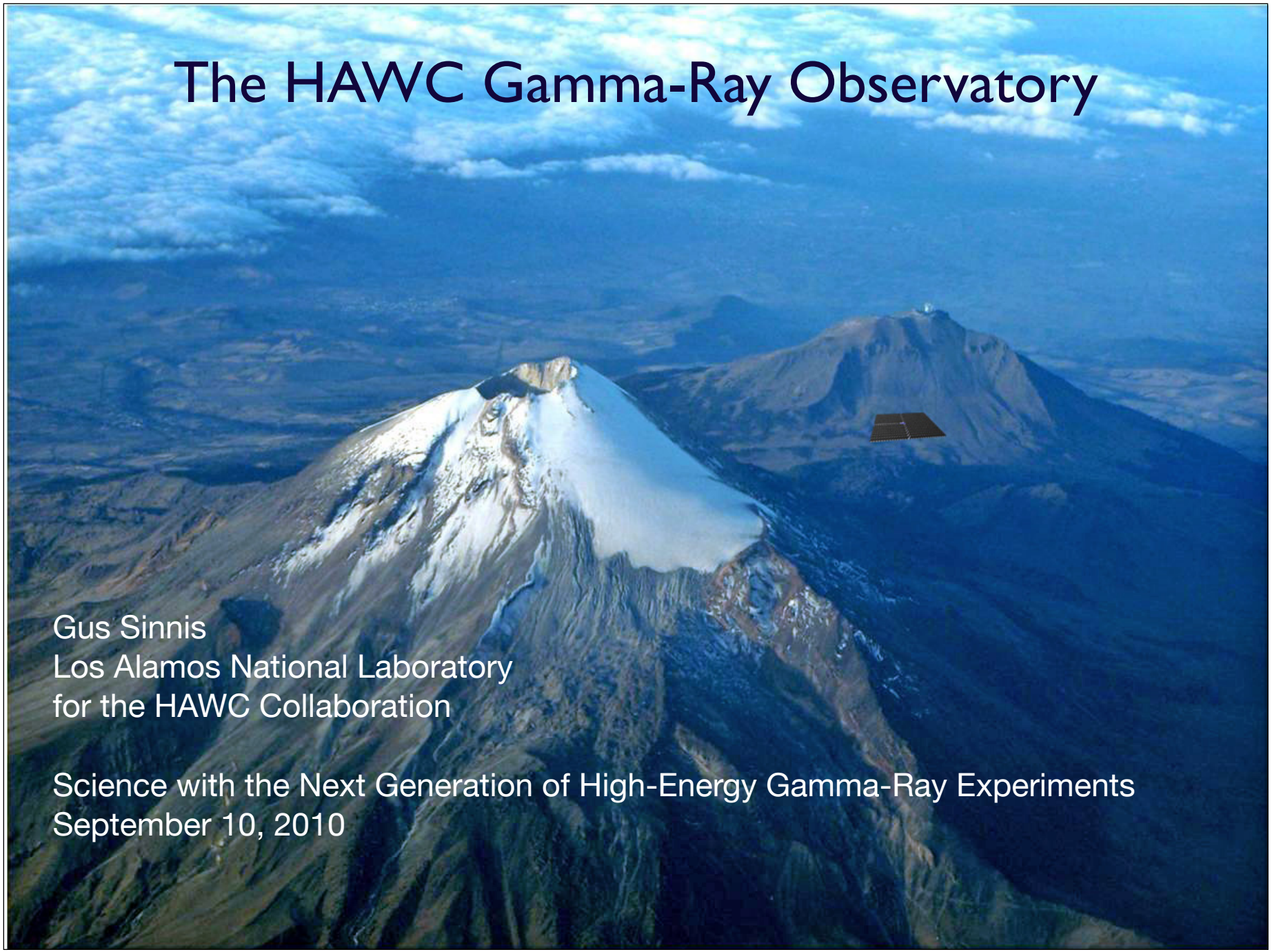
The HAWC Gamma-Ray Observatory

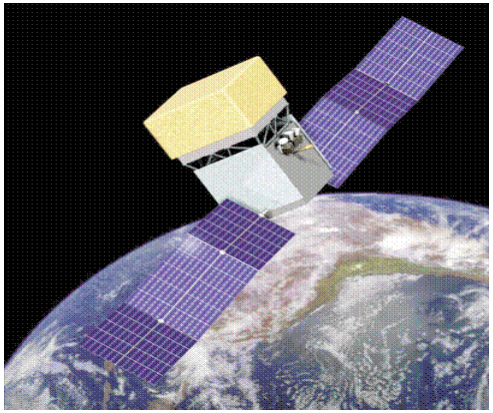


Gus Sinnis
Los Alamos National Laboratory
for the HAWC Collaboration

Science with the Next Generation of High-Energy Gamma-Ray Experiments
September 10, 2010

Gamma-Ray Telescopes

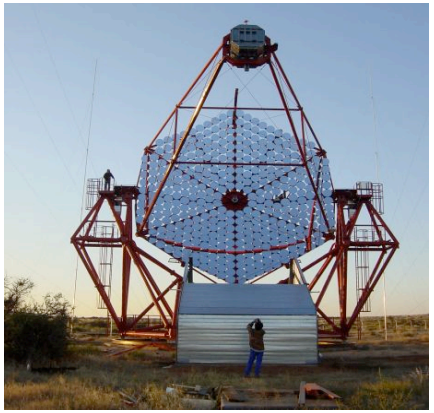
Pair Production Telescopes
EGRET/Fermi



0.1 - 100 GeV
Space-Based (small area)
Background free
Large Aperture/High Duty Cycle

All-sky survey & monitoring
Extra-Galactic (AGN, GRB)
Diffuse emission
Dark matter

Atmospheric Cherenkov Telescopes
H.E.S.S./VERITAS/MAGIC



50 GeV - 100 TeV
Large Area
Excellent background rejection
Small Aperture/Low Duty Cycle

Study known sources
Deep surveys of limited regions
Source morphology (SNRs)
Fast transients (AGN flares)
High resolution spectra
Dark matter

Particle Detection Arrays
Milagro/Tibet/ARGO

100 GeV - 100 TeV
Large Area
Good background rejection
Large Aperture & Duty Cycle

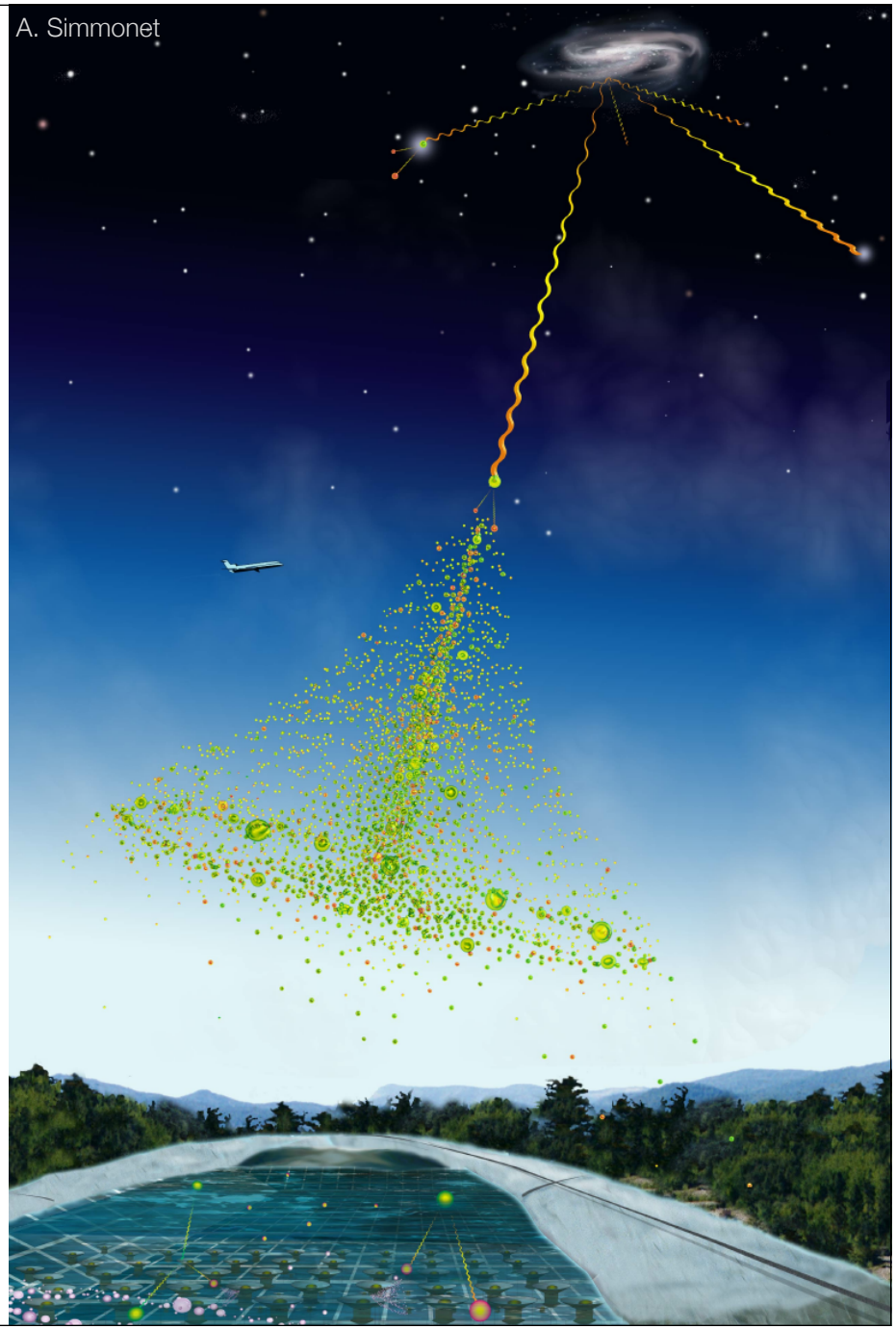
Partial sky survey & monitoring
Extended Sources
Transients (GRBs, AGN flares)
Highest Energies (>10 TeV)

Science Goals of a Wide-Field Instrument

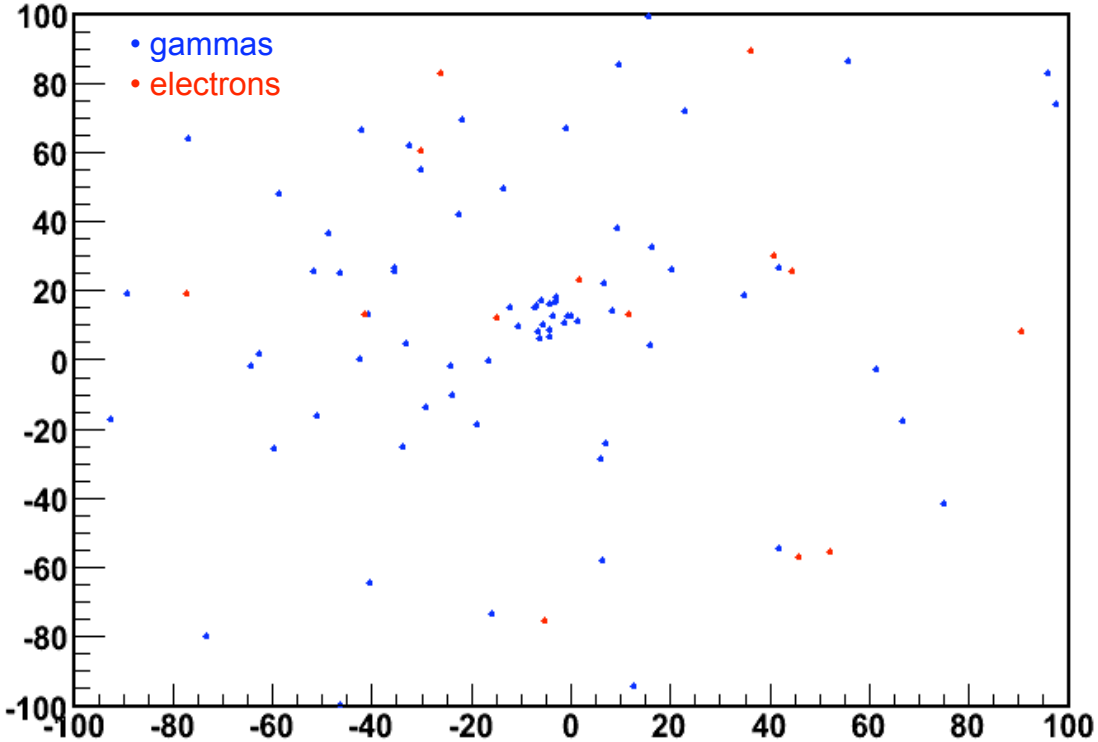
- Galactic Cosmic Ray Origins
  - Galactic Diffuse Emission
  - Highest Energies (10 - 100 TeV) for Galactic Sources
- Particle Acceleration in Jets
  - Gamma Ray Bursts at Highest Energies
  - AGN Flaring
  - Multi-wavelength and multi-messenger campaigns
- Complete Survey
  - Discovery potential
  - Alert system

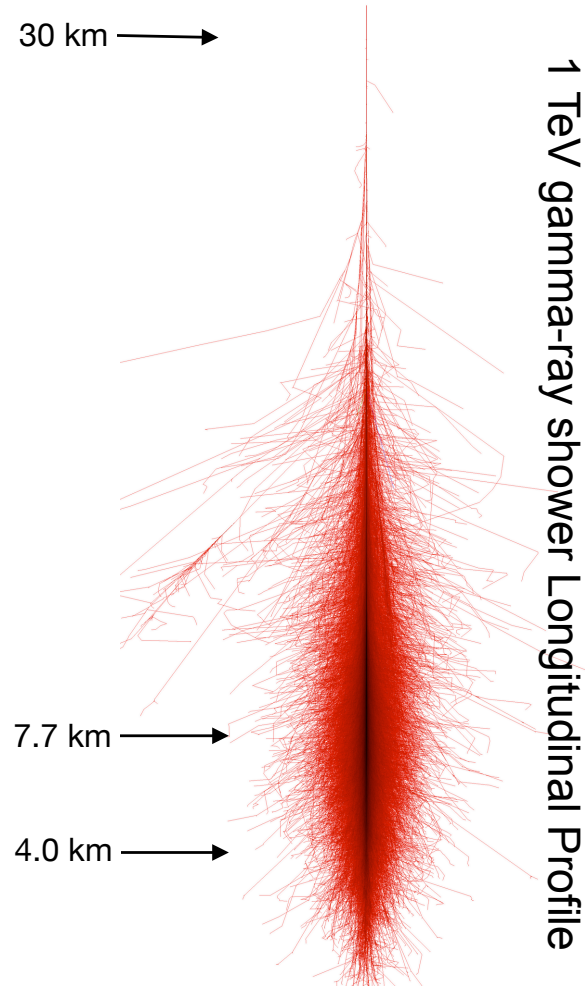
Extensive Air Shower Gamma Ray Telescopes

- Gamma rays interact in the atmosphere, form particle cascades
  - 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
- Duty factor >95%



Extensive Air Shower Arrays

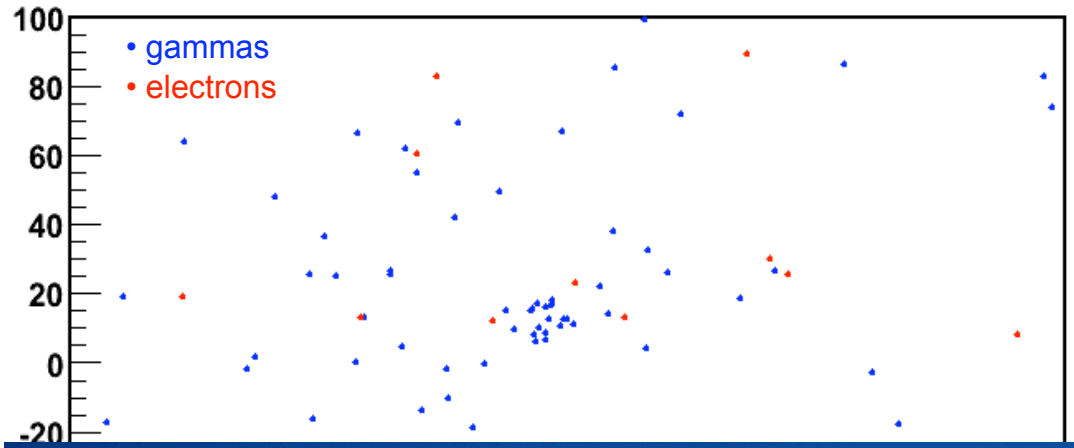


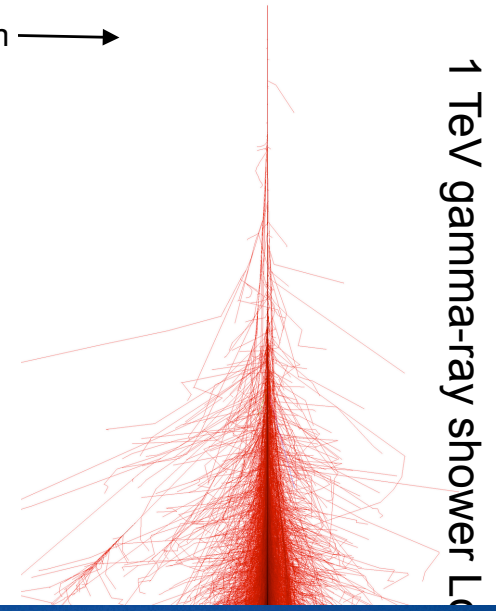


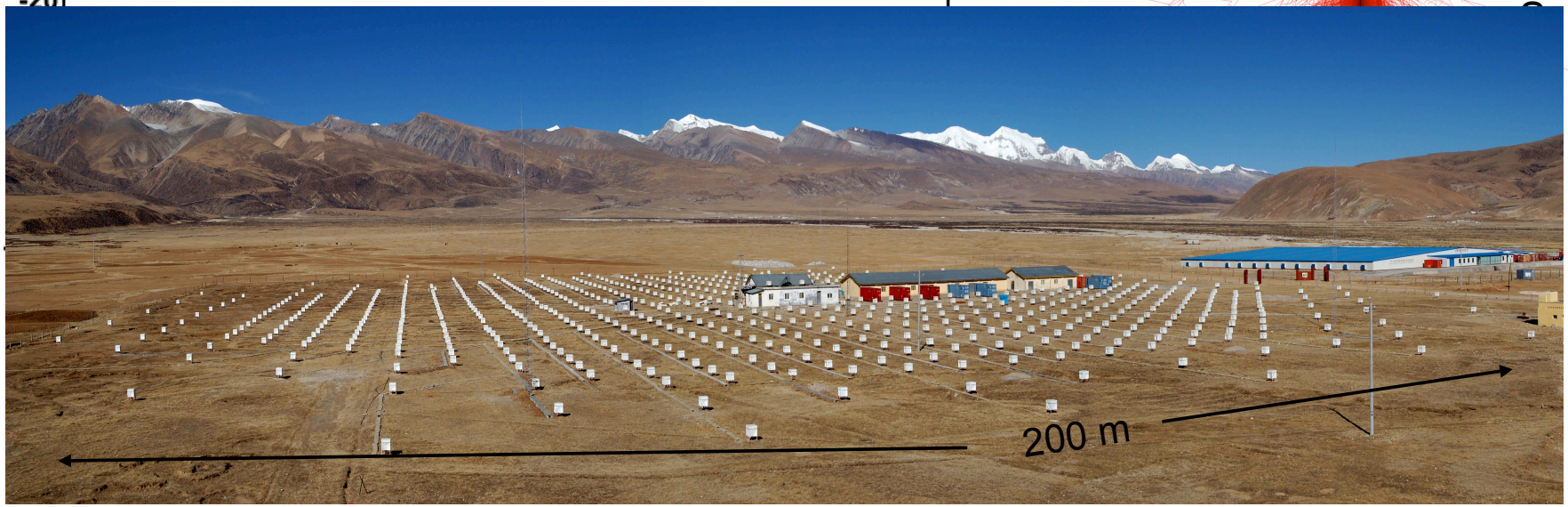
1 TeV gamma-ray shower Longitudinal Profile

http://www.ast.leeds.ac.uk/~fs/photon-showers.html

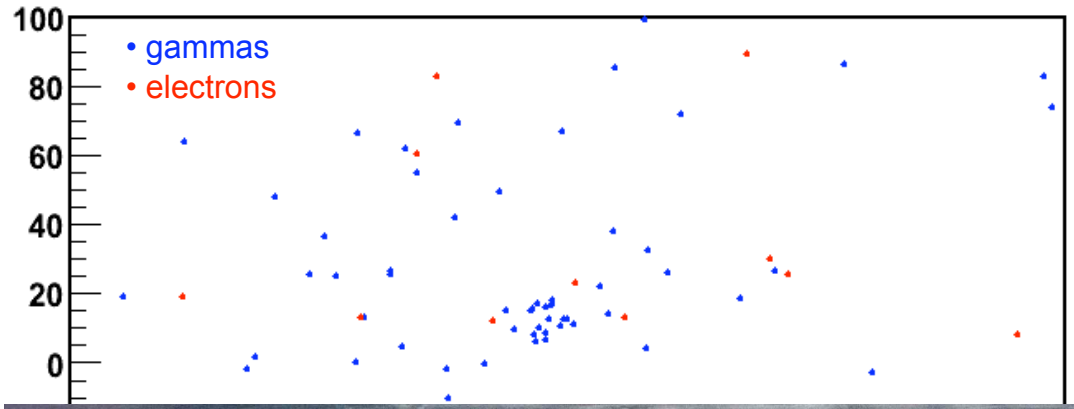
Extensive Air Shower Arrays

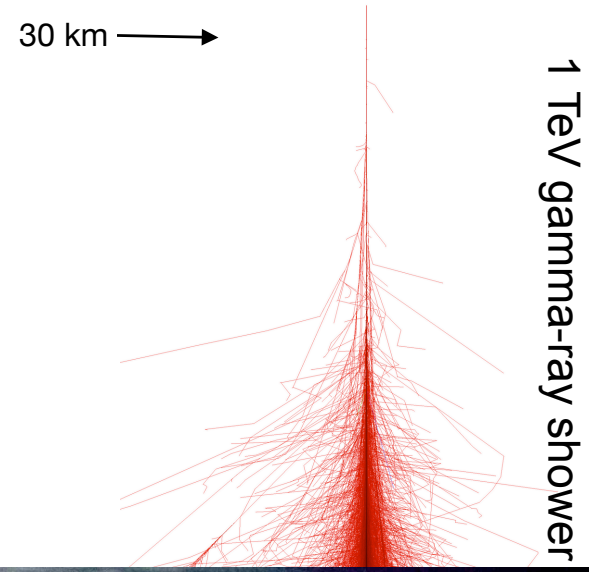


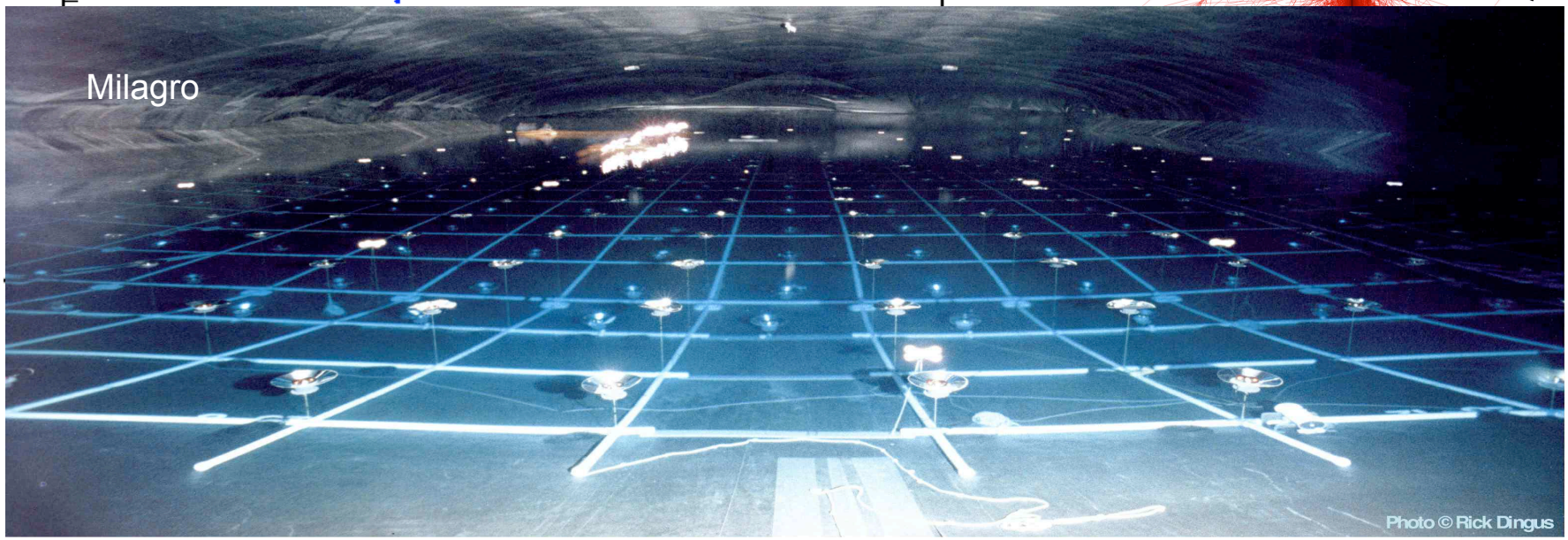




Extensive Air Shower Arrays







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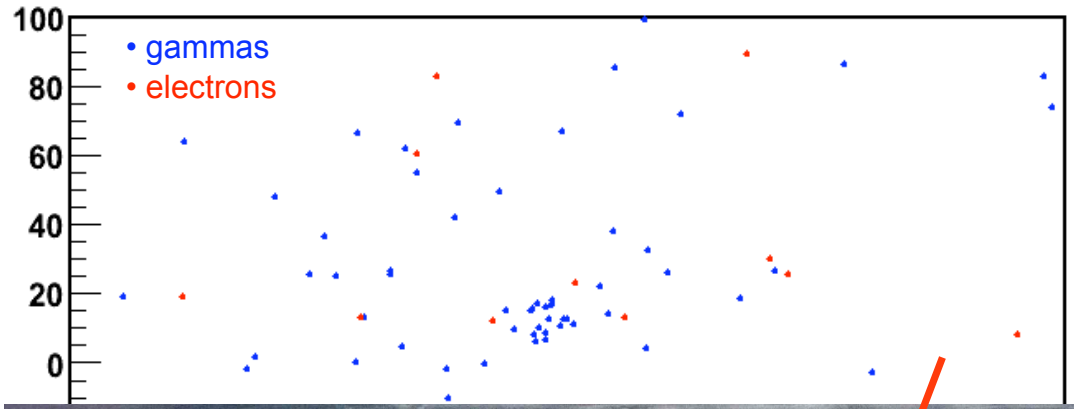

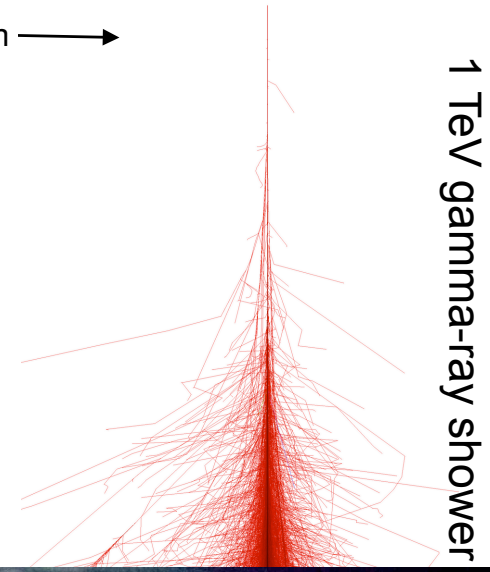

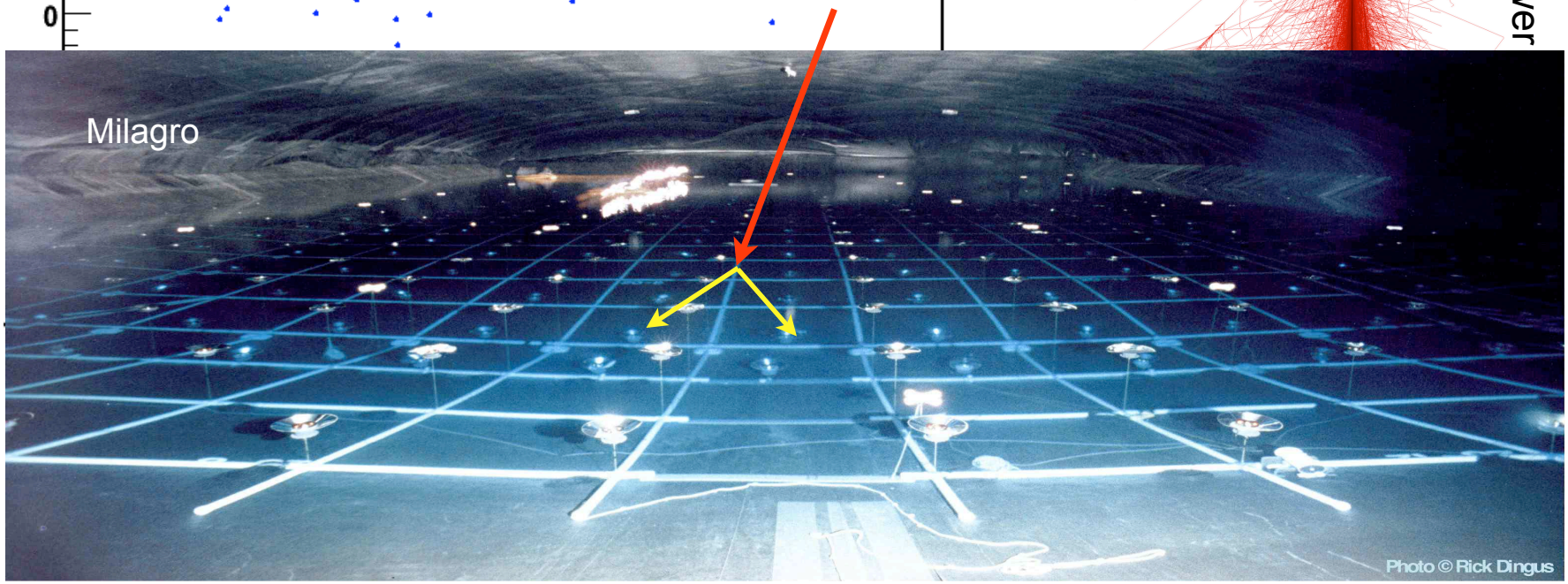

From Milagro to HAWC

- 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 2,400 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

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Los Alamos National Laboratory: Gus Sinnis, Brenda Dingus, John Pretz

University of Wisconsin: Teresa Montaruli, Stefan Westerhoff, Segev Ben Zvi, Juanan Aguilar, Dan Wahl

University of Utah: Dave Kieda, Wayne Springer

Univ. of California, Irvine: Gaurang Yodh'

Michigan State University: Jim Linnemann, Kirsten Tollefson, Dan Edmunds

George Mason University: Robert Ellsworth

Colorado State University: Miguel Mustafa, Dave Warner

University of New Hampshire: James Ryan

Pennsylvania State University: Tyce DeYoung, Patrick Toale, Kathryne Sparks

University of New Mexico: John Matthews, William Miller

Michigan Technical University: Petra Hüntemeyer

NASA/Goddard Space Flight Center: Julie McEnery, Elizabeth Hays, Vlasios Vasileiou

Georgia Institute of Technology: Ignacio Taboada, Andreas Tepe

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Universidad Autónoma de Chiapas: Cesar Álvarez, Eli Santos Rodriguez, Omar Pedraza

Universidad de Guadalajara: Eduardo de la Fuente

Universidad Michoacana de San Nicolás de Hidalgo: Luis Villaseñor, Umberto Cotti, Ibrahim Torres, Juan Carlos Arteaga Velazquez

Centrode Investigacion y de Estudios Avanzados: Arnulfo Zepeda

Universidad de Guanajuato: David Delepine, Gerardo Moreno, Edgar Casimiro Linares, Marco Reyes, Luis Ureña, Mauro Napsuciale, Victor Migenes

HAWC

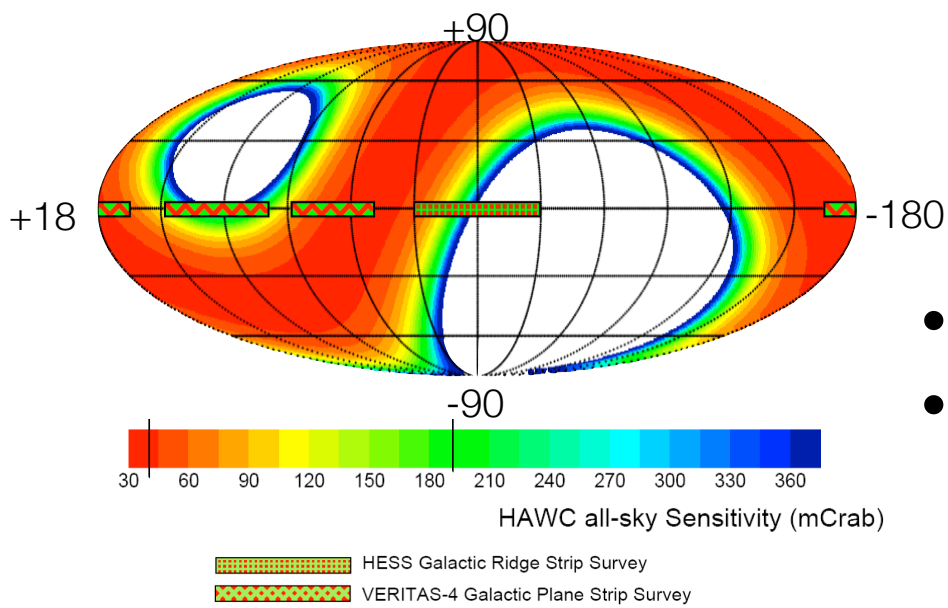
Pico de Orizaba, altitude 4100 m, latitude 18º 59’ N
Two hours drive from Puebla, four hrs from México City
Site of Large Millimeter Telescope (infrastructure exists)

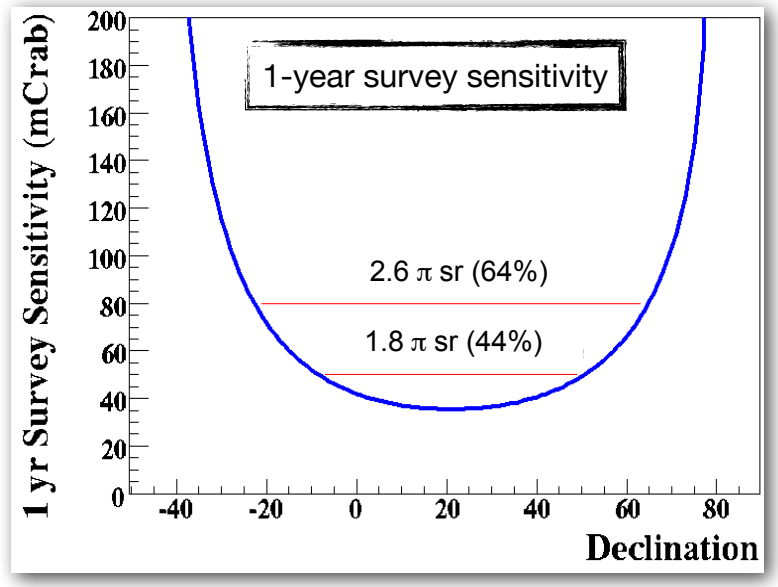
HAWC

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

HAWC Site Location

- Latitude (19° N) gives access to over 1/2 the sky
  - 40% overlap with HESS Galactic Plane survey
  - 90% overlap with IceCube
- Longitude (97° W) gives simultaneity with
  - VERITAS
  - Pan-American Observatories

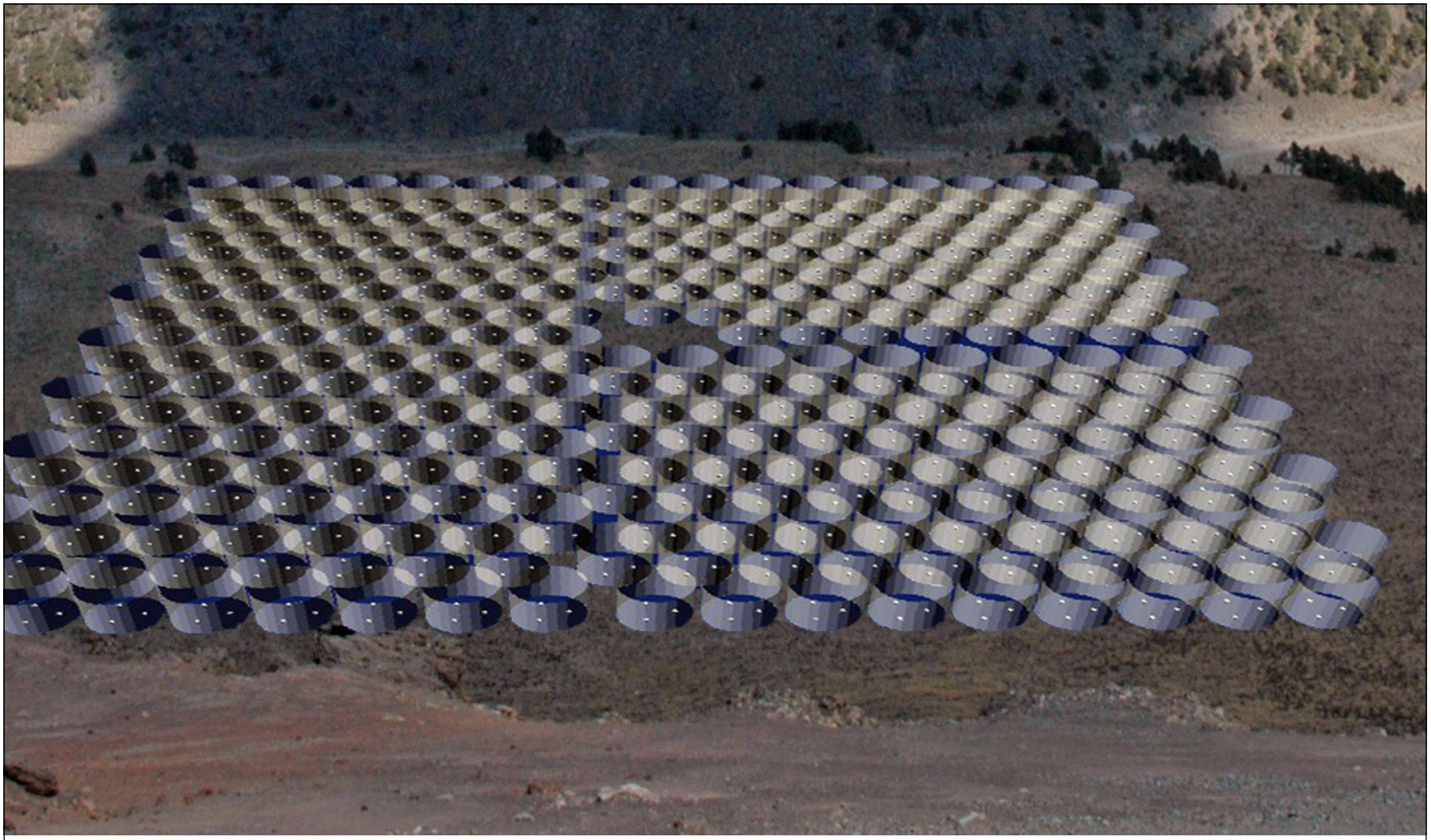




- Crab Nebula transits 3° from zenith
- Galactic Center visible at 48° zenith angle

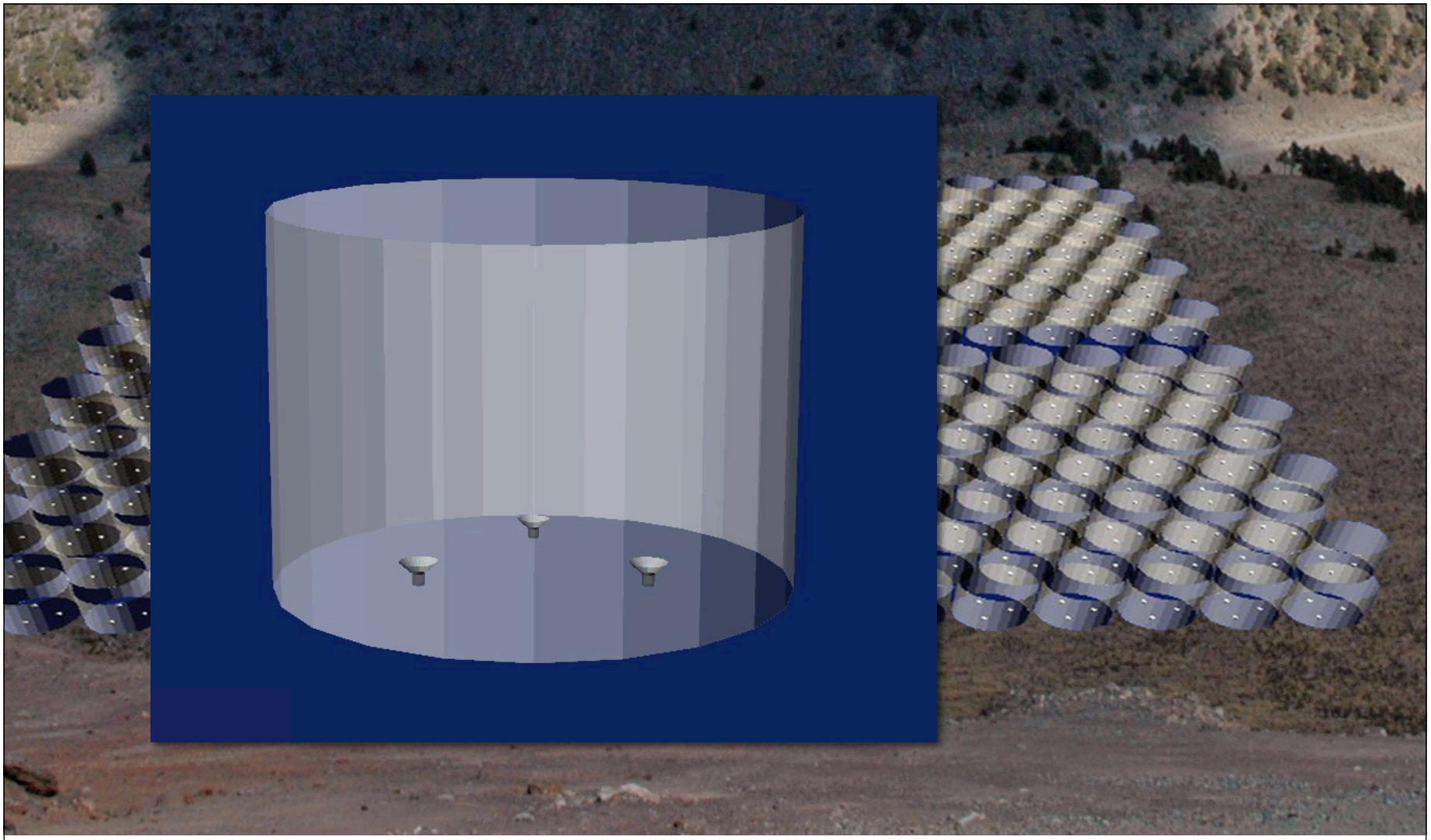
HAWC

Array composed of 300 large steel water storage tanks
Plastic bladder (water in, light out) - non-reflective surfaces
7.3 m diameter 4.5 m height
Close-pack array (~1-2m spacing of tanks)



Design

- 300 large steel water tanks
- ~20,000 m^2 array area
- >60% of area instrumented



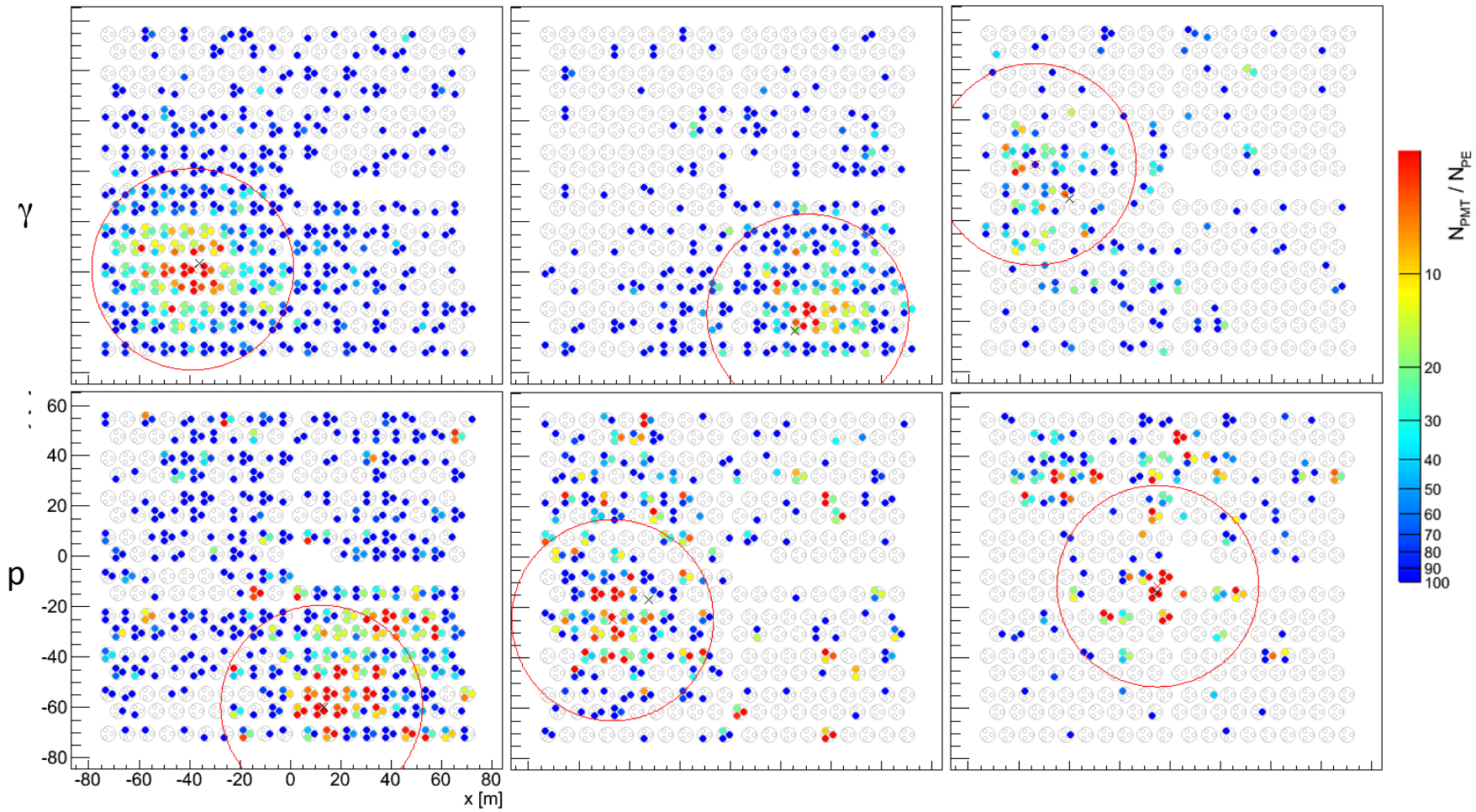
Design

- Each tank instrumented with 3 upward facing 8” PMTs
- 900 PMTs total
- Interior surfaces non-reflecting (maintain timing integrity)

HAWC Detectors

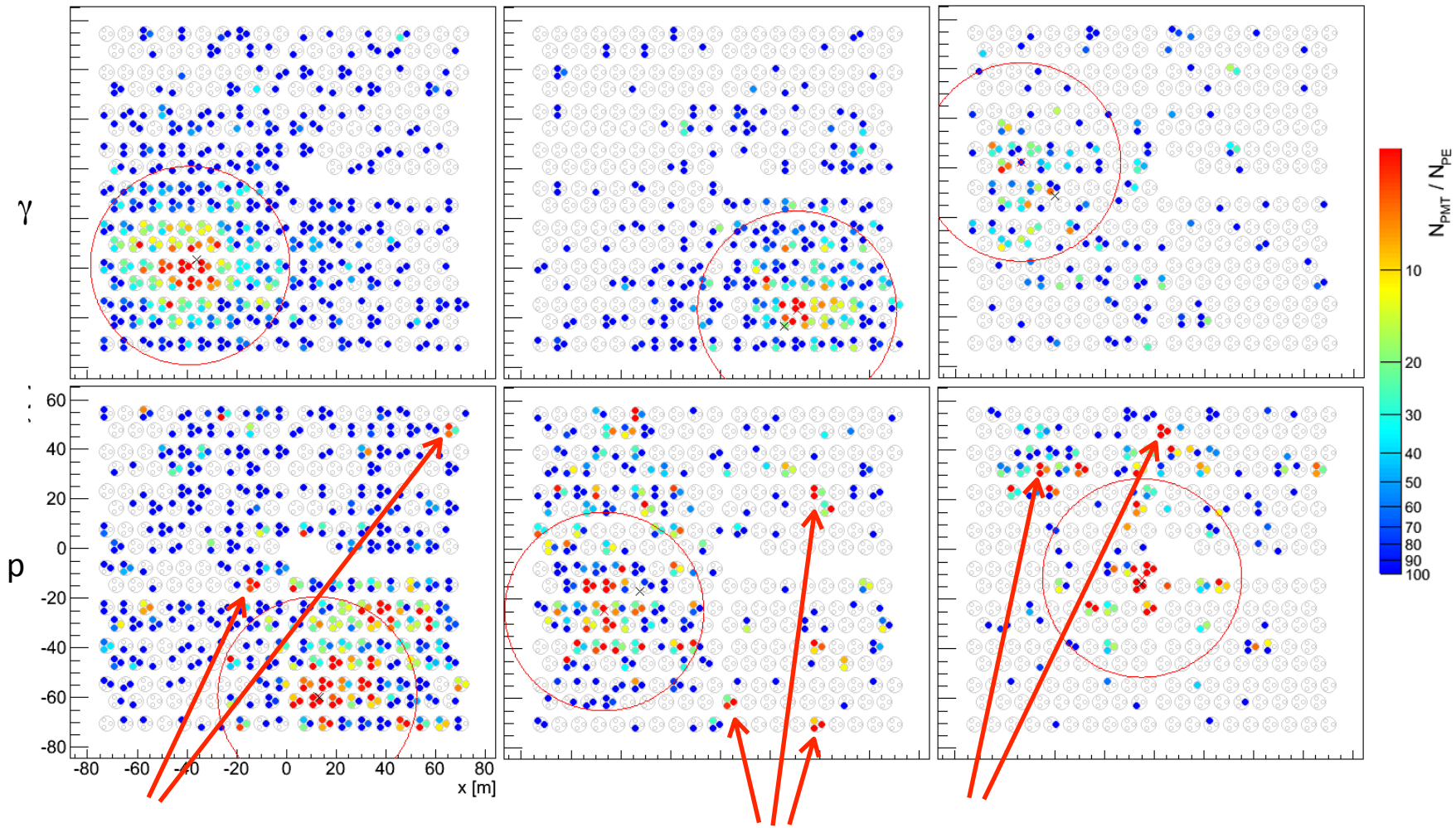
- Steel cylinders with liners, assembled in place
  - Light-tight, black plastic bladder to hold water
  - Water filtered and demineralized during fill
  - 3 upward looking PMTs with <1 ns time resolution
- 900 8” Hamamatsu PMTs and most electronics re-used from Milagro

Hadron Rejection



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

Hadron Rejection



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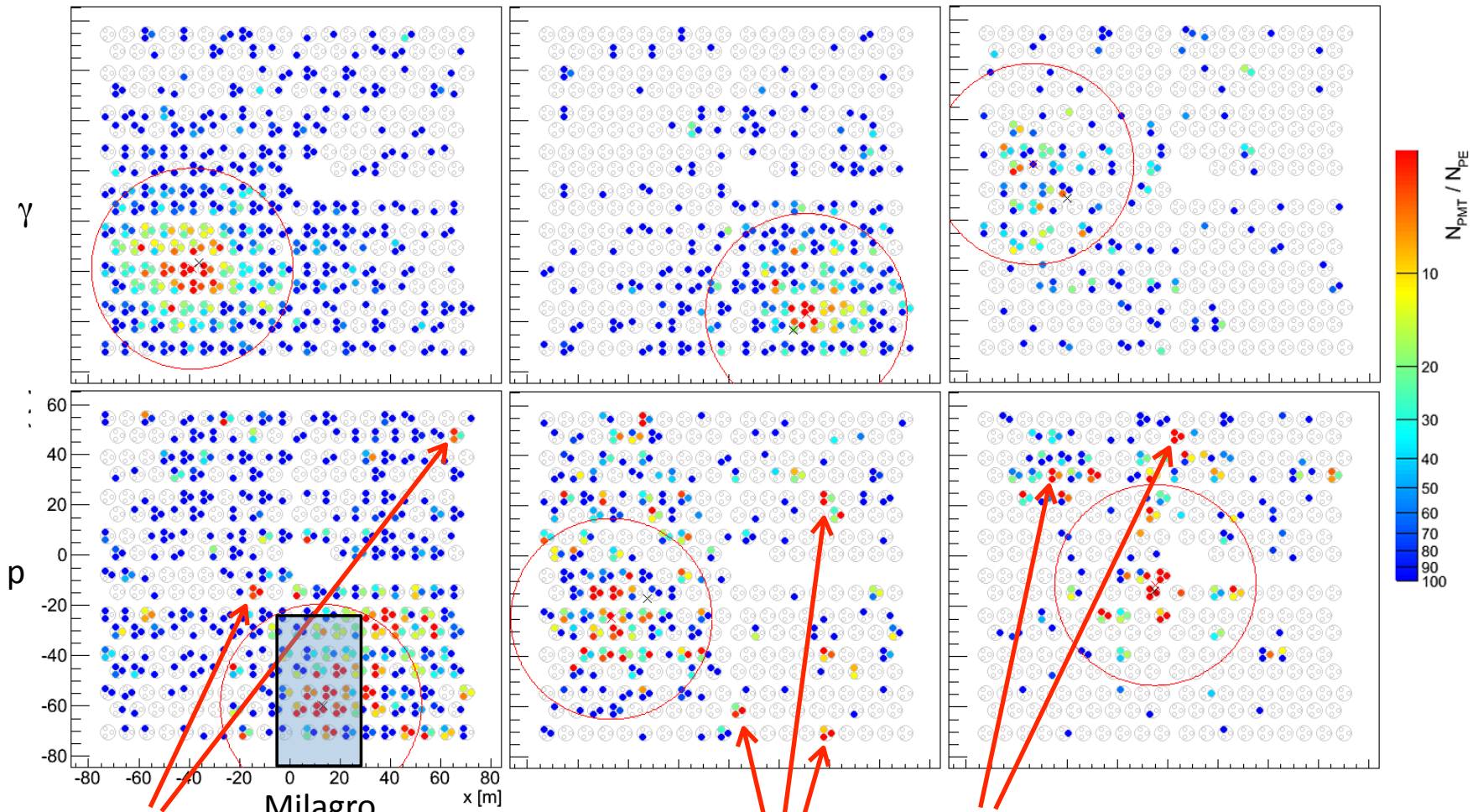
Hadron Rejection

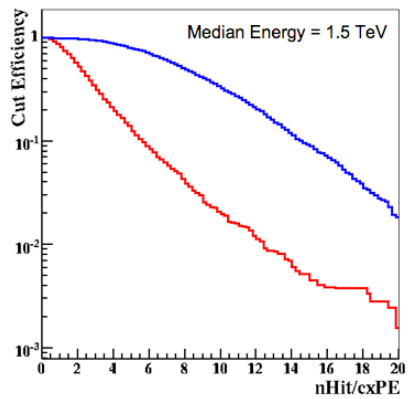


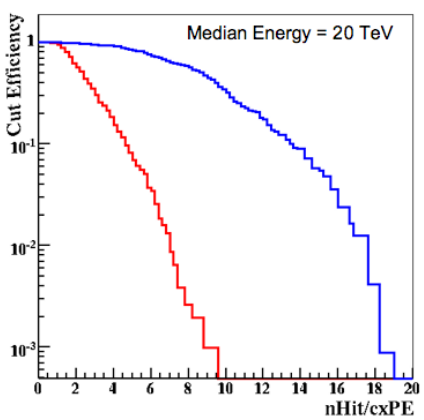
Milagro
bottom layer

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

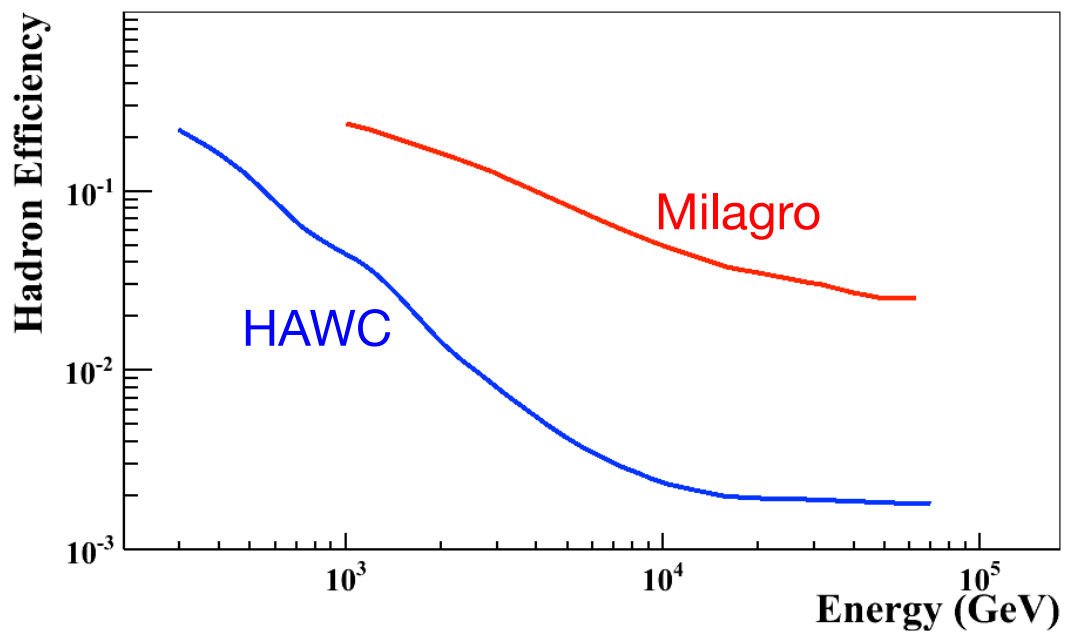
Gamma-Hadron Separation

- Parameter C = nHit / cxPE (cxPE = largest nPEs >40m from core)
- ~10x better rejection than Milagro



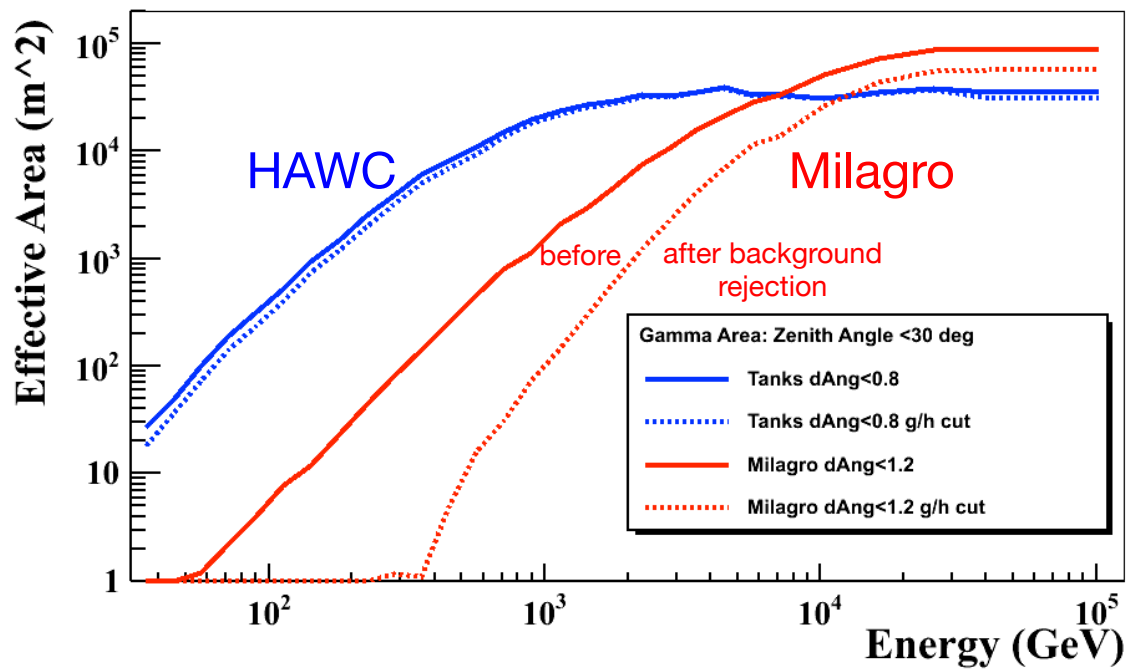


G-H separation at 50% gamma efficiency



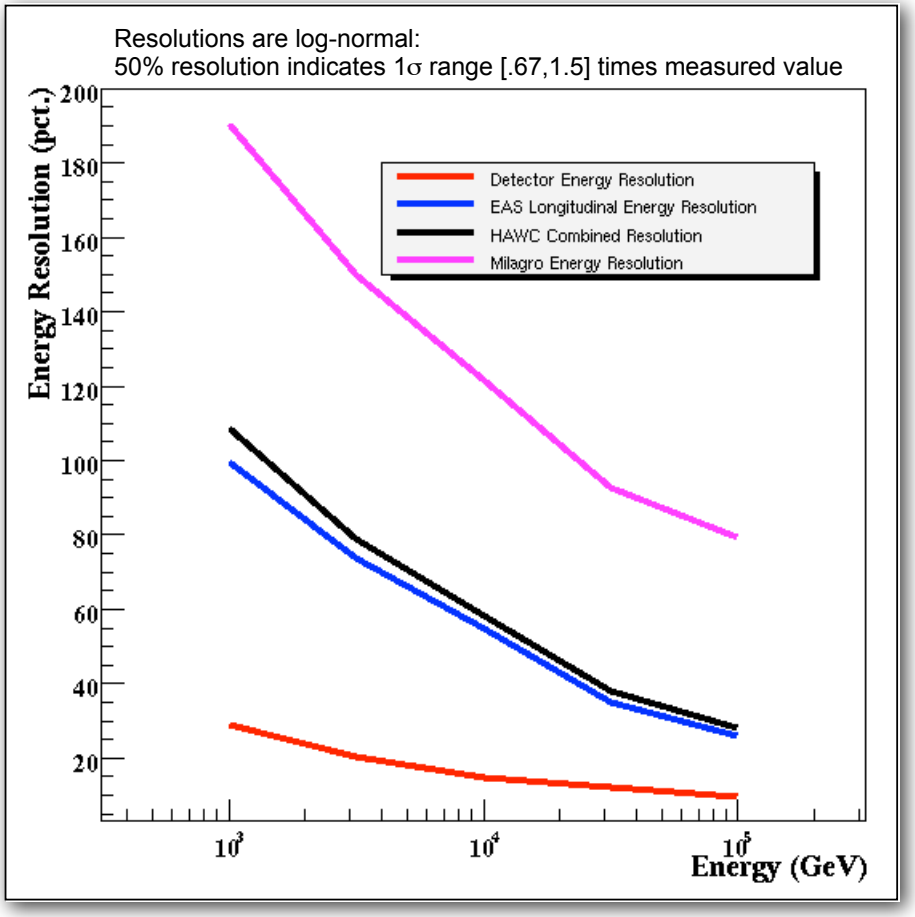
Energy Threshold and Effective Area

- Higher altitude leads to a lower energy threshold
  - Shower fluctuations (depth of first interaction) lead to 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

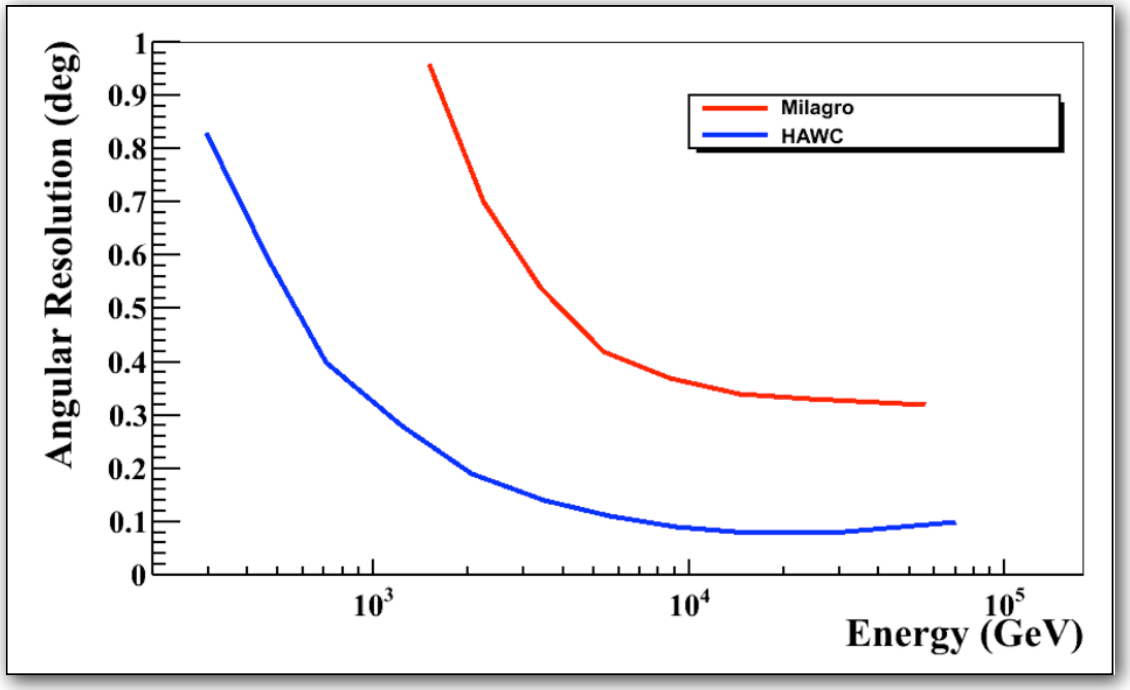


Energy Resolution

- Uncertainty from two sources:
  - Measurement of energy deposited at ground level
  - Fluctuations in shower development in atmosphere (naturally log-normal)
- Higher elevation closer to shower max
  - Comparable resolution at ~1/10 the energy of Milagro
  - HAWC resolution approaches limit from shower fluctuations



Angular Resolution



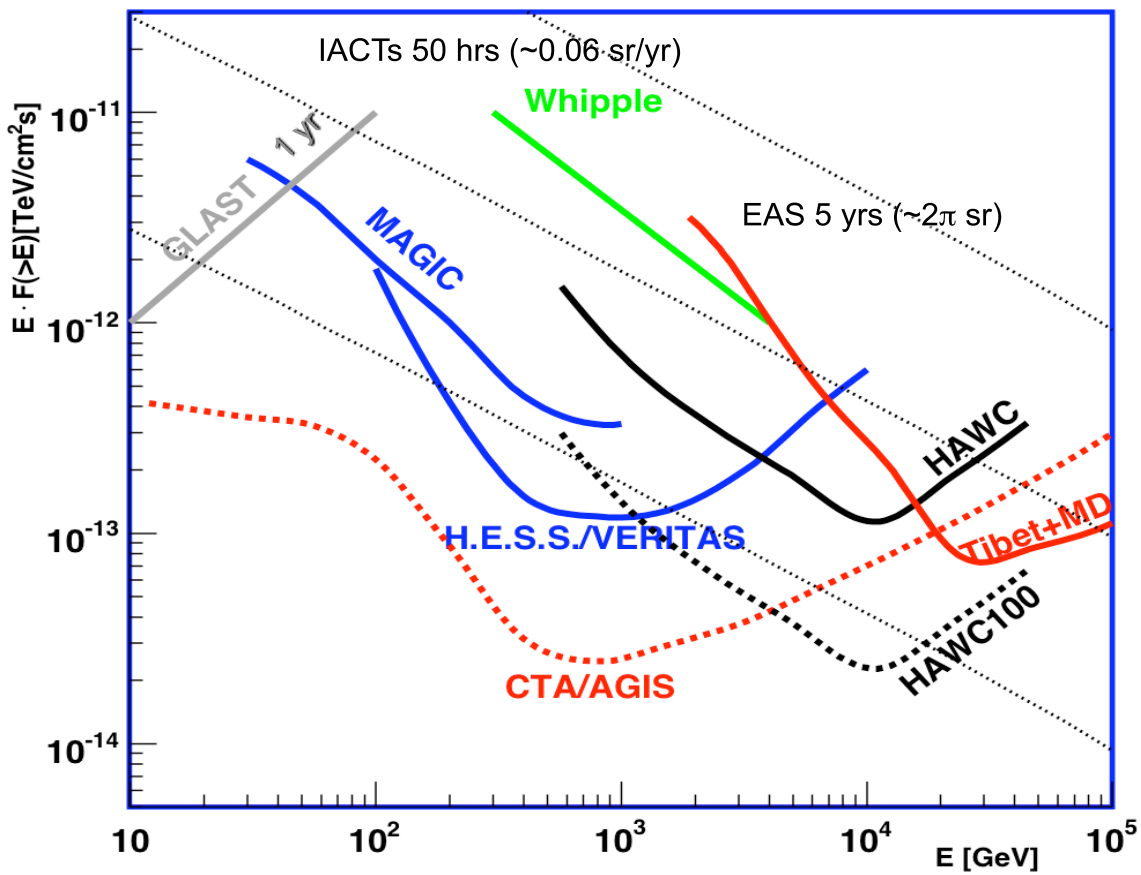
- Significant increase over Milagro – limited by information in the particles that reach the ground
  - Based on Milagro algorithms – improvements possible (esp. at higher E)

Sensitivity to Point Sources

- Long integration times (1000 hrs/year)
  - excellent sensitivity at highest energies (> few TeV)

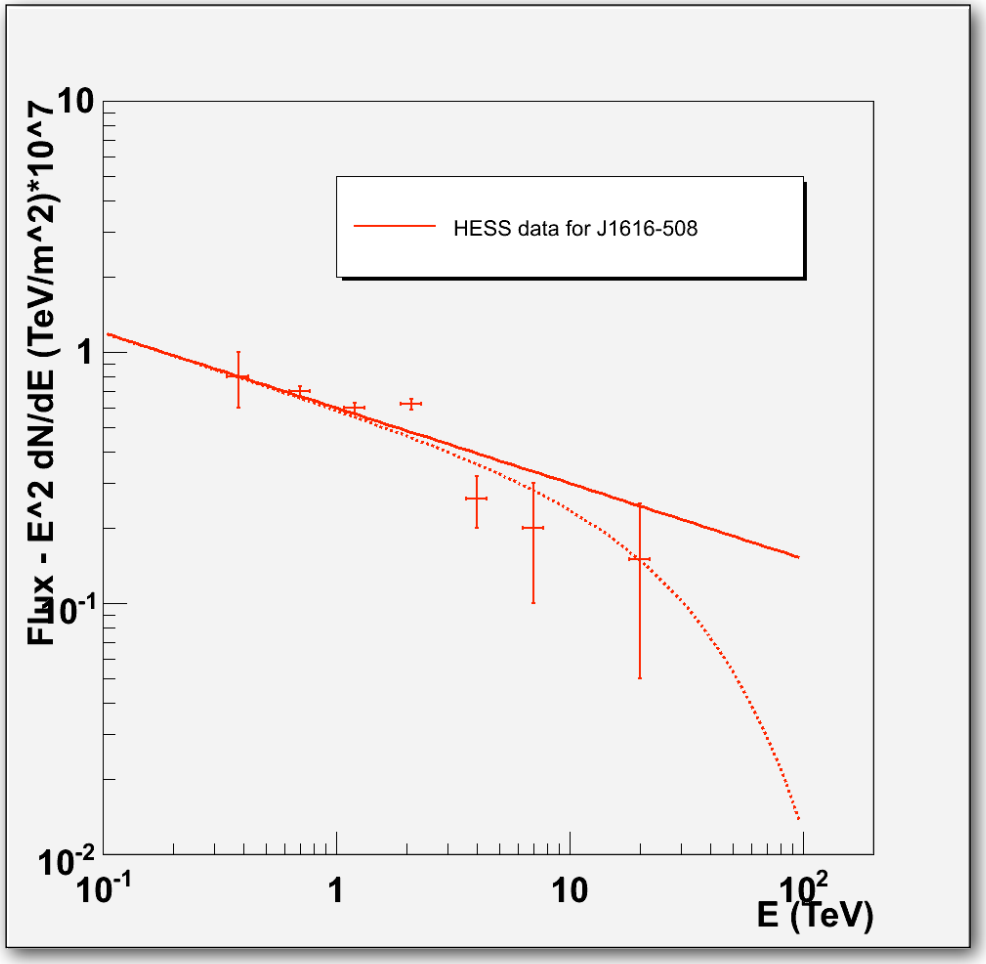
- 5σ sensitivity to
  - 10 Crab in 3 min
  - 1 Crab in 5 hr
  - 0.1 Crab in ⅓ year

- 10-15x Milagro sensitivity
  - Lower energy threshold
  - Improved angular resolution
  - Improved energy resolution
  - Improved CR rejection



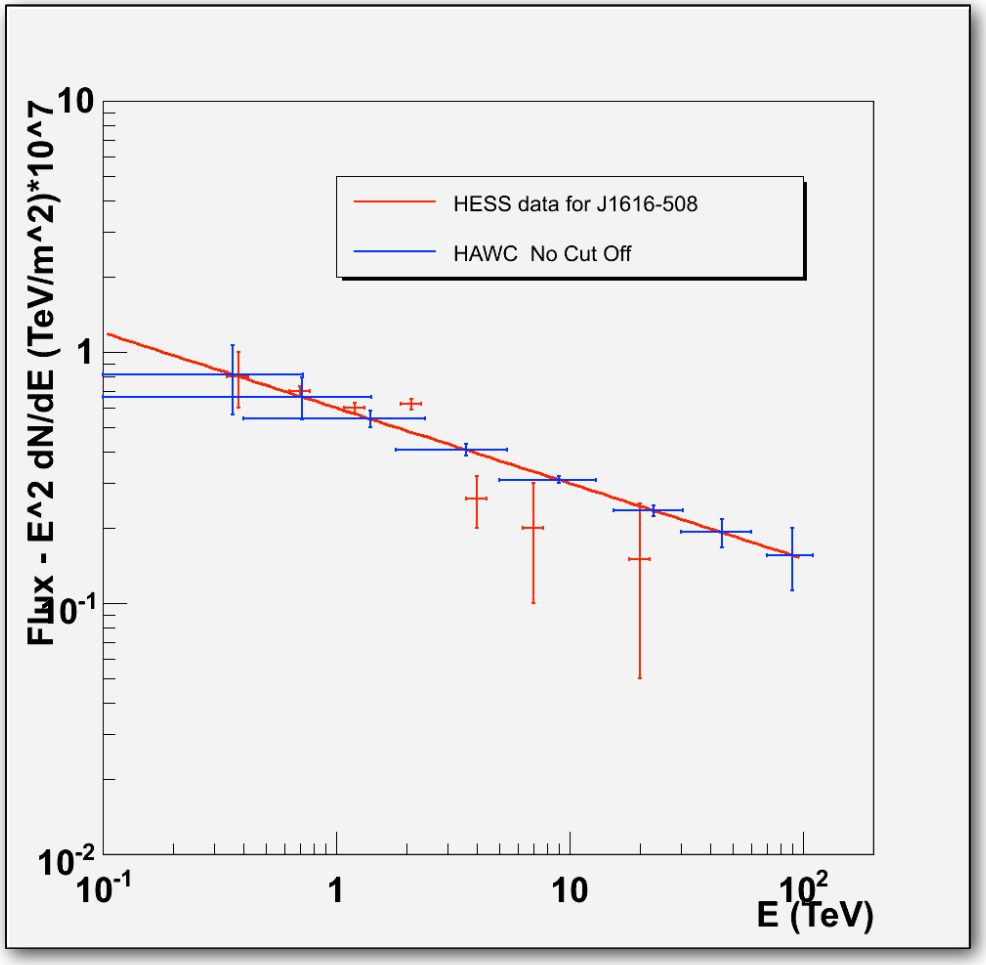
Measuring Spectra at the Highest Energies

- HESS J1616-508
  - 0.2 Crab @ 1 TeV, α=-2.3
  - Highest energy ~20 TeV



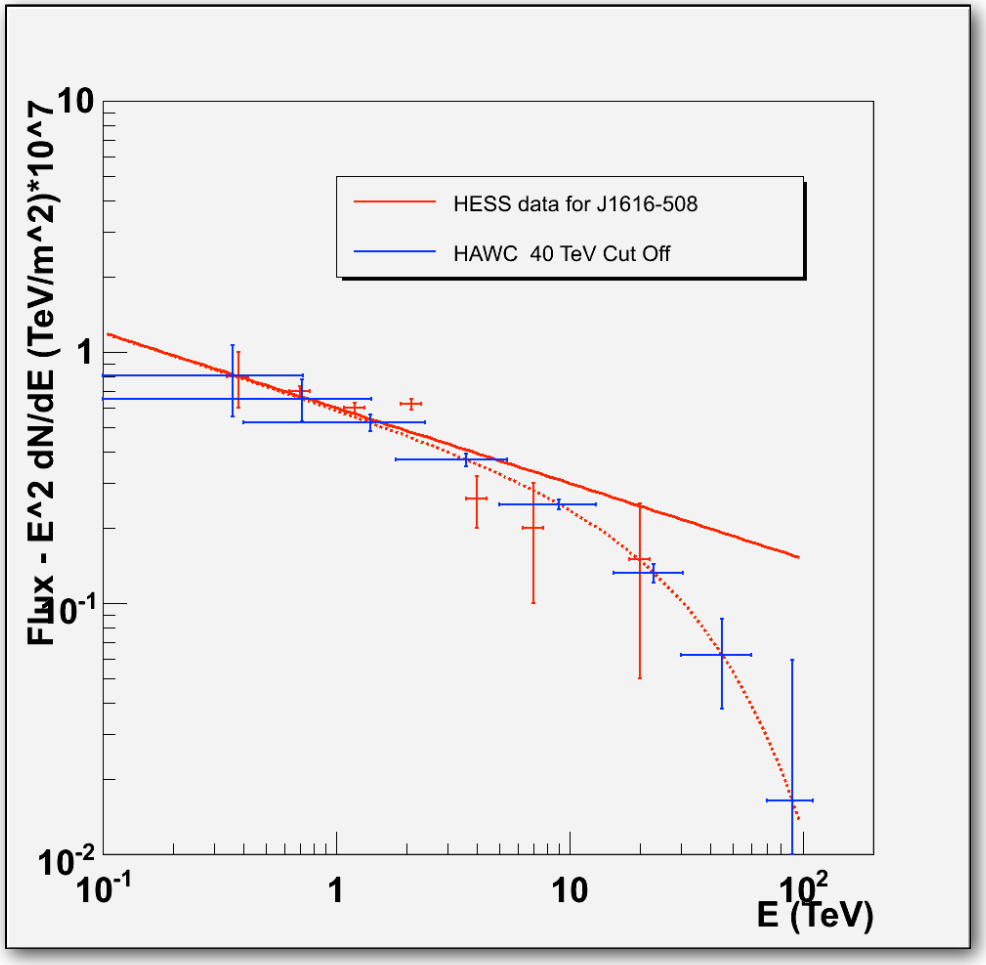
Measuring Spectra at the Highest Energies

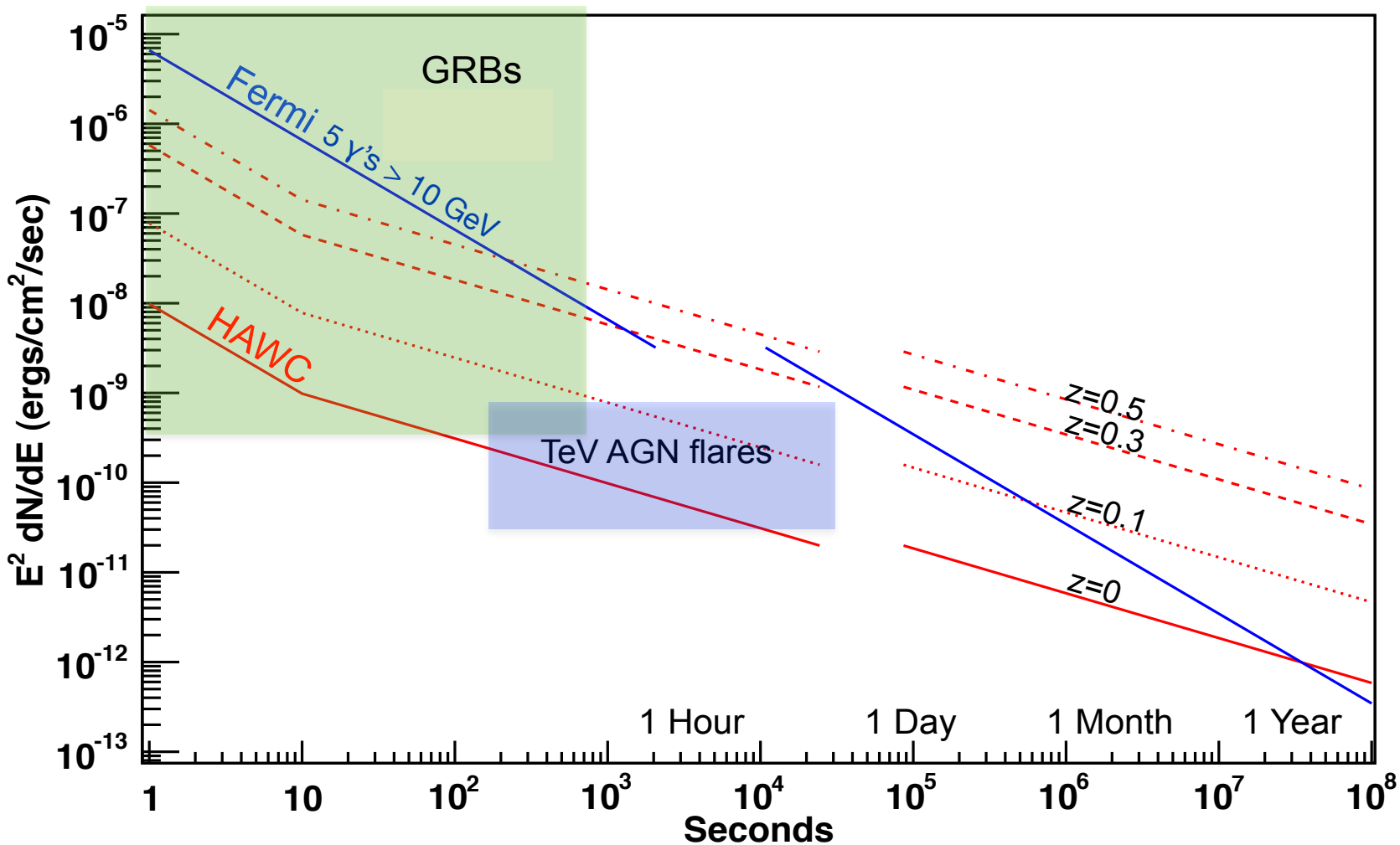
- HESS J1616-508
  - 0.2 Crab @ 1 TeV, α=-2.3
  - Highest energy ~20 TeV
- Simulated HAWC data for 1 year with no cutoff



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



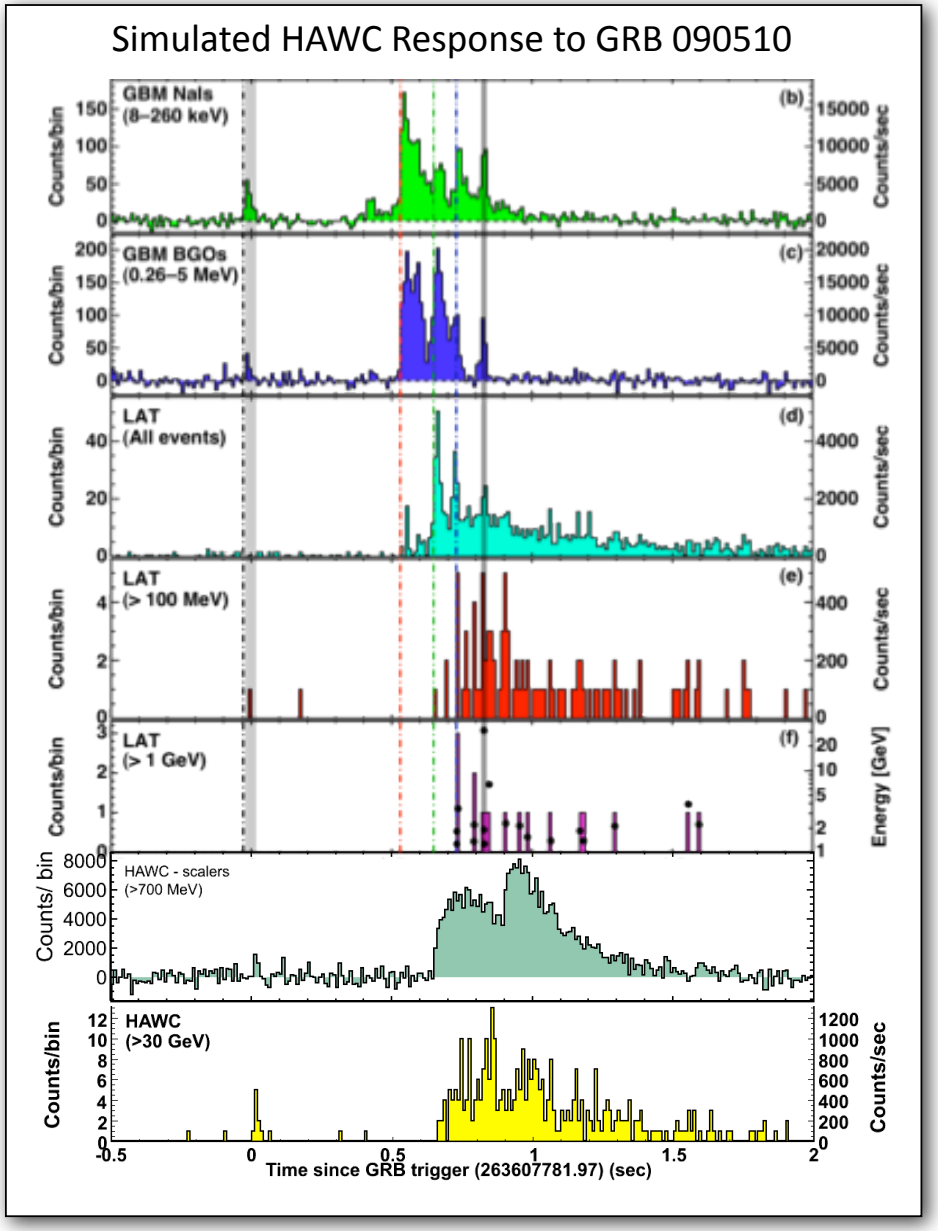


Transient Sensitivity

Assumed E^{-2} emission spectrum
Full HAWC simulation (5 σ or 10 photons)
Fermi-LAT assumed 0.8 m^2 effective area, no background

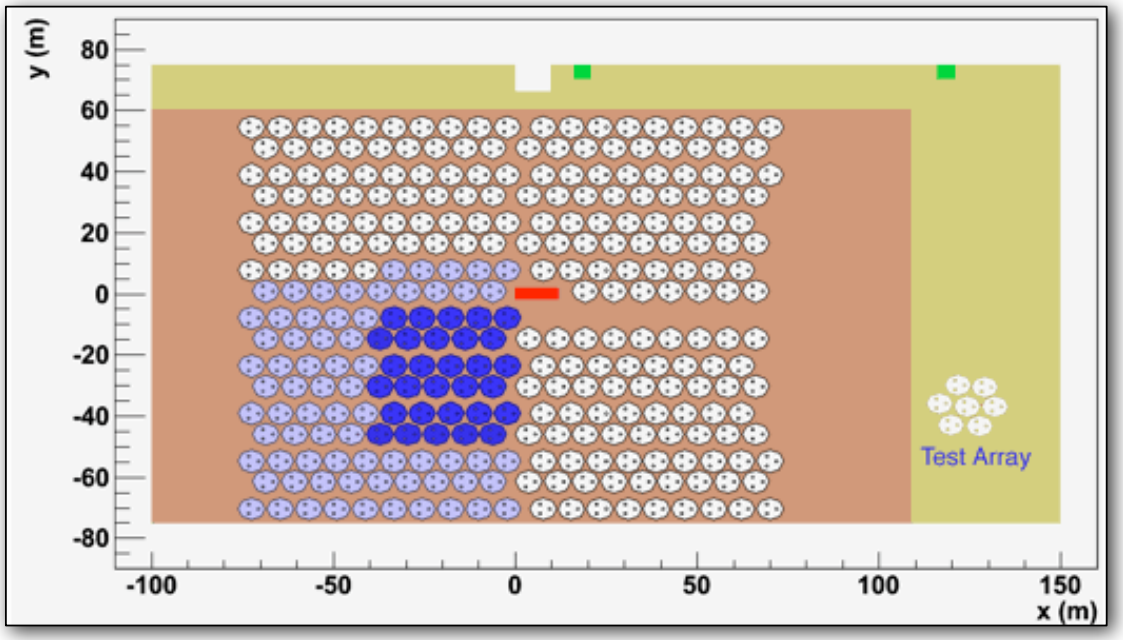
Sensitivity to High Energy Transients

- 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

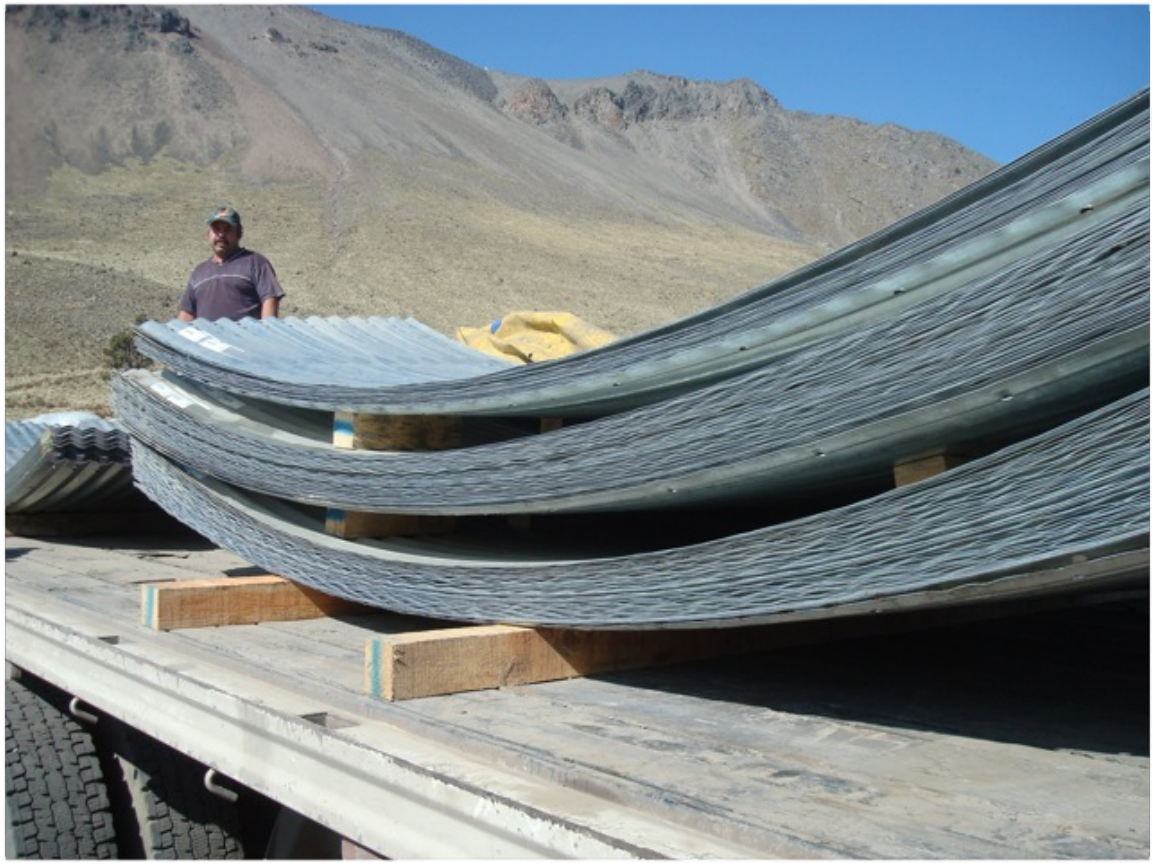
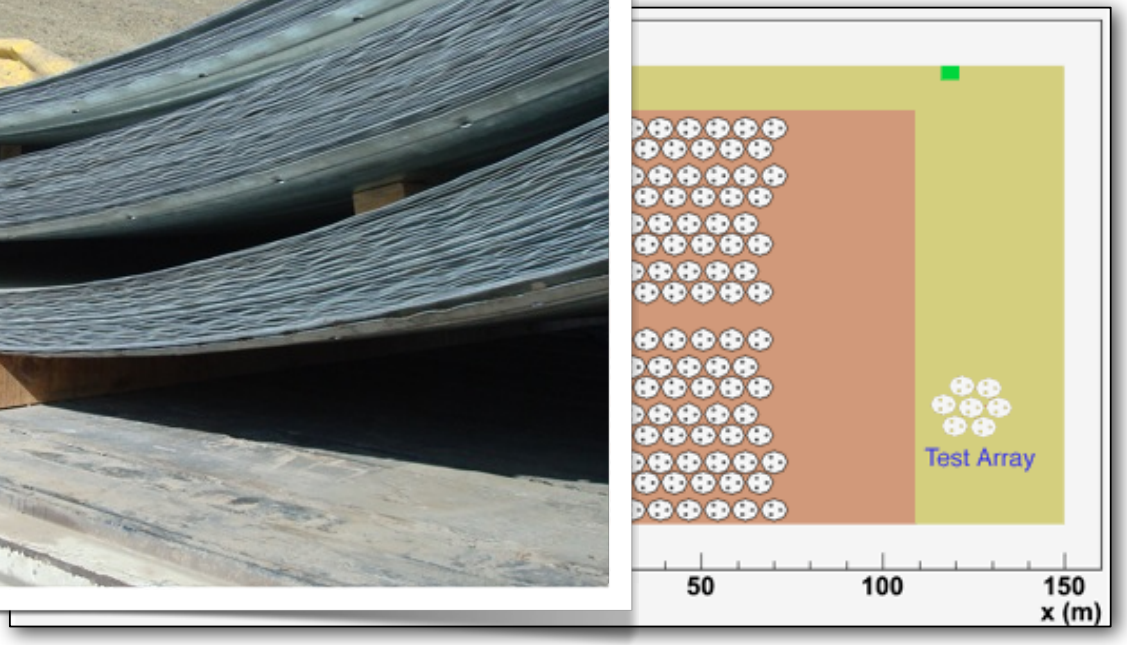


HAWC Construction Schedule

- VAMOS
  - Verification Assessment Measuring Observatory Subsystems (3 months)
- HAWC-30
  - Implementation of all subsystems (complete 2011)
- HAWC-100
  - Science operations with 2 times Milagro's sensitivity (complete 2012/13)
- HAWC-300
  - Full detector (complete 2014)



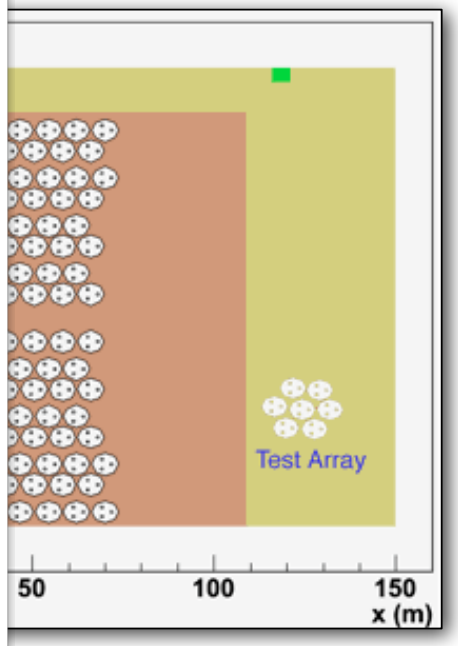
HAWC Construction Schedule

- ns (3 months)
- 
- 

- HAWC-300
  - Full detector (complete 2014)

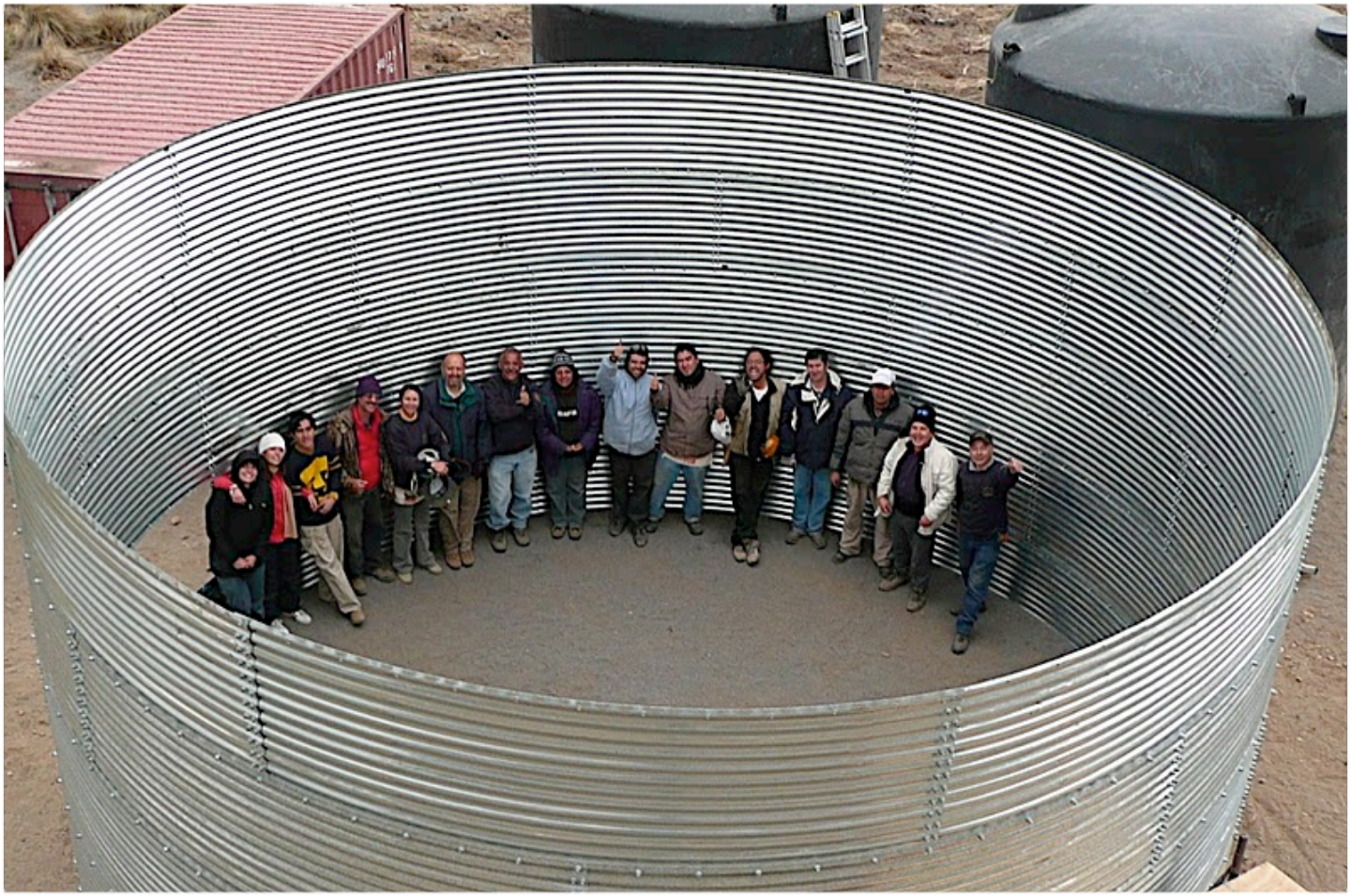
HAWC Construction Schedule

(3 months)



HAWC Construction Schedule

HAWC Construction Schedule



HAWC Construction Schedule

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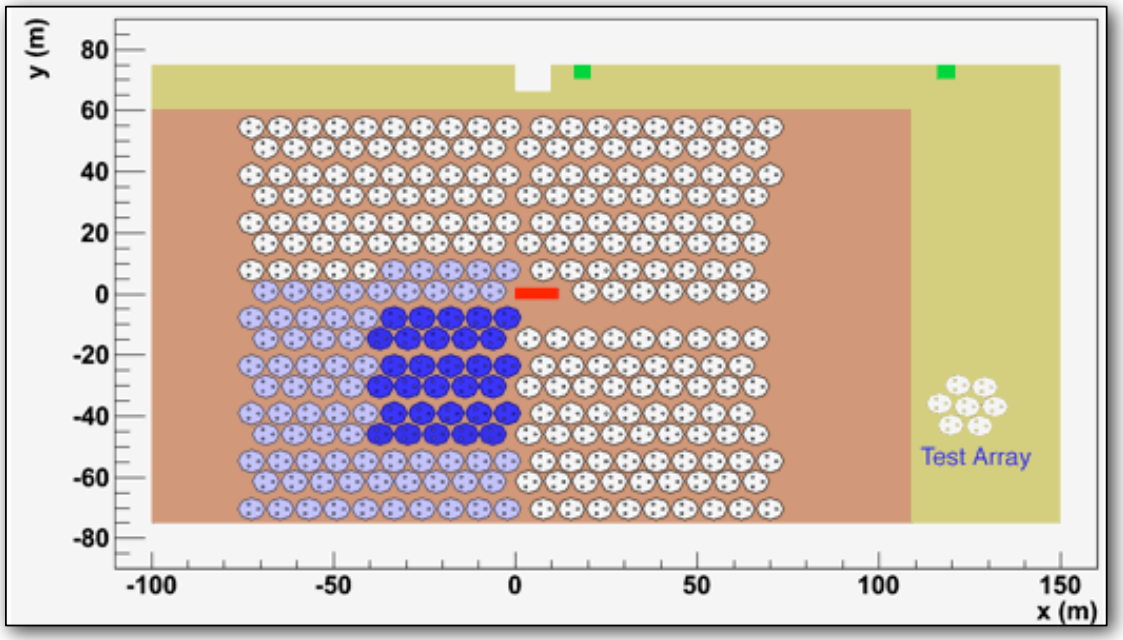

HAWC Status

- Evolution of Milagro: altitude, size, optical isolation
  - ~10-15x sensitivity of Milagro
  - Straightforward design
- Funding approved by NSF, DOE in US and by CONACyT in México
  - Site is approved for our use
  - 7 detector array (VAMOS) under construction, first detector operational
  - Plan for operation with 100 detectors in 2012
  - Full array of 300 detectors operational by 2014
- Wide field of view and high duty cycle at 100 GeV – 100 TeV
  - Excellent discovery potential
  - Complement to other current and future instruments