HAWC and the cosmic ray quest

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Structure of the talk:

1) The HAWC gamma-ray observatory
2) Resolution and sensitivity
3) Cosmic rays at HAWC
4) Summary

1) The HAWC γ-ray observatory

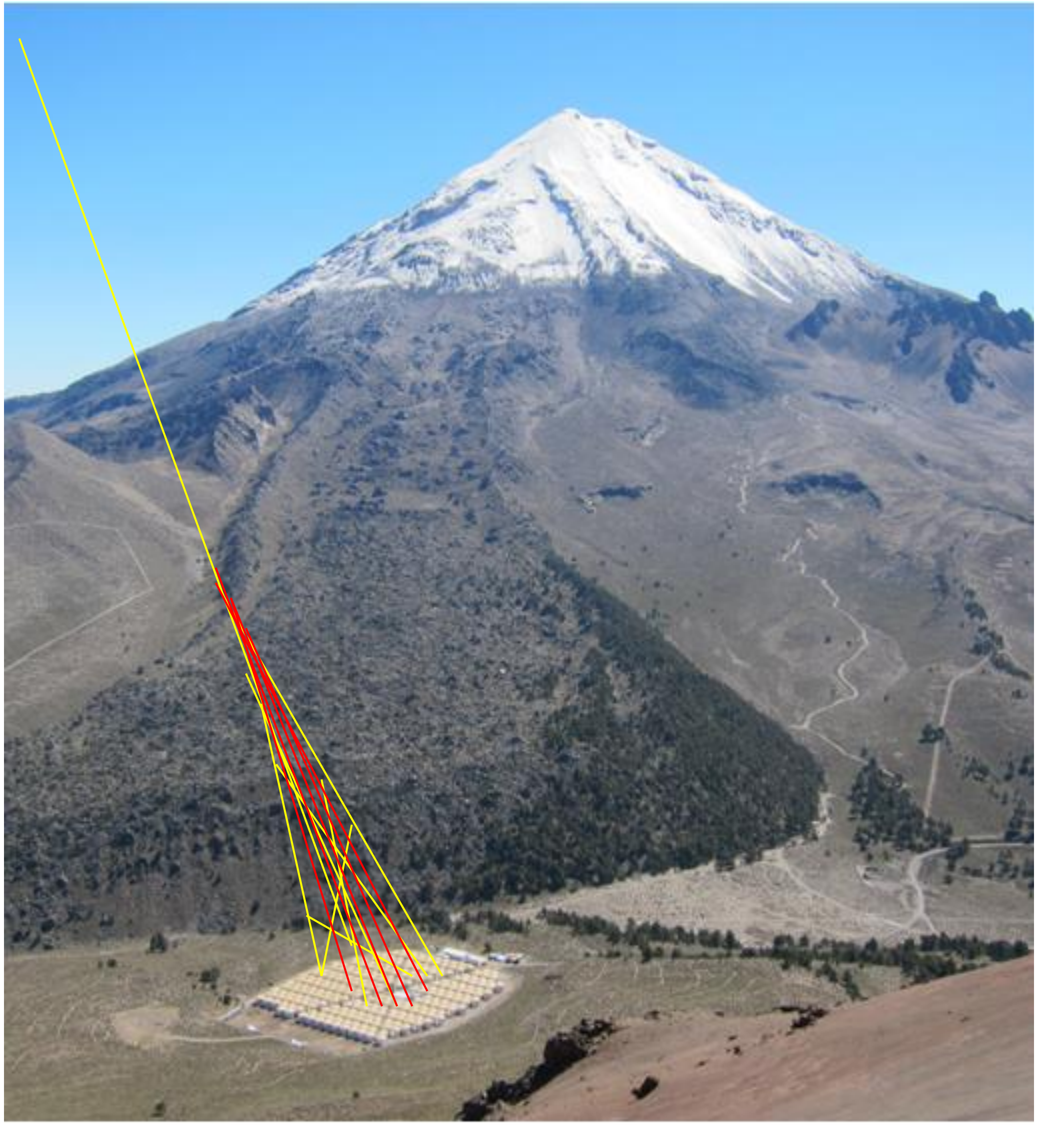
Location:

- Volcano Sierra Negra, Puebla, Mexico
- 19° N and 97° W

Altitude:

- 4100 m a.s.l. (640 g/cm^2)

1) The HAWC γ-ray observatory



Type of γ detector:

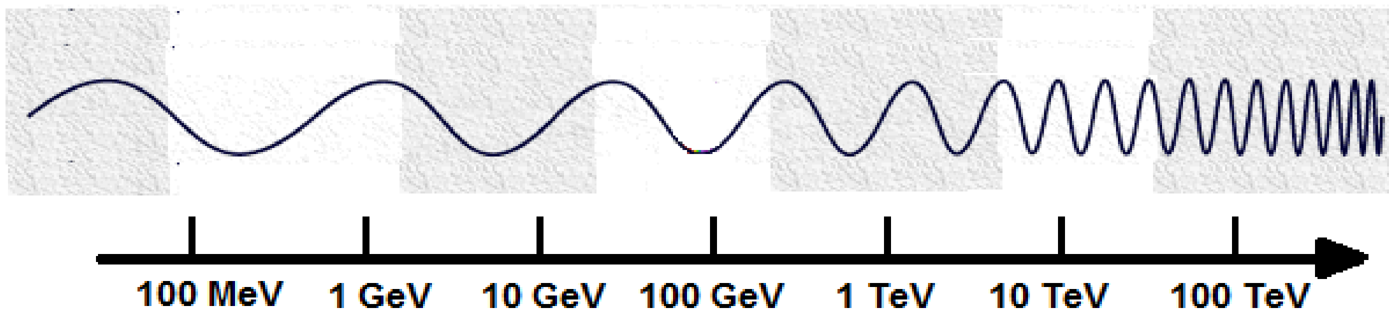
- Air-shower observatory
- Ground-based Cherenkov array

  E = 100 GeV – 100 TeV

Scientific objectives:

- Extend γ-ray observations up to 100 TeV
- Galactic and extragalactic astrophysics
- Cosmic ray physics
- Particle physics
- Prompt campaing of multimessenger observations

γ-ray observations



10 MeV – 300 GeV
Space telescopes

10 GeV – 100 TeV
Cherenkov telescopes

100 GeV – 100 TeV

Air shower observatories

HAWC is the firts of a new generation of TeV γ-ray detectors with improved sensitivity and statistics

TeV – O(PeV)

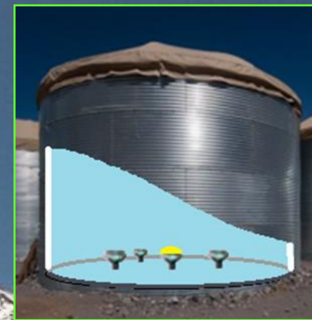
100 GeV – 100 PeV

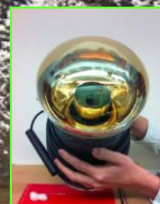
10 GeV – O(100 TeV)

10 GeV – 100 TeV

HAWC

- 300 WCD's
- 1200 PMT's
- 22,000 m^2 of area
- ≈ 135 m × 150 m
- 62 % coverage by the WCD
- Duty factor >90%
- Field of view of 2 sr





Water Cherenkov Detectors
- Steel tanks
- 7.3 m Ø
- 4.5 m height

PMT's
- 3 × 8" PMT's
  Spaced 6ft from center
- 1 × 10" PMT's
  > Efficiency to LE showers

Inner bladders
- Tyvek
- 200, 000 lt of pure water

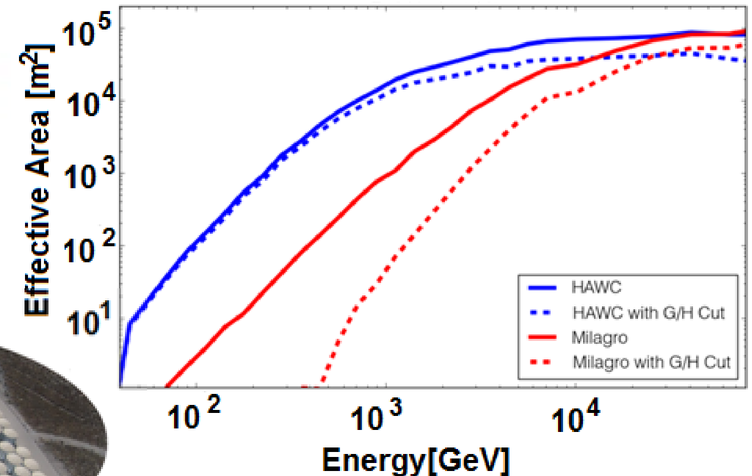
Utility building
- Water filtration system
- Tests of plastic bladders

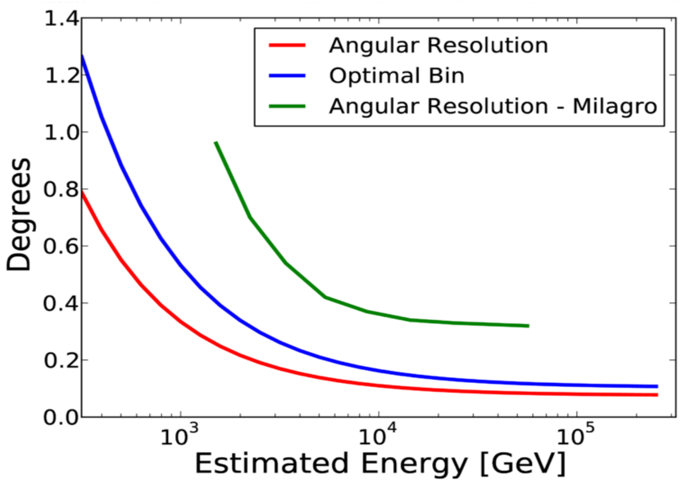
Counting House
- DAQ
- Laser calibration system

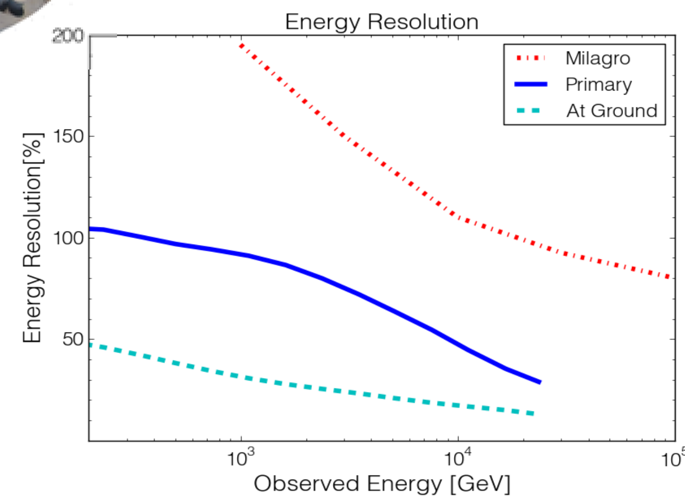
2) Resolution and sensitivity

HAWC-300

- Aeff ~ 10^5 m^2 @ E > 10 TeV
- ΔE < 50% @ E > 10 TeV
- Δθ ≈ 0.1° @ E > 10 TeV





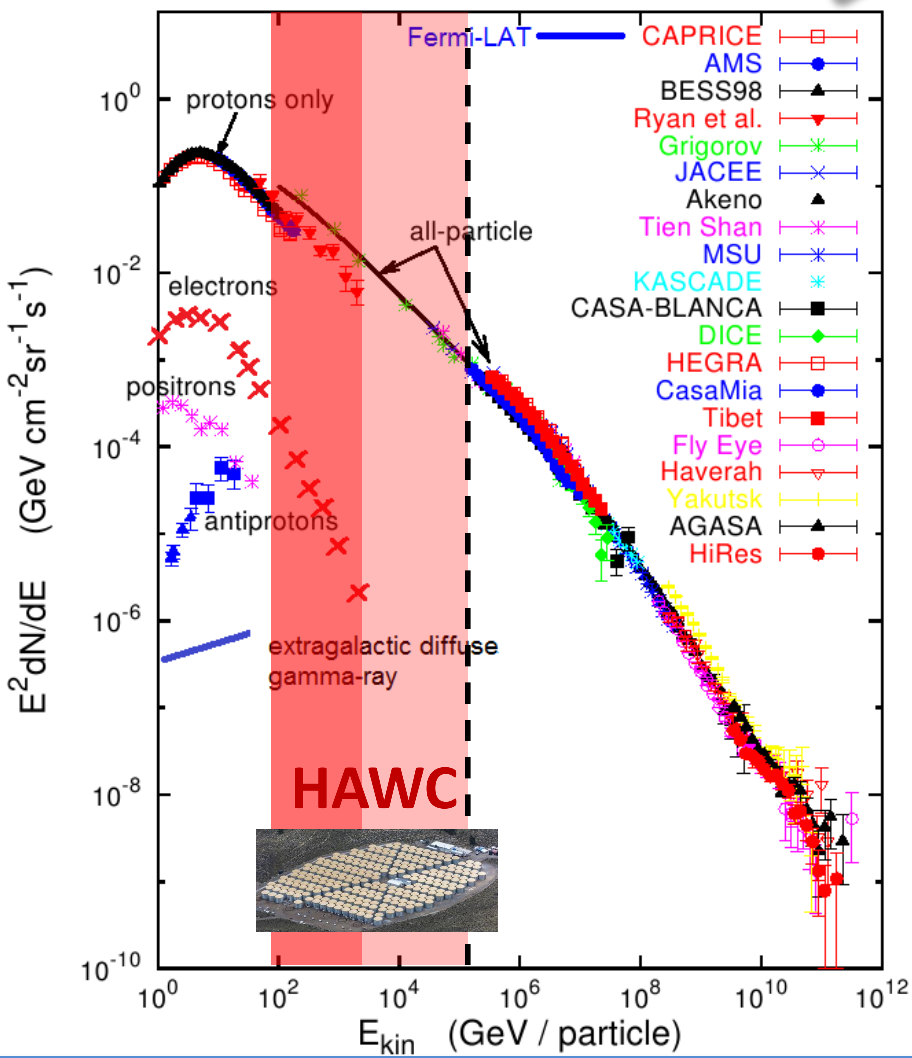


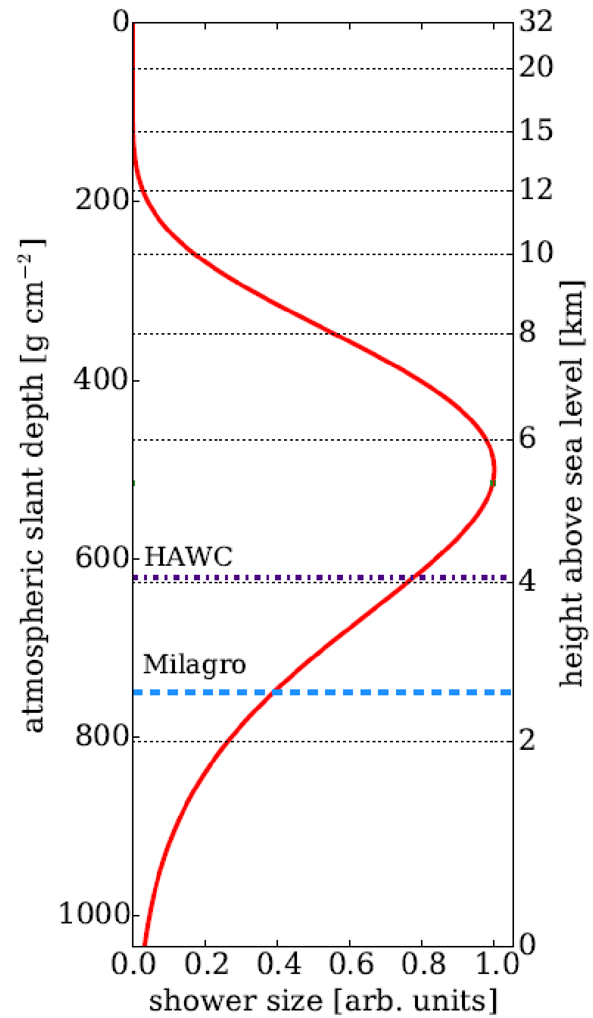
Abeysekara et al., Astropart. Phys 50-52 (2013) 26

3) Cosmic rays at HAWC

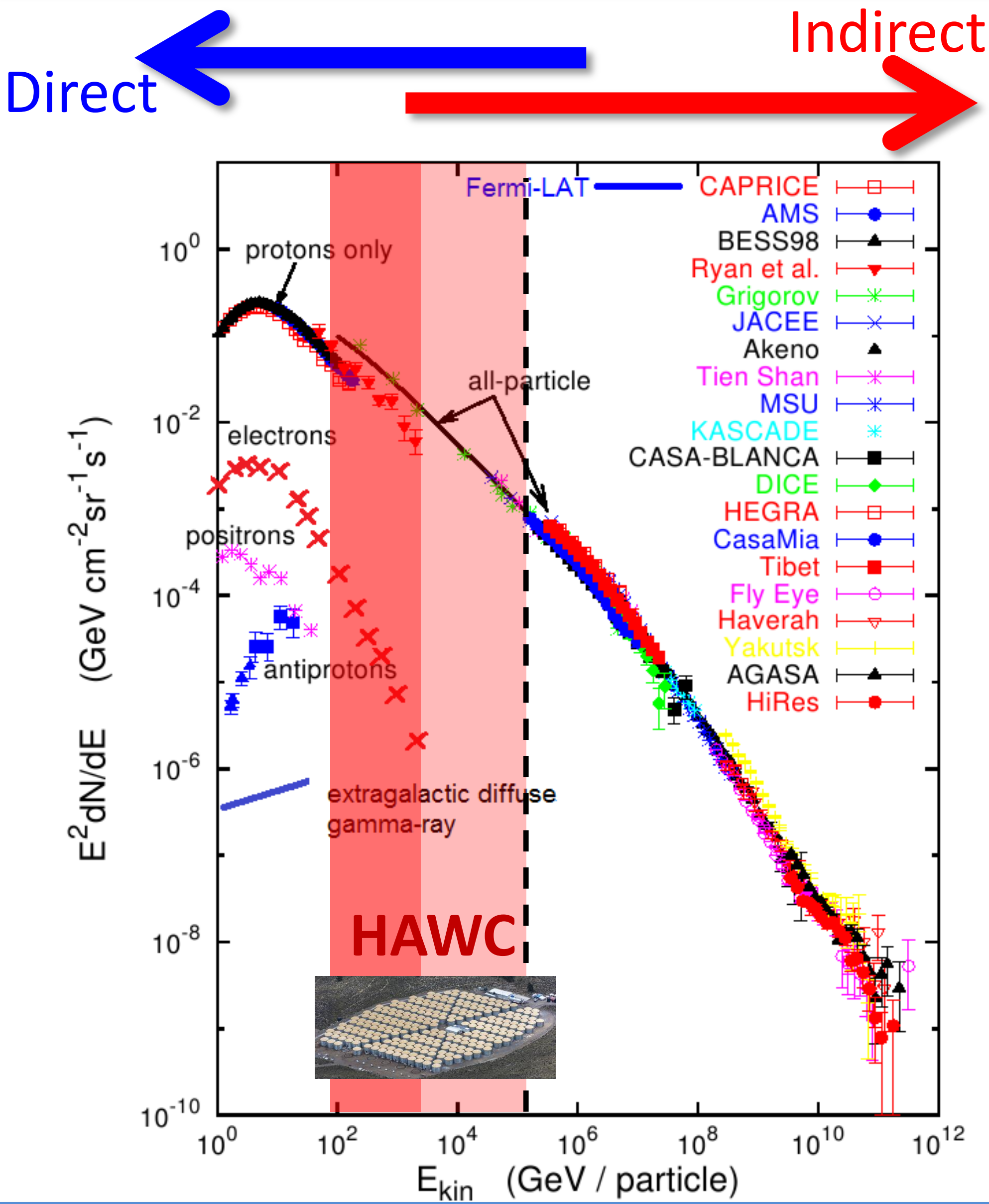
Direct

Indirect





M. DuVernois, ICRC 2015, #418



- EAS energy interval:

  100 GeV – 100 TeV

- Trigger rate: 25 kHz

- 99.9 % of events are hadronic

- CR rate @ E > 1 TeV:

  0.1 part/m^2.s.sr

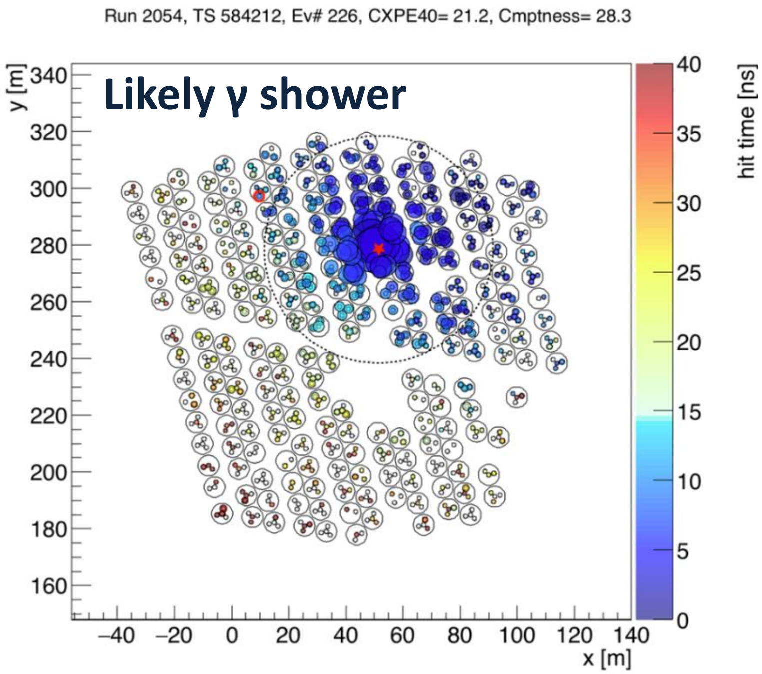
+ 10^3 times greater than flux of the brightest γ-ray source

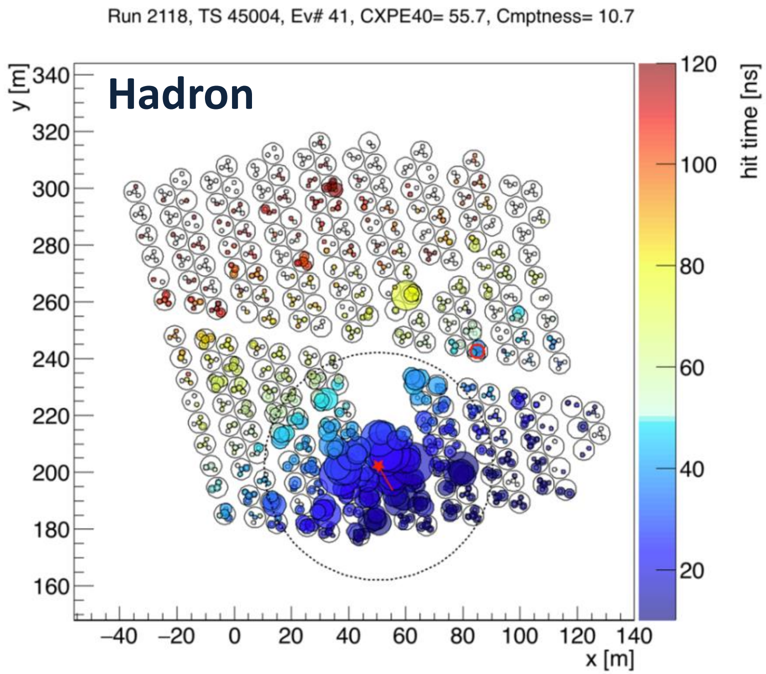
+ > 10^4 times $\Phi_{e\pm}$

S. BenzVi, D. Fiorino, et al., ICRC 2015, #216

A. Smith, ICRC 2015, #397

γ/hadron separation





- Bigger shower sampling region

  Better hadron rejection

- Discrimination is based on distribution of charged deposition

  γ: compact cores/smoothed distribution   Hadron: energetic clumps far from core

Compactness = Total # of PMT's activated/largest hit channel outside radius of 40 m

3) Cosmic rays at HAWC

γ/hadron separation

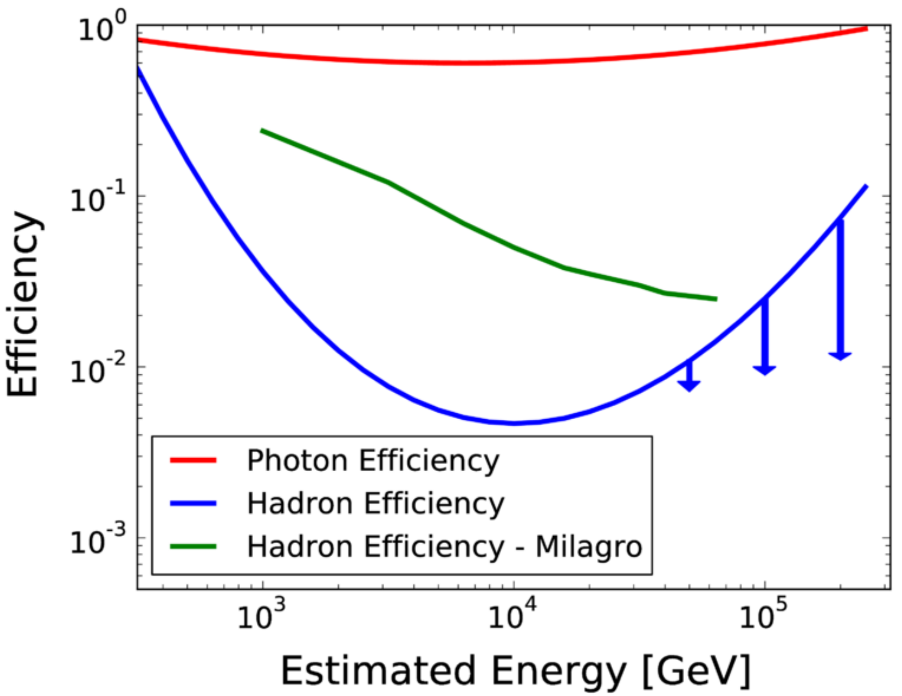
- Capacity to discriminate hadronic from e.m. shower

- For point sources:

$Q = \varepsilon_\gamma / \sqrt{\varepsilon_{CR}} \sim 5$ @ $E_\gamma >$ TeV's

ε_γ : Fraction of γ's classified correctly

ε_{CR} : Fraction of hadrons classified as γ's



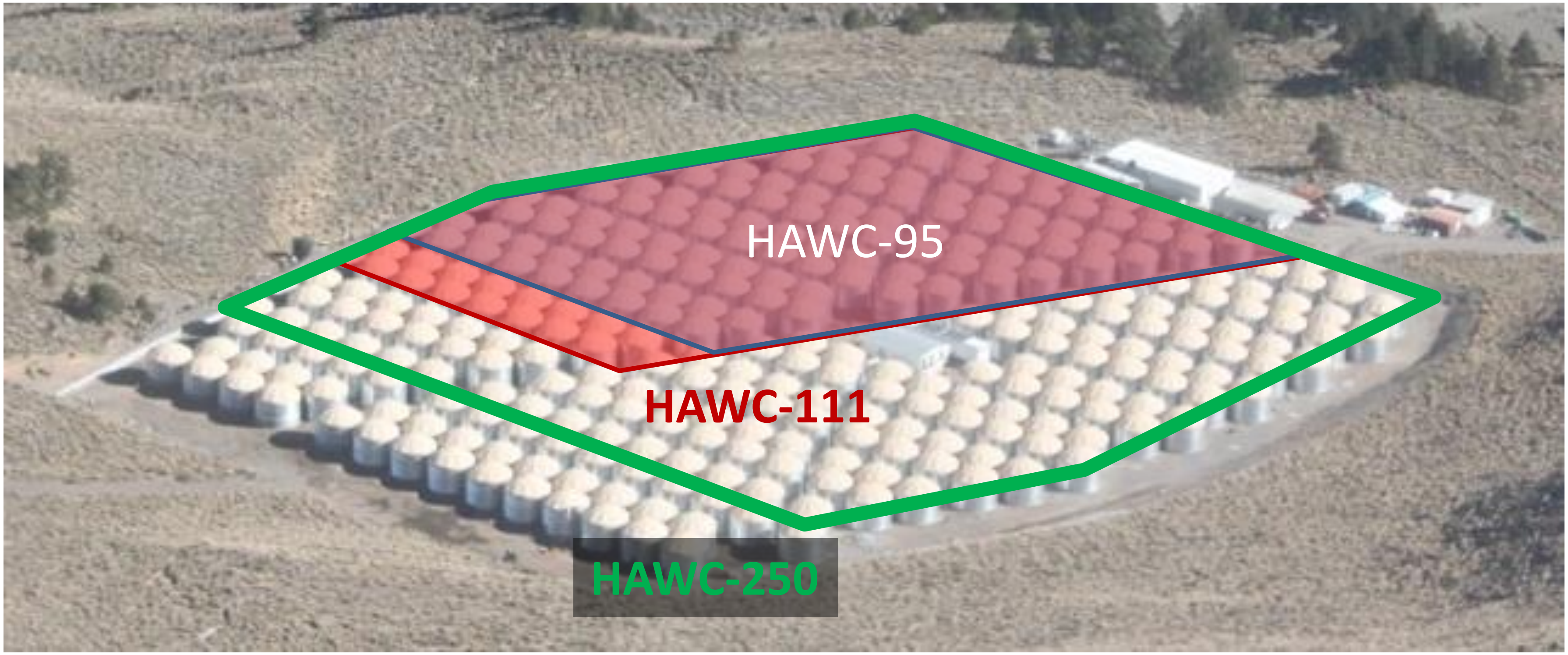
Abeysekara et al., Astropart. Phys 50-52 (2013) 26

3) Cosmic rays at HAWC

I. Direct cosmic ray studies at HAWC:

- Shadow of the Moon and the Sun.
- Large- and small-scale anisotropies.
- Combine HAWC/ICECUBE small-scale anisotropy maps. **In progress**
- Energy spectra from different regions in the sky. **In progress**
- All-particle energy spectrum. **In progress**
- Cross-check of results from EAS technique and direct CR measurements. **In progress**

3) Cosmic rays at HAWC

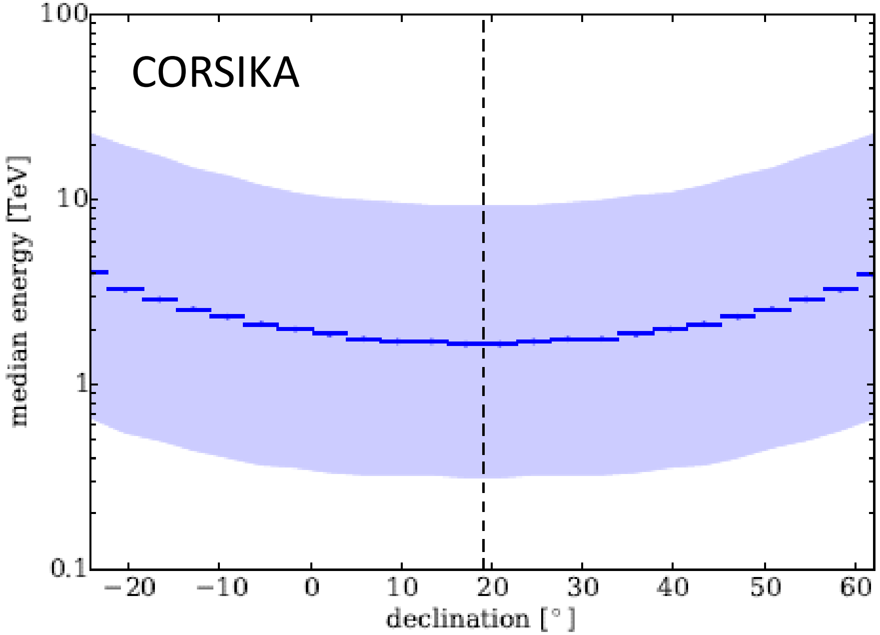


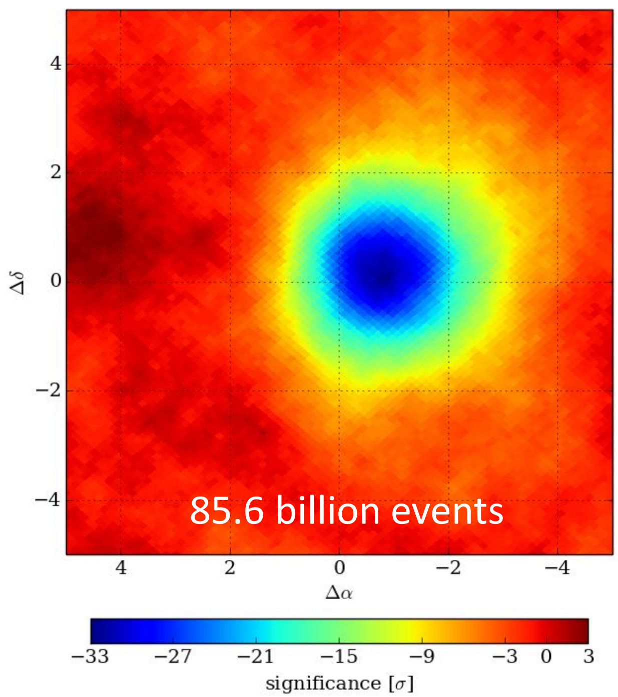
- **HAWC-95/111**: June 2013 – July 2014
- **HAWC-250**: Nov.2014 – May 2015

A. Smith, ICRC 2015, #397

3) Cosmic rays at HAWC

HAWC-95/111 cosmic ray data set





Median CR Energy:

E = [1.7 TeV, 4 TeV]

δ = [-20°, 60°]

HAWC Coll., Astrophys. J, arxiv: 1408.4805

Shadow significance = -32.5 σ

- Ang. Resolution ≤ Shadow width 1.2°
- Deflection 0.9° (2 TeV median energy)
- Moon/Sun shadows verify pointing resolution.

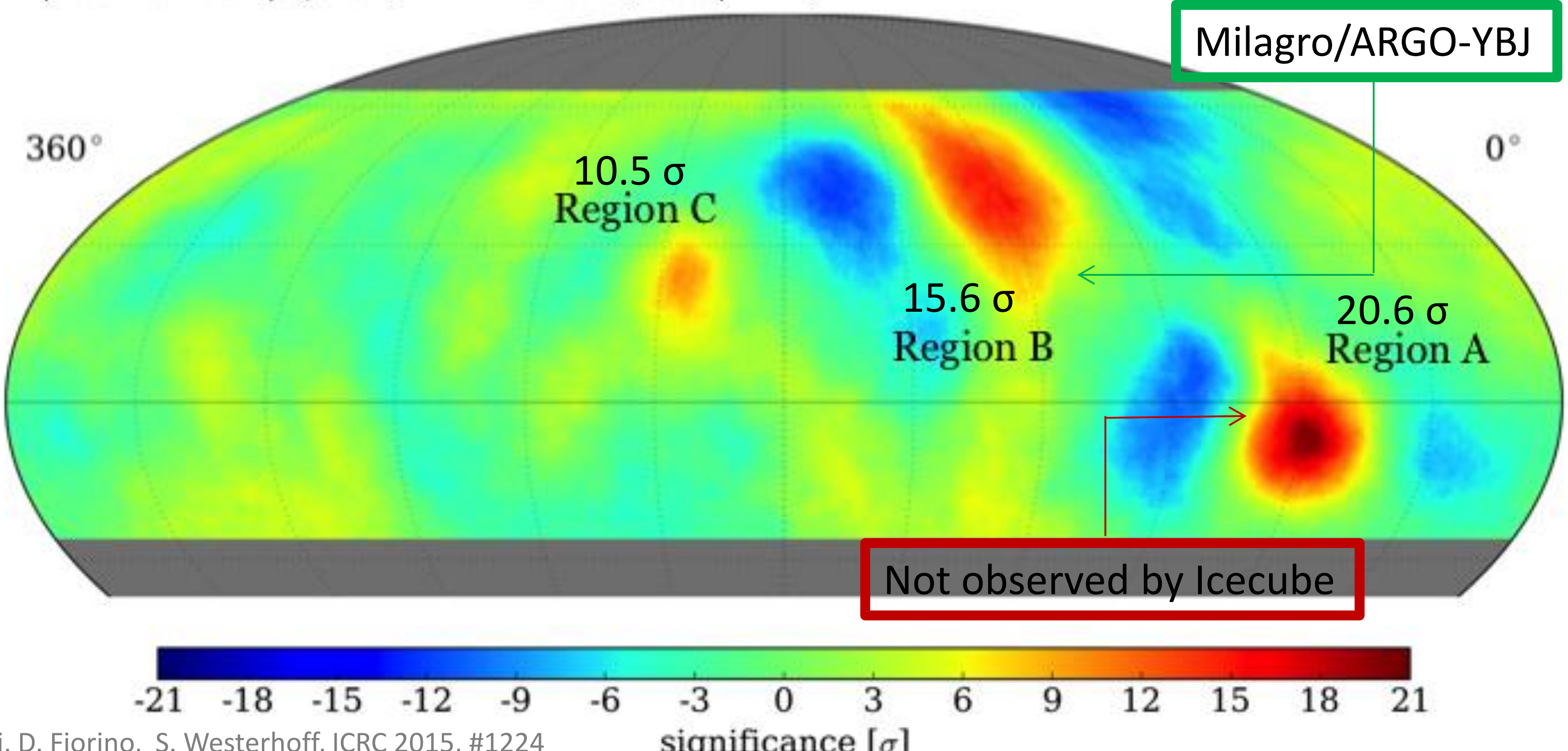
Small-scale Anisotropy

HAWC-95/111

Small-scale (< 60°)
Large-scale removed (dipole,quadrupole,+octupole)
10° smoothing applied
86 billion events over 181 days

In press with Astrophys. J. (arXiv 1408.4805 [astro-ph.HE])

3 significant excesses
- A – strongest, harder spectrum than bkg, at ~10 TeV consistent with Milagro
- B – most extended
- C – confirms Argo-YBJ observation



S. Bezvi, D. Fiorino, S. Westerhoff, ICRC 2015, #1224

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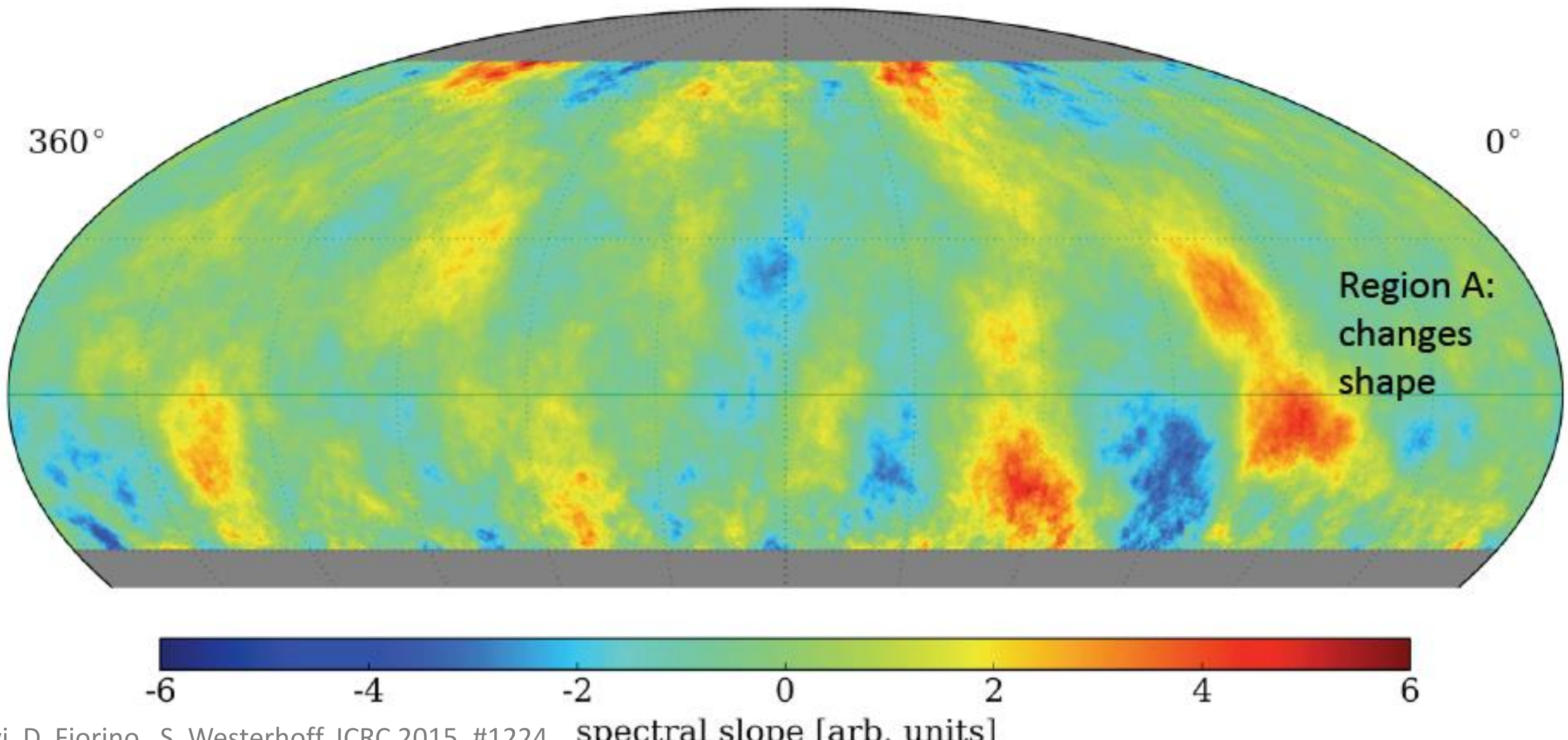

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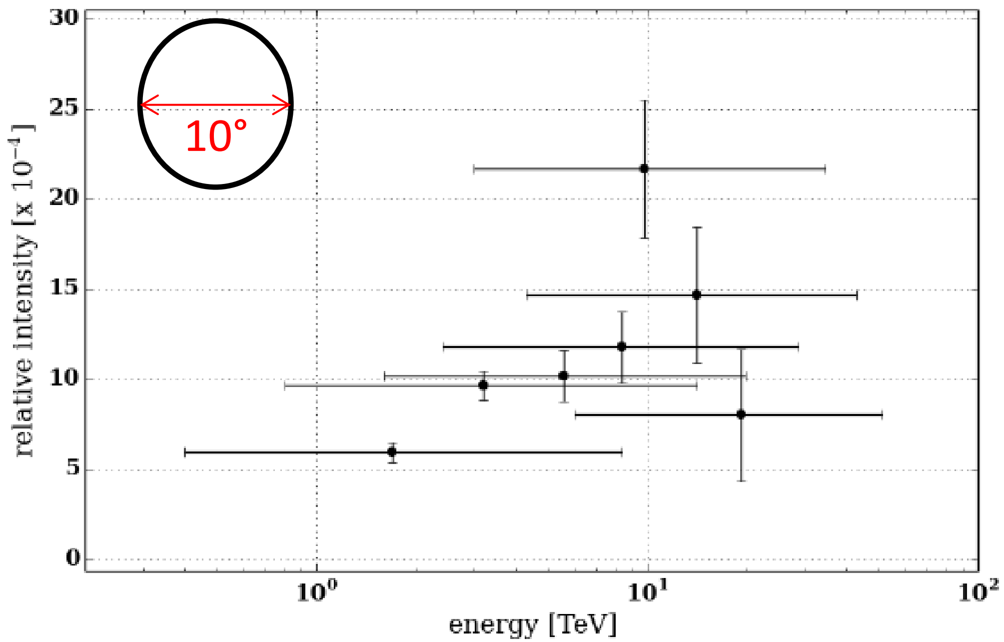
Energy spectrum in relative intensity for region A

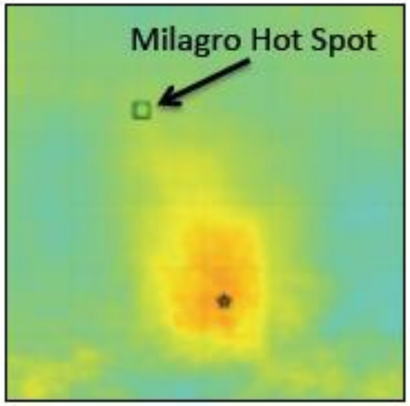


Energy bin	E_{median}(TeV)
1	1.7
2	3.2
3	5.6
4	8.4
5	9.8
6	14.1
7	19.2

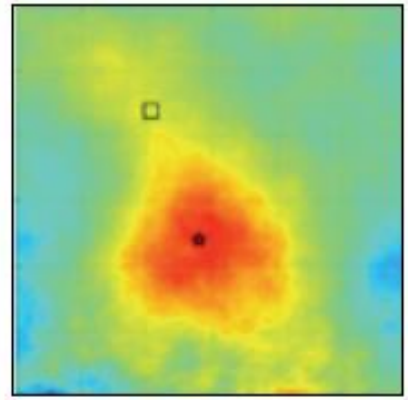
Harder than off-source regions: 4.2 σ effect

S. Bezvi, D. Fiorino, S. Westerhoff, ICRC 2015, #1224

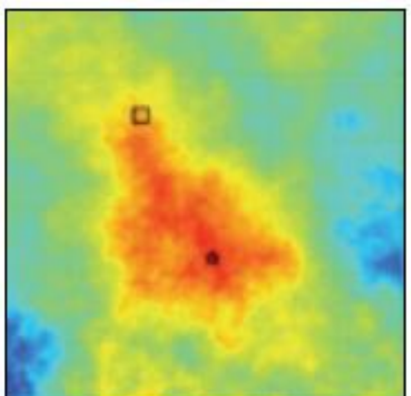
Energy dependence for region A



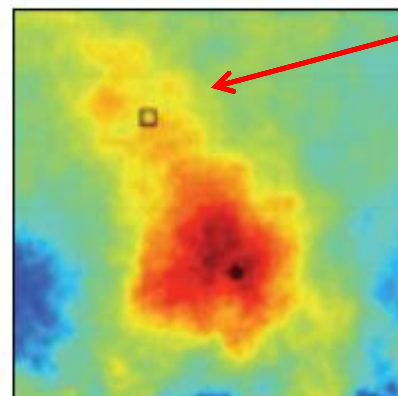
1.7 +6.6/-1.3 TeV



3.2 +10.9/-2.4 TeV



5.6 +14.2/-3.9 TeV



14.1 +28.7/-9.9 TeV

At > 10 TeV a northern sub-region appears

S. Bezvi, D. Fiorino, S. Westerhoff, ICRC 2015, #1224

II. Indirect cosmic ray studies with TeV γ-rays:

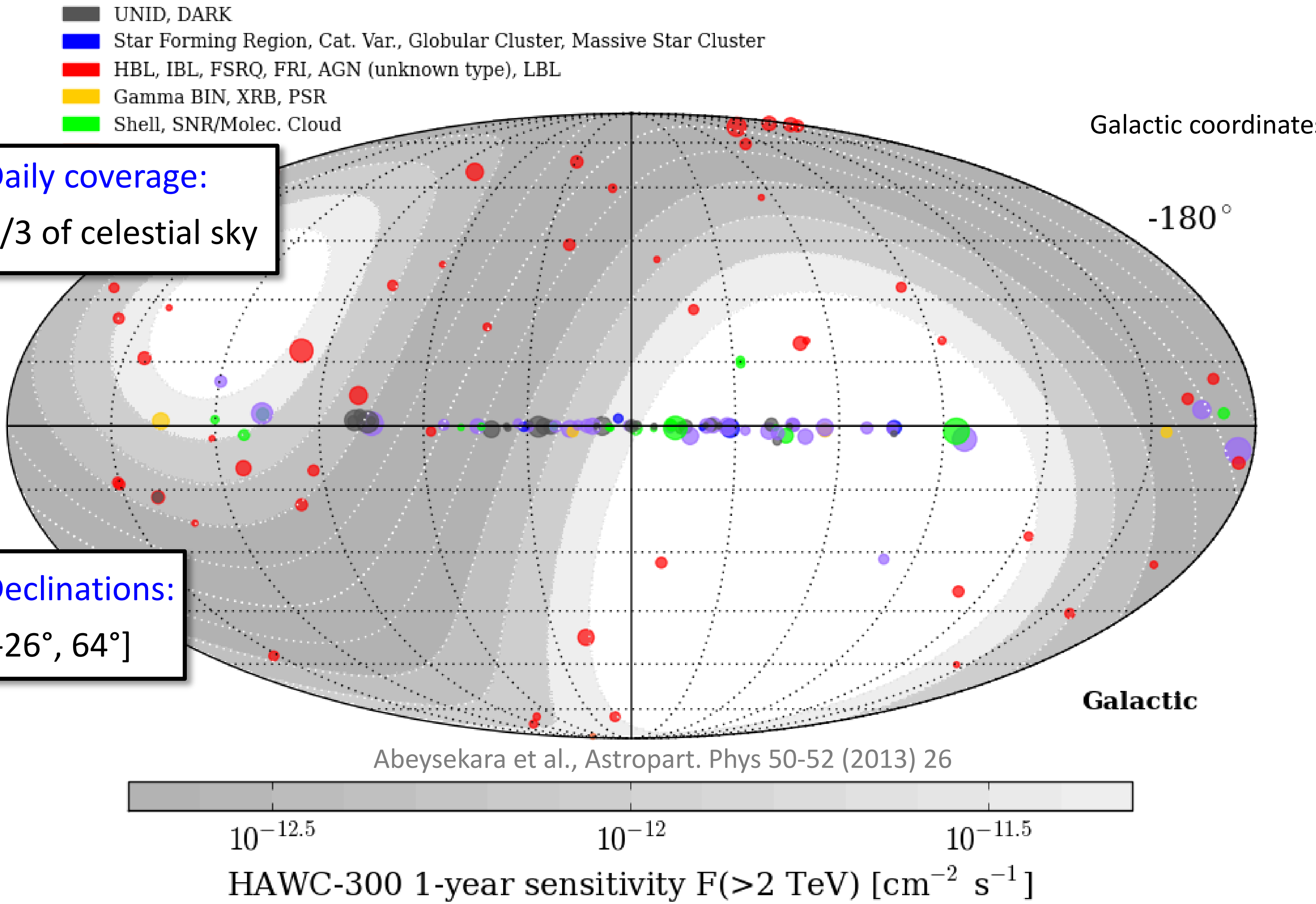
- Extend γ-ray observations up to 100 TeV.
- Look for Pevatrons and new TeV γ-ray sources (point, extended).
- Study morphology and spectrum of TeV sources.
- Study the galactic diffuse γ-ray emission.
- Participation in multimessenger searches.

→

- Understand **particle acceleration**.
- Look for **cosmic rays sources** .
- Study **density distribution** and **propagation** of cosmic rays in our galaxy.
- Put tighter constrains on galactic cosmic ray **emission**.

HAWC Collaboration, arxiv: 1310.0071,.

3) Cosmic rays at HAWC

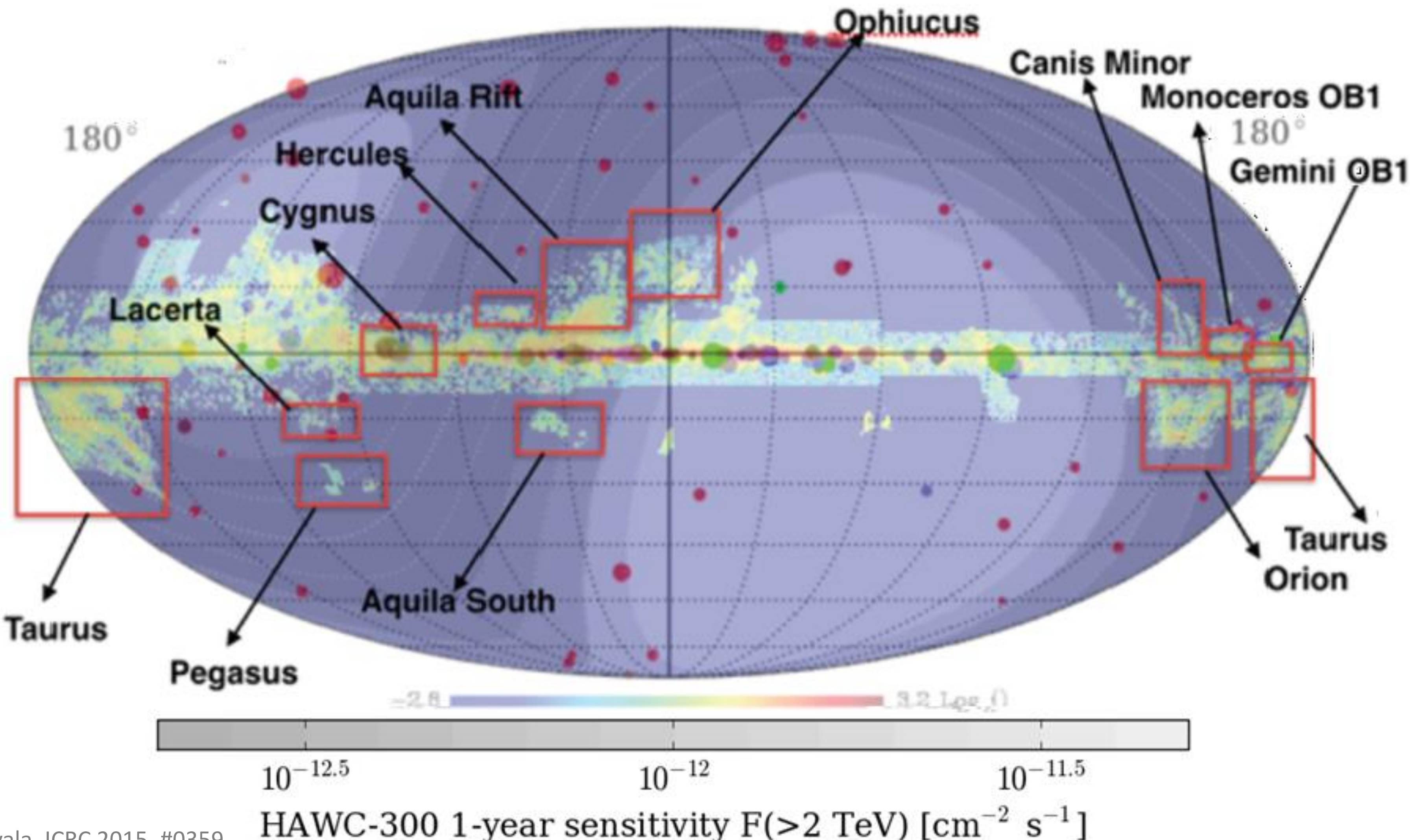


- **Daily coverage:**
  2/3 of celestial sky

- **Declinations:**
  [-26°, 64°]

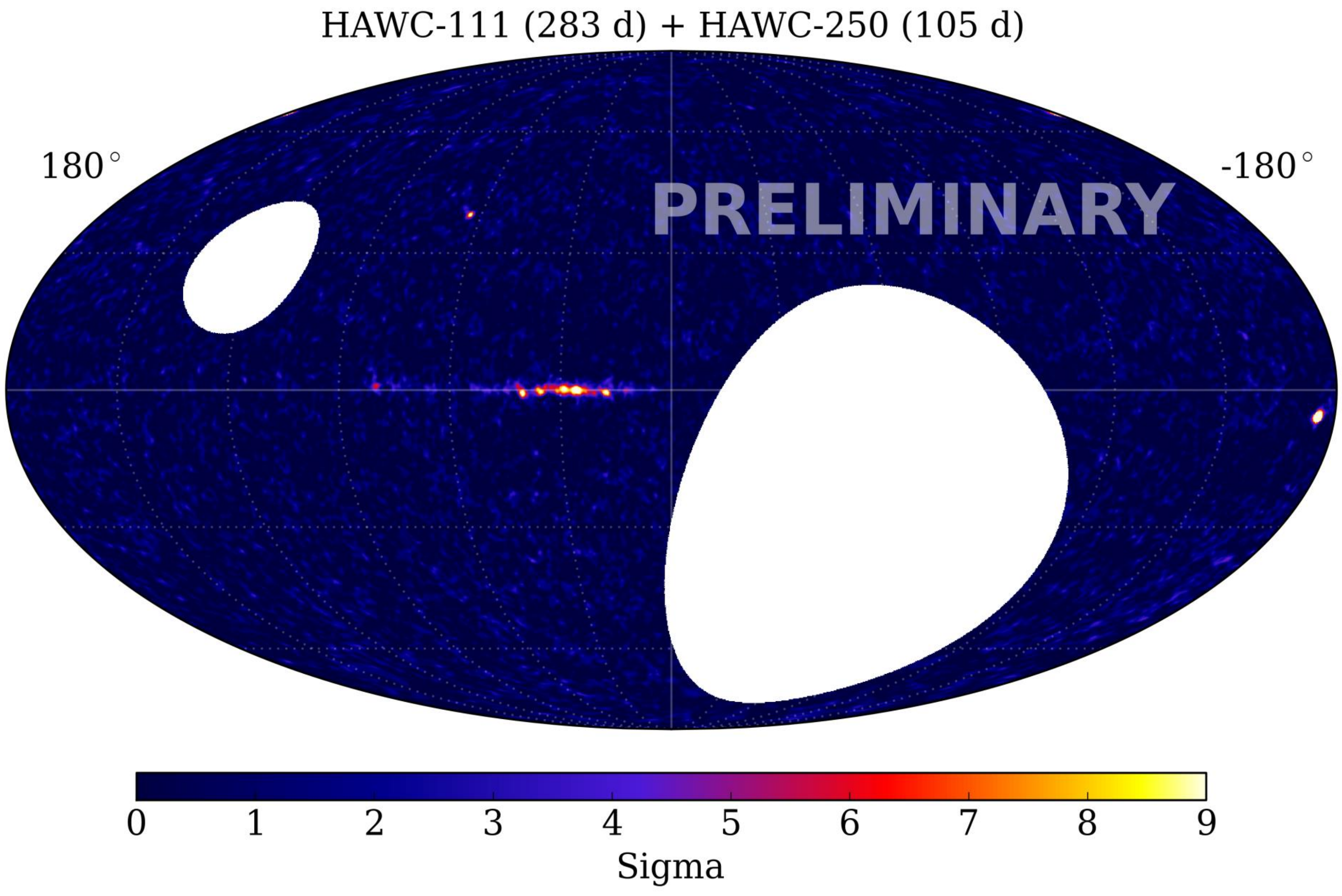
3) Cosmic rays at HAWC

Dame CO survey overlapped with 1 year of HAWC Sensitivity

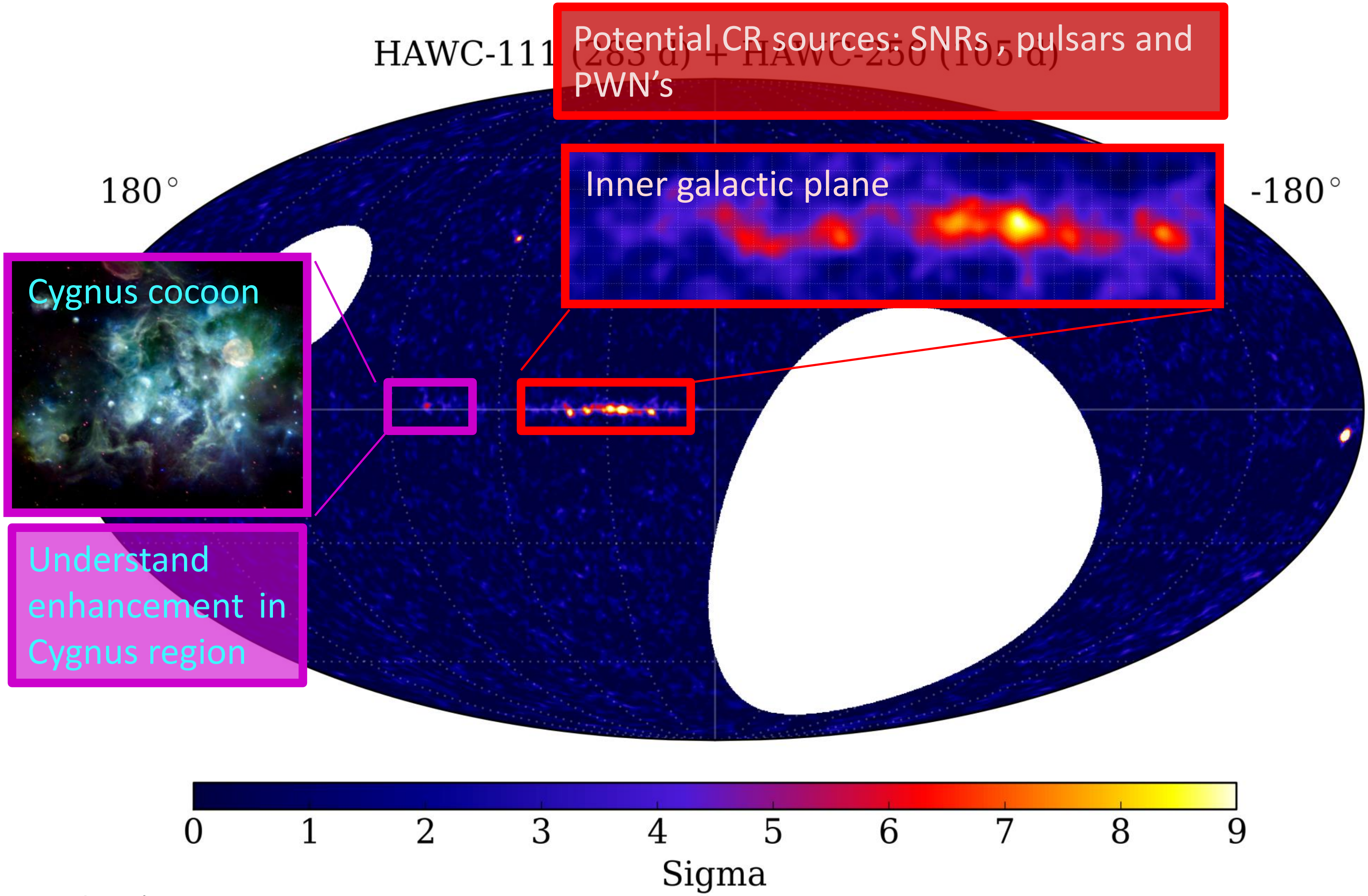


H. Ayala, ICRC 2015, #0359

3) Cosmic rays at HAWC



3) Cosmic rays at HAWC

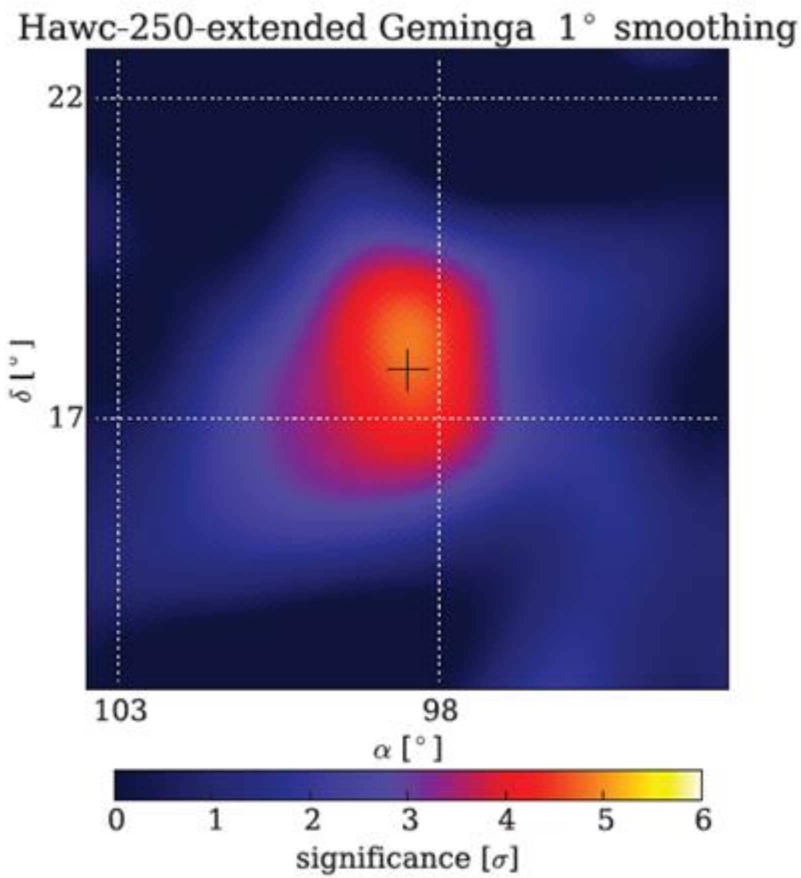


C.M. Hui & H. Zhou, ICRC 2015, #0323

3) Cosmic rays at HAWC

TeV γ-ray emission from Geminga

- Closest (d~250 pc) known middle-aged pulsar (340 kyr).
- XMM-Newton observed a PWN.
- Observed in TeV by MILAGRO as an extended object (~ 2.6° extension).
- Not observed by IACT´s.



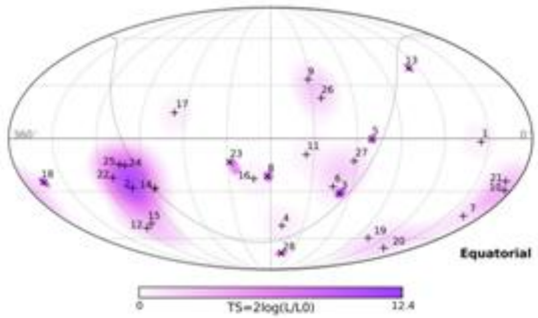
149 days live-time

- Possible nearby source of accelerated cosmic rays.
- Possible explanation for the observed positron excess.

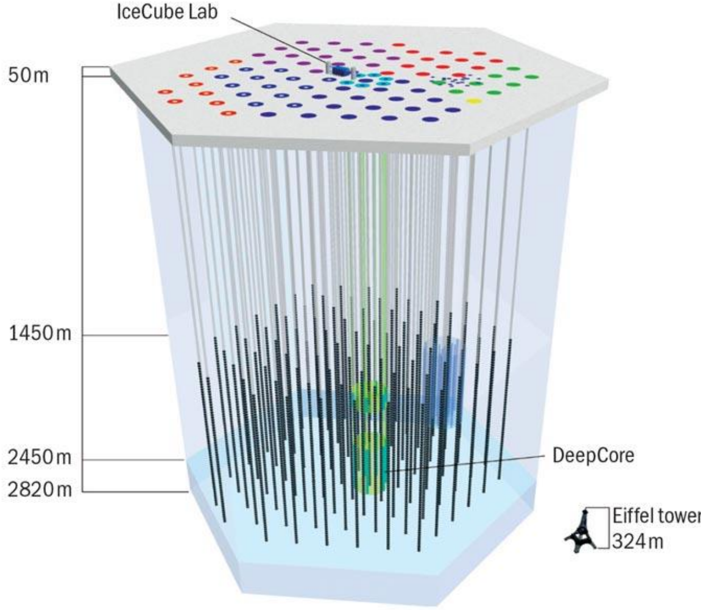
B.M. Baughmann & J. Wood, ICRC 2015, #247

Multimessenger astronomy

Looking for possible TeV γ-ray sources associated with ICECUBE ν signals



HAWC-300



Future improvements:

- Working on better γ/hadron separation techniques.
  - Neural-Network methods (T. Capistran, ICRC 2015, #692)
  - Log-likelihood formalism (P. W. Younk, ICRC 2015, #238)
- Better EAS reconstruction and energy determination procedures.
- Increase effective area (~ 3.5 times) for EAS > 10 TeV with an outrigger (A. Sandoval, ICRC 2015, #529).

4) Summary

Cosmic rays:

- Small-scale structures are observed @ E_{median} = 2 TeV . They match previous observations by other instruments.

- Energy dependence of small-scale anisotropies is observed.

Gamma rays:

- HAWC confirms Milagro's observation of an extended source spatially coincident with Geminga.

4) Summary


HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory
Thank you!
HAWC Collaboration Meeting, June 2015
Puerto Vallarta, México