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Deployment of an array of water-cherenkov Detectors for Extensive Air Shower Experiments

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Abstract: A new small array of cherenkov detectors has been deployed in Tehran, 1200 m above sea level. This array contains of four tanks full of distilled water with diameter of 64 cm and height of 130 cm. The effective area of each tank is about $6.5 \times 10^3 cm^2$. They are used to detect the air showers and to record the arrival time of the secondary particles. We have collected about 486643 EAS in 5270 h of observation time from Nov-2006 to May-2007. We find zenith and azimuth distribution of EAS with this array. A $\cos^n \theta$ distribution with $n = 7.3 \pm 0.1$ was obtained for zenith angle. Since this tank of distilled water is cheaper and more available than Scintillators it is preferable to use them instead of Scintillators in our future larger array.

1. Introduction

Extensive air shower (EAS) are initiated by ultra high energy ($> 10^{13} eV$) radiation (Cosmic Rays or Cosmic Gamma Rays) entering the earth atmosphere and are recorded by the detection of a fraction of its charged secondary particles reaching the ground level. EAS Experiments have played an important role in the study of ultra high energy cosmic rays. In particular with the observation of TeV gamma-Ray emission from EGRET point sources first reported by Khakian et al.[1], it is possible that it will play a yet more important role in UHE gamma-Ray research in coming decades. The most common detector used in EAS experiments is plastic scintillators viewed normally by one PMT and placed in different types of light enclosures and the detectors arranged in arrays of various geometry and size. In the present investigation we have explored the possibility of using a much less expensive and less complicated hand-made water Cherenkov detector deployed in array for EAS experiments. Large water tank Cherenkov detectors viewed by three PMTs are used in Pierre Auger Observatory[2]. Here we have used small tanks viewed by a single PMT to replace the scintillator detector together with its high enclosure in the array. In sec.2 this detector and tests and experimental arrangements are described. The results of these experiments and its data analysis are described in sec.3, while sec.4 is devoted to some concluding remarks.

2. Description of Experiments and Measurements

2-1. Description of water-cherenkov detectors

The water-cherenkov detectors used in the array are home made consisting of a metallic cylindrical tank 64 cm in diameter and 130 cm height filled up to a height of 120 cm with 382 litters of distilled water. It is coated with white diffuse paint inside and viewed with single PMT, 5 cm in diameter (model EMI 9813KB) which goes through the top lid of the tank and special arrangements are made to avoid entering the PMT in the water and at the same time avoiding extra reflection of light reaching the PMT. The tanks are filled with distilled wa-
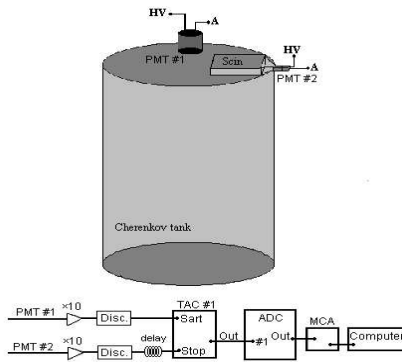
Figure 1: Schematic view of Test measurement on water Cherenkov detectors, and the electronic circuit.

Figure 2: Schematic view of water Cherenkov detectors as a square array, and the electronic circuit.

ter of very low conductance using water distillation with solar energy. The tank has a facet near bottom edge for simple drain and cleaning of the tank. The top lid and the PMT going through it has been secured tightly with black tape to avoid the leakage of outside light into the tank and each of the whole water-cherenkov detectors have been firmly covered with a water protective tarpaulin cloth cover to insure proper performance of the detector in the open air (e.g. rain and sunlight etc.). The tests described below preformed on each detector have been carried out with the detector in the open air and the data acquisition electronic is indoor.

2-2. Test measurements on water-cherenkov detectors

In order to test the proper ferdioring of each water-cherenkov detector to be used in the EAS array and to compare their detection performance with each other and with scintillator-light-enclosure detectors commonly used in EAS arrays. To test the detectors response to the passage of a secondary cosmic ray (CR) and measure its detection efficiency, a plastic scintillator($15cm \times 15cm$) with an EMI 9813KB PMT connected to its $15 \times 1cm^2$ side via a regular plastic light guide was placed directly upon the water-cherenkov detector. The passage of a CR is recorded by having signals from these two PMTs (the one at the end of plastic scintillator and the one viewing water in the cherenkov tank) within less than 200ns. The circuit diagram for the tests car-
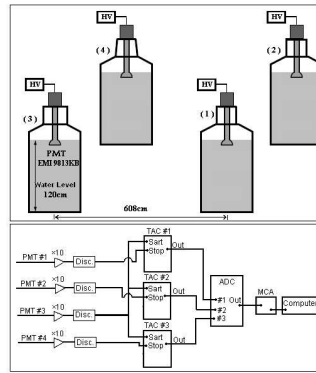
ried out in this part is shown in fig.1 identical electronic settings (gates, thresholds, TAC range, etc.) and duration time of experiment were used for each of the four home-made water-cherenkov detectors used in the present small array. This data acquisition circuit is almost identical to the one we have used to carry out "comparison of the performance of light enclosures for EAS experiments". Therefore, for the sake of concisement here we do not go into describing its technical details and function and we rather refer the interested reader to our previous published work[3]. The data obtained in these tests is given and analyzed in sec.3-1.

2-3. EAS experiments with small array of water-cherenkov detectors.

The four water-tank cherenkov detectors are arranged in a squire array of 6.08 meters on the side on the roof top of the physics building of Sharif university of technology, Tehran, Iran ($35°43'N, 51°20'E, 1200a.s.l = 890gcm^{-2}$), and the signals from the 4 PMTs viewing water in the cherenkov detectors were brought to the data acquisition room located on the roof of via ducted cables. The data acquisition circuit diagram used for experiments in this part is shown in fig.2 and it is almost identical to the one we have used for a similar small array of plastic scintillators with pyramidal light enclosure and collected EAS events. Therefore, for the sake of concisement here, we omit the description of the technical
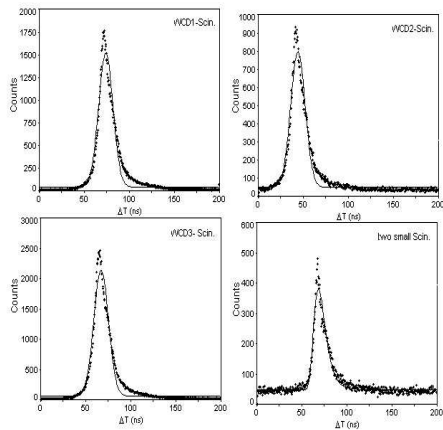
Figure 3: Time coincidence diagram between Water- cherenkov detector and a small Scintillator

Figure 4: Schematic view of water-Cherenkov and Scintillator detectors as two set of triangle array, and the electronic circuit.

details and function of this circuit, and rather refer the interested reader to our previously published work[3]. The data obtained in the experiments in this part is analyzed in sec.3.

3. Data analysis and results

3-1. Coincidence time between water-Cherenkov and Scintillator detectors

To test the WCD response to the passage of a secondary cosmic ray and measure its detection efficiency, a small plastic Scintillator detector was placed upon each of the WCDs, fig.1. Fig.3 shows the time difference distributions between one WCD and small Scintillator, furthermore the last distribution is related to time difference distribution of the two small scintillator detector placed on top of each other. We can derive the dispersion of times of events recording by each detector from Half- Width- Half- Maximum(HWHM) of this distribution and put them as error of time of reaching secondary cosmic ray. From these results for WCD error in time is $\Delta T_{Cher.} = 9.6ns$ and for scintillator is $\Delta T_{Scin.} = 9.3ns$[3].
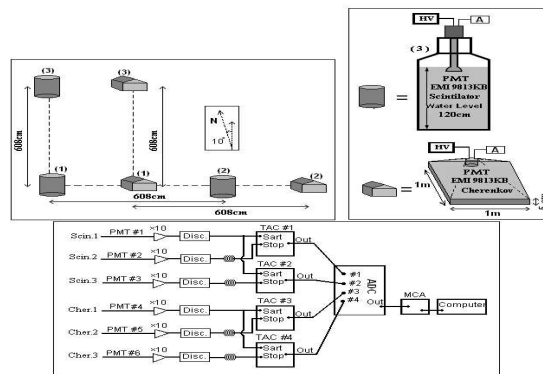
3-2. Array of Water- Cherenkov and scintillator detectors

To compare array of WCD and scintillator we arranged two sets of array, the former consists of three scintillators detectors and the latter consists of three WCD. Shape and size of these two arrays are similar and they record each event coincidentally, fig4. From time difference between each two detectors in each two arrays we can calculate the local coordinate, zenith angle and azimuth angle, of each shower recorded with two arrays at the same time. 4800 showers were collected in duration of 64 hours and the difference between zenith and azimuth angle of each shower calculated by two arrays are derived. From zenith and azimuth difference distribution of these 4800 showers, fig.5, we find that the local coordinates of most of these showers are measured equally for WCD and scintillator detectors. Half- width- Half-Maximum (HWHM) of these two distributions are $\Delta\theta = 14°$ for zenith angle and $\Delta\varphi = 29°$ for azimuth angle.

3-3 Zenith angle distribution of EAS events obtained the square array of WCDs

Our detection procedure is based on the time differences between each two detectors [4]. we used

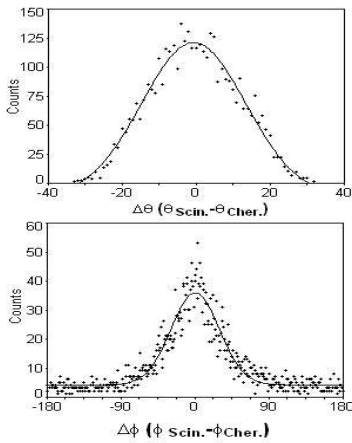Figure 6: Frequency of air showers vs. zenith angle.

Figure 5: distribution of zenith and azimuth difference between water- cherenkov and scintillator detector arrays.

least square method [5] to calculate θ. Zenith angle distribution of EAS events is shown in fig.6. Since the thickness of the atmosphere increases with increasing zenith angle, θ, the number of EAS events is strongly related to θ, as shown if fig 6. The differential zenith angle distribution can be represented by

$$dN = constant.(\delta_1 \cos\theta + \delta_2 \sin\theta) \cos^n \theta \sin\theta d\theta. \quad (1)$$

Where we split into particles entering through the lid of cylindrical tank of water-cherenkov-detector or through its walls. The first term in parenthesis of Eqn.(1) is related to the lid and the second to the walls. The parameter δ_1 includes the area of lid surface, S_1, and detection probability of particles entering through the lid, P_1. The parameter δ_2 also includes the greatest surface area of vertical profile of the water-cherenkov-detector, S_2 and detection probability of particles entering through its walls, P_2. So we can split $\delta_j(j = 1, 2)$ in the form of

$$\delta_j = S_j P_j, \quad (2)$$

where only P_{js} are determined from the simulation[6]. S_1 and S_2 are respectively $32 \times 10^2 cm^2$ and $89 \times 10^2 cm^2$. By fitting Eqn(1) on our experimental data, n=7.3 is obtained.
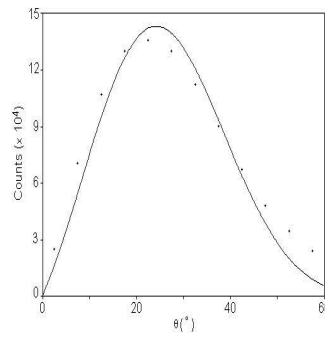
4. Concluding Remarks

We have described the design and operation of the first stage of the water cherenkov detector array located in the Sharif University of Technology in Tehran. Analysis of the data collected so far allows us to conclude that the WCD array shows good conformity with the scintillator detectors. We have measured the zenithal angles distribution, and found that it can be fitted by the function $A(\delta_1 \cos\theta + \delta_2 \sin\theta) \cos^{7.3} \theta \sin\theta$, in agreement with our before works[7].

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