Proton-Induced Radiation Damage in LYSO and BaF_2 Crystals

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***Abstract*– One crucial issue of using inorganic scintillators in future high energy physics experiments is radiation damage in severe environment. The high-luminosity large hadron collider, for example, will present an environment, where up to 130 Mrad ionization dose, 3×10^{14} charged hadrons/cm^2 and 5×10^{15} neutrons/cm^2 are expected. We report results of proton-induced radiation damage in LYSO and BaF_2 crystals. Crystals from various vendors were irradiated up to 3×10^{15} p/cm^2 by 800 MeV protons at LANSCE and up to 8×10^{15} p/cm^2 by 24 GeV protons at CERN. The results show that LYSO and BaF_2 crystals are radiation hard against charged hadrons.**

I. Introduction

FUTURE high energy physics (HEP) experiments at the energy frontier, such as the High-Luminosity Large Hadron Collider (HL-LHC) faces a challenge of severe radiation environment by ionization dose and hadrons. While radiation damage induced by ionization dose was well studied, damage induced by hadrons, including both charged hadrons and neutrons, are still under investigation. Fig.1 shows the photon and proton energy spectra expected at the HL-LHC from FLUKA simulation [1]. While the photon energy is peaked between 200 keV to 2 MeV, the charged hadrons are peaked at several hundred MeV. The 800 MeV proton beam at the Los Alamos Neutron Science Center (LANSCE) thus is ideal for investigations on charged hadron induced radiation damage.

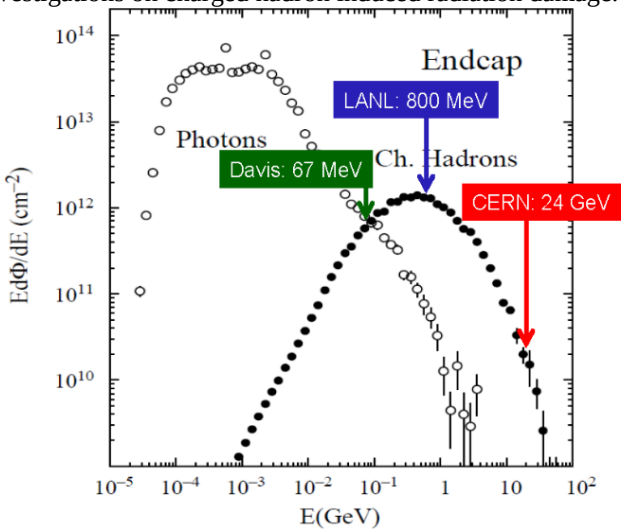

Fig. 1. Energy spectra of photons and charged hadrons expected at the HL-LHC calculated by FLUKA simulation. [1].

Manuscript received October 3, 2019. This work was supported by the U.S. Department of Energy, Office of High Energy Physics program under Award No. DE-SC0011925 and DE-AC52-06NA25396.

Three proton irradiation experiments 6501 (2014), 6990 (2015) and 7324 (2017) were carried out by using 800 MeV protons at LANSCE. Inorganic crystals of various size up to 200 mm long were irradiated up to 3×10^{15} p/cm^2 with their longitudinal transmittance measured *in situ*. LYSO/LFS plates of up to 5 mm thick were also irradiated by 24 GeV protons at CERN up to 8×10^{15} p/cm^2. This paper reports proton-induced damage in LYSO and BaF_2 crystals.

II. Samples and Experimental Setup

Fig. 2 is a schematic showing a setup, consisting of a linear stage, an optical fiber and a lock-in amplifier based spectrophotometer used to measure crystal's transmittance *in situ* at LANSCE. The linear stage with a travel distance of 1 m was used to move samples into the proton beam via remote control. A part of the chopped light from a 150 W Xe lamp through a monochromator was monitored by a reference photodiode (Thorlabs DET10A). The main part of the light was injected into the crystal sample via 0.365-mm quartz fibers and through two collimators at the front and back of the crystal, and was measured by a signal photodiode (Oriel 70336). The lock-in amplifier (Oriel Merlin) measured the ratio between the signal and reference photodetectors. The precision and stability of this ratio is about 1%, and is free from fluctuations of both the light source intensity and the phosphorescence background in the sample.

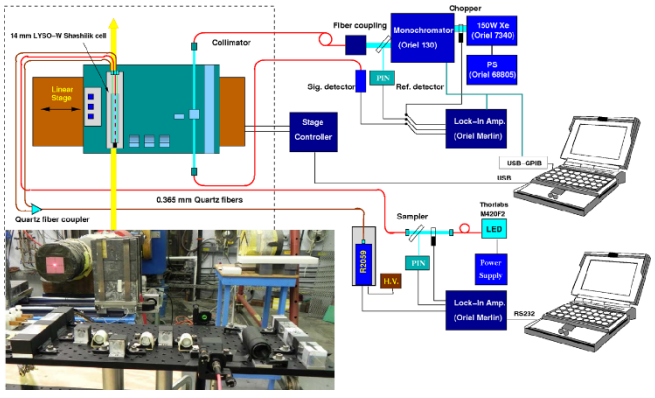

Fig. 2. A schematic showing the experimental setup used to measure crystal's transmittance spectra *in situ* during the experiment 7324. The inset photo shows the eight samples on the linear stage.

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The photo inset shows the samples loaded on the stage, including 3 stacks of small samples with each consisting of 2 PWO, 2 BaF_2 and 3 LYSO plates, one 5 mm PWO sample, one 20 mm BaF_2 sample and one 200 mm LYSO sample.

III. Results and Discussion

Fig. 3 summarizes the values of the emission weighted radiation induced absorption coefficient (EWRIAC) as a function of proton fluence for LYSO (black circles), BaF_2 (red squares) and PWO (blue triangles) samples irradiated at LANSCE, as well as LFS (black squares) and LYSO (black triangles) plate samples irradiated at CERN. The EWRIAC value provides a representation of the radiation induced absorption coefficient (RIAC) across the emission spectrum, so is a direct measure of damage for crystal's scintillation light. They are calculated by using the longitudinal transmittance (LT) data measured before and 181 days after irradiation by a PerkinElmer LAMBDA 950 spectrophotometer at Caltech. They are 7, 18, and 71 m^{-1}, respectively, for LYSO, BaF_2, and PWO after a proton fluence of 9.7×10^{14} p/cm^2, indicating excellent radiation hardness of LYSO and BaF_2 crystals against charged hadrons.

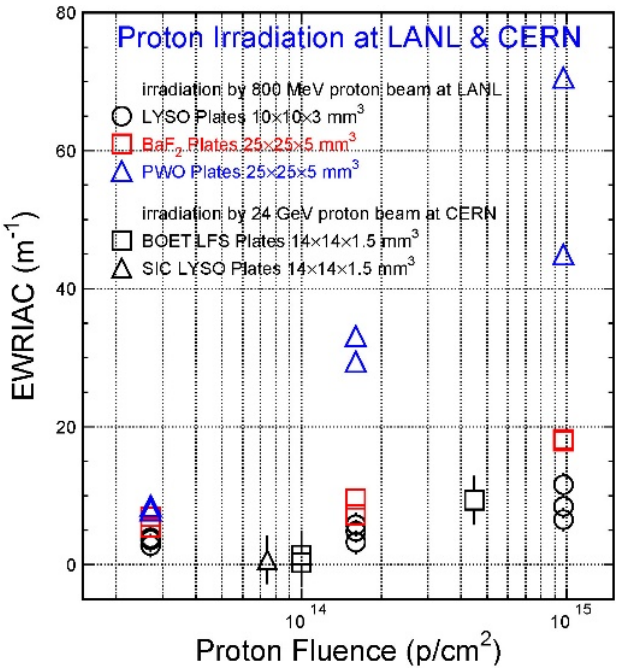

Fig. 3. EWRIAC values are shown as a function of proton fluence for LYSO, BaF_2 and PWO samples.

Fig. 4 summarizes the normalized light output (LO) as a function of the proton fluence for LYSO (black circles), BaF_2 (red squares) and PWO (blue triangles) samples irradiated at LANSCE, as well as LFS (black squares) and LYSO (black triangles) samples irradiation at CERN. The LO losses are 10% and 13%, respectively, for the LYSO and BaF_2 samples after a proton fluence of 9.7×10^{14} p/cm^2, confirming the excellent radiation hardness of LYSO and BaF_2 crystals against charged hadrons. The LO of PWO samples after proton of 9.7×10^{14} p/cm^2 is too low to be experimentally determined.

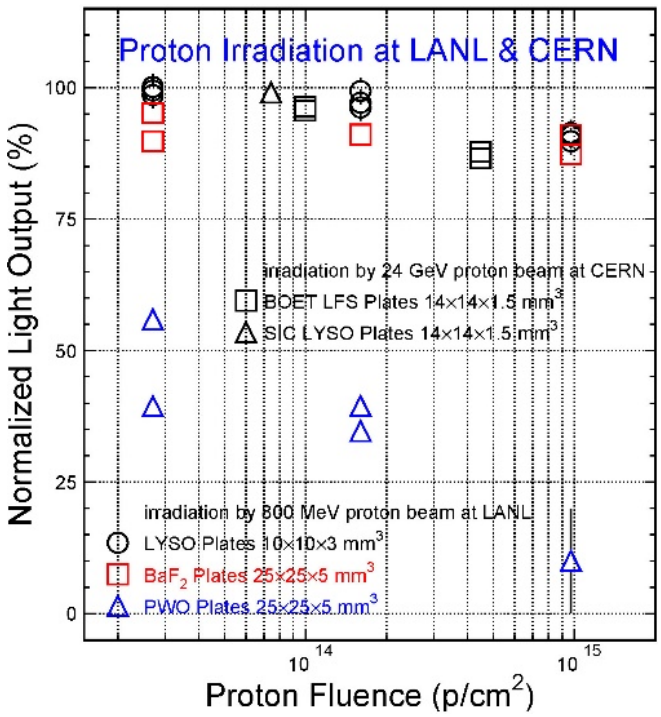

Fig. 4. Normalized light output is shown as a function of the proton fluence for LYSO, BaF_2 and PWO samples.

Fig. 5 shows the RIAC values at the emission peak as a function of proton fluence for LFS and LYSO long crystals irradiated in 6990 (black) and LYSO crystal irradiated in 7324 (blue), as well as LYSO plates irradiated at CERN (red). Also shown in the figure is a linear fit. LYSO crystals from different vendors show consistent damage for proton of 800 MeV and 24 GeV with RIAC @430 nm = 1.3×10^{-14} F_p.

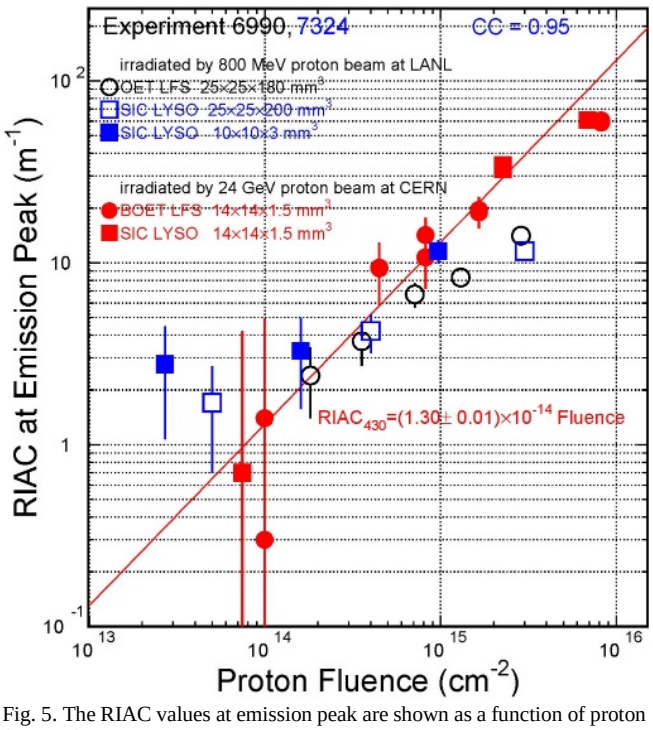

Fig. 5. The RIAC values at emission peak are shown as a function of proton fluence for LYSO/LFS crystals with various dimensions and vendors.

IV. 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 = 1.3×10^{-14} F_p for protons of 800 MeV and 24 GeV.

The result shows that commercial available LYSO crystals are expected to meet the radiation hardness specification of the CMS barrel timing layer (BTL) detector for the HL-LHC: induced absorption <3 m^{-1} for proton fluence of 3×10^{13} p/cm^2. BaF_2 crystals show a similar radiation hardness as LYSO at high fluence.

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

References

[1] The ECAL Technical Design Report, document CERN/LHCC 97-33, The CMS ECAL Collaboration, 1997.