2016

Characterizing CROP Photomultiplier Tube Behavior at 1000 Volts

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Abstract

The Cosmic Ray Observatory Project (CROP) is a "statewide outreach project whose goal is to involve Nebraska high school students, teachers, and college undergraduates in a multi-faceted, hands-on research effort to study extended cosmic-ray air showers.[1]" In order to achieve this goal, the CROP staff at the University of Nebraska is responsible for building and maintaining simple cosmic ray detectors. These detectors consist of two primary components; the plastic scintillation panel responsible for "catching" the cosmic rays, and a photomultiplier tube (PMT) used to convert the flashes of light within the scintillator panel into an electrical pulse. Typical operating voltages for PMTs can range between 1000 – 1600 Volts.

CROP had been operating their PMTs at voltages ranging between 1350-1650 Volts. During the Fall of 2015, documentation was uncovered that suggested some of the PMTs should not be operated above 1100 Volts for long periods of time. In order to fully understand how the PMTs would operate at this new, lower operating voltage, a set of detectors were built using PMTs that had not been exposed to high voltages. These detectors were thoroughly tested and used to establish new benchmark scan results. The three primary tests performed on the detectors were Threshold Scans, Efficiency Scans, and Time-Stability Scans.

Figure 1 – CROP Photomultiplier Tube

Threshold Scan

The Threshold Scan is the first test done to test the functionality of a detector. Not all pulses coming from the PMTs are created equally. A larger particle passing through the detector will create a larger pulse. The threshold setting of a detector determines how large a pulse must be for it to be counted as a real event. The ideal threshold level is high enough that it eliminates electronic noise coming from the PMT, but is low enough to ensure that the number of particles counted by the detector is maximized. The optimal threshold setting of a detector has been shown to be linearly proportional to the operating voltage of the detector. Thus, it is expected that by decreasing the operating voltage of the CROP detectors down to 1000 Volts, then the threshold levels should be lower than previous scan results.

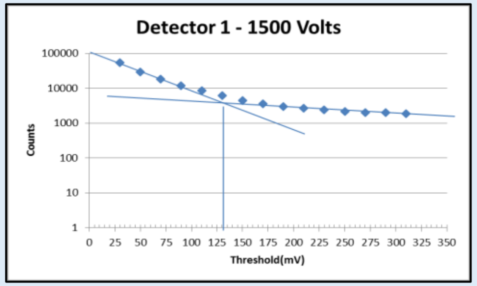

Figure 2 – Threshold Scan at 1500 Volts

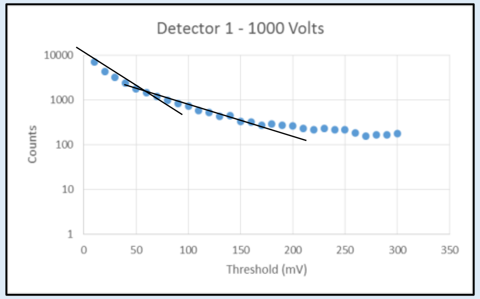

Figure 3 – Threshold Scan at 1000 Volts

Efficiency Scan

The Efficiency Scan is used to determine the operating efficiency of a pair of detectors. The scan is performed by stacking four detectors in a single tower, and the four detectors are connected to high voltage. The top and bottom detectors are called trigger detectors. Any time both trigger detectors fire at the same time, meaning they both saw a particle pass through at the same time, the test detectors are checked to see if they saw a particle at the same time. If the test detector sees a particle under these conditions, it can be said that this is a confirmed particle. The efficiency of a detector is calculated by dividing the number of confirmed particles the detector saw by the number of trigger events. When the detectors were operating at 1000 Volts, the efficiency tended to be around 50%. When the detectors were operating at a much higher voltage, such as 1650 Volts, the efficiency tended to be in the 55%-65% range.

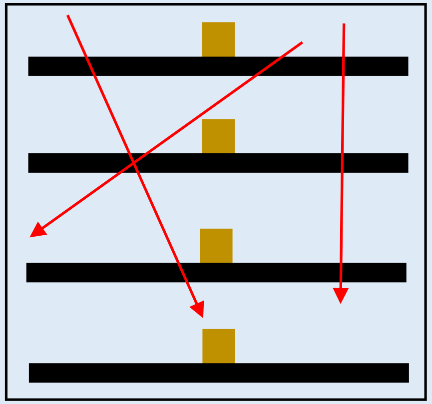

Figure 4 – Efficiency Scan Diagram

Time Stability

Outside of a brief 15 minute warm-up period, the count rate of a PMT should be fairly steady. Due to the random nature of cosmic rays, it is expected that there will be some variance from one time interval to the next. For this test, the detectors were set to an optimal threshold, and the counts for each detector were recorded in five minute intervals. If the detectors are performing as expected, then a histogram of the count rate per five minutes will be normally distributed in a Gaussian manner. The first graph below is the histogram of a detector operating at 1000 Volts, while the second one is that of a detector operating at 1500 Volts. For the detector operating at 1000 Volts, it is easy to see that the count rate is indeed normally distributed about some mean value. Since the spread in the data is greater for the detector operating at 1500 Volts, it is harder to see the normal distribution, though a rough shape is visible.

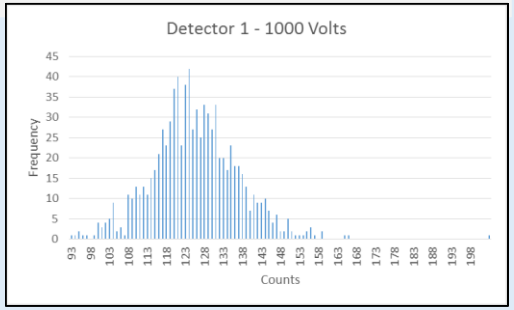

Figure 5 – Histogram of Detector operating at 1000 Volts

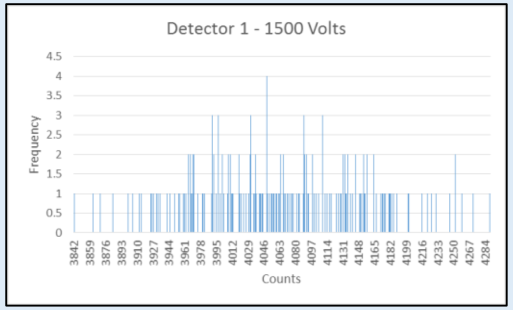

Figure 6 – Histogram of Detector operating at 1500 Volts

Conclusions

- The optimal operating threshold of the PMTs decreased, as predicted by older scan results (Summer 2015 and back). New thresholds are expected to be in the 50-60 mV range.
- The efficiency of the detectors was found to have decreased by 10-15%. This may be attributed to the significantly lower event rate.
- The time stability of the PMTs was found to be exceptional. This shows that the detectors are operating reliably for long term scans.

I would like to thank Professors Greg Snow and Dan Claes and the entire CROP Staff for providing the guidance and equipment necessary to make this project a success. I would also like to thank the University of Nebraska's UCARE program for providing the funding that made this research possible.

References:

CROP Project Statement:
http://crop.unl.edu/about/statement.html

CROP Book 2.0, T. Struble, E. Larse, and E. Van Winkle