The HAWC Observatory in Mexico

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HAWC Science

HAWC will explore

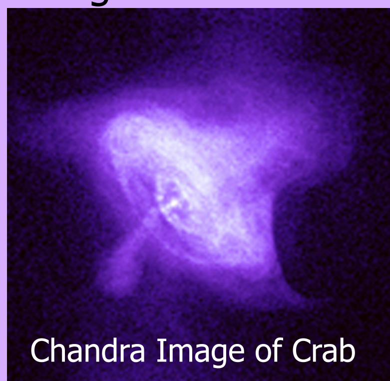
- the origin of cosmic rays,
- study the acceleration of particles in extreme physical environments,
- and search for new TeV physics.

- How?
  - By measuring large and intermediate scale structure of galactic cosmic rays
  - By observing gamma-ray sources, extended and diffuse gamma-ray emission, measuring their spatial distribution, energy spectra and time variability

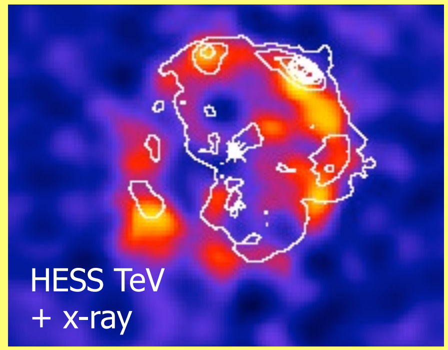
Nature’s Particle Accelerators

Galactic

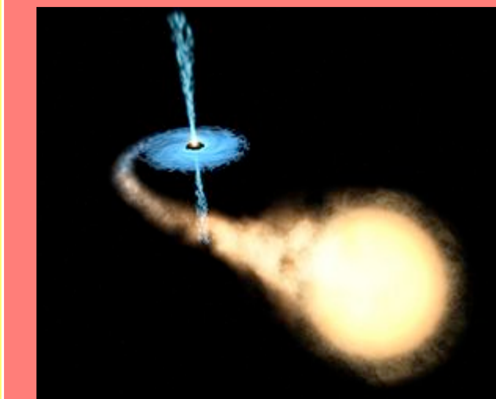
Pulsar Wind Nebula:
Spinning Neutron Star powering a relativistic wind



Supernova Remnant



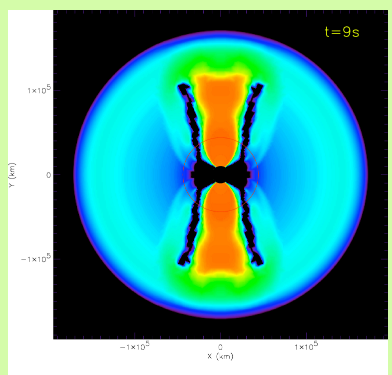
X-ray Binaries/ Microquasars



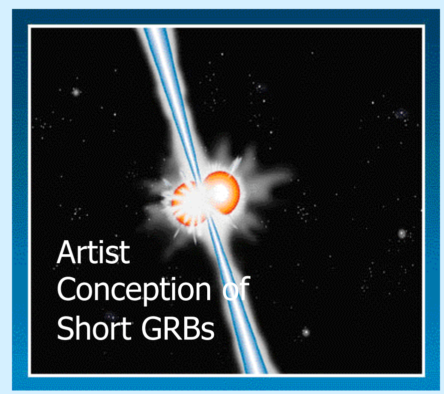
ExtraGalactic

Active Galactic Nuclei (AGN):
Black Hole producing relativistic jet of particles

Long Gamma-Ray Burst:
Massive Star Collapsing into a Black Hole



Short Gamma-Ray Burst:
Binary Neutron Star Coalescing

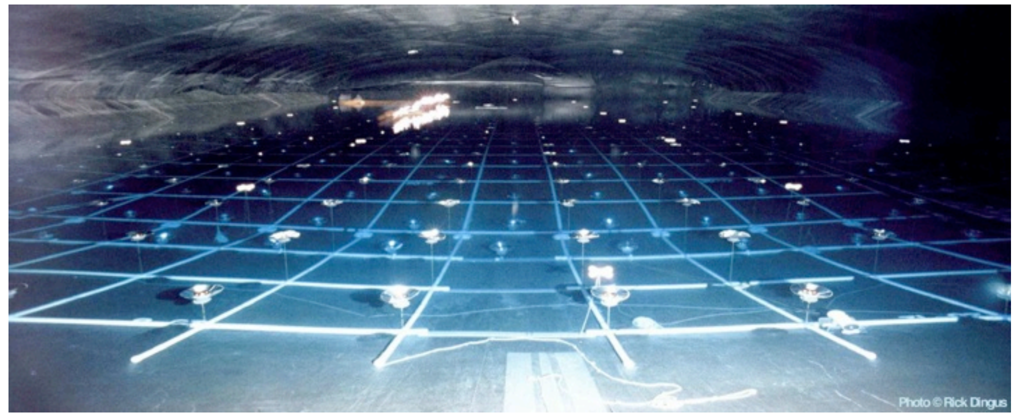


The “perfect” TeV Gamma-ray Detector

- Angular resolution of an IACT
- Large field of view of an WCD array
- Large duty cycle of a WCD array
- Sensitivity to GeV energies (IACT)
- Sensitivity at > 100 TeV (WCD array)
- Energy resolution of an IACT
- Gamma/hadron separation of an IACT (though WCD array has very good resolution a higher energies as well, a lot of progress has been made)
- < $50 million

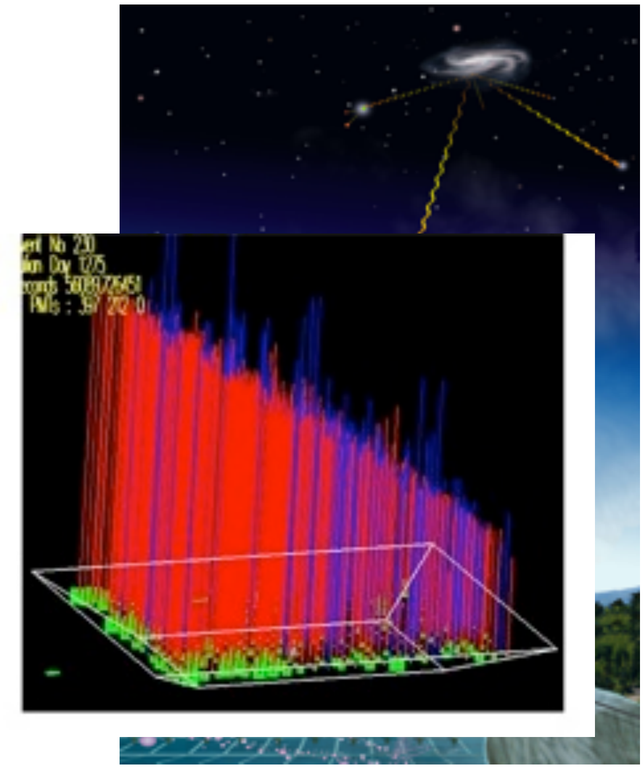
Historic Example of a Large Field of View Detector: Milagro

- Milagro was a *first generation* wide-field gamma-ray telescope:
  - Proposed in 1990
  - Operations began in 2001/04
  - Ended in 2008

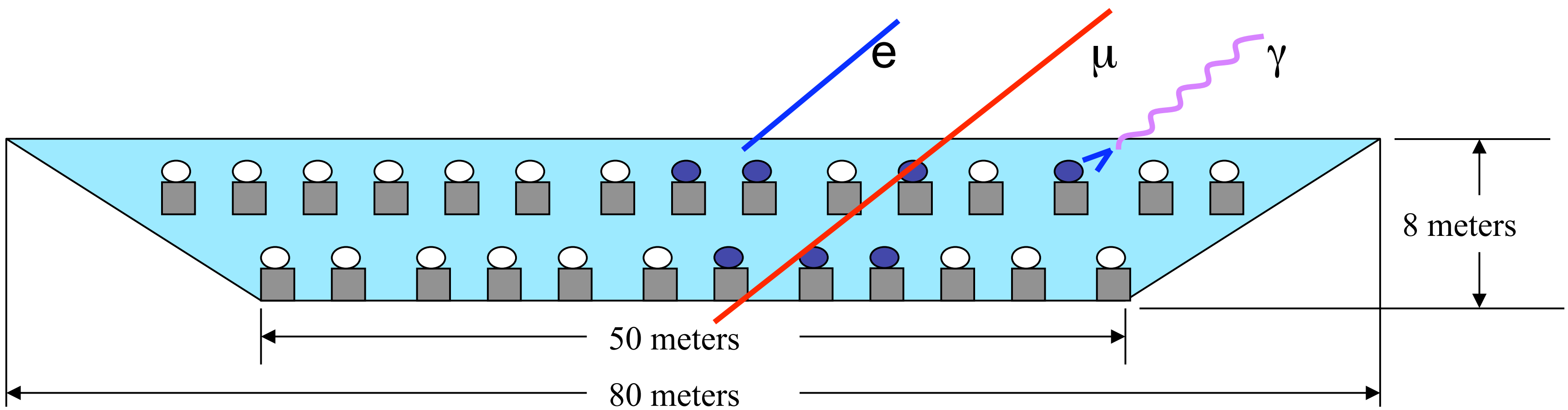


- Discovered:
  - A number of TeV sources
  - Diffuse TeV emission from the Galactic plane
  - A surprising directional excess of cosmic rays
- Showed that a lot of the bright galactic GeV sources extend to the TeV

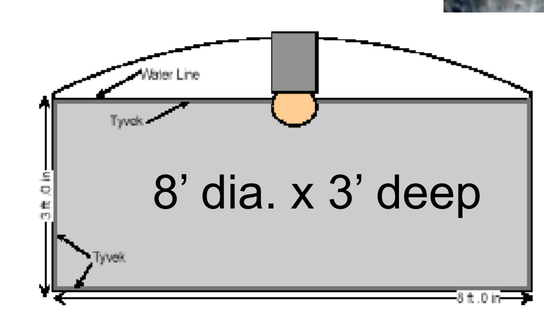
How Did Milagro Work?



- Detect Particles in Extensive Air Showers from Cherenkov light created in 60m x 80 m x 8m pond containing filtered water
- Reconstruct shower direction to ~0.5° from the time different PMTs are hit
- 1700 Hz trigger rate mostly due to Extensive Air Showers created by cosmic rays
- Field of view is ~2 sr and the average duty factor is >90%



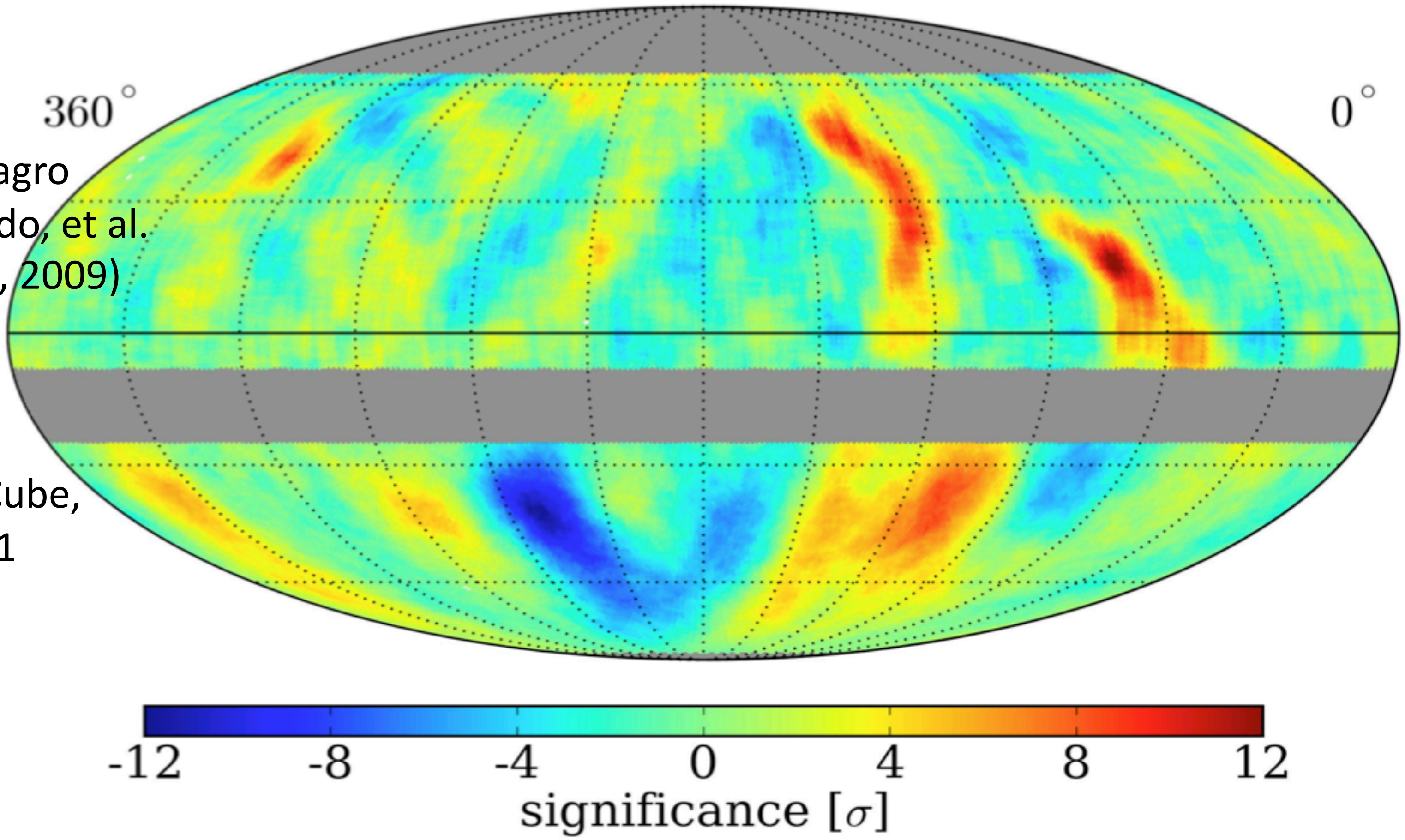
Array of 175 Outriggers



Results Example 1: Intermediate Cosmic Ray Structure Milagro (1-10TeV) & IceCube (20TeV)

Milagro (Abdo, et al. PRL, 2009)

IceCube, 2011

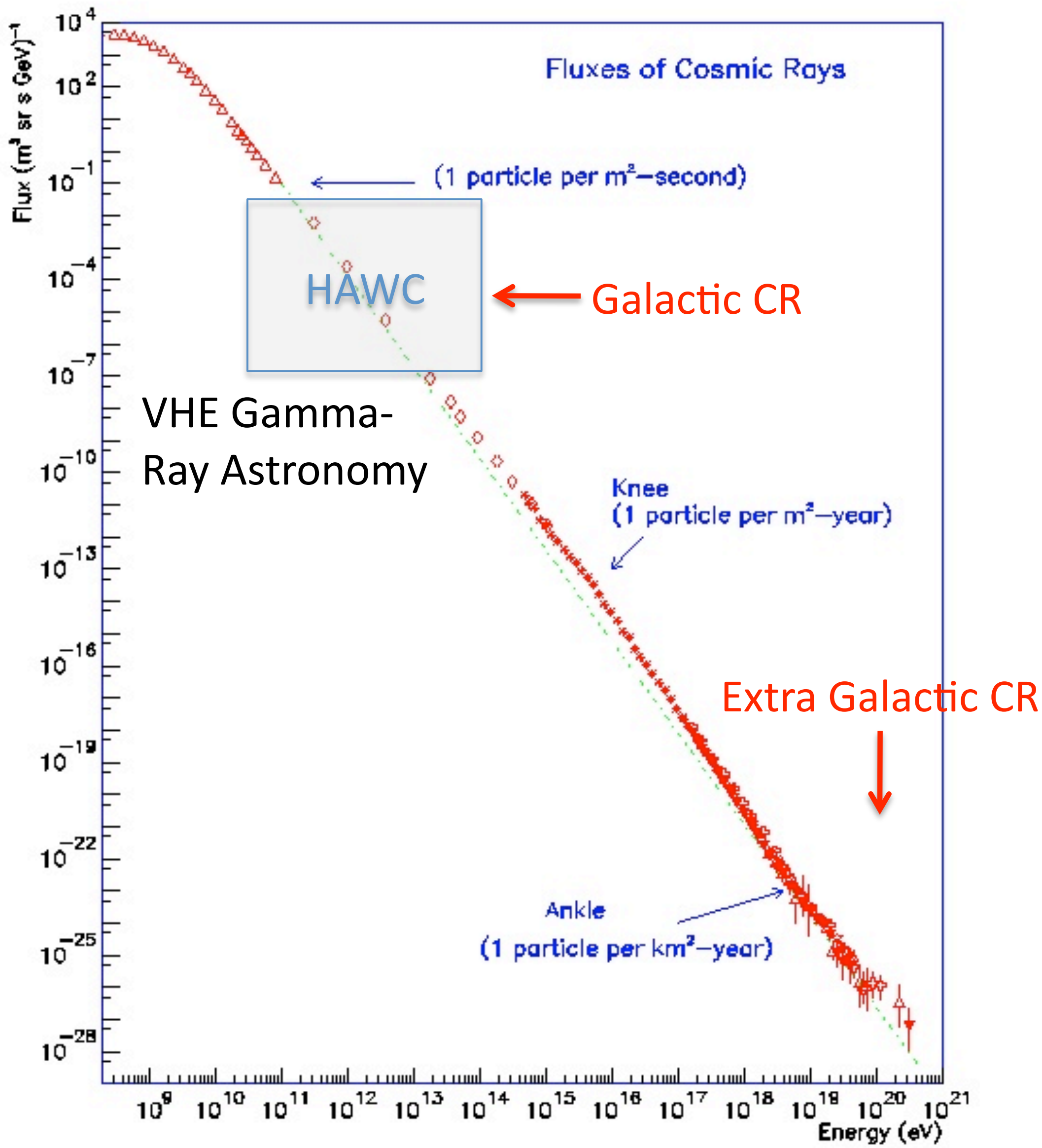


The Cosmic-Ray Spectrum

What are Cosmic Rays?

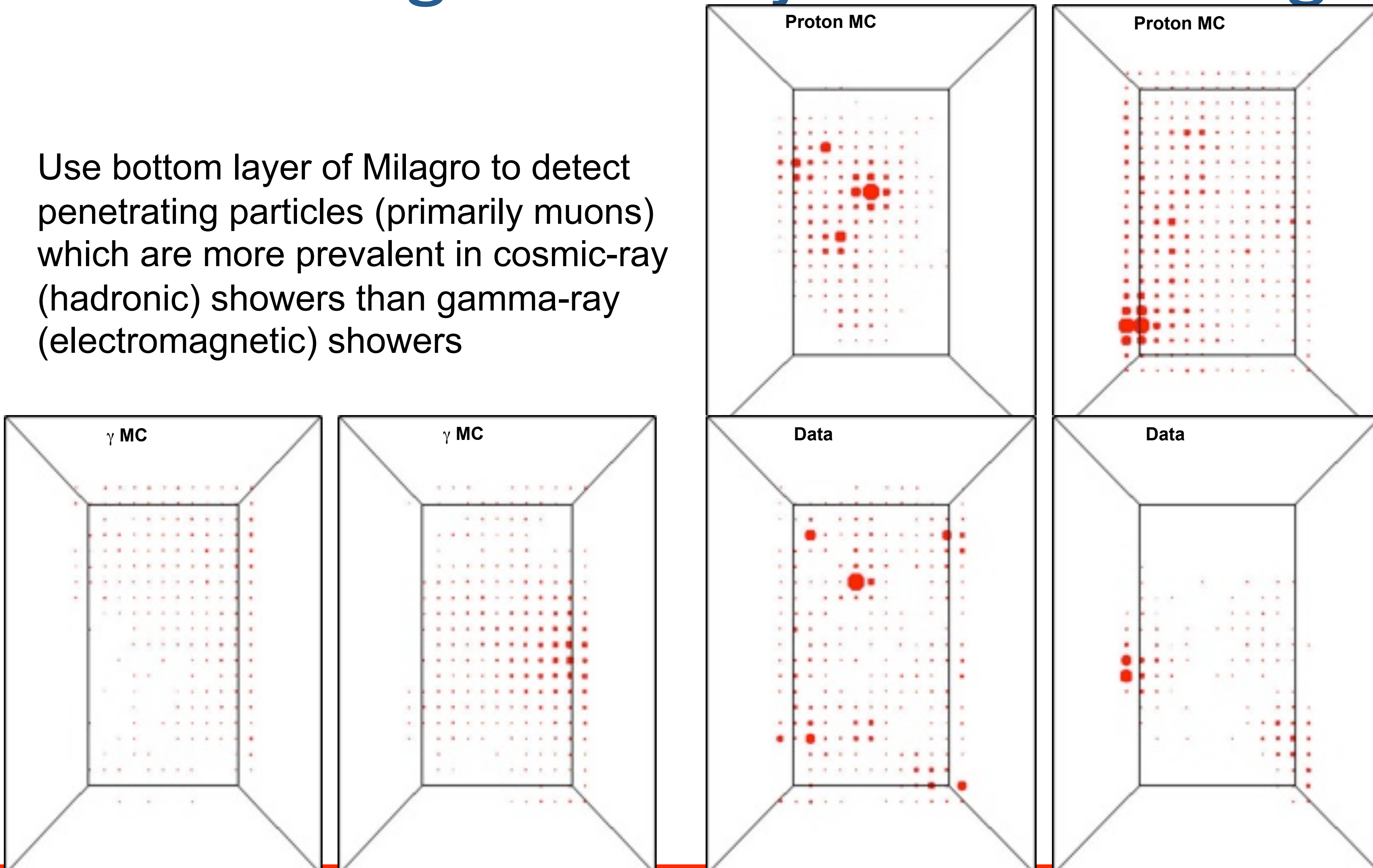
e.g. around the knee:

- proton
- helium
- carbon
- silicon
- iron
- electrons
- gamma rays (<0.1%)



Background Rejection in Milagro

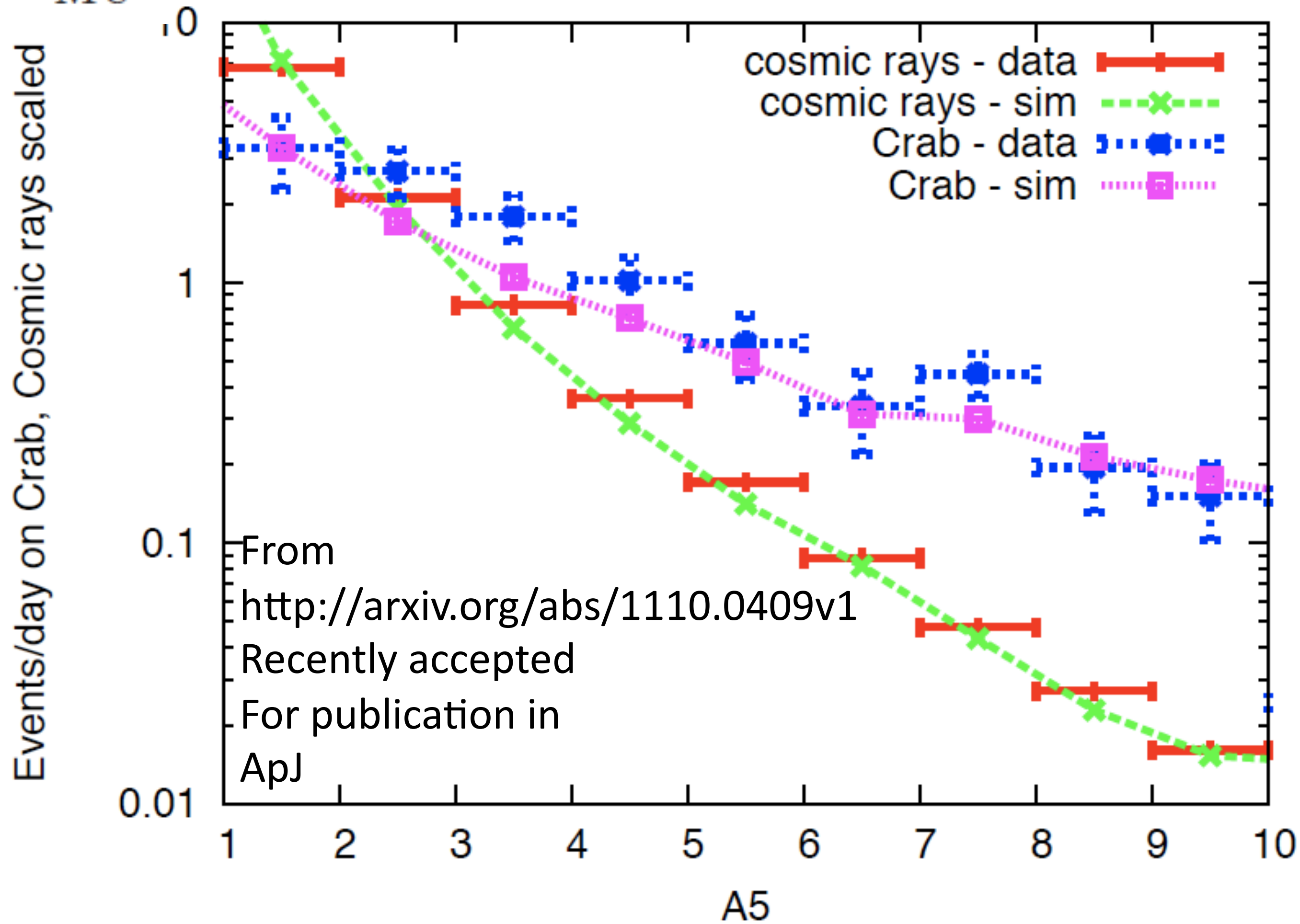
Use bottom layer of Milagro to detect penetrating particles (primarily muons) which are more prevalent in cosmic-ray (hadronic) showers than gamma-ray (electromagnetic) showers



Background Rejection in Milagro

$$A5 = 400 \cdot \frac{\mathcal{F} \cdot \zeta(\mathrm{t}) \cdot \mathrm{F}_{\mathrm{fit}}}{\mathrm{MaxPE}_{\mathrm{MU}}}$$

Calculate weights based on A5 that represent likelihood that airshower is produced by a gamma ray



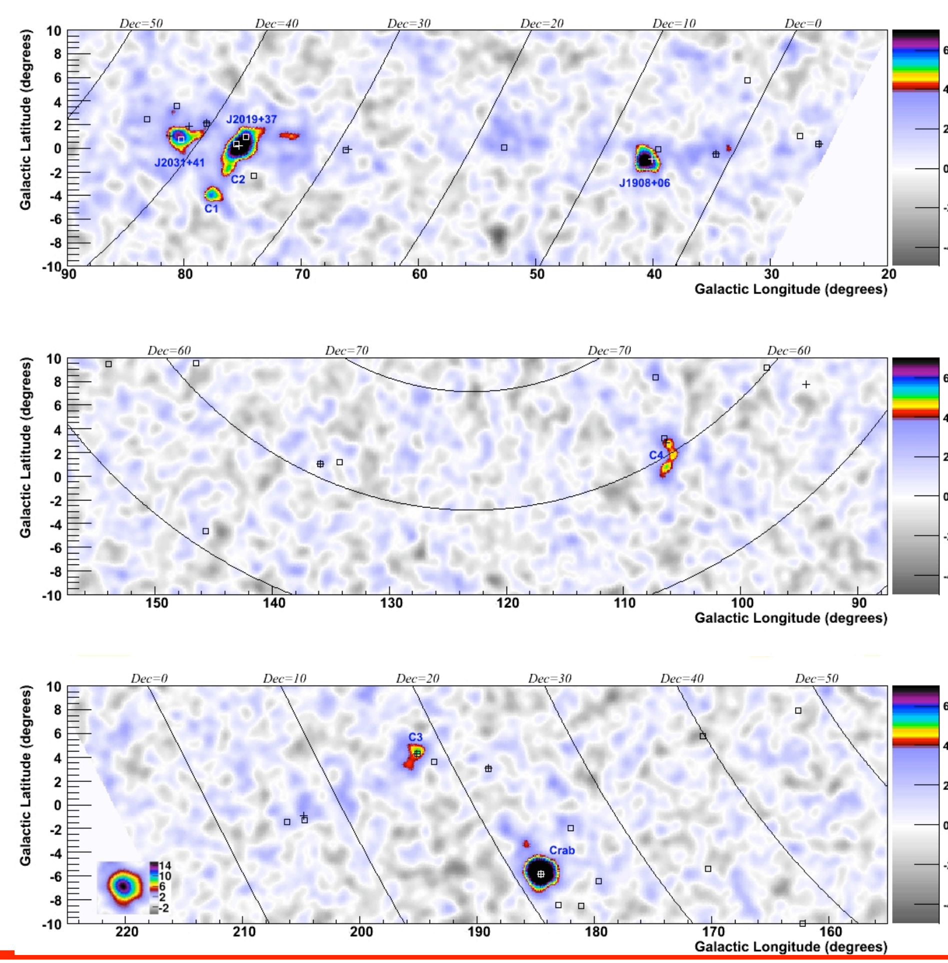
Results Example 2: Galactic Plane Survey

Published Milagro Galactic plane survey in 2006 based on data collected up to June 2006.

Detected 4 sources at >5σ post-trials.

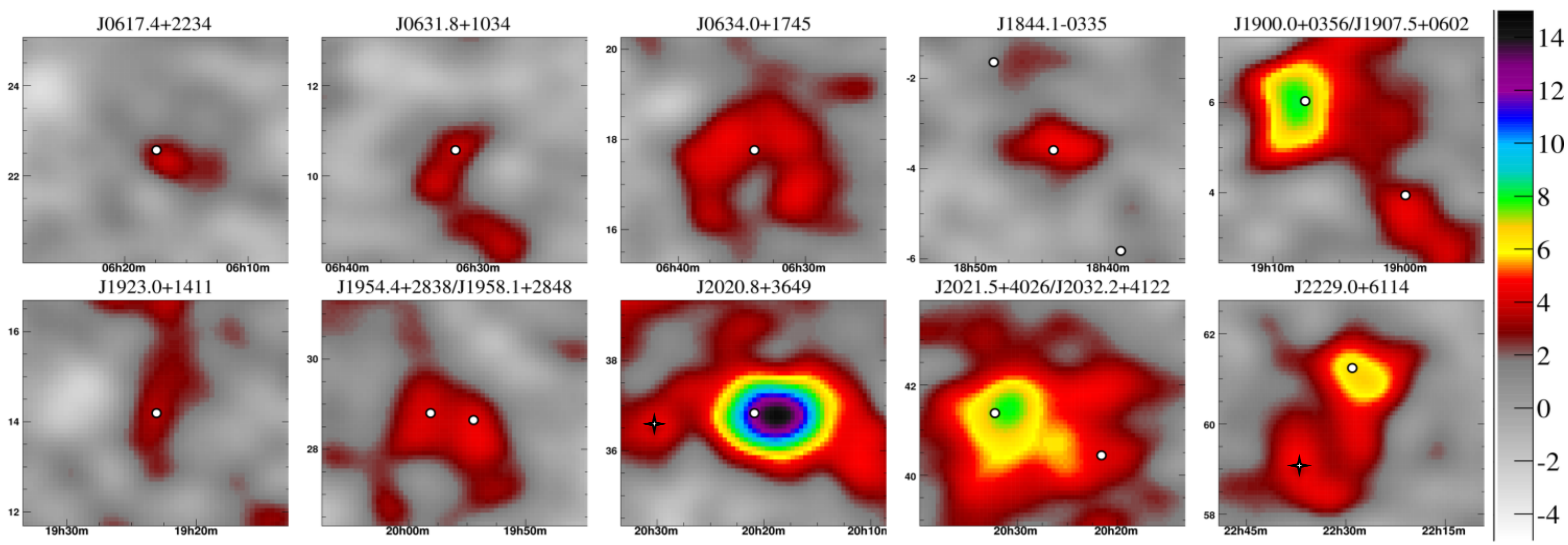
Detected 4 candidate sources at >4.5σ pre-trials.

~100,000 trials in Galactic plane, 500,000 in the sky.



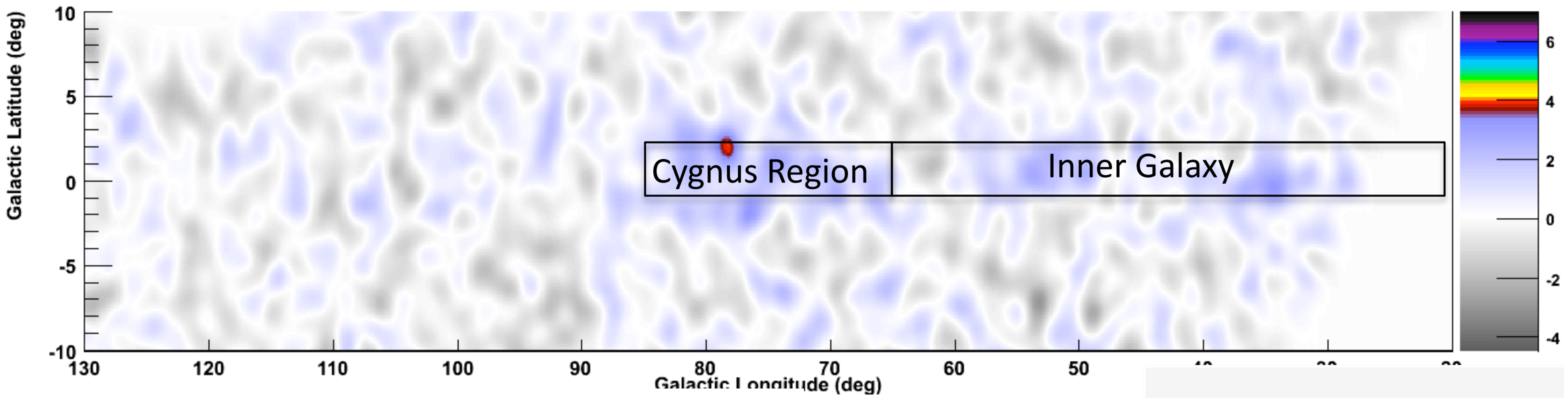
A Second Look

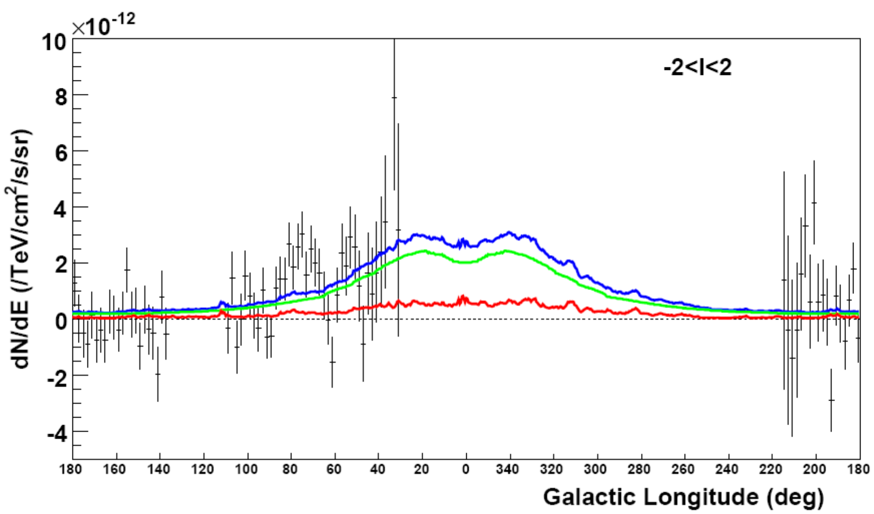
- After publication of BSL by Fermi
- 16 GeV - TeV associations
  - 11 associated with pulsars
  - 3 associated with SNR
  - 2 associated with unknown GeV source



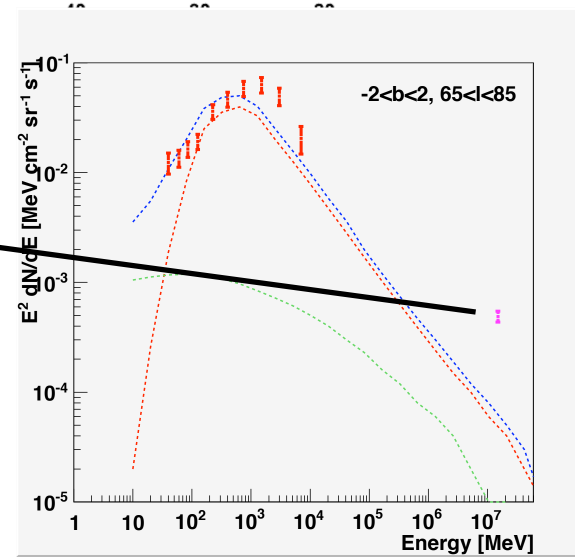
All brightest Milagro excesses in the Galactic plane are coincident with GeV Pulsars (Abdo et al., ApJ Lett 2009)

Example 3: Zoom in on The Cygnus Region

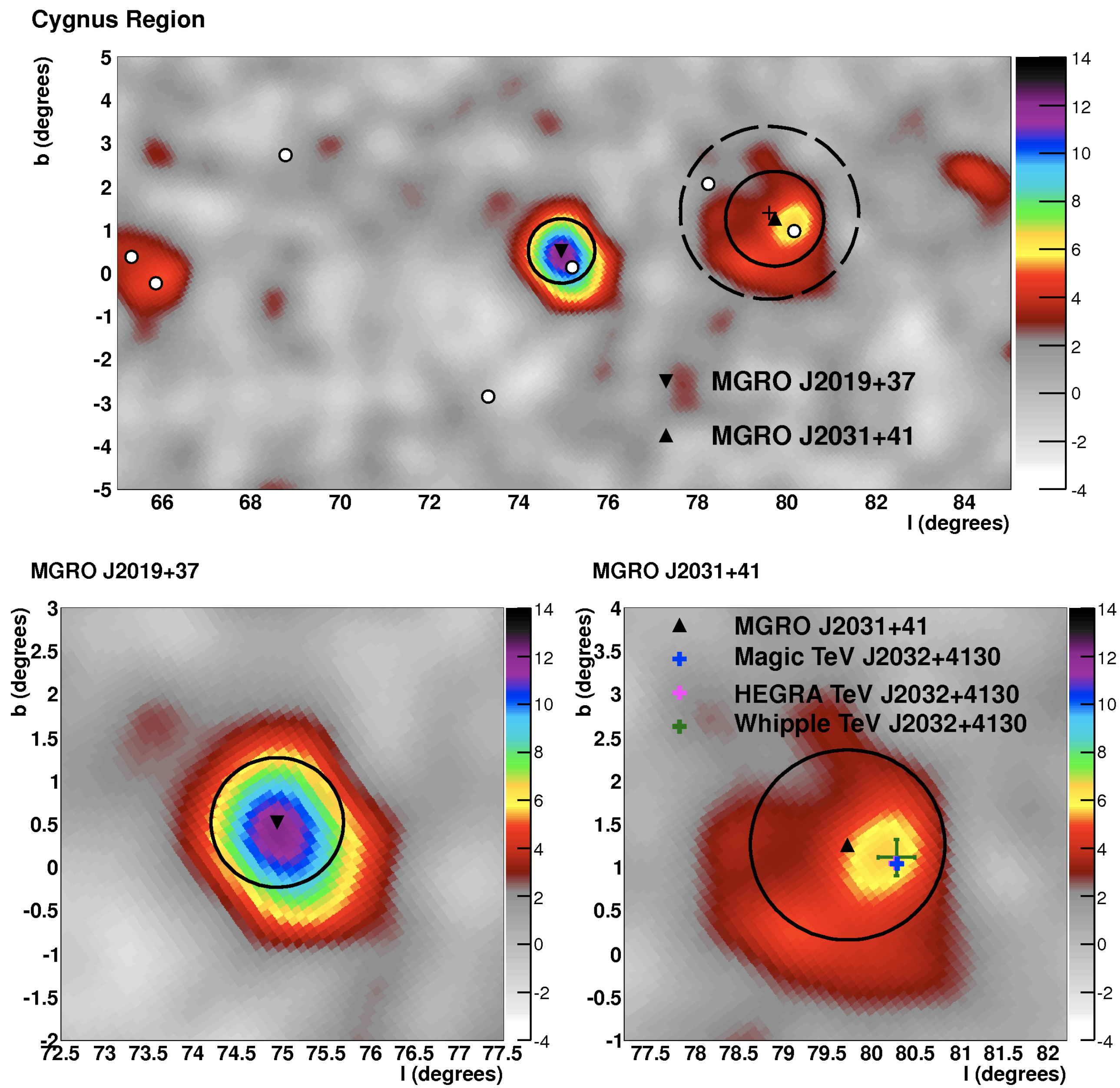




8x pred., unresolved Sources?



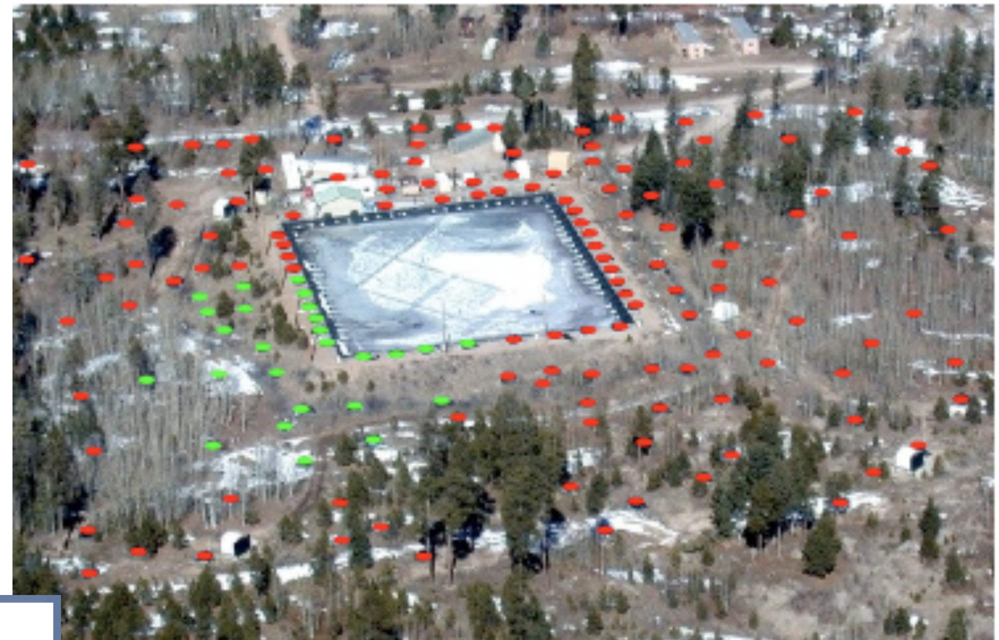
The Cygnus Region

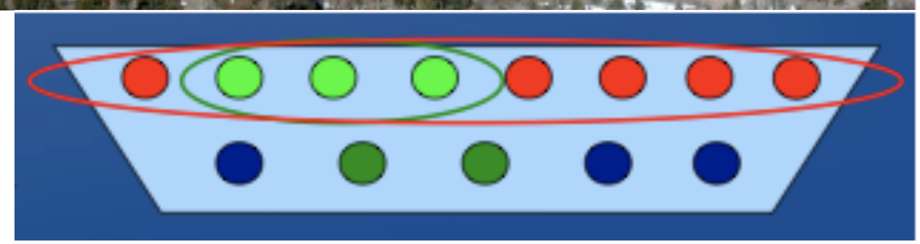


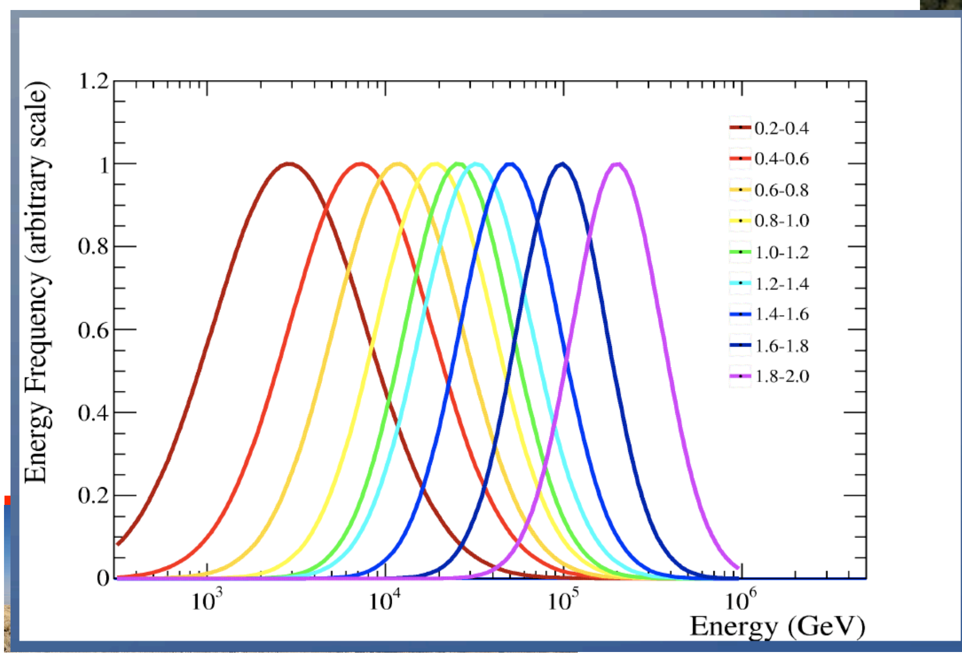
A5 weighted +
PSF smoothed maps

Method: Reconstructing Energy

$$f = \frac{N_{AS}}{N_{AS}^{live}} + \frac{N_{TA}}{N_{TA}^{live}}$$







i.e. only data collected after 2004 was used,
Corresponds to 906 days or 12.1 σ

Method: The Fit

2 parameter fit:

$$\frac{dN}{dE}(I_o, \alpha, E_{\mathrm{cut}}) = I_o(\frac{E}{10TeV})^{-\alpha}$$

3 parameter fit:

$$\frac{dN}{dE}(I_o, \alpha, E_{\mathrm{cut}}) = I_o(\frac{E}{10TeV})^{-\alpha} \exp(\frac{-E}{E_{\mathrm{cut}}})$$

Minimize

$$\chi^2(I_o, \alpha, E_{\mathrm{cut}}) = \sum_{i=f-bins} \frac{(P_i(I_o, \alpha, E_{\mathrm{cut}}, \delta) - M_i)^2}{(dP_i)^2 + (dM_i)^2}.$$

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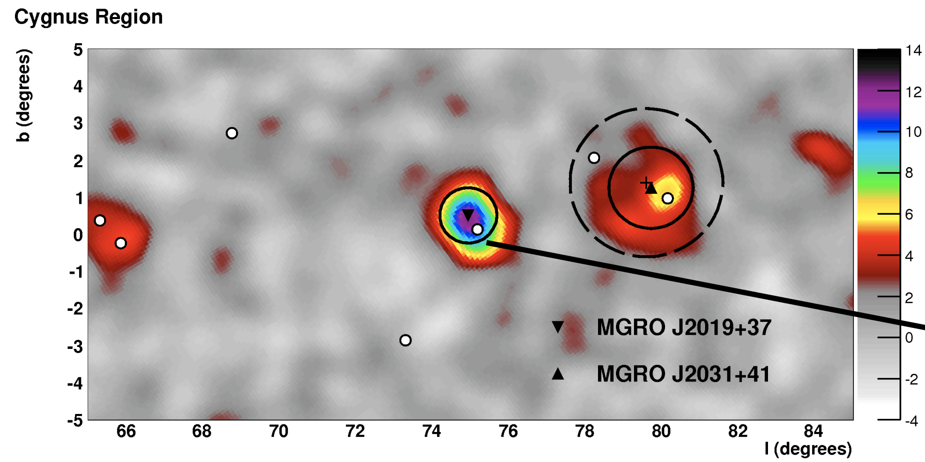
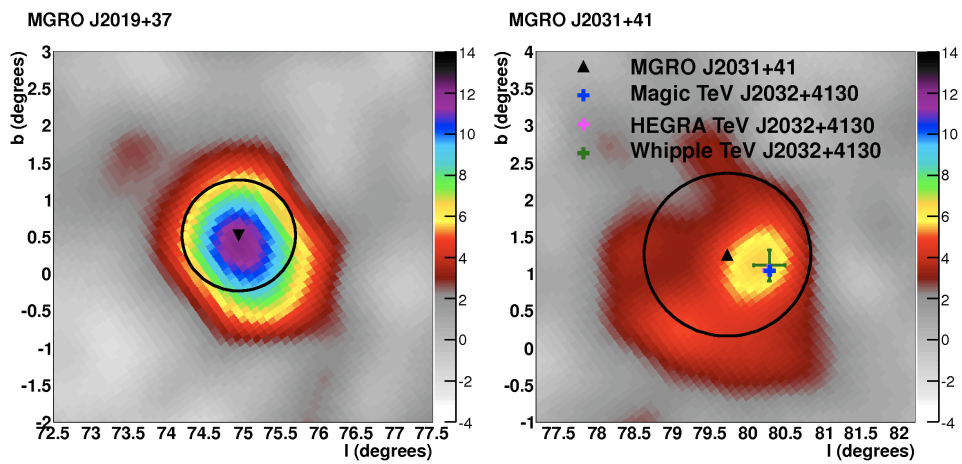
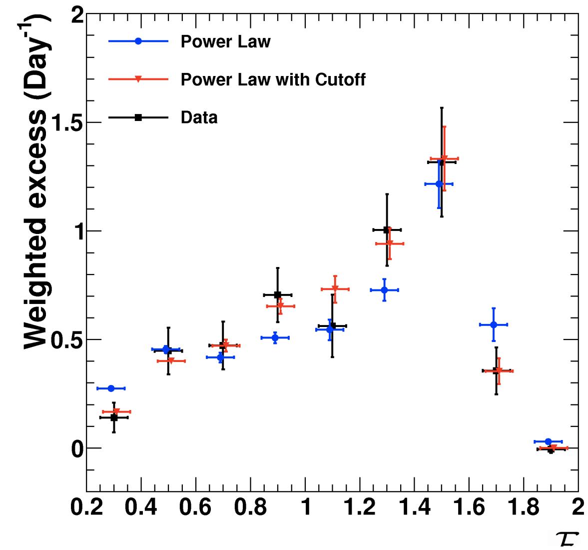
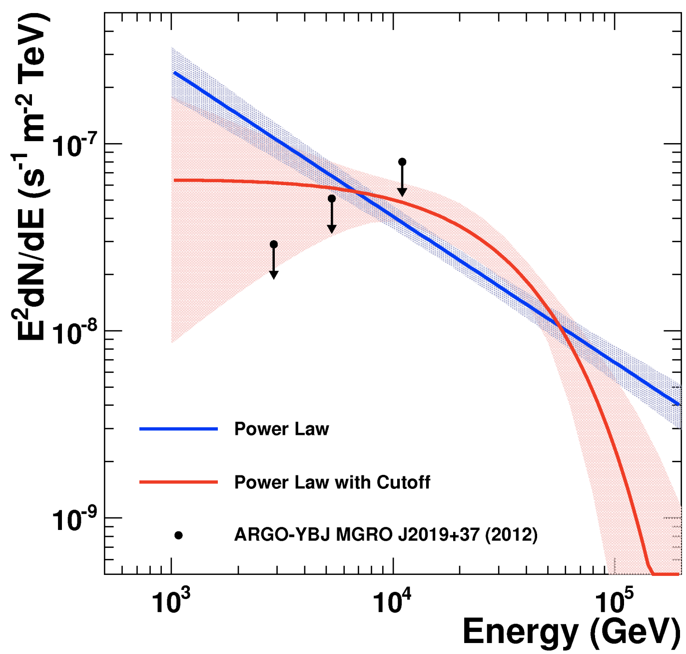
The Cygnus Region

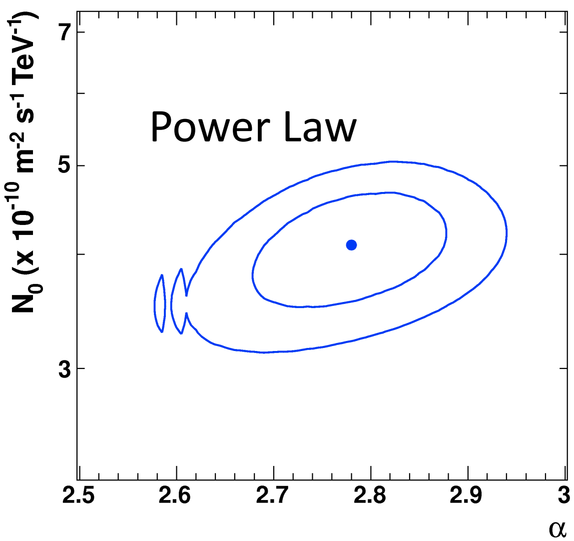




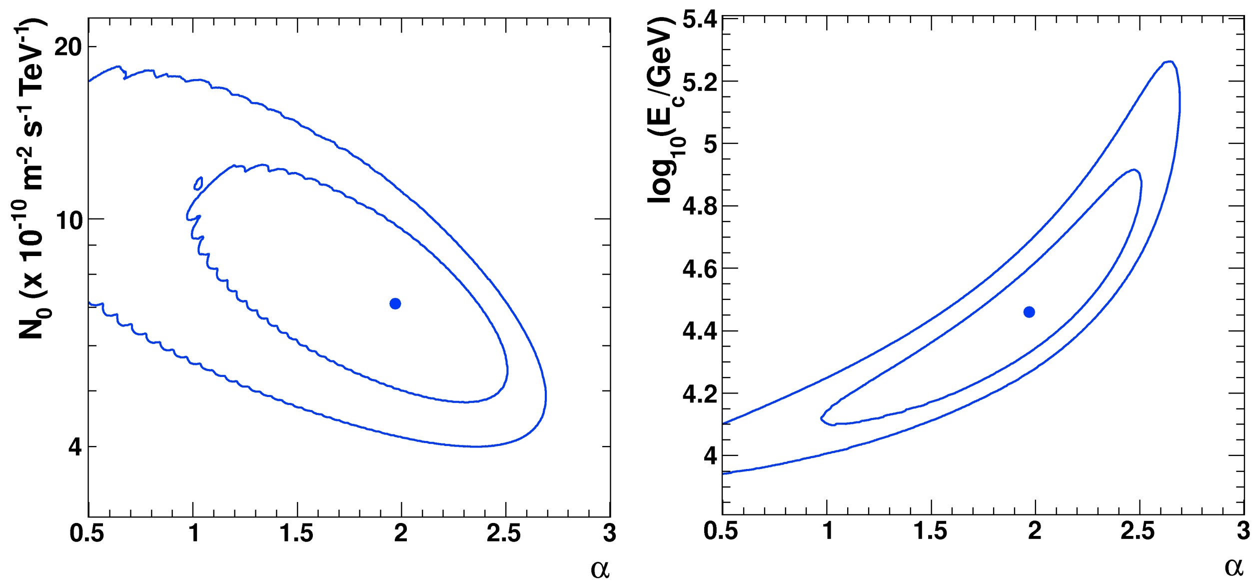




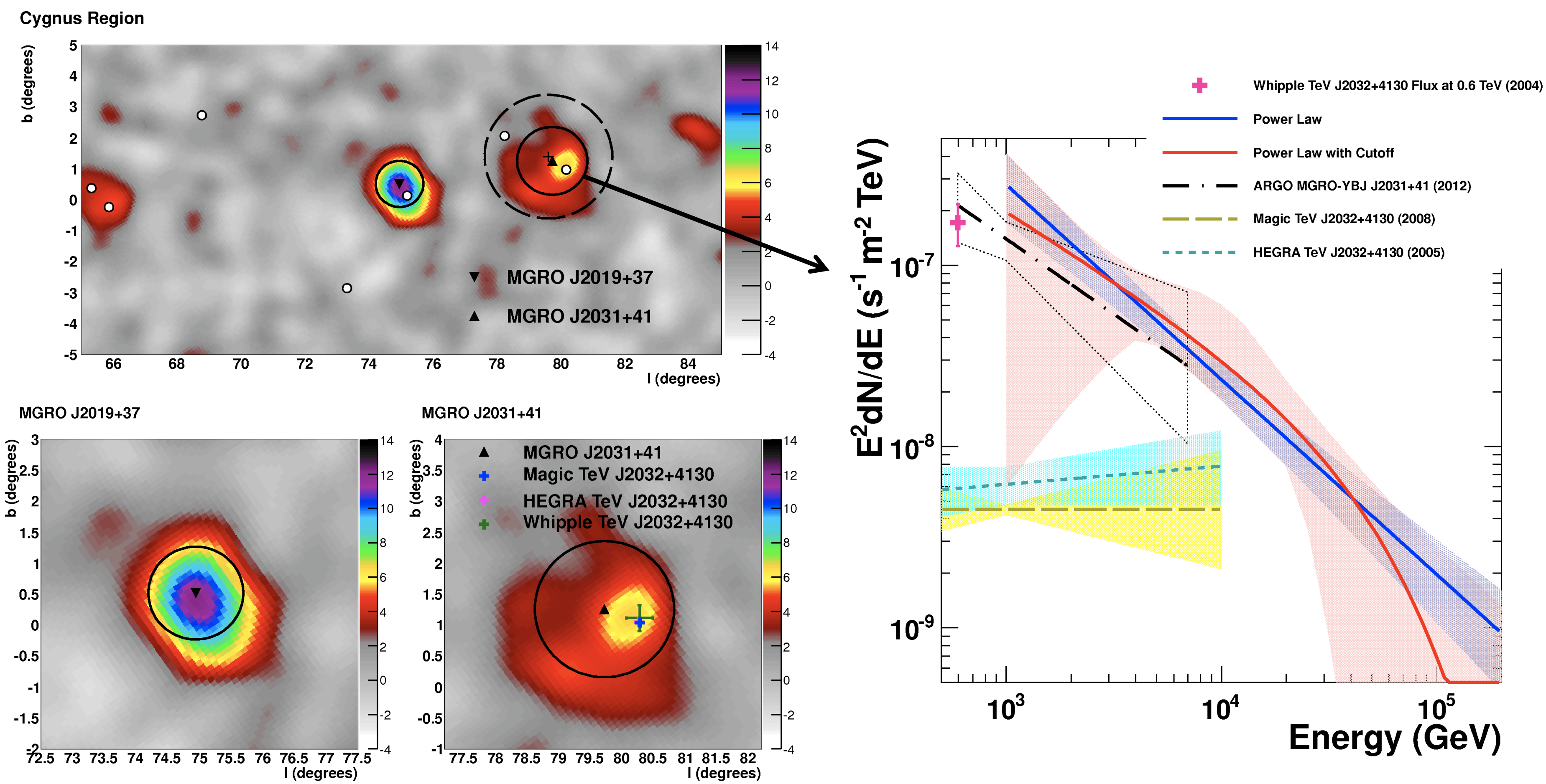
MGRO 2019+37



Power Law + exp. Cutoff
according to F-test preferred at > 98%

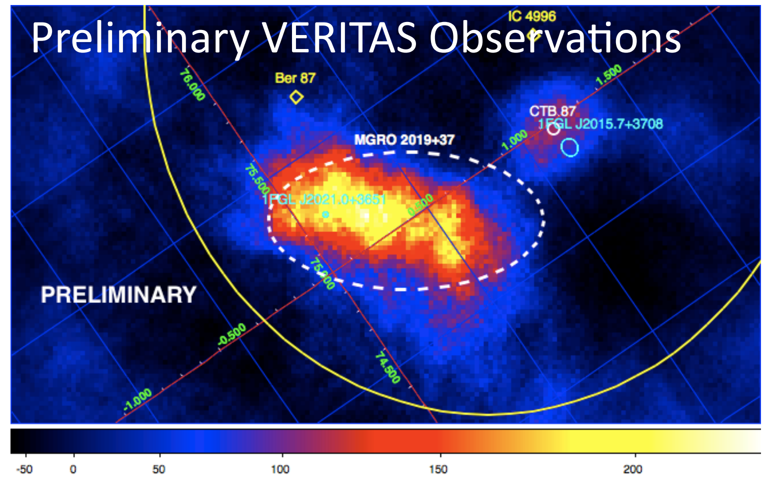


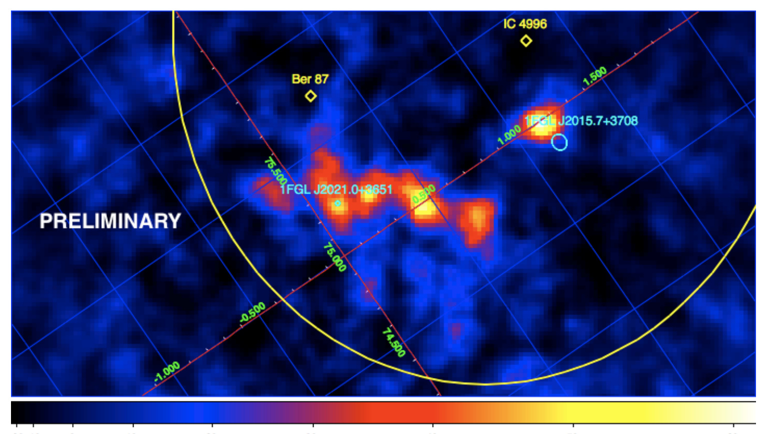
The Cygnus Region



The Cygnus Region

- Synergistic observations with Atmospheric Cherenkov Telescopes
- Deep (75 hours) VERITAS observations reveal possible structure and hard spectrum

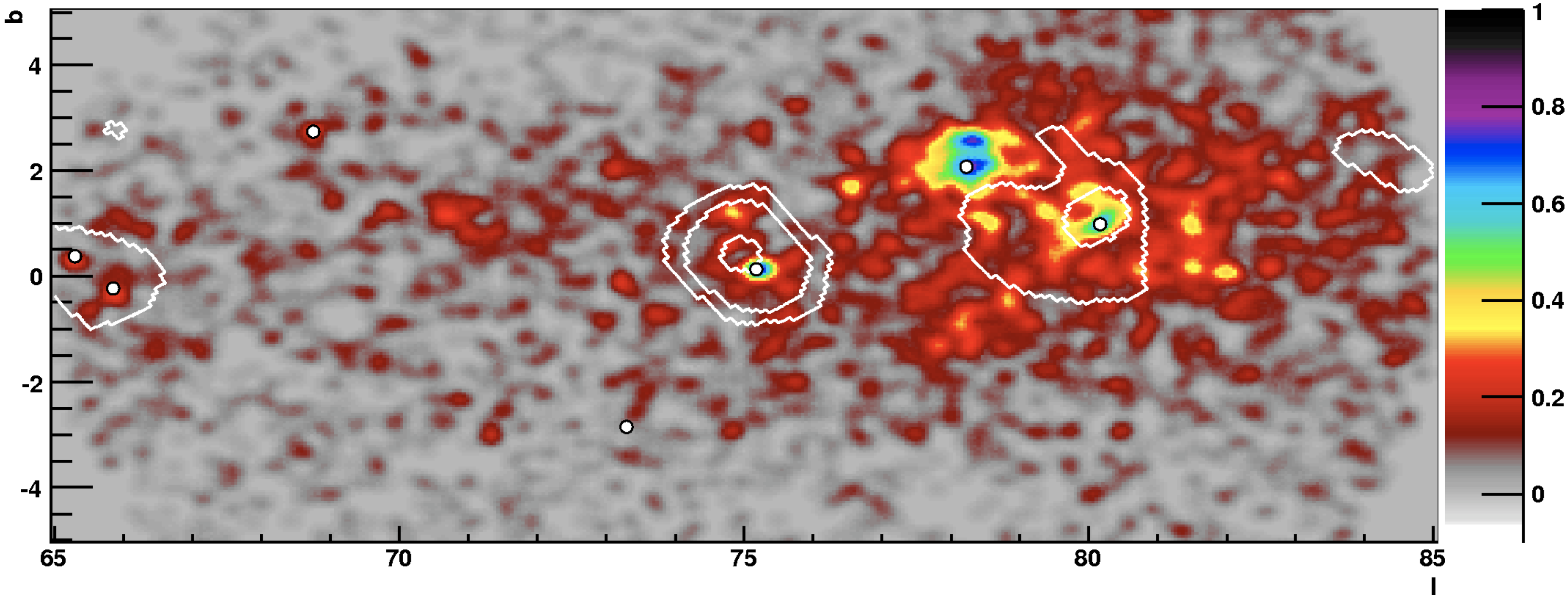




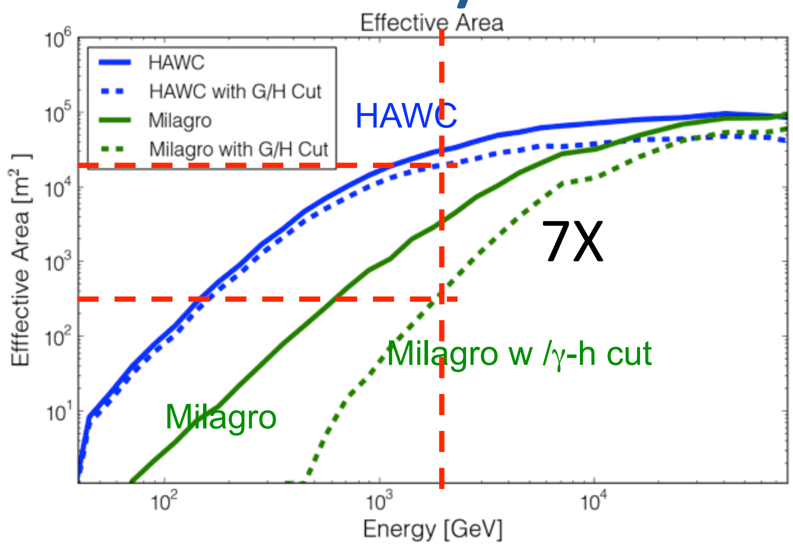
The Cygnus Region

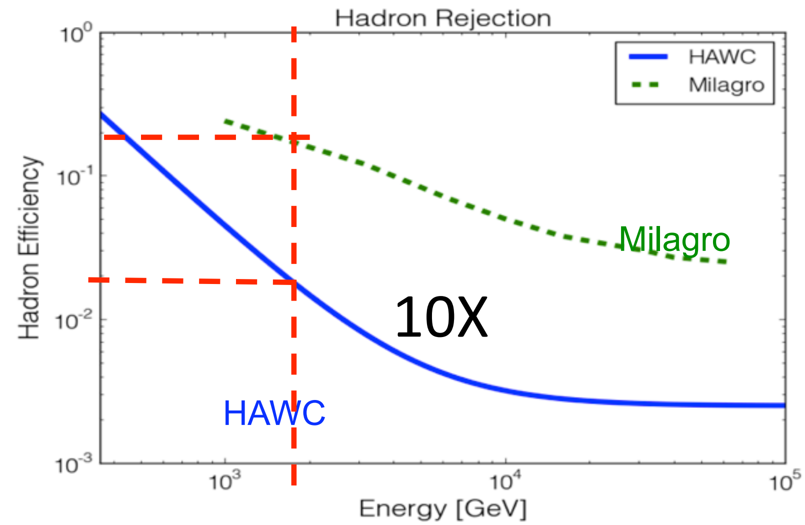
Synergistic observations with Fermi

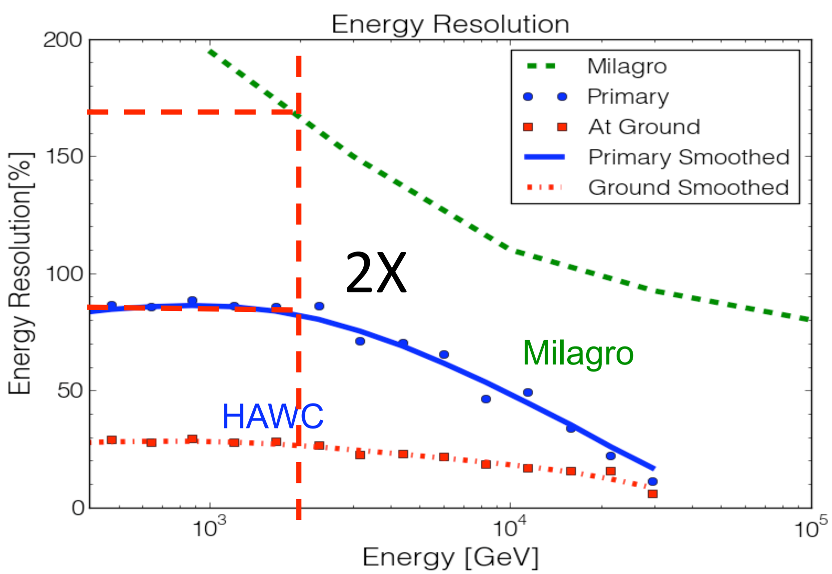
- map is photon counts in Fermi Data >10 GeV
- white contours are sigma contours in Milagro data (3, 5, and 11 σ)

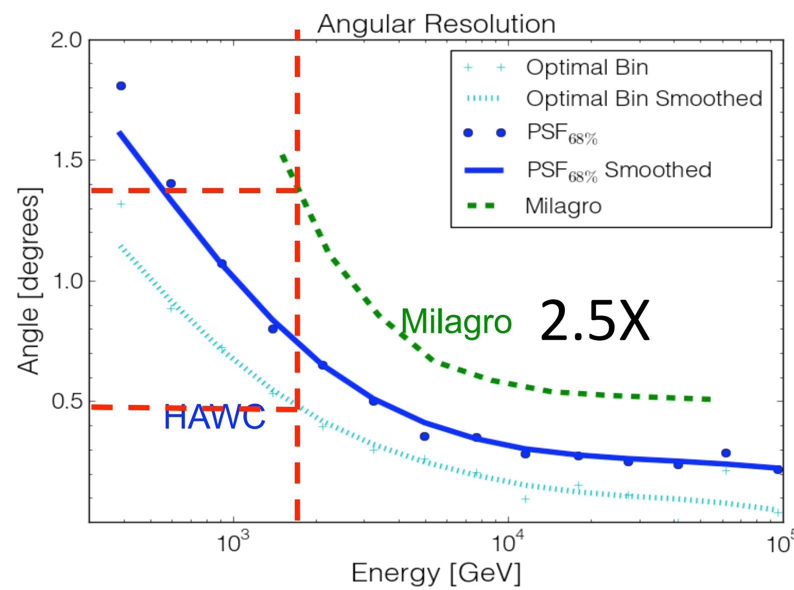


Why will HAWC be Better?









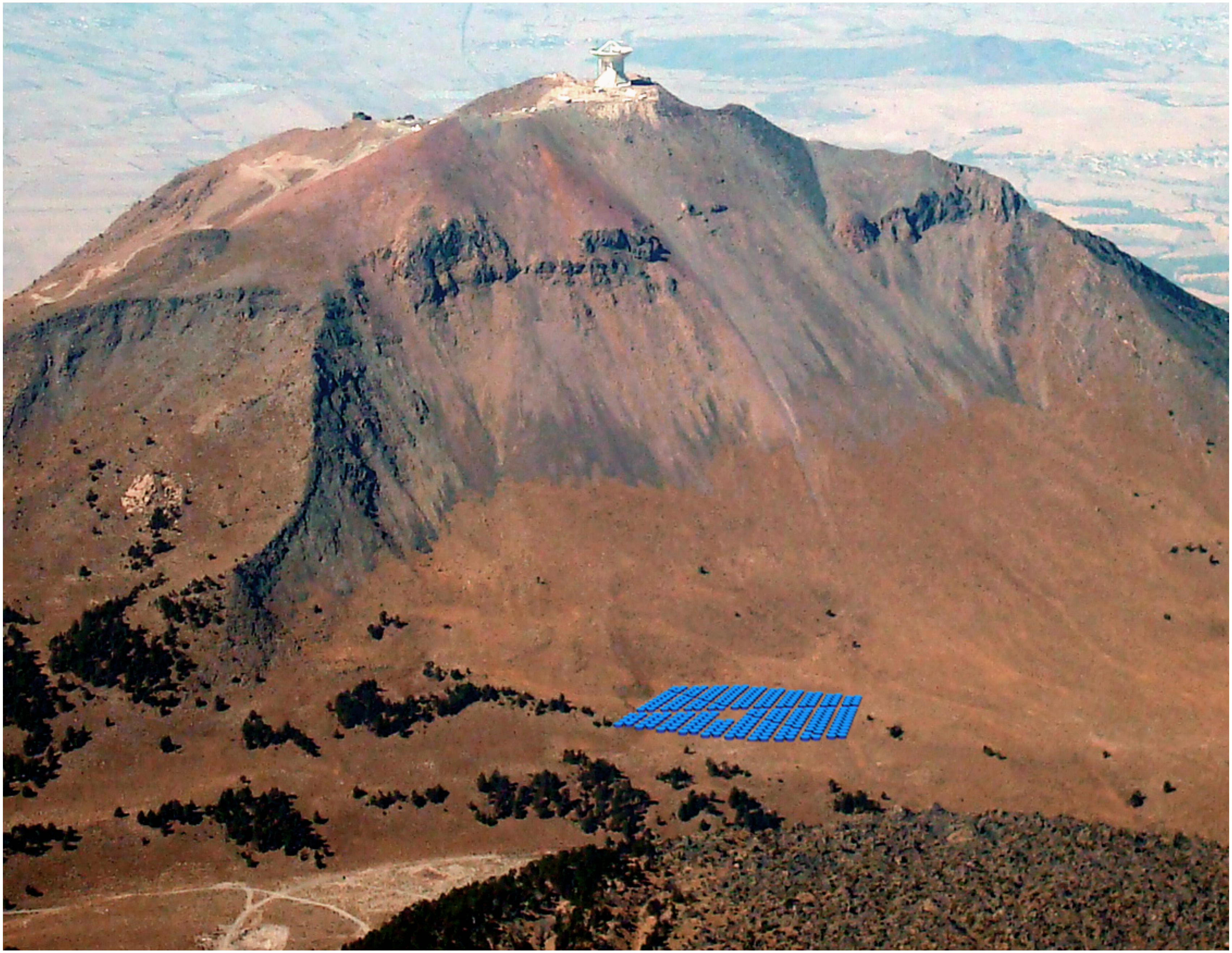
How is this achieved: From Milagro to HAWC

- Move it to higher altitude
- Improve optical isolation
- Cover more area with deep water
- Original concept was 150mx150m pond with optical barriers in a building

- Milagro
- 2350m asl
- One big pond
- Pond area 4,000 m^2

- HAWC
- 4150m asl
- Individual tanks
- Tank area ~20,000 m^2

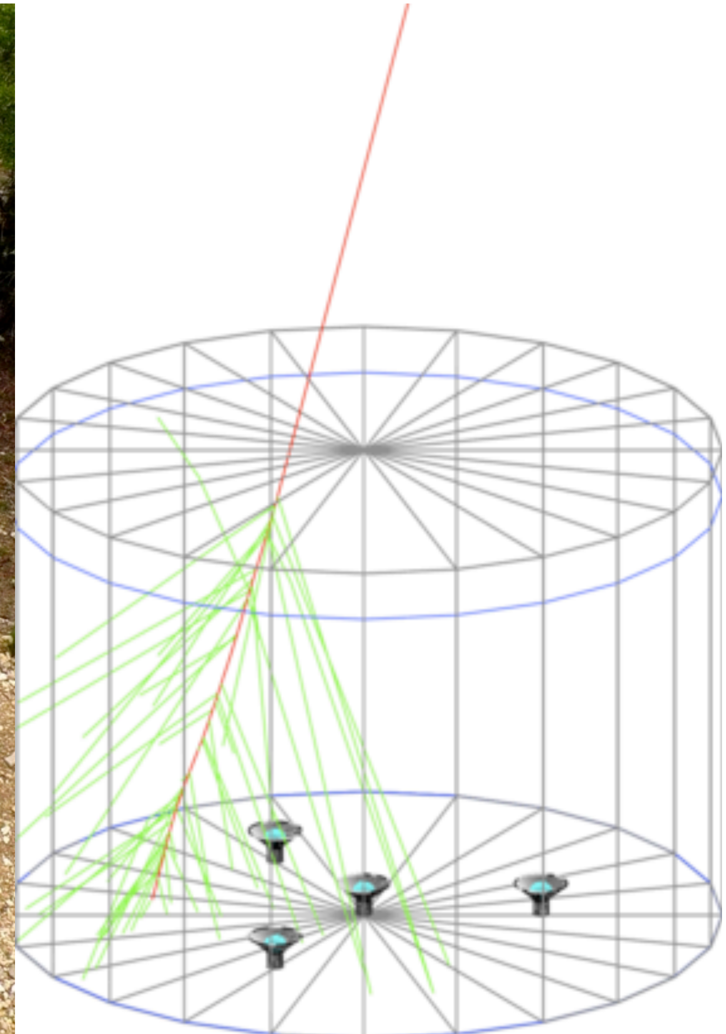
Pico de Orizaba and Sierra Negra




HUB
HAWC Site
VAMOS

HAWC Baseline Design

HAWC WCD



Technical Requirements

1. **50 mCrab sensitivity at 5σ in a one-year**
   - HAWC will observe Galactic sources with a sensitivity similar to that of Fermi
   - Detect diffuse emission from 5x5 sq degree regions of the Galactic plane
   - Sensitive to see known TeV AGN and the brightest known GeV GRBs
   - Have a large enough step in sensitivity to likely discover new phenomena
2. **2 sr field of view**
   - Observe diffuse gamma-ray emission from the plane of the Galaxy over a broad range of Galactic longitudes reaching to the Galactic center.
   - Catch transients within HAWC's field of view such as GRBs which are rare, from an unknown direction, and last only a few seconds.
   - Discover new TeV sources and flaring in known sources that may have no low energy counterpart
3. **Five years of operation with >80% duty cycle**
   - Sufficient exposure to measure the low fluxes at higher energies.
   - Long enough to detect and monitor a variety of transient sources.
4. **Median energy <1 TeV for a Crab-like spectrum**
   - Observe extragalactic sources that are attenuated at high energies by pair production with intergalactic photons.

Functional and Operational Requirements

1. >80% on-time for scientific data taking.
2. Onsite infrastructure and facilities for stable operation.
3. Monitoring of atmospheric conditions, temperature, and pressure.
4. Autonomous (unmanned) operation with automated alert system.
5. Real-time reconstruction and analysis of data with online GRB and flare searches.
6. Remote monitoring system for off-site shift takers.

The HAWC Collaboration

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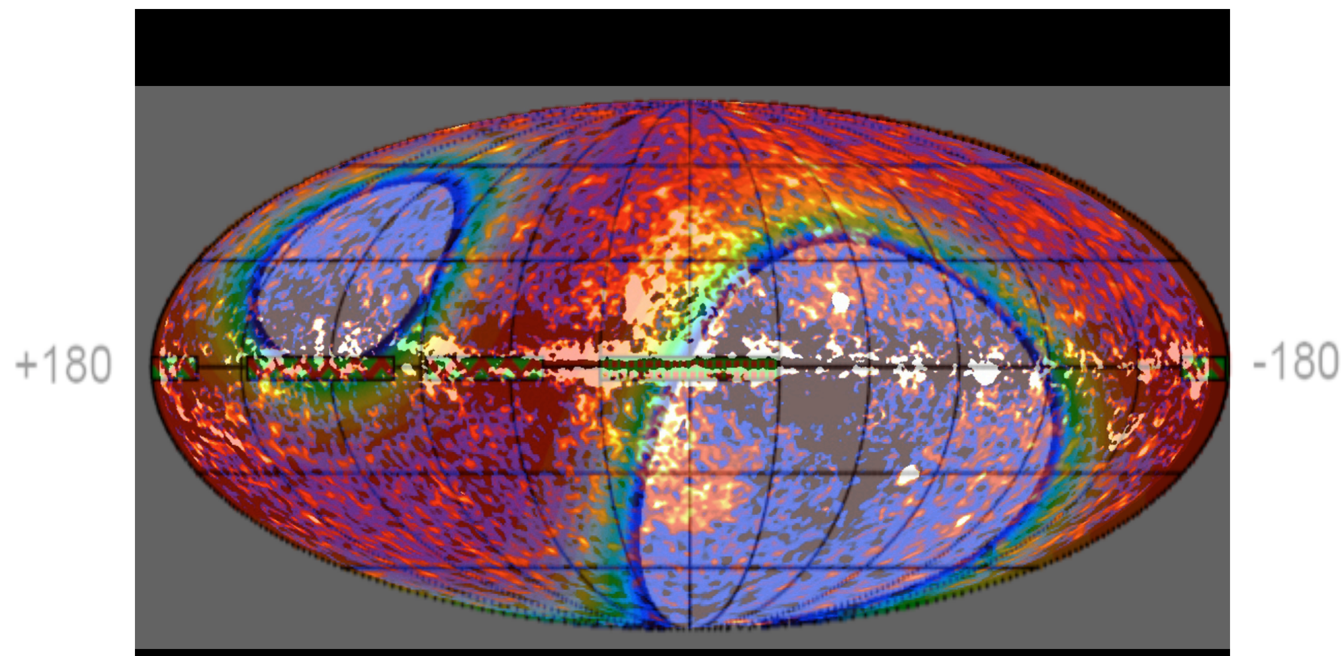
Luis Villaseñor	UMSNH
Juan de Dios Álvarez Rom	UMSNH
César Alvarez Ochoa	UNACH
Roberto Arceo Reyes	UNACH
Eli Santos Rodríguez	UNACH

Mexico


GAP

The near and far future

- Fermi bubbles
  - GeV emission explains WMAP haze as electrons (NOT DARK MATTER)
  - Hard spectrum to >50 GeV requires recent acceleration (BUT NO OBVIOUS ACCELERATOR)
  - HAWC detection or upper limit would further constrain mechanisms
- Should we go even further south?



Science Summary

- HAWC has unique scientific capability
  - Large field of view
  - High Duty Factor
  - Broad Energy Range
- HAWC's rapid construction will result in overlapping observations with Fermi to simultaneously survey the GeV to TeV sky