Measurement of Energy and Arrival Direction of Air Showers by Synchronized Compact Arrays

Nobuaki Ochi,[1] Atsushi Iyono,[2] Toru Nakamura,[3] Takao Nakatsuka,[4] Nobuharu Ohmori,[3] Kazuhide Okei,[5] Junpei Tada,[5] Shuhei Tsuji,[6] Tomonori Wada,[5] Isao Yamamoto,[7] Yoshihiko Yamashita,[5] and the Large Area Air Shower (LAAS) group
(1) Simulation Science Center, Okayama Univ. of Science, Okayama 700-0005, Japan
(2) Dept. of Computer Simulation, Okayama Univ. of Science, Okayama 700-0005, Japan
(3) Fac. of Science, Kochi Univ., Kochi 780-8520, Japan
(4) Okayama Shoka Univ., Okayama 700-8601, Japan
(5) Dept. of Physics, Okayama Univ., Okayama 700-8530, Japan
(6) Dept. of Information Sciences, Kawasaki Medical School, Kurashiki 701-0192, Japan
(7) Dept. of Information and Computer Engineering, Okayama Univ. of Science, Okayama 700-0005, Japan

Abstract

In Okayama, Japan, we have installed four compact air shower arrays, as the LAAS/ARPEGIO experiment. They are operating simultaneously and independently, and synchronized with an accuracy of 1μs by GPS receivers. By counting the number of coincident triggers between various array-combinations, we can estimate fluxes of primary cosmic rays at various energies, so the energy spectrum can be constructed. In addition, the improvement of angular accuracy can be expected by combining timing data from plural arrays. These schemes allow us to execute competitive observation of ultra-high-energy cosmic rays with limited-scale equipment.

1. Introduction

The Large Area Air Shower (LAAS) group has been observing EAS ($E \approx 10^{13-16}$eV) by synchronized compact arrays scattered over a very large area for more than 6 years [3–10, 12]. Since 2002, as a part of the LAAS group, the Okayama observation site has been reinforced by installing new detectors and by lowering trigger-thresholds of the arrays. Now, four EAS arrays are simultaneously operating within a radius of 600m, called the LAAS/ARPEGIO (Local Area Air Shower And Radio Pulse Echo Gazing Instruments at Okayama). Here we show the concept for the improvement of measurements of EAS parameters by

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Table 1. The List of LAAS/ARPEGIO Stations. (N_c=Number of counters)

Station Name	Position (m) X	Y	Alt. (m)	N_c	Trig. Rate (/24h)	Working since	2coin. since
OU	0	0	30	8	15934	09/12/1996	05/14/2002
OUS1	554	994	63	8	16493	09/02/1996	05/21/2002
OUS2	510	902	81	8	18178	04/23/2002	05/29/2002
OUS3	637	916	65	5	21088	12/29/2002	12/29/2002

the LAAS/ARPEGIO experiment. Preliminary results employing observational data are also presented.

2. Experiment

As the LAAS/ARPEGIO experiment, four sets of scintillation counter arrays and Yagi antennas have been installed in the campuses of Okayama Univ. (OU) and Okayama Univ. of Science (OUS). The antennas are to detect radar echoes from air shower columns, and described elsewhere [2]. The profiles of the counter arrays are summarized in Table 1. They are capable of measurement of arrival times, arrival directions and particle densities of EAS. The arrival times with an accuracy of 1μs are provided from GPS receivers. Since May 2002, trigger conditions are uniformly set at 2-fold coincidence of the counters separated by 80cm. A preliminary simulation result shows that the mean energy of EAS detected under this condition is around 100 TeV [1]. More detailed description on the arrays can be found in [11].

3. Coincident Trigger Search

Since mutual distances between the LAAS/ARPEGIO stations are 100–130m for OUS–OUS and 1.1km for OU–OUS, we can expect the detection of larger EAS as coincident triggers among the arrays. The GPS provides sufficiently accurate time stamps of EAS triggers for this purpose. In this report, we employed EAS data up to 03/31/2003.

As an example, Fig. 1. (left) shows the result of searching for coincident triggers between OUS1 and OUS2. The X-axis corresponds to arrival time differences (TD) between any EAS pairs observed at the two stations. For TD= 0μs pairs, $x = -6.2$ was assigned in the figure. The number of *chance coincidence* pairs decreases exponentially. The overflow of EAS pairs with TD$\leq$ 3μs is outstanding and undoubtedly interpreted as the detection of large EAS covering the two arrays. We can confirm it through Fig. 2., which shows clear correlations between shower angles determined independently by each station. Fig. 3. (left)

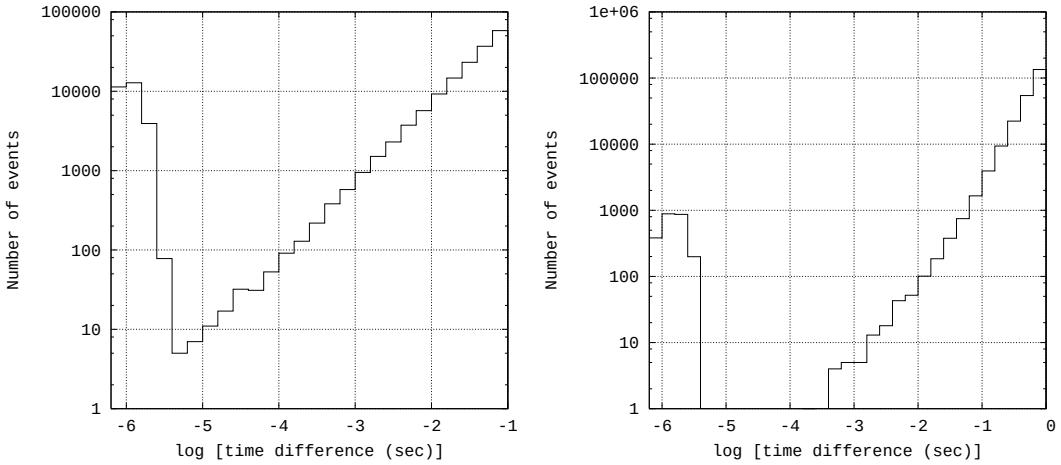

Fig. 1. Distributions of EAS arrival time differences between OUS1–OUS2 (left) and OUS1–OUS2–OUS3 (right)

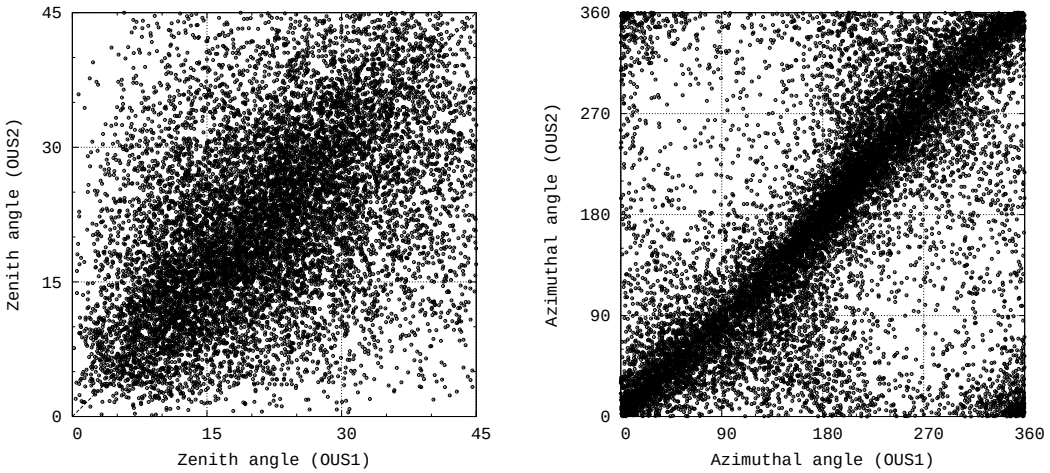

Fig. 2. Correlation between shower angles of EAS pair with TD$\leq 3\mu$s. (OUS1–OUS2)

displays the smallness of angular distances between EAS in the coincident EAS pairs compared to chance pairs, further verifying the same EAS origins of them. Fig. 1. (right) and Fig. 3. (right) are for coincident trigger searching among 3 stations (OUS1, OUS2 and OUS3) and can be interpreted in the same way.

The OUS1–OUS2 coincident trigger rate is 124/day and the OUS1–OUS2–OUS3 rate is 28/day. The coincident triggers among 4 stations (OU–OUS1–OUS2–OUS3) is quite rare; we have 2 such events in 83 days.

4. Discussion and Conclusion

Mutual distances between three arrays in OUS are 100–130m each other, while the OU array is about 1.1km distant from them. According to preliminary

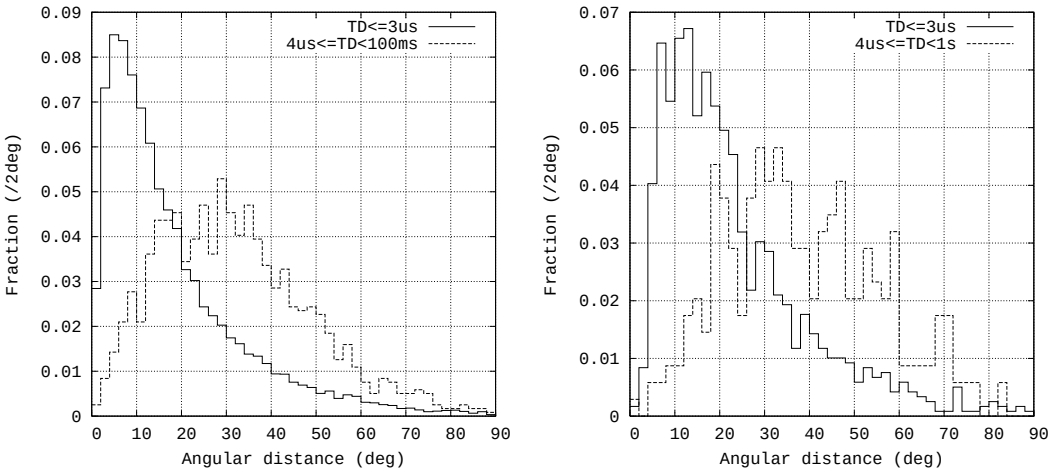

Fig. 3. Distribution of angular distances between EAS in coincident pairs and chance pairs. OUS1–OUS2 (left) and OUS1–OUS2–OUS3 (right)

simulations, the former distance corresponds to the average span of EAS with energy of $10^{15.6}$ eV and the latter 10^{18} eV [1]. This means that by counting the number of coincident triggers between various array-combinations, we can estimate fluxes of primary cosmic rays at various energies, so the energy spectrum can be constructed. In addition, the improvement of angular accuracy can be expected by combining timing data from plural arrays. The simulation work for these purposes is in progress, at the same time we are accumulating EAS data in the LAAS/ARPEGIO experiment.

Part of this work was supported by the Frontier Project of the Ministry of Education, Science, Sports and Culture of Japan.

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