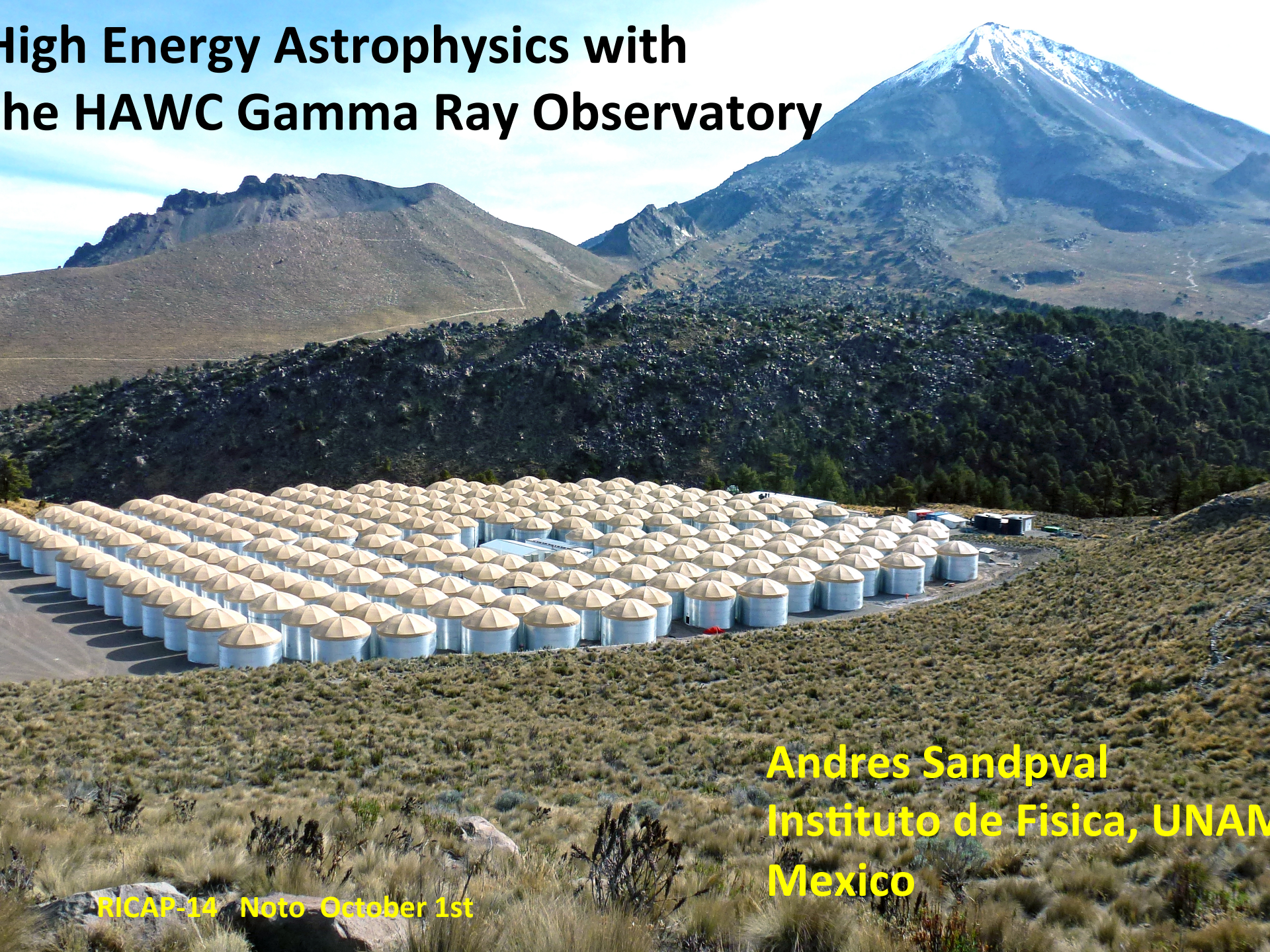
High Energy Astrophysics with the HAWC Gamma Ray Observatory

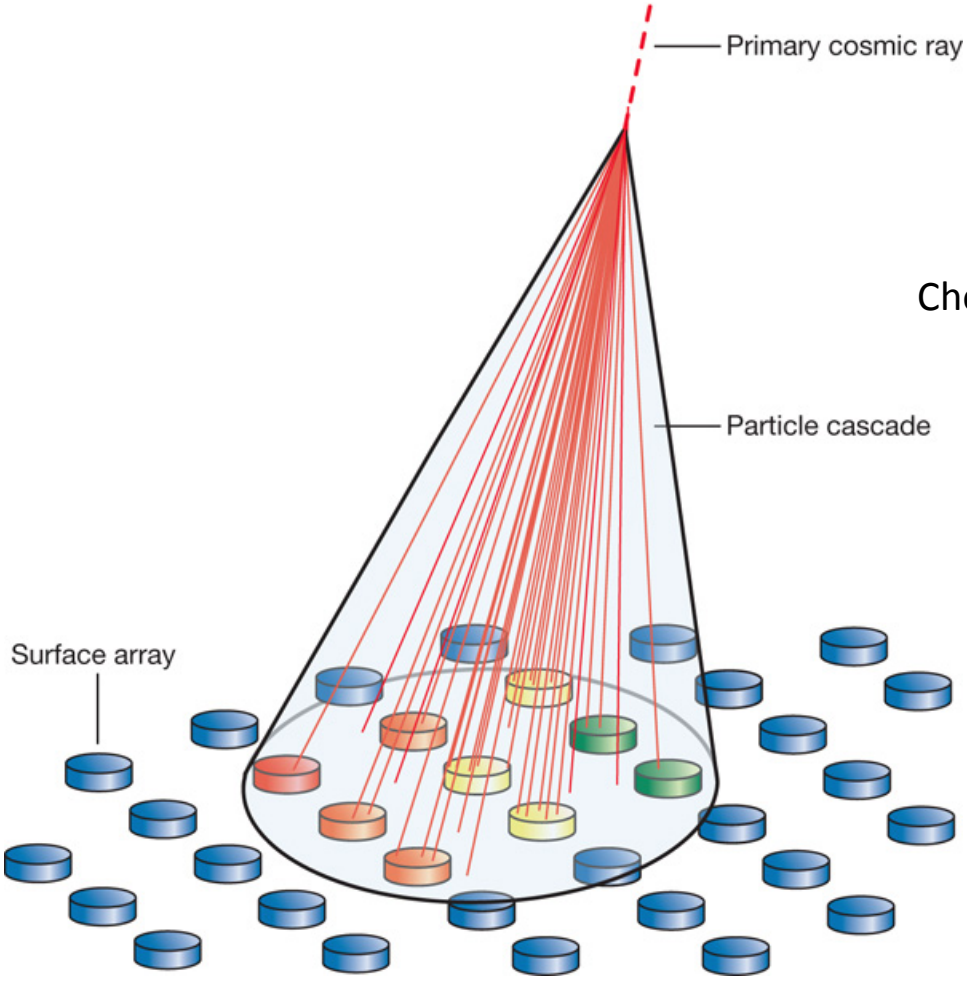


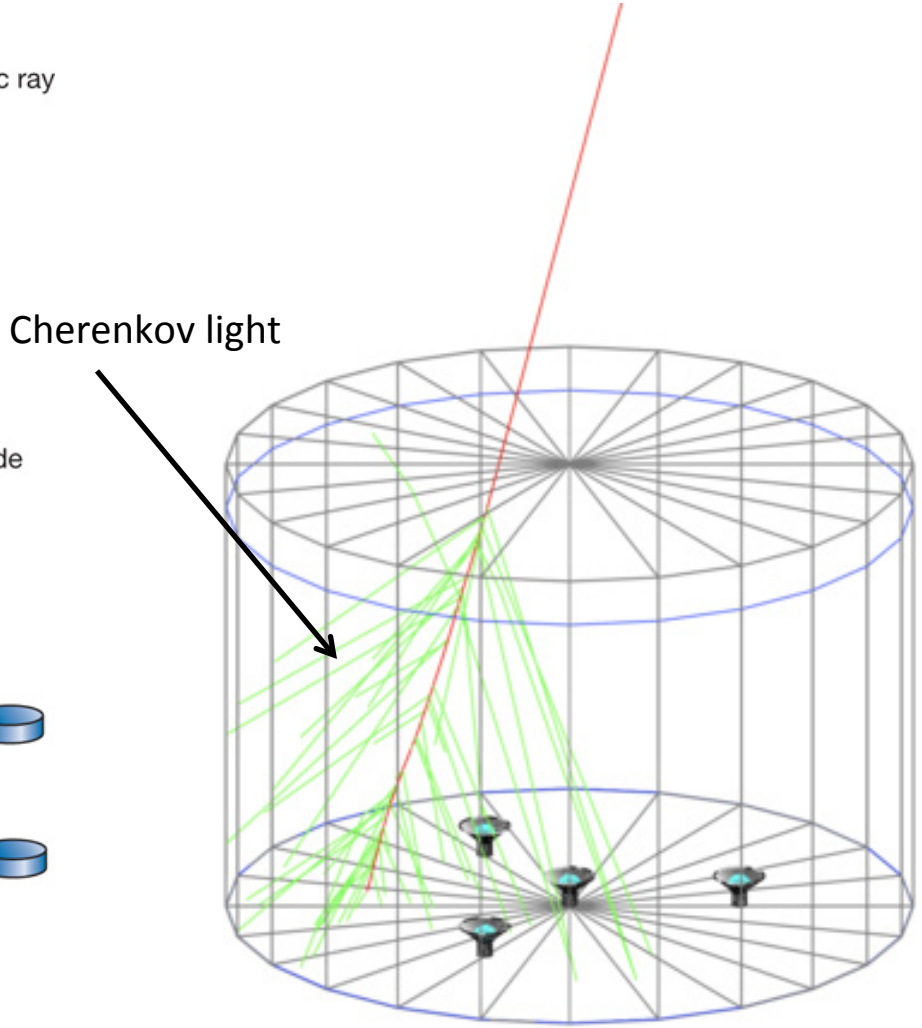
Andres Sandpval
Instituto de Fisica, UNAM
Mexico

RICAP-14 Noto October 1st


Site
Volcán Sierra Negra, central Mexico
latitude 19º North
altitude 4,100 m asl

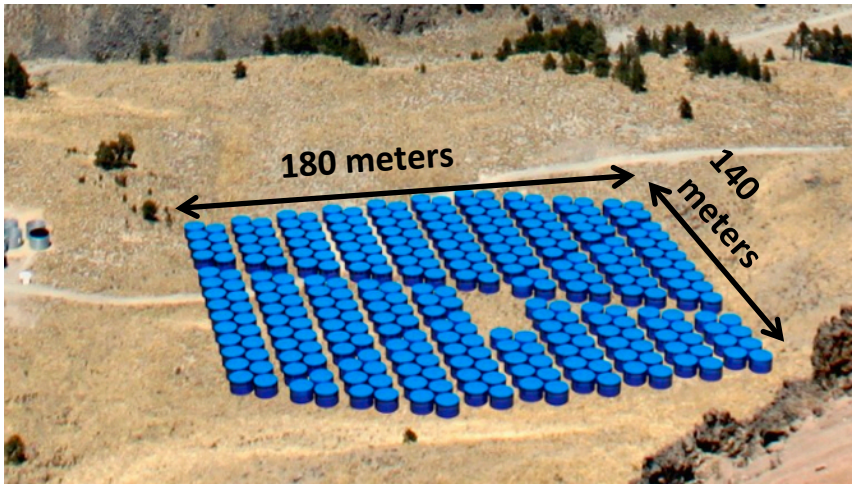
HAWC High Altitude Water Cherenkov Detector

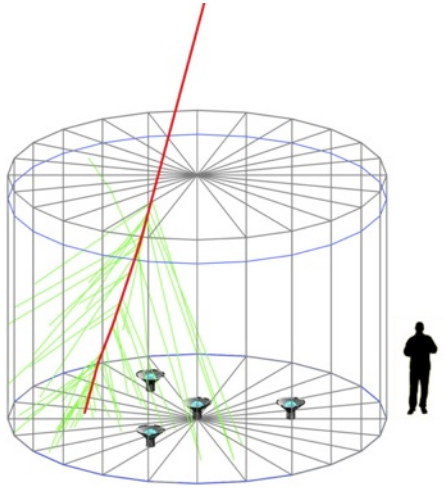




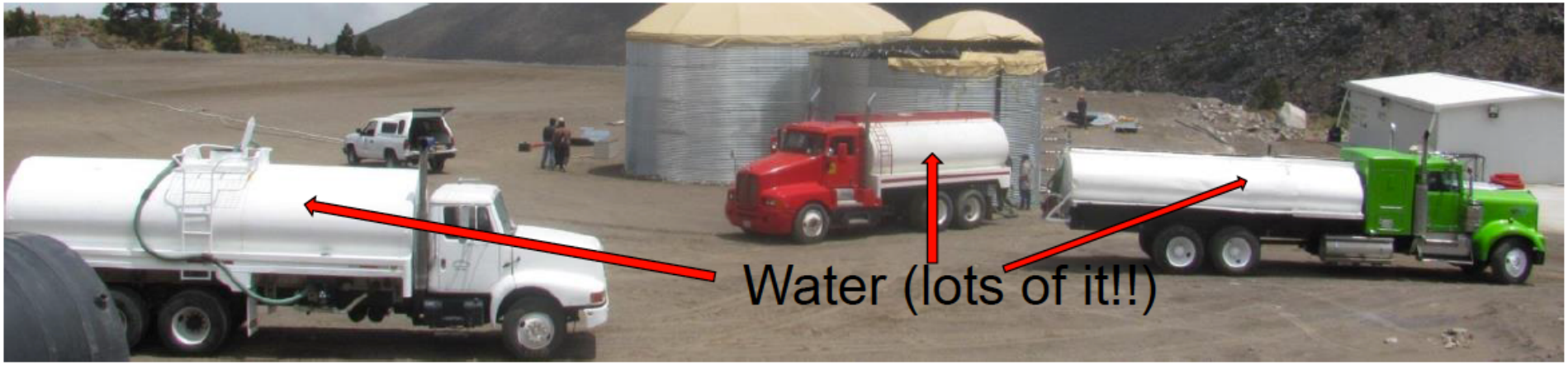
HAWC Design

300 Water Cherenkov detectors with 200,000 liters each. Instrumented with 4 upwards looking photomultipliers to detect the Cherenkov light





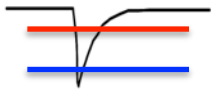
Components of the Water Cherenkov Detectors (WCD)

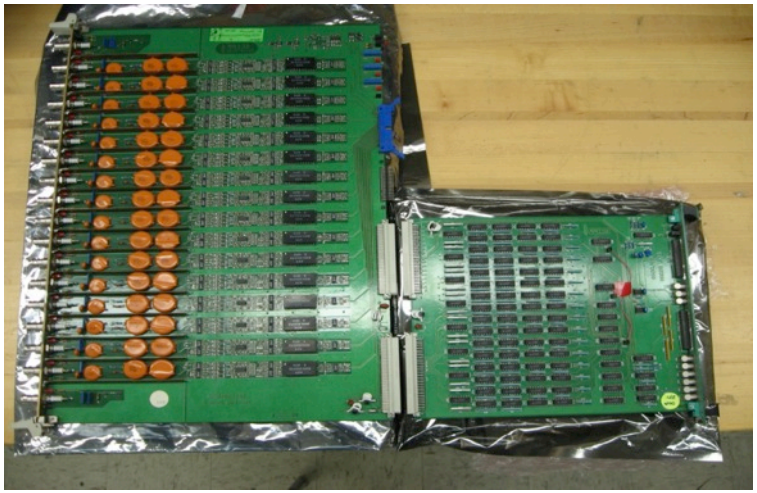


Front End Electronics

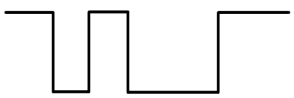
ToT (Time over Threshold)

Photo-multiplier Tube





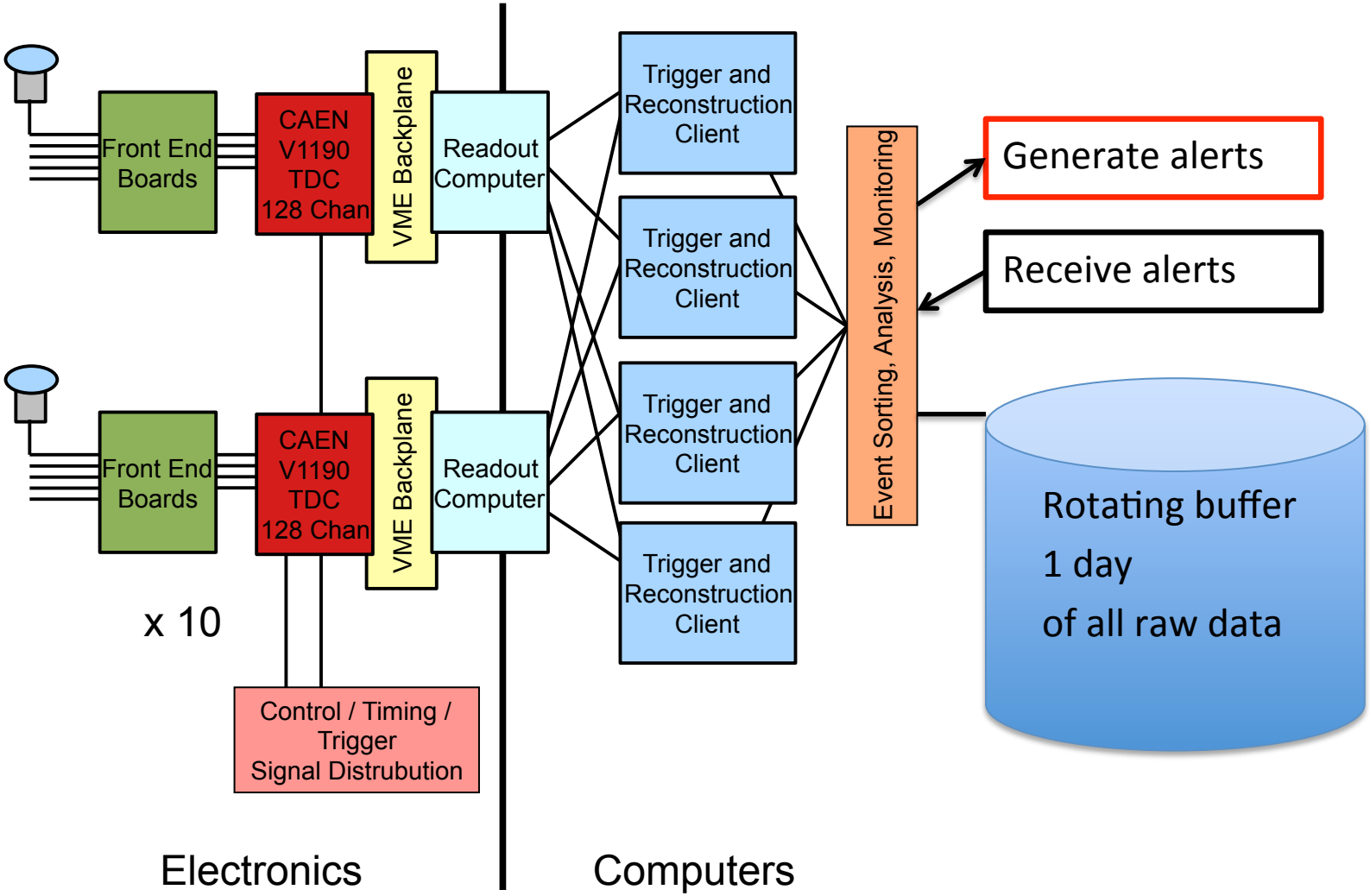
Custom Front-End Electronics
Pick-off circuits and discriminators.



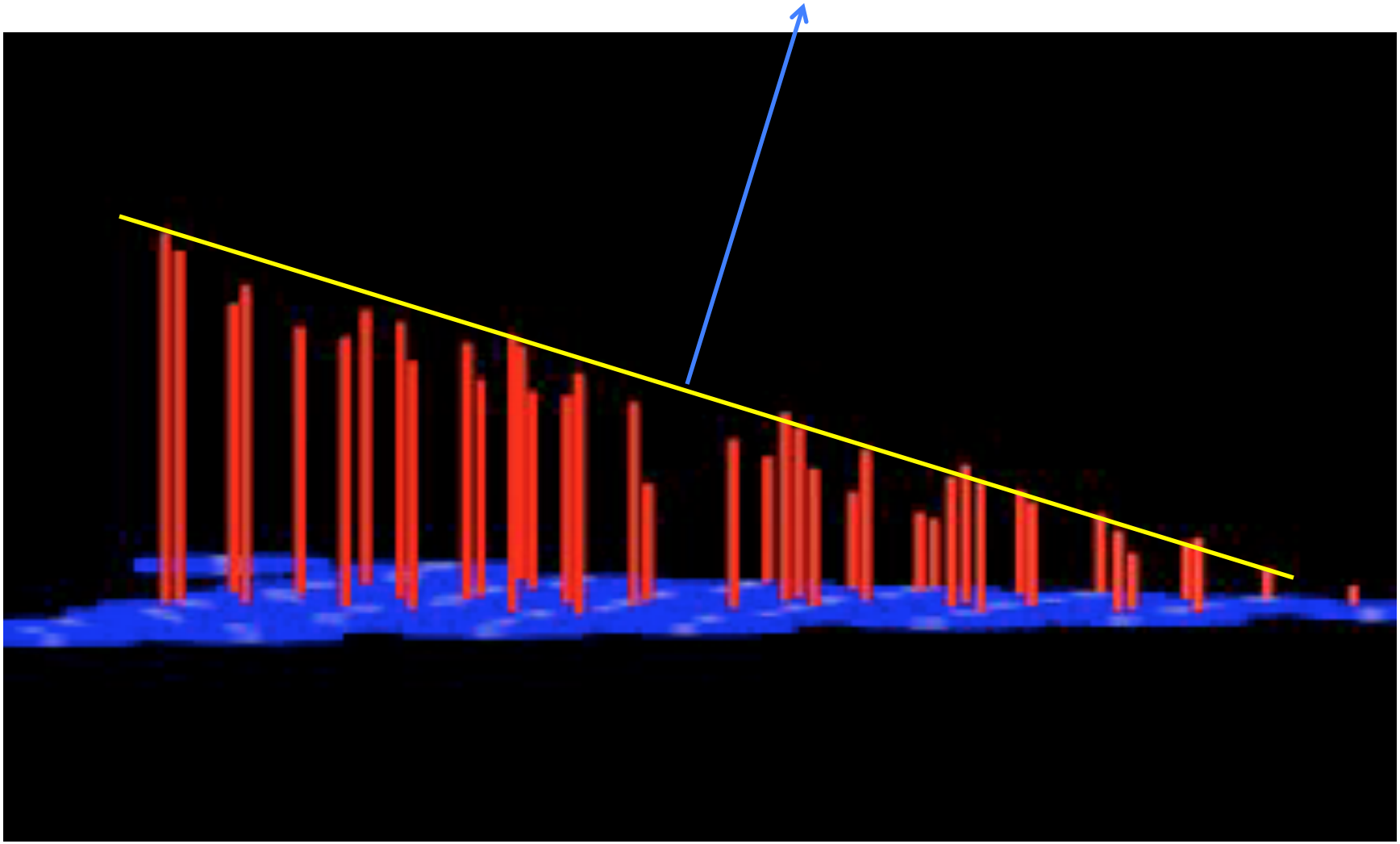
CAEN Vx1190
Time-to-Digital
Converters

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

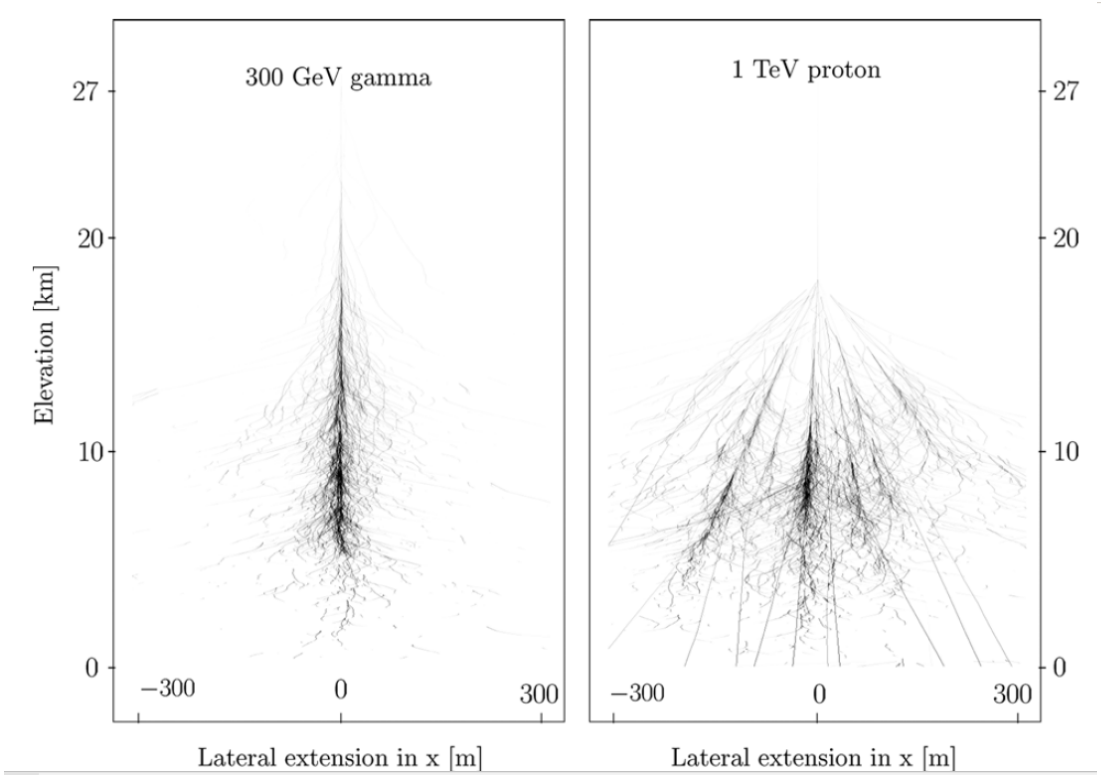
DAQ

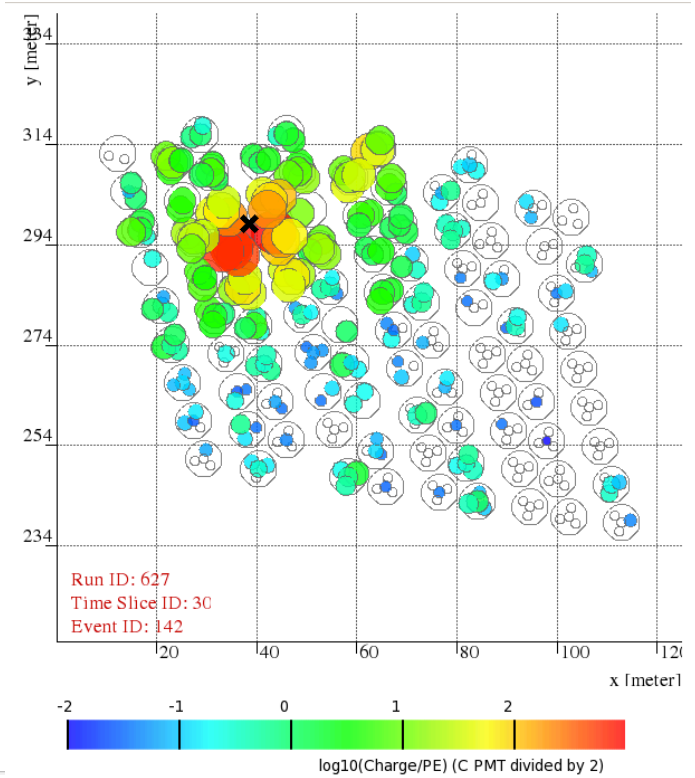

Front End Boards
CAEN V1190 TDC 128 Chan
VME Backplane
Readout Computer
Front End Boards
CAEN V1190 TDC 128 Chan
VME Backplane
Readout Computer
x 10
Control / Timing / Trigger Signal Distrubution
Trigger and Reconstruction Client
Trigger and Reconstruction Client
Trigger and Reconstruction Client
Trigger and Reconstruction Client
Event Sorting, Analysis, Monitoring
Generate alerts
Receive alerts
Rotating buffer
1 day
of all raw data
Electronics
Computers

Reconstructing the direction of the primary particle from the shower front fit to the arrival times

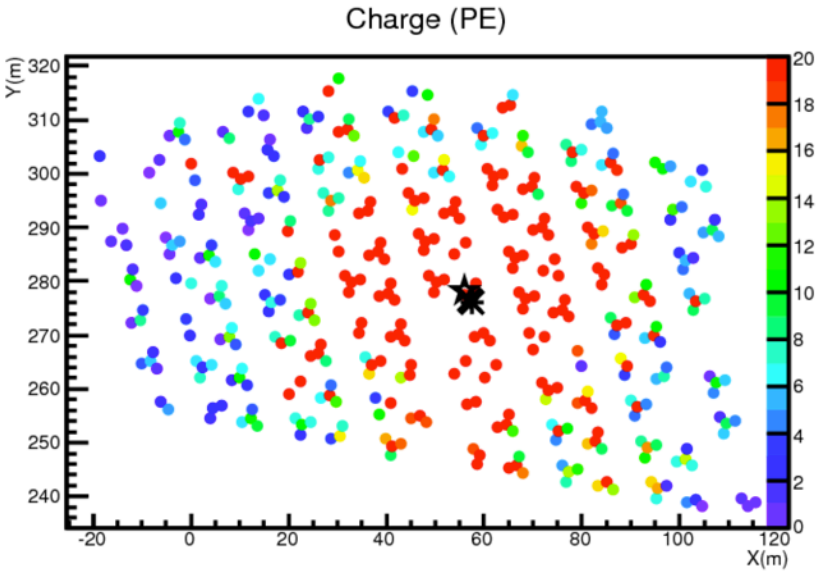


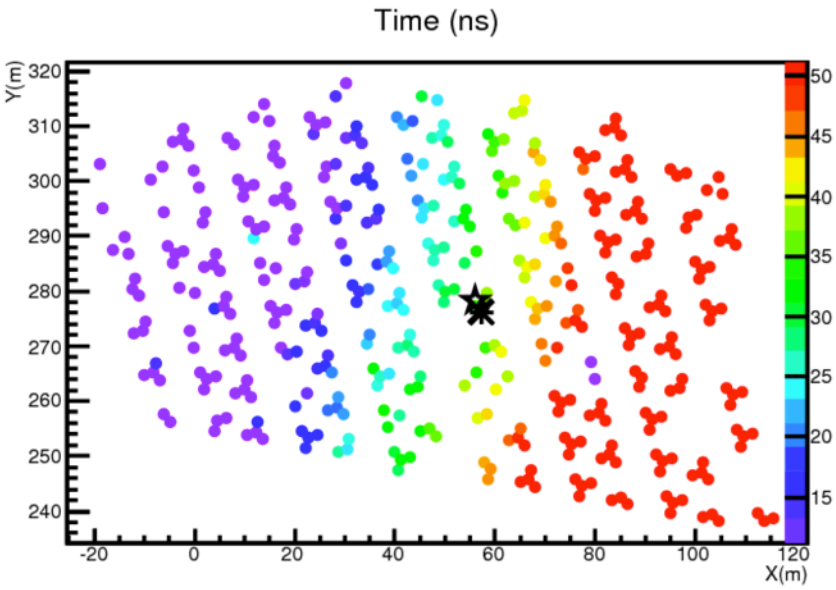
Electromagnetic and hadronic showers can start being separated in HAWC-100

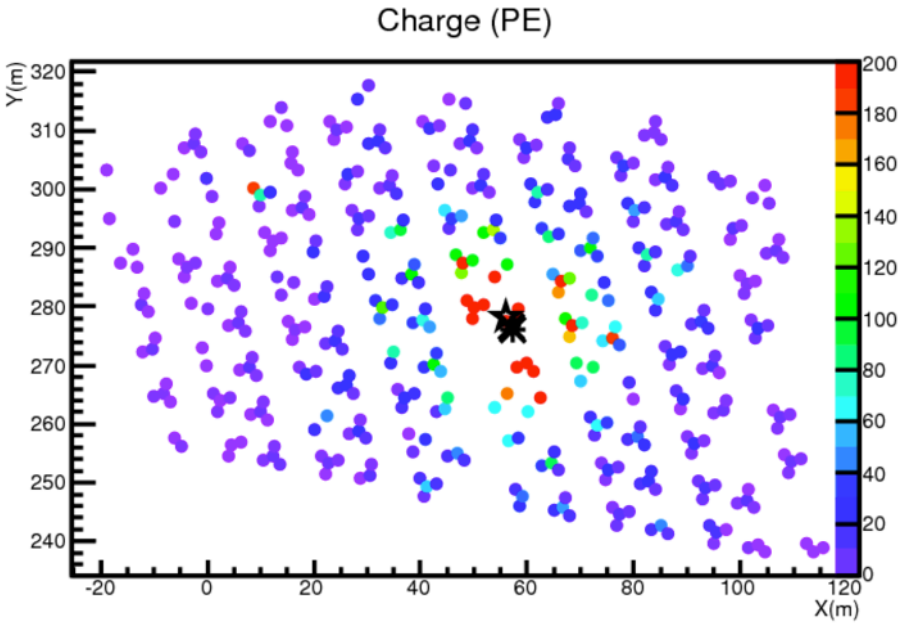


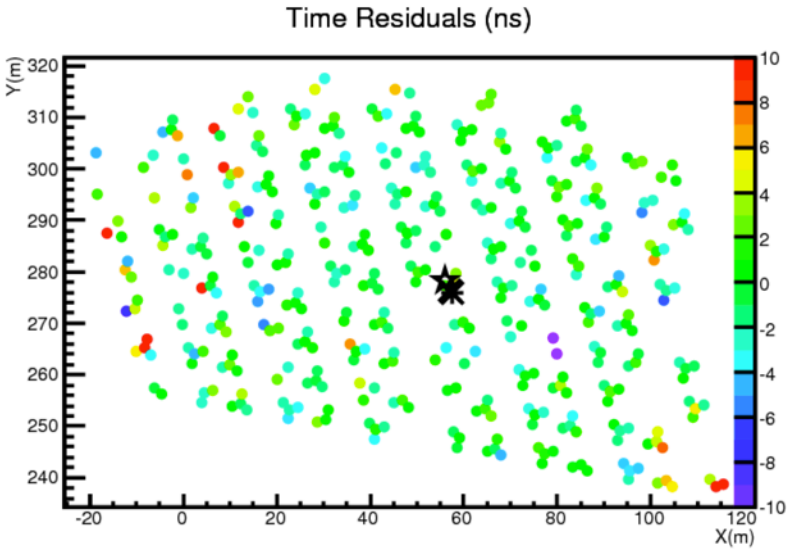


Gamma-like Events from the Crab









HAWC Collaboration

Los Alamos National Laboratory
University of Maryland
University of Wisconsin
University of Utah
Univ. of California, Irvine
Michigan State University
George Mason University
Colorado State University
University of New Hampshire
Pennsylvania State University
University of Alabama
University of New Mexico
Michigan Technical University
NASA/Goddard Space Flight Center
Georgia Institute of Technology

Universidad Nacional Autónoma de México (UNAM):
- **Instituto de Astronomía**
- **Instituto de Física**
- **Institudo de Ciencias Nucleares**
- **Institudo de Geofísica**

INAOE
Universidad Autónoma de Chiapas
Universidad Autónoma del Estado de Hidalgo
Universidad Politécnica de Pachuca
Universidad de Guadalajara
CINVESTAV
CIC Instituto Politécnico Nacional
FCFM Benemérita Universidad Autónoma de Puebla
Universidad Michoacana de San Nicolás de Hidalgo

USA:
15 institutions,
54 scientists

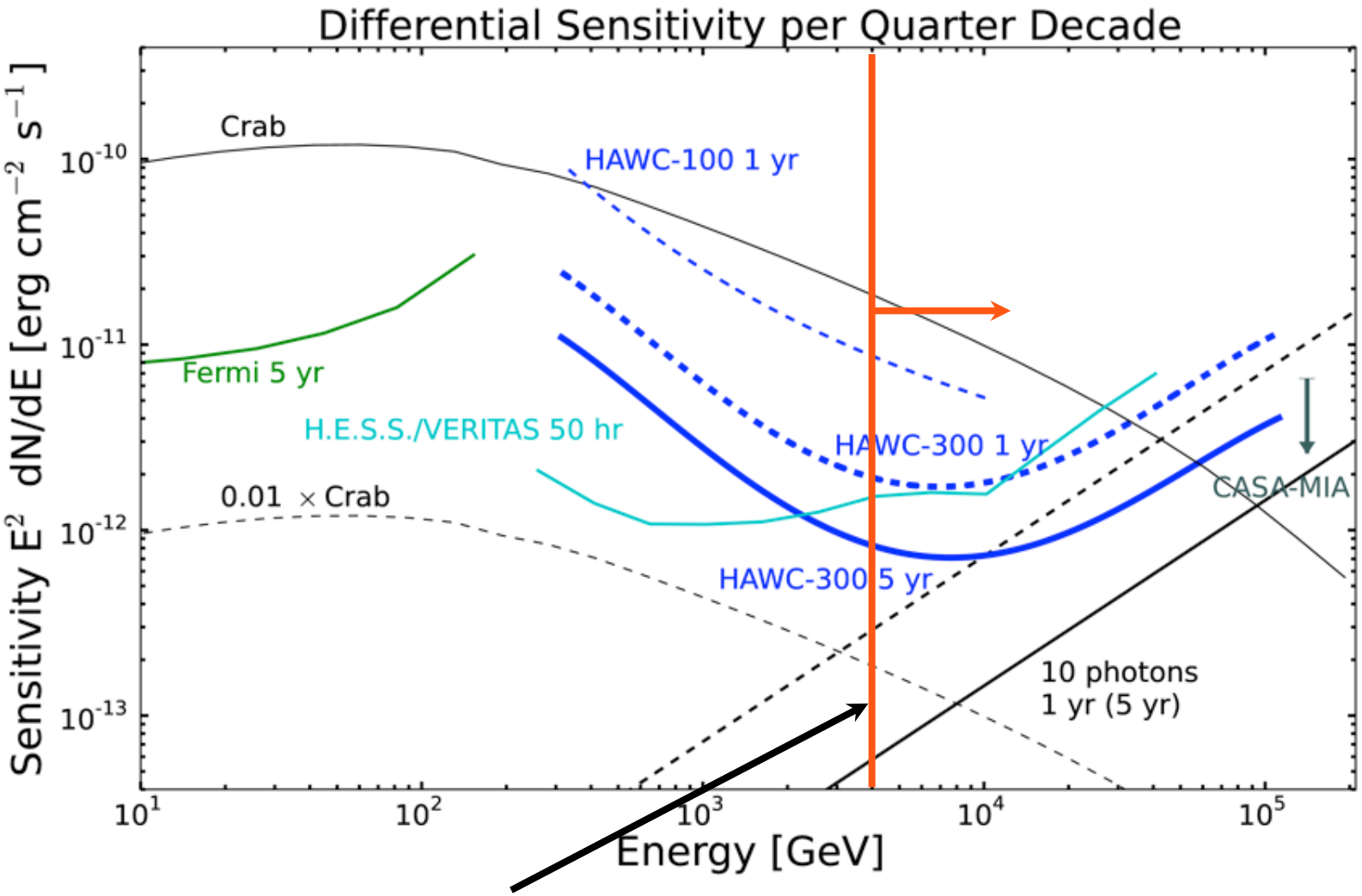
Mexico:
13 institutions,
54 scientists

Timeline

- Site selected in 2007
- 2008 – 2010 construction of prototypes and writing of proposals
- February 2011 project funded $15M USD
- 2011 site preparation ordering of components
- 2012 – 2014 construction
- 1 August 2013 start of operations HAWC-100

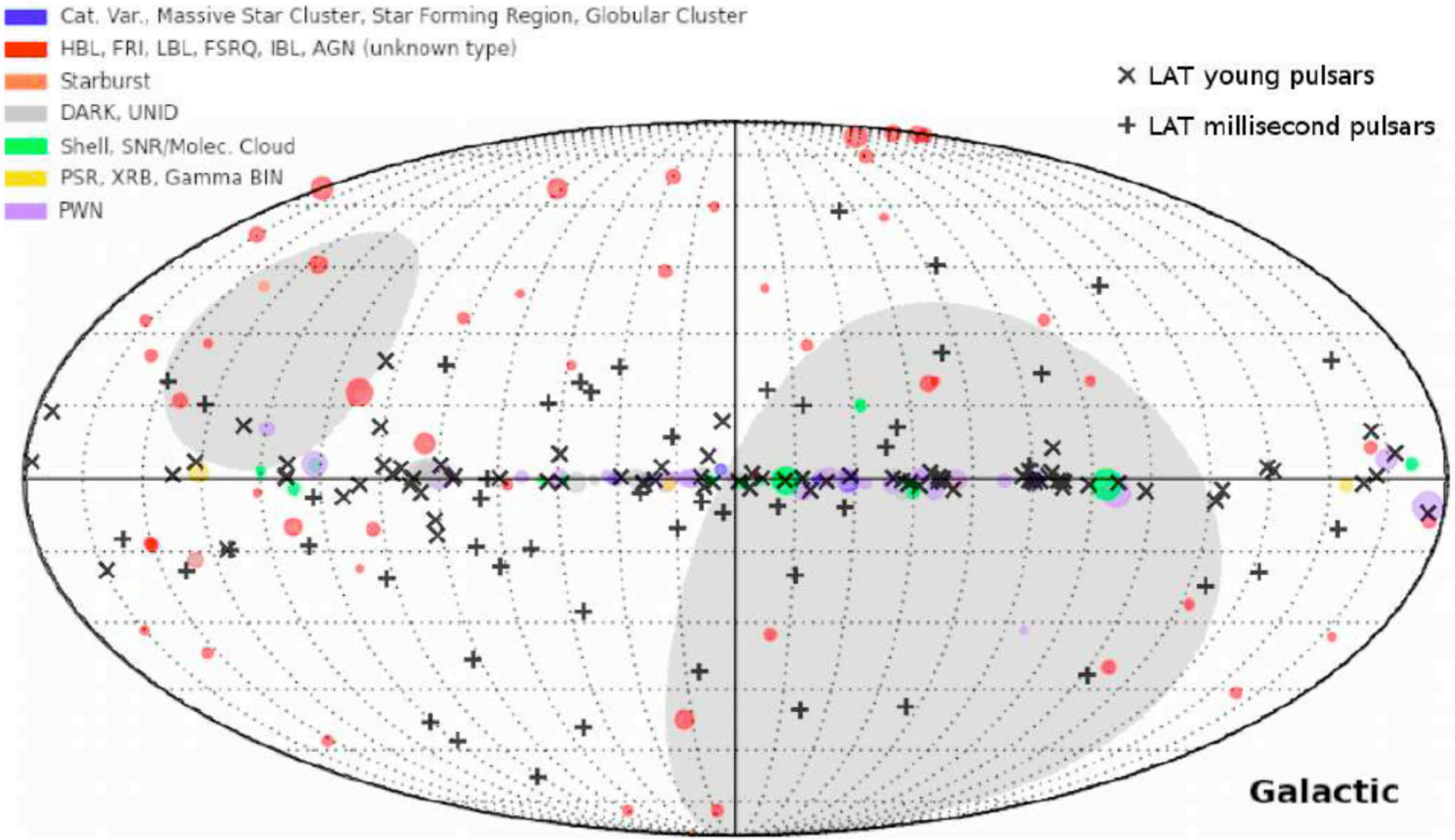
- **HAWC inauguration 19-20 March 2015**

• HAWC Performance



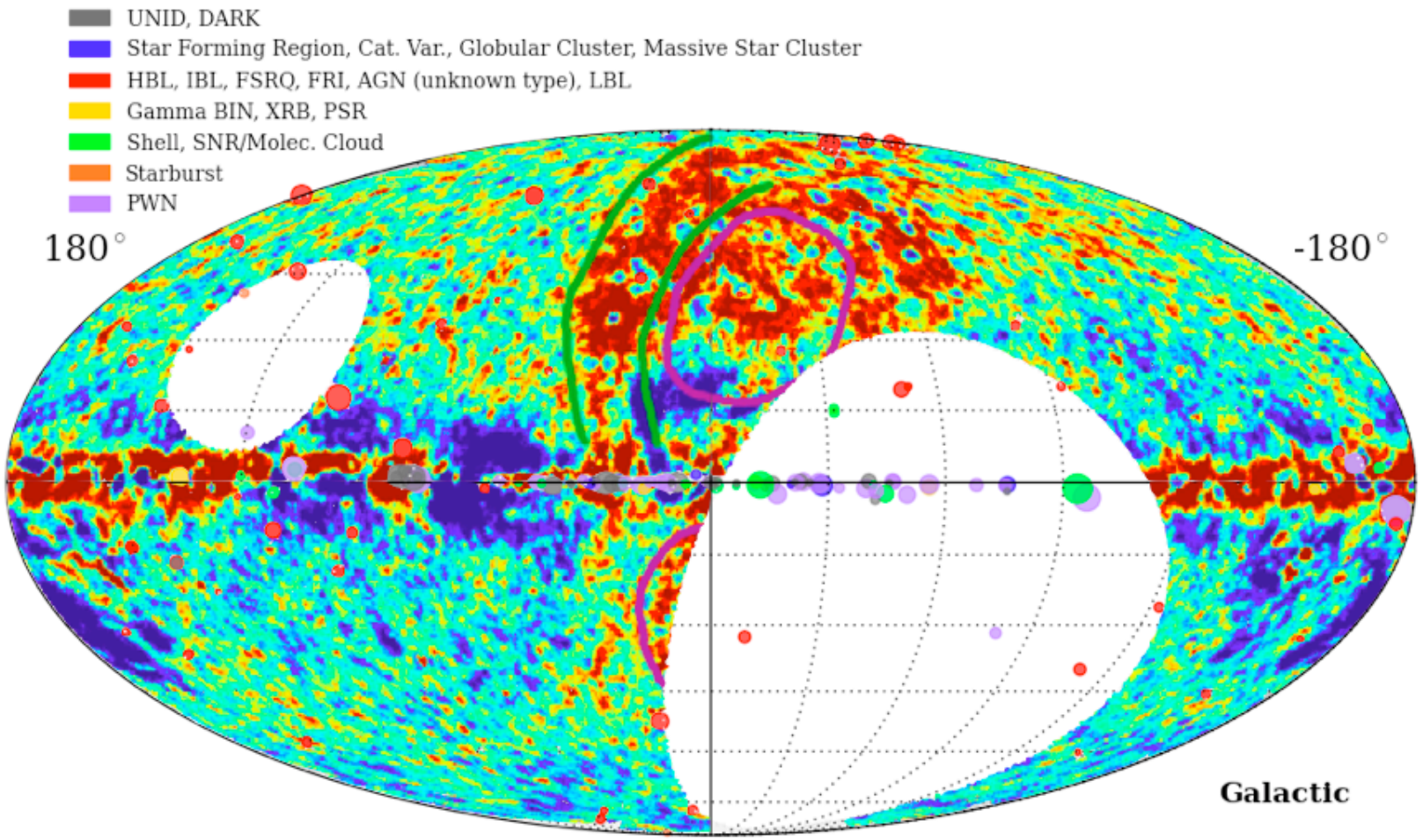
Above 4 TeV **every source** will have the equivalent of a 50-hour observation in 1 year by a IACT.

Sources in the HAWC Field of View



Fermi Bubbles – With Fermi

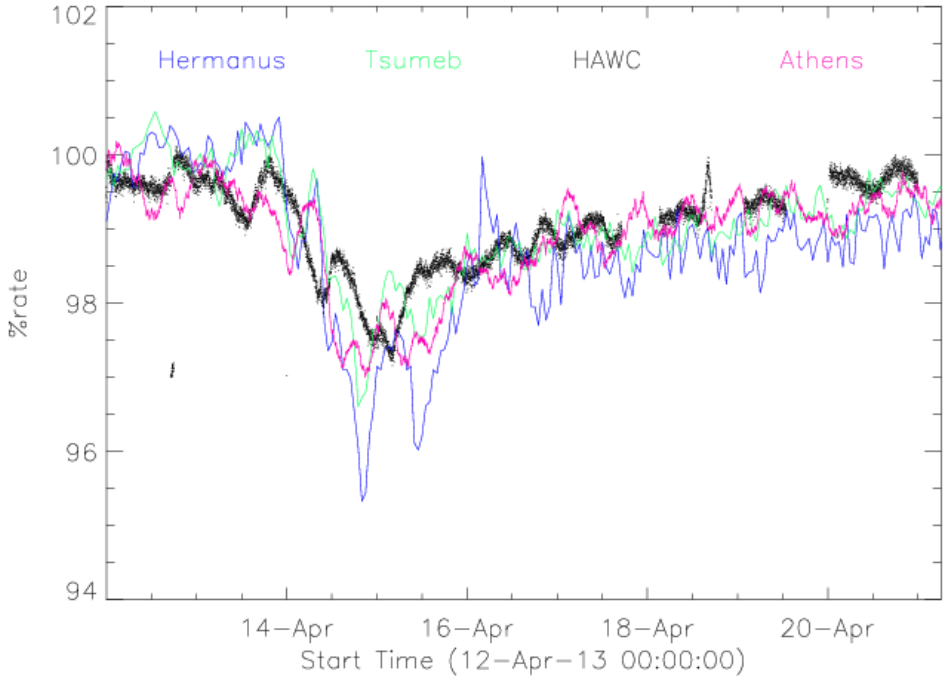
ApJ, 750, 35v(2012)



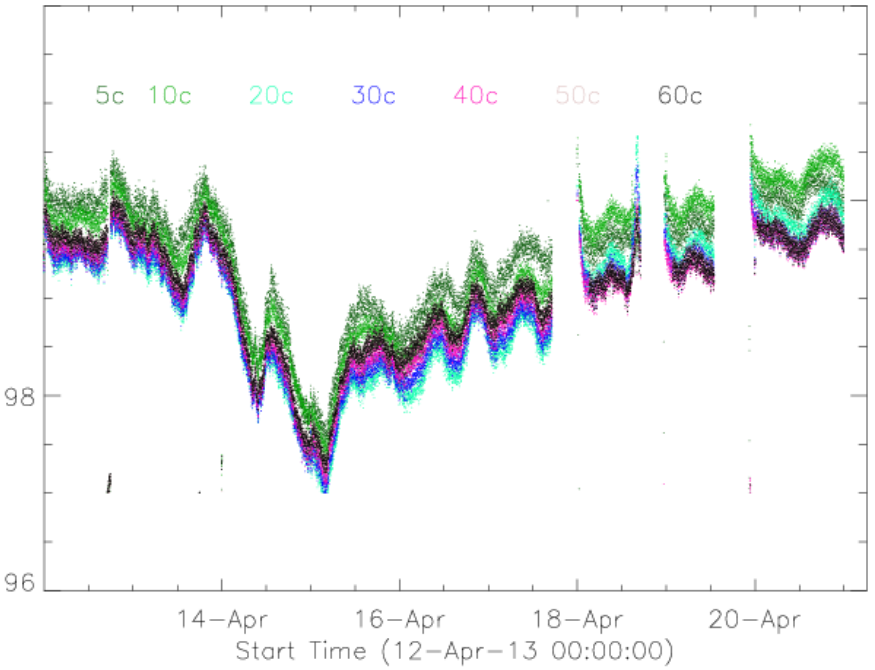
First HAWC Results

- Cosmic Rays:
  - Forbush decreases, Moon shadow, Sun shadow, Anisotropy of cosmic ray arrival directions
- Gamma Rays:
  - Crab Nebula
  - Full Galactic sky map
  - Others sources: Markarian 421, 501
  - GRB limits
  - Dark Matter limits

Forbush decreases caused by coronal mass ejections of the Sun in Earth direction are seen in the scaler rates of the HAWC PMTs



12th April 2013



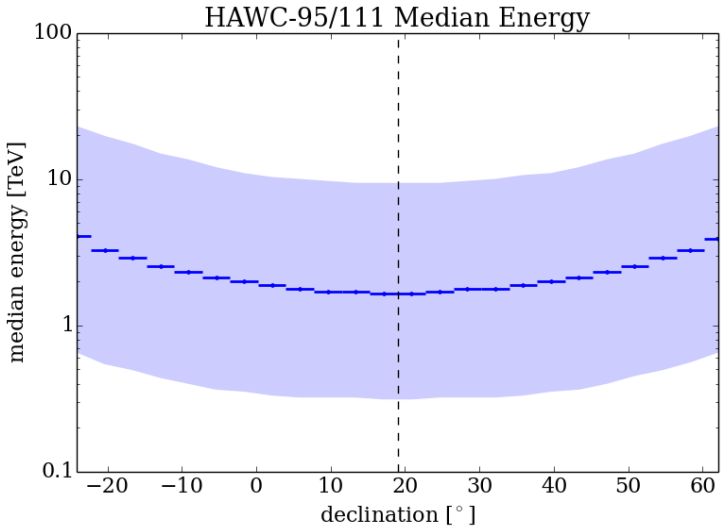
Cosmic Ray anisotropy

Data Set

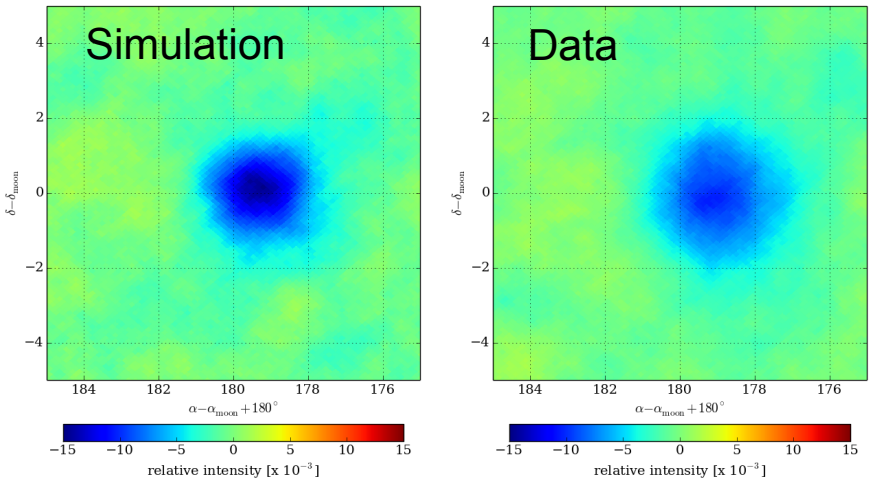
Using HAWC-95 and HAWC-111

June 2013 – February 2014
114 full sidereal days

50 billion events,
1.2° median ang. res.,
1.8 TeV median energy



HAWC-111 Moon Shadow



Observation of Small-scale Anisotropy in the Arrival Direction Distribution of TeV Cosmic Rays with HAWC [arXiv:1408.4805 [astro-ph.HE]]

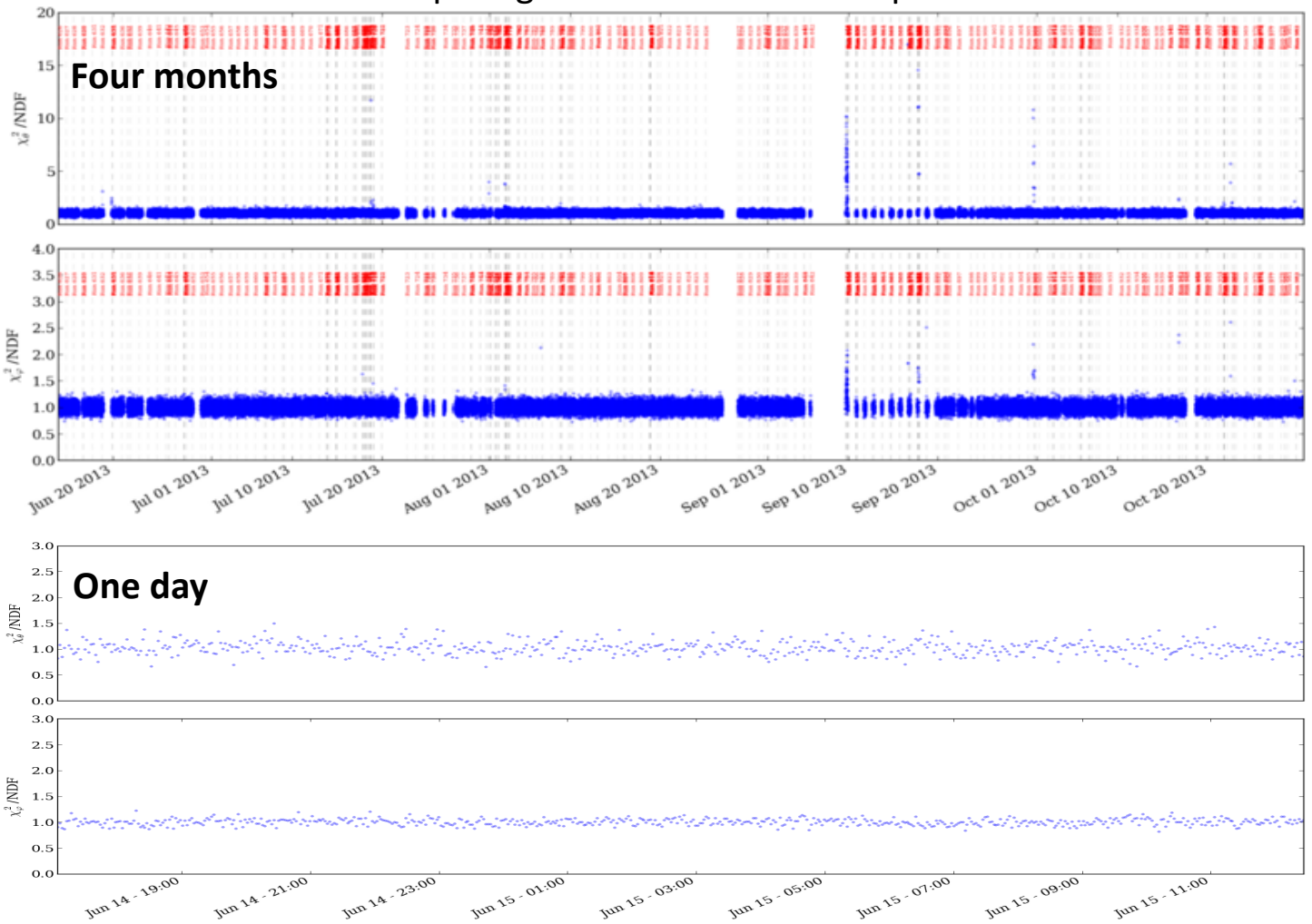
Data Stability

Reduced Chi-Squared

Comparing subrun of data to the previous

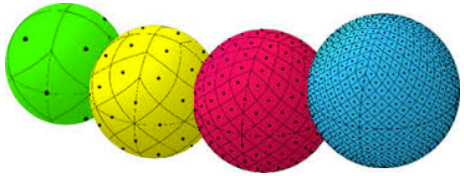
Zenith Angle Distrib.

Azimuth Angle Distrib.



Analysis Technique

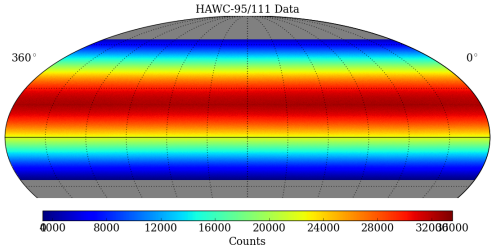
HEALpix (K.M. Gorski et al., Astrophys. J., 2005, 622, 759)
Equal-area binning of the sphere

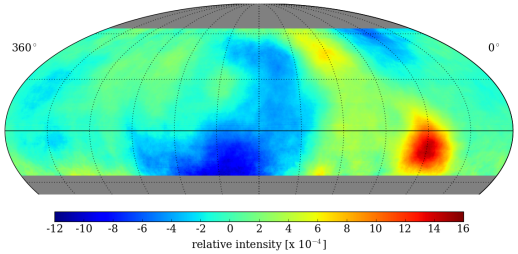


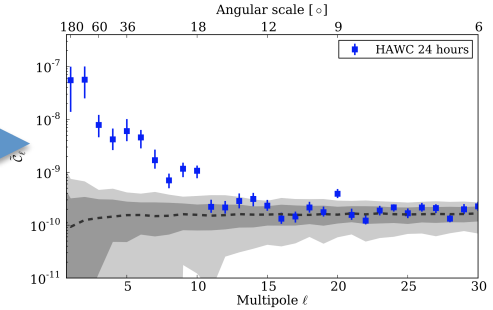
"Direct Integration" (R.Atkins et al., Astrophys. J., 2003, 595, 803.)
Method to estimate background using the data themselves

PolSpice (I. Szapudi et al. 2001, Astrophys. J., 548, L115)
Software to compute power spectrum with partial sky coverage

HEALpix "Direct integration" PolSpice







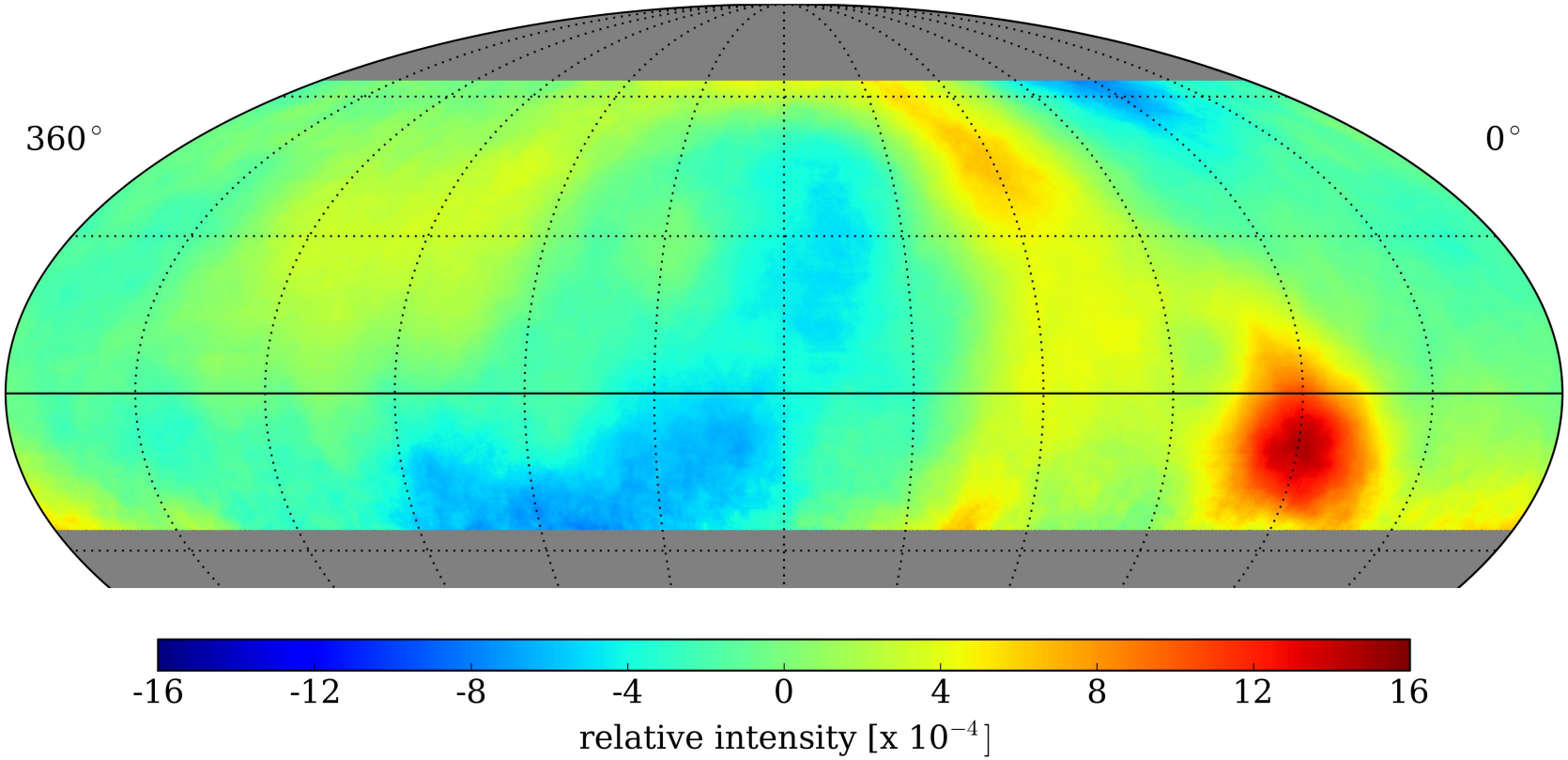
Binned data

Data & reference map
→ relative intensity

Power Spectrum

Large-Scale Anisotropy

Shows largest accessible features (24 hr background estimation)
Smoothed 10°
Dipole deficit is consistent with previous observations (1 x 10^{-3} @ ra=200°, dec)
Brightest region sits in region of general excess (ra=60°, dec=-10°)

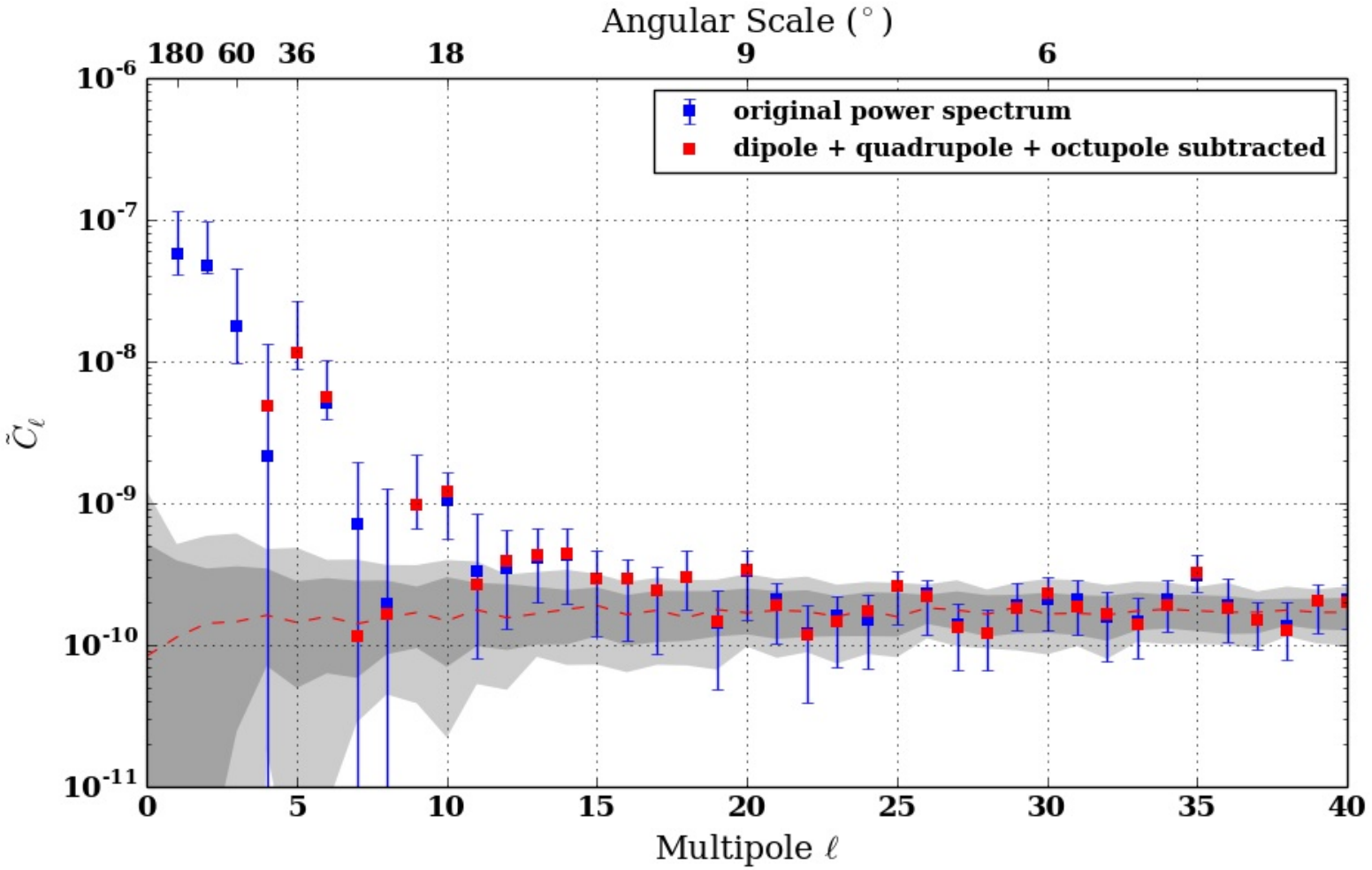


1.8 TeV median

Power Spectrum of CR Anisotropy

Power spectrum of Large-Scale (24h bkg est)
Strong dipole + quadrupole

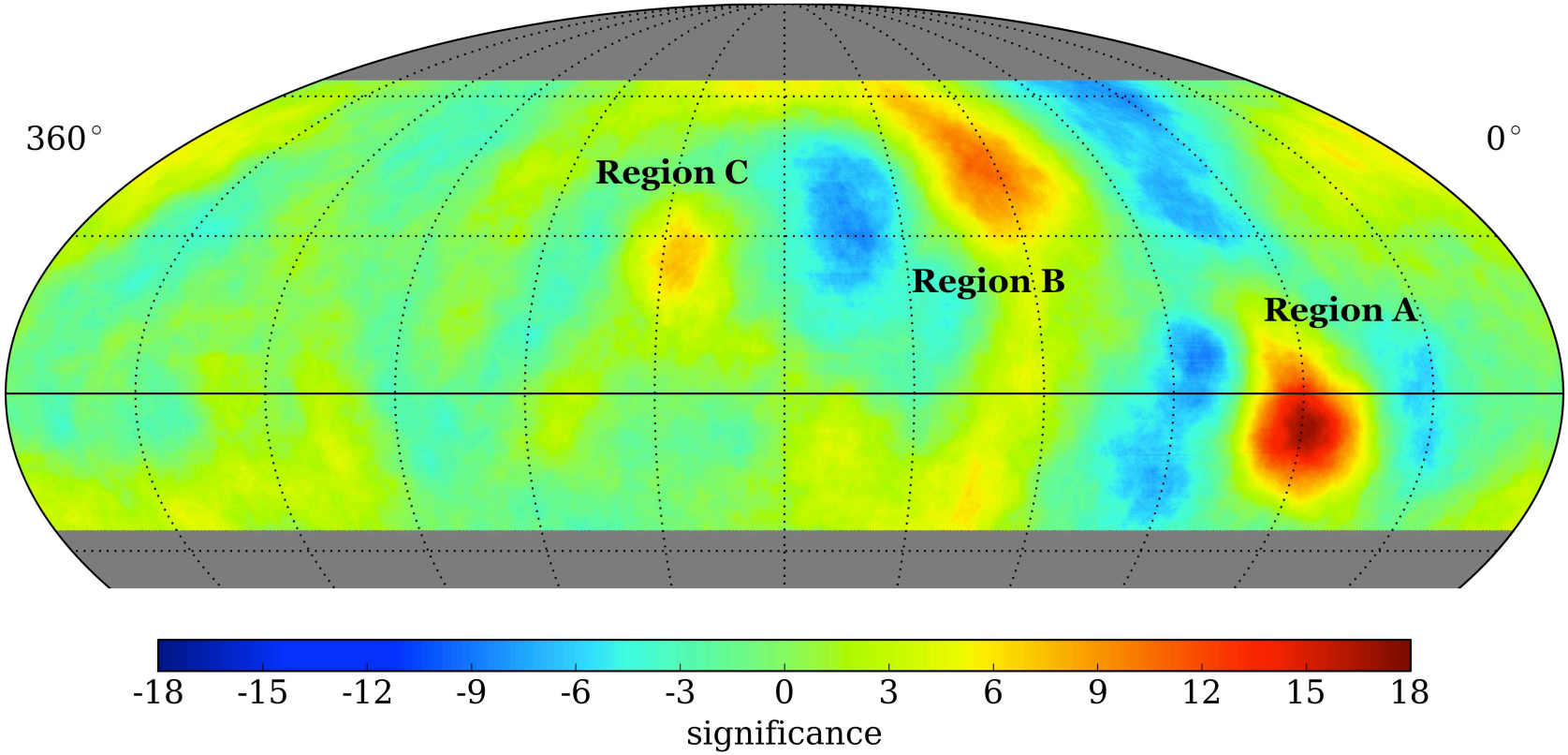
For details of the analysis see:
"Observation of Anisotropy in the Arrival Directions of Galactic Cosmic Rays at Multiple Angular Scales with IceCube"
http://arxiv.org/pdf/1105.2326.pdf (section 3.3)



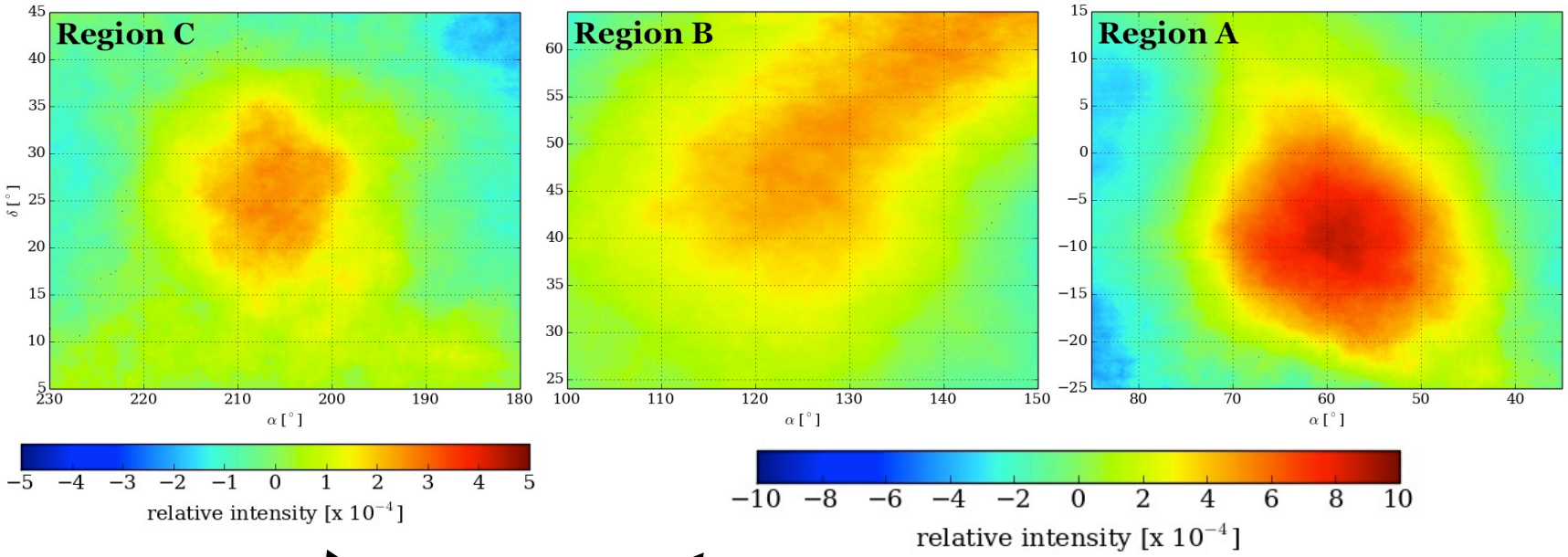
Small-Scale Anisotropy

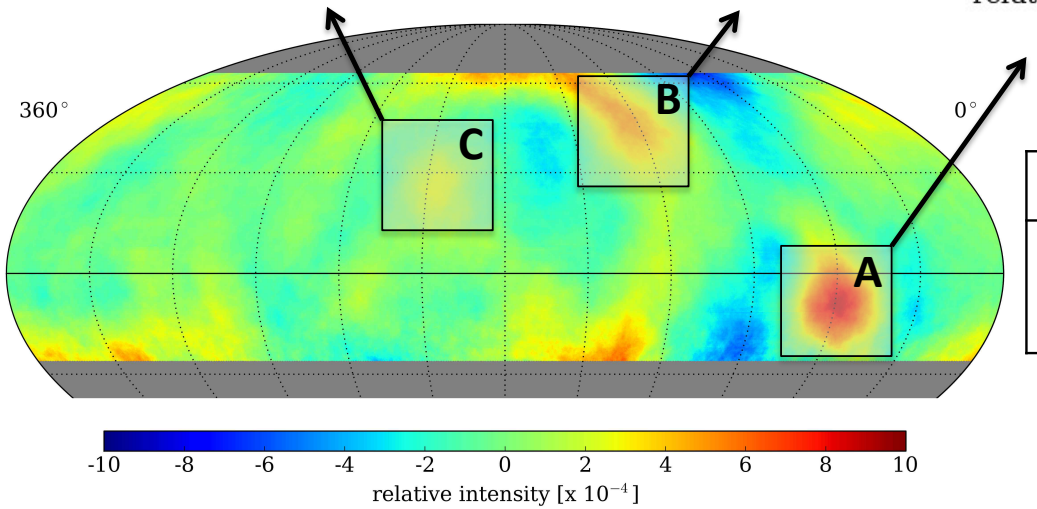
Fit dipole+quadrupole to map for 24-hr background estimation

Subtracted fit relative intensity from 24-hr map



Small-Scale Anisotropy





Region C	Region B	Region A
2.4×10^{-4}	6.0×10^{-4}	9.0×10^{-4}

Region A

Explanations for localized excess?

Local interstellar magnetic fields

M. Amenomori et al., Astrophys. Space Sci. Trans. 6, 49 (2010).

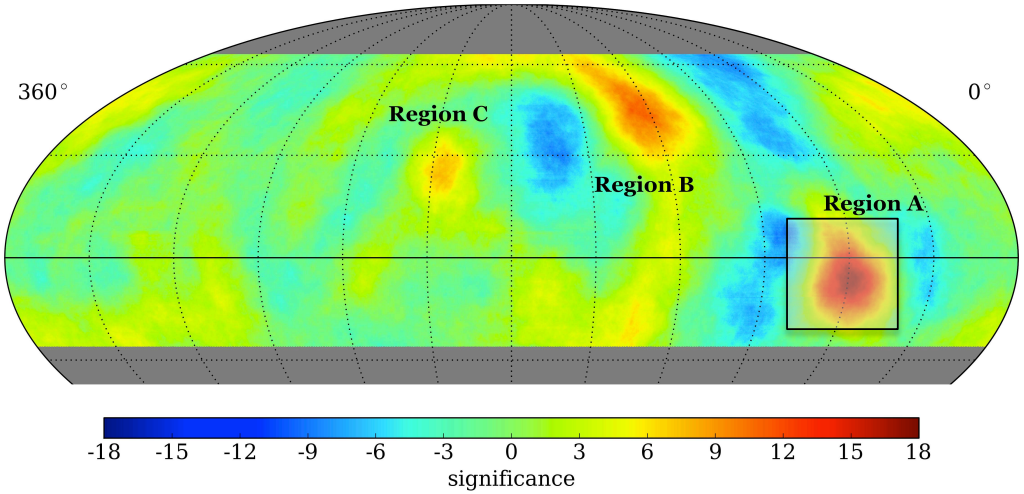
A. Lazarian and P. Desiati, Astrophys. J. 722, 188 (2010).

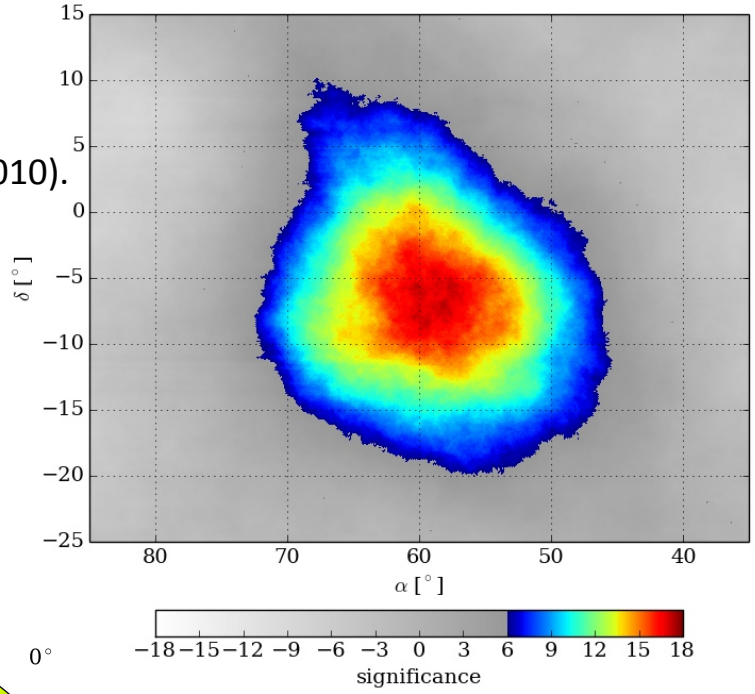
Magnetic bottle

L. Drury and F. Aharonian, Astropart. Phys. 29, 420(2008).

Dark Matter interpretation

J. Harding arXiv:1307.6537





Far south for Milagro and ARGO (35°N and 30°N latitude)

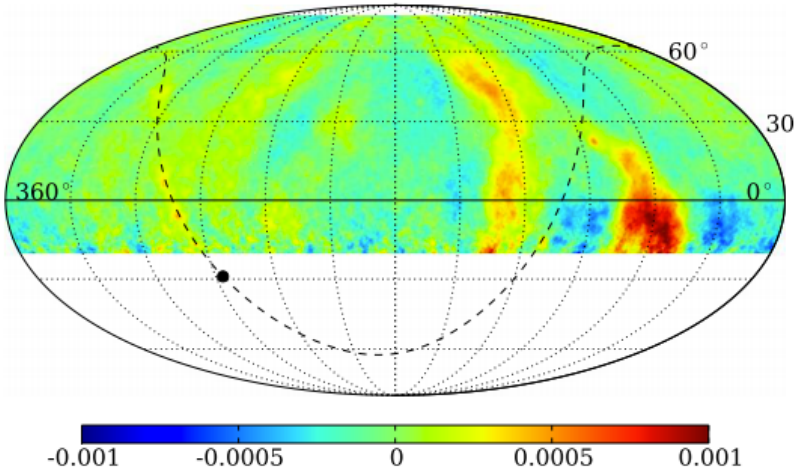
Sits on large-scale maximum

$(8.9 \pm 0.6) \times 10^{-4}$ excess

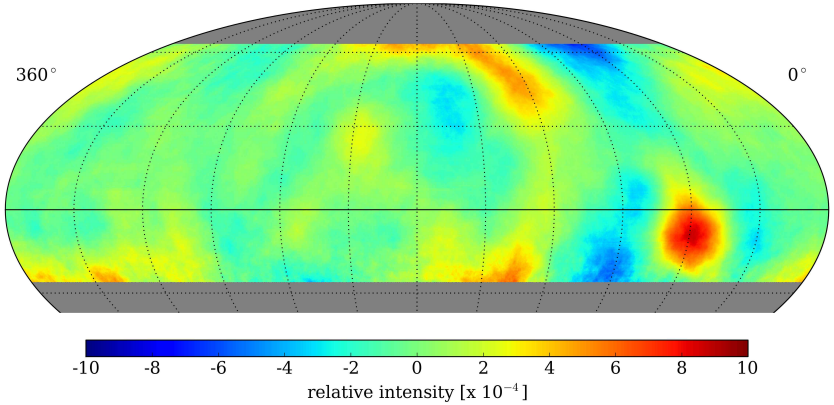
Milagro saw cutoff at ~ 4 – 20 TeV

Comparisons

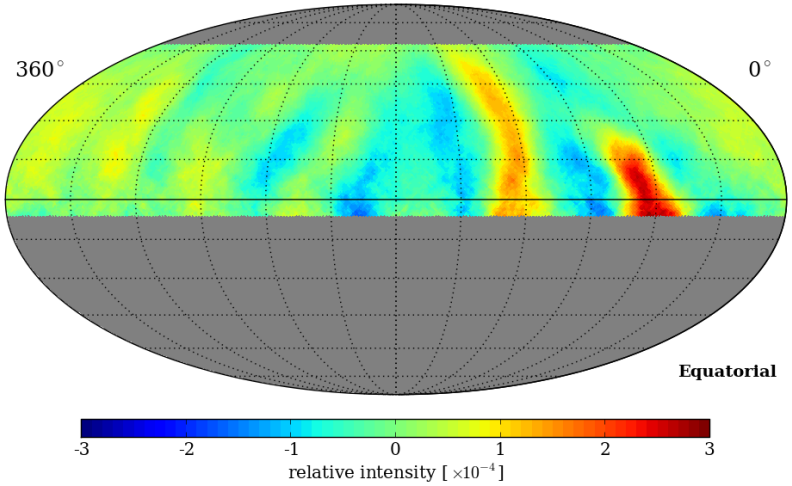
ARGO



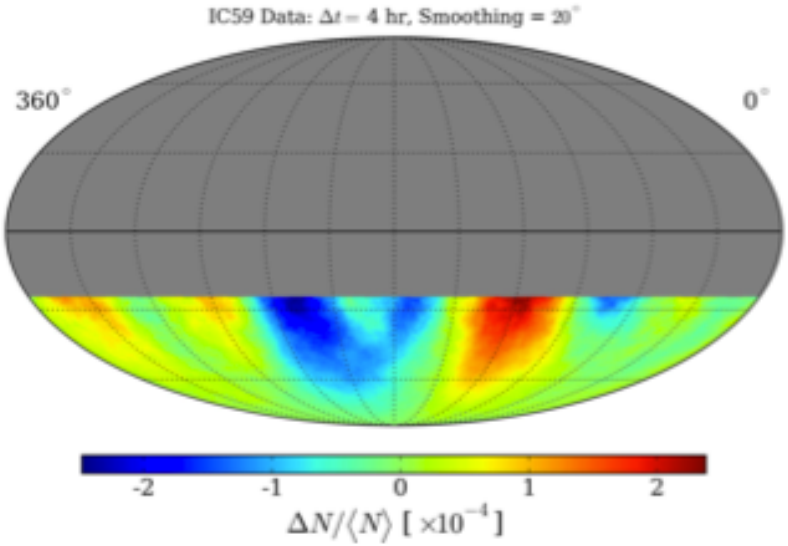
HAWC



Milagro



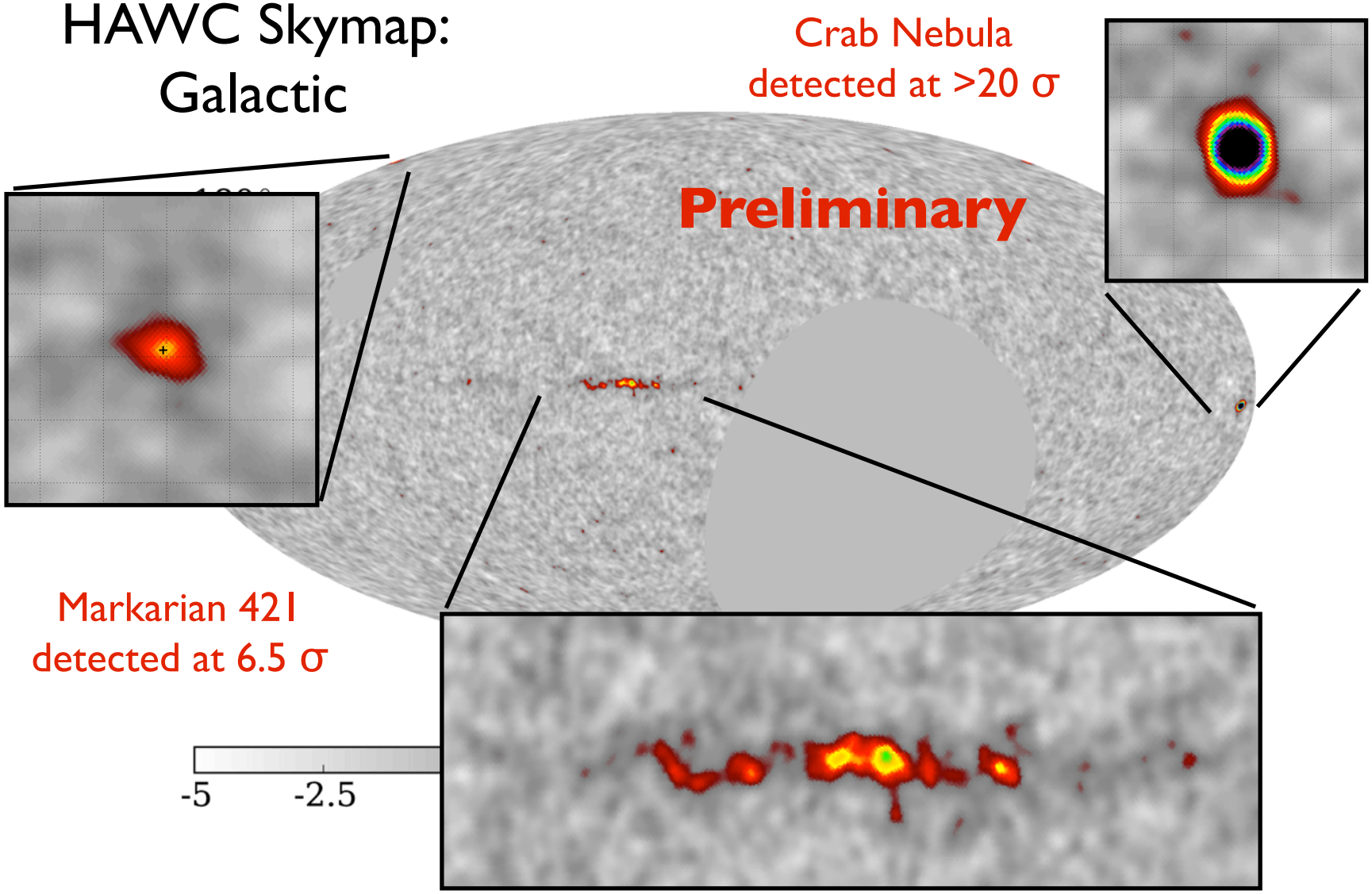
IceCube



Gamma Rays

- As with the detector, the reconstruction and analysis software is a construction site.
- Cuts on gamma/hadron and reconstruction quality being optimized
- 260 days with ~1/3 of the detector August 2013 – June 2014
- Median energy ~ 2 TeV depending on source, declination etc
- Angular resolution between 1.4^{o} and 0.2^{o} depending on the size of the shower

HAWC Skymap: Galactic



Clear emission from multiple source regions along the Galactic Plane.

GRBs

- On average there is ~ one GRB alert per week in the FOV of HAWC

RECENT GCNS

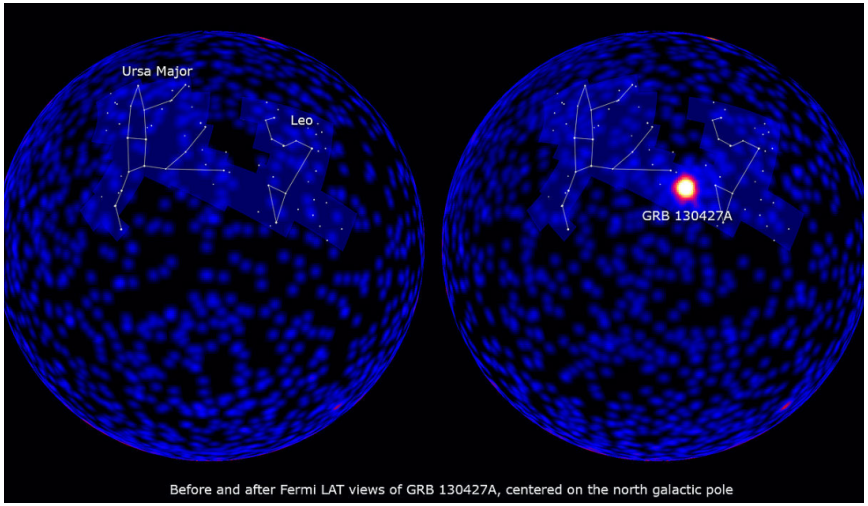
Below is a list of GCNs reported by various experiments through the **GCN** network. The list is comprised of alerts from **Fermi**, **Maxi**, **Swift**, **INTEGRAL**, and **AGILE**. I have also calculated the zenith angle for the burst at the HAWC site and provided a plot of the time evolution of the zenith angle as a function of time. Lines highlighted in red indicate GCNs which occurred within 45° of zenith at the HAWC site.

Time (UTC)	Zenith [deg]	Trigger	ra [deg]	dec [deg]	Error [deg]	Instrument
2014-10-01 08:22:50	68.27	433844573	319.27	63.73	34.73	Fermi
2014-10-01 00:37:21	41.33	433816644	238.08	20.48	31.63	Fermi
2014-09-30 19:41:42	131.68	614094	6.35	24.30	0.00	Swift
2014-09-30 14:27:02	101.94	9308677083	344.15	52.75	1.00	MAXI

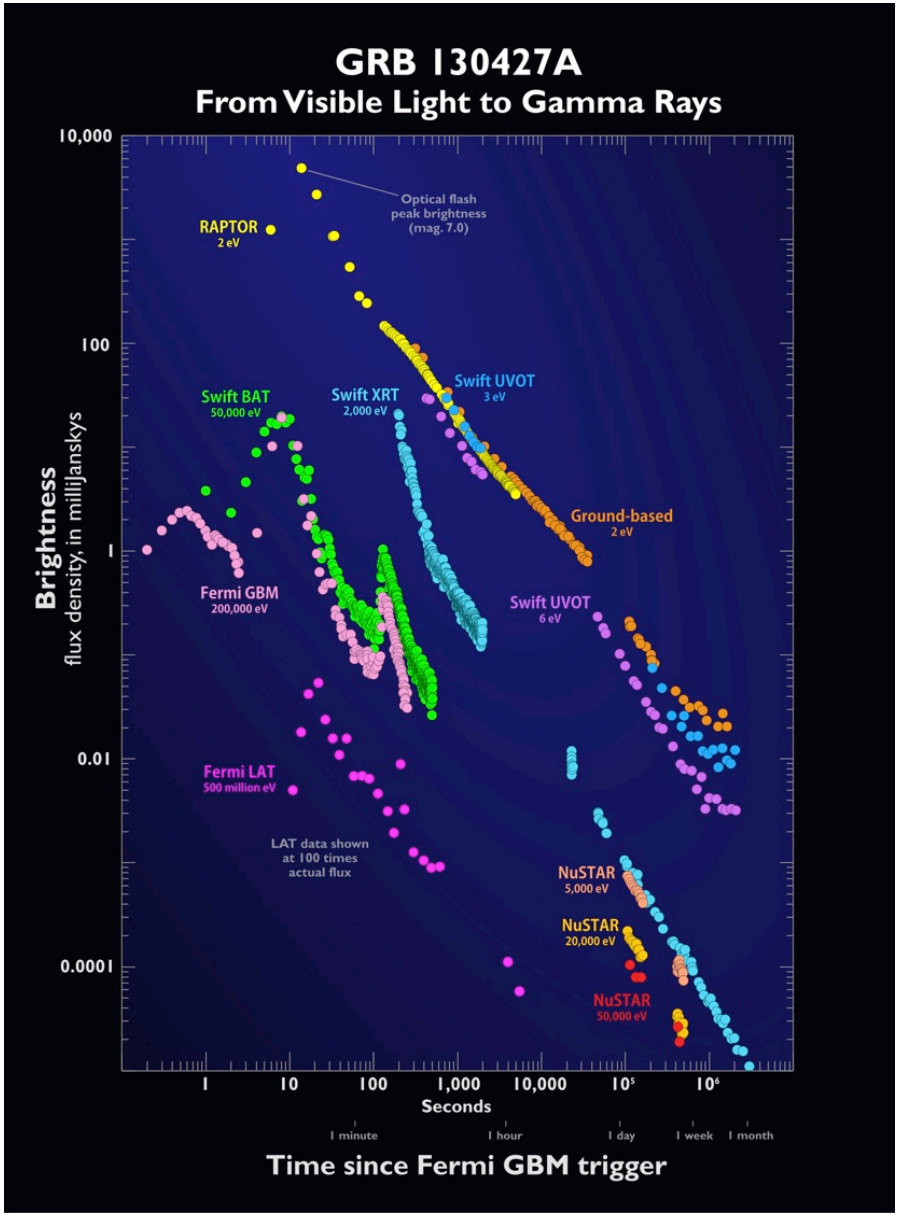
GRB 130427A

On April 27th 2013 Fermi and SWIFT detected one of the brightest GRBs.

Fermi LAT detected a 95 GeV gamma



Before and after Fermi LAT views of GRB 130427A, centered on the north galactic pole



GRB 130427A

Misfortune 1

- The main DAQ was offline
- Luckily, the scaler DAQ was taking data

➡ Monitoring the rate of 29 tanks (HAWC 30) with 112 PMTs

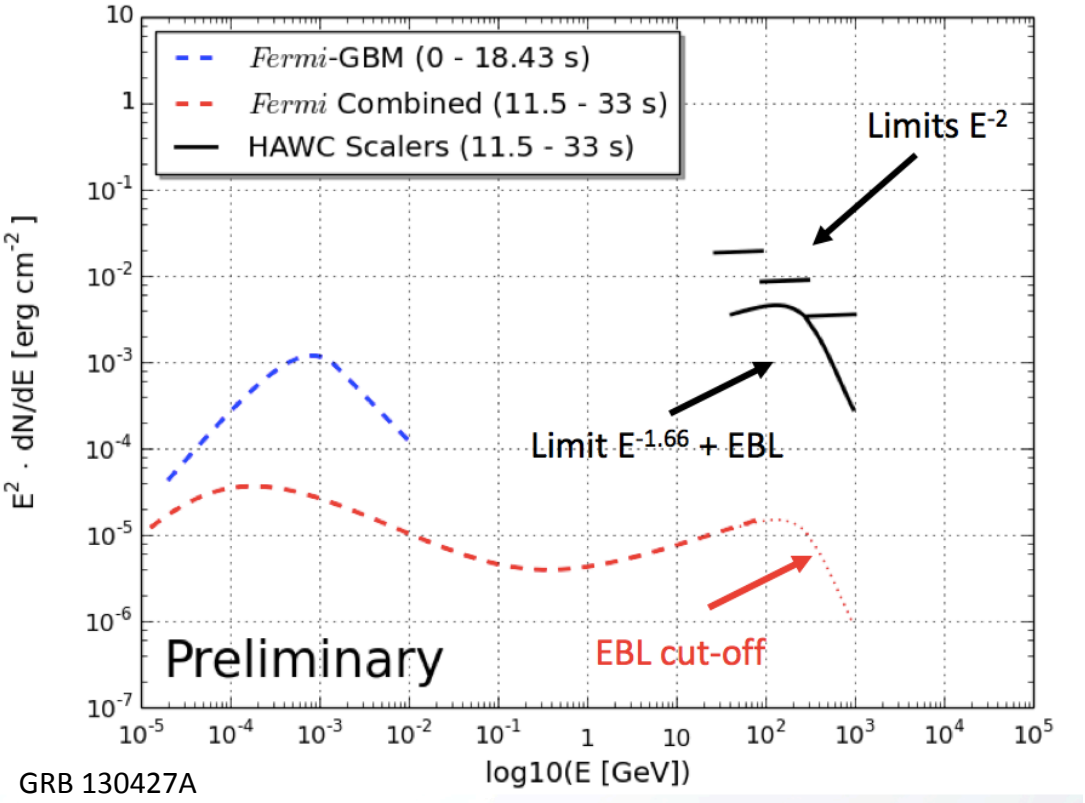
Misfortune 2

- The GRB had an elevation of only 33° in the HAWC field of view

➡ Sensitivity is about 2 orders worse than at zenith

➡ Increased energy threshold

Gamma-Ray Burst (130427A) with HAWC

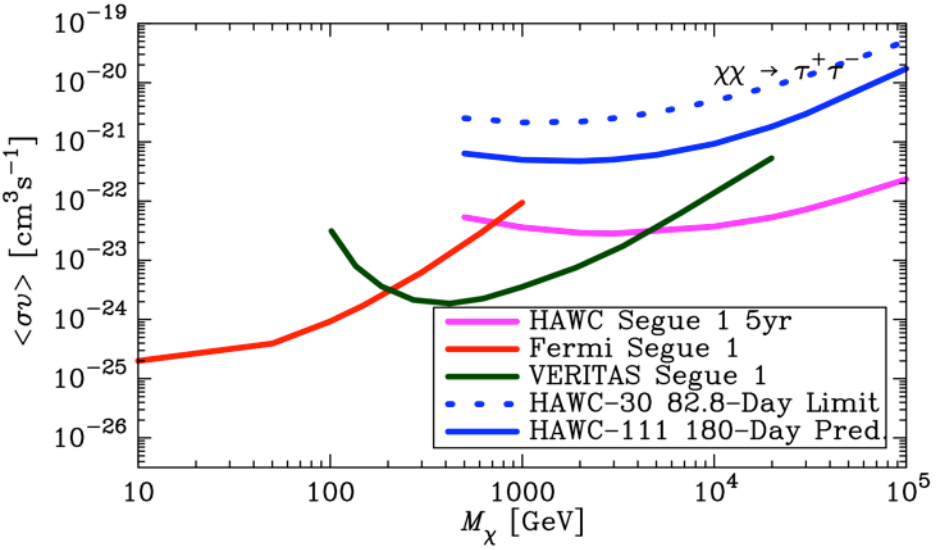


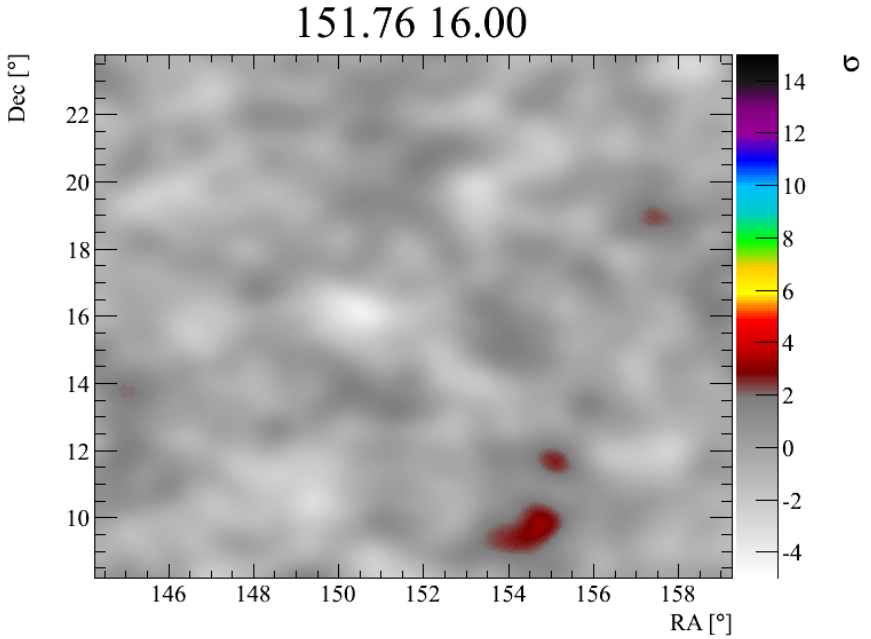
GRB 130427A

- Searches with two independent systems:
  - Triggered ("Main")
  - DAQ, Scaler DAQ
- Were able to set limits with scaler DAQ

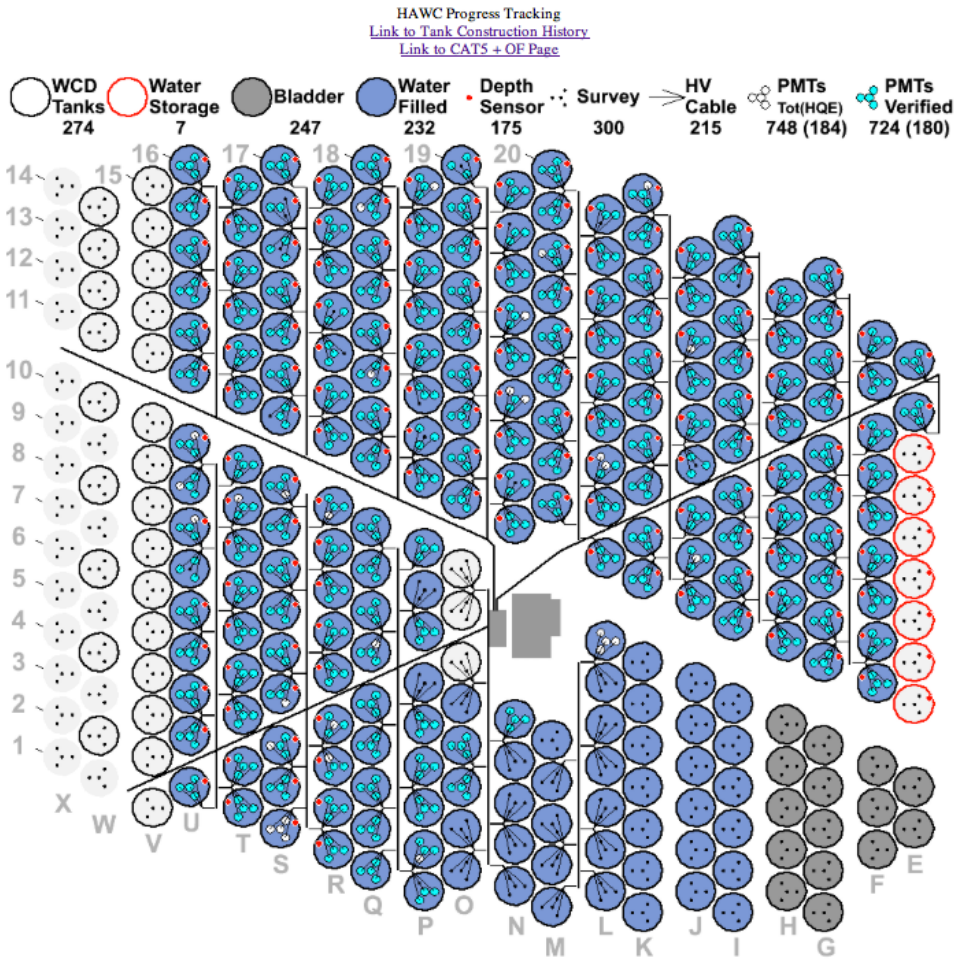
Dark Matter Searches

Segue 1 , preliminary





Present status of the construction heading to complete HAWC by early 2015



Outlook

- HAWC construction will be finished within the next 6 months
- We will start a 10 year period of continuous operation
- The first HAWC bright source catalog should be ready in about six months after completion
- We are learning how to generate and receive alerts for transient phenomena

- We think we know how to build a 3rd generation Water Cherenkov detector

started discussions on HAWC South

- 5,000m a.s.l. 6,000m possible?
- 50,000 m^2 active area (4xHAWC)