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PULSE SHAPE ANALYSIS AND TIMING INFORMATION USING THE FLASH-ADC READOUT OF THE HEGRA IACTS

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ABSTRACT

The Cherenkov telescopes of the HEGRA IACT system (Daum, 1997) 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 recorded pulse shapes are subject to a digital deconvolution, reducing the effective integration time and the influence of night-sky background light. Based on the pulse shape, noise hits can be rejected and overflow pulses can be partially recovered, increasing the dynamic range. The timing of pixel signals can be determined with a precision of about 1 ns. Timing fluctuations are a tool for gamma-hadron separation. In a multi-telescope system, the relative timing of the different telescopes can furthermore be used to cross-check the reconstruction of shower parameters based on the images. The algorithms for the analysis of the Flash-ADC data are summarized, and examples for the use of the timing information in the selection and reconstruction of showers are given.

THE AMPLIFICATION CHAIN OF THE HEGRA IACTS

The pulse shape which is digitized by the Flash-ADC is influenced by the constituents of the amplification chain (Figure 1). A Cherenkov flash which hits the photocathode of a PMT produces a fast signal at the output of the PMT. A preamplifier which is located next to the PMT amplifies the signal before it is transmitted via a coaxial cable of 22 m length to the readout electronics. A pulse shaper which is required to suppress the signal components above the Nyquist frequency is implemented at the input of the 120 MHz Flash-ADC. The pulse response $s(t)$ of the shaper, which consists out of two identical integrators, is given by $s(t) \propto \; t \cdot e^{\frac{-t}{\tau}}$ where τ denotes the shaping time which is adjusted to 12 ns. The conversion factor k_{pe} relating the Flash-ADC amplitude to the number of photoelectrons has been derived with two independent methods. Both are in good agreement and give $k_{pe} \approx 1$.

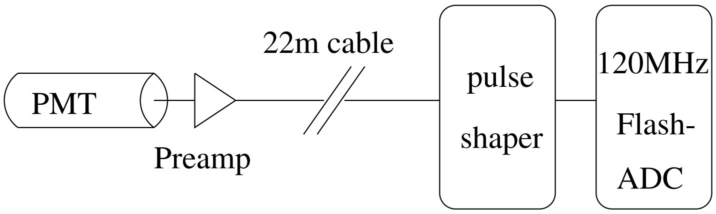

Fig. 1: Sketch of the amplification chain of a PMT in a HEGRA system camera.

ANALYSIS OF THE FLASH-ADC DATA

The first step is the pedestal subtraction. The pedestals are continuously monitored using Flash-ADC samples before the shower signal. For signals which do not saturate the Flash-ADC dynamical range, the signal is digitally deconvoluted. The deconvolution reverses the effect of the signal shapers. It shortens the signal and hence the effective integration time, thereby reducing the influence of the sky noise. A time bin of the deconvoluted pulse can be derived as a linear combination of three consecutive time bins of the pedestal subtracted pulse shape. The coefficiants c_i depend on the sampling time Δ of the Flash-ADC and the shaping time τ of the signal.

$$c_1 = \frac{e^{x-1}}{x} \qquad c_2 = \frac{-2 \cdot e^{-1}}{x} \qquad c_3 = \frac{e^{-x-1}}{x} \qquad \text{with} \quad x = \frac{\Delta}{\tau} \tag{1}$$

After the deconvolution, the signal should be concentrated in two subsequent time slices. Figure 2 illustrates the average signal shape before and after deconvolution. The deconvolution assumes a linear response and cannot be applied to signals saturating the dynamical range of the Flash-ADC. In case of saturation, the area under the raw signal is determined, and is converted into a signal amplitude using a calibration function. The calibration function is obtained by simulating the effect of signal sampling by the Flash-ADC using the real pulse shape which is derived from the data (Figure 2). Overflow pulses can easily be simulated be cutting off the peak of the pulse at several amplitudes. With the resulting correction, the dynamic range of the system can be increased by least a factor of 2, up to about 500 photoelectrons.

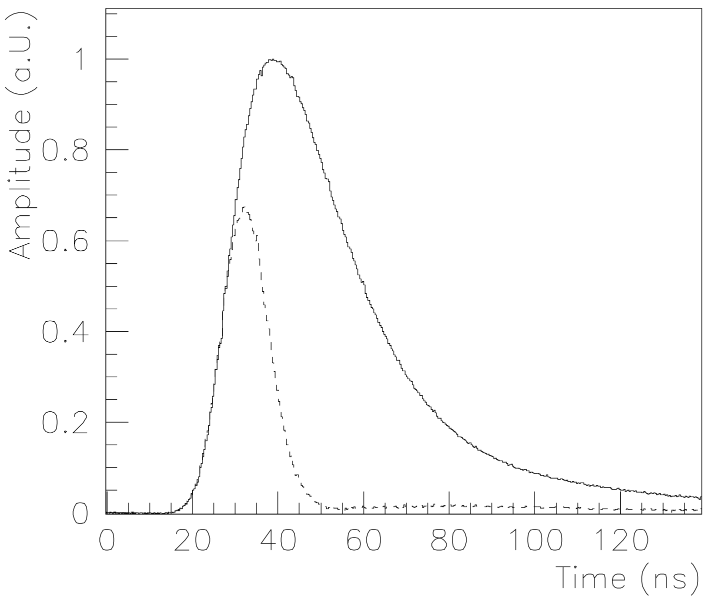

Fig. 2: PMT signal before and after digital deconvolution of the Flash-ADC data, averaged over many pulses.

The timing of a pixel is defined 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, which provide a simultaneous illumination of all PMTs in the camera and are corrected. The main reason for the channel-dependent timing variations in the order of a few ns is the high voltage which is individually adjusted for each PMT within a range of 300 Volt to adjust the gain of all PMTs to the same value. Single pixels may contain small noise signals. Therefore a mean event time t_{event} is calculated using pixels which exceed an amplitude threshold of $\approx$ 8 photoelectrons while excluding pixels with a DC-current of more than 5 μA.

To calculate the number of Cherenkov photons in the pixels two different approaches are possible: the amplitude calculated from the maximum bins of the deconvoluted signal (or the corrected amplitude sum for overflow pulses), and the signal intensity in the Flash-ADC samples around the mean event time t_{event}. The first approach represents an optimal noise filter while neglecting a time-spread of the Cherenkov light (at least a time spread which is wider than the sampling time Δ of the Flash-ADC). The second one takes into account a variance of the arrival times but is more sensitive to noise hits. While for most events all pixels show signals at the same time (within a few ns), there are some events with a wide dispersion of signal arrival times between pixels (Figure 3). These anomalous events could be identified as high energy showers with a distant impact point and a large angle with respect to the telescope axis. For such showers, there is a difference of some 10 ns between the light arriving from the head and the tail of the shower.

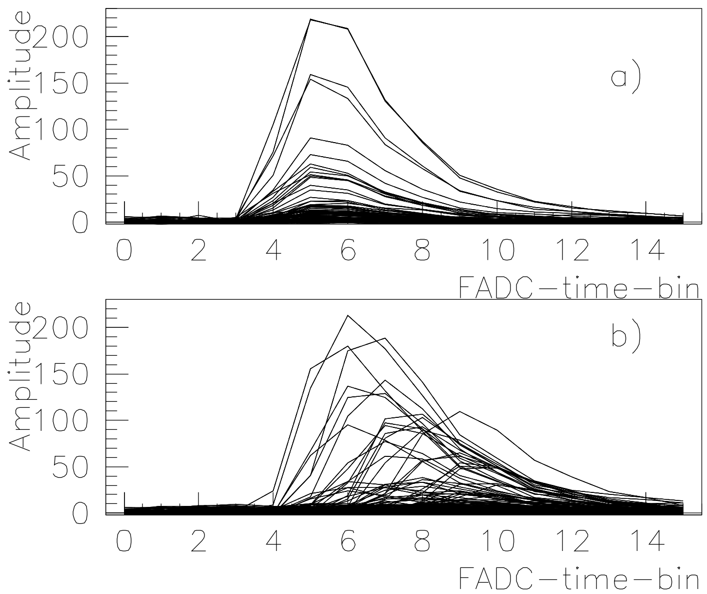

Fig. 3: Pedestal subtracted Flash-ADC signals for a typical event (a), with all signals arriving at the same time, and for an event with large variance in arrival times (b).

RELATIVE TIMING OF THE SIGNALS

The relative timing of the telescopes is measured using the Flash-ADC data and the timing of the system-trigger as a synchronization-mark which is also recorded in a separate Flash-ADC channel. For more details of the system-trigger see (Hermann, 1997b). In a multi-telescope system a shower is stereoscopically reconstructed using the images in the cameras of the telescopes (Aharonian et al., 1997). 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 of the Cherenkov light front at two telescopes. A spherical shape of the light front is assumed. The expected arrival time is compared with the measured one (Figure 4). The result is a Gaussian distribution with a width of σ=1.5 ns. The quality of the shower reconstruction based on images and the time resolution of the analysis of the Flash-ADC data in 2 telescopes contribute to this width.

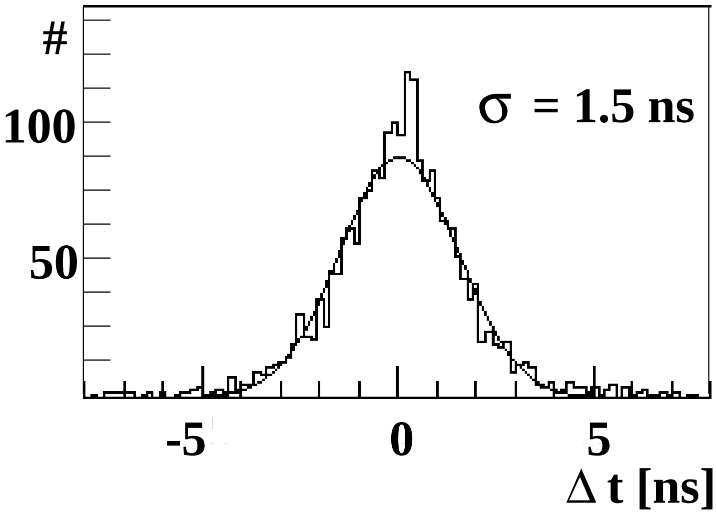

Fig. 4: Difference between the relative timing at two telescopes based on the image reconstruction and the measured relative timing using the Flash-ADC data.

Another result of the analysis of the Flash-ADC data is the determination of the position of a TeV-γ-ray source by using the relative timing between the telescopes. Under the assumption of a spherical shape of the light front and the knowledge of the shower impact point (taken 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 standard candle of the TeV-γ-ray astronomy, the Crab Nebula, with a system of 4 telescopes. Events were selected with at least 3 telescopes exceeding an amplitude threshold in order to be able to derive a definite shower direction. The result is presented in Figure 5: The number of events versus the angular distance to the Crab position show a clear excess in the ON-data from the direction of the Crab Nebula while the background distribution is flat. The angular resolution of this procedure turned out to be 0.27° which is worse than the 0.1° obtained from the shower reconstruction purely based on images. The results concerning the relative timing prove the self-consistency of the analysis and further investigations are going on to combine the two methods in one fit procedure.

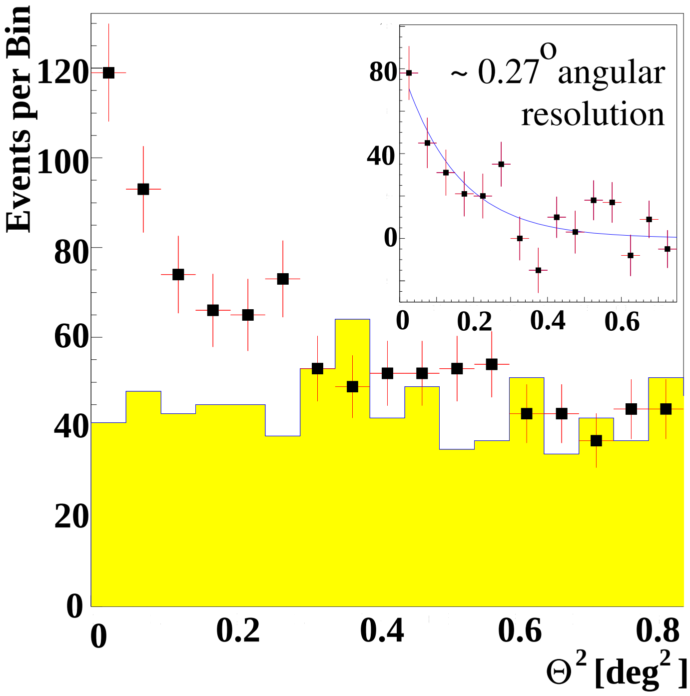

Fig. 5: Reconstruction of the position of the Crab Nebula using the relative timing of the telescopes under the assumption of a spherical lightfront and the knowledge of the shower impact point (7h observation time).

TIMING FLUCTUATIONS

Fluctuations in the arrival time of the Cherenkov light have been proposed to separate γ's from hadrons (Aharonian et al., 1997). The measured arrival times in the individual PMTs of a telescope allow to investigate this. These investigations are still in an early phase and only very preliminary results are presented here. All pixels in a telescope surviving the 2-level-tailcut are selected. Pixel signals must either exceed an amplitude threshold of 6 photoelectrons or a threshold of at least 3 photoelectrons while having a neighbour pixel exceeding the higher threshold. For the measured arrival times of the selected pixels the RMS value is calculated for each telescope. Averaging over all telescopes exceeding the trigger threshold gives the mean time fluctuation T_{RMS} of the shower. Using the data taken on the AGN Mkn501 (Hermann, 1997a) a γ-ray enriched sample of events was produced by selecting events from the source direction. By a similar procedure a sample $T_{RMS,CR}$ of pure background events is produced. The difference of these distribution represents the γ-distribution $T_{RMS,\gamma}$. Both distributions of the timing fluctuations, $T_{RMS,CR}$ and $T_{RMS,\gamma}$, are compared. The normalized distributions are shown in Figure 6. The γ-ray events are obviously shifted to lower values compared to the background, their Cherenkov light arrives with a smaller spread in time. Even with this simple approach a γ-hadron rejection is possible. Further investigations are planned to develop analysis tools to improve these results.

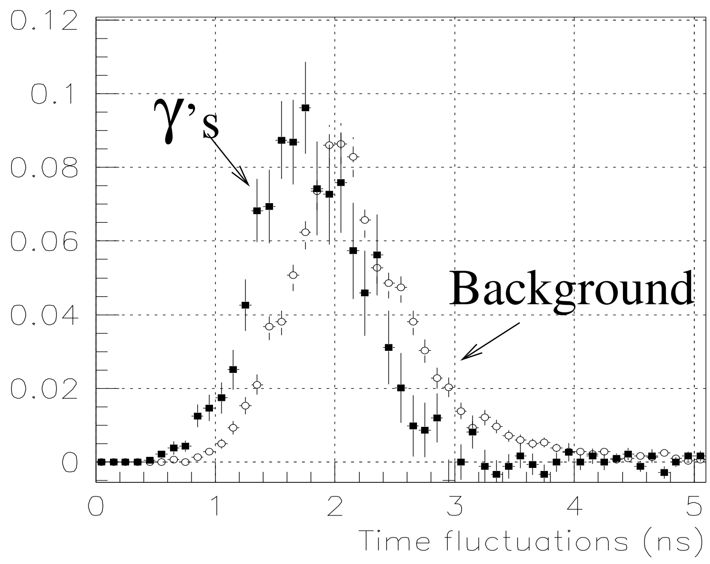

Fig. 6: Normalized distributions of the measured timing fluctuations of the image pixels averaged over the telescopes for CR-background events and for γ-showers.

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