STUDY OF NEW TRIANGULAR TYPE FNAL-NICADD EXTRUDED SCINTILLATOR FOR THE MINERνA DETECTOR

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1 NICADD NIU
2 FNAL

INTRODUCTION

The tested scintillator is to be used in the MINERνA detector, which will be located on the Fermilab site. The detector will use the NuMI beam and will be positioned in the MINOS Near Detector Hall. The main goal of this detector is to understand neutrino interactions. The essence of the MINERνA detector is that it must reconstruct exclusive final states (high granularity for charged tracking particle ID, low momentum thresholds [e.g. $\nu_\mu n \rightarrow \mu^- p$]), but must also contain electromagnetic showers (π^0, $e^\pm$), high momentum hadrons ($\pi^\pm$, ρ, etc.), $\mu^\pm$ from CC (enough to measure momentum), and nuclear targets (high A, Fe of interest for MINOS) [1].

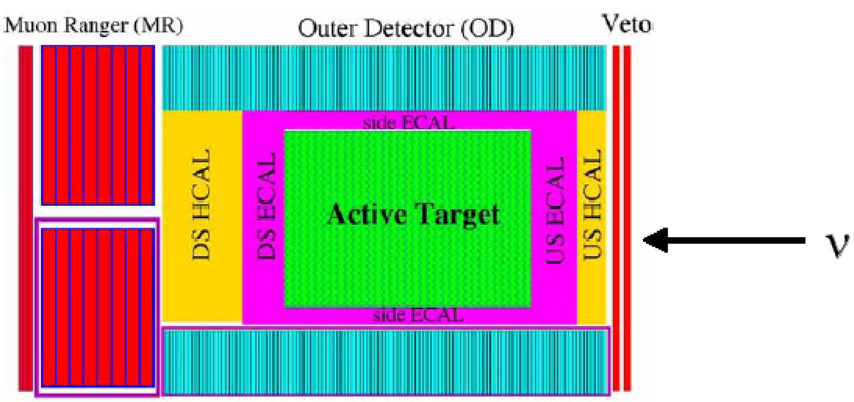

Fig. 1: Detector Overview [1]

The large size of the calorimeter lends itself to the use of extruded plastic scintillator strips instead of utilizing cast plastic scintillator because the price of the extruded material is approximately $10 per kg compared to the price of cast scintillator at about $40-$70 per kg [2,3]. The scintillator used in these detectors will be extruded at FNAL using the FNAL-NICADD Extrusion Facility [4,5]. The optical characteristics of the bulk material are the same as those of the MINOS and K2K extrusions. Figure 2 shows the transmittance and fluorescence spectra for this blue-emitting scintillator. It presents an absorption cut-off at ~ 400nm (for a 1-cm path length) and an emission maximum at 420 nm. The extruded scintillator for the Active Target will have a triangular shape, with approximately a base of 31 mm and a height of 17 mm. The strip contains a hole centered along the vertical axis where a 1.2-mm diameter WLS fiber will be inserted. The diameter of the hole is specified at 1.5 ± 0.1 mm. The strips will be assembled into planes, which then can be stacked on top of one other [1].

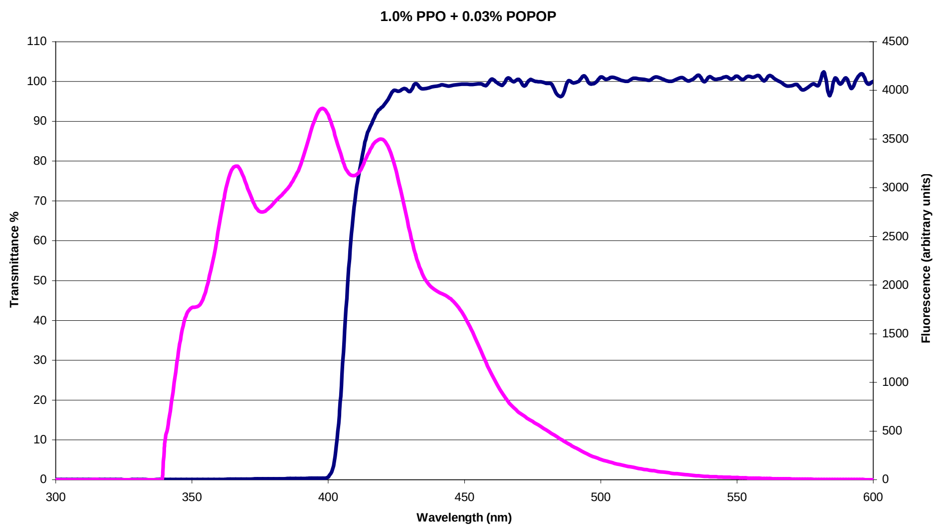

Fig. 2: Transmittance and fluorescence spectra of Minerva extruded scintillator

As part of the R&D for the Minerva experiment, various extrusion runs have been carried out to prepare the triangular scintillator strips. These strips are used in the current study. Here we present the results of the attenuation lengths measurements performed, the effect of the hole diameter on light yield and the light yield determined using the cosmic ray test-stand.

SETUP 1: ATTENUATION LENGTH

In order to measure the attenuation length of the triangular strips (Fig. 4) we first selected fourty different 1-m long strips; half of which had a hole that would fit a 1.2-mm WLS fiber (called the 1.2-mm hole), and the other half with a hole that would suit a 1.5-mm diameter WLS fiber (called the 1.5-mm hole). We then polished one end of the strip, placed the strip in a Tyvek sock (one sock formed to slide on and off from each strip as to avoid irregularities in separate wrappings), and inserted it inside a black box with the polished end touching the PMT. A WLS fiber was not used in this setup. Then by measuring the light yield induced by a ^{137}Cs gamma source along a number of set points down the strip, we can compute the attenuation length by examining the exponential growth of the derived light yields.

As expected, the attenuation lengths were independent of the hole sizes; the long and short components were 42.15 ± 1.14 cm and 30.52 ± 0.74 cm respectively for the 1.2-mm hole, and 44.05 ± 0.94 cm and 30.33 ± 0.77 cm for the 1.5-mm hole. These give errors of 2-3 %, which makes for very homogenous results. This bares witness to the even distribution of the dopants in the plastic and the consistent quality of the process utilized. Figure 4 shows the homogeneous distribution of attenuation lengths for a random sample of nine of the strips.

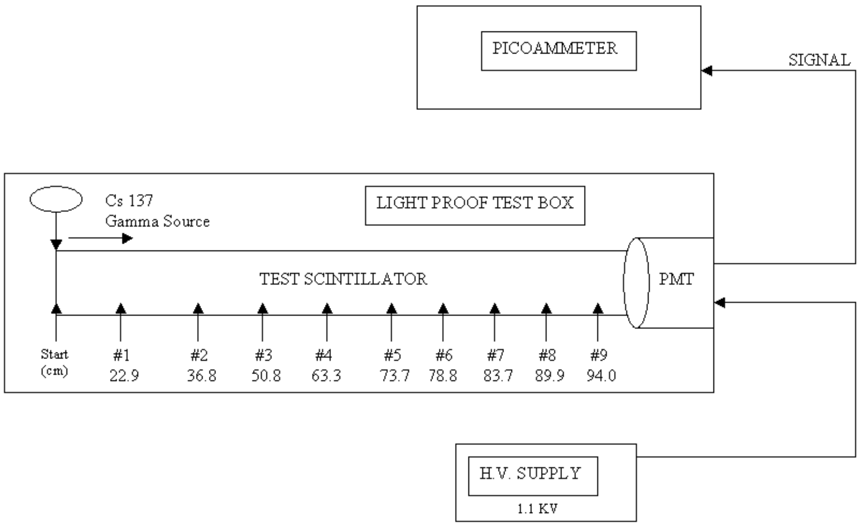

Fig. 3: Attenuation Length Measurement Setup

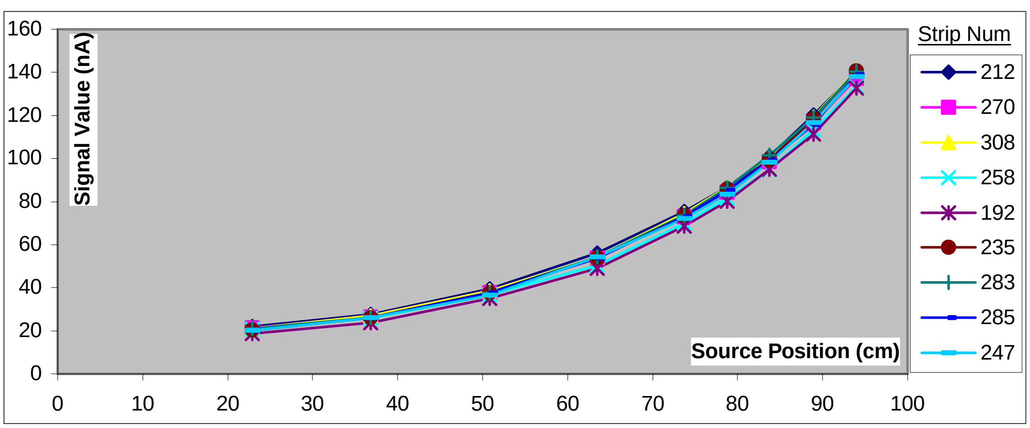

Fig. 4 Attenuation Lengths

SETUP 2: RELATIVE LIGHT YIELDS

The setup was similar to that of the attenuation length measurements, with a few changes to accommodate for the optical WLS fiber (Fig. 5). We wound the fiber (about 1.5 m long) around into the photomultiplier tube, and used a fixture to hold it so there was direct contact with the surface of the PMT. We measured only four points along the strip because of the small change in light yield due to the long attenuation length of the WLS fiber (on the order of five meters). Then we took measurements of an assortment of different strips with varying hole diameters.

In order to measure if the size of the hole would affect the light yields of scintillator strips we measured a sample with a variety of hole sizes. Regardless of the hole size, we inserted the same 1.2-mm WLS fiber and measured the resultant light yield. Figure 6 shows the approximate ratios of hole size to fiber size, with 0.9 being a close fit and 0.3 being very loose. A total of 25 strips were measured.

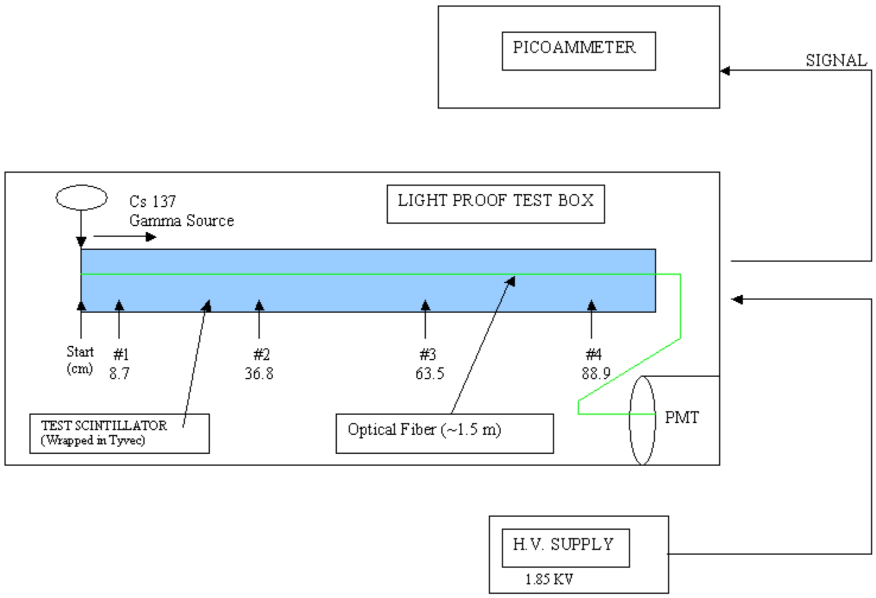

Fig. 5: Light Yield Measurements with WLS Fiber

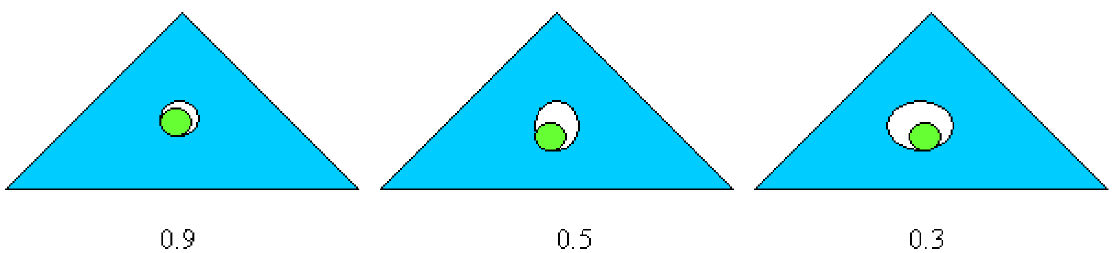

Fig. 6: Hole to fiber ratios

The strips in Figure 7 were measured with a reflective foil touching the far end of the WLS fiber, but in order to avoid irregularities in the contact with the fiber we also re-measured without foil (Fig. 8). The average light yield of the scintillator strips with the reflective end compared to that of the strips without the foil was 1.41 times greater. The "Far Light Yield" and the "Near Light Yield" refer to the points measured farthest from and nearest to the PMT respectively. "Average Light Yield" is the mean of all four data points. The data plotted in Figure 7 shows that there are only small variations in light yield throughout the strips measured. The average relative light yield is 20 ± 1 nA. The spread of the measurements is approximately 5 %. A better match between hole and fiber diameter (0.75-0.9 ratios) does not render a higher light yield. A large mismatch between hole and fiber diameter represented in the lower-ratio range results in light yields that are similar to the rest of the data. The variations in the measurements were larger when the light yield was measured without a foil at the farthest end of the scintillator strip. The average light yield was 14 ± 2 nA. The spread of the measurements is approximately 9 %. However, no correlation is observed in the case either between the hole/fiber ratio and the light yield. Figures 7 and 8 illustrate that the hole size does not have a significant effect in the light yields.

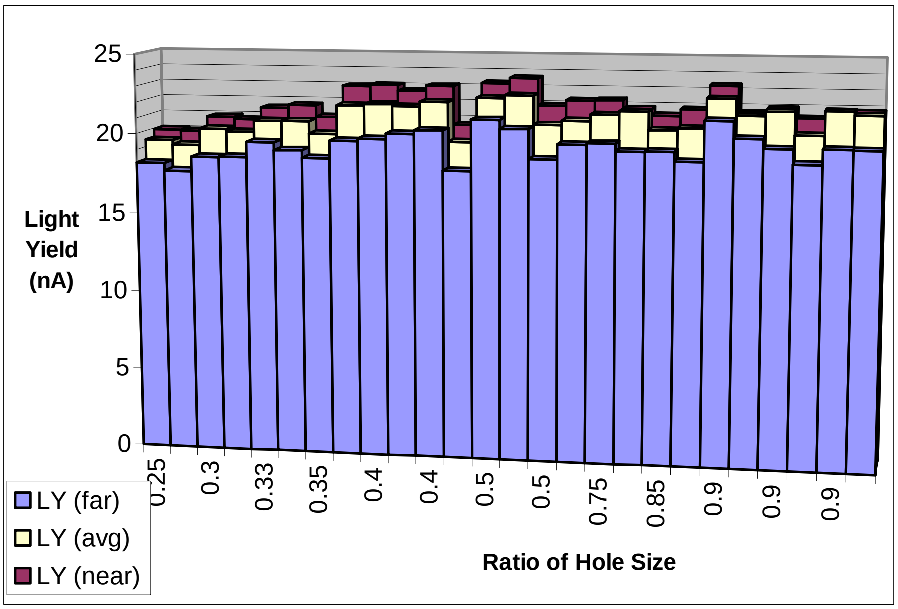

Fig. 7: Effect on Light Yield Due to Hole Sizes with Reflective End

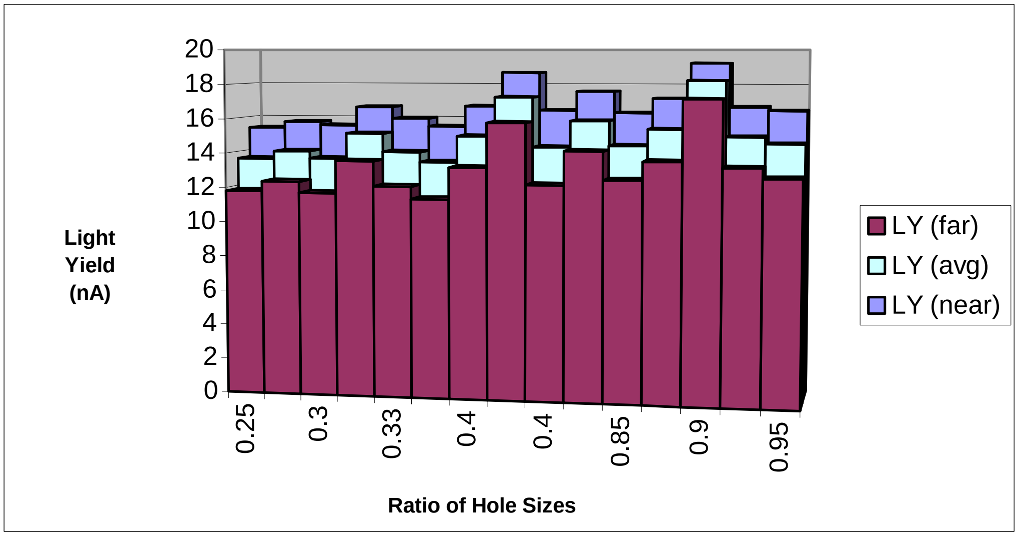

Fig. 8: Effect on Light Yield Due to Hole Sizes without Reflective End

During summer 2004, using a setup similar to the one shown in Figure 5, we had measured the light yield of a scintillator strip with and without mineral oil filling the hole. We found that the light yields were 1.5 times higher when the mineral oil was utilized (Fig. 9). We wanted to try now a more formal experiment to see if the results were reproducible.

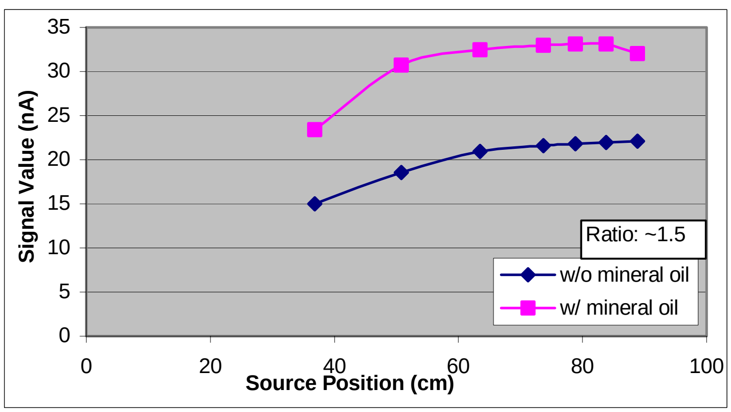

Fig. 9: Scintillator with and without Mineral Oil

In preparation to check the glue effect in the light yield, we selected six fibers and six strips without the reflective foil. Using the setup described in Figure 5, we measured each fiber in one strip of scintillator as a means of calibrating the fibers (Fig. 10).

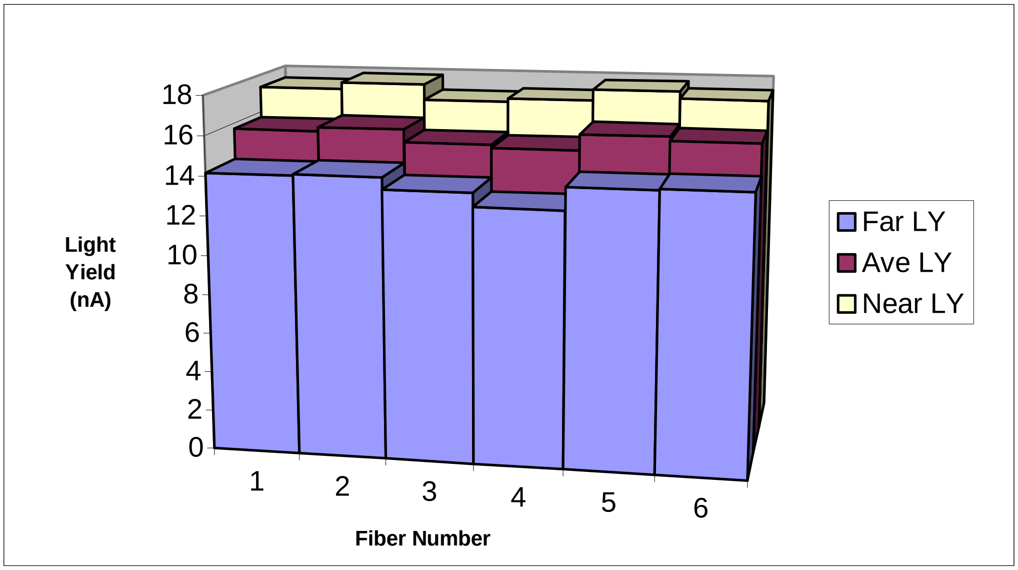

Fig. 10: Optical Fiber Calibration

After comparing the fibers, we then inserted each one into a designated scintillator strip. Each strip was selected to show the effects of a wide range of hole sizes. The approximate hole to fiber ratios were: 0.9, 0.9, 0.4, 0.3, 0.3, and 0.3. After normalizing the strips to the calibrated fiber data previously mentioned (as to ignore the effects of separate fibers), we again found that the size of the hole had no significant effect on the resultant light yields (Fig. 11). We then filled the holes of the six scintillator strips with BC600 glue to examine how it would affect the results. Each fiber was kept in the same scintillator strip to avoid any inconsistencies. The light yields of the scintillator strips with the glued fiber were approximately 1.9-2.0 times higher (Fig. 12-14) that those without glue.

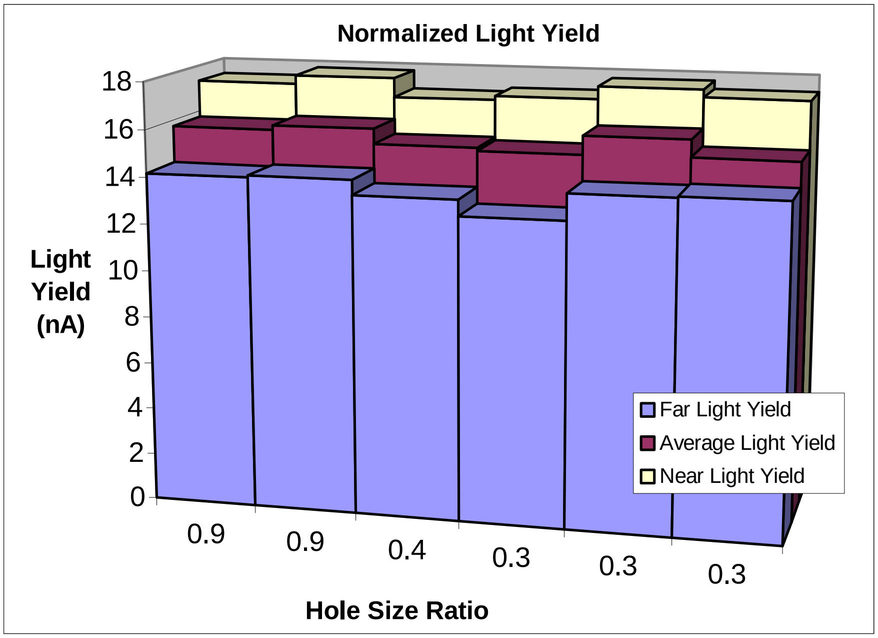

Fig. 11: Normalized Light Yield Without Glue

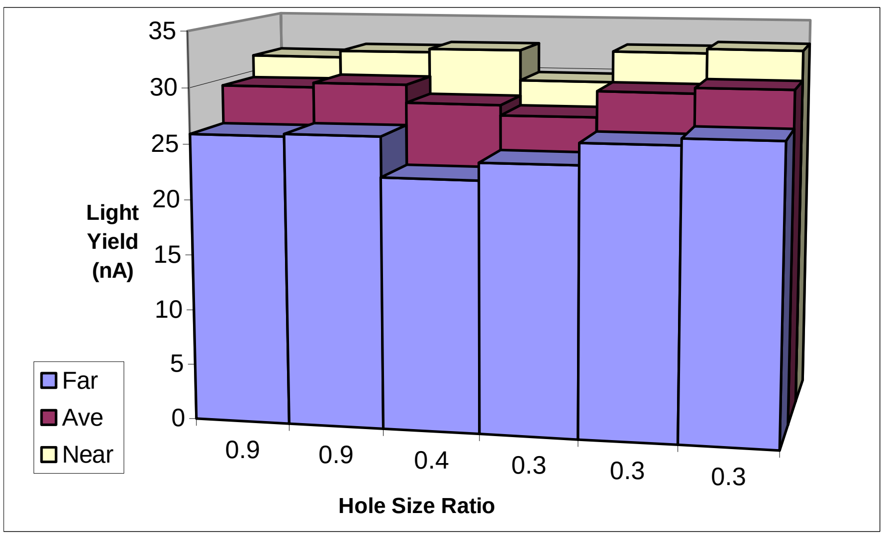

Fig. 12: Normalized Light Yield with BC600 Glue

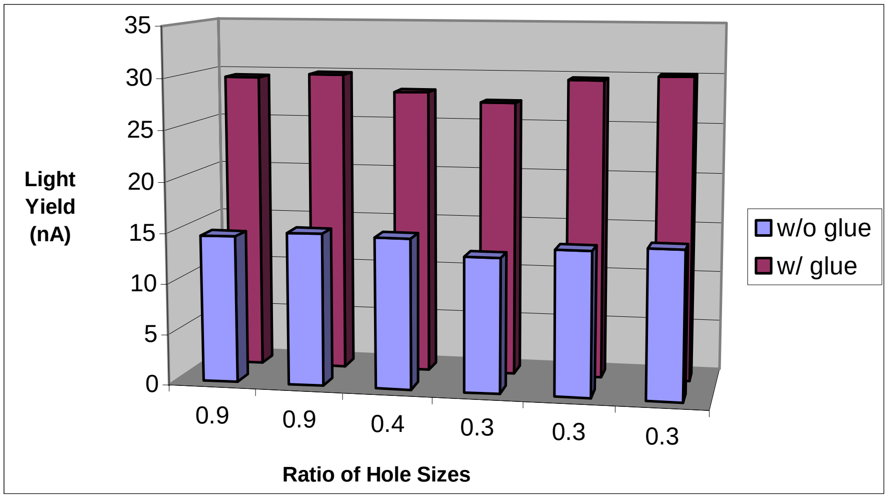

Fig. 13: Average Light Yield With and Without Glue

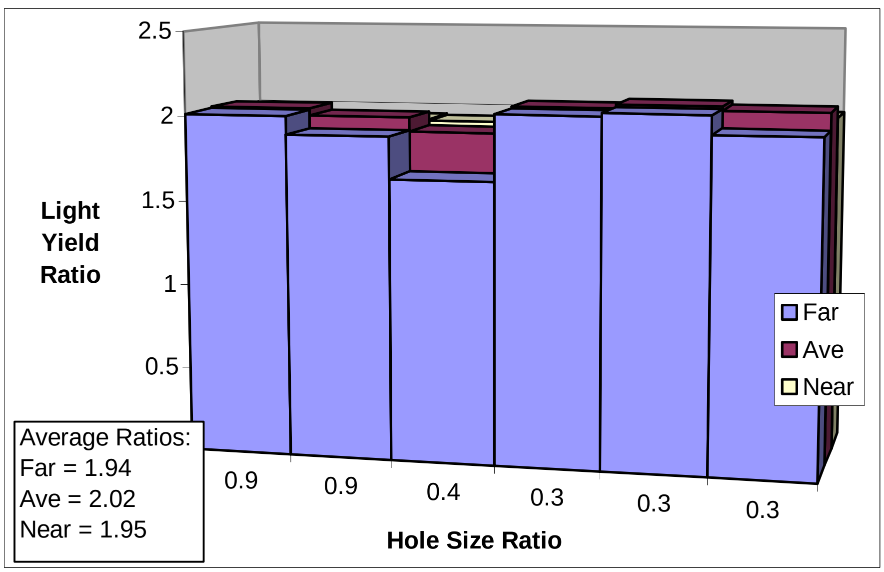

Fig. 14: Ratio of Glued to Unglued Light Yields

SETUP 3: COSMIC RAY TEST

The last test performed on the triangular scintillator was to determine the light yield expressed as number of photoelectrons. The Cosmic Ray test-stand described in Figure 6 was used for this purpose. Two scintillator strips (1 m long) individually wrapped in Tyvek and taped together were used. The WLS fibers were glued in the hole using BC600. The fibers were connected to a photomultiplier tube (PMT) which proceeded to a delay and finally to an analog-digital converter (ADC). The total length of

WLS fibers was 1.5 m. Hamamatsu H3178-61 PMT was used for these measurements. This PMT has a bialkali photocathode with peak wavelength sensitivity at 420 nm. The size of the trigger counters was significantly less than size of one triangle side. The surface of each counter was about 15 cm^2 which corresponds to 0.7 % of the total surface of the side where the triggers were mounted. Both trigger counters were positioned in the middle of the scintillator strip and connected to an amplifier (A), discriminator (Dis), and coincidence unit (&), which subsequently linked to the ADC. All the components involving scintillator or photomultiplier tubes were placed inside a lightproof box.

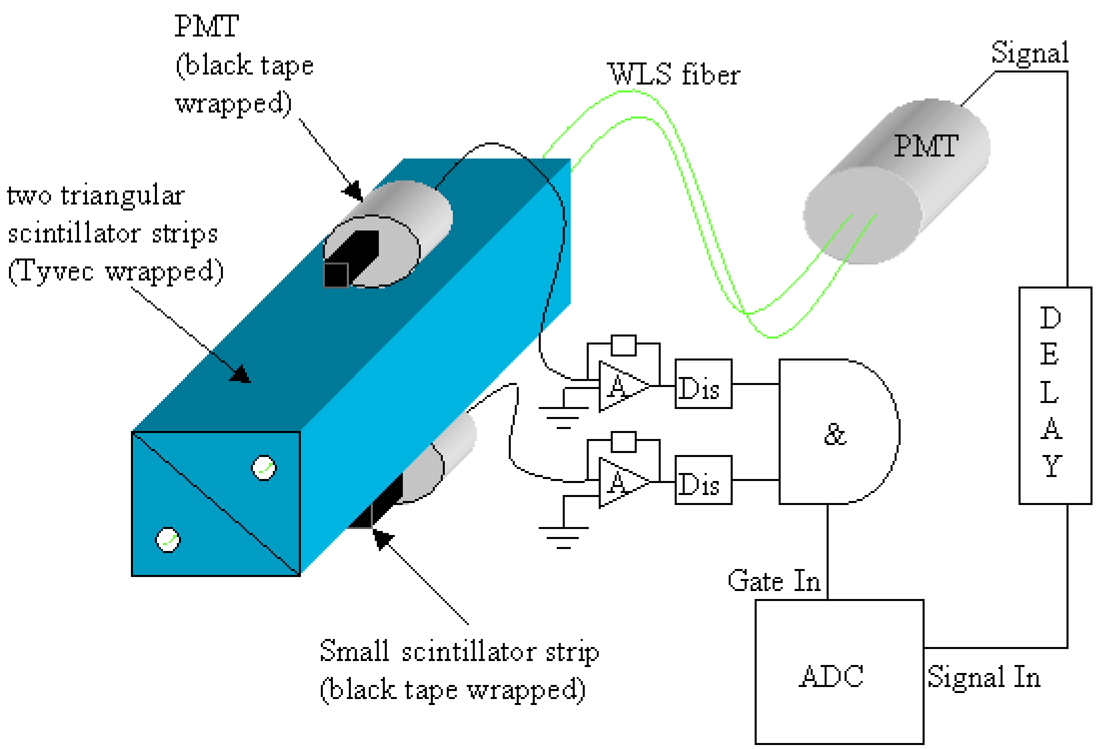

Fig. 15: Cosmic Ray Test Setup

The average number of photoelectrons, N, can be estimated from the charge spectrum utilizing the following relationship:

$$N = \left(\frac{A}{\sigma}\right)^2$$

In this equation, A is the mean of the entire distribution and σ is the standard deviation for the entire distribution [6]. The mean and the standard deviation can be derived from fitting the data of the charge spectrum to a Gauss distribution. The amplitude distribution and fit to the left edge of the distribution is shown on Fig. 16. The pedestal is in count number 49 of the ADC. In our measurements, N was 18.4 ± 1.5 photoelectrons for a one triangular strip normalized to the thickness of 1.7 cm. The scaling to the first electron distribution gives approximately the same value. The result was consistent within 20 %

for the three measurements performed. The measurements were done without reflective end. The use of a reflective end will increase the light yield by a factor of 1.4 to 1.5 as mentioned in an earlier section.

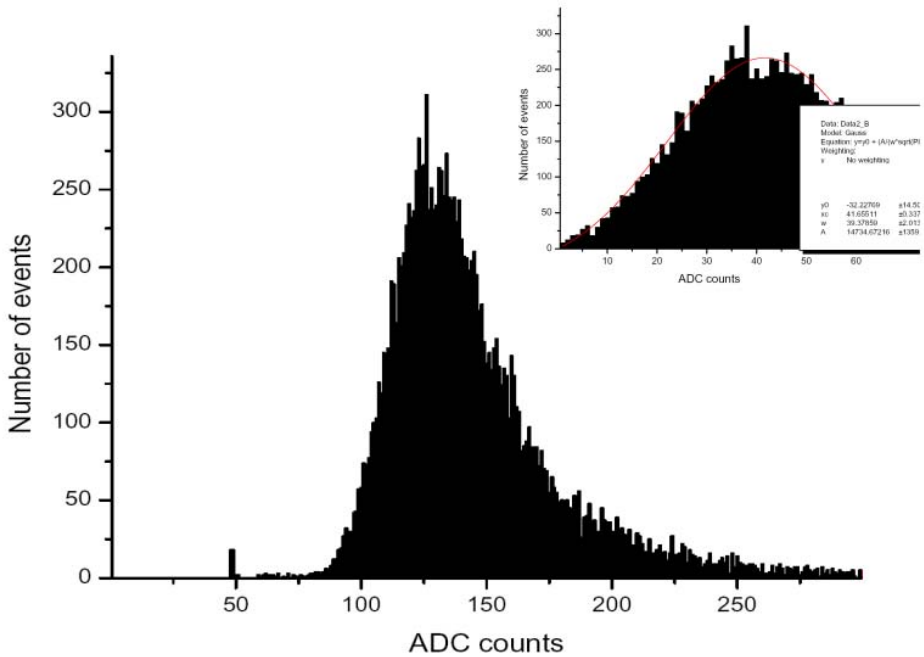

Fig. 16: Amplitude distribution

Summary

Measurement Synopsis	*Number of Strips Measured*	*Results*	*Comments*
Measured Attenuation Lengths	40 (20 1.2mm hole) (20 1.5mm hole)	*1.2mm hole:* 42.15±1.14 cm 30.52±0.74 cm *1.5mm hole:* 44.05±0.94 cm 30.33±0.77 cm	Witness to a consistent process (2-3% Spread) (Fig. 4)
Effect on Light Yield due to hole size (with reflective end)	26	*Spread:* Far: 4.82% Ave: 4.68% Near: 4.56%	No visible relationship between light yields and hole sizes (Fig. 7)
Effect on Light Yield due to hole size (without reflective end)	15	*Spread:* Far: 11.92% Ave: 9.01% Near: 6.76%	No visible relationship between light yields and hole sizes (Fig. 8)
Measured Light Yields with WLS Optical Fibers	1 (6 fibers)	*Spread:* Far: 3.66% Ave: 2.18% Near: 1.83%	Calibrated and Normalized fibers (Fig. 10)
Measured Light Yield of strips, each with their own optical fiber	6	*Spread:* Far: 5.90% Ave: 4.25% Near: 3.91%	No visible relationship between light yields and hole sizes (Fig. 11)
Measured scintillator with mineral oil (Summer 2004)	1	*Without Oil:* Ave: 20.28 nA *With Oil* Ave: 31.11 nA	~150% increase in light yield compared to without Mineral Oil (Fig. 9)
Measured Light Yield of strips, each with their own fiber and glue	6	*Without Glue:* Ave: 14.39 nA *With Glue:* Ave: 29.02 nA	~190-200% increase in light yield compared to without BC600 glue (Fig. 11-14)
Cosmic Light Yield	2	18.4(for the side of 1.7 cm) Photoelectrons	Fig. 16

$$\left(SPREAD = \frac{STANDARD\ \ DEVIATION}{AVERAGE} * 100 \right)$$

ACKNOWLEDGEMENTS

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