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OBSERVATION OF MARKARIAN 501 WITH THE STEREOSCOPIC IACT SYSTEM OF THE HEGRA–COLLABORATION

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ABSTRACT

Measurements of high energetic γ–rays from the Active Galactic Nuclei Markarian 501 at energies above 500 GeV are reported. The observations have been performed with the stereoscopic system of imaging atmospheric Cherenkov telescopes (IACT) of the HEGRA–collaboration in early 1997. First results on the time variability and on the energy spectrum are presented and the analysis method is described.

INTRODUCTION

Active Galactic Nuclei (AGN) have been shown to be emitters of TeV–γ–radiation making use of the imaging atmospheric Cherenkov technique (e.g. Punch et al. 1992, Quinn et al. 1996). One of the remarkable features of these sources is the high variability of their flux. The Questions on acceleration and radiation mechanisms and on the size of the sources is closely related to the typical timescales of changes in the intensity of the high energetic radiation. Secondly the measurement of their spectra will allow to set limits on the density of the extragalactic infrared and optical background fields. High energetic γ–rays are absorbed by these low energetic photons through pair production with a cross section peaking near the threshold. Eventually this process can cause cutoffs in the observed energy spectra.

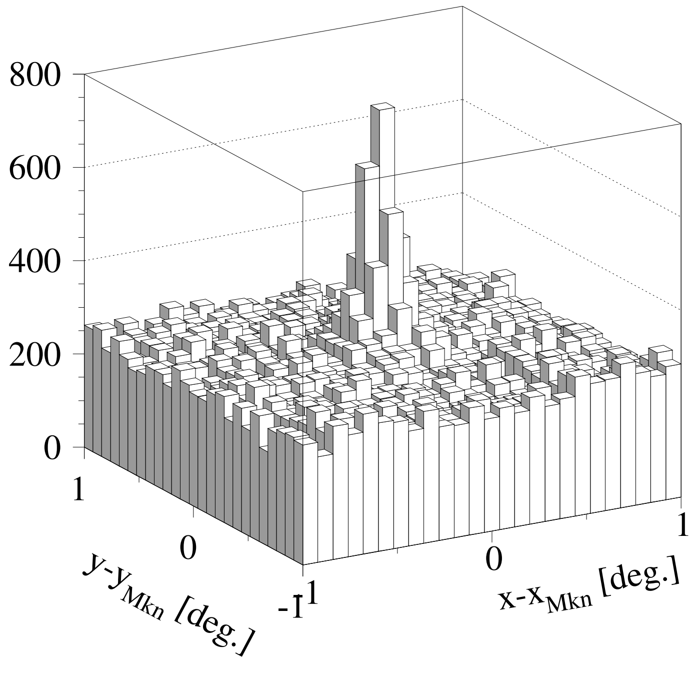

Fig. 1: Distribution of the reconstructed shower directions with respect to the position of Mkn 501 before cuts.

While the average flux levels of the AGNs Mkn 421 and Mkn 501 in the TeV energy range were during last years of the order of a few percent of that from the Crab Nebula, currently Mkn 501 is in a high state. Since March 1997 the HEGRA collaboration observes this source again with its imaging atmospheric cherenkov telescopes (see OG 10.3.17). Results from these observations with the two prototype telescopes are described in Deckers et al. (OG 4.3.2). In this report we show first results from the observations with the stereoscopic IACT–system. Presently this system consists of 4 IACTs with a mirror area of 8.5 m^2 each, equipped with 271 pixel high resolution cameras. One of the outstanding features of the stereoscopic system is the high accuracy, achieved in measuring the shower parameters on an event by event basis (Aharonian et al. 1997): an angular resolution of better than 0.1°, an accuracy of 15 m for the core location, and an energy resolution of better than 25 %. The latter is essential for the investigation of characteristic features of the energy spectra, like for example sharp cutoffs.

DATASET AND EVENT SELECTION

The dataset of the following analysis, refers to observations performed between March 16 and April 14, 1997. During this periode about 26.7 hours of ON–source time could be accumulated. The source was observed with the optical axis of the telescopes displaced by $\pm 0.5°$ with respect to the nominal source position with the sign of the displacement changing every 20 minutes (see also OG 10.3.17). For the determination of the background distributions a region located in the opposite direction with respect to the optical axis is taken. Only events are included, where at least two telescopes have a light yield of more than 40 photoelectrons and at least three pixels in the image. The description of the images follows the second moment parametrization, and the reconstruction of the shower parameters is done geometrically (see e.g. Daum et al. 1997). The resulting distribution of the reconstructed shower directions is shown in figure 1 for the selected events without any additional cuts. A strong signal above a uniformly distributed background is visible from the direction of Mkn 501. In a region with a radius of 0.22° around the source position the number of excess events amouts to 3574, corresponding to a rate of 134 events/hour, while 6779 background events are counted.

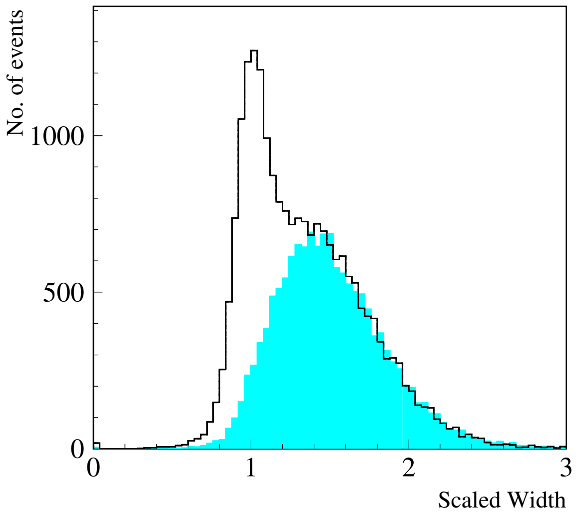

Fig. 2: Distribution of the scaled width of the events for the ON–source region and for the background (shaded histogram).

For a further analysis the signal to noise ratio can be increased by selecting γ–like showers through the shape of the images. Usually this is done by applying cuts, which are optimized for a maximum signal to noise ratio. However, with the application of such cuts, further results depend strongly on the knowledge of the selection efficiencies for γ–showers. This is usually derived from Monte Carlo simulations. In order not to depend strongly on Monte Carlo based corrections, we have choosen rather loose cuts based on the *width* of the images: the width of each image in a given event is normalized to the expected value for γ–showers, as derived from Monte Carlo simulations, dependent on the image amplitude, the zenith angle, and on the distance to the shower core. The latter can be determined accurately in the stereoscopic mode. Then the average of the normalized width values is calculated (*scaled width*) and used as discriminator. Figure 2 shows the *scaled width*–distributions for measured events

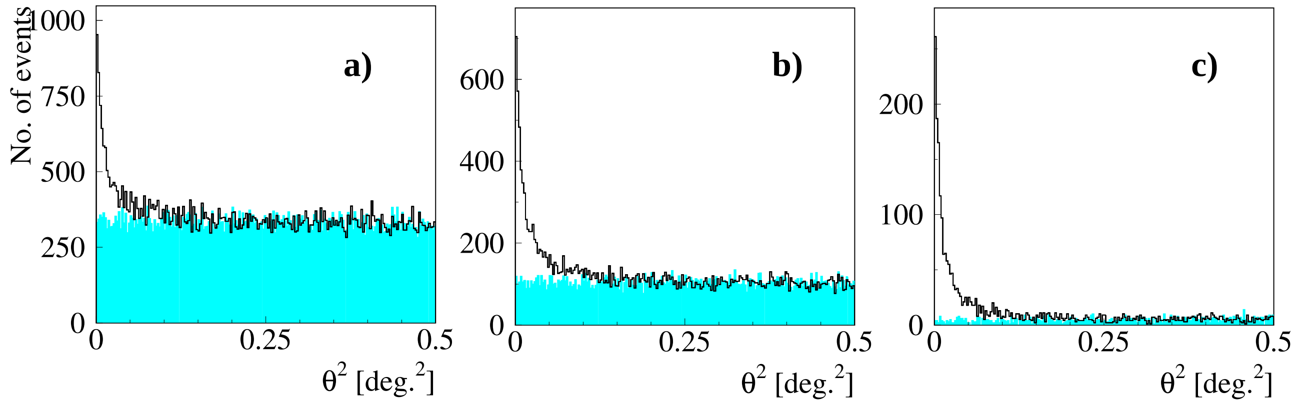

Fig. 3: Distribution $dN/d\Theta^2$ of the angle Θ in space between the the direction of the shower and the source location, before cuts (a), after a loose cut on the scaled width (b), and after tight cuts, optimized for maximum sensitivity (c). The shaded histograms represent the background.

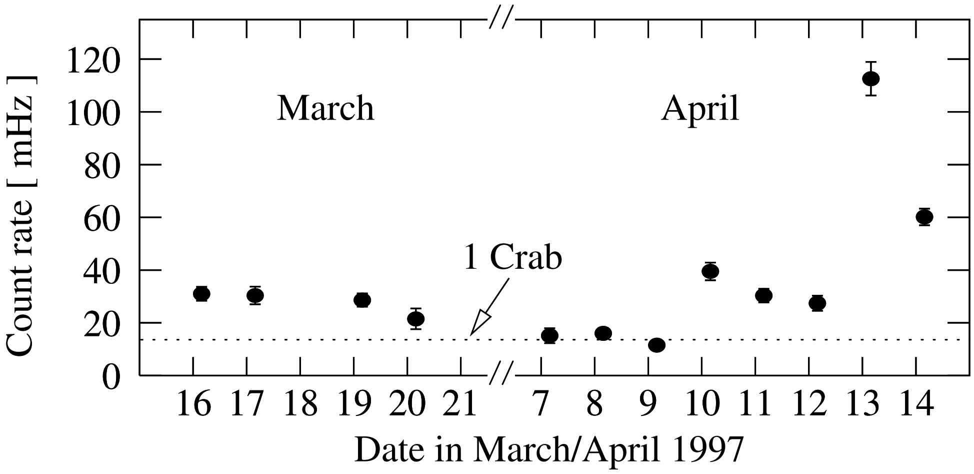

Fig. 4: Background subtracted detection rate of Mkn 501 after loose cuts on a night by night basis, averaged over observations with zenith angles below 30°.

within 0.3° radius from the source and for the background region. The distribution for the source region shows a clear excess around unity, generated by the narrow images of γ–showers. For the suppression of hadron showers only events with a *scaled width* below 1.3 are accepted. This cut reduces the background by a factor of 3, while the number of excess events is nearly unchanged. The advantage of this selection procedure is a constantly high selection efficiency for γ–showers even for high energies. Since this cut leaves the γ–distributions nearly unaffected, as could be verified on the data, systematic uncertainties are reduced to a minimum. The figures 3 (a) and (b) show the resulting angular distributions of the events before and after this cut. In addition in figure 3 (c) the nearly background free distribution after tight, for maximum sensitivity optimized cuts (Daum et al. 1997) is shown.

RESULTS

Variability

For the investigation of the variability of the source the loose cuts are applied and only events within 0.22° around the source position are considered. Then the events are grouped in different time intervals. Figure 4 shows the average excess rate versus the date, for observations with zenith angles below 30°. While the count rate decreased between March 16 and April 9 from about twice to once the typical detection rate for the Crab Nebula, a strong increase within 24 hours by a factor of about 3.5 and 4 occured on April 10 and 13, respectively. However investigations on finer time scales, down to 5 minutes for each night, did not show significant deviations from a constant flux within few hours. Nevertheless variations by a factor of 2 on such short scales cannot be excluded.

Energy Spectrum

With the knowledge of the core position, as provided by the stereoscopic method, it is possible to measure the energy on an event by event basis with an accuracy of better than 25 % and to investigate differential energy spectra. In our present analysis, for each telescope the distance to the shower core is calculated and the light yield in each image is related to an energy estimate. The correlation between the light yield, the core distance, and the energy is derived from Monte Carlo simulations. Then the energy of an event is calculated from the weighted mean value of the single estimates. In order to guarantee a proper event reconstruction, only showers with at least 3 recorded images are considered. For the event selection the loose cuts are applied and only events were counted within a radius of 0.22° from the source and from the corresponding background regions. The determination of the effective collection area is done, using an energy dependent selection on the maximum allowed distance from the shower core to the central telescope, such, that the trigger efficiency is well above 80 % (see Köhler et al. 1996). Figure 5 shows the differential energy spectrum of Mkn 501, as obtained from 4.7 hours of observations below 30° zenith angle during 4 nights in March. The energy spectrum is compatible with a pure power law in the shown energy range, and extends up to 10 TeV. The average integral flux above 1 TeV amounts to $2.25\pm0.2\cdot10^{-11}/cm^2s$ with a differential spectral index of 2.49 ± 0.11. For comparision the same method has been applied to 8.7 hours of observations on the Crab Nebula. The corresponding values amount to $1.0\pm0.1\cdot10^{-11}/cm^2s$ and 2.71 ± 0.17, respectively. The errors given here are statistical only. By variing different parameters in the fitting and reconstruction procedure, an upper limit on the systematic errors, which arises from the analysis method, could be determined to be 25 % for the flux and 0.25 for the spectral index. An additional error of about 36 % on the flux is due a 20 % uncertainty of the absolut energy scale.

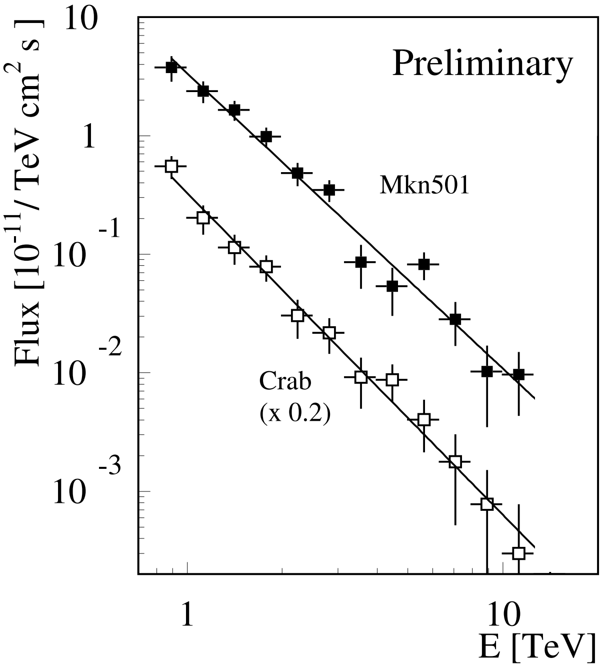

Fig. 5: Differential energy spectrum of γ–rays from Mkn 501 and from the Crab Nebula. Errors are statistical only.

SUMMARY AND OUTLOOK

Observations of Mkn 501 during a high state of activity show strong variability of the flux on time scales of a day. The differential energy spectrum has been measured on an event by event basis, taking advantage of the stereoscopic approach. The shape of the spectrum of Mkn 501 is comparable to that of the Crab Nebula and no indication for a cutoff up to energies of about 10 TeV could be found. Meanwhile (May 1997) more than 18000 γ–events were accumulated. This dataset will enable a much more detailed analysis of systematic effects. Furthermore the spectrum will be investigated at energies above 10 TeV.

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