PROCEEDINGS OF SCIENCE

ALPACA experiment: A new air shower array to explore the sub-PeV gamma-ray sky in the southern hemisphere

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PoS(ICHEP2022)091

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In the last few years, gamma-ray astronomy opened a new window in the sub-PeV to PeV range inaugurated by the Tibet ASγ collaboration followed by the HAWC and LHAASO collaborations. These three successful experiments are located in the northern hemisphere and are not able to study the southern sky where potential interesting objects are known to exist.
Andes Large area PArticle detector for Cosmic ray physics and Astronomy (ALPACA) is a project to cover the southern sub-PeV to PeV sky using a new air shower array at the plateau of the Chacaltaya mountain at the altitude of 4,740 m in Bolivia. The prime target of ALPACA is to reveal PeV cosmic-ray accelerators presumably existing in the galactic plane, including the galactic center. A prototype array ALPAQUITA consisting of 97 surface counters and 900 m^2 muon detectors is now under construction and planned to partly start data taking in 2022. The extension to the 401 counters and 3,700 m^2 muon detectors is scheduled in 2024. In this contribution, a general introduction to ALPACA, the current status of ALPAQUITA, and an extension plan after 2023 are presented.

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1. Introduction

Since the successful detection of >100 TeV photons from the Crab nebula by the TibetASγ collaboration in 2019 [1] followed by the HAWC [2] and LHAASO [3] collaborations, so-called sub-PeV gamma-ray astronomy started. In addition to the pulsar wind nebula like Crab, Supernova Remnants [5] [6] , Star Forming Region [4] are also known as sub-PeV emitters. Photons above PeV [7] and diffuse photons along the galactic plane [8] are also detected. Sub-PeV photons are emitted through the inverse Compton process from sub-PeV electrons or decay of neutral pions produced in the hadronic interaction of multi-PeV nucleons and the interstellar matter. Identification of multi-PeV nucleon accelerator is extremely important because this energy is known as *knee* in the cosmic-ray energy spectrum, which is thought to be the acceleration limit of proton cosmic rays in our galaxy. Emission from G106.3+2.7 is considered a good candidate of hadronic origin, but its current maximum energy does not reach to the knee [5]. So far there is no definitive evidence of hadron accelerator up to the knee energy, but the existence of sub-PeV diffuse photons assures the existence of multi-PeV nucleons in the galaxy [8]. Because the three experiments introduced above are operating in the northern hemisphere, they have not enough sensitivity in the vicinity of the galactic center region, where many energetic sources are known by the H.E.S.S. galactic plane survey at the TeV energy range [9] .

In this paper, a new cosmic-ray air shower experiment Andes Large area PArticle detector for Cosmic ray physics and Astronomy (ALPACA) is presented. ALPACA is under construction in Bolivia highland. Using the technique of the TibetASγ, ALPACA will explore the sub-PeV gamma-ray sky first time in the southern hemisphere. Design and sensitivity of ALPACA together with the current status and future prospects are presented.

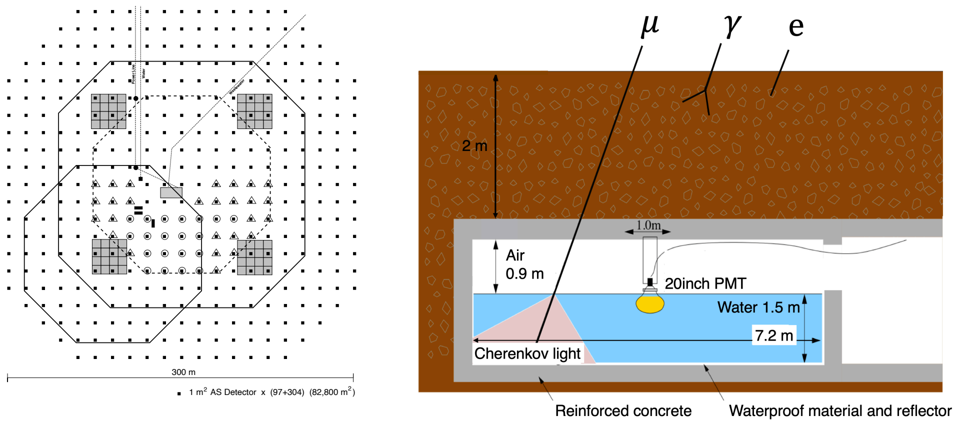

Figure 1: (Left) Layout of ALPACA array. Small dots indicate SDs and grey hatched areas indicate MDs. The enclosed area in the left bottom corner is the ALPAQUITA array under construction. Full coverage array ALPACA will be eventually achieved after ALPAQUITA. (Right) Schematic view of an MD zooming in a single cell. A reinforced concrete structure is constructed under 2 m soil. MDs are filled with water of 1.5 m depth and Cherenkov lights in each of 56 m^2 cell are monitored by a 20" PMT.

2. The ALPACA Project

ALPACA is under construction near the Chacartaya mountain at an altitude of 4,740 m above sea level in Bolivia. Basic specifications are summarized in Tab.1. As shown in Fig.1 (left), total 401 plastic scintillating counters of 1 m^2 (5 cm thickness) aligned with a 15 m interval cover the 82,800 m^2 ground area and consists of a surface detector (SD) air shower array. Using the signal size and timing measured by the SD array, arrival direction and energy of the primary particle, respectively, are determined. In addition to this conventional SD array, four underground water Cherenkov muon detectors (MDs) are constructed below 2 m soil overburden (Fig.1 (right)). Each MD is composed of 16 cells, where a single cell has a 7.5 m×7.5 m area filled with 1.5 m deep water and monitored by a 20" PMT. Because of the soil layer, most of the electromagnetic particles are absorbed and only muons above 1 GeV can be detected. Using this high-purity muon signal, mu-poor electromagnetic showers produced by gamma-ray primaries are selected from the sea of mu-rich isotropic hadronic showers. This technique was first proposed and established by the TibetASγ collaboration [10] [11] .

Table 1: Specifications of the ALPACA design. Details in the different construction stages are summarized in Tab.2.

Location	Chacaltaya plateau, Bolivia
Longitude and Latitude	68°08' W, 16°23' S
Altitude	4,740 m a.s.l. (572 g/cm^2)
Surface area	82,800 m^2
Underground muon detector area	3,700 m^2
Number of surface detector	401 (1 m^2×5 cm^t each)
Energy resolution (100 TeV)	20%
Angular resolution (100 TeV)	0.2°

3. Current Status of ALPACA : ALPAQUITA

The enclosed 97 SDs and one MD at the left-bottom corner of Fig.1 (left) is called ALPAQUITA. By the conference of ICHEP in July 2022, installation and cabling of ALPAQUITA SDs are completed as shown in Fig.2. Soon after the conference in September 2022, operation of ALPAQUITA SDs has started. The design of the first MD is at the final stage and the construction will start early 2023. In the end of 2023 full ALPAQUITA operation will start. According to the performance study of ALPAQUITA [12], some bright TeV sources are detected above 100 TeV above 5σ level after 1 year observation.

4. Prospects and Summary

Construction of full ALPACA will start in 2024 with ALPAQUITA in operation. The sensitivity of ALPACA is shown in Fig.3 (light blue curve). One of the most important observations, Galactic

PoS(ICHEP2022)091

Figure 2: Photograph of ALPAQUITA taken in June 2022. White boxes are scintillating counters whose signal and high voltage cables are connected to the electronics hut at the right-middle of the image.

Center diffuse emission [13] , is within the 1 year - 5 σ sensitivity of ALPACA at 100 TeV. The time line at each construction stage is summarized in Tab.2. Here a future proposal named Mega ALPACA is also included. Mega ALPACA is a possible extension idea of ALPACA to cover 1 km^2 (1 Mega m^2). With a sensitivity of Mega ALPACA shown in Fig.3 (red curve), photon emission above PeV can be studied with a high sensitivity. Using Mega ALPACA detail studies of sub-PeV sources, identification of the highest-energy galactic accelerators, distribution of cosmic-ray particles inside the galaxy through the observation of diffuse gamma rays, photon-photon attenuation inside the galaxy and nearby extra-galactic sources will be within the scope.

Table 2: ALPACA staging

Stage	Construction Year	Surface coverage (Number of SDs)	Number of MDs (1=16 cells)	Reference
ALPAQUITA	2022-2023	18,450 m^2 (97)	1	[12]
ALPACA	2024	82,800 m^2 (401)	4+	
Mega ALPACA	2028+	1,000,000 m^2 (1500)	50	

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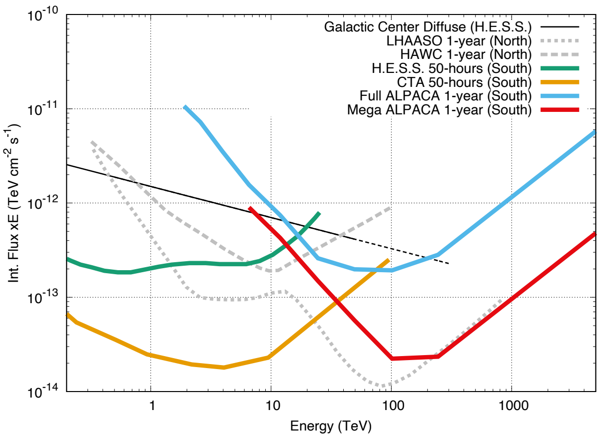

Figure 3: 5σ sensitivities of ALPACA (light blue) and Mega ALPACA (red) together with other experiments at the similar energy range.

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