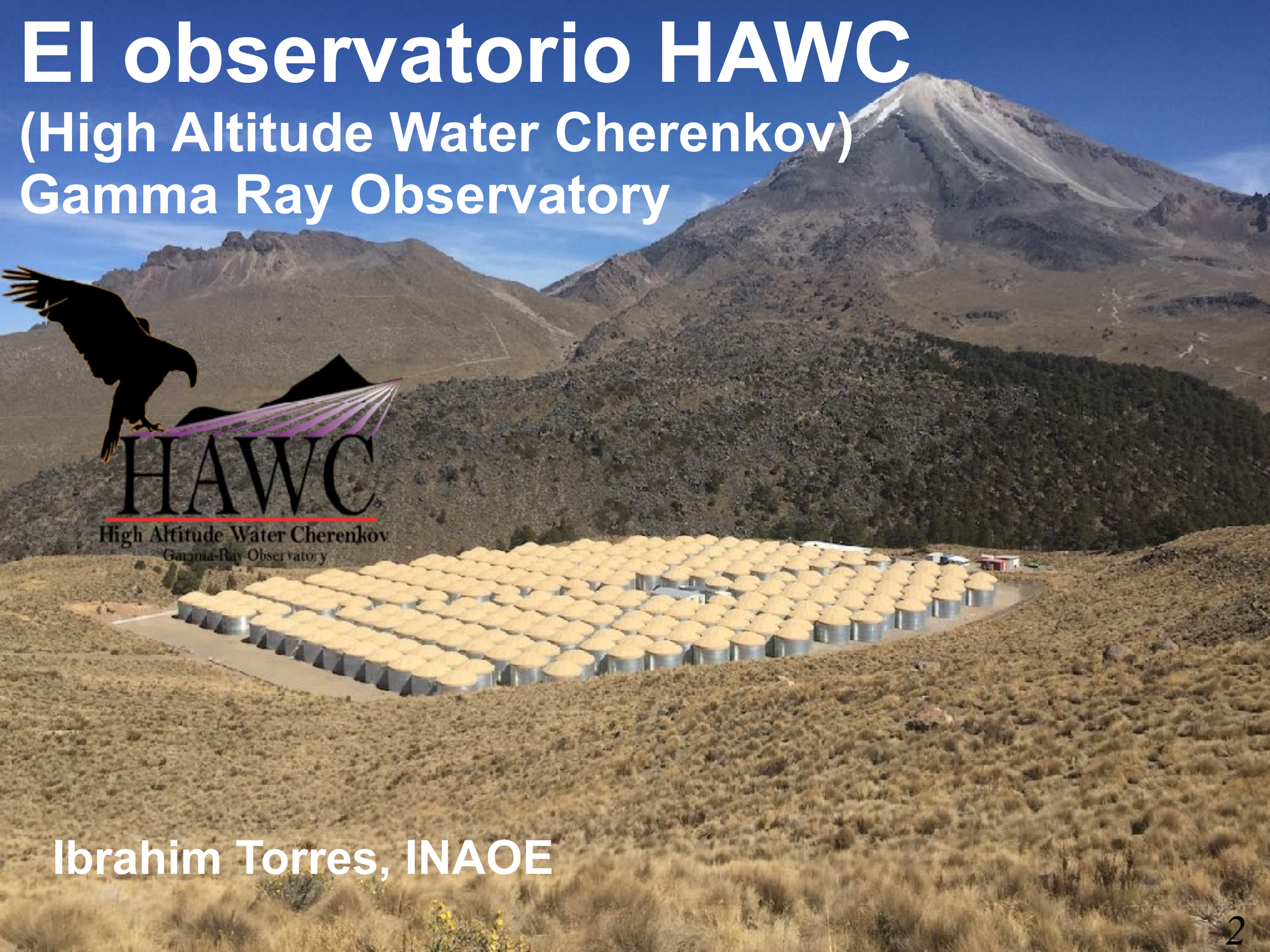
El observatorio HAWC
(High Altitude Water Cherenkov) Gamma Ray Observatory



Ibrahim Torres, INAOE

Mapping the Northern Sky in High-Energy Gamma Rays

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

HAWC Observatory

HAWC operates day and night, providing a large field of view for the observation of the highest energy gamma rays.

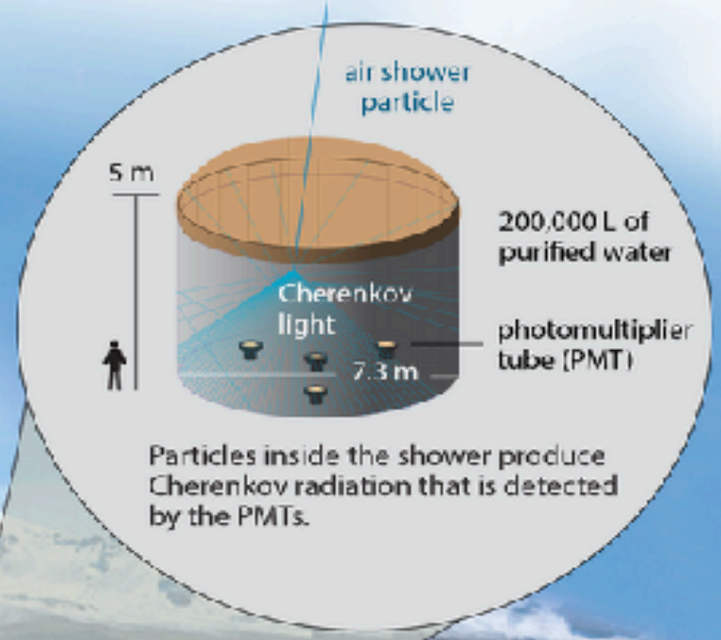
Pico de Orizaba
(5,626 m)

HAWC is located at 4,100 m above sea level, covering an area of 20,000 m².

150 m

Water Cherenkov tank

HAWC comprises an array of 300 tanks that record the particles created in gamma-ray and cosmic-ray showers.

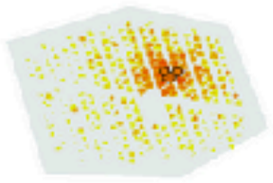


Particles inside the shower produce Cherenkov radiation that is detected by the PMTs.

Gamma rays vs cosmic rays

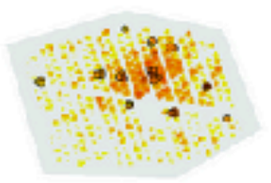
HAWC selects gamma rays from among a much more abundant background of cosmic rays.

gamma-ray shower



"hot" spots concentrate around the core

cosmic-ray shower

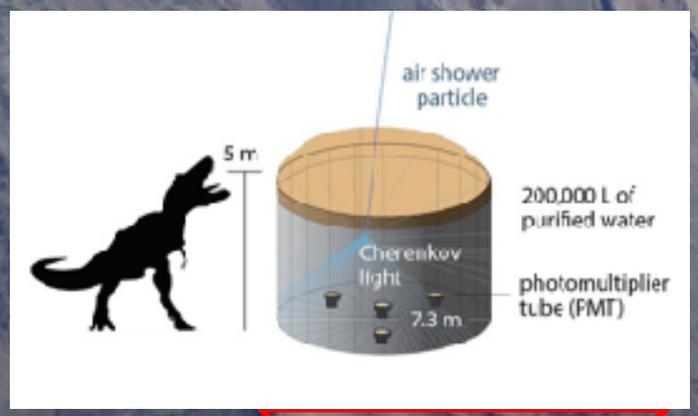


"hot" spots are more dispersed

HAWC Detector

- ***22,000 m²*** *air shower array*
- ***300 Water Cherenkov detectors*** *(WCD)*
- ***200,000 liters*** *of purified water* ***per WCD***
- ***4 sensors (photo-multiplier tubes) per WCD***
- ***Completed March 2015***

Citlaltepetl
Pico de Orizaba
5160m a.s.l.



HAWC
4100 m a.s.l.

Tliltepetl
Sierra Negra
4582m a.s.l.

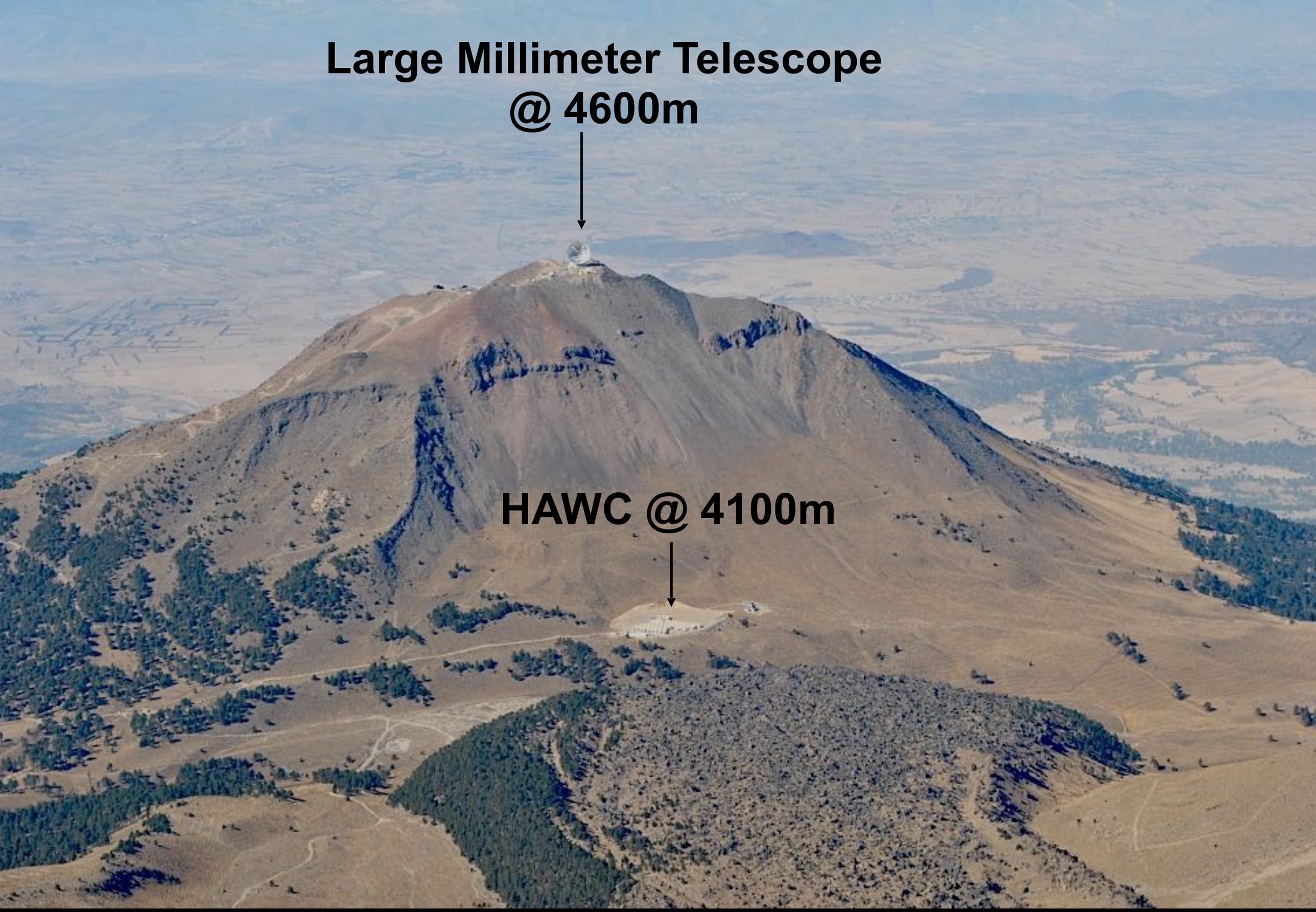
***L**arge **M**illime*
***T**elescope*

HAWC

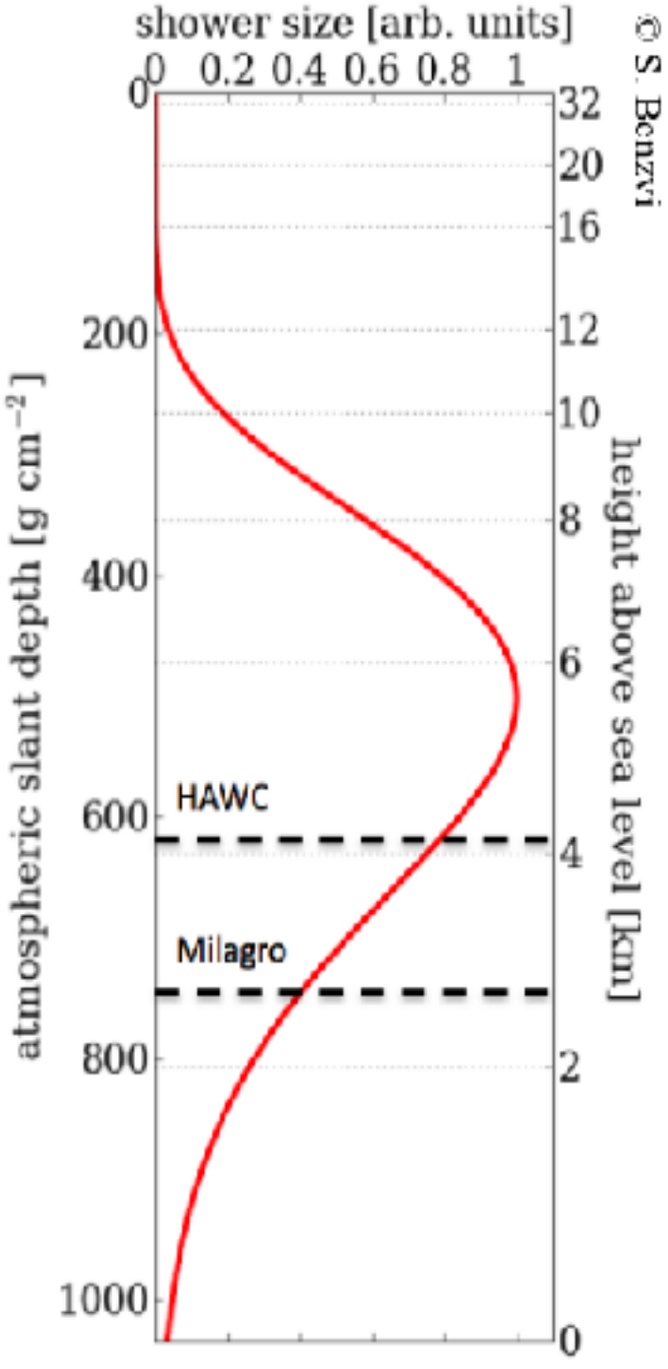
Pico de Orizaba
“Citlaltepetl”
5610m (18,400 ft)

Sierra Negra
“Tliltepetl”
4582m (15,000 ft)

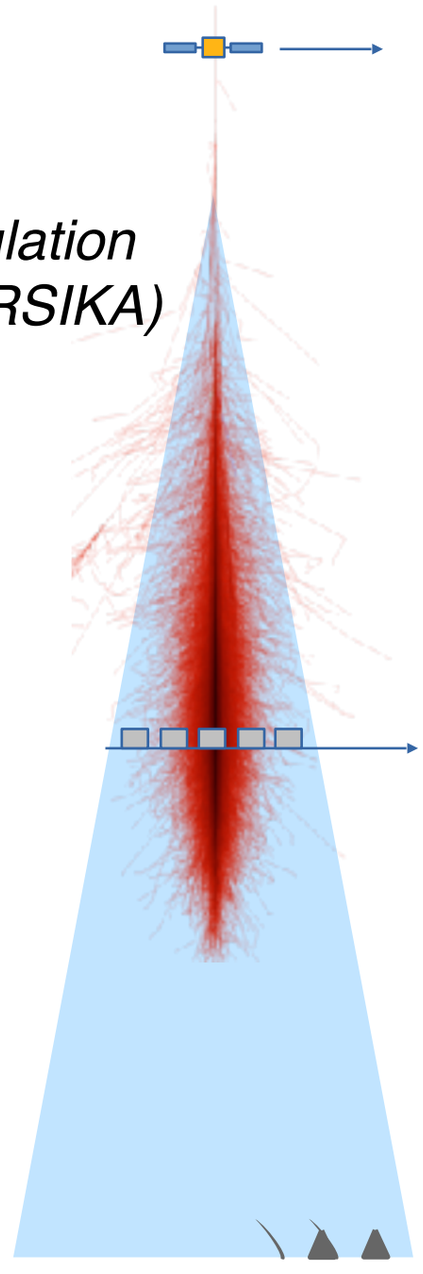
Latitude 19ºN, Longitude = 97ºW.
In the Mexican state of Puebla,
4hr drive East of Mexico City.


Large Millimeter Telescope
@ 4600m
HAWC @ 4100m

High Energy Gamma-Ray Detectors



Simulation (CORSIKA)



Wide Field of View, Continuous Operations

Satellite Detector

Extensive Air Shower (EAS) Detector

TeV Sensitivity

Imaging Atmospheric Cherenkov Telescope (IACT)

HAWC Site in Mexico

- High Altitude Site of 4100 m
- Temperate climate
- Existing infrastructure of electricity and internet within 1 km at LMT
- Latitude of 19 deg N

Gran Telescopio Milimétrico Alfonso Serrano (50m dia dish)

Pico de Orizaba 5600 m (18,500')

The HAWC Collaboration

Mexico

Instituto Nacional de Astrofísica, Óptica y Electrónica

Universidad Nacional Autónoma de México

- Instituto de Astronomía UNAM
- Instituto de Ciencias Nucleares UNAM
- Instituto de Física UNAM
- Instituto de Geofísica UNAM

Benemérita Universidad Autónoma de Puebla

Instituto Politécnico Nacional

- Centro de Investigación y Estudios Avanzados
- Centro de Investigación en Cómputo

Universidad Autónoma de Chiapas

Universidad Autónoma del Estado de Hidalgo

Universidad de Guadalajara

Universidad Michoacana de San Nicolás de Hidalgo

Universidad Politécnica de Pachuca

United States

Los Alamos National Lab

University of Maryland

Georgia Institute of Technology

Michigan State University

Michigan Technological University

Pennsylvania State University

NASA GSFC & MSFC

University of New Mexico

University of Rochester

University of Utah

University of Wisconsin

Europe & Central America

Max Planck Institute, Heidelberg

University of Costa Rica

Krakow Nuclear Institute, Poland

- **HAWC construction began 2011 and finished March 2015.**
- **The project cost ~15M USD and was funded by NSF, DOE, and CONACYT.**
- **HAWC is planned to operate for at least 10 years.**

HAWC Detectors

High Altitude Water Cherenkov
Gamma-Ray Observatory

Steel frame construction

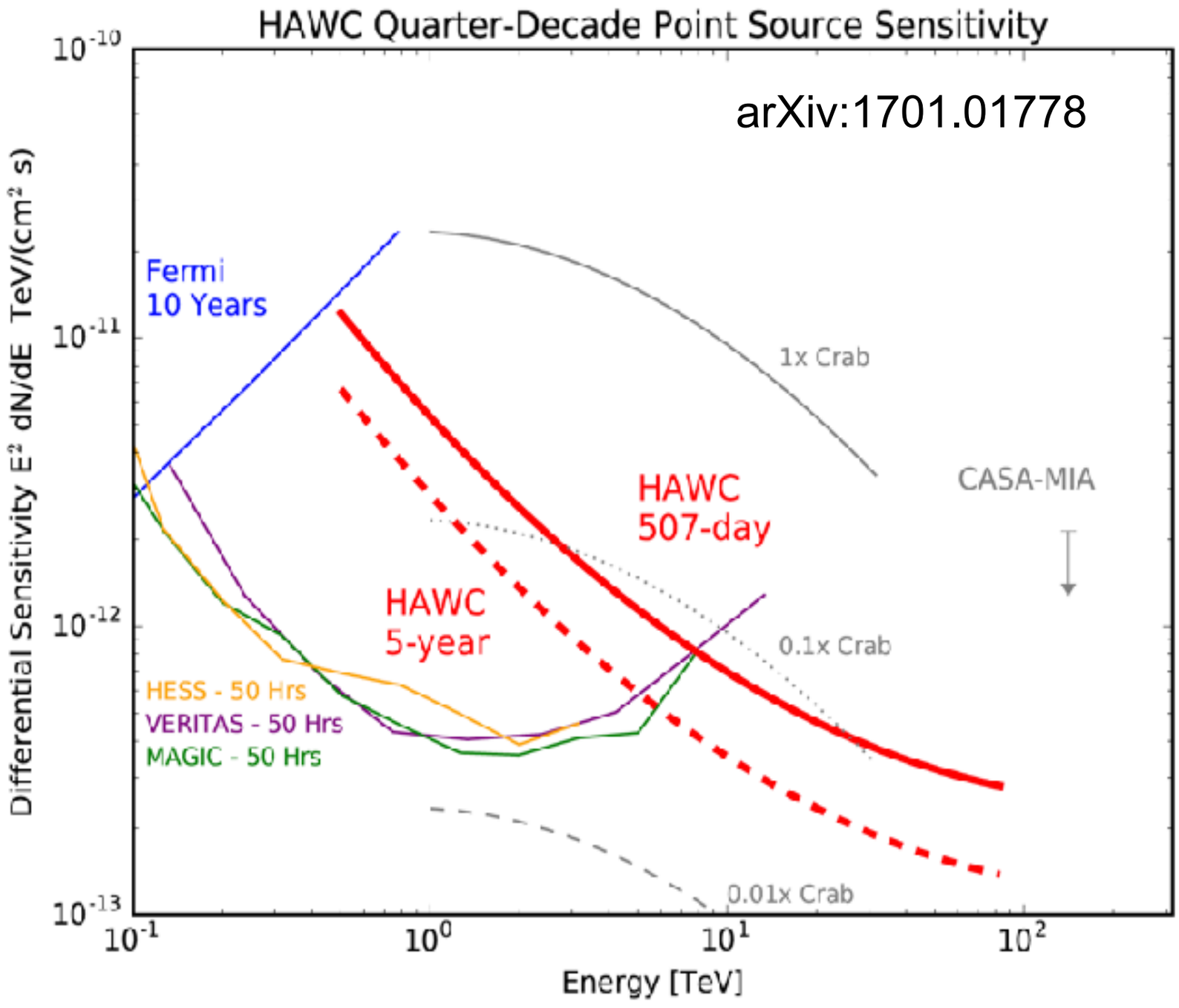
Large plastic bag container

Water trucks filling the tanks

8-inch 10-inch PMTs

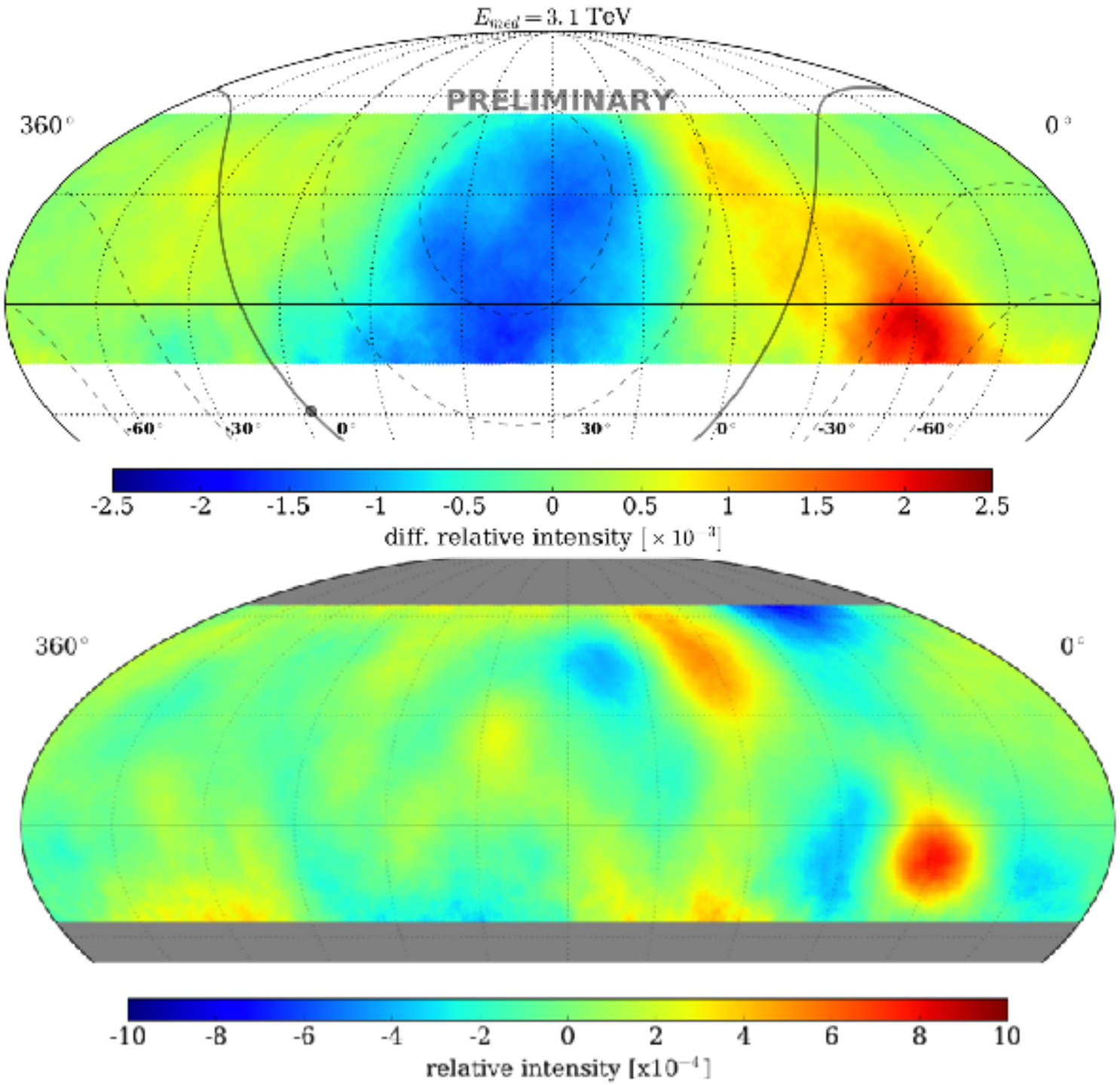
HAWC is the most sensitive observatory to the highest energy gamma rays

- HAWC has ~2 sr field of view and observes ~2/3 of the sky each day
- Long integration times give sensitivity to the highest energy gamma rays
- Angular resolution and field of view are similar to Fermi LAT



HAWC detects cosmic-rays, too (actually, mostly)

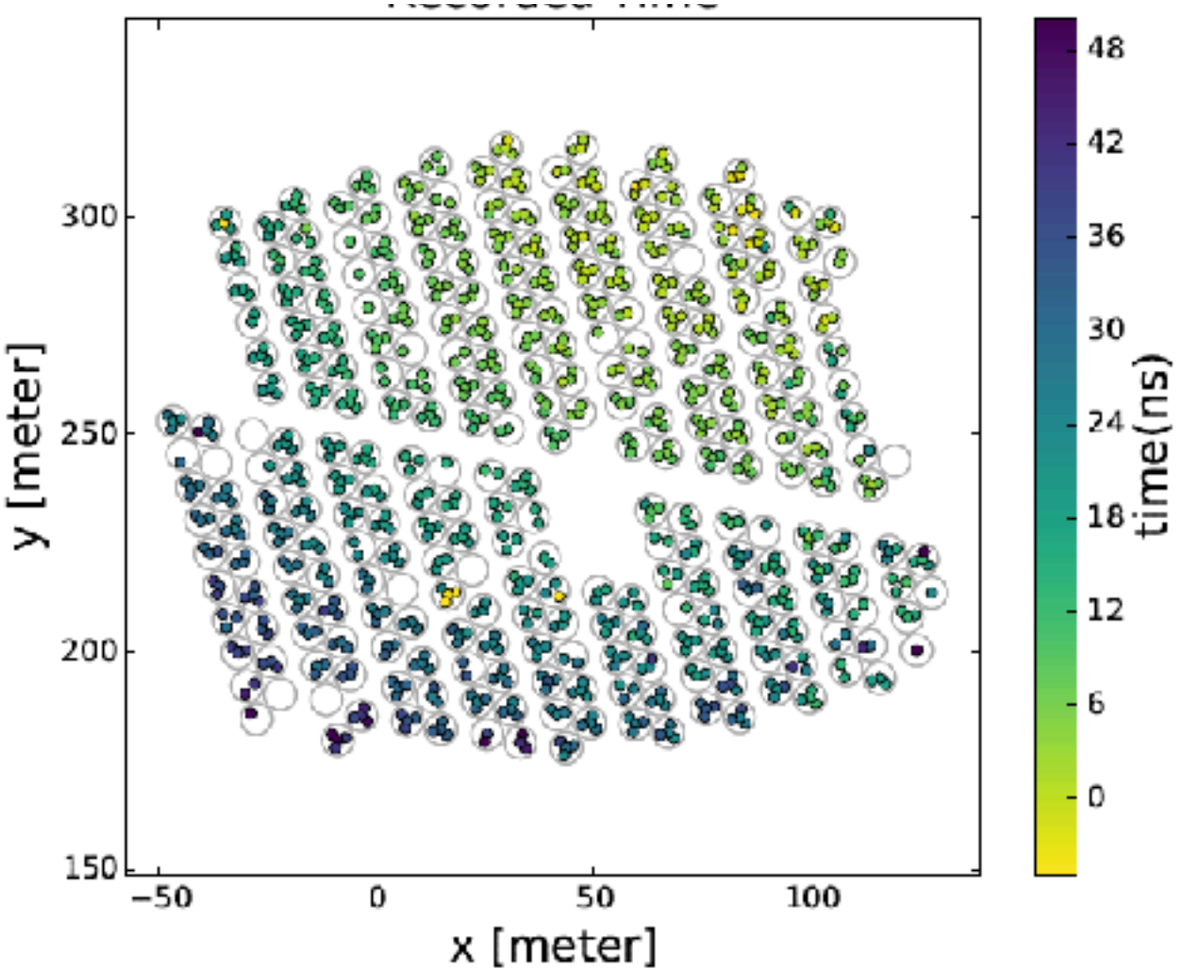
- ~20,000 cosmic rays showers are detected per second
- HAWC detects small fractional anisotropies on few degree angular scales
- Explanation likely requires non-isotropic propagation



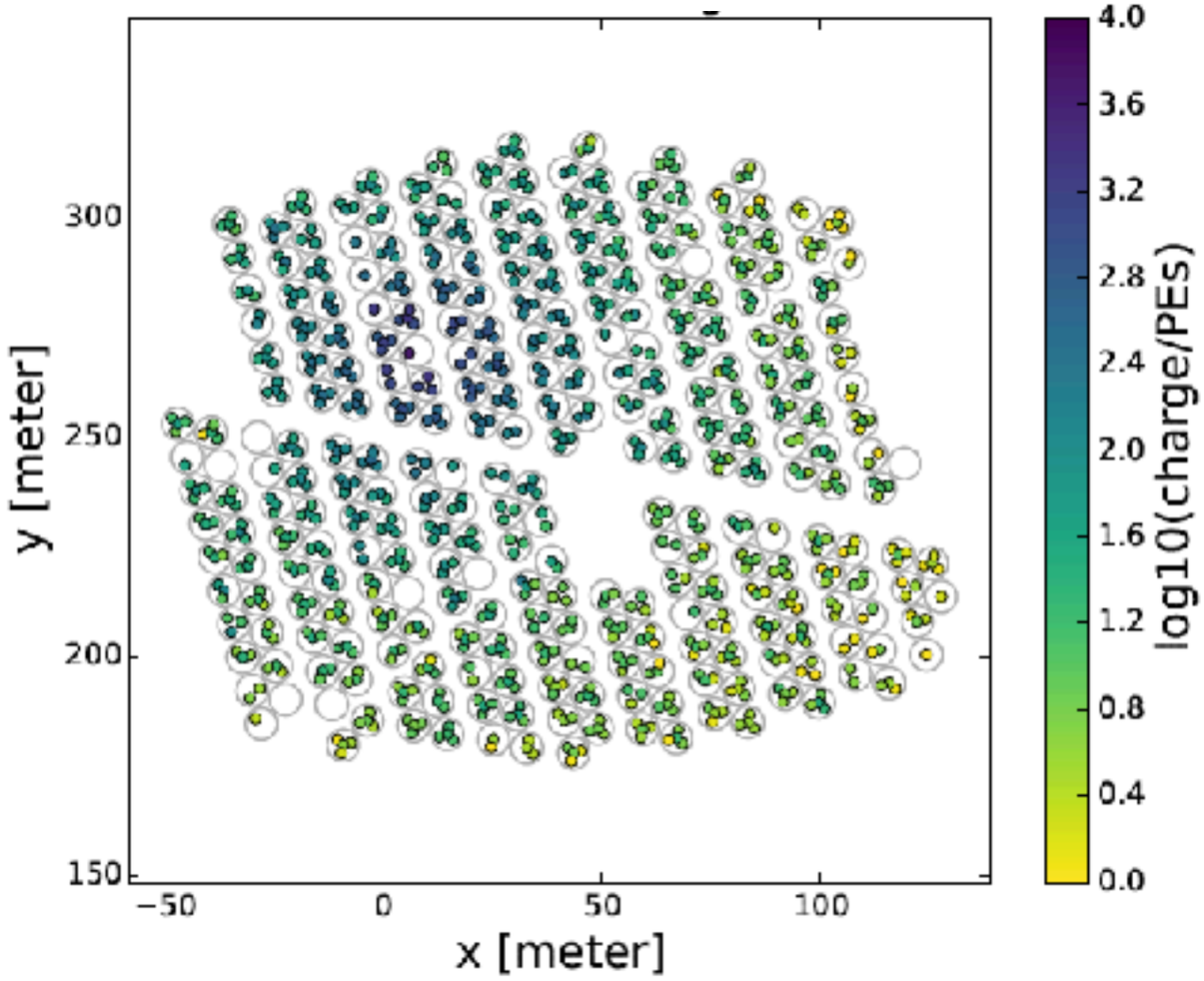
Shower reconstruction

- Measure: time and light level in each of our detectors
- Estimate: direction, location, energy, and background rejection

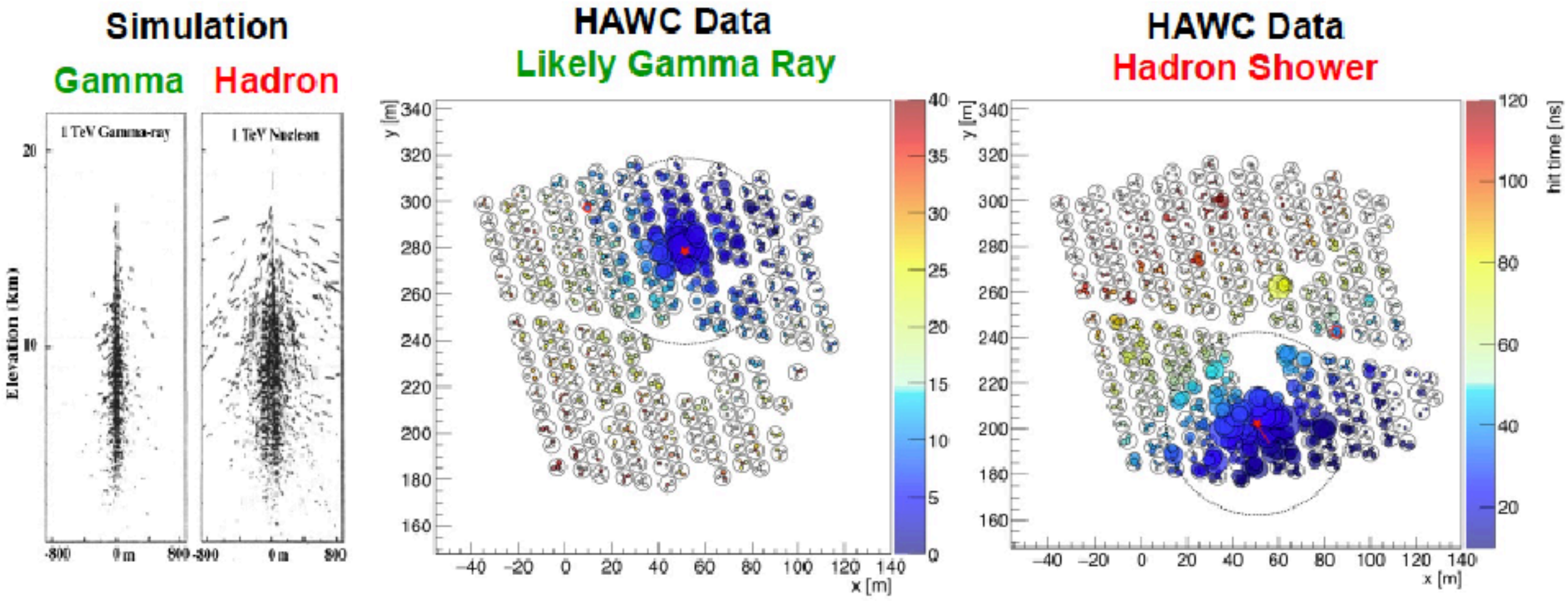
Measured Time



Measured Light Level



Gamma/Hadron separation

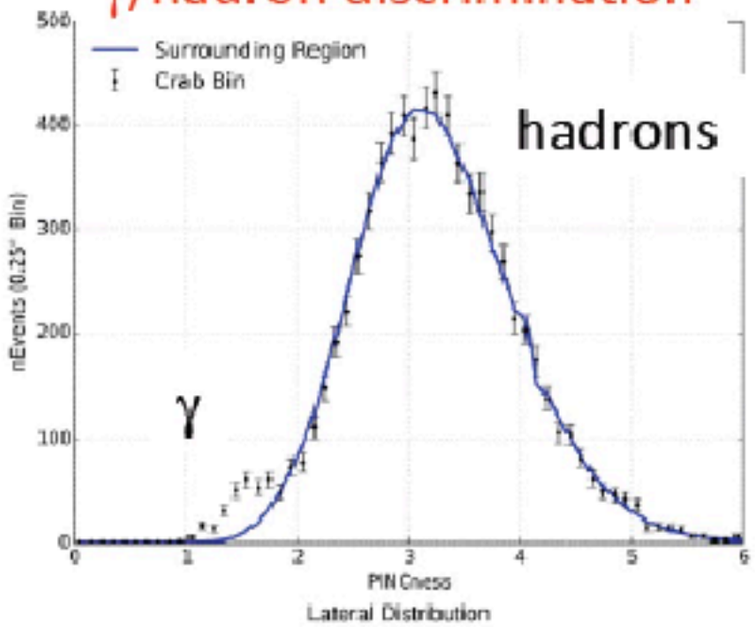


- Main background is hadronic CR, e.g. 400 γ/day from the Crab vs 15k CR/s.
- Gamma/hadron can be discriminated based on the event footprint on the detector: gamma-ray showers are more compact, cosmic rays showers tend to "break apart".

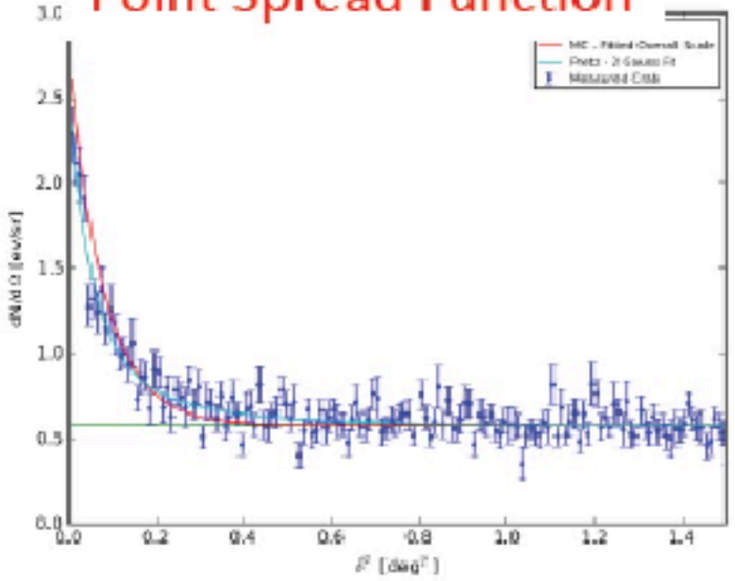
Crab with HAWC

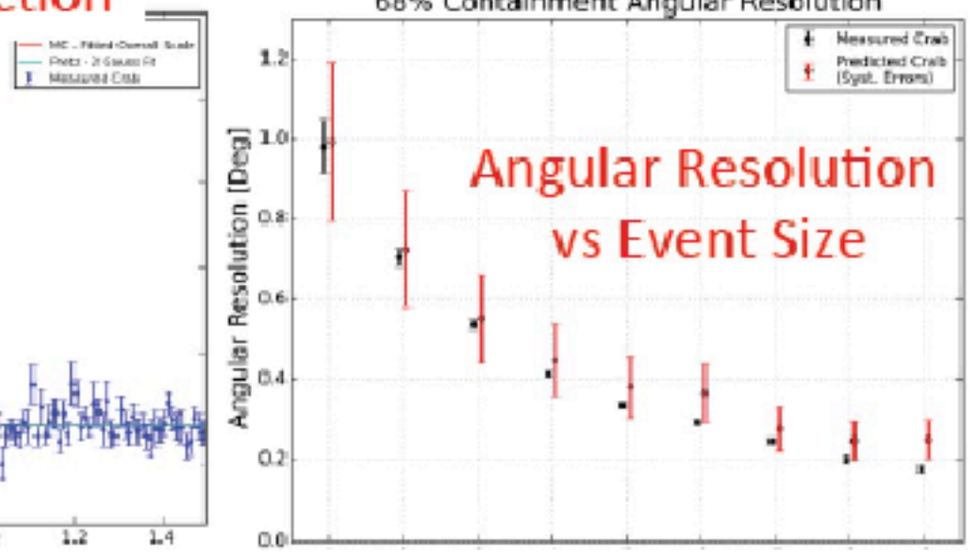
- The Crab is the brightest γ source detected by HAWC and is used to refine the analysis, validate the simulations, and probe the highest energy emission

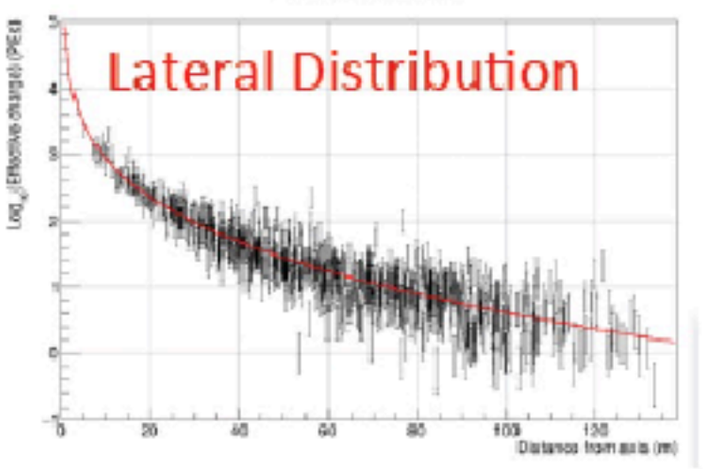
γ/hadron discrimination

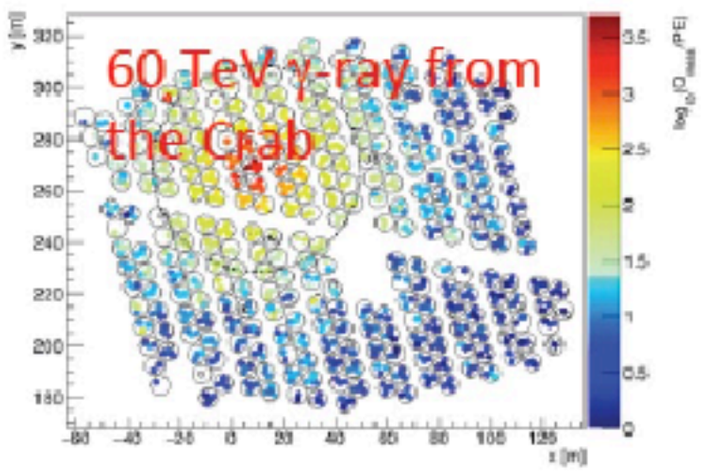


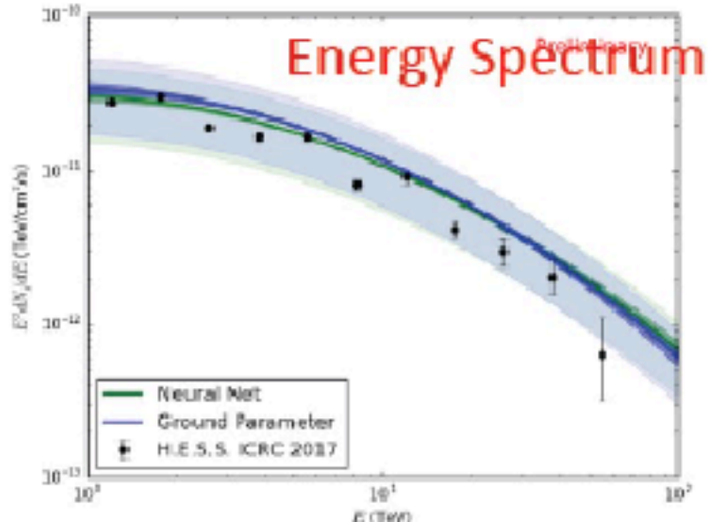
Point Spread Function



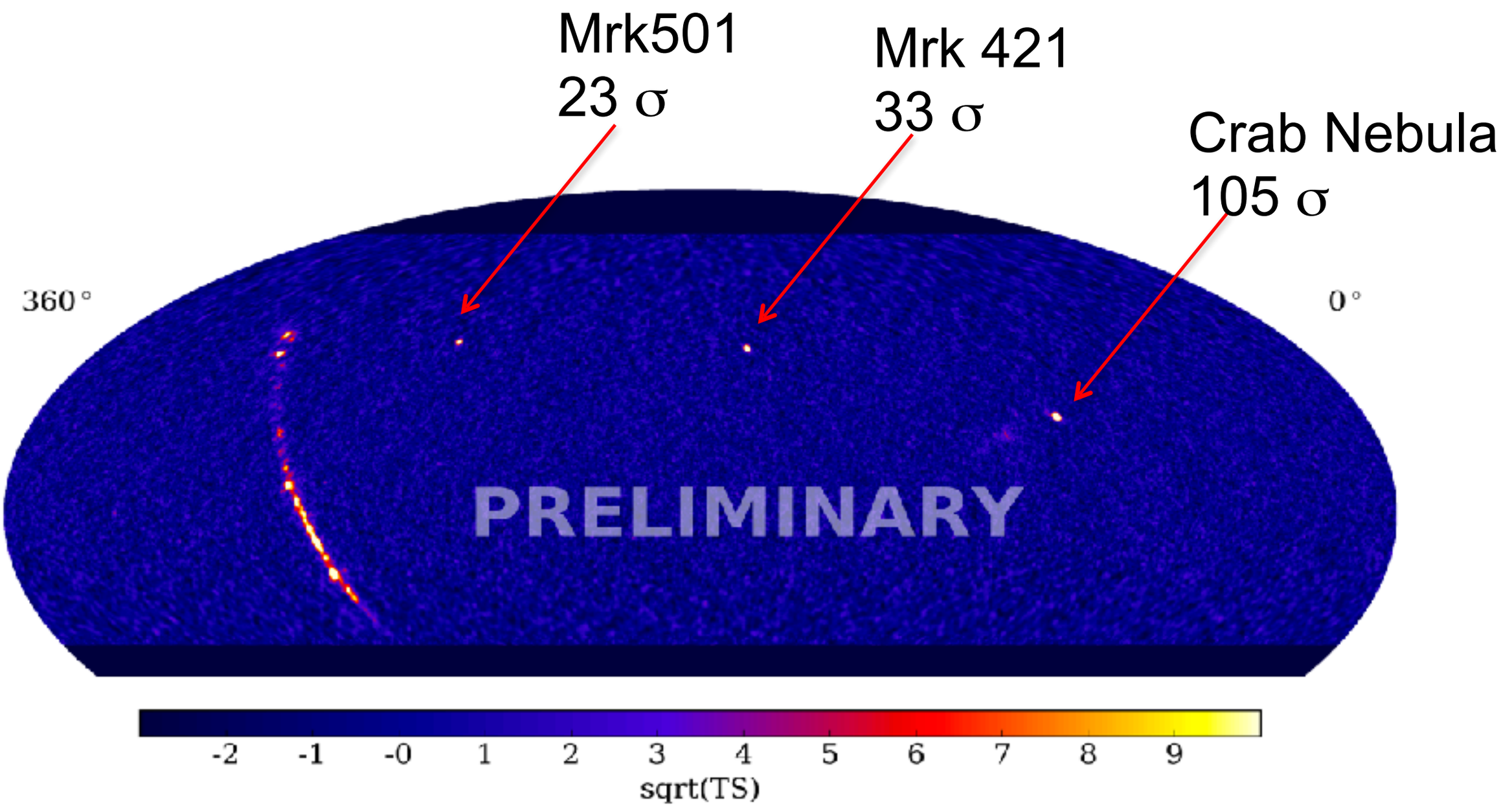






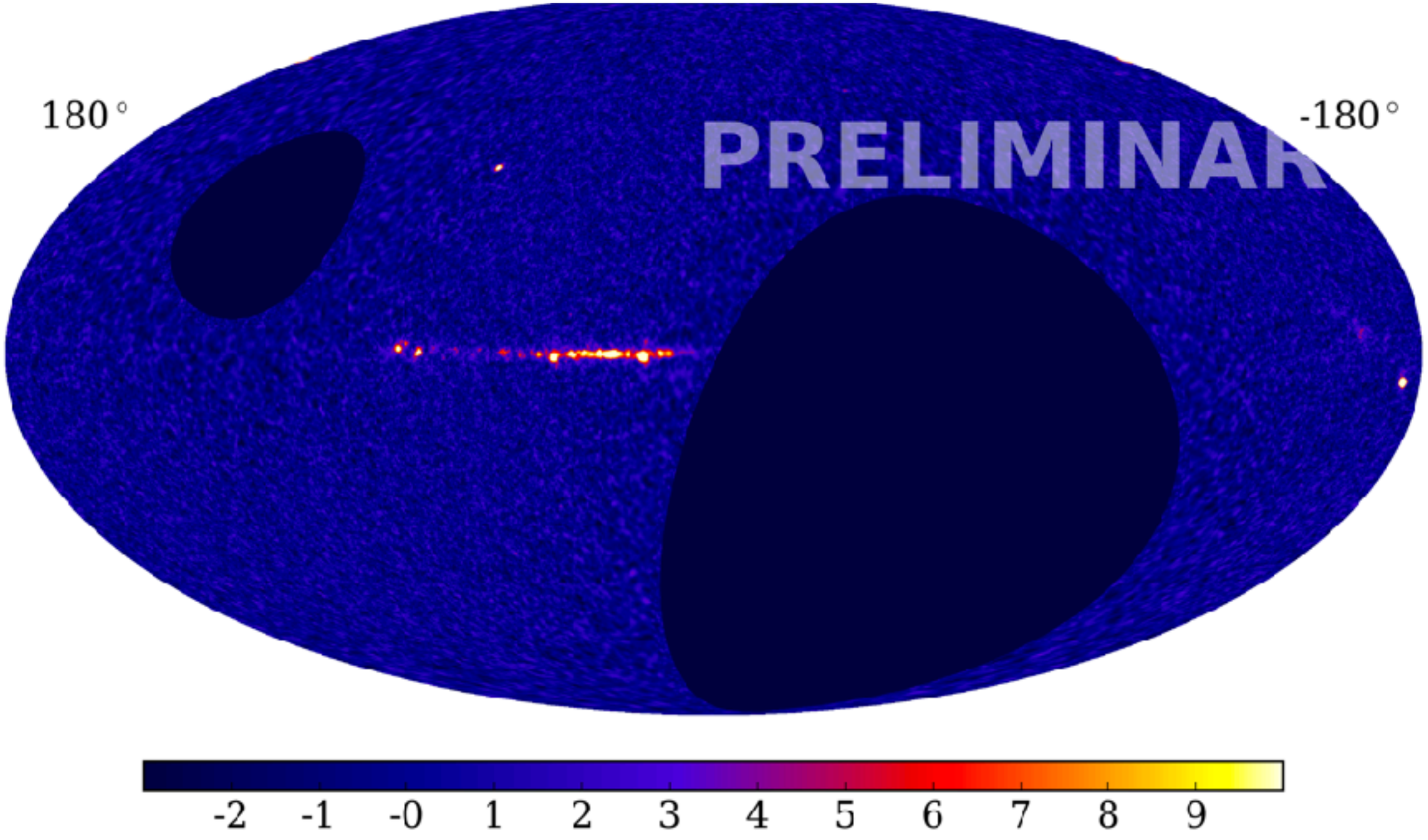


HAWC's 17 month Sky Map



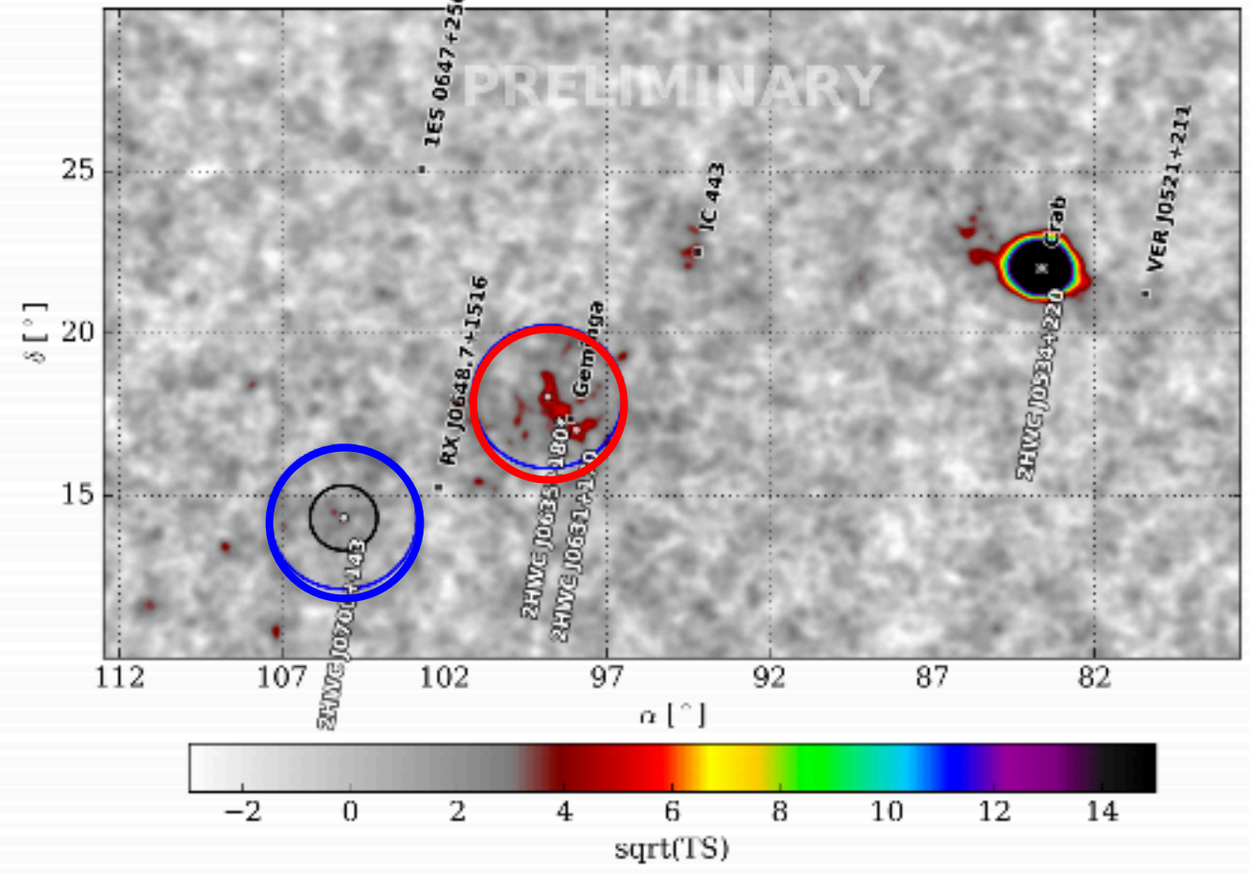
2HWC catalog arXiv:1702.02992

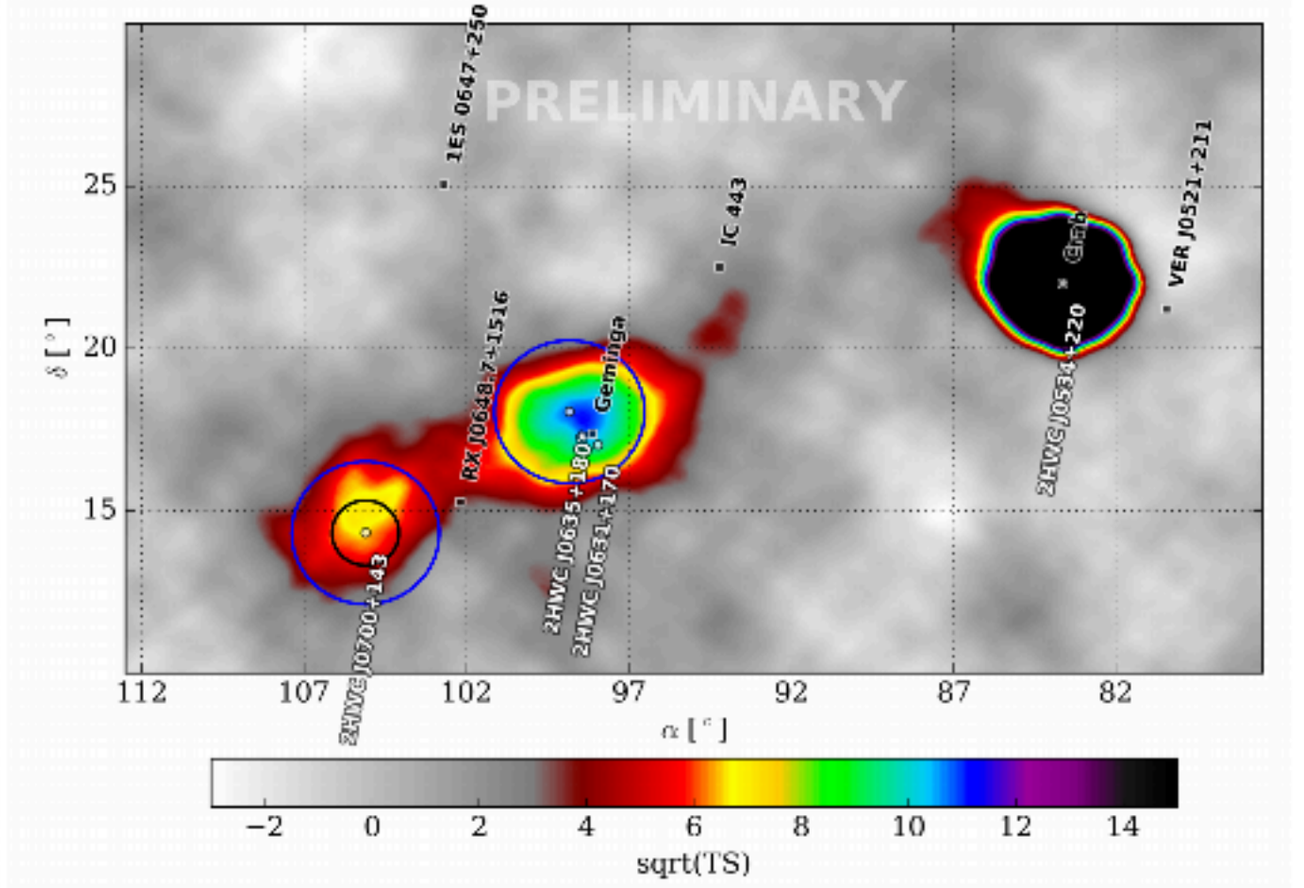
HAWC's 17 month Sky Map
In Galactic Coordinates



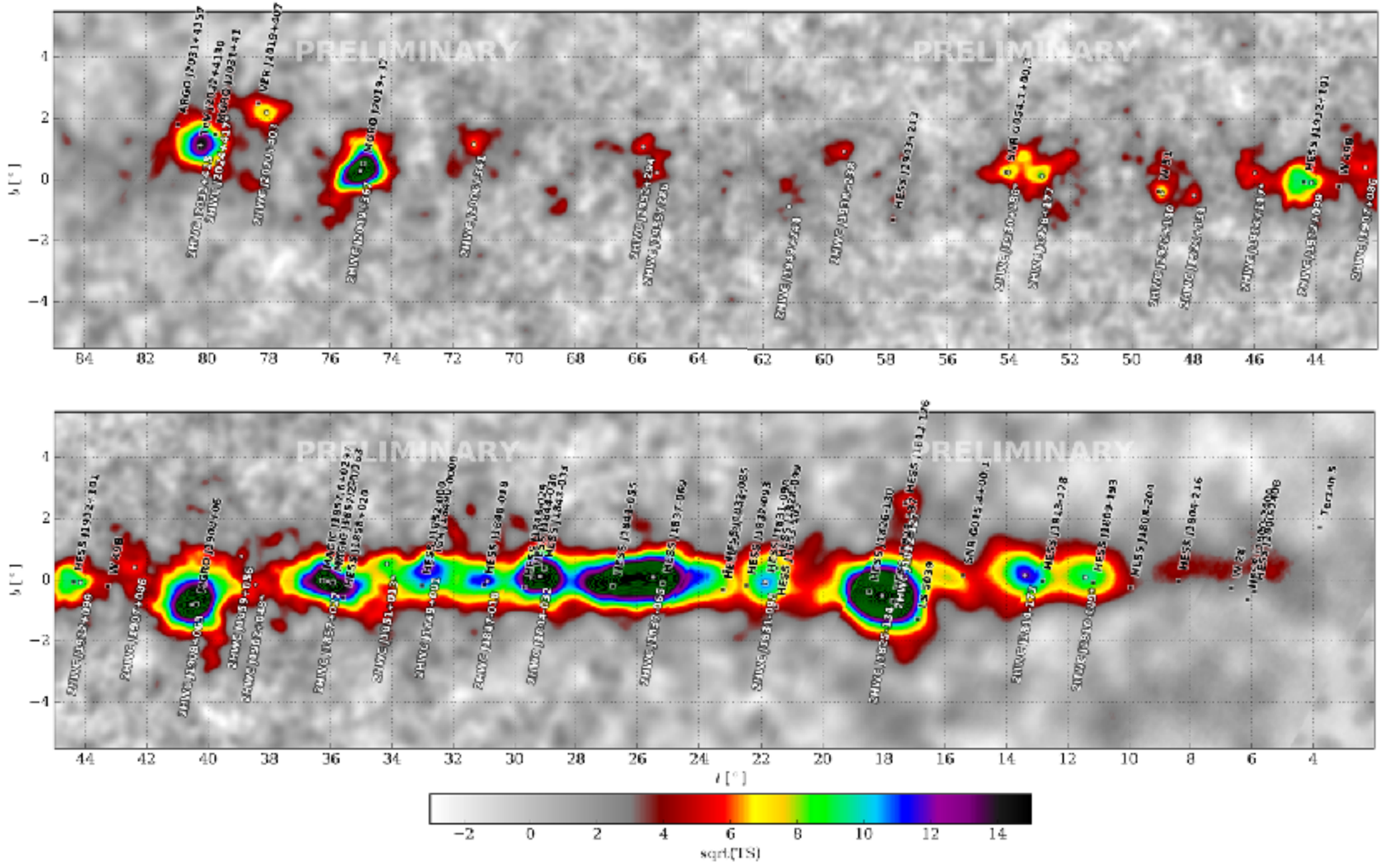
Nearby PWN are very extended

- **Geminga** and **PSR J0659+1414** (associated with Monogem SNR) are seen in 2^{o} radius (~ 10 pc) smoothed HAWC maps (right hand plot)
- Geminga (PSR J0659+1414) is 3(1)x10^{5} years old, low E/Edot~10$^{34.5}$ ergs/sec at distance ~250(288) pc and moderate velocity
- Postulated sources of PAMELA and AMS positron excess are the ~ 5 nearest pulsars of which these are two



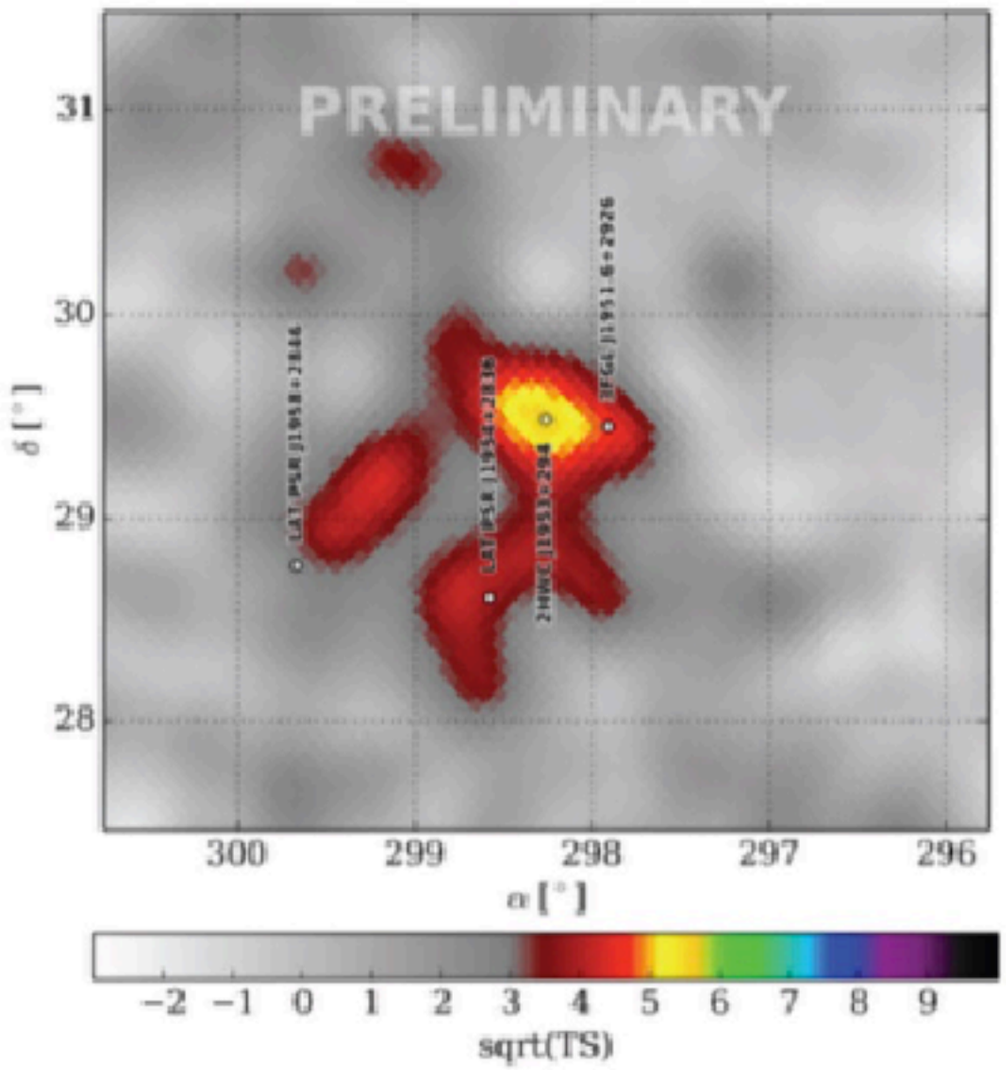


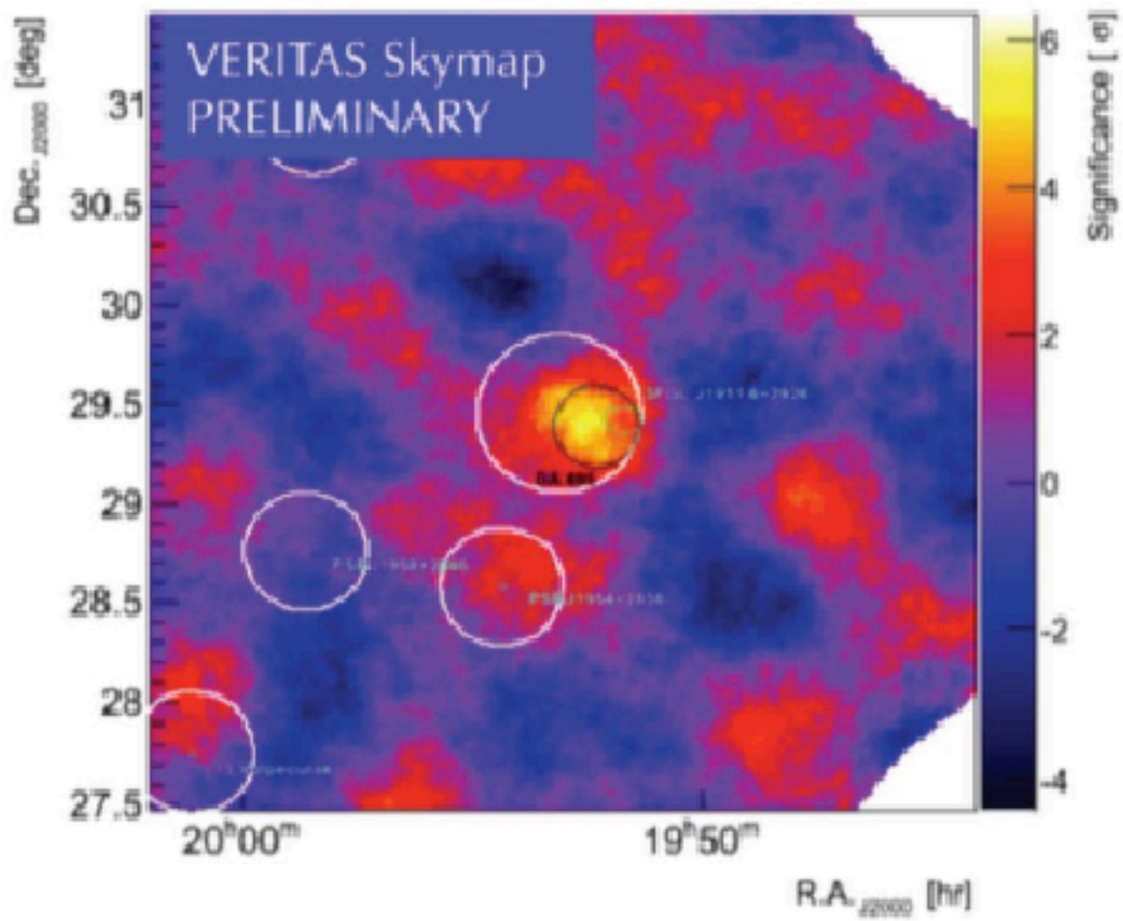
HAWC's current Galactic Plane has ~40 sources of which 1/4 are new



High Altitude Water Cherenkov
Gamma-Ray Observatory

VERITAS Confirms HAWC detection





Active Galactic Nuclei are Variable

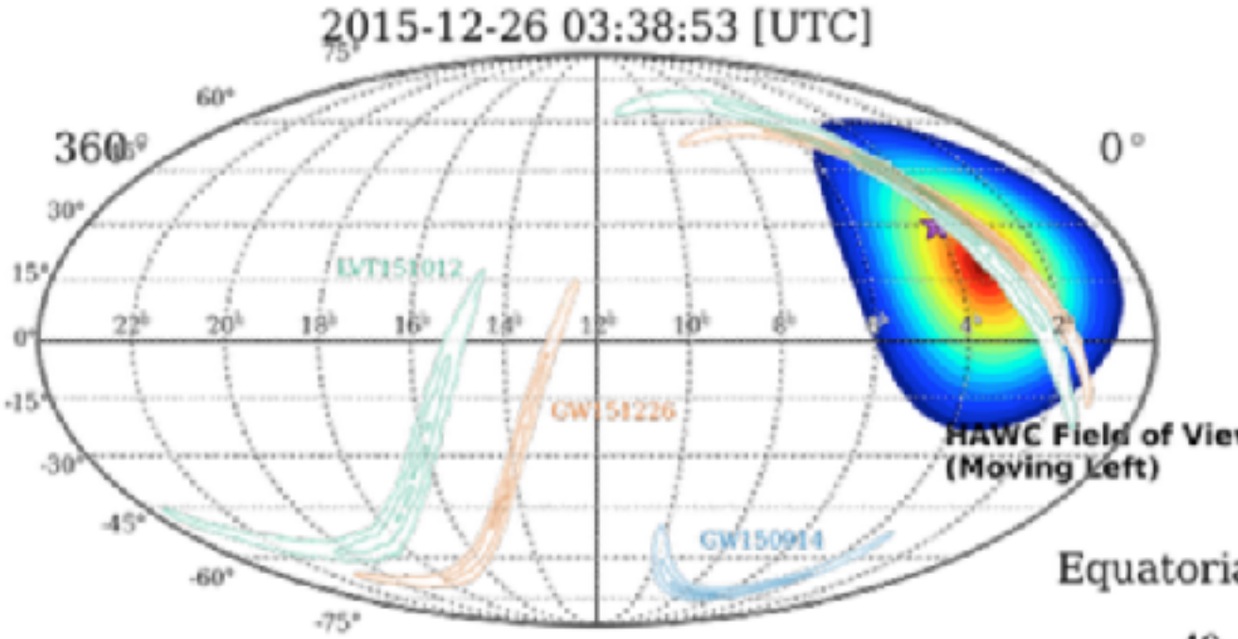
PRELIMINARY

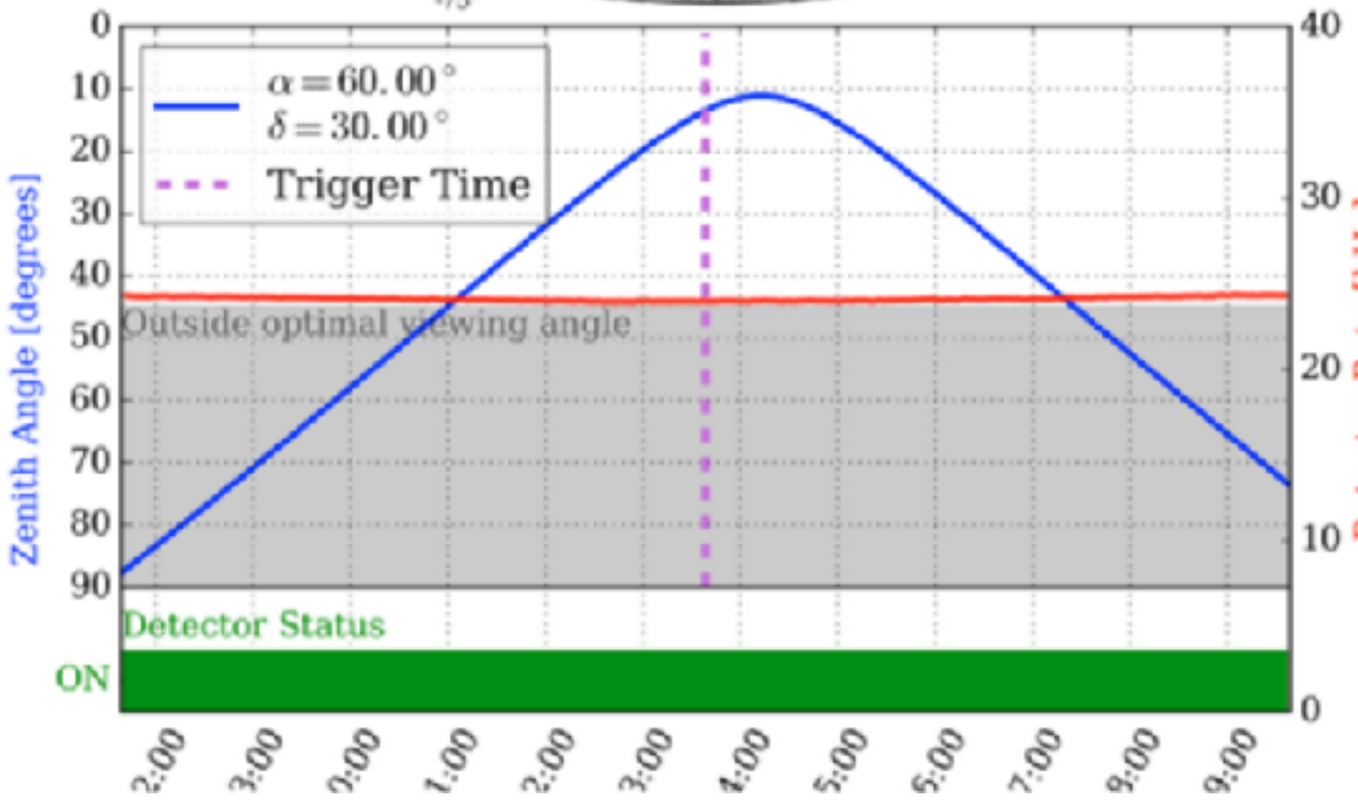
Gravitational Waves

GW151226

- 2015 Dec 26 03:38:53.6 UTC
- >5 sigma
- 14.2M⊙ + 7.5M⊙ ➡ 21.8M⊙
- z=0.09 +0.03 -0.04

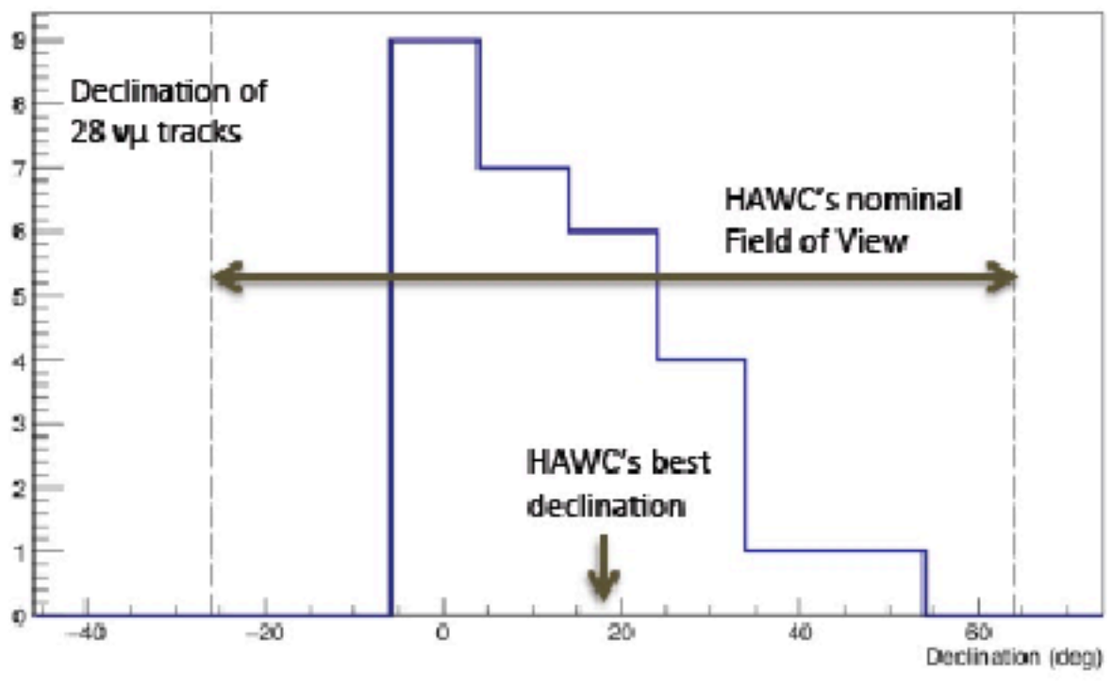
In HAWC we found a transient 9.93 seconds after the LIGO trigger with a duration of 10 s with 5 σ pre-trial but with a post-trial p=0.08 it is compatible with background.

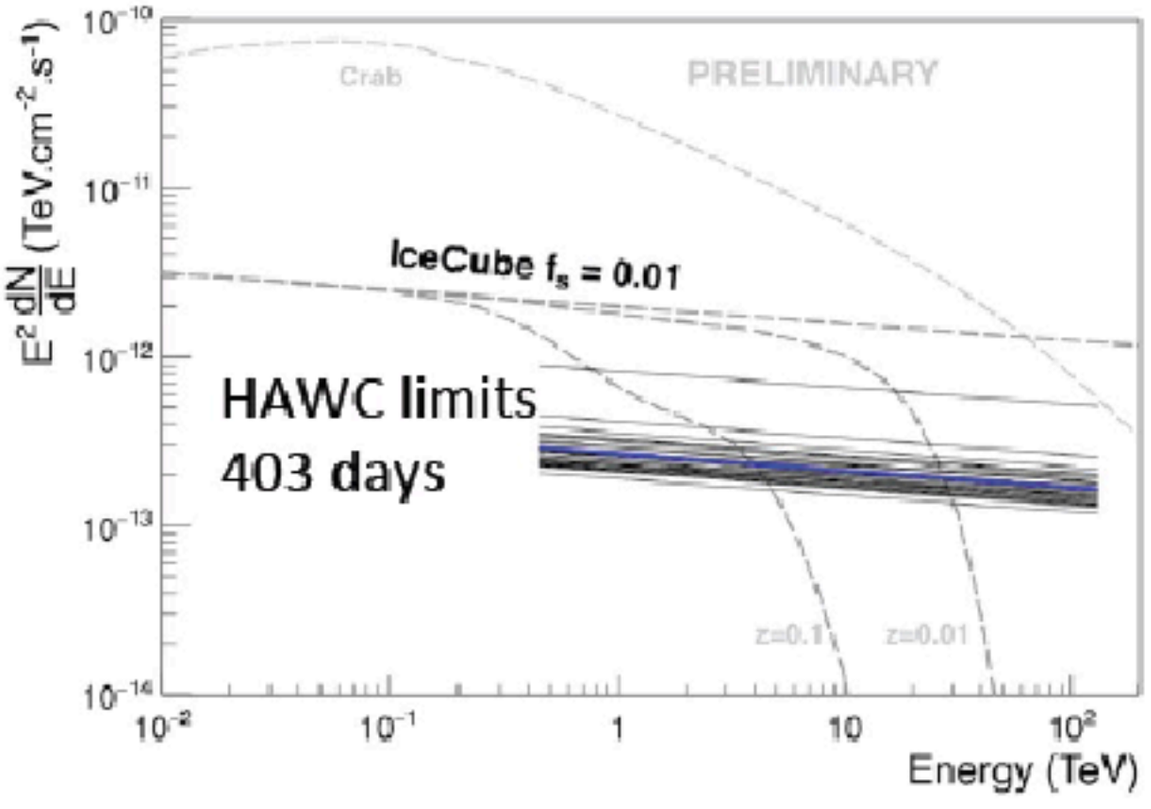




Search for TeV γ-ray Counterparts to IceCube astrophysical ν

- We have looked for γ sources in the direction from where the 28 highest energy ν_μ arrived.

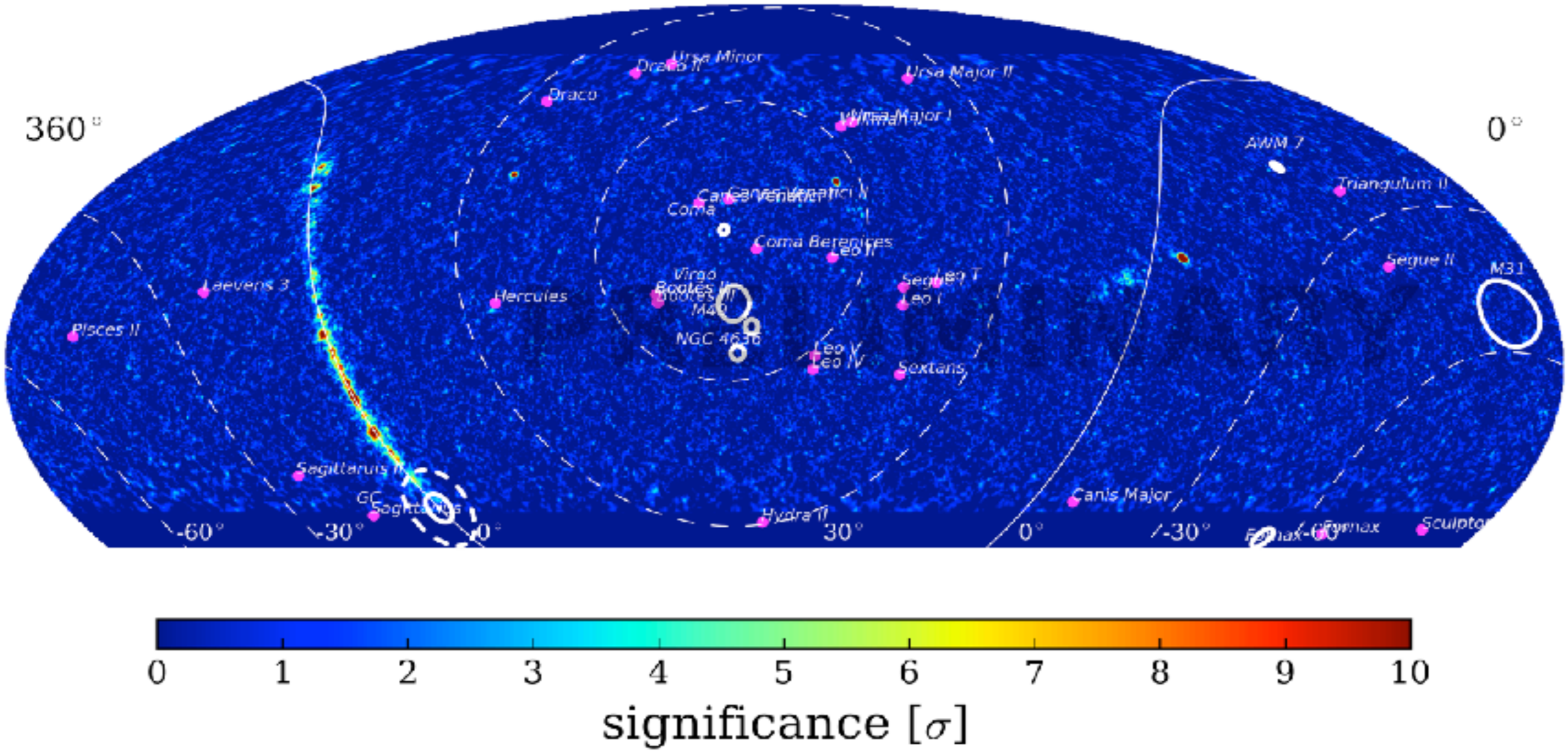




- No sources detected
  - sources opaque to γ ?
  - sources too far away ?
  - too many sources?

Also searching in real time in case they are transient

Many DM targets in HAWC's field of view

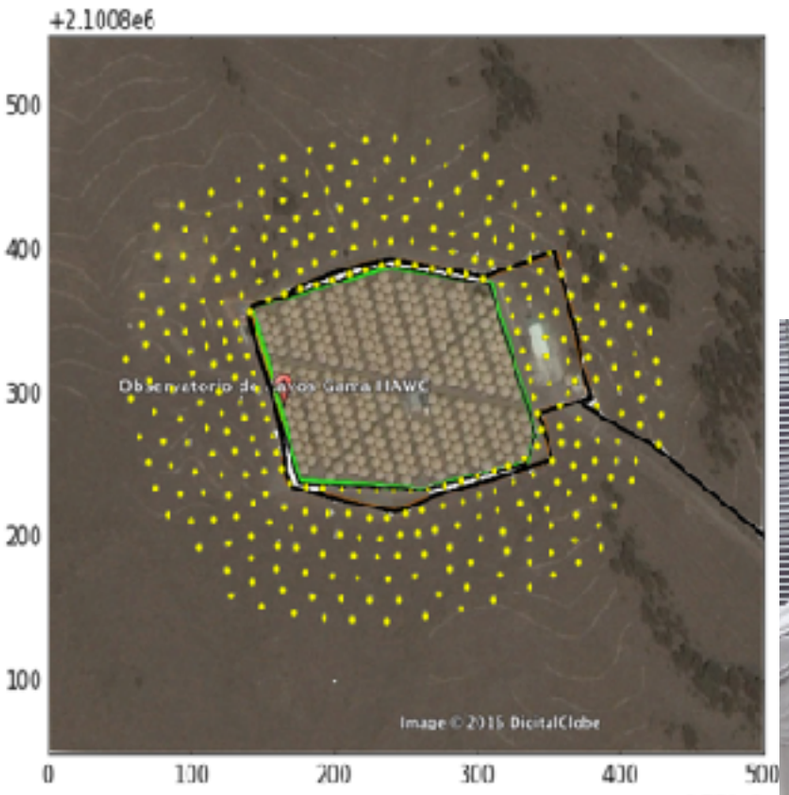


Mexican contribution

- Deployment and design of Outriggers detectors
- Cosmic Rays anisotropy
- GRB search
- EBL attenuation
- Física Solar
- AGN’s
- Cosmic Rays composition
- Artificial inteligente algorithms for improving the reconstruction and G/H separation
- DM search
- Mrks multi wavelength

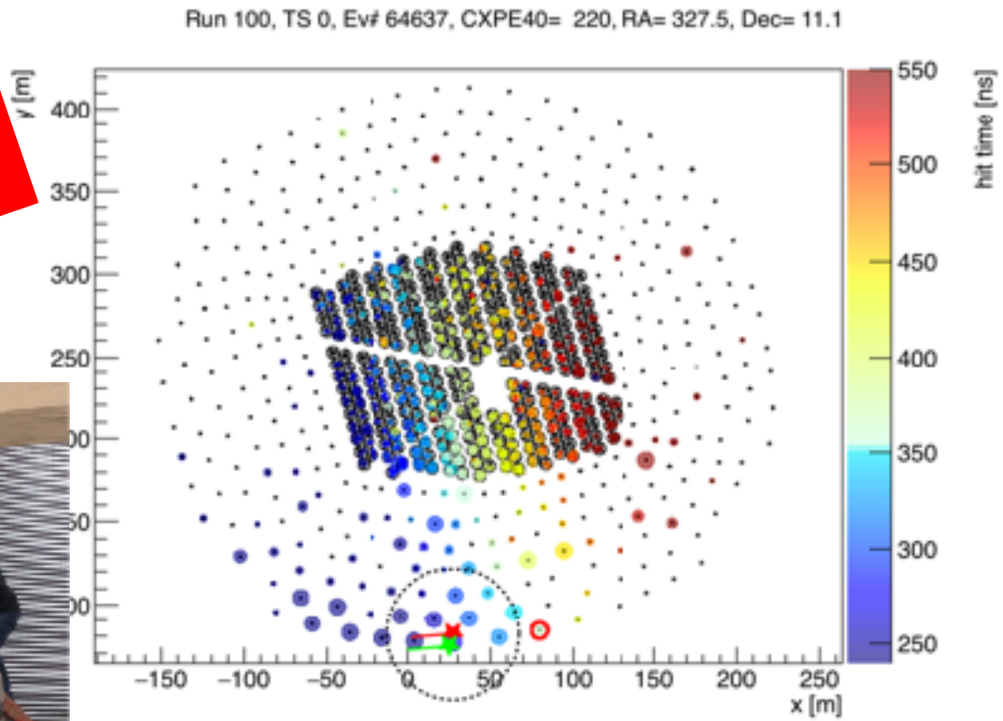
HAWC is getting better with “Outrigger” extension project

- We can increase the sensitivity to the highest energy events by determining the core position for showers that fall off the array.
- The 350 small WCD outrigger detectors cover an area 4x HAWC and will increase by 3-4x the sensitivity at 50 TeV.



Layout

Funded and in progress



Simulated event

Conclusion

- HAWC is beginning to survey the TeV sky
  – Papers appearing recently including “Crab”, “2HWC Catalog”, “Mrk421 & Mrk501”, “Geminga & 0656+14”, “GRB Search”, “Dark Matter Search”

- More exciting results to come!
  – Spectra to > 100 TeV with better energy algorithms and outrigger detectors
  – Improved localiza3on and multi source resolution using better point spread function at higher energies
  – More prompt transient notifications with online analysis and better low energy reconstruction algorithms

- Need multiwavelength observations to further explore the physical mechanisms in these extreme sources