



# The High Altitude Water Cherenkov Detector

Gus Sinnis  
Los Alamos National Laboratory

on the occasion of  
TrevorFest a workshop in honor of Trevor Weekes

# Extensive Air Shower Arrays

## IACTs

H.E.S.S./VERITAS/MAGIC



50 GeV - 100 TeV

High Instantaneous Sensitivity  
Excellent background rejection  
Small Aperture/Low Duty Cycle

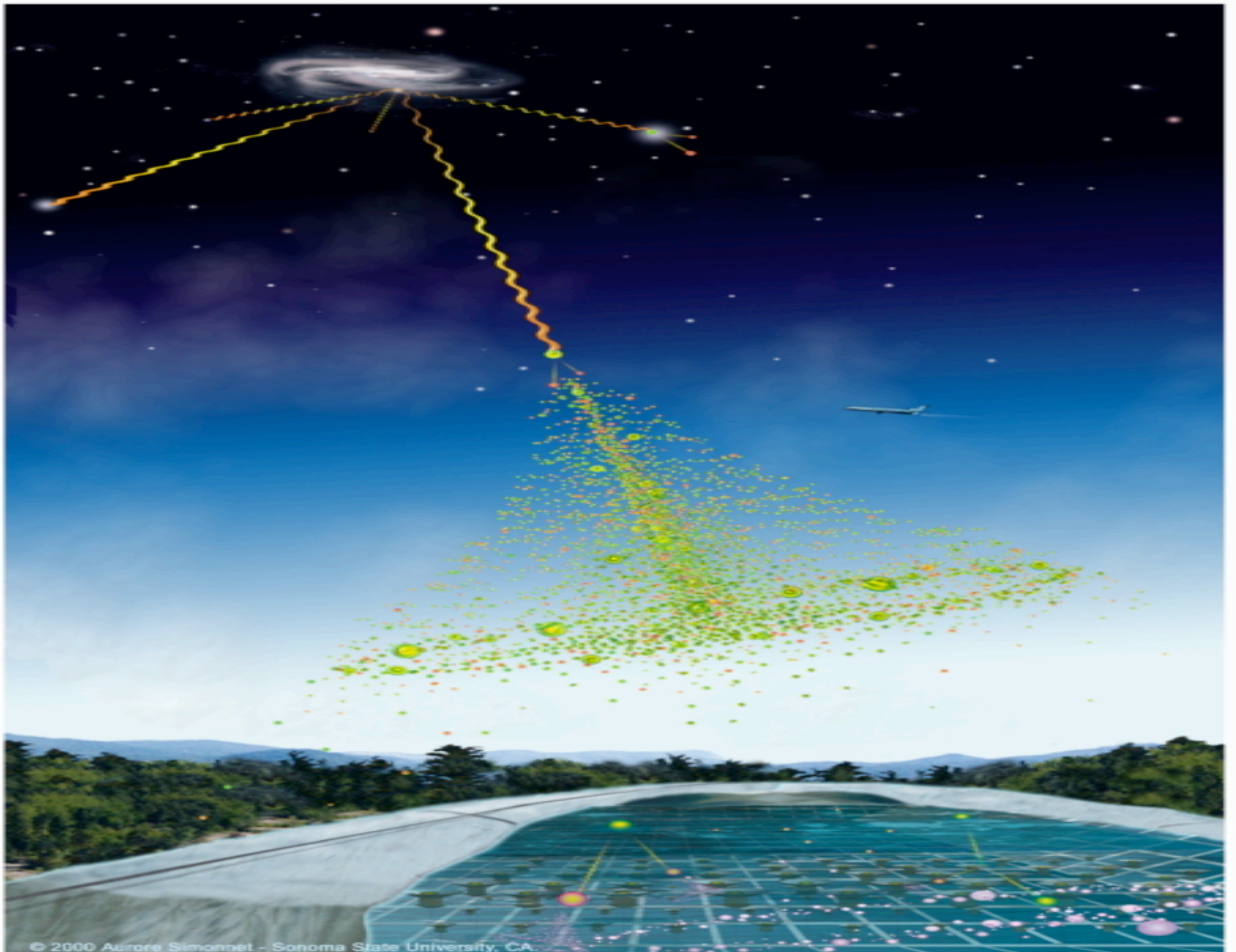
## EAS Arrays

Milagro/Tibet/ARGO/HAWC



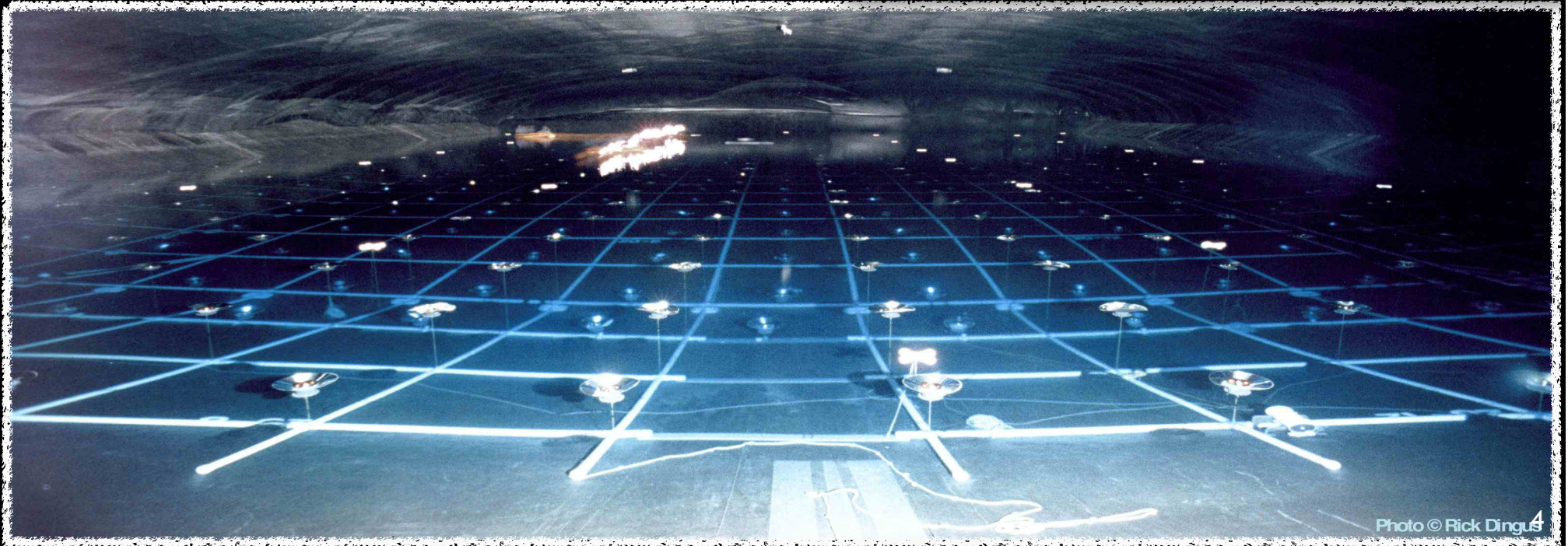
100 GeV - 100 TeV

Large Exposure to Entire Sky  
Good background rejection  
Large Aperture & Duty Cycle



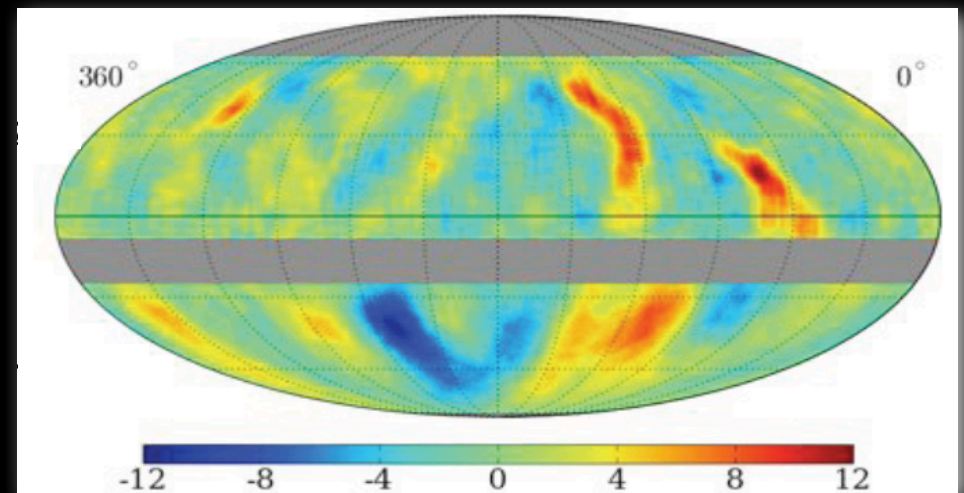
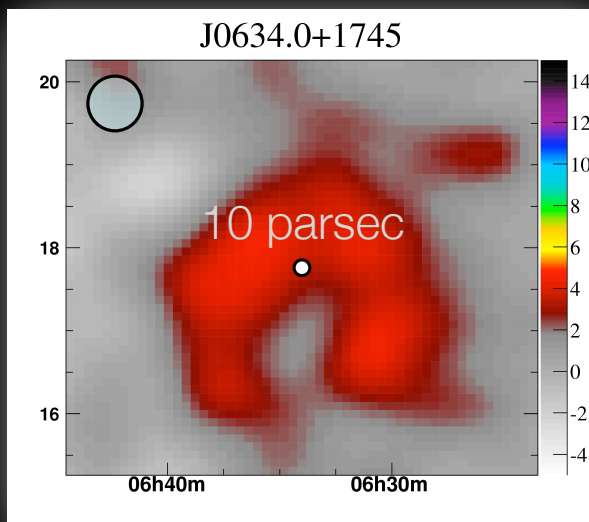
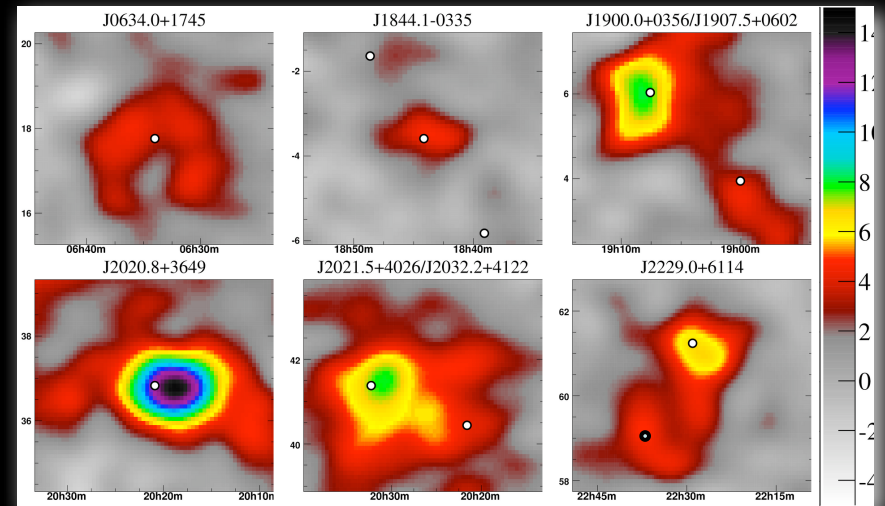
# Milagro

- 2600m asl
- 5000 m<sup>2</sup> reservoir
- 2000 m<sup>2</sup> muon detector
- 40,000 m<sup>2</sup> outrigger array
- 1700 Hz trigger rate
- 2-40 TeV median energy



# Milagro Key Discoveries

- Galactic diffuse emission @20 TeV
- Galactic GeV-TeV correlation (PWN)
- Cosmic-ray anisotropy
- Geminga (potential explanation of positron excess)



# The HAWC Observatory

- Sierra Negra, Mexico (19° north, 97° west)
- Higher elevation (4100m)
- 4x Larger dense sampling region (~22,000m<sup>2</sup>)
- 10x Larger muon detection area (~22,000m<sup>2</sup>)
- Optical isolation of detector elements
- ~10-15x more sensitive than Milagro





# HAWC Collaboration



Los Alamos National Laboratory  
University of Utah  
George Mason University  
University of New Mexico  
Georgia Institute of Technology  
UC Santa Cruz

University of Maryland  
Univ. of California, Irvine  
University of New Hampshire  
Michigan Technological University  
University of Alabama

University of Wisconsin  
Michigan State University  
Penn State University  
NASA/Goddard  
Colorado State University

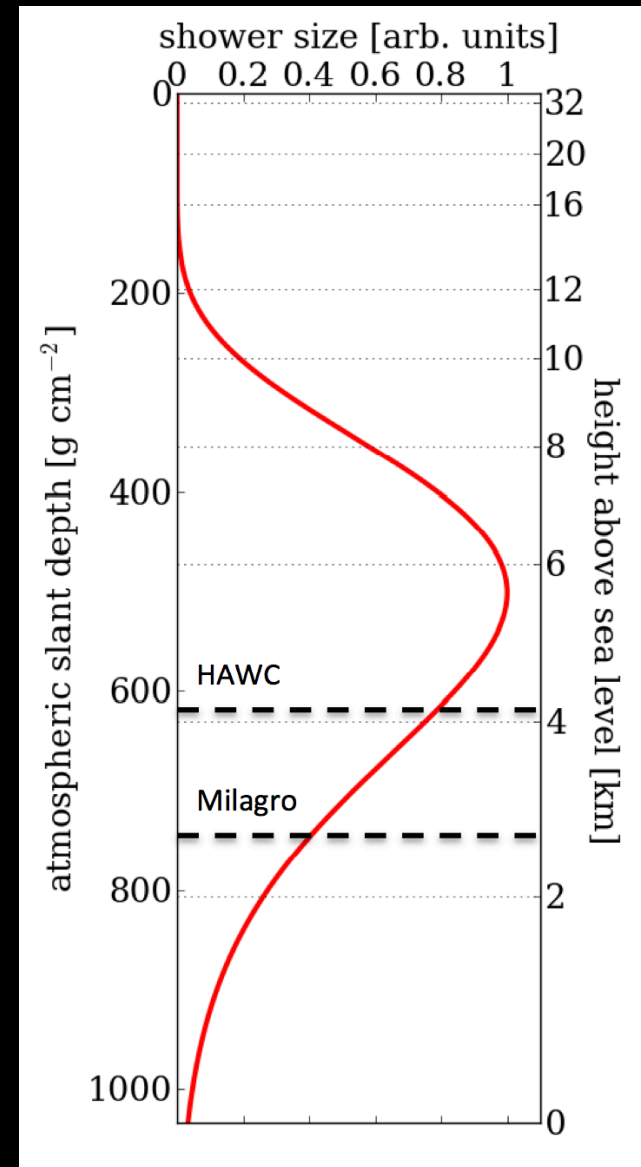
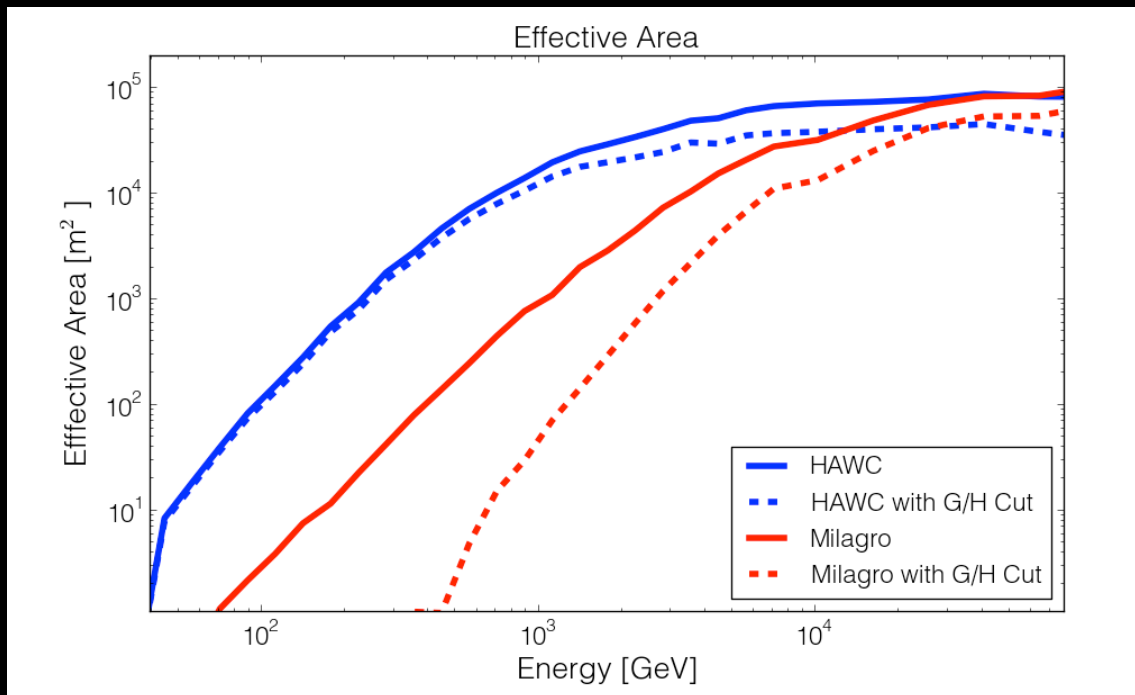
Instituto Nacional de Astrofísica Óptica y Electrónica (INAOE)  
Universidad Nacional Autónoma de México (UNAM)  
Benemérita Universidad Autónoma  
Universidad Autónoma de Chiapas  
Universidad Autónoma del Estado de Hidalgo  
Universidad de Guadalajara  
Universidad Michoacana de San Nicolás de Hidalgo  
Centro de Investigación y de Estudios Avanzados  
Universidad de Guanajuato



HAWC Meeting  
September 23-25, 2013  
Michigan Technological University  
Houghton, Michigan

# HAWC Improvements

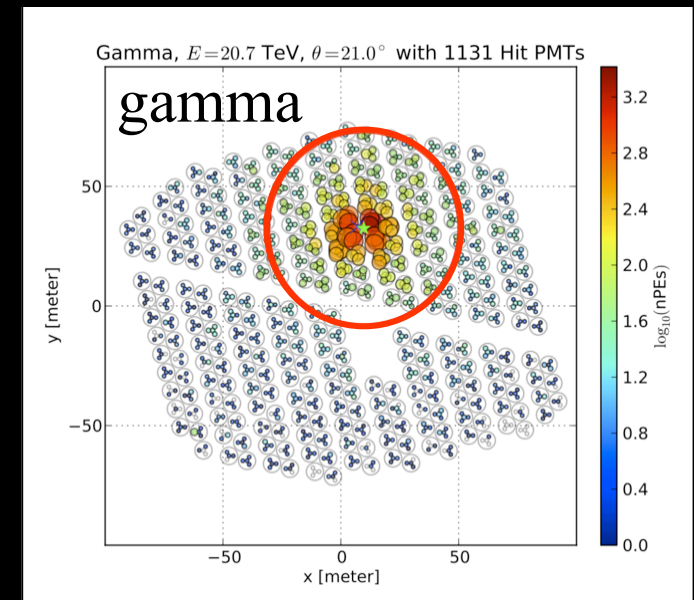
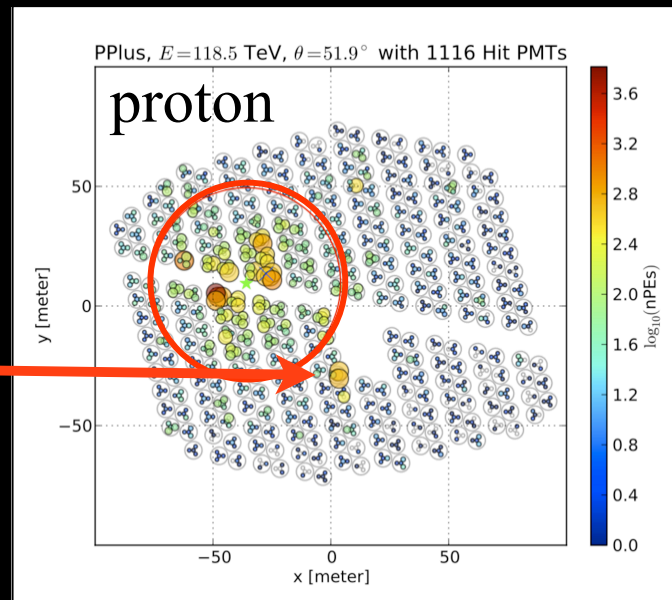
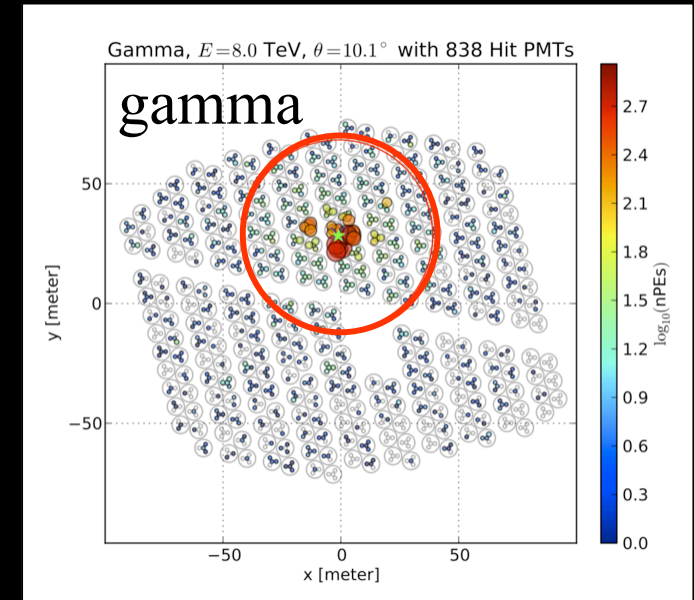
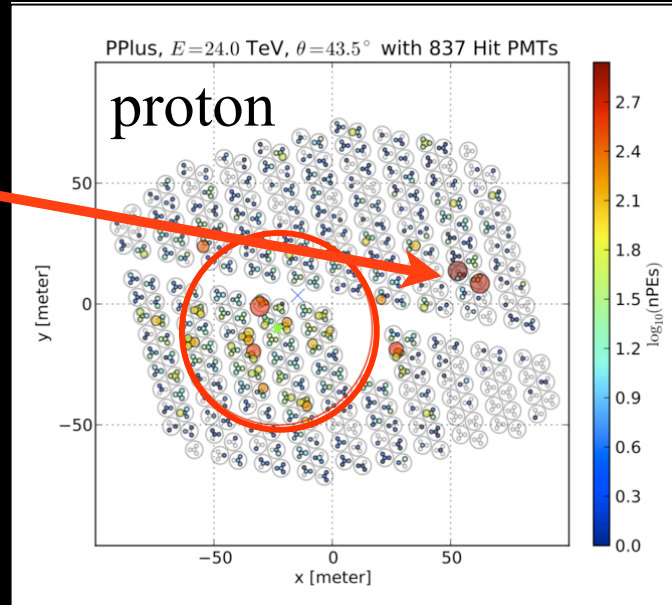
- High altitude 4100m asl
- Large, 22,000 m<sup>2</sup> muon detector
- Optical isolation



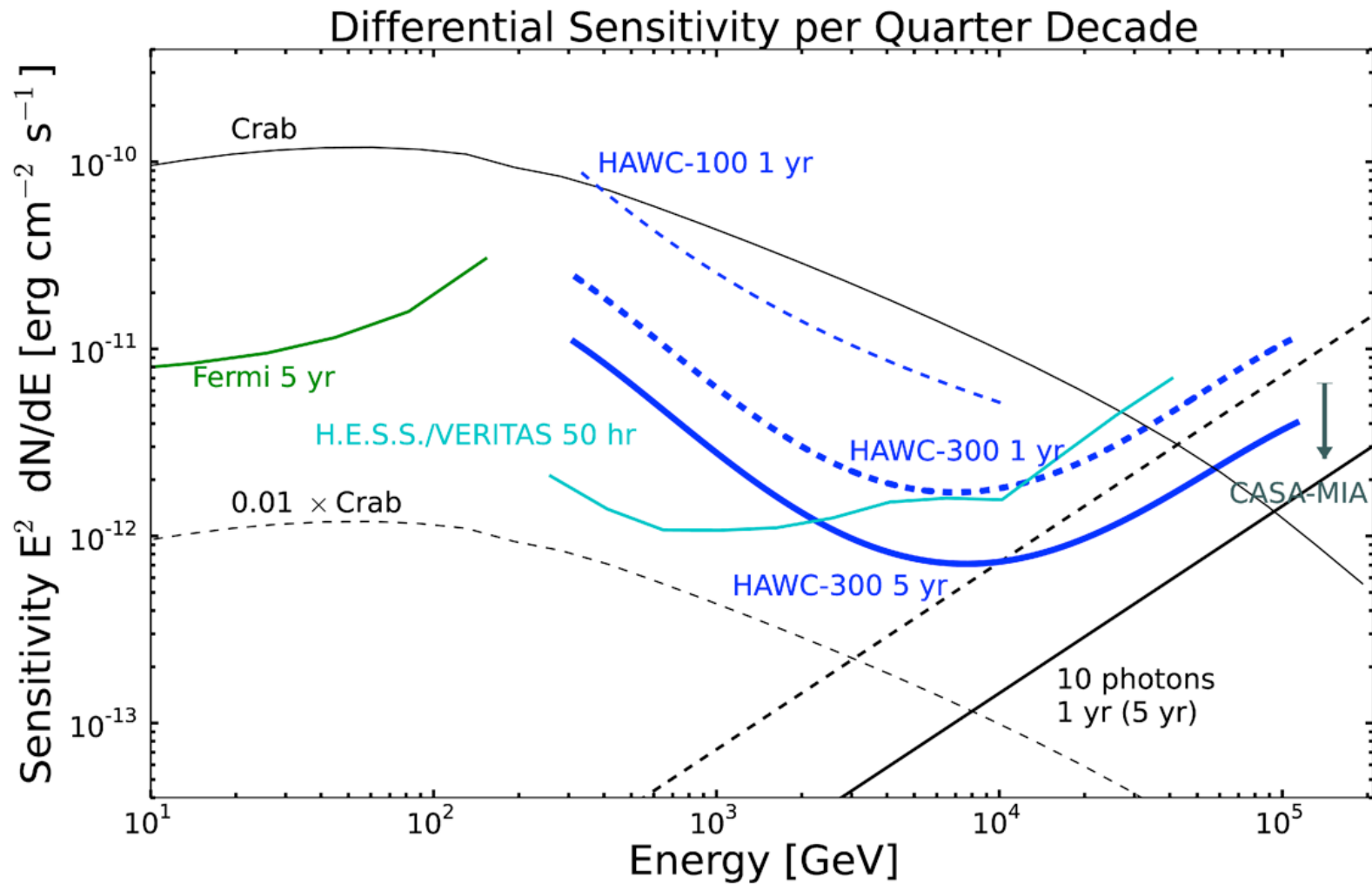


# Background Rejection

Hadronic signature  
Large amplitude >40m from core



# HAWC Sensitivity



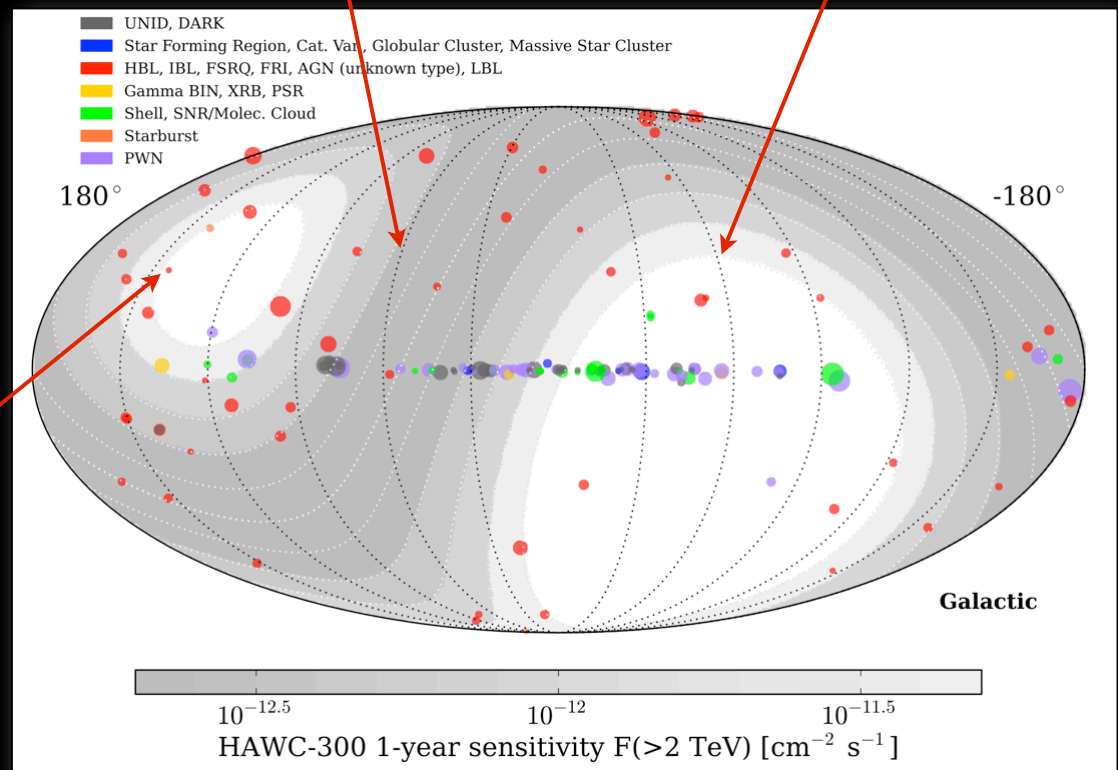
# HAWC Sky Coverage

- Simultaneous sky with VERITAS
- Same sky viewed by IceCube
- Crab Nebula overhead
- Galactic Center visible (~45° transit)
- View 8 sr of sky every day

Declination 75°

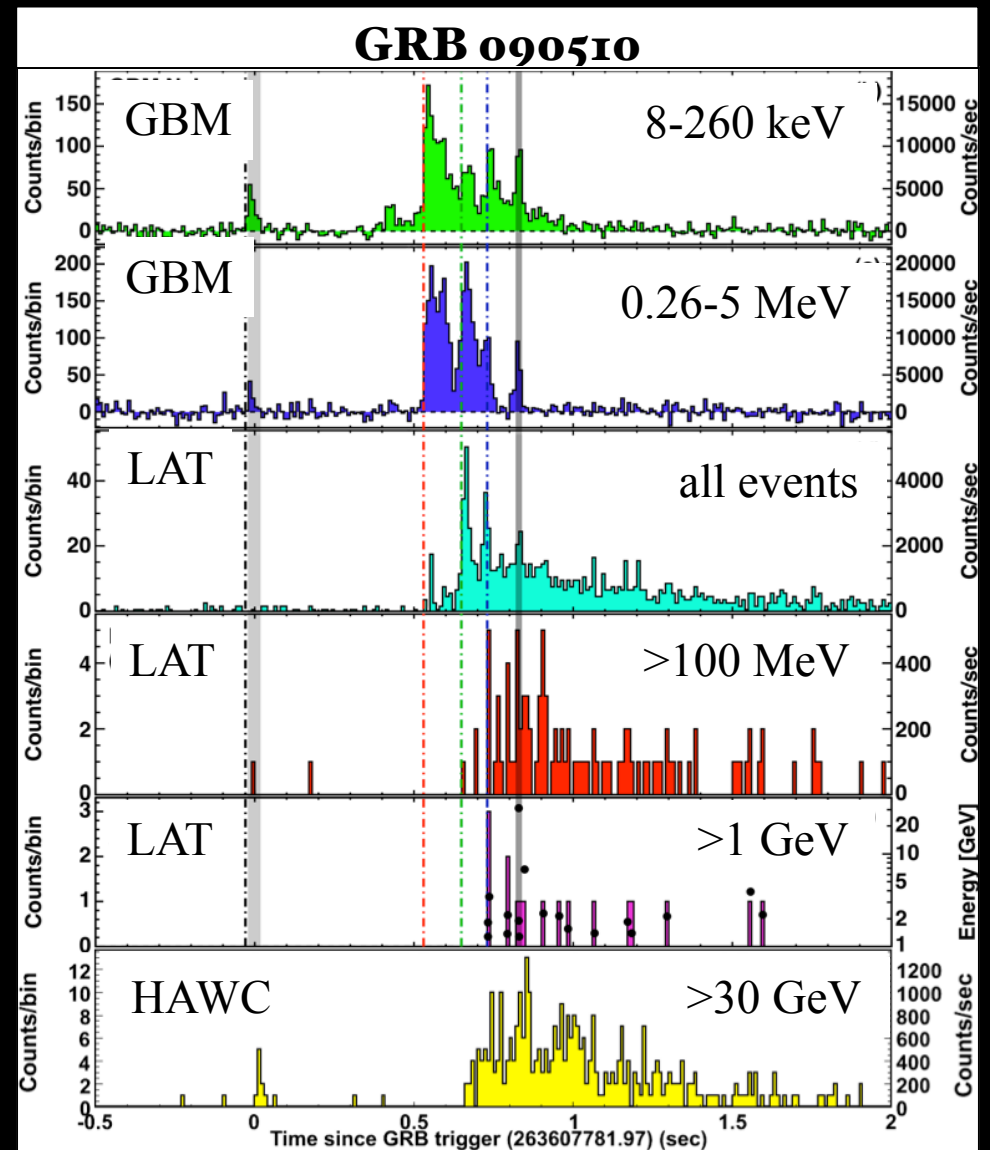
5% of Crab sensitivity

45° zenith transit



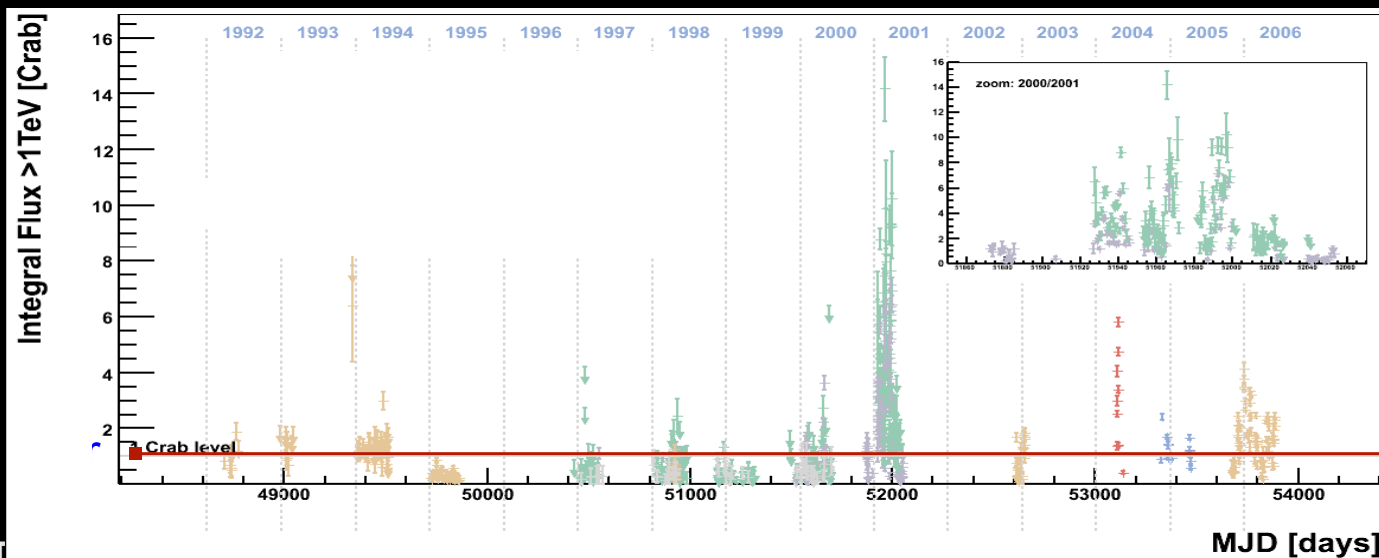
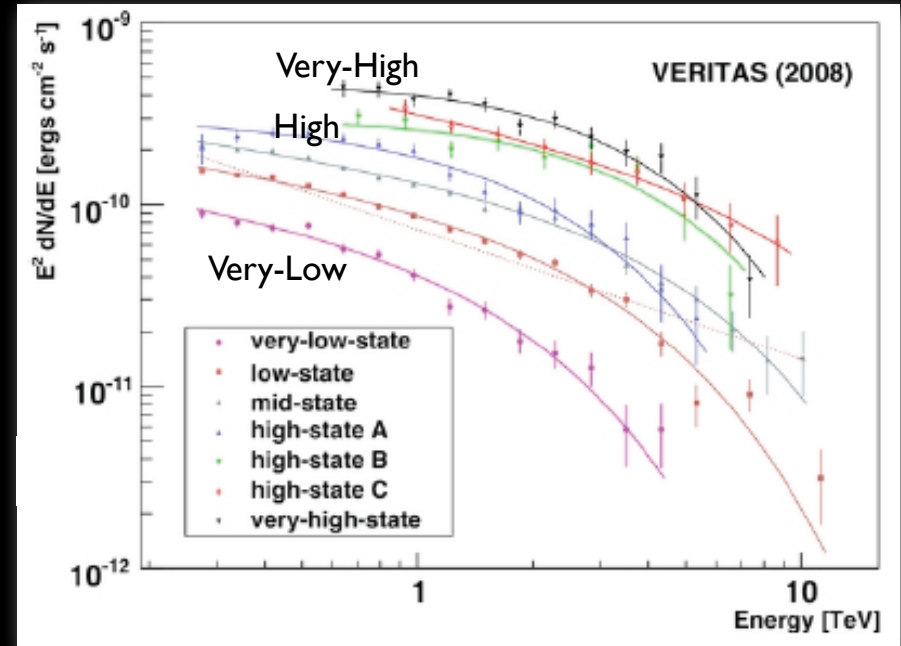
# Gamma-Ray Bursts

- Fermi observation of GRB 090510 ( $z = 0.9$ )
- Simulated HAWC light curve assuming extension of spectrum with LAT index
  - EBL absorption included
- $\sim 200$  events expected above 30 GeV
- Detection ( $5\sigma$ ) by HAWC if emission cuts off at 50 GeV
- HAWC more sensitive than LAT above 10 GeV for short GRBs
- Expect  $\sim 1.5$  GRB/yr in HAWC (Taboada & Gilmore arXiv:1306.1127)



# Active Galaxies

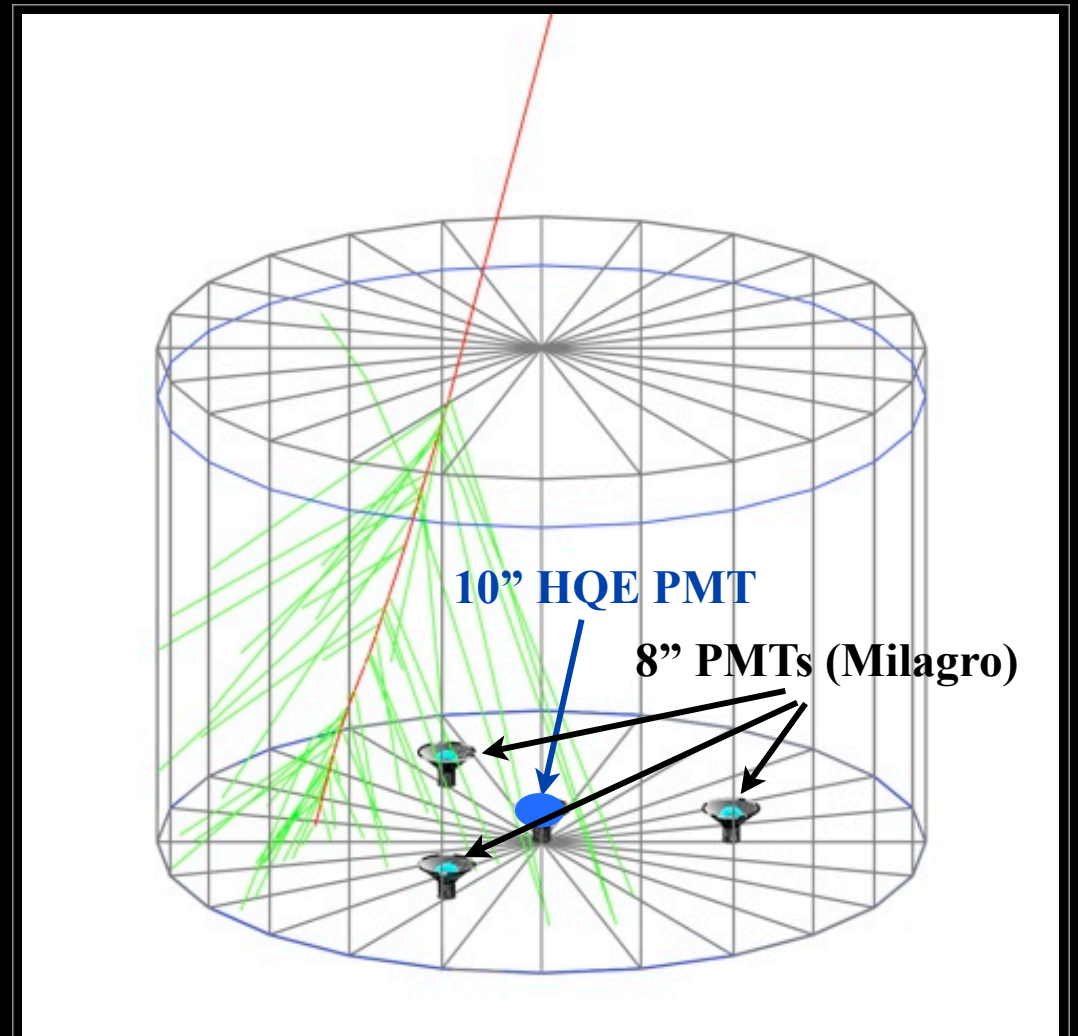
- >50 AGN detected at TeV energies
- >1000 AGN detected by Fermi-LAT
- HAWC will observe 8 sr of the sky every day
- Mrk-421 detectable:
  - “very-high-state” in 30 minutes ( $8\sigma$ )
  - “high state” 1 day
  - “very-low-state” 1 month



HAWC 1-day  
sensitivity

# HAWC Design

- 300 steel tanks
- 4 PMTs/tank
- No hardware trigger
  - all hits readout
  - software trigger
  - ~500 MBytes/sec
- Retain all data for 24 hrs (40 TBytes)
- Reconstructed data ~600 TBytes/yr



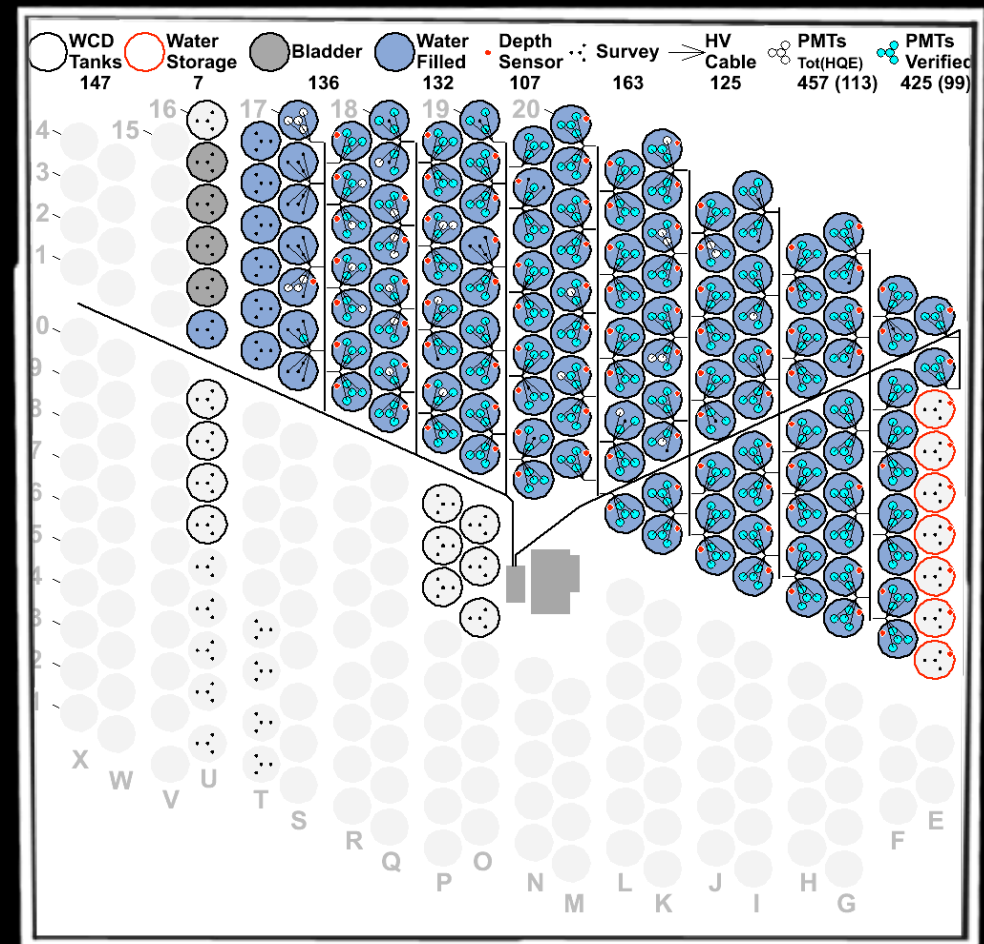
October 20, 2013



# Construction Status

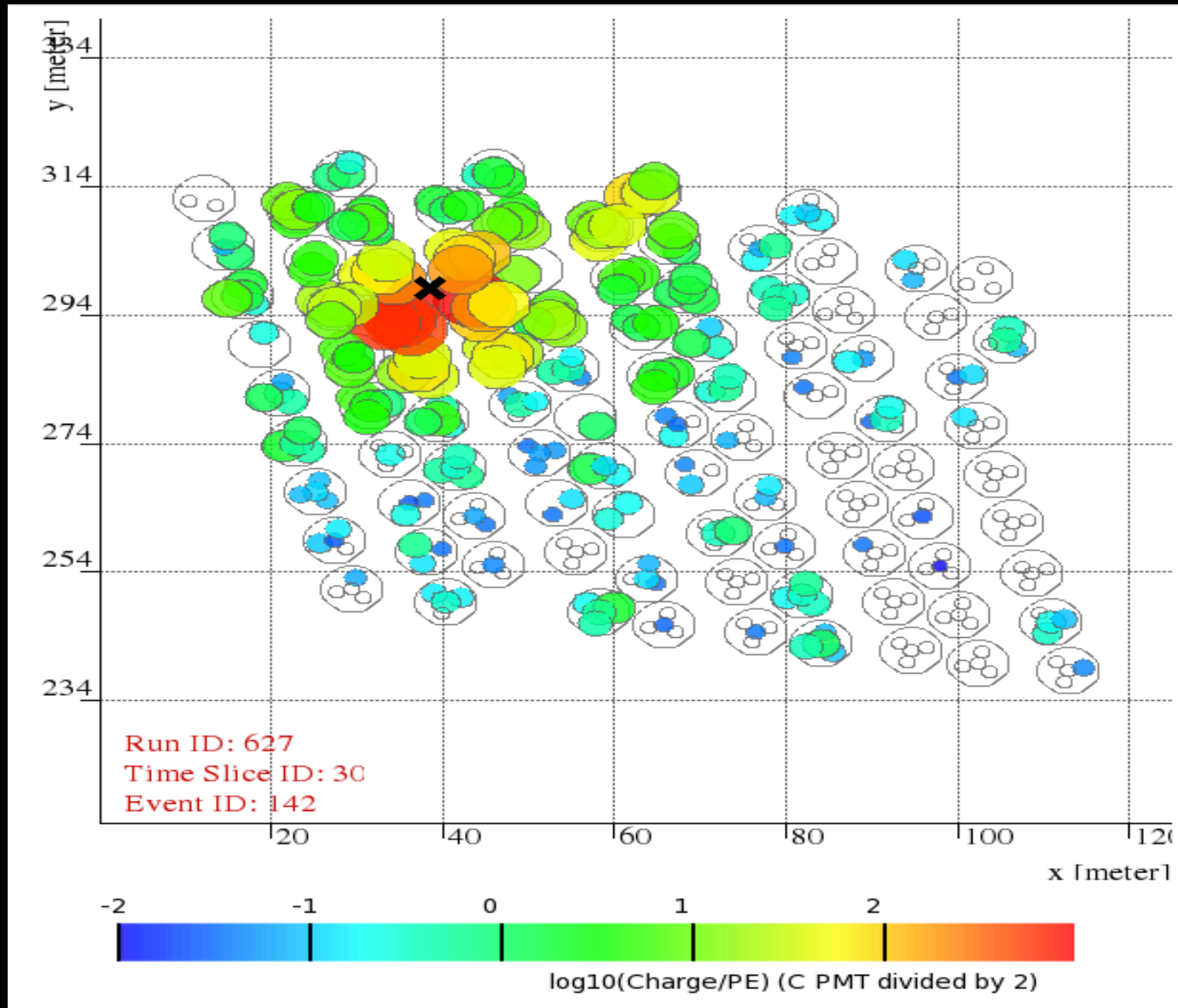
October 20, 2013

- 146 tanks completed
- 132 with purified water
- 457 PMTs installed
  - 114 tanks
- Operations of HAWC-III began August 1, 2013
- HAWC complete August 2014



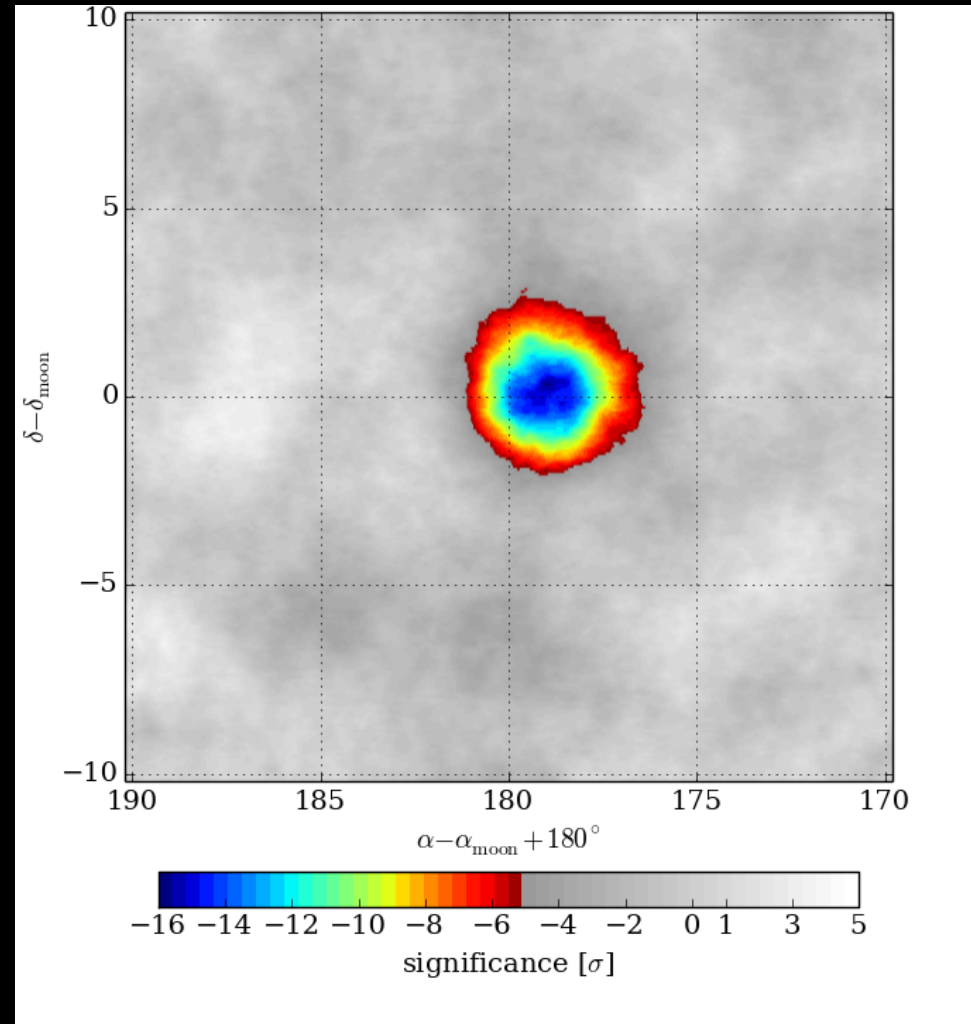
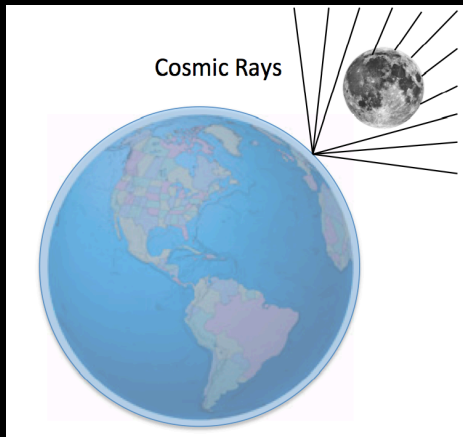


# HAWC Event

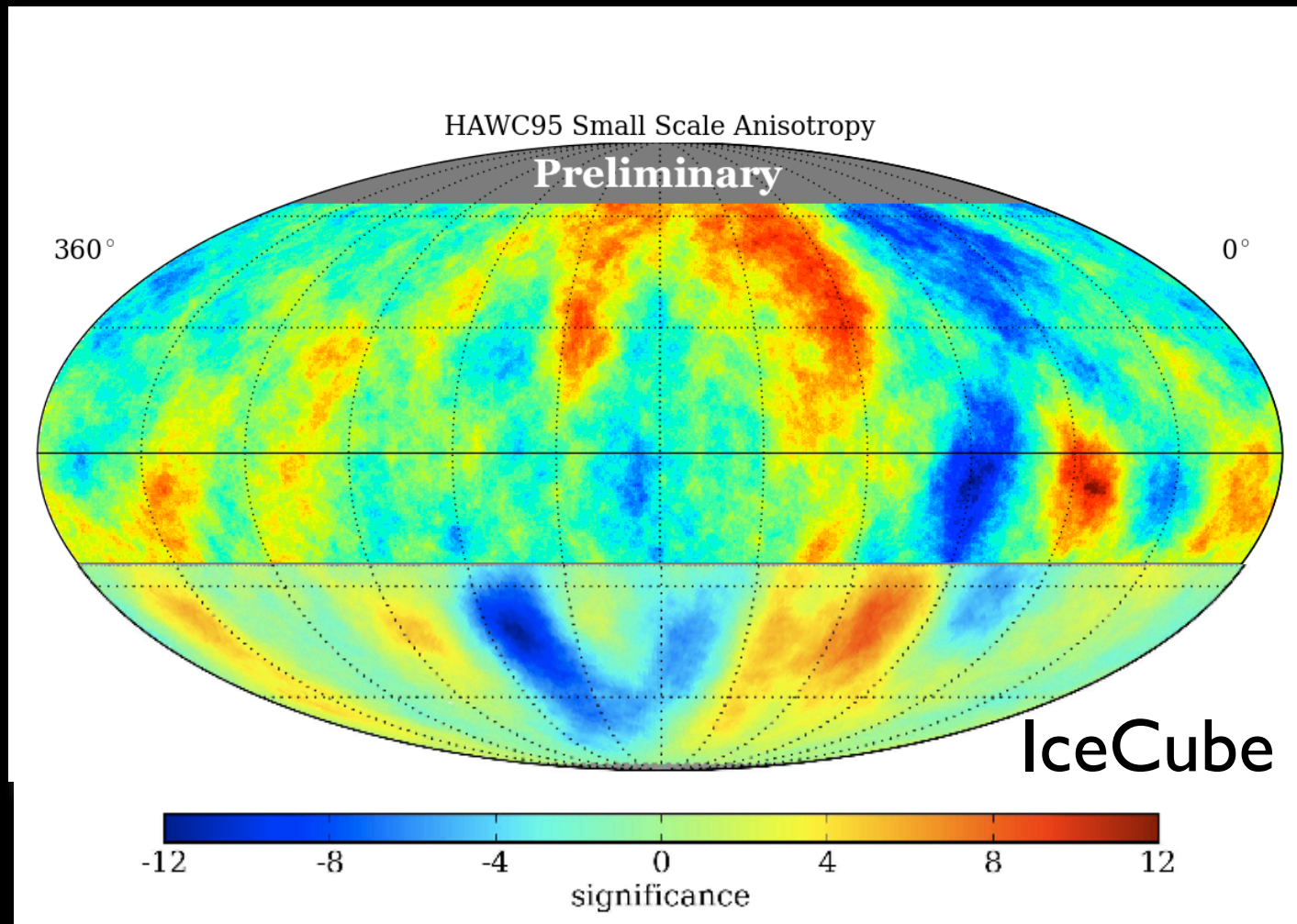


# Moon Shadow

- HAWC-95 data
  - 52 days
  - 18 billion events
- $E_{\text{med}} \sim 1.6 \text{ TeV}$  (protons)
- Deflection in RA
  - Expect  $1^\circ$  for 1.6 TeV proton
  - Observe  $1.04^\circ \pm 0.11^\circ$
- Width RA =  $1.39 \pm 0.12$
- Width Dec =  $1.36 \pm 0.13$

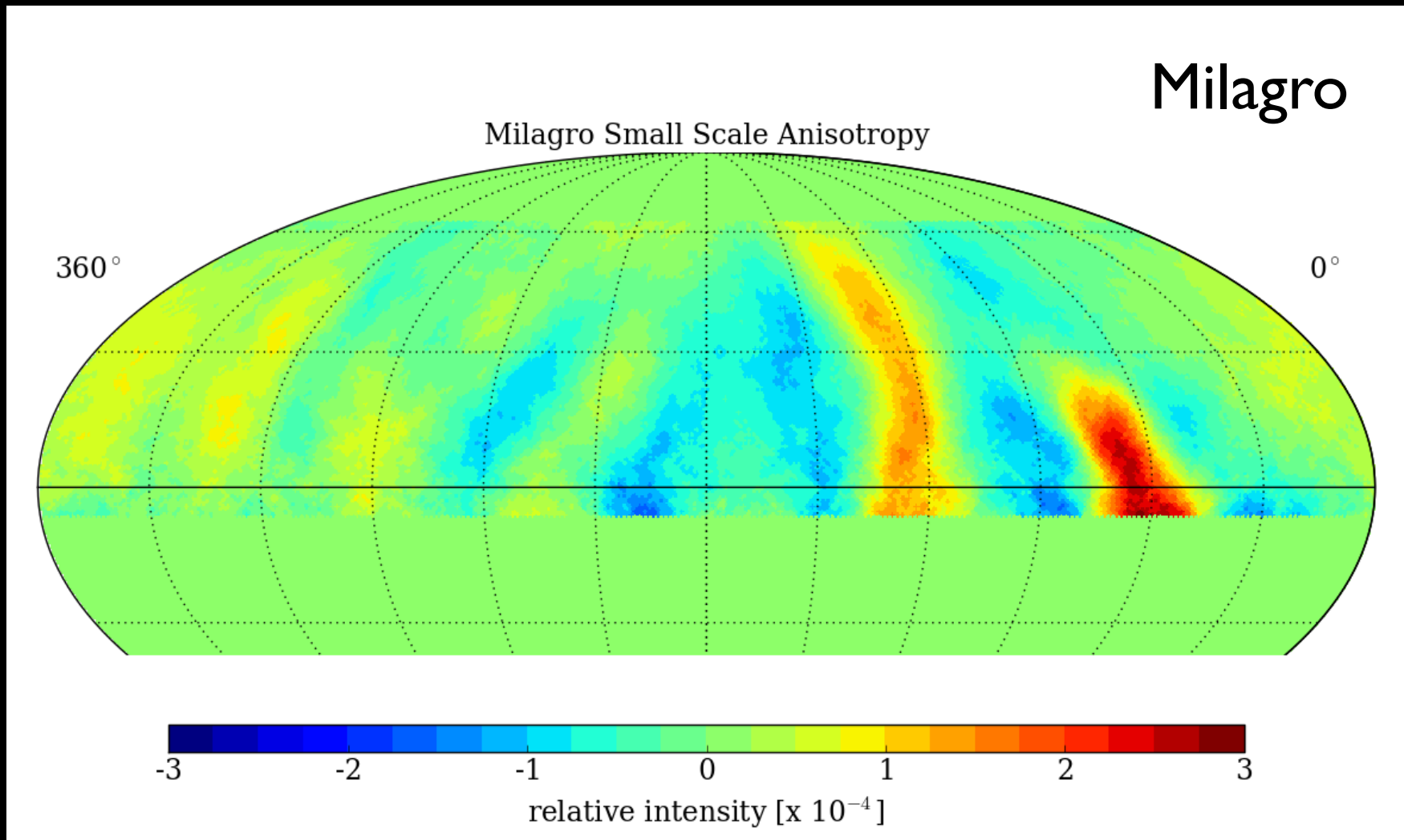


# Cosmic Ray Anisotropy



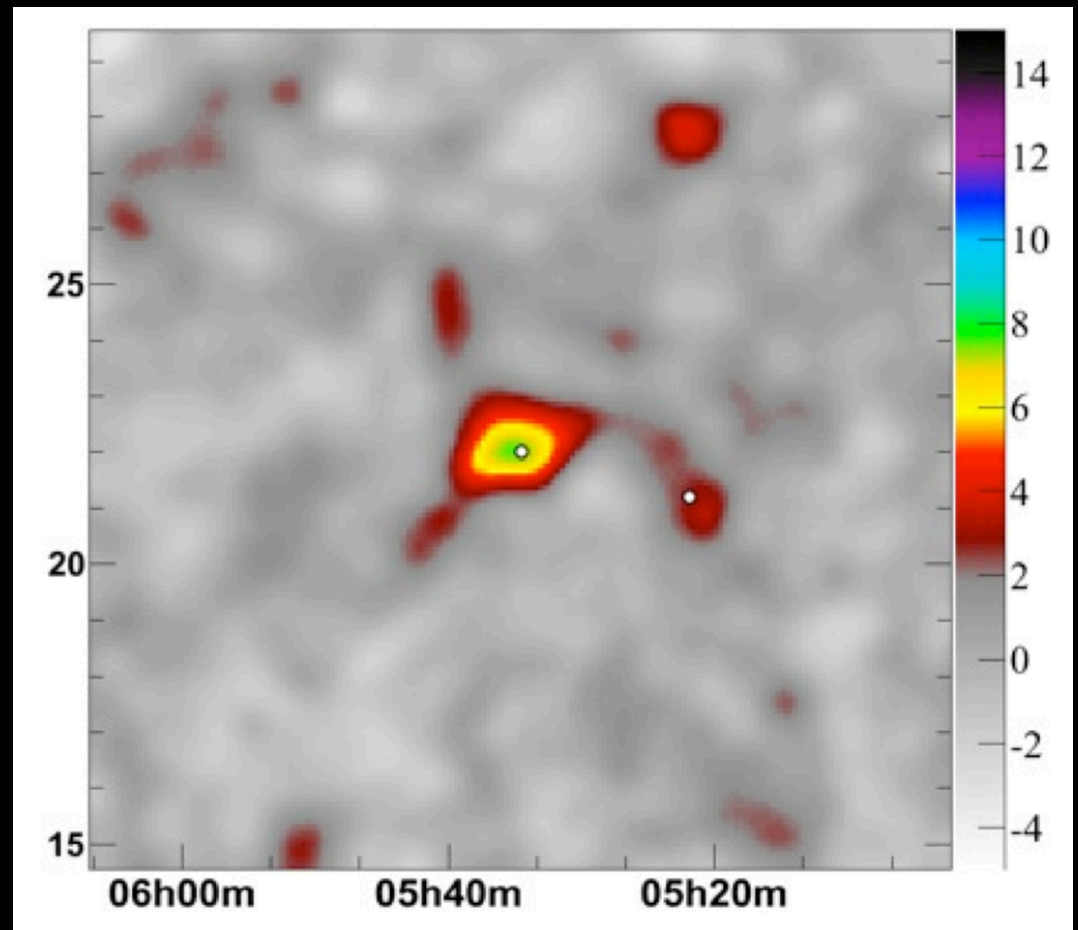
- 17.5 billion events
- $10^\circ$  smoothing scale
- Similar structure to Milagro and ARGO

# Cosmic-Ray Anisotropy



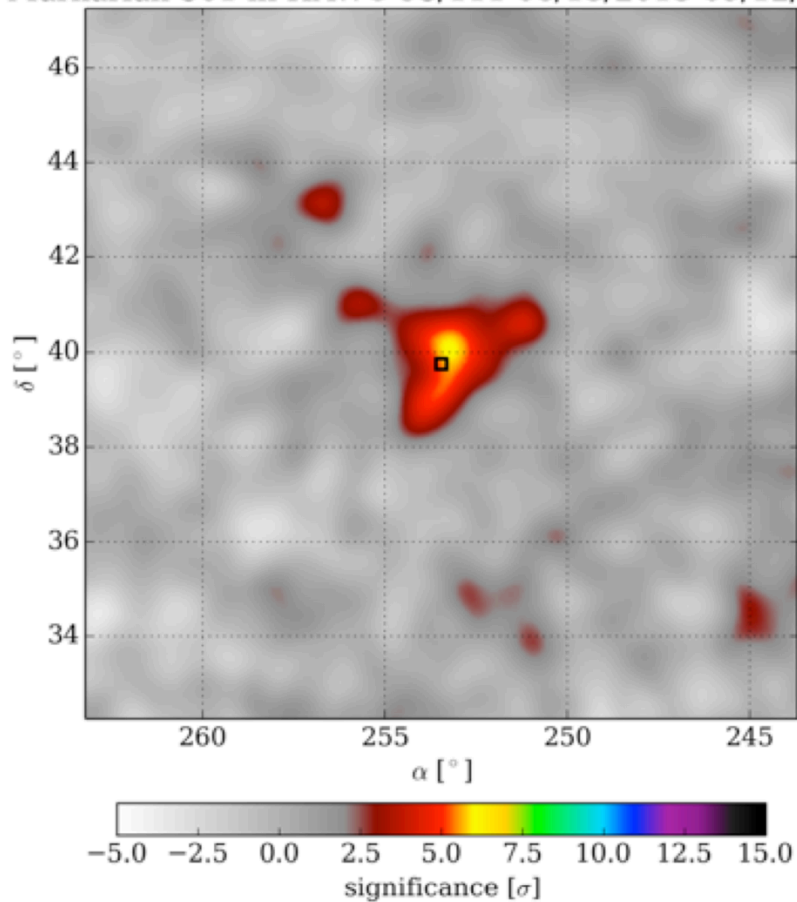
# Crab Nebula

- 43 days HAWC-95
- 29 days of HAWC-III
- Survey not complete
- Calibration not complete
- $7.5\sigma$  at Crab location

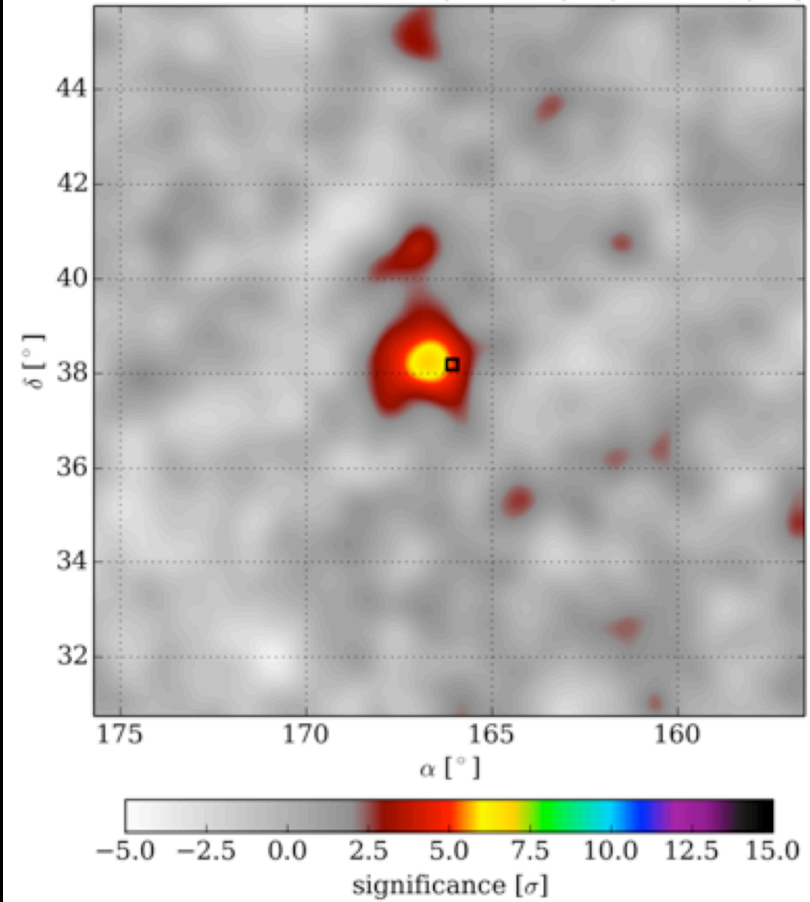


# Mrk 501 and Mrk 421

Markarian 501 in HAWC-95/111 06/13/2013-09/12/2013



Markarian 421 in HAWC-95/111 06/13/2013-09/12/2013



# Summary

- Milagro has demonstrated the capability of the water Cherenkov technique
- HAWC will survey 8 sr of the sky with  $\sim 50$  mCrab sensitivity at 1 TeV
- HAWC will have excellent sensitivity to AGN flares
- HAWC will discover many Galactic objects
- HAWC-III is complete and operational (August 1, 2013)
- HAWC-III data looks excellent
  - substantially better sensitivity than Milagro
- Full HAWC complete August 2014