Time and charge calibration of the LHAASO electromagnetic particle detectors

Binyu Pang[a], Hongkui Lv[b], Xiangdong Sheng[b], Jia Liu[b], Xiaopeng Zhang[b] and Yu He[a] on behalf of the LHAASO Collaboration

a School of Physical Science and Technology, Southwest Jiaotong University, Chendou 610031, China

b Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China

ONLINE ICRC 2021 THE ASTROPARTICLE PHYSICS CONFERENCE Berlin | Germany 37th International Cosmic Ray Conference 12–23 July 2021

Abstract:

The one square kilometer array (KM2A), a sub-array of Large High Altitude Air Shower Observatory (LHAASO) experiment, consists of 5195 electromagnetic particle detectors (EDs) and 1188 muon detectors (MDs), has been built over three-quarters scale. Its main scientific goal is to search gamma-ray sources at energies above 100 TeV. Offline calibration method has been used to calibrate thousands of EDs to guarantee the key performances of the array such as angular resolution and pointing accuracy within 0.1° during long-term operation. The experimental results of the 3/4 array show that this method can be used to determine the detector time offset with an accuracy of 0.5 ns and the particle number density with an accuracy of a few percent. Furthermore, we monitor the calibration parameters during the array operation and update the calibration results regularly to ensure the data quality of the detector.

1. Introduction

LHAASO is located on Haizi Mountain in Daocheng, Sichuan Province, China. It is a large hybrid extensive air shower (EAS) array consists of three sub-arrays (Fig. 1), namely a 1.3 km² array (KM2A), water Cherenkov detector array (WCDA) and wide field-of-view air Cherenkov/fluorescence telescopes array (WFCTA) [1]. KM2A is unique for its unprecedented sensitivity for gamma-ray sources at energies above 20 TeV. 5195 EDs in KM2A are deployed to detect densities and arrival time of extensive air shower (EAS) charged particles produced by the primary particles.

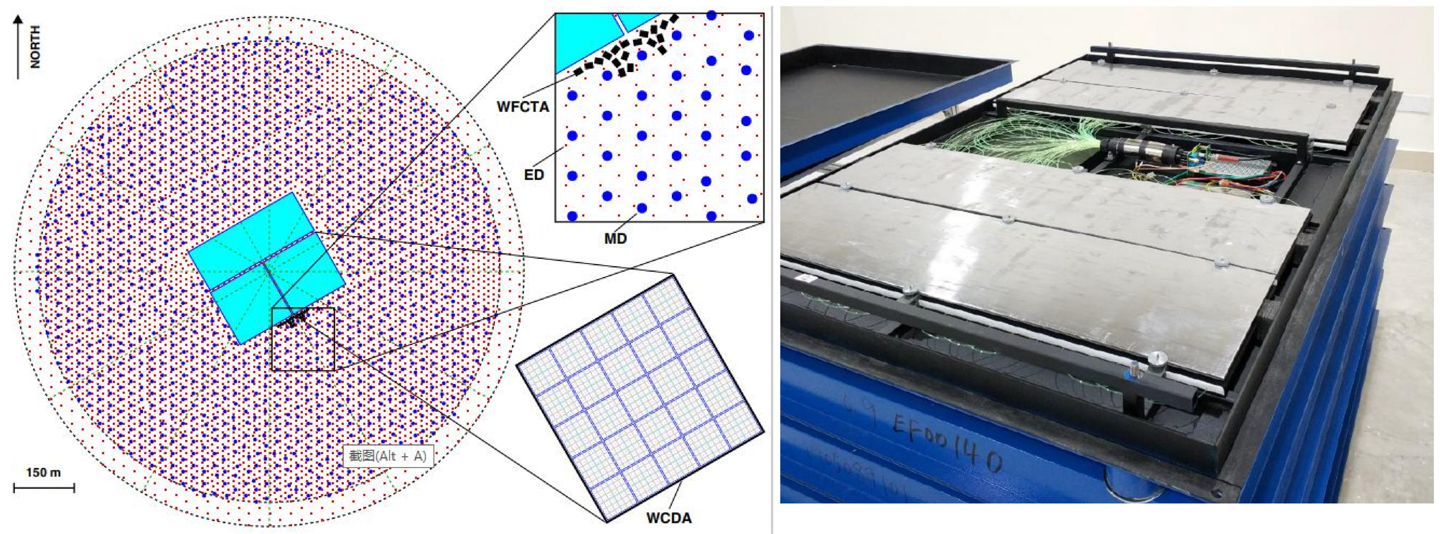

Fig. 1: Left: The layout of the LHAASO experiment. LHAASO consists of one square kilometer array (KM2A), water Cherenkov detector array (WCDA) and wide-field Cherenkov telescope array (WFCTA). Right:Schematic of a ED.

In order to guarantee the angular resolution of the array better than 0.5° above 30 TeV and the pointing accuracy better than 0.1° , the time synchronization accuracy of EDs must to be within 1 ns. Besides, primary energy reconstruction depends on the measured signal integrated charge recorded by each fired ED units, a reliable detector charge calibration is required for energy interpretation [2].

2. Time calibration

The ED consists four plastic scintillation tiles of 100 cm×25 cm×1 cm each, several wavelength-shifting fibers, one 1.5 inch photomultiplier tube (PMT), and a front-end electronics (FEE) (Fig. 1). The charged particles hit the plastic scintillator and pproduce photons. The photons are transmitted to the photocathode of PMT through the wavelength shifting fibers and converted into electronic pulses, finally, the PMT signal is recorded by FEE .

The time offset is measured as a cumulative effect of several processes described above. The main uncertainties on the measured hit times come from the time offset spread among the EDs. A reliable reconstruction of the primary gamma-ray direction requires the accurate determination of the arrival time of EAS particles on each detector. Therefore, the time synchronization of thousands of EDs is crucial to guarantee the performance of the array to achieve the expected.

2.1 Time calibration principle

The offline calibration is an automatic self-calibration method, which uses EAS charged particles as the calibration beam. Since the EAS front approximately sustains a conical shape. The time offset of the i-th ED Δt_i located at position coordinates (x_i, y_i) is determined, event by event, as follows:

$$\Delta t_i = t_i - t_i^{real} = \left[(l-\bar{l})\frac{x_i}{c} + (m-\bar{m})\frac{y_i}{c}) + \sqrt{1-\left(l-\bar{l}\right)^2-(m-\bar{m})^2}\frac{z_i}{c} + \alpha r_i + t_0 \right] \quad (1)$$

where t_i and t_i^{real} are the measured arrival time of EAS particle for i-th ED and the expected "real" one, respectively; l and m are two components of the reconstructed direction vector ($l = \sin\theta\cos\phi$, $m = \sin\theta\sin\phi$ (θ and ϕ are the zenith and azimuth angles, respectively));

To get the accurate direction of EAS, the two directions (l,m) have been modified using the mean value of reconstructed direction (l , m) , which is the so-called characteristic plane (CP) described in [3]; Other parameters in the equation such as the conicity coefficient α and the time parameter t_0 are obtained from the fitting process of direction reconstruction, and the transverse distance of the i-th ED from the shower core r_i can be obtained as the shower core is reconstructed.

2.2 Time calibration results

We selected 9 hours of data and determined the time offset by fitting the most probable value of the time residuals distribution which are calculated according to Equation 1. As shown in Figure 2, the time offset distribution width of 3937 EDs in the 3/4 array is less than 1ns.

To verify the applicability of this method and estimate its precision, hardware calibration is performed using a muon telescope system. Comparing of the ED time offset results determined by two independent methods yields a direct prediction of the precision of the calibration method. As shown in Figure 3, the root mean square of the differences between ED time offsets obtained from two calibration methods is 0.4 ns, which is well within the required precision of the experiment.

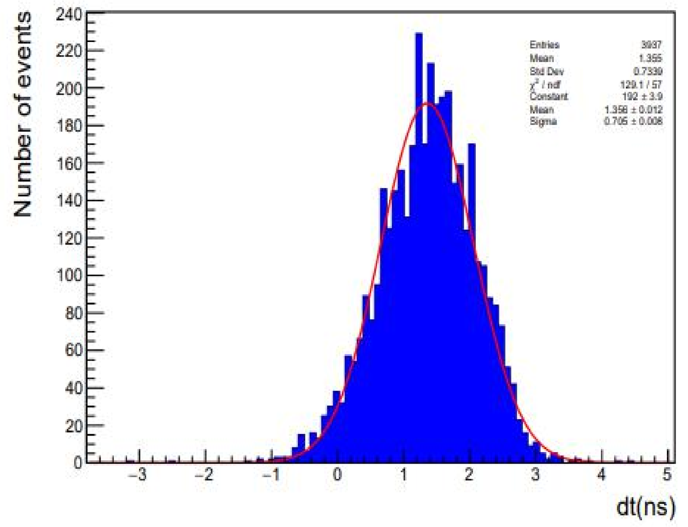

Fig. 2: The time offsets distribution of EDs in the 3/4 array.

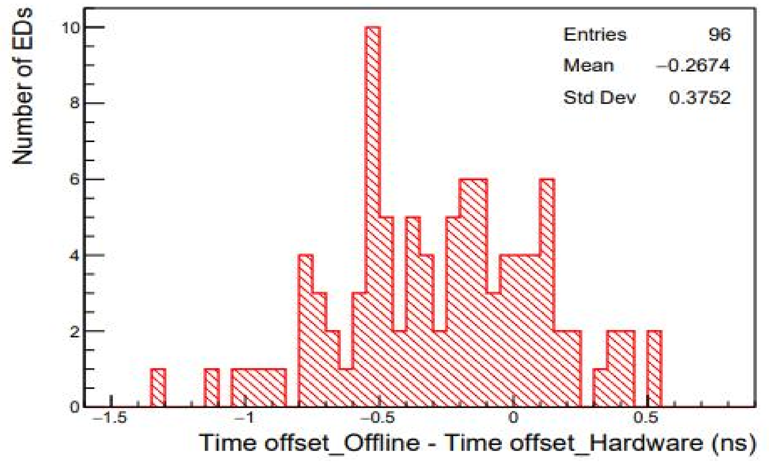

Fig. 3: The differences distribution between hardware calibration and offline calibration.

3. Charge calibration

The energy reconstruction depends on PMT signal integrated charge recorded by each fired EDs. Converting the integrated charge from ADC units to particle number is crucial for the accuracy of energy reconstruction to provide a common reference standard for energy reconstruction between individual EDs. The most probable value (MPV) of integrated charge spectrum is fitted to get the amplitude of charge corresponding to a single particle signal (Fig. 4), then the charge calibration is performed using the MPV value above. Furthermore, The MPV of the charge distribution of 3964 EDs in 3/4 array is shown in Figure 4.

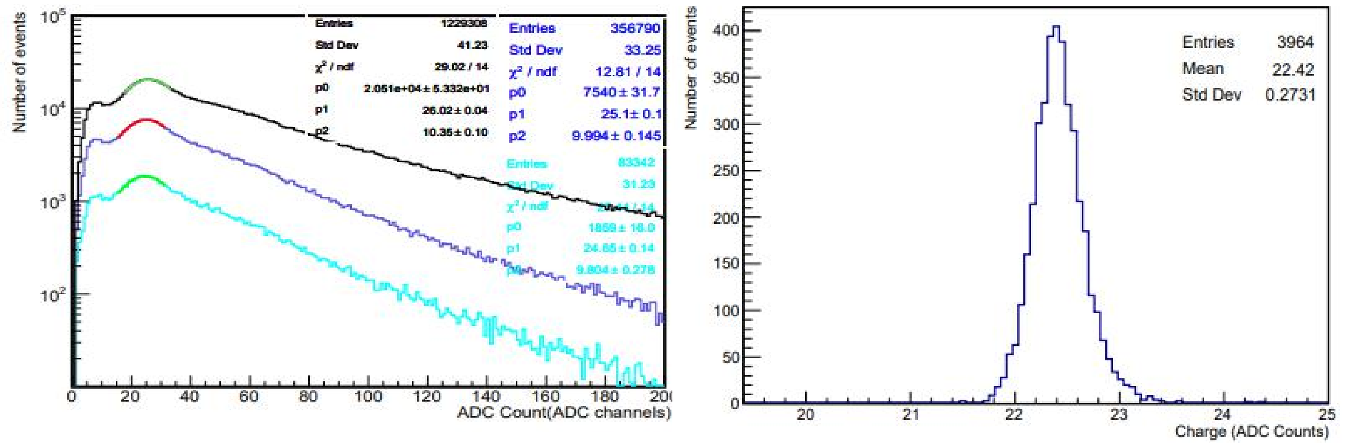

Fig. 4: Left: Single MIP spectrum is obtained by the offline calibration method (black line). The blue line is the data selected from the distance greater than 100 m. The data at the distance greater than 200 m is selected (light blue line); Right: The MPV distribution of EDs in 3/4 array.

4. Calibration parameters monitoring

Long-term monitoring of the calibration parameters is helpful to understand the performance of the detector and array stability. 1/2 array has been operating steadily more than one year and 3/4 array has been operating for half year. This allows us to analyze the long-term stability of the calibration parameters. The MPV of integrated charge distribution and the time offset value for each ED have been monitored (Fig. 5). The time offset values have a little fluctuation,it also reflects that the detector is very stable. The calibration file is updated periodically to ensure the accuracy of event reconstruction and stability of the array performance. In addition, the offline calibration also offers an ideal method to judge the working state of the detector.

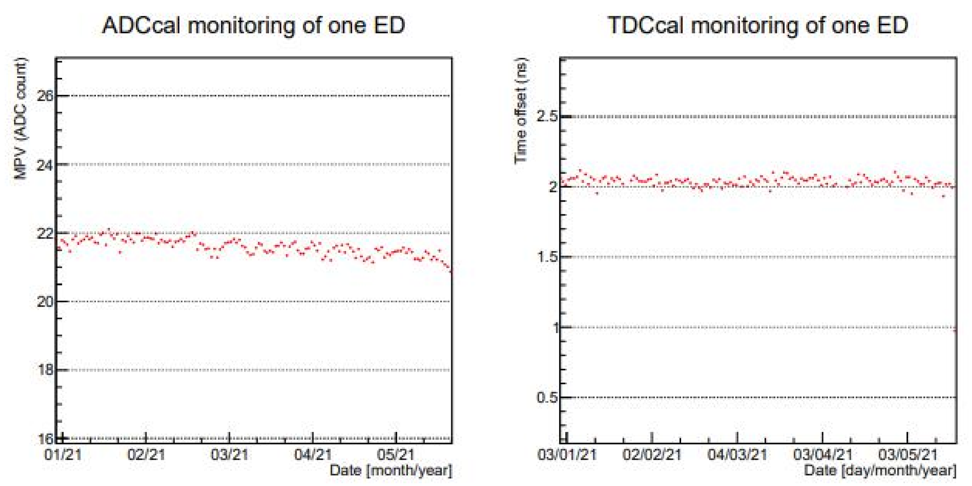

Fig. 5: Left: Monitoring of charge calibration parameter of a single ED, the MPV is affected by temperature; Right: Long-term stability distribution of time offset of a single ED.

Reference

[1] S.Z.Chen, et al., Chinese Physics C, 2021, 45 (02): 522-534.
[2] Hongkui Lv, et al., Astroparticle Physics 100 (2018) 22–28.
[3] H.H.He, et al., Astroparticle Physics 27 (2007), 528-532