ALPACA project to observe sub-PeV gamma-ray sky in the southern hemisphere

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ABSTRACT: Though the maximum energy of the charged cosmic ray observations exceeds 100EeV, the energy frontier of the gamma-ray observations is PeV. In the past years, Tibet ASγ, HAWC and LHAASO opened a new window of astronomy in the sub-PeV to PeV range, which is important to unveil yet unknown PeV cosmic accelerators in our galaxy. As these 3 experiments are all located in the northern hemisphere, observations in the southern hemisphere have been awaited. Andes Large area PArticle detector for Cosmic ray physics and Astronomy (ALPACA) is a new air shower array experiment under construction in the Bolivian Andes to explore the southern gamma-ray sky for the first time in this energy range. In this presentation, we will provide an overview of the ALPACA project, including the initial observational results from a quarter-sized array named ALPAQUITA, which has been operating since 2023. A successful detection of the shadow of the moon, for example, validates the designed performance of the array. We will also outline the plan for the full-scale construction of ALPACA.

1. INTRODUCTION

Since the discovery of sub-PeV (>100 TeV) gamma-ray emission from the Crab nebula by the Tibet ASγ collaboration in 2019 [1], gamma-ray astronomy entered in a new era also with HAWC and LHAASO [2] [3]. To understand the cosmic rays in our galaxy, the sub-PeV observations in the southern hemisphere is essential. As the first southern sub-PeV observatory, a new air shower array experiment, the Andes Large area PArticle detector for Cosmic ray physics and Astronomy (ALPACA), is under construction near the Chacartaya mountain in Bolivia[4][5].

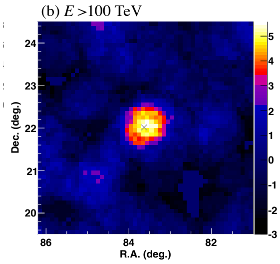

Fig.1 Significance map around the Crab nebula above 100TeV observed by TibetASγ[1].

2. DESIGN OF ALPACA AND ALPAQUITA

Fig.2 shows the layout of the ALPACA array. A surface array of 401 plastic scintillation counters covers the total area of 82,800 m². Four units of underground muon detectors (MDs) with the total area of 3,600 m² will be used as a veto counter to reject hadronic CR background events. With 2m soil overburden the MDs have energy threshold of 1.2GeV and a >99.9% BG rejection power at 100TeV.

Since April 2023, a partial array called ALPAQUITA has been in operation with 97 scintillation counters (red area). A construction of the first MD at the left bottom corner of Fig.2 will start soon. Surrounding the MD with additional 60 counters, ALPAQUITA+MD (yellow area) will start a gamma-ray sensitive observations in 2025.

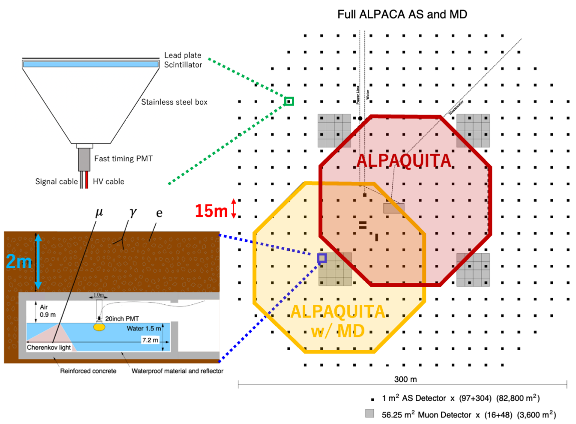

Fig.2 Layout of the ALPACA array with the currently operating ALPAQUITA surface array (red) and the ALPAQUITA+MD under construction (yellow).

3. Source sensitivity

The flux sensitivity of ALPACA and ALPAQUITA (+MD) is shown in Fig.3. The thin lines are the energy spectra of known sources based on the H.E.S.S. galactic plane survey [6] within the field of view of ALPACA. The solid lines are the best fit spectra in the measured energy range while the dashed lines are the extrapolations. Extrapolations of half of the known sources are within the reach of the ALPACA sensitivity (1yr, 5σ). It is also important that about five sources are within the sensitivity of ALPAQUITA around 100TeV. Energy spectrum of a peculiar hard source discovered by H.E.S.S., HESS J1702-420A [7], can be tested by the initial observation of ALPAQUITA.

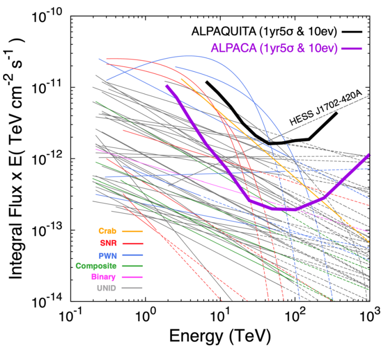

Fig.3 Sensitivities of ALPACA (purple thick curves) and ALPAQUITA (black thick curve). Thin curves are the fluxes of known southern gamma-ray sources. The solid lines are the measured fluxes while the dashed lines are the extrapolations of the fitting.

4. INITIAL PERFORMANCE OF ALPAQUITA

The deployment of the ALPAQUITA surface detectors were completed in 2022 August as shown in Fig.4. After a half year of a pilot operation, a stable operation started in 2023 April.

A first test of the array performance is to analyze the intensity of air shower events around the direction of the moon. Because the trajectories of cosmic rays are blocked by the moon, a deficit of the intensity, called 'shadow of the moon' is expected [8]. Fig.5 shows the intensity map around the moon (left) and the time evolution of the deficit amplitude (right). A clear shadow of the moon is detected and it assures the pointing accuracy of the array. A slight blur into the western direction is as expected due to the geomagnetic effect between the moon and the earth. A linear evolution of the amplitude indicates a stable operation of the array. The slope is consistent with the angular resolution at the mode energy (a few TeV).

Fig.4 ALPAQUITA array in Bolivia.

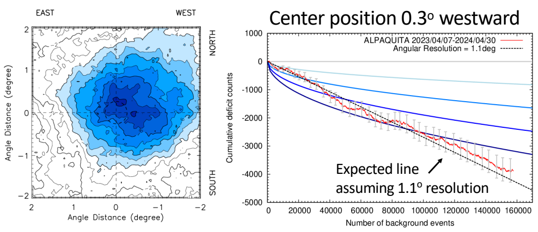

Fig.5 Shadow of the moon observed by ALPAQUITA (left) and time evolution of the deficit (right).

Another test called 'even-odd analysis' was applied. The counters are alternatively grouped into two arrays, and the arrival directions are independently reconstructed. Fig.6 shows the distribution of the opening angles between two reconstructed directions. It is found that the distributions of the experimental data (blue; median 1.95°) and the MC simulation (green; median 1.76°) agree well. Considering the division of the data and the calculation of difference, half of the median value, ~1°, indicates the 50% angular resolution and it is consistent with the result of the moon's shadow.

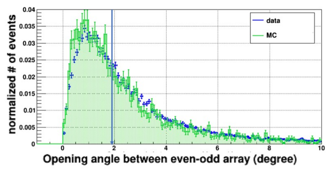

Fig.6 Distribution of the opening angles reconstructed by the divided arrays. Blue shows the experimental result of ALPAQUITA and green shows Monte Carlo caluculation.

5. SUMMARY

ALPACA will open a new window of the southern sub-PeV sky. A partial array ALPAQUITA has been stably operating since 2023 and shows expected performance in the CR shower observations. With the first MD, whose construction will start soon as illustrated in Fig.7, ALPAQUITA will start gamma-ray sensitive operation in 2025. The extension to the full ALPACA follows it and will reveal the PeV accelerators in our galaxy. As a next generation observatory, Mega ALPACA is also proposed [9] as well as SWGO [10] to observe PeV gamma rays with 1 km² scale air shower array.

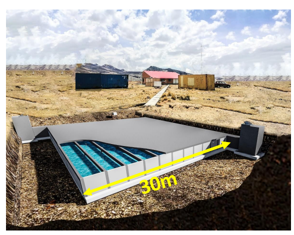

Fig.7 Artistic view of the first MD.

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