Recent TeV Gamma Ray Observations from AGNs with the HEGRA System of Imaging Atmospheric Cherenkov Telescopes

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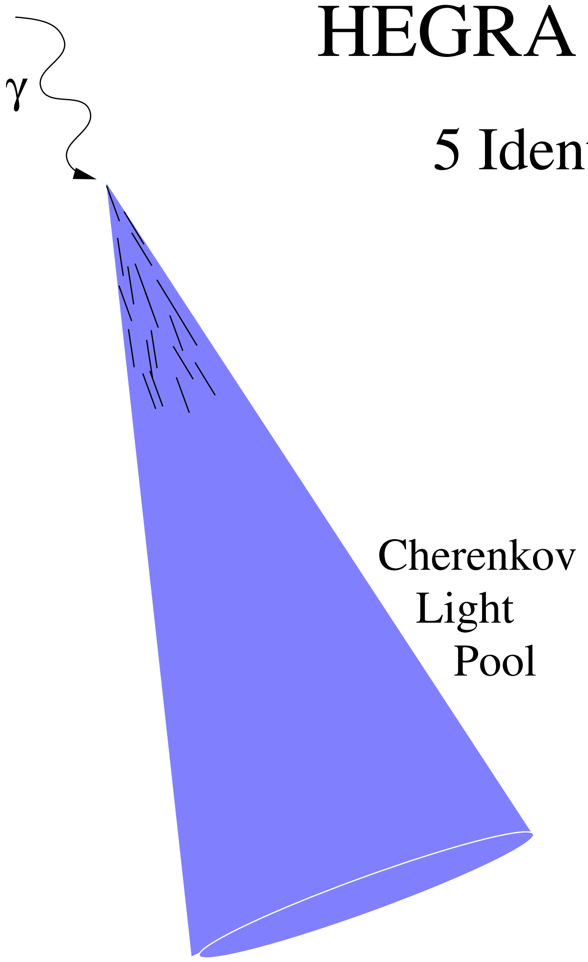
Abstract

The HEGRA system of Imaging Atmospheric Cherenkov Telescopes on the Canary Island La Palma is almost completed. The performance of the system recently has been studied using the TeV gamma radiation of the Crab Nebula. The first results are very encouraging and demonstrate the high potential of the stereoscopic approach. The system provides an energy threshold of $0.5\,\mathrm{TeV}$, an angular resolution of 0.1°, and sensitivity to point sources at the level of 0.3 Crab for observation time 1 h. Detection of such strong sources is almost background free.
The system has been used for detection of VHE emission from 2 nearby BL Lac objects – Mkn 501, and Mkn 421. The first source is in very high state since March 1997. The average count rate ($\sim 100\,\gamma$'s per 1 h) is about twice the count rate of γ-rays from the Crab, but during some nights the flux has been observed at the level of up to 10 Crab. This allows to study the time variation of the γ-ray flux on time scales down to 5 min or even less. The differential average spectrum of the source, measured between 1 and 10 TeV, shows a power-law behaviour with spectral index ≈ 2.5. The average flux of Mkn 421 during the same period of observations is lower than Mkn 501, however it also shows dramatic time variations.

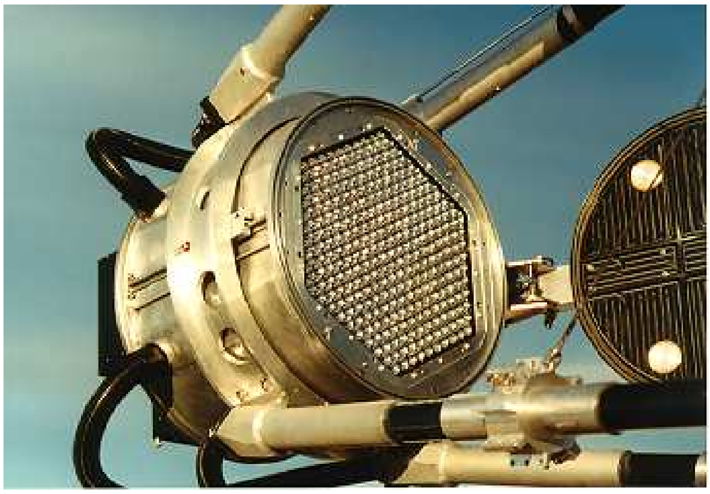
Poster presented at JENAM-97, 6th European and 3rd Hellenic Astronomical Society Conference, July 2–5, 1997

HEGRA IACT SYSTEM

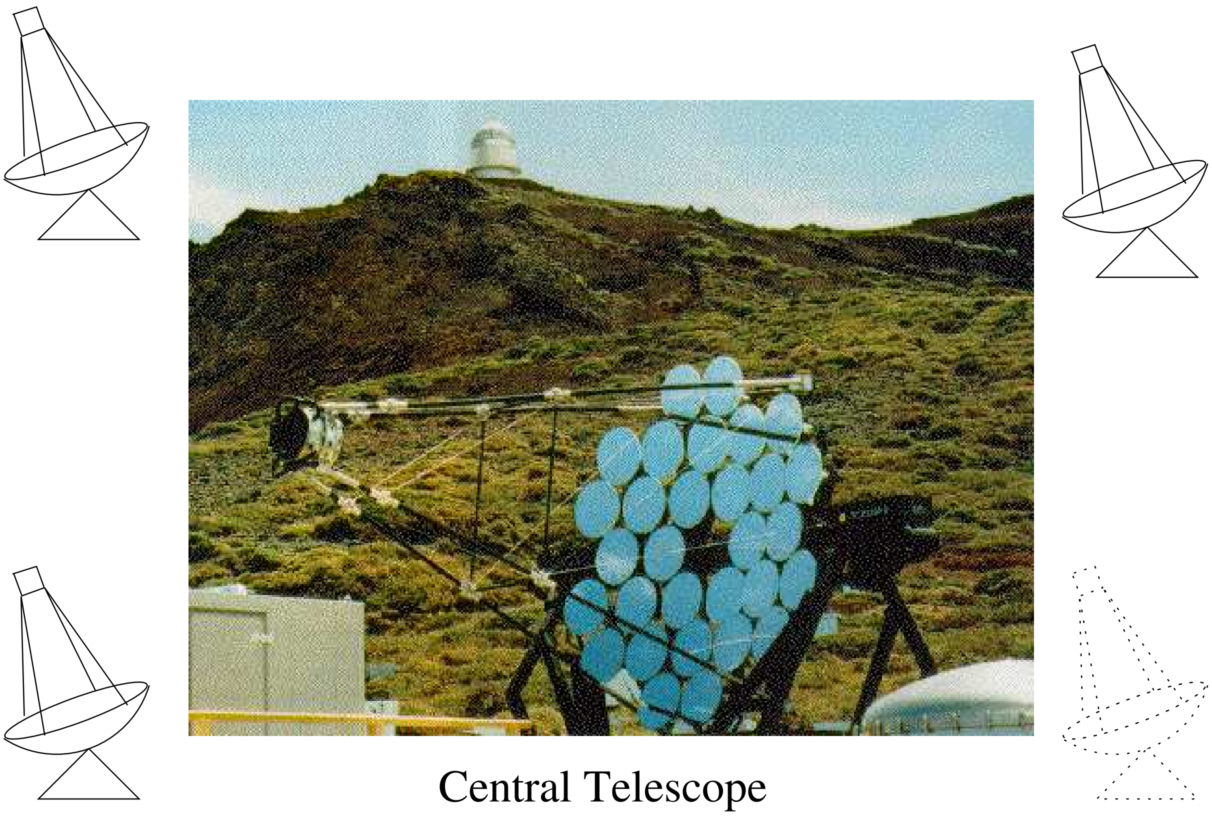
5 Identical Telescopes



Observatorio Roque de los Muchachos
Canary Island La Palma
28.75° N, 17.89° W



Camera



Central Telescope

SYSTEM DETECTOR

- **Reflector** 30 (front aluminized & quartz coated) 60 cm diameter spherical glass mirrors; $\mathrm{S_0} = 8.5\,\mathrm{m}^2$; $\mathrm{f} = 5\,\mathrm{m}$; $\sigma \approx 3$ arcmin
- **Mount** alt-azimuth; pointing accuracy ≈ 20 arcsec
- **Camera** close-packed cluster of 271 PMTs (EMI 9083) faced with hollow hexagonal light guides; pixel size = $0.25°$, FoV $\simeq 4.3°$
- **Electronics** in VME standard; 120 MHz FADCs
- **Triggers**

local	– '2 pixels from 271' ($\mathrm{q_{min}} \sim 10\,\mathrm{ph.-e.}$)	(<July '97)
	– '2 neighboured pixels from 271' ($\mathrm{q_{min}} \sim 8\,\mathrm{ph.-e.}$)	(>July '97)
system	– 'n from 4 (later 5) IACTs' ($\mathrm{n} \geq 2$)	

PERFORMANCE OF THE HEGRA 5-IACT SYSTEM

- **Energy Threshold:** $\mathrm{E_{th}} \sim 500\,\mathrm{GeV}$
- **Angular Resolution:** $\delta\theta < 0.1°$
- **Energy Resolution:** $\delta\mathrm{E/E} \leq 25\%$
- **Flux Sensitivities:**

Point Sources:

SURVEY mode: 'background-free' ~ 10 γ's in effective FoV=$1.5° \times 1.5°$

$\mathrm{J_{min}} = 0.2\,\mathrm{Crab}\,(\mathrm{t}/1\,\mathrm{h})^{-1}$ for $\mathrm{t} \leq 1\mathrm{h}$

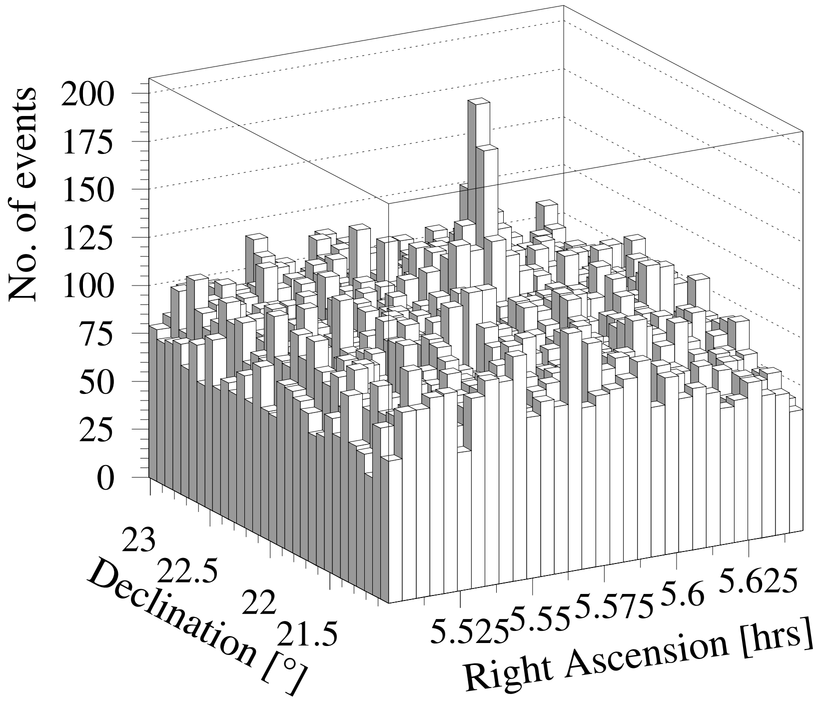
TARGET mode: '5σ' detection

$\mathrm{J_{min}} = 0.04\,\mathrm{Crab}\,(\mathrm{t}/25\,\mathrm{h})^{-1/2}$ for $\mathrm{t} \geq 1\mathrm{h}$

Extended Sources: $\mathrm{J_{min}} = 0.15\,\mathrm{Crab}\,(\phi/1°)\,(\mathrm{t}/100\,\mathrm{h})^{-1/2}$

Transient Sources: Fluence $\simeq 3 \times 10^{-8}\,\mathrm{erg/cm^2}$ for $\Delta\mathrm{t} \leq 1\,\mathrm{h}$

CRAB AS CALIBRATION SOURCE



Source:

Crab Nebula

Reconstructed Source Position:

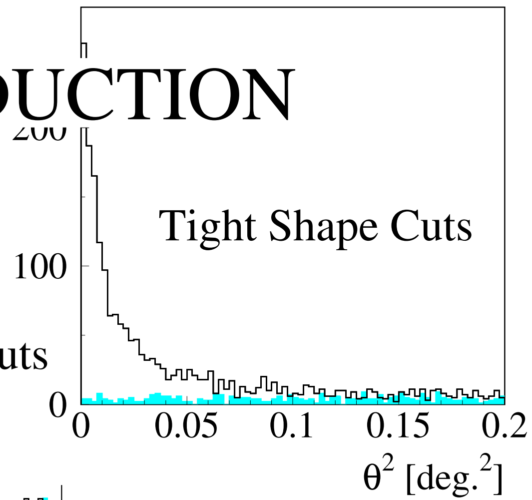
Ra: 5.5720 hrs

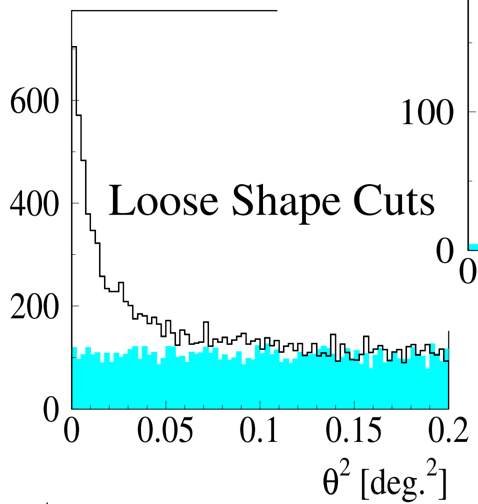
Dec: 22.020°

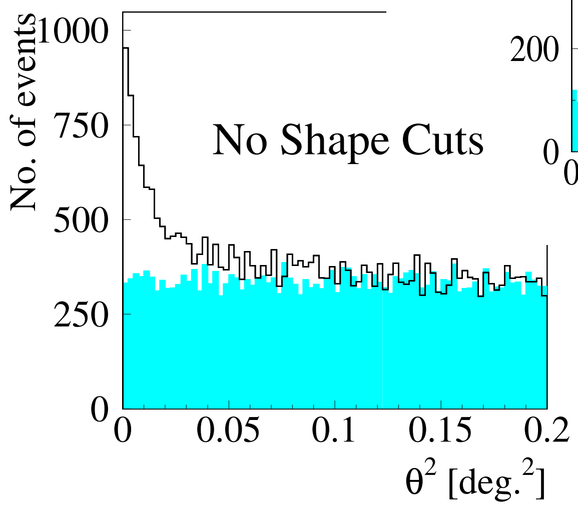
Distance to Radio Source:

0.010° ± 0.010°

BACKGROUND REDUCTION







θ = Distance to Source Position

MKN 501

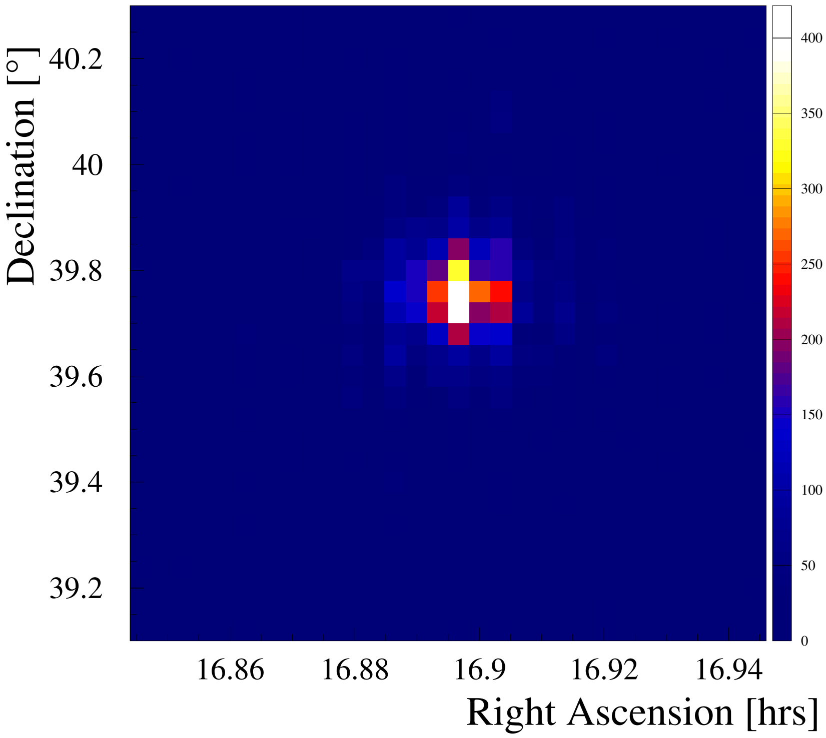
Reconstructed Source Position:

Ra: 16.8970 hrs

Dec: 39.757°

Distance to Radio/X-ray Source:

0.011° ± 0.010°



PRELIMINARY

MKN 421

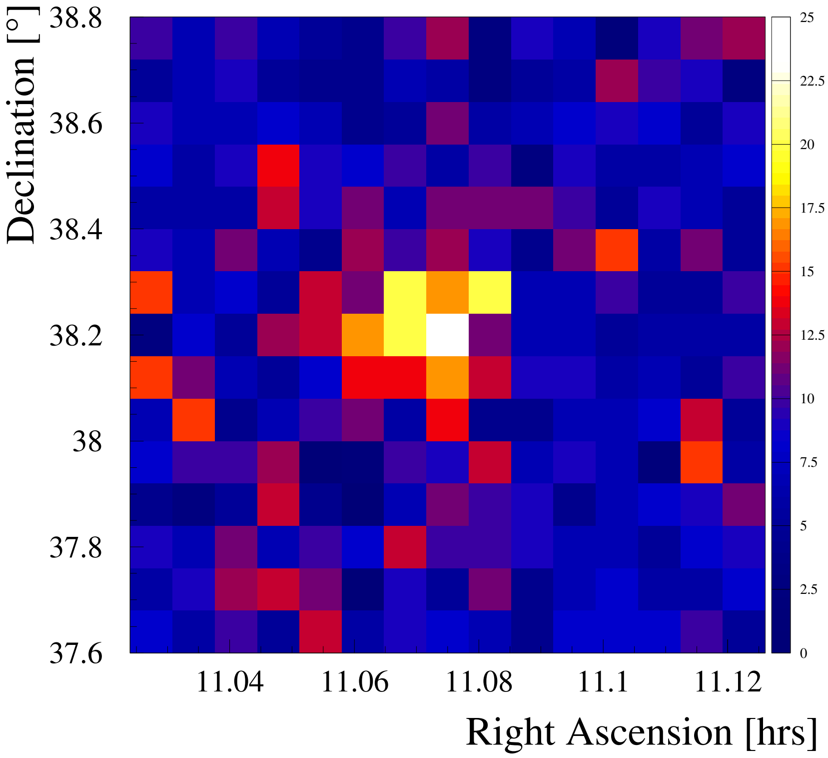
Reconstructed Source Position:

Ra: 11.0713 hrs

Dec: 38.217°

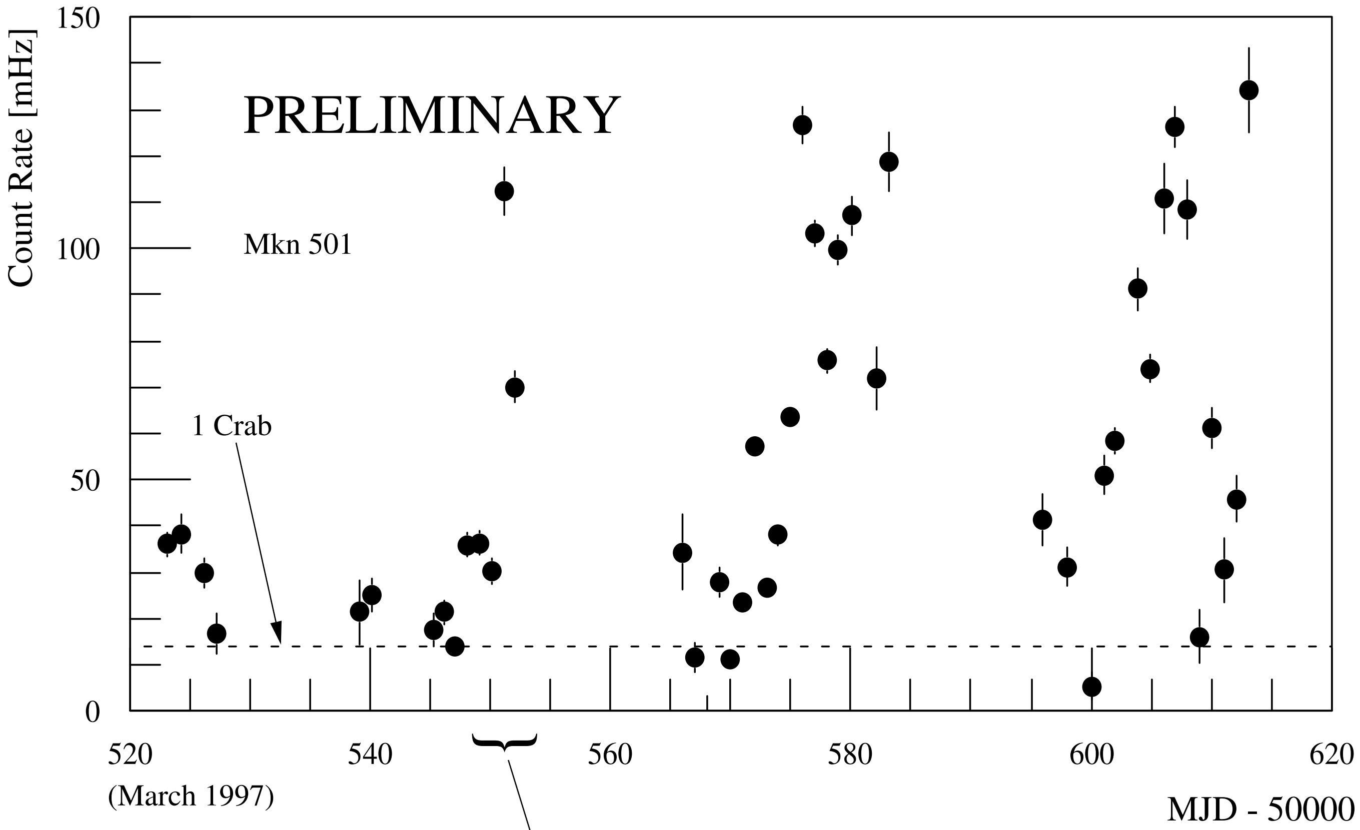
Distance to X-ray Source:

0.009° ± 0.010°

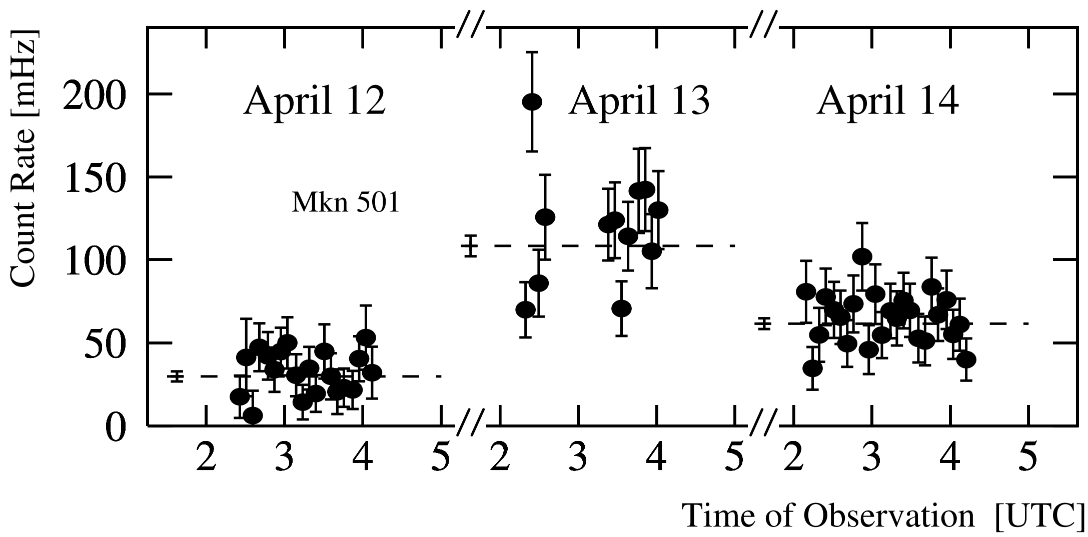


TIME VARIABILITY

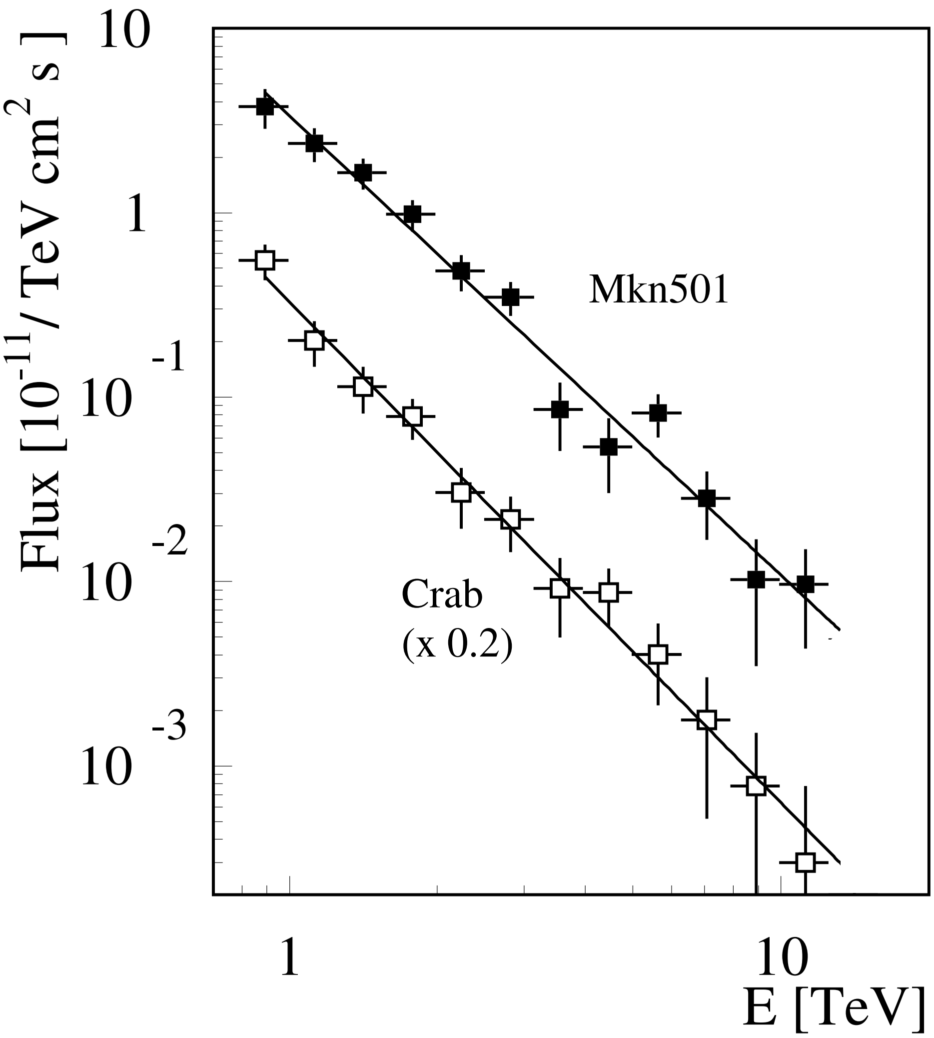
Count Rate on a Night by Night Basis



Count Rate on a Short Time Scale (5 min.)



ENERGY SPECTRUM



Differential

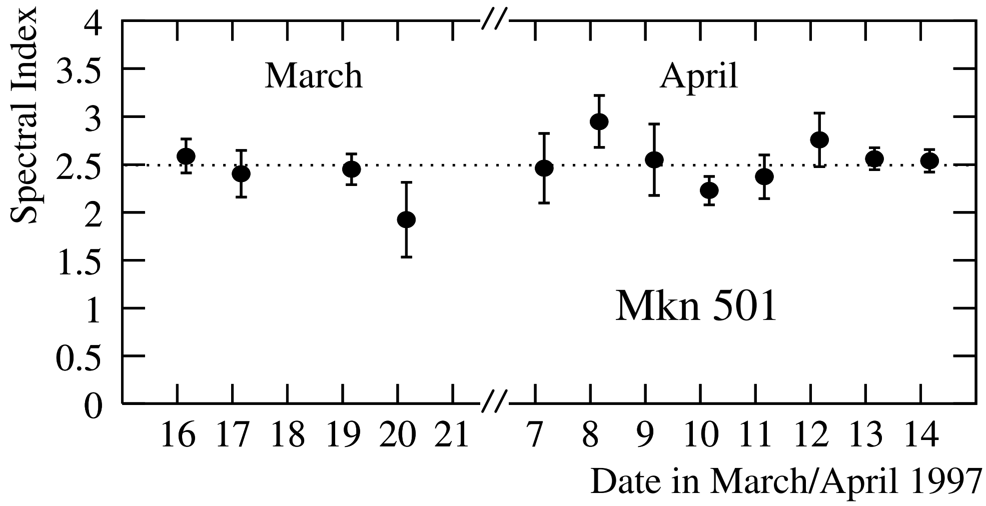
Spectral Index

Mkn 501:

$2.49 \pm 0.11 \pm 0.25$

Crab Nebula:

$2.71 \pm 0.17 \pm 0.25$



Spectral Index on a Night by Night Basis (Statistical Errors only)

1	2
3	4
5	6
7	8

• **2,3** The HEGRA Collaboration has installed 6 Imaging Atmospheric Cherenkov Telescopes, one prototype and 5 identical system telescopes. Four system telescopes are running in coincident stereoscopic mode since Dec. 1996.
Cherenkov telescopes use the Cherenkov light emitted by the secondary particles in an extended air shower to reconstruct direction, energy and nature (γ-ray/charged cosmic ray) of the primary particle.

• **4 upper figure** The Crab Nebula which is known as a steady emitter of TeV γ-rays was used to test the performance of the detector.
Even without background suppression, a clear signal arises in less than 12 hrs. of observation time. The stereoscopic reconstruction provides an angular resolution of 0.1° for each γ-ray induced event.

• **4 lower figure** Charged cosmic rays which make an uniform background of 99.9% of the total rate can be discriminated using the shape of the 3-dimensionally reconstructed air shower.
Loose image cuts reduce the background by a factor 3, while the number of γ-ray events remains almost unchanged. At the expense of signal statistics, the background can be almost completely eliminated (tight cuts).

• **5** Two BL Lac objects, Markarian 501 and Markarian 421, were detected as TeV γ-ray emitters.
The source position is determined from the two-dimensional distribution of the reconstructed shower directions, after application of the loose cuts. The accuracy achieved is about 0.01° (systematic error).

• **6** The radiation from Mkn 501 was found to be highly variable in time.
The time scales imply severe limitations on the combination of the size of the source and the Doppler factor in the relativistic jets.

• **6 uppper figure** The average daily excess count rate of Mkn 501 is shown.
We required that at least two telescopes triggered, and applied a loose angular cut of $\theta = 0.22^\circ$ as well as a loose shape cut of images. The zenith angle ranges up to 45°, and the count rate was corrected for slightly fluctuating weather conditions using the cosmic ray rate. No correction was applied for zenith angle dependencies.

• **6 lower figure** For the high statistics Mkn 501 data a time binning of 5 min. could be applied.
Additionally the zenith angle was restricted to less than 30° to be (almost) free of zenith angle dependencies.

• **7 upper figure** The energy spectrum of Mkn 501 is shown in comparison to the Crab Nebula.
The HEGRA IACT system with its energy resolution of 25% allows detailed studies of the spectrum of γ-ray sources. To derive the flux F(E) only events where at least three telescopes triggered were used, to guarantee good stereoscopic reconstruction. In the determination of spectra, only runs with zenith angles below 30° were included. The resulting Mkn 501 fluxes for the first four days of observation are shown together with the spectrum of the Crab Nebula analyzed in identical fashion. Both spectra are compatible with pure power laws up to at least 10 TeV.

• **7 lower figure** The temporal behaviour of the Mkn 501 spectral index is shown.
The spectral index is determined on a day by day basis and compared to the average value.