The HAWC γ-ray observatory generating big data in México

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HAWC-MX spokesperson & Director General INAOE

- The HAWC collaboration
- Cosmic-rays and gamma-rays
- Air shower arrays & water Cherenkov observatories
- HAWC: development, science & data

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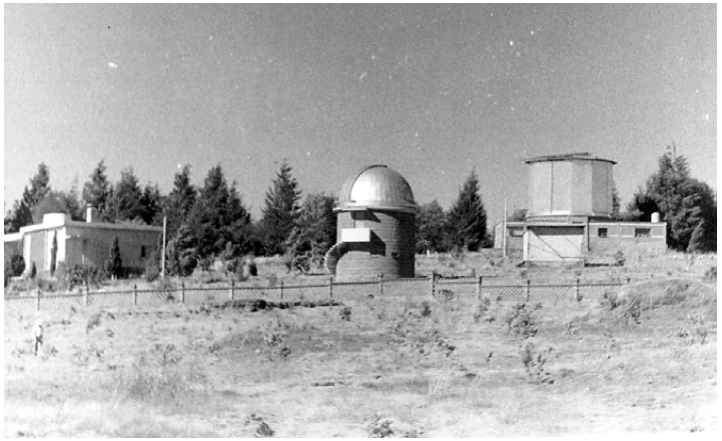
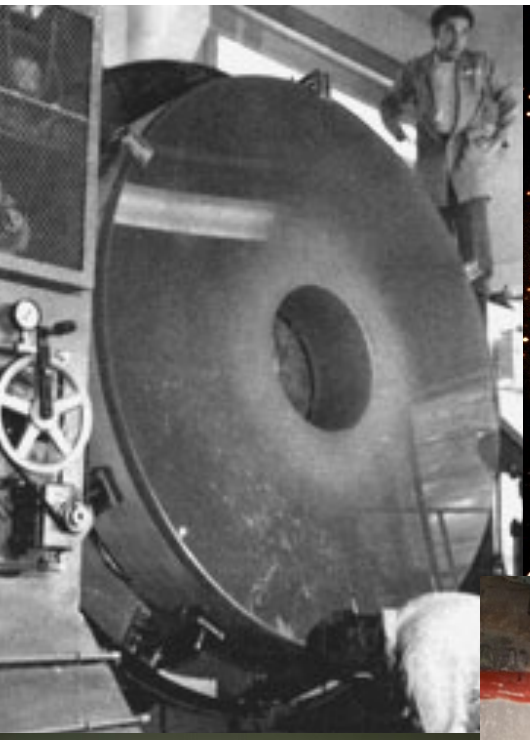
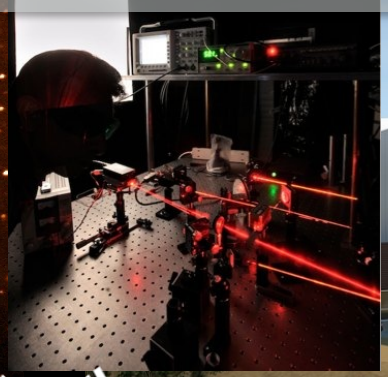
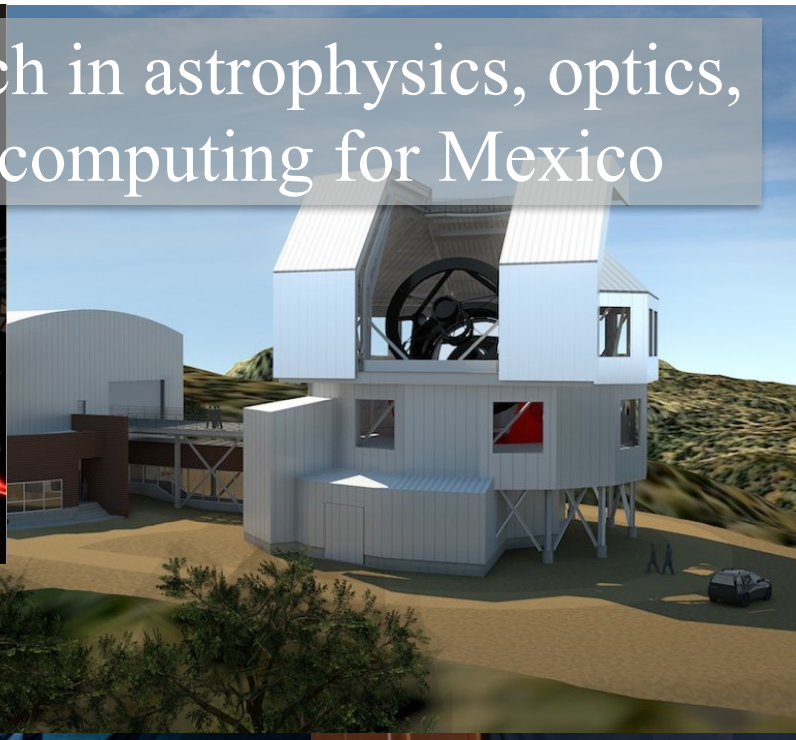


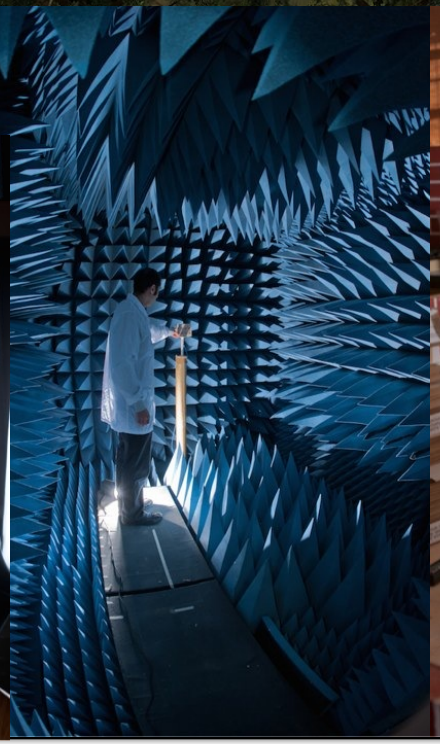
- The Observatorio Astrofísico Nacional de Tonantzintla (OAN-Ton), Puebla, was founded by Luis Enrique Erro in 1942.
- OAN-Ton was transformed in INAOE by Guillermo Haro in November 1971.
- INAOE was created with the project of establishing the Cananea observatory - today Observatorio Astrofísico Guillermo Haro, in operation since 1988.

43 years of research in astrophysics, optics, electronics and computing for Mexico



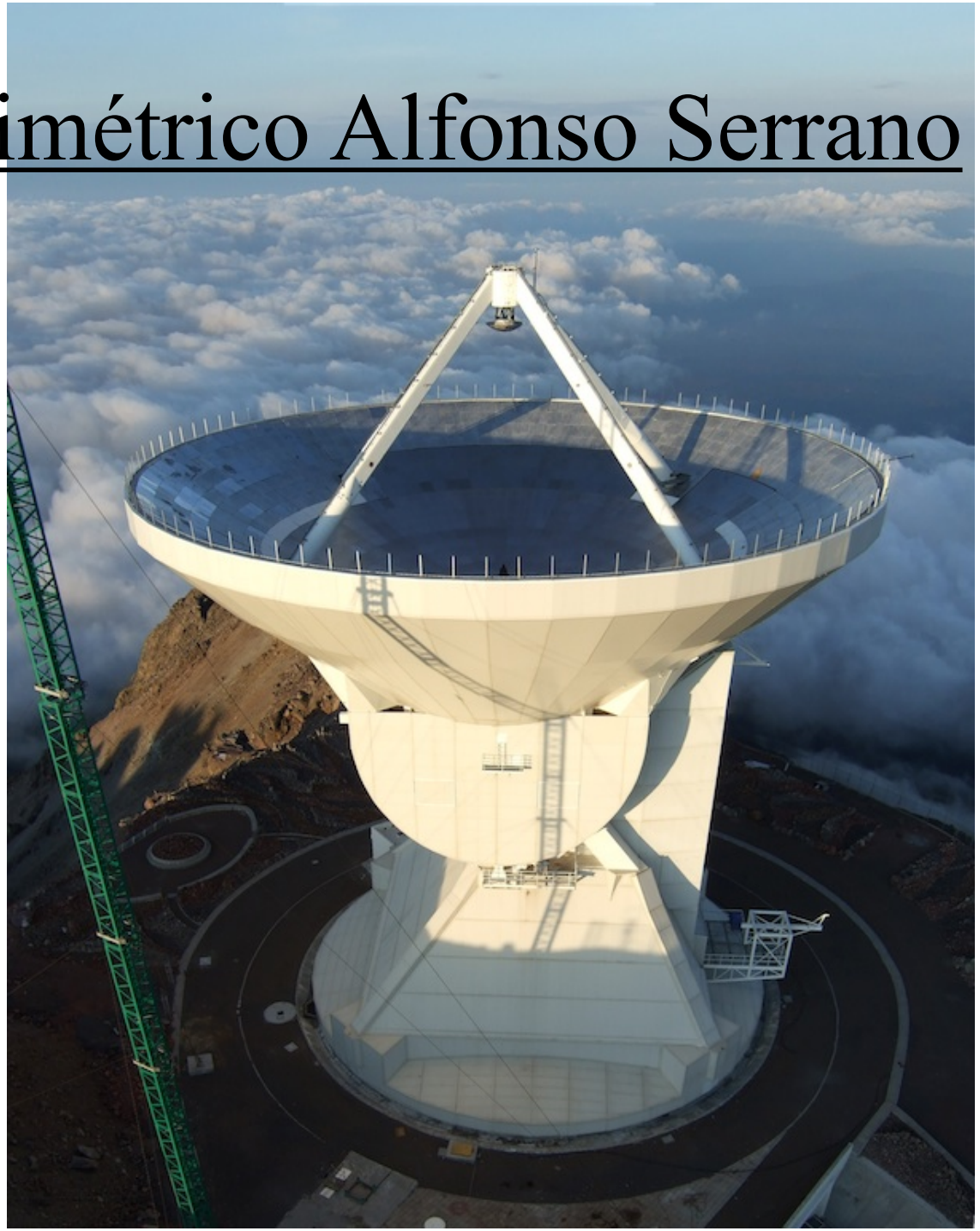



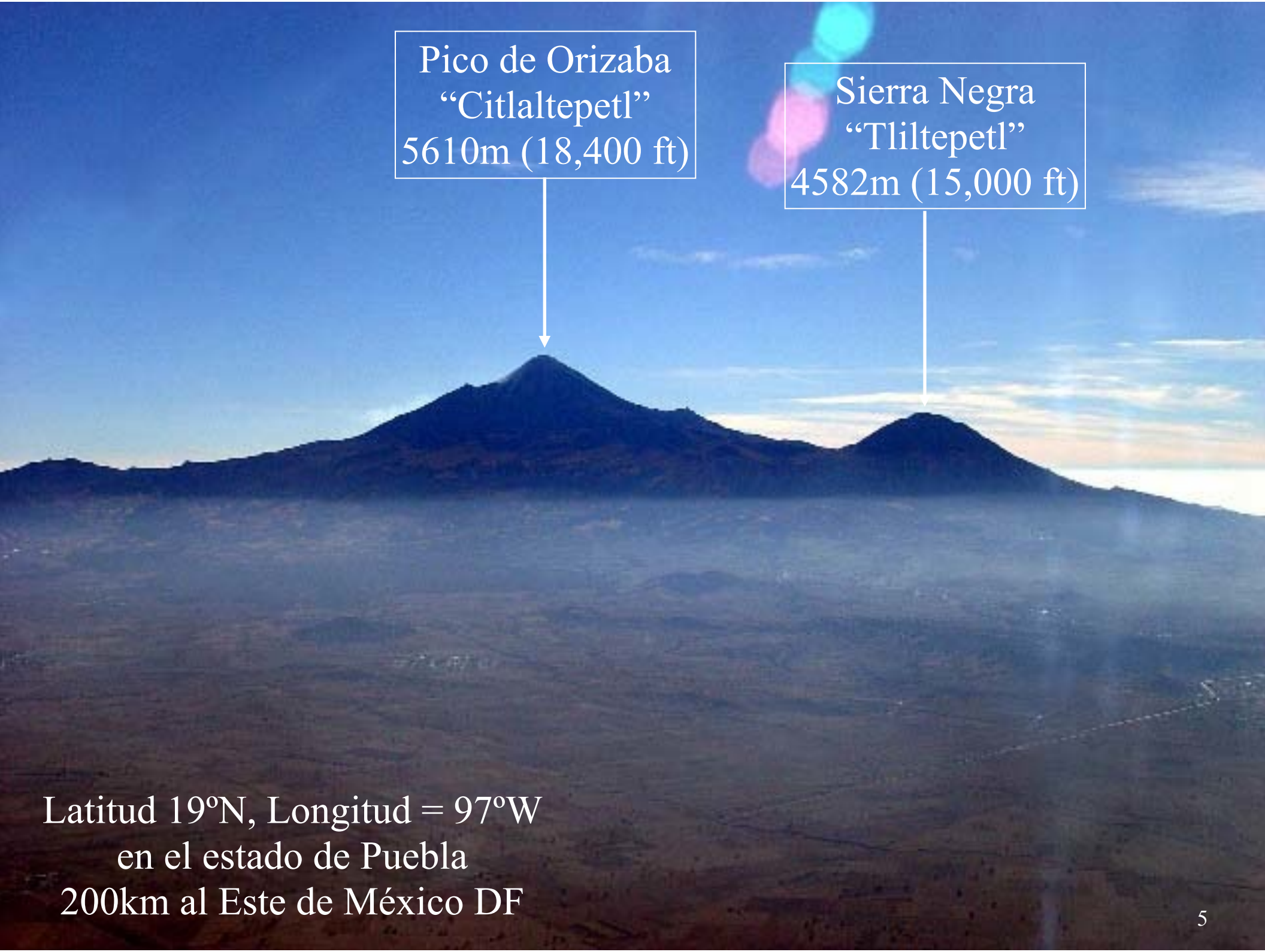



Gran Telescopio Milimétrico Alfonso Serrano

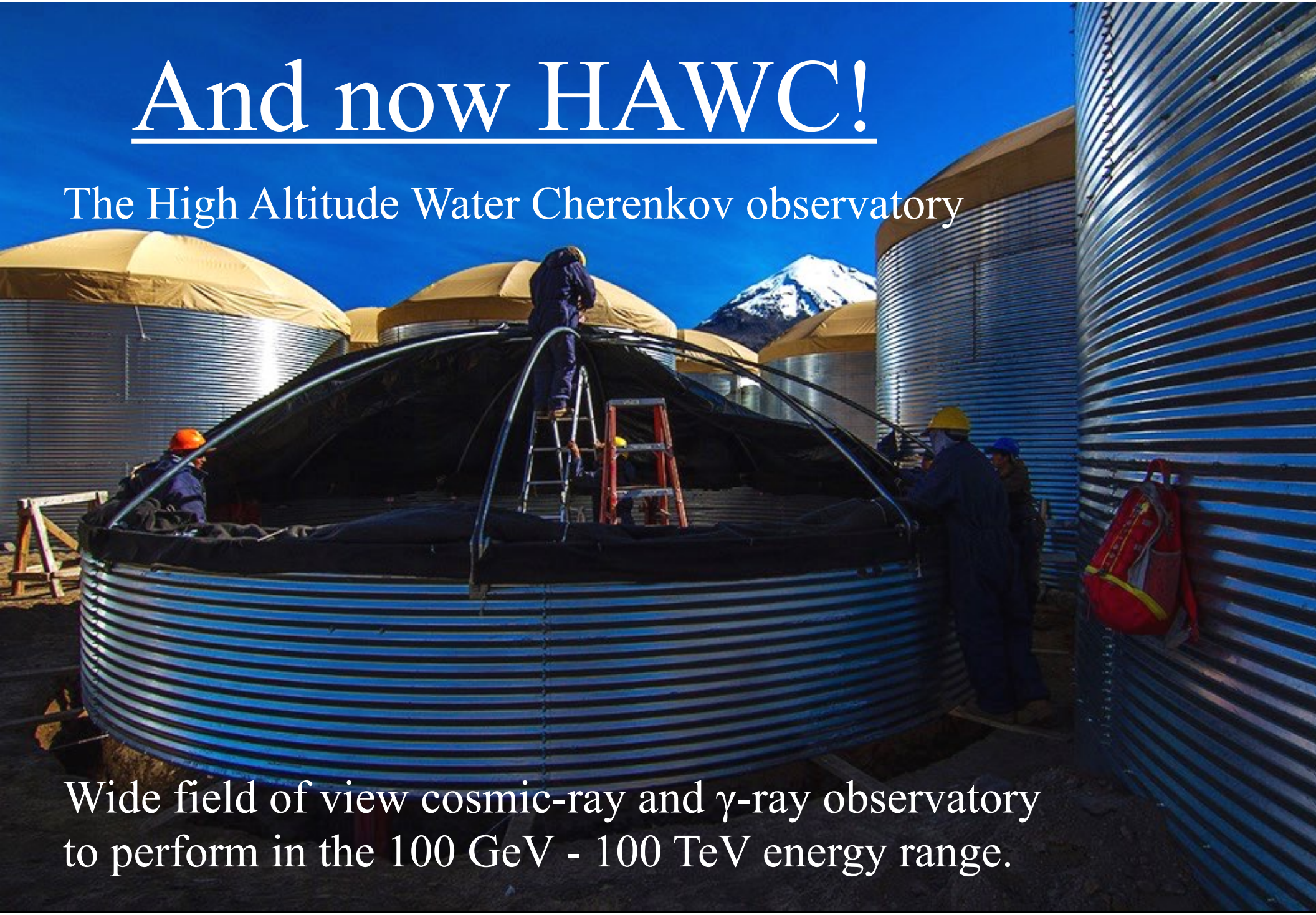
- The Large Millimeter Telescope Alfonso Serrano (LMT/GTM).
- Twenty year collaboration between INAOE and UMASS, Amherst, to build and operate the largest single dish mm telescope in the world.
- A 50m diameter antenna for observations in the 0.8-4.0mm band.
- Installed at the top of Sierra Negra at an altitude of 4593m.
- Operational since May 2013 with a functional aperture of 32m.




Pico de Orizaba
“Citlaltepetl”
5610m (18,400 ft)
Sierra Negra
“Tliltepetl”
4582m (15,000 ft)
Latitud 19ºN, Longitud = 97ºW
en el estado de Puebla
200km al Este de México DF

And now HAWC!

The High Altitude Water Cherenkov observatory



Wide field of view cosmic-ray and γ-ray observatory to perform in the 100 GeV - 100 TeV energy range.

The HAWC collaboration

Mexico		**United States**	
Instituto Nacional de Astrofísica, Óptica y Electrónica	(INAOE)	University of Maryland	(UMD)
Universidad Nacional Autónoma de México		Los Alamos National Laboratory	(LANL)
Instituto de Astronomía UNAM	(IA-UNAM)	Colorado State University	(CSU)
Instituto de Ciencias Nucleares UNAM	(ICN-UNAM)	George Mason University	(GMU)
Instituto de Física UNAM	(IF-UNAM)	Georgia Institute of Technology	(GATECH)
Instituto de Geofísica UNAM	(IG-UNAM)	Michigan State University	(MSU)
Benemérita Universidad Autónoma de Puebla	(BUAP)	Michigan Technological University	(MTU)
Instituto Politécnico Nacional		Pennsylvania State University	(PSU)
Centro de Investigación y Estudios Avanzados	(CINVESTAV)	NASA GSFC	
Centro de Investigación en Cómputo - IPN	(CIC-IPN)	University of California Santa Cruz	(UCSC)
Universidad Autónoma de Chiapas	(UNACH)	University of California Irvine	(UCI)
Universidad Autónoma del Estado de Hidalgo	(UAEH)	University of New Hampshire	(UNH)
Universidad de Guadalajara	(UdG)	University of New Mexico	(UNM)
Universidad Michoacana de San Nicolás de Hidalgo	(UMSNH)	University of Rochester	(UR)
Universidad Politécnica de Pachuca	(UPP)	University of Utah	(UU)
		University of Wisconsin	(UW)


Instituto Nacional de Astrofísica Óptica y Electrónica
Reunión de la colaboración HAWC
Complejo Cultural Universitario BUAP del 27 al 29 de octubre de 2014
INAOE
HAWC

Cosmic Rays

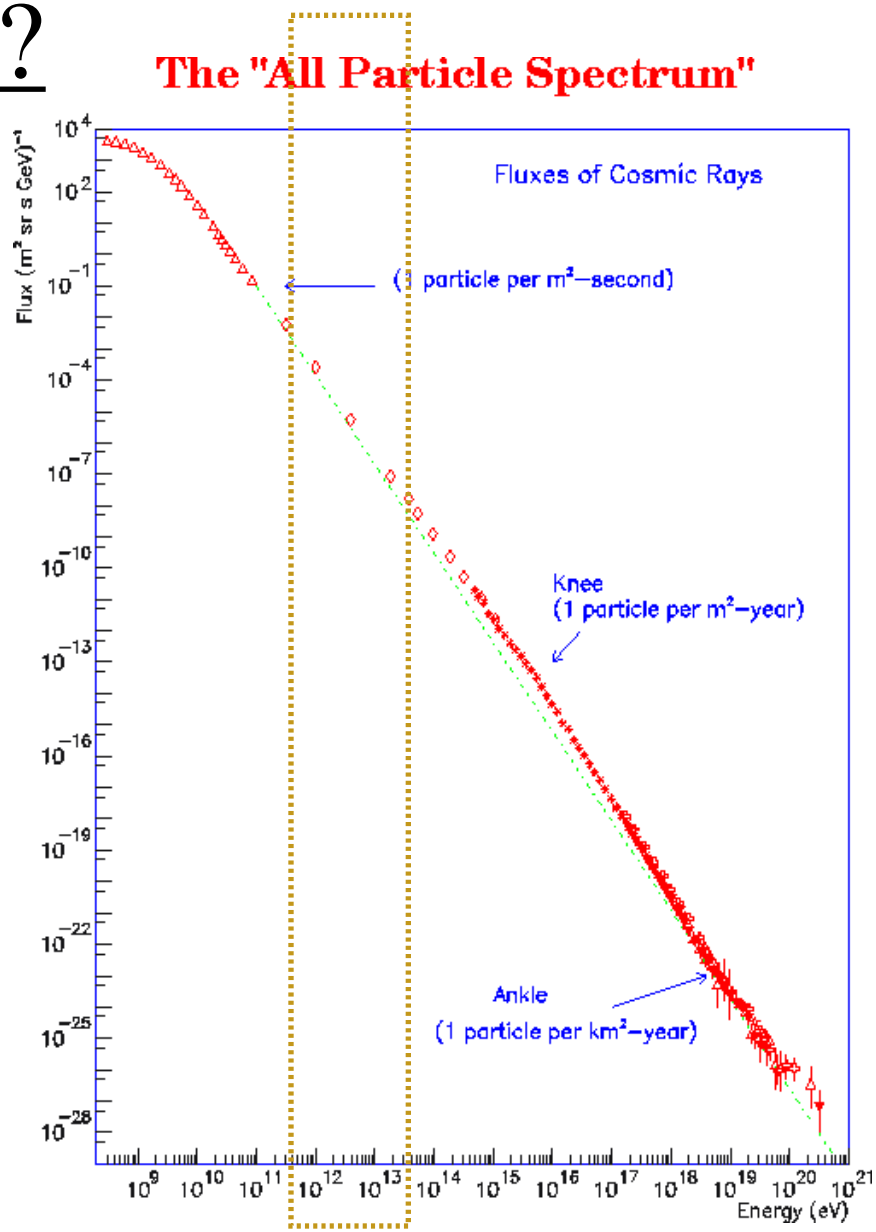
- Discovered as ionizing particles of cosmic origin (Hess 1912).
- Highly energetic particles from 10^9 to 10^{20} eV.
- Mostly nuclei {p, He} + 1% electrons
- Travel in chaotic trajectories in the Galactic magnetic field,

$$r_\ell = 0.03\,\mathrm{pc}\left(\frac{E/Z}{\mathrm{TeV}}\right)\left(\frac{3\,\mu\mathrm{G}}{B}\right)$$

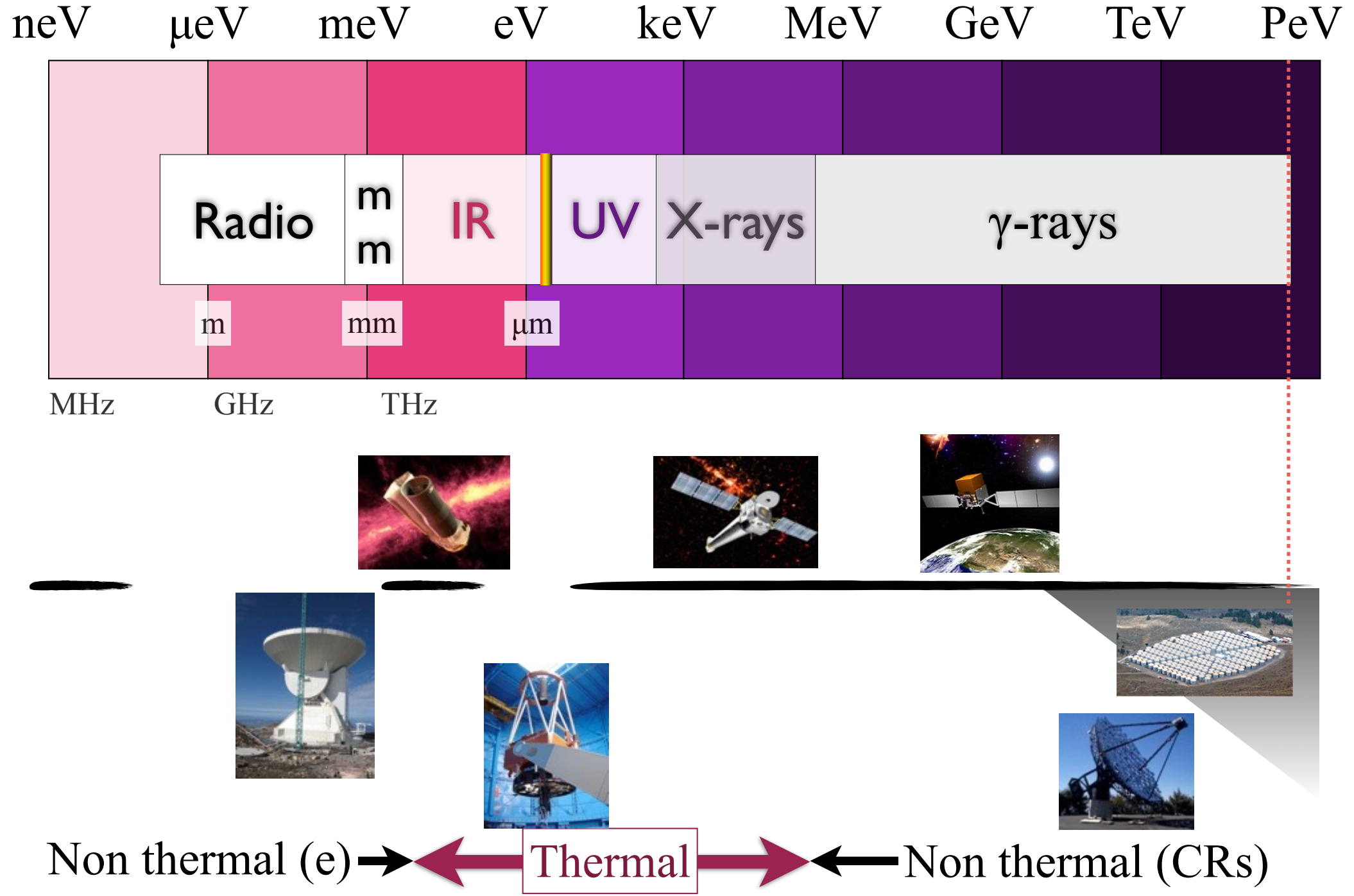
➡ isotropic distribution

The origin of cosmic-rays?

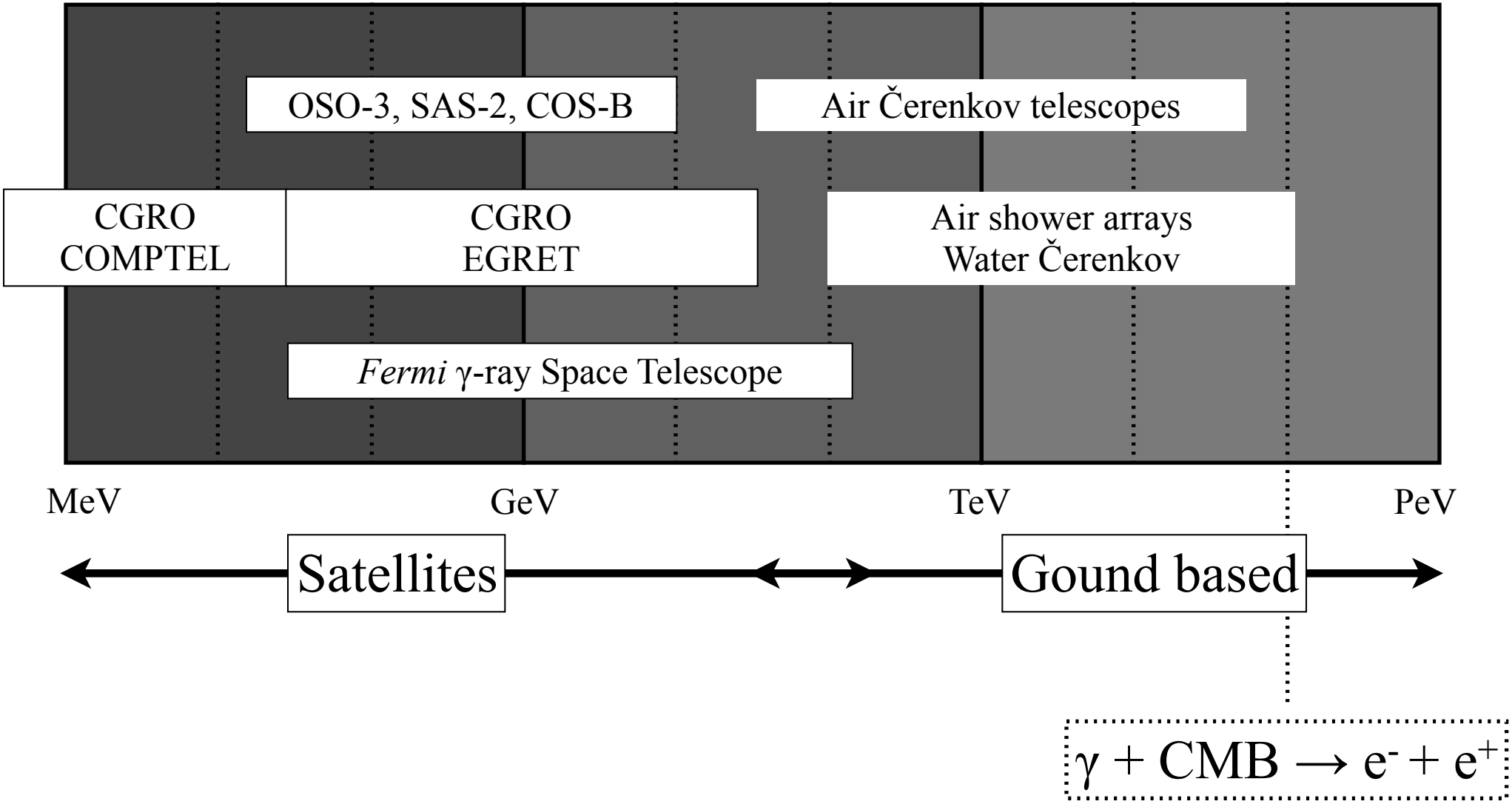
- Cosmic-rays loose directional information and do not point to their sources.
- Fermi (1949) proves that shocks produce $F(E) \propto E^{-(2+\delta)}$ power-law; proposes molecular clouds as the potential sources of cosmic-rays.
- Fermi (1954) shows that SNe explosion energetics are more than sufficient to power cosmic-rays in the Galaxy.
- The production of cosmic-rays particles *must* result in production of γ-rays, pointing to their sources.



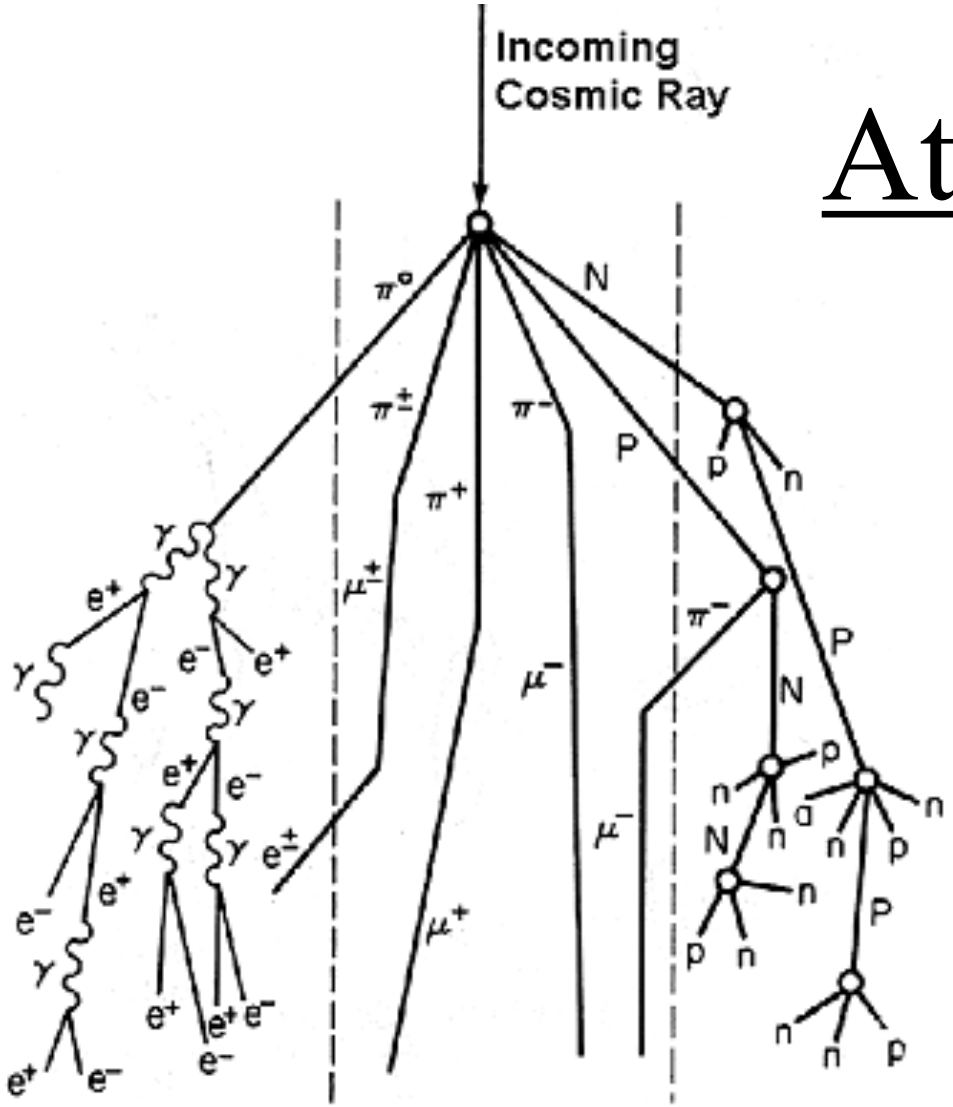
http://pdg.lbl.gov/2014/reviews/rpp2014-rev-cosmic-rays.pdf

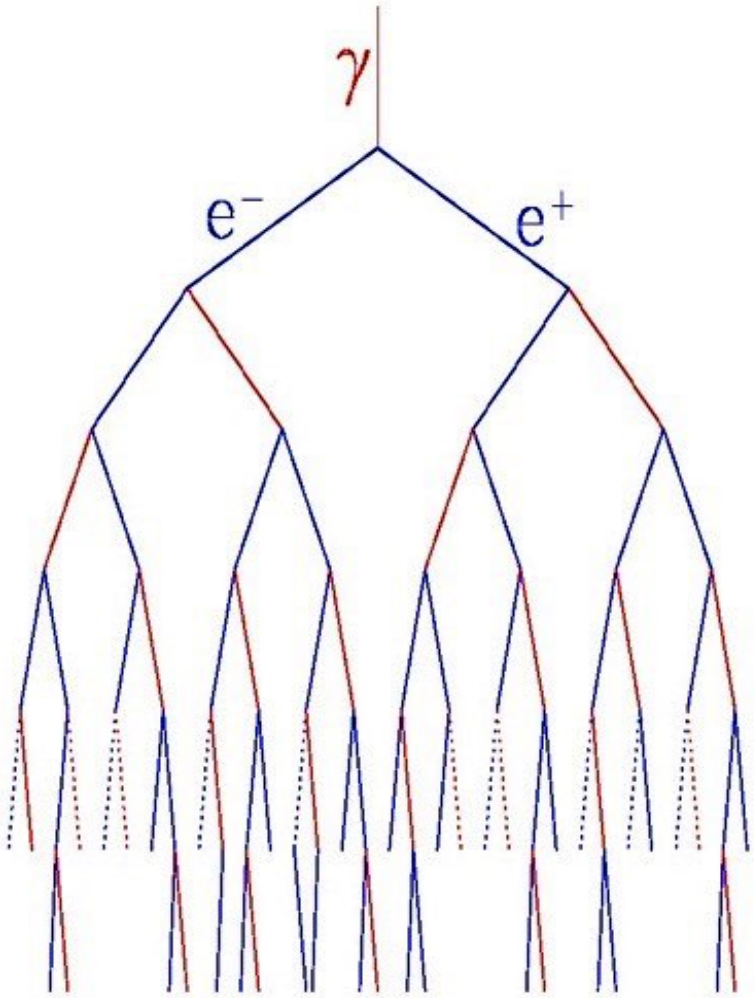

neV
μeV
meV
eV
keV
MeV
GeV
TeV
PeV
Radio
m
m
IR
UV
X-rays
γ-rays
m
mm
μm
MHz
GHz
THz
Non thermal (e)
Thermal
Non thermal (CRs)

The gamma band



Atmospheric cascades





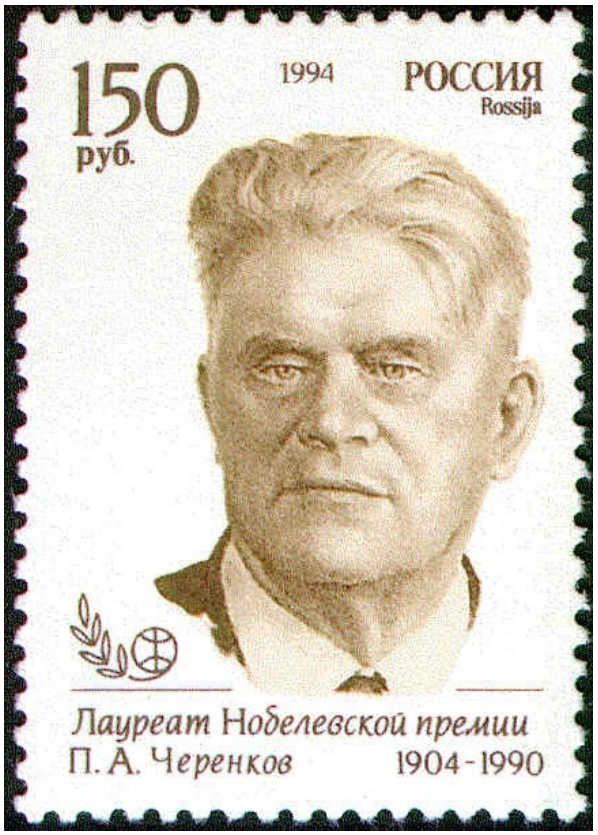
Čerenkov radiation

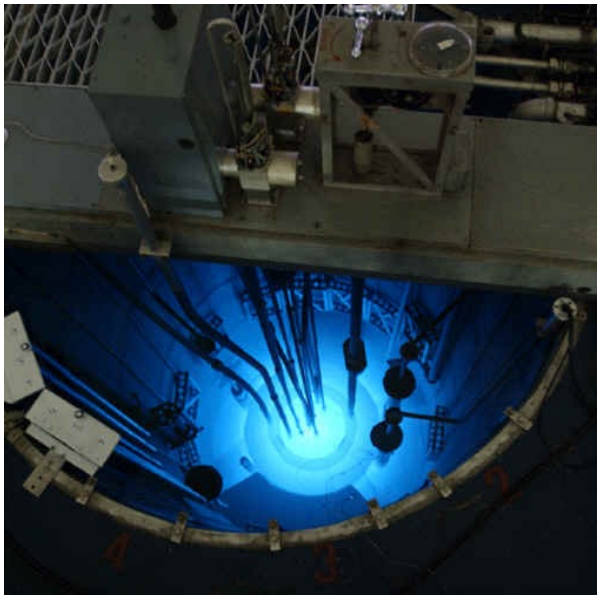
- Emitted when charged particles move faster than the light in a medium:

$$v > c/n.$$

- Restricted to a cone behind the particle:

$$\cos\theta = 1/\beta n.$$





	n	Threshold (γ m_e c^2)	θ_{max}
Air	1.0003	20.8 MeV	1.4º
Water	1.335	0.77 MeV	41.2º

Some air shower arrays

Haverah Park	Water Cherenkov	England	1967 - 1987	Very high energy cosmic rays
Pierre Auger observatory	WČ & fluorescence (hybrid)	Argentina	2004 -	Ultra high energy CRs
Cygnus array	Scintillator & WČ	New Mexico (2100m)	1986 -	CRs (and γ-rays)
Tibet AS	Scintillation counters	Yangbajing, Tibet (4300m)	1990 -	CRs (and γ-rays)
Milagro	γ-WČO	New Mexico (2600m)	1999 - 2008	γ-rays

The Milagro γ-ray observatory

First water Cherenkov gamma-ray observatory

Located in New Mexico (altitude 2650m & latitude 36ºN)

Operational between 1999 and 2008

Median energy = 40 TeV

Plane of 2GeV Photons at 20°

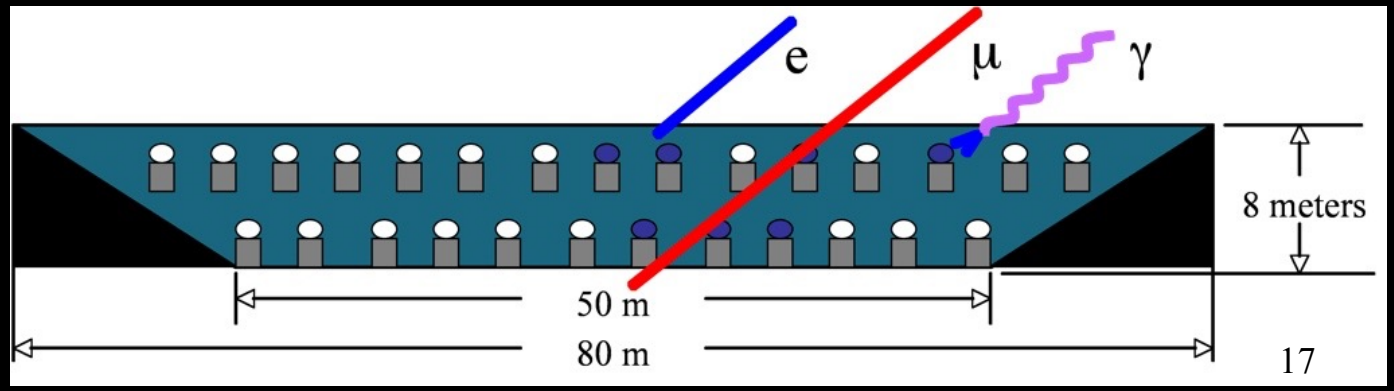
Side View

Again notice the detailed structure of the showerfront in the pond, and the very deep penetration. The refraction of this showerfront is delayed until very deep in the pond due to the penetration of the energetic gamma photons.

Red - electrons and positrons

Green - secondary gammas

Blue - Cherenkov Photons



Located in Sierra Negra at higher altitude 4100m and lower latitude 19ºN

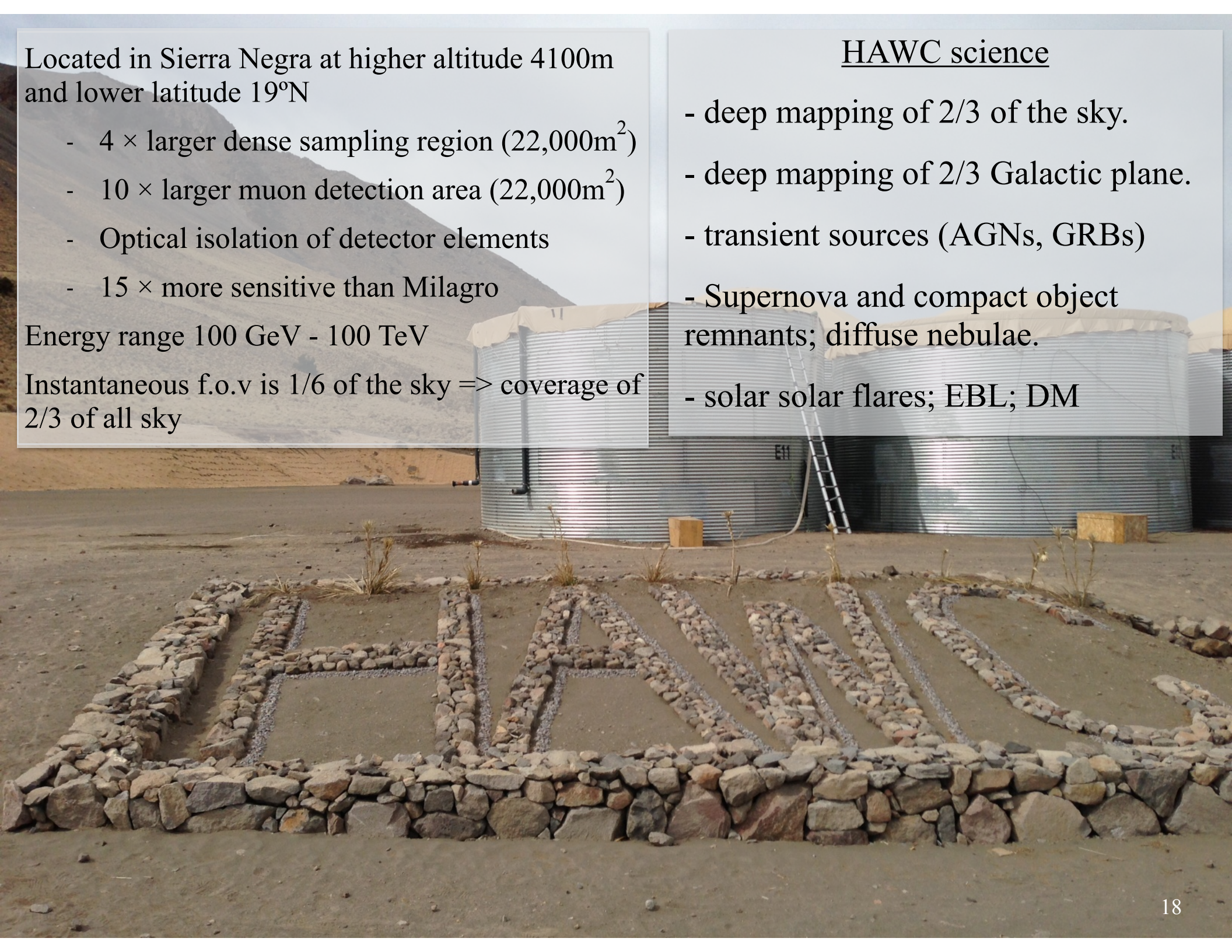
- 4 × larger dense sampling region (22,000m^2)
- 10 × larger muon detection area (22,000m^2)
- Optical isolation of detector elements
- 15 × more sensitive than Milagro

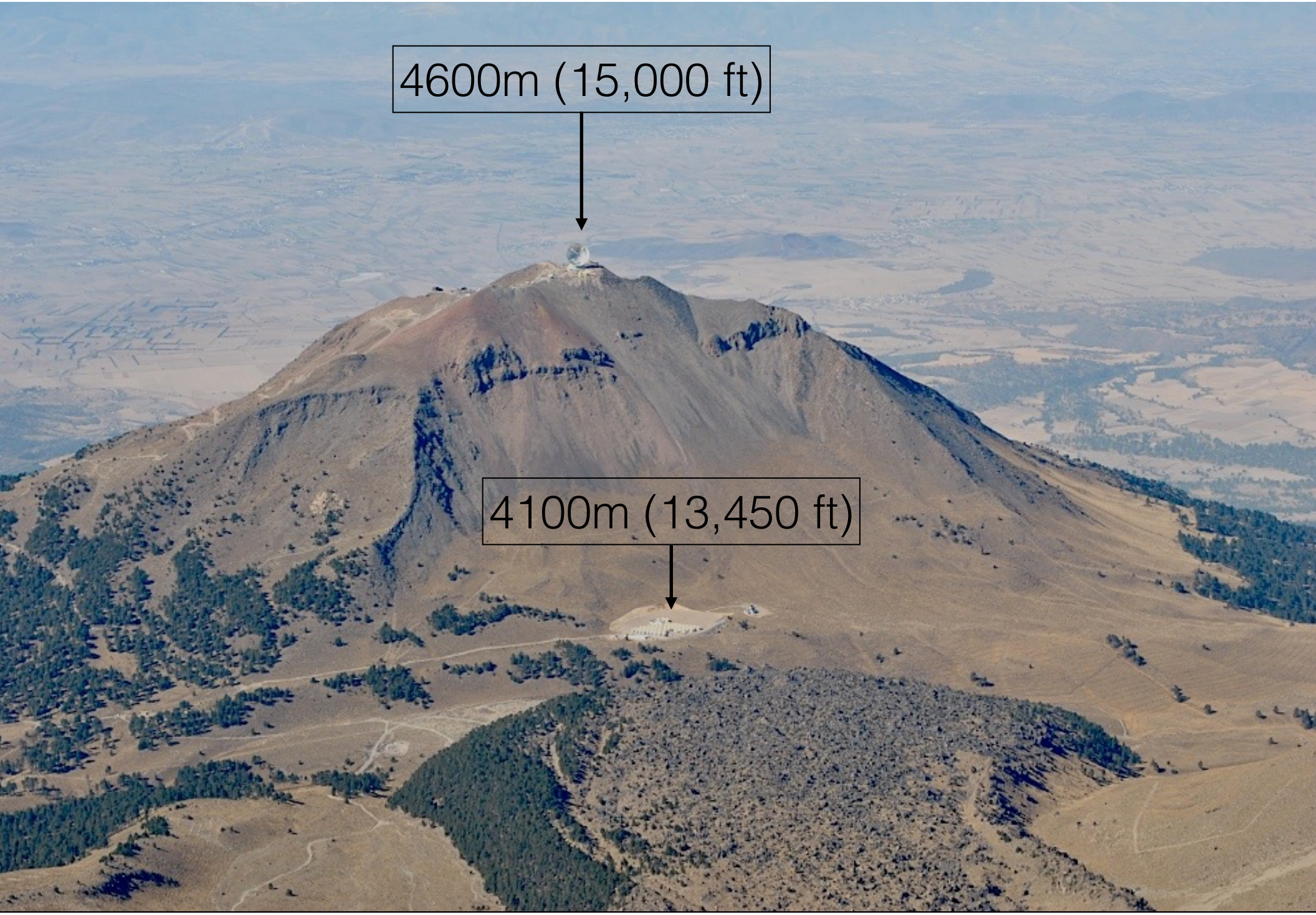
Energy range 100 GeV - 100 TeV

Instantaneous f.o.v is 1/6 of the sky => coverage of 2/3 of all sky

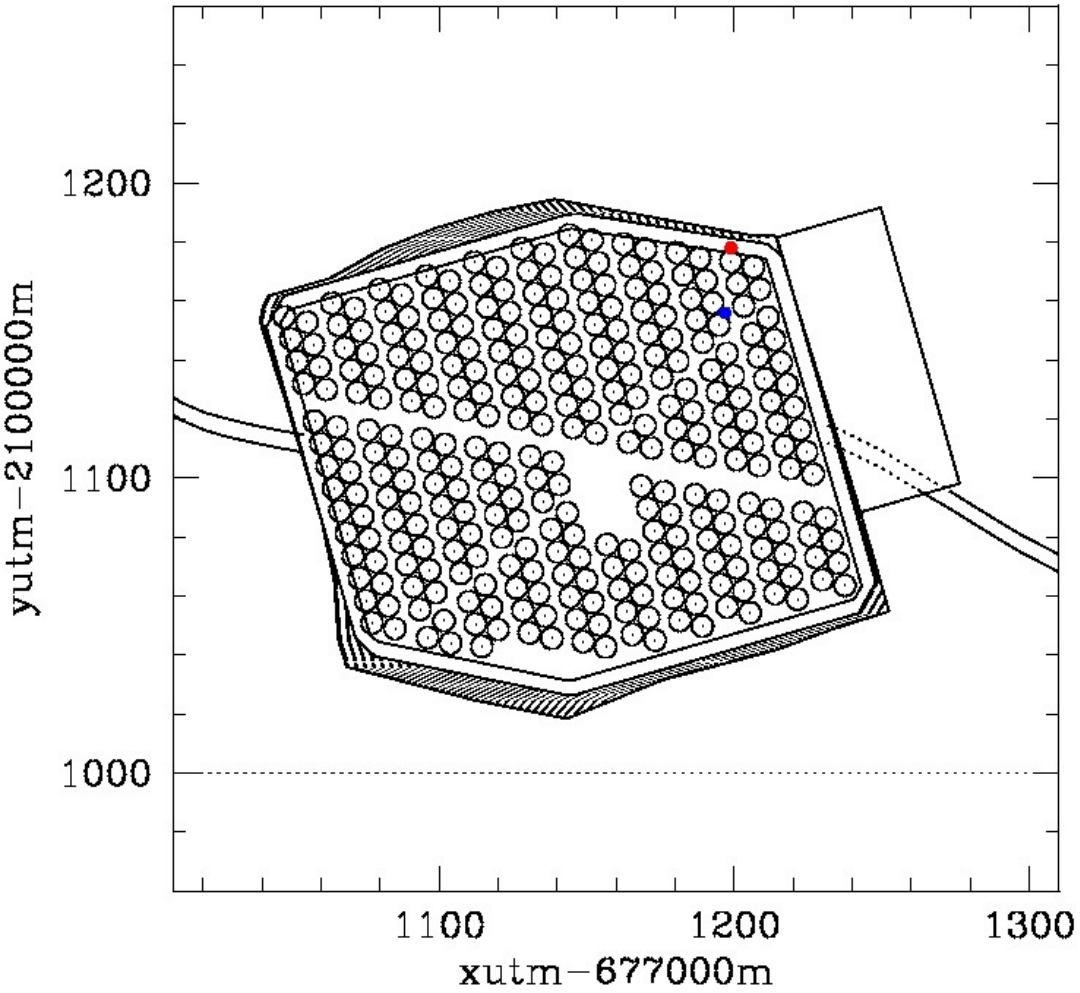
HAWC science

- deep mapping of 2/3 of the sky.
- deep mapping of 2/3 Galactic plane.
- transient sources (AGNs, GRBs)
- Supernova and compact object remnants; diffuse nebulae.
- solar solar flares; EBL; DM




4600m (15,000 ft)
4100m (13,450 ft)

HAWC design



A *compact* air shower array.

300 individual WCDs with 3+1 PMTs each = 1,200 PMTs.

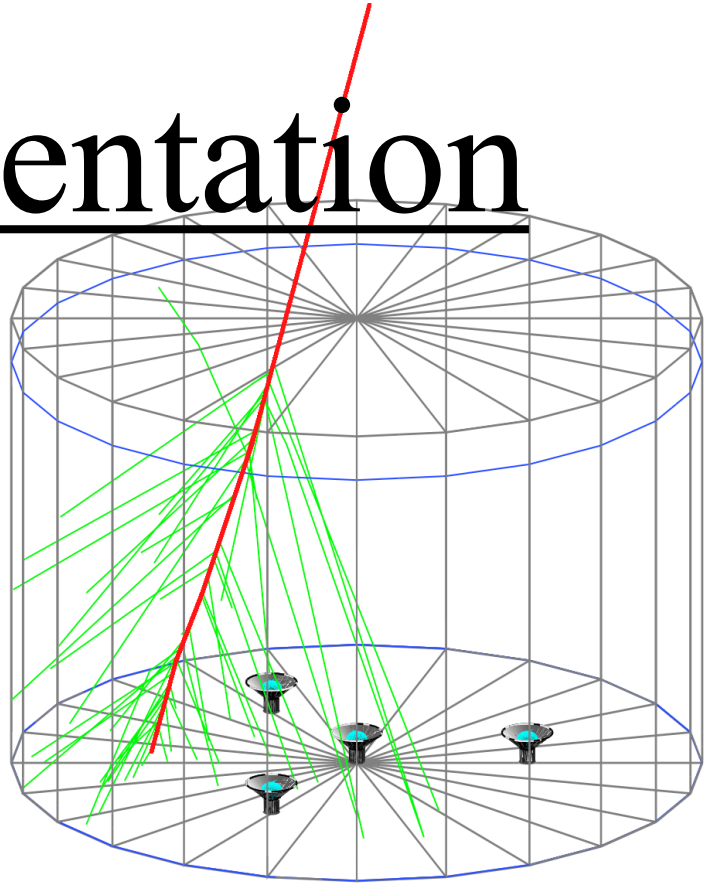
Covers 22,500 m^2, of which 12,000 m^2 are detector area.

Modular design:

- ➡ Better environmentally
- ➡ Project phases: engineering, data, early science operations

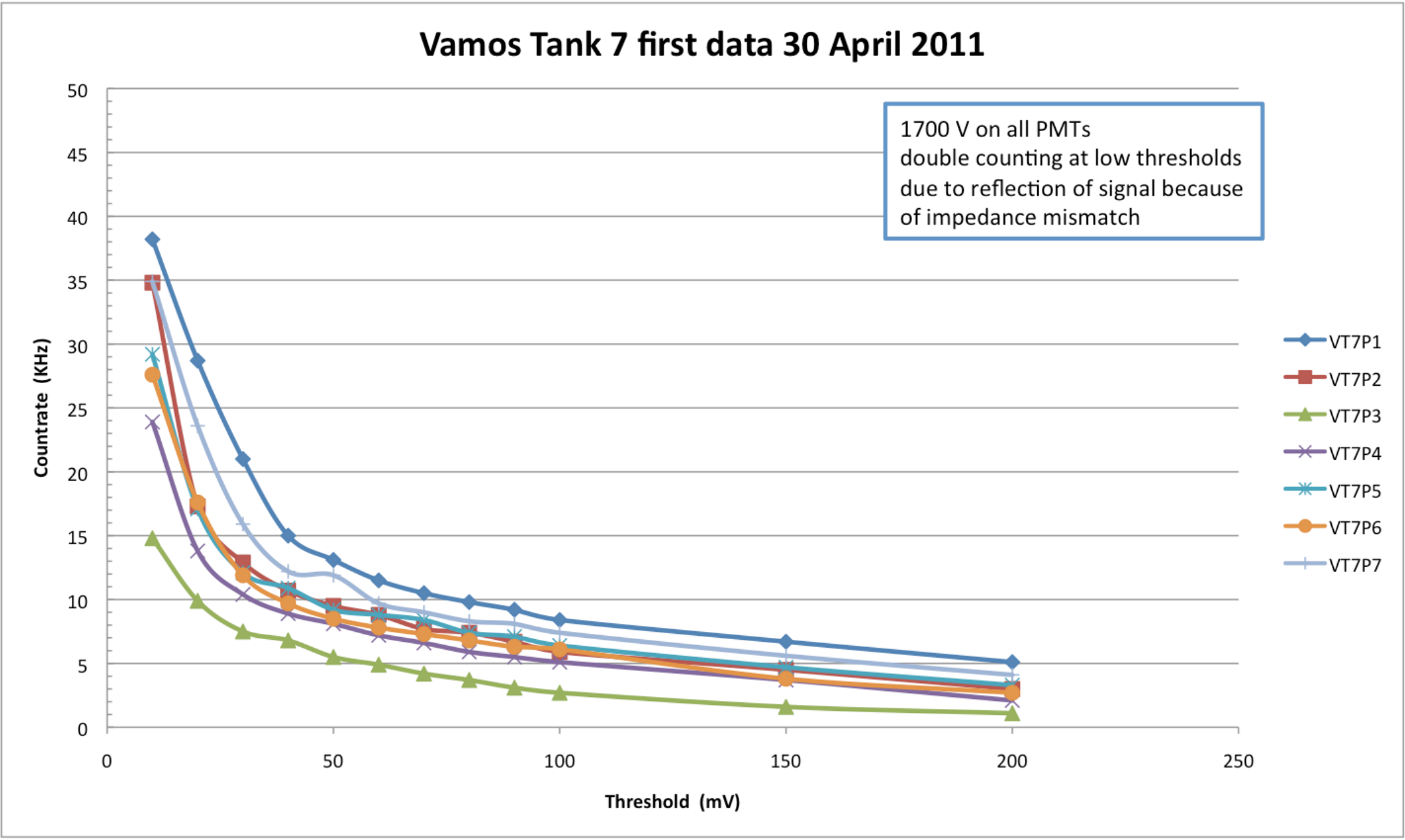
WCD instrumentation

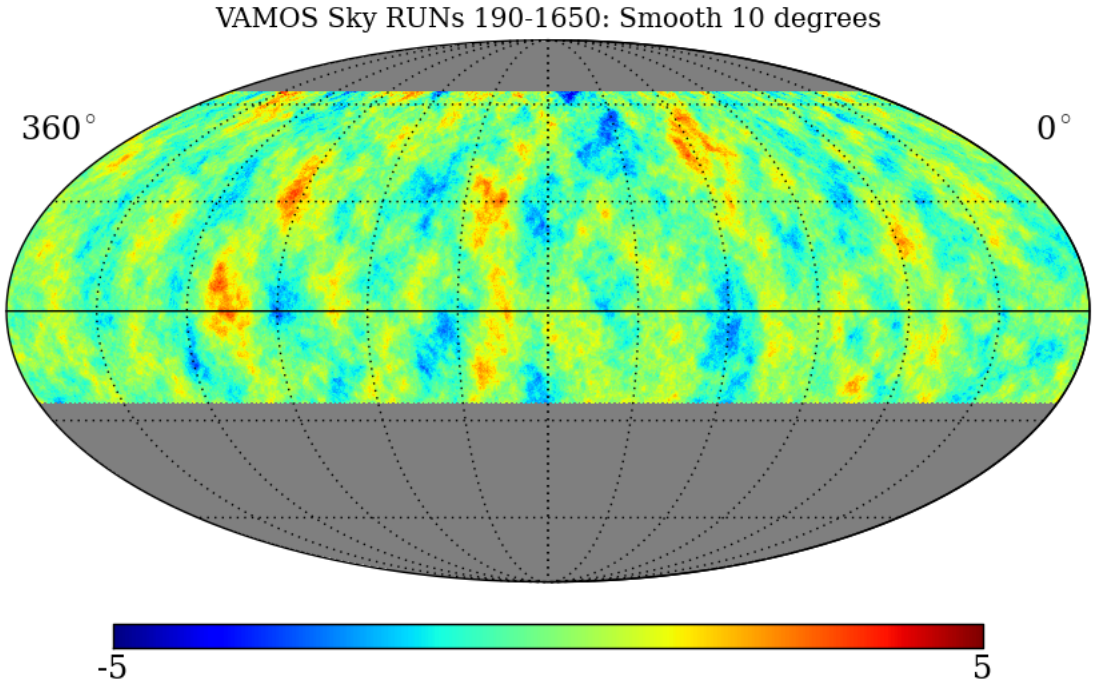
- Each water tank is filled with 180,000 liters of water.
- Water is treated to ensure maximum transparency.
- Each WCD has 3(8”) + 1(10”) PMT: fast response and good QE to Cherenkov light (blue to UV).
- Optical fiber for calibration.
- Each WCD is connected to the central counting house.



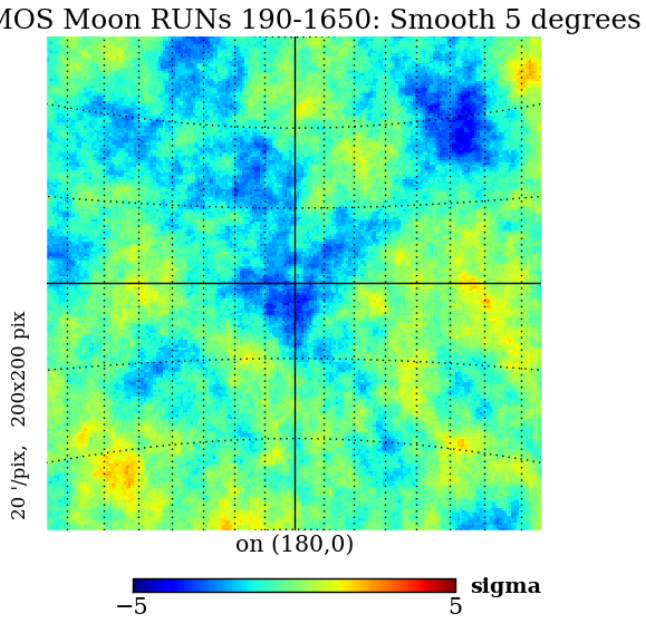
Water Cherenkov Detectors

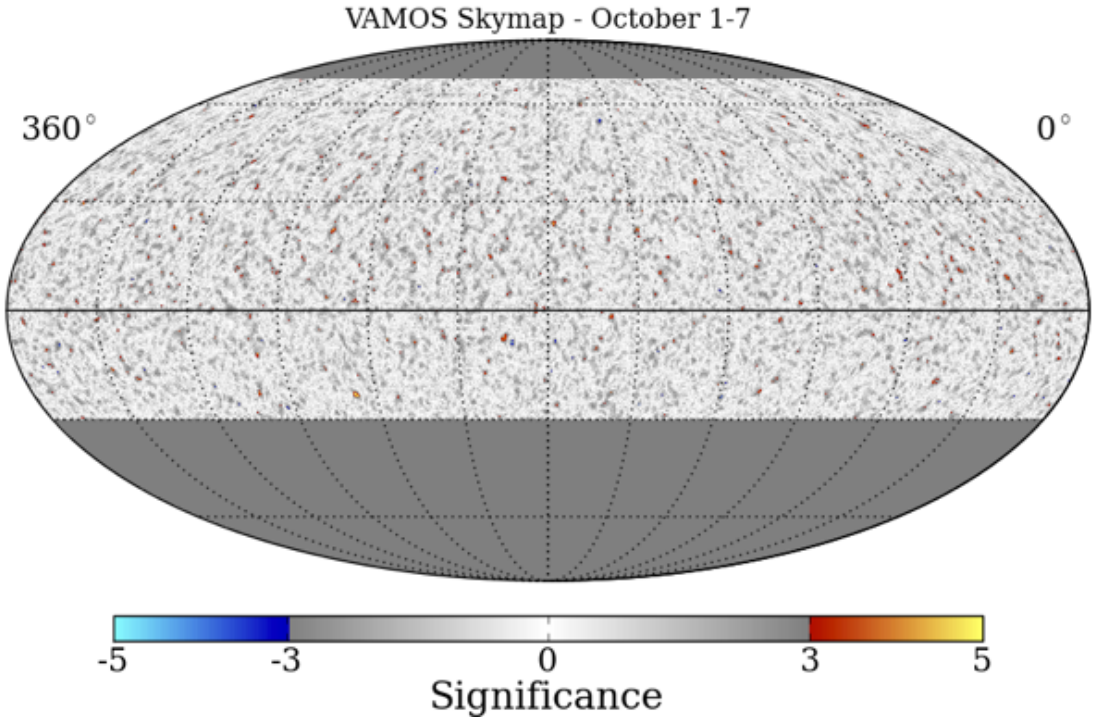
VAMOS (2010-2011)


Vamos Tank 7 first data 30 April 2011
1700 V on all PMTs
double counting at low thresholds
due to reflection of signal because
of impedance mismatch
Countrate (KHz)
Threshold (mV)
0
5
10
15
20
25
30
35
40
45
50
0
50
100
150
200
250
VT7P1
VT7P2
VT7P3
VT7P4
VT7P5
VT7P6
VT7P7



RC





Abeysekara et al.
(Astrop. Phys 62, 125, 2015;
arxiv 1408.3477)

γ

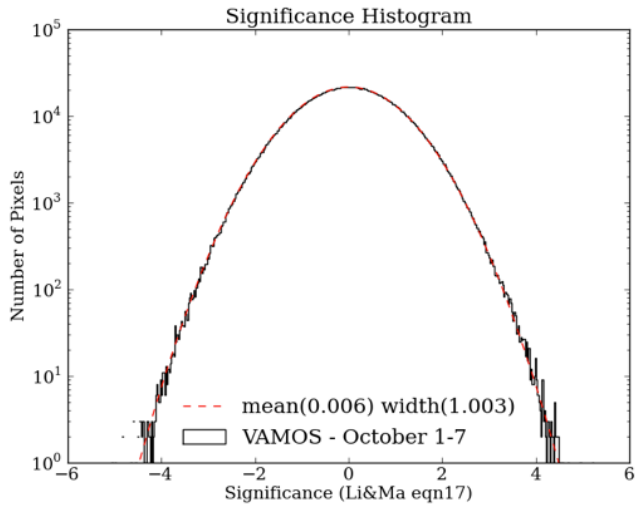



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Image © 2013 DigitalGlobe
125 m
Google earth
Imagery Date: 10/10/2012 18°59'41.26" N 97°18'26.99" W elev 4098 m eye alt 4.73 km

Journal home : Nature | INAOE | BBC News - Hawc gamma | Weekly Site Meeting - 201

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15 April 2013 Last updated at 05:22 GMT

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Hawc gamma-ray telescope captures its first image

By Jason Palmer
BBC News, Denver

The Hawc facility is able to spot the highest-energy light ever seen on Earth - possibly the highest we will ever see

A new set of "eyes" to capture the Universe's highest-energy particles and light has snapped its first image.

The High-Altitude Water Cherenkov Observatory or Hawc, high on a Mexican plain, now holds the record for the highest-energy light it can capture

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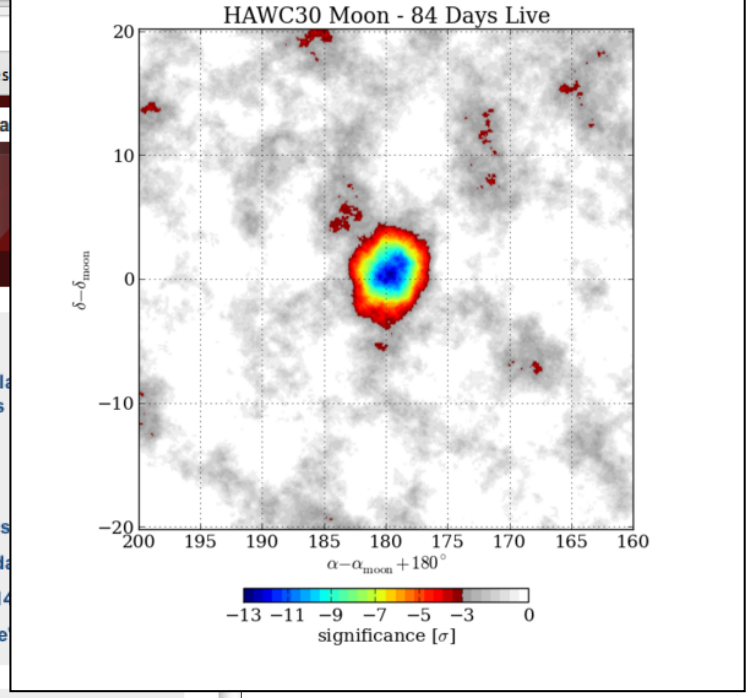
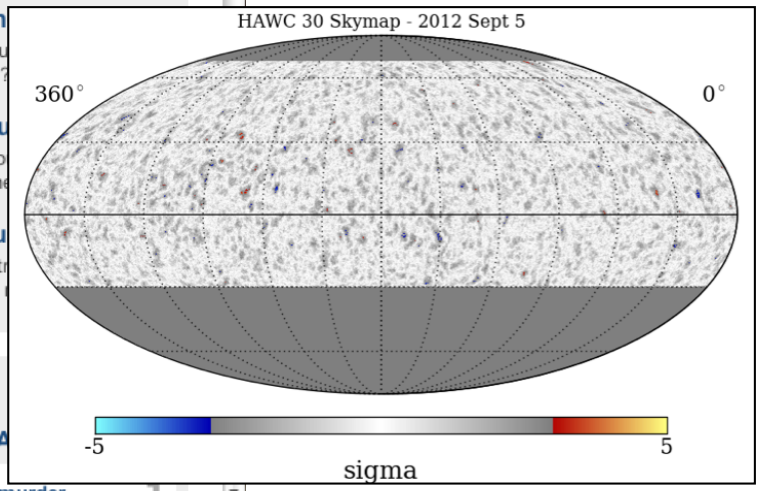





HAWC-100
Sept 2013

HAWC-100
Sept 2013

HAWC Utility Building

- Water filtration
- Bladder testing

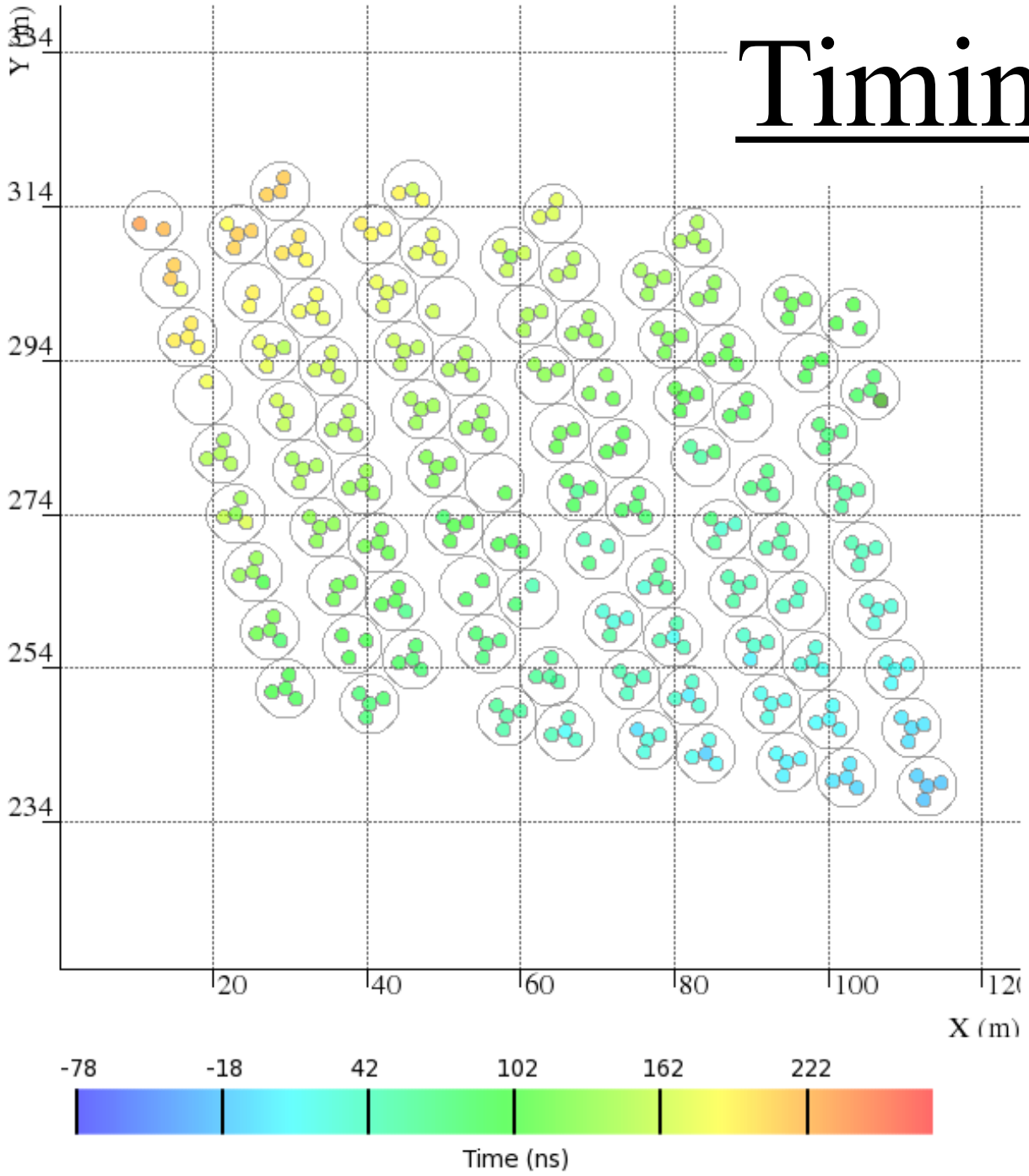
Counting house

- DAQ & laser calibration
- system

HAWC Utility Building

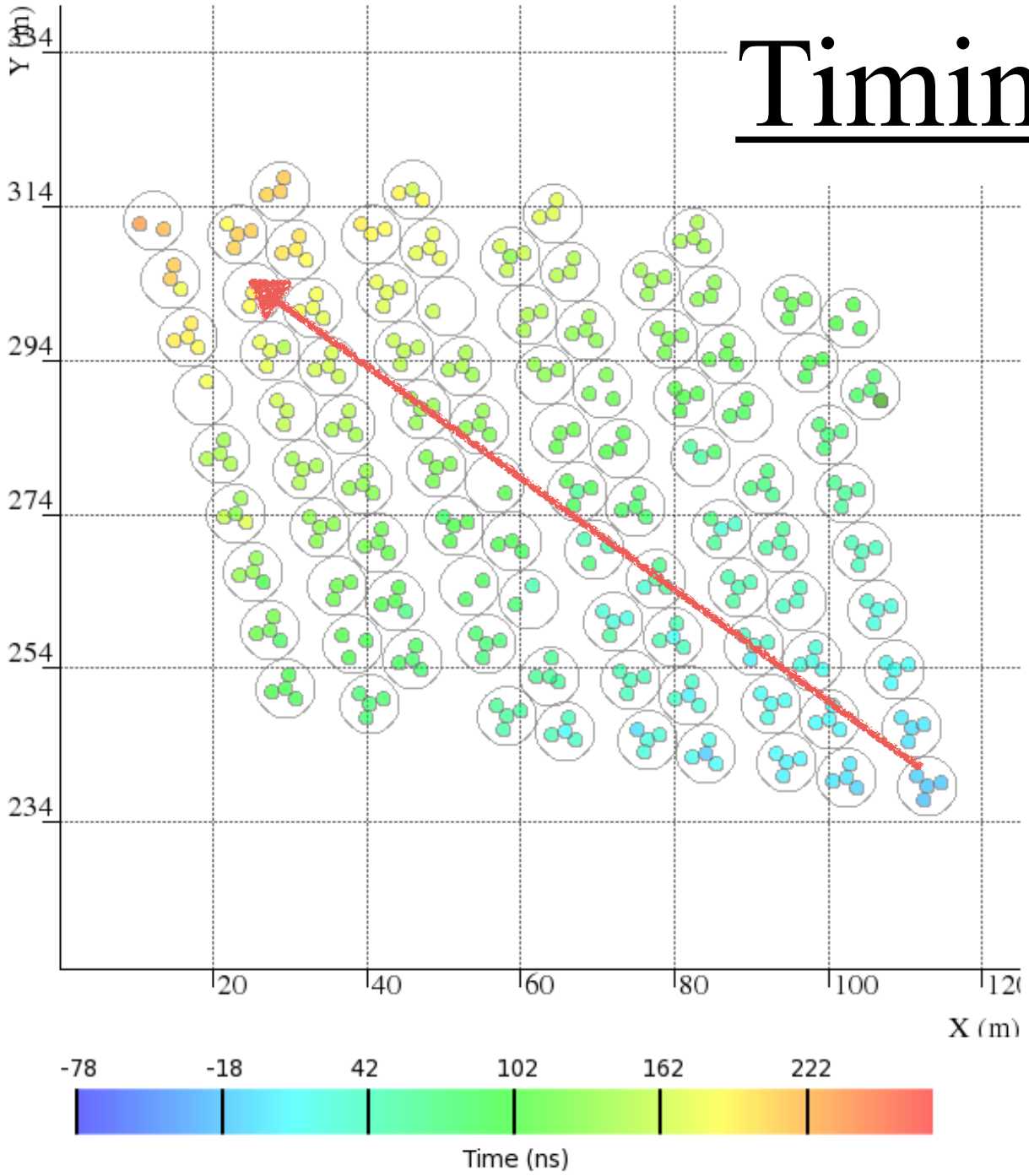
- Water filtration
- Bladder testing

Timing information



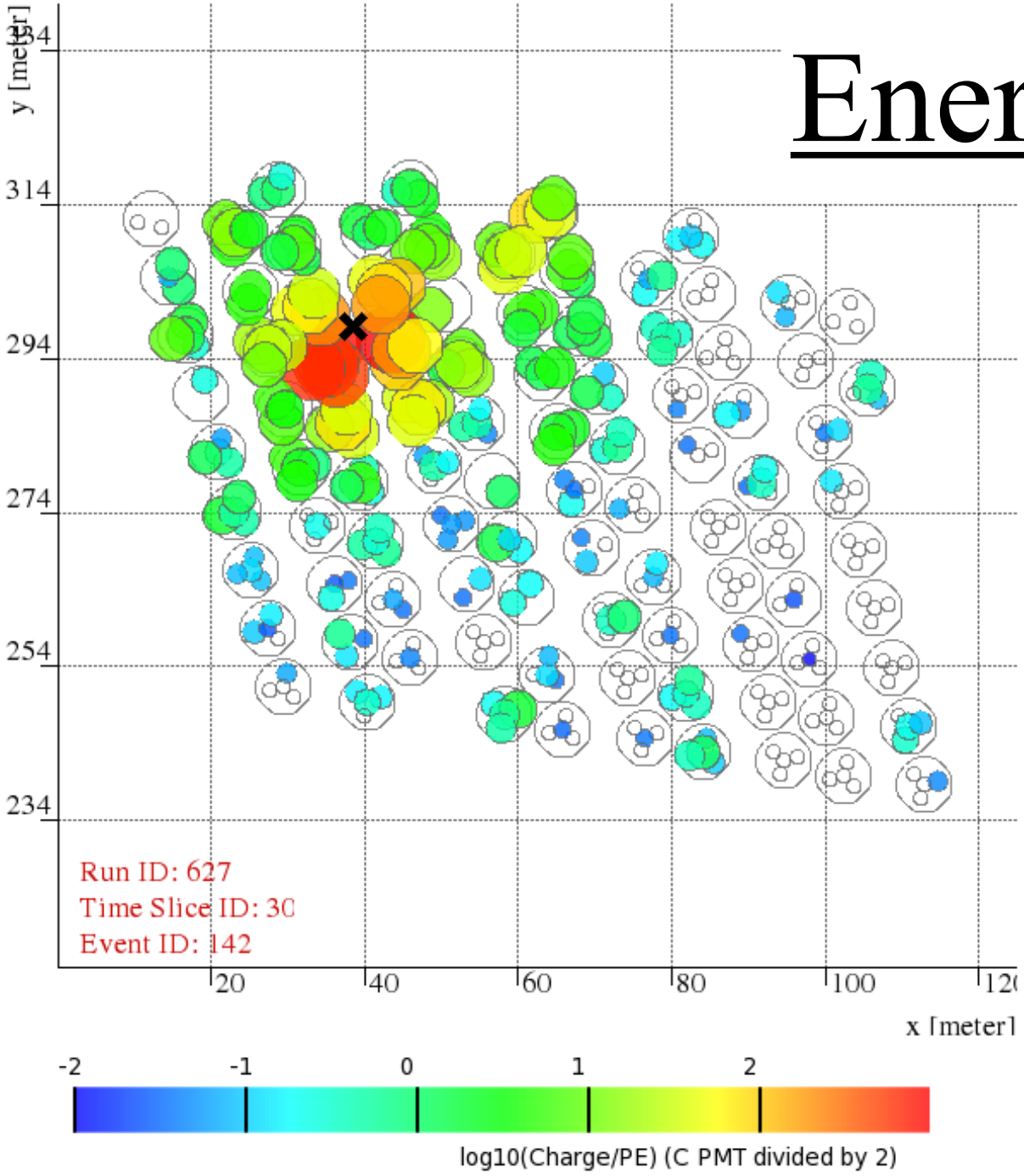
- Relative timing of signals allows determining position of primary in the sky.

Timing information



- Relative timing of signals allows determining position of primary in the sky.
- Tank spacing is around 25 to 50 light-ns.
- Arrival times are fitted to a curved plane.
- HAWC timing residuals below 1ns

Energy deposition



- PMTs measure individual pulses of light.
- Energy estimation.
- Must define the core and model energy deposits according to standard (NKG) shower models and simulations of the response of HAWC

HAWC DAQ rates

- HAWC acquires about 15,000 events per second
  $= 1.3 \times 10^{9}$ per day
  $= 0.47 \times 10^{12}$ per year
- Each event: timing, PE for 1200 channels + collective signal.
- Also extensive monitoring data
- About 1.5 Tbytes / day

	F (m^{-2} s^{-1} sr^{-1})	F.A.Ω (Hz)
E>1 GeV	10600	—
E>300 GeV	0.65	29300
E>1 TeV	0.084	3800
E>100 TeV	3.3×10^{-5}	1.5

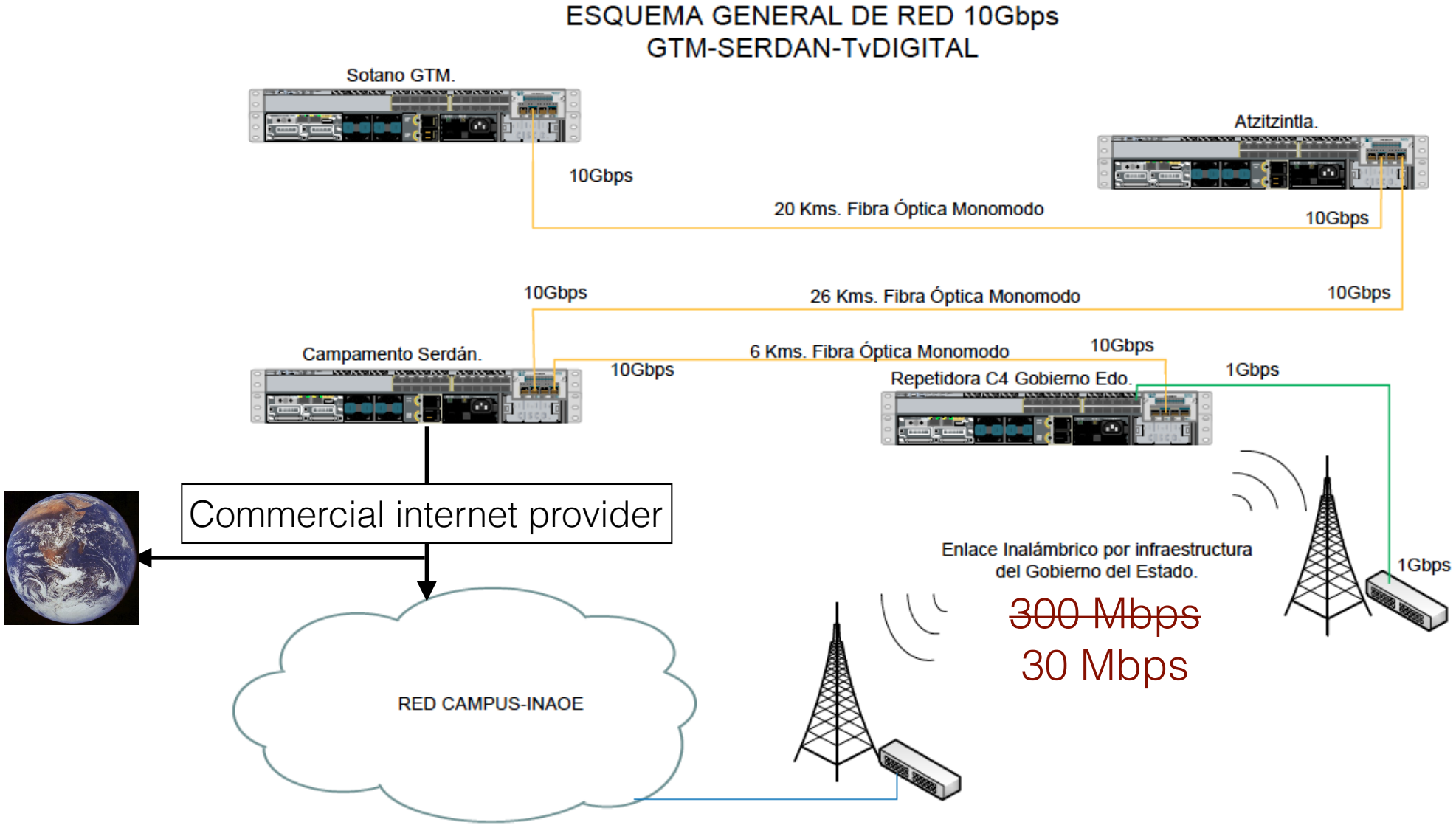
HAWC

A=22,500; Ω=2 sr

The intensity of primary nucleons in the energy range from several GeV to somewhat beyond 100 TeV is given approximately by

$$I_N(E) \approx 1.8 \times 10^4 \, (E/1\ \mathrm{GeV})^{-\alpha} \, \frac{\text{nucleons}}{\mathrm{m^2\ s\ sr\ GeV}} \,, \qquad (28.2)$$

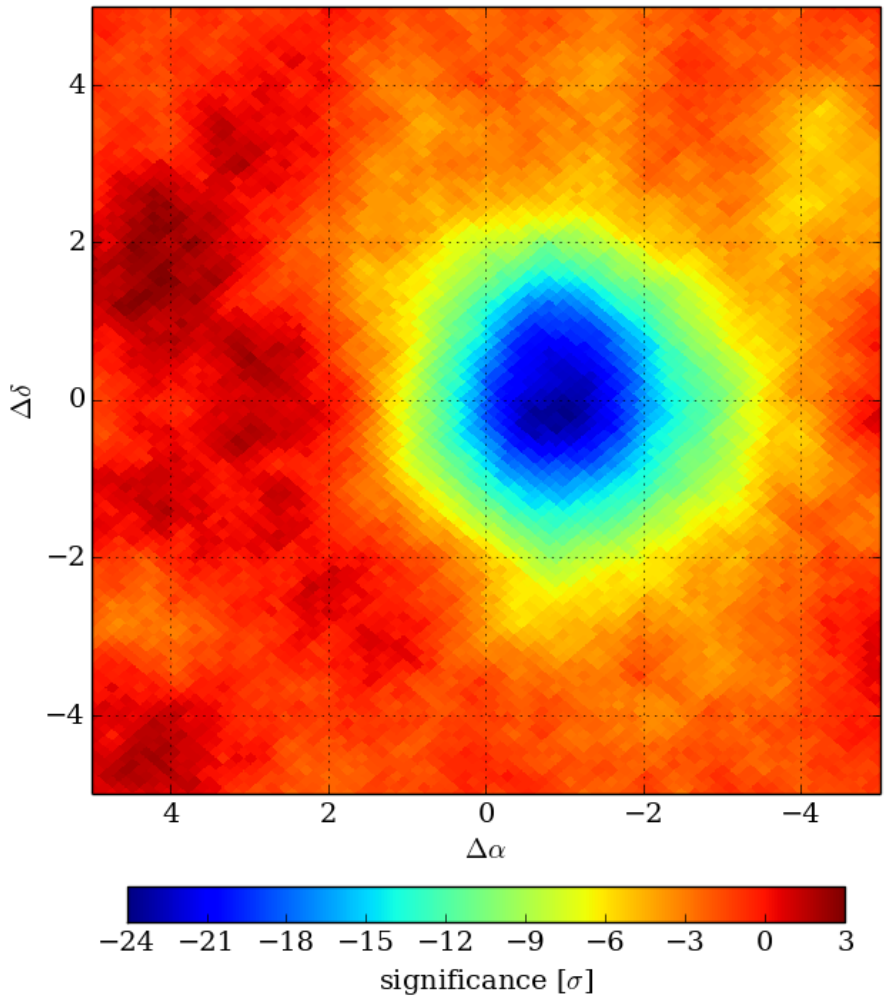
where E is the energy-per-nucleon (including rest mass energy) and α $(\equiv \gamma + 1) = 2.7$ is the differential spectral index of the cosmic-ray flux and γ is the integral spectral



- Data are sent by road to HAWC data center at ICN-UNAM and mirrored at UMD
- Sierra Negra internet connection used for HAWC monitoring and communications.
- Sierra Negra connection also has to support LMT/GTM data transmission and other users.

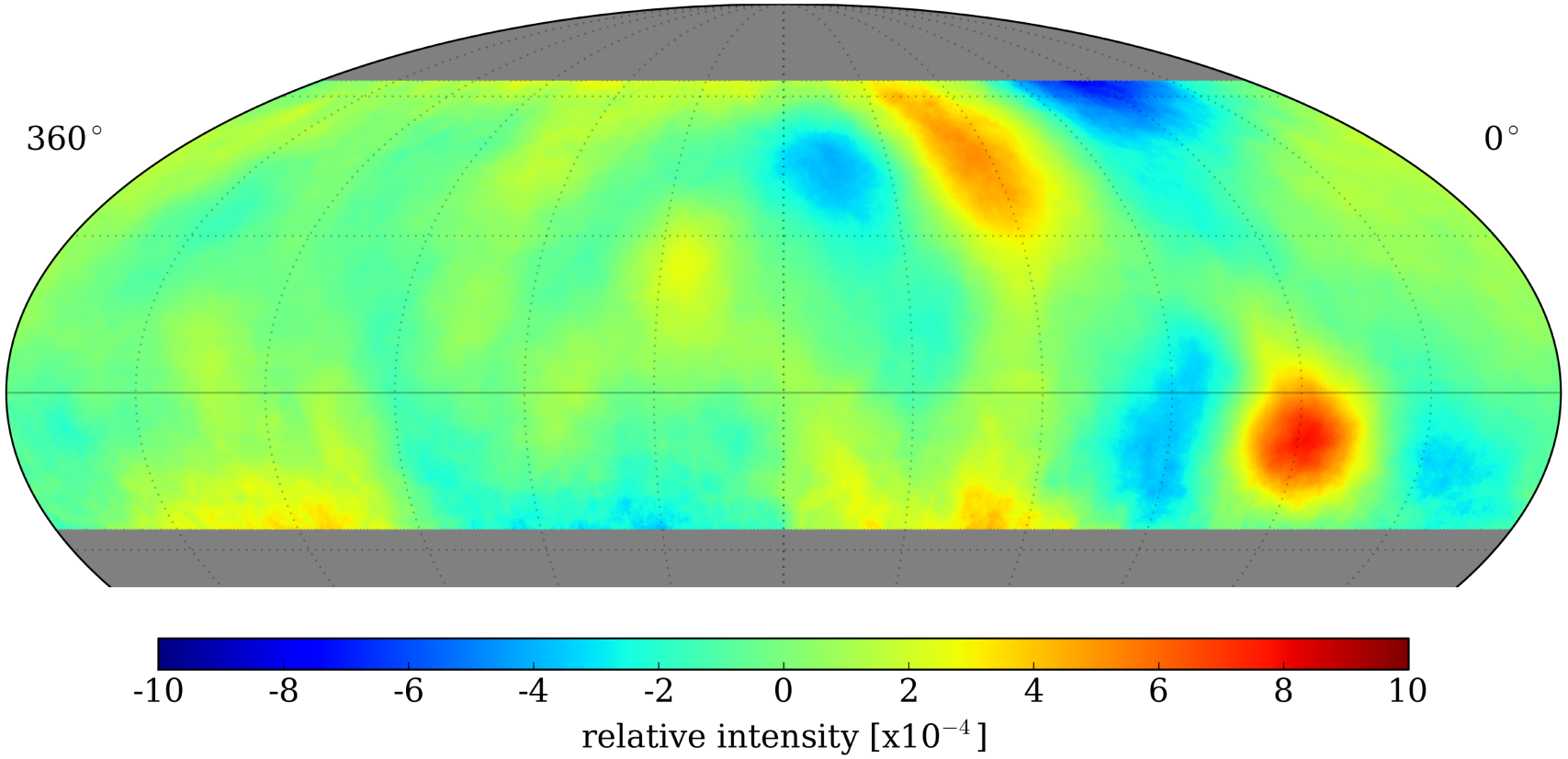
HAWC cosmic-rays

- HAWC-95 and HAWC-111
- 12 June 2013 to 8 July 2014
- Full runs: contiguous 24hrs:
  - 181 days (4332 hours)
  - 85.6×10^9 events
- Median energy: 2 TeV



Abeysekara et al.
ApJ 796, 108 (2014)
astro-ph/1408.4085

Cosmic-ray anisotropy

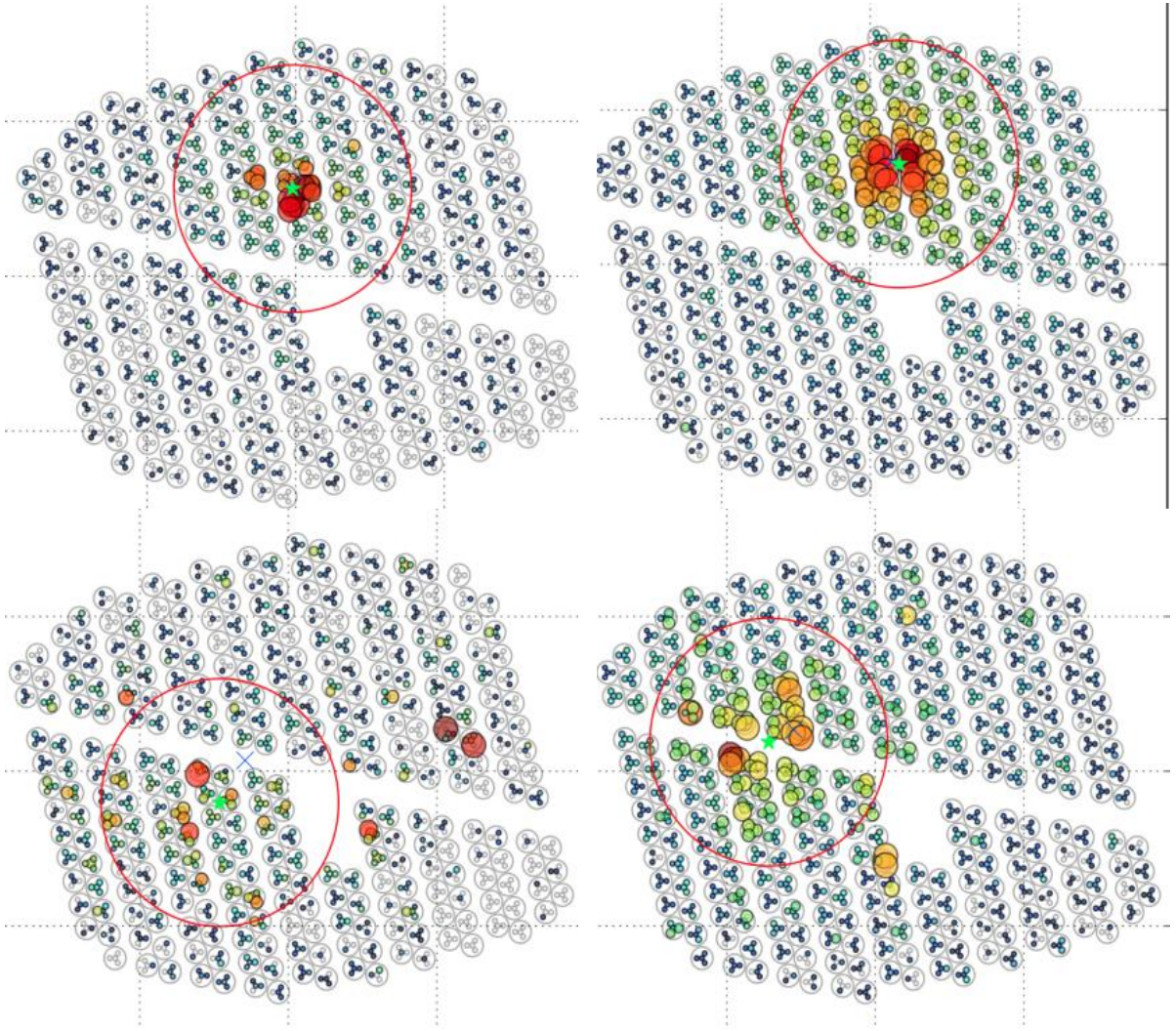


- Related to magnetic field inhomogeneities and/or nearby cosmic-ray source

γ / hadron discrimination

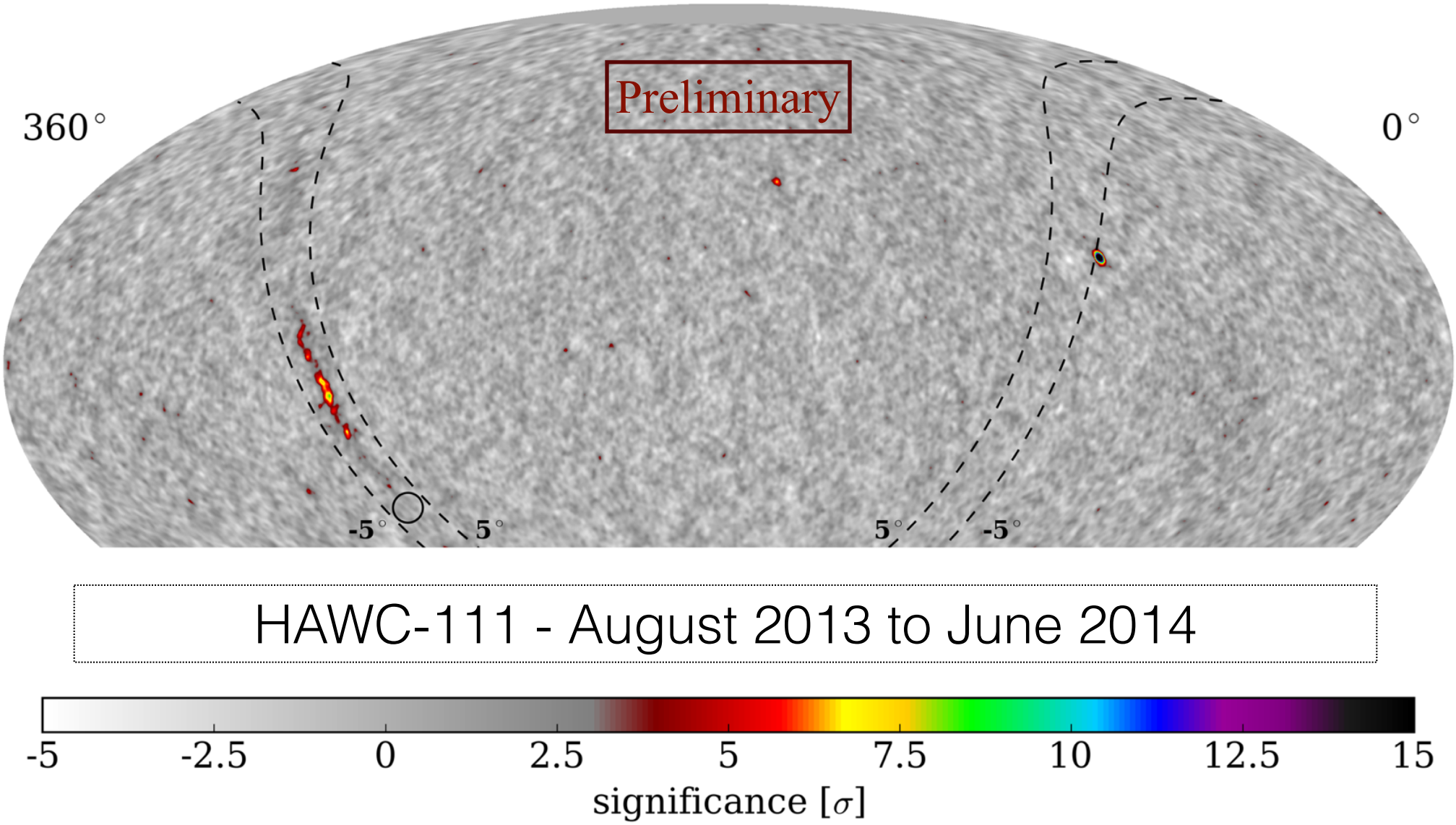
γ-ray

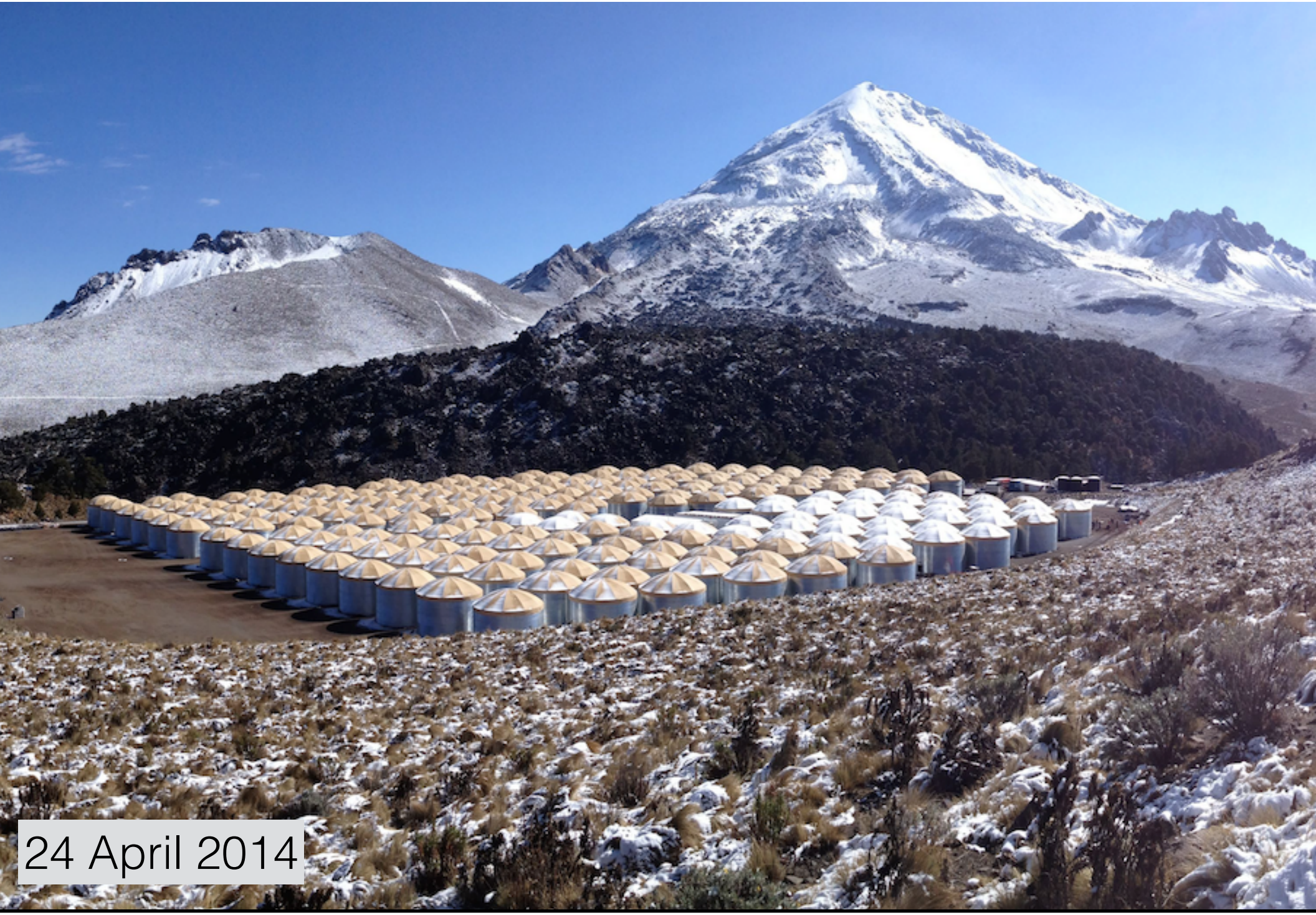
Hadron

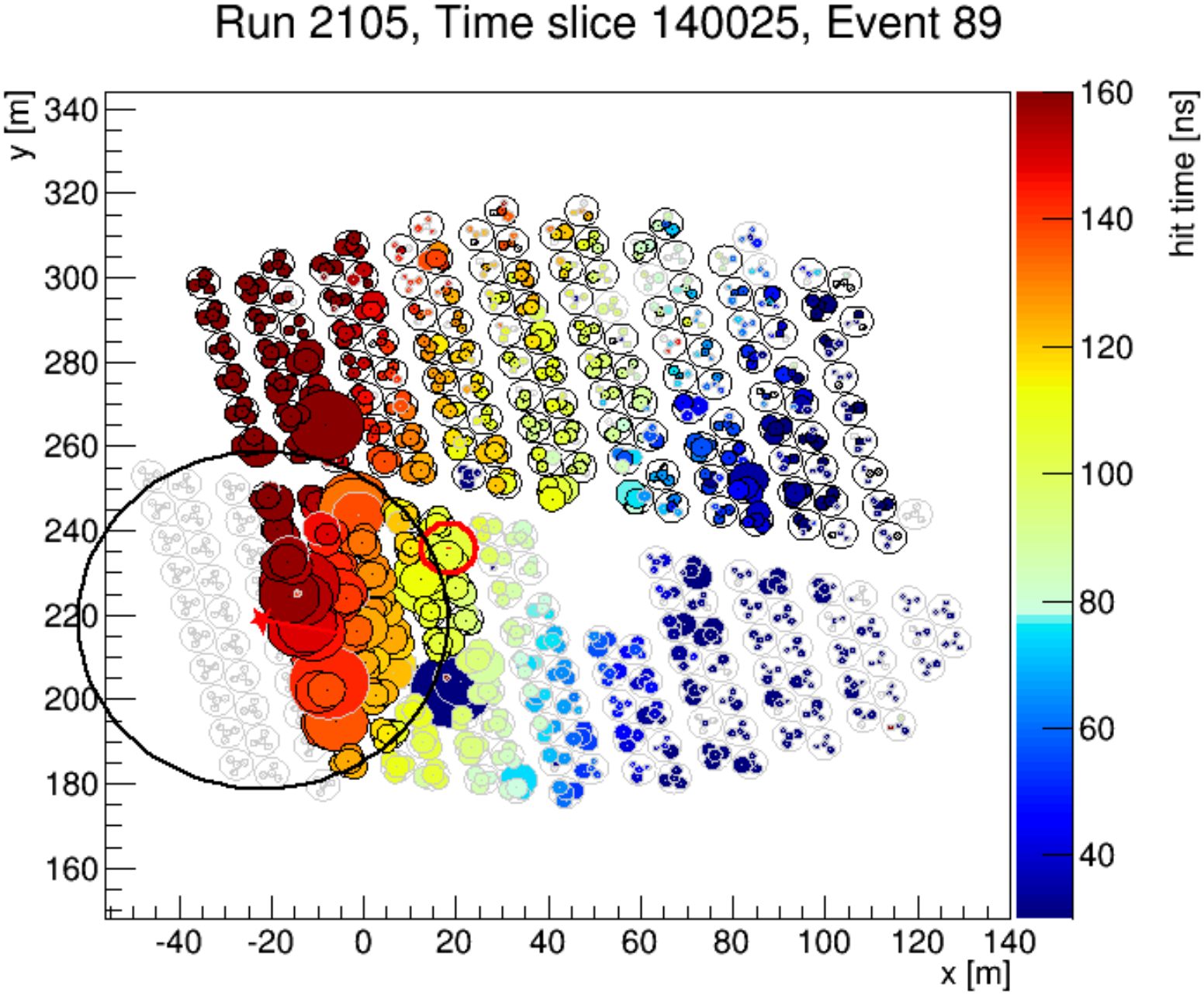


E

HAWC-111 γ-ray skymap

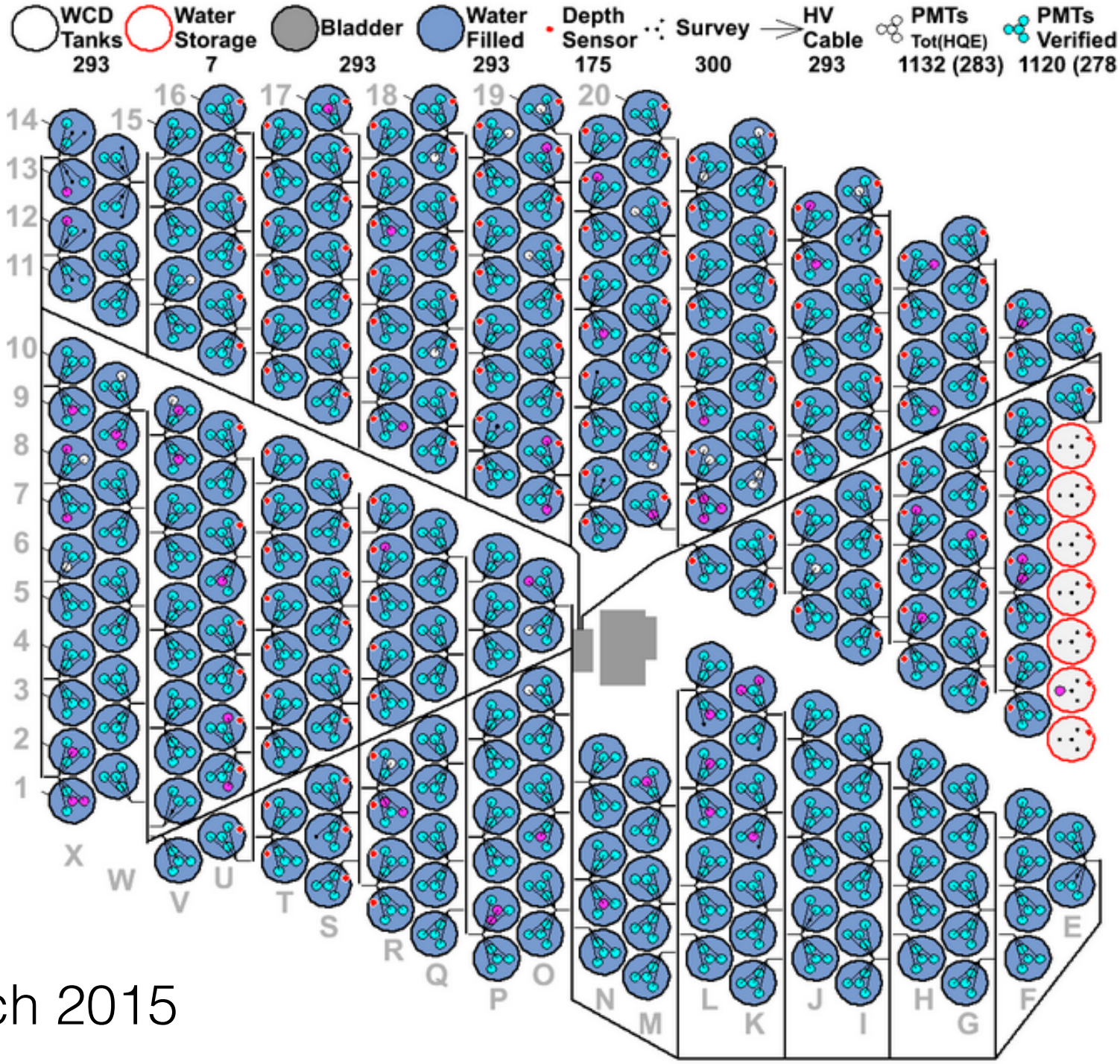



24 April 2014



HAWC-250: November 27, 2014.


15 December 2014
X01 => HAWC 300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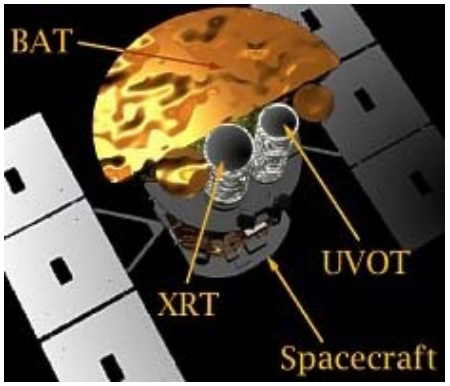
Water Storage 7
Bladder 293
Water Filled 293
Depth Sensor 175
Survey 300
HV Cable 293
PMTs Tot(HQE) 1132 (283)
PMTs Verified 1120 (278
14 15 16 17 18 19 20
13 12 11 10 9 8 7 6 5 4 3 2 1
X W V U T S R Q P O N M L K J I H G F E

March 2015


HAWC
HAWC 300
Full operations
DATE: 03/20/2015
TIME: 12:26:30
SONY

HAWC MoUs



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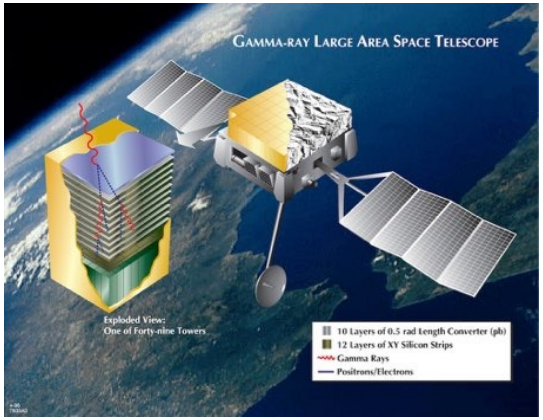
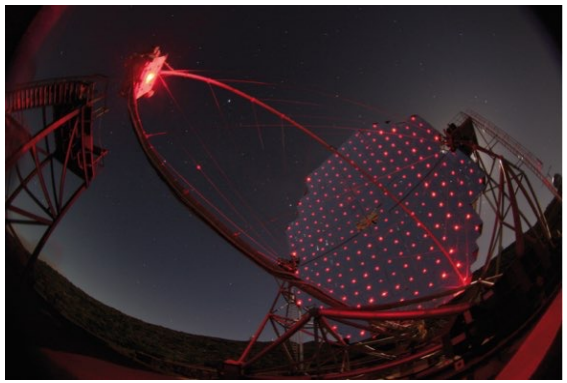


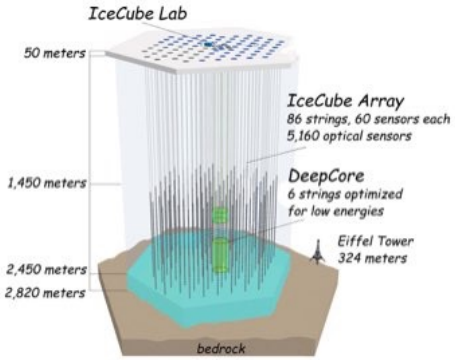
Fermi-LAT

VERITAS



MAGIC

FACT



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