Characterisation of reference detectors for TAXI

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Abstract

The TAXI array sees atmospheric muon events, and will lead to a surface veto array for the IceCube experiment. The experiments in this report start to characterise the reference detectors of TAXI. Event rates were expected to be $\sim$20 $m^{-2}s^{-1}$, and were observed to be $\sim$7 Hz within a 25 cm$\times$25 cm scintillator segment. A Monte Carlo simulation was used to estimate the time resolution of the signal chain from PMT to TDC.

Contents

1 Introduction

The "Transportable Array for eXtremely large area Instrumentation studies", or TAXI, is an R & D system designed to test new detector instrumentation and boundary conditions for large area detectors, including IceCube[1]. A problem for IceCube is that there is a lot of background noise from atmospheric muons. TAXI could pave the way for a surface veto array for IceCube.

Eventually, TAXI will operate as a collection of modular components, or 'stations'. One station would be made up of three scintillators, which would function as the reference detectors; a power source; the detector to be tested; and a DAQ. This report summarizes information that characterises these scintillators [2].

2 Theory

2.1 Rate of muon events

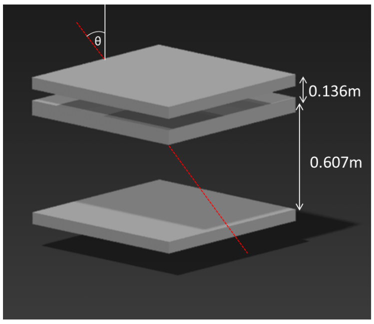

Figure 1: Diagram showing maximum angle at which a muon can enter the scintillator set up.

TAXI is being used to identify atmospheric muons, and the expected rate of muons going through the whole scintillator set up is 22 $m^{-2}s^{-1}$. As each section is a 25 cm×25 cm, the expected rate is 5.5 Hz. The angular distribution of muons at ground is $\propto \cos^2\theta$. The intensity of vertical muons exceeding 1 GeV/c is 70 $m^{-2}s^{-1}sr^{-1}$ [4].By integrating $\cos^2\theta$ over the maximum angle at which a muon can go through all three scintillators (within one 25 cm×25 cm segment, see figure 1), and multiplying by the intensity, one can calculate the expected muon rate per square metre, as in equation 1.

$$70m^{-1}s^{-1}sr^{-1} \times \int_0^{2\pi}\int_0^{\arctan(0.25/0.743)} \cos^2\theta \sin\theta d\theta d\phi \qquad (1)$$

2.2 Simulation of experiment to determine time resolution

MATLAB was used to program a simulation that could be used to estimate the time resolution of the signal chain from the PMT.

Initially a random position was generated within a 25×25 cm square, using the $rand()$ function in MATLAB. A random direction was then generated from a spherical distribution, which was added on to the first position to generate two coordinates; one in the plane of the middle plate, and one in the plane of the bottom plate. If the coordinates did not land within the x and y coordinates defining the $25 \times 25cm$ cm square, they were rejected. The distances, x and y between the initial coordinates and the accepted middle and bottom plate coordinates were used to calculate the muon flight time, assuming a muon velocity of 3×10^8 ms^{-1}.

The time it takes for the light signal to traverse the scintillator to the PMT is not negligible; it is assumed that the speed of light in an optical fibre is 2×10^8 ms^{-1}. This time is added on to the muon's flight time.

The time difference of each muon was then used as the mean for a normal distribution, and a time resolution was guessed to be used as the standard deviation. The original time difference was then replaced by a new value pulled from this normal distribution, creating a smearing effect from the time resolution.

By iteratively comparing the full width half maximum of the experimental time differences to the full width half maximum of the simulated time differences, it was possible to estimate time resolutions. 1,000,000 muons were simulated as going through the top layer.

3 Experimental Method

3.1 Producing gain curves for PMT R5900-03-M4

The gain of the photomultiplier was measured with respect to operating voltage. The PMT was split into 4 segments, or channels which were measured. An LED, with a wavelength of 520nm, was attached to an optical fibre, which fed into one channel of the PMT. The LED was powered with a 2.15V pulse at 50Hz, emitting a single photon with each pulse. The PMT, optical fibre, and LED was placed in a black box, and covered with black cloth to remove excess light. The readout from the PMT went to a LeCroy 612A PM Amplifier unit and then through an ADC unit (C.A.E.N module V265). The signal generator powering the LED was used with the C.A.E.N Dual timer module N93B to provide the trigger for the ADC.

A LabView program recorded the charge from the PMT via the ADC module, for 10,000 events per measured operating voltage. Voltages from 800-900V were measured, with intervals between 5 and 30V.

[1]

3.2 Scintillator setup

When muons went through the scintillator, light was produced and carried out to two PMTs via wavelength-shifting optical fibres [3]. The scintillator was split into four segments, and each PMT had four channels; the set-up had 8 outputs in total - two per segment, which could be used in coincidence to distinguish between muon events and noise. The PMTs in scintillators TM08C5 and TM03C5 were powered with 850V. The new scintillator was powered with 800V.

3.3 Determining threshold voltages for scintillators TM08C5 and TM03C5

A threshold voltage was needed to distinguish scintillator noise from muonic events.

The signal from one scintillator output channel was put through an amplifier. One output from the amplifier was then given a 120ns delay, and fed into the ADC. The other

[1]Serial number 7B18R4

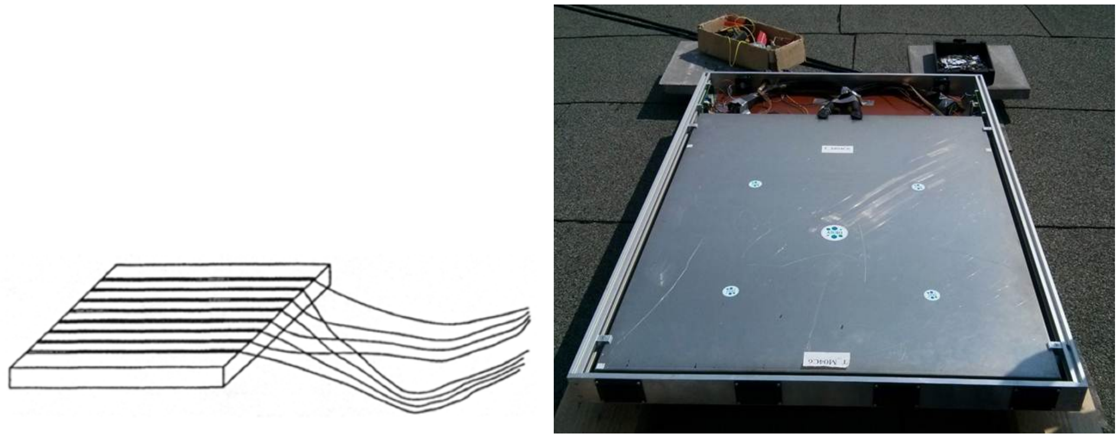

Figure 2: Left: Diagram showing optical fibres glued to scintillator segment[3]; Right: Scintillator made up of four segments; each segment takes a signal to two PMTs.

was put through a discriminator, where the threshold voltage was adjusted, then through a dual timer module, which then went to the gate on the ADC to act as a trigger. See figure 3.

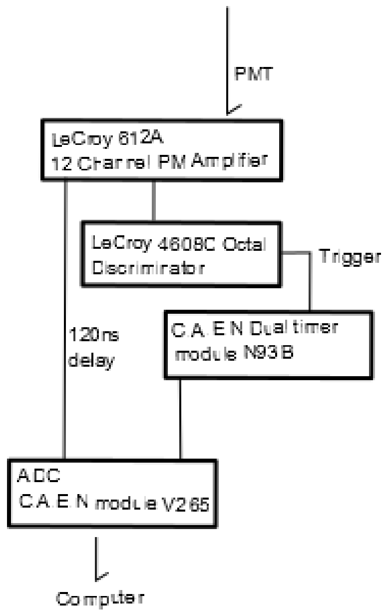

Figure 3: Schematic showing signal chain from PMT to LabView program, when determining threshold voltages.

The experiment was repeated for output channels 1.1-1.4 and 2.1-2.4 on each scintillator (TM08C5 and TM03C5). The threshold voltage (with a $\times 10$ gain) was increased from 200mV to 700-1000mV depending on the response from the scintillator, with intervals between 20-100mV.

The ADC recorded the charge from the PMT per threshold, and each experiment was carried out for 1,000-10,000 events, depending on the time taken for the experiment to run, which was also recorded.

3.4 Time Resolution

Three scintillators were laid on top of each other, as shown in the left of figure 4. Scintillator TM03C5 was on top, TM08C5 was on the bottom, and a new scintillator with integrated electronics was placed in the middle. The signal from the middle scintillator went straight to the coincidence unit; threshold voltages were adjusted in the integrated electronics.
Signals from TM03C5 and TM08C5 went through an amplifier and discriminator; a low

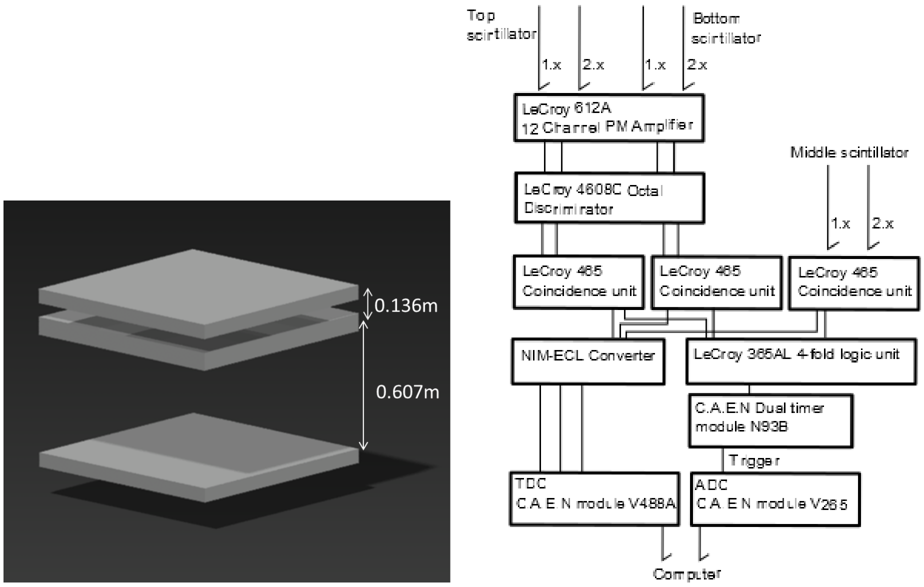

Figure 4: Left: Diagram showing separation of scintillators; Right: Schematic showing signal chain from PMTs to LabView program.

threshold voltage of 100 mV was used. The two signals from each scintillator then went through a coincidence unit, then to a NIM-ECL converter the TDC, and to a logic unit which selected events where all three scintillators saw a signal, then through to dual timer and to the gate on the ADC. The TDC was set to common stop.

The time difference between the start and stop signals was recorded from all three scintillators over 100,000 events, and was repeated for all four scintillator segments.

4 Results

4.1 Producing gain curves for PMT R5900-03-M4

Figure 5 shows gain curves of each PMT channel, and the following table shows the gradient of each curve.

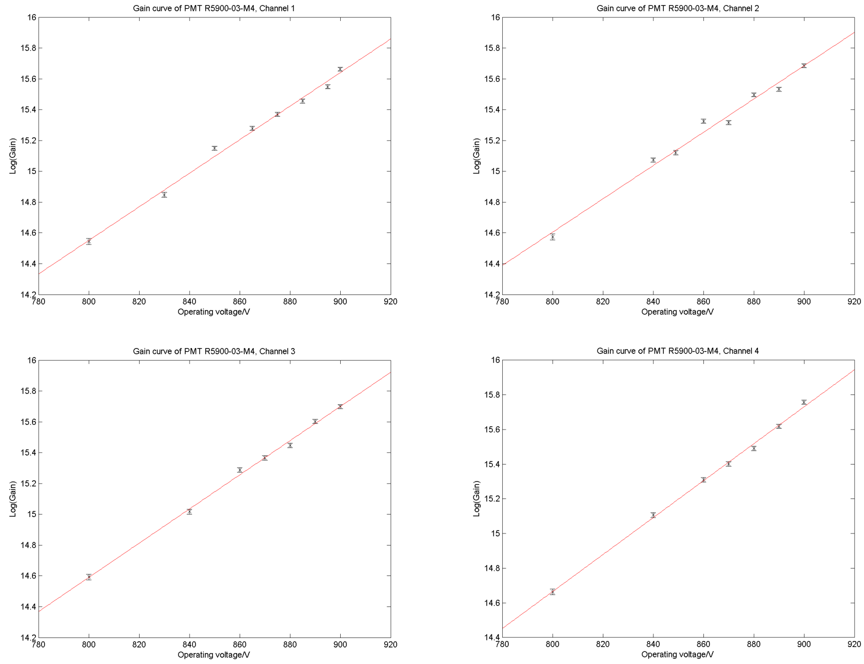

Figure 5: Graphs showing gain curves of 4 channels for PMT R5900-03-M4.

PMT Channel	Gradient of log(Gain) against operating voltage	Reduced χ^2
1	0.0109 ± 0.0004	5.6
2	0.0108 ± 0.0005	11.4
3	0.0111 ± 0.0003	2.3
4	0.0107 ± 0.0002	2.5

An operating voltage of 850 V was used to power the PMTs in scintillators TM08C5 and TM03C5.

4.2 Determining threshold voltages for scintillators TM08C5 and TM03C5

4.2.1 TM08C5

The curves of event rate against threshold voltage for each channel showed a plateau around frequencies less than 40Hz, and so 40Hz was used to choose threshold voltages, shown in the following table.

Channel	Threshold voltage
1.1	384mV
1.2	446mV
1.3	385mV
1.4	357mV
2.1	423mV
2.2	480mV
2.3	1000mV
2.4	390mV

4.2.2 TM03C5

The curves of event rate against threshold voltage for each channel showed a plateau around frequencies less than 20Hz, and so 20Hz was used to choose threshold voltages, shown in the table below.

Channel	Threshold voltage
1.1	380mV
1.2	280mV
1.3	250mV
1.4	245mV
2.1	400mV
2.2	260mV
2.3	195mV
2.4	200mV

4.3 Time Resolution

The following table shows time resolutions that were used in the scintillator simulation to match simulated results with experimental results. The top scintillator is referred to as the 1st layer, the middle as the 2nd, and the bottom scintillator as the 3rd layer. Each scintillator is split into 4 segments, and these are referred to as sections 1-4 in the table.

Section 1	Experimental FWHM	Simulated FWHM	Time resolution/ns
1st layer → 2nd layer	1.483	1.5521	<0.0001
2nd layer → 3rd layer	1.698	1.7064	0.50
1st layer → 3rd layer	2.667	2.6772	1.01

Section 2	Experimental FWHM	Simulated FWHM	Time resolution/ns
1st layer → 2nd layer	1.500	1.552	<0.0001
2nd layer → 3rd layer	1.762	1.761	0.54
1st layer → 3rd layer	2.511	2.519	0.94

Section 3	Experimental FWHM	Simulated FWHM	Time resolution/ns
1st layer → 2nd layer	2.354	2.352	0.75
2nd layer → 3rd layer	2.275	2.270	0.81
1st layer → 3rd layer	3.098	3.112	1.21

Section 4	Experimental FWHM	Simulated FWHM	Time resolution/ns
1st layer → 2nd layer	1.912	1.909	0.47
2nd layer → 3rd layer	1.909	1.910	0.62
1st layer → 3rd layer	2.700	2.699	1.02

5 Discussion

5.1 Determining threshold voltages for scintillators TM08C5 and TM03C5

Despite choosing thresholds that were around 20 Hz and 40 Hz for TM03C5 and TM08C5 respectively (and therefore around the expected muon rate), coincident rates measured using these threshold voltages (rates when channels 1.x and 2.x both gave a signal) were found to be only a few Hz. This suggests that noise was significantly reduced by considering coincidence.

During the time resolution experiment, it was decided that threshold voltages be kept around 100 mV for TM03C5 and TM08C5, to ensure muonic events were recorded.

5.2 Time Resolution

Time resolutions were found to be $\sim$1ns. It should be noted that some of the parameters of the simulation, such as the travel time of light in an optical fibre were very rough assumptions, and that each run will give a slightly different result ($\pm$0.01 ns). It also does not account for the thickness of the scintillators, nor the efficiency. It would be very difficult to estimate any error at this stage, so these tables should be recognised as rough results.

It should also be noted that the event rates were $\sim$7 Hz.

6 Conclusions

The operating voltage of the PMTs in scintillators TM03C5 and TM08C5 was chosen to be 850 V.

Threshold voltages were lowered to 100 mV during the time resolution experiment, as higher threshold voltages saw a significant reduction in coincident rate experiments.

The time resolution of the signal chain from PMT to computer was estimated to be $\sim$1ns using a simple Monte Carlo simulation.

Event rates through all three scintillators were found to be $\sim$7 Hz.

References

[1] M. Ackermann, R. Nahnhauer. . http://www-zeuthen.desy.de/tauros/RD-2014/DESY-ICRD-activities-v3.pdf (accessed 28/09/2014).

[2] DESY. TAXI. www-zeuthen.desy.de/tauros/BANFF/TAXI-%20Banff-1.pptx (accessed 28/09/2014).

[3] J Bahr, H.-J Grabosch, V. Kantserov, H. Leich, R. Leiste, R.Nahnhauer. AIP Conf. Proc. 450, 385 (1998); doi: 10.1063/1.56946

[4] J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012)