A new air shower array in the Southern Hemisphere looking for the origins of Cosmic rays: the ALPACA experiment

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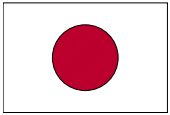
The ALPACA collaboration



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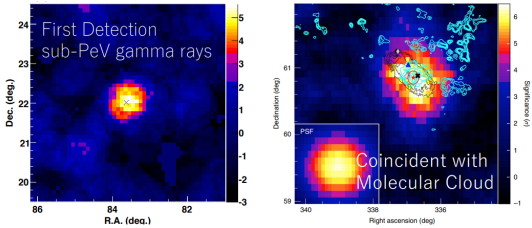
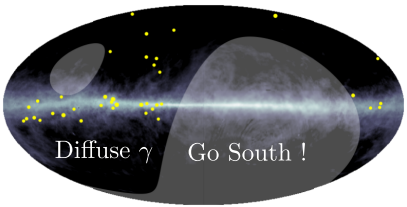
Andes Large Area PArticle detector for Cosmic ray physics and Astronomy

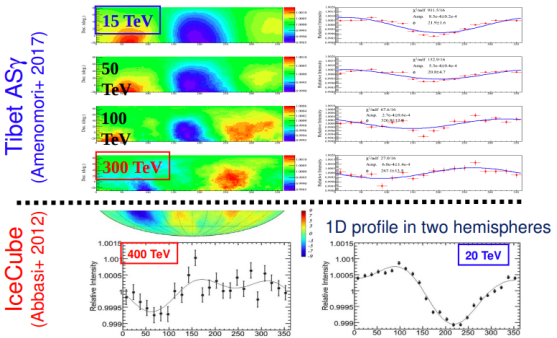
sub-PeV γ-ray Astronomy

- 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 PeV Galactic diffuse γ-rays. Tibet ASγ, PRL (2021)
- Detection of dozen PeV γ-ray sources. LHAASO, Nature (2021)





Other Physics: Cosmic Ray observation



- Observation of CR anisotropy at both Hemispheres.
- Interplanetary space physics with **Sun shadow of CRs**
- Composition of Primary Cosmic-Ray Nuclei around **knee** region.

ALPACA experiment: Why Bolivian Andes?

- Flat and high altitude (4740 m).
- Galactic center (Site coordinates: $16^\circ 23' \mathbf{S}$, $68^\circ 8' \mathbf{W}$).
- Long-term collaboration Bolivia and Japan.

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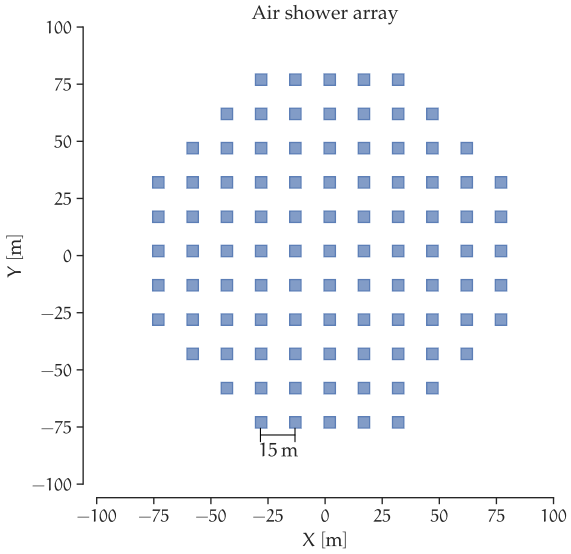
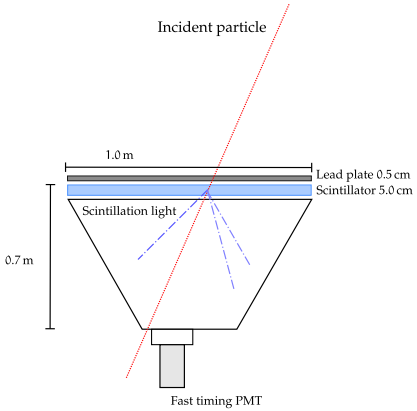
Experimental technique: Surface array detector

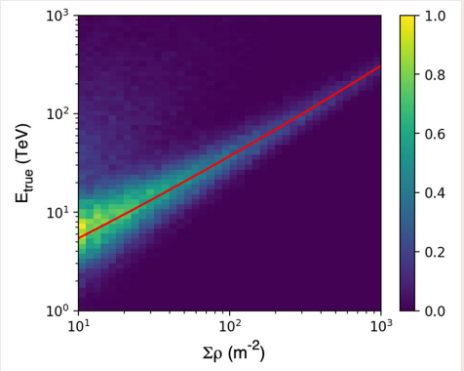


- Area coverage: 18 450 m^2
- Number of elements: 97
- Single-particle peak: 9.4 MeV

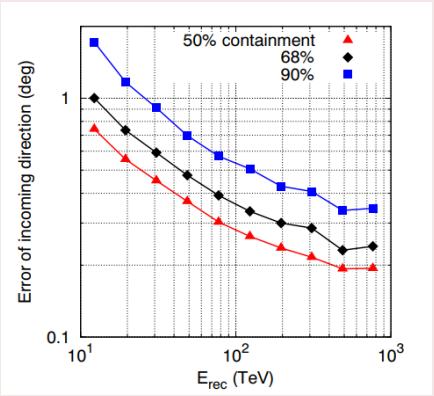


Experimental technique: event reconstruction

Primary energy using energy deposit

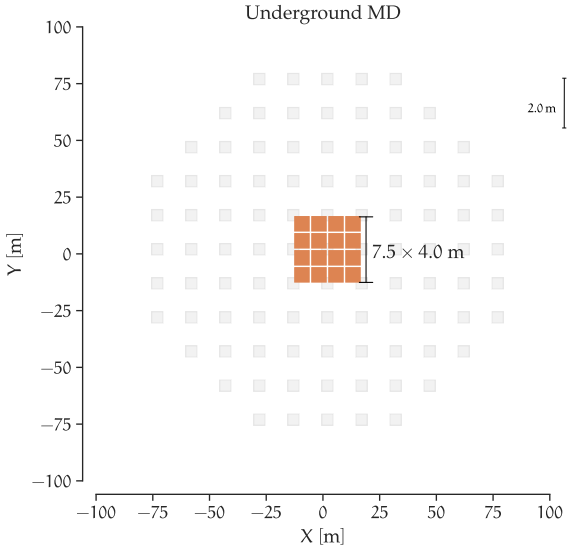


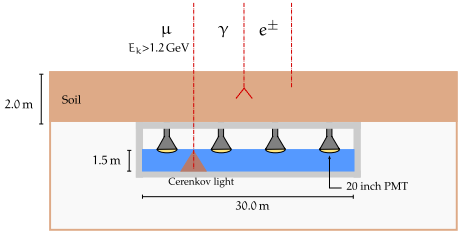
Arrival direction using particles timing



S.Kato et al., Experimental Astronomy (2021) 52:85-107

Experimental technique: Underground muon detector

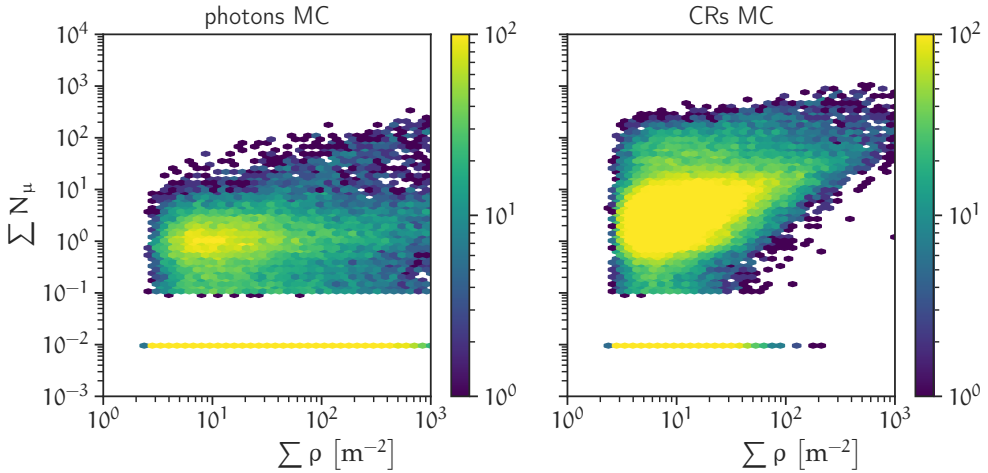




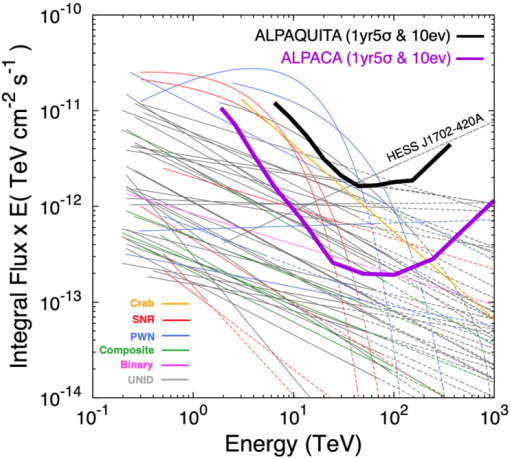
- Area coverage: 900 m^2
- Number of elements: 16 cells.
- Single-muon peak: 24 pe*

* S.Kato et al., Experimental Astronomy (2021) 52:85-107

Experimental technique: γ/CR separation



Sensitivity to VHE γ-ray sources



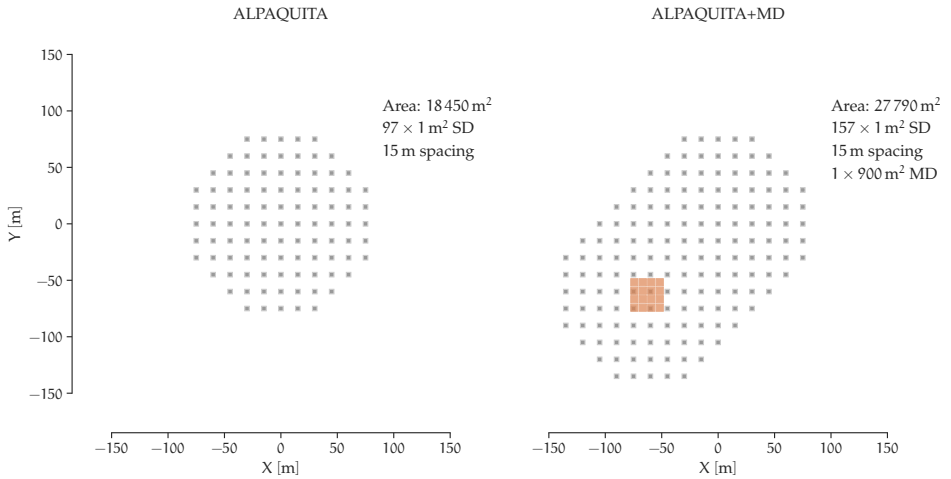
Sensitivity curves in 1 yr 5σ

Sources will be detected above 100 TeV in 1yr:

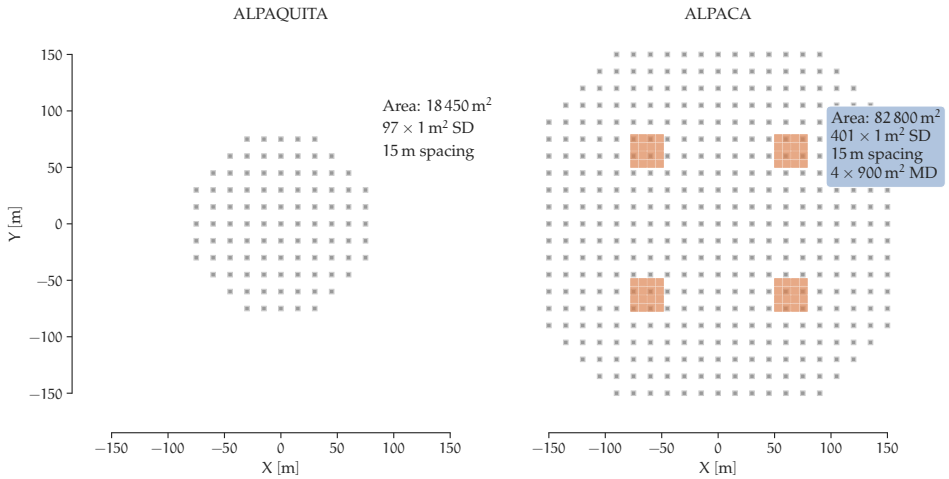
- HESS J1616-508
- HESS J1702-420
- HESS J1708-443
- HESS J1843-033

* S.Kato et al., Experimental Astronomy (2021) 52:85-107

ALPACA experiment in steps



ALPACA experiment in steps

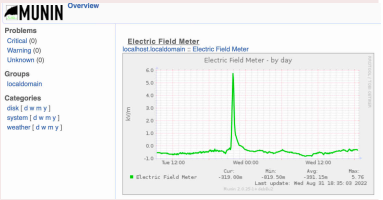


The road to ALPACA

Assembly finished and cabling (June 2022)

The road to ALPACA

Electic field and weather monitors (August 2022)

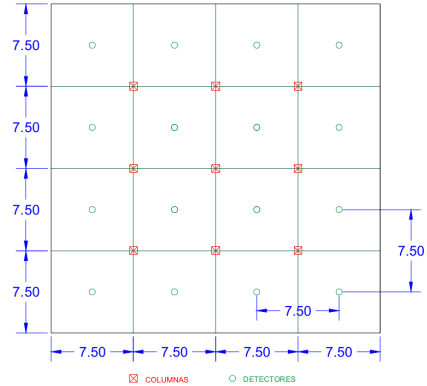


ALPAQUITA full operation April 2023

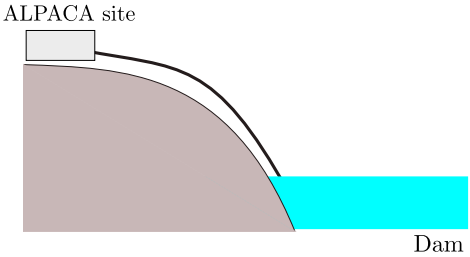
ALPAQUITA current status

- All PMTs installed and calibrated.
- Air shower trigger condition:
  - Any 4 detectors > 0.6 particles within 600 ns.
  - Air shower trigger rate 280 Hz.
  - Cosmic-ray mode energy 7 TeV.
- Full operation since April 2023.

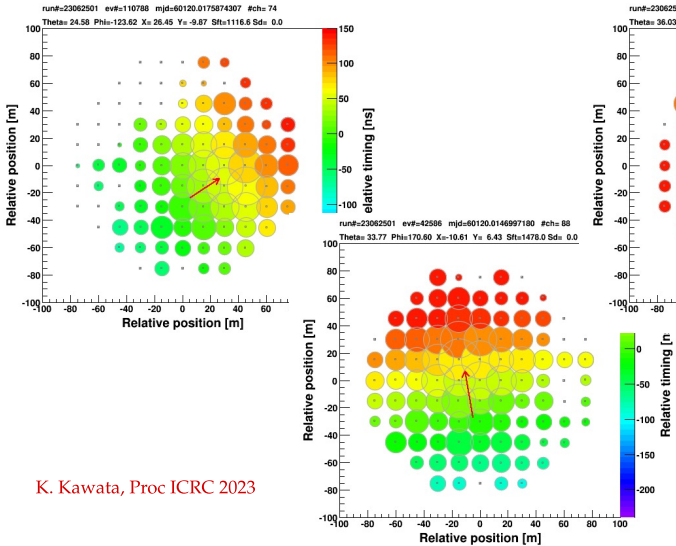
Progress on MD pool construction



- Optimization of the MD design.
- Guarantee safe operation.
- How filling the detector?
- Test of water transparency.



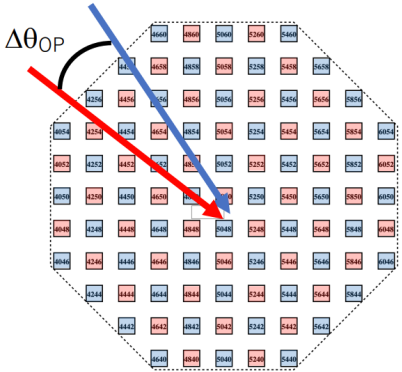
> 100 TeV Events !!!

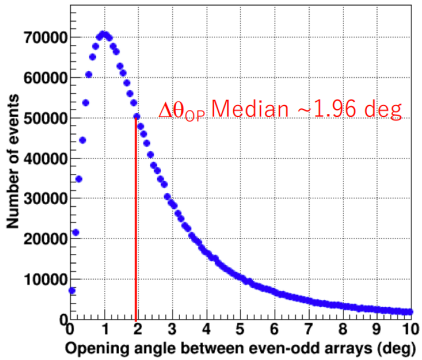


K. Kawata, Proc ICRC 2023

Angular resolution by Even-Odd method

Even-Odd opening angle: Opening angle between directions determined by two independent arrays

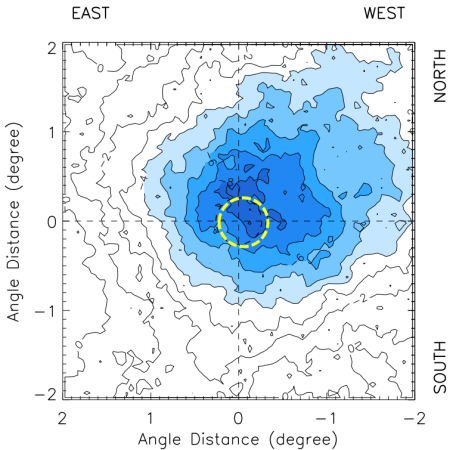




Angular resolution:

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

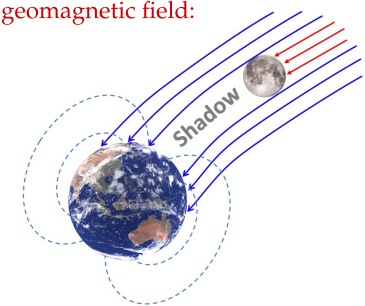
Moon shadow detection



K. Kawata, Proc ICRC 2023

Displacement by geomagnetic field:

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



- April 7 – November 30, 2023 (225 days).
- Cable length correction.
- Successfull detection at 8.0σ.
- Shift westward ~ 0.2° as expected.
- Confirmed ~ 0.9° resolution.

Beyond PeV: Mega-ALPACA

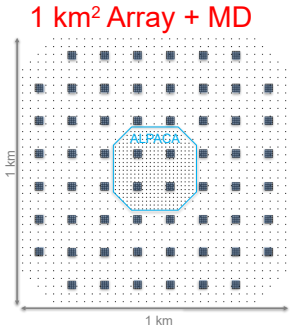
Where is the highest energy accelerator in our Galaxy?

30 m spacing AS array
Area 1,011,600 m^2
# of det. 1185

15 m spacing AS array
Area 82,800 m^2
# of det. 313
(Additional to 15 m spacing)

# of total det. 1185 + 313 = 1498

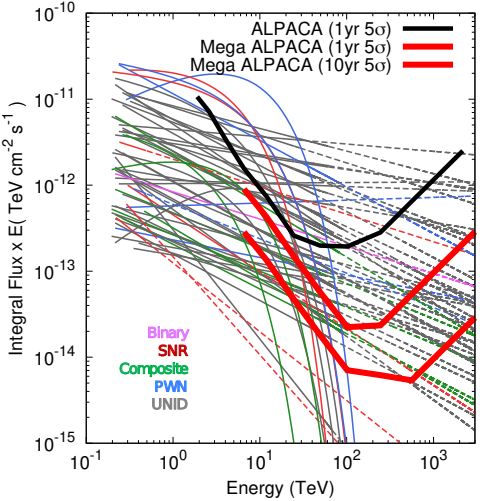
Muon Detector (MD) Array
900 m^2 (16 Cells) x 60
= 54,000 m^2
# of cells 960



Mega-ALPACA was featured in the GA Rapporteur talk ICRC 2023

Beyond PeV: Mega-ALPACA

Source sensitivity of Mega ALPACA



Sensitivities of Mega ALPACA for 1 year and 10 years observation periods (red thick curves) compared to the 1 yr sensitivity of ALPACA (black thick curve. Various thin curves are the fluxes of known gamma-ray sources within the field of view of Mega ALPACA. The solid lines are the measured fluxes while the dashed lines are the extrapolations of the fitting.

Summary

- Southern sub-PeV γ-ray sky is yet to be explored.
- ALPACA is a new air shower array under construction in Bolivia.
- We successfully detected Moon shadow with ALPAQUITA at 8.0σ.
- Angular resolution is estimated to be $\sim 0.9^{\circ}$.
- We will start the construction of one MD pool in 2024.
- We will start the operation of the full ALPACA array (4 MDs) in 2025.
- Observations of sub-PeV γ-rays in the Southern Hemisphere will begin soon.