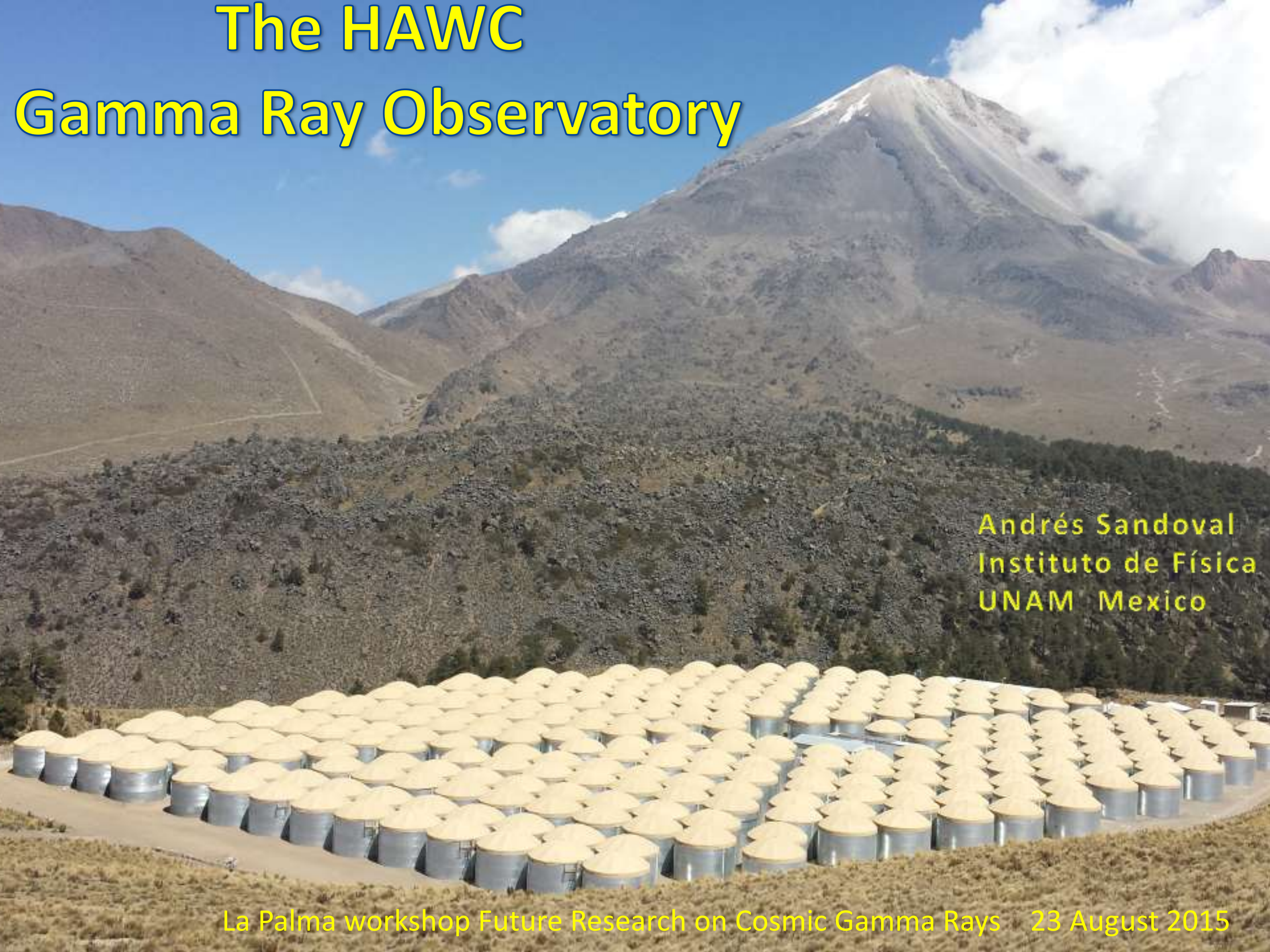
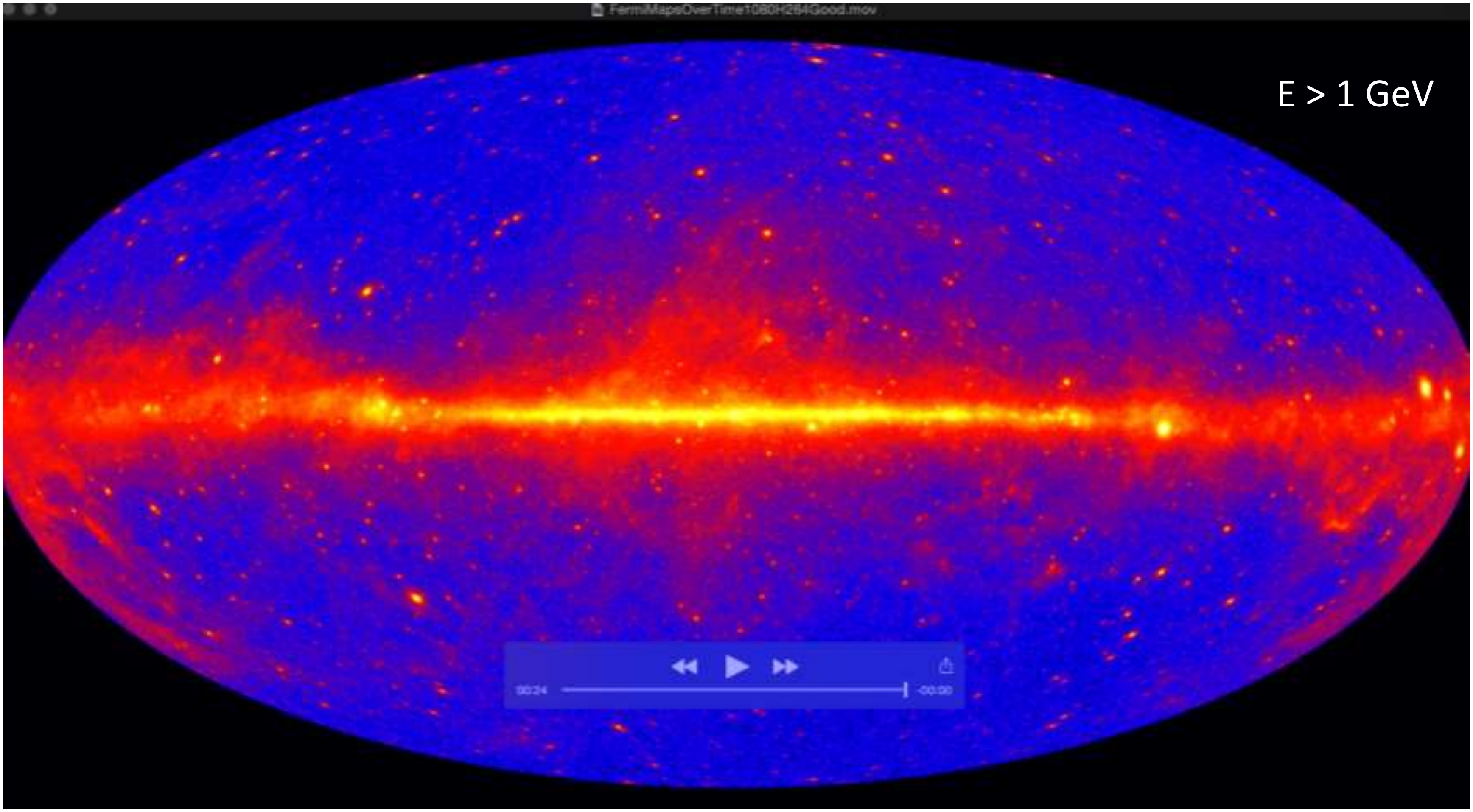
The HAWC Gamma Ray Observatory



Andrés Sandoval
Instituto de Física
UNAM Mexico

La Palma workshop Future Research on Cosmic Gamma Rays 23 August 2015

7 years of Fermi LAT



High **A**ltitude **W**ater **C**herenkov

a detector for gamma and cosmic rays in the 100 GeV to 100 TeV energy range
it is situated on the slopes of Volcan Sierra Negra, central Mexico
at 4,100 masl and (19^{o} N, 97^{o} W)

HAWC Collaboration

USA:

Pennsylvania State University
University of Maryland
Los Alamos National Laboratory
University of Wisconsin
University of Utah
Univ. of California, Irvine
University of New Hampshire
University of New Mexico
Michigan Technological University
NASA/Goddard Space Flight Center
Georgia Institute of Technology
Colorado State University
Michigan State University
University of Rochester
University of California Santa Cruz

Mexico:

Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE)
Universidad Nacional Autónoma de México (UNAM)
- Instituto de Física
- Instituto de Astronomía
- Instituto de Geofísica
- Instituto de Ciencias Nucleares

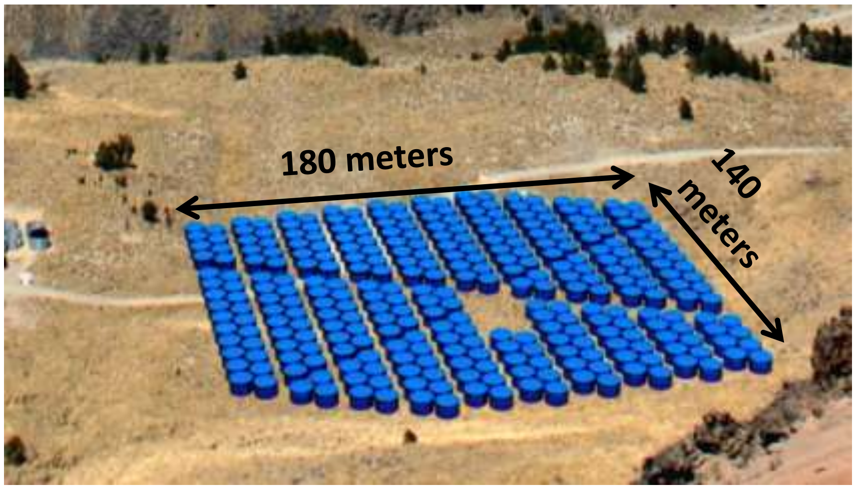
Universidad Politécnica de Pachuca
Benemérita Universidad Autónoma de Puebla
Universidad Autónoma de Chiapas
Universidad Autónoma del Estado de Hidalgo
Universidad de Guadalajara
Universidad Michoacana de San Nicolás de Hidalgo
Centro de Investigación y de Estudios Avanzados
Instituto Politécnico Nacional
Centro de Investigación en Computación - IPN

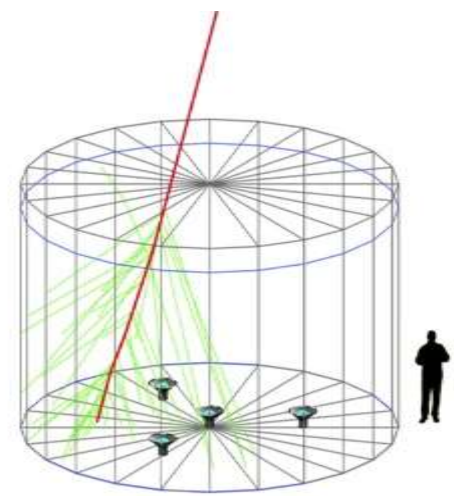

HAWC detects continuously airshower particles
with 300 Water Cherenkov Detectors
over a large field of view,
day and night


surveying every day 2/3 of the sky

HAWC Design

300 close packed water tanks (7.3m dia x 4.5 m deep of 200,000 liters) each with 4 upward facing photomultiplier tubes at the bottom



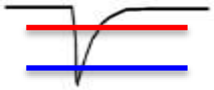


Components of the Water Cherenkov Detectors (WCD)

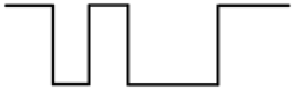
Front End Electronics

ToT (Time over Threshold)

Photo-multiplier Tube



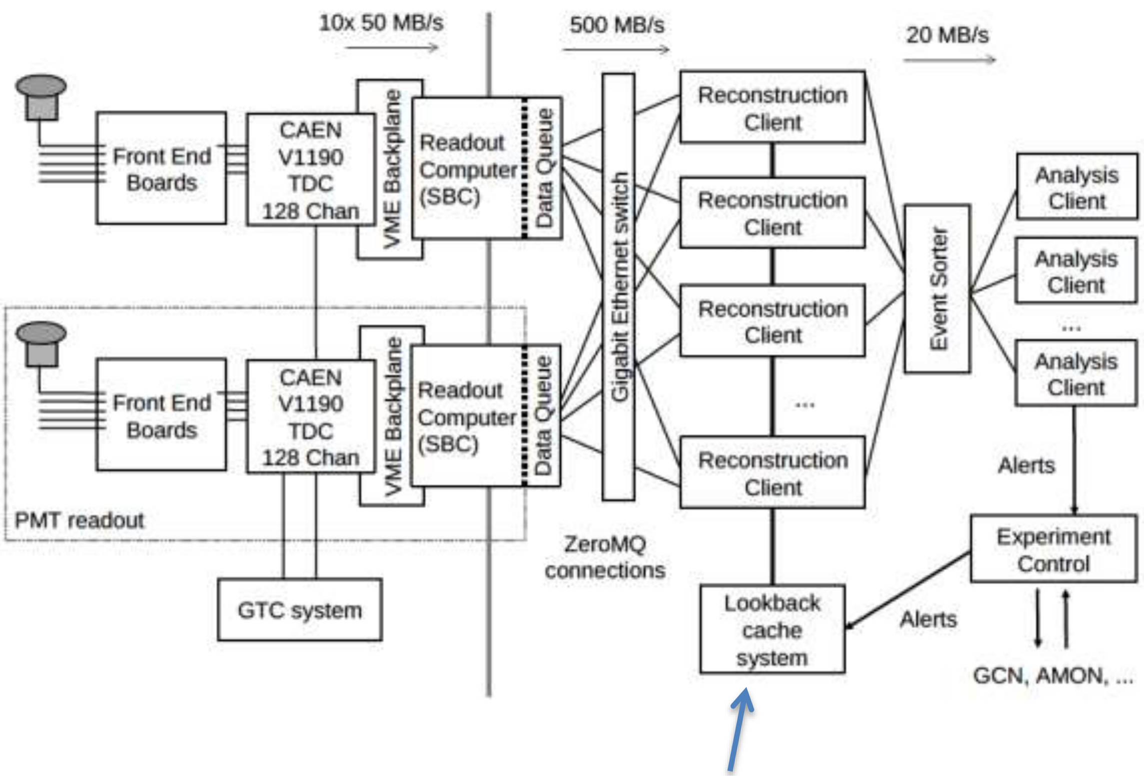
Custom Front-End Electronics
Pick-off circuits and discriminators.



CAEN Vx1190
Time-to-Digital
Converters

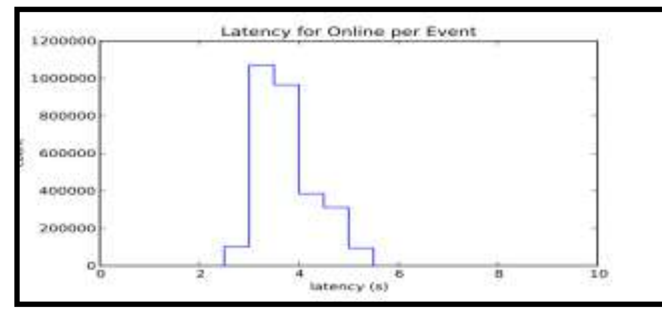
Digitizing the times with 100 ps least count
20 – 40 kHz signal rate per PMT (8”, 10”)

HAWC data acquisition and online analysis

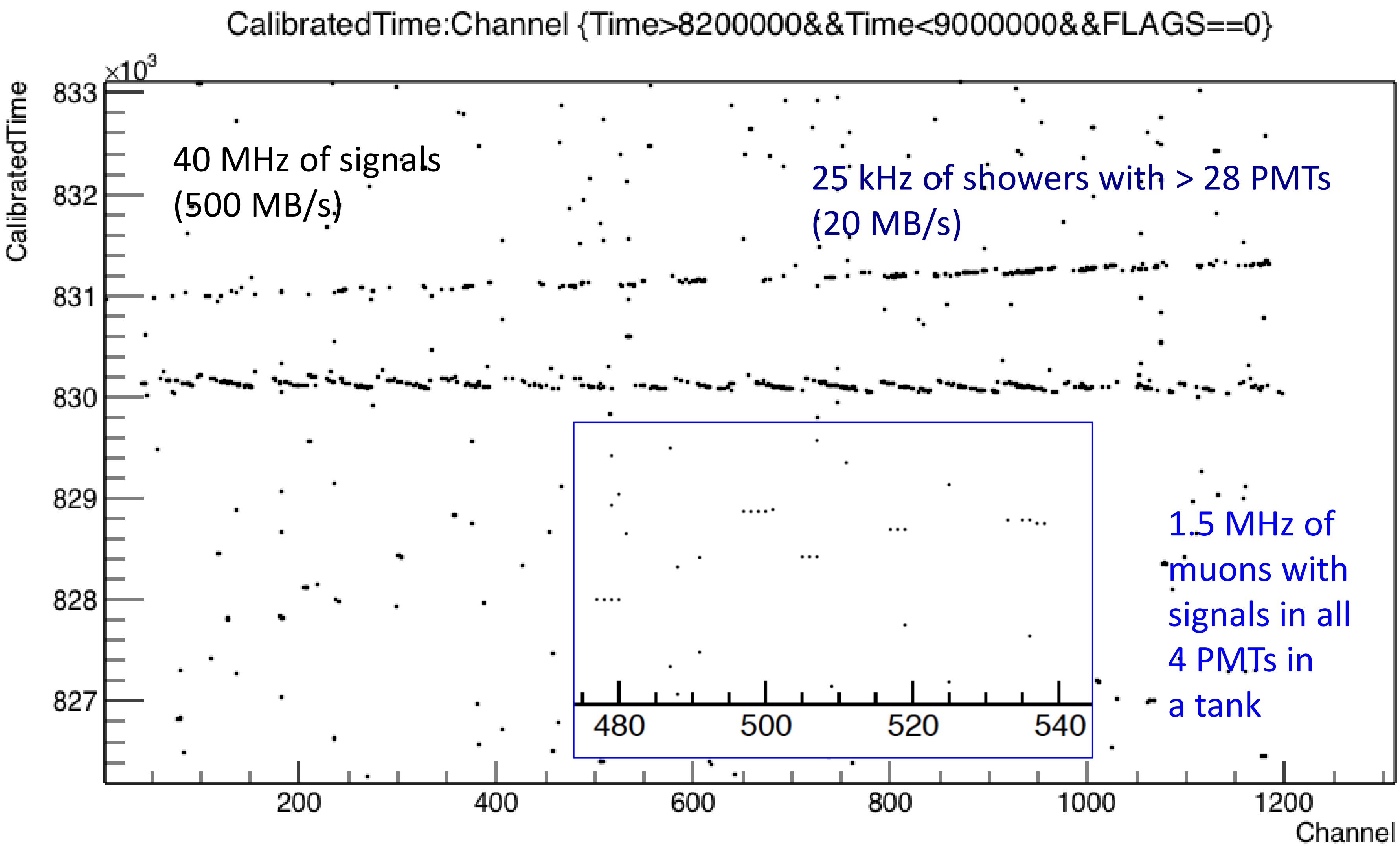


24 h raw data
buffer
2 TB

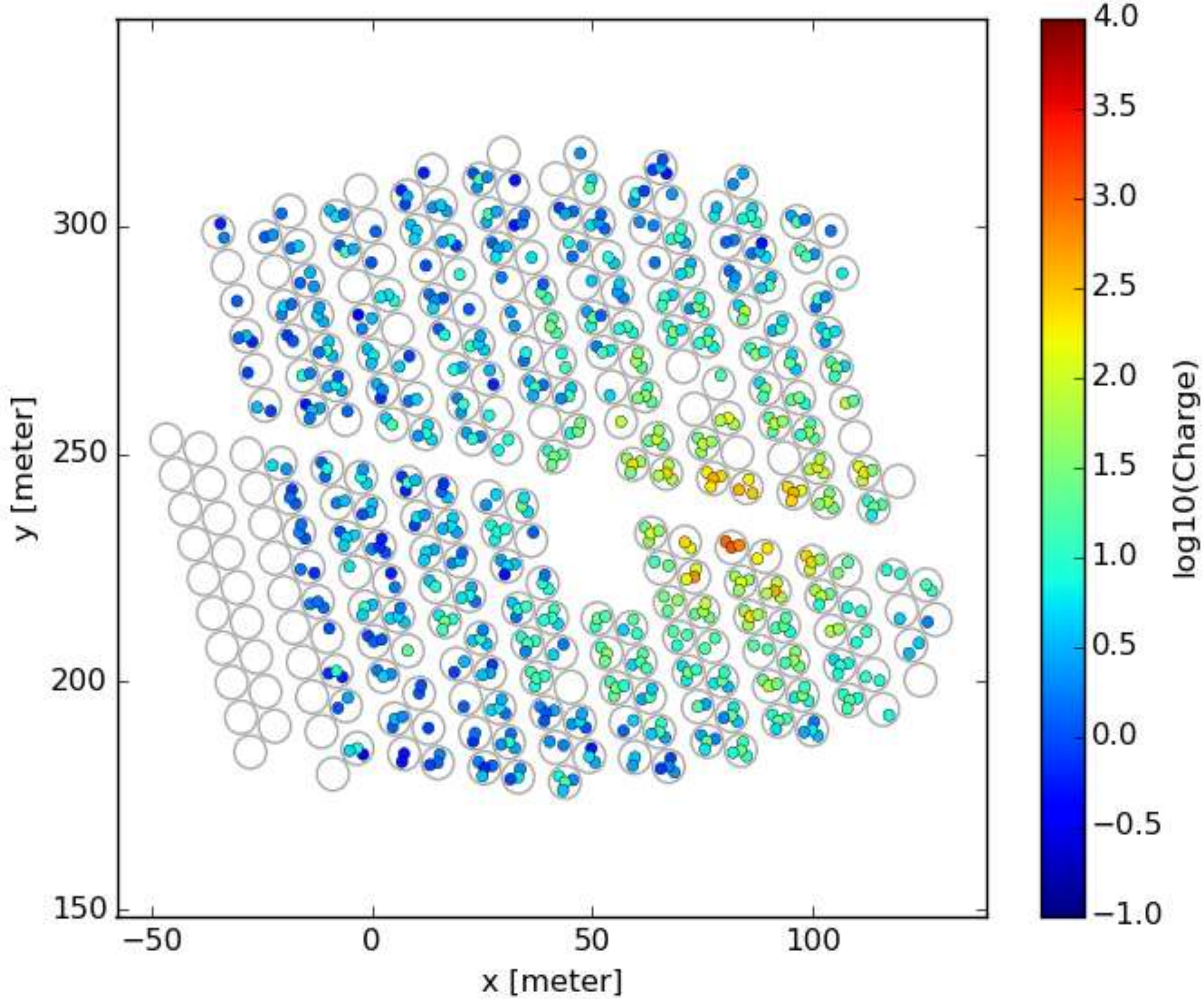
On line transient analysis
4s latency
to generate
alarms and save ROI

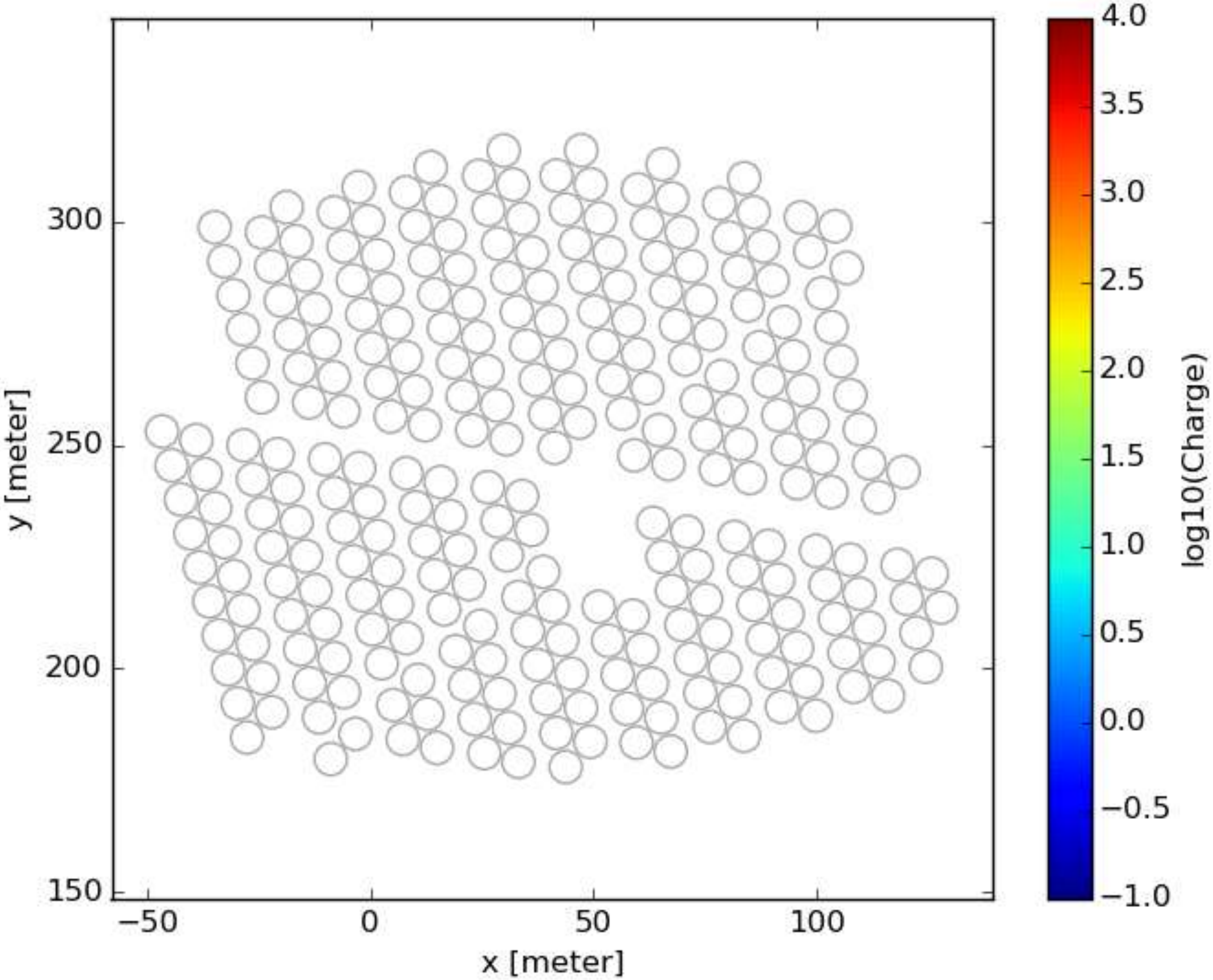


Raw Data
1200 PMTs – 6 μs



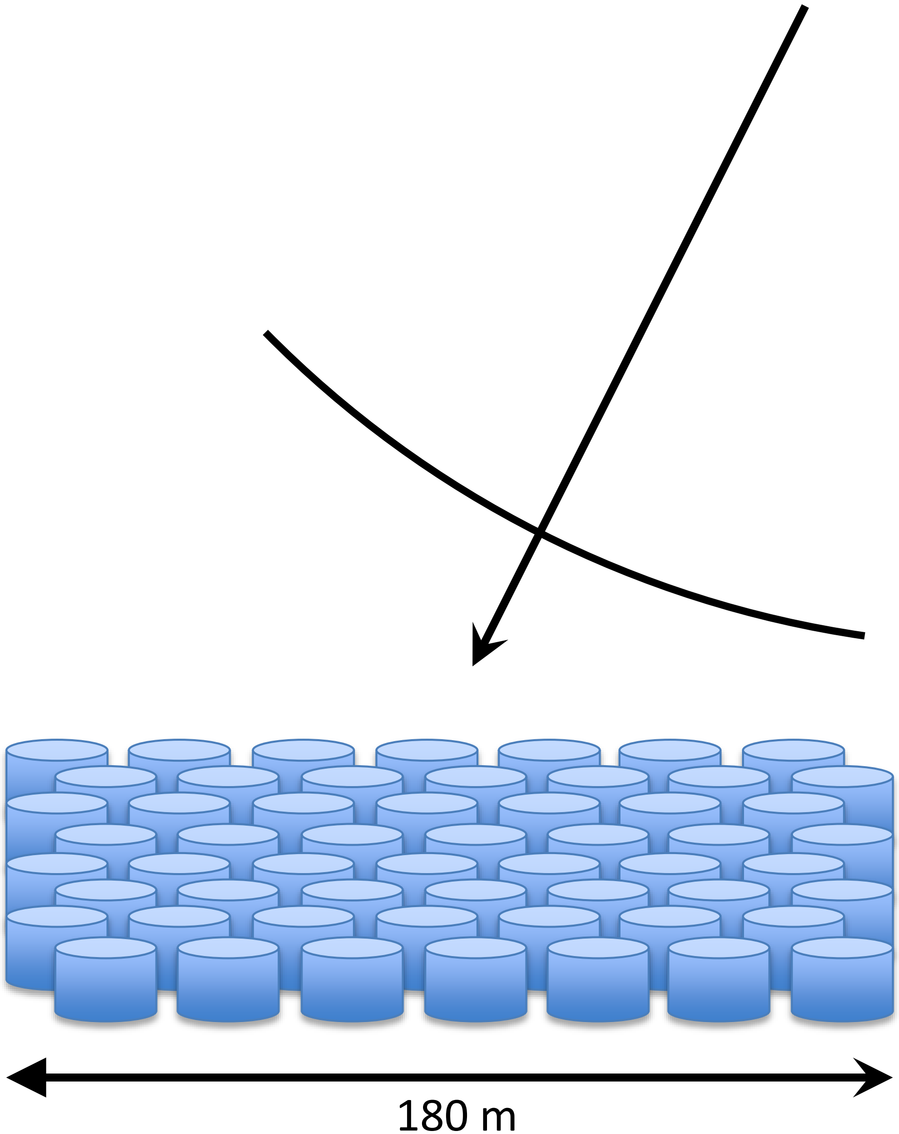
Shower info: amplitude and arrival time in each of the 1200 PMTs





4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
log10(Charge)
300
250
200
150
y [meter]
−50
0
50
100
x [meter]

Event reconstruction



Obtain the shower core position

- Center of Gravity, NKG lateral distribution, others.

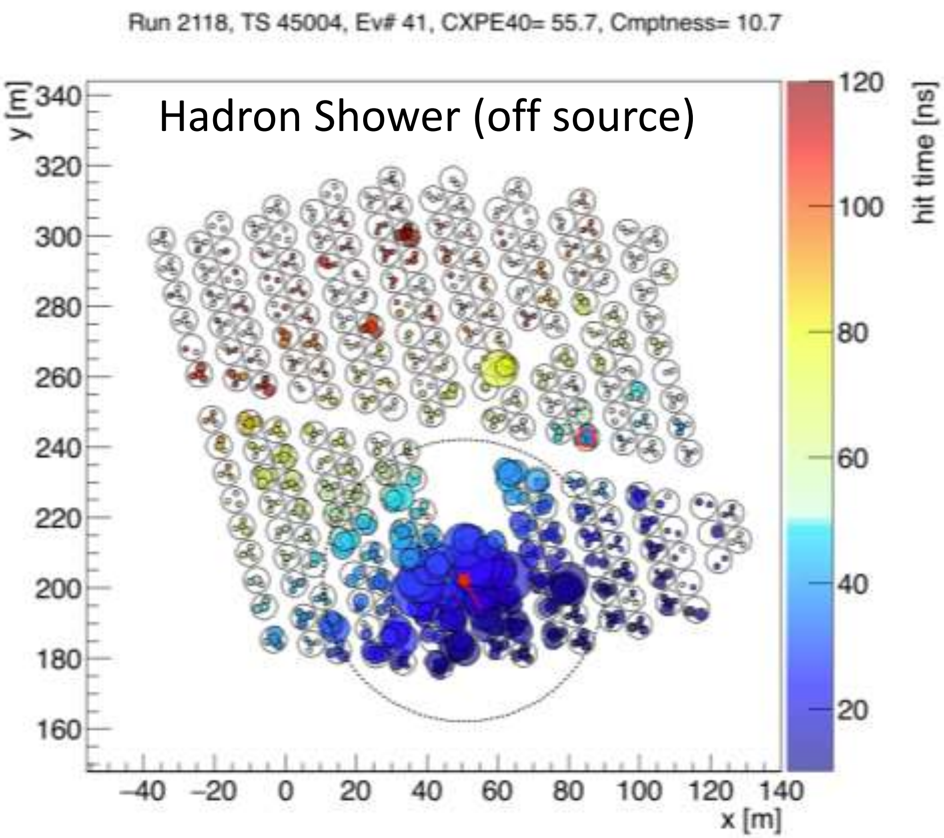
Fit the shower direction

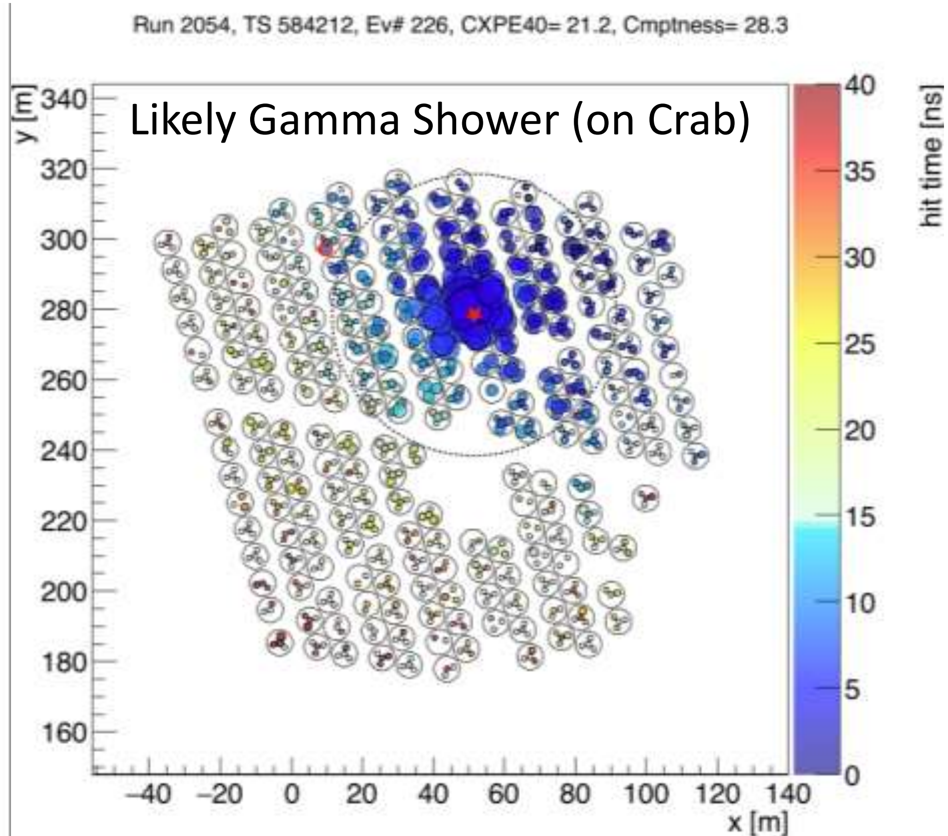
- Time of arrival of each signal. including the shower front curvature.
- Direction of primary is the perpendicular to the shower front

Estimate the shower energy

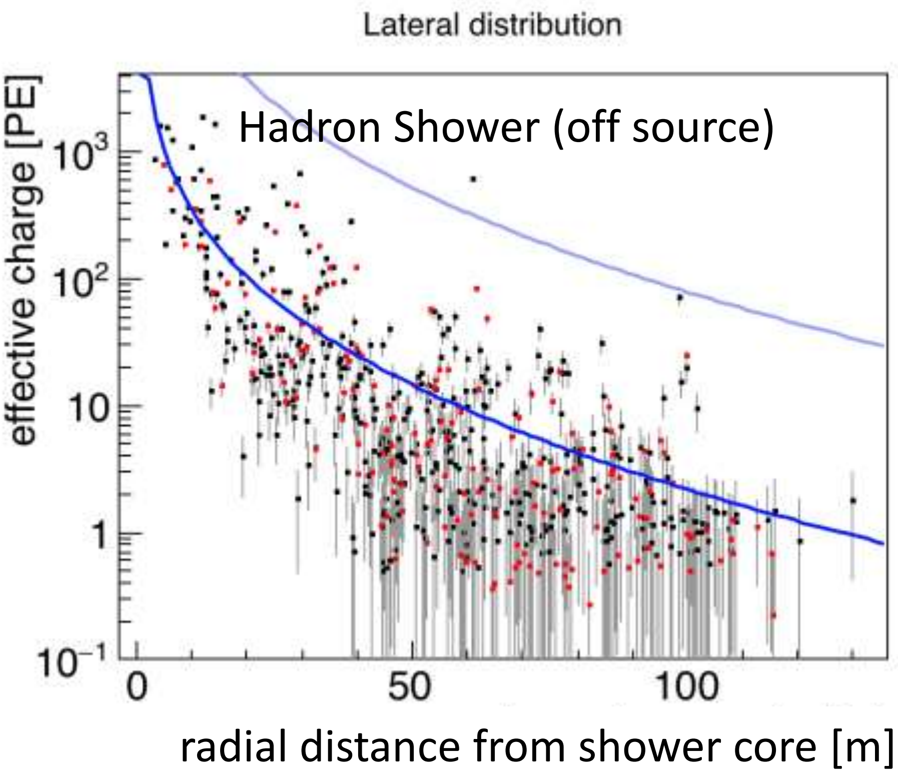
- Event size, PMT charge, etc.

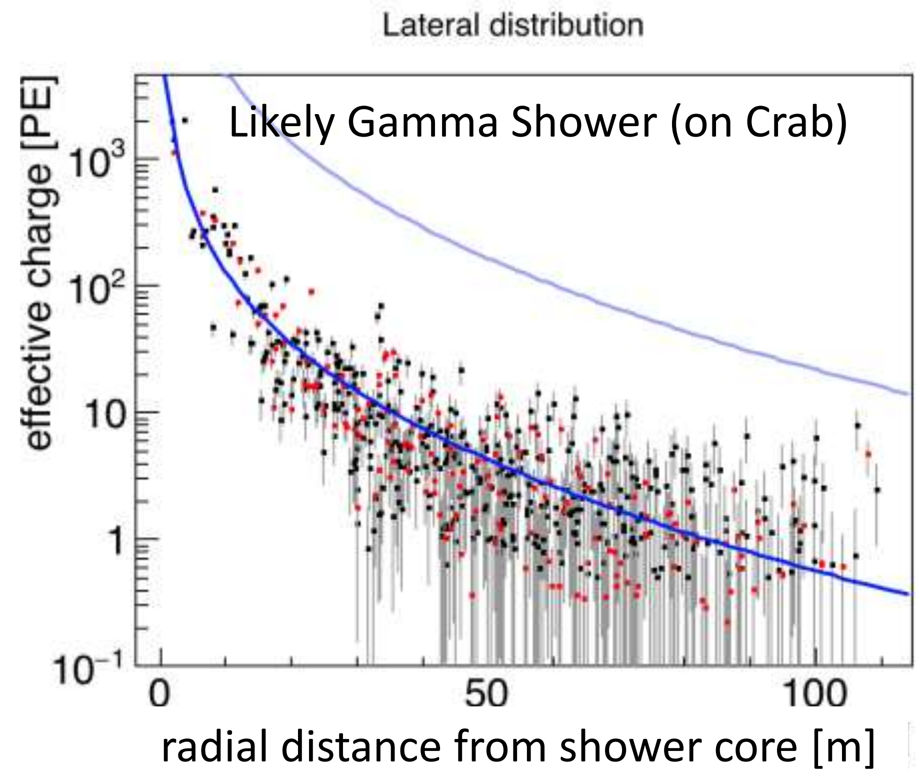
HAWC gamma/hadron discrimination





HAWC-250 gamma/hadron





NKG (Nishimura-Kamata-Greisen) fits to lateral distribution function of an EM shower.

Kamata, Nishimura Prog. Theo. Phys. (1958)
Greisen Ann. Rev. Nucl. Sci. (1960)

Time Line

- Site selected in 2007 at the ICRC meeting in Merida
- 2008 – 2010 construction of prototypes and writing of proposals
- February 2011 project funded
- 2011 site preparation and procuring of components
- 2012 – 2014 construction of the 300 WCD
- 1 August 2013 start of continuous operations HAWC-100

- HAWC inauguration 19-20 March 2015

HAWC Cost and Funding

- $15 million USD shared equally between 3 funding agencies and managed by 4 PIs

CONACYT, Mexico

Andres Sandoval UNAM

Alberto Carramiñana INAOE

NSF, US

Jordan Goodman, Univ. Maryland

DoE, US

Brenda Dingus, Los Alamos National Lab


October 2011

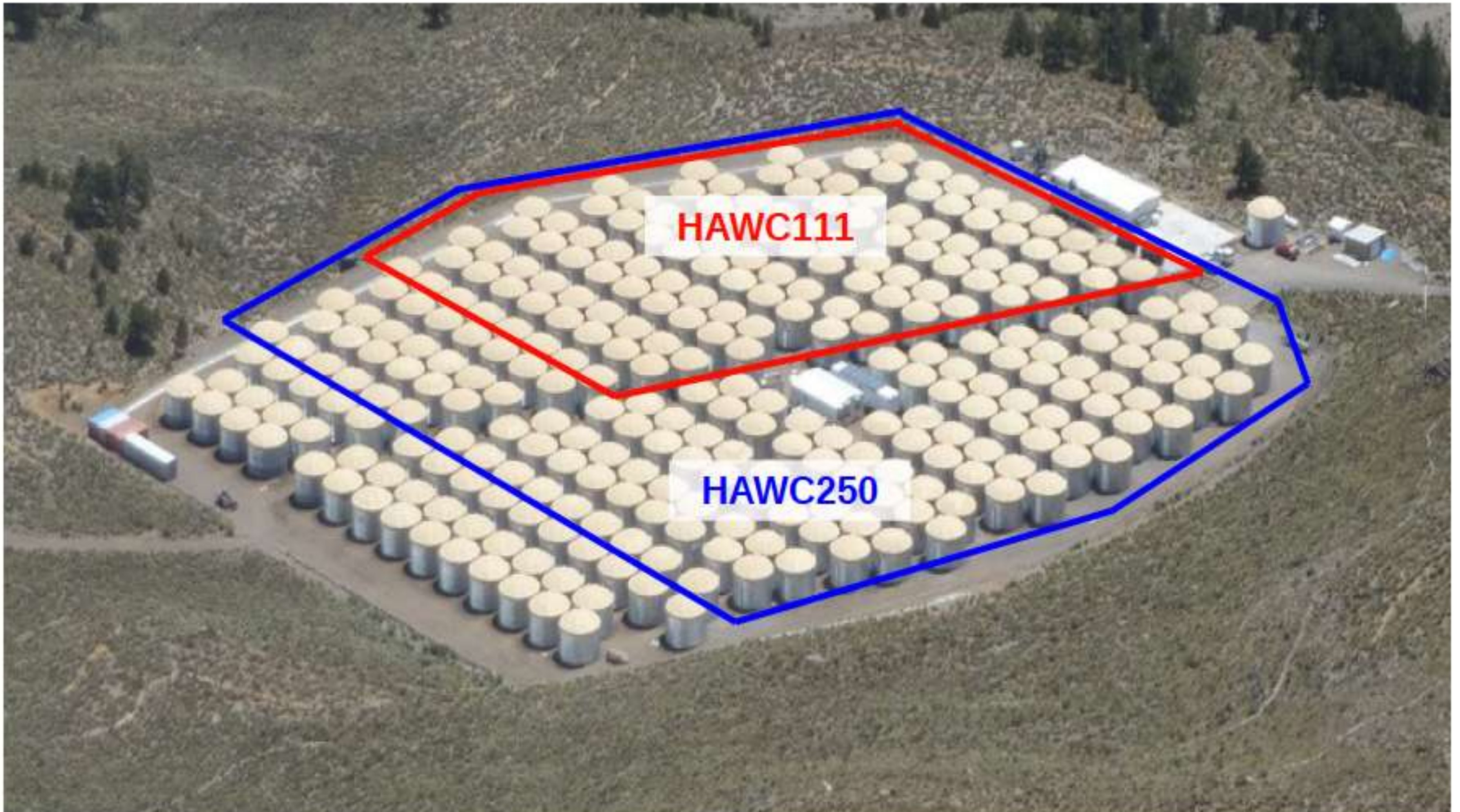

August 2012


October 2013


January 2014

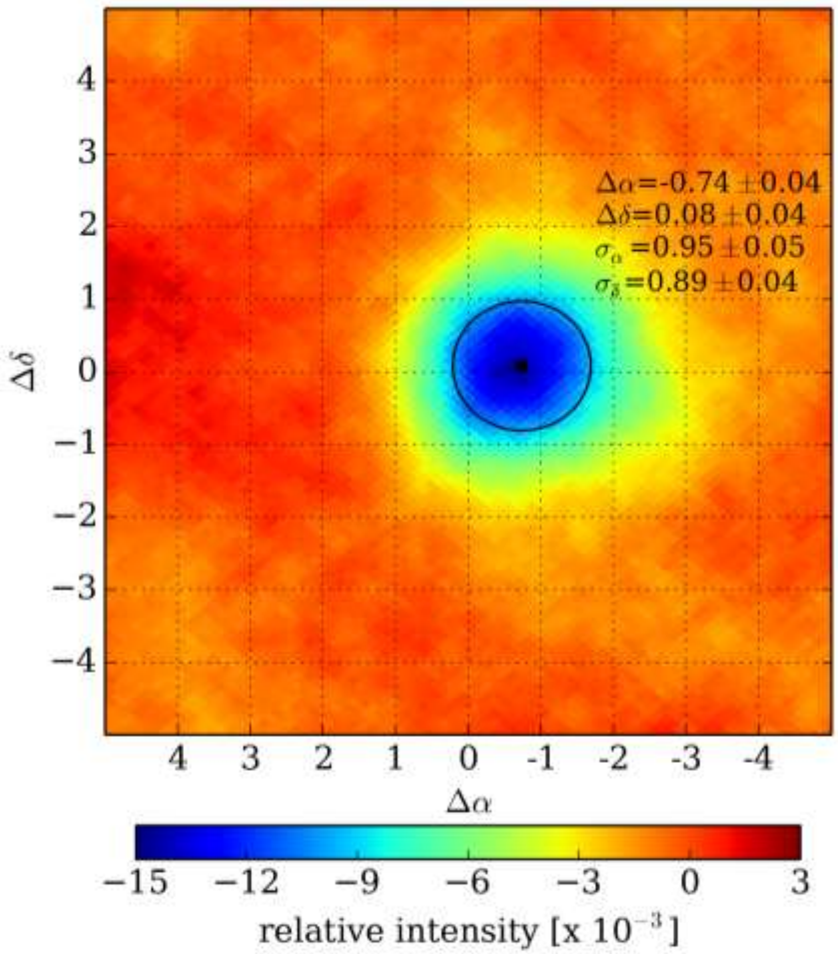

HAWC Inauguration
March 20 2015

Data sets



HAWC111: Aug 2nd 2013 – Jul 7th 2014 (106 - 133 WCDs)
HAWC250: Nov 26th 2014 – May 6th 2015 (247 - 293 WCDs)

Cosmic Ray Moon Shadow



HAWC-250

- 52 full sidereal days
- 32 billion events
- 2 TeV median energy

- Center displacement

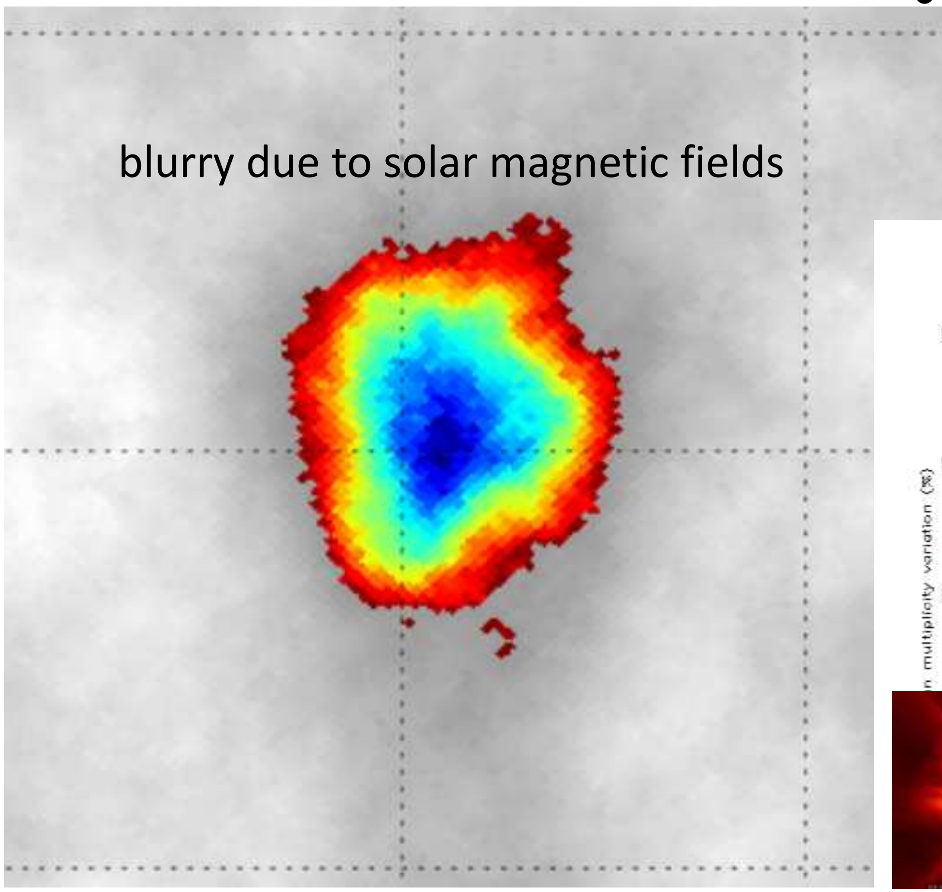
$\Delta\alpha$ = - 0.74° ± 0.04°

$\Delta\delta$ = 0.08° ± 0.04°

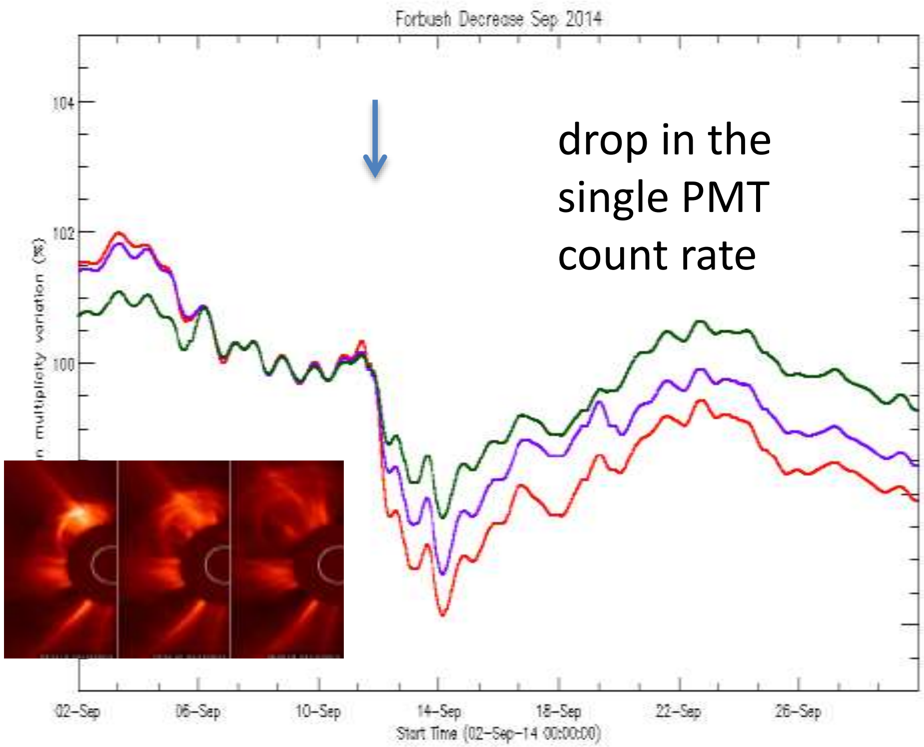
agrees with deflection of CR due to the Earth B field

$\Delta\alpha$ = 1.6° Z/E [TeV]

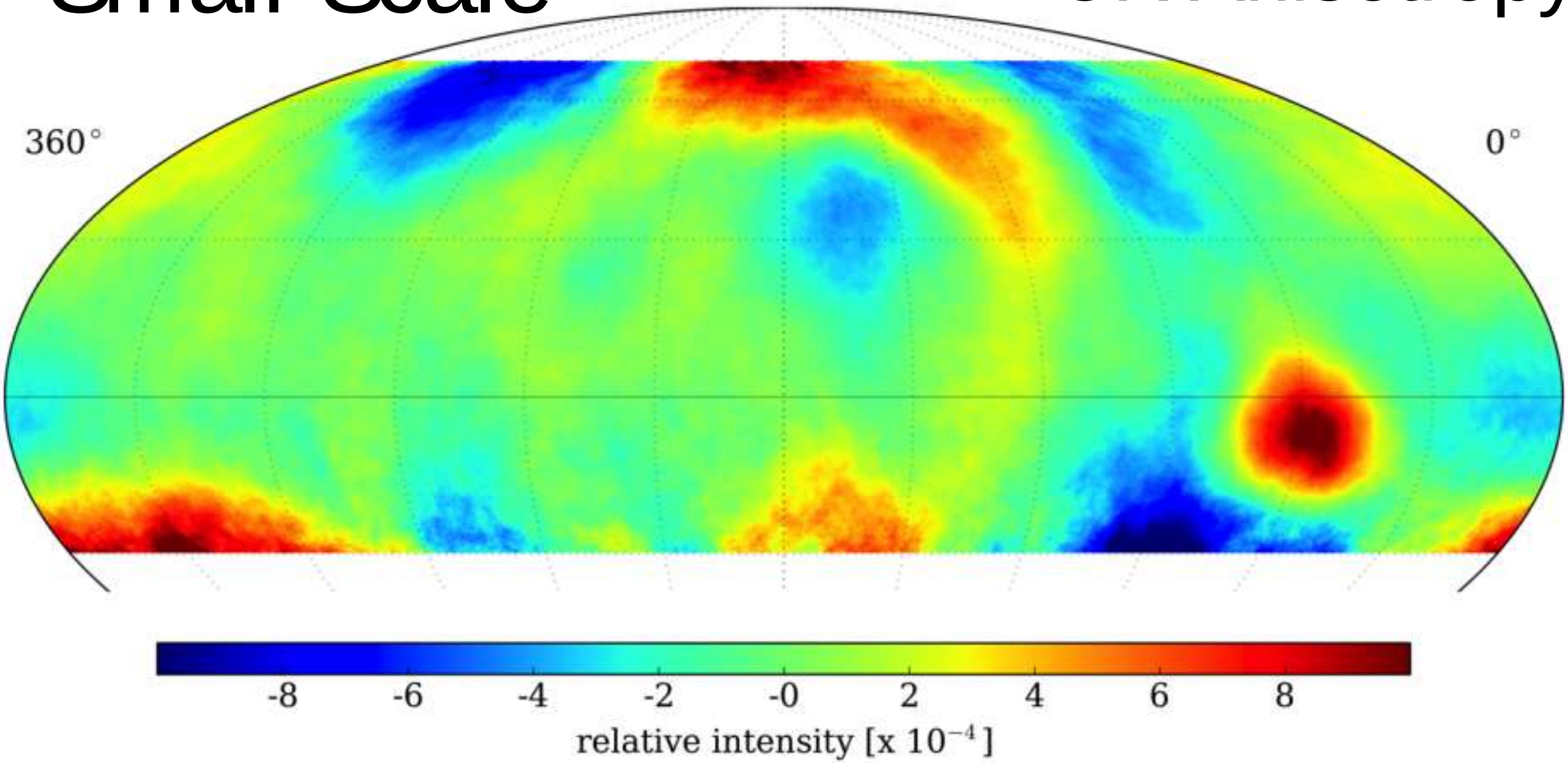
Sun Shadow and Forbush Decreases



- CME in Earth direction modify the geomagnetic environment



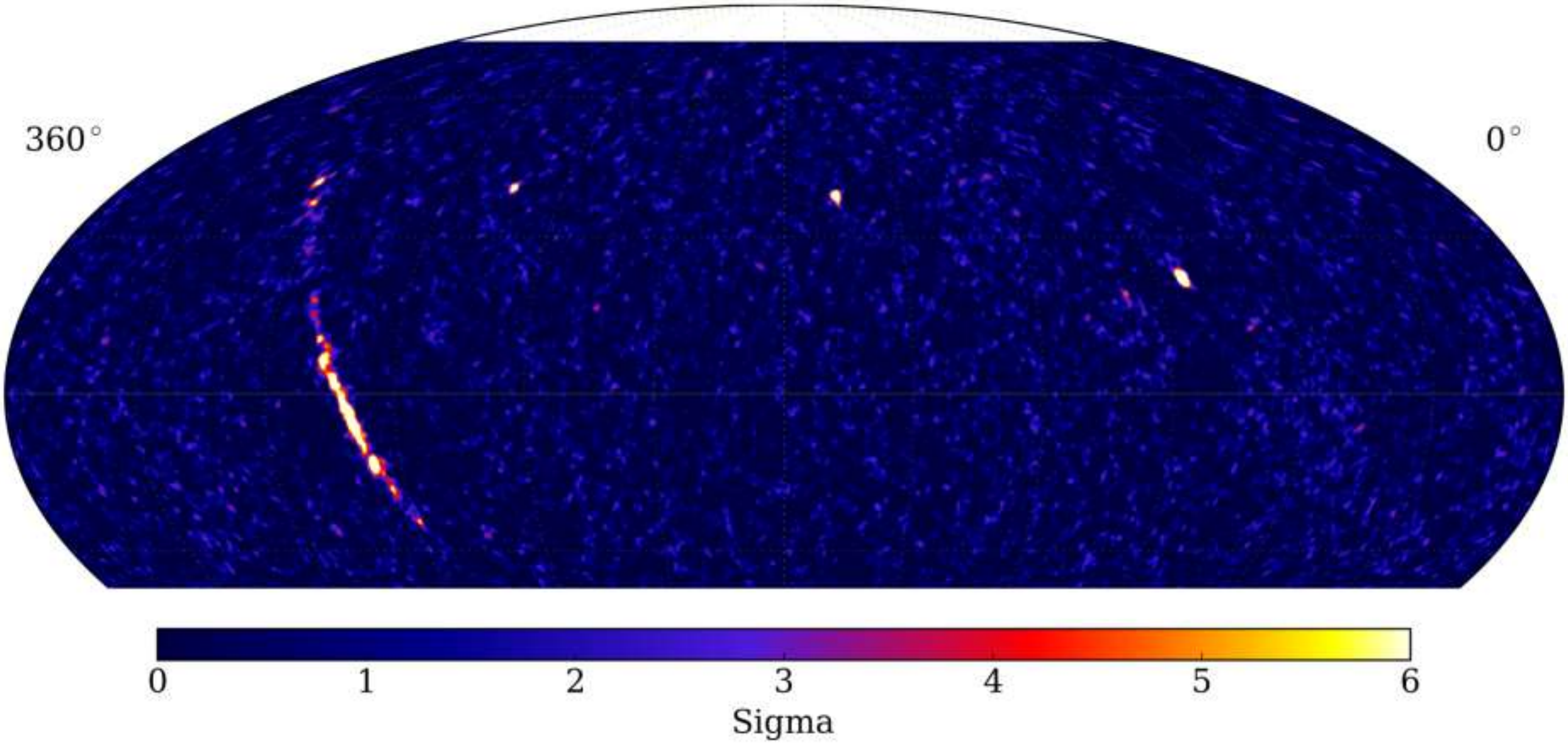
Small-Scale HAWC-111 CR Anisotropy



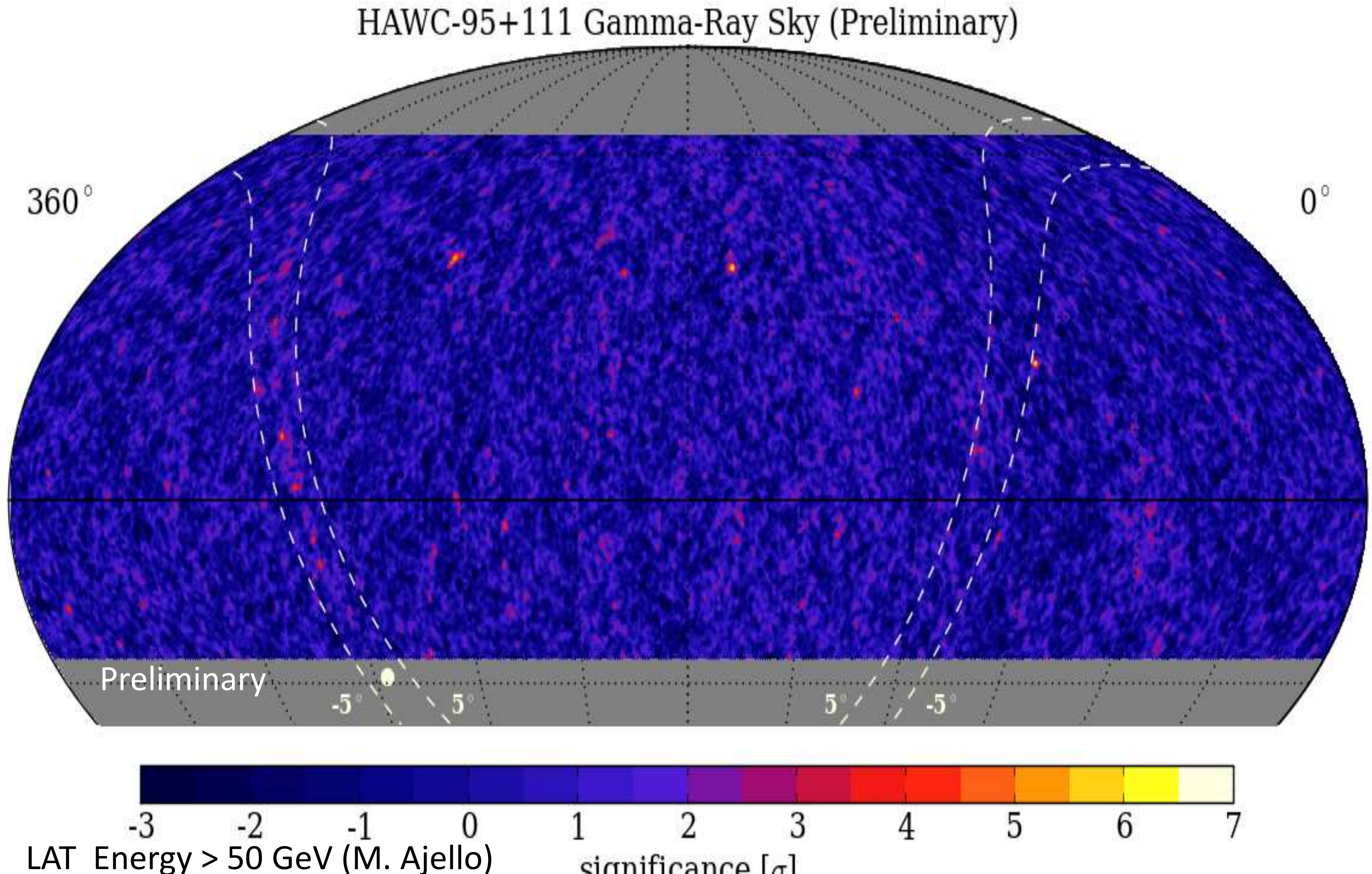
Detailed studies will be made over the next few years
already did a combined fit with IceCube CR data

The HAWC γ-ray Sky

HAWC-111 + HAWC-250

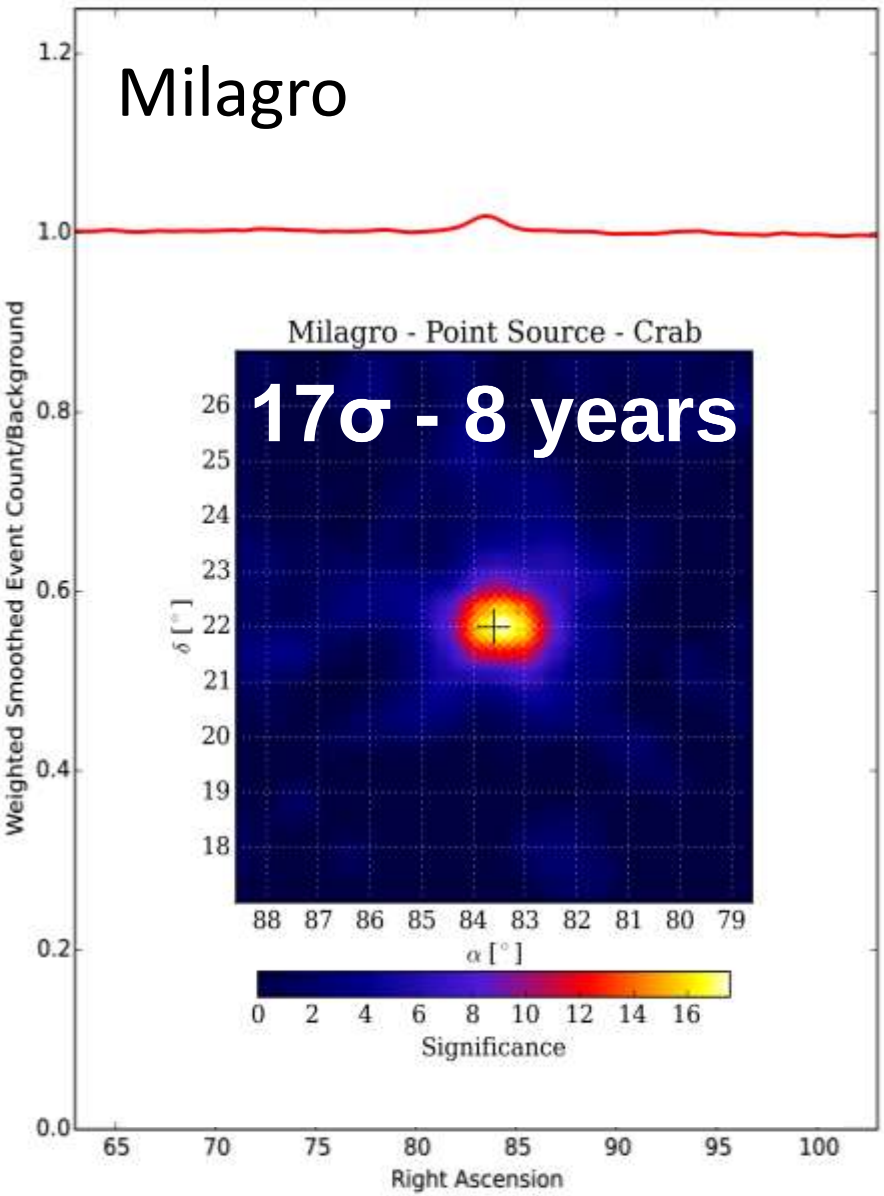


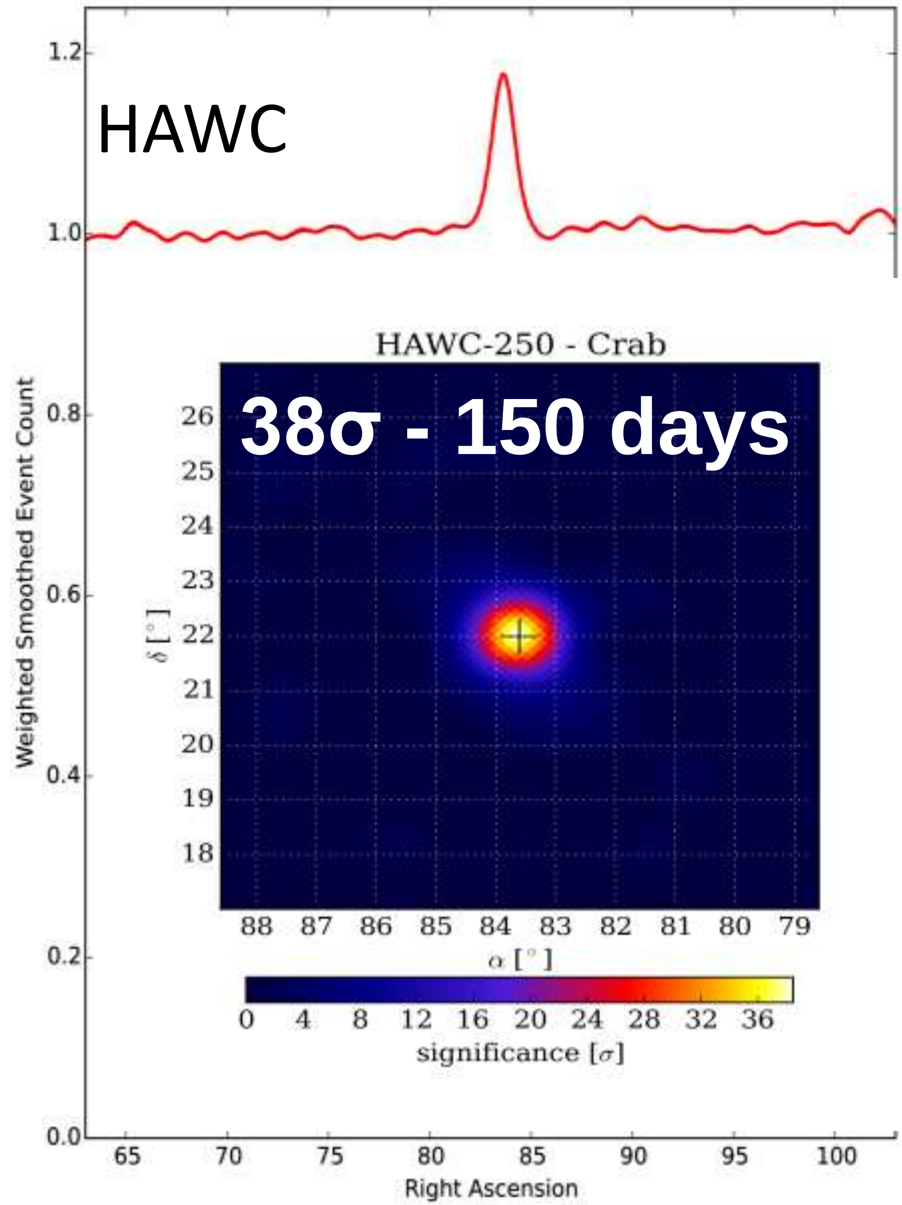
Connecting the GeV and TeV Skies



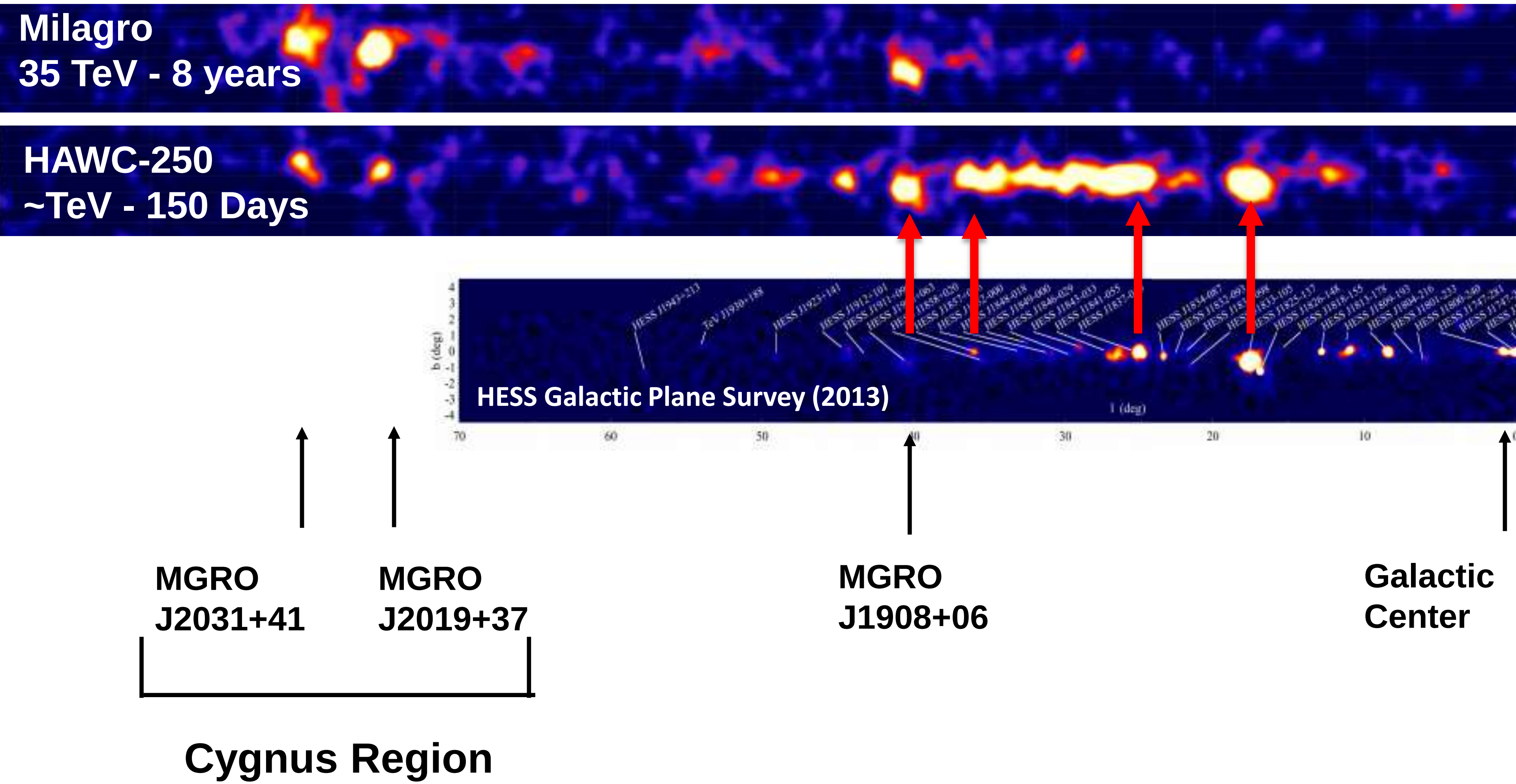
LAT Energy > 50 GeV (M. Ajello)

Crab Nebula

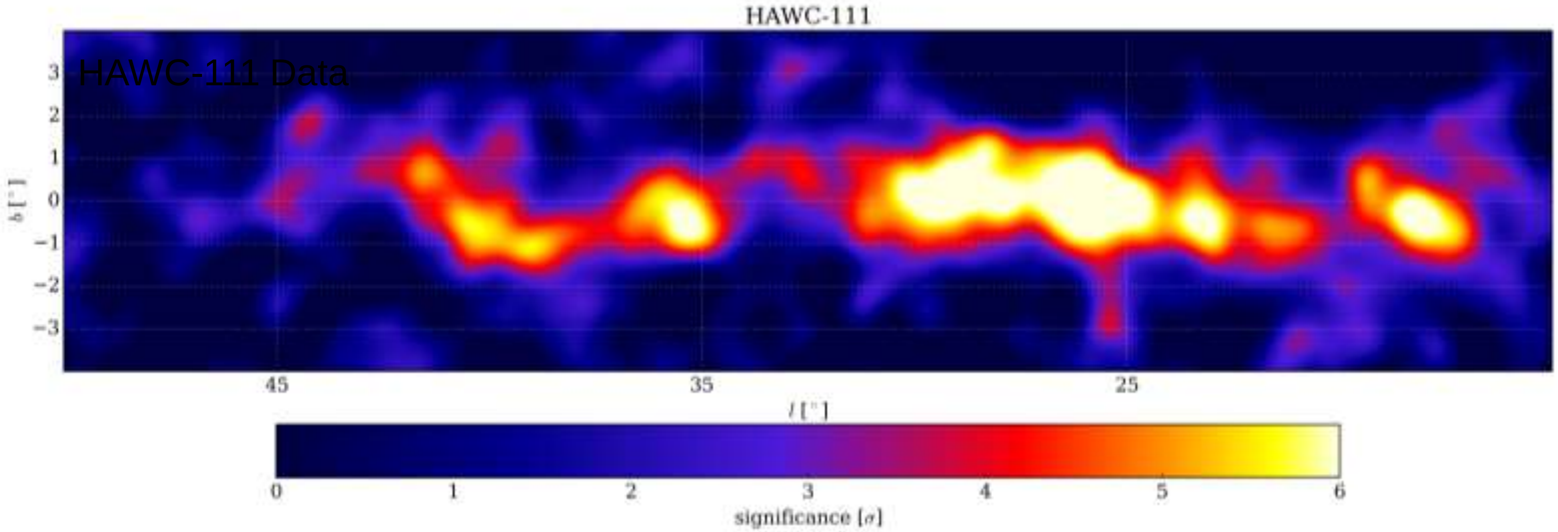

Milagro
Milagro - Point Source - Crab
17σ - 8 years
Significance
Weighted Smoothed Event Count/Background
Right Ascension

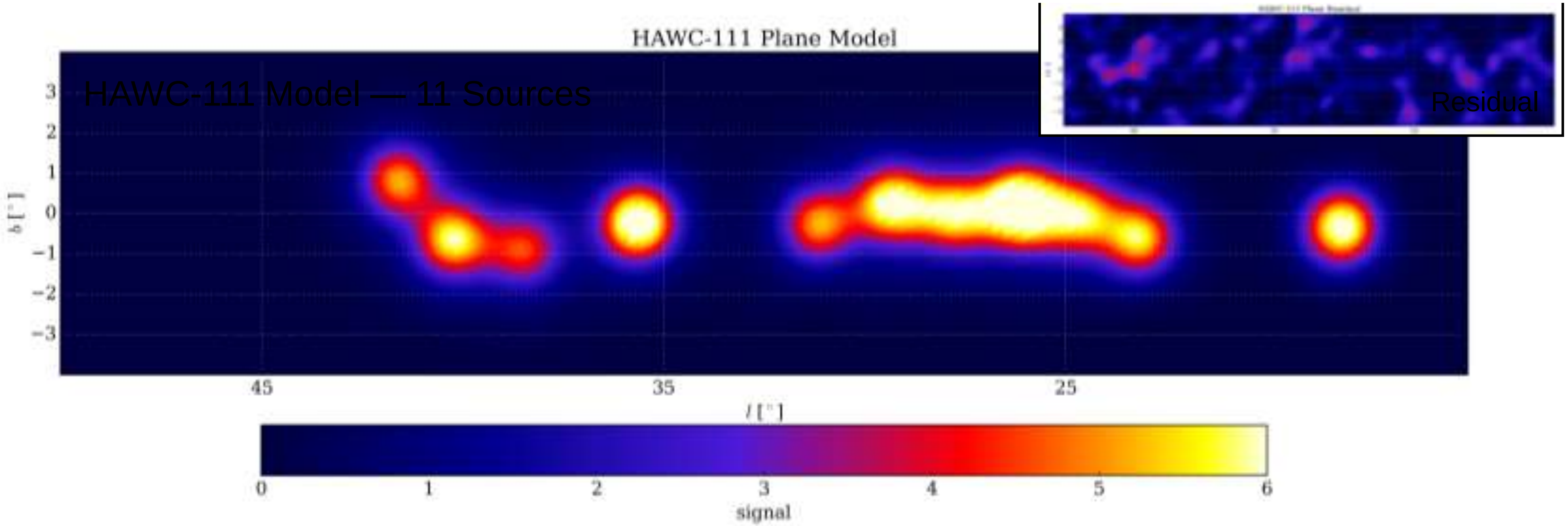

HAWC
HAWC-250 - Crab
38σ - 150 days
significance [σ]
Weighted Smoothed Event Count
Right Ascension

Galactic Plane Preliminary results
3 months HAWC-250

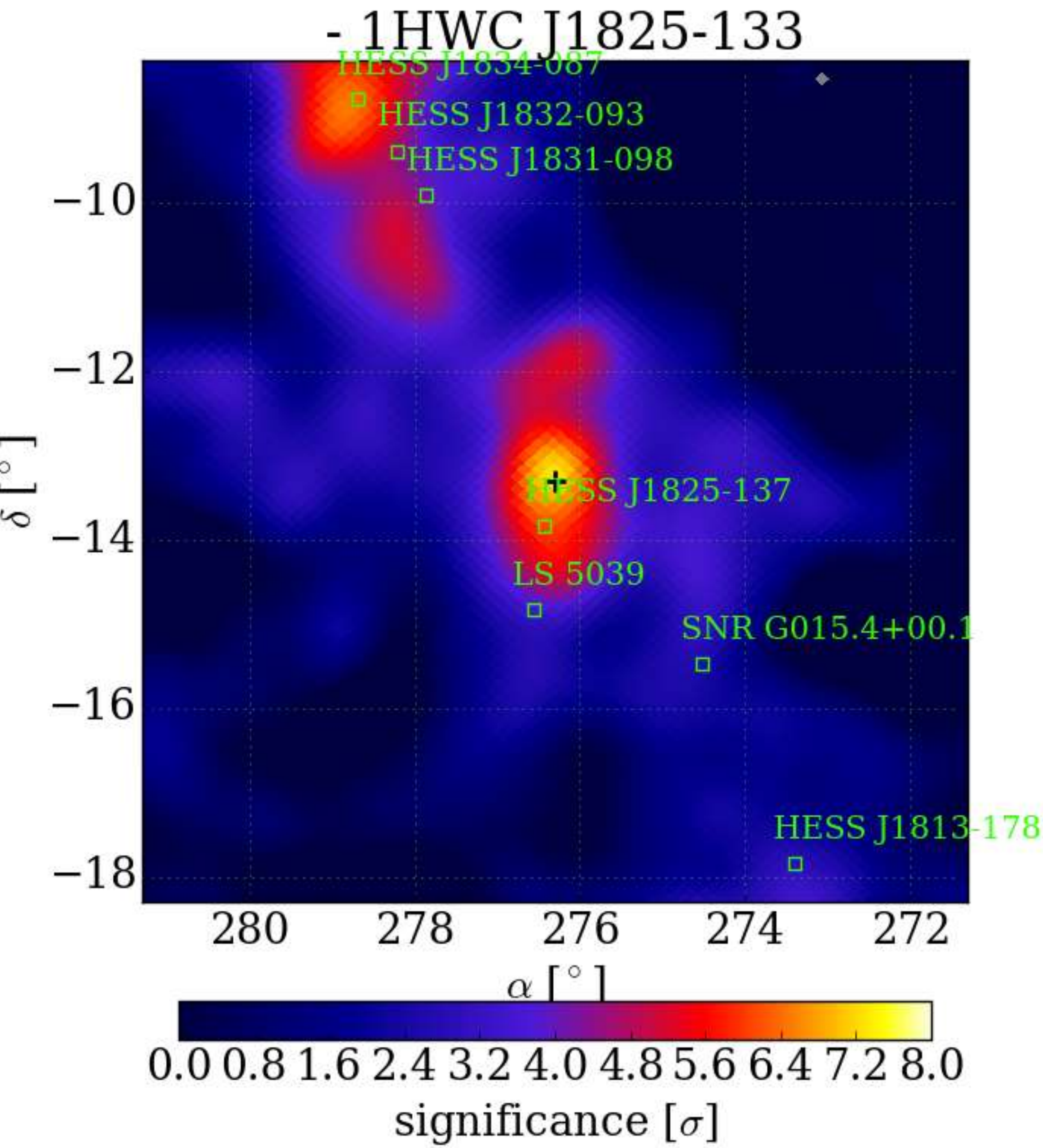


HAWC-111 Galactic Plane Analysis : 11 sources





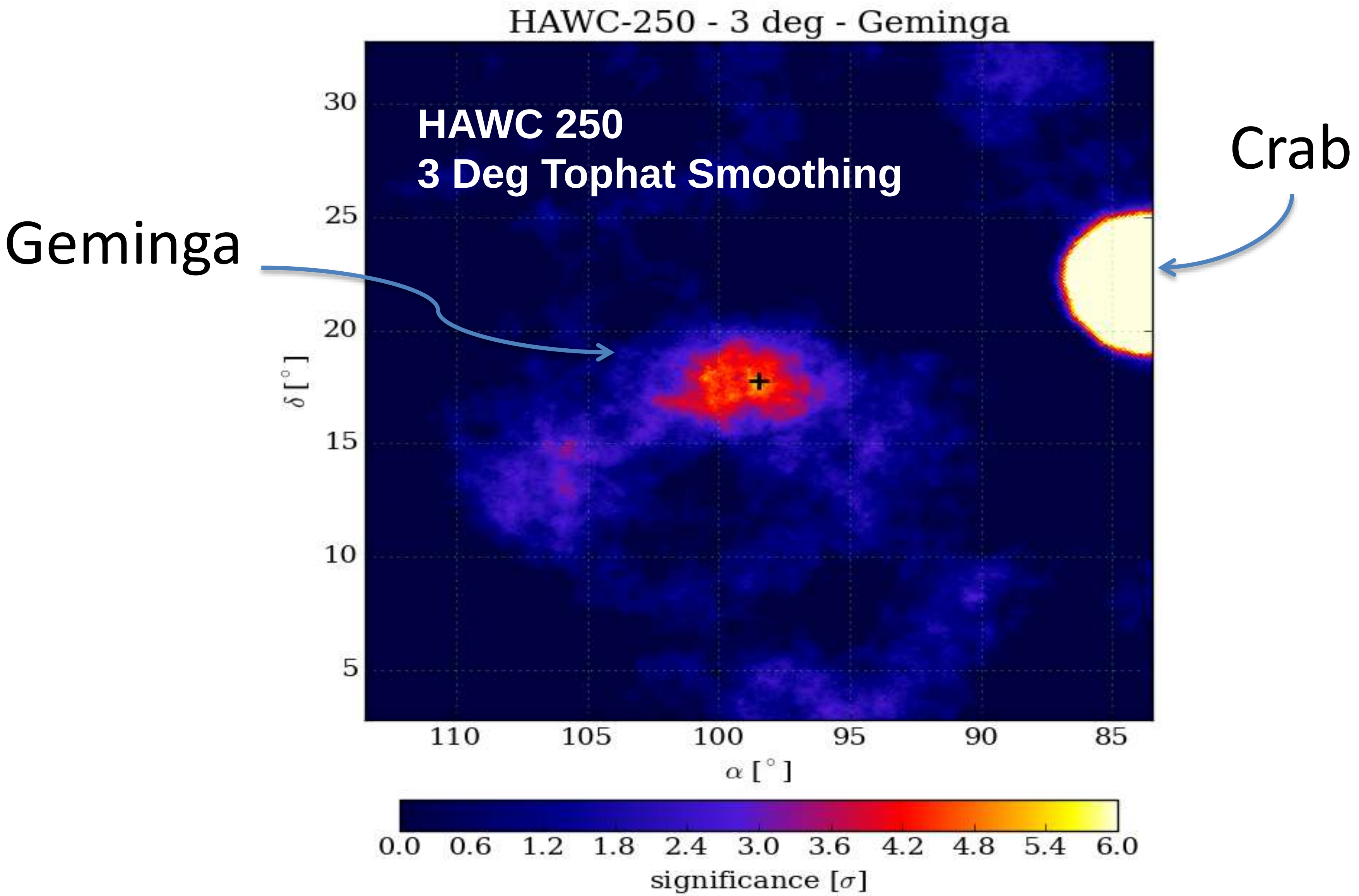
HAWC-111 Galactic Plane Analysis Sampler



1HWC J1825-133

- Coincident with Pulsar Wind Nebula
  HESS J1825-137

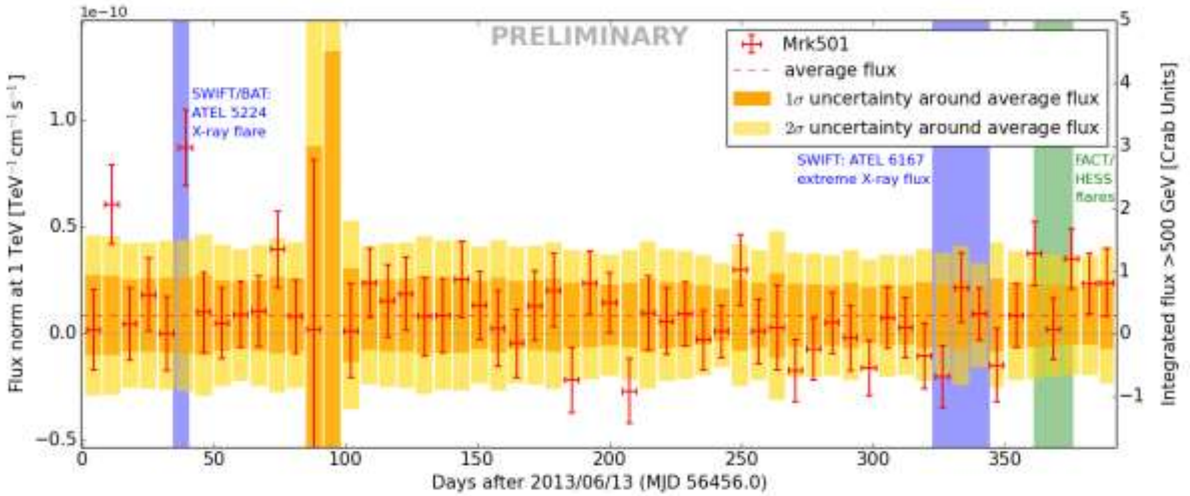
Detection of extended sources

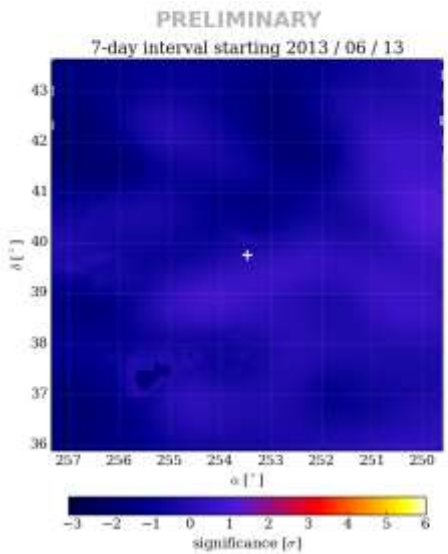


Blazar light curves and flares

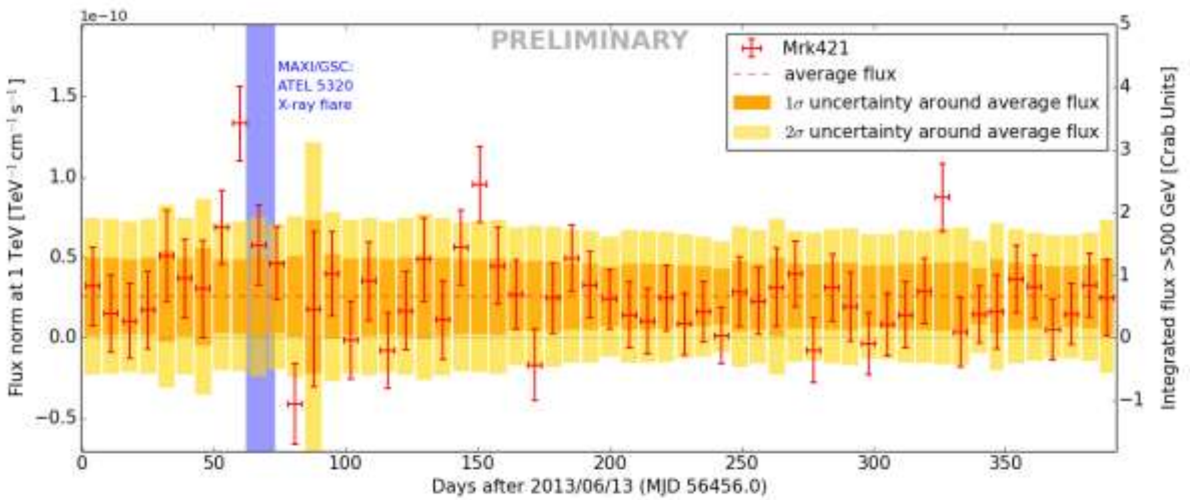
HAWC-111

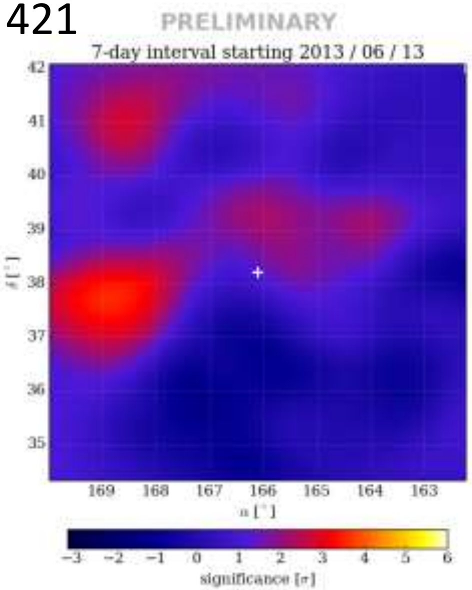
Markarian 501





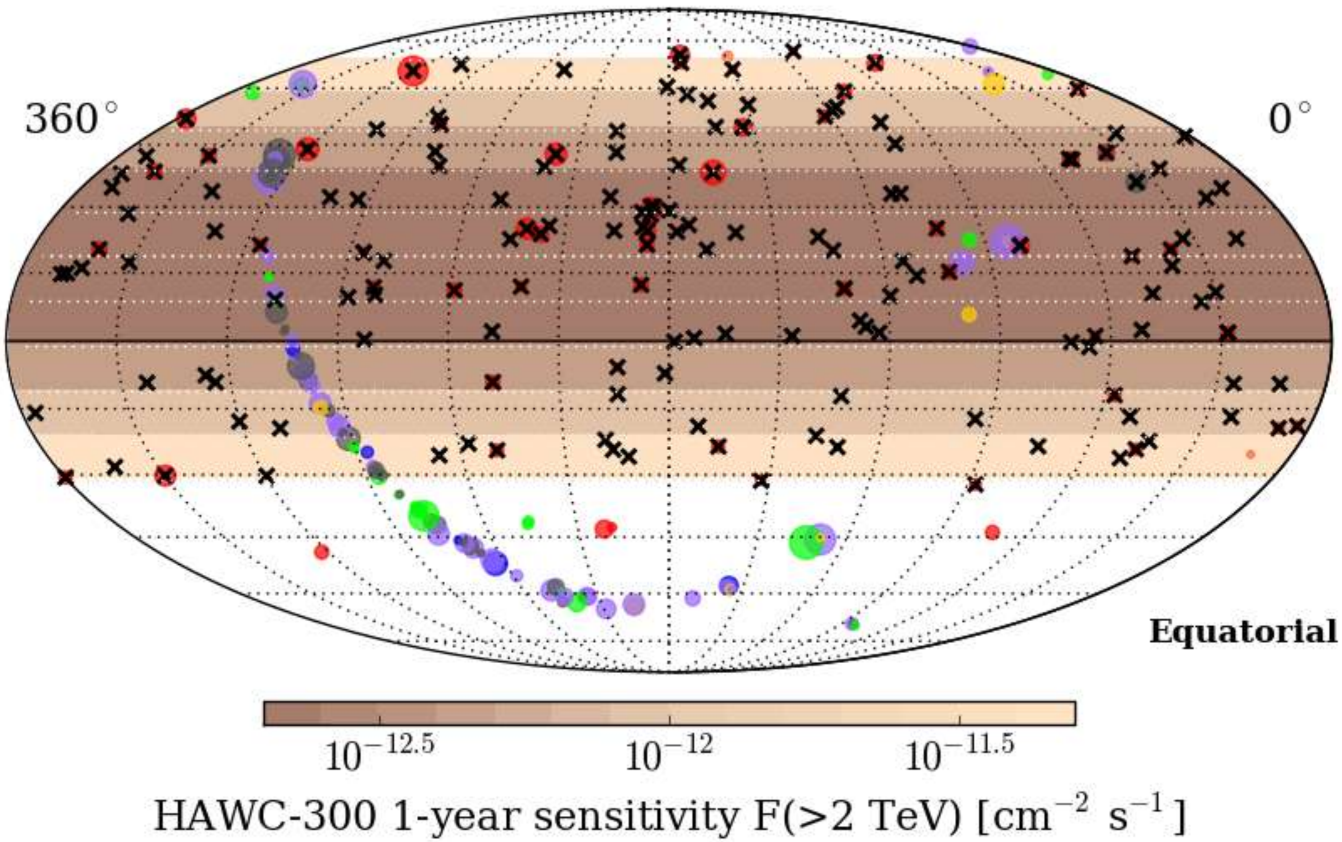
Markarian 421



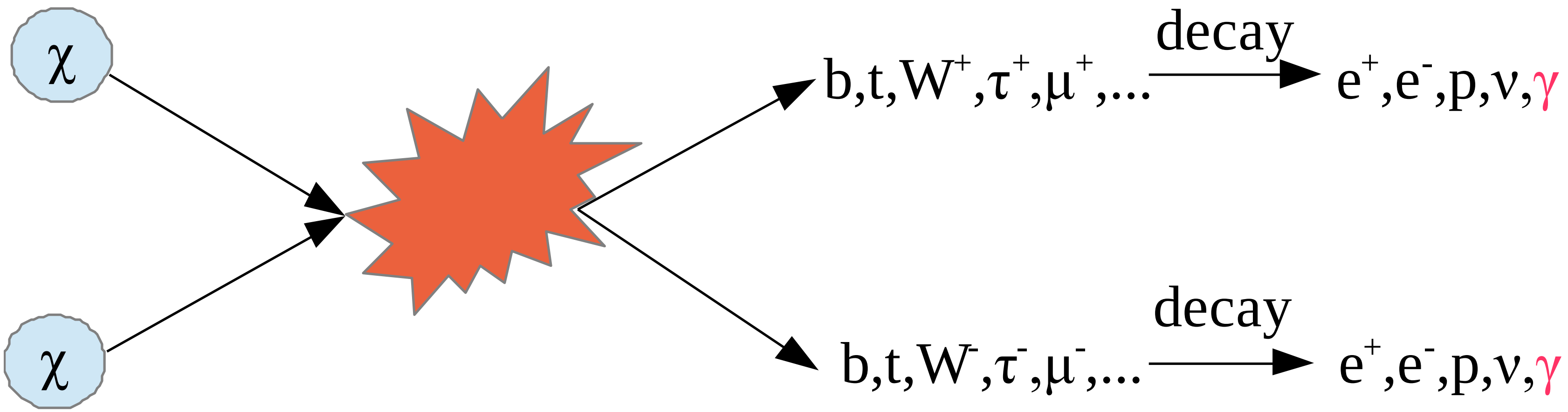


HAWC Online Monitoring

Presently monitoring daily 170 sources: all VHE Blazars and 1FHL blazars with z<1



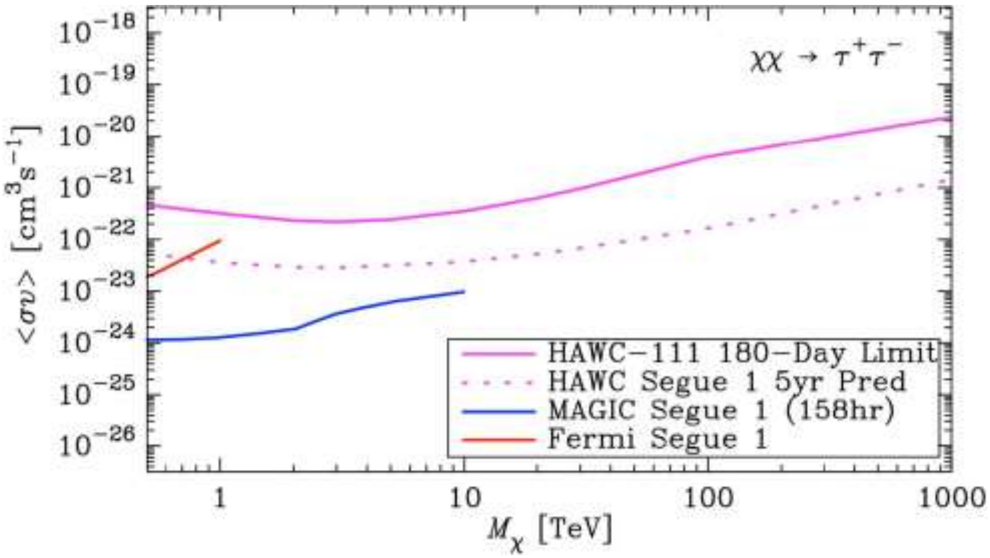
Dark Matter indirect detection

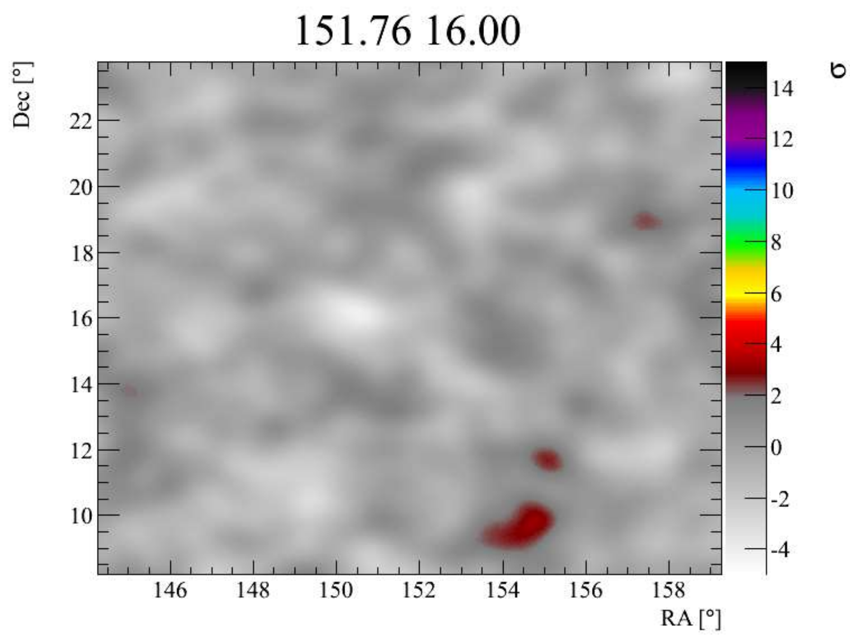


$$Flux_{Annihilation} \propto \frac{\langle \sigma v \rangle}{M_\chi^2} \frac{dN_\gamma}{dE} \int_{l.o.s.} dx \rho^2(r)$$

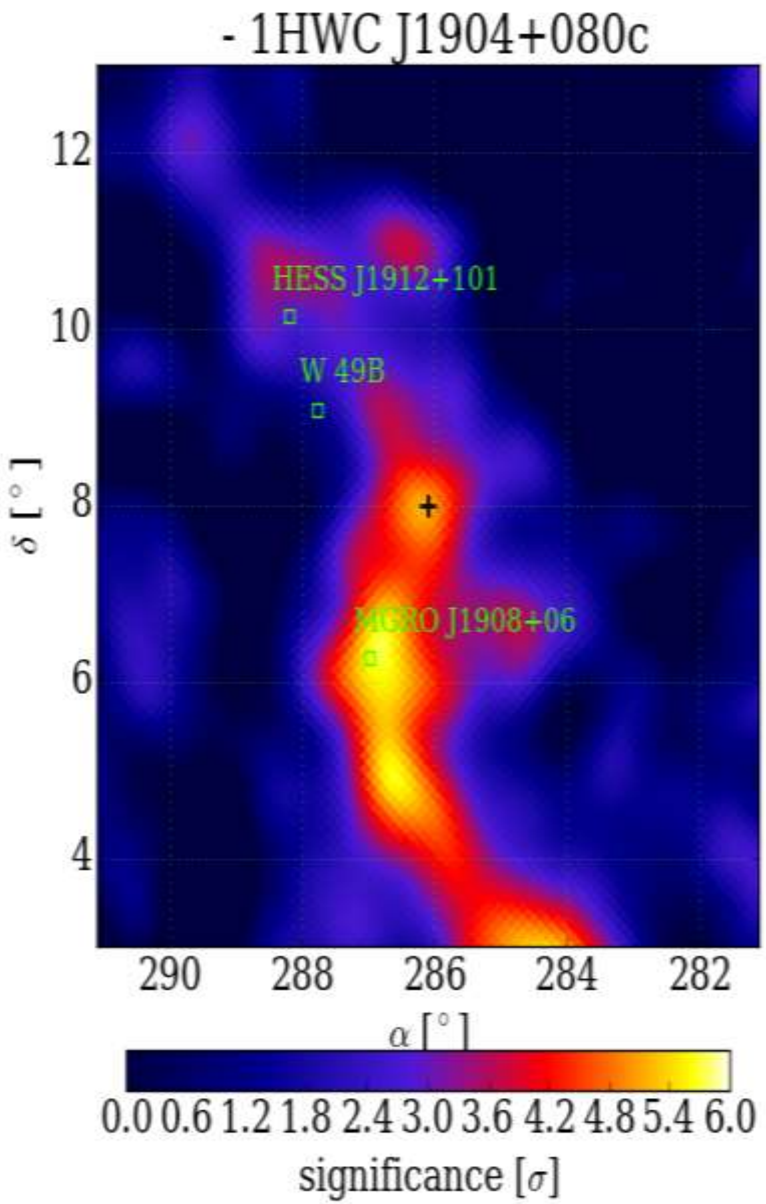
$$Flux_{Decay} \propto \frac{1}{\tau} \frac{1}{M_\chi} \frac{dN_\gamma}{dE} \int_{l.o.s.} dx \rho(r)$$

HAWC-111 DM limit for Segue-1





Multi-Wavelength Response and Follow-up



MOUs: VERITAS, MAGIC, HESS (soon), FACT, FERMI, SWIFT, Chandra, IceCube, Virgo/Ligo, AMON

Two MOU Paradigms

HAWC-Triggered

1HWC J1904+08c seen at 3.9σ post-trials in HAWC-111. MOU partners notified.

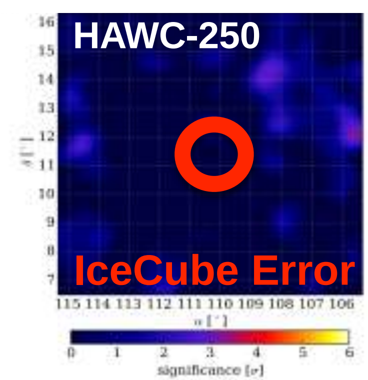
VERITAS observed (moon and dark observations) and set a point source upper limit.

AMON Integration

Externally Triggered

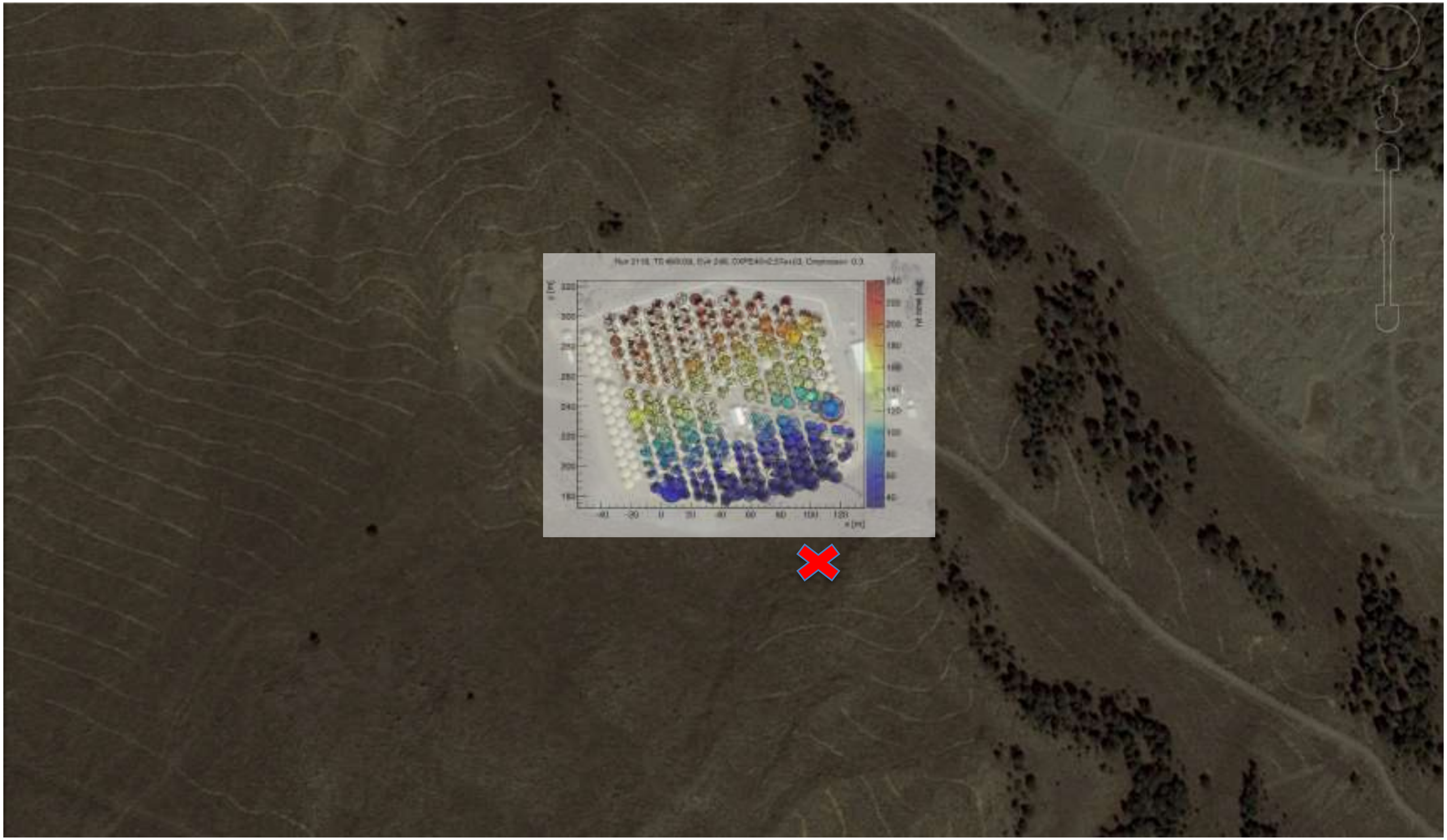
IceCube notified HAWC of a high-confidence neutrino for HAWC followup. Atel IceCube, Atel from HAWC

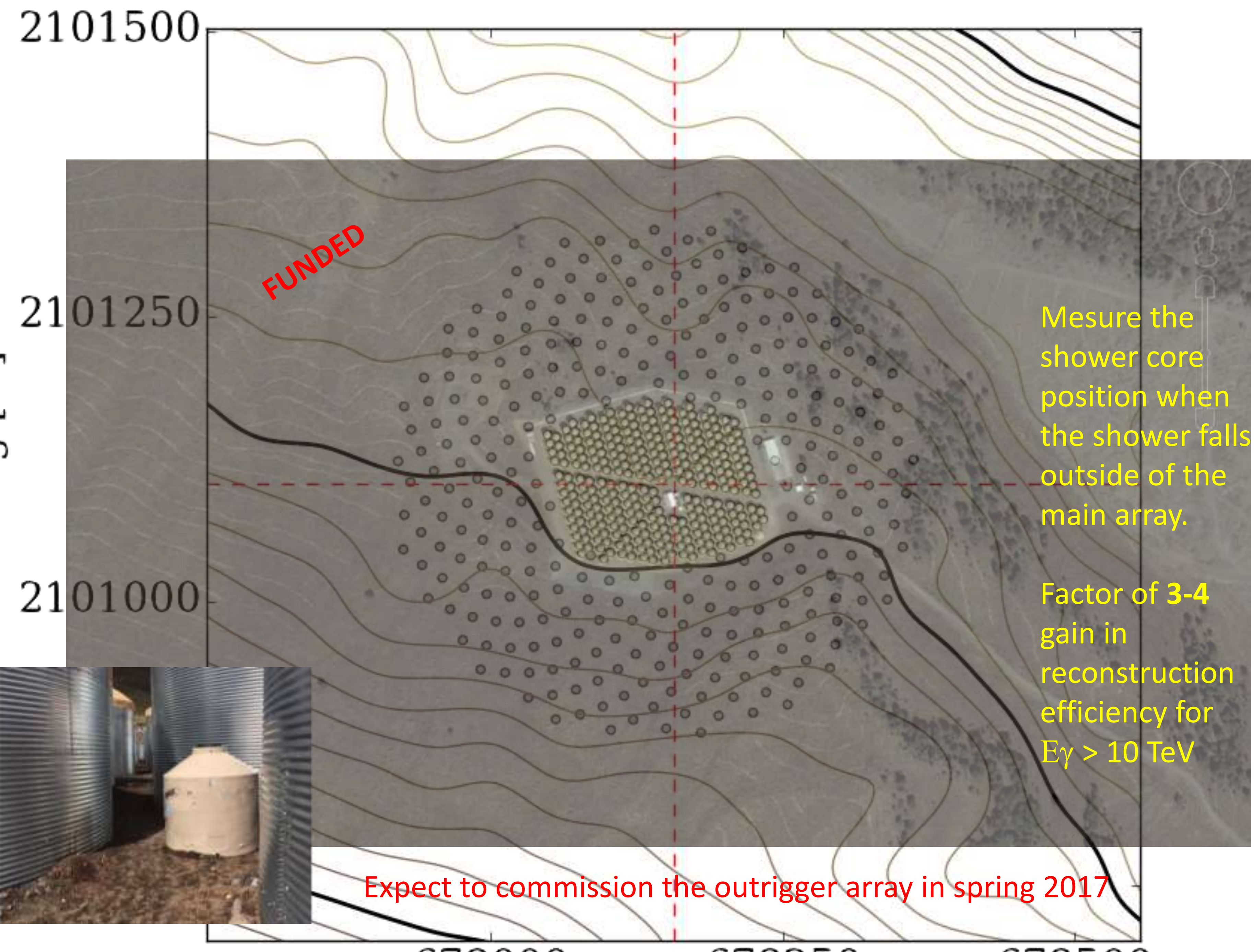
Fermi-LAT team asked about TeV emission from several of their sources.



HAWC upgrade with a sparse outrigger array

Most very high energy triggered showers fall outside of the array



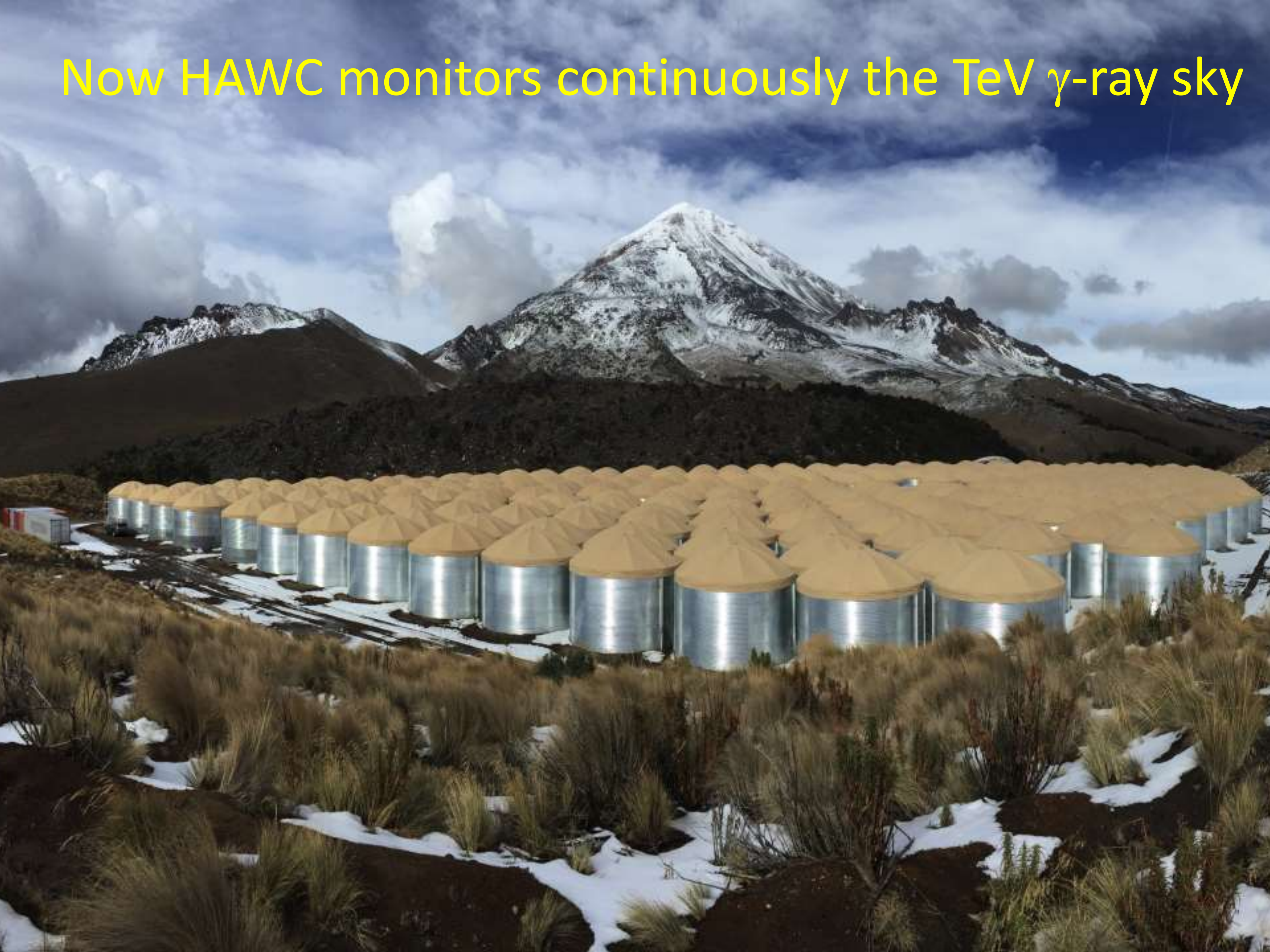


Mesure the shower core position when the shower falls outside of the main array.

Factor of **3-4** gain in reconstruction efficiency for $E\gamma$ > 10 TeV

Expect to commission the outrigger array in spring 2017

Now HAWC monitors continuously the TeV γ-ray sky



Now HAWC monitors continuously the TeV γ-ray sky

First bright source catalog in about a year from now

HAWC South

- 3rd generation water Cherenkov detector
- higher altitude, more sensitive than HAWC
- for example at the Alma site at 5,000 masl