An Optical Calibration System for Engineering Array of LHAASO-WCDA

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Abstract: As a prototype for the time calibration and PMT gain monitoring, a dedicated system based on optical fibers and LEDs has been installed in the engineering array of LHAASO-WCDA experiment. The setup of this calibration system is introduced, and its operating principle is explained. Finally the performance of the system, via various measurements carried out on the engineering array, is presented and discussed.

Keywords: LHAASO, WCDA, PMT, time calibration, optical fiber, LED

1 Introduction

The LHAASO-WCDA[1, 2] (Water Cherenkov Detector Array) will be built at 4300 m in Yang-Ba-Jing (4300m a.s.l), Tibet, China. The WCDA covers an area of 90000 m^2, either configured as a big pond or subdivided into four small ponds, the whole pond of WCDA, with an effective water depth of 4m, is partitioned by curtains into 5 m $\times$5 m. A hemispherical photomultiplier tube (PMT) 8 in. diameter is located at the bottom-center of each cell, facing upward, to collect the Cherenkov light produced by shower particles in water. The WCDA's physics goal is to survey the northern sky for very-high-energy (above 100GeV). The simulation shows that in order to guarantee the sensitivity of the whole array, PMT channel to channel time jitter should be less than 1.5 ns and must be stable in the long run. Considering the big area and so many detector cells (3600), we propose to use a method called "cross-calibration" and an Optical fiber-LEDs based optical calibration system for the purpose of timing calibration. In this paper, we will describe the "cross-calibration" method and some measurements of the calibration system prototype installed in the engineering array.

2 Optical Calibration System

2.1 "Cross-Calibration" method

The WCDA experiment contains more than 3000 detector cells, if we want to calibrate the whole array at the same time, we will use at least 215 m long optical fiber each detector cell and it is hard to install or maintain the calibration system in this way. To make optical calibration system simple and easily operated, we subdivide the whole array into clusters as you can see in Fig. 1 (9 cells/group, 4 groups/cluster), each cluster uses one optical calibration module, each calibration module contains 36 short optical fibers (30 m) and 2 long fibers (45 m). The short fiber are assembled to PMT, the 2 extra long fibers is assembled to one PMT in the neighbouring clusters (figure 1). The short fibers calibrate the PMTs in one cluster while the long fiber will calibrate the chosen PMT in neighbouring cluster. In this way, we will save optical fiber cost and the whole calibration system is easily operated.

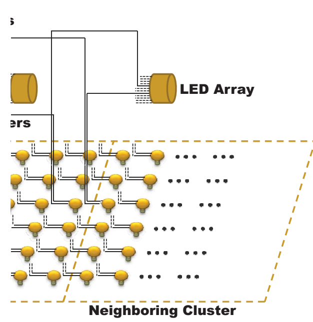

Figure 1: Cross calibration.

2.2 LED

The light source is one of the most important parts of the optical timing calibration system, currently a plethora of ultra bright blue LEDs are available in the market. We choose the 3 mm single quantum well InGaN blue led GNL-3014BC which is produced by Ningbo G-nor Opto

Electronics Company[2]. Albeit the LED's emission spectrum does not suite well to R5912 PMTs photocathode sensitivity curve, the LED has much higher light yield than violet LEDs and the most important that they are very fast LEDs without slow components tail at all and have good temperature behavior.

2.3 LED driver

To drive the LED, one type of eletronics driver based on avalanche transistors is widely used, it is simple and stable. We developed our led driver based on an avalanche transistor 2N5551. The V_{cc} is adjusted to 170 V to make 2N5551 works in avalanche region(160-180 V), the input signal is a positive pulse with 5ns rise-time and 1μs width, the output signal is a negative pulse, its rise-time, pulse width and amplitude are changeable via changing R_c and C_l. The driver is built on a 90 mm×50 mm PCB board. Both the circuit scheme and the photo of LED driver are presented in Fig. 2 and Fig. 3.

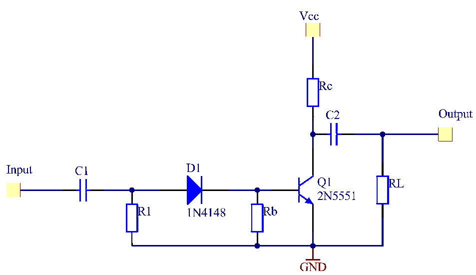

Figure 2: LED driver scheme.

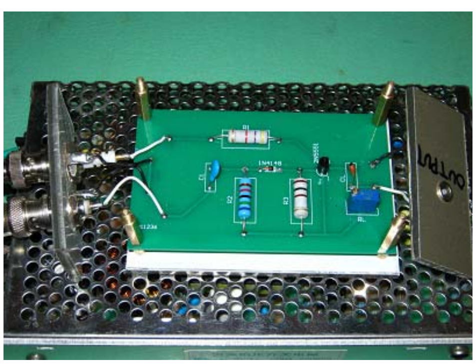

Figure 3: LED driver photo.

Table 1 shows the stability of LED driver's amplitude, rise-time, pulse width and hit-time. All the results measured by a digital oscilloscope(Tektronix TDS3034B 300 MHz 2.5G/s). measurements.

2.4 Optical fiber

The PMMA fiber (1 mm diameter) wrapped in the PE protection layer (0.6 mm thickness) is suitable for light transferring[4], it is easily assembled and its physical characteristics are stable. We use 2 different length 30 m and 45 m for "cross-calibration". While we assemble the fibers, the bending radius is not the same between each other. Fig. 4 shows the dependence of PMT_{fb} to PMT_{fs} [1] time offset T_{offset} on bending radius R_b. As it can be seen from the figure that T_{offset} does not depend on the bending radius obviously in the condition of possible installation ($R_b \geq 50$ cm).

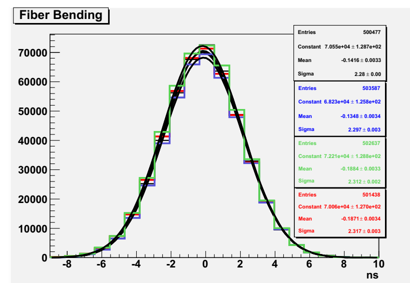

Figure 4: Dependence of T_{offset} on bending radius R_b of optical fiber. Red line : R_b=10 cm; Green line : R_b=20 cm; Blue line : R_b=50 cm; Black line : $R_b=\infty$ (not straight strictly). As it is shown in the figure, T_{offset} only changes 37ps from R_b=10cm to fiber straight.

3 Calibration system test

The optical calibration system's main purpose is to monitor the channel to channel time offset stability. After the system is installed, we place one piece of Teflon sheet (0.6 mm thickness) between LED and fiber bundle to make LED light uniform before it illuminates the fibers. The end of the fiber is fixed to the PMT (1.0 cm from the PMT surface). The PMTs' gain are adjusted to 2×10^6[5]. For the time calibration, we illuminate all the PMTs by using LED light pulses through optical fibers and adjust the PMT amplitudes to 2 V. A threshold (15PEs) is set to all the PMTs for triggering. We choose one PMT as reference (named PMT_{ref}) then we measure the time offset between PMT_{ref} and the other PMTs. For example, Fig. 5 shows the time offset (T_{offset})between PMT_1 and PMT_{ref}.

All the time offsets are showed in Tab. 2.

After we correct the time offsets between PMT_{ref} and other PMTs, long-term stability of the system is important. Fig. 6 shows that after 32 runs (about 1 week), the PMT' charge stability and Fig. 7 shows one channel to another channel time offset variation. All the results show that the calibration system has good stabilities at PMT charge and time monitoring.

1. fb="fiber bend", fs="fiber straight"

Table 1: LED driver stability. All the data is fitted with Gaussian function, as it is shown in the table, the LED driver performs very good stability on amplitude and time characteristics.

Amplitude (V)		Rise time (ns)		Pulse width (ns)		Hit time(ns)	
Mean	FWHM	Mean	FWHM	Mean	FWHM	Mean	FWHM
3.05	0.15	3.20	0.06	17.23	0.18	100.5	0.14
4.12	0.13	3.54	0.06	18.17	0.16	100.5	0.13
5.02	0.14	4.00	0.05	19.10	0.15	100.4	0.13
6.03	0.12	4.23	0.04	19.91	0.13	100.3	0.11
7.12	0.12	4.39	0.05	20.23	0.12	100.1	0.12
8.22	0.11	4.52	0.05	21.17	0.10	99.9	0.11
9.10	0.10	4.60	0.05	22.23	0.11	99.5	0.10
10.2	0.10	4.62	0.04	23.43	0.10	99.3	0.09

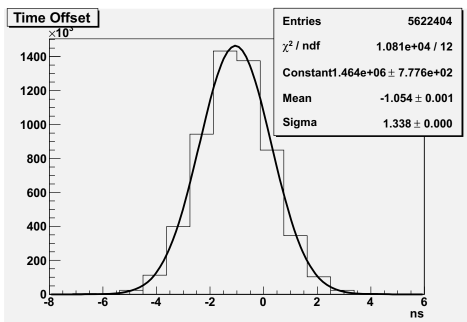

Figure 5: Time offset between PMT_1 and $PMT_{\rm ref}$. The offset comes from the signal cable, the electronics channels and optical fiber.

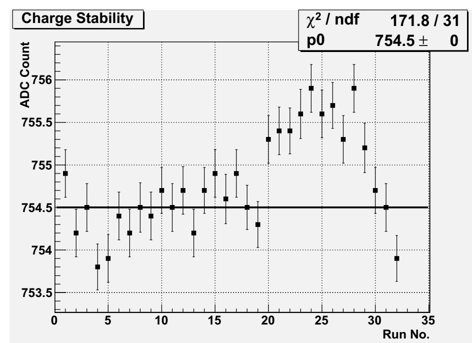

Figure 6: Charge stability. After 32 runs, the pmt's charge variation is less than 0.4%.

Table 2: Time offsets.

PMT No.	Mean (ns)	FWHM (ns)
1	0.362	1.490
2	2.775	1.785
3	3.559	1.254
4	-0.314	1.327
5	-1.523	1.311
6	1.378	1.344
7	2.323	1.324
8	-1.223	1.234

4 Conclusion

The optical calibration system prototype developed for LHAASO-WCDA engineering array shows good performances, in particular their timing stability. It is cheap, simple and easily operated. Future efforts will focus on optimizing the light yield (and fiber to fiber uniformity) and the design of the distributed calibration system for the whole LHAASO-WCDA array, and tank diffuser mounting plan.

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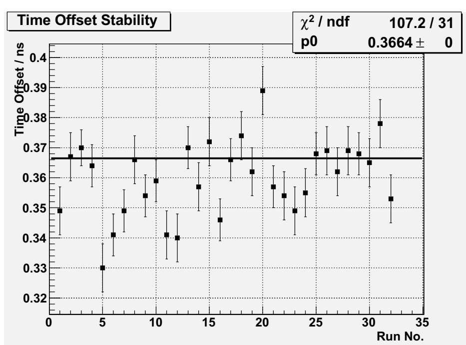

Figure 7: Time offset stability. After 32 runs, the 2 channel time offset variation is better than 0.06ns.