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Development of a liquid scintillator detector for new EAS hybrid Experiment

Ying Zhang,[a,*] **J. Huang,**[a] **D. Chen,**[b] **L.M. Zhai,**[b] **X. Chen,**[b] **Y. Meng,**[a,c] **K.Y. Hu,**[a,c] **Y.H. Zou**[a,c] **and Y.L. Yu**[a,c]

[a] *Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China*

[b] *National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, China*

[c] *University of Chinese Academy of Sciences,Beijing 100049, China*

E-mail: yingzhang@ihep.ac.cn

We plan to develop a portable and low-cost liquid scintillator detector for future planning. The prototype experiment will be built at Yangbajing, Tibet (4300 m above sea level) this year. The prototype experiment will be jointly run with the Tibet ASgamma experiment in a hybrid array to test the performance. In this paper, we will report the development of liquid scintillator detector and its optimization test has been studied in detail.

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[*]Speaker

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1. Introduction

The observation of high-energy gamma rays (HE gamma rays: 20MeV-30TeV) is closely related to the astronomical phenomena such as double neutron-star merger, cosmic-ray accelerators, galactic supernova, active galactic nucleus (AGN), etc. Satellite experiments represented by the Fermi Gamma-ray Space Telescope have achieved great success in gamma-ray observations in the MeV-GeV energy region [1][2], but they are powerless above 100GeV because of limited exposure time and small detective area. So the task of HE gamma-ray observations relies on the ground-based indirect measurements due to the large active area, the high duty cycle, and wide field of view, such as the Tibet ASγ[3], the HAWC[4], and the LHAASO[5].The sensitivity of these experiments in the energy region above tens of TeV has been greatly improved, but for the 100GeV to 1TeV energy region, the current ground EAS experiments are almost blank.

The SWCDA is an R&D project aiming to design a very-high-energy (VHE) gamma-ray observatory sensitive to energies above ~100 GeV. The science goals include continuous observation of VHE gamma-ray sources and transients such as Gamma-Ray Bursts (GRBs). With these objectives, SWCDA is designed to have a low energy threshold with a wide field-of-view of about 2 sr, at a high altitude, and combines liquid scintillator (LS) array and a water Cherenkov detector array. The water Cherenkov detector is used to observe the muon component of the secondary particles in the cosmic ray shower and to identify protons and gamma rays, while the LS is used to eliminate a large number of noise signals. In this contribution, we focus on introduce the development and design of LS detector only. For the LS detector, we plan to carry out the development of liquid scintillator, wavelength shifting (WLS) fibers and clear optical fibers while greatly reducing the cost, and its volume and weight are also reduced which will make it convenient to make. The LS prototype experiment will be built at Yangbajing, Tibet (4300 m above sea level) this year and will be jointly run with the Tibet ASγ experiment in a hybrid array to test the performance.

In this paper, we will report the development of LS detector, as well as the optimization test has been studied in detail.

2. Design of liquid scintillator detector

For the LS detector, we plan to carry out the development of liquid scintillator and optical fibers. Each LS detector consists of $1m^2$ liquid scintillator, 240 fibers with a length of 234 cm and a photomultiplier tubes (PMT), as shown in Fig.1. In order to have quick response time, the LS with an area of $1m^2$ is divided into 16 small units contained in Polymethyl methacrylate (PMMA) box whose size is 25 cm × 25cm × 5cm (length × width× thickness). Such a design ensures the time resolution of detector is less than 2 ns[6]. The scintillation light is collected by using double cladded fibers, WLS fibers (BCF92) and clear optical fibers (CK-60). Fifteen WLS fibers of 1.5 mm diameter and 54 cm length have been glued into grooves of 1.6×1.6 m^2 at the PMMA board surface under the PMMA box. One end of these fibers is plated with aluminum for the reflection. The other ends are connected to 180 cm long clear optical fibers. Compared with an air guide, the use of optical fibers can reduce the volume of detector, as well as improve the non-uniformity. The separation betwee fibers is 1.7 cm. The fifteen clear optical fibers are attached to a PMT (CR285,1.5 inch end window) for readout. Each small unit is wrapped with a layer of Tyvek sheet to improve

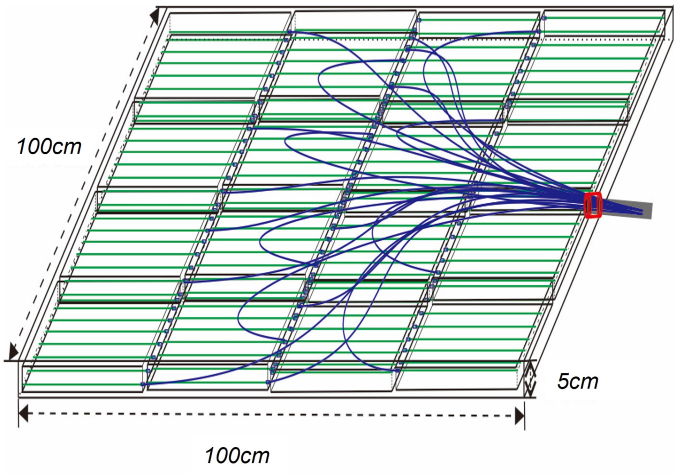

Figure 1: The schematic view of LS detector. Each LS detector consists of $1m^2$ liquid scintillator, 240 fibers and a photomultiplier tubes (PMT).

photon collection efficiency and then covered with a black mask to avoid external and inter optical crosstalk on the outermost.

3. Test of liquid scintillator detector

In order to eliminate a large number of noise signals as trigger system, it is neccessary to measure the number of shower particles after passing through each LS detector. For the LS detector, it is suitable to obtain about 10 photoelectrons (PEs) when a single particle hit in a detector, which is consistent with the expected design of the LS detector array. Therefore, we tested the performance of various components of the detector to achive the goal as below:
1) Test the characteraistic of liquid scintillator.
2) Test the linearity of the quantity of fibers.
3) Test the PMT linearity by High Voltage (HV).
4) Test the single particle output of LS detector unit.

3.1 Test the characteraistic of liquid scintillator

When charged particles passed through the LS, the quantity of scintillation light depends on the energy deposits, which is in proportion to the length of MIP's (Minimum Ionization Particle) track in the dector. Thus, the linearity of charge output versus the thickness of LS is measured. The resolution of the ADC is 0.25 pC/count. Fig.2 shows the correlation between the charge output and the thickness of LS, which can be fitted with a linear function y = k*x with k to be determined from measurements. The red solid circles denote the experimental data. The black solid line denotes the best fit result by the linear function. It can be seen that there is a good linear relationship between the charge output and the LS's thickness. In addition, the light yield of LS will change under different temperatures. Considering the large temperature difference in Yangbajing within one year even one day, the variation of LS's light yield versus temperature is also measured. We found that the effect

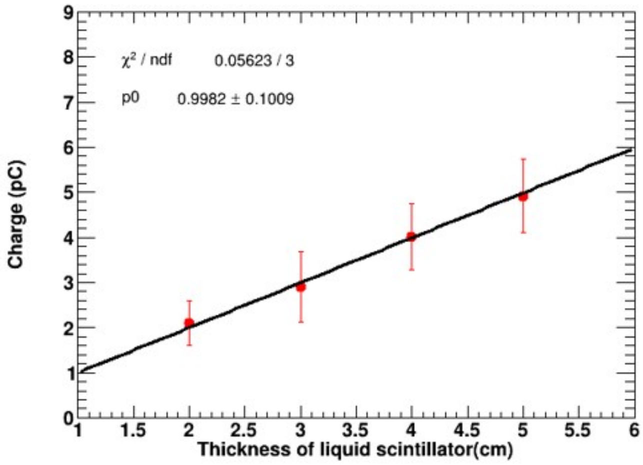

Figure 2: The correlation between the charge output and the thickness of liquid scintillator.

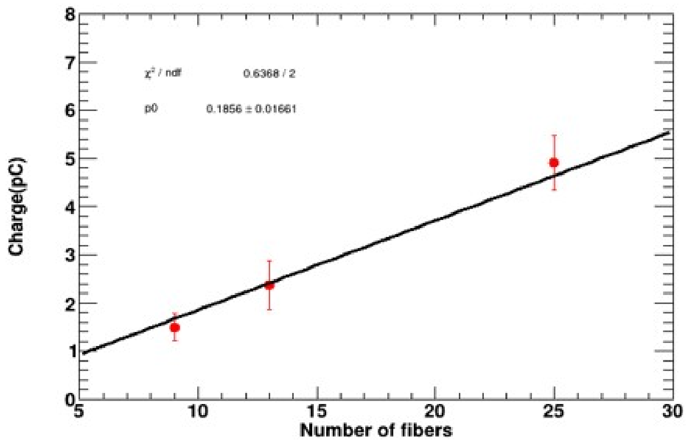

Figure 3: The charge output of LS detector varies linearly with the quantity of fibers.

of temperature changes on the light output of Linear Alkylbenzene (LAB) based LS is less than 40% in a range from -30° to 40°. In fact, the prototype array will perform a real-time calibration every 20 minutes during the data acquisition similar to the Tibet ASγ experiment[7]. Therefore, the variation of light yield emitted by LS with temperature changes can meet our requirements.

3.2 Test the linearity of the quantity of fibers

In order to optimize the light collection, the WLS fiber (BCF92) has been chosen because its absorption spectrum matches the emitting wave band of the liquid scintillator. According to the datasheet of BCF92, only about 7% of scintillation photons can be trapped in the WLS fibers. It is essential for each fiber to transmit as many photons as possible to its far end, which is attached to the PMT. So one end of WLS fiber is plated with aluminum for the reflection. The other end is connected to 180 cm long clear optical fibers which have better light transmission performance.

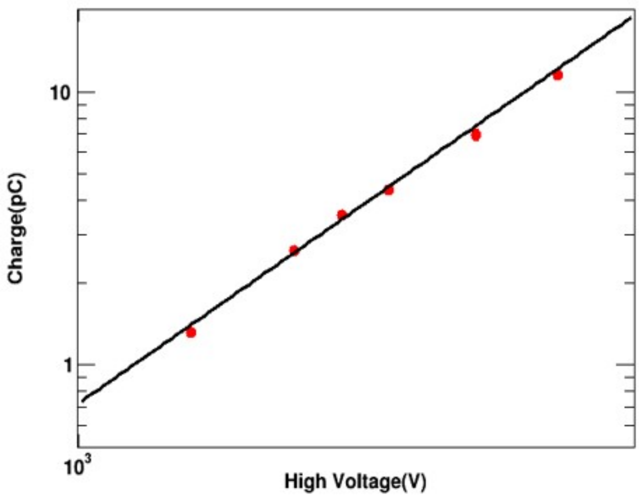

Figure 4: The charge output for CR285 as a function of high voltage.

As we know, the quantity of scintillation light depends on the quantity of fibers. Therefore, the linearity of the quantity of fibers is also tested. Fig.3 shows that the charge output of LS detector varies linearly with the number of fibers. It indicates that our testing system has no issues. On the other hand, it can provide an important reference for the design of the detector with the combined parameters such as LS's thickness.

3.3 Test the HV linearity of PMT

One of the important features for PMT is the charge output with respect to the supplied high voltage (HV), as shown in Fig.4. The relationship between charge output (Q) and input high voltage (V) is described by

$$Q = \alpha V^{\beta} \tag{1}$$

with α and β to be determined from measurements. The power law index parameters β is determined to be 6.95 ± 0.15. This is consistent with the typical value of CR285 made by Beijing Hamamatsu.

3.4 Test the single particle output of LS detector unit

As mentioned above, it is suitable to obtain about 10 PEs when a single particle hit in a detector for LS detector. In fact, the number of obtained PEs varies with the detecor's thickness and the quantity of fibers. Considering the cost and performance of the detector, the suitable design of the LS unit is with the size of 25 cm×25 cm×5 cm and 234 cm-long fibers (54 cm WLS fibers+180 cm clear optical fibers) embedded into grooves at the PMMA board surface. The separation between fibers is 1.7 cm, as shown in Fig.5(a). Fig.5(b) shows the PEs distribution of a single particle measured by the LS detector. The red solid circles denote experimental data and the black solid line is the fitting result to the PEs distribution by landau distribution. In this figure, the most probable value (MPV) value is about 10 PEs with a resolution of 14.8% which can meet our requirements.

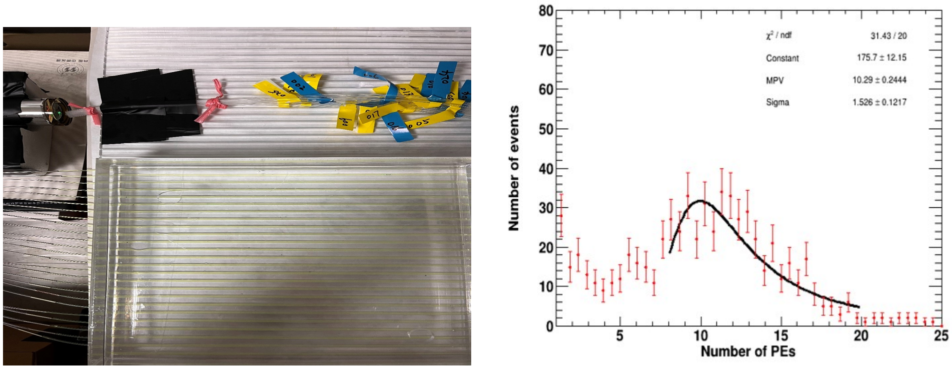

Figure 5: (a)The inner structure of LS unit;(b)The photoelectrons (PEs) distribution of a single particle measured by LS unit.

4. Summary

In this paper, we present the development and performance of LS detector for SWCDA project. In order to obtain about 10 photoelectrons (PEs) when a single particle hit in a detector, which is consistent with the expected design of the LS detector array, we tested the performance of various components of the detector to achive the goal. Finally, the suitable design of the LS unit is with the size of 25 cm×25 cm×5 cm and 234 cm-long fibers (54 cm WLS fibers+180 cm clear optical fibers) embedded into grooves at the PMMA board surface. The separation between fibers is 1.7 cm. The prototype experiment will be built at Yangbajing, Tibet this year. The prototype experiment will be jointly run with the Tibet ASγ experiment in a hybrid array to test the performance.

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