Snowmass2021 - Letter of Interest

[Development of Radiation-Hard Scintillators and Wavelength-Shifting Fibers]

Instrumentation Frontier Topical Groups: (check all that apply □/■)

□ (IF1) Quantum Sensors
■ (IF2) Photon Detectors
■ (IF3) Solid State Detectors and Tracking
□ (IF4) Trigger and DAQ
□ (IF5) Micro Pattern Gas Detectors (MPGDs)
■ (IF6) Calorimetry
□ (IF7) Electronics/ASICs
□ (IF8) Noble Elements
■ (IF9) Cross Cutting and Systems Integration

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Abstract: Future circular and linear colliders as well as the Large Hadron Collider in the High-Luminosity era have been imposing unprecedented challenges on the radiation hardness of particle detectors that will be used for specific purposes e.g. forward calorimeters, beam and luminosity monitors. We perform research on the radiation-hard active media for such detectors, particularly calorimeters, in two distinct categories: Quartz plates coated with thin, radiation-hard organic or inorganic compounds, and intrinsically radiation-hard scintillators. In parallel to the effort on identifying radiation-hard scintillator materials, we also perform R&D on radiation-hard wavelength shifting fibers in order to facilitate a complete active medium for detectors under harsh radiation conditions. This Letter of Interest describes the recent advances in the developments of radiation-hard scintillators and wavelength shifting fibers.

Development of Radiation-Hard Scintillators and Wavelength-Shifting Fibers

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Narrative: Quartz Cerenkov radiators have implementations in beam and luminosity monitors as they are intrinsically radiation-hard. To improve the light production inside the quartz plates, we considered various light enhancement tools: p-Terphenyl (pTp), 4 % Gallium doped Zinc Oxide (ZnO:Ga), o-Terphenyl (oTp), m-Terphenyl (mTp), and p-Quarterphenyl (pQp). After 20 MRad of proton irradiation, the light output of pTp drops to 84 % of the initial level, then it slowly flattens, and after 40 MRad of radiation we still observe less than 20 % loss of light production [1-3]. We have built a quartz plate calorimeter prototype consisting of 20 layers of quartz plates (15 cm x 15 cm x 5 mm, 2 μ pTp deposited on one side) with 7 cm iron absorbers. The stochastic term of the energy resolution of this prototype for hadrons was 211% and for electrons was 26%. Details about these measurements can be found in [4].

We have investigated scintillators that are intrinsically radiation-hard. The samples probed were thin plates of Polyethylene Naphthalate (PEN) and Polyethylene Terephthalate (PET) and thin sheets of HEM. These materials have been used in beamline instrumentation but a study for calorimetry has not been performed so far. We studied radiation damage and recovery properties in detail [5,6]. As a candidate of a novel, intrinsically radiation-hard scintillator, Peroxide-cured polysiloxane bases were doped with the primary fluors p-terphenyl (pTP), p-quarterphenyl (pQP), or 2.5-Diphenyloxazole (PPO) and/or the secondary fluors 3-HF or bis-MSB. The polysiloxane scintillator base, HARDSIL, and other chemicals were purchased from Gelest, Inc.. The scintillation yield of the pTP/bis-MSB sample was compared to a BGO crystal using a setup with $_{90}$Sr source, and the pTP/bis-MSB was measured to yield roughly 50% better light production compared to the BGO crystal. Recently, the production process was optimized with upgraded control circuits and modified oven. With the recent advances, tiles of sizes from 3cm x 3cm to 10 \cm x 10cm can be produced as well as the so-called finger tiles of size 2 cm x 10 cm. Tiles can be machine-grooved for wavelength-shifting (WLS) fibers and dimples to directly couple the Silicon Photomultipliers (SiPMs), and can be optical-finish polished.

In 2017, two 3cm x 3cm tiles with photodetectors (Hamamatsu S12572-15) directly coupled to dimples were tested at CERN H2 beam line. One tile was polished whereas the other one was not. During the tests, the SiPMs coupled to the dimples were downstream and the tiles were centered with respect to the beam. 150 GeV muon beam was used to measure the response of the tiles to Minimum Ionizing Particles (MIPs). The muons passing through the tile and 1 mm away from the SiPM location are selected using wire chamber profiles. Figure 1 shows the charge spectrum of the new development of scintillators in response to traversing MIPs with polished (left) and unpolished (right) configurations. The distributions are fit to Gaussian + Landau with the mean for the Gaussian and the most probable value for the Landau functions constrained to be identical. The mean response of the polished tile corresponds to ~18 photons, and of the unpolished tile ~14 photons. These results validate the recent production process modifications and the feasibility to extend the production to various specifications. The tiles were exposed to various irradiation sources and performances observed. As an example, Fig. 2 (left) shows the radiation damage and recovery of the PEN tile after irradiation with $_{137}$Cs gamma source to 14 Mrad [5]. The PEN tile recovers from an initial damage of 55% to a permanent damage of 18%. We have also investigated the LED stimulated recovery of the scintillators from radiation damage and have obtained promising results. Figure 2 (right) shows the effect of the red-green-blue LED stimulated recovery of the first generation polysiloxane scintilator. The LED stimulation improves the radiation damage recovery by more than 20 % [6].

The development of the wavelength shifting materials proceed in two directions: Thin film depositions on quartz rods and quartz capillaries. For this purpose, we investigated doped ZnO:Zn/Mg, 3HF, Teflon and sylgard. Recently, we constructed a WLS fiber as a Pt-cured silicone capillary (2.3 mm outer diameter, 1 mm inner diameter, certified for gamma sterilization) with a silicone gel conveying 3HF. Holes were drilled through the centers of three 5 mm thick blue scintillator tiles of lateral size 2.5 cm x 2.5 cm. The silicone-based WLS fiber was placed through the center hole, and it was coupled to a Hamamatsu S12572-10. The fiber was parallel to the beam direction. The response to 150 GeV muons was measured by selecting the muons passing through the tiles and 1 mm away from the SiPM/fiber using the wire chamber profiles. The mean response was approximately 21 photons. Also, we have developed Cerium-doped scintillating glasses which can also be drawn in fibers. Hence they are candidates for single solid radiation-hard wavelength shifting fibers.

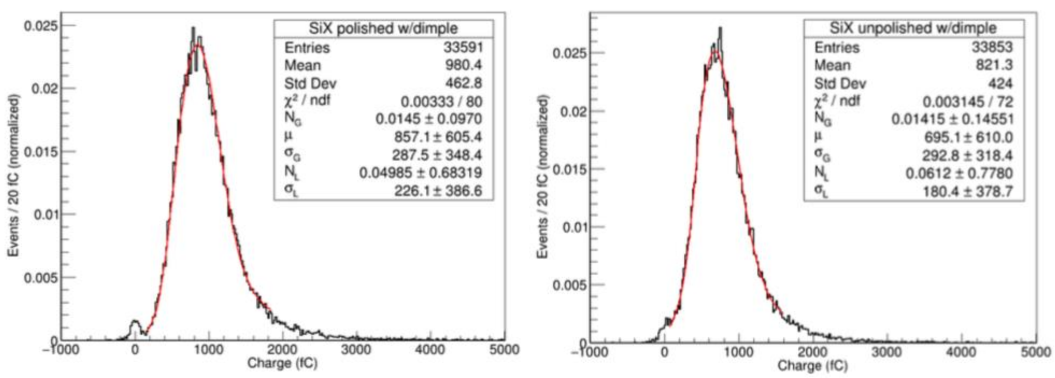

Figure 1. The MIP charge spectrum of the new scintillators. polished (left) unpolished (right)

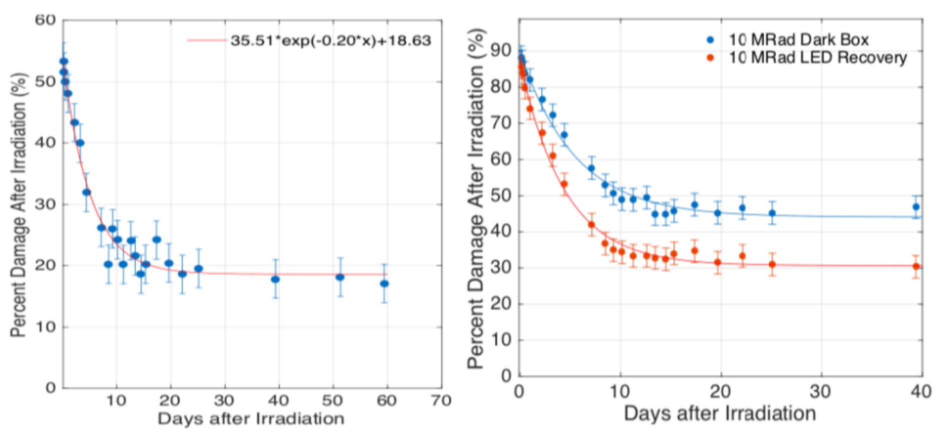

Figure 2. Radiation damage and recovery of PEN (left) and LED stimulated recovery of PEN (right).

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