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An absolute light flux calibration for the MAGIC telescope

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Abstract:

The 17 m diameter Air Cherenkov Telescope MAGIC will start taking data this year. The 577 pixel photomultiplier camera 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 wavelenghts: 370 nm, 460 nm and 520 nm. We aim to achieve an absolute calibration at these three wavelengths by comparing the signal of the pixels with the one obtained from a photomulitplier which is darkened with a well calibrated attenuation filter and thus operated in single photon counting mode. The light flux of the pulsers is cross-calibrated by a 1 cm^2 PIN diode (Hamamatsu), read out via a charge sensitive preamplifier. The PIN diode, in turn, is calibrated with 59.95 keV photons (from an ^{241}Am source) producing a precise signal of 16570 electron-hole pairs. We introduce a more detaild calculation of the total excess noise of the telescope and examine dependencies on photon wavelength and incidence angles. The telescope will be calibrated and flat-fielded in photons instead of photo-electrons.

Introduction:

The 17m diameter Air Cherenkov Telescope MAGIC will house a camera of 577 pixels, each read out with 330 MHz flash-ADCs [2]. In order to calibrate the amount of Cherenkov light produced by the shower, a precise and regular absolute calibration of the camera with respect to the light flux is mandatory over a large dynamic range.

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 thus able to calibrate the whole electronic chain from the PMT to the DAQ with respect to linearity. We present here three methods for the absolute light flux calibration: a) by a single photo-electron counting PMT, b) by a calibrated PIN diode and c) using the excess noise factor method. See also [3] and [4] and figure 1 for the schematics of the whole setup. Figure 2 displays the functionalities of the pulser board.

Fig.1: Schematics of the setup.

Fig.2: The functionalities of the pulser board:
- *A circuit of two avalanche transistors discharges a small capacitance charged with 600V through five parallel LEDs providing an ultra-short (3-4 ns) and powerful light pulse (left).*
- *The pulser board integrates 16 of such circuits (second left) housing LEDs in one of the three colours: green, blue and UV.*
- *The pulser board and steering electronics (500 MHz bandwidth GaAs analog switch controlled by CAN bus).*
- *The LED slots can be switched on and off individually thus allowing for different intensities and colours (right). The light uniformity at the camera is around 2-3%.*

Calibration in thee colours:

The quantum efficiences of the MAGIC PMTs are strongly dependent 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 with respect to different wavelengths.

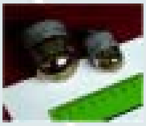

Fig.3: The EMI PMTs used in the MAGIC camera: 397 inner pixels (right) and 180 outer pixels (left).

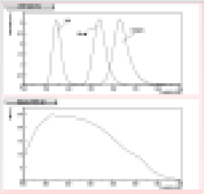

Fig.4: Three LED colours (top) and the quantum efficiency of the MAGIC PMTs (bottom).

The "blind pixel" method:

The first light flux calibration 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 known area. The normal pixels will then provide a strong signal while the blind pixels resolves single photoelectrons. Its photo-electron spectrum can be fitted by the sum of Gaussian distributions whose amplitudes are Poisson distributed:

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

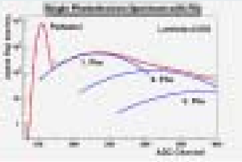

Fig.5: Single photo-electron spectrum of the "blind pixel" fitted to eq. (1). Systematic errors such as from electron back-scattering can be estimated to <5%.

The PIN-diode method:

This method also measures the absolute light flux with a PIN diode monitoring the light pulses at 150cm distance and read out with a charge sensitive pre-amplifier (shaping time only 25ns). Electronic pre-amplifier noise of 1500 photoelectrons is observed. The PIN diode is calibrated with an ^{241}Am source emitting 59.95 keV gammas generating a charge distribution peaking at 16570 ± 50 photoelectrons [5]. 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 [6]. Light reflections on the diode and charge collection at the surface are then already included.

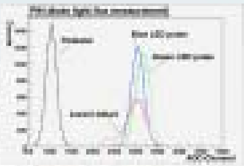

Fig.6: Measurement of the flux of the green and blue LED pulser in comparison with the signal of the ^{241}Am source:

$$PhE = 16570 \cdot \frac{Q(Pulser)}{Q(60\,keV)}$$

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:

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

ρ_0 describes the electronic noise, ρ_1 the measured standard deviation of the signal peak and μ is the distrance of the signal peak to the pedestal.

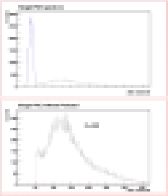

Fig.7: Measurement of the excess noise factor using the single photo-electron peak (to be performed for each PMT separately):

$$F = 1 + \frac{\sigma_1^2 - \sigma_0^2}{\mu_1^2}$$

Comparison:

Many Cherenkov telescopes have been calibrated with the excess-noise factor method in the past [7]. However, the total excess noise of the telescope is bigger than only the PMT part:

$$F(\lambda, HV) = N_\gamma \cdot \mathrm{var}(\eta_{tot}(\lambda)) + \frac{1}{\eta_{tot}(\lambda)} \cdot F_{PMT}(HV) \qquad (3)$$

Here, N_γ is number of photons, var($\eta_{tot}(\lambda)$) is the reduced variance of the total light transmission probability folded over the light incidence angles. Winston cones in front of the photo-cathode guide light such that double crossing of the photo-cathode is observed at high incidence angles. This effect differs from PMT to PMT and has to be taken into account in the flat-fielding procedure (The "blind pixel" is not affected by this effect). F_{PMT} is the pure PMT excess noise factor used in method 3. It is more accurate 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 two measurements are independent and each imports different systematic errors increasing the stability of the result.

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 producing 3-4 ns pulses and a very high flux of around 10^9 photons/sr.

It is useful to have three independent methods for the flux calibration of the camera making it possible to monitor changes in the PMTs (or the measuring devices). The first two methods measure the number of photons while the last (and old) calculate the number of photo-electrons arriving at the first dynode.

We will measure conversion factors to the number of photons and aim for an accuracy of better than 5%, The effect of the night sky background is negligible, This improves on the accuracy of the excess noise factor calibrations of past Cherenkov telescopes and can incorporate new features like wavelength- and intensity-calibration.

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