# Science verification of the new FlashCam-based camera in the 28m telescope of H.E.S.S.

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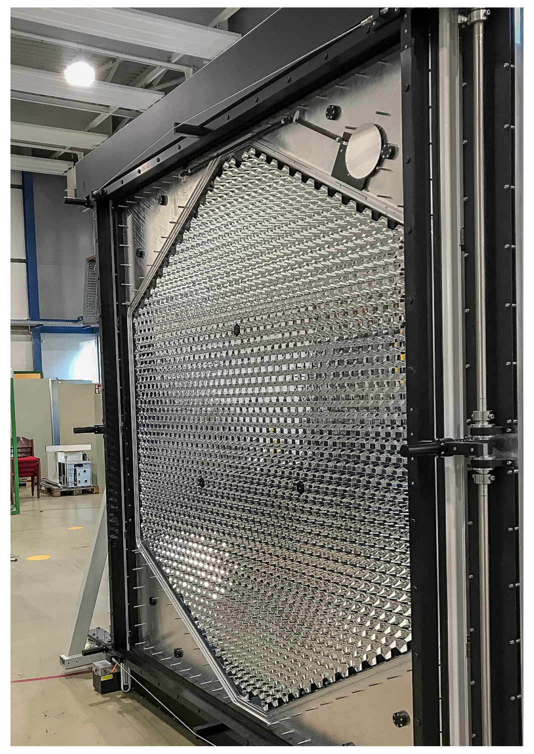
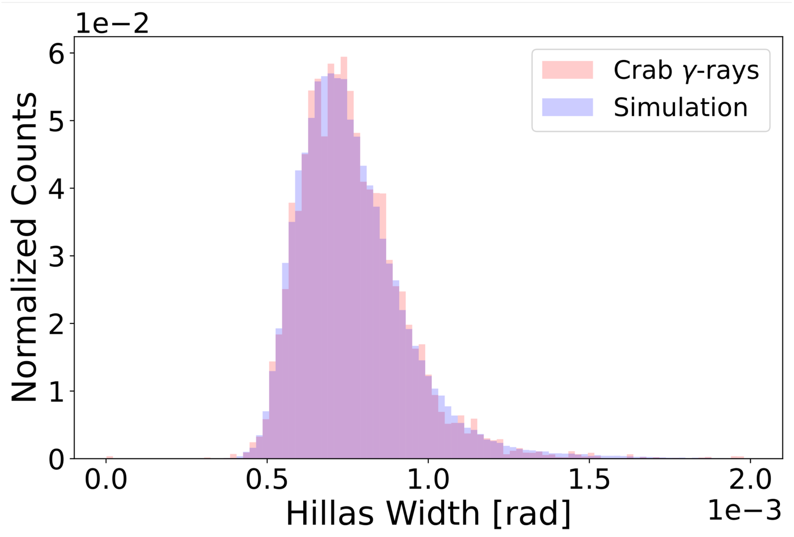
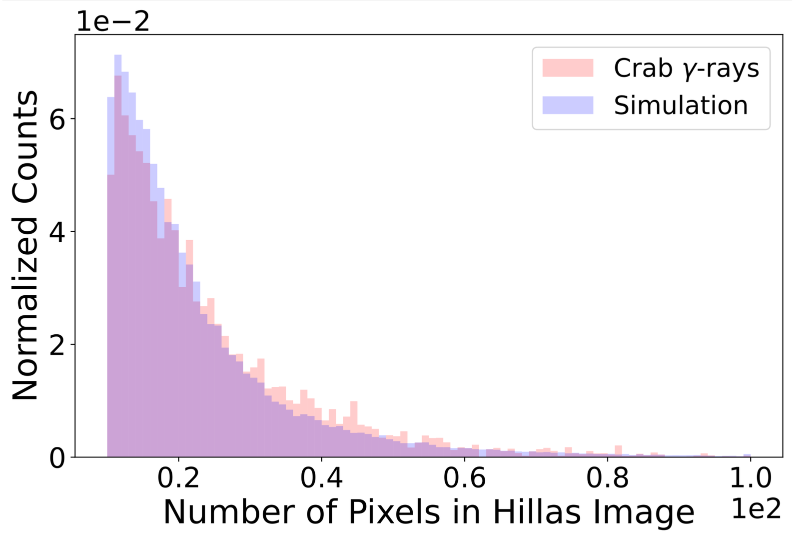
## FLASHCAM MEETS H.E.S.S.-CT5




In October 2019 the central 28 m telescope of the H.E.S.S. experiment (CT5) has been upgraded with a new camera. The camera is based on the FlashCam design [1] which has been developed in view of a possible future implementation in the medium-sized telescopes of the Cherenkov Telescope Array (CTA) [2,3,4,5]. We report here on the results of the science verification program that has been performed after commissioning of the new camera, to show that the camera and software pipelines are working up to expectations.

## VERIFICATION OF LOW-LEVEL IMAGE PARAMETER DISTRIBUTIONS



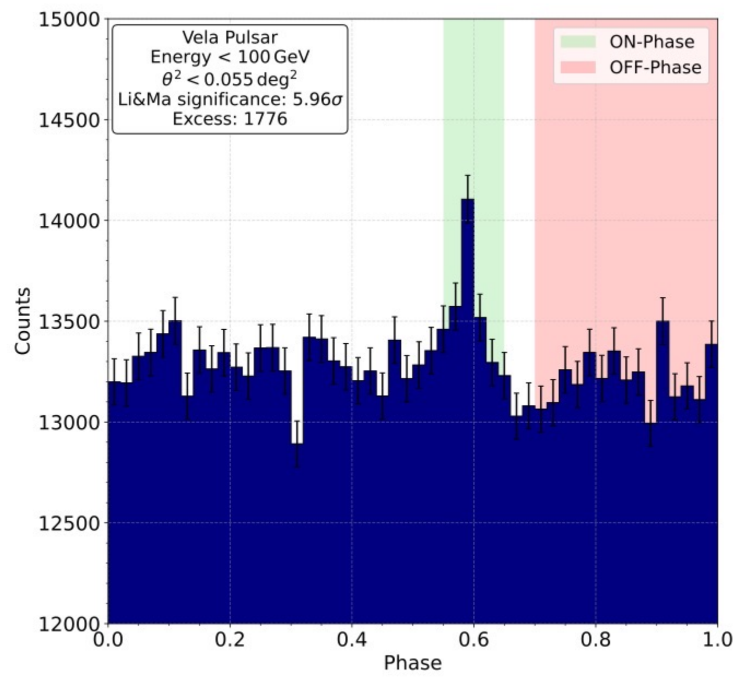

Hillas parameters are a standard way to analytically parametrize air shower images that are recorded by Cherenkov telescopes. Hillas parameters are used to reject background events induced by primary hadrons, either by applying cuts on them or by multivariate analyses such as the TMVA framework which is employed for H.E.S.S. data analysis. Hillas parameters also provide starting points for elaborate shower direction and energy reconstruction methods, which use the pixel-wise event information and compare the data to shower templates as derived from simulations.

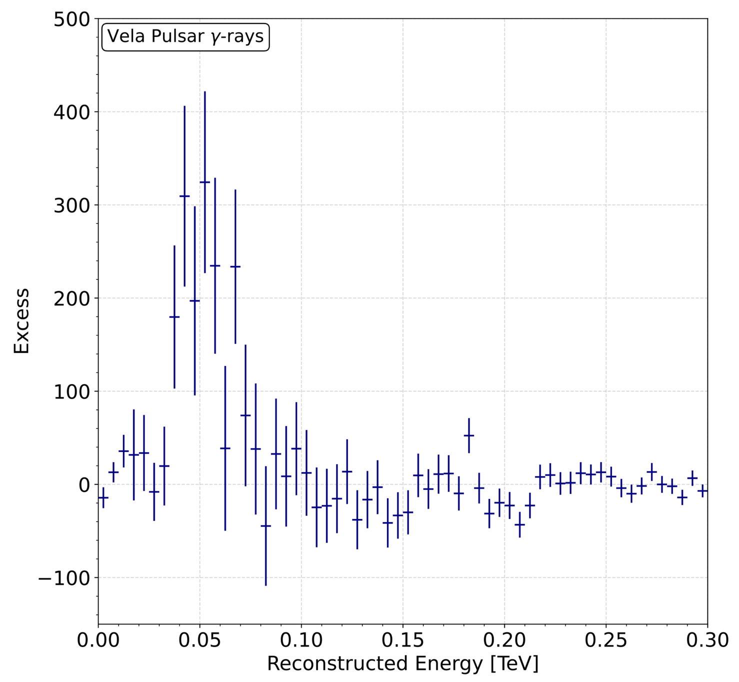
An efficient way to verify that the camera simulations - and therefore derived selection and reconstruction efficiencies - are well understood is to compare Hillas parameter distributions from observational data to parameters from matching simulations. Here, we show results from Crab gamma-ray data (observed excess after background subtraction). Simulations are matched to the observation conditions such as zenith angle and to analysis settings such as image tail cuts. The shown distributions (Hillas width at the upper panel, number of pixels included in image parametrization at the lower panel) demonstrate the excellent match between simulations (blue histograms) and data (red histograms).

## References

[1] Hermann G. et al. 2008. *"A Trigger and Readout Scheme for future Cherenkov Telescope Arrays"*. AIP Conf. Proc. 1085: 898.
[2] Pühlhofer G. et al. 2013. *"FlashCam: A fully digital camera for future Cherenkov Telescope Array"*. Proc. of the 33rd ICRC, p.3080
[3] Pühlhofer G. 2017. *"The medium size telescopes of the Cherenkov telescope array"*. AIP Conf. Proc. 1792, Issue 1, id.080002
[4] Pühlhofer G. et al. 2019, *"FlashCam: a fully digital camera for the Cherenkov telescope array medium-sized telescopes"*, Proc. SPIE 11119, Id. 111191V
[5] Werner F. et al. 2017. *"Performance verification of the FlashCam prototype camera for the Cherenkov Telescope Array"*. NIM-A. 876 (November 2016): 31.
[6] H.E.S.S. collaboration 2018. A&A 620, A66

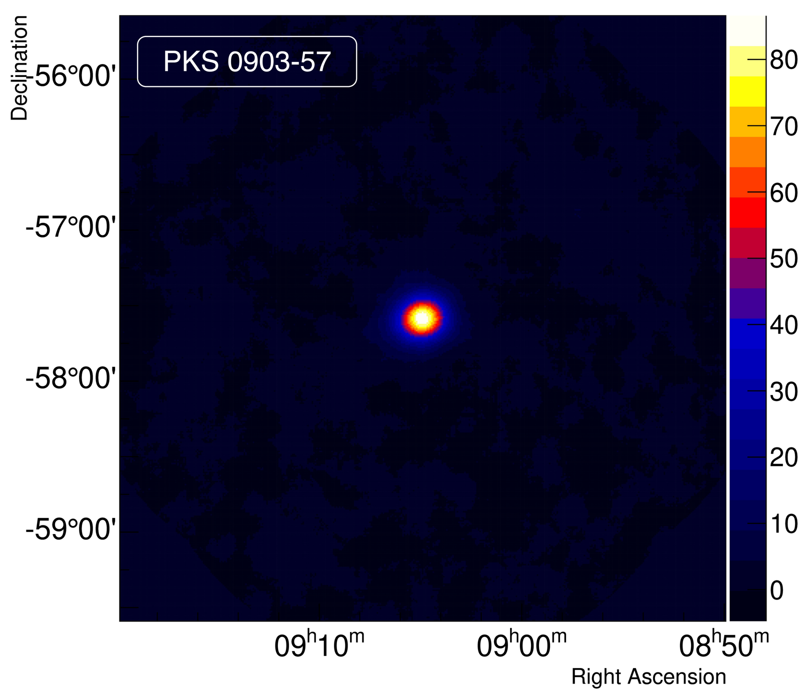
## VERIFICATION OF EVENT TIMING

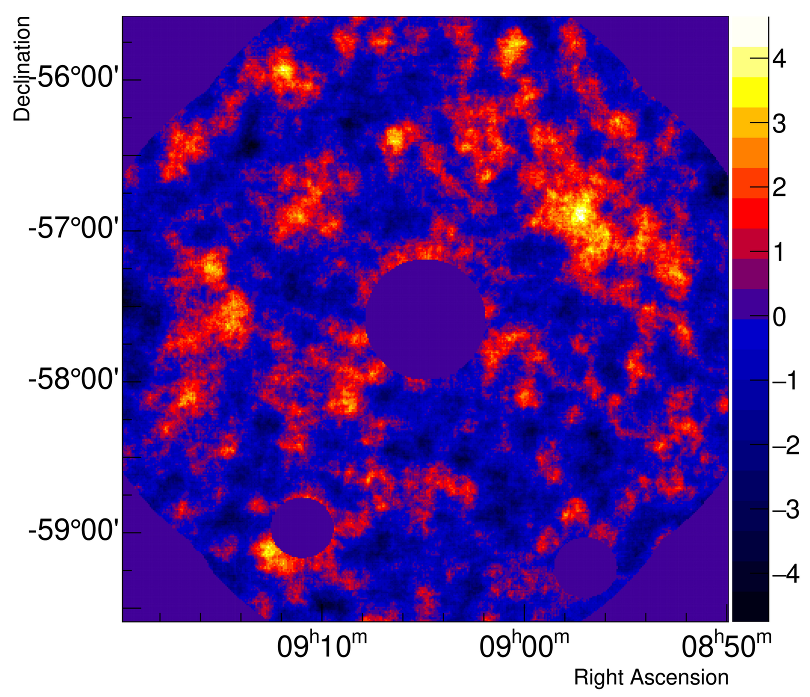


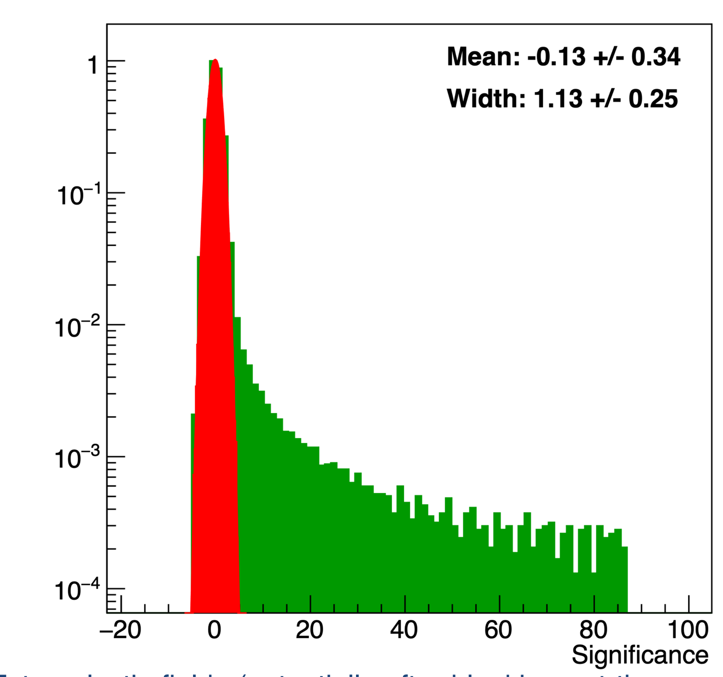




FlashCam obtains its time synchronization via a White Rabbit system. To verify that the event time stamps are correct, observations of the Vela pulsar were performed, from which a pulsed signal has already been detected close to the energy threshold of CT5, using the previous camera [6]. The phase-folded light curve obtained with FlashCam in CT5 is shown in the left panel, exhibiting the signal at the correct phase and at the correct intensity level. This verifies that event time stamping works correctly. Additionally, the data can be used to estimate the energy threshold of the observations, given the very steep gamma-ray spectrum of Vela pulsar close to the threshold of the instrument. Simulations show that the expected bias in energy reconstruction at the energy where the bulk of the signal is detected (~50 GeV, right panel) is of order 50%, the peak of the true energy distribution is therefore estimated to be at ~35 GeV.

## VERIFICATION OF BACKGROUND REJECTION STABILITY



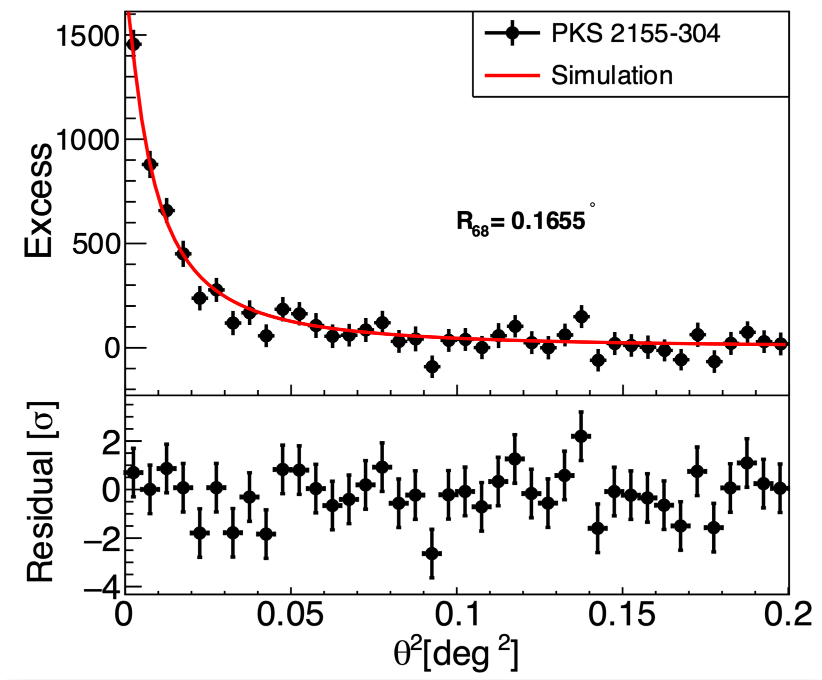

Even for CT5 mono reconstruction, the gamma-ray point spread function of the instrument is substantially smaller than the field of view (in terms of sky field from which gamma-rays can be reconstructed with high efficiency). The expected background (from residual hadrons after cuts and from electrons) at the source position can therefore be estimated from other positions in the field of view. The simplest approach is to use a ring around the tested source position as background estimate, taking a correction for the radially symmetric acceptance drop towards the edge of the field of view into account. This method is used to create sky maps and to search for new sources in observed fields. If the method works and the background acceptance is indeed flat (after radial correction), a distribution of excess count significances across the field of view should behave like a Gaussian with mean of 0 and width of 1.

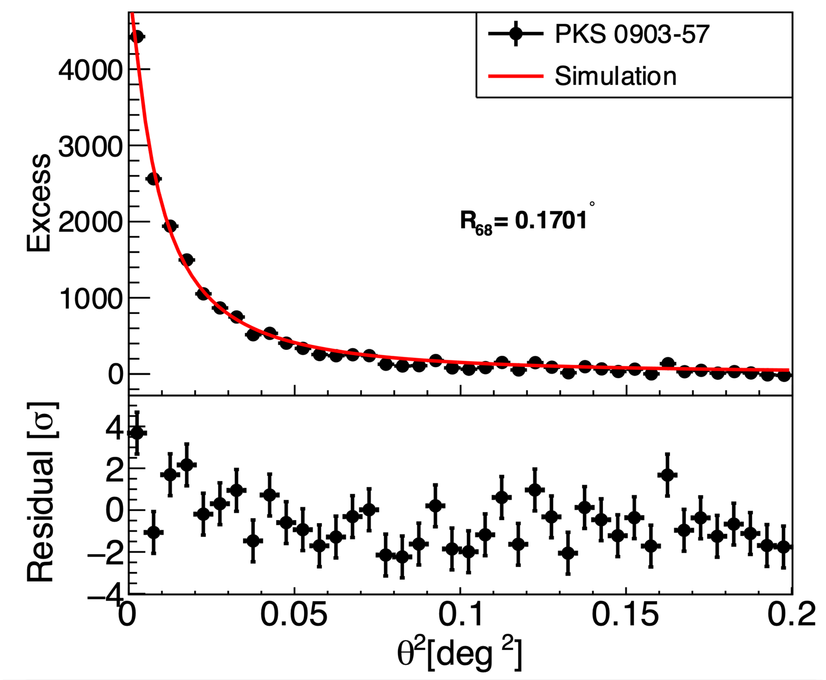
Extragalactic fields (potentially after blanking out the source of interest) are well-suited for such tests. The top left panel shows a sky map derived from observations on the source PKS 0903-57. Known sources are observed in wobble-mode, where the source is observed with alternating offset from the field-of-view center (this permits more sophisticated background estimates for the source position). The shown significance sky map (using the ring background) merges therefore two fields of view with 1° distance. After blanking the source position and two bright stary at the South (top right panel), the significance distribution shows that no artificial sources are detected in the field at high significance. The corresponding significance distribution (red histogram in the lower left panel) across the entire field of view is compatible with pure noise fluctuations.

## ANALYSIS CONFIGURATION

For the results presented here, a preliminary release of the HAP software, which incorporates the CT5-FlashCam-related software and configuration updates, was used. HAP is one of the H.E.S.S. standard pipeline software packages. All results were derived from CT5 data alone (``mono'' reconstruction), the other telescopes of H.E.S.S. were not included in the analysis. Except for the Vela pulsar analysis, the reconstruction was performed applying a conservative image analysis threshold of 250 p.e. For the Vela pulsar analysis, a low image analysis threshold of 25 p.e. was applied, reflecting the very steep spectrum of the source. Optimizations of all analysis configurations are still ongoing at the time of this presentation.

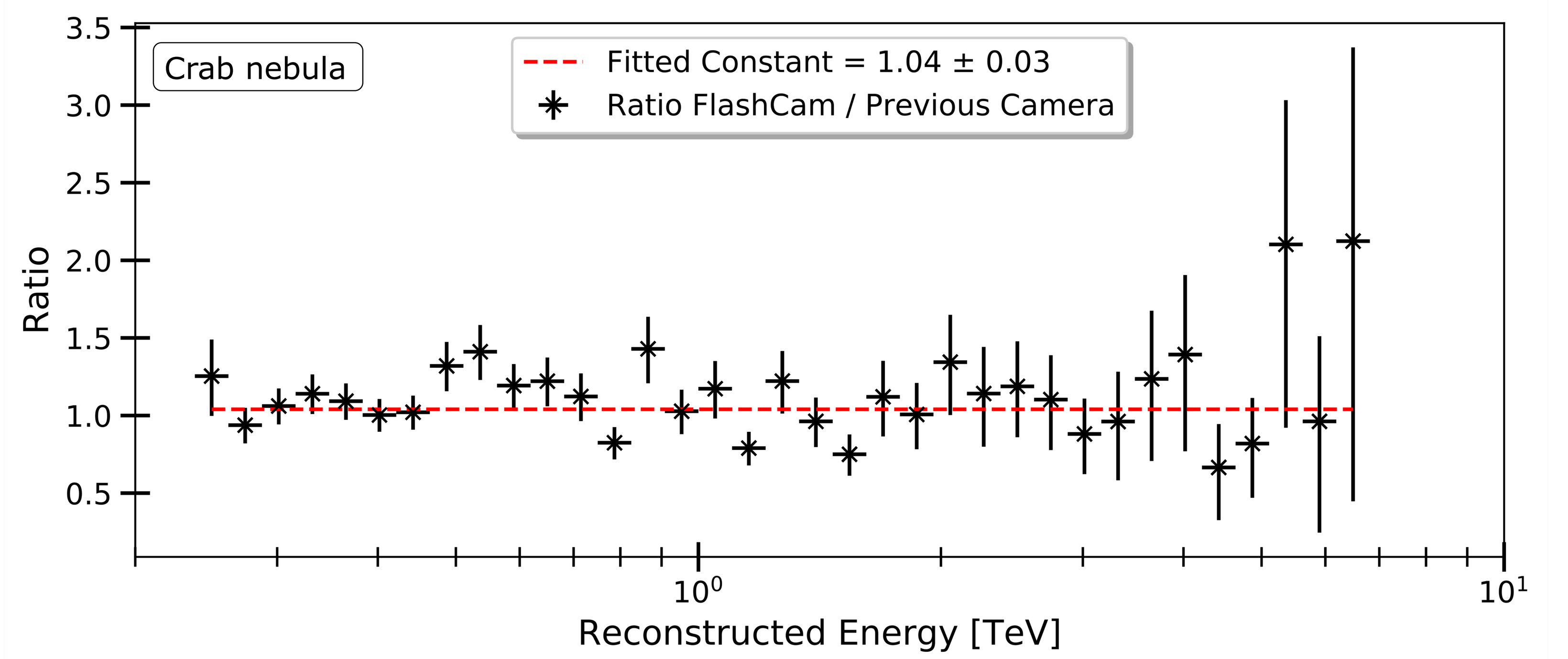
## VERIFICATION OF POINTING AND POINT SPREAD FUNCTION




The gamma-ray point spread function of the instrument was verified using observations of strong gamma-ray sources like PKS 2155-304 (left panel), PKS 0903-57 (right panel), or Crab (not shown). The measured event distribution as a function of the squared distance (where the subtracted background has a nearly flat distribution) is compared to the expectation. The expected distribution (shown in red) is represented by a King's profile that was fitted to matching simulations, and afterwards only normalized to the measured data. $R_{68}$ is the 68% containment radius of the fit. The plots demonstrate the excellent match of observations and simulations. A miscalibration of the telescope pointing would at some stage also affect the measured point spread function. More sensitive to check the pointing calibration is the reconstruction of the centroid position of the excess events in the 2-dimensional sky maps. The positions of all three point sources mentioned above agree with catalog values within 95% c.l. of the accuracy that is expected from the pointing calibration method (~25 arcsec for a CT5 mono analysis).

## VERIFICATION OF SPECTRAL RECONSTRUCTION




Ultimately, to verify that spectral and flux reconstruction works, Crab nebula observations are used. To be free of telescope calibration effects that are independent of the cameras, we plot here the ratio of the reconstructed Crab spectrum derived with FlashCam in CT5 and the spectrum derived with the previous camera from 2018 observations. As expected, the ratio is flat and compatible with 1. Nevertheless, some uncertainties of the calibration of these recent CT5 data sets are still under investigation at the time of this presentation.