Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008

Vol. 4 (HE part 1), pages 813–816

ID 648

30TH INTERNATIONAL COSMIC RAY CONFERENCE

ICRC'07 Mérida, México

Photocathode-Uniformity Tests of the Hamamatsu R5912 Photomultiplier Tubes Used in the Milagro Experiment

V. VASILEIOU[1], R. W. ELLSWORTH[2], A. SMITH[1]

[1]*Department of Physics, University of Maryland, College Park, MD*

[2]*Department of Physics and Astronomy, George Mason University, Fairfax, VA*

vlasisva@umd.edu

Abstract: The Milagro experiment observes the extensive air showers produced by very high energy γ-rays impacting the Earth's atmosphere. Milagro uses 898 Hamamatsu R5912 Photomultiplier Tubes. To complete our Monte Carlo simulations, we tested the photocathode uniformity of our PMTs. The main finding was that the PMT gain and detection efficiency are a function of the distance from the center of the photocathode. Both quantities become considerably smaller as the illumination position nears the edge of the photocathode.

Introduction

Milagro [1] is a water-Cherenkov detector at an elevation of 2650m at the Jemez Mountains in New Mexico. It comprises a central 60m x 80m x 8m pond surrounded by a 200m x 200m array of 175 "outrigger" tanks. The pond, covered with a light barrier, is instrumented with two layers of photomultiplier tubes (PMTs). The top "air-shower" layer consists of 450 PMTs while the bottom "muon" layer has 273 PMTs. Each outrigger tank contains $\sim$4000l of water and one PMT. The PMTs collect the Cherenkov light produced by the air shower particles, as they transverse the detector's water volume. The AS and OR layers allow the accurate measurement of the air shower particle arrival times used for reconstructing the direction of the shower-initiating particle. The greater depth of the muon layer ($\sim$17 radiation lengths) is used to distinguish deeply penetrating muons and hadrons, which are common in hadron induced air showers, from electrons and γ-rays.

The motivation for the uniformity tests described here was a disagreement between the single-muon response of the muon-layer PMTs and a Monte Carlo simulation of this response. According to the PMT tests performed by the IceCube experiment[1], the photocathode response of their 10' PMTs is not uniform all over the photocathode's surface. Before the experimental work reported in this paper, the Milagro PMTs were simulated as having the same properties all over the face of the PMT. We thought it possible that the way the PMTs were simulated was the cause of the disagreement regarding the single-muon response of the muon-layer PMTs.

For that reason, an apparatus was constructed to examine the dependence of the gain and detection efficiency on the distance of the photon-detection position from the center of the photocathode.

Experimental setup

A light source that produced a narrow parallel beam of light was constructed. Its body was composed of two threaded tubes and a ND2 optical filter between them. Two end-caps were attached to the edges of the light source. Each end-cap had a hole of 4.8mm diameter. One of the end-caps was used to firmly hold an LED and the other as a collimator. The light was produced by a 5mm diameter red NSPR518AS LED by Nichia Corp. Its biggest advantage is that its spectral response is narrow (<30nm FWHM) and that it is stable under

1. http://www.ppl.phys.chiba-u.jp/research/IceCube/docs/presentations/index.html

changes in temperature. The resulting light beam had an opening angle of $\sim 1^o$.

Three Hamamatsu R5912 PMTs from Milagro were tested. From these, one (PMT #1024) was extensively tested.

The tests required the light source to be positioned in predefined positions with respect to the PMT face. A wooden structure was built for that purpose. With the help of clamps, the PMT and the light source were mounted steadily on the structure. The light source was always touching the surface of the glass and was oriented perpendicularly to it.

In all the tests, the PMT was in an optically shielded black box. Before each test, the PMT was conditioned under voltage until its dark noise rate fell to normal levels (<2KHz). The magnetic field at the location of the tests was measured to be about 0.5Gauss. Unless otherwise noted, the tests were made using PMT #1024, the supply voltage was 1800V and the PMT was in the vertical position (photocathode facing up).

The tests

Examining the gain of the PMT

The best way to examine the gain was to measure the charge of the pulses. However, due to the fact that no instruments with this capability were available, we measured the pulse heights instead. As it was found, the widths of the pulses were almost independent of their height. For that reason, we could assume that the charge of a pulse was directly proportional to its height. Thus, the gain could be examined by measuring the pulse heights.

For making the pulse height distributions, the PMT pulses were analyzed with a digital oscilloscope. For this test, the light source was operated in pulsed mode. In this mode a pulse generator was used for driving the light source and for triggering the oscilloscope. The oscilloscope measured the amplitudes of the PMT pulses, and sent the results to a PC through the serial port. The light level was low enough that the PMT detected a signal from only a small percentage of the light pulses, so almost all of the PMT pulses corresponded to a single PE. The dark rate of the PMT was about 2KHz, so on average there was just one dark noise hit digitized every $\sim 2 \cdot 10^4$ triggers.

In all the following pulse height spectra, the pedestal [2] is suppressed and the curves are normalized.

Dependence of the gain on the photon-detection position

Pulse height distributions were made for different illumination positions on the photocathode. One of the PMTs was extensively tested (PMT #1024). For the other two PMTs, only the side (equator) and top illumination positions were examined.

The results of the tests on PMT #1024 are shown in figures 1 and 2. The angle of an illumination position is defined as the distance of this position from the center of the photocathode (measured on the surface of the PMT) over the total distance from the center to the equator times 90^o. This way, 0^o corresponds to the center of the photocathode and 90^o to the equator. The gain was significantly reduced when the illumination position was near the the equator of the PMT. While it remained almost constant from the center of the photocathode to about 52^o, there was a sharp transition after that point, with the gain reducing in size by a factor of ~ 2.7 in only 20^o.

The gain for illumination at 90^o was also significantly reduced in the other two tested PMTs.

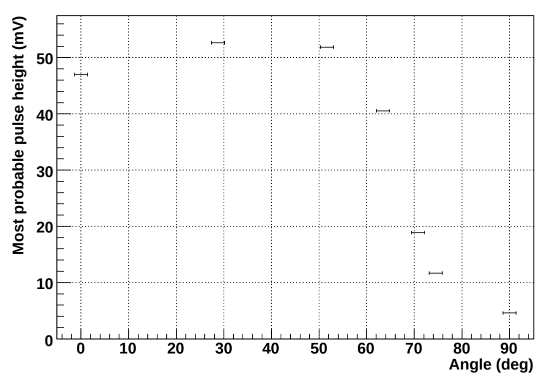

Figure 1: Most probable pulse height for each of the examined illumination positions

2. Pulse height<5mV

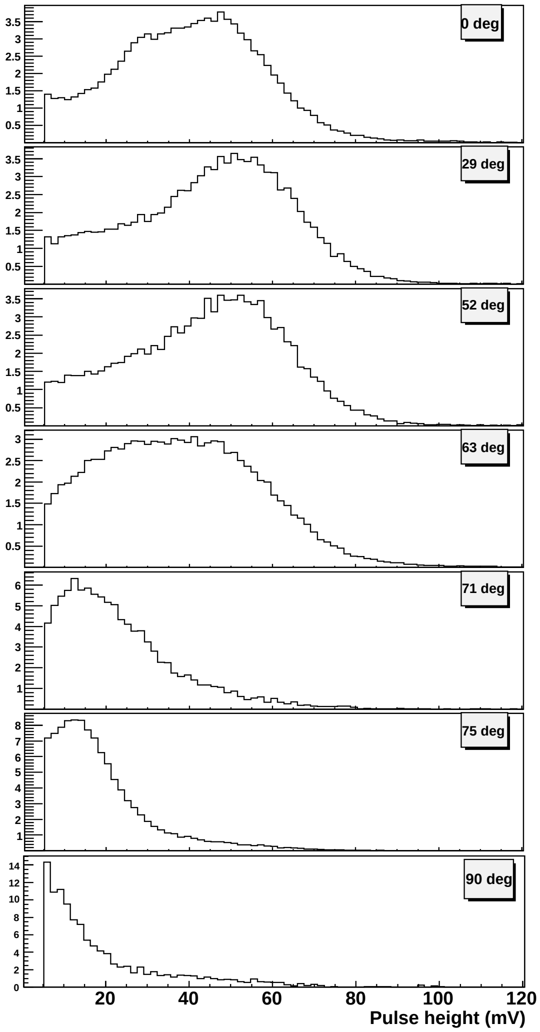

Figure 2: Pulse height distribution for illumination of different positions on the photocathode

Dependence of the gain on the supply voltage and PMT orientation for illumination at the top and the side of the photocathode

To further examine the dependence of the gain on the photon-detection position, we tried to find any correlations between this dependence and the supply voltage and PMT orientation. Pulse height distributions were made for different supply voltages (1600V, 1800V and 2000V), illumination positions (top and near the equator), and PMT orientations (horizontal and vertical). While in the horizontal orientation, a vector which was perpendicular to the center of the photocathode and pointing outwards, pointed south.

Initially, the gain was examined with illumination of the center of the photocathode (figure 3). Only a small dependence of the gain on the PMT orientation was found. Next, the same PMT orientations and supply voltages were tested for illumination of the side of the photocathode. As in the previous section, the gain for illumination at the side of the PMT was considerably lower than the one for illumination at the top (figures 4 and 5). Again, in the horizontal position the gain was slightly higher than in the vertical position. Increasing the supply voltage (and as a consequence, the voltage between the photocathode and the first dynode) increased the gain only when the PMT was in the horizontal position.

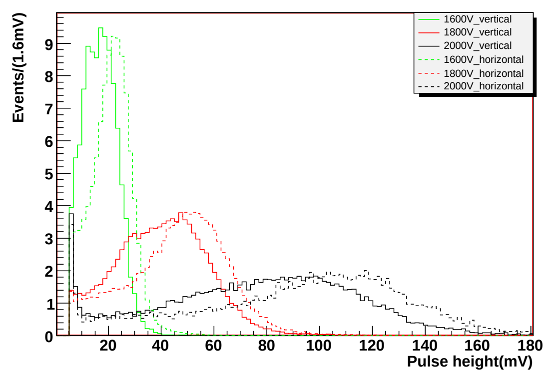

Figure 3: Pulse height distribution for illumination at the center of the photocathode for different PMT orientations and supply voltages.

Dependence of the detection efficiency on the photon-detection position

The light source was connected to a voltage supply that was always on. The PMT signal was sent to a discriminator, which was connected to a scaler. A gate generator, used as a timer, was used to start and stop the discriminator. When the gate generator was on, the discriminator compared the pulse heights against its lowest discrimination threshold (10mV), and the scaler counted the triggers from the discriminator. The measurements were multiplied by an appropriate counting-efficiency factor to account for the pulses between the pedestal

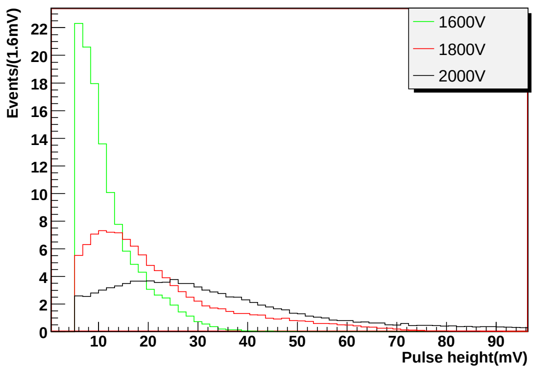

Figure 4: Pulse height distribution for illumination of a point near the equator with the PMT horizontal for different supply voltages.

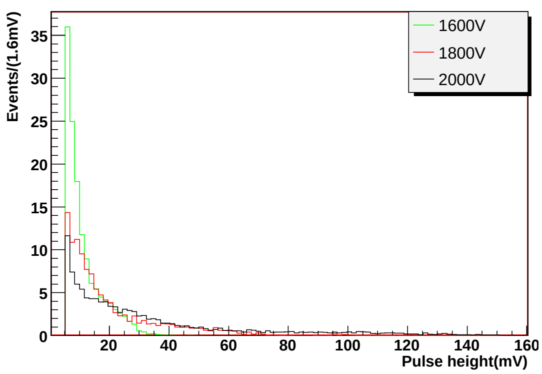

Figure 5: Pulse height distribution for illumination of a point near the equator with the PMT vertical for three different supply voltages.

(5mV) and the discrimination threshold (10mV) that could not be counted.

There were seven different sets of measurements, each one corresponding to a different illumination position. Each set was composed of two background measurements, followed by two signal measurements and then followed by two background measurements. The duration of each measurement was 10sec. The count rate, when the PMT was illuminated, was of the order of tens of KHz.

Table 1 shows the relative detection efficiency for illumination at various points of the photocathode vs illumination at its center.

Angle (deg)	Relative detection efficiency (%)		
	PMT #1024	*PMT #394*	*PMT #992*
0	100±0.5	100±0.5	100±0.8
29	92.4±0.5		
52	88.7±0.3		
63	62.7±0.3		
71	65.5±0.6		
75	65.9±0.3		
90	44.1±0.2	30.8±0.1	33.4±0.1

Table 1: Relative detection efficiency vs illumination position

Conclusion

The photocathode uniformity of the Hamamatsu R5912 PMTs used in the Milagro experiment was examined. The tests showed that the PMT gain and detection efficiency are a function of the photon-detection position. Both quantities are smaller when points near the edge of the photocathode are illuminated. This effect was present in all tested PMTs and was not negligible in magnitude.

Before this study, the Milagro PMTs were simulated as having the same properties all over the face of the PMT. After using the experimental results in the simulation of the PMTs, the simulation now predicts that an atmospheric muon produces ∼110PEs (down from ∼200PEs) in the PMTs of the muon layer compared with ∼100PEs at the experiment.

References

[1] A. et al., Tev gamma-ray survey of the northern hemisphere sky using the milagro observatory, ApJ 608 (2004) 680–685.