Absolute Gain Calibration of PMT for the Fluorescence Detector of the Telescope Array Experiment

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***Abstract*. An absolute gain calibration of PMTs for the fluorescence detector of the TA experiment was performed by using Rayleigh scattered photons from the pulsed nitrogen laser. We describe the setup, the calibration procedure and the result.**

I. Introduction

The imaging camera of TA fluorescence telescope is composed of a matrix of 16 x 16 PhotoMultiplier Tubes (PMT: HAMAMATSU photonics R9508). Fluorescence photons from the air shower are detected by the PMTs and the waveform of the output signal (arrival time and amplitude) is recorded by a 10 MHz FADC readout system. The estimation of absolute PMT gain and the adjustment of relative gains among PMTs are required in order to obtain the energy of the shower with the best accuracy. For the energy determination, we need to calculate the number of photons entering the PMTs from the integration of the digitized waveform. We installed 3 standard PMTs in each camera, whose absolute gains were calibrated in the laboratory before installation. In the following section, the development and procedure of calibration using a pulsed UV light source of known absolute intensity are described. The gains of other PMTs in the camera are equalized in situ to the standard PMT using a diffused light source Xenon flasher. The gains of the standard PMT measured in the laboratory calibration and that in the observation site were monitored by the YAP $YAlO_3$ scintillator pulser attached to the standard PMT (Fig.1).

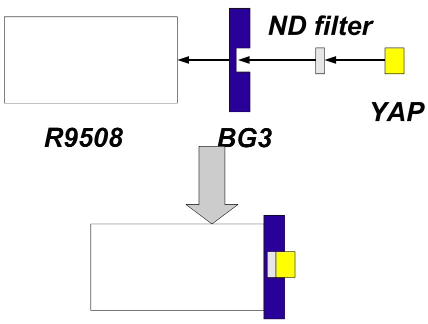

Fig. 1. Intensity of output from PMT with angle of linear polarization.

II. Setup

The conception diagram of calibration system is shown Fig.2. We called this system CRAYS(Calibration using RAYleigh Scattering).

A laser we use as light source is VSL-337ND-S, Laser science, 337.1nm wavelength and 300 μJ/pulse. We let a N_2 laser of wavelength 337.1nm be incident on a scatter box and perform calibration by side-scatter light. In the light path, at first laser beam is attenuate and narrowed a diameter by aperture installed close at hand. Next, ND filter installed as attenuator and splitter, and intensity of spllited light is detected by pyroelectric energy meter(Rjp-435) to monitoring relative energy of laser. A flipper installed for taking data to estimate pedestal. Besides dark current, it is considerable patch noise to get mixed into PMT signal accompanied with laser emitted, we must take pedestal data by flahing laser and blocking it. 2000 events taken in a measurement and flipper on/off is changed by every 100 triggers. Because photons are polarized by throwing ND filter, polarizer and wavelength transformer installed to convert polarization to random polarization. Before incident to chamber, laser beam is narrowed by aperture again. Scatter box is connected to a vacuum pump(DAU-100, ULVAC) and can go down for a vacuum of 266Pa at maximum. Pressure in the box is measured by pressure gauge and temperature is measured by thermistor. This

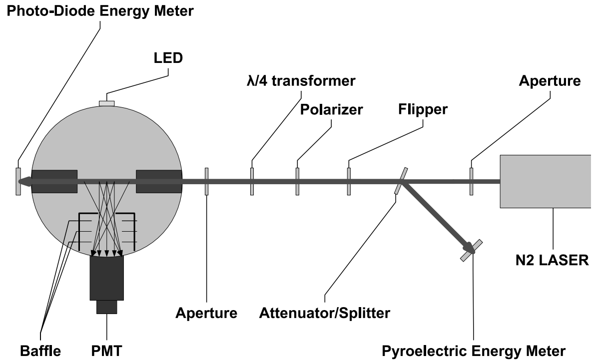

Fig. 2. CRAYS concept

pressure gauge measures relative pressure for pressure in a laboratory, so pressure of outside is measured other gauge. Chamber is cylinder form of a radius of 30cm and filled up with pure gas its purity is 99.9995%, like Nitrogen or Argon.

PMT is installed in the flank of the beam path, flashed by side-scattered photon. Baffle is installed in front of PMT to decrease background photons except direct incident from Rayleigh scattering. 4cm $\times$ 1cm square window of foreground of baffle decides aperture for laser. Wimdows of entrance into box and exit to outside and to PMT, is made from anti-reflection coated CaF_2, 99.7% transmissivity. A photodiode energy probe(Rjp-465) on beam line detects absolute power of laser. This output is used for counting number of photon incident PMT surface. Both of energy probes are calibrated with 5% precision. Area of PMT surface opend to airlight can be limitted by mask. Masks have size variation and we can check consistency with other 2 dimensional inhomogeneity scanning. Readout electronics and signal cables used for calibration in labo are same as used in observation site, we make conditions between labo and observation sight equal. Waveform is recorded at 512 bin, 10MHz. Accuracy of High-Vloltage suppliers in laboratory and in observation site are equal is checked by same multimeter.

Disp	measure
200	200.10
300	300.40
400	399.60
500	499.20
600	599.00
700	699.00
800	799.00
900	898.00

Disp	measure
-884	-884.9
-883	-883.4
-887	-887.1
-865	-865.2
-864	-863.8
-822	-821.8
-850	-850.8
-896	-896.8

List.1: Result of HV measurement. Left was measured in the laboratory with RPH-31(Repic). Right was measured in site.

From left list, the HV module in laboratory is running correctly at less than 1% accuracy, From right, the HV module in site is running correctly too. This measurment was performed with same multimeter FLUKE-177. LED light source is installed in the opposite side of PMT.

III. Performance of Light Source

Cross section of Rayleigh scattering is written by following expression.

$$\frac{d\sigma}{d\Omega} = \frac{24\pi^3}{\lambda^4 N^2}\left(\frac{n^2-1}{n^2+1}\right) F_k \frac{3}{16\pi}(1+\cos^2\theta) \qquad (1)$$

λ is wavelength, N is density of molecule, n is refractive index,F_k is called King correction Factor. Theoretical value calculated from eq.(1) is checked by experimental method accuracy of 1%.[1], so photon intensity hit PMT surface can be estimated precisely.eq.(1) is expression in case of non-polarized light, so it should be considered polarization. Polarization of laser is less than 2%.Fig.3

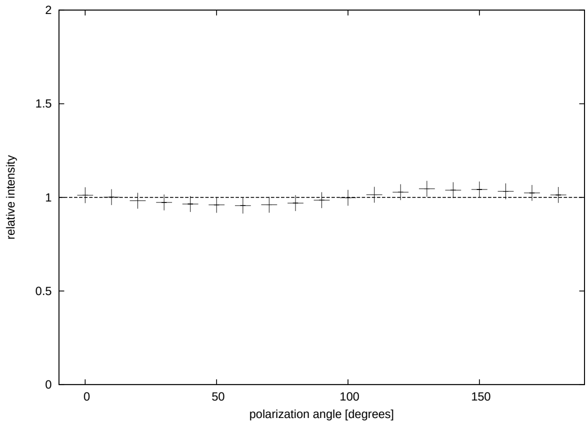

Fig. 3. Polarization of laser

To estimate background photon and To check linearity for density of molecular, we research ADC count with changing pressure of gas in chamber. Result is shown in Fig.4.There is a background of 2% and linearity for pressure.

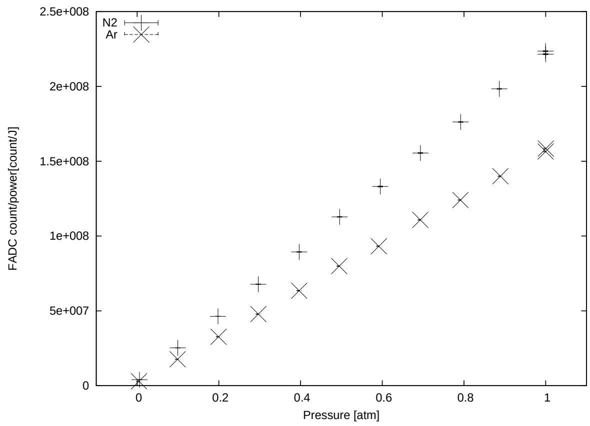

Fig. 4. horizontal:pressure of filled gas, vertical:output from PMT revised by laser power.

To get more information about background, we perform an experiment that let linear polarization incident on gas. So when polarization angle is changing, angle dependence should form sine curve. Result of experiment is shown at Fig.5.

Systematic error of CRAYS is cased by calibration accuracy of energy probe mainly, other factors are geometric paerture calculate and reflection in the scatter box. All of them become 8% in total.

IV. Measurement, Adjustment and Analysis

We adjgusted gain of PMTs 7×10^4. Items measured are followings.

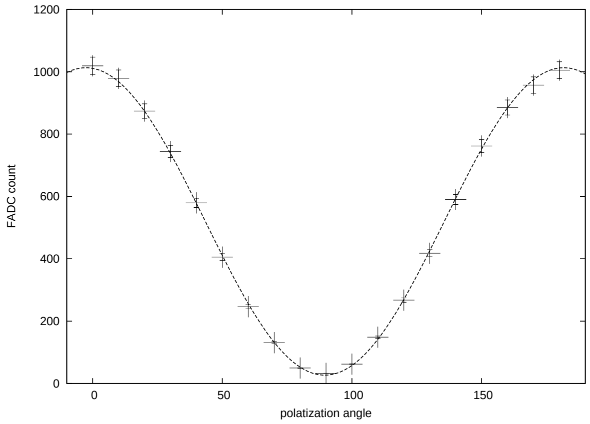

Fig. 5. Intensity of output from PMT with angle of linear polarization.

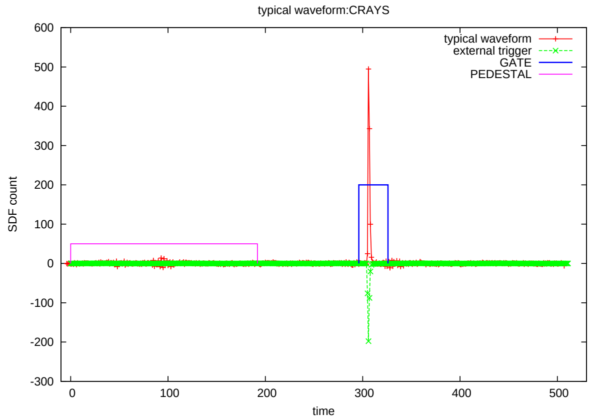

Fig. 6. Typical output of CRAYS and external trigger pulse.

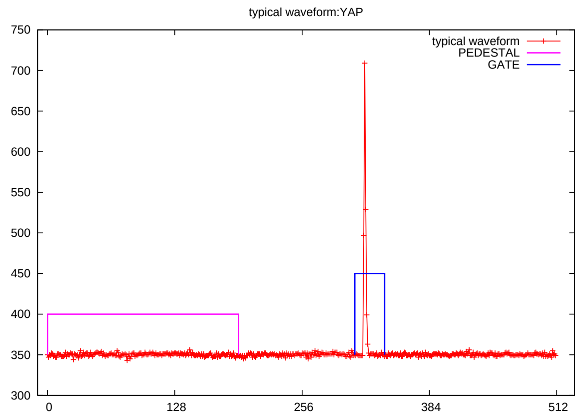

Fig. 7. Typical output of YAP.

1) Gain curve. we measured dependence of gain for applied high voltage with 3 levels of light intensity. Intensity was controlled by changing mask size. The voltage was raised by 100V and measured 1250V from 700V. 2000 triggers taken in 1 measurement.
2) HV value. we coordinated HV so that gain of PMTs became 7×10^4 by CRAYS.
3) YAP pulse in HV determined previous process. we use this data to carry calibration value to observation site.

While calibration was performing, temperature in a laboratory was kept about 25 degrees by air-conditioner. Pressure in a laboratory was measured by mercury barometer. In our calibration of PMT, we use 3 light source, CRAYS, YAP and LED. CRAYS and LED flash by external trigger. An integral region of the waveform is determined from information of external trigger. Peak position of output signal of PMT and external trigger are equal in almost events. So region is selected as from 10 bin to back 20 bin. In case of YAP, its data is taken by internal(self) trigger, integral region is determined by peak of their own. Pedestal is estimated from area initial point to 192th bin, shown Fig.6, Fig.7.

Fig.8 is spectrum of FADC count. Value represents a spectrum is calculated from gaussian fitting. We evaluated value of count/photon. For our purpose, the value should be adjusted 0.501 count/photon. We coordinated HV to be so. We calibrated HV with center 18mm radius of PMT opened. Even 10mm radius and state without the mask went equally successively.

V. Results

We have calibrated 75 PMTs in total. As a result of calibration, distribution of value that count/photon is shown at Fig.10.

PMT gain have been adjusted by RMS of 1%. Distribution of adjusted HV is shown at Fig.11.

Inhomogeneity check by CRAYS was performed by mask changing, result of it is shown Fig.12, Fig.13.Comparing 10mm radius with 18mm radius, relative response of 10mm for 18mm is 28.5% in average.Ralative response between witohout mask and 18mm radius, the value is 263.6%.In a paper[2], value of the former is 28.8%, the latter is 272.0%.In accuracy of these measurment, it can be said that these results are consistent.

In 75 PMTs, 5 PMTs measured twice leaving 6 months to check the stability.The latter result reproduced previous resulst with 1.3% precision.

VI. Acknowledgements

The Telescope Array experiment is supported by the Ministry of Education, Culture, Sports, Science and Technology-Japan through Kakenhi grants on priority area (431) "Highest Energy Cosmic Rays", basic research awards 18204020(A), 18403004(B) and 20340057(B); by the U.S. National Science Foundation awards PHY-0601915, PHY-0703893, PHY-0758342, and PHY-0848320 (Utah) and PHY-0649681 (Rutgers); by the Korean Science and Engineering Foundation (KOSEF, Grant No. R01-2007-000-21088-0); by the

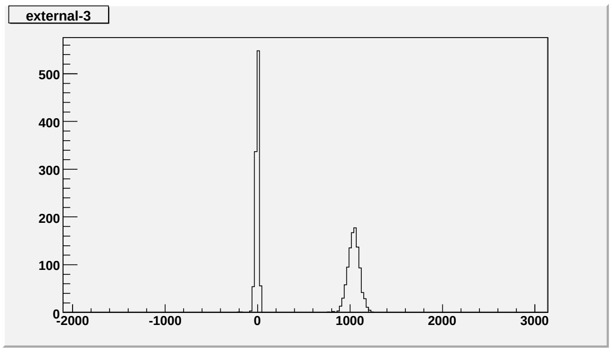

Fig. 8. Left histgram is pedestal data, its peak is nearby 0. Right one is equivalent to events laser incindents, its width is 1σ=5.7%

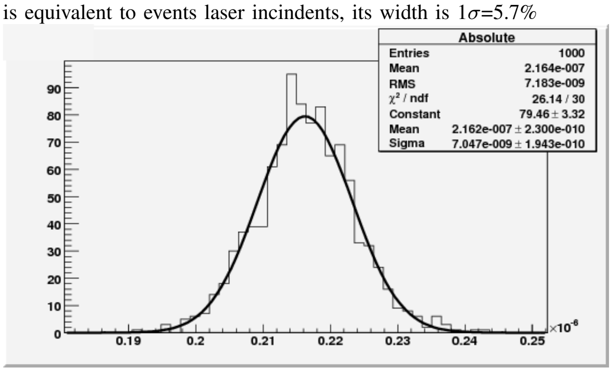

Fig. 9. Example of spectrum of laser energy. Mean is 216.2nJ, 1σ=3.4%.

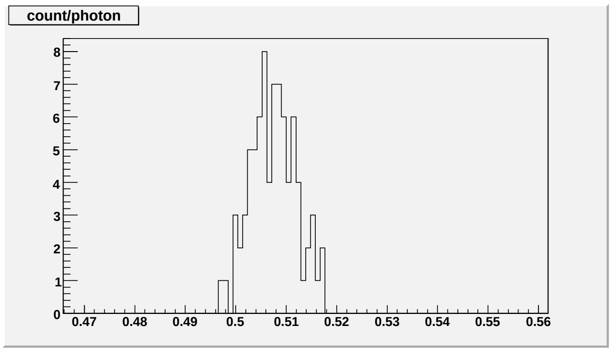

Fig. 10. Distribution of 75 PMTs with mask of 18mm radius.

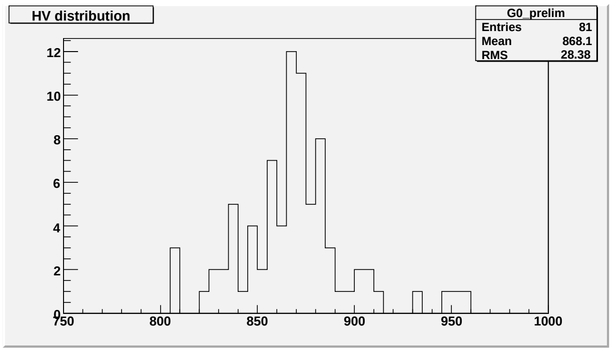

Fig. 11. Adjusted HV

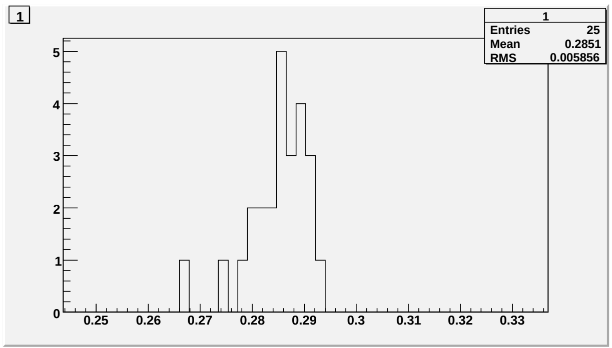

Fig. 12. Comparison between 10mm radius and 18mm radius.

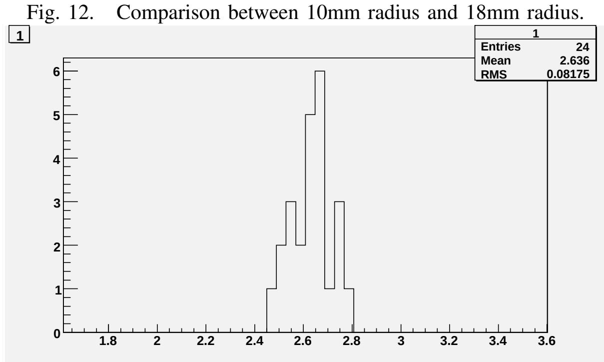

Fig. 13. Comparison between full opened measurement ant 18 mm radius.

Russian Academy of Sciences, RFBR grants 07-02-00820a and 09-07-00388a (INR), the FNRS contract 1.5.335.08, IISN and Belgian Science Policy under IUAP VI/11 (ULB). The foundations of Dr. Ezekiel R. and Edna Wattis Dumke, Willard L. Eccles and the George S. and Dolores Dore Eccles all helped with generous donations. The State of Utah supported the project through its Economic Development Board, and the University of Utah through the Office of the Vice President for Research. The experimental site became available through the cooperation of the Utah School and Institutional Trust Lands Administration (SITLA), U.S. Bureau of Land Management and the U.S. Air Force. We also wish to thank the people and the officials of Millard County, Utah, for their steadfast and warm support. We gratefully acknowledge the contributions from the technical staffs of our home institutions.

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