Progress Report on the MD-A under TIBET III array

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Abstract: The underground muon detector array of 4500m^2(5 modules) is constructed underneath the Tibet ASγ experiment, improving the γ/P separation ability and then the sensitivity for gamma ray observation around 100 TeV. Each module of the muon detector is a large water tank with PMTs in the center, using water Cherenkov technique to obtain the muon signal. In one module (MD-A), the large Tyvek bag is employed filled with high-purity water keeping long-term stability of the water quality. The test run data of MD-A have shown the detector has good position uniformity, and the muon signal can be clearly separated from the noises. In this paper, the design and performance of the detector are presented.

Keywords: gamma ray, Tibet III Array, Muon detector, Water Cherenkov

1 Introduction

In 1912, Victor Hess found a radiation of very great penetrating power enters our atmosphere from above[1], which signified the discovery of cosmic ray. One century has passed, the origin and acceleration of cosmic rays still has not been satisfactorily resolved. High energy gamma rays, as neutral particles which will not be deflected in the magnetic field, are the best probe of the undergoing cosmic accelerators.

As we know, the very high energy gamma rays are generate in electromagnetic processes (mainly by the inverse Compton scattering) and hadronic cascades (the decay of π^0s generated in cosmic rays hadronic interaction with ambient gas). Up to now, almost all detected gamma ray sources can be well described by electromagnetic processes and no-one is conclusively proven to be a hadronic source. Theoretically speaking, the gamma ray spectrum from hadronic process may extend to PeV energy or higher, while its might not be easily produced by electrons. Then, the observation of gamma rays in 100 TeV energy region is very important in search for source of hadronic causation, which related to the acceleration of cosmic rays.

The Tibet III array, as its high altitude and large area, would be an ideal experiment in observing 100 TeV gamma rays if it has the γ/P separation ability. To improve the sensitivity to observe gamma ray source around 100 TeV, the muon detector (MD) array using water Cherenkov technique is being built under the Tibet Air Shower (AS) array.

2 TIBET III array and MD 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. After more than ten years of extension, the area of the Tibet AS array was enlarged up to 36,900 m^2 as TIBET III array which consists of 728 fast-timing counters and 28 density counters in 2003[2]. Each counter has a plastic scintillator plate of 0.5 m^2 in area and 3 cm in thickness.

The TIBET III array has been working in a wide energy range from TeV to 100 PeV. For 100 TeV gamma ray, the angular resolution is about 0.2 degrees and the energy resolution is about 40%. However, up to now, except Crab Mrk421 and Mrk501[3, 4, 5], neither point source nor diffuse gamma rays has been detected by Tibet AS array[6, 7, 8]. The main reason is that the Tibet AS array, as a simple scintillator array, did not have the discrimination power in distinguishing the gamma rays from the overwhelming cosmic ray background.

To improve the sensitivity of gamma ray observation above 10 TeV, we have planned to construct a 10000 m^2 underground muon detector array using water Cherenkov technique, to form the TIBET III+MD hybrid array[9, 10]. The MD array has 12 modules (each module has 16 muon detector) with 2.5 m overburden, and each muon detector is a waterproof concrete square pool with 7.2 m in side length and 2.4 m in height. The secondary particles in air shower induced by primary gamma rays contain much less muons than those in the hadrons induced shower. In this case, the number of muons in the shower is one powerful parameter to discriminate gamma rays from the cosmic rays background. Monte Carlo (MC) simulation shows that nearly 99.99% of the background events will be rejected using full-scale MD array[11].

In the late fall of 2007, two prototype detectors were constructed under the Tibet III array. The typical photoelectron number (N_{pe}) for vertically penetrating muon is 17[12]. In 2010, five out of 12 modules (MD-I, approximately 4500 m^2 in total) have been constructed, as shown in the red box of Figure 1. Different from the other four modules, the top right module (MD-A) uses large Tyvek bag filled with high purity water. In this paper, the design and performance of MD-A is described.

3 The design features of the MD-A

To keep long-term stability of water Cherenkov detector, either water-recycling system or closed container technique is used. For example, in the Super-Kamiokande, 50

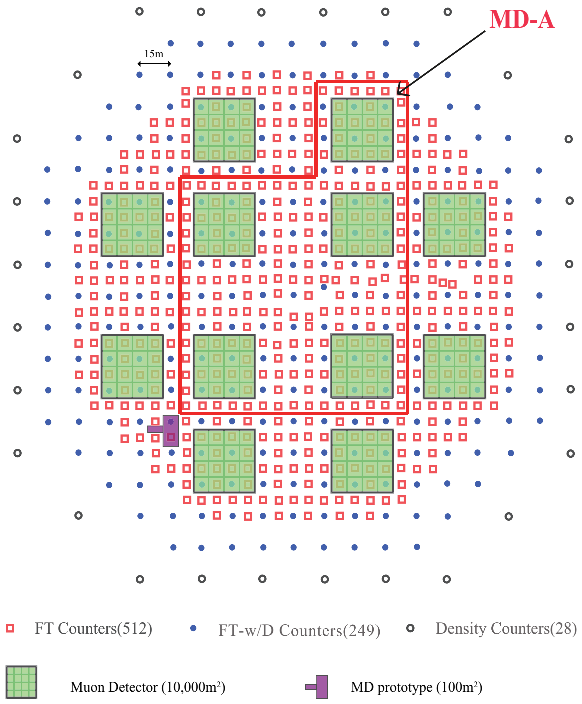

Fig. 1: Schematic view of the Tibet III+MD array. Open squares denote fast timing counters with a FT-PMT (FT counters); filled circles is FT counters with a D-PMT (FT-w/D counters); open circles is density counters with a D-PMT. The red box indicates MD-I (5 modules, 4500 m^2 in total, 16 pools each module), constructed in 2010. Module MD-A is located at the upper right corner of MD-I.

kilotons of purified water is continuously reprocessed in a closed cycle system[13] and by using the closed container technique, the Pierre Auger Surface Detector is designed to have an operational life span of at least twenty years[14]. In MD-A, enclosing water in a large bag is used to stabilize the water quality in the pool. The advantage of this technique not only saves water but also does not require routine maintenance after the detector installation.

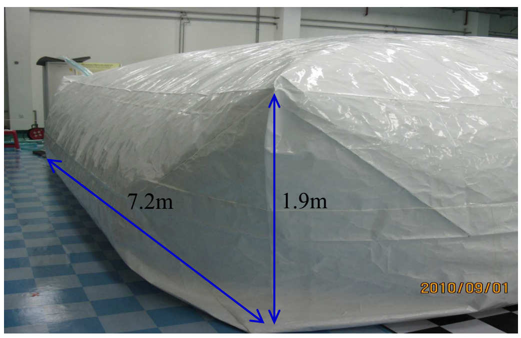

Fig. 2: One of the Tyvek bags (7.2 m in side length and 1.9 m in height) filled with air in clean hall.

For this kind of detector, the reflectivity of the bag and the transparency of the water are the most important factors. In MD-A, we use the reflective Tyvek (1082D, manufactured by Dupont, when the wave length is longer than 350 nm, its diffuse reflectivity is better than 90%) film as the lining of the bag. This material is exible, hard wearing, resistant to biological activity and has minimal dissolvable content which might deteriorate the water quality[15]. By using the sealing machine, we successfully produced the wind-tight large Tyvek bag (7.2 m in side length and 1.9 m in height). One Tyvek bag filled with air is shown in Figure 2. To increase the transparency of the water for Cherenkov photons, the Tyvek bag is filled with the high-purity water provided by a water purification system. By five stages purification, in the Tyvek bag, the water of resistivity above 3MΩ·cm. Each pool is equipped with one 20 inch-diameter PMT (HAMAMATSU R3600) at the center of the ceiling. Figure 3 shows the schematic view of one pool.

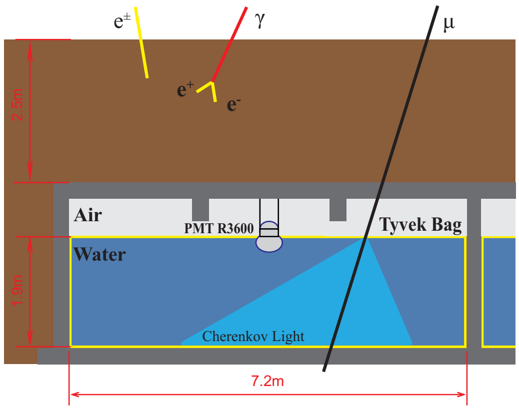

Fig. 3: Schematic view of one pool in MD-A. One 20-inch PMT is mounted at the center of the ceiling and dip into the water to overlook the pool. The Tyvek bag is filled with high-purity water to keep long-term stability of the water quality.

4 Performance of the MD-A

To study the performance of the detector, we have carried out the following measurements[16]:

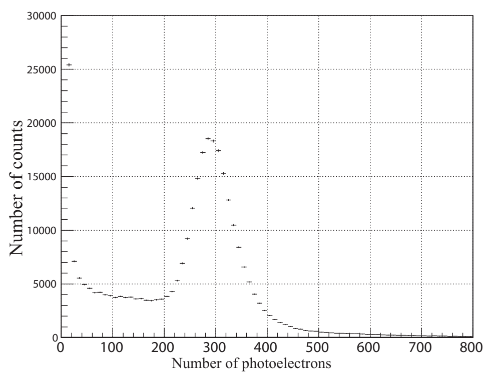

Fig. 4: A clear single muon peak has been observed. The fitted peak position is 291 photoelectrons.

4.1 The signal of single muon events

Two square scintillation counters of 1 m^2 area with 0.67 m vertical spacing (forming a simple muon telescope) were placed on ground above the center of one pool to choose the near vertical incident muon around the center of the pool by requesting a coincident signal in the muon telescope. Figure 4 shows the measured single muon amplitude spectrum. There is a clear peak around 291 photoelectrons, indicating the average number of measured photoelectrons when one near vertical muon passes through the center of the pool.

4.2 Position non-uniformity

Since we do not know the incident position for each muon passed through the pool when the Tibet III+MD array operation, the position non-uniformity is directly related to the muon number resolution of the detector. The above-mentioned muon telescope was placed above the pool on four positions as shown in Figure 5(a): the center of the pool (Position A), the side of the pool (Position B), the corner of the pool (Position C), the middle of A and C (Position D). By the muon telescope, the vertical incident muons (the vertical spacing between two scintillation counters is 2.9 m) are selected. Figure 5(b) shows the measured result. The obtained non-uniformity of the muon peak is better than 6%.

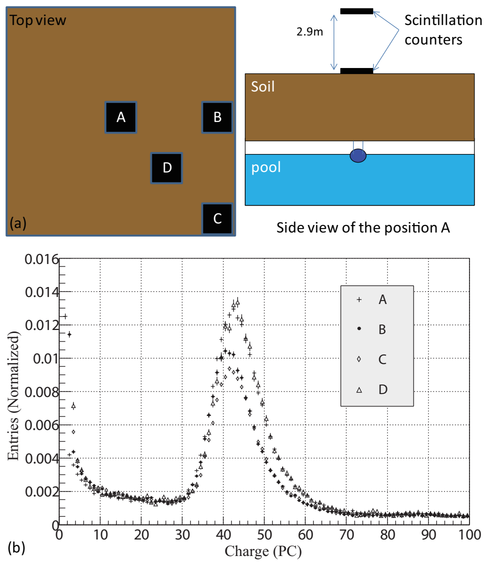

Fig. 5: (a) The schematic view of different positions A, B, C and D; (b) The single muon amplitude spectrums for near vertical muon entering at Position A, B, C or D.

4.3 Long-term stability

To study the long-term stability, the single muon amplitude spectrum was continuously monitored with one of the operated pools. In the operation time of 164 days, the total decay of the peak value is about 13% and the most recent data show that the detector is gradually turning into a stable situation, as shown in Figure 6. Between October and December, other detectors were installed and we stopped the monitor system.

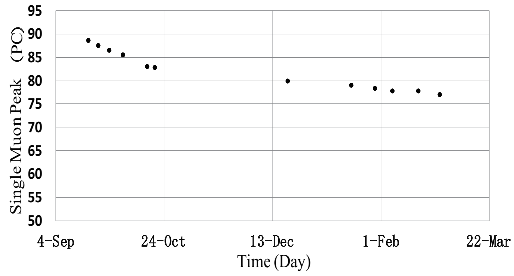

Fig. 6: Long-term stability of the tested MD-A.

5 Summary

In an attempt to optimize the Tibet MD array, the large Tyvek bag technique is used in MD-A. The test run data have shown that the single muon peak can be clearly separated from the detector noise and the detector has good position uniformity. Moreover, the long-term stability of the muon detector is being continuously monitored. This year, Tibet III array will be recovered. Further study of the Tibet III+MD hybrid array is under way.

6 Acknowledgment

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