

Liquid scintillator tiles for high radiation environments

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Abstract

Future experiments in high energy and nuclear physics may require large, inexpensive calorimetry that can operate to doses of 50 Mrad or more. We present the results of a study of a scintillator tile based on EJ-309 liquid scintillator using cosmic rays, test beam, and ^{60}Co irradiations that shows little degradation of output under irradiation.

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

1. Introduction

Sampling calorimeters using plastic scintillator tiles with wave length shifting (WLS) fibers, such as the CDF plug calorimeter [1] and the CMS Barrel[2] and Endcap[3] hadron calorimeters, are popular due to their low cost and ease
5 of construction. Plastic scintillator is available commercially from companies

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like St. Gobain and Eljen. When irradiated, however, the performance of plastic scintillator and WLS fibers deteriorate; light self-absorption (yellowing) increases and light output decreases. The resulting loss of light output for this kind of tile has been studied [4][5]. Generally, the light output decreases exponentially with dose, with an decay constant on order of a few Mrad. Future high energy and nuclear experiments, however, may have to operate in environments that will deliver doses of tens of Mrad. In this paper, we present the design and optimization of a liquid scintillator tile, based on EJ-309 liquid scintillator, that can operate in this kind of environment.

2. Tile design

Our tile is based on EJ-309 scintillator, from Eljen Technology, which uses naphthalene as the substrate with wavelength shifting additives. EJ-309 has a light output that is 75% of anthracene, a wavelength of maximum emission of 424 nm, a refractive index of 1.57, and a flash point of 144°C. The low flash point is important for its suitability for a collider environment.

The design of a tile to hold the liquid needs to consider light collection efficiency, light collection uniformity, and cost. The container should not leak, and there should not be interactions between the container and its contents that degrade the light output over time or compromise the integrity of the container. Figure 1 shows the mechanical construction of our prototype. The case is made of aluminum. Two transparent support tubes with outer diameter of 2 mm run through the liquid and can hold either wavelength shifting fiber or liquid wavelength shifter. The index was measured at the Quattrone Nanofabrication facility at the University of Pennsylvania to be **need jeff's number**. When wavelength shifting fiber was used, the end of the fiber not connected to the photodetector was coated with Al to increase the light output unless otherwise noted. The support tube is sealed to the case with a viton fluoroelastomer o-ring. The thickness of the top and bottom Aluminum plates is 0.5 mm. The total internal volume is 88 mm x 88 mm x 4 mm. The inner surface of the container is a lapped

thickness, quartz support tubes, and a 0.9 mm diameter Y-11 WLS fiber unless otherwise stated.

3. Light yield and uniformity as measured in test beam

The light yield and uniformity of the tiles was measured in the H2 test beam
55 facility at CERN using 120 GeV muons. The trigger required coincidence of two
out of four plastic scintillator hodoscopes. The effective beam cross sectional
area, after trigger requirements, was $14 \times 14 \text{ cm}^2$. The positions of the muons
was measured with five wire chambers. The position obtained from the counter
closest to the prototype was used. We also required the signal in each wire
60 chamber be consistent with that of a single muon, and that the difference in
positions in sequential chambers be consistent within uncertainties. As many
groups were using the same test beam, there was material upstream of our
counters. For some runs, several iron blocks were used to support experiments
upstream of our counters. Because the muons were high energy, the probability
65 of a muon-induced shower was non-negligible. (This was verified later at a test
beam at FNAL that had a cleaner beam line and through simulation.) We
present here the results from the runs and tiles with the smallest upstream
material.

The wavelength shifting fiber was connected to a clear fiber using a connector
70 designed at FNAL. The clear fiber was lead away from the beam line. The light
output was measured using a Hamamatsu R7600U-200-M4 photomultiplier tube
and a custom ASIC that integrates and digitizes the resulting charged, called
the “QIE” [6]. The photomultiplier has a peak quantum efficiency of 40% at a
wavelength of 400 nm and produces a clear single photoelectron (pe) peak. The
75 integrated charge is digitized every 25 ns. Ten digitizations were recorded per
muon trigger. The sum of the signal in the 4th to 7th sample was used.

The average number of pe’s produced per minimum ionizing particle (mip)
was estimated by doing a gaussian fit to the peak centered on the pedestal. The
mean number of pe’s was calculated using the fraction of events in this peak,

80 assuming a poisson distribution. The nominal tile produced 1.7 pe's per mip.
 Tiles for the CMS hadron calorimeter typically produce 3 pe's per mip[2]. The
 results have a systematic uncertainty related to the handling of the events with
 showering muons. We evaluate this uncertainty by looking at the results after
 truncating the distribution at around 25 pe's (2500 adc counts). The results
 85 were stable to within 5%. In addition, runs taken with varying amounts of
 material in front of our detector, from several radiation lengths to a **what was
 the upstream material for the best** resulted in a 15% variation in light yield.
 We therefore take a 16% uncertainty due to upstream material.

The uniformity of the light collection was also studied at the CERN test
 90 beam. Figure 2 shows the fraction of events with at least one pe versus the
 impact position of the mip along the axis parallel to the support tubes (left)
 and perpendicular to the support tubes (right). As expected, there is little
 dependence on the coordinate parallel to the support tubes. The light yield
 does depend on the perpendicular distance. The light collection efficiency is
 95 maximum at for muons near the WLS fiber and is approximately 30% lower
 for muons in the center or edges of the tile. For most hadron calorimetry
 applications, we verified through simulation that this degree of nonuniformity
 would not aversely affect jet resolutions.

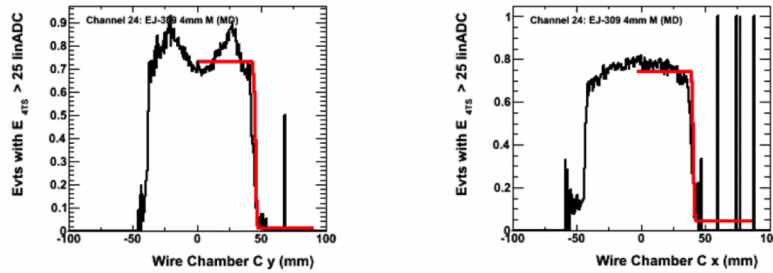


Figure 2: For the nominal liquid tile, fraction of mips with at least one pe as a function of the
 impact position of the mip along the axis parallel to the support tubes (left) and perpendicular
 to the support tubes (right).

4. Light yield dependence on tile parameters

100 The dependence of the light yield on variations in the design parameters was studied using cosmic ray data taken at the University of Maryland. Scintillator-based counters above and below the tile were used for triggers. The tile light output was measured using a Hamamatsu R7600U-200-M4 photomultiplier tube. Fibers were connected to the tube using optical glue. Data was collected with
105 a Techtronix MSO 5204 oscilloscope. No attempt was made to select minimum ionizing muons. The muons thus are low energy and will produce more light than those studied at the CERN test beam. We found an average of 2.88 ± 0.05 for the nominal tile. A similar tile but without the mirroring yielded 1.98 ± 0.03 pe, a reduction of a factor of 1.45. A tile with a 6 mm thickness of liquid, non-mirrored, yielded 2.61 ± 0.05 pe, an increase over the 4mm non-mirrored tile of
110 a factor of 1.32.

The light yield was also studied using the capillary instead of WLS fiber **no documentation at all in Sung Woo'd note on this**

5. Radiation hardness tests

115 Several different tests were made using irradiations with a ^{60}Co source located at the University of Maryland. Performance of the tile under irradiation in a proton-proton collision environment will be the subject of a future paper.

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120 6. Comparison with simulation, and optimization

We use the GEANT4 [7] package to simulate the optics of our tile. GEANT4's optical package includes simulations of refraction, reflection, wave length shifting, and light attenuation. A variety of options for the reflection are available. We used the "Specular Spike" option for the Al and an absorption length of 2m
125 for the EJ-309. When simulating the WLS fiber, an air gap was included between the fiber cladding and the support tube, while no such gap exists for the

simulation of the capillary. An index of refraction of 1.57 is used for the EJ-309. The index for sapphire used was 1.77. For quartz, values between 1.46 and 1.55 were used. Photons are generated at random positions inside the liquid volume,
130 with a wavelength corresponding to the emission maximum of EJ-309.

As shown in Figure 3 left, we find the simulation reproduces the light collection nonuniformity when a reflectivity of 0.9 is used for the mirrored Al.

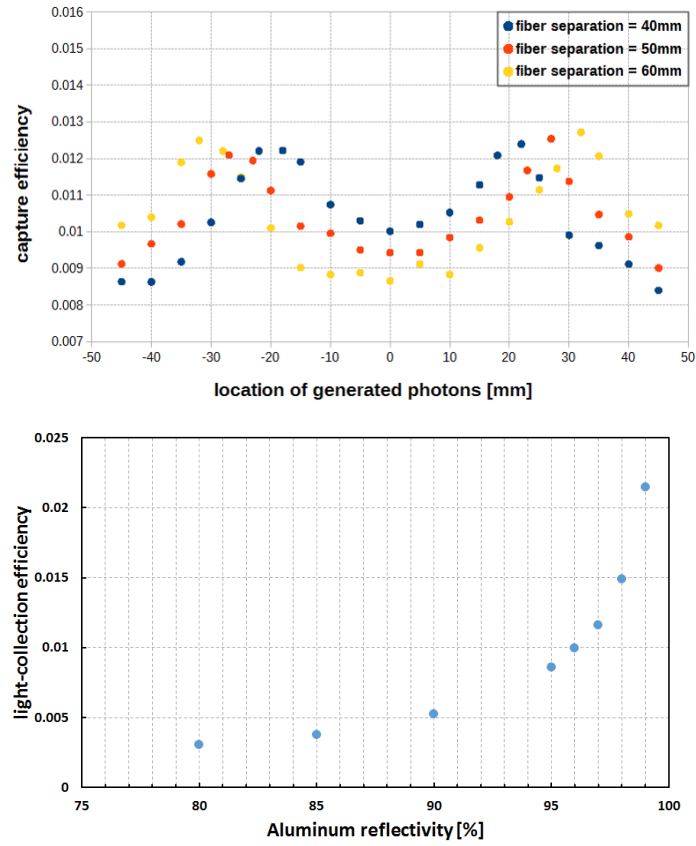


Figure 3: (left) Ratio of light yield to maximum light yield from simulationed tile as a function of the distance perpendicular to the support tubes. figure is place holder until Zishuo gives right one (right) Light collection efficiency vs Aluminum reflectivity Zishuo can you make this a ratio plot? pick some point and divide the rest by it?

We find that the light collection efficiency is a strong function of the reflectivity of the Al (Figure 3 right).

135 We find the best light collection comes when the support tube has the lowest possible index of refraction for liquid WLS. The opposite is true for a fiber with an air gap (and plastic WLS). For a 1mm diameter for the WLS, the light collection efficiency increase by a factor of **Zishuo please add this number** going from an index of 1.55 to 1.46 for liquids. Presumably this difference would
140 decrease as the reflectivity of the Al increases. For a fiber with an air gap, the efficiency decreases by a factor of **Zishuo please add this number** going from an index of 1.77 to 1.46.

7. Conclusions

We presented results for a liquid scintillating tile using wavelength shifting
145 fiber readout. For our nominal design, 1.7 ± 0.2 pe's were produced for minimum ionizing particles.

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