Time calibration of LHAASO-WCDA engineering array

XIAOHOUYOU\textsuperscript{1,2}, BOGAO\textsuperscript{2}, ZHIGUOYAO\textsuperscript{2}, MINGJUNCHEN\textsuperscript{2}, BINZHOU\textsuperscript{2}, HUICAILI\textsuperscript{3,2}, HANRONGWU\textsuperscript{2}

\textsuperscript{1}Hebei Normal University, Shijiazhuang, 050016, China
\textsuperscript{2}Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, 100049, China
\textsuperscript{3}Southwest Jiaotong University, Chengdu, 610031, China

yourex@ihep.ac.cn

Abstract: The Water Cherenkov Detector Array of LHAASO is a high-sensitivity gamma-ray and cosmic-ray detector. The main purpose of it is to survey the northern sky for very-high-energy gamma ray sources. The shower direction is reconstructed by the hit time so that the precise time calibration between PMT channels are essentially very important. In this paper, firstly we present a calibration method based on LED and optical fibers, then the setup of the calibration system in the engineering array is introduced. At last, the test results of future plans are given.

Keywords: WCDA, Water Cherenkov, Gamma-ray, Cosmic Rays.

1 Introduction

A large high altitude air shower observatory (LHAASO)\textsuperscript{[1]} is to be built at Shangri-La, Yunnan Province, China. One important physics goal of LHAASO is to survey VHE (\(\geq 100\text{GeV}\)) gamma ray sources in northern sky by using its water Cherenkov detector array (WCDA). For the ground-based air shower detector arrays, the direction of the origin particle is reconstructed by measuring the hitting time of the secondary component which recorded by the detector cells. According to LHAASO-WCDA, the signal is the Cherenkov photons generated by particles in the water received by the PMT. To reach a high direction reconstruction precision, a reliable detector time calibration is required.

2 The LHAASO-WCDA time calibration

The LHAASO-WCDA\textsuperscript{[2]} is to be built as a water pond, with an area of 90,000m\(^2\) and an effective water depth of 4.5 m. The pond will be divided into 3,600 detector cells by black polyethylene (PE) curtain which can avoid the “cross-talk” effect between neighbouring cells when a particle passing through the detector. Each cell detector is 5m × 5m in area and a 8-inch PMT is fixed on the ground at the center. Considering the electronics and DAQ design, 9 cell detectors forms a group, 4 neighbouring group forms a cluster.

2.1 Time calibration requirement

The primary goal of the timing calibration system is to monitor the time stability of the PMTs and related read-out/digitization electronics. For the gamma ray source such like Crab, the main signal reaches to the ground can generate a very small shower. Due to the trigger design of WCDA and simulation, a number of multiple hits is around 20 when a shower is recorded. To achieve an angular resolution \(\leq 0.1^\circ\), a simple simulation is done. In the simulation, 20 detectors are selected randomly in a cluster (6 × 6), each detector is given the same systematic error from 0.06ns to 0.35ns, and the shower front is fitted by plane function, the result shows that the systematic error needs to be less than 0.12ns (see in Fig.1).

Fig. 1: Relationship between reconstruction direction error and detector time resolution.

2.2 Time calibration method

As the LHAASO-WCDA structure mentioned above, it is very difficult to implement a single light source calibration system such as a laser combines optical fibers, as the fiber length will be longer than 200 m, it is very hard to preserve. So a new time calibration method is proposed. As it is shown in Fig.2, each cluster contains two sets of optical fibers which are in the same length of 40 m, illuminated by one LED. One set of fibers is implements in the cluster, the other set of fibers, part of them are implemented in the cluster, others are implemented in the neighbouring cluster, the whole WCDA are chained cluster by cluster to achieve the goal of whole detector array time calibration.

3 Time calibration of LHAASO-WCDA engineering array

To study “cross” calibration method, a time calibration system prototype has been made for LHAASO-WCDA engineering array\textsuperscript{[3]} (See in Fig.3). The prototype mainly consists 3 parts: LED, LED driver and optical fibers.
3.1 LED
The LED used in the time calibration system prototype is manufactured by GreeThink Corp, which diameter is 5 mm and light emitting wavelength is around 470 nm, Fig. 4 is the wavelength distribution of the LED.

3.2 LED driver
In order to obtain a stable, fast and narrow pulse, an easy LED driver has been made. It is a simple and stable, and used successfully in the engineering array. The circuit is based on an avalanche transistor (2N5551), with a DC power supply of 180 V, 1 A. The driver is triggered by a fast positive pulse signal (rise time less than 5 ns). The output signal is adjust to -9V in amplitude and 5ns in width. Fig.5 is the driver circuit and simulated output signal by Multisim.

3.3 Optical fiber
The optical fibers is the light transmitter, the fiber used in the system is PMMA plastic fiber, the bending radius and temperature effect of the fiber is tested in the lab by using oscilloscope and PMT XP2012B manufactured by Photronics Corp., the results are shown in Fig.6, the signal rise time does not depend on the bending diameters of the fiber, whereas the noticeable change of the signal transmission time starts at diameter 10 cm; The temperature of pool bot-

4 Calibration results
The online time calibration of engineering array is set under in shower mode (trigger multiplicity = 3) with the PMT threshold set to 1/3 PE, the LED frequency is set to 5Hz, every data taking time is set to 10 minutes. The single time calibration result is got through Gaussian fitting. Three values are concerned (see in Fig.7): short fiber time offset between test PMT and reference PMT (S.T); long fiber time offset between test PMT and reference PMT (L.T); time offset long fiber and short fiber of one PMT (∆T).

4.1 Single measurement precision
Single measurement precision represents the accuracy of calibration system prototype, PMT, cables, electronics system. Four principal influence factors are identified: LED light respond time, TDC accuracy (0.5 ns), T.T.S of PMT
Fig. 7: Example of LED signals between test channel and reference channel.

in the case of multi-photoelectron and the light pulse time width depending on the length of fiber.

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\sigma_{\text{all}} = \sqrt{\sigma_{\text{LED}}^2 + \sigma_{\text{DC}}^2 + \sigma_{\text{fiber}}^2 + TTS^2}
\]  

(1)

Fig. 8 demonstrates the results of single measurement between one test channel and reference channel of short fiber and long fiber, and Fig. 9 demonstrates the results of time difference between long fiber and short fiber in test channel and reference channel separately.

Fig. 8: Left: Time offset measurement between short fiber; Right: time offset measurement between long fiber. The precision is about 0.9 ns (short fiber) and 1.3 ns (long fiber).

Fig. 9: Left: time offset between long fiber and short fiber of reference channel; right: time offset between long fiber and short fiber of test channel.

4.2 Long-term stability

The long-term stability is crucial in detector running, the time calibration of engineering array has been done in 2 months. Fig. 10 shows the operating state of two test channels which illuminated by 2 separate LEDs. The signal amplitude of the short-fiber is relatively larger than that of the long-fiber for the 2 test channels. The time stability of channel is not heavily dependent on the amplitude of signal, it depends on the relative variation of the signal amplitude. But the charge distribution of signal varied less than 5% in the operating time, so it does not have a serious impact on time calibration. The long-term monitoring results are shown in Fig. 11. As it can be seen, the average accuracy of short fiber channel is 0.12 ns, but the long fiber channel is 0.22-0.23 ns. The difference is caused by the influence of different fiber length broadening pulse width and signal overshoot. During operation in the site, the impact of environmental change on the calibration system cause about 0.1 ns error and this also characterize the stability of calibration system for the change of external environment. Optimizing the signal delay and uniforming the output light can further improve the measurement accuracy.

Fig. 10: The running status of 2 PMTs illuminated by separate LEDs in one week. From top to bottom is: 1) room temperature; 2) LED light intensity; 3) short fiber time offset between reference PMT and test PMT; 4) long fiber time offset between reference PMT and test PMT; 5) time offset between short fiber and long fiber of one PMT.

Fig. 11: Top: The distribution of short-fiber time offset mean value between test channel and reference channel; middle: The distribution of long-fiber time offset mean value between test channel and reference channel; bottom: The distribution of time offset mean value between short-fiber and long-fiber.

5 Conclusion

The principle of the LED and dual fiber calibration have been proven feasible and the precision can reach expecta-
tions. According to the experience of LAWCA time calibration, PMT time performance need to more strict test. We will focus on improving reliability of the calibration system as well as the design of the spectrometer in the future.

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