

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*Skobel'syn 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 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 crosslinking in the polymer, and affect mechanical properties [14]. Studies, though, have also found little correlation between mechanical problems and color center formation [15].

There have been studies of the effect on LET radiation on plastic scintillators [8, 16, 17, 18]. Especially [?] has a nice summary of the physics involved. need to recheck these papers. also missed 2 have found equivalent damage from protons, neutrons and gammas when kerma factors [19] are taken into account.

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 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].

UNITS:
- mm
Max sample Size:
- 7mm x 114 mm x 114 mm

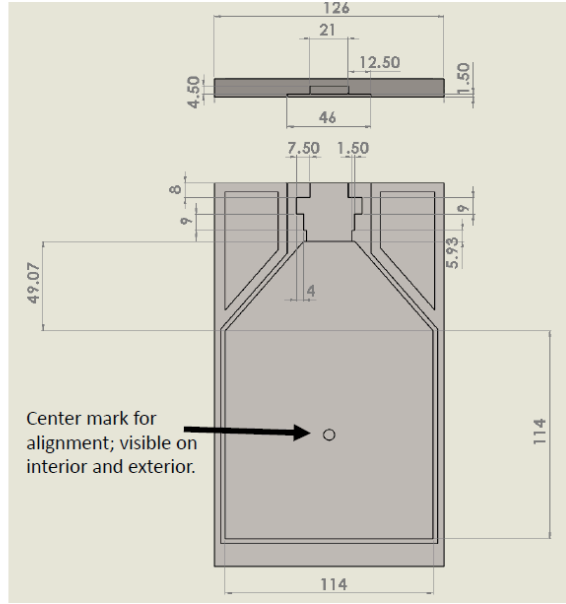


Figure 1: Design for fiber glass holder used for irradiations.

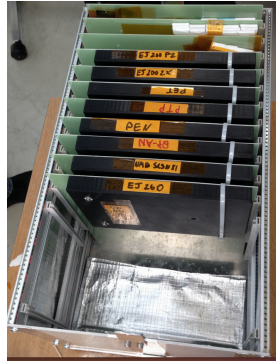


Figure 2: Design for Aluminium box holding samples.

The dimensions of the plastic scintillator was 10 cm x 10 cm x 4 mm. One was
60 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. An-
other 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
65 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 made from Aluminum and filled with a scin-
tillating liquid (EJ-309 from Eljen Technology). Quartz support tubes running
70 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.

75 In the primary method, the response of the scintillator was measured using
a columnated beta source (**which?**). A SiPM (Hamamatsu **I don't know**) 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
80 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
85 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
90 SiPM seen in data taken with a random trigger.

5. Results

6. Conclusions

We presented results on radiation damage to scintillating materials in

7. Acknowledgments

95 The authors would like to thank Randy Ruchti of Notre Dame for providing
the capillaries. We would like to thank the University of Maryland FabLab,
especially **who helped**, for help with fiber sputtering. This work was supported
in part by U.S. Department of Energy Grant DESC0010072.

References

- 100 [1] N. Giokaris, M. Contreras, A. Pla-Dalmau, J. Zimmerman, K. Johnson,
Study of dose-rate effects on the radiation damage of polymer-
based scsn23, scsn81, scsn81+y7, scsn81+y8 and 3hf scintilla-
tors, Radiation Physics and Chemistry 41 (12) (1993) 315 – 320.
doi:http://dx.doi.org/10.1016/0969-806X(93)90069-7.
105 URL [http://www.sciencedirect.com/science/article/pii/](http://www.sciencedirect.com/science/article/pii/0969806X93900697)
0969806X93900697
- [2] ECFA High Luminosity LHC Experiments Workshop: Physics and Tech-
nology Developments Summary submitted to ECFA. 96th Plenary ECFA
meeting.
110 URL <https://cds.cern.ch/record/1983664>
- [3] V. Hagopian, I. Daly, Radiation damage of fibers, AIP Conference Proceed-
ings 450 (1) (1998) 53–61. doi:http://dx.doi.org/10.1063/1.56958.
- [4] A. Byon-Wagner, Radiation hardness test programs for the {SDC}
calorimeter, Radiation Physics and Chemistry 41 (12) (1993) 263 – 271.
115 doi:http://dx.doi.org/10.1016/0969-806X(93)90064-2.

- [5] J. F. Butler, D. U. C. B.-L. I. Contardo, M. M. Klute, J. U. o. M. Mans, L. I.-B. Silvestris, Technical Proposal for the Phase-II Upgrade of the CMS Detector, Tech. Rep. CERN-LHCC-2015-010. LHCC-P-008, CERN, Geneva, upgrade Project Leader Deputies: Lucia Silvestris (INFN-Bari), Jeremy Mans (University of Minnesota) Additional contacts: Lucia.Silvestris@cern.ch, Jeremy.Mans@cern.ch (Jun 2015).
URL <https://cds.cern.ch/record/2020886>
- [6] I. Bohnet, R.-P. Feller, N. Krumnack, E. Moeller, H. Prause, H. Salehi, K. Wick, Long-term studies of the optical components in the ZEUS calorimeter using a moving Co-60 source, Nuclear physics / A 599 (2009) 53–59. doi:10.1016/j.nima.2008.10.035.
- [7] C. Zorn, Plastic and liquid organic scintillators, in: F. Sauli (Ed.), Instrumentation in High Energy Physics, 2nd Edition, World Scientific, 1993, Ch. 4, pp. 218–279. doi:10.1142/9789814360333_0004.
- [8] U. Holm, K. Wick, Radiation stability of plastic scintillators and wavelength shifters, Nuclear Science, IEEE Transactions on 36 (1) (1989) 579–583. doi:10.1109/23.34504.
- [9] K. Wick, D. Paul, P. Schrder, V. Stieber, B. Bicken, Recovery and dose rate dependence of radiation damage in scintillators, wavelength shifters and light guides, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 61 (4) (1991) 472–486. doi:http://dx.doi.org/10.1016/0168-583X(91)95325-8.
- [10] B. Bicken, U. Holm, T. Marckmann, K. Wick, M. Rohde, Recovery and permanent radiation damage of plastic scintillators at different dose rates, Nuclear Science, IEEE Transactions on 38 (2) (1991) 188–193. doi:10.1109/23.289295.
- [11] B. Bicken, A. Dannemann, U. Holm, T. Neumann, K. Wick, Influence of temperature treatment on radiation stability of plastic scintillator and

- 145 wave-length shifter, Nuclear Science, IEEE Transactions on 39 (5) (1992) 1212–1216. doi:10.1109/23.173180.
- [12] A. Bross, A. Pla-Dalmau, Radiation damage of plastic scintillators, Nuclear Science, IEEE Transactions on 39 (5) (1992) 1199–1204. doi:10.1109/23.173178.
- 150 [13] E. Biagtan, E. Goldberg, R. Stephens, E. Valeroso, J. Harmon, Gamma dose and dose rate effects on scintillator light output, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 108 (12) (1996) 125 – 128. doi:http://dx.doi.org/10.1016/0168-583X(95)00874-8.
- 155 [14] E. H. Lee, Ion-beam modification of polymeric materials – fundamental principles and applications, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 151 (1–4) (1999) 29 – 41. doi:http://dx.doi.org/10.1016/S0168-583X(99)00129-9.
URL http://www.sciencedirect.com/science/article/pii/S0168583X99001299
- 160 [15] R. Clough, K. Gillen, G. Malone, J. Wallace, Color formation in irradiated polymers, Radiation Physics and Chemistry 48 (5) (1996) 583 – 594. doi:http://dx.doi.org/10.1016/0969-806X(96)00075-8.
URL http://www.sciencedirect.com/science/article/pii/0969806X96000758
- 165 [16] G. Buss, A. Dannemann, U. Holm, K. Wick, Radiation damage by neutrons to plastic scintillators, Nuclear Science, IEEE Transactions on 42 (4) (1995) 315–319. doi:10.1109/23.467829.
- 170 [17] B. Bodmann, S. Gb, U. Holm, {LET} effects of neutron irradiated plastic scintillators, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 208 (0) (2003) 495 –

499, ionizing Radiation and Polymers. doi:[http://dx.doi.org/10.1016/S0168-583X\(03\)00664-5](http://dx.doi.org/10.1016/S0168-583X(03)00664-5).

- [18] B. Bodmann, U. Holm, Neutron-irradiated plastic scintillators, Nuclear
175 Instruments and Methods in Physics Research Section B: Beam Interactions
with Materials and Atoms 185 (14) (2001) 299 – 304. doi:[http://dx.doi.org/10.1016/S0168-583X\(01\)00762-5](http://dx.doi.org/10.1016/S0168-583X(01)00762-5).
- [19] R. S. Caswell, J. J. Coyne, M. L. Randolph, Kerma factors for neutron
energies below 30 mev, Radiation Research 83 (2) (1980) pp. 217–254.
- [20] P. Gttlicher, Design and test beam studies for the {CASTOR} calorimeter
180 of the {CMS} experiment, Nuclear Instruments and Methods in Physics
Research Section A: Accelerators, Spectrometers, Detectors and Asso-
ciated Equipment 623 (1) (2010) 225 – 227, 1st International Confer-
ence on Technology and Instrumentation in Particle Physics. doi:<http://dx.doi.org/10.1016/j.nima.2010.02.203>.
185
- [21] S. Abdullin *et al.*, Design, performance, and calibration of cms hadron-
barrel calorimeter wedges, The European Physical Journal C 55 (1) (2008)
159–171. doi:10.1140/epjc/s10052-008-0573-y.
- [22] Liquid scintillator tiles for high radiation environments submitted to NIM.