January 18, 2001-Revision Includes:
Experimental Setup; Reference- Fit
To Convolution(Landau and Gauss)

Study of fiber gluing and quality of fiber grooves in plastic scintillator with green wave-length-shifting fibers and the light yield which follows.

C. Milsténe

I) Introduction

Following NUMI and Yuri Kudenko's results, we have studied the effect on the signal of gluing fibers to the grooves in the plastic scintillator paddle used to collect energy from high energy cosmic muons (E> 4GeV). The setup is a telescope where 3 paddles are used to trigger the signal from high energy muons detected by the paddle under study, referenced to as the "Test Paddle". This setup is represented in Figure 1 but here the "Test" paddle is a smaller one used in the prototype of the CKM veto system, its size is 10cmx10cmx0.5cm, the size of the small trigger paddle sitting on top of it.

The result in the light yield was very much affected by the presence of impurities in the grooves to which the fibers were glued, e.g. air bubbles trapped between the plastic scintillator and the fiber. The quality of the groove appeared to be a very important factor as well in the homogeneity of the gluing process. The question which soon rise was, the contribution of the quality of the groove itself, in the improvment of the signal . This was only checked for a groove spacing of 1 cm and the result might be different for a wider fiber spacing.

II) The groove characteristics

Careful studies have been made for plastic scintillator paddles, of Bicron BC404, of dimensions 10cm$\times$10cm$\times$0.5cm with wave shifting fibers in the

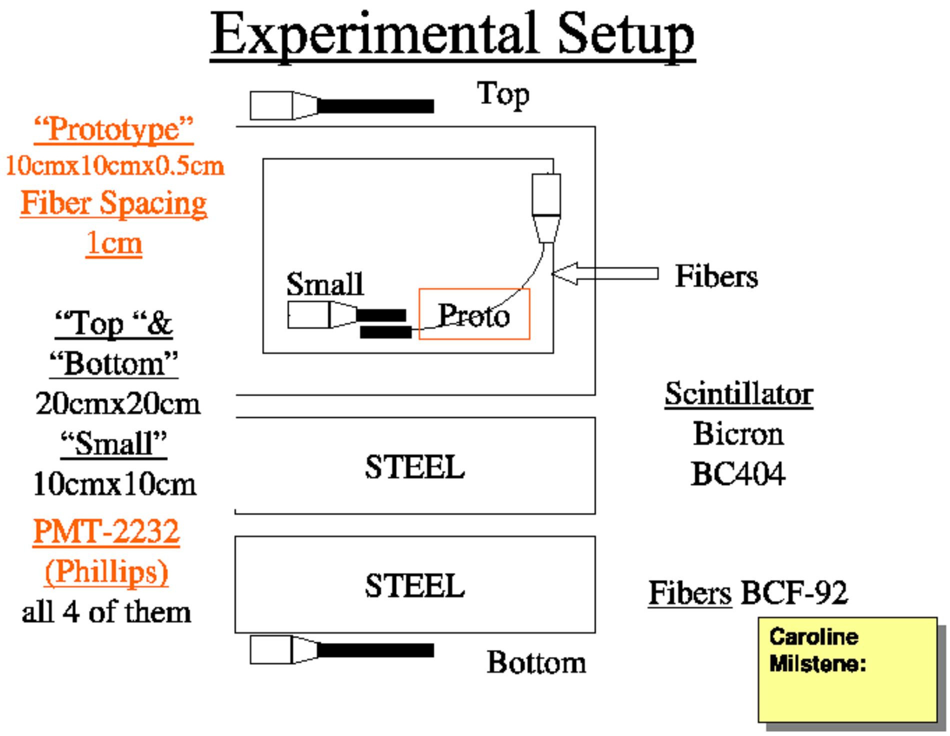

Figure 1: Telescope:test of the Prototype Paddles with High Energy Cosmic Muons

green bicron BCF92, having a diameter of 1mm and a double cladding. Those fibers have an aluminized mirror on one end for light reflection at the edge of the paddle. The other end of the fibers is bundled for all the fibers into a cookie to which they are glued. The light transferred to a Photo tube Phillips 2232 in close contact with the cookie. The plastic scintillator paddle has been wrapped in Tyvek for light reflection. It has been shown in a previous note that Tyvek was providing the best reflectivity among all the materials tried. The grooves had a U shape in the bottom and was 1.7mm deep and had a 1.1 mm diameter. The grooves are 1cm apart. They have been made:

1. With a straight Cutter, in a set of 5 straight passes at a speed of 3000 Rotations Per Minute(RPM). The feed was 3000 inches/mn which is 76.2 mm/minute. Each pass was cutting out 0.228 mm (0.009 inches) of depth.

2. With a ball cutter in a set of 4 passes 0.152mm each (0.006inch) In one of the pieces, paddle 7 only, an extra pass was done in reverse direction, without gaining any depth and just to smoothen the edges of the groove.

The size of both the end mill (straight cutter) and the ball nose is 0.044 inches. It is a requirement, in order to get a smooth surface, that both cutters have the same size. The quality of the ball noise is also very important. The groove smoothness decreases for a jagged ball nose.

III) The gluing Process

The homogeneity of the glue is crucial.

1. We have first degazed the glue by spinning it in a centrifuge for a minute or two and then we did put the glue in an open container in a vacuum bell untill a pressure of 0.3 atm was reached. This pressure was kept for 5 minutes

2. We have blown the scintillator and the fibers with pressured nitrogen to make dirts and other statics go away.

3. We have used a glue from Bicron, BC600. The glue was first put in the groove and then one fiber end was introduced.

The aluminized mirror was inserted in the groove and an angle was maintained between the fiber and the surface of the glue, this allowed to push away the air as the fiber was slowly inserted in the groove.

This part of the process was crucial to avoid air bubbles to set in the glue. During the glue degazing under the vacuum bell, many air bubbles would first escape, then, we kept it under vacuum of 0.3 atm until the glue became really transparent and homogeneous. This took approximatively 5 minutes depending on the athmospheric conditions that day.

The fiber insertion was done under microscope at a magnification of 25. Once the glue set, the quality of the gluing was checked again under microscope to spot bubbles and inhomogeneities. The result was perfect. A picture was taken and shows the effect of the refraction index at the edges between glue and air. Remark: Air bubbles which did setup on top of the glued fiber did not matter being part of the air surface. It is the air bubbles trapped inside the glue which are changing the optical parameters.

In the table are reported the signal and their Gaussian fit for the three prototype paddles. In two paddles with man-made grooves, one with glued fibers the other not. In one paddle the grooves were produced by the Thermwood machine and the fibers are not glued.

The pedestal are taken during the whole run in anti-coincidence with the signal.The signal+pedestal and the pedestal alone are accumulated in a computer and fed to 2 different plots during a run. At the end of the run the two plots are subtracted bin by bin, allowing to get rid of the noise as well. In the table the results are recorded after the pedestal subtraction.

Triggers	Paddle	$< Count > \pm$ (RMS/$\sqrt{Trig}$) PS .	RMS	Gaussian Fit Mean Sigma
Signal: 890 Pedestal: 9320	Prototype-9 Glued fibers	198.3±2.3	68.7	$193.1^{(ps)}\pm 2.28$ $54.24^{(ps)}\pm$ 2.02
Signal: 1790 Pedestal: 18927	Prototype-7 Unglued fibers	199.0±2.0	75.1	$187.0^{(ps)}\pm 1.8$ $57.5^{(ps)}\pm 1.7$
Signal: 810 Pedestal: 8470	Prototype-8 Unglued fibers Thermwood	166.5±2.45	71.2	$154.1^{(ps)}\pm 1.97$ $48.0^{(ps)}\pm 1.7$

Table 1: Mean Signal and Pedestal recorded *PS* stands for Pedestal Subtracted

The glued fibers are in Figure 3

IV) Experimental Results

Are summarized in the table. The signal in prototypes paddles 7 and 9 are compared to the signal in prototype paddle 8. The mean signal in paddles 7 and 9 are comparable and more than 5 sigma away of the signal in paddle 8. In the figure below are represented the prototype 7 and 9 with the man-made grooves. Paddles 7 and 9 had there grooves machined manually, while cooled by blowing cold air during the process, toward greater smoothness, whereas, the grooves of paddle 8 have been machined with the Thermwood at a speed of 20000 Rotations per minute (RPM) and a feed of 54 inch/minute, 7 passes were done by the machine. The speed and feed of the Thermwood was limited by the fact that the plastic Bicron 404 of the paddle was getting hot and could melt.

The differences between paddle 7 and paddle 9 come from the fact that paddle 7 got extra smooth edges. The grooves being improved further more to make the edges smooth as well, whereas the fibers of paddle 9 have been glued to the groove using Bicron 600 glue for its optical properties. The extra smoothness of the edges of paddle 7 have been achieved by an extra pass of the ball nose without going deeper. This extra pass was not included in paddle 9 The signal from paddle 7 is shown below in Figure **??**

One can see that the signal in both paddle 7 and paddle 9 are equivallent but significantly better than the signal in paddle 8. This seems to point out to the fact that the better the groove the better the signal.The optical contact being the important parameter. This could contribute to the higher signal with the glue too, since, the gluing process requires smooth grooves as explained above. A study of the groove quality, between different Thermwood production was first done and allowed us to choose the speed and feed. The RPM tested were 26K RPM and 20kRPM with feeds of 18, 36, 54, 72 inch per/minute, and each case 7 passes were done with the machine. The limitation in RPM and feeds comes from the fact that heat is being developped in the process and could melt the groove. The bicron 404 is known to be more sensitive than some other plastics regarding the process. The smoothest groove was obtained for the 20000 RPM and 54inch/minute and is compared to the "man" made groove. The groove quality was also checked under microscope with the same magnification of 25 before introducing the fibers. In order to keep the unglued fibers in the grooves a point of of epoxy RTV615 from GE, which was chosen since its easy to take out.

Below are represented the signals in the 2 man-made paddles. Their characteristics have been derived and reported in a table.

The fit was done using a maximum Likelihood fit to a convolution of a Landau and a Gaussian extracted from Jay Orear's notes on statistics for physicists[1]. The Number of Photo-electrons/Mev(PE/MeV) is given as well as the Photo-electron/Minimum Ionizing particle(PE/MIP) and the number of MeV/MIP assuming 4GeV muons. One can see that the results from the 2 paddles are very close.

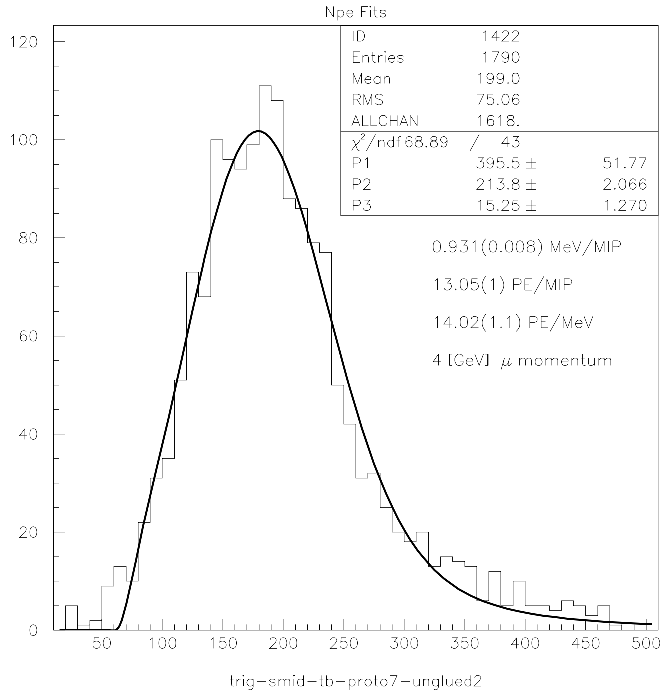

Figure 2: Signal From Prototype paddle 7 with unglued fibers,with a Maximum Likelihood fit [1]

An extruded Russian paddle with grooves 1cm apart has been re-tested by Vitaly Siemenov, with and without glued fibers with a similar result. The gluing process did not bring a real improvment in the light yield. It seems to be, therefore that extrusion which provides a smoother groove gives a similar light yield without glue with less mess and less worry about the behavior under the vacuum of VVS. This is now been tested again extensively at lab6.

VI) Conclusion

We have compared a regular paddle with two paddles where the grooves have been made with extra caution for smoothness. In one of the cases the edges of the grooves got an extra path of the ball nose cutter to get smooth edges too. In the other case the fibers have been glued to the groove. In both cases the

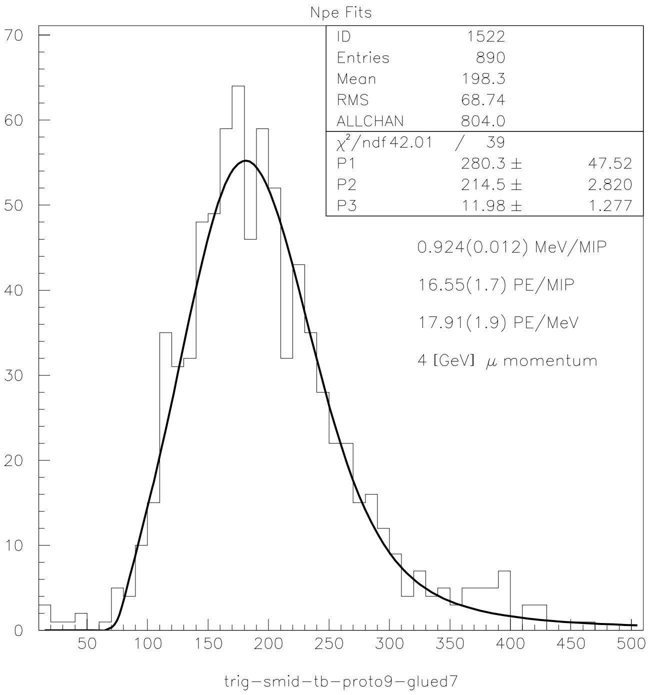

Figure 3: Signal From Prototype paddle 9 with glued fibers,with a Maximum Likelihood fit [1]

groove haa an higher quality than the grooves machined with the Thermwood in paddle 8 and the signal has improved. The improvement obtained from the paddle with glued fibers is not better than the improvment of the paddle with extra-smooth edges of the groove. Another set of paddles have been checked with similar results. This has been tested for paddles with grooves located 1cm apart. We have not tested if the procedure gives the same results in the case of fibers located more distant grooves. In our case it appears that the smoothness of the groove really matters, therefore Extrusion might be the Solution being a faster and more straightforward way to reach the same quality. The shape of the groove allows that extra good optical contact with the fiber without requiring glue to keep the fiber in. This procedure described above has been tried in 6 paddles and it would be nice to increase the statistics. The quality of the ball nose is critical. It is deteriorating with

Paddle	$< Count > \pm$ (RMS/$\sqrt{Trig}$) Pedestal Subtracted .	PE/MIP	MeV/MIP	PE/MeV
Prototype-9 Glued fibers	198.3±2.3	16.55±1.7	0.924±0.012	17.91±1.9
Prototype-7 Unglued fibers	199.0±2.0	13.05±1.0	0.931±0.008	14.02±1.1

Table 2: Light Yield from Maximum Likelihood[1]

a life time of $\simeq$ 20 grooves to be good, $\simeq$ 40 grooves acceptables and $\simeq$ 60 grooves to be in decline, the mean of the signal getting lower by $\simeq 3\sigma$ than for the first 20 grooves machined. We have taken advantage of one new ball nose that we had, the price of the ball nose as given by "Preferred Tools" in October 2000, is $44.10 per piece, and becomes $19.60 per piece for a bunch of 50 or even $16.50 per piece if 100 of them are purchased

The relative size of the cutter and the ball nose is also very important. The price of the end-mills from "Preferred Tools" is of the order of magnitude of $20.50 per piece for 10 pieces as for December 2000.

The high quality grooves were "man made" with great care by R. Maly from lab6. In this work the help of R. Denim Taylor from lab6 at Fermilab was crucial.

List of Tables

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References

[1] Jay Orear- Notes on statistics for Physicists,CLNS 82/511,Cornell, Lab. for Nucl. Studies, July 28,(1982).