A new high energy gamma-ray observatory in the southern hemisphere: The ALPACA experiment

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Abstract. The ALPACA experiment is a new international project between Bolivia and Japan. It is going to consist of an 83,000 m² surface air-shower array and a 5,400 m² underground water Cherenkov muon detector array, and the experimental site is at Mt. Chacaltaya plateau at an altitude of 4,740 m. Its main target is to observe 100 TeV gamma rays and explore high-energy gamma-ray sources in the southern sky. This is because such high-energy gamma rays hold the key to identify the origin of cosmic rays at the knee region of the energy spectrum. So far many high-energy gamma-ray sources have been found in the southern sky. They are emitting gamma rays of several tens of TeV, so some of them could be PeVatrons which accelerate cosmic rays to PeV energy region in the Galaxy. By observing them in higher energy region, we will obtain new knowledge of
cosmic-ray acceleration to the knee region, and discover new gamma-ray sources. As the prototype experiment of ALPACA, the ALPAQUITA experiment is now under construction. In a MC simulation, we found that ALPAQUITA has the ability of detecting bright gamma-ray sources in the southern hemisphere such as Vela X within 1 year.

1. ALPACA Experiment

1.1. Motivation

The main motivation of ALPACA is to explore galactic high-energy gamma-ray sources visible in the southern sky. It targets the energy region from TeV to PeV because this is the order of the energy of gamma rays generated from cosmic-ray interactions at the knee energy region. We also investigate cosmic-ray physics, such as cosmic-ray anisotropy and chemical composition in the energies from TeV to PeV, as well as solar physics such as interplanetary magnetic field by observing the cosmic-ray shadow of the Sun [1].

1.2. Detector design

Figure 1: (Left) Schematic view of ALPACA air shower array. (Right) Sideview of an MD cell.

The location of ALPACA is Mt. Chacaltaya plateau which is at 16° 23′S, 68° 08′W. The experimental site has a very flat ground and high altitude of 4,740 m, where the size of an air shower of a 100 TeV gamma ray becomes maximum.

Fig.1 (Left) shows a schematic view of ALPACA. ALPACA consists of a surface air shower array (enclosed by green lines) and an underground water Cherenkov muon detector (MD) array (blue boxes). The surface air shower array consists of 401 plastic scintillators (black dots) having an area of 1 m² and has the total area of 83,000 m². The MD array is located at 2.2 m depth under the ground. It consists of 8 pools, and has a total area of 5,400 m². Each pool has 12 cells having a detection area of 56 m² as shown in Fig.1 (Right).

The MD array is used to discriminate signal gamma-ray events from cosmic-ray background events by detecting muons in the air showers. Since the soil layer above the MD corresponds to 18 radiation lengths, electromagnetic component of an air shower is mostly absorbed in this layer and highly pure signal from muons can be obtained. Therefore ALPACA has a very high rejection power of background cosmic rays, for example, more than 99.9% in 100 TeV region according to a MC simulation.

2. Performance of ALPACA

2.1. Basic properties

We summarize basic properties of ALPACA in Table 1. The angular and energy resolution are 0.2° and 20% respectively for 100 TeV gamma-rays. Since an air-shower array can operate with a high
duty cycle (> 90%) and a very wide field of view (2 sr), ALPACA will achieve a large exposure more than 2000 hours/year for many sources in the southern sky.

**Table 1: Basic properties of ALPACA**

| Property                        | Value                        |
|---------------------------------|------------------------------|
| Modal energy                    | 3 TeV                        |
| Angular resolution              | 0.2° @ 100 TeV               |
| Energy resolution               | 20 % @ 100 TeV               |
| Duty cycle                      | > 90 %                       |
| Field of view                   | ~2 sr                        |
| CR rejection power              | > 99.9 % @ 100 TeV           |
| γ-ray detection efficiency      | ~90 % @ 100 TeV              |

2.2. Sensitivity to gamma-ray sources

Fig.2 (Left) shows the sensitivity curve of ALPACA to gamma-ray sources compared to other gamma-ray experiments. ALPACA is designed to be sensitive to 100 TeV gamma-ray energy region by optimizing the altitude of the experimental site, the size of AS and MD arrays, and the air-shower reconstruction. As seen in Fig.2, the ALPACA will be the most sensitive to this energy region.

Fig.2 (Right) shows the ALPACA 1-year and 10-year sensitivity curves together with the gamma-ray spectra discovered by H.E.S.S. Galactic plane survey in the southern sky [2]. The spectra without cut off are simply extrapolated to a higher energy region as shown by the dashed lines. ALPACA will be able to observe dozens of these sources in 100 TeV energy region within 1 year, and enable us to discover new gamma-ray sources in the southern sky.

![Figure 2: (Left) Sensitivity curve of ALPACA to a point-like gamma-ray source compared to other gamma-ray experiments. (Right) ALPACA 1-year and 10-year sensitivity curves compared with the fluxes of gamma-ray sources discovered by H.E.S.S. Galactic plane survey in the southern sky. The spectra without cut off are simply extrapolated to a higher energy region as shown by dotted lines.](image)

3. ALPAQUITA

ALPAQUITA is the prototype experiment of ALPACA. The array consists of 97 plastic scintillators, having the total size of 25 % of the ALPACA AS array, and small MD of about 800 m² under the ground.

The construction of the ALPAQUITA AS array has already started in August 2019. We show some pictures in Fig.3 of the current status of ALPAQUITA. The electronics hut has been built, and
20 plastic scintillator detectors have been completed and set. Digging of drains for signal and high voltage cables and the construction of a fence for experimental materials are now ongoing.

Using a MC simulation, we estimated the sensitivity of ALPAQUITA to Vela X, which is a bright gamma-ray source in the southern sky. The gamma-ray spectrum from Vela X is assumed to be a power law with exponential cutoff measured by H.E.S.S. [3]. The development of air showers in the atmosphere and the detector responses of AS and MD arrays are simulated using CORSIKA7.6400 [4] and GEANT4.10.04.p02 [5], respectively. The results are shown in Table 2. $\Sigma \rho$ is total number of particles detected by the ALPAQUITA AS array in an event. As seen in the table 2, ALPAQUITA has enough sensitivity to the flux of Vela X in several tens of TeV energy region for 1 year. The optimal location of the MD and the sensitivity to other gamma-ray sources are now under investigation.

![Figure 3: Current status of ALPAQUITA.](image)

**Figure 3: Current status of ALPAQUITA.** The construction of the AS array and facilities are now ongoing. From the left, the installation of 20 plastic scintillators and the electronics hut, dig construction of drains for signals and high voltage cables, and fence poles.

**Table 2: Detection significance of Vela X with ALPAQUITA in 1-year observation in three energy regions.** $\Sigma \rho$ is total number of particles detected by the AS array in an event. Significance is calculated by $S/\sqrt{S + B}$, where $S$ is the number of signal gamma rays and $B$ is the number of background cosmic rays.

| Energy   | $\Sigma \rho$        | Significance |
|----------|----------------------|--------------|
| $\sim 10$ TeV | $39.8 - 63.1$       | 3 $\sigma$   |
| $\sim 20$ TeV | $63.1 - 100$      | 3.8 $\sigma$ |
| $\sim 30$ TeV | $100 - 158$       | 2.8 $\sigma$ |

**Summary**
The ALPACA experiment will become a pioneer in the highest-energy gamma-ray astronomy in the southern sky, taking advantage of its very high rejection power of background cosmic rays with the MD array. Also, based on the result of the MC simulation, ALPAQUITA, the pathfinder of ALPACA, has enough sensitivity for bright gamma-ray sources such as Vela X. The construction of the ALPAQUITA is ongoing, and we aim for observation in the next year.

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