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Estimation of EAS parameters from synchronized compact arrays within 1km baseline

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To measure EAS parameters (primary energy, arrival direction etc.) as accurate as possible is essential for a variety of cosmic ray studies in UHE region. However, accomplishing high-accuracy measurement is not an easy task, especially for small-scale experiments. In Okayama area, Japan, we have been simultaneously operating four compact scintillation counter arrays within 1km baseline, as the LAAS/ARPEGIO experiment. The arrays, each of them is building-sized, are precisely synchronized by the use of GPS. Air showers with the lateral expansion of a few hundreds of meters or more can trigger plural arrays coincidently, thus by combining data from the arrays it is expected that we can obtain more accurate EAS parameters. We have been accumulating such multi-triggered EAS data about 100 events per day. Here we show the energy classification procedure by selecting array-combinations and the preliminary energy spectrum around the 'knee' derived from it.

1. Introduction

To measure EAS parameters as accurate as possible is essential for a variety of cosmic ray studies in ultra-high-energy (UHE) region. As an example of EAS analyses, from estimation of primary energies we can obtain the energy spectrum of primary cosmic rays. In particular, in the UHE region the change of the spectrum index at $E \approx 4$ PeV (called 'knee') has attracted much attention because it is believed to contain information about cosmic ray acceleration mechanisms. As another example, from distribution of arrival directions we can examine the anisotropy of primary cosmic rays, which gives us some hints on cosmic ray sources and/or propagation processes from them [1].

However, accomplishing high-accuracy measurement is not an easy task, especially for small-scale experiments. The Large Area Air Shower (LAAS) group has been performing EAS observation by small-scale ('building-sized') scintillation counter arrays scattered over a very large area [2]. Information which can be derived from one array data is very limited, but by combining data from multiple arrays we can obtain more EAS parameters. In this report we introduce the energy classification procedure using coincident trigger events among various array-combinations. As a preliminary result we show the primary energy spectrum around the 'knee'.

Table 1. LAAS/ARPEGIO array profiles (N_c shows the number of counters)

Station Name	N_c	Trig. Rate (/day)	Data Period
OU	8	1.6×10^4	05/14/2002 – 06/30/2004
OUS1	8	1.6×10^4	05/21/2002 – 06/30/2004
OUS2	8	1.8×10^4	05/29/2002 – 06/30/2004
OUS3	5	2.1×10^4	12/29/2002 – 06/30/2004

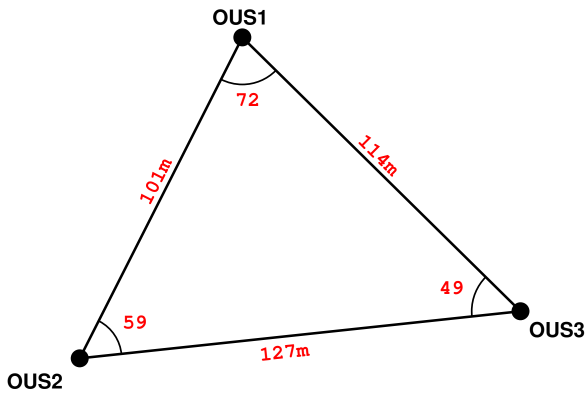

Figure 1. Mutual positions of OUS arrays

2. Experiment

In Okayama area, Japan, we have been simultaneously operating four compact scintillation counter arrays within 1km baseline. As a part of the LAAS experiment, this is called the LAAS/ARPEGIO experiment. Table 1 shows the array profile. In this table 'OU' means Okayama University and 'OUS' means Okayama University of Science. Mutual positions of the three arrays in OUS are shown in Figure 1. The OU array is about 1.1 km away from the OUS arrays. The trigger conditions of the arrays are set at 2-fold coincidence between counters separated by 80 cm. Most importantly, each array is equipped with the GPS receiver, which gives 1μ s-accuracy time stamp to each EAS trigger. By using this time stamp, we can select coincident trigger events among the arrays. For details of the experiment, see reference [2].

3. Results

Because mutual distances between OUS arrays are 100–130m, EAS with the lateral expansion of a few hundreds of meters or more can trigger multiple arrays coincidently. Using GPS time stamps of EAS arrivals, we searched coincident triggers for each array-combination. As an example, the distribution of EAS arrival time differences between OUS1 and OUS2 is shown as Figure 2. In this figure, the leftmost bin corresponds to the time difference of less than 1μs. Clearly separated from the chance coincidence, which decreases exponentially with time difference, coincident trigger events can be seen at less than 4μs. We confirmed this feature for all combinations of OUS arrays and summarized as Table 2.

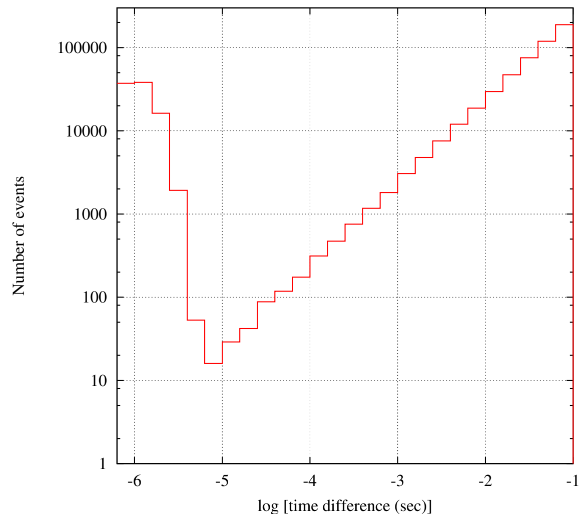

Figure 2. EAS arrival time difference distribution between OUS1 and OUS2

Table 2. Rates of coincident trigger event between OUS arrays

Station combination	distance (m)	days	Number of events	Rate (/day)
OUS1 & OUS2	101	659	81925	124.3
OUS1 & OUS3	114	453	42128	93.1
OUS2 & OUS3	127	457	37783	82.7
OUS1 & OUS2 & OUS3	$\sim$127	447	13006	29.3

On the other hand, coincident trigger events between the OU array and the OUS arrays are quite rare because of its distance (about 1.1 km), and we have not sufficiently accumulated such events yet.

From the rates of coincident trigger event between OUS arrays (shown in Table 2), we calculated the indices of primary cosmic ray spectrum for various energies. The detailed procedure and simulation techniques are described in Ref [3]. The result is shown as Figure 3. Though the error bars are rather wide, we can find the change of the spectrum index from smaller values of $\approx$2.3 ($E <$10 PeV) to larger values of $\approx$3.1 ($E >$ 10 PeV). This result is consistent with the feature of 'knee' reported by other experimental groups.

4. Conclusions

From EAS data sets registered at three nearby arrays (distance 100 – 130 m), coincident trigger events have been clearly selected. By taking array-combinations with various mutual distances and calculating the coincident event rates, we can estimate primary cosmic ray flux at various energies, so the energy spectrum can be constructed. The preliminary result shows the sign of the 'knee' at $E \sim$ 10 PeV, which is consistent with the reports by other experimental groups.

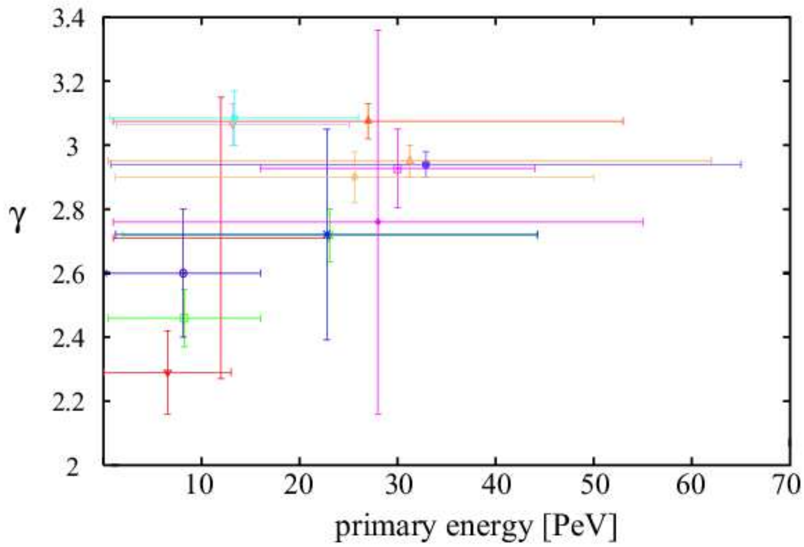

Figure 3. Spectrum index estimated from coincident trigger event rates

References

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