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Calibration of Photonis XP3062/FL Photomultiplier Tube

G. Xiao[a,b], Y. Zhang[b], Y. Bai[b] and Z.Cao[b]

(a) South-West Jiaotong University of China, 111 North Section I of Circle II, Chengdu, 610031, P. R. China

(b) Institute of High Energy Physics 19B Yuquan Lu, Shijingshan, Beijing, 100049, P. R. China

Presenter: Z.Cao (caozh@ihep.ac.cn), chn-xiao-G-abs1-he15-oral

The absolute gain, linearity, photo-cathode response as a function of location and wavelength of PMT Photonis XP3062/FL is measured in this paper. The relative gain of the PMT as a function of the high voltage (HV) is calibrated from 600V to 2200V. The absolute gain of the PMT at 2000V is measured by using the single photoelectron technique. Based on these measurements, the working high voltage at 1300V is determined. The linearity of the PMT over 3.5 orders of magnitudes is calibrated. The PMT's response to different wavelength light sources is measured from 200~500nm. The location dependence of the photocathode is measured by using a light source (UV LED) to scan the surface of the photocathode millimeter by millimeter.

1. Introduction

Cosmic Rays tau Neutrino Telescope (CRTNT) detector use a spherical mirror to collect fluorescence light and Cerenkov light produced by charged particles in an air shower and use a cluster of 256 PMT's to record the image of the air shower. The movement of the image crossing over the cluster corresponds to the development of the shower at different depths in the air. Since the measured light intensity is proportional to the number of charge particles in the shower, one can reconstruct the whole shower development by measuring the light intensity as the shower passes through the field of view of the detector. The number of shower particles changes over orders of magnitudes during the development, therefore, the fluorescence light intensity changes over orders of magnitudes as well. In order to measure the light intensity, the PMT's must be calibrated within a large dynamic range, i.e. the absolute gain of the PMT must be measured and the linearity must be calibrated. The dependence of the gain to the wavelength needs to be calibrated because the nitrogen fluorescence light distributes over a range from 300 nm to 400 nm. Since the quantum effect and absorption effect of the PMT window is not uniform across the surface of the photocathode, the PMT response as a function of the location on the photocathode needs to be measured. With all these properties of the PMT measured, one could use the cluster of the calibrated PMT's to measure the air shower development. There are 16 telescopes for the full-balloon CRTNT project, therefore we need to calibrate at least 4096 PMTs. The development of a procedure for the calibration is necessary to handle such a large number of PMT's. In this paper, we describe the calibration procedure and report the calibration results.

2. Absolute Gain Measurements

In order to measure the sensitivity of a PHOTONIS XP3062/FL photomultiplier tube (PMT), we measure the PMT gain and photoelectric effect. At first, we calibrate the PMT gain as a function of the high voltage to determine the working HV. Secondly, we measure the gain using single photoelectron technique that usually requires a higher voltage than the working HV. We derive the absolute gain at the working HV following the measured HV dependence of the PMT.

2.1. Setup: A pulse generator used to drive a blue LED at 420nm as a light source. In order to uniformly shed the light on to the surface of the photocathode of the PMT, two layers of teflon films are used before the light coming out from a small hole. This system is set so that the light comes out within about 30 degrees from the hole and can be treated as a point-like light source to the photocathode with a diameter of about 40 mm at a certain distance. The PMT and the light source system are put into a light-tight box. In order to reduce the pollution from the reflected light from the walls of the box, a set of black buffers are set between the PMT and the light source. Signals from the PMT are DC coupled through a 50Ω resistor and are collected by an oscilloscope, Tektronix TDS 3034B, that is triggered by the same pulses used to drive the LED. Measured signals including the height and width of the pulse are recorded by a computer which is connected to the oscilloscope through the ether net.

2.2 Response to HV: With a fixed pulse width, amplitudes of the PMT outputs are measured under HV's that varies from 600V to 2200V. A distribution of the amplitudes shows that the system is stable and the precision of the measurement is about 0.5%. Figure 1 shows how the PMT output pulse amplitude responses to the supplied high voltage. With deviations less than 5%, it follows a power law. Since the variation of the pulse width is small (<1%), this indicates that the PMT gain follows the same power law denoted as $G = G_0 \cdot (\frac{HV}{HV_0})^{\beta}$, where G and G_0 are absolute gains of the PMT at supplied high voltages HV and HV_0, respectively. The exponent β = 6.18±0.01 is determined by fitting to the response in Figure 1.

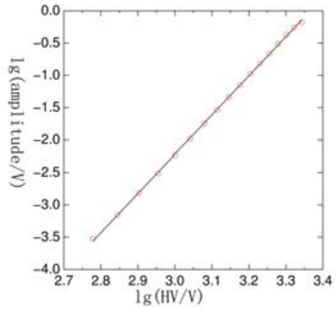

Figure 1 PMT output pulse amplitudes vs. HV.

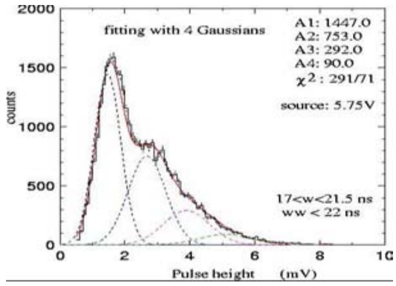

Figure2. pe spectrum as a PMT output pulse amplitude distribution at HV_0=2kV

2.3 G_0 measurement using single photoelectrons: At HV above 2000V, the PMT has such high gain that the quantum effect of the photocathode starts to be observed, while the input light intensity is reduced to a single photon level. A clear photoelectron (pe) spectrum can be observed as shown in the Figure 2. Changing the incident light intensity around, the locations and the widths of the peaks do not change while the numbers of the single pe events, double pe events and so on change correspondingly. Tuning the light intensity lower down to the level that only single photon comes out from the light source in most of the pulses, a single pe distribution fits a Gaussian very well after subtracting the pedestals. The peak is located at 1.5mV with a RMS of 0.4mV. The $\chi 2$ of the Gaussian fit is about 2 pdf mainly due to the double pe tail.

For a slightly raised input level, the pe spectrum is fitted with a combined function with multiple Gaussians. The peaks and widths of the Gaussians are fixed as m*1.5mV and $\sqrt{m}$*0.4mV, respectively, where m is the multiplicity of the pe's. The fitting result is shown in Figure 2, where A_m is relative height of the peaks, the contribution for m>5 is negligible.

The gain G_0 is measured as $(0.710\pm0.002)\text{x}10^7$.

In order to collect fluorescence light from a sub-EeV cosmic ray air shower, the CRTNT detector is designed to handle small signals and have a big dynamic range, e.g. from a few pe's to more than 10k pe's per pixel. The working HV is then selected at 1.3kV.

3. Linearity

3.1 Apparatus: It is difficult to have a calibrated light source which intensity can be changed over orders of magnitudes. In this paper, we tune the light intensity that sheds on the photocathode by changing the distance between the point source and the cathode, because the light intensity is inversely proportional to the square of the distance. The light source must be stable during the measurement. We set the PMT and the point-like source inside a long dark box which allows the distance between them can be changed from 10 cm to 3.3 m, this provides us with about 3 orders of magnitudes variation of the light intensity. The rest part of the device is the same as that used for PMT gain measurement.

3.2 Result and discussions: As mentioned in the PMT gain measurement, the PMT output pulse height and width are measured. As shown in Figure 3, the PMT output pulse area (Vns) changes with the input photon intensity (in arbitrary unit) following a linear relationship well over a range of 3 orders of magnitudes in the left panel. In order to look at the linearity more closely, this result is represented in a ratio between the pulse area and the photon intensity (R) as a function of the photon intensity as shown in the right panel of Figure 3. The ratio is normalized at photo intensity of 600 (arbitrary unit). The linearity is well defined within ±8%, the RMS is less than 5%. The temperature dependence of the LED as a light source is a very important effect. The temperature of the whole system is controlled in ±1° C during the measurement. The other effect is the saturation of the last dynode while the input signal is large. The load resistor is adjusted to avoid the positive correlation between the anode current and the large input photo intensities.

Figure 3. The linearity of the PMT over a range from a few pe's to thousands pe's.

4. Location dependence of the PMT sensitivity

The PMT sensitivity is known not to be so uniform across the surface of the photocathode. It results that the signals strength varies as the image moves across the PMT. In order to correct this effect, the PMT has to be calibrated for the location dependence. A light source driven by UV LED as described above is used to move across the surface of the photocathode millimeter by millimeter from a distance about 1 mm. The light comes out from a hole of 1 mm diameter within a cone of about 30 degree that simulates the light path from a reflector to a PMT of the CRTNT detector. The tube response profile is measured as shown in Figure 4.

The uniformity in the central area of the photocathode is less than 15%.The integral of the profile gives a total sensitivity of the PMT. This can be used to test the uniformity between PMT's. More usefully, the overall sensitivity of each PMT will be used to determine the working HV to maintain a uniformity between PMT's in a CRTNT telescope.

5. PMT response to different wavelength

Using WBr light and a monochromatic meter, a DC light source with a 1 nm bandwidth is used to calibrate the wavelength dependence of the PMT. The wavelength is changed from 200nm to 500nm. The spectrum of the PMT output is shown in Figure 5. The cut-off effect below 300 nm indicates that the UV light absorption of the PMT window plays an important role. This causes the output of the PMT not to be measured correctly. In order to measure the spectrum under 300nm, the input light intensity is increased by about a factor of 7 as shown in red and light blue dots. The spectra shown in Figure 5 are normalized using dots between 320 and 350 nm.

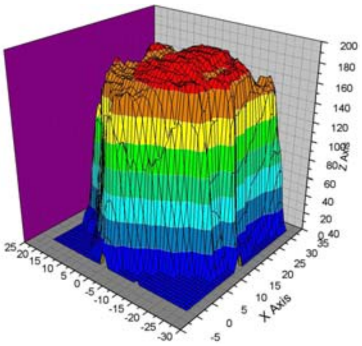

Figure 4. A profile of the PMT response.

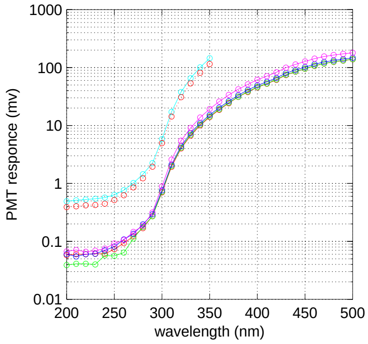

Figure 5. Wavelength dependence of the PMT response.

6. Conclusion

We have calibrated Photonis PMT XP3062/FL for its absolute gains, HV dependence, linearity, wavelength dependence and sensitivity profile using LED and WBr light driven monochromatic meter. The PMT has a dynamic range over 3 orders of magnitudes and has a linear response within ±8% over that range. An overall PMT sensitivity measurement by scanning the photocathode has been developed into a standard procedure to select the PMT's and fine tune the HV supply to the individual PMT to achieve a uniform response throughout the whole cluster. We have calibrated only one PMT in this paper, all tubes provided by Potonis have gains similar to each other, the deviation is less than 40%. Photonis PMT XP3062/FL is shown to be appropriate for the CRTNT telescopes. This type of PMT's has been tested by HiRes group[1] and the results are similar to that reported in this paper, except the linearity of the PMT has been calibrated over a much wider dynamic range in this paper.

7. Acknowledgements

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Reference:

[1] D. Bird *et al.*,NIM, **349**, 592, 1994