Time and charge calibration of the LHAASO electromagnetic particle detectors

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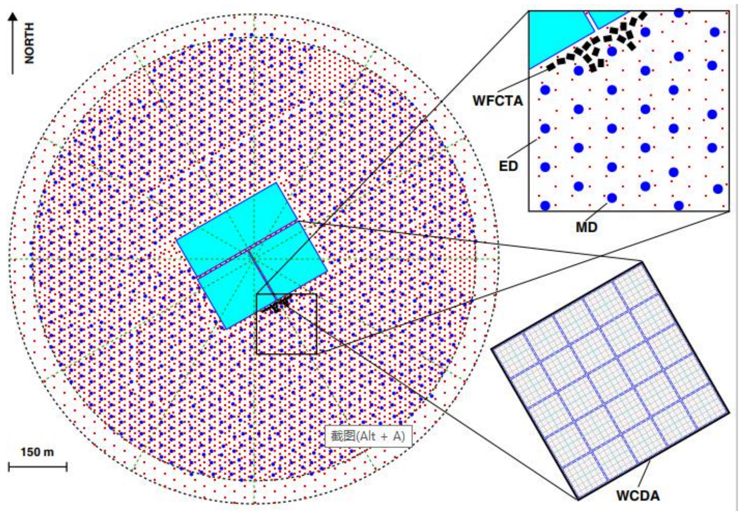
1. Introduction

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.

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.



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).

2. Time calibration

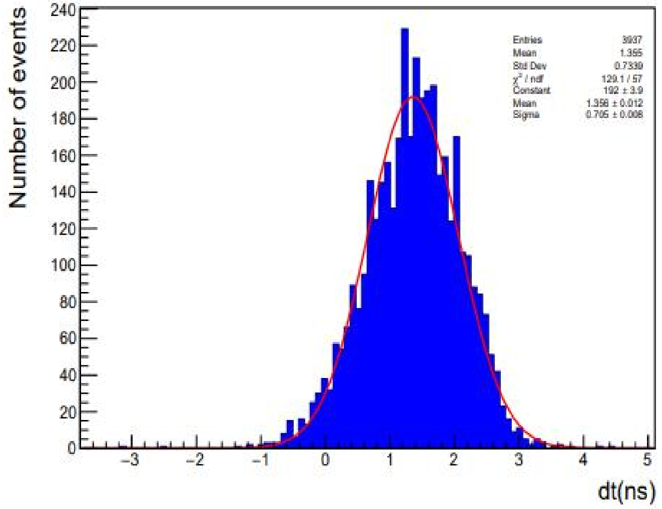
The offline calibration is an automatic self-calibration method, which uses EAS charged particles as the calibration beam. Since the EAS front approximately sustains a conical shape. The time offset of the i-th ED Δt_i located at position coordinates (x_i, y_i) is determined, event by event, as follows:

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

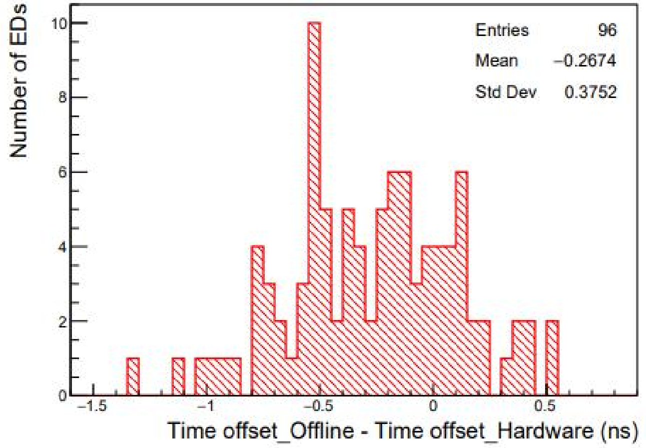
where t_i and t_i^{real} are the measured arrival time of EAS particle for i-th ED and the expected "real" one, respectively; l and m are two components of the reconstructed direction vector ($l = \sin\theta\cos\phi$, $m = \sin\theta\sin\phi$ (θ and ϕ are the zenith and azimuth angles, respectively));

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 the upper left.

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 the right-down figure.



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

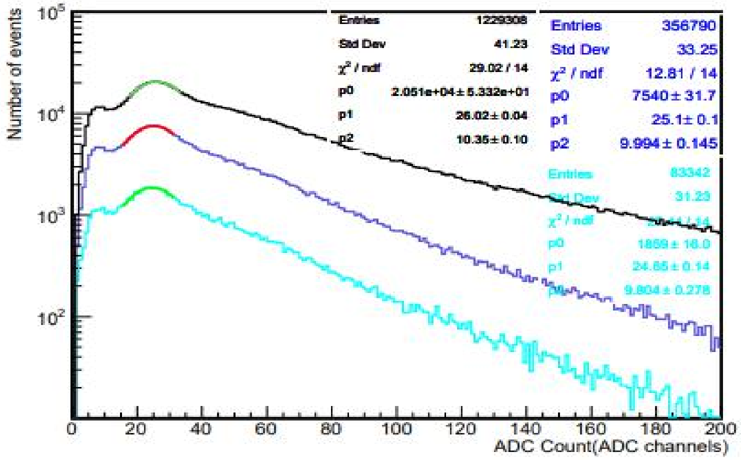


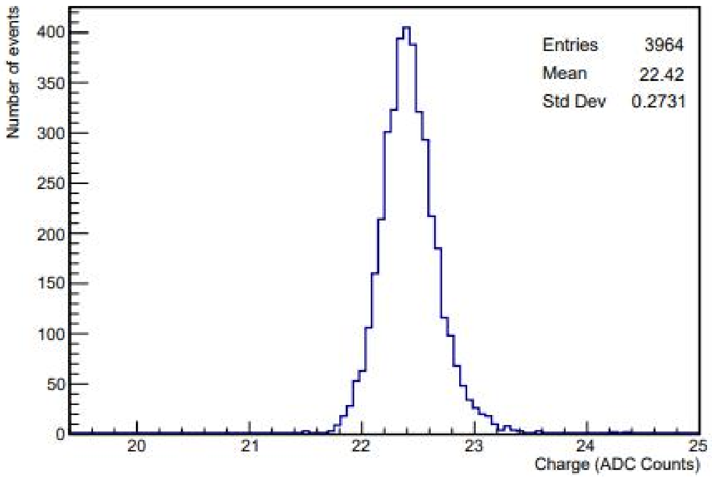
The differences distribution between hardware calibration and offline calibration.

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, 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.



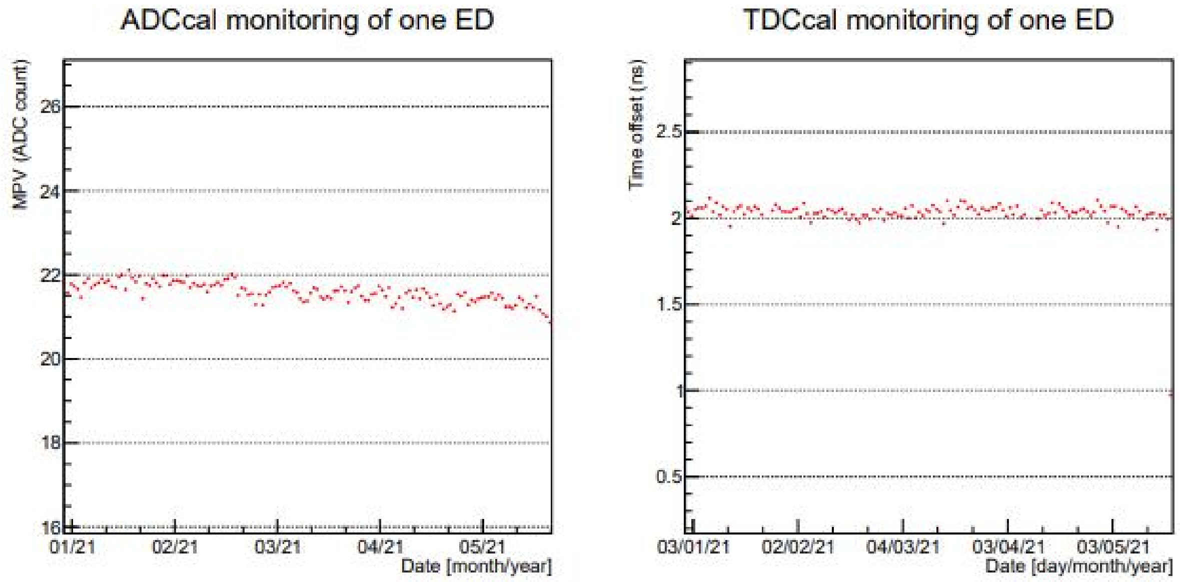


Left: Single MIP spectrum is obtained by the offline calibration method (black line). The blue line is the data selected from the distance greater than 100 m. The data at the distance greater than 200 m is selected (light blue line); Right: The MPV distribution of EDs in 3/4 array.

4. Calibration parameters monitoring

Long-term monitoring of the calibration parameters is helpful to understand the performance of the detector and array stability.

The MPV of integrated charge distribution and the time offset value for each ED have been monitored. 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.



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.

5. Conclusion

- the offline calibration has been successfully applied to 3/4 array. The relative time offsets can be periodically calibrated with a precision of better than 1 ns and charge calibration precision is sufficient within the KM2A performance requirements.

- we set up a monitoring program to monitor the calibration parameters in real time.

Thanks