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Pulse shape analysis and the Flash-ADC readout

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timing information using

of the HEGRA IACTs

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Abstract

Since December 1996 the HEGRA collaboration is operating a system of 4 identical Imaging Atmospheric Cherenkov Telescopes (IACTs). The IACT system is dedicated to the investigation of cosmic TeV γ-rays.

The telescopes are equipped with Flash-ADCs which record the time history of signals in the camera pixels at a sampling rate of 120 MHz for 34 μs. The Flash-ADC readout allows a delayed trigger decision, based on a multi-telescope coincidence.

The Flash-ADC data combined with the stereoscopic reconstruction of a shower opens up the possibility to study the time and intensity profile within a camera image as function of the shower distance and the type of the primary particle as well as the relative timing between the telescopes.

The amplification chain
and the pulse response of a single channel

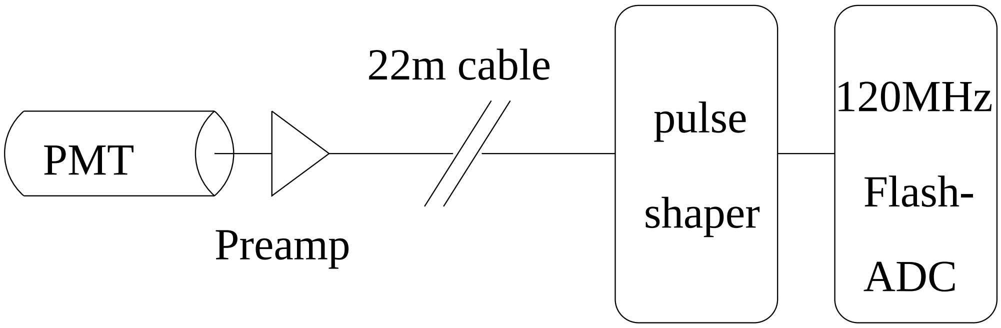

Figure 1

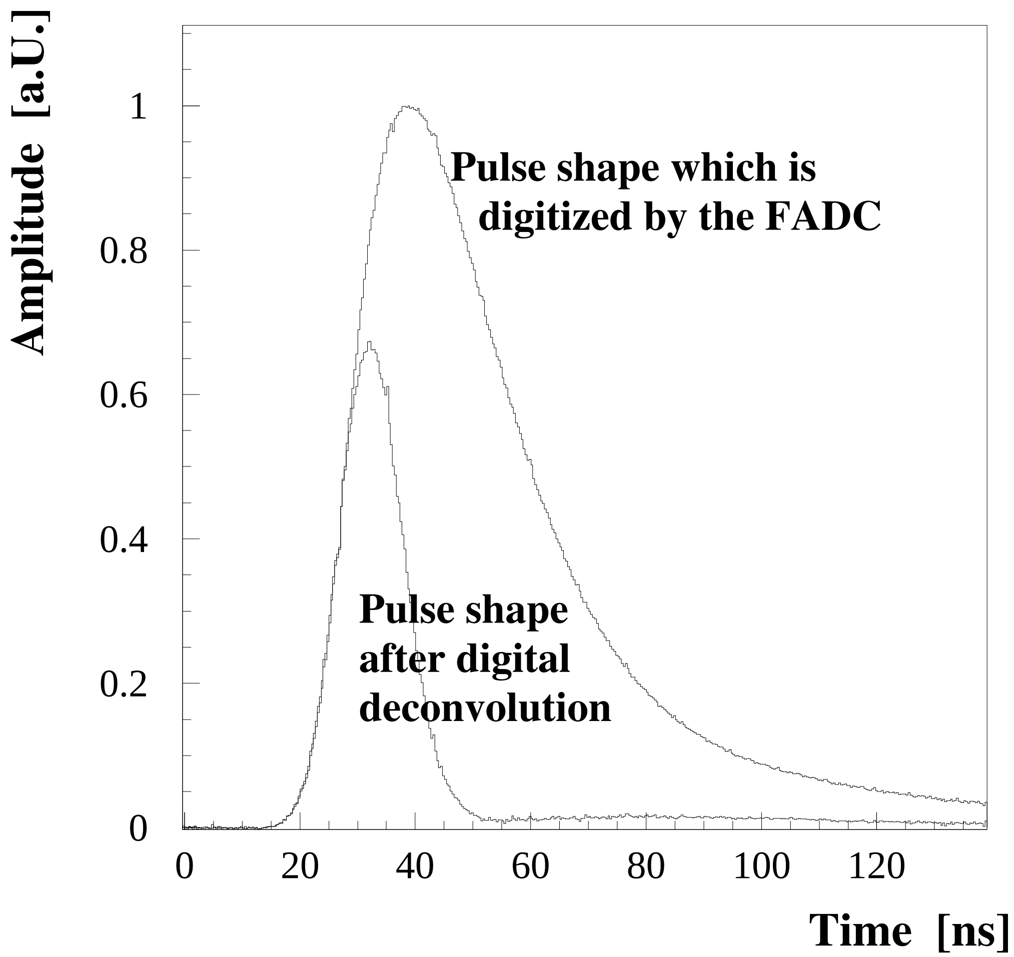

Figure 2

Analysis of the Flash-ADC data

The pulse shape which is digitized by the Flash-ADC is influenced by the constituents of the amplification chain (Figure 1). For signals which do not saturate the Flash-ADC dynamical range, the signal is digitally deconvoluted. The deconvolution shortens the signal (Figure 2) and hence the effective integration time. In case of saturation, the area under the raw signal is determined. The timing of a pixel is determined as the c.o.g. of the deconvoluted pulse. Timing offsets in the response of individual pixels are determined from the analysis of laser runs. The reason for the channel dependent timing is the high voltage which is individually adjusted for each PMT (Figure 3).

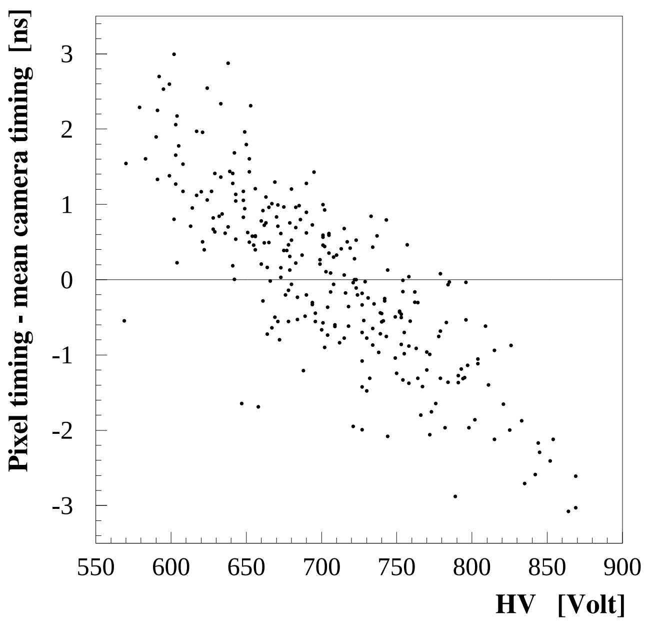

Figure 3

A mean event time is calculated using pixels exceeding a threshold of about 8 photoelectrons. The signal intensity in the Flash-ADC samples around the mean event time are summed up to get the number of photoelectrons in a pixel.

Intensity and timing profile of images

The fully reconstruction of the shower axis allows systematic studies of the intensity and timing profiles of cherenkov images. Images with an amplitude between 100 and 400 p.e. are superpositioned leading to the mean intensity and timing profile :
The images are transformed into a coordinate system with the shower direction as the origin and the x-axis pointing to the c.o.g.. The profile along the x-axis represents the longitudional profile of the shower. This procedure allows a finer resolution (0.1°) than the granularity of a pixel (0.25°).
The profiles can be studied for hadronic and γ-ray showers separately by analyzing the data from a strong γ-ray source. Events from the source direction and an OFF-region are selected to extract the mean γ-ray images. Figure 4 shows the mean intensity and timing profile of hadron induced images while Figure 5 and Figure 6 show the mean longitudinal profiles for γ-ray and hadron induced images.
The longitudinal timing profile of hadronic images can be approximated by a straight line. The slope as a function of the distance to the shower core is presented in Figure 7.
Timing fluctuations have been proposed to be a tool for γ-hadron separation. Figure 8a shows the raw RMS of the arrival times of the image pixels while Figure 8b shows the RMS under the assumption that the shower was initiated by a γ-ray.

Mean intensity and timing profile of hadronic induced images

- core distance : 100-120 m
- inclination : 0-1 deg with respect to the telescope axis
- $\Theta_{x,y}$: angle between shower direction and emitted cherenkov light

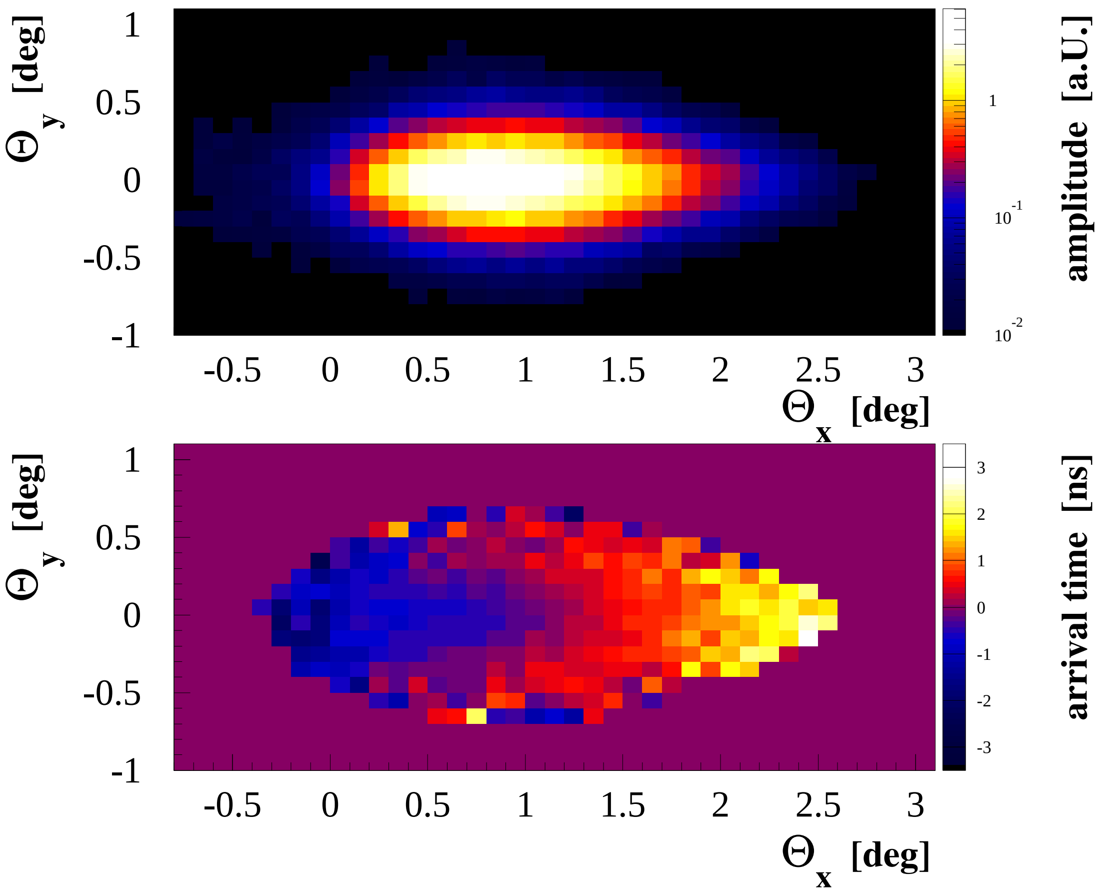

Figure 4

Longitudinal intensity and timing profile of γ-ray induced images

- **core distance : 100-120m**
- **inclination : 0-1 deg with respect to the telescope axis**

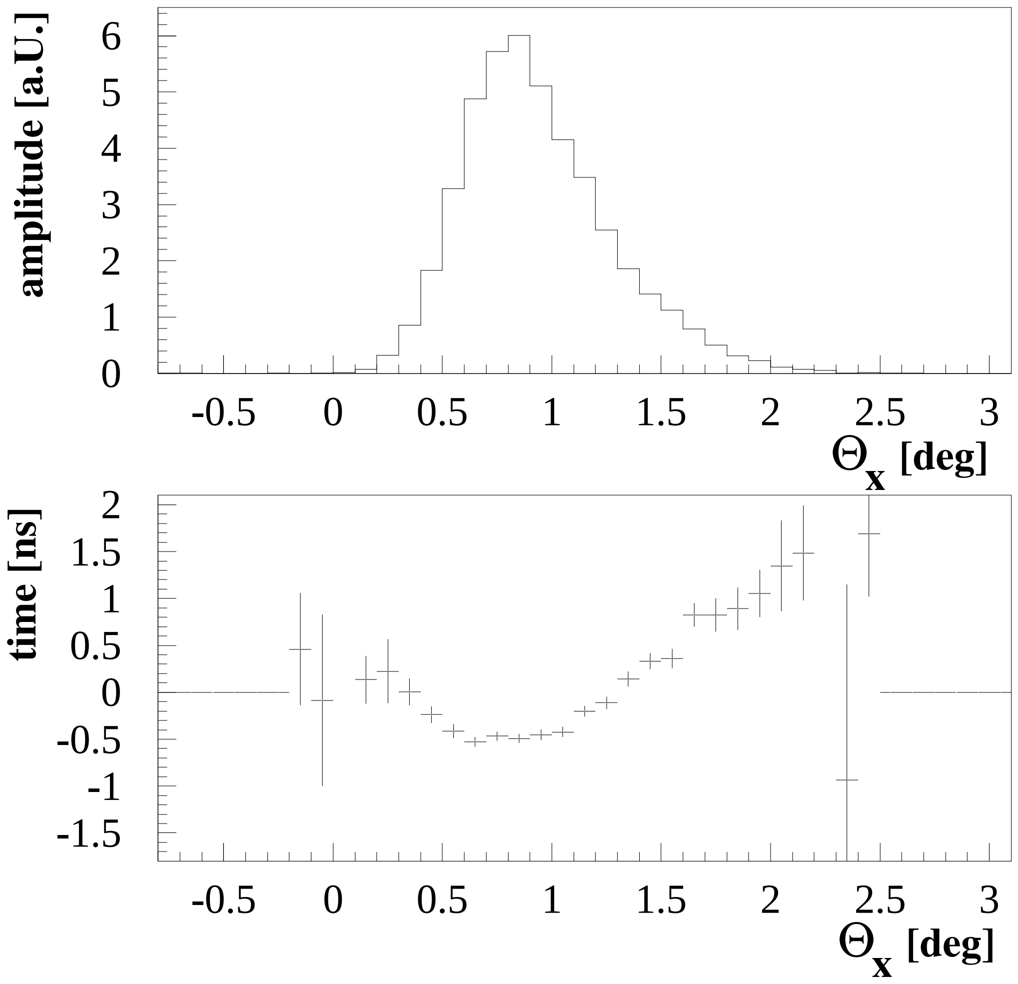

Figure 5

Longitudinal intensity and timing profile of hadron induced images

- core distance : 100-120m
- inclination : 0-1 deg with respect to the telescope axis

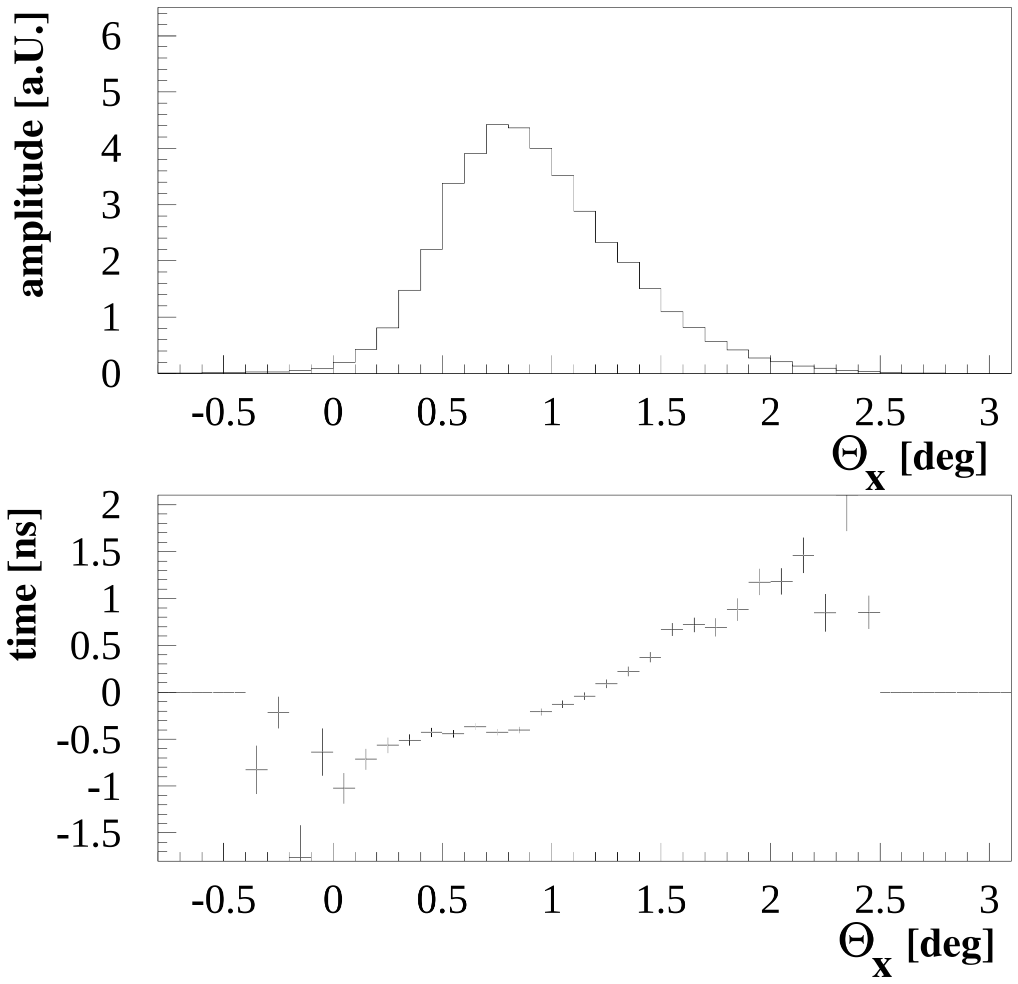

Figure 6

Time gradient over the image of hadron induced showers as a function of the distance to the shower core

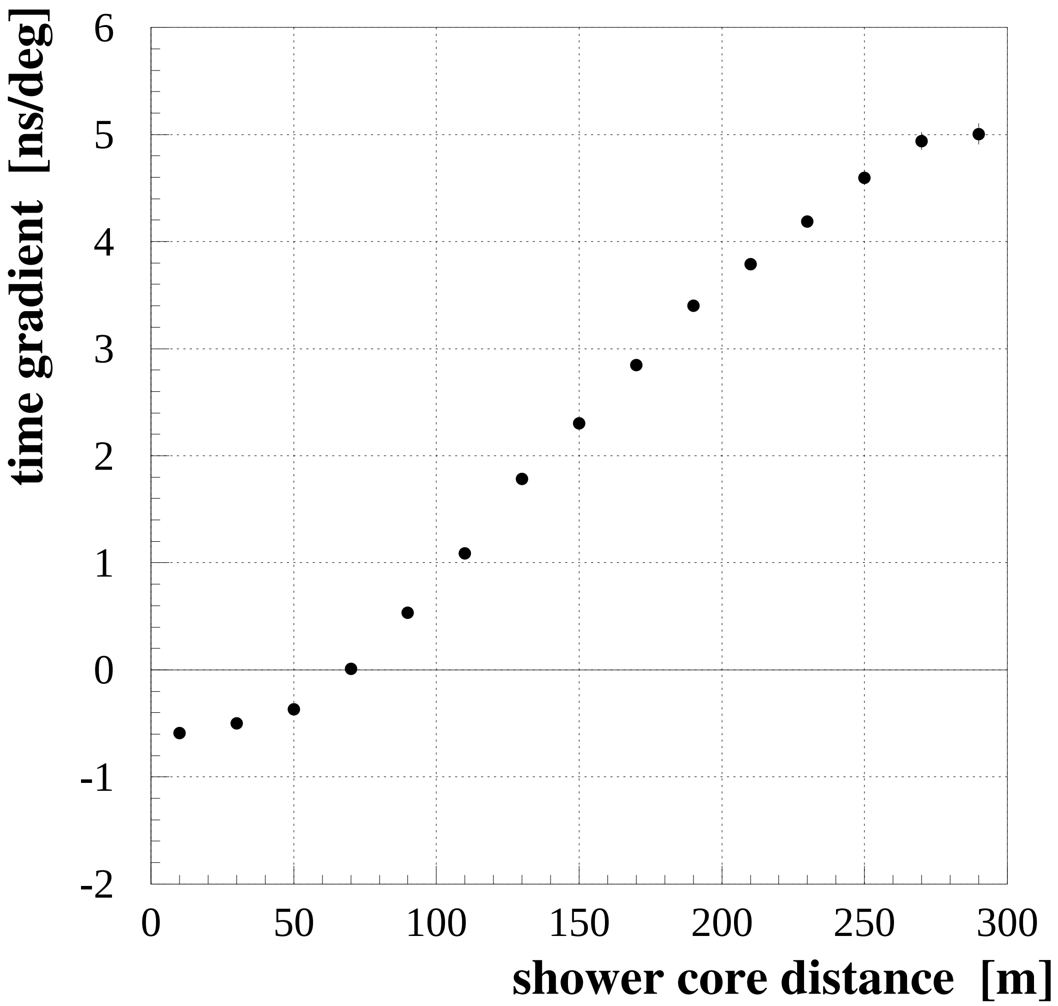

Figure 7

Timing variations within an image as a tool for γ-hadron separation

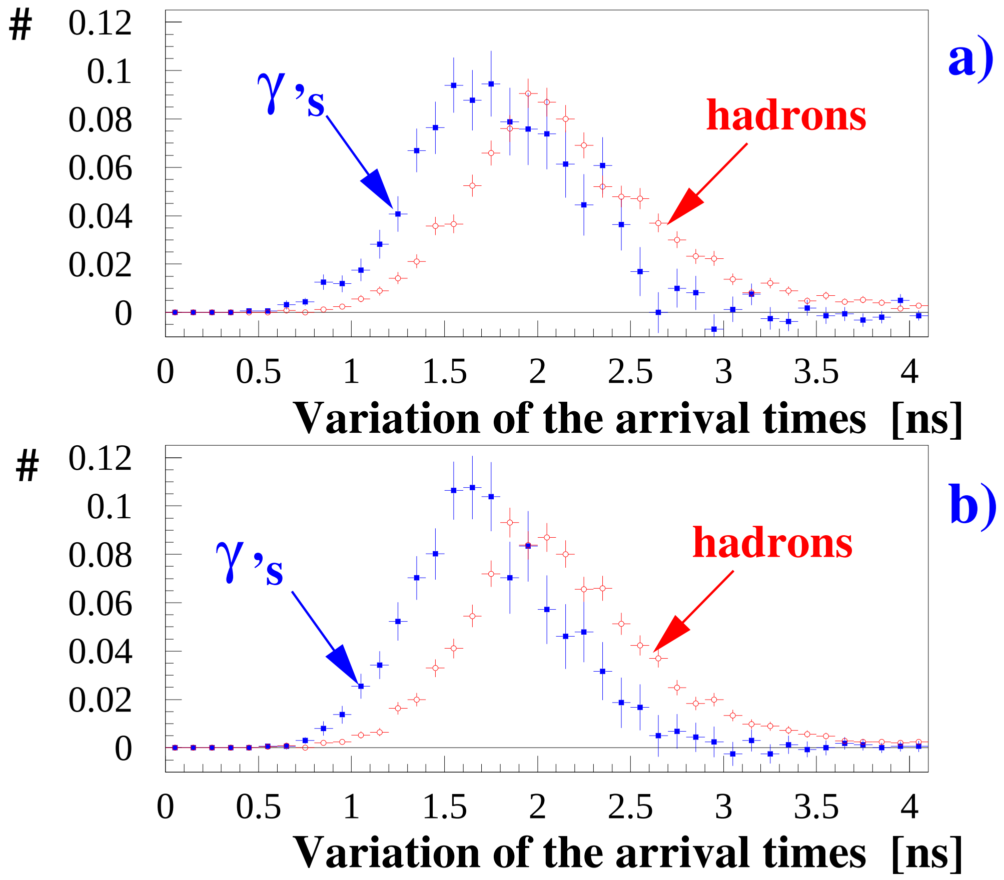

Figure 8

Raw RMS of the arrival times of the image pixels (a).

RMS of the arrival times of the image pixels under the assumption of a timing profile of a γ-ray induced image (b).

Relative timing of the telescopes

The relative timing of the telescopes is measured using the Flash-ADC data combined with the timing of the system-trigger as a synchronization-mark which is also recorded in a separate Flash-ADC channel.
In a multi-telescope system a shower is stereoscopically reconstructed using the images in the cameras of the telescopes. The timing information can be used to cross check the results of the imaging technique. For a fully reconstructed shower one can calculate the relative arrival time at two telescopes under the assumption of a spherical light front. The expected arrival time is compared with the measured one (Figure 9).
Under the assumption of a spherical light front and the knowledge of the shower impact point (from the image analysis) the shower direction can be calculated using the timing information. The method was applied to 7 hours of data taken on the Crab Nebula. Events were selected with at least 3 telescope exceeding the amplitude threshold. The number of events from the direction of the Crab show a clear excess compared with the background distribution (Figure 10). The angular resolution is worse than the 0.1° obtained from the shower reconstruction purely based on images.

The relative arrival times between the telescopes as a cross check of the image reconstruction

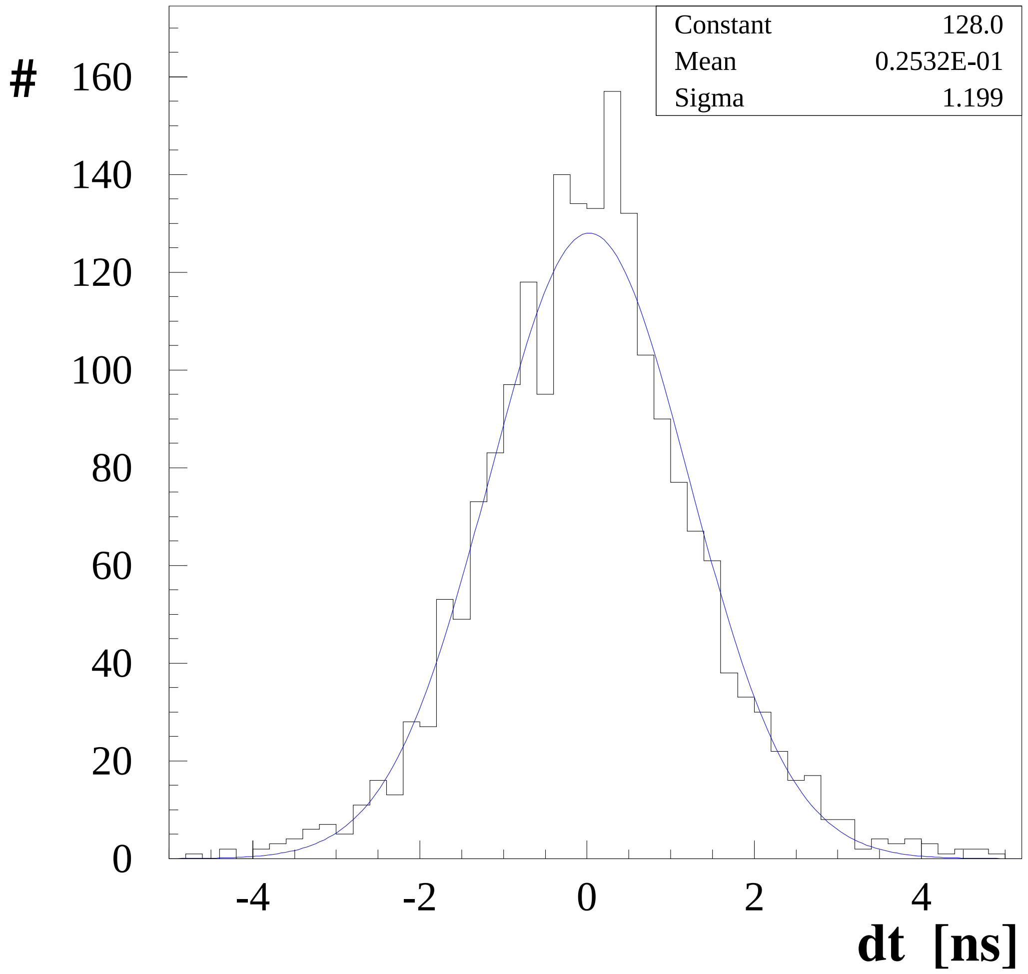

Figure 9

Difference between the relative timing at two telescopes based on image reconstruction under the assumption of a spherical light front and the measured relative timing using the Flash-ADC data.

Reconstruction of the position of the Crab Nebula using the relative timing of the telescopes

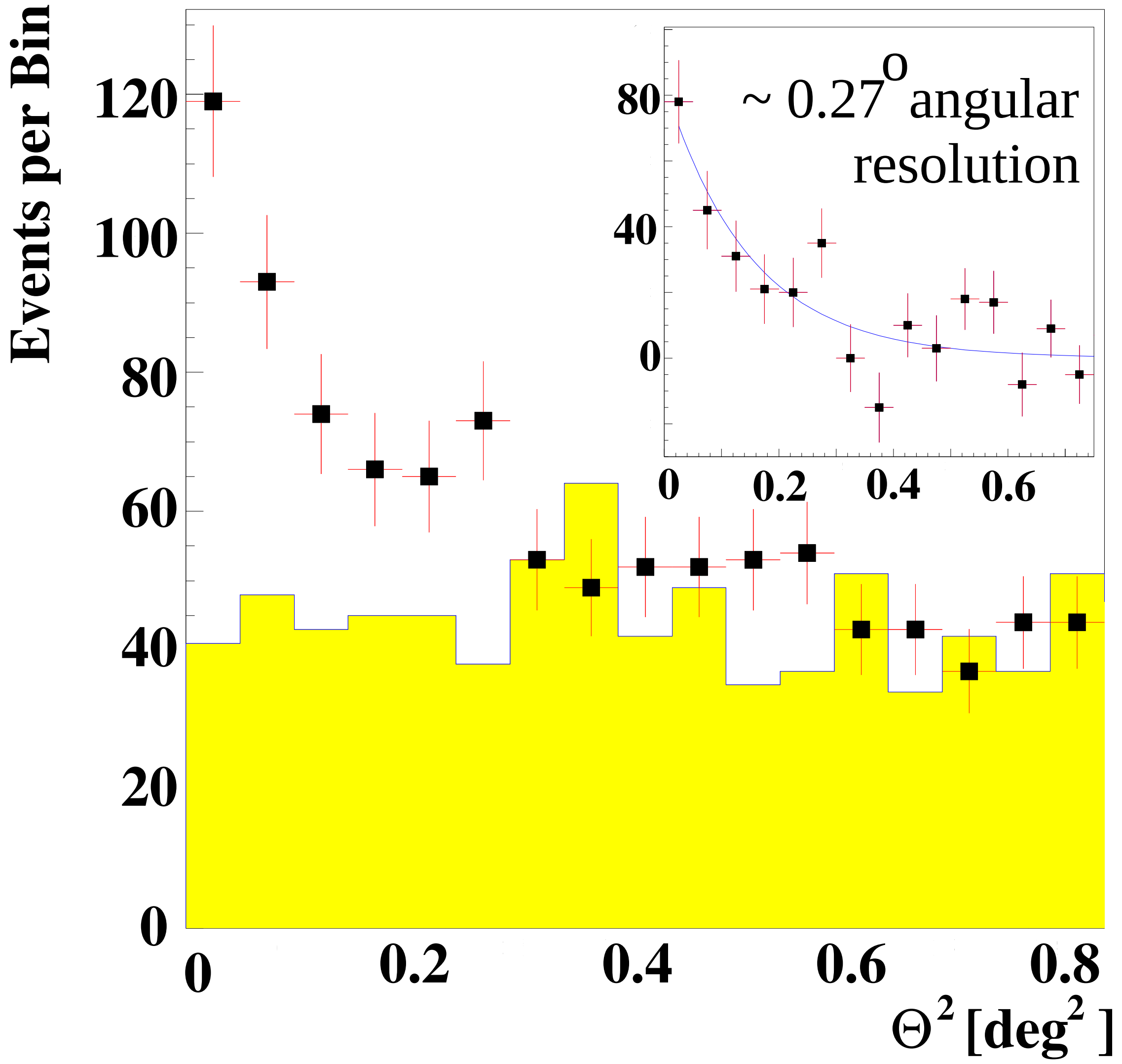

Figure 10

Shower reconstruction under the assumption of a spherical lightfront and the knowledge of the shower impact point taken from the image analysis (7h observation time).