

# Results of brightness and uniformity measurements of various scintillator tiles at the CERN H2 test beam

Jeff Calderon<sup>a</sup>, Alberto Belloni<sup>a</sup>, Pawel De Barbaro<sup>b</sup>, Sarah C. Eno<sup>a</sup>,  
Geng-Yuan Jeng<sup>a</sup>, Mahan Amouzegar<sup>a</sup>, Yao Yao<sup>a</sup>

<sup>a</sup>*Dept. Physics, U. Maryland, College Park MD 30742 USA*

<sup>b</sup>*The University of Rochester, Rochester, NY, USA*

---

## Abstract

Radiation damage has been shown to reduce the overall output of scintillating material. Not all materials, however, are as susceptible. To subject the prototype liquid tile to realistic detector conditions, the test was conducted at the H3 Test Beam facility of CERN's Large Hadron Collider (LHC) complex. At the H2 site muons of specific energies are peeled away from the particle beam which approximate the conditions in which the Hadron calorimeter (HCAL) will actually function. In this way the H2 provides a particle gun which can be turned off and on for data acquisition. We collect our scintillator light output information using a Data Acquisition (DAQ) system designed for the phase one upgrade featuring Silicon Photomultipliers (SiPM). An attempt was made to compare the light yields, efficiencies, and uniformity of prototype liquid tiles and traditional plastic tiles. Here we present our finding and report upon the feasibility of liquid tile replacements to exiting plastic tiles.

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

---

## 1. Introduction

Run 2 began at The Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider in summer of 2015. Research into the possibility of radiation resistant scintillators has shown that CMS presently has scintillators which are  
5 will degrade over time and cause photon re-absorption. This will in turn cause

the degradation of the output signals to the photomultiplier tubes, ultimately reducing the sensitivity of the CMS experiment. This degradation is expected to become increasingly severe in the near future due to the increased luminosity from upgrades performed prior to Run 2. This unavoidably exposes equipment  
10 to increasing levels of radiation. Plastic scintillators are particularly susceptible to this radiation and research is needed to find alternative technologies which will continue to function for the life of the machine. To that end, we conducted experiments aimed at comparing the light yield and efficiency of liquid scintillator prototypes. The prototypes tested varied in design. One design featured  
15 a plastic-free liquid wave-length shifting capillary in place of traditional plastic wavelength shifting fibers, while another uses traditional plastic fibers. The plastic free design represents our fully radiation resistant solution.

## 2. Experimental Area

This experiment was conducted at the H2 Beam Line located at the Pre-vessin site of the LHC complex. The H2 Beam Line is part of the Super Proton Synchrotron (SPS). Since The SPS is capable of accelerating protons to 450 GeV it is useful for gauging the effectiveness of scintillators under realistic Beam on conditions. Magnets bend and focus the collimated beam directly onto a movable table. The Table can move in all three dimensions allowing the user to align the target with the beam. This allows for gross output measurements of the scintillators, and equally important, it provides a means for making sure our target is properly aligned. Since we wish to maximize the sensitive areas of our detector we need a proper alignment to ensure we have sufficient coverage over the area of the tile. Prior to the reaching the table the beam traverses reveal intermediary objects for precise tracking. In order of increasing distance from the beam pipe where the following instruments: wire chamber "A," 4 large scintillating plastic "paddles," wire chamber "B", wire chamber "C" and finally the movable table with the attached tiles. The uniformity measurement is made possible by the 3 wire chambers. After the beam exits the beam pipe it en-

counter the set of 100 by 100 millimeter electron drift chambers: wire chambers "A," "B," and "C." As the particles traverse the chambers the position of the particle is known to within a one half of a millimeter. The flow of electrons into the wires relay the position signature for each event and this information is stored along with the event number. The chambers also insure that the beam is properly aligned and focused. Each position registered on the wire chamber indicates a particles passing through the wire chamber. The aggregate position measurements are used to infer the trajectory of each muon and hence its intersection point with the tile. This position is matched with a signal light pulse which is transmitted to the SiPM and then to the rest of the data acquisition system. A histogram of the signal output would indicate the responsiveness of any region the tile. Because of the limitation of the wire chambers, this experiment kept the beam rates to  $10^3$  particles per burst. Also we note that the highest efficiency region of the wire chambers is the  $80 \text{ mm}^2$  center.

### 3. Scintillators

20 The plastic tiles used were cut into 10 cm x 10 cm x 5 mm squares. Each tile contained a sigma shaped groove. This grove holds a fiber which leads out of the tile and into a connector. The connector was shaped specifically to fit in a plastic case which houses each tile. This housing served the dual purpose of holding the sample in place and keeping outside light from effecting the scintillator measured  
25 output. The plastic connector rested between the two halves of the case. This connector is used to attach the WLS from the tiles to the longer fiber optic transfer cable; these longer fibers lead to the optical device unit (odu). The ODU is part of the larger the Readout Module. The ODU contains 217 fiber connections which terminate at the face of yet more fibers which terminate on a  
30 battery of SiMPs arranged in a 6 x 8 array. Each SiMP transmits an electrical signals to the Front End Create where a series of Charge Integrator and Encoder (QIE10) chips are housed. These chips convert the along signal from the SiPMs to a digital signal integrated over a 25 nanosecond time window. The Front

End Electronics (FEE) contain the alignment and formatting (FE-FPGA), the  
35 trigger-primitive and pipeline electronics (uHTR) and the cDAQ link (AMC13).  
From the front end electronics the data is transferred via Gigabit Optical Link  
(GOL) to the back-end Electronics at 1.6 Gbps. A more detailed treatment on  
the electronics used in this set up can be found in CERN-LHCC-2012-015 /  
CMS-TDR-010 a technical design report.

40 It is important to note that the triggering mechanism for this experiment  
differed from that of the technical design report. The triggering for the data  
acquisition system is accomplished by two scintillating paddles. These paddles  
are located between wire chamber "A" and "B" arranged one behind another in  
such a way that overlapping regions are perpendicular to the beam. Coinciding  
45 signals from both paddles result in a trigger condition. Of necessity we required  
a triggering mechanism which allows us to predict precisely when to expect  
muons to deposit their energy and register a hit in our efficiency calculation.  
For this analysis we had to calibrate our trigger such that data acquisition  
commences prior to the expected muon interaction time. This allows us to  
50 compare the interaction SiMP output to the background "dark current" signal.  
This "dark current" must be subtracted away from the total integrated charge,  
in this manner we can measure the true output signal. The plots which follow  
were produced by subtracting away the pedestal in this manner.

Among the plastic scintillators tested are: SCSN-81, EJ-260, EJ-309 and EJ-  
55 200. One of the tiles was made of SCSN-81. SCSN-81 is the blue-scintillating  
plastic by Kuraray which is presently used through out the CMS detector. EJ-  
200 is blue scintillator by Eljen Technology, it is similar to BC-408 which is  
used in the first layer of the CMS calorimeter. EJ-260 is a standard industrial  
plastic scintillator made of the same Polyvinyltoluene base as EJ-200. The  
60 liquid Scintillator material used in this experiment was EJ-309. EJ-309 is a  
xylene based scintillaotr. J-309 is also made by Eljen Technology and features  
a higher flash point than previous liquids, while presevering comparable light  
emmission. More information on EJ-309 can be found at Eljen's website: <http://www.eljentechnology.com>

65 Two separate Aluminum tiles were prepared. One with quartz support tubes  
running through the liquid to hold 1 mm Y-11 WLS fiber. Another Aluminum  
tile was prepared which had liquid capillaries containing a liquid wavelength  
shifting material rather than Y-11 fiber. Like Y-11, the liquid the shifts blue  
scintillator light into the blue frequency range. Prior to mounting the tiles on to  
70 the target the liquid scintillator was poured into the aluminum tile in a nitrogen  
environment. Details on the tiles can be found in [22]. Special care was taken to  
pour the liquid scintillator into our aluminum tiles under nitrogen environment  
as oxygen.



Figure 1: Container for Aluminum tile with capillaries.

Details on the tiles can be found in [22].

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

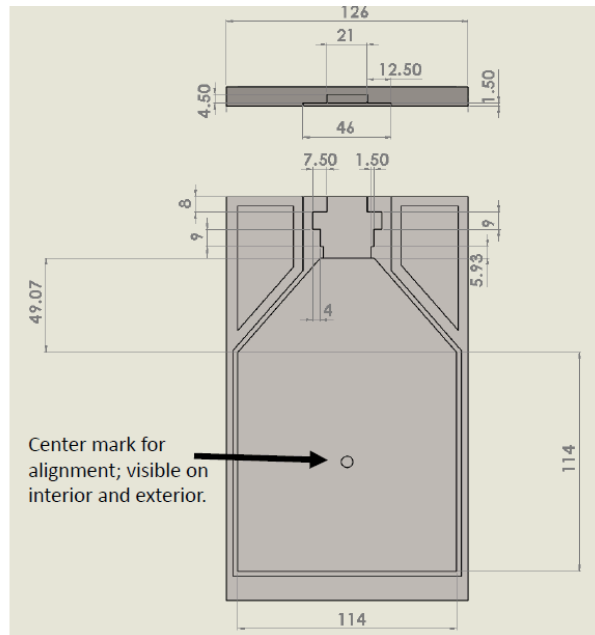


Figure 2: Container for plastic tiles with capillaries.

#### 4. Data Samples

#### 5. Energy Analysis

#### 6. Time Analysis

#### 7. Conclusion

#### 8. Acknowledgments

The authors would like to thank Randy Ruchti of Notre Dame for providing the capillaries. Grant DESC0010072.

#### References

- [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](http://dx.doi.org/10.1016/0969-806X(93)90069-7).

URL <http://www.sciencedirect.com/science/article/pii/S0969806X93900697>

- 90 [2] ECFA High Luminosity LHC Experiments Workshop: Physics and Technology Developments Summary submitted to ECFA. 96th Plenary ECFA meeting.

URL <https://cds.cern.ch/record/1983664>

- [3] V. Hagopian, I. Daly, Radiation damage of fibers, AIP Conference Proceedings 450 (1) (1998) 53–61. doi:<http://dx.doi.org/10.1063/1.56958>.

- 95 [4] A. Byon-Wagner, Radiation hardness test programs for the {SDC} calorimeter, Radiation Physics and Chemistry 41 (12) (1993) 263 – 271. doi:[http://dx.doi.org/10.1016/0969-806X\(93\)90064-2](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).

100 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](https://doi.org/10.1016/j.nima.2008.10.035).

- 110 [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](https://doi.org/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](https://doi.org/10.1109/23.34504).  
115
- [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](https://doi.org/http://dx.doi.org/10.1016/0168-583X(91)95325-8).  
120
- [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](https://doi.org/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 wave-length shifter, Nuclear Science, IEEE Transactions on 39 (5) (1992) 1212–1216. [doi:10.1109/23.173180](https://doi.org/10.1109/23.173180).  
125
- [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](https://doi.org/10.1109/23.173178).  
130
- [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](https://doi.org/http://dx.doi.org/10.1016/0168-583X(95)00874-8).  
135
- [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:](https://doi.org/http://)  
140



[//dx.doi.org/10.1016/S0168-583X\(99\)00129-9](http://dx.doi.org/10.1016/S0168-583X(99)00129-9).

URL <http://www.sciencedirect.com/science/article/pii/S0168583X99001299>

- [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](http://dx.doi.org/10.1016/0969-806X(96)00075-8).  
URL <http://www.sciencedirect.com/science/article/pii/0969806X96000758>
- [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](http://dx.doi.org/10.1109/23.467829).
- [17] B. Bodmann, S. Gb, U. Holm, {LET} effects of neutron irradiated plastic  
scintillators, Nuclear Instruments and Methods in Physics Research Sec-  
tion 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  
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  
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>.

- [21] S. Abdullin *et al.*, Design, performance, and calibration of cms hadron-  
170 barrel calorimeter wedges, The European Physical Journal C 55 (1) (2008)  
159–171. [doi:10.1140/epjc/s10052-008-0573-y](https://doi.org/10.1140/epjc/s10052-008-0573-y).
- [22] Liquid scintillator tiles for high radiation environments submitted to NIM.
- [23] A. Heering, J. Rohlf, S. Los, J. Anderson, J. Freeman, Y. Musienko,  
I. Schmidt, C. Tully, S. Dugad, An 18 element strip of 1 mm<sup>2</sup> g-apds for  
175 cms hcal upgrade results of cern test beam 2009, in: Nuclear Science Sym-  
posium Conference Record (NSS/MIC), 2009 IEEE, 2009, pp. 2190–2196.  
[doi:10.1109/NSSMIC.2009.5402087](https://doi.org/10.1109/NSSMIC.2009.5402087).