PROCEEDINGS OF SCIENCE

The overview of the ALPACA Experiment

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The ALPACA experiment is a new project aimed at wide field-of-view high-sensitivity observations of high-energy cosmic rays and cosmic gamma rays, launched between Bolivia and Japan in 2016. It is composed of an 83,000 m^2 air shower array and a 5,400 m^2 underground muon detector array, on a highland at the altitude of 4,740 m, halfway up Mount Chacaltaya on the outskirts of La Paz, Bolivia.

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1. Introduction

In the southern celestial hemisphere, the H.E.S.S. group reported the discovery of 14 new gamma-ray sources by the galactic plane survey [1]. Surprisingly, most of them were Unidentified (UNID) sources and faint in X-rays or other wavelengths. As the H.E.S.S. survey was limited within the galactic plane in the southern celestial hemisphere due to its narrow field of view, the importance of a wide field-of-view unbiased survey is emphasized. Furthermore, many of the 14 sources have a harder energy spectrum at TeV energies (indices: -1.8 to -2.8) than the standard Crab candle (index; -2.6). Although, the energy spectra were mostly measured below approximately 10 TeV due to the sensitivity limit of the H.E.S.S. air Cherenkov telescopes, they suggest that they extend up to the 100 TeV region. The number of TeV sources now amounts to approximately 200. However, the origin of the cosmic rays has not yet been clarified.

Cosmic rays are supposed to be accelerated up to the knee energy (PeV) region at supernova remnants (SNRs) in our galaxy. Therefore, we naturally expect gamma rays at 100 TeV energies, which originate in π^0 decays produced by the accelerated cosmic rays interacting with matter surrounding the SNRs. However, on-going experiments focus on measuring gamma rays in the $1-10$ TeV region. The gamma-ray emission of electron origin might be highly suppressed above 10 TeV due to the rapid decrease of the inverse-Compton cross section by the Klein-Nishina effect as well as synchrotron radiation energy losses in the strong magnetic field around SNRs.

The detection and spectral measurement of gamma rays in the 100 TeV region from their celestial sources, together with multi-wavelength (radio, X-ray, gamma-ray) observations, will be an important experiment enabling us to discriminate between the two processes (cosmic-ray / electron origins), to locate the acceleration site of cosmic rays (PeVatrons which accelerate cosmic rays up to PeV energies) and to verify the standard acceleration model. Some of the H.E.S.S. 14 sources are very promising candidates for the cosmic-ray PeVatron. Furthermore, the energy spectrum of diffuse gamma rays from the extended region around the galactic center marginally measured by H.E.S.S. up to approximately 10 TeV also strongly indicates the existence of PeVatrons [2], from which we expect to detect gamma rays at 100 TeV energies. Thus, a wide field-of-view gamma-ray imaging at 100 TeV energies in the southern sky, where the H.E.S.S. sources, the Fermi bubbles and the galactic center are located within the field of view, will be a key experiment.

2. Experiment

The experimental site for the ALPACA (Andes Large area PArticle detector for Cosmic ray physics and Astronomy) project is located on a plateau called Chacaltaya Hill (4,740 m above sea level, $16°23'$ S, $68°08'$ W), as shown in Fig. 1, around Mount Chacaltaya, near La Paz, Bolivia. This plateau is a flat and horizontal land covering the area of more than 500 m $\times$ 500 m. Our detectors will be set up in some part of this area.

We plan to set up a 5,400 m^2 underground (approximately one to a few meters) muon detector array (MD) and an 83,000 m^2 air shower array (AS), shown in Fig. 2 [3]. The MD of the water Cherenkov type is composed of eight pools with each pool (approximately 1 m deep) containing twelve 56 m^2 unit detectors. AS is made up of 401 1.0 m^2 plastic scintillation counters at 15 m spacing.

Figure 1: Experimental site for the ALPACA experiment, Chacaltaya Hill (4,740 m above see level, 16°23′ S, 68°08′ W), near Mount Chacaltaya, in Bolivia.

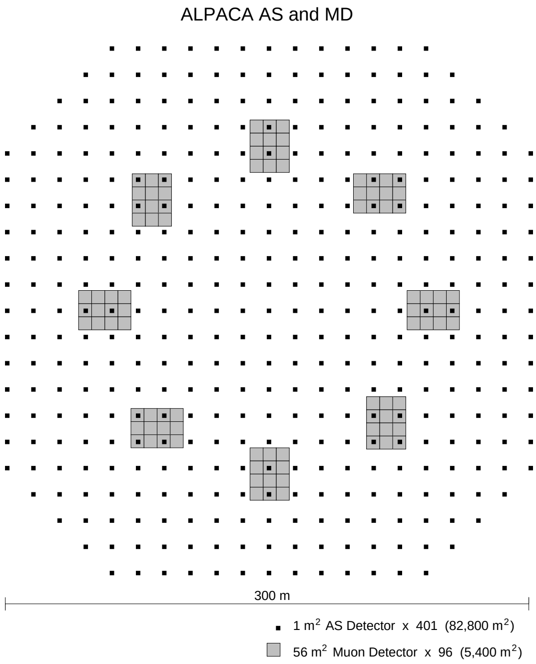

Figure 2: Schematic view of the ALPACA experiment. The small black squares indicate 401 1.0 m^2 plastic scintillator detectors, forming an air shower array with 83,000 m^2 in area. The grey rectangles indicate eight underground muon detector pools, each of which contains twelve 56 m^2 muon detector units. The total area of the underground muon detector array is 5,400 m^2.

The AS field of view is roughly 2 steradians. The expected angular resolution of AS is approximately 1 degree at 5 TeV and 0.2 degrees around 100 TeV for gamma rays. For 100 TeV gamma rays, the AS energy resolution is estimated to be $\sim 25\%$. The hadron rejection power of MD is more than 99.9% at 100 TeV, while keeping most of gamma-ray events. The long-term detector stability, angular resolution, pointing accuracy and energy scale can be calibrated by the cosmic ray shadow of the Moon as well as by some of the bright stable TeV gamma ray sources in the southern sky.

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3. Physics Targets

We have four physics targets in the ALPACA experiment:

1. Measurement of high-energy (5 TeV − 1 PeV) cosmic gamma rays.
2. Measurement of cosmic ray energy spectra around the Knee energy region (100 TeV − 100 PeV).
3. Measurement of cosmic ray anisotropy > 5 TeV in the sidereal time frame.
4. Measurement of the Sun shadow in cosmic rays > 5 TeV.

We aim at low-background detection of celestial gamma rays in the 100 TeV region with a world-best sensitivity (an order of magnitude better than any previous / existing experiments) and at locating the origins of cosmic rays accelerated up to the knee energy region in the southern sky. Assuming the presence of a Crab-like gamma-ray source in the southern sky, with a power-law differential energy spectrum proportional to $E^{-2.6}$ extending up above 100 TeV where E is energy of a gamma ray, the ALPACA experiment is sensitive to the source with $\sim$ 15% Crab intensity during one calendar year, as demonstrated in Fig. 3.

The ALPACA experiment will be a unique experiment complementary to on-going experiments (FERMI, H.E.S.S., VERITAS, MAGIC, CALET, Tibet ASγ, HAWC) and future projects (LHAASO, CTA) in this field, which are either located in the northern hemisphere or aiming at gamma-ray astronomy below 10 TeV region, or having a narrow field-of-view. Thus, the new energy window in the 100 TeV region observing gamma rays with a wide field-of-view will be opened first in the southern sky by the ALPACA experiment. We expect to detect more than a dozen established sources, *i.e.*, young SNRs (SN 1006 Remnant, RX J1713.7 − 3946, RX J0852.0 − 4622), Pulsar Wind Nebulae, the galactic center *etc.* in the 100 TeV region, some of which may be

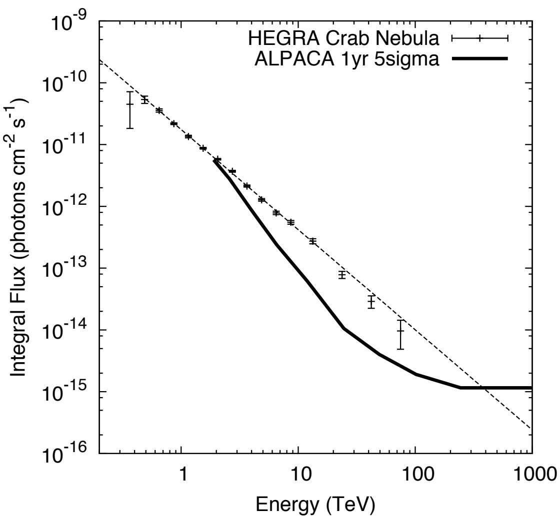

Figure 3: Sensitivity of ALPACA to high-energy gamma-ray point sources. The experimental points are from Ref. [4]. The ALPACA sensitivity is evaluated from Ref. [5].

cosmic-ray PeVatron candidates. Furthermore, our wide field-of-view sensitivity to diffuse gamma rays allows us to study extremely diffuse gamma-ray sources which are difficult to detect by IACTs. The diffuse gamma rays from the Fermi bubbles recently reported by the Fermi-LAT group may be clearly detected, if they extend up to the 100 TeV region. Similarly, the detection of diffuse gamma rays above 100 TeV from an extended region from the galactic center is promising, where the gamma-ray energy spectrum strongly suggests the existence of PeVatrons. Detection and spectral measurement of gamma rays in the 100 TeV region from these celestial sources, together with multi-wavelength observations (radio, X-ray, gamma-ray), are key points enabling us to discriminate between the two processes (cosmic-ray/electron origins), to locate the acceleration site of cosmic rays and to examine the standard acceleration model of cosmic rays.

From the astronomical point of view, we pioneer ultra-high energy gamma-astronomy (above 100 TeV) in the southern sky. Besides, gamma-ray emission from near-by extra-galactic sources, *e.g.* M87, Cen A, gamma rays of dark matter origin, those from the Sun disk recently observed by Fermi [6] may be interesting subjects.

We also aim to measure the energy spectra of proton, helium and iron components separately around the knee energy region with the ALPACA experiment. The standard cosmic-ray acceleration model at SNRs predicts the knee energy of each nucleus component being proportional to Z (atomic number). We can discriminate proton and iron components by MD, as an iron nucleus produces approximately twice as many muons as a proton with the same energy. Thus, the cosmic-ray acceleration scenario (SNR shock acceleration) will be verified by observing the linearly Z-dependent knee (=bent) positions of proton, helium, iron components around the knee energy region.

Precise cosmic-ray anisotropy measurements in the sidereal time frame in the TeV energy region in the southern sky provide unique data for the community to understand the magnetic field structure in the heliosphere. The ALPACA experiment gives complementary data in the TeV region to those from IceCube above a few tens of TeV.

Furthermore, measurements of the Sun shadow in cosmic rays above the TeV energy region in the southern hemisphere also helps understand the modeling of the magnetic fields between the Sun and the Earth, complementary to the observations in the northern hemisphere.

4. Summary

We have started up the ALPACA project which aims at imaging the southern sky by means of gamma rays in the 100 TeV region, composed of a southern-hemisphere air shower array (83,000 m^2) with a large (5,400 m^2) underground water Cherenkov muon detector array in the Andes highland (4,740 m above sea level) in Bolivia. The muon detector array enables us to discriminate the muon-poor gamma-ray component from the muon-rich hadronic component, allowing us to make low-background observations of gamma rays in the 100 TeV region. This will be the first important attempt in the southern sky in this field. It should be stressed that, until now, there has not existed any high-sensitivity experiment capable of probing the gamma-ray southern sky around 100 TeV with a wide field-of-view and high duty cycle.

The ALPACA experiment covers a wide range of cosmic ray physics, *e.g.*, measurement of the chemical composition and energy spectra around the knee energy region, measurement of the cosmic ray anisotropy above the TeV energy region in the southern hemisphere, measurement of the Sun shadow in cosmic rays in the southern hemisphere *etc.*

Thus, the expected impacts upon the field are promising, as the project gives an important clue to the problem which has remained over 100 years since the discovery of cosmic rays: the origin, acceleration and propagation mechanism of cosmic rays.

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