The Telescope Array Experiment: The Search for The Clusters in The Northern Hemisphere Sky with A Large Scintillator Array

M.Chikawa,[1] M.Fukushima,[2] K.Hashimoto,[5] Y.Hayashi,[3] N.Hayashida,[2] K.Hibino,[4] K.Honda,[5] H.Kawai,[11] S.Kawakami,[4] T.Matsuda,[6] T.Nakamura,[7] M.Ohnishi,[2] H.Ohoka,[2] N.Sakurai,[2] M.Sasano,[8] K.Tanaka,[9] M.Teshima,[10] S.Yoshida,[11] T.Yoshikoshi[3] and TA Collaboration.

(1) Kinki University, Osaka 577-8502, Japan
(2) Institute for Cosmic Research, University of Tokyo, Chiba 277-8582, Japan
(3) Osaka City University, Osaka 558-8585,Japan
(4) Kanagawa University, Yokohama, 221-8686, Japan
(5) Yamanashi University, Kofu 400-8510, Japan
(6) Institute of Particle and Nuclear Studies, KEK, Tsukuba 305-0801, Japan
(7) Kochi University, Kochi 780-8520, Japan
(8) Communication Research Laboratory, Tokyo 184-8795, Japan
(9) Hiroshima City University, Hiroshima 731-3194, Japan
(10) Max Plank Institute for Physics, 80805 Muenchen, Germany
(11) Chiba University, Chiba 263-8522, Japan

Abstract

In addition to the existence of extremely high energy cosmic rays (EHECRs) above GZK cutoff, the results of AGASA shows the clustering of EHECRs above $10^{19.6}$ eV. Confirming such clusters and identifying the corresponding astronomical object is crucial to understand the origin of EHECRs. The northern hemisphere sky is ideal for this purpose since the deflection by the galactic magnetic field is expected to be small and uniform compared to the southern hemisphere. In this paper, we report a design of the large ground array placed at the center of the hybrid-TA experiment. The array has an acceptance 9 times larger than AGASA. Using this detector, the cluster in the northern hemisphere will be searched with an angular resolution better than 1 degree.

1. Introduction

So far AGASA has obtained nice results about the existence of super-GZK particles. The results suggest a uniform distribution in the arrival direction of EHECRs and at the same time the existence of clustering in some directions (see

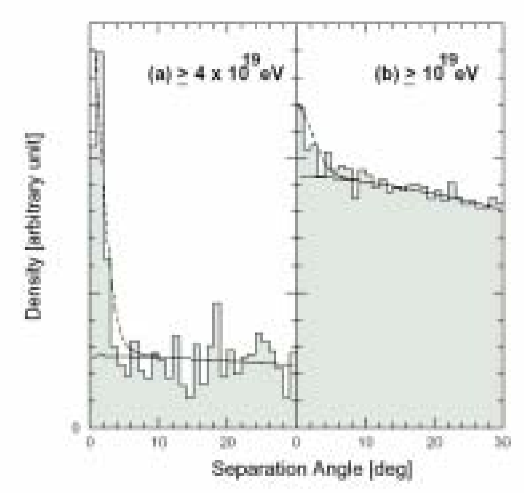

Fig.1 Distribution of spatial angle between two cosmic rays measured by AGASA. All possible combinations are included.

Fig.1). The candidate astronomical objects should have a large enough volume to accelerate the nucleons up to 10^{20}eV or higher, but we so far have not been able to locate any such object within 50 Mpc of the Earth as sources of those EHECRs and clusters. This introduces serious problems to understand the origin and acceleration mechanism of EHECRs.

Several models have been proposed to try to give answer for these issues, such as a decay of super massive relic particles or cosmic strings[1], a breakdown of special relativity at the energy above 10^{20}eV[2] and so on. But none of them seems to be able to convince people. Considering these problems we have keen interest to confirm the existence of super-GZK cosmic rays and especially their clustering.

2. Performance of Hybrid-TA Ground Array

The overall plan of hybrid-TA is presented elsewhere in this conference. One of the major aims of the hybrid-TA is to quickly settle the issues around the clustering of EHECRs with higher statistics. To achieve this target, we have decided to add conventional scintillation detectors as a ground array in addition to the fluorescent detectors originally planned in the TA project. Here we would like to concentrate on presenting the design and the performance of the ground detector array. Total 576 detectors are to be distributed in 24x24 matrix covering the area of 760 km^2 in 1.2 km mesh. Its acceptance is 9 times larger than that of present AGASA. Each detector is a plastic scintillator of 3 m^2 area and 2 cm thickness. The scintillation light is collected to a photomultiplier using wave length shifter bars installed in a groove cut on the surface of the scintillator. We calculated the detection efficiency for the present arrangement; it is around 50% at $10^{18.5}$ eV and becomes full above 10^{19} eV.

The plastic scintillator mainly measures the electrons and positrons in the air shower. It is easier than measuring other components such as muons and hadrons, since the total number of electrons and positrons is roughly 10 times larger and no special preparation is required. Better statistics in terms of the number of charged particles in the detector can be achieved with smaller detector size compared to the water Cherenkov detector. In addition, the measurement of electrons and positrons are less affected by the primary composition and the details of the hadronic interaction at UHE because nearly 90% of the total energy is converted to the electromagnetic component near the shower maximum where the ground detector samples the air shower. This means the plastic scintillator has inherently better energy resolution and less systematic uncertainty compared to other types of particle detectors. It should also be noted that, starting as low as 10^{14} eV, a series of energy spectrum measurements has been made by the plastic scintillator array, including AGASA, and valuable experiences have been accumulated. The continuation and consistency is a good asset for establishing a reliable energy spectrum at extremely high energy.

We adopt two approaches to achieve a good angular resolution with the present ground detector system; One is to obtain a good timing standard for all the 576 counters and another is to obtain a good timing resolution for the hitting time of each counter, which is achieved by recording the time profile of all the charged particles hitting the counter by the flash ADC. As the time standard, we found an accuracy of 20ns can be rather easily achieved with ordinary GPS, and a better time resolution can be expected with the differential GPS system or by some other means such as selecting the same set of satellites for all the counters. These techniques are now being tested. We eventually aim at reaching 10ns accuracy by adopting these methods.

Fig.2 Prototype Flash ADC Board

The Flash ADC board developed for the ground array is shown in Fig.2. It has a 50 MHz 12-bit ADC, a comparator for generating a local trigger, a CPU and a TCP/IP network interface. The connection to the GPS is made by a RS232 serial port. With a conventional fast timing system, one measures the timing of first arriving particle at the front of the shower disk. The arrival direction of the air shower is determined by combining all the timing information and fitting it to the shape of the shower front. In such a case, there can be a large fluctuation in timing measurement, especially where the particle density is sparse, and achieving a good angular resolution is limited. Using the flash ADC system, a complete history of ~10μs after the arrival of the shower front will be recorded with 20ns time resolution. We then can observe the distribution of arriving particles with time and determine the structure of the shower disk. It will give us a great advantage to have better resolution in the angle measurement. We are expecting the accuracy of 1 degree can be achieved with the present FADC system.

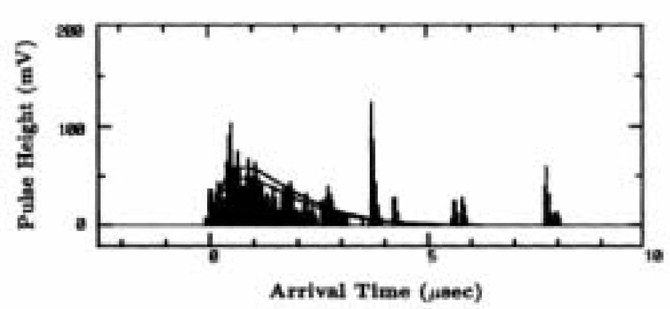

Fig.3 Time profile of 30 m^2 scintillation counter signal observed 2 km away from the shower core of a large air shower event (E=$2x10^{20}$ eV) observed by AGASA.

In terms of the energy resolution of present design, major contribution comes from the fluctuation in the sampling of shower particles. We presently estimate that the error for the determination of primary energy is around 30% at $10^{19.5}$eV and 25% at 10^{20}eV. On the other hand, we expect that the systematic uncertainty of the energy determination will improve because the time structure of the shower disk will be better understood for the new array. An example is shown in Fig.3. This time profile is obtained by a large ($30m^2$) scintillator near the core of AGASA EHECR event. The signals 4,6 and 8 μs after the shower front is considered to be delayed neutrons associated with the shower. In the new flash ADC system, we can explicitly exclude these signals from the energy calculation and improve the systematics, though the energy shift of AGASA arising from these effects is estimated to be only 5%[3].

The whole system will be operated stand alone using a solar panel power generation. Since a large amount of detectors are required, stable and reliable detectors are essential. We believe the present system is robust and easy to deploy and maintain in the desert.

3. References

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