Study of the large Tyvek bag technique for the water Cherenkov detector in TIBET AS+MD

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Abstract: The Tibet AS-gamma collaboration is constructing 4500 m^2 underground muon detector array by using water Cherenkov technique, to form the TIBET AS+MD hybrid array. The muon detector will improve the sensitivity of gamma ray and electron observation above 10 TeV by rejecting the cosmic ray background. In TIBET AS+MD, both water-recycling system and closed container techniques are now being studied. In this paper, the progress and performance of the large Tyvek bag is reported.

Keywords: Tibet AS array, Muon detector, Tyvek, water Cherenkov

1 Introduction

In 1980s, the only firmly confirmed celestial gamma ray source at TeV energy was the Crab nebula, firstly detected by the Whipple telescope experiment [1]. In recent twenty years, the number of discovered TeV gamma-ray sources increased rapidly, and more than 100 sources are observed, with the development of the third generation of Imaging Atmospheric-Cherenkov technique, especially after the operation of HESS Experiment in 2004. At GeV energy, 1873 sources are detected by Fermi Gamma-ray Space Telescope in its first two years' operation, after its launch on June 2008 [2].

As we know such high energy gamma rays is generated in electromagnetic processes (synchrotron, inverse Compton, or bremsstrahlung) and hadronic cascades(π^0 decay). But up to now, the energy spectrum of almost all these gamma ray sources can be well described by electromagnetic processes. No single one is conclusively proven to be a source of hadronic causation, neither Galactic nor extragalactic origin. Because the gamma rays will be greatly suppressed in 10TeV by synchrotron radiation and Klein-Nishima effect, the observation of gamma rays in 100TeV energy range will be a new window to distinguish hadronic processes, which related to the acceleration of cosmic ray.

To improve the sensitivity to observe celestial gamma rays source around 100TeV, the muon detector (MD) array are being built under the Tibet air shower (AS) array, using water cherenkov technique.

2 Tibet AS array

Since 1990, the Tibet AS array has been in operation at Yangbajing ($90^0 31'$ E, $30^0 06'$ N; 4300 m above sea level) in Tibet, China. Tibet I array was constructed in 1990 with 65 scintillation counters [3], and it was gradually expanded by increasing the number of detectors to the Tibet II in 1994 and the Tibet HD in 1996 [4]. Each counter has a plastic scintillator plate of 0.5 m^2 in area and 3cm in thickness, in which be equipped with a fast-timing 2-inch-diameter photomultiplier tube (FT-PMT) called fast timing (FT) counter and be equipped with a wide dynamic range 1.5-inch-diameter PMT (D-PMT) called density (D) counter. A 0.5 cm thick lead plate is put on the top of each counter in order to increase the counter sensitivity by converting gamma rays into electron-positron pairs in an electromagnetic shower. In the late fall of 2003, the area of the Tibet AS array was further enlarged up to 36,900 m^2 which consisted of 728 FT-counters (249 of which also have a DPMT) and 28 D-counters [5].

The energy range of Tibet AS array is from TeV to 100PeV. At 100 TeV, the angular resolution is about 0.2 degree and the energy resolution is about 40%. In the successful operation of more than twenty years, the Tibet AS array achieved lots of important physical result. In 1999, Tibet AS array firstly detected the multi-TeV gamma ray signal from Crab among a conventional AS arrays and later observed flaring emissions from Mrk501 in 1997 and from Mrk421 between 2000 and 2001 [4, 6, 7]. Tibet array also firstly obtained the two-dimensional high-precision large-scale cosmic-ray anisotropy in the northern sky and pointed out new component of anisotropy in the direction of Cygnus region at multi-TeV energies [8], where the discovery of TeV diffuse gamma-ray signal is then claimed by Milagro [9].

However, up to now, except Crab Mrk421 and Mrk501, neither point source nor diffuse gamma rays has been detected by Tibet AS array [10, 11, 12]. The main reason is that the Tibet AS array is unable to distinguish gamma rays from hadrons.

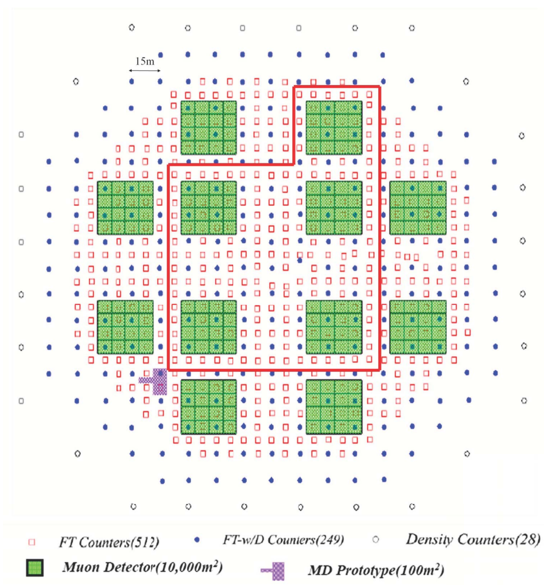

Figure 1: Schematic view of the Tibet AS+MD array. In red pane there is MD-I (5 modules, 4500 m2 muon detector), constructed in 2010. MD-A is at the upper right corner of the 12 MD modules

To improve the sensitivity of gamma ray observation above 10 TeV, we plan to construct the 10,000 m^2 underground muon detector array using water Cherenkov technique, forming the TIBET AS+MD hybrid array [13, 14]. The Tibet MD array consists of 192 muon detectors with 2.5 m overburden, and each muon detector is a waterproof concrete pool (7.2 m wide × 7.2 m long × 2.4 m high in size), equipped with 20 inch-diameter PMT (HAMAMATSU R3600). The timing and charge information for each PMT is recorded by a trigger generated from surface AS array. The secondary particles in air shower induced by primary gamma rays have much less muons than that induced by hadrons. In this case, the number of muons in the shower is one important parameter to significantly discriminate gamma rays from background cosmic rays. MC simulation predicts that the cosmic-ray background events will be rejected by approximately 99.99% at 100 TeV using full-scale MD array [15]. At present, we are building 5 modules (MD-I, approximately 4500 m^2, each module has 16 pools) among the full-scale MD array, as shown in Figure 1. The large Tyvek bag is used to contain clear water in one MD module (MD-A), and such technique is described here.

3 The large Tyvek bag technique using in TIBET AS+MD

For water Cherenkov Detector, long term stability of the water transparency is very important. In many experiments, water-recycling system and closed container techniques are in common use. For example, the 50 ktons of water in the Super-Kamiokande tank is continuously reprocessed by water-recycling system and the closed container technique used in the Pierre Auger Surface Detector is designed to have an operational lifespan of at least twenty years. In MD-A, we used the later technique (i.e. big bag enclose the water volume) to keep the water quality in pool. The advantage of this technique is water saving, easy in operation and maintenance.

For this kinds of detector, the reflectivity of the bag and the transparency of the water are two critical factors in determining the signal quality. We use the Dupont Tyvek as the material of the bag, because this material is flexible, hard wearing, resistance to biological activity and outstanding diffuse reflectivity (when the wave length larger than 350nm, its diffuse reflectivity is more than 90%) [16]. As the Tyvek have high air permeability, outside of the bag a three-layer coextruded low-density polyethylene (LDPE) film is added. Then the thickness of the material is about 375 μm. Using the sealing machine, we successfully produced the windtight large Tyvek bag (7.2 m wide $\times$ 7.2 m long $\times$ 1.9 m deep in size).Some photos in their production are shown in Figure 2. With this method, we can prevent water from the contamination, and also good reflection of Cherenkov photons in the water.

To achieve the lowest attenuation for Cherenkov lights and stability of the water, the Tyvek bag is filled up with the high-purity water, by water purification system. The water purification system consists of five stages purification:

1. Pre-processing: to eliminate suspended solids, colloid, organism, free chlorine and other particles greater than 5 μm, and to ensure that the water fed into Reverse osmosis is qualified.

2. Reverse osmosis: it is a filtration method that removes many types of large molecules and ions from water by applying pressure to the source water side of a selective membrane. The resistivity of the output water is above 30 k$\Omega\bullet$cm.

3. Ultraviolet purification: UV disinfection with a 254 nm UV source and a 185 nm unit, to kill germ from the water and decompound total Organic Carbon (TOC) below 500 ppb.

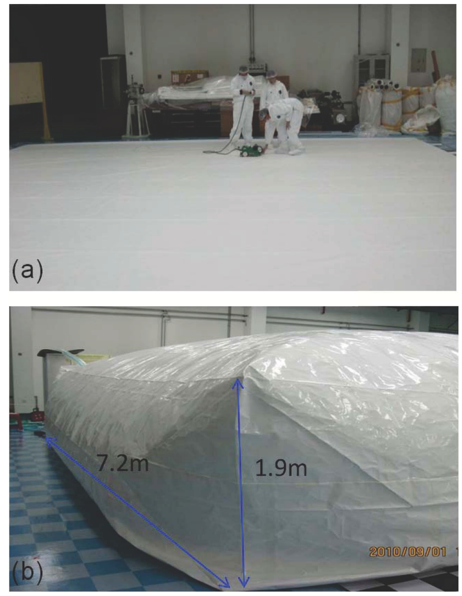

Figure 2: (a) Weld to the large Tyvek bag in laboratory; (b) One of the Tyvek bag (7.2 m wide $\times$ 7.2 m long $\times$ 1.9 m deep in size).

4. Electro-deionization: it uses ion exchange resins to absorb ions from a dilute water stream and then transports the absorbed ions through ion-exchange membranes into a concentrate water stream under the influence of an applied electro field. This process can produce ultra-pure water (resistivity above 10 M$\Omega\bullet$cm).

5. Ultra filter: to eliminate particles greater than 0.2 μm.

By using perfluoroalkoxy (PFA) tubing, pools were filled with water with resistivity more than 3M$\Omega\bullet$cm. We just finished one of the pool's installations in Jun, 2011. Figure 3(b) is the scene of the installation.

4 Result and Discussions

To study the signal of the detector, we must obtain the absolute gain of the PMT by measuring the single photoelectron peak firstly. In the case a face down PMT was installed on the upside of the pool, a LED was used as a light source. The voltage applied for this LED is generated by the pulse generator, which also provides a trigger signal to the DAQ system simultaneously. By changing the amplitude and width of the output pulse, we tune the amount of photons reaching the PMT until the ratio of the signal and noise is near 1:9. In this case, the single photoelectron peak is obtained for this PMT. After measuring the gain as a function of the applied high voltage, the absolute gain at a certain high voltage can be calculated [17].

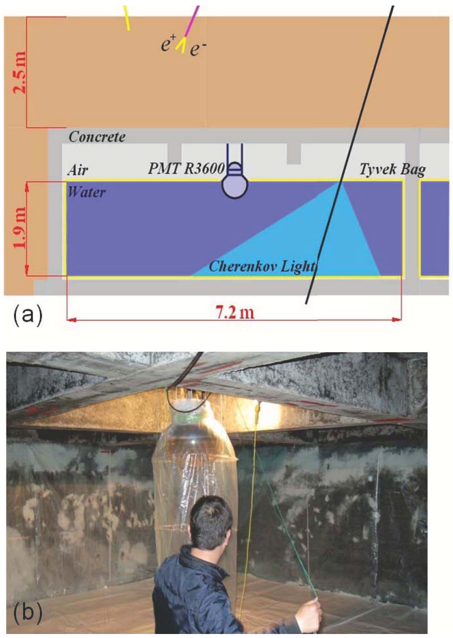

Figure 3: (a) Schematic view of one pool. In the center of the pool equipped with one twenty inch PMT and the bag is filled up with the high-purity water to keep the water quality long term stability; (b) The scene of the installation.

To study the signal of single muon events for the muon pool, two scintillation counters of 1 m^2 in area were placed above the center of the pool, and the near vertically incident muon around center of the pool was selected in this setting. Figure 4 shows the photoelectron distribution by the PMT from such muon events. In this figure, a clear peak is around 300 photoelectrons, indicating the average photoelectrons when one muon passes through the pool. The single muon resolution (FWHM) is about 33%. The detailed data analysis and MC simulation of the MD-A are in progress.

5 Summary

In an attempt to optimize the Tibet MD array, the large Tyvek bag technique is used in MD-A. Up to now, three of the bags have been successfully installed and other pools are under installation. The preliminary data analysis shows that the single muon peak can be clearly separated from noise signal. We will continue to monitor the variation of the single muon peak in the long term stability operation of the muon detector array. The large Tyvek bag technique for the water Cherenkov detector in TIBET AS+MD is under study.

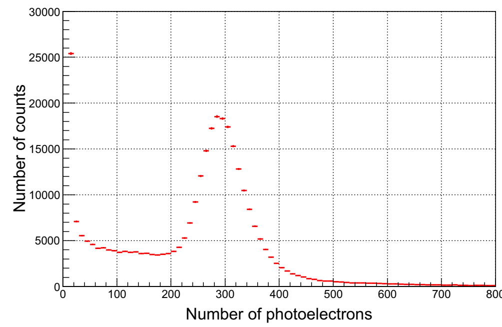

Figure 4: A clear single muon peak observed. The number of the collected photoelectrons was obtained for one single muon incident to the center of the pool. The peak is estimated to be 300 photoelectrons.

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