LHAASO Project: detector design and prototype

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Abstract**. The Large High Altitude Air Shower Observatory (LHAASO) project focuses mainly on the study of 40GeV-1PeV gamma ray astronomy and 10TeV-1EeV cosmic ray physics. It consists of a $1km^2$ extensive air shower array with $40,000m^2$ muon detectors, $90,000m^2$ water Cerenkov detector array, $5000m^2$ shower core detector array and an air Cerenkov/fluorescence telescope array. Prototype detectors are designed with some of them already in operation. A prototype array of 5% size of LHAASO will be built at the Yangbajing Cosmic Ray Observatory and used to coincidently measure cosmic rays with the ARGO-YBJ experiment.**

Keywords**: LHAASO, Gamma Ray Astronomy, Cosmic Ray Physics**

I. INTRODUCTION

The Large High Altitude Air Shower Observatory (LHAASO) project [1] is proposed to study

- gamma ray astronomy from 40GeV to 1PeV by
  1. searching for cosmic ray sources using gamma rays above 30TeV,
  2. survey in the whole northern sky for gamma ray sources above 100GeV and
  3. gamma ray source observation using high resolution telescopes and
- cosmic ray physics from 10TeV to 1EeV in
  1. energy spectrum for individual composition above 10TeV and
  2. energy spectrum and composition above 100PeV.

Ground-based Extensive Air Shower (EAS) detector is the only choice to cover the wide (about 8 orders of) energy range. The proposed detector consists of the following components:

- a $1km^2$ EAS array (KM2A),
- 4 water Cerenkov detector arrays (WCDAs),
- a $5000m^2$ shower core detector array (SCDA),
- a wide field of view (FOV) Cerenkov/fluorescence telescope array (WFCA) and
- 2 large imaging Cerenkov telescopes (LIACTs).

A tentative site is located at Yangbajing (4300m a.s.l.), Tibet, China, near the $AS\gamma$ [2] and ARGO-YBJ [3] experiments. In this paper we describe the detector design and prototype.

II. DETECTOR DESIGN AND PROTOTYPES

A. KM2A

KM2A aims to search for Galactic gamma ray sources above 30TeV in the northern hemisphere and to measure the high energy end of their spectra up to 1PeV. For that purpose a ground-based detector with large field of view (FOV) and high duty cycle is recommended and an EAS array is the best choice. An extrapolation of the spectra of known Galactic gamma ray sources to the high energy end shows that the required sensitivity for such a detector is $\sim 1\% I_{Crab}$ at 50TeV, which corresponds to an exposure of $\geq 1000 km^2 hr/year$ to single sources. Considering the typical observation time of an EAS array to a source is about 1000hrs/year, the array should cover an area of the order of $1km^2$. The array should be fully efficient at 50 TeV with an energy resolution of $\leq 30\%$, thus the coverage of the charged particle detectors is estimated to reach 0.5%. Since the cosmic ray background is more than 4 orders higher than the flux of the gamma rays, such an array should be able to sufficiently discriminate between gamma showers and hadronic ones. That can be achieved by measuring the muon content in an air shower with muon detectors taking the fact that gamma showers are poor in muon contents. To reach background free observation to gamma rays at above 50TeV, the coverage of muon detectors should be $\sim 5\%$. Therefore a $1km^2$ EAS array is proposed and optimized through Monte Carlo simulation [4] with its layout shown in (Fig.1).

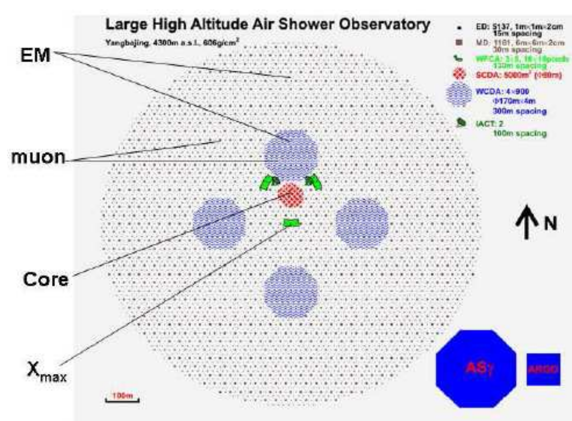

Fig. 1: LHAASO layout.

KM2A, with a radius of 560m, consists of 5137 scintillation detectors (EDs, $1m \times 1m \times 2cm$) to measure the secondary charged particles in an air shower and 1161 muon detectors (MDs) to measure the muons. An ED is made up of 16 scintillation tiles $25cm\times25cm\times2cm$ each. Scintillation lights from each tile are collected by 8 double cladding fibers glued into grooves at the tile surface. A total of 128 fibers in one ED is coupled to the cathode of a photomultiplier tube (PMT). MDs are implemented by covering the scintillators ($6m\times6m\times2cm$ each, made of the same tiles in EDs) with 2.8m thick earth overhead to shield secondary electromagnetic components in an air shower with a threshold energy of 1.3GeV for muons. Monte Carlo simulation [4] shows that KM2A has sufficient sensitivity (Fig.2).

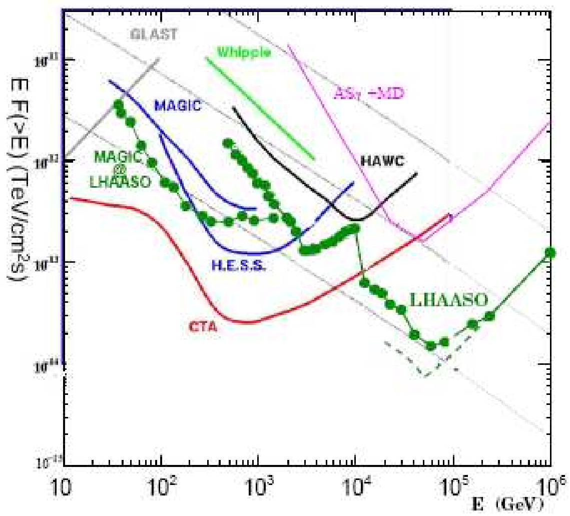

Fig. 2: LHAASO sensitivity compared with that of other experiments/projects.

B. WCDA

WCDA will survey the northern hemisphere with a high sensitivity and monitor any transient phenomenon at the TeV region. Four water pools (each 4m deep with 170m diameter, corresponding to an area of $22,500m^2$, see Fig.1) with a total area of $90,000m^2$ will be implemented inside the KM2A. One pool is partitioned by curtains into 30×30 detector units with a diameter of 5m. A PMT (R5912) sits at the bottom center of each detector unit to collect Cerenkov lights generated by the charged particles in water (see Fig.3). Mont Carlo simulation [5] shows that the Cerenkov lights generated by muons are about 20 times stronger than that by electrons, positrons or gammas, thus enabling the detector to discriminate primary gamma rays from hadrons by using the muon information, reaching a sensitivity of $2\%I_{Crab}$ (Fig.2).

The spacing between any two WCDAs are larger than 300m to avoid overlapping due to EAS lateral extension thus achieving a maximum total effective area. Furthermore, uniformly deployed in the KM2A, the 4 WCDAs can provide, through hybrid observation, shower muon information, primary direction and core location constraint to the KM2A thus an enhancement in the KM2A sensitivity shown in Fig.2 can be expected.

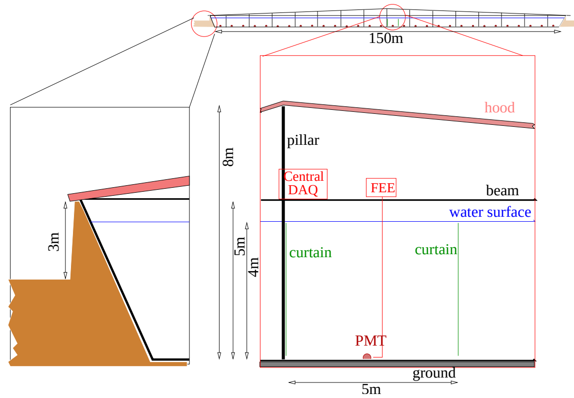

Fig. 3: Sketch of WCDA.

To study the performance of WCD and MD, a water tank (Fig.4) 7m in diameter and 5m in height was constructed at the Institute of High Energy Physics (IHEP), CAS, with a water circulation system to keep the water pure. Two R5912 PMTs are placed respectively at the bottom and middle center of the tank looking upward at the Cerenkov lights generated by charged particles inside the water. Two scintillation detectors are deployed at the top of the tank with another one in a groove below the tank, forming a charged particle telescope. A three-fold coincidence in the telescope can identify muons passing through the water tank, while a two-fold coincidence of the top two scintillation detectors vetoed by the bottom one provides an electron event to the water tank. Performance of the WCD prototype including detection efficiency, time resolution, amplitude and signal shape of WCD PMTs will be studied under different water depth. All the scintillation detectors can be moved along the groove direction to choose events with different directions and locations, thus enabling the study of the WCD performances varying with particle direction and location.

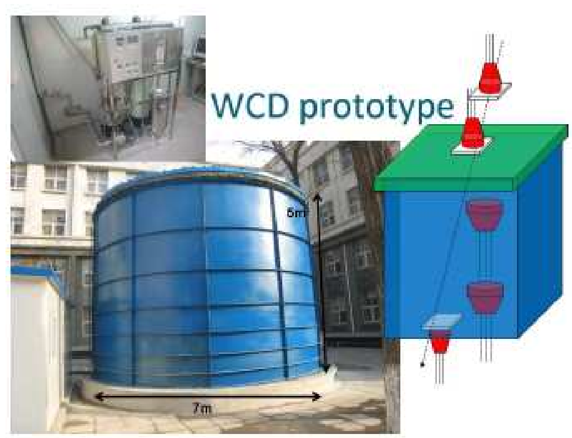

Fig. 4: A water Cerenkov detector prototype with the water circulation system shown in the top-left. The experimental configuration is shown in the right.

The scintillation detector below the tank is the same as a prototype ED and can act as a prototype MD with the overhead water as the shielder. The performance of the MD will be studied and optimized by changing the water depth overhead.

C. LIACTs

As shown in Fig.1, two LIACTs are proposed to measure the energy spectra above 40GeV of the gamma ray sources to be discovered by KM2A and WCDAs and study detailed morphology of the source region basing on their high angular resolution, energy resolution and strong power in gamma and hadron separation. Combining KM2A, WCDA and LIACTs, the energy spectra of Galactic gamma ray sources can be well measured in a wide energy range from 40GeV up to 1PeV, which provides strong evidence in searching Galactic cosmic ray accelerators.

According to a full Monte Carlo simulation ([6], the two LIACTs will be deployed inside the KM2A along the east-west direction with a spacing of 100m to achieve a better angular resolution. The performances of LIACTs can be further improved with the shower core information provided by the nearby WCDA through hybrid observation.

D. WFCA and SCDA

With such a large ground array at high altitude, one can measure the cosmic ray spectrum at high accuracy above 10TeV, well overlapped with the direct measurements using balloon borne detectors. In order to connect with the direct measurements, cosmic rays have to be separated specie by specie. Two more minor components of detectors are needed. One is a wide FOV Cherenkov/fluorescence light telescope array (WFCA) for shower maximum measurement and the other is a shower core detector array (SCDA)[7] for measurement of the shower high energy particles near cores as shown in Fig.1.

The SCDA, 80m in diameter, covers a total area of $5000m^2$ with 400 scintillation detectors, $0.5m \times 0.5m \times 1cm$ each covered with 7 r.l. think of lead. A SCDA prototype array with 16 detector units have been developed and deployed inside the $AS\gamma$ EAS array for hybrid observation with the $AS\gamma$ experiment (Fig.5).

The WFCA consists of 24 telescopes in 3 groups, covering the sky with zenith angle up to 35^o with the FOV shown in Fig.6. With 16×16 PMTs, each telescope covers a FOV of $14^o \times 16^o$ and points to different directions. The FOV of neighborhood telescopes overlaps with each other for inter-calibration purpose. The telescope groups are 130m from each other and 75m from the SCDA. The configuration enables air showers with cores location inside SCDA to be well measured by the WFCA.

Two WFCA prototype telescopes have been designed and placed near the ARGO-YBJ experimental hall (Fig.7). They have been operating since 2007 with more than 500,000 Cerenkov events acquired in coincidence with ARGO-YBJ experiment.

Fig. 5: SCDA prototype array (in the center of the figure) with 16 detector units operating at Yangbajing, a probe detector is deployed above for calibration purpose.

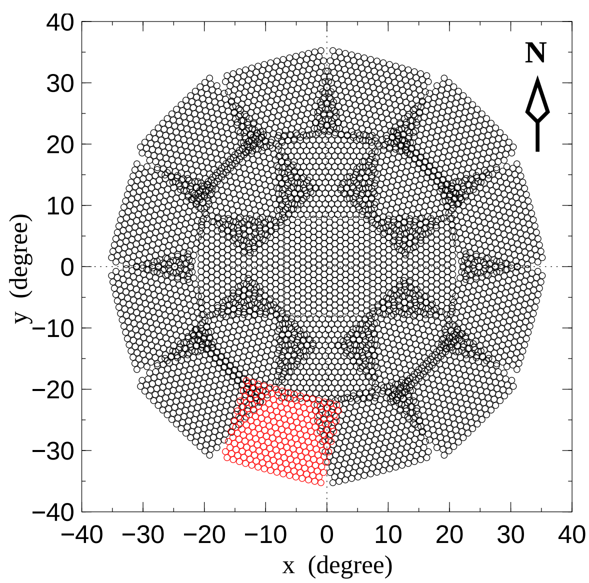

Fig. 6: WFCA FOV. Each circle represents the FOV of a PMT. The FOV is plotted in polar coordinate system, where (0,0) is the zenith.

E. Cost-free reconfiguration of WFCA

To extend the spectrum to higher energies and make a connection with experiments such as TA and Auger at altitude around 1600m a.s.l., the WFCA can be reconfigured as shown in Fig.8 to monitor the sky above the KM2A from a distance of 4-5km by detecting shower fluorescence lights. The WFCA is reconfigured in 3 groups. The main group is composed of 16 telescopes covering elevations from $3°$ to $59°$. Each of the other two groups consists of 4 telescopes, covering elevations from $3°$ to $31°$, observing showers from perpendicular directions. Showers above 100PeV will be detected by the three groups of telescopes stereoscopically to maintain a high resolution of shower maximum depth. With the muon content measured by KM2A, the second knee of the spectrum and corresponding composition

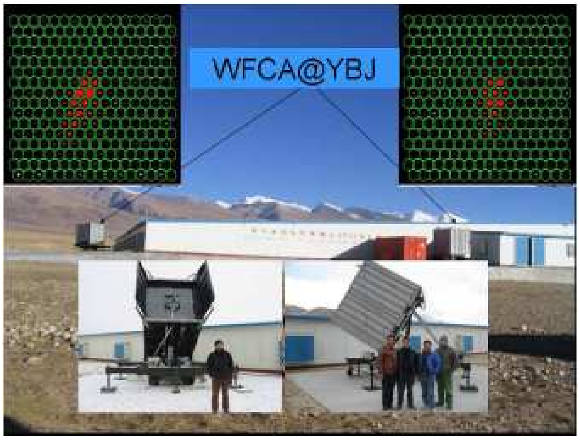

Fig. 7: Two WFCA prototype telescopes operating at Yangbajing. The Cerenkov light images of one stereoscopic event observed by the two telescopes are shown at the top.

variation will be measured [8].

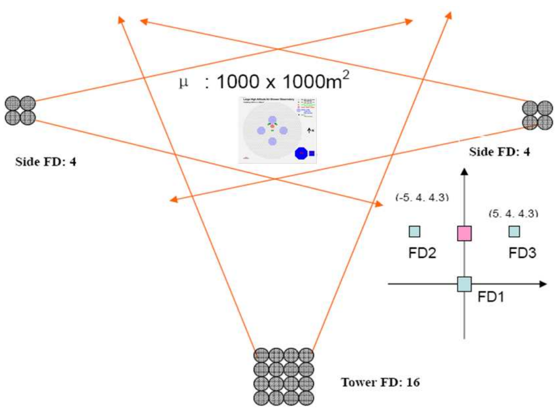

Fig. 8: Cost-free reconfiguration of WFCA. The red arrows show the FOV of each telescope group.

III. Prototype Array

A LHAASO prototype array (Fig.9) will be constructed at Yangbajing Cosmic Ray Observatory, with 38 EDs, 4 muon MDs and 9 WCDs. The EDs are deployed inside the ARGO-YBJ experimental hall with the same spacing as in the KM2A, fully overlapping with the ARGO-YBJ array. The prototype array generates a trigger if more than four EDs are fired, collecting time and amplitude information of all the fired detectors for further primary geometry reconstruction. A GPS-based timing system records the event time with an accuracy better than 100ns, by which a coincidence with the ARGO-YBJ events can be done off-line. The estimated coincident event rate is about 50Hz and the energy threshold is $\sim$15TeV. The performances of detector units, angular and energy resolution of the array and the shower muon content will be studied with one year of operation in 2010.

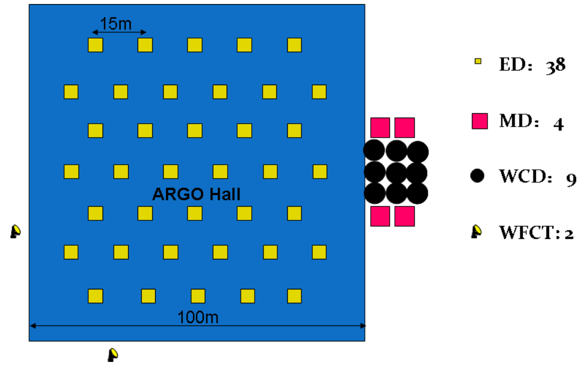

Fig. 9: LHAASO prototype array at Yangbajing

IV. Conclusions

LHAASO is designed to fulfill the physical goals in gamma ray astronomy and cosmic ray physics. Prototype detectors are designed with some of them already in operation. A prototype array will be built at the Yangbajing Cosmic Ray Observatory and used to coincidentally measure cosmic rays with the ARGO-YBJ experiment.

V. Acknowledgements

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