An Absolute Light Flux Calibration for the MAGIC Telescope

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Abstract

The 17 m diameter Air Cherenkov Telescope MAGIC [1,2] has a 577 pixel photomultiplier camera which requires precise and regular calibration over a large dynamic range. A system for the optical calibration consisting of a number of ultra-fast and powerful LED pulsers is presented. We calibrate each pixel with up to 2000-3000 photoelectrons in three different wavelengths. We achieve an absolute calibration by comparing the signal of the pixels with the one obtained from a darkened photomultiplier thus operated in single photon counting mode. The light flux of the pulsers is cross calibrated by a 1 cm^2 PIN diode, read out via a charge sensitive preamplifier. The PIN diode, in turn, is calibrated with 59.95 keV photons from an ^{241}Am source. The telescope is calibrated and flat-fielded in photons instead of photo-electrons.

1. Introduction

MAGIC houses a camera of 577 pixels, each read out with 300 Msample/sec flash-ADCs [3] (500 MHz bandwidth) and a 260 MHz optical link to transfer the electronic signal over 160 m to the counting house. The quantum efficiences of the MAGIC PMTs strongly depend on the incident wavelength. Moreover, differences in the exact shape of QE(λ) between PMTs have been observed. It is therefore desirable to calibrate the PMT response at different wavelengths.

We use a system of very fast (3–4 ns FWHM) and powerful (10^8–10^{10} photons/sr) light emitting diodes in three different wavelengths (370nm, 460nm and 520nm) and different intensities (up to 2000–3000 photo-electrons per pixel and pulse) and are able to calibrate the whole readout chain (from the PMT to the DAQ) with respect to linearity. The pulse rate is about 1 kHz and the total dissipated power in the LED very small (some μW). Changes with temperature affect only the light intensity but not the relative timing between LEDs.

We present three methods for the absolute light flux calibration: a) with a single photo-electron counting PMT, b) with a calibrated PIN diode (Hamamatsu)

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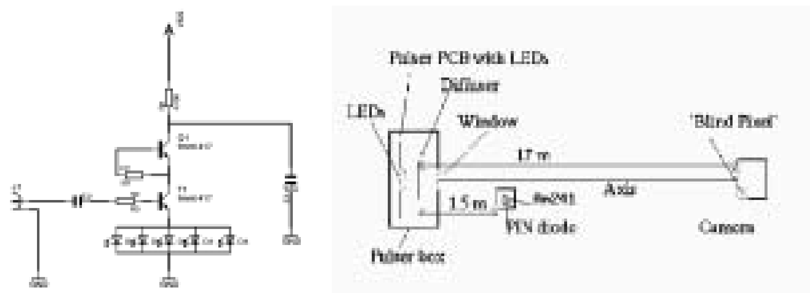

Fig. 1. Left: A circuit of two avalanche transistors discharges a small capacitance charged with 600V through five parallel LEDs providing a short (3–4 ns FWHM) and powerful light pulse. The board integrates 16 of such circuits each housing LEDs in one of the three colours: green, blue and UV. The LED slots can be switched on and off individually allowing for different intensities and colours. Right: Schematics of the entire setup.

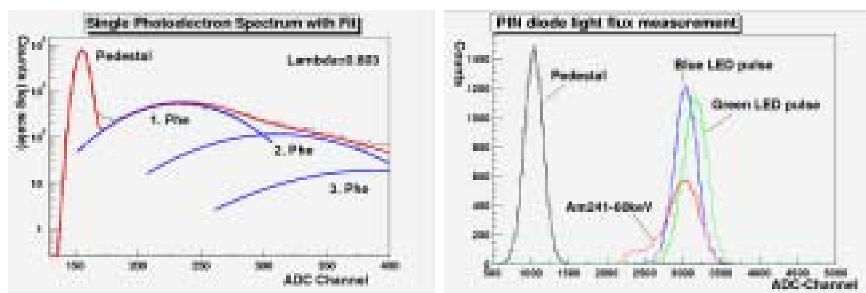

Fig. 2. Left: Single photo-electron spectrum of the "blind pixel" fitted to eq. 1. Right: Light flux measurement of the green and blue pulsed LED pulser with the PIN diode in comparison with the signal of the ^{241}Am source: $N_{PhE} = 16570 \cdot \frac{Q(pulser)}{Q(59.95\,keV)}$

and c) using the excess noise factor method. See also [4,5]. Fig. 1. shows a scheme of the setup and the functionalities of the pulser board.

1.1. The "blind pixel" method

This method compares the signal in the camera pixels with the response of a darkened pixel, attenuated by a factor 1000 ("blind pixel") and being illuminated through a diaphragm of exactly 1 cm^2. The normal pixels will then provide a strong signal while the blind pixel resolves single photo-electrons. Its photo-electron spectrum can be fitted by the sum of Gaussian distributions whose amplitudes are Poisson distributed (see fig. 2.).

$$f(x) = \sum_{k=0}^{N} \frac{e^{-\lambda} \cdot \lambda^k}{k!} \cdot \frac{e^{-\frac{(x-\mu_k)^2}{2\,\sigma_k^2}}}{\sigma_k\,\sqrt{2\pi}} \qquad (1)$$

The fit provides together with the values of σ_k the mean number of photo-electrons, λ, which in turn is used to calculate the mean number of incident photons.

1.2. The PIN-diode method

This method measures the absolute light flux with a PIN diode monitoring the light pulses at 150 cm distance and read out with a charge sensitive pre-amplifier (shaping time 25 ns). Electronic pre-amplifier noise of 1500 photo-electrons is observed. The PIN diode is calibrated with an ^{241}Am source emitting 59.95 keV gammas generating a charge distribution peaking at 16570 $\pm$ 50 photoelectrons [6]. The quantum efficiency of the diode is obtained by comparison with a calibrated PIN diode. An average QE is obtained by folding the LED spectrum with the QE for each wavelength. Light reflections on the diode and charge collection at the surface are then already included (see fig. 2.).

1.3. Excess noise factor method

This method measures the number of photo-electrons reaching the first dynode of the PMT and being amplified. If the mean value and the variance of the pedestal and the signal peak are known, it is possible to extract the number of photo-electrons:

$$N = F \cdot \frac{\mu^2}{\sigma_1^2 - \sigma_0^2} \qquad (2)$$

σ_0 describes the electronic noise, σ_1 the measured standard deviation of the signal peak and μ is the distance of the signal peak to the pedestal. F stands for the excess noise factor, previously measured in the lab.

2. Comparison

Many Cherenkov telescopes have been calibrated with the excess-noise factor method in the past. However, the excess noise factor of a PMT may change with time as well as the average total transmission probability of an incident photon. It is therefore more adequate to directly measure the excess noise imported by the whole amplification chain via a measurement of the response to a known light flux (methods 1 and 2). The three measurements are independent and each contains different systematic errors increasing the reliability of the result.

3. Conclusions

The MAGIC telescope is a new generation Cherenkov telescope with high sensitivity. To achieve precise measurements of astrophysical phenomena, an improved calibration procedure is necessary. We use a simple electronic circuit

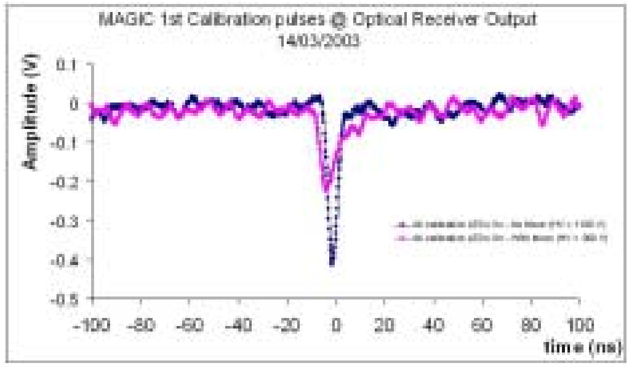

Fig. 3. Calibration light pulse read out from one of the camera pixels at the optical receiver in the counting house. Two pulses are displayed at different PMT amplifications - with and without moonshine.

producing 3–4 ns FWHM pulses and a very high flux of around 10^9 photons/sr. This system provides three independent methods for the calibration of the camera which increases reliability and allows one to monitor changes in the PMTs (or the measuring devices). The first two methods measure the number of photons while the last one calculates the number of photo-electrons arriving at the first dynode.

The calibration system is already installed at La Palma and global functionning has been demostrated (see fig. 3.). We will present at the conference more detailed tests and precise measurements of the accuracy of the above given quantities.

Acknowledgments

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4. References

1. M. Martinez for the MAGIC collaboration, these proceedings
2. J. A. Barrio et al., MAGIC design study, Preprint MPI-Phe/18-5, 1998
3. Ostankov A. 2001, Nucl.Inst.Meth. A471, 188
4. Frass A., Hermann G., Hess M., Hofmann W., Koehler C. 1997, astro-ph/9707304, MPI-H-V-30-1997
5. Mirzoyan R. 1995, Proc. IV Int. Workshop towards a Major Atmospheric Cherenkov Detector, Padova, Italy, 230
6. Holl L., Lorenz E., Mageras G. IEEE Transactions of Nuc. Science 35 1, 1988