The HAWC Observatory

PENNSTATE 1855

Tyce DeYoung
Department of Physics
Penn State University

GeV and TeV Sources in the Milky Way
Aspen Summer Workshop
June 14, 2010

From Milagro to HAWC

- The High Altitude Water Cherenkov Observatory
- Redeploy Milagro detectors at Volcán Sierra Negra, México
  - Increase altitude from 2650 m to 4100 m
  - Increase area from 3,600 m^2 (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

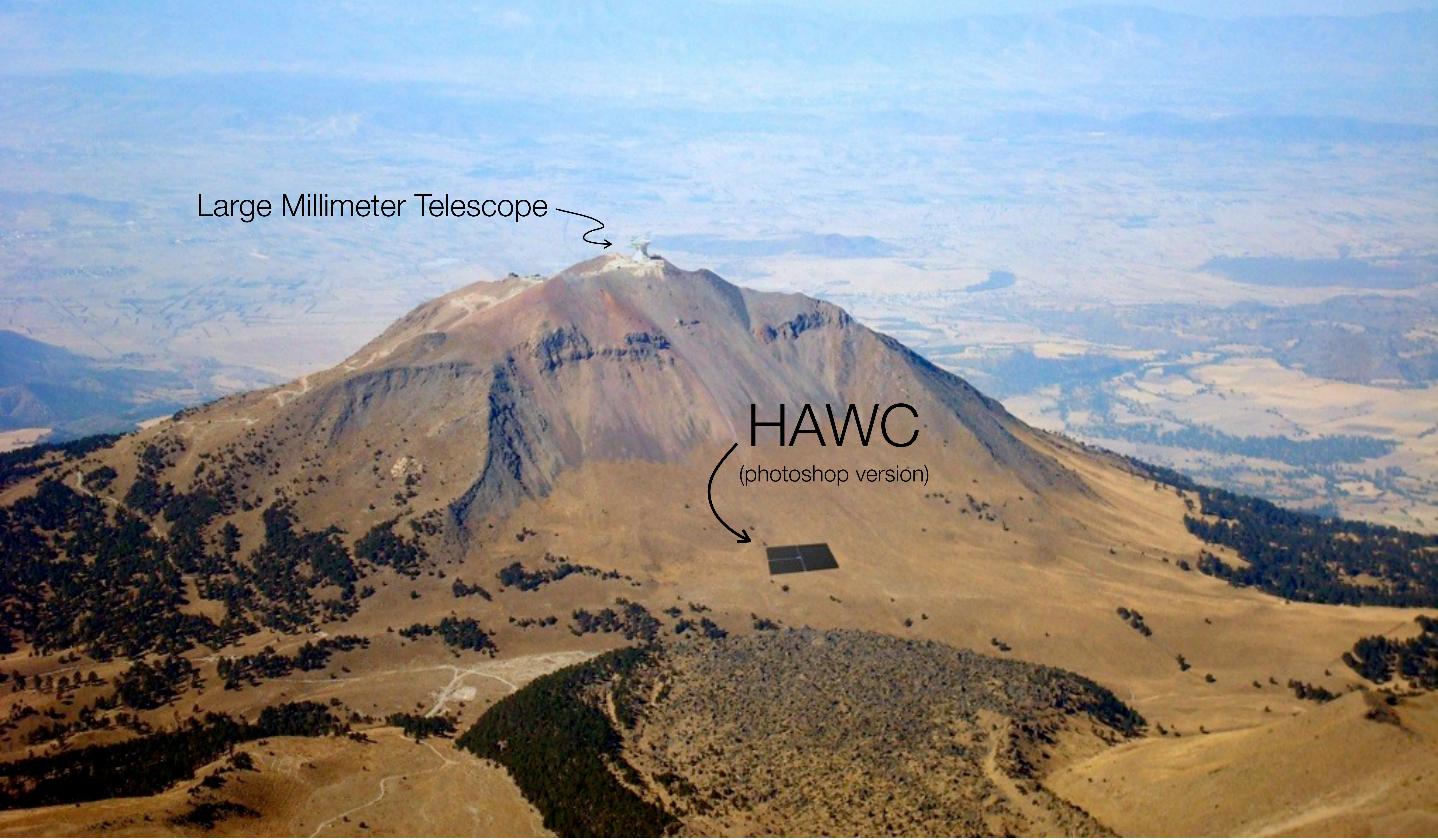
The HAWC Collaboration

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

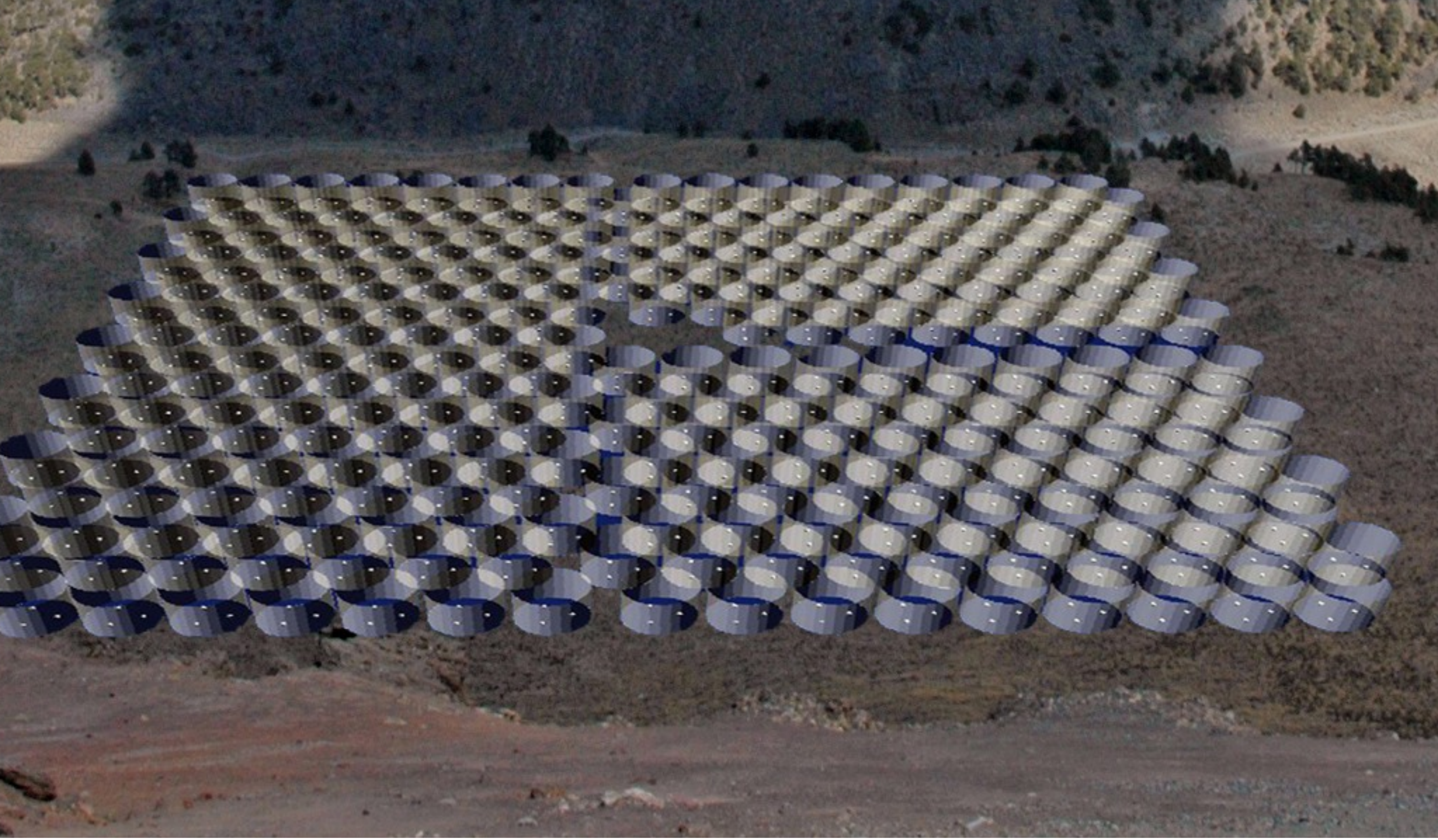


HAWC

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)

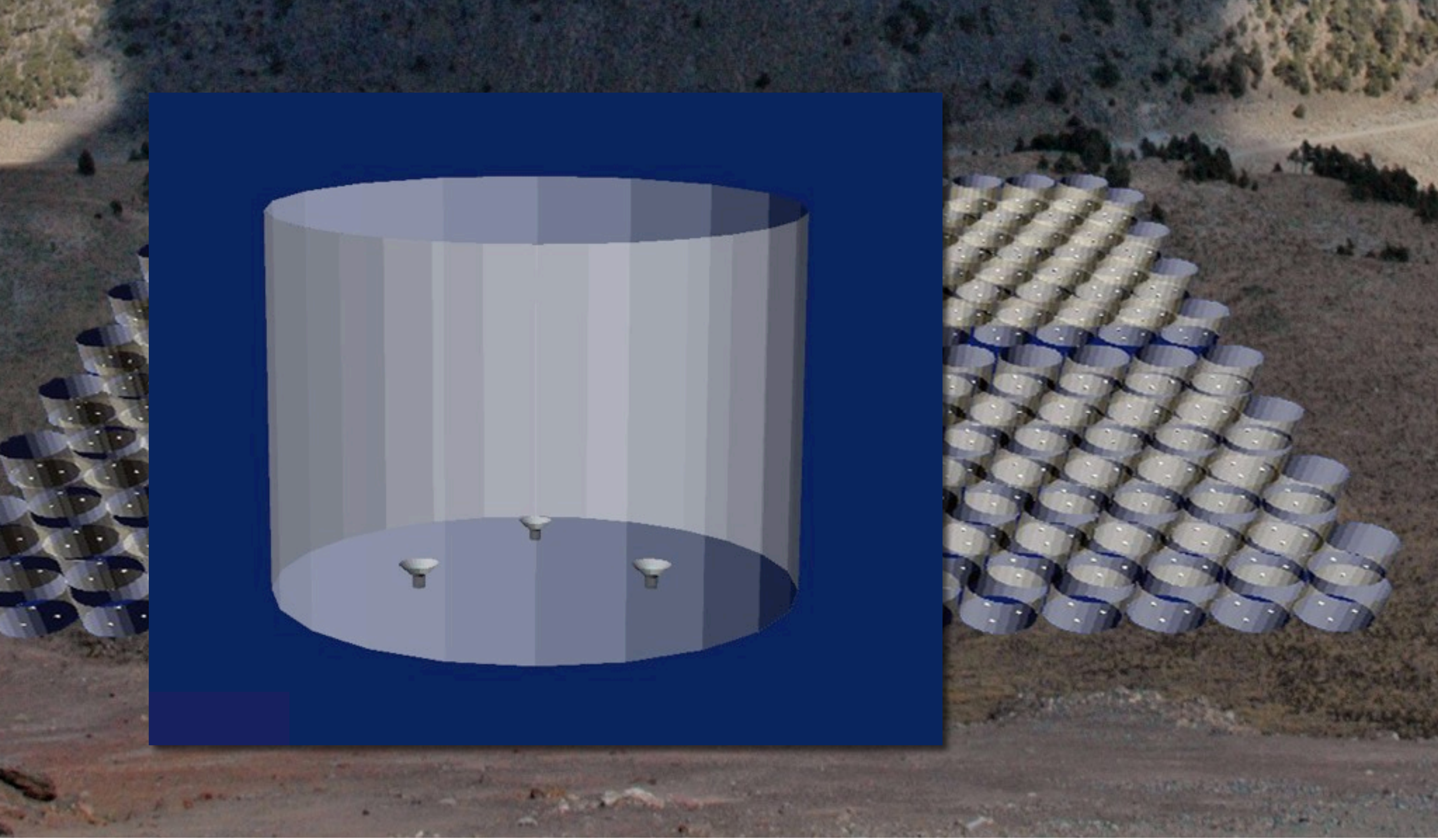
HAWC

Site is a saddle point between Sierra Negra & Orizaba
National park, existing scientific cosortium
Temperatures mild, wind/rain patterns known



Design

300 tanks, 7.3 m diameter by 4.5 m tall
3 x 8” PMTs per tank
~20,000 m^2 area, >60% active Cherenkov volume



Design

300 tanks, 7.3 m diameter by 4.5 m tall
3 x 8” PMTs per tank
~20,000 m^2 area, >60% active Cherenkov volume

Design

300 tanks, 7.3 m diameter by 4.5 m tall
3 x 8” PMTs per tank
~20,000 m^2 area, >60% active Cherenkov volume

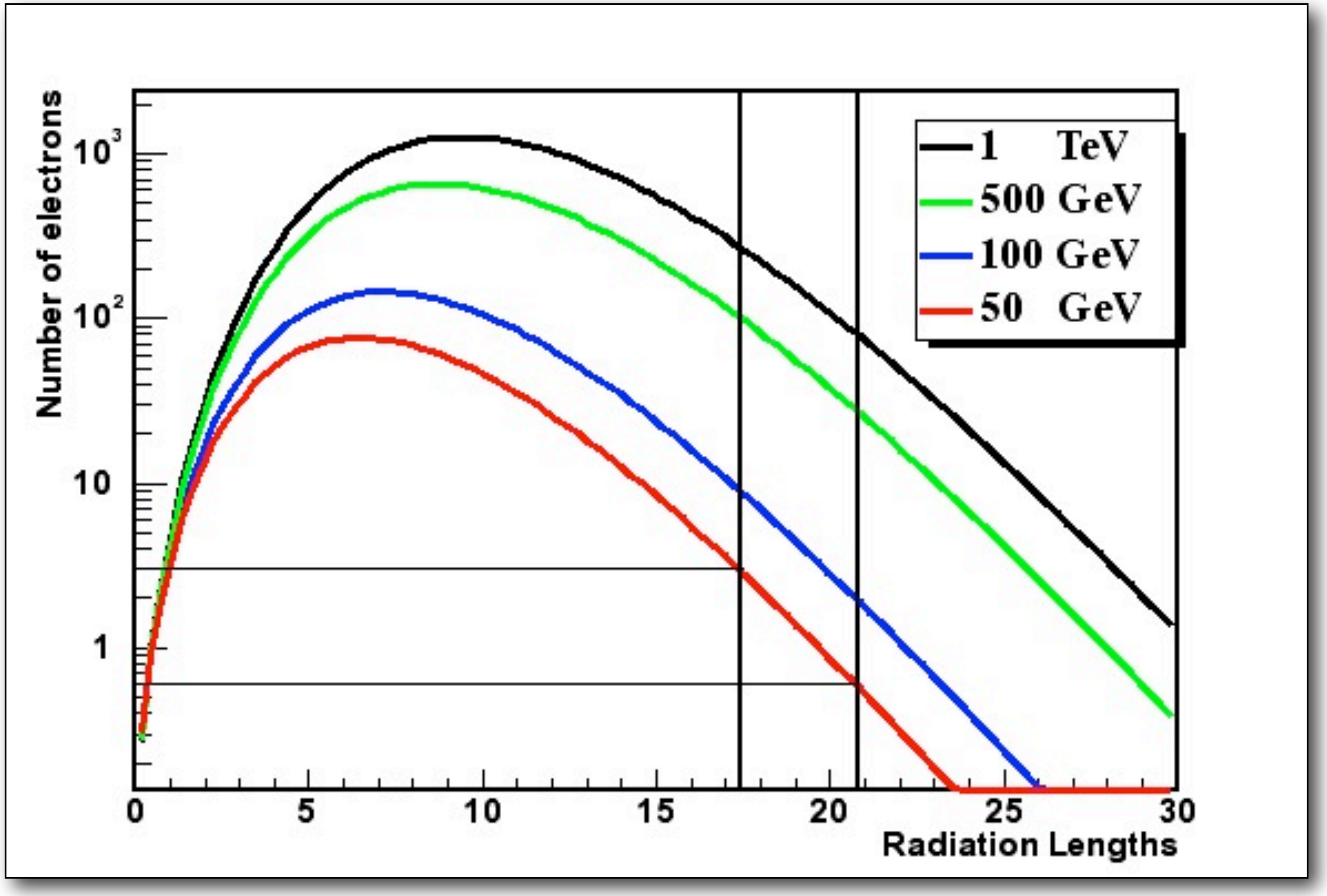
HAWC Tanks

- Prefabricated steel cylinders
    - Light-tight, black plastic bladder to hold water
    - attenuate scattered light so that photons not promptly detected are efficiently absorbed
    - Reduces late tails in the PMT photon distribution and reduces noise rate
- 900 8” Hamamatsu PMTs re-used from Milagro

Benefits of Higher Altitude

- Number of particles in the shower reaches maximum, then declines exponentially due to atmospheric absorption

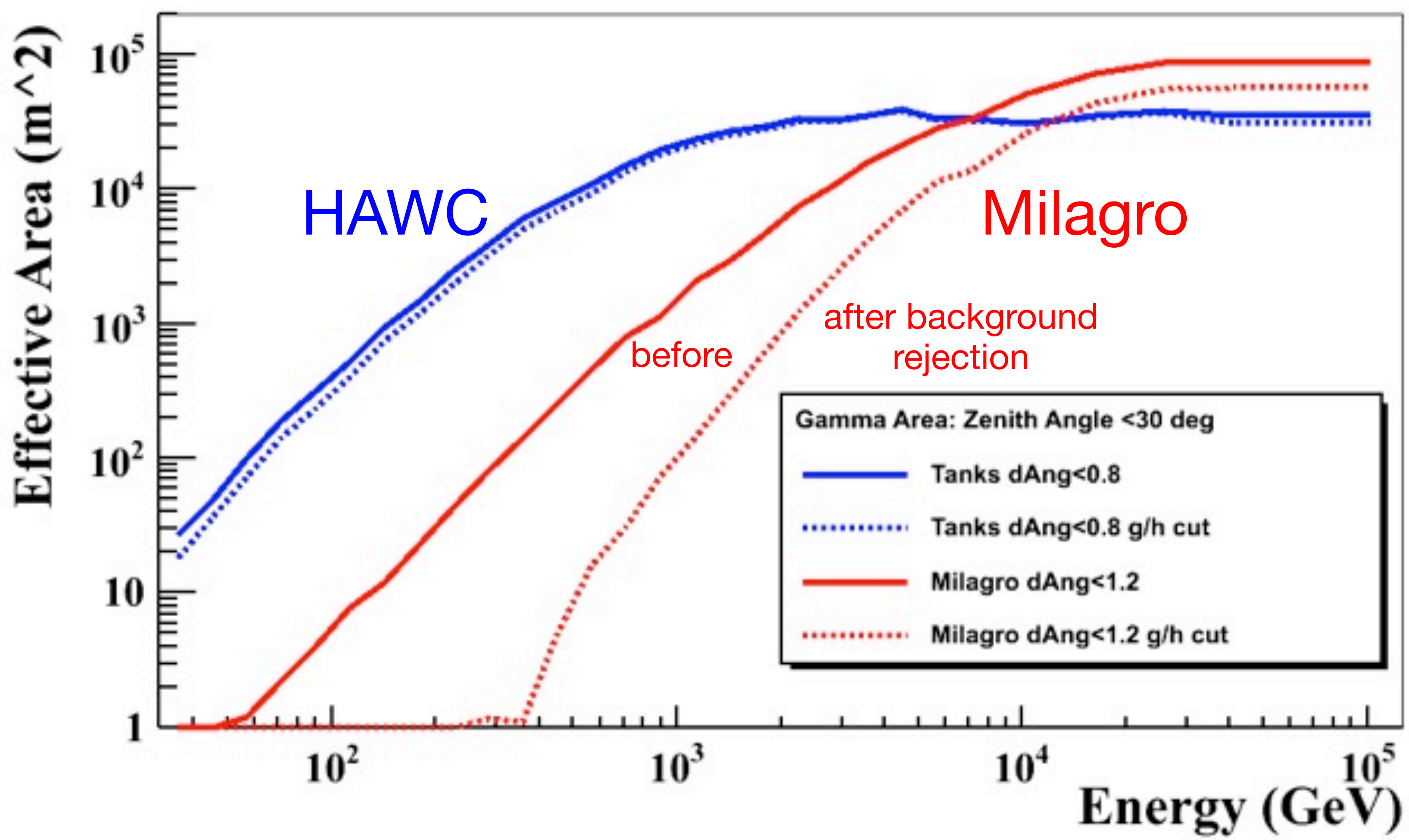
- Higher altitude means more particles survive to reach the ground
  - More information about the air shower



- Lower energy threshold, better angular resolution, better energy resolution, better background rejection

Energy Threshold and Effective Area

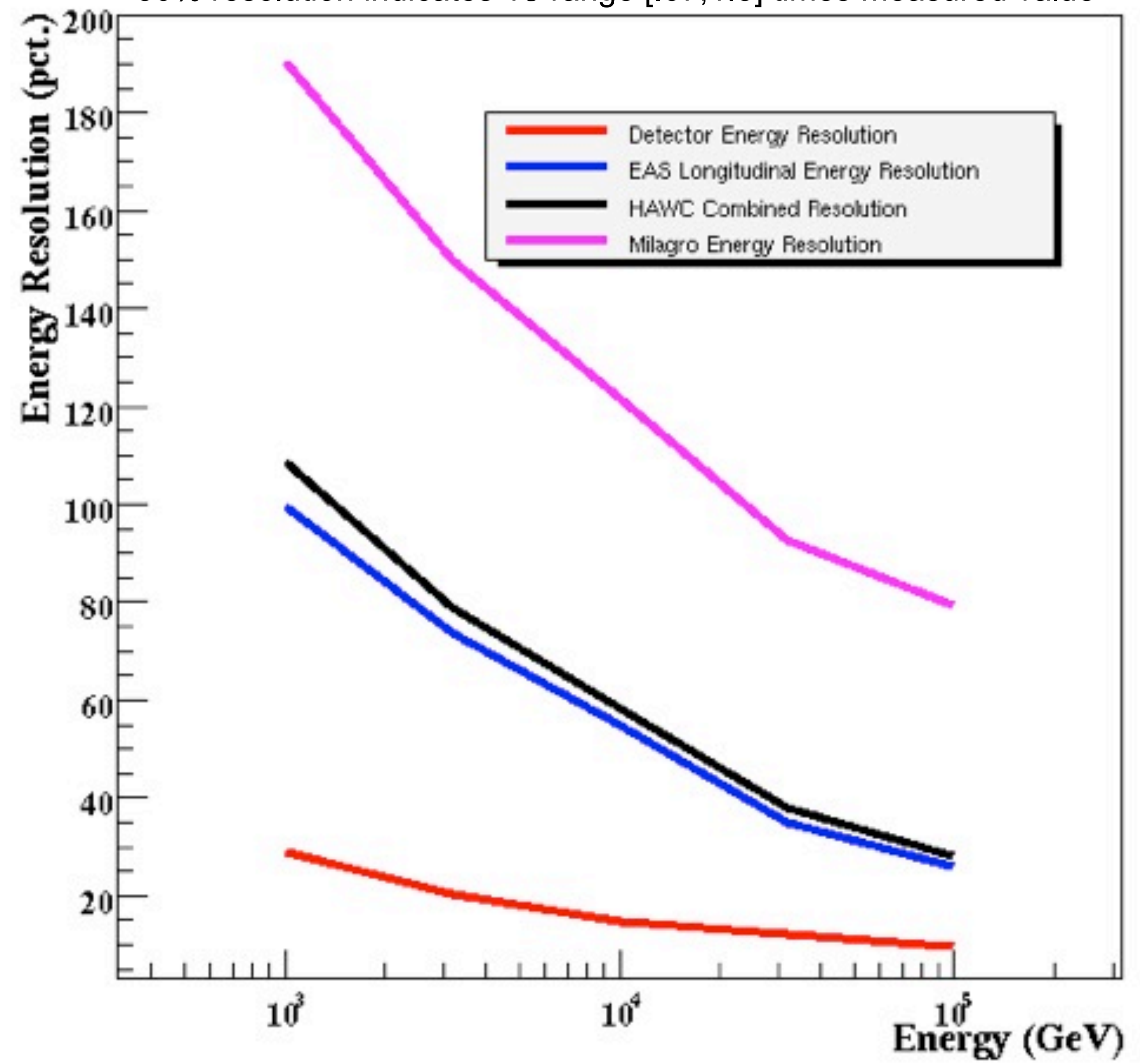
- Higher altitude leads to a lower energy threshold
  - Stochastics of shower development lead to very soft threshold
- HAWC will be fully efficient above ~2 TeV
  - Still >100 m^2 effective area at 100 GeV
- Improvements even more significant after hadron cuts



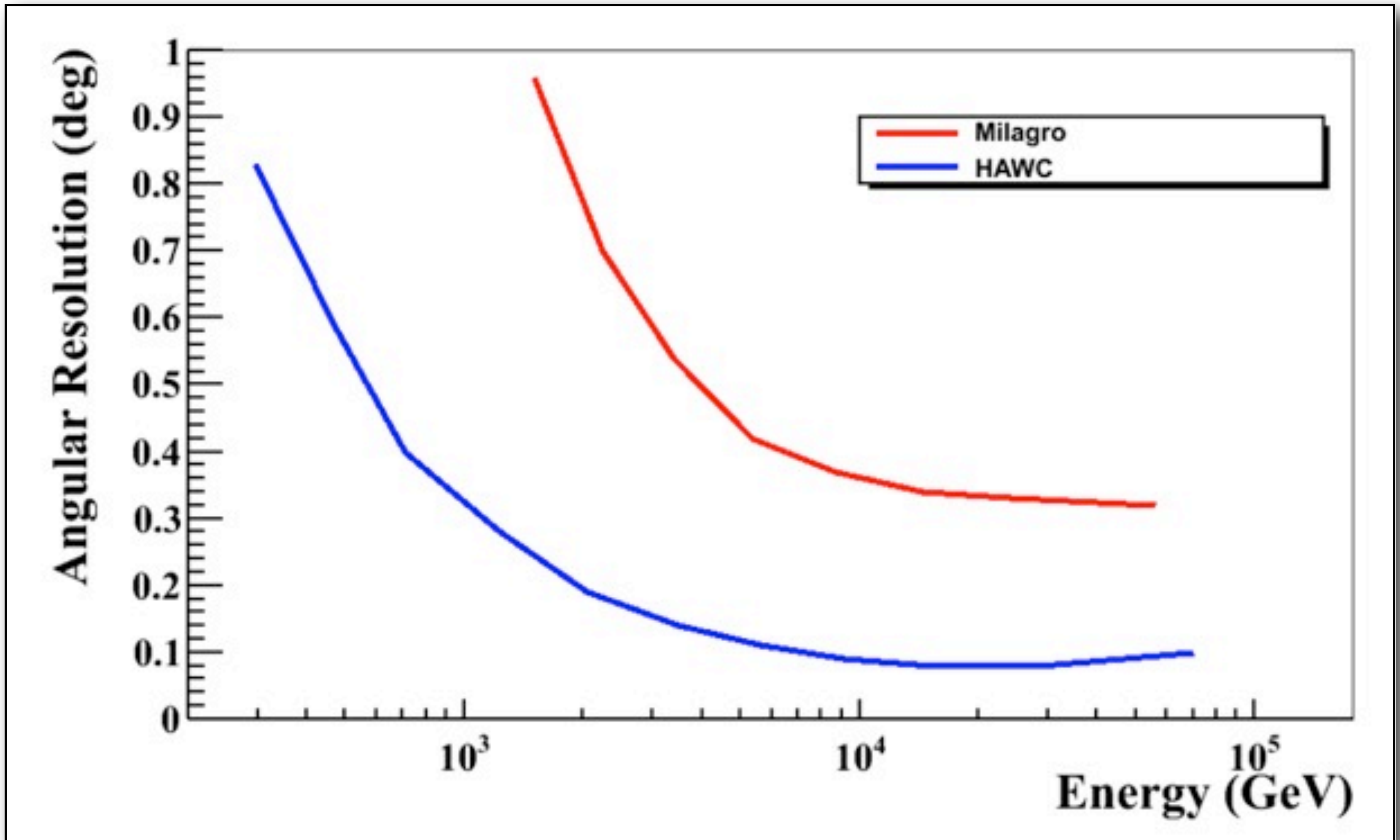
Energy Resolution

- Uncertainty from two sources:
  - Measurement of energy deposited at ground level
  - Fluctuations in shower development in atmosphere (naturally log-normal)
- Higher elevation means HAWC has a big advantage over Milagro
  - HAWC resolution very close to theoretical limit due to shower stochastics

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

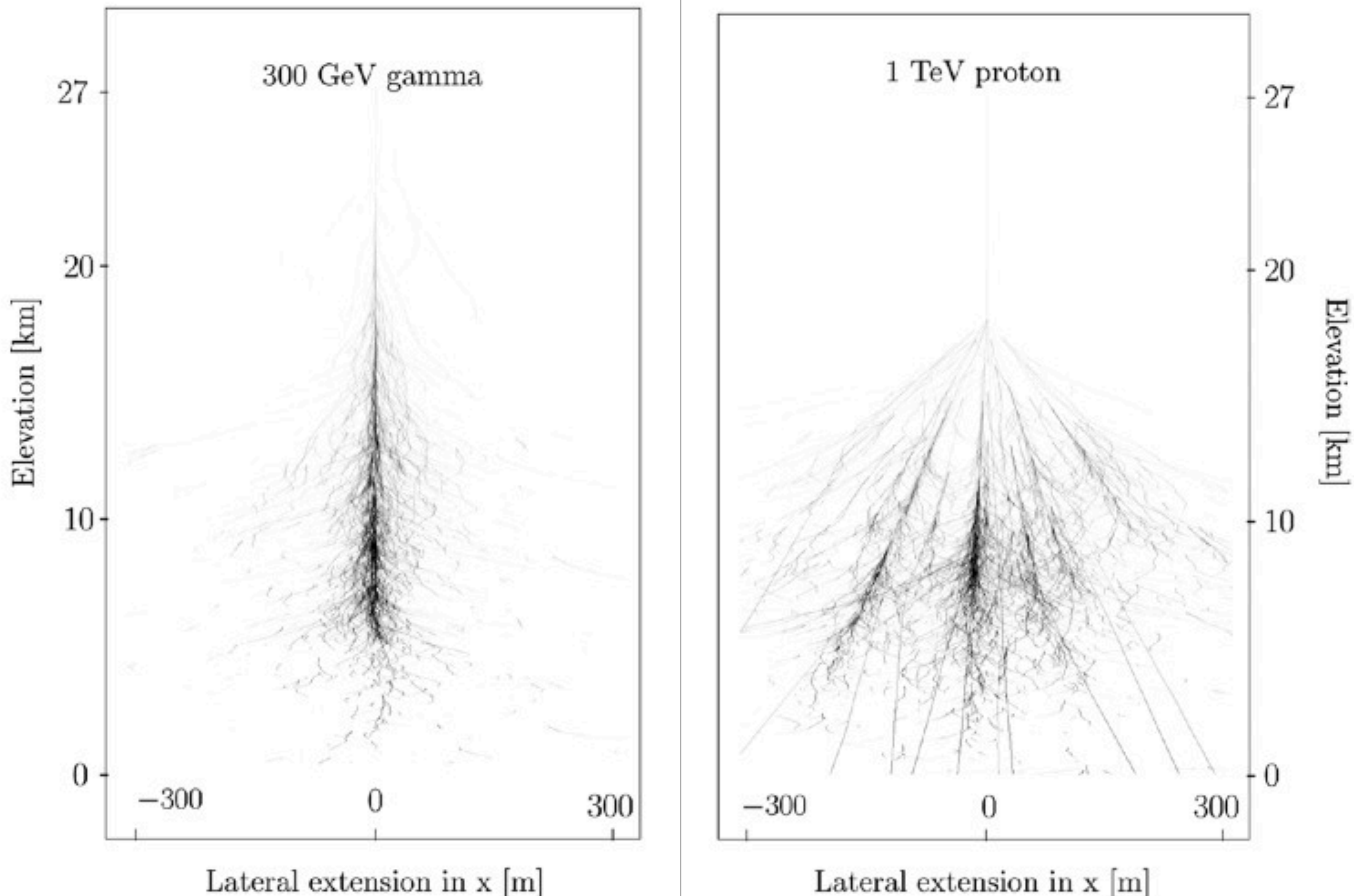


Angular Resolution

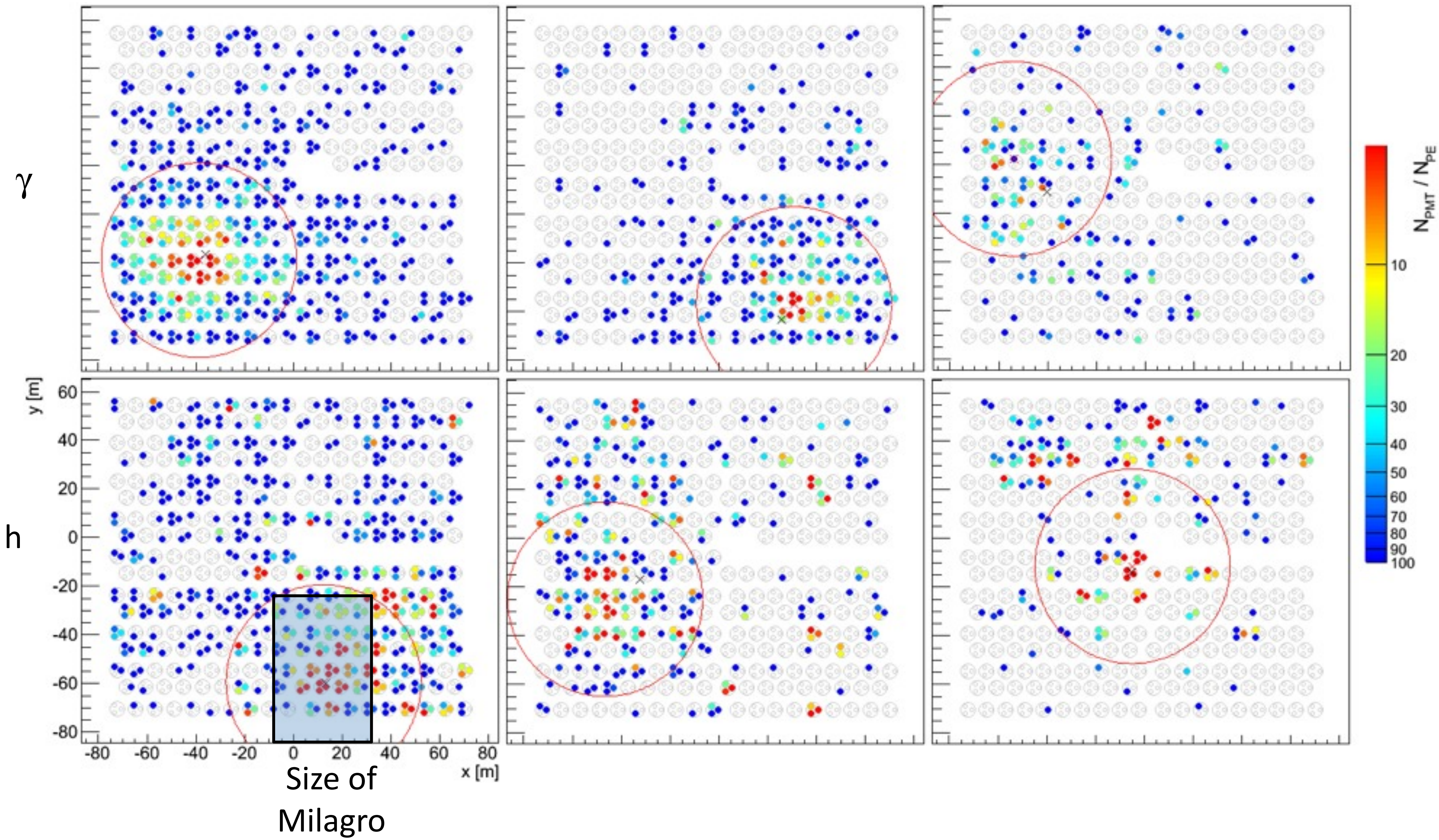


- Significant increase over Milagro – limited by information in the particles that reach the ground
  - Based on Milagro algorithms – improvements expected (esp. at higher E)

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

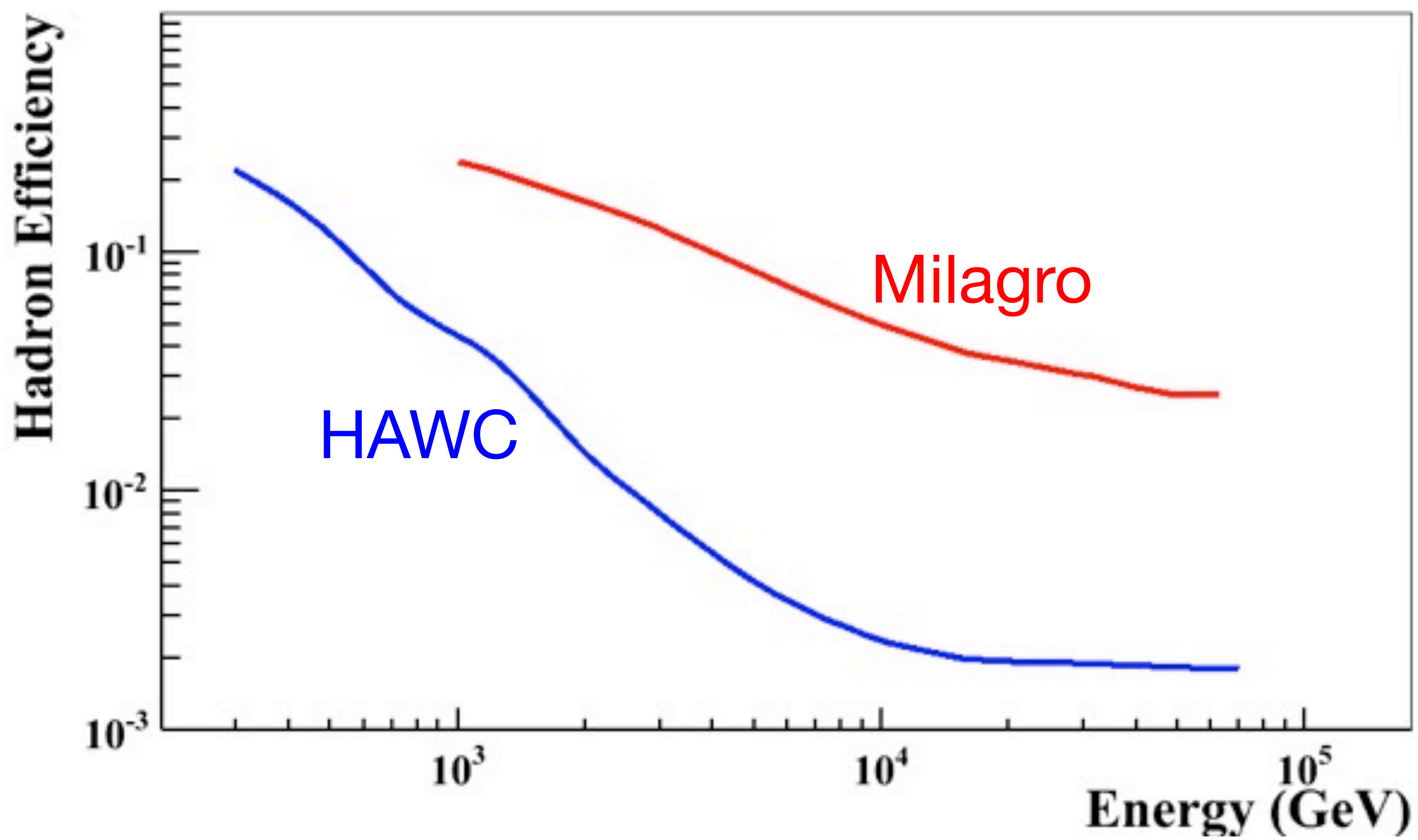
Gamma-Hadron Separation

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

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

- Conservative: more sophisticated algorithms possible

G-H separation at 50% gamma efficiency

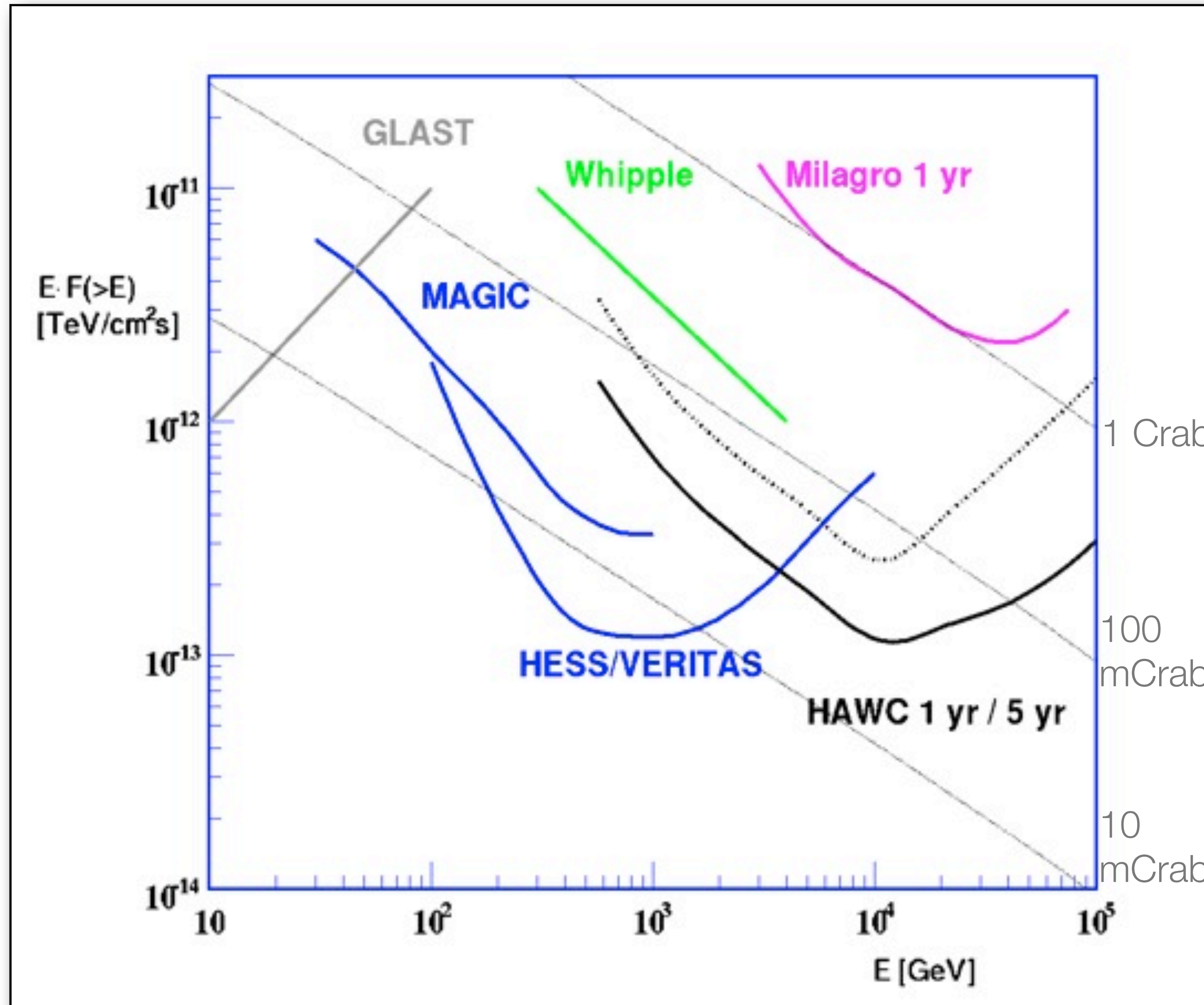


Sensitivity to Crab-like Point Sources

- Long integration times lead to excellent sensitivity at highest energies (> few TeV)

- 5σ sensitivity to:
  10 Crab in 3 minutes
  1 Crab in 5 hr (1 transit)
  0.1 Crab in ⅓ year

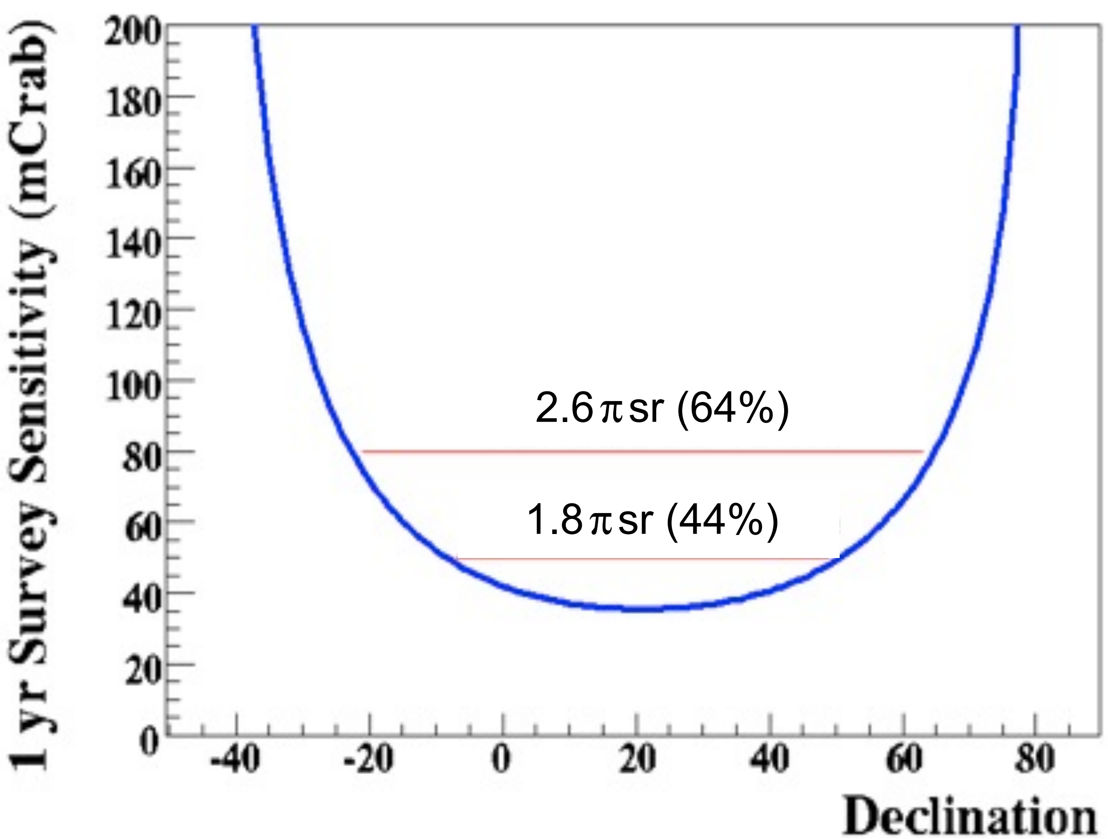
- 10-15x Milagro sensitivity
  - Lower energy threshold
  - Better angular resolution
  - Better rejection of cosmic rays

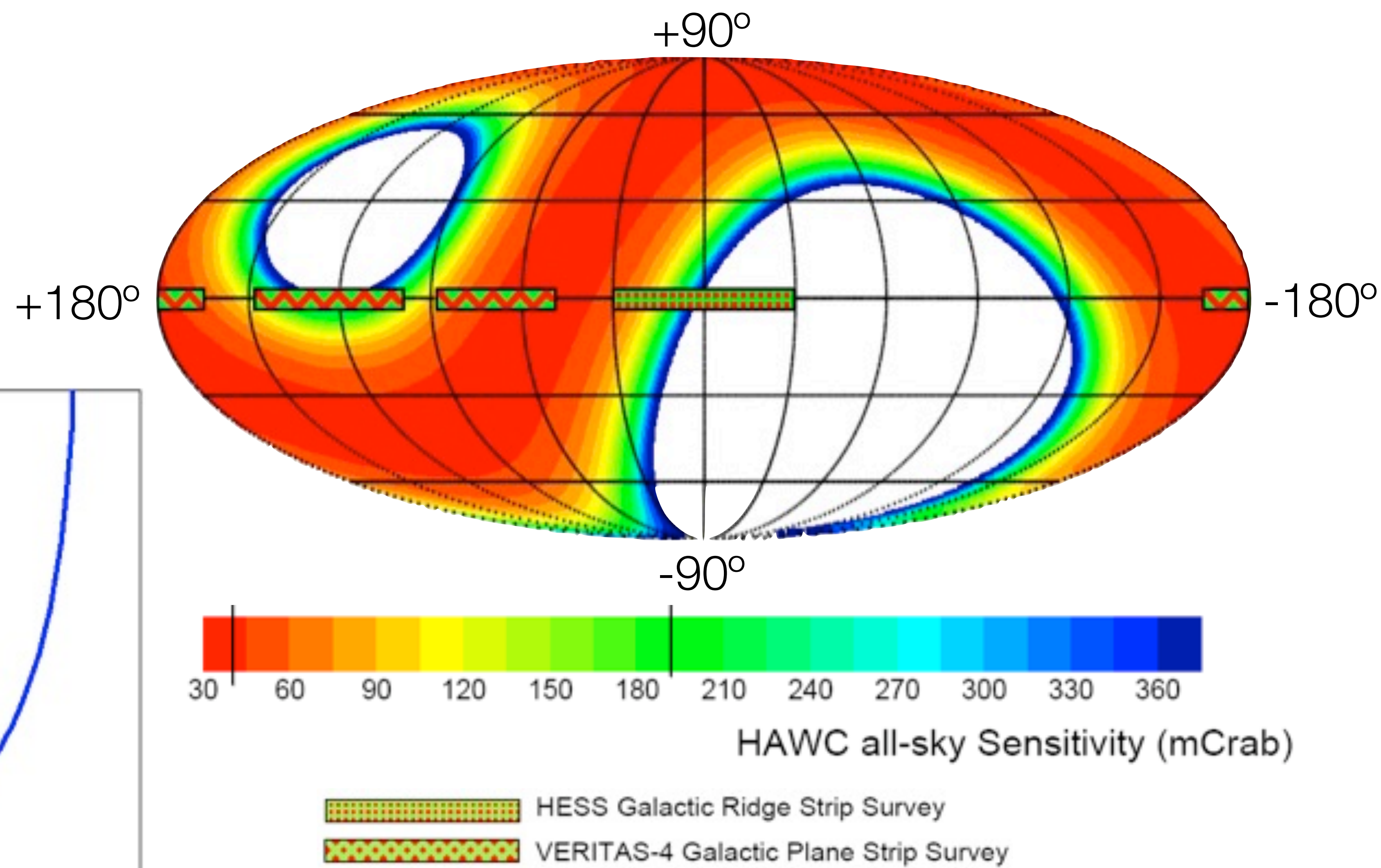


50 hr observation time assumed for IACTs,
HAWC source transit 15° off zenith

Field of View

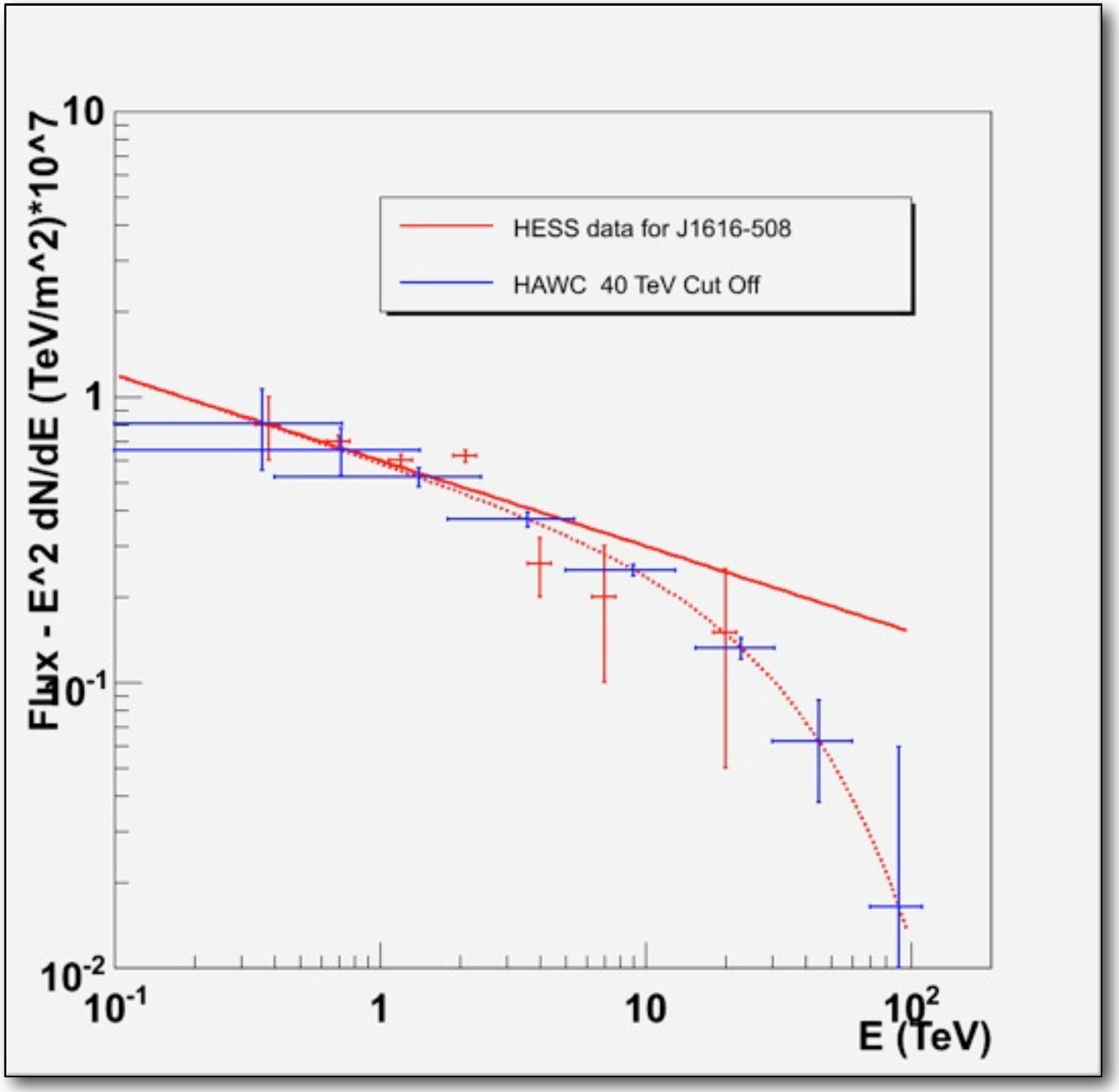
- Wide field of view, limited by atmospheric depth
  - 45° from zenith (Milagro standard analysis)
  - 50 mCrab survey in 1 yr

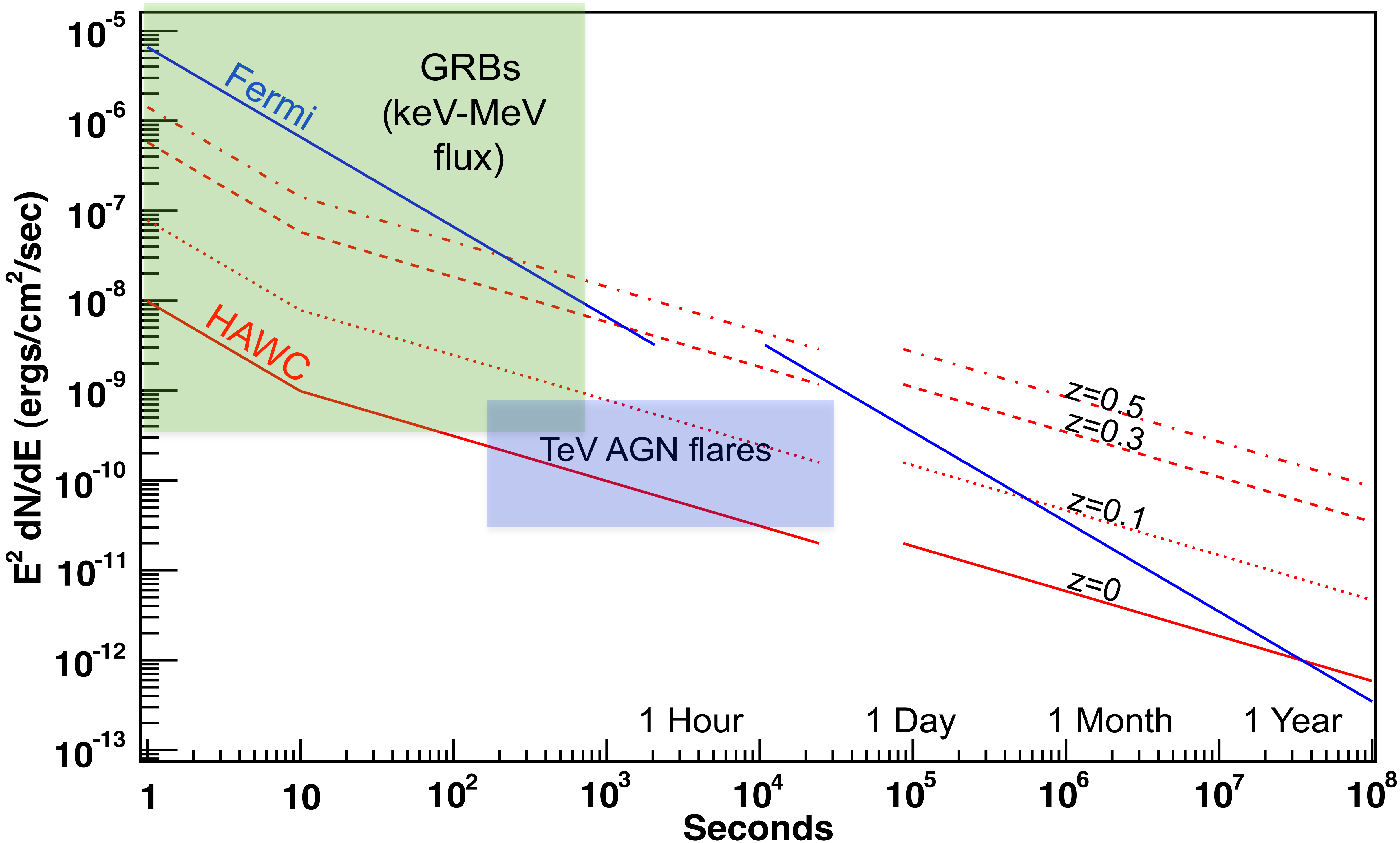




Measuring Spectra at the Highest Energies

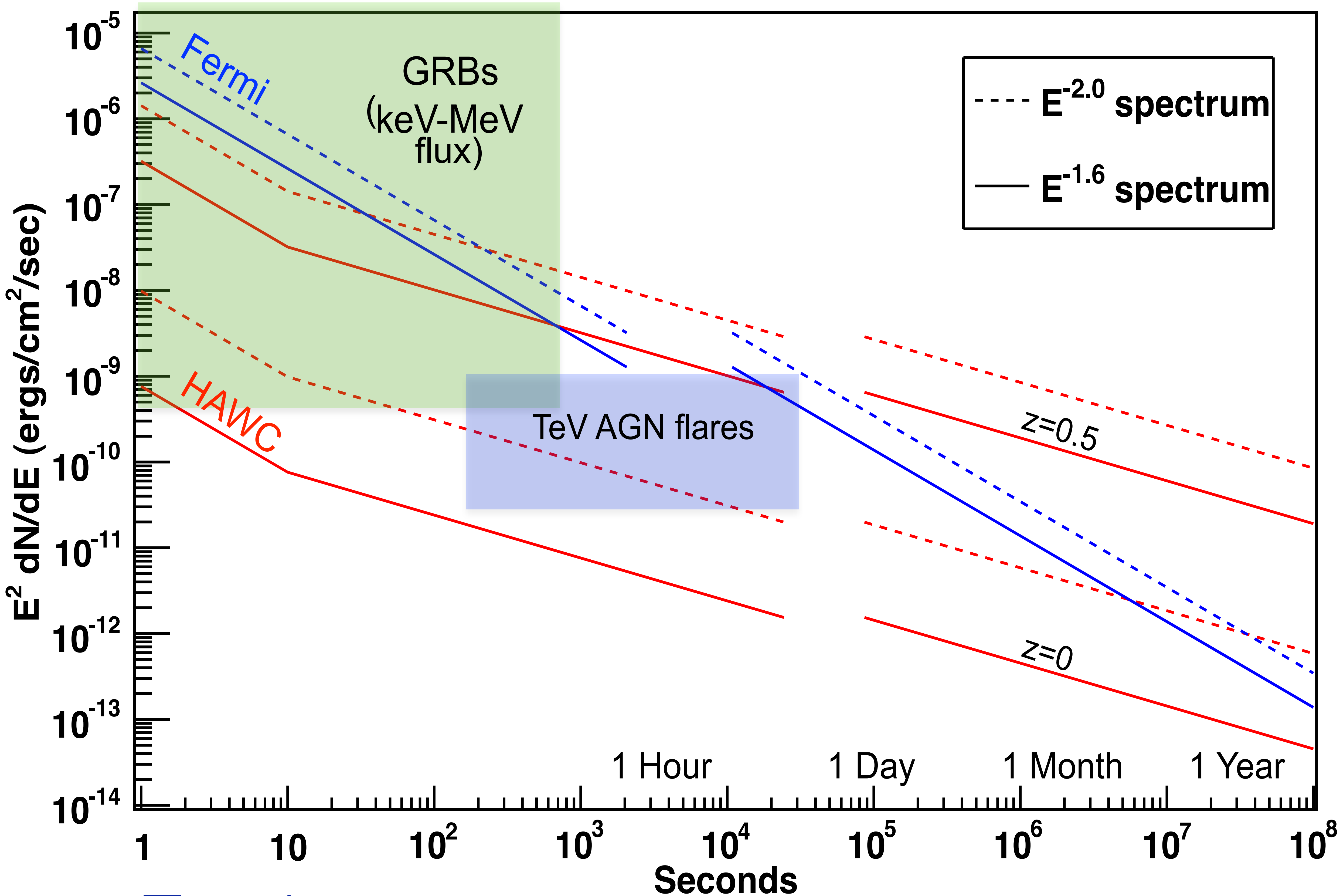
- HESS J1616-508
  - 0.2 Crab @ 1 TeV, α=-2.3
  - Highest energy ~20 TeV
- Simulated HAWC data for 1 year with no cutoff
- ...or with a 40 TeV exponential cutoff





Transient Sensitivity

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



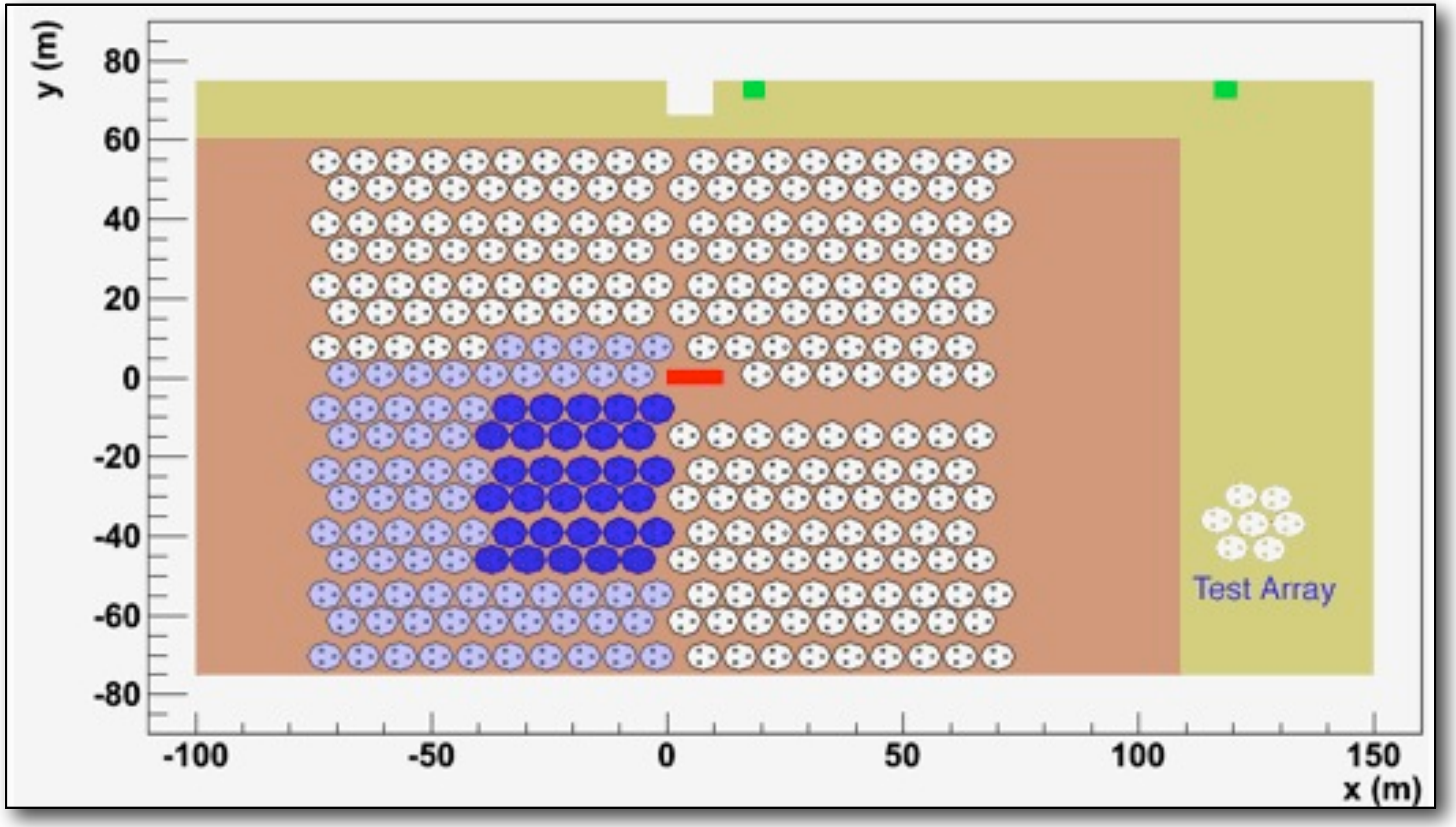
Transient Sensitivity

Harder spectra give significant increase in sensitivity

Fluxes normalized at 10 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

Questions for Discussion

- What else should we be thinking about?
  - Sky survey
  - High energy observations
  - Extended/diffuse emission
  - Transients/variable sources
- We plan to alert the community to transients via GCN – are there other types of rapid communications that would be useful?
- Is there a way to exploit better the relative advantages of HAWC (extended/HE emission) and IACTs (angular resolution) to understand complex areas such as the Cygnus region?