



## ボリビア・チャカルタヤ山宇宙線観測所における 高エネルギー $\gamma$ 線・宇宙線観測のための 空気シャワー実験

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横浜国大・工学研究院  
片寄 祐作

令和5年度東京大学宇宙線研共同利用研究成  
果発表会

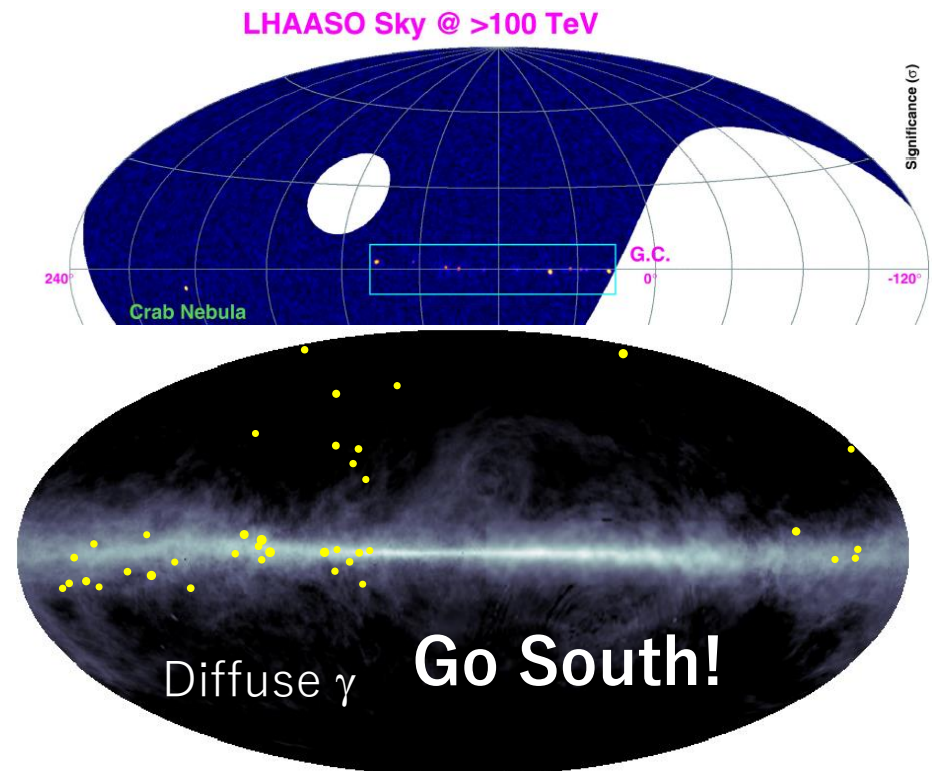
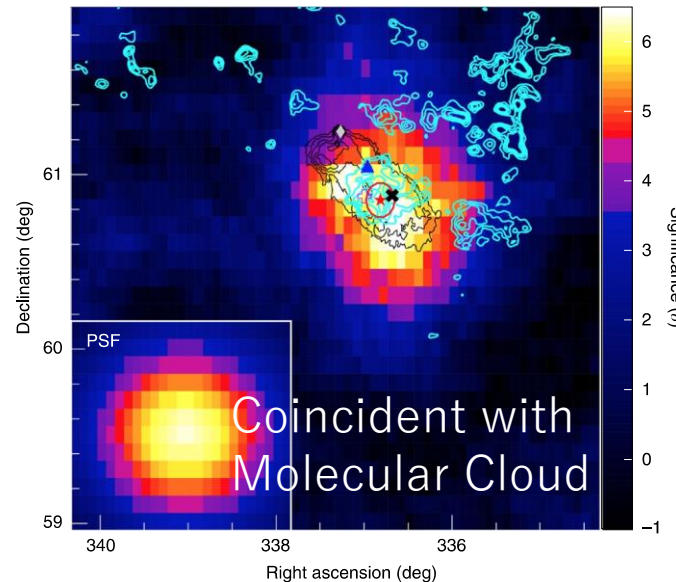
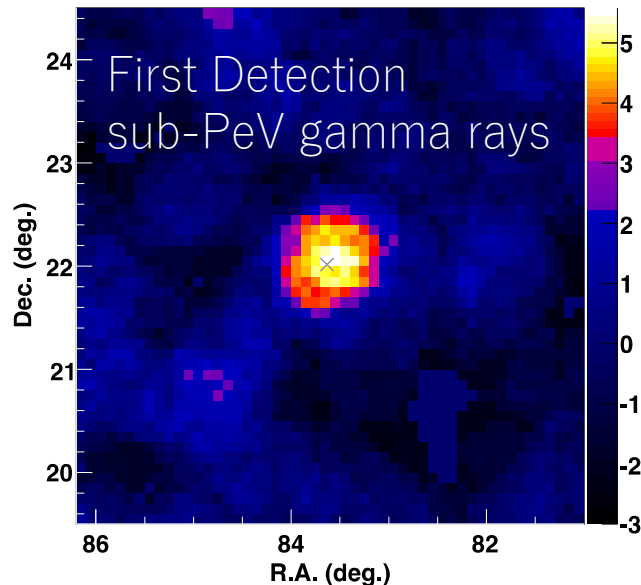
2024年2月22日 13:50 - 14:10

# sub-PeV $\gamma$ -Ray Astronomy

★ sub-PeV  $\gamma$ -ray astronomy developed by Tibet AS $\gamma$ , HAWC, LHAASO

- First detection of sub-PeV  $\gamma$ -rays (Crab Nebula) *Tibet AS $\gamma$ , PRL (2019)*
  - Detection of PeVatron candidate (G106.3+2.7) *HAWC, ApJ (2020) Tibet AS $\gamma$ , Nat. Astron. (2021)*
  - First detection of sub-PeV Galactic diffuse  $\gamma$ -rays *Tibet AS $\gamma$ , PRL (2021)*
  - Detection of dozen sub-PeV  $\gamma$ -ray sources *LHAASO, Nature (2021)*
- All results by air shower arrays

in the northern hemisphere



# The ALPACA Collaboration

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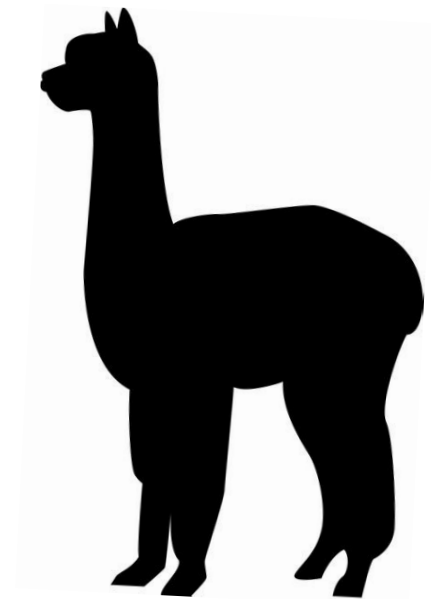
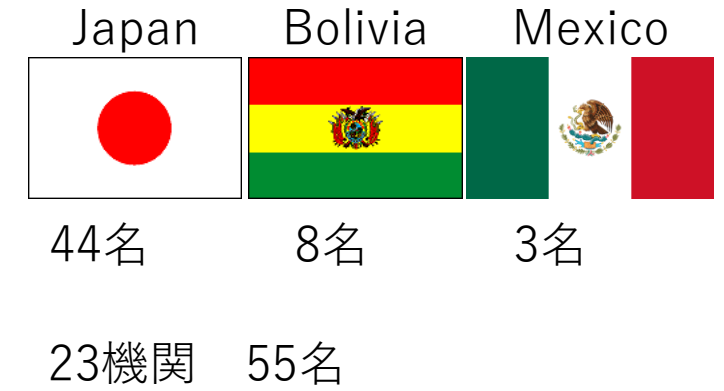
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# 2023年度ボリビア実験関係 共同利用研究採択課題一覧

1. **ボリビア・チャカルタヤ山宇宙線観測所における  
高エネルギー $\gamma$ 線・宇宙線観測のための空気シャワー実験（継続）  
（常定芳基 大阪市立大学大学院理学研究科）**
2. **アンデス高原における雷雲からの高エネルギー放射線の研究（継続）  
（日比野欣也 神奈川大学工学部物理学教室）**
3. **南半球で観測する宇宙線中の太陽の影を用いた太陽磁場の研究（継続）  
（川田和正 東大宇宙線研）**
4. **ボリビア・チャカルタヤ山宇宙線観測所における高エネルギー宇宙線異方性の研究（新規）  
（佐古崇志 東大宇宙線研）**

# ボリビア実験関係共同利用研究 経費執行状況

研究費： 申請額 443.76万円 → 配分額 200万円

チャカルタヤ観測所運営分担金や

ALPAQUITA準備に使用。

旅費： 申請額 558.2万円 → 配分額 139.9万円

ボリビア出張海外旅費や宇宙線研での国内研究打ち合わせなどに使用。

ご支援、どうもありがとうございます！

# 活動状況

## ● ボリビア渡航: 延べ6人 (インフラ整備、装置建設、打ち合わせ等のため)

2023 6/9-6/27	大西宗博 (東大宇宙線研) /	2023 6/9-6/27	川田和正 (東大宇宙線研)
2023 6/9-6/27	加藤 勢 (東大宇宙線研) /	2023 12/5-12/23	佐古崇志 (東大宇宙線研)
2023 12/5-12/23	Anzorena Marcos (東大宇宙線研)		
2023 12/5-12/23	加藤 勢 (東大宇宙線研) /	2024 1/25-2/9	瀧田正人 (東大宇宙線研)

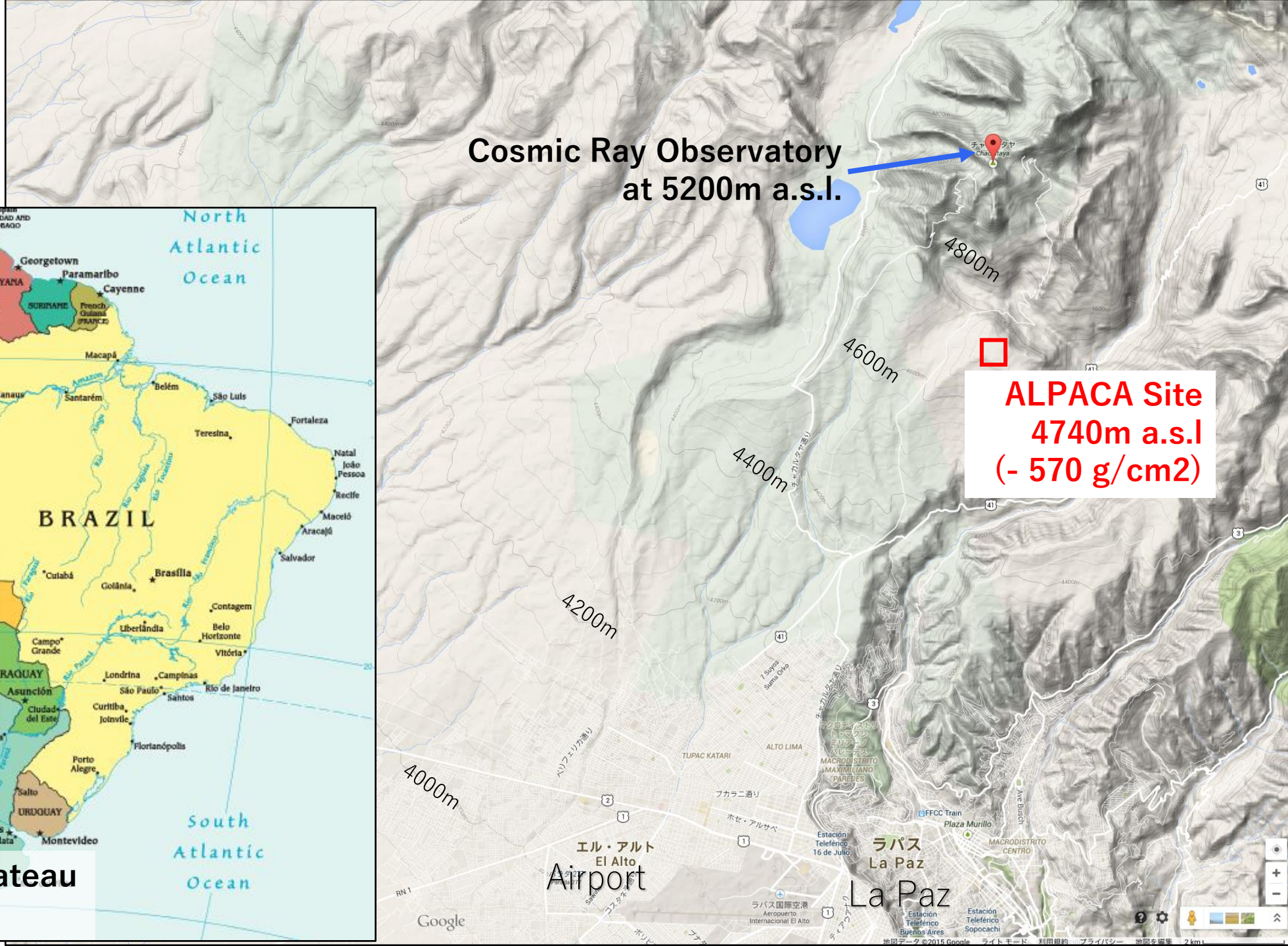
## ● 国際会議など

ICRC 2023 (7/26 - 8/3, Nagoya, Japan)	6講演
The 1st IReNA-Ukakuren Joint Workshop (8/28 - 9/1, Mitaka, Japan)	1講演
Windows on the Universe 2023 (8/6 - 8/12, Quy Nhon, Vietnam)	1講演
XVIII TAUP 2023 (8/28-9/1, Vienna, Austria)	1講演
TeV Particle Astrophysics (9/11 - 9/15, Napoli Italy)	1講演
BSM 2023 (11/6 - 11/9, Hurghada ,Egypt)	1講演

## ● 国内学会など

9/16 - 9/19 日本物理学会 第78回年次大会 (東北大)	4講演
9/19 - 9.22 日本天文学会 2023年秋季年会 (名古屋大)	1講演
3/11 - 3/15 日本天文学会 2024年春季大会 (東京大&オンライン)	1講演 (予定)
3/18 - 3/21 日本物理学会 2024年春季大会 (オンライン)	5講演 (予定)

# ALPACA Site



# ALPACA Project

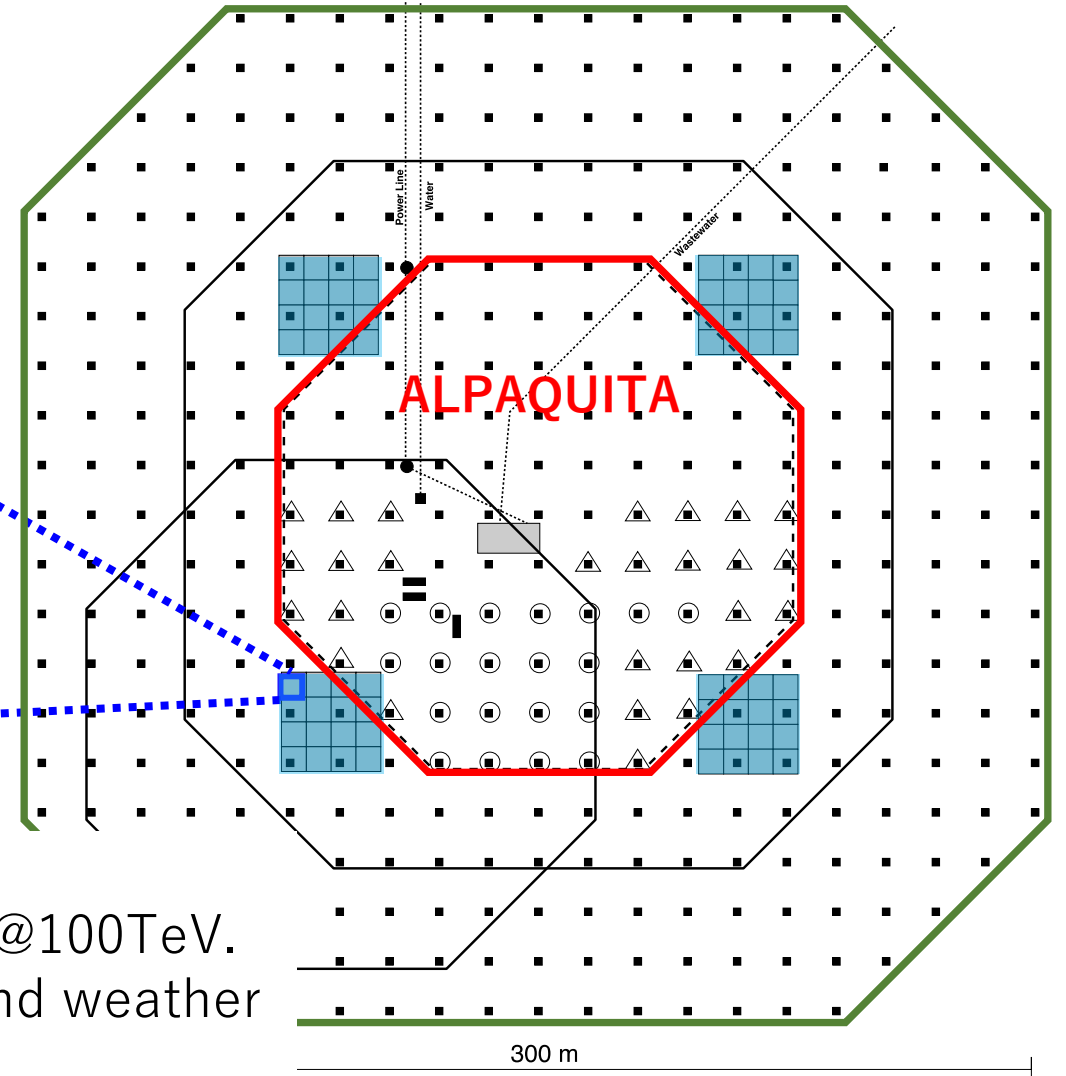
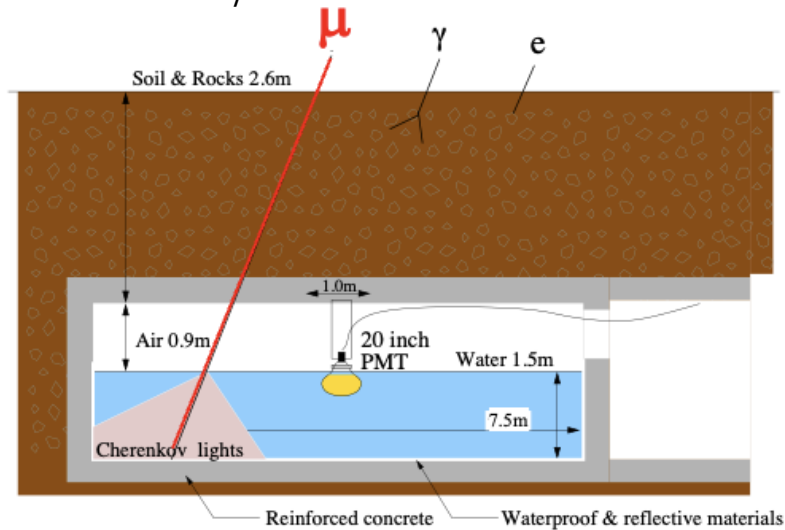
## 1. Air Shower (AS) Array ~83,000m<sup>2</sup>

= 401 x 1m<sup>2</sup> Scintillation Detector

## 2. Underground Muon Detector (MD) ~3600m<sup>2</sup>

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

56m<sup>2</sup> with 20"  $\phi$  PMT x 64 Cells



- ✓ 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 Air Shower Array

$\frac{1}{4}$ ALPACA-scale air shower array  
1m<sup>2</sup> scintillation detector x 97 with 15m spacing  
Effective area ~18,000m<sup>2</sup>



1m<sup>2</sup> 5mm lead plate  
1m<sup>2</sup> 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  $>0.6$  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

# ALPAQUTA建設状況



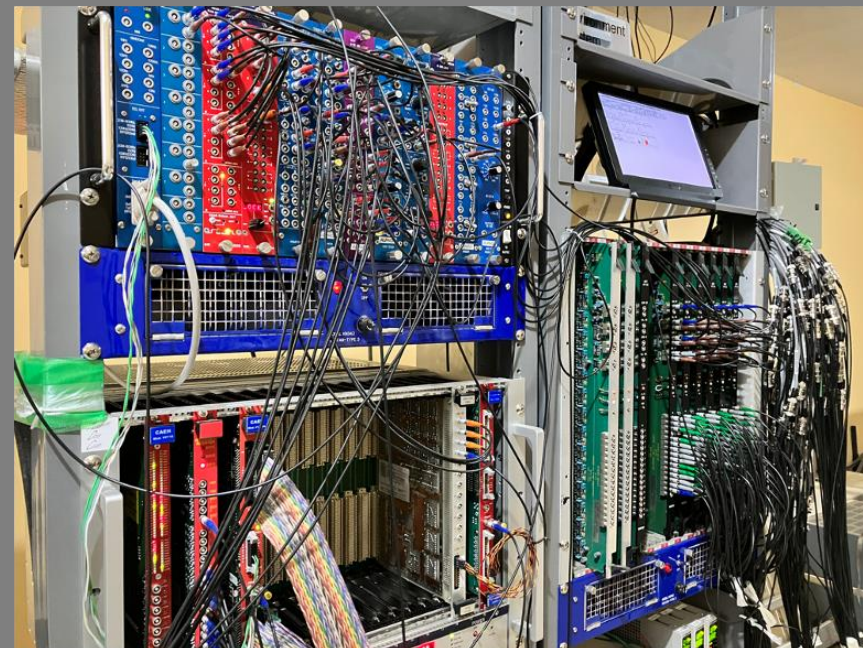
Installation of cables



Installation of PMTs



GPS survey



DAQ system

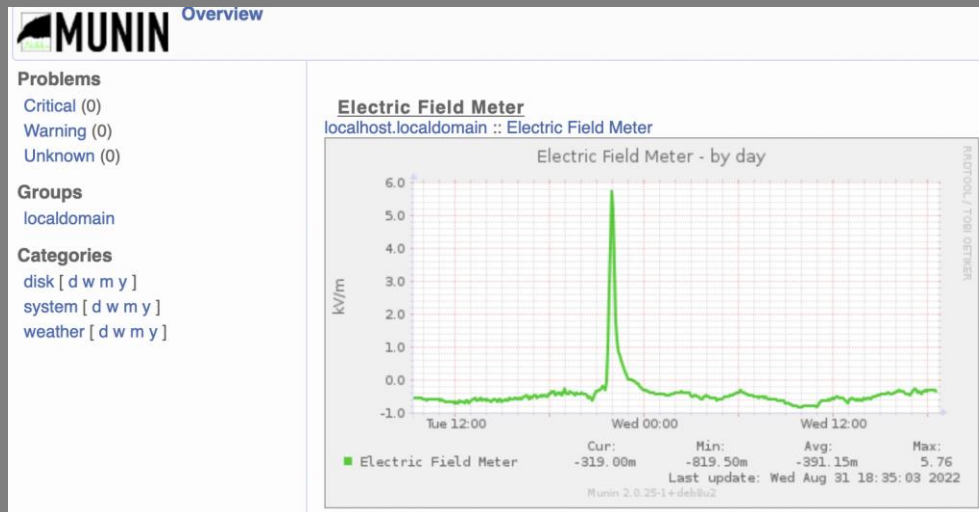
# ALPAQUTA建設状況



Weather monitors



Electric field monitor



# ALPAQUITA Air Shower Analysis

$\gamma$ -ray/cosmic ray

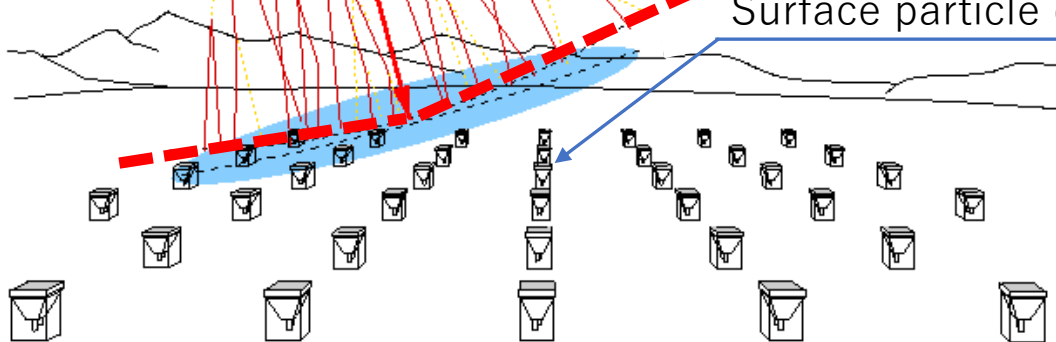
Interaction with atmosphere

Secondary particles (Air shower)

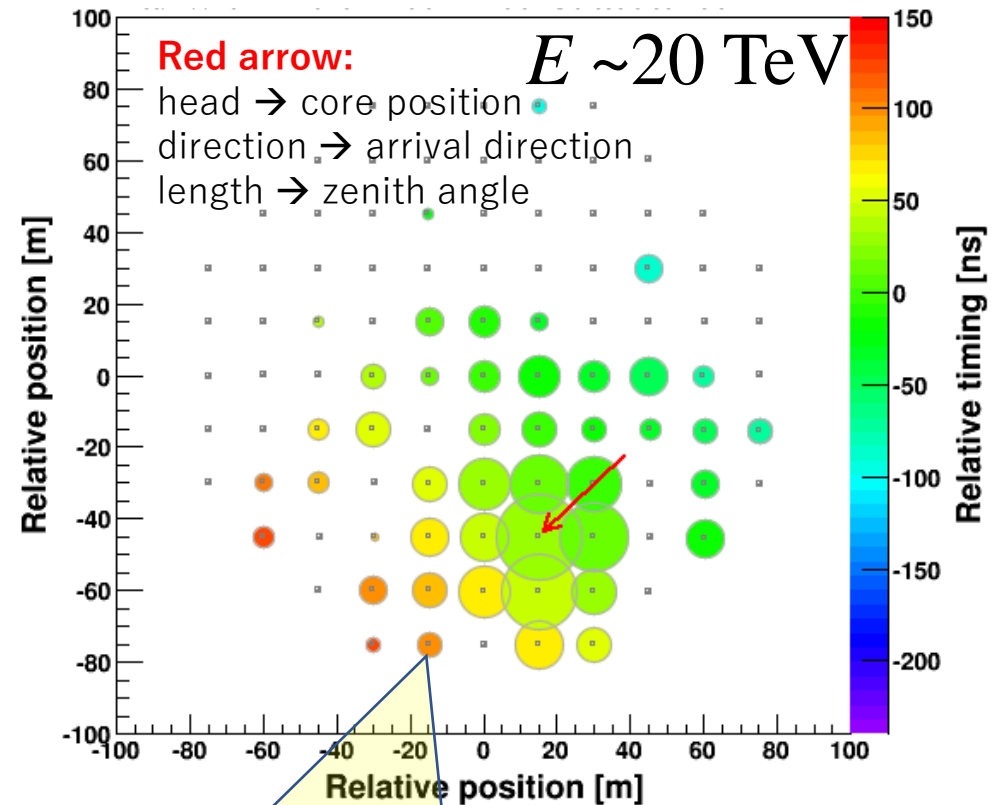
Electromagnetic ( $e^{+/-}$ ,  $\gamma$ )  
Muons ( $\mu^{+/-}$ )  
Hadrons ( $\pi^{+/-/0}$  ...)

conical shape fitting

Surface particle detector



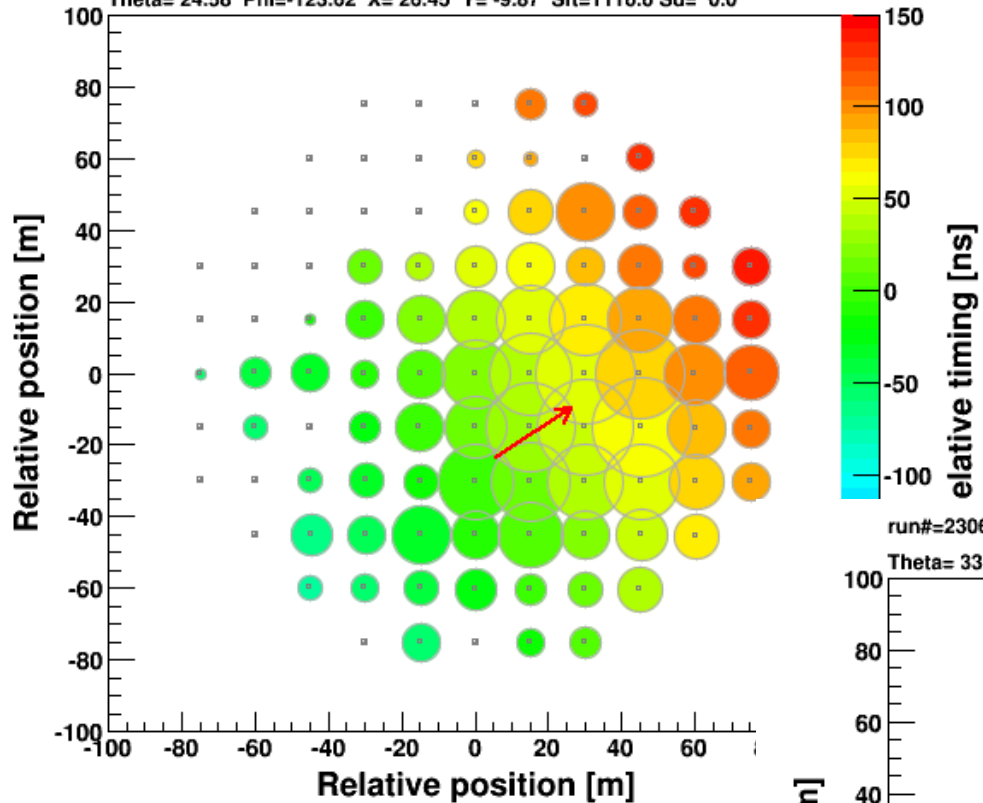
Air Shower Array



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

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

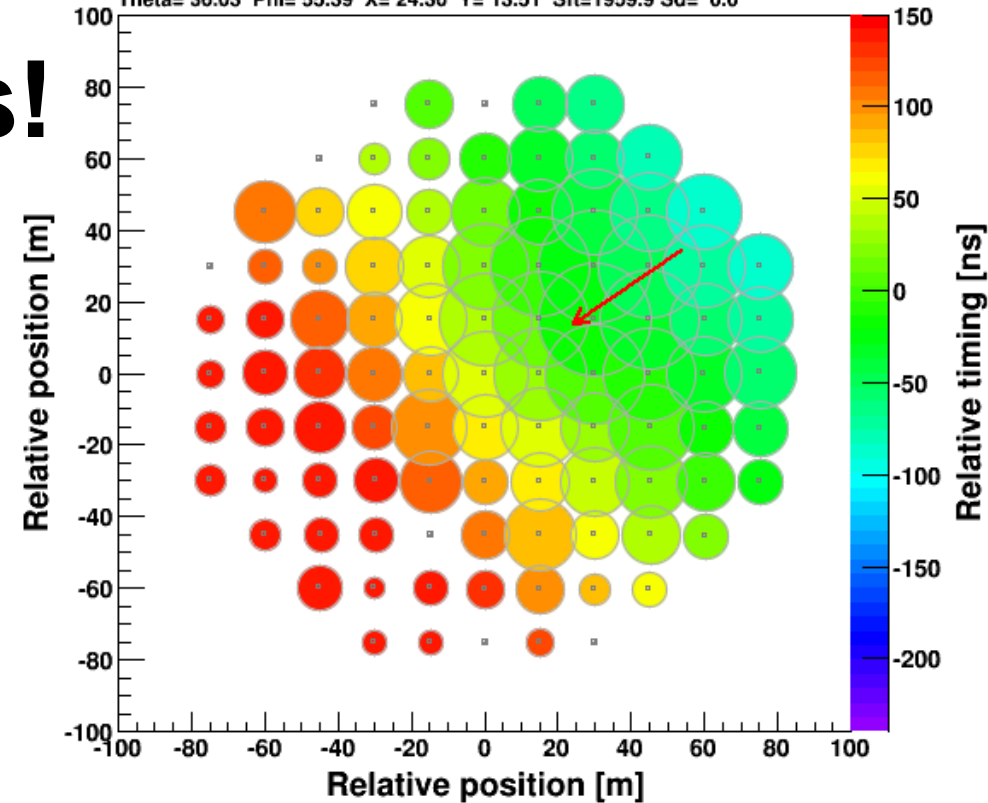
Theta= 24.58 Phi=-123.62 X= 26.45 Y= -9.87 Sft=1116.6 Sd= 0.0



# Big Events!

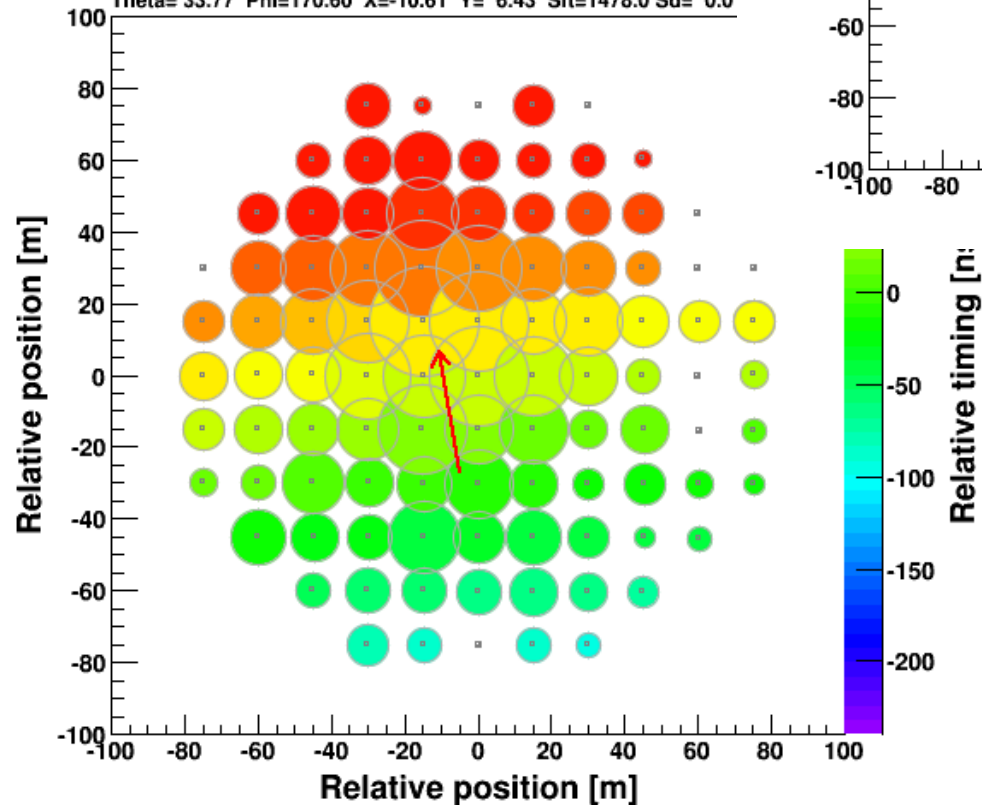
run#=23062501 ev#=111107 mjd=60120.0176029972 #ch= 90

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

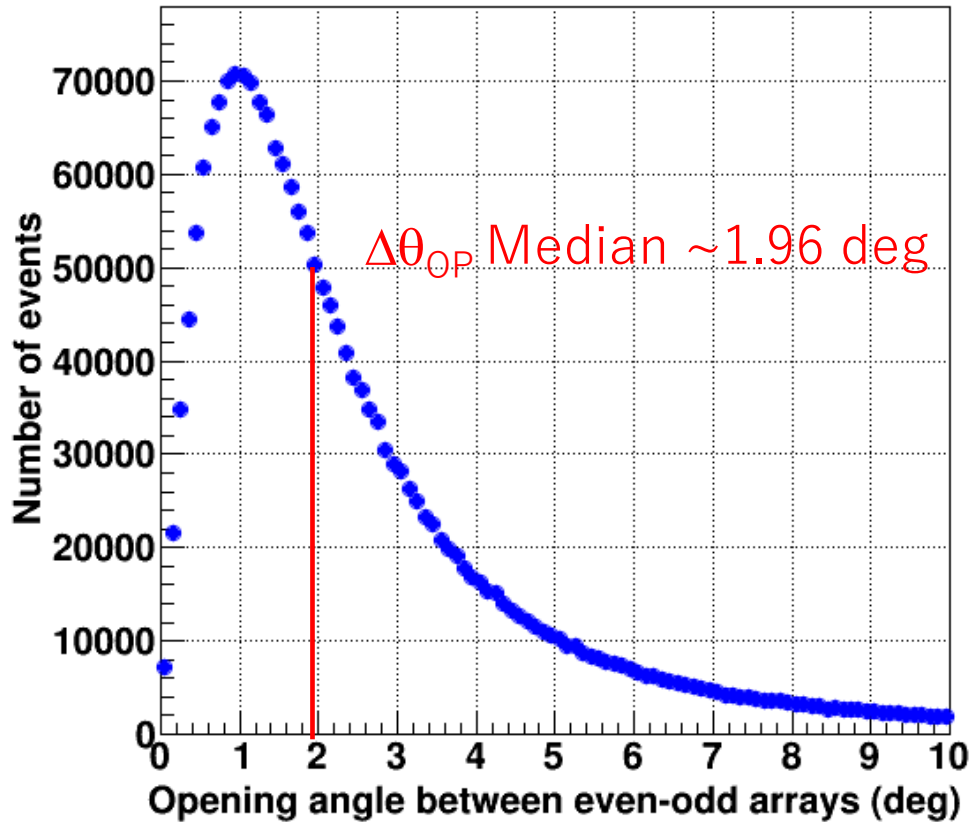
Theta= 33.77 Phi=170.60 X=-10.61 Y= 6.43 Sft=1478.0 Sd= 0.0



$E > 100$  TeV

# Even-Odd Method

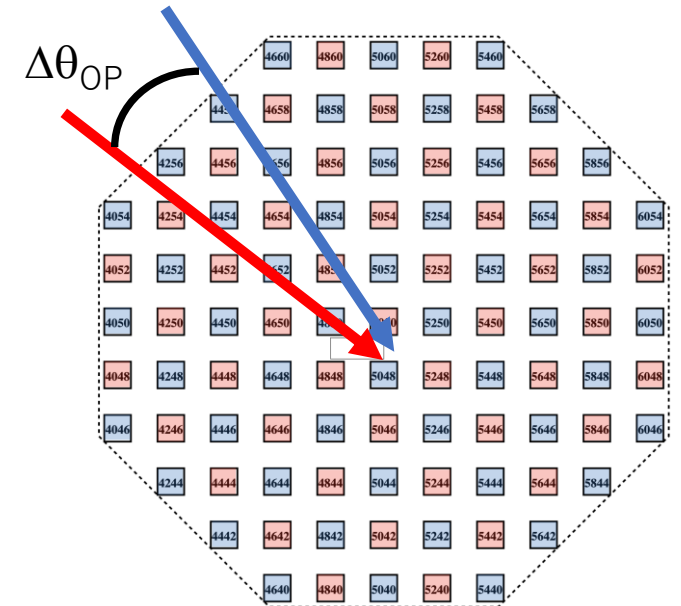
- Event selection criteria:
- Zenith angle < 40deg
  - In Array flag = on
  - 1.25 Any 4 flag = on
  - Residual error < 1.0



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

Angular resolution

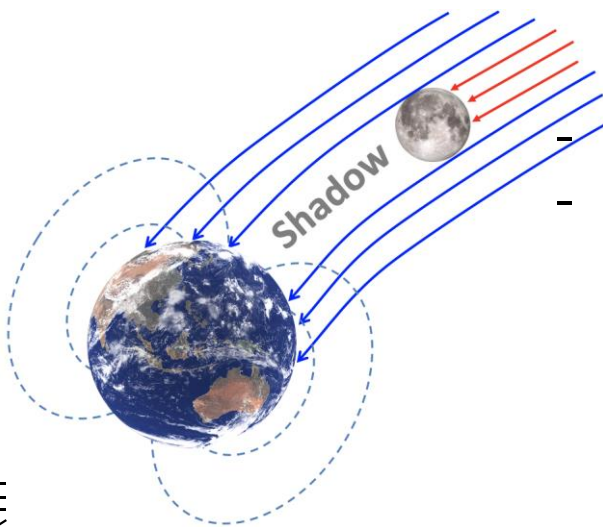
$$\sigma_{50} = \Delta\theta_{OP} / 2 = \sim 1^\circ$$



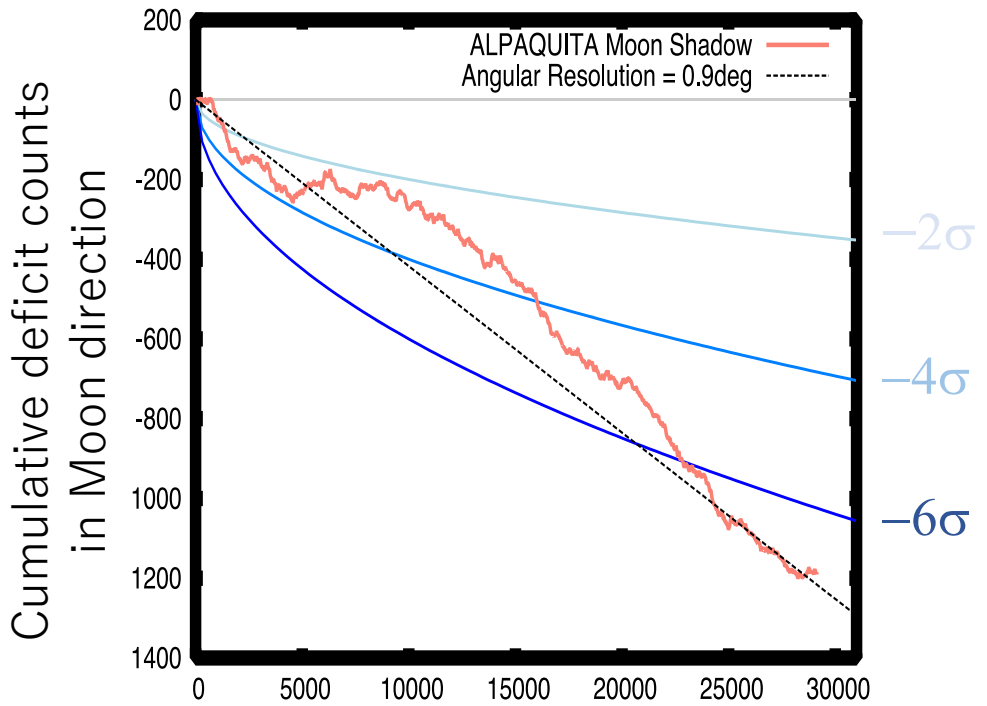
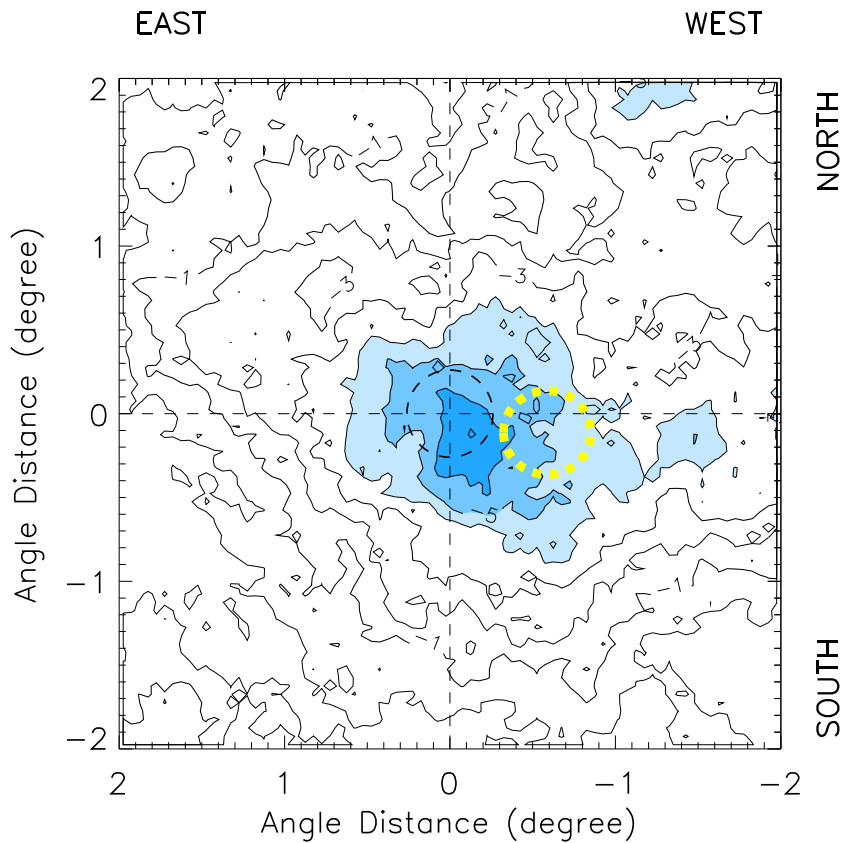
# Moon Shadow Detection

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

- 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  $6.7\sigma$
- Westward shift  $\sim 0.2^\circ$  as expected
- Moon shadow verified  $\sim 0.9^\circ$  resolution



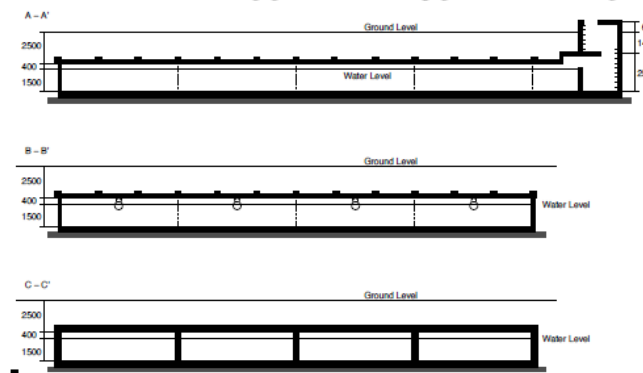
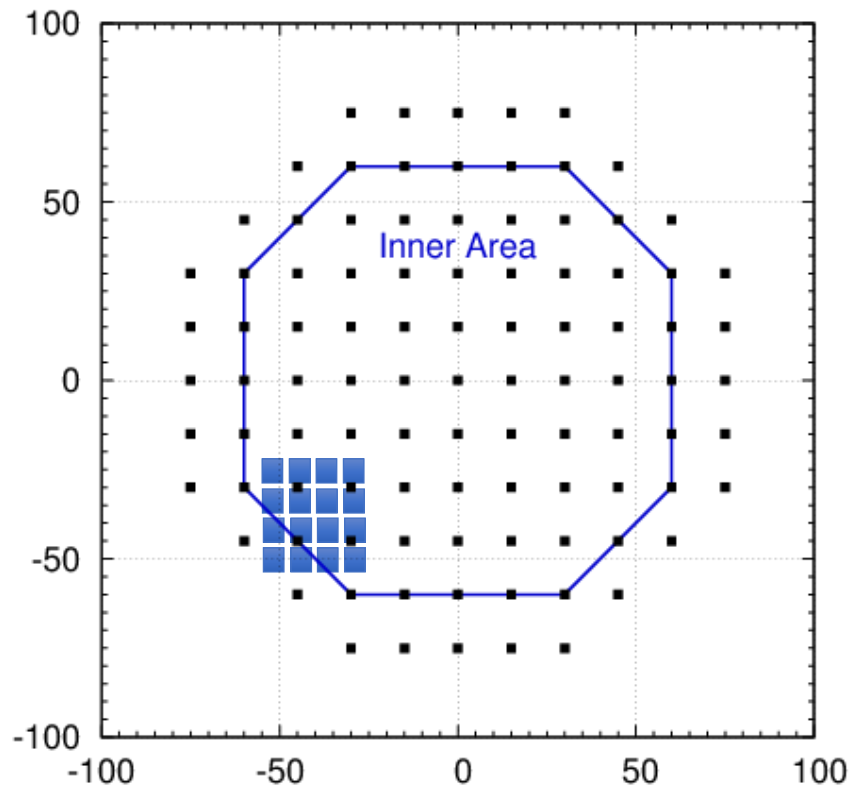
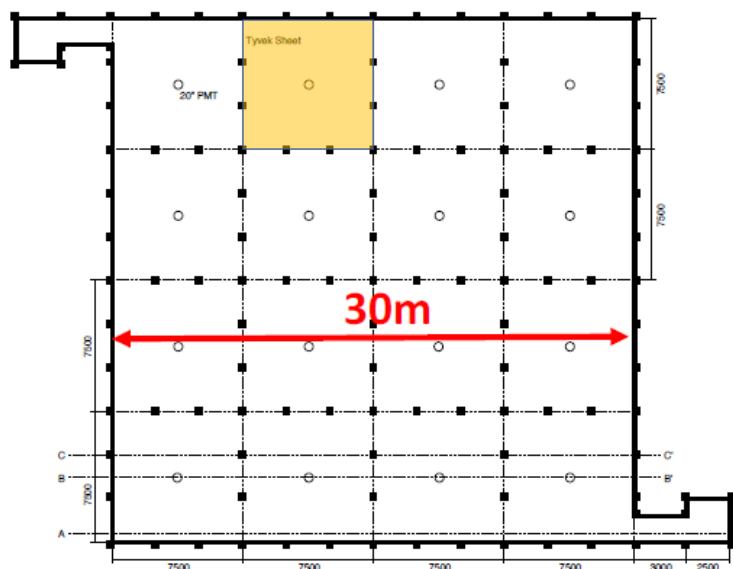
Time cumulative background events

# 今後の予定

## ミューオン検出器

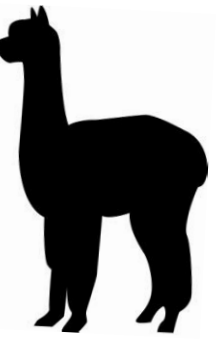
### 2024年度に建設予定

- 土盛り+コンクリート天井2.5m ( $E_{\mu} > 1\text{GeV}$ )
- 7.5m×7.5mのユニットを16基
- 1ユニットあたりPMT 1本
- 内壁をタイベックシートで覆い集光
- 25 p.e./1 MIP (Tibet実績)





# まとめ



- ✓ We successfully detected the Moon Shadow at  $6.7\sigma$  with ALPAQUITA (83 live days).
- ✓ Angular resolution is estimated to be  $\sim 0.9^\circ$  as expected.
- ✓ We will start construction of one underground MD pool in 2024.
- ✓ We will start full ALPACA AS array and 4 MD pools in 2025.
  - sub-PeV  $\gamma$ -ray/CR observation will start soon in the southern hemisphere!

