



## R&D of LHAASO-WCDA

MINGJUN CHEN<sup>1</sup>, ZHIGUO YAO<sup>1</sup>, BO GAO<sup>1</sup>, BIN ZHOU<sup>1</sup>, HANRONG WU<sup>1</sup> AND HUICAI LI<sup>2</sup> FOR THE LHAASO COLLABORATION

<sup>1</sup>*Institute of High Energy Physics, CAS, Beijing, 100049, China*

<sup>2</sup>*Southwest Jiaotong University, Chengdu, 611756, China*

*mjchen@ihep.ac.cn*

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**Abstract:** As one of the important parts of the LHAASO Project, the Water Cherenkov Detector Array (WCDA) is planned to be built in Yangbajing, Tibet, China soon. In order to fully understand the engineering issues and the basic performance of the water Cherenkov detection technique, a prototype water Cherenkov detector has been built and operated in Beijing, and an engineering array has been constructed on site. With the help of the prototype detector, performance related to cosmic muon signals and water quality maintenance has been studied and acquired. Studies of the engineering array are also progressing smoothly: nine 8-in PMTs and their electronics and DAQ systems have been deployed; an optical calibration system, a water recycling and purification system, and a slow control system, have been installed; the data taking started, and the data analysis is going on. These studies will offer a great help to the future work of the full array.

**Keywords:** LHAASO, WCDA, prototype, engineering array.

## 1 Introduction

The Large High Altitude Air Shower Observatory (LHAASO)[1] has been proposed and will be funded in the next five year. The origin of the cosmic ray, the very high energy gamma ray sources and the precise measurement of the components at the knee region are the main scientific goals of LHAASO. As we know, the water Cherenkov detectors[2, 3] have been in large use during the last 20 years in the high energy and cosmic ray physics, and this unique detector is capable of continuously surveying the TeV sky for steady and transient sources from 100GeV to 100TeV with a good gamma/hadron discrimination, high angular resolution and background rejection power, WCDA[4] is the one of the major and important components of LHAASO project. Furthermore, its construction will be firstly started at Yangbajing, Tibet, China. WCDA will cover an area of 90,000m<sup>2</sup>, configured as a whole octagonal pond or four individual small octagonal ponds depending on the engineering factors and the sensitivity optimization. The baseline detector design calls 780×4 cells(5×5m<sup>2</sup>×4m depth) each instrumented with a single 8-in photomultiplier tube(PMT) looking up at the bottom center to collect the Cherenkov light produced by the shower particles in water.

Since WCDA will be a very large engineering issue and the basic performance of the water Cherenkov detection technique should be well understood firstly, a prototype

water Cherenkov detector[5] has been built and operated in Beijing and an engineering array has been constructed on site. In this paper, the related research and progress are presented.

## 2 The prototype water Cherenkov detector

The main component of this prototype is a cylindrical steel container, which is 7.07m in diameter and 5.0m in height and placed on a ferroconcrete platform 8.0m in diameter and 0.5 m in height above the ground. Both outer and inner surfaces of the water tank are coated with anti-rust paint. A black polyethylene liner with reflectivity less than 10% is embedded inside the tank. To shield the leakage of external light, the top of the tank is covered by three layers of light-proof curtains and a roof in the outermost layer made of insulating color-bond. Three L3+C plastic scintillator modules are used to form a muon telescope for detecting and selecting cosmic muons. Two of the modules are placed on the roof of the tank, while the rest is inserted in a groove of the platform below the tank. All three plastic scintillator modules are able to move along a radial direction to select cosmic muons impinging on different positions of the tank and from different zeniths.

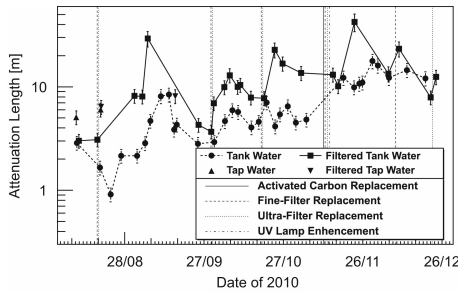


Figure 1: Variation of attenuation length of light (405 nm) in water. After the stable maintenance of the recycling and purification system, the water attenuation length is able to keep up above 15m.

## 2.1 Water quality control

The water quality and its stability are critical for successful long-term operation of WCDA. The tank for this prototype experiment is simply filled with the tap water after purification by a small recycling and purification system. To keep water quality, a water pump continuously circulates water between the tank and the purification system through the pipes with a flux of 35liters per minute( $\sim 4$ days/volume). To monitor the water attenuation length, the tank water is periodically sampled and measured using a delicate device consisting of a water pipe, an LED and a PMT. The monitoring data (figure 1) shows that the water is not very clean at the beginning. However, the quality of the water improves obviously when subsequent components are added, and filters are changed, as indicated by the vertical lines in figure1. The UV lamp at 185 nm wavelength is a critical component of this system because it can decompose dissolved organic carbon, which is the major pollution source in the water.

## 2.2 $N_{pe}$ distribution of vertical muon signals

In the configuration of the vertical alignment of three scintillator modules and an 8-in PMT located at the bottom center in the tank, a long-range  $N_{pe}$  distribution with two peaks is observed. The whole distribution(figure 2, top) can be well fitted by a small Gaussian signal riding on top of a Landau function. A Monte Carlo simulation with the same configuration and water attenuation length is developed to verify the experimental measurements (figure 2, bottom). A two-peak structure in the distribution is also evident. The two peaks of simulation data are 6.5% and 4.9% lower than those of data, significantly below the systematic error because the quantum and collection efficiency of the PMT have not been measured for this experiment(the values adopted in the simulation are typical values from the manufacturer).

The first peak is made up of the pure geometrical effects of the selected muons, whereas the long tail, as the Landau

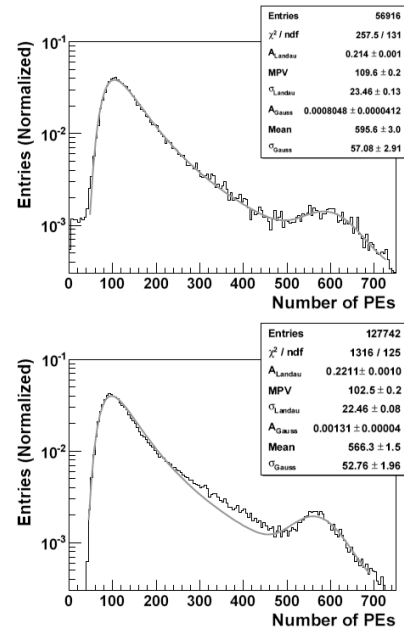


Figure 2:  $N_{pe}$  distribution of vertical muon signals detected by the PMT, superimposed with a Landau plus Gaussian fit. Top: experimental data. Bottom: simulation results.

function describes, mainly comes from  $\delta$ -rays generated by the cosmic muons. The second peak is produced by muons directly hitting the PMT photo-cathode. The Gaussian part contributes approximately 2.5% of the total events, agreeing well with the ratio between solid angles of the PMT photo-cathode and the bottom scintillator detector seen by the top scintillator detectors. In this case, most collected Cherenkov light is emitted along with a short track very close to the PMT cathode. This results in a possible way for WCDA to calibrate and monitor the PMT and electronics by the measurement of charge[7].

Additionally, the counting rate of the PMT in the tank varying with different thresholds and time profile(rise time and amplitude) of the cosmic muon signals are measured and analyzed. At a threshold of 1/2 photo-electron, the rate reaches nearly 16KHz at sea level.

## 3 The engineering array of the water Cherenkov detector

In the middle of 2010, the construction of an engineering array of the water Cherenkov detector, which is the so called 1% scale of the full array and has  $3 \times 3$  cells, was started. It is located at the northwest ARGO experiment hall. And generally, it includes nine 8-in PMTs, the electronics system, DAQ system, the water recycling and purification system, the slow control system, the optical calibration system and so on.

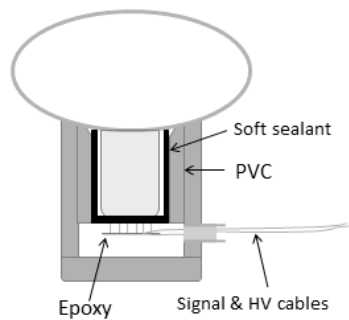


Figure 3: The water-proof potting structure of R5912 PMT.

### 3.1 Testing of PMT

The nine PMTs are 20cm in diameter and made by Hamamatsu(model R5912). With the experience from Milagro experiment and Daya Bay experiment[6], a new water-proof potting method(figure 3), which will be more reliable and operational, was developed.

Before nine PMTs deployed in the engineering array, we set up a complicated and stable stand to measure the detailed specifications[8], such as the SPE spectrum, the relation of HV VS. Gain, the non-linearity, the dark noise rate, TTS, the rise time(RS) and so on. The methods of the first four measurements are similar to that of Auger project by UCLA group[9] and will be ignored here. For the measurements of TTS and RS, a pico-second laser source(Hamamatsu C10196), which has very narrow pulse width and high stability, is used. A TDC module, CAEN V775, records the fluctuation of the transit time, and an oscillograph(Tektronix 3054B) reads the rise time of PMT signal.

Considering the dynamic region and signal amplitude, gain  $2 \times 10^6$  is selected for our project. Since PMT has the better resolution for detecting single photoelectron with the higher value of peak-to-valley ratio, all P/V values that we tested are almost larger than 2.5. The non-linearities go down to 10% when about 700PEs for the current base design. The  $\beta$  values in the relation of gain VS. HV( $gain \sim (HV)^\beta$ ), are close to 8. The dark noise rates are all close to 1KHz when 1/2PE threshold set. The TTS values,  $\sim 2.0$ ns, are almost similar to Hamamatsu datasheet's. The RS values are all about 3.3ns.

### 3.2 Electronics and DAQ system

A 9U electronics board based on VME standard, holding 9 PMTs' signals, is already developed by one of our group. The electronics system includes three parts: the linear pre-amplifier which divides the signal into two individual channels with two gains(1X and 26X), then after 100meter cables, the signals go to the analog circuit and are shaped, finally the information of amplitude and time is handled by the digital circuit. About the specifications of this board,

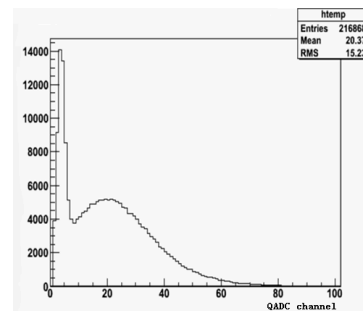


Figure 4: SPE spectrum of channel 8. The right small peak means the SPE measured.

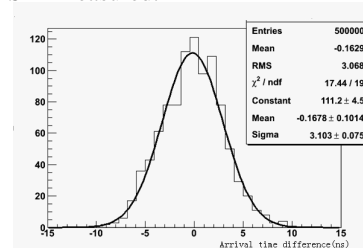


Figure 5: The arrival time difference between channel 2 and 4. The difference comes from the signal cable, the electronics channels and optical fiber.

the resolution of time measurement is 0.89ns with 0.45ns RMS, the discrimination of multi-hits with  $\geq 25$ ns interval time is capable, the input amplitude region is from 0.8mV to 3.2V, 10% resolution for SPE measurement and so on.

The trigger pattern is optimized by the simulation, and five cases concerned are listed as follows: 1), Within 100ns window, 3 channels of nine PMTs are fired; 2), Within 100ns window, 2 channels of nine PMTs are fired, filtered with 1/100(only one trigger outputs when 100 times); 3), 1 channel is fired, filtered with 1/10000; 4), 1Hz force trigger; 5), External trigger(possibly from ARGO-YBJ or other detectors). And the above five cases work with OR mode.

Generally speaking, the DAQ online software firstly configures the electronics module, then reads the data from the board by the VME bus and transfers the data to the local PC. Simultaneously, the run status and online histograms sampled from the data could be shown in the screen.

As for now, many tests have been done for this system. For example, the results of SPE measurement and arrival time difference are shown in figure 4 and 5.

### 3.3 Water recycling and purification system

As is mentioned above, the water quality is a critical issue for our experiment. Therefore, a delicate water recycling and purification system is designed and installed by a professional company. The idea of the elements of the water purification system is originated from the prototype with

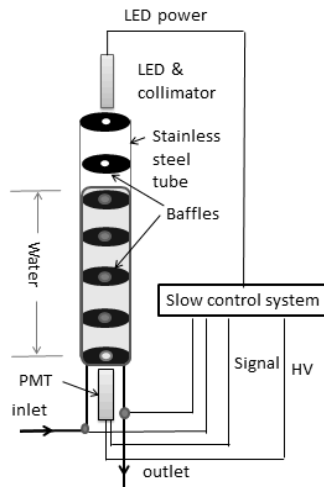


Figure 6: The schematic of water attenuation length measurement setup.

the similar filtration setup and a capacity of 85 liter per minute. In total,  $\sim 16$  hundred tons of fresh filtered water is required, and supplied by a well located 100m far from the site. In this system, the active carbon filter and multi-media filter precede a series of progressively smaller filtration stages from 5 microns to 1 micron to ultrafilter. At last, the water is also sterilized using two UV light sources(185nm and 253nm). This system will be used to fill the pond initially as well.

### 3.4 Slow control system

The development of this system is based on a signal board computer(Technologic Systems, TS-7350) and a micro control unit (MCU). And this system is used to monitor the following parameters.

- Monitoring the HV values of 9 PMTs. Once the fluctuation with  $\geq 5\%$  happens, the system will automatically shut the HV down.
- Monitoring the humidity, air pressure and temperature of the control room.
- Recording the water level and temperature of the pond.

Besides, the online measurement of water attenuation length(figure 6) is also combined in this system. It supplies the power to the LED and PMT, reads the PMT signal and water level. And it also controls the water volume by two electromagnetic valves. Finally, it could automatically and remotely measure the water attenuation length everyday as required.

### 3.5 Optical calibration system

Like other experiments, an optical calibration system[10] is deployed in the engineering array to monitor the gain changes and the stability of the electronics system. The basic idea is that nine equally long(30m) optical fibers, which are separately fixed nearby each PMT photo-cathode, guide a uniformed LED light to each PMT. At the mean time, a 2-in PMT is also used to monitor the stability of LED light. Besides, one more fiber(45m) will be added to calibrate the TDC with the same LED light source.

## 4 Summary

After having operated the prototype water Cherenkov detector for more than one year, the characteristics of water Cherenkov technique have been understood. The successful experience of the water quality control will be applied to the future experiment. A two-peak structure of the  $N_{pe}$  distribution for near vertical muons has been observed. Simulation results are in good agreement with the measurements. As a continuation of this prototype experiment, an engineering array consisting of  $3 \times 3$  cells of WCDA is under construction on site. Now, we are doing the final tests and some upgrading work. As we wish that the engineering array would start data taking in the end of this July. The analysis of the subsequent data combined with the ARGO-YBJ experiment will provide more information about water Cherenkov performance.

## References

- [1] Zhen Cao for the LHAASO collaboration, PROCEEDINGS OF THE 31st ICRC,LORZ (2009)
- [2] Y.Fukuda, *et al.*, Measurement of the solar neutrino energy spectrum using neutrino-electron scattering, Phys.Rev.Lett. **82** (1999)
- [3] J. Abraham, *et al.*, Properties and Performance of the Prototype Instrument for the Pierre Auger Observatory, NIM, **A523**(2004),50
- [4] Zhiguo Yao for the LHAASO collaboration, ROCEEDINGS OF THE 32nd ICRC,Beijing (2011)
- [5] Q.An, *et al.*, Nucl. Instr. and Meth. A(2011), doi:10.1016/j.nima.2011.04.016
- [6] Mary Stuart, internal report, DYB-doc-3432
- [7] Hanrong Wu for the LHAASO collaboration, ROCEEDINGS OF THE 32nd ICRC,Beijing (2011)
- [8] Bin Zhou for the LHAASO collaboration, ROCEEDINGS OF THE 32nd ICRC,Beijing (2011)
- [9] M. Ambrosio, *et al.*, GAP-2002-040
- [10] Bo Gao for the LHAASO collaboration, ROCEEDINGS OF THE 32nd ICRC,Beijing (2011)