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Status and first result of LHAASO-WCDA

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The Water Cherenkov Detector Array (WCDA) is an important component of Large High Altitude Air Shower Observatory (LHAASO), which mainly aims at surveying the northern sky for VHE gamma ray sources. The WCDA has three pools with the area of 78,000 m^2, and is sub-divided into 3,120 cells by black curtains. Currently, the installation of the first pool is already finished and normally operated. This paper will describe the preliminary results of the first pool and the optimized design of the two other pools.

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1. Introduction

The Large High Altitude Air Shower Observatory (LHAASO) project[1,2] is a new generation multi-component instrument, and under construction at 4,410 meters of altitude in the Sichuan province of China, with the aim to study with unprecedented sensitivity the spectrum, the composition and the anisotropy of cosmic rays in the energy range between 10^{12} and 10^{18} eV, as well as to act simultaneously as a wide aperture, continuously-operated gamma ray telescope in the energy range between 10^{11} and 10^{15} eV. Very-high-energy (VHE, >100 GeV) gamma ray astronomy has been an interesting field over the past 30 years. Since the first detection of TeV gamma rays from the Crab Nebula with the Whipple experiment in 1989[3], more than 100 sources of VHE gamma ray emission have been discovered. Among these sources, more than 60 have been identified as galactic, including supernova remnants, pulsar wind nebulae, and gamma ray binaries; the rest, except the unidentified ones, have been of extragalactic origin. Surveying the sky for more sources in this energy band and monitoring their emission intensity are very important to understand the evolution of galaxies and the acceleration mechanisms in gamma ray sources.

As one of the major components of LHAASO, Water Cherenkov Detector Array(WCDA)[4,5] using the Cherenkov radiation mechanism via the water media, has very high duty-circle(>95%), and large field of view($>2\pi/3$), and great background rejection power. Gamma rays and cosmic rays enter the Earth at the top of the atmosphere, interacting with the air nuclei to form air shower. The secondary particles in the air shower, such as gamma photons, positron and electrons, muon and a few hadrons, will reach the ground and hit the WCDA detector to produce Cherenkov light in the water. Part of the Cherenkov light will be collected by a large area of the photomultiplier tube, converted into electrical signals, transfered to the the electronics system, and ultimately formated digital signal data. These digital signals have information such as the arrival time of the secondary particles, the charge of generated signal. Combined with the triggered detectors unit position, with the data reconstruction, the direction and other parameters relatiing with primary cosmic ray particles, can be determined.

2. Detector

The WCDA covering an area of about 78,000 m^2 area, is constituted by 3,120 detector units divided into 3 separate arrays (Fig.1). Every array is a single water pond with a 4.4 m depth. Two of them with an effective area of 150×150 m^2 contain 900 detector units separately. The third pond with an area of 300×110 m^2 contains 1,320 detector units. Each detector unit has a 5×5 m^2 area divided by black plastic curtains (3.3 m $\times$ 4.7 m) vertically hung in the water to attenuate scattered light. The curtains of the cells are made in black plastic to minimize late light from reflections. The side wall of the pond and the bottom of the lining with 2 mm thickness HDPE film to ensure that the experimental water from the outside world. To guarantee an attenuation length of near-ultra-violet light longer than 15 meters a sophisticated water purification and recirculation system is operated.

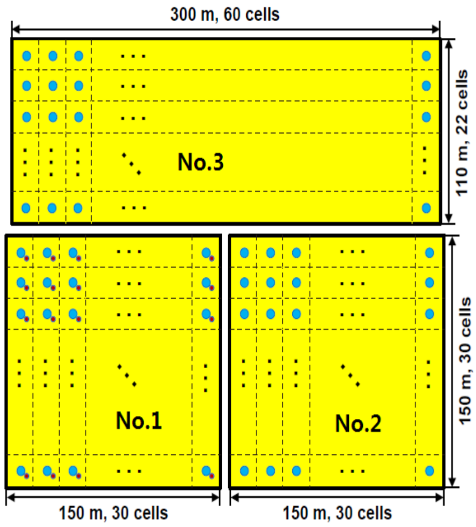

Figure 1, the layout of WCDA.

The No.1 pool has 900 WCD units, equipped by a large 8-inch PMT for timing and a small 1.5-inch PMT[4] for pulse size at the center of each unit 4 m beneath the water surface, and measures shower directions with a resolution better than 0.2◦ above 10 TeV and 1.0◦ above 600 GeV. This is based a good timing resolution of 0.5 ns of the Front End Electronics (FEE) [5] of the large PMTs, watching upwards for direct Cherenkov light only. The dynamic range of the detector is enlarged very much by using the small PMT [6]. This enables the measurement of the detailed particle density distribution in the shower cores without significant saturation even for energetic showers up to 10 PeV and achievement of the core location resolution better than 3 m over a wide energy range. This is designed for the identification of the primary particle species in the cosmic ray composition and spectrum measurements. It is also very useful in locating the shower inside the pool with minimal loss of good detected events. This pool has already be turned on for operation in April, 2019.

In order to enhance the gamma ray detecting sensitivity at low energies, at which the showers are small in terms of total number of particles that reach to the pools, therefore the secondary particles generate faint Cherenkov signals in detector units even near the cores of the showers. Enlarging the sensitive photocathode of the PMT is one very effective way to catch the faint signals. LHAASO's upgrading design is to replace the 8-inch PMTs by 20-inch PMTs in the rest two ponds of 55,500 m^2 in total. The customized design of the PMTs using multi-channel-plate (MCP) [7] instead of the traditional dynodes enables good uniformity between PMTs as well as the Transit Time Spreads (TTS) less than 7 ns, and Cathode Transit Time Distribution (CTTD) less than 2 ns. The photo cathode is a factor of 6.25 larger than the 8-inch tube, therefore the dynamic range is also shrunk by the same factor. In order to compensate the loss, a 3-inch PMT is installed beside this large PMT in each unit, read out only for the pulse size by a simplified version of FEE covering 4 orders of amplitudes in number of photoelectrons.

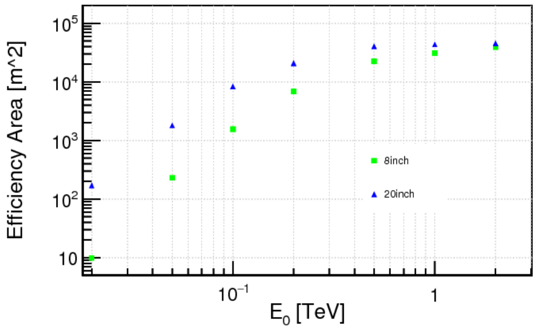

Figure 2, Comparison of the effective area of the two tube types at different energy. And the energy is increased by 7.9 times at 50 GeV and by 5.4 times at 100 GeV.

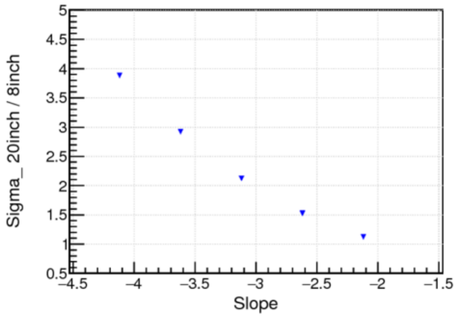

Figure 3, the relation between the increased proportion of significance and spectrum index.

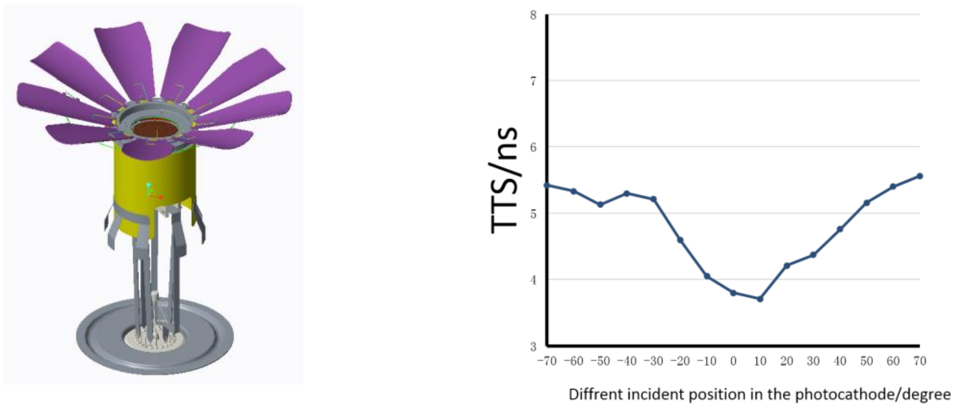

Figure 4, the left plot shows the dynode structure with the unique lotus-like focus electrode. The right plot is the typical distribution of TTS along with different incident position in the photocathode.

The four types of PMT mentioned above all requires detailed performance testing and waterproof packaging. And the electronic boards are located in the pool of distributed electronic crates, and each crate will collect the PMTs' signal from the surrounding 36 units. During the operation of the detector, the real-time time calibration system [8], the charge calibration system and water quality measurement, and the slow control system to monitor the pool environment will also be deployed.

3. Operation of No.1 pool and some preliminary results.

In February, 2019, the detector installation of No.1 pool was completed, and the depth of water reaches 4.4m after more than one month of the purified water injection. Through the continuous testing, we started the normal operation of the first pool in the end of April. After almost two months' dry run and three months' operation, about 30TB raw data was already recorded, the live time is almost close to 95%. The following figures show some of the preliminary results of the run.

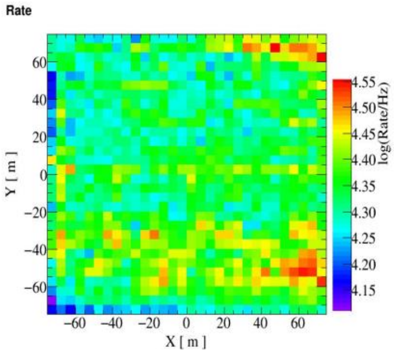

Figure 5, Rate distribution of 8-inch PMT.

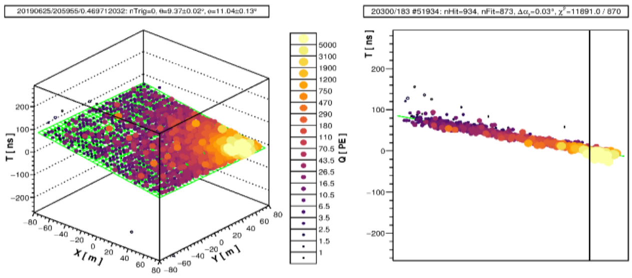

Figure 6, A typical arrival time distribution of the shower event's front.

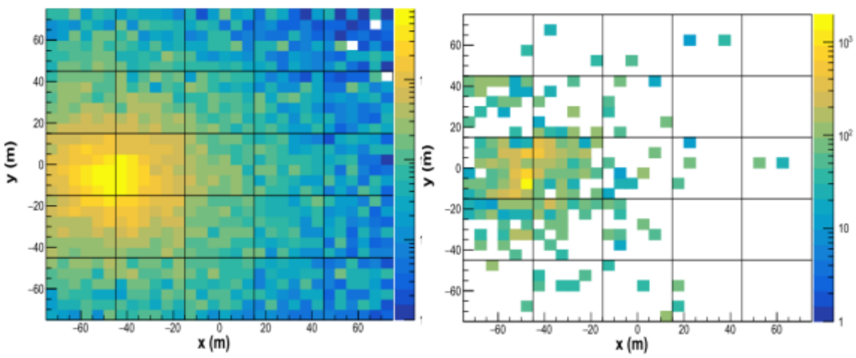

Figure 7, the coincidence charge distribution of 8-inch PMTs and 1.5 inch PMTs.

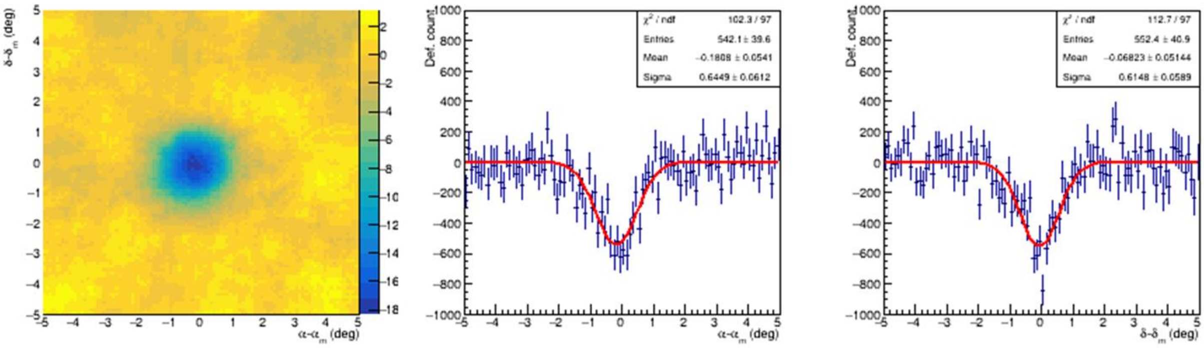

Figure 8, the pointing deviation of moon shadow is close to 0.05◦ with 137.4 hrs.

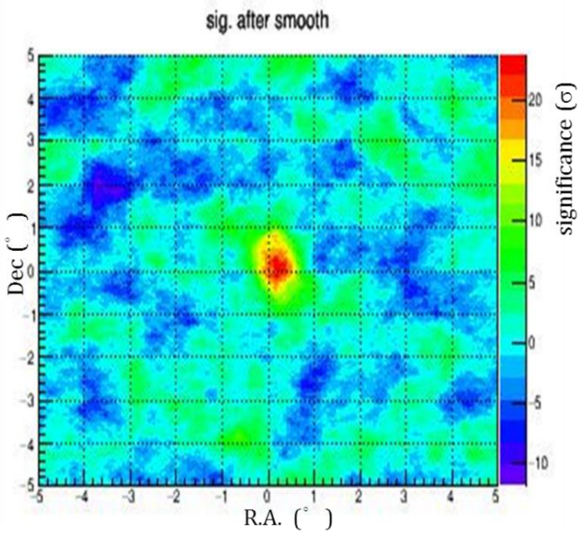

Figure 9, The very preliminary observation of Crab Nebula with 137.4 hrs, and the highest significance reaches to 23σ as expected

4. Summary

The detector installation of WCDA started from the last October, the first pool (150m×150m) has already be operated in April, 2019 and runs smoothly. After about three months' operation, the preliminary result shows that the he highest significance reaches to 23σ as expected by the observation of Crab Nebula with 137.4hrs, and the pointing deviation of moon shadow is close to 0.05◦. In the rest two ponds, 20-inch PMT in replace of 8-inch will be deployed. We hope that the full array of WCDA will start normally run in early of 2021. WCDA of 78,000 m^2 water Cherenkov detector array, will play an important role for a long time in the next decade.

5. Acknowledgements

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