



Status of the ALPACA/ALPAQUITA experiment

Yusaku Katayose (Yokohama National University)
for the ALPACA Collaboration

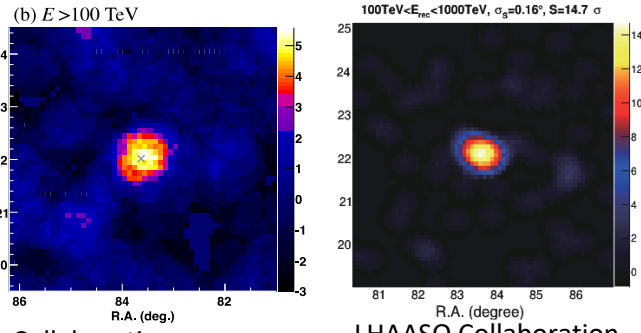
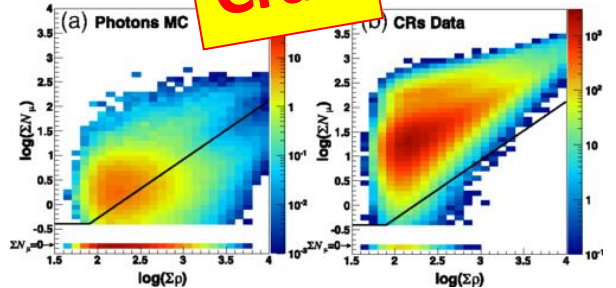


TeVPA 2024 Chicago USA, Aug. 26th 2024

sub-PeV γ -Ray Astronomy(2019~)

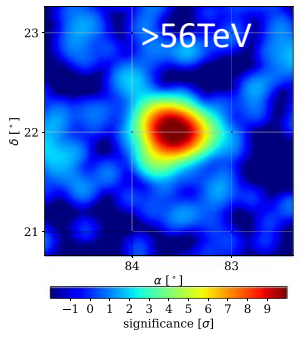
- ✓ Search for Galactic PeV cosmic-ray accelerators, PeVatrons
- ✓ Tibet AS γ , HAWC, and LHAASO in the northern hemisphere

Crab

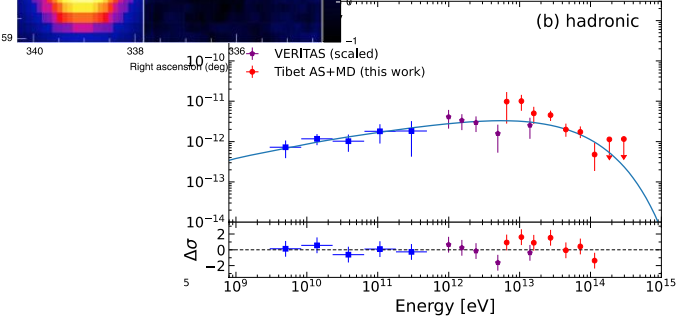
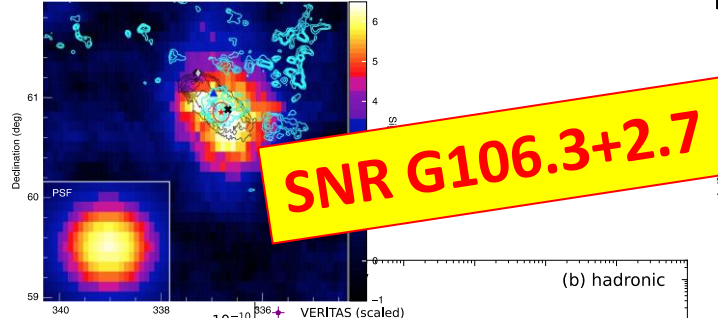


Tibet AS γ Collaboration, PRL 123, 051101 (2019)

LHAASO Collaboration, Chin. Phys. C45, 023002 (2021)

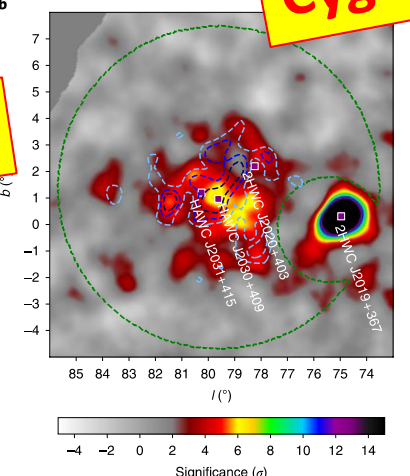


HAWC Collaboration, ApJ 881:134 (2019)

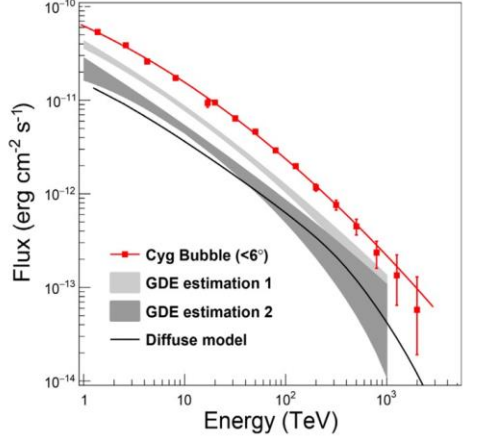


Tibet AS γ Collaboration, Nature Astron., 5, 460-464 (2021)

Cygnus Cocoon

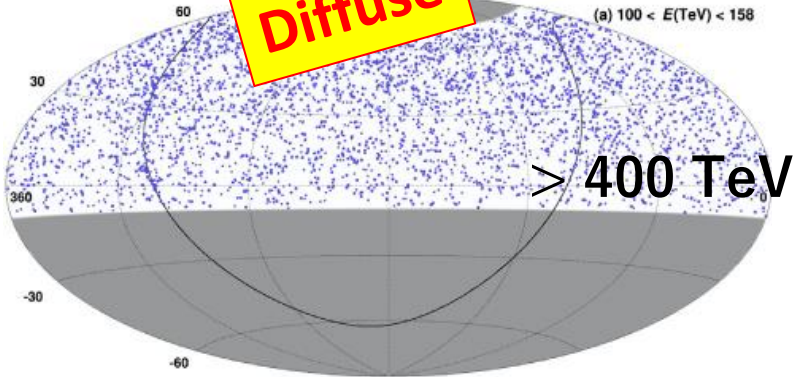


Abeysekara et al., Nature Astronomy (2021)



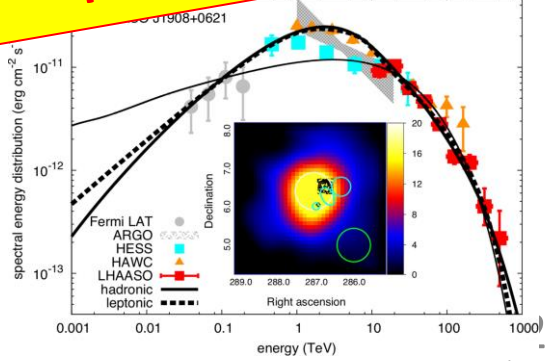
LHAASO Collaboration Sci. Bull. 69, 449 (2024)

Diffuse



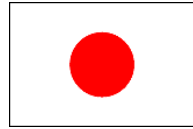
Tibet AS γ Collaboration, PRL 126, 141101 (2021)

LHAASO J1908+0621 PWN? SNR?



LHAASO Collaboration, Nature, 594, 33-36 (2021)

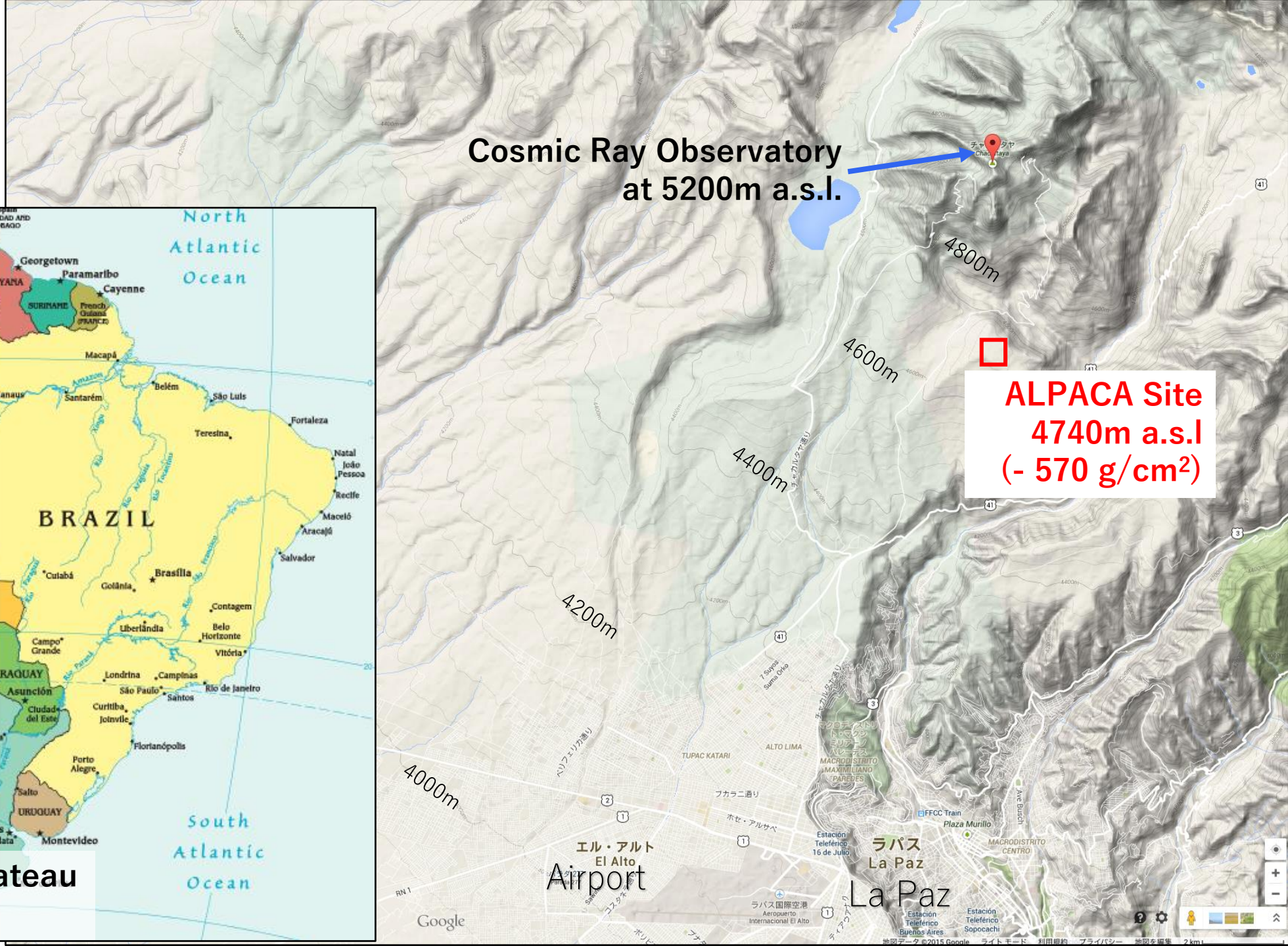
The ALPACA Collaboration



**M. Anzorena¹, D. Blanco², E. de la Fuente³, K. Goto⁴, Y. Hayashi⁵,
K. Hibino⁶, N. Hotta⁷, G. Imaizumi¹, A. Jimenez-Meza³, Y. Katayose⁸,
C. Kato⁵, S. Kato¹, T. Kawashima¹, K. Kawata¹, T. Koi⁴, H. Kojima⁴,
T. Makishima⁸, Y. Masuda⁵, S. Matsuhashi¹⁰, M. Matsumoto⁵, R. Mayta²,
P. Miranda², A. Mizuno¹, K. Munakata⁵, Y. Nakamura¹, C. Nina²,
M. Nishizawa¹⁰, Y. Noguchi⁸, S. Ogio¹, M. Ohnishi¹,
S. Okukawa⁸, A. Oshima⁴, M. Raljevich², T. Saito¹¹, T. Sako¹, T. K. I.,
J. Salinas², T. Shibasaki¹³, S. Shibata⁴, A. Shiomi¹²,
M. A. Subieta Vasquez², N. Tajima¹⁴, W. Takano⁶, M. Takita¹, Y. Tameda¹⁵,
K. Tanaka¹⁶, R. Ticona², I. Toledano-Juarez³, H. Tsuchiya¹⁷, Y. Tsunesada⁹,
S. Udo⁵, R. Usui⁸, R. I. Winkelmann², K. Yamazaki⁴ and Y. Yokoe¹ (The
ALPACA collaboration)**

¹ICRR, University of Tokyo, ²IIF, UMSA, ³U. de Guadalajara, ⁴Chubu University, ⁵Shinshu University, ⁶Kanagawa University, ⁷Utsunomiya University, ⁸Yokohama National University, ⁹Osaka Metropolitan University, ¹⁰National Institute of Informatics, ¹¹Tokyo Metropolitan College of Industrial Technology, ¹²Dept. of Info. and Elec., Nagano Pref. Inst. of Tech, ¹³Nihon University, ¹⁴RIKEN, ¹⁵Osaka Electro-Communication University, ¹⁶Hiroshima City University, ¹⁷Japan Atomic Energy Agency.

ALPACA Site



ALPACA

(Andes Large area PArticle detector for Cosmic ray physics and Astronomy)

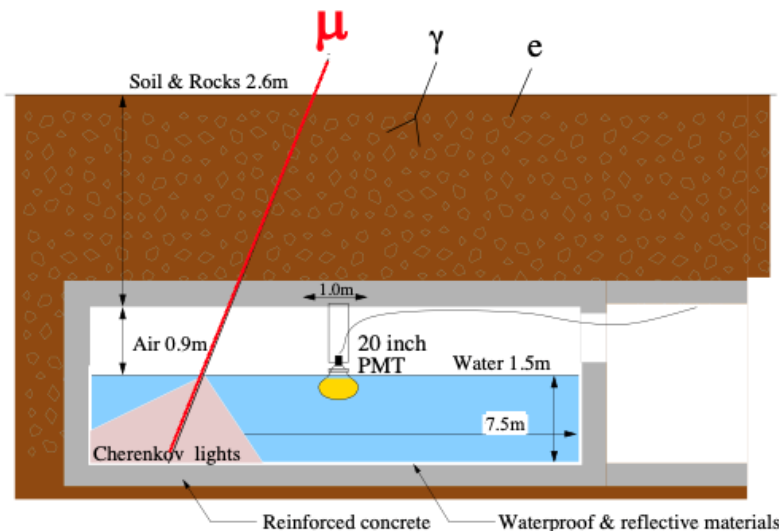
1. Air Shower (AS) Array ~83,000m²

= 401 x 1m² Scintillation Detector

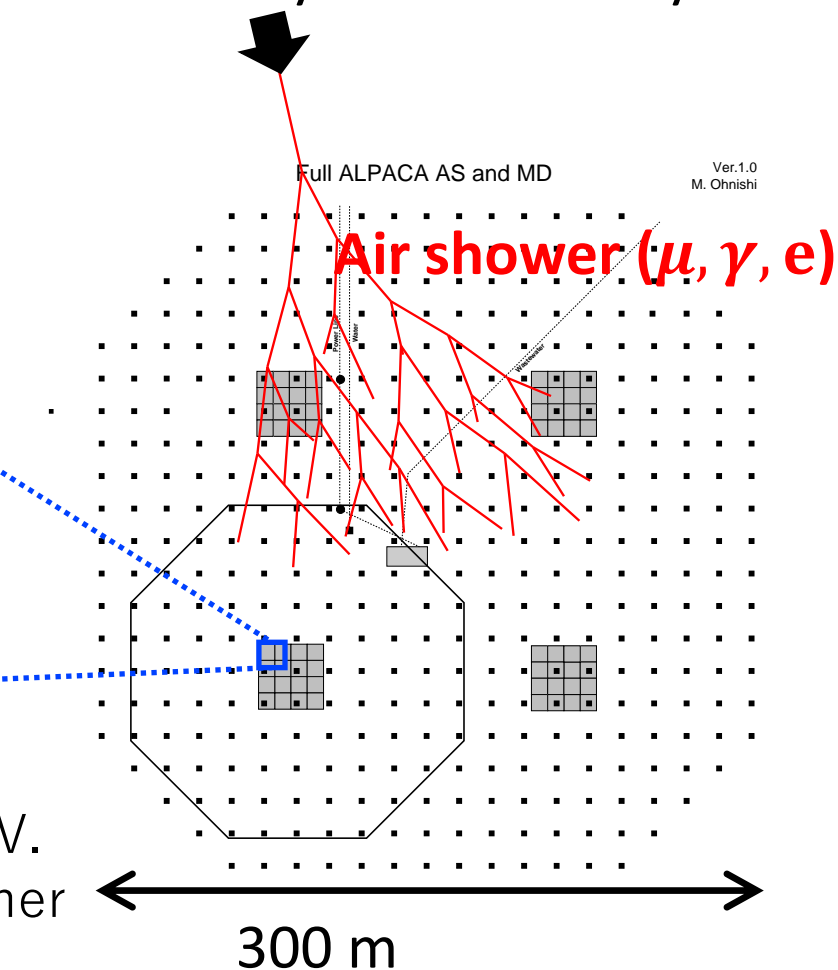
2. Underground Muon Detector (MD) ~3600m²

= Water-Cherenkov-Type, 2.5m overburden ($\sim 19X_0$)

56m² with 20" ϕ PMT x 64 Cells



Gamma rays & Cosmic rays



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

ALPAQUITA AS array

Surface Air Shower Array
(Coverage: **18,450 m²**)

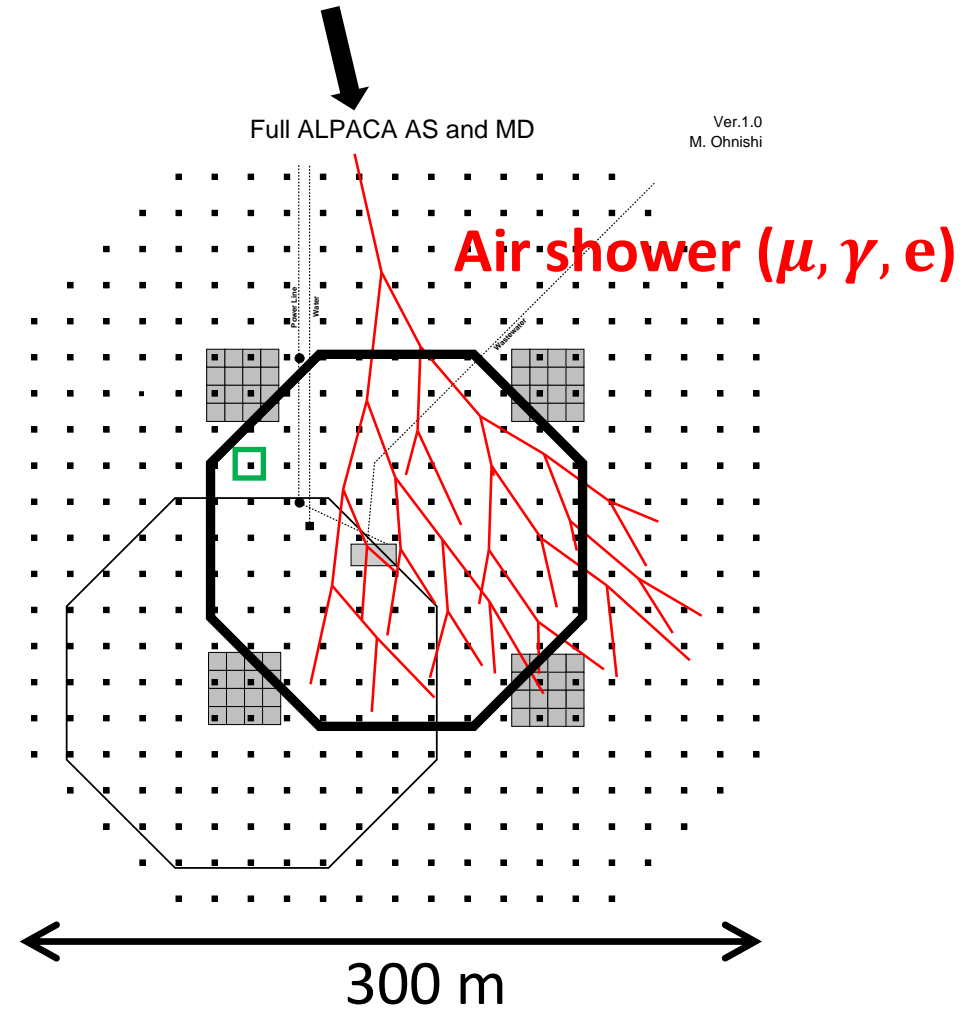
- 1 m² scintillation detector (× 97)



- 1m² 5mm lead plate
- 1m² Scintillator(50cm x 50cm x 5cm x4)
- Inverse pyramid shape
- Stainless steel box (White painted inside)
- 2-inch PMT x1

- ✓ Air Shower Trigger Condition:
Any 4 detectors with > 0.7 particles within 600 ns
→ Air shower trigger rate: ~280 Hz
(Any 3 trigger has been implemented since June 2024)
- ✓ Cosmic-ray mode energy ~7 TeV

Gamma rays & Cosmic rays



Construction status:

- 2022 Jun. Deploy detectors
- 2022 Sep. Partial operation
- 2023 Apr. Full operation

ALPAQUITA Air Shower Analysis

γ -ray/cosmic ray

Interaction with atmosphere

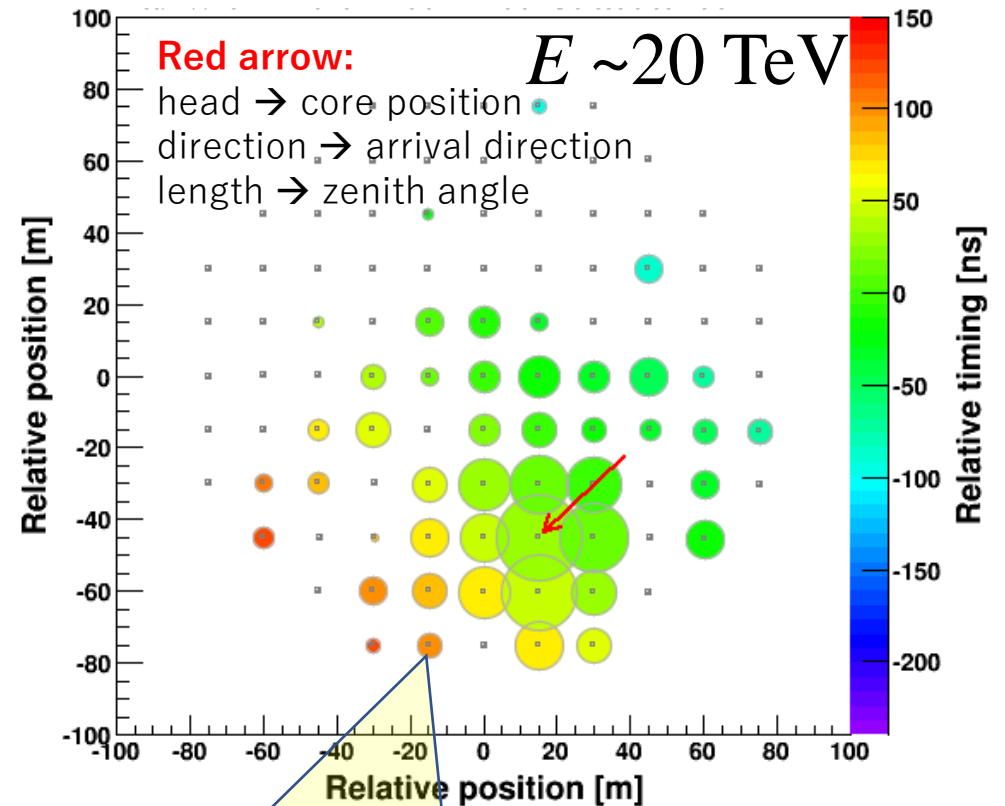
Secondary particles (Air shower)

Electromagnetic ($e^{+/-}$, γ)
Muons ($\mu^{+/-}$)
Hadrons ($\pi^{+/-/0}$...)

conical shape fitting

Surface particle detector

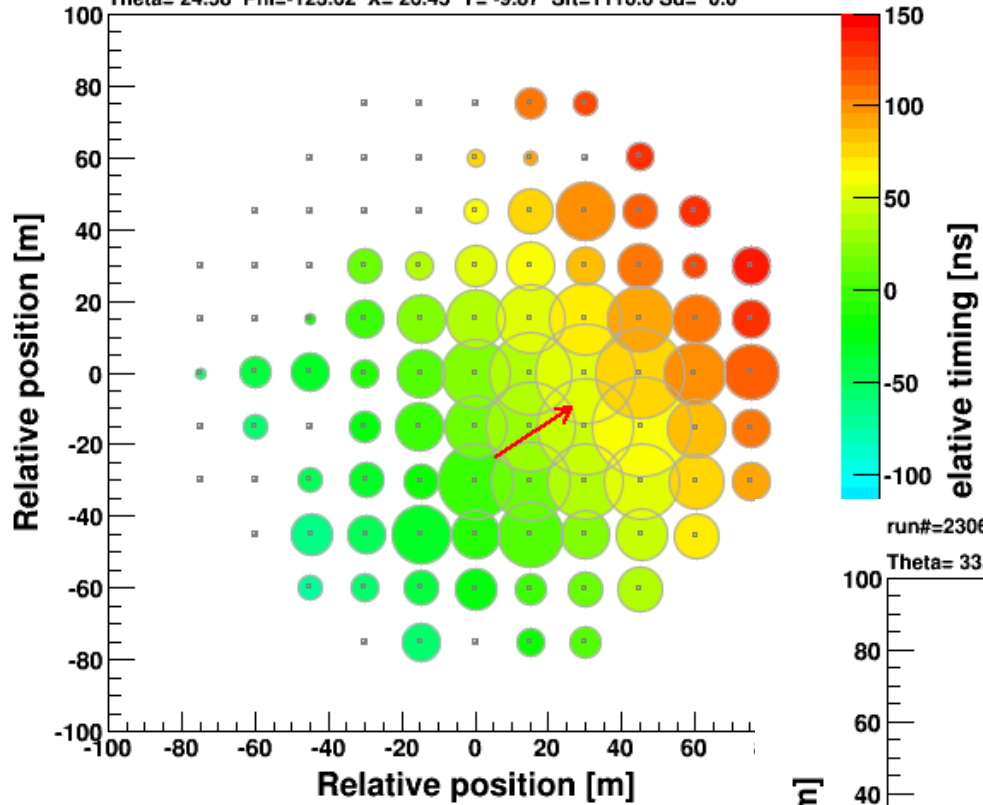
Air Shower Array



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

run#=23062501 ev#=110788 mjd=60120.0175874307 #ch= 74

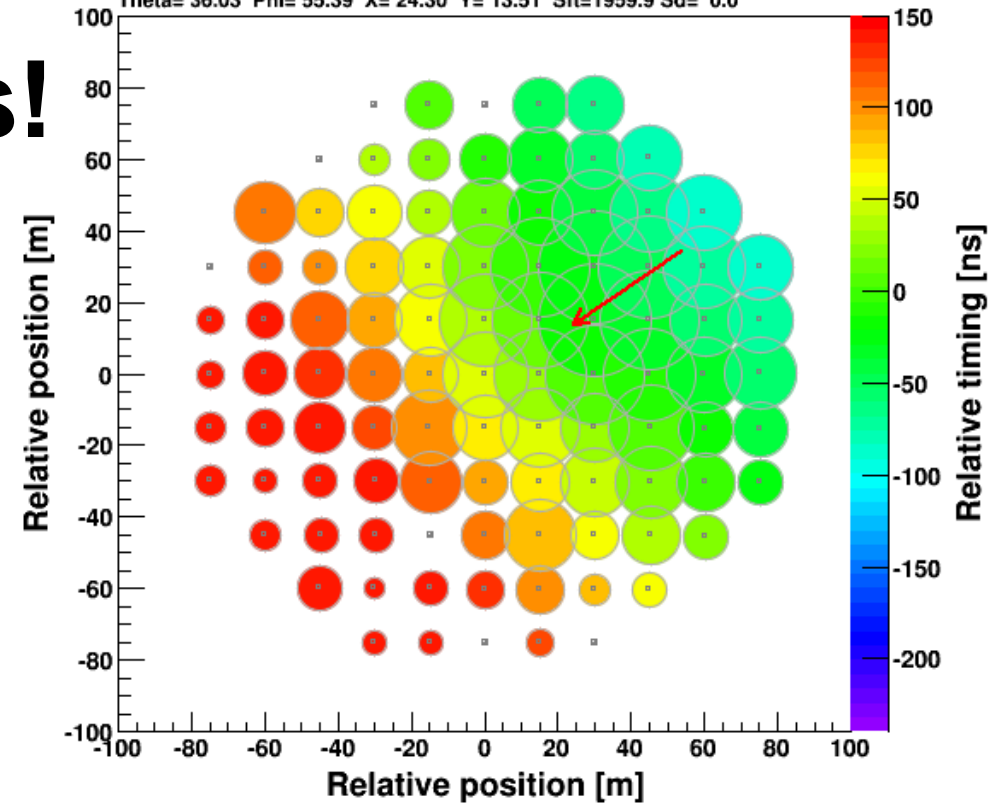
Theta= 24.58 Phi=-123.62 X= 26.45 Y= -9.87 Sft=1116.6 Sd= 0.0



Big Events!

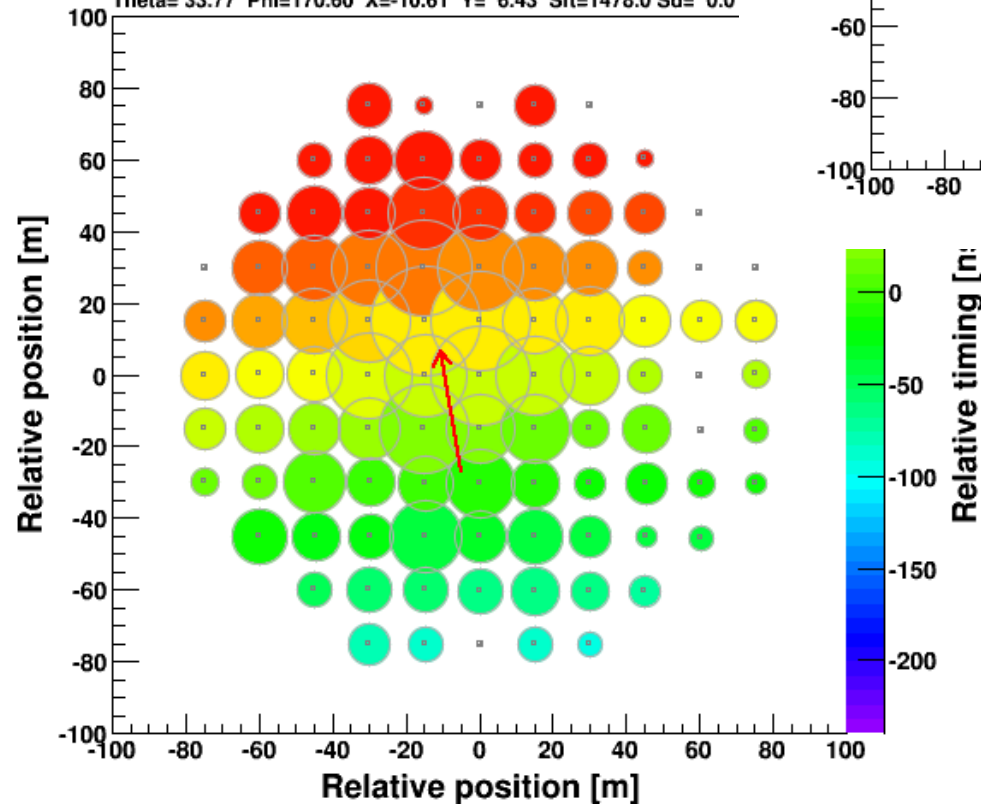
run#=23062501 ev#=111107 mjd=60120.0176029972 #ch= 90

Theta= 36.03 Phi= 55.39 X= 24.30 Y= 13.51 Sft=1959.9 Sd= 0.0



run#=23062501 ev#=42586 mjd=60120.0146997180 #ch= 88

Theta= 33.77 Phi=170.60 X=-10.61 Y= 6.43 Sft=1478.0 Sd= 0.0



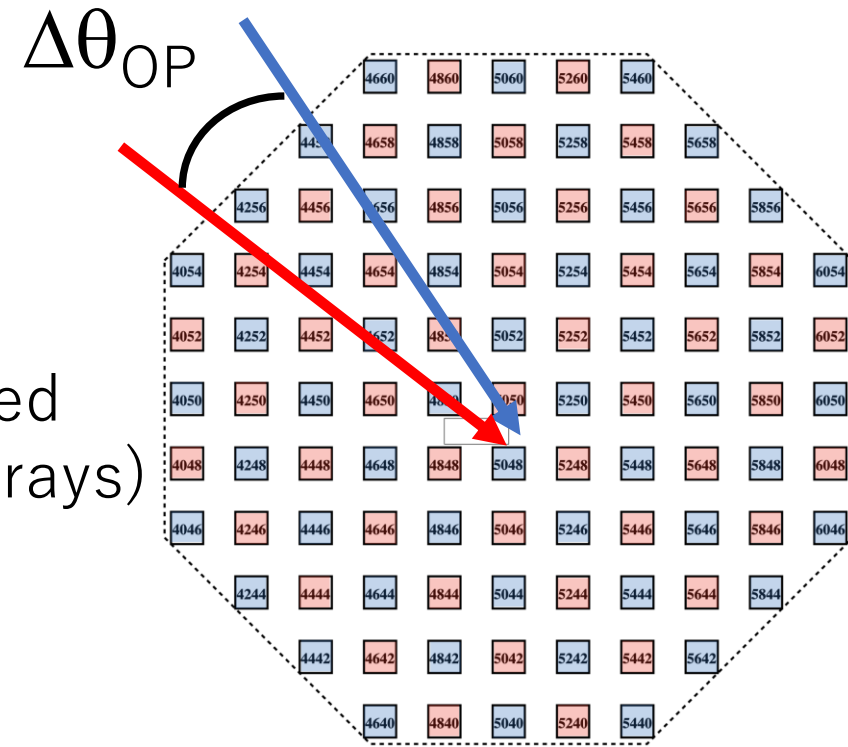
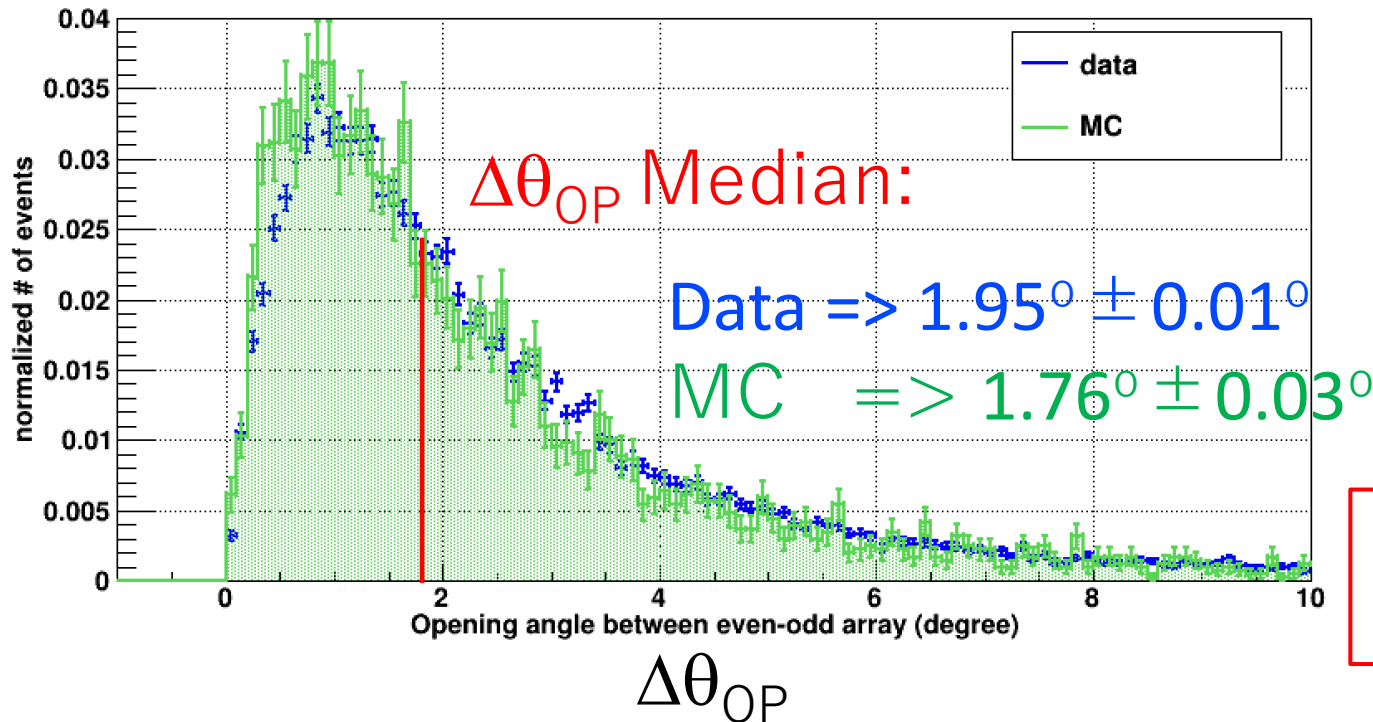
$E > 100$ TeV

Even-Odd Method

✓ For estimation of **angular resolution**

Even-Odd opening angle $\Delta\theta_{OP}$:

Opening angle between directions determined by two independent arrays (even and odd arrays)



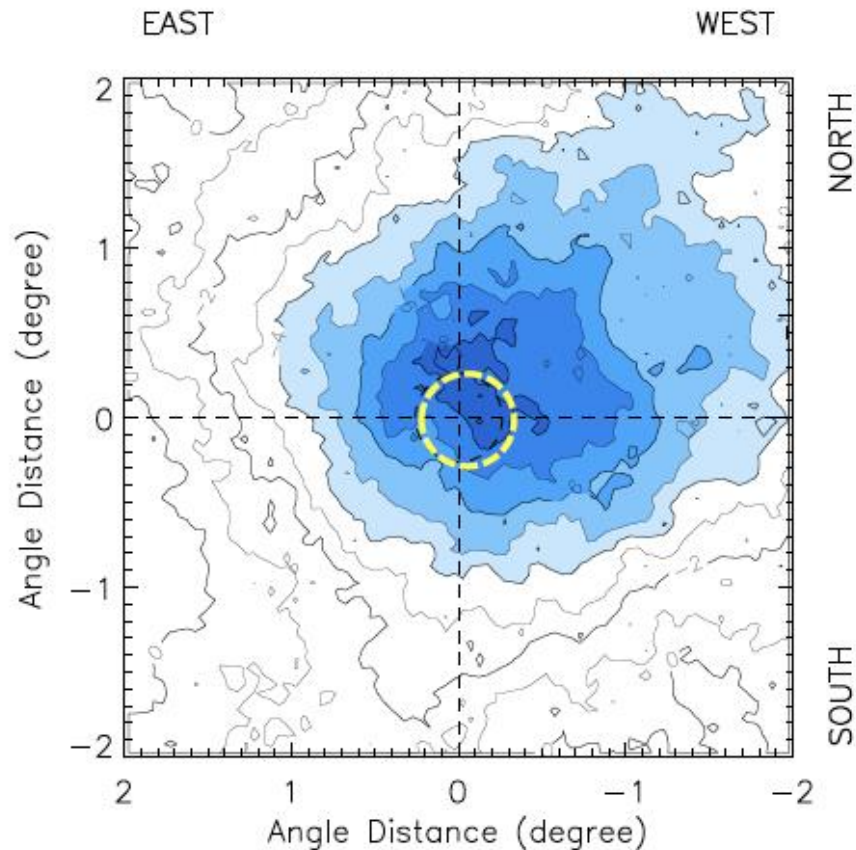
Event selection criteria:

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

✓ Angular resolution
 $\sigma_{50} \sim (\Delta\theta_{OP} \text{ Median}) / 2 = \sim 1^\circ$

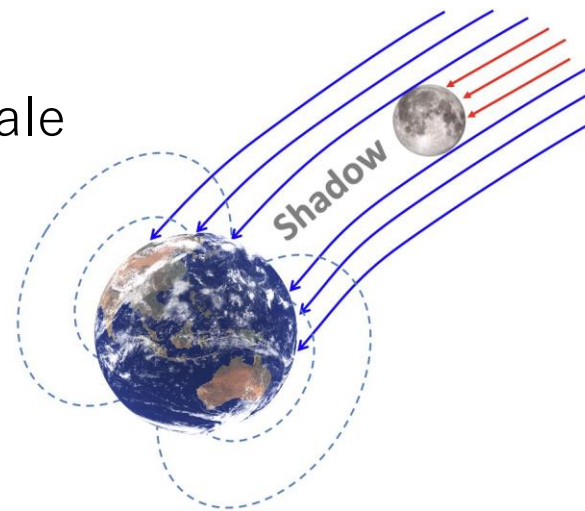
Moon shadow

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



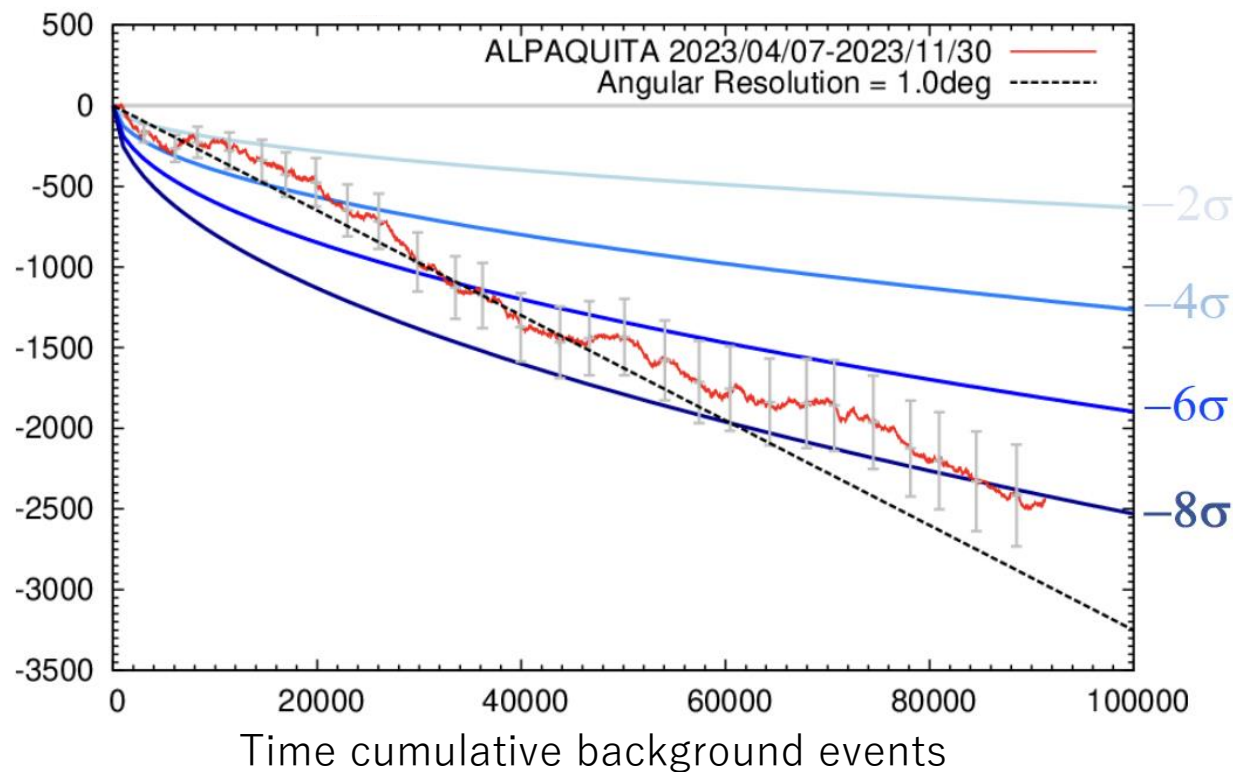
- April 7 – November 30, 2023 (225 days)
- Successful detection at 8.0σ
- Shift westward ~ 0.2 degrees as expected.
- Confirmed ~ 1 degree resolution

Cumulative deficit counts
in Moon direction



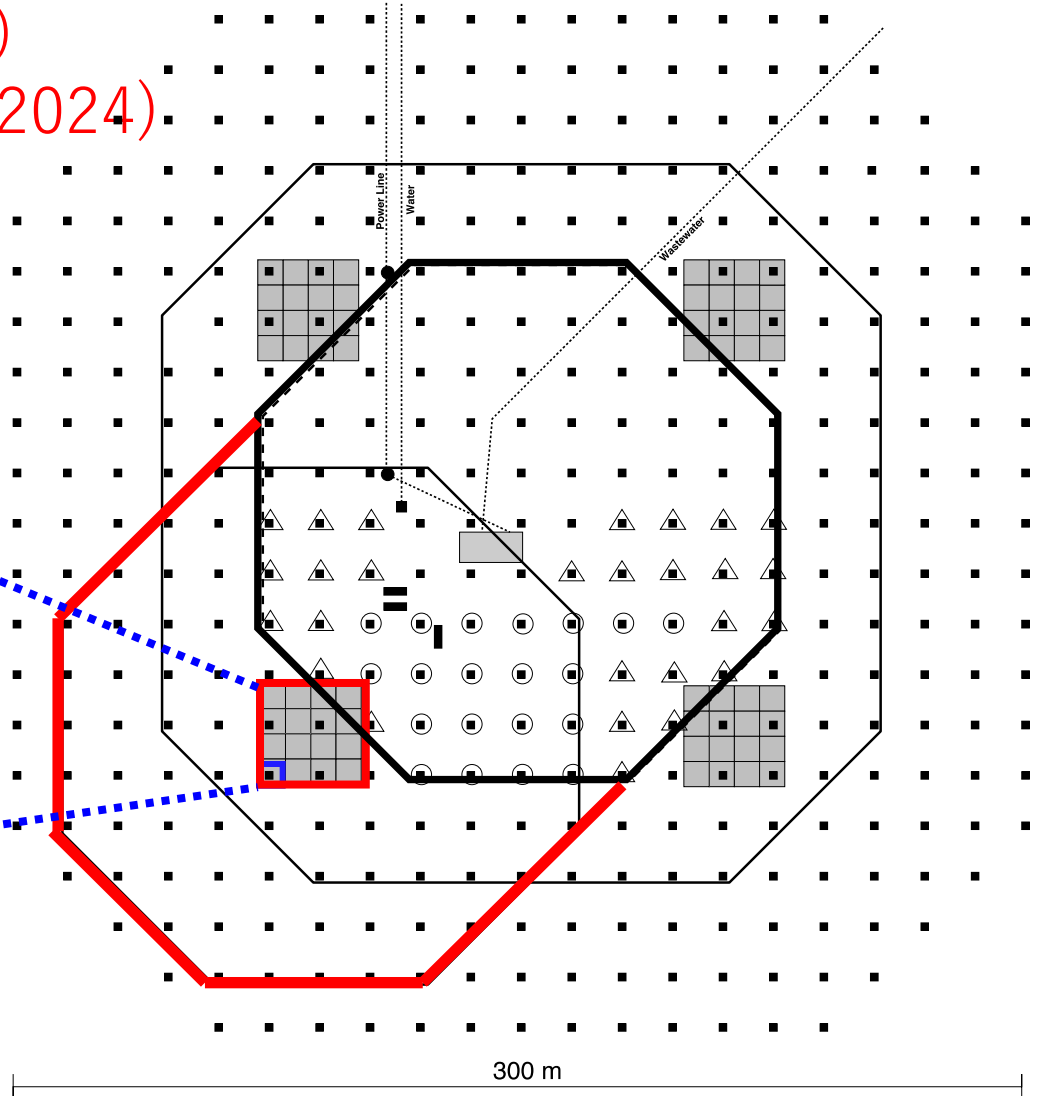
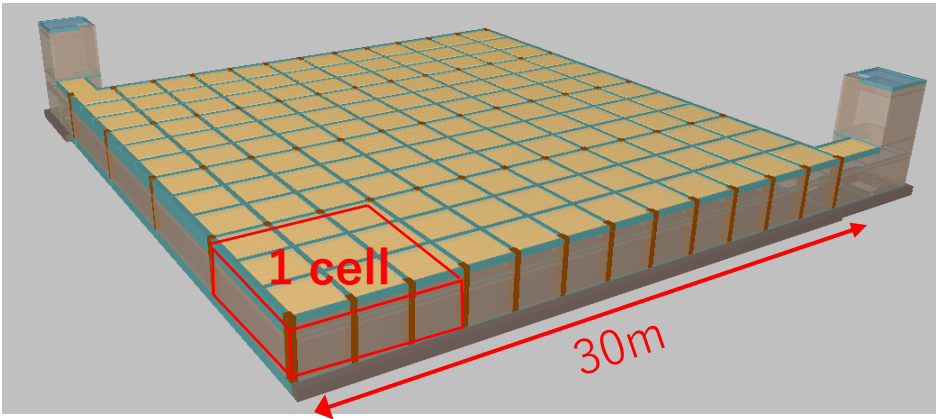
Displacement
by geomagnetic field:

$$\Delta\theta \sim \frac{1.6^\circ}{E[\text{TeV}]}$$



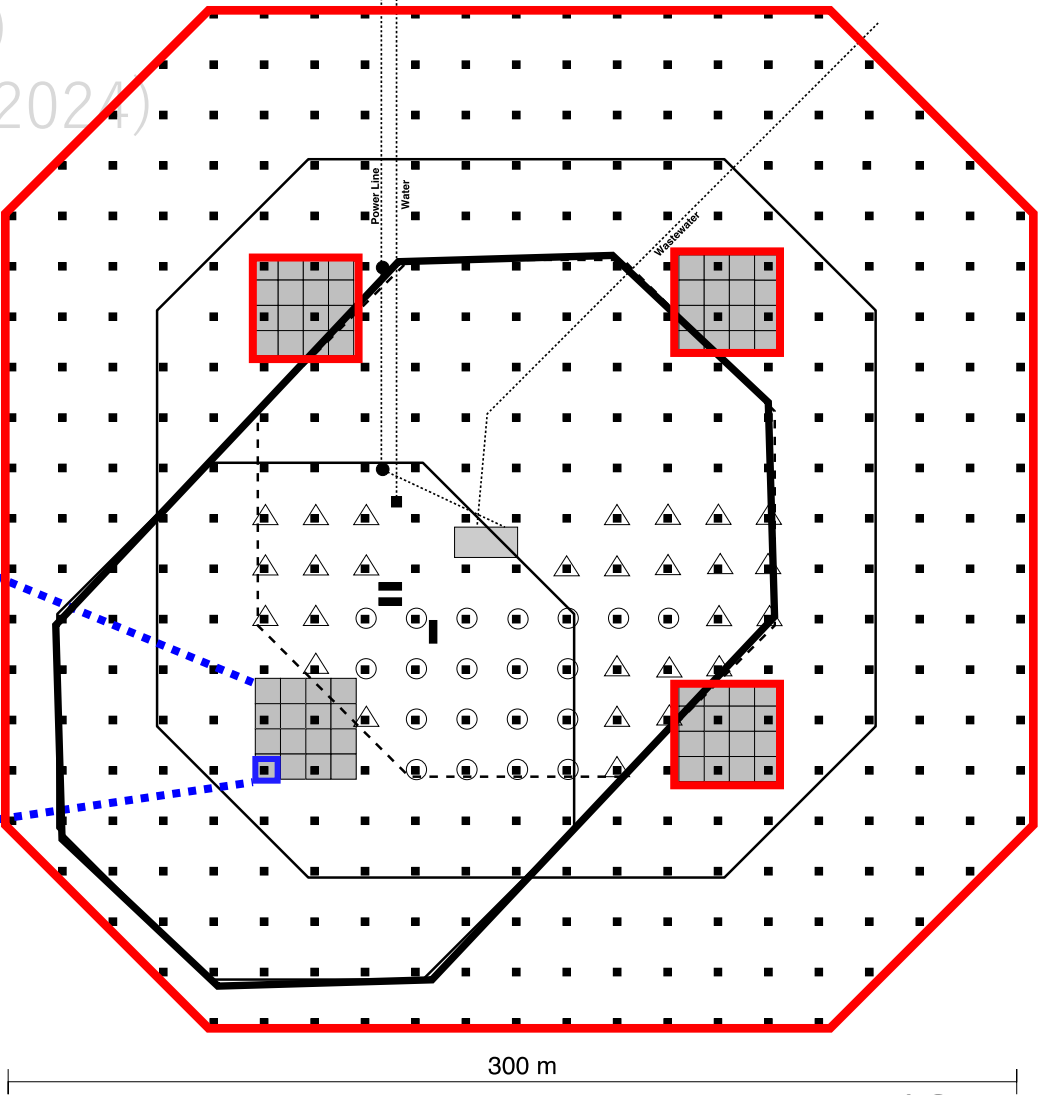
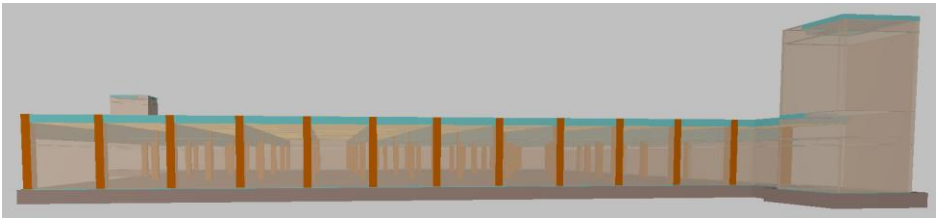
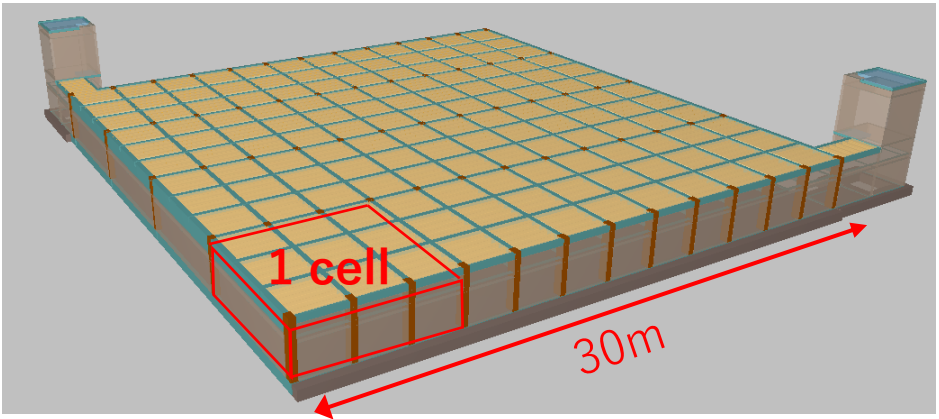
Schedule of ALPAQUITA MD construction

- 1. Construction of the Southwest MD (2024)
- 2. Extension of SDs in the Southwest area (2024)
- 3. Construction of the other three MDs (2025)
- 4. Extension of SDs in the whole area (2025)



Schedule of full ALPACA construction

- 1. Construction of the Southwest MD (2024)
- 2. Extension of SDs in the Southwest area (2024)
- 3. Construction of the other three MDs (2025)
- 4. Extension of SDs in the whole area (2025)





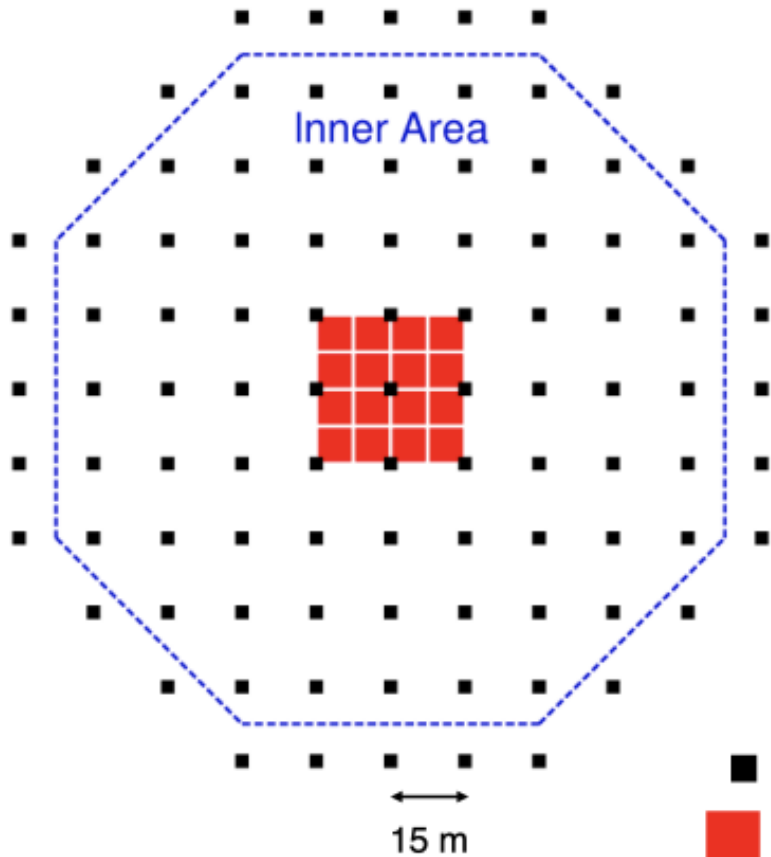
Chicago 2024

Summary & Prospects

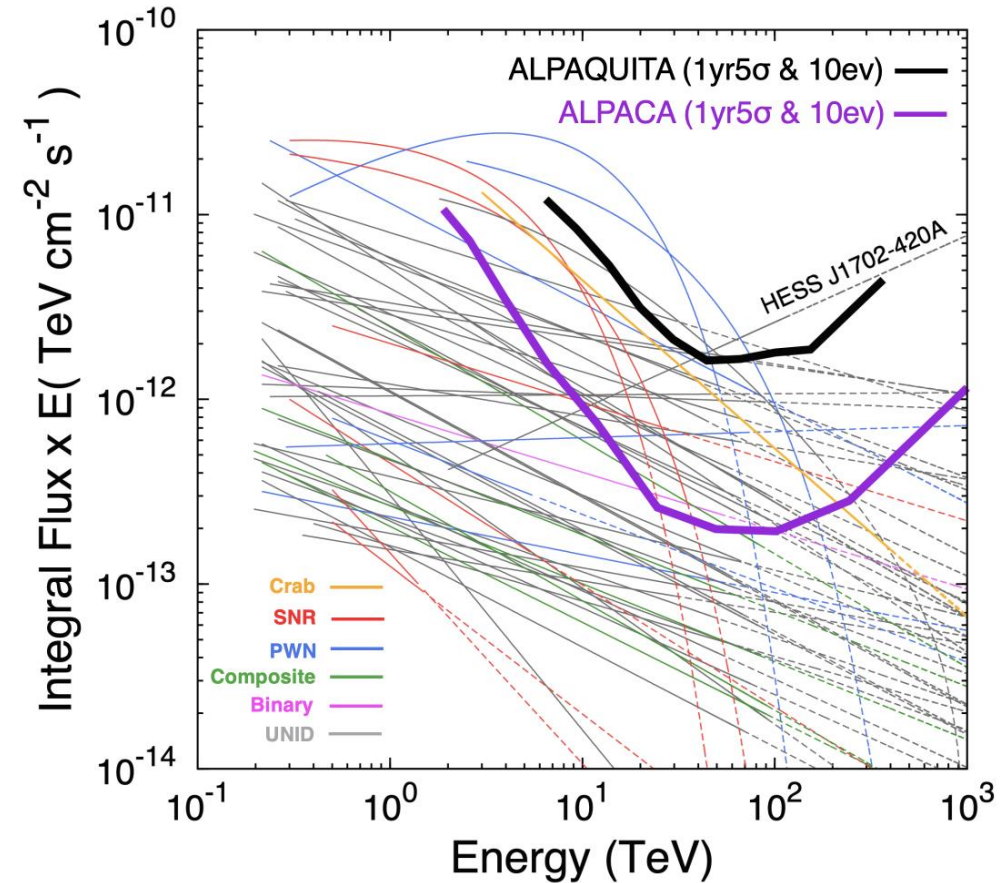
- ✓ALPACA aims to observe sub-PeV gamma-ray sources
in the southern galaxy and the Galactic Center
- ✓ALPAQUITA AS array: 2022-
- ✓Moon Shadow is successfully detected at 8.0σ
- ✓Angular resolution is estimated to be ~ 1 degree (CRs with mode energy < 10 TeV).
- ✓Schedule:
 - ✓Construction of ALPAQUITA with one MD: 2024-
 - ✓Full ALPACA operation (4 MDs): 2025-
 - sub-PeV γ -ray/CR observation will start soon in the southern hemisphere!

BACKUP SLIDES

ALPAQUITA Sensitivity

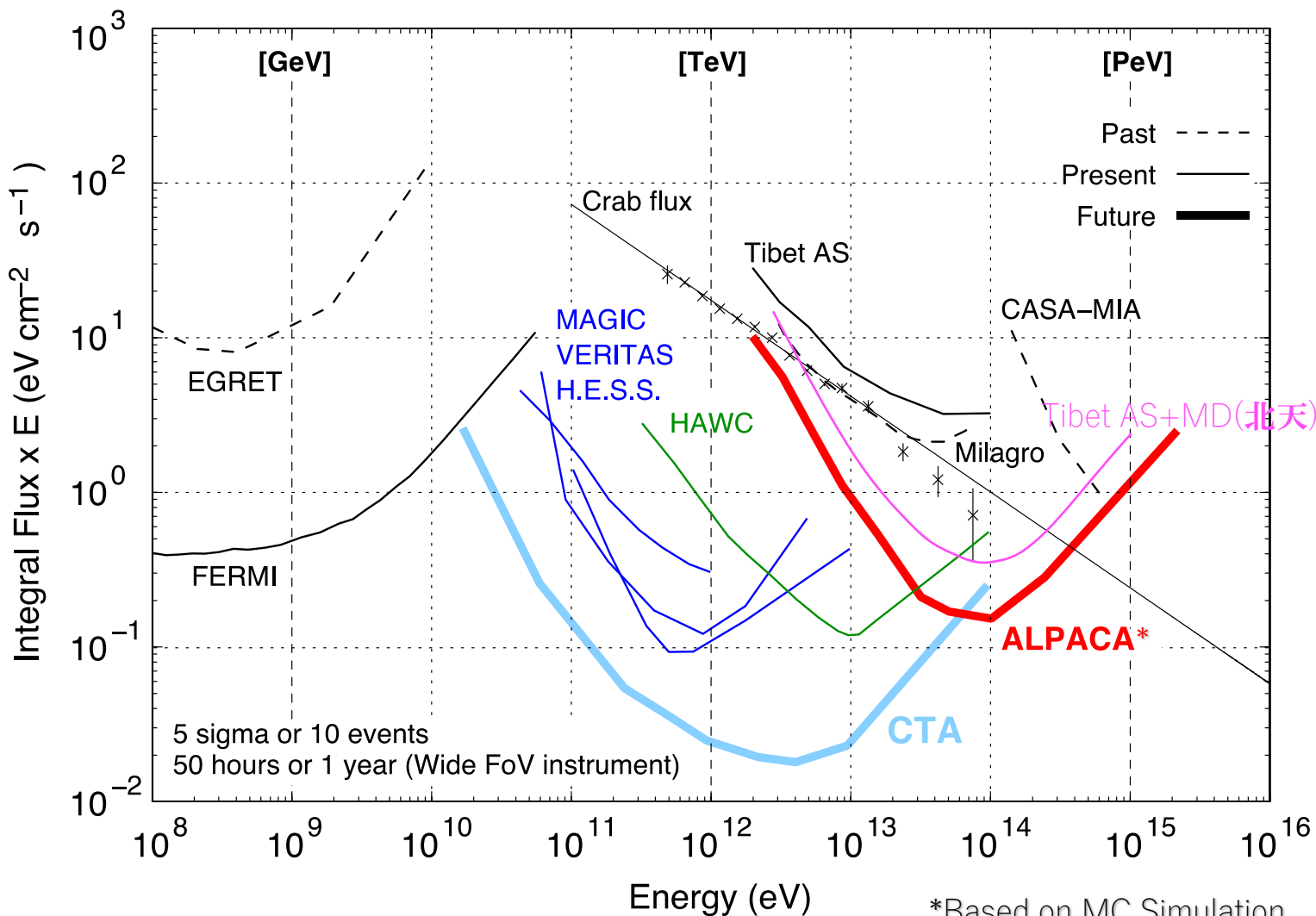
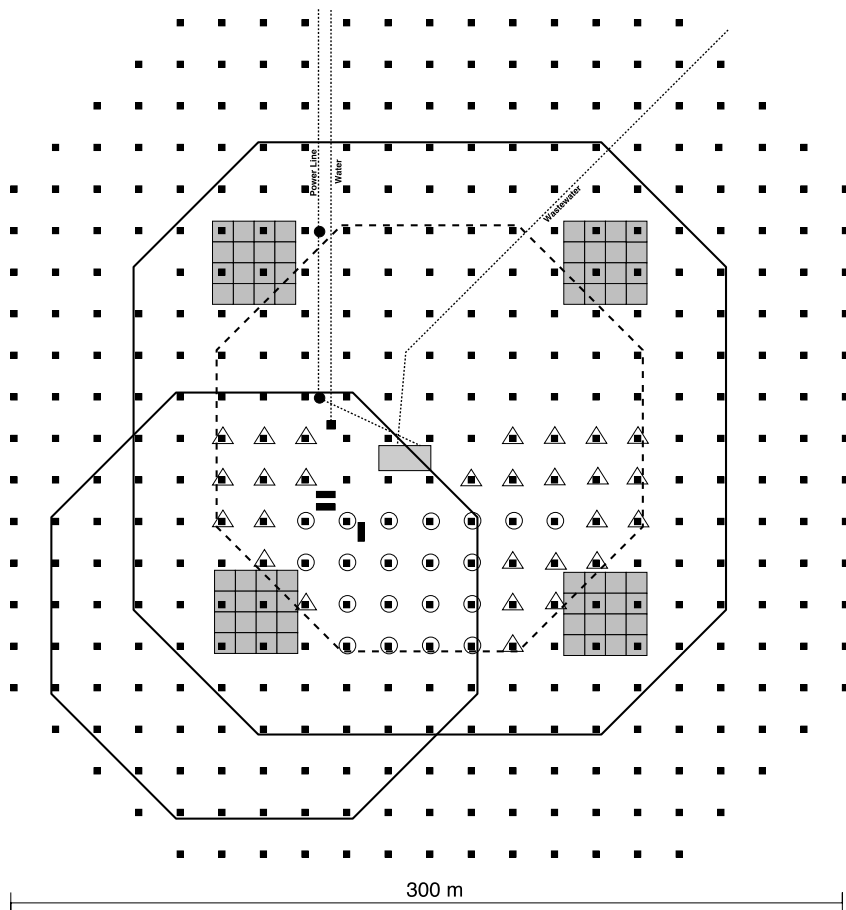


- Plastic scintillators (1 m²)
- MD cells (56 m²)



Kato et al (ALPACA Collob.), Exp. Astro., 52, 85 (2021)

ALPACA Sensitivity



*Based on MC Simulation
For the Tibet AS+MD