Proton Induced Radiation Damage in Fast Inorganic Crystals

Chen Hu, Fan Yang, Liyuan Zhang, Ren-Yuan Zhu

California Institute of Technology

Jon Kapustinsky, Ron Nelson and Zhehui Wang

Los Alamos National Laboratory

Paper N-02-05 presented in NSS-MIC-2019 at Manchester, Oct. 28, 2019

Introduction

Future HEP experiments at the energy frontier (HL-LHC) faces a challenge of severe radiation by ionization dose, as well as charged and neutral hadrons

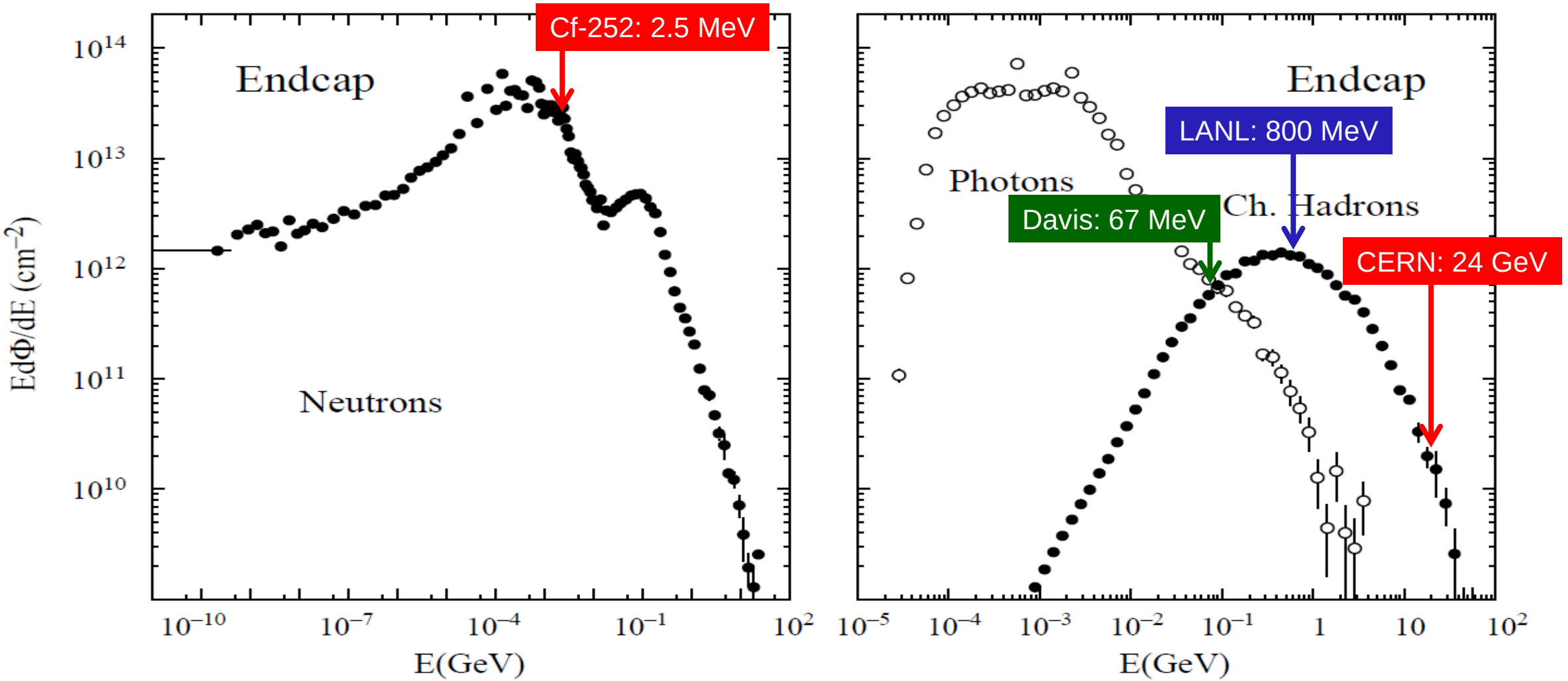
The 800 MeV proton beam at the Weapons Neutron Research facility of Los Alamos Neutron Science Center (WNR of LANSCE) is ideal for investigations on charged hadron induced radiation damage.

Three experiments 6501 (2014), 6990 (2015) and 7324(2017) were carried out at LANSCE. Inorganic crystals of various size were irradiated up to 3 x 10^{15} p/cm^2 with their longitudinal transmittance measured *in situ.* In addition, LYSO plates of up to 5 mm thick were also irradiated by 24 GeV protons at CERN up to 1.2 x 10^{15}/cm^2.

This report focuses on results of LYSO and BaF_2 crystals for future HEP experiments at the energy and intensity frontiers.

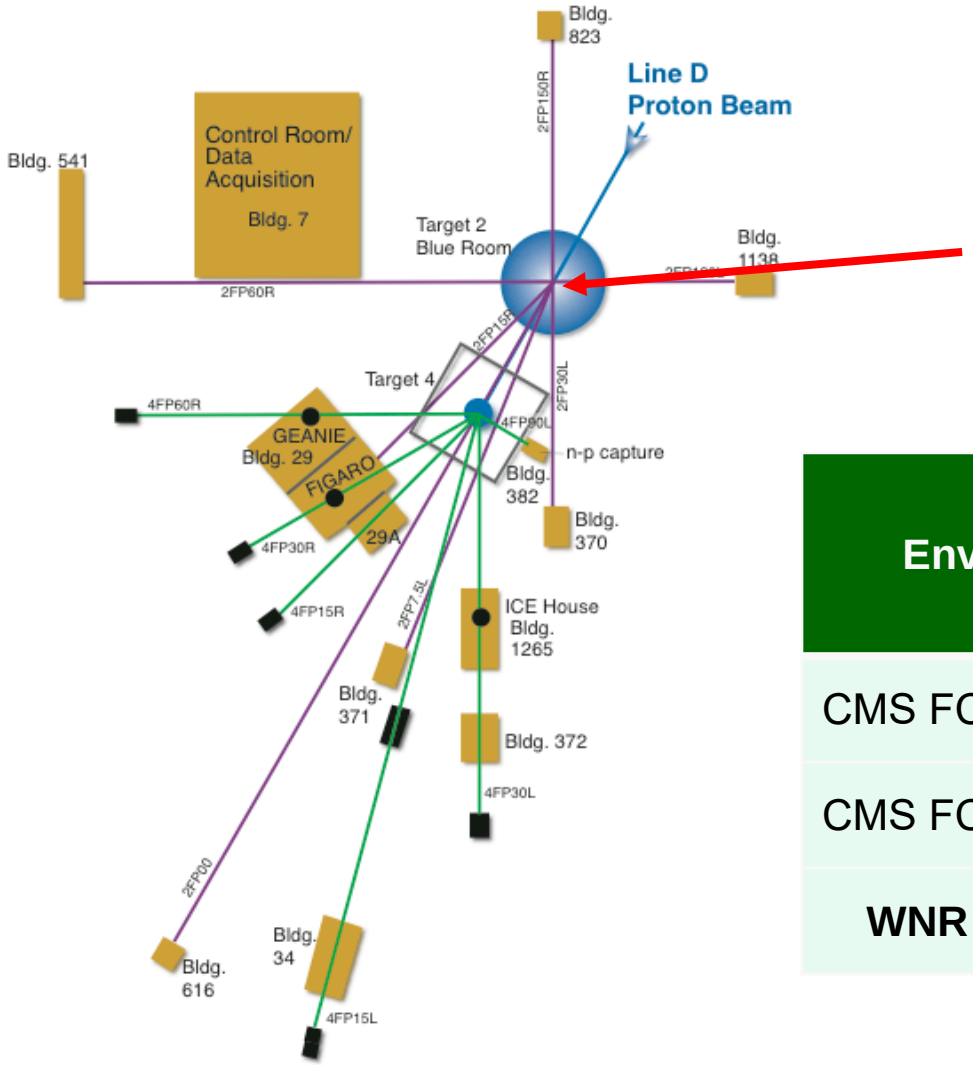
Energy Spectra Expected at HL-LHC

FLUKA simulations: charged hadrons and neutrons are peaked at hundreds MeV and MeV respectively
Proton and neutron (Paper N21-6) induced damages are investigated at Blue Room and East Port of LANSCE



Proton Irradiation at LANSCE

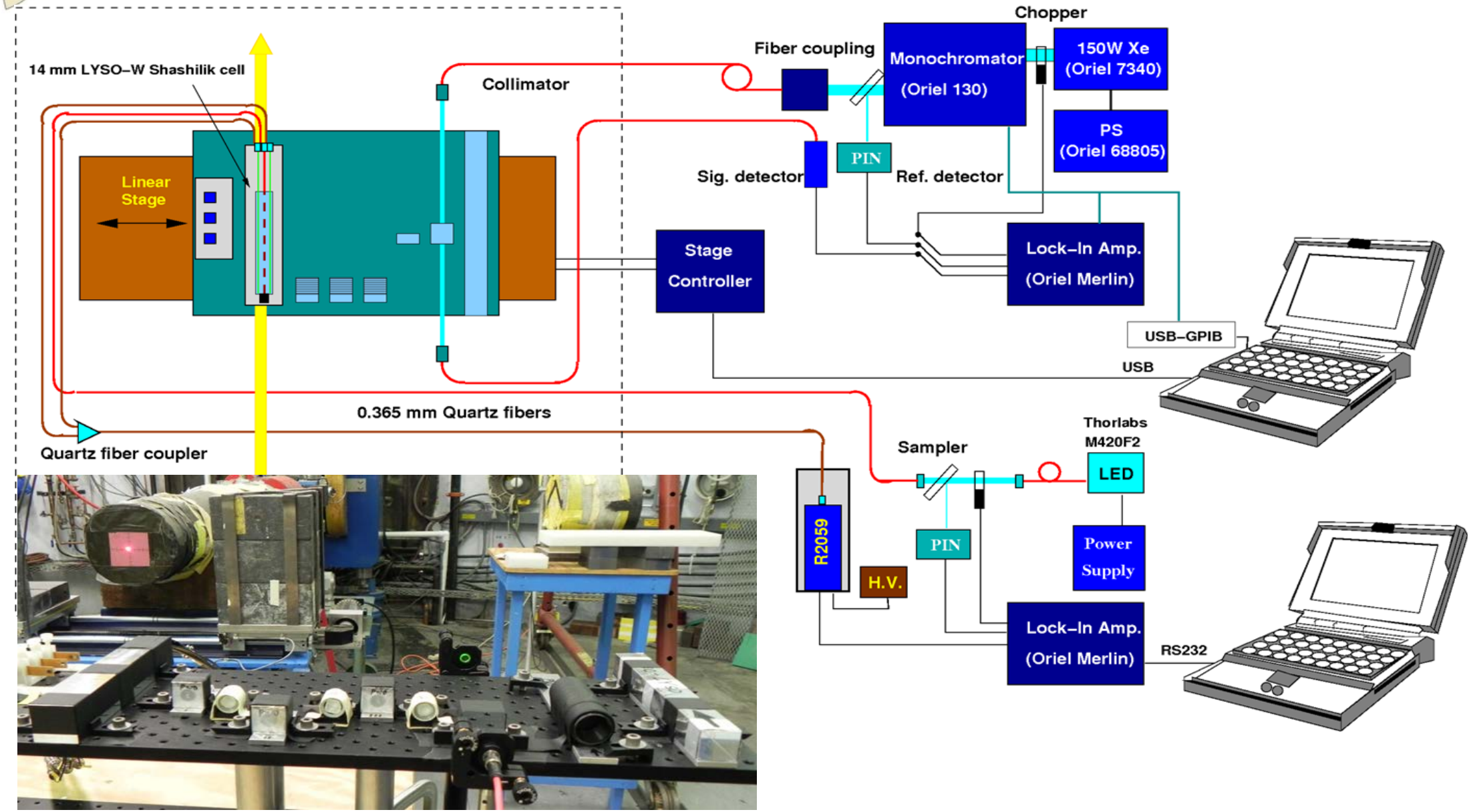
Los Alamos Neutron Science Center (LANSCE)



800 MeV proton beam (FWHM= 2.5 cm)

Environment/Source	Proton Flux ($p\ s^{-1}\ cm^{-2}$)	Fluence on Crystal ($p\ cm^{-2}$)
CMS FCAL (η=1.4) at HL-LHC	2.8×10^{5}	2.5×10^{13} / 3000 fb^{-1}
CMS FCAL (η=3.0) at HL-LHC	2.3×10^{6}	2.1×10^{14} / 3000 fb^{-1}
WNR facility of LANSCE	**Up to 2×10^{10}**	**Up to 3×10^{15}**

Setup for Experiment 7324

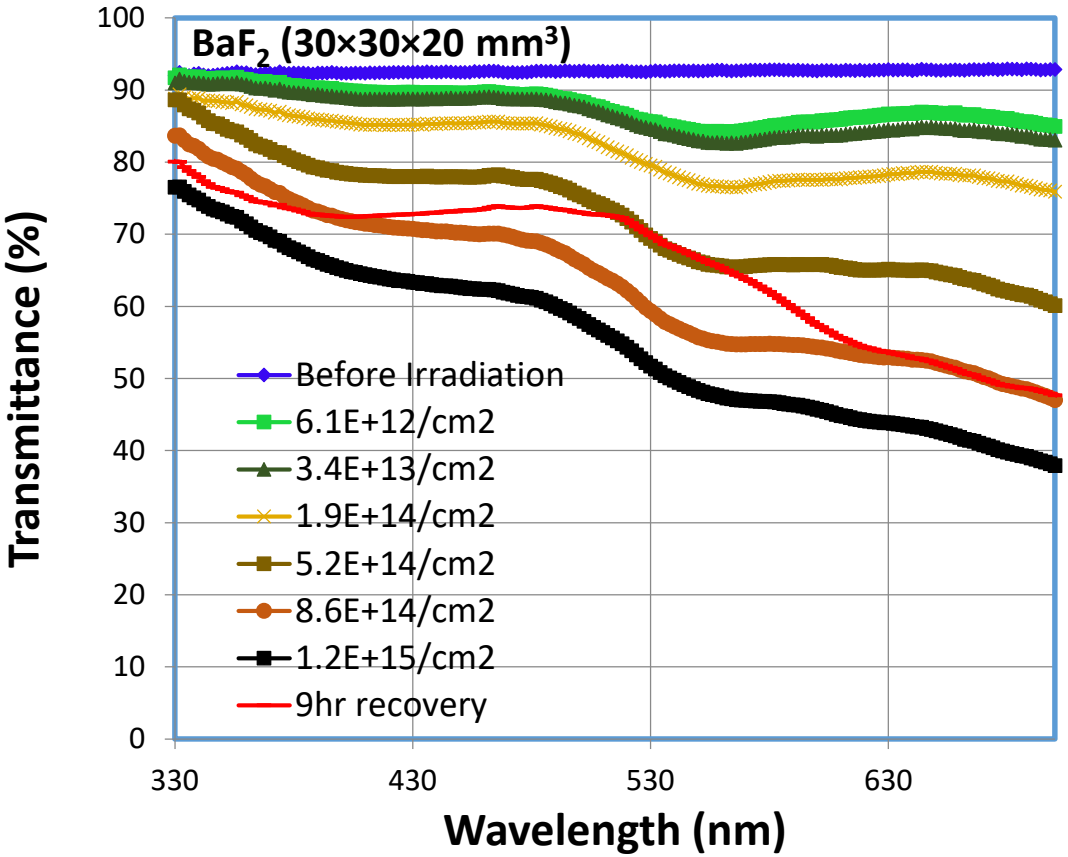


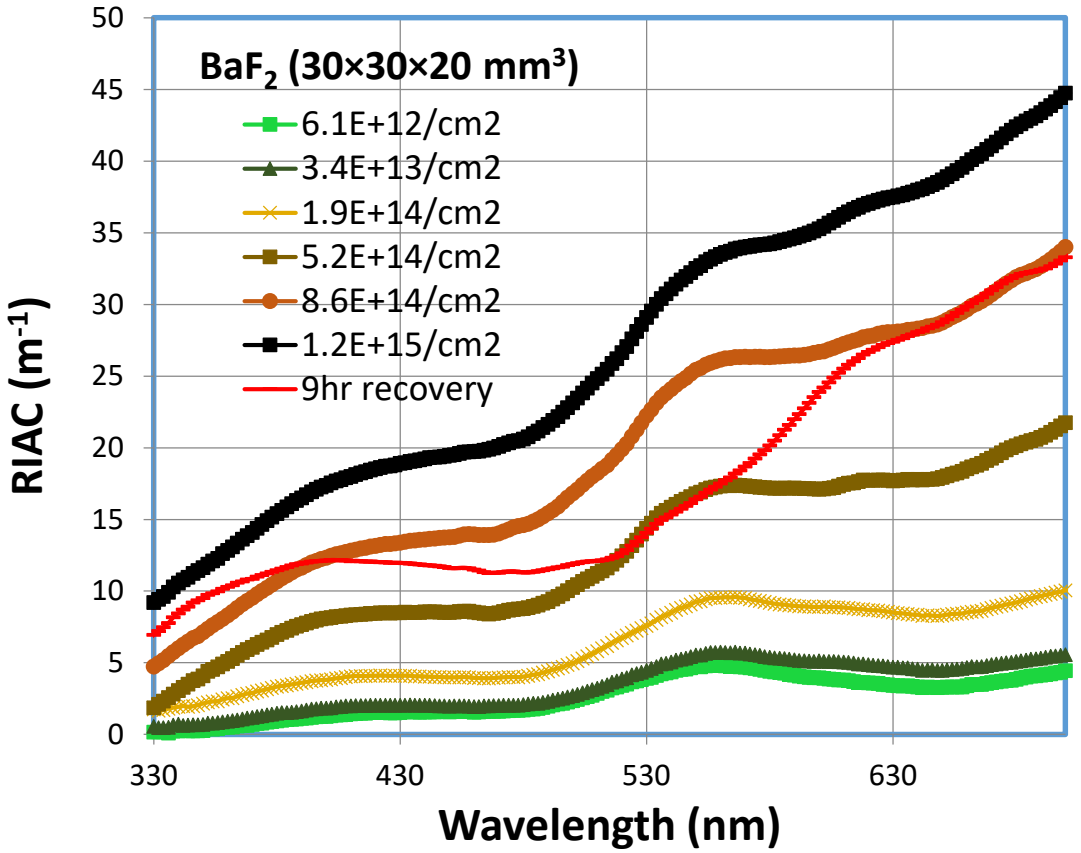
Samples and 800 MeV Proton Fluence

No.	Samples	Dimensions (mm^3)	Fluence (p/cm^2)	Experiment
1	BaF_2	30×30×20	6.1×10^{12} – 1.2×10^{15}	7324
2	BaF_2	30×30×20	2.9×10^{14}	6990
3	BGO	25×25×200	1.8×10^{14}	6990
4	BGO	17×17×17	2.9×10^{14}	6990
5	SIC LYSO	25×25×200	5.0×10^{13} - 3.0×10^{15}	7324
6	LFS	25×25×180	1.8×10^{14} – 2.9×10^{15}	6990
7	SG LYSO	25×25×200	1.6×10^{14} - 3.3×10^{14}	6501
8	Shashlik (LFS/W/Capillary)	34×34×215	1.2×10^{15} – 1.9×10^{15}	6990 and 7324
9	PWO	25×25×5	4.4×10^{12} – 1.2×10^{15}	7324
10	PWO	$28.5^2\times30^2\times220$	1.8×10^{14}	6990
11	2×PWOs, 2×BaF_2	25×25×5	2.7×10^{13}	7324
	3×LYSO	10×10×3		
12	2×PWOs, 2×BaF_2	25×25×5	1.6×10^{14}	7324
	3×LYSO	10×10×3		
13	2×PWOs, 2×BaF_2	25×25×5	9.7×10^{14}	7324
	3×LYSO	10×10×3		

BaF_2: LT Damage and RIAC

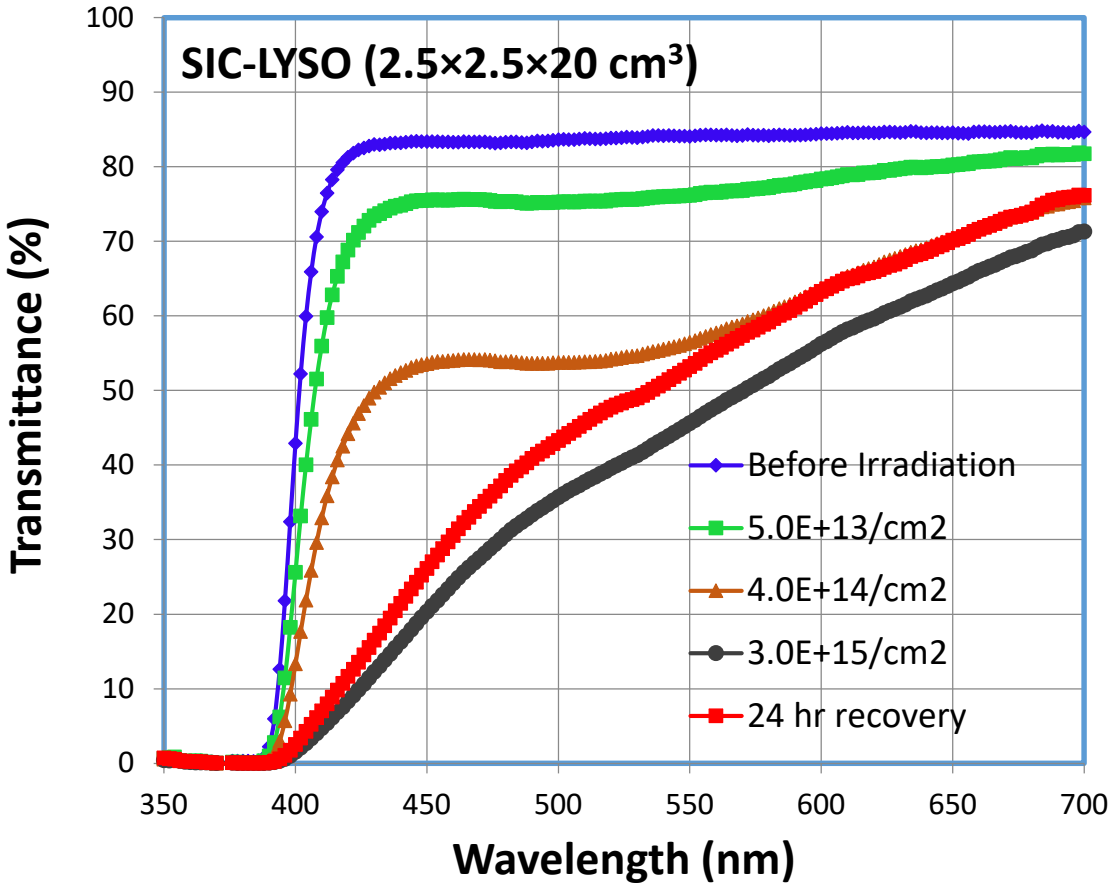
A 2 cm Hellma BaF_2 was irradiated from 6.1×10^{12} to 1.2×10^{15} p/cm^2 in six steps with transmittance between 330 and 650 nm measured *in-situ, and was later* measured at Caltech between 200 and 650 nm with consistent result, indicating a promising radiation hardness for its fast component.

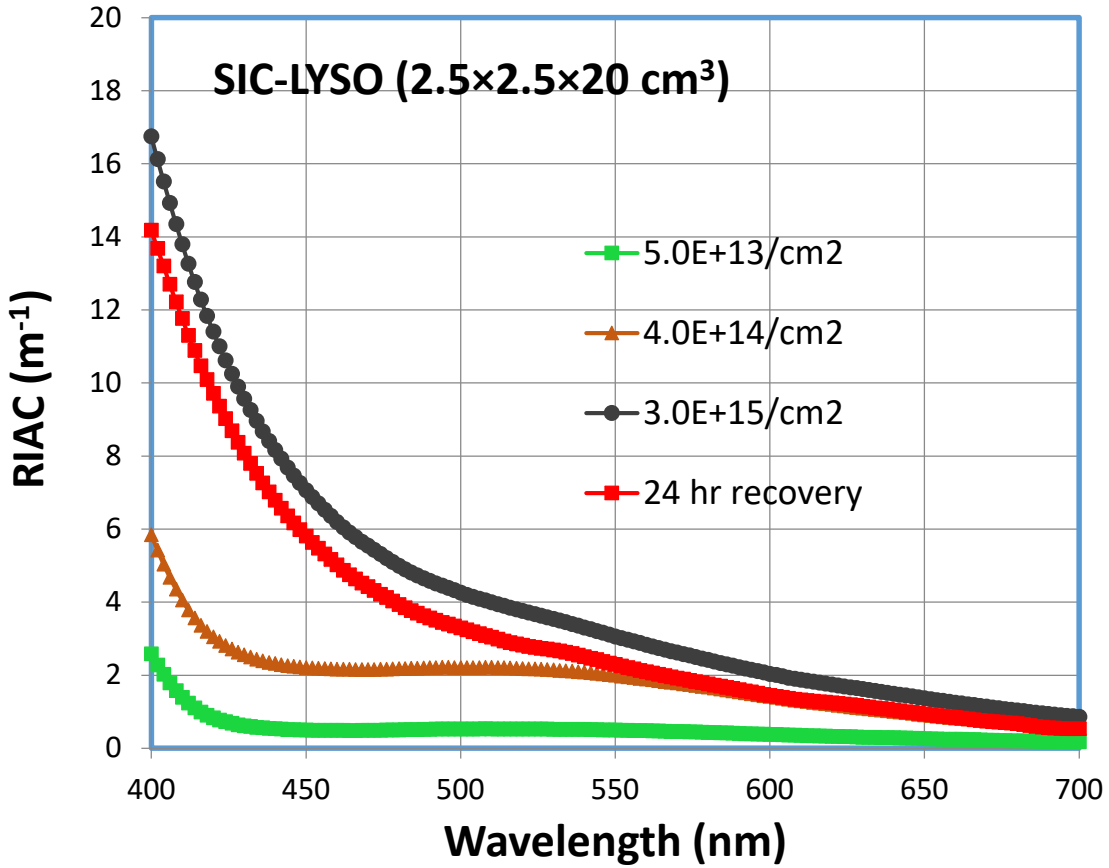




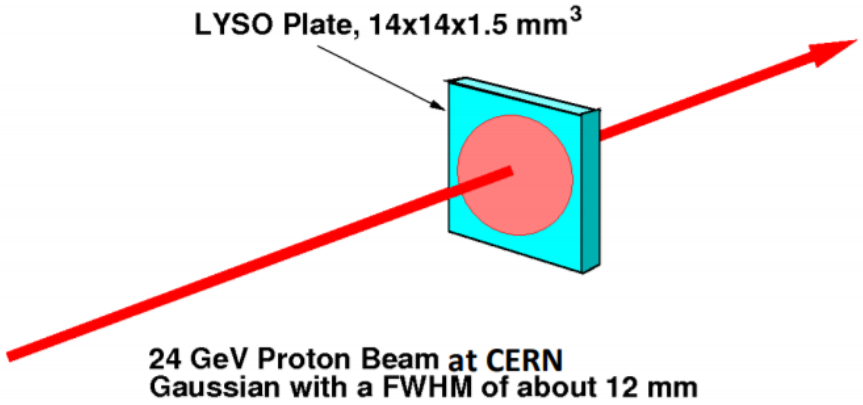
LYSO: LT Damage and RIAC

In Exp-7324, a 20 cm long SIC-LYSO was irradiated from 5.0×10^{13} to 3.0×10^{15} p/cm^2 with longitudinal transmittance measured *in-situ,* showing inferred absorption coefficient consistent with 20 cm long SG-LYSO (Exp-6501, 2014) and 20 cm long LFS (Exp-6990, 2015).





Proton IR Experiment at CERN



3 batches of samples were irradiated by proton at CERN. The proton fluences were measured by dosimeters with dimension of 10×10 and 20×20 mm^3 respectively for each batch.

Data from CERN: http://ps-irrad.web.cern.ch/documents/run2017/Sets-2017.html

Set	Requested Fluence	Delta SEC	Date In	Date Out	Dosimeter	Fluence (p/cm²)	Error (± %)	Comment
3000-3006	4.00E+13 p/cm²	3.02E+07	20/11/2017 10:00	20/11/2017 14:13	3736	**7.46E+13**	7.0	10x10
		3.02E+07	20/11/2017 10:00	20/11/2017 14:13	3740	**5.64E+13**	7.0	20x20
3006-3013	2.00E+14 p/cm²	1.52E+08	18/11/2017 19:33	20/11/2017 09:59	3737	**3.75E+14**	7.0	10x10
		1.52E+08	18/11/2017 19:33	20/11/2017 09:59	3739	**2.83E+14**	7.0	20x20
3014-3020	1.00E+15 p/cm²	1.80E+08	08/11/2017 18:34	18/11/2017 19:33	3735 /3745/3751	**1.27E+15**	7.0	10x10
		2.36E+08	08/11/2017 18:34	18/11/2017 19:33	3738/3758	**1.09E+15**	7.0	20x20

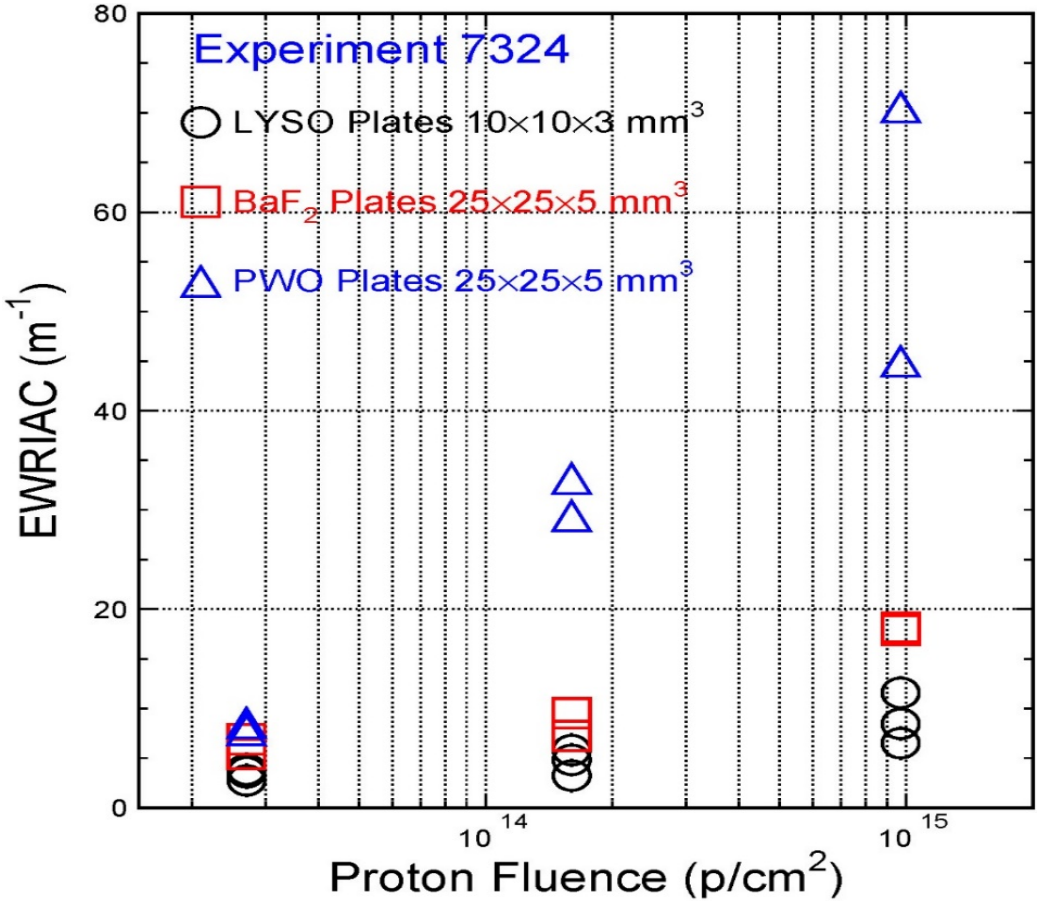
Sample list for Proton IR at CERN

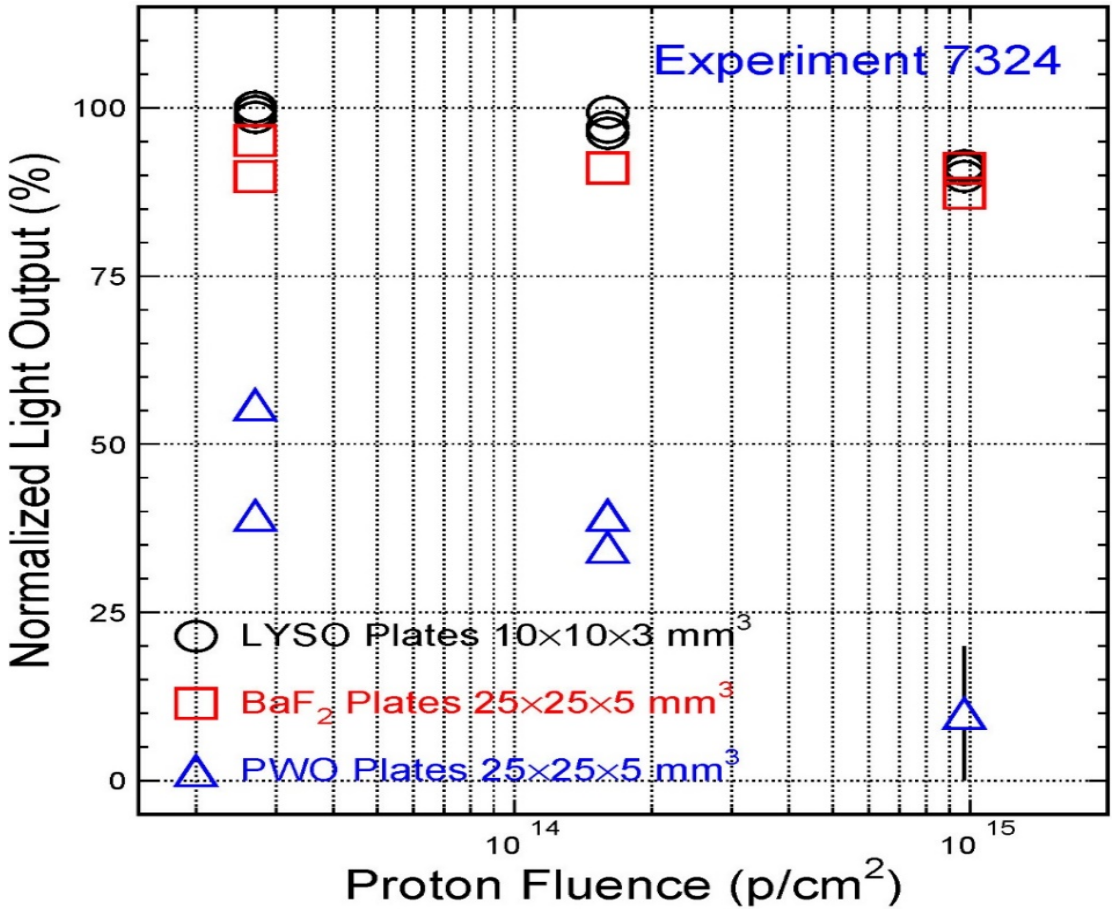
The fluence values were calculated based on samples cross section

Group	Samples	Vendor	Dimensions (mm^3)	Quantity	SN	Mark	CERN ID	Fluence	Date
1	BaF_2:Y/BaF_2	BGRI	10×10×5	2	BU1/BY1	BU1, BY1	3000/3001	**7.46E+13**	11/20
		SIC	10×10×5	2	Y5-1/U5-1	Y1, U1	3002/3003	**7.46E+13**	11/20
	LYSO:Ce,Ca	SIC	20x20x 2	1	170809-6	6	3004	**5.64E+13**	11/20
		Tianle	10×10×1.5	1	B3	B3	3005	**7.46E+13**	11/20
	LuAG:Ce	SIC	Φ14×1	1	G4	G4	3006	**7.13E+13**	11/20
	Total			**7**					
2	BaF_2:Y/BaF_2	BGRI	10×10×5	2	BU2/BY2	BU2, BY2	3007/3008	**3.75E+14**	11/18
		SIC	10×10×5	2	Y5-2/U5-2	Y2, U2	3009/3010	**3.75E+14**	11/18
	LYSO:Ce,Ca	SIC	20×20×2	1	170809-5	5	3011	**2.83E+14**	11/18
		Tianle	10×10×1.5	1	B9	B9	3012	**3.75E+14**	11/18
	LuAG:Ce	SIC	Φ14×1	1	G5	G5	3013	**3.58E+14**	11/18
	Total			**7**					
3	BaF_2:Y/BaF_2	BGRI	10×10×5	2	BU3/BY3	BU3, BY3	3014/3015	**1.27E+15**	11/8
		SIC	10×10×5	2	Y5-3/U5-3	Y3, U3	3016/3017	**1.27E+15**	11/8
	LYSO:Ce,Ca	SIC	20x20x2	1	170809-7	7	3018	**1.09E+15**	11/8
		Tianle	10×10×1.5	1	B10	B10	3019	**1.27E+15**	11/8
	LuAG:Ce	SIC	Φ14×1	1	G6	G6	3020	**1.24E+15**	11/8
	Total			**7**					
	Grant Total			**21**					

EWRIAC and Light Output Loss

LYSO and BaF_2 plates show low EWRIAC and 85% light output after 10^{15} p/cm^2, indicating excellent radiation hardness against protons

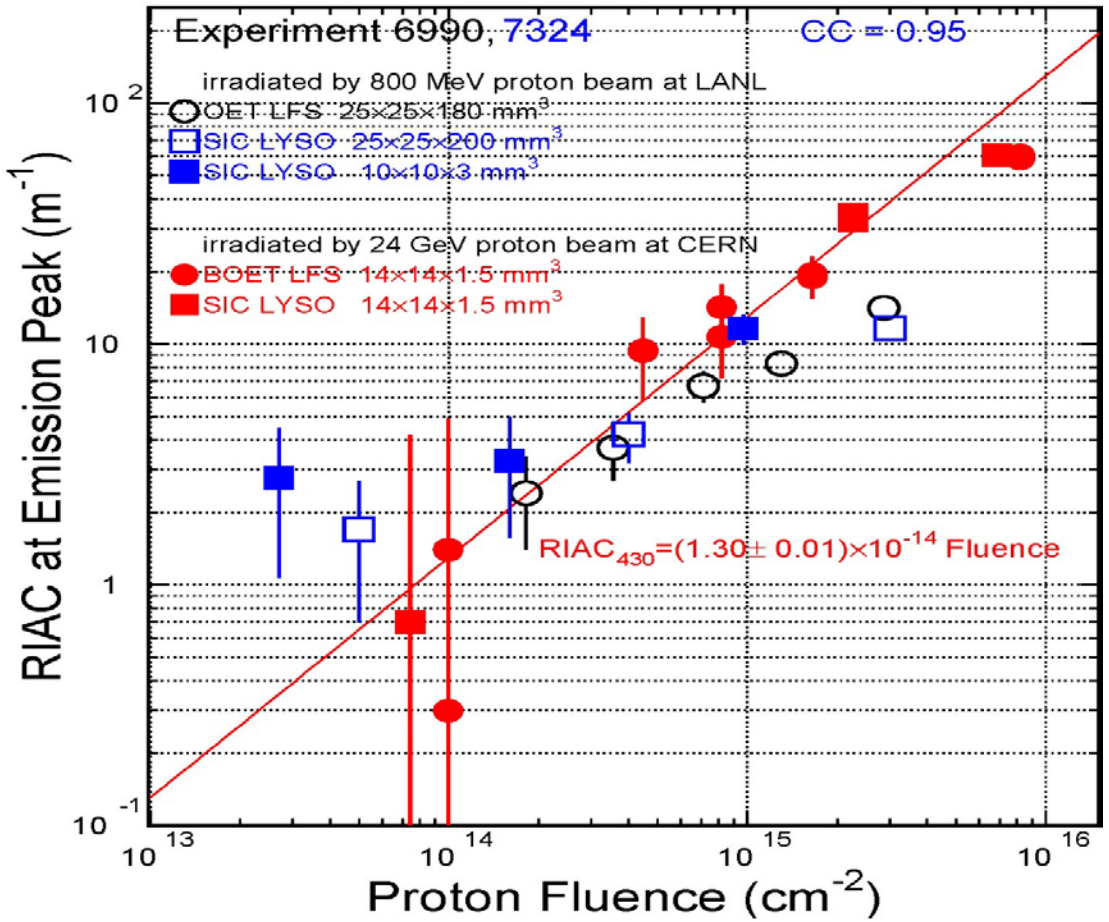


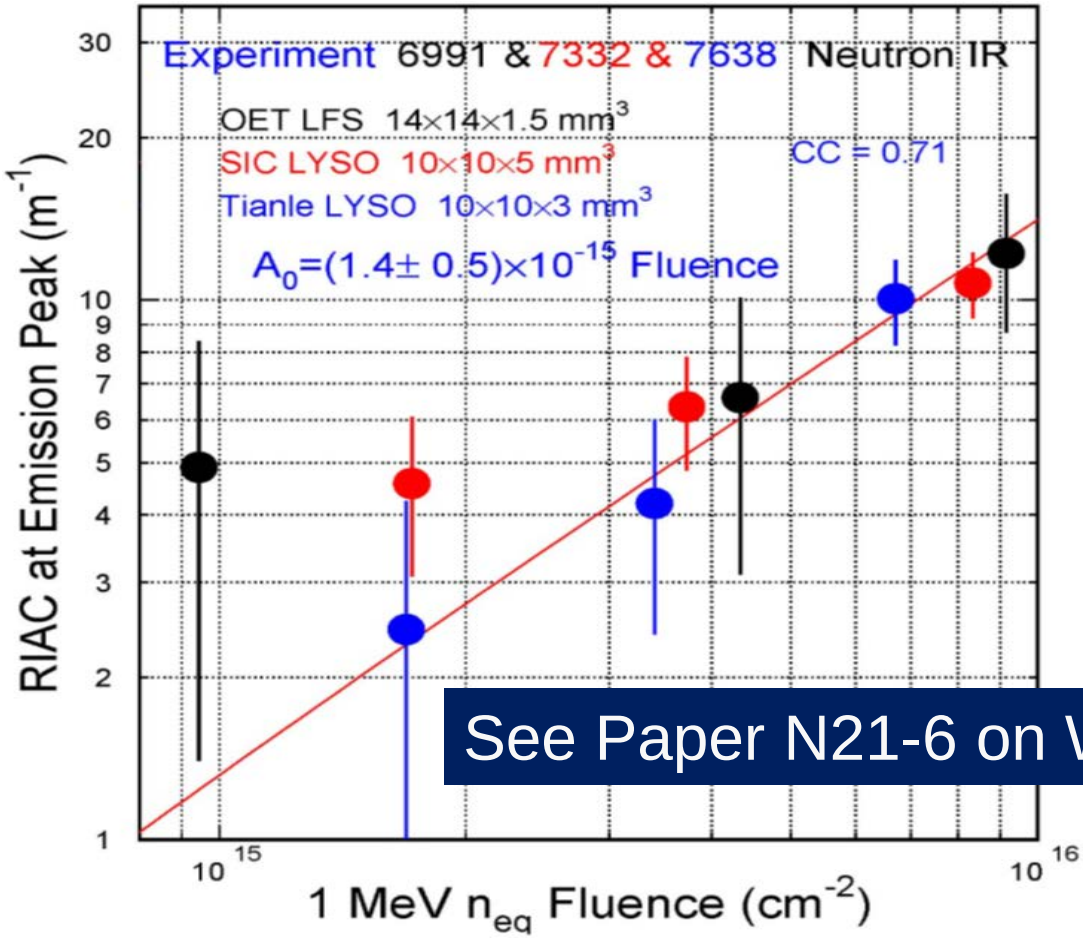


C. Hu, F. Yang, L. Zhang, *et al.*, *IEEE Trans. Nucl. Sci.* vol. 65, pp. 1018-1024 (2018)

Proton and Neutron Induced RIAC in LYSO

LYSO crystals from different vendors show consistent damage for protons of 800 MeV and 24 GeV: RIAC @ 430 nm = 1.3 x 10^{-14} F_p

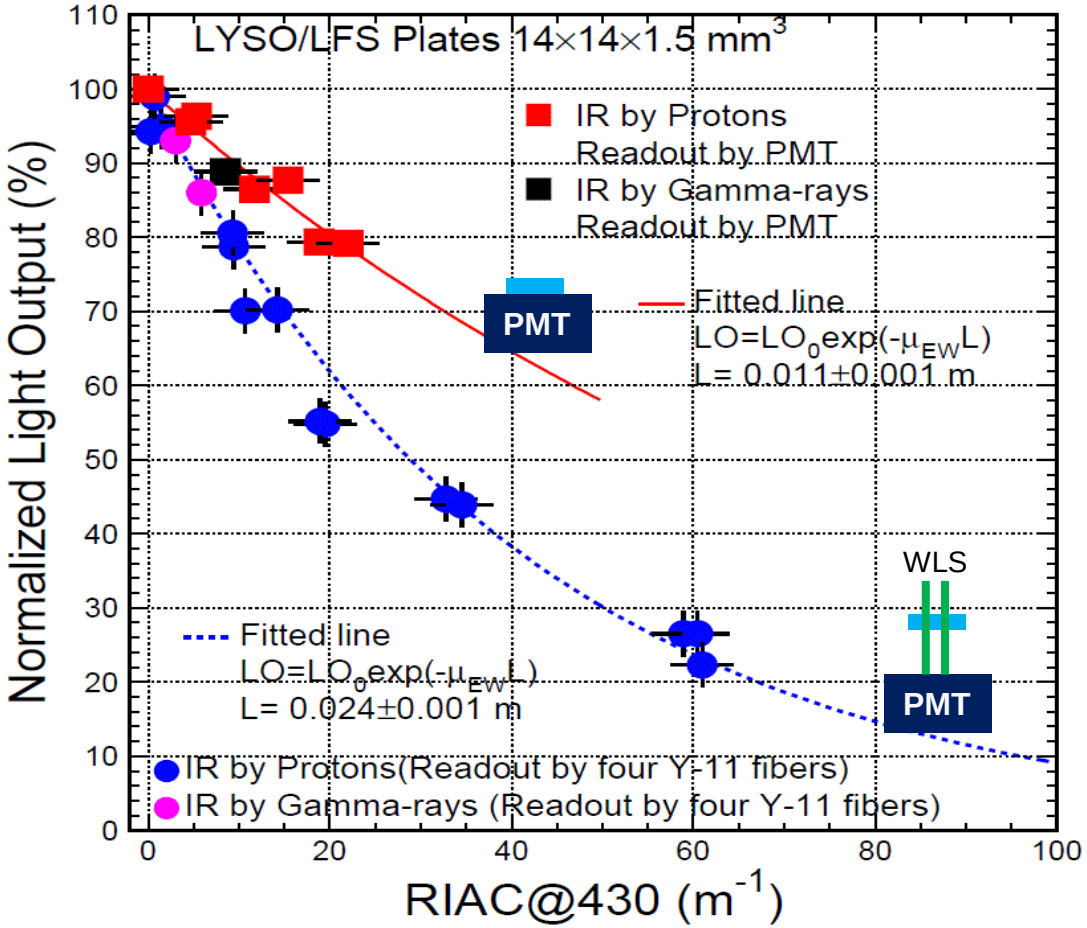


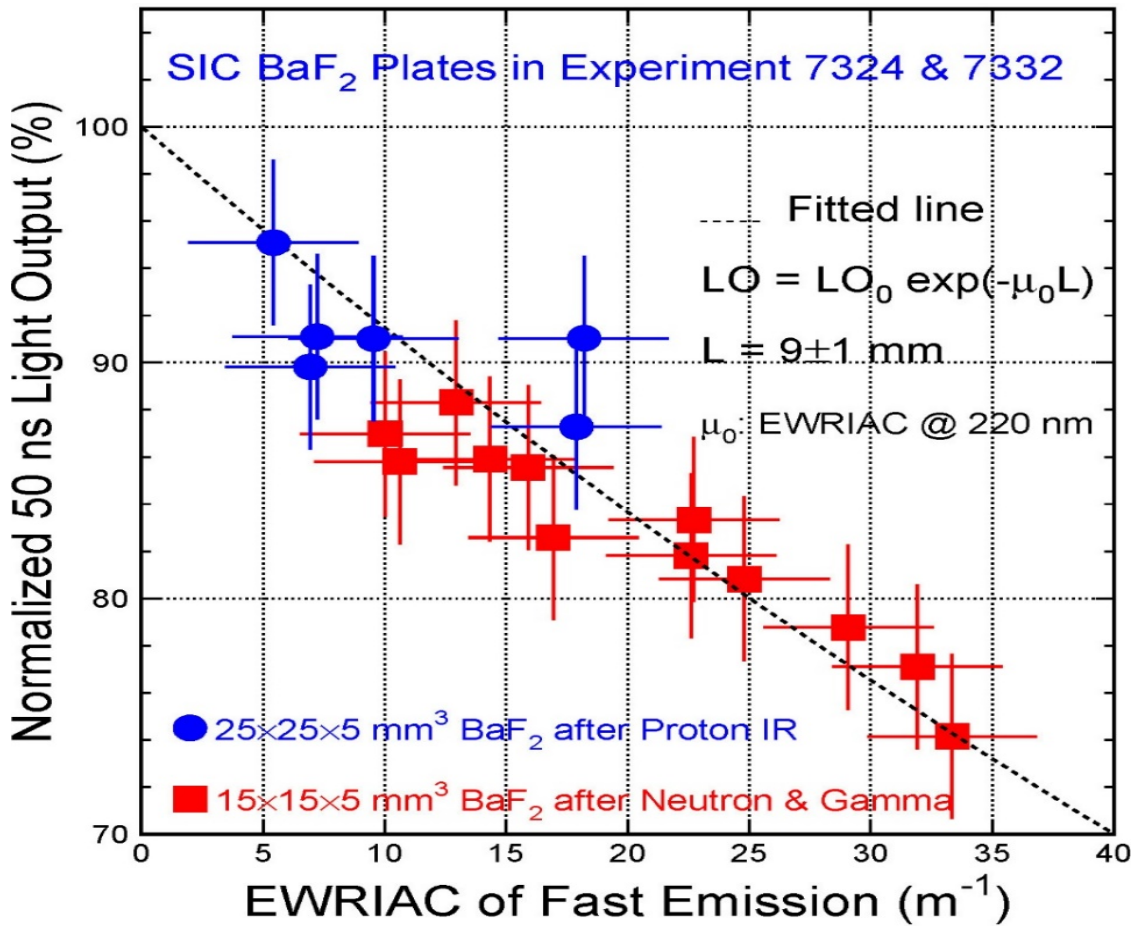


See Paper N21-6 on Wed

LO versus RIAC

LYSO and BaF_2 crystals irradiated by protons show consistent correlation with RIAC values for samples irradiated by gamma and neutrons, indicating proton induced LO loss can be corrected by a precision monitoring system.





Summary

Fast crystal scintillators were irradiated by 800 MeV and 24 GeV protons at LANL and CERN respectively. LYSO and BaF_2 show good radiation hardness.

LYSO crystals from different vendors show consistent damage: RIAC @ 430 nm = 1.3 x 10^{-14} Fp for protons of 800 MeV and 24 GeV. It is chosen to construct CMS BTL for the HL-LHC.

BaF_2 show similar radiation hardness to LYSO at high fluence. Works are needed for further understanding BaF_2:Y crystals.

Investigations will continue to compare damage in various inorganic crystal scintillators induced by ionization dose, protons and neutrons.

Acknowledgements

Drs. David Bailleux and Federico Ravotti helped proton irradiation at the CERN IRRAD facility.

This work was supported in part by the US Department of Energy Grants DE-SC0011925 and DE-AC52-06NA25396.