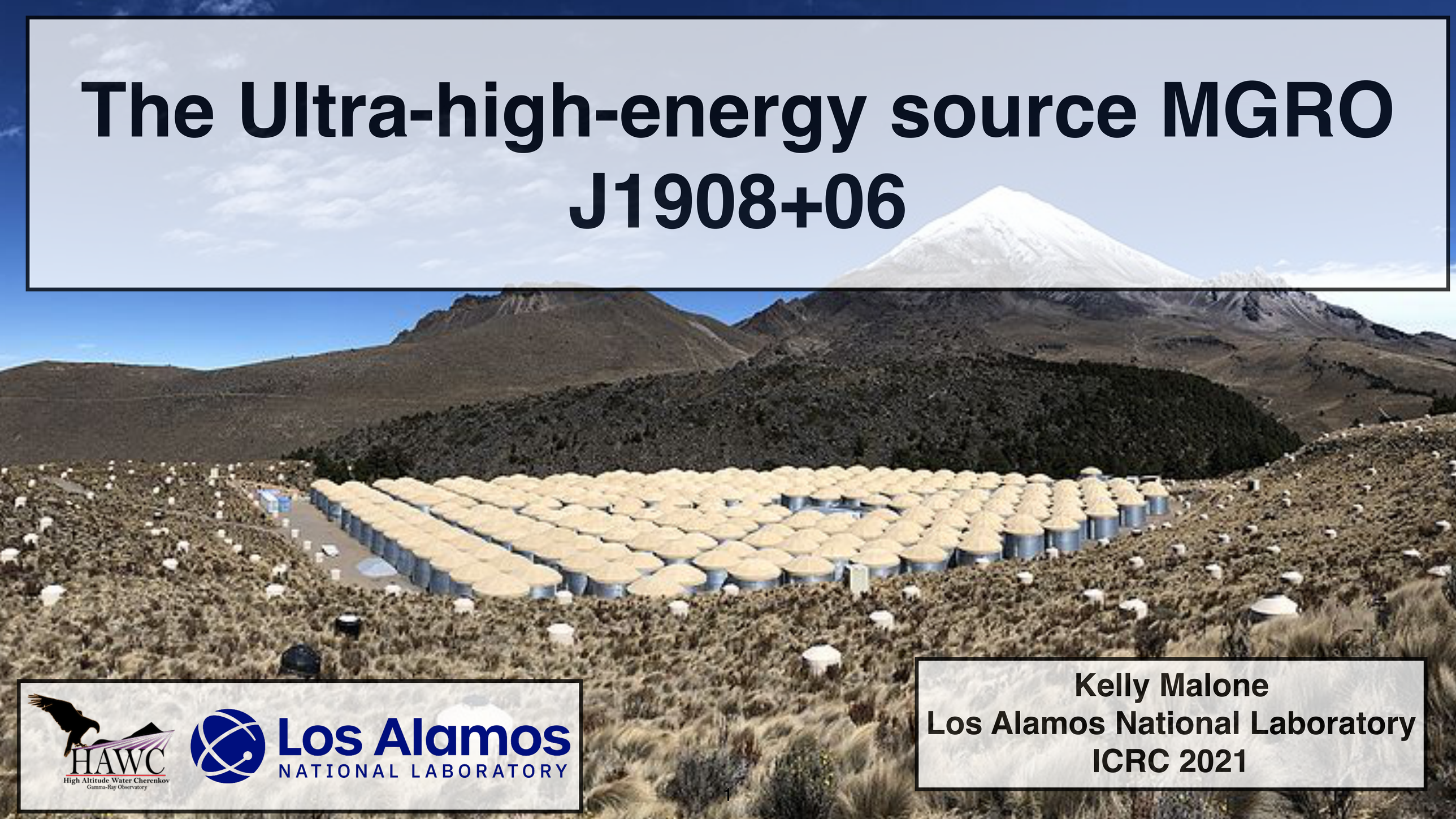
The Ultra-high-energy source MGRO J1908+06



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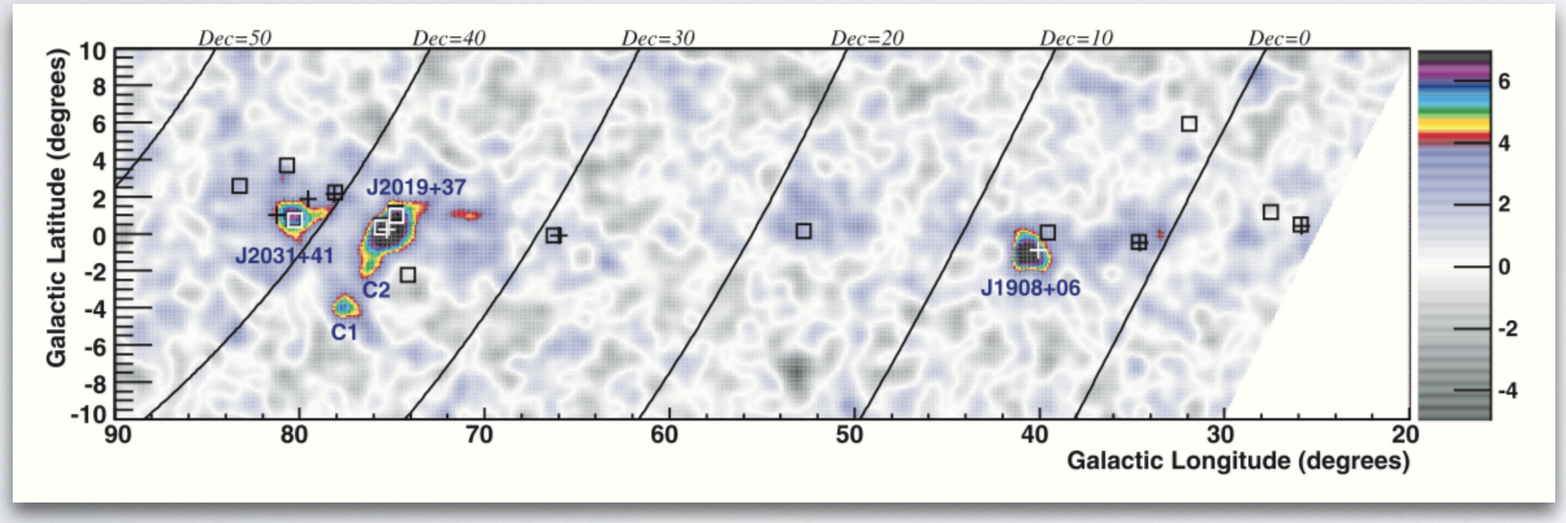
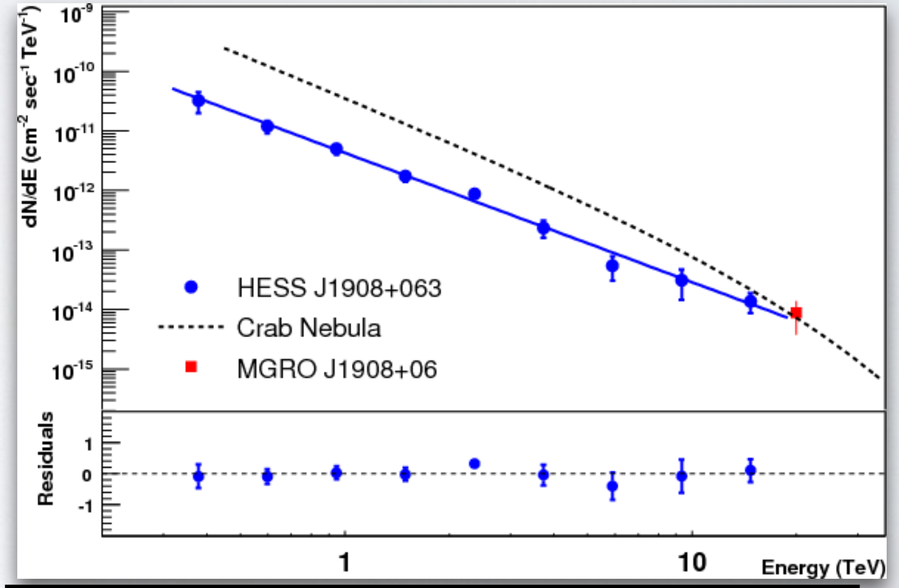
ICRC 2021

Previous TeV observations of MGRO J1908+06

- Discovered by Milagro in 2007, subsequently observed by H.E.S.S., VERITAS, and Argo
- Bright source with a hard spectrum, little or no curvature up to ~20 TeV
- Shown to emit above 100 TeV by HAWC in 2020.



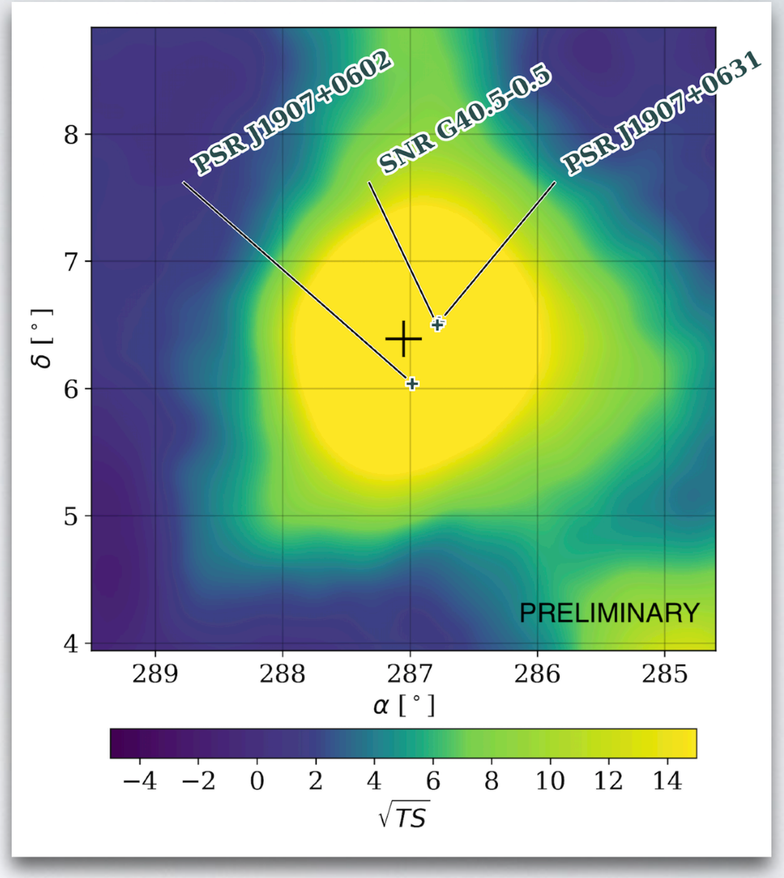
Milagro Collaboration
Abdo et al, ApJ, 664 L91 (2007)



HESS Collaboration
Aharonian et al, A&A, 499 3 (2009)

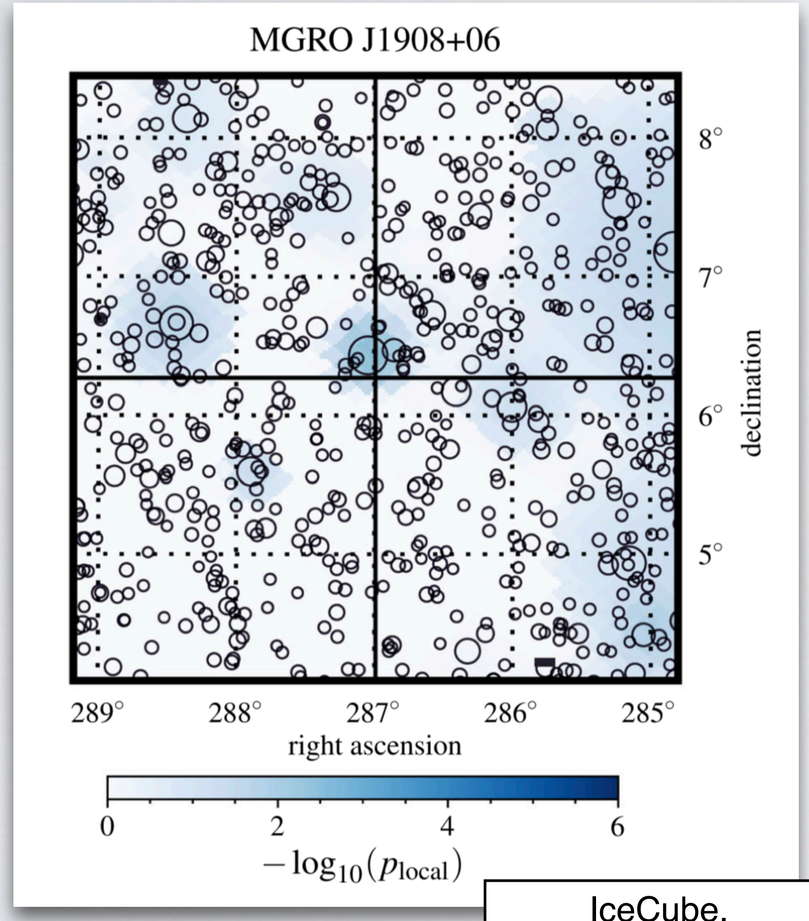
Possible counterparts

- Crowded region: Two pulsars, an SNR remnant, and molecular clouds are all present.
- PSR J1907+0602 is a young (~20 kyr) radio-quiet pulsar that is extremely high-Edot (2.8 x 10^{36} ergs/s)
  - Historically the TeV emission has been attributed to this pulsar, but other objects could also contribute to the emission



HAWC significance map with potential counterparts labeled. The cross is the center of the HAWC source

Multi-messenger observations



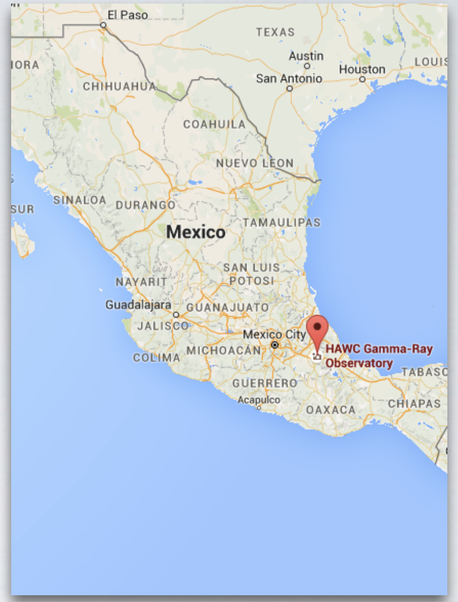
IceCube, European Physics Journal (2019)

- Due to it's hard spectrum, it has long been considered a potential neutrino source.
- Best p-value for a Galactic source in IceCube catalog searches, although still consistent with background.

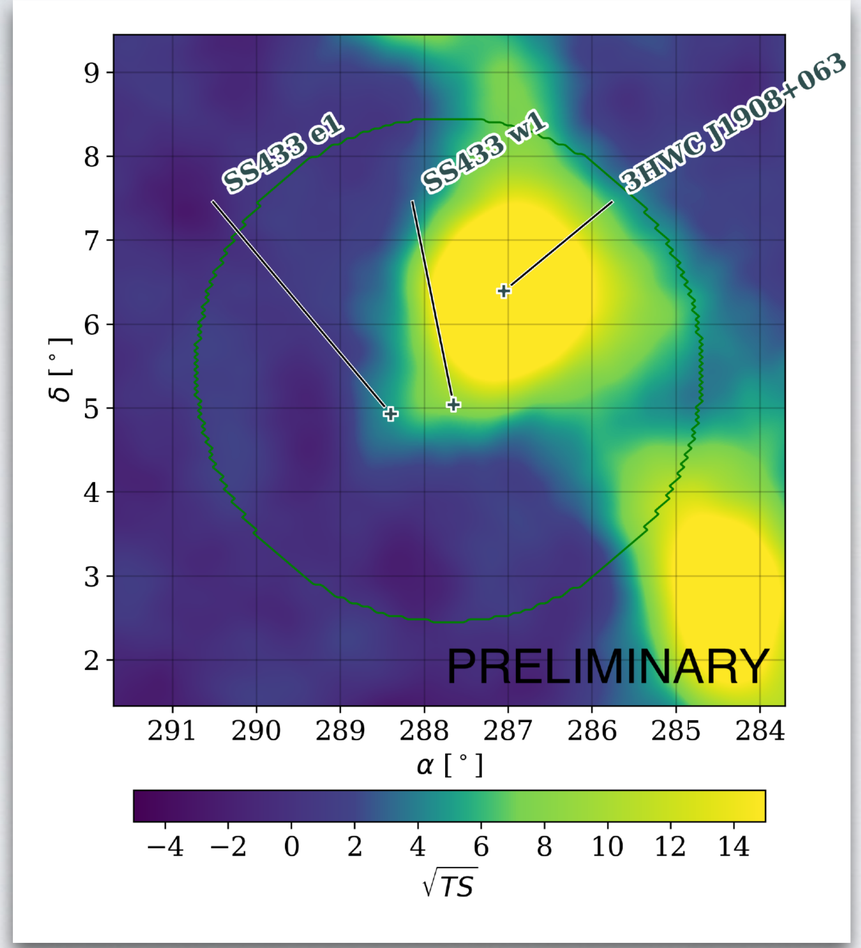
Introduction to HAWC

HAWC with Pico de Orizaba in the background

Number of tanks	300 (4 PMTs/200,000 L of water in each)
Area	22,000 m^2
Location	Puebla, Mexico (19° North)
Altitude	4100 m
Duty Cycle	> 95%
Coverage	2/3 of sky per day
Sensitivity	300 GeV to > 100 TeV
Angular resolution	> 0.1 degrees



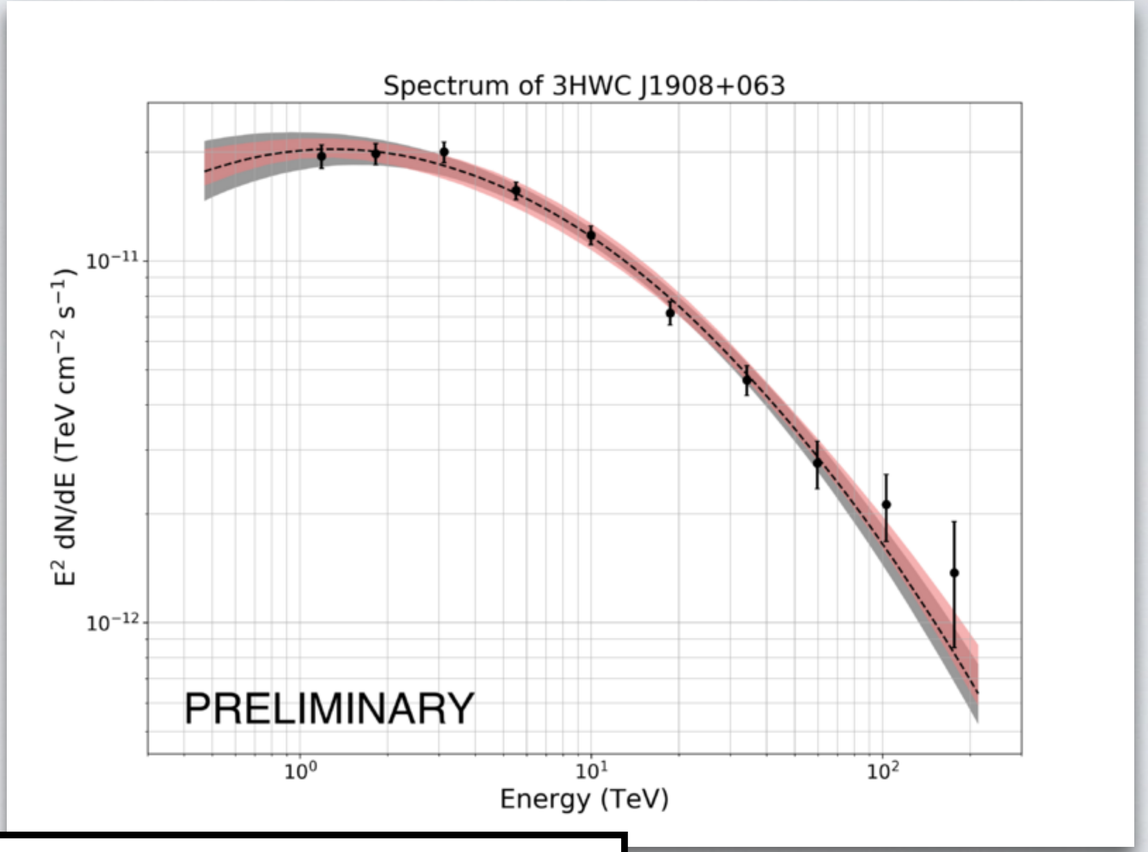
Significance map of the region



- 1343 days of data with reconstructed energies above 1 TeV
- Likelihood fit containing 3HWC J1908+063 plus the nearby lobes of SS433
- Performed using the HAWC Accelerated Likelihood (HAL) plugin to 3ML (Multi-mission maximum likelihood)
  - Publicly available: https://github.com/threeML/threeML

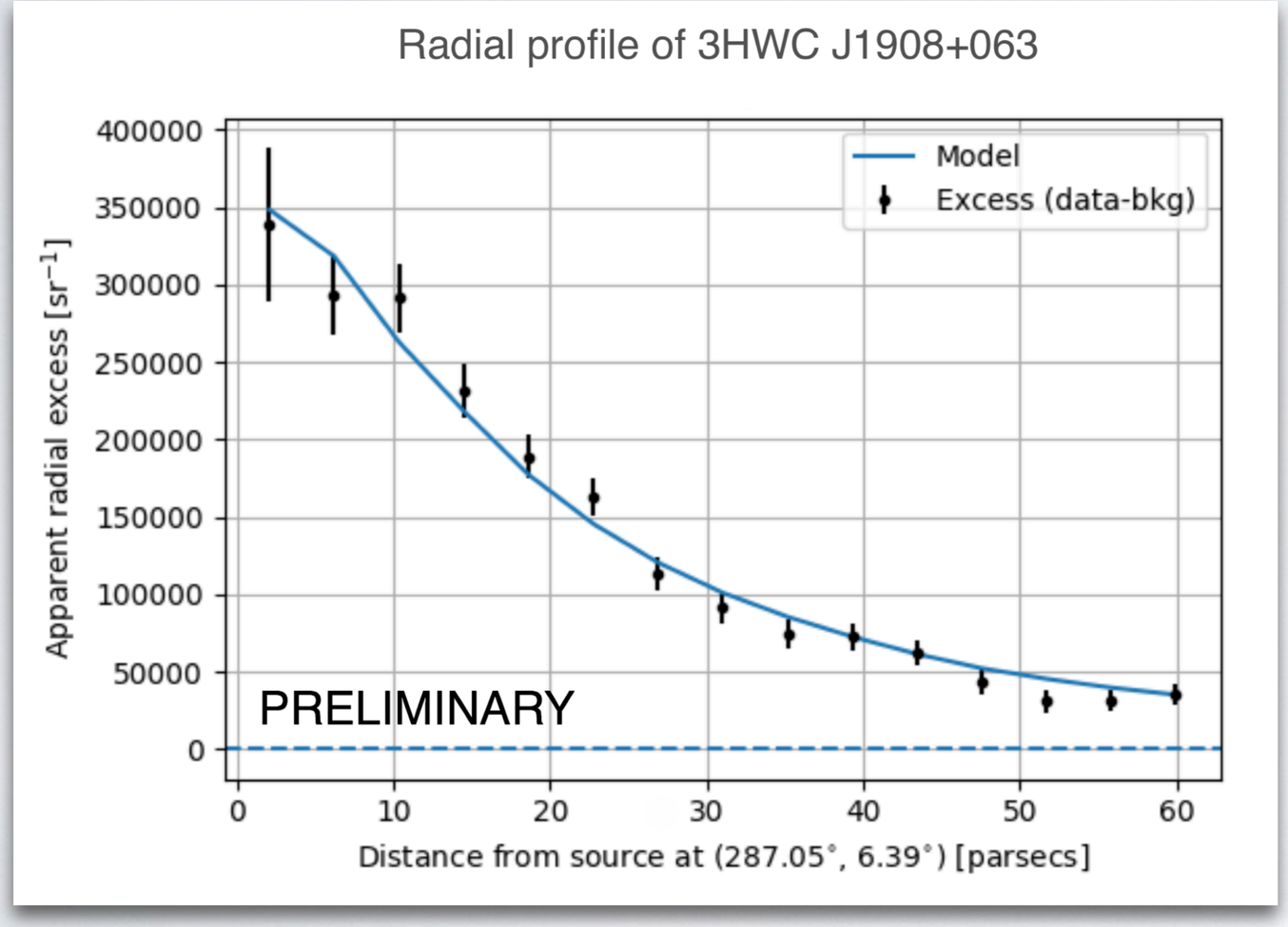
HAWC spectrum

- Best-fit spectrum is a log-parabola
- Best-fit morphology is a diffusion morphology with particles continuously injected from the center of the source
- Spectrum extends past 200 TeV



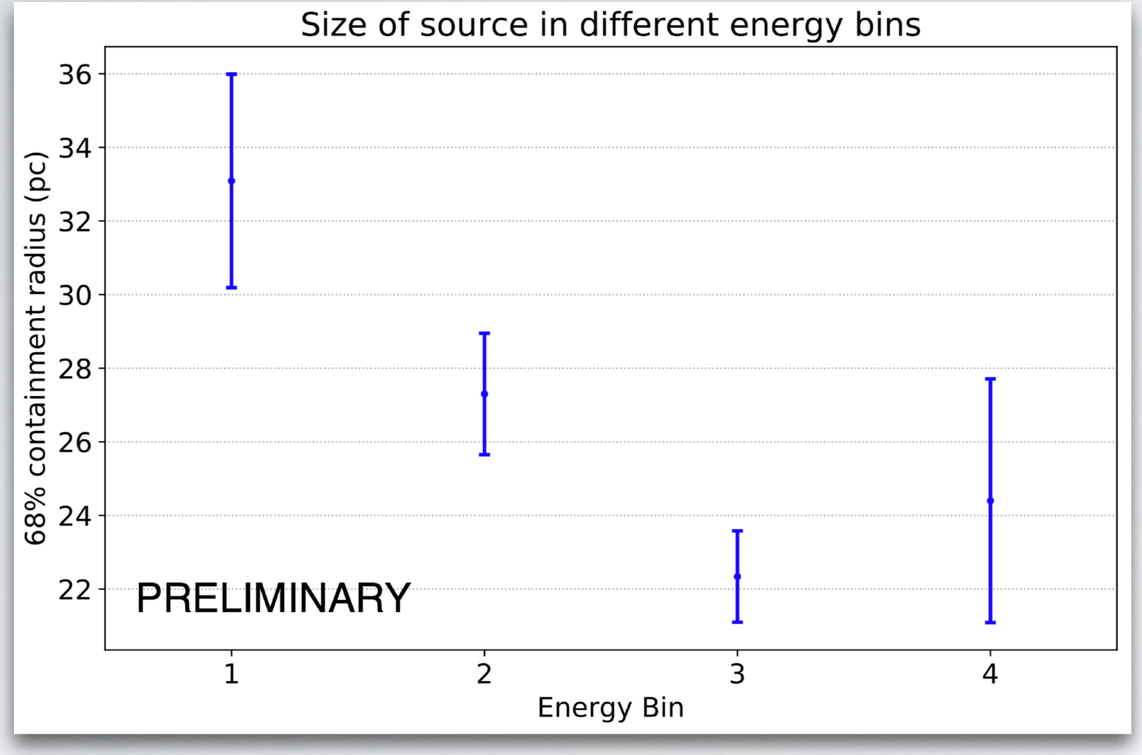
LEGEND
Grey = Statistical uncertainties
Pink = Systematic uncertainties

Radial profile



- The morphology of the source matches expectations for diffusion with continuous injection from the central point.
- The source is assumed to be 2.37 kpc away (the distance to PSR J1907+0602)

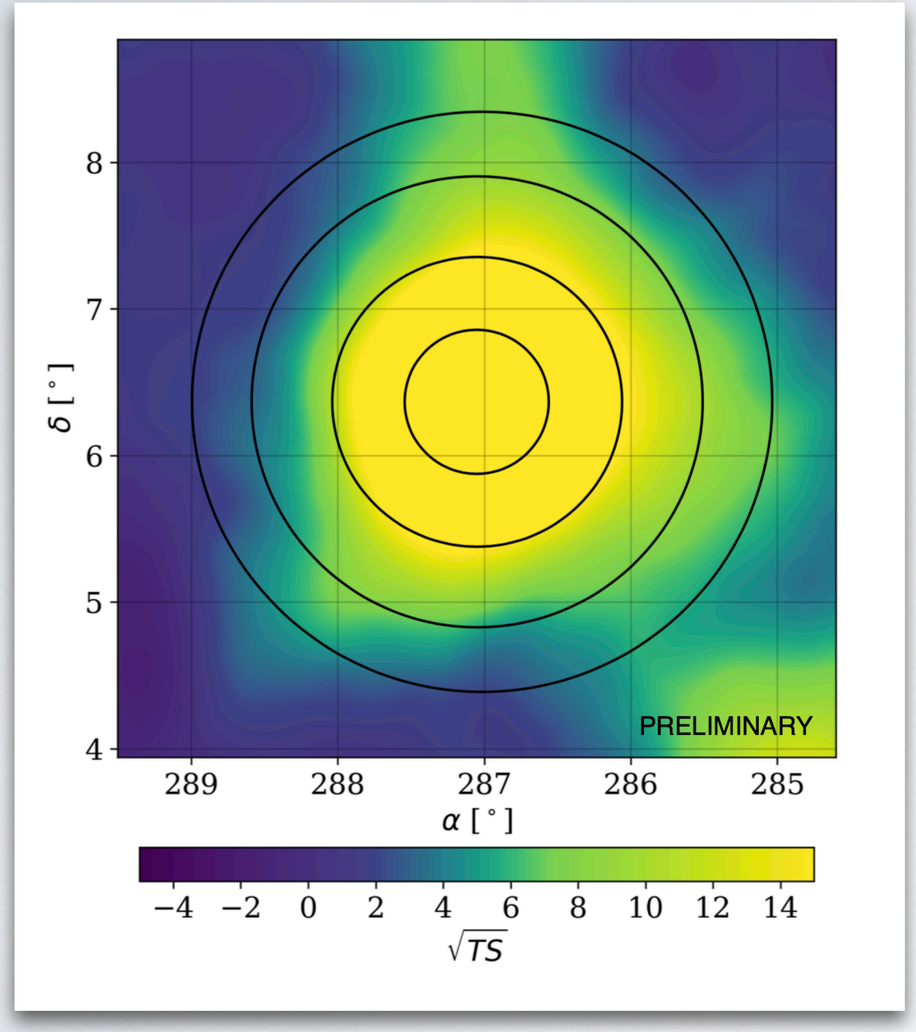
The size of the source decreases with energy



Energy bin	Minimum reco energy (TeV)	Maximum reco energy (TeV)
1	0.5	1.7
2	1.7	10
3	10	56
4	56	316

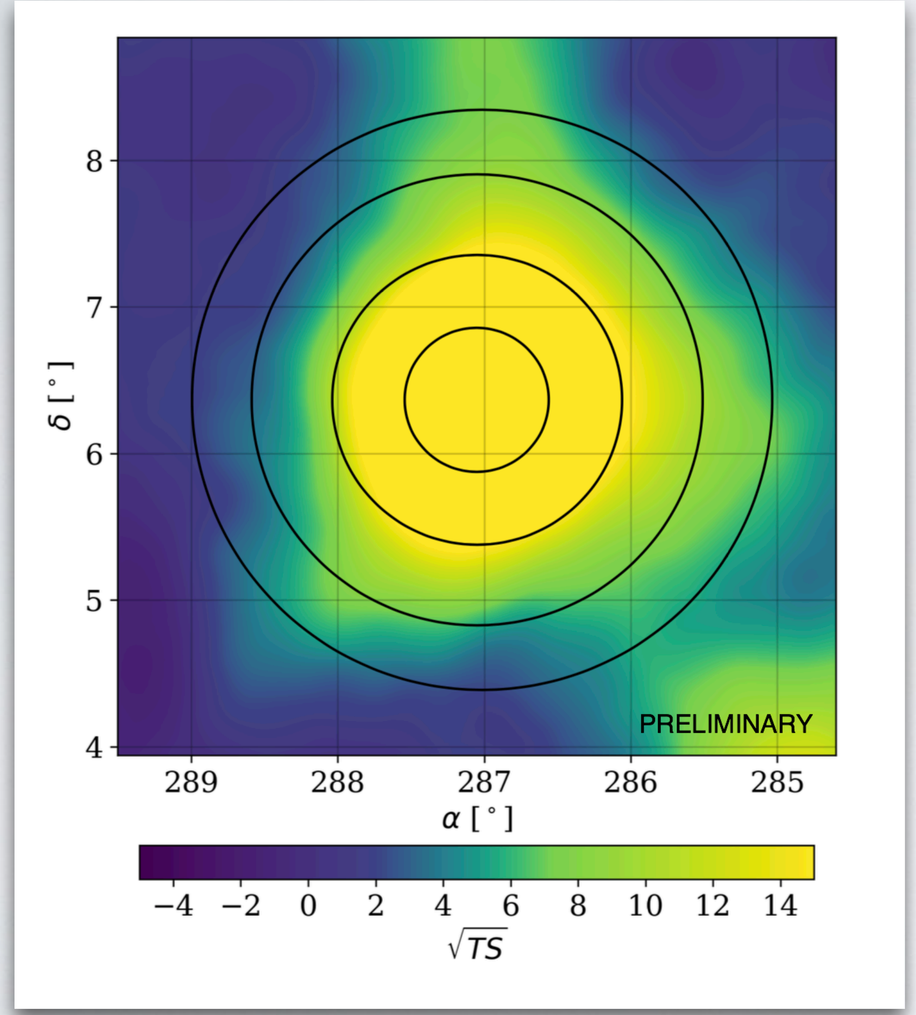
- Gaussian width shrinks as energy increases
- Indicative of leptonic emission

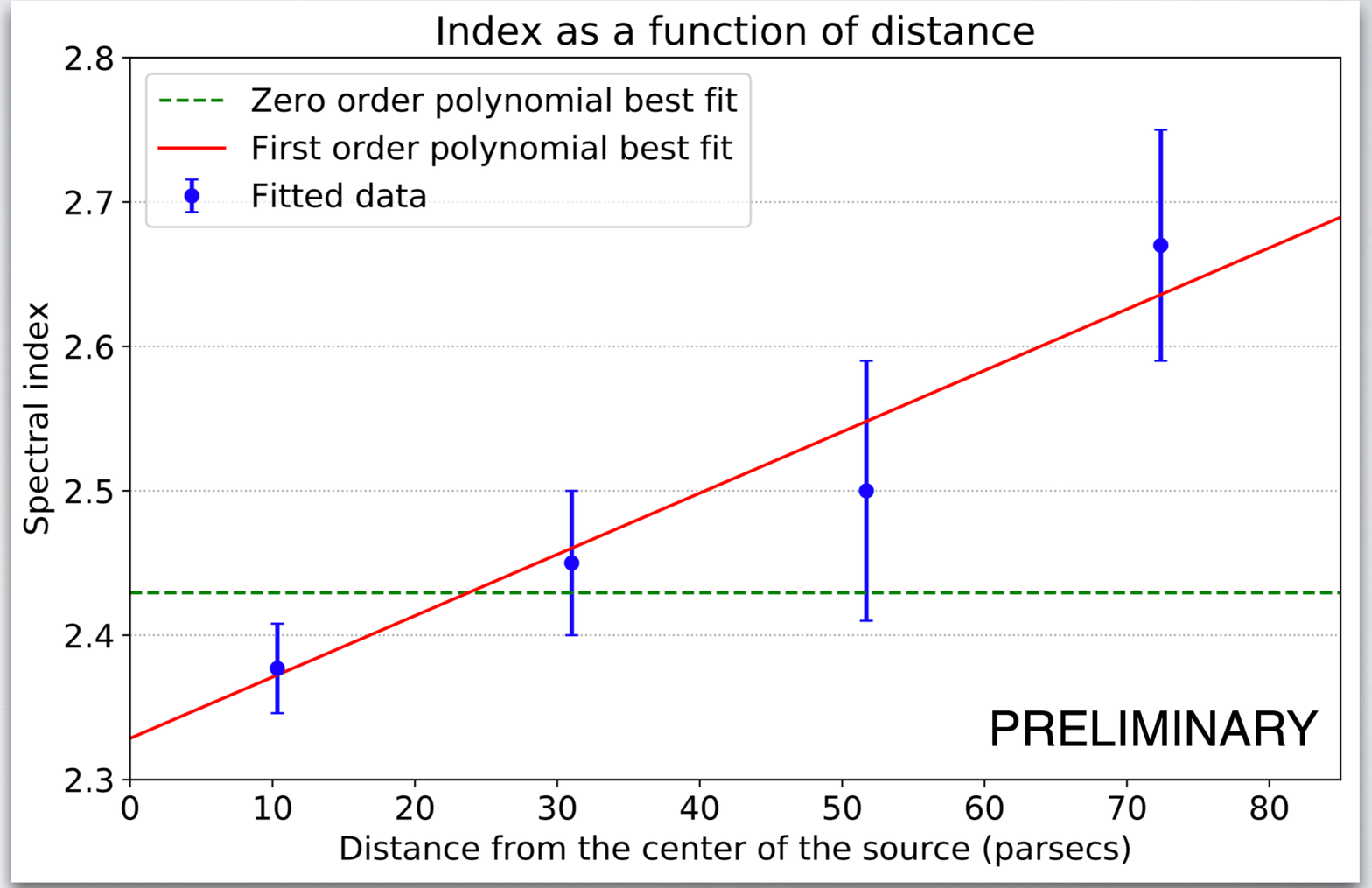
The spectral index can be spatially resolved



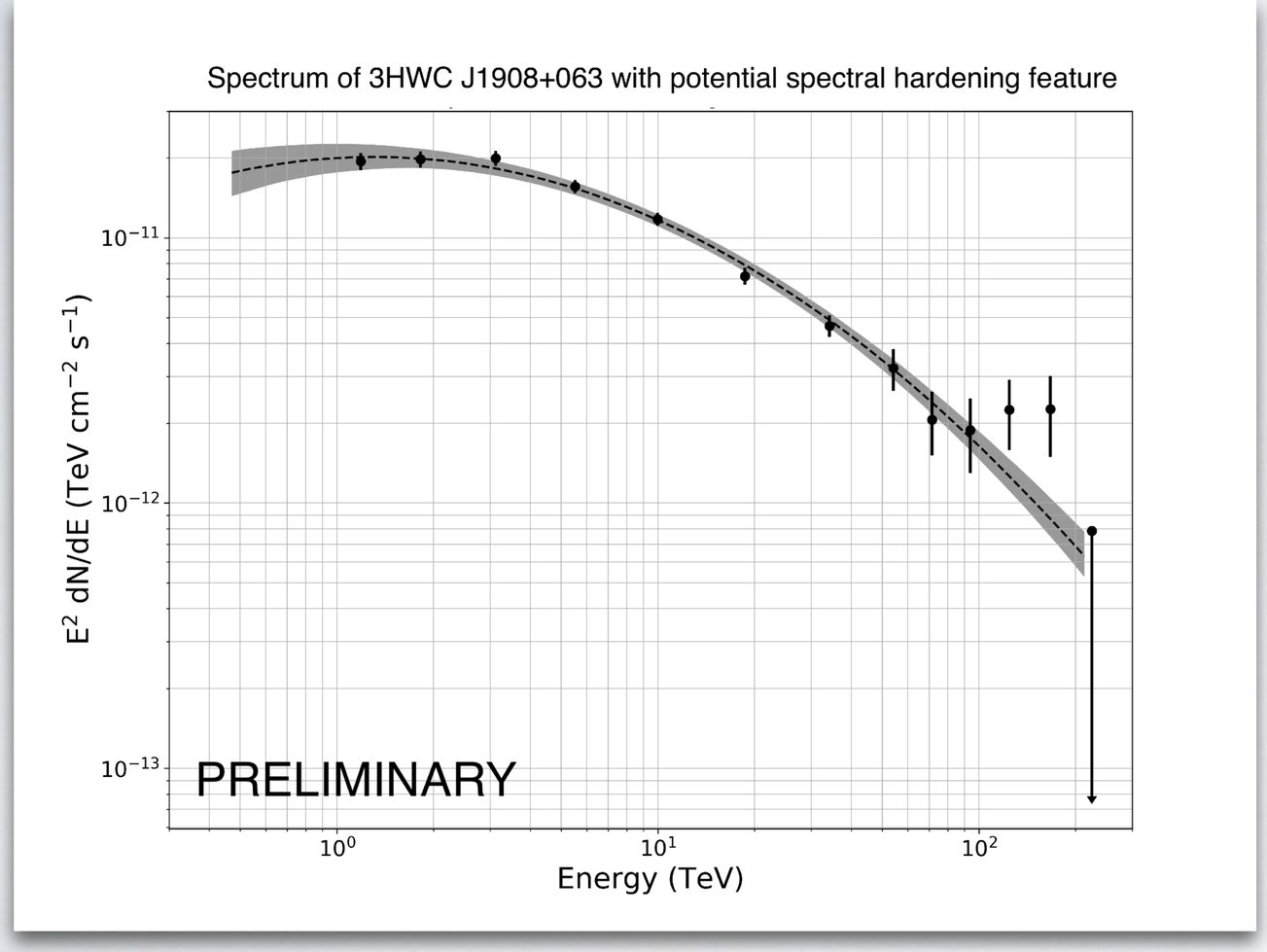
- Fit spectral index in four concentric rings drawn around the center of the source
- Statistically significant softening of the spectrum as distance from the center of the source increases
- Also indicative of leptonic emission
  - Electrons far away from the center of the source are older and have cooled.
  - No spectral change expected for hadrons

The spectral index can be spatially resolved





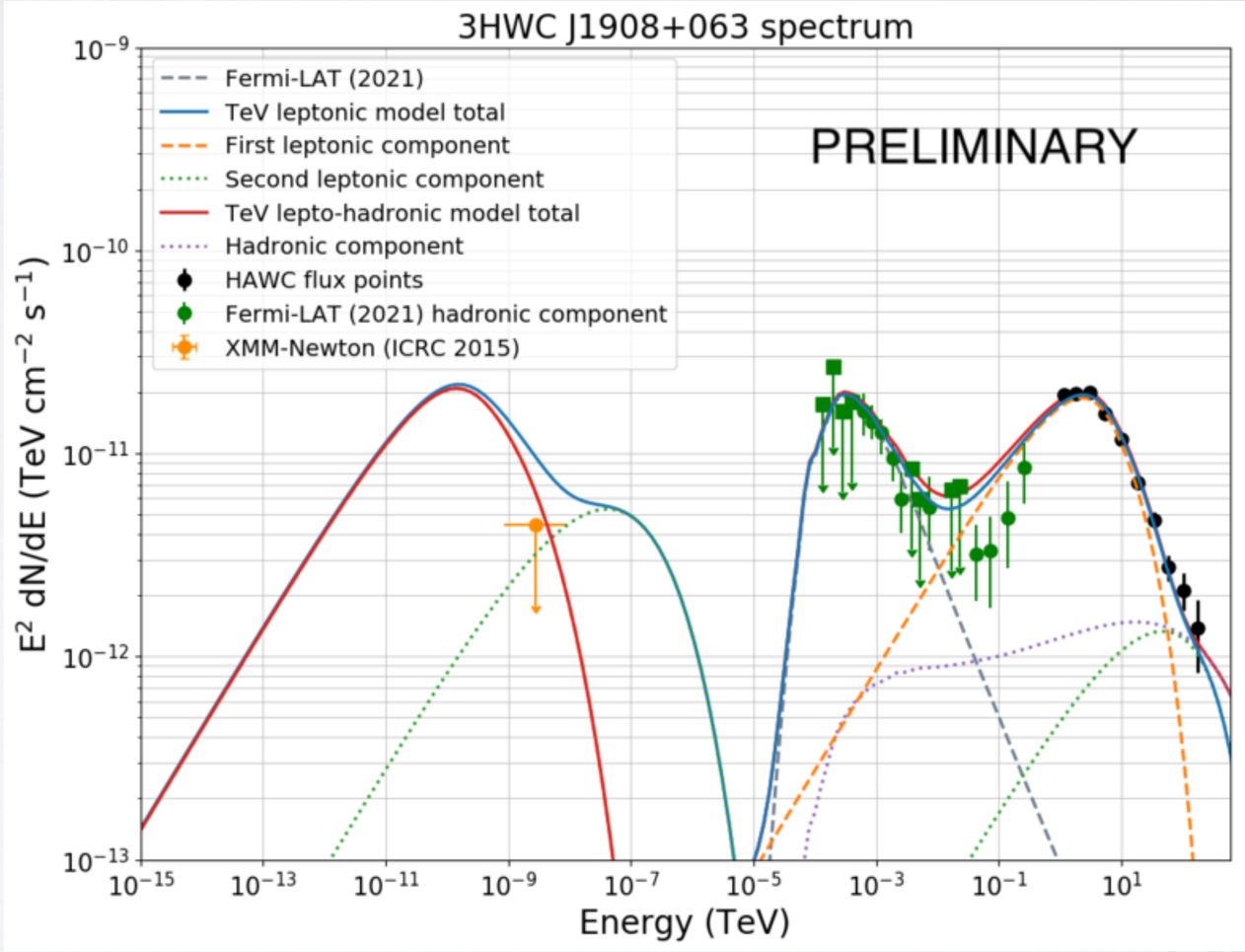
Potential spectral hardening feature



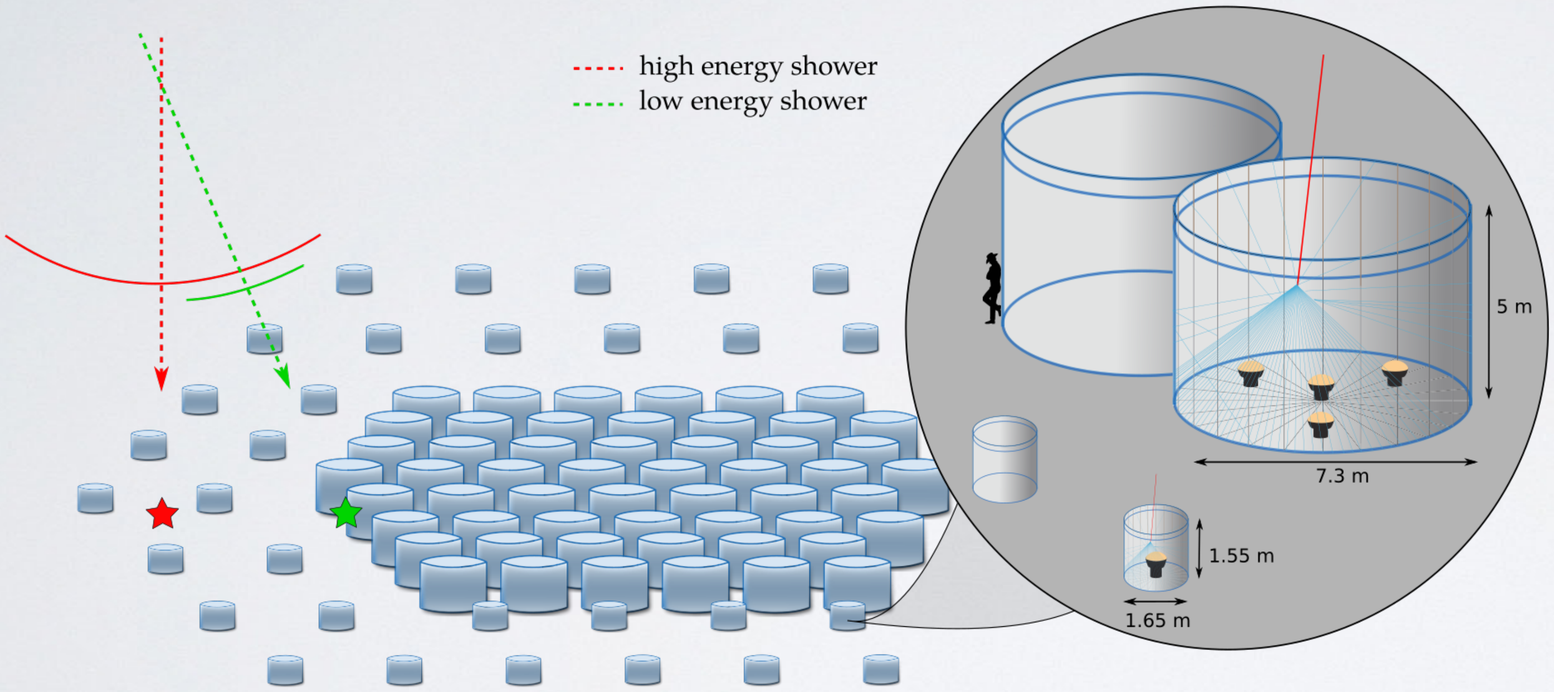
- When the last three energy bins are subdivided into six smaller bins of equal size, an apparent flattening in the spectrum can be seen by eye.
- Deviation from best-fit log-parabola by ~2 sigma.
- Second population of particles at the highest energies?
- See poster on searches for spectral hardening in HAWC sources

Modeling indicates that two populations of particles are needed to explain the shape of the spectrum

- HAWC's uncertainties are currently too large to determine if this second component is leptonic or hadronic in origin.
- Interesting target for upcoming gamma-ray experiments with better sensitivity at the highest energies
- Implications for detections by multi-messenger experiments



Future outlook



- HAWC's outrigger array is now operational
- Will soon have data with at least 2x sensitivity to gamma rays above 10 TeV
- Will allow for more detailed observations of 3HWC J1908+063

Conclusions

- 3HWC J1908+063 is one of the highest energy gamma-ray sources ever detected
- Modeling indicates that two populations of particles are needed to fit this source.
  - The first component is leptonic and is responsible for most of the emission. The second component may be either hadronic or leptonic.
  - This has implications for detection by multi-messenger experiments.