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

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

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Position (m)</th>
<th>Alt. (m)</th>
<th>(N_c)</th>
<th>Trig. Rate (/24h)</th>
<th>Working since</th>
<th>2coin. since</th>
</tr>
</thead>
<tbody>
<tr>
<td>OU</td>
<td>0 0 30 8</td>
<td>15934 9/12/1996</td>
<td>05/14/2002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OUS1</td>
<td>554 994 63 8</td>
<td>16493 9/02/1996</td>
<td>05/21/2002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OUS2</td>
<td>510 902 81 8</td>
<td>18178 04/23/2002</td>
<td>05/29/2002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OUS3</td>
<td>637 916 65 5</td>
<td>21088 12/29/2002</td>
<td>12/29/2002</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 \(1\mu s\) 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= 0\(\mu s\) pairs, \(x = -6.2\) was assigned in the figure. The number of chance coincidence pairs decreases exponentially. The overflow of EAS pairs with TD \(\leq 3\mu s\) 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 ≤ 3µs. (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.

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5. References

1. Iyono A. et al. 2003, this conference
2. Iyono A. et al. 2003, this conference
11. Ochi N. et al. 2003, this conference