

Status of the Large High Altitude Air Shower Observatory Project

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Abstract: The Large High Altitude Air Shower Observatory (LHAASO) is a multipurpose project with a complex detector array for high energy gamma ray and cosmic ray detection. The array of 1 km² is composed of five types of detectors to measure shower arrival direction, total number of secondary particles, muon content, Cherenkov image and high energy gamma rays near shower core, respectively. The main scientific goals are (1) searching for galactic cosmic ray origins by extensive spectroscopy investigations of gamma ray sources above 30 TeV; (2) all sky survey for gamma ray sources at energies higher than 300 GeV; (3) energy spectrum and composition measurements of cosmic rays over a wide range covering knees with fixed energy scale and known fluxes for all species at the low energy end. In this paper, the progress on relevant researches and detector developments are reported, including constructions of prototype detectors at Tibet site and coincidence operation with the ARGO-YBJ resistive plate chamber full coverage array at 4300 m a.s.l.

Keywords: galactic cosmic ray origin, gamma ray source, cosmic ray composition, complex detector array

1 Introduction

The proposed Large High Altitude Air Shower Observatory (LHAASO) project is designed for three major scientific goals[1, 2, 3]. Firstly, the project is designed to search for high energy cosmic ray origins by extensive spectroscopy investigations of gamma ray sources above 30 TeV. More than 140 gamma ray sources have been discovered in this so-called Very High Energy (VHE) range. Observing gamma rays with good statistics and measuring their energy spectrum up to 1 PeV with high energy resolution for galactic sources is a promising approach to collect important evidences for the origins of the photons, either from cosmic ray pevatrons or well known electron sources. Besides, the high energy sky has revealed a stunning richness of new phenomena and puzzling details in the observation of the existing sources. A deep survey over the whole sky for more sources with high sensitivity and a clock-round monitoring for transient phenomena of the VHE sources are very important as an essential part of the multi-wavelength investigation in order to understand the evolution of galaxies (such as AGN) and particle acceleration procedures and radiation mechanisms in the gamma ray sources. With strong complementary to the Cherenkov telescopes, the ground-based particle detector arrays play irreplaceable roles in the gamma ray astronomy due to their large acceptance in terms of high duty cycle of >95% as well as large field of view of the whole hemisphere. Particularly, the proposed project will be at least one order of magnitude more sensitive than the Cherenkov Telescope Array (CTA) above 10 TeV.

Secondly, measuring energy spectra above 1 PeV for individual cosmic ray species is the ultimate way to understand the origin of knees. Major difficulty is to distinguish different primary cosmic ray composition in the air shower observations. A detector array like LHAASO at an altitude of 4300 m could naturally be used for this purpose because air showers around few PeV just reach their maximum as they touch down the ground, thus the effects due to shower fluctuations can be minimized. In order to gain photon/hadron discrimination power, the proposed LHAASO

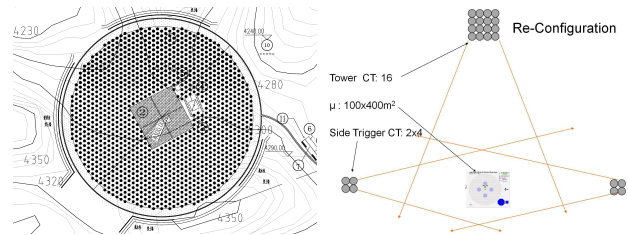


Fig. 1: Left panel is LHAASO detector layout, and on the right hand side the layout of the fluorescence detector array and the LHAASO array

SO array has been equipped with the large muon detector array. The high statistic measurements on muon content will make a significant contribution to the separation between primary species. In addition, the high altitude of the site enables a threshold energy to be lower than 100 TeV in the spectrum measurements. It is important because of the overlap with the balloon or space borne experiments such as CREAM. The comparison between the direct measurement and ground based experiments will provide a natural calibration in both energy scale and flux normalization for each species. The scales will be propagated up to higher energies in the experiments with LHAASO. This will bridge the space borne direct measurements of cosmic rays and ground-based ultrahigh energy cosmic ray experiments which are troubled by the issues.

2 Base-line detector array design

In order to fulfill all the goals mentioned above, a large scale complex of many kinds of detectors is needed. Figure 1 is a sketch map of LHAASO detector array which is composed of three major components. The simulated sensitivity curve of LHAASO project for the gamma ray observation is shown in figure 2. The sensitive curves for oth-

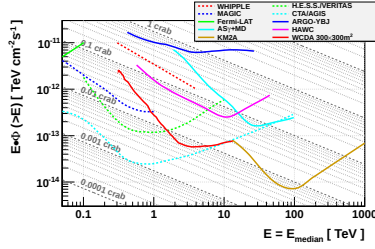


Fig. 2: The sensitivity of LHAASO-WCDA + LHAASO-KM2A. The curves for other experiments and projects are drawn for comparison. The observation times is 1 year and 50 hour for wide field-of-view detectors and IACT respectively.

er projects are also shown in the same figure for comparison.

2.1 Search for cosmic ray origins among galactic gamma ray sources

Among known sources discovered in the all sky survey, many of them will be investigated for their emission mechanism. This can be done by measuring the energy spectra of gamma rays up to a few hundred TeV. To search for galactic cosmic ray origins among them, the focus is the high energy ends of the spectra where one expects to see differences between origins of gamma rays, either through inverse Compton scattering of high energy electrons or from decays of neutral pions which are produced in interactions between accelerated high energy protons and ambient material near the sources. For this purpose, a particle detector array with an effective area of 1 km² is proposed (KM2A) including a muon detector array using water Cherenkov technique with 40,000 m² active area. This allows a background-free measurement of gamma ray spectra above 50 TeV without any contamination by simply selecting muon-poor air showers. 5635 scintillator detectors (1 m² each) are arranged in a triangle grid with a spacing of 15 m, while the spacing is set as 30 m between 1221 muon detectors.

2.2 All sky survey for gamma rays above 300 GeV

To survey gamma ray sources, a Water Cherenkov Detector Array (WCDA) with a total active area of 90,000 m² is proposed[4], marked by the four octagons in figure 1. It is sensitive to gamma ray showers above few hundred GeV. The sensitivity to a source like the Crab Nebula is about 0.7% of the crab unit, I_{crab} , namely the significance reaches to 5 σ in one year observation, shown in figure 2.

WCDA consists of 4 water ponds, each of which has a size of 150×150 m². The depth of the pond is about 4.5 m. Each pond is subdivided into 30×30 = 900 cells sized 5×5 m² each, partitioned by black plastic curtains to prevent the penetration of light yielded in neighboring cells. An 8 inches hemispheric PMT resides at the bottom of each cell, looking upward to collect Cherenkov lights produced by charged particles in the water pond, recording the arrival time and the charge of pulses. The later is in proportional to the product of the number of particles in the shower and their energies.

2.3 Identification of Primary Particles around 1 PeV

To measure energy spectra for individual species of cosmic ray particles, one needs a reliable primary particle identification algorithm for observed air showers. A multi-parameter measurement is probably a plausible approach. In general, the shower maximum position, the muon content and the high energy component near the shower core are three independent parameters that can be used for deducing signatures of showers induced by different nuclei[5, 6]. Thus two more detector arrays are proposed to be the extra components of LHAASO project. They are designed to measure the shower maximum location and high energy components near cores, respectively. They are Wide Field of view Cherenkov Telescope Array (WFCTA) composed of 24 telescopes and the high threshold Shower Core Detector Array (SCDA) with an effective area of 5000 m², shown as three rectangles and a very dense area at the center of the array in Figure 1 respectively.

2.4 Extension to higher energies beyond the first knee

To extend the spectrum measurements to higher energies with calibrated energy scale and composition, we have to re-arrange the detector arrays for larger effective area and larger exposure. A simple re-arrangement of the WFCTA is necessary to form a hybrid experiment together with the 1km² KM2A as a whole instead of SCDA which is only 5000 m². The energy coverage can be extended to 10PeV regime. In order to connect with other experiments, such as TA and Auger, at altitudes around 1600m a.s.l., an even larger effective area is required. The wide FOV telescopes will be re-arranged and modified to measure shower fluorescence light and monitor the space above the ground array from a distance of 4-5 km cost-free. The detector configuration is shown in figure 1, in which the main detector array is composed of 16 telescopes covering elevations from 3° to 59° and two other detector arrays, covering elevations from 3° to 31°, to observe showers from perpendicular directions. Showers above 100 PeV will be detected stereoscopically to maintain a high resolution of shower maximum position. Combining with the muon content measured by KM2A, the telescopes will achieve the spectrum and the composition measurements around the second knee.

2.5 Electronics and DAQ

The tasks of LHAASO data acquisition system (DAQ) are designed to carry out the configuration of hardware, reading out the data from the front end electronics and monitoring the running status of detector. The system must be flexible and universal to cope with the multiple subsystems, such as WCDA, WFCTA etc., with different types of front-end electronics. The DAQ, therefore, is based on a fiber network constructed with many layers of switches in a complex topology. The same fiber network is shared by clock distribution under the White Rabbit protocol which is designed to automatically synchronize the clock within sub-nanosecond and stem every single pulse with a GPS trained absolute time. At the front ends, data had been digitized using the clock as early as possible, and transited through the network to the back-end. The central computer system is designed to not only collect the data but also carry out the so-called soft trigger for event building, and send off control commands and collect monitoring information

of the whole detector system.[7]. A baseline design of the LHAASO DAQ system is tested at a moderate scale in lab with following major features (1) A distributed electronics scheme; (2) A compacted Front-end Electronics system based on ASIC design; (3) FPGA-based TDC; (4) Triggerless DAQ system.

3 R/D of all detectors

3.1 LHAASO-KM2A

The Electromagnetic particle Detector (ED) in LHAASO-KM2A consists of 4×4 plastic scintillation tiles ($25 \text{ cm} \times 25 \text{ cm} \times 2 \text{ cm}$ each) packed in an steel box with an area of $1 \text{ m} \times 1.2 \text{ m}$. Four wavelength-shifting fibers (BCF92) of 1.5 mm in diameter and 150 cm long in each are embedded in eight dips on the tile to collect the scintillation lights as charged particles pass through. A photomultiplier tube touched to all 128 ends of the fibers from the 16 titles collects the scintillating photons.

To test the validity of the design and the performance of the detectors, an array of 1% of the full scale LHAASO-KM2A, namely 42 detector units, has been built and tested at ARGO-YBJ site in Tibet since Mar. 2010. The prototype detectors were uniformly distributed on top of the central carpet of the ARGO-YBJ array[9] with the spacing of 15 m as proposed for LHAASO-KM2A covering an area around $75 \text{ m} \times 75 \text{ m}$. The detector array[10] has been in operation since Oct. 2010, the trigger rate is about 48 Hz with > 5 triggered detectors. Around 1.5 GB data per day is collected and transferred to IHEP. Among them more than 95% recorded showers matched with events recorded by ARGO-YBJ experiment within a $\pm 500 \text{ ns}$ time window. The observed moon shadow is shown in figure 3, a significance of 5.3σ for the shadow is accumulated for events with number of fired detectors, N_{hits} , greater than 5. Both the significance and the location of the shadow are within the statistic errors.

The Muon Detector (MD) in LHAASO-KM2A is a water-Cherenkov detector in a concrete tank covered by 2.5m of dirt. Each MD is 3.6 m in radius $\times$ 1.2 m in height and 2.5 m underneath the surface, i.e. about 12 radiation length before shower particles reach to the water surface. Most of electromagnetic particles in the air showers can not survive from the absorption layer. Each tank is equipped with an 8" PMT watching into a highly reflecting liner bag fully filled with pure water. A prototype detector is running at the ARGO-YBJ site. Some preliminary results, such as the charge of muon signal pulses are quite stable within 2% over last three months and the detector simulation reproduces muon arrival time distribution quite well as shown in figure 4

3.2 LHAASO-WCDA

After the single unit prototype of the water Cherenkov detector concluded[12], an engineering array of 3×3 cells of LHAASO-WCDA[14] was constructed at the northwest corner of the ARGO-YBJ experiment hall in Tibet. It is about 1% of the full scale water pond in LHAASO. For nine 8" PMTs, all front-end-electronics, DAQ, water recycling and purification system, slow control system, optical calibration system[15] etc are fully equipped as a full detector array. In the coincident operation with the ARGO-YBJ RPC carpet together, the water Cherenkov detector performance is tested, including the arrival direction recon-

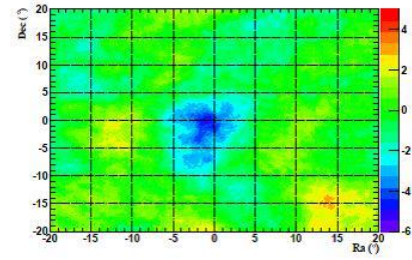


Fig. 3: The significance map of the moon shadow observed by LHAASO-KM2A 1% array using two years data.

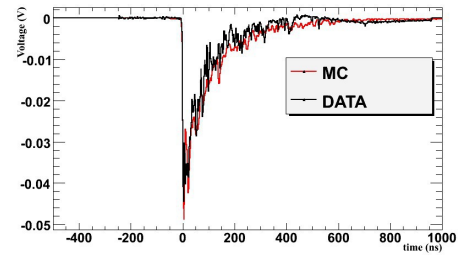


Fig. 4: The arrival time comparison between data and MC simulation.

struction accuracy, trigger efficiency of air showers and zenith/azimuth angle distributions and so on. The distribution of core positions of all showers triggered on both detectors is shown in figure 5. The core locations are reconstructed by using ARGO-YBJ carpet data.

3.3 LHAASO-WFCTA and SCDA

The prototype telescope of the Wide Field of view Cherenkov Telescope Array (WFCTA) in LHAASO is mainly composed of a 4.7 m^2 spherical aluminized reflective light collector and an imaging camera, a set of 256 hexagonal PMTs arranged in a 16×16 array located at the focal plane of the reflector, thus form a field of view (FOV) of $14^\circ \times 16^\circ$ in total since the single PMT as a independent pixel has a size of approximately 1° . The whole system, including electronics, DAQ, slow control and monitoring system, is installed in a compact shipping container with a dimension of $2.5 \text{ m} \times 2.3 \text{ m} \times 3 \text{ m}$. The telescope as a whole is mounted on a standard dump truck frame with a hydraulic lift that allows the pointing direction to cover the elevation angle from 0° to 60° . The particular portable design of the telescope enables a flexibility of switching between the configurations an array consists of the telescopes for different physics targets. The detailed testing results and performance of the telescope can be found elsewhere[16].

Two prototype telescopes for LHAASO-WFCTA were deployed to the Tibet site of the ARGO-YBJ experiment in the year of 2007. Up to now millions of cosmic ray events that simultaneously trigger the telescopes and the ARGO-YBJ RPC carpet array have been collected. Many interesting works has been carried out, such as using background starlight to monitor the local weather etc. With its independent measurement about the shower longitudinal development, the two telescopes are used to select proton and Helium showers together with the RPC carpet that measures the lateral distribution of shower particles in a very small regions near the cores, namely less than 2 m. The hybrid

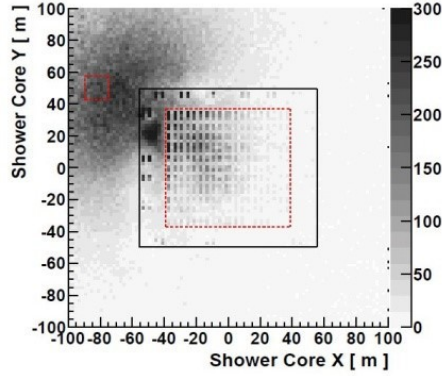


Fig. 5: The distribution of shower core position from the coincident events from LHAASO-WCDA and ARGO-YBJ experiments.

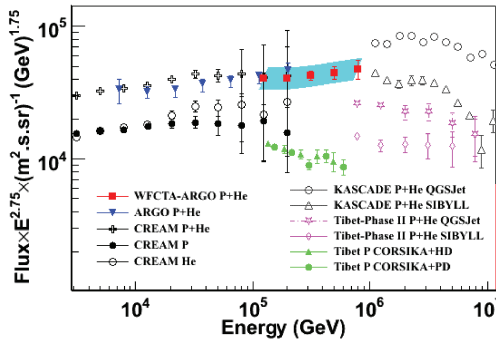


Fig. 6: The energy spectrum of protons and Helium nuclei using the hybrid measurement with LHAASO-WFCTA prototype and ARGO-YBJ RPC carpet array.

measurement of the energy spectrum of protons and Helium nuclei[17, 18] is shown in Figure 6. It shows a clear extension of the spectrum from the similar measurements by ARGO-YBJ and CREAM at slightly lower energies. Recently an energy calibration and atmospheric monitoring facility using nitrogen laser was deployed on the site[19].

Figure 7 is a picture of the prototype Shower Core Detector Array (SCDA) which is currently operated together with AS-gamma, one of the two major experiments at the Tibet site. Relevant analysis is under going mainly for cosmic ray composition and energy spectrum.

4 Summary

In order to achieve the scientific targets of LHAASO project, a complex detector array in an area of one square kilometer is proposed with five types of detectors as its major components. Many progresses have been made in R/D of all five types of the detectors. In order to develop all relevant components in the array except for the single detector units only, engineering arrays at 1% of the full scale LHAASO components are constructed using LHAASO-KM2A, LHAASO-WCDA, LHAASO-WFCTA and SCDA detectors at the ARGO-YBJ and AS-gamma site in Tibet. Hybrid measurements of air showers using the engineering arrays and ARGO-YBJ experiment yield interesting results, including the spectrum of cosmic pro-



Fig. 7: A picture of the prototype shower core detector

tons and Helium nuclei in the energy gap between 100TeV and 1PeV.

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