令和4年度東京大学宇宙線研共同利用研究成果発表会

2023年2月21日　15:25 - 15:45

# 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γ線・宇宙線観測のための空気シャワー実験

神奈川大学　日比野 欣也

# 令和 4年度ボリビア実験関係
# 共同利用研究採択課題一覧

F13 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γ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)

F14 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)

F15 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　東京大学宇宙線研究所)

F16 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（継続）
(佐古崇志　東京大学宇宙線研究所)

F17 Development of new trigger electronics for the ALPACA experiment（新規）
(Marcos Anzorena　東京大学宇宙線研究所)

# 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 493.8万円　→　配分額 185万円

チャカルタヤ観測所運営分担金や

ALPACA建設の一部に使用

旅費：　申請額 558.2万円　→　配分額 213万円

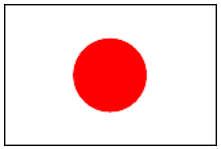
宇宙線研での国内研究打合せやボリビア出張の一部に使用

ご支援、どうもありがとうございました！

# 2022年度のアウトプット (国内：8、国際：6、査読論文：1）

- 国内学会関係
  - ALPACA実験24：建設状況と2022年の計画, 日本物理学会第77回年次大会
  - ALPACA実験25：ALPACA実験の性能評価シミュレーション, 日本物理学会第77回年次大会
  - ALPACA実験24：ALPACA実験26：ガンマ線強度推定におけるハドロン相互作用モデルによる不確定性, 日本物理学会第77回年次大会
  - ALPACA実験27：光電子増倍管のダイナミックレンジの拡張, 日本物理学会第77回年次大会
  - ALPACA experiment 28: status of the ALPAQUITA array and first observations, 日本物理学会秋季大会（岡山理科大 9/6-8）
  - ALPACA実験29：光電子増倍管のダイナミックレンジの拡張, 日本物理学会秋季大会（岡山理科大 9/6-8）
  - ALPACA実験3: ALPAQUITA建設報告2022, 日本天文学会2022年秋季年会(新潟大学 9/13-15)
  - ALPACA 実験におけるガンマ線検出効率のハドロンモデル不定性,太陽地球環境と宇宙線モジュレーション」, 「太陽風プラズマ物理の最新成果と今後の展望」および「太陽圏・宇宙線関連の共同研究成果報告会」 2022年3月2日
- 国際会議関係
  - "ALPACA experiment: A new air shower array to explore the sub-PeV gamma-ray sky in the southern hemisphere”, ICHEP2022 (Bologna), 2022
  - "Hadronic Interaction Model Dependence in Cosmic Gamma-ray Flux Estimation Using Ground-based Air Shower Array with Underground Water Cherenkov muon detector array" , 21st International Symposium on Very High Energy Cosmic Ray Interactions, 2022
  - "The ALPACA experiment: observing sub-PeV gamma-rays in the Southern Hemisphere”, The 27th ECRS, 2022
  - "The performance of the half density ALPACA", The 27th ECRS, 2022
  - "The performance of half density ALPACA for sub-PeV gamma rays from the Galactic Center region", APPC15, 2022
  - "Sensitivity of half density ALPACA for sub-PeV gamma rays from around the Galactic Center", IAUGA2022, 2022
- 査読論文
  - "Hadronic interaction model dependence in cosmic Gamma-ray flux estimation using an extensive air shower array with a muon detector" , Experimental Astronomy (2023)

# The ALPACA Collaboration

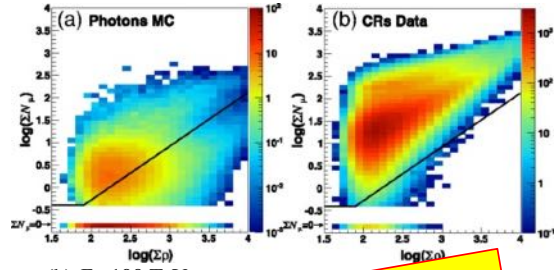



**M. Anzorena [A], C. A. H. Condori [C], E. de la Fuente [D], A. Gomi [E], Y. Hayashi [B], K. Hibino [F], N. Hotta [G], A. Jimenez-Meza [D], Y. Katayose [E], C. Kato [B], S. Kato [A], I. Kawahara [E], T. Kawashima [A], K. Kawata [A], T. Koi [H], H. Kojima [I], D. Kurashige [E], R. Mayta [J,K], P. Miranda [C], K. Munakata [B], K. Nagaya [E], Y. Nakamura [A], C. Nina [C], M. Nishizawa [M], R. Noguchi [E], S. Ogio [A], M. Ohnishi [A], S. Okukawa [E], A. Oshima [H], M. Raljevich [C], H. Rivera [C], T. Saito [N], Y. Sakakibara [E], T. Sako [A], T. K. Sako [A], T. Sasaki [F], S. Shibata [I], A. Shiomi [L], M. Subieta [C], N. Tajima [O], W. Takano [F], M. Takita [A], Y. Tameda [P], K. Tanaka [Q], R. Ticona [C], I. Toledano-Juarez [D], H. Tsuchiya [R], Y. Tsunesada [J,K], S. Udo [F], K. Yamazaki [H], Y. Yokoe [A] et al. (The ALPACA Collaboration)**

*ICRR, Univ. of Tokyo [A], Dept. of Phys., Shinshu Univ.[B], IIF, UMSA [C], Univ. de Guadalajara [D], Fac. of Engn., Yokohama Natl. Univ.[E], Fac. of Engn., Kanagawa Univ.[F], Utsunomiya Univ.[G], Coll. of Engn., Chubu Univ.[H], Astro. Obs., Chubu Univ.[I], Grad. Sch. of Sci., Osaka Metro. Univ.[J], NITEP, Osaka Metro. Univ.[K], Coll. of Ind. Tech., Nihon Univ.[L], NII [M], Tokyo Metro. Coll. of Ind. Tech.[N], RIKEN [O], Fac. of Engn., Osaka Electro-Comm. Univ.[P], Fac. of Info. Sci., Hiroshima City Univ.[Q], JAEA [R]*

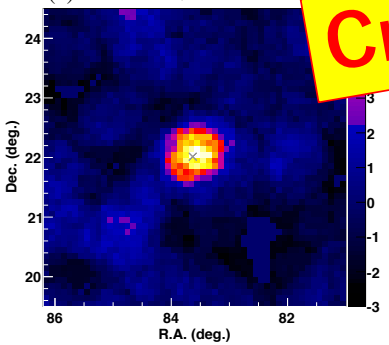
共同研究者51名

# Dawn of sub-PeV gamma-ray astronomy

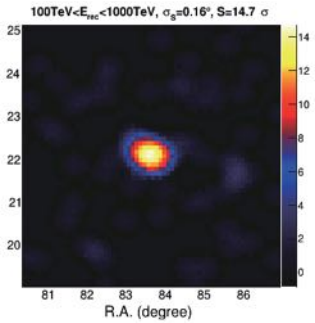



(b) $E$ >100 TeV

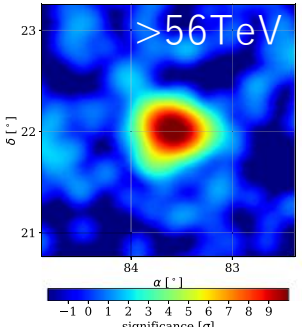
**Crab**



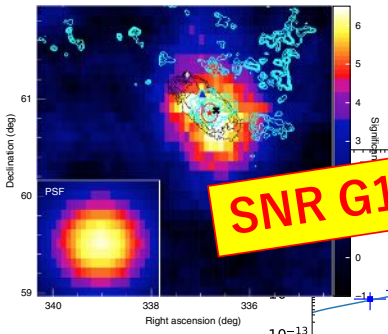

Tibet AS $\gamma$ Collaboration,
PRL 123, 051101 (2019)




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

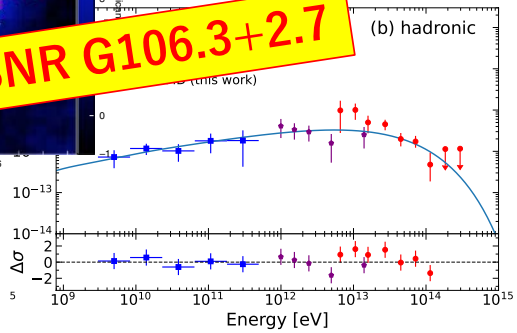


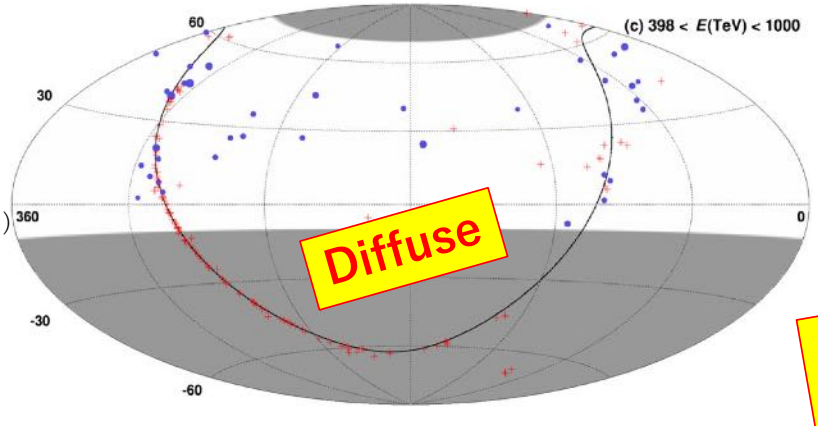

HAWC Collaboration,
ApJ 881:134 (2019)




Tibet AS $\gamma$ Collaboration,
Nature Astron., 5, 460-464 (2021)

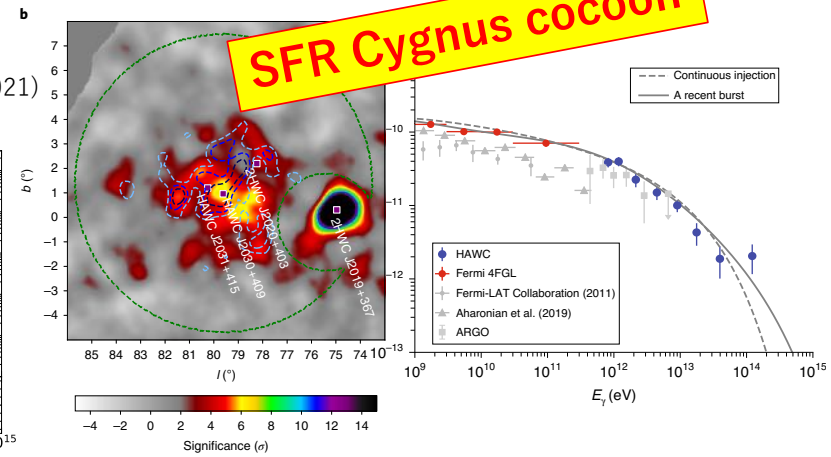
**SNR G106.3+2.7**



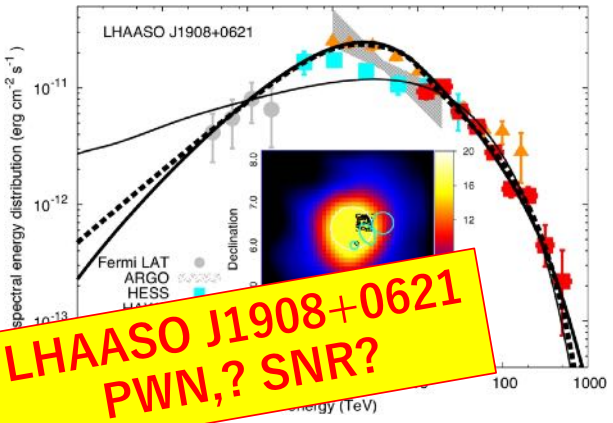




Tibet AS $\gamma$ Collaboration, PRL 126, 141101 (2021)

**SFR Cygnus cocoon**




HAWC Collaboration, Nature Astron., 5, 465-471 (2021)



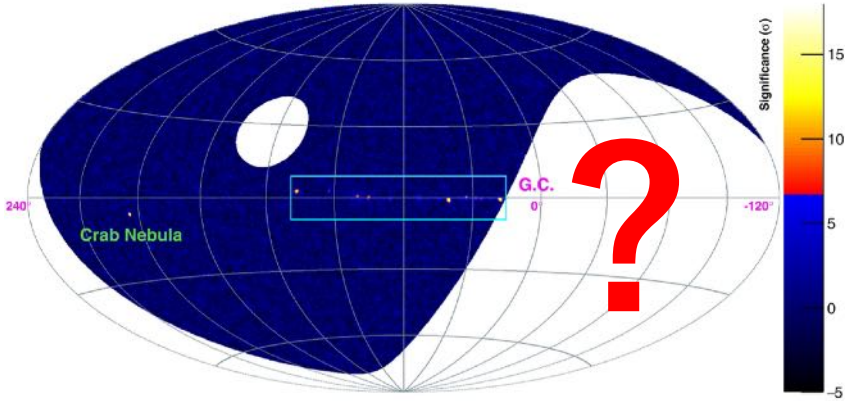

**LHAASO J1908+0621**
**PWN,? SNR?**

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

# Let us go to south!

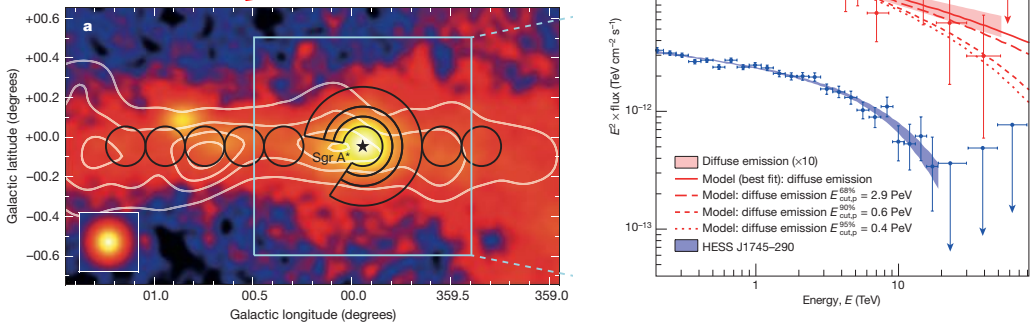
**Tibet ASγ >100TeV diffuse γ**


**LHAASO Sky @ >100 TeV**



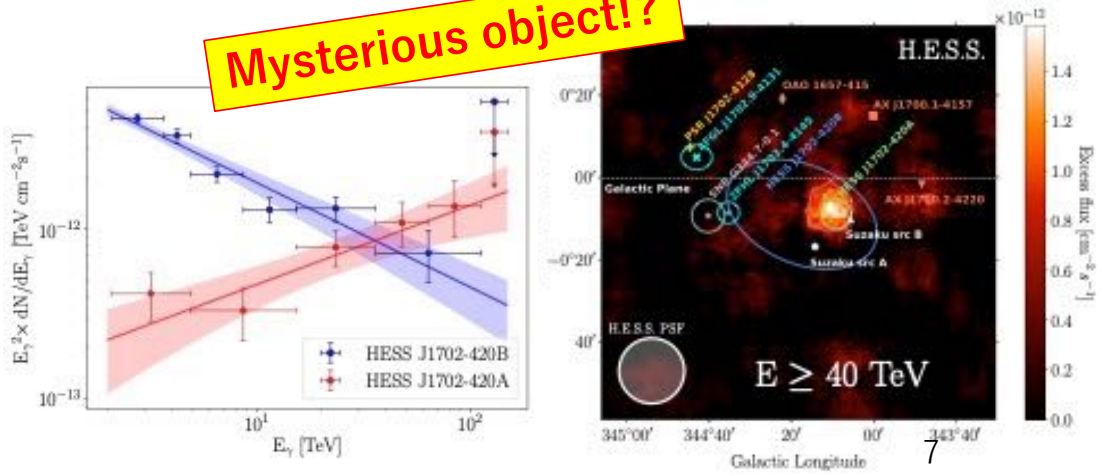

LHAASO Collaboration, Nature, 594, 33-36 (2021)

**Galactic center**




HESS Collaboration, Nature, 531, 476-479 (2016)

**Mysterious object!?**

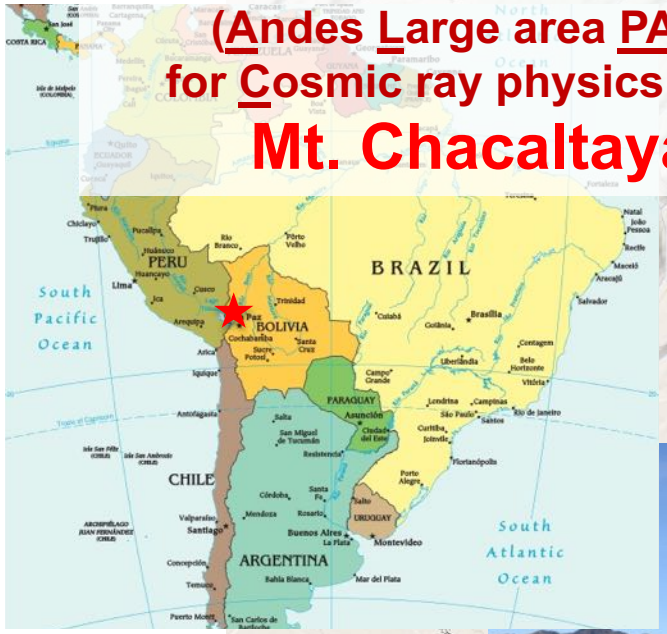


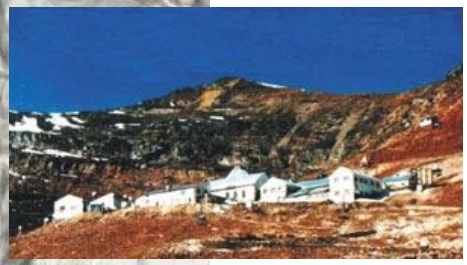

HESS Collaboration, arXiv:2106.06405 (2021)

# ALPACA

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

**Mt. Chacaltaya, Bolivia**



**UMSA CR Observatory**
**5200 m a.s.l.**

4600m

4400m

**ALPACA site**
**4740 m a.s.l.**

4,740 m above sea level
(16° 23′ S, 68° 08′ W)

~570 g/cm$^2$

**La Paz**

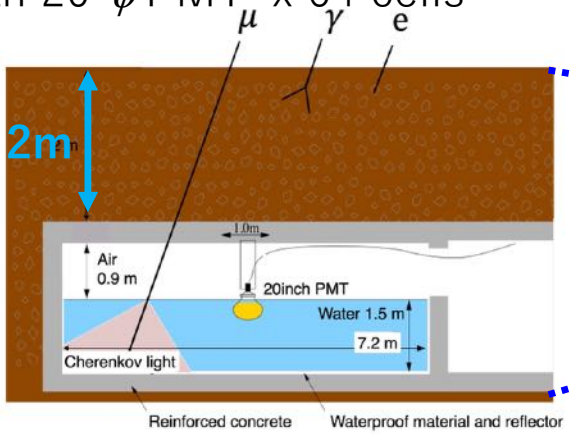


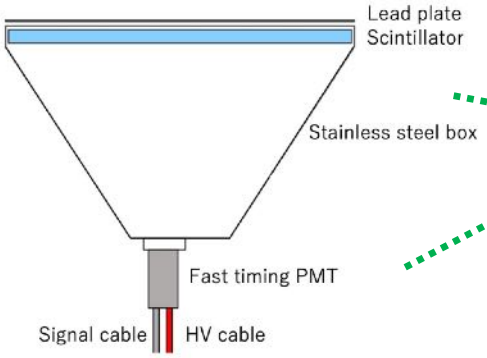
8

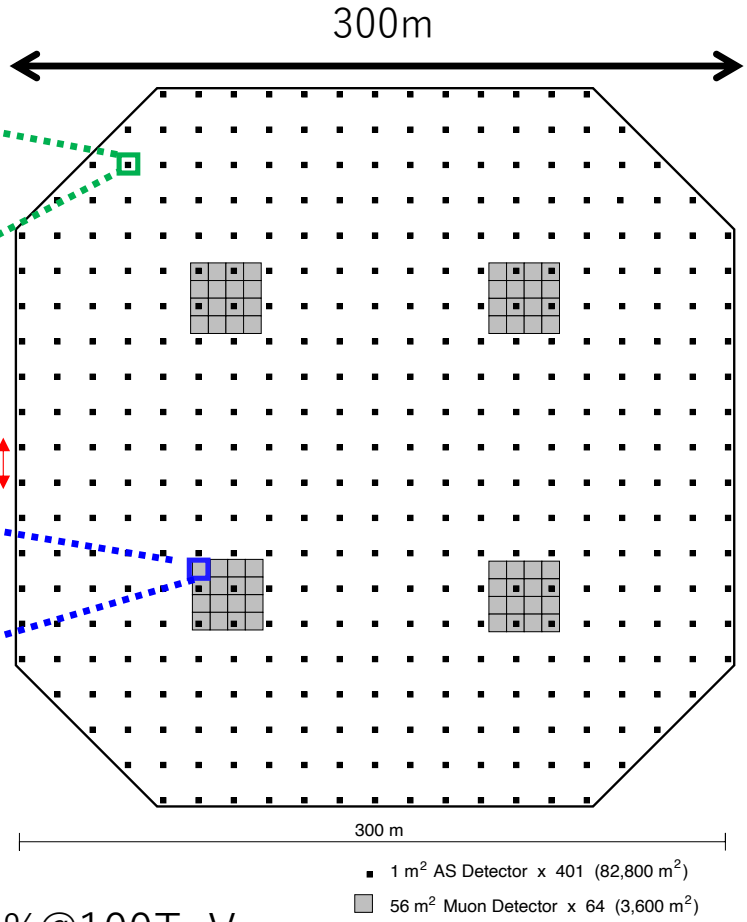
# Original ALPACA design

1. **Array coverage 82,800m²**
   = 401 x 1m² plastic scintillators

2. **Underground water Cherenkov muon detector (MD) 3600m²**
   Soil over 2m (~16$X_0$)
   = 56m² with 20"$\phi$PMT x 64 cells

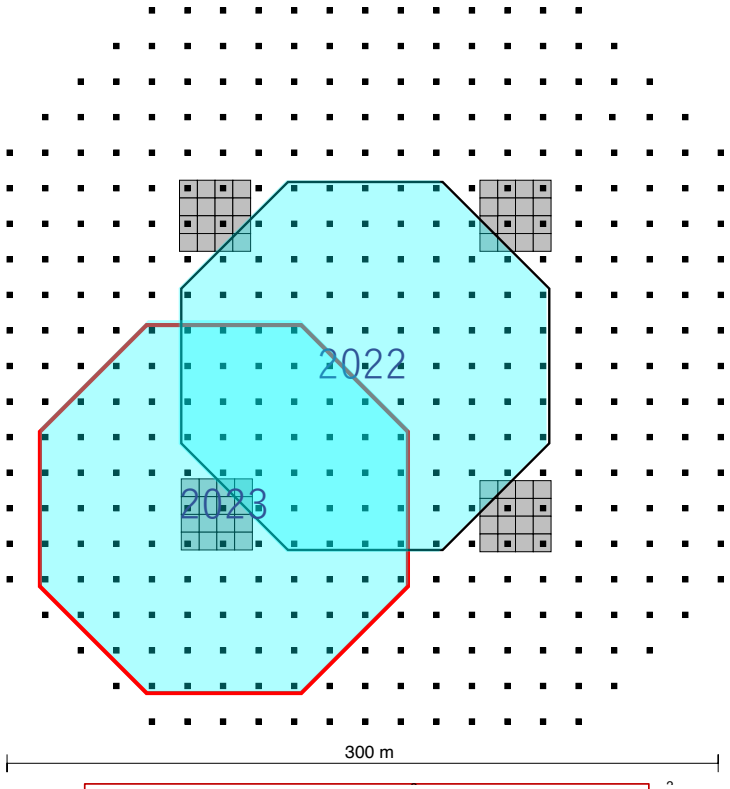


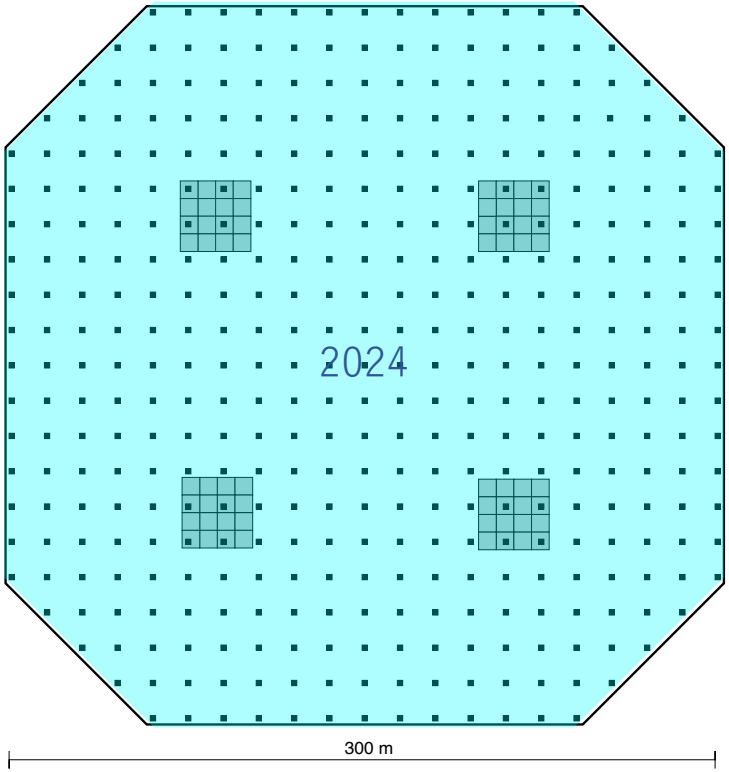

- ✓ Cosmic-ray BG rejection power >99.9% @100TeV.
- ✓ Angular resolution ~0.2° @100TeV, Energy resolution ~20%@100TeV
- ✓ 100% duty cycle, FOV $\theta_{zen}$<40° (well studied), $\theta_{zen}$<60° (in study)

# ALPACA staging plan




**ALPAQUITA in 2023**

**(97 + 60) SDs + 1 MD**

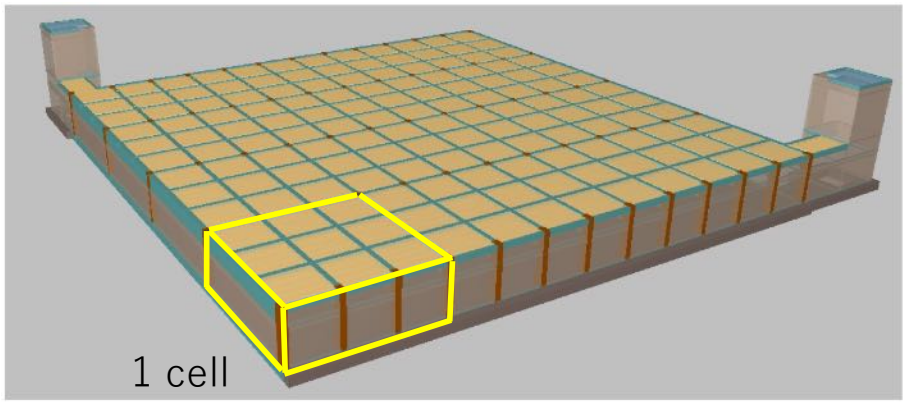


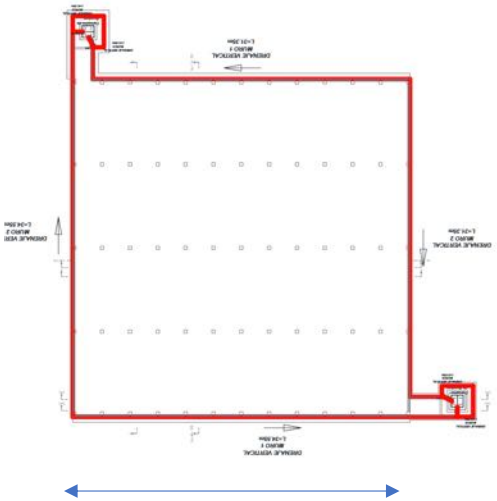

**ALPACA in 2024**

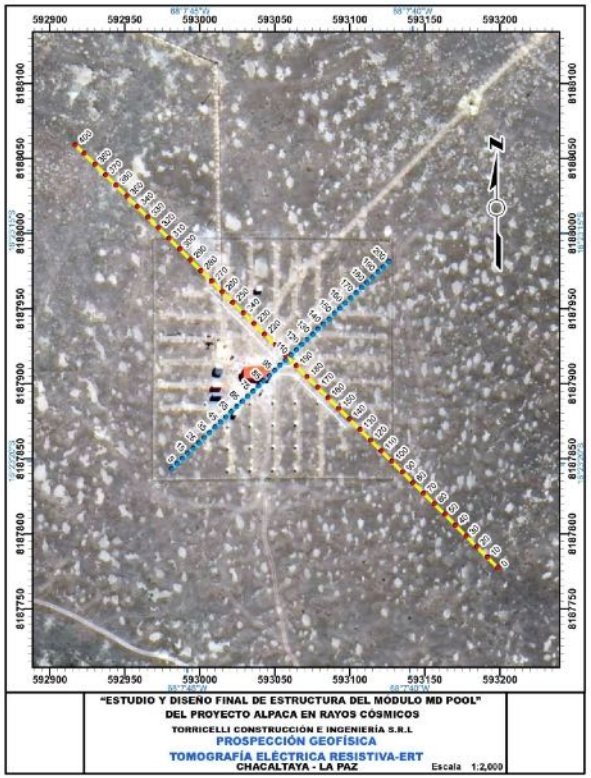
**401 SDs + 4 MD**

# MD design (1 MD = 4 x 4 cells)

地質調査　⇒　問題無し



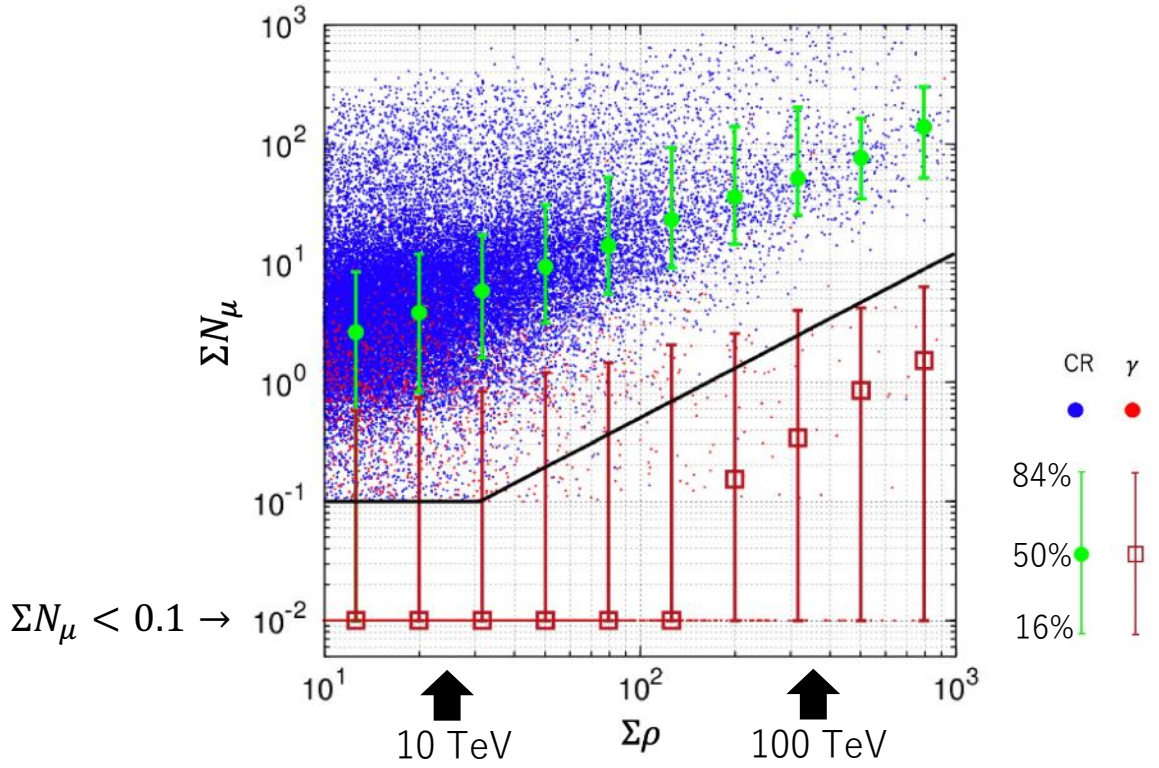




2023: 1 MD
2024: 3 MDs

# Muon Selection Criterion

*To maximize the detection significance of signal $\gamma$ rays*

$\Sigma N_\mu$ : Total number of muons recorded with the muon detector

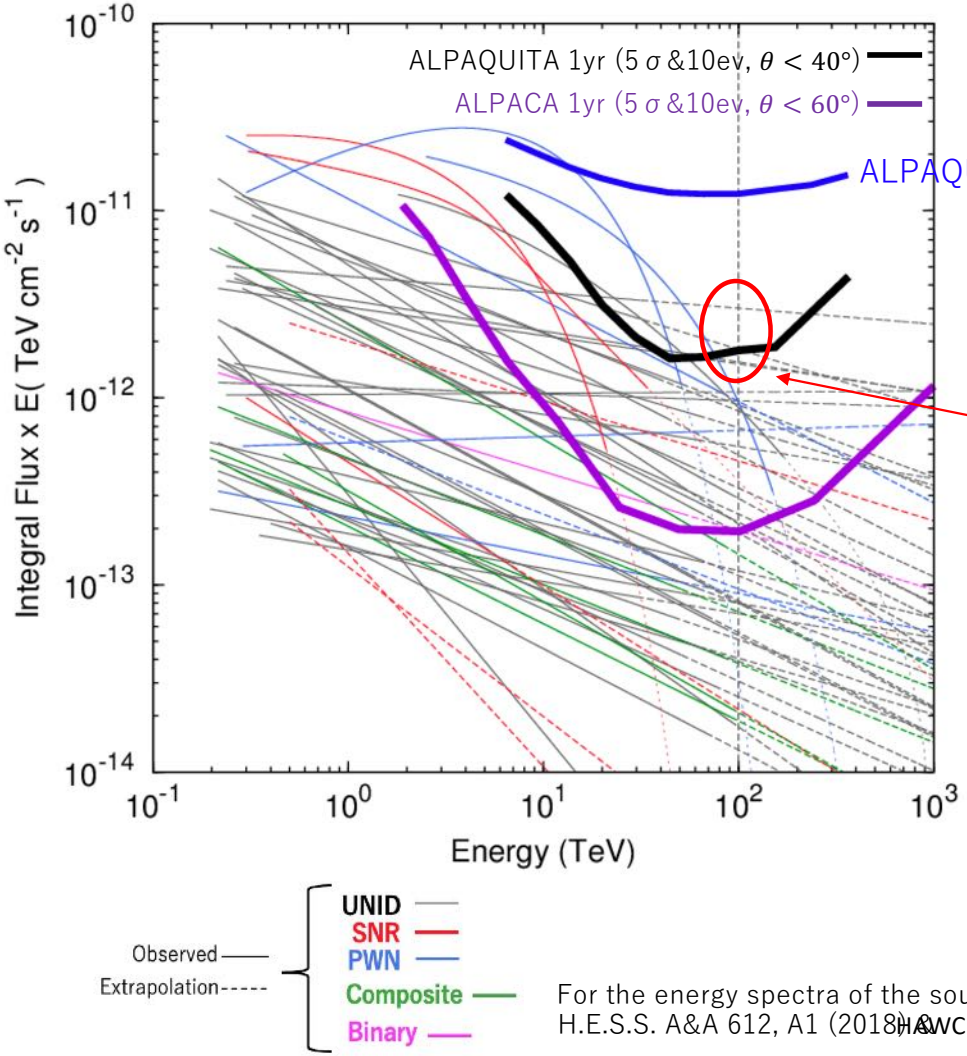



Survival ratio of gamma rays $\simeq 80$ % @100 TeV

Rejection power for BGCRs $\simeq 99.9\%$ @100 TeV $\gamma$ . eq.

# Sensitivity to VHE Gamma-Ray Sources

*Sensitivity curves in 1yr5 σ*




- ~7 sources in 1-yr obs. above 10 TeV
- 4 sources will be detected above 100 TeV !
  HESS J1616-508
  HESS J1702-420
  HESS J1708-443
  HESS J1843-033

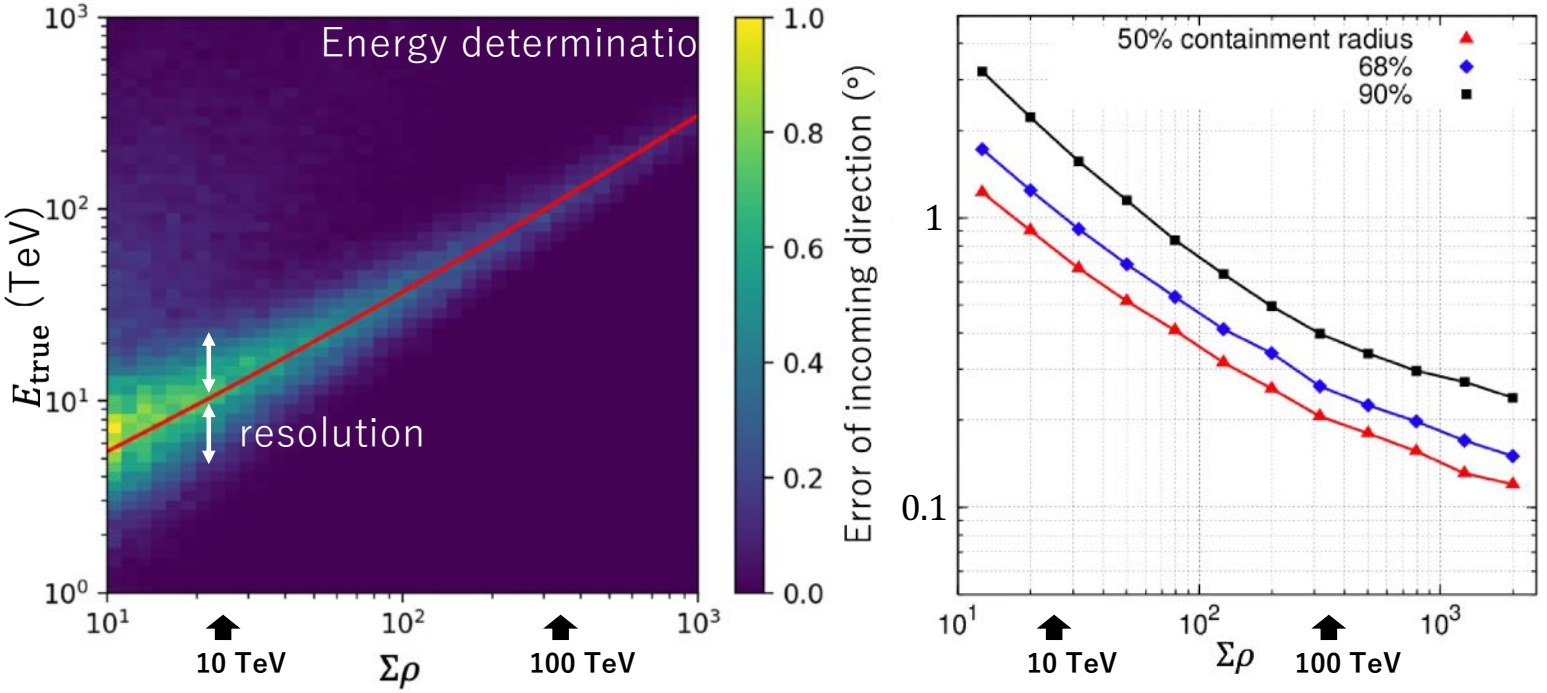
For the energy spectra of the sources:
H.E.S.S. A&A 612, A1 (2018) & HAWC Phys. Rev. Lett 124, 021102 (2020)

# ALPAQUITA AS Array Performance for Gamma Rays

Target events: Gamma rays w/ $\Gamma = -2.5$ & $\theta_{\mathrm{true}} < 40°$

| | |
|---|---|
| Trigger efficiency* | 100% ≥20 TeV |
| Energy resolution | $+27\% - 21\%$ @ 100 TeV |
| Angular resolution | $\simeq 0.2°$ @ 100 TeV (50% containment) |

*Efficiency for events w/ true core positions inside the AS array

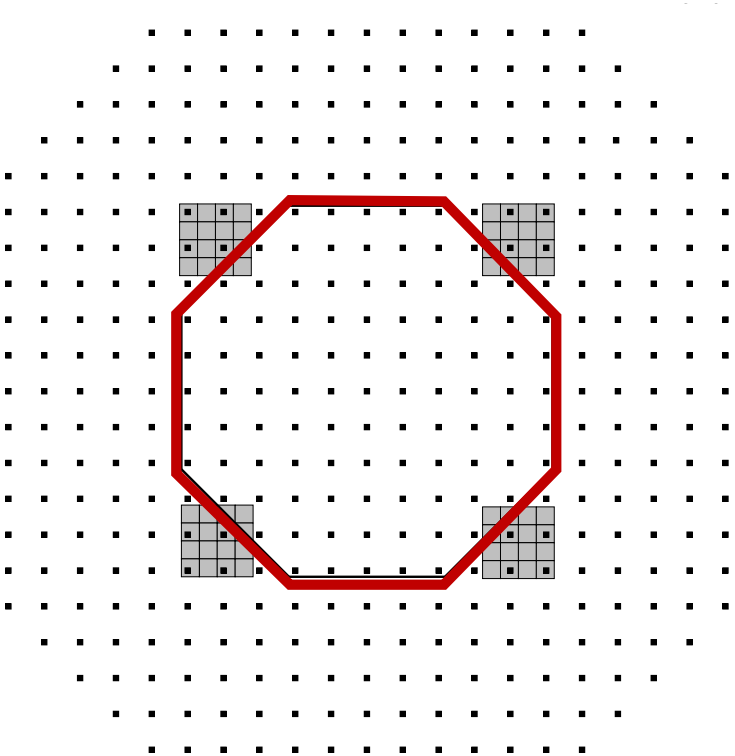



$\Sigma\rho$: Total density of particles recorded the AS array

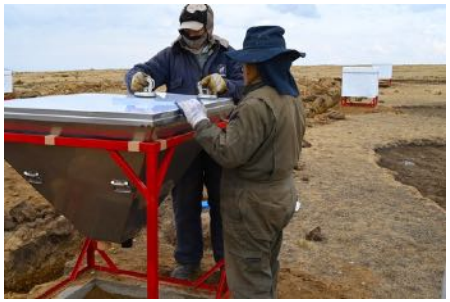
# ALPAQUITA
## (little ALPACA)

- Prototype array of 25% ALPACA area coverage
  - 97 surface detectors
  - 1 MD

- Targets
  - Infrastructure establishment
  - A few bright >100TeV sources
  - CR anisotropy



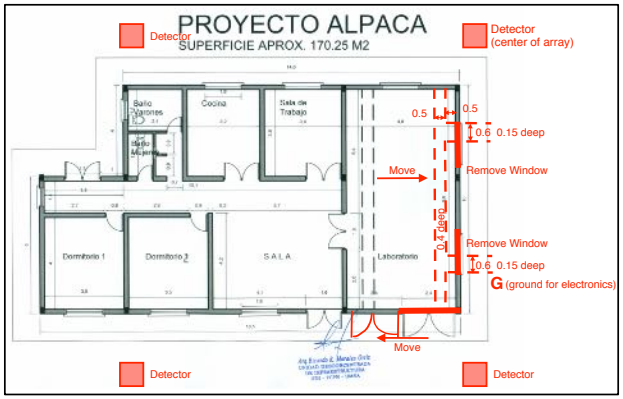
MD 設計済、まもなく工事開始

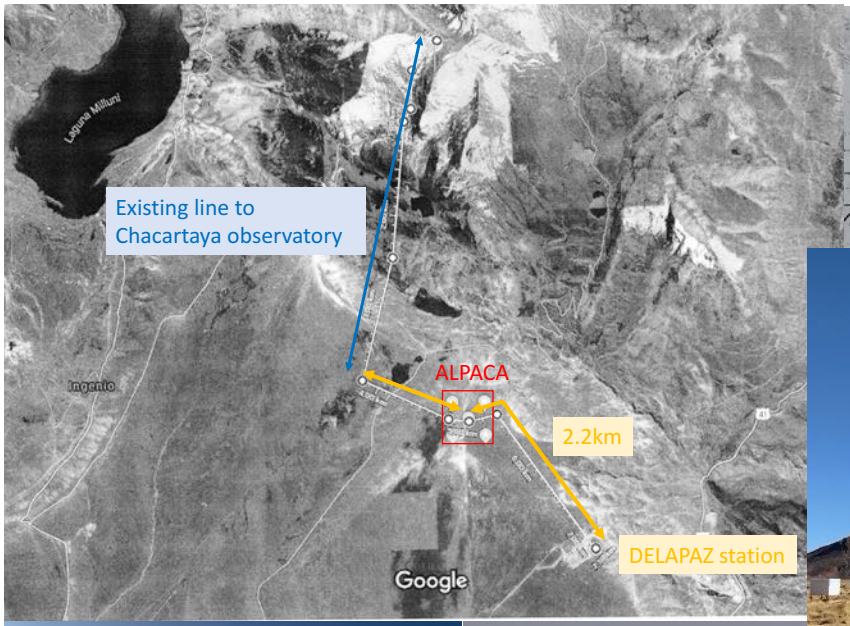


# 2022年5月末～（3年ぶり！）

# ALPAQUITA & infrastructure

- Central electronics hut
- Perimeters
- Powerline（branch from the substation-Chacaltaya observatory line）
- Cable drains
- Lightning rods
- Long distance Wifi
- Water system

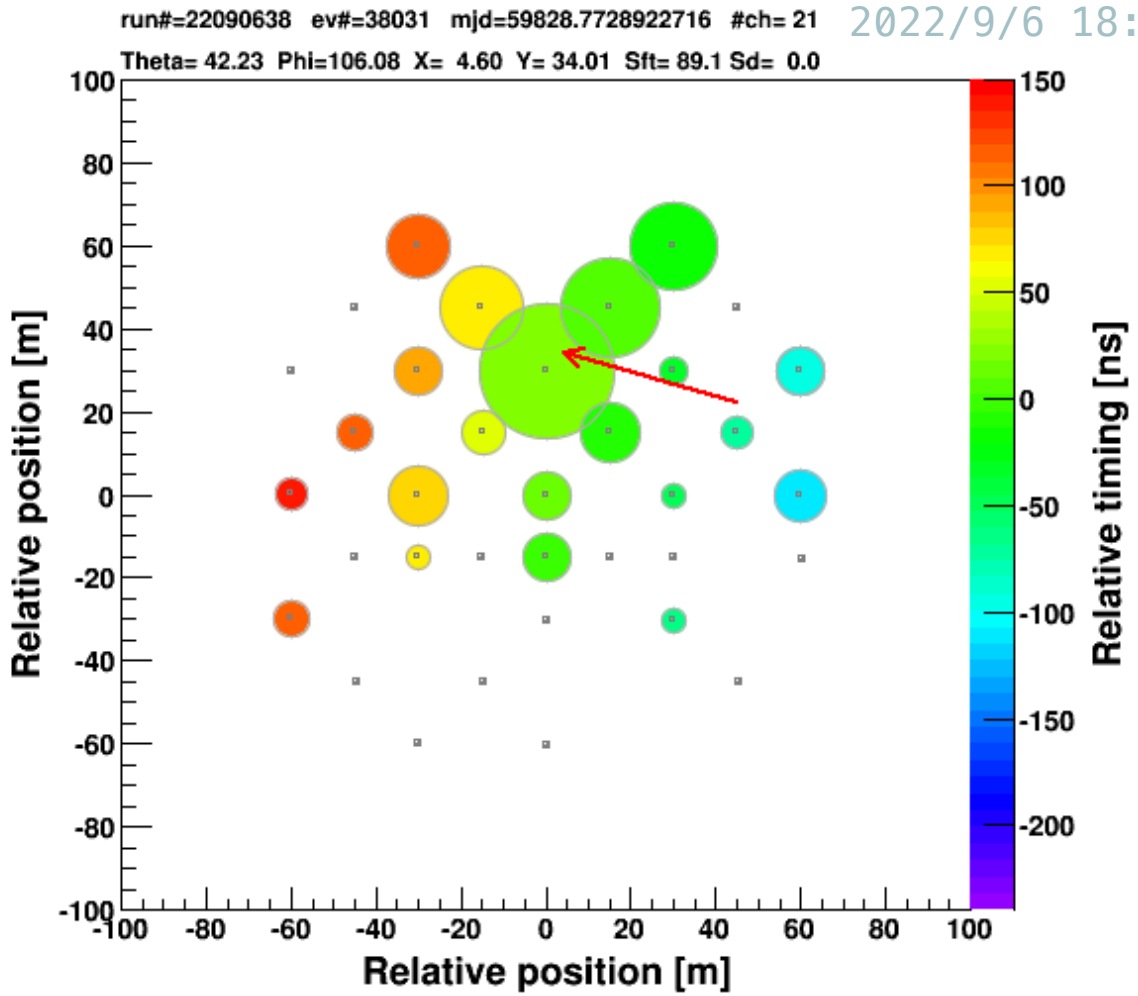




Laguna Miñiqui
Existing line to
Chacartaya observatory
Ingenio
ALPACA
2.2km
DELAPAZ station
Google

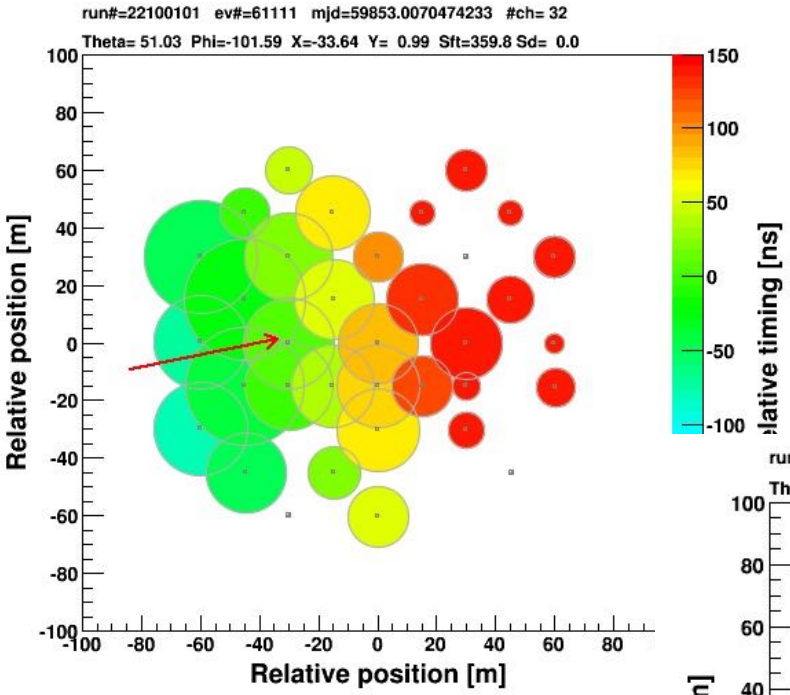
# ALPAQUITA　(Current Status)

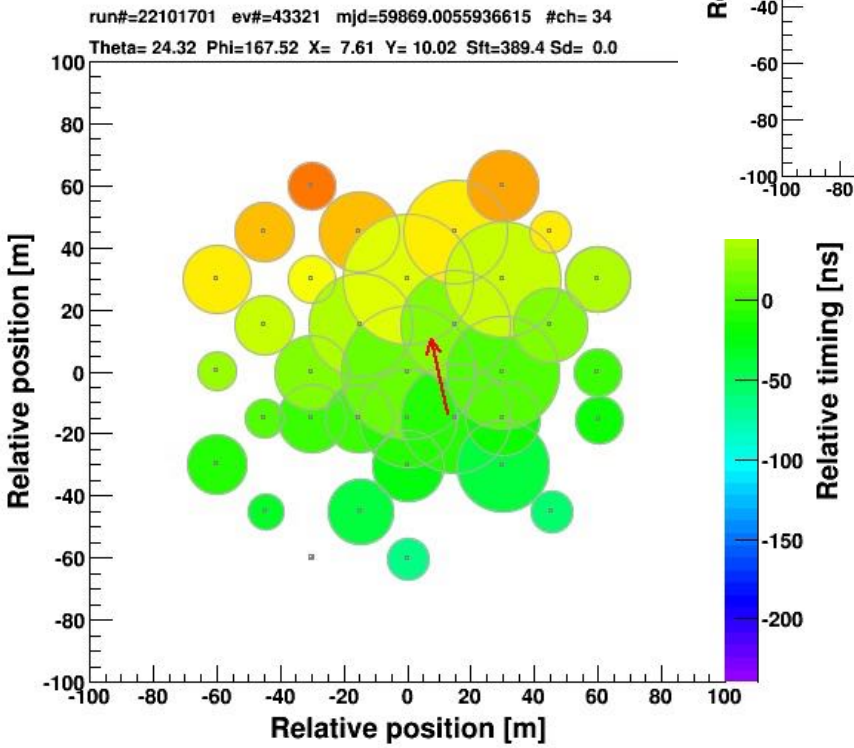
- PMTs have not yet been installed in all channels.
- Observational period: 2022 Sep 6 – 2023 Feb 6)
- Total live days: 118 days (x Dead time ratio)
- Hardware trigger: 0.7 particles any 4 folds
- Total number of analyzed events: ~ 5 x $10^8$
- PMT through time calibration has not been done yet.

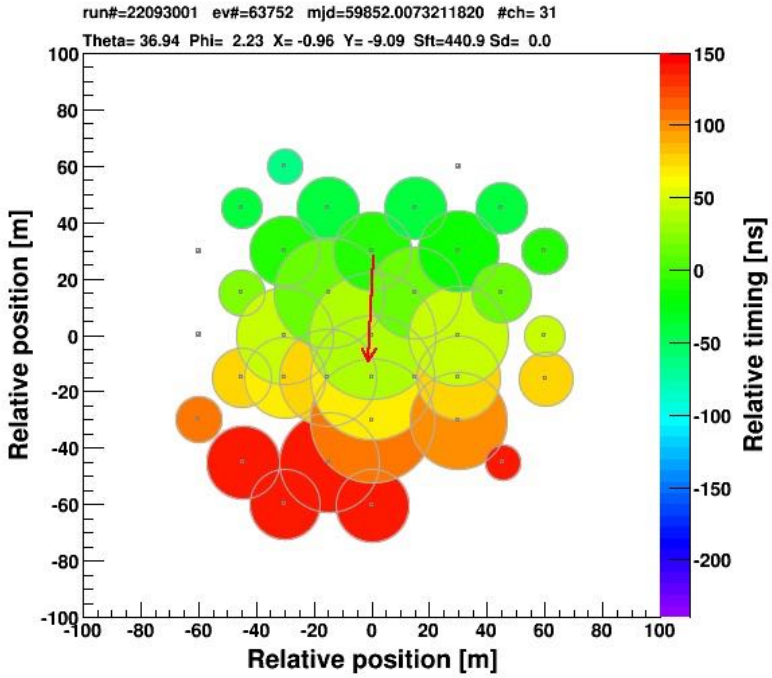
# First Good Event



# Big Events!

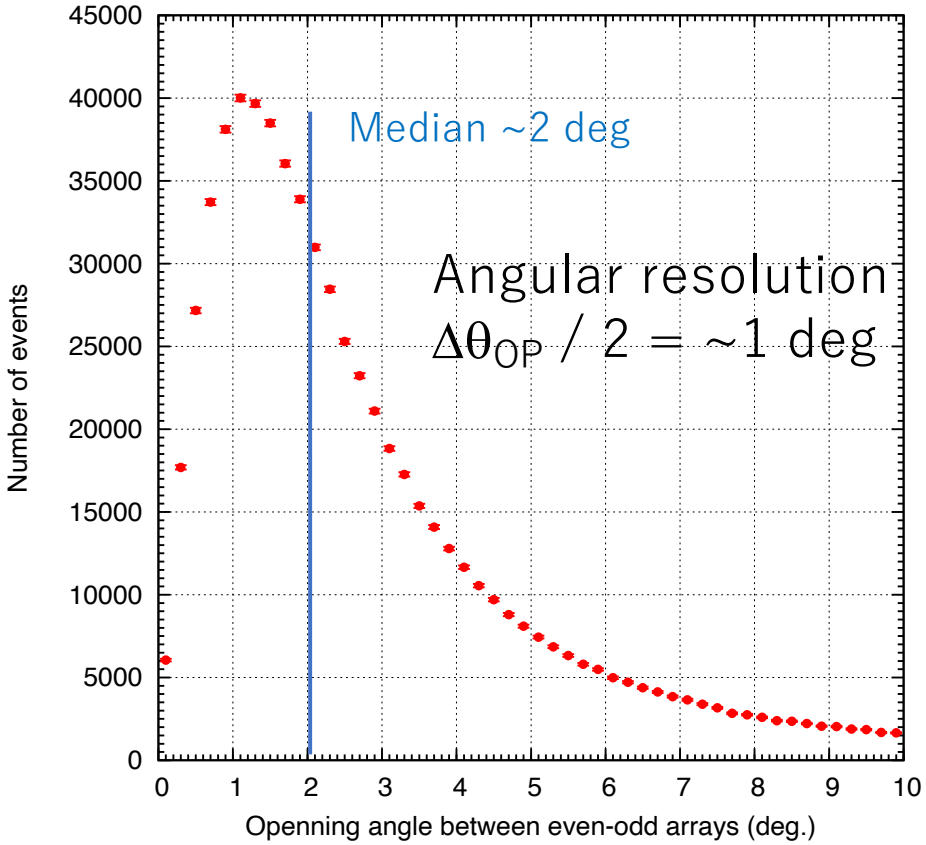

run#=22100101 ev#=61111 mjd=59853.0070474233 #ch= 32
Theta= 51.03 Phi=-101.59 X=-33.64 Y= 0.99 Sft=359.8 Sd= 0.0
Relative position [m]
Relative position [m]
Relative timing [ns]

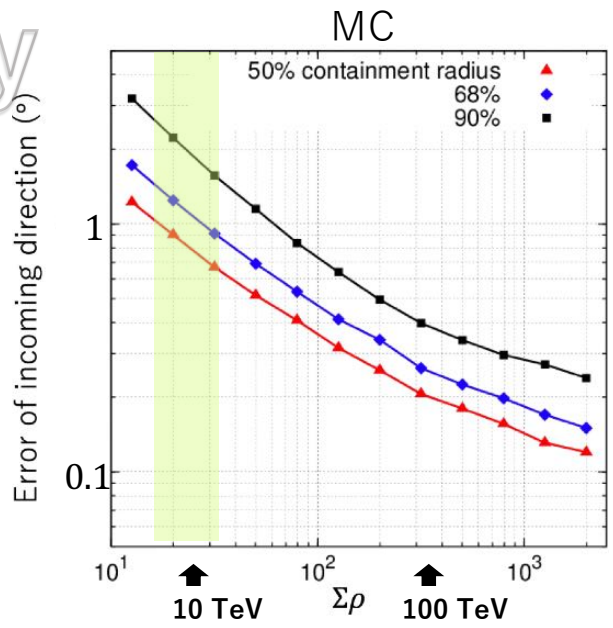

run#=22101701 ev#=43321 mjd=59869.0055936615 #ch= 34
Theta= 24.32 Phi=167.52 X= 7.61 Y= 10.02 Sft=389.4 Sd= 0.0
Relative position [m]
Relative position [m]
Relative timing [ns]


run#=22093001 ev#=63752 mjd=59852.0073211820 #ch= 31
Theta= 36.94 Phi= 2.23 X= -0.96 Y= -9.09 Sft=440.9 Sd= 0.0
Relative position [m]
Relative position [m]
Relative timing [ns]

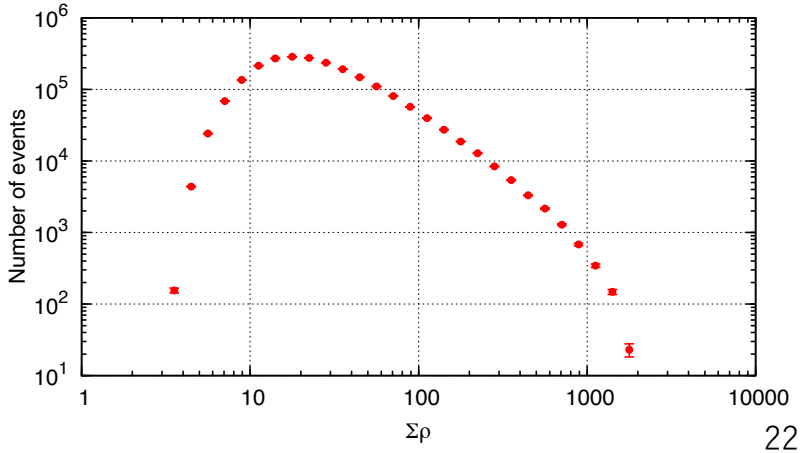
Preliminary

# Even-Odd Array



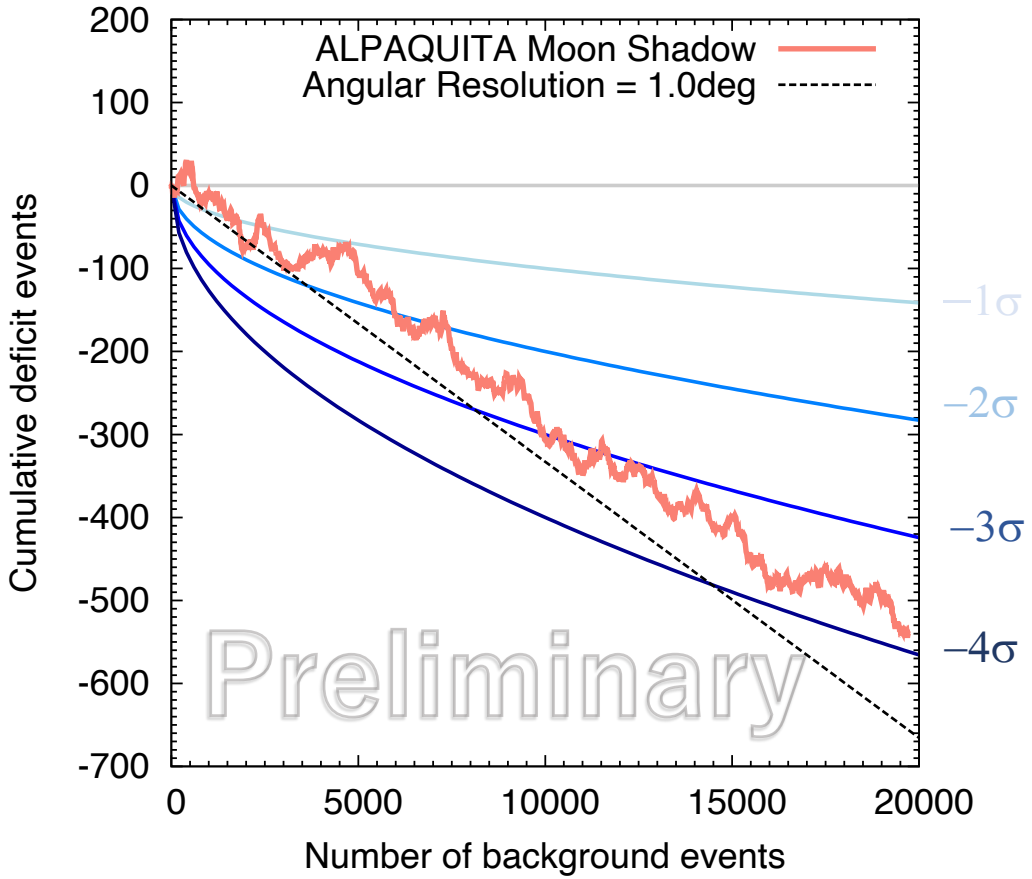



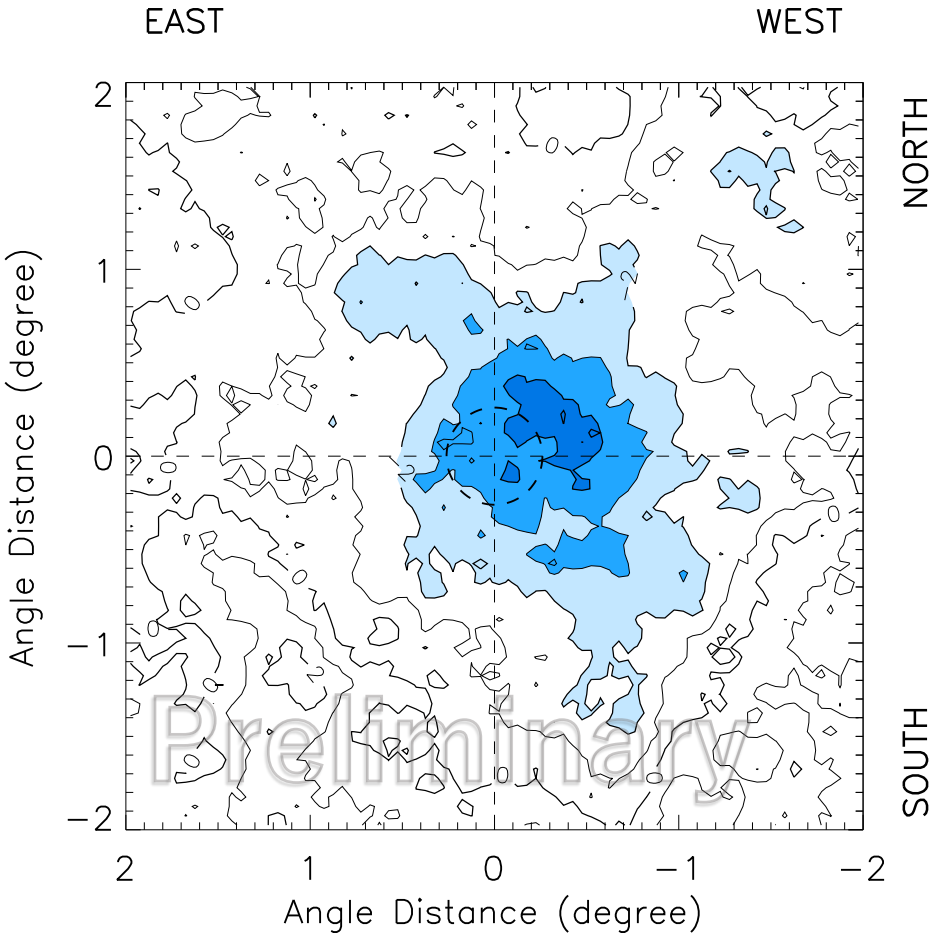

$\Sigma\rho_{FT}$ (Sum of number of particles)



# Moon Shadow

before calibration of the PMT transit time




Observation time ~118 days

# Summary

- ✓ **ALPACA explores southern sky in Bolivia first time with the technic established by Tibet AS$\gamma$**
- ✓ **A part of ALPAQUITA started operation in 2022**
  - ✓ **Air shower data is good and performing well**
- ✓ **First MD will be constructed in 2023**
- ✓ **ALPACA will start operation in 2024**

- ✓ **Mega ALPACA is discussed as a future plan to explore PeV energy range**

引き続き、ご支援のほどよろしくお願いいたします。