High Altitude Water Cherenkov Telescope

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for the HAWC Collaboration

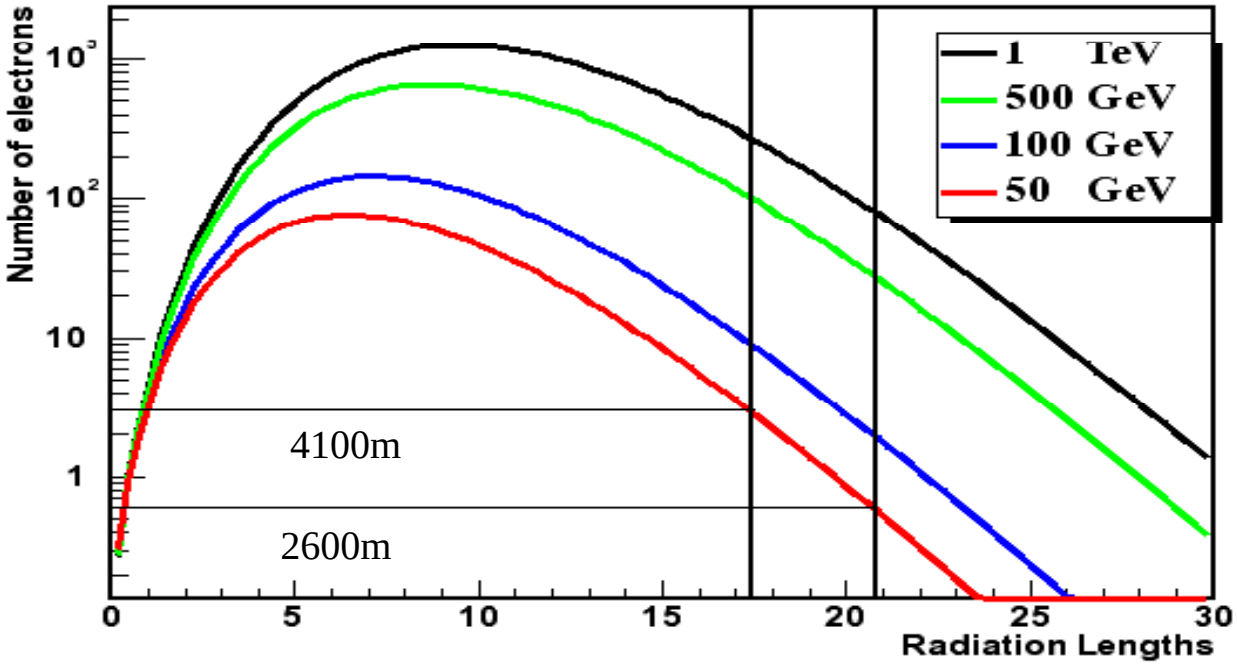
Scientific Goals of HAWC

- What are the origins of Galactic cosmic rays?
  - Detailed map of the Galactic diffuse emission
  - Extended sources - Morphology & Energy Spectra
  - Energy spectra to > 100 TeV
- X-Ray Binary systems
  - Long-term monitoring (extended orbital periods)
  - Multi-wavelength data sets
- Active Galaxies
    - Long-term monitoring
    - Global energetics - flare duty cycles
    - Many multi-wavelength and multi-messenger observations
- Gamma-ray bursts
    - TeV emission?
    - Lorentz factor of acceleration region?
- Fundamental physics & cosmology
  - Constraints/measure Lorentz invariance?
  - Do primordial black holes exist?

How to Improve on Milagro?

- Build at higher altitude (>4 km)
- Make a larger detector
  - Improved effective area
  - Improved background rejection
  - Improved angular resolution (larger lever arm)
  - Improved energy resolution
- Optically isolate PMTs
  - Remove single/multiple muon triggers
  - Improve angular resolution
  - Improve energy resolution

Altitude Effect



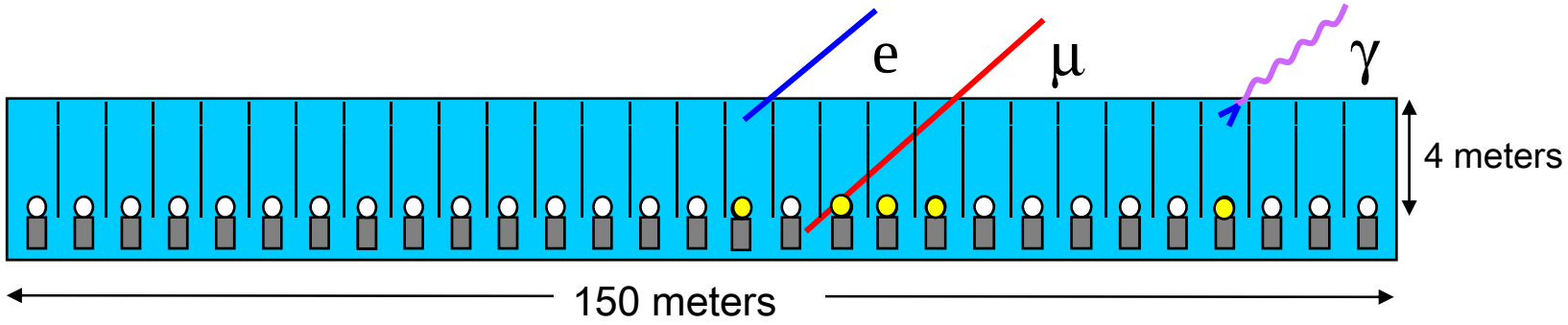
Difference between 2600m (Milagro) and 4100m:

~ 5-3x number of particles (energy dependent)

~ 3x lower median energy

HAWC: High Altitude Water Cherenkov

- Build pond at extreme altitude (Tibet 4300m, Mexico 4100m)
- Incorporate new design
  - Optical isolation between PMTs
  - Larger PMT spacing
  - Single PMT layer (4m deep)
- Reuse Milagro PMTs and electronics
- 22,500 m^2 sensitive area



~$6M for complete detector

~10-15x sensitivity of Milagro

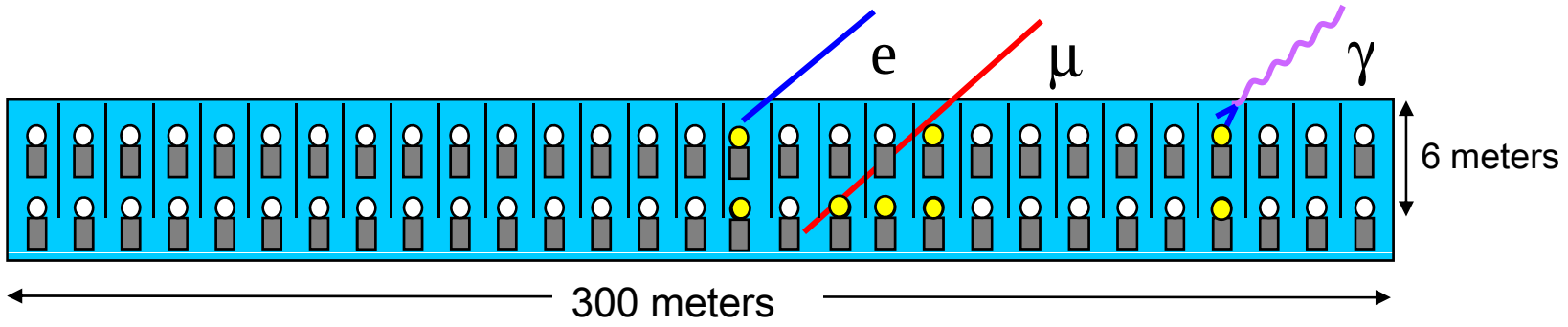
Crab Nebula in 1 day (4 hours) [Milagro 3-4 months]

4x Crab flux in 15 minutes

GRBs to z < 0.8 (now 0.4)

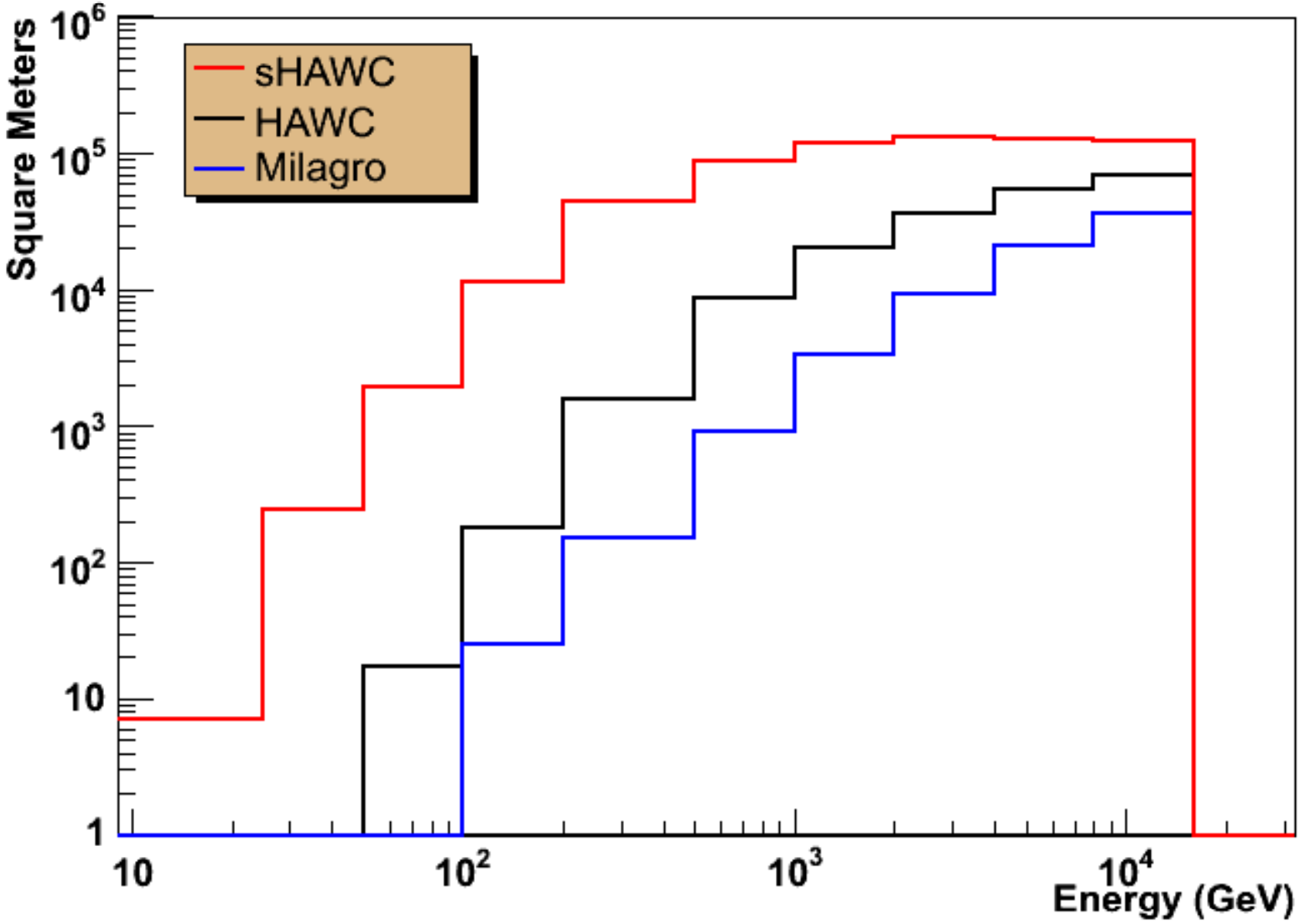
Farther Future: sHAWC

- Build pond at extreme altitude (Tibet 4300m, Bolivia 5200m, Mexico 4030m)
- Incorporate new design
  - Optical isolation between PMTs
  - Much larger area (90,000 m^2)
  - Two layer design (2 m and 6 m below water surface)
- Advanced electronics and DAQ (~200MBytes/sec)

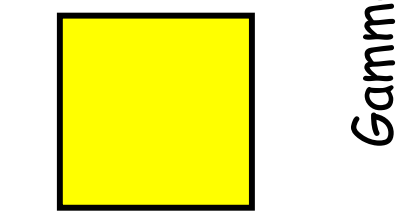


~$50M for complete detector
~60x sensitivity of Milagro
Crab Nebula in 30 minutes
4x Crab flare in 2 minutes
GRBs to z >1 (now 0.4)

HAWC Effective Area v. Energy



Gamma/Hadron Separation

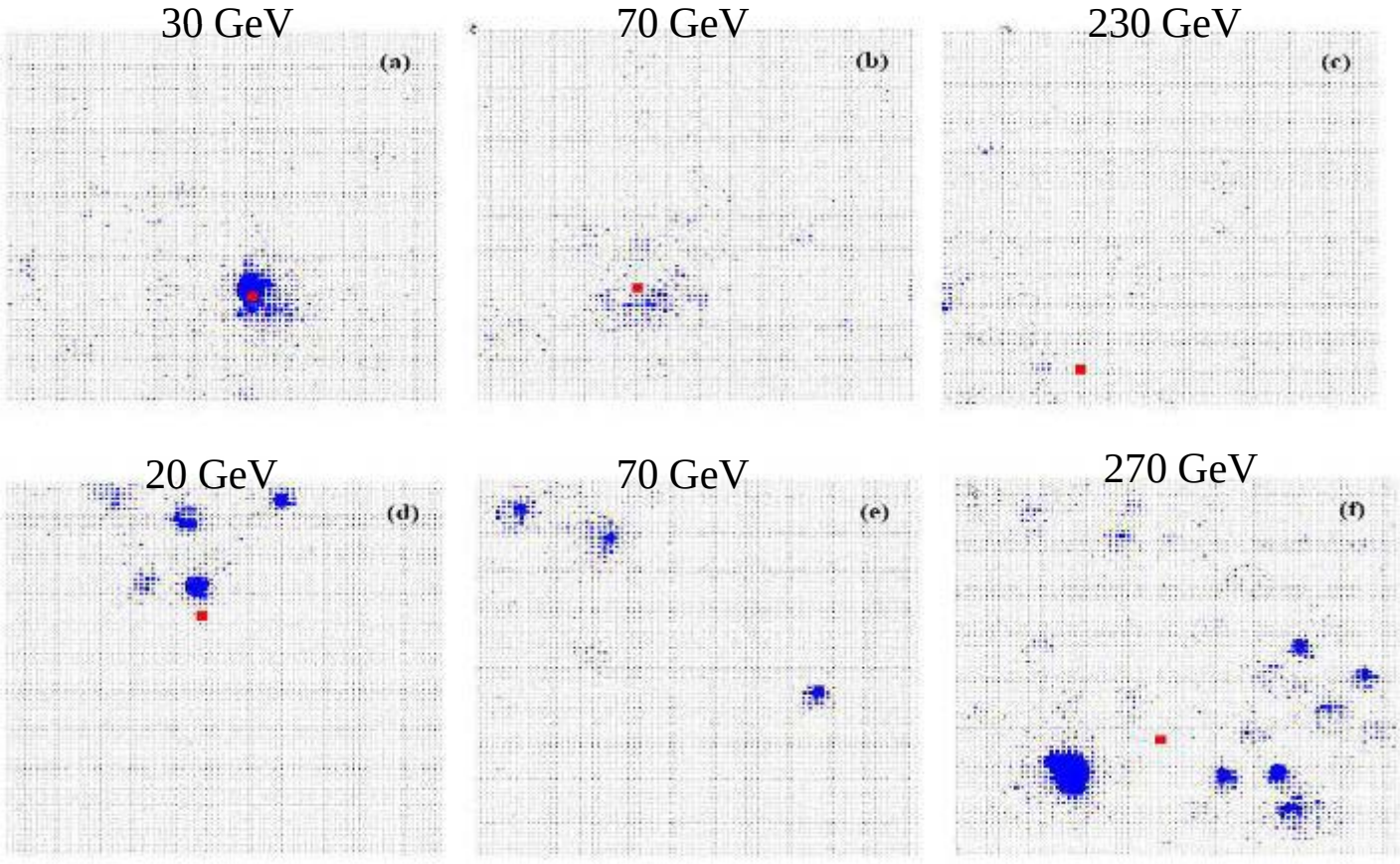


Size of HAWC

Size of Milagro deep layer

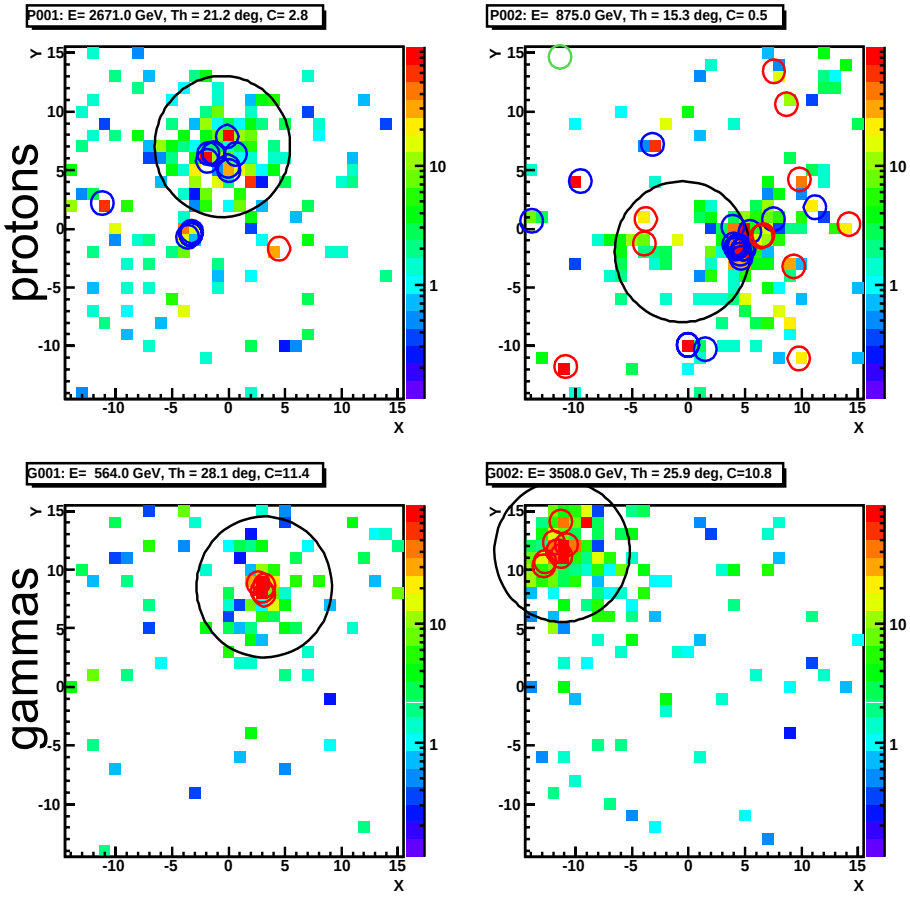
Gammas

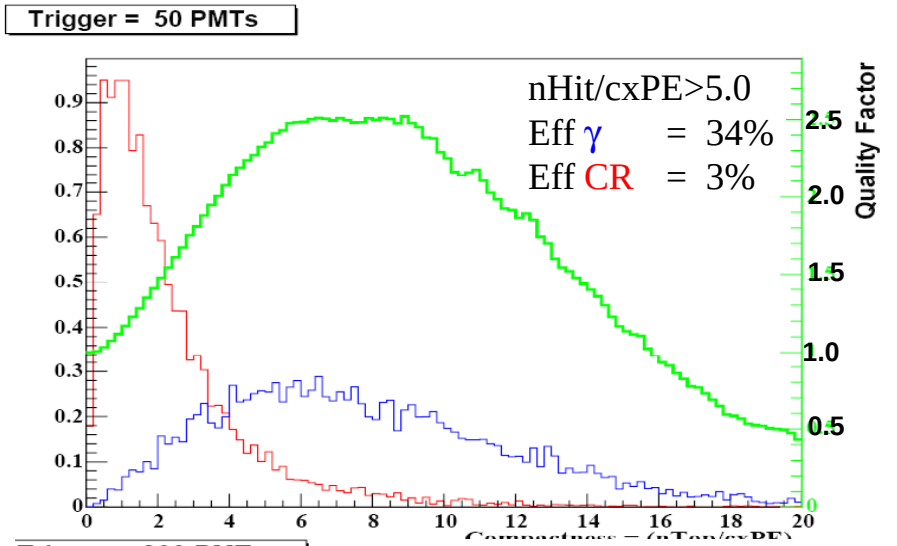
Protons

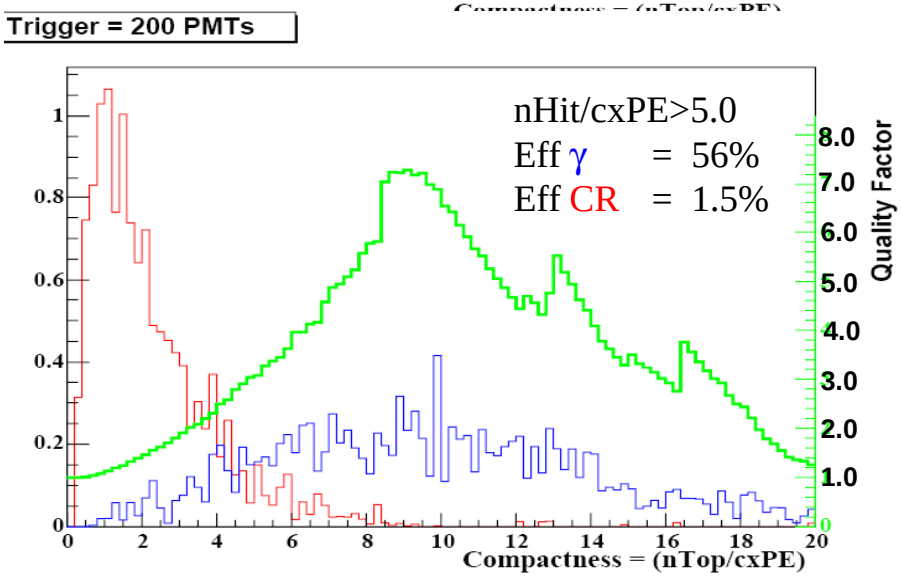


Energy Distribution at ground level

Background Rejection







Circles are EM particles > 1 GeV
Circles are μ's & hadrons > 1 GeV
Circles are 30m radius (~area of Milagro μ layer)

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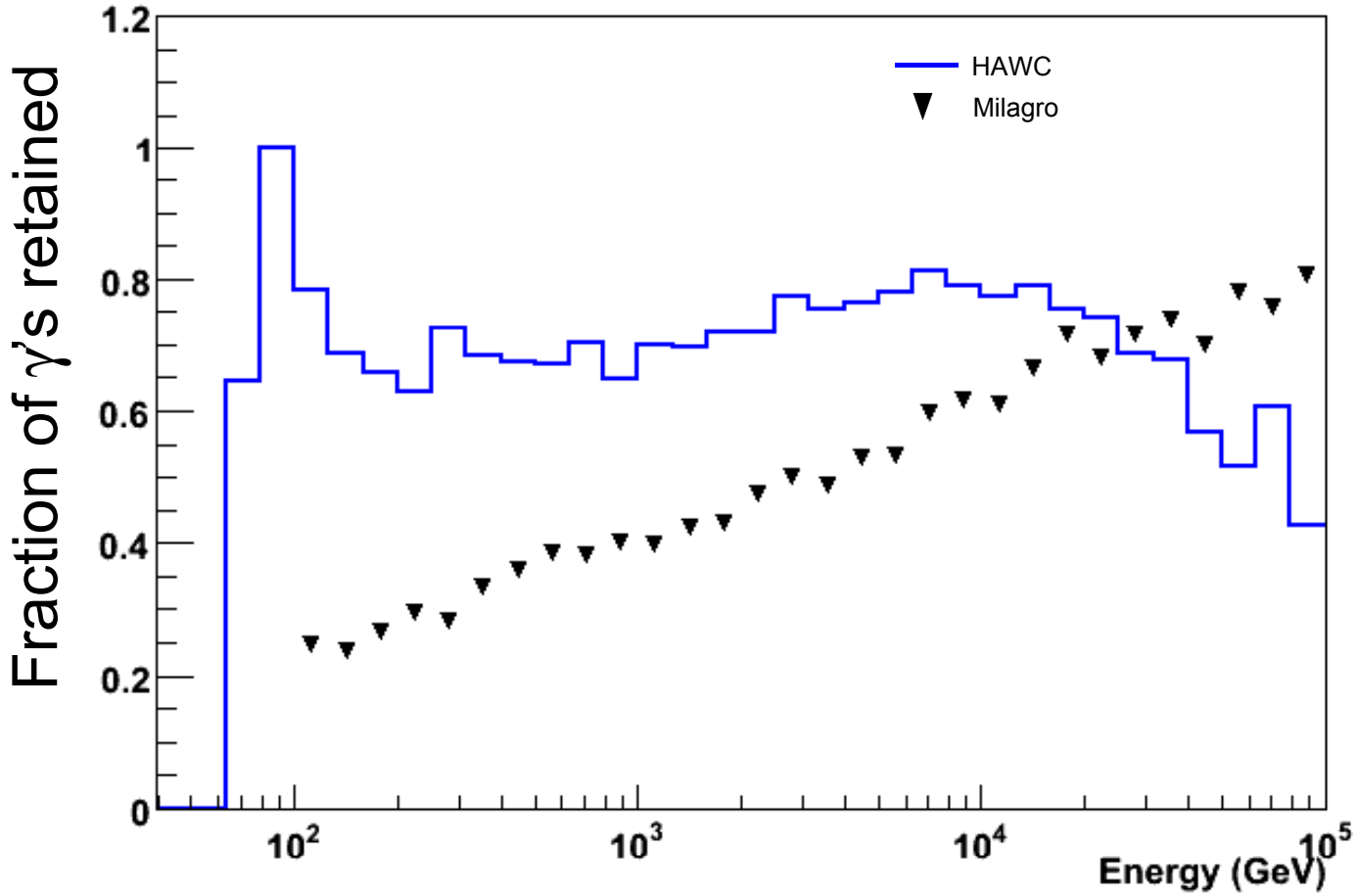
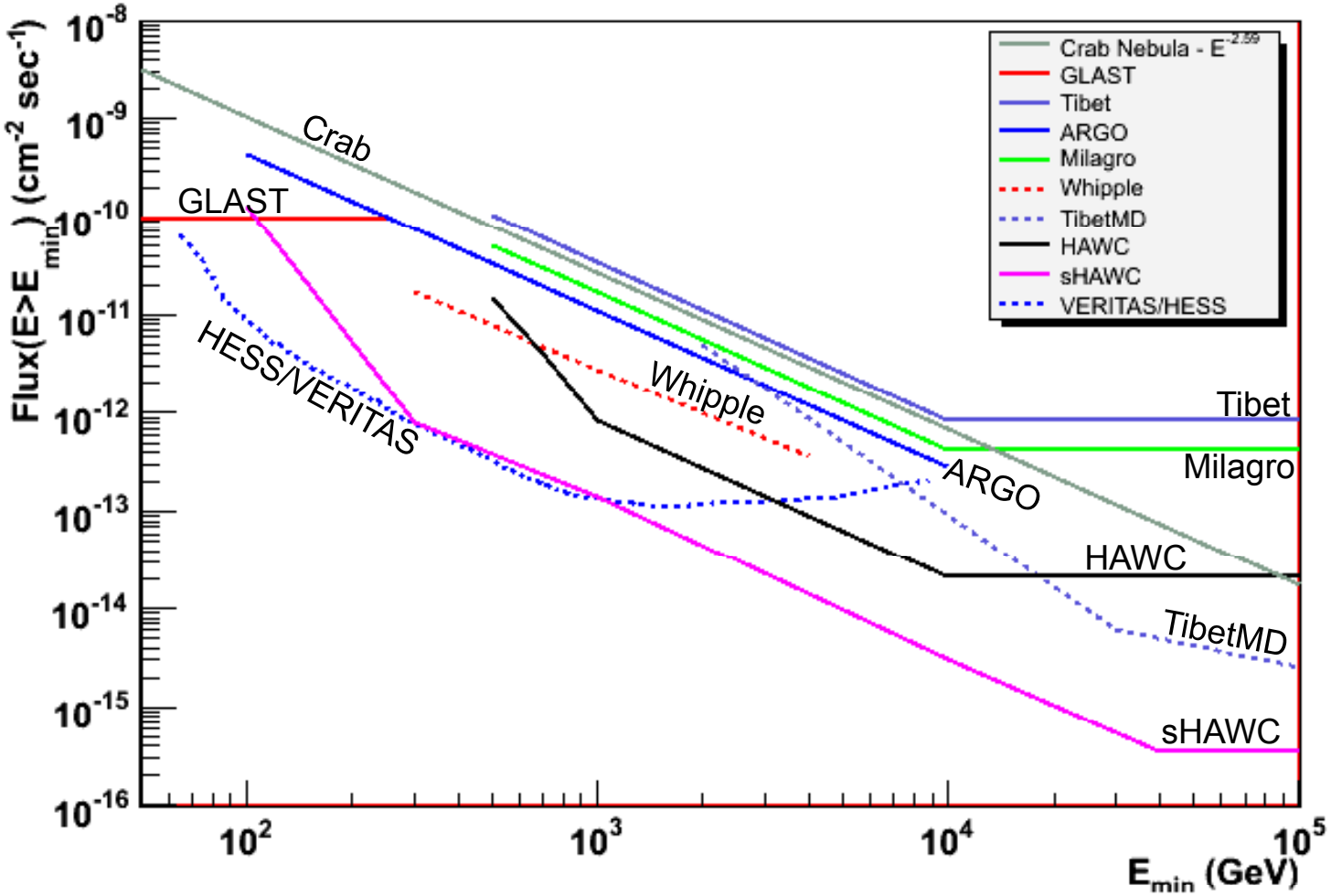
Background Rejection in HAWC

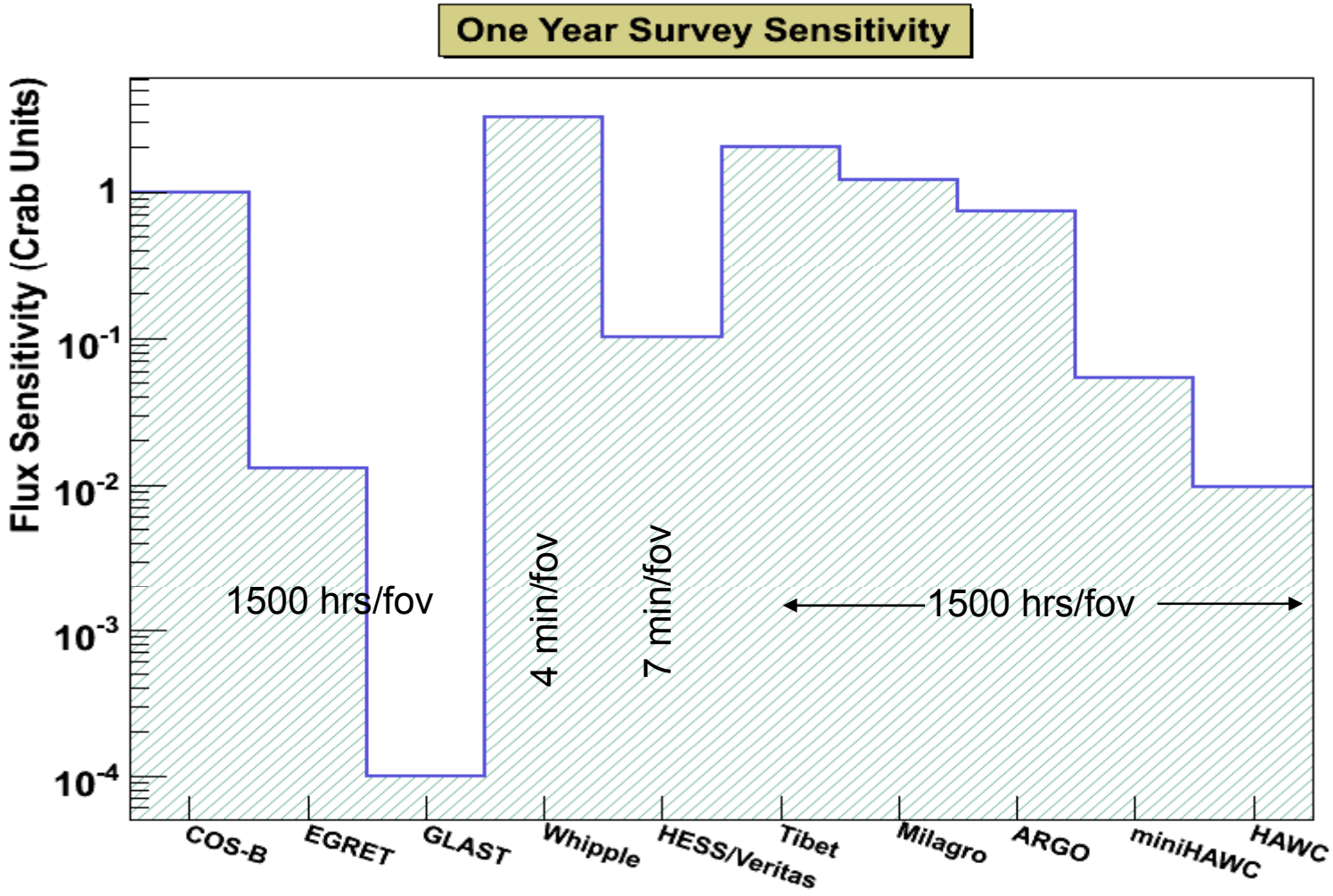


By excluding region near core (30m) HAWC can retain low energy gamma events

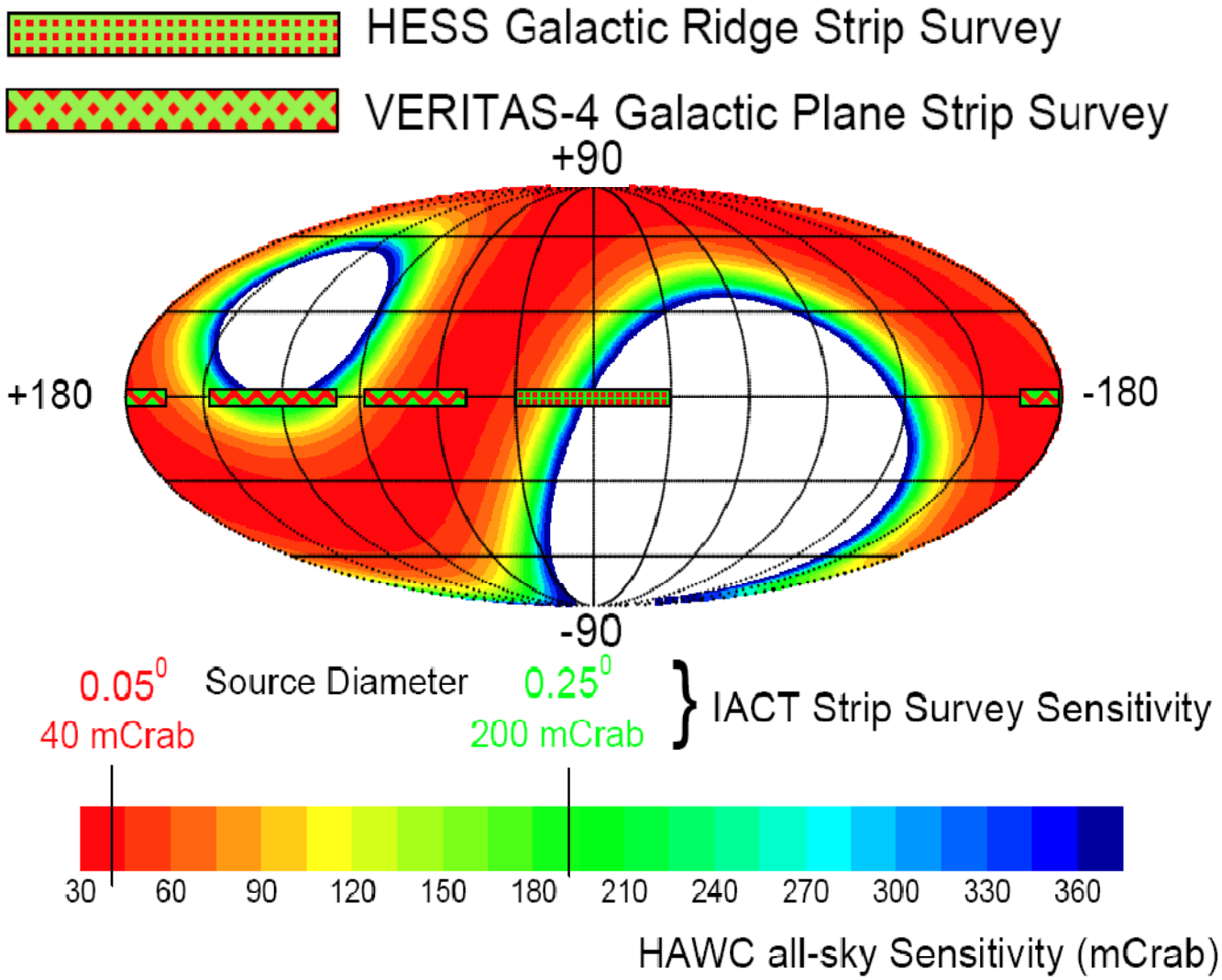
Sensitivity of Synoptic TeV Telescopes



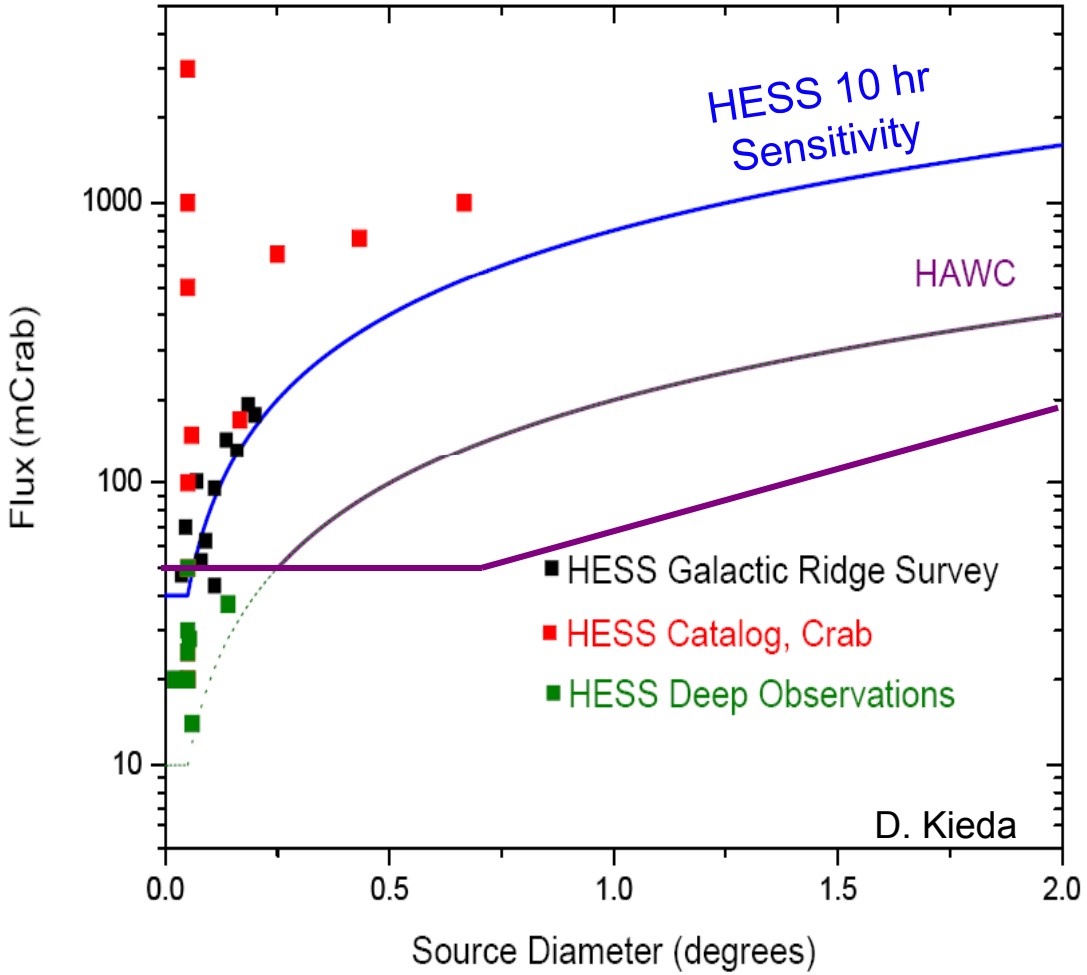
Survey Sensitivity



HAWC Sky Survey



Sensitivity vs. Source Size



Large, low surface brightness sources require large fov and large observation time to detect.

$$S_{\text{extended}} \approx S_{\text{point}} \frac{\sigma_{\text{source}}}{\sigma_{\text{detector}}}$$

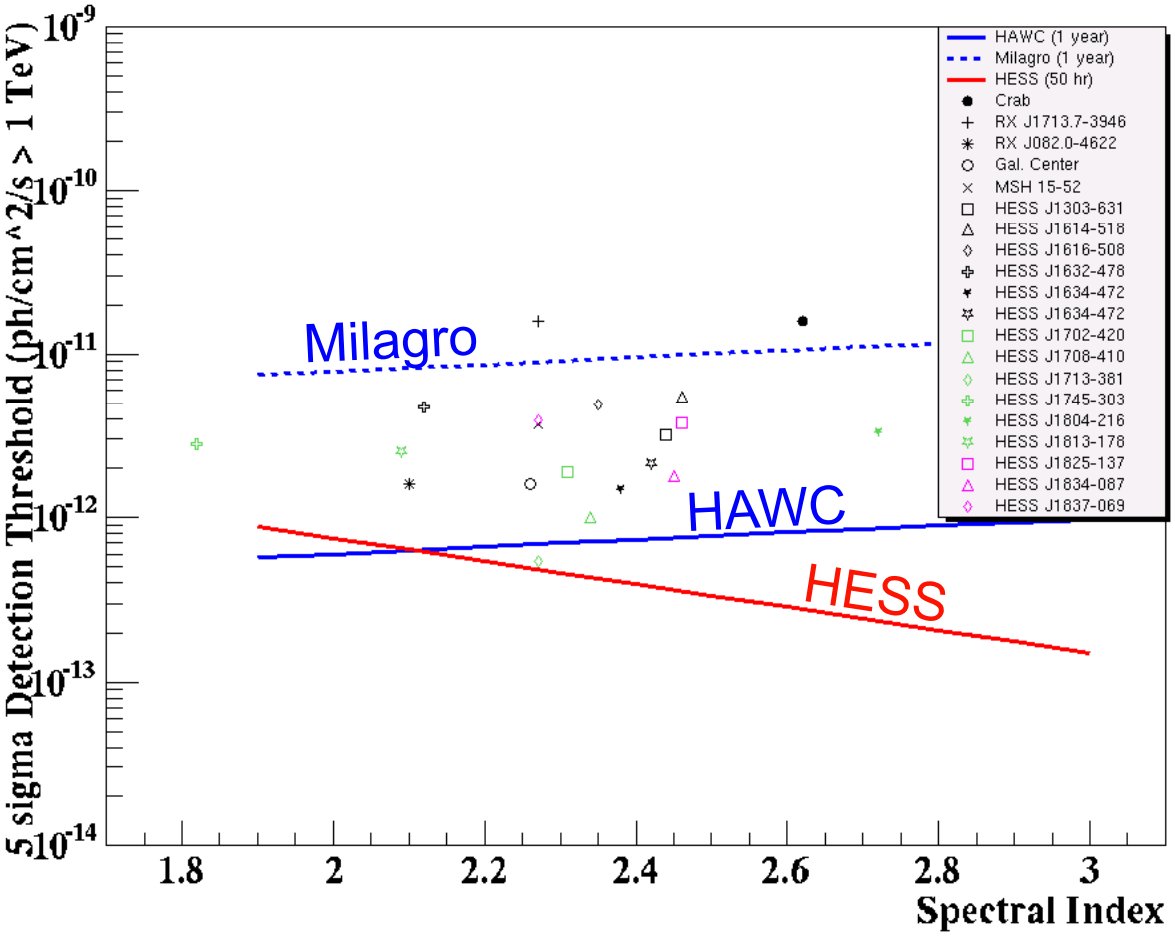
EAS arrays obtain >1500 hrs/yr observation for every source.

Large fov (2 sr):

Entire source & background simultaneously observable

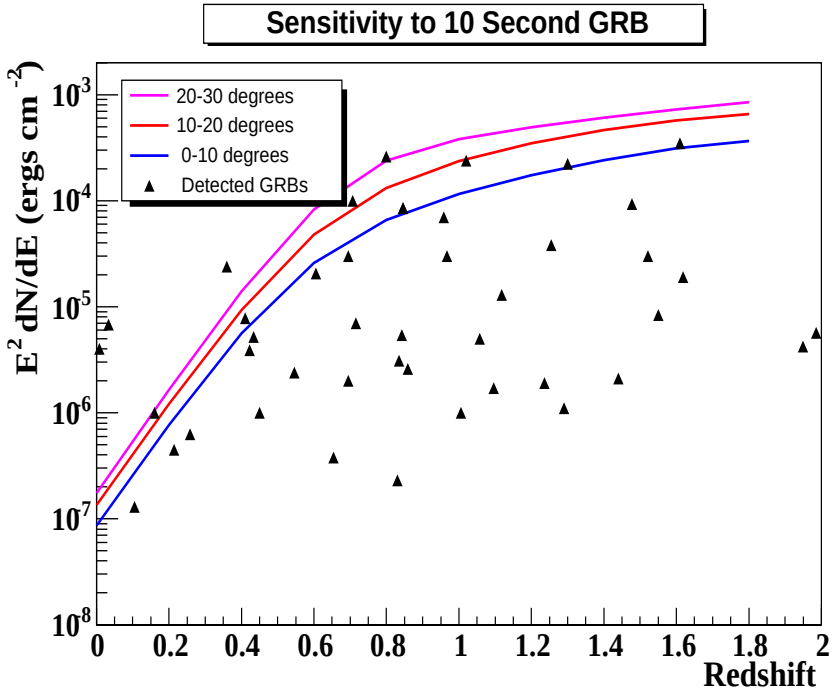
Background well characterized

Sensitivity vs. Source Spectrum

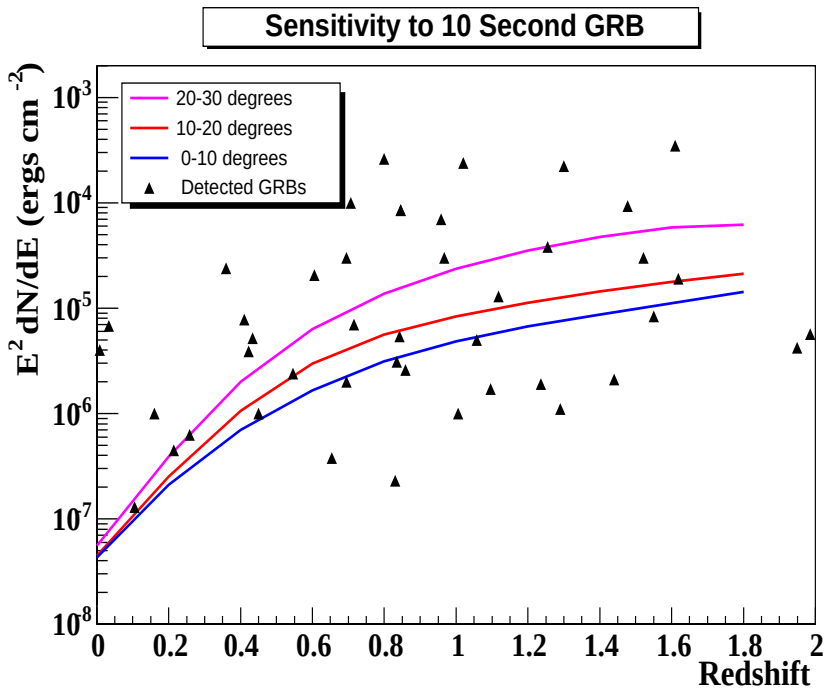


GRB Sensitivity

Milagro



HAWC



Fluence Sensitivity to 10s GRB.

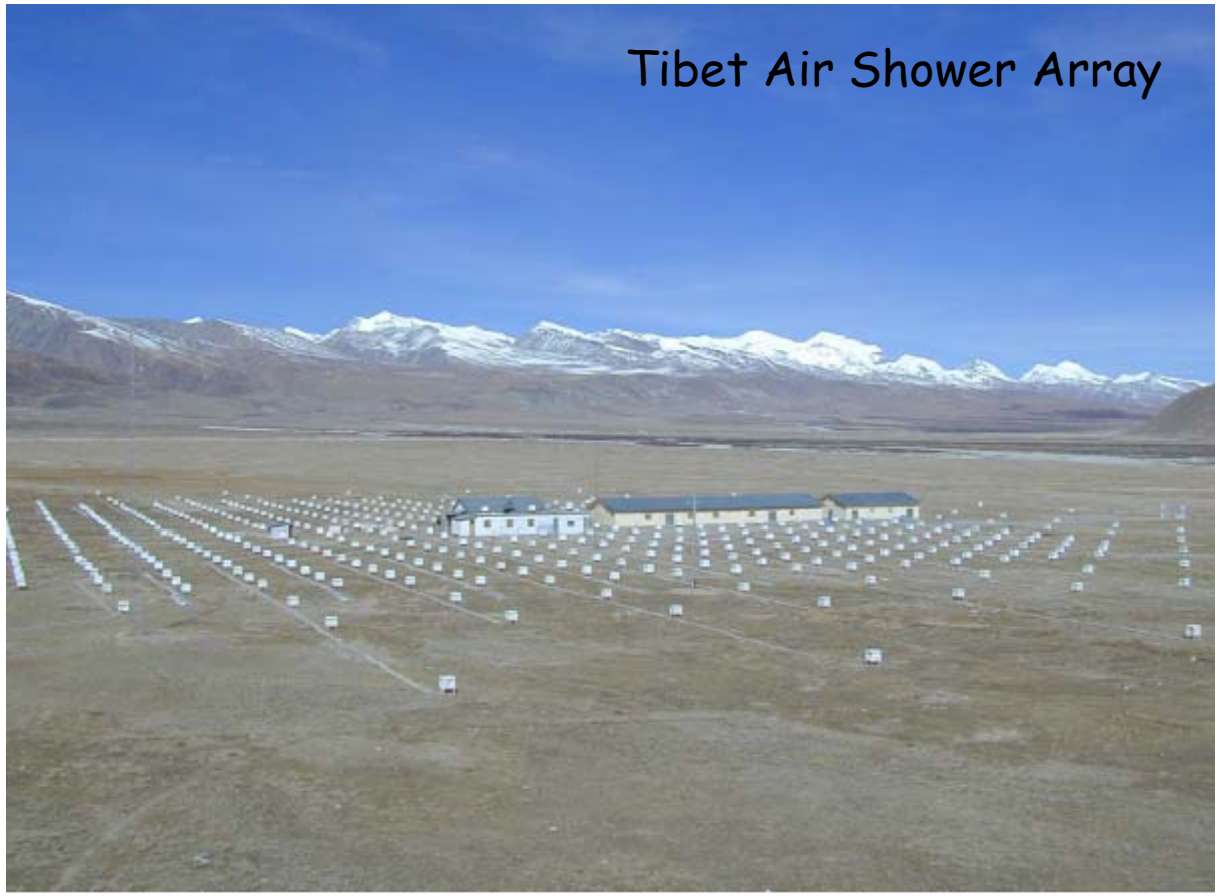
Both Milagro and HAWC can "self trigger" and generate alerts in real time.

GRB rate in FOV ~100 GRB/year (BATSE rate)

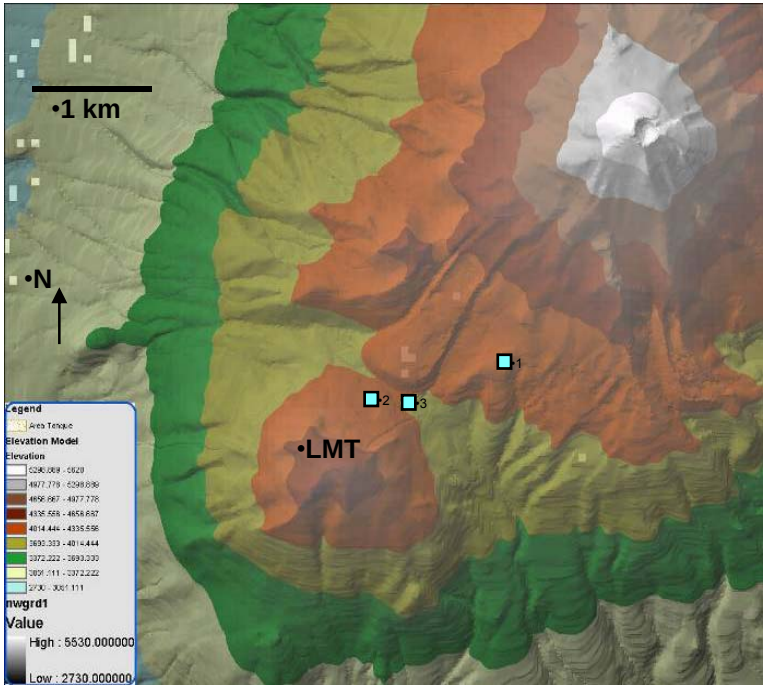
YBJ Laboratory – Tibet, China

Elevation: 4300m
Latitude: 30^{O} 13′ N
Longitude: 90^{O} 28′ E

Lots of space.
Available power.
Available water.



Sierra Negra, Mexico

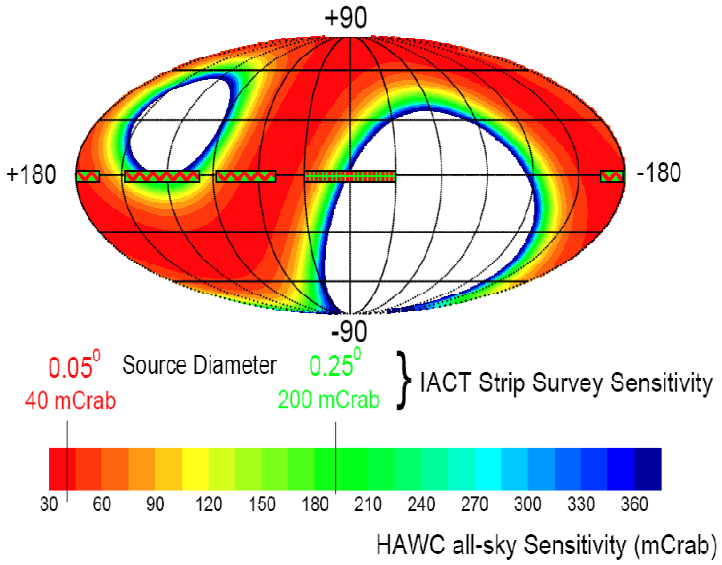


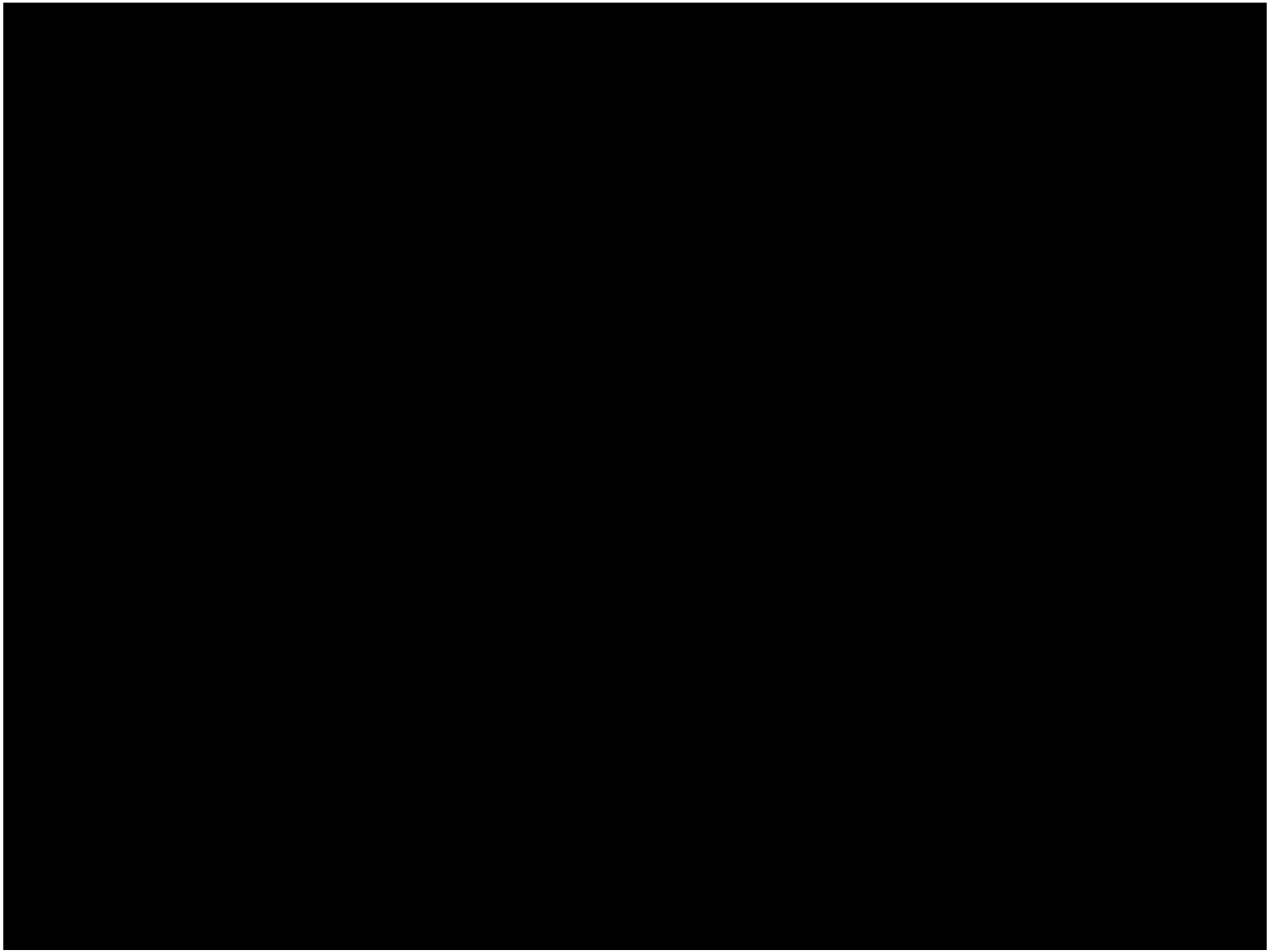
Elevation = 4100m or 4300m
Latitude = 19^{O} 00'N
Longitude = 97^{O} 17' W

LMT nearby (mountain top)
Power available
Sufficient flat land area
Water still not certain

Conclusion

- Enormous progress has been made in the past decade in TeV survey technology
- Large improvements are straightforward
  - ~2x Milagro cost yields ~10x sensitivity
- HAWC can attain high sensitivity over an entire hemisphere
  - ~10-15 times the sensitivity of Milagro
  - ~5 sigma/√day on the Crab
  - 30 mCrab sensitivity over hemisphere
  - Unsurpassed sensitivity to extended sources
  - Study Galactic diffuse emission
  - Unique TeV transient detector
    - (4*x* Crab in 15 minutes)

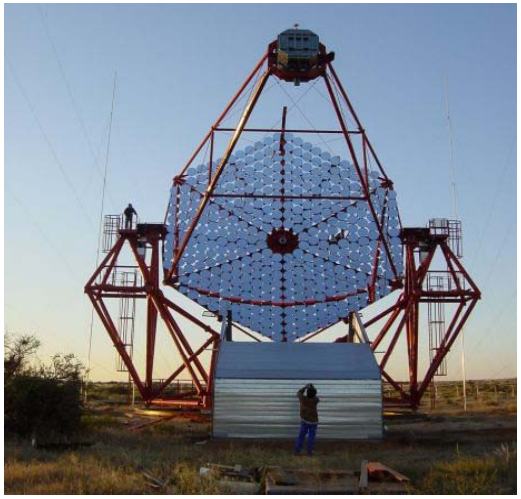




Detectors in Gamma-Ray Astrophysics

High Sensitivity

HESS, MAGIC, CANGAROO, VERITAS

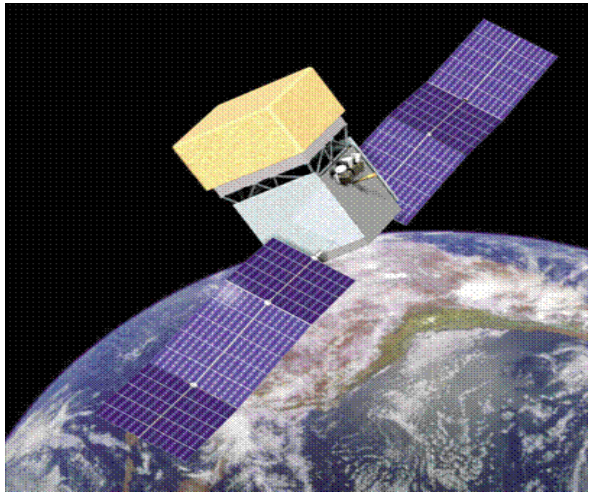


Energy Range .05-50 TeV
Area > 10^4 m^2
Background Rejection > 99%
Angular Resolution 0.05°
Aperture 0.003 sr
Duty Cycle 10%

High Resolution Energy Spectra
Studies of known sources
Surveys of limited regions of sky

Low Energy Threshold

EGRET/GLAST



Energy Range 0.1-100 GeV
Area: 1 m^2
Background Free
Angular Resolution 0.1° - 0.3°
Aperture 2.4 sr
Duty Cycle > 90%

Unbiased Sky Survey (<100 GeV)
Extended Sources
Transients (AGN, GRBs) <100 GeV
Simultaneous ν Observations

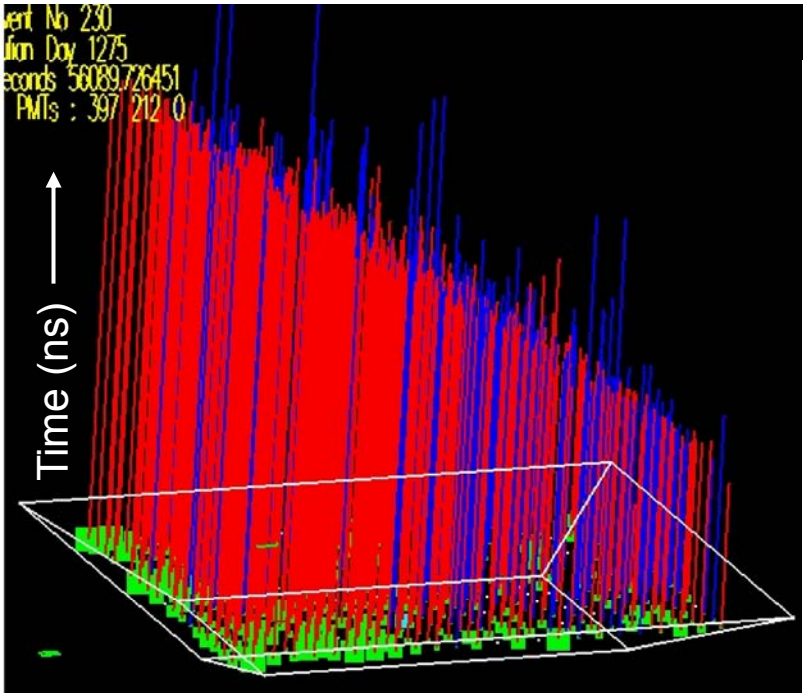
Large Aperture/High Duty Cycle

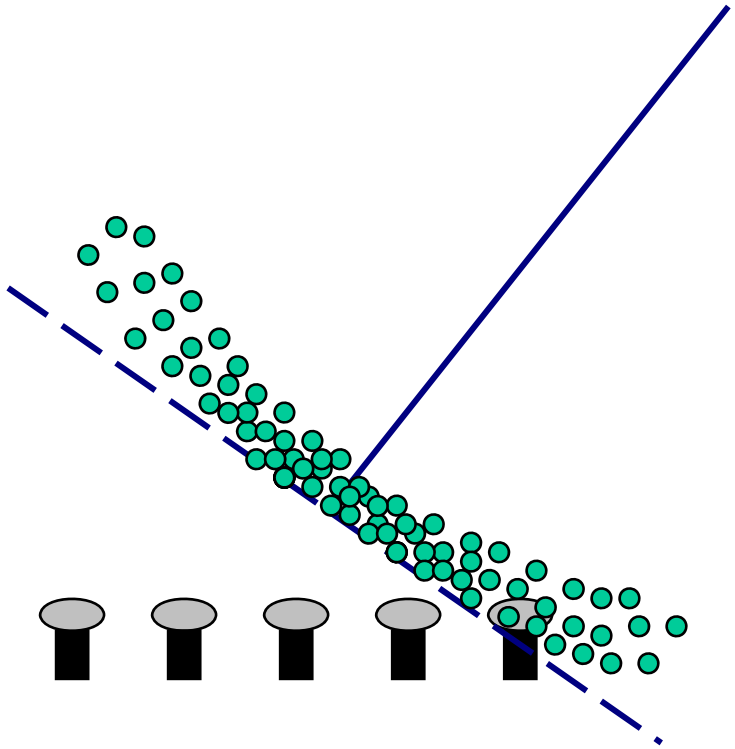
Milagro, Tibet, ARGO, HAWC

Energy Range 0.1-100 TeV
Area > 10^4 m^2
Background Rejection > 95%
Angular Resolution 0.3° - 0.7°
Aperture > 2 sr
Duty Cycle > 90%

Unbiased Sky Survey
Extended Sources
Transients (GRB's)
Simultaneous ν Observations

Event Reconstruction





Measure time to <1 ns

Direction reconstruction 0.5^{o} to 1.4^{o} (size dependent)