High Energy Experiments in Astronomy

Multiple Galactic Sources

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TFPAC - MEFT

Cosmic-Rays

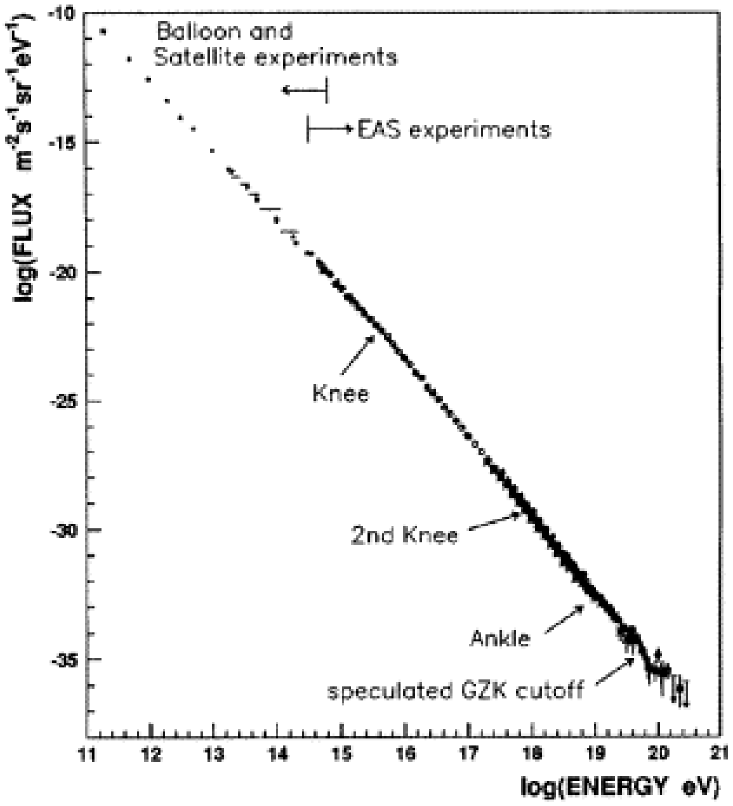
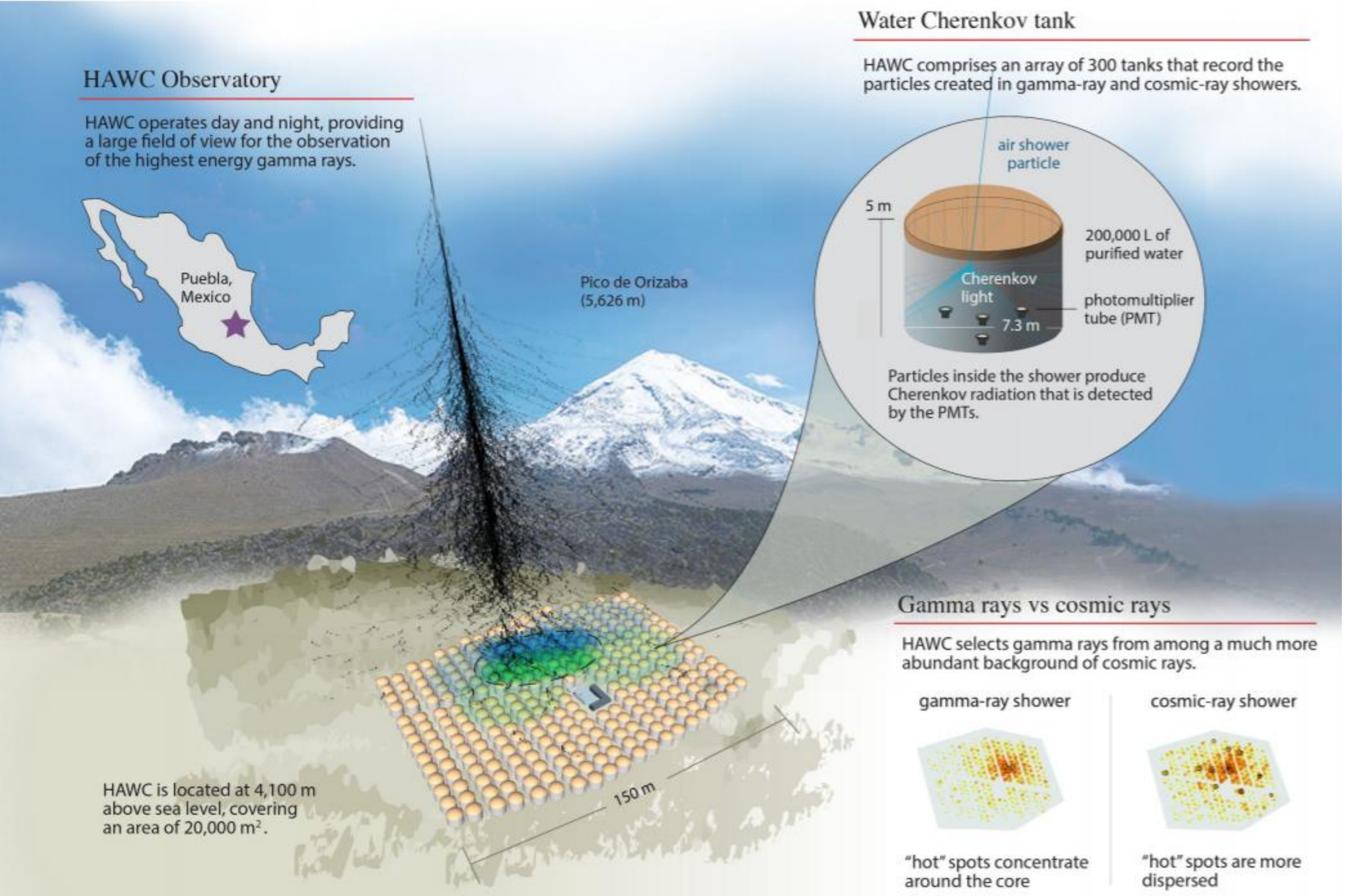
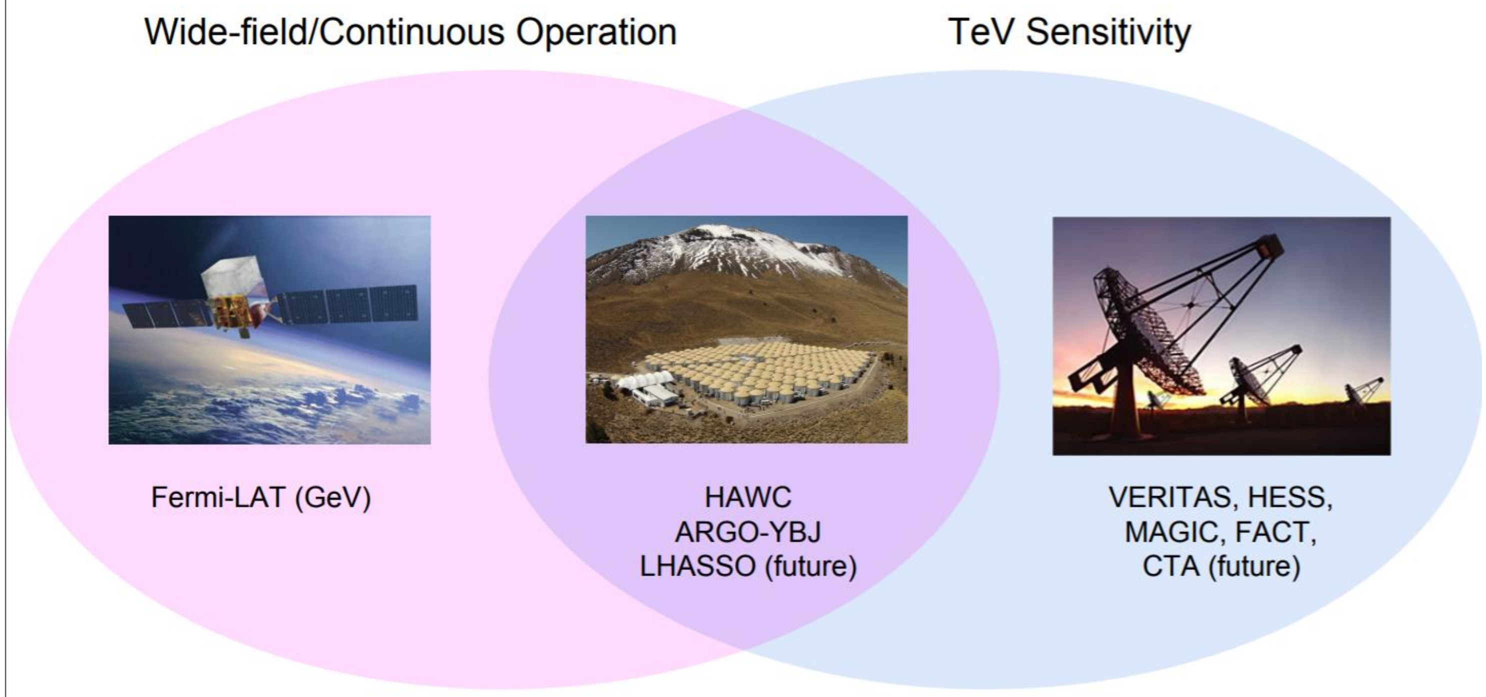


Fig. 1 - Example of all-particle energy spectrum of cosmic-ray

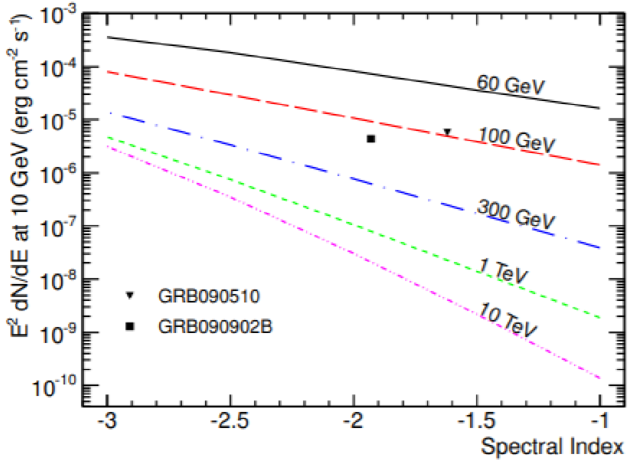
- MISTERIES OF COSMIC-RAYS
- The 'knee' in the spectrum, around 1 PeV
  - Sources of galactic origin
- 'Ankle' situated at around 3 EeV
  - Sources of extra-galactic origin
- Detection via balloons and space experiments only possible up to 10^{14} eV


HAWC Observatory
HAWC operates day and night, providing a large field of view for the observation of the highest energy gamma rays.
Puebla, Mexico
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.
air shower particle
5 m
200,000 L of purified water
Cherenkov light
photomultiplier tube (PMT)
7.3 m
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
cosmic-ray shower
"hot" spots concentrate around the core
"hot" spots are more dispersed

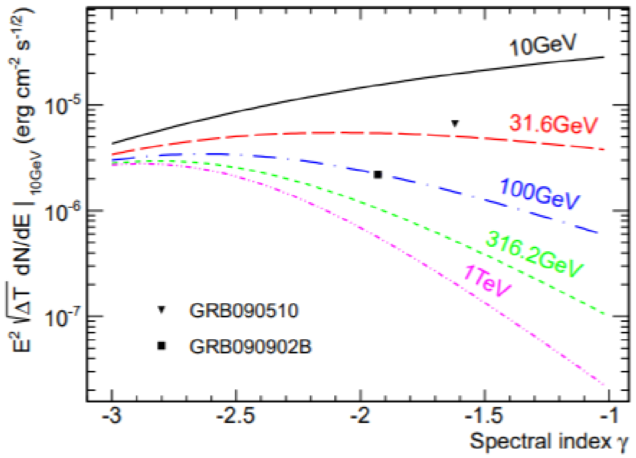
Detectors



	Cherenkov Telescope	Air Shower Array
Energy Threshold	Low (<200 GeV)	High (>10 TeV)
Background Rejection	Excellent (>99.7%)	Moderate (>50%)
Field of View	Small (<2°)	Large (>45°)
Duty Cycle (uptime)	Low (5-10 %)	High (>90%)



(a) Main DAQ



(b) Scaler DAQ

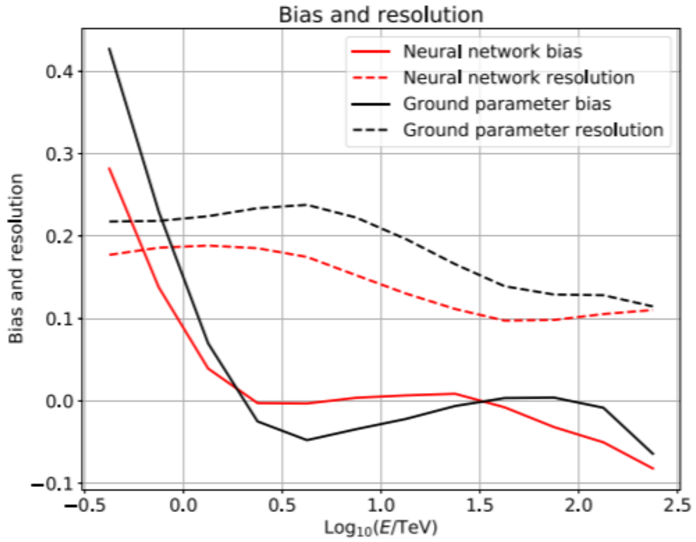
Fig. 2 – HAWC Sensitivity to Short GRBs.

Experimental Procedure

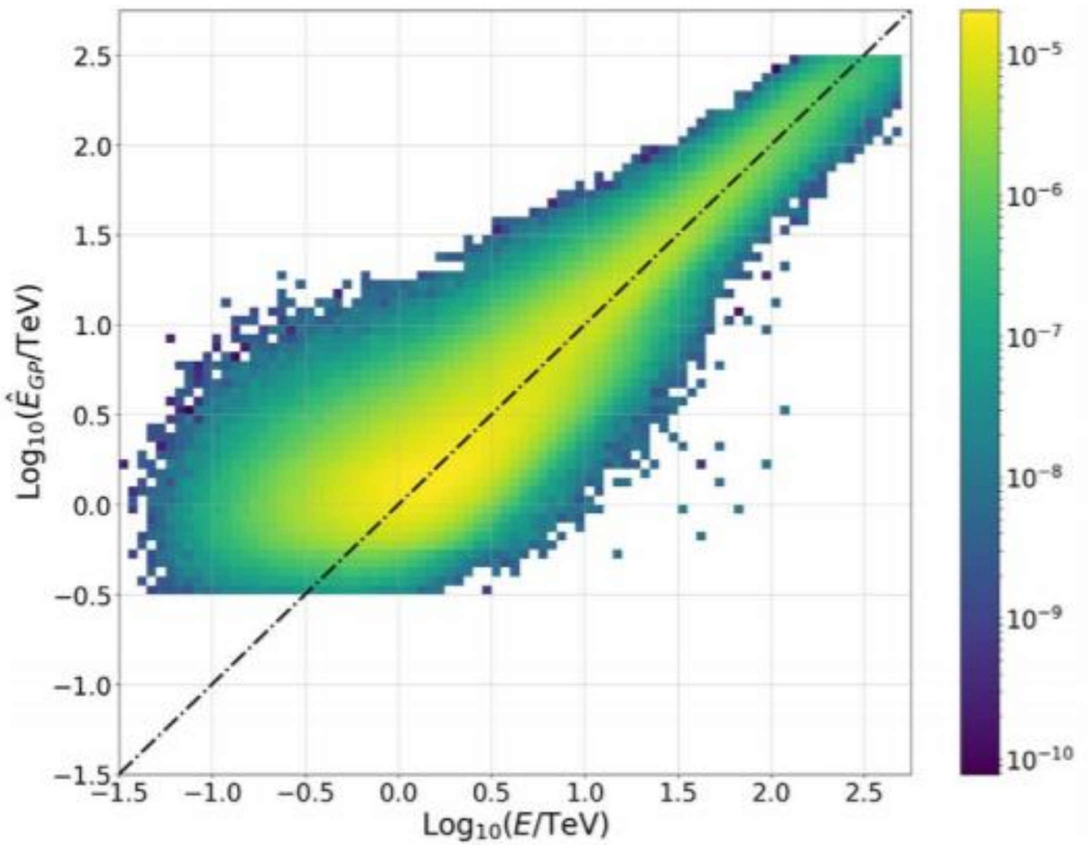
Ground Parameter Method v Neural Network Method

HAWC's Estimators Performance

- GP has a higher bias below 1 TeV
- HAWC has a higher sensitivity to TeV than GeV; the low bias does not affect the fit.
- GP method is more suitable because it has better performance for temperatures above 32 TeV.



Bias and resolution for both energy estimates in HAWC



Mixing Matrices for the GP

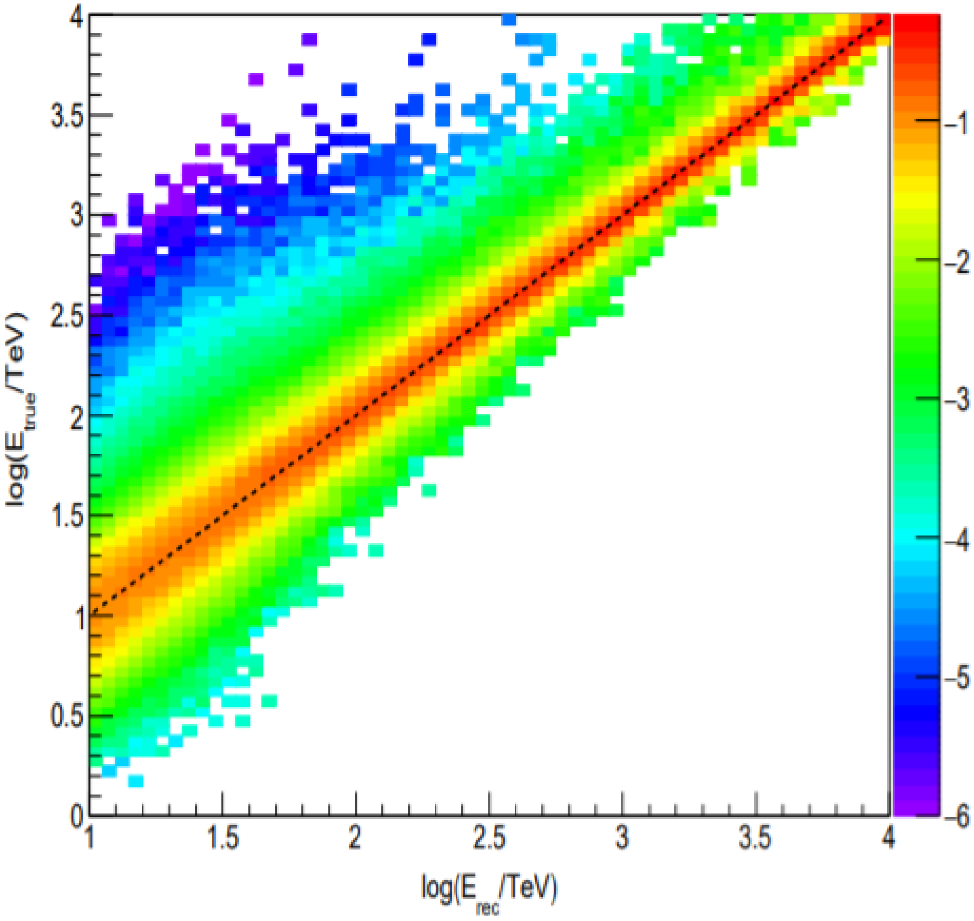
LHAASO Estimators Performance

The energy resolution is energy and zenith angle dependent.

Event-by-event comparison of the primary true energy and the reconstructed energy for simulated gamma-ray events over zenith angles 0º−50º.

The color represents the log probability density within each reconstructed energy E_{rec} bin.

In this work, the events with reconstructed energy above 10 TeV are divided into five bins per decade.



ANALYSIS METHOD

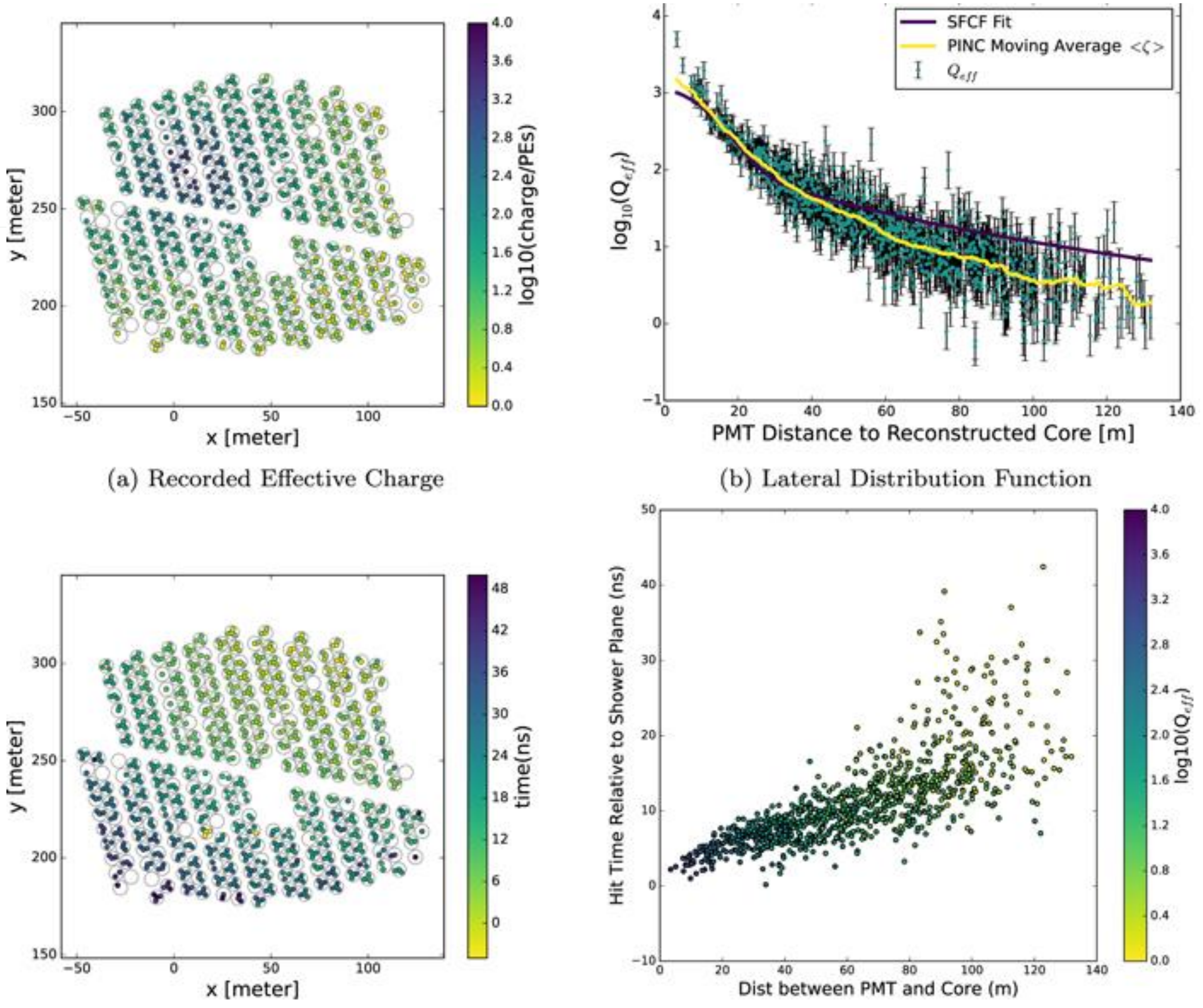
→ Reconstruction

  → **Core Reconstruction**

  → Direction Determination

→ Likelihood fit

→ Event's selection



(a) Recorded Effective Charge

(b) Lateral Distribution Function

(c) Recorded Time

(d) Shower Curvature/Sampling

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  - Core Reconstruction
  - **Direction Determination**
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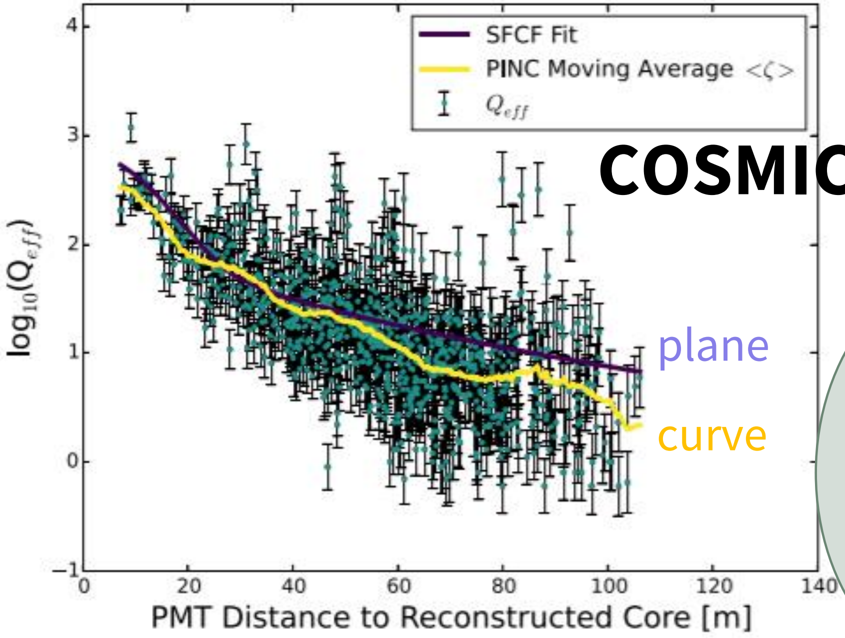
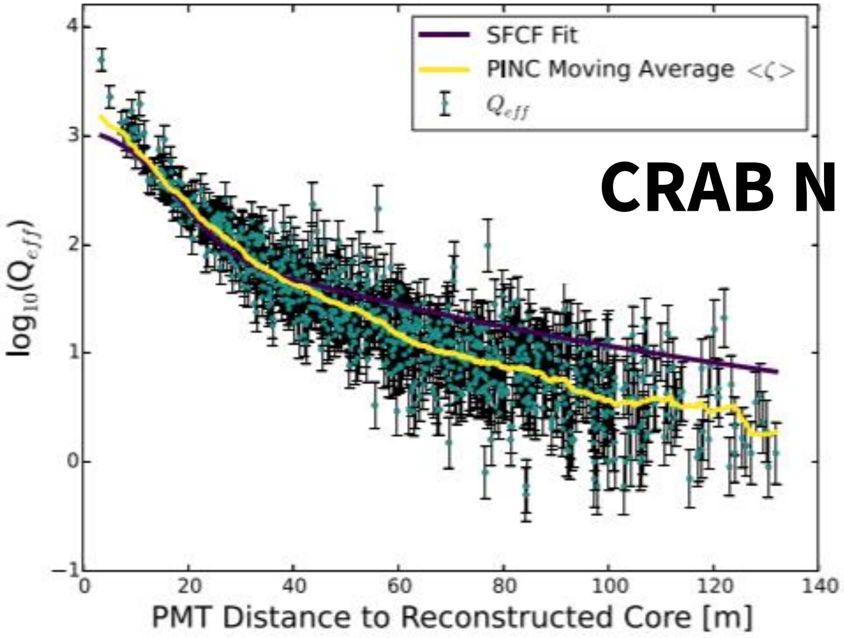


COSMIC RAYS

plane

curve

hadronic shower have sporadic high-charge hits



CRAB NEBULA

curved shape of the air shower

ANALYSIS METHOD

- Reconstruction
  - Core Reconstruction
  - Direction Determination
- **Likelihood fit**
- Event’s selection

The fit for sources like Crab Nebula Log parabola:

$$\frac{dN}{dE} = \phi_0 \left(\frac{E}{E_0}\right)^{-\alpha-\beta\, ln\left(\frac{E}{E_0}\right)}$$

Others were used the power-law with an exponential cutoff:

$$\frac{dN}{dE} = \phi_0 \left(\frac{E}{E_0}\right)^{-\alpha} exp\left(\frac{-E}{Ecut}\right)$$

The test statistc equation:

$$TS = 2\, ln\left(\frac{L_{s+b}}{L_b}\right)$$

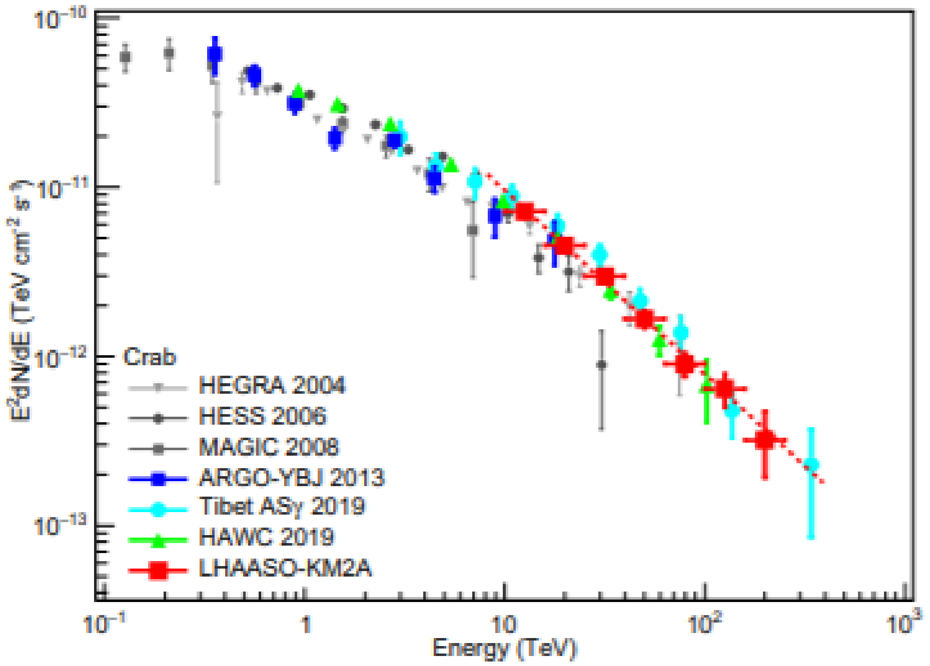
Results and Discussion

Observations of the Crab Nebula

Crab Nebula Spectrum Comparison

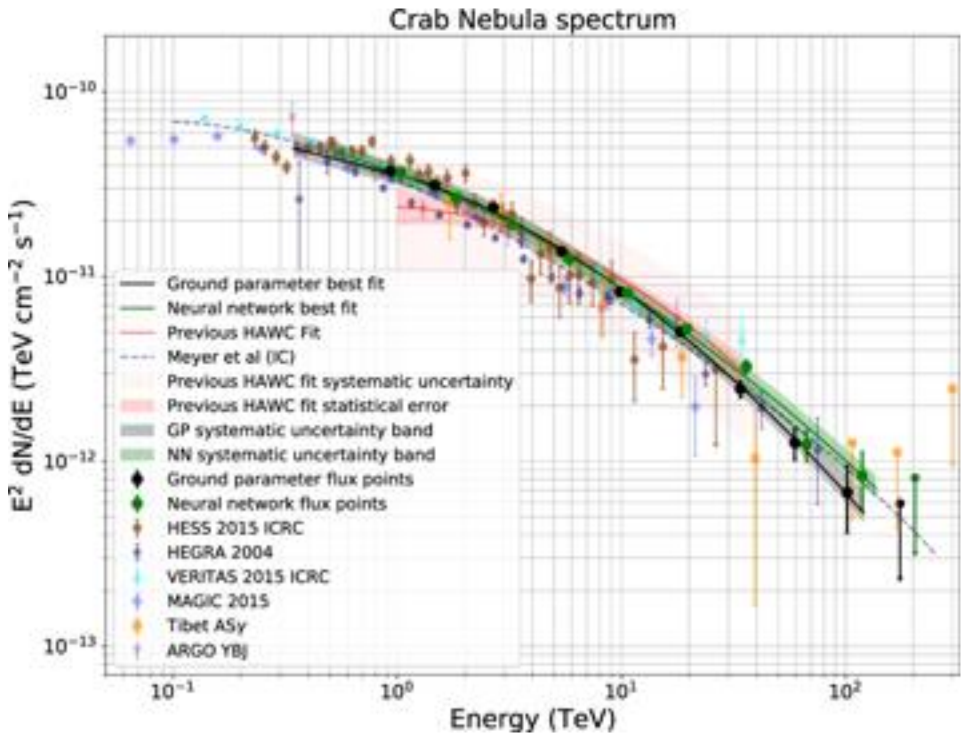
LHAASO

- The statistical significance of the gamma ray signal from Crab Nebula is 14.7 σ past 100 TeV.
- The spectrum from 10 TeV to 250 TeV is well fitted with a power-law function with a spectral index of 3.09



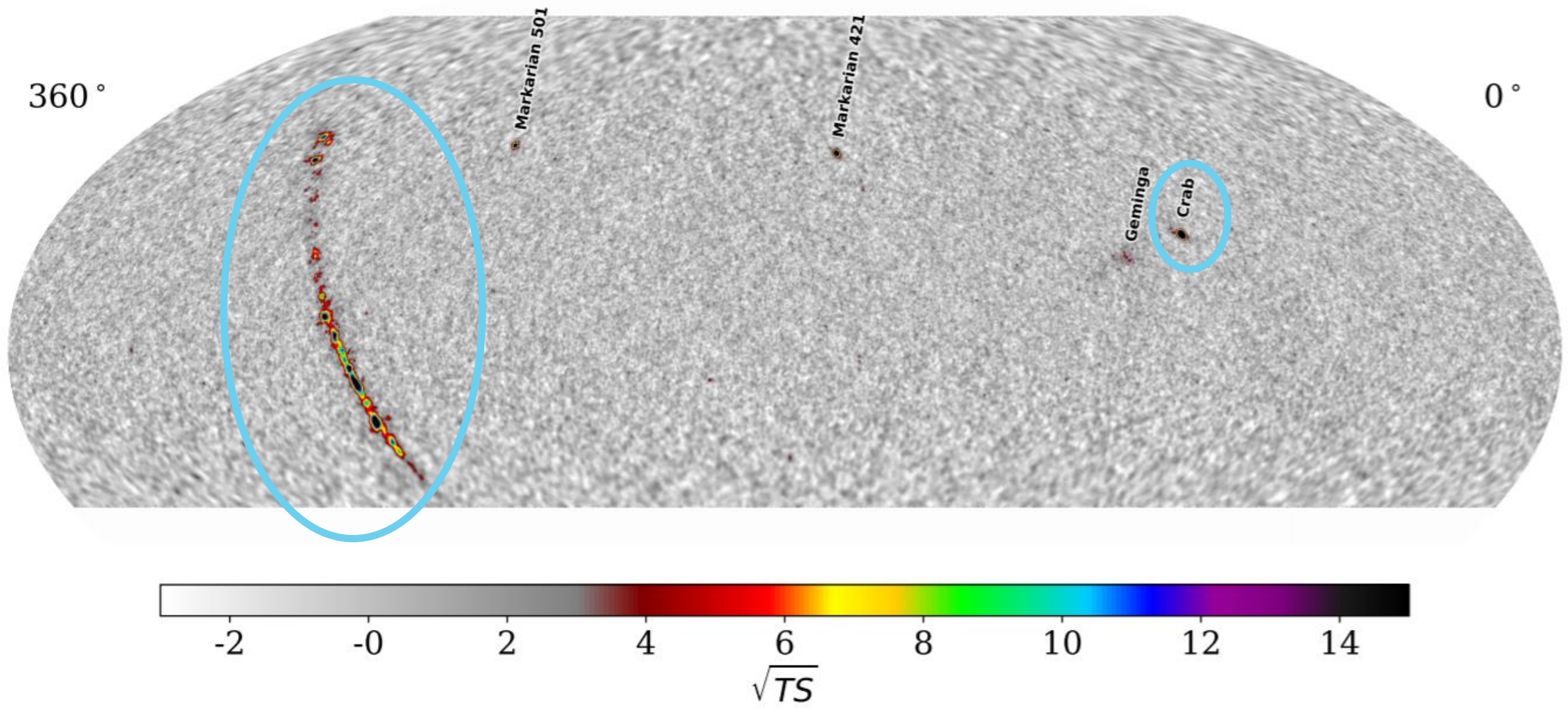
HAWC

- The statistical significance in the fit is above 2σ past 100 TeV
- To 100 TeV log-parabola fit is preferred over the cutoff
  - 0.2σ for the GP and 2.4σ for the NN
- Log-parabola fit is preferred over the log parabola convolved with a hard cutoff at 56 TeV
  - 5.12σ for the GP and 6.99σ for the

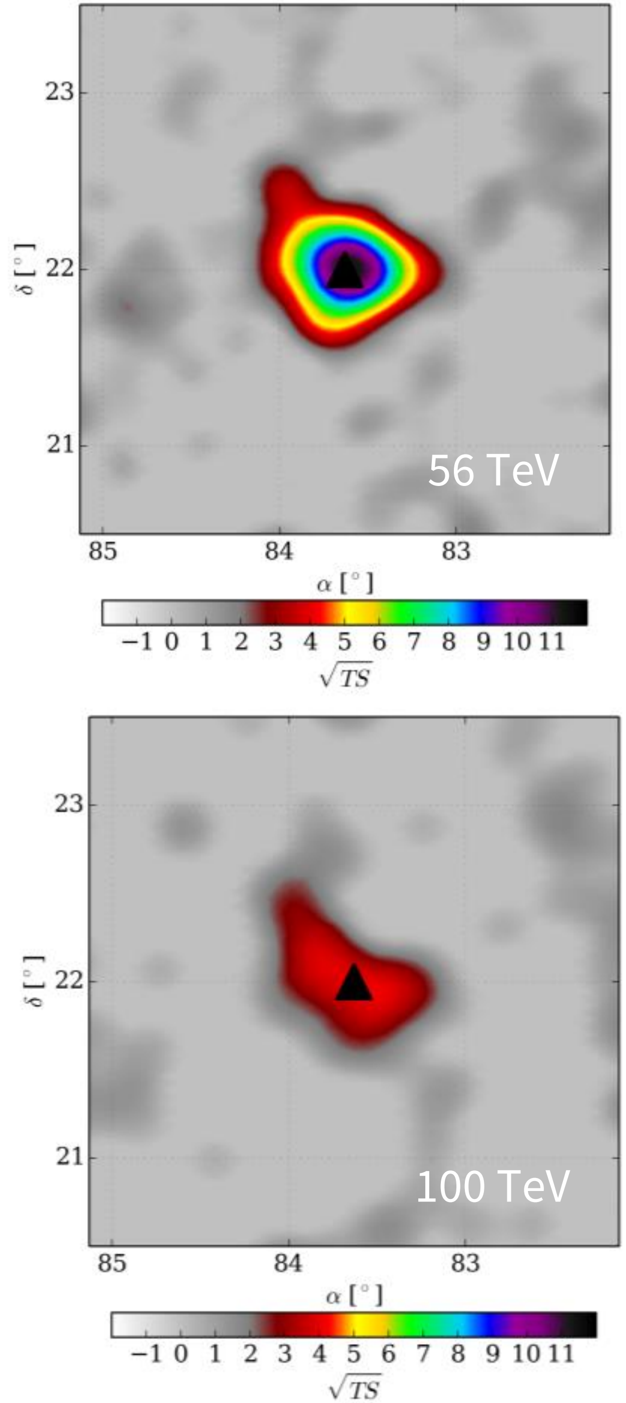


Maps

SUMMARY OF 2HWC CATALOG:

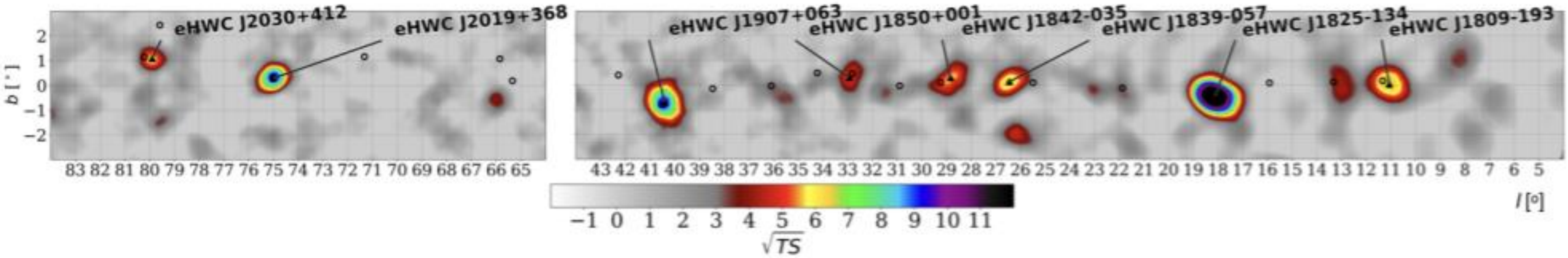


CRAB NEBULA :

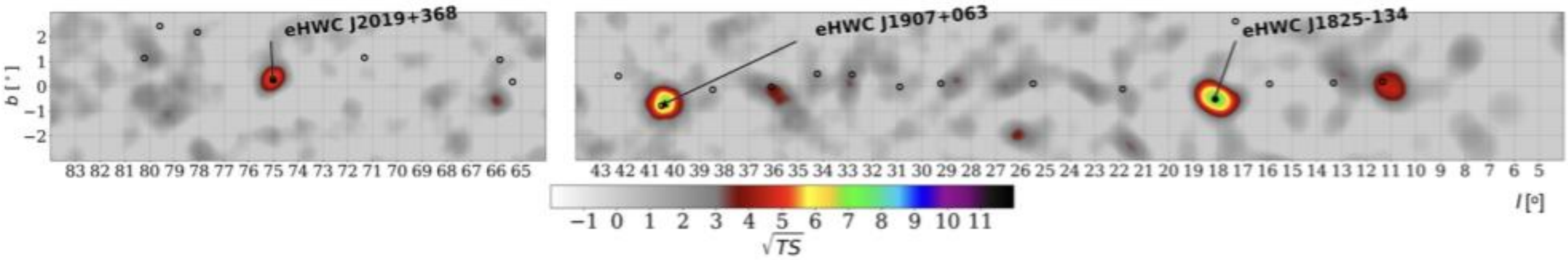


Maps in more detail:

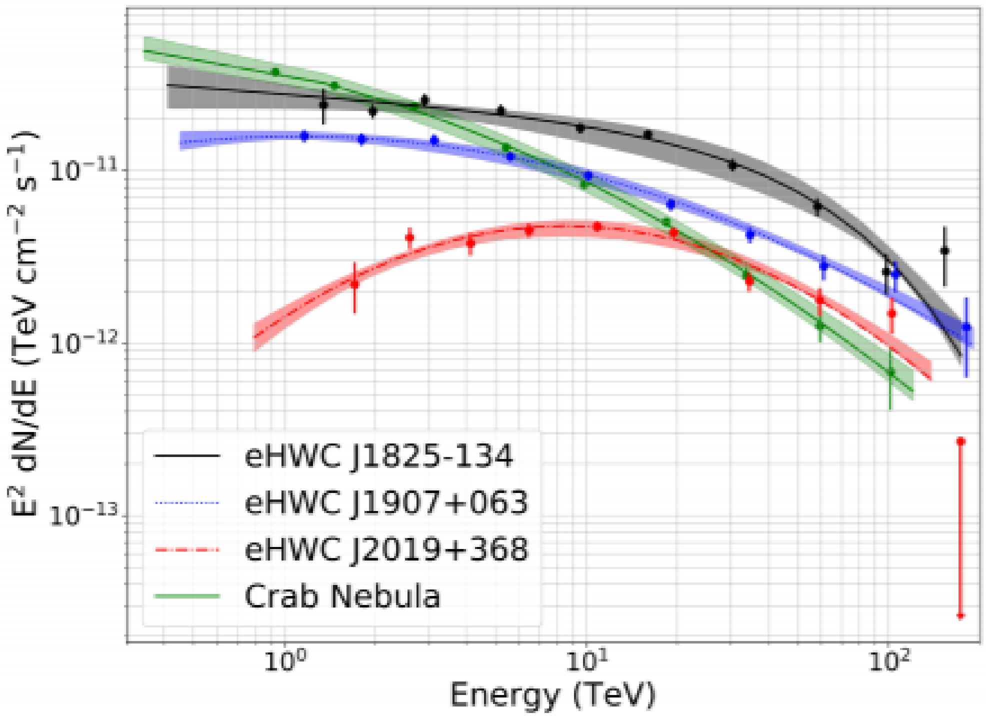
56 TeV



100 TeV



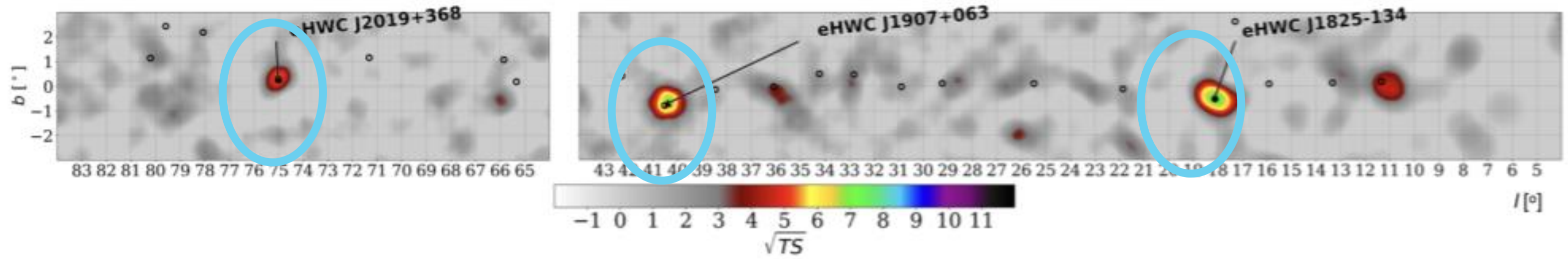
Other sources' spectra past 100 TeV



In one of the sources (eHWC J1825-134) power-law with an exponential cutoff; the other two sources are fit to a log-parabola

Note that in the spectrum of eHWC J1907+063 has a relatively hard spectral index and less curvature than other sources!

Also, in IACTs… but HAWC tends to measure higher fluxes.



Questions and discussion!

HAWC

Crab Nebula

Mechanisms?

What comes next?