PMT Testing and Night Sky Background Results for WACT

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1 Introduction

Over the past several months Gus Sinnis, Javier Bussons-Gordo, Morgan Wascko, Frank Samuelson, and myself have made various measurements of the night sky background (NSB) at Fenton Hill in order to determine whether or not the currant pmt base design (a positive HV model of the Cygnus-I base) will be acceptable for the use with the WACT experiment. The NSB measurements have consisted of anode current measurements and count rate vs. threshold measurements. The gain of the pmts have also been measured. This memo will describe the techniques used, give the results of the measurements, and discuss the implications of the results.

2 Gain Measurement

One of the defining parameters of a pmt is its gain. Gain is defined as the ratio of the anode charge to cathode charge (number of photoelectrons times the elementary charge). The gain can be measured in different ways, but perhaps the easiest way is the RMS method. The RMS method assumes that the number of pes created is large enough that the fluctuations about the mean number of pes are Gaussian. This requirement can be easily satisfied by using a relatively large amount of light. So, if you know the charge on the anode of the pmt and you know the sigma of that charge distribution, then you can determine the gain of the pmt and the average number of pes:

$$Neg = Q_A, \tag{1}$$

$$\sigma^2 = Ne^2g^2, \tag{2}$$

Combining these two equations we find

$$g = \frac{\sigma^2}{Q_A e}. \tag{3}$$

In the above equations N is the number of pes, Q_A is the charge on the anode,and g is the gain of the dynode chain. Q_A and σ can be found by making an analog to digital converter (ADC) histogram of Q_A. The histogram is fit to a Gaussian function and Q_A is taken to be the mean of the fit. Once you know these parameters the gain can be easily calculated. The accuracy of this method is tied to the assumption that the width of the ADC histogram is due only to the Gaussian variations in the number of pes.

The experimental setup for the gain measurement consisted of a pmt in a dark box. The pmt cathode was illuminated by a blue, 5mm LED, that produces light at 430nm. The LED was driven with a Philips PM 5771 pulse generator. The pmts used were Amperex XP2262 pmts that were originally used in the Cygnus-I experiment. The XP2262 is a 12-stage linear focused pmt and is reported to have a quantum efficiency of .25 at 400nm. The cathode of the pmt is a semi-transparent bi-alkaline type D photo-cathode (Sb K Cs). The pmt base is a Cygnus-I base that was been modified to run on positive HV. The pmt output was, in cases of low applied voltage, passed through a Phillips 16-channel amplifier, and was then sent to a Lecroy ADC. The trigger for the ADC came from the Philips pulse generator that was used to drive the LED. The ADC was read out through a GPIB CAMAC crate controller that was being controlled by a PC running Labview.

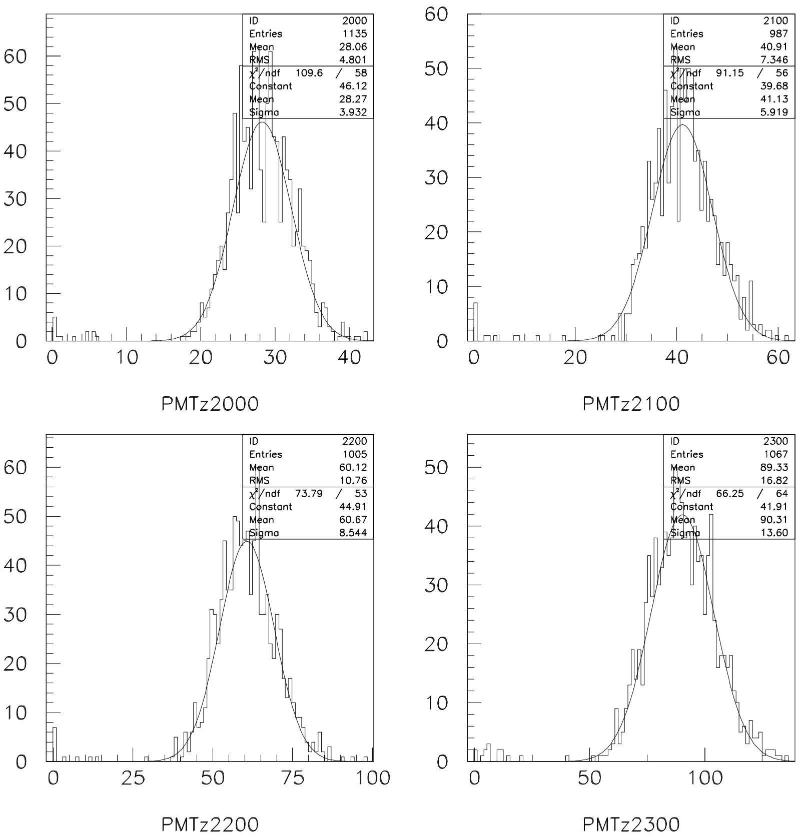

Figure 1: Typical ADC spectra at different voltages. It should be noted that the important parameter is the ratio of σ to the mean anode charge. The intensity of the light changed from histogram to histogram, thus no meaning can be attached to the the mean anode charge. Only the ratio of σ to the anode charge is meaningful

The histograms in figure 1 are a representative sample of the ADC histograms for the pmts at different voltages. Voltages ranged from 800 volts up to 2300. Below 1100 volts the pmts exhibited a poor response to the LED. The gain vs. voltage plots for the two tubes in figure 2 shows the expected log linear relation. See figure 2.

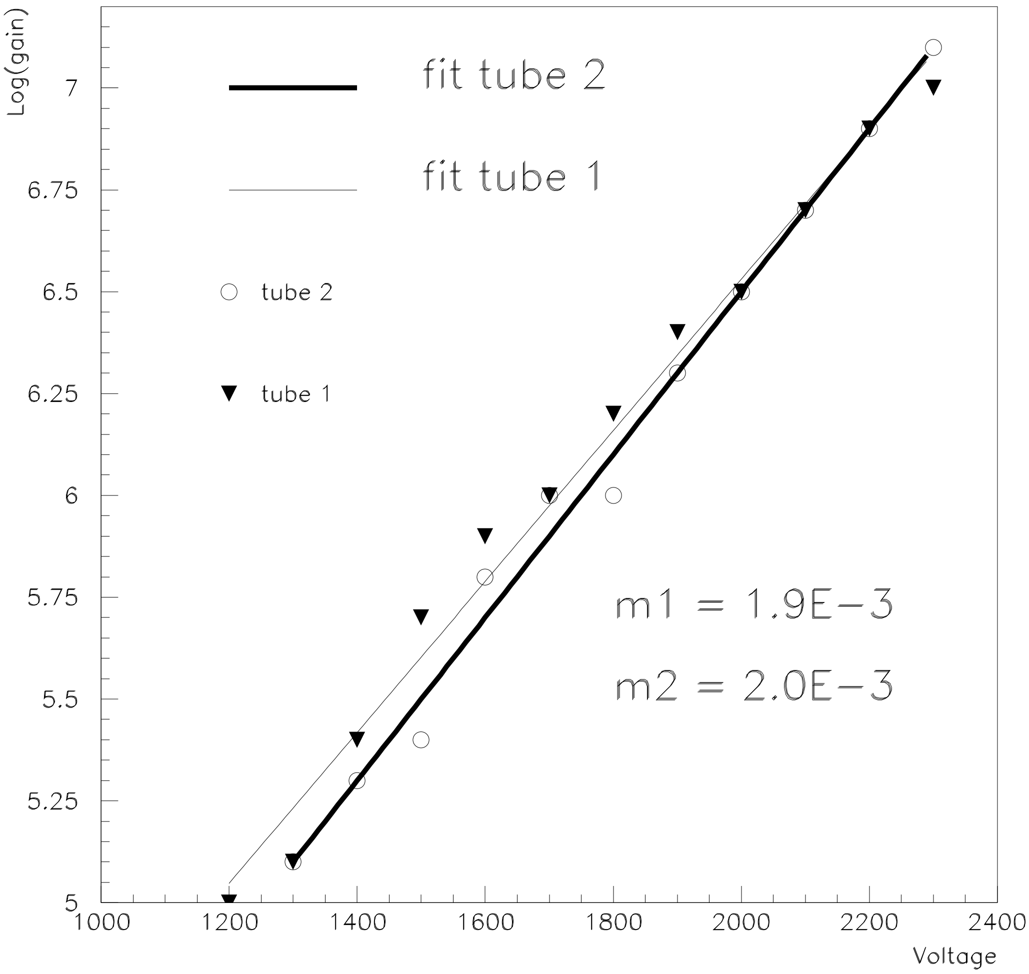

Figure 2: Gain vs. Voltage measurements and linear fits to Log (Gain)= m*Voltage

As stated earlier the accuracy of this method is tied to the assumption that the variations in the number of pes is Gaussian. This will be true if the LED luminosity is close to being Gaussian. In the future I would like to confirm these results with an occupancy method that uses the Milagro laser and a series of neutral density filters. In the next section, the measured gains were used to calculate the average night sky background at Fenton. If the gain measurement were perfect then one would obviously expect to see the same NSB result for both pmts.

	Tube 1				*Tube 2*		
I(μA)	*Volts*	*gain*	*pe/ns*	*I(μA)*	*Volts*	*gain*	*pe/ns*
2.6	1200	9.6E+4	.17	.09	1100	4.7E+4	.01
8.4	1300	1.2E+5	.44	2.8	1200	NA	NA
19.6	1400	2.3E+5	.53	8.5	1300	1.2E+5	.44
41.0	1500	5.7E+5	.45	26	1400	2.2E+5	.73
83.0	1600	8.3E+5	.62	53	1500	2.8E+5	1.18
183	1700	1.0E+6	1.14	114	1600	6.1E+5	1.17
890	1800	1.7E+6	3.27	900	1700	9.8E+5	5.73

Table 1: Data from anode current measurements for NSB. Currents greater then 1 mA are likely to cause damage to the anode of the pmt and thus 1800 was the highest voltage used on the pmts. The average pe rate for tube 1 is .56 $\pm$.131 pes/ns and the average pe rate for tube 2 is .71 $\pm$ .223 pes/ns. For voltages greater the 1800 and 1700 respectively the pe rates in the tubes increased dramatically.

3 Measurements at Fenton

3.1 Photoelectron Rates

The average night sky background current in the pmt was measured with a picoamp meter while the pmt was located at the focus above the WACT mirror. By measuring the current on the anode of the pmt, and knowing the gain of the pmt, the average photoelectron (pe) rate can be determined.

Excessive DC current in the pmt can cause damage to the anode from overheating. This is why the pmts have been operated at relatively low gain. However, even at the low gains the DC current in the base became quite high. See Table 1. The ratio of the anode current to the dynode current is an important parameter in determining the response of the tube. Dynode current refers to the DC current that exists in the resistor chain of the base. It is calculated by V=IR,where R is the total resistance of the base and V is the applied high voltage) As the anode current approaches that dynode current the pmt will begin to saturate. When this happens the gain of the tube will drop rapidly. To avoid this saturation regime, the ratio of the anode current to the dynode current should be kept below $I_A/I_D \ll 0.1$. The existing base has a total resistance of 2.1MΩ, and from the DC anode current at 1300 volts we get I_A/I_D ratio of .02. By decreasing the total resistance of the base it will be possible to move further below the saturation region.

Once a pmt has become saturated, the anode current should be almost the same as the dynode current. The dynode current in tube 1, at 1800 volts, is about 850μA and I_A/I_D is essentially one. It would appear then that at voltages on the order of 1700 - 1800 volts the pmt is well into the saturation region.

Photon fluxes at CACTI were reported to b 5E+12 $\gamma m^{-2}s^{-1}sr^{-1}$(Paling, 1997) in the range of 300nm to 600nm. This flux is a measure of the NSB and does not include Cherenkov light. The photon fluxes at Fenton should be somewhat different than the fluxes at CACTI. Integrating the CACTI flux over the collection area of the WACT mirror and the field of view of a single pmt (1.2 degrees), we find that the expected pe rate is about .2 pes/ns. Given the uncertainty in the photon flux at Fenton, the measured rate seems to agree with the expected rate. However, any error in measurement of the pmt gains, will introduce error into the pe rate measurement.

3.2 Rate Vs. Threshold

The rate vs. threshold measurement was done to determine where the Cherenkov light in an EAS becomes large enough to be seen in the pmt signal over the NSB. This measurement was done with two pmts located over the WACT mirror at the focus. The rate vs. threshold was recorded for each individual tube as well as in coincidence with each other. The pmt signal was run through a descriminator with a window of coincidence of 100ns.

Cherenkov photon fluxes (order of magnitude) can be calculated from the pmt trigger rate by measuring the width of the pmt signal on an oscilloscope. For pmt 1 the rate at 35 mV was 1494Hz and the trace on the scope was about 5ns wide. See Figure 3 at 35mV. This information, along with the area of the WACT mirror ($3.8m^2$) and the solid angle subtended (3.4E-4 sr), imply a photon flux on the order of $10^7\ \gamma/m^2 \cdot s \cdot sr$. The combined efficiency for the pmt and the mirror was taken to be 0.10. When compared to the night sky background expected, we see that the Cherenkov photon flux is less by a factor of 10^5.

4 Conclusions

The pmt development for WACT is going well. It is not yet clear that the present base design will satisfy the requirements of WACT. In the near future we will have a UV laser to use in pmt testing. With the laser we can make better measurements of the gain characteristics, as well as make linearity measurements and timing measurements. Additional tests will also be performed to better understand the saturation of the tube. To do this, we will use the LED to simulate the NSB. We can then look at laser pulses and see how gain and the linearity vary in the NSB enviroment.

The primary remaining tasks are the construction of Winston cones and a wheel system for the WACT buildings. Once the Winston cones are built, a camera can be fashioned and we can start taking preliminary data with WACT. The wheel system can, in principle, be constructed at a later time. Currently, Gus Sinnis is working on a wheel system for WACT. Winston cones are being developed at UC Riverside. Monte Carlo simulations are being worked on by Tom Stephens at NMSU and by Frank and myself at LANL. The camera is also being constructed at NMSU. It is my sincere hope that WACT will start taking data with at least two telescopes equipped with Winston cones sometime during the next 3 months.

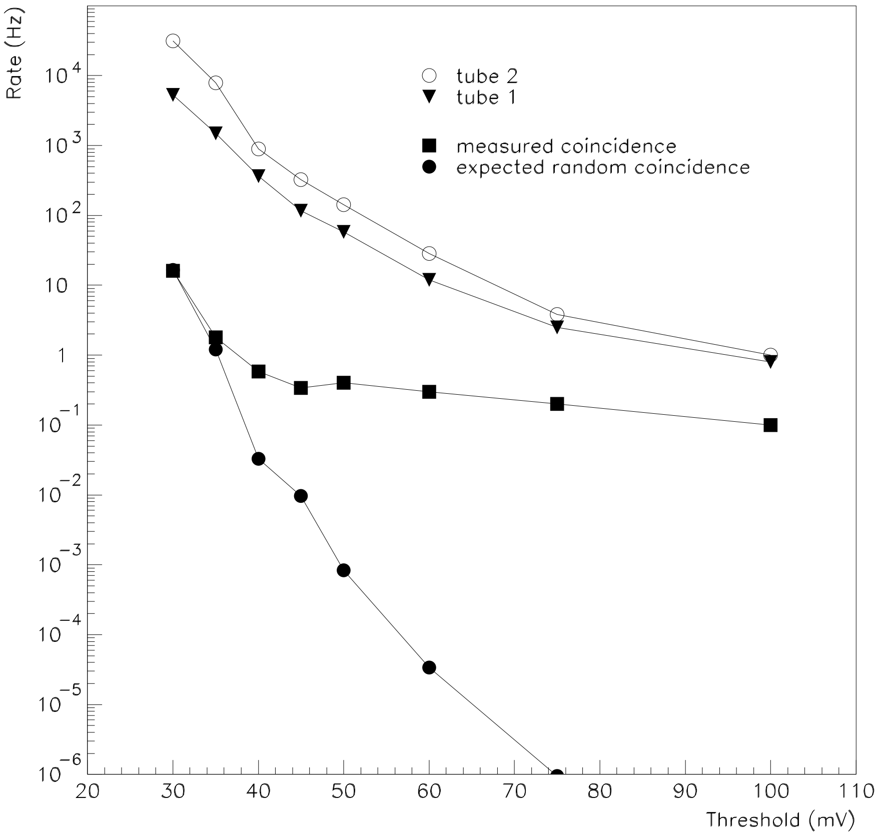

Figure 3: Just beyond 30mV in threshold the random coincidence rate in the tubes drops by orders of magnitude. This indicates a clear separation of Cherenkov light from the random night sky background. The slope of tube 1 (tube 2) is -2.4 (-2.9). The slope of the coincidence rate is -2.006. For tubes one and two the slope was calculated from the last two points. The coincidence slope was calculated from the last four points. The rate of random coincidence was taken to be $R_C = R_1 R_2 (100\text{ns})$,where R_1 and R_2 are the rates of tube 1 and tube 2. Both of the pmts were operated at 1500 volts.

5 References

Paling, S. M. 1997, Ph.D. Thesis, University of Leeds, Dept of Physics and Astronomy