The HAWC Observatory

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

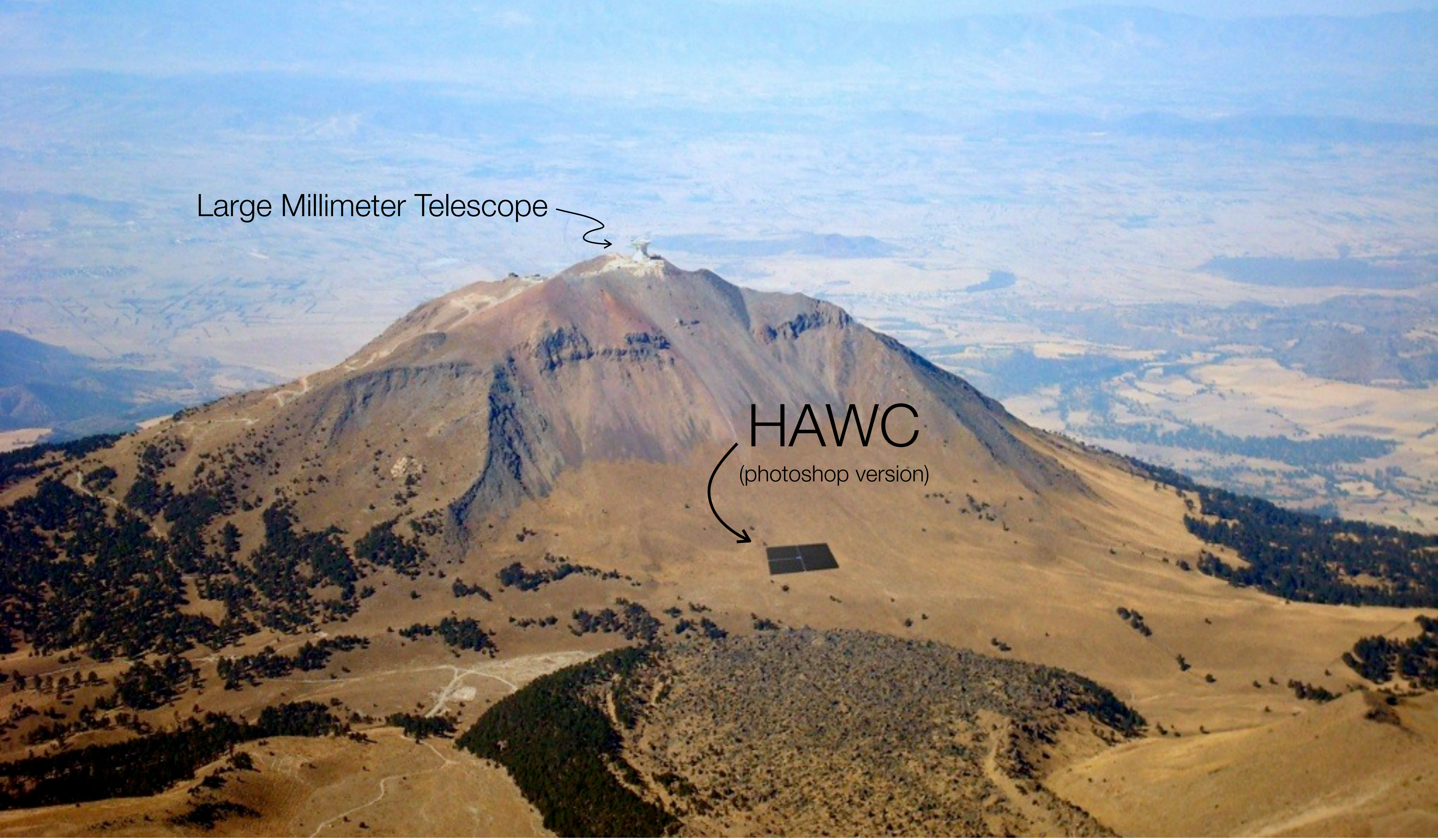
The HAWC Collaboration

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

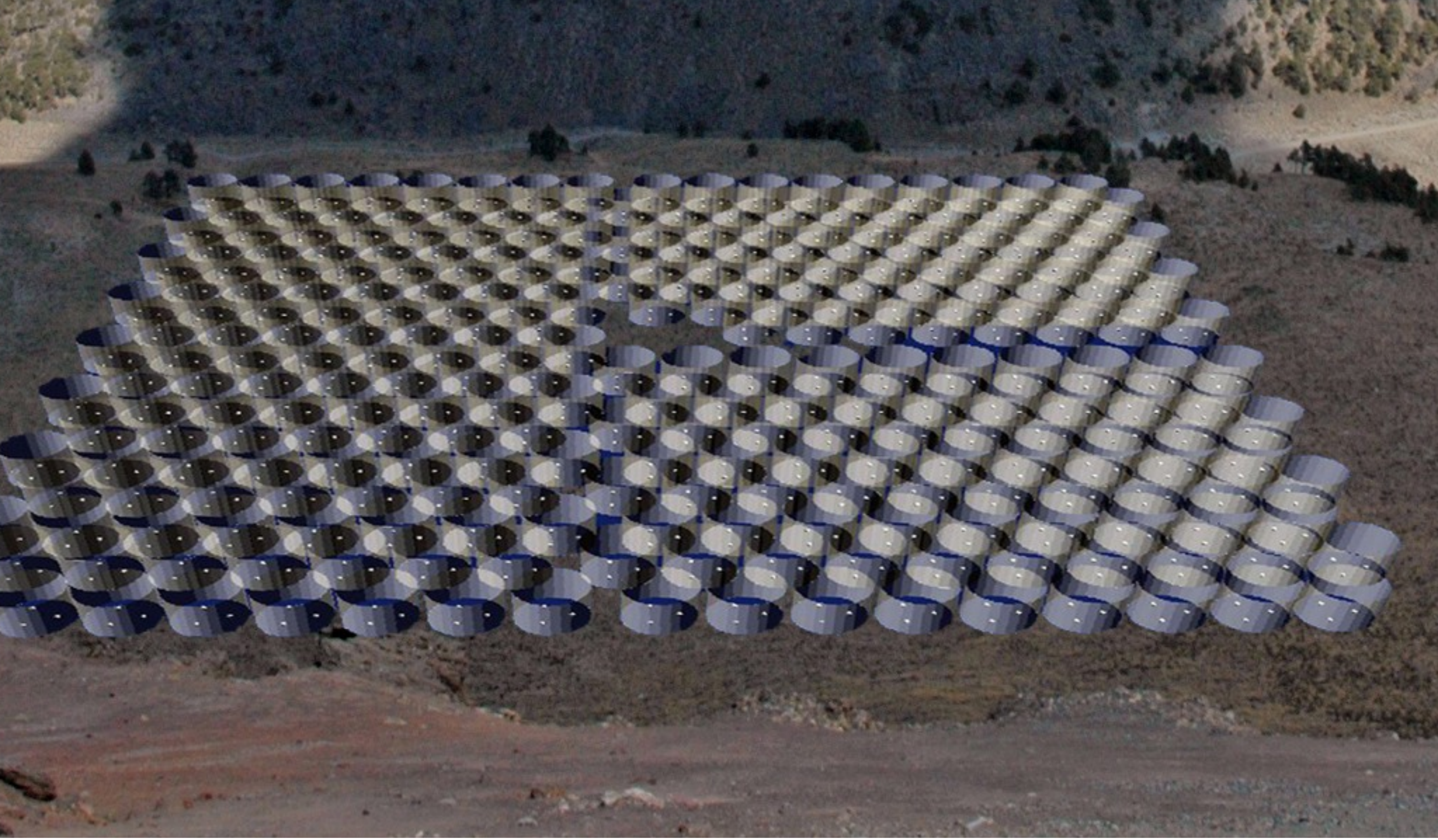


HAWC

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

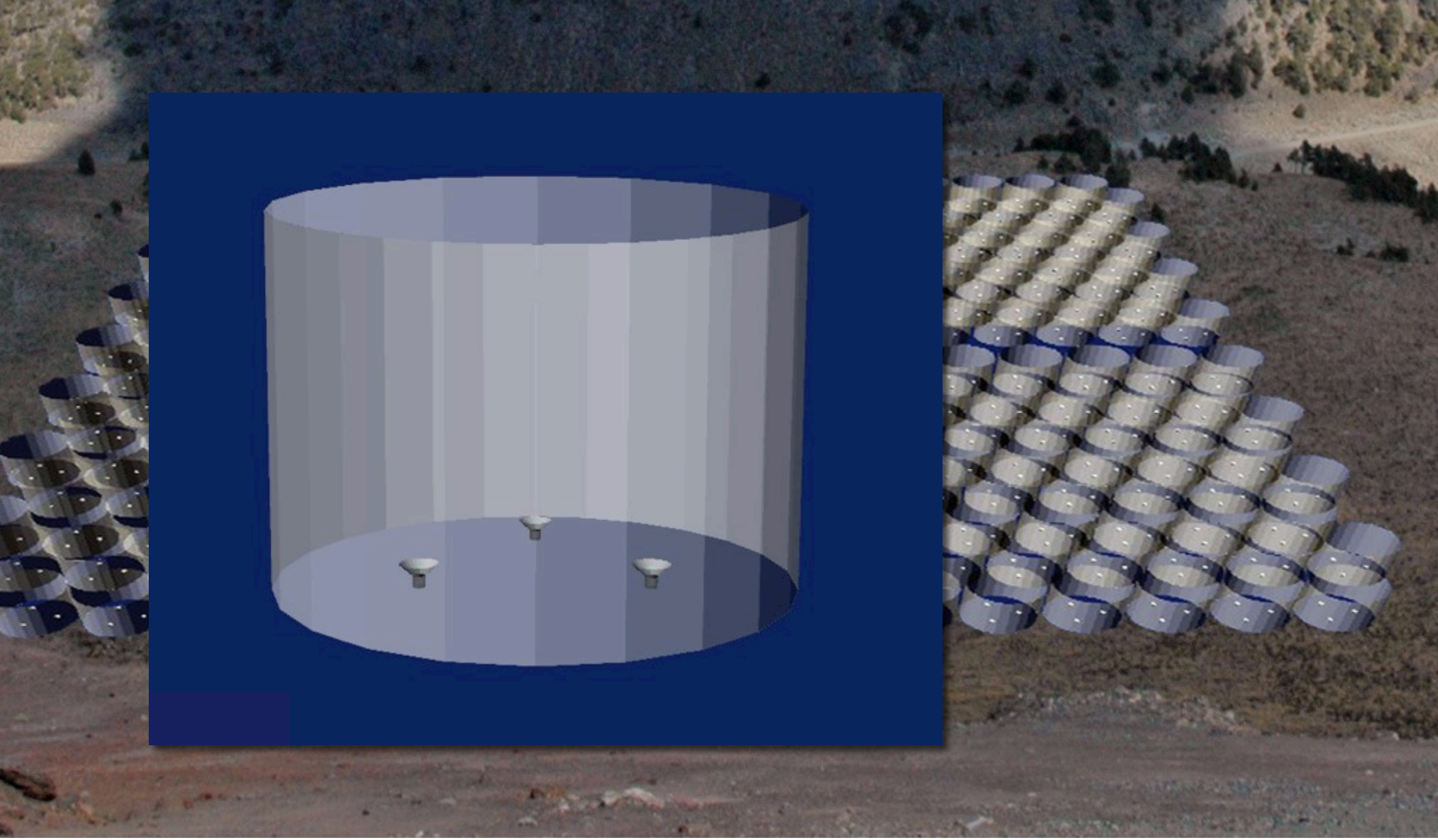
HAWC

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

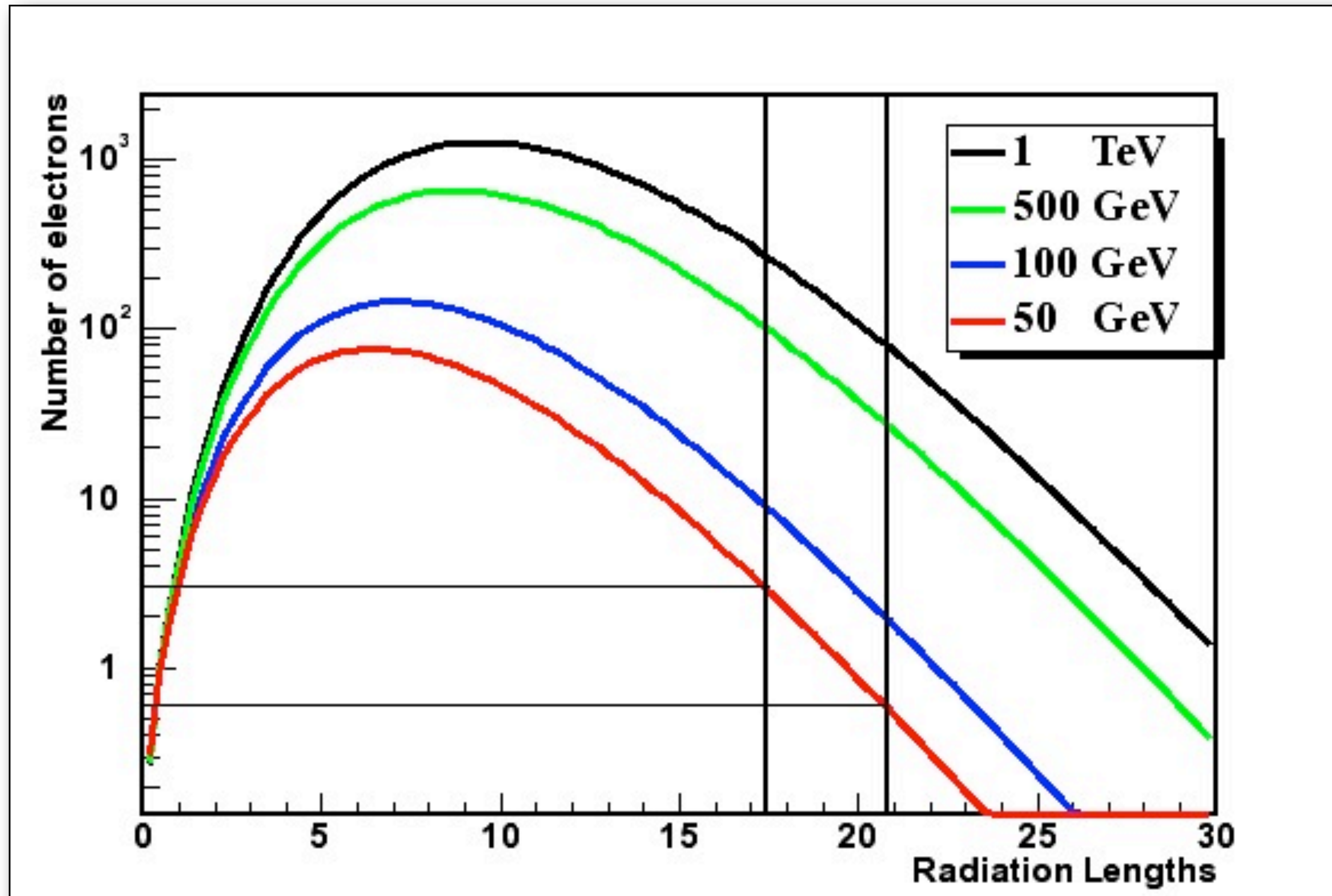
HAWC Tanks

- 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

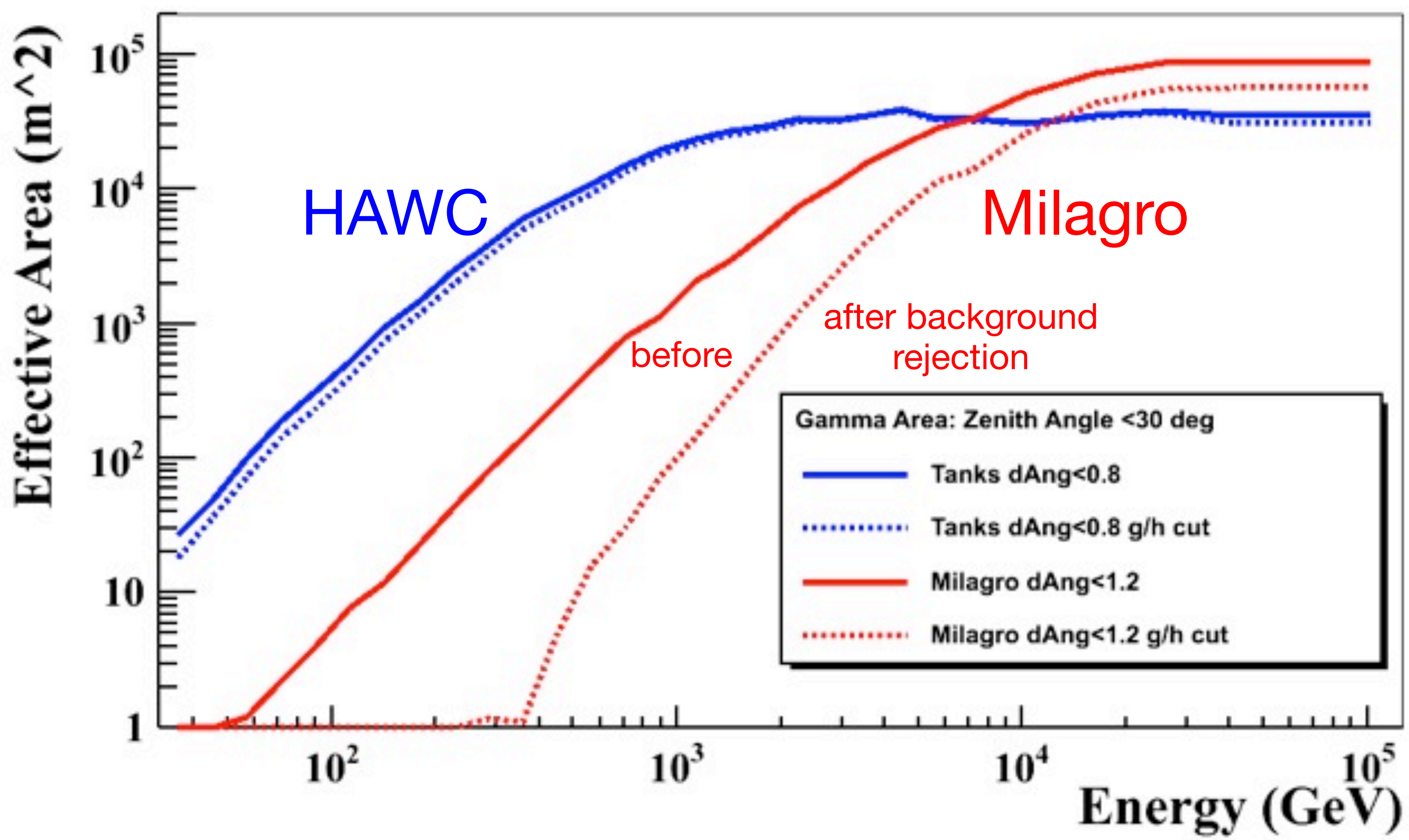
- Higher altitude means more particles survive to reach the ground
  - More information about the air shower



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

Energy Threshold and Effective Area

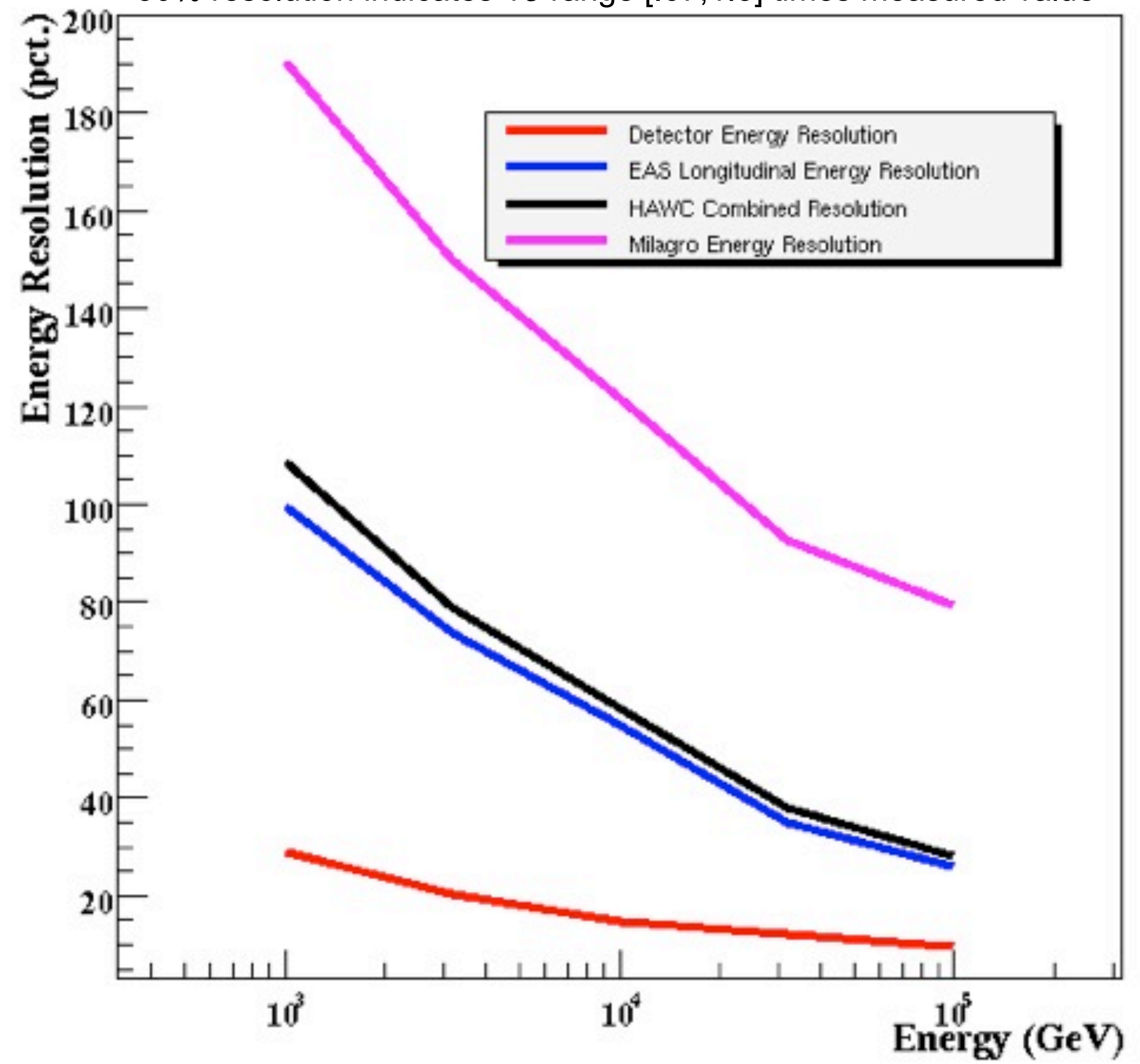
- Higher altitude leads to a lower energy threshold
  - Stochastics of shower development lead to very soft threshold
- HAWC will be fully efficient above ~2 TeV
  - Still >100 m^2 effective area at 100 GeV
- Improvements even more significant after hadron cuts



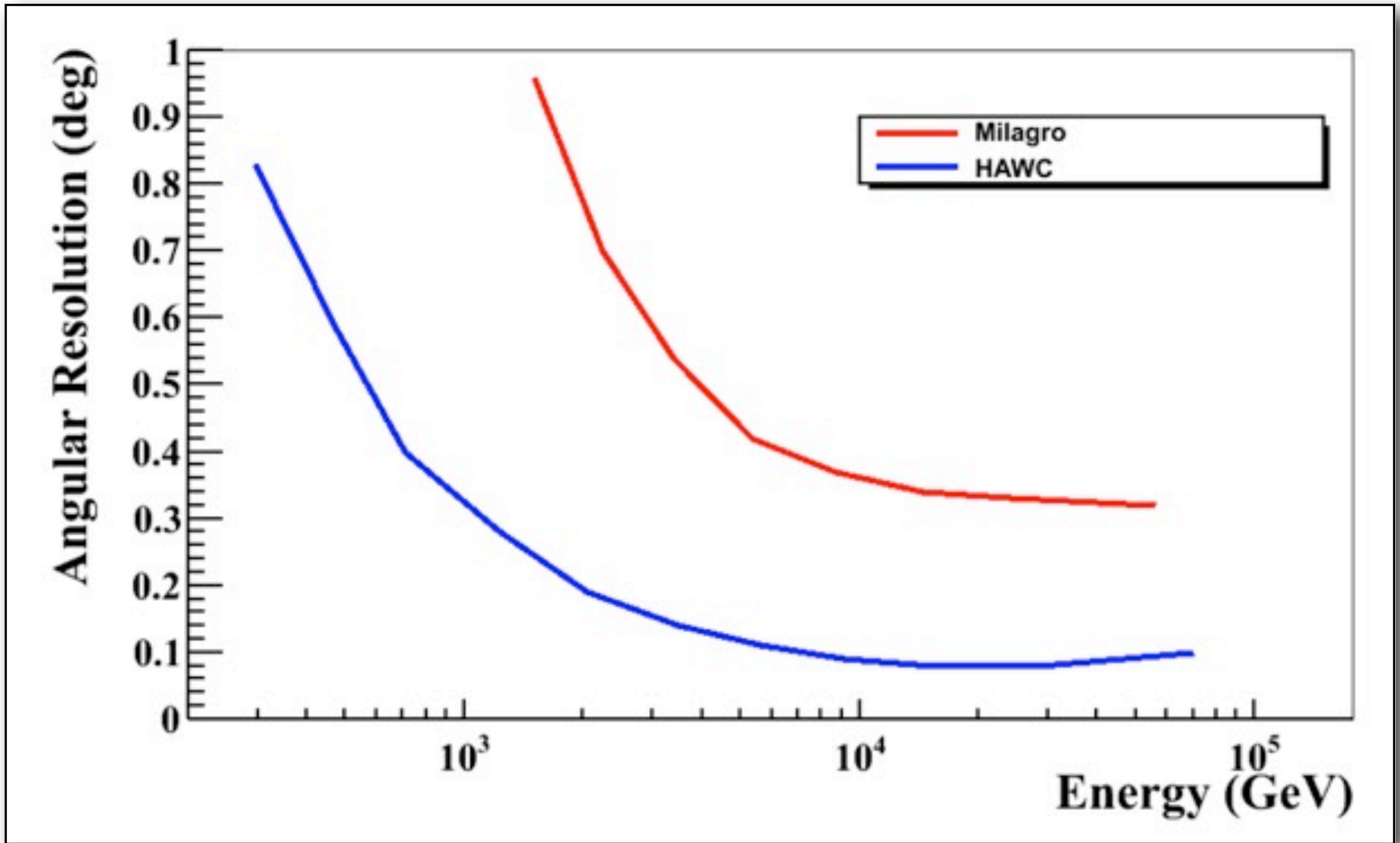
Energy Resolution

- 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

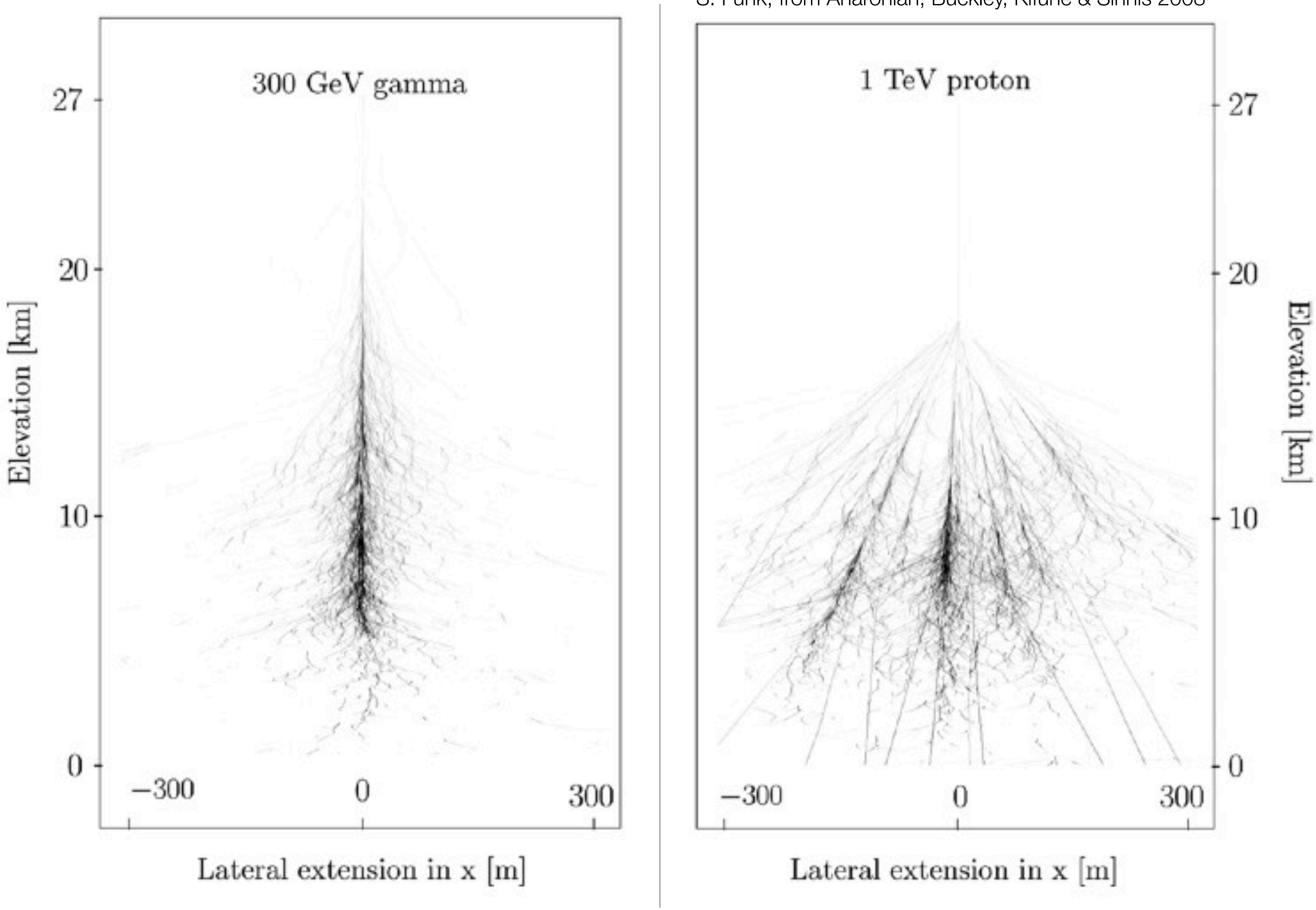


Angular Resolution

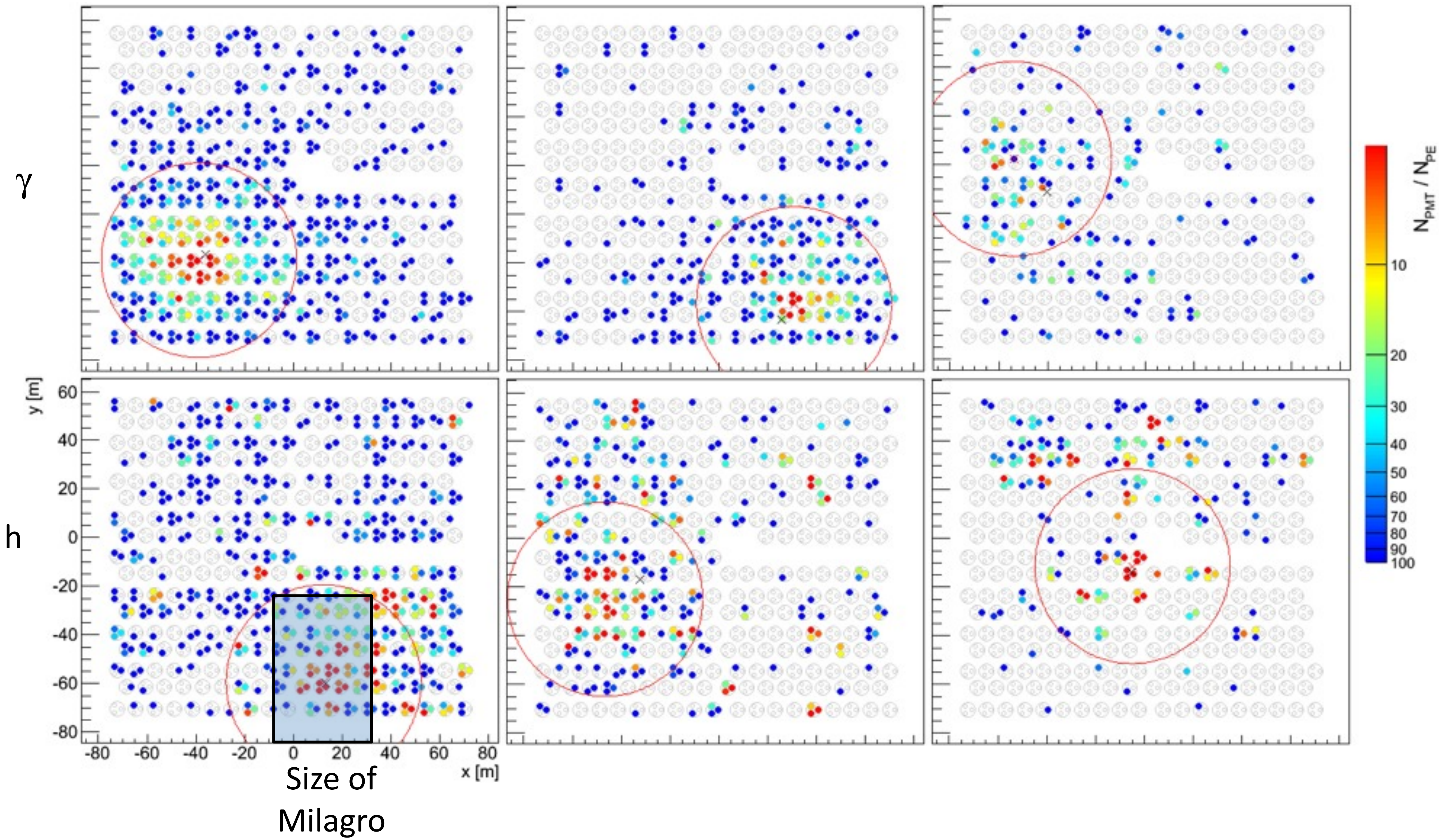


- Significant increase over Milagro – limited by information in the particles that reach the ground
  - Based on Milagro algorithms – improvements expected (esp. at higher E)

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

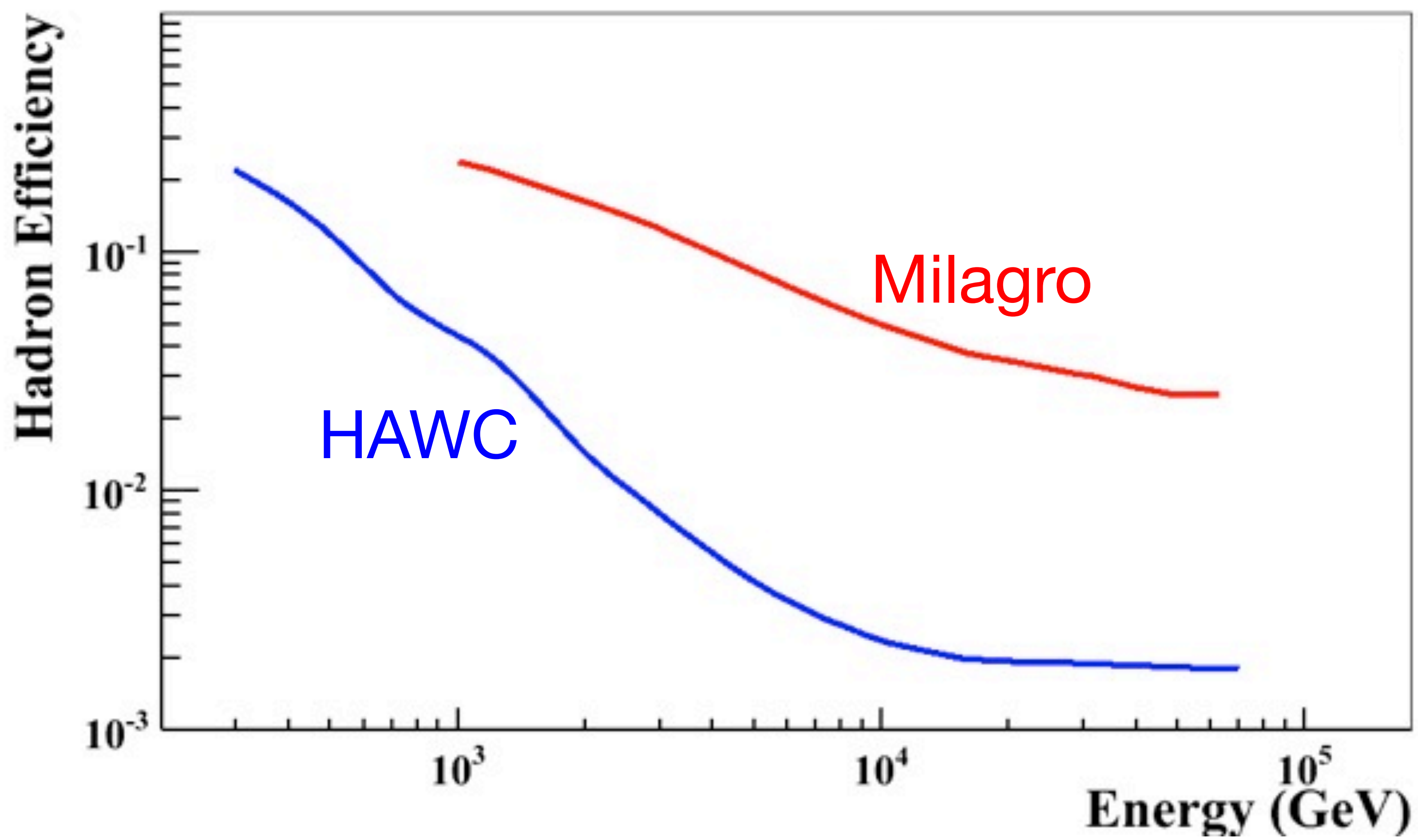
Gamma-Hadron Separation

- 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

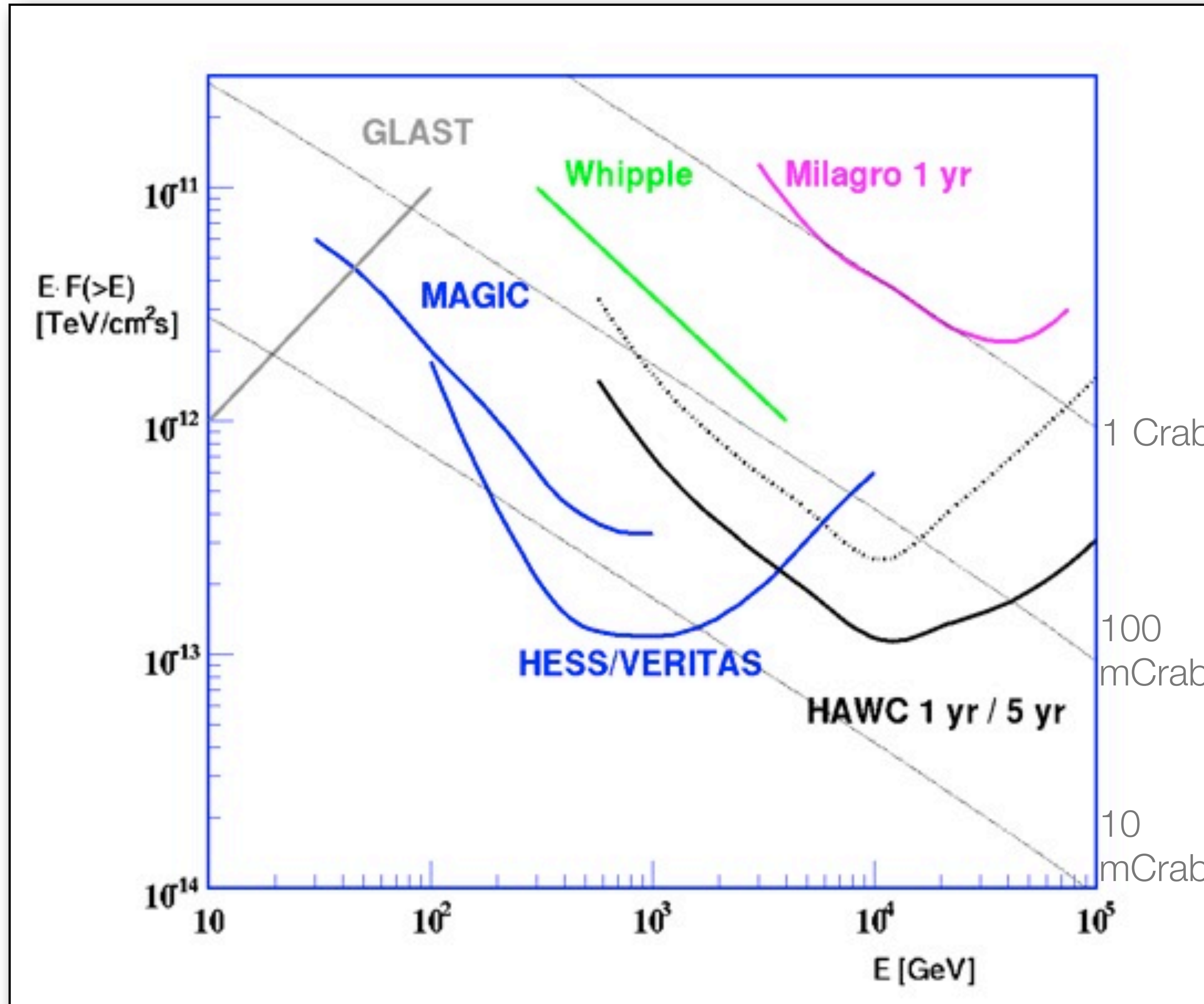


Sensitivity to Crab-like Point Sources

- 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

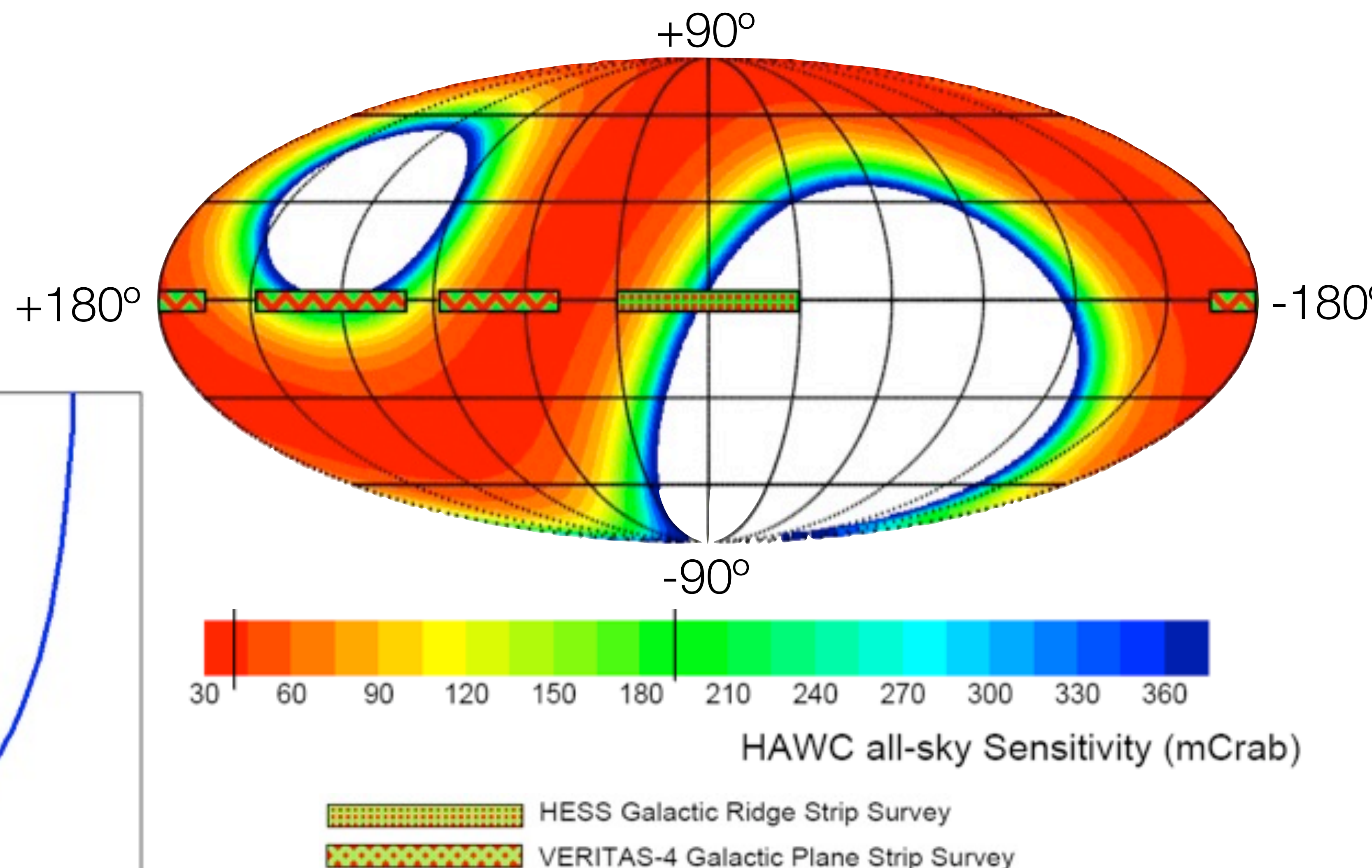
- 10-15x Milagro sensitivity
  - Lower energy threshold
  - Better angular resolution
  - Better rejection of cosmic rays

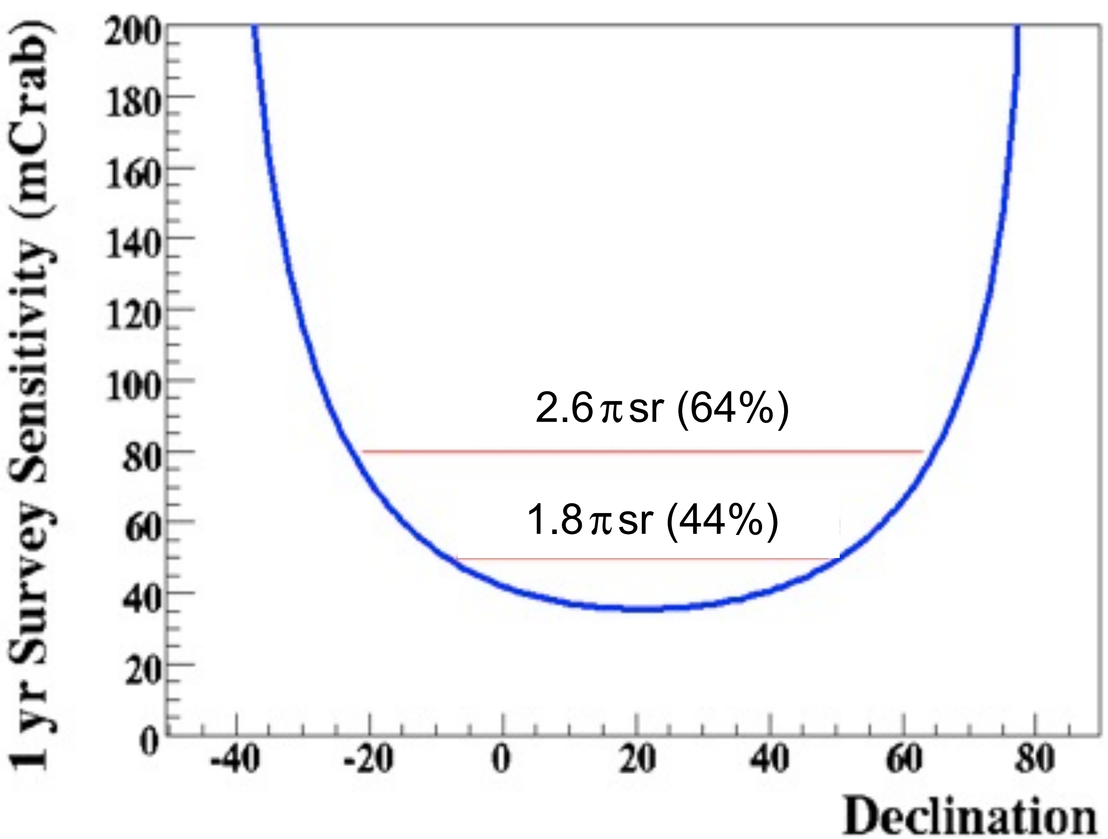


50 hr observation time assumed for IACTs,
HAWC source transit 15° off zenith

Field of View

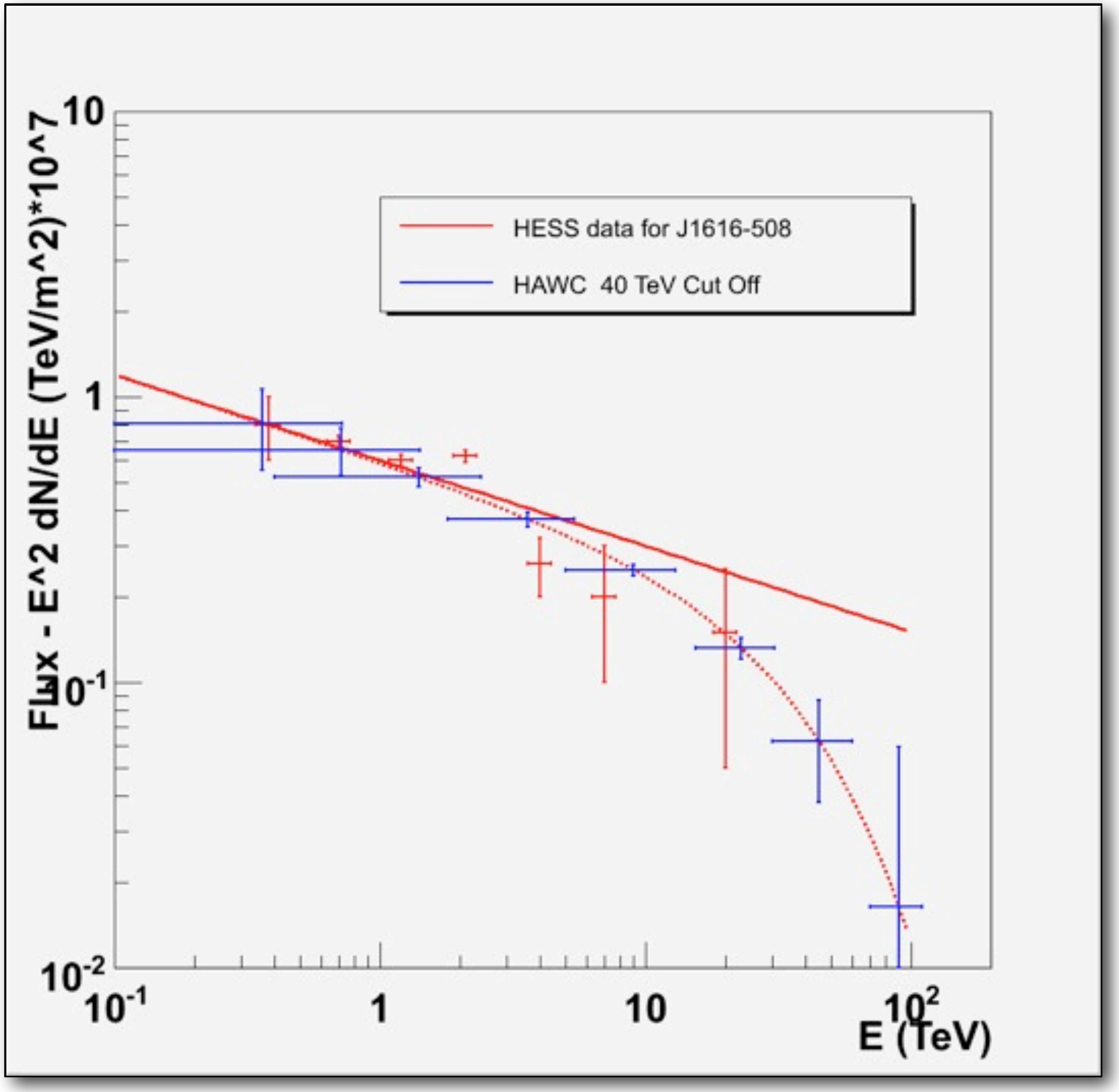
- Wide field of view, limited by atmospheric depth
  - 45° from zenith (Milagro standard analysis)
  - 50 mCrab survey in 1 yr

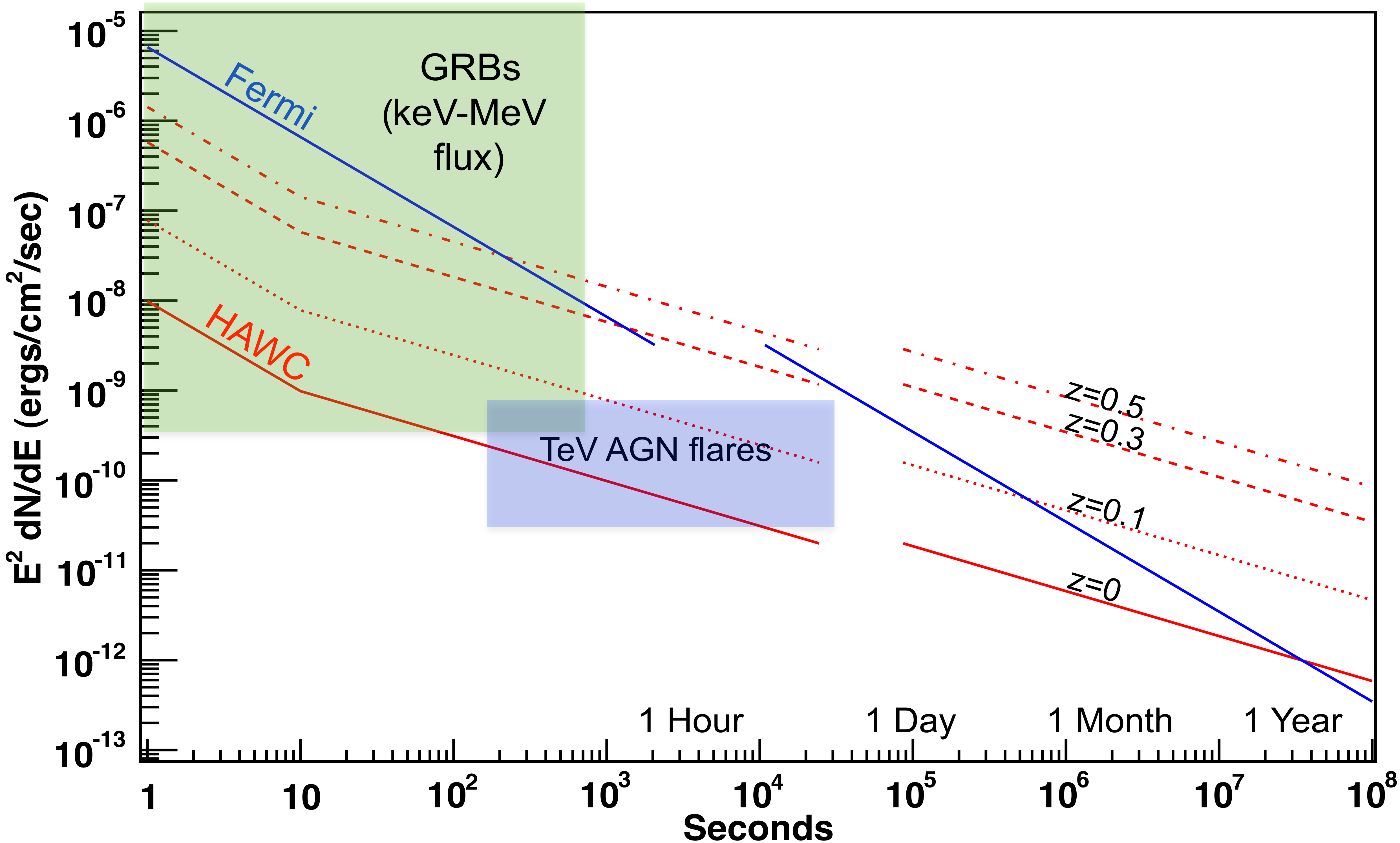




Measuring Spectra at the Highest Energies

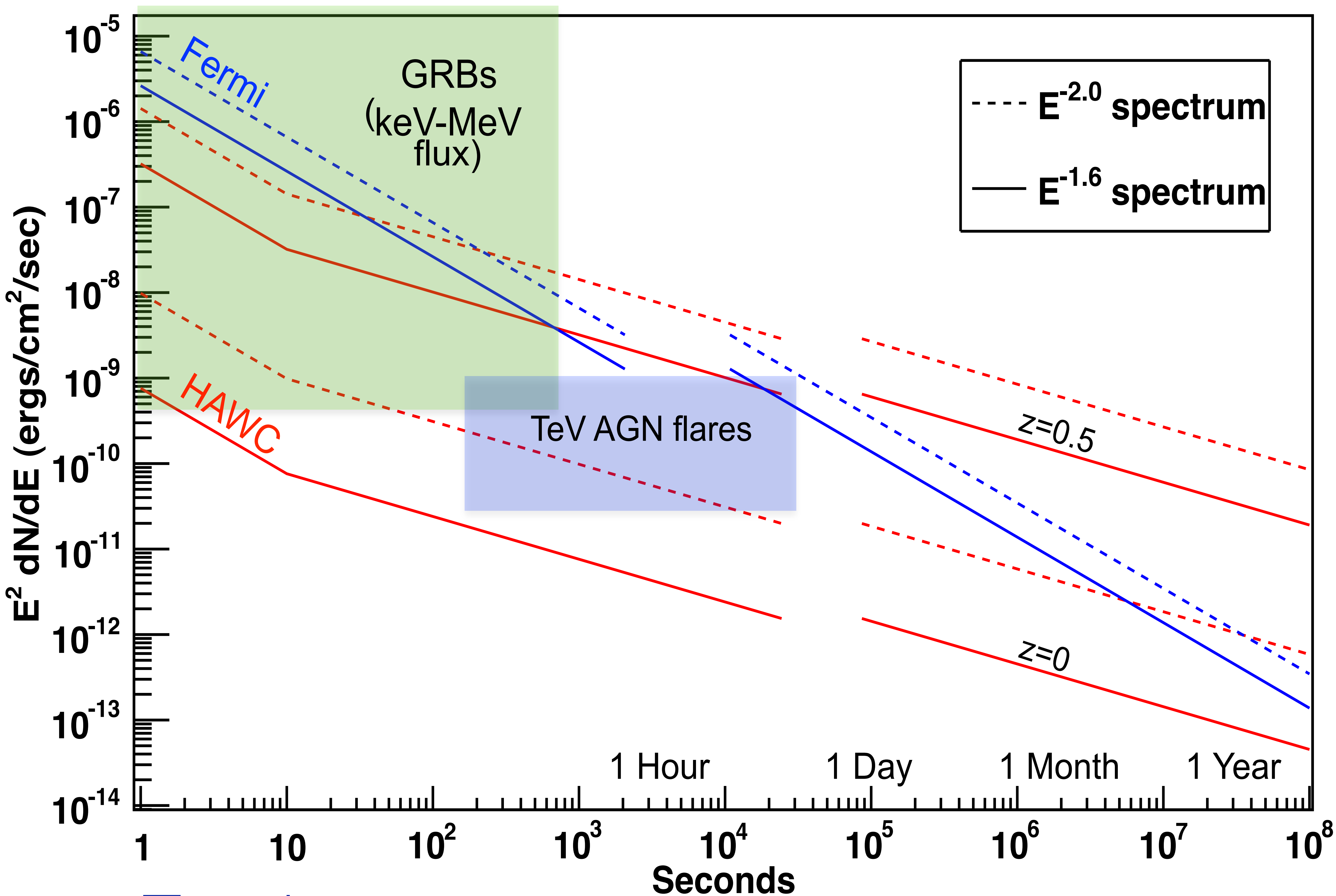
- HESS J1616-508
  - 0.2 Crab @ 1 TeV, α=-2.3
  - Highest energy ~20 TeV
- Simulated HAWC data for 1 year with no cutoff
- ...or with a 40 TeV exponential cutoff





Transient Sensitivity

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

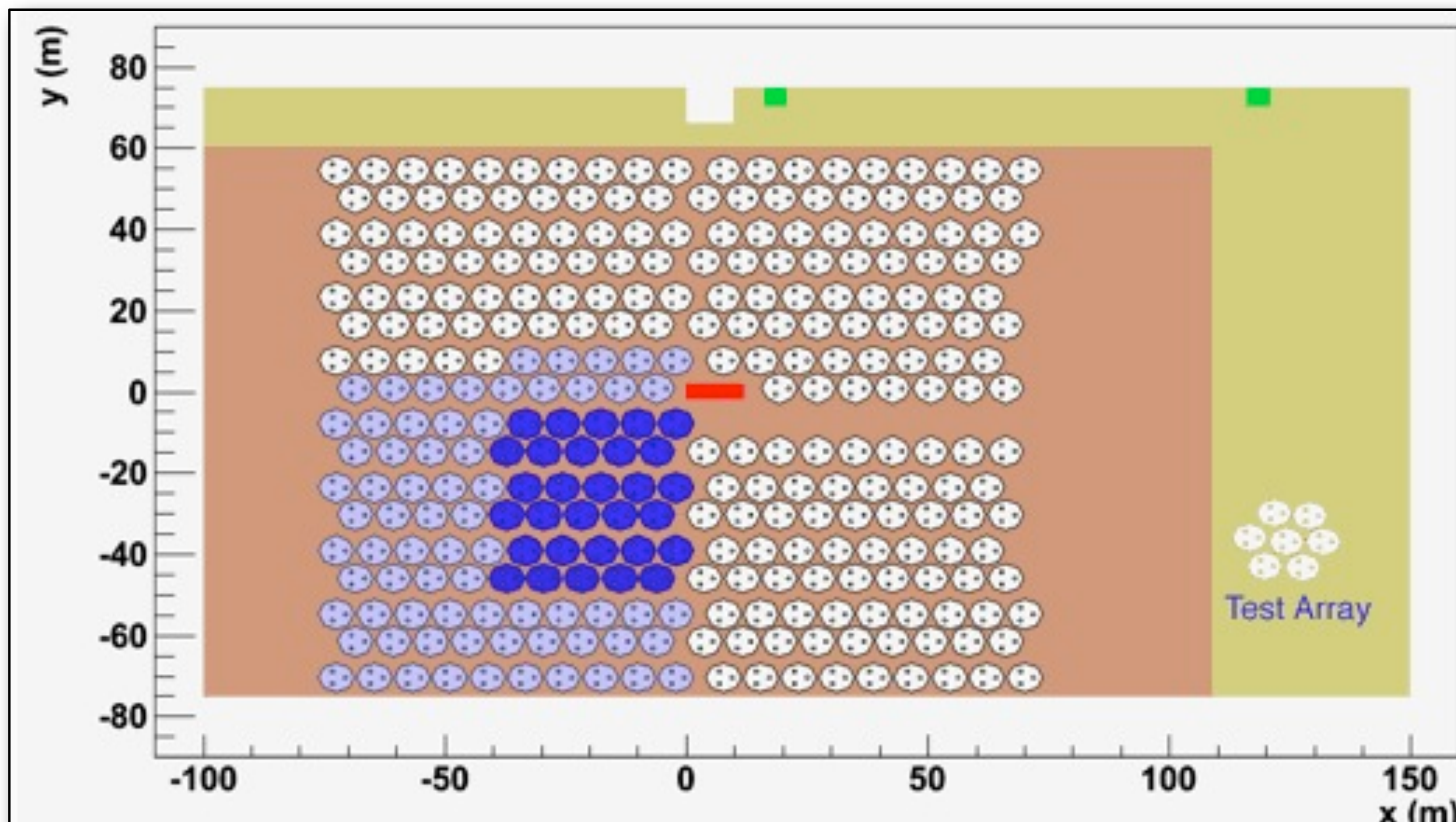


Transient Sensitivity

Harder spectra give significant increase in sensitivity
Fluxes normalized at 10 GeV

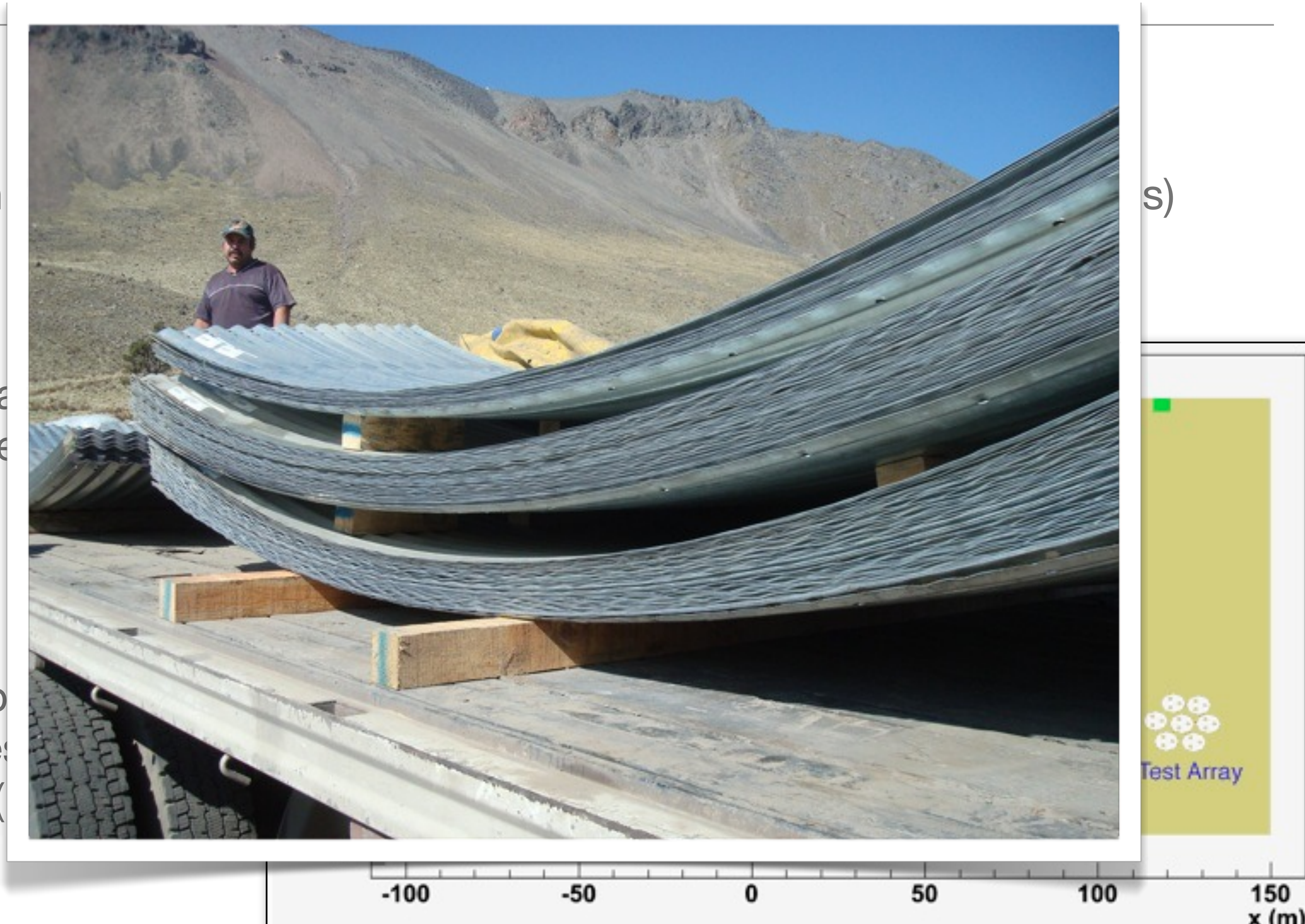
HAWC Construction Schedule

- 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

- VAMOS
  - Verification … s)
- HAWC-30
  - Implementa… all subsyste… (6 months)
- HAWC-100
  - Science op… with 2 times… sensitivity (…
- 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?