STACEE Observations of Extra-galactic Sources

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OUTLINE of the TALK:

-motivation for a low threshold detector

- description of STACEE – concept and instrument

- historical progress: - Crab
  - Mrk 421

- present status of the detector

- observations made 2001-2002

-plans for the future

For further details see posters by
Boone *et al* (Mrk421)
Covault *et al* (STACEE instrument)

Motivation for STACEE

- EGRET discovered 68 Blazars and many unidentified sources in the range 30 MeV to 10 GeV

- EGRET detected pulsed gamma rays at E < 10 GeV from 7 pulsars

-current generation imaging air-Cherenkov telescopes (IACTs) have seen
    - 6 blazars (at small z)
    - no pulsed emission from pulsars

-EGRET runs out of statistics at ~10 GeV
-IACTs have thresholds above 200-300 GeV

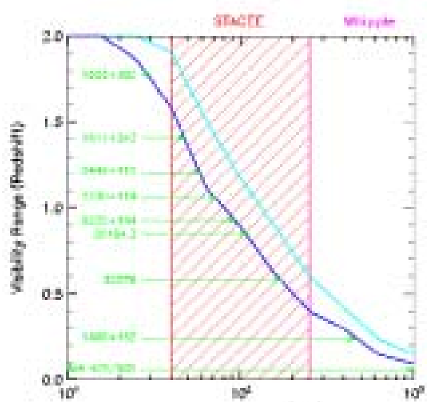
- something interesting is happening in between

- a detector that can cover the region 30-300 GeV would be a valuable resource

Low energy detectors see further:

$$\gamma\gamma \rightarrow e^+e^-$$

depending on the gamma-ray energy, different target photons are involved - lower energy gammas need higher energy targets; there are less of them



How to lower the energy threshold:

The problem is one of detecting low photon densities from low energy showers in the presence of background from the night sky (scattered starlight *etc*)

simple formula:

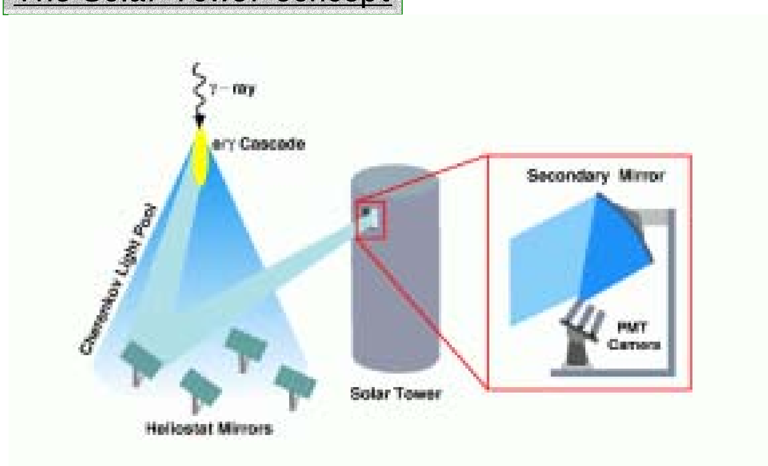
$$E \propto \sqrt{\frac{\Phi \Omega \tau}{\varepsilon \mathrm{A}}}$$

- E energy threshold
- Φ night sky background
- Ω solid angle (field of view)
- τ resolving time
- ε collection efficiency
- A collection area

the resolving time and solid angle are limited by the physics of the shower

concentrate on improving the efficiency and area

The Solar Tower Concept



The essential idea:

use the enormous area of heliostats at a central-tower solar power facility to collect the Cherenkov photons

STACEE

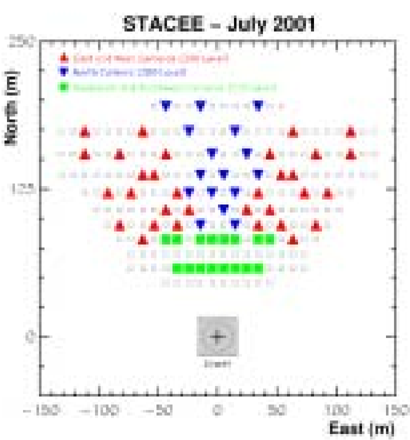
Solar Tower Atmospheric Cherenkov Effect Experiment

National Solar Thermal Test Facilty (NSTTF)
Sandia National Labs, Albuquerque, NM

34.96^{o} N   106.51^{o} W 1700 m altitude

212 heliostats, each 37 m^2 in area
70 m high tower

STACEE Heliostats

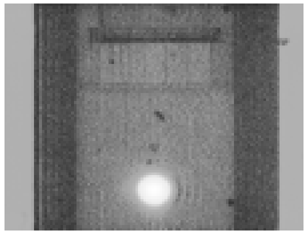


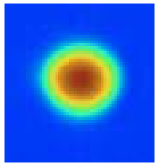
5 secondary mirrors,
each with its own camera

260-level:
2 metre mirrors, 16 channels each
(north, east and west)

220-level
1 metre mirrors, 8 channels each
(south-east and south-west)

STACEE Components





each heliostat is a 5 x 5 array of 4-foot-square mirrors

they can be individually oriented and (crudely) focussed so as to make an image of the sun ~ 2 m in diameter at the tower

all heliostats are independently targetable with a precision of 3 arc-minutes

Secondary Mirrors and Cameras

- 3 secondaries on the 260 (top) level

- each has diameter ~2 m (7 hex facets)

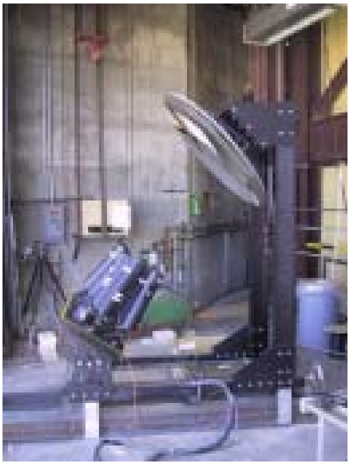
- light from a given heliostat is mapped onto a unique phototube (16 for each camera)

NORTH SECONDARY

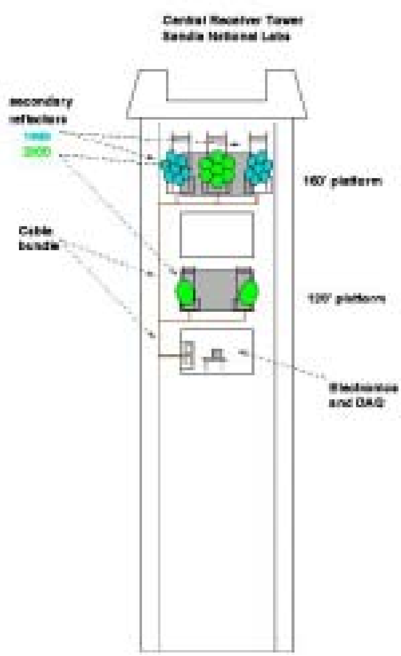
NORTH CAMERA

CAMERA AT NIGHT

220 - level Secondaries and Cameras



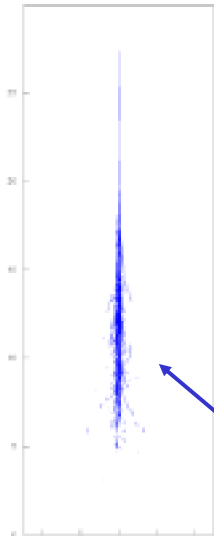
- installed spring - summer 2001
- first used in the 2001-2002 campaign
- look at heliostats nearest the tower
  smaller scales --> 1 m mirrors
- 2 assemblies of mirror and 8-channel camera



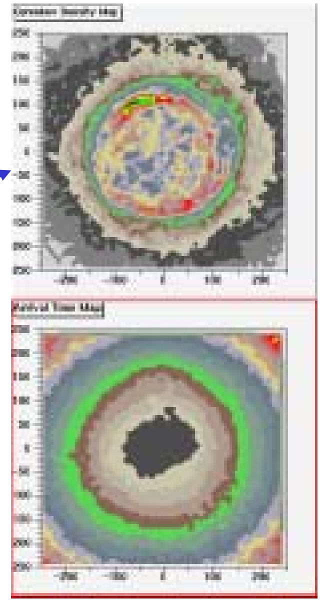
Schematic of STACEE Setup

Cherenkov Light

Simulation of light emitted by a 100 GeV gamma shower



paths of radiating particles (electrons)

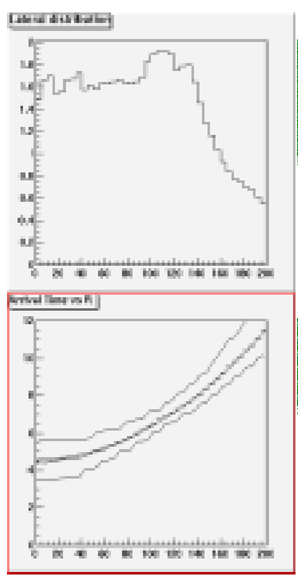


impact points of Cherenkov photons

arrival time profile is smooth and spherical

Light Pool Profile

100 GeV γ shower



photoelectrons per square metre *vs* distance from centre

Photon arrival times *vs* distance from centre

wave-front is spherical and about 2 ns thick

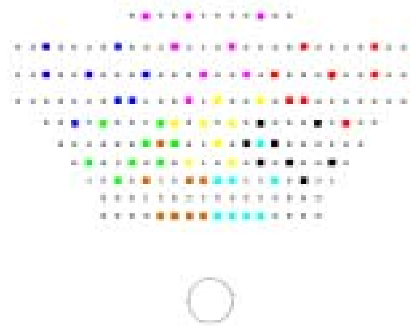
Electronics and DAQ

signals are:

- filtered (75 ns)
- amplified (x100) 15 m from PMTs
- sent to electronics room on 70 m low loss cables
- discriminated (threshold order 4-5 photo-electrons)
- delayed using a custom made digital delay system (1 ns step size)
- brought into coincidence for high multiplicity trigger

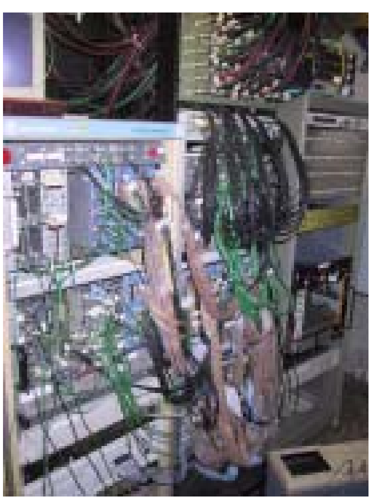
heliostats are grouped into 8 clusters of 8

triggers like
5/8 pmts/cluster
5/8 clusters
ensure a broad light pool (for cosmic ray rejection)



Electronics continued

Readout uses real-time Linux computer in a VME crate with bridges to CAMAC



Modules include:
2 GHz multihit TDCs
scanning ADCs (currents)
scalers (rates, deadtime)
GPS clock

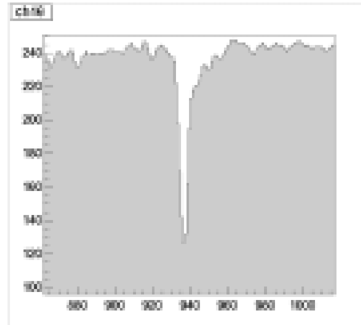
New for 2001-2002 season:

1 GHz FADC system (Acqiris)

-one digitizer per channel

-sample rate: 1 per ns

-save 192 ns waveform around trigger



Advantages

precise timing

more accurate pulse height measurements
- fit for shower core

software padding possible
- equalize on-off rates

WORK IN PROGRESS

NB: until end of March, 2002 we ran with 2 channels into each digitizer – more difficult to analyse but cheaper

Data-taking

observe on clear, moonless nights
(between sunset and moonrise
or moonset and sunrise)
typically 2 - 3 weeks/month depending on season

track the source of choice (*eg* Crab)
when it is within 45 degrees of Zenith

use ON-OFF strategy
- 28 minutes on-source
- 2 minutes changeover
- 28 minutes off-source (same declination but 30 minutes different in right ascension)
- 2 minutes change back

ON-OFF difference is the gamma-ray signal

Data analysis

clean up data :

- reject runs (or parts) with rate or photocurrent surges due to clouds, airplanes raising the backgrounds
- reject runs (or parts) where one or more heliostats did not track properly

re-assert trigger with tighter cuts

- use time from TDC and/or trigger system

fit shower front to a spherical front

- cut on quality of fit

compare ON-source with OFF-source (look for excess)

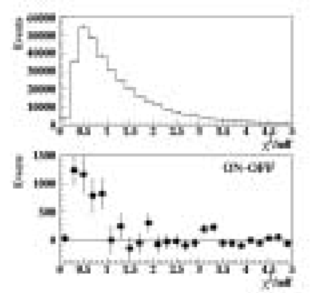
compute effective area as function of energy using Corsika Monte Carlo program – fold with assumed spectrum to get flux and effective threshold for integral measurement

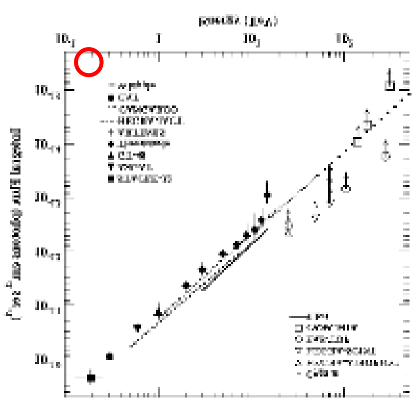
Results from STACEE-32

- 32 channel incarnation of STACEE (east and west cameras only)
- ran during the 1998-99 season

signal from the Crab was observed

- (5σ raw - 7σ after sphere-fit cuts)
- upper limit on pulsed emission (< 6%)





threshold achieved: 190 +/- 60 GeV

integral spectrum is consistent with extrapolation from higher energy measurements

(Oser *et al* ApJ 547, 949 (2001))

STACEE-48

next step on the road to the design instrument

- -addition of north camera fills in gap in the field
- -heliostats tuned up for better optical throughput
- -albedo from asphalt under heliostats reduced
- -re-surfaced secondary mirrors
- - improved electronics and DAQ

running from January 2001

-RXTE and HEGRA report MrK421 is in a very active state

-STACEE observes Mrk421 from February to April 2001

45 hours of on-source data acquired
26 hours after quality cuts (sky conditions, rate stability *etc*)

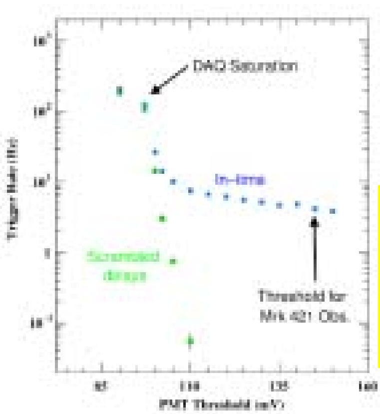
-Raw ON-OFF significance ~ 12 σ

Mrk 421 DATA

A slight problem with the Mrk421 signal:

the field of view of STACEE (when aimed at Mrk421) contains a magnitude 6 star

- -raises the photocurrents and individual channel rates
- -could 'promote' sub-threshold events
- -generates a spurious ON-OFF difference



this effect has been checked by observing a different field which contains a magnitude 6 star (HIP80460) but (presumably) no gamma-ray source; effect is there but at a small level

Comparison to Whipple Data

Tucson, AZ

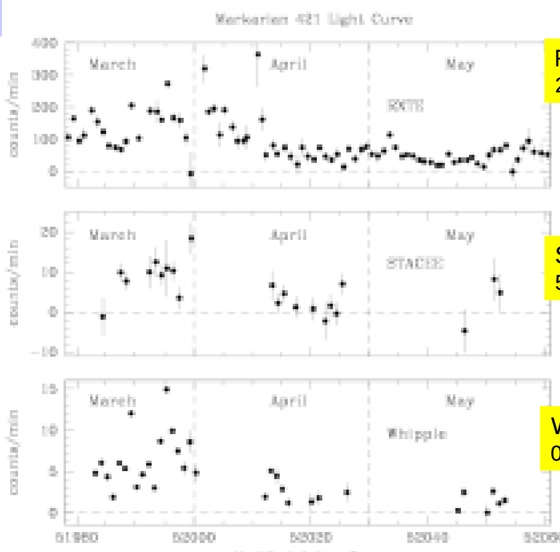
Albuquerque, NM

due to rapid variability of the source it makes sense to compare data from nearby detectors

Comparison with other data

RXTE All Sky Monitor Team

Holder *et al* Proc 27 ICRC

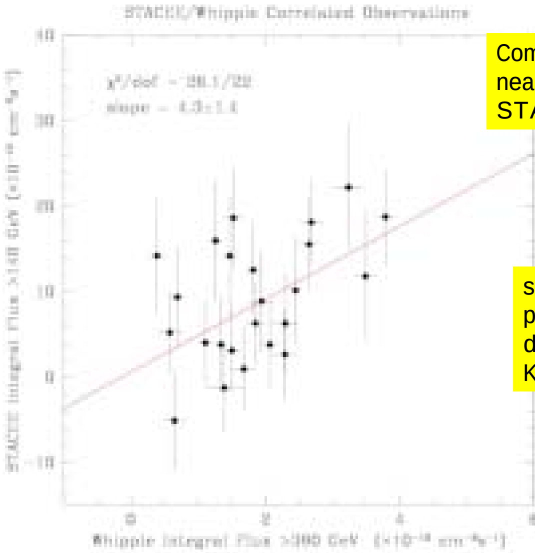


RXTE
2 – 10 keV

STACEE
50-300 GeV

Whipple
0.25 – 8 TeV

Whipple-STACEE correlation plot

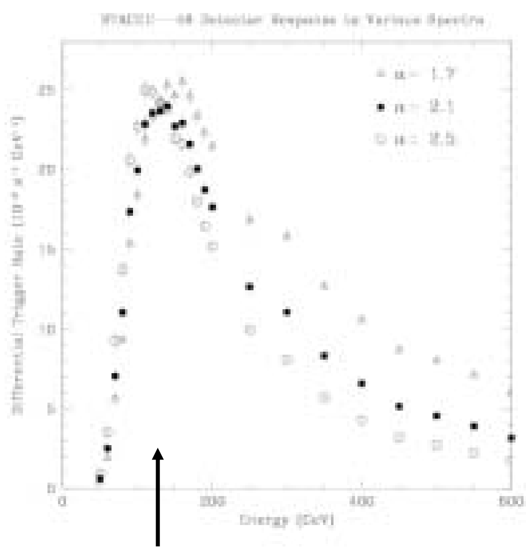


Comparison of flux measurements from nearly simultaneous (within 0.5 hour) STACEE pairs and Whipple runs

slope of 4.3 is consistent with power law index of 2.14 from differential spectrum of Krennrich *et al* (2001)

STACEE response as a function of energy for different power law spectra

each spectrum has the same integrated flux above 50 GeV



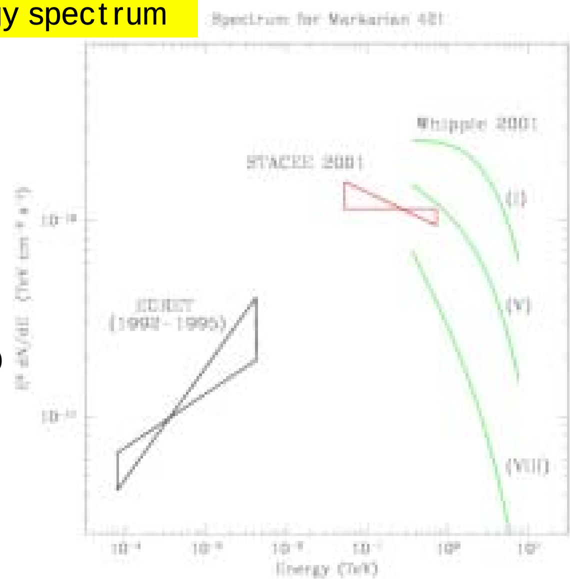
peak at 140 GeV

Mrk421 high-energy spectrum

STACEE butterfly assumes spectral indices between 2.00 and 2.20 and are integrated over the length of the flare

Whipple data are from periods of different flux levels within flare (see Krennrich *et al* 2002)

EGRET data are from cycles 1 through 5 (low state for Mrk 421)



Integral measurement:

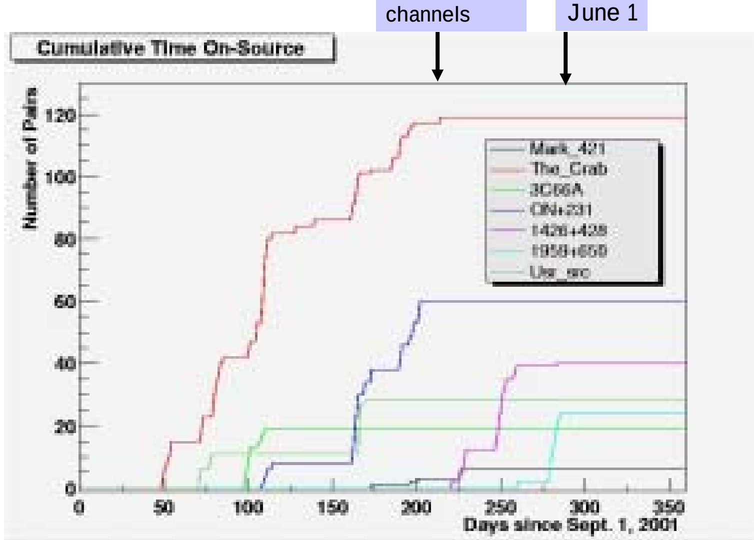
flux above 140 GeV = (8.0 +/- 0.7 $_{stat}$ +/- 1.5 $_{sys}$) x 10^{-10} cm^{-2} s^{-1}

(background effect of star contributes +/- 1.3 x 10^{-10} to systematic)

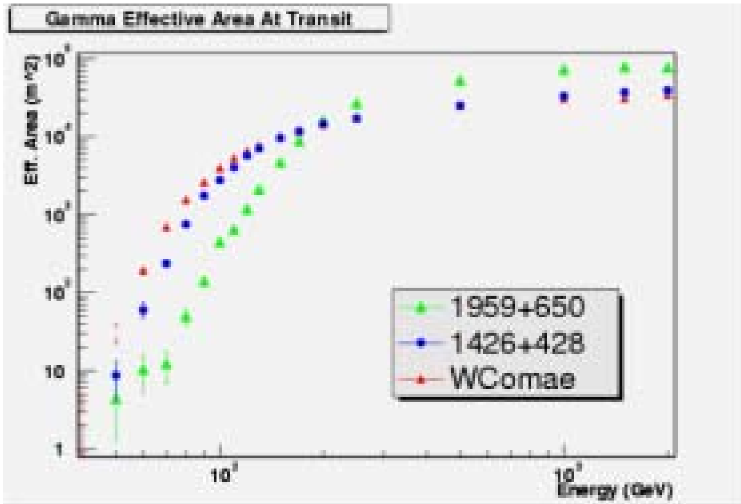
2001 – 2002 season

FADCs on all channels

June 1



Energy Dependence of STACEE's Effective Area



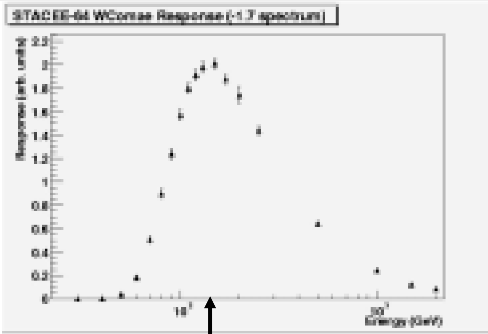
W-Comae (ON+231)

BL Lac object with peak at low frequency
- seen by EGRET but not by IACTs above 250 GeV

redshift: z = 0.10 (further than Mrk 421 and Mrk 501 but not an order of magnitude)

spectrum: power law with index = 1.73 +/- 0.18 measured by EGRET
- strong source for STACEE if power law continues to higher energies

interesting source physics: 1998 Beppo SAX spectrum fit from 0.1 to 100 keV data predicts very low fluxes at STACEE energies
- all leptonic models (eg SSC) cut off near 100 GeV
- hadronic jet models predict detectable fluxes at E > 100 GeV (see Boettcher, Mukherjee, Reimer 2002)



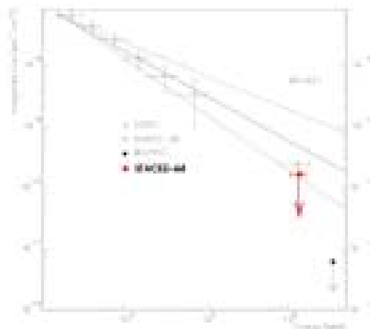
peak at 140 GeV

threshold 140 +20/–30 GeV

W-Comae (ON+231)

integral spectrum point based on 6.12 hours of on-source data:

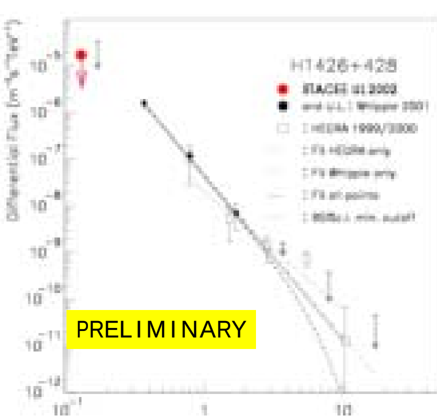
flux above 140 GeV < 1.41 x 10^{-10} $cm^{-2}s^{-1}$ (90% CL)



PRELIMINARY

H1426+428

weak TeV source detected by Whipple and HEGRA
flux ~ 3% of Crab



STACEE acceptance peaks at 120 GeV for a spectral index of –3.5

Upper limit (90% CL)
1.96 x 10^{-5} m^{-2} s^{-1} TeV^{-1}

based on 7.2 hours of data

(plot from Petry *et al* 2002 astro-ph/0207506)

Plans for 2002-2003

-detector tune-up during September/October

-measure optical pulsar from Crab

-check out instrument with Crab gamma rays
  - test new canting schemes for better background rejection

- reduce energy threshold
  - lower discriminator thresholds
  - tighter time coincidences

- run on selection of blazars (and PSR 1951+32)