A First Look at the Very Highest-Energy Gamma-Ray Sky from HAWC

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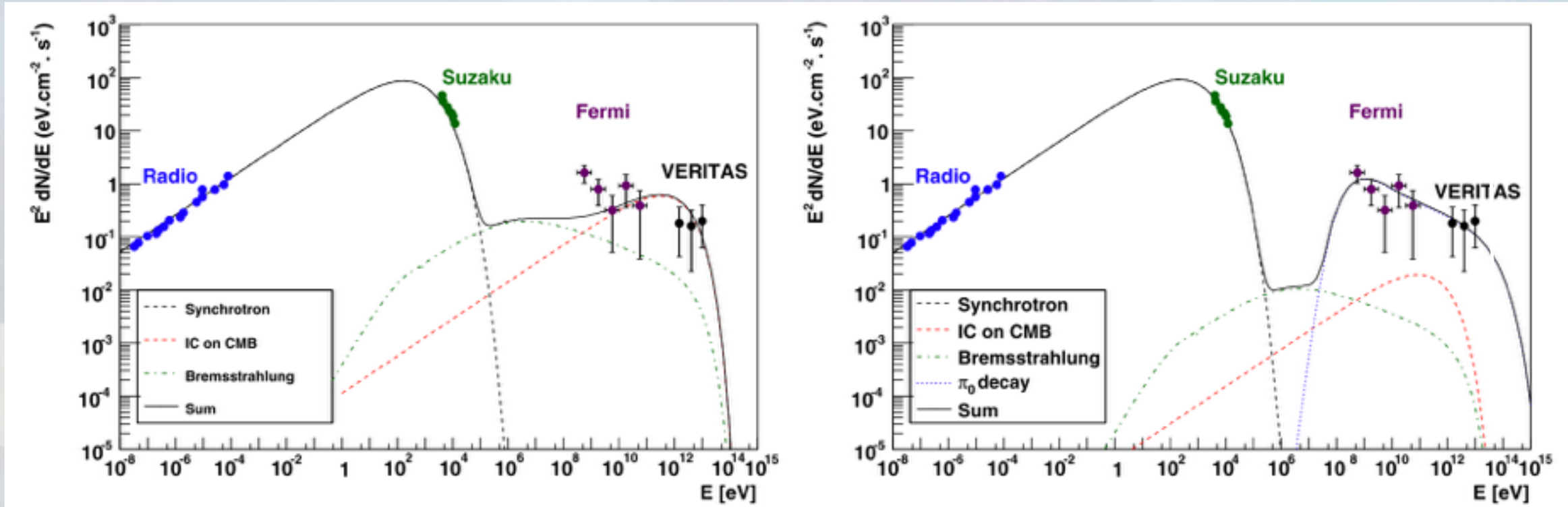
TeV Particle Astrophysics 2017
HAWC Collaboration
Pennsylvania State University

Measuring gamma-ray spectra up to 100 TeV will allow us to determine the nature of cosmic accelerators

Tycho SNR

Giordano et. al ApJ (2012)



Leptonic model

Hadronic model

Electrons in leptonic models suffer from synchrotron loses, leading to differing cutoffs and spectral indices between leptonic and hadronic models

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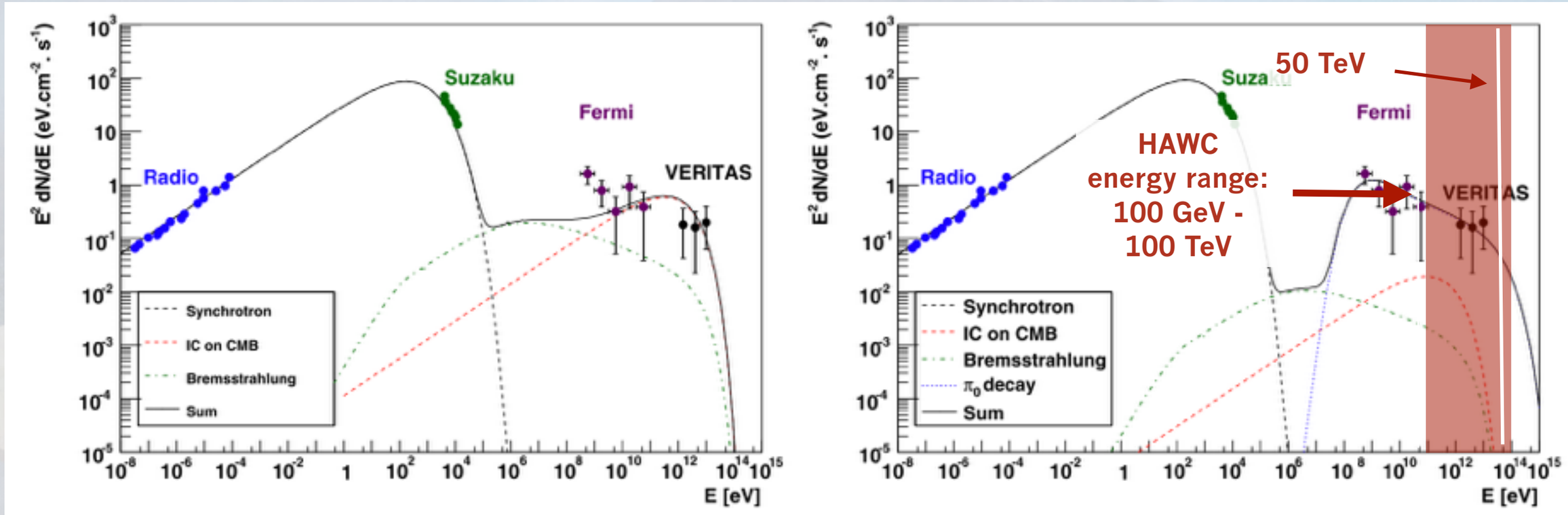

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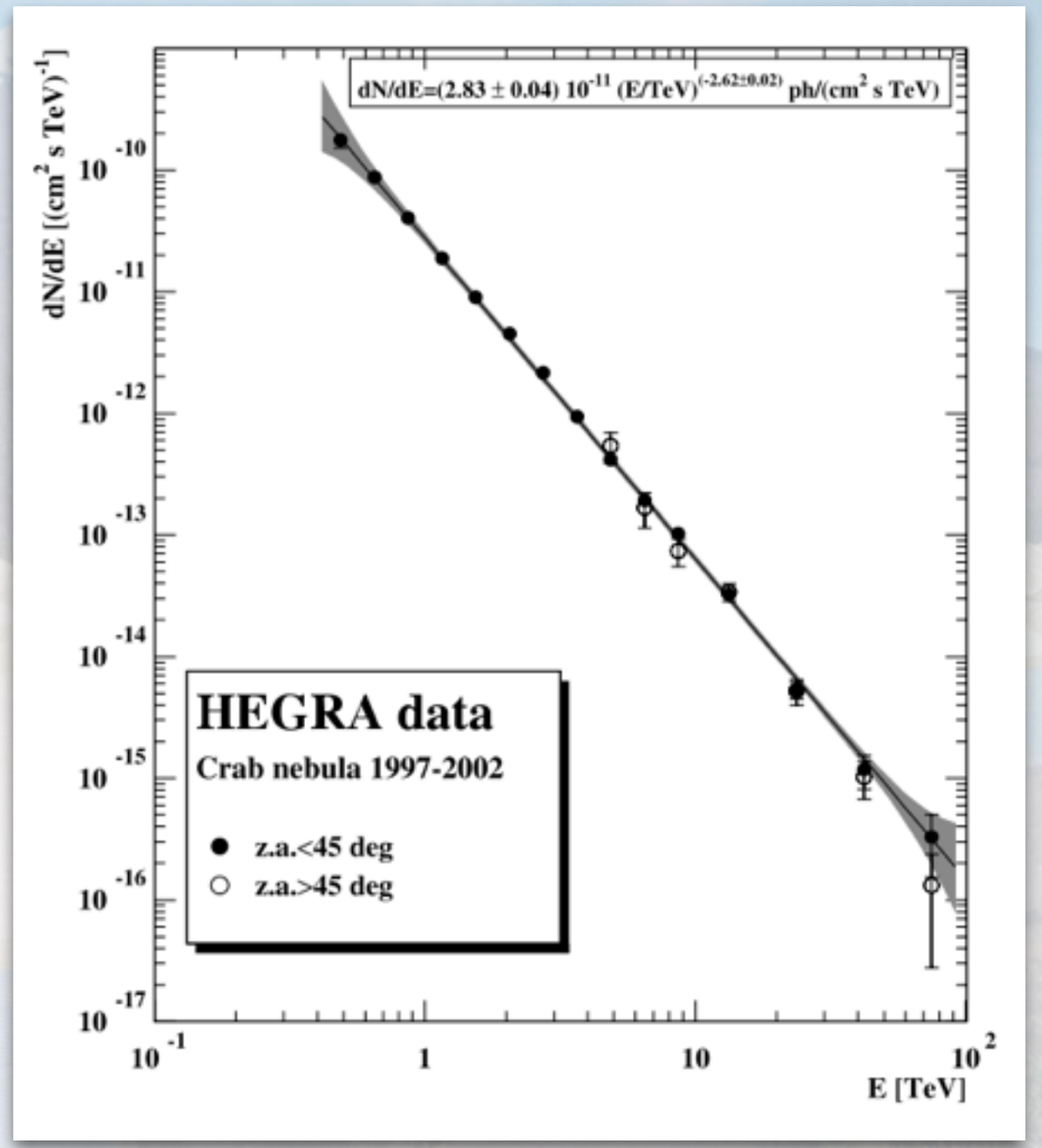
The current state of high-energy gamma-ray observations

- Many sources detected up to a few tens of TeV. Observations sparse above that

HEGRA

- Crab spectrum went up to 80 TeV
- Last bin is centered at 74 TeV, significance 2.7σ

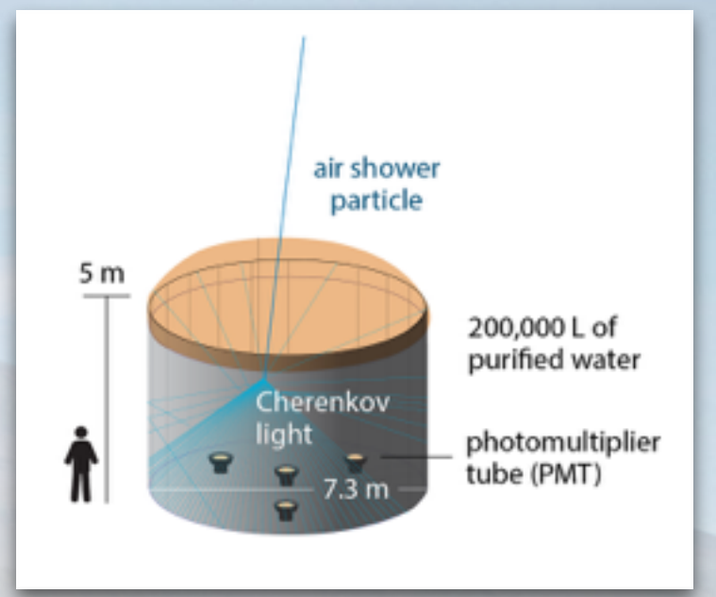
- **Tibet Air Shower Array** and **CASA-MIA** both placed limits on > 100 TeV emission from the Crab Nebula
- Searches for PeV and above gamma rays by IceCube, Auger, etc. have not led to any detections



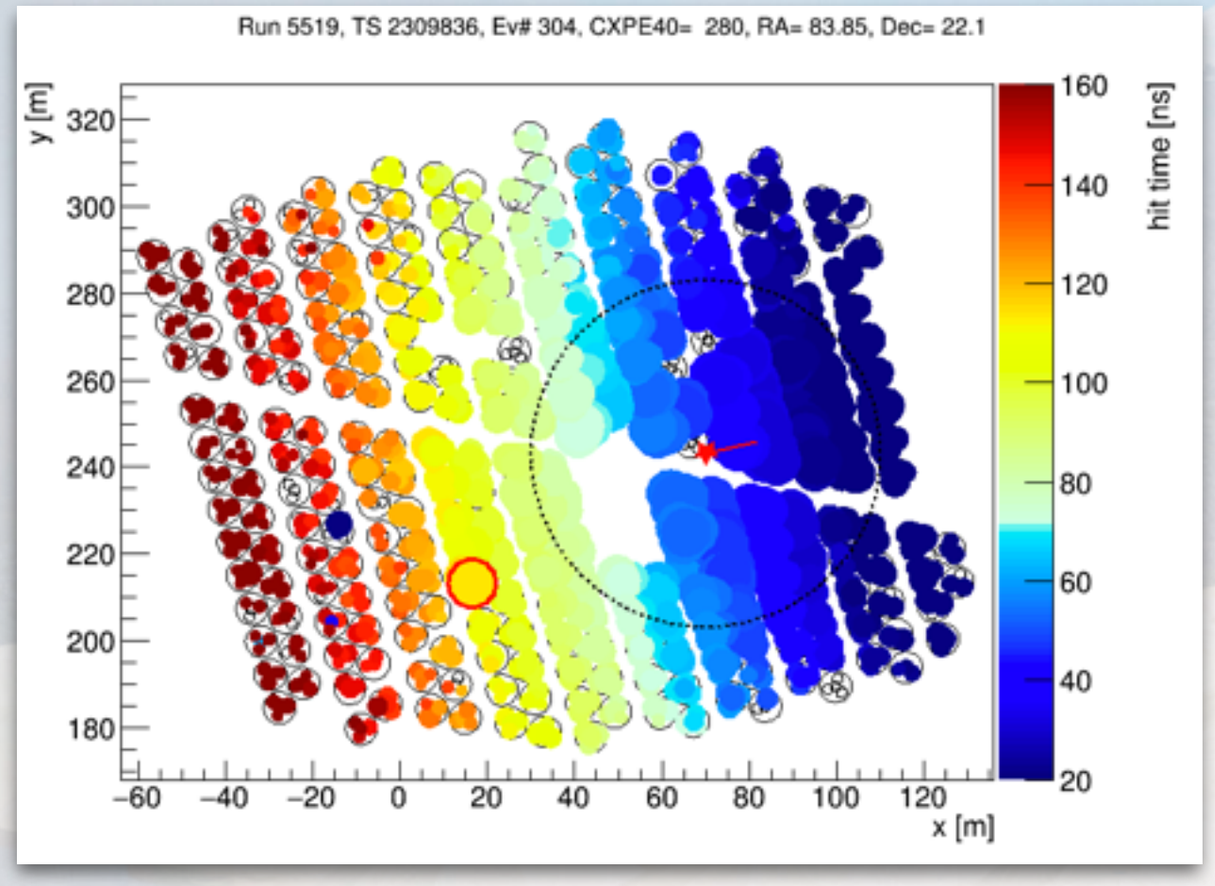
Aharonian et. al ApJ (2004)

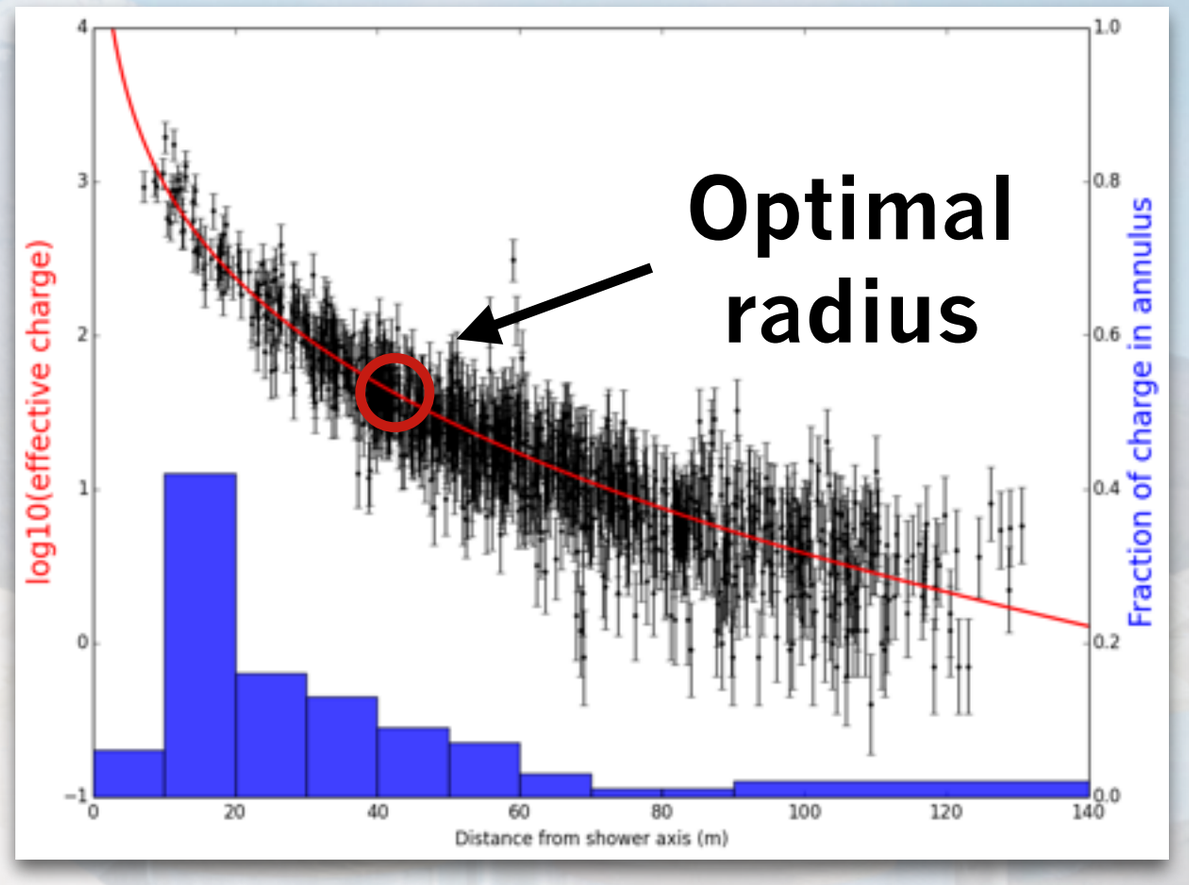
The HAWC Observatory

Number of tanks	300 (4 PMTs/20,000 L of water in each)
Area	20,000 m^2
Location	Puebla, Mexico (18° North)
Altitude	4100 m
Duty Cycle	~100%
Coverage	2/3 of sky
Sensitivity	100 GeV-100 TeV



Gamma-ray energy estimation techniques

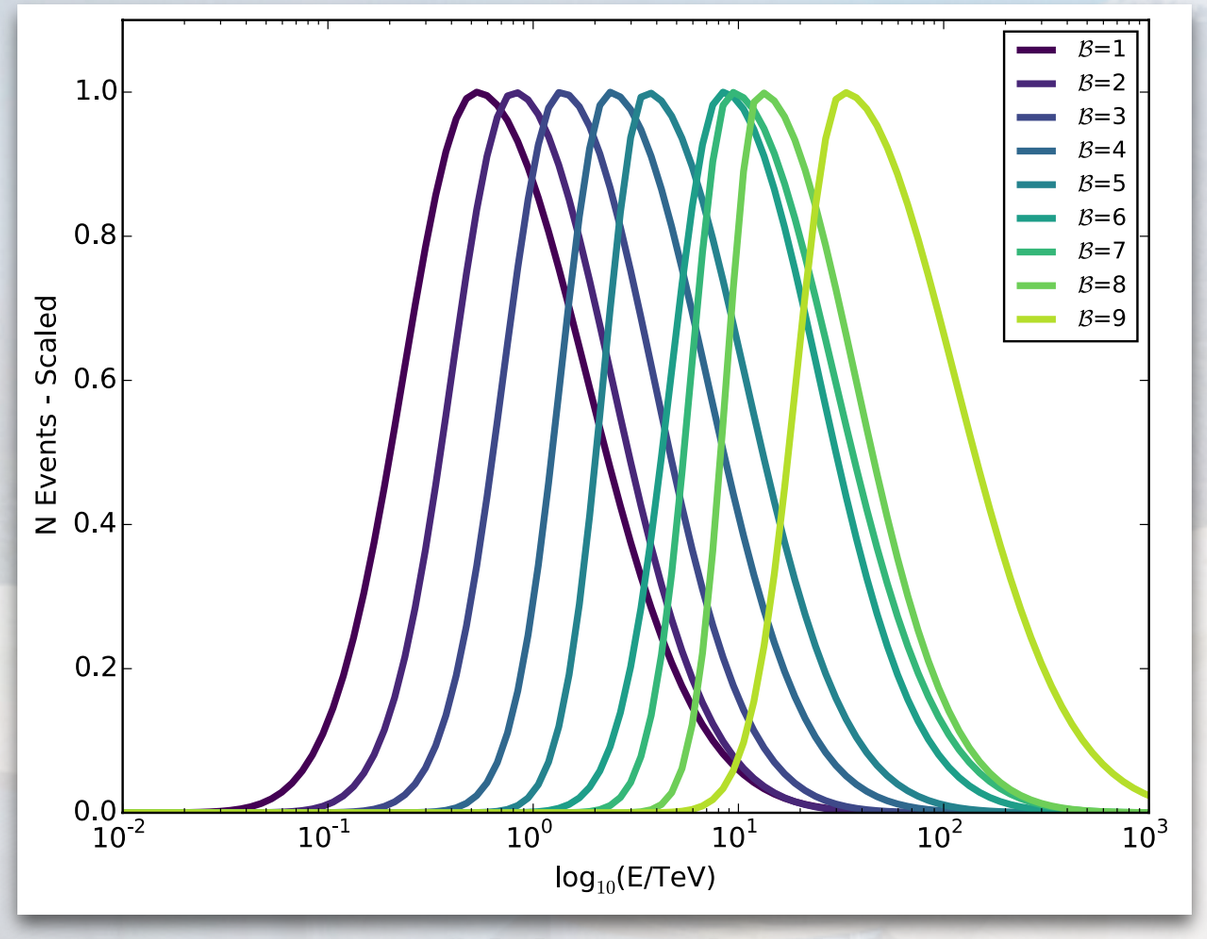




Two event-by-event techniques currently being developed for gamma ray analyses:

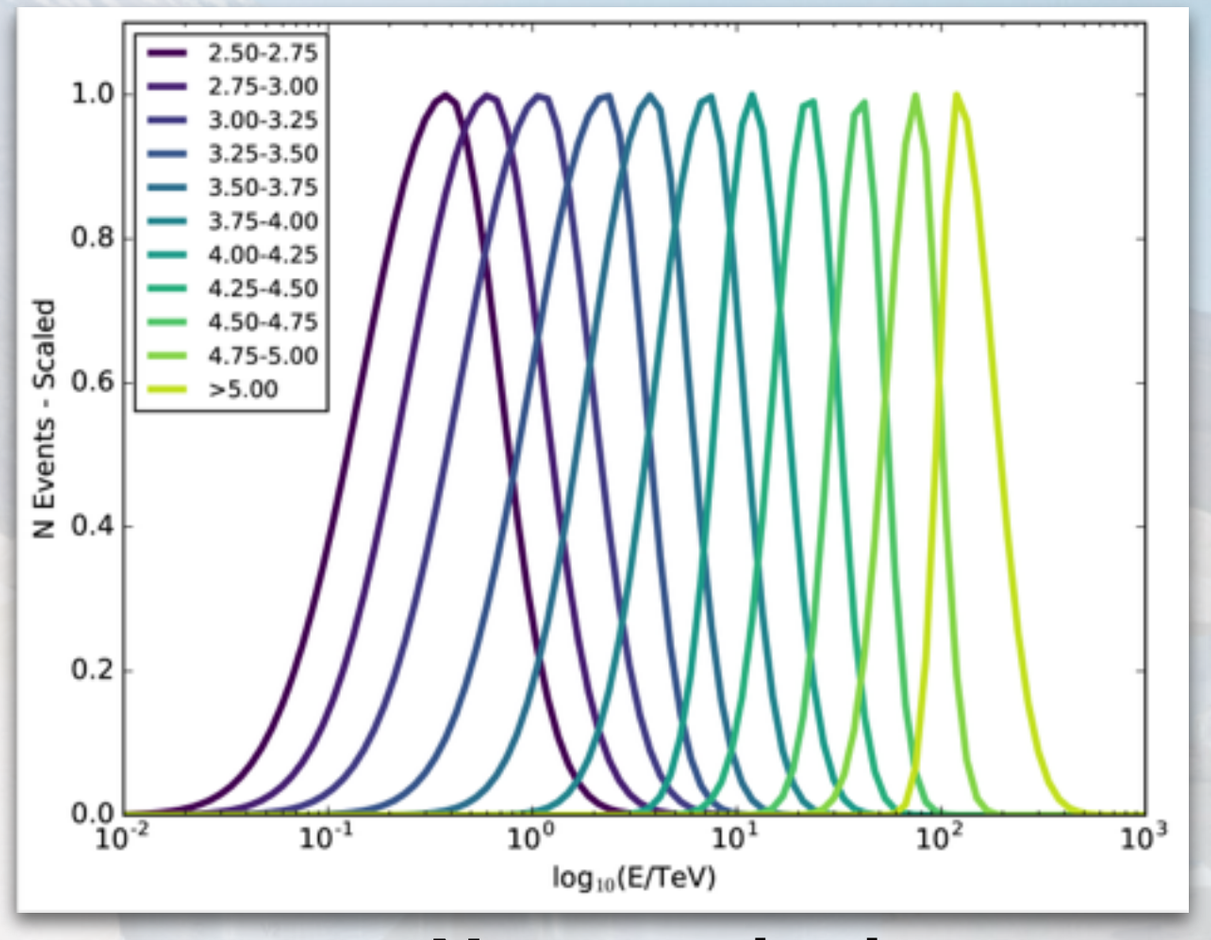
- **Ground parameter (used in this presentation)**
- Neural network (August 9 @ 16:30, S. Marinelli)

Advantages of this energy estimation method



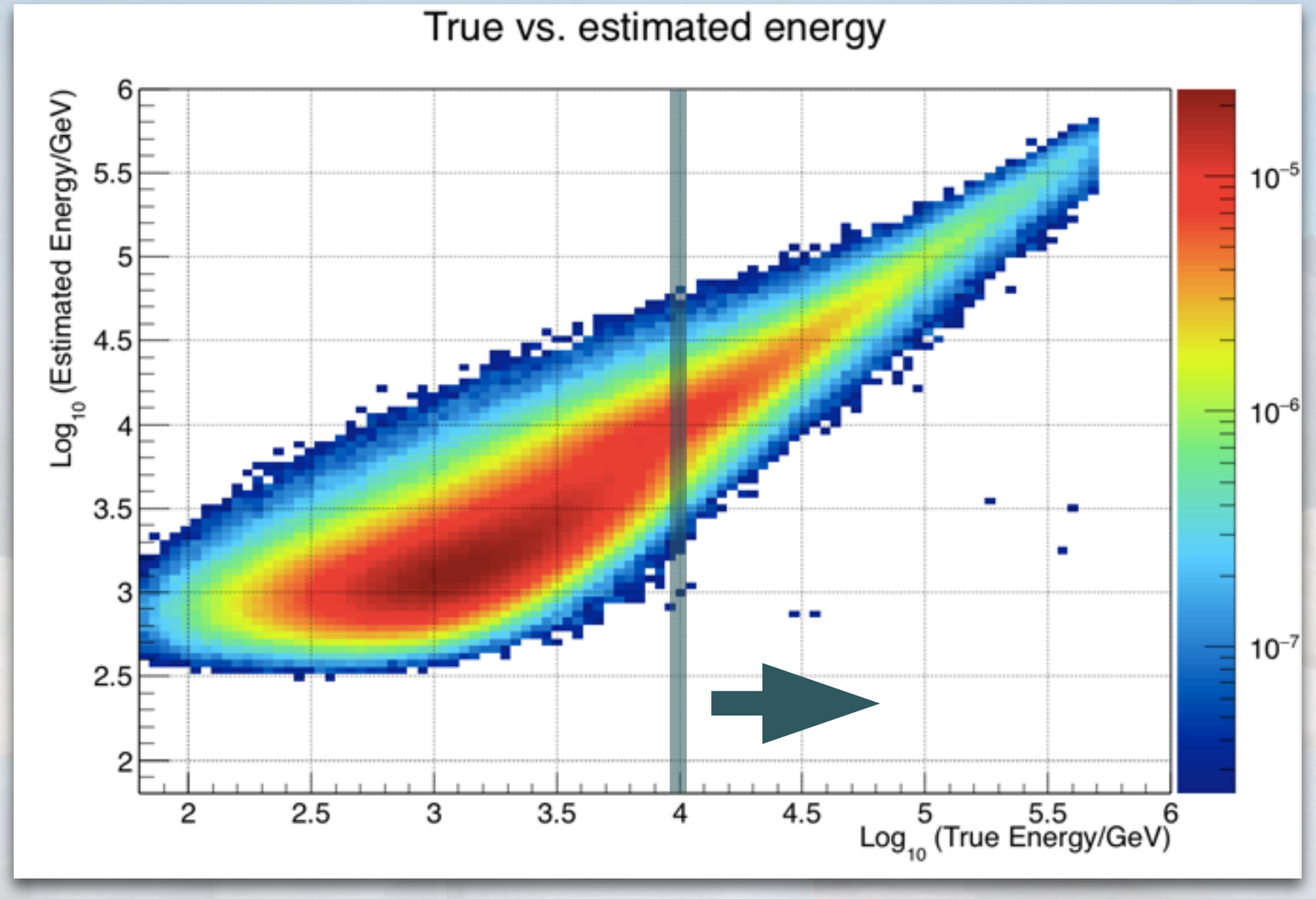
Old method

arXiv:
1701.01778v1



New method

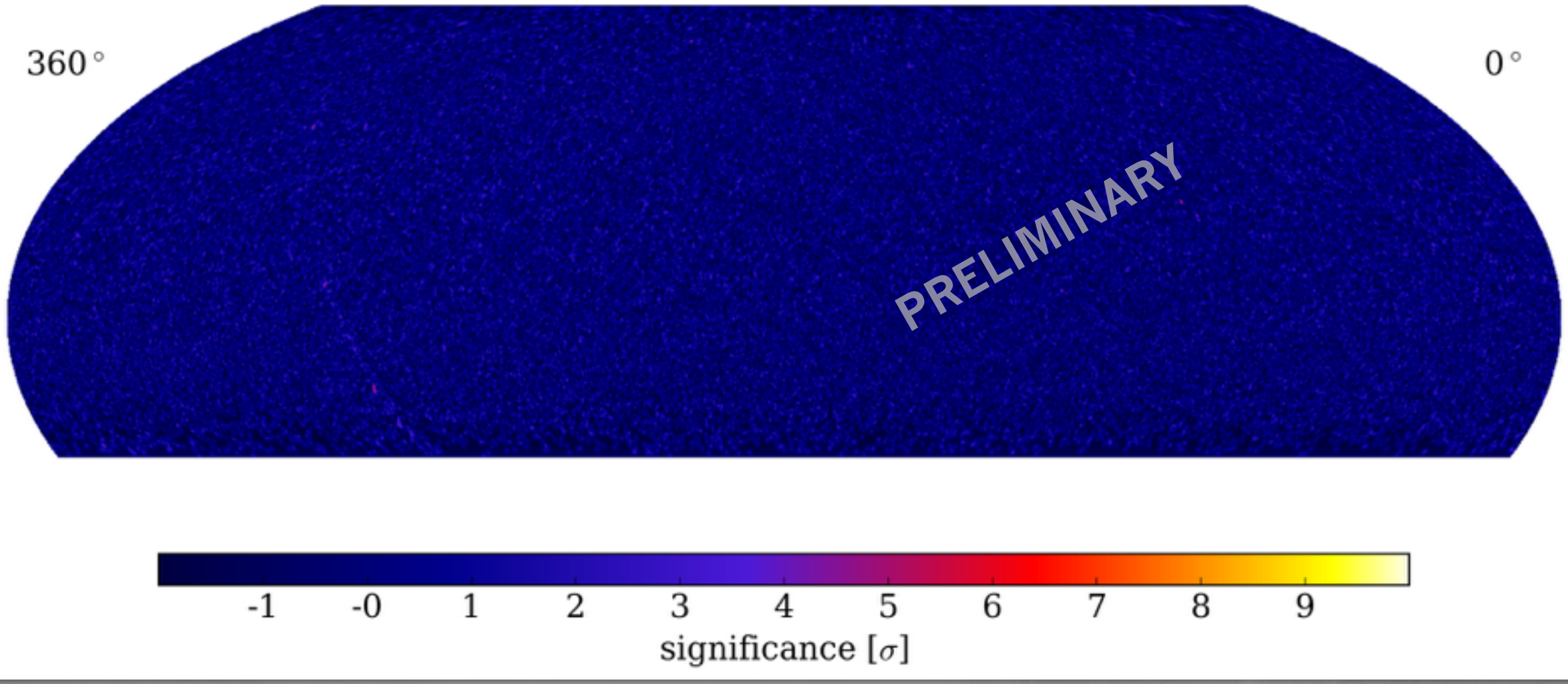
Ground parameter has very good resolution, especially at the highest energies



- All showers to the right of the vertical line previously fell in our highest analysis bin and we could only extract the mean energy of the ensemble
- Recovery of dynamic range above ~10 TeV

The gamma-ray sky as seen by HAWC:
E > 56.2 TeV
Point source hypothesis

- Power law with index of 2.7 assumed
- Data taken between 11/2014 and 6/2016



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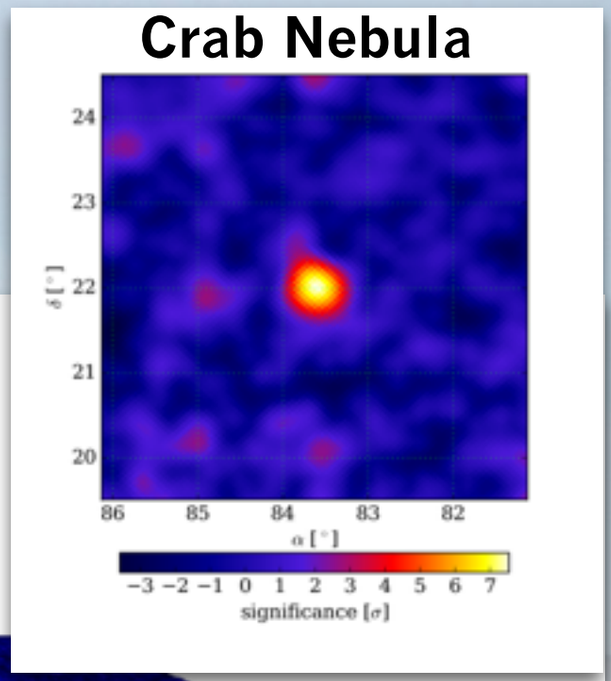

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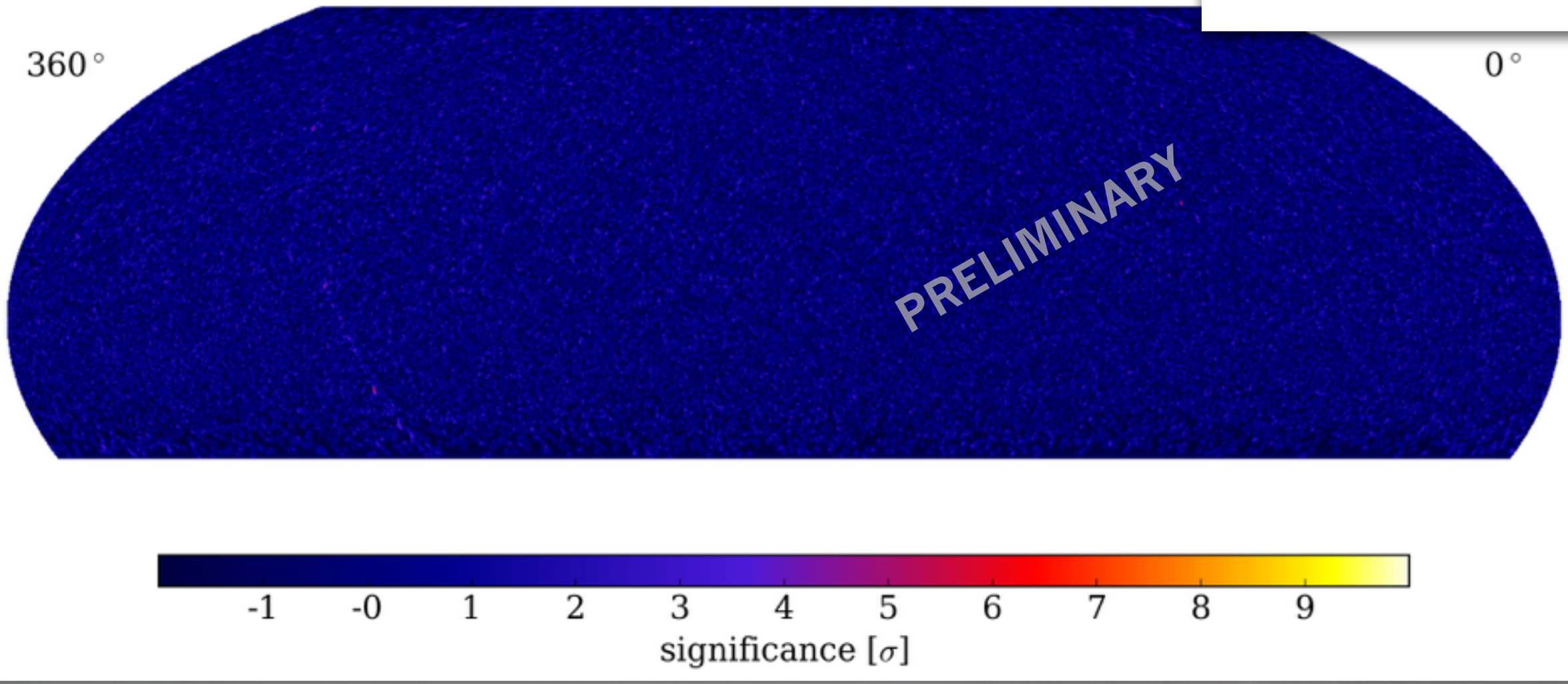

The gamma-ray sky as seen by HAWC:
E > 56.2 TeV
1.0 degree extended source hypothesis

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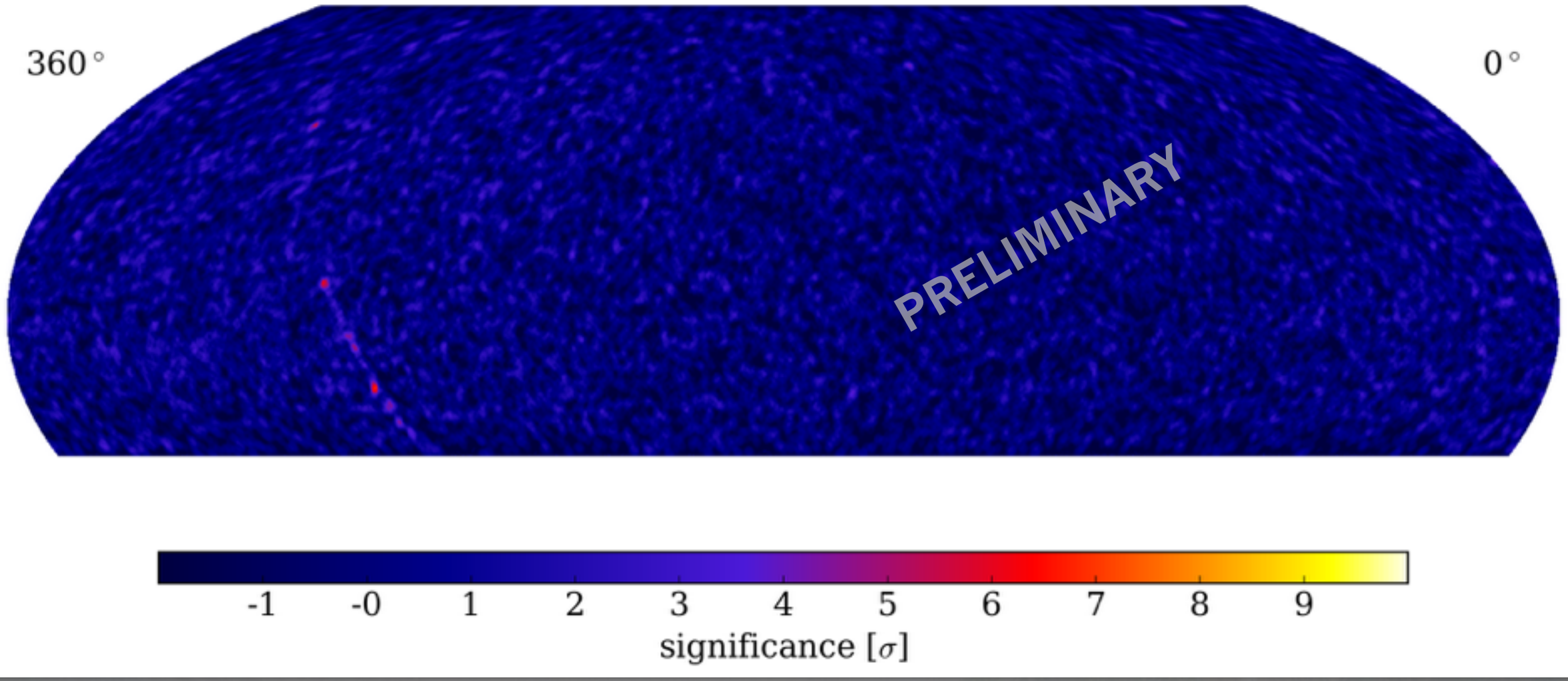
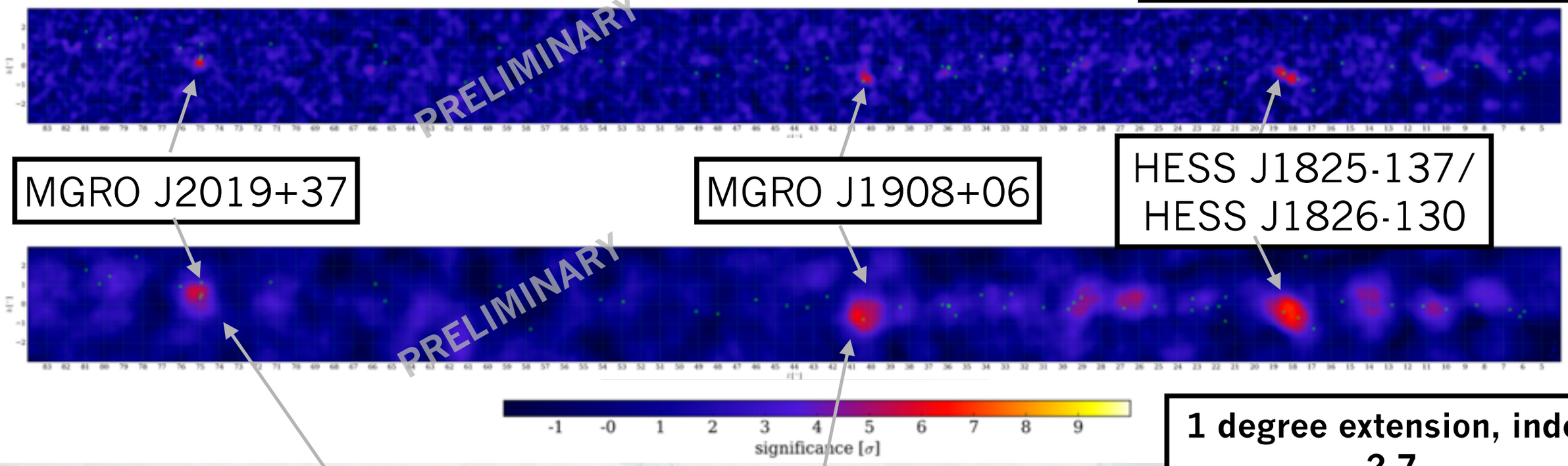


HAWC has sensitivity at the highest energies

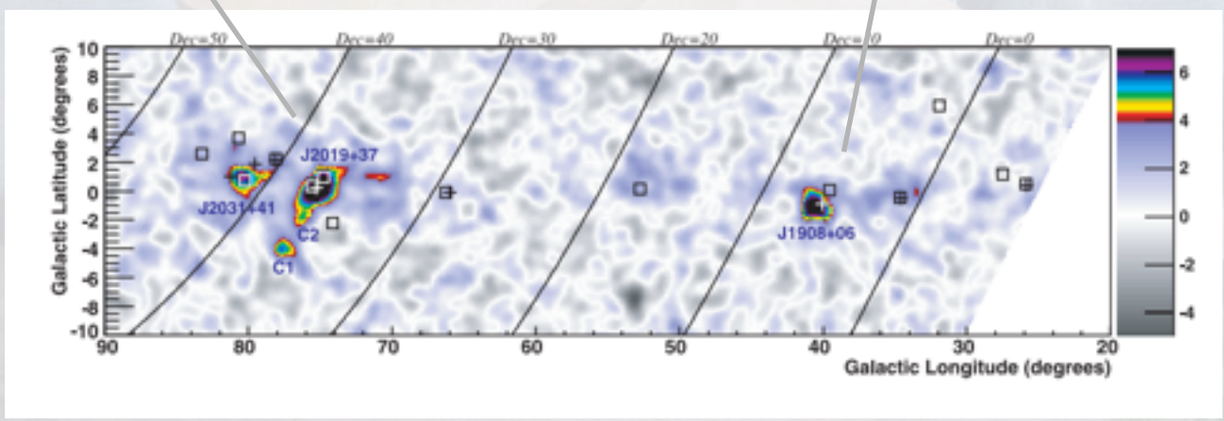
Galactic plane for > 56 TeV

Point Source Search, index 2.7

Green dots denote TeVCat source locations



1 degree extension, index 2.7

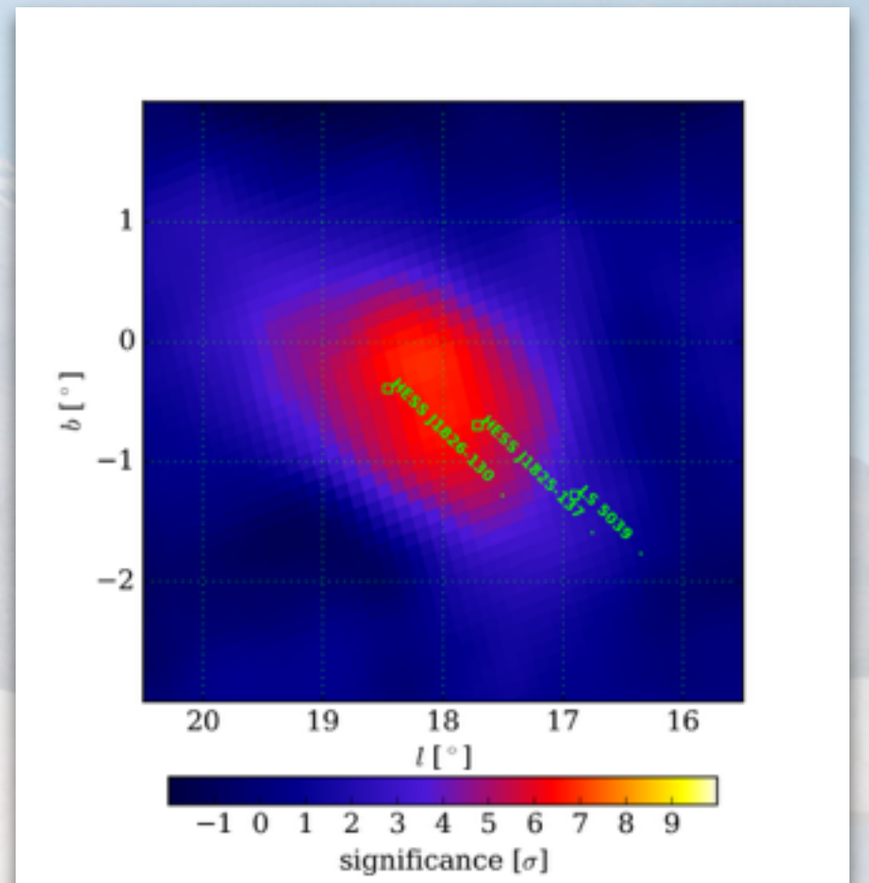


Milagro Galactic Plane map (median energy ~20 TeV)

Abdo et. al, ApJ (2007)
Arxiv 0705.0707

What kinds of objects emit > 50 TeV?

- 3 regions detected > 5σ in this preliminary analysis
- **MGRO 1908+06** is an unidentified source, although there is a pulsar in the region
- **MGRO 2019+37** and **HESS J1825-137/ HESS J1826-130** regions are confused and have both unidentified sources and PWN in the vicinity
  - **MGRO 2019+37** is also near star-forming region Sh 2-104
  - Hard to disentangle emission, multiple source fits in progress



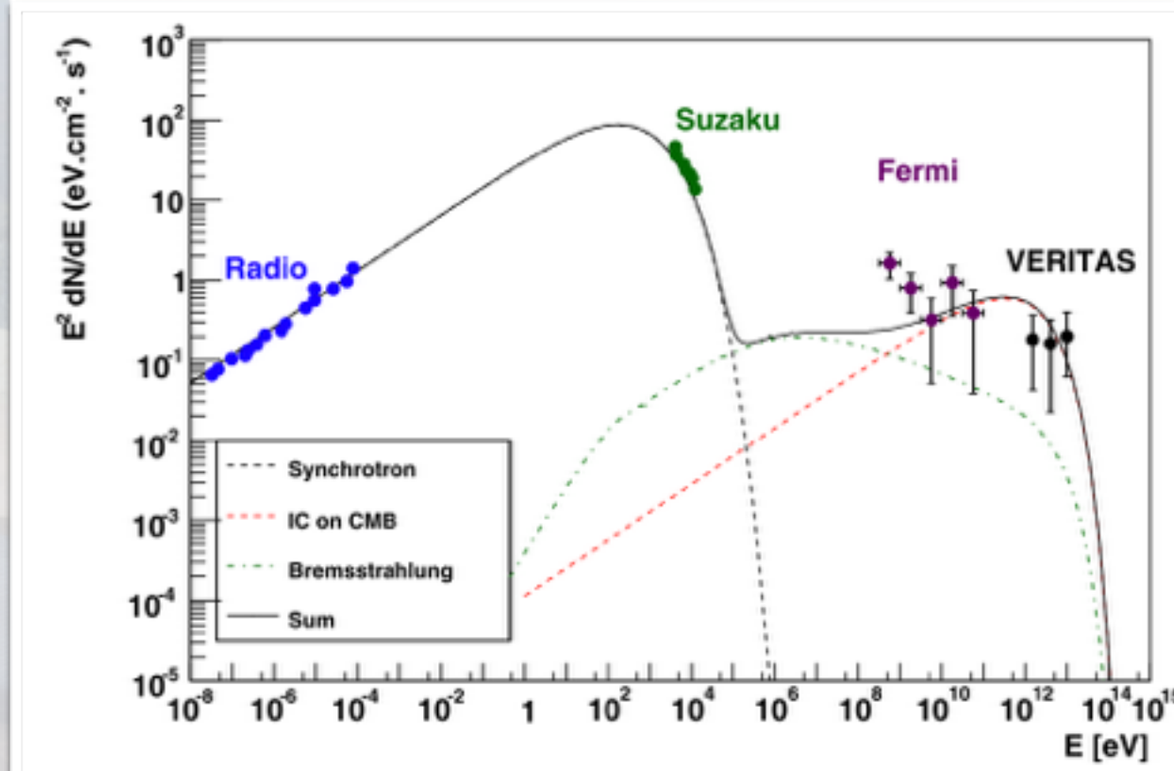
HESS J1825-137/ HESS J1826-130: Confused region with HAWC

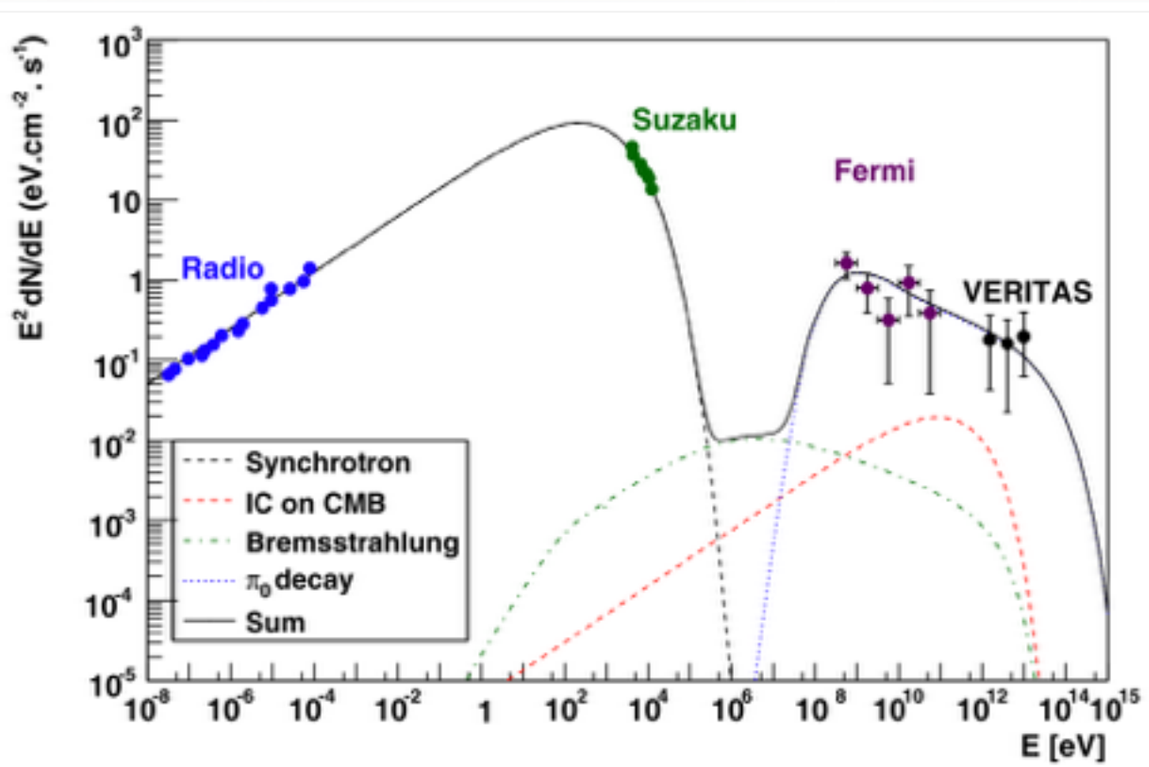
Implications of high-energy observations

Source model determination | Searches for PeVatrons | Lorentz invariance violation

Tycho SNR

Giordano et. al ApJ (2012)





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Hadronic model

Implications of high-energy observations

Source model determination | **Searches for PeVatrons** | Lorentz invariance violation

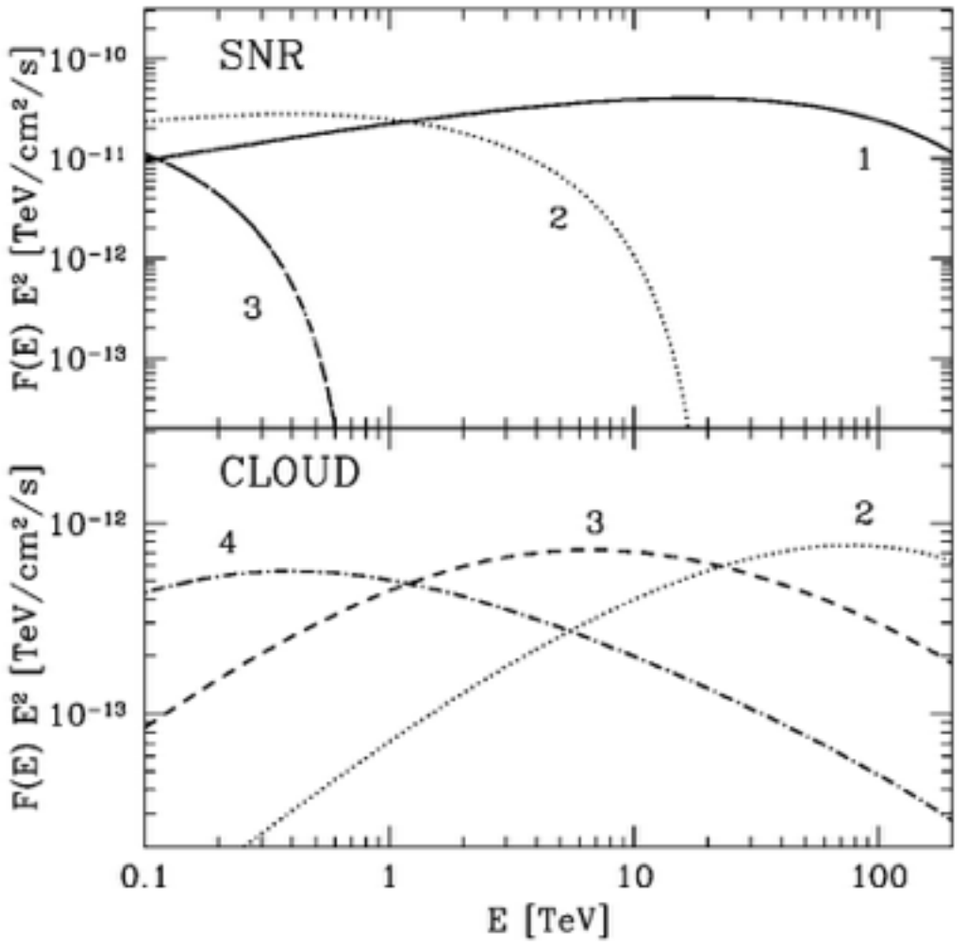
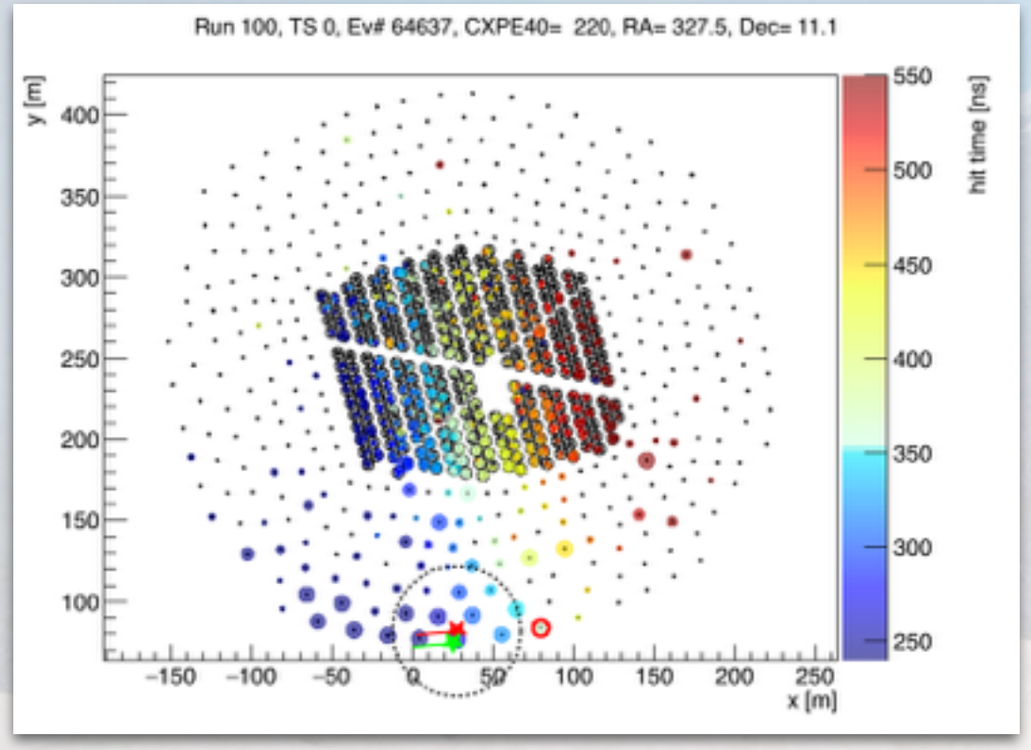


FIG. 1.—Gamma-ray spectra from the SNR (*top*) and from a cloud of $10^4\ M_\odot$ located 100 pc away from the SNR (*bottom*). The distance is 1 kpc. Curves refer to different times after the explosion: 400 yr (*curve 1*), 2000 yr (*curve 2*), 8000 yr (*curve 3*), and 3.2×10^4 (*curve 4*) yr.

Gabici and Aharonian, ApJ (2007)

- Gabici and Aharonian, ApJ (2007):
  - Multi-PeV protons escape from SNR into interstellar medium
  - If a molecular cloud is close enough (~100 pc) of SNR, delayed emission of multi-TeV γ-rays (along with neutrinos)
  - Klein-Nishina effects greatly reduce efficiency of IC scattering at > 100 TeV, any γ-rays in this range are almost certainly from π^0 decay → **identification of a PeVatron**

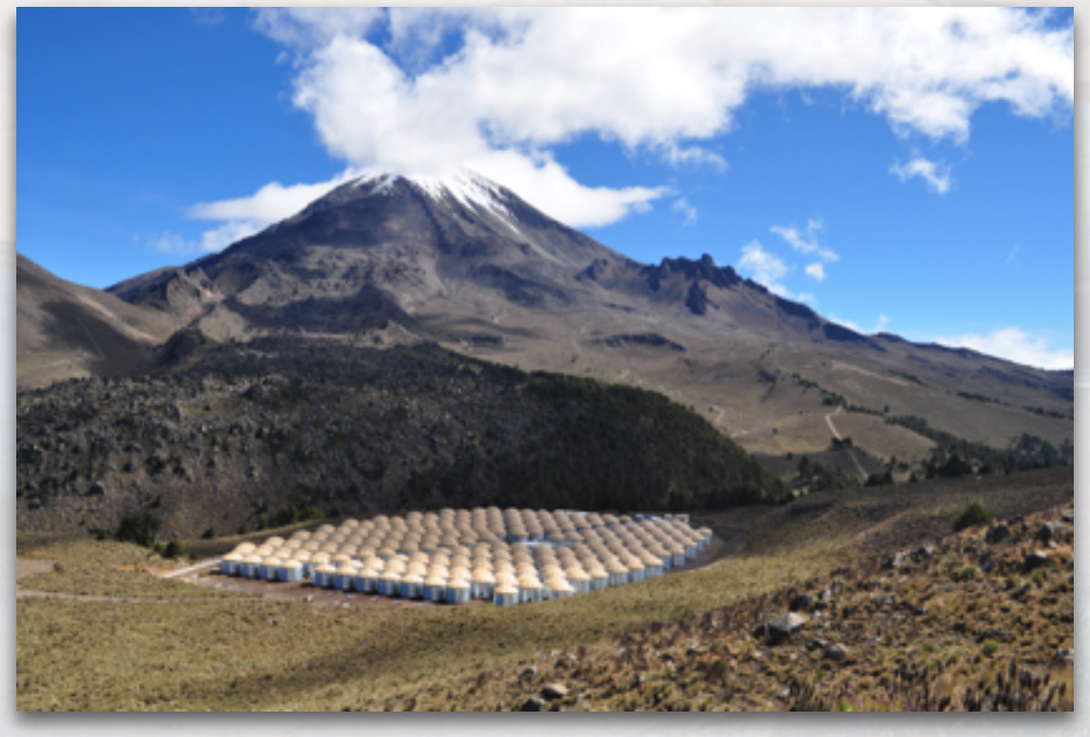
Upcoming outrigger installation will increase sensitivity at high energies



- 300 smaller tanks, will make core determination possible for the highest energy events with cores off the array
- 3-4x increase in effective area, leading to **2x or greater sensitivity increase above 10 TeV**
- Break degeneracy between deep penetrating, high energy showers far from the array and shallow, low energy showers closer to the array
- Deployment currently underway

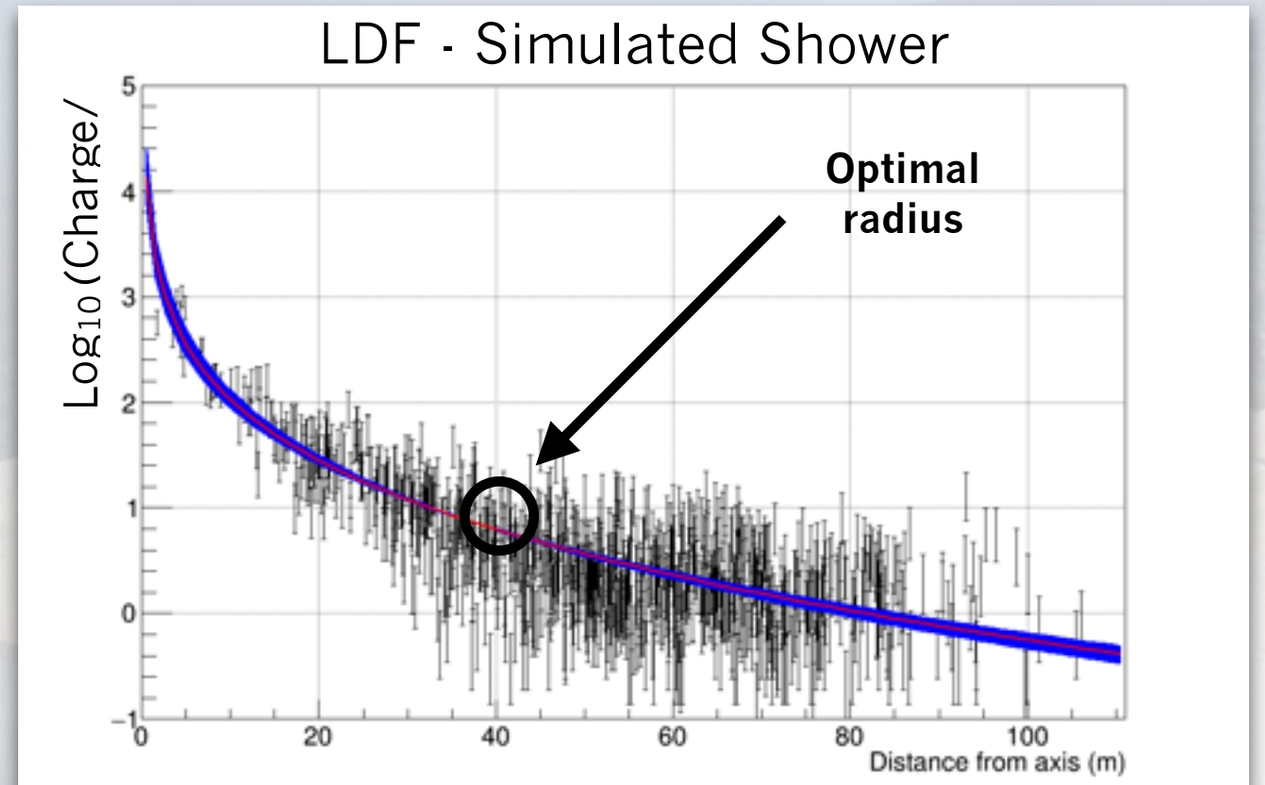
Conclusions

- HAWC has sensitivity in the 50-100 TeV range. Both the Crab Nebula and sources in the galactic plane are visible
- These gamma ray sources are among the highest energy sources even seen
- Implications include distinguishing between different source models, identification of PeVatrons, and setting limits on Lorentz invariance
- Spectra and fluxes above 50 TeV coming soon



Backup Slides

Energy Estimation



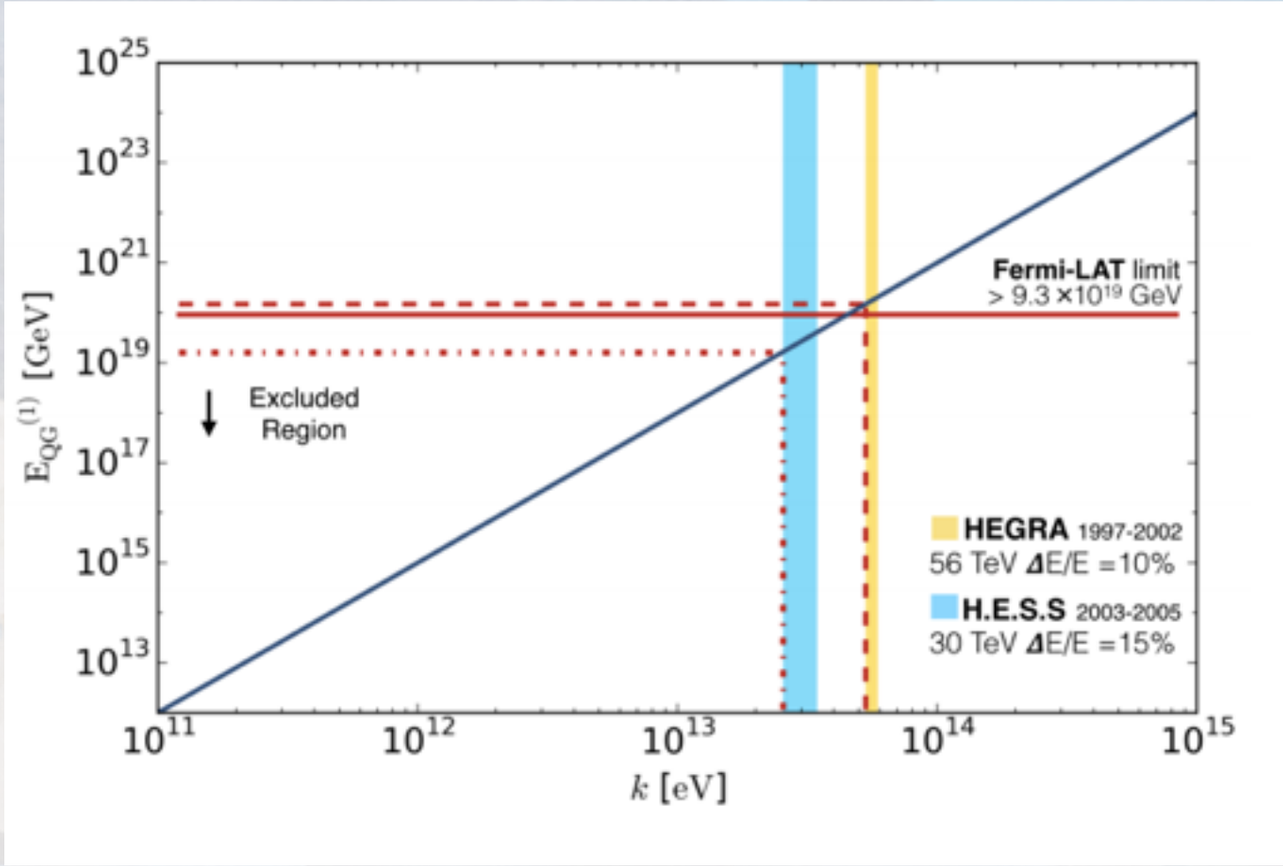
- This is fit to an NKG-like function:

$$Q(r) = A\left(\frac{r}{R_{mol}}\right)^{s-3}\left(1+\frac{r}{R_{mol}}\right)^{s-4.5}$$

Implications of high-energy observations

Source model determination | Searches for PeVatrons | **Lorentz invariance violation**

- Photon decay predicted in some quantum gravity models
  - Observing VHE photons constrains this limit
- See S. Marinelli's talk on Wednesday



Martinez-Huerta and Perez-Lorenzana (Phys Review D, 2017)