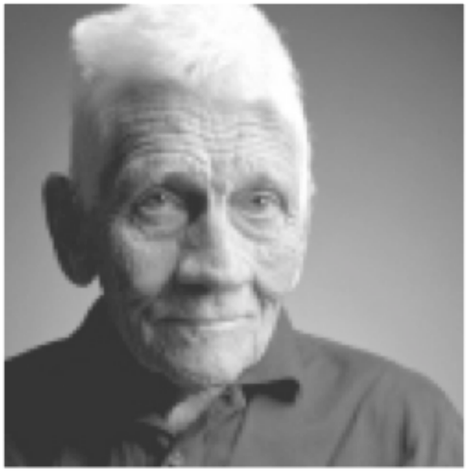

HAWC
HAWC
A Next-Generation Water-Cherenkov
Air Shower Observatory
J. Goodman – IPA 2013 Madison

Darragh Nagle
1919 -2013



- A long history of scientific success
- He was with Enrico Fermi for the first reactor at Stagg Field and at the Trinity Site for the first nuclear explosion
- We was a co-discoverer of the pion
- He was instrumental in the design of the LAMPF accelerator.
- He started the CYGNUS array at Los Alamos and was the major force behind Milagro.
- He had the idea of using the geothermal reservoir at Fenton Hill to build Milagro.
- We dedicated Milagro to Darragh in our inauguration ceremony for the experiment.

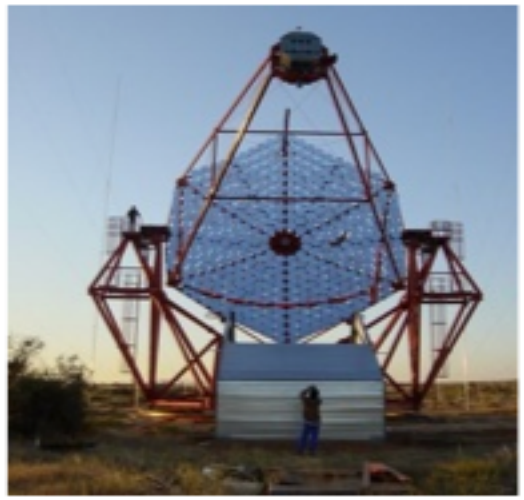
Comparison of Gamma-Ray Detectors

Low Energy Threshold
Fermi

Space-based (Small Area)
"Background Free"
Large Duty Cycle/Large Aperture

Sky Survey (< 300 GeV)
AGN Physics
Transients (GRBs) < 100 GeV

High Sensitivity
HESS, MAGIC, VERITAS, CTA



Large Effective Area
Excellent Background Rejection
Low Duty Cycle/Small Aperture

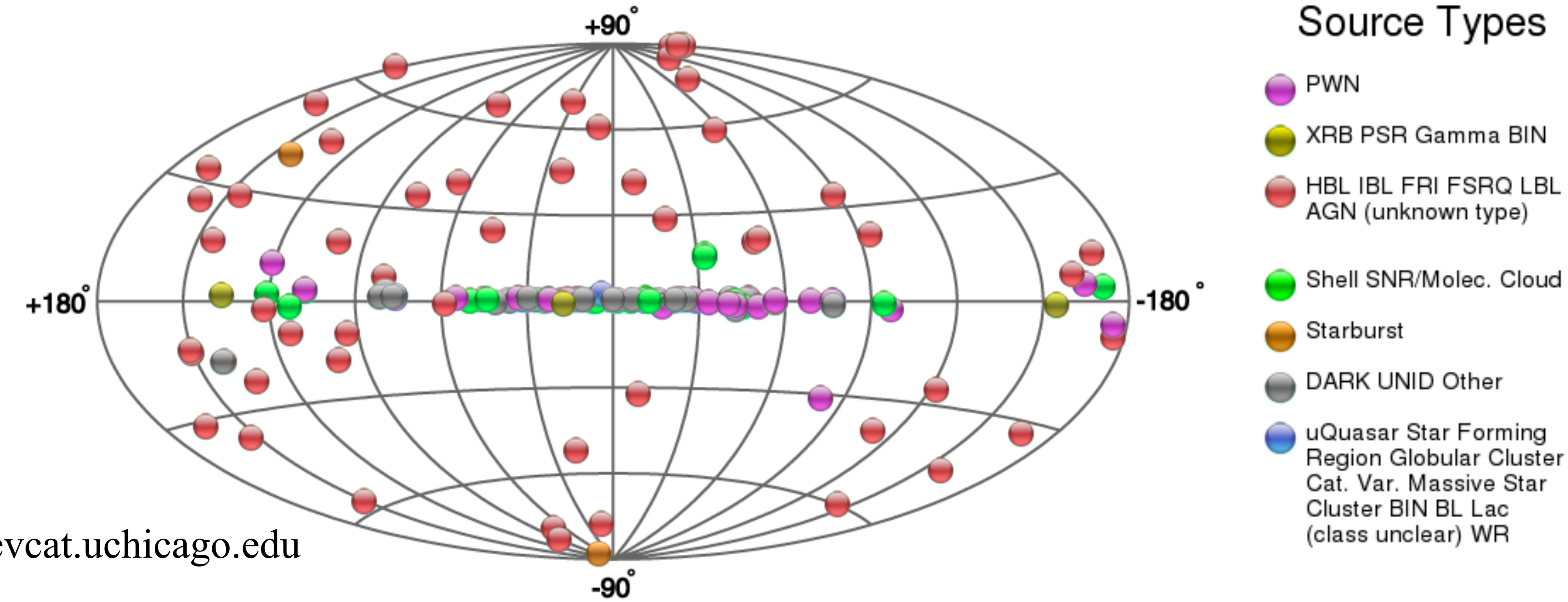
High Resolution Energy Spectra
Studies of known sources
Surveys of limited regions of sky at a time

Large Aperture/High Duty Cycle
Milagro, Tibet, ARGO, HAWC

Moderate Area
Good Background Rejection
Large Duty Cycle/Large Aperture

Unbiased Sky Survey
Extended sources
Transients (GRB's)
Solar physics/space weather

TeV Gamma Ray Sources



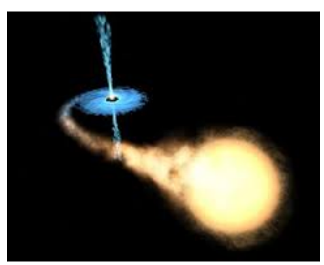
tevcat.uchicago.edu

143 known TeV gamma-ray sources (as of 4/16/2013)

Galactic:

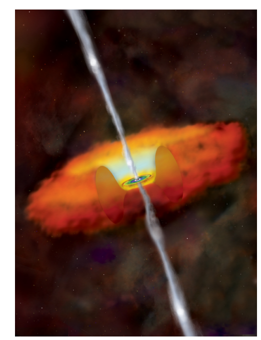
Supernova Remnants

Binary systems



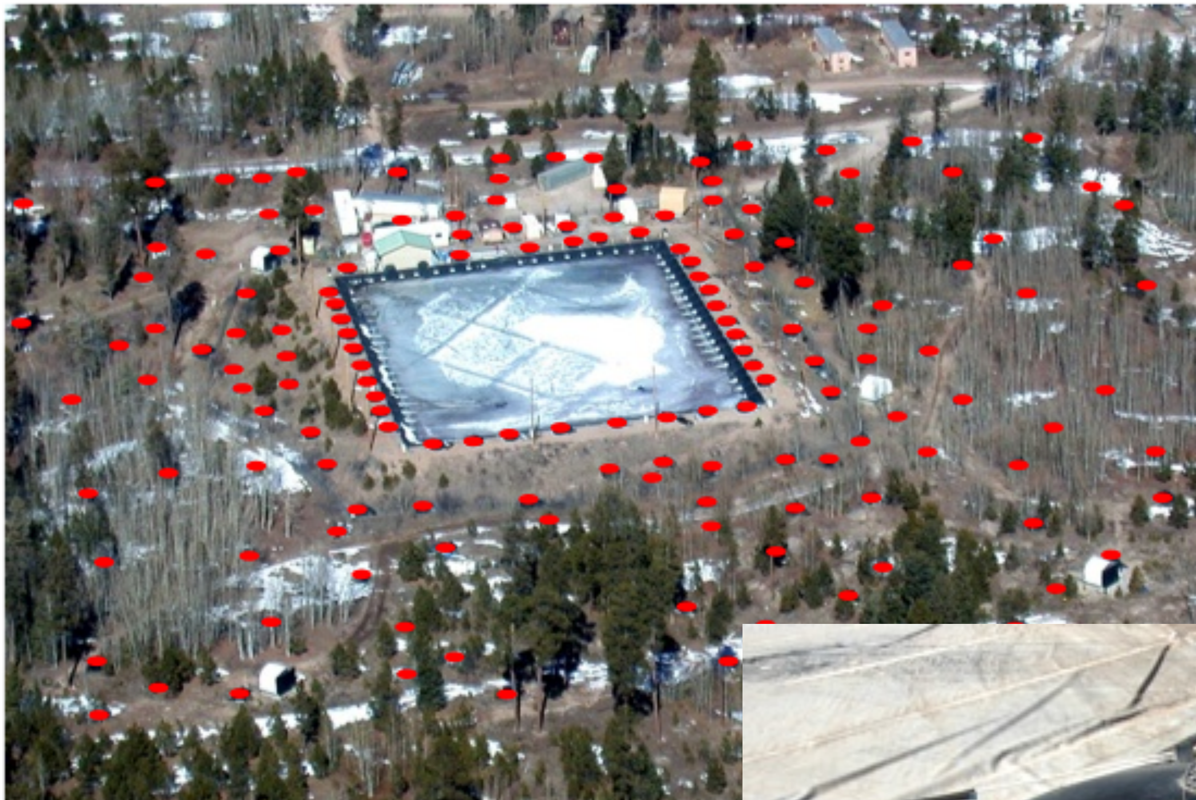
Extragalactic:

AGNs



GRBs (GeV)

Milagro



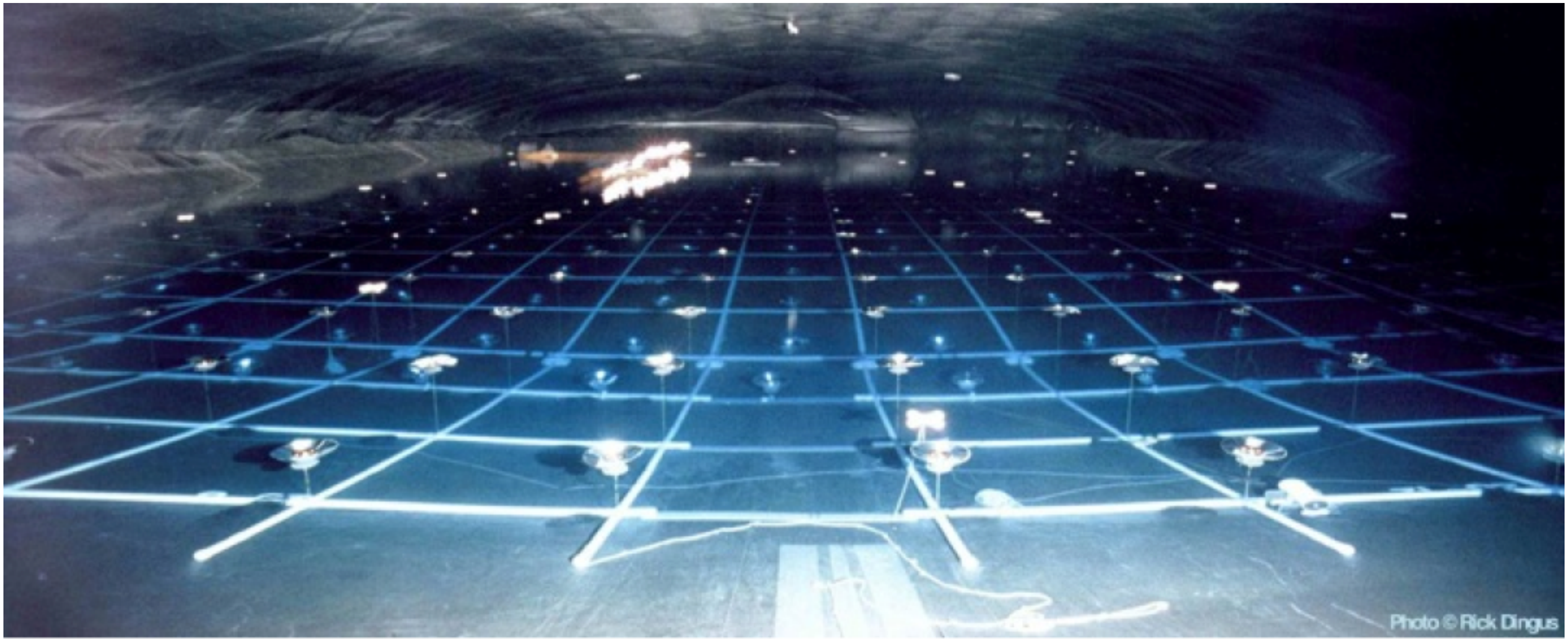
2630 m altitude

Pond: 80 m x 60 m

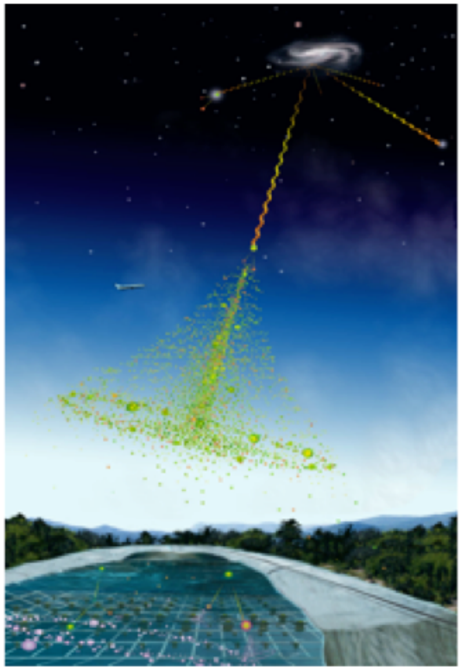
8 m deep

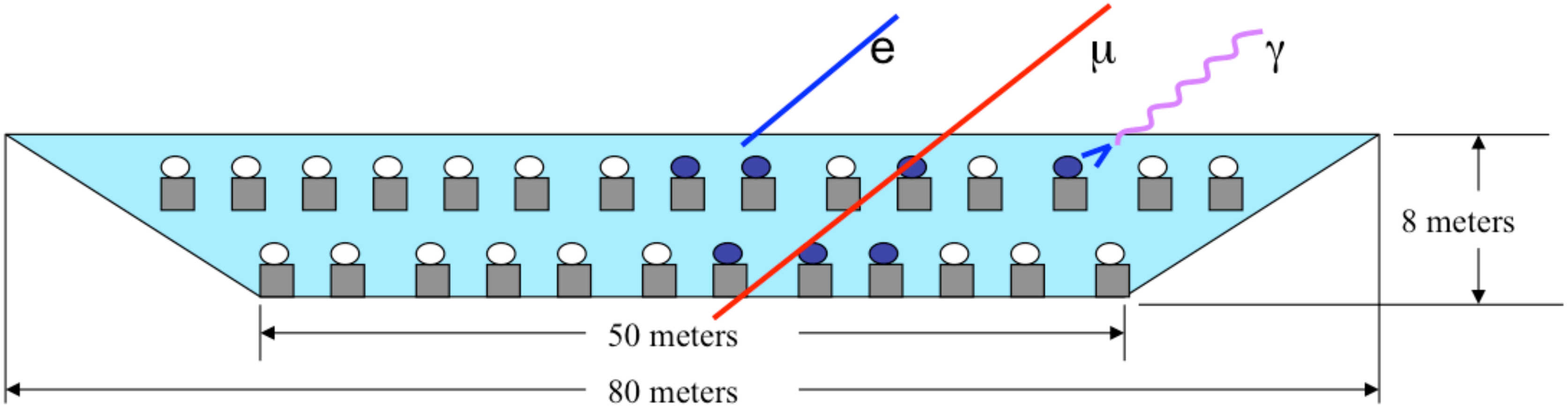
175 outriggers

The Milagro Pond

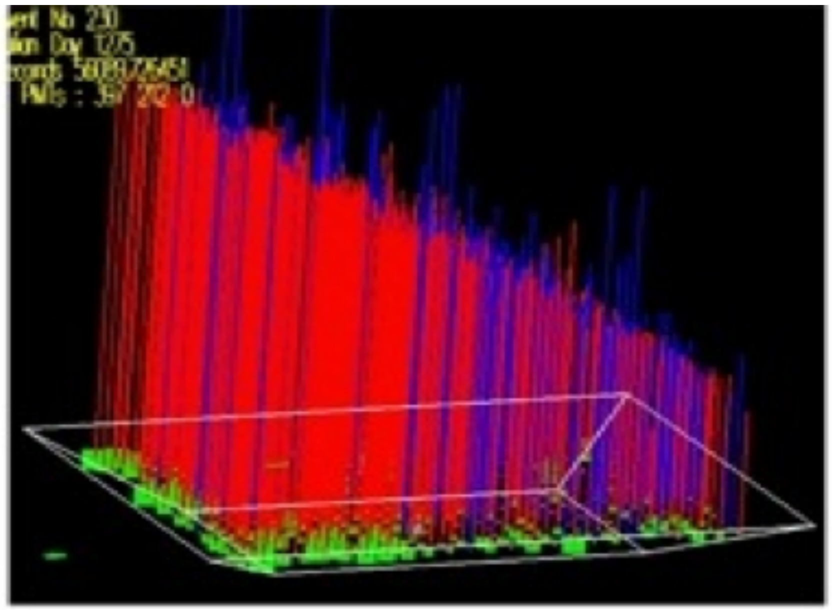


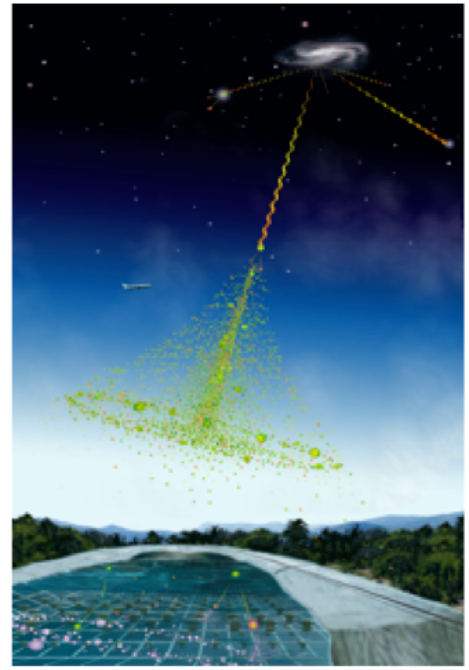
Air Shower Detection

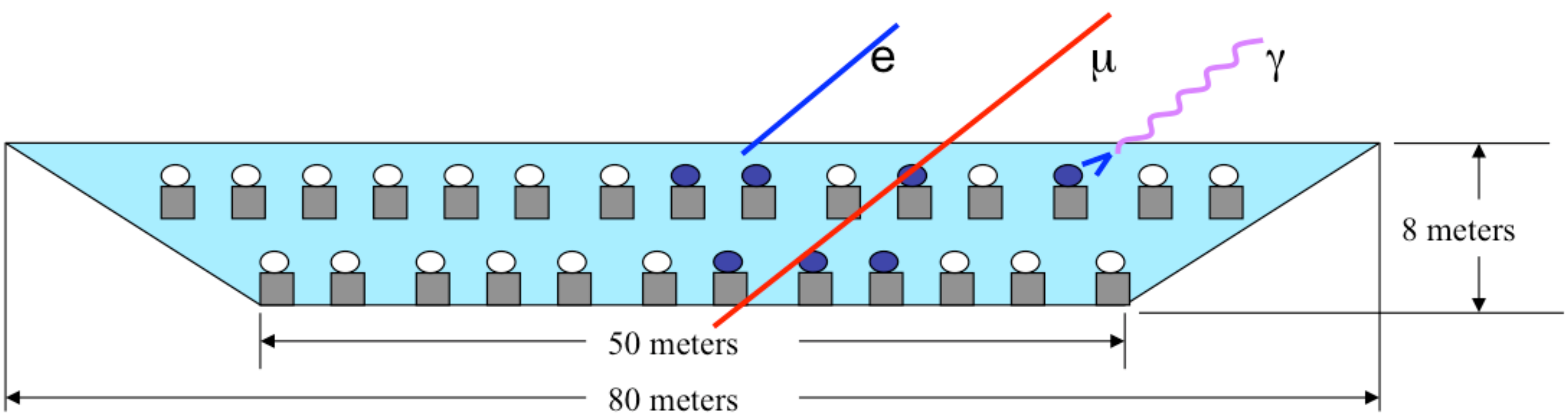




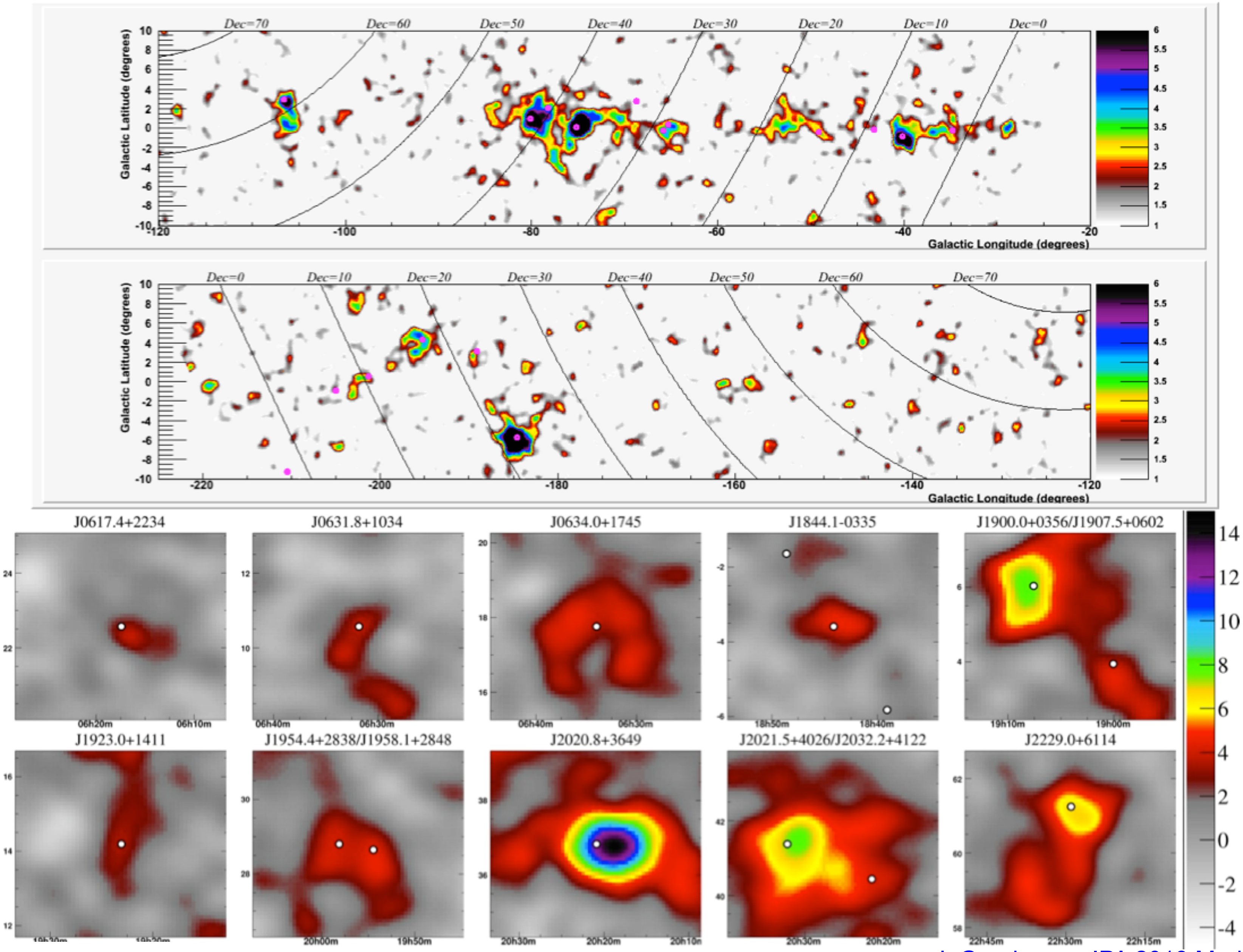
Air Shower Detection







Milagro TeV Sources



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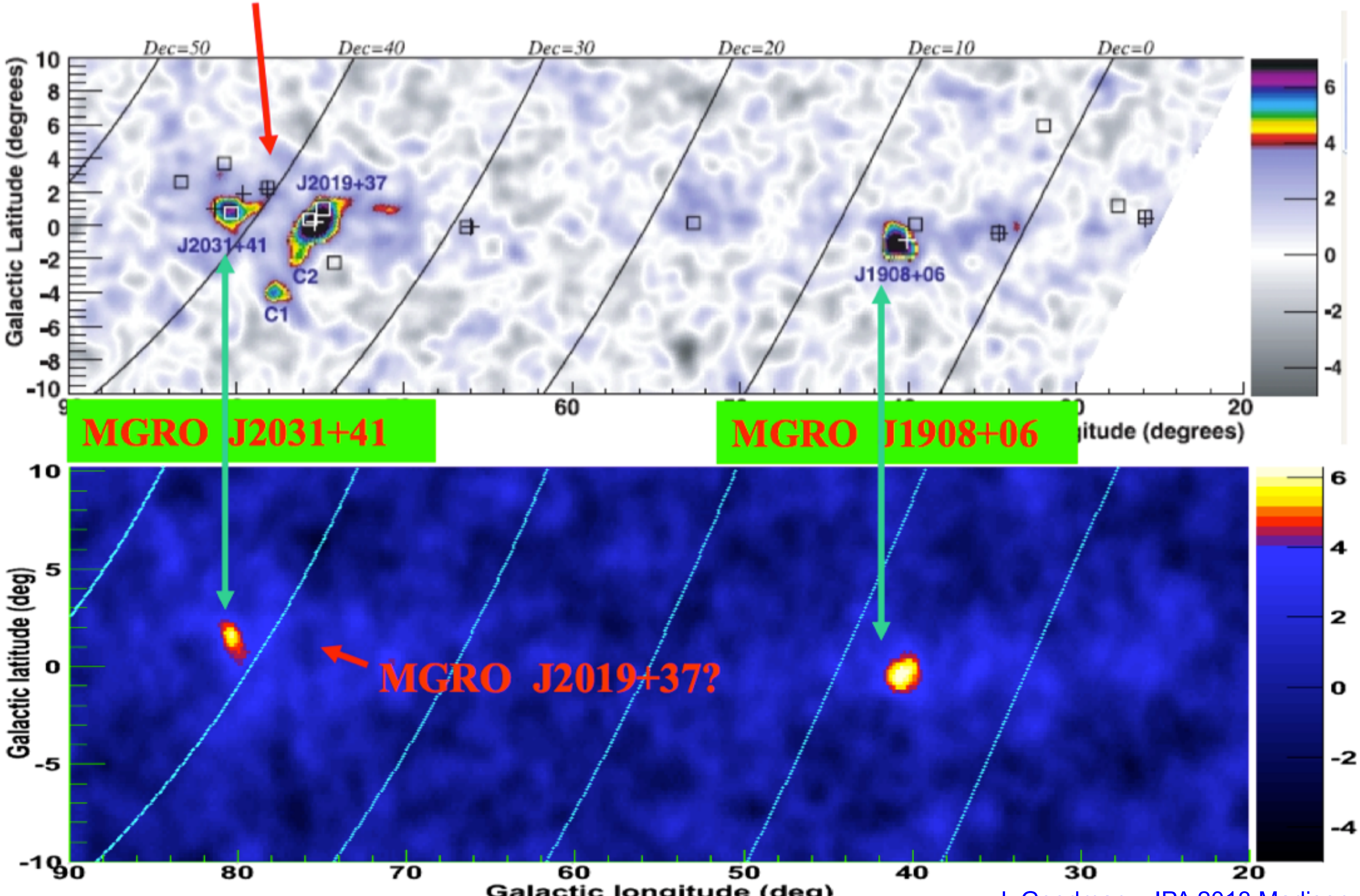
Cygnus region   Milagro and ARGO (Tibet)



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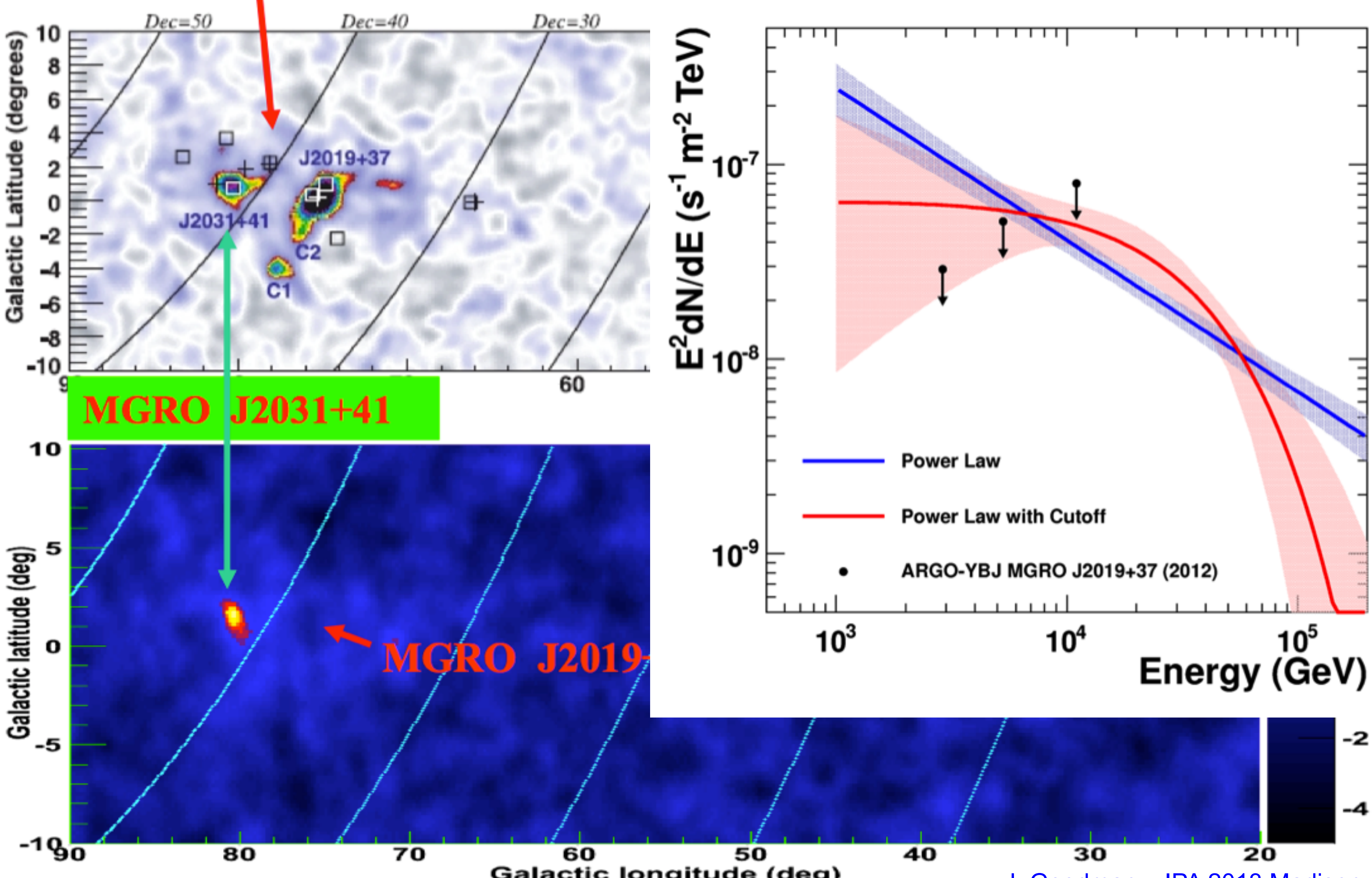
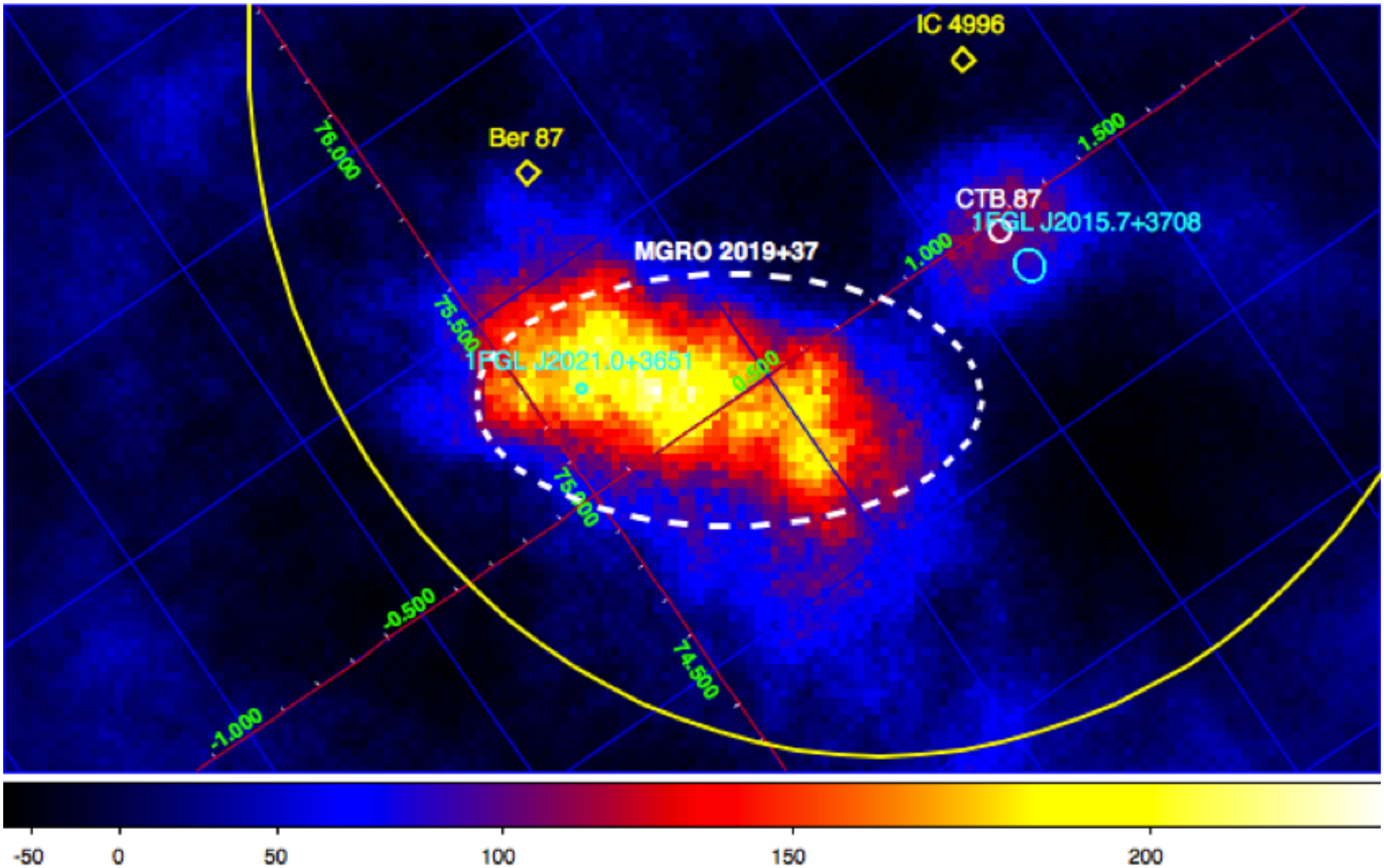
Cygnus region Milagro and ARGO (Tibet)



VERITAS Observation of the Cygnus Region

75 hours on-time



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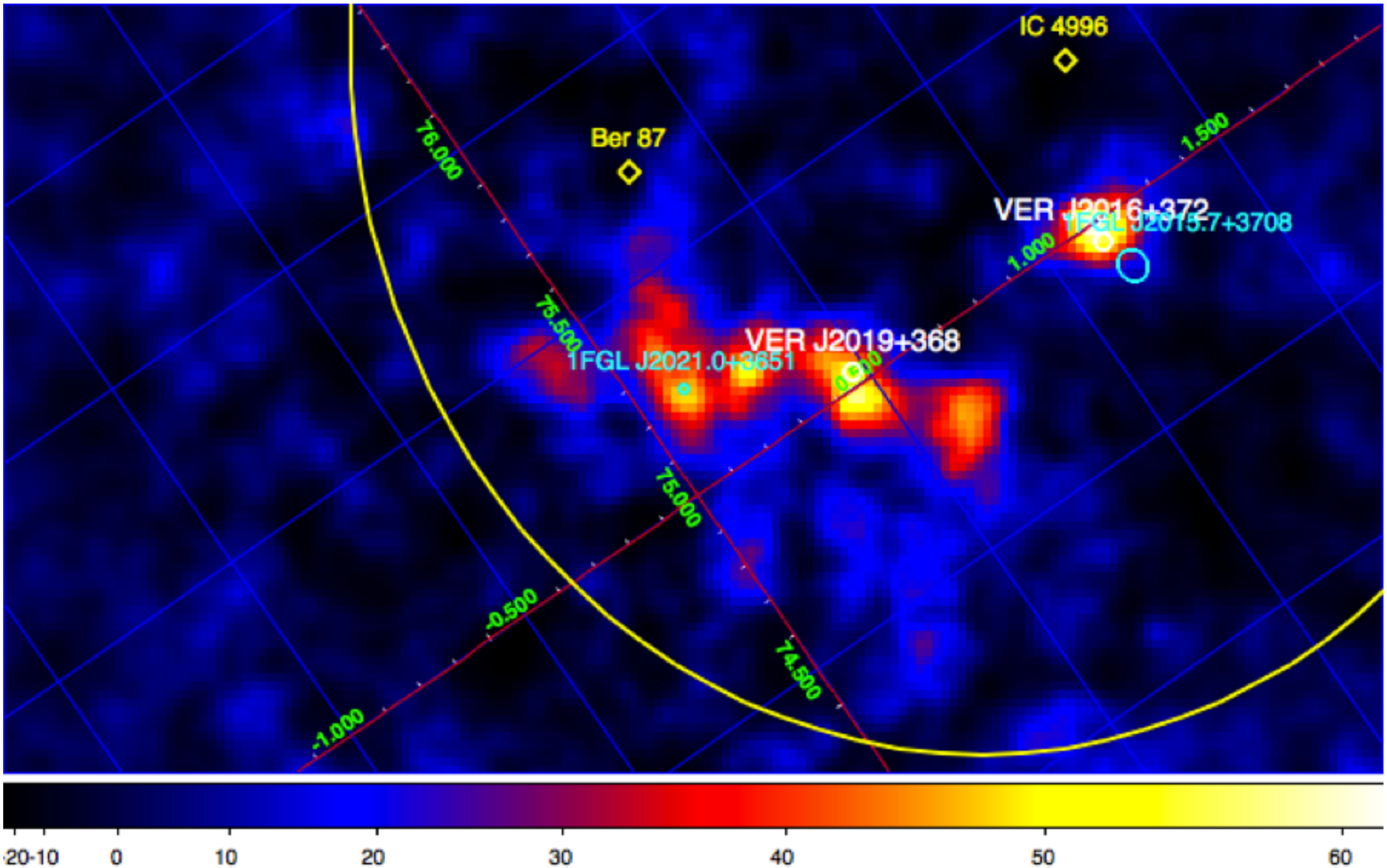
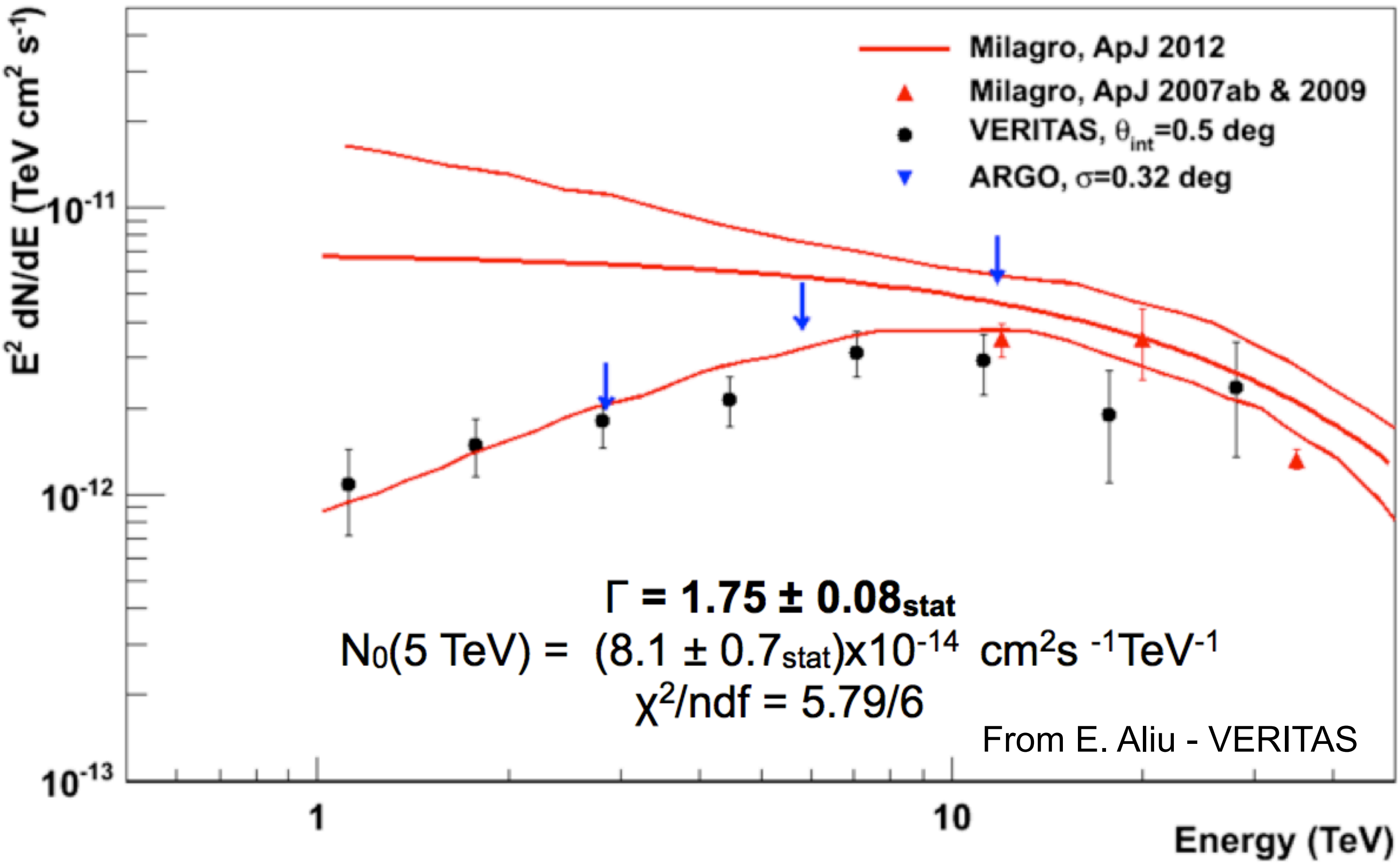
VERITAS Observation of the Cygnus Region

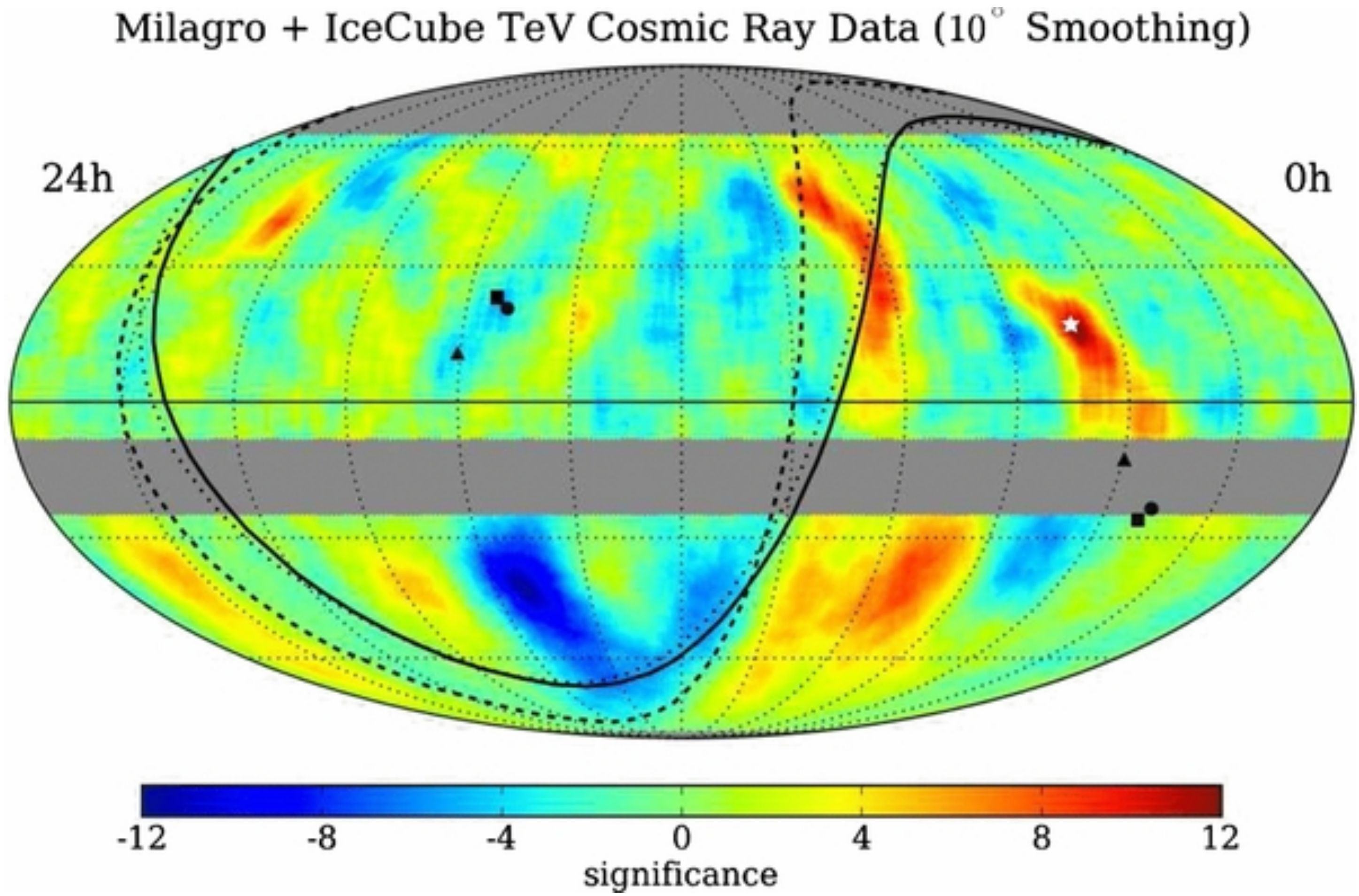
75 hours on-time E > 600 GeV



VERITAS Spectrum



Small Scale Anisotropy

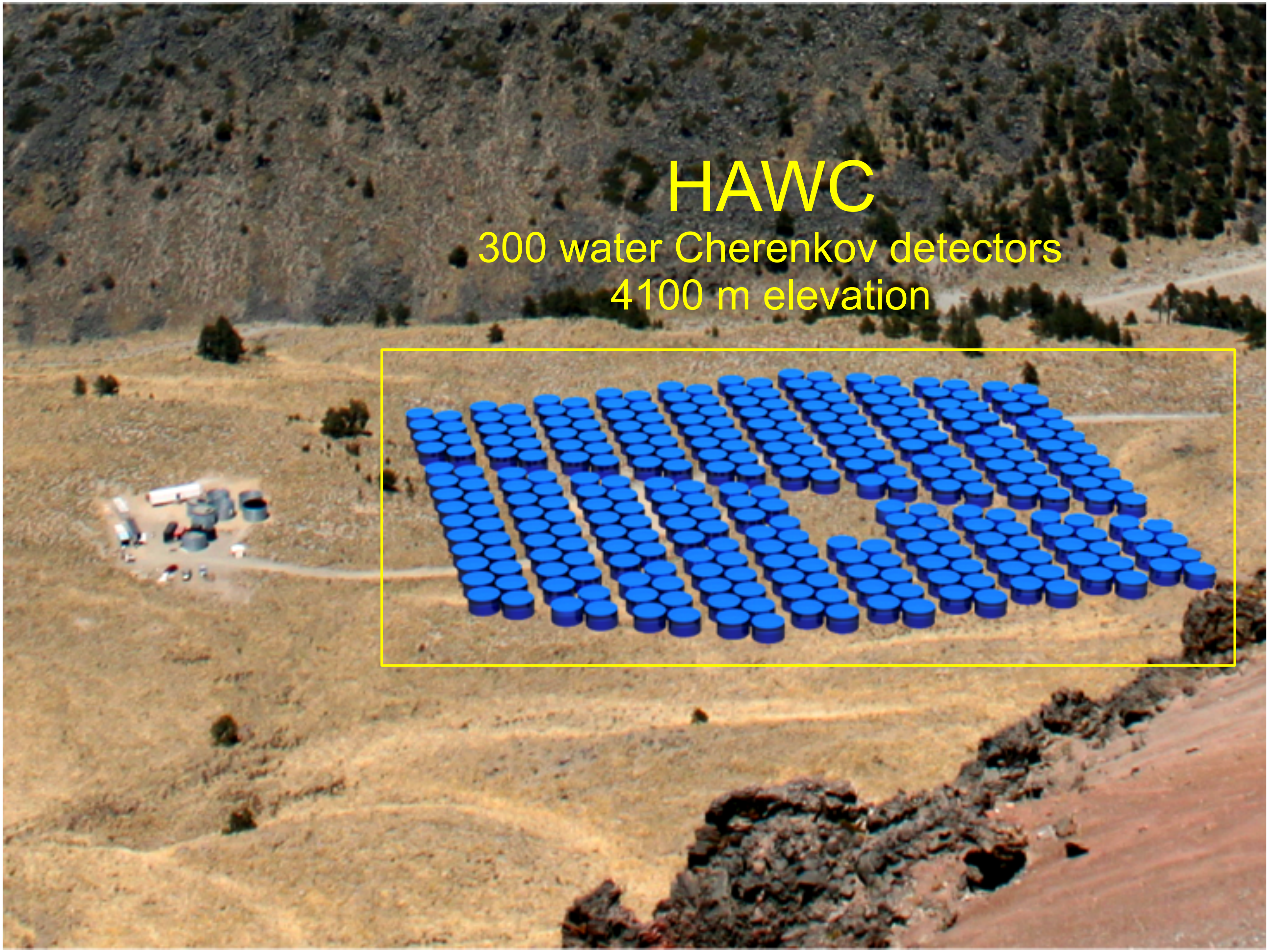


Milagro + IceCube

ApJ 740, 16 (2011)

How Could we Improve Milagro?

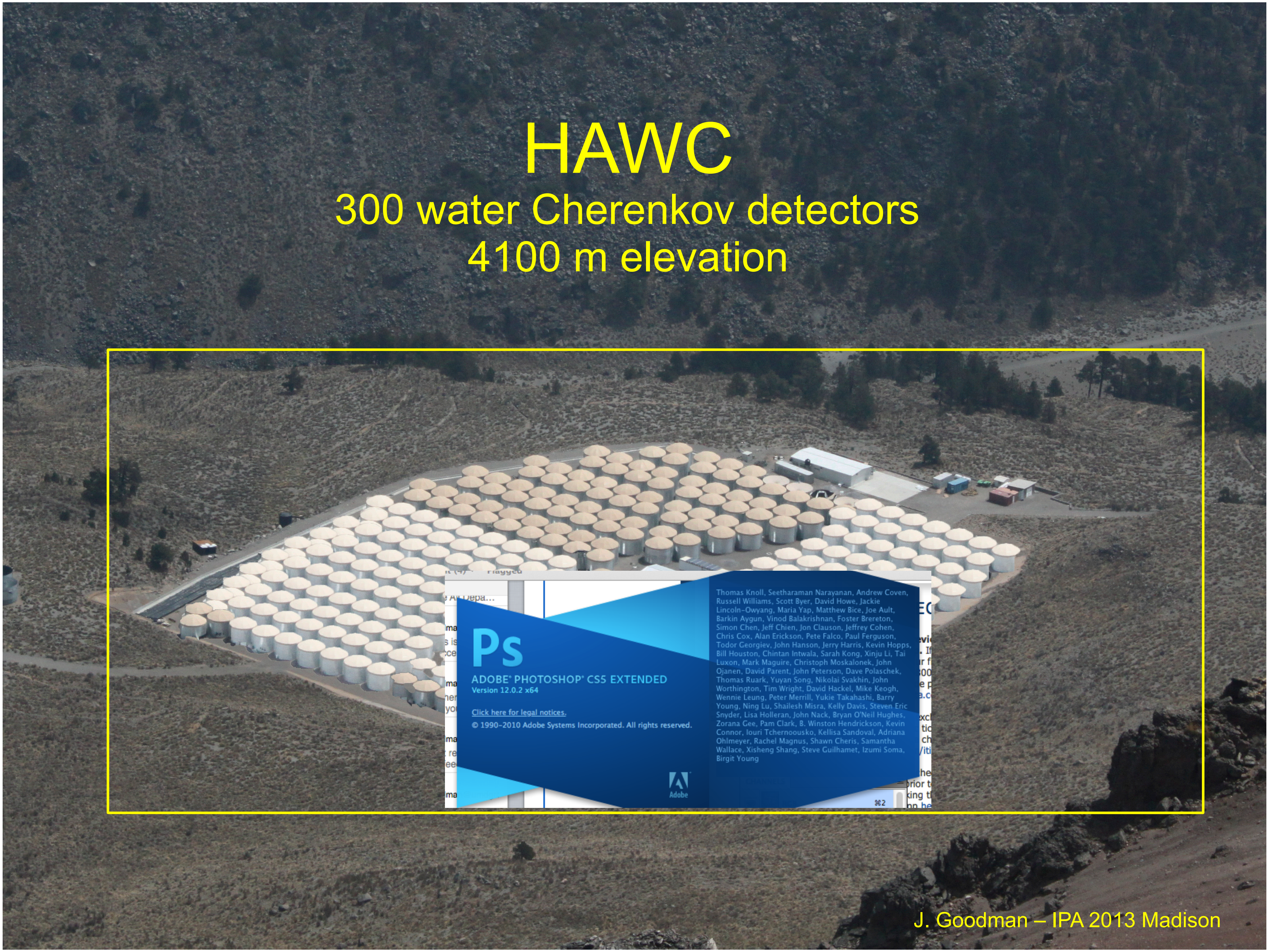
- Larger area of high PMT density and deep water
  - Improve sensitivity and hadron rejection
- Optical isolation
  - Improve hadron rejection
- Higher altitude site
  - Improve effective area at low energies
- Modular design
  - Operate detector while it is being built


HAWC
300 water Cherenkov detectors
4100 m elevation

HAWC

300 water Cherenkov detectors

4100 m elevation



The HAWC Collaboration

University of Maryland
Los Alamos National Laboratory
University of Wisconsin
University of Utah
Univ. of California, Irvine
Michigan State University
George Mason University
University of New Hampshire
Pennsylvania State University
University of New Mexico
Michigan Technological University
NASA/Goddard Space Flight Center
Georgia Institute of Technology
University of Alabama
The Ohio State University
Colorado State University
University of California Santa Cruz

Instituto Nacional de Astrofísica Óptica y Electrónica (INAOE)
Universidad Nacional Autónoma de México (UNAM)
- Instituto de Física
- Instituto de Astronomía
- Instituto de Geofisica
- Instituto de Ciencias Nucleares

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 Investigacion y de Estudios Avanzados
Universidad de Guanajuato

~120 Members

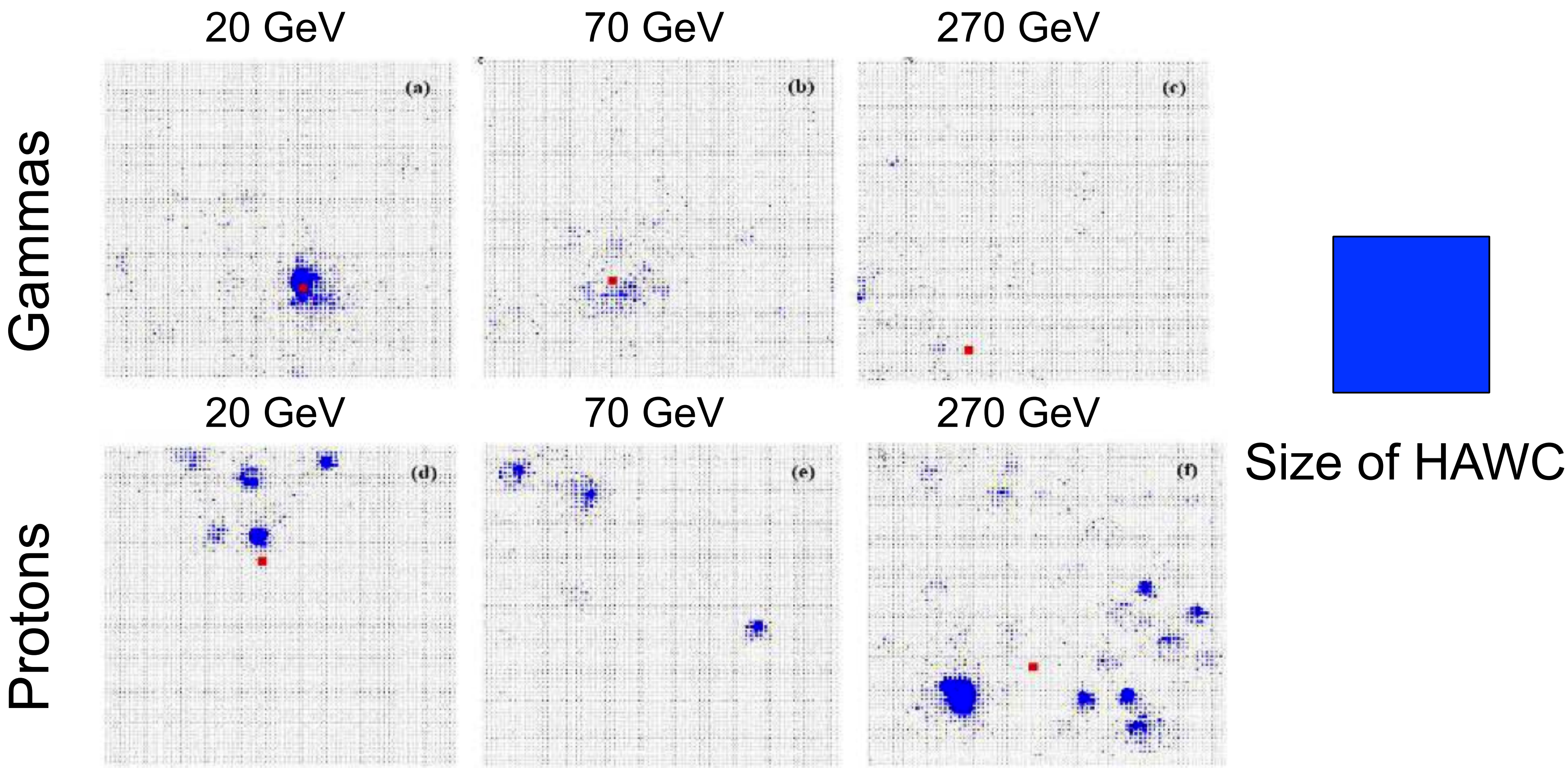
USA

Mexico

HAWC Science Objectives

- Probe the origin of cosmic rays by measuring gamma-ray spectra to 100 TeV
  - Hadronic sources have unbroken spectra beyond 30-100 TeV
  - Galactic diffuse gamma rays probe the distant cosmic ray flux
- Record transient phenomena with wide field of view, high duty factor observations
  - Trigger Multi-Messenger/Multi-Wavelength Observations of Flaring Active Galactic Nuclei (including TeV orphan flares)
  - Detect Short and Long Gamma-Ray Bursts
- Discover new TeV sources via HAWC's unbiased survey of half the sky
- Study the local TeV cosmic rays and their anisotropy

Gamma/Hadron Separation

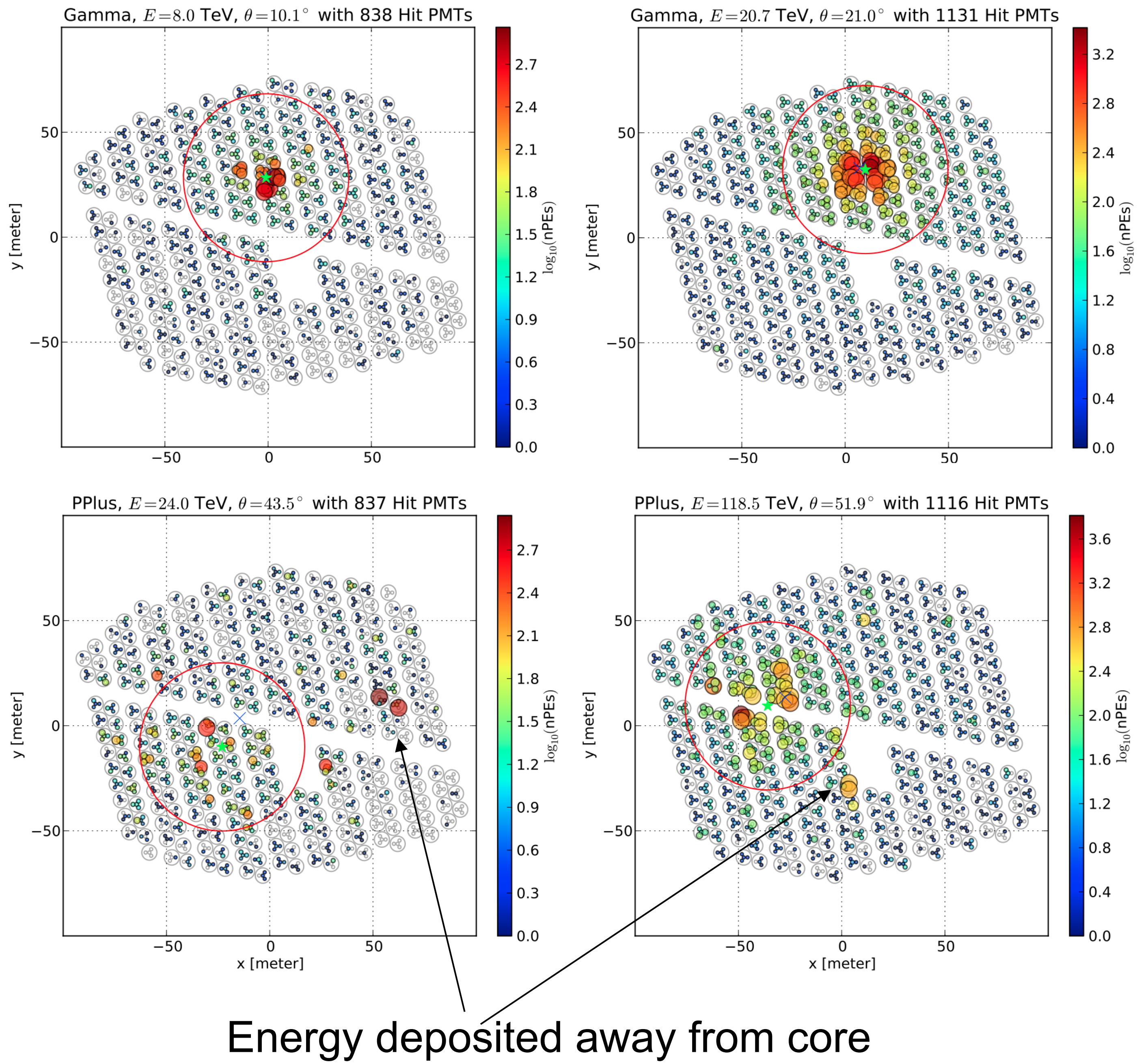


Background rejection improves with increasing size

HAWC Sensitivity $\propto N_{tanks}$ (not $\sqrt{N_{tanks}}$)

Gammas

Protons



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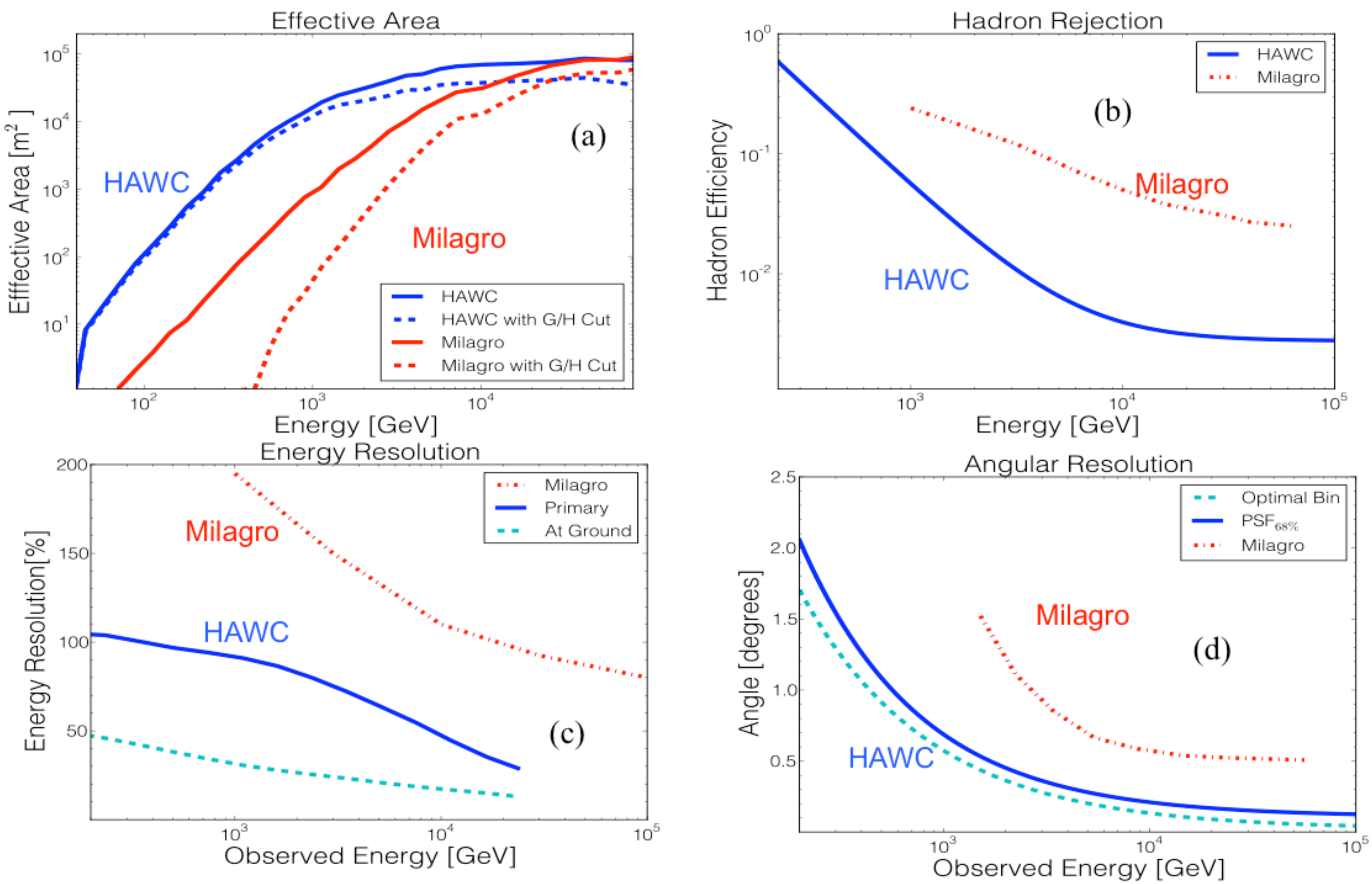
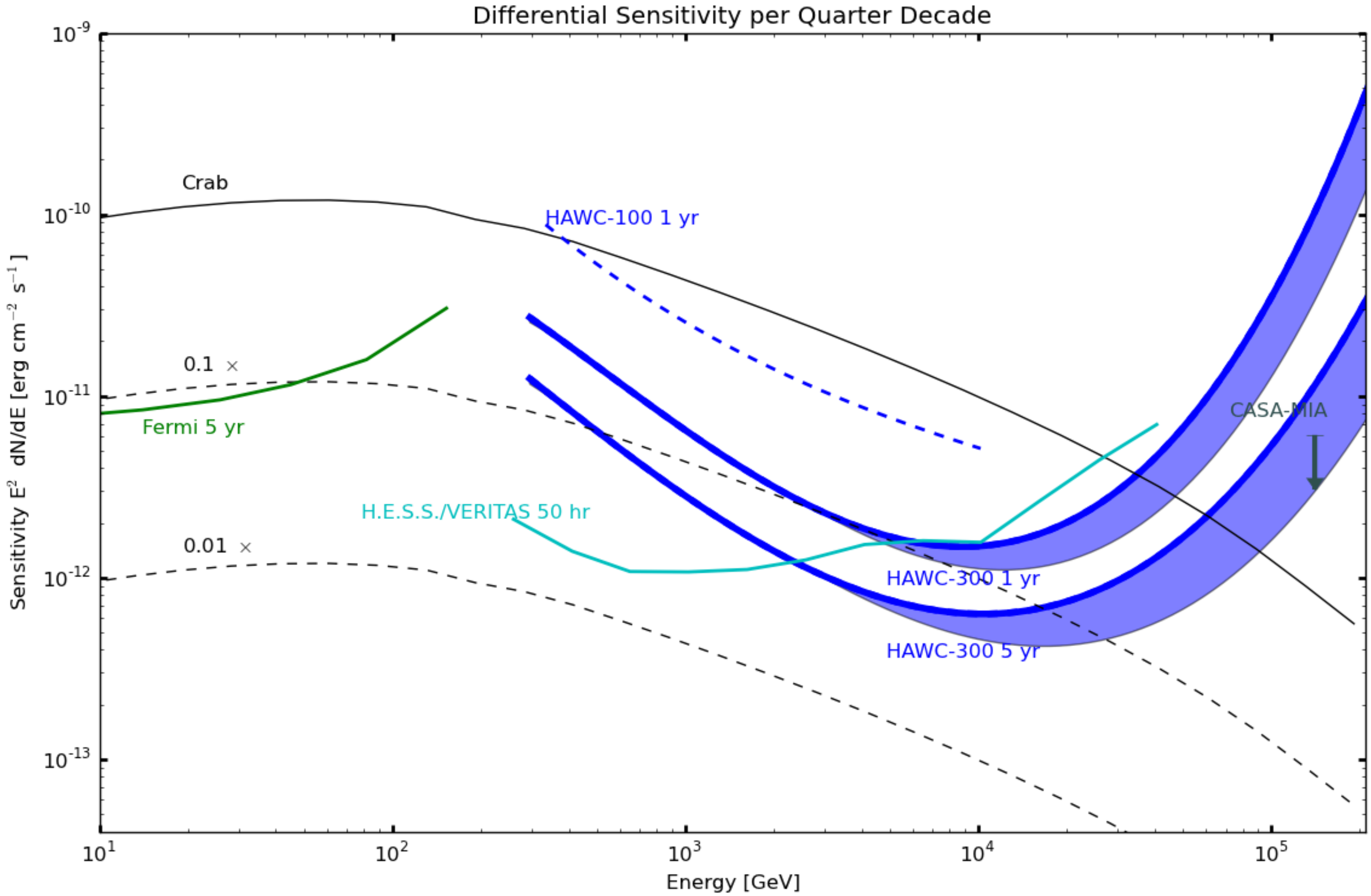
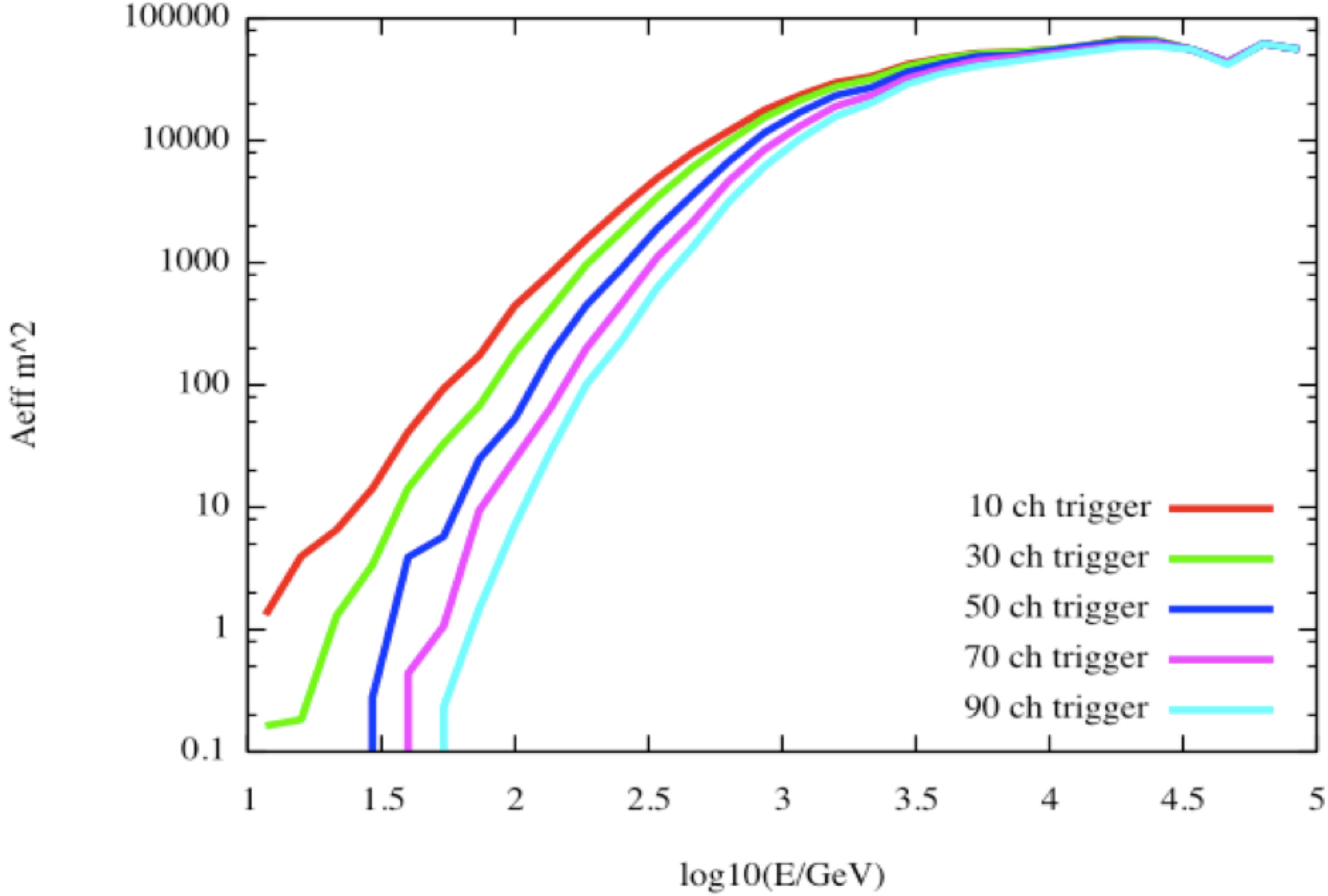
HAWC Performance



HAWC Sensitivity

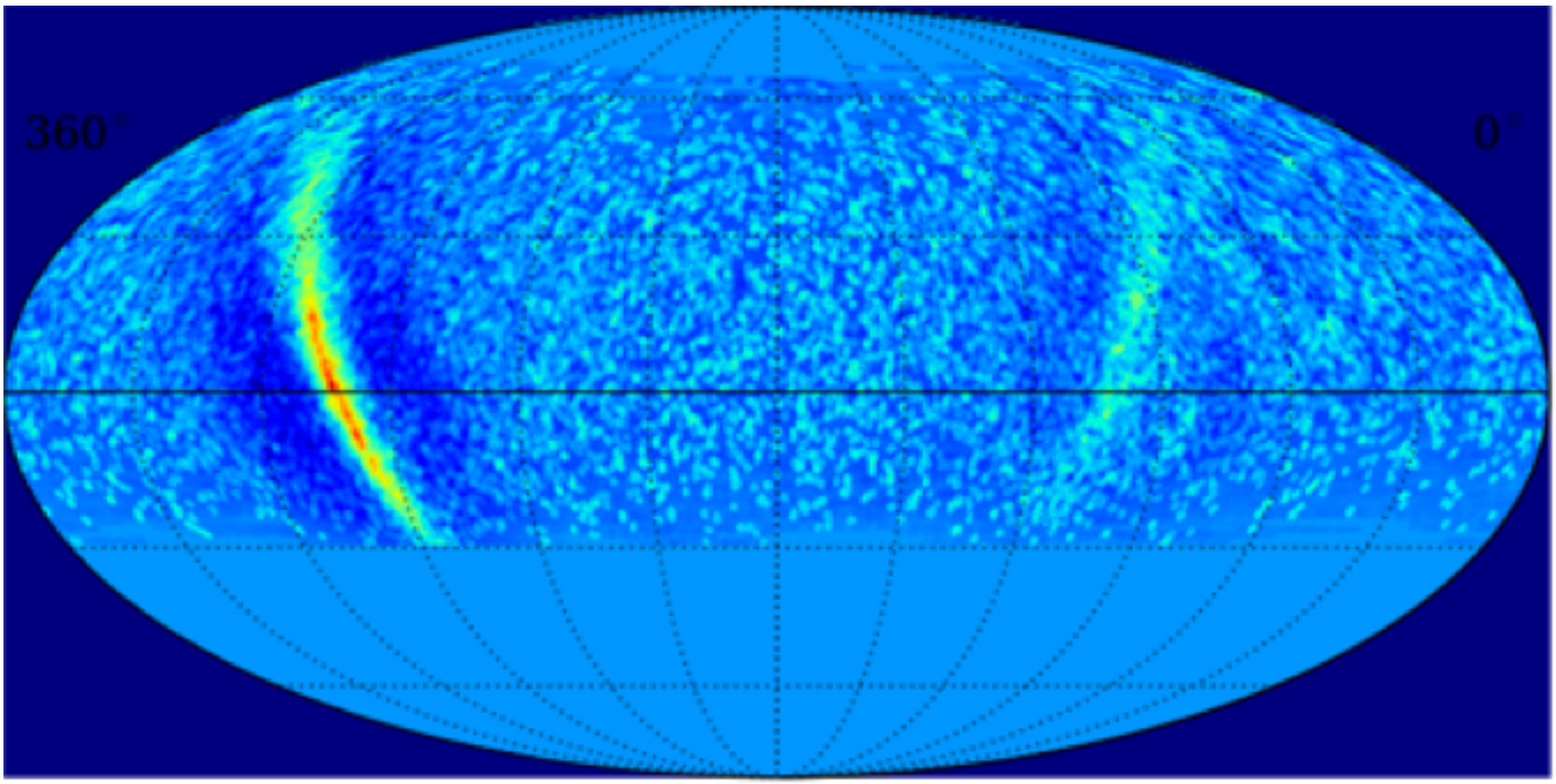


HAWC Low-Energy Response



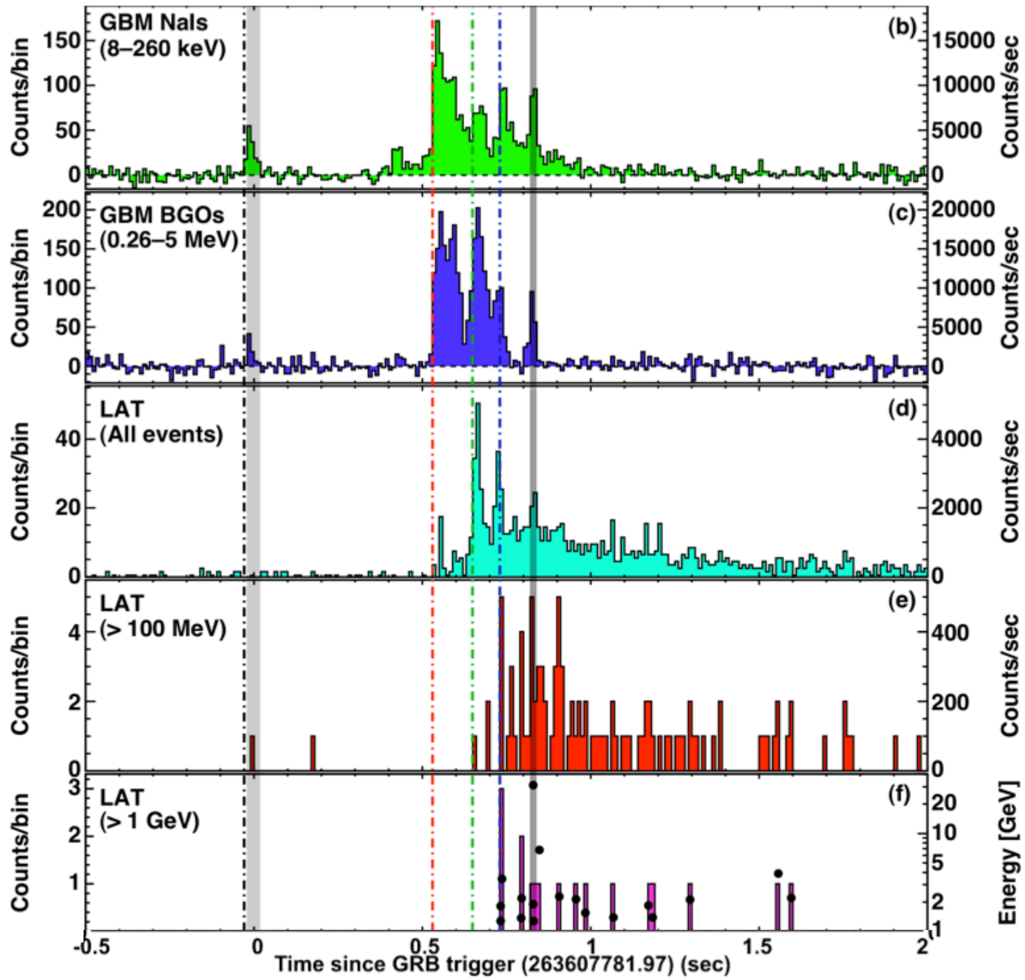
Diffuse Emission

Simulation of Galprop model



Fermi Observation of GRB 090510

- Bursts have energies up to at least ~100 GeV
- Highest energy photons were emitted (i.e. corrected for the observed redshift) at energies of 70, 60, 94, and 61 GeV, GRBs 080916C, 090510, and 090902B, 090926.



Fermi Observation of GRB 090510

- Assume spectrum extends to 125 GeV and attenuation with EBL model of Gilmore

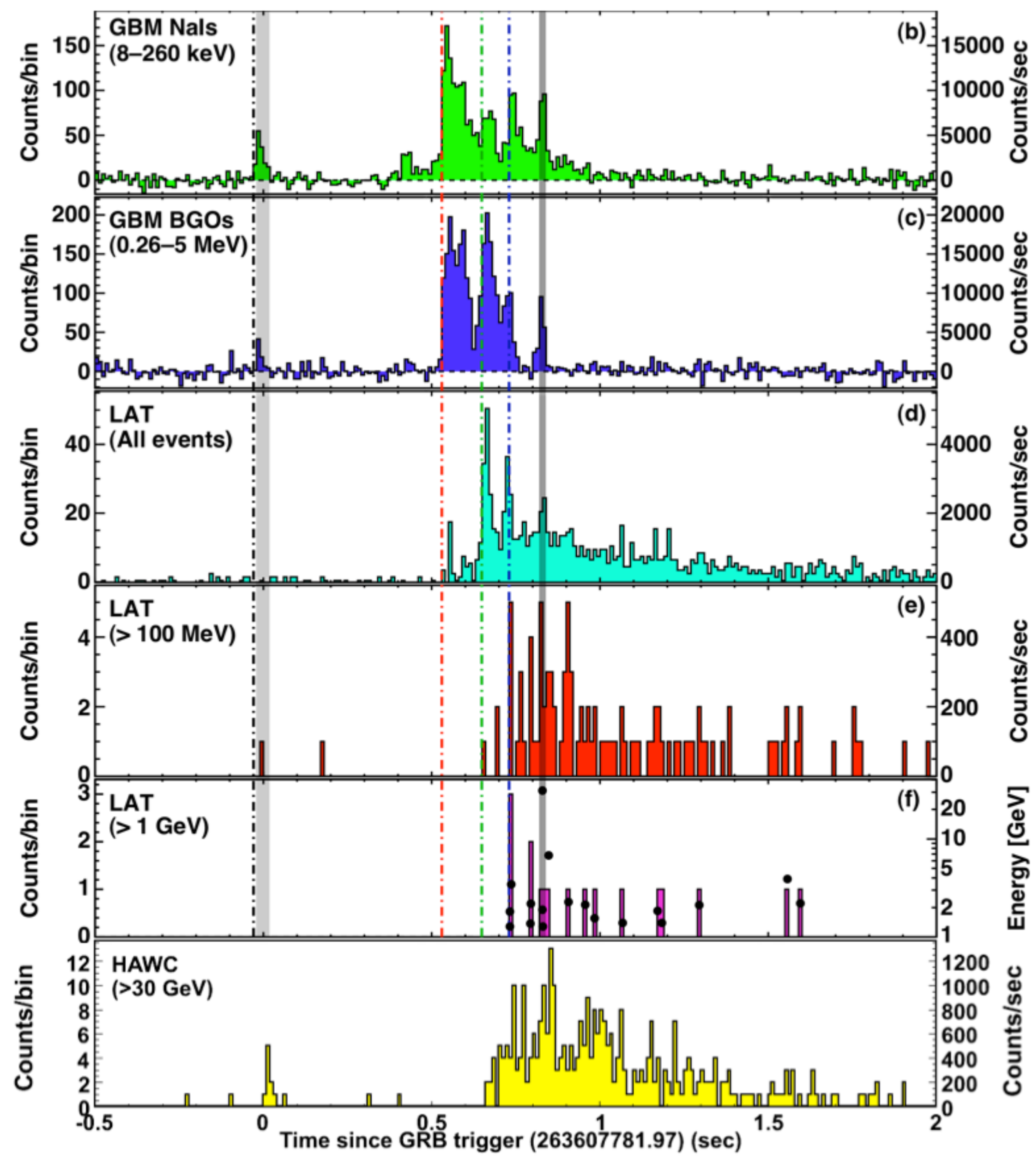
- HAWC: 200 events from GRB 090510 if near zenith

~few background events

- Major Improvements!

– Low-threshold DAQ
– 10-inch PMTs

→ HAWC would observe 100s of events for spectrum to only 31 GeV



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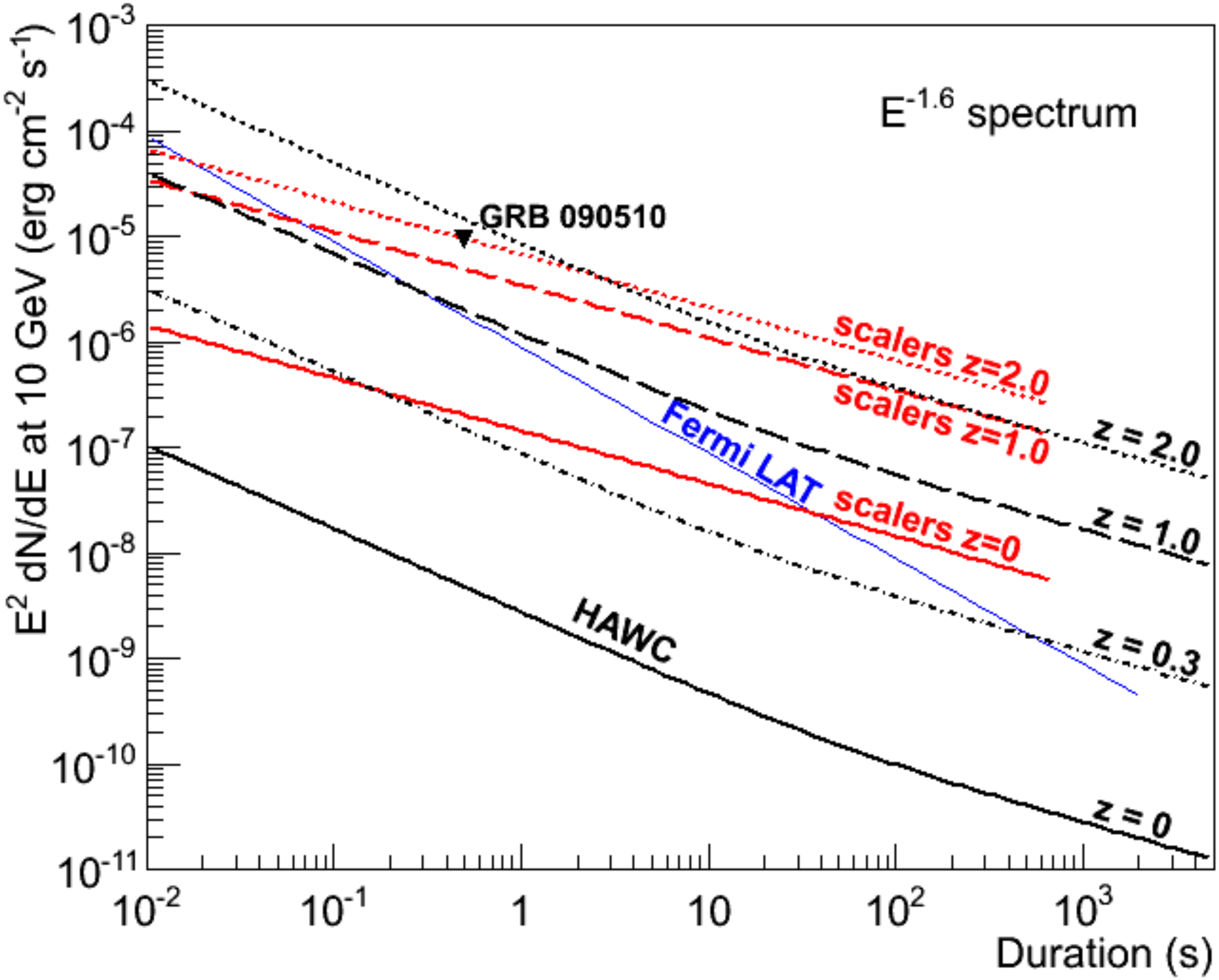
GRB Sensitivity



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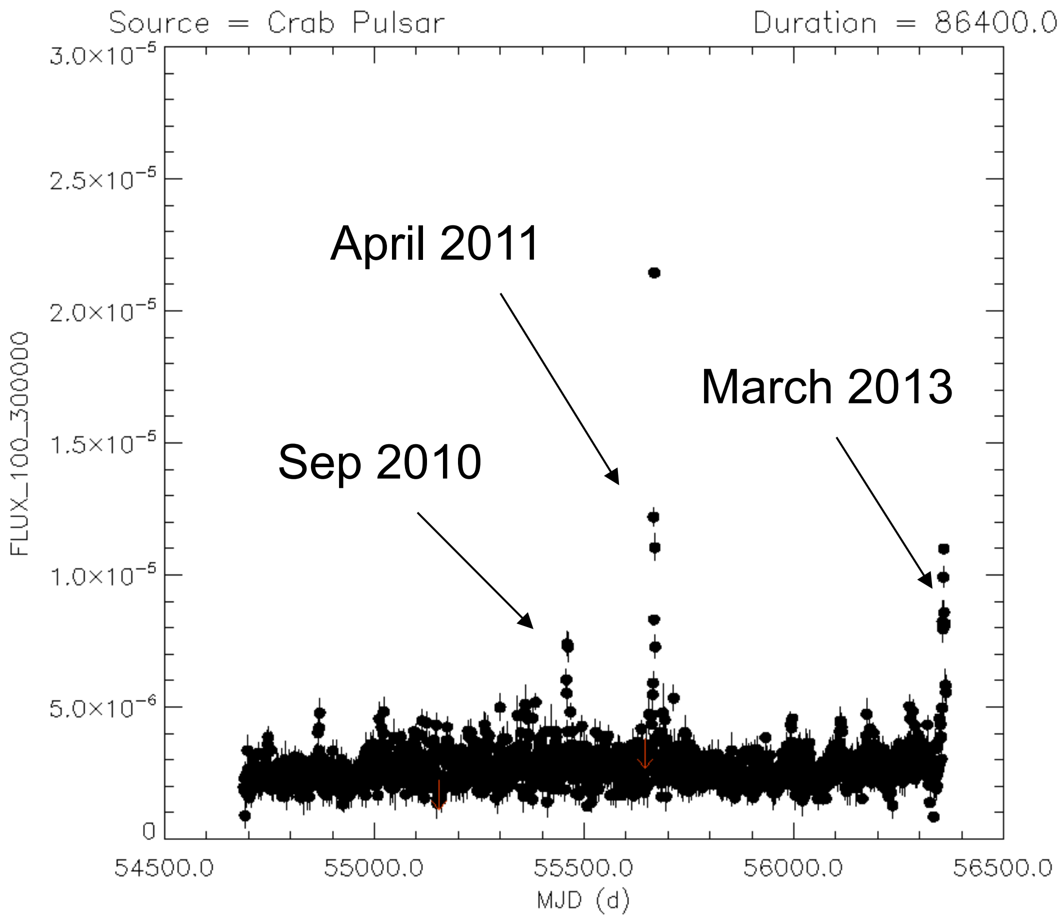
Transients: The Crab

- Considered a reference source
- Sep. 2010: Fermi and AGILE observe a 3x flare at > 100 MeV
- April 2011: Fermi and AGILE observe a 30x flare!
- Mar. 2013: Fermi and AGILE observe a 4-5x flare

Fermi-LAT >100 MeV



Transients: The Crab

- Flares show structure at 12-hour time scales

- Flares are likely synchrotron emission from freshly accelerated ~PeV electrons that rapidly cool
  - Acceleration mechanism is not understood
  - Implies TeV – PeV inverse Compton emission

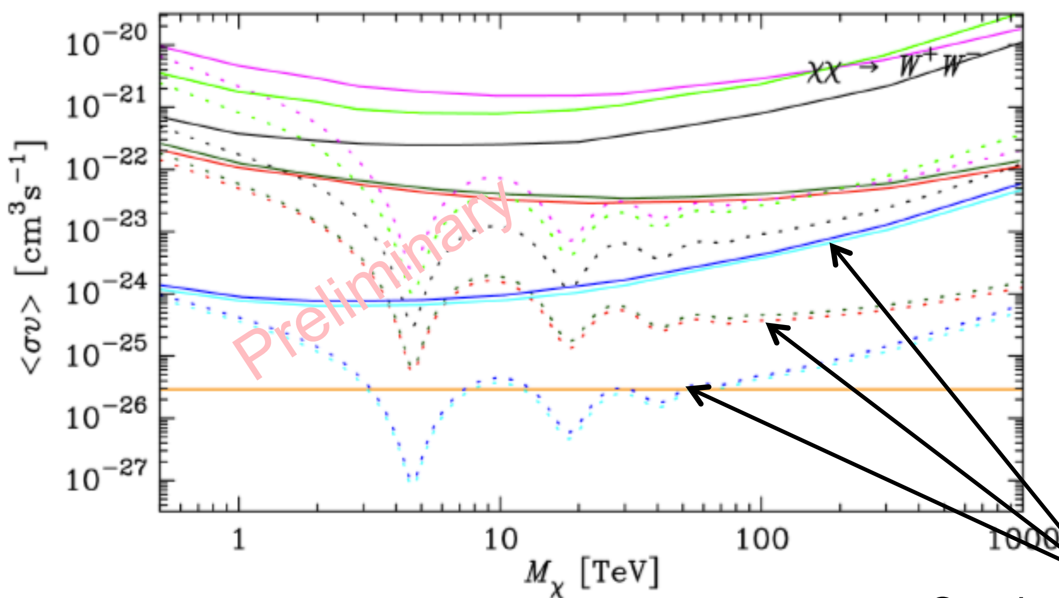
  $\rightarrow$ TeV observations probe Lorentz factor of acceleration region

- ARGO-YBJ reports an excess during September 2010 and April 2011 flares

- Perfect science for HAWC:
  - Crab transits overhead; sensitivity: 8σ per day
  - 10x Crab flare at >5σ in ~2 minutes

Dark Matter

Spectrum peaks sharply at ~1/30 of mass (bb)
or ~1/3 of mass (ττ)
Largest density is at Galactic Center (dec=-29°)
Density depends strongly on DM profile, as does optimal bin



1-year observation limits

Magenta – Draco Dwarf
Green – Coma Berenices Dwarf
Black – Segue 1 Dwarf
Dark Green – GC (NFW)
Red – GC (Einasto)
Dark Blue – GCOH (NFW)
Light Blue – GCOH (Einasto)
Orange – Thermal DM expectation

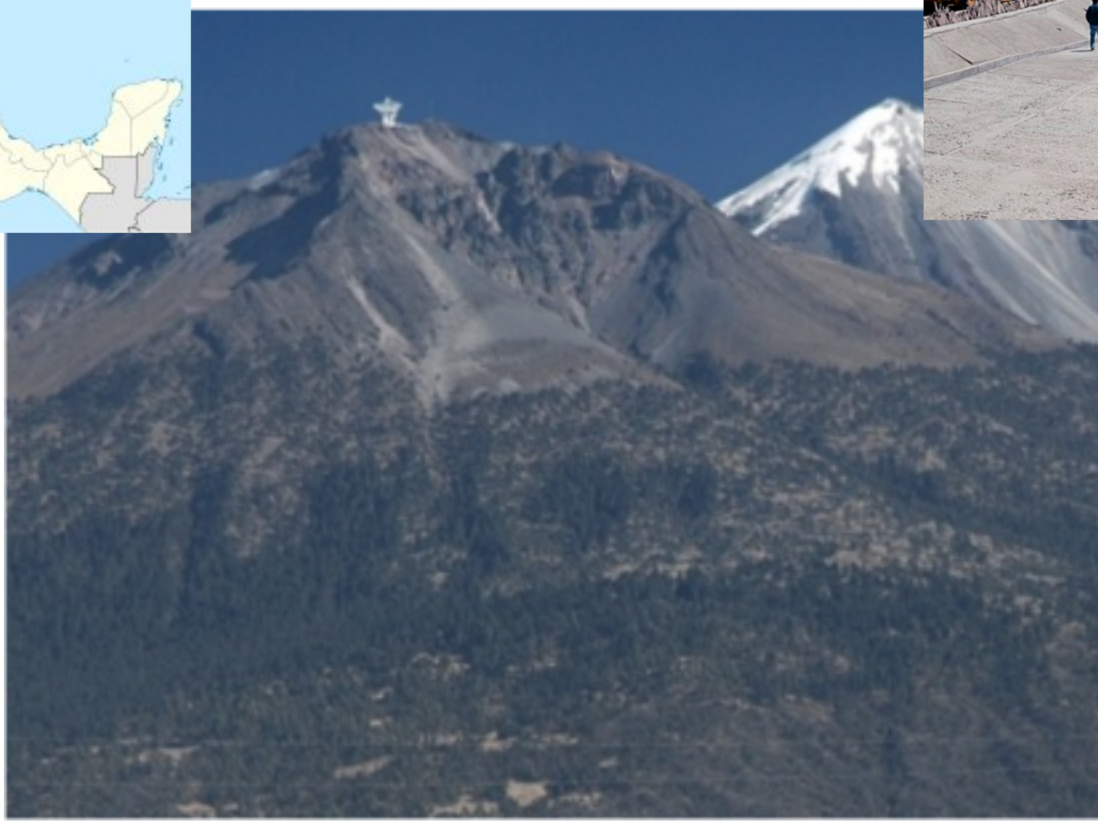
Solid lines – Limits without S.E.
Dotted lines – Limits with S.E.

Southern Hemisphere HAWC

HAWC Site

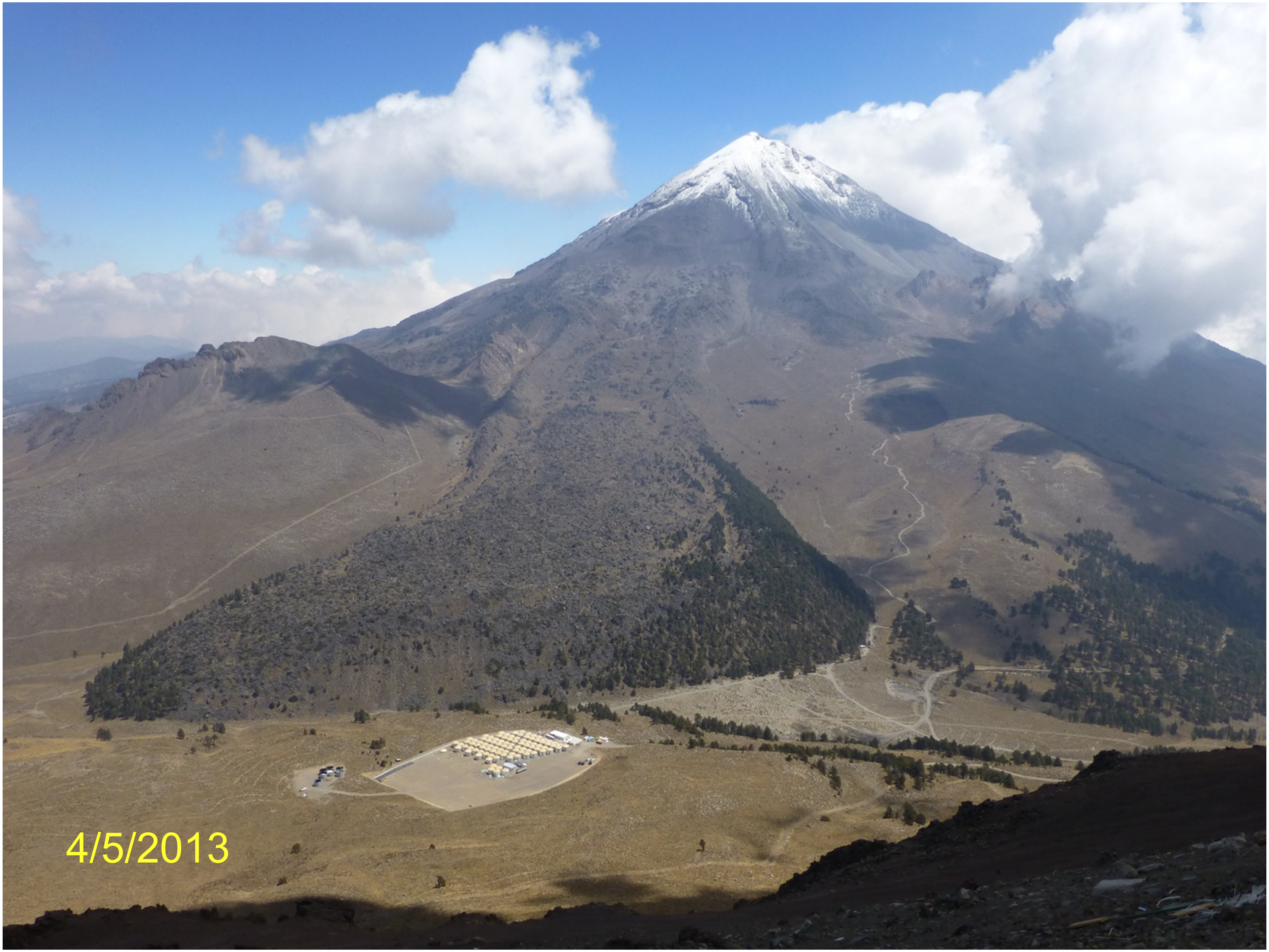
Site located at 4100 m on Sierra Negra in Mexico

LMT Infrastructure: Access road, electrical power, network nearby

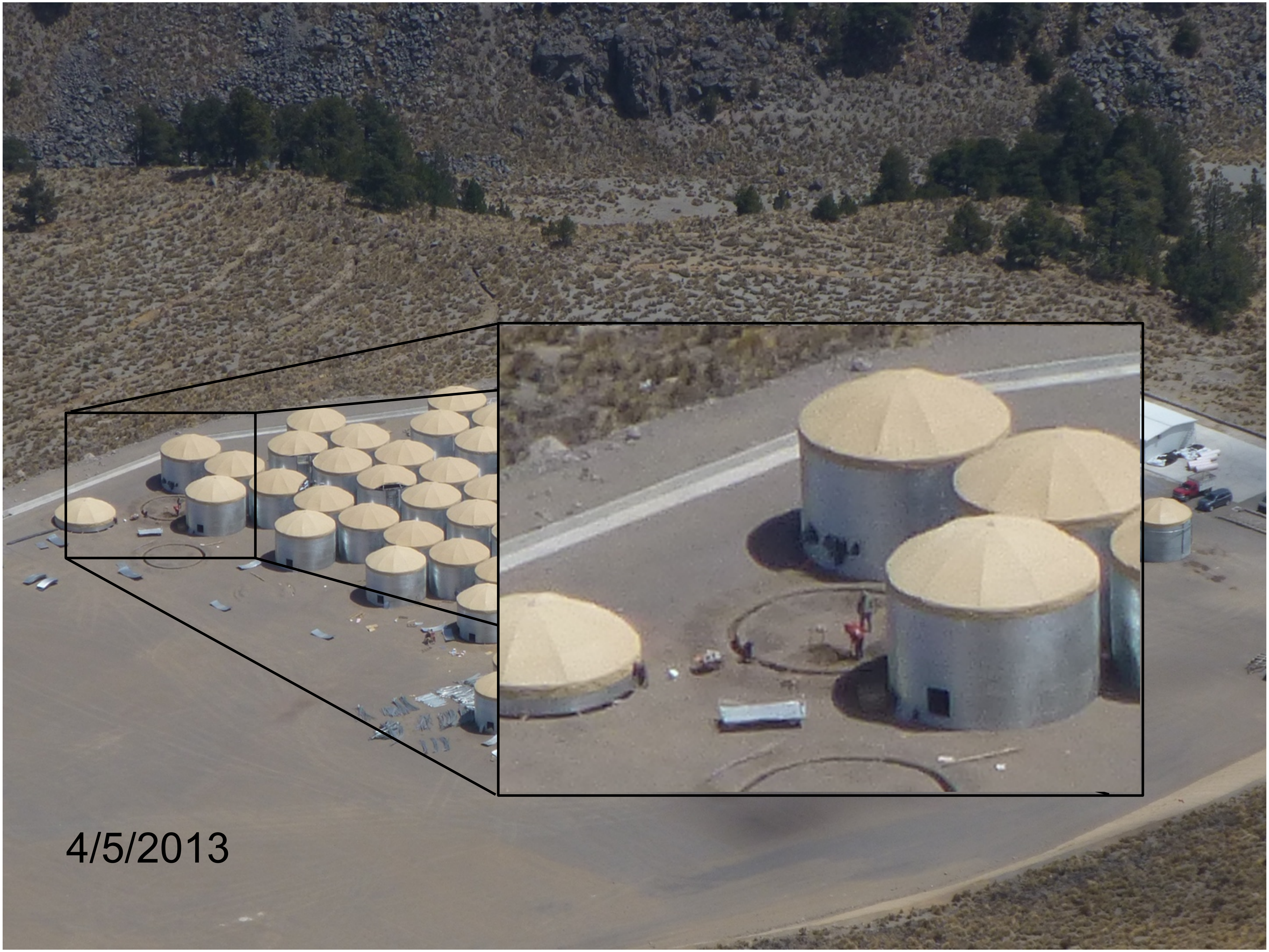


Existing Infrastructure


2001
2013
10/12/2012
Image NASA
Google earth


4/5/2013

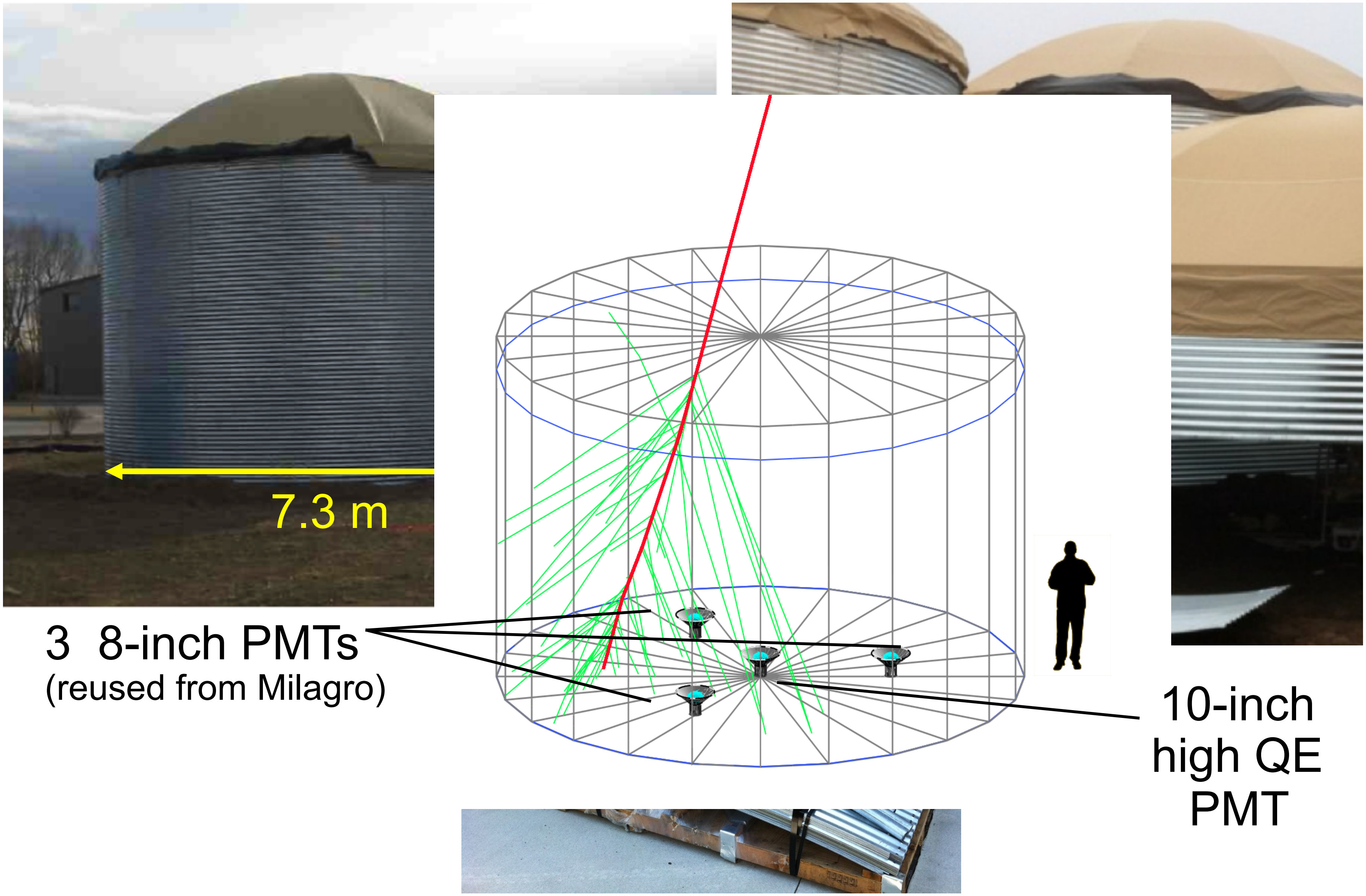

4/5/2013


4/5/2013

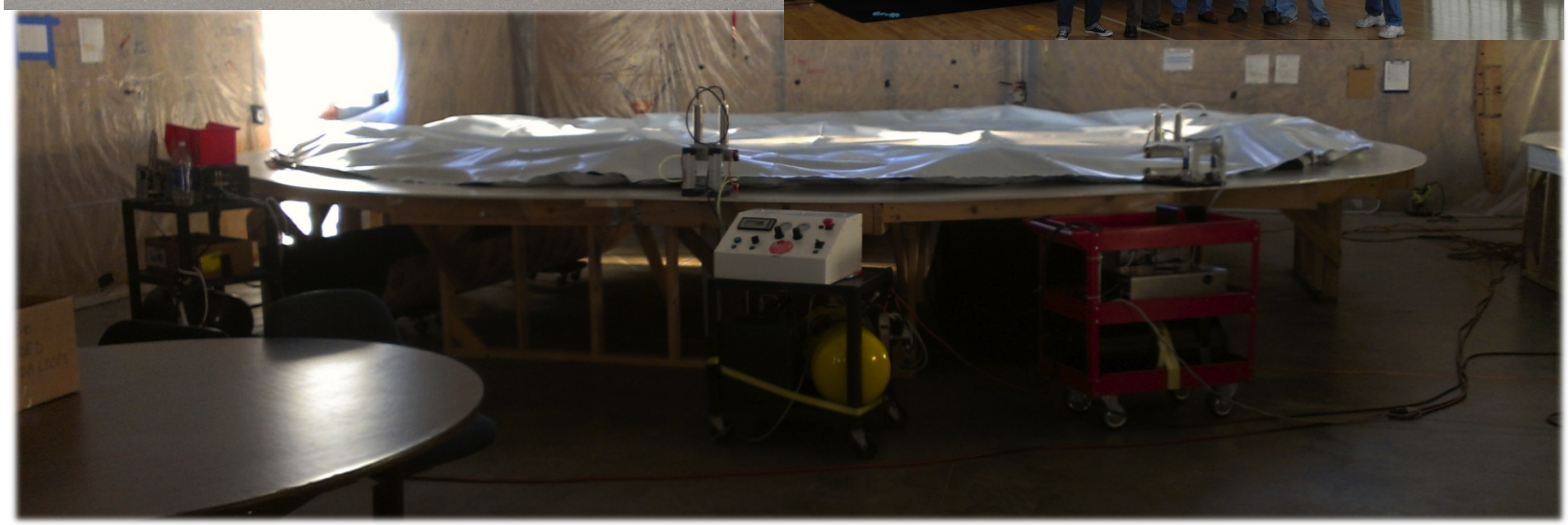

4/30/2013

HAWC Water Cherenkov Detectors

HAWC Water Cherenkov Detectors

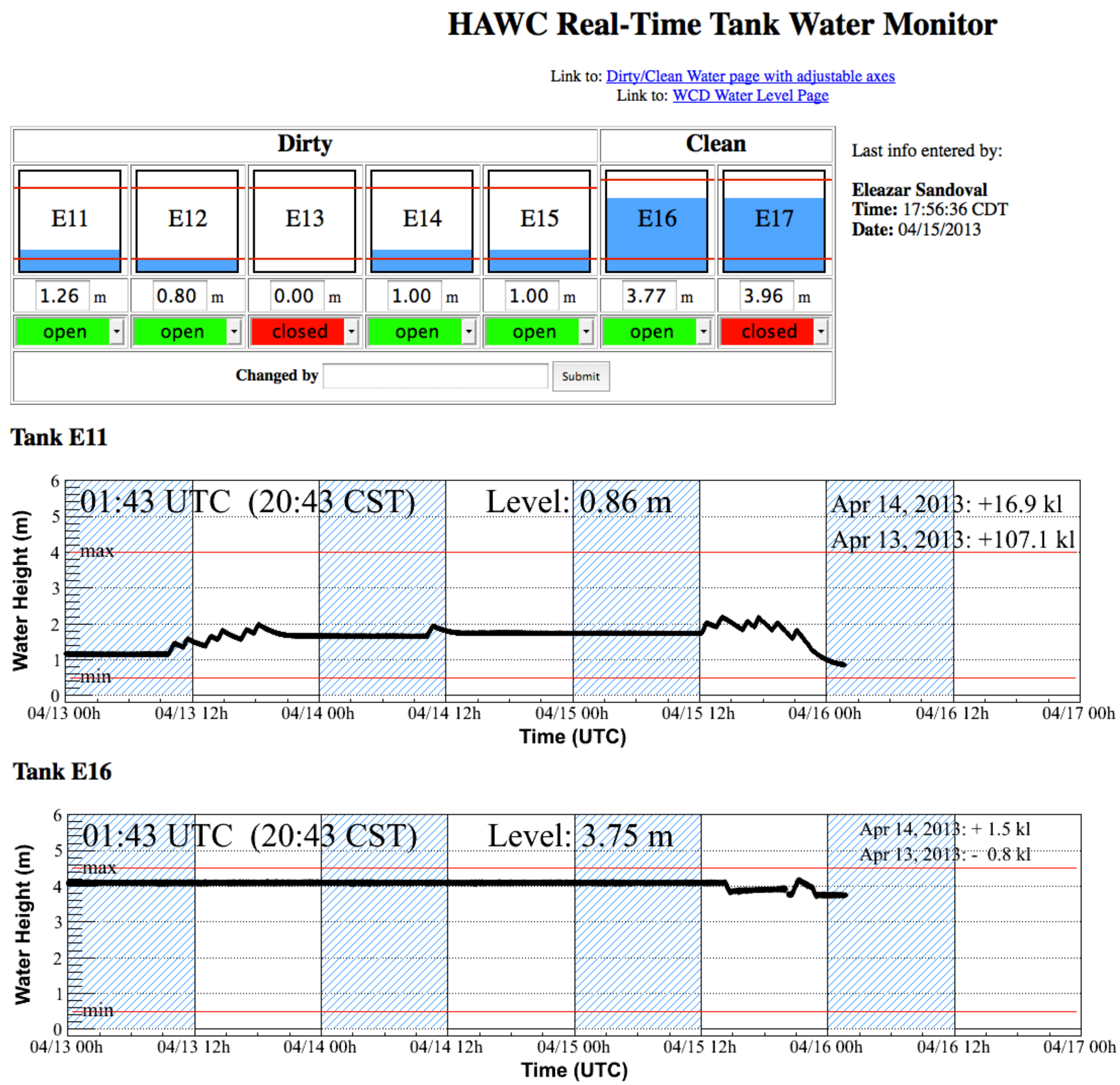


HAWC Water Cherenkov Detectors



HAWC Water System

- Water trucked to site:
  - Spring on mountain
  - Well in nearby town
- Incoming "Dirty" water is purified:
  - Micron filtration
  - UV sterilization
- Attenuation length >20 m
- 188,000 liters of water per tank
- ~5 hours to fill a tank



HAWC
As of 5/13:

106 tanks constructed

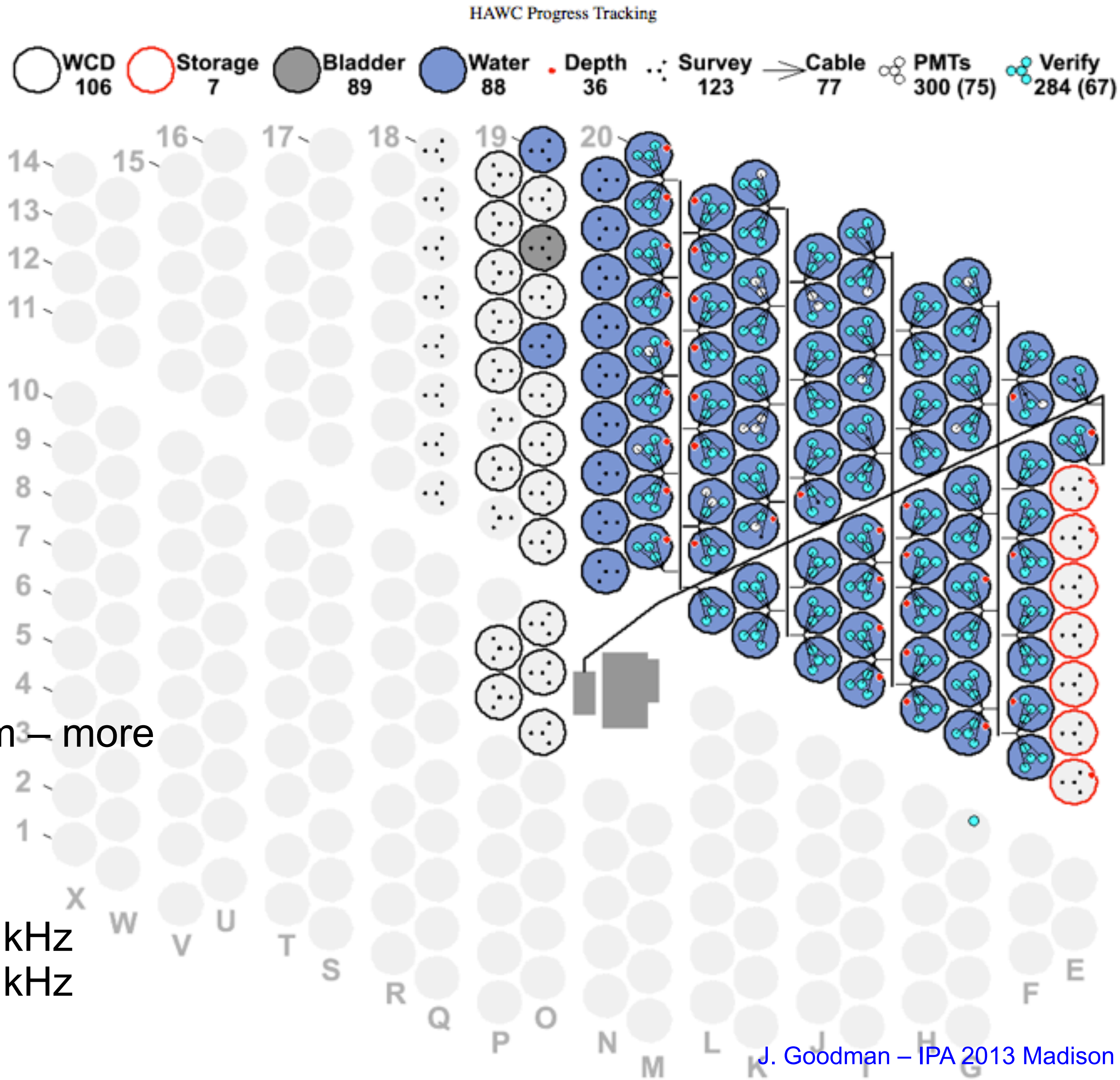
77 tanks deployed

PMTs are deployed into filled tanks

43 tanks
In data stream – more today

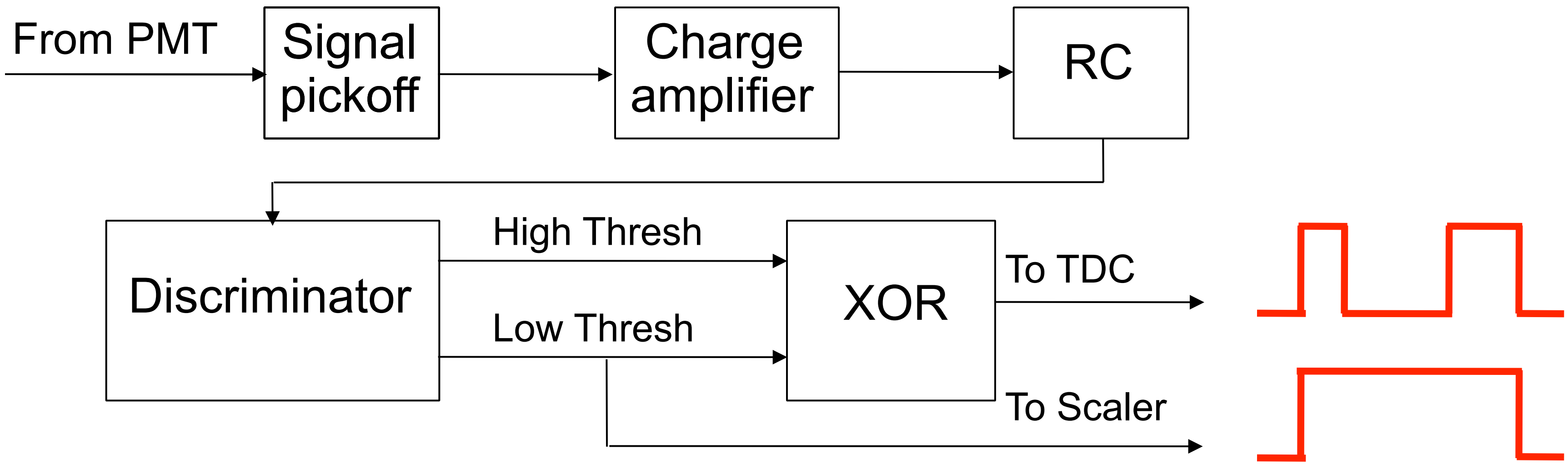
PMT Rates:

8”: 20 – 30 kHz
10”: 40 – 60 kHz



HAWC DAQ

- HAWC uses Milagro front end electronics:



- Record data with CAEN VX1190 VME TDCs
- Time-over-threshold roughly proportional to log(charge)
- Calibration with laser and fibers to each tank
  – TOT → charge
  – Timing offset

HAWC TDC DAQ

- Multiple TDCs are held in phase by common 40 MHz clock
- Continuous acquisition with common 40 kHz trigger

  → 25 μs data blocks containing all edges
- GPS timing signals digitized by TDC every 10 μs
- TDCs read out by VME single-board computer
- Triggering is done entirely in software

HAWC Data

- All edges are recorded
- TDC rate: ~400 kB/s per channel
  - ~50MB/s per VME backplane

  → 500 MB/s for 300 tanks

- Data are processed entirely by software:
  - Extract air shower events
  - Measure rates of uninteresting events
    - Single muons
    - Track rates of all PMTs
- Edges from air shower events are stored permanently

  → 5 – 20 MB/s; Data centers at UMD RDC and UNAM
- Full data will be saved for ~24 hours (40TB)
- Full data set stored in US & MX will be ~600TB/yr

What Else Can We Do With All TDC Edges?

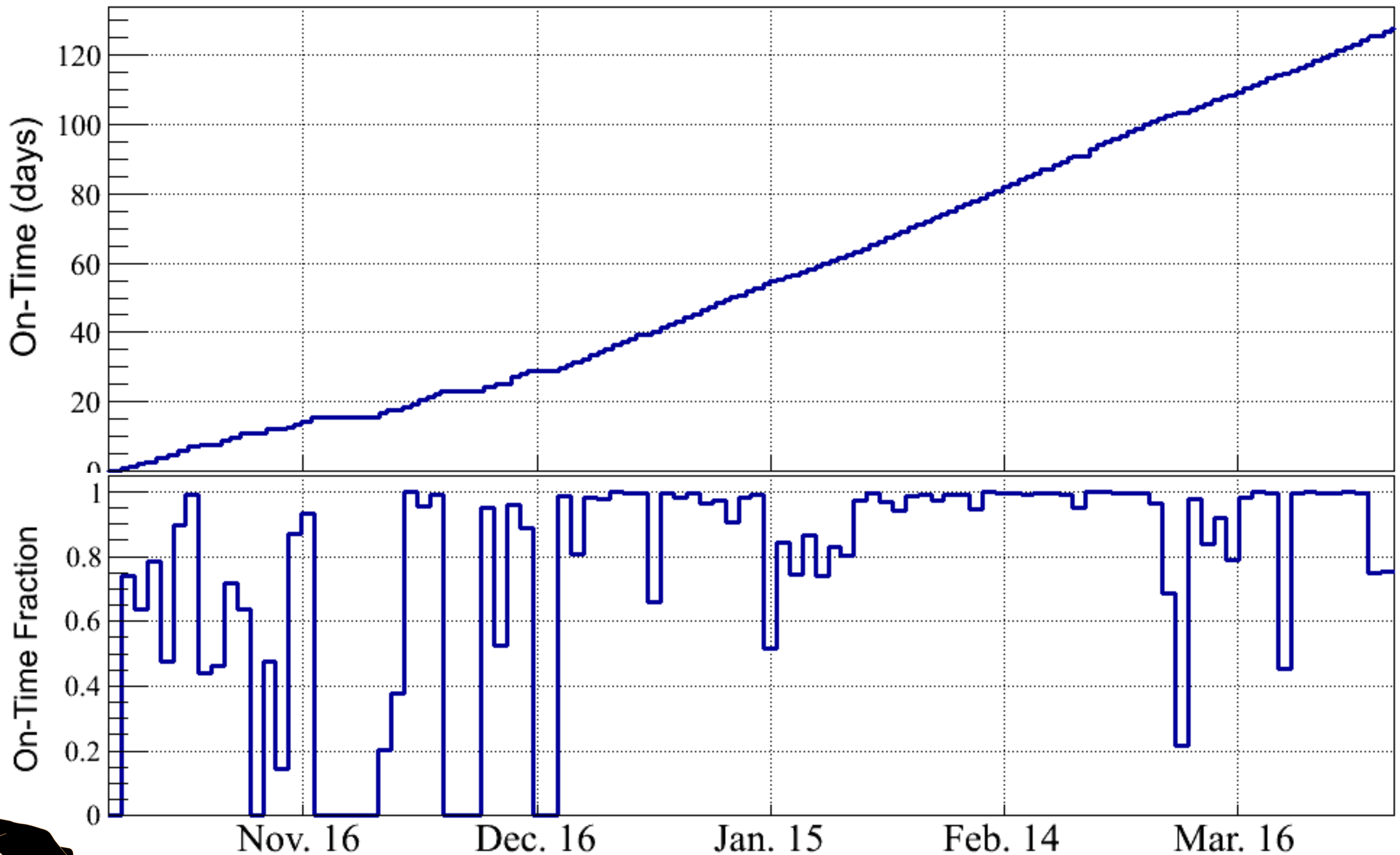
- Sophisticated air-shower trigger algorithms
  - Can apply charge/timing calibration before triggering
  - Can use detector geometry easily

- Q-ball trigger
  - Q-ball dissociates nucleons
  - Releases a burst of pions → large signal within a tank

  → Look for multiple large signals within a tank

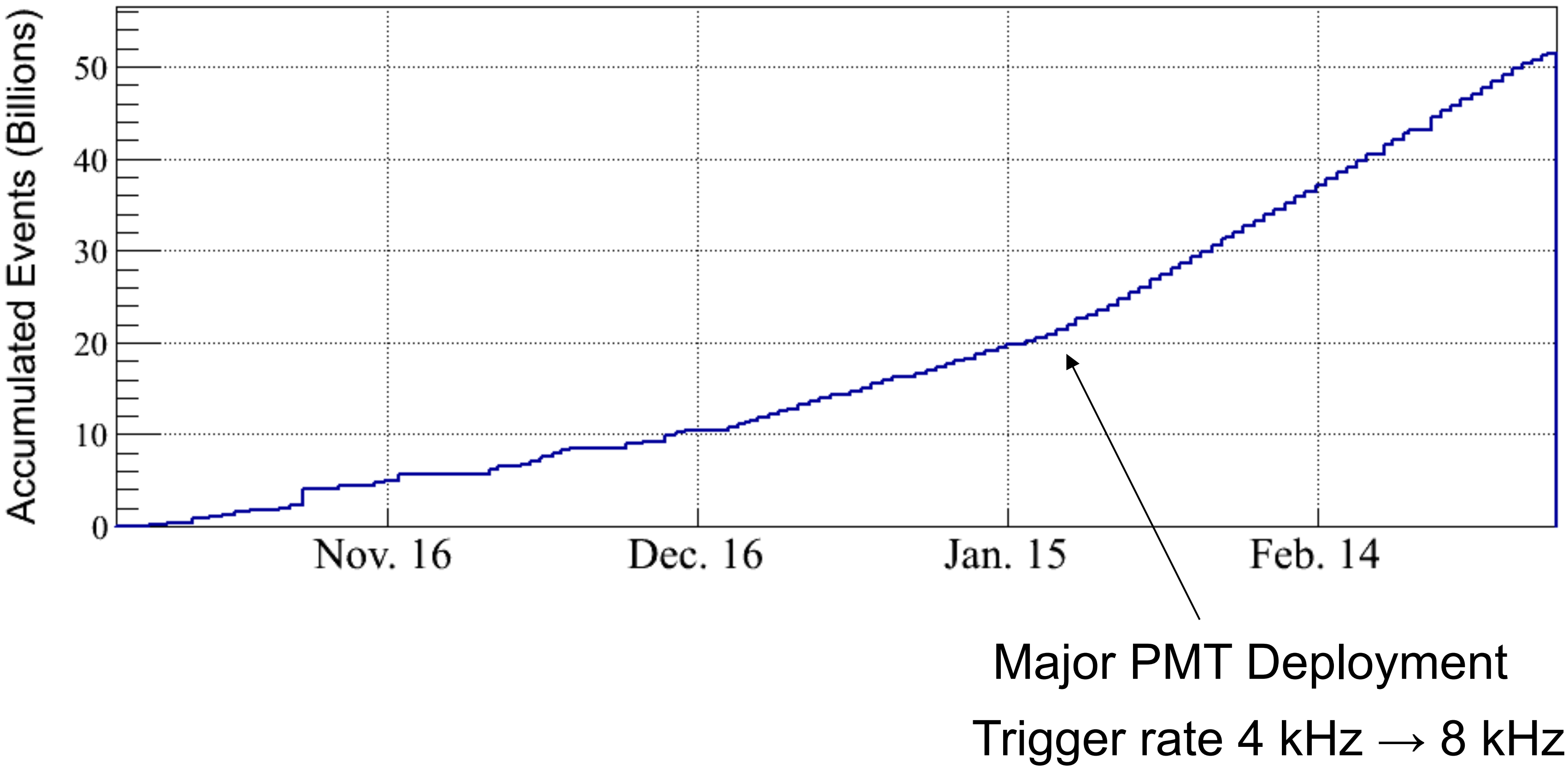
- “Vector Telescope”
  - Reconstruct direction of all sets of 3 hits into sky bins
  - Observe large numbers of showers when each is individually below the trigger threshold

HAWC On-Time During Construction



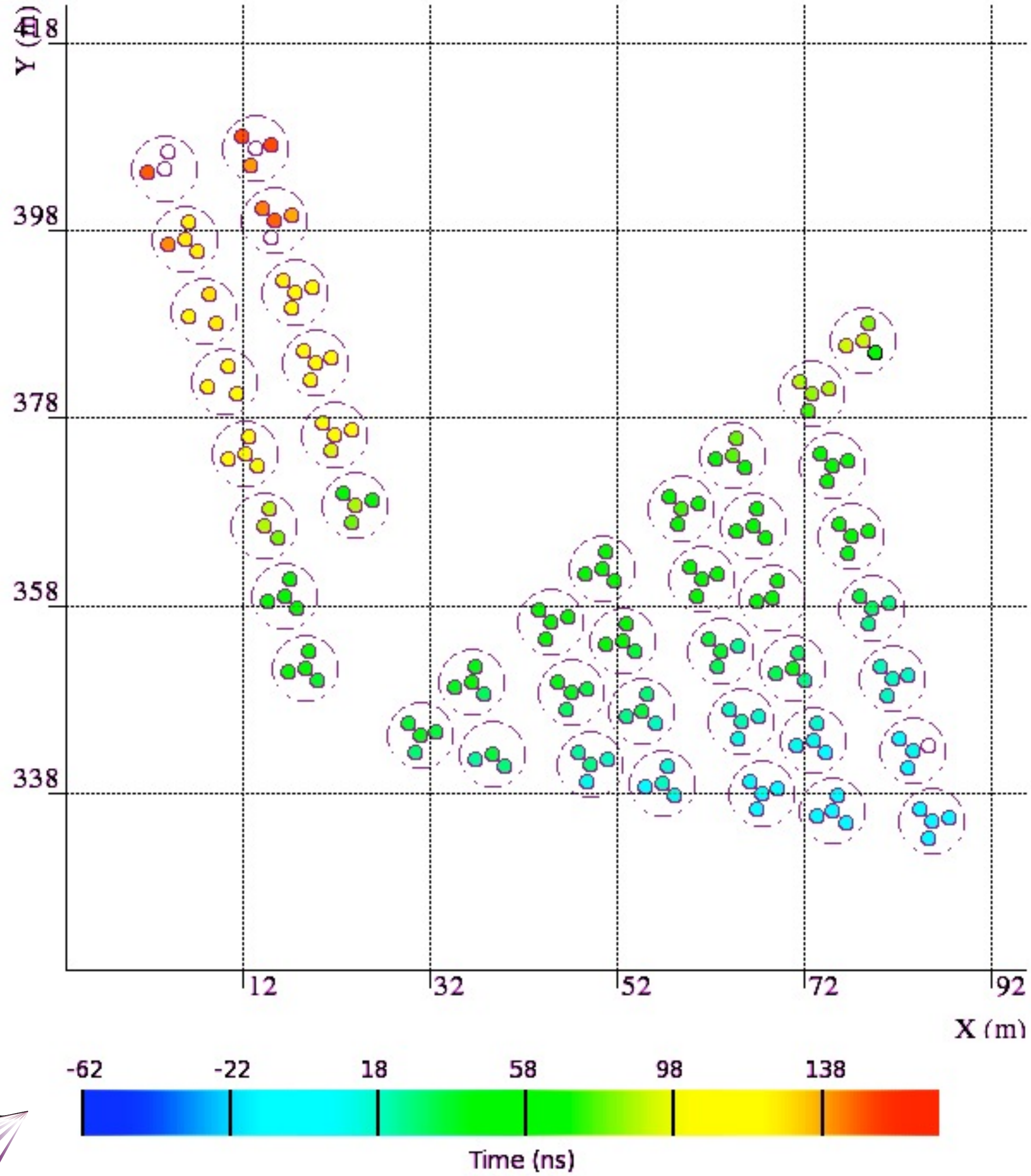
HAWC

HAWC Accumulated Events



50 billion events reconstructed through early March

A HAWC Event



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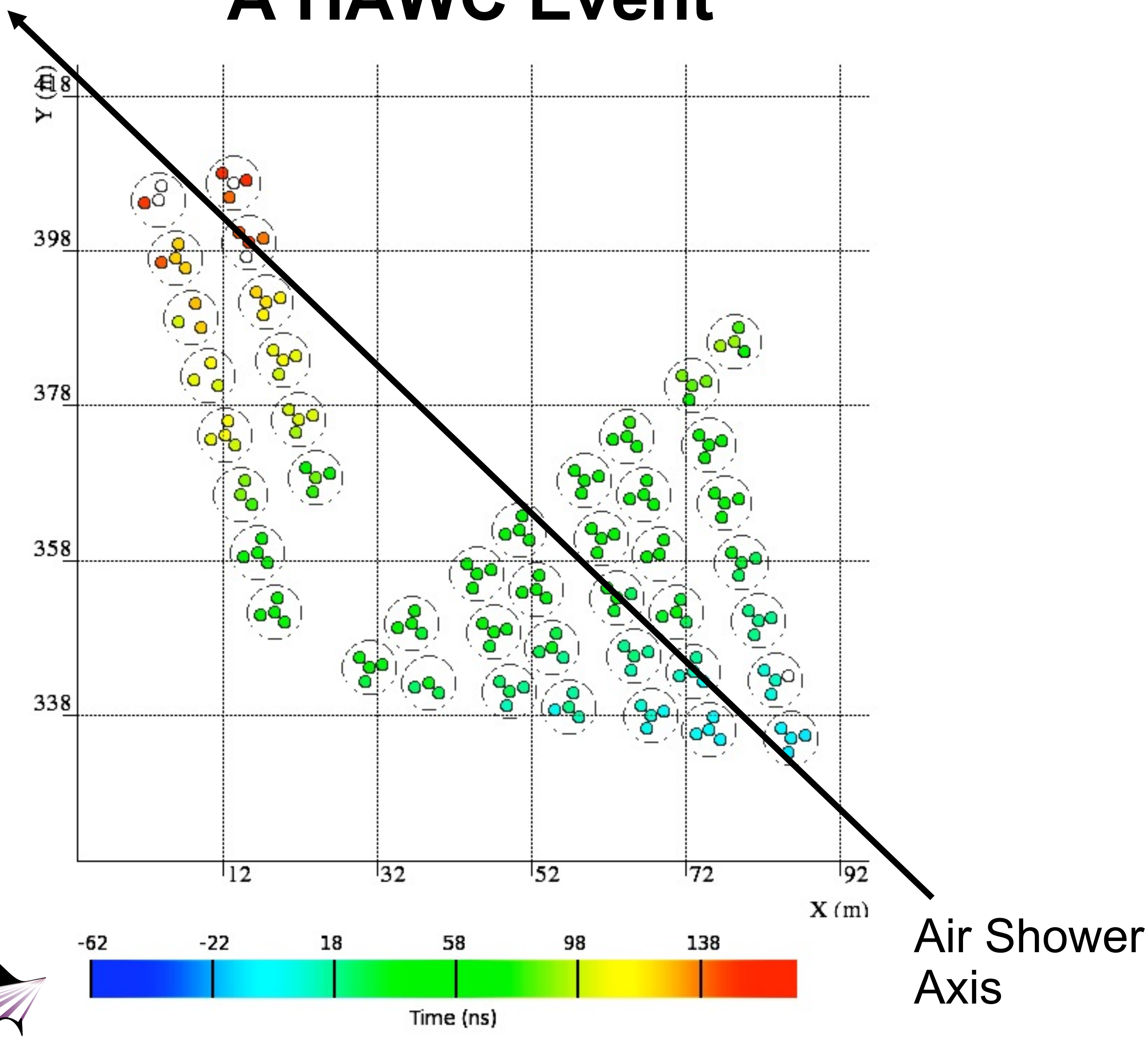
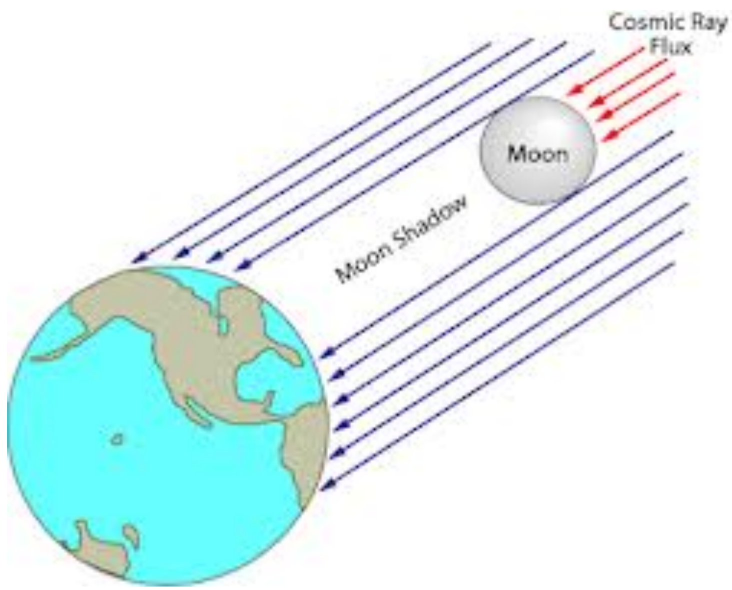
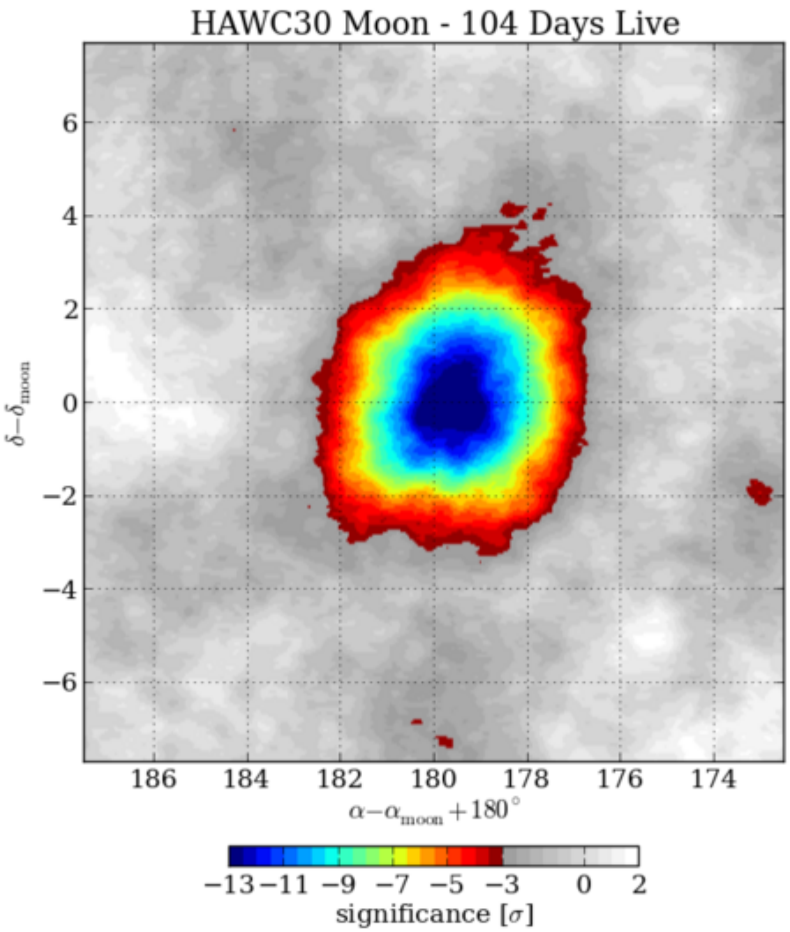
A HAWC Event



Y (m)
418
398
378
358
338
12
32
52
72
92
X (m)
-62
-22
18
58
98
138
Time (ns)
Air Shower Axis

HAWC-30 Results: Moon Shadow





13 σ deficit observed

→ Confirms systematic pointing accuracy

HAWC's First Discovery!

Breakfast with Andrew Dunkley

6:00am - 6:40am
6:55am - 7:45am

HAWC discovers Moon

17/04/2013 , 8:44 AM by Andrew Dunkley

It's not what you think, we don't have a new Moon orbiting the planet.

This is about a new telescope in Mexico which has been built at an altitude of 4,400 metres and it's very different.

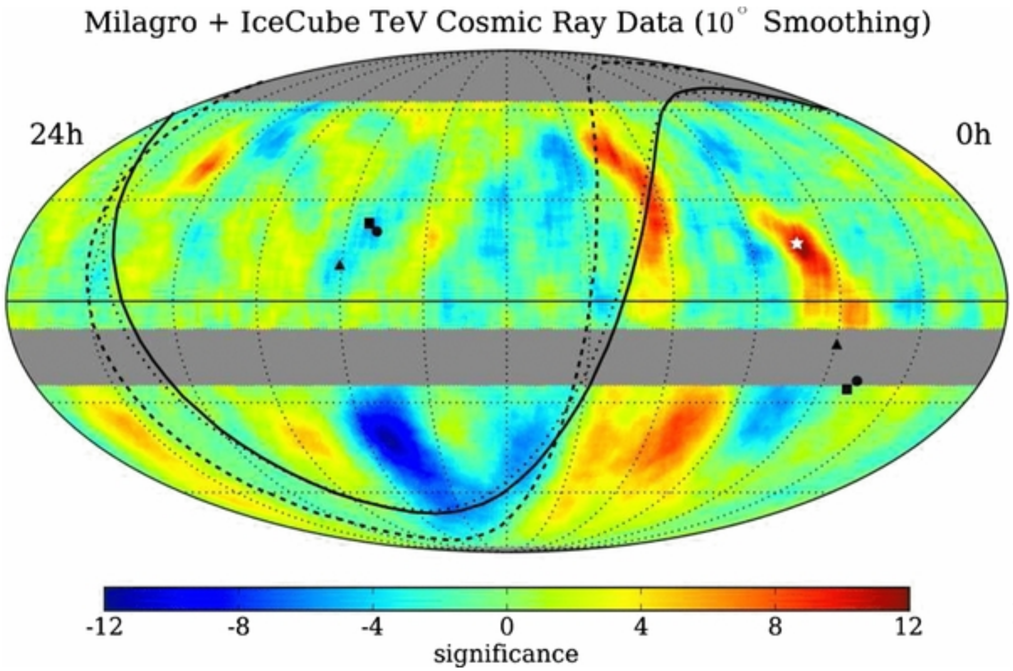
This one doesn't use light and mirrors to see what's going on in space it uses water which is held in a series of tanks designed to catch cosmic particles.

In a test run the High Altitude Cherenkov Water Observatory or HAWC detected our Moon, which simply confirmed that the thing works.

Fred Watson from the Australian Astronomical Observatory explains...

http://blogs.abc.net.au/nsw/2013/04/hawc-discovers-moon.html

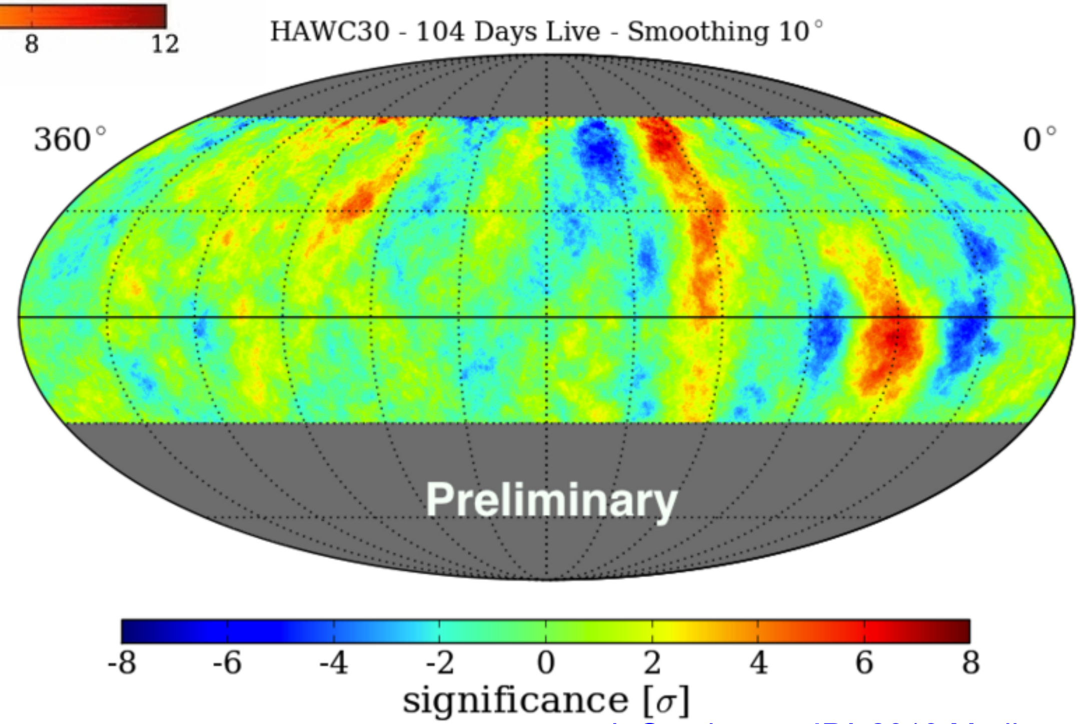
Small Scale Cosmic Ray Anisotropy



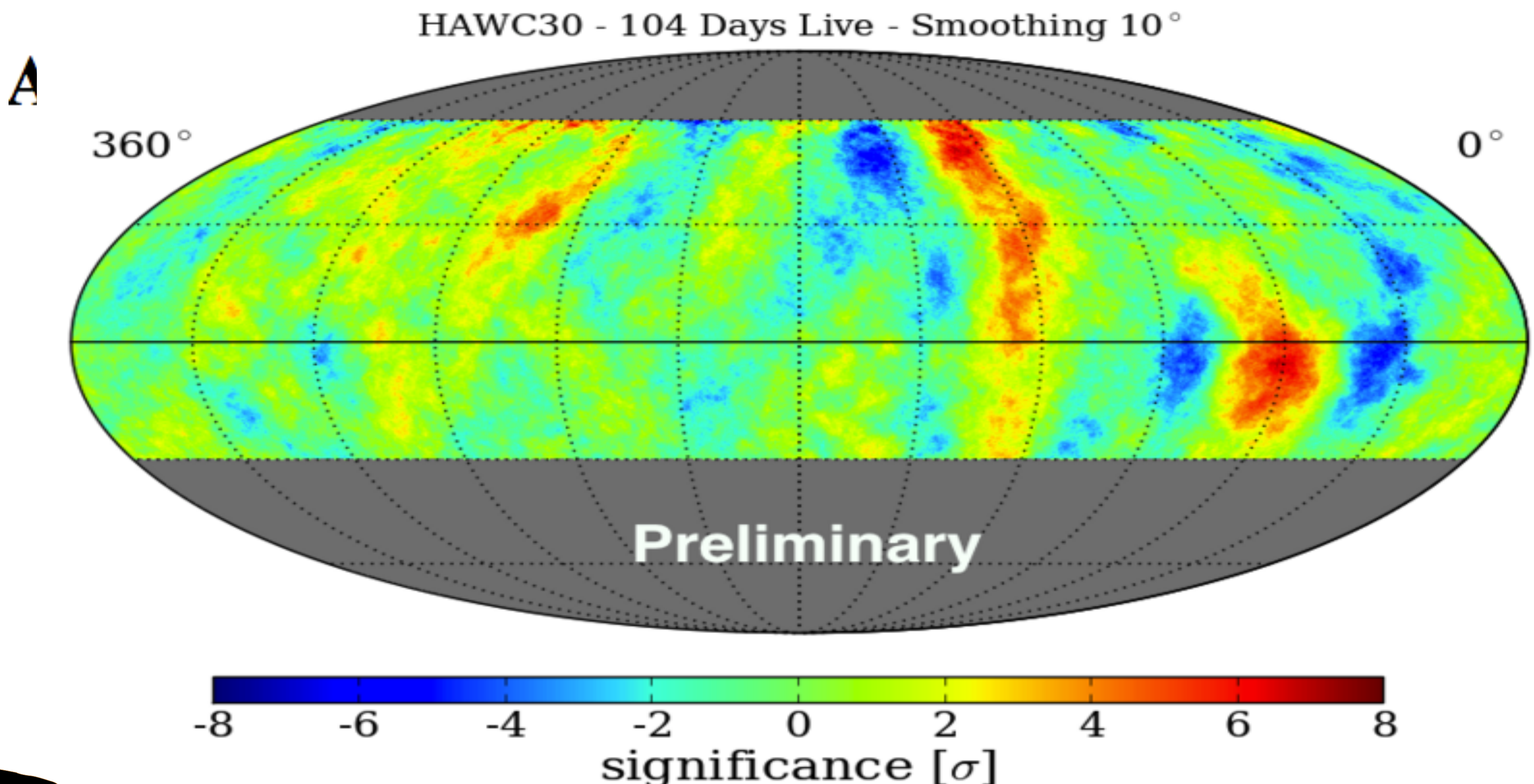
Milagro + IceCube

ApJ 740, 16 (2011)

HAWC

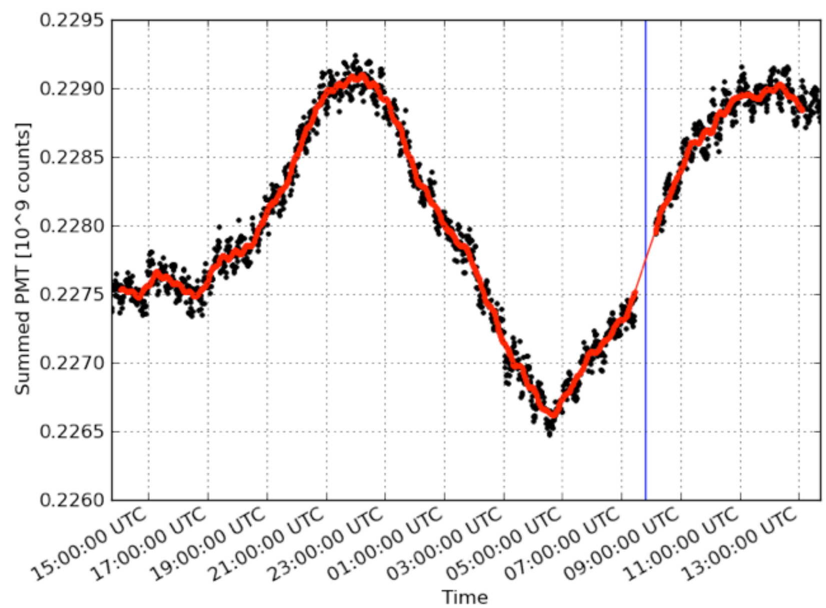


HAWC-30 - ARGO


HAWC30 - 104 Days Live - Smoothing 10°
360°
0°
Preliminary
-8
-6
-4
-2
0
2
4
6
8
significance [σ]

GRB 130427a

- This was the extremely bright GRB detected by Fermi on April 27, 2013
- The burst was at a zenith angle of 57^{o} at HAWC and setting
    - Sensitivity at this zenith angle is ~ 2 orders of mag less than at near zenith
- The main DAQ was not running
- The scaler DAQ was running

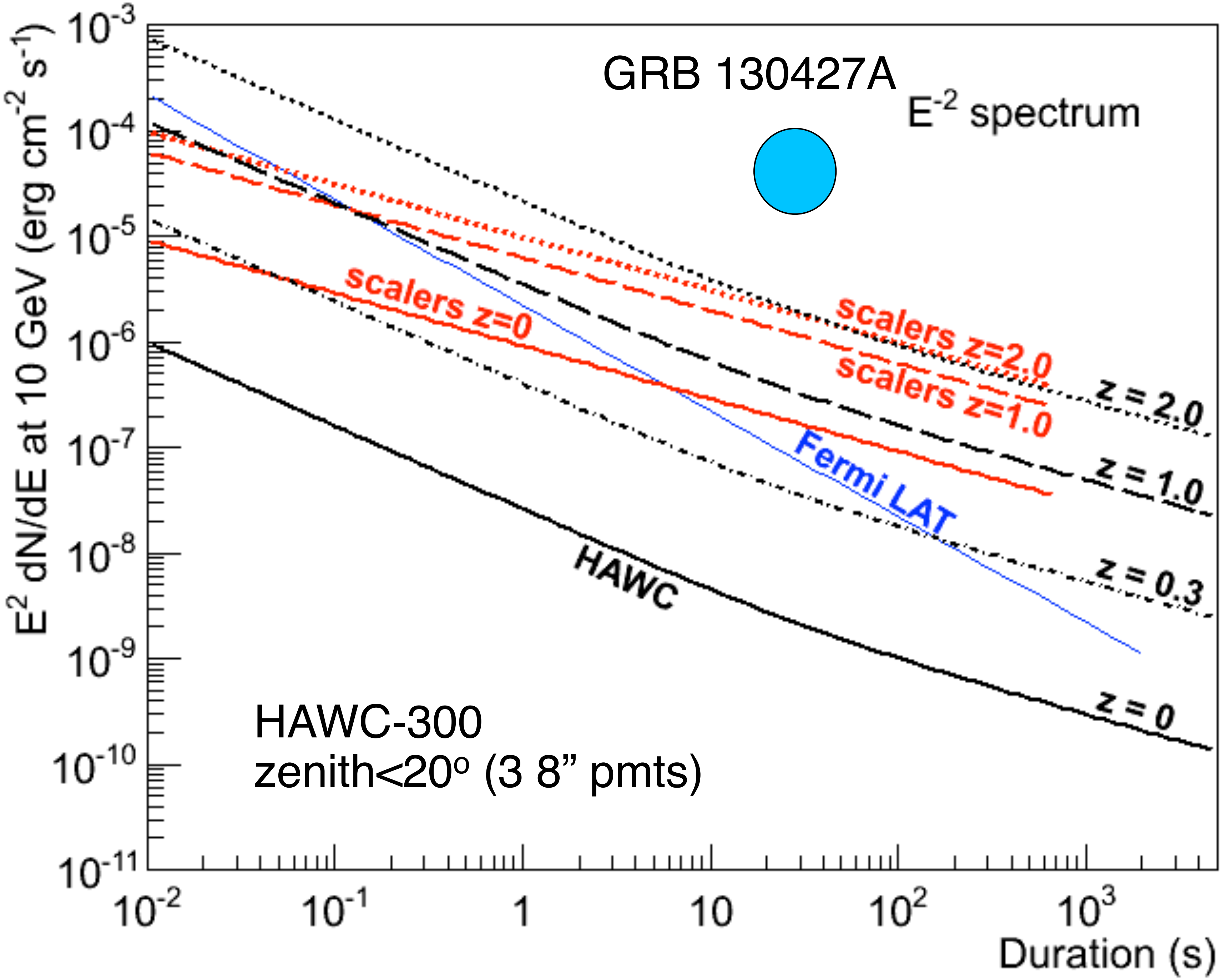


GRB 130427a

- We used 6 search windows

0 to 20s	-5 to 55s	-5 to 145s	120 to 300s	230 to 290s	-10 to 290s
+38960	-77884	-337877	-165991	-519485	-1036
17%	78%	95%	71%	90%	50%

Our observations are consistent with background only.



GRB 130427A
E^-2 spectrum
scalers z=0
scalers z=2.0
scalers z=1.0
z = 2.0
z = 1.0
z = 0.3
z = 0
Fermi LAT
HAWC
HAWC-300
zenith<20° (3 8" pmts)
E^2 dN/dE at 10 GeV (erg cm^-2 s^-1)
Duration (s)
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-2
10^-1
1
10
10^2
10^3

HAWC Construction Schedule

Feb. 2011: Construction began

Now: 87 tanks, 43 in data stream another ~40 this week

Summer 2013: 111 tanks

Sensitivity: ~5x Milagro

Fall 2014: 250 tanks (300 by end of fall)

Sensitivity: ~15x Milagro