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MRS Photodiode Coupling with Extruded Scintillator via Y7 and Y11 WLS Fibers

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Abstract— **Extruded scintillator with co-extruded hole and reflective coating will be used both in MINERvA and T2K experiments. We have studied WLS (wavelength shifting) fiber (Y11 and Y7) for different shapes of the extruded scintillator readout using MRS (Metal/Resistor/Semiconductor) photodiode. The Y7 fiber was considered because of its lower then Y11 cost. The purpose was to find out which fiber performs better in above configurations. First, the responses for both types of fibers, with and without optical grease, were measured by PMT (Photomultiplier Tube). The PE (photoelectron) yield from cosmic rays for different scintillator shapes and both fiber types, as seen by MRS photodiode, are reported. The attenuation lengths of Y11 and Y7 were measured using MRS. Y7 fiber shows somewhat better performance at small distances from the photo detector.**

I. INTRODUCTION

To take the full advantage of the physics potential of the currently planned e+e- linear collider detector [1] [2], and the T2K neutrino beam near detector [3], the presence of the strong magnetic field will be required.

The performance requirement of the photodetectors in the magnetic field has directed our attention to the MRS photodiode that is known to be insensitive to the magnetic fields of 9T [4]. As silicon based device, MRS has a different spectral sensitivity then PMT. Using this photodiode we studied the properties of two Kuraray [5] multicladed wavelength shifting (WLS) fibers: Y7 and Y11; and the coupling of the photodiode to the extruded [6] scintillator via those fibers. Attenuation length, light yield of the scintillator used, and effect of optical grease in the co-extruded hole on scintillator-fiber coupling were studied. These results are useful for any detector using WLS fibers.

II. DESCRIPTIONS AND SCHEMATICS

A. MRS Photodiode Description and Operational Principle

The MRS photodiode is a multi-pixel solid-state device with every pixel operating in the limited Geiger multiplication mode. A resistive layer on the sensor's surface accomplishes avalanche quenching. The devices used were of round shape, and they had ~ 1000 pixels per 1.1mm diameter photosensitive area, with quantum efficiency (QE) of the device reaching ~25% at 500nm, and reaching peak QE of approximately 30% at ~550nm [7]. In addition, MRS is found to be non-sensitive to the magnetic fields of up to 9T [4].

B. Types of Scintillator Used

The following types and shapes of the scintillator were used: extruded scintillator with co-extruded hole and coating for the MINERvA [8] (both triangular and rectangular shaped) (Fig. 1), and the K2K SciBar [9] 1.3x2.5cm^2 rectangular extruded scintillator also with co-extruded hole and coating.

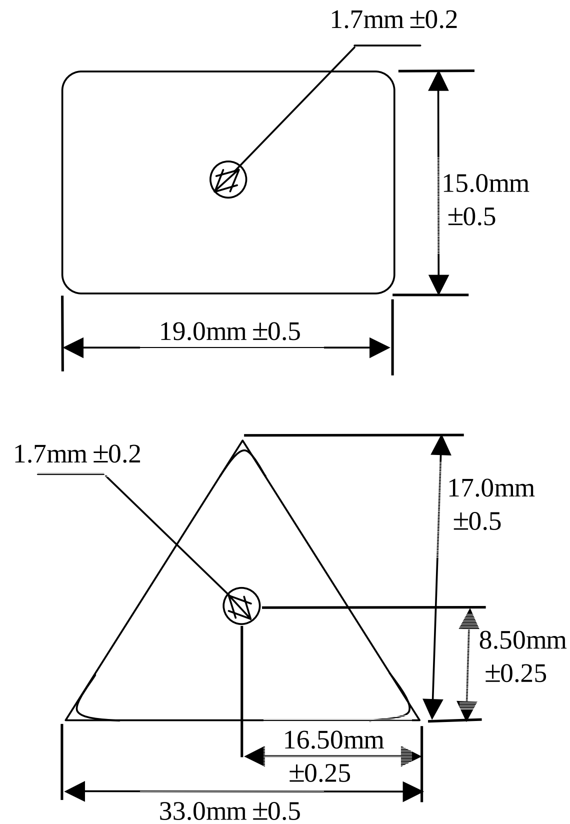

Fig. 1. MINERvA rectangular (top) and triangular (bottom) shaped extruded scintillator with co-extruded hole and coating.

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C. Schematics of PMT Measurements

Light output measurements for different WLS fiber diameter with and without optical grease in the co-extruded hole for Y11, and for 1.2mm outer diameter Y7 fiber were conducted using the Hamamatsu PMT R580 [10]. The PMT was readout by Keithley [11] 6485 picoammeter. The Y11 fibers with different diameters were tested to see the light yield change for each diameter in the same sized co-extruded hole; the Y7 fiber was 1.2mm outer diameter only. Fibers were cut from a reel. All fibers were 16cm in length, this is 2cm longer then the scintillator piece used in this setup. The fibers' ends in contact with PMT were polished using a fly-diamond technique. The other ends of the fibers were cut at 45^o and painted black to prevent reflections.

The attenuation length of scintillator without fiber was measured using same PMT-picoammeter setup. The triangular shaped extruded scintillator bar with co-extruded coating was testede. The setup schematics of these measurements are given in Fig. 2.

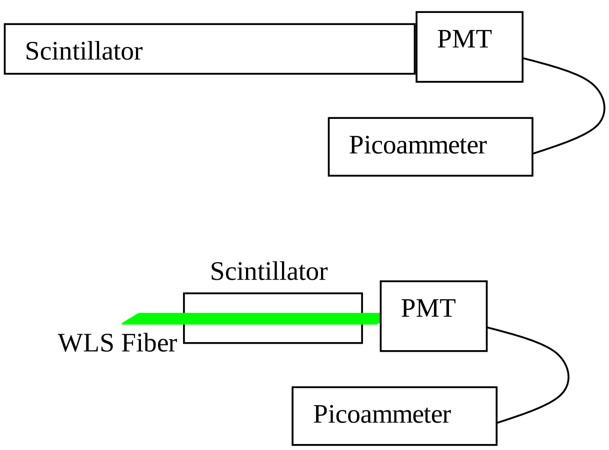

Fig. 2. Setup for scintillator attenuation length measurements (top), and for measurements with WLS fibers (bottom).

For attenuation length measurements, the radioactive source was placed on the center of the 33m base of triangular scintillator with an accuracy of approximately 3 mm and was not collimated. In addition, the attenuation measurement was repeated using a Bivar [12] LED5-UV-400-30 T1 3/4 5mm UV LED with peak emission at 400nm, to see how the results may change with a different way to excite a scintillation light.

D. Measurements using MRS Photodiode

For the measurements with cosmic rays, the ~14cm long pieces of SciBar and MINERvA scintillators were used in conjunction with 1.2mm pieces of Y11 and Y7 WLS fibers. The fibers were ~16cm long, polished at one end and cleaved at 45^o and painted black on the other because using mirrored fiber option was unavailable at that time. There was ~1 cm between the sensor's cap (that held the fiber in alignment with photosensitive are of MRS) and the scintillator. For top and bottom triggers, the 1x2x10cm pieces of extruded [6] scintillator with co-extruded coating were used, coupled directly to the PMT face using optical grease.

For the fiber attenuation length measurements, the 1.2mm outer diameter 3m long Y11 and Y7 fibers were used. In both samples, the concentration of dopant was 175ppm. Both fibers were polished at one end, and cleaved at 45^o and painted black at the other. As a light source, a Bivar [12] UV LED coupled to 2x2x3cm extruded [6] scintillator with co-extruded hole was used. The pulse generator was providing the gate signal as well as 15ns wide square pulses for LED.

The schematics for both setups are presented in Fig. 3.

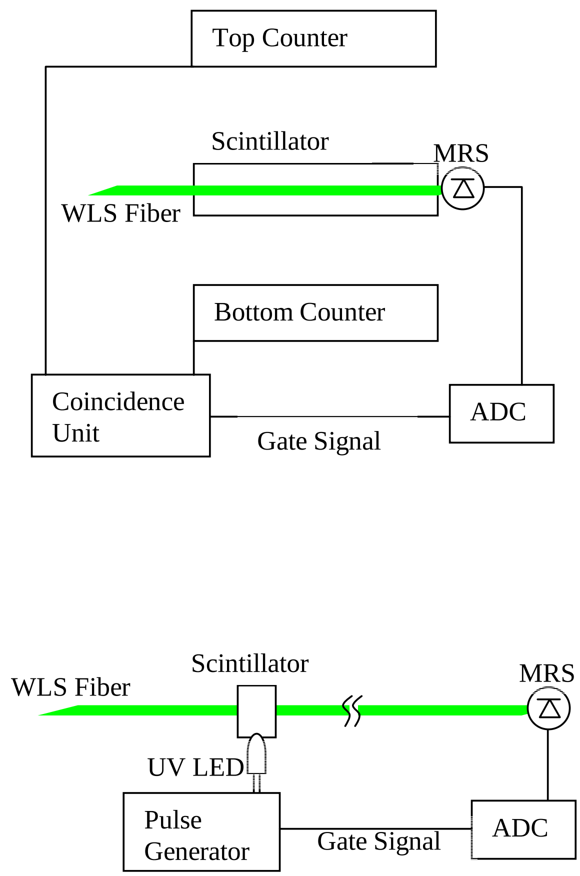

Fig.3. The setup for cosmic rays (top), and for fiber attenuation length (bottom) measurements.

III. Experimental Results

A. PMT Measurements

The results for the light output for different diameter fibers (Y11), and 1.2mm Y7, with and without optical grease, are presented in Fig. 4. For these measurements, the R580 PMT was biased at 1300V and directly connected to the picoammeter. The scintillator was illuminated by UV LED. Special care was taken to prevent LED light from reaching the PMT directly. A non-transparent cap was placed on the PMT to provide this needed light insulation and to hold fiber in place. All tested fibers were placed in front of the same photocathode area during this measurement. The Bicron BC-630 [13] optical grease was used.

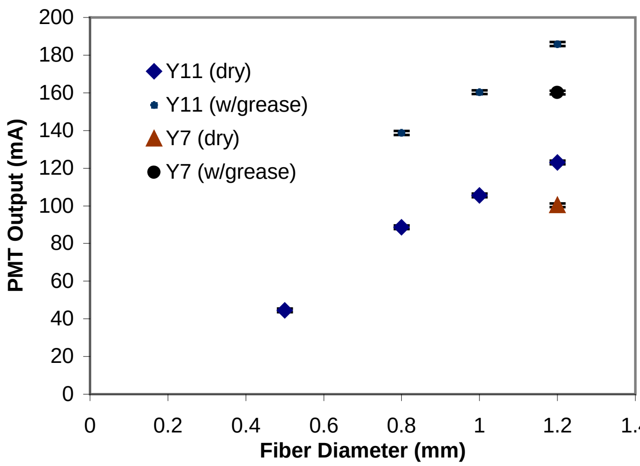

Fig. 4. The PMT output for various WLS fibers (with and without optical grease for each fiber tested).

From Fig. 4 we see the ~53% increase in light yield when the optical grease is used. It indicates that gluing WLS fiber inside the co-extruded hole will provide similar increase in light output. The light yield of the 1.2mm outer diameter Y7 WLS fiber, as measured by PMT, is lower than that of the 1.2mm outer diameter Y11 WLS fiber.

The results for the bulk scintillator light attenuation length of the triangular shaped MINERvA bar is shows in Fig. 5. Measurements were conducted using ^{137}Cs and UV LED, yielding similar results. For technical reasons, the zero position in radioactive source measurements is defined at the PMT, and at the end farthest from the PMT for LED measurements. A ~60cm long scintillator bar was used. For this test, a casing with ~1mm diameter hole for light output was built for the LED. Such LED light source was better collimated then the radioactive source. A wand configuration of gamma source without additional collimator was used.

The tests yield results of ~10.1cm for UV LED measurement and ~10.2cm for ^{137}Cs. The difference between results is ~1% indicating that UV LED in the attenuation length measurement performs similar to the radioactive source.

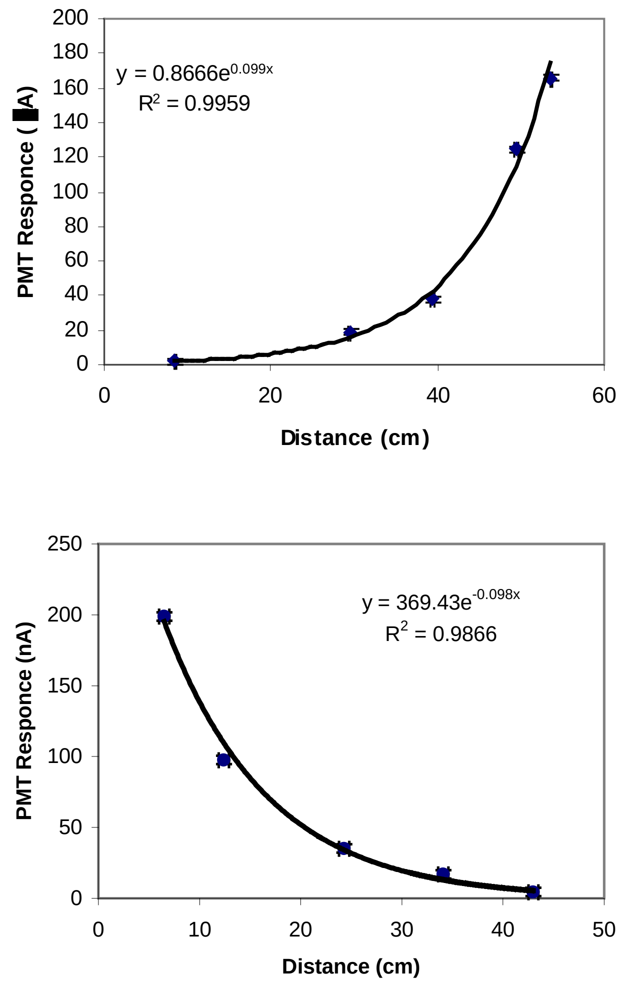

Fig. 5. PMT response to UV LED position (top) and radioactive source position (bottom) along the bulk triangular shape scintillator without WLS fiber, yielding attenuation lengths of ~10.1cm and ~10.2 cm respectively.

B. Measurements using MRS Photodiode

The measurements conducted using the MRS photodiode include light yield from cosmic rays for various scintillator coupled to the sensor with Y11 and Y7 WLS fibers, and the attenuation lengths for both of these fibers.

The schematic for cosmic rays measurements is in Fig. 3 (top). MRS photodiode was calibrated using the procedure described in [14]. The optimal operating bias voltage was found to be 27.84V. From calibration, one PE corresponded to ~8.15 ADC (analog-to-digital converter) channels.

Results are displayed in Table I. The ADC channels mean values and the PE conversions are indicated and are rounded off to first digit after decimal point. For MINERvA triangular scintillator, two results are quoted: "center" and "side". For "side" measurements, top trigger was turned 90^{o} (thus becoming 1cm wide) and placed over the edge of the triangular scintillator. In all results quoted, the position of pedestal is subtracted.

TABLE I
LIGHT YIELD FROM COSMIC RAYS FOR VARIOUS SCINTILLATOR COUPLED TO THE SENSOR WITH Y11 AND Y7 WLS FIBERS

Scintillator	Fiber (1.2mm)	MRS Response (ADC Channels)	MRS Response (PE)
MINERvA Rectangular	Y11	159.2	19.5
SciBar	Y11	139.2	17.1
MINERvA Rectangular	Y7	179.4	22.0
SciBar	Y7	159.7	19.6
MINERvA Triangular (center)	Y7	138.2	17.0
MINERvA Triangular (side)	Y7	48.9	6

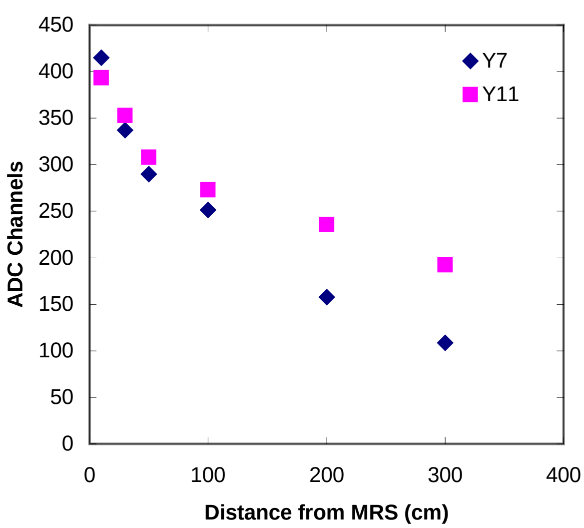

Fig. 6. Response of Y11 and Y7 WLS fibers vs. distance from photodetector. The respective error bars are smaller then size of markers and are not shown.

Out of all recorded data, the lower signals discernable from noise were ~47 ADC channels (~5.8PE). In MINERvA "side" test, this value is indicative of the measurable response of the scintillator edge.

The schematic for the light attenuation measurements in Y7 and Y11 fibers is shown in Fig 3 (bottom). A small 2x2x3cm piece of scintillator without coating and with co-extruded [6] hole was used in conjunction with UV LED as a light source. The results of these measurements are presented in Fig. 6. As seen, Y7 performs better at short distance whereas Y11 is better at large distances away from photodiode. The fitting with double exponent yields the following results: for Y11 get 35.5±0.3cm and 463.4±1.2cm, and for Y7 we get 11.2±0.3cm and 293.1±5.6cm.

IV. CONCLUSIONS

The comparison of the Y7 and Y11 WLS fibers is important for the R&D of the T2K project, for which both types of fibers were considered initially. Even though that Y7 fiber yields more light for a short distance from photo detector (as seem by MRS photodiode), for the length of fibers over 2m, as needed for T2K project, Y11 is preferable.

The ~53% increase in light output was detected for WLS fibers of different diameters when optical grease was used in co-extruded hole. Two geometries of the MINERvA scintillator bar were tested, triangular and rectangular. For triangular case, the lower response to cosmic rays measured for side was ~6PE (near photo detector), whereas at the center that value was ~17PE. The attenuation length for the bulk triangular scintillator was found to be ~10.1cm and ~10.2cm by using UV LED and radioactive source.

ACKNOWLEDGMENT

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