HAWC: A Next Generation All-Sky VHE Gamma-Ray Telescope

Collaboration

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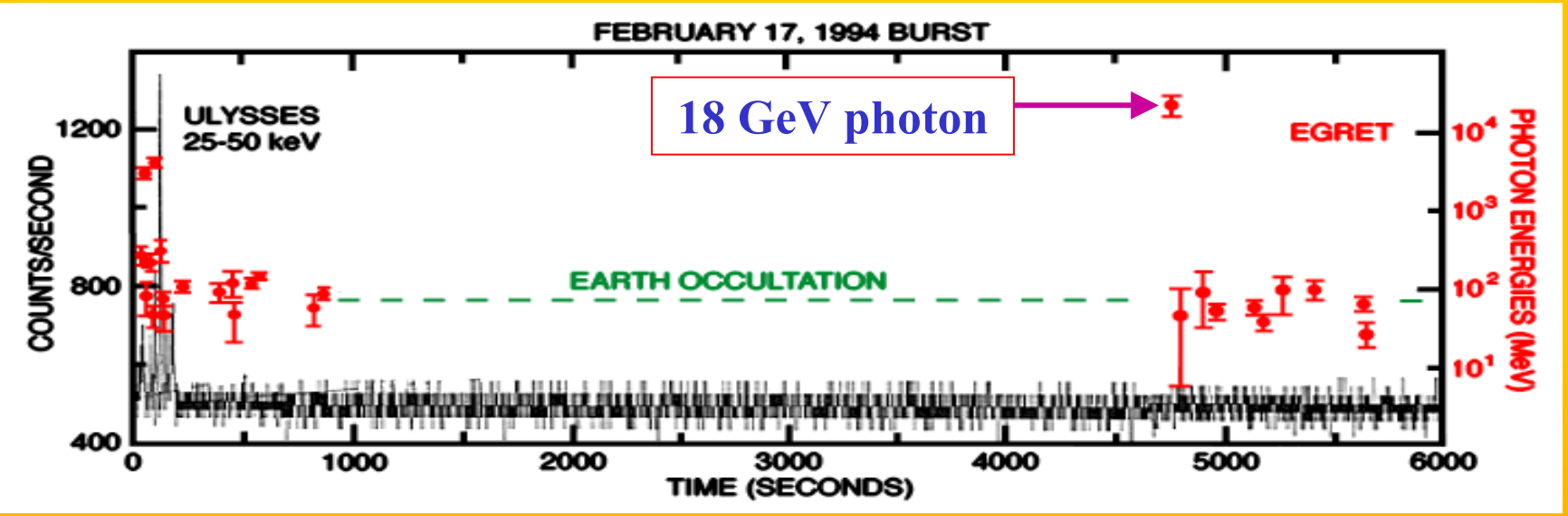
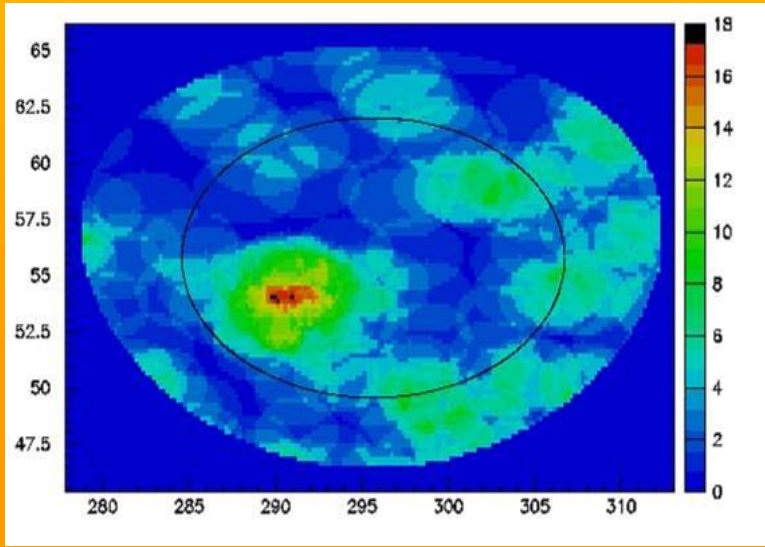
The Need for HAWC

- GLAST
  - Will discover 1000's of sources
  - Many variable
  - ACTs can monitor ~15/year at stated sensitivity
- GRBs
  - Detect highest energy photons in prompt phase
- AGNs
  - Detect/Monitor AGN at redshift < 0.3
  - Study AGN transients in VHE regime
  - Populations studies
- Fundamental Physics
  - Lorentz violation at high energies (quantum gravity?)
  - Dark matter
- Sensitive Sky Survey (~40 mCrab/sqrt(#yrs))
- Time Domain Astrophysics in the VHE Regime
  - Extreme states of extreme systems

GRBs: High Energy Emission





GRB 970417a – Milagrito

10^{-3} chance probability

>650 GeV photons

Quantum Gravity

- Quantum gravity may violate Lorentz invariance
- Most theories predict energy dependent speed of light
  - Interactions with Planck mass particles distort spacetime: yielding larger distances for HE gammas
  - Planck scale vacuum fluctuations probed by HE gammas
- Dynamics of the theory unknown
- Explore possible modifications to dispersion relation (Amelino-Camelia *et al.*)

$$m^2 \cong E^2 - p^2\left(1 - \eta \frac{E}{E_{QG}}\right)$$

For photons this leads to an energy dependent velocity

$$v \approx c\left(1 - \frac{\eta}{2}\frac{E}{E_{QG}}\right)$$

Quantum Gravity & GRBs

For E=1 TeV: $E/E_{QG} = 10^{-16}$

Distant sources of HE γ-rays can amplify this effect

$$\Delta t \approx \eta \frac{LE}{cE_{QG}} = 40\eta\, zE_{TeV} \text{ sec}$$

Figure of Merit: $E_{probe} = 4\times10^{17} \frac{zE_{GeV}}{\Delta t_{\text{sec}}}$

A single detection allows one to set a compelling limit

To prove an effect from QG requires multiple GRBs at different redshifts

GLAST

- E = 30 GeV
- Δt = 1 sec
- z = 1
- $E_{probe} = 1.2\ E_{Planck}$

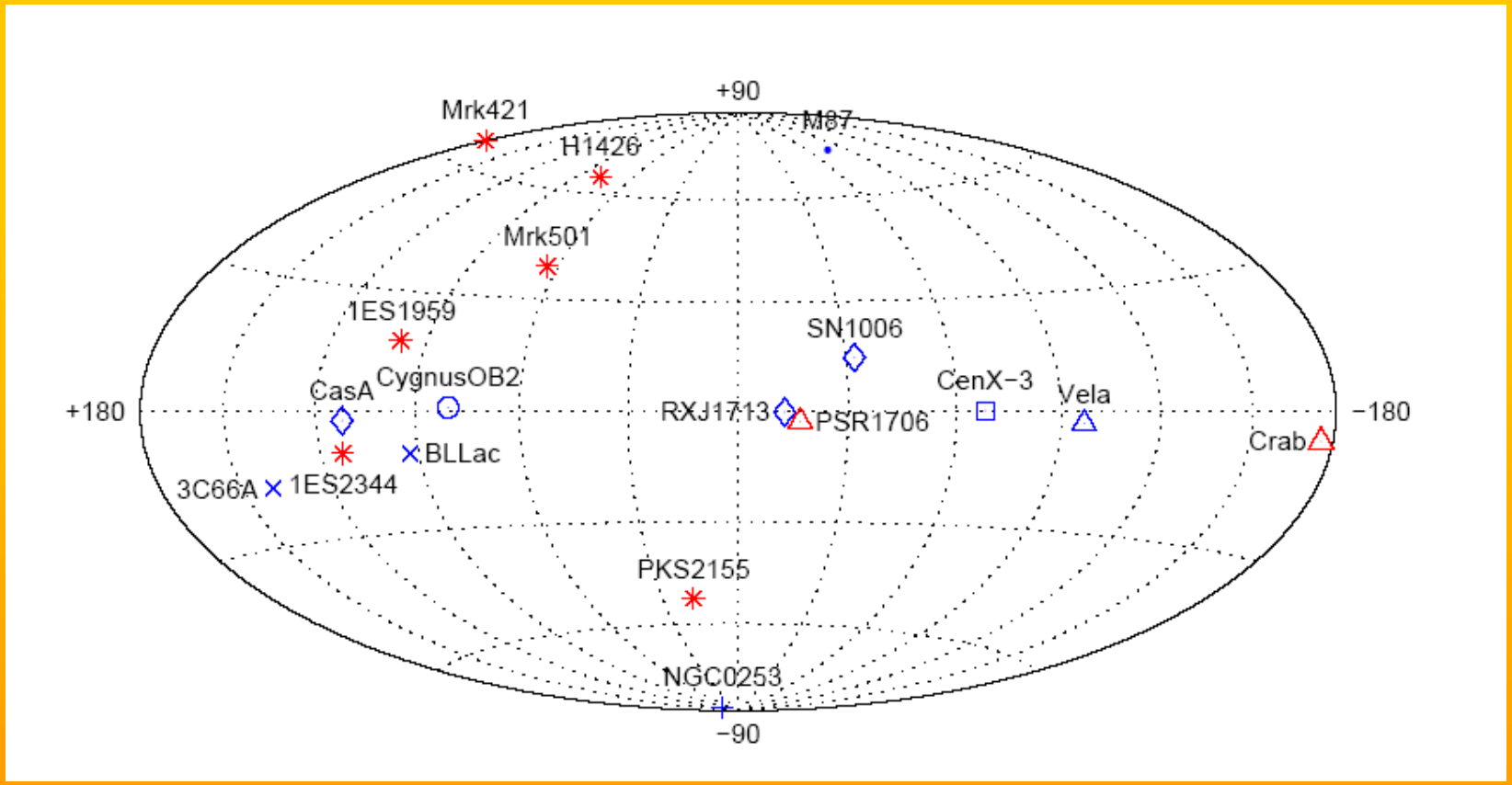
Milagro

- E = 300 GeV
- Δt = 1 sec
- z = 0.2
- $E_{probe} = 2.5\ E_{Planck}$

HAWC

- E = 50 GeV
- Δt = 1 sec
- z = 1
- $E_{probe} = 2\ E_{Planck}$

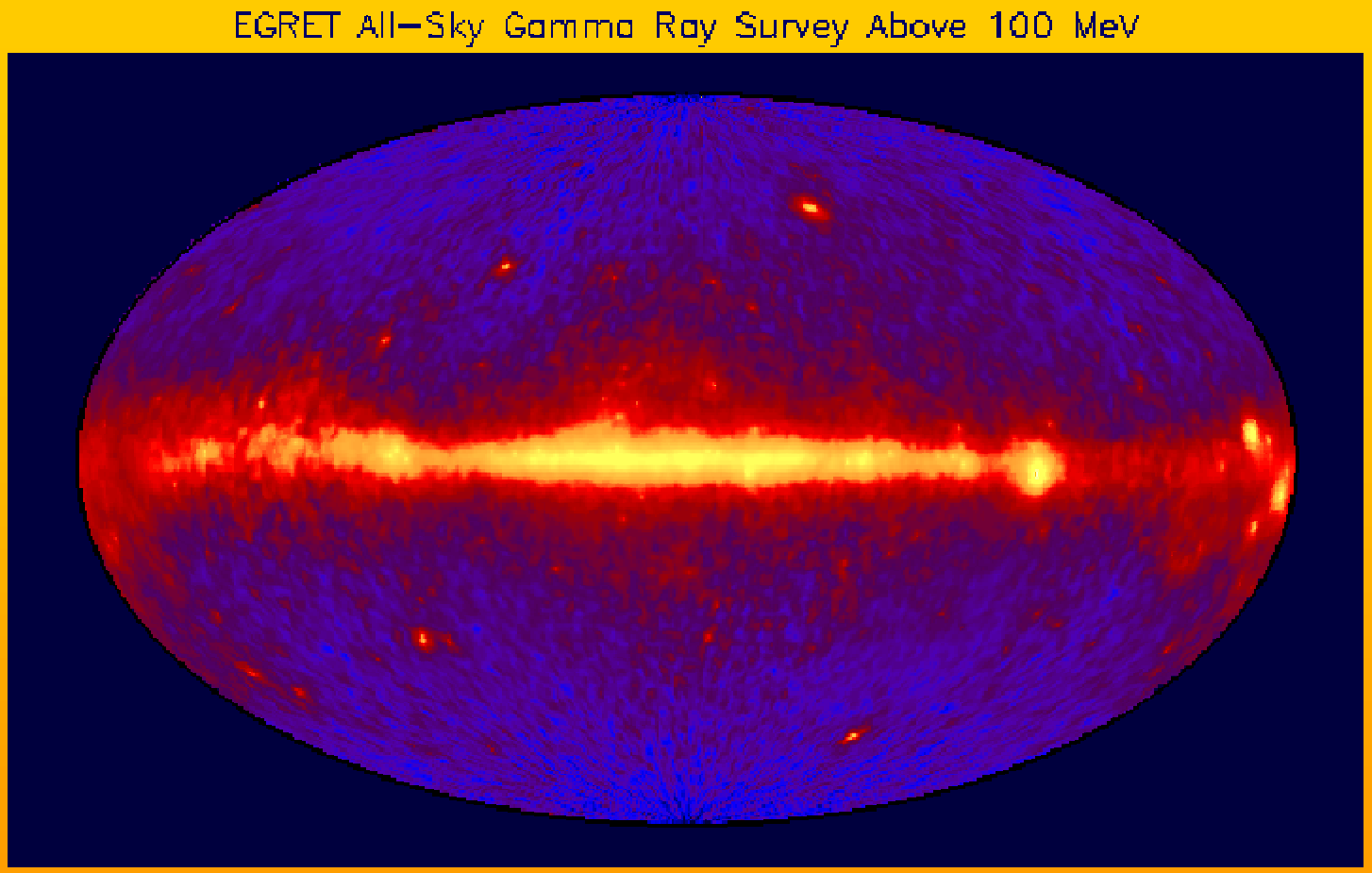
VHE Sky Map



8 verified (A) sources, 5 B sources, 5 C sources
10 extragalactic source, 8 galactic

Horan & Weekes 2003

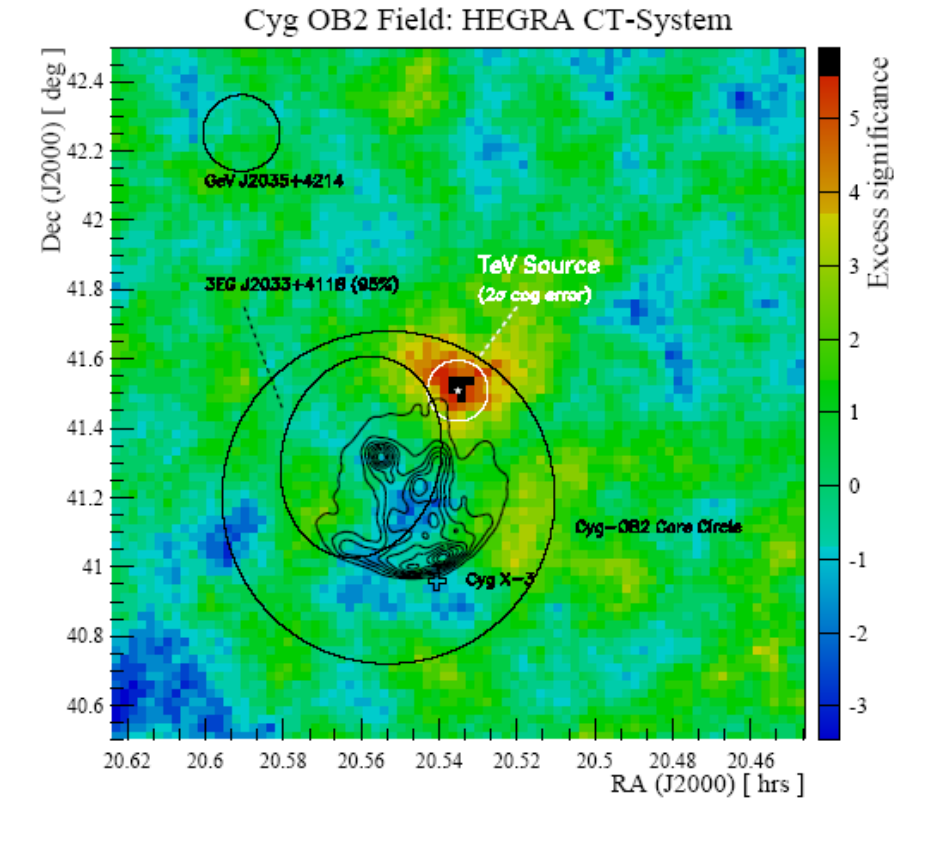
EGRET Sky Map



270 sources (150 unidentified)

6 GRBs (in 9 years)

The First Unidentified TeV Source



HEGRA: Deep observation

113 hours of observation (3 years)

4.6σ significance

30 mCrab strength

Centered on Cygnus OB2 (dense region of young, massive stars)

Possibly an extended source

Current Status of VHE Astronomy

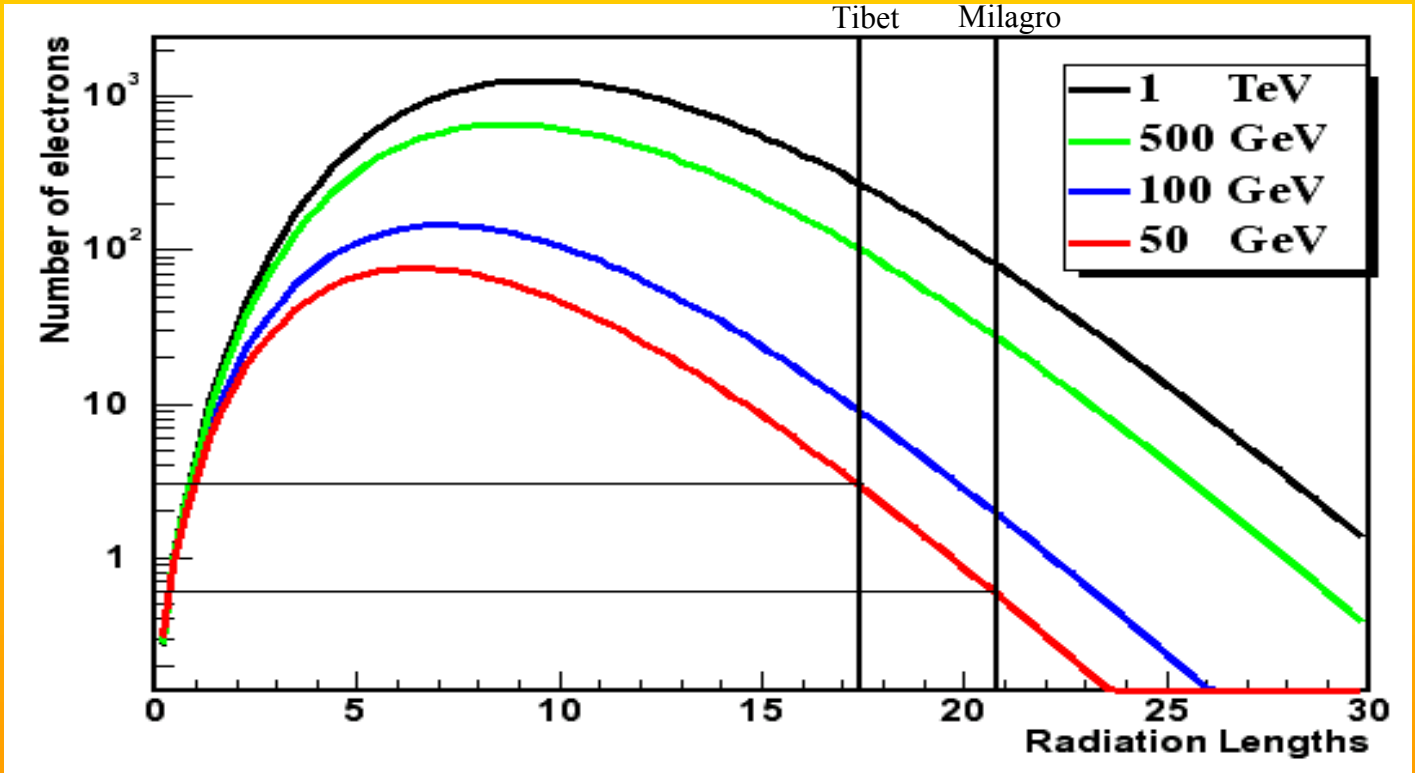
- Only 8 confirmed sources (89, 92, 2*x*95, 97, 2*x*99, 2002)
- 1 unidentified source
- Lack of sources due to:
  - Small field of view of sensitive instruments (ACTs)
  - Low sensitivity of all-sky instruments (Milagro, AS γ)
- Small source counts lead to poor understanding of VHE sources
- VHE GRBs inconclusive (Milagrito)
- HAWC – high sensitivity over entire sky
  - Detect/Discover many sources
  - Monitor transient sources
  - Discover VHE emission from GRBs
  - Limit/Measure effects of quantum gravity
  - Develop time domain astrophysics in VHE regime

HAWC Performance Requirements

- Low Energy Threshold < 50 GeV
  - GRBs visible to redshift ~1
  - Near known GRB energy
  - AGN to redshift ~0.3
- Large fov (~2 sr) / High duty cycle (~100%)
  - GRBs prompt emission
  - AGN transients
  - Time domain astrophysics
- Large Area / Good Background Rejection
  - High signal rate
  - Ability to detect Crab Nebula in single transit
- Moderate Energy Resolution (~40%)
  - Measure GRB spectra (inter-pulse spectra)
  - Measure AGN flaring spectra

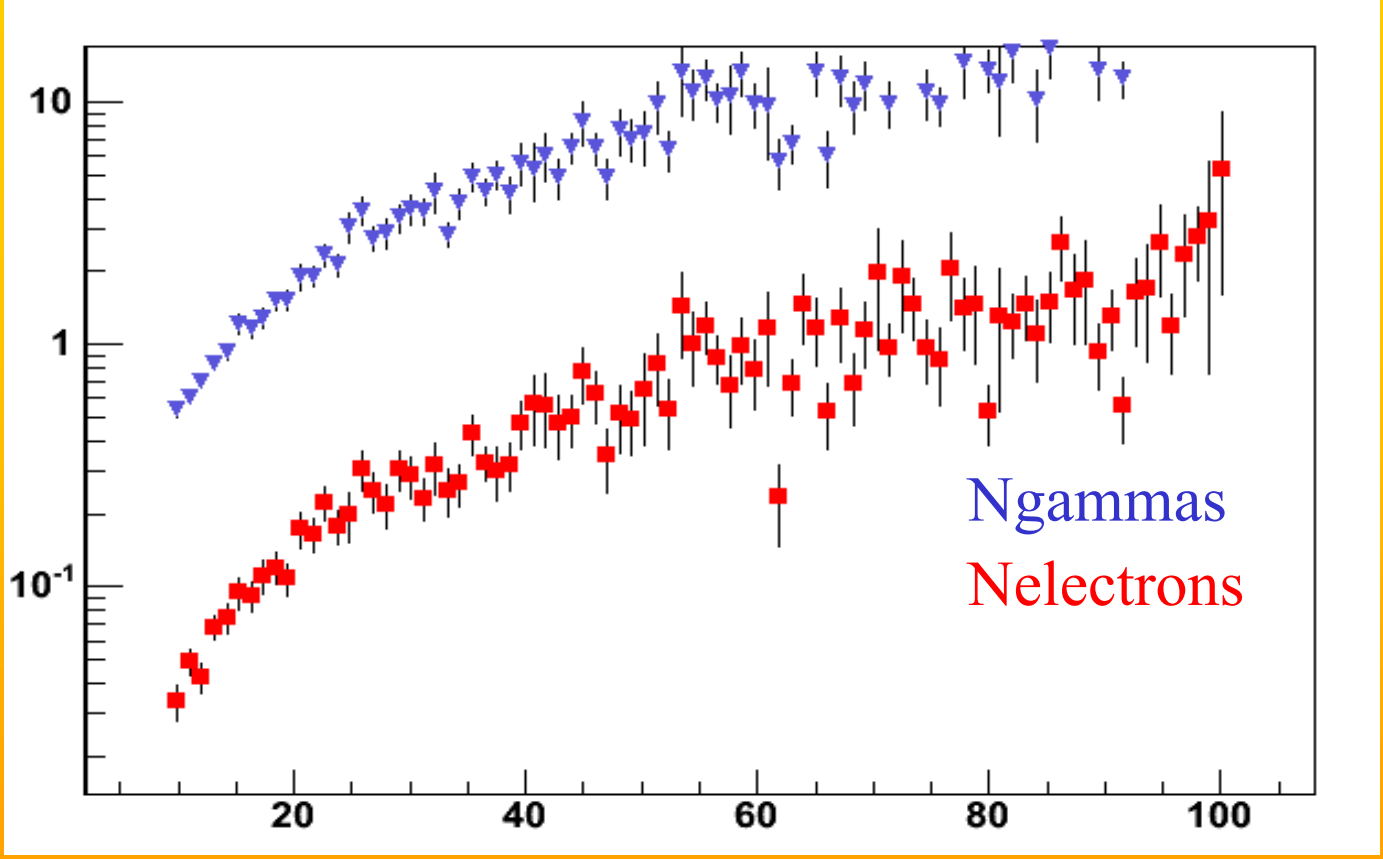
Effect of Altitude

Approximation B



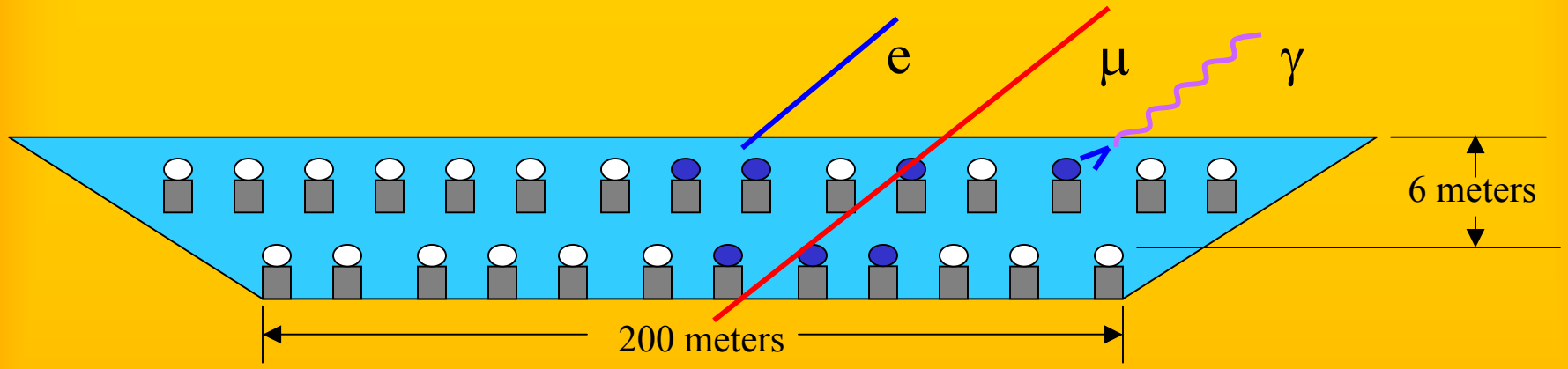
Low Energy Threshold Requires High Altitude

EAS Particle Content



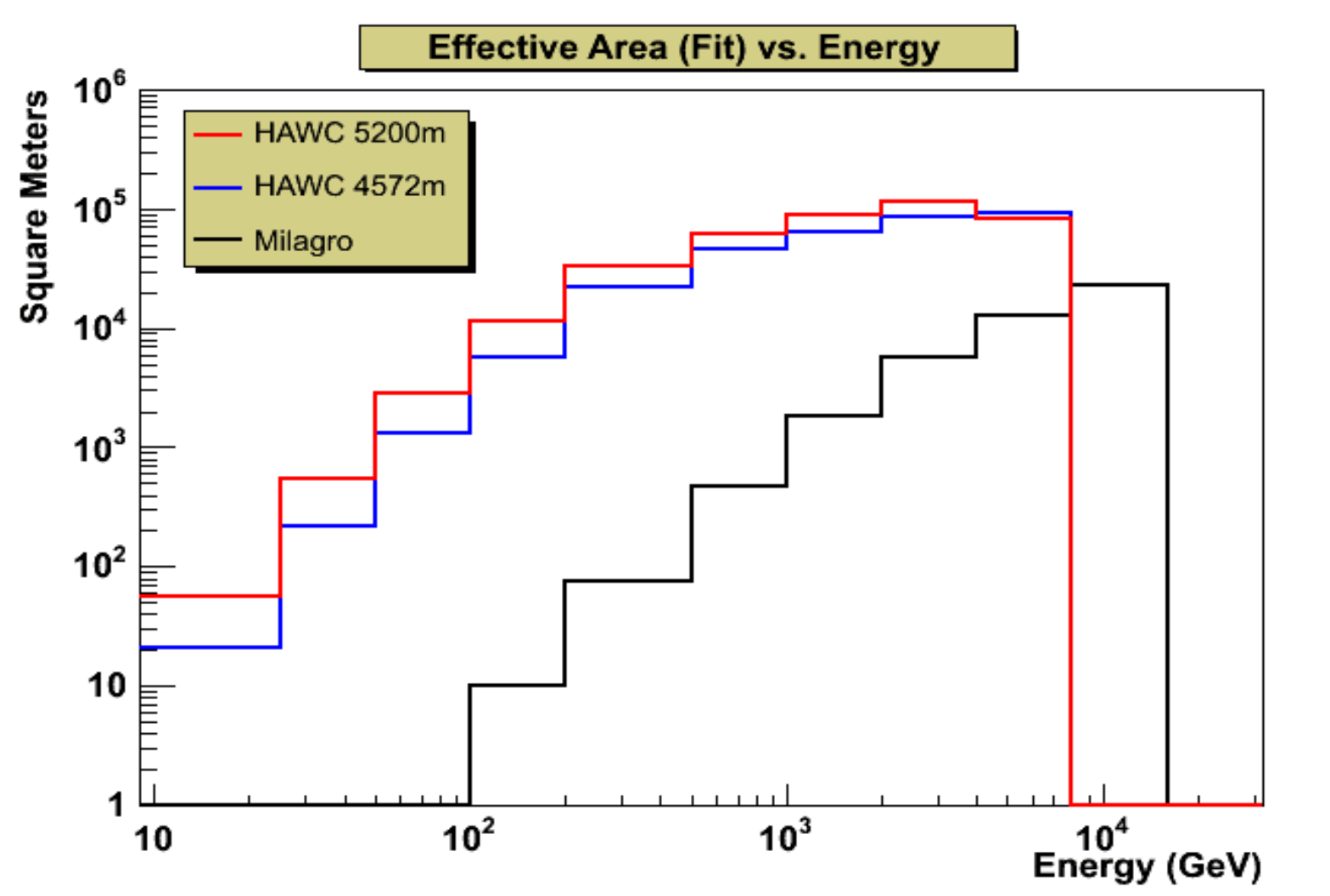
Low Energy Threshold Requires Detection
of Gamma Rays in EAS

HAWC Strawman Design



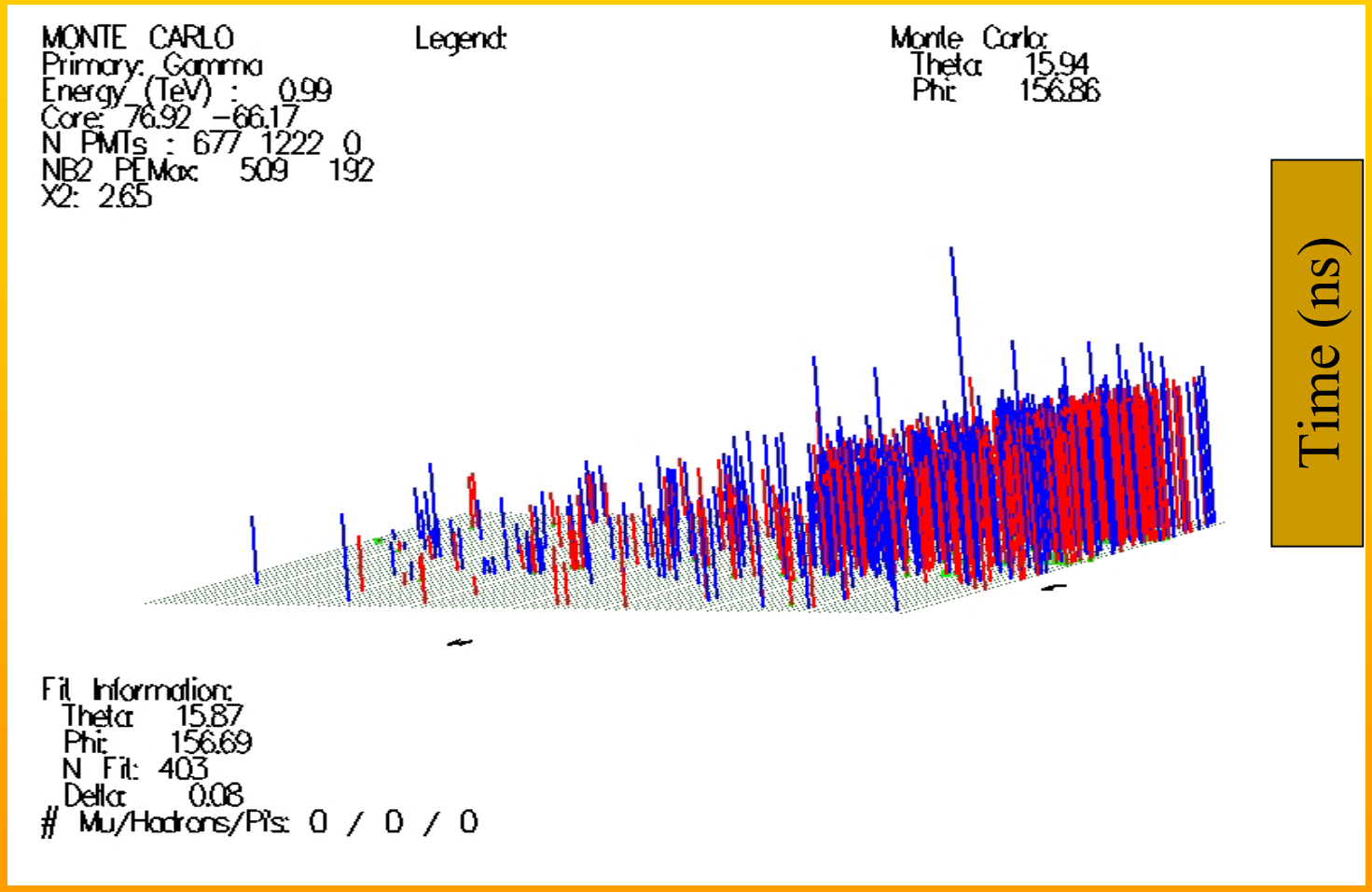
- 200m x 200m water Cherenkov detector
- Two layers of 8” PMTs on a 2.7 meter grid
  - Top layer under 1.5m water (trigger & angle)
  - Bottom layer under 6m water (energy & particle ID)
  - ~10,000 PMTs total (5,000 top and 5000 bottom)
  - Trigger: >50 PMTs in top layer
- Two altitudes investigated
  - 4500 m (~Tibet, China)
  - 5200 m (Atacama desert Chile)

Effective Area vs. Energy



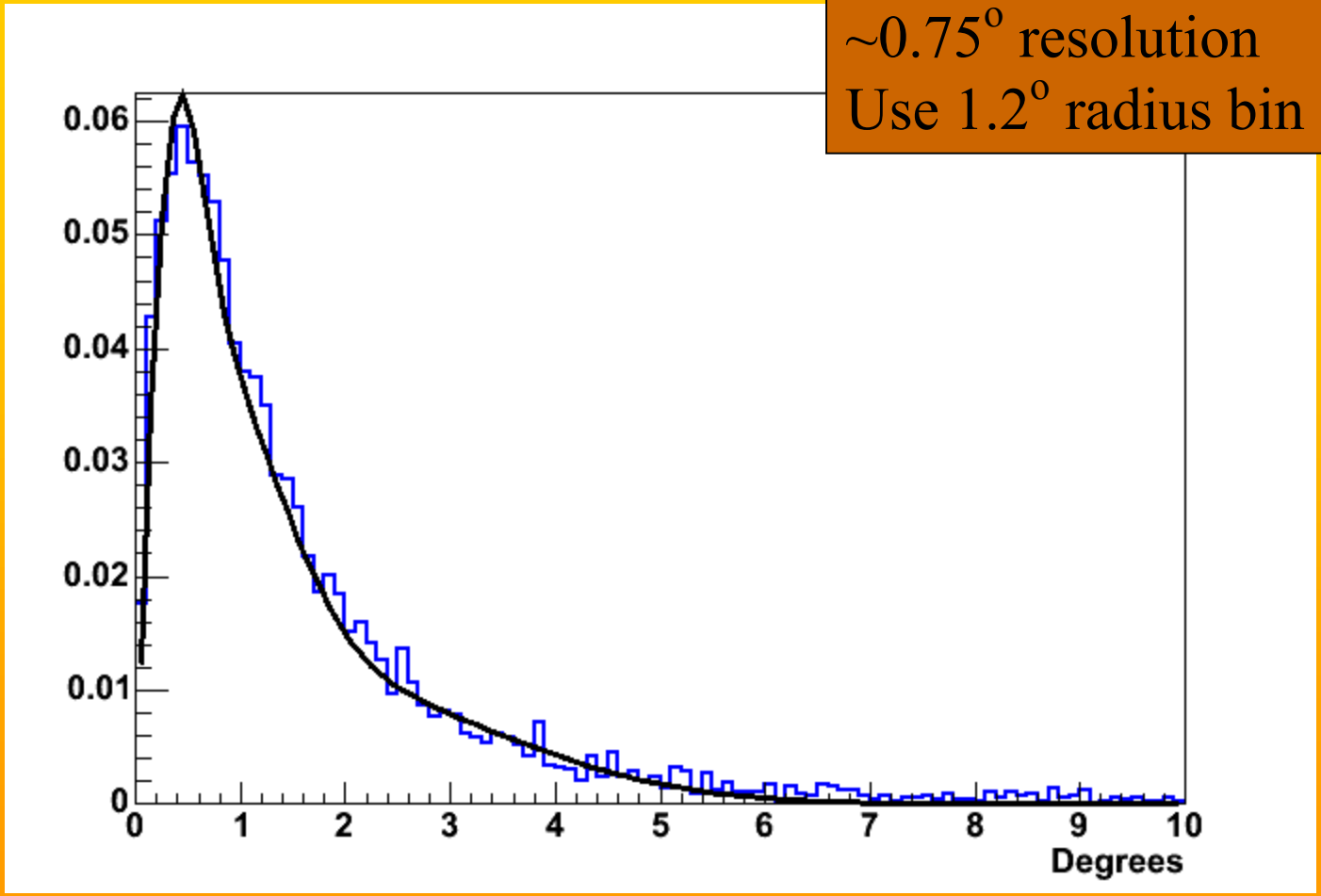
Reconstructed events

Event Reconstruction

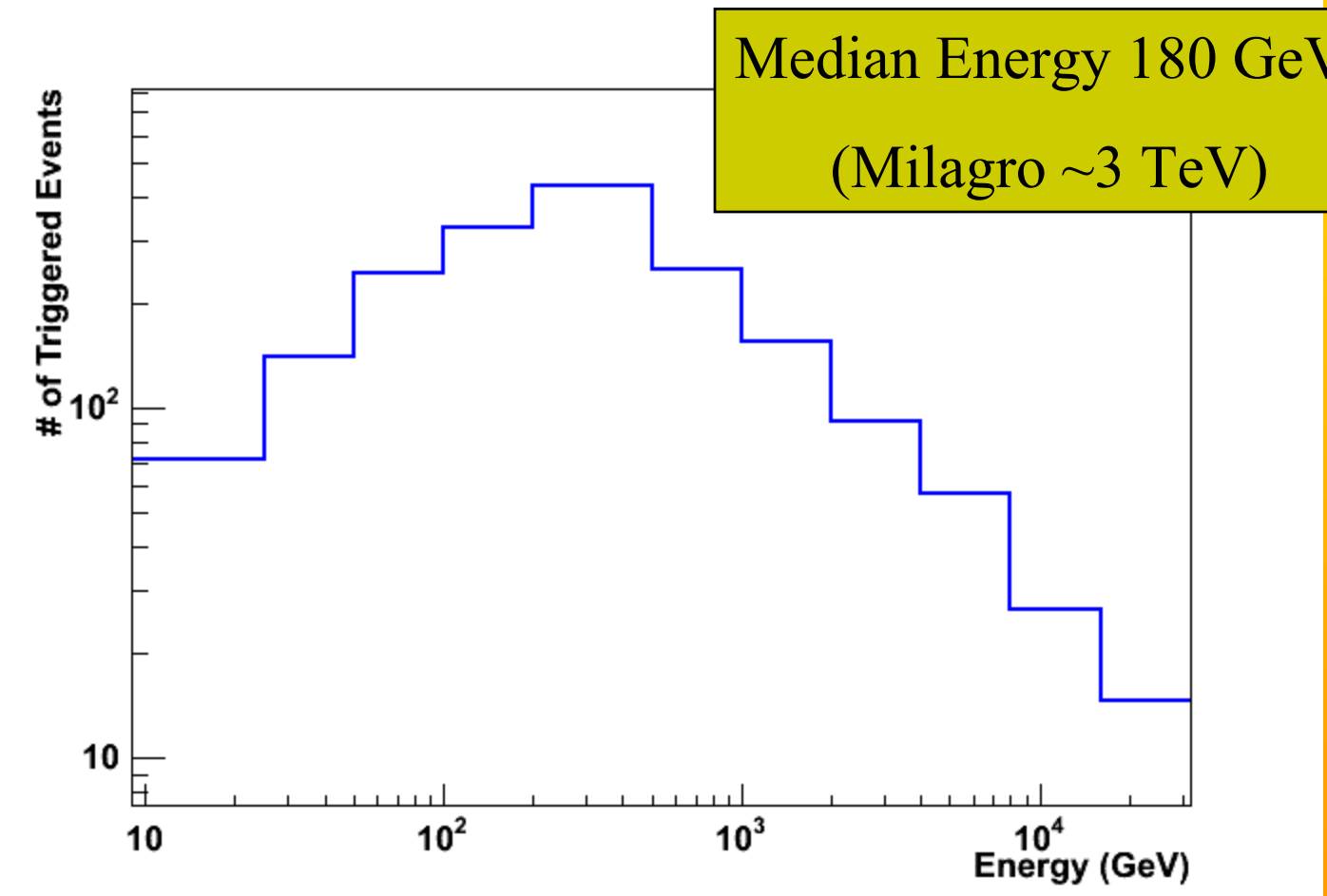


Angular Resolution

~0.75° resolution
Use 1.2° radius bin



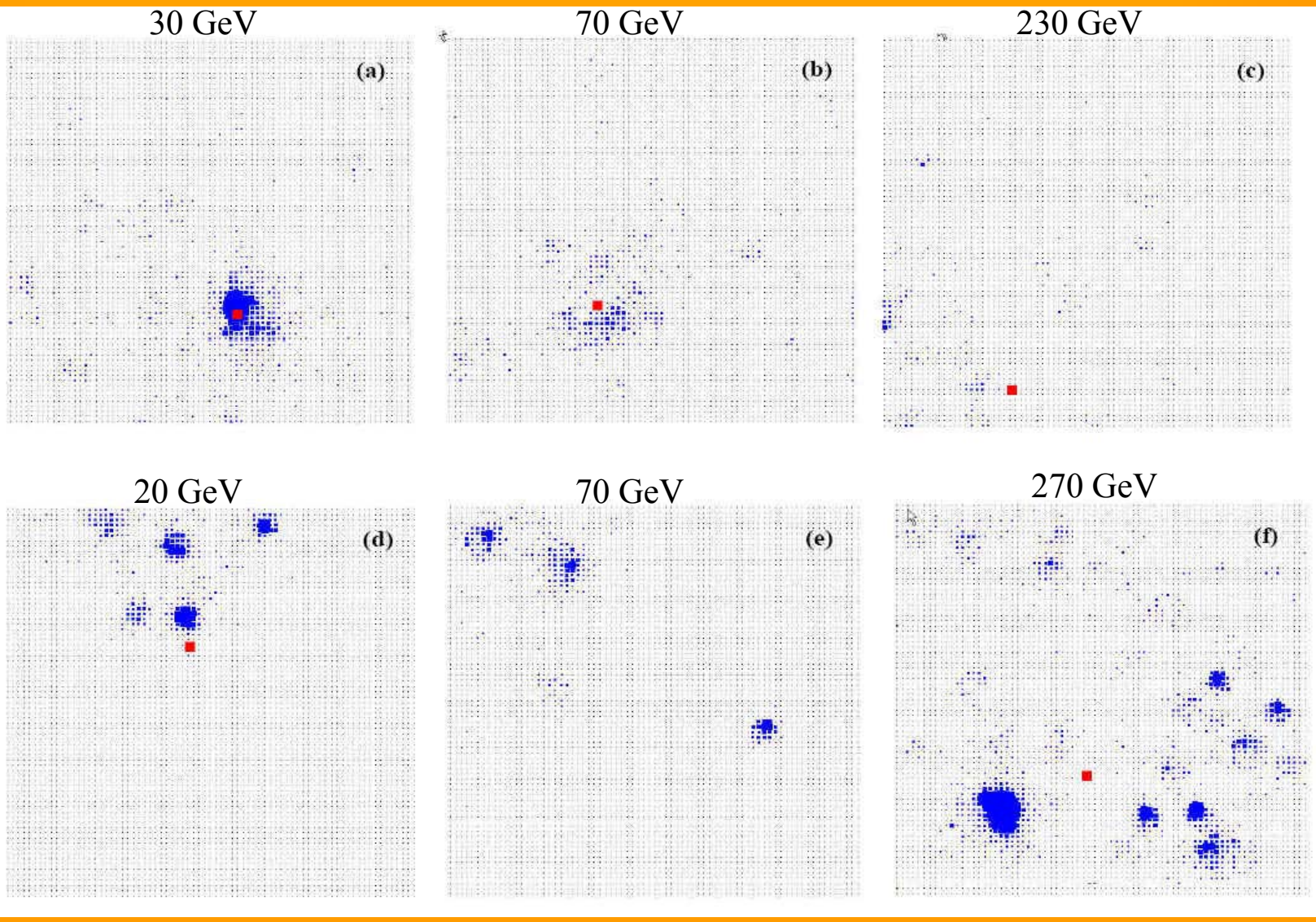
Energy Distribution of Fit Events



Background Rejection: Bottom Layer

Gammas

Protons



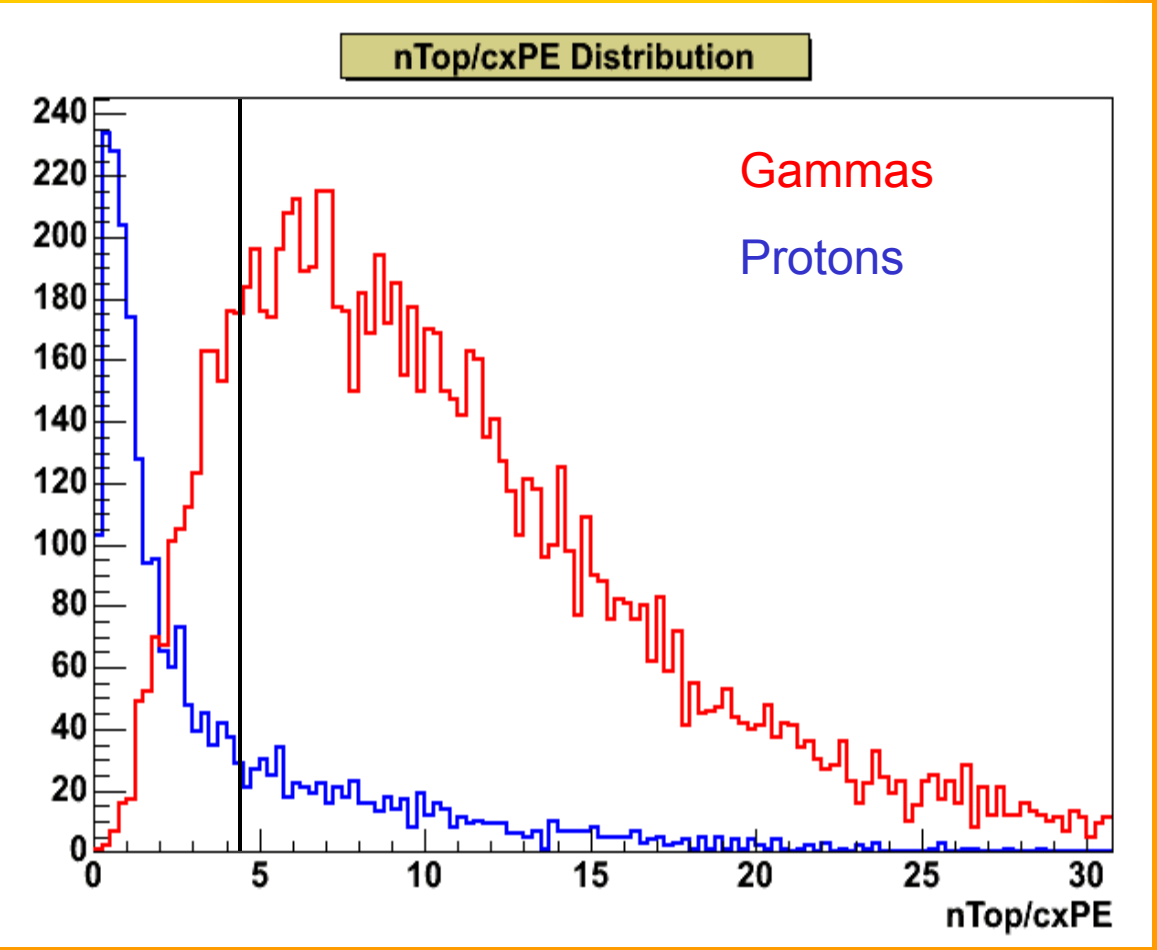
Background Rejection

Uniformity Parameter nTop/cxPE > 4.3

Reject 70% of protons

Accept 87% of gammas

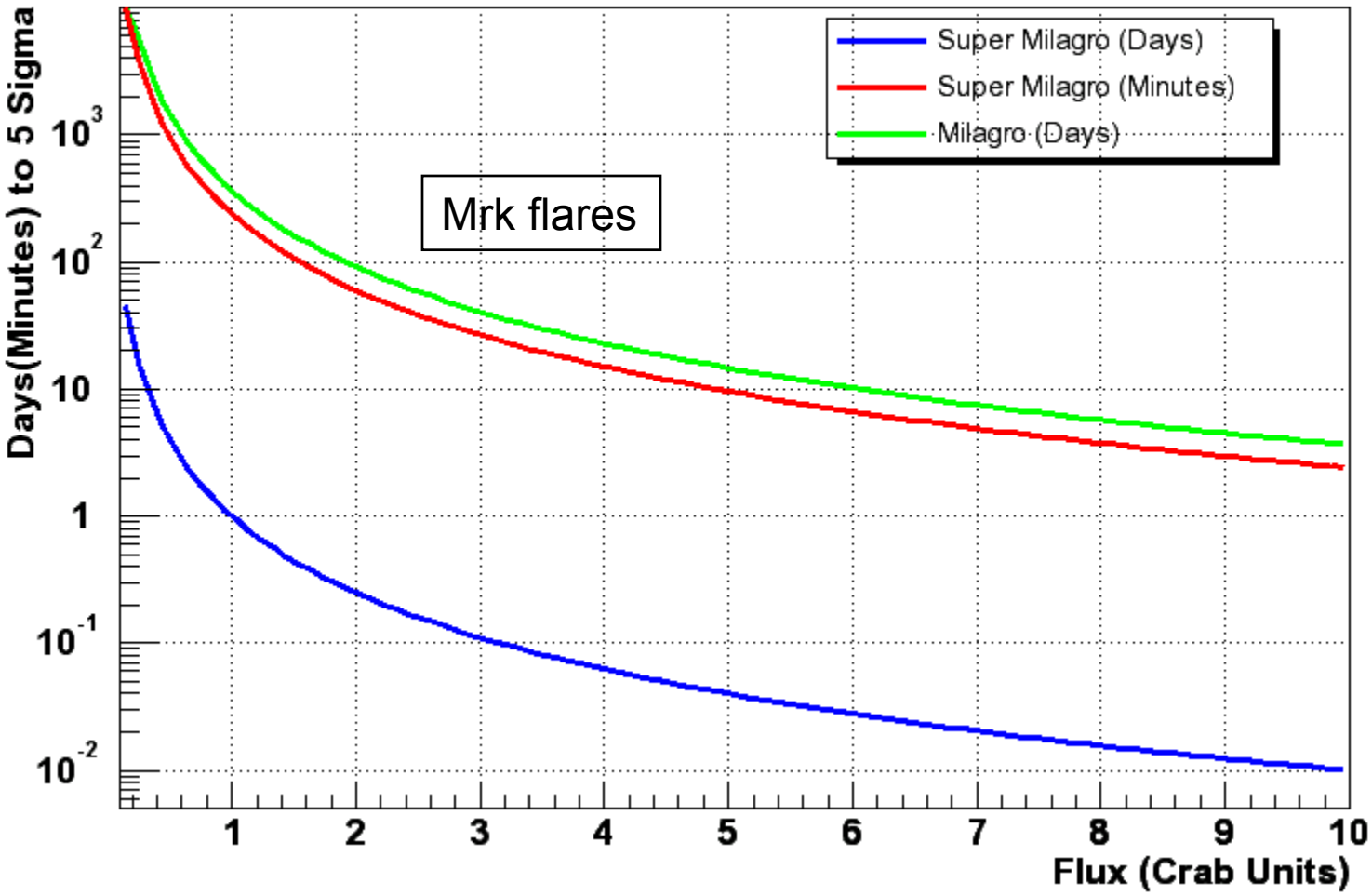
1.6*x* improvement in sensitivity



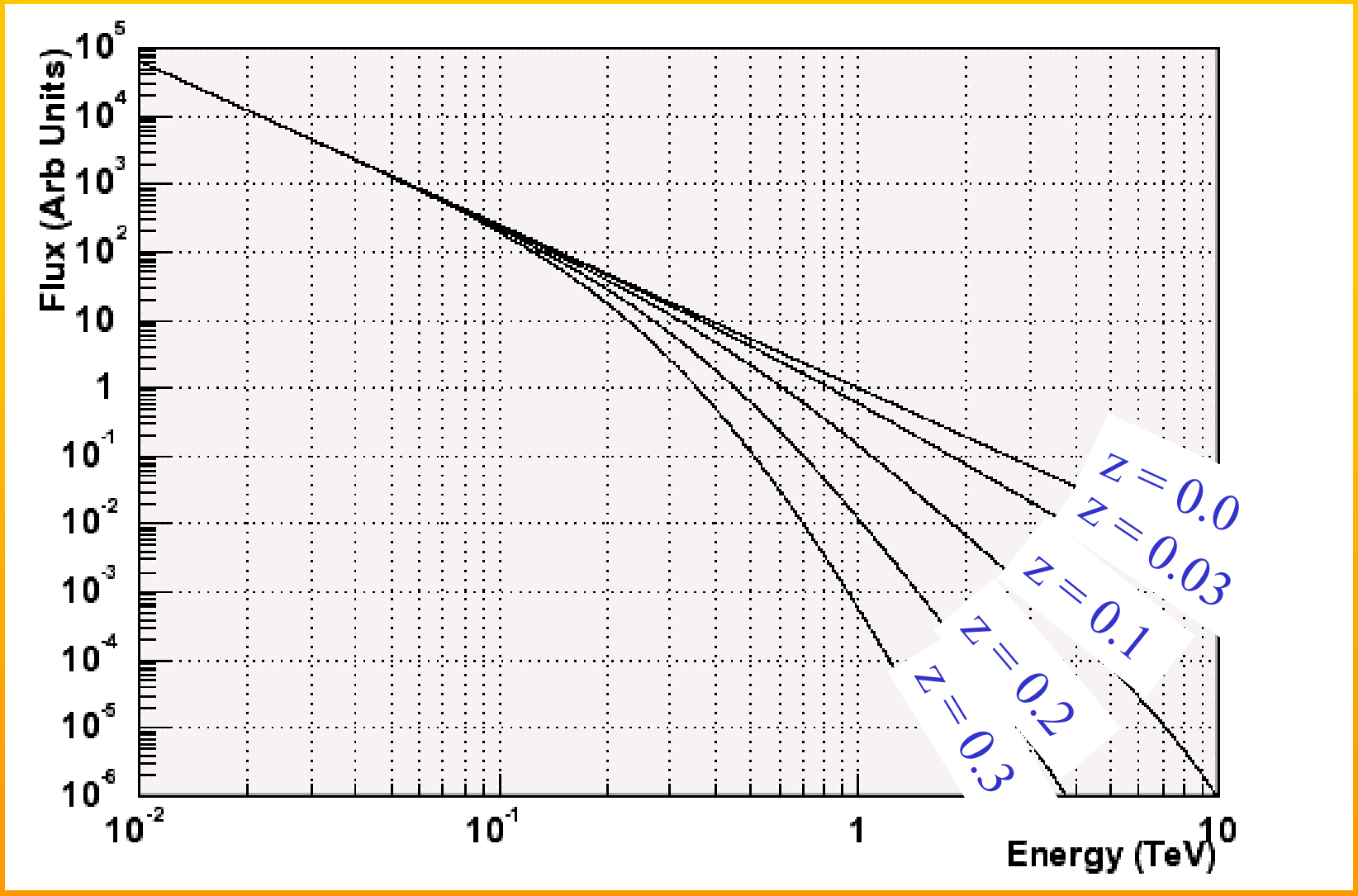
D.C. Sensitivity: Galactic Sources

- "Crab" Spectrum: $dN/dE = 3.2 \times 10^{-7} E^{-2.49}$
  - Milagro 0.002 (0.001) Hz raw (cut) rate
  - HAWC 0.220 (0.19) Hz raw (cut) rate
  - Whipple 0.025 Hz
  - Veritas 0.5 (.12) Hz raw (cut) rate
- Background rate 80 (24) Hz raw (cut)
- 4 σ/sqrt(#days) raw data
- 6 σ/sqrt(#days) cut data
  - 120 σ/sqrt(#yrs)
- 40 mCrab sensitivity (all sky) in one year
  - Whipple: 140 mCrab per source (15 sources/year)
  - VERITAS: 5 mCrab per source (15 sources/year)

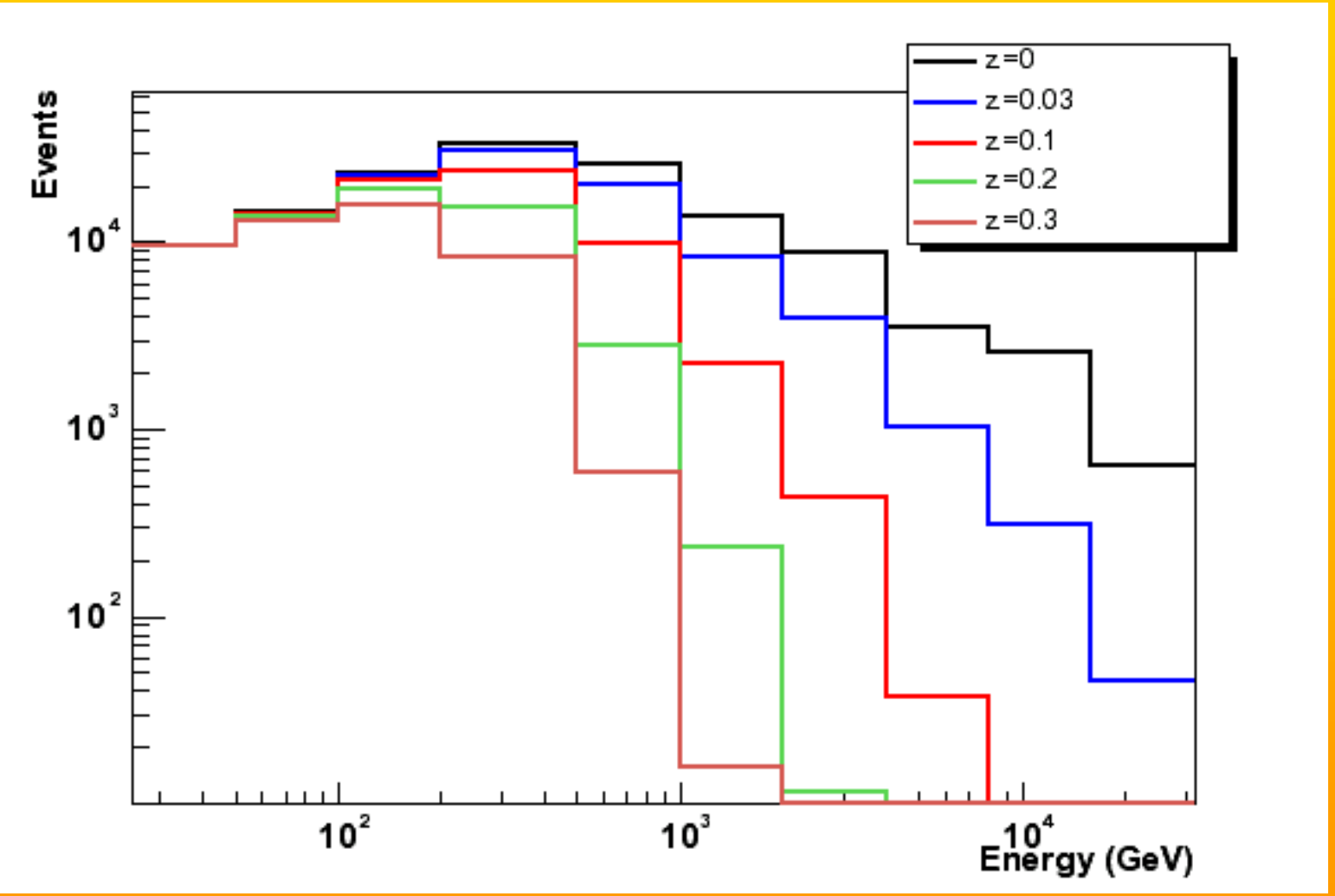
Transient Sensitivity



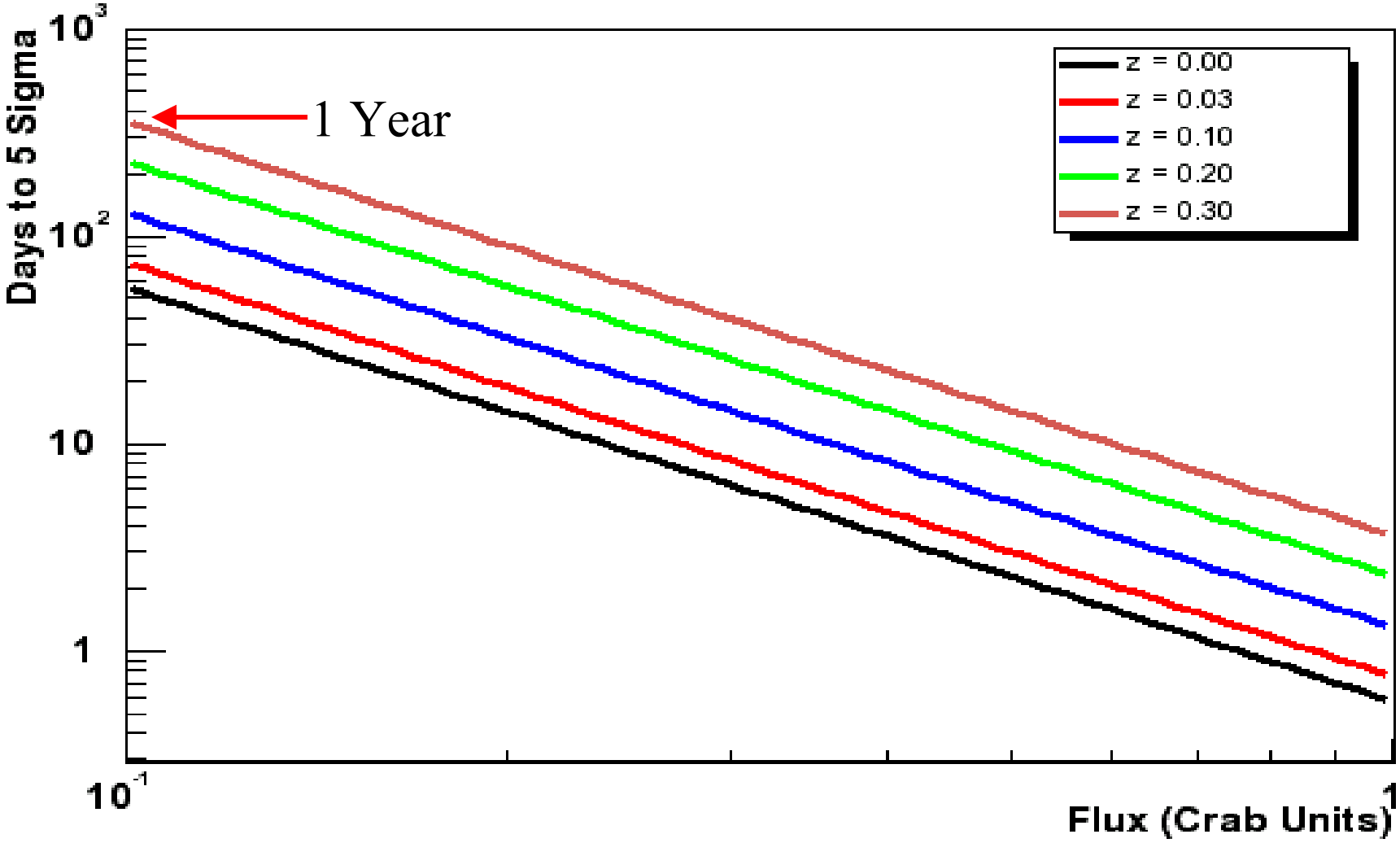
Effect of EBL on Distant Sources



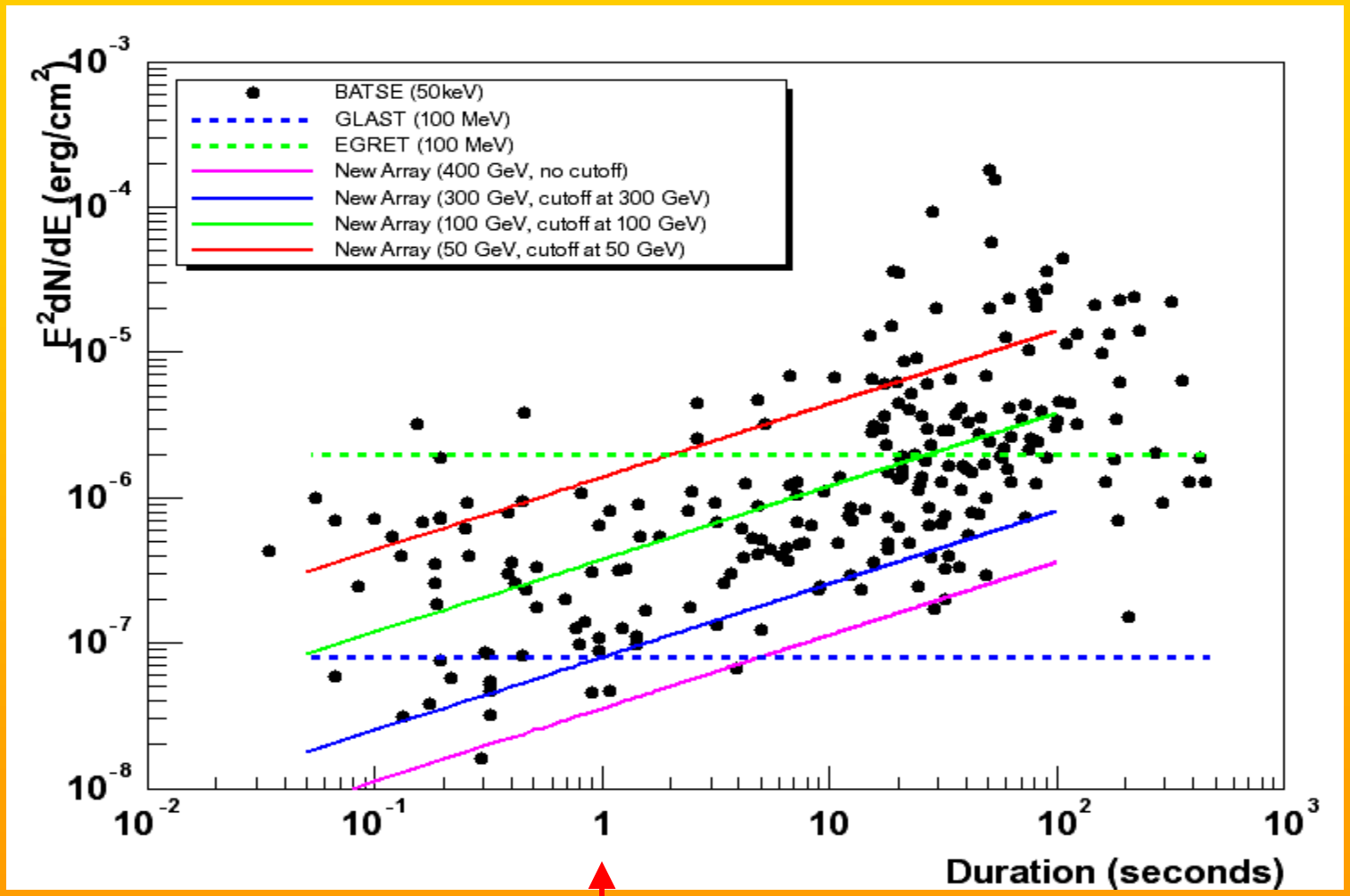
Energy Distribution After EBL



AGN Sensitivity

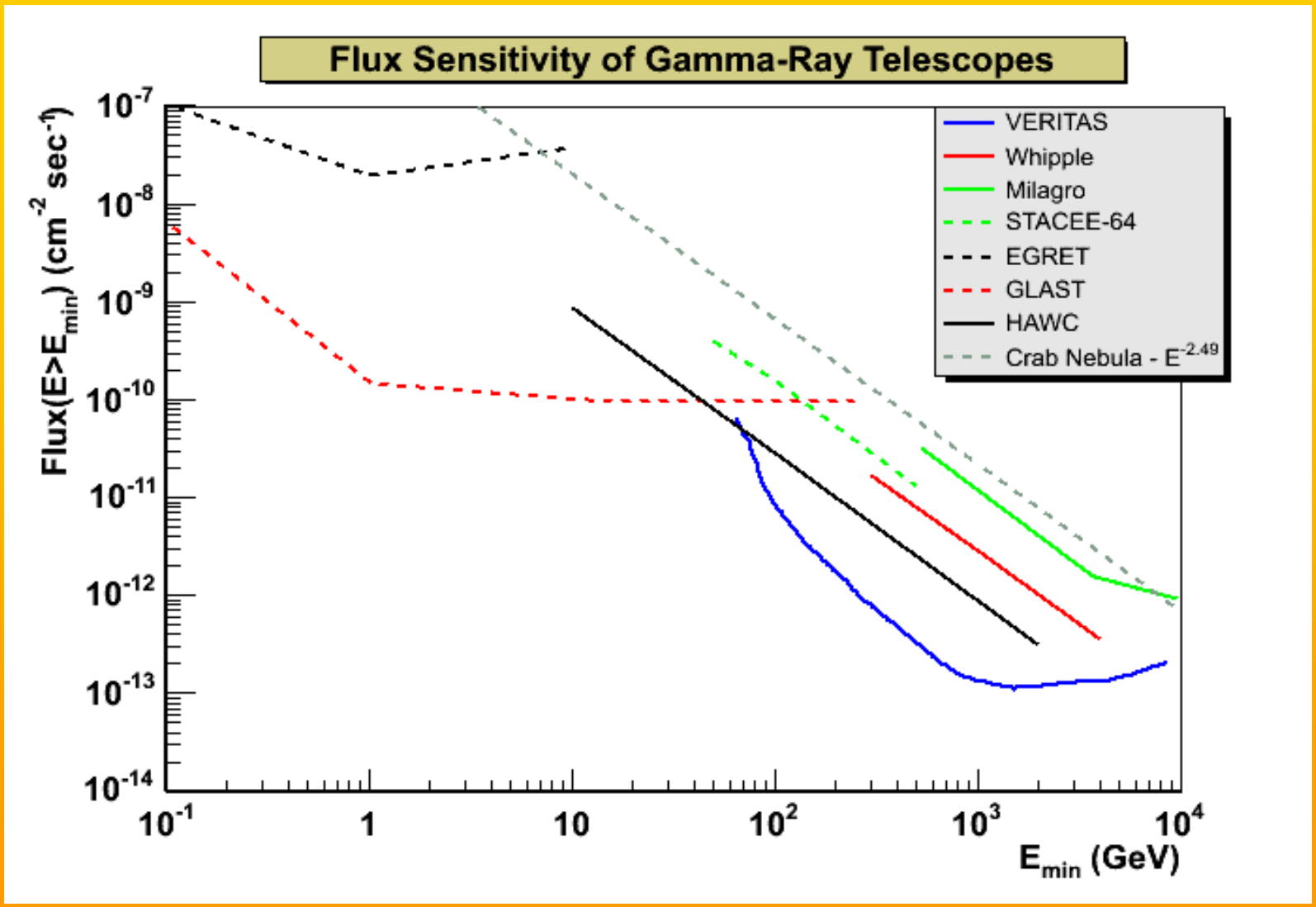


Gamma Ray Burst Sensitivity

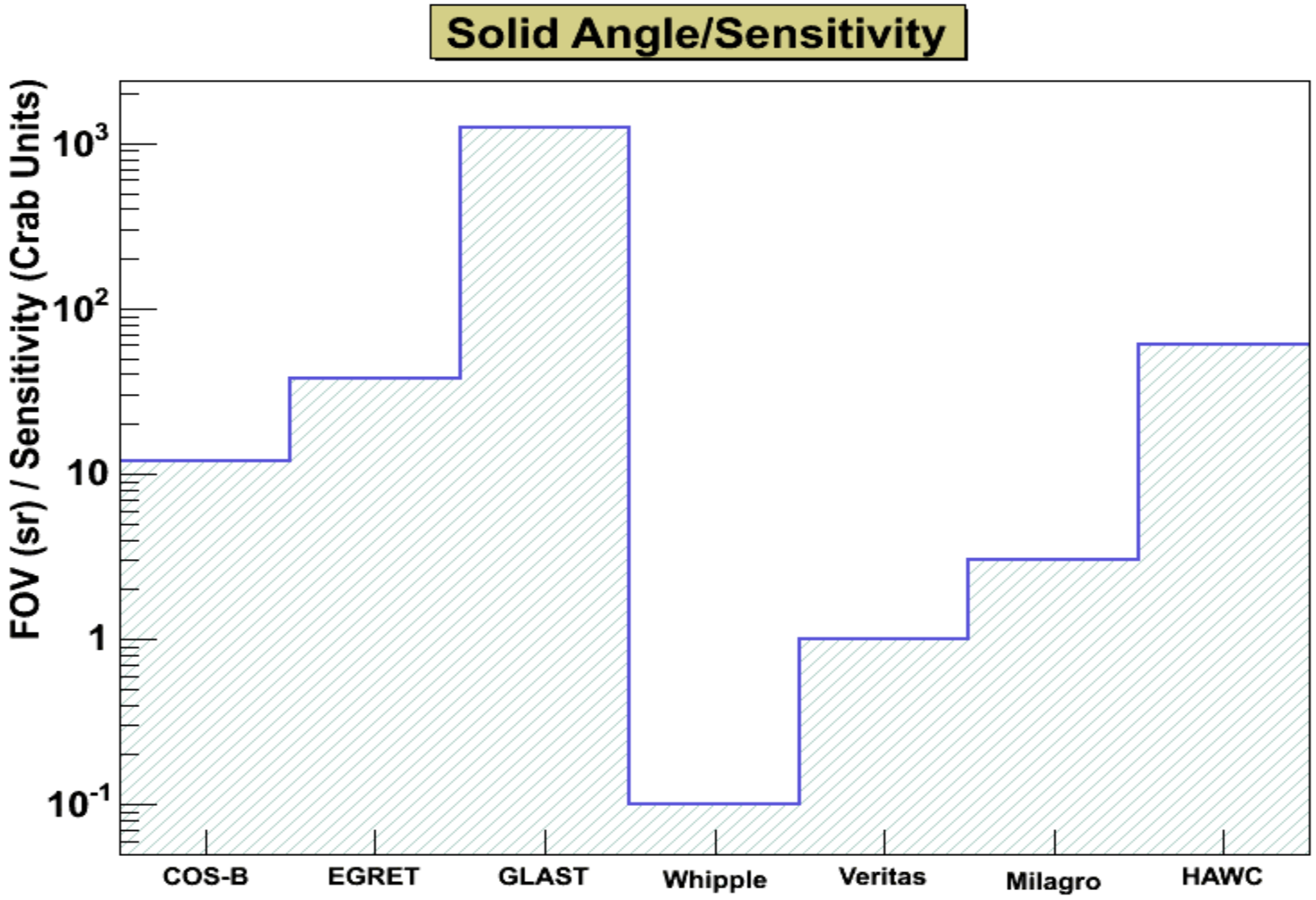


50 events

Point Source Sensitivity



Time Domain Sensitivity



Conclusions

- A large area, high altitude all sky VHE detector will:
  - Detect the Crab in a single transit
  - Detect AGN to z = 0.3
  - Observe 15 minute flaring from AGN
  - Detect GRB emission at ~50 GeV / redshift ~1
  - Detect 6-10 GRBs/year (EGRET 6 in 9 years)
  - Monitor GLAST sources
  - Perform Time Domain Astrophysics in VHE Regime
    - **Extreme States of Extreme Systems**
- Continuing work
  - Improve background rejection & event reconstruction
    - Increase sensitivity by ~50% - 100%?
    - Develop energy estimator
  - Detailed detector design (electronics, DAQ, trigger, infrastructure)
  - Reliable cost estimate needed (~$30M???)
  - Site selection (Chile, Tibet, White Mountain)
- Time Line
  - 2004 R&D proposal to NSF & DOE (LANL & UNM)
  - 2006 full proposal to NSF & DOE
  - 2007-2010 construction

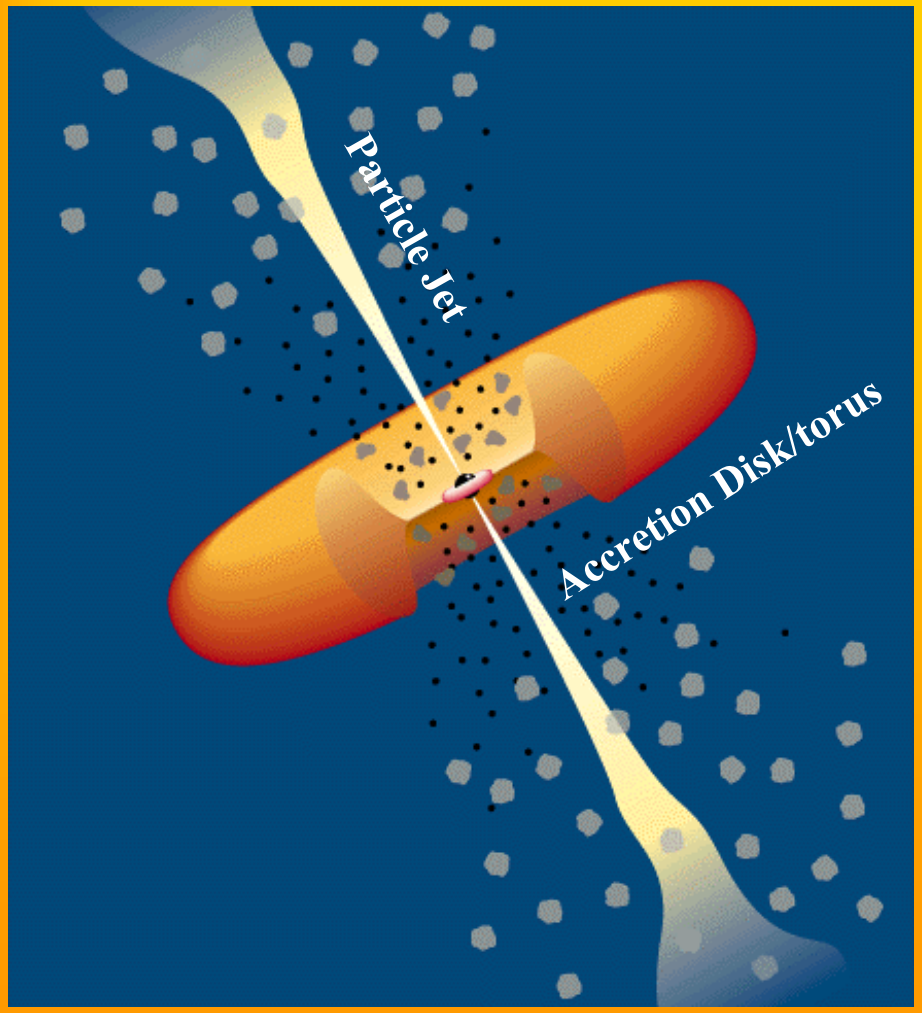
Site Visit: YBG 4/1-6

- Excellent location
  - Land available
    - many km^2 available at 4300m
    - Room at ~4800m
  - Power available (3 MWatts generated in YBJ)
  - Water available
  - Dormitories (“Western rooms”)
- Existing gamma ray detectors
  - ASγ array
  - ARGO detector

Site Visit: IHEP Beijing

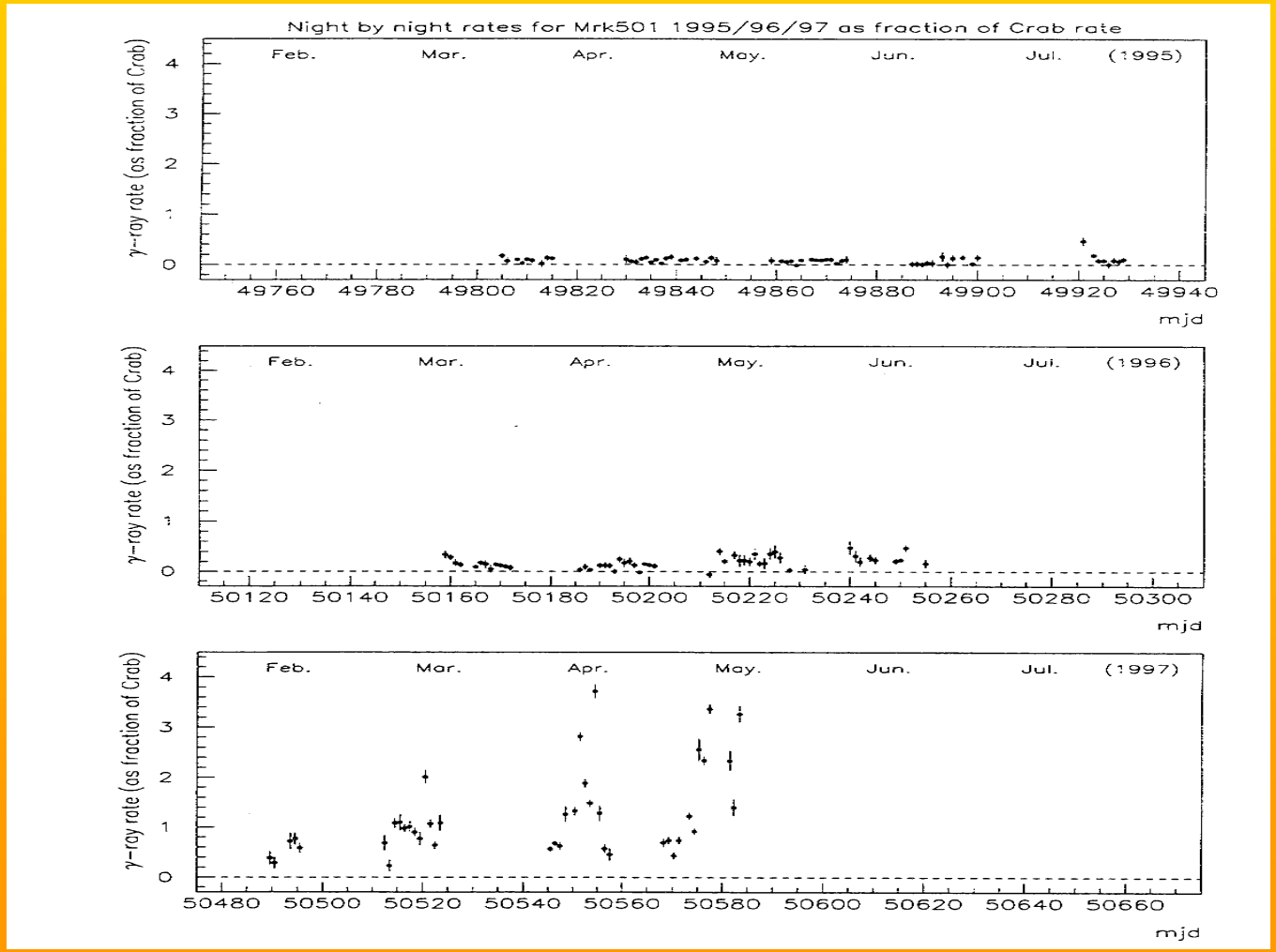
- Scientists excited by project (IHEP and Tibet University)
  - Would like full-scale collaboration
  - Have experience with ASγ and ARGO
- IHEP Director Hesheng Chen enthusiastic about project
  - Committed to provide land, power, water, and people
    - Will provide letter to NSF on request
  - Funds for infrastructure (building, etc) can not be promised at this time
    - They paid ~$2M for ARGO building/infrastructure

Active Galactic Nuclei

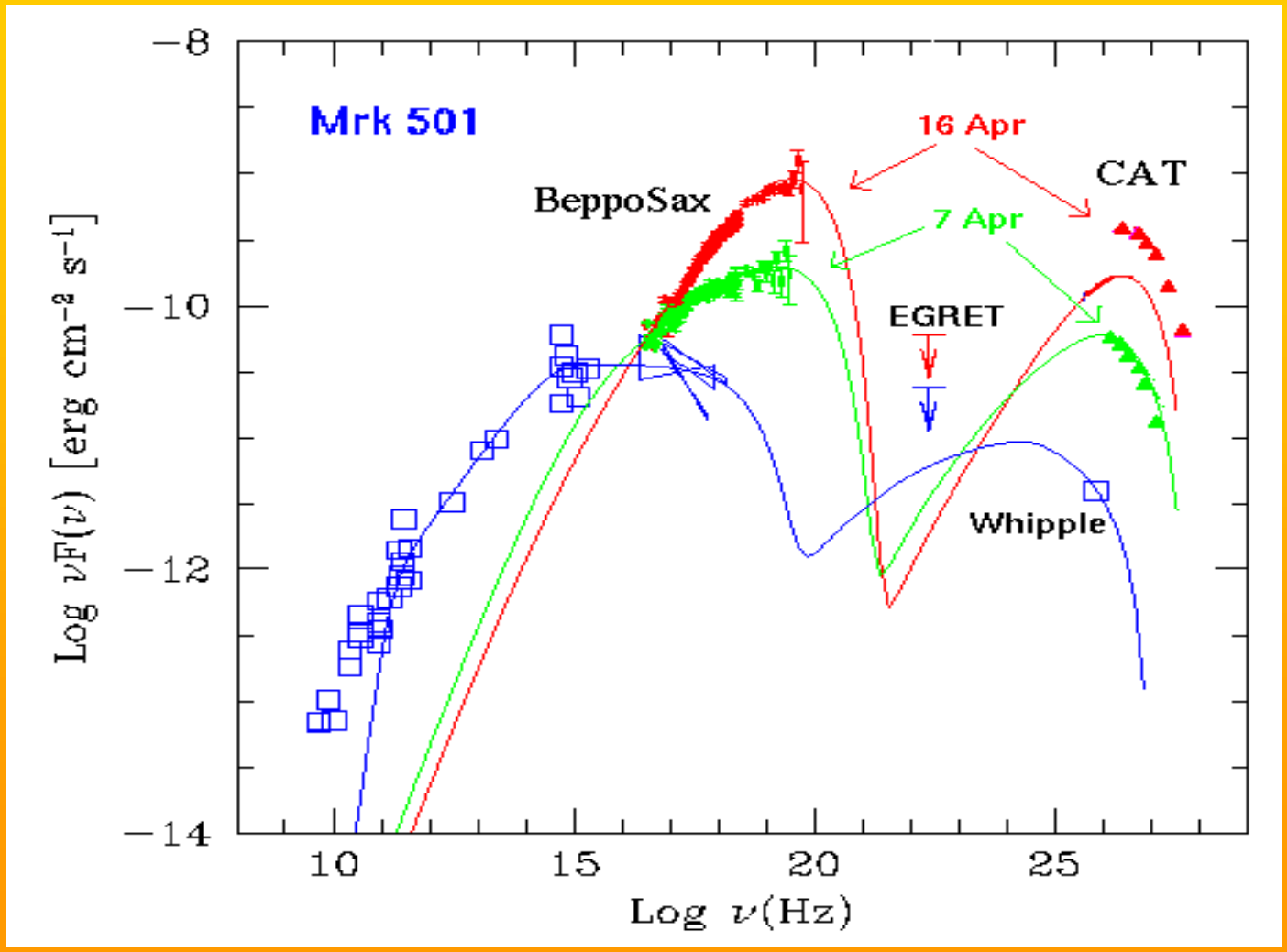


- Supermassive Black Hole
  $10^{8\text{-}10}\ M_{sun}$
- Rotating magnetic field converts rotational energy of hole into kinetic energy.
- Shocks propagate along jets and accelerate particles.
  $\Gamma \sim 50$
- 10^{48} ergs/sec
- Highly variable in VHE band

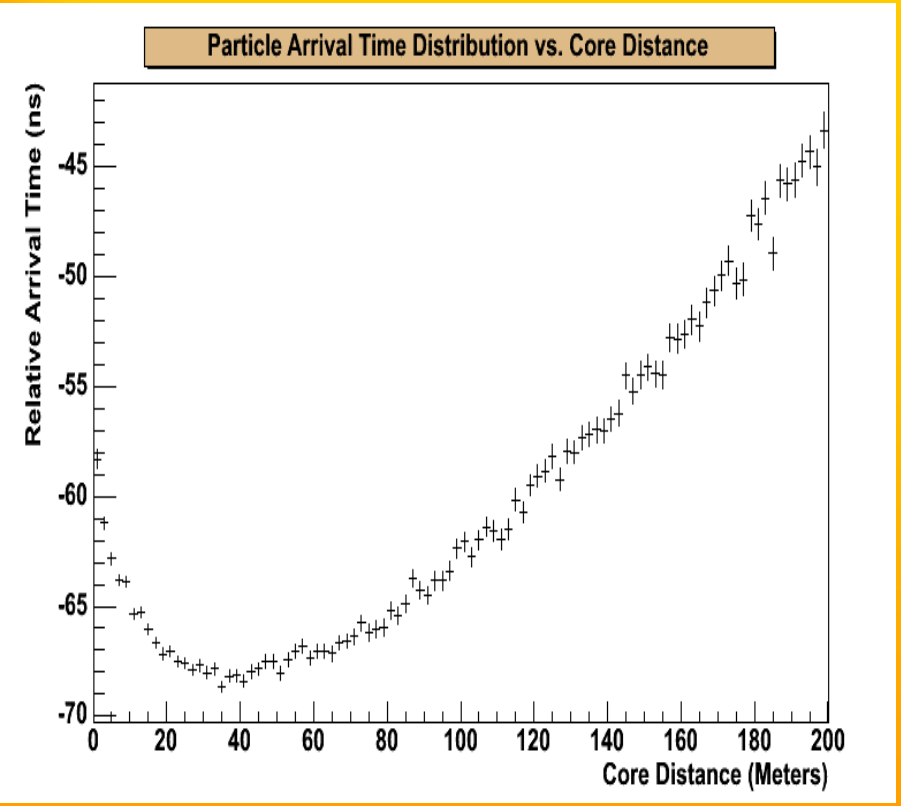
Mrk 501 Longterm Variability

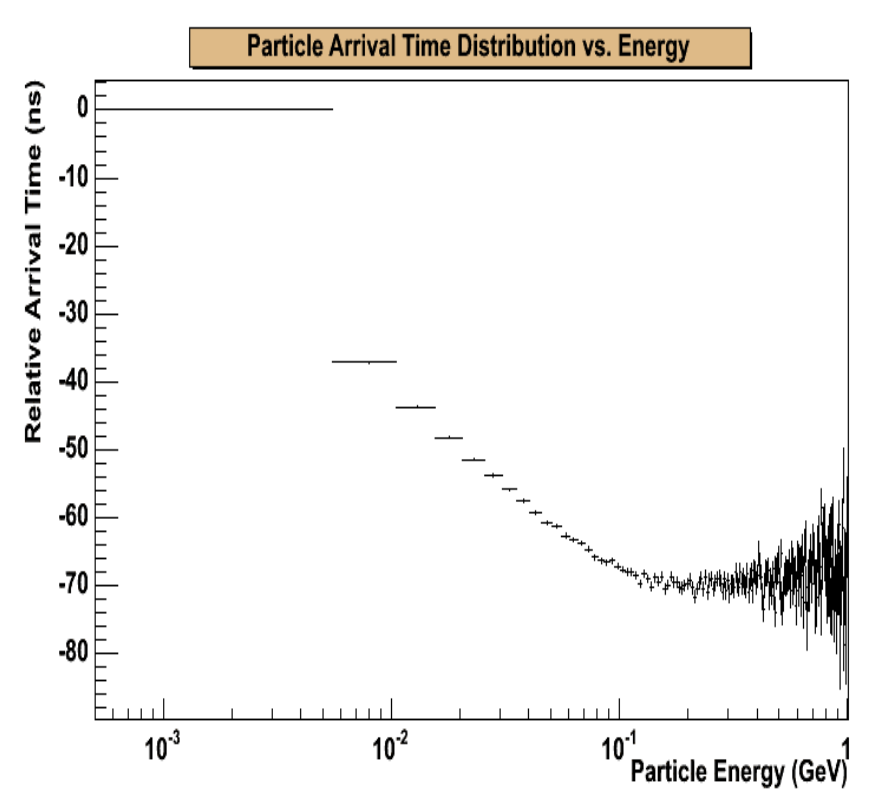


AGN Spectra

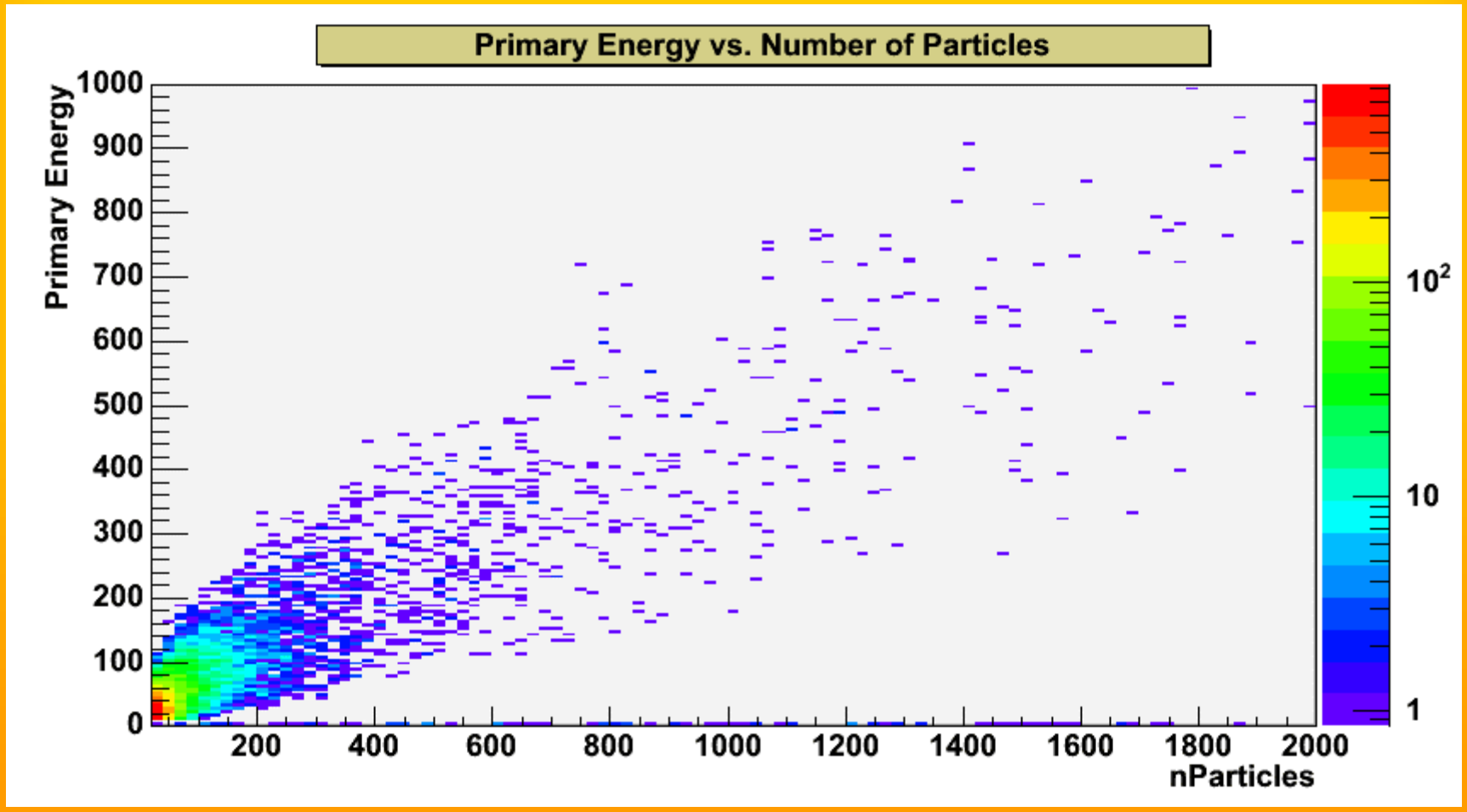

Mrk 501
16 Apr
CAT
BeppoSax
7 Apr
EGRET
Whipple
−8
−10
−12
−14
10
15
20
25
Log νF(ν) [erg cm⁻² s⁻¹]
Log ν(Hz)

Event Reconstruction

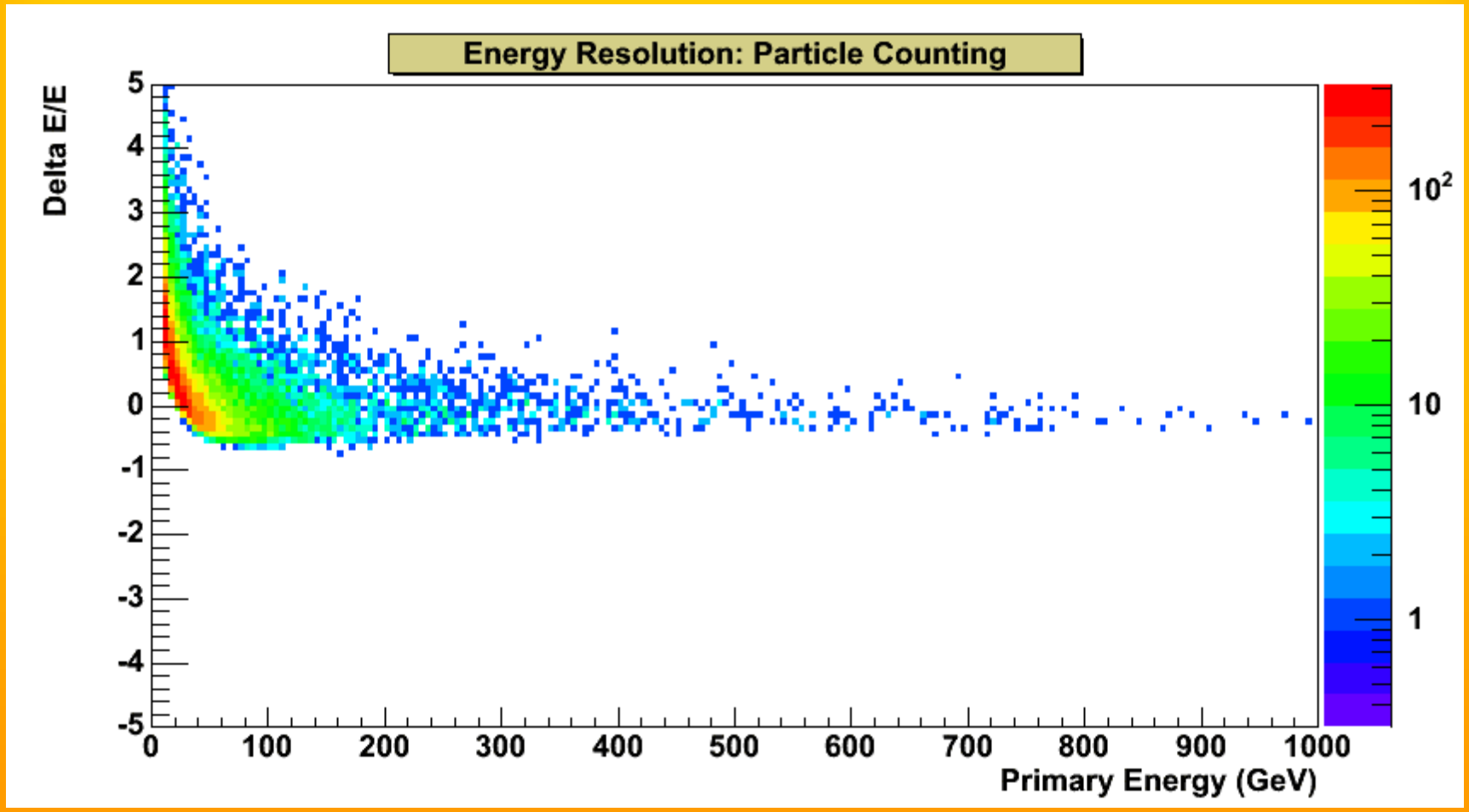




CORSIKA: Energy Resolution



CORSIKA: Energy Resolution



CORSIKA: Energy Resolution