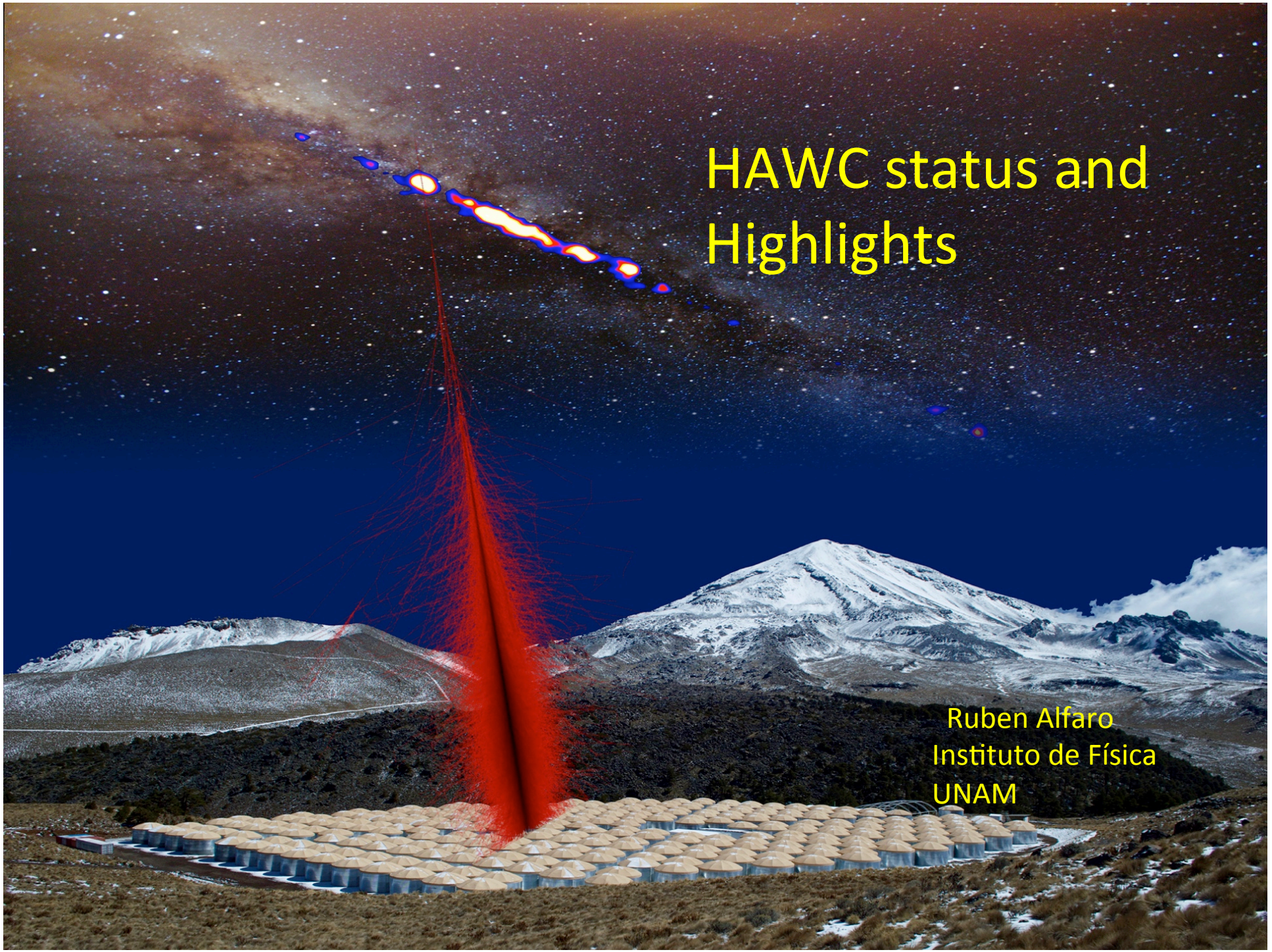

HAWC status and
Highlights
Ruben Alfaro
Instituto de Física
UNAM

Outline

- High Energy Gamma-Ray Observatories
- The HAWC Observatory.
  - Development
  - Performance

Scientific Achievements

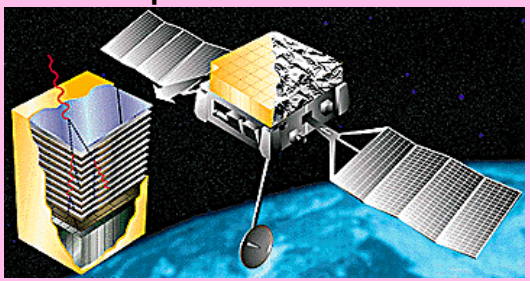
  - 1 year survey
  - Extended Sources
  - Flaring Events
  - Multi-Messenger Multi-Frequency
  - Dark Matter Limits

- Future
  - HAWC “Outriggers” expansion for higher energies
  - A South array ?

Gamma-Ray Detectors

Wide Field of View, Continuous Operations

Space Based



Fermi
AGILE
EGRET

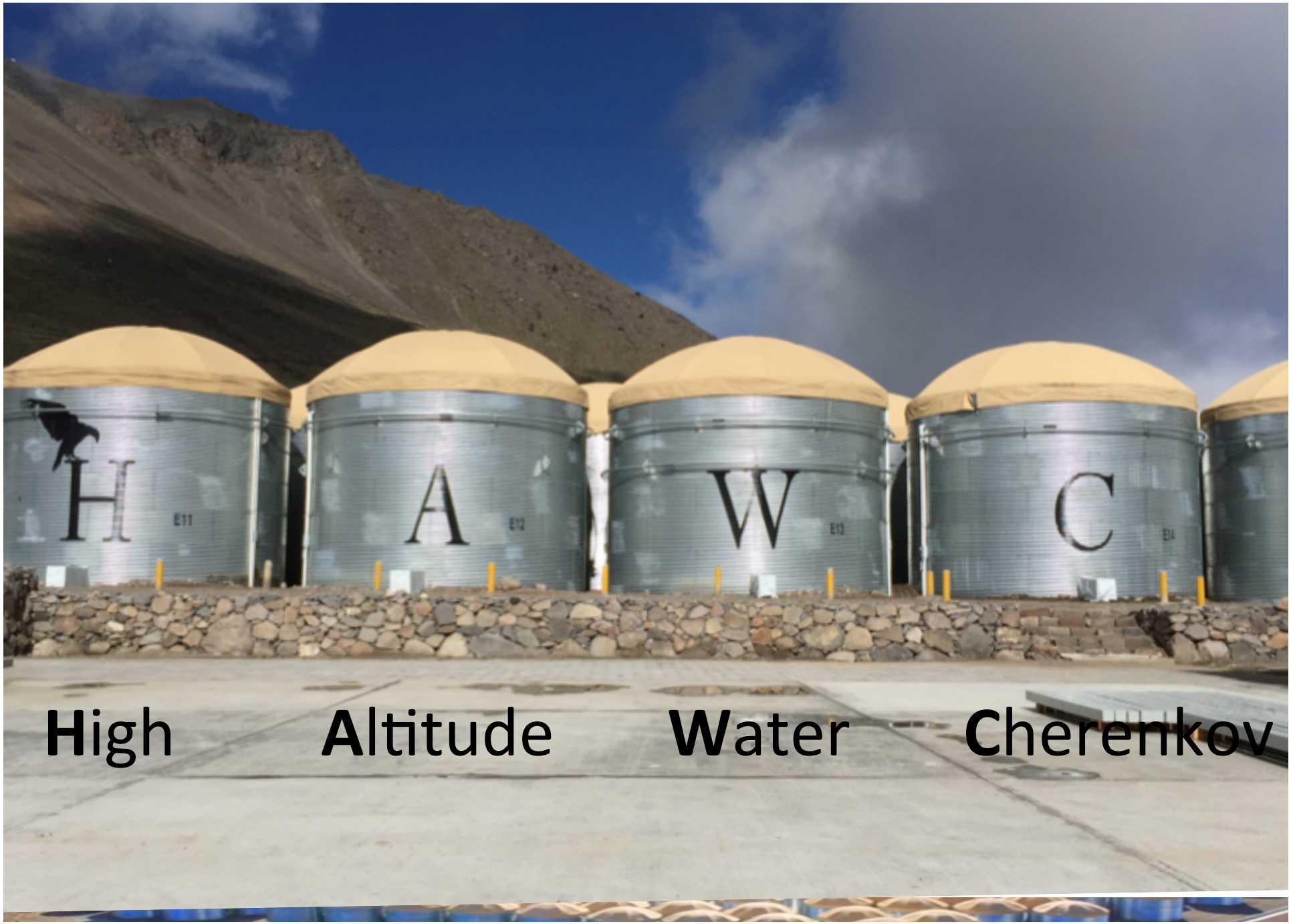
TeV Sensitivity

Extensive Air Shower (EAS) Arrays

HAWC
ARGO
Milagro
Tibet

Imaging Atmospheric Cherenkov Telescopes (IACTs)

VERITAS
HESS
MAGIC
FACT


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

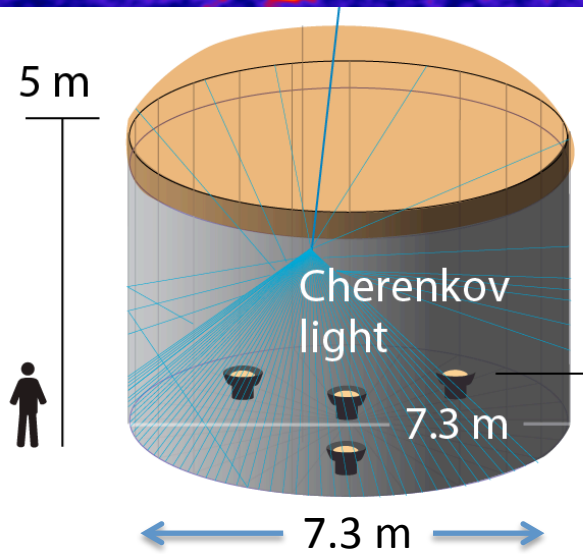
HAWC Collaboration

18 USA Institutions
14 Mexican Institutions

> 100 Scientists
Recently 2 UE Institutions


Sierra Negra
4640m
Pico de Orizaba
5636m
HAWC Site
4100m

300 Water Cherenkov Detectors



200,000 L of purified water

photomultiplier tube (PMT)

Development

Counting house
- Data acquisitions
- Laser calibration system

HAWC Utility Building
- Water filtration
- Bladder tests

Development

HAWC registers 20,000 cosmic rays per second

HAWC got funded: February 2012

HAWC array construction started: February 2013

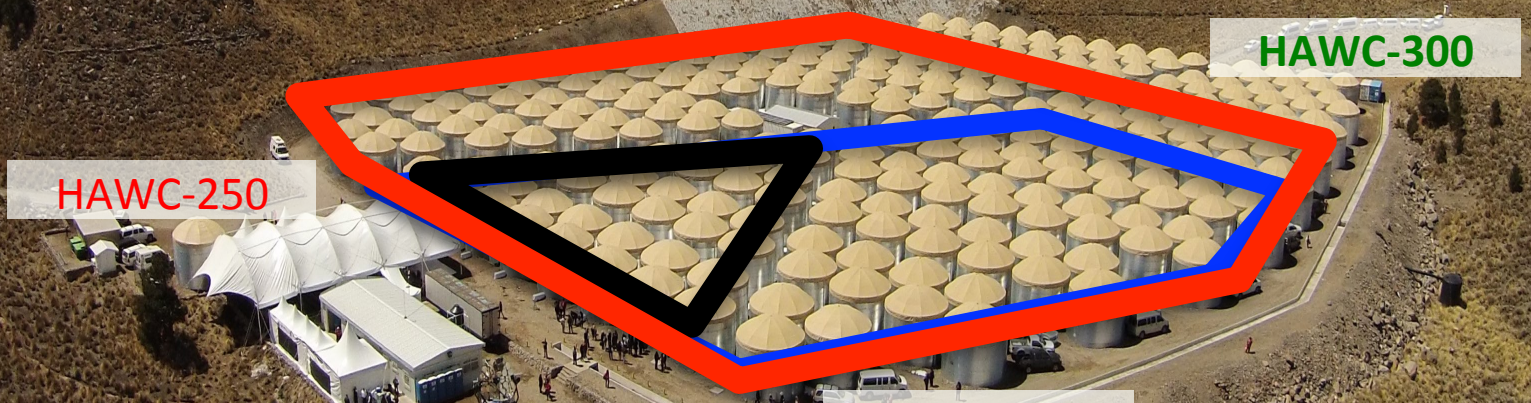
HAWC-30: Engineering Test of full detector April 2013

HAWC-111: Operations Begins: August 2013 (283 days)

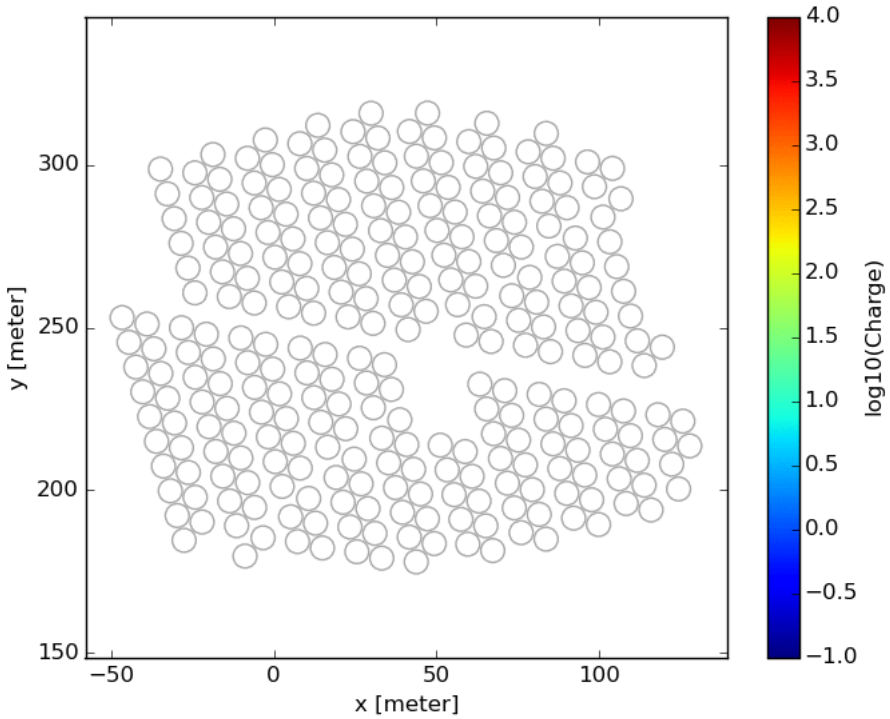
HAWC-250: November, 2014 (~150Days)

HAWC-300: March 2015 – Present : >95% uptime

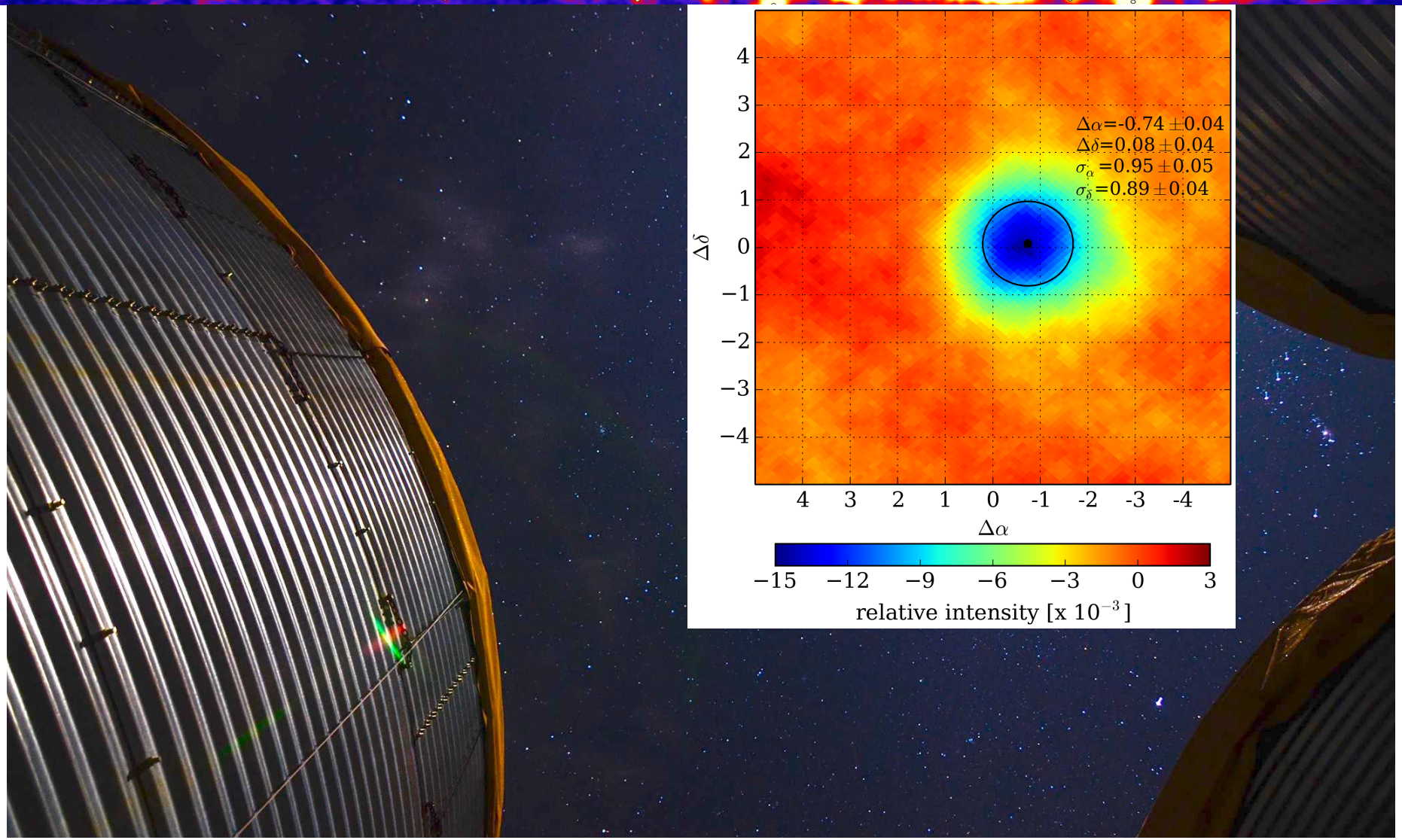
HAWC Inauguration, HAWC-300: March, 2015



Event reconstruction

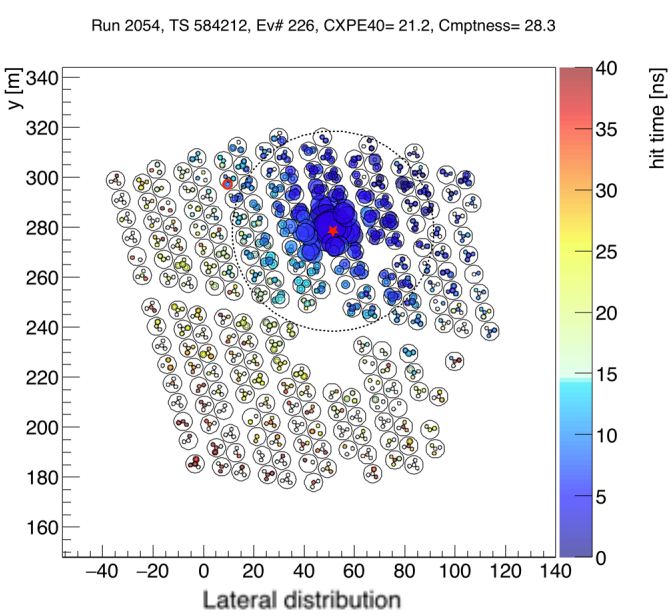


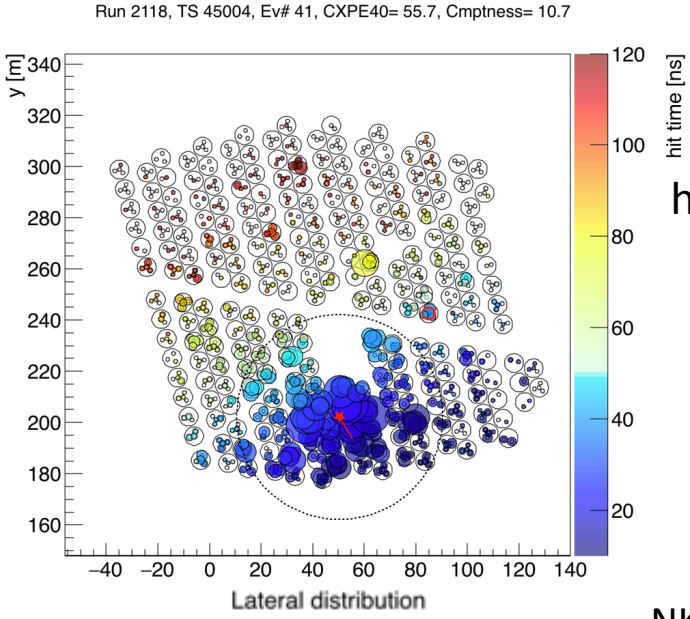
Moon shadow


$\Delta\alpha$=-0.74 ±0.04
$\Delta\delta$=0.08 ±0.04
σ_α =0.95 ±0.05
σ_δ=0.89 ±0.04
$\Delta\delta$
$\Delta\alpha$
relative intensity [x 10^{-3}]

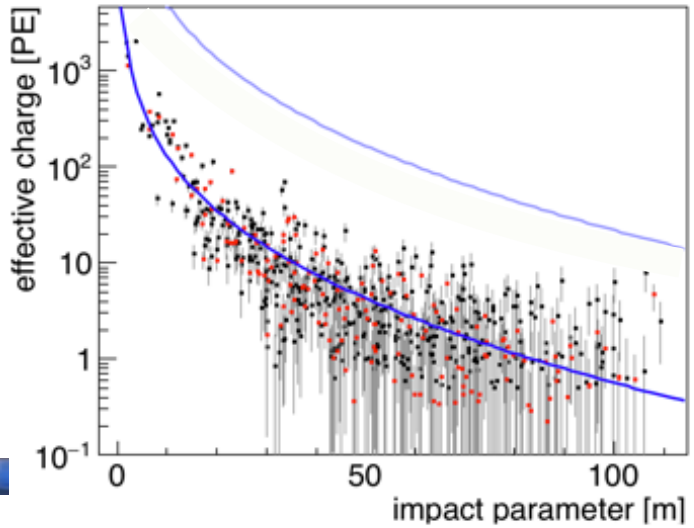
gamma/hadron identification

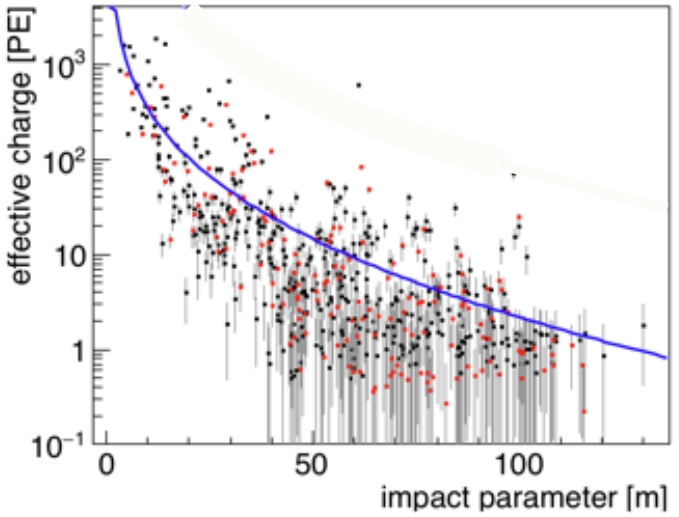
gamma





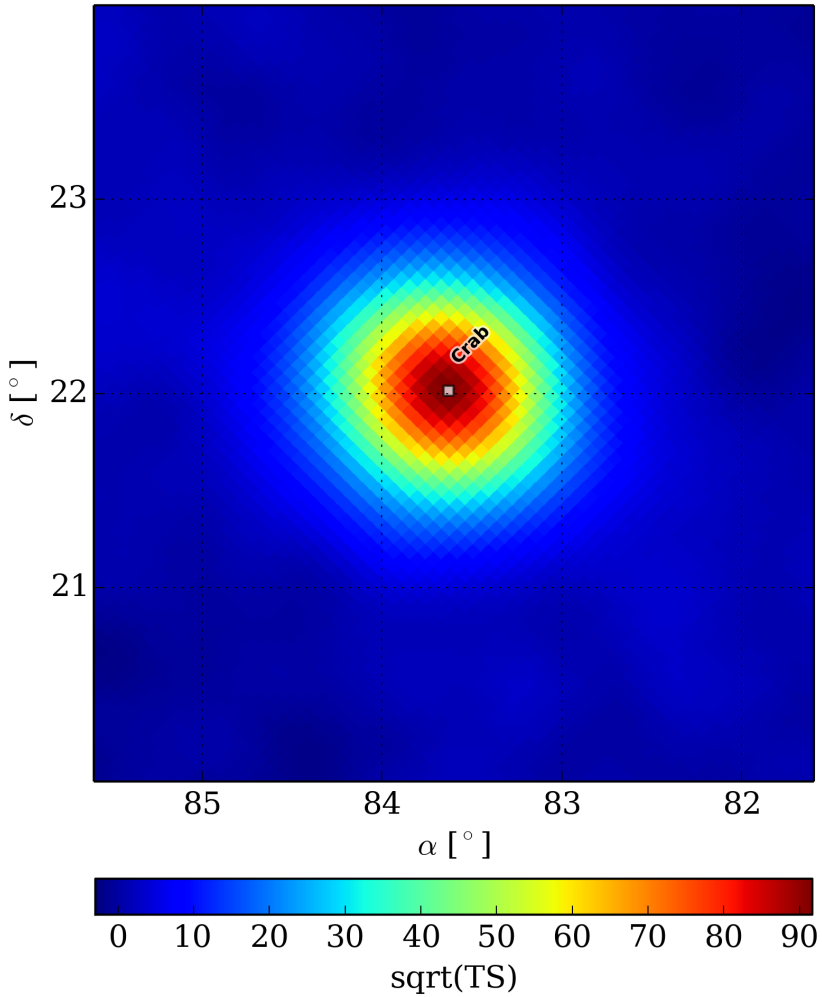
hadron

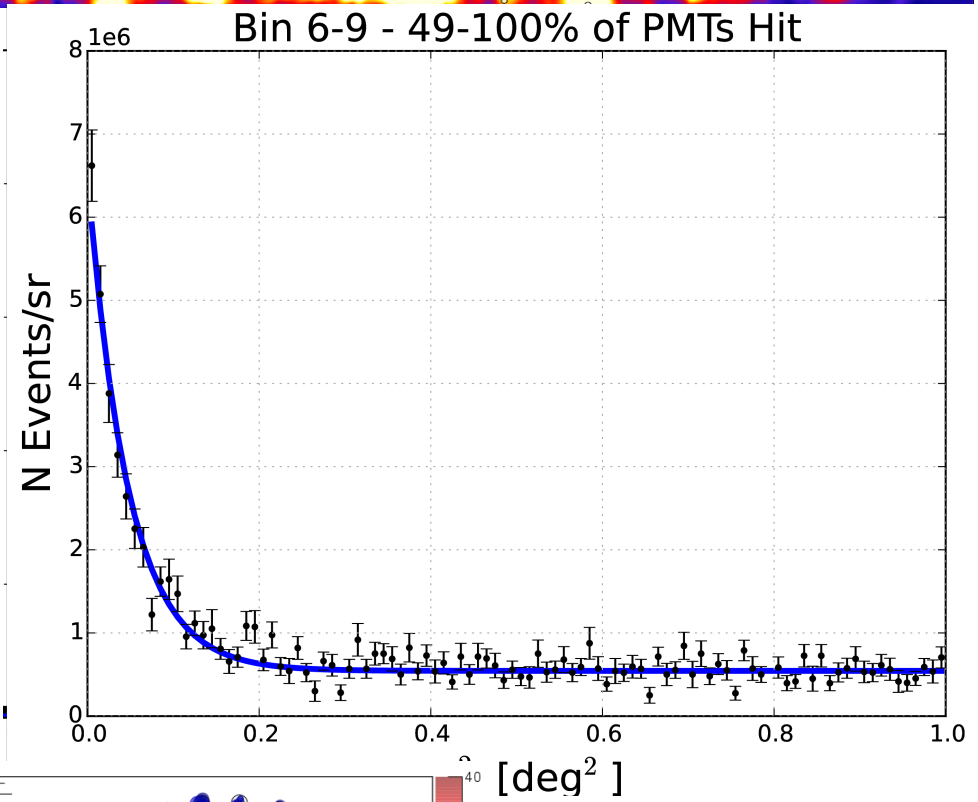


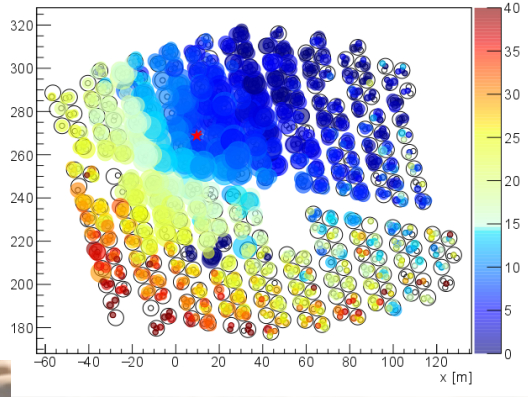


NKG (Nishimura-Kamata-Greisen) fits to lateral distribution function of an EM shower.

The standard candle

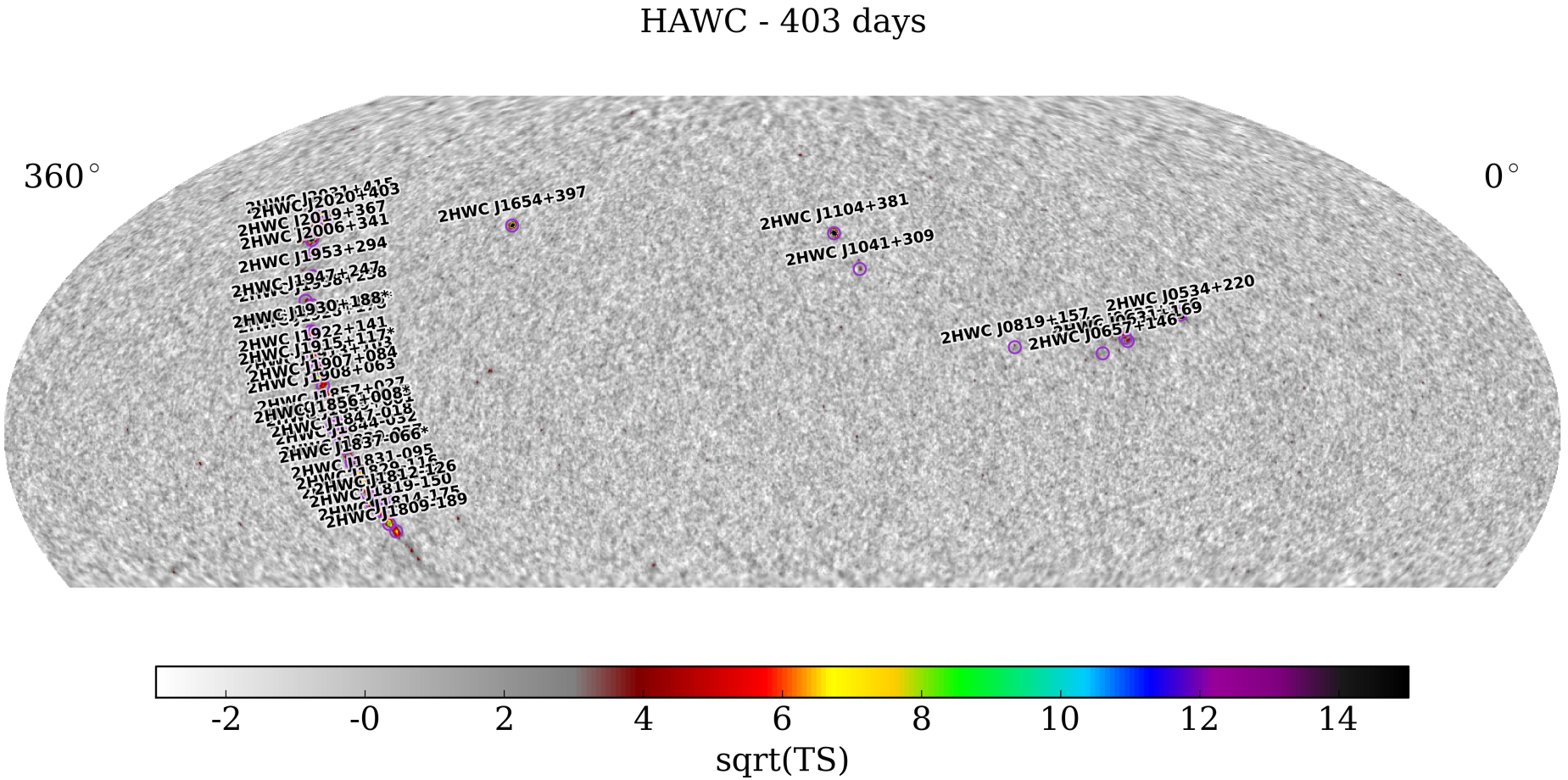




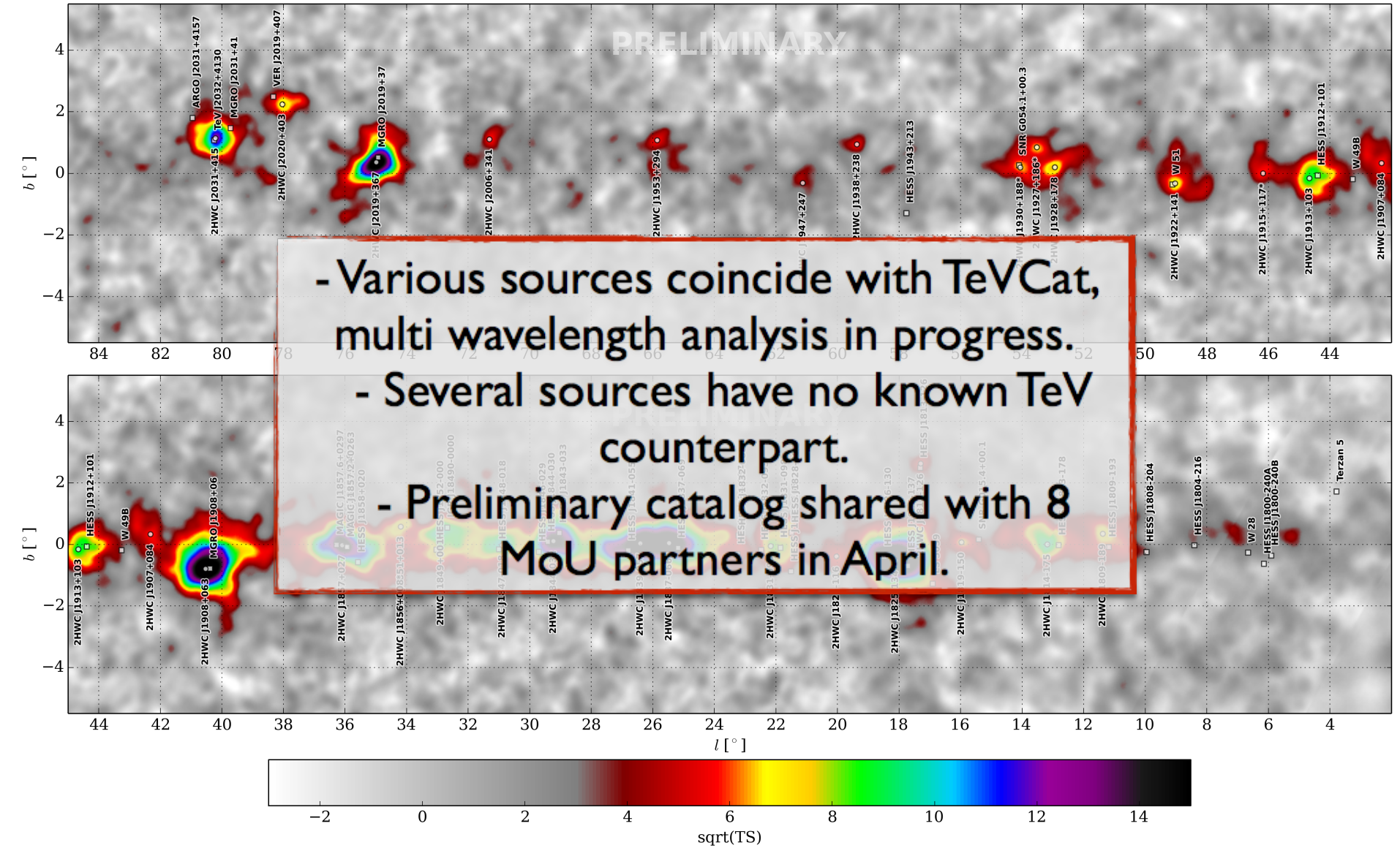


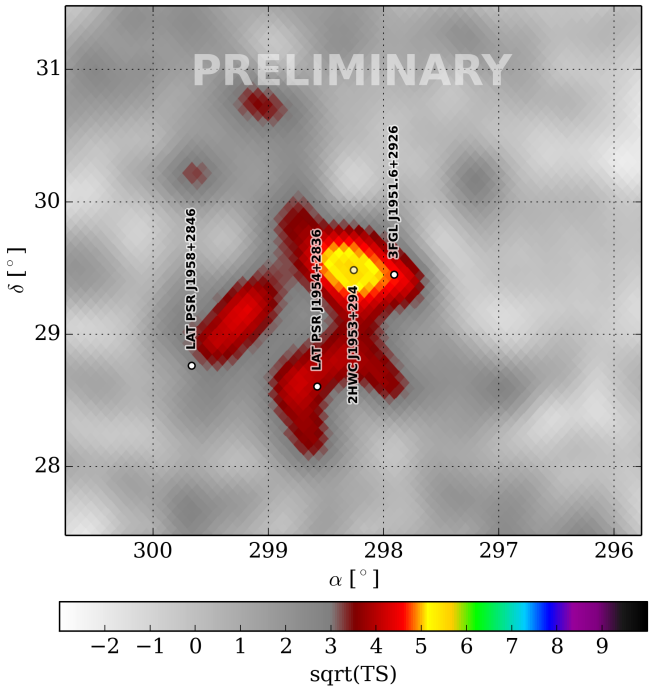
60 TeV event from the Crab

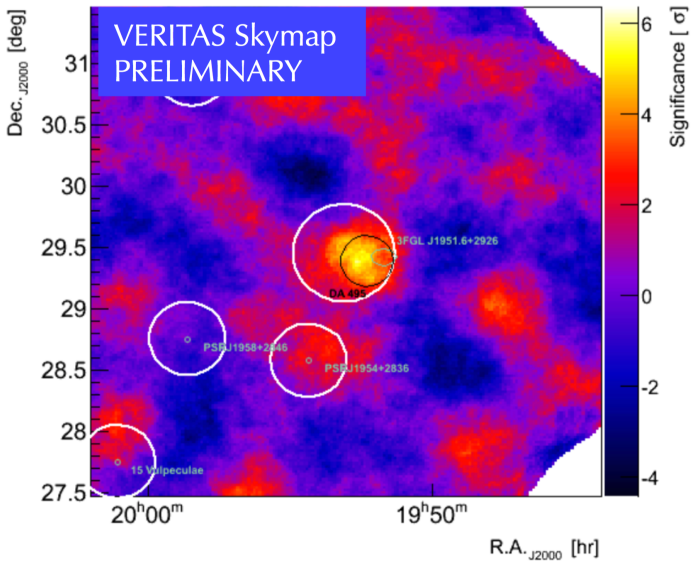
HAWC γ Sky Map with fixed index power law



Galactic Plane





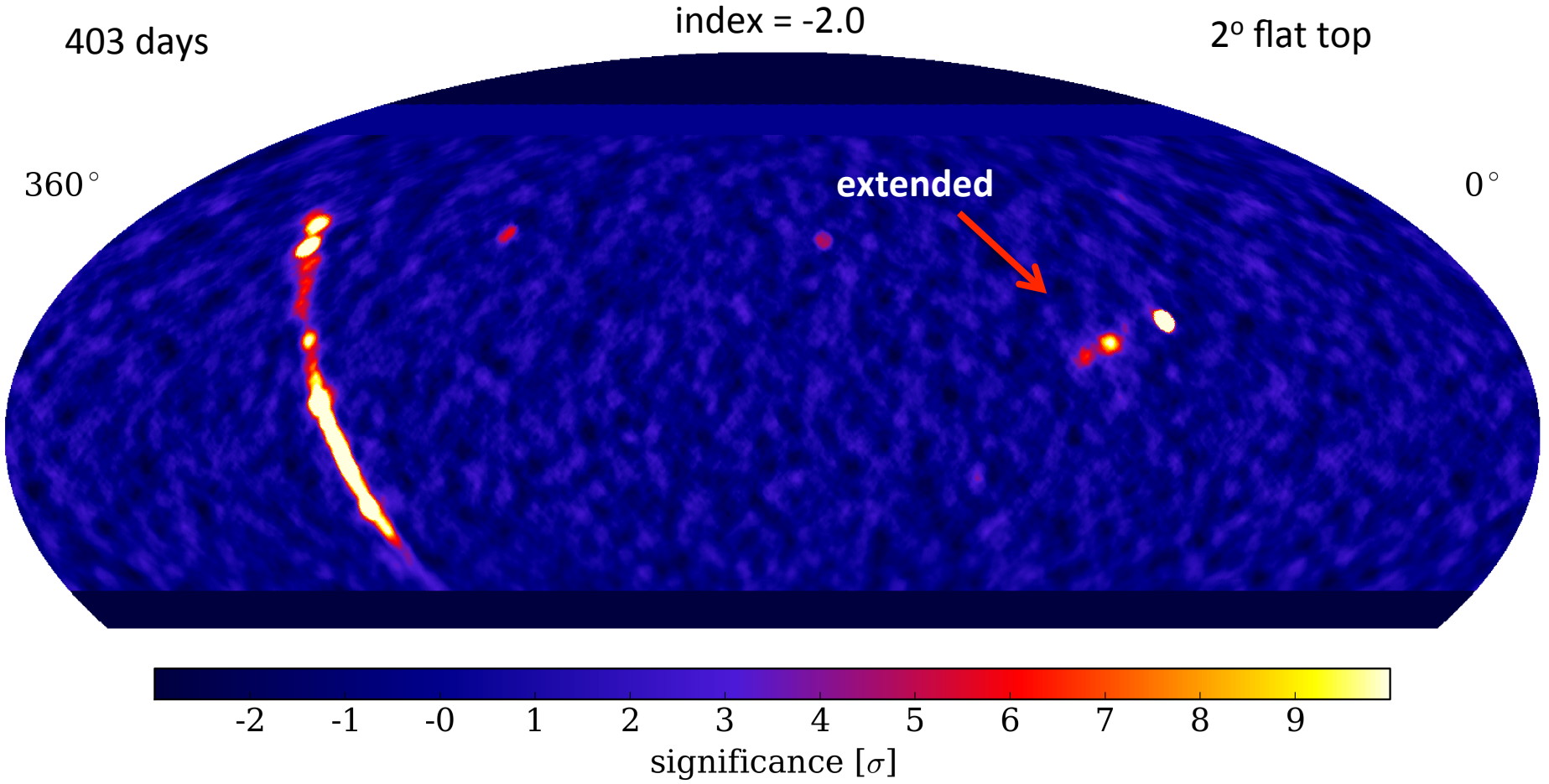


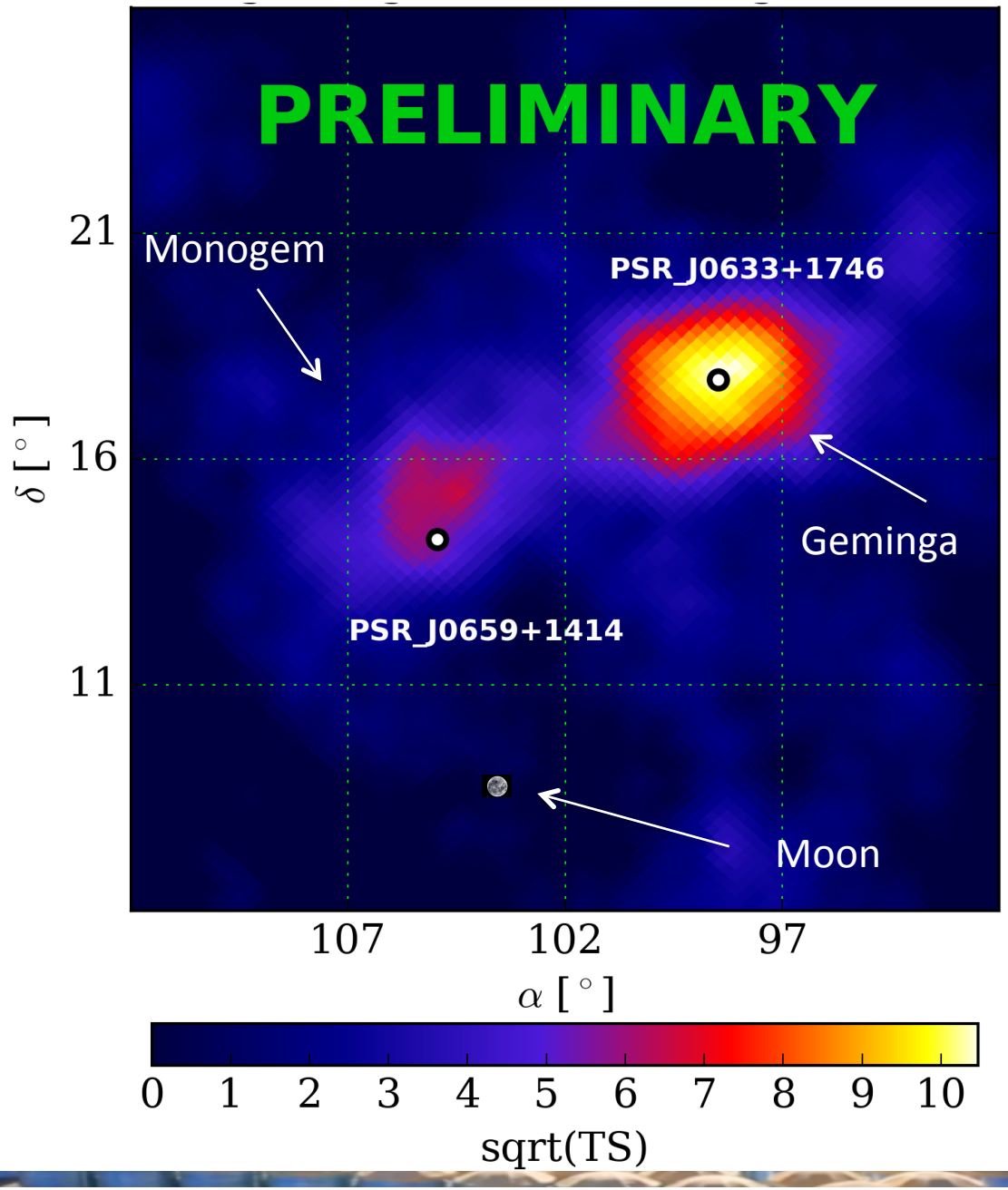
Name	$\sqrt{TS}$	Index	Flux for index at 7 TeV [$\mathrm{TeV^{-1}cm^{-2}s^{-1}}$]
2HWC J1953+294	5.58	-2.76 ± 0.15	1.1e-14 ± 4.2e-15

Preliminary. Reported errors are stat. only

- **No previously known TeV source.**
- **New analysis by VERITAS, archival plus new data, source confirmed.**
- **Tentative association 3FGL J1951.6+2926 / PWN DA 495?**

HAWC search for extended sources

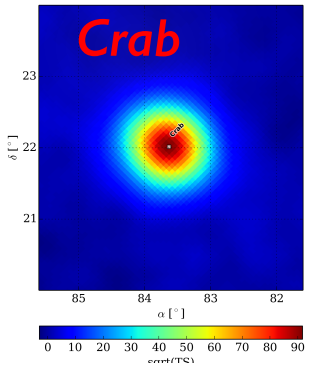


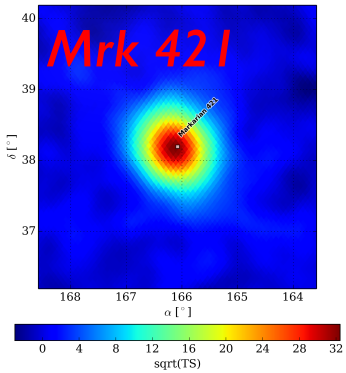

PRELIMINARY
Monogem
PSR_J0633+1746
Geminga
PSR_J0659+1414
Moon
21
16
11
δ [°]
107
102
97
α [°]
0 1 2 3 4 5 6 7 8 9 10
sqrt(TS)

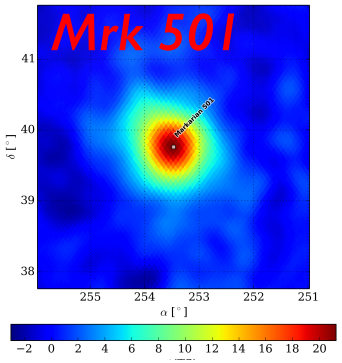
Geminga and Monogem

- both are nearby, middle aged pulsars
- both have very hard gamma ray spectra
- what is their morphology and flux?
- can we determine from the γ spectrum an e^+e^- diffusion coefficient?
- can the e^+, e^- reach the Earth and contribute to the positron excess?

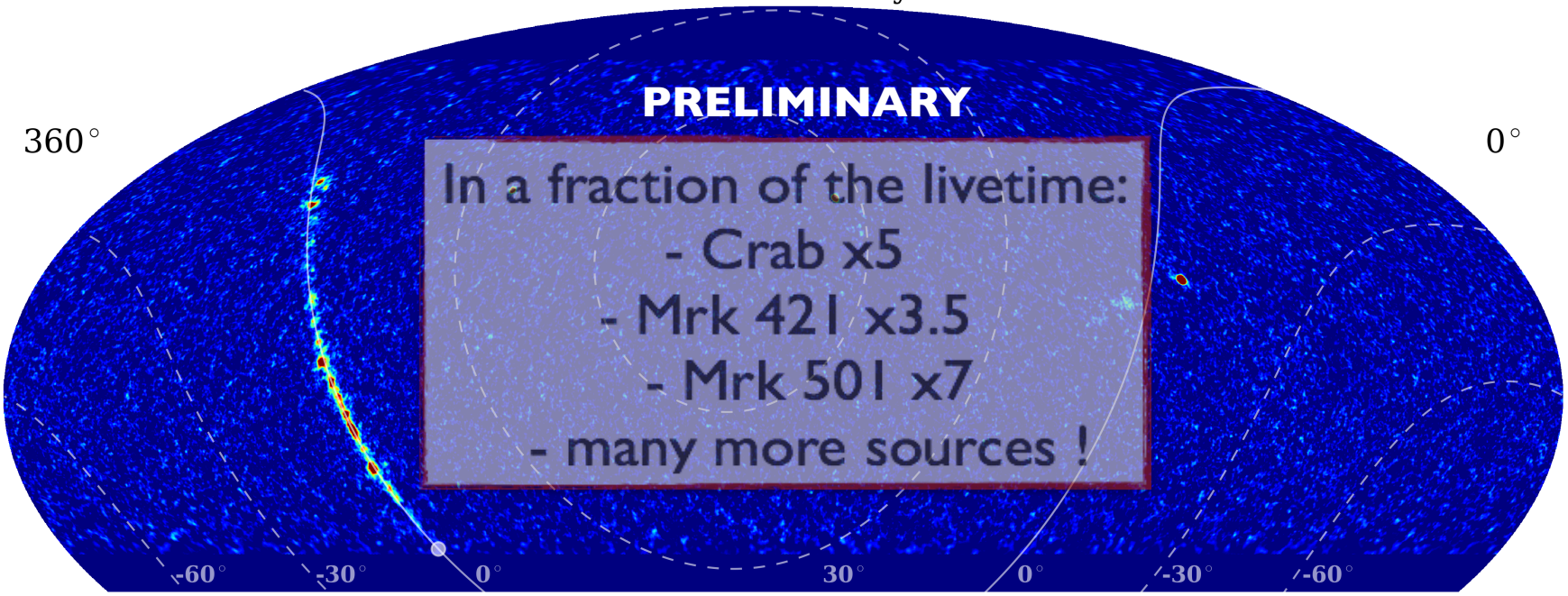
Flaring events



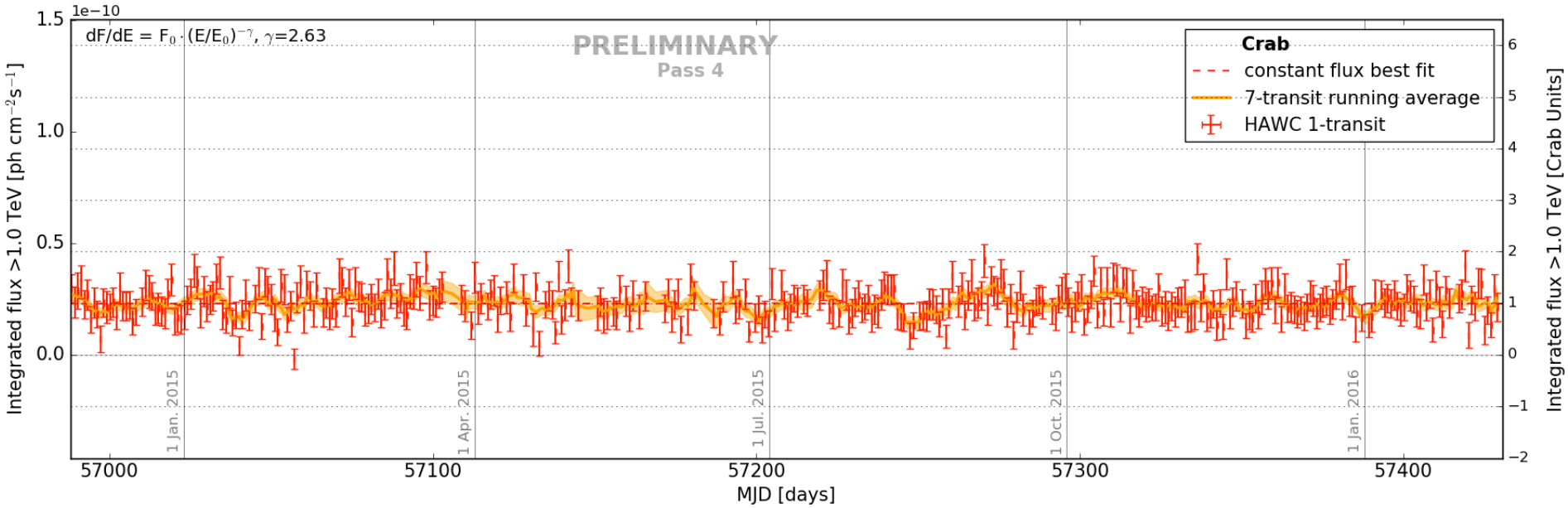




HAWC - 403 days

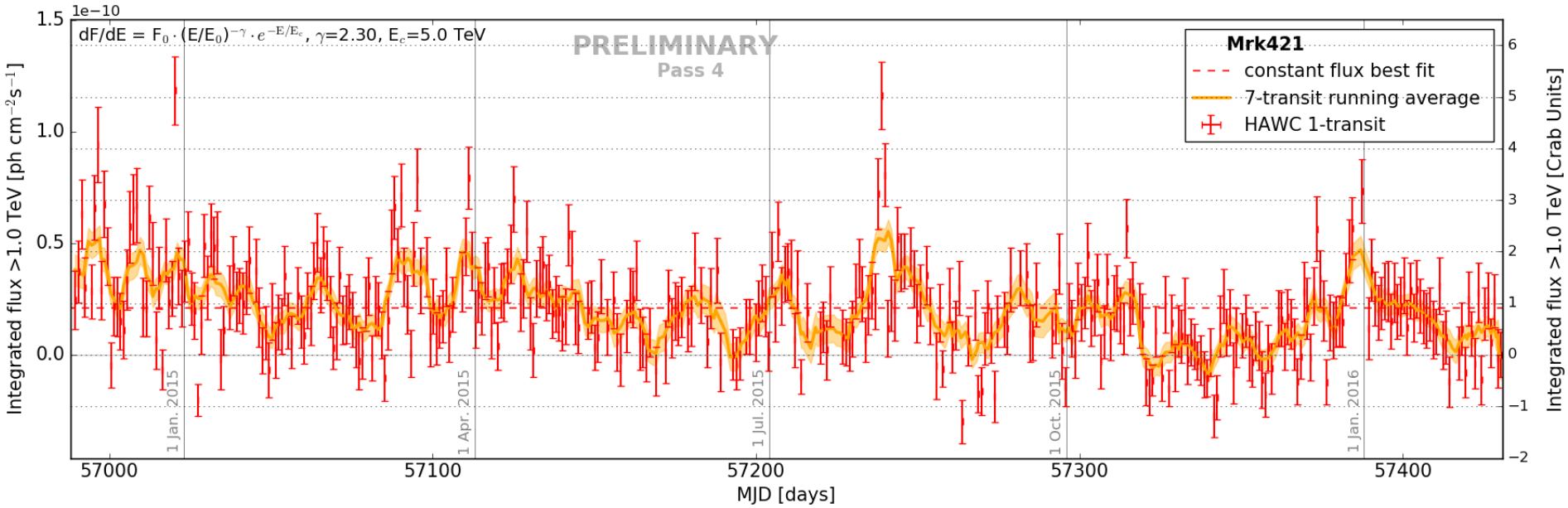


Crab light curve



A likelihood test shows that the **data is consistent with a constant flux**. Coincident observations with **Fermi-LAT reported Crab flare at lower gamma-ray energies** (>100 MeV) show **no TeV variability** 95% C.L. upper limit on 13-day averaged flux >1 TeV: **1.01 x avg. Crab flux (2.34 ph cm-2s-1)**

Markarian 421 light curve



Variability: **Inconsistent with constant flux, p-value <10-10**

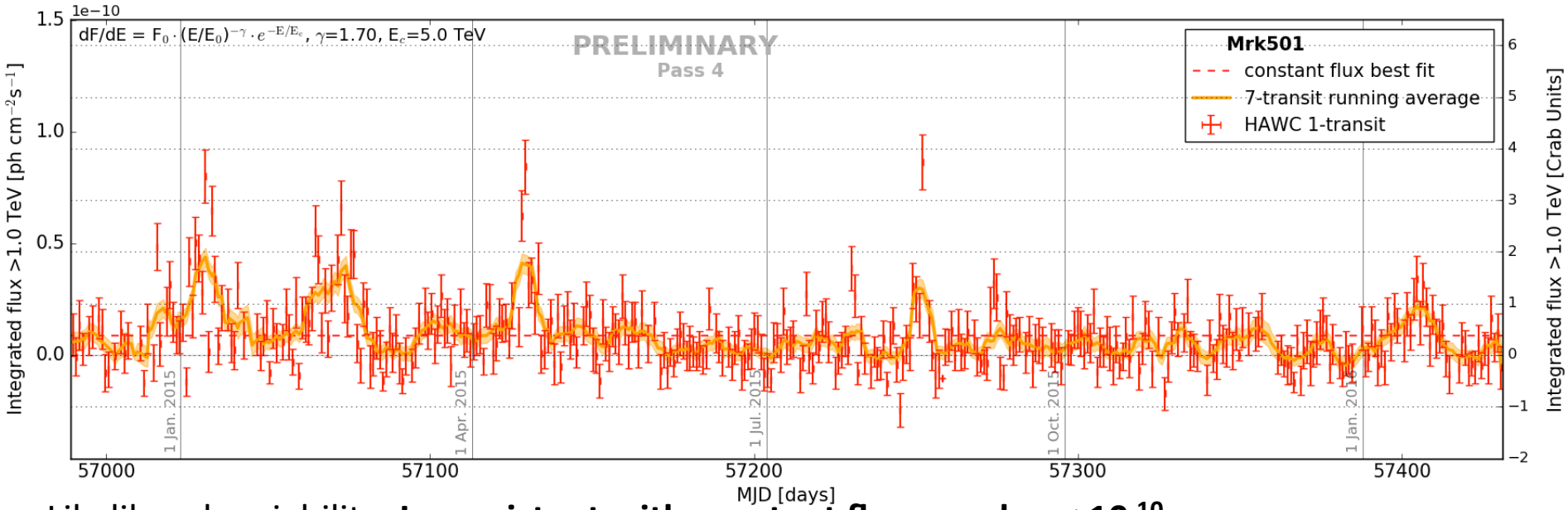
Nov 26, 2014 – Feb 12, 2015

Individual errors: 1σ statistical Overall scaling: 35% systematic uncertainty

High States: - A large number of high states, **year-averaged flux about equal to the Crab flux** - wide distribution of intermediate flux states

- **10 transits show a flux > 3 σ above the fitted average (~3 CU)**constant flux is rejected with a p-value < 10^{-10}.

Markarian 501 light curve



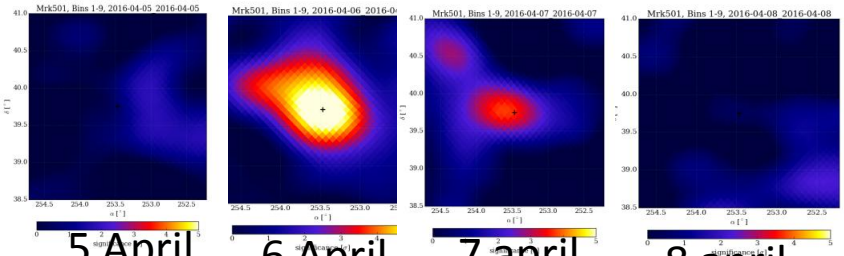
Likelihood variability: **Inconsistent with constant flux, p-value < 10^{-10}**

High States: **19 transits show a flux 3 σ above the fitted average (~2.5 CU)**

First HAWC-triggered blazar flare alert:

HAWC detection of increased TeV flux state for Markarian 501

ATel #8922; *Andrés Sandoval (IF-UNAM), Robert Lauer (UNM), Joshua Wood (UMD) on behalf of the HAWC collaboration*
on 7 Apr 2016; 23:38 UT



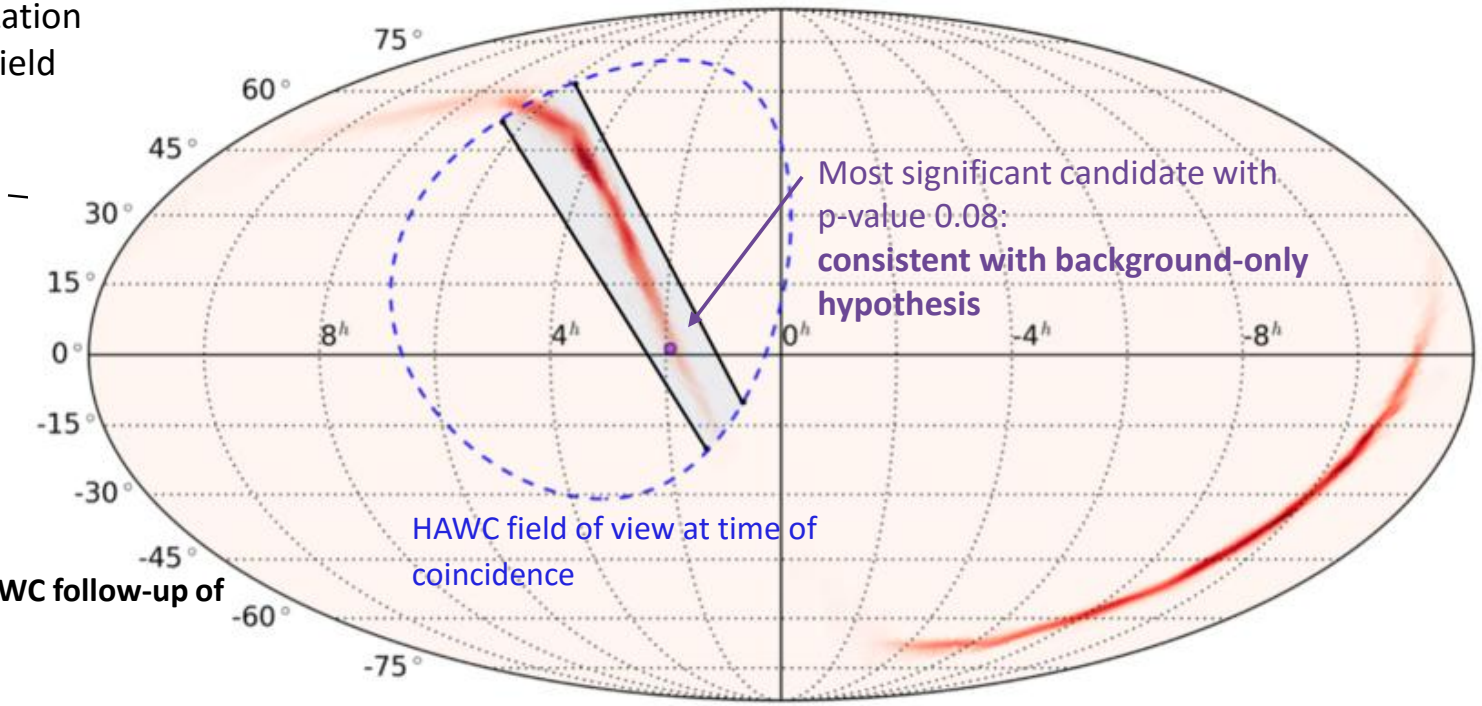
~2 Crab units, elevated flux for ~2 days

Multi-frecuency

Follow-up on 2nd Gravitational Wave Alert

LIGO GW150914: Outside HAWC field of view

LIGO GW151226, 2015-12-26 03:38:53 UTC:
Large part of the localization Contour within HAWC field of view at time of coincidence

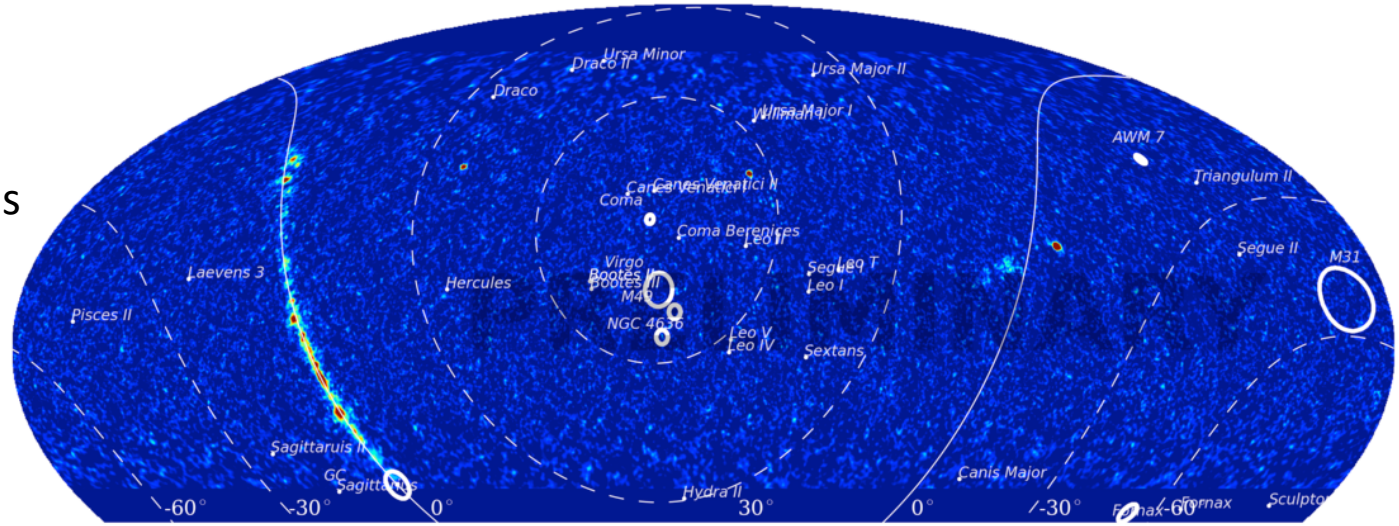


A GRB-optimized search within ±10 s shows no significant excesses, see:
GCN CIRCULAR #19156
LIGO/Virgo G211117: HAWC follow-up of northern sky

Search for Dark Matter

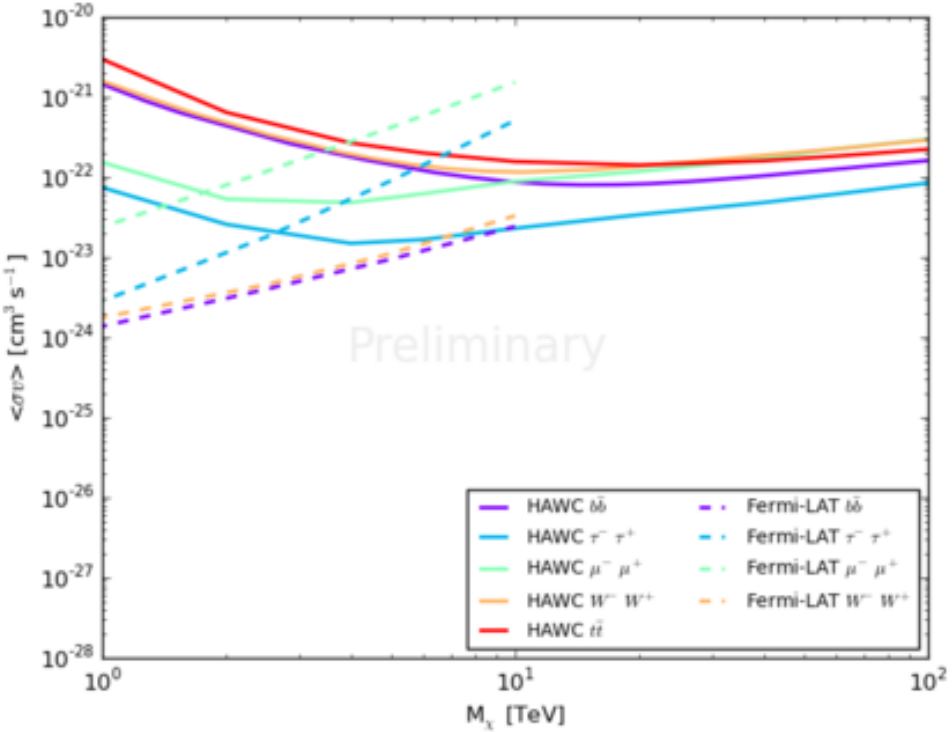
- Decay or annihilation of DM particles in the regions of enhanced DM density to SM particles eventually leads to γ rays. If m_{DM} is 1 TeV-100 TeV HAWC could detect them indirectly.

Virgo Cluster
M31
Galactic Center
dwarf spheroidals

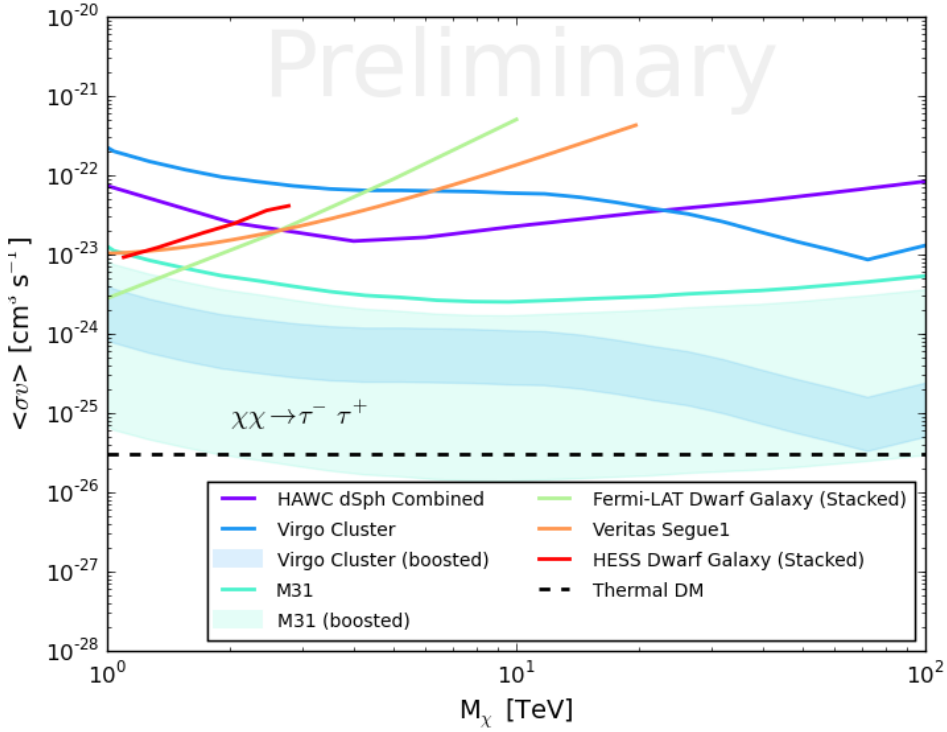


DM upper limits

DM limits for a stacked analysis of 14 dwarf spheroidal galaxies

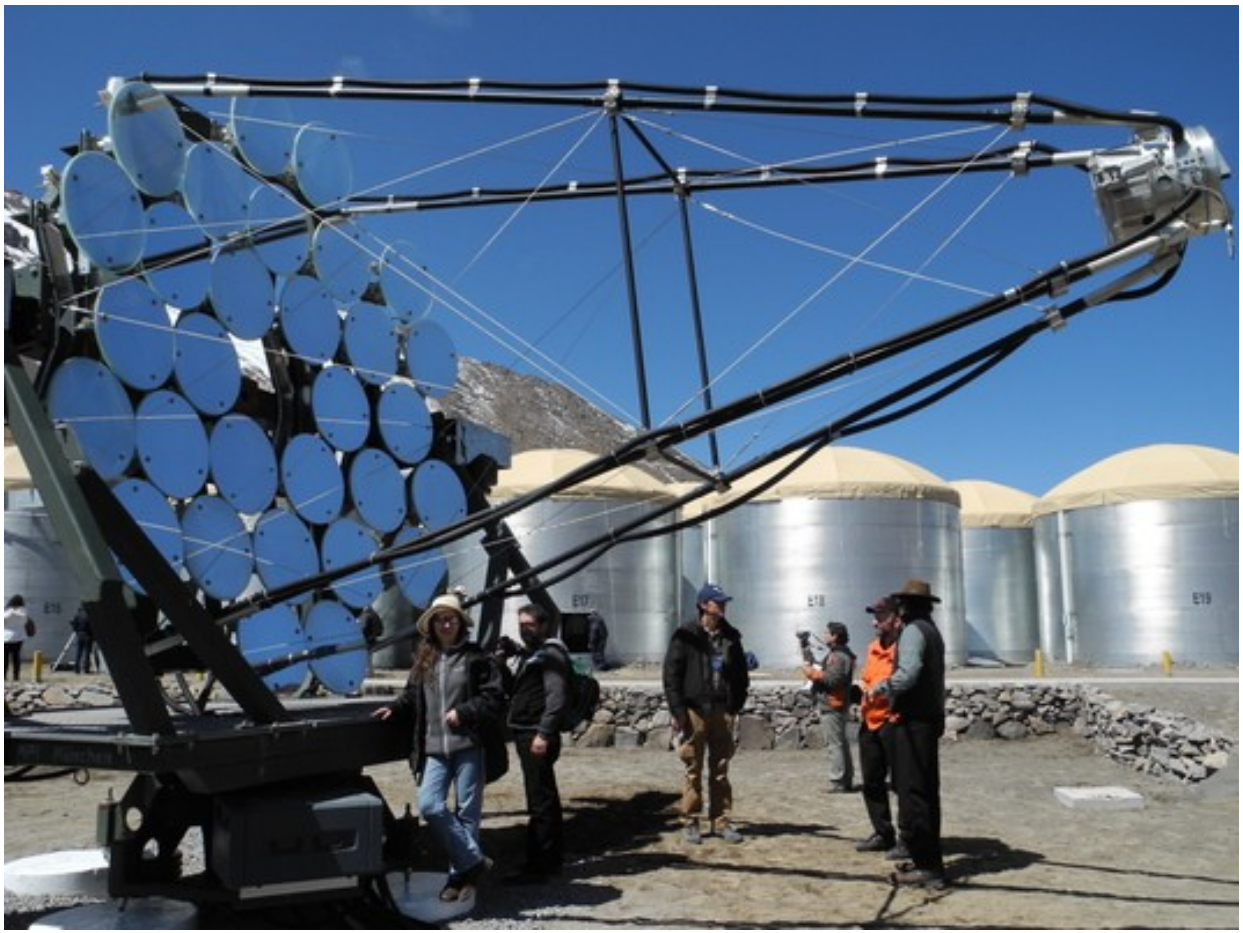


DM limits for Virgo, M31 and dSph



The Future

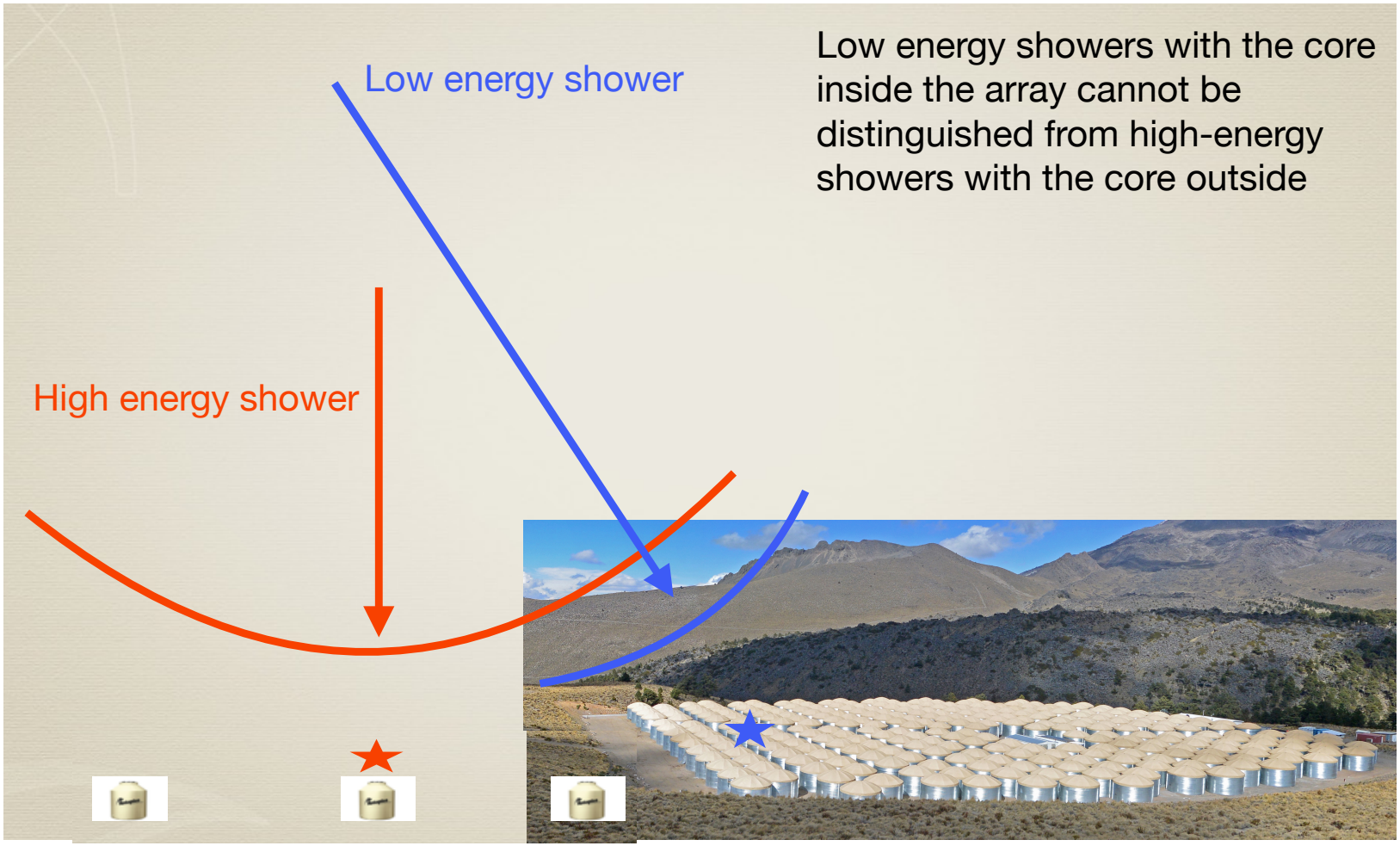
There is things we can improve



Energy resolution, Specially at the low end.

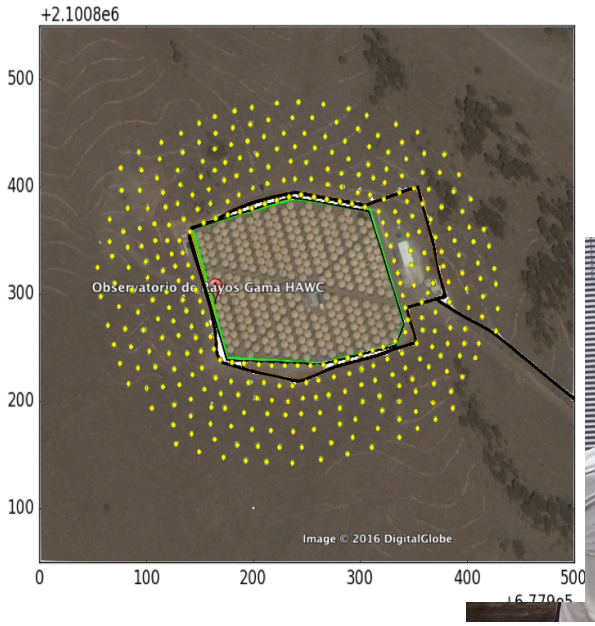
The future

There is things we can improve



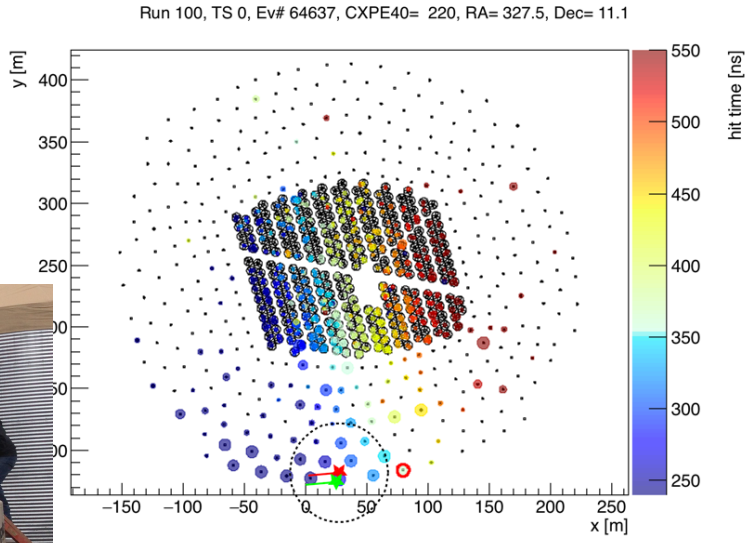
“Outrigger” extension project

- We can increase the sensitivity to the highest energy events by determining the core position for showers that fall off the array.
- The 350 small WCD outrigger detectors cover an area 4x HAWC and will increase by 3-4x the sensitivity at 50 TeV.



Layout

Funded and in progress



Simulated event

The Future

- The success of HAWC and it's complementarity to other IACTs and CTA make us think that there should be a next generation Water Cherenkov Detector in the Southern Hemisphere.

Workshop
"Wide Field of View Southern Hemisphere TeV Gamma ray observatory",
in Puebla México on Thursday November 10 and Friday November 11
with a site visit to the HAWC Observatory on Saturday November 12

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

Workshop on a wide field-of-view Southern Hemisphere TeV gamma ray observatory

10-12 November 2016 *Puebla, Mexico*
US/Central timezone

We wish to invite the broader gamma-ray community to a discussion of a future wide field-of-view TeV observatory for the Southern Hemisphere. The HAWC collaboration will host this meeting on the 10th and 11th of November followed by a visit to the high-altitude HAWC site a couple of hours from Puebla on the 12th. Transport up the mountain and lunch will be provided.


Thank you
Work partially supported
By the program DGAPA-PAPIIT
IN109916.