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A charge calibration method for LHAASO-WCDA dynamic range expansion system

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The LHAASO-WCDA dynamic range expansion system (WCDA++) is designed as an important link between WCDA and WFCTA. It is used to transfer energy scale, and measure precisely the shower core of events, which is an important parameter to identify the composition of the primary particles, at the energy range from 1 TeV to 10 PeV. The photomultiplier tubes (PMT) used in WCDA++ are operated at a gain of about 2×10^5. In order to calibrate the working states of these PMTs, we had developed a dynamic calibration system, based on a network consisting of LEDs and optical fibers. At the beginning of 2019, this system has been installed and related testing is underway.

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1. Introduction

The Large High Altitude Air Shower Observatory (LHAASO) is a hybrid extensive air shower(EAS) array, which is being built in Sichuan Province (P.R. China) 4410m above sea level. The main body consists of an area of 1.3km^2(KM2A), a 78000 m^2water Cherenkov detector array (WCDA) and 12 wide-field air Cherenkov/fluorescence telescopes (WFCTA) [1], as shown in Fig. 1. The main scientific goal of WCDA is to focus on surveying the northern sky for steady and transient sources from 100GeV to 30TeV [2]. In order to transfer energy scale from WCDA to WFCTA and offer the information of the shower core to identify the composition of the primary particles, a 1.5-inch photomultiplier tube is placed next to each the 8-inch PMT, as shown in Fig.2.All the 900 small PMTs produced by Hainan Zhanchuang Photonics Technology Co.,Ltd (HZC) constitute the WCDA dynamic extend system (WCDA++).

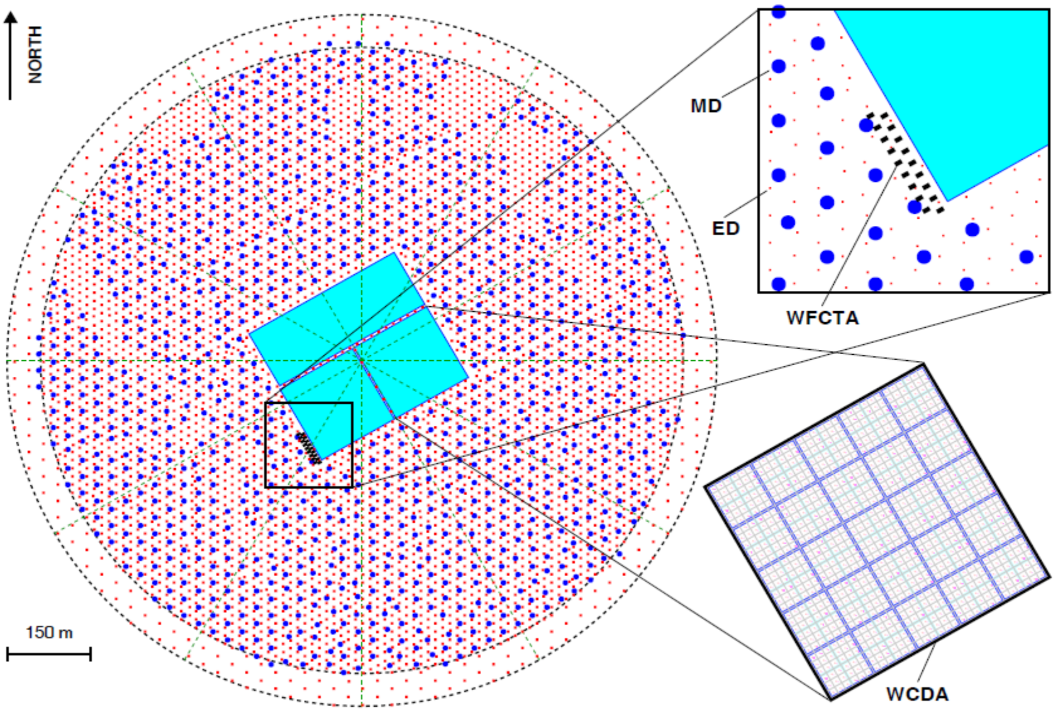


Figure1: The overall structure of the LHAASO

Usually, all the air shower experiments have their own calibration method, about using single particle [3] or the signal photoelectron (SPE) [4]. It is hard to calibrate the 1.5-inch PMTs with these traditional method at the working gain about 2×10^5. For its low working gain, a method for dynamically calibrating PMTs is designed, based on an array of LEDs and light fiber bundle.

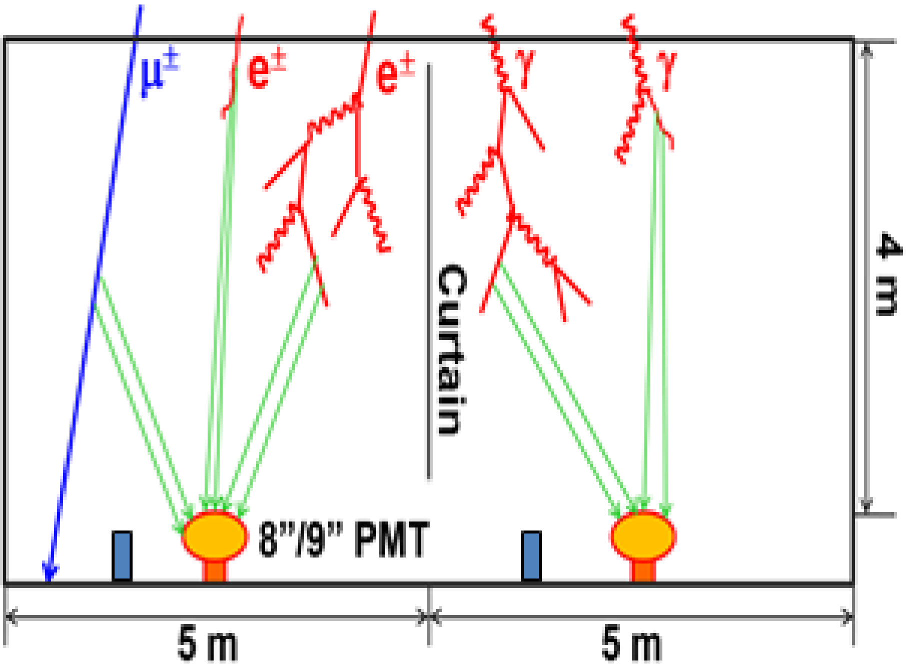


Figure 2: Each cell has two types PMT

This paper is mainly divided into the following sections. In section 2, running mode and calibration method are introduced. The prototype introduction and performance testing are mentioned in section 3. The long time monitoring results are touched about anode signal and the charge output ratio between the anode and the dynode (AD ratio) of WCDA pool 1 in section 4.

2. Mode and Method

In the water Cherenkov array experiment, the factors affecting the detector signal change can be divided into two aspects: one is the change of the external environment, such as temperature, water quality, etc. The other type mainly includes electronics board, power supply system, etc. that the inherent factors of the detection system itself.

At present, we have set two working modes, one is to regularly calibrate the working gain of the PMTs, which is calibrated once a year; the other is to monitor the performance of the PMTs for a long time. The monitoring items include anode signal and AD ratio, which is calibrated once every 2~3 days to achieve stable monitoring and correction of PMTs performance.

For this type of PMT working at a gain of about 2×10^5,the SPE spectrum can be tested at a 2200V position voltage ,which the testing gain of the PMT is greater than 3×10^6. Under the same LED light intensity about hundreds of Pes, the anode output chargre is measured at different working high voltages that vary from 1100V to 2200V with a step of 50V. And β can be obtained from the high voltage response curve according to this relation formula $G = AV^{\beta}$,the exponential ralationship between the anode output charge with differernt working high voltages. Then, the working high voltage can be deduced of the working gain of 2×10^5.The AD ratio can be got with a large light intensity.

3. The calibration system introduction and performance testing

In order to meet the array calibration requirements about 36 PMTs as a cluster, we designed a system consisting of LED driver board, 8-in-1 light guiding fiber, light tube and 1-minute-41 branch fiber, shown in Fig. 3.

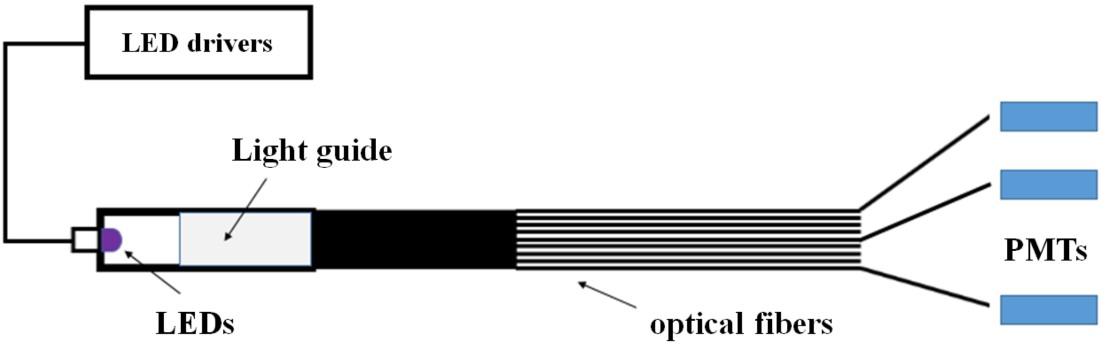
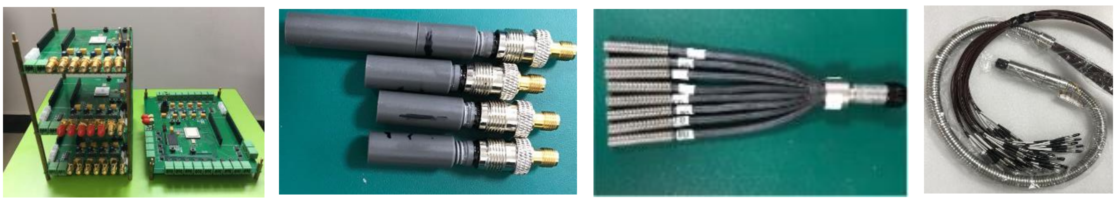


Figure 3: The schematic of the calibration system

The prototype shown in Fig.4. The LED driver board can provide pulse signals with different pulse widths and different frequencies at a single voltage amplitude. In order to meet different light intensity requirements, a group of LEDs with different illuminating properties were selected to provide SPE, Pes and large light intensity. The 8-in-1 light guiding fiber can mix different types of led optical signals and output them. The light tube can further uniformly mix the LED light signal, and the length of the tube can be changed to adjust the light intensity. Finally, the 1 minute 41 fiber distributes uniform light to each photomultiplier tube.



(a) LED driver (b) LEDs (c) 8-in-1fiber (d)1-minte-41 fiber

(e) The light tube

Figure 4: The prototype of charge calibration system for WCDA++.

Since the prototype must calibrate 36 PMTs at a time, the light output difference between the 41 branch fibers is designed to be less than 10% in order to obtain a better consistent source, as shown in Figure 5. At the same time, in order to obtain better uniform light, the 8-in-1 light guiding fiber is uniformly woven by not less than 1500 glass fibers with a diameter of 50 microns, that the different types of LED light intensity received can be mixed evenly, shown in Fig.6. Certainly, the large light intensity can be provided for its multiple branches.

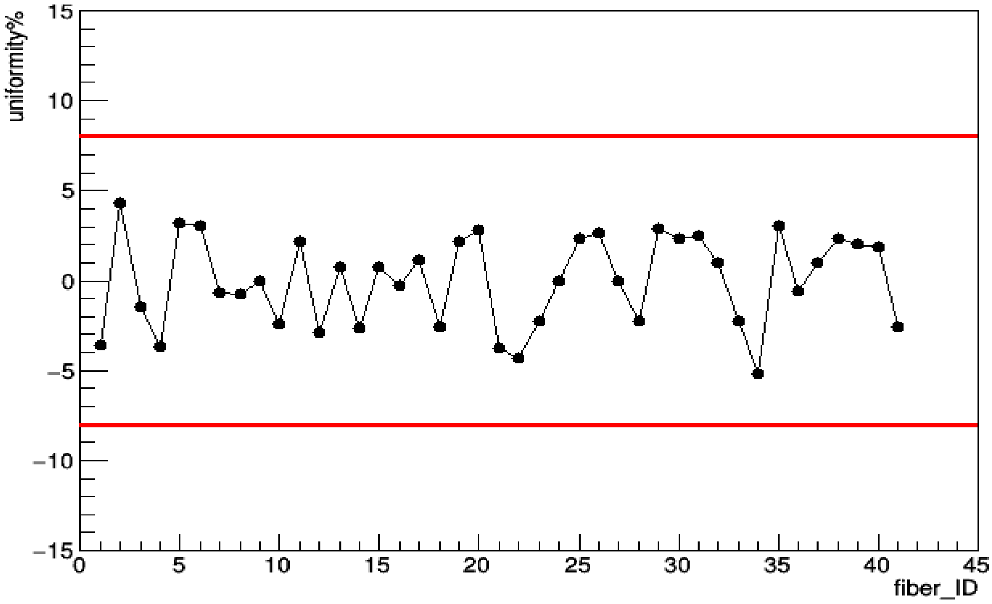


Figure 5: The charge difference between 41 branch fibers (<=10%)

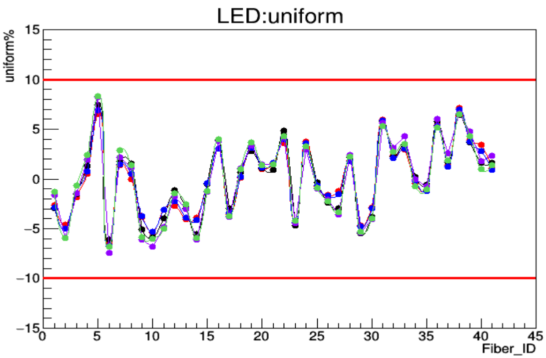
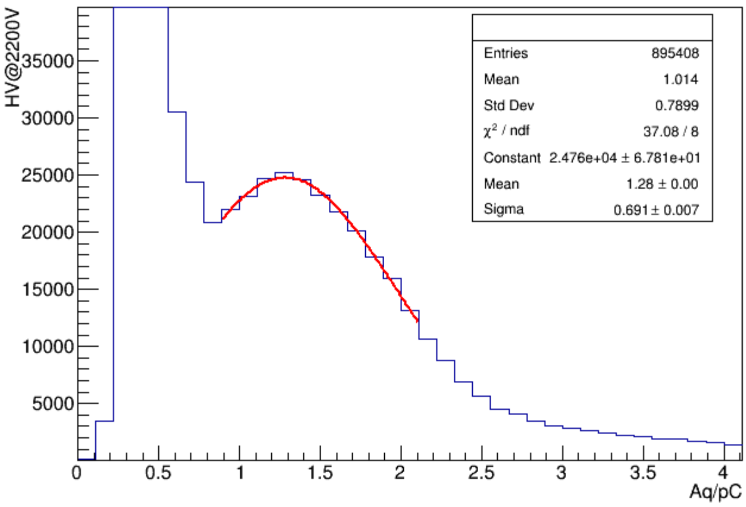
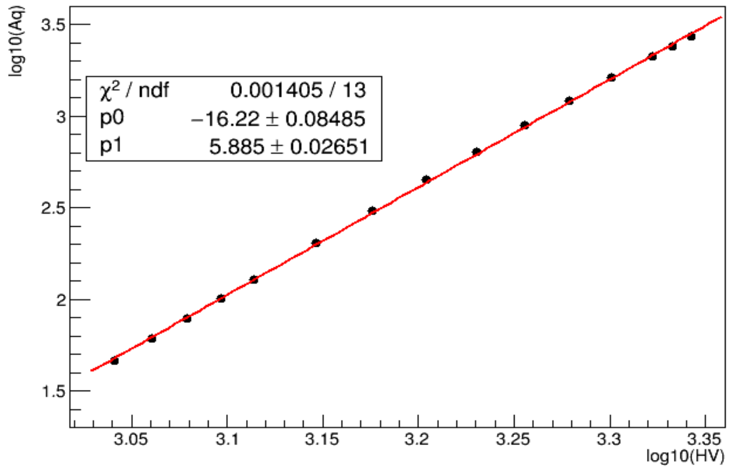


Figure 6: The performance of 8-in-1 fiber: The light output surface of 8-in-1fiber(left); The charge uniformity of different types LEDs(right).

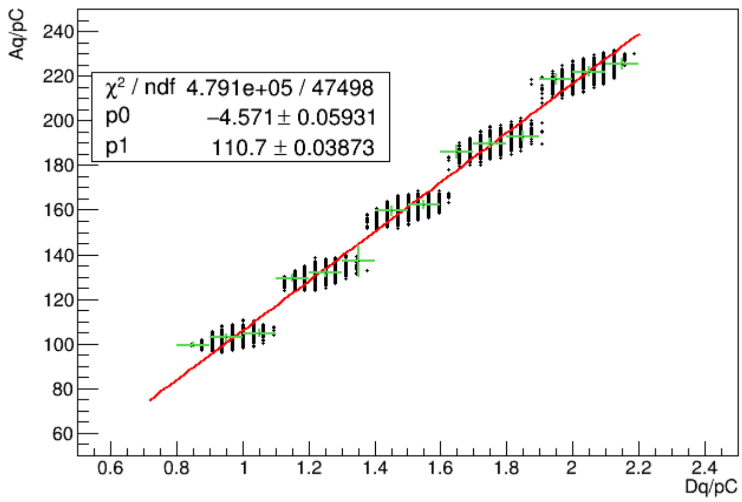
The main characteristic of the PMTs, such as the SPE, the high voltage response and the AD ratio. Take a PMT as an example(fee==11&&db==1&&pmt==2), by measuring the SPE spectrum at a 2200V position voltage and the high voltage response curve (1100V~2200V), we can calculate the working high voltage corresponding to the working gain with this calibration system shown in Fig.7.Therefor, the working voltage of this PMT at the working gain is 1176.1V, the AD ratio is 110.7.



(a) The SPE spectrum : the working gain is 8×10^6@HV==2200V



(b) The high voltage response curve: $\beta = 5.89$.

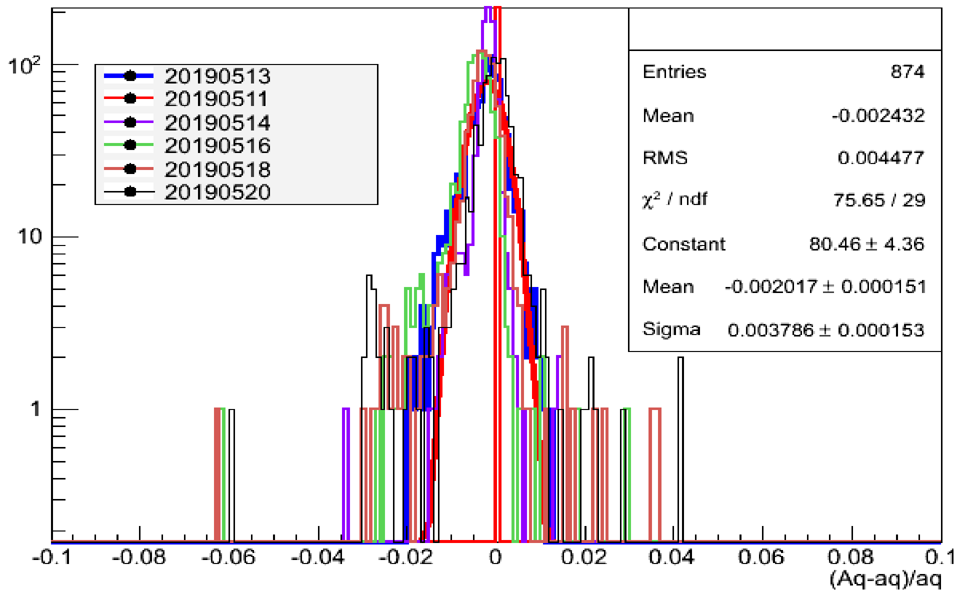


(c) The AD ratio with different LED widths: $\mathrm{AD} = 110.7$.

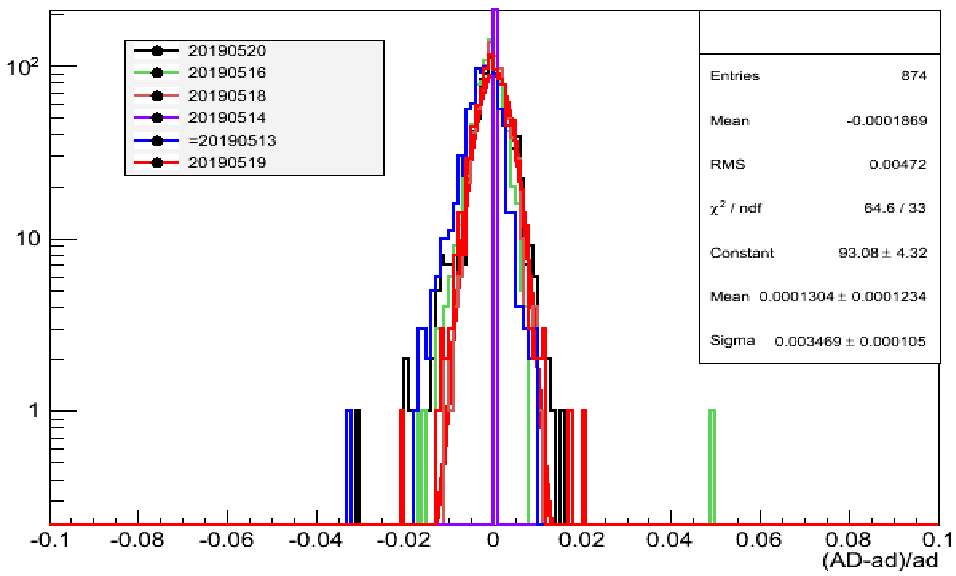
Figure 7: The charge calibration of the PMT (fee==11&&db==1&&pmt==2)

4. Monitoring of 900PMTs

By mid-March 2019, we completed the installation of 900 PMTs and 25 sets of prototypes were also installed and commissioned. In order to monitor the working state of the PMT for a long time, we run a led with a pulse width of 30 ns, and the light intensity is about 1500 PEs, which can measure the anode signal and the AD ratio very well. Here are the results of the 10 days of monitoring in May, shown in Fig.8. For some reasons, there are 26 PMTs that are not working properly. Based on this monitoring result, we can control the stability of the tube to 0.5% within 10 days, which is far better than the 2% index we designed. What we want to say is that the monitoring results of PMT stability include the stability effects of the LED light source.



(a) The monitoring of anode signal: sigma==0.38%.



(b) The monitoring of AD ratio: sigma==0.35%.

Figure 8: The monitoring of PMT working gain includes anode signal and AD ratio.

5. Conclusions

A calibration system that dynamically calibrates the charge of the PMT is designed based on the LED source group and the multi-branch light guide fiber, which can be used to generate single photons, multiple photons, and large light intensities. The rapid calibration of the detector's working gain is achieved by studying the SPE spectrum at the high working gain, the high voltage response curve, and the AD ratio at different pulse widths. This calibration method has been used in the LHAASO-WCDA quarter pool to calibrate the working gain of PMTs and to monitor the change of the gain. This calibration method can also be used in similar detectors with low gain, which can improve the precision of energy reconstruction.

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