Progress report of the ALPACA experiment

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For the ALPACA Collaboration

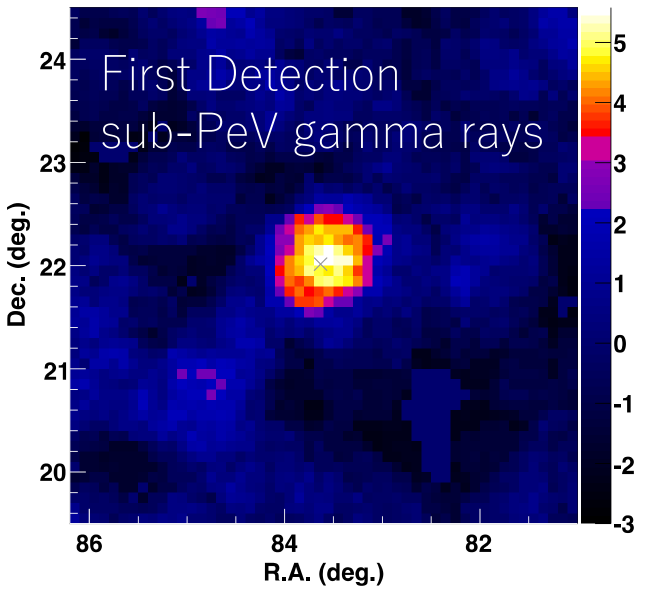
TeVPA 2023 Napoli Italy, Sept. 14th 2023

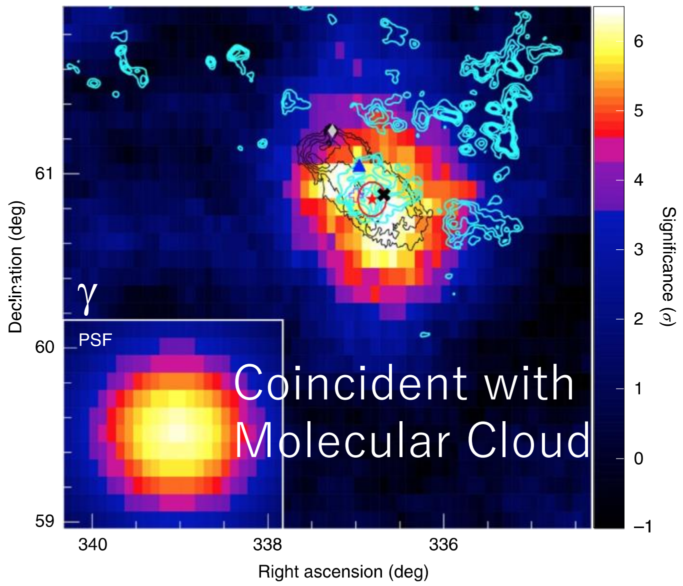
sub-PeV γ-Ray Astronomy

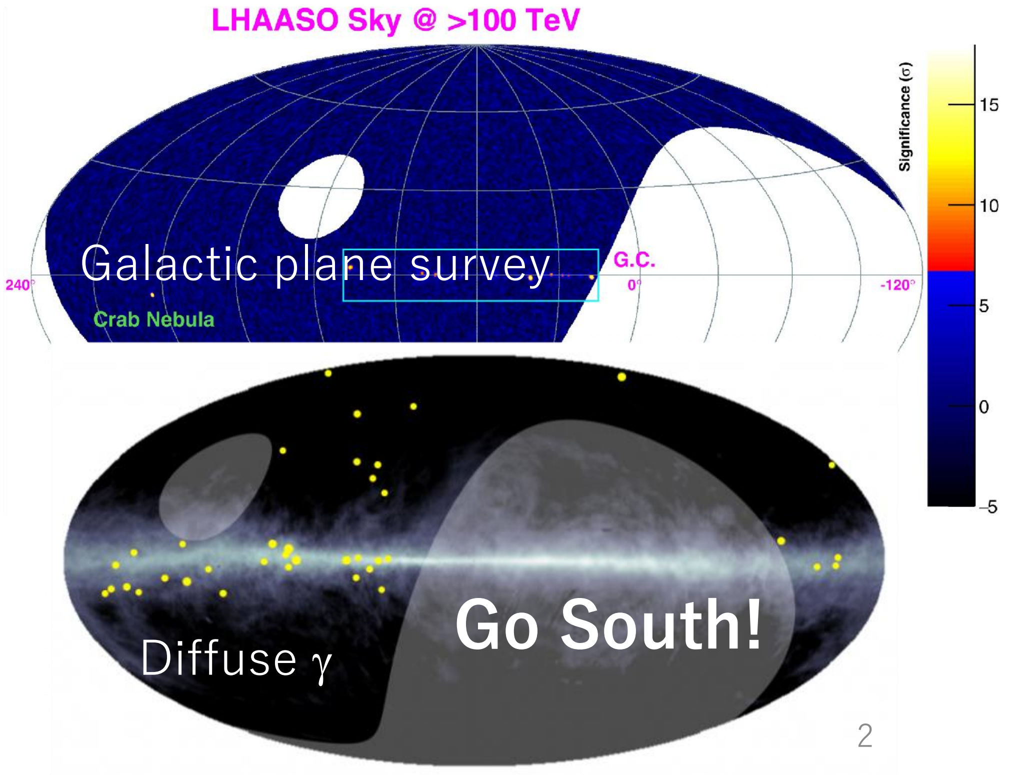
★ sub-PeV γ-ray astronomy developed by Tibet ASγ, HAWC, LHAASO

- First detection of sub-PeV γ-rays (Crab Nebula) *Tibet ASγ , PRL (2019)*
- Detection of PeVatron candidate (G106.3+2.7) *HAWC, ApJ (2020) Tibet ASγ , Nat. Astron. (2021)*
- First detection of sub-PeV Galactic diffuse γ-rays *Tibet ASγ, PRL (2021)*
- Detection of dozen sub-PeV γ-ray sources *LHAASO, Nature (2021)*

→ All results by air shower arrays in the northern hemisphere







The ALPACA Collaboration

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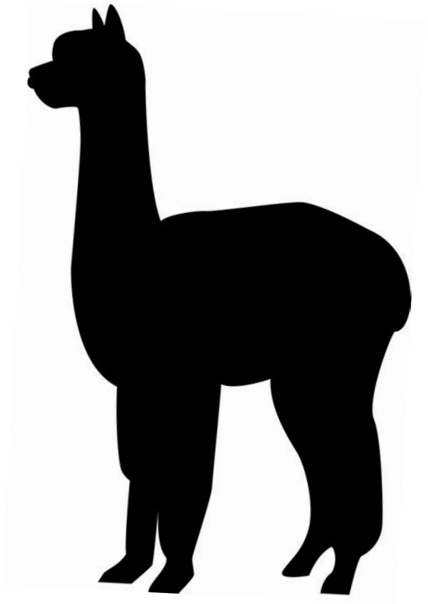
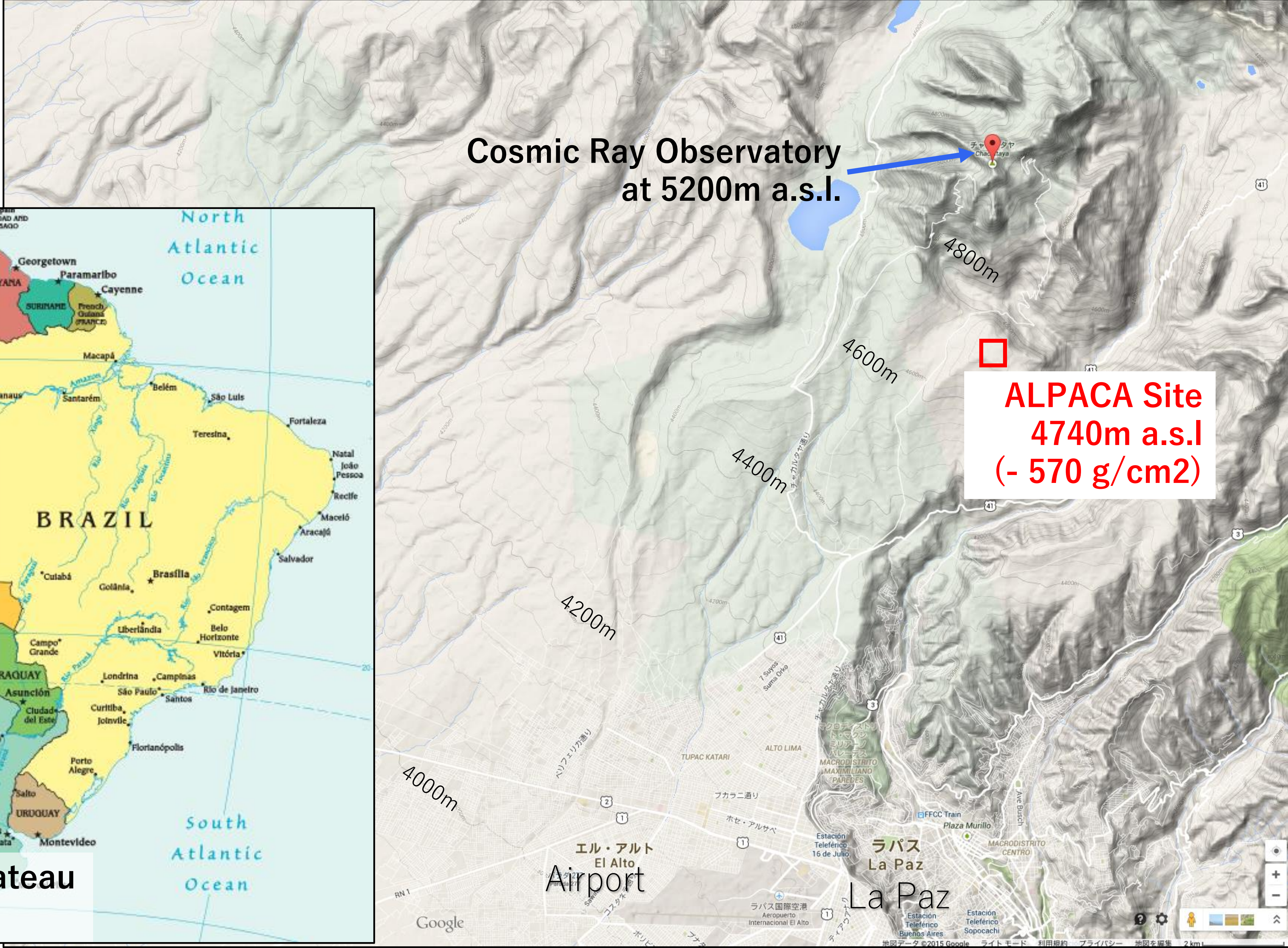


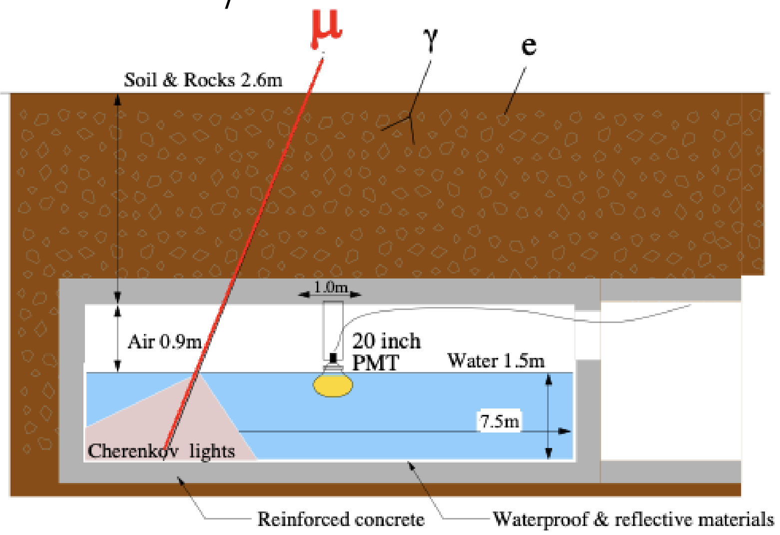
ALPACA Site

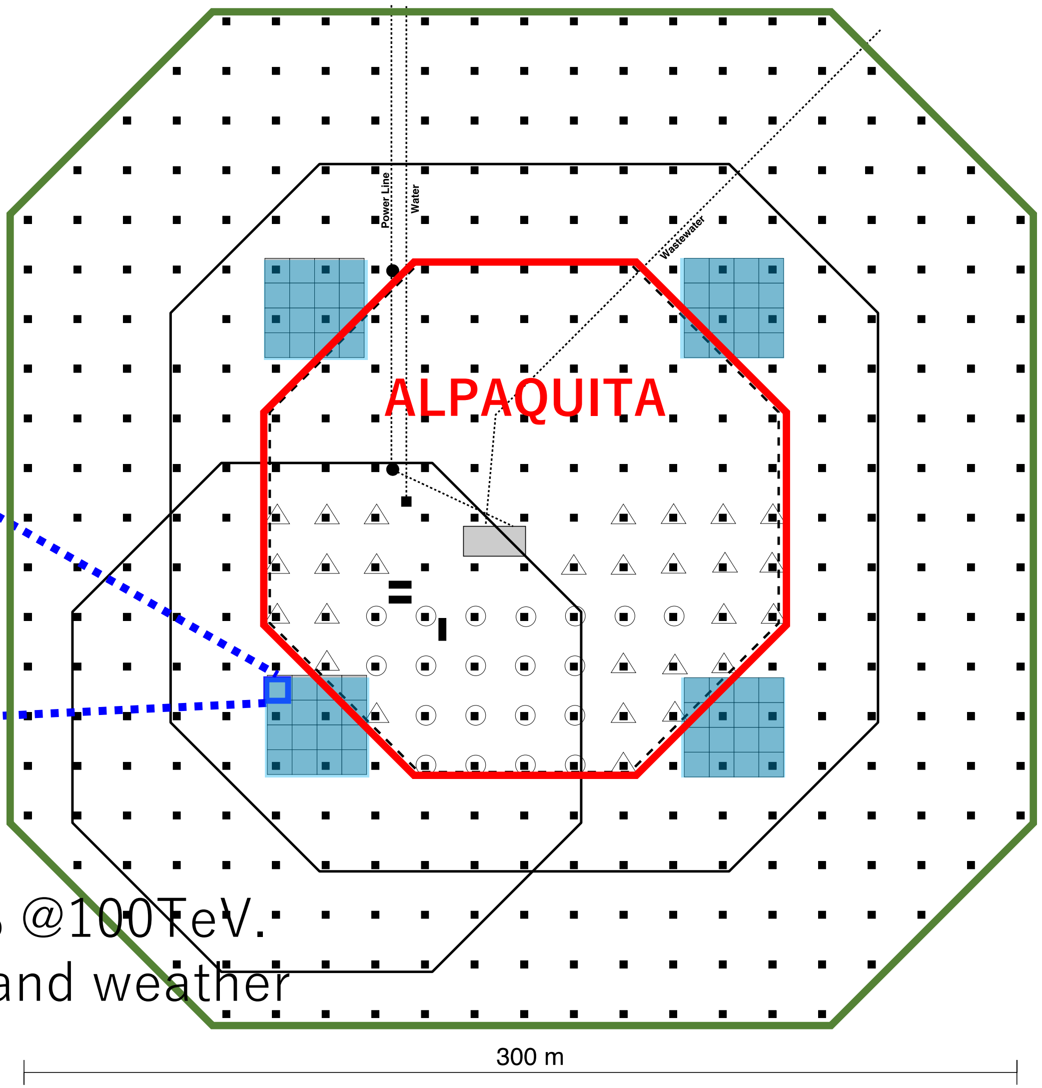


Bolivia・Chacaltaya plateau
(16° 23’ S, 68° 08’ W)

ALPACA Project

1. **Air Shower (AS) Array ~83,000m²**
   ＝ 401 x 1m² Scintillation Detector
2. **Underground Muon Detector (MD) ~3600m²**
   ＝ Water-Cherenkov-Type, 2.5m overburden (~19X_0)
   56m² with 20"ϕ PMT x 96 Cells





- ✓ Gamma-ray air shower has much less muons.
  Background cosmic rays can be rejected by >99.9% @100TeV.
- ✓ Wide FoV (~2sr) observation regardless day/night and weather
  - Angular resolution ~0.2° @100TeV
  - Energy resolution ~20% @100TeV

ALPAQUITA Air Shower Array

¼ALPACA-scale air shower array
$1m^2$ scintillation detector x 97 with 15m spacing
Effective area ~18,000m^2

$1m^2$ 5mm lead plate
$1m^2$ Scintillator
(50cm x 50cm x 5cm x4)

Inverse pyramid shape
Stainless steel box
(White painted inside)

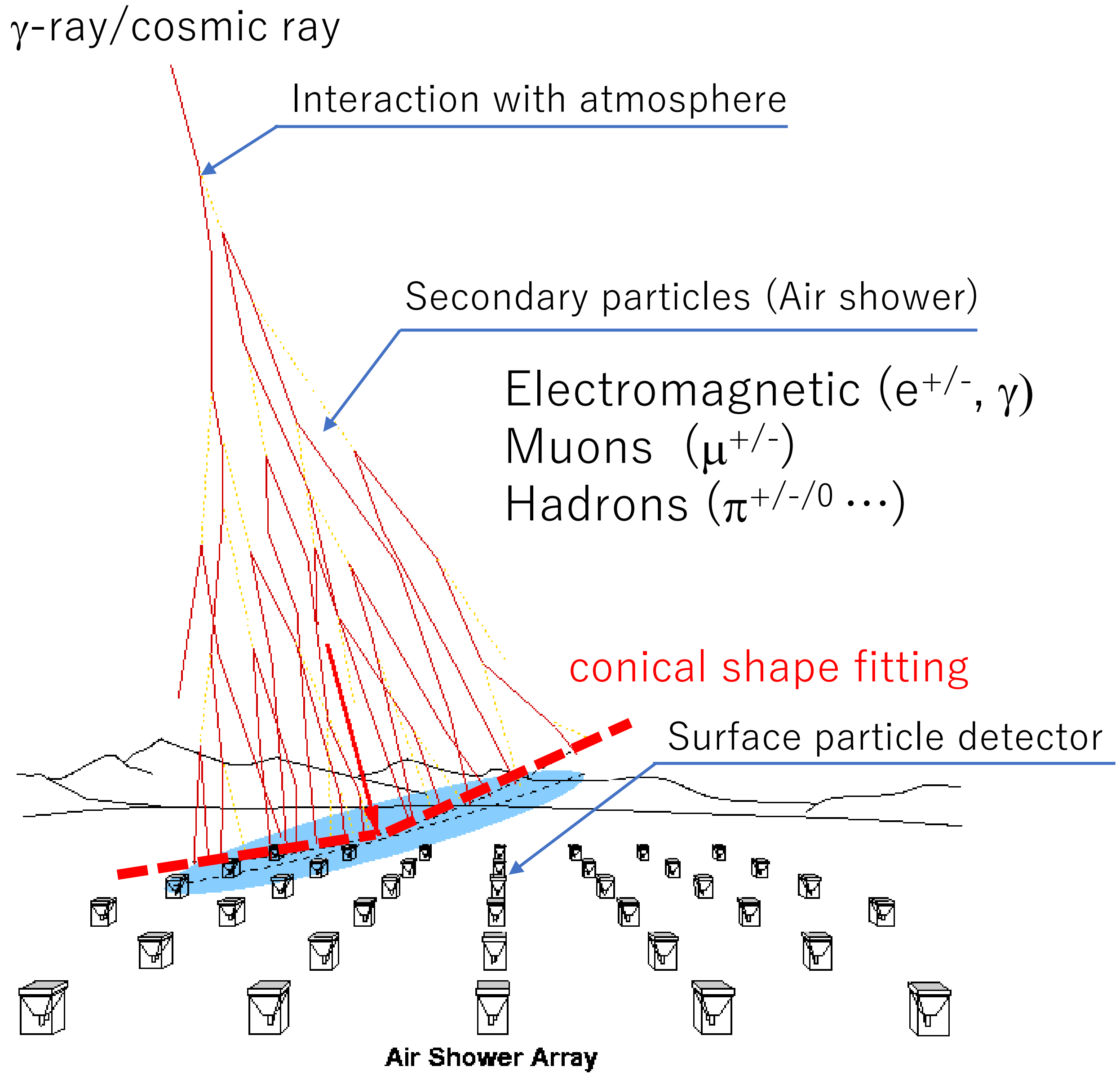
2-inch PMT x1

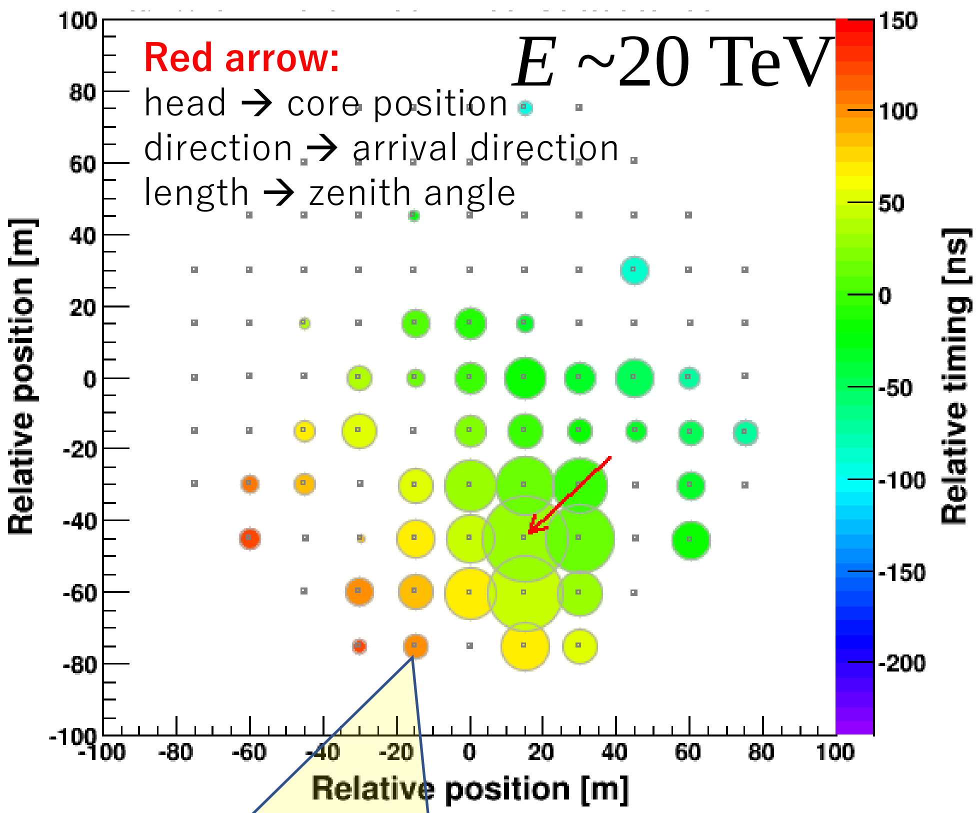
<u>Air Shower Trigger Condition：</u>

Any 4 detectors with >0.6 particles within 600ns
→ Air shower trigger rate ~280Hz
Cosmic-ray mode energy ~7 TeV

Construction status:
2022 Jun. Deploy detectors
2022 Sep. Partial operation
2023 Apr. Full operation

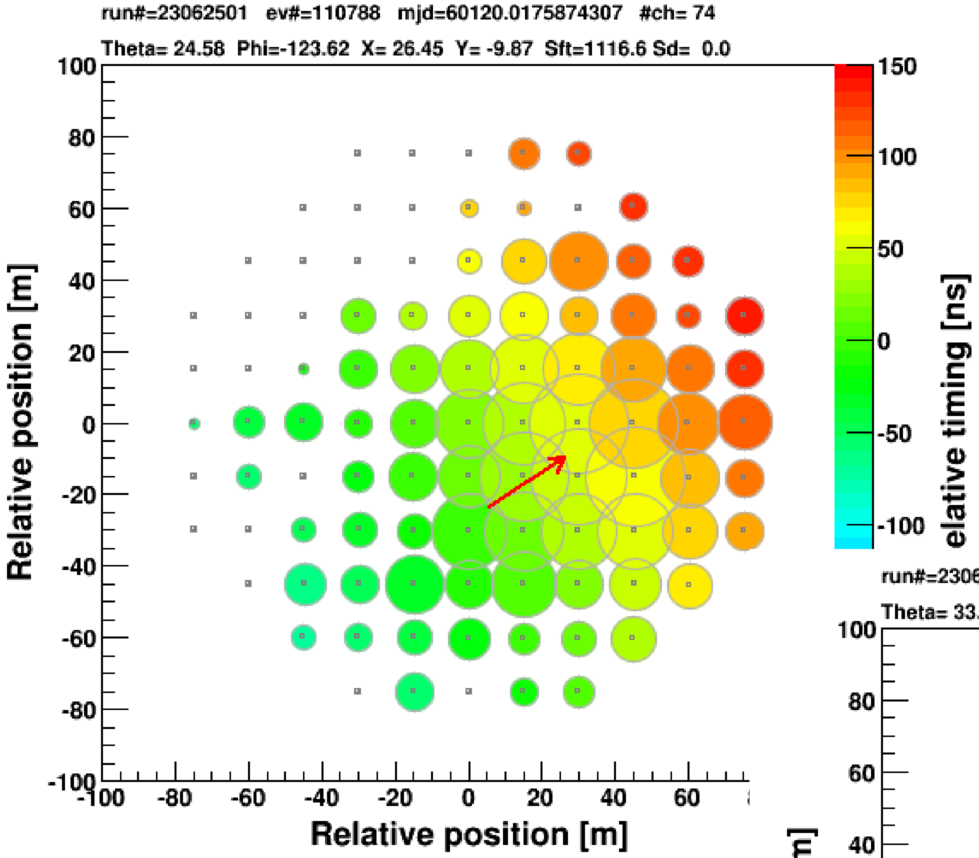
ALPAQUITA Air Shower Analysis

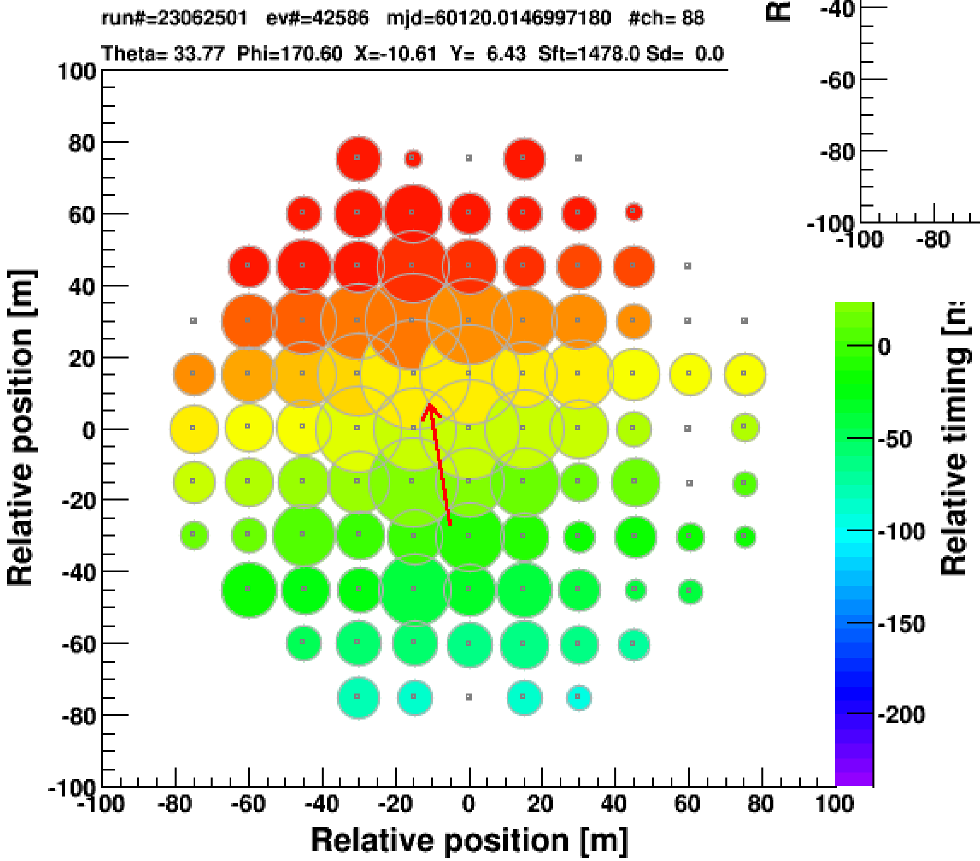


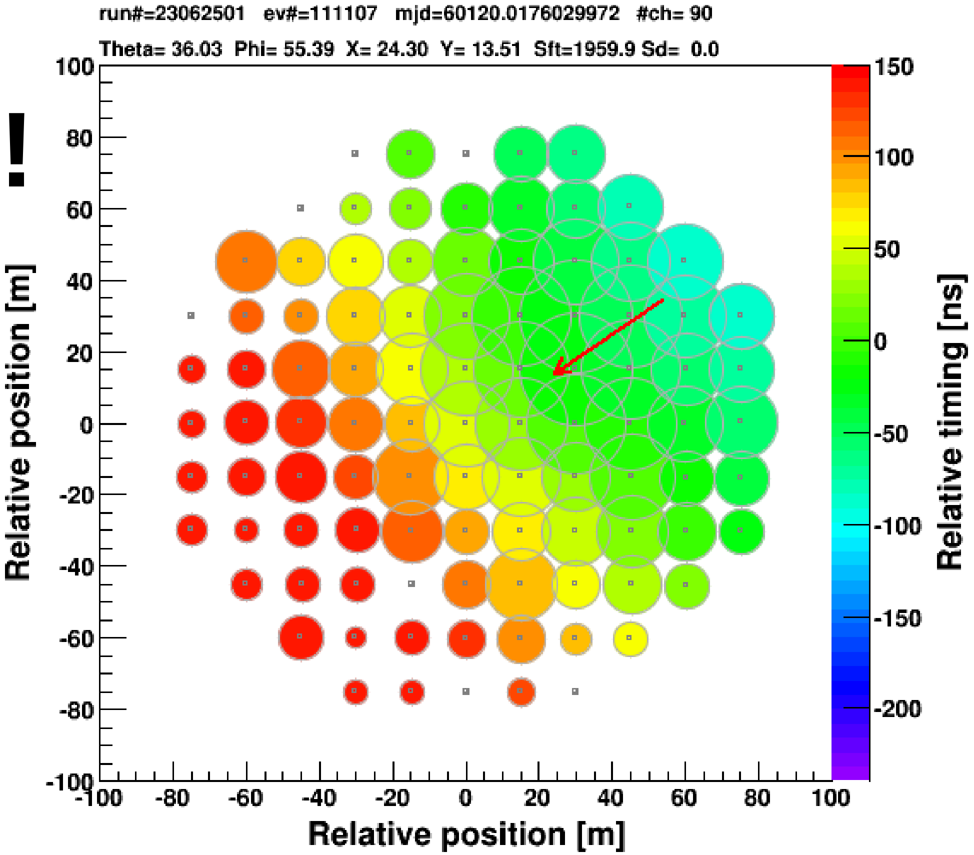


1. Relative arrival timing (Color scale)
2. Number of particles (Circle size)
→ Reconstruct direction and energy

Big Events!



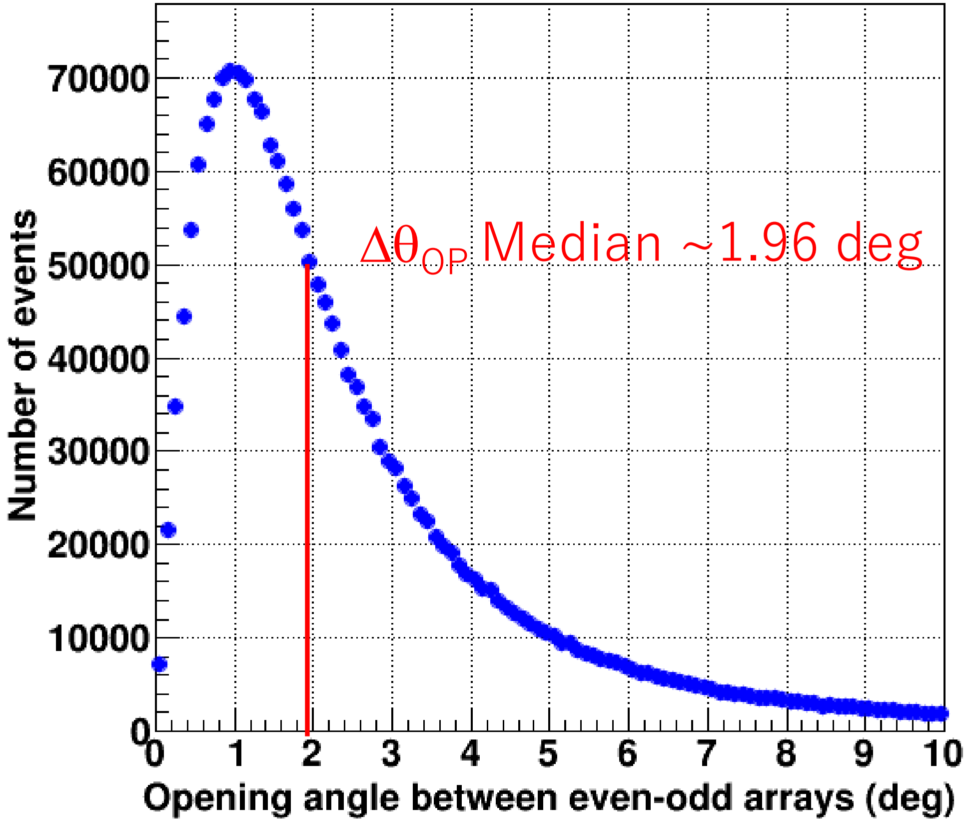




E >100 TeV

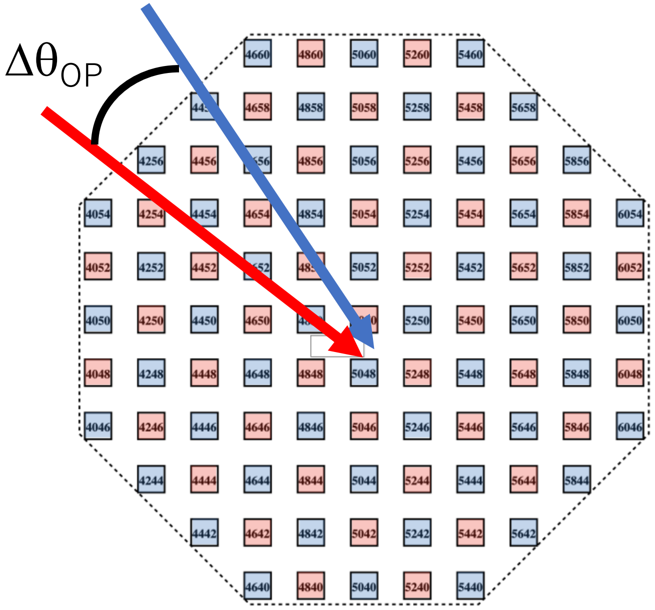
Even-Odd Method

Event selection criteria:
- Zenith angle < 40deg
- In Array flag = on
- 1.25 Any 4 flag = on
- Residual error < 1.0



Even-Odd opening angle：
Opening angle between directions determined by two independent arrays (even and odd arrays)

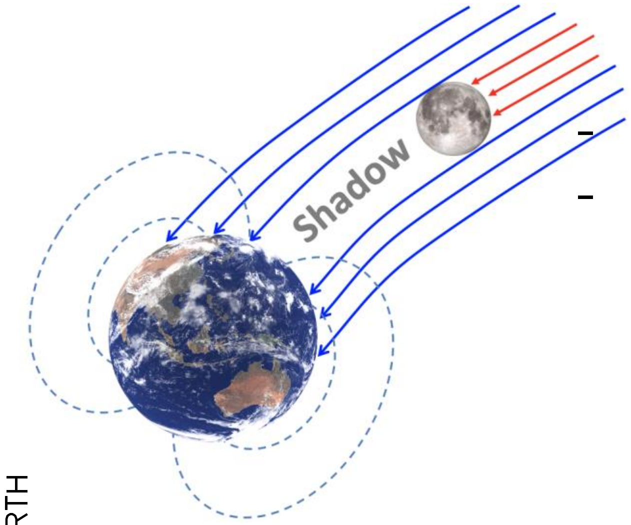
Angular resolution
$\sigma_{50} = \Delta\theta_{OP} / 2 = \sim 1^{o}$



Moon Shadow Detection

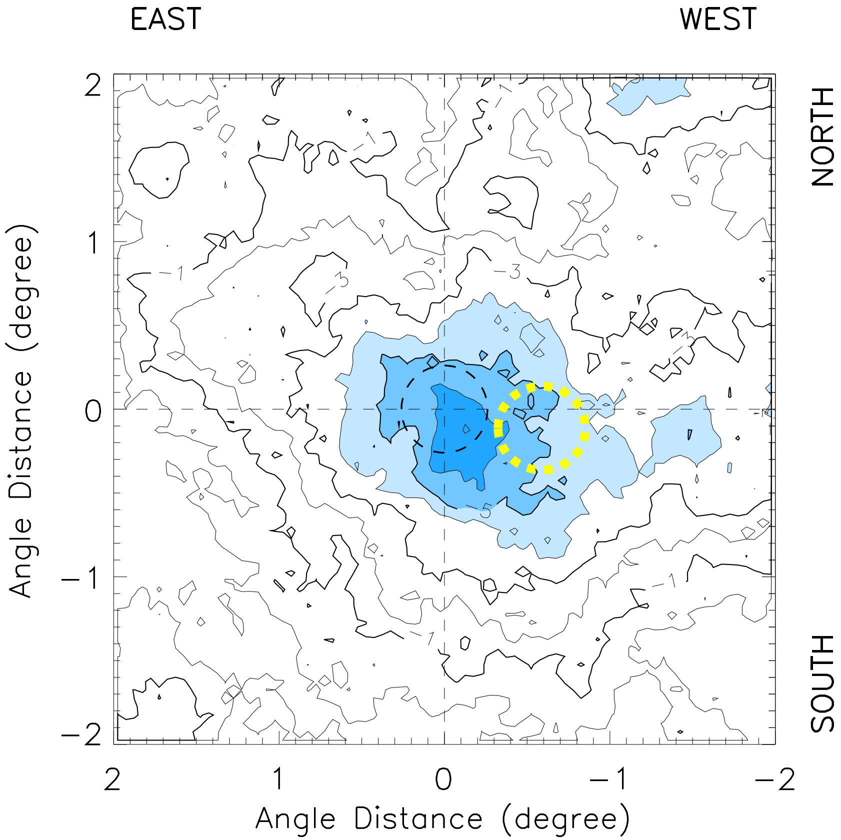
Displacement
by geomagnetic field $\Delta\theta \sim \frac{1.6^o}{E[\mathrm{TeV}]}$

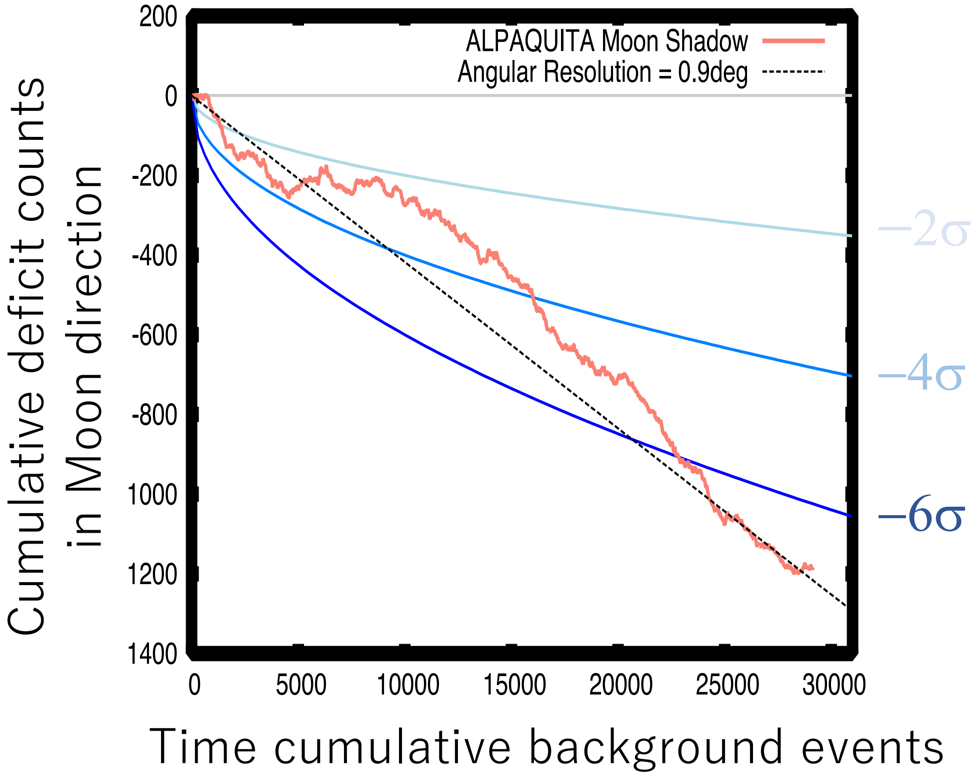
We can check
- ✓ Angular resolution
- ✓ Pointing accuracy
- ✓ Absolute energy scale



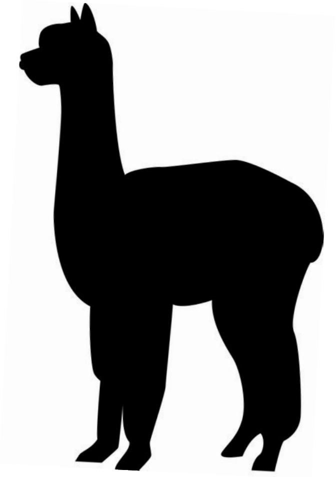
- April 7, 2023 – July 16, 2023 (83 days)
- With cable length correction

→ Successfully detected at 6.7σ
→ Westward shift ~0.2^o as expected
→ Moon shadow verified ~0.9^o resolution

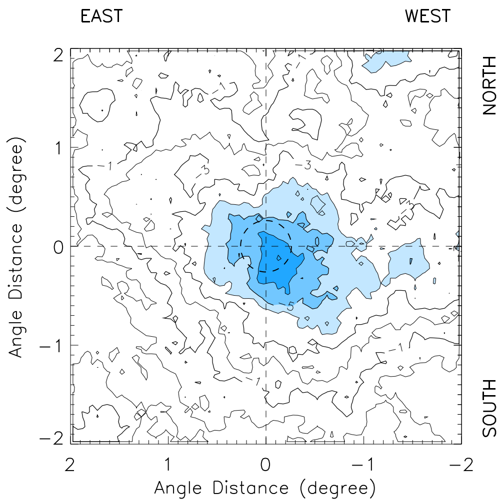




Summary & Prospects



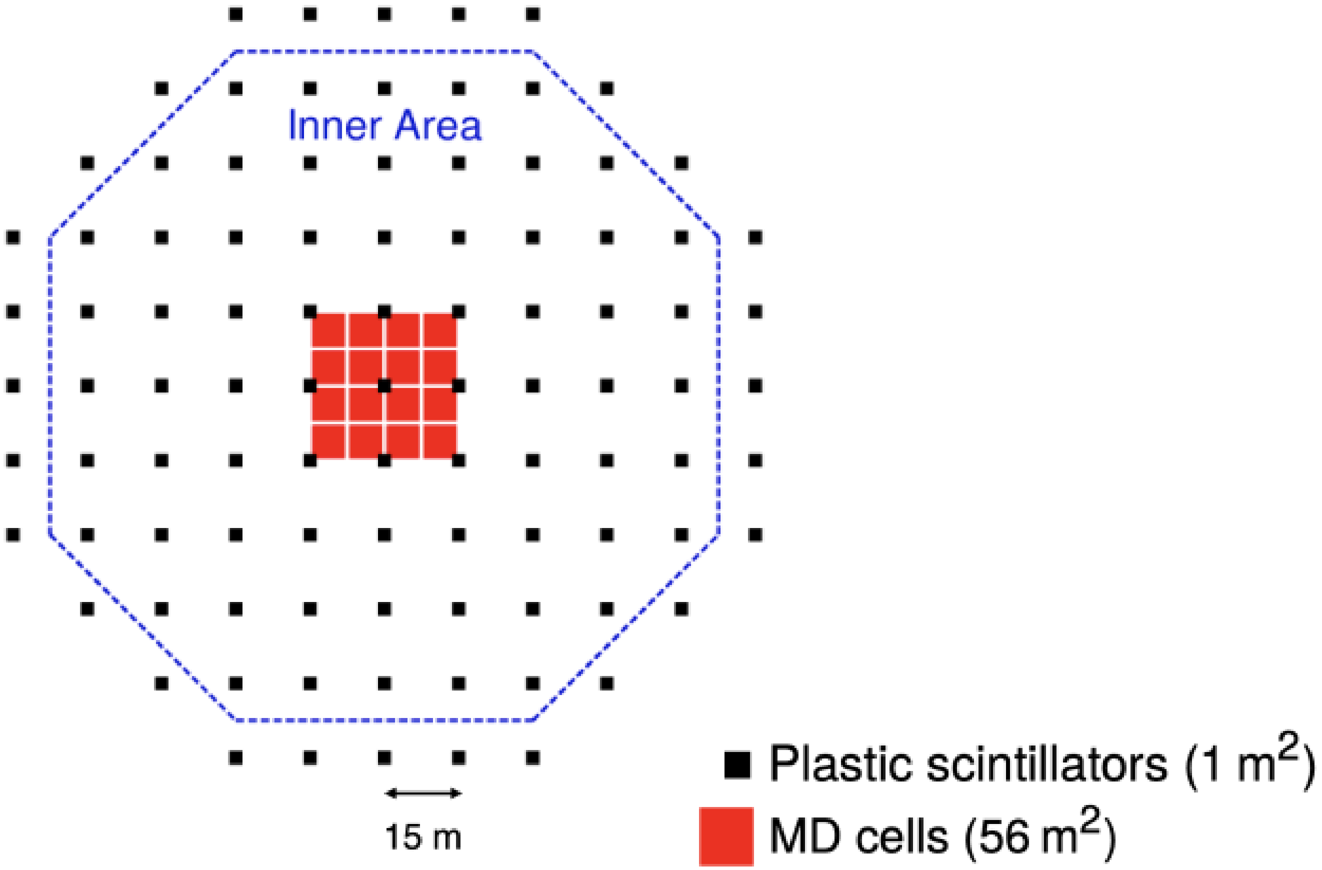
- ✓ Data period: 2023 April 7 – 2023 July 16 (83 live days).
- ✓ We successfully detected the Moon Shadow at 6.7σ.
- ✓ Angular resolution is estimated to be ~0.9^{o} as expected.
- ✓ We will start construction of one underground MD pool in 2023.
- ✓ We will start full ALPACA AS array and 4 MD pools in 2024.
  → sub-PeV γ-ray/CR observation will start soon in the southern hemisphere!

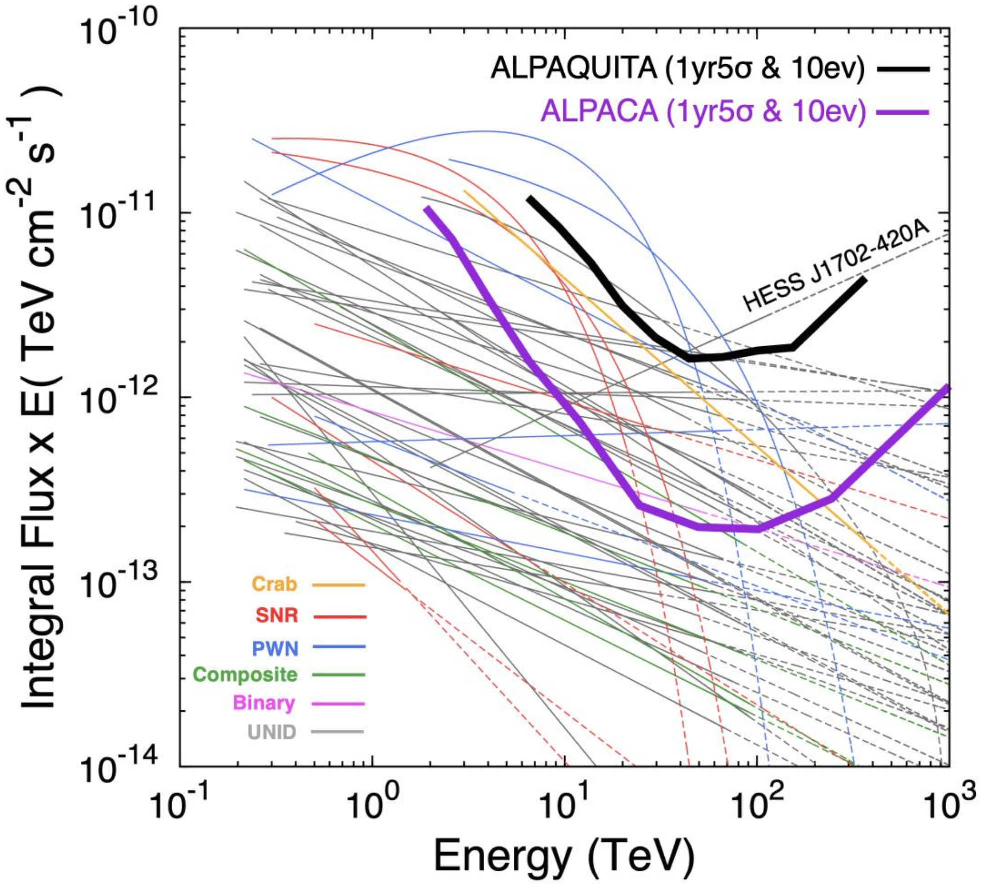


BACKUP SLIDES

ALPAQUITA Sensitivity

Kato et al (ALPACA Collob.)
"Detectability of southern gamma-ray sources beyond 100 TeV with ALPAQUITA, the prototype experiment of ALPACA", Exp. Astro., 52, 85 (2021)

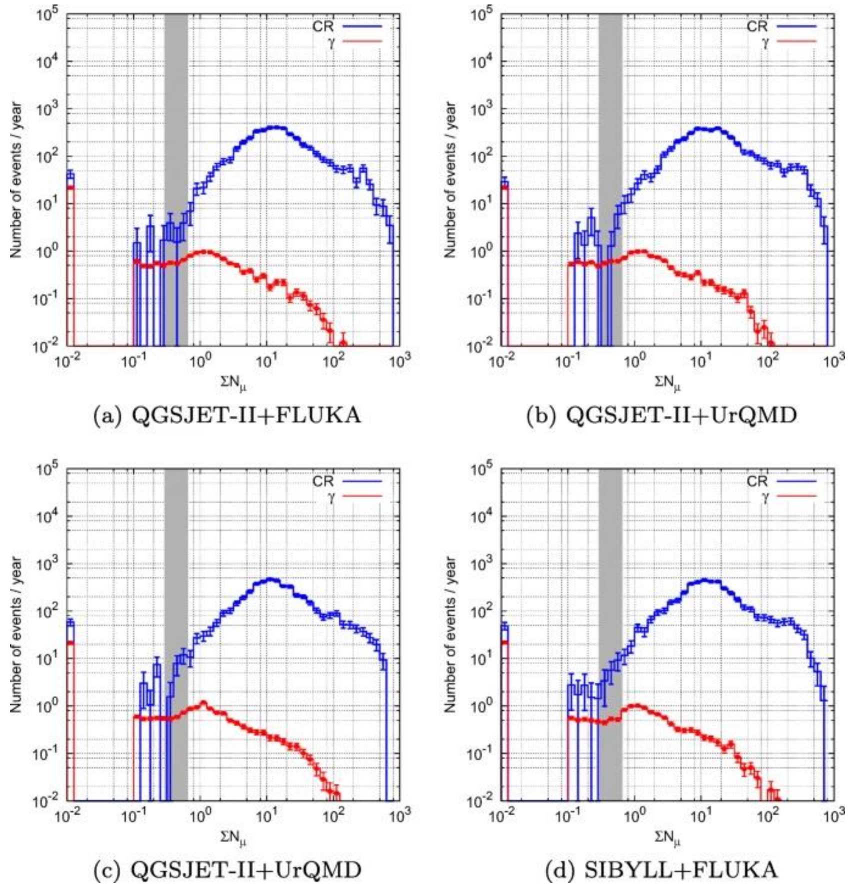


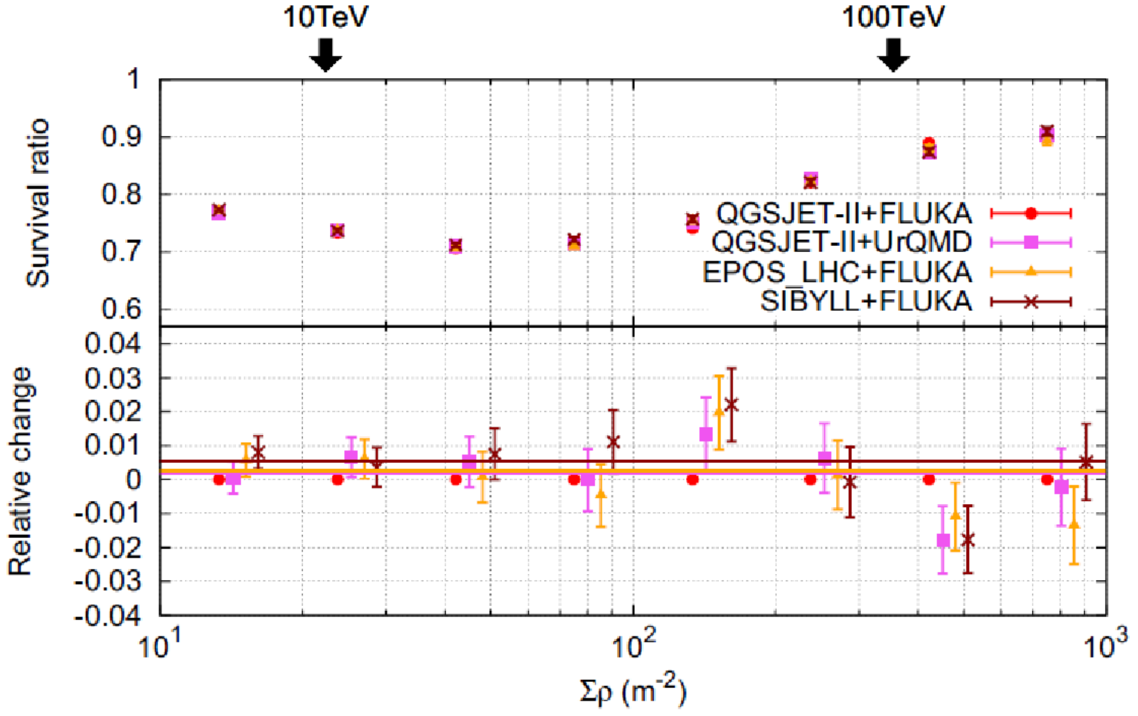


“Hadronic interaction model dependence in cosmic Gamma-ray flux estimation using an extensive air shower array with a muon detector”

S. Okukawa et al., Exp. erimental Astron., 55, 325 (2023）

Expected numbers of gamma-ray and CRs as a functions of the number of detected muons



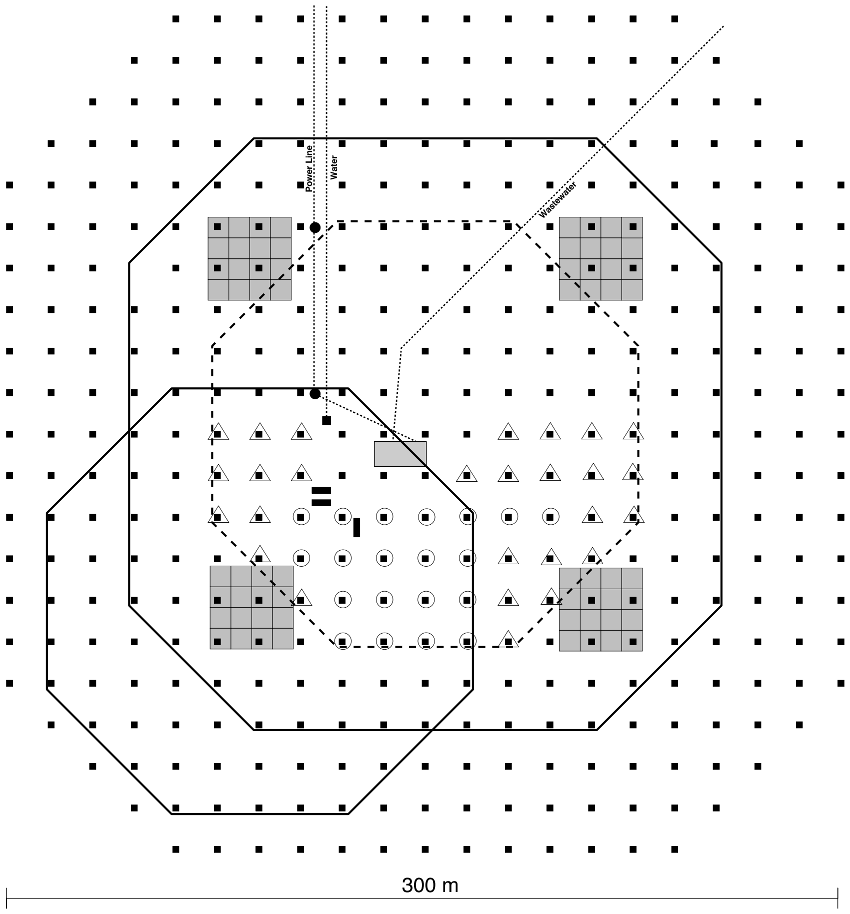


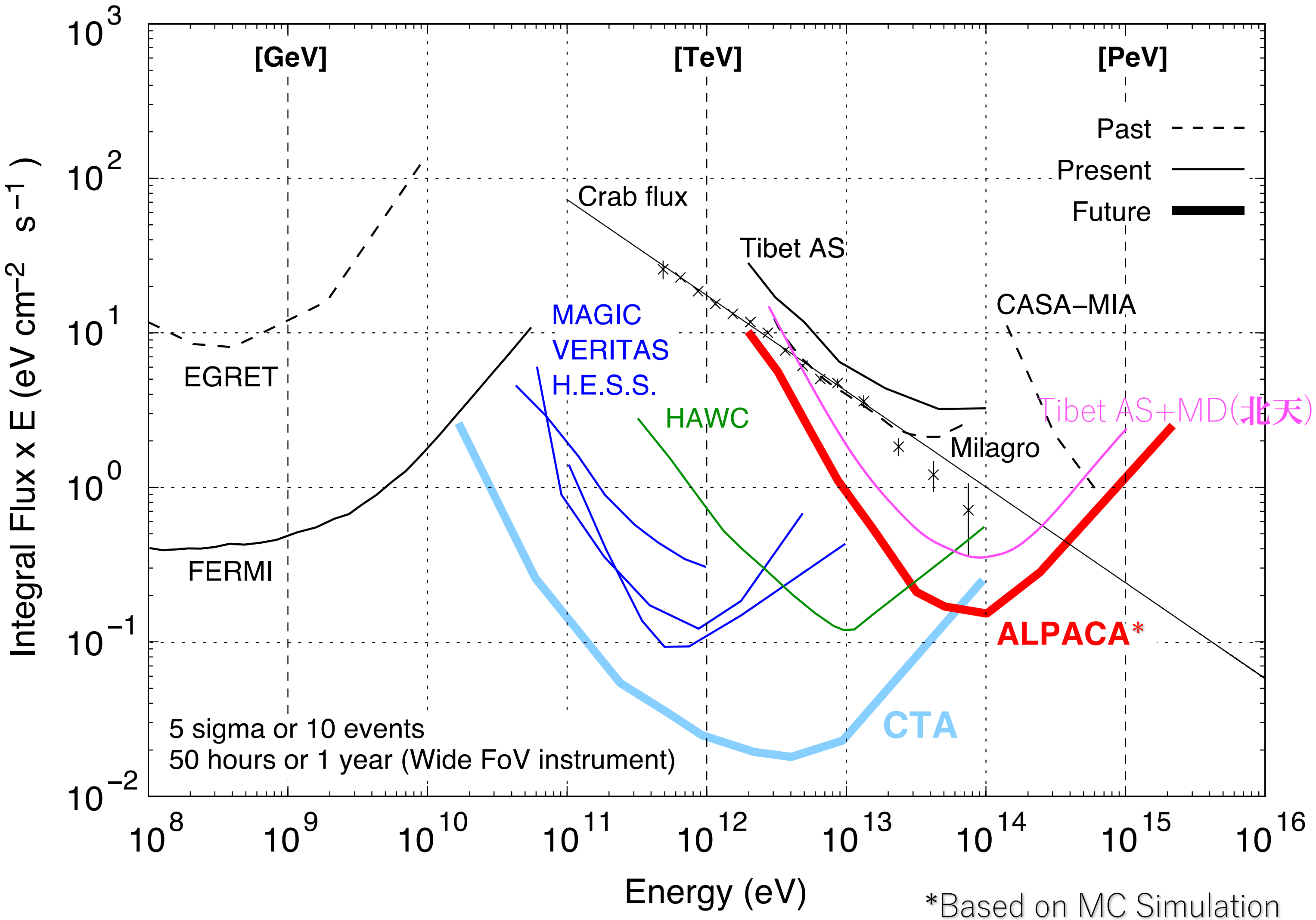
(c) Optimal survival

Hadronic interactions dependence in the typical gamma-ray flux estimation performed by ALPAQUITA ＜3.6%

$56.2 < \Sigma\rho < 100$ (E_γ of 28.8 TeV)

ALPACA Sensitivity



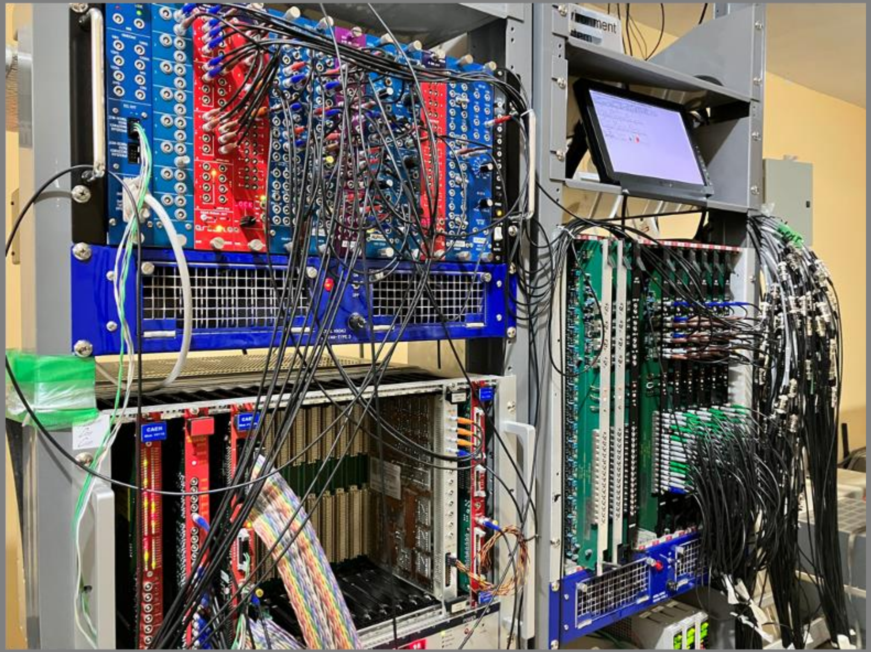


*Based on MC Simulation
For the Tibet AS+MD


Installation of cables

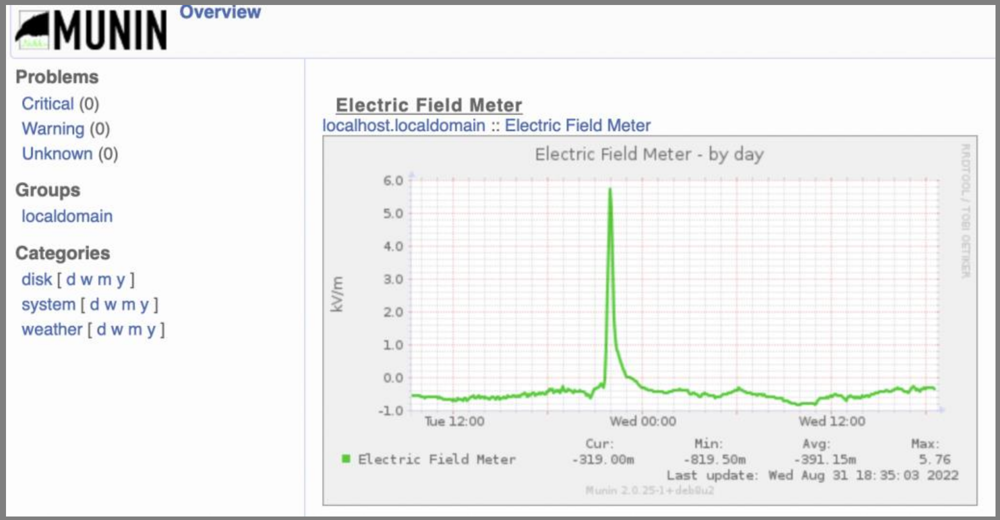

Installation of PMTs


GPS survey


DAQ system

Weather monitors

Electric field monitor



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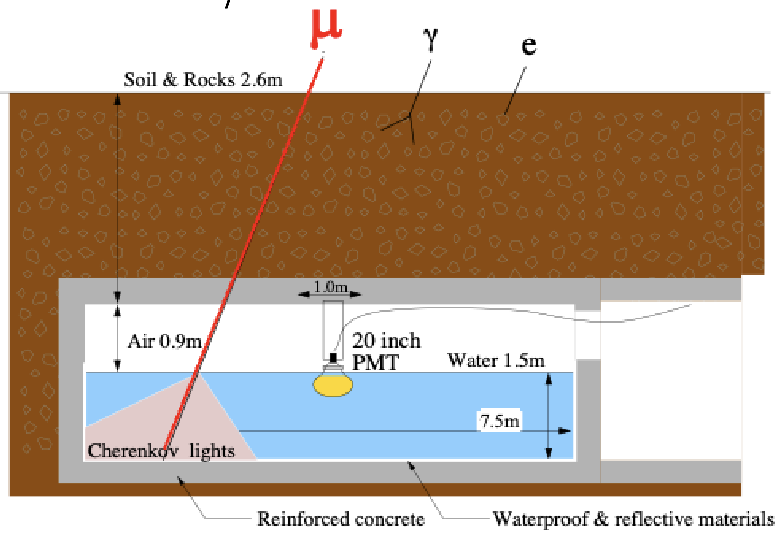

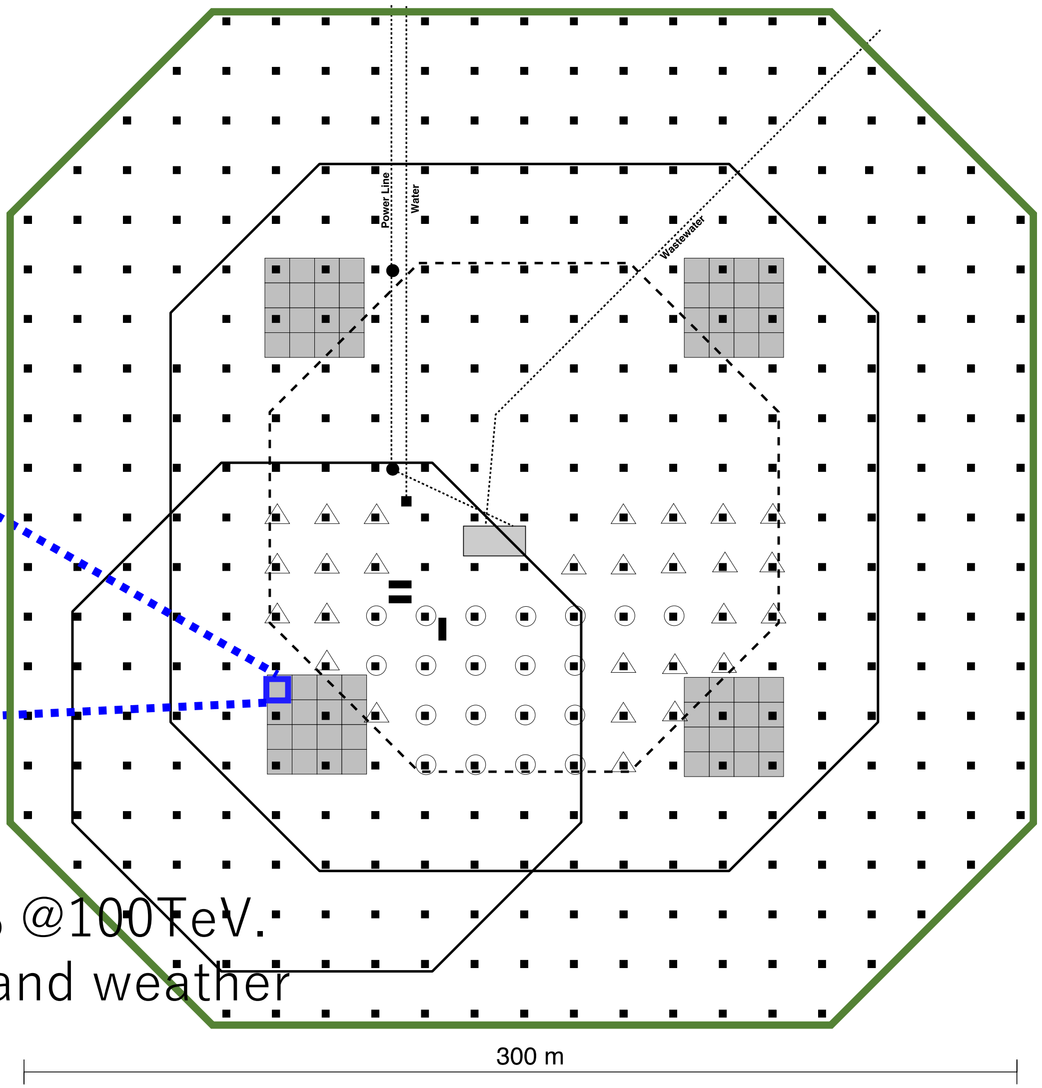

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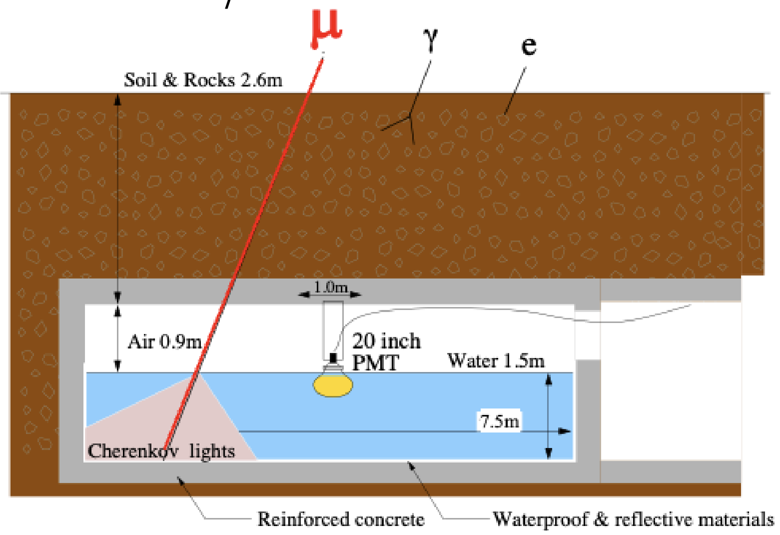

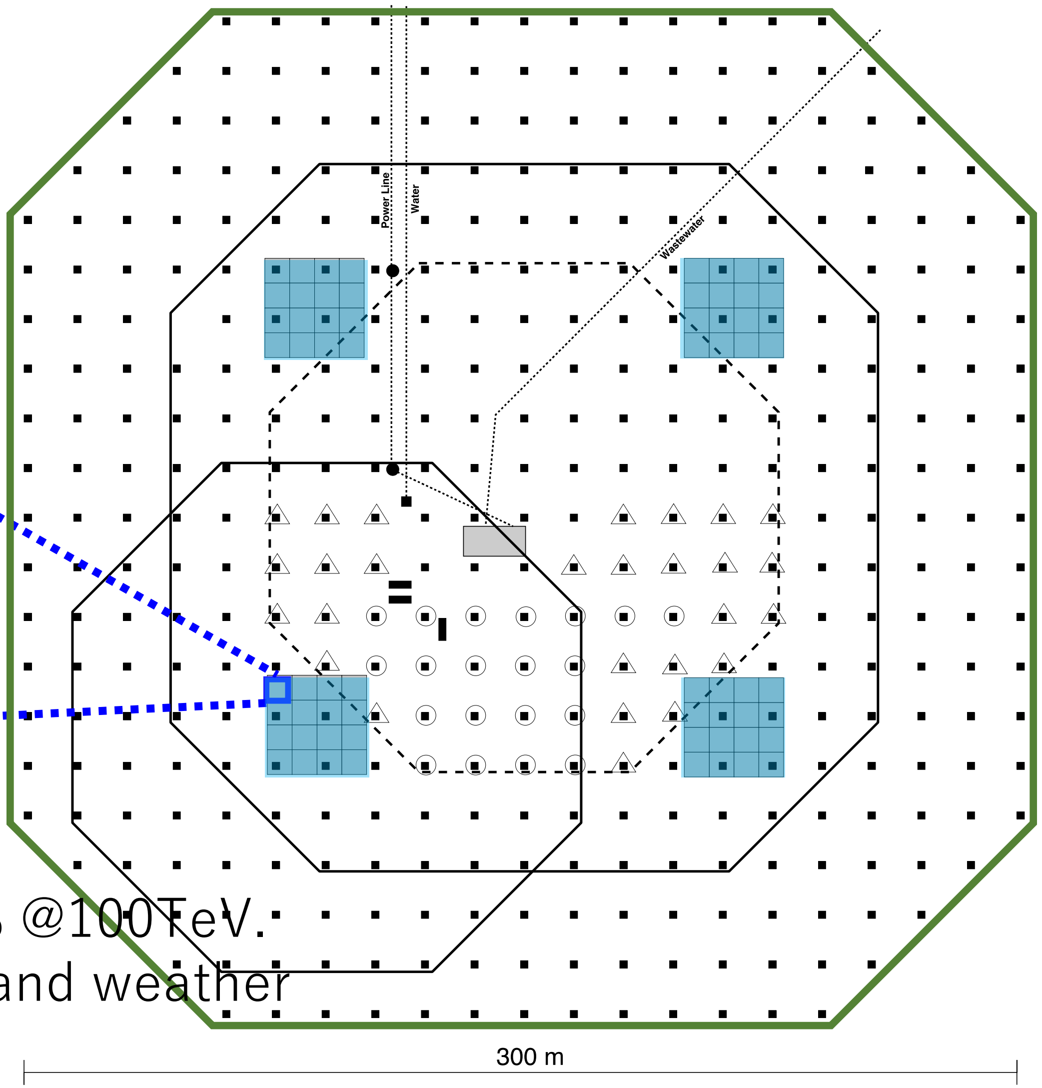

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