A Generic Algorithm for IACT Optical Efficiency Calibration using Muons

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Abstract

Muons produced in Extensive Air Showers (EAS) generate ring-like images in Imaging Atmospheric Cherenkov Telescopes (IACTs) when travelling near parallel to the optical axis. From geometrical parameters of these images, the absolute amount of light emitted may be calculated analytically. Comparing the amount of light recorded in these images to expectation is a well established technique for telescope optical efficiency calibration. However, this calculation is usually performed under the assumption of an approximately circular telescope mirror. The H.E.S.S. experiment entered its second phase in 2012, with the addition of a fifth telescope with a non-circular 600m^2 mirror. Due to the differing mirror shape of this telescope to the original four H.E.S.S. telescopes, adaptations to the standard muon calibration implementation were required. We present a generalised muon calibration procedure, adaptable to telescopes of differing shapes and sizes, and demonstrate its performance on the H.E.S.S. II array.

Introduction

- **Energy reconstruction** based on the **image intensity** is strongly influenced by the **optical efficiency** of the telescope-camera system.
- **Ring images** due to single muons generate a **predictable** intensity signal, usable for optical **efficiency calibration.** [1]
- The **distance** across the mirror surface *D* may be determined analytically for **circular** mirrors [1]
- For the fifth H.E.S.S. telescope, CT5, with **non-circular** mirror shape, assuming a circular mirror could lead to biases in the calibration (**figure1**).

Method

- M**uon rings** are identified via a **circle fit** to cleaned images [2,3]
- The image charge is **summed** along the **radial** direction for all azimuth angles.
- The 1D profile of charge as a function of azimuth angle is **smoothed** with a 4 pixel smoothing window.
- This summed charge at each azimuth angle is **radially spread** according to a **gaussian**.

$$I_{pe} = \varepsilon_\mu I(\theta_c, \rho, \phi, \omega) = \varepsilon_\mu \frac{\alpha}{2}\frac{\omega}{\theta_c} I \sin(2\theta_c) D(\rho, \phi)$$

- The predicted pixel intensity, I, calculated using the above equation, depends on the distance *D,* along which light is integrated across the mirror surface. [2]
- An **interpolation** between a set of points defining the mirror edges is used to find *D* instead of assuming a circular mirror shape.
- The intensity expectation is fitted to the smoothed image in a **2D pixel log-likelihood** fitting procedure, with the optical efficiency as a free parameter. [4]
- An example raw muon event and 2D pixel expectation is shown in **figure 2**.

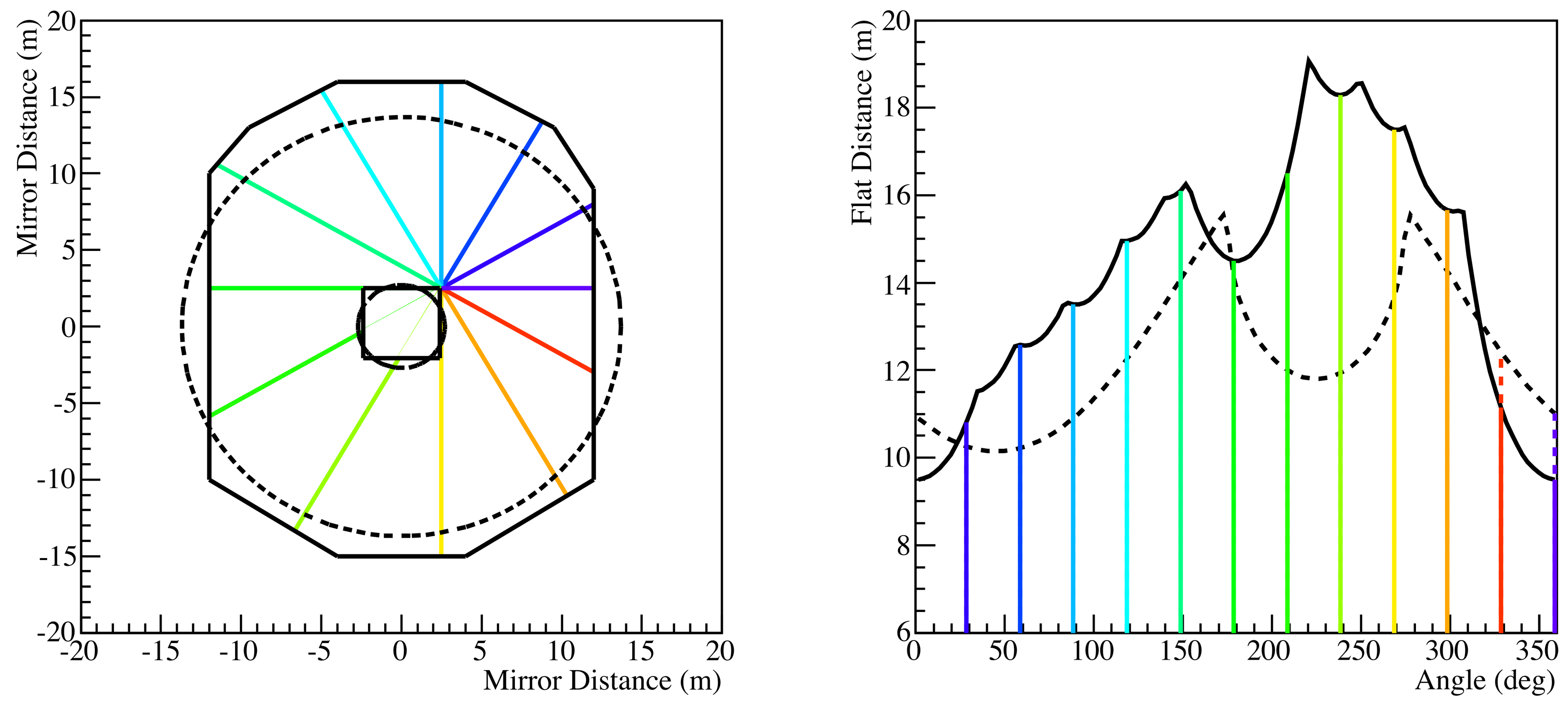

Figure 1: Line integration along the mirror surface as a function of **azimuth angle** for a given impact position, shown for CT5 with the true mirror profile (solid line) and under a circular approximation (dashed line).

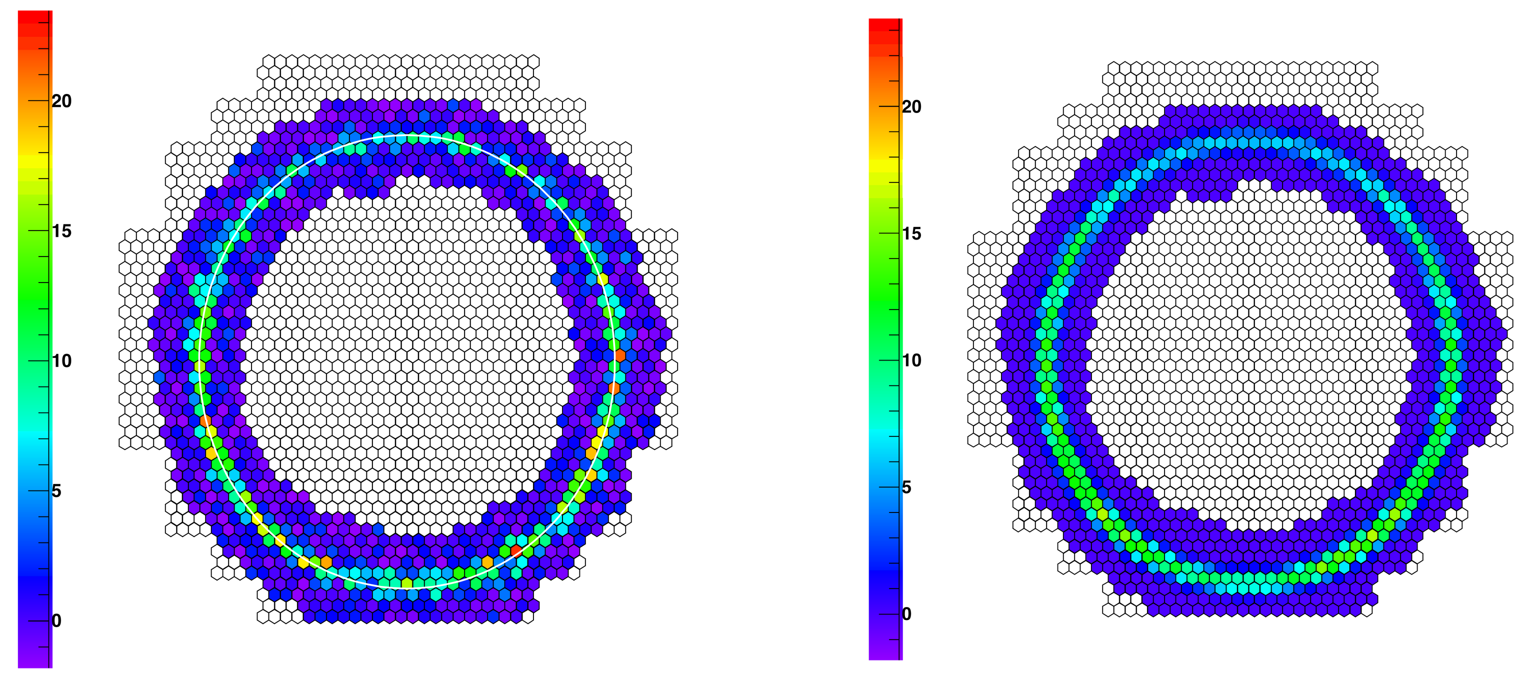

Figure 2: Muon event as seen in the CT5 camera (left) and the expectation from the 2D fit (right).

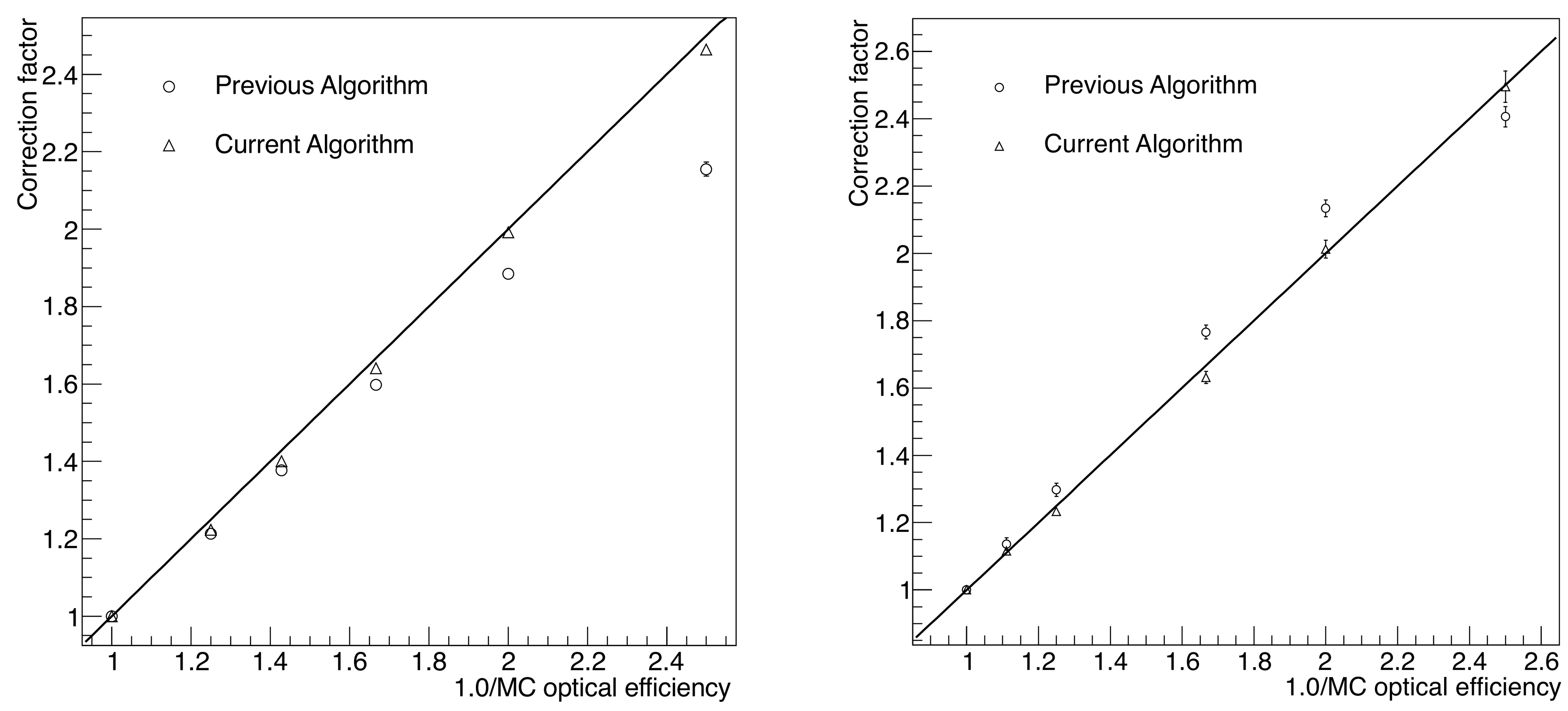

Figure 3: **Linearity** of previous and new codes for both the H.E.S.S. I telescopes (left) and for CT5 (right). In both cases, an **improvement** over the performance of the previous code is seen.

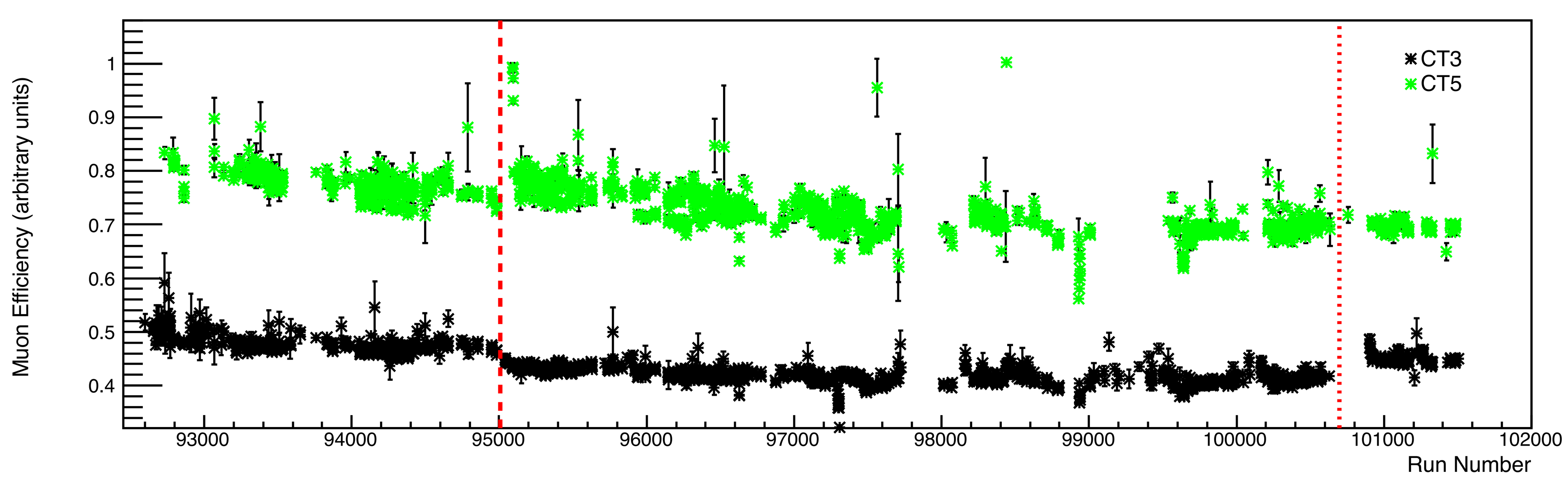

Figure 4: **Evolution** of the muon efficiency of CT5 and one of the H.E.S.S. I telescopes over 2013-2014. Discontinuous shifts due to known camera adjustments are marked by red lines.

Results

- This calibration is applied by multiplying energy estimates by a **correction factor**, comparing the muon efficiency to a **reference** from Monte Carlo (MC)

$$c = \varepsilon_\mu(\mathrm{data})/\varepsilon_\mu(\mathrm{MC})$$

- The correction factor should remain **linear** with optical efficiency degradation. This is tested on MC by the correlation of 1/(MC input efficiency) with correction factor $c = \varepsilon_\mu(\mathrm{degraded\ MC})/\varepsilon_\mu(\mathrm{nominal\ MC})$ obtained by the performing the analysis on MC muons.
- The updated algorithm markedly **improves** the code linearity (**figure 3**).
- This generic algorithm is now implemented as standard within the H.E.S.S. calibration chain.
- **Figure 4** shows the evolution of optical efficiency over time. The newer telescope has much higher efficiency.
- Discontinuous shifts correlating with camera adjustments are identifiable.

Conclusions

- This **generic algorithm** for muon calibration, motivated by addition of the fifth telescope of the H.E.S.S. array, demonstrably **improves performance**.
- Two main changes are the distance across the mirror dish being obtained by interpolation and the use of a **2D pixel log-likelihood** minimisation.
- This algorithm is flexible and can be adapted to telescopes of varying specifications.

References

[1] Vacanti et al. Astroparticle Physics 2, (1994), 1-11
[2] Bolz PhD thesis, University of Heidelberg (2004),
[3] Leroy PhD thesis, Ecole Polytechnique (2004),
[4] de Naurois and Rolland, Astroparticle Physics 32, (2009) 231-252

Acknowledgements:

Please see standard acknowledgement text in H.E.S.S. papers, not reproduced here due to lack of space.

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