January 17, 2001
Revised: August 30, 2001

Plastic Scintillator for the CKM Veto system-RND

B. Gonzales, C. Milsténe, R. Tschirhart

I) Introduction

This is the summary of a study done in the summer 2000 of the light yield of plastic scintillator paddles with double-cladded fibers wave lenght shifting in the green to be used in the CKM Veto systems. The signal is coming from cosmic high energy muons. A block of 90cm of steel provides a muon energy cutoff of 900 MeV, the mean energy of the muons detected is $\simeq$ 4 GeV and the setup is a telescope built around the paddle to test.

II) Experimental Setup

A "Test" Paddle 42cm$\times$30cm$\times$0.5cm, with double-cladded 1mm diameter fibers, with a fiber spacing of 1cm in the plastic scintillator grooves. A telescope built of 2 plastic paddles 20cm$\times$20cm$\times$0.5cm , referred as the "Big" paddles or "Top" and "Bottom" paddles, referring to their position in the Telescope, a "Small" plastic paddle 10cm$\times$10cm$\times$0.5cm in between. The setup is shown in the Figure 1

We have used for the "Test" paddle as well as for the Telescope paddles, plastic scintillator Bicron BC404. All the fibers where green wave shifting double clad fibers Bicron BCF92. The "Test" paddle was located in a light tight box , with the "Small" paddle sitting on top of the "Test" paddle.. The "Bottom" paddle was located below blocks of steel under the light tight box , the "Top" paddle above the light tight box. The trigger comes from the signal recorded in coincidence in the "Top" "Bottom" and "Small" paddles. The signal is the energy deposited in the "Test" paddle. The steel is used to make sure that we are dealing with High Energy cosmic muons, ($>$ 4GeV) Each of the paddles is connected by its fibers to a Photo-Multiplier tube Phillips 2232 via a plastic cookie to allow light collection wherever a high energy cosmic muon leaves energy in the paddles.

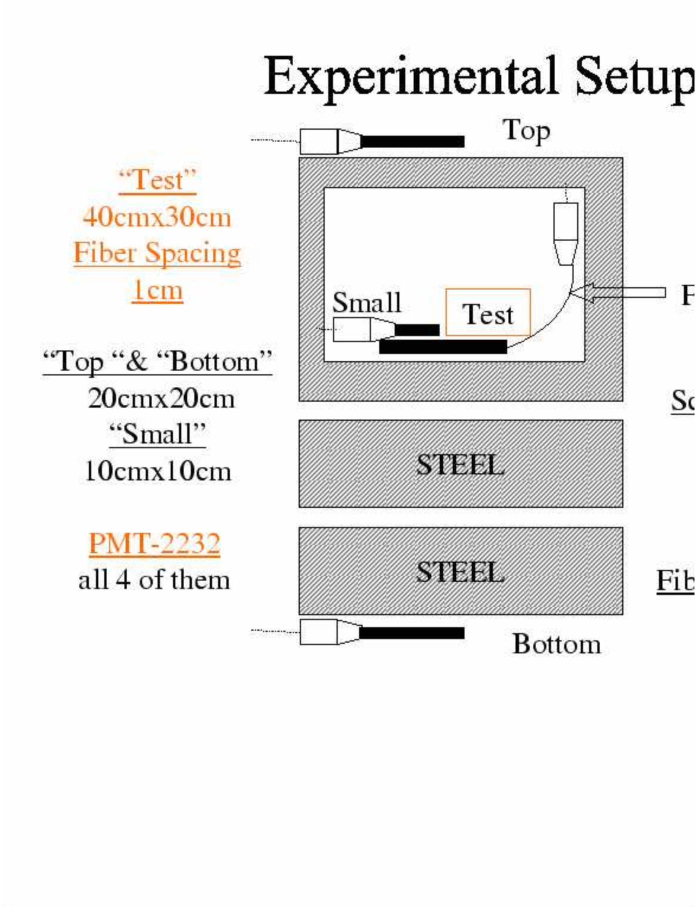

Figure 1: Telescope

III) The Electronics

When a cosmic muon leaves energy in the 3 paddles of the Telescope, the signal collected by each of the Photo-Multipliers is going to a coincidence unit which is a Le Croy Discriminator with a threshold at -50mV and a 100ns width. A Dual gate generator LRS 222 is used in order to re-time the signal for the computer. It provides a "hold" of 10ms for the start and of 1 microsecond for the end. From the Coincidence unit the signal is connected to the gate of the Analog to digital convertor ADC 2249A, whereas the signal from the "Test" paddle is connected to one of the signal input points of the same ADC2249A. The PMT signal has been studied for each of the paddle PMT, and their Plateau determined. A high voltage in the Plateau has been picked up as the working point.

1. For the "Test" Paddle -1760 V
2. For the Coincidence Unit: "Top" Paddle -1800 V
3. "Bottom" Paddle -1900 V
4. " Small" Paddle -1700 V

The coincidence rate was about 2 counts/minute and the tube gain of the order of $\simeq 1. \times 10^{07}$.

IV) Response Study

a) The Stability Checks

have tested the stability of the system.

1) First the Pedestal stability has been studied

In a run overnight for 17 hours, a number of 7000 triggers have been taken and represented below is the number of ADC counts each trigger in the Figure 2. One can see that the number of counts is rather constant , with a mean pedestal value of 35.03 counts (250fc/count).

2) The Signal stability over a long run

The 8000 triggers signal collected in a long run of $\simeq$ 72 hours over the week-end from $\mu \simeq$4 GeV is represented in the Figure 3 below.

In the next Figure 4 we have gathered the number of ADC counts for that long run in bunches of 400 triggers ($\leq$ 3.5hours run), and have represented the mean ADC count per bunch with their error as a more striking test of the stability, with a meaningful statistic at each point.

In another Figure 5 the number of ADC counts Pedestal subtracted is represented. In that figure is represented on the x axis the number of ADC counts Pedestal subtracted, due to muons $\simeq$ 4 GeV, which are Minimum

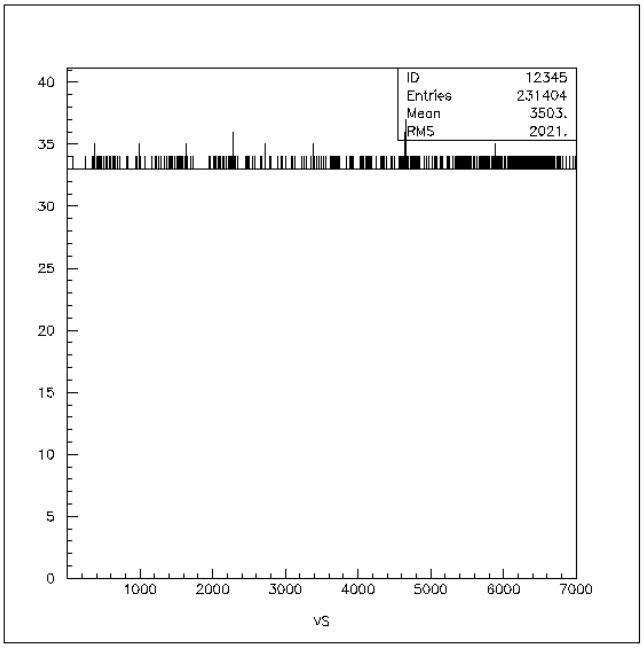

Figure 2: Pedestal- Stability over $\simeq$17 hours

Ionizing Particles (MIP), and on the y axis the number of triggers of such a muons. The pulse height distribution observed can be described by a convolution of a Landau distribution describing the deposition of ionization energy in the scintillator, with a mean value given by the Bethe-Block formula, and a statistical distribution describing the number of photo-electrons observed for a given energy deposit and which is represented by a Poisson distribution.

A convolution of a Landau with a Poisson fit has been done. A routine has been setup by P.S. Cooper and allow to measure the scintillator photo-electron Yield. In the mean time a note has been written by P.S.Cooper on the actual fit [1]. In reference [1] it is shown that the mean energy deposited

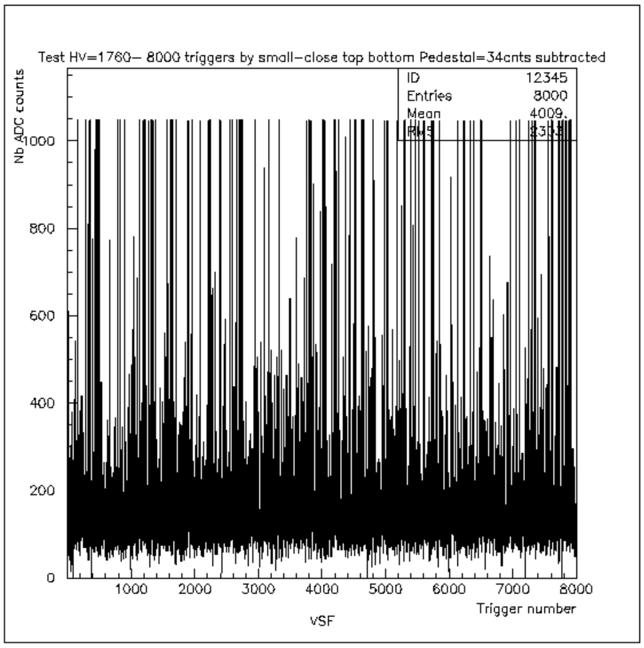

Figure 3: High Energy Cosmic Muon Signal- Stability over $\simeq$ 72 hours

by a MIP in the paddle of scintillator 0.5 cm thick is $\simeq$ 1.267 MeV.

The result of the fit in each case tested, is given in the corresponding figure, and all the cases are summarized in table 1.

b) The Light Transmission tests

The mean number of photo-electrons has been recorded in runs with different conditions. Those conditions have been reported in the table 1 below and are considered here in more details. In the table we are giving the mean count with its statistical error as well as the number of MeV deposited in the material per Minimum Ionizing particle (from the Landau part of the fit), as well as the number of photo-electrons per MeV, and their product the number of photo-electrons/MIP.

1) The wrapping material

Wrapping of Aluminium foil, Tyvek or no wrapping were studied. It appeared that the best light yield was obtained with the Tyvek wrapping. All the data were taken with the Tyvek wrap unless mentioned. Below in the Figure 6 which shows the signal fit for the "Test" paddle without Tyvek wrap using the convolution of a Landau with a Poisson.

2) The Fibers Test

The same test have been done with 1/2 the fibers and then 1/4 of the fibers. The spacing between fibers being increased by a factor two each time. For 1/2 the fibers the spacing between fibers bringing the light to the PM is 2cm instead of 1 cm , the number of photo-electrons/per MIP goes from 12 ± 0.4pe/MIP to 10pe±2.4/MIP. However for 1/4 of the fibers and a spacing of 4cm, the yield drops to 6.34 ± 1.0 pe/MIP. The data fit to a convolution of Landau and a Poisson distribution are shown in the Figure 7 for the 2cm spacing with the number of pe/MIP obtained from the fit.

In Figure 8 we represent the Landau fit with a 4cm fiber spacing. There is a sensible decrease in the number of photo-electrons per MIP comparatively to the previous cases.

A small change in the fiber length does not really lower the light yield, as shown in the Figure 9

3) Pressure Test

A module of the Vacuum Veto system is made of 81 sandwiches of thickness 0.5cm Scintillator/0.1cm Pb. When the module is standing on its side during fabrication, the plastic scintillator located at the bottom is supporting a weight of 112kg. To test the effect on the signal we have looked at the response of the "Test" paddle under such a weight and after the weight has been removed. It appears that the light yield improves when the stack is loaded and returns to its previous value once the stress is over. This can be seen in the Figure 10 which shows the signal and its Gaussian fit while the weight is applied and in Figure 11 once the weight of 112 kg has been taken off again.

In the table one notices that in 2 cases, when the paddle is aluminum wrapped and when the fibers have no mirror for which the number p.e./MeV and p.e./MIP is surprisingly low. In both cases the statistics is relatively low and the reliability of the Landau fit is in question and it's best to use the ratio of relative mean counts to the nominal configuration to determine the loss in light yield. We have included the distribution for the aluminum wrap in the Figure 12 to illustrate the low statistics.

Parameter	Mean Count $\pm$RMS/sqrt(ntrig)	RMS	p.e./MeV	MeV/MIP	p.e./MIP
	149.9 ± 0.81	71.95 8000 trig	11.66 ± 0.5	0.991 ± 0.005	11.56 ± 0.4
Weight 112 kg	161.4 ± 2.135	82.69 1500trig	13.97 ± 4.2	1.016 ± 0.025	13.97 ± 4.2
After Weight	150.1 ± 1.807	69.99 1500trig	11.62 ± 3.3	0.971 ± 0.025	11.28 ± 3.3
No Tyvek	73.64 ± 3.682	45.02 400trig	6.51 ± 4.1	1.0 ± 0.079	6.51 ± 4.1
Aluminium wrap	129.7 ± 3.207	64.13 400trig	3.83 ± 2.7	0.778 ± 0.135	2.98 ± 2
1/2 fibers	111.1 ± 1.717	61.63 1288 trig	10.22 ± 2.3	1.021 ± 0.021	10.43 ± 2.4
1/4 fibers	69.31 ± 1.351	47.43 1233 trig	6.13 ± 1.00	1.033 ± 0.018	6.34 ± 1.0
All Fibers No Mirrors but polished	95.97 ± 2.675	54.88 421 trig	3.66 ± 2.4	0.843 ± 0.146	3.09 ± 2
1/2 shorter fibers	105.8 ± 1.661	58.02 1219 trig	7.85 ± 2.5	0.994 ± 0.033	7.81 ± 2.5

Table 1: Test piece response dependency in various parameters, where errors are just statistical

4) Fibers Gluing Test

Following discussions with NUMI-RND group, further studies have been made to check if gluing the fibers to the grooves provides a light yield improvment. The results of that test have shown that for a fiber spacing of 1 cm the groove quality is as much an important factor than the gluing itself, this is discussed in detail in the note [2] The NUMI group ensured us that the lack of improvment due to the gluing comes from the fact that the fiber spacing is only 1cm but that with a 2cm fiber spacing the improvment due to the fiber gluing is much more clear. It has not been cross-checked by us. Furthermore studies have also been done using green extended Photo-Multipliers tubes and the results have been summarised in [3].

V) Conclusion

A quantitative overview of the Veto system shows that for the Vacuum Veto System alone, we will be needing plastic scintilator plates of 40cm$\times$30cm=1200cm^2 surface. There will be 81 sheets/module, 16 modules per ring and 34 such rings in the VVS. This corresponds to 1200$\times$81$\times$16$\times$34=5287m^2 of plastic scintillator 0.5 cm thick, namely, 26,438 m^3 of scintillator. As for the fibers, if we adopt a fiber spacing of 1cm there will be 30 such fibers per paddle, and if we take into account that, in order to reach the Photomultiplier the fiber should be about twice the paddle length we will need 2$\times$40cm$\times$30=24m We have 81 such paddles/module, 16 modules/ring and 34 rings for the VVS, therefore we will need 24$\times$81$\times$36$\times$24=1060km of fibers, we better try to make it cheap.

References

[1] CKM31 Measuring Scintillators photo-electron Yield; P. S. Cooper.

[2] CKM52 Study of fiber gluing and quality of fiber grooves in plastic scintillators and the light yield which follows; C. Milsteńe

[3] CKM51 Study of the light yield from plastic scintillator with green extended fibers using green extended Photo-Multiplier tubes; C. Milsteńe

List of Figures

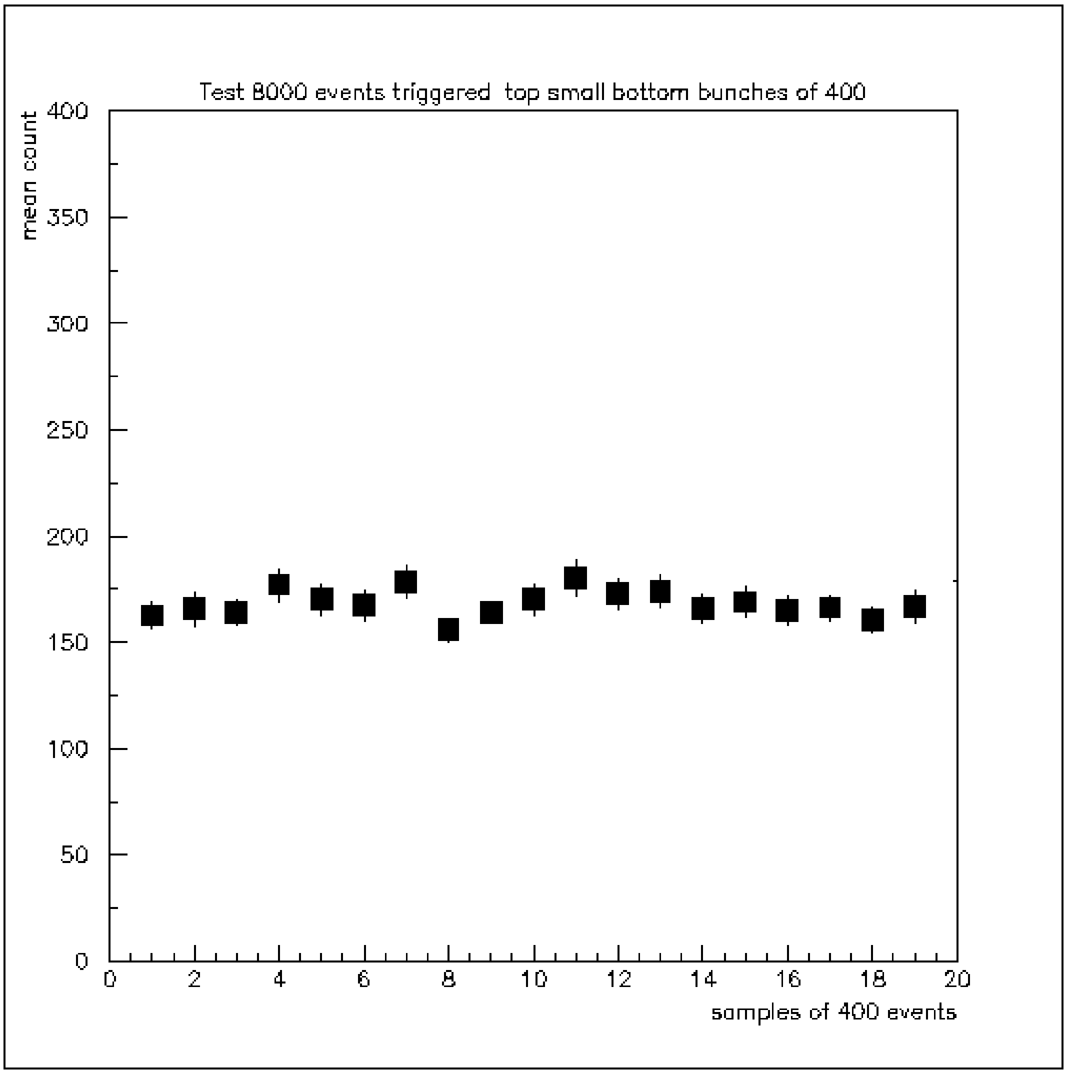

Figure 4: Signal: ADC counts per bunch of 400 triggers and errors for 8000 triggers taken over 72 hours

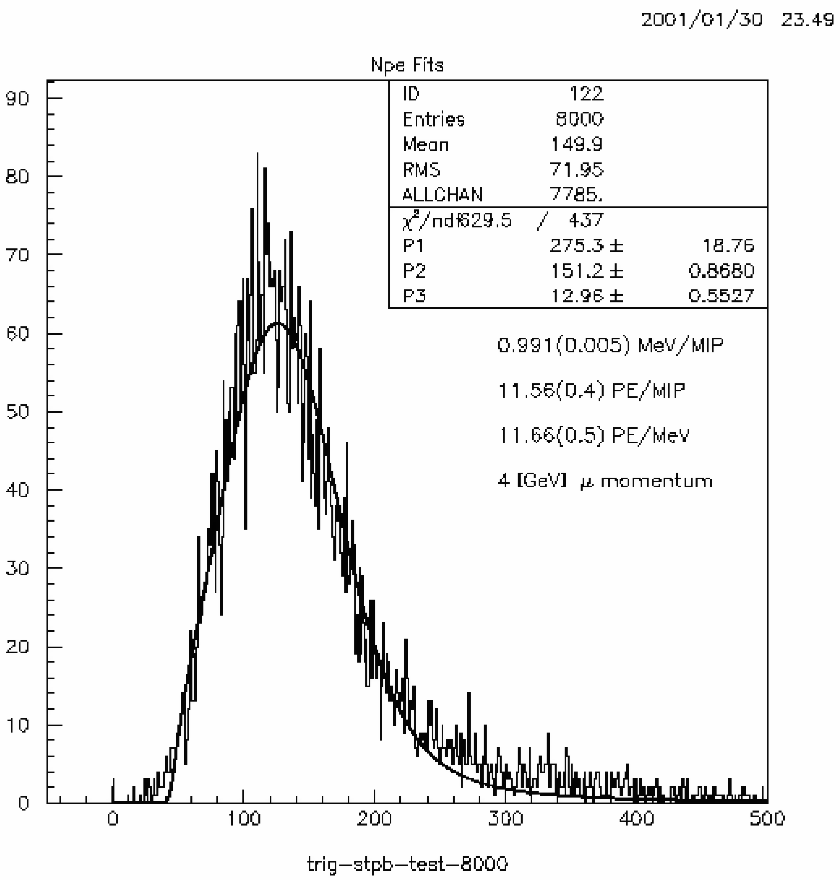

Figure 5: Signal:Number of ADC counts Pedestal Subtracted. Fit of the Signal by a Landau distribution convoluted with a Poisson distribution

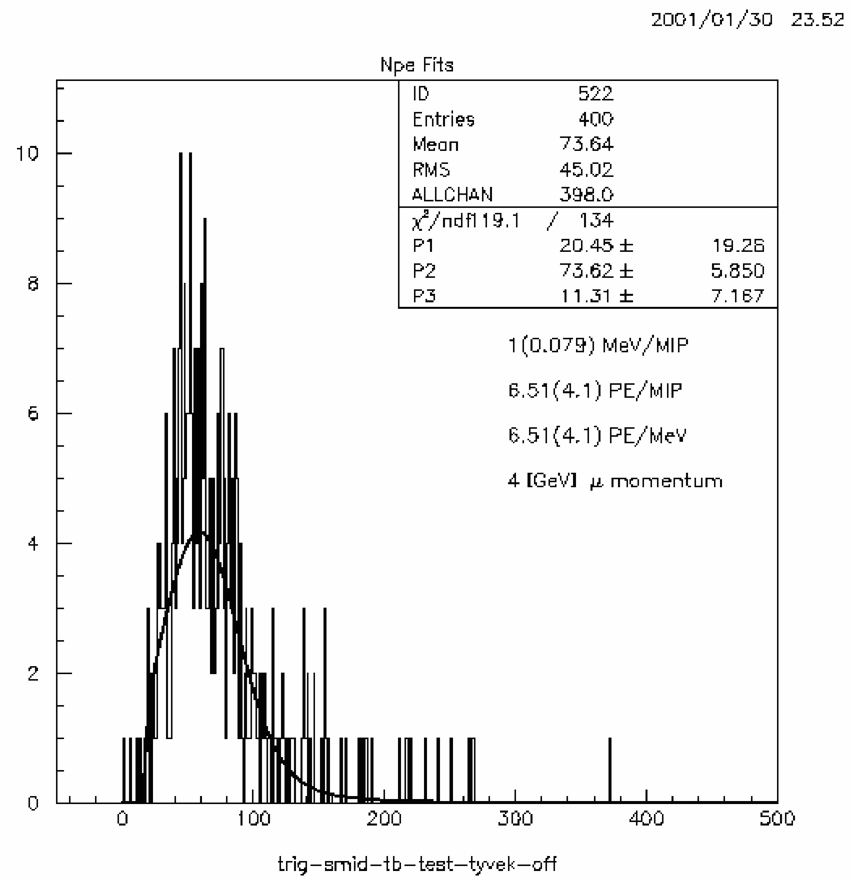

Figure 6: Signal:A convolution Landau and Poisson fit of the Signal from a test paddle without Tyvek wrap

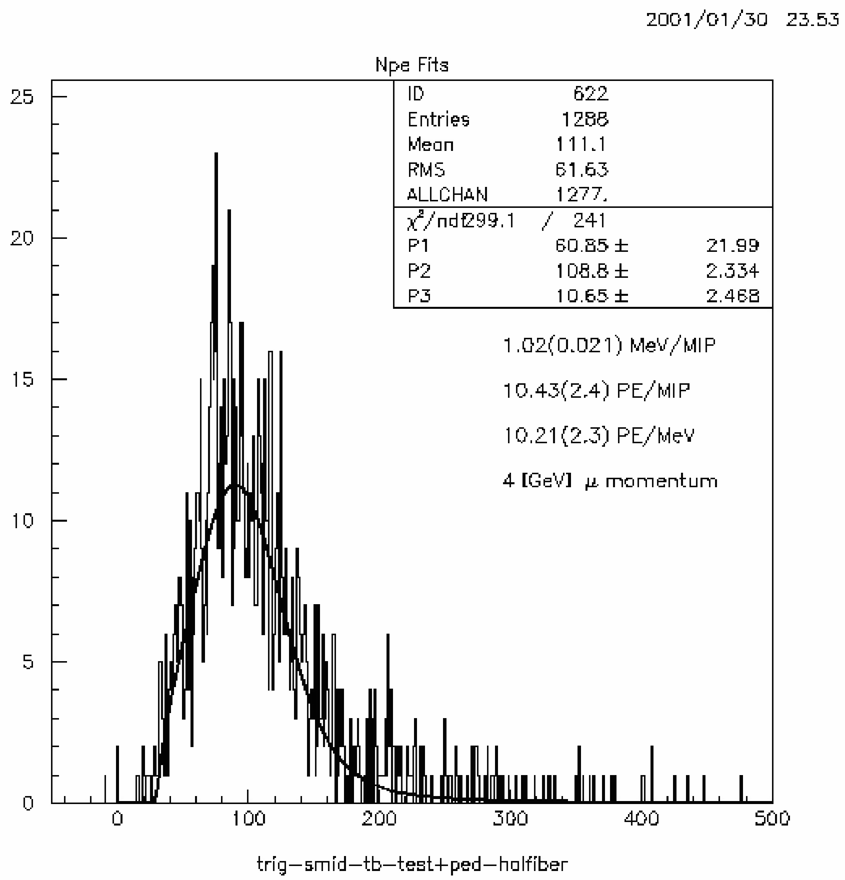

Figure 7: Signal-A fit by a convolution of Landau and Poisson of the Signal measured with a 2cm fiber spacing

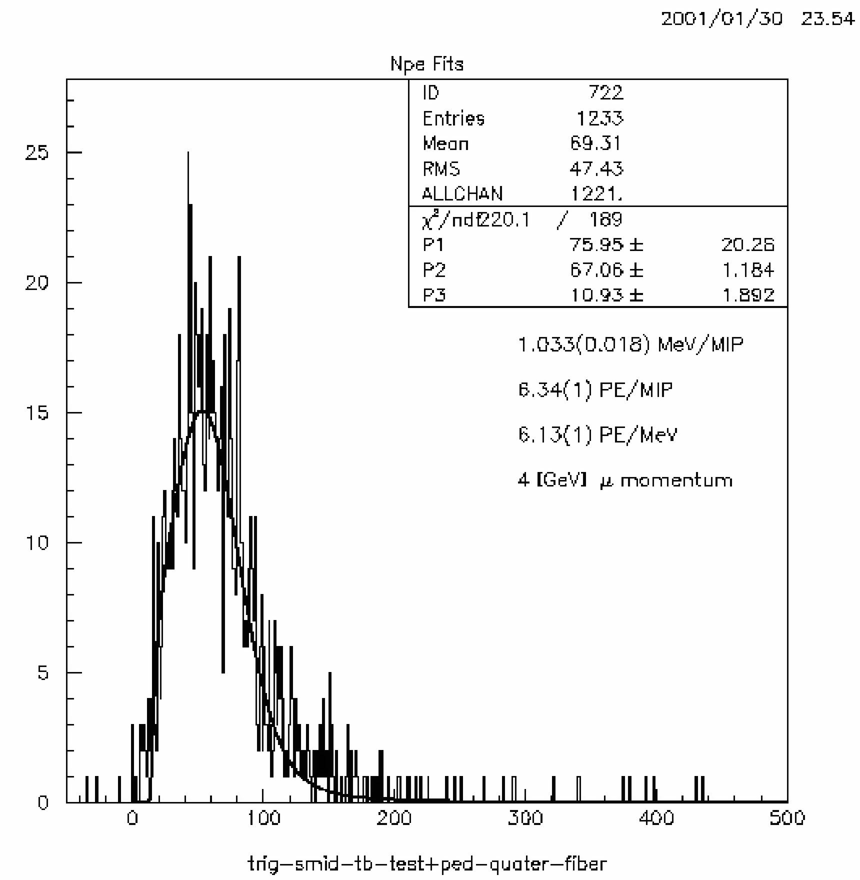

Figure 8: Landau fit of the Signal once a quater of the fibers are left

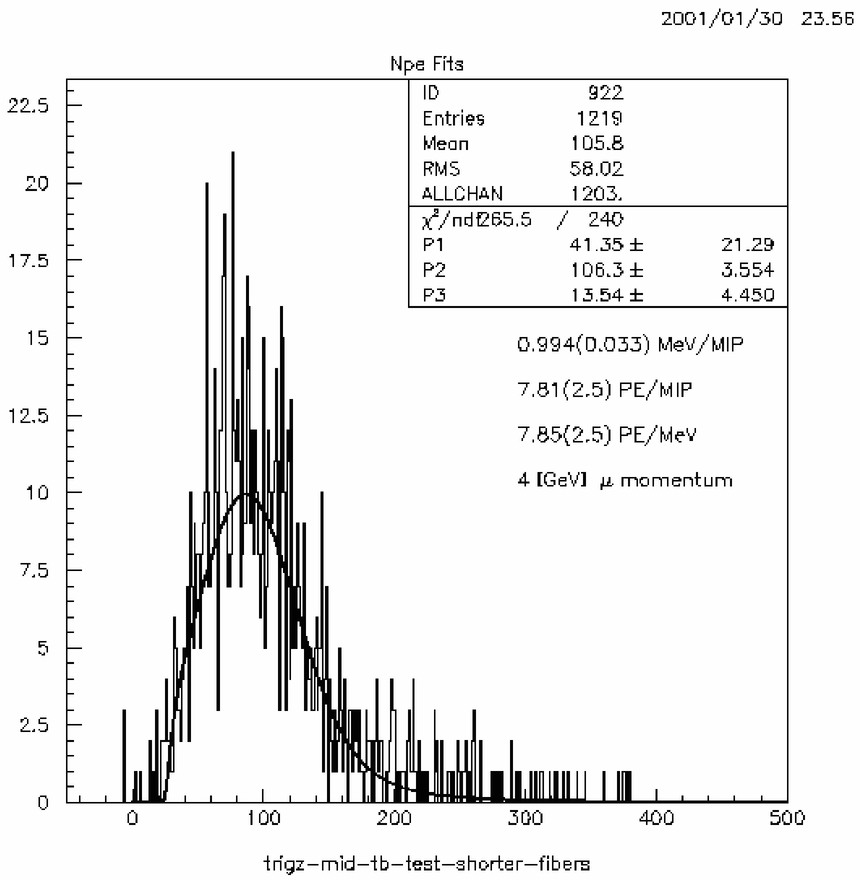

Figure 9: Landau fit of the Signal with shorter fibers

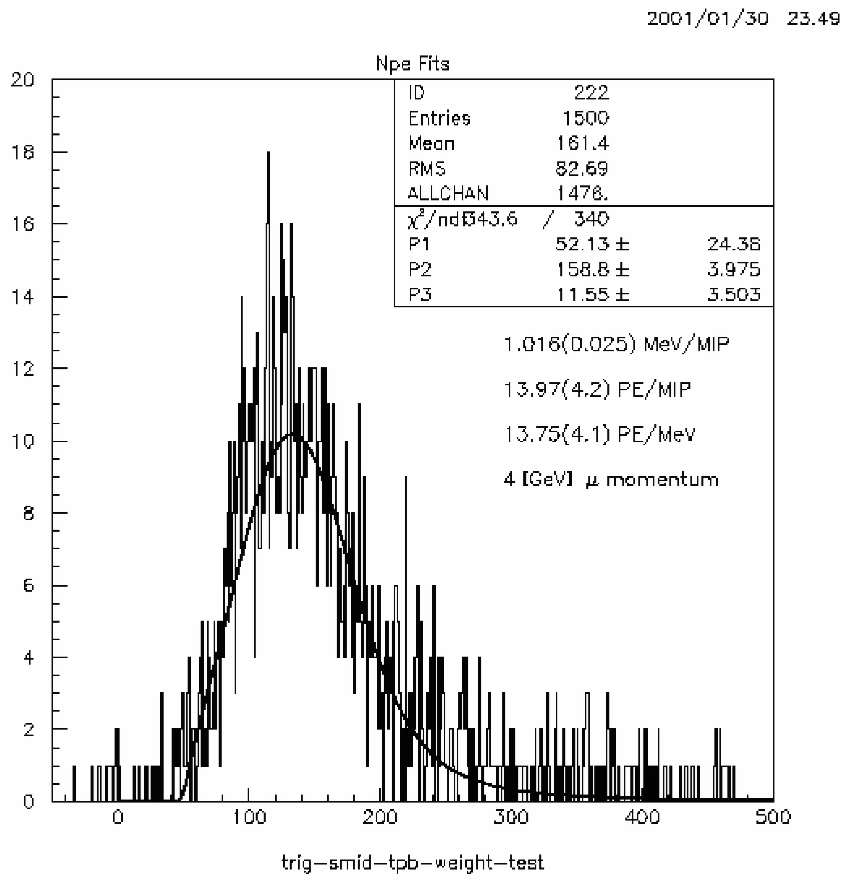

Figure 10: Signal:fit by a convolution Landau and Poisson of the Signal obtained while 112kg weight has been applied

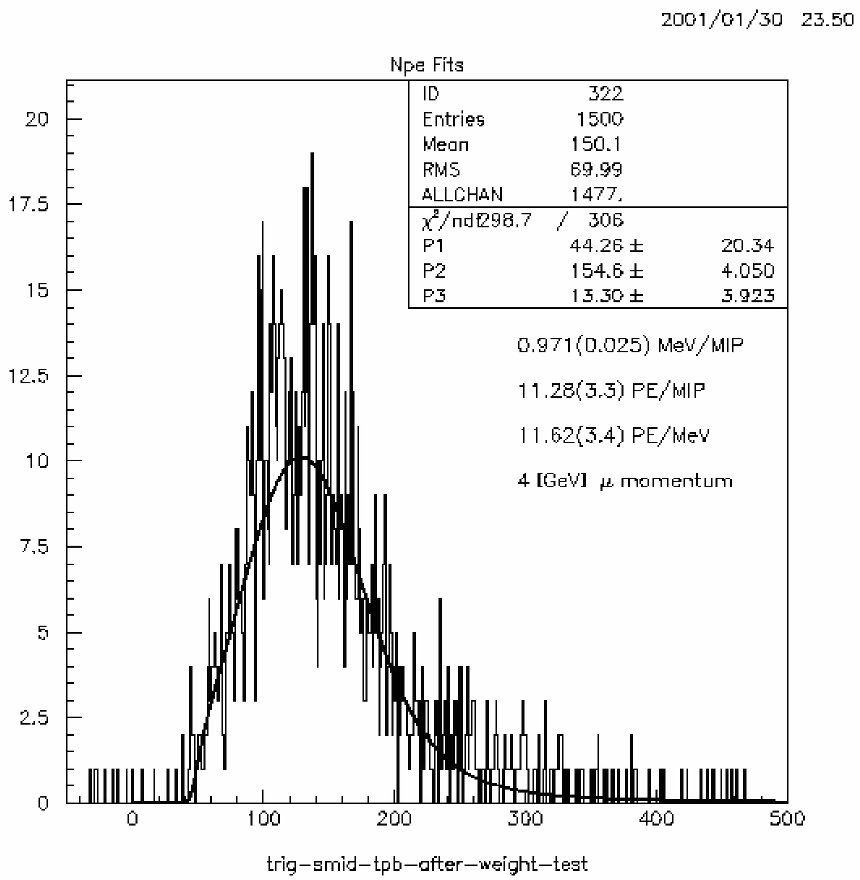

Figure 11: Signal:fit by the convolution Landau and Poisson of the Signal once the weight is taken off

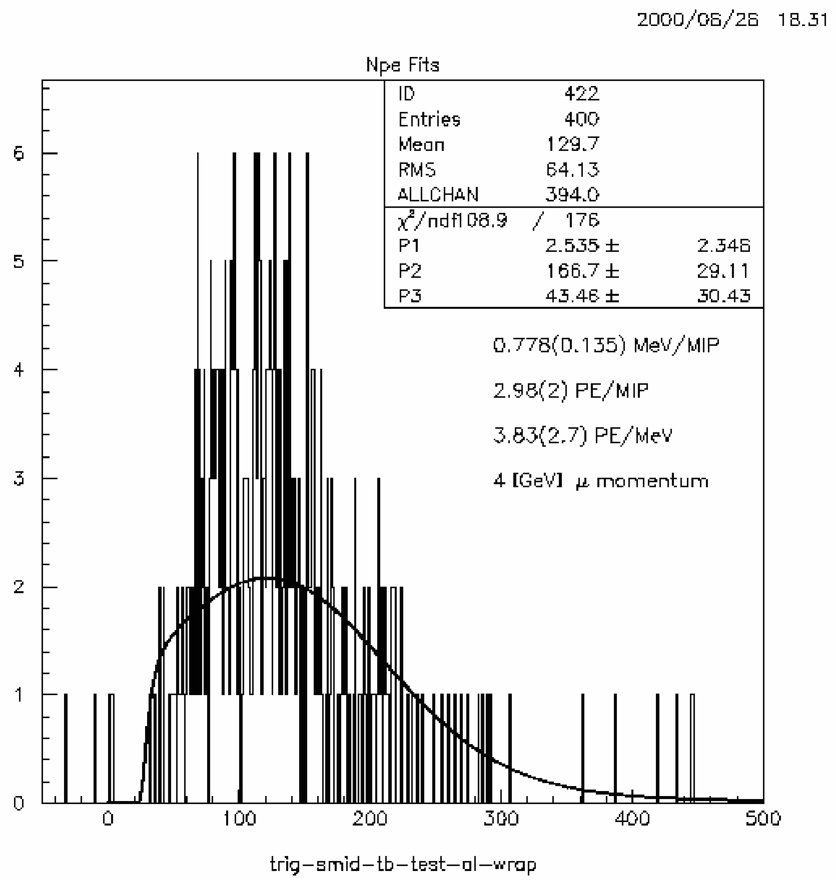

Figure 12: Signal:fit by the convolution Landau and Poisson of the Signal when an Aluminum foil has been used to wrap the paddle.