The HAWC gamma-ray observatory: results and prospects

Harm Schoorlemmer,
on behalf of the HAWC collaboration

A collaboration between Mexico, USA, Germany, Poland, Costa Rica and Italy








Ground based TeV gamma-ray astronomy

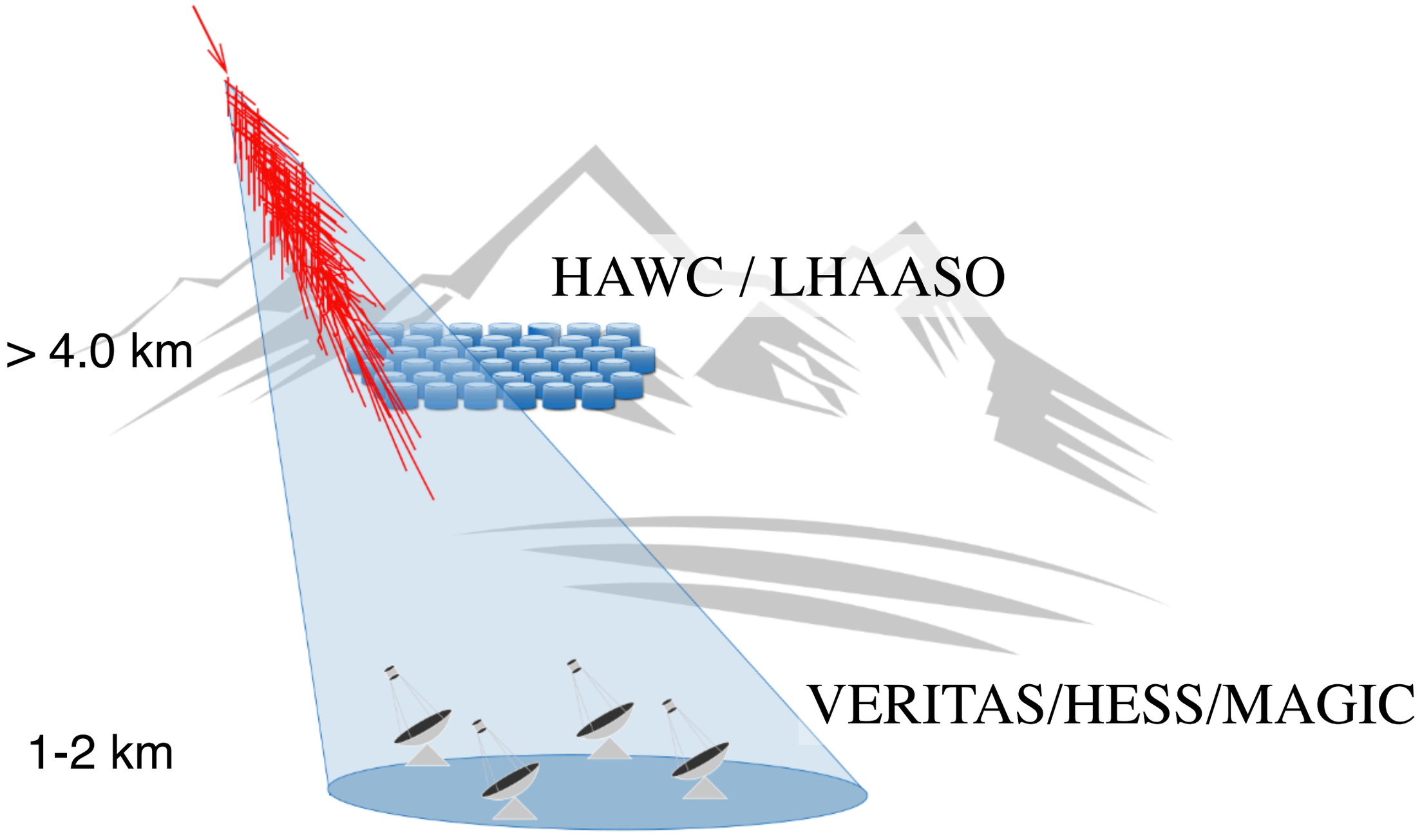


image credit: A. Jardin-Blicq

High Altitude Water Cherenkov gamma-ray observatory

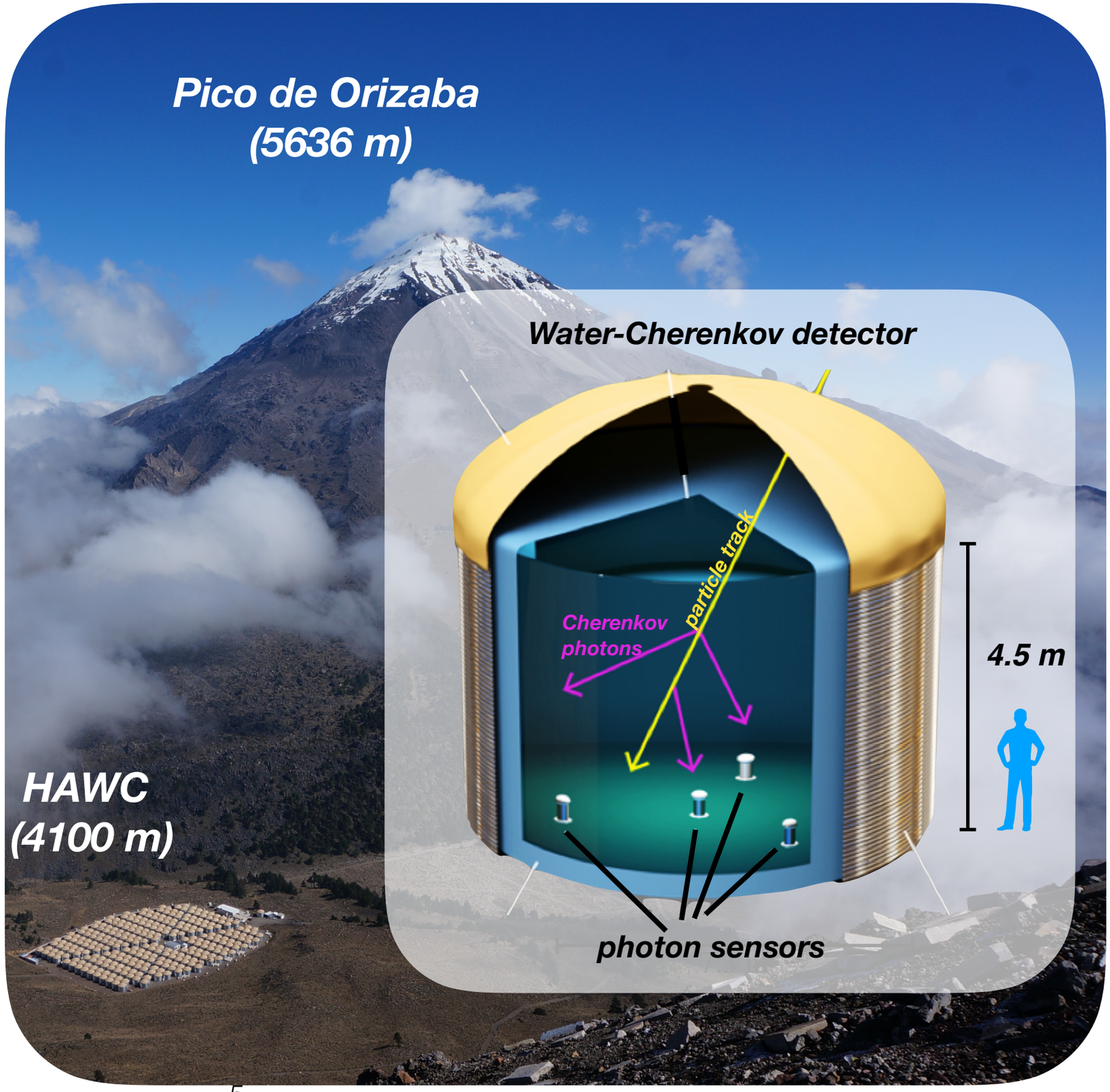
Location

- Elevation 4100m a.s.l.
- Lattitude 19° N

High Altitude Water Cherenkov gamma-ray observatory

Specs:

- 300 Water Cherenkov Particle detectors
- 1200 Photo-Multiplier-Tubes
- Continuous read-out of full array => ~95% uptime
- Full array data since March 2015
- Software trigger
- Area: 22 000 m²



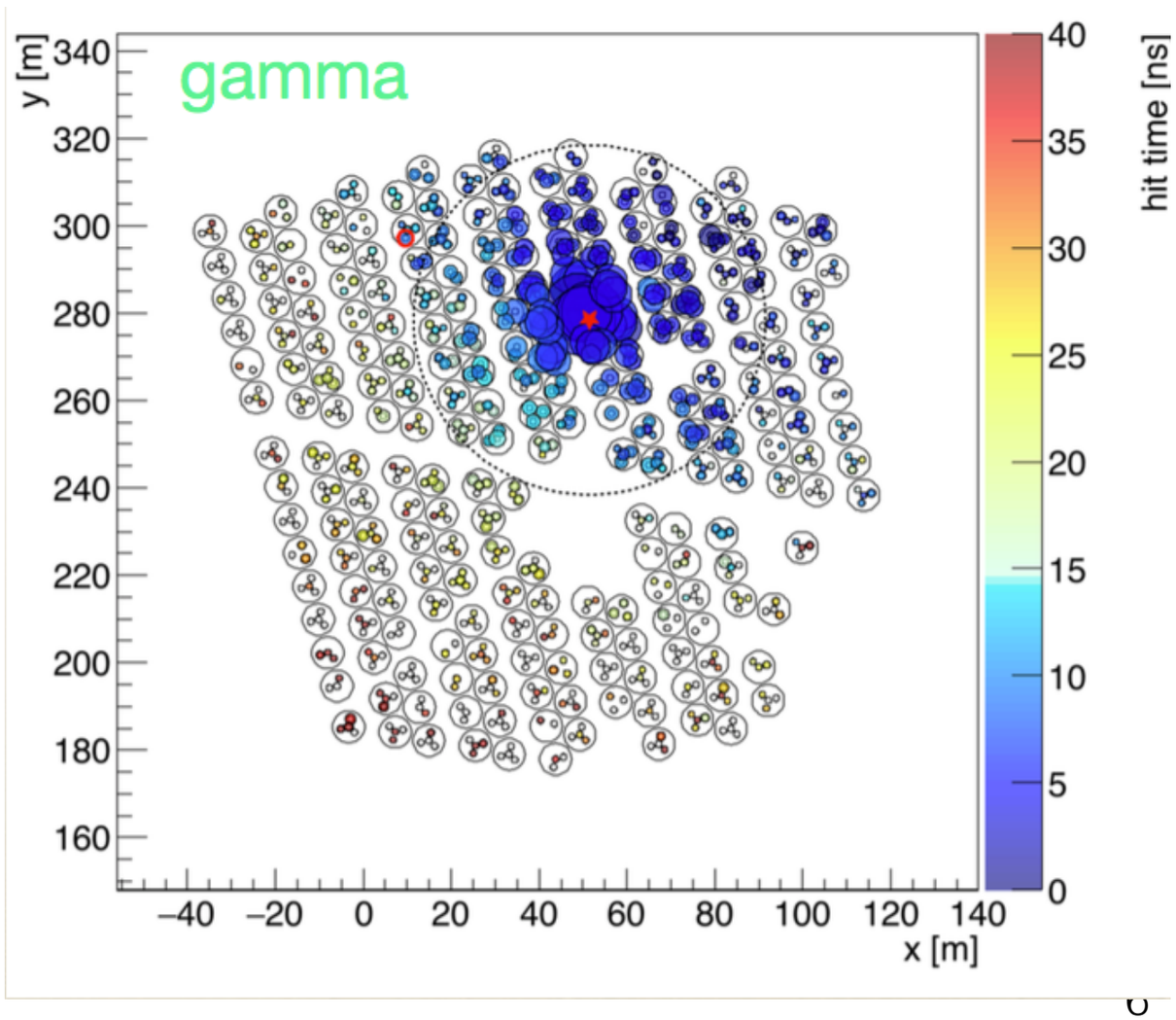
Shower type identification

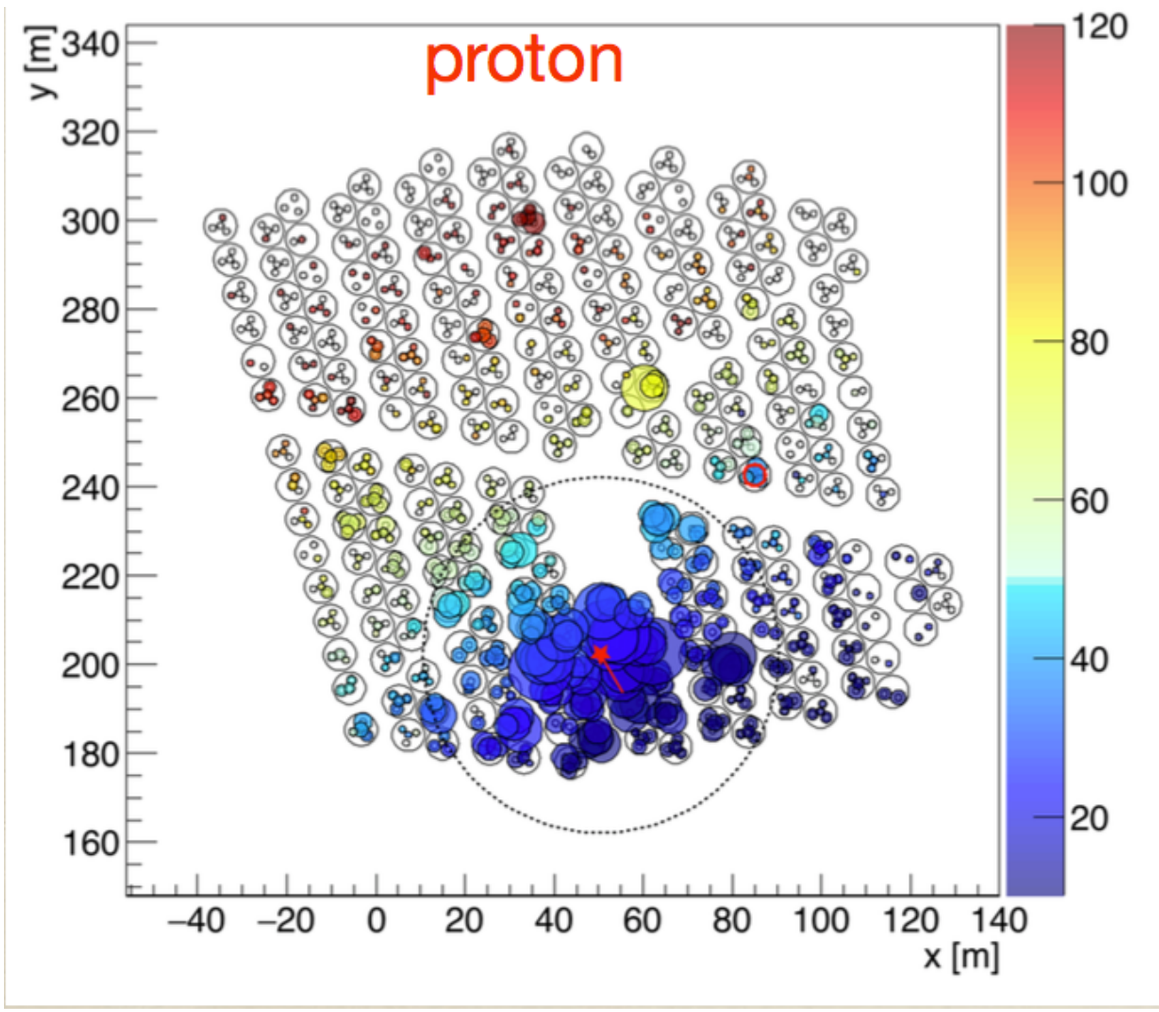
γ-rays produce an electromagnetic cascade:

- **Very little to no muons**
- **Smooth lateral distribution around the impact point**

Atomic nuclei generate "hadronic" cascade:

- **Significant amount of primary energy into muon production**
- **Particle distribution on ground irregular**

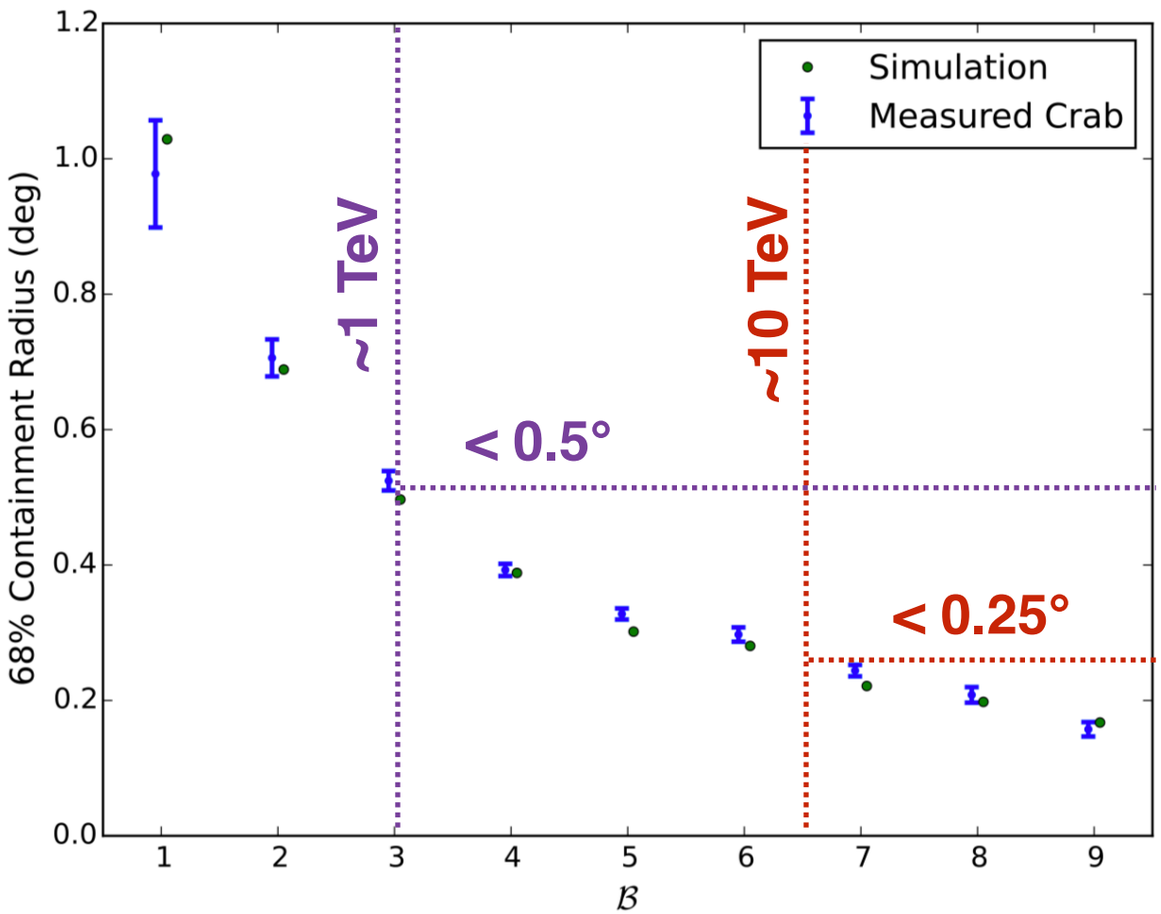




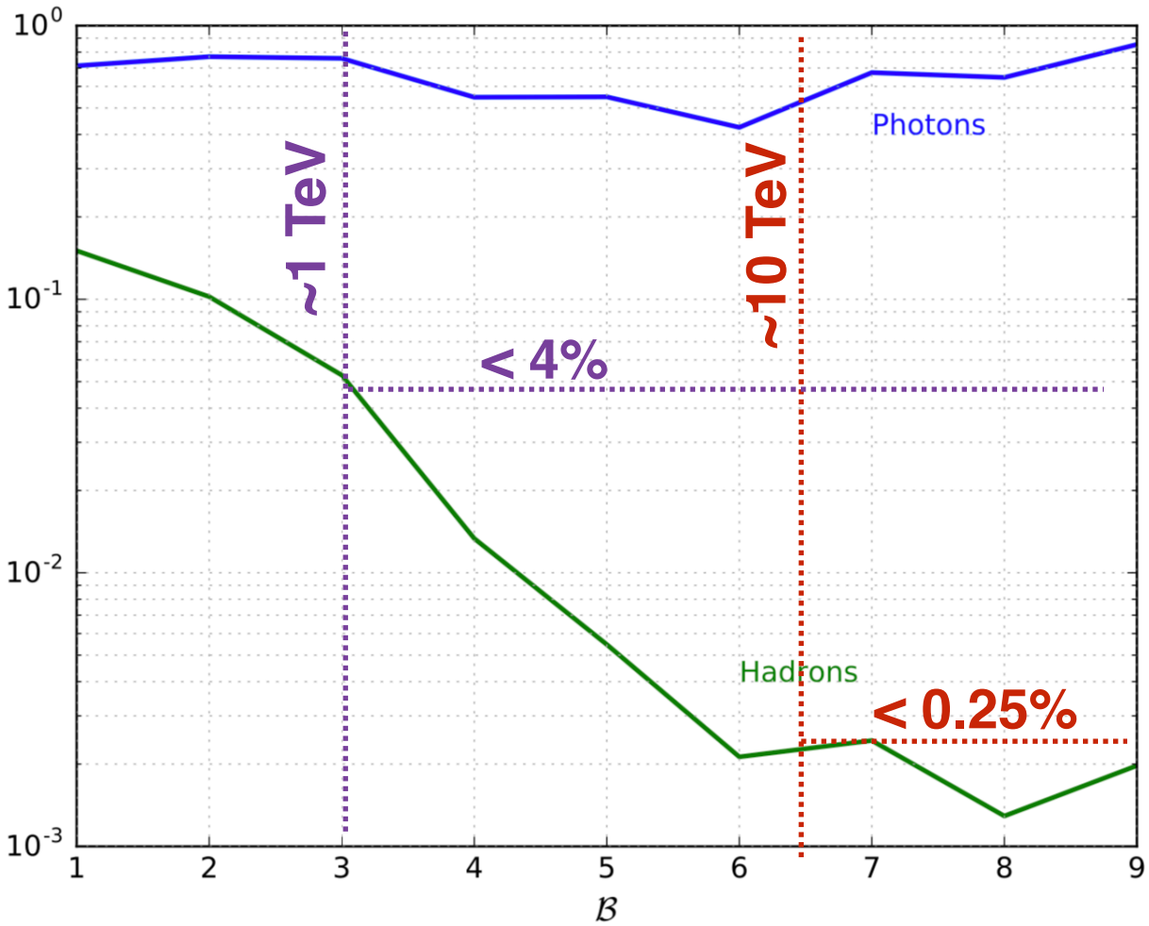
Performance in a nut shell

- Events are binned by size (number of pmts)
- For each bin cuts are optimized

Angular resolution



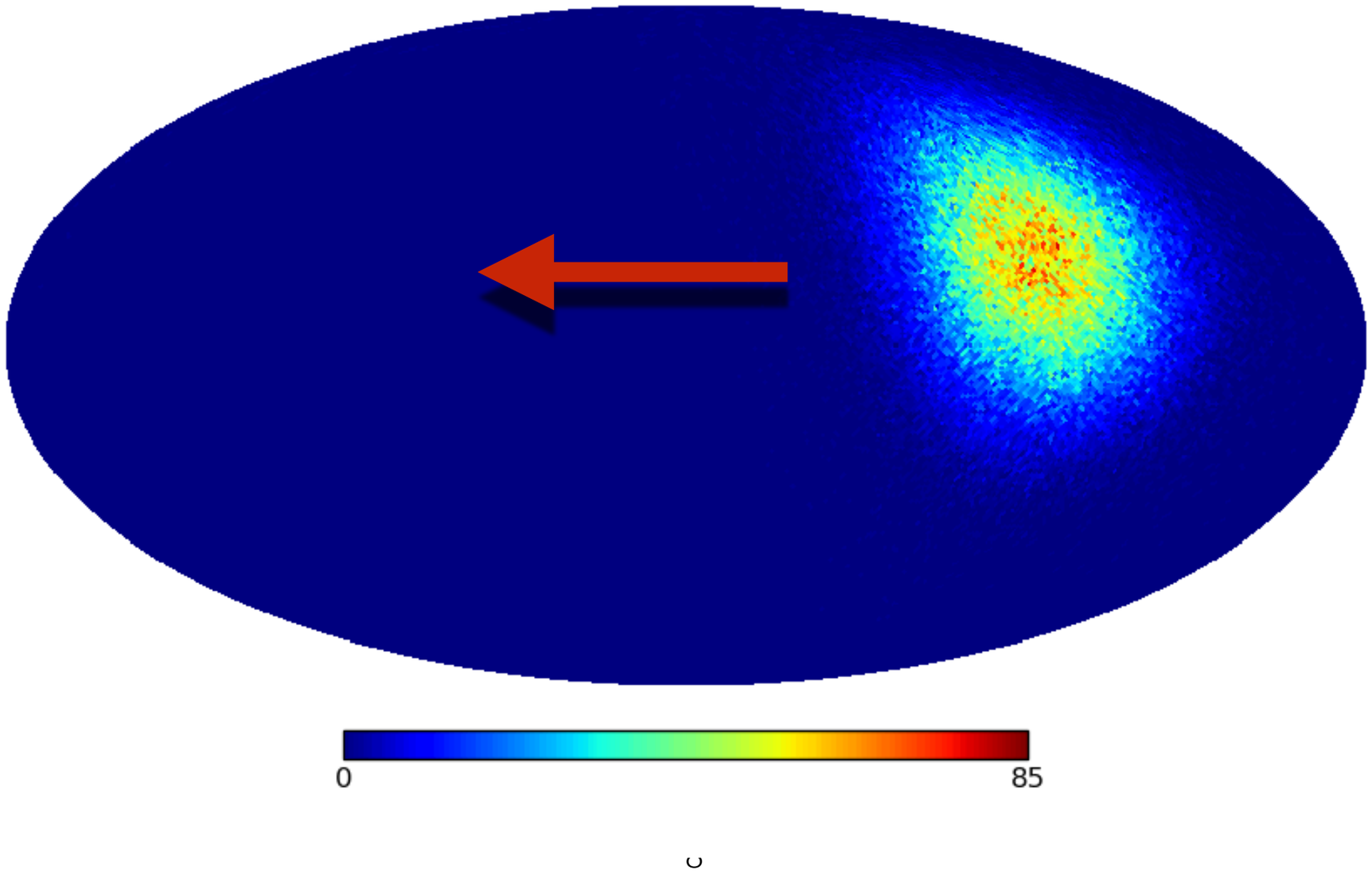
Gamma / Hadron - Cut efficiency



A. U. Abeysekara, *et al*, *ApJ*, **843**, 2017 / `arXiv:1701.01778`

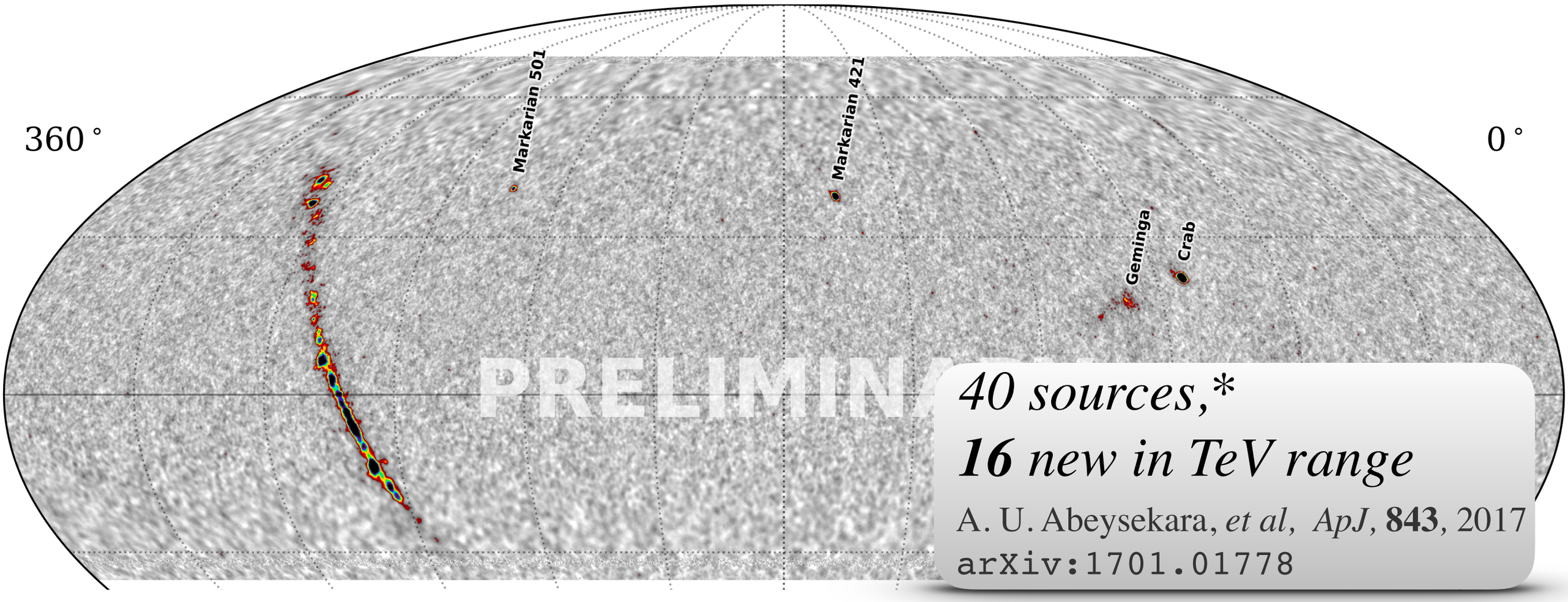
High Altitude Water Cherenkov - gamma ray observatory

- Wide Field-of-View: ~2 sr (90 degree)
- ~2/3 of the sky per day
- Sensitive to γ-rays from ~0.1TeV to ~100 TeV



The sky observed by HAWC

- Current 1128 days map
- Point Source Hypothesis, with spectral index 2.7



*40 sources,**

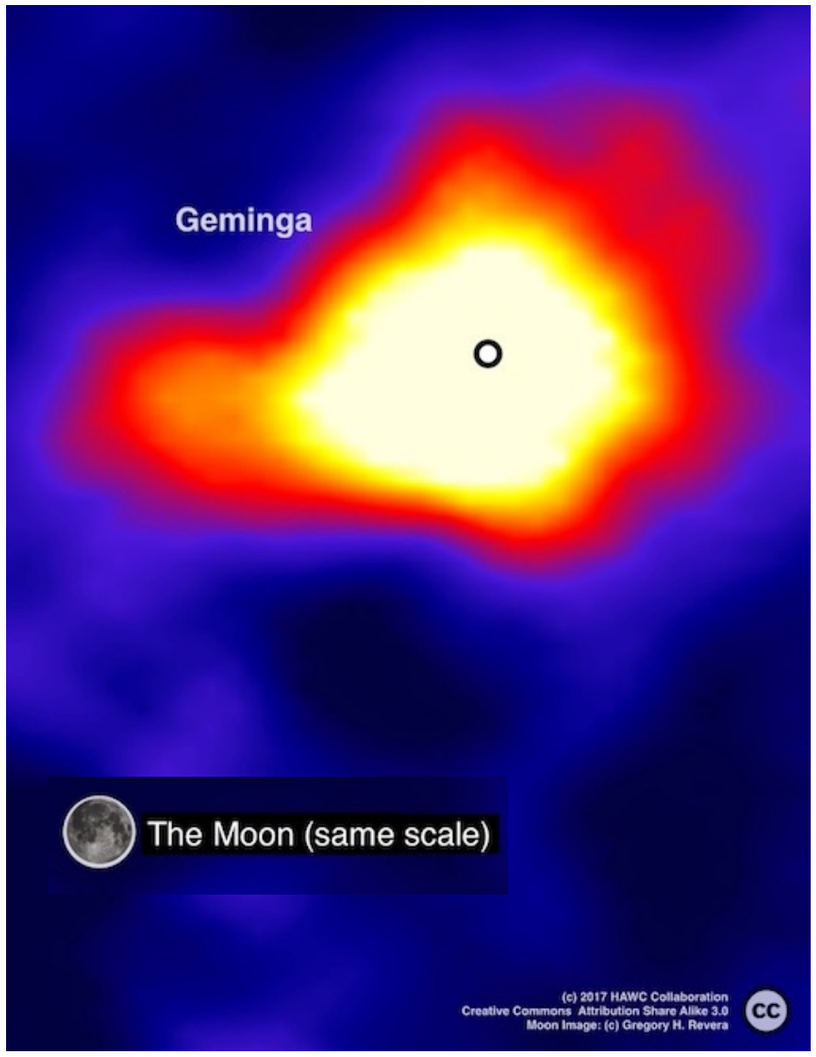
***16** new in TeV range*

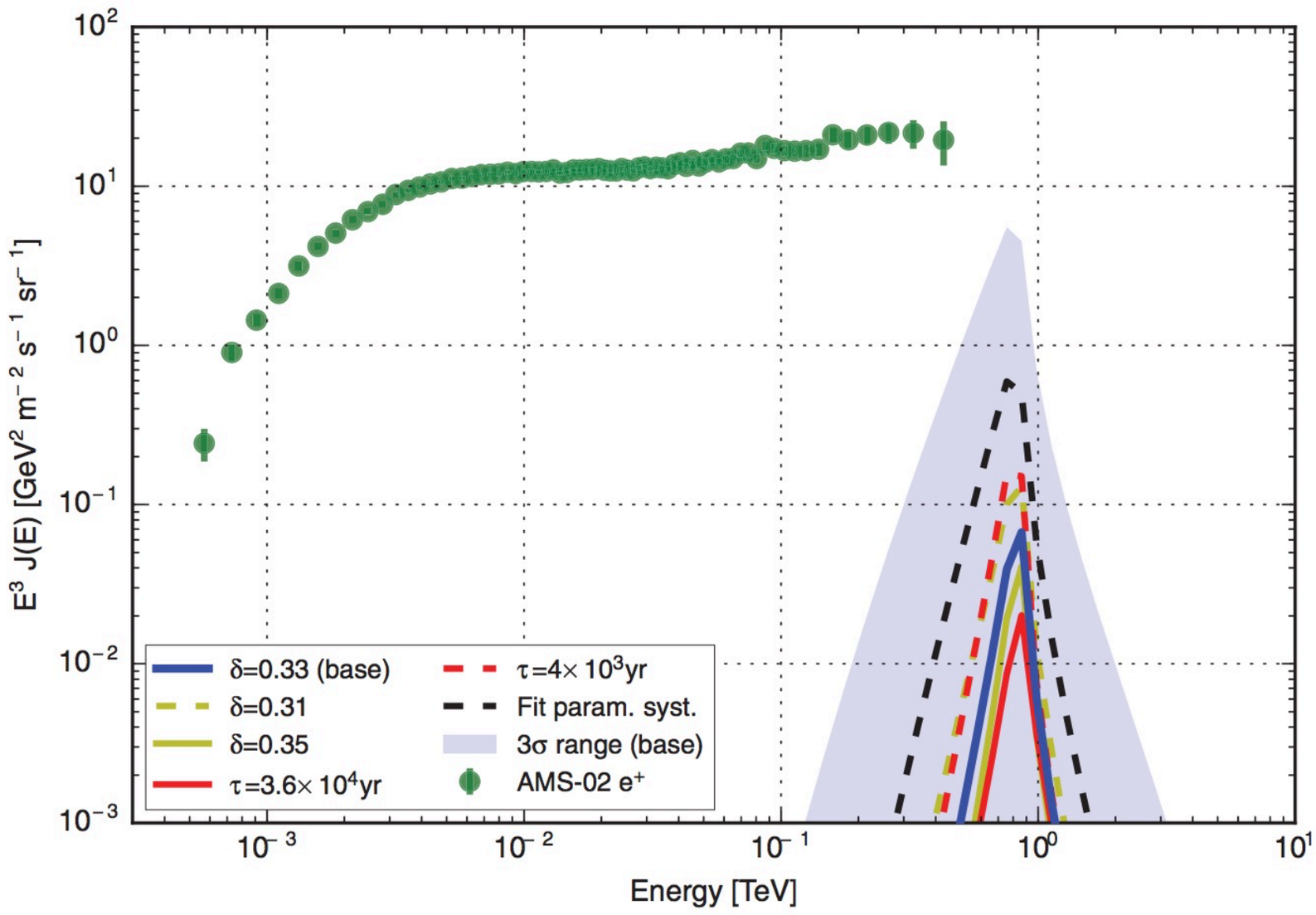
A. U. Abeysekara, *et al*, *ApJ*, **843**, 2017
arXiv:1701.01778

** based on 507 days*

Extended emission around nearby middle-aged pulsars

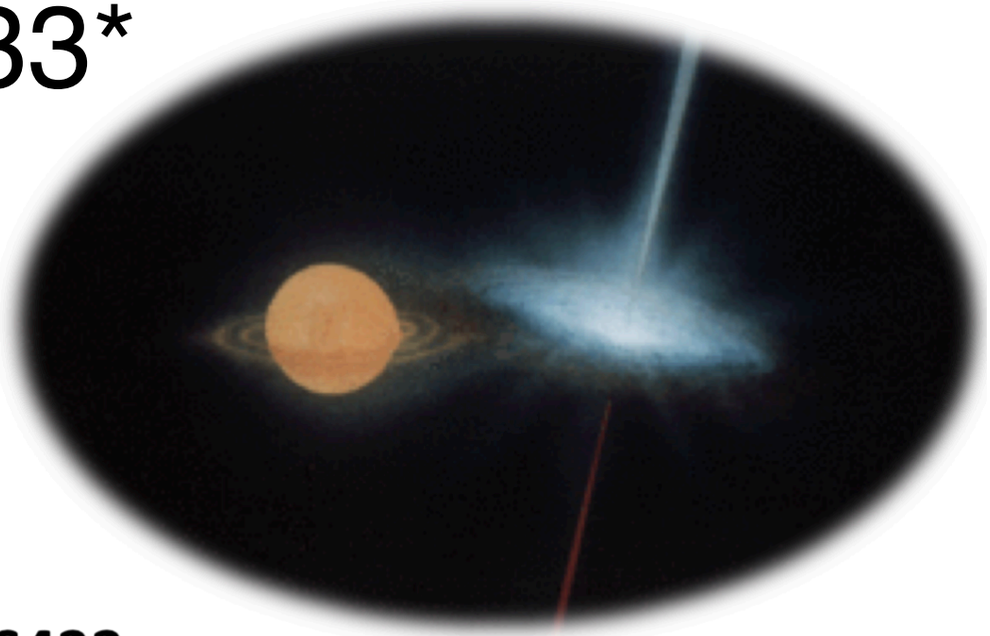
- Profile fits well with diffusion profile
- Fitted diffusion constant predicts too little positrons at Earth to explain positron excess
  (under the assumption of homogenous isotropic diffusion)





*A. U. Abeysekara et al, Science **358** (2017)*

SS 433*

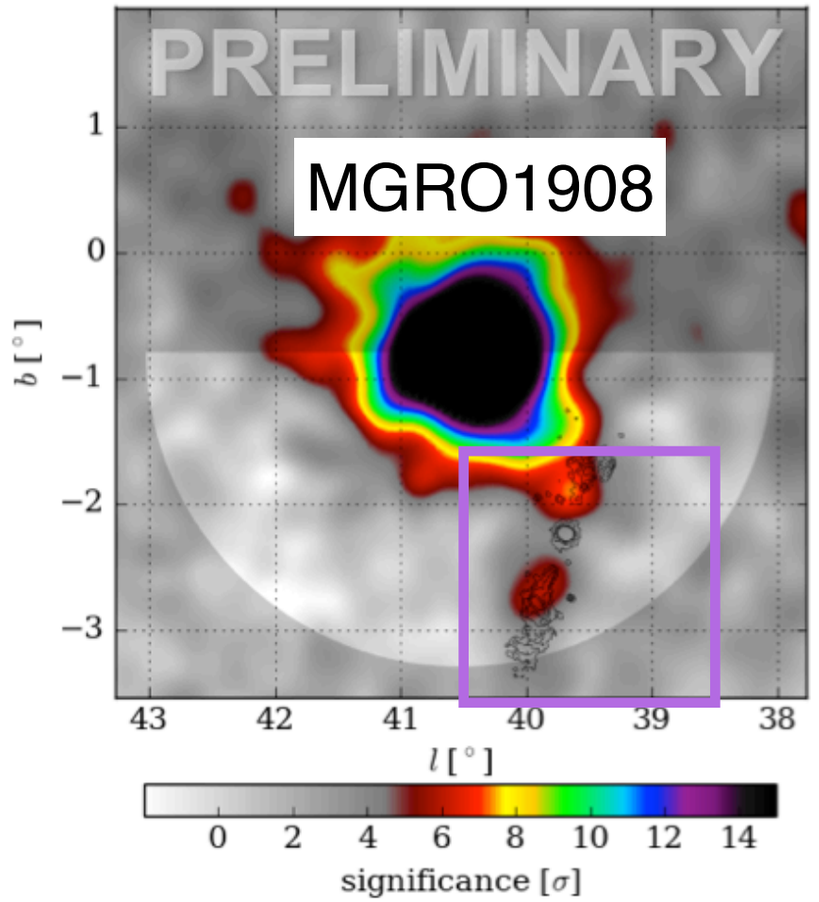


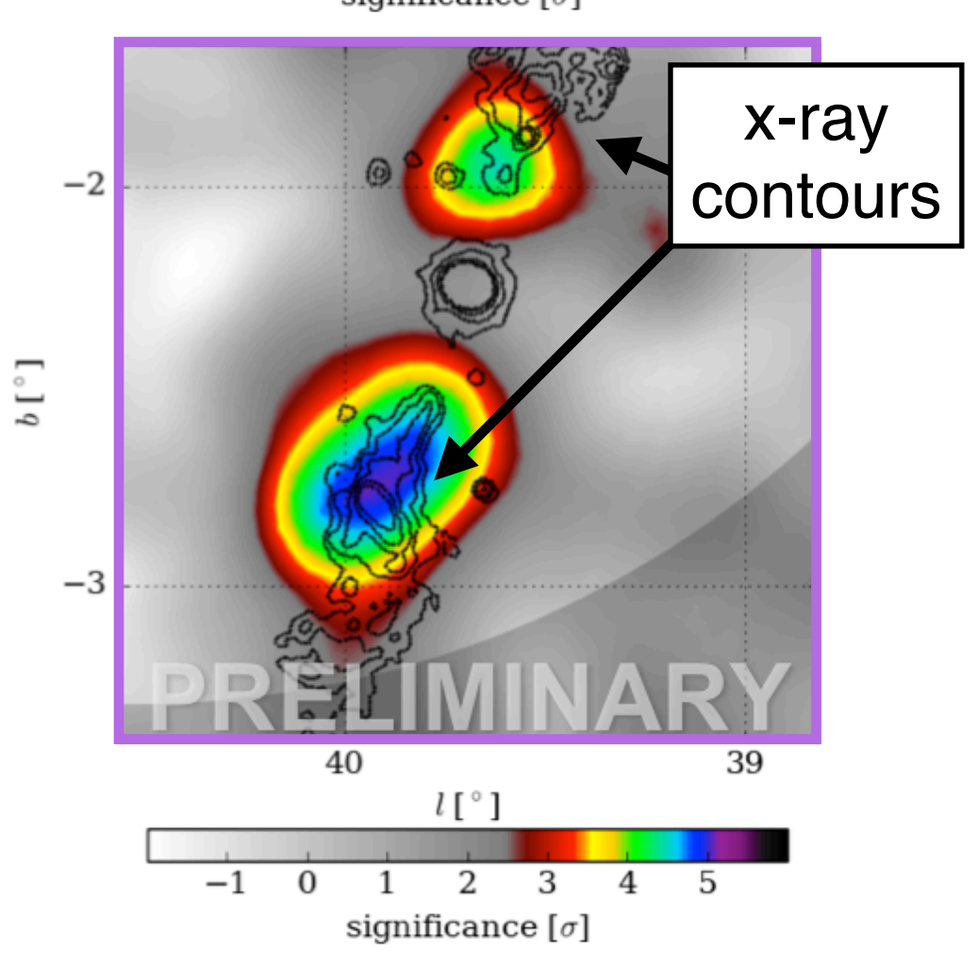
SS433:

X-ray Binary, star with ~30 $M_\odot$ and compact object with many $M_\odot$

- First time jets are resolved at such high energies
- TeV emission from jet, not the central binary
- Leptonic scenario favored over pure-hadronic scenario

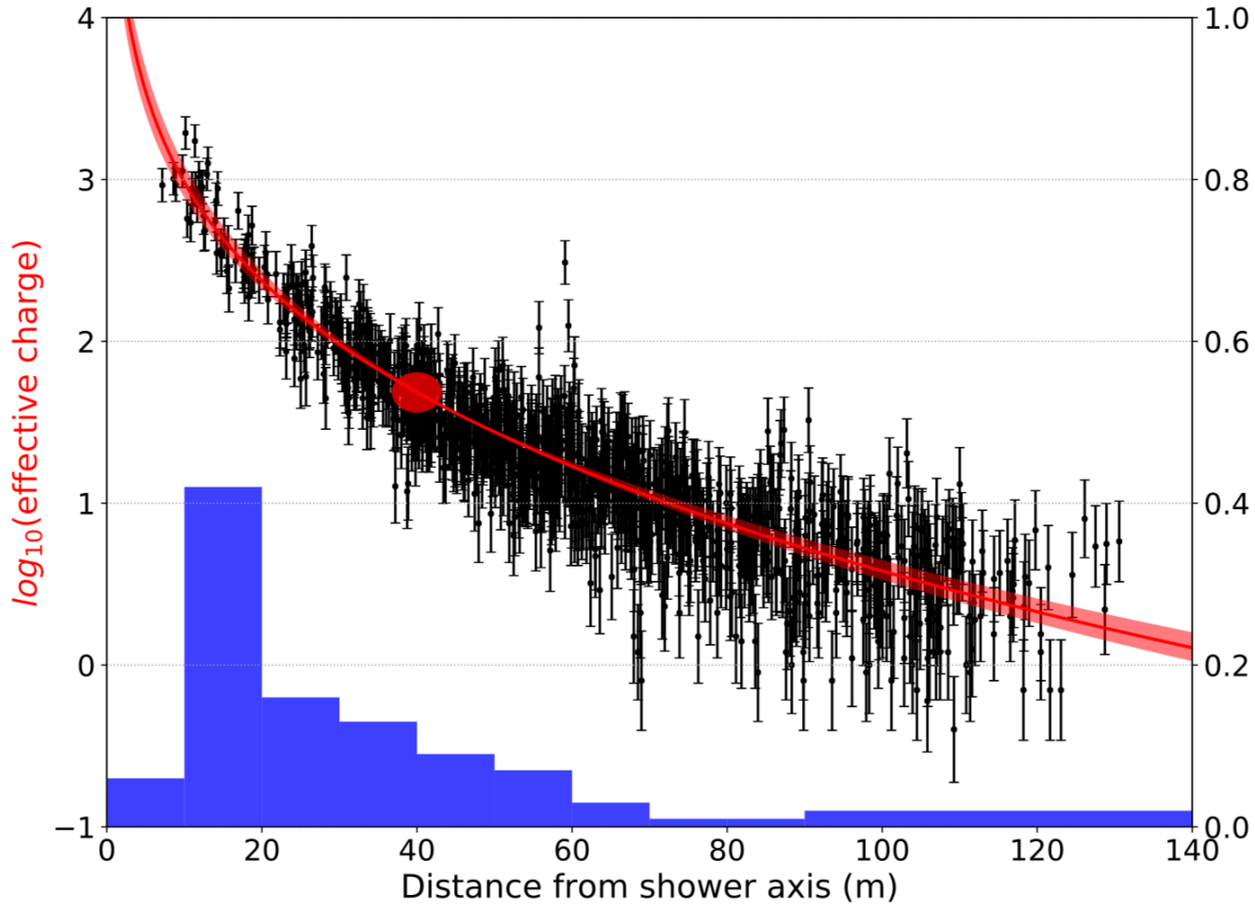
*A. U. Abeysekara et al, Nature **562** (2018)*

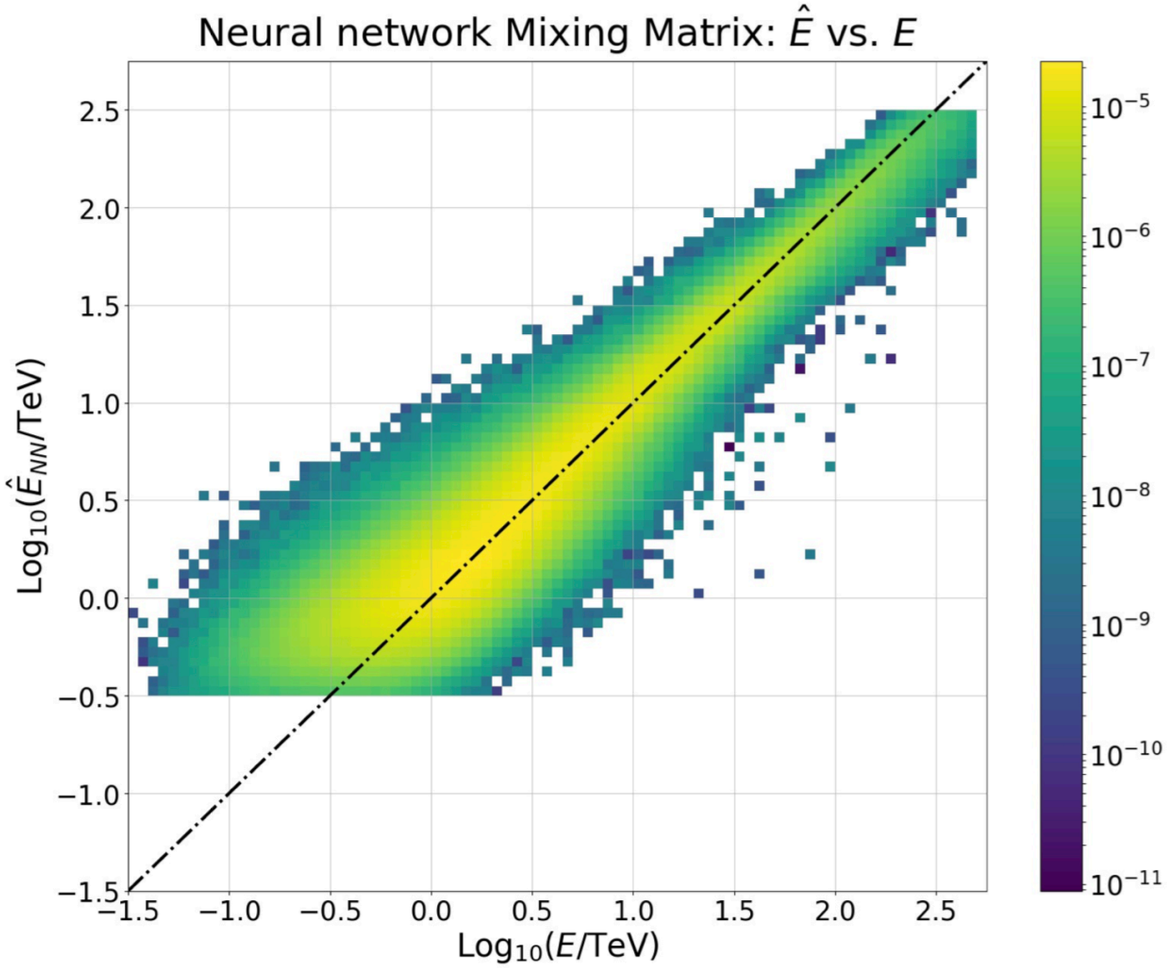




New! Event by event energy reconstruction

- Two methods for energy reconstruction:
  1. Classic evaluation of lateral distribution function
  2. Neural network
- Energy resolution ~50% at 1 TeV, and 25% at 50 TeV
- Reconstruction of energies > 100 TeV

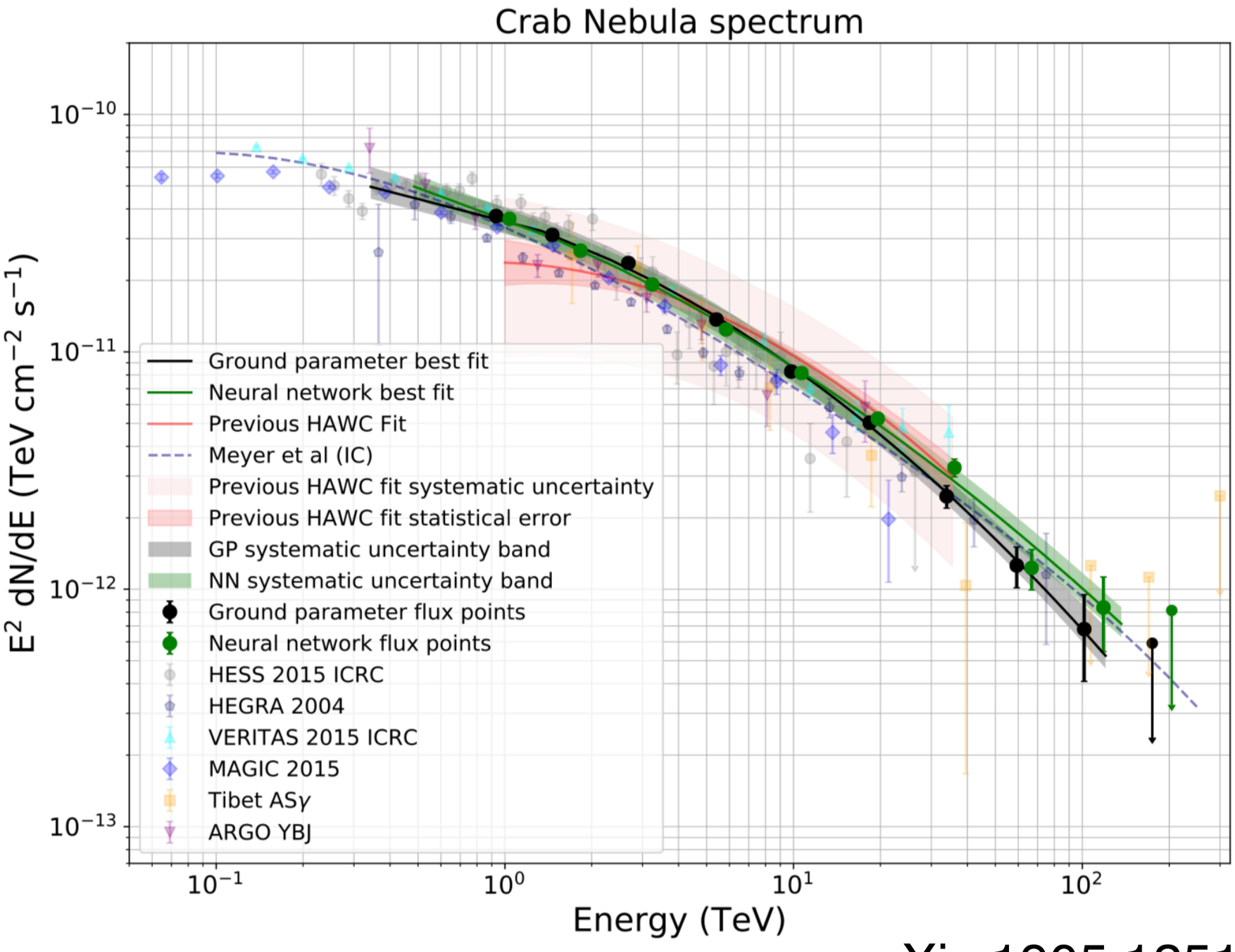




arXiv:1905.12518

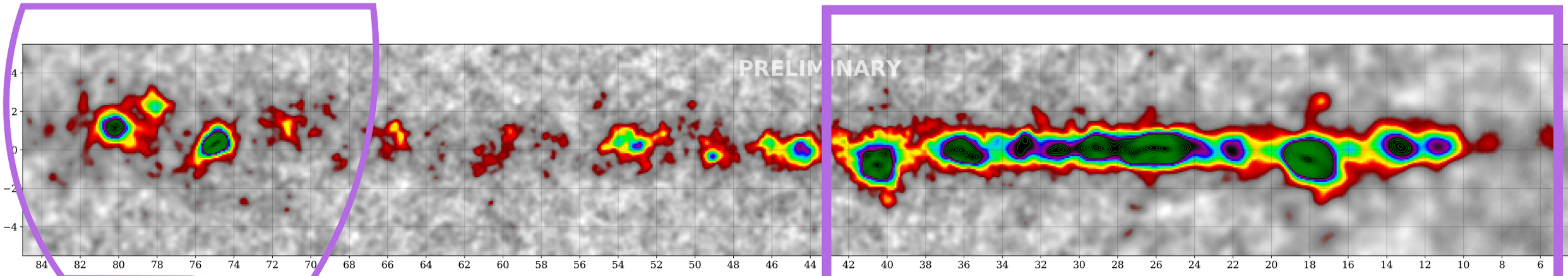
New! Crab spectrum 837 days of data

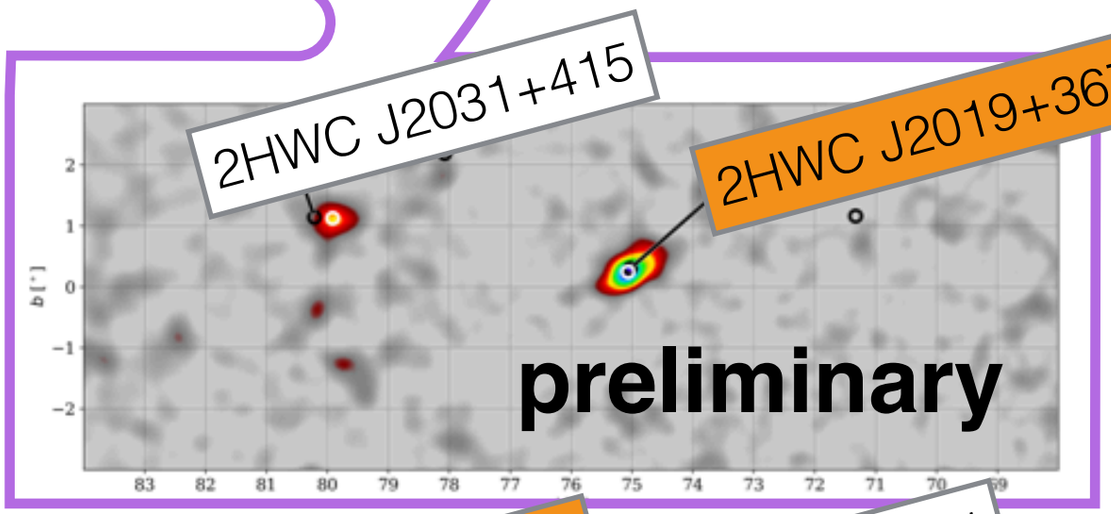
- Good agreement with other observatories
- Extending the spectrum towards higher energy
- Significant reduction in systematic uncertainties

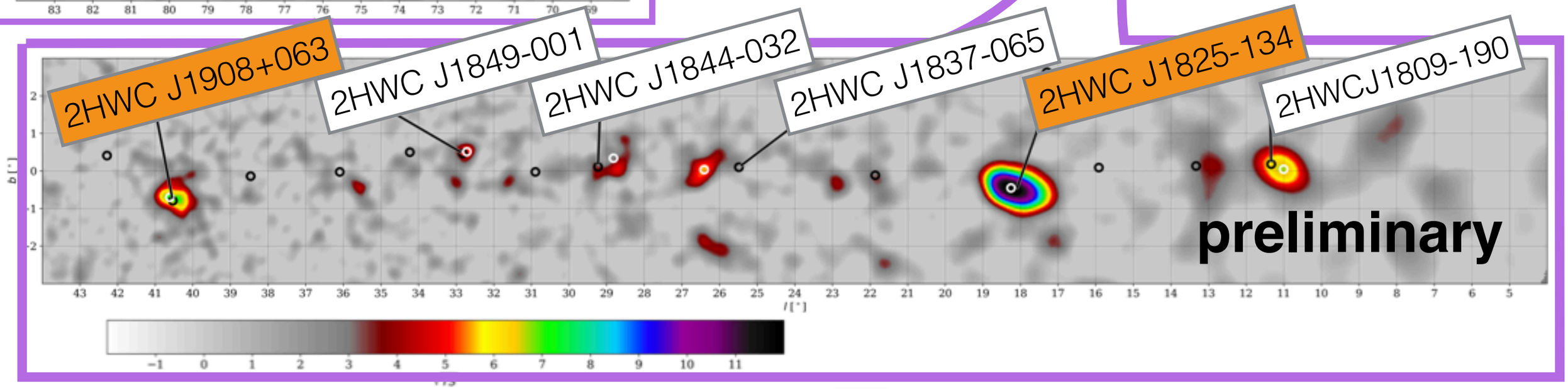


arXiv:1905.12518

The sky observed > 56 TeV **reconstructed** energy







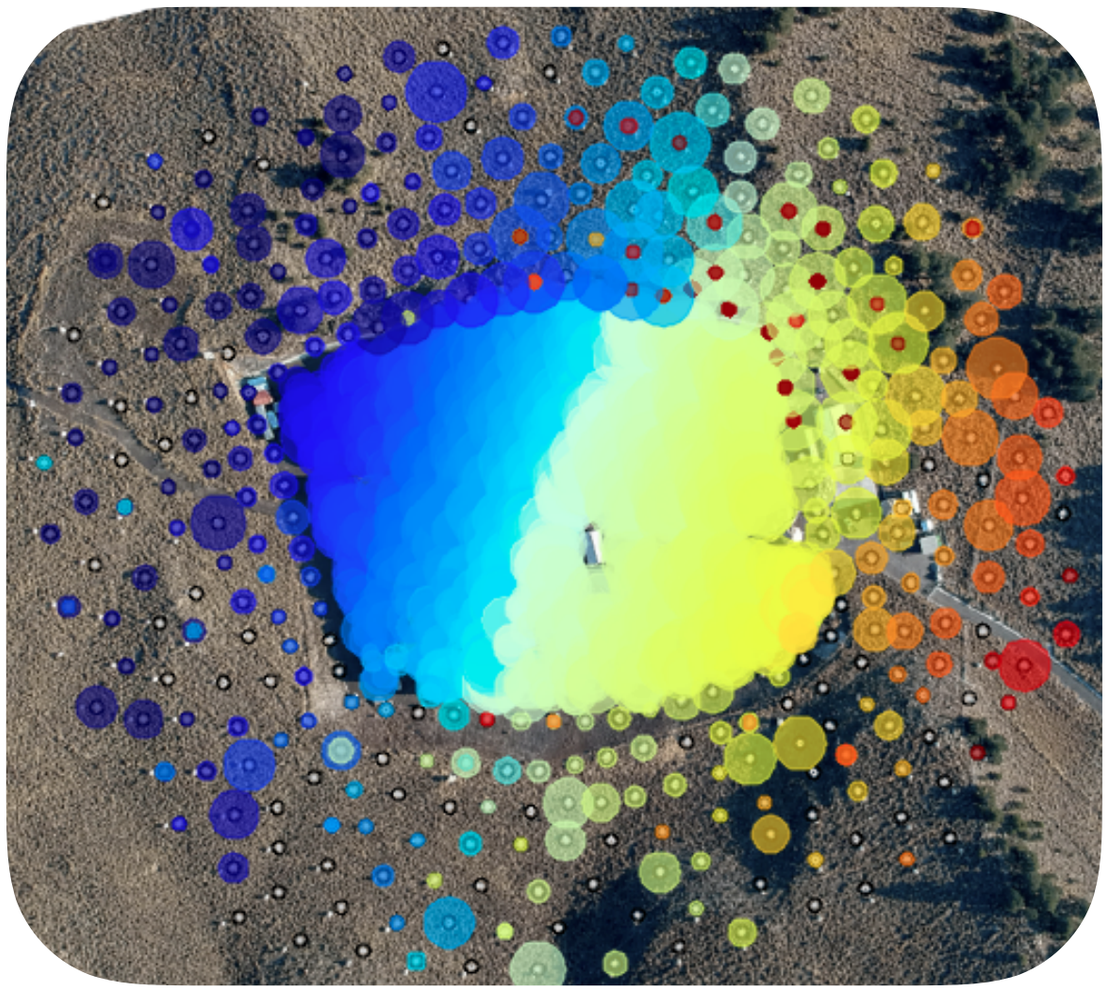
> 100 TeV

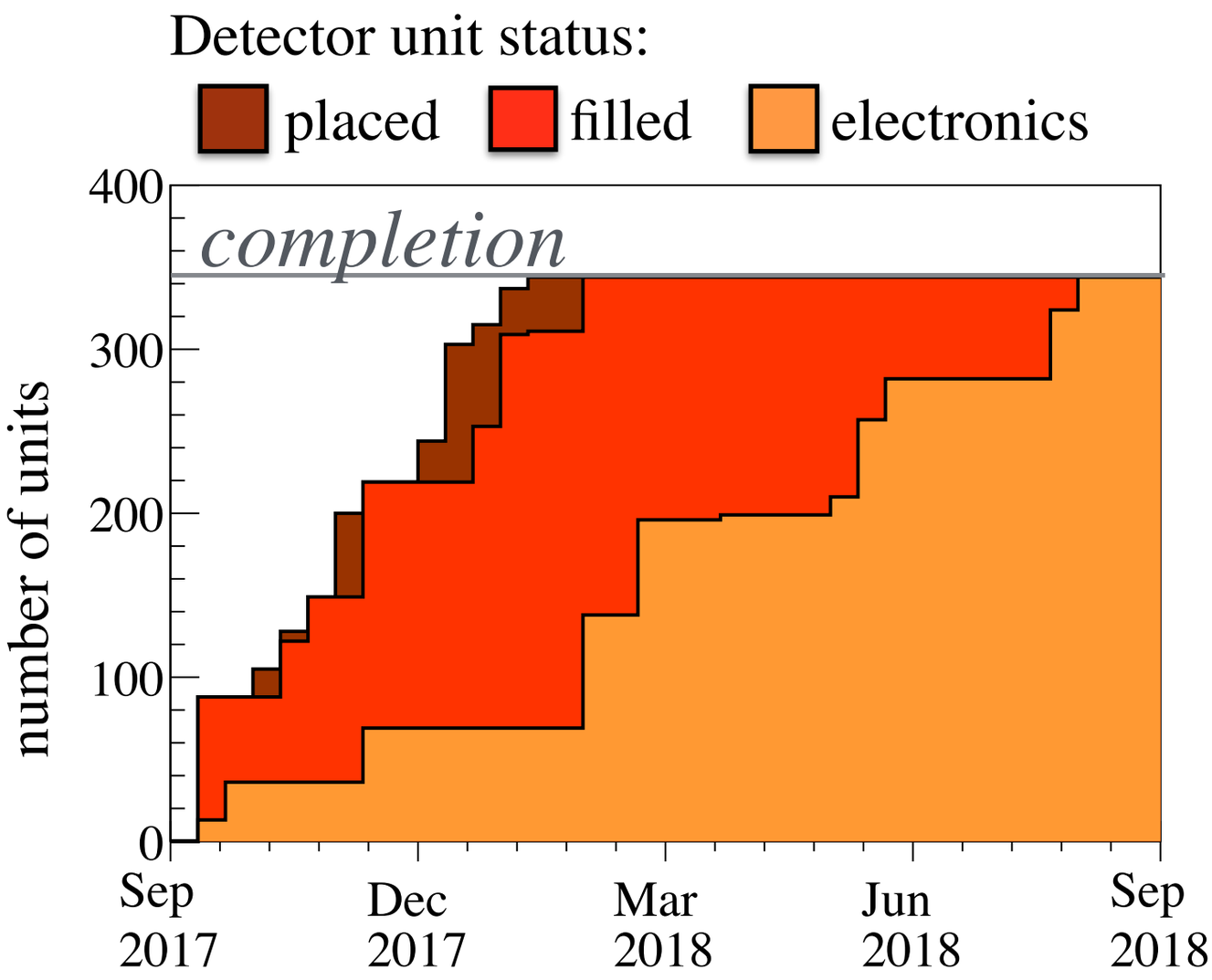
High Energy Upgrade: Outrigger Array

- 345 water-Cherenkov detectors in a sparser array surrounding the main-array
- Instrumented area increase by a factor of 4
- Waveform readout

High Energy Upgrade: Outrigger Array

- Full array is installed
- Data recording started August 2018





Summary

Results

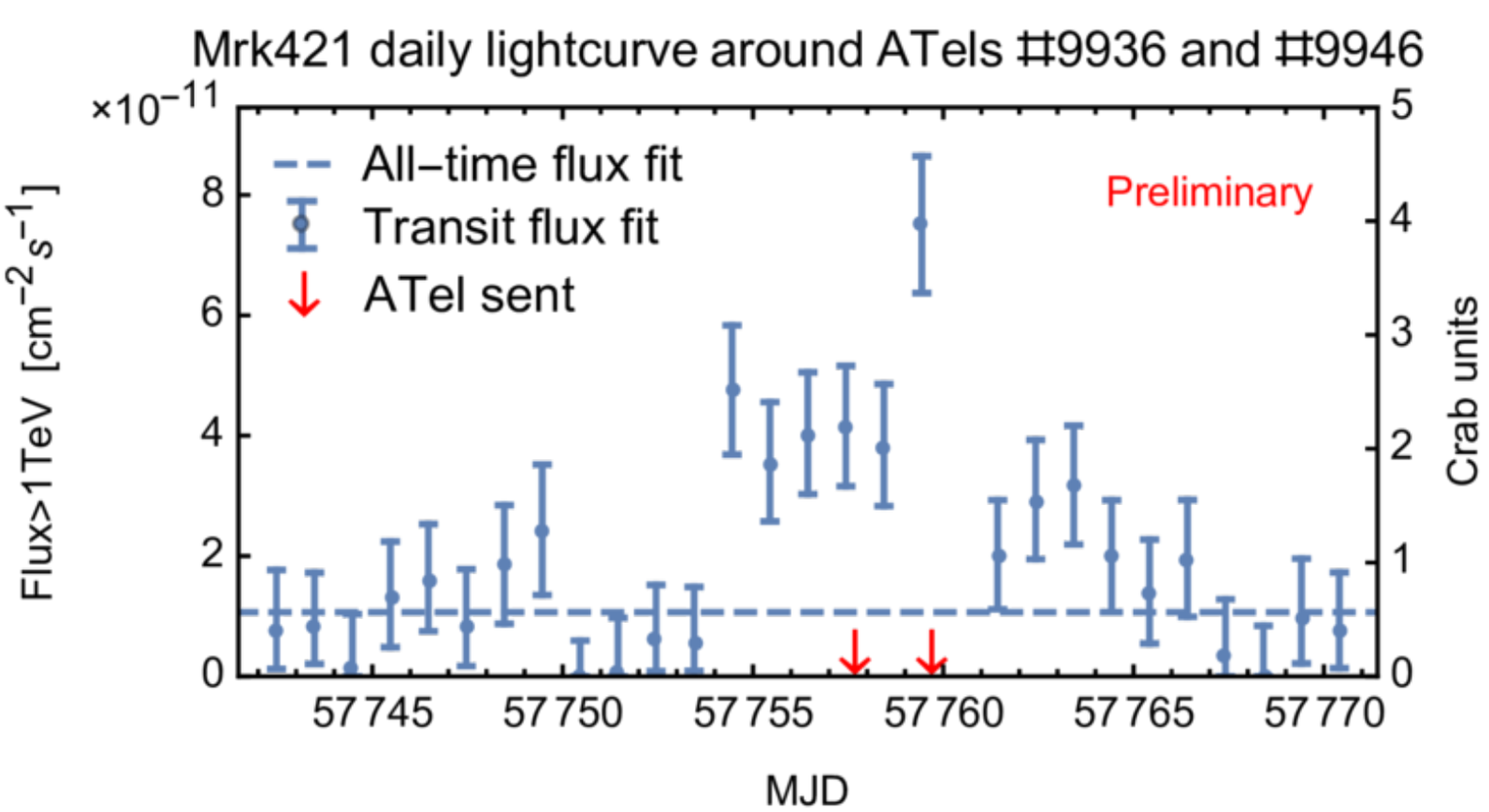
- HAWC has recorded ~3.5 years of data
- Interesting new sources
- Improvement in energy reconstruction
- High-Energy upgrade operational since August 2018

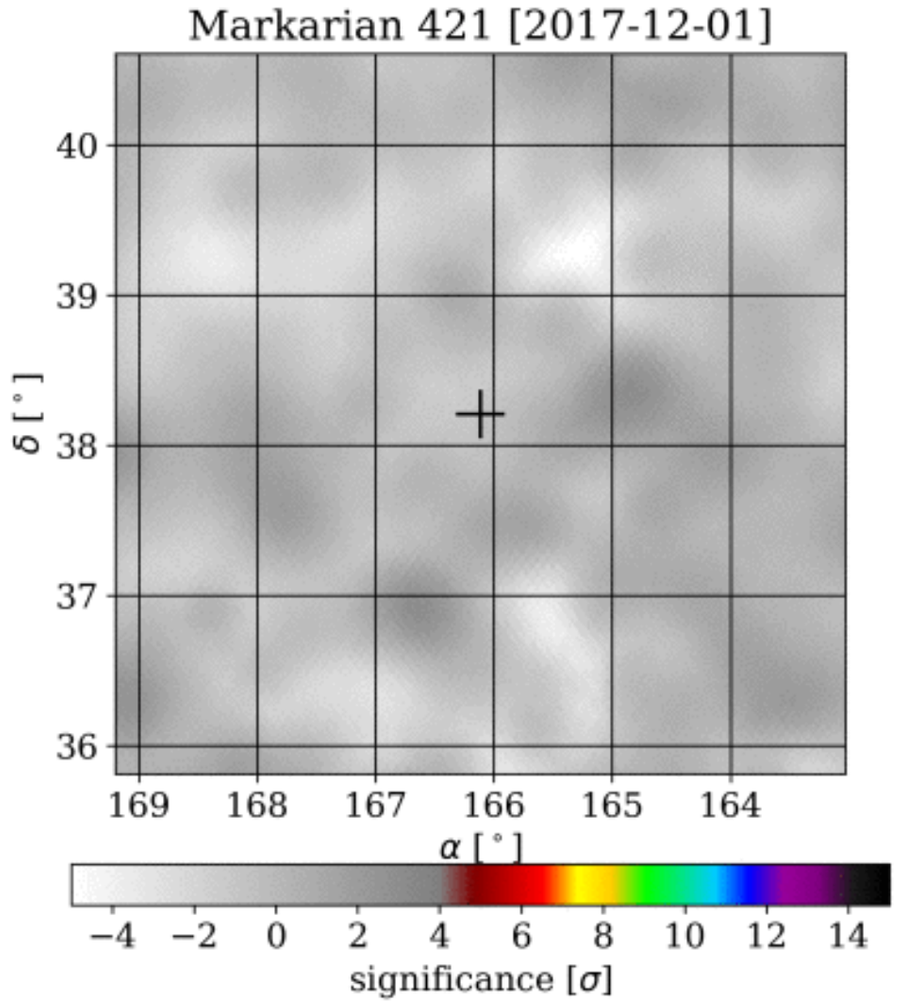
Prospects

- More detailed studies individual sources
- Increasing sensitivity at highest energies
- Improved reconstruction at lowest energies
- More alerts and multi-messenger follow-up

BACK - UP

Monitoring the variable sky: AGNs

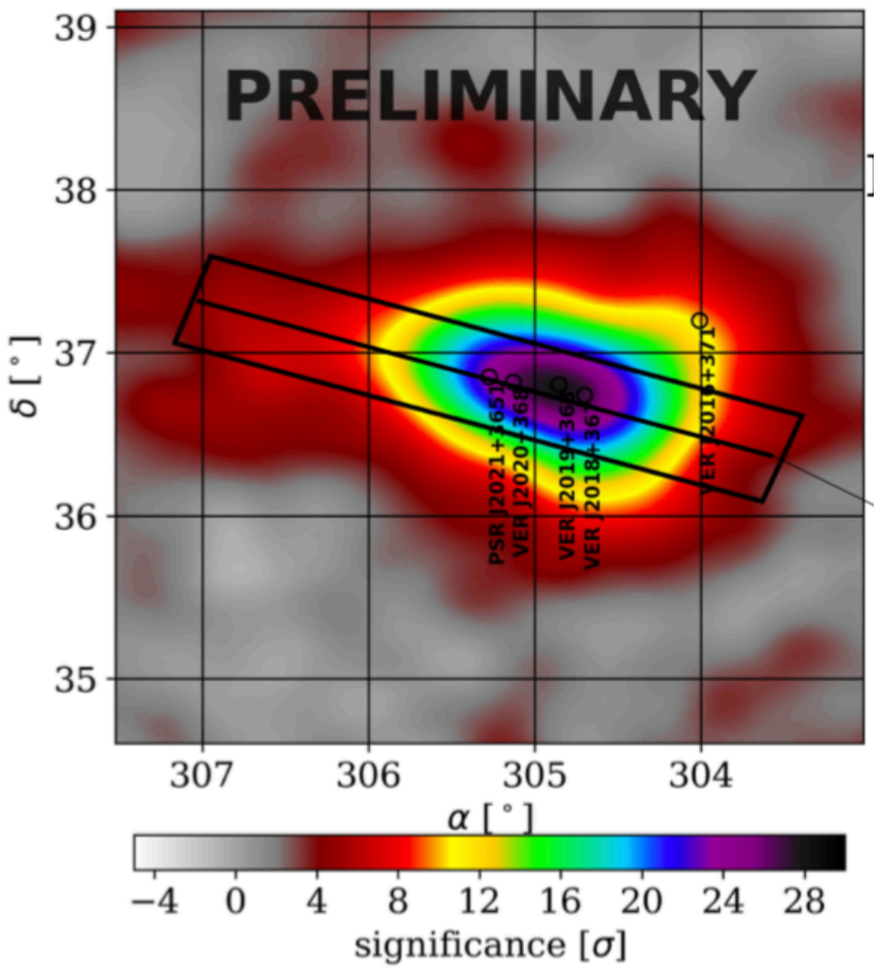


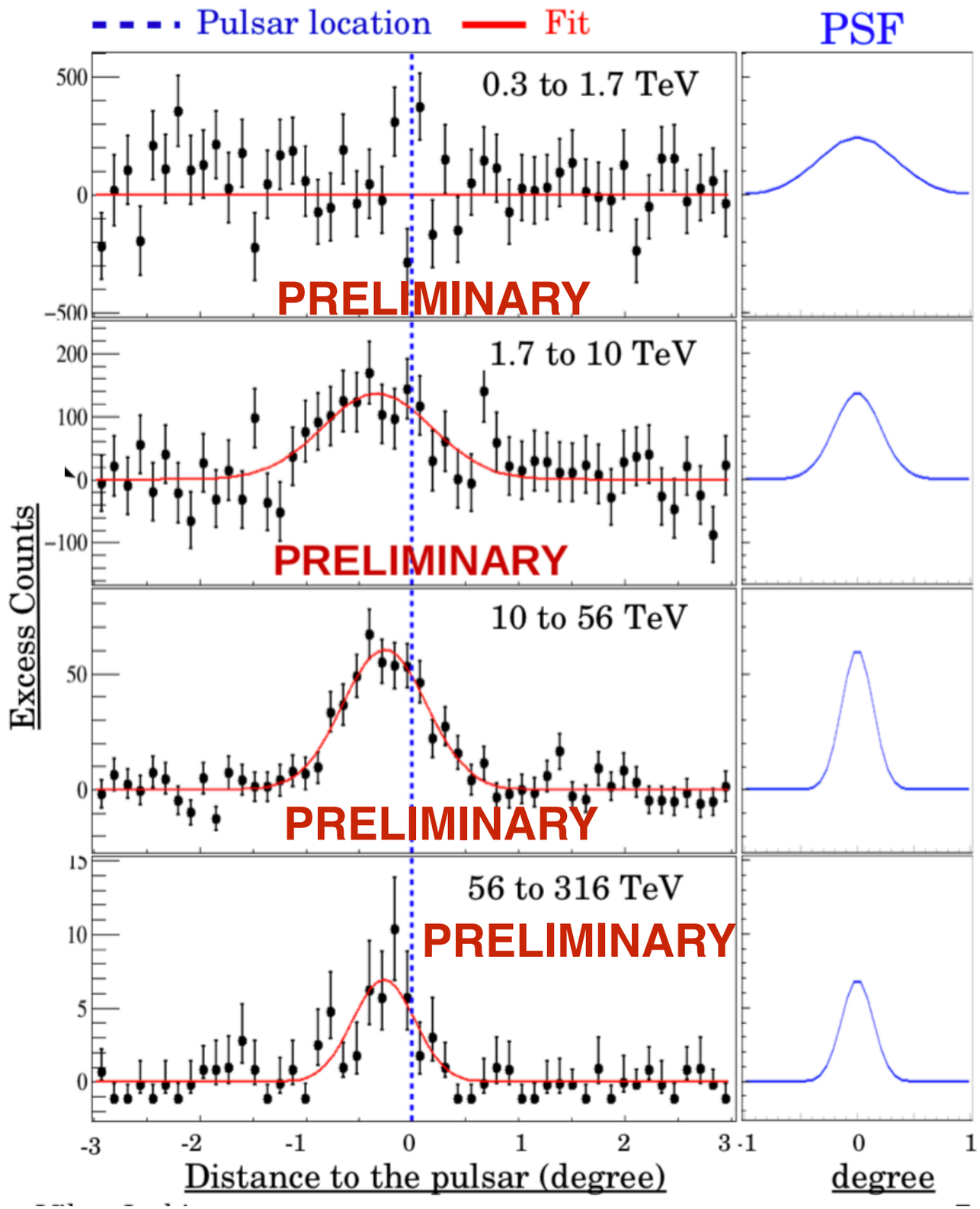


Monitoring AGN flares (Mrk 421 & 501): Atel #8922, #9137, #9936, #9946, #11077, #11194.

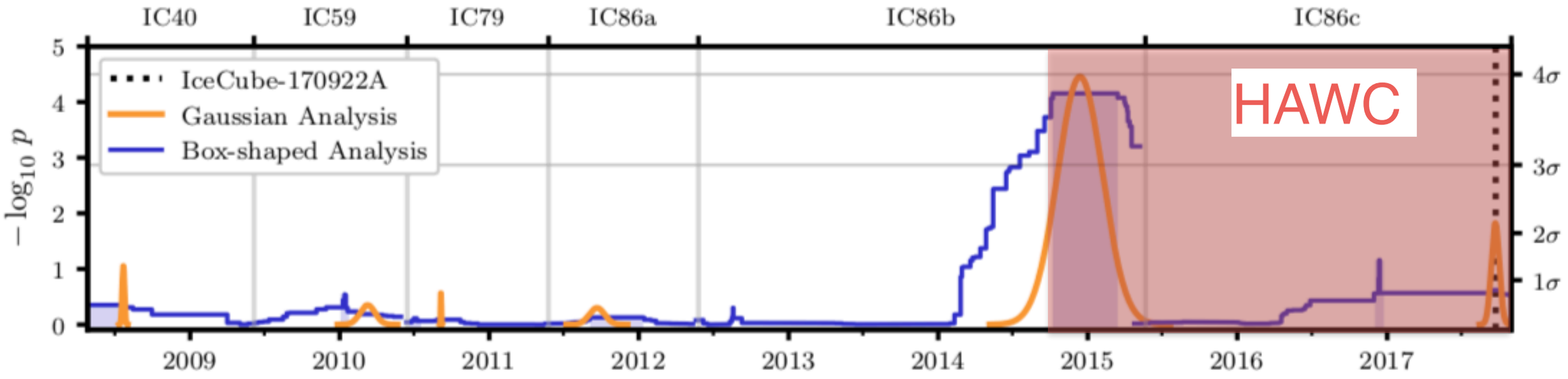
Very-High-Energy emission from 2HWC J2019+367

- Study morphology: Extended & possible energy dependent
- Orientation similar as in X-ray and VERITAS observations





Monitoring the variable sky: Neutrino “Flare” from TXS 0506+056 ….



M.G. Aartsen et al. Science (2018)

- Enhanced flux in direction from TXS 0506+056 in period 2014-2015…

- HAWC came online in that period

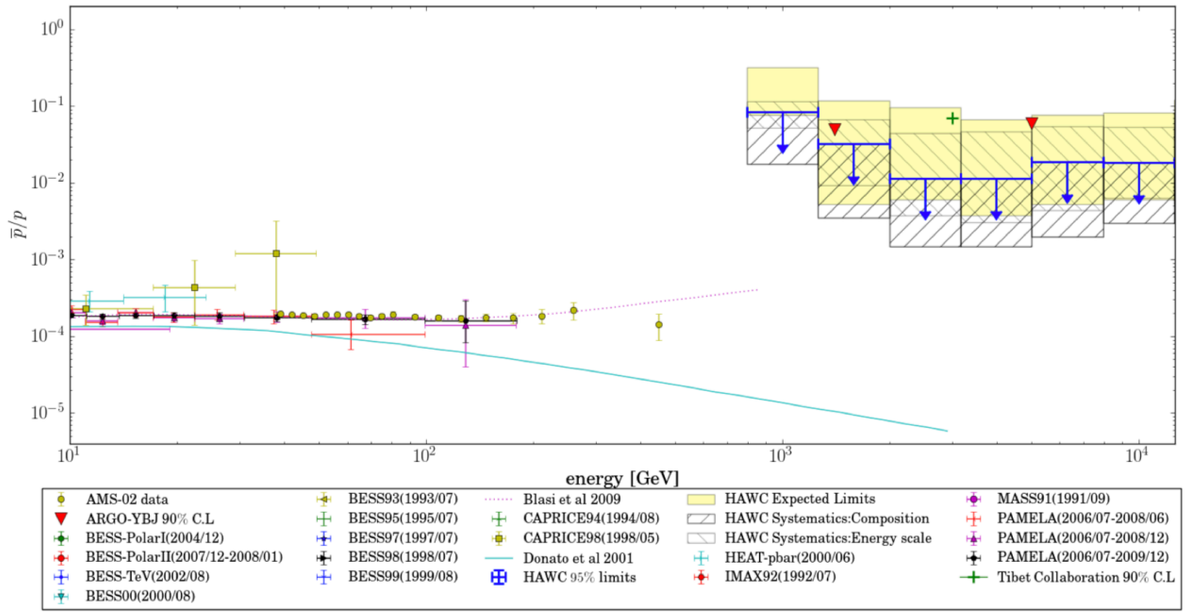
- Publication in progress, stay tuned!

Observations of Cosmic Rays

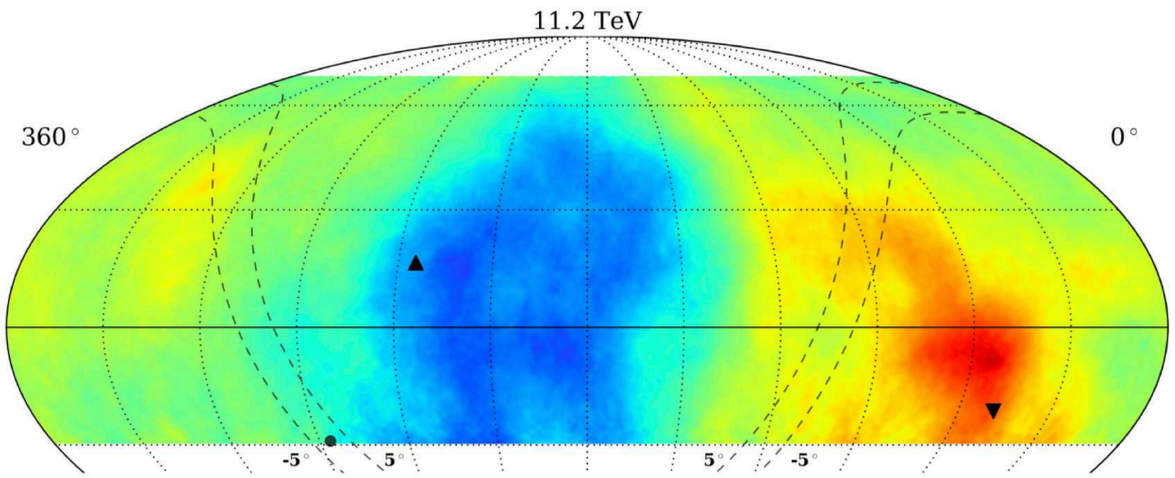
- Not only background!
- Large statistics

$\bar{p}/p$ - ratio using the moon shadow

PRD, ***97***, *2018*

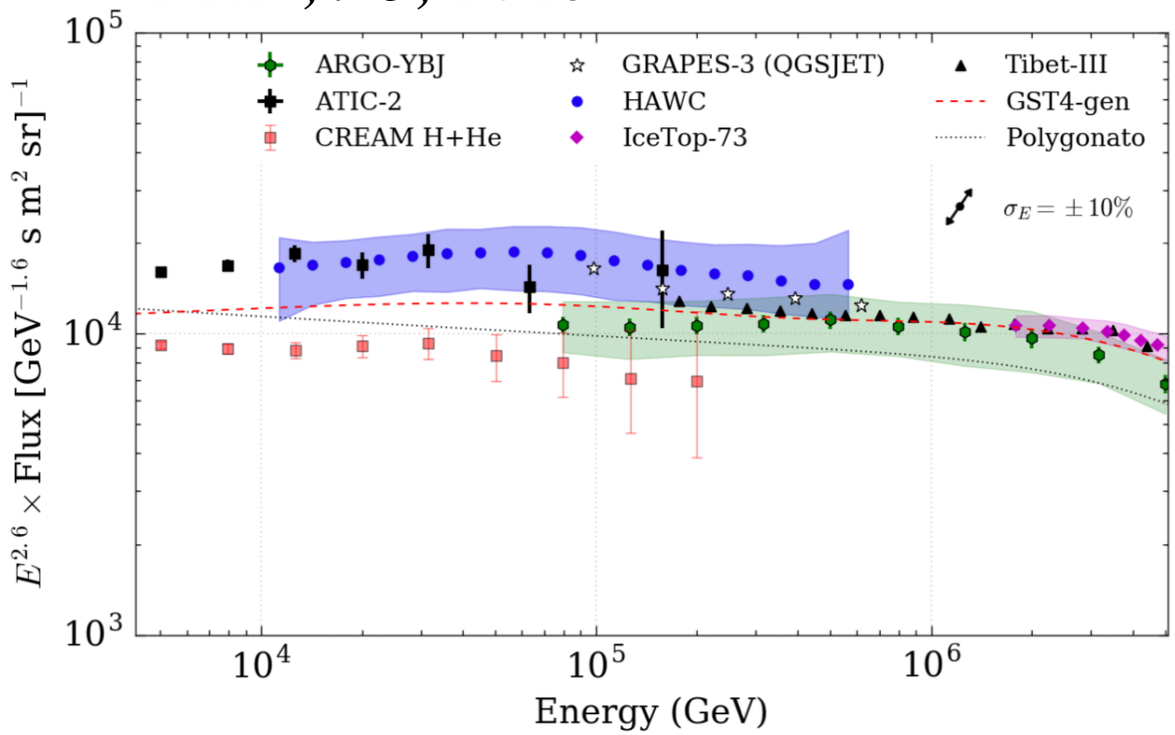


Anisotropy: Accepted ApJ (Aug. 2018)



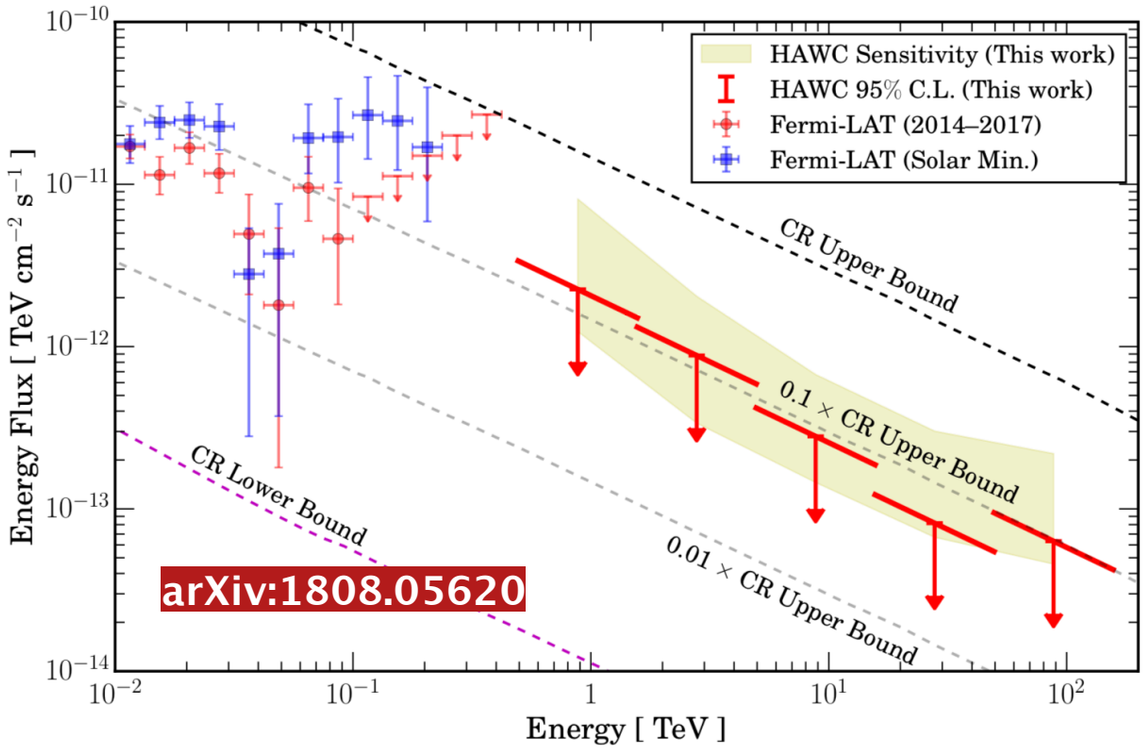
All particle spectrum

PRD, ***96***, *2017*

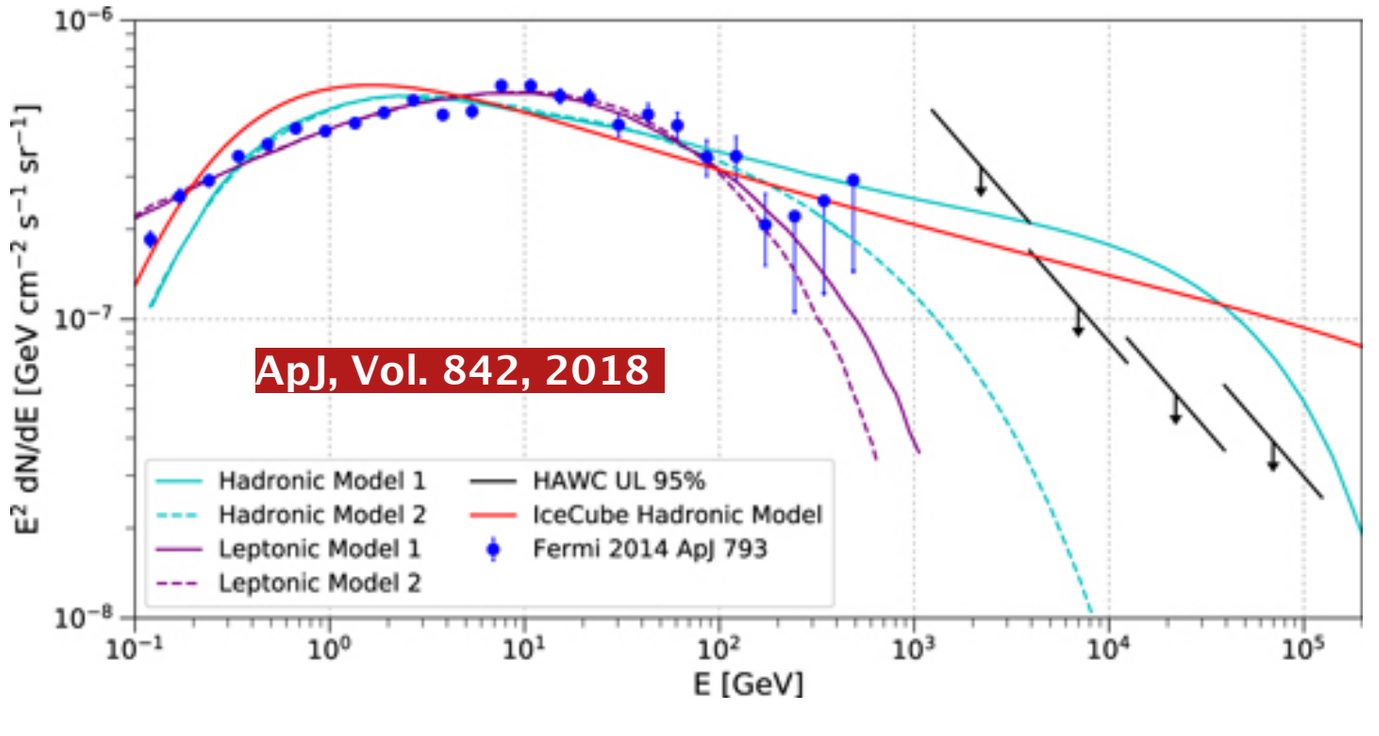


Gamma-ray upper limits

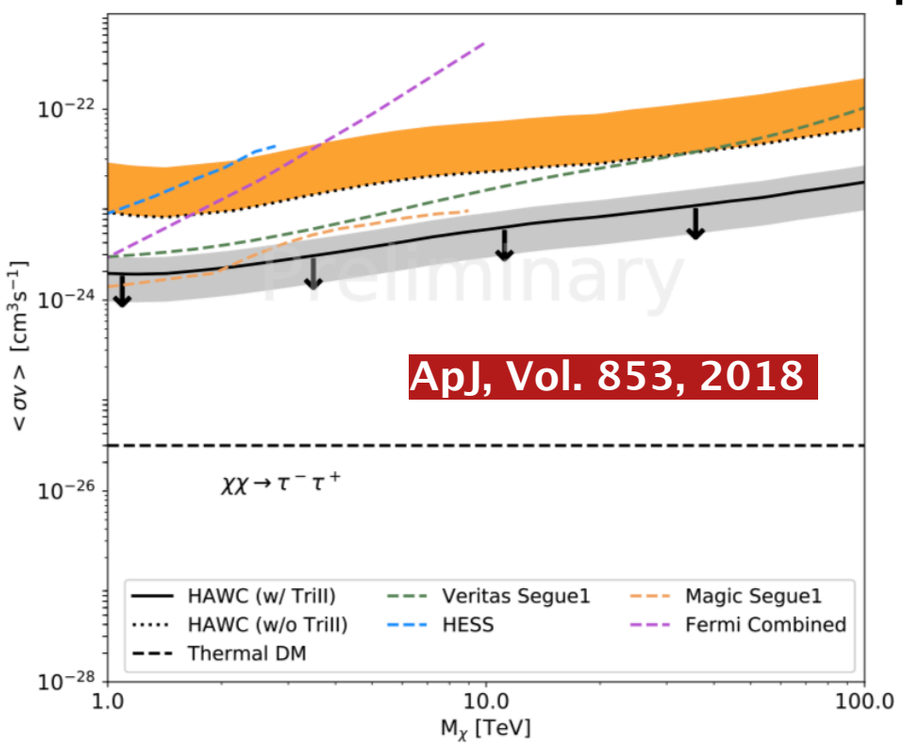
The sun



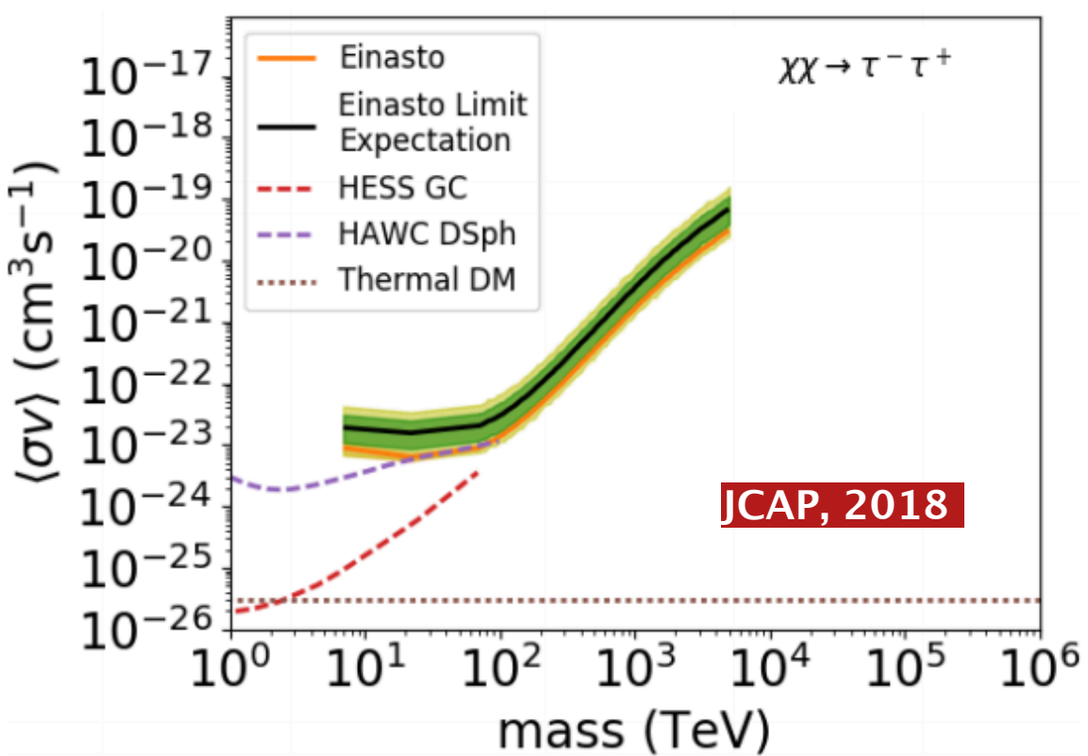
The northern fermi-bubble



Dark-Matter annihilation in dSph



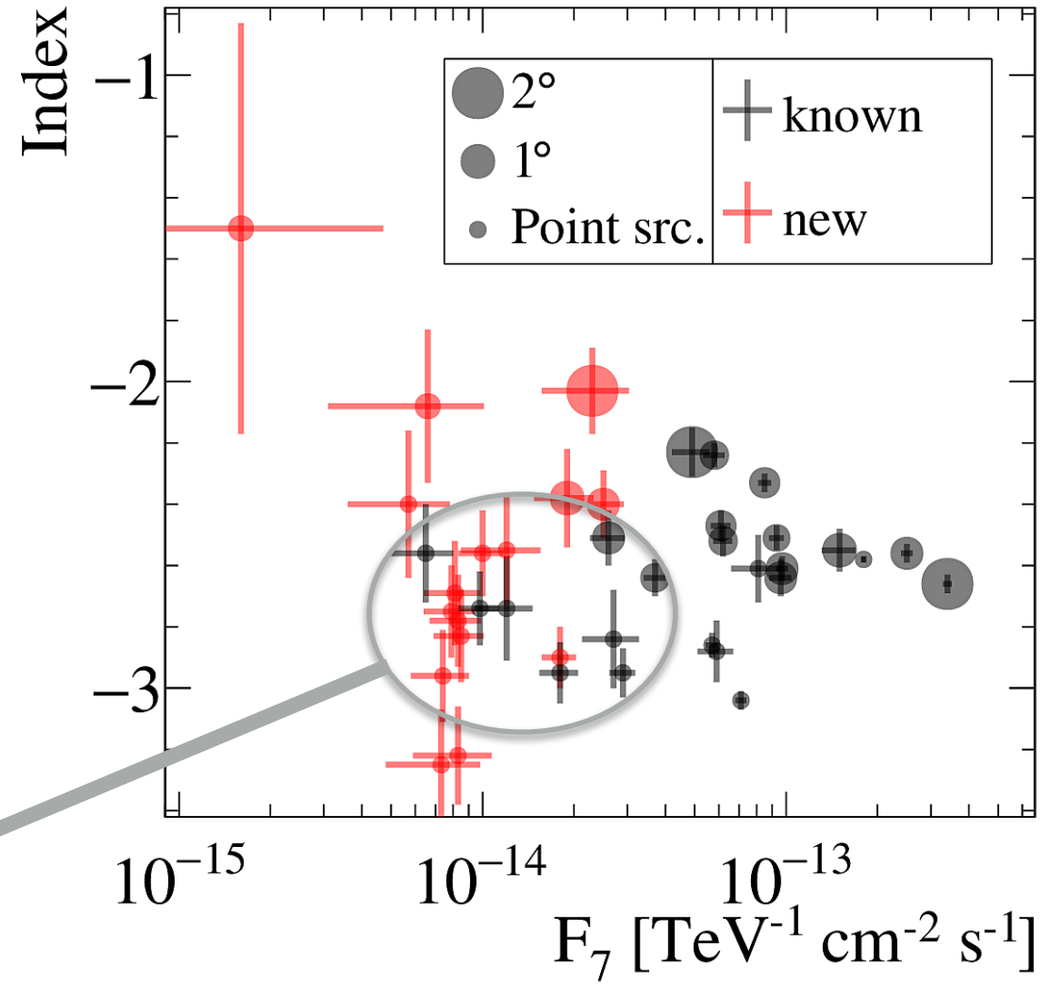
Dark-Matter Galactic Halo



HAWC's view on the sky (2HWC catalog 507 days)

1. Catalog is build from maps with 4 hypothesis.
2. Sources are flagged when TS > 25
3. Separation of neighboring sources sqrt(TS) > 2
4. When sources are identified their size and spectral index are fitted

Size	PL Index
Point Src	-2.7
0.5	-2.0
1.0	-2.0
2.0	-2.0



Result: 40 sources,
***16** previously unknown in TeV range*

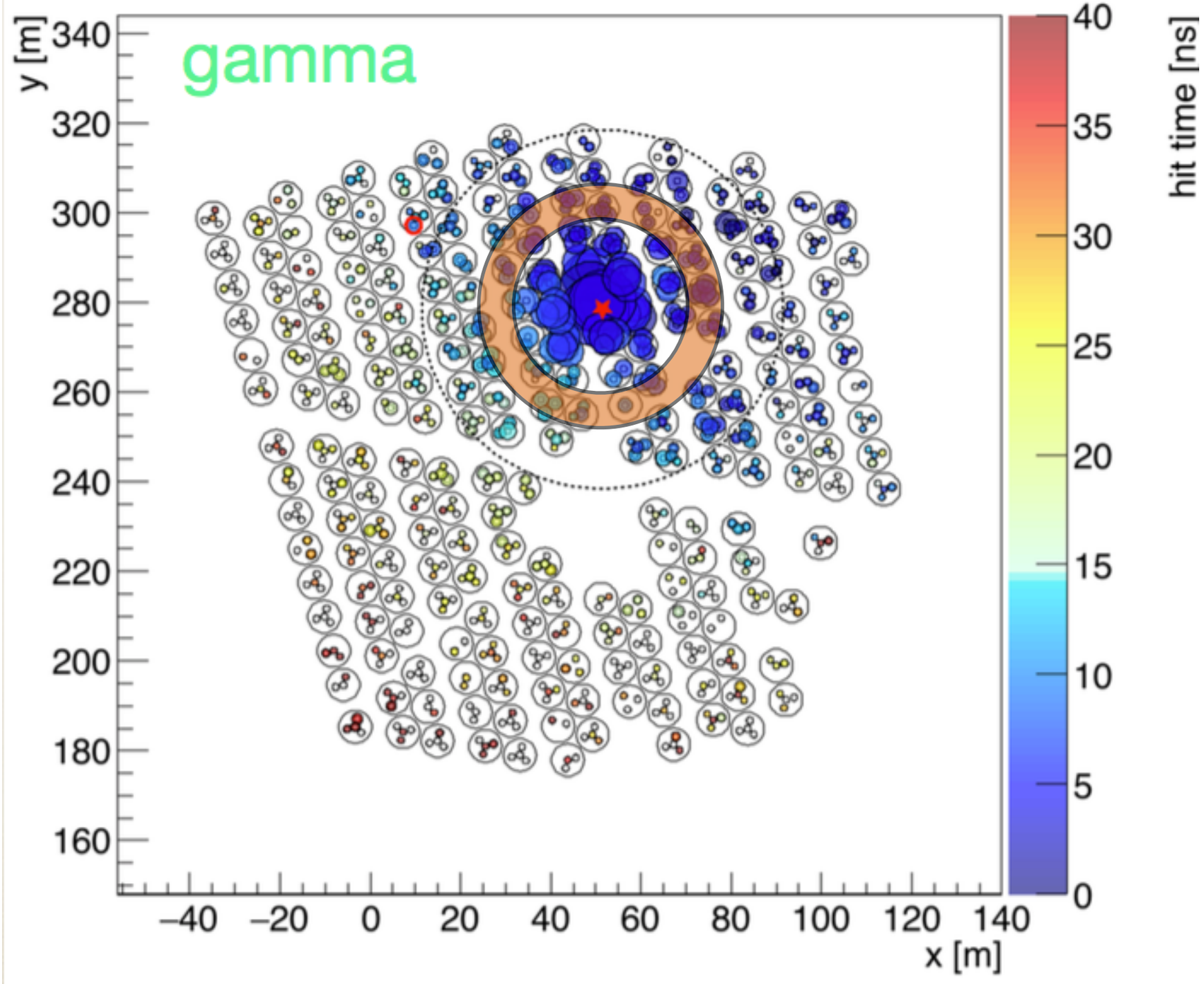
Follow-up by IACTs?

A. U. Abeysekara, *et al*, *ApJ*, **843**, 2017 / arXiv:1701.01778

PINC

Sum over the deviations from the average in an annulus around the impact point.

Measure of the smoothness of the lateral particle distribution.

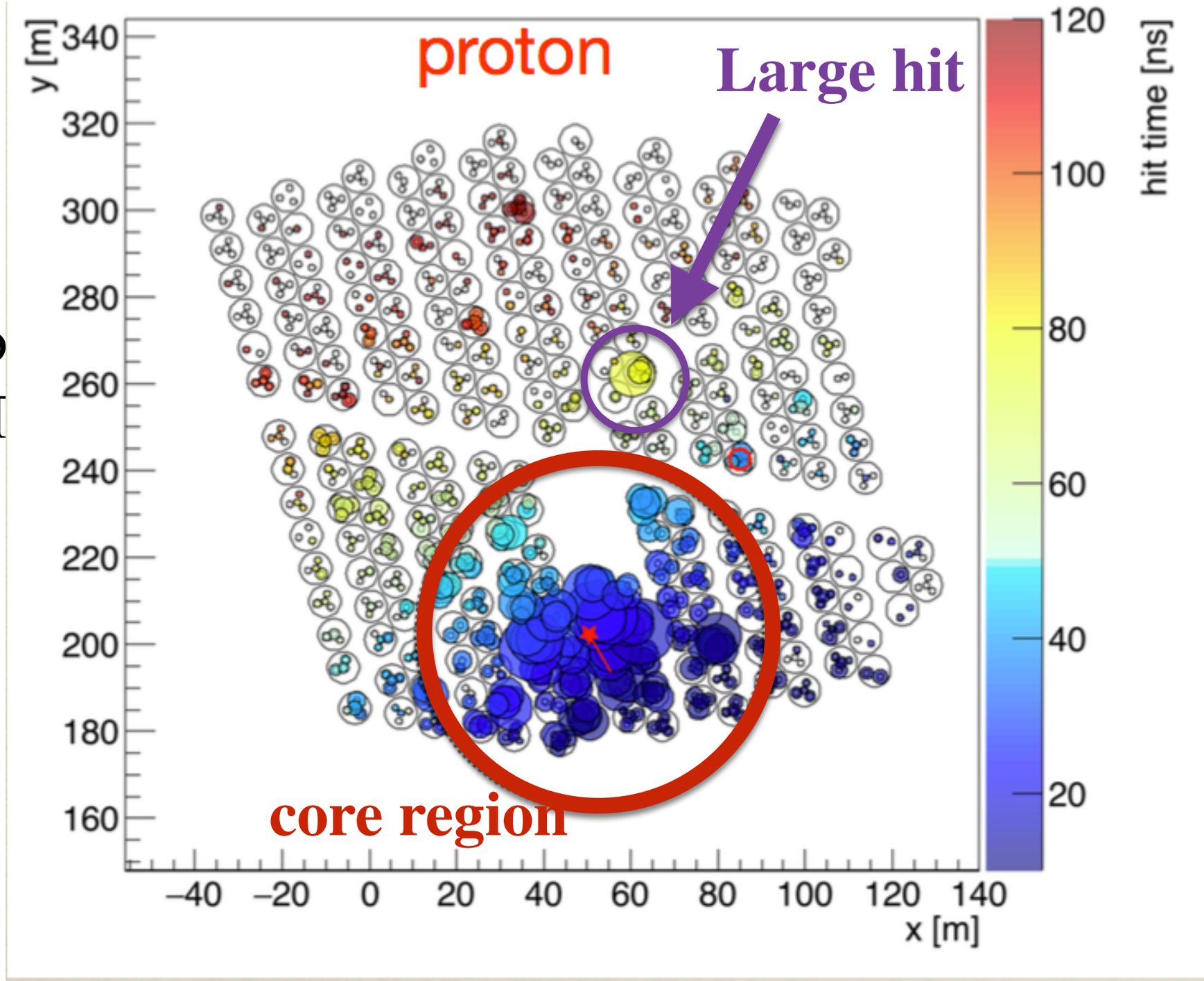


Shower type identification

1/Compactness:

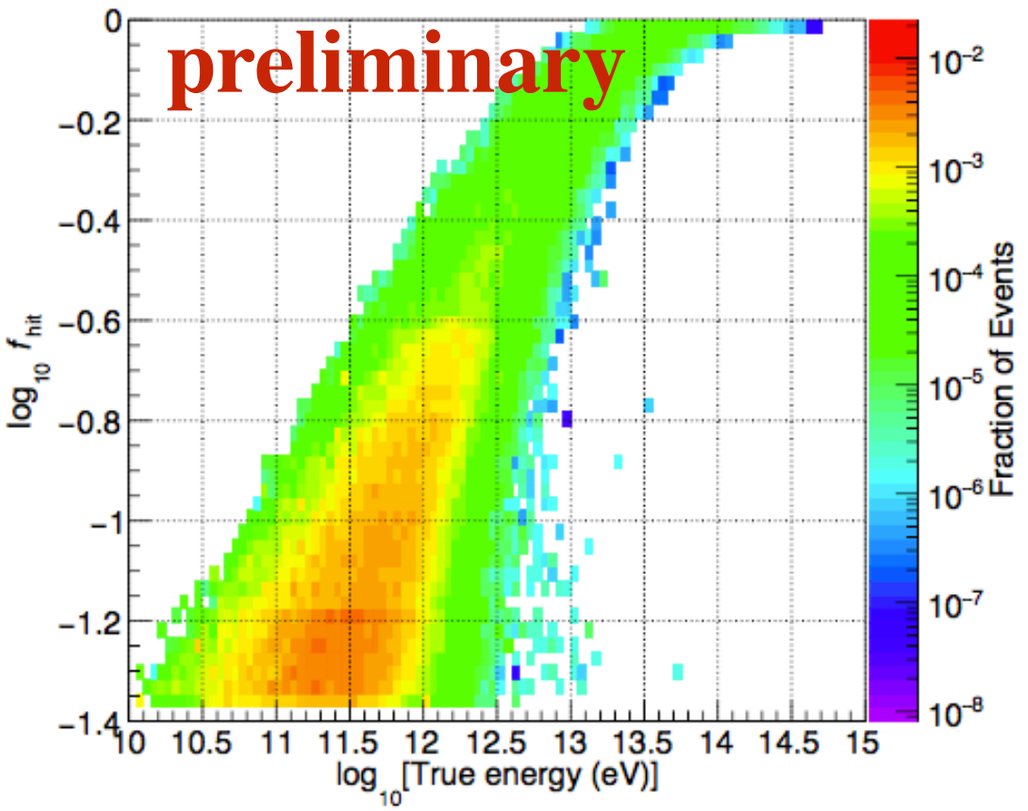
Largest signal outside the impact region compared to the number of PMT hit: $\mathbf{Q_{max}/N_{sp}}$

Sensitive to sub-showers & muons

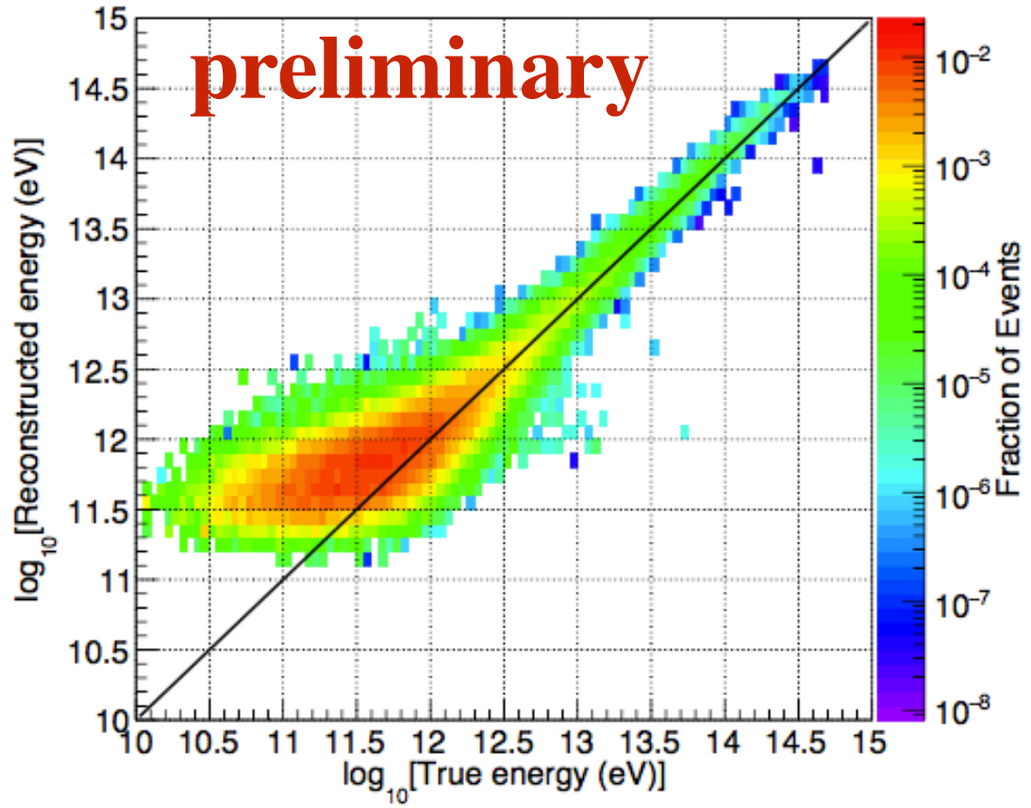


Energy Reconstruction

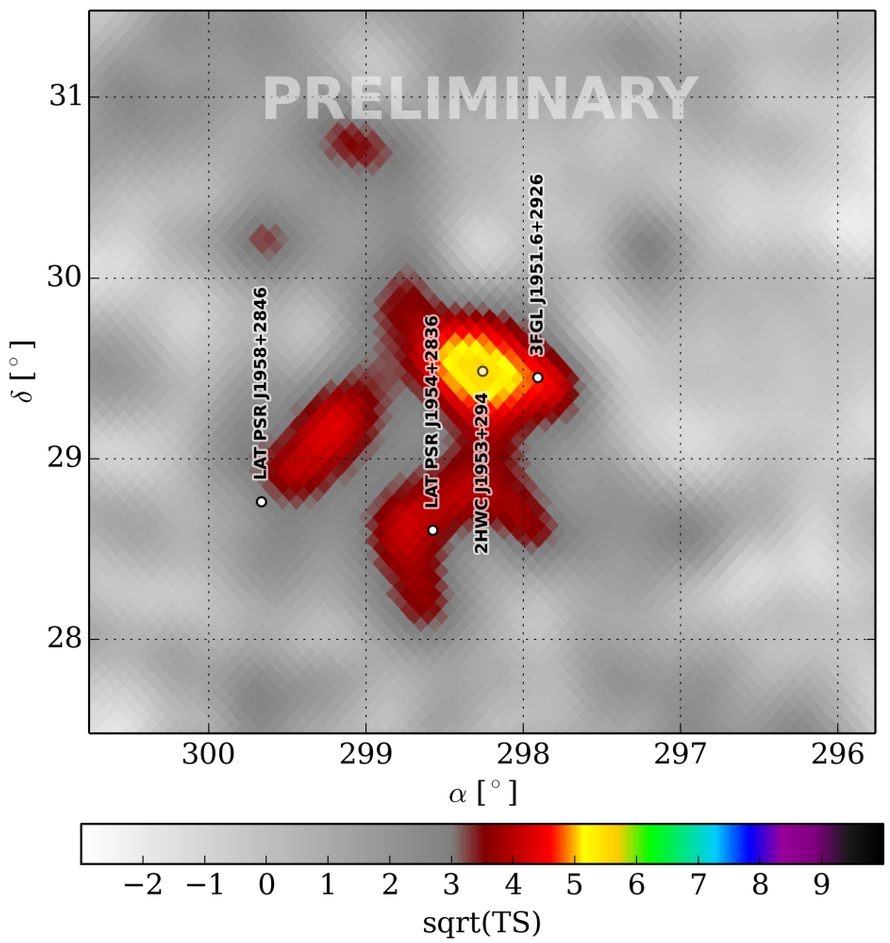
Old “energy-estimator”

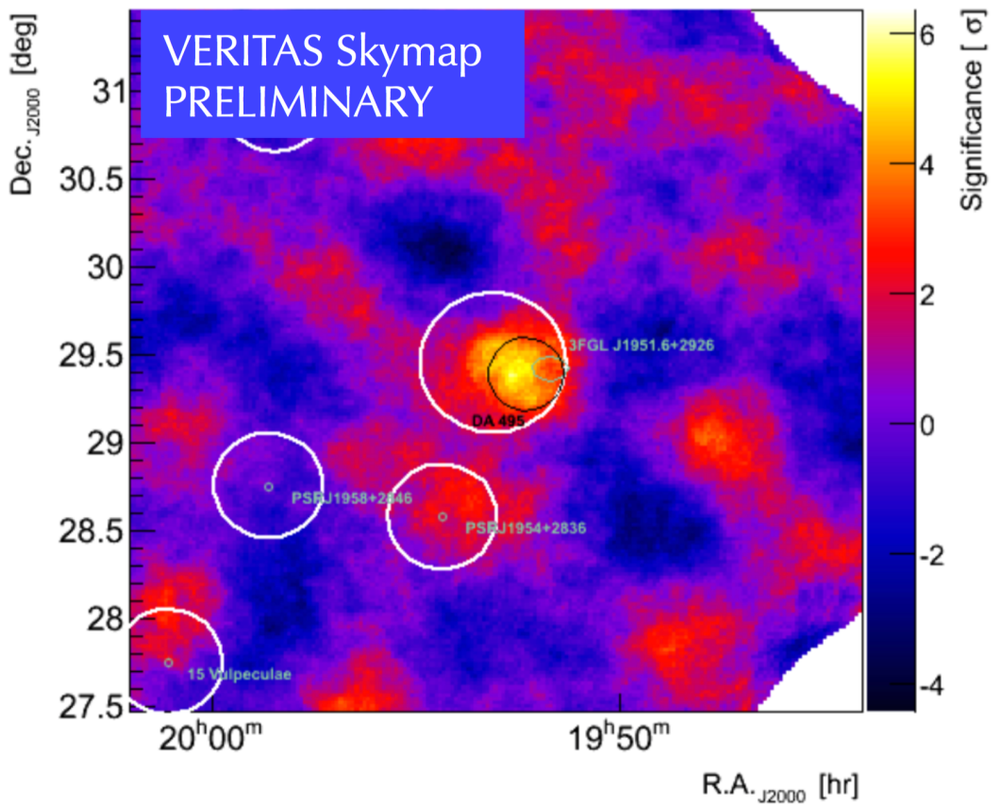


New energy-estimator



Galactic sources: HAWC source confirmed by Veritas



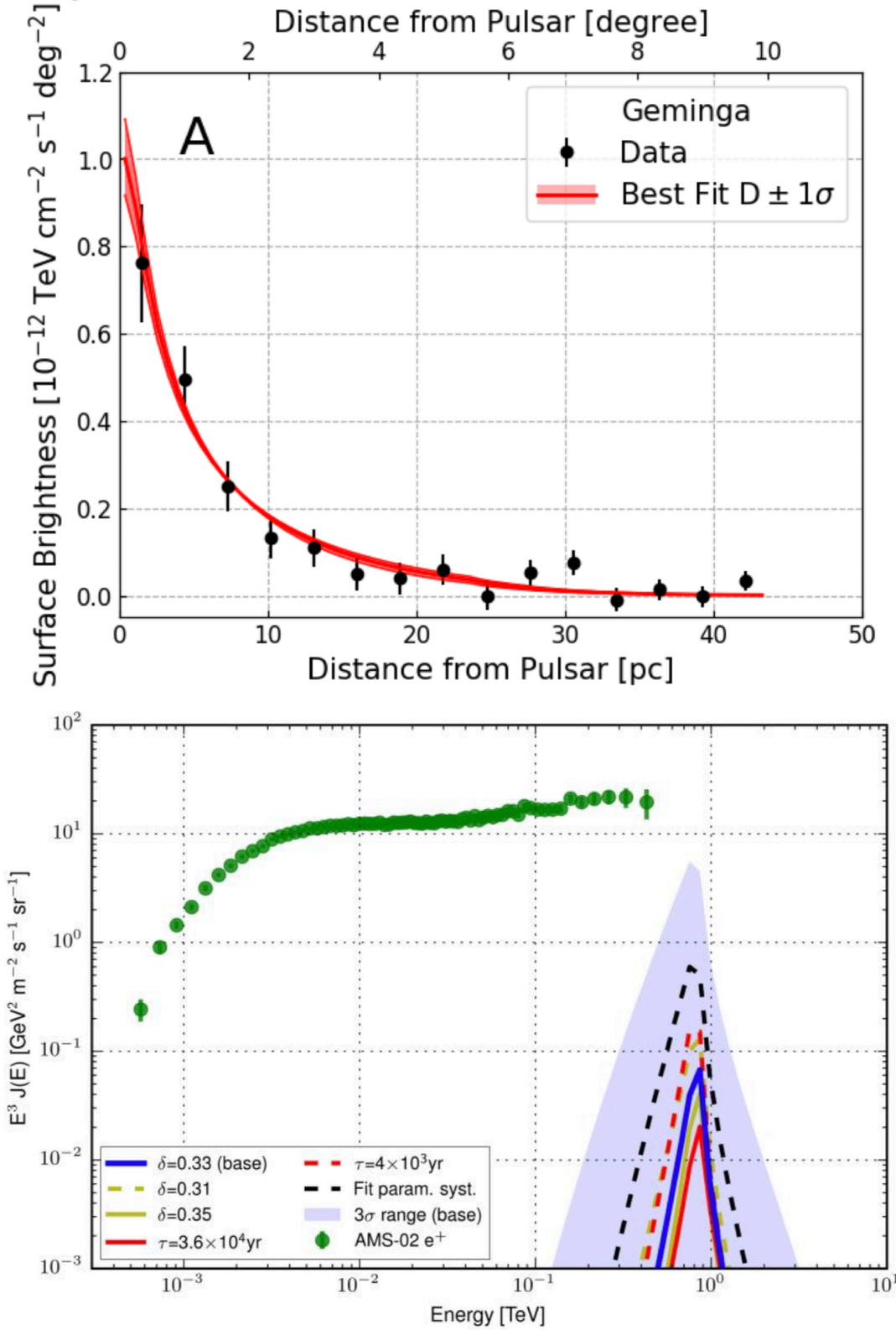


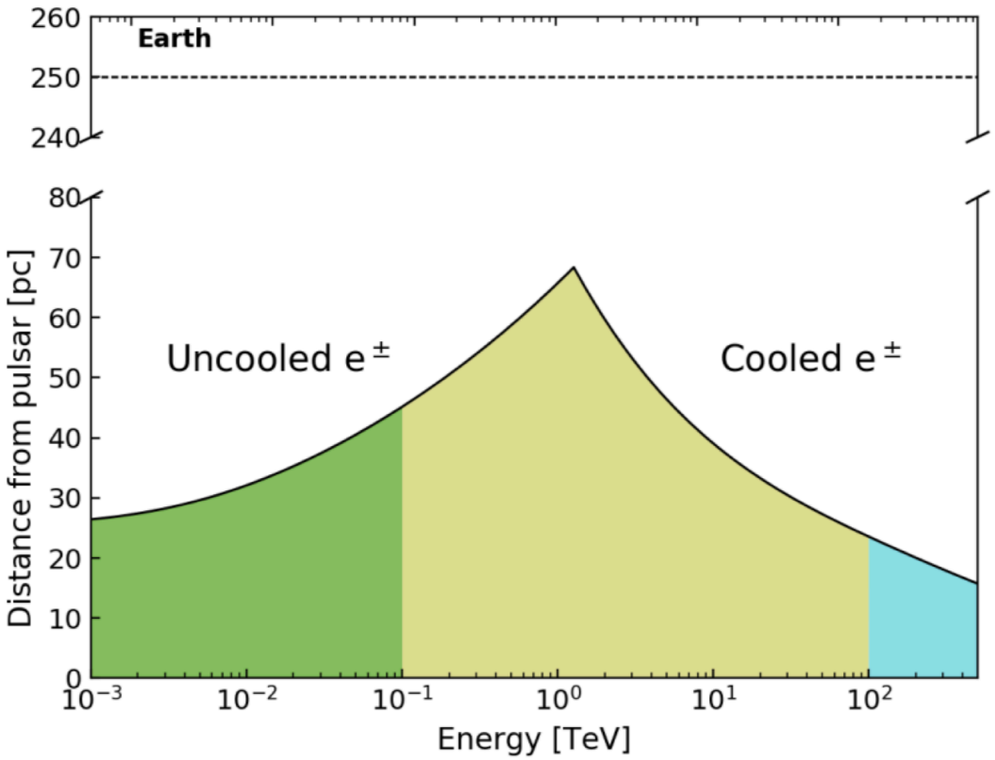
Name	$\sqrt{TS}$	Index	Flux for index at 7 TeV [$\mathrm{TeV^{-1}cm^{-2}s^{-1}}$]
2HWC J1953+294	5.58	-2.76 ± 0.15	1.1e-14 ± 4.2e-15

Confirmed by VERITAS in combination of archival + new data!!

TeV emission around Middle-aged Pulsars

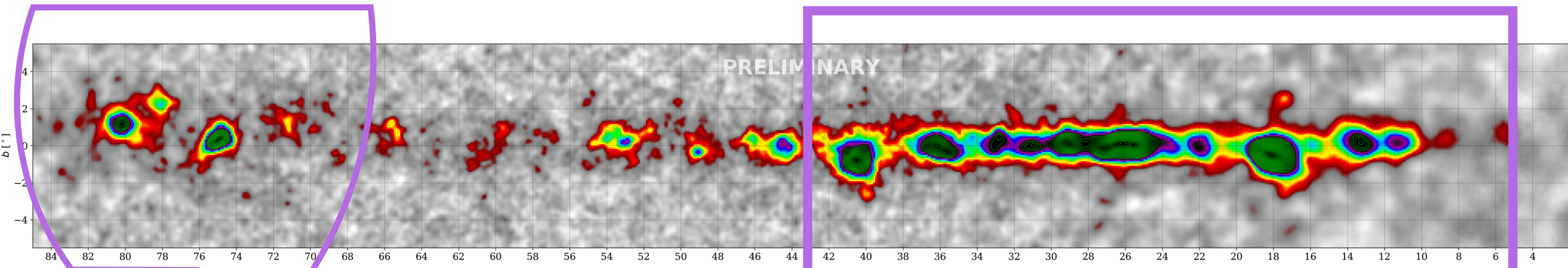
- Surface brightness consistent with diffusion
- Fitted diffusion radius is small
- Under assumption of isotropic & homogenous diffusion, Geminga is ruled out as the source for the positron flux at Earth

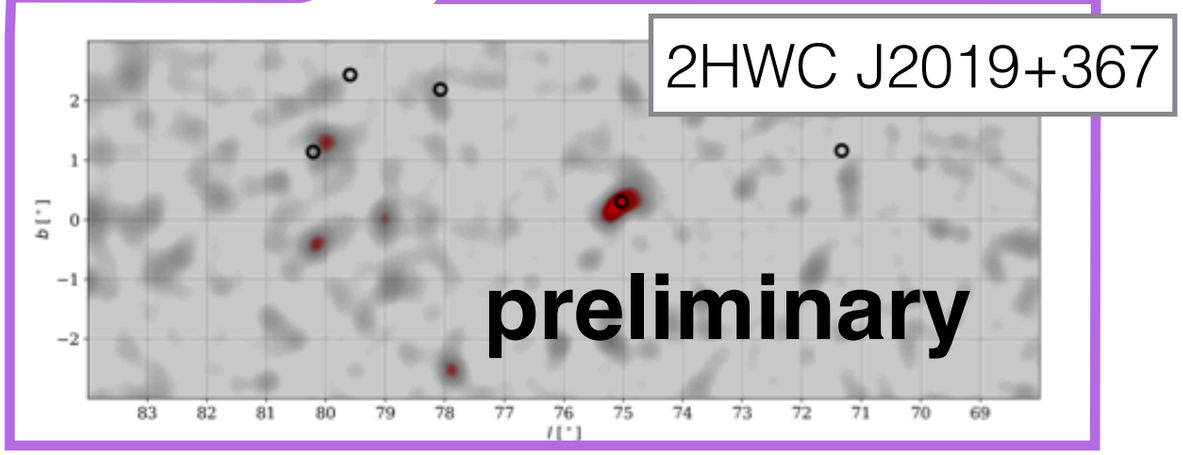


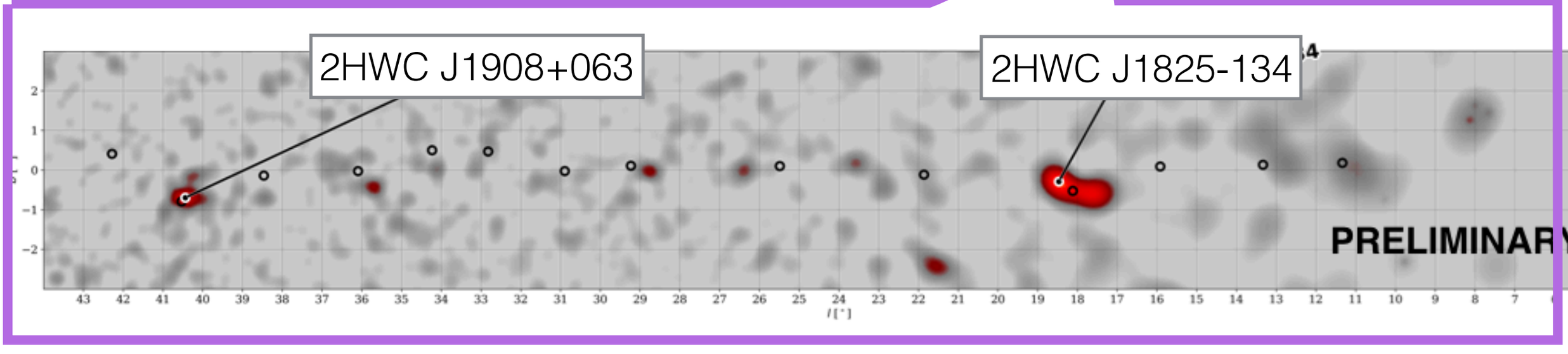


A. U. Abeysekara, *et al*, *Science*, **358**, 2017 / arXiv:1711.06223

The sky observed > 100 TeV **reconstructed** energy

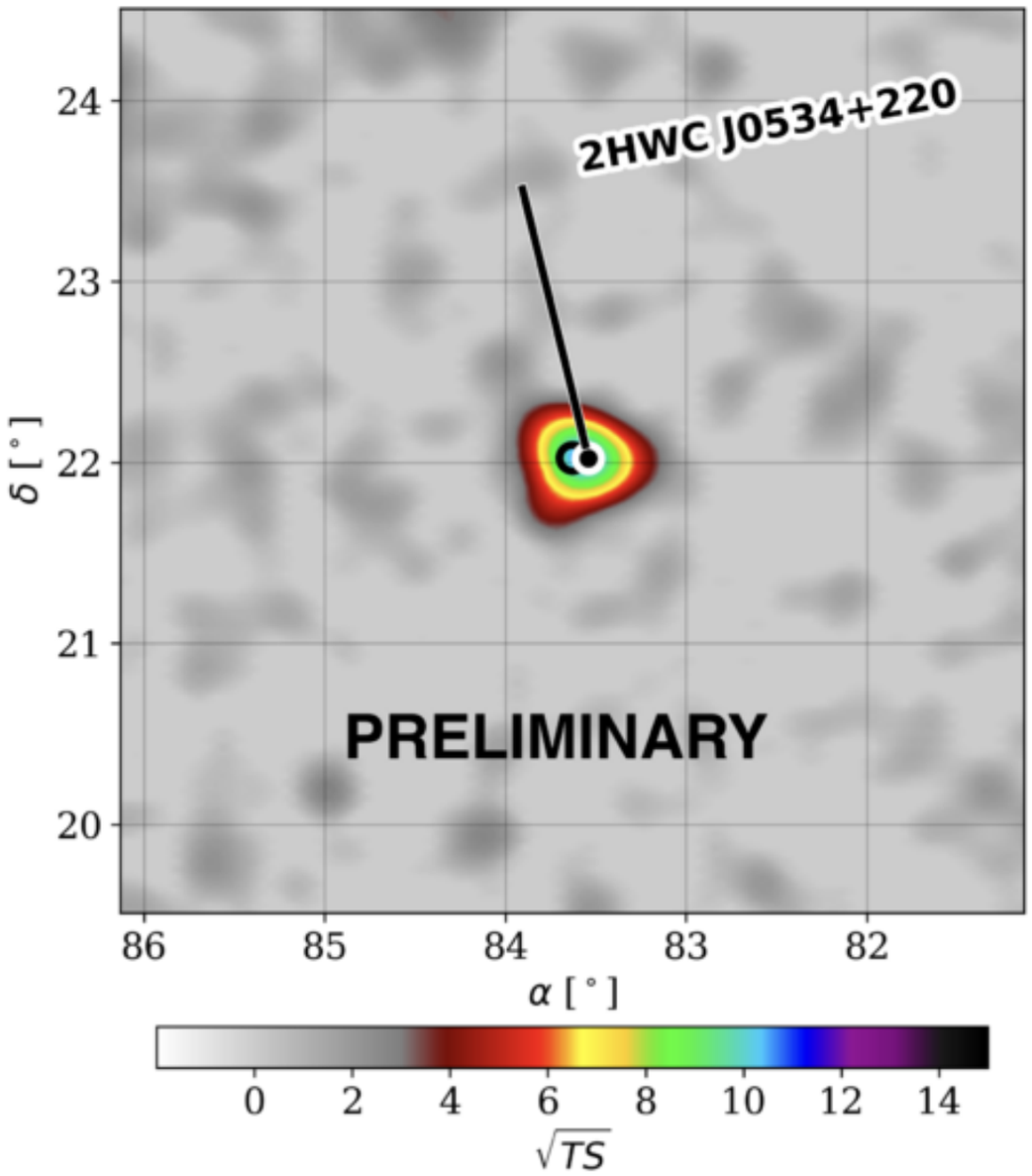




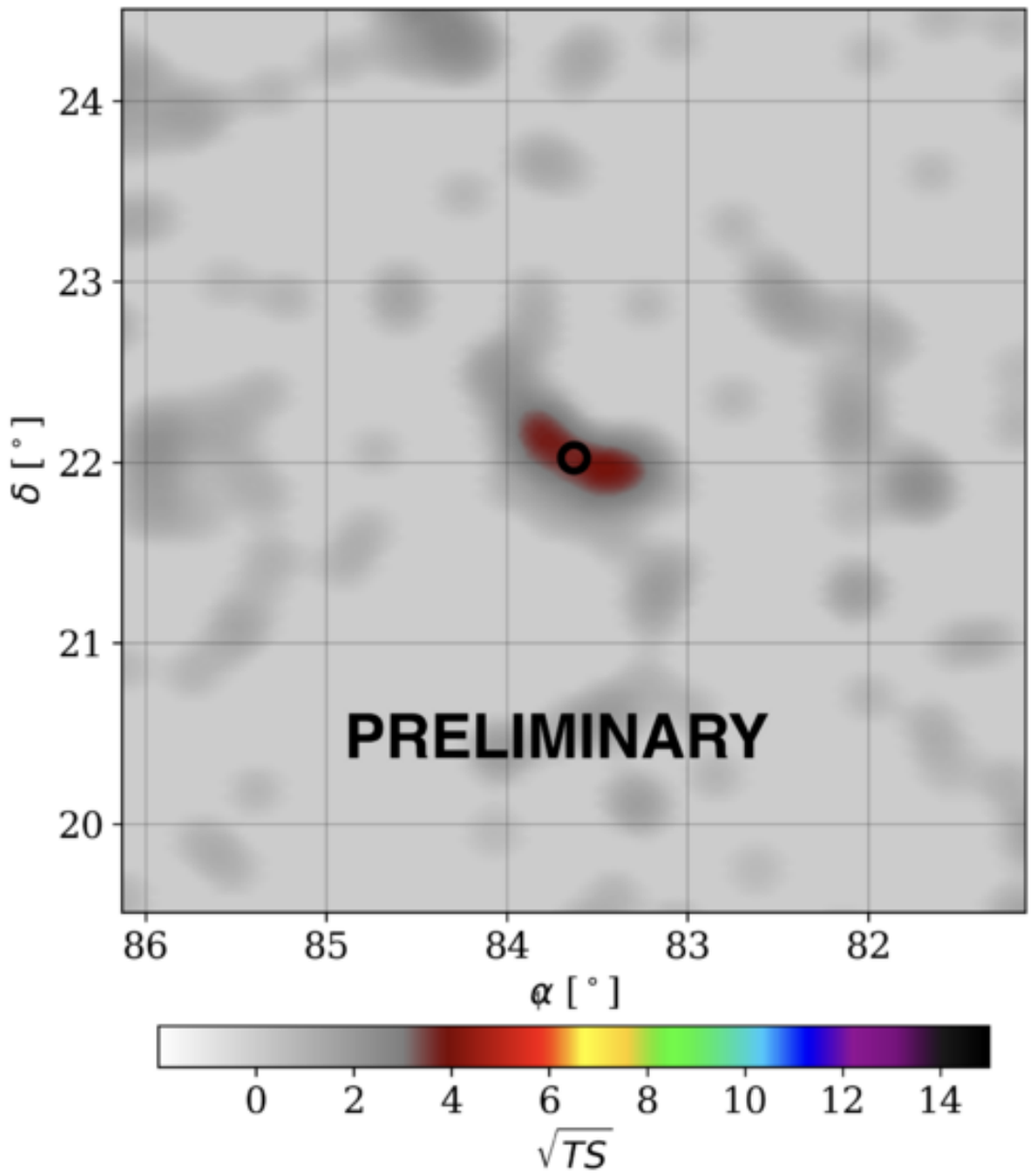


The crab at the highest energies

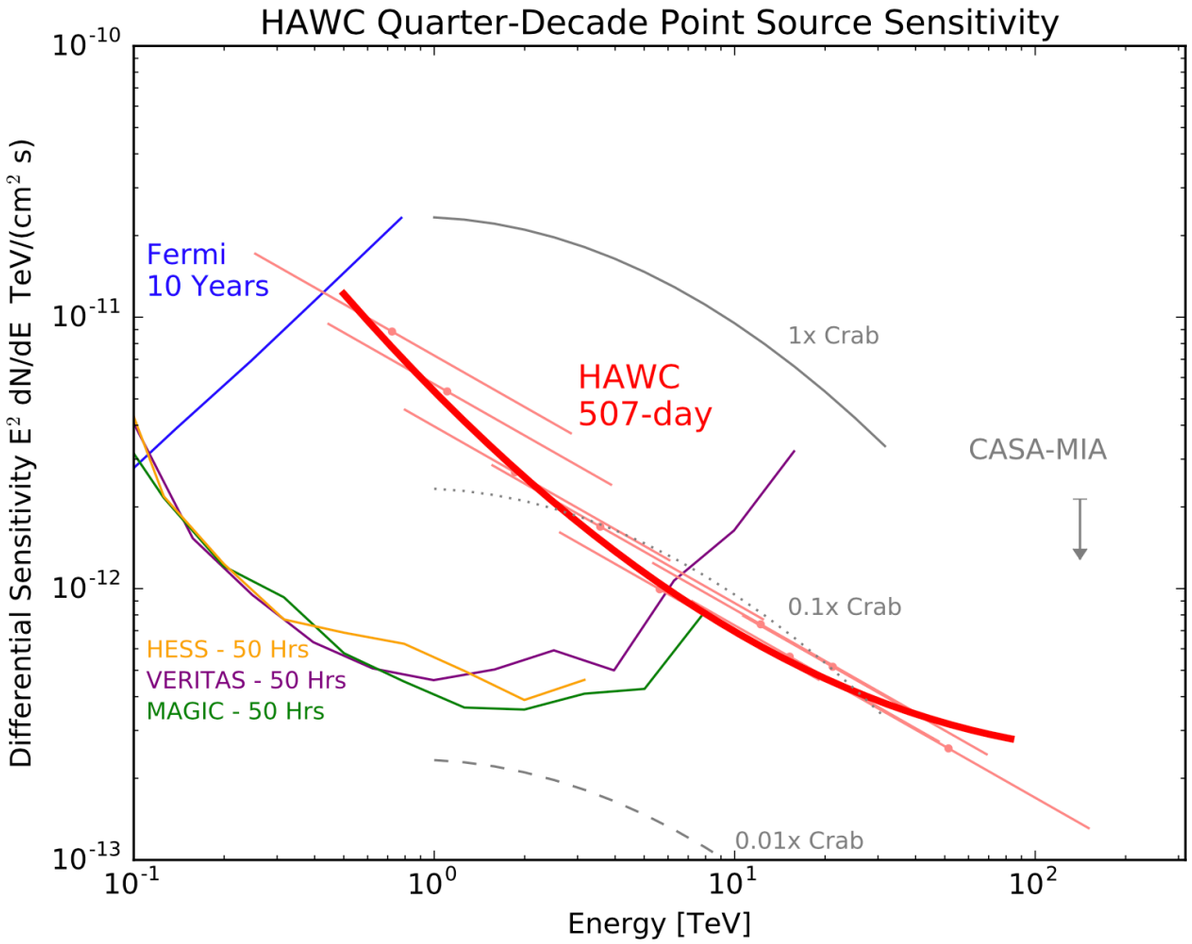
> 56 TeV

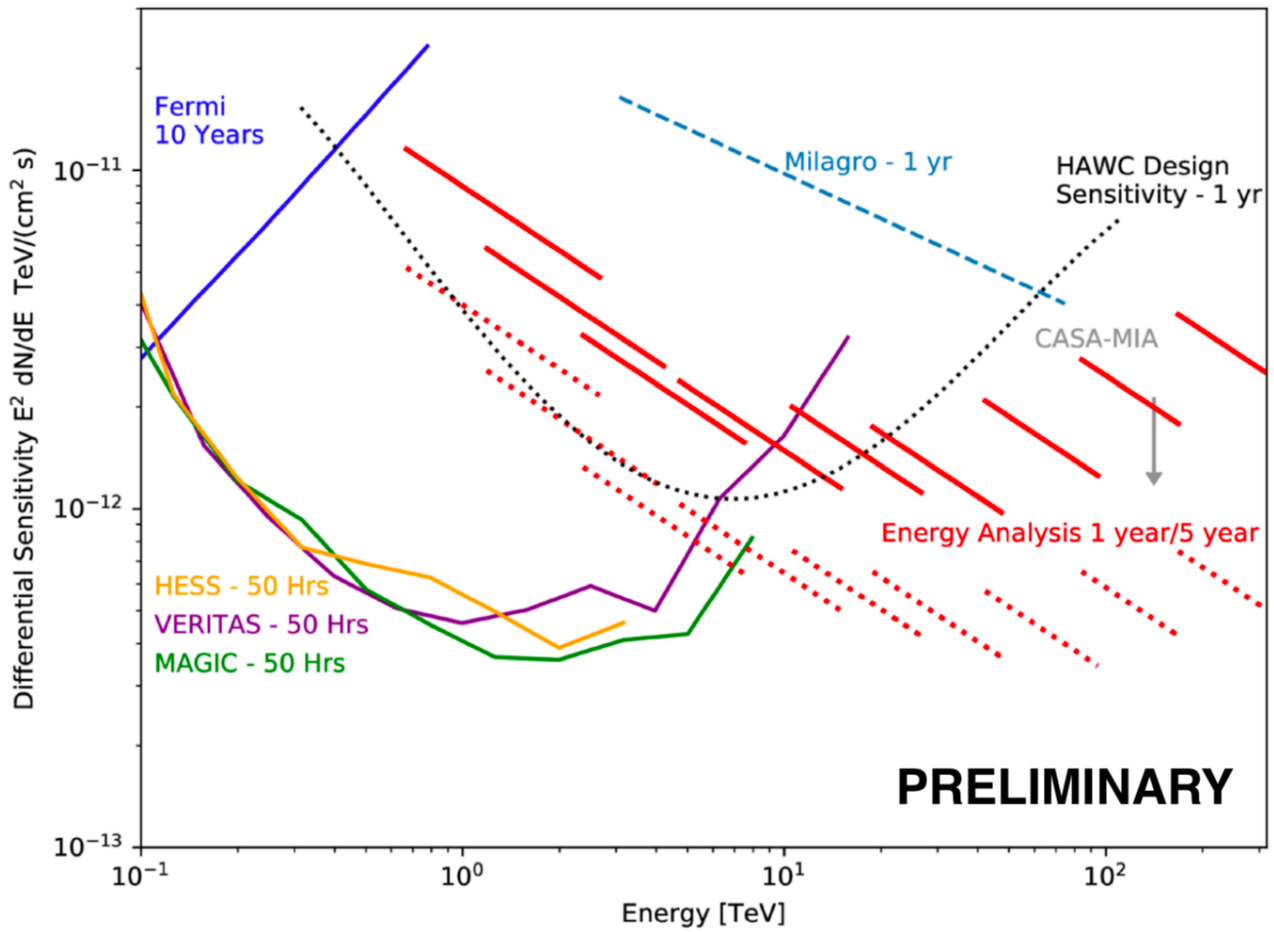


> 100 TeV



Sensitivity



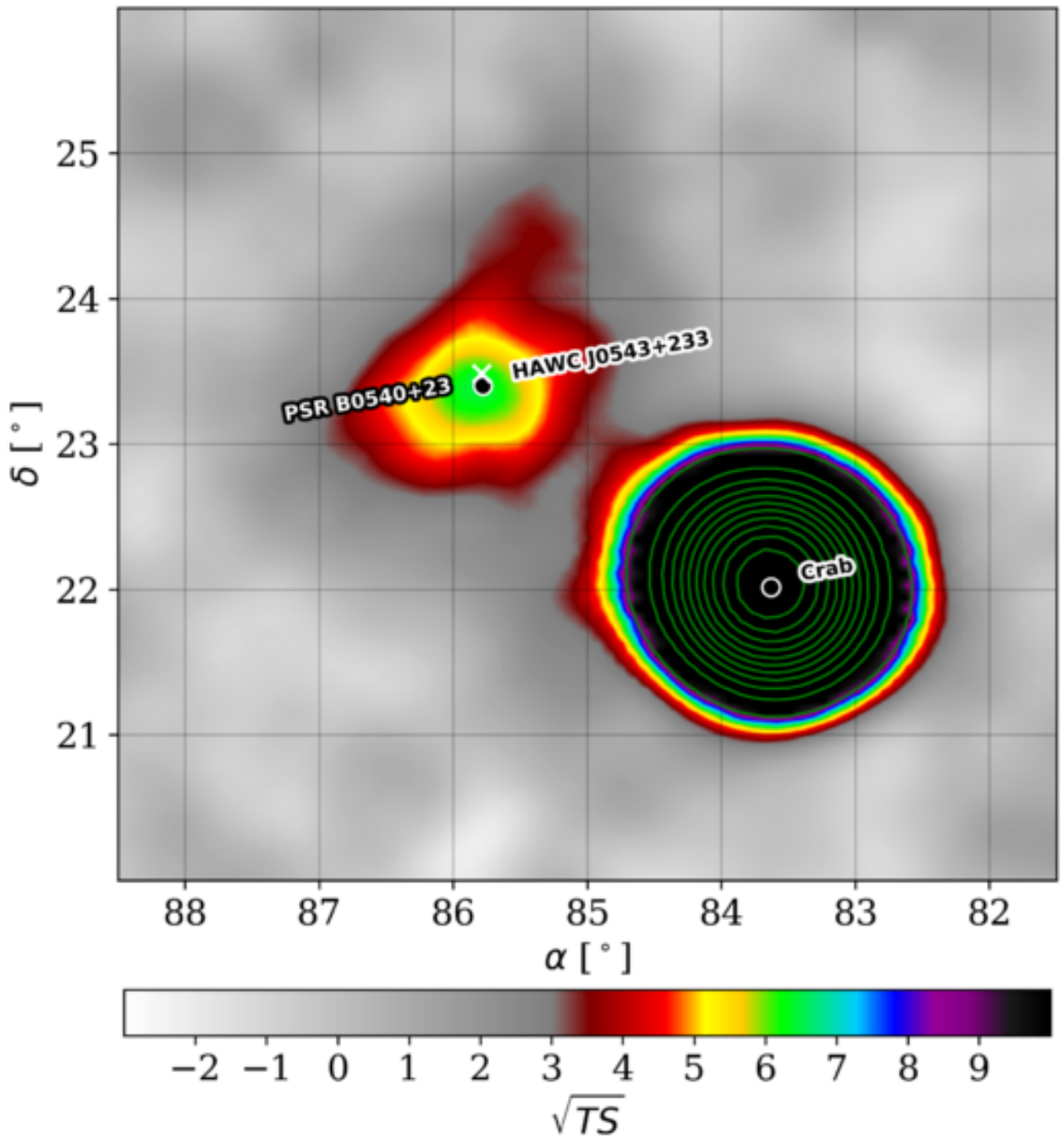


A. U. Abeysekara, *et al*, *ApJ*, **843**, 2017
`arXiv:1701.01778`

B0540: Hiding in plane sight

HAWC J0543+233:
- Found in extended source search
- Might be associated with *PSR B0540+23*:

-> Age: pulsar 253 kyr
-> Distance: 1.5 kpc
-> Edot = 4 $\times 10^{34}$ ergs s^{-1}



http://www.astronomerstelegram.org/?read=10941