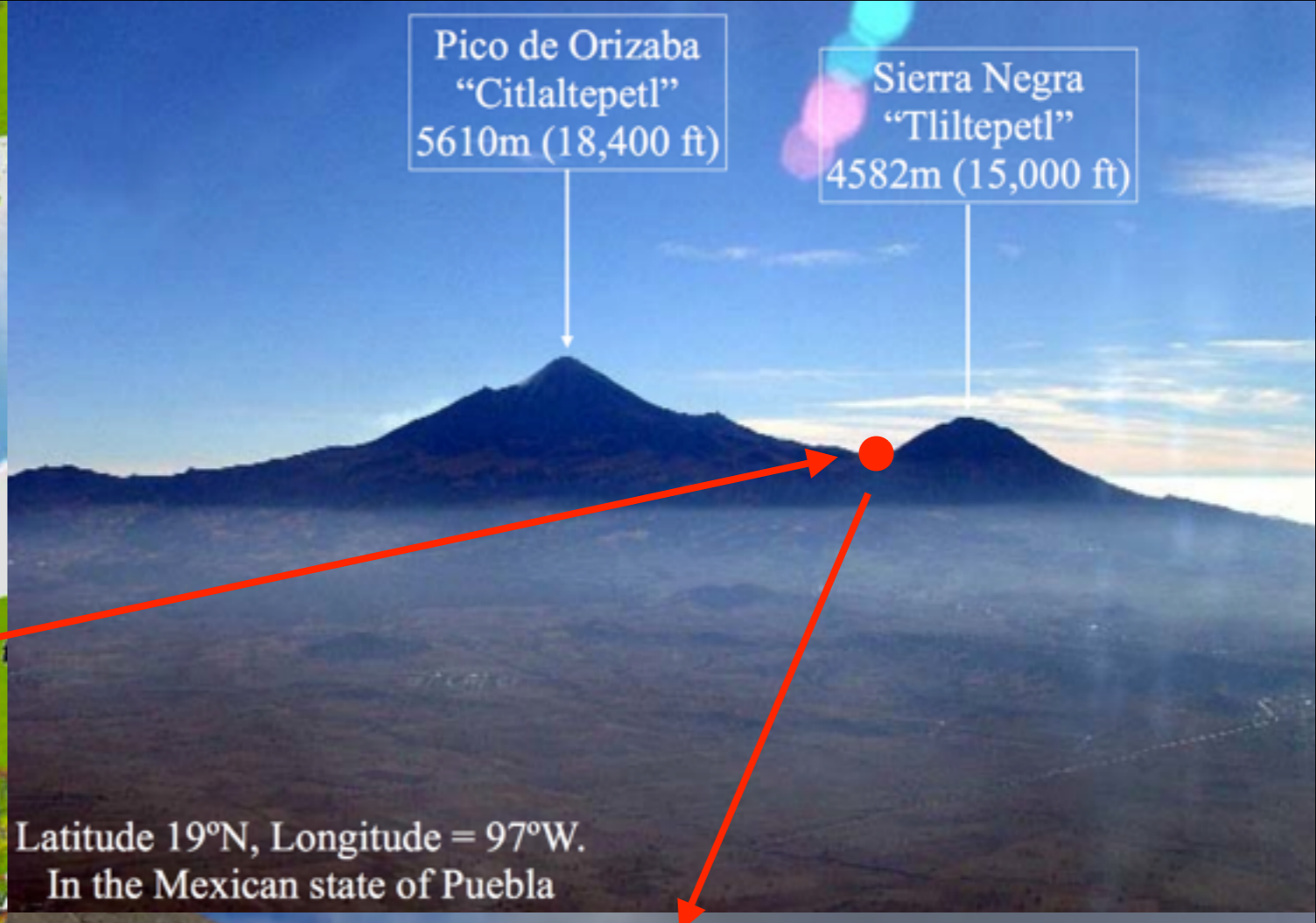


The Galactic TeV Gamma Ray Sky with the HAWC Observatory

Artist conception

Hao Zhou for the HAWC Collaboration
6th Fermi Symposium
Nov, 2015





19°N, 97°W, 4100 m a.s.l.

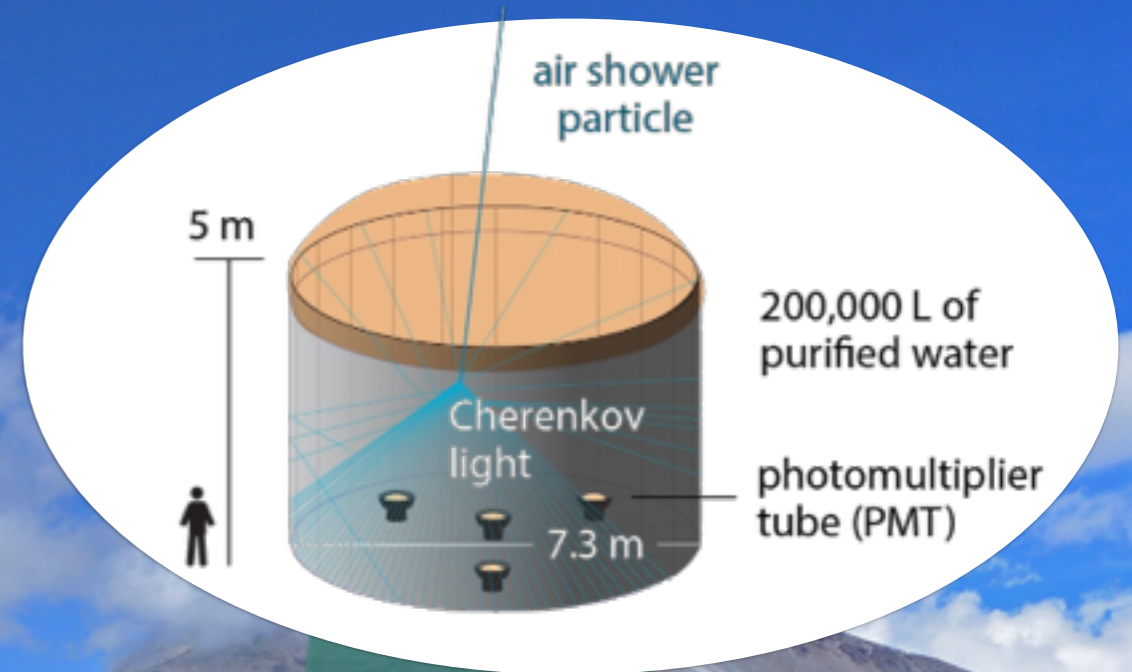


High Altitude Water Cherenkov



HAWC Design

- **100 GeV - 100 TeV** Sensitivity
- **300** Water Cherenkov Detectors
- **22,000 m²** detector area
- Average Angular Resolution (68% Cont.) **0.5°**
- Wide field of view: **~2 sr**
- High duty cycle: **>95%**

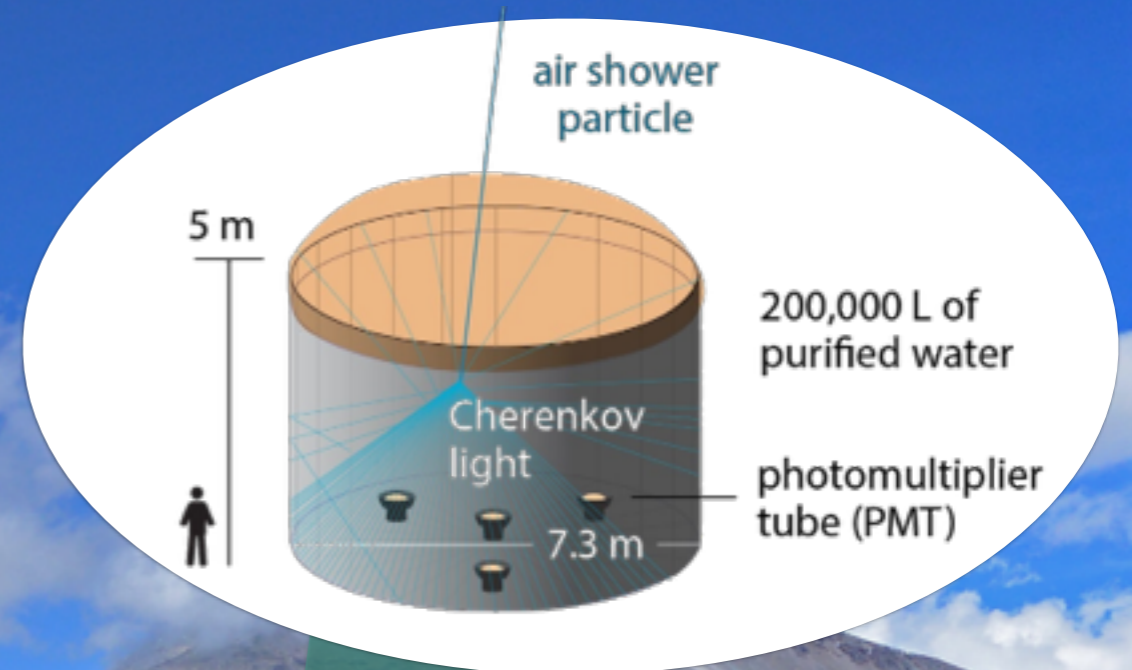


Strengths:

Unbiased sky survey
Extended/large structures

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Strengths:

Unbiased sky survey

- J. Wood: GRB results (S.5, Tue)
- A. Abeysekara: Blind Source Search (S.11A, Thu)

Extended/large structures

- H. Ayala: Fermi Bubble Results (S.16A, Thu)



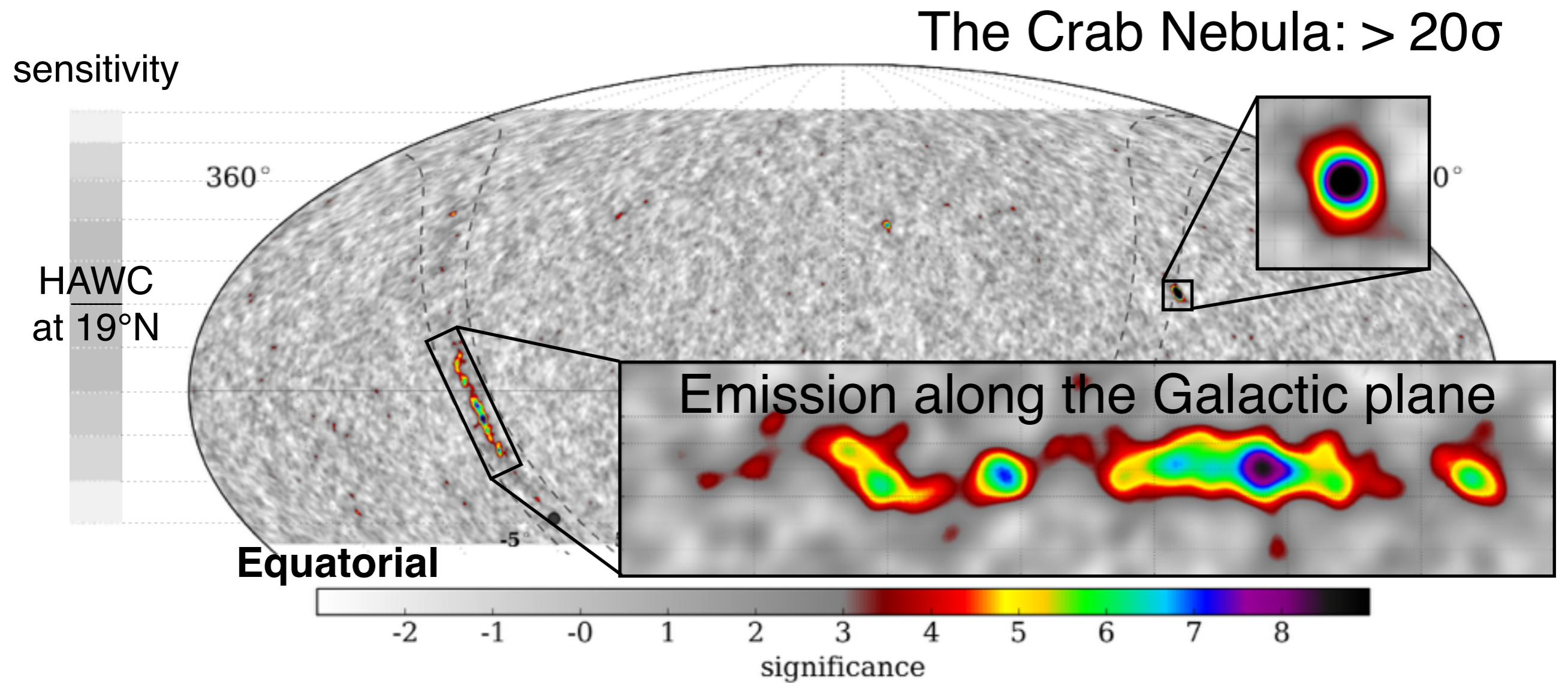
HAWC Pass 1 Data

Partial Array: 108 to 134 tanks
Duration: August 2, 2013 - July 9, 2014 (283 days)
Paper: Searching Galactic Sources

HAWC-111

October 2013

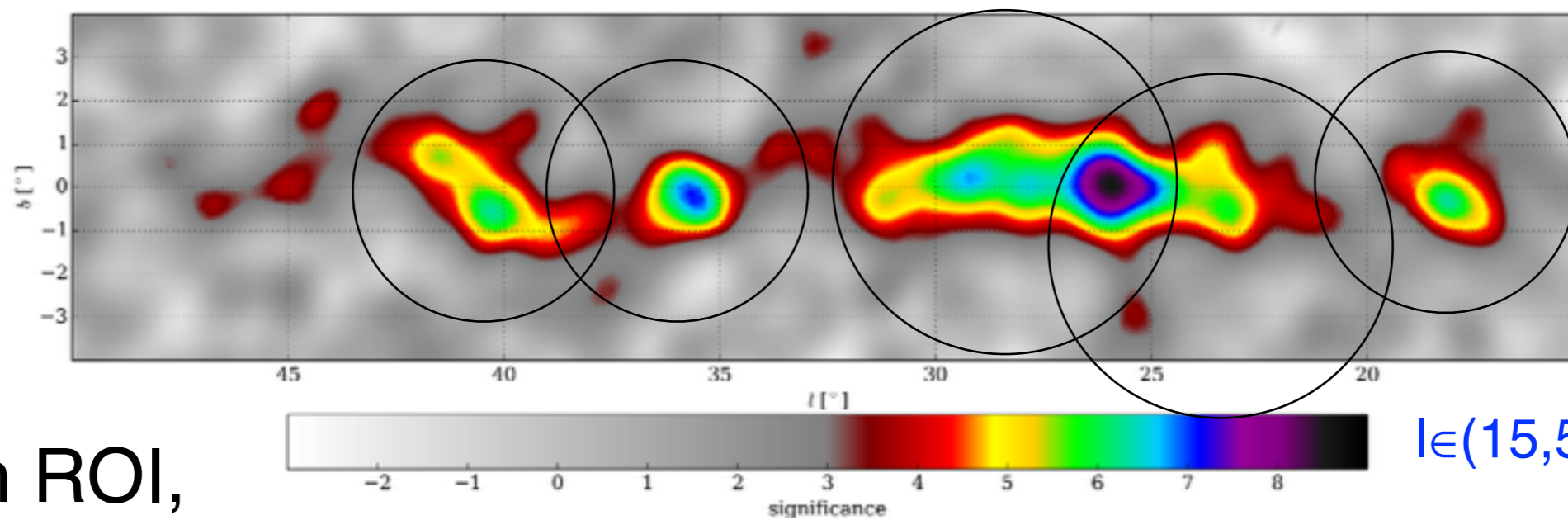
HAWC Pass 1 283-Day TeV Sky



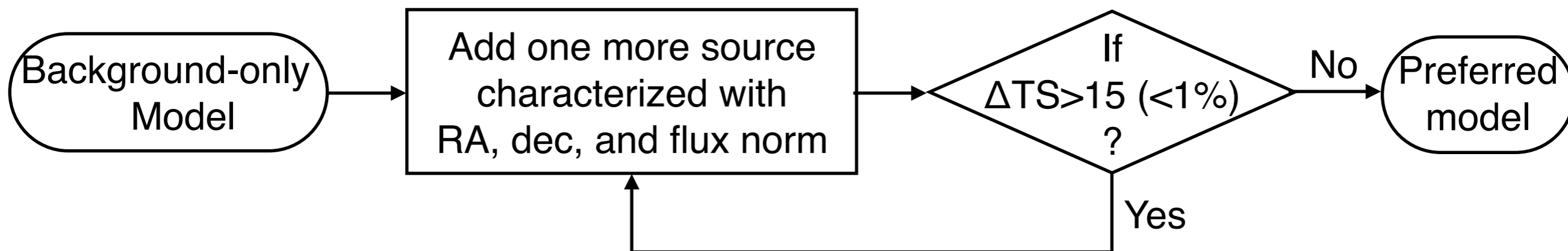
HAWC Pass 1 Galactic Plane Survey

For the analysis of this dataset using **maximum Likelihood method**,

- all sources are considered as **point sources**;
- the spectral index is **fixed at 2.3**.

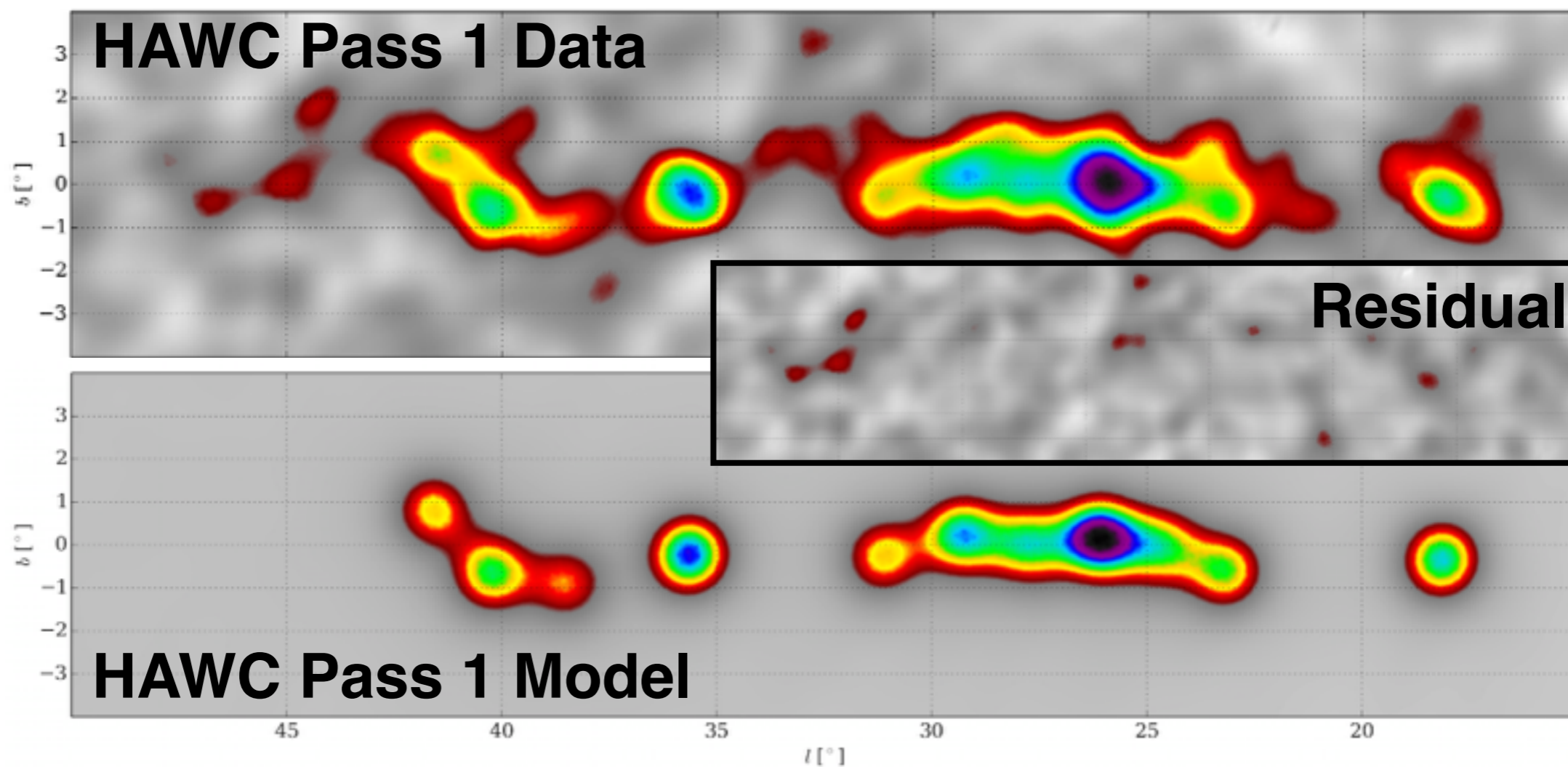


In each ROI,



HAWC Pass 1 Galactic Plane Survey

Paper submitted (arXiv:1509.05401)



- **Ten** sources/candidates are $>3\sigma$ post-trials.
- **Three** firm detections and **seven** candidates;

HAWC Pass 1 Galactic Plane Survey

Table 5. Possible TeV Gamma-Ray Source Counterparts

Source	Possible Counterpart	Counterpart Classification	Distance to Counterpart (°)	Published Angular Extent (°)	Extrapolated Published Flux	Flux Normalization ^a	Pivot Energy (TeV)
1HWC J1907+062c	MGRO J1908+06	UID	0.38	< 2.6	36	22.0±4.6	4
	HESS J1908+063	UID	0.19	$0.34^{+0.04}_{-0.03}$	22.5		
	MGRO J1908+06 (ARGO)	UID	0.29	0.49 ± 0.22	61		
	MGRO J1908+06 (VERITAS)	UID	0.04	0.44 ± 0.02	20.0		
1HWC J1857+023	HESS J1857+026	UID	0.37	$(0.11 \pm 0.08) \times (0.08 \pm 0.03)$	13.0	18.0±3.0	5
	MAGIC J1857.2+0263	PWN	0.33	$(0.17 \pm 0.03) \times (0.06 \pm 0.03)$	16.6		
	HESS J1858+020	UID	0.35	$(0.08 \pm 0.02) \times (0.02 \pm 0.04)$	1.8		
1HWC J1838-060	HESS J1841-055 (ARGO)	UID	0.16	$0.40^{+0.32}_{-0.22}$	41	11.3±1.2	7
	HESS J1841-055	UID	0.77	$(0.41 \pm 0.04) \times (0.25 \pm 0.02)$	11.7		25
	HESS J1837-069	PWN	0.97	$(0.12 \pm 0.02) \times (0.05 \pm 0.02)$	6.1		
1HWC J1844-031c	HESS J1843-033	UID	0.32	extended	N/A	11.8±2.4	6
	HESS J1846-029	PWN	0.61	point-like	1.1		
	ARGO J1841-0332	UID	0.87	point-like	N/A		
1HWC J1849-017c	HESS J1848-018	MSC ^b	0.20	0.32 ± 0.02	2.5	9.1±2.2	6
1HWC J1836-090c	HESS J1834-087	UID	0.31	point-like+ (0.17 ± 0.01)	1.0	5.8±1.3	8
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1HWC J1836-074c	HESS J1837-069	PWN	0.55	$(0.12 \pm 0.02) \times (0.05 \pm 0.02)$	6.1	6.9±1.4	7
1HWC J1825-133	HESS J1825-137	PWN	0.55	$(0.23 \pm 0.02) \times (0.26 \pm 0.02)$	10.6	7.3±1.4	9

- **Eight** of them are likely associated with known **TeV** sources;
- **Five** of them have possible counterparts in **2FHL**

HAWC Pass 1 Galactic Plane Survey

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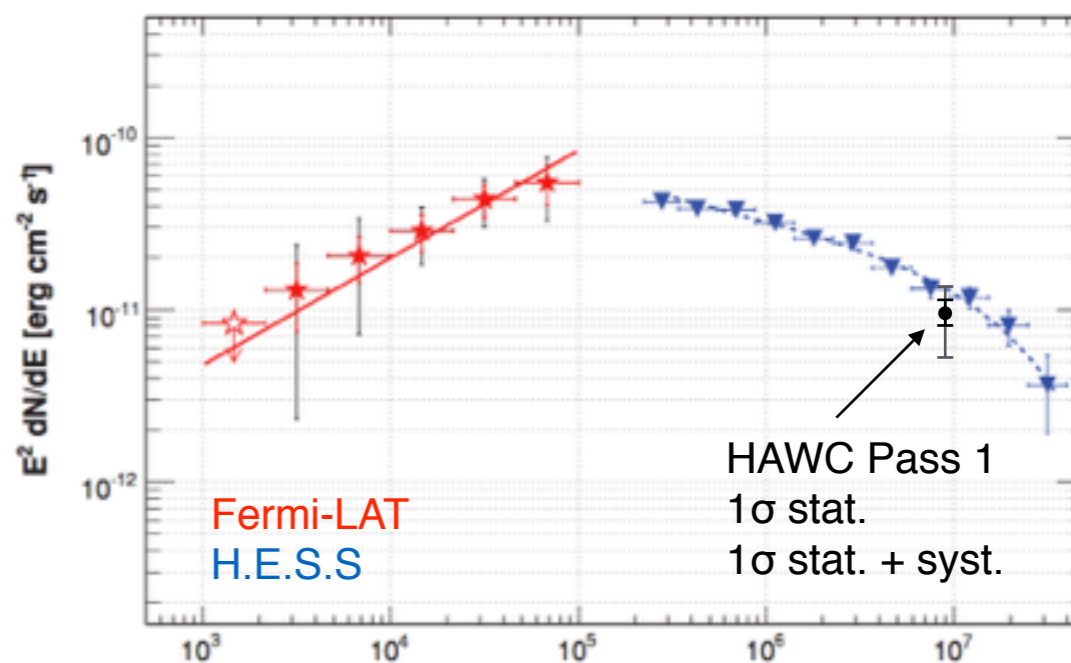
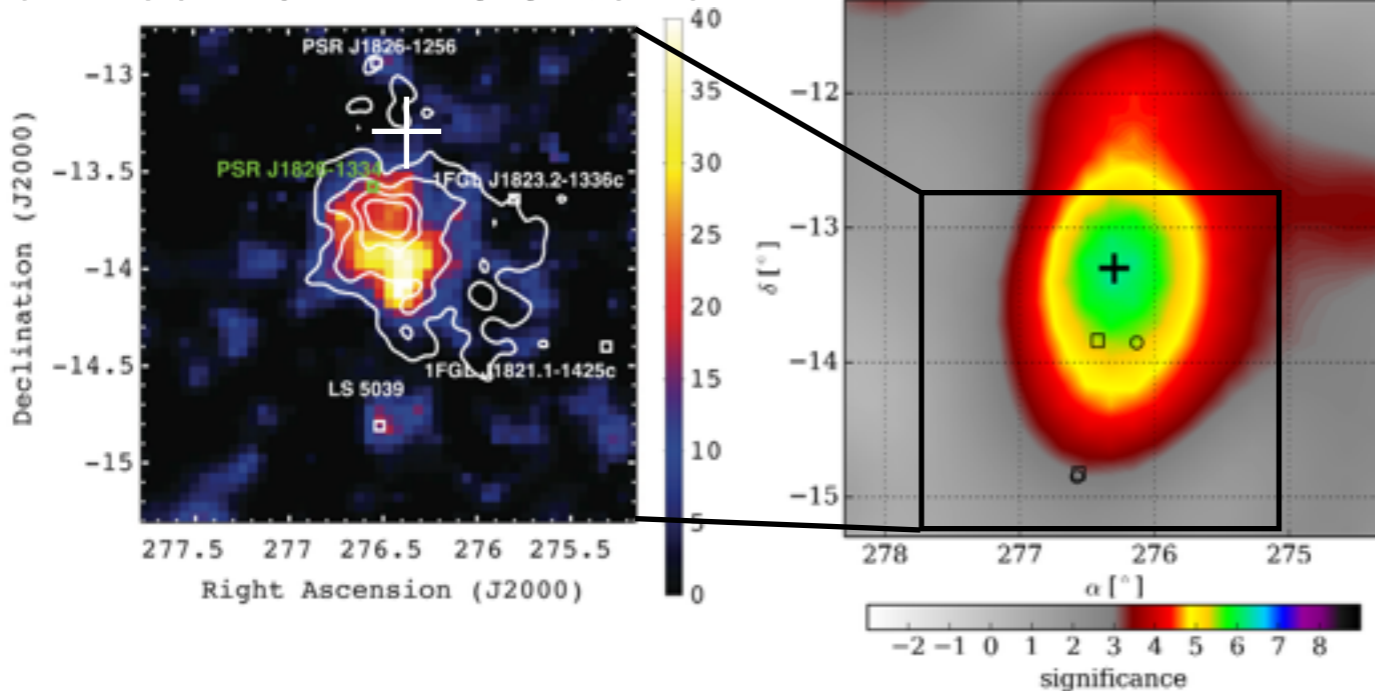
- **Eight** of them are likely associated with known **TeV** sources;
- **Five** of them have possible counterparts in **2FHL**

1HWC J1825-133

Fermi Counts + H.E.S.S. contour

HAWC Pass 1

ApJ 738:42 (2011)



ApJ 738:42 (2011)

- 2FHL J1824.5-1350e
 - extent ($> 50\text{GeV}$): 0.75°
- HESS J1825-137
 - spectral softening as a function of radius
- Pulsar Wind Nebula

- 1HWC J1825-133 (5.4σ post-trial)
 - $276.3 \pm 0.1, -13.3 \pm 0.2$
 - Compatible flux at 9 TeV



HAWC-250 Data

Quasi-full Array: 247 to 293 tanks
Duration: Nov 26, 2014 - May 6, 2015 (150 days)
Preliminary: Geminga

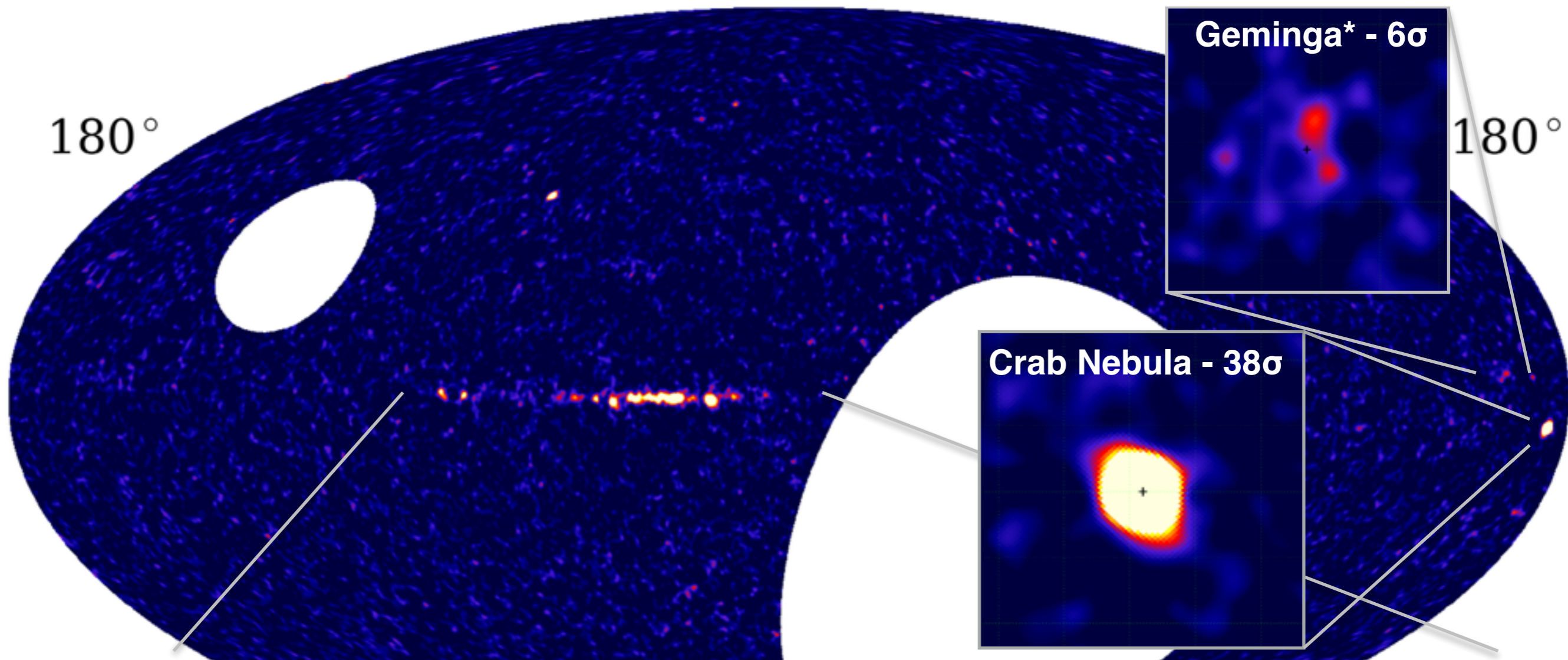
HAWC-250

- March 20 2015:**
- HAWC inauguration
 - Full operation began



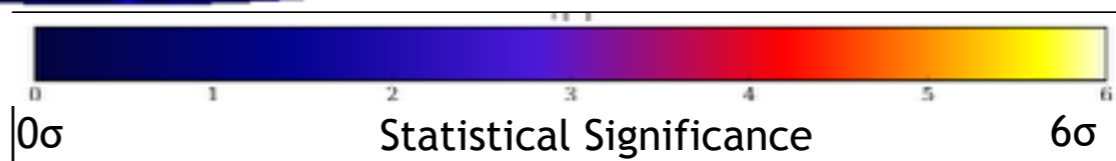
HAWC-250 150-Day TeV Sky

38 σ Crab



Galactic Plane

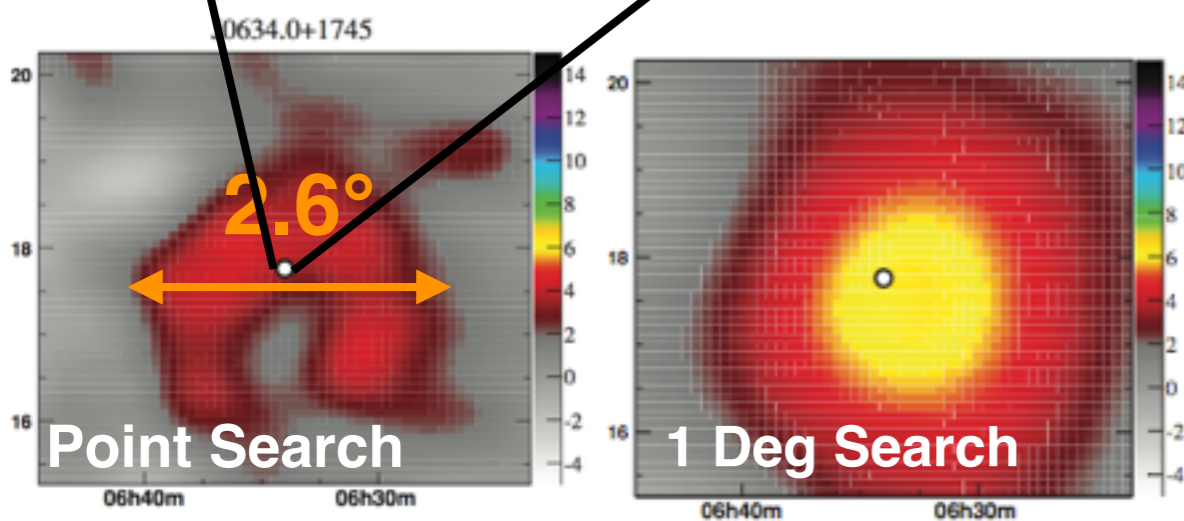
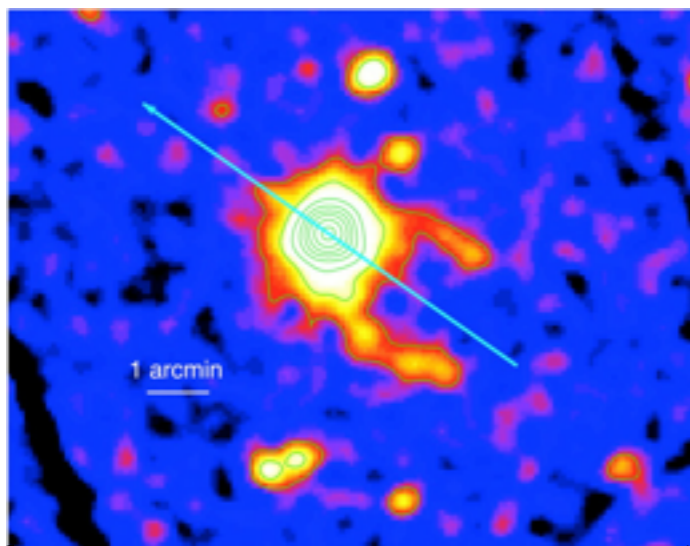
Galactic



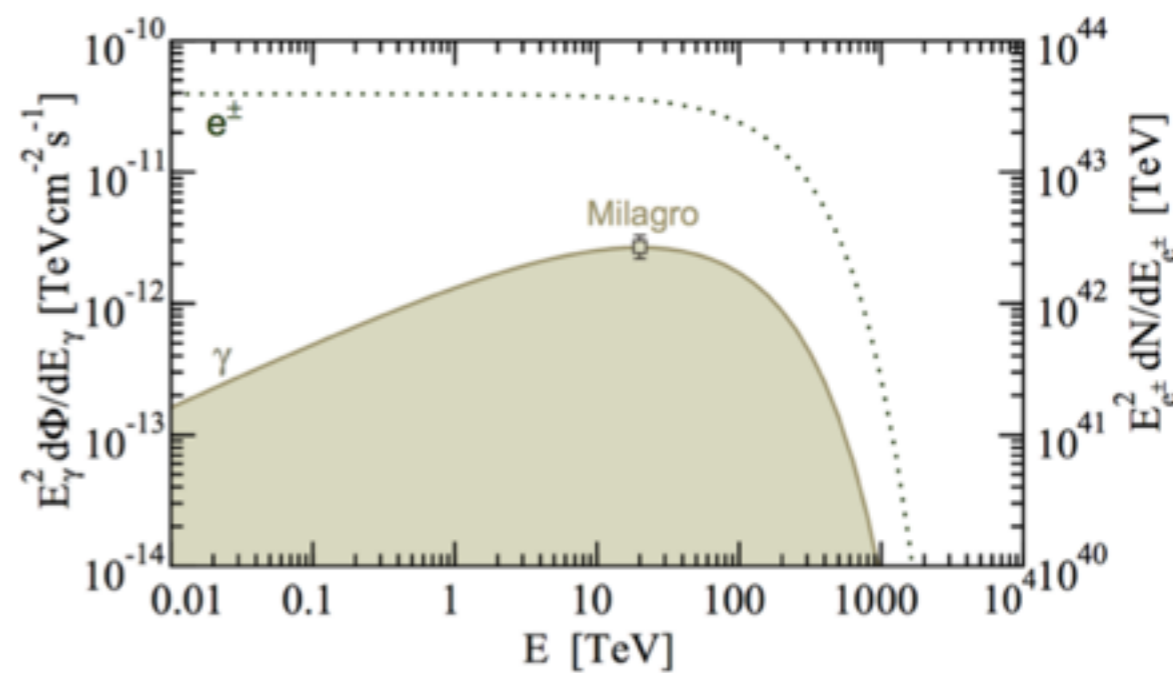
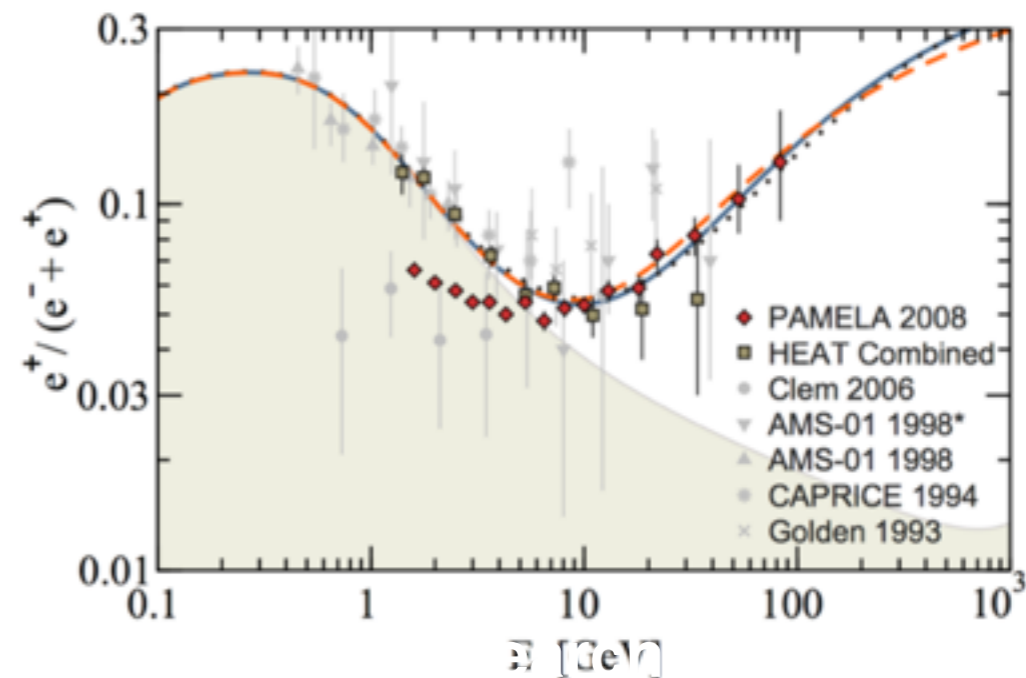
Extended Source: Geminga

A nearly particle accelerator,
Contributor to the positron excess?

X-ray: XMM-Newton



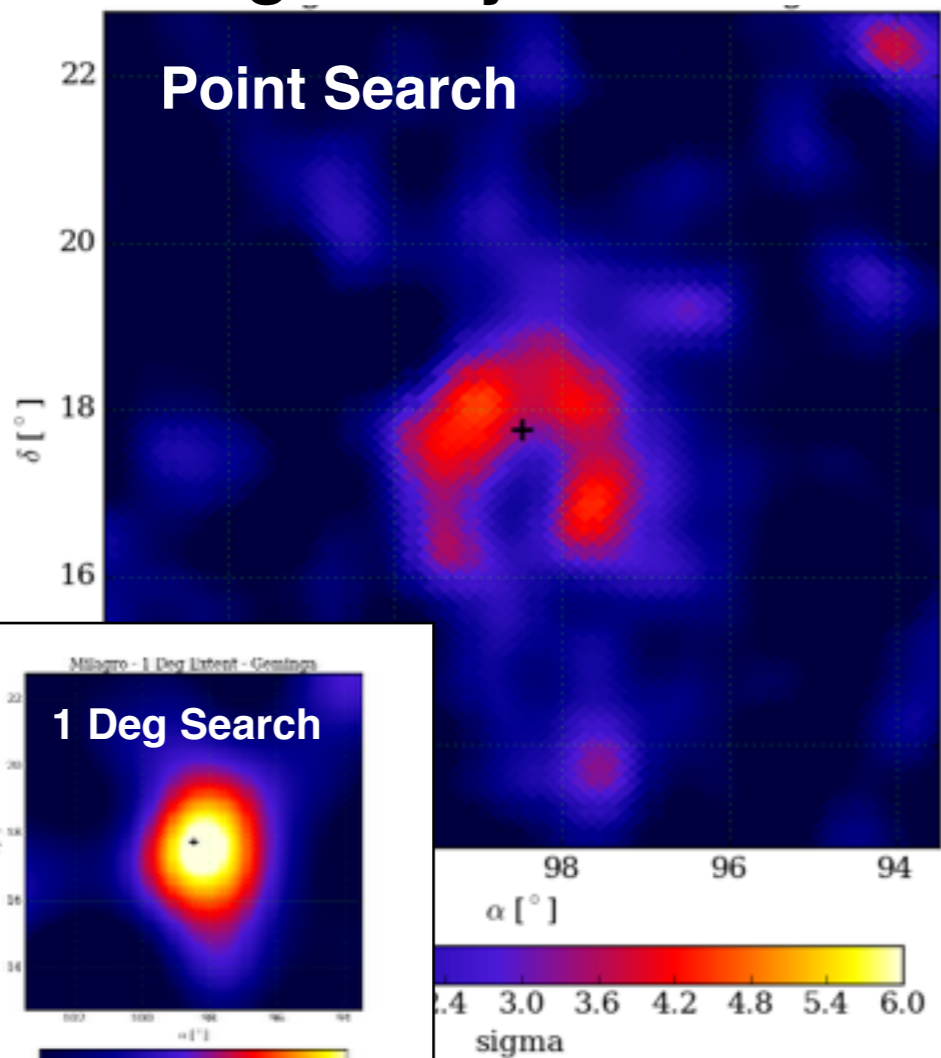
TeV: Milagro



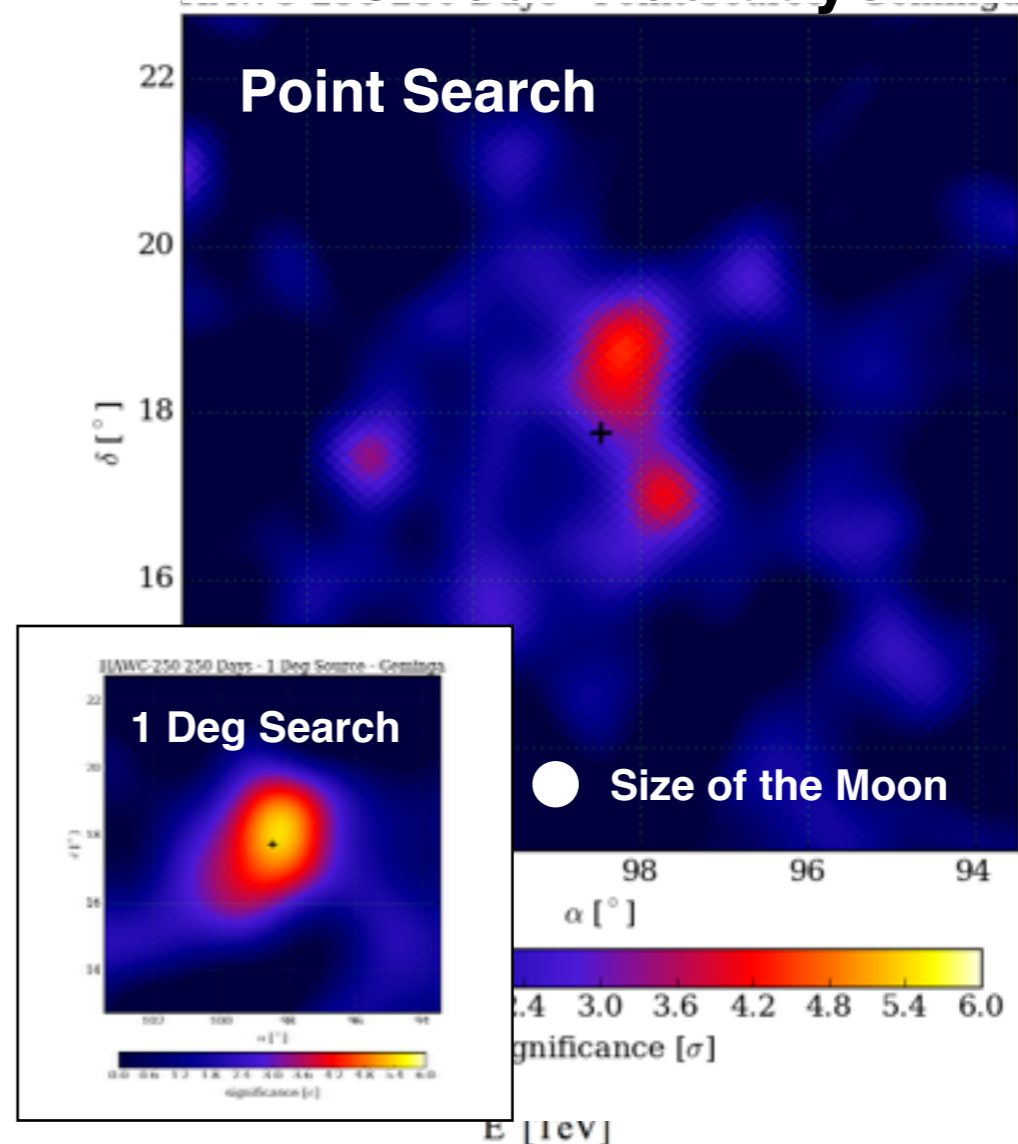
Extended Source: Geminga

A nearly particle accelerator,
Contributor to the positron excess?

Milagro - 8 years



HAWC 250 - 150 days



Yuksel, Kistler & Stanev. PRL. (2009).

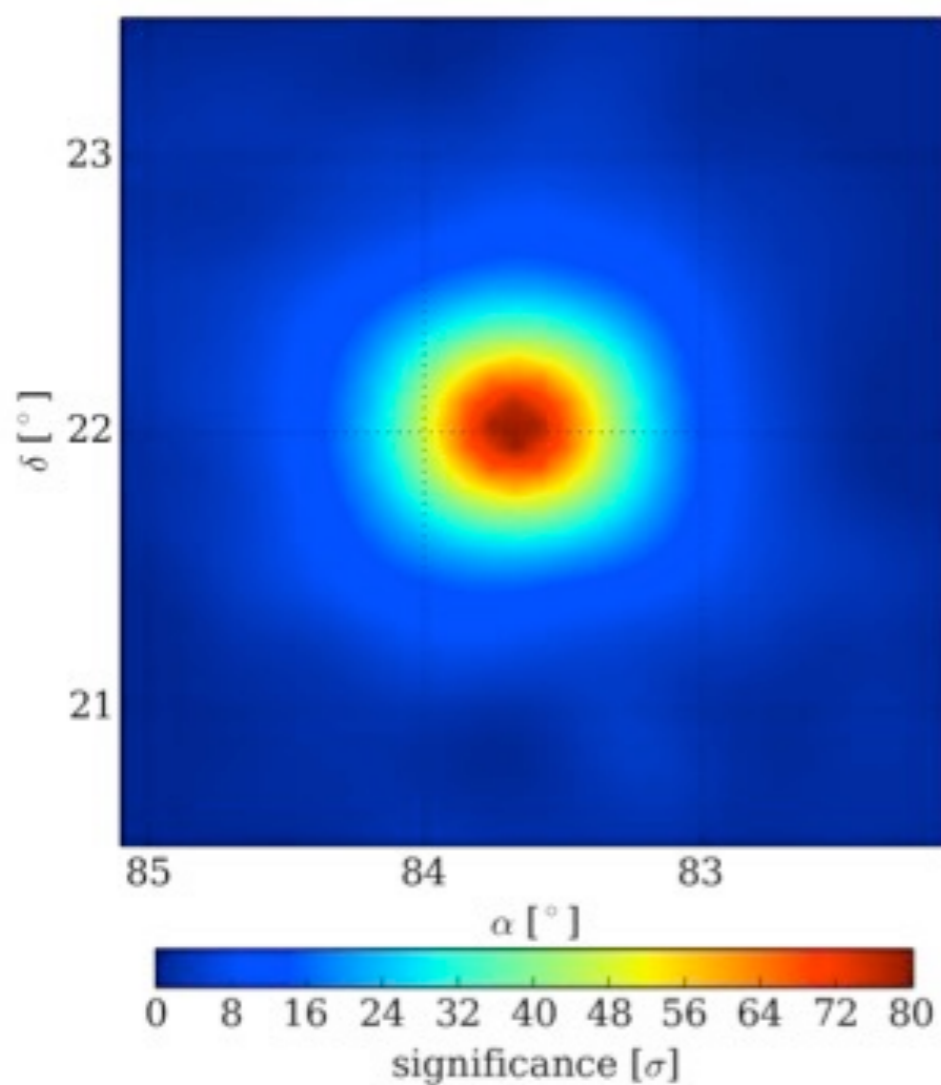
Appears very large (3°)*
Spatial and spectral analysis in progress.

***PRELIMINARY**

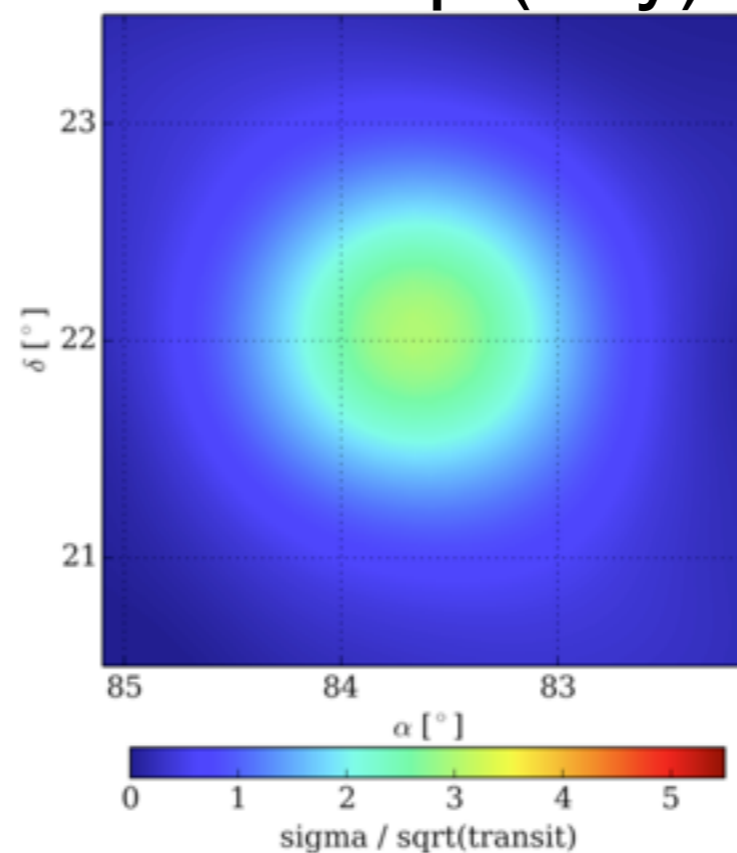
Improved Reconstruction: Crab

Preliminary

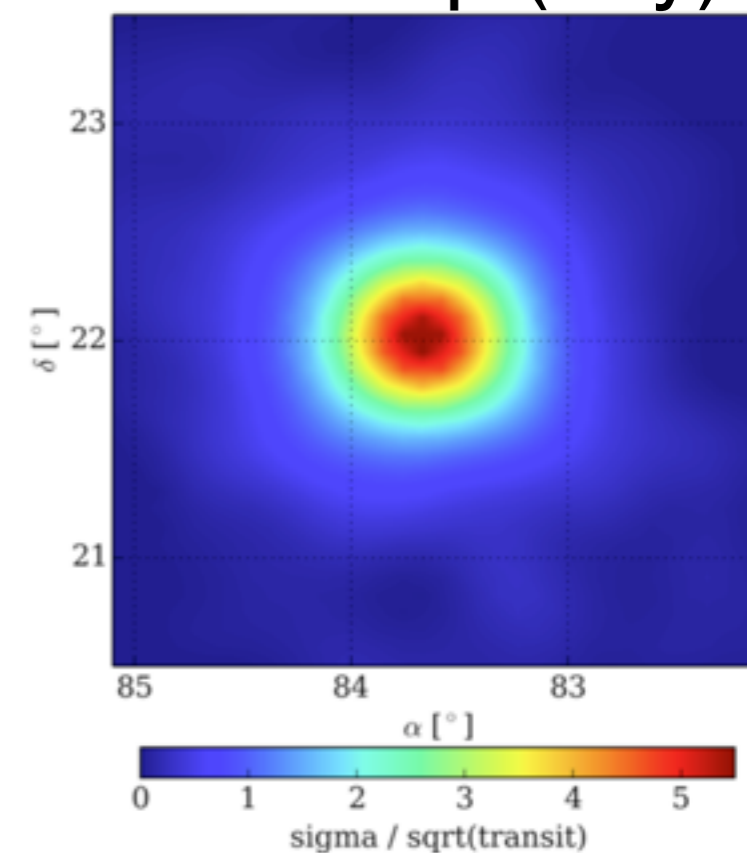
80 σ on the Crab in 211 days



Current
3.1 $\sigma/\sqrt{\text{day}}$

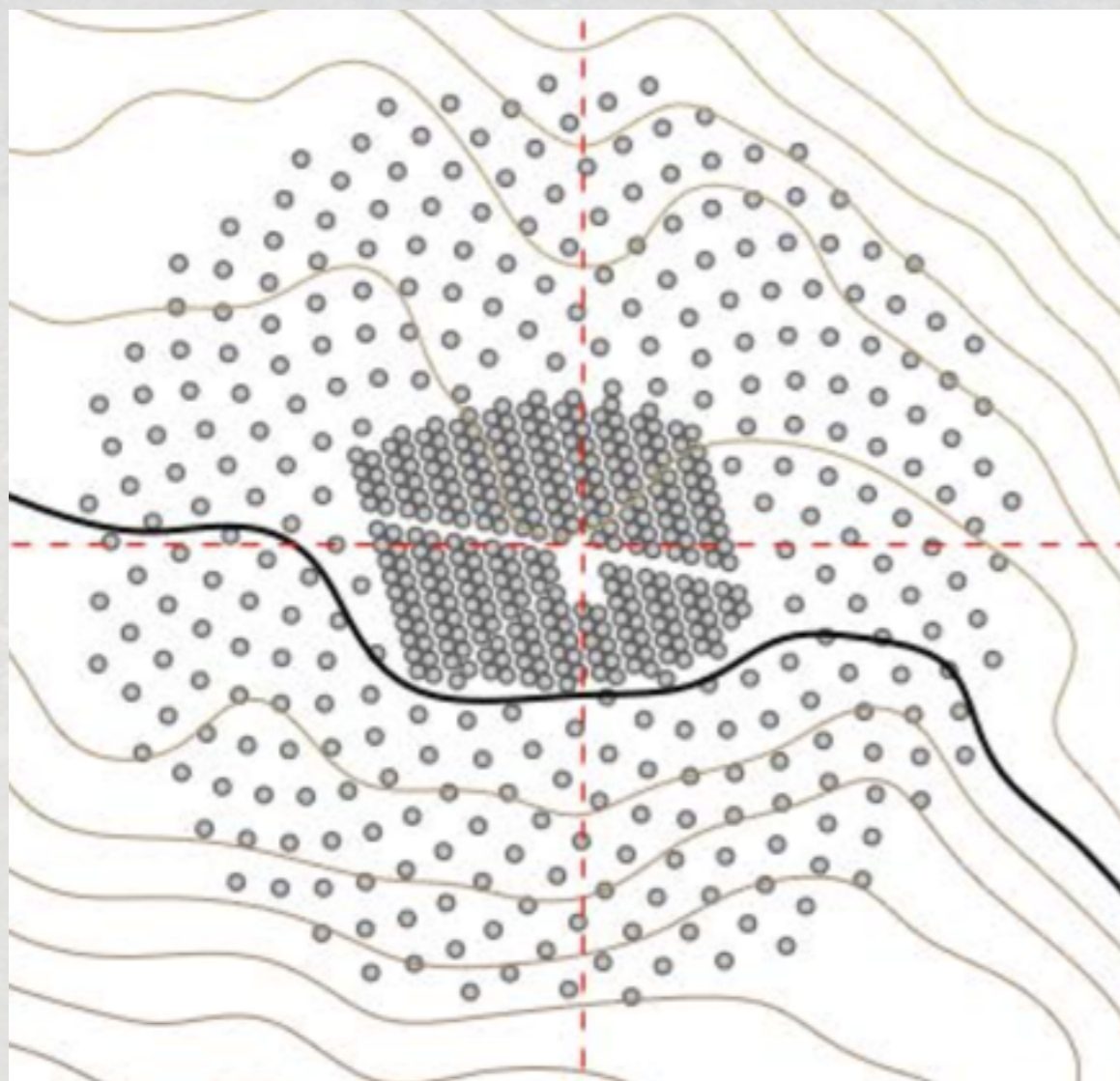


New
5.5 $\sigma/\sqrt{\text{day}}$



Achieving proposed angular resolution and sensitivity

Outlook



- **More sensitive data with full detector and improved analysis:** allow more sensitive sky survey and more precise spectral and morphological studies.
- **The Multi-Mission Maximum Likelihood (3ML) framework:** perform joint analysis with data from different instruments.
- **HAWC Sparse Outrigger Array:** Increase array size by 4X enhance sensitivity above 10 TeV

HAWC Pass 1 Galactic Plane Survey

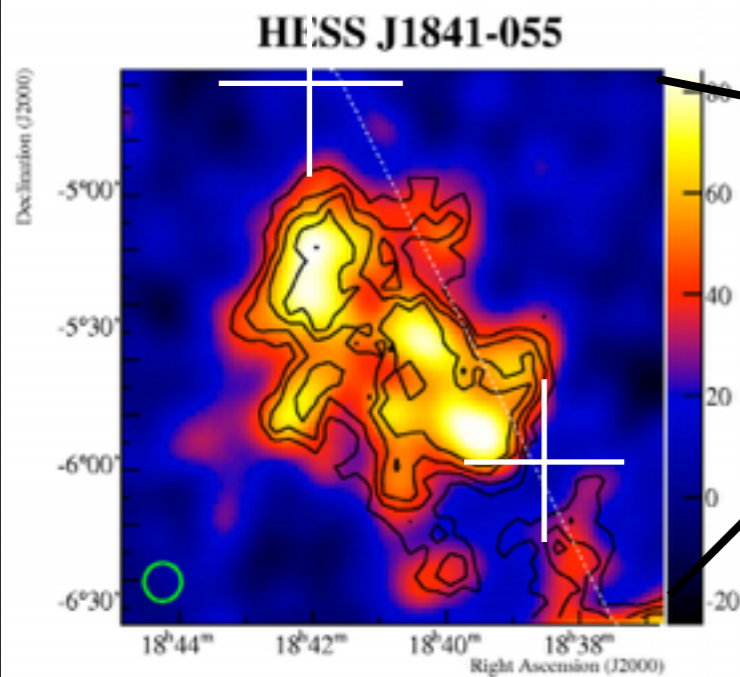
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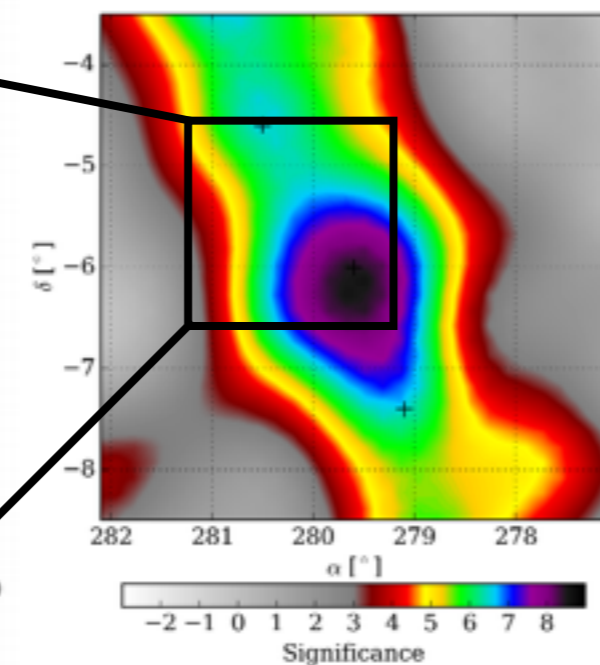
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1HWC J1838-060

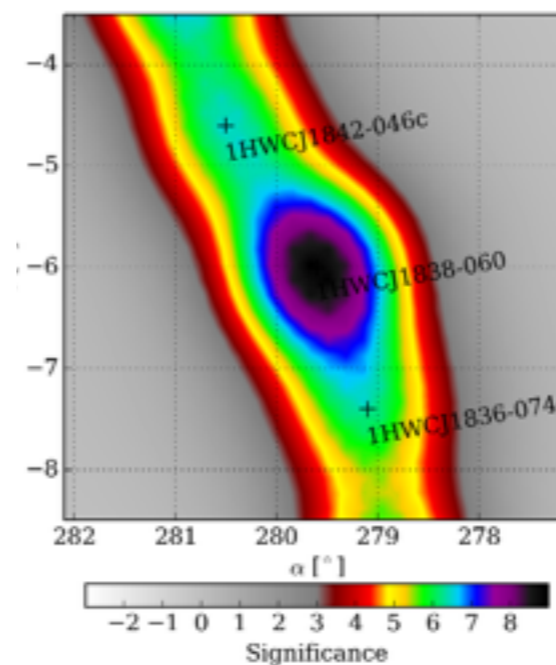
Aharonian et al. A&A 477, 353 (2008)



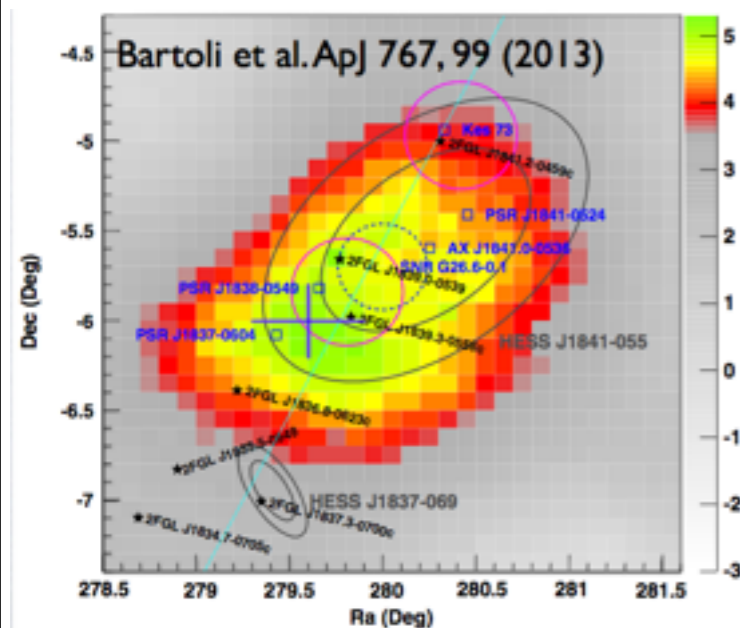
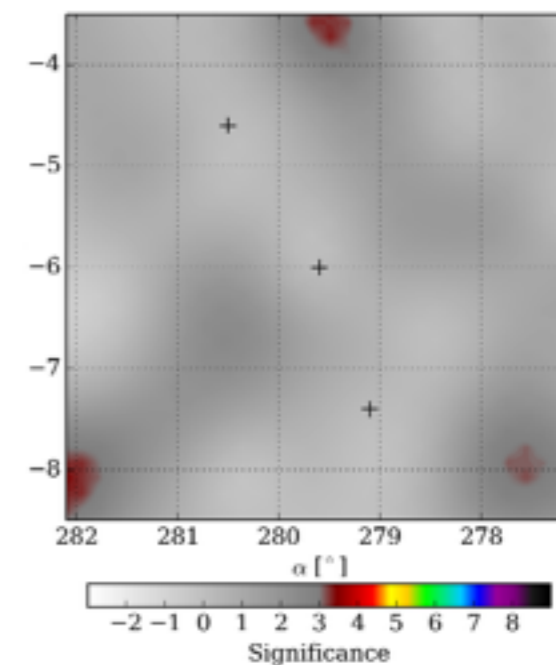
Data



Model



Residual



1HWC J1838-060 (6.1σ post-trial)

- 0.77° away from HESS J1841-055 centroid
- 0.16° away ARGO reported position of HESS J1841-055
- Compatible flux with HESS J1841-055, lower than ARGO reported flux

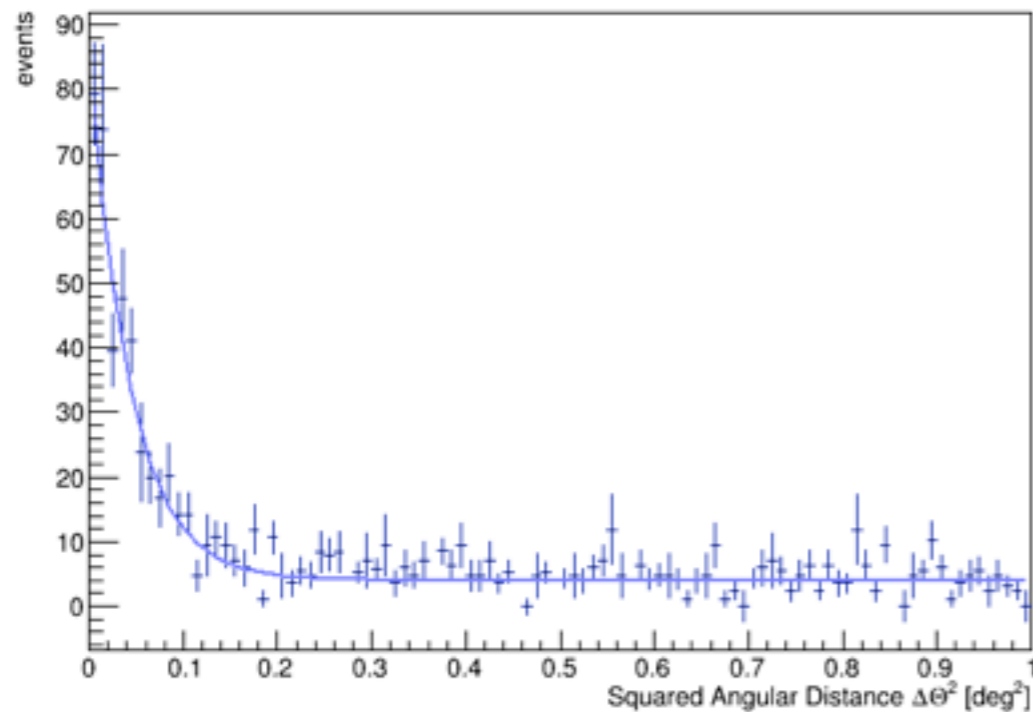
1HWC J1842-046c (3.4σ post-trial)

- 0.9° away from HESS J1841-055 centroid

2FHL J1840.9-0532e

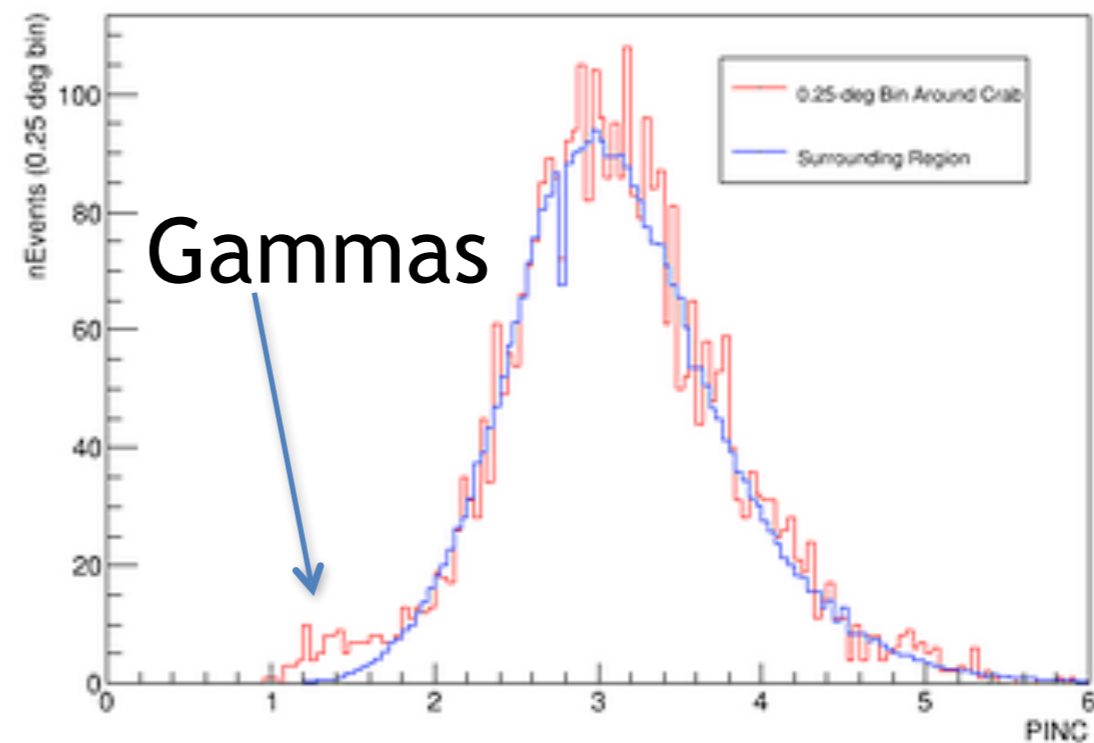
Angular Resolution and Gamma/Hadron Separation - Data from the Crab (preliminary)

Bins 7-9



Angular resolution for large events:
Gaussian “sigma” $\sim 0.15^\circ$
68% containment: 0.24°
Achieving proposed resolution

>85% PMTs Hit



PINC - Parameter for Identification of Nuclear Cosmic Rays.
Reject >99.9% of hadronic background for large events while retaining >50% of gamma rays.