Study of Performance Improvement for Air Shower Array with Surface Water Cherenkov Detectors

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Unlike Imaging Atmospheric Cherenkov Telescopes (IACTs), Extensive Air Shower (EAS) arrays can observe cosmic rays with wide fields of view of about 2 sr and with duty cycles of almost 24 hours every day regardless of weather conditions or the moonlight. Some EAS arrays are located at high altitudes to lower their observation thresholds of cosmic rays and successfully observe gamma rays in the range of several TeV. However, sensitivity of EAS arrays is not as good as IACT mainly because the angular resolution of EAS arrays is poor. In this paper, we report the progress of performance study of an EAS array of scintillation detectors with surface water Cherenkov detectors (WCDs) for improving its angular resolution.

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1. Introduction

Cosmic rays up to the knee region are theoretically considered to be accelerated by supernova remnants in our galaxy. Gamma rays from π^0 decays produced by cosmic rays interacting with interstellar matter near the acceleration sites may be observed up to the 100 TeV region. Therefore, observation of 100 TeV region gamma rays is important for searching origins of cosmic rays. As an experiment currently in operation, there is a possibility that a hybrid experiment of an EAS array of scintillation detectors and muon detectors such as the Tibet ASγ experiment will open an observation window for the 100 TeV region gamma rays[1]. One of the merits of EAS arrays is that they can directly observe the secondary particles regardless of day and night, and can always observe the wide fields of view about 2 sr, which means EAS arrays having such characteristics are more advantageous than IACTs in the low flux of gamma rays expected in 100 TeV region. However, the angular resolution of EAS arrays such as Tibet array is about 0.2 degrees for 100 TeV gamma rays [1] , and the angular resolution of < 0.1 degrees above at 10 TeV or more has not been achieved, so it is a point to be improved. It is also important to be able to investigate more detailed structures of spreading sources.

In order to improve angular resolution, it is necessary to increase the filling ratio of detectors and to determine the shower front more accurately by sampling more time information of secondary particles. By simply placing scintillation detectors at a filling ratio of nearly 10%, it will be considered possible to reach nearly 0.05 degrees at 100 TeV by simulation, but this is costly. WCDs would have ambiguity about particle density and time information as compared to scintillation detectors. However, its effective area is easy to widen, and it is also sensitive not only to secondary electrons but also to secondary gamma rays. Furthermore, since it is possible to increase the filling ratio of detectors at lower cost, it is promising. A scintillation detector capable of accurately measuring secondary particles samples a part of the longitudinal development of extensive air showers, and the accuracy of energy determination can be about 15% in the 100 TeV region by EAS array [2], and combining the both detectors will make it possible to observe the energy spectrum of gamma rays more accurately. By exploiting the advantages of the both, we will study how far we can improve the angular resolution by experiments of water Cherenkov detectors, based on simulation and prototype detectors.

2. Simulation

We have assumed the array of 36 WCDs arranged at 45 m intervals built at an altitude of 4700m a.s.l.. Each WCD consists of a cylinder tank in a diameter of 8.0 m and variable in height, with a maximum of 13 units, 8 or (virtually) 16 inch PMTs arranged as shown in figure 1 and 2. Air showers are generated with the Corsika Ver.7.4 code [3], using QGSJET-II-04 and GHEISHA as a hadronic interaction model. Primary gamma rays are vertically generated at 10 TeV aimed to the center of the array. The number of generated air showers is 10^3. After simulating the response of the WCD array for the air showers with the GEANT4.10.02 [4], we obtain the detection efficiency and will obtain the estimated arrival direction in the next step. In this simulation, the maximum quantum efficiency of PMTs is set to 20%. For WCD, it was confirmed that the light intensity reached its maximum at the depth of 1.5 m (from the top of PMTs).

From center
No.1: 31.8m
No.2: 71.2m
No.3: 95.5m
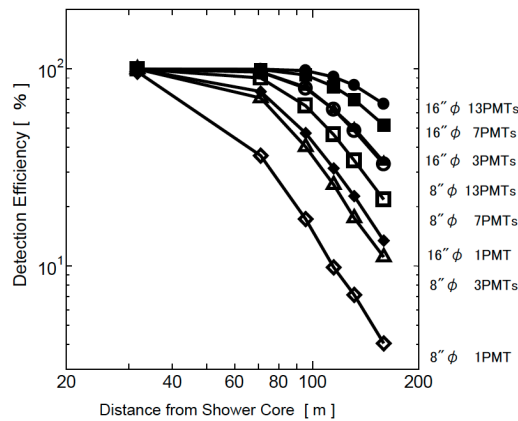No.4: 114.7m
No.5: 131.2m
No.6: 159.1m

45m

300m
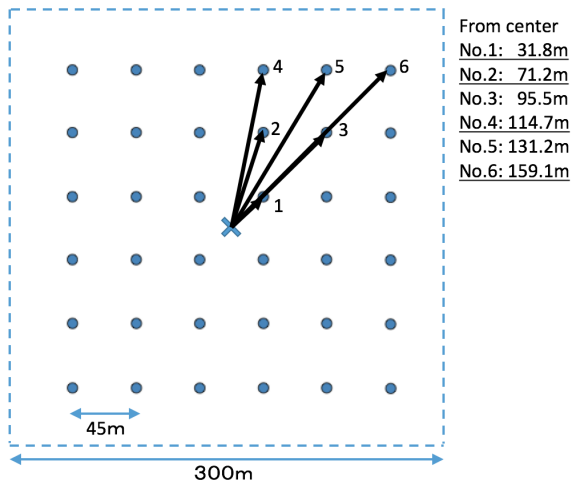
Figure 1: Schematic view of the water Cherenkov detector array. Enclosed by the dashed line is the area of assumed air shower and muon detector array. Gamma rays are vertically injected to the center of the array in this simulation.
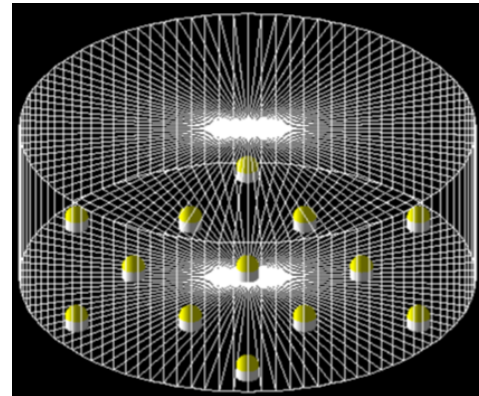
Figure 2: Schematic view of a WCD. WCD is made of a 3.0 mm-thick stainless steel water tank of 8.0 m diameter. The water level can be changed, and one or 13 upward-facing 8 inch ϕ or (virtually) 16 inch ϕ PMTs are installed on the floor.

3. Results and Discussion

In this simulation, we explain the detection efficiency of WCDs at the depth of 1.1 m (from the top of PMTs). We investigate the detection efficiency for the case of one PMT in the center, three near the center, seven around the center, and 13 PMTs in the WCD.
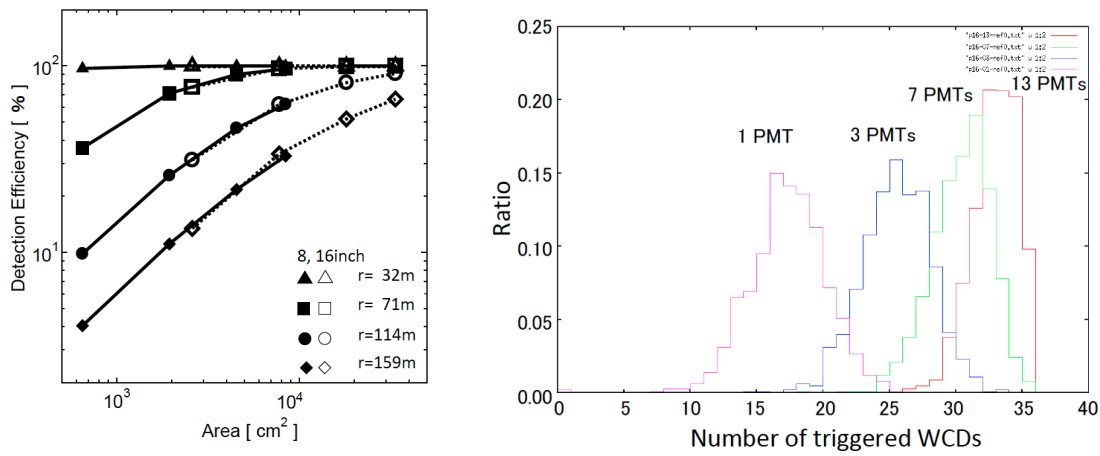
Detection Efficiency [%]

Distance from Shower Core [m]

16″ϕ 13PMTs
16″ϕ 7PMTs
16″ϕ 3PMTs
8″ϕ 13PMTs
8″ϕ 7PMTs
16″ϕ 1PMT
8″ϕ 3PMTs

8″ϕ 1PMT

Figure 3: The detection efficiency as a function of the distance between each WCD center and shower core. Trigger condition is any one of PMTs ($\geq$3 p.e.) in any WCD.

In figure 3, it can be seen that when the distance from the shower core to the center of WCDs is 80 m or more, the detection efficiency of WCDs is greatly reduced, and it changes with the number and sizes of the PMTs. Figure 4 shows the detection efficiency as a function of the sum

of all photosensitive areas of PMTs in a WCD (left) and the ratio of number of triggered WCDs in case of 16" PMTs (right). The trigger condition is any one of PMTs ($\geq$3 p.e.) in any WCD. And the case where the trigger condition is any three of PMTs ($\geq$3 p.e.) in any one WCD is shown in figure 5. It is understood that the detection efficiency correlates with total photosensitive areas in a WCD. Naturally, when the trigger condition is changed from any one to any three, the probability increases as the number of PMTs increases, so the detection efficiency increases as the number of PMTs increases even in the same photosensitive area.

When seven 16 inch PMTs were set in a WCD, it was found that more than 27 WCDs out of 36 detect about 90% of vertical 10 TeV gamma rays under trigger conditions at any one of PMTs in each WCD. Under trigger condition at any three of PMTs in each WCD, it was found that more than 16 WCDs out of 36 detect about 90% of vertical 10 TeV gamma rays.

Figure 4: Left: The detection efficiency as a function of the sum of all photosensitive areas of PMTs in a WCD. Right: The ratio of number of triggered WCDs in case of 16 inch PMT. Trigger condition is any one of PMTs ($\geq$3 p.e.) in any one WCD.
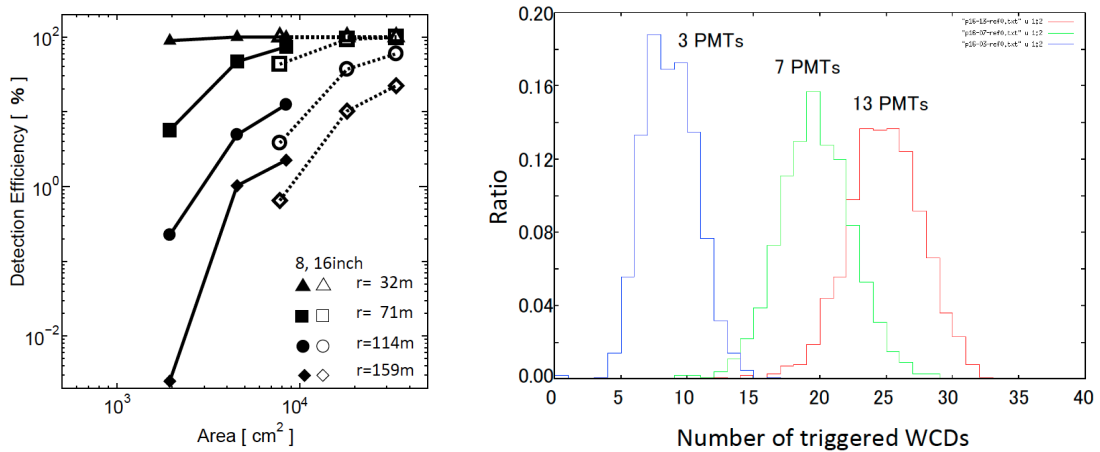
Figure 5: Left: The detection efficiency as a function of the sum of all photosensitive areas of PMTs in a WCD. Right: The ratio of number of triggered WCDs in case of 16 inch PMT. Trigger condition is any three of PMTs ($\geq$3 p.e.) in any one WCD.

In the future, we will investigate the response of a prototype WCD, develop the direction determination algorithm, determine the angular resolution, and explore how angular resolution changes depending on depth, WCD and PMT arrangement, etc.

Acknowledgments

References

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