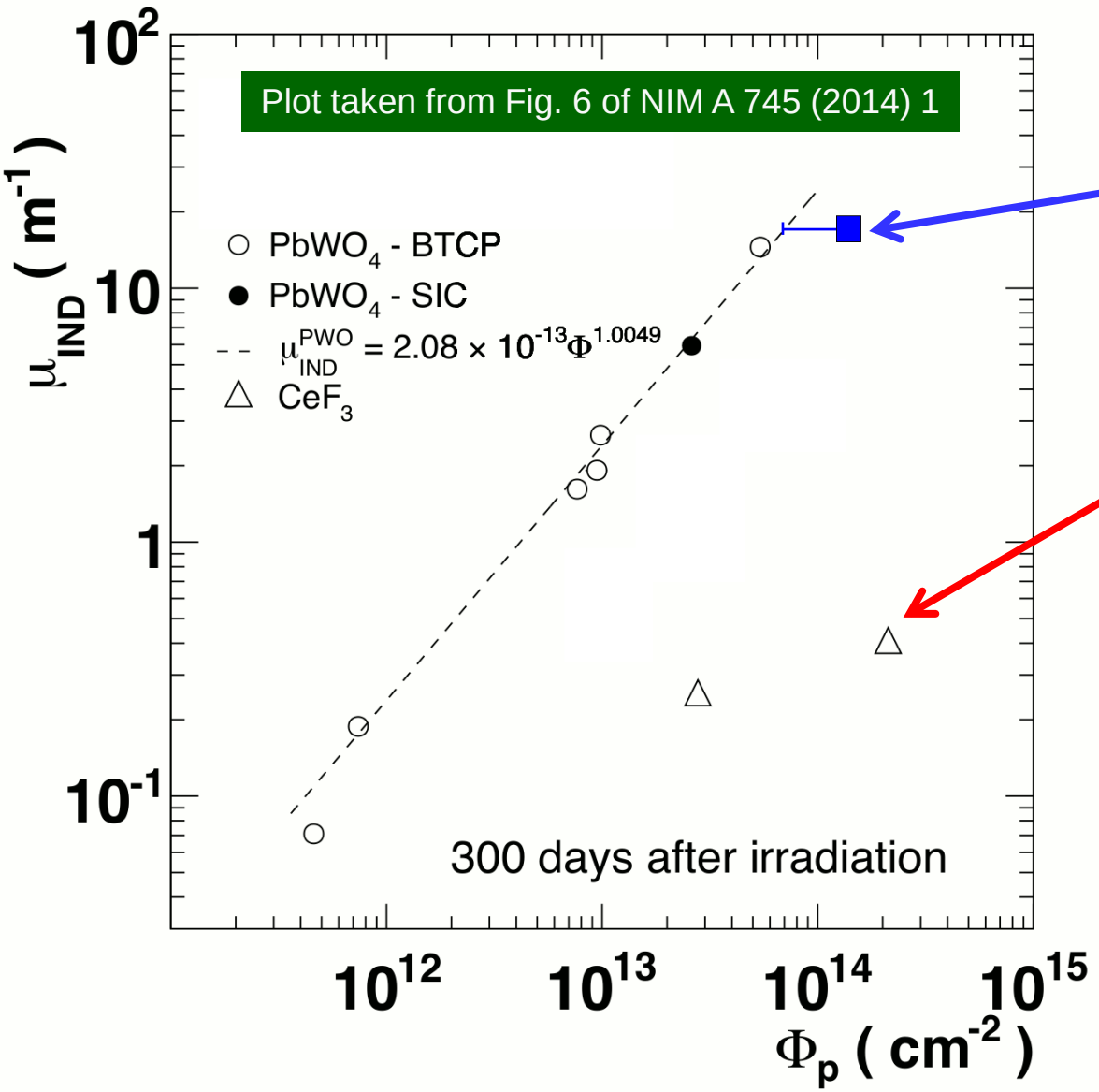
800 MeV proton induced radiation damage in LYSO (blue dots) is much smaller than 24 GeV data (red) reported by the ETH group. It seems caused by the different proton energies, indicating our estimation based on 24 GeV data is conservative.

10 cm long LYSO irradiated at CERN by 24 GeV protons

SG LYSO ($2.5 \times 2.5 \times 20$ cm^3) irradiated at LANL by 800 MeV protons

CeF_3: A Comparison between Protons of 800 MeV and 24 GeV



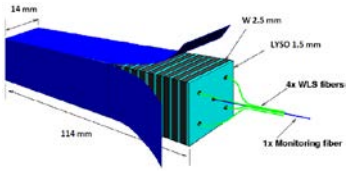


SIC CeF_3 ($2.2 \times 2.6 \times 15$ cm^3) irradiated at LANL by 800 MeV protons taken immediately after the irradiation

14 cm CeF_3 sample irradiated at CERN by 24 GeV protons

800 MeV proton induced radiation damage in CeF_3 (blue square) is much larger than 24 GeV data (open triangles). It seems caused by poor sample quality and the recovery since the later was taken after 300 days.

Summary



- An experimental setup was built for experiment 6501, which is used to measure crystal's transmittance *in situ*.
- Three samples (4 sealed capillaries & 3 Y-11, a LYSO and a CeF_3) were irradiated to the maximum expected fluence of about 3 x 10^{14} p/cm^2 by 800 MeV protons at Los Alamos.
- The results show that the emission weighted radiation induced absorption in a 20 cm long LYSO crystal is about 1 m^{-1} after 3.3 x 10^{14} p/cm^2, indicating excellent radiation hardness of LYSO against charged hadrons.
- The 800 MeV proton beam at the WNR facility of LANSCE is ideal for the investigation of charged hadron induced radiation damage in crystal scintillators. Additional runs are needed at Los Alamos in Fall, 2015, when the beam is expected to be available again, to irradiate various large size crystal scintillators, so that charged hadron induced radiation damage in crystal scintillators is understood.