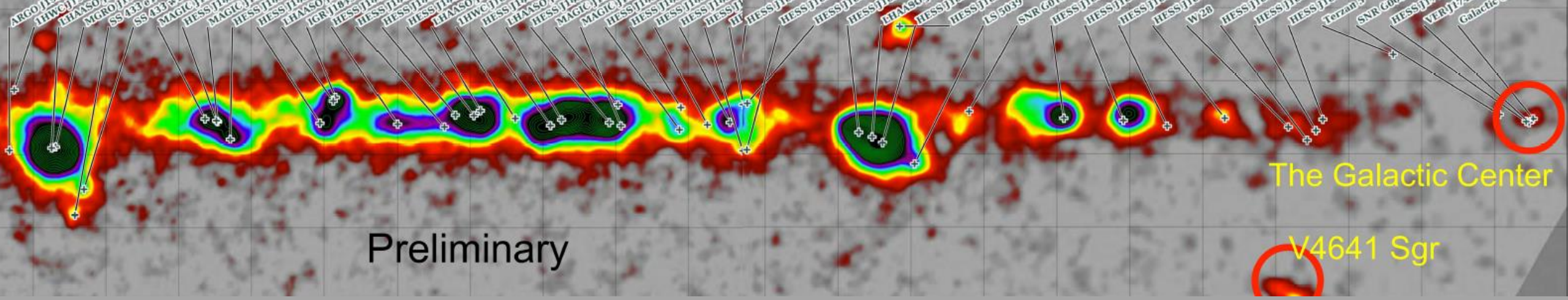
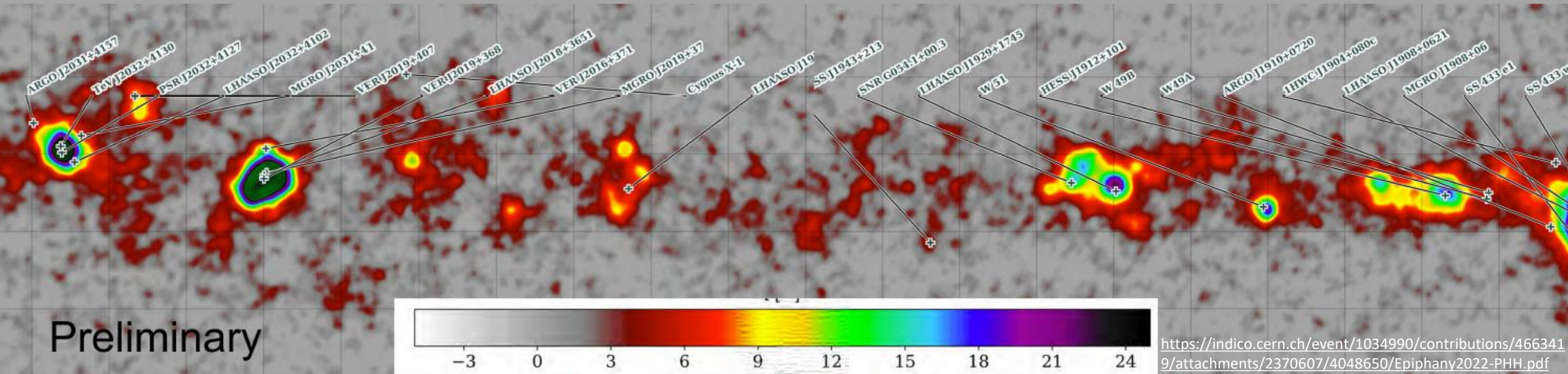


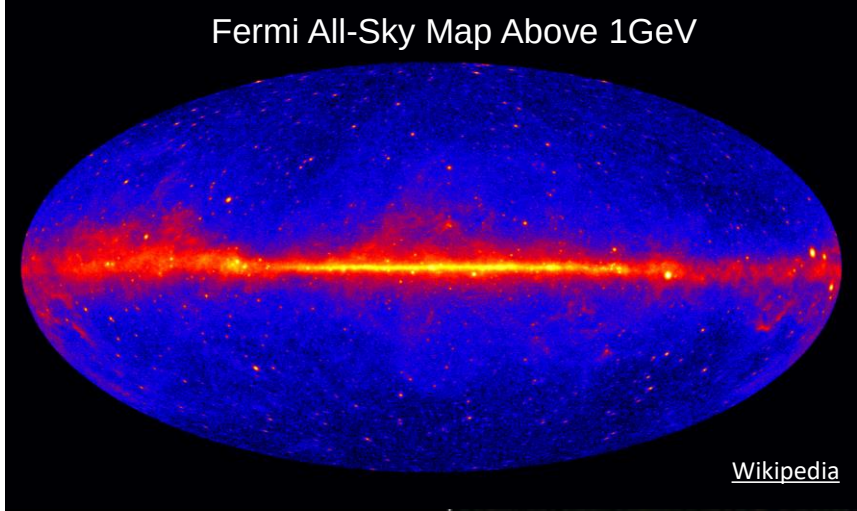
High-Energy Gamma-Ray Astronomy with Water Cherenkov Detectors

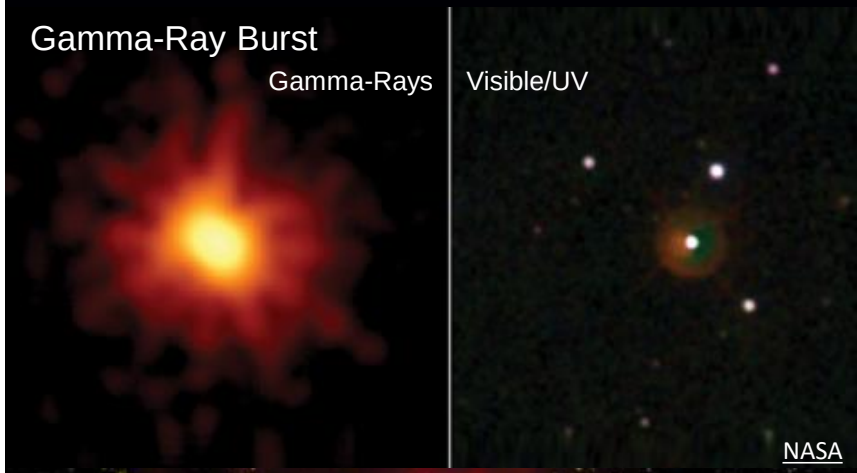


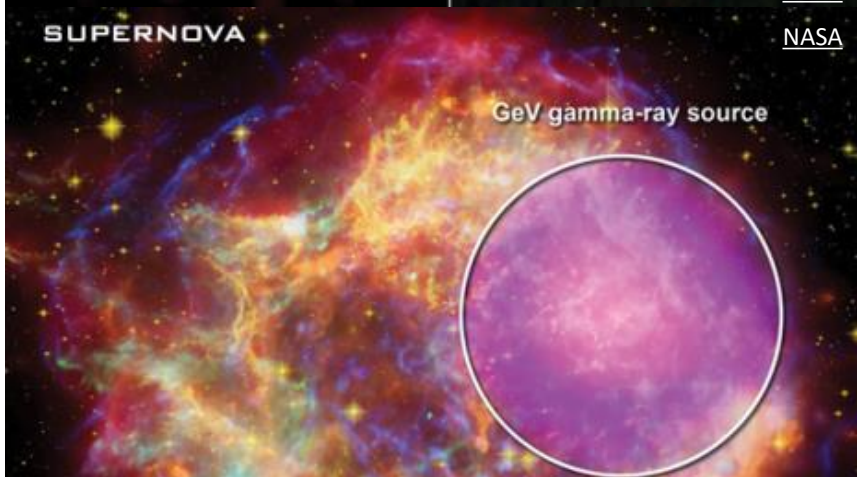
https://indico.cern.ch/event/1034990/contributions/4663419/attachments/2370607/4048650/Epiphany2022-PHH.pdf

High-Energy Gamma-Ray Astronomy

- 100MeV ≤ E ≤ 1PeV
- leptonic production processes: synchrotron radiation, Bremsstrahlung, inverse Compton effect + hadronic production processes
- galactic (pulsars, pulsar wind nebulae, galactic center) and extra-galactic (gamma-ray bursts, galactic nuclei) sources
- linked to cosmic rays: high-energy charged particles, get deflected in magnetic fields, gamma-rays can be direct messengers
- physics beyond the SM: test of dark matter theories
- fundamental physics: test of Lorentz invariance







Detection Methods

Experimental Challenges:

- large energy range (MeV – PeV)
- small flux (10^{-11} photons/cm^{2}s), decreases with energy
- large background from cosmic rays (10^3)
- atmosphere is opaque

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Satellites

+ direct detection

– energy limit of 10GeV

Egret
GAMMA RAY OBSERVATORY

Wikipedia

Fermi
Gamma-ray
Space Telescope

Wikipedia

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Egret GAMMA RAY OBSERVATORY

Wikipedia

Fermi Gamma-ray Space Telescope

Wikipedia

Ground-based detectors: showers

Extensive Air Shower (EAS) Array

+ large field of view

+ high duty factor

– small detection area (<1%)

Argo–YBJ

CASA

Wikipedia

Atmospheric Cherenkov Telescope (ACT)

+ low energy threshold

– small field of view

– needs good weather

H.E.S.S.

VERITAS

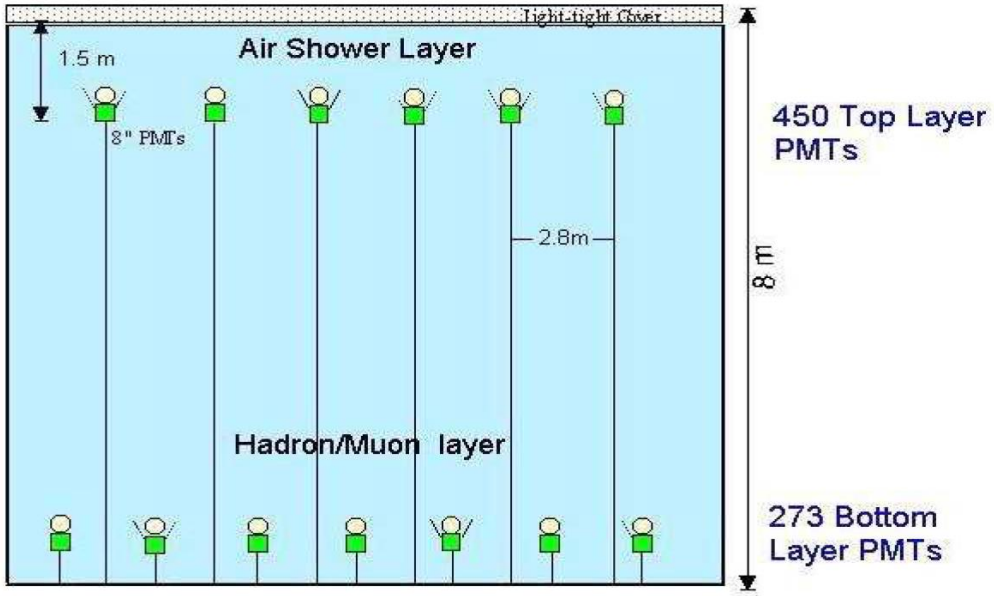
Wikipedia

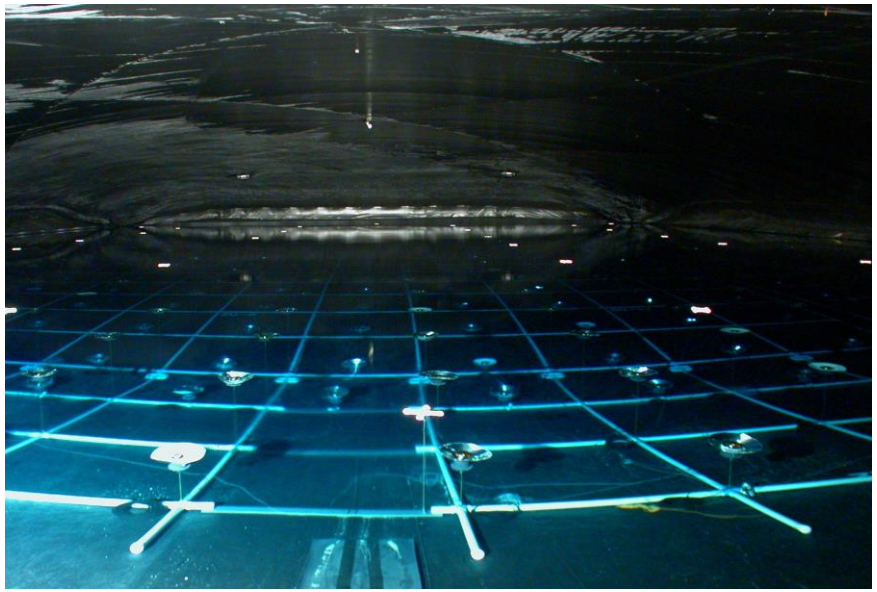
→ Water Cherenkov Detectors

Milagro

- New Mexico, 2650m above sea level
- build into existing pond, 60m x 80m x 8m, 24 million l water
- 723 20cm PMTs in two layers
- build in 2000, data-taking until 2008

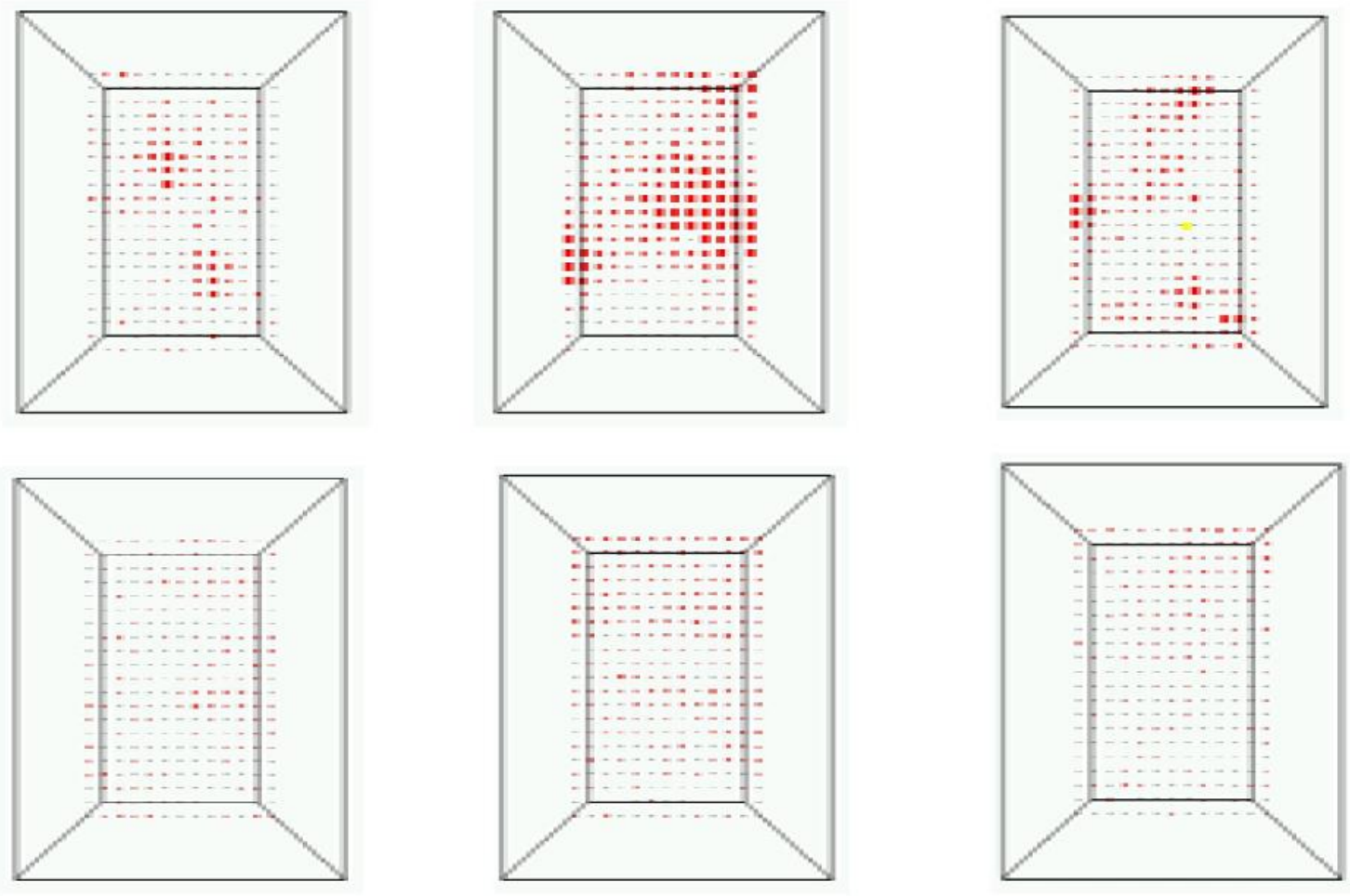
arXiv:astro-ph/9906383





https://physics.nyu.edu/experimentalparticle/milagro.html

Milagro – Background Rejection



hadronic shower with muons/hadrons:

high intensity, localised

electromagnetic shower:

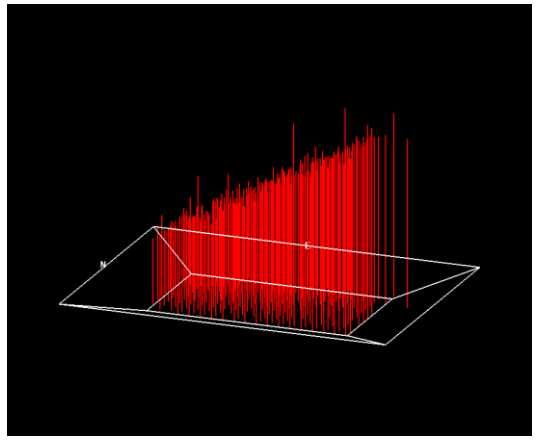
low intensity, uniform

$$C = \frac{N_{PMT \geq 2PE}}{PE_{max}}$$

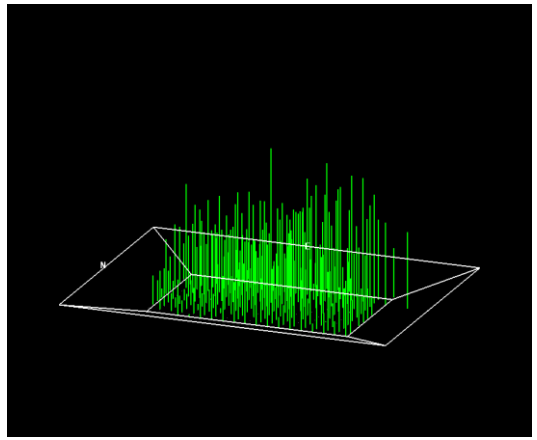
https://adsabs.harvard.edu/full/2005ICRC...10..227S

Milagro – Data Processing

- tigger condition: ≥60 PMTs in a window of 200ns
- event rate: 1700Hz, reconstructed in real-time



- arrival time distribution → shower front
  → primary particle direction
- resolution is depended on the number of PMTs hit
- average resolution: 0.75°

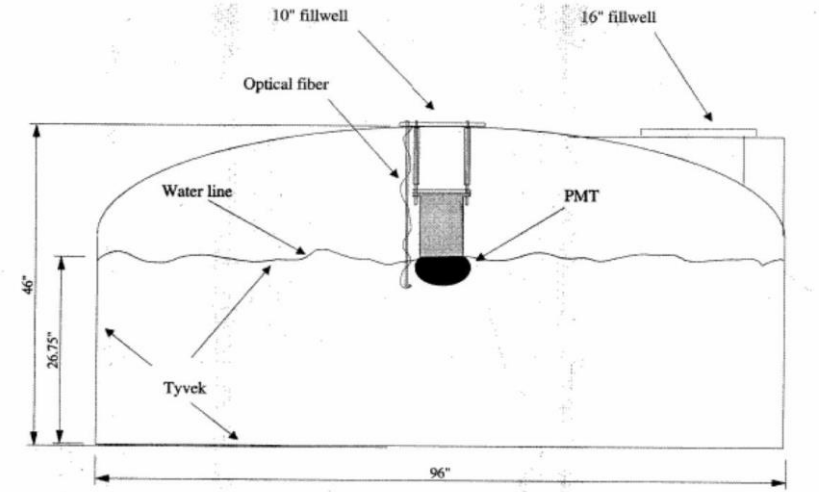


- intensity and distribution of PMT signals
  → primary particle energy through correlation with C-value
- depends on ability to locate the shower core
- resolution: >>30%

https://physics.nyu.edu/experimentalparticle/milagro.html

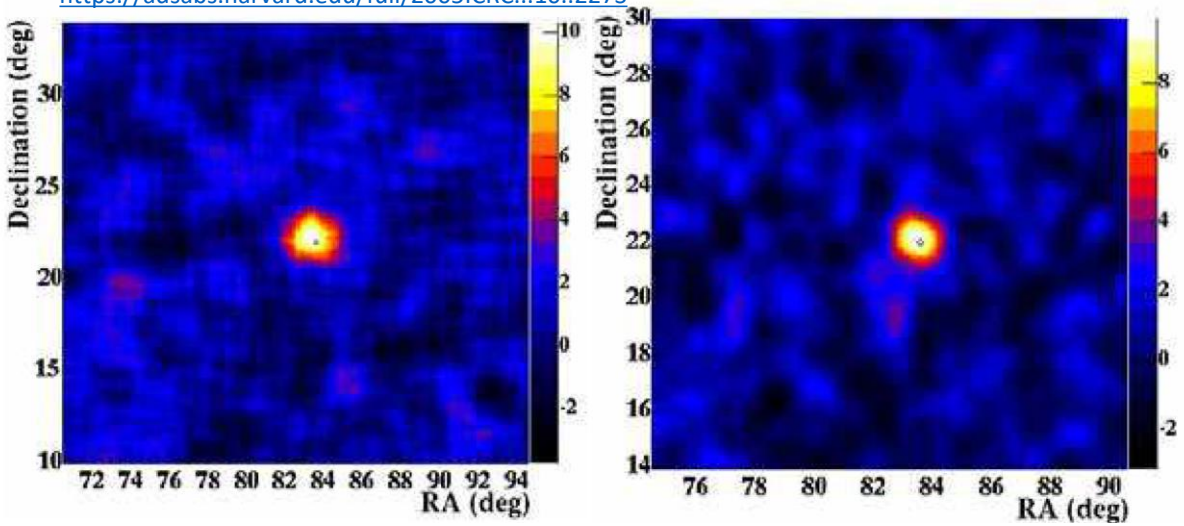
Milagro – Outrigger Array

- precise determination of the shower core
  → improved angular and energy resolution
- 175 individual WCD around the pond
- covered area: 40.000m^2
- 2000l tanks, single PMT



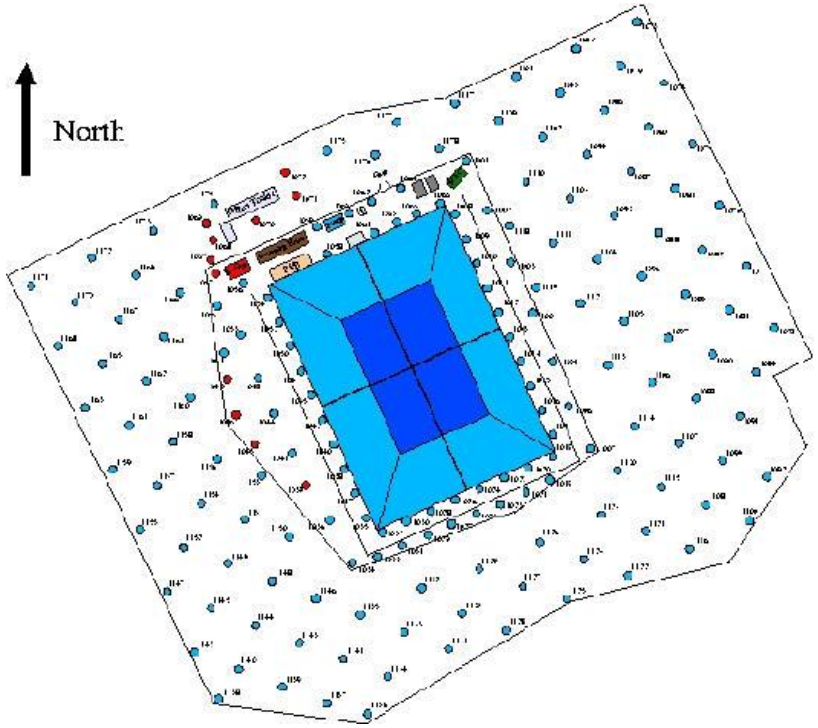
https://nmcpp.unm.edu/auger_north_ucolorado.pdf

https://adsabs.harvard.edu/full/2005ICRC...10..227S



R=0.75°

R=0.4°

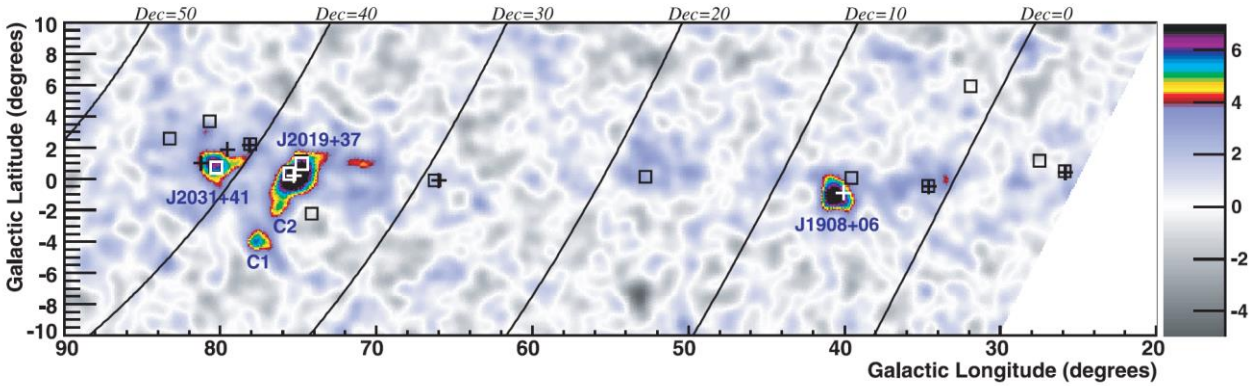


https://physics.nyu.edu/experimentalparticle/milagro.html

Milagro – Scientific Results

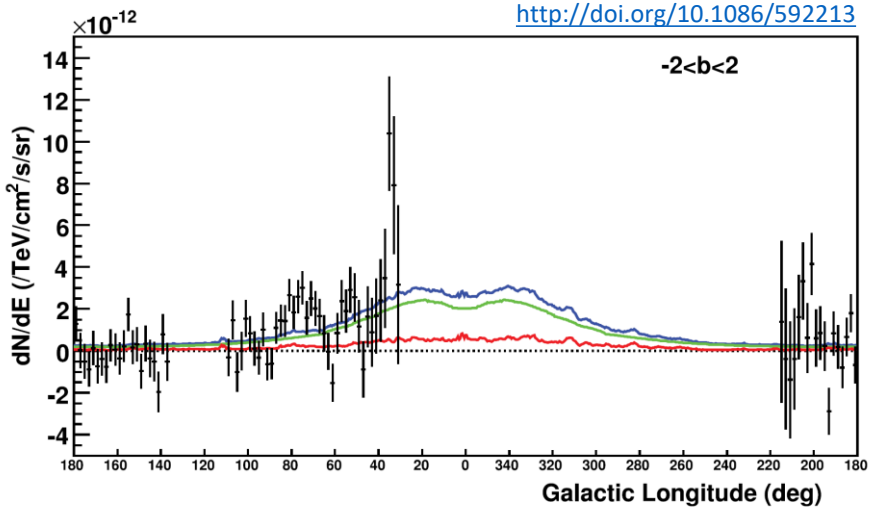
new gamma-ray sources

http://doi.org/10.1086/520717



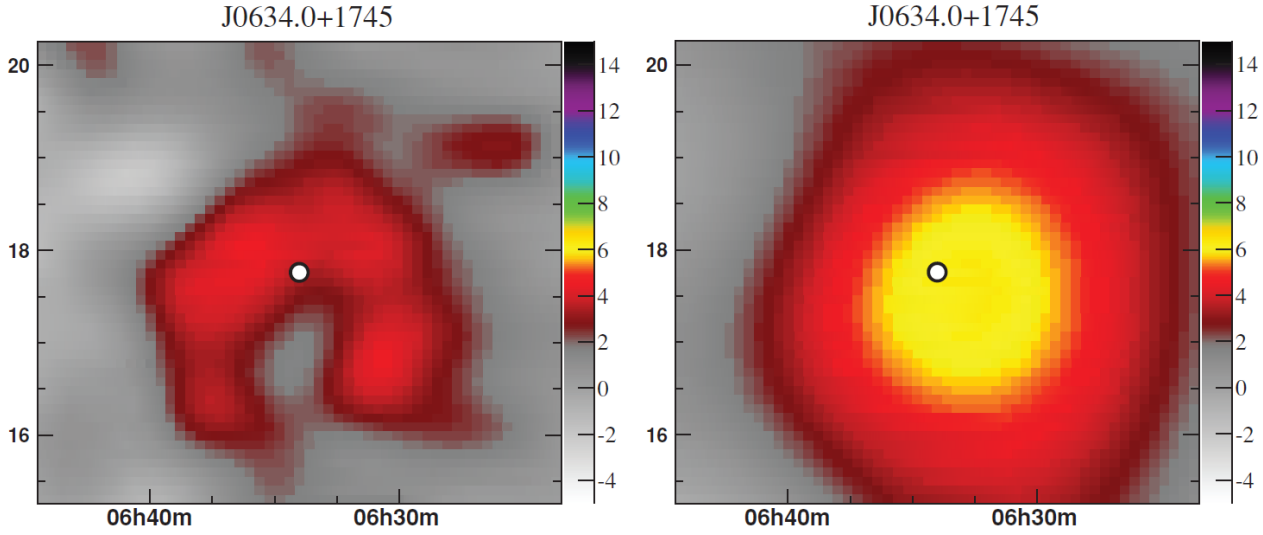
diffuse 10TeV emission

http://doi.org/10.1086/592213



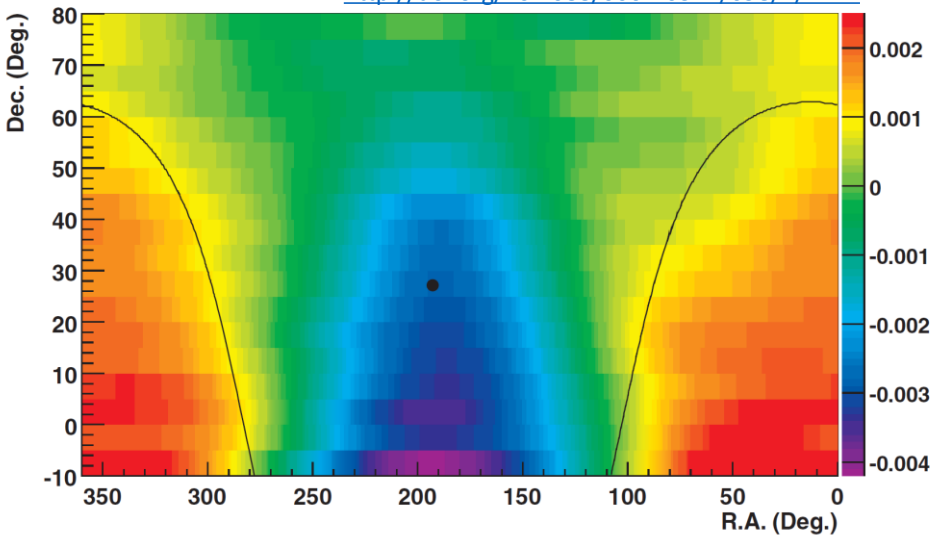
extended sources

http://doi.org/10.1088/0004-637X/700/2/L127



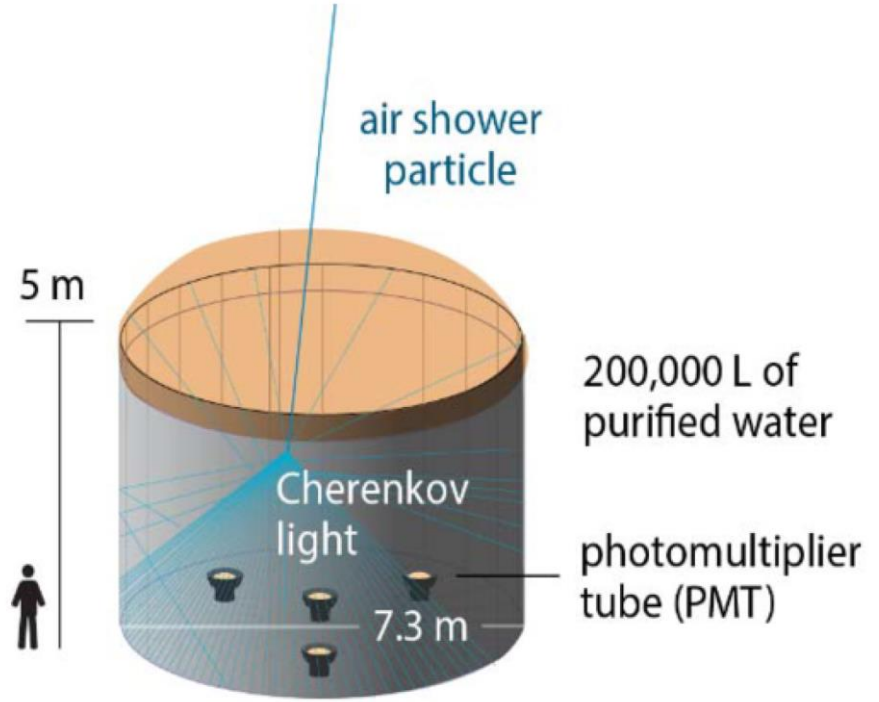
cosmic ray anisotropy

http://doi.org/10.1088/0004-637X/698/2/2121

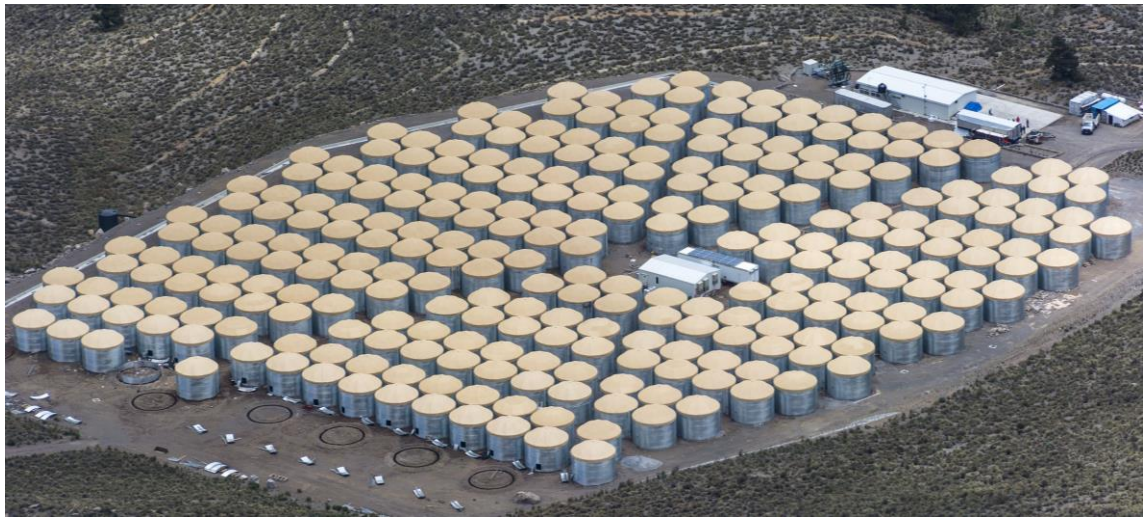


HAWC

- **H**igh **A**ltitude **W**ater **C**herenkov experiment – 4100m above sea level
- total area: 20.000m^2
- 300 tanks with 200.000l water and 4 PMTs
- outrigger array of 345 small WCD
- data taking since 2016



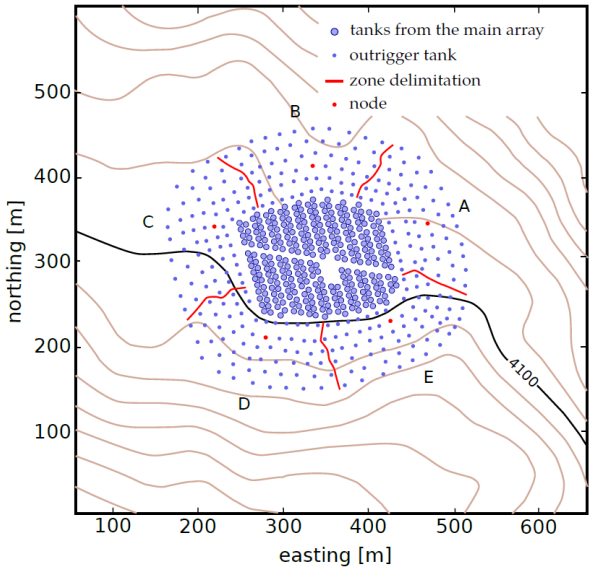
https://doi.org/10.1016/j.nuclphysbps.2016.10.013



Wikipedia

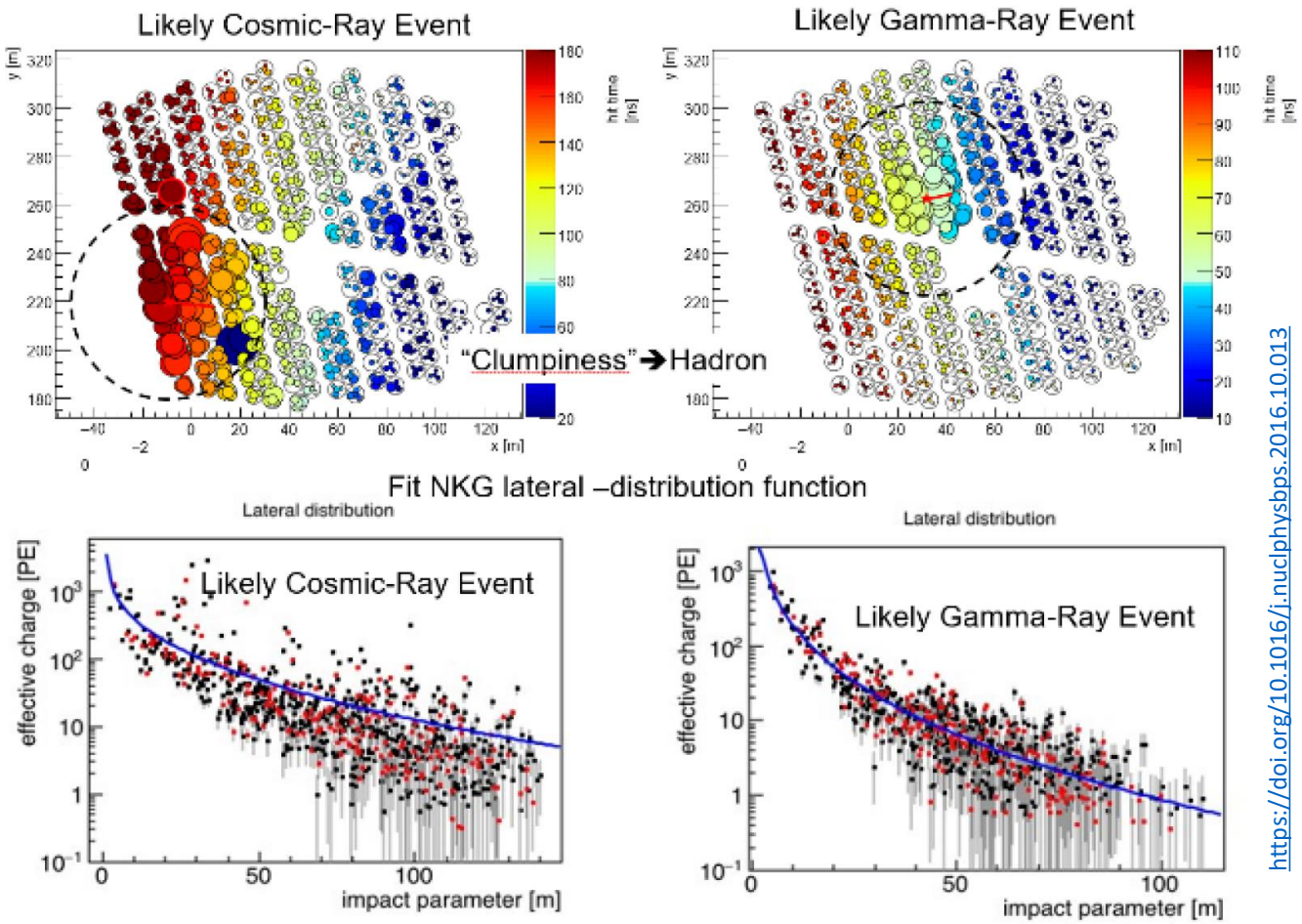
Wikipedia

https://doi.org/10.48550/arXiv.1908.07634



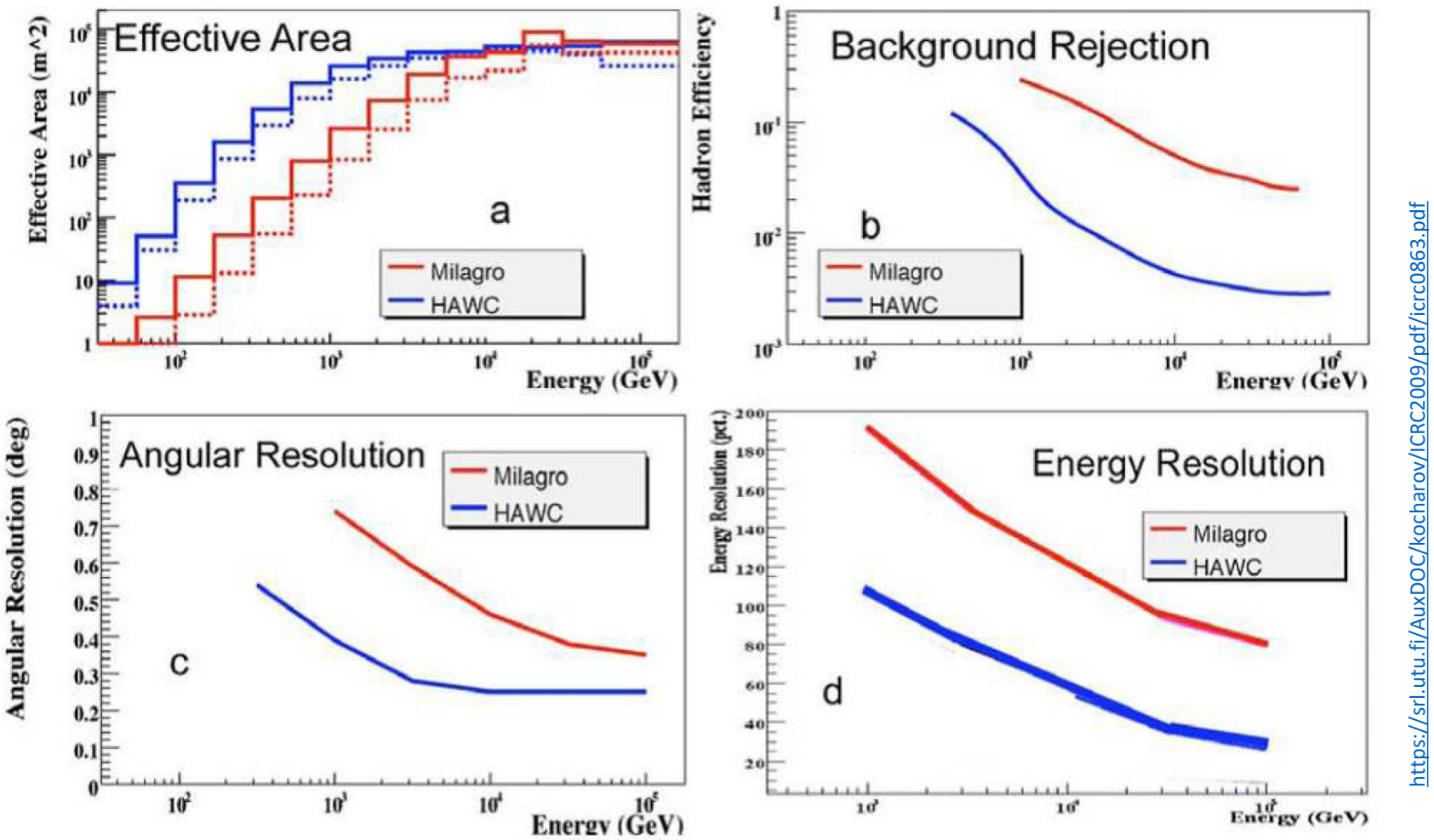
HAWC – Data Processing

- trigger condition: ≥28 PMTs in a window of 150ns
- time-over-threshold measurement
- trigger rate: 25kHz, reconstruction in real time, 20MB/s permanently saved
- background rejection method: C-value and fit of the lateral shower distribution
- energy resolution is limited by fluctuations in the shower development in the atmosphere



https://doi.org/10.1016/j.nuclphysbps.2016.10.013

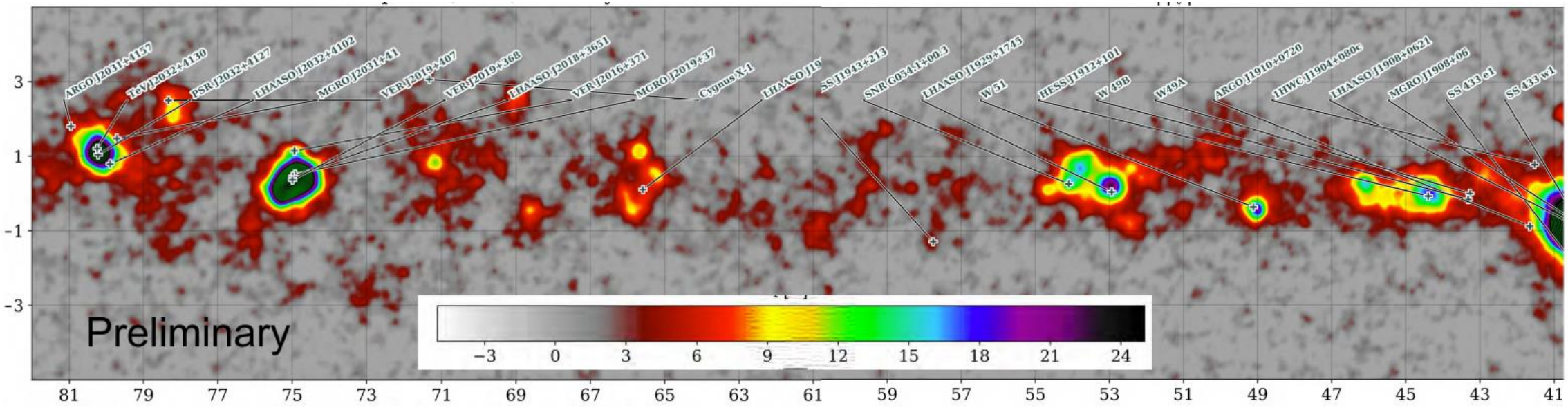
HAWC and Milagro



https://srl.utu.fi/AuxDOC/kocharov/ICRC2009/pdf/icrc0863.pdf

HAWC – Scientific Results

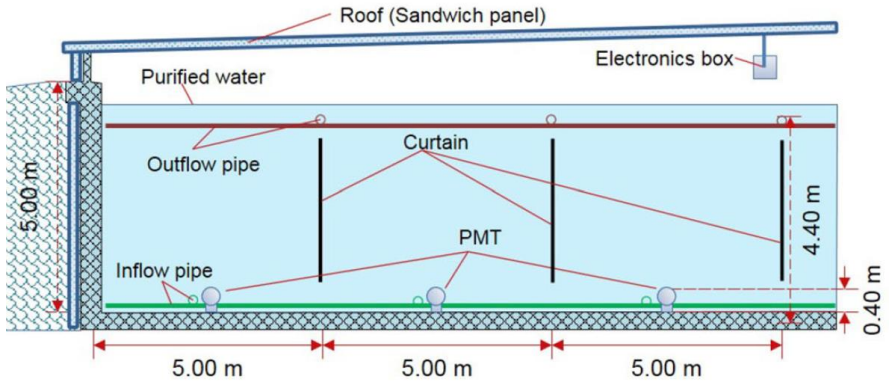
- observation of sources up to higher energies, new sources
- TeV gamma-rays from halos around pulsars
- search for PeVatrons
- test of Lorentz invariance
- cosmic ray observations and multi-messenger astronomy



https://indico.cern.ch/event/1034990/contributions/4663419/attachments/2370607/4048650/Epiphany2022-PHH.pdf

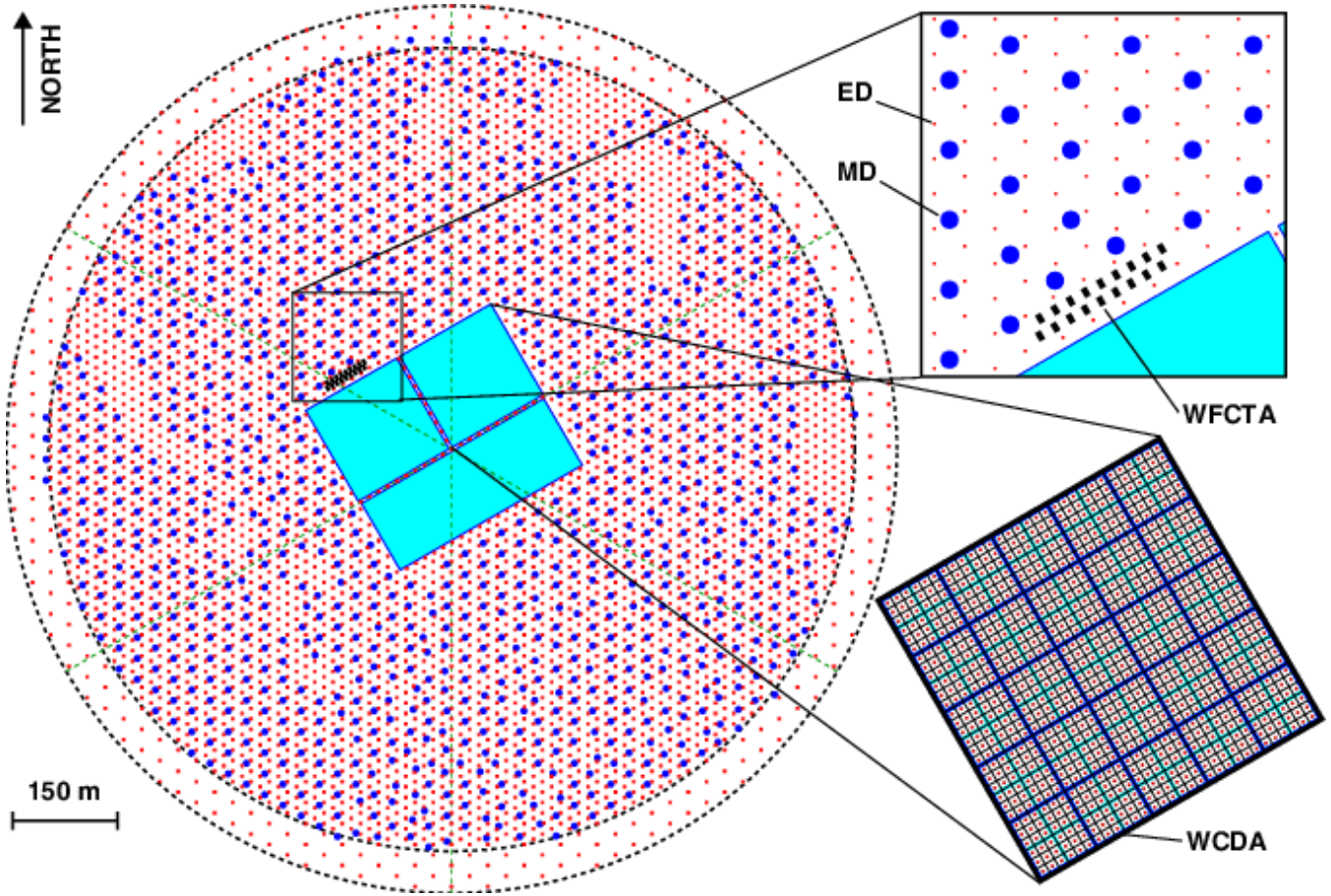
LHAASO

- **L**arge **H**igh **A**ltitude **A**ir **S**hower **O**bservatory
- 4410m above sea level, Tibet
- combination of air shower arrays, water Cherenkov detectors and atmospheric Cherenkov telescopes
- partially build, observations started in 2019



https://doi.org/10.1007/s41605-018-0037-3

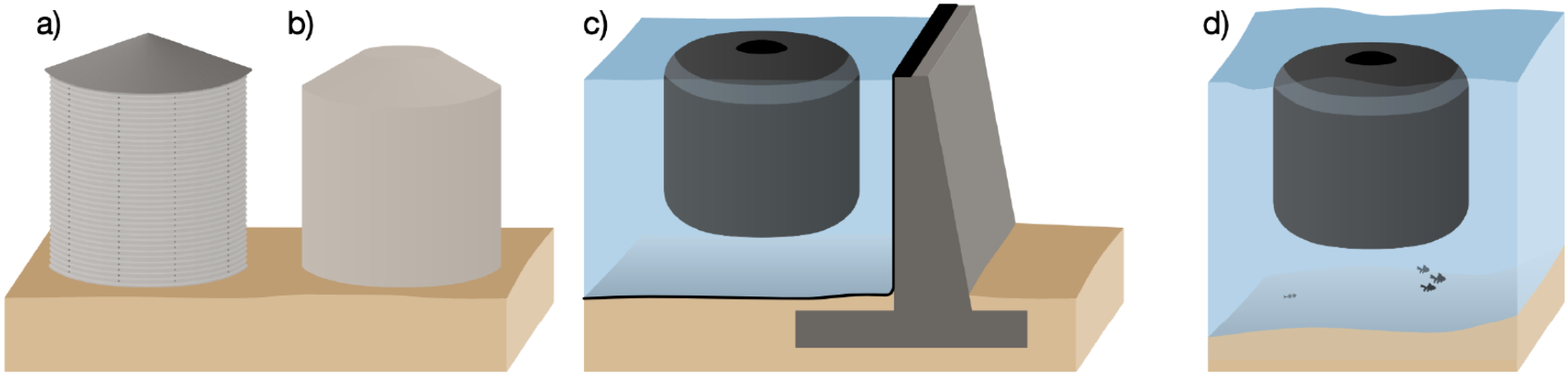
https://doi.org/10.1007/s41605-018-0037-3



ED + MD – scintillation detectors
WFCTA – atmospheric Cherenkov telescopes
WCDA – water Cherenkov detectors

SWGO

- **S**outhern **W**ide-field **G**amma-ray **O**bservatory
- Water Cherenkov detector in the southern hemisphere
- site evaluation: location, altitude, topology and environment, access, availability of water, power and network connectivity
- detector design: area, choice of PMTs, separation of PMTs, costs, impact on the natural environment, ability to reuse, repurpose or deconstruct the experiment



https://doi.org/10.22323/1.395.0714