The HEGRA Stereoscopic System of Imaging Cherenkov Telescopes

presented by

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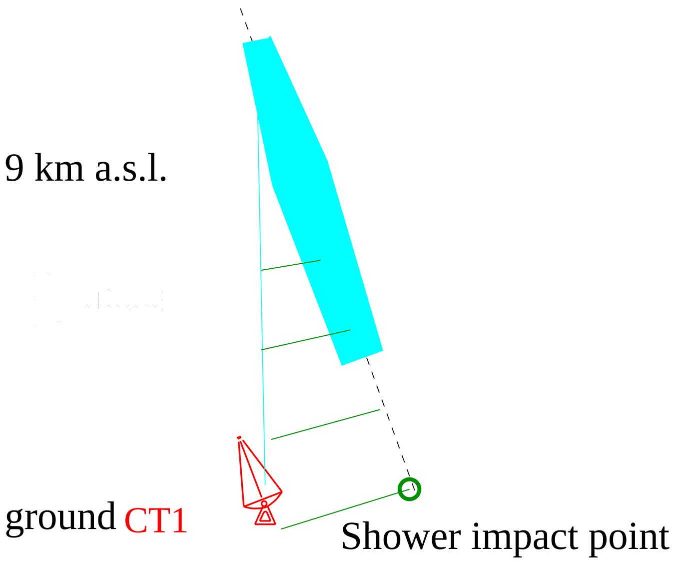
(HEGRA–Collaboration)

Overview:

1) Principle of Stereo Imaging
2) Description of the HEGRA System
3) Performance of the HEGRA System
4) Further Studies (optional)
5) Observations
6) Conclusions and Outlook

The Kruger National Park Workshop on
TeV Gamma-Ray Astrophysics, 1997

1) Principle of Stereo Imaging



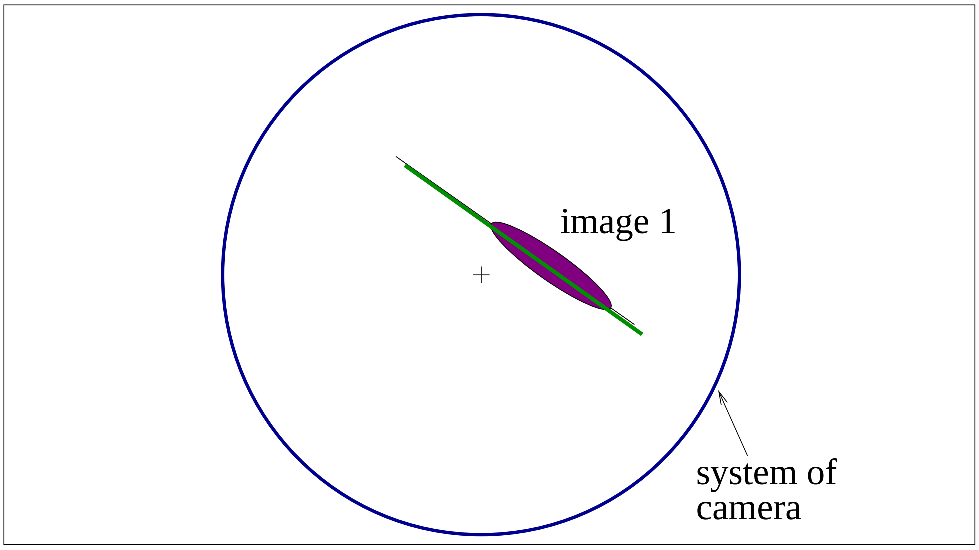
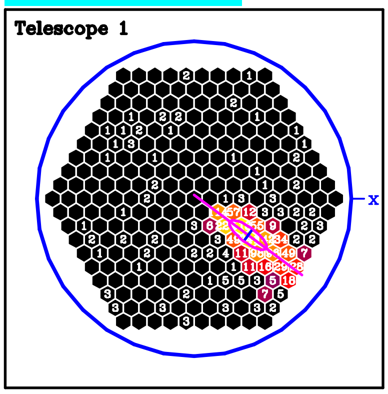
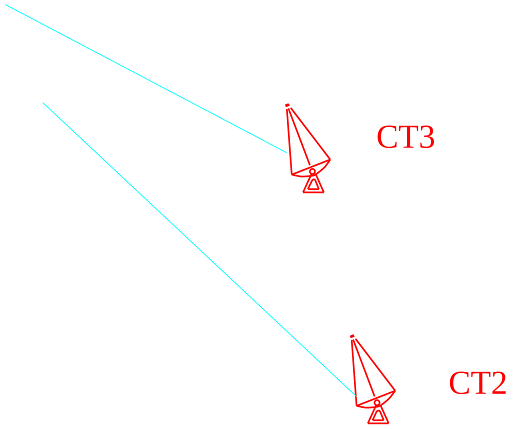
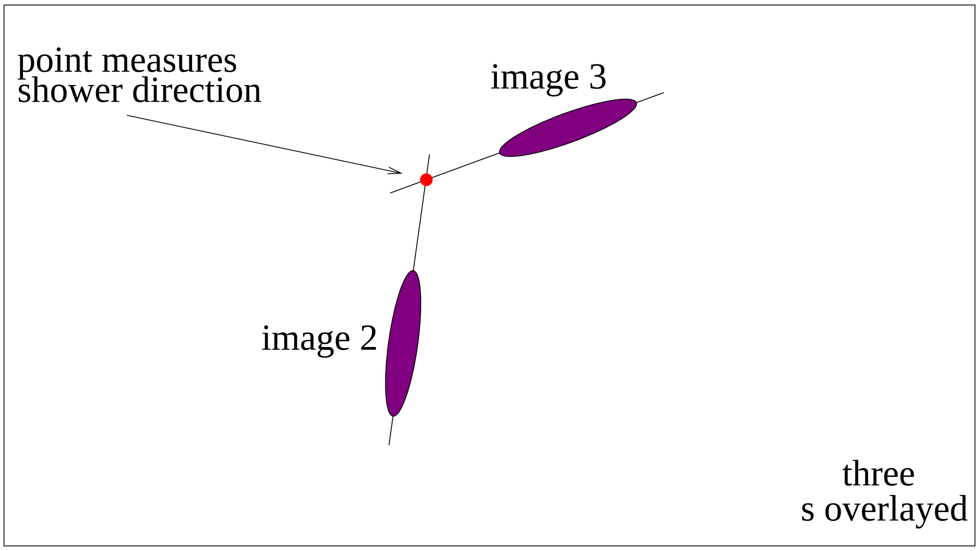


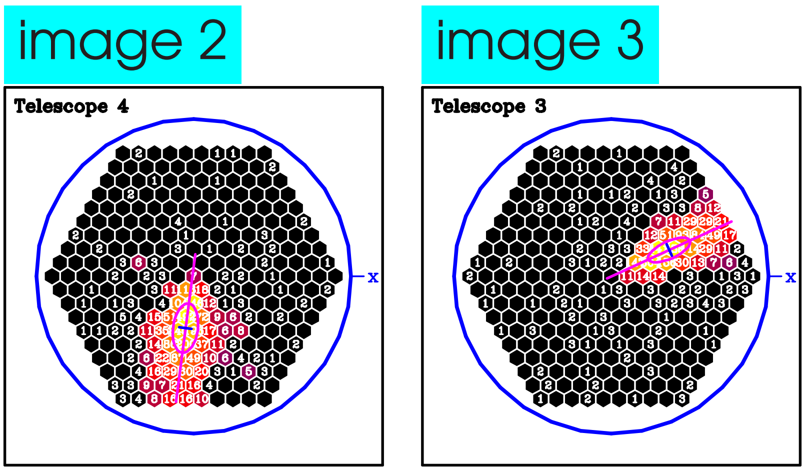
image 1



1) Principle of Stereo Imaging



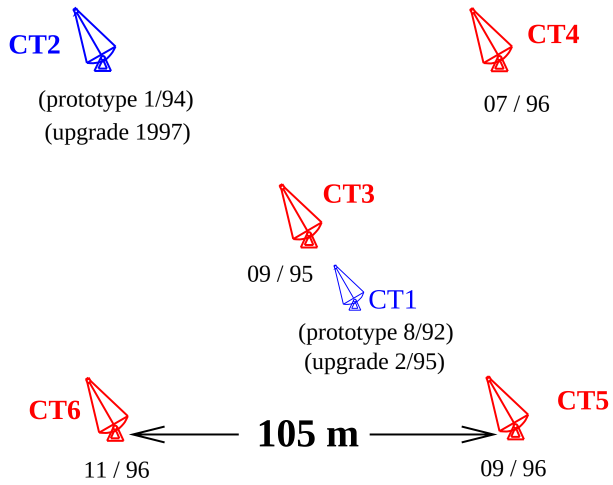


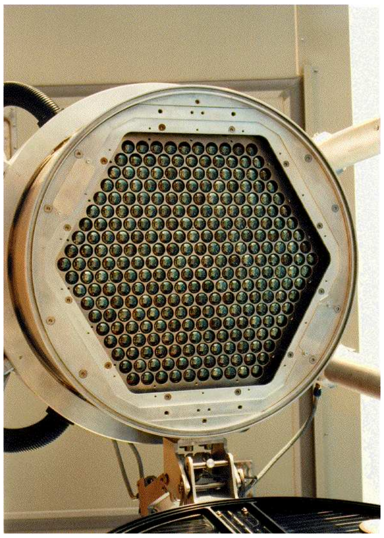


2) Description of the HEGRA CT System

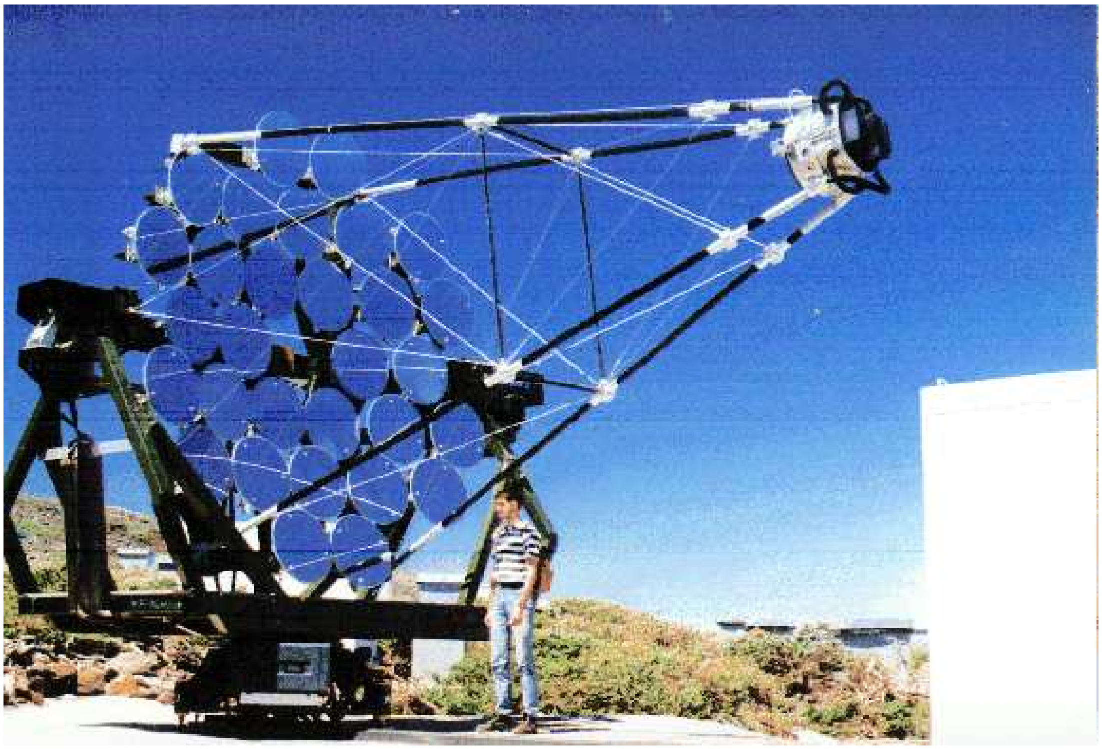
4(5) identical telescopes CT2-6;

1 central trigger station; 1 main computer for control and online event building.





PMT Camera



central telescope CT3

- **Location:** Canary Island of La Palma
  28.75^oN , 17.89^oW , 2200m a.s.l.

- **Telescopes:**

  Reflector: 8.5 m^2 mirror area;
  focal length ≈5 m; $\sigma \approx 3$ arcmin

  Mount: alt-azimuth; position control 1.2 arcmin;
  stepping motors 1.2 arcsec per step.

  Camera: closed packed cluster of 271 PMTs;
  faced with hollow hexagonal light guides;
  pixel size = 0.25^o, FoV $\approx 4.3^o$

  Electronics: placed nearby in a hut;
  VME standard; 120 MHz 8-bit FADC
  with 34μsec ring buffer in hardware;

  Trigger: 2/271 (>10mV≈ 8 p.e.)
  2/271 neighboured pixels (>8mV≈7p.e.) since July '97

- **Central Trigger Station:**

  System Trigger: 2/4 telescopes (70ns coincidence gate);
  cumputer controlled delays of telescope triggers;
  distribute system trigger and event number tag;

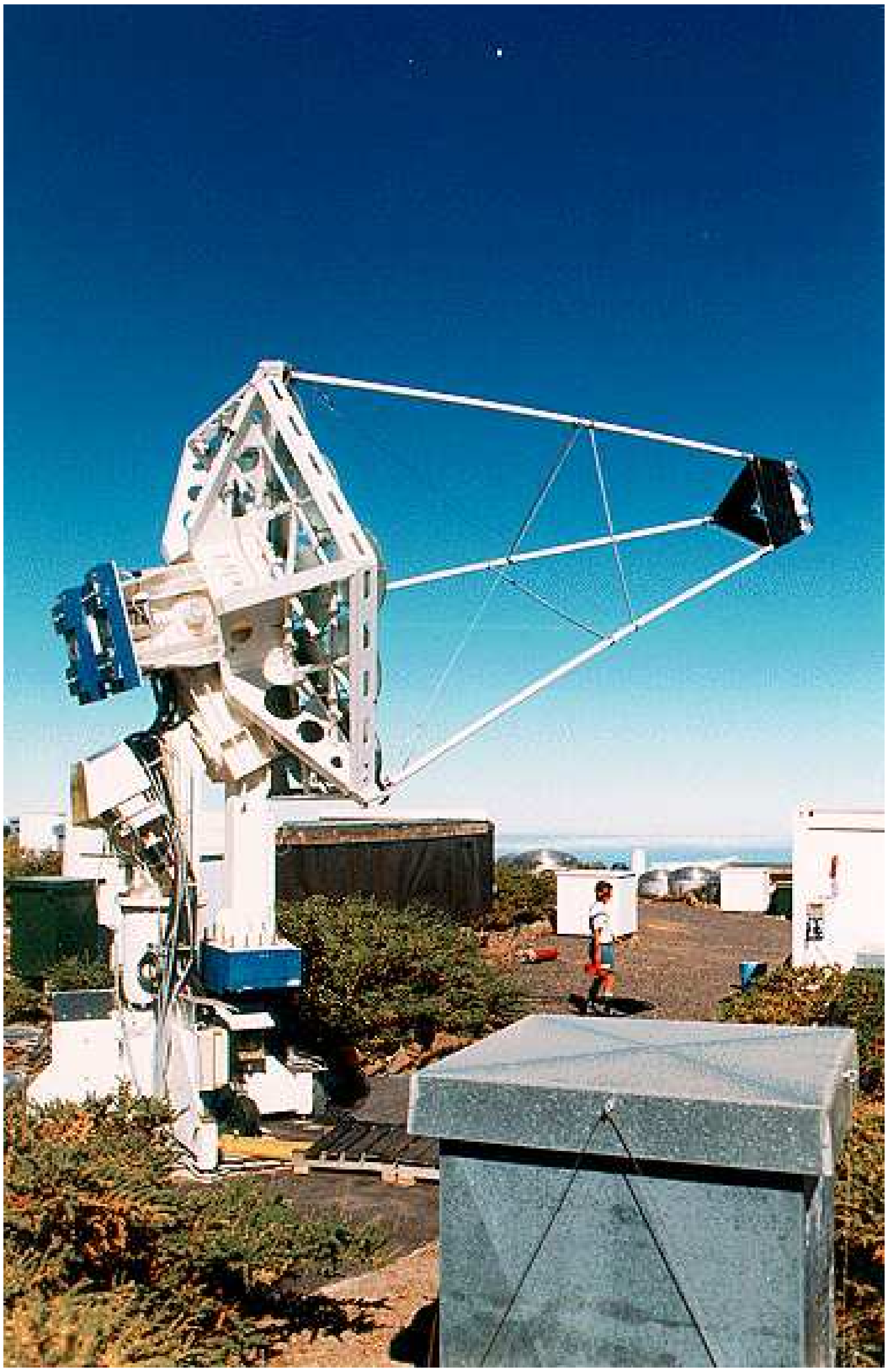
- **Control:**

  Front End: Motorola 86040 CPUs placed inside VME electronics; LynxOS real time system, interrupt handling, multi threading;

  Main computer: 90 Pentium PC; Linux System;
  online event building; graphical user interface;

  Software: C source code; Tk/Tcl based mouse menus;
  VOGL based graphical display; shell scripts for control;

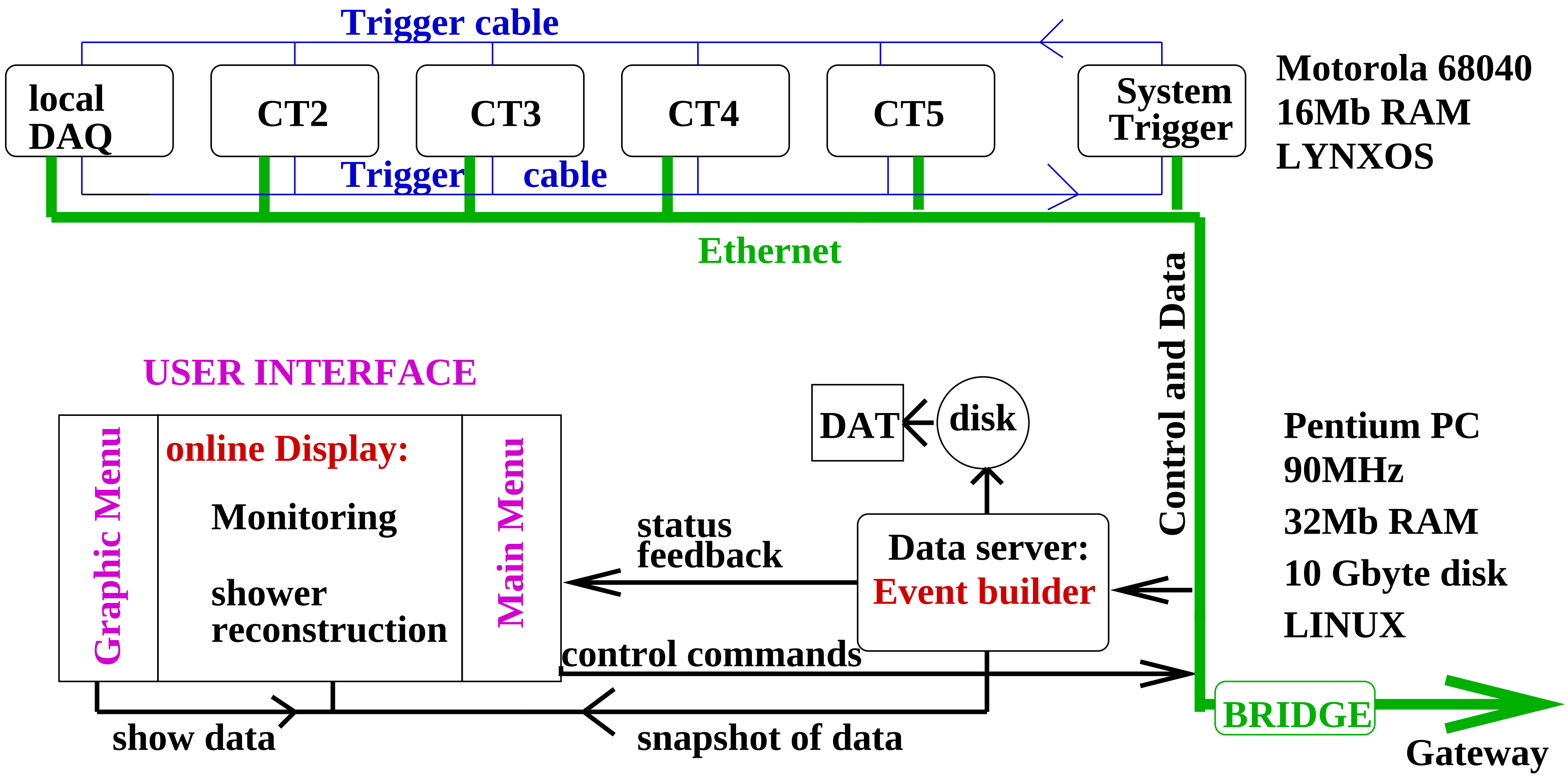
CT1 Prototype Telescope



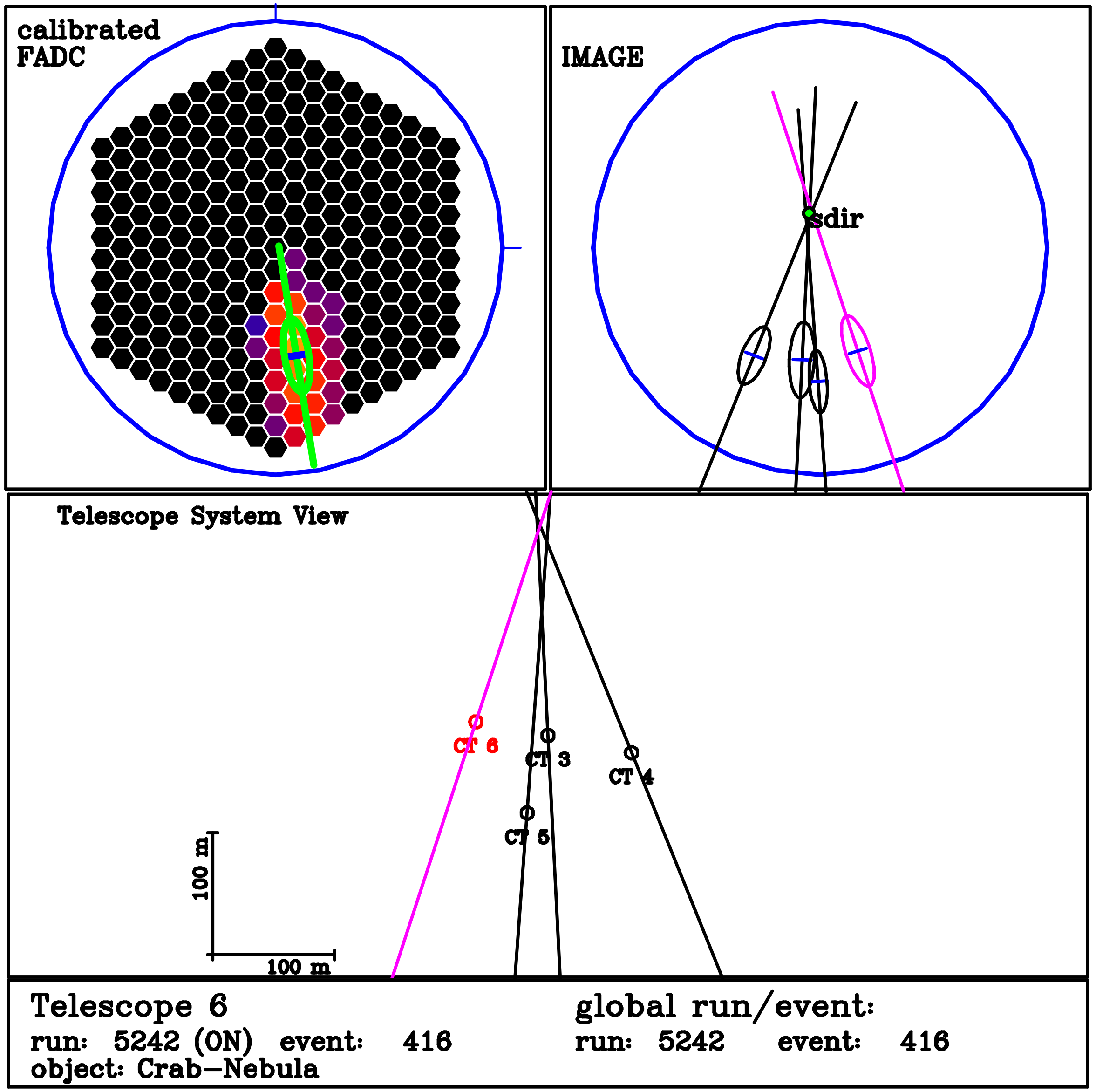
Since 1992 in operation.

Recent Mkn501, Mkn421 and Crab Nebula detections.

Architecture of the DAQ of a 5 CT System



Online Terminal:Reconstructed Air Shower Event



Upper left:

Cherenkov light image seen by a telescope's camera

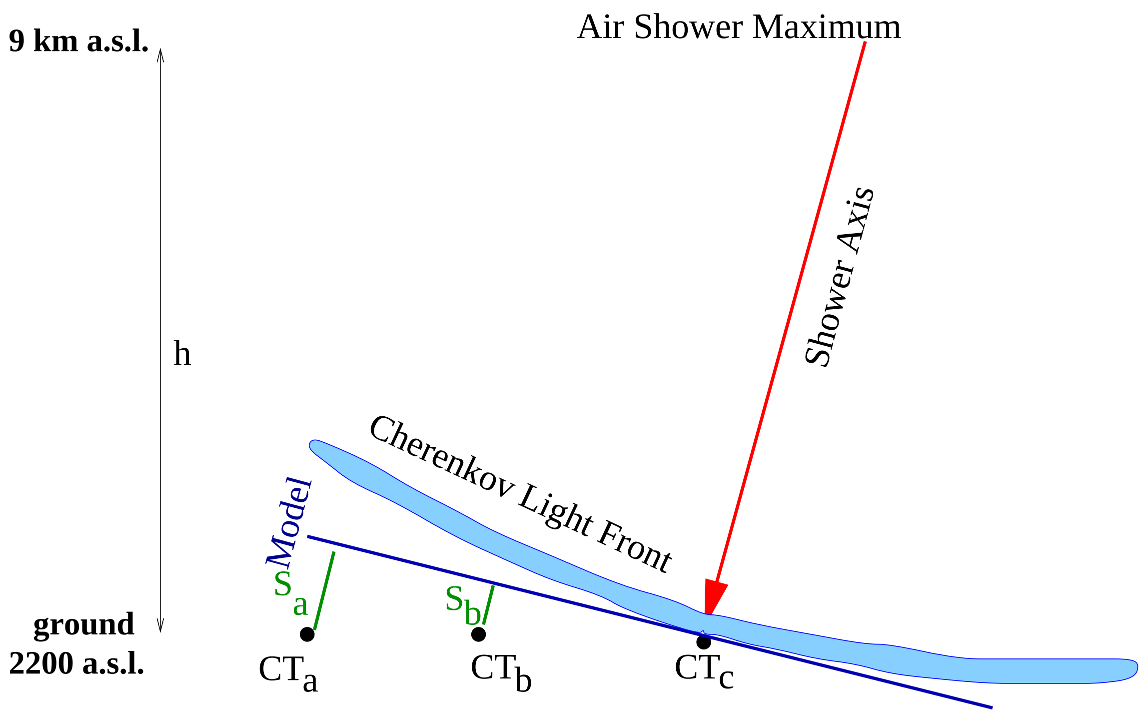
Upper right:

Overlay of all 4 images recorded by the telescopes. The intersection point of the long axis of the ellipses is a measure of the air shower's direction. The unambigous reconstruction is based on the stereoscopic principle. Online reconstruction of a system event is made possible by online event building.

Lower part:

Reconstruction of the shower core

System Trigger and Timing



Online Implementation of System Trigger:

- Flat light front model

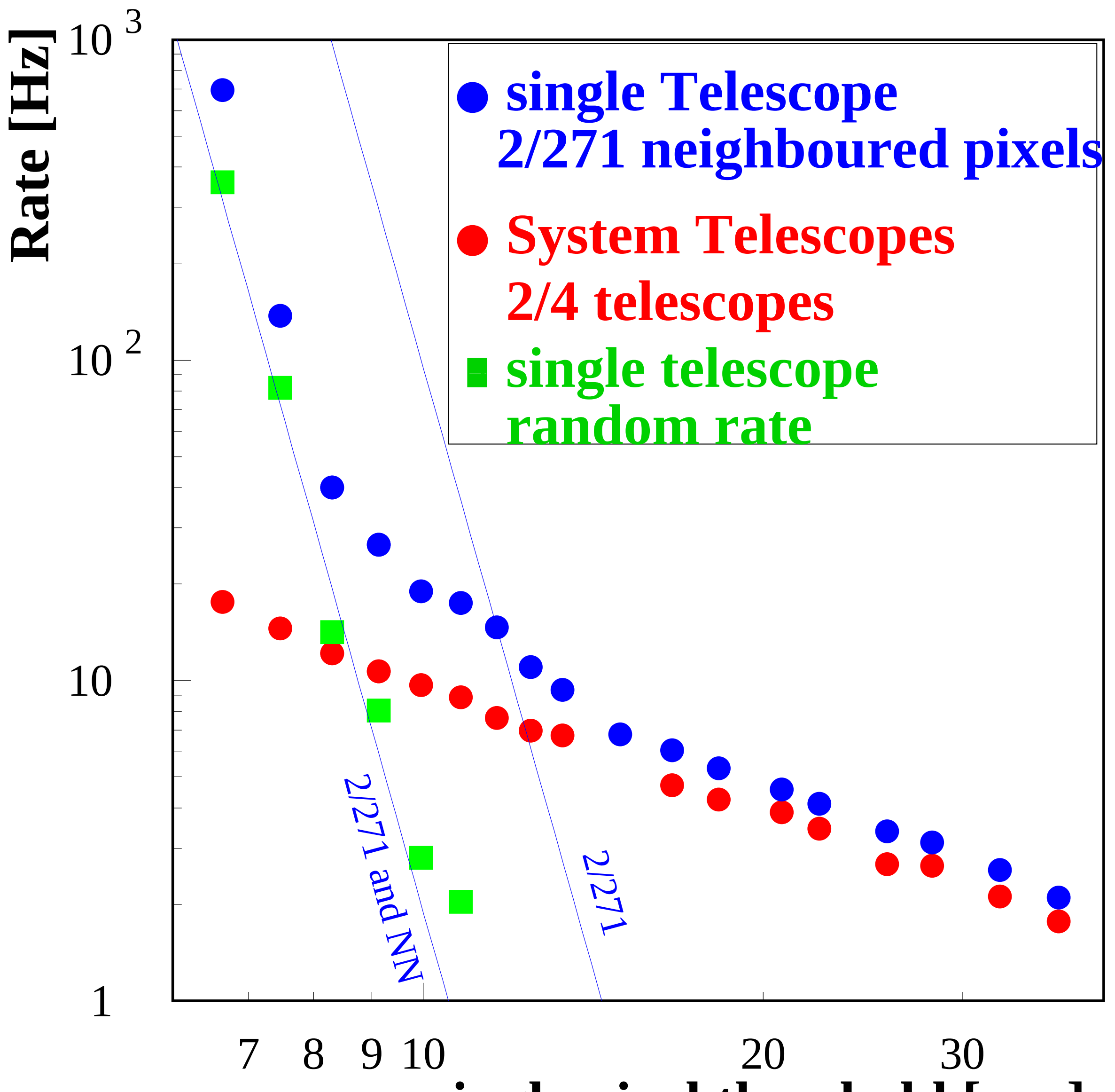
$\rightarrow$ Timing independant of shower impact point

- ALT-AZM depending computer controlled delays
  of single telescope trigger

Offline Timing Analysis:

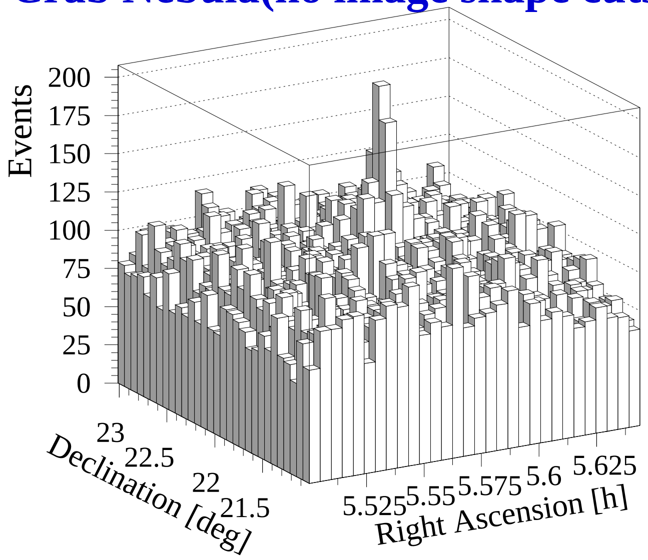
- Reconstruction of shower direction
  core location from normal imaging

Measured Trigger Rates of HEGRA CT3 and System of Telescopes

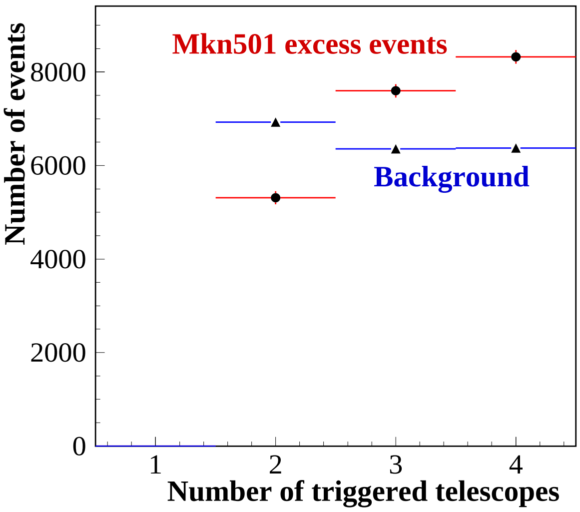


3) Performance of the HEGRA IACT System

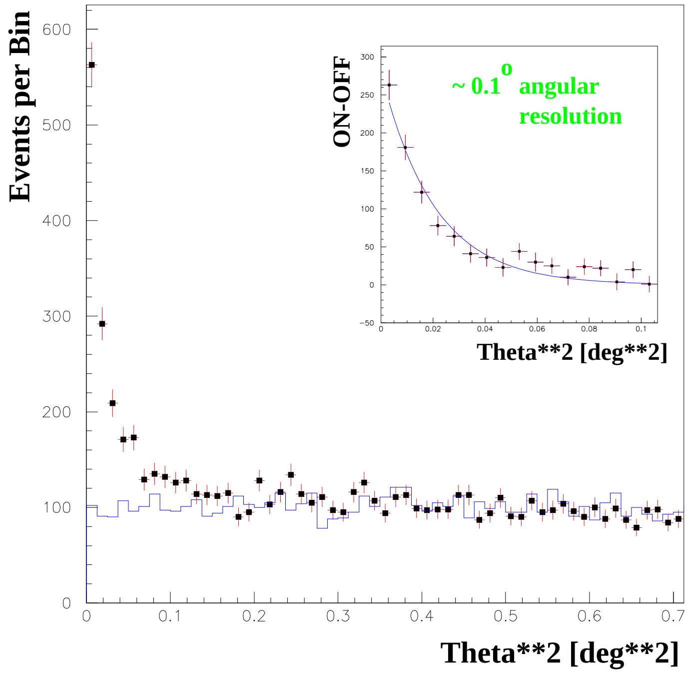
Crab Nebula(no image shape cuts)



Telescope Coincidences



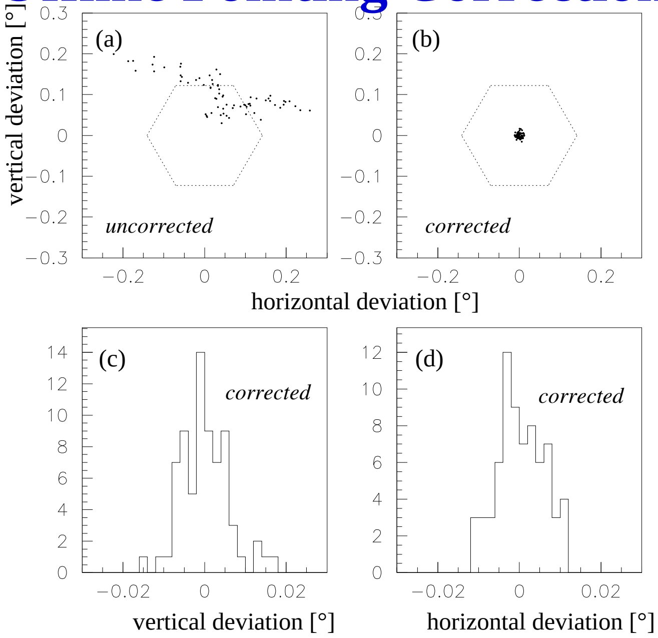
Crab Nebula (11.7 hours ON)



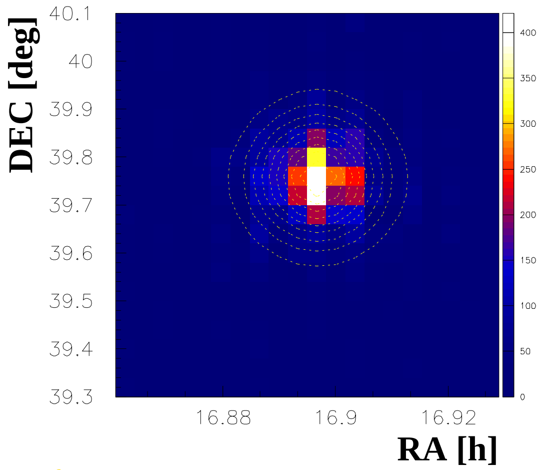
- $\approx 6\sigma/\sqrt{h}$ for a Crab Flux level;
- $\leq 0.1^o$ angular resolution of single γ;
- 0.01^o resolution of point source location;

Determination of Source Location

Offline Pointing Correction



Mkn 501 63hours



2d Gaussian 10%-90%

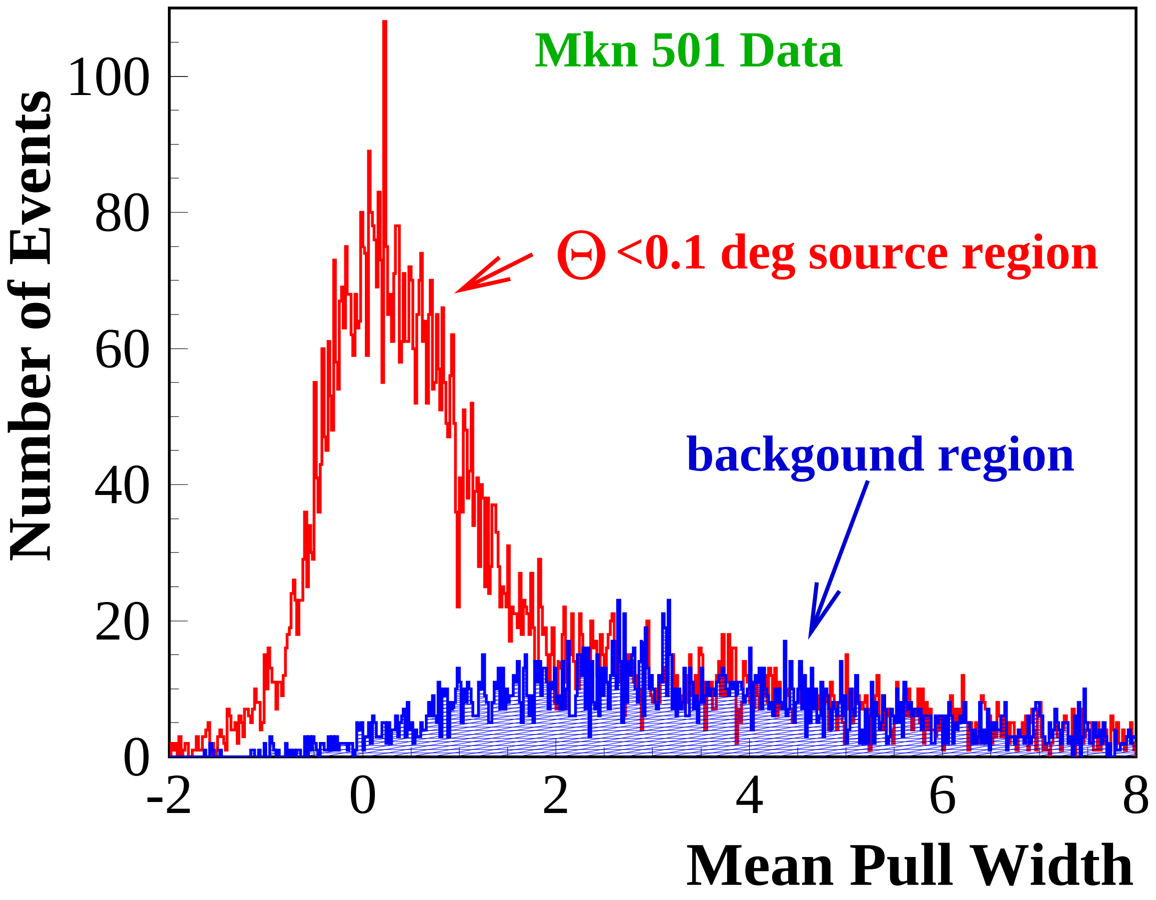
$\rightarrow$ 0.08^o Gaussian resolution

0.007^o $\pm$ 0.007^o distance to radio source in RA,DEC

confirmed with Crab (normal) and Mkn501 (reverse)

Gamma/Hadron Separation

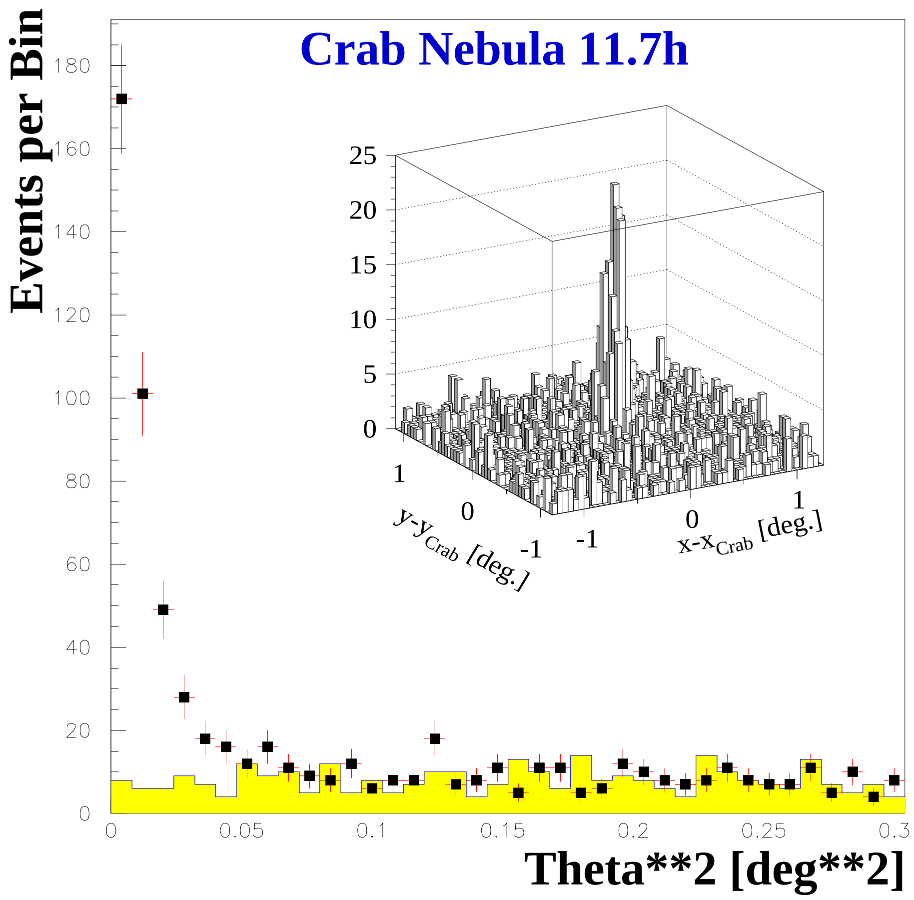
- Measure 2nd Moments of Image Amplitudes
- MC Simulation:
  Mean and RMS of Width and Length as
  f(amplitude,distance telescope-core)
  for Gammas and Hadrons 2d binning
- Pull=(Measured Value-Mean MC)/(RMS MC)
- Scaled=(Measured Value)/(Mean MC)



tight cuts: $\approx$40% γ efficiency,
$\approx$1% hadron efficiency

loose cuts: $\approx$95% γ efficiency,
$\approx$30% hadron efficiency

Background "free" TeV γ-ray detection



width and lenght=f(core location,amplitude,altitude)

$\Theta < 0.13^o$

$\rightarrow$ 23 excess events per hour

1.2 background events per hour

$\rightarrow$ **Flux Sensitivity of the 4 IACT System:**

Target Mode (5σ detection in 100h):

J_{min}=0.03 Crab

Extended Source (1^o diameter, 5σ in 100h):

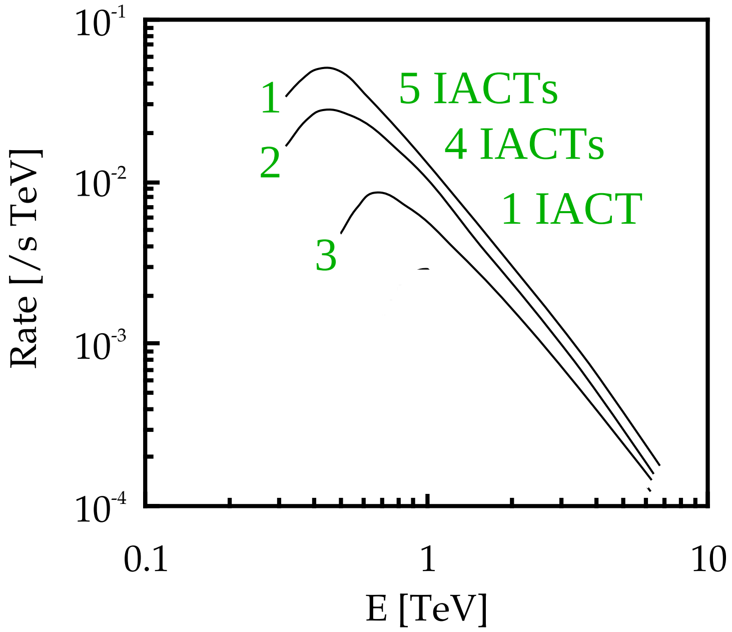
J_{min}=0.15 Crab

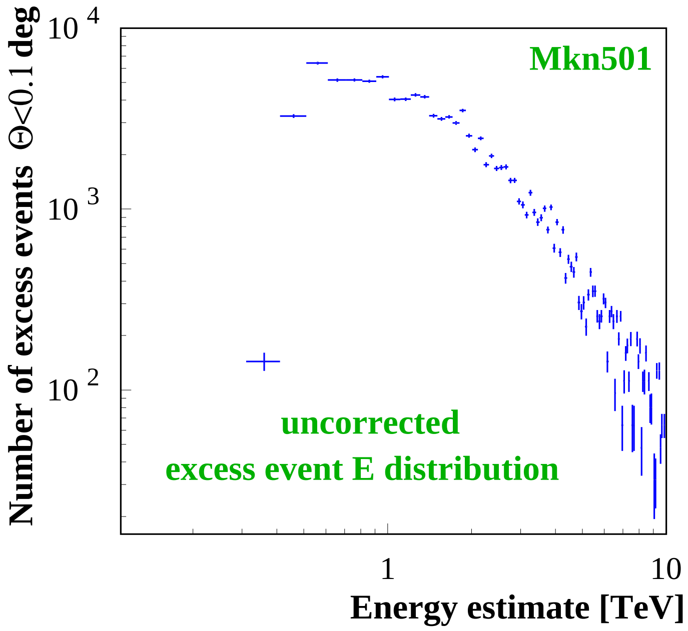
Survey Mode (10γ's "background free" in 1 h):

J_{min}<0.5 Crab, (effective FoV=2^ox2^o)

Energy Threshold

Simulated differential detection rates

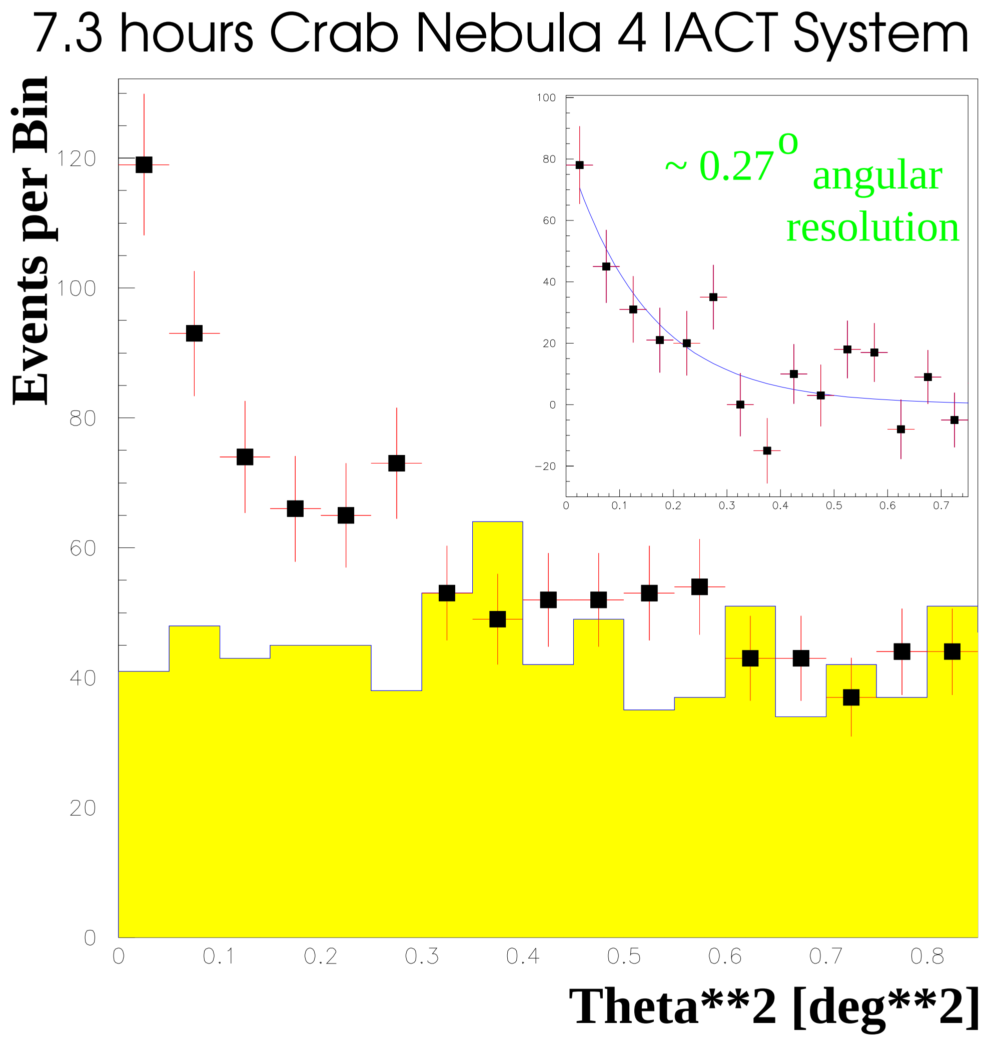




$\rightarrow$ γ-Energy Threshold $\approx$ 500 GeV

Shower Direction by relative Timing of the Telescopes

Shower impact point from normal imaging
$\rightarrow$ fit of shower direction to a
spherical light front model



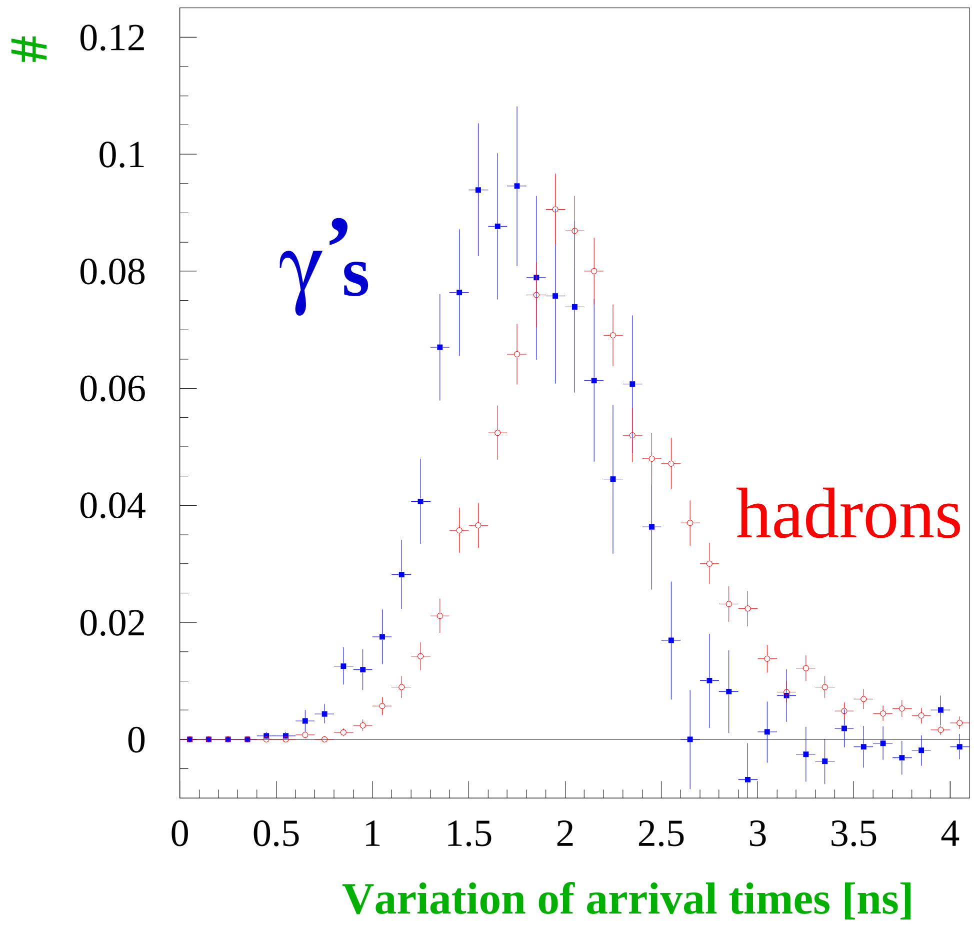
$\Rightarrow$ Reconstruction based on Timing works !

Timing variations within an Image

- 120 MHz FADC System
- readout of 133ns pulse amplitude history
- deconvolution of shaped PM signals
- offline correction for different pixel timing

$\rightarrow$ Light arrival time per Pixel

$\rightarrow$ RMS of arrival times of image pixels



$\Rightarrow$ γ/hadron Separation !

BUT: highly correlated with
2nd moments of image amplitudes

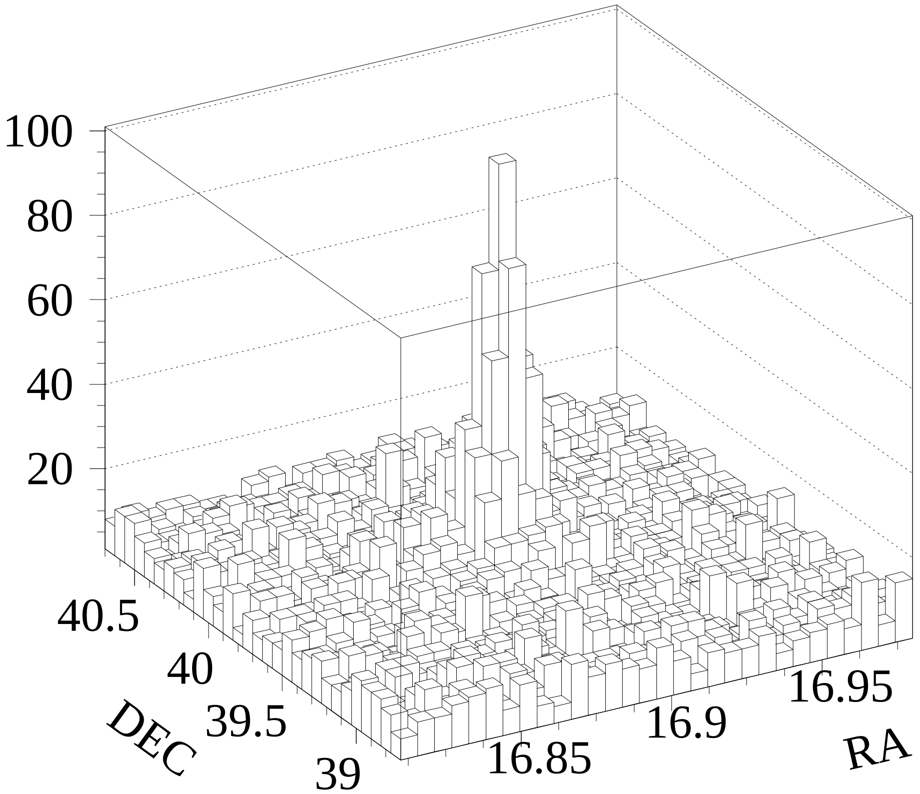
5) Observations

TeV γ Detections:

Crab Nebula
Mkn 501
Mkn 421

⇒ A&A Letter; Astrop. Phys. Paper;
KNPW G.Hermann Friday morning

26/27 June 1997: Mkn501 1 hour of observation:

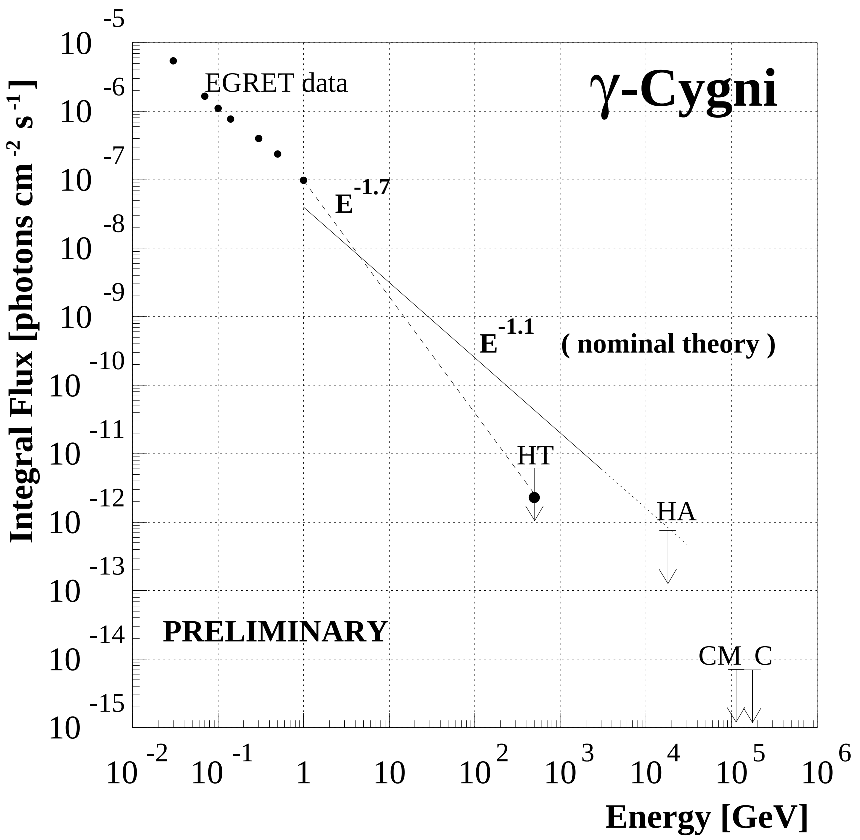


⇒ Outburst of Mkn 501 allows determination of spectral index and flux on the timescale of few minutes

Preliminary Upper Limits :

BL Lac 2202+42	< 0.21 Crab
	(4h, 2/3+3/4 July '97)
1ES2344+514	< 0.15 Crab
	(25h 3CT, Oct/Nov '96)
GRS1915+105	< 0.07 Crab
	(34h, April-July '97)
G78.2+2.1	< 0.19 Crab in 1^o diameter
	(interim 3CT System, Sep/Nov '96)
IC443	< 0.32 Crab in 0.75^o diameter
	(Dec'96-April'97)

SNR upper limits start to constrain Calculations:

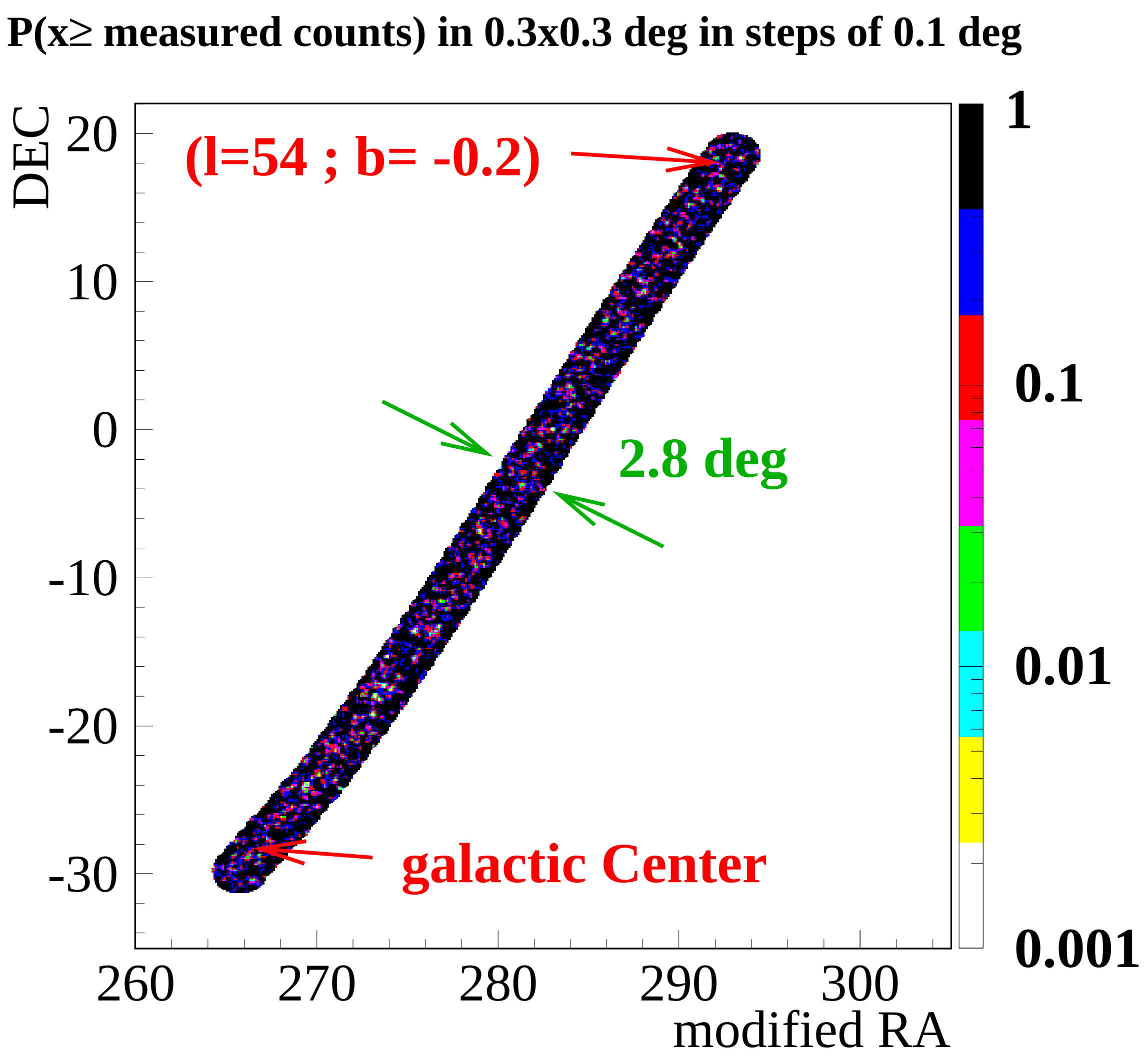


⇒KNPW Friday noon: H.Völk

Recent and Ongoing Observation

Survey of galactic Plane June/July '97

Search for Point Sources:
γ/hadron selection; Calculate Poisson Probability to find $\geq$counts in an area $\approx$typical point source size;



$\Rightarrow$no outstanding source found so far
in $1.7 \cdot 10^4$ tried positions

6) Conclusions and Outlook

Stereoscopic Observation Works !

Angular Resolution

Single γ	$< 0.1^o$
Source Location	$\approx 0.01^o$

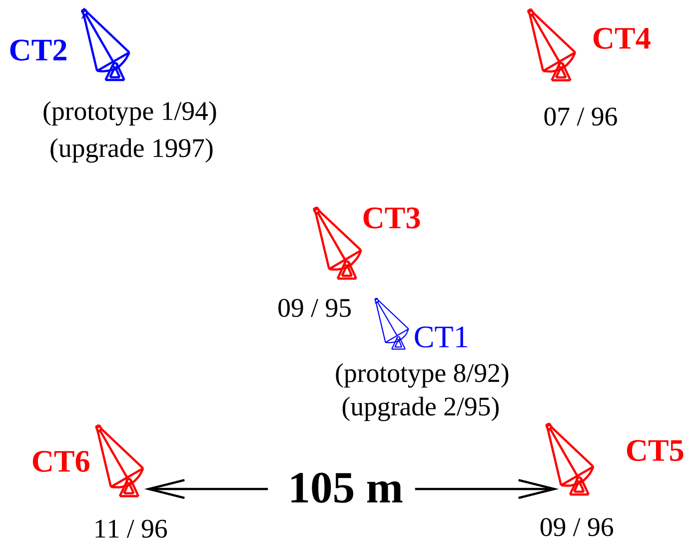
Energy Threshold $\approx$ 500 GeV

Energy Resolution $\approx$ 20% single γ

Sensitivity

Point Source	3% Crab	(100 h)
Extended Source	15% Crab	(100 h)
Survey Mode	50% Crab	(1 h)

Extension to a 5 IACTs System



Ongoing investigation of systematics
$\Rightarrow$ "Bias free" determination of source parameters based on unambigous and redundant information of a TeV event