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The optical calibration system for the CTA-North Large Sized Telescope camera

M. Iori[1,2,*], *F.* Ferrarotto[1,**], *A.* Girardi[1,***], *R.* Lunadei[1,****], and *L.* Recchia[1,†]

[1]INFN Roma 1
[2]Universitá di Roma La Sapienza

Abstract. The first Large-Sized Telescope (LST-1) for the Northern Site of the Cherenkov Telescope Array Observatory (CTAO) was inaugurated in October 2018 at the Observatorio del Roque de Los Muchachos (ORM) on La Palma (Canary Island). Other three LSTs are planned to be operational from 2026 in the same site. The LST camera requires a precise and regular calibration. The CaliBox is designed to fulfill the requirements for the camera calibration: monitoring the photon flux to guarantee the laser stability, uniform illumination, and intensity range. We present the design and performance of the optical system, photon flux monitor, related electronics, and evaluations and tests of the photon flux at the camera plane carried out at the INFN Rome1 Electronic laboratory.

1 Introduction

Cherenkov Telescope Array Observatory (CTAO) will be the next generation ground-based high energy (20 GeV to 300 TeV) gamma ray observatory [1]. The international collaboration is formed by 31 countries, more than 200 institutes and more than 1400 members. It will be located in the North Hemisphere (La Palma de Tenerife) and South Hemisphere (Chile, Paranal) to have a full sky coverage. The two sites will be equipped on an area respectively of 1 and 3 km^2 with 3 different sizes of telescopes: Large (LST - 23 m diameter), Medium (MST - 12 m diameter) and Small (SST - 4 m diameter).

The scientific program of High Energy γ-ray astronomy is very wide and is the energy frontier in Astrophysics with key science project spanning both galactic and extragalactic phenomena.

2 The Camera Calibration System

LST-1 is the first Large Sized Telescope installed at CTA-North on December 2018 and is taking data since 2019 [2]. The Camera Calibration System (CaliBox) is installed in the center of the LST-1 dish, firing on the LST-1 camera (1855 Photomultipliers, PMT, over 4.5 m^2) 28 m away, see Fig. 1a top.

*e-mail: maurizio.iori@roma1.infn.it
**e-mail: fabio.ferrarotto@roma1.infn.it
***e-mail: antonio.girardi@roma1.infn.it
****e-mail: riccardo.lunadei@roma1.infn.it
†e-mail: luigi.recchia@roma1.infn.it

A good uniformity and a continuous calibration are essential for the performance of the LST's camera[3]: calibrations are made at 1000 Hz before all runs and at 100 Hz continuously during data taking.

The CaliBox structure consists mainly of two optically connected and hermetically closed (IP67 certified) aluminum boxes fixed on a large aluminum plate to properly dissipate the heat generated by all the internal components.

The main concept in the CaliBox design is to disentangle the optics and electronics blocks by putting them inside separate boxes, and have the optics block IP67 sealed and filled with nitrogen to be independent from external environmental conditions.

The main hardware used by the CaliBox is :
- UV Laser Teem Photonics [4] - λ= 355 nm - 400 ps signal embedded Peltier with a dedicated laser controller
- 2 Filter wheels [5] with 6 positions each, 5 neutral OD filters each (OD from 1 to 4 each set) to tailor the dynamics of the laser signal on the camera
- Ulbricht sphere [6] to diffuse the laser signal to the camera and monitoring devices
- SiPM and Photodiode for laser signal internal monitoring read by a dedicated ADC peak and hold circuitry driven by a dedicated IRQ signal
- Voltage regulator circuitry for SiPM voltage temperature compensation
- Laser trigger TTL translated to an optical signal transmitted to the LST camera Trigger Interface Board [7] to keep calibration under control
- ODROID C1+ Linux computer to control all components and communicating via OPC-UA server to the LST1 system control software
- Hardware circuitry for interlock to laser

The signal from the laser, after the wheels, is sent to a 3-hole Ulbricht Sphere to be diffused both to the camera and to 2 photosensors for signal monitoring (see Fig. 1a bottom). The signal (after the sphere) is comparable with the expected Cherenkov shower signal shape. One of laser beams is then split by a beam splitter between a Slicon Photomultiplier (SiPM) and a Photodiode (PD) to have sensitivity to both low (SiPM) and high (PD) number of photons.

2.1 Measurements in laboratory

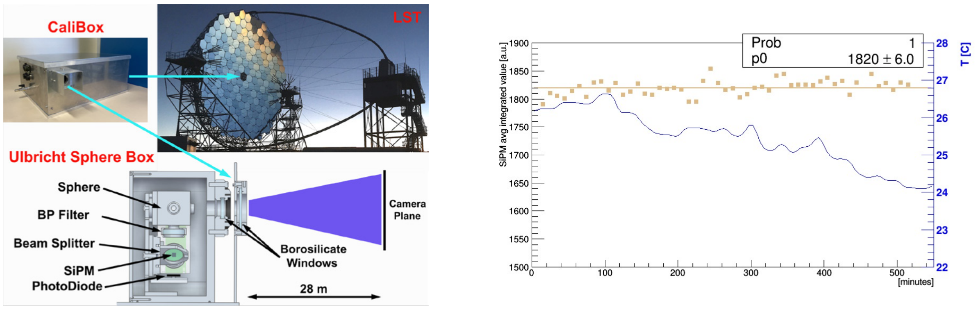
In this section we show the results made in the Electronic laboratory of iNFN Roma1 on the latest versions of the CaliBoxes for LSTs 2-4.

The laser signal stability is controlled every 10 minutes with SiPM integrated signal, sampled by a DRS4 evaluation board [8] at 2 GHz (1000 events/point) : it is stable below 1% during several hours, see Fig. 1b. The ambient temperature (blue line in. Fig. 1b) is monitored during the measurement and the SiPM Voltage is compensated for T by a dedicated sensor to the voltage regulator, The Peak to peak stability during the test is at 1.2%.

Fig. 2a shows the integral variance σ^2 vs mean SiPM integrated signal (sampled by DRS4@2 GHz - 1000 events/point) for several filter combinations (transmittance in the range $10^{-3} \div 10^{-4}$); from the linear fit slope parameter we derive the pulse-integral/photoelectron used in the evaluation of CaliBox photon flux sent to the camera.

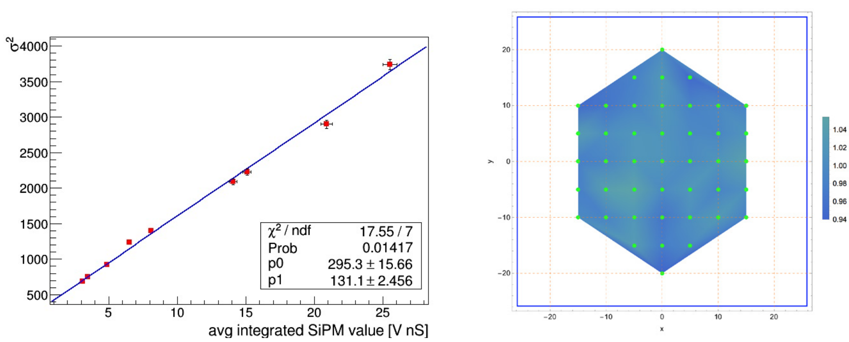
At 6 cm from the center of the Ulbricht sphere we have estimated $(3.3 \pm 0.2) \times 10^7$ photons/cm^2, which guarantees the dynamics of photons sent to the LST camera.

The photon uniformity has been measured on a plane at 5 m distance from the CaliBox at better than 1% over ± 25 cm, equivalent, at 28 m distance, to the PMT camera span, whose projection is shown in Fig. 2b.



(a) (b)

Figure 1: (a) : Top, Right : the LST-1 telescope, Top, Left : the CaliBox. Bottom: Ulbricht sphere block internal structure with the SiPM and PhotoDiode collecting photons reflected by the Beam Splitter
(b) : Scatter plot of the laser beam average signal (brown) and the recorded internl box temperature (blue) versus time over nine hours



(a) (b)

Figure 2: (a) : Signal integral variance vs mean SiPM integrated signal with several filter combinations,
(b) : Normalized photon densities on a plane at 5 m distance with the projected area for the LST camera (blue)

Fig. 3 shows the σ^2 of the ADC measurement for the SiPM vs the ADC signal average over 1000 events for several filter combinations (transmittance in the range $10^{-3} \div 10^{-4}$).

The errors includes the variation of the jitter of the Channel Select (CS) of the ADC IRQ signal. From this we evaluate the photoelectron/ADC conversion factor which is used in the monitoring system.

The thermal isolation of the CaliBox optical box, filled with Nitrogen, has been tested inside a climatic chamber with a water-filled bowl to mantain RH = 96% at T = 30.5 ^{0}C by monitoring temperature and relative humidity inside the box as function of time.
The tests show the device is free of water vapor condensation since the optics system is isolated from the electronics components and with Nitrogen filling.

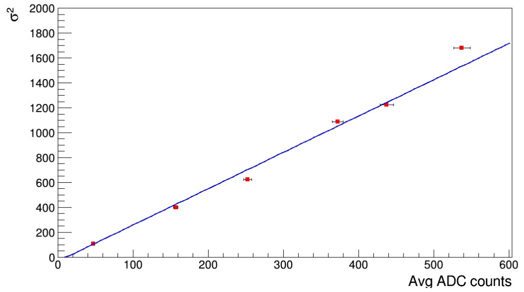


Figure 3: Variance of average ADC counts vs average ADC counts for the SiPM with several filter combinations

2.2 Conclusions

The performances of the CaliBox are in line wit the requirements from the CTAO Collaboration [2]:
- Time stability of the photon flux : peak-to-peak stability 1.2% and constant within 1.0 % on a time span of 9 hours, consistent with a night shift run
- Photon flux Uniformity measured at < 1% at 5 m distance within a field of view of about 3.4 degrees
- Photon flux range from O(1) to O(10^4) to the LST camera SiPMs by the usage of different OD filter combinations
- Temperature and Relative Humidity under control inside internal and external boxes
- System under experiment control via OPC-UA server running on Odroid C1+ controlling all hardware

The laboratory test measurements shown have been performed on the newer models of CaliBox built at INFN Roma1 Electronic laboratory, profiting from the experience of the CaliBox working on LST-1 since 2018.

Three of these CaliBoxes are in INFN Roma1 Electronic laboratory and ready to be mounted in 2025-2026 on the LST2-4 at CTA-North

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