Tests of the radiation hardness of scintillators in a high energy proton-proton collider environment

Joshua Kunkle[a,*], Serhat Atay[h], Alberto Belloni[a], Jeff Calderon[a], Pawel De Barbaro[f], Sarah C. Eno[a], Kenichi Hatakeyama[d], Geng-Yuan Jeng[a], Alexander Kaminskiy[g], Aliko Mestvirishvili[f], Julie Schnurr[a], Yao Yao[a], Sung Woo Youn[b]

[a] *Dept. Physics, U. Maryland, College Park MD 30742 USA*
[b] *Institute for Basic Science, Center for Axion and Precision Physics Research, IBS Center for Axion and Precision Physics Research Room 4315, Department of Physics, Natural Science Building (E6-2), KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, South Korea*
[c] *Fermi National Accelerator Laboratory, Batavia, IL, USA*
[d] *Baylor University, Waco, Texas, USA*
[e] *The University of Iowa, Iowa City, IA, USA*
[f] *The University of Rochester, Rochester, NY, USA*
[g] *Skobelsyn Institute of Nuclear Physics, Lomonosov Moscow, Russia*
[h] *Istanbul Technical University, Istanbul, Turkey*

Abstract

Radiation damage to the attenuation length and light output of scintillating materials may depend not just on the deposited energy, but also on the dose rate and the types and energies of the interacting particles. We present the results of measurements of the damage to several different types of scintillating materials irradiated in the CMS collision hall during running with a center-of-mass energy of 13 TeV at the Large Hadron Collider. The materials received doses ranging from xxx over a period of xxx months. The light output was measured at several intermediate doses.

Keywords: organic scintillator, liquid scintillator, radiation hardness, calorimetry

*Corresponding author
Email address: jkunkle@cern.ch (Joshua Kunkle)

1. Introduction

Radiation damage to the attenuation length and light output of scintillating materials may depend not just on the deposited energy (dose), but also on the dose rate and the types and energies of the interacting particles. We present the results of measurements of the damage to several different types of scintillating materials irradiated in the CMS collision hall at the Large Hadron Collider (LHC) during its operation at a center-of-mass energy of 13 TeV during 2015. The materials received doses ranging from xxx over a period of xxx months. The light output was measured at several intermediate doses. Irradiation in the collision hall of a running high energy proton-proton collider allows access to very low dose rates that would not be affordable at reactors, electron linacs, and ^{60}Co sources, with the particle type and energy spectrum most appropriate for those designing detectors for hadron colliders.

In-situ tests are of particular interest, as several experiments have found unexpected large radiation damage in operation compared to expectations based on irradiations using reactors, linacs and ^{60}Co sources. In the CDF experiment, scintillators placed close to the beam line received much larger damage than expected [1]. During the running of the LHC from its commissioning in 2009 through 2012, the CMS detector was exposed to an integrated luminosity of 25 fb^{-1}. Parts of the CMS endcap calorimeter are estimated to have received doses of 0.1 to 0.2 Mrad [2]. Studies of the radiation hardness of scintillator tiles prior to installation in the detector, using an electron linac and ^{60}Co sources, indicated an exponential reduction in light output with accumulated dose, with a exponential constant of around 7 Mrad [3, 4]. However, although the dose received by the CMS tiles was small compared to this number, significant light loss was observed [5]. Experiments using scintillator at HERA, however, saw damage consistent with expectations [6].

One possible explanation is dose rate effects. Several studies have shown larger damage for the same dose at lower dose rate both for light self absorption before annealing (although after annealing the permanent damage seems to be independent of dose rate) and initial light output [7, 8, 9, 10, 11, 12, 1, 13].

Another possible explanation is damage that is dependent on particle type and energy. Especially, interactions of high energy neutrons (E > 10 keV), which through scattering with the hydrogen in the polymer can produce highly ionizing protons (LET), are known to produce a high density of radicals and cross-linking in the polymer, and affect mechanical properties [14].

While some studies have also found little correlation between mechanical problems and color center formation [15], detailed studies have found fast neutrons to be more damaging than photons. The effect of LET radiation on plastic scintillators was studied in detail in [8, 16, 17, 18]. Especially [18, 17] have summaries of the chemistry involved. The 2001 paper [18] reported results of irradiation of SCSN-81 by fast reactor neutrons. They found gammas more damaging to the dopants, but neutrons created a factor 5 more color centers for wavelengths > 420 nm. The 2003 paper [17] looked at effects to the substrate for polyvinyltoluene (BC-404) and polystyrene. They found neutron damage in polystyrene from fast neutrons was 4-5 times larger for wavelengths of 420-460 nm and in polyvinyltoluene a factor two more damaging. PVT was also found to form internal cracks after irradiation (oddly only mentioned in the summary). Doses were calculated from the fluences using kerma (kinetic energy released in matter) factors [19]. In this paper, contributions to color center formation from specific radicals was extracted.

2. Irradiation conditions

For irradiation, samples were placed in the CMS collision hall on the structure that housed the CMS CASTOR [20] forward calorimeter, 14.3 m away from the CMS interaction point. They were held in fiber glass holders (Figure 1) suspended in an Aluminum box (Figure 2). Parts of the samples are as close as 22 mm to the beam pipe. The temperature in the box i don't know The atmosphere was i don't know

The dose was measured using FWT-60-00 Radiochromic dosimeters (thin

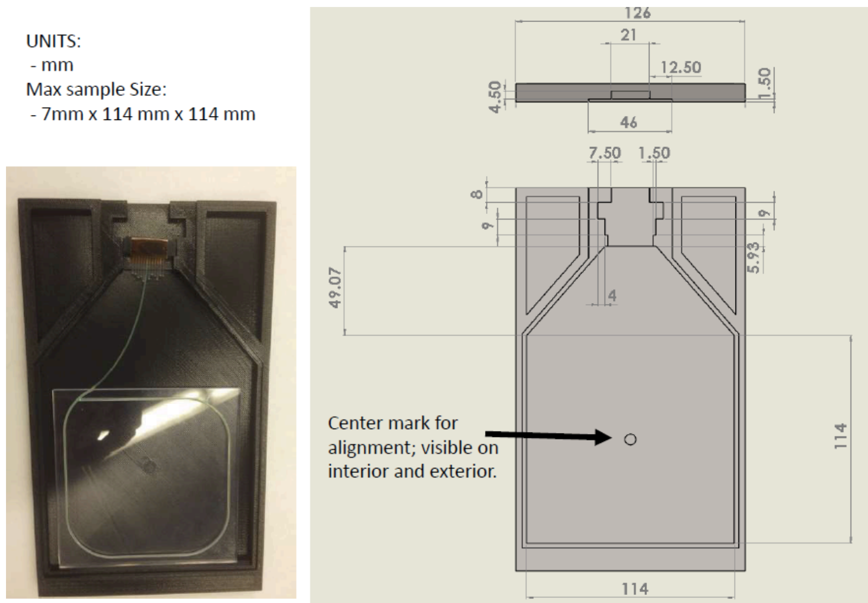

Figure 1: Design for fiber glass holder used for irradiations.

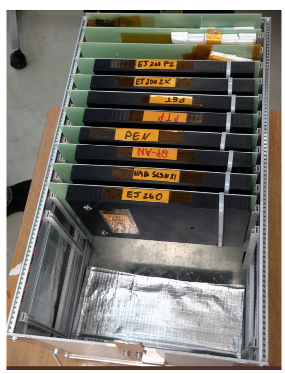

Figure 2: Design for Aluminum box holding samples.

films) by Far West Technology, RADMON detectors produced by CERN PPD, and using Silicon Diodes. The FWT dosimeters are attached directly to the scintillator samples.

The samples were installed during June of 2015. The samples were removed and measurements were made on put dates here.

3. Tile designs

In this paper, we reports results for A six of the scintillators that were tested.

Four of our tests used scintillators with embedded wavelength-shifting (WLS) fibers similar to those in the used in the CMS barrel hadron calorimeter [21]. The dimensions of the plastic scintillator was 10 cm x 10 cm x 4 mm. One was made of SCSN-81, the blue-scintillating plastic by Kuraray used for most of the CMS tiles. One used EJ-200, a blue scintillator by Eljen Technology similar to BC-408, the scintillator used for the first layer of the CMS calorimeter. Another used EJ-200 but with the concentration of the first WLS dopant doubled. The fourth tile used EJ-260, a green scintillator. SCSN-81 uses polystyrene as substrate, while EJ-200 and EJ-260 (and BC-408) use polyvinyltoluene.

The blue scintillators used 1 mm diameter Y-11 blue-to-green WLS fibers from Kuraray, while the green used 1 mm O-2 green-to-orange WLS fiber.

Also included were two tiles make from Aluminum and filled with a scintillating liquid (EJ-309 from Eljen Technology). Quartz support tubes running through the liquid hold 1 mm Y-11 WLS fibers. Details on the tiles can be found in [22].

4. Measurement techniques

The light output before and after irradiation in the CMS collisions hall was measured using two different methods.

In the primary method, the response of the scintillator was measured using a columnated beta source (which?). A 1 mm^2 Silicon Photomultiplier (SiPM) by Zecotec [23] was used as the photodetector. The scintillator was placed in a dark box, and a clear fiber was used to connect it to the photodetector, outside the box. The resulting current was measured using a Keithley 2001 or 6487 picoameter. The SiPM was calibrated by plotting the dark current versus bias voltage and locating the break down voltage. The data was taken with a bias voltage one volt above the breakdown. The temperature was also monitored.

A secondary measurement used the light output produced by cosmic rays. Scintillator-based counters above and below the irradiated tiles were used for triggering. No attempt was made to select minimum ionizing (mip) muons. The muons were thus of low energy and produce more light than mips. The SiPM was used for the photodetector. Data was recorded with a DRS4 Evaluation Board from the Paul Scherrer Institute with a sampling rate of 1 GHz. Gain was monitored using the position of the single photoelectron (pe) peak from the SiPM seen in data taken with a random trigger.

5. Results

6. Conclusions

We presented results on radiation damage to scintillating materials in

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