Observing the TeV γ-ray sky with the **H**igh **A**ltitude **W**ater **C**herenkov observatory

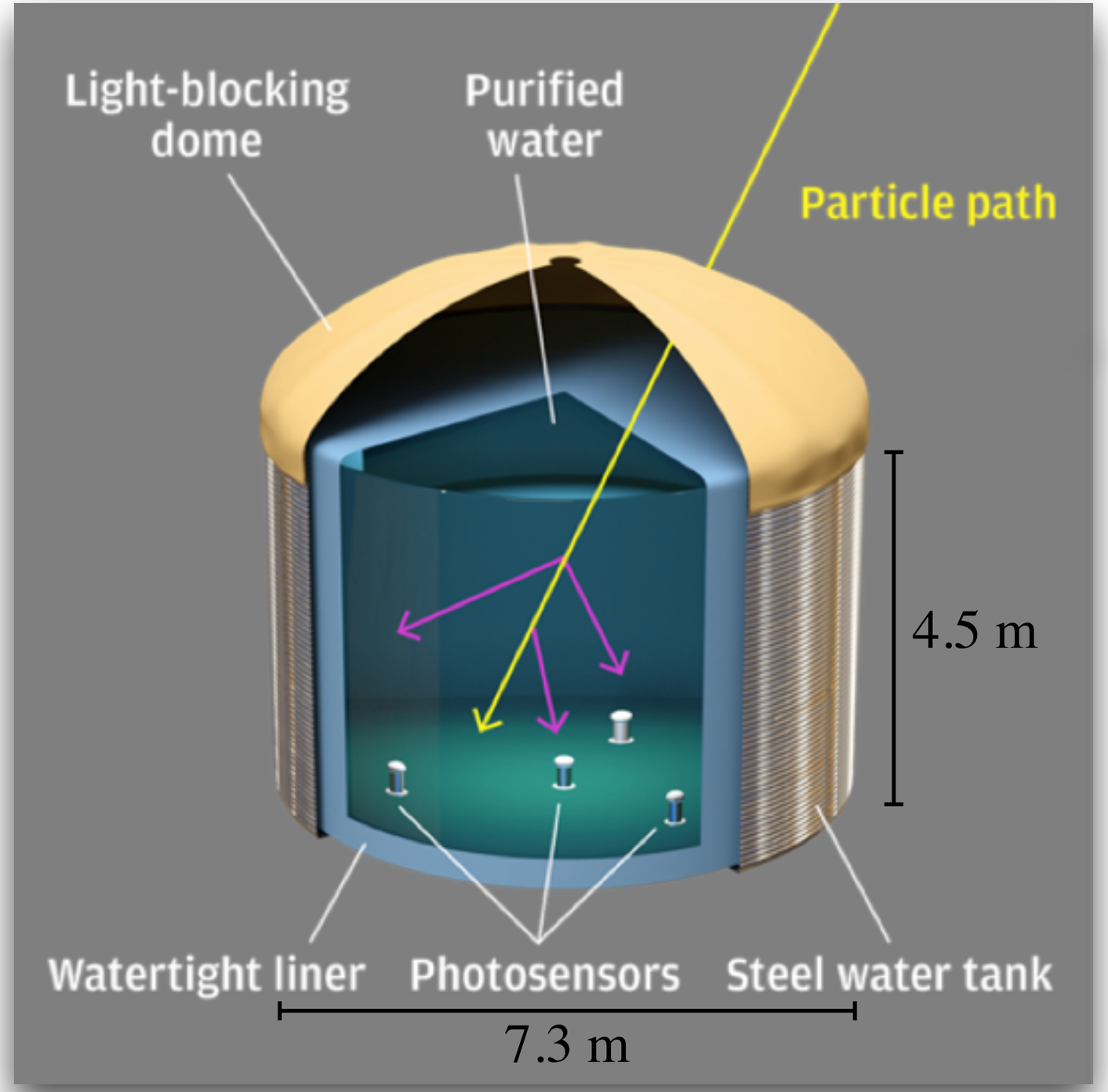
Harm Schoorlemmer, on behalf of the HAWC - collaboration

The HAWC observatory

Site specifications

- **4100 m above sea level**
- **Mexico, Sierra Negra, Lat. +19°**
- **300 water-Cherenkov tanks**
- **Full array operational since March 2015**
- **22000 m², with 57% coverage**

The water Cherenkov detectors



- **200 000L of purified water**
- **4 PMTs: one central 10” PMT surrounded by three 8” PMTs**
- **Signals measured using a Time to Digital Convertor**

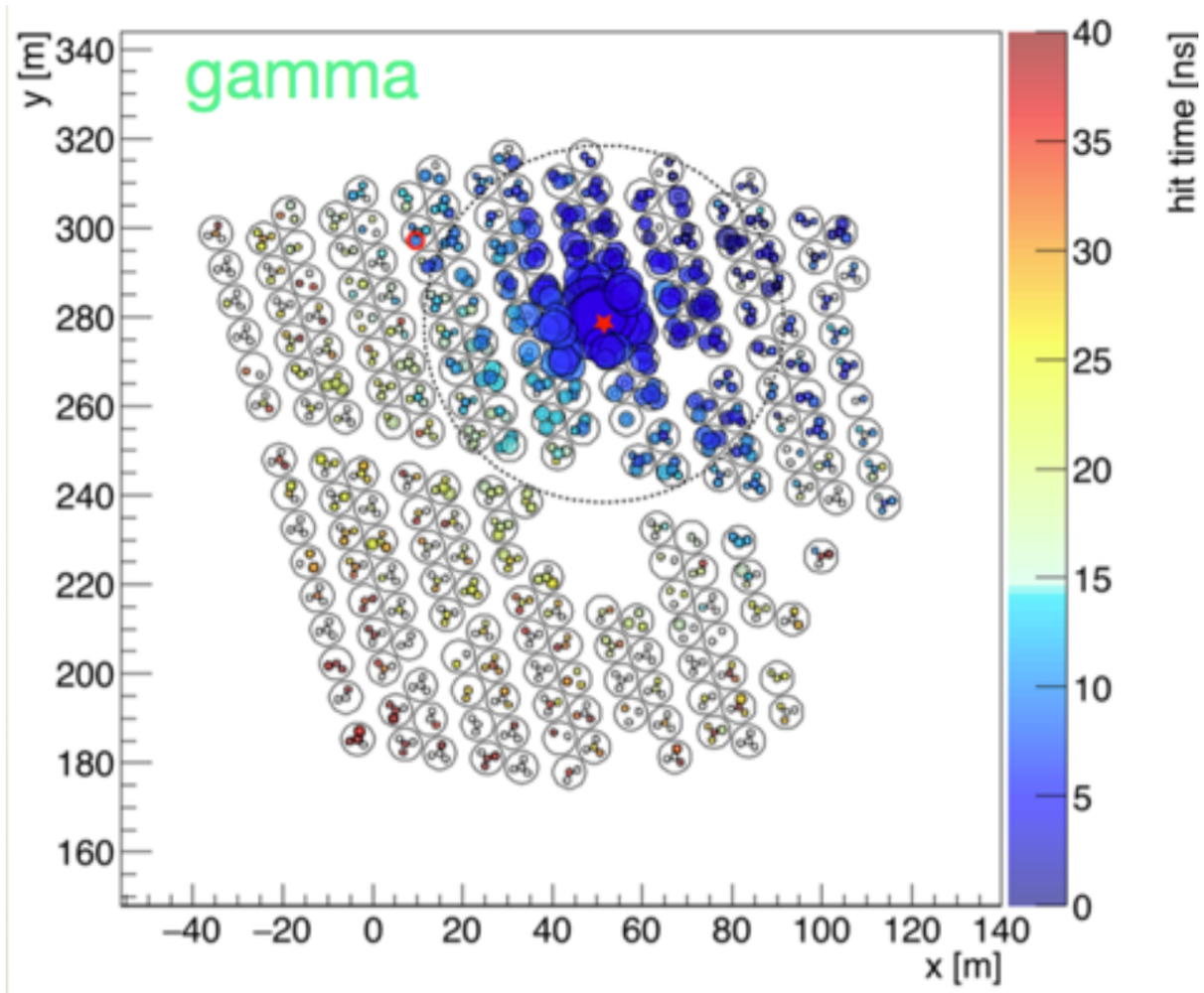
Shower type identification

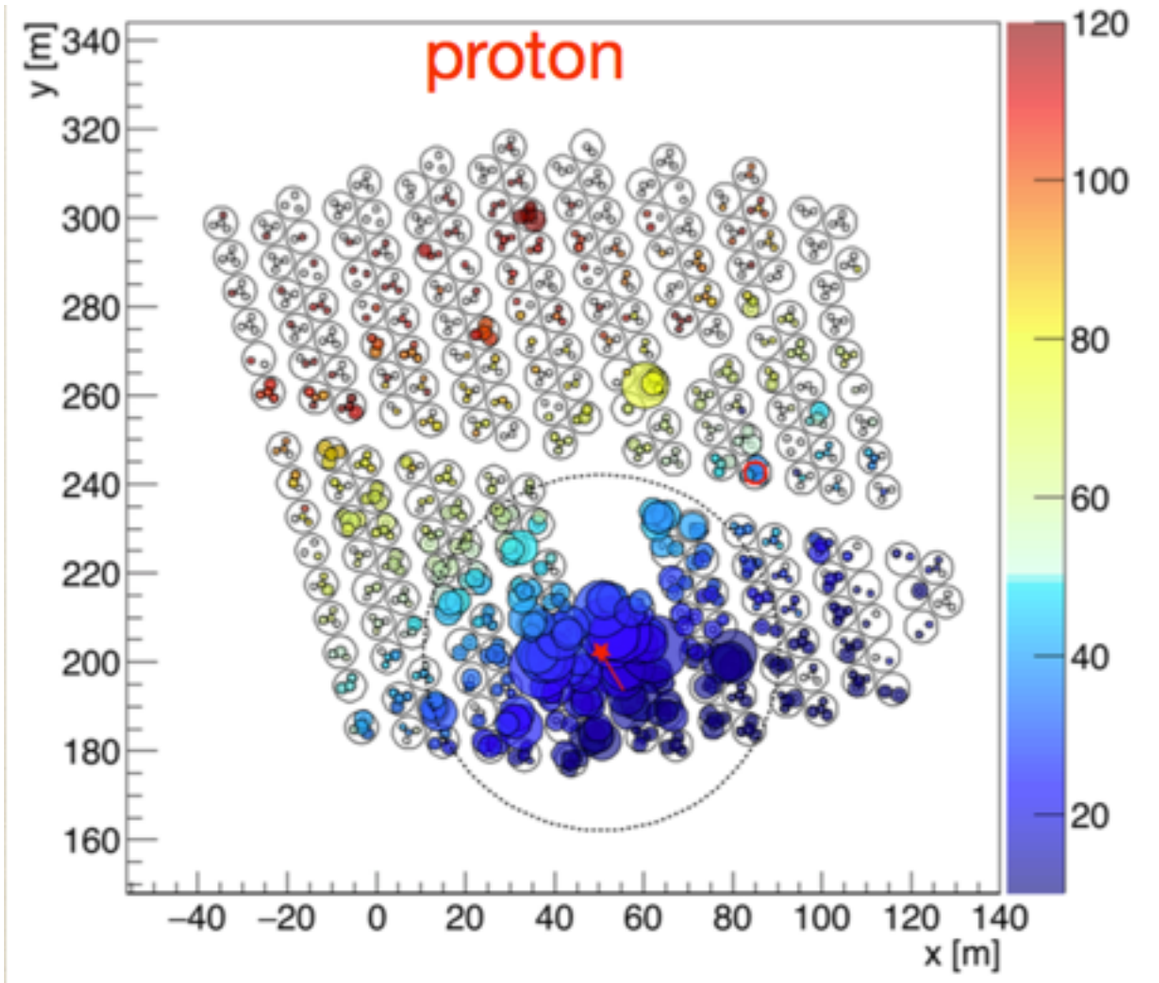
γ-rays produce an electromagnetic cascade:

- **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**



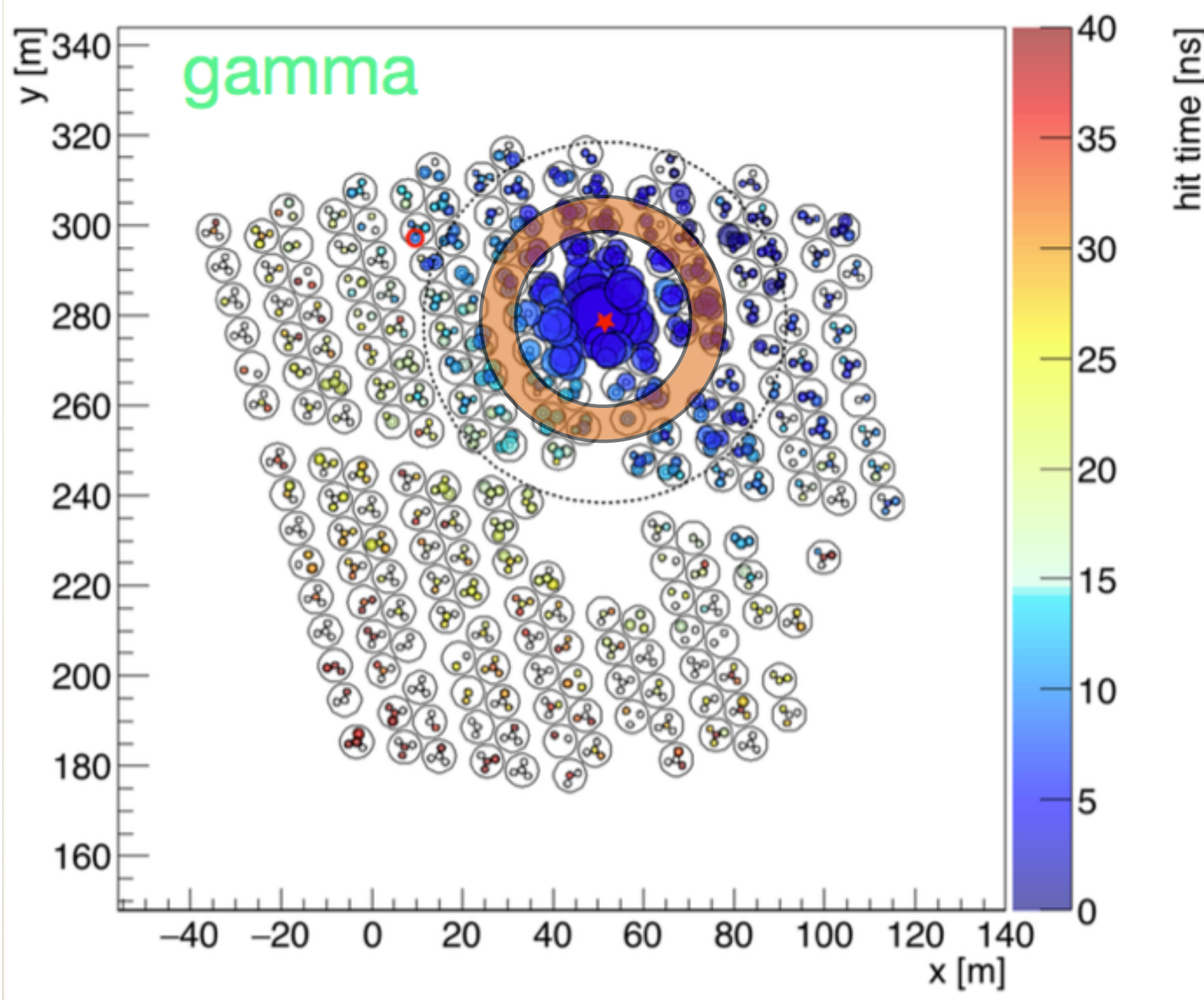


Shower type identification

PINC

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

Measure of the smoothness of the lateral distribution.

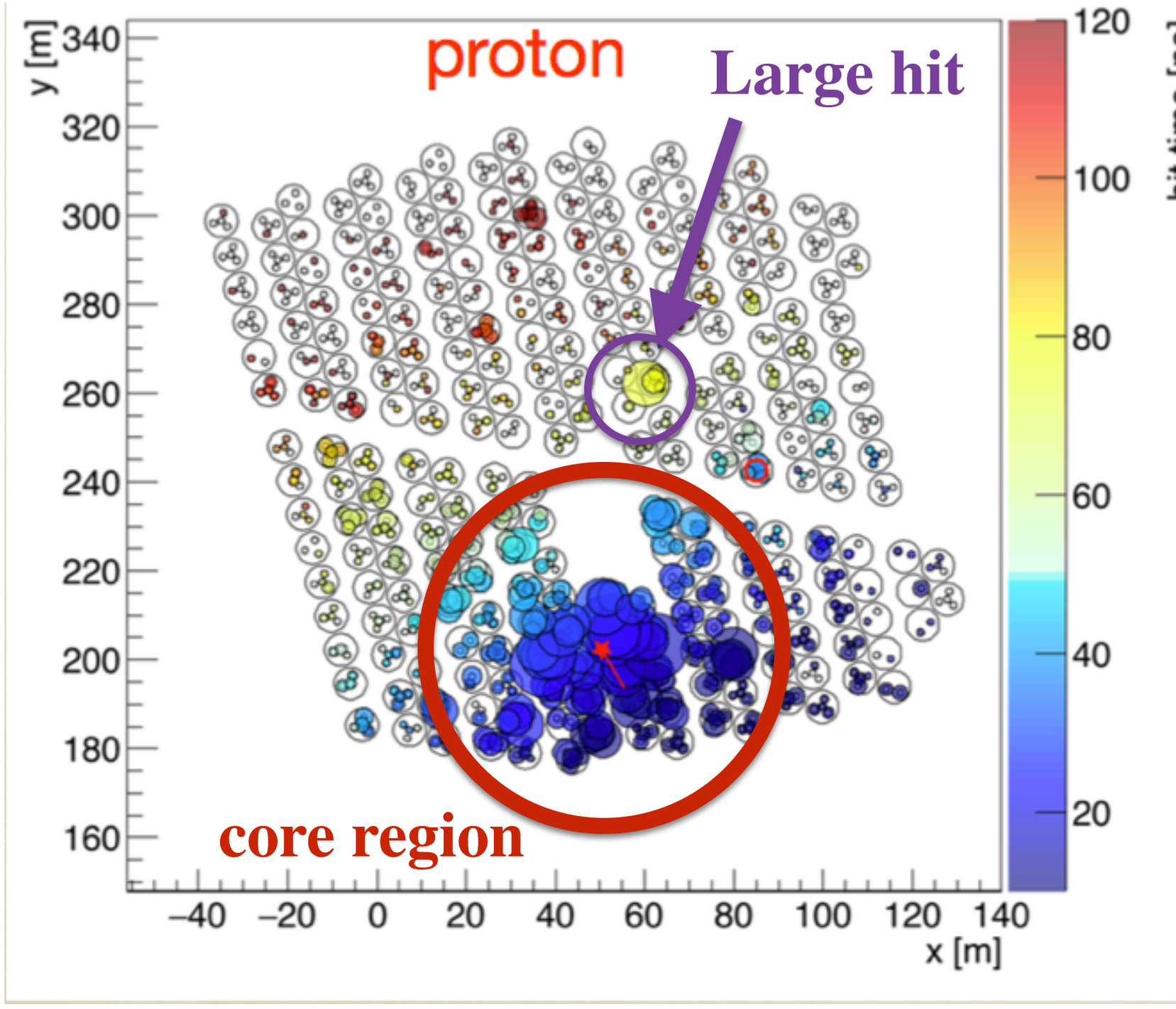


Shower type identification

1/Compactness:

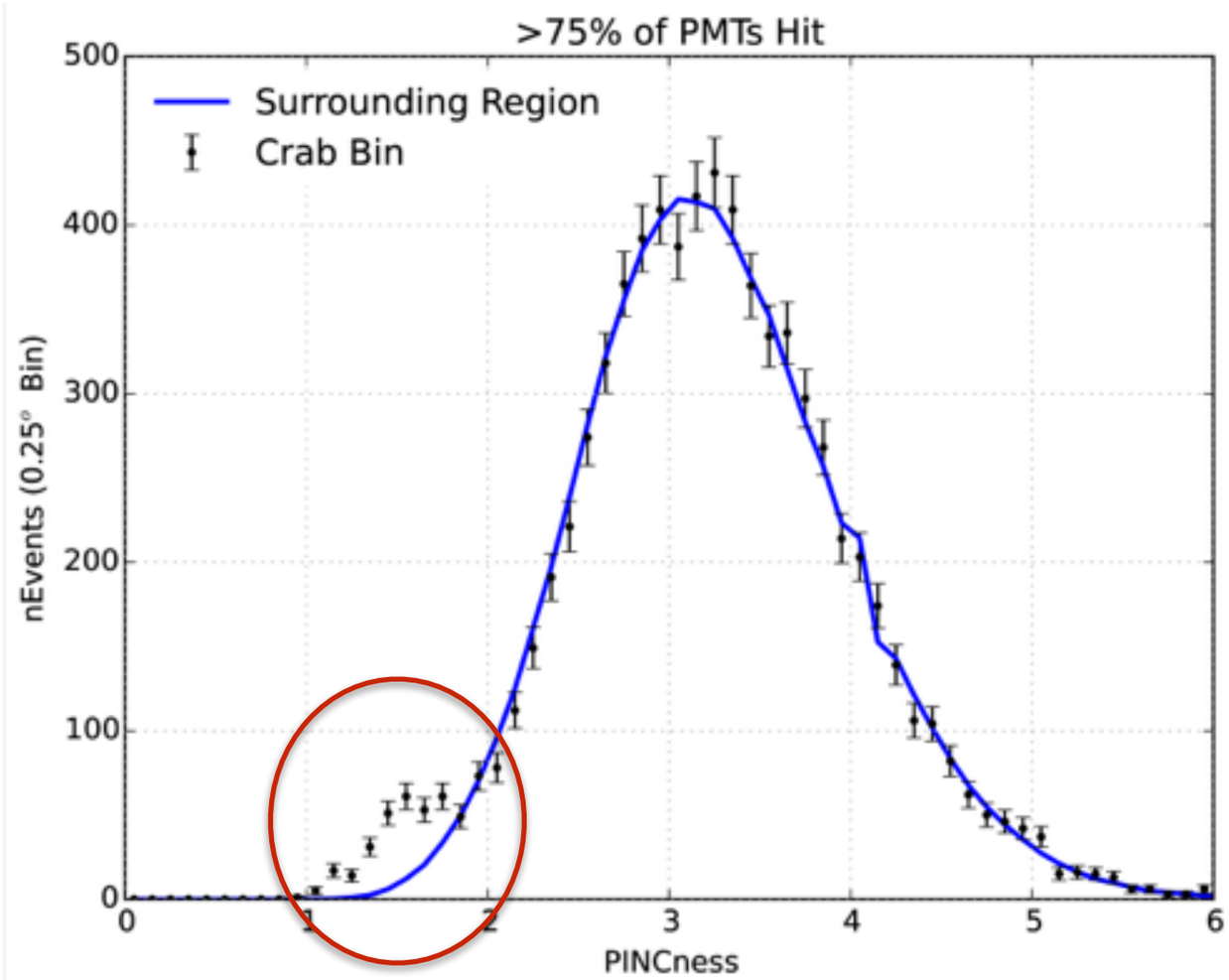
Largest signal outside the impact region compared to the number of pmt hit: $\mathbf{Q_{max}/N_{sp}}$

Sensitive to sub-showers & muons

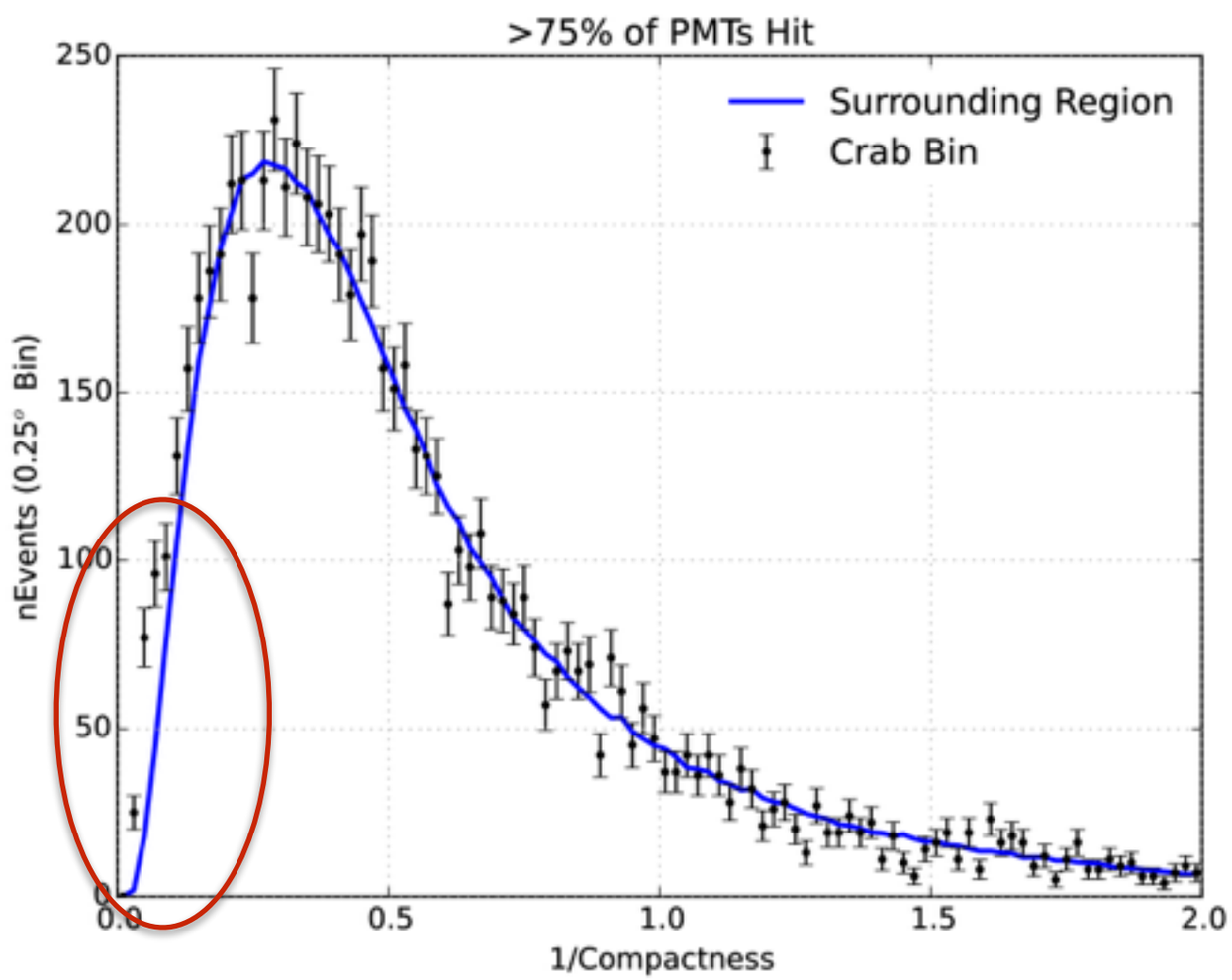


Shower type identification using the crab-region

PINC

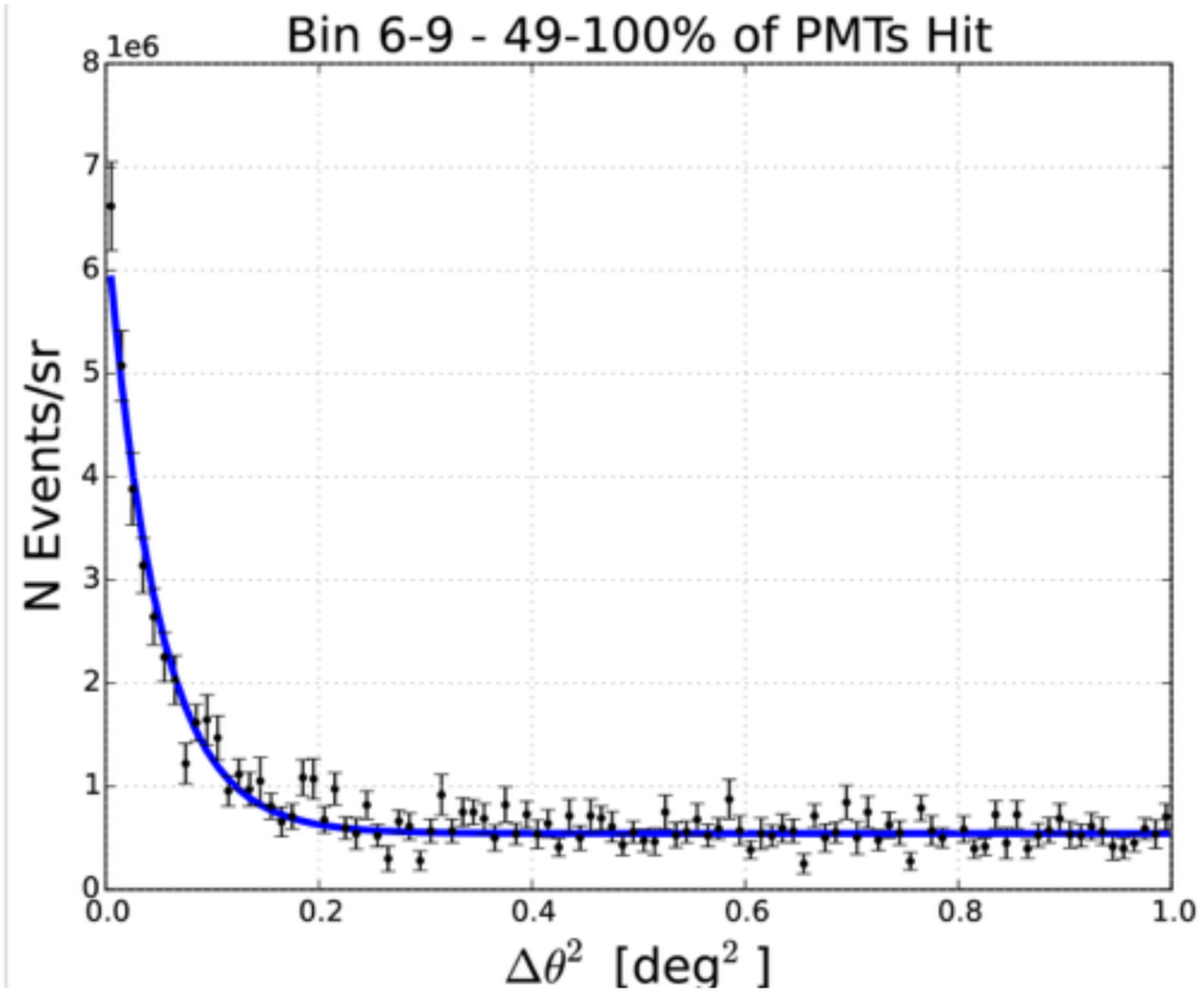


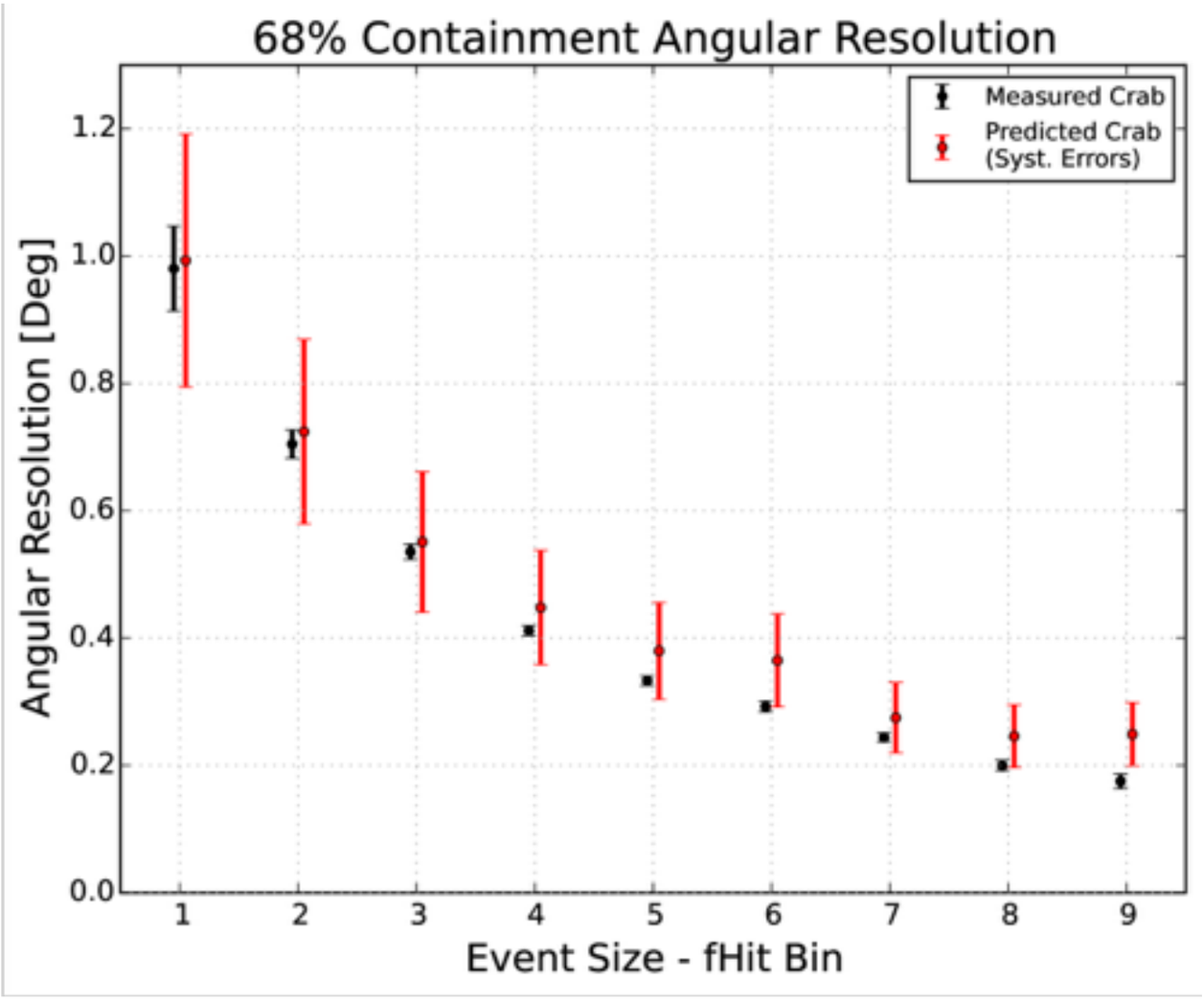
1/Compactness



Distribution in the presence of a γ-ray source follow a different distribution than background regions

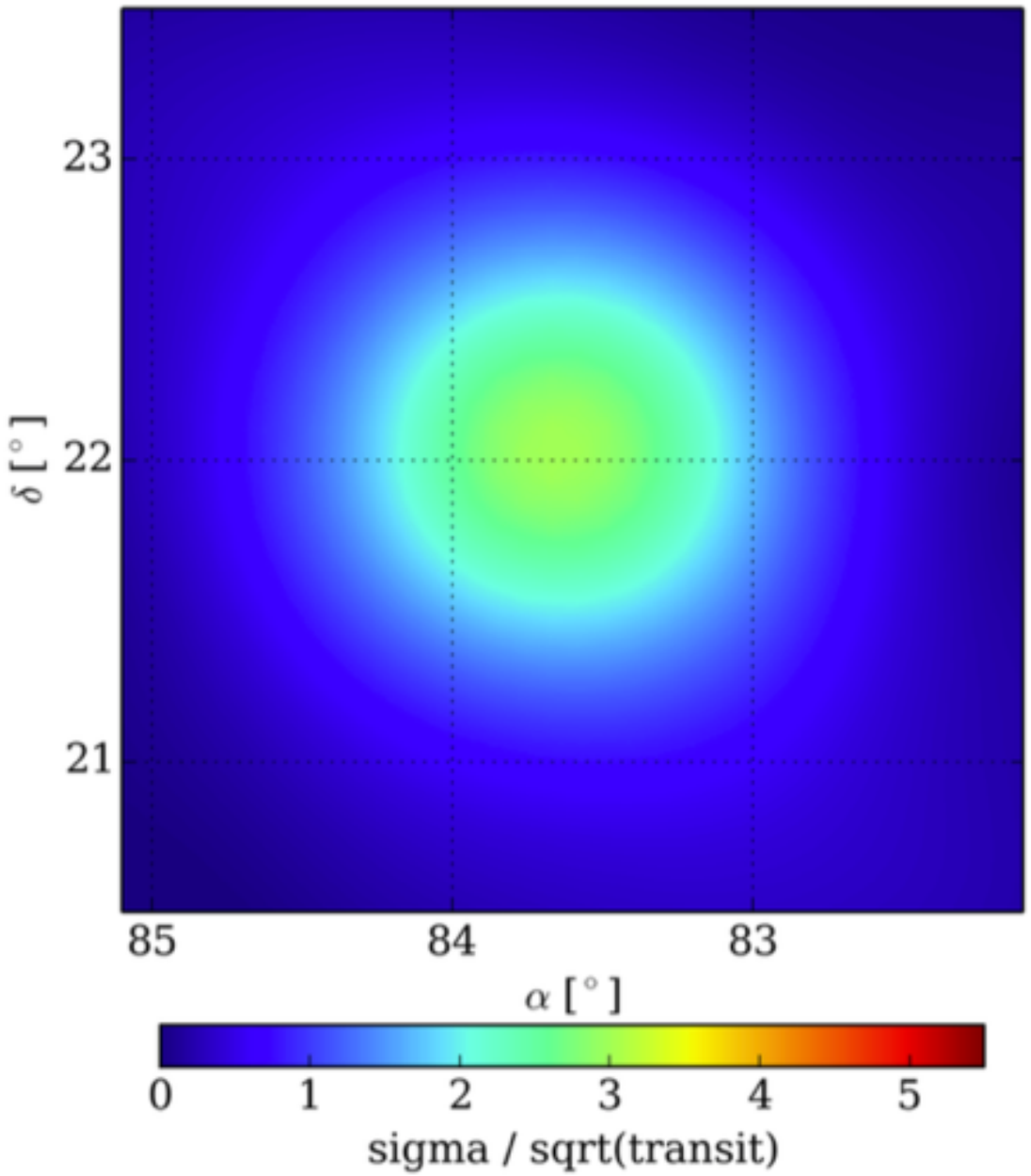
Angular reconstruction performance using the crab



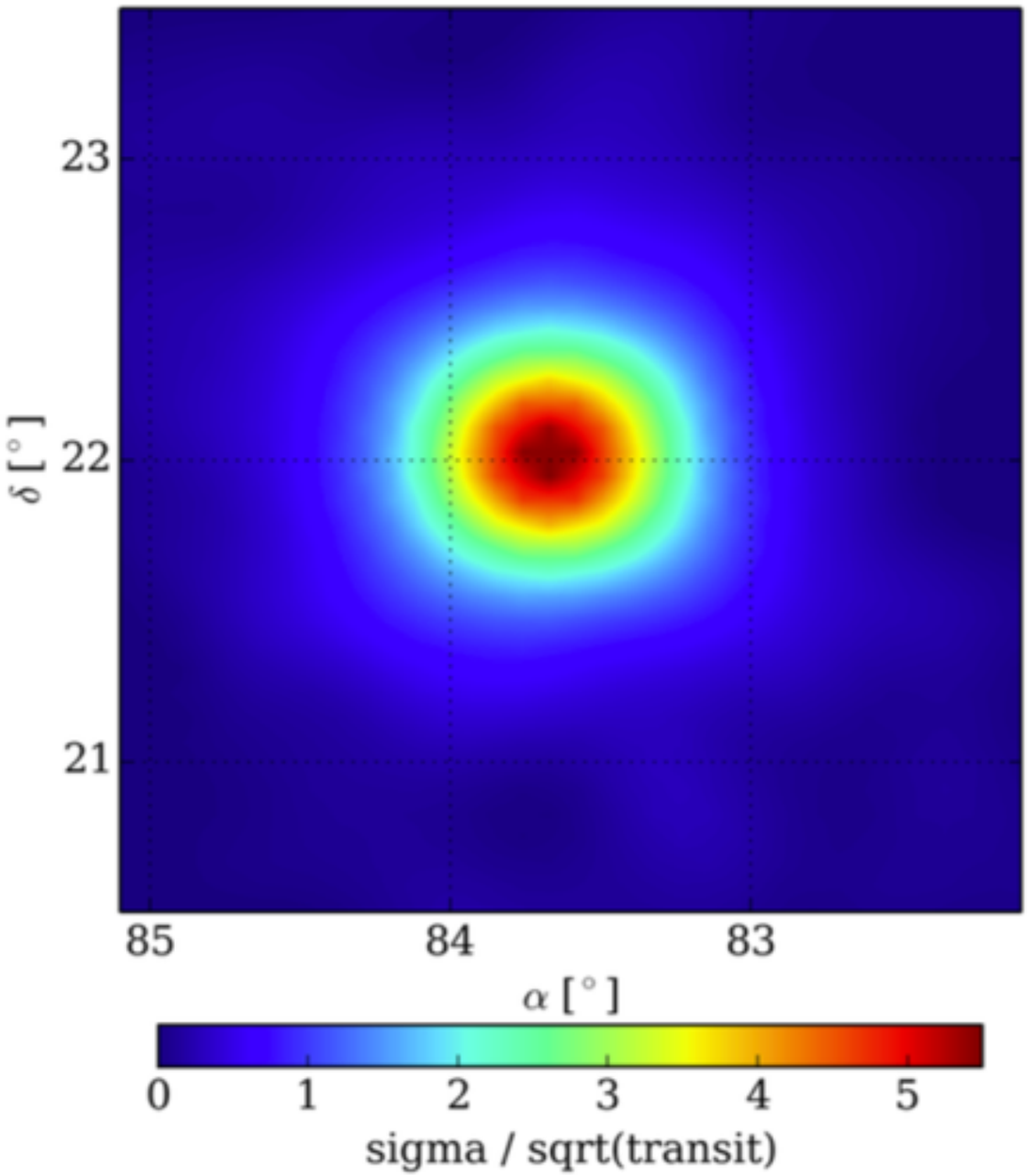


Improvements on the shower reconstruction algorithms

Pass 3

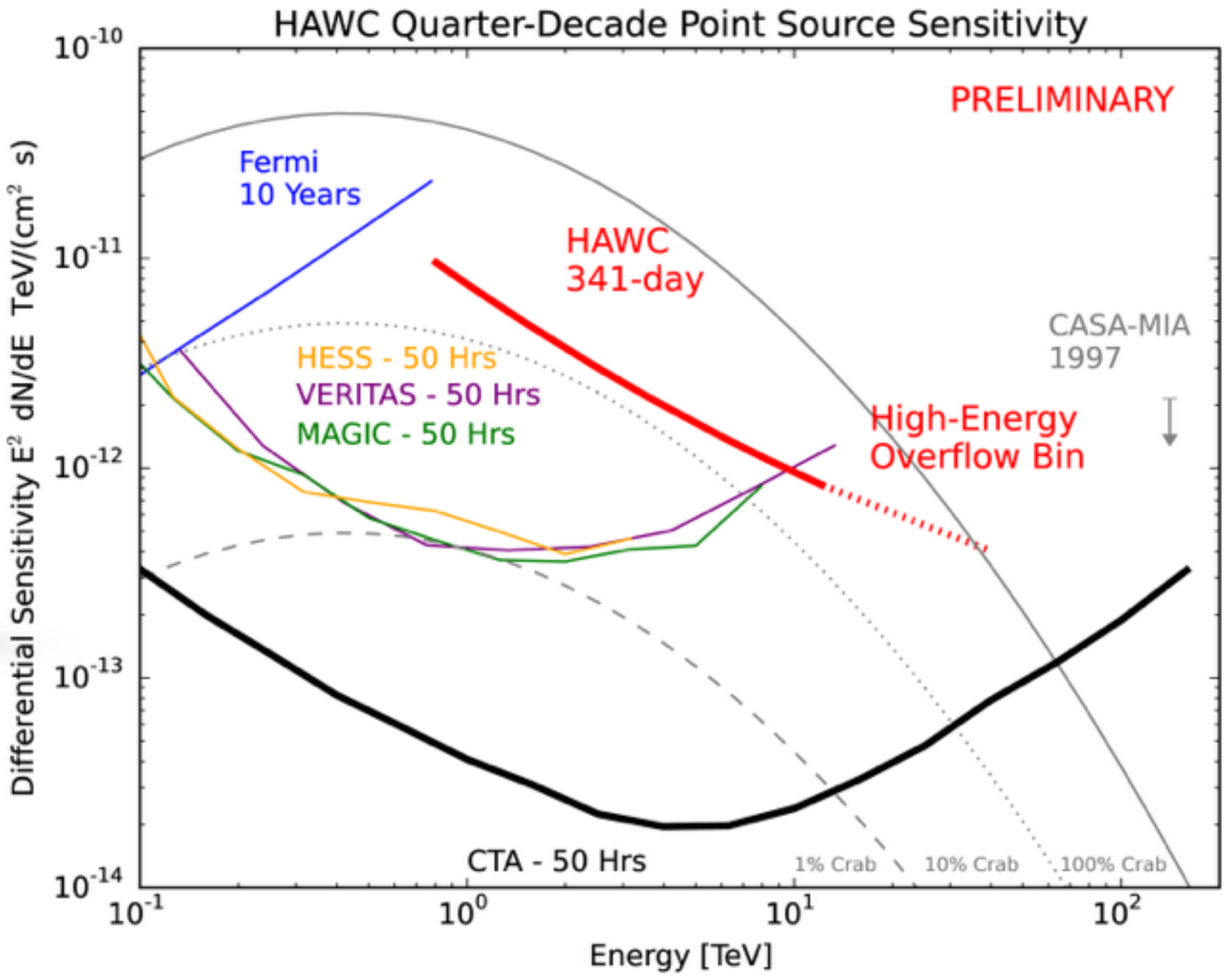


Pass 4

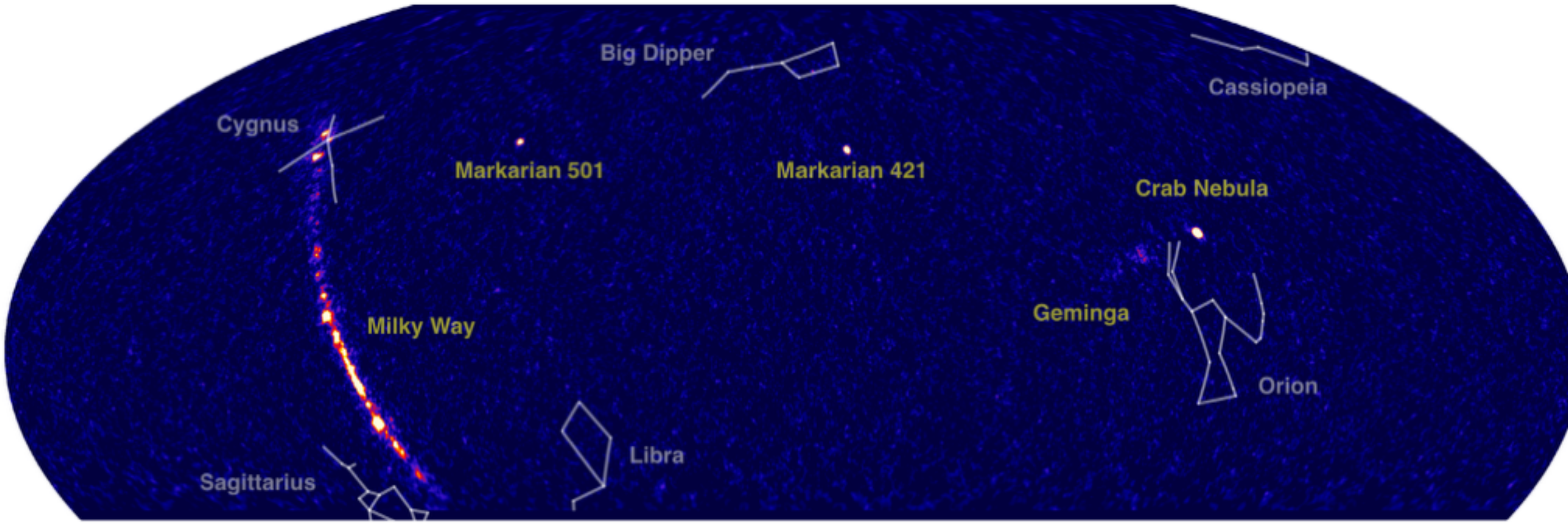


Performance: Point Source Sensitivity

- **15 times more sensitive than previous generation WCD (Milargro)**
- **Above 10 TeV more sensitive than current IACTs for point sources within a year**

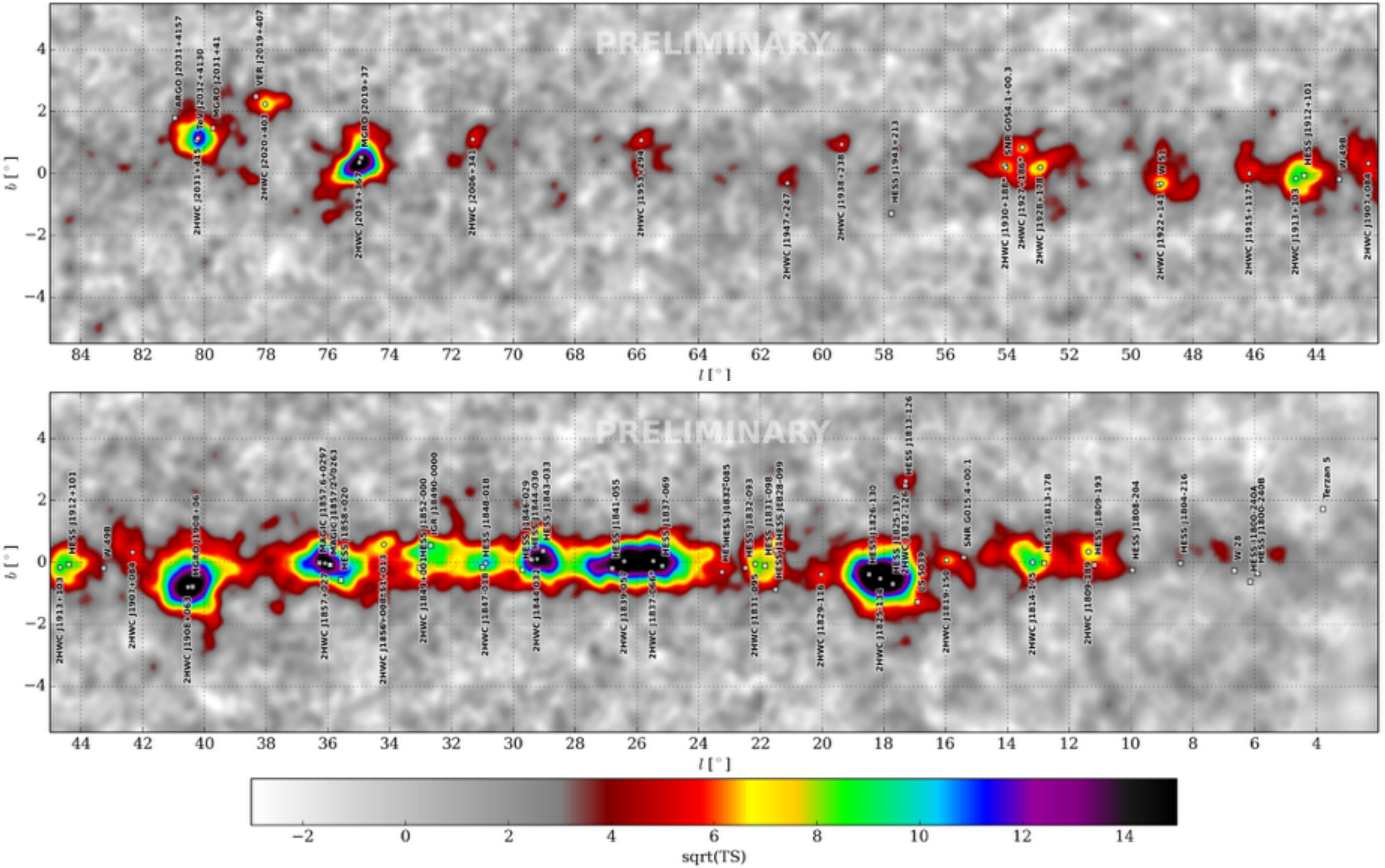


The TeV γ-ray sky observed by HAWC



- 340 days from November 2014 - November 2015
- ~2/3 of the full sky, every day!!!
- > 95 % uptime

Galactic sources: inner galactic plane (403 days)

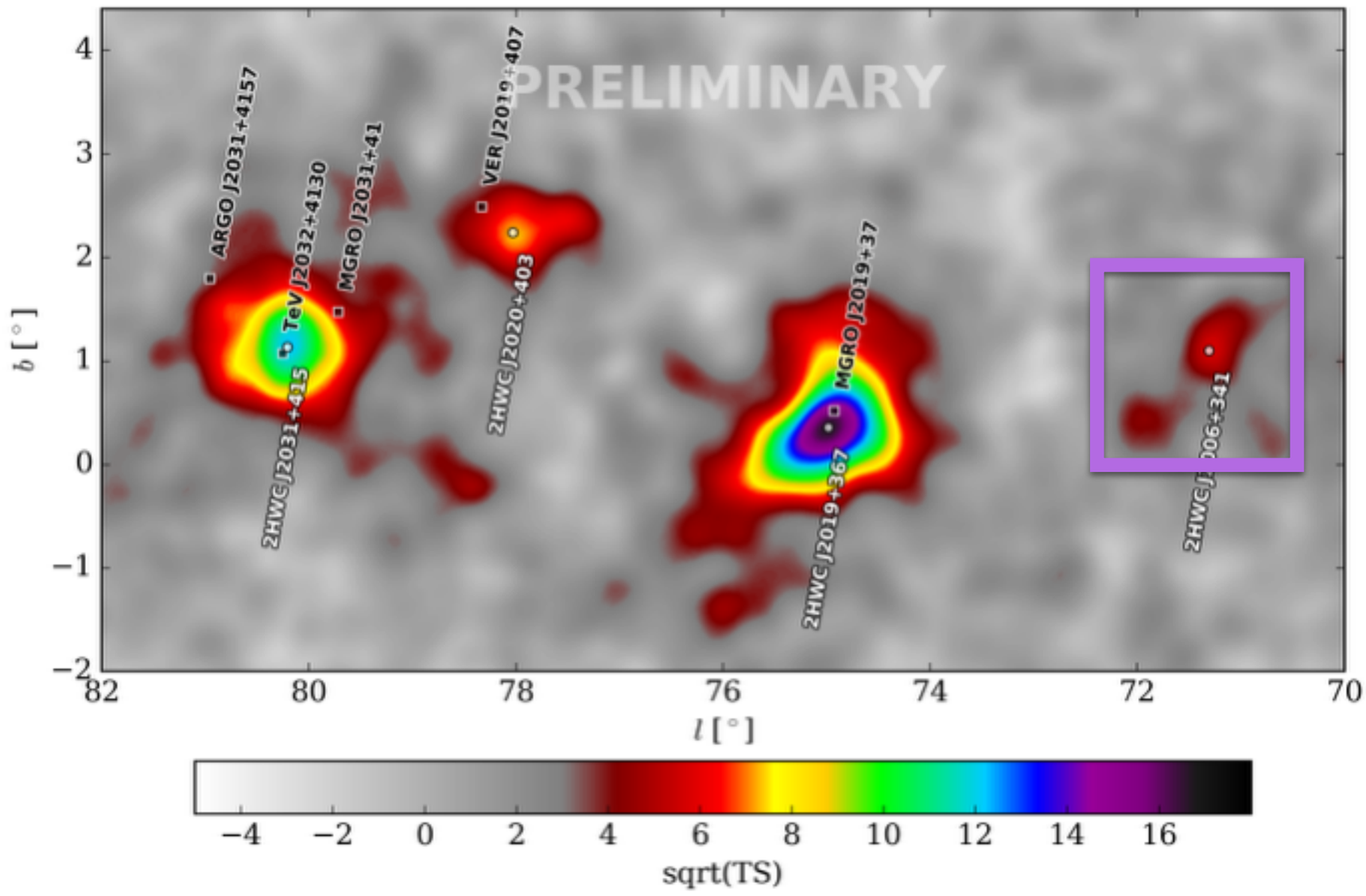


Galactic sources: Cygnus region (403 days)

New TeV source:

2HWCJ2006+341

> 6σ pre-trails



Galactic sources: Cygnus region (403 days)

New TeV source:

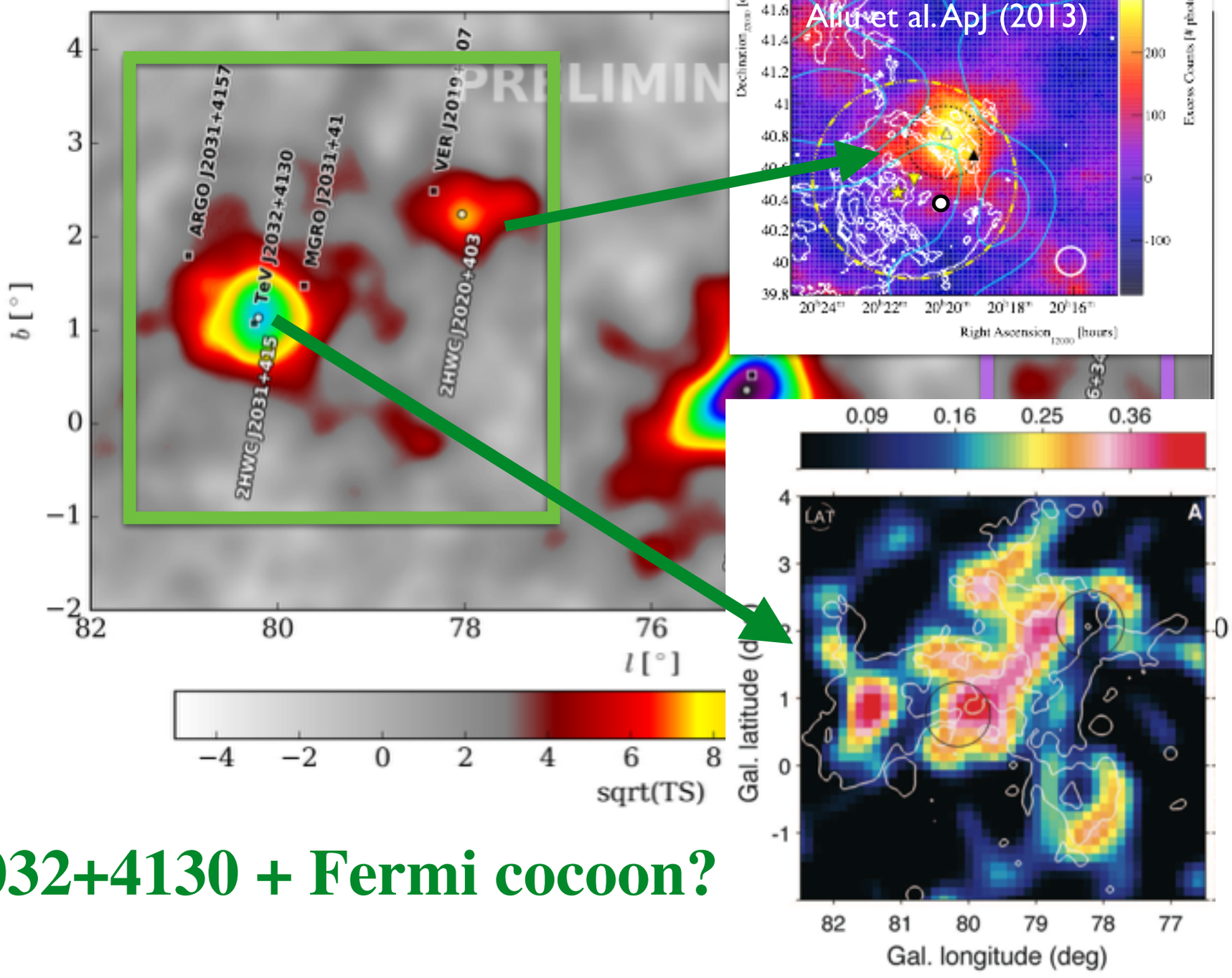
2HWC J2006+341

> 6σ pre-trails

MGRO J2013+403

resolved into two sources:

- 2HWC J2020+403 (VER J2019+407)
-2HWC J2031 + 4026 (TeV J2032+4130), a PWN or binary?



TeVJ2032+4130 + Fermi cocoon?

M. Ackermann *et al* Sci. (2011)

Galactic sources: Cygnus region (403 days)

New TeV source:

2HWC J2006+341

> 6σ pre-trails

MGRO J2013+41

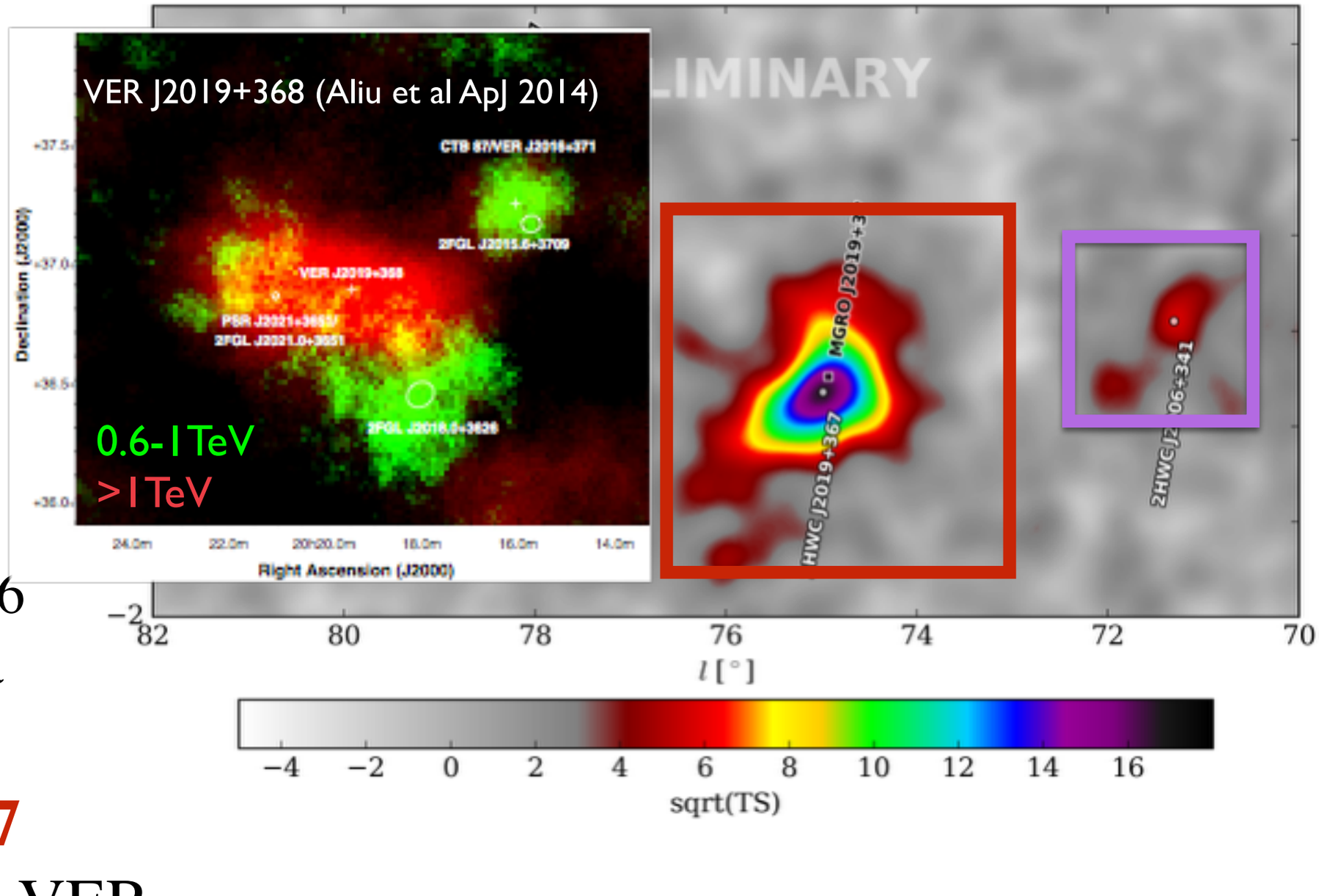
resolved into two sources:

- 2HWC J2020+403 (VER J2019+407)

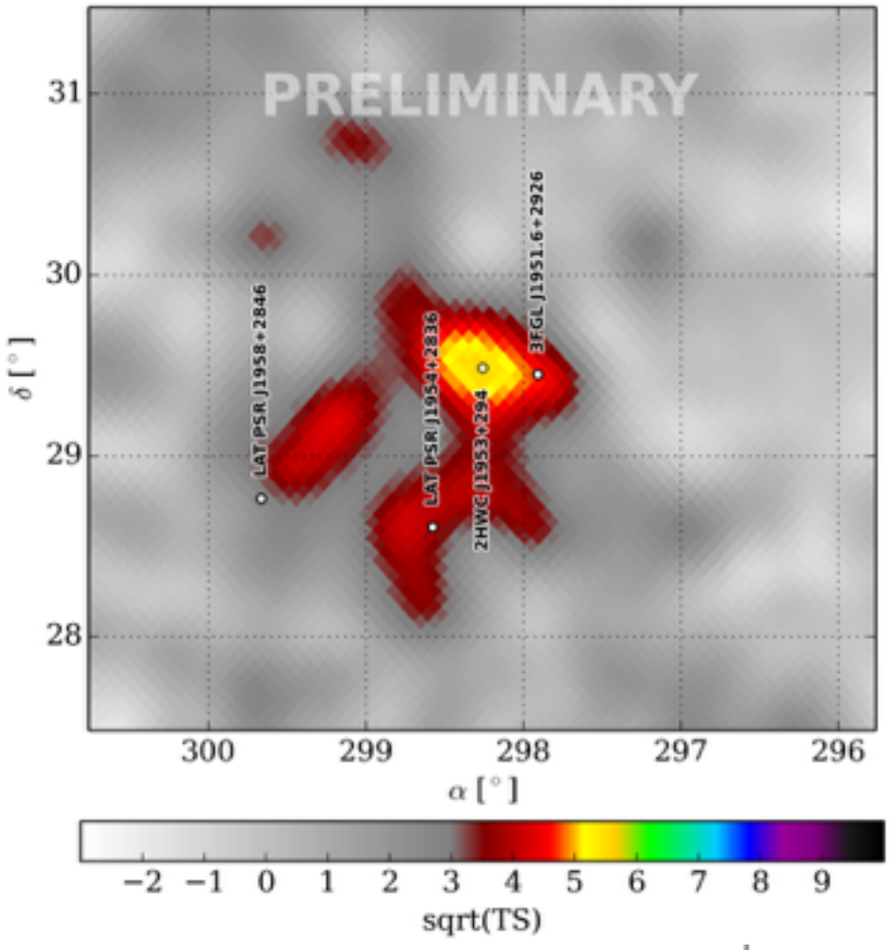
-2HWC J2031 + 4026 (TeV J2032+4130), a PWN or binary?

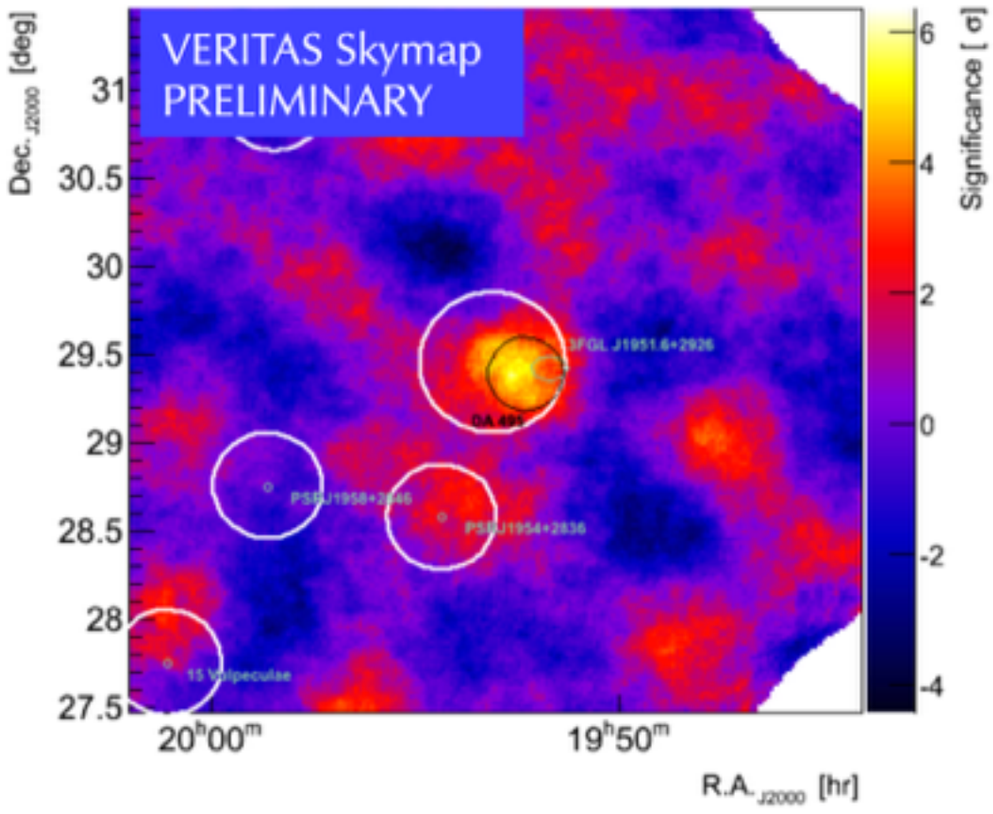
2HWC J2019+367

(MGRO J2019+37 VER J2019+368)



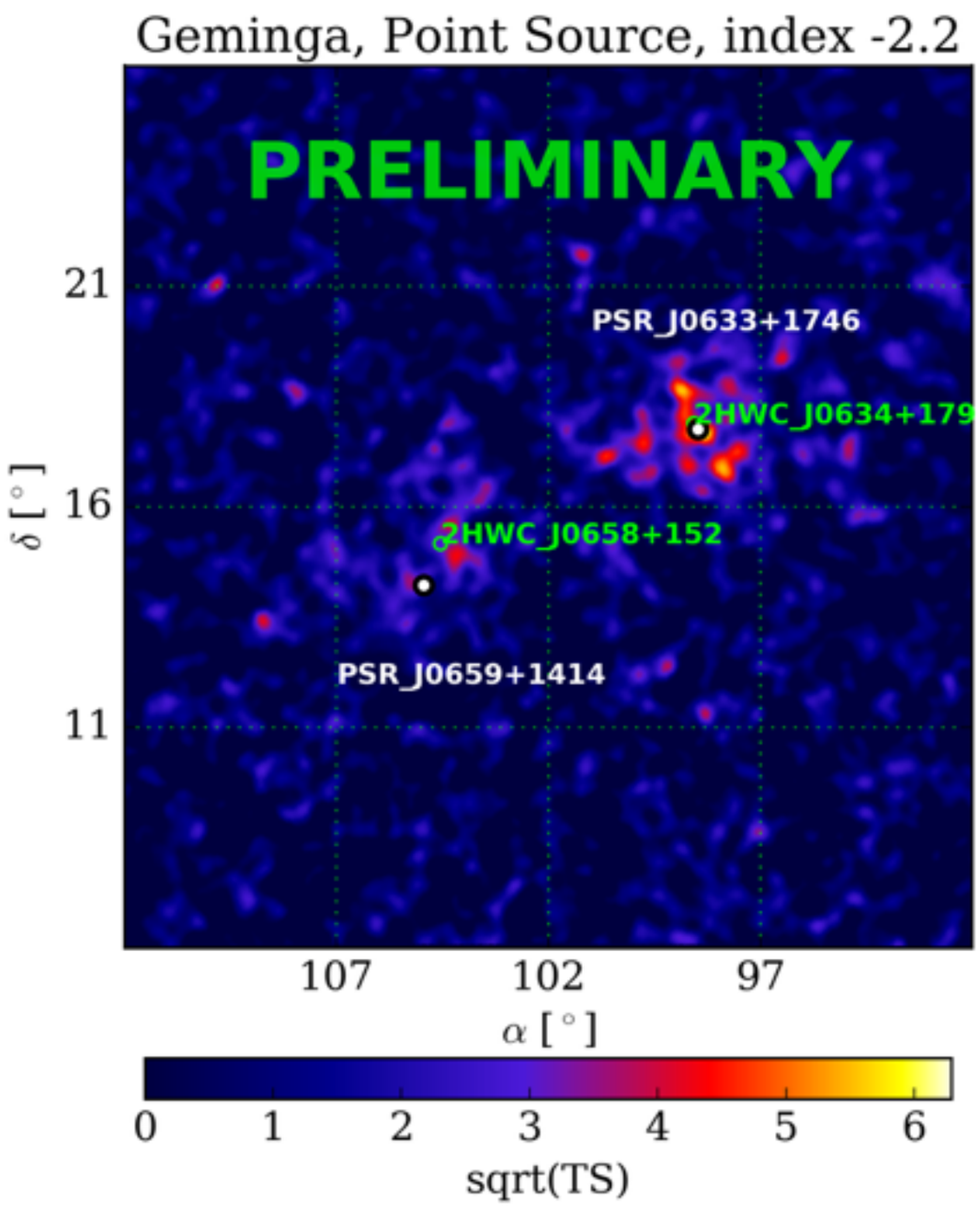
Galactic sources: HAWC source confirmed by Veritas

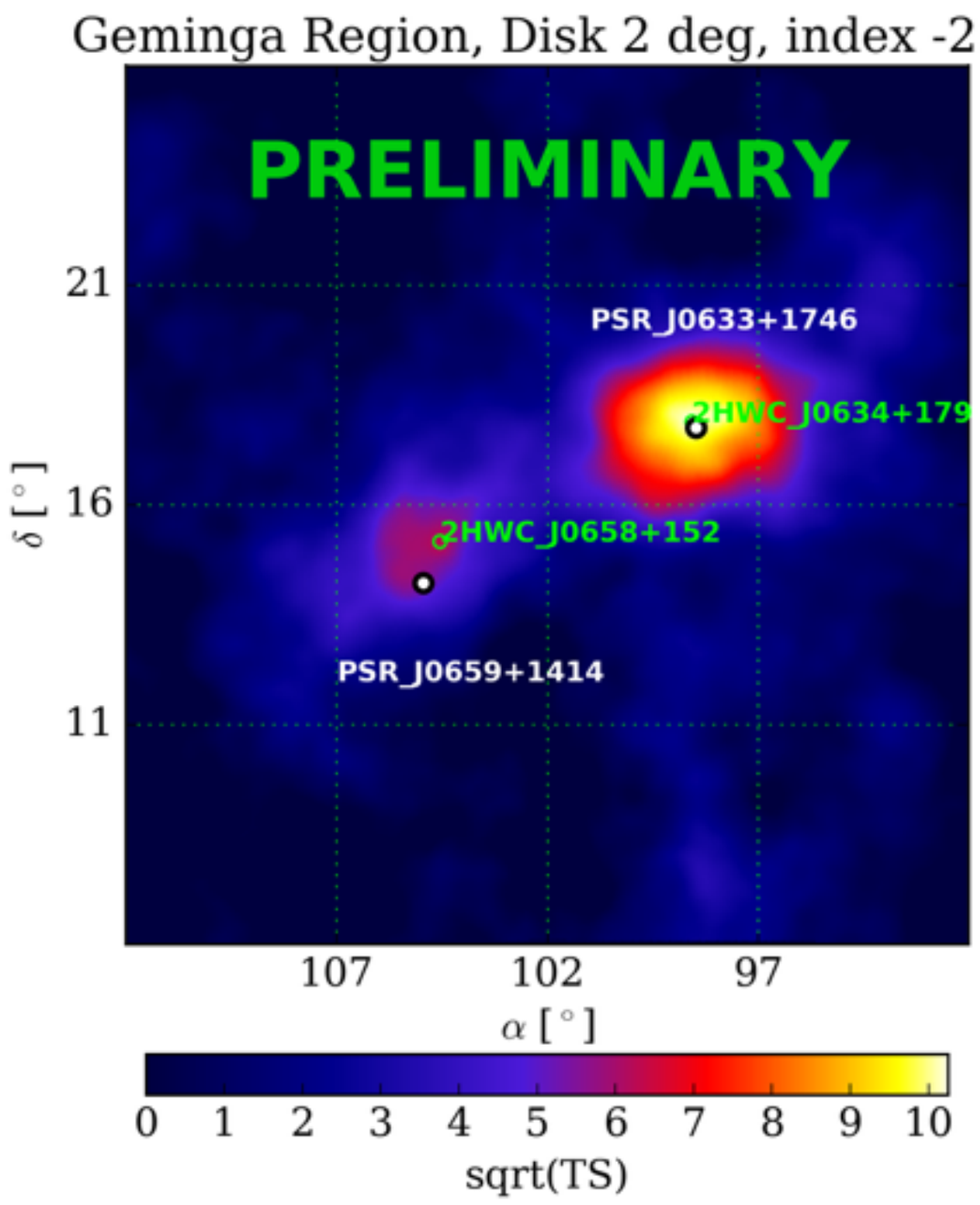




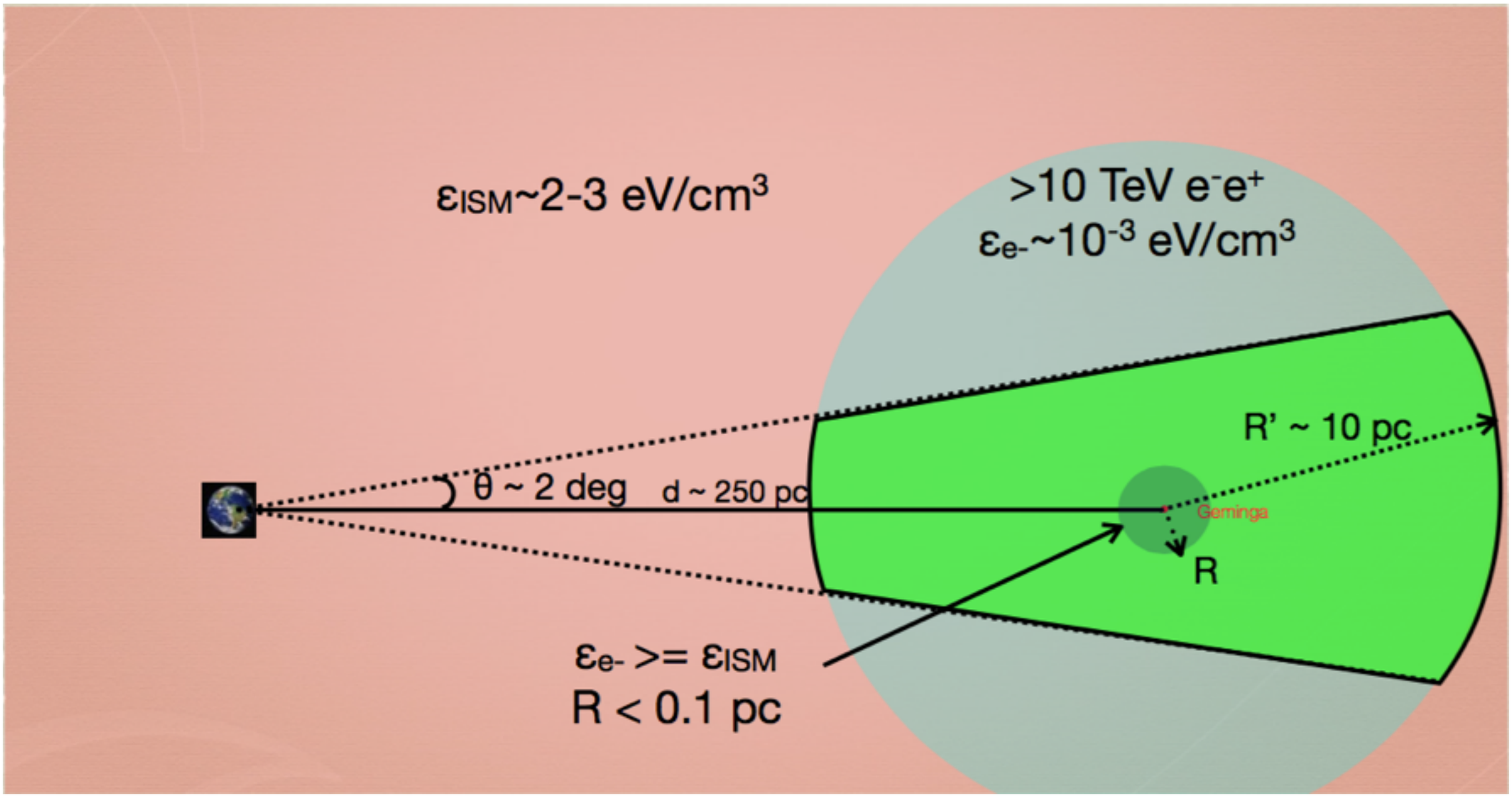
Name	$\sqrt{TS}$	Index	Flux for index at 7 TeV [$\mathrm{TeV^{-1}cm^{-2}s^{-1}}$]
2HWC J1953+294	5.58	-2.76 ± 0.15	1.1e-14 ± 4.2e-15

Galactic sources: Nearby old pulsars (>100 kyr)





Galactic sources: Nearby old pulsars

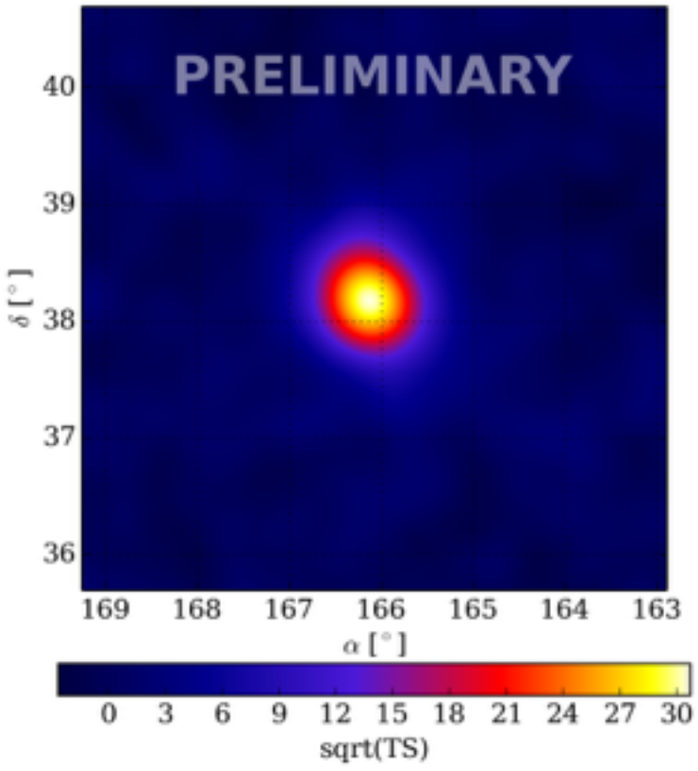


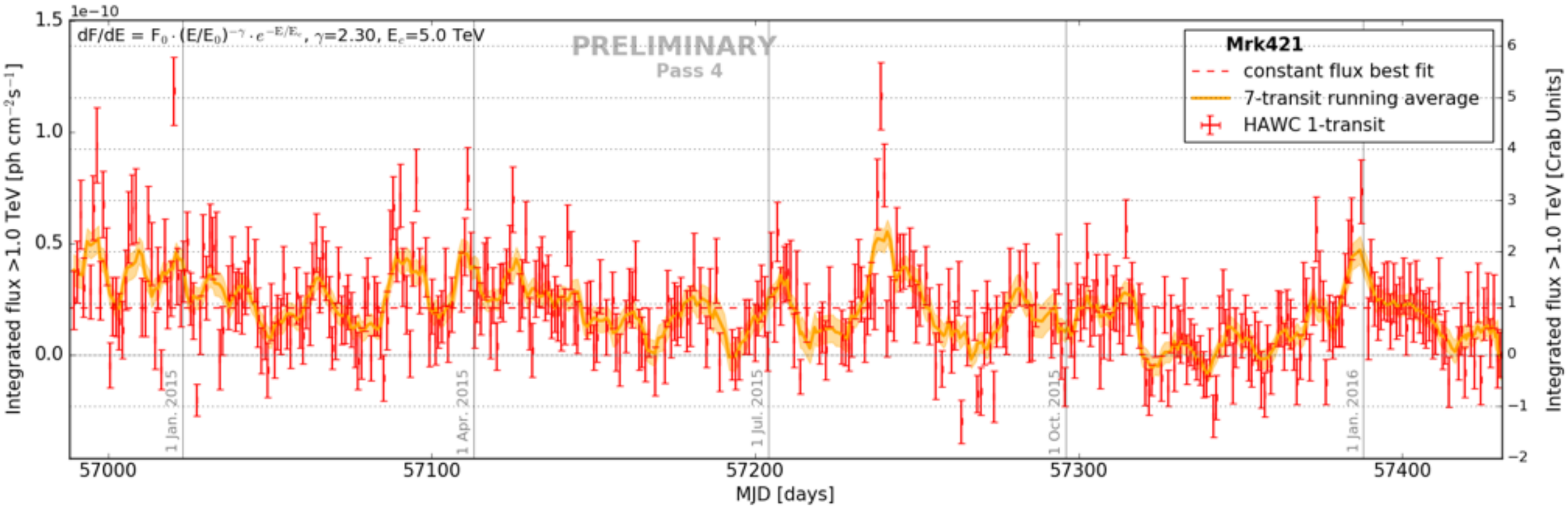
- Energy budget ~10^{44} erg: the emission is not coming from the standard PWN, but from emission from electrons the ISM
- Potential source for the e^+/e^- excess observed near Earth => Using energy dependent morphology to constrain e+e- flux at Earth

Extra-galactic sources: Mrk421

Monitoring the variations in the light curves on a daily basis

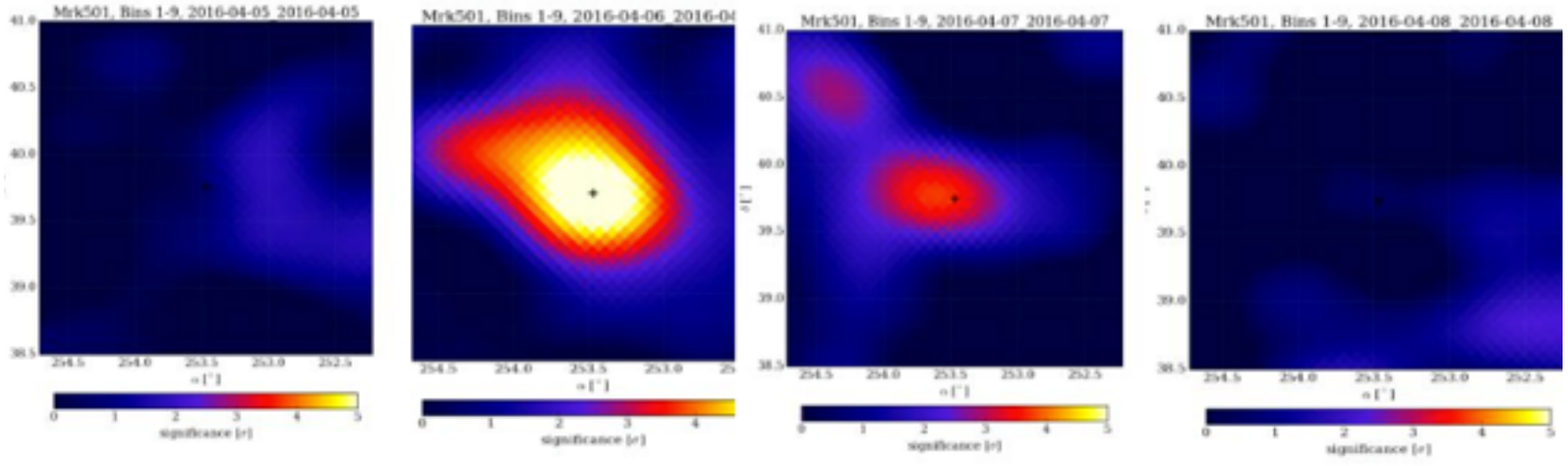
Correlation studies with
Fermi-LAT, Swift-BAT, FACT ongoing

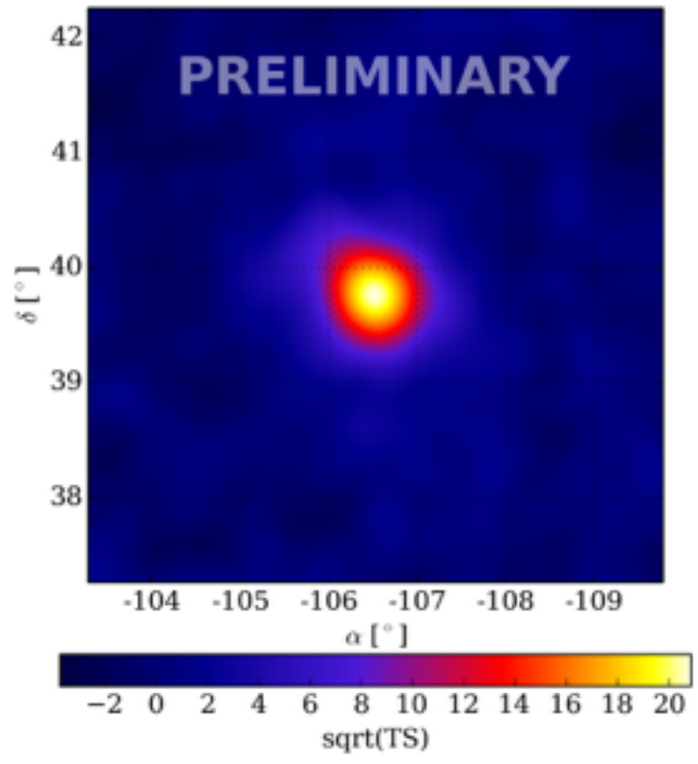




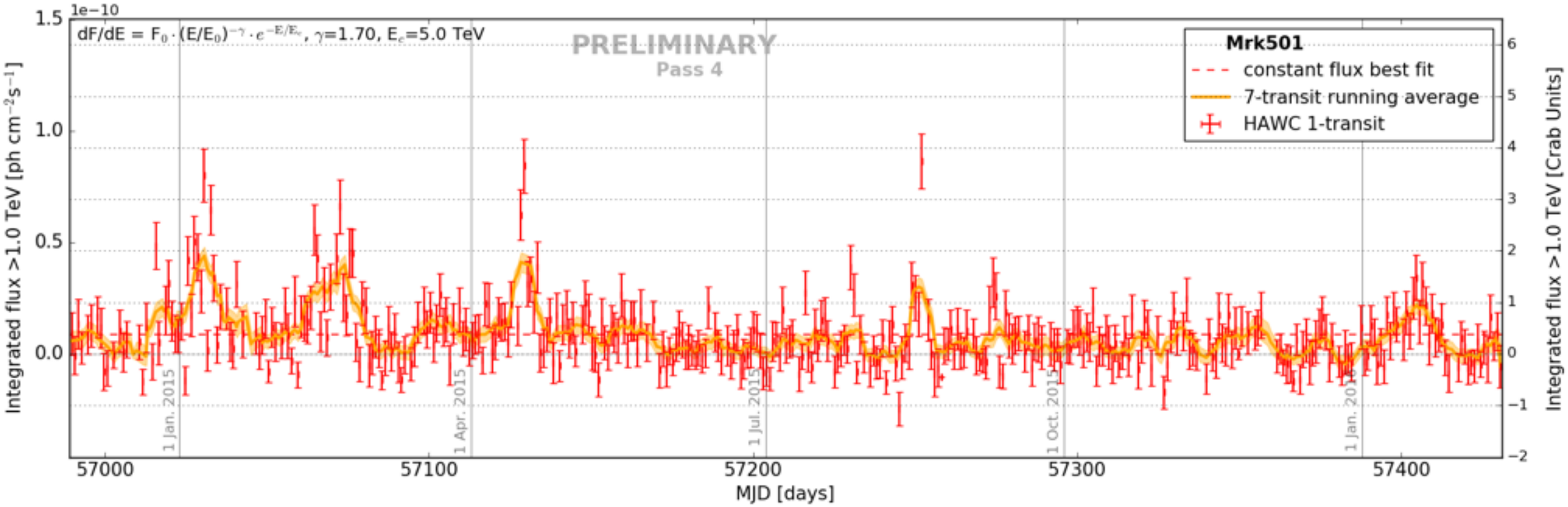
Extra-galactic sources: Mrk501

First ATEL send out on 6th of April 2016

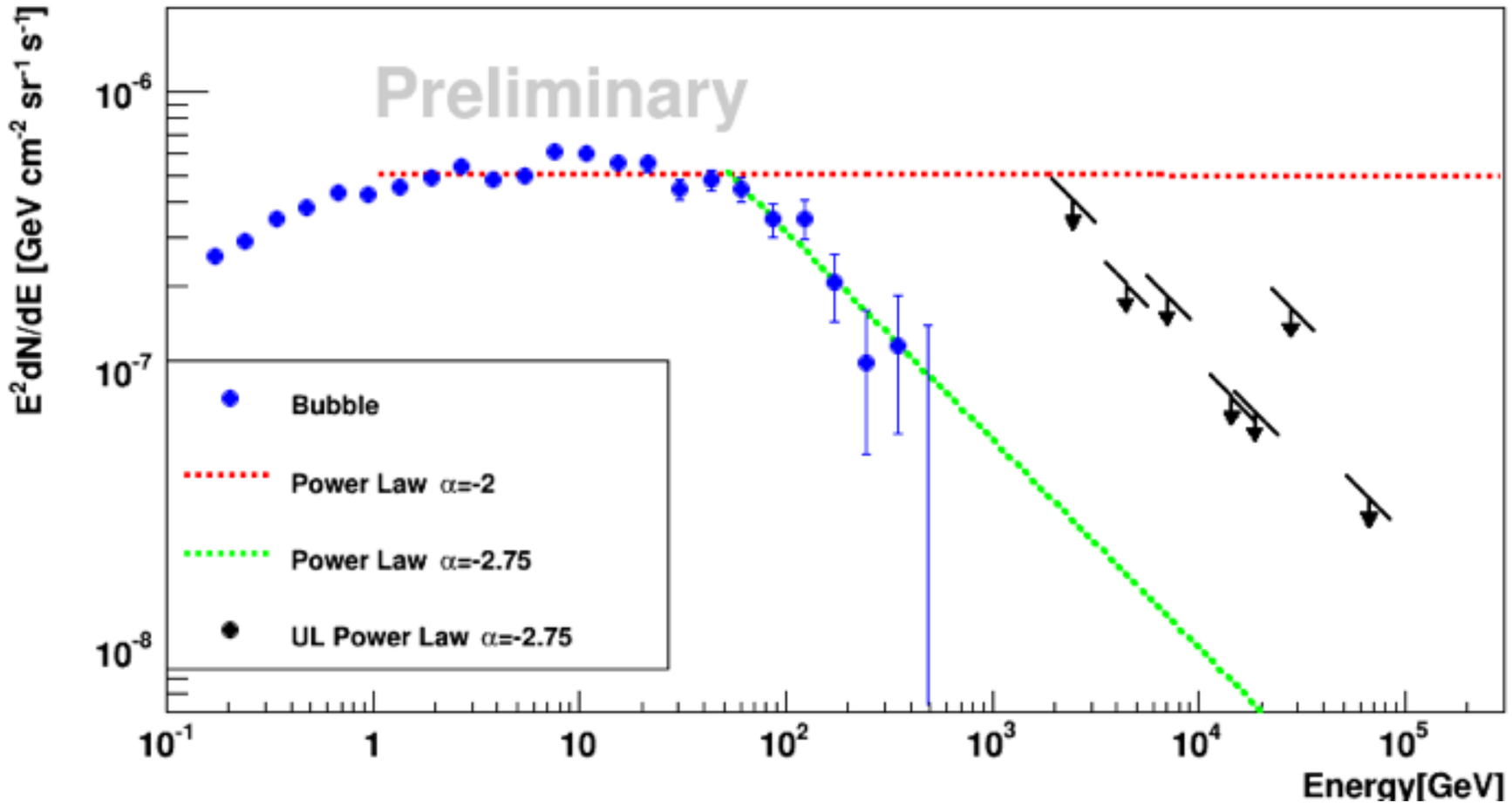




~2 Crab units, elevated flux for ~2 days

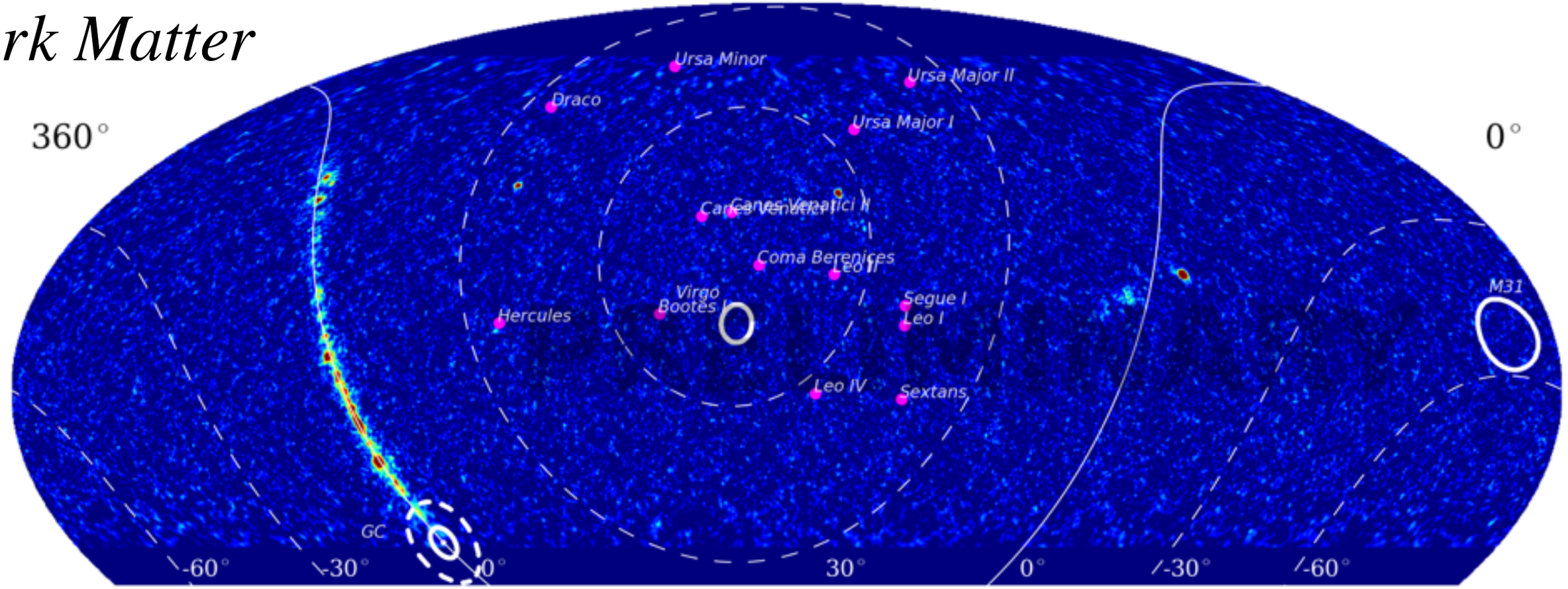


Fermi-Bubbles



- Currently no excess found
- Upper-limits set at 95% confidence level
- Improvements expected: improvement in the reconstruction of small showers, more accurate energy estimator, more data

Dark Matter



Annihilation

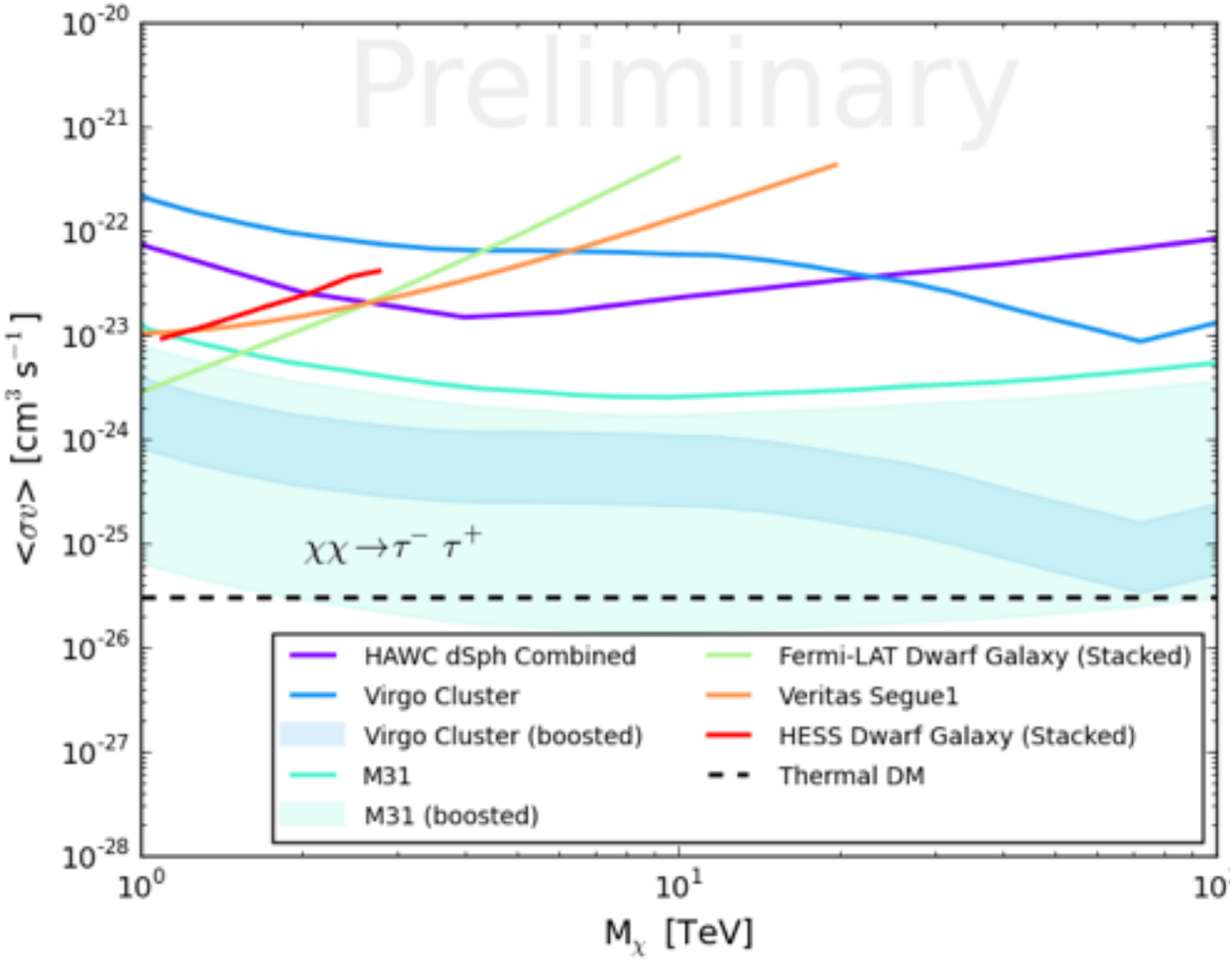
$$Flux_{ann} \propto \frac{\langle \sigma v \rangle}{M_\chi^2} \frac{dN_\gamma}{dE} \underbrace{\int d\Omega \int_{l.o.s.} dx \rho^2(r)}_{\text{J - factor}}$$

Decay

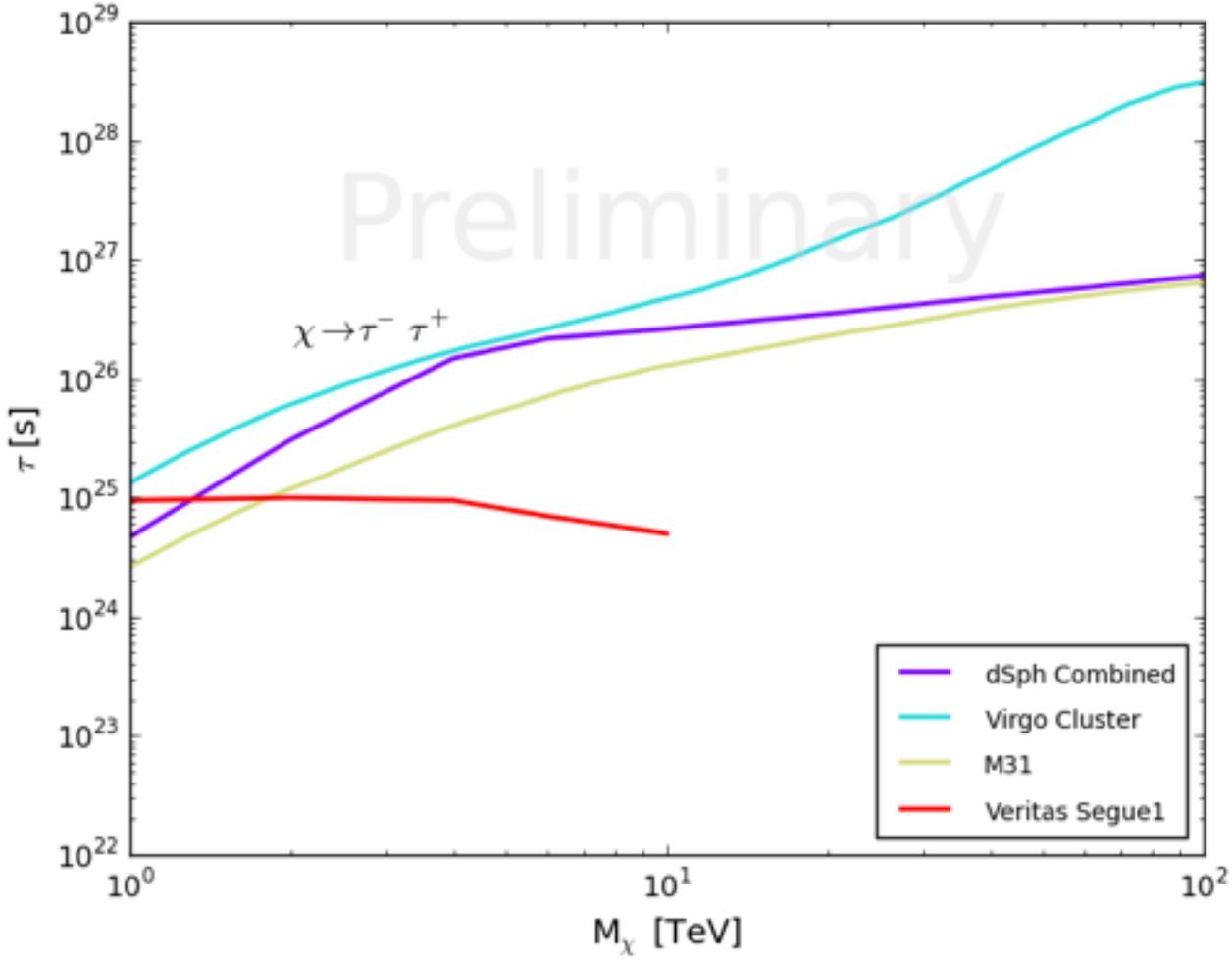
$$Flux_{decay} \propto \frac{1}{\tau} \frac{1}{M_\chi} \frac{dN_\gamma}{dE} \underbrace{\int d\Omega \int_{l.o.s.} dx \rho(r)}_{\text{D - factor}}$$

Dark Matter

Annihilation cross section



Decay time



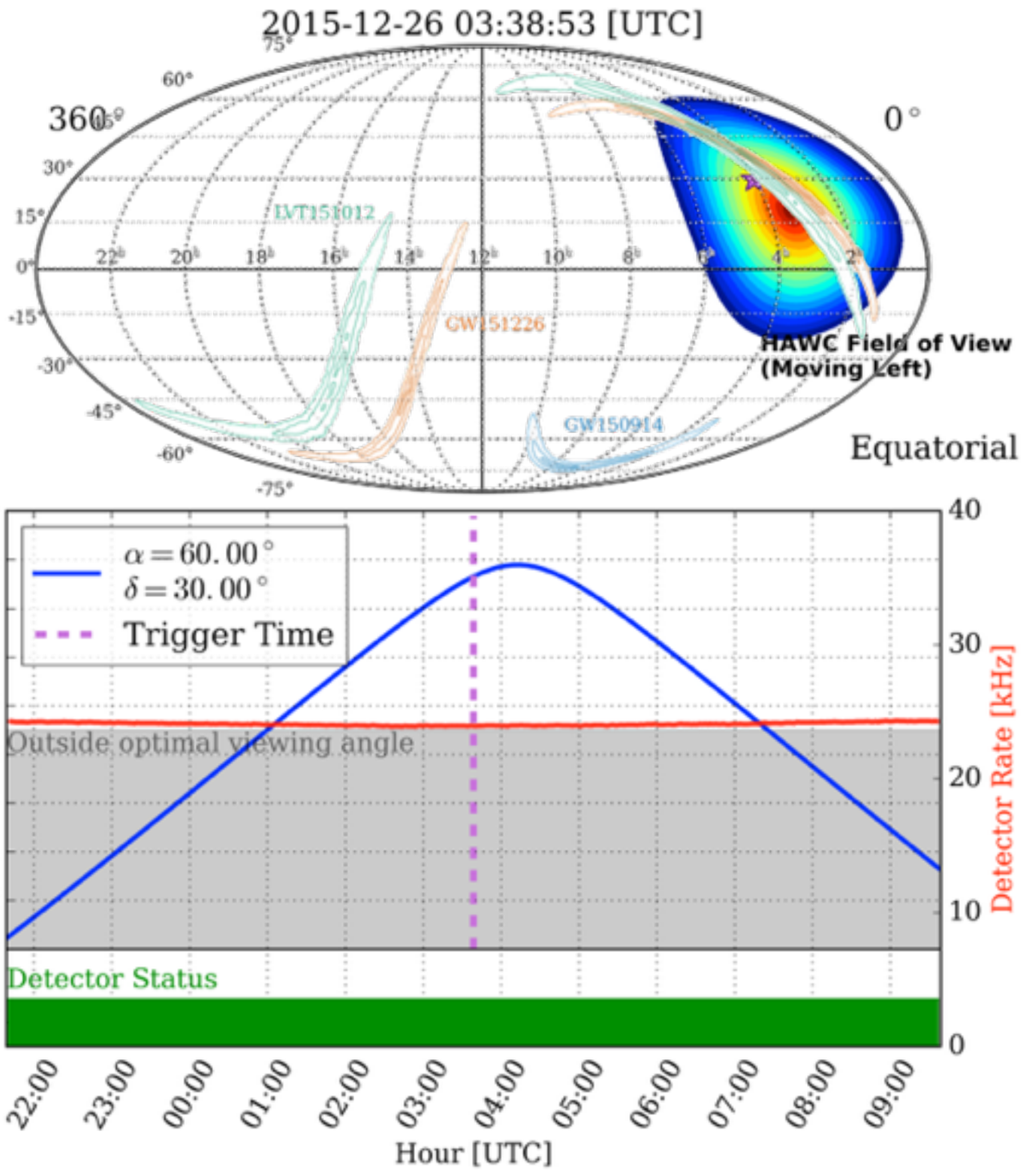
- Examples results of 14 stacked dSph, M31, Virgo for annihilation and decay in $\tau^+ \tau^-$: Paper in progress (stay tuned!)
- Improvements expected: More dSph, better event reconstruction at lowest and highest energies, more data

Follow-up on Ligo's Gravitational Waves

GW151226

- 2015 Dec 26 03:38:53.6 UTC
- >5 sigma
- 14.2M⊙ + 7.5M⊙ ➡ 21.8M⊙
- z=0.09 +0.03 -0.04

In HAWC we found a transient 9.93 seconds after the LIGO trigger with a duration of 10 s with 5 σ pre-trial but with a post-trial p=0.08 it is compatible with background.

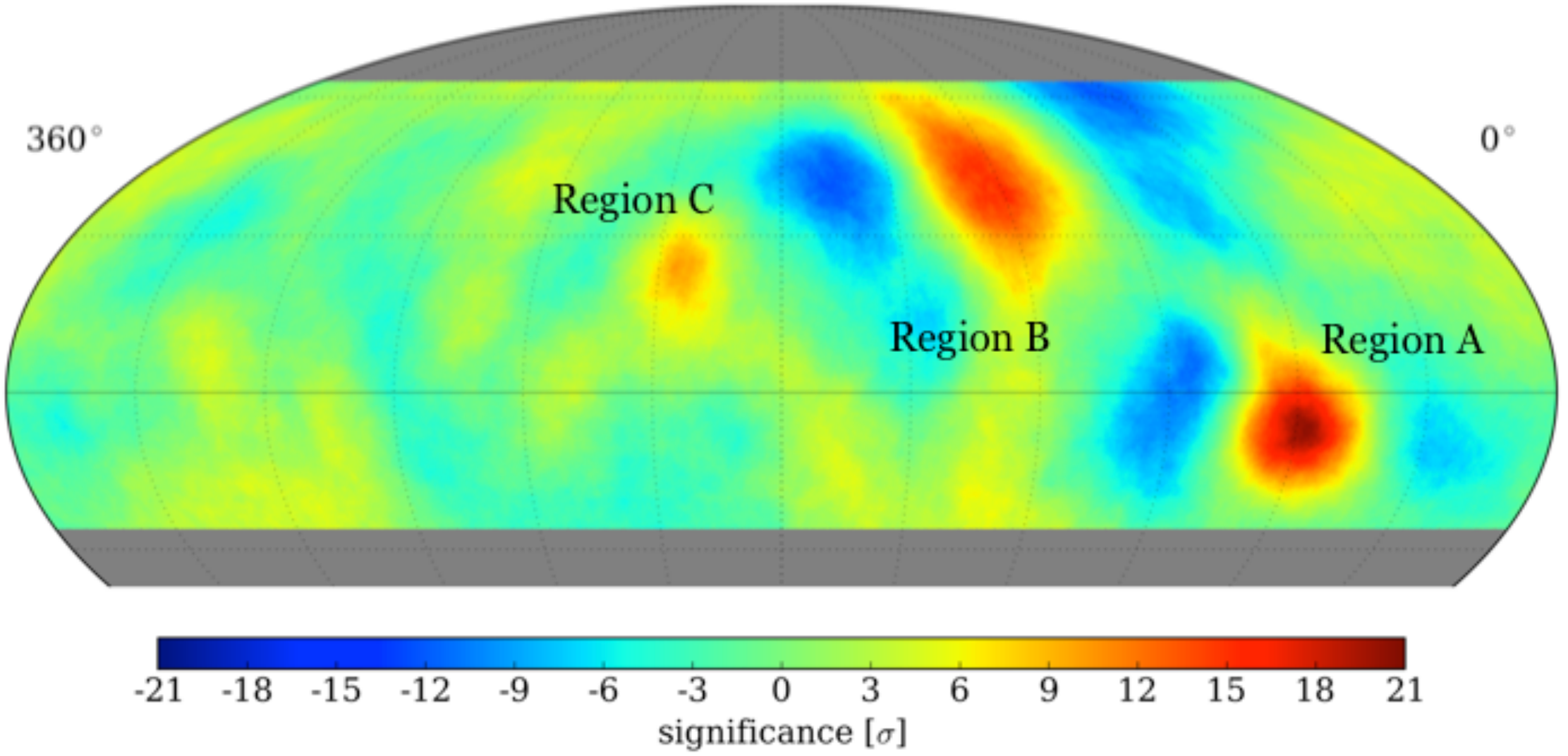


Cosmic rays Anisotropy

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])

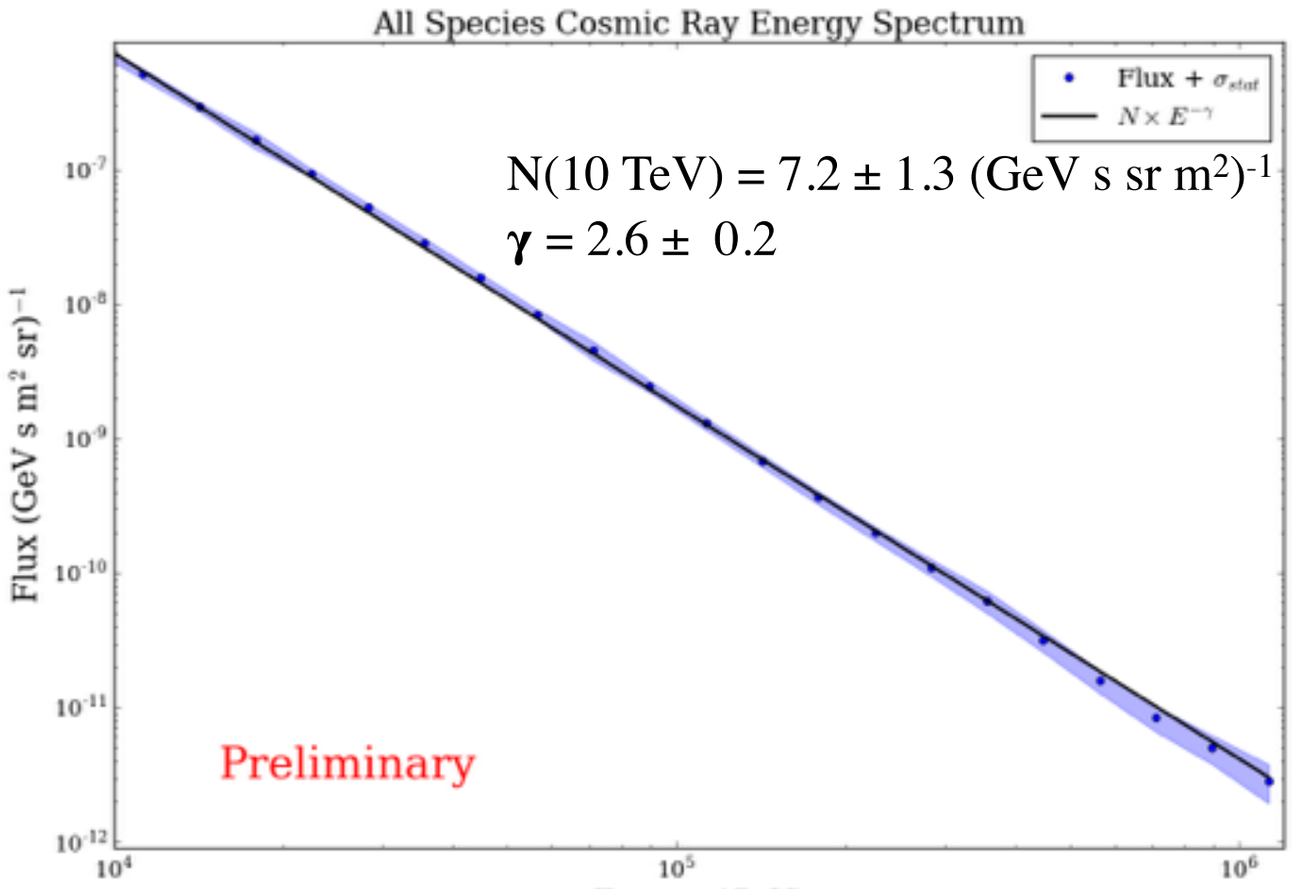
3 significant excesses
- A – strongest, harder spectrum than bkg, at ~10 TeV consistent with Milagro
- B – most extended
- C – confirms Argo-YBJ observation



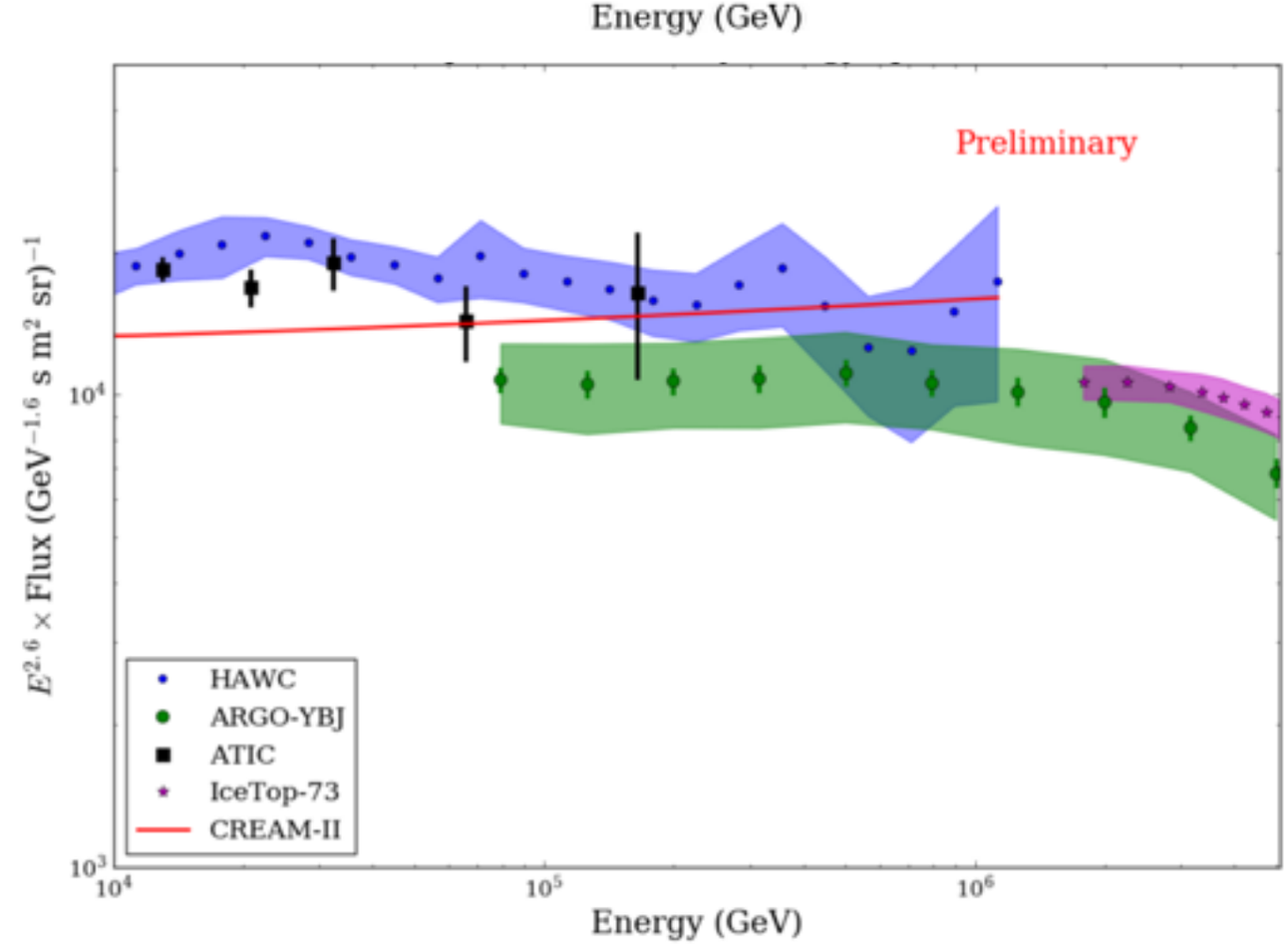
Cosmic rays spectrum

All particle cosmic ray spectrum from 0.01 - 1 PeV

Strict cuts on zenith angle and core location



Consistency with other experiments



Summary

2/3 of the sky observed with full sensitivity over one year:

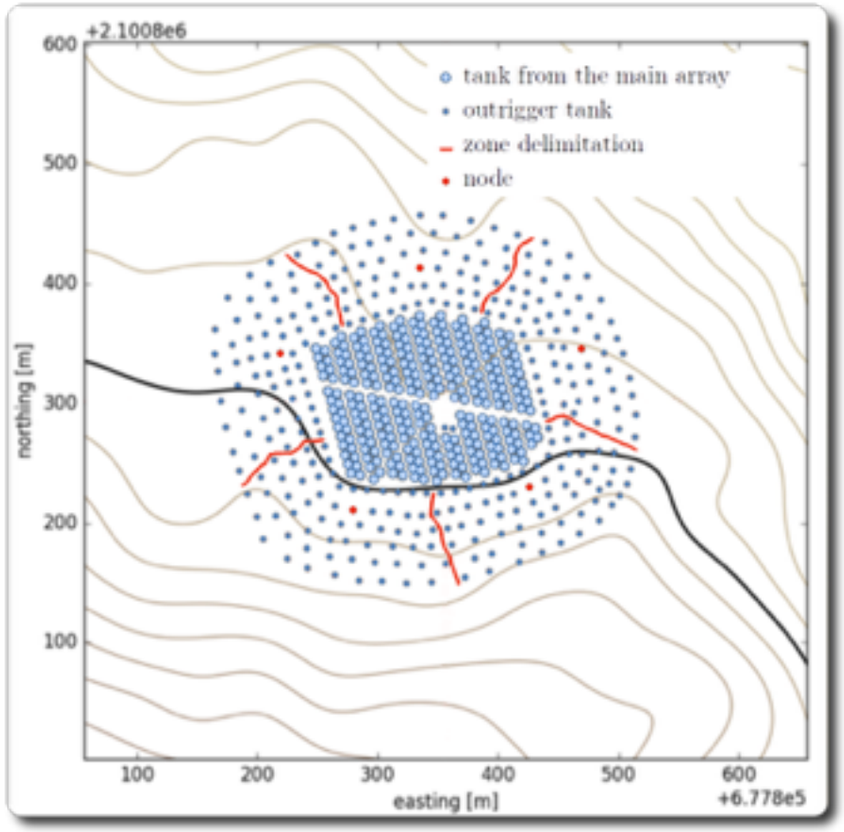
- Many (>10) new unknown sources
- Confirmed known extended sources with higher accuracy
- Able to follow-up and generate transient events alerts
- Constrains on Fermi-Bubbles and DM candidates

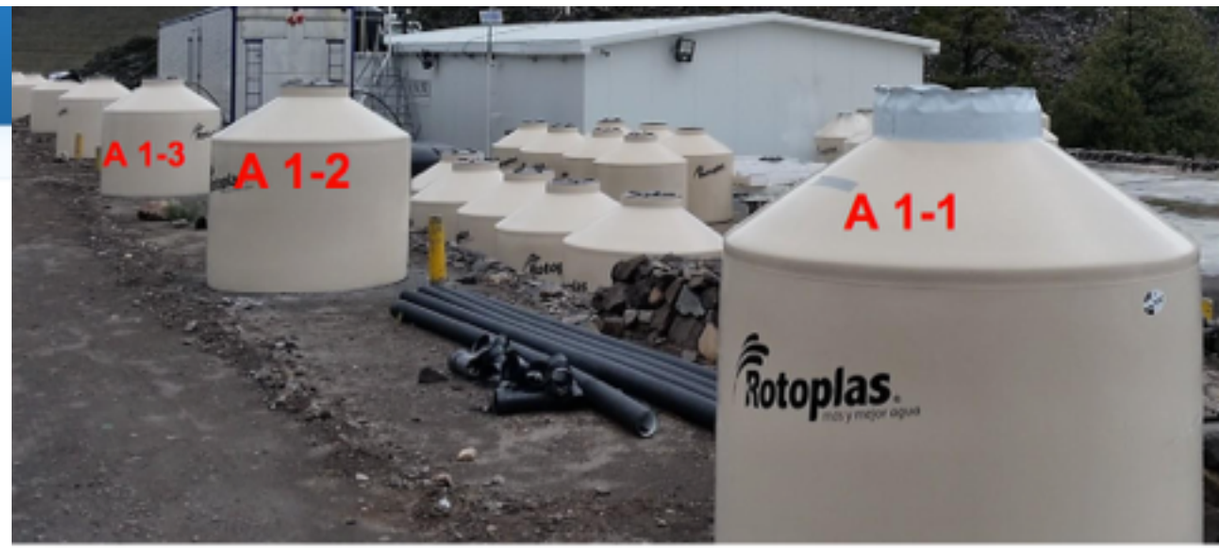
Papers coming up:

- Source catalogue
- Dark matter
- Crab paper
- Old nearby pulsar paper
- Light curves…
- …

What to expect next?

- More data
- Improvement in reconstruction
- High Energy extension:
  - Sparser array with 350 smaller tanks
  - Installation began August 2016 and will be finished early 2017
- Development for a next generation observatory in the southern hemisphere

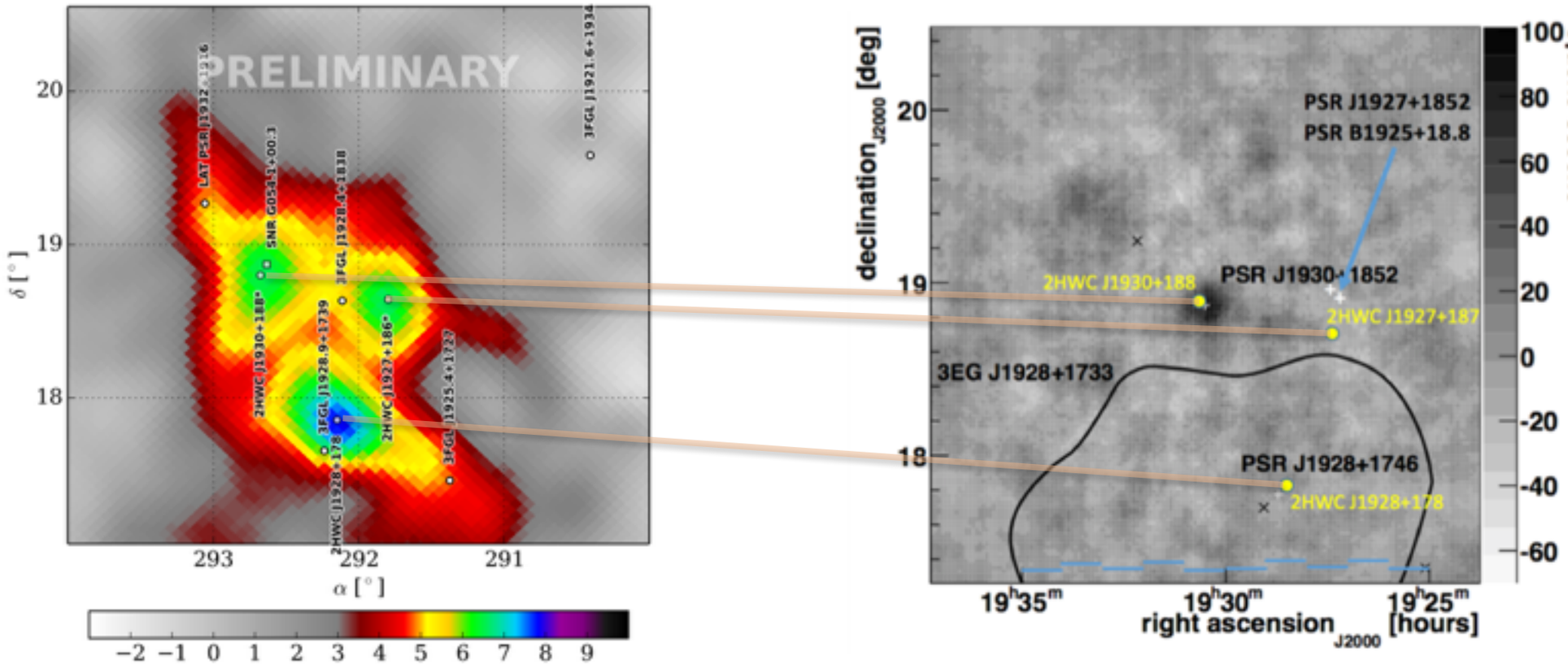




http://events.icecube.wisc.edu/conferenceDisplay.py?confId=81

Thank you for your attention!

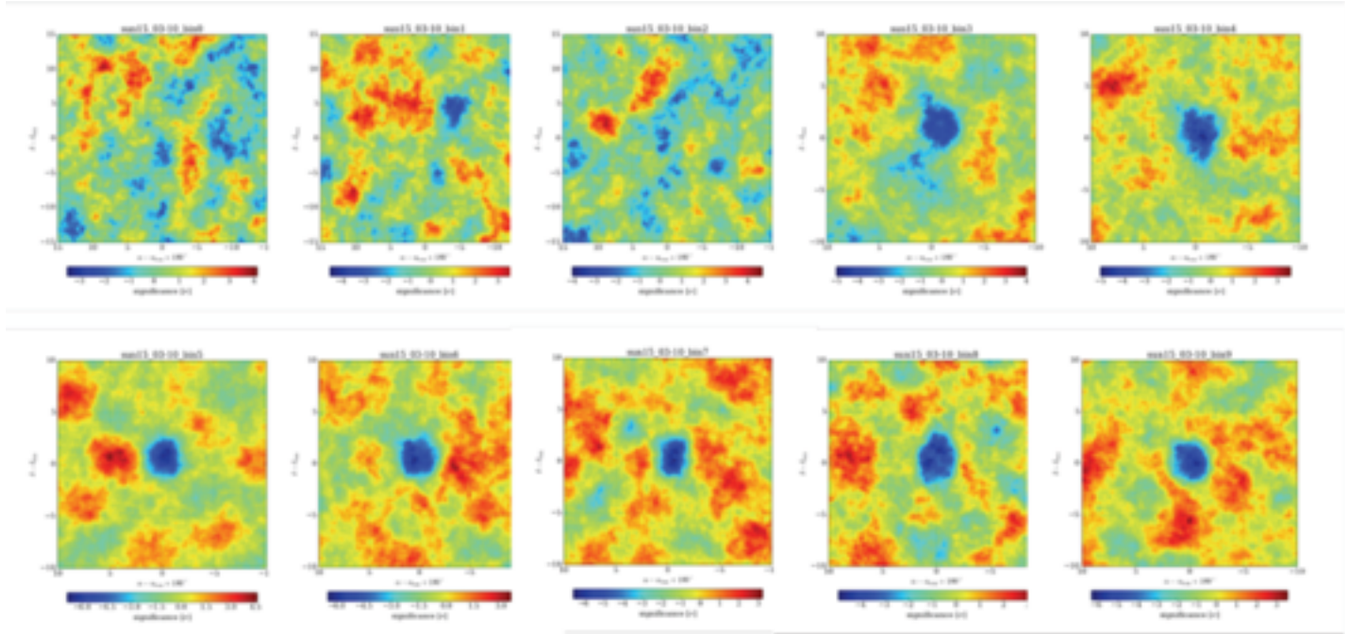
Galactic sources: "Executioner" (403 days)



[VERITAS, Acciari, et al. 2010]

Cosmic rays

Sun shadow



Moon shadow