

## Monitoring for Telescope Array fluorescence detector PMT Camera by YAP and Xe flasher

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**Abstract:** Gain stability of the photomultiplier (PMT) cameras for The Fluorescence Detectors (FD) in the Telescope Array experiment has been monitored by using Am-241 loaded scintillator pulsers (YAP) and diffused xenon flashers (TXF). Each FD camera consists of  $16 \times 16$  PMT(Hamamatsu-R9508) array, and contains two or three absolutely calibrated PMTs carrying a YAP. YAP, which is attached on an PMT cathode, is a small light source which emits UV photons at 50Hz. A TXF which is a relative calibration installed on each camera shoots photons simultaneously on all the 256 PMTs uniformly from about 3 meter away. From the monitoring of YAP pulsers over 4 years of FD operation we found an annual average of slow monotonic PMT gains drift is  $0.01 \pm 0.31(\text{stat.}) \pm 0.21(\text{syst.})\%$  and it's sigma is 1.7%. In conclusion, no systematic PMT gain decrease by the night sky background was observed. A gains monitoring by the TXF also shows the same PMT gain drifts within the annual magnitude of  $0.86 \pm 0.13(\text{stat.})\%/year$ .

**Keywords:** icrc2013, PMT , Xenon flasher, YAP, Monitoring , fluorescence detector

### 1 Introduction

The Telescope Array (TA) experiment was installed in the west desert of Utah, USA, and has been observing the ultra-high energy cosmic rays (UHECRs) in the northern hemisphere sky since commissioning in 2007 [1]. The TA consists of a 507 plastic scintillator array (SD) to measure secondary particles on the ground, and three fluorescence telescope stations (FD) to measure the longitudinal development of EAS in the atmosphere. [2].

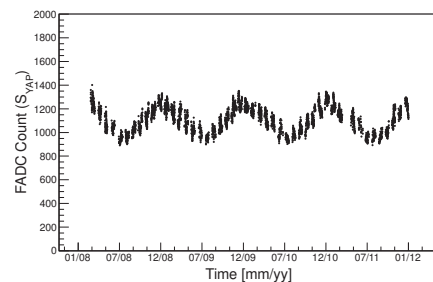
The FD telescope of two stations named BRM and LR has a spherical mirror of a 3.3m diameter and an imaging camera installed at the focal point at 3.0m away from the mirror [2]. The camera is composed of a matrix of  $16 \times 16$  PMTs with a UV filter (Hamamatsu R9508 with BG3) installed in a camera box with a ultraviolet (UV) transparent acrylic front window. The UV filters and front window are transparent to UV air fluorescence light and block out the night sky background light in the visible wavelength. The rear side of the PMT is equipped with a High Voltage(HV) divider circuit and a preamplifier. The ambient temperature in the camera box is measured by a thermistor probe (Nikkiso-Therm Co., Ltd., YSI44006) [3].

The FD observations are performed only at clear moonless nights. The accumulated observation time is approximately 12% of the total elapsed time. The preamplifier output of the PMT is transmitted to a Signal Digitizer and Finder (SDF) module. The SDF digitized the signal and recorded the waveform at 10MHz sampling speed with 14-bit dynamic range [4, 5].

### 2 YAP Pulser

A pulsed UV light source with absolute calibration, CRAYS (Calibration using RAYleigh Scattering), was used to calibrate a combined set of the PMT, the preamplifier, and

the readout electronics. The CRAYS comprises a nitrogen laser and a gas-filled chamber in which laser photons are Rayleigh-scattered by the gas molecules and detected by a PMT to be calibrated [6]. A total of 50 PMTs were calibrated by the CRAYS at the laboratory in the Institute for Cosmic Ray Research (ICRR), Japan, and transported to the TA experimental site in Utah, USA. We call these absolutely calibrated PMTs "standard PMTs", and we installed two or three standard PMTs on each FD camera. Moreover, each standard PMT has a YAP pulser as a calibrated light source. The YAP pulser is  $\text{YAlO}_3:\text{Ce}$  scintillator with Am  $\alpha$  source in an aluminum can. It is potted in a hole positioned at the center of the BG3 filter by epoxy glue. YAP pulser generate UV photons (wavelength 350nm; width 40ns) at 50Hz. The temperature coefficient of the YAP light yield is known to be small ( $-0.23\%/^\circ\text{C}$ ).

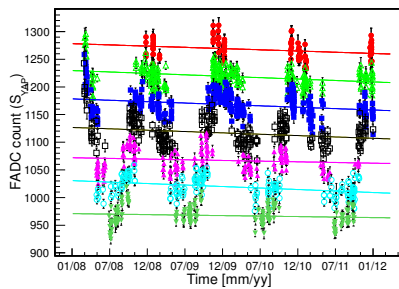


**Fig. 1:** History of  $S_{\text{YAP}}$  for the standard PMT in the #LR00 telescope over 4 years.

Every hour, YAP data were taken for continuous 100 shots in one minute by switching the SDF to a dedicated single-pixel trigger mode (YAP mini-run). The length of a signal series data from SDF is  $51.2\mu\text{s}$  (512 samplings)

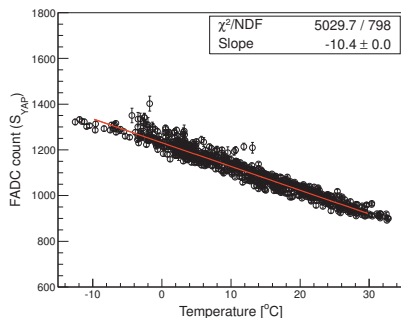
divided into four frames of  $12.8\mu\text{s}$ , and the trigger point is always placed in the second frame. [4] For calculation of YAP signal strength ( $S_{YAP}$ ), we integrate FADC counts in the signal region over 11 time bins ( $1.1\mu\text{s}$ ) around the signal peak, after subtracting the DC offset estimated from the average FADC counts of the first 120 time bins ( $12\mu\text{s}$ ) for each waveform. From the distribution of integrated YAP signals The aging of  $S_{YAP}$  from one YAP mini-runs for a standard PMT are shown in Figure 1 from March 2008 to December 2011.

A subset of the  $S_{YAP}$  data used from Figure 1 is shown in Figure 2. This subset is classified into the seven groups shown in different colors according to the ambient temperature. From high FADC counts to low, the ambient temperature of each group is  $-5\pm 1\text{C}$ ,  $0\pm 1\text{C}$ ,  $-25\pm 1\text{C}$ , respectively. The lines are fitted line of each temperature range.



**Fig. 2:** Seasonal variation of YAP signal for the standard PMT in the #LR00 telescope. Color-markers with fitted line is subsets of temperature range  $5^\circ\text{C}$  step from  $-5^\circ\text{C}$  (top) to  $+25^\circ\text{C}$  (bottom)

It is seen over four years that the time variation of  $S_{YAP}$  is characterized by a periodical and annual variation correlated with the ambient temperature and also it shows overall trend toward monotonic drift. A relation of  $S_{YAP}$  with temperature for the standard PMT in the #LR00 telescope at 2008 is fitted with a line shown in Figure 3.

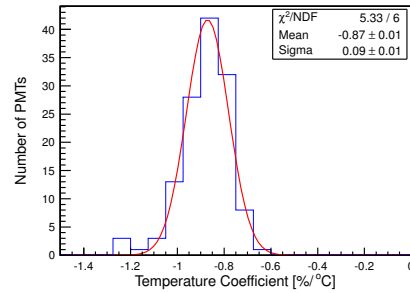


**Fig. 3:** Behavior of the YAP signals as a function of ambient temperature of the camera in the #LR00 telescope at 2008.

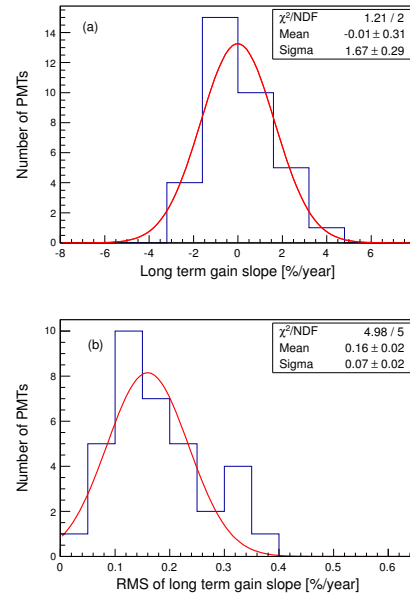
During this analysis, we found that sudden changes of  $S_{YAP}$  occur in some YAPs. This phenomenon rare, once or twice a year at a maximum, but discrete and reproducible changes of the  $S_{YAP}$  at the level of about 10% were recorded for specific unstable YAPs. We discard these unstable YAPs for further analyses. In order to select stable ones we use a

criterion based in the  $\chi^2/\text{NDF}$  of the linear fitting shown in Figure 3. We only use such YAPs that are stable for at least three consecutive calendar years. This condition is satisfied by 35 YAPs out of the total 50 in the experiment.

Figure 4 shows the distribution of the fitted temperature coefficients for the 35 selected PMTs channels. The temperature coefficients is  $-0.87 \pm 0.09(\sigma)\%/^\circ\text{C}$  and it is consistent with the laboratory test in Japan [3];  $-0.73\%/^\circ\text{C}$  for the PMT and the preamplifier and  $-0.23\%/^\circ\text{C}$  for the YAP light output at  $24^\circ\text{C}$ .



**Fig. 4:** Distribution of the fitted temperature coefficients for the 35 selected PMTs satisfied with the condition.



**Fig. 5:** Long-term behavior of (a) PMT gain slopes and (b) their systematic deviations for the 35 selected PMTs measured by the YAP.

The time variation of  $S_{YAP}$  in the specific temperature range was fitted with the line for all the 35 selected PMTs, as an example is shown in Figure 2. From the fitting for the five temperature ranges, i.e.,  $0\pm 1^\circ\text{C}$ ,  $5\pm 1^\circ\text{C}$ ,  $10\pm 1^\circ\text{C}$ ,  $15\pm 1^\circ\text{C}$ , and  $20\pm 1^\circ\text{C}$ . we obtained the average and root-mean-square (RMS) of the gain slope (=  $\%/ \text{year}$  change of  $S_{YAP}$  for 4 years). The result is plotted in Figure 5 for the 35 PMTs. From Figure 5(a) we obtained the averaged a long-term gain change of the PMT-electronics channels to be  $-0.01 \pm 0.31(\text{stat.})\%/ \text{year}$ . The standard deviation

in Figure 5(a) is 1.7%/year. This indicates that individual standard PMTs, together with its electronics, have a slow drift of gain at the level of about  $\pm 1.7\%/year$ , while the average gain of the 35 PMTs is kept unchanged at the level of  $-0.01 \pm 0.31(stat.) \pm 0.21(syst.)\%/year$ . The systematic uncertainty of the gain slope is estimated from number of year selection for stable calendar year (0.14%) and from the RMS deviation of the temperature slopes corresponding to different temperature ranges (0.16%/year) obtained from Figure 5(b). We observed no long-term degradation of the PMT gain over 4 years of the FD operation as described above.

### 3 Telescope Xenon Flasher

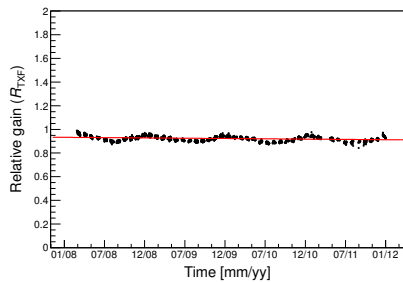
The TXF consisting of a Xenon flasher lamp and a teflon diffuser is mounted at the center of each primary mirror. TXF can emit photons uniformly on all the PMTs of camera.

During normal FD observations ten TXF flash events are taken just after every hourly YAP mini run. At first each TXF signal of every channels is integrated from 128th to 512th bin after subtracting a pedestal in event by event. After that a TXF signal strength  $S_{TXF}$  is obtained as an average for ten ten events. Each  $S_{TXF}$  is corrected based on the geometry between the TXF to the corresponding PMT. Also,  $S_{TXF}$  is corrected with the signal strength caused by extra reflected photons by a mirror and a camera surface. The correction value is estimated with a similar TXF measurement with covering a primary mirror.

A relative gain,  $R_{TXF}$ , of each PMT-electronics channel is obtained by the following relation,

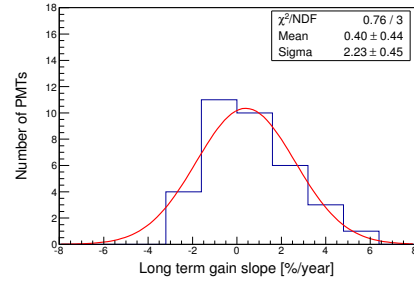
$$R_{TXF} = S_{TXF} / A_{TXF} \quad (1)$$

where  $A_{TXF}$  is the average of  $S_{TXF}$  over 256 channels in one camera for each TXF mini-run. Time history  $R_{TXF}$  with a linear fit for a standard PMT in the telescope ID of LR00 is plotted in Figure 6, and the distribution of slope for all selected PMT is shown in Figure 7

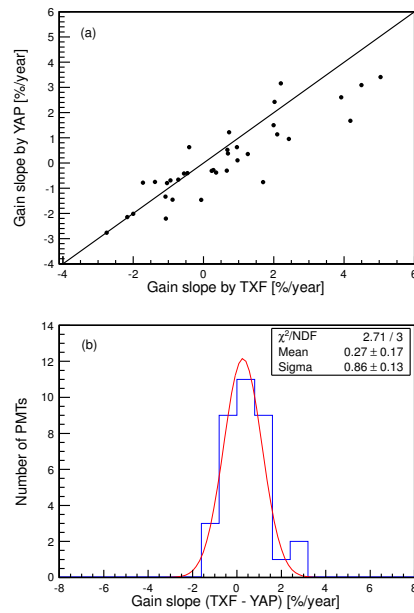


**Fig. 6:** History of relative gain ( $R_{TXF}$ ) for the standard PMT in the #LR00 telescope. Seasonal variation of  $R_{TXF}$  in the figure is due to temperature coefficient of each PMT.

A correlation between the long-term gain drift obtained by YAP analysis ( $S_{YAP}$ ) and by the TXF analysis ( $R_{TXF}$ ) is shown in Figure 8 for the 35 selected PMTs. The long-term gain history from slope liner fitting is stable over the time both the YAP and the TXF and the difference of the slopes is  $0.27 \pm 0.17(stat.)\%/year$  with an RMS of  $0.86 \pm 0.13(stat.)\%/year$ , as shown in Figure 8(b).



**Fig. 7:** Distribution of long-term gain slopes measured by the TXF.

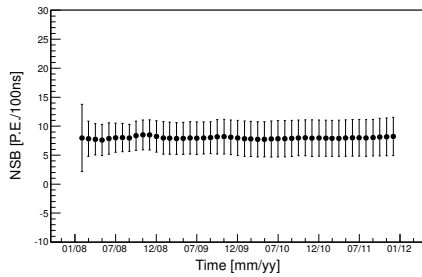


**Fig. 8:** (a) scatter plot of long-term gain slopes and (b) the difference of long-term gain slopes measured by the YAP and TXF calibrations.

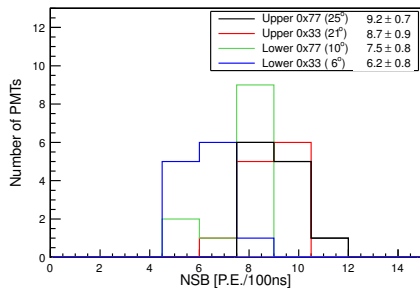
### 4 Night Sky Background

The PMTs of the FD telescopes are operated under night sky background (NSB). NSB is caused by bright stars, and other natural and artificial light sources. The signal strength by NSB per 1 time bin ( $=100ns$ ),  $N_{pe}(100)$ , for each PMT is obtained by comparing the DC level measured when the building shutter was open with the level when the shutter was closed. Time variation of  $N_{pe}(100)$  for standard PMT in LR00 is shown in Figure 9.

The distribution of  $N_{PE}(100)$  is depending on elevation angles, shown in Figure 10. The average of NSB is 8.2 photo-electrons/100ns. The flux of NSB is estimated to be  $4.8 \times 10^{11}$  [photons/( $m^2$  sr s)] using  $6.8m^2$  for the primary mirror surface area,  $1.6 \times 10^{-4}$  sr for the effective solid angle coverage of one PMT and  $\sim 16\%$  for the averaged total optical efficiency of the camera. With the PMT gain of  $6 \times 10^4$ , Amount of NSB corresponds to the PMT dark current of 3.0Coulomb/year with assuming 12% duty factor.



**Fig. 9:** History of night sky background level over 4 years observed at the standard PMT in the #LR00 telescope. Each data point and its error denote the mean and standard deviation obtained from a Gaussian fit with one month data, respectively.



**Fig. 10:** Distribution of average  $N_{PE}/100ns$  depending on the different elevation angles indicated inside the figure box.

## 5 Summary

In total 6144 PMTs are installed in the two FD stations. Among them, fifty PMTs are standard PMTs, which were calibrated by CRAYS at the ICRR and TA site with an accuracy of 7.2% and 3.7% [6]. Gains of other PMTs were equalized at level of 2% by adjusting HV values on PMTs to have a flat response for the TXF flasher [7].

The gain of the CRAYS-calibrated PMTs were monitored by YAP pluser over 4 years, from March 2008 to December 2011, for the 35 selected PMTs. The long term gain drifts measured through monitoring YAP signal strength are distributed with the standard deviation of 1.7%/year, and the average is estimated  $-0.01 \pm 0.31(\text{stat.}) \pm 0.21(\text{cyst.})$  %/year using 35 standard PMTs. Measured long term gain by the YAP was also tracked by the TXF xenon flasher within an accuracy of  $0.86 \pm 0.13(\text{stat.})$  %/year, which was consistent with  $3.3 \pm 0.5(\text{stat.})$  % over 4 years. Overall gain accuracy of the PMT in FD camera was measured to 9% shown in summarized Table 1.

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**Table 1:** Overall gain accuracy of the PMT in FD camera

Item	Accuracy
Calibraiton at ICRR	7.2%
Calibration at TA on-site	3.7%
HV adjustment	2%
Temp. dependence	0.6%
Aging effect	3.3%
Total	9%

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