PROCEEDINGS OF SCIENCE

Overview status of the ALPACA experiment

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The ALPACA experiment, short for the Andes Large area Particle detector for Cosmic ray physics and Astronomy, is an international project initiated in 2016 by Bolivia and Japan. This collaboration is supported by a long-standing tradition of scientific collaboration between the two countries through their respective research institutions: IIF (Instituto de Investigaciones Físicas) in Bolivia and many Japanese institutes including ICRR (Institute for Cosmic Ray Research). In particular since 1961, the collaboration between IIF with ICRR has been ongoing and has recently been joined by the University of Guadalajara, Mexico. The ALPACA project aims to establish a gamma-ray observatory in La Paz, Bolivia, located near Mt. Chacaltaya at an altitude of 4740 meters above sea level (coordinates: 16°23′ S, 68°08′ W). The primary advantage of observing cosmic rays and gamma rays from the southern hemisphere is the broader field of view, which includes the center of our galaxy, an intriguing region for studying gamma-ray emission mechanisms. The focus of the cosmic-ray studies will be in the energy range around the "knee," spanning from 100 TeV to 100 PeV, while the gamma-ray observations will cover energy ranges from 5 TeV to 1 PeV. The full-scale ALPACA observatory is planned to consist of 401 scintillator detectors, spread over a large area of 83,000 m^2, with a separation of 15 meters between each detector. In addition, there will be underground muon detectors (MD) covering an area of 3,600 m^2. Despite the challenges posed by the COVID-19 pandemic, the first phase of the ALPACA observatory, known as "ALPAQUITA" (which means "small ALPACA" in Spanish), has begun. It currently features 97 plastic scintillator detectors deployed in an area of 18,450 m^2. Additionally, the construction of the muon detector, covering 900 m^2, is currently underway. In this paper, we will provide a comprehensive report on the current status of the ALPACA experiment.

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1. Introduction

The ALPACA experiment (Andes Large Area Particle Detector for Cosmic Ray Physics and Astronomy) is a joint effort between cosmic ray research institutes in Bolivia (IIF "Instituto de Investigaciones Físicas" University Mayor de San Andrés) and Japan (ICRR "Institute for Cosmic Rays Research" University of Tokyo). Recently, the physics department at CUCEI of the University of Guadalajara, Mexico, has also joined the project.

The total area covered by the particle detectors in the ALPACA experiment is over 83,000 m^2. This includes 401 Surface Scintillator Detectors (SSDs). Additionally, ALPACA's detector array includes Underground Muon Detectors (UMDs), which are intended to cover an area of over 5,000 m^2. A schematic view of the ALPACA detector is shown in Fig. 1.

The SSDs in ALPACA have an expected field of view of approximately 2 sr and a resolution of around 1° at 5 TeV and 0.2° at 100 TeV. The expected energy resolution for gamma rays at 100 TeV is approximately 25%. Furthermore, ALPACA has a capability of rejecting primary cosmic ray hadrons with a probability of about 99.9%.

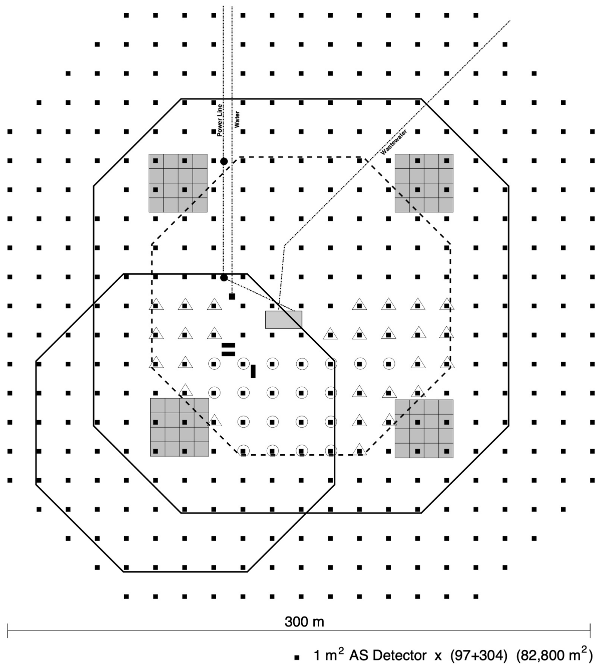


Figure 1: A schematic view of ALPACA experiment is shown. The small black squares represent Surface Scintillator Detectors, each covering an area of 1 m^2. These detectors are distributed over a total area of 83,000 m^2. The grey rectangles represent the Underground Muon Detectors, which are made up of units with an area of 56 m^2. In total, the Underground Muon Detectors cover an area of 5,400 m^2.

The ALPACA experiment will be unique and serve as a complementary detector to other experiments that are already running, such as VERITAS [1], Tibet ASγ [2] [3], LHAASO [4], and HAWC [5]. It will also complement future experiments like SWGO [6]. However, ALPACA aims to be a pioneer in observing high-energy gamma rays from the southern hemisphere, particularly from the South American Andes at high altitude. ALPACA is expected to detect dozens of sources, including young Super Nova Remnants (SNR 1006, RXJ1713.7 - 3946, RXJ0852.0 - 4622), Plerions, the Galactic Center, and others, some of which may be Pevatron candidates. Its wide field of view and excellent sensitivity make ALPACA's detection capabilities unique, especially in the detection of diffuse gamma rays.

2. ALPACA Physics motivation

In 2005, the H.E.S.S collaboration reported the discovery of 14 new sources of gamma rays emerging from the galactic plane while observing from the southern hemisphere of Earth [7]. Surprisingly, as of that date, most of the newly discovered gamma ray sources had not yet been identified. They were only reported as sources of X-ray, among other wavelengths. Due to the H.E.S.S collaboration's narrow field of view of the southern hemisphere, observations were primarily limited to the galactic plane. This motivated efforts to improve observations in an ideally located region of the southern hemisphere. Despite this limitation, H.E.S.S observations revealed that the majority of the 14 gamma ray sources had a higher energy spectrum than the Crab Nebula, reaching up to TeV range, Additionally, H.E.S.S's observations suggested possible candidates for Pevatrons [8]. Cosmic rays have the capability to be accelerated to high energy levels, reaching the PeV range, also known as the "knee region." The potential mechanisms responsible for this acceleration are believed to be supernova remnants (SNR) within our galaxy. Consequently, it is naturally expected that gamma rays in the range of several hundred TeV can be generated through the decay of π^0, which are produced by collisions between cosmic rays near SNRs. In summary, it is crucial to detect high-energy gamma rays (approximately 100 TeV) in the southern hemisphere of the Earth in order to better understand the mechanisms behind the acceleration of cosmic rays and to discover new astrophysical sources. This can be achieved by combining observations in different wavelengths such as radio and X-ray. The ALPACA observatory, being situated in the southern hemisphere, plays a vital role in pursuing the aforementioned physics objectives. Therefore, the main physics motivations of the ALPACA experiment are outlined below:

- Study the galactic gamma rays in the energy range of 5 TeV to 1 PeV from the southern hemisphere.
- Investigate the anisotropy of cosmic rays with energies greater than 5 TeV from the southern hemisphere.
- Examine the energy spectrum of cosmic rays in the knee region, ranging from 100 TeV to 100 PeV.
- Study the solar shadow phenomenon for energies greater than 5 TeV.

Considering sources like the Crab Nebula [9] but located in the southern hemisphere, with an energy spectrum proportional to $E^{-2.6}$ extending up to the 100 TeV energy regime, the ALPACA experiment will be highly sensitive to such sources. The experiment expects to detect an intensity of at least one year of data taking, approximately 15% as reported in [11]. As a result, ALPACA will provide a high-energy observation window (approximately 100 TeV) in the southern hemisphere [10].

ALPACA will conduct accurate measurements of cosmic rays anisotropy in the TeV range. This will provide valuable information for understanding magnetic fields in the heliosphere region. Additionally, ALPACA will measure the cosmic rays spectrum for protons, helium, and iron in the knee region. ALPACA experiment can test the standard model acceleration mechanisms for SNR, which predicts a behavior proportional to Z for the knee energy region. Lastly, precise measurements of solar shadow in the TeV range from the southern hemisphere will offer crucial information to comprehend the complex behavior of magnetic fields between the earth and the sun.

3. The current status of the ALPACA experiment

Below, we will provide an overview of the current status of the ALPACA experiment. Firstly, we will discuss the ALPACA prototype detector, known as "ALPAQUITA." Following that, we will outline our short and mid-term goals.

3.1 ALPAQUITA detector

During the last year (2022), 97 surface plastic scintillator detectors (SSD) were set up as a prototype experiment for the complete detector array that will be developed in the coming years. These detectors have been deployed over an approximate area of 18,450 m^2, as shown in Figure 2a. The scintillator detectors are designed in an upside-down pyramidal style (see Fig. 2b), with a 0.5 cm thick lead plate on the top to enhance the detection sensitivity of gamma rays from Extensive Air Showers (EAS). Each pyramidal structure is supported by an iron structure, which is placed on a concrete platform. A fast timing photomultiplier (PMT) is positioned at the bottom of each stainless steel pyramidal structure. These PMTs collect the scintillation light that is diffusely reflected inside the pyramidal structures. Additionally, to protect the detectors from harsh environmental conditions, they are covered with white material. On the other hand, construction is currently in progress for an underground muon detector that will cover an area of 900 square meters. Fig. 4a provides an overall view of the current ALPAQUITA detector.

The study of Monte Carlo simulations shows that the sensitivity of ALPAQUITA to gamma-ray sources will be equivalent to that of five gamma-ray sources observed by H.E.S.S. and HAWC in the TeV energy range [12]. Furthermore, the performance of ALPAQUITA will be excellent, achieving a 100% trigger efficiency above the 20 TeV energy range. Additionally, the angular resolution at 100 TeV is expected to be approximately 0.3 degrees, thanks to the accurate estimation of the shower core position with a resolution of 2.7 meters.

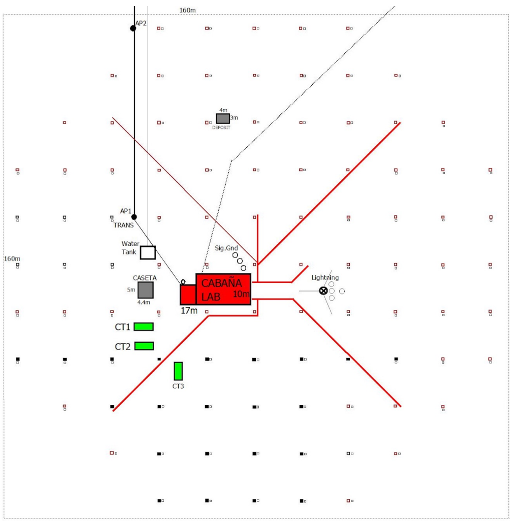
Since the final step of ALPAQUITA will include an underground muon detector (MD) with an area of 900 square meters (a diagram of future MD is shown in Fig. 4b), simulations have shown that 80% of gamma-ray events will survive beyond 100 TeV, while 99.9% of hadron cosmic ray (CR) events will be rejected. The expected number of CR events that contaminate gamma-ray events from a point source is less than one in the gamma-ray equivalent energy range of 100 TeV during one year of observation. Furthermore, ALPAQUITA's gamma ray point source observations are predicted to detect five sources above a 5 sigma significance level beyond the 10 TeV energy range within one year of observation. Specifically, one of the five observed sources above 300 TeV will be HESS J1702-420A [13], which has no clear counterparts in other wavelength ranges. This will lead to very interesting discussions regarding the emission mechanism of gamma rays beyond 100 TeV with ALPAQUITA's capabilities.

Ultimately, ALPAQUITA successfully began collecting data in late 2022. Promising preliminary results will be presented as a contribution during ICRC2023.

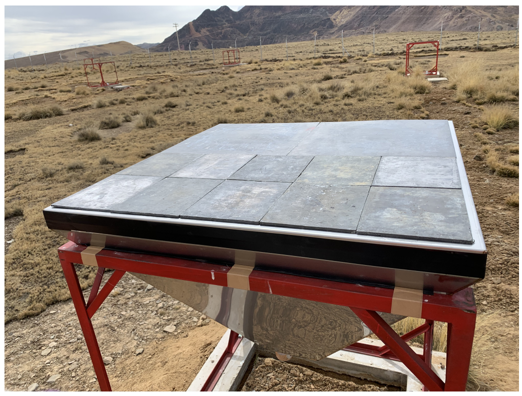
3.2 Prospects and summary

In the coming months, the construction of the first underground muon detector will begin. As we mentioned before, it will consist of an infrastructure based on concrete material known as the cell unit. Each cell unit will have an area of 56 m^2, with a total of 16 units covering an area of 900 m^2. After completion, ALPAQUITA will start collecting data in early 2024. The full-scale ALPACA experiment is expected to be operational by 2025-2026, consisting of 401 plastic scintillator counters and at least 4 underground muon detectors, covering a total area of about 3,600 m^2.

Since late 2022, the study to implement a surface Water Cherenkov Detectors array (WCDs) has begun. These WCDs will serve as a complement to the underground muon detectors and scintillators.



(a) A diagram showing the layout of the ALPAQUITA detector is presented above. The squares represent 97 plastic scintillator counters, each with an area of 1 square meter, and separated by a distance of 15 meters. The containers CT1, CT2, and CT3 are shown in green, and the red rectangle represents the hut housing the control room.



(b) The photo shows a scintillator counter with 0.5 cm thick lead plates on the top of the detector. The detector is supported by an iron structure, which is secured to a concrete base. Additionally, there is a stainless steel pyramidal structure that is 1 mm thick, which is also held by the iron structure.

Figure 2: A schematic view of the ALPAQUITA detector (a) and a photograph of the scintillator detector (b).

By the end of this decade (2028-2030), there is a very promising idea to extend the ALPACA array up to 1,000,000 square meters. This Mega ALPACA array is expected to consist of 1500 plastic scintillator arrays and at least 50 underground muon detectors. With the Mega ALPACA array, it will be possible to study photon emission in the energy region above PeV (as shown in Fig.

3). Additionally, detailed studies of sub-PeV sources and the identification of the highest-energy galactic cosmic ray accelerators will be possible. By achieving this milestone by the end of this decade, ALPACA will be a pioneering observation in high-energy gamma-ray astronomy, observing from the southern hemisphere.

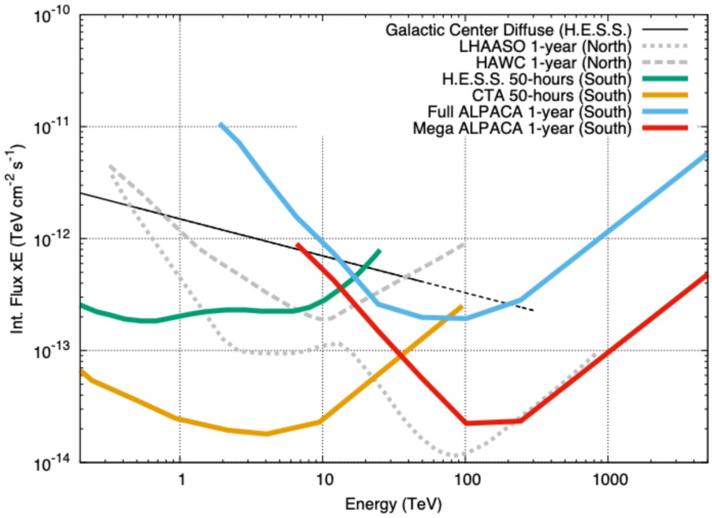


Figure 3: The sensitivity of ALPACA and Mega ALPACA to high-energy gamma ray sources will be evaluated in comparison to other experiments operating in a similar energy range. Reference picture from [14].

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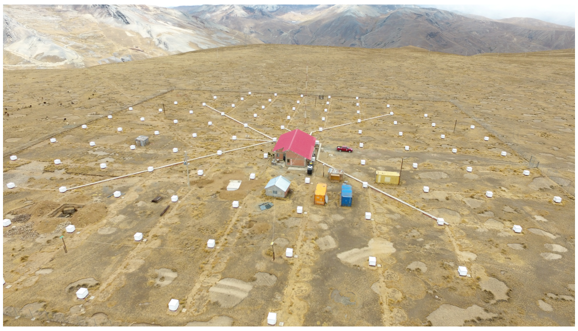
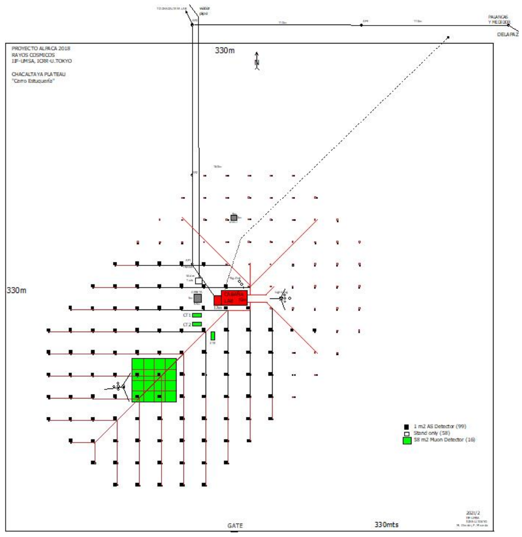


(a) A photo of the current overall view of ALPAQUITA (Experimental site @ 4740 meters above sea level: 16°23′ S, 68°08′ W).



(b) Layout of the ALPAQUITA detector, including the design of the muon detector (represented by green square). The muon detector consists of 56 m^2 cell units, which are repeated 16 times to cover a total area of about 900 m^2.

Figure 4: A photo of ALPAQUITA curren overall view (a). A schematic view of the ALPAQUITA muon detector (b).

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