Design and characterization of the Flat-Field Calibration of the NectarCAM Camera

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ABSTRACT

The NectarCAM flat-field flasher is a calibration device for the Medium-Sized Telescopes (MSTs) at the Cherenkov Telescope Array Observatory (CTAO) northern site. Installed 16 meters in front of the camera, it emits short (FWHM ≈ 5 ns), uniform (2–4%) light pulses to illuminate the focal plane, enabling precise gain computation and correction for pixel-to-pixel efficiency differences. We evaluate several flasher units on a dedicated test bench, assessing reliability and describing the application of flat-field (FF) coefficients to ensure a few-percent-level response uniformity across all 1855 pixels. With MST deployment planned for 2027, this work supports the finalization of CTAO camera calibration systems.

NectarCAM

The NectarCAM will equip the Medium-Sized Telescopes of the CTAO. To ensure accurate signal reconstruction, NectarCAM undergoes a detailed calibration process—currently being implemented at CEA Irfu—including pedestal, gain, and flat-field coefficient validation for consistent pixel response.

Characterization of the flasher's light-front

To improve FF calibration with **2% precision**, the flasher's light-front shape is modeled as a 2D Gaussian representing the expected illumination pattern.

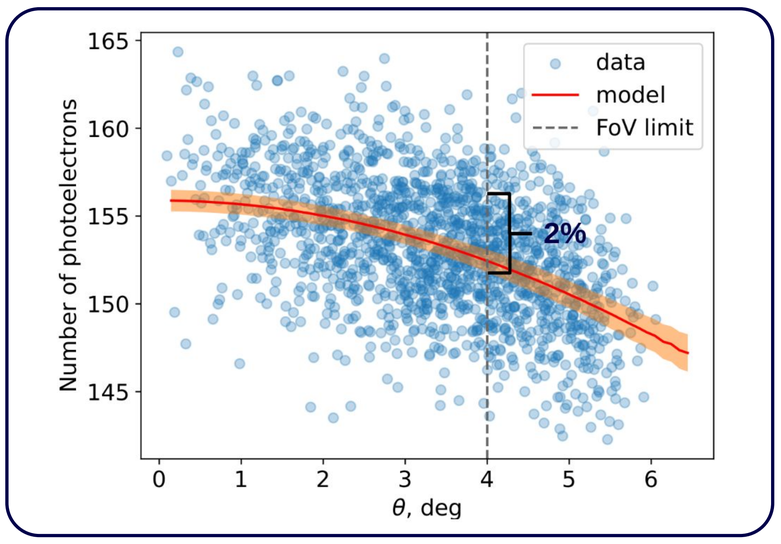

Fig. 2: Reconstructed intensity as a function of angular distance from the peak of the fitted Gaussian. The gray dashed line shows the end of the field of view of NectarCAM 16m away from the flasher. The data were obtained for a distance of 12m.

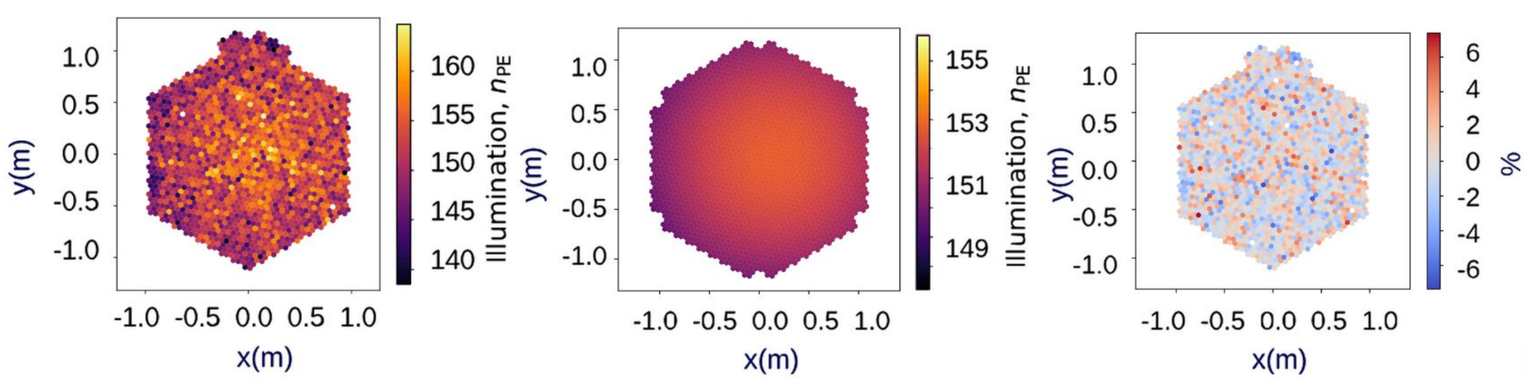

Fig. 1: Data from the run, 2D Gaussian best fit, and corresponding residuals. In the panel (a) the illumination of the camera, (b) the fitted illumination, and (c) the corresponding residuals between data and the model. All quantities are presented as functions of pixel coordinates.

FF Coefficients

In Fig.1, the result of the fit to the data, and the residuals are presented. In Fig.2, the same fit result is presented as a radial profile, plotting the pixel values as a function of their angular distance from the centre of the fitted Gaussian. We obtained an uncertainty on the fitted model of 0.4%.

The FF coefficient for a given gain channel i and pixel j is defined as:

$$C_{\mathrm{FF}}(i,j) = \frac{A_{\mathrm{pix}}(i,j)}{\mu_{\mathrm{cam}}(i)},$$

where $A_{\mathrm{pix}}(i,j)$ is charge for pixel *j* in gain channel *i*, $\mu_{\mathrm{cam}}(i)$ is the expected amplitude in channel *i*.

In Fig.3, the distribution of the FF coefficients over the camera is shown. The standard deviation of the FF coefficients for the run is 0.02.

IJCLab tests results

In parallel with CEA Irfu, at the IJCLab test bench, all the flashers are tested using one camera module. The light front was compared for both test benches. The resulting Gaussian widths are the following: σ = 0.1928±0.0003 rad, for the IJCLab test bench, and σ = 0.19±0.01 rad for CEA, which proves that we can characterize the light front using the data from camera runs.

Conclusion

We developed and validated the flat-field calibration system for NectarCAM, confirming the flasher's stability and spatial uniformity (2–4%) with ~5 ns light pulses. A 2D Gaussian fit enabled FF coefficient extraction with few-percent precision, and consistent results across two test setups confirmed the system's reliability for integration into the camera pipeline.

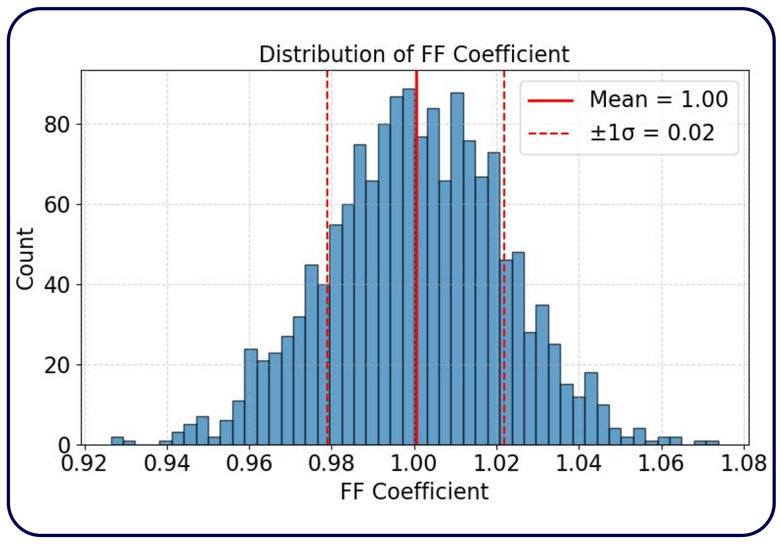

Fig. 3: Distribution of the FF coefficients.

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