The HAWC Observatory

PENNSTATE

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for the HAWC Collaboration

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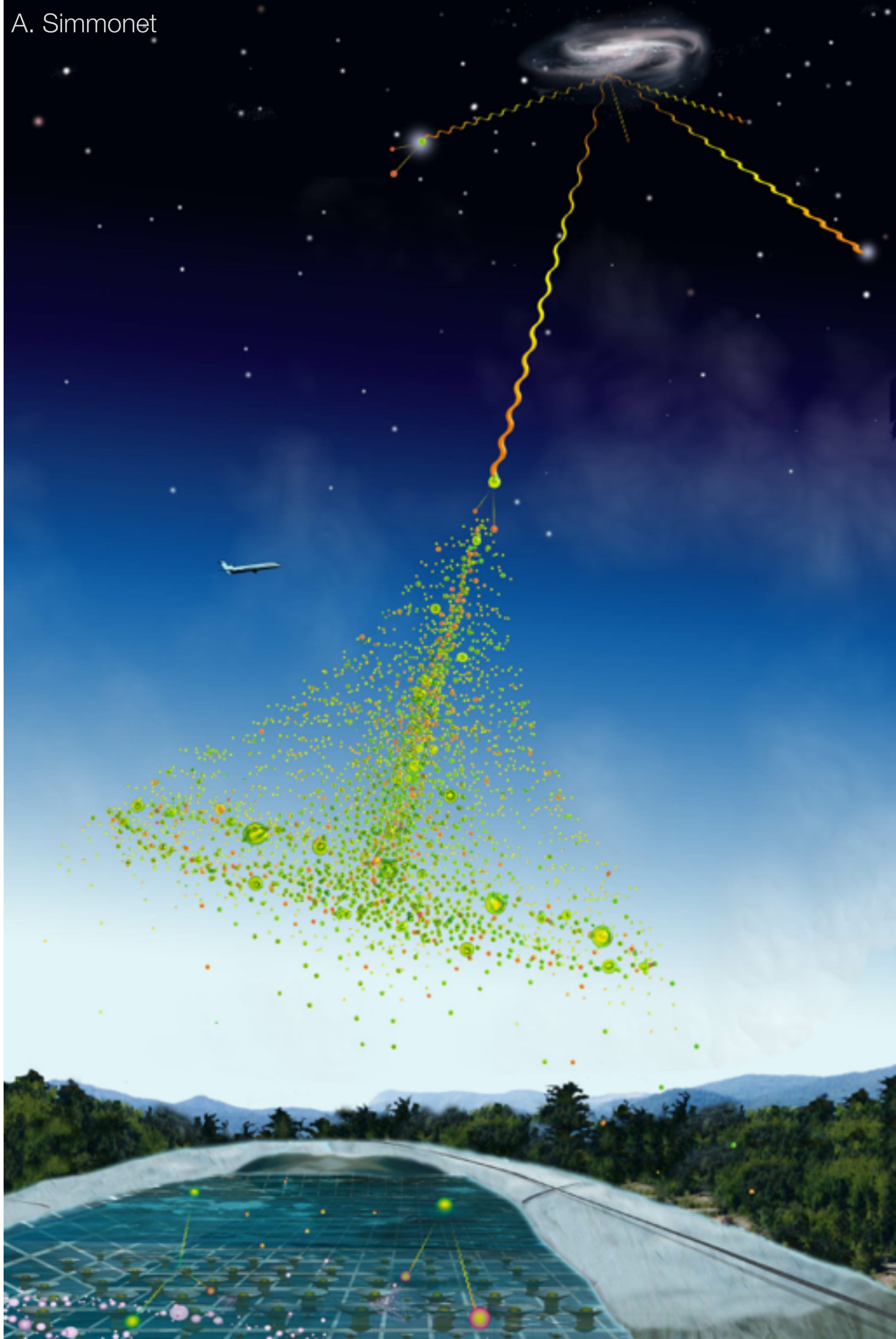
Extensive Air Shower Gamma Ray Telescopes

- Gamma ray interacts in the atmosphere, forms particle cascade
    - Particles produce Cherenkov light in water at ground level
- Reconstruct shower direction from timing of PMT hits across the detector
- Most triggers come from cosmic rays (1700 Hz in Milagro, 5 kHz expected in HAWC)
- Field of view ~2 sr, typical duty factor >95%



Milagro Gamma Ray Observatory

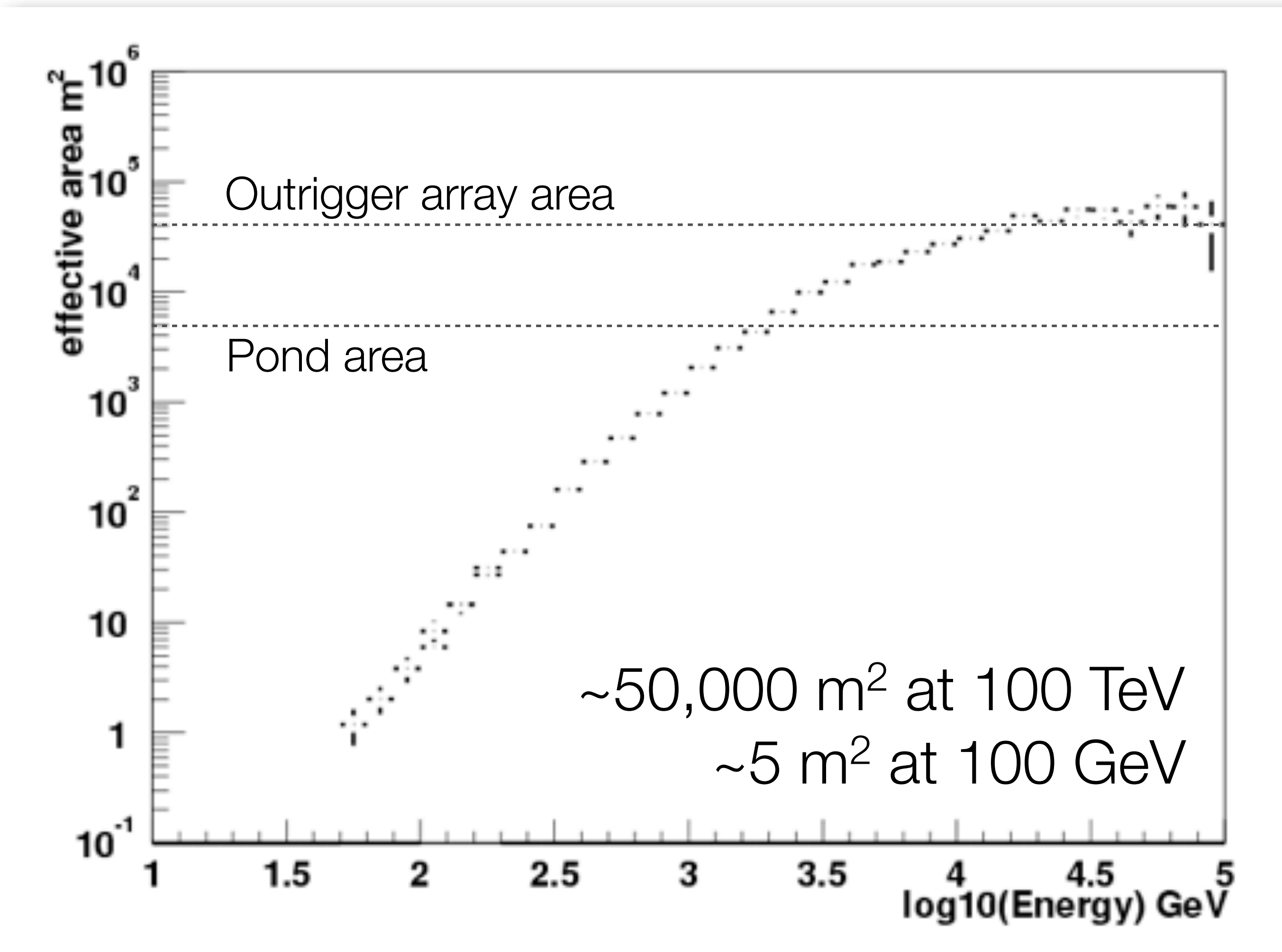
2630 m altitude, near Los Alamos, New Mexico

Los Alamos National Laboratory
University of Maryland
UC Santa Cruz
Michigan State University
UCIrvine University of California, Irvine
New York University
New Hampshire

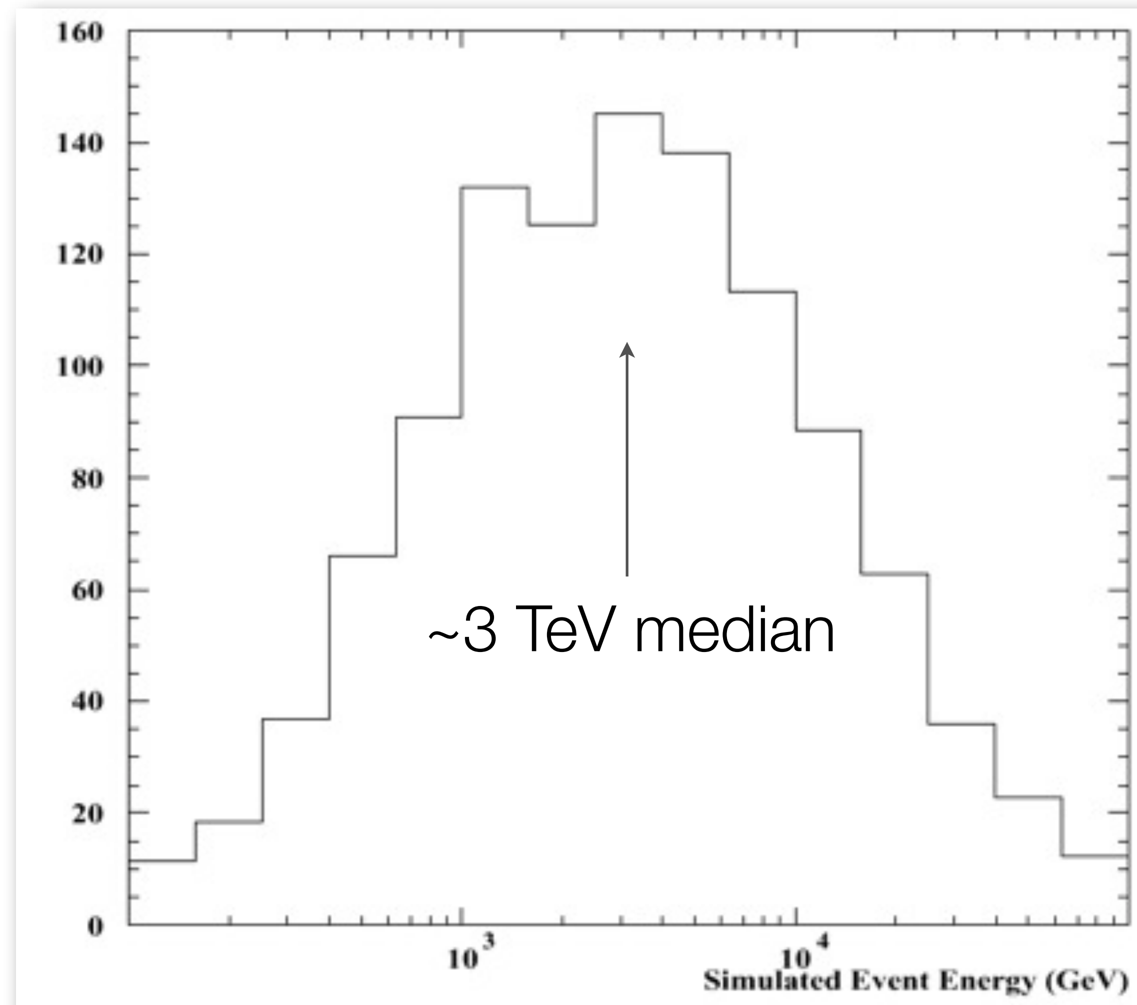
A. Abdo, B. Allen, D. Berley, T. DeYoung, B. L. Dingus, R. W. Ellsworth, M. M. Gonzalez, J. A. Goodman, C. M. Hoffman, P. Huntemeyer, B. Kolterman, C. P. Lansdell, J. T. Linnemann, J. E. McEnery, A. I. Mincer, P. Nemethy, J. Pretz, J. M. Ryan, P. M. Saz Parkinson, A. Shoup, G. Sinnis, A. J. Smith, G. W. Sullivan, D. A. Williams, V. Vasileiou, G. B. Yodh

Milagro Capabilities

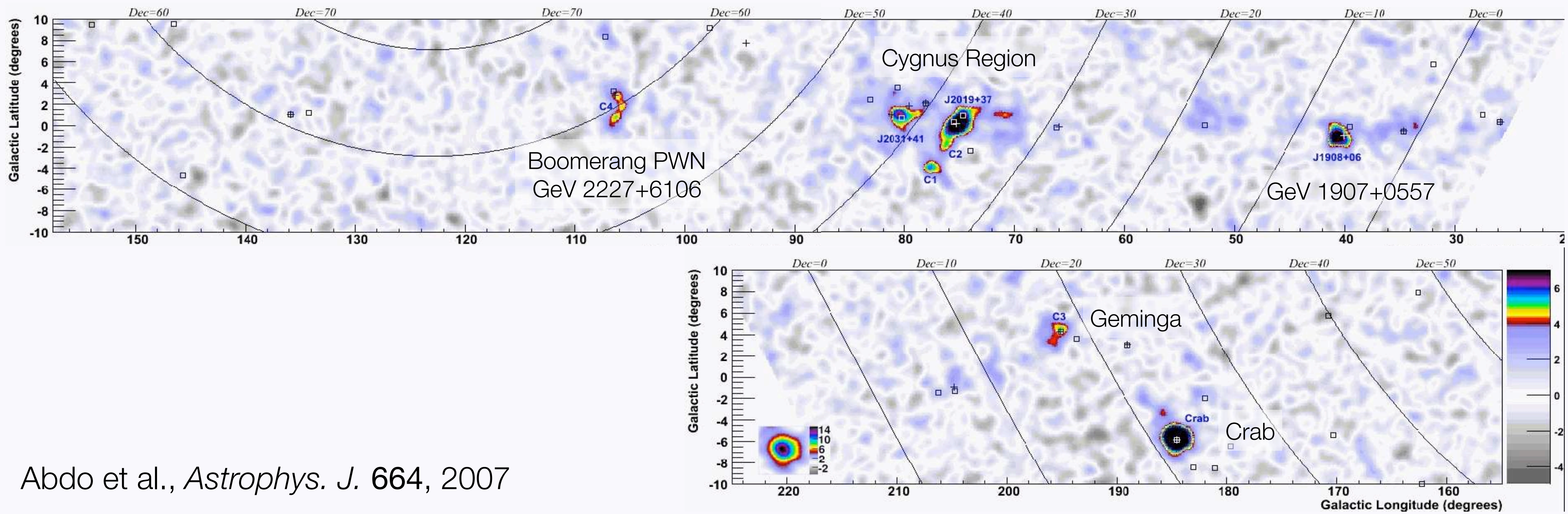
Effective Area



Energy Response (Crab)



Milagro TeV Survey of the Galactic Plane



Abdo et al., *Astrophys. J.* **664**, 2007

- Observations with Milagro wide-field TeV telescope, 2000–06
  - 4 detected sources, additional 4 candidates (<5σ post-trials)
  - 5/7 have EGRET GeV counterparts (13 sources in the region, p=3x10^{-6})
  - Significant diffuse emission, especially in the Cygnus region

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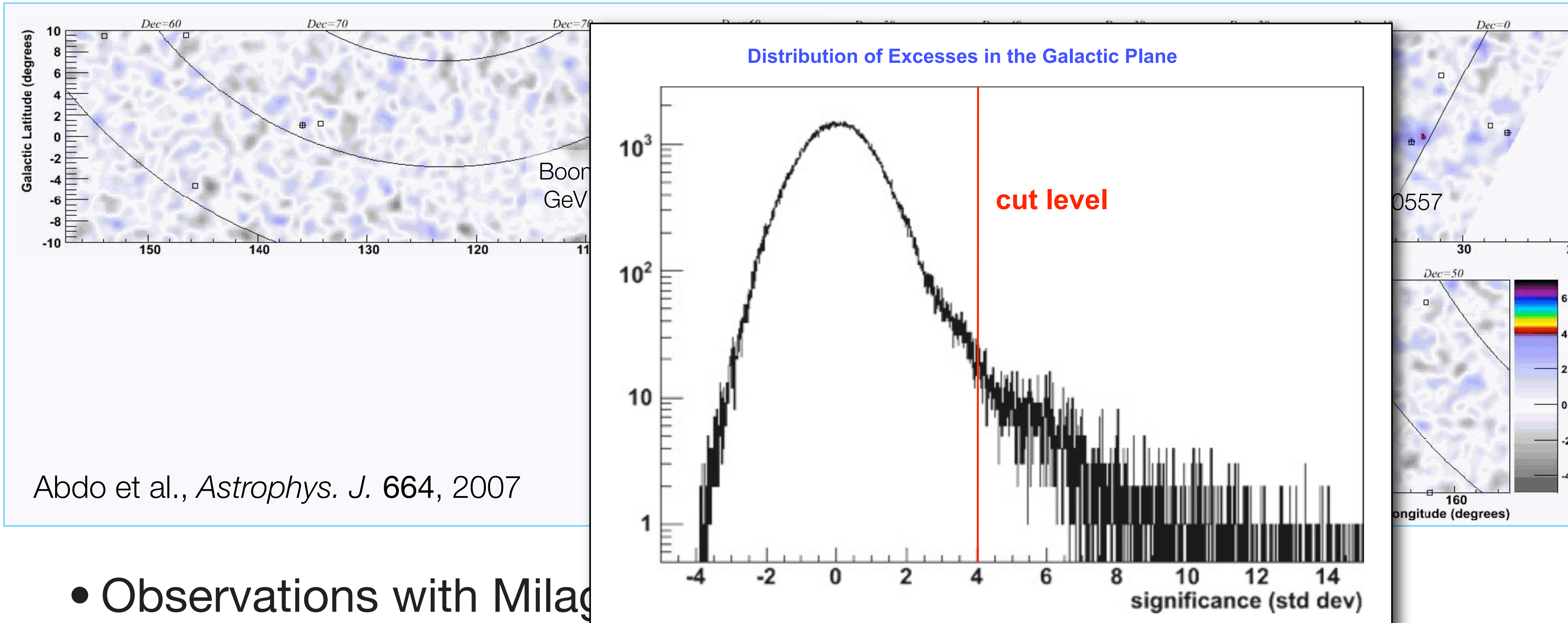

Abdo et al., *Astrophys. J.* **664**, 2007

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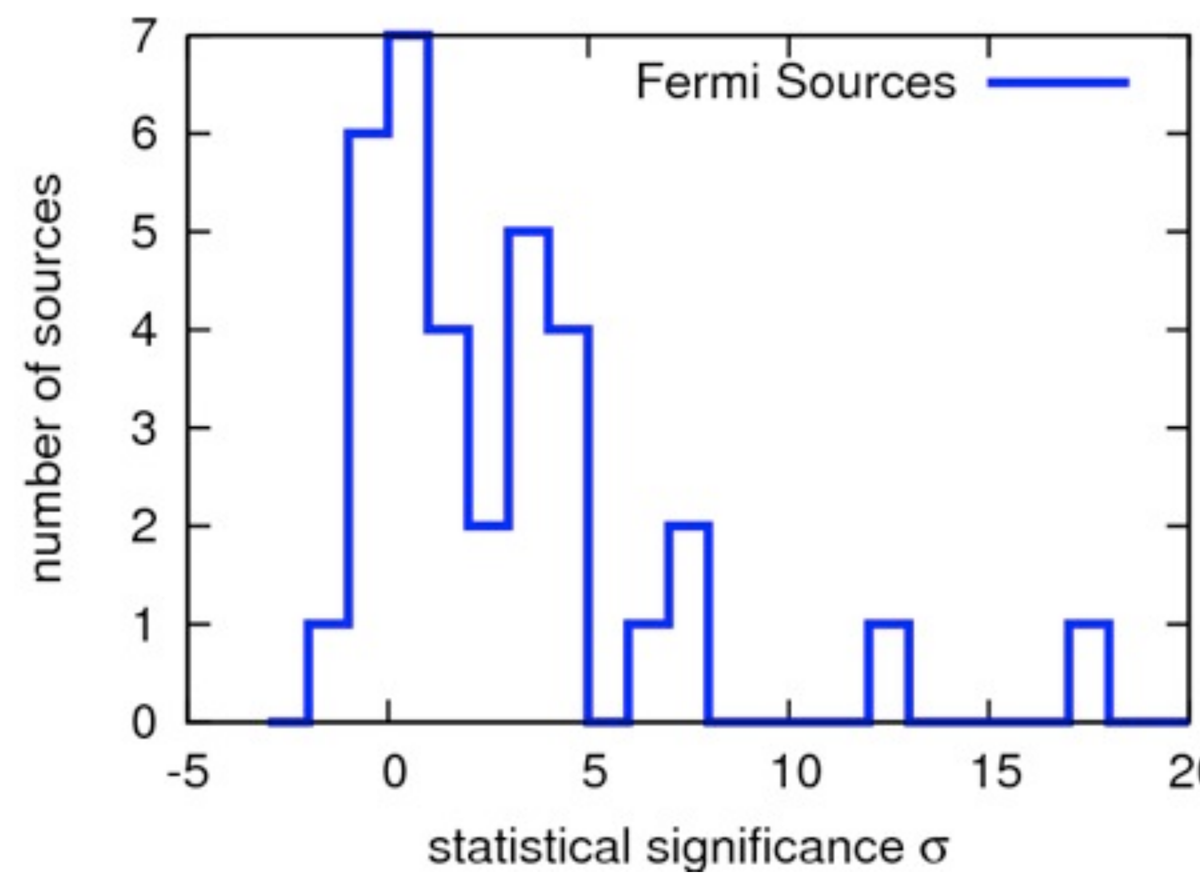
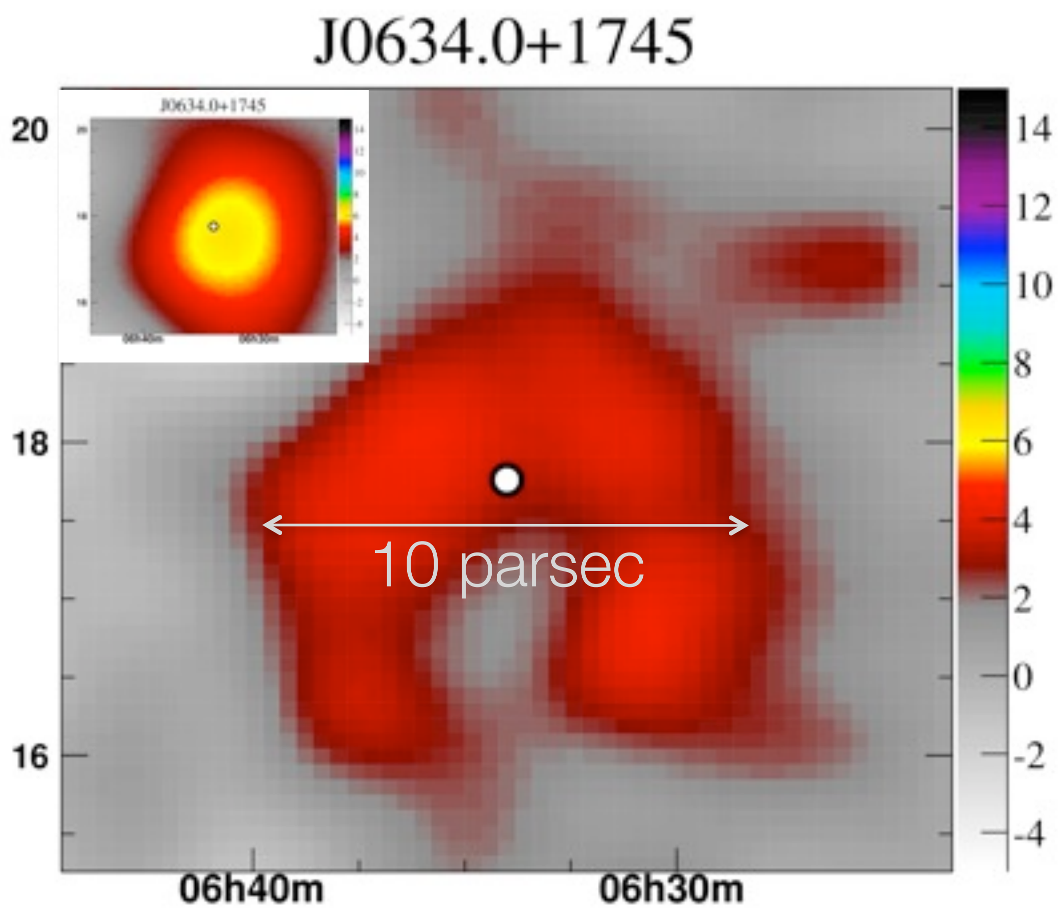
Milagro Observations of Fermi BSL Objects

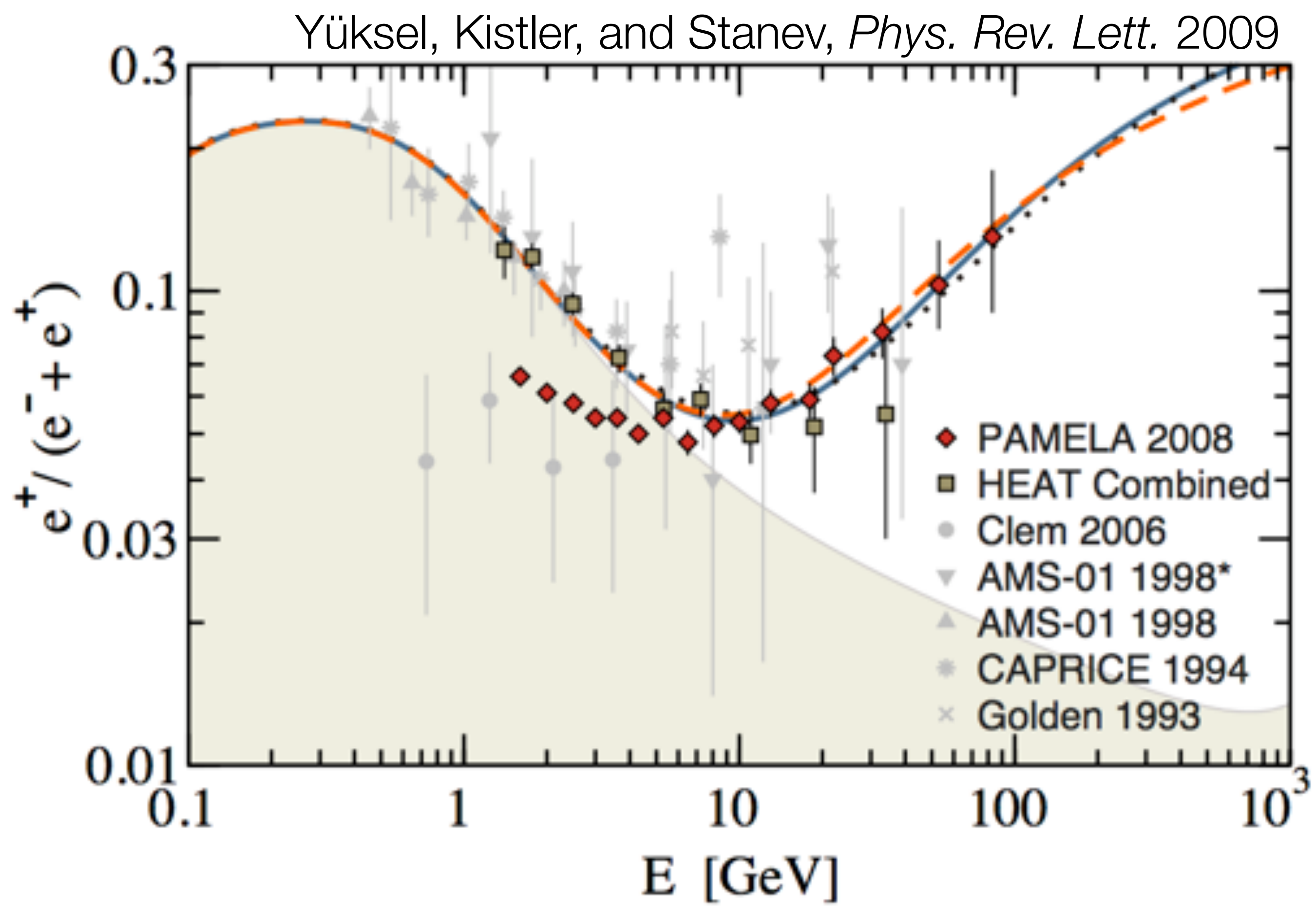
Abdo et al., *Astrophys. J. Lett.* **700**, 2009

- 34 of 205 BSL sources are definitely or possibly Galactic and in Milagro's field of view
  - 16 pulsars, 1 XRB, 5 SNRs, 12 unknown (poss. extragalactic)
- 14 of the 34 are observed at $>3\sigma$ in Milagro data set
  - 6 of 14 are previous Milagro sources
  - 9 of 14 are pulsars (incl. all 6 previously reported), 3 are SNRs
  - 6 of 14 not previously reported at TeV energies
- Probability of even a single 3σ detection in 34 trials is 4.4%



Geminga as a Local Positron Source





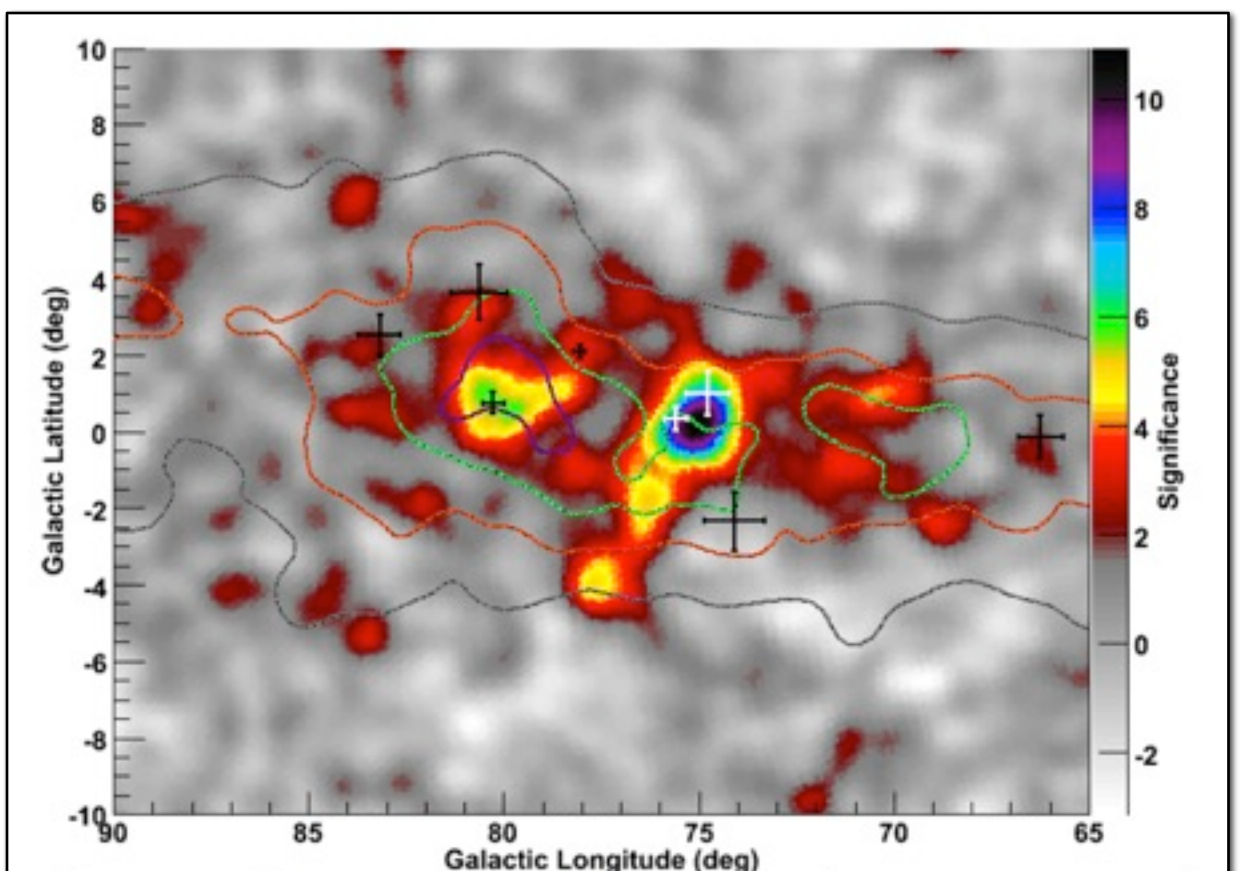
- Milagro detects an extended gamma ray source coincident with the Geminga pulsar

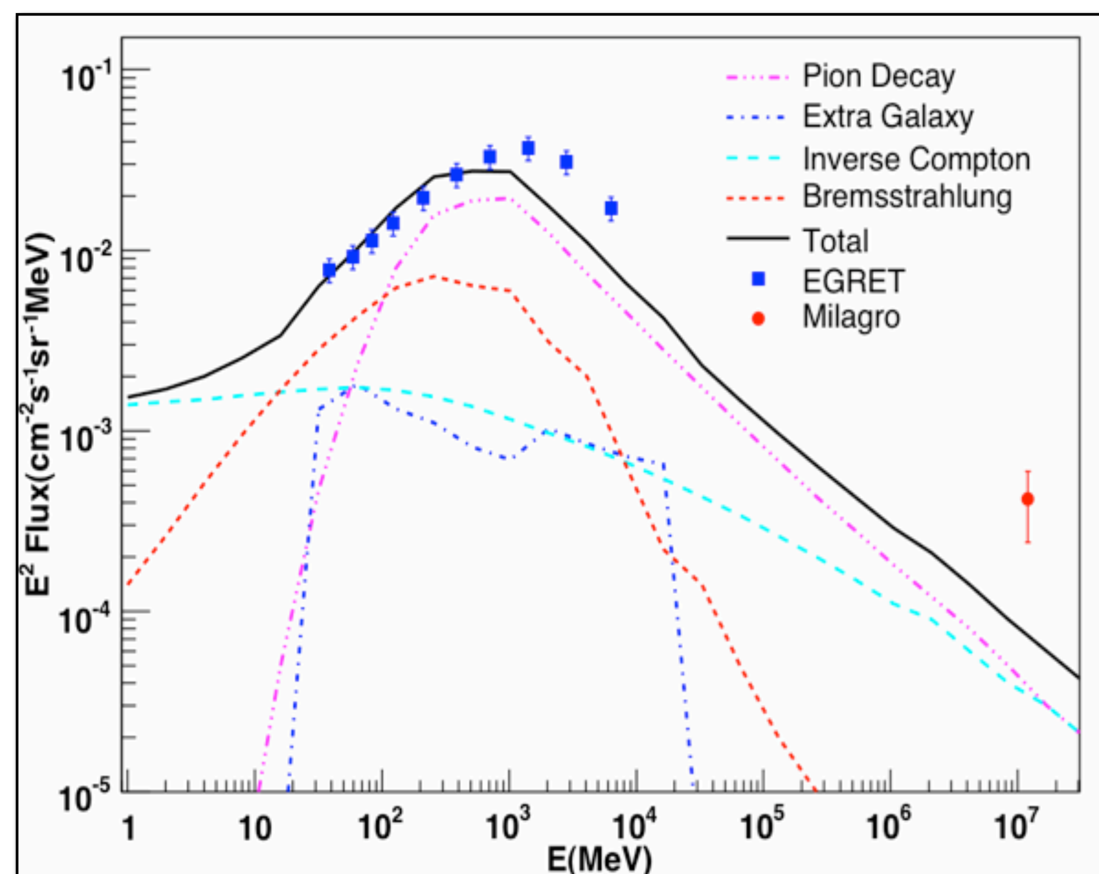
- Has been argued that PAMELA's positron excess can be explained as due to Geminga, based on Milagro's flux measurement

Galactic Cosmic Ray Acceleration Regions?

Abdo et al., *Astrophys. J.* 2007

- Milagro observations of Cygnus arm of the galaxy
  - Measure diffuse emission (cosmic rays on dust) after sources subtracted
  - EGRET excess not confirmed by Fermi, but TeV excess still unexplained – higher CR density, harder spectrum, unresolved sources, dark matter?





From Milagro to HAWC

- The High Altitude Water Cherenkov Observatory
- Redeploy Milagro detectors at Volcán Sierra Negra, México
  - Increase altitude from 2630 m to 4100 m
  - Increase area from 3,600 m^2 (bottom layer of pond) to 20,000 m^2
  - Segment the Cherenkov medium: separate tanks instead of a single pond
  - Better angular resolution and background rejection, lower energy threshold
- Achieve 10-15 x sensitivity of Milagro
  - Detect Crab at 5σ in 6 hours instead of 3 months
- Cost: ~$10M

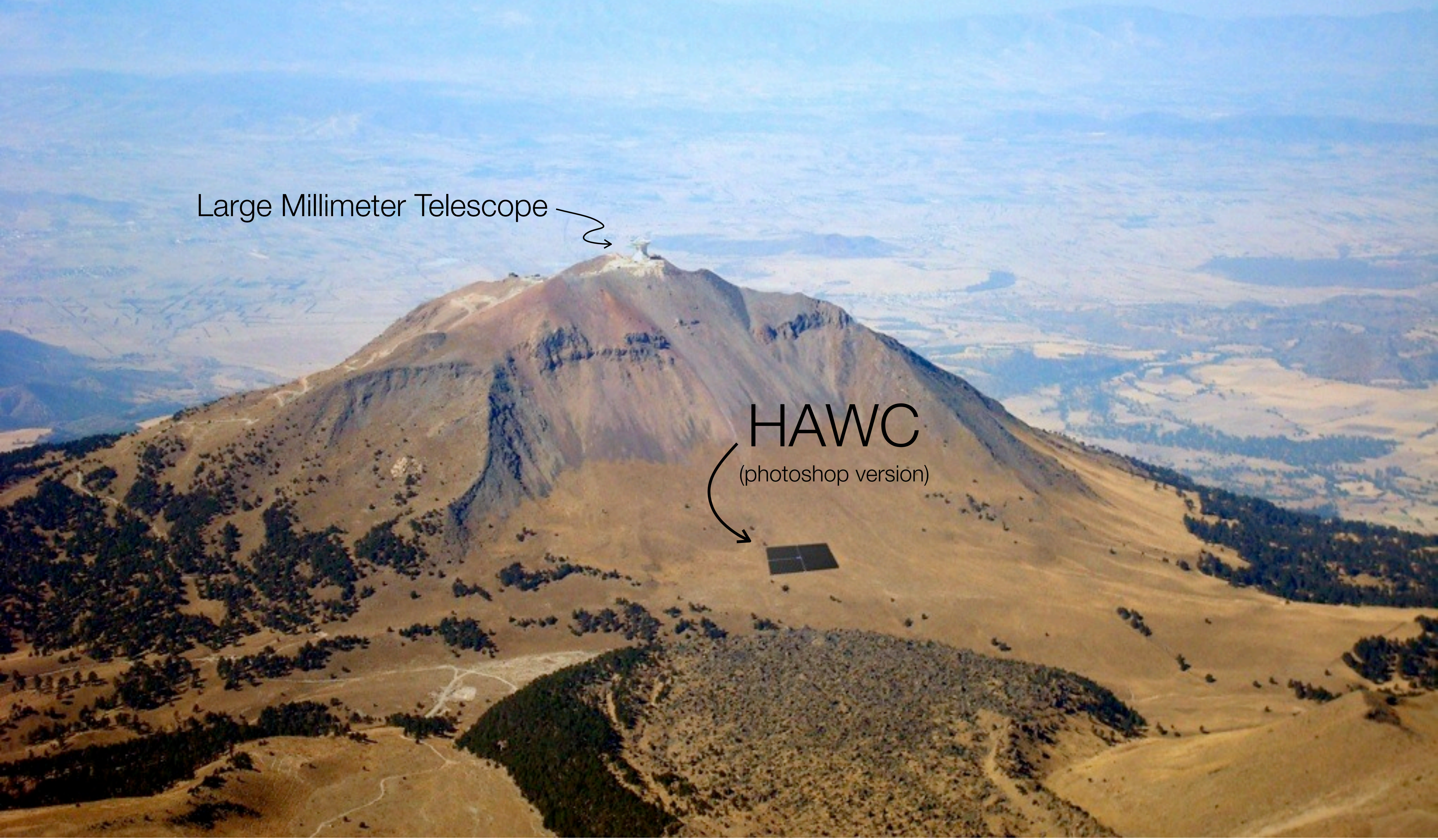
The HAWC Collaboration

USA

- University of Maryland
- Los Alamos National Laboratory
- University of California, Irvine
- University of California, Santa Cruz
- Colorado State University
- George Mason University
- Georgia Institute of Technology
- Goddard Space Flight Center
- Harvey Mudd College
- Michigan State University
- Michigan Technological University
- University of New Hampshire
- University of New Mexico
- Pennsylvania State University
- University of Utah
- University of Wisconsin, Madison

México

- Instituto Nacional de Astrofísica Óptica y Electrónica (INAOE)
- Universidad Nacional Autónoma de México (UNAM)
- Universidad Autónoma de Chiapas
- Universidad de Guadalajara
- Universidad de Guanajuato
- Universidad Michoacana de San Nicolás de Hidalgo
- Centro de Investigación y Estúdios Avanzados (CINVESTAV)
- Benemérita Universidad de Puebla

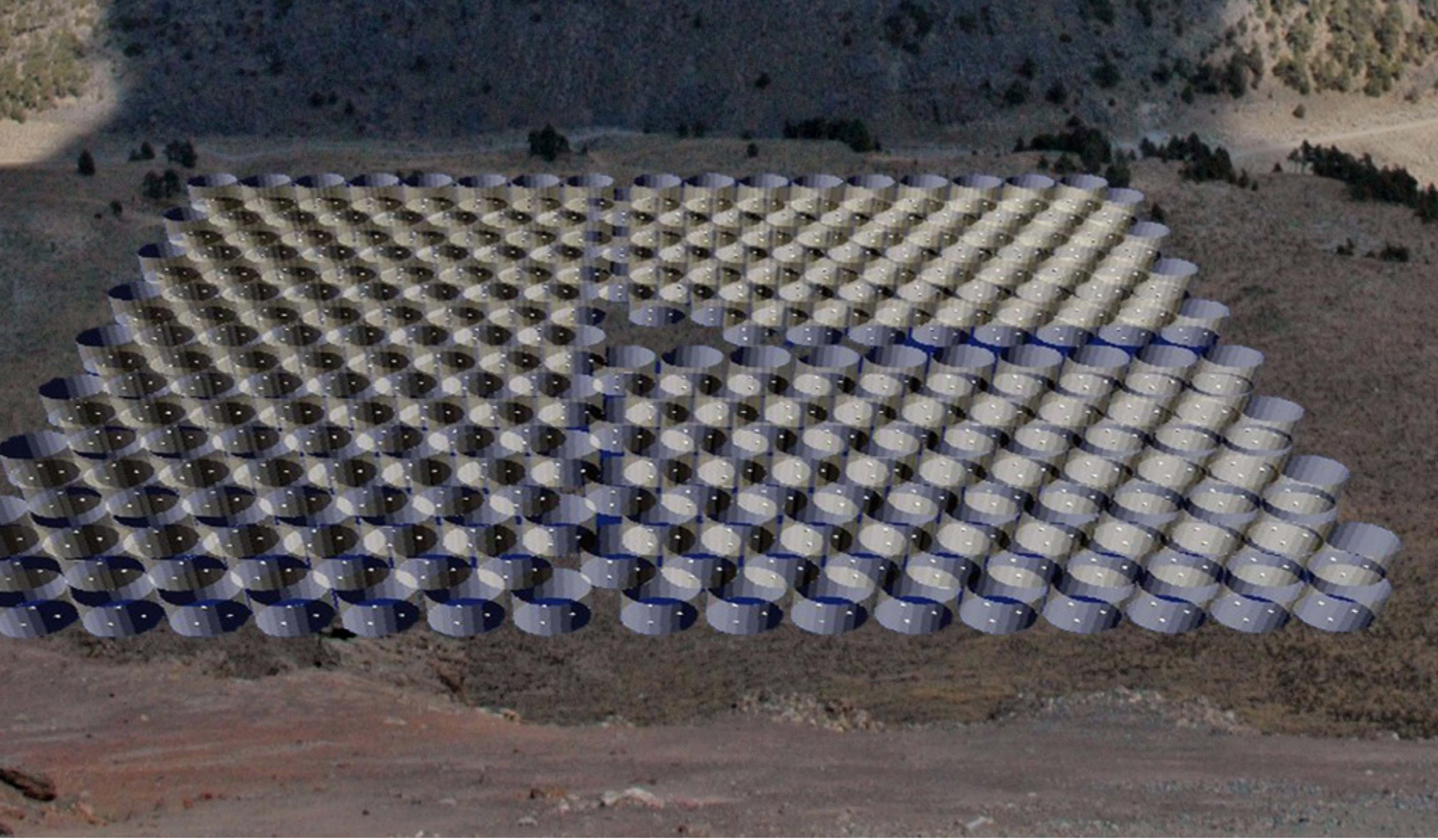


HAWC

Pico de Orizaba, altitude 4100 m, latitude 18° 59’ N
Two hours drive from Puebla, four from México City
Site of Large Millimeter Telescope (infrastructure exists)

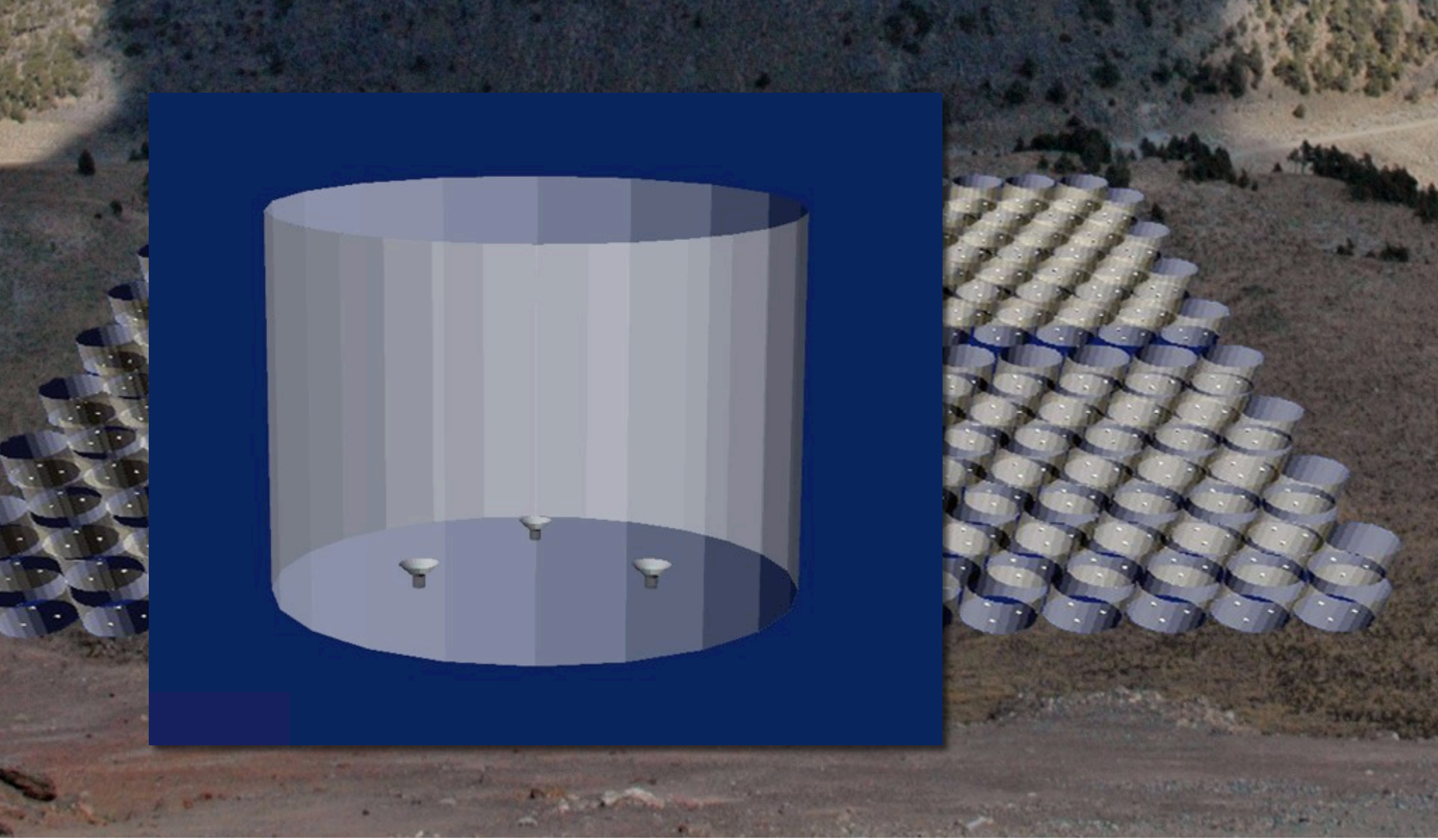
HAWC

Site is a saddle between Sierra Negra and Pico de Orizaba
In a national park, existing scientific consortium at peak
Temperatures mild, wind/rain patterns known



Design

300 water Cherenkov detectors, 7.3 m diameter x 4.5 m tall
200,000 liters water with 3 upward looking 8” PMTs per tank
~20,000 m^2 area, >60% active Cherenkov volume



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HAWC Detectors

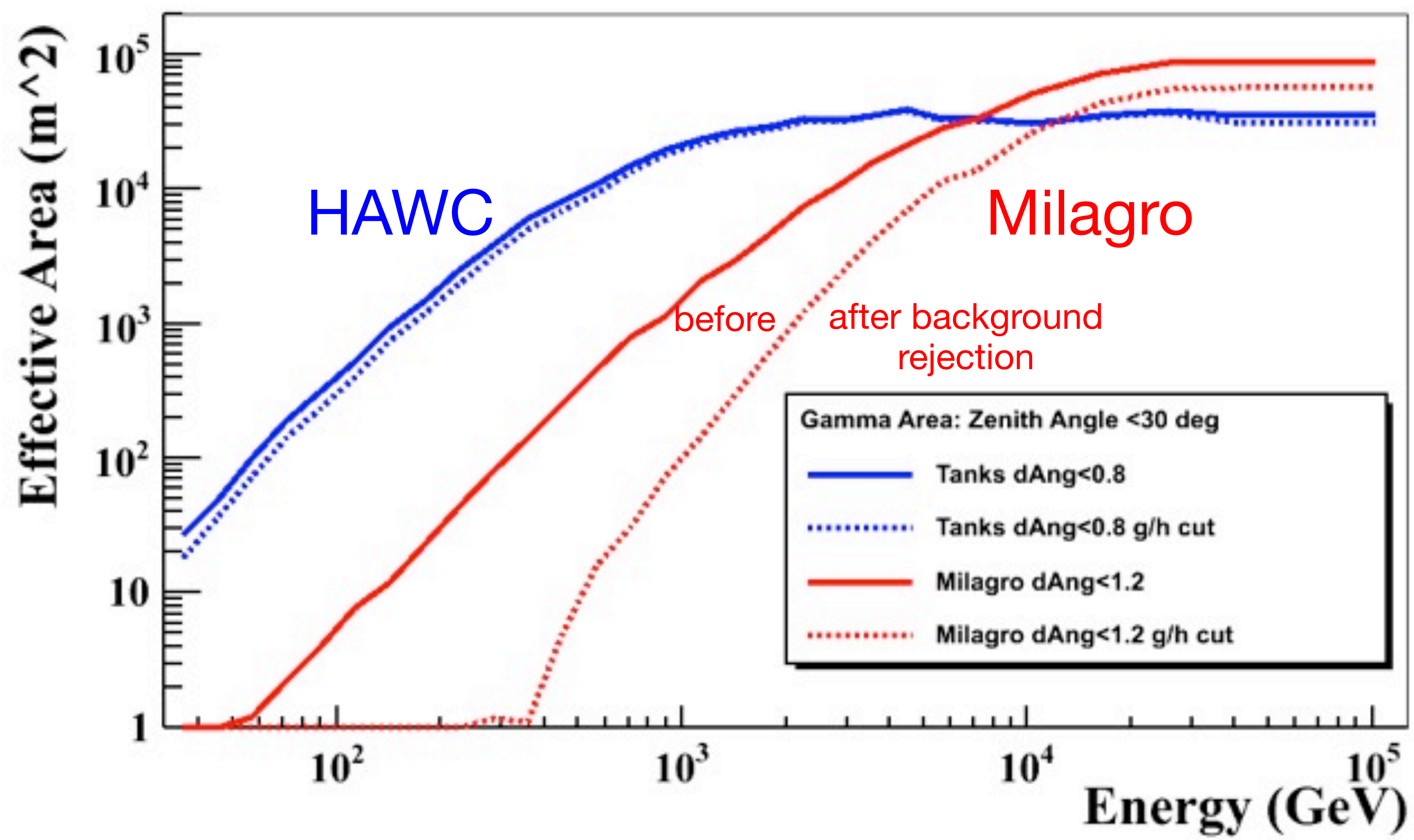
- Steel cylinders with liners, assembled in place
  - Light-tight, black plastic bladder to hold water
  - Ultra-pure filtered and demineralized water
  - 3 upward looking PMTs with <1 ns time resolution
- 900 8" Hamamatsu PMTs and most electronics re-used from Milagro

Energy Threshold and Effective Area

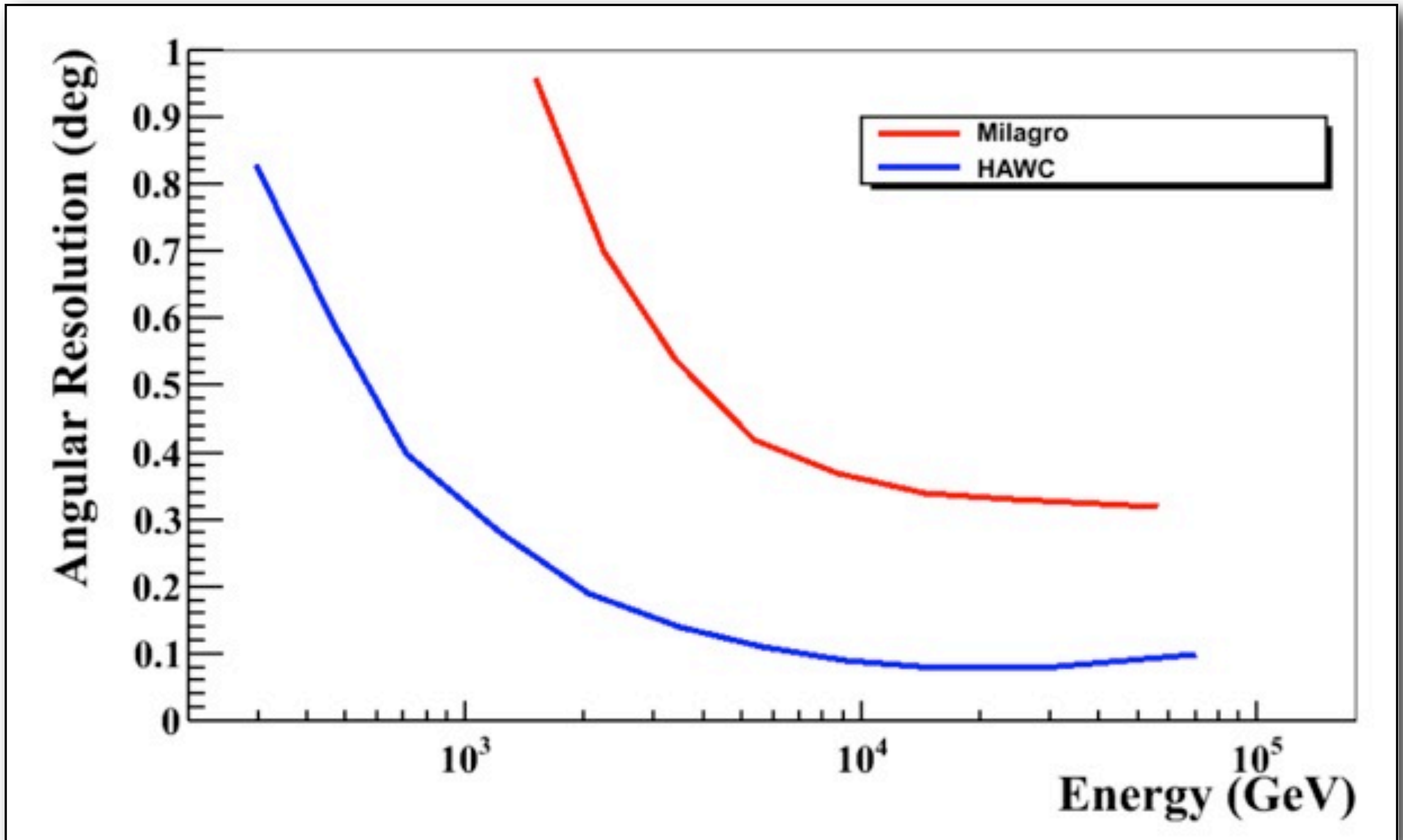
- Higher altitude leads to a lower energy threshold
  - Stochastics of shower development lead to very soft threshold

- HAWC will be fully efficient above ~2 TeV
  - Still >100 m^2 effective area at 100 GeV

- Relative improvement even more significant after hadron cuts



Angular Resolution

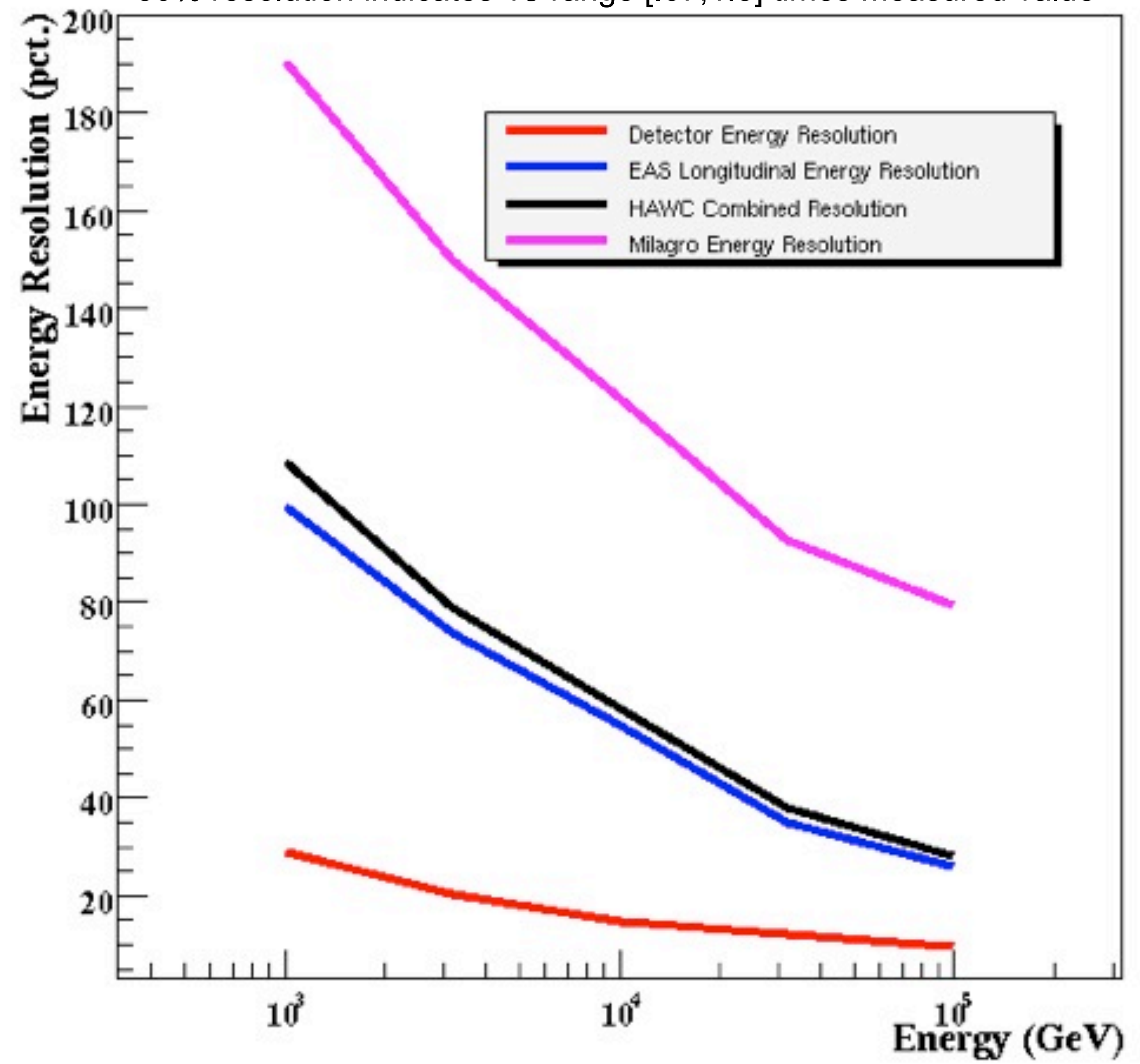


- Significant increase over Milagro – limited by information in the particles that reach the ground
  - Based on Milagro algorithms – improvements expected (esp. at higher E)

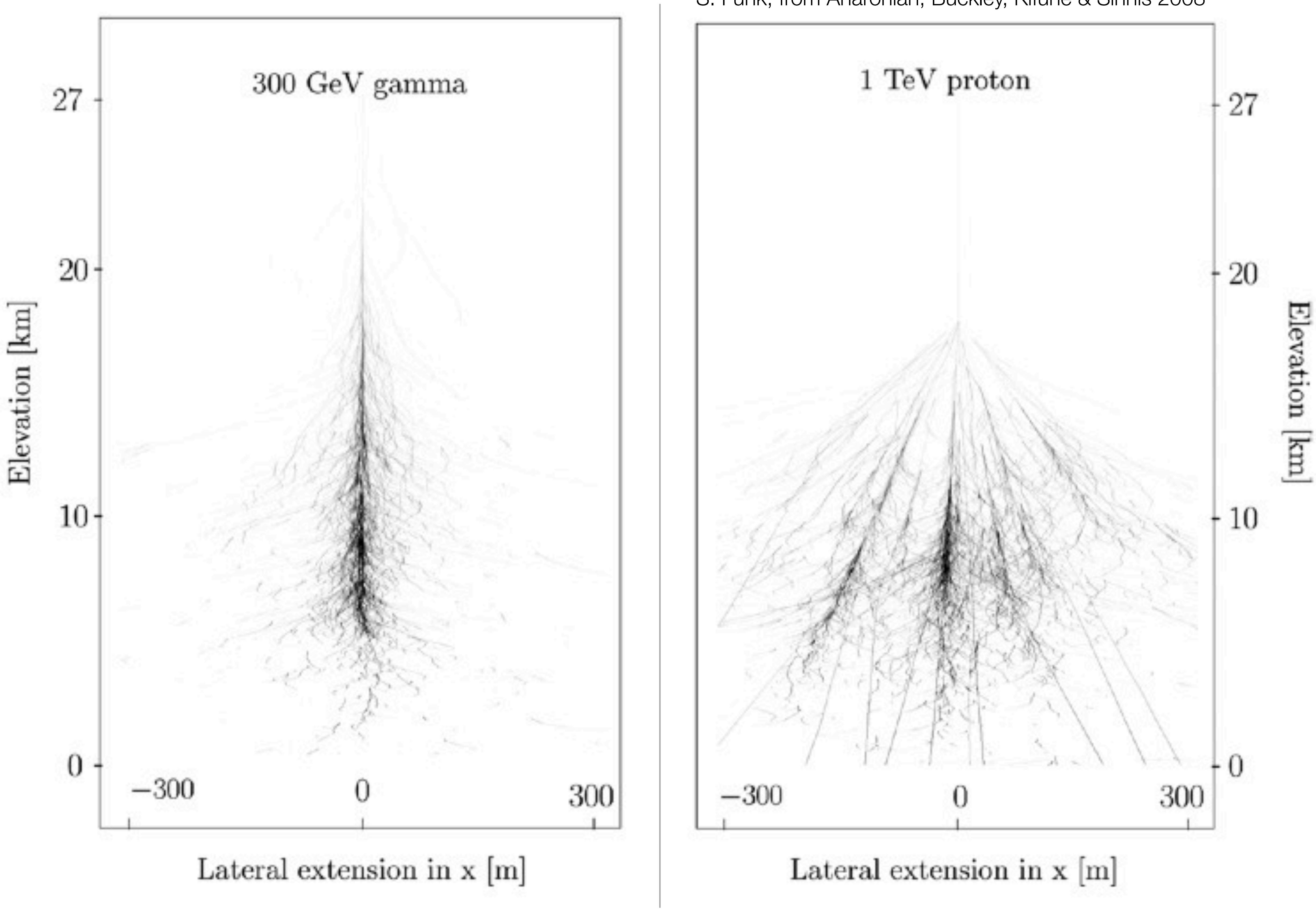
Energy Resolution

- Uncertainty from two sources:
  - Measurement of energy deposited at ground level
  - Fluctuations in shower development in atmosphere (naturally log-normal)
- Higher elevation brings HAWC closer to shower max
  - Fluctuations less important
  - HAWC resolution approaches limit due to stochastics in shower development

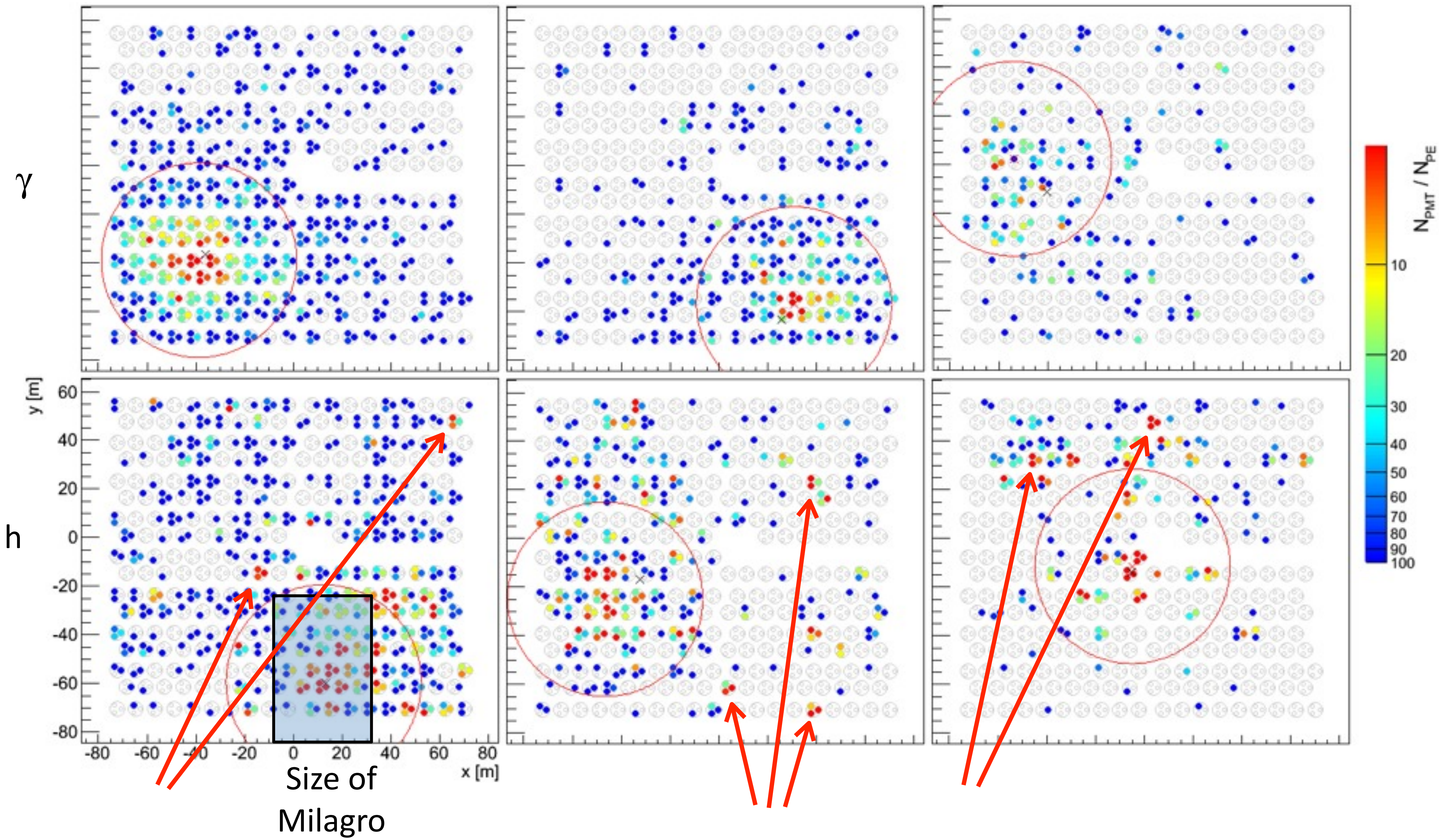
Resolutions are log-normal:
50% resolution indicates 1σ range [.67,1.5] times measured value



S. Funk, from Aharonian, Buckley, Kifune & Sinnis 2008



Cosmic ray background rejection based on search for substructure in air showers



Hadron Rejection

Algorithm looks for high-amplitude hits more than 40 m from the reconstructed core location

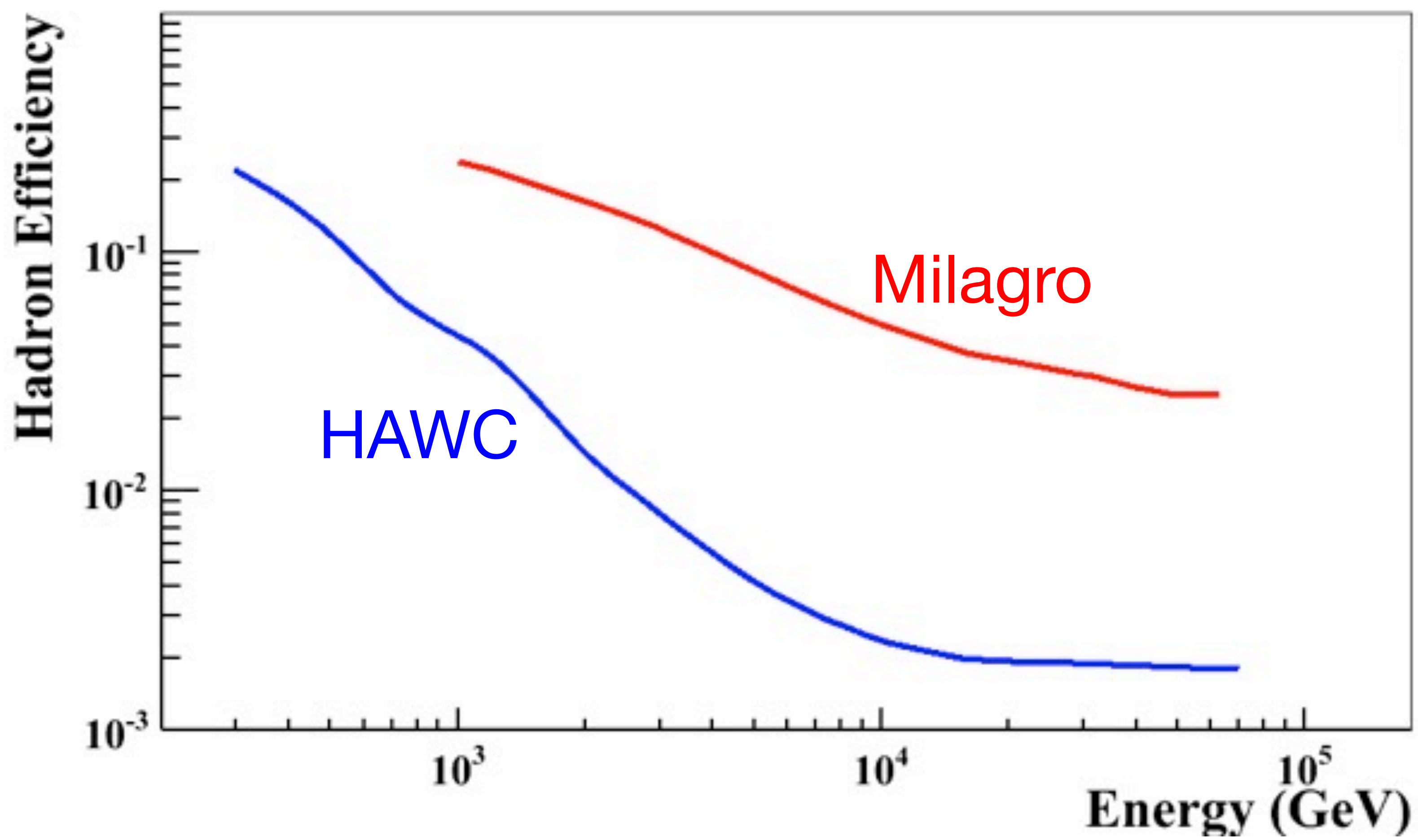
Gamma-Hadron Separation

- Currently use parameter C = nHit / cxPE
  (cxPE = largest hit (in PEs) >40m from shower core)

- Already gives ~10x better rejection than Milagro at fixed (estimated) energy

- Conservative: more sophisticated algorithms possible

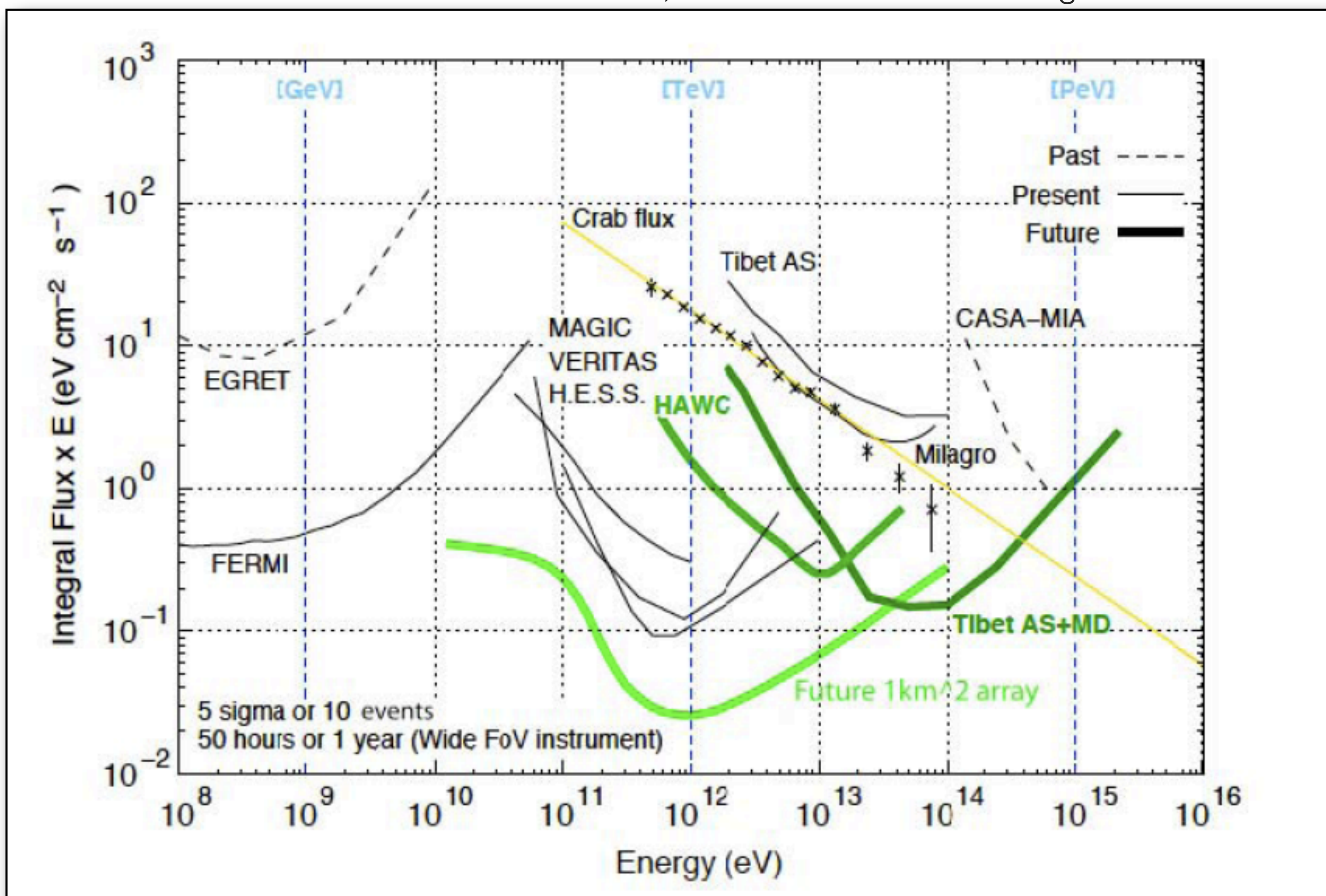
G-H separation at 50% gamma efficiency



Sensitivity to Point Sources

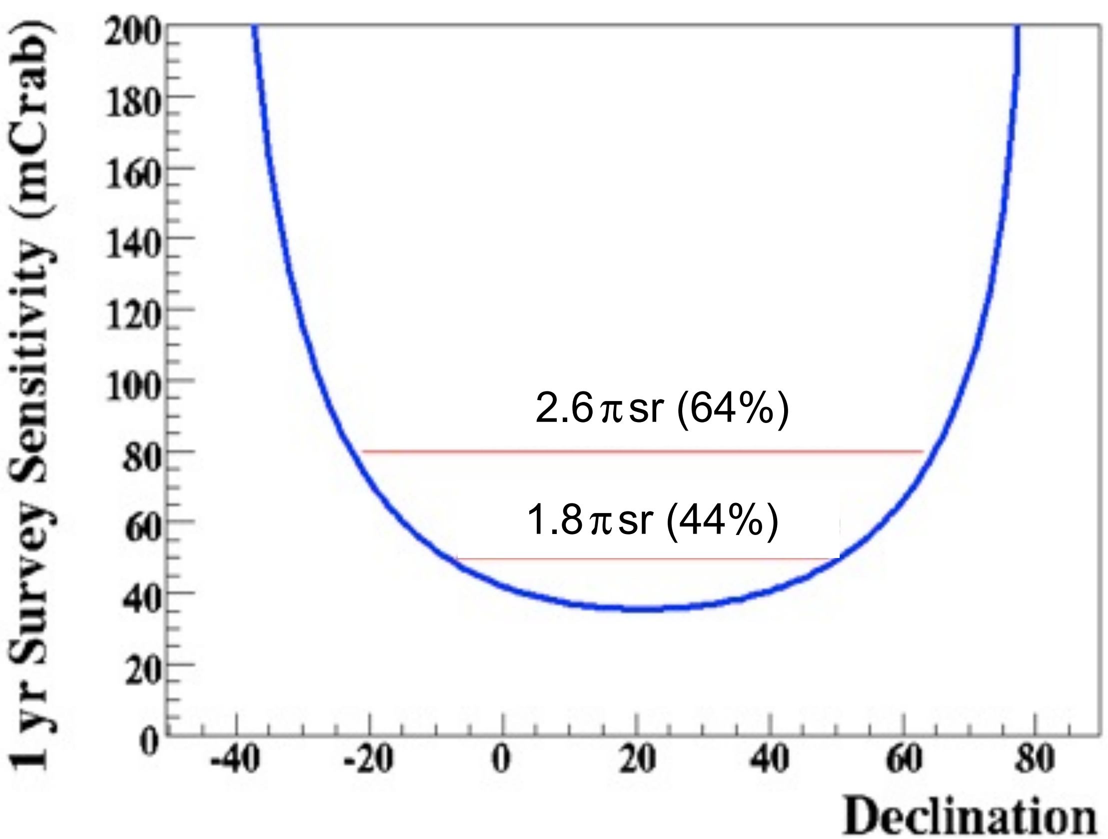
- Long integration times lead to excellent sensitivity at highest energies (> few TeV)
- 5σ sensitivity to:
  10 Crab in 3 min
  1 Crab in 5 hr
  0.1 Crab in ⅓ year
- 10-15x Milagro sensitivity
  - Lower energy threshold
  - Better angular resolution
  - Better CR rejection

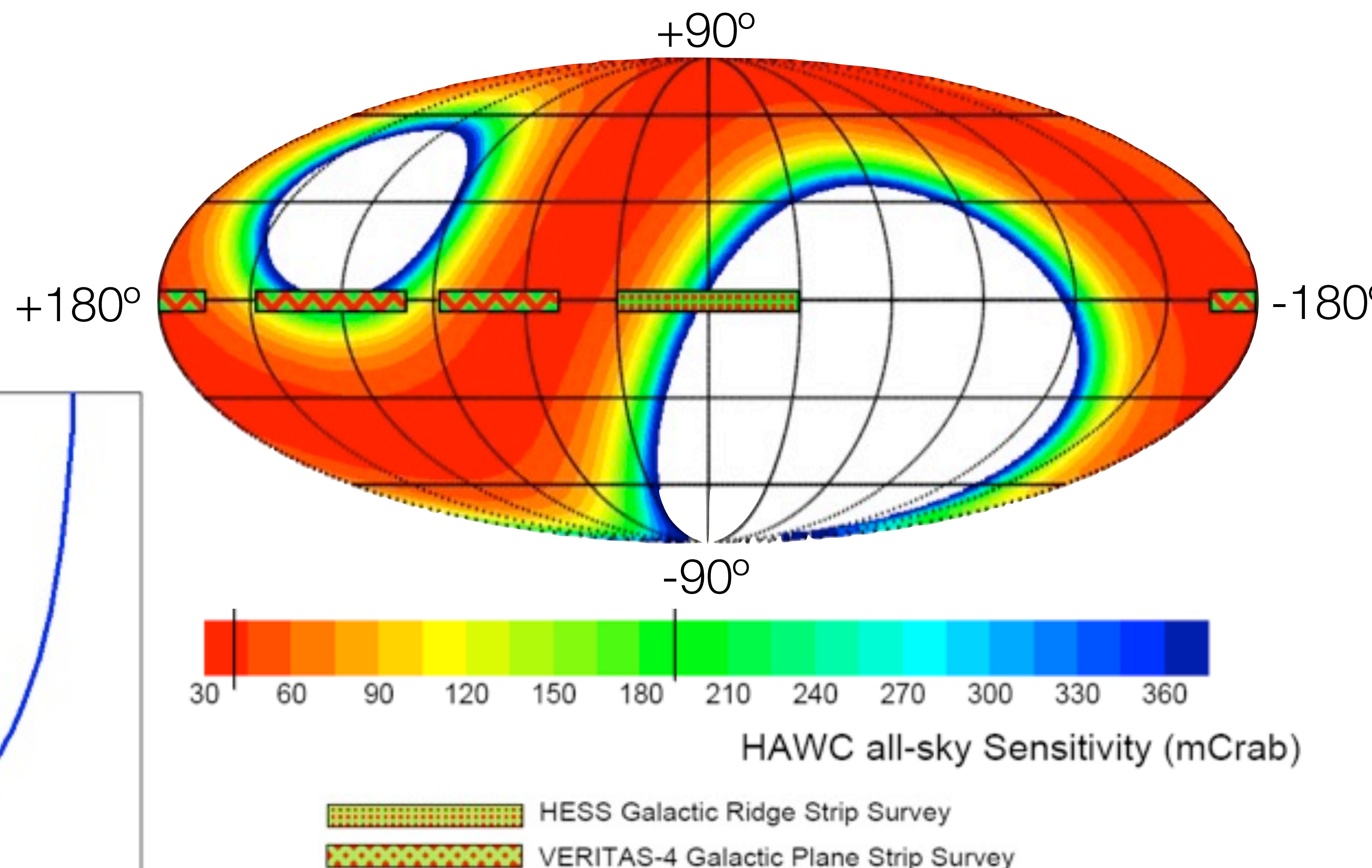
50 hr observation time assumed for IACTs, HAWC source culminating 15º from zenith



Field of View

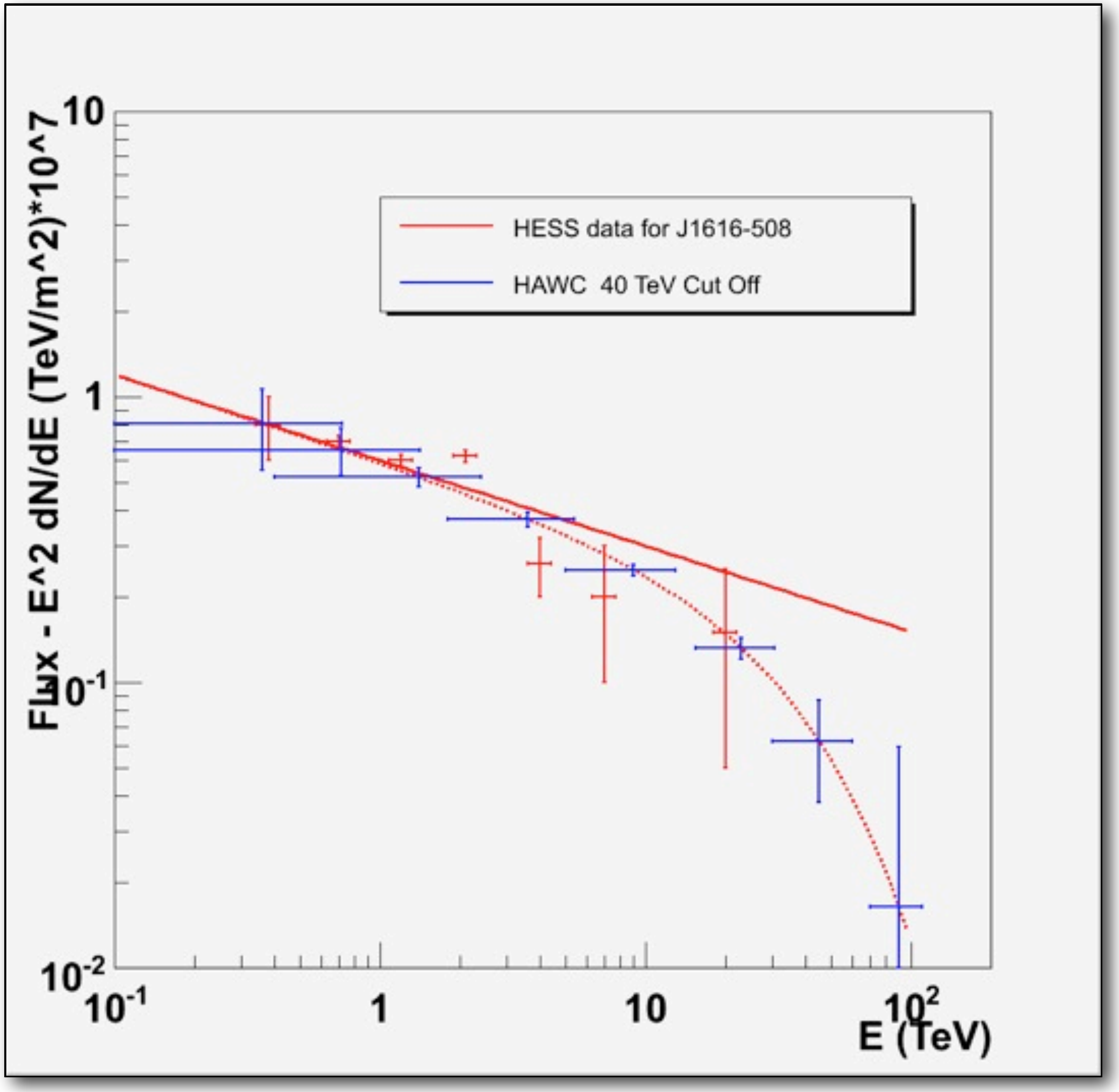
- Wide field of view, limited by atmospheric depth
  - 45° from zenith (Milagro standard analysis)
  - 50 mCrab survey in 1 yr

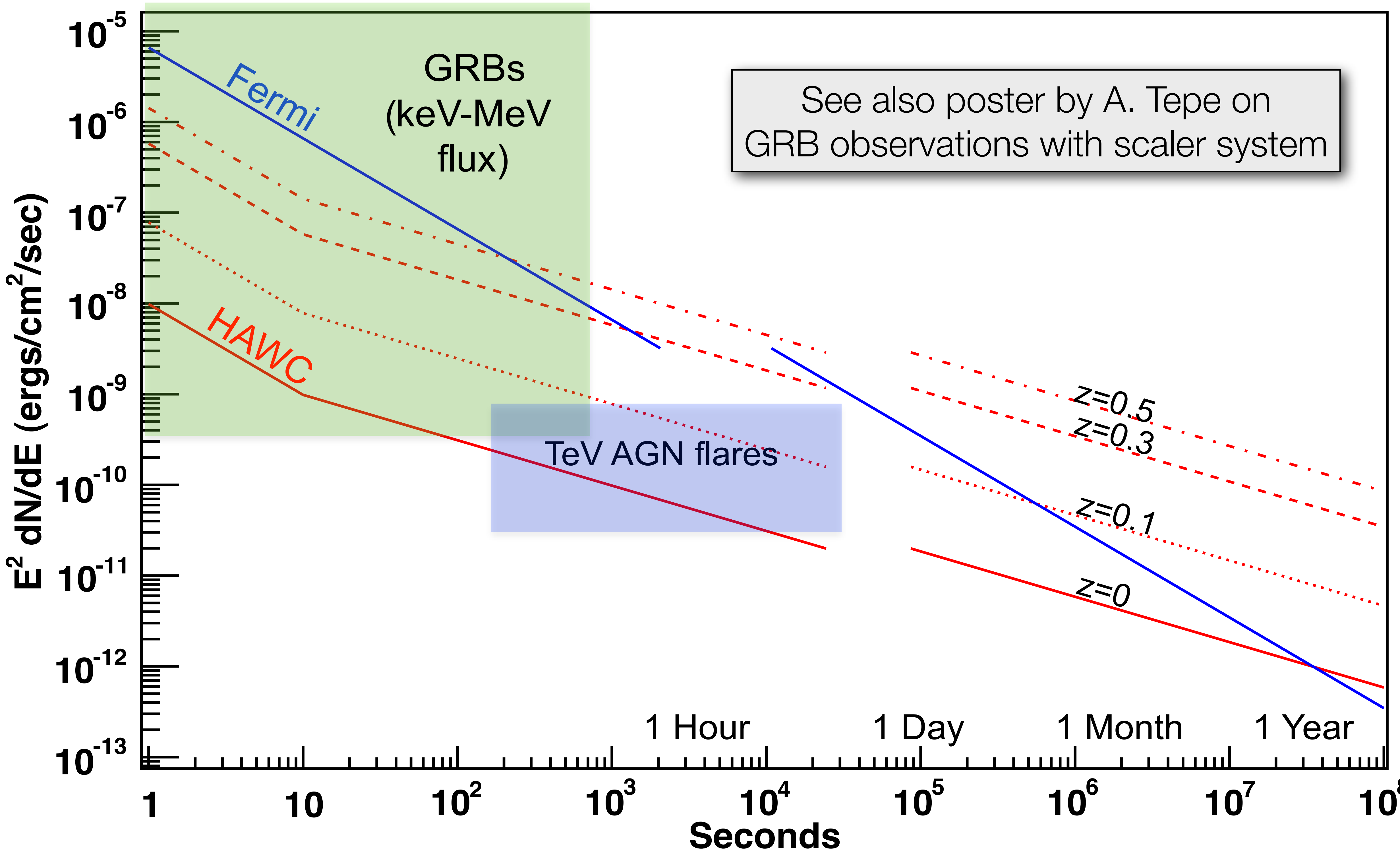




Measuring Spectra at the Highest Energies

- HESS J1616-508
  - 0.2 Crab @ 1 TeV, α=-2.3
  - Highest energy ~20 TeV
- Simulated HAWC data for 1 year with no cutoff
- ...or with a 40 TeV exponential cutoff



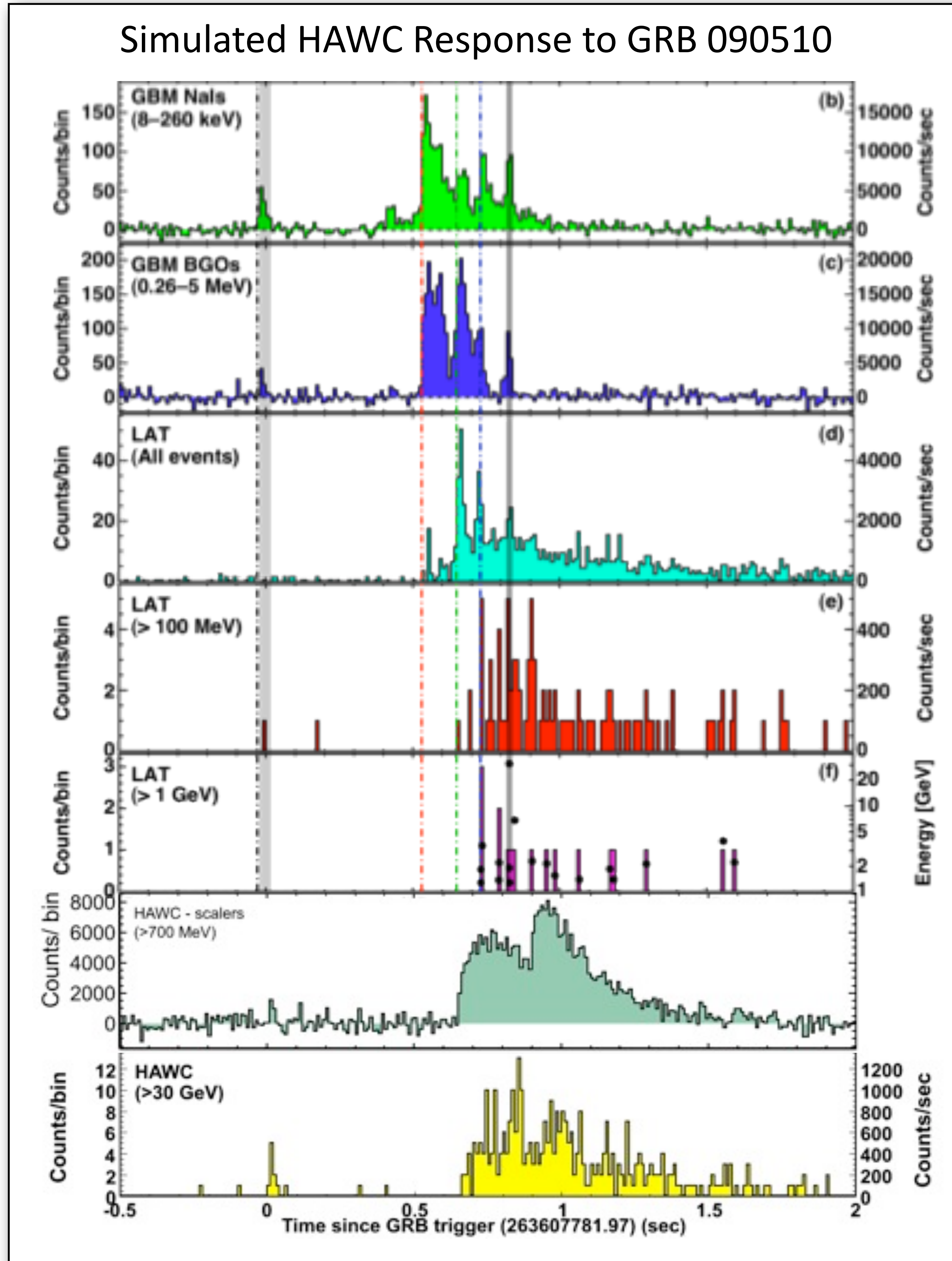


Transient Sensitivity

Assumed E^{-2} emission spectrum
Full HAWC simulation
Fermi-LAT assumed 0.8 m^2 effective area, no background

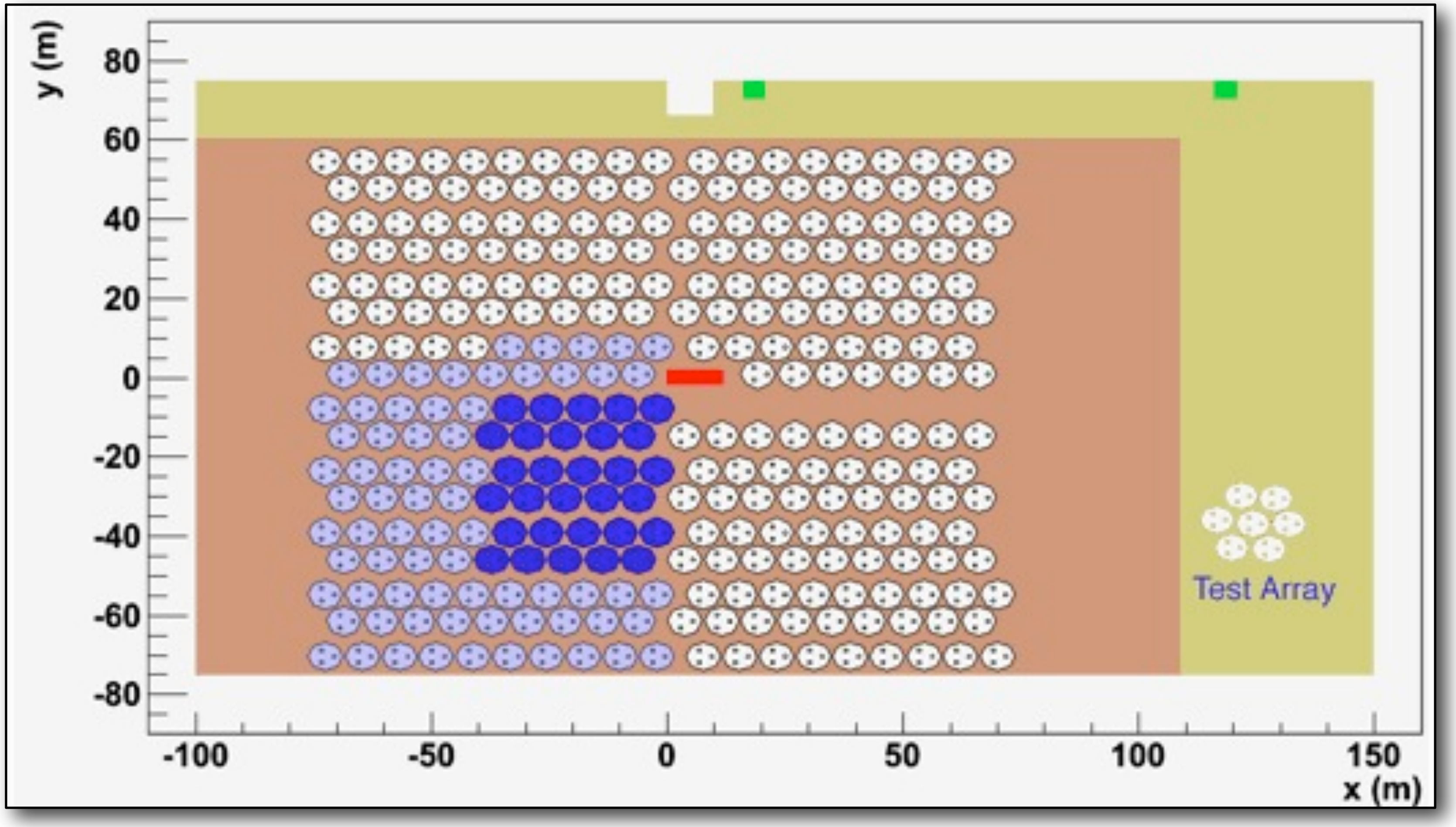
Sensitivity to High Energy Transients

- Fermi observation of GRB 090510 (z = 0.9) in GBM and LAT
- Simulated HAWC light curve assuming extension of spectrum with LAT index
  - EBL absorption included
  - Cosmic ray background included
- ~200 events expected above 30 GeV
- Detection (5σ) by HAWC if emission extended to 50 GeV



HAWC Construction Schedule

- VAMOS
  - Verification Assessment Measuring Observatory Subsystems (3 months)
- HAWC-30
  - Implementation of all subsystems (6 months)
- HAWC-100
  - Science operations with 2 times Milagro's sensitivity (12 months)
- HAWC-300
  - Full detector (15 months)



HAWC Construction Schedule

HAWC Status

- Evolution of Milagro: size, altitude, optical isolation
  - 10-15x sensitivity of Milagro
  - Straightforward design, only new aspect is large water tanks
- Funding approved by NSF, DOE in US and by CONACyT in México
  - 7 detector array (VAMOS) under construction, first detector operational
  - Modular array – data taking will begin before full array is complete
  - Plan for operation with 100 detectors in late 2011, full array of 300 detectors to be operational by 2013
- Wide field of view and high duty cycle at 10 GeV – 100 TeV makes HAWC an excellent complement to other current and forthcoming instruments