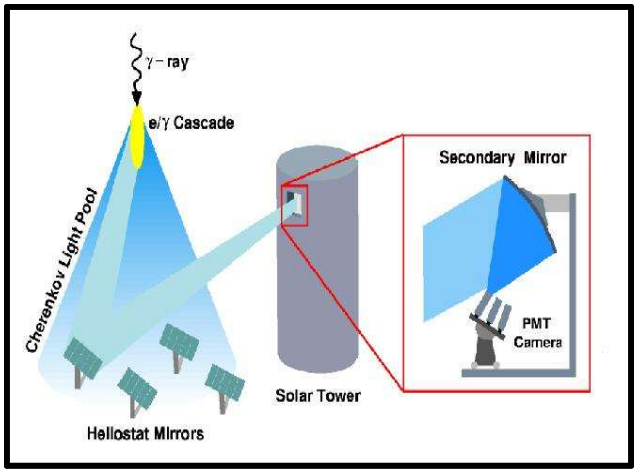
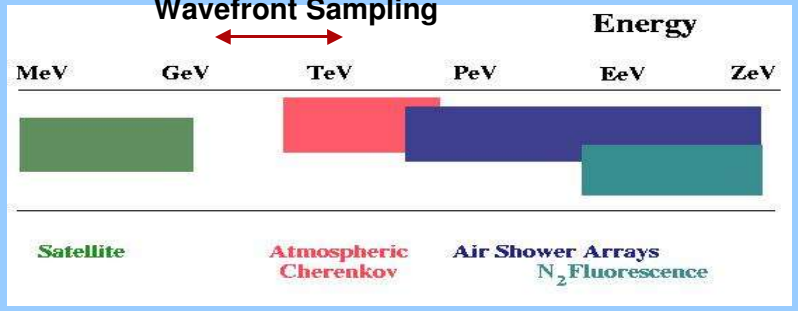
Observations of LBLs with STACEE

Reshmi Mukherjee,
Barnard College, Columbia University, New York

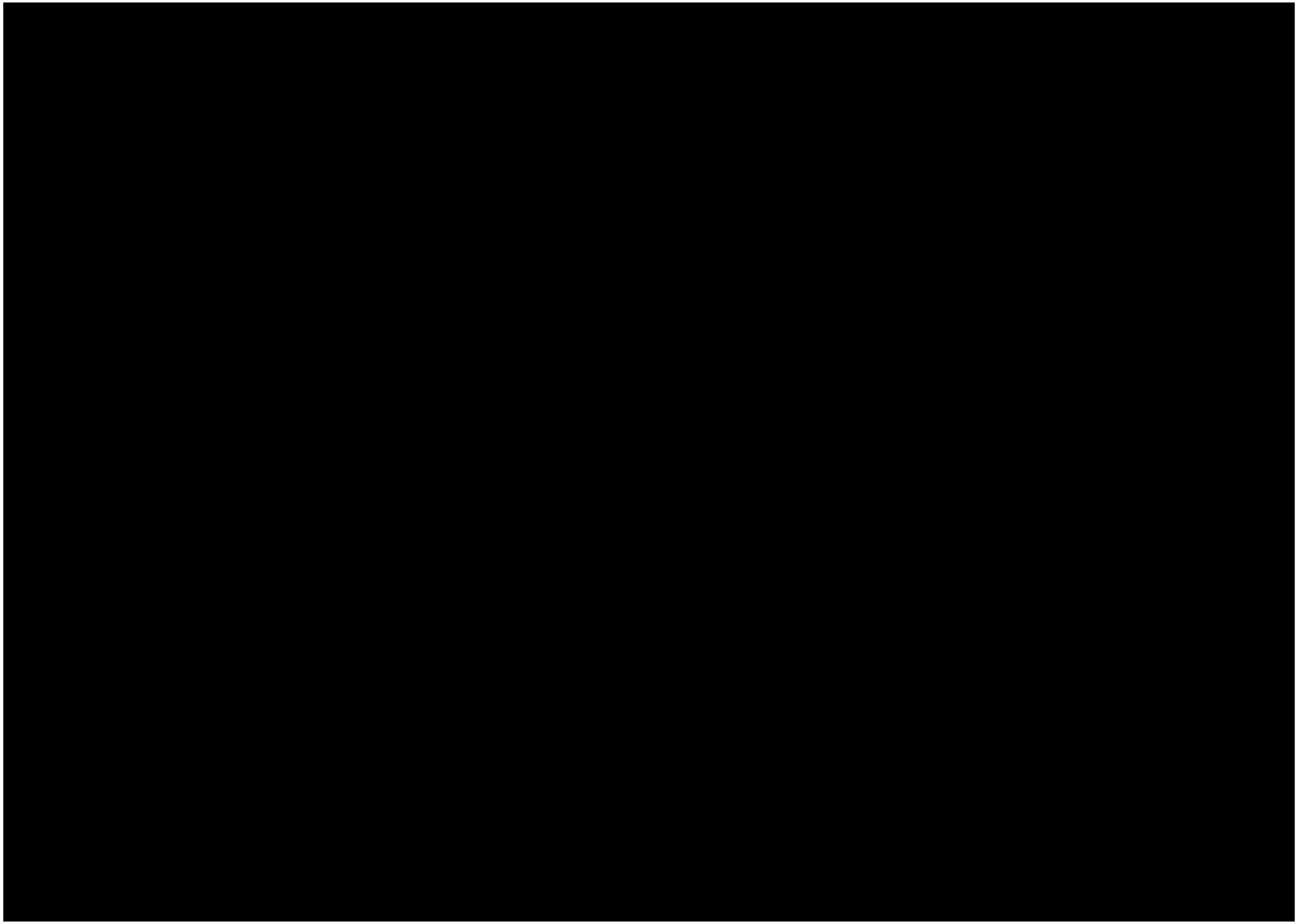
Solar Tower Atmospheric Cherenkov Effect Experiment



Air Cherenkov,
Wavefront Sampling

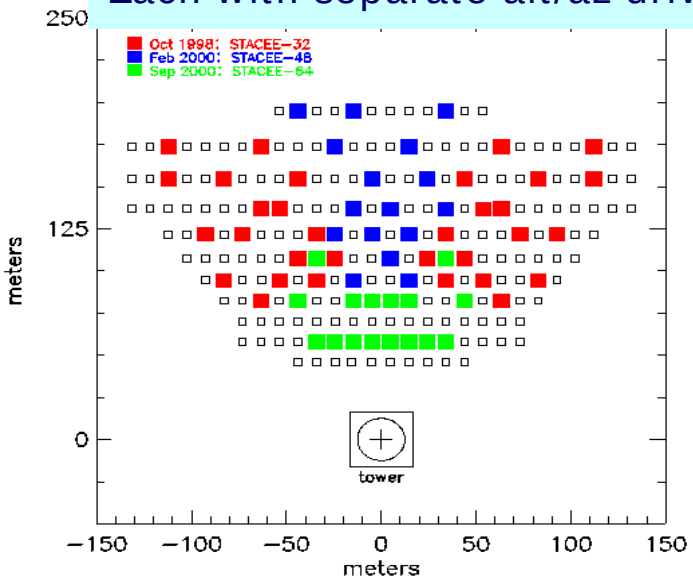


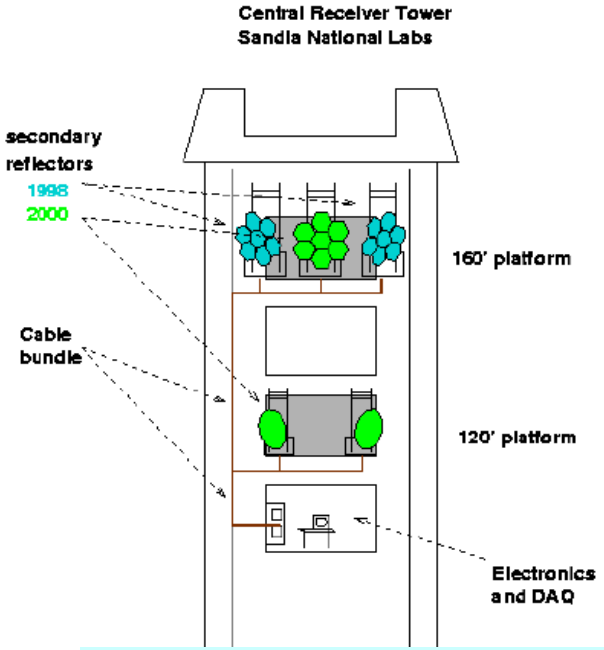
The STACEE Collaboration



The STACEE Detector

64 Heliostats (40 m^2 each)
Each with separate alt/az drive





Optics/Electronics:

- 1 heliostat = 1 PMT
- Digital delay (1 ns)
- Two-level trigger system (24 ns window):
  - cluster: ~ 10 kHz
  - array: ~ 7 Hz

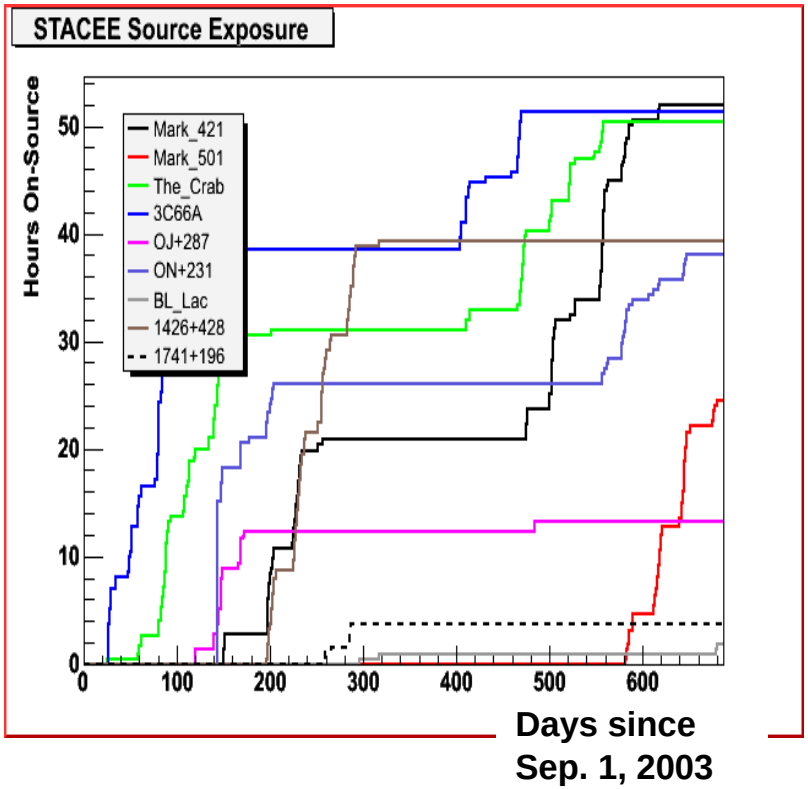
Recent heliostat upgrade

★ faster slewing (1 min to GRB location)

(See poster by A. Jarvis for more details.)

STACEE AGN Observations 2003-2005

Source	Year	# Pairs
3C 66A	2003-2004	85
OJ287	2003-2004	28
Mrk 421	2003-2004 2004-2005	43 70
W Comae	2003-2004 2004-2005	25 26
1H 1426+428	2003-2004	86
Mrk 501	2004-2005	50
1741+196	2003-2004	8
BL Lac	2003-2004	4



STACEE observes in ON/OFF mode.

- typically 28 min ON source, followed by 28 min OFF source
- OFF source data used for hadronic background rejection

STACEE Data Analysis

Analysis:

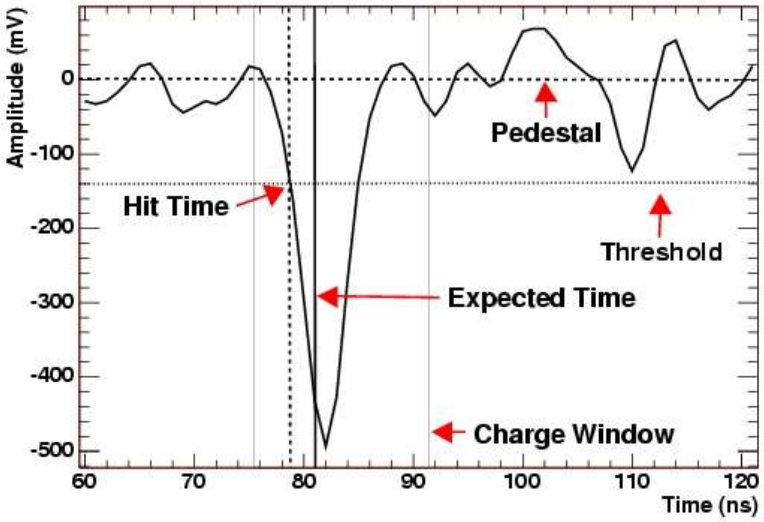
- Cuts for data quality
- Correction for unequal NSB levels
- Cosmic ray background rejection
- Significance & flux determination

Recent improvements in analysis: (See J Kildea's poster)

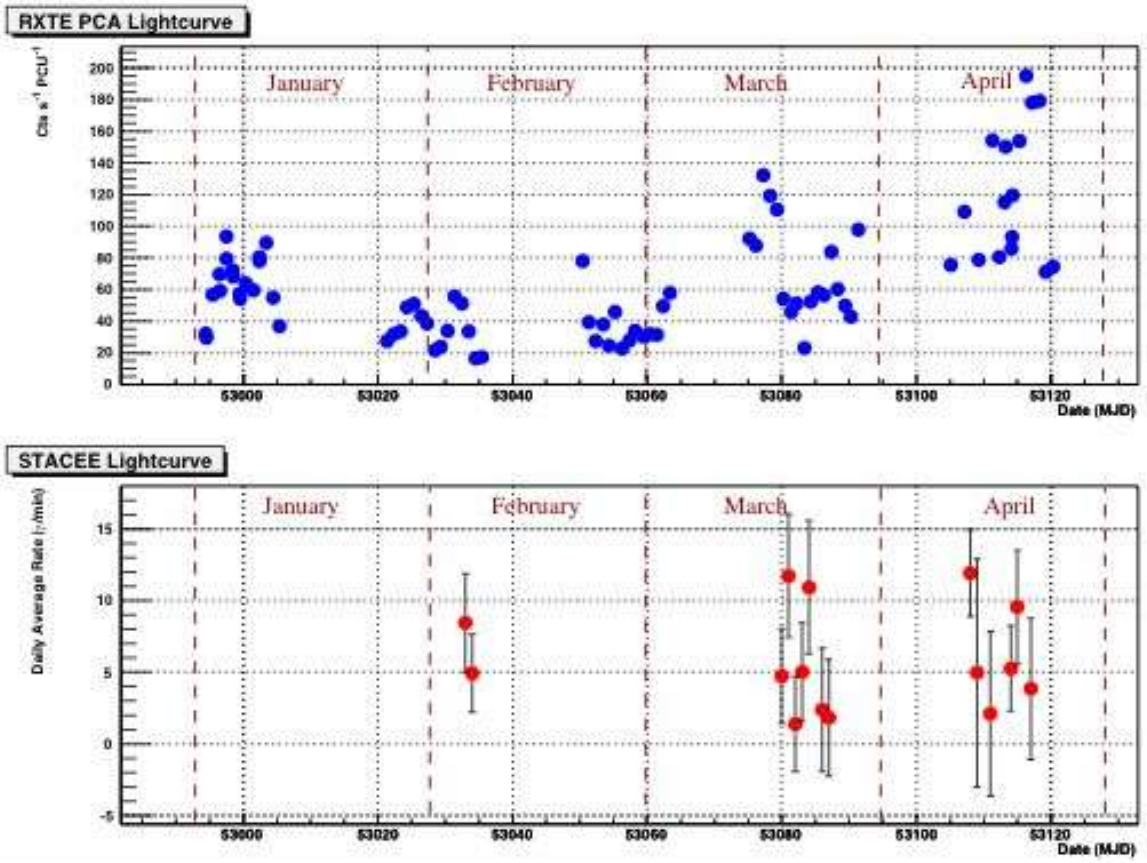
- Significant advances in analysis, using full power of FADC data
- Event reconstruction
- Gamma-hadron separation

8 bit Flash ADCs

- one per channel (64)
- 1 GS/s



STACEE AGN Observations - Mrk 421



Earlier STACEE detection: Spring 2001 (Boone et al. '02)

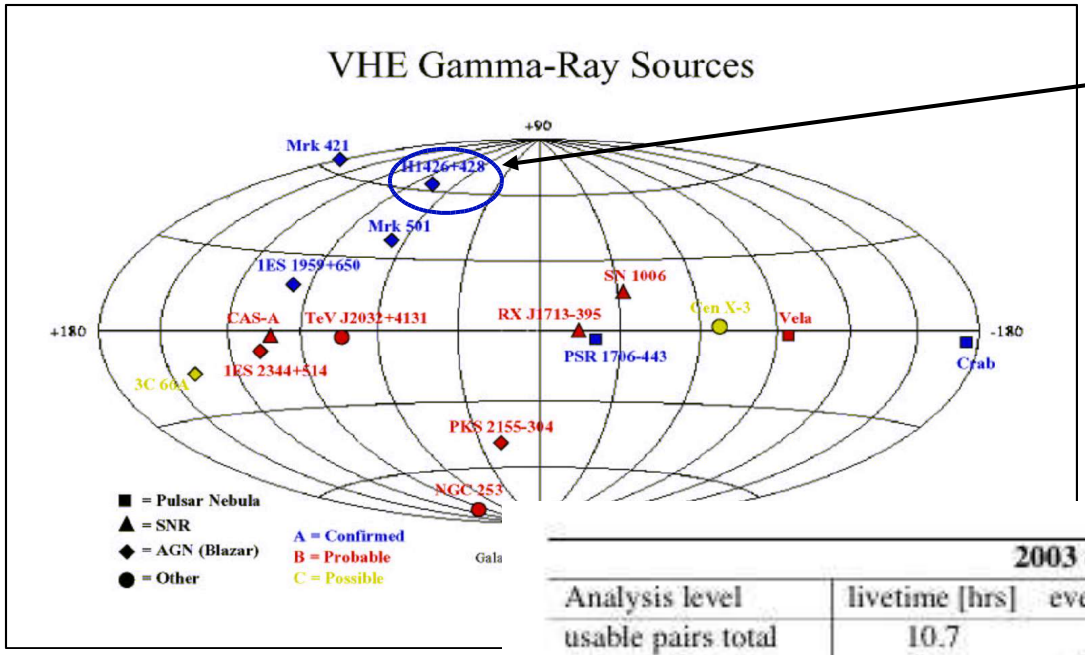
2004 data yielded the first STACEE measurement of spectrum above 100 GeV. (See J. Carson's talk for more details.)

PCA data courtesty of W.Cui, Blazejowski et al 2005 (for publication in ApJ)

Mrk 421 was in a high X-ray state in Spring 2004 (RXTE)

- Total livetime ON source: 9.1 hours (after cuts).
- STACEE detection: 5.8 σ

STACEE AGN Observations - H1426+128



H 1426+ 428
- HBL
- z = 0.129
- Well-studied at TeV energies
- High-energy peak is at ~ 100 GeV
- Potential to constrain the optical EBL

No detection by STACEE

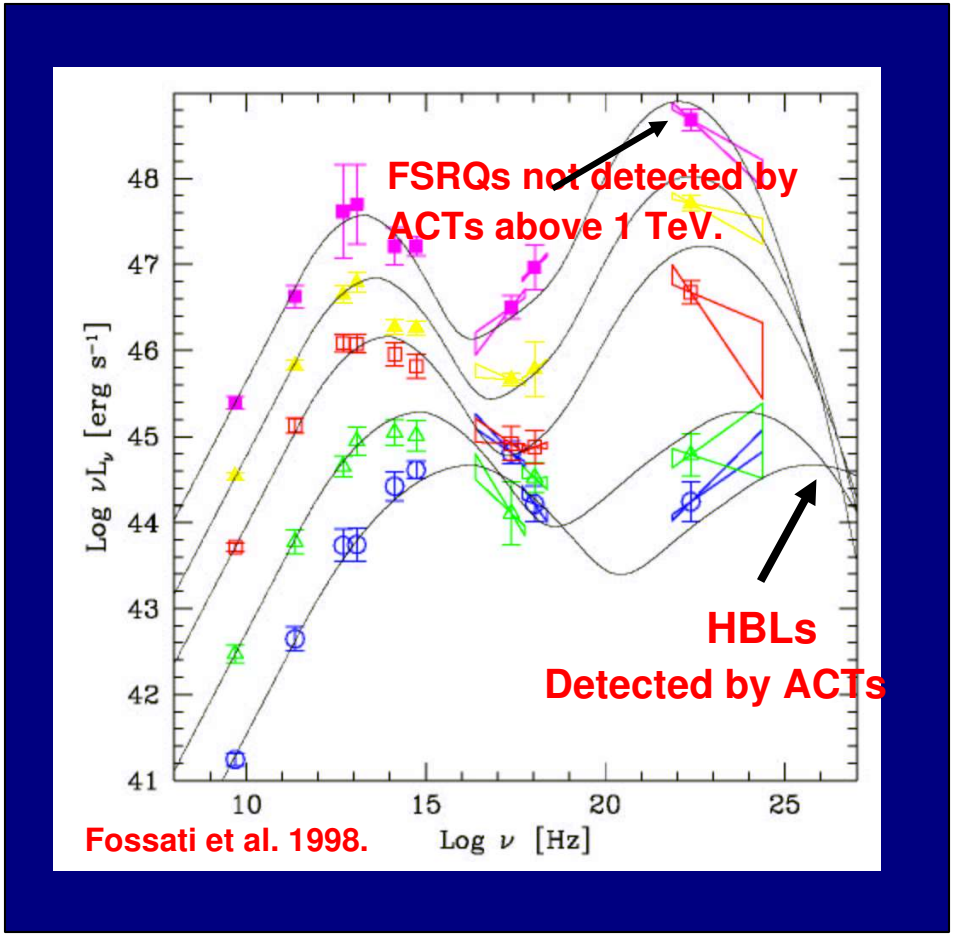
2003 observations

Analysis level	livetime [hrs]	events ON	events OFF	excess	significance [σ]
usable pairs total	10.7	–	–	–	–
data quality cuts	6.9	124384	123604	780	1.9
trigger reimposition	6.9	113277	112450	827	2.1
software padding	6.9	86556	86461	95	0.5

2004 observations

Analysis level	livetime [hrs]	events ON	events OFF	excess	significance [σ]
usable pairs total	31.0	–	–	–	–
data quality cuts	14.1	270914	270499	415	0.8
trigger reimposition	14.1	235350	234889	461	0.9
software padding	14.1	171235	170545	690	1.4

Understanding SEDs of Blazars



To date, all confirmed blazars detected at TeV (10^{12} eV) energies by ACTs have been low z, HBLs.

STACEE's low energy threshold allows for the possibility to explore intermediate- and low-frequency peaked BL Lacs (LBLs).

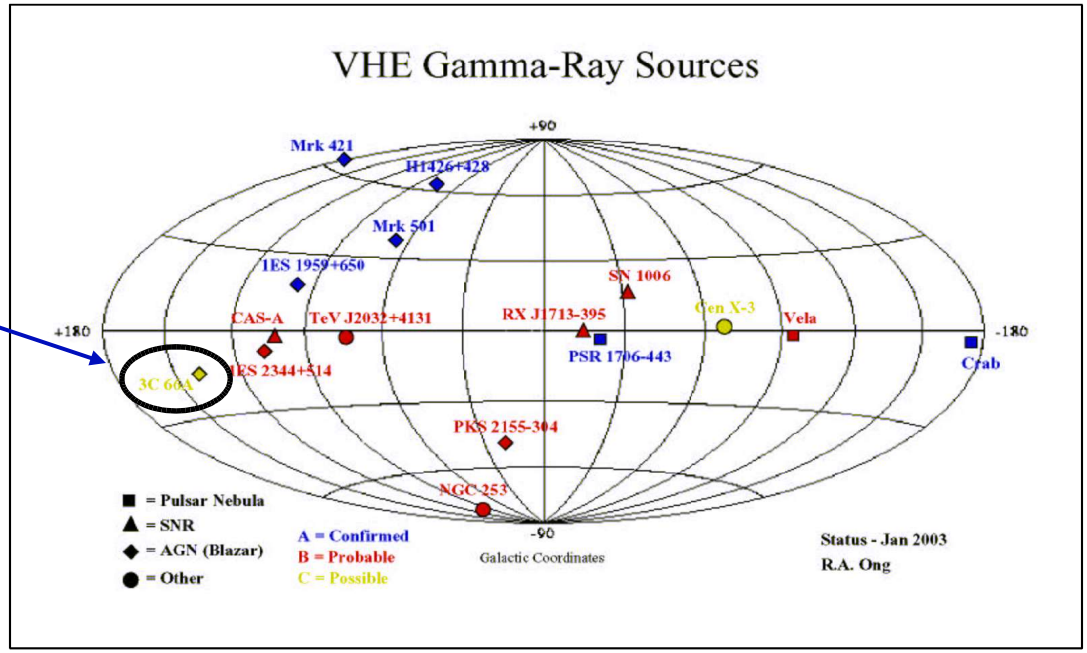
Two LBLs observed by STACEE:

- W Comae (ON+ 231)
- 3C 66A

The lack of sufficient number of GeV-TeV blazars limits our understanding of the γ-ray emission, and our ability to extrapolate results to the larger population of radio sources

STACEE Observation of 3C 66A

- z = 0.444
- Low-frequency peaked BLL
- Strong source at energies < 10 GeV (EGRET)
- Unconfirmed detection at TeV energies (Crimea) - (Stepanyan et al. 2002)



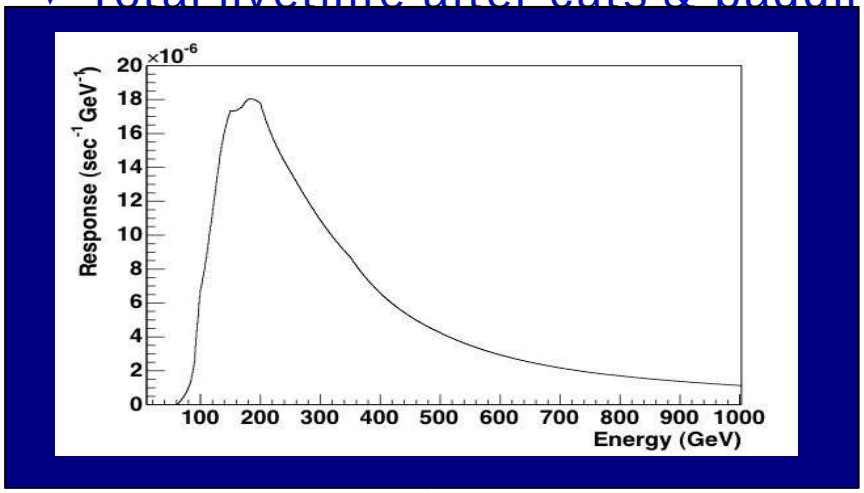
Attractive STACEE target for several reasons:

- LBL - Synchrotron peak at higher energies than typical LBLs.
- Relatively high redshift ⇙ attractive target for optical/IR EBL studies.
- Previous EGRET detection (3EG J0222+4253).
- STACEE observations in 2003-2004 were part of an extensive MW campa

3C 66A (2003-2004)

The STACEE data set:

- 85 ON-OFF pairs: 33.7 hours on-source livetime before data-quality cuts.
- Data-quality cuts --
  Hardware problems, HV trips, heliostat problems.
  Bad weather, changing atmospheric opacity.
- Software padding - to counter the effects of field brightness differences
- Total livetime after cuts & padding: 16.3 hours



STACEE response curve, assuming diff.
photon spectral index -2.5.

3C 66A integral flux ULs
Units: 10^{-10} ph cm^{-2}s^{-1}

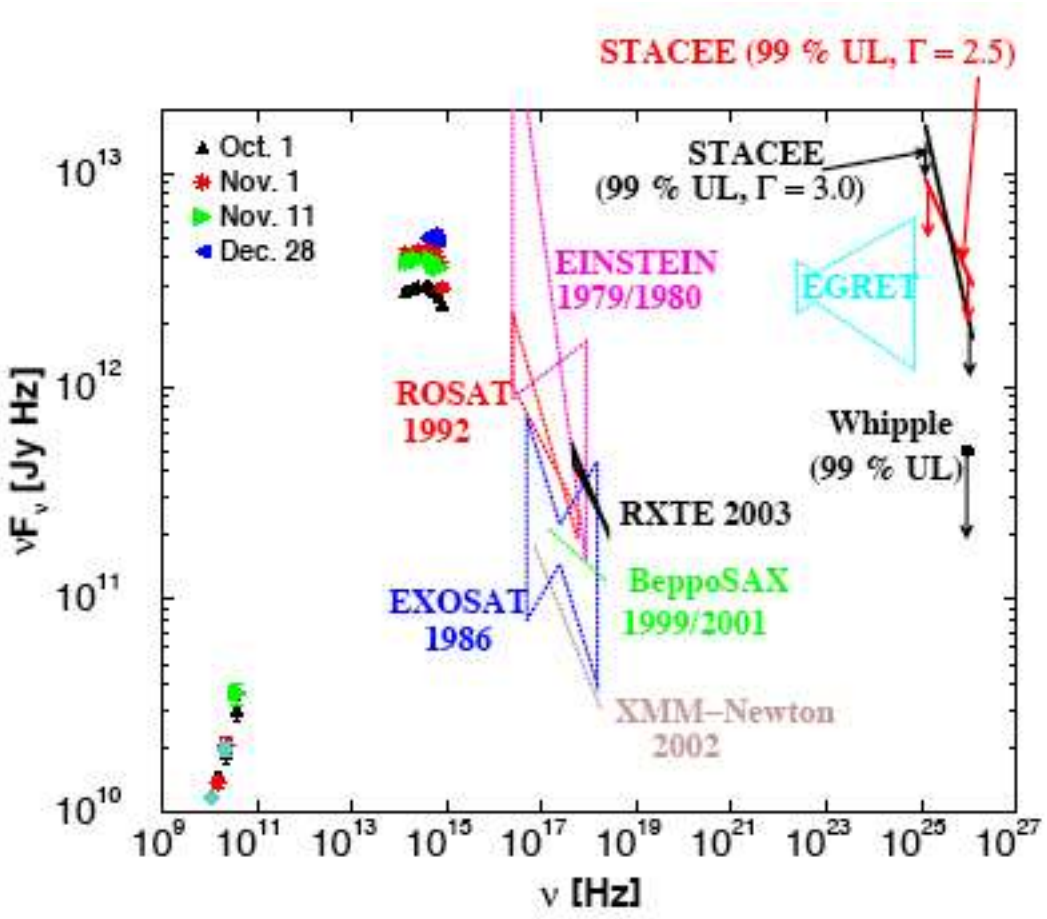
Spectral Index	$\Gamma = \infty$ [a] E_{thresh} [b]	99%CL[c]	$\Gamma = 200$ [a] E_{thresh} [b]	99%CL[c]
−2.0	200	< 1.0	150	< 1.9
−2.5	184	< 1.2	150	< 1.9
−3.0	150	< 1.7	142	< 2.1
−3.5	147	< 1.8	137	< 2.3

Bramel et al. 2005; ApJ, astro-ph/0504515

3C 66A - Multi-Wavelength Observations

Subject of extensive MW monitoring July 2003 - Apr 2004 (core period: Sep-Dec 2003).

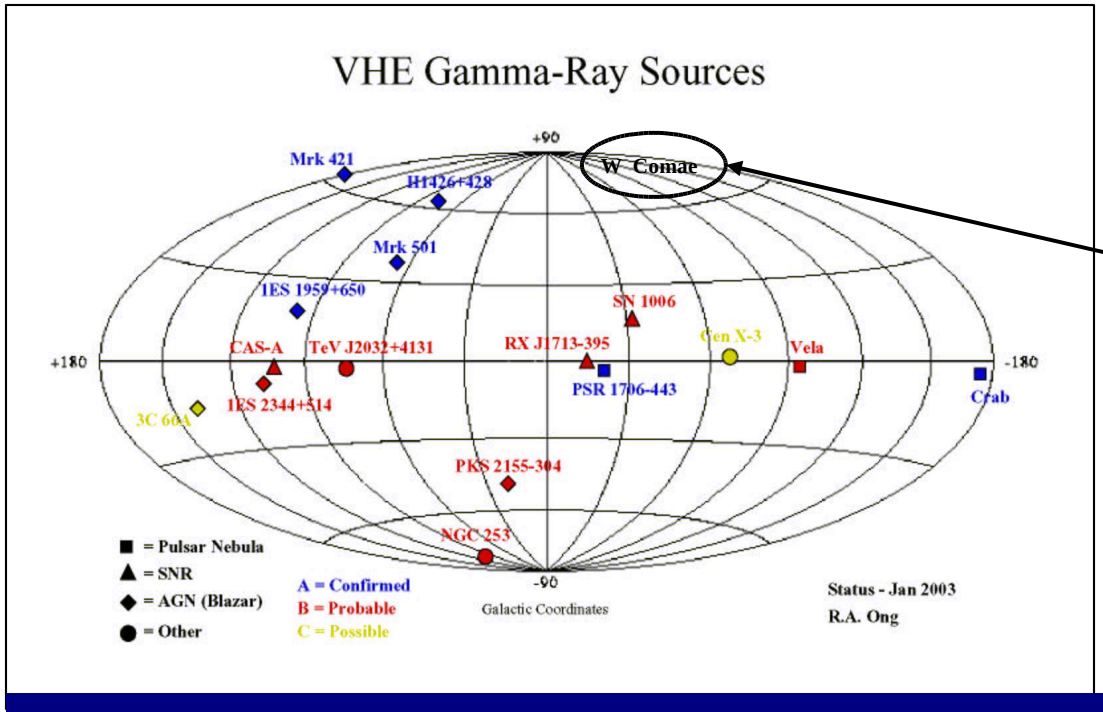
- Radio/IR/optical with WEBT-ENIGMA
- VLBA
- RXTE
- STACEE
- VERITAS



(Boettcher et al. 2005)

3-10 keV X-ray flux was at its historically high, spectrum soft. Low freq. component of the broadband SED extends beyond ~ 10 keV.

STACEE Observation of W Comae



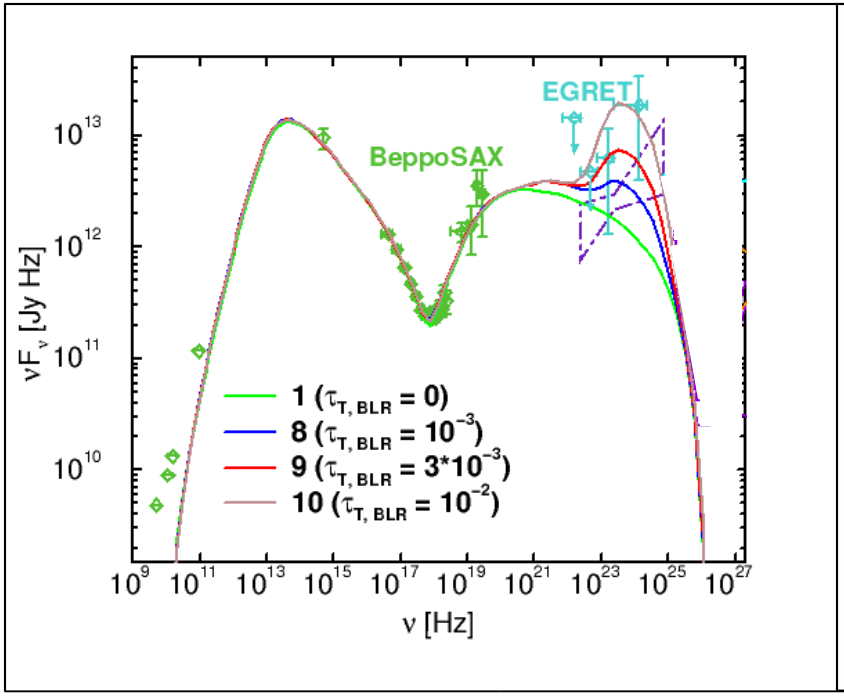
- z = 0.102
- Hard EGRET spectrum

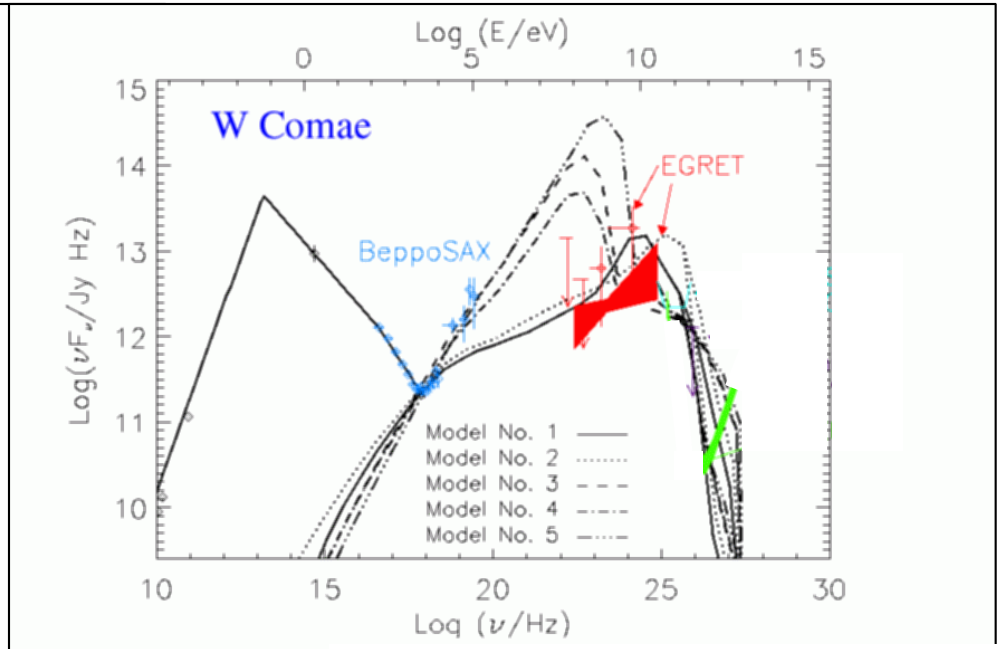
Attractive STACEE target for several reasons:

- LBL - X-ray spectrum shows clear evidence of HE component beyond ~ 4
- Relatively high redshift ⇙ attractive target for optical/IR EBL studies.
- Previous EGRET detection, with hard spectrum: $\alpha = 1.73$.
- STACEE flux limit (Scalzo et al. 2004).
- Predicted to be excellent test case for leptonic/hadronic modelling studie

Models of W Comae

Predicted differences around 100 GeV





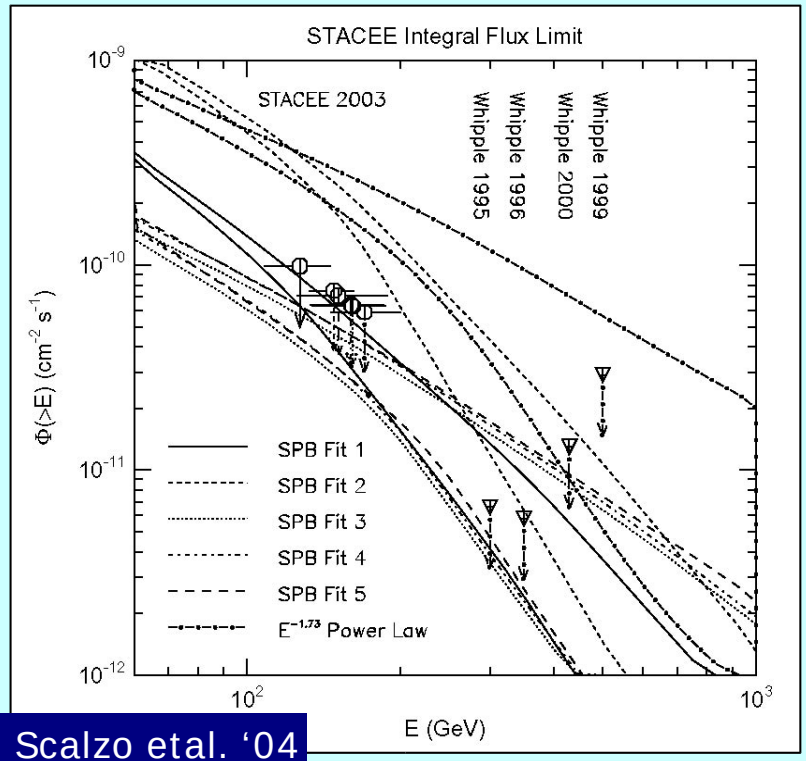
Boettcher, Mukherjee, Reimer 2002

Leptonic models
o emission predicted above 100 Ge

Hadronic models
ignificant emission above 100 Ge

BeppoSAX measurements allow strong constraints for modelling studies of SE
~ 100 GeV interesting range for study.

STACEE Observation of W Comae - 2003-2005



R. Scalzo etal. '04

STACEE Data: 2003

- 10.5 hr on-source
- No significant emission
- ULs derived for different models, power law

STACEE flux limit constrains hadronic emission models:
$\Phi < \sim 2.5 \times 10^{-10}$ cm^{-2} s^{-1} for hadronic models above 165 GeV

Unfortunately, total livetime in 2004+ 2005 less than that in 2003.

Year	Total Hrs	Hours after cuts	σ
2003	13.5	10.5	0.67
2004	9.7	4.6	0.2
2005	9.4	5.1	-1.5

Summary & Future Prospects

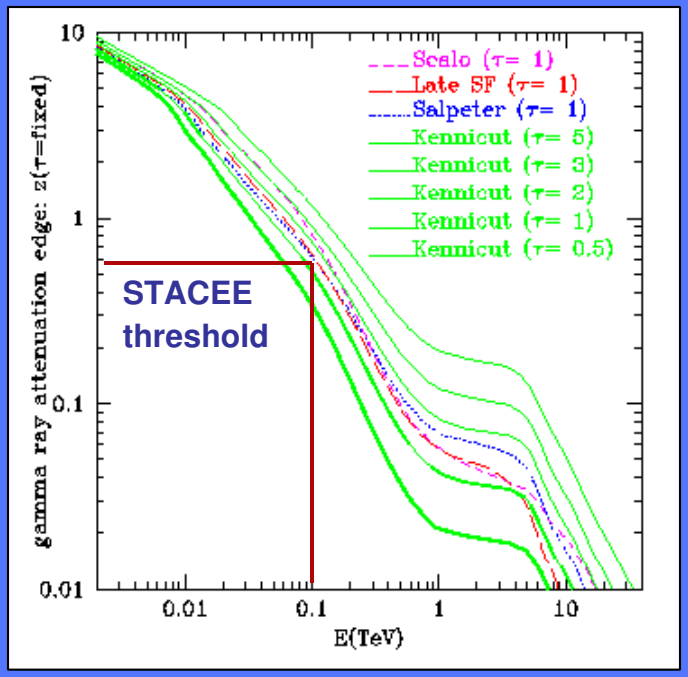
- STACEE is fully operational and stable.
- STACEE AGN observations will continue atleast until mid-2006
  Sources will include:
  - "standard" TeV sources: Mrk 421, Mrk 501
  - Intermediate and low-frequency-peaked BL Lacs: 3C 66A
  - Other non-AGN sources
- Main thrust in the future will be on the analysis front:
  - Continued improvements in data analysis, advanced event reconstruction, take full advantage of FADC data
  - Re-analyze data on 3C 66A & W Com using improved data analysis methods, event reconstruction techiniques recently developed by STACEE (ref: J Kildea)

Extra Slides

Why Solar Tower?

[redacted]

γ-ray horizon plot defining relation between distance (z) and cut off energy $\tau_{\gamma\gamma}(z,E) = 1$



More sources are accessible to STACEE because of its low energy threshold.

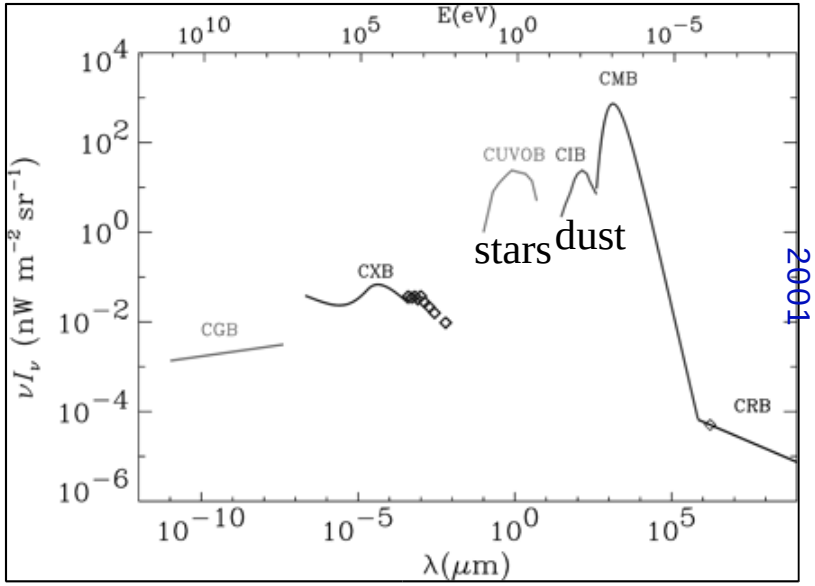
STACEE uses the large areas of heliostats to achieve a low energy threshold --

- 64 heliostats provide a total collection area of ~ 2400 m^2
- Energy threshold ~ 100 GeV range

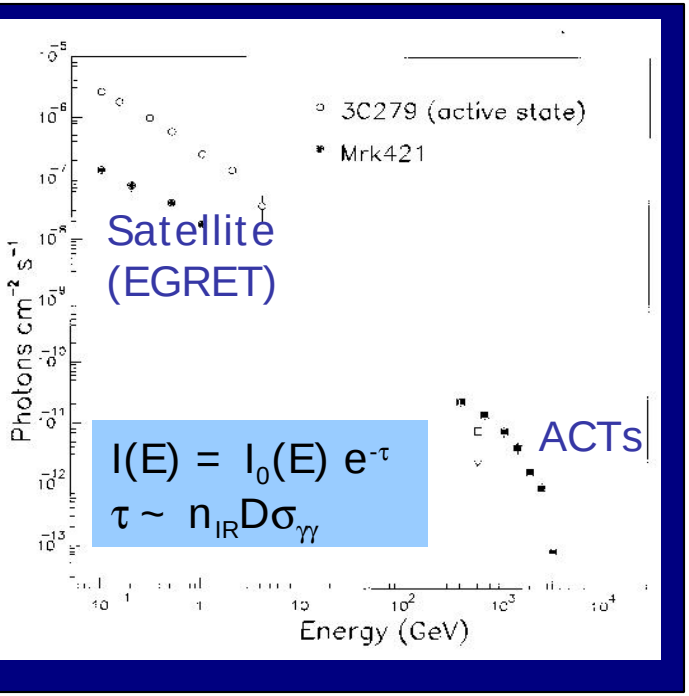
STACEE: Possibilities for AGN Studies

- Indirect measurement of the optical/IR extragalactic background li

- Difficult to measure optical background directly:
- γ-rays pair produce with EBL
- > 100 GeV, sensitive to optical/UV



Hauser & Dwek 2001



Most EGRET blazars are not detected > 250 GeV

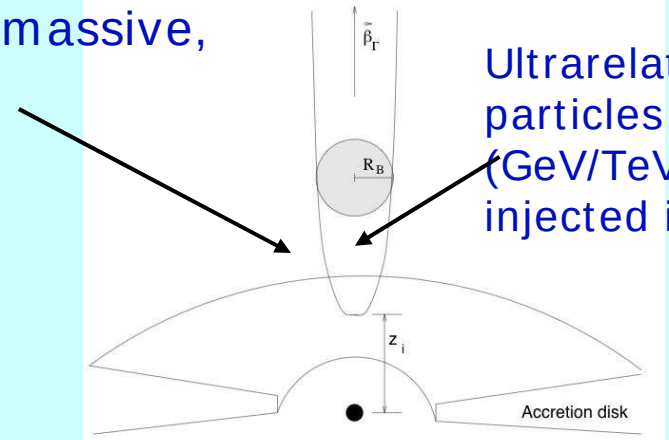
Cutoffs -- intergalactic absorption, intrinsic.

STACEE: Possibilities for AGN Studies

- **Study the physics of blazars**

Jet powered by accretion of matter onto supermassive, central object.

One-zone, relativistic jet model



Ultrarelativistic particles (GeV/TeV) injected into blob

Fig: Boettcher et al. 1997

Current paradigm:

- Synchrotron self Compton
- External Compton
- Proton induced cascades
- Proton synchrotron

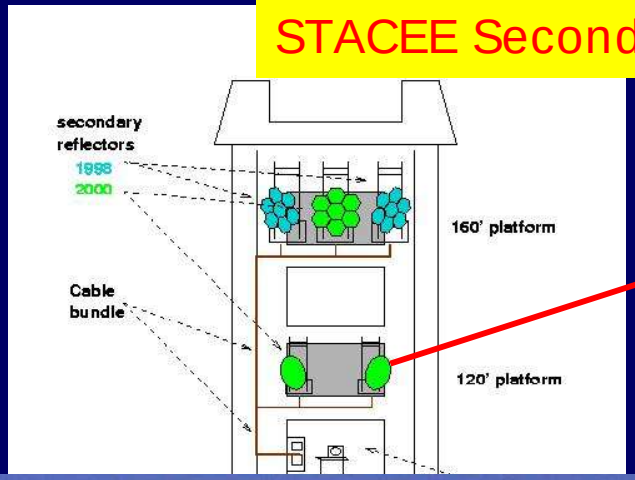
Energetics, formation & collimation of jet, nature of plasma, accel. mechanisms, & magnetic fields are

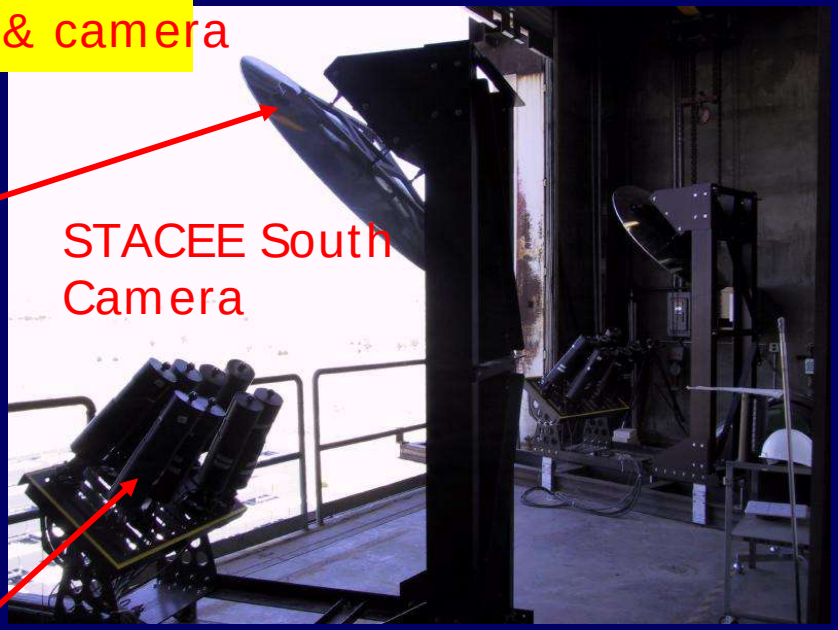
See e.g. Boettcher 2002 (leptonic)
Reimer 2003 (hadronic)

~ 100 GeV γ-ray observations can distinguish between models

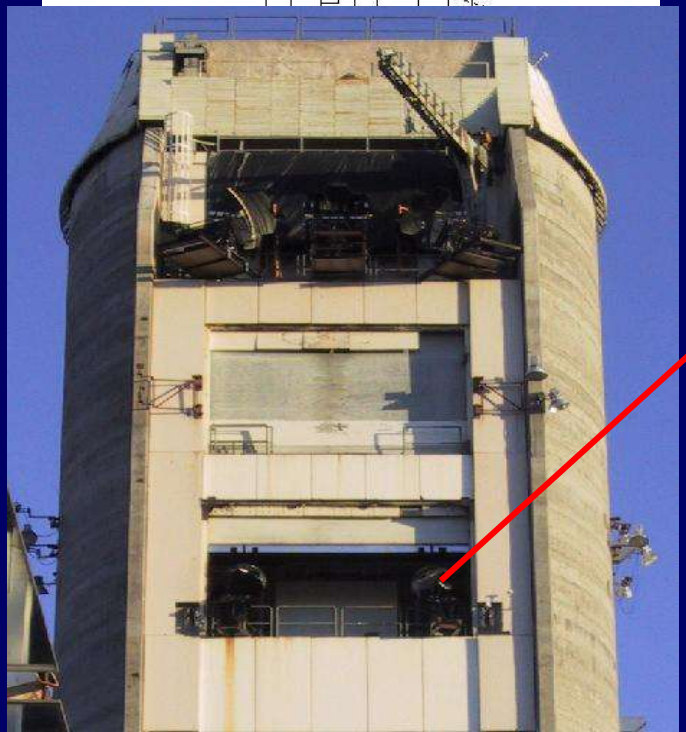
STACEE - More Pictures from the Field

STACEE Secondary optics & camera





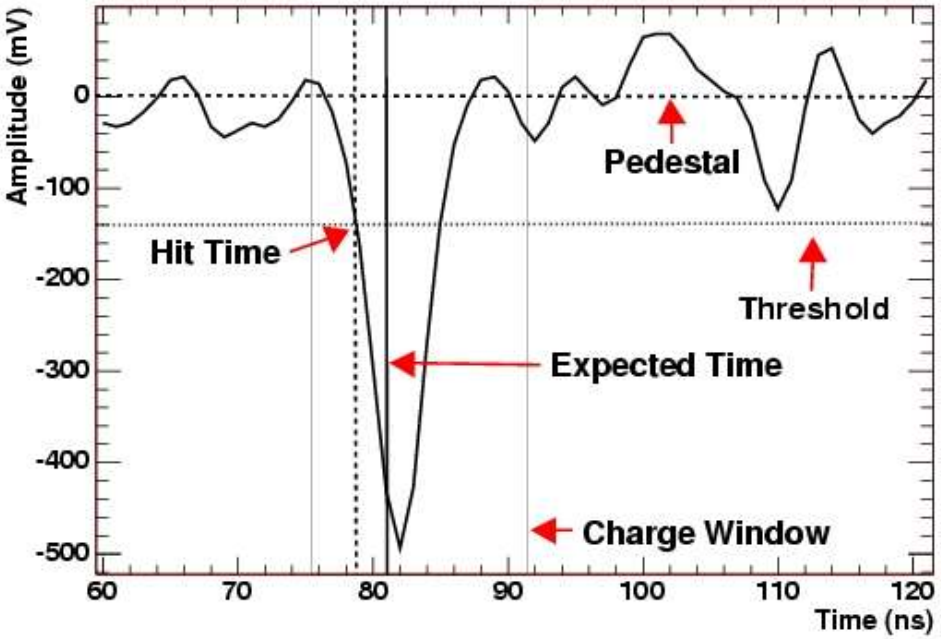
STACEE South
Camera



STACEE primary optics
(Heliostats)

8 bit Flash ADCs

- ✸one per channel (64)
- ✸1 GS/s



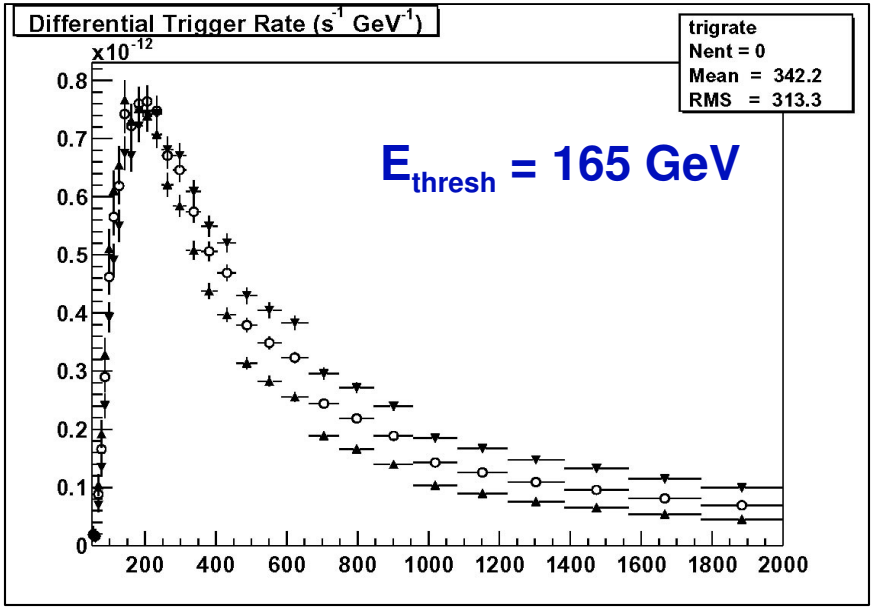
Recent heliostat upgrade

- ✸faster slewing (1 min to GRB location)

(See poster by A. Jarvis for more details.)

STACEE Advantages / Disadvantages

- 2-level trigger system ↙
  good hardware rejection of hadrons
- GHz FADCs ↙
  pulse shape information
- Large mirror area (64X37m2) ↙
  low energy threshold

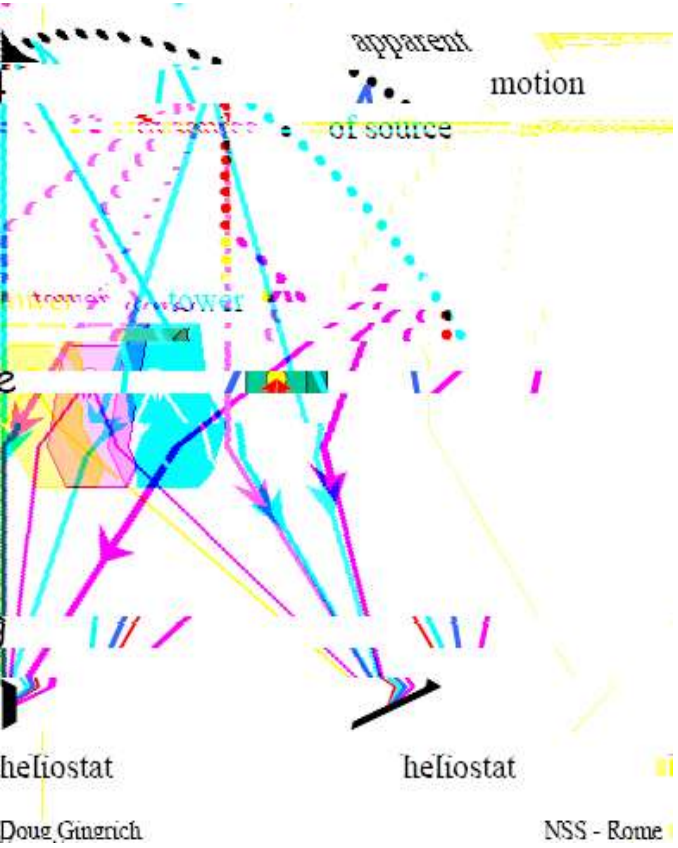


But…

- Limited off-line cosmic ray rejection
  ↙ limited sensitivity: 1.4σ/hour on the Crab Nebula
- Compare to Whipple sensitivity: 3σ/hour above 300 GeV

"τ" for electronic integration time -- at the trigger level

- As earth rotates, 1 ns changes in optical paths occur ~twice per minute.
- Single photoelectron rates are 1 GHz per PMT, or more.
- STACEE has discriminators, then pipeline delays, then coincidences.



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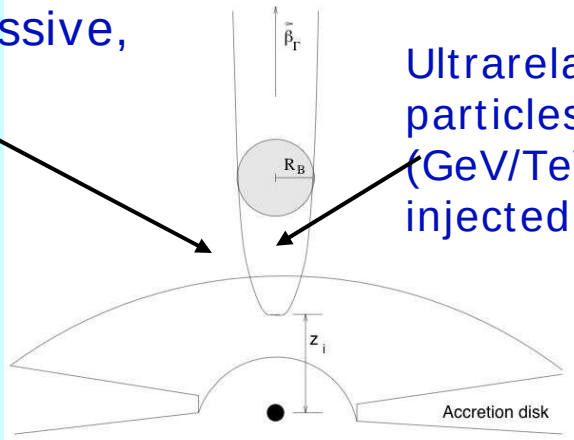

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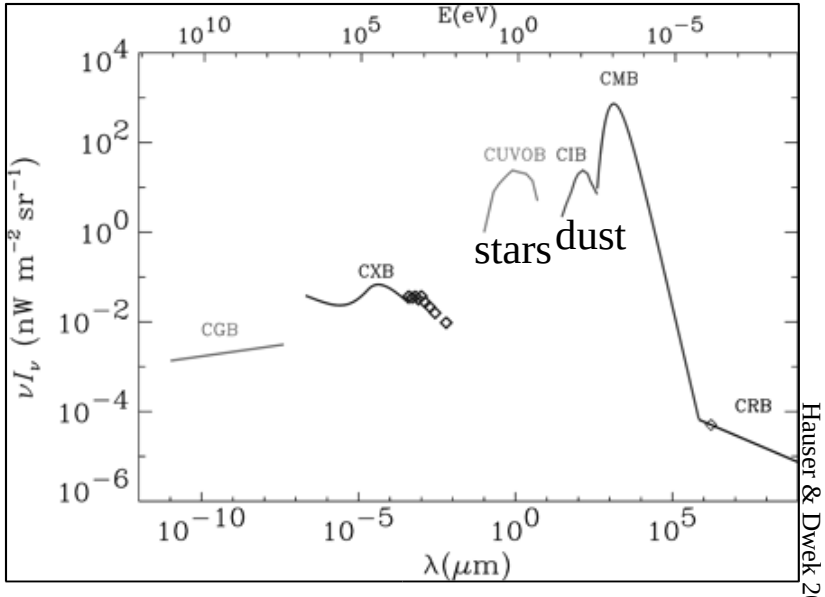
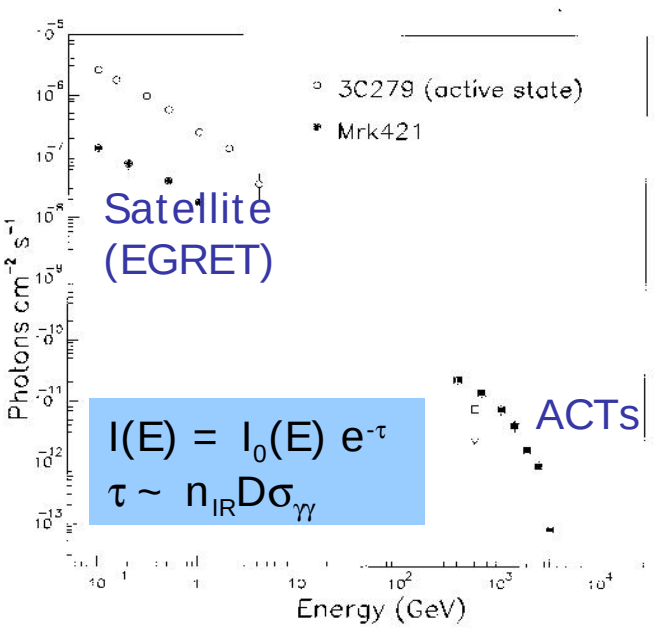


Hauser & Dwek 2001



$I(E) = I_0(E)\, e^{-\tau}$

$\tau \sim n_{IR} D \sigma_{\gamma\gamma}$

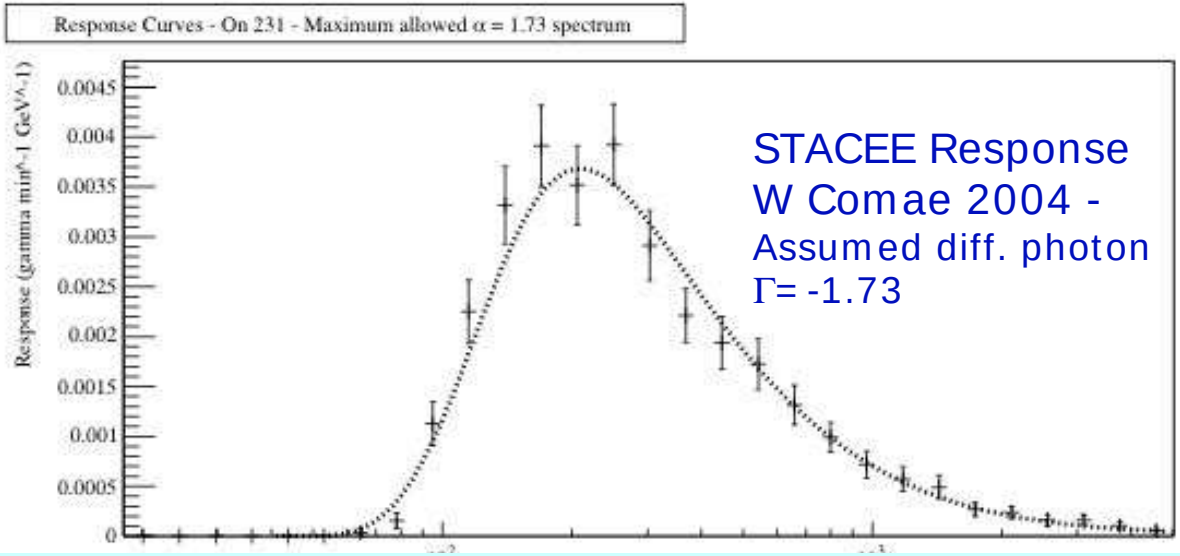
Most EGRET blazars are not detected > 250 GeV

Cutoffs -- intergalactic absorption, intrinsic.

The study of blazars below 250 GeV is a physically interesting subject.

STACEE Observation of W Comae - 2004-5

Year	Total Hrs	Hours after cuts	σ
2003	13.5	10.5	0.67
2004	9.7	4.6	0.2
2005	9.4	5.1	-1.5



STACEE Response W Comae 2004 - Assumed diff. photon $\Gamma = -1.73$

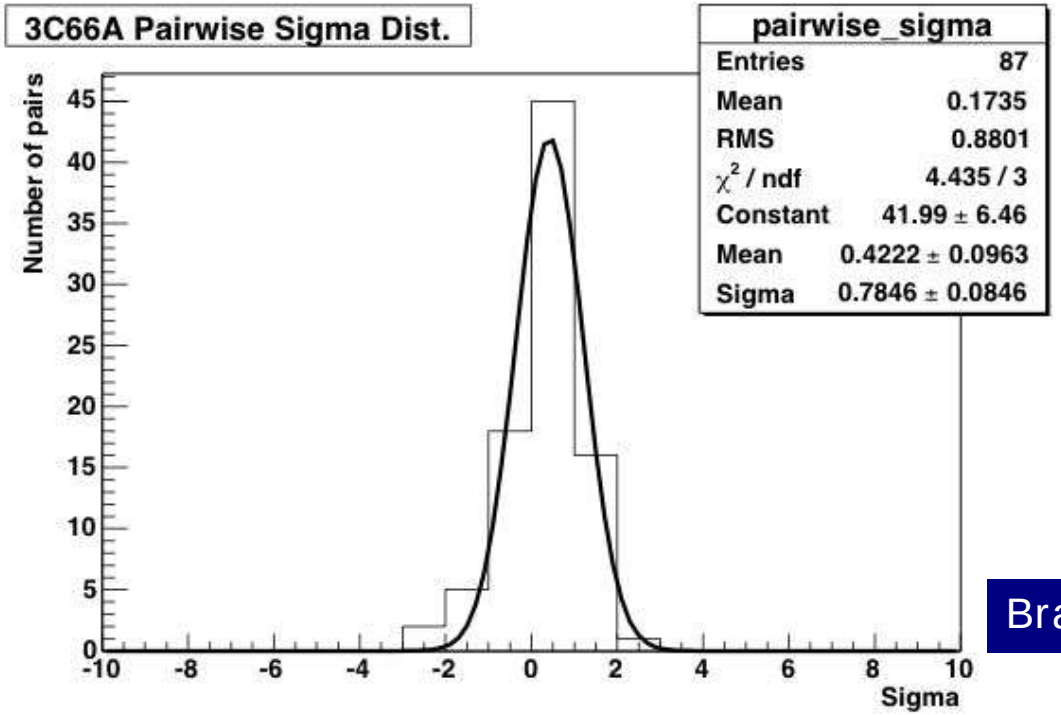
No significant emission detected from W Com in either 2004 or 2005.

Unfortunately, total livetime in 2004+ 2005 less than that in 2003.

3C 66A (2003-2004)

The STACEE data set:

- 85 ON-OFF pairs: 33.7 hours on-source livetime before data-quality cuts.
- Data-quality cuts --
  Hardware problems, HV trips, heliostat problems.
  Bad weather, changing atmospheric opacity.
- Software padding - to counter the effects of field brightness

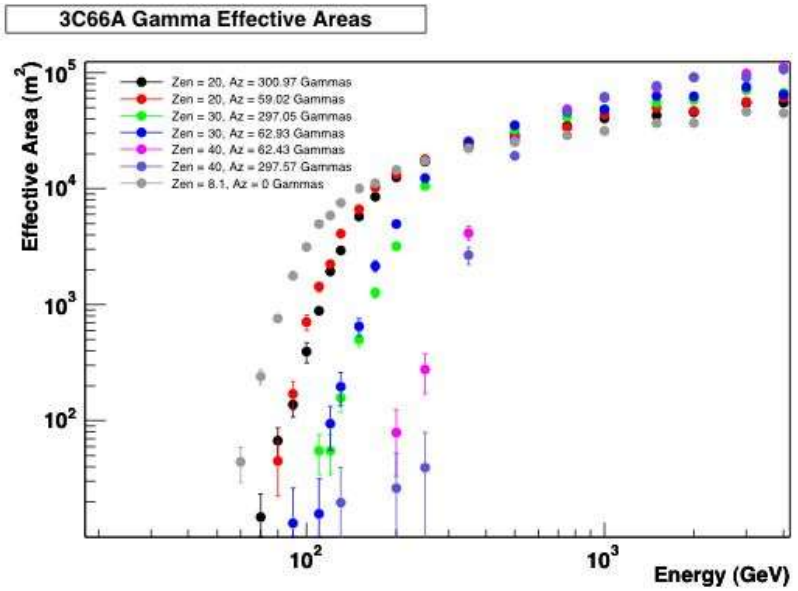


Total livetime after cuts & padding: 16.3 hours.

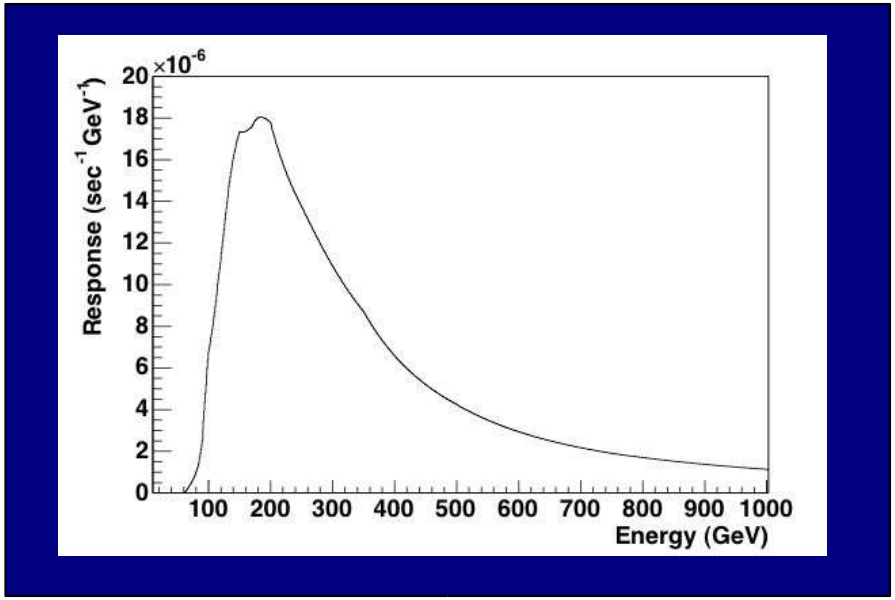
On-source excess: 2.2 σ

Bramel et al. 2005; astro-ph/0504515

3C 66A - Detector Simulations



γ-ray effective areas for STACEE for different hour angles



STACEE response curve, assuming diff. photon spectral index -2.5.

Spectral Index	$\Gamma = \infty$ [a] E_{thresh} [b]	99%CL[c]	$\Gamma = 200$ [a] E_{thresh} [b]	99%CL[c]
−2.0	200	< 1.0	150	< 1.9
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3C 66A integral flux ULs
Units: 10^{-10} ph cm^{-2}s^{-1}

The 3C 66A Redshift