

## Characterization of the PMTs for the Telescope Array experiment

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The Telescope Array (TA) experiment is being constructed in Utah, USA in order to confirm or refute the existence of super-GZK cosmic rays observed by the AGASA shower array. This paper describes the methods of calibration and characterization in the laboratory for TA PMTs used for the ground array detectors. Their gain, charge response, and their dynamic range have been extensively scanned and calibrated. All the results have been combined and provided in the form of the data library for being implemented by the detector Monte Carlo simulation. The prospect of contributions of the present calibration to the TA event analysis is also briefly mentioned.

### 1. Introduction

The Telescope Array (TA) is a high energy cosmic ray hybrid detector which consists of a ground array covering approximately 900 km<sup>2</sup> and three stations of fluorescence detectors. They are deployed in desert of western Utah, USA. The surface detector (SD) in the array uses two layers of scintillation counters viewed by two photomultiplier tubes (PMTs). A majority of TA events consists of particle density and timing profile recorded in individual surface detectors. An accurate understanding of the PMT response is, therefore, necessary in order to determine both the geometry of these events as well as to reconstruct their energies. In this paper we describe our relative and absolute calibration of the PMTs for the SDs in the laboratory.

### 2. PMT calibration system

Figure 1 illustrates the calibration system for the PMTs. Seven PMTs put in a dark box are illuminated by diffuse light from UV LEDs for measuring the PMT gain, single photoelectron (SPE) response, and dark count rate. Signals from the PMTs are read out by the CAMAC ADC module, the FADC module used in the front-end electronics of the TA experiment, and the digital scope, depending on different aspects of the PMT characterization. For example the data taken by the scope indicated that a SPE waveform has been found to be represented well by double-Gaussian and variations of the waveform from tube to tube can be negligible.

### 3. SPE response

The charge response for SPE detection has been extensively studied. Figure 2 in the left panel shows an example of the calibration data. Using a PMT amplifier with gain of  $\sim 10^6$  leads to a clear SPE peak. The peak-to-valley ratio (P/V) is 1.5. This SPE peak has been used as an indicator of the PMT gain, which allows to study the gain - HV scan. The right panel of Figure 2 shows an example. We scanned all the PMTs to confirm they satisfy the following criteria:

- (1) The gain of  $4 \times 10^6$  can be realized by high voltage lower than 1600 volts.
- (2) P/V is better than 1.

More than 95 % of the tubes we have scanned passed these requirements. The numbers like P/V, HV dependences of gain, and time width of SPE waveform are recorded into a database, which is used by the detector Monte Carlo simulation.

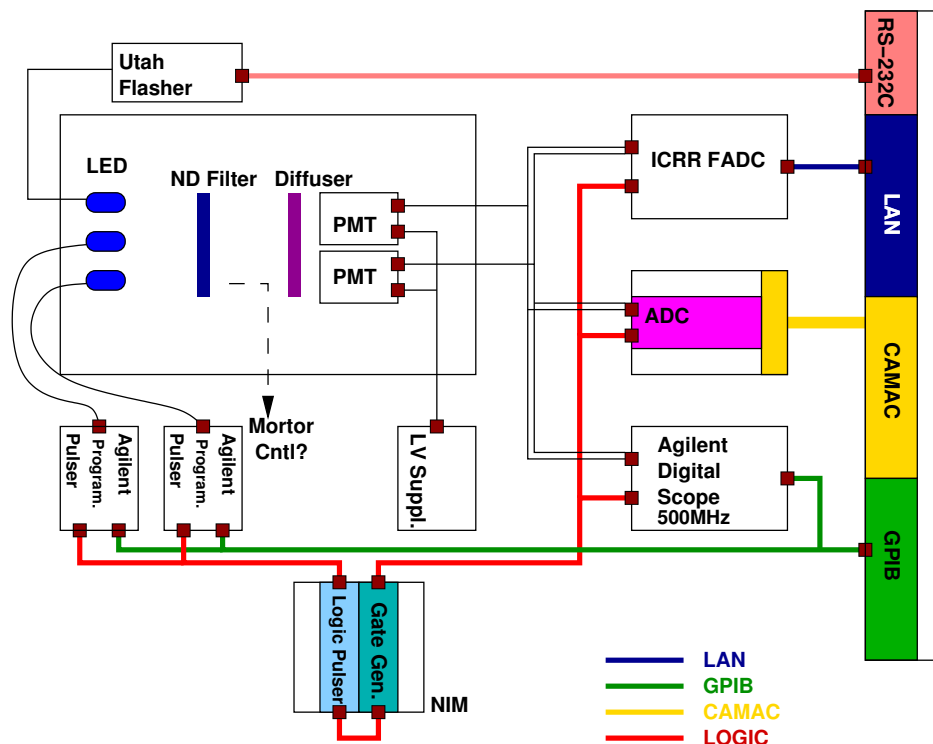


Figure 1. Left panel: Schematic view of the PMT calibration system.

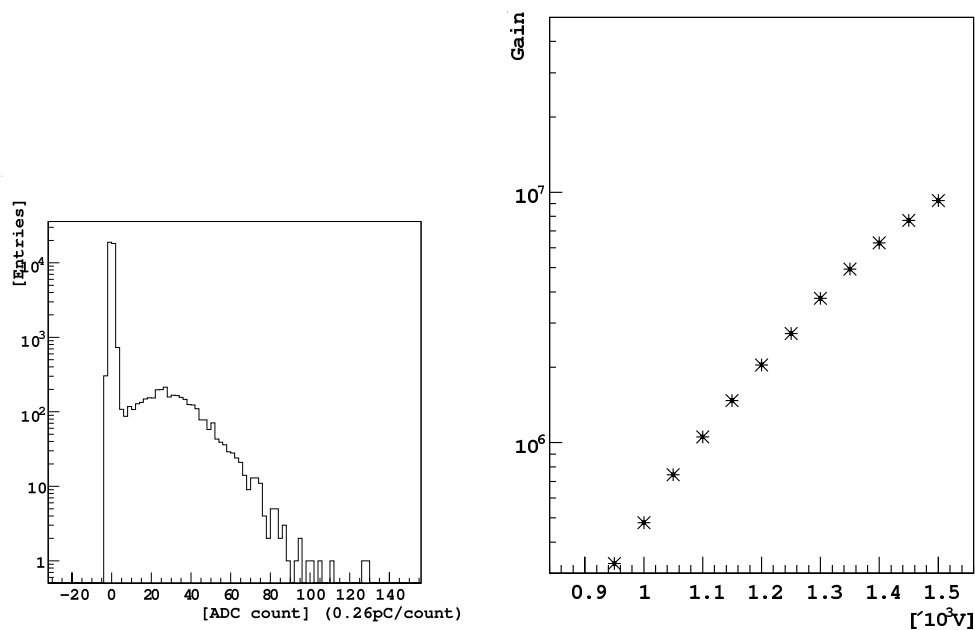
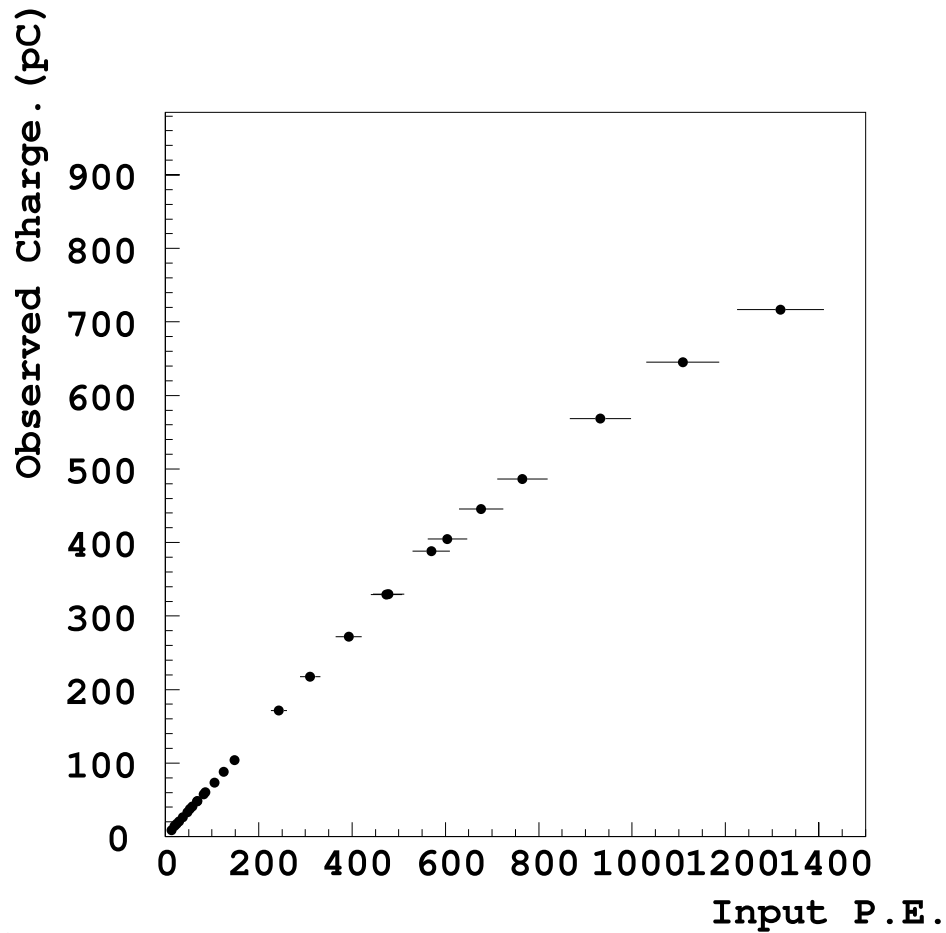


Figure 2. Left panel: The charge histogram of a PMT illuminated by a dim UV LED light. One can see a SPE peak accompanied by the pedestal peak. The PMT gain in this plot is  $4 \times 10^6$ , which equals to the planned number in the actual operation. Right panel: Gain of a PMT as a function of applied high voltage.



**Figure 3.** PMT linearity data. The output charge is plotted as a function of the number of photoelectrons corresponding to the LED luminosity. The PMT gain is  $4 \times 10^6$ .

#### 4. Dynamic range

It is also important to measure the linearity of the PMT response to multiple photoelectrons. A bright LED with a set of calibrated neutral density filters is used to provide various luminosities of UV photons for such a linearity measurement. The result is shown in Figure 3. The number of photoelectrons is estimated from the SPE peak and the attenuation factor of each filter. It is found that an TA PMT has a linear response up to approximately 500 photoelectrons at the gain of  $4 \times 10^6$ . Since a representative FWHM of the LED light pulse is 30 nsec in this measurement, the corresponding current where the PMT deviates from the linear response is  $\sim 10$  mA.

