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The EAS time profile measurements in the Large Area Air Shower experiments

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The arrival timing profiles of EAS particles simultaneously observed at 1km baseline EAS arrays have been simulated in order to estimate individual EAS energies. Large Area Air Shower (LAAS) experiments in Okayama area, have operated 4 sets of EAS arrays with GPS-synchronized UT time stamp system. These arrays provide us to detect large EAS events which hit multiple arrays simultaneously. We simulated EAS time structures observed at each array, and estimated the dependences of time difference on the primary energy and core distance. To collect such large EAS events effectively, new trigger modules were installed at 4 arrays.

1. Introduction

Primary cosmic rays with energies above 10^{18}eV produce extensive air shower (EAS) of which radius(core distance) is extend to several hundreds meters to several kilometers at sea level. The surface detector system are widely used to detect such higher energy cosmic rays. Each detector separations are selected with a suitable distance for objective energy range. To determine EAS energy, the dense arrangement of particle detectors is generally required in the EAS particle sampling system and so it is difficult to determine EAS energies with EAS array systems with rather small area(several hundred square meter).

Large Area Air Shower (LAAS) [1] registering system operated in Japan, has 9 sets of EAS array with 1μsec. accurate Universal Time by using GPS event timing module(Kaizuworks KC3501A) ,of which core module is a GPS controlled time and frequency generator (FURUNO GF-77 series). The baselines of each EAS array are ranging from 100 meter to 800km.

2. EAS time profile simulations

To simulate EAS particle distribution in the shower front, the fomulae described by Linsley [2], are used. The deviations $\sigma_{e,\mu}$ [nsec.] of arrival timing of electrons and muons depend on core distance R_c [m] and these expressions are

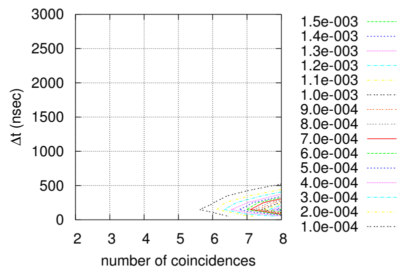

Figure 1. $E = 10^{18}$ eV, $R_c = 300$ m

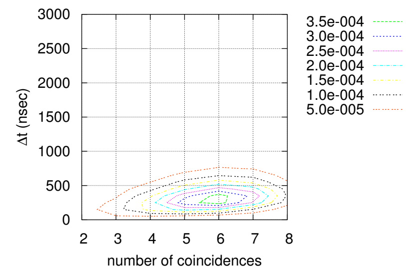

Figure 2. $E = 10^{18}$ eV, $R_c = 400$ m

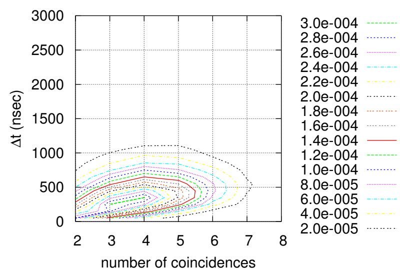

Figure 3. $E = 10^{18}$ eV, $R_c = 500$ m

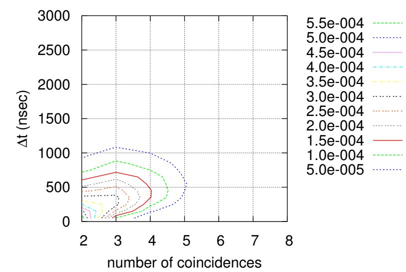

Figure 4. $E = 10^{18}$ eV, $R_c = 600$ m

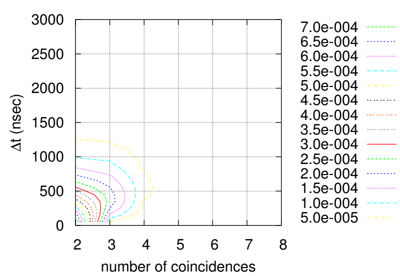

Figure 5. $E = 10^{18}$ eV, $R_c = 700$ m

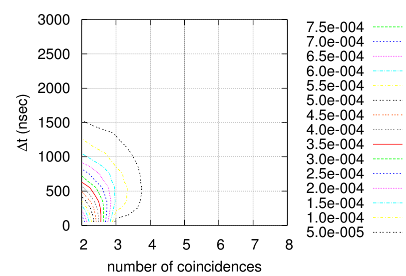

Figure 6. $E = 10^{18}$ eV, $R_c = 800$ m

$$
\begin{aligned}
\sigma_e &= 1.49(1 + \frac{R_c}{30})^{1.54} \\
\sigma_\mu &= 2.65(1 + \frac{R_c}{30})^{1.09}
\end{aligned}
$$

If parameters σ_e, σ_μ are determined at each EAS arrays, core distances R_c are deduced by these formulae. In this simulations, we used the time difference Δt instead of σ since rather small number of scintillation counters used in LAAS EAS arrays. In Fig. 1 to 12, are shown probability contour maps as a function of the number of

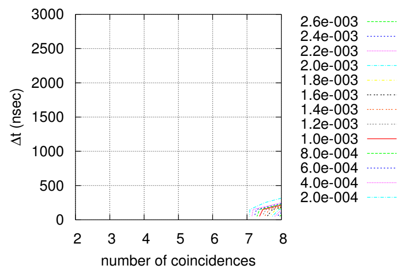

Figure 7. $E = 10^{19}$ eV, $R_c = 400$ m

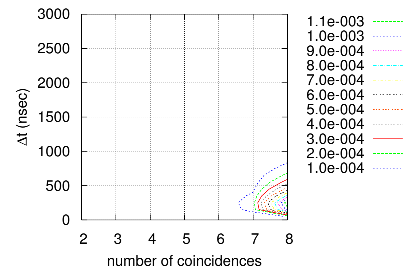

Figure 8. $E = 10^{19}$ eV, $R_c = 500$ m

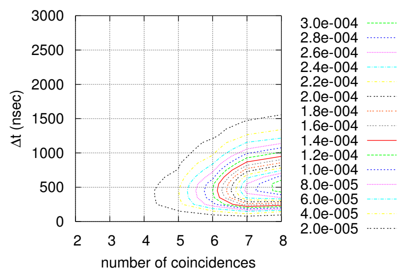

Figure 9. $E = 10^{19}$ eV, $R_c = 600$ m

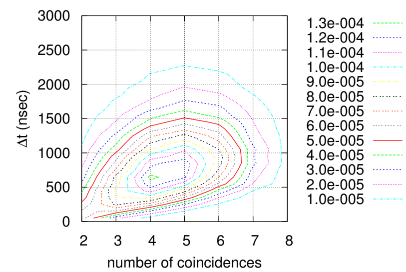

Figure 10. $E = 10^{19}$ eV, $R_c = 800$ m

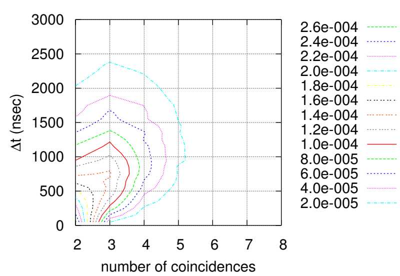

Figure 11. $E = 10^{19}$ eV, $R_c = 1000$ m

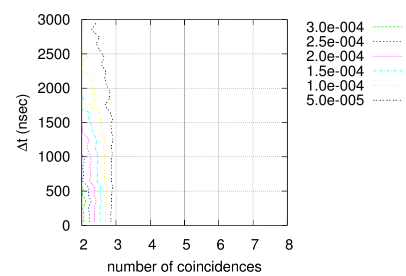

Figure 12. $E = 10^{19}$ eV, $R_c = 1600$ m

counters hit by EAS for Δt observed at each arrays. To compare these data obtained at one array with those done by others provide the primary energy and core distance informations.

3. EAS trigger rates by any-3 coincidence module

To perform EAS particle time profile measurements effectively in LAAS experiments, new trigger modules were installed. Typically, trigger mode applied by LAAS/Okayama area, was 2-fold coincidence within 100nsec. time width at two detectors of which distance is 80cm. The trigger rate in the 2-fold mode was about 2500 EAS events/day. The any coincidence module(MPK:ANY-NIM) were developed and installed, which enables us to select any coincidence level(1 to 3) from 8 input signals. The simulation results of trigger rates once installed any 3 coincidence were shown in Fig. 13. The event rate profiles observed were also shown in Fig. 14.

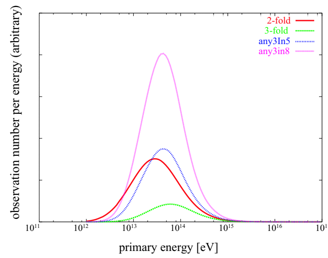

Figure 13. Comparison of event rates for 2-fold and any 3 coincidence

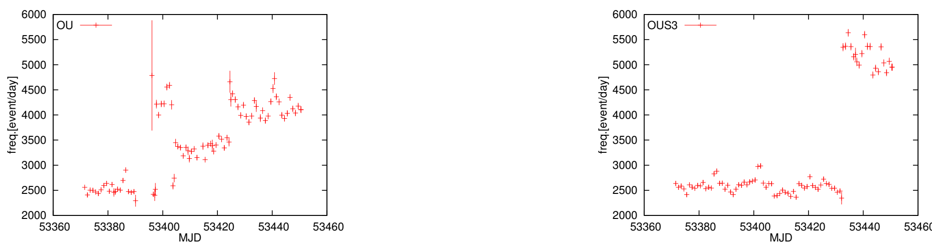

Figure 14. Event rate profiles at OU(left panel)and OUS3(right panel)

4. Conclusion

We have computed the time differences of EAS particles at multiple LAAS arrays. These results provide us to determine primary energy and core distance for individual EAS with multiple observations of compact EAS arrays. To perform EAS time profile measurements, new any coincidence modules for triggering have been developed and installed on LAAS experiments.

5. Acknowledgments

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