Characterization of the Hamamatsu R8900-M16 for Application in Ground-Based Cherenkov Experiments

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Abstract

The Track Imaging Cherenkov Experiment (TrICE), is the first experiment to implement multianode photomultiplier tubes (MaPMTs) in a camera used to image Cherenkov light[1]. Testing was carried out to determine which 7 of 10 Hamamatsu R8900-M16 MaPMTs would be used to complete the 16-MaPMT TrICE camera; the primary selection criterion was low pixel-to-pixel gain variation. Linear gain increase with voltage increase was also considered. Tests were carried out in a dark box setup with a circuit-pulsed LED as the photon source; the test stand's DAQ system converted the integrated charge of the photomultiplier anode pulses to ADC counts and wrote the counts to a RAW data file. These files were analyzed in ROOT to create a pixel-by-pixel gain map for each tube. Three R8900s were found to have significantly higher gain variation among pixels than the rest. Exponential gain increase with voltage increase was similarly linear among all tubes, and the slope of this line was found to be extremely similar among pixels of the same tube. Results from these experiments will be used to interpret results from TrICE and, eventually, to develop improved photomultiplier cameras for gamma-ray telescopes.

1. Introduction

Photomultiplier cameras in ground-based Cherenkov telescopes detect and record Cherenkov light produced by cosmic rays in Earth's atmosphere. Given sufficiently fine camera pixel size and fast signal timing, "direct" Cherenkov light can be separated from night sky background and "extensive air shower" Cherenkov light, allowing for better characterization of cosmic ray composition at a wider range of energies.[2] The Track Imaging Cherenkov Experiment (TrICE) functions both as a ground-based Cherenkov experiment in its own right and as a test bed for the development of finer-resolution photomultiplier cameras and faster telescope electronics.[3] TrICE's photomultiplier camera will eventually consist of sixteen Hamamatsu R8900-M16 multianode photomultiplier tubes (MaPMTs), each with sixteen 6mm by 6mm pixels.

Since gain can vary greatly from pixel to pixel on the R8900, individual pixels must be well characterized before installation so that normalization software can be correctly calibrated and results from TrICE properly understood. Furthermore, TrICE's triggering mechanism necessitates that each individual tube have the lowest possible gain variation among its pixels; extreme variation might cause a "hot" pixel to trigger on a false event while the other fifteen see nothing. Tube-to-tube gain variation is less important, as it can be adjusted by regulating the high voltage going into each tube. Since each tube has only one power input, however, pixel-to-pixel gain cannot be corrected in this way, and results must be normalized by software after data have been taken.

While other types of photomultipliers with significantly lower gain variation, comparable quantum efficiency and crosstalk, and satisfactory current-handling capabilities exist, the R8900 was chosen for TrICE because of its relatively well-resolved

single-photoelectron peak.[4] This peak is important for accurate gain characterization and because TrICE is operated in a low-light environment. Nine Hamamatsu R8900-M16 photomultipliers are already in place in the TrICE camera. Ten more were characterized for gain variation and gain-voltage linearity, and the best seven were selected for placement in TrICE.

2. Experimental Details

Testing was done inside a dark box containing a circuit-pulsed LED from which two optical fibers were routed, one to a motorized stager arm that positioned the fiber against the R8900's photocathode, and the other to a reference Hamamatsu 1161 single anode phototube assembly held at -1116V. A filter wheel, adjusted by a user-controlled stepper motor, allowed for control over the intensity of light reaching the photocathodes.

Circuitry in the test stand RABBIT crate triggered the LED pulse, then sampled integrated charge from the R8900 and reference tube anode pulses.[5] One iteration of this process constitutes one "event". Data were written to the DAQ computer in a RAW file.

Since gain is at a maximum at pixel centers, ensuring that the LED fiber would shine directly on pixel centers was necessary to prevent characterizing a pixel's gain as lower than it actually was. Before gain mapping, therefore, 1000 events per millimeter were taken across an approximately 8mm horizontal range on the R8900 surface, near where a pixel center was expected. Counts were plotted against x-position in ROOT, the curve was fit to a Gaussian, and the Gaussian mean was taken to be the x-coordinate of a pixel center. The process was repeated for the y-axis, and pixel centers were assumed to be evenly spaced across the photocathode.

One pedestal run per voltage was taken for every MaPMT. In a pedestal run, two 1000-event runs were recorded with the dark box LED turned off. This results in a "signal" composed primarily of electronics noise (with a very small dark current component), which can then subtracted from gain-mapping runs.

The filter wheel was then rotated to provide enough photons to the R8900 for about 2000 counts over pedestal: sufficient for statistically significant results, but not so many as to remove the experiment from the "few photoelectrons" range (roughly, $5 \leq N_{pe} \leq 15$).

For each pixel, two runs of 500 events each were recorded for at least two voltages (600V and 650V). Ideally all 16 pixels would have been run at 575V, 600V, 650V and 800V in order to obtain a detailed gain-to-voltage plot, but due to time constraints, only pixels 1-4 were tested at all four voltages. The stager was then moved to the next pixel in a predetermined sequence until all sixteen pixels had been tested.

Data, in the form of the number of ADC counts per channel per event, were written to a RAW file. A suite of ROOT macros, written by Robert Wagner, created a histogram of ADC counts for each pixel's signal and pedestal files, performed a Gaussian fit, and calculated gain according to the following formulae:

$$N_{ADC}^{sig} = ADC_{sig} - ADC_{ped} \qquad \sigma_{ADC}^{sig} = \sqrt{\sigma_{sig}^2 - \sigma_{ped}^2}$$

$$N_{pe} = \left(\frac{N_{ADC}^{sig}}{\sigma_{ADC}^{sig}} \right)^2 \qquad G = \frac{N_{ADC}^{sig}}{140 N_{pe}}$$

The program then wrote a .gif depiction of each pixel on the tube surface, the number of photons calculated to have hit it, and its gain. In some cases, usually because

of an overly opaque filter wheel setting, insufficient photons reached a pixel. In order to prevent an inaccurate gain report because of a pedestal-dominated reading, the gain macro is set up to fill in zeroes on the gain map where this has happened, and usually does so for all pixels after this point in the scan. Gain and N_{pe} were calculated by hand according to the above equations in these cases, and were added to the .gif files later using Microsoft Paint.

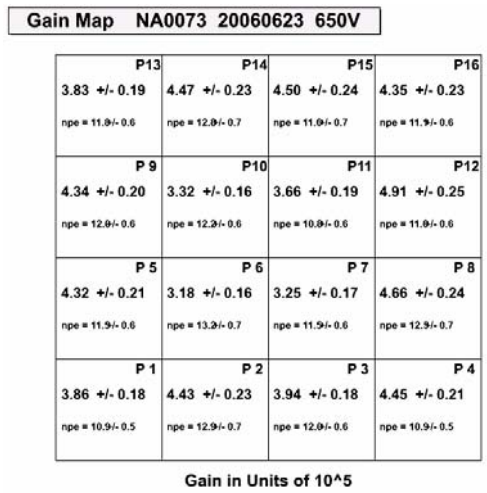

Figure 1. Sample gain map macro output.

3. Results

Gain variation at 600 volts ranged from 1:1.54 to 1:3.03, and at 650 volts ranged from 1:1.54 to 1:2.69. The 1:1.54 variation is comparable to the 1:1.5 maximum manufacturer-specified gain variation for the Burle Planacon microchannel plate photomultiplier at its standard operating voltage (-2500V).

All tubes were found to have a similar exponential gain increase with voltage; the slope of this increase, plotted on a logarithmic scale, did not differ alarmingly among pixels of the same tube.

Tube Number	Gain ratios		Average gains	
	600V	650V	600V	650V
NA0054	1:1.87	1:1.74	$1.974 \cdot 10^5$	$4.620 \cdot 10^5$
NA0066	1:1.82	1:2.05	$2.026 \cdot 10^5$	$4.359 \cdot 10^5$
NA0073	1:1.58	1:1.54	$1.863 \cdot 10^5$	$4.092 \cdot 10^5$
NA0067	1:1.75	1:1.67	$1.976 \cdot 10^5$	$4.243 \cdot 10^5$
NA0030	1:1.82	1:1.92	$1.633 \cdot 10^5$	$3.702 \cdot 10^5$
NA0047	1:1.70	1:1.73	$2.031 \cdot 10^5$	$4.832 \cdot 10^5$
NA0052	1:1.54	1:1.63	$1.991 \cdot 10^5$	$4.032 \cdot 10^5$
NA0009	1:1.99	1:1.82	$3.342 \cdot 10^5$	$7.232 \cdot 10^5$
ZA1917	1:2.59	1:2.43	$1.720 \cdot 10^5$	$3.838 \cdot 10^5$
ZA1910	1:3.03	1:2.69	$2.456 \cdot 10^5$	$5.584 \cdot 10^5$

Table 1. Lowest-to-highest pixel gain ratios and average gain over all 16 pixels for the ten Hamamatsu R8900 MaPMTs tested. Rejected tubes printed in dark red.

Tube	*Incl.*	St. Dev.	Tube	*Incl.*	St. Dev.
NA0054	*1-4*	0.00236	**NA0047**	*1-4*	0.00114
NA0054	*ALL*	0.00205	**NA0047**	*ALL*	0.00219
NA0066	*1-4*	0.00013	**NA0052**	*1-4*	0.00016
NA0066	*ALL*	0.00085	**NA0052**	*ALL*	0.00039
NA0073	*1-4*	0.00041	**NA0009**	*1-4*	0.00072
NA0073	*ALL*	0.00169	**NA0009**	*ALL*	0.00175
NA0067	*1-4*	0.00035	**ZA1917**	*1-4*	0.00040
NA0067	*ALL*	0.00103	**ZA1917**	*ALL*	0.00156
NA0030	*1-4*	0.00067	**ZA1910**	*1-4*	0.00050
NA0030	*ALL*	0.00210	**ZA1910**	*ALL*	0.00223

Table 2. Standard deviation of gain-voltage slopes for pixels 1-4 at four voltages ("*1-4*") and all pixels at two to three voltages ("*ALL*").

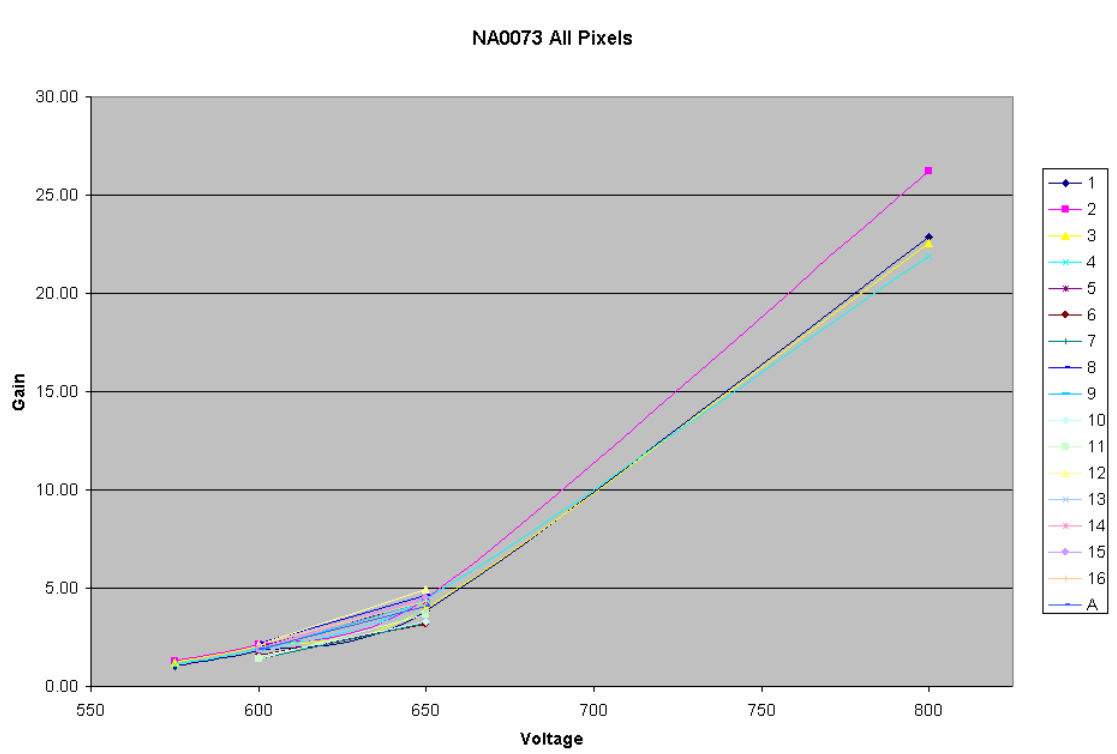

Figure 2. Gain-to-voltage relationships for all sixteen pixels, plus the average over all pixels, of NA0073.

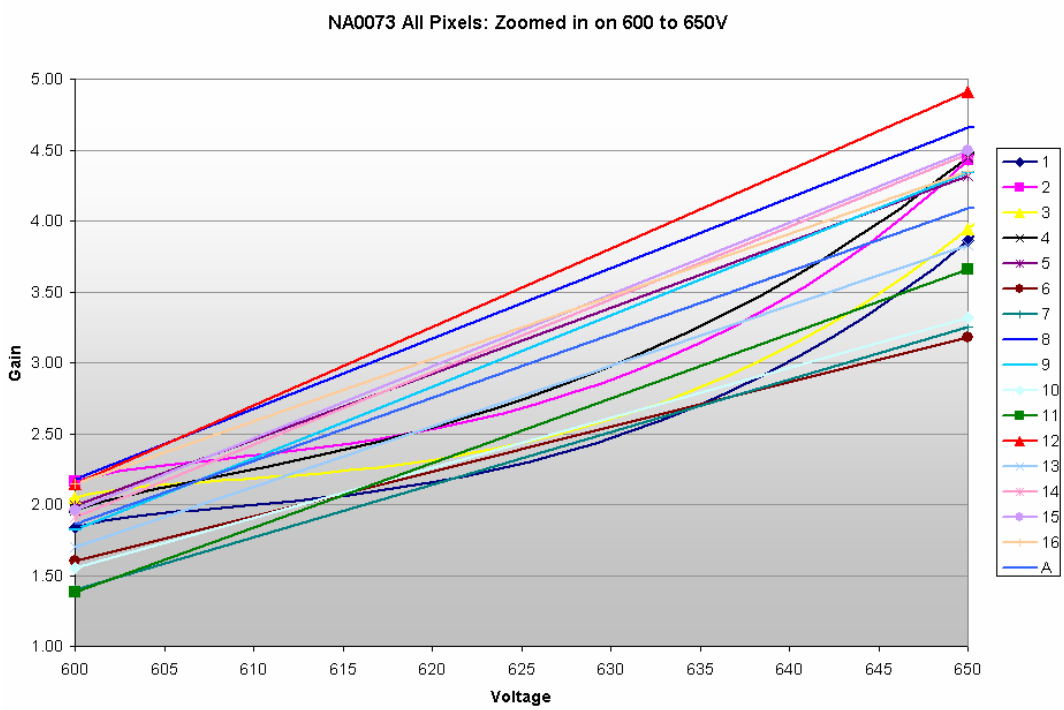

Figure 3. The same data as Figure 2, but shown only over the 600V to 650V range.

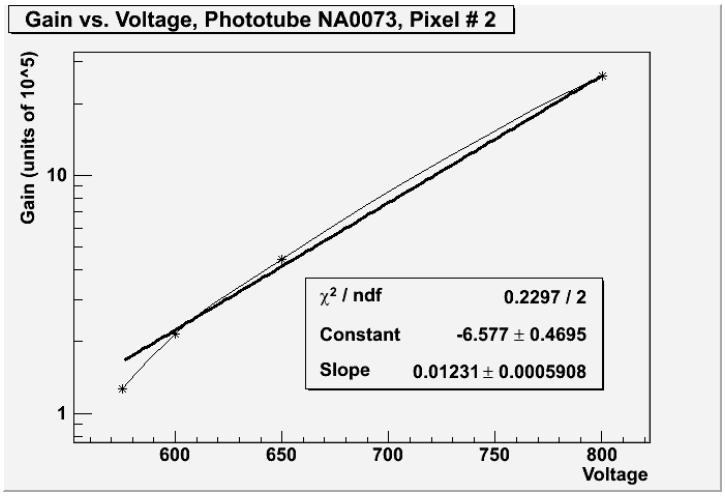

Figure 4. One pixel's gain variation with voltage plotted on a logarithmic scale. Output from Melinda Morang's voltplot macro.

4. Discussion

In light of these results, it is recommended that phototubes NA0066, ZA1917, and ZA1910 not be used in the TrICE camera except in case of damage to one of the currently placed camera tubes. It has been suggested that PMT 1, which has one "hot" pixel, may be just such a problem tube. In this case NA0066 is recommended above ZA1917 and ZA1910.

All raw data from these experiments are available at www.hep.anl.gov/scanlon, except that which is already posted at www.hep.anl.gov/morang.

5. References

[1] Byrum K, Drake G, Hays L, Kieda D, Swordy S, Wagner R, Wakely S, Wissels S. "A Track Imaging Cherenkov Experiment (TrICE)." Abstract submitted to IEEE May 2006; accepted for presentation at IEEE 2006 Nuclear Science Symposium, Medical Imaging Conference and 15th International Room Temperature Semiconductor Detector Workshop.

[2] Kieda DB, Swordy SP, Wakely SP. "A High Resolution Method for Measuring Cosmic Ray Composition Beyond 10 TeV." Astroparticle Physics Volume 15 Number 3, 4 August 2003.

[3] Byrum et al.

[4] Wagner, RG. MAPMT Tests for Selection of Initial TrICE Camera Phototube. TrICE collaboration meeting, Argonne National Laboratory. 30 August 2005.

[5] Wagner, RG. "Plan for Testing the Hamamatsu H8500 Multianode Phototube for TRICE Use." TrICE Internal publication, 31 January 2005.