Arcsecond Level Pointing Of The H.E.S.S. Telescopes

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Abstract

Gamma-ray experiments using the imaging atmospheric Cherenkov technique have a relatively modest angular resolution of typically 0.05 to 0.1 degrees per event. The centroid of a point-source emitter, however, can be determined with much higher precision, down to a few arcseconds for strong sources. The localization of the Crab TeV source with HEGRA, for example, was dominated by systematic uncertainties in telescope pointing at the 25 arcsecond level. For H.E.S.S. with its increased sensitivity it is therefore desirable to lower the systematic pointing error by a factor of 10 compared to HEGRA. As the exposure times are on a nanosecond scale it is not necessary to actively control the telescope pointing to the desired accuracy, as one can correct the pointing offline. We demonstrate that we can achieve the desired 3 arcseconds pointing precision in the analysis chain by a two step procedure: a detailed mechanical pointing model is used to predict pointing deviations, and a fine correction is derived using stars observed in a guide telescope equipped with a CCD chip.

1. Introduction

Each H.E.S.S. telescope has a stiff support structure that bears the alt/az-mounted primary mirror and the camera in the primary focus. In combination with the drive system the construction allows the detector to point with an accuracy of ∼60 arcseconds to any position in the sky. However, the centroid of TeV point sources can be determined to an accuracy of few arcseconds. Thus the systematic pointing error should be lowered to the same level.

Aside from an improved instrumental sensitivity this also has astrophysical applications. M87 [1] is one example, where arcsecond level pointing allows for the determination of whether the TeV-emission is coming from the centre of the galaxy or from the jet, as the separation is ∼10 arcseconds. A high pointing resolution can also contribute to the distinction between pulsar and nebula emission for plerionic sources hosting a pulsar. In addition a possible future TeV detection of the galactic centre requires the localization of the emission to a few arcseconds.

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2. Methods and Limits

Due to mechanical imperfections of a telescope, its pointing is not fully determined by the axes' positions. There are pointing errors due to:

- Reproducible mechanical errors, *e.g.* the bending of the structure under gravity or imperfectly aligned axes
- Irreproducible effects, such as wind loads or obstacles on the drive rails

Reproducible errors can be determined once, then predicted and corrected in the future. Irreproducible effects can only be corrected by the observation of some known reference - preferably star light. In H.E.S.S. the approach is to predict reproducible errors (1^{st} step) and then employ a fine correction based on the observation of stars in parallel to TeV observations (2^{nd} step). Unfortunately the camera (basically a phototube array) cannot be used to determine the correction as the point spread function of the dish is comparable in size with the pixels of the array * [2].

Therefore a CCD camera is mounted on the dish. It observes the images of stars on the closed lid of the camera [2]. The such recorded positions in the focal plane are related to the phototubes using LEDs mounted in the corners of the array. By observing many bright stars, the mispointing as a function of altitude and azimuth is sampled. Afterwards a detailed mechanical model, whose parameters describe the reproducible mechanical errors, is fit to the data. It allows in turn the first step correction: Given a telescope pointing the model returns the expected mispointing. A nice side-effect is, that the mechanical meaning of the fit parameters can be used to monitor the mechanical stability of the telescopes.

The fine correction is determined using a guide telescope mounted parallel to the optical axis. It registers stars with a second CCD camera ("Sky-CCD"). After identification using a pattern match algorithm the stars' positions are predicted using a similar mechanical model, but with different offsets and focal length. The observed positions will differ from the prediction due to the mispointing (including irreproducible effects and reproducible errors not represented by the model). Thus the difference measures the mispointing and it is therefore the fine correction to be applied.

Table 1 lists the effects that limit the pointing accuracy when using these methods and shows their respective contributions as measured. The mechanical model should achieve a pointing resolution of ~6 arcseconds (2D rms). Using the fine correction should further improve it to 2.5 arcseconds.

*If the point spread function was much bigger than a pixel the light distribution of a star could be fit over several pixels, if it was much smaller transits of stars from one pixel to another could be used.

Table 1. Limits of the Pointing Asccuracy

Principle Limits	Measured Values	Sum
Accuracy of the reference LED positions	1.4”	
Reproducibility of the mechanical deformations	1.4”	
Stability of the tracking system	1.3 ”	
Accuracy of star position determination	0.8 ”	2.5”
Limits for Mechanical Model		
Positioning accuracy of the drive system	3.5”	
Deformations of the drive rails’ shapes	3.5”	
Principle limits (above)	2.5”	
Inaccuracy of the shaft encoders	2 x 1.5”	5.9”

3. Results

The pointing of the first two telescopes has been studied. As the results are similar only data for the first telescope is presented. An example of measured mispointing vectors as a function of altitude and azimuth is given in Fig. 1. Without any correction the raw mechanical pointing accuracy is 28 arseconds (2D rms) as Fig. 2 shows. After application of the model, the residual is 8 arcseconds, approximately in agreement with the limit for the mechanical model (Table 1).

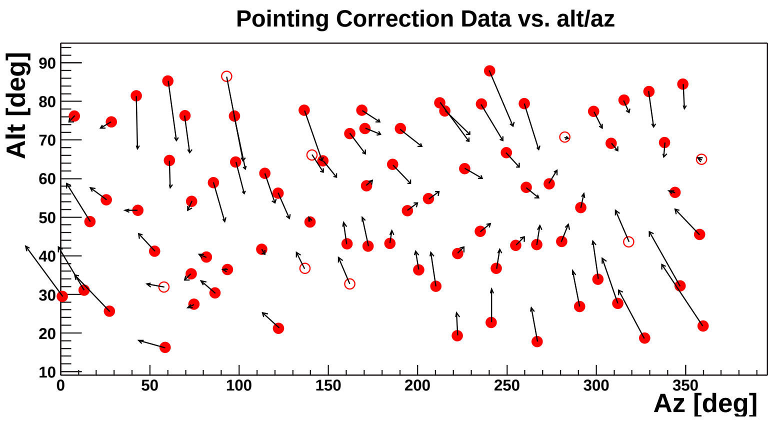

Fig. 1. Measured mispointing for the first telescope as a function of altitude and azimuth. Arrows are artificially enlarged

In order to test the fine correction, the SkyCCD has recorded the same stars that are used for the determination of the mechanical model. The same kind of model is used to describe these positions in the SkyCCD, resulting in similar residuals. If the residuals in the focal plane are actually due to mispoint-

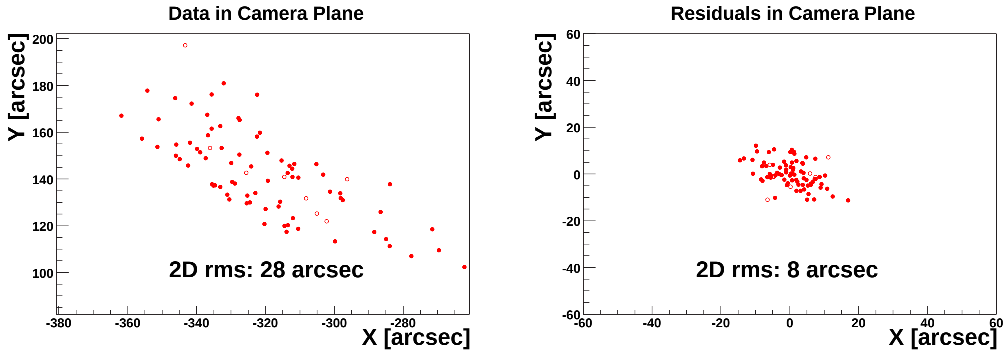

Fig. 2. Left: Raw positions in the focal plane before the application of the model Right: After application of the fit (same scale)

ing, they must agree point by point with the residuals from the SkyCCD fit. A correlation plot for two residuals is given in Fig. 3, clearly showing the expected correlation. Thus the SkyCCD residual can be used to measure the focal plane residual, allowing for the desired fine correction. After its application a 2D rms of ∼2.5 arcseconds remains, which agrees with the principle limit from Table 1.

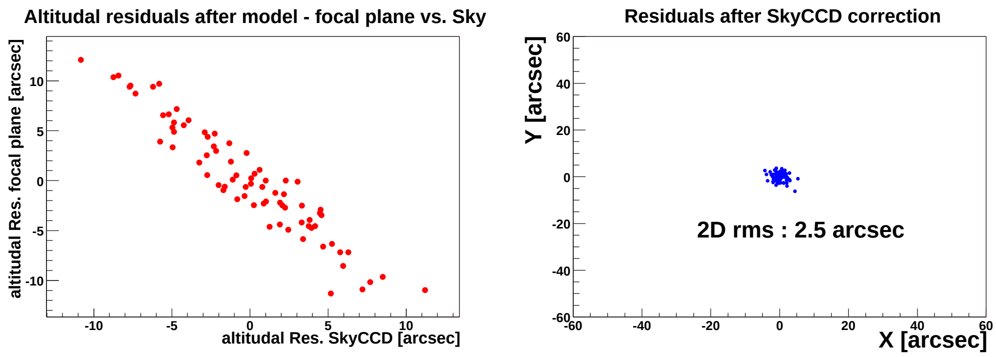

Fig. 3. Left: (Vertical) residual in the focal plane vs. residual in SkyCCD Right: Positions in the focal plane after the fine correction (same scale as Fig. 1)

4. Conclusion

The described two-step procedure allows the offline pointing control of the H.E.S.S. telescopes to attain the desired accuracy of 2.5 arcseconds. It will allow H.E.S.S. to address many morphological questions in TeV astronomy.

1. F.A. Aharonian et al. (HEGRA collaboration) 2003, A&A 403, L1-L5
2. R. Cornils et al. 2003, The optical system of the H.E.S.S. imaging atmospheric Cherenkov telescopes, Part II, submitted to APP