Arrival Time Distribution of The Electromagnetic Components in Air Showers at Large Core Distances Observed at AKENO

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Abstract

Observations of the arrival time distribution of the electromagnetic component in air showers at large core distances have been carried out at AKENO from June, 1986. The average rise time of the signal at core distance above 700m is fitted by the function of $t/t_0 \times exp(-t/t_0)$, where to depends on core distance. A parameter T_{15}, the rise time from 10% to 50% of the integrated signal, depends strongly on the core distance. T_{15} is, however, very weakly dependent on the zenith angle and the primary energy.

§1. Introduction

A study of the arrival time distribution of air shower particles at large distance from the shower axis is very interesting in the following aspects.

(1) The rise time of the arrival time signal contains information on the longitudinal development of air showers and hence may reflects the chemical composition of the primary particles (Lapikens *et al.* 1979).
(2) Since the time profile of the signal depends strongly upon the core distance, the information of the pulse shape may be used to measure the core distance from the shower axis and hence the effective area to detect large showers can be increased with a mini-array, without distributing many detectors over the huge area (Linsley 1986).
(3) In a huge surface array, core positions and particle numbers must be determined with detectors of wide separation, because of economical reason. It is necessary to design the electronics of the detector to cover a rather broad arrival time dispersion of shower particles at far from the core.
(4)Though it is known to be delayed particles at far from the core, their characteristics have not yet systematically investigated.

So far several experiments have been carried out on the time profile of shower particles and the physical interpretations have been discussed.(Lapikens *et al.* 1977, Walker and Watson 1981, 1982, Hazen *et al.* 1989, Kakimoto *et al.* 1983, Inoue *et al.* 1989) In this paper, we present the arrival time distributions of EAS at core distances between 500m to 1500m measured by the scintillation detectors of 30m^2 area in total, deployed at the corner of Akeno air shower array. By increasing the statistics of the events and the range of distance from the core, new attempts of their implications will be tried in near future.

§2.Experiment and Analysis

The arrival time distribution of the electromagnetic components at large core distances of EAS with the primary energy above 10^{17} eV is measured with the scintillation detectors of the total area 30m^2 at the north-east corner of the AKENO air shower array (Tsushima *et al.*1987). The signal shapes of the pulses are recorded by the Wave Memory wherever the trigger pulses are issued from the air shower array. The covered area is about 4km^2 for series 1 and is about 20km^2 for series 2 (Honda *et al.* 1990). The time response of the system measured with the time resolution of 10ns for the average single particle is as follows,

< the pulse height > = 11.8 ±20% mV, <FWHM> = 92.4 ±15% ns
< the integrated area >= 1152 ± 15% mV•ns

Table 1. The observational condition and the number of event.

	observation period	wave window (μ sec)	time re-solution (ns)	observa-tion time (days)	correspond event with AKENO	selected events	
						> 1 part.	> 10 part.
Series 1	'86/06/09 -- '88/06/09	16	20	657	1351	692	440
Series 2	'88/07/07 -- '93/02/03	100	50	1311	9871	2642	1022
total				1968	11222	3334	1462

Total observation time is about 5.4 years and we obtained about 41500 events including the events with no signal incidence in the 30m^2 detector. The time resolution of the Wave Memory is 20ns for series 1 and 50ns for series 2. The observational conditions are listed in Table 1. The selection criteria of the air showers are

1. The air shower core hits inside the array.
2. The number of hit detectors is more than 6.
3. The zenith angle is less than 45°.
4. The shower size is above 10^7.

For the signal shape analysis, following conditions are used.

1. The saturated events in the recorder above about 500mV are excluded.
2. The accidental events are excluded from the start time distribution of the signal. The start time of the signal means the time delay of the trigger signal from the array center and distributes from 66μs to 82μs.
3. The accidental signals delayed more than R/c are excluded, where R is the core distance and c is the light velocity.

The number of events selected with these conditions are listed in Table 1. The time response of our system is negligible in the present analysis.

§3. Results and Discussions

In order to obtain the average rise times of the signal, the pulses are integrated and the incident particles are normalized to 100. Fig. 1 show these shapes for three different core distances from 500m to 1120m. The arrival time is normalized at 50 %. The error bars in these figures are probable errors of the distributions. The dot line is the integrated Gaussian distribution fitted at the average at 10% and 20% of the integrated signal. To find the best fitted function, we use the following function with the parameter $t_0(R)$,

$$f(t,R) = \frac{t}{t_0(R)} exp\left(-\frac{t}{t_0(R)}\right) \qquad (1)$$

where R is core distance and t is the time from the start signal.

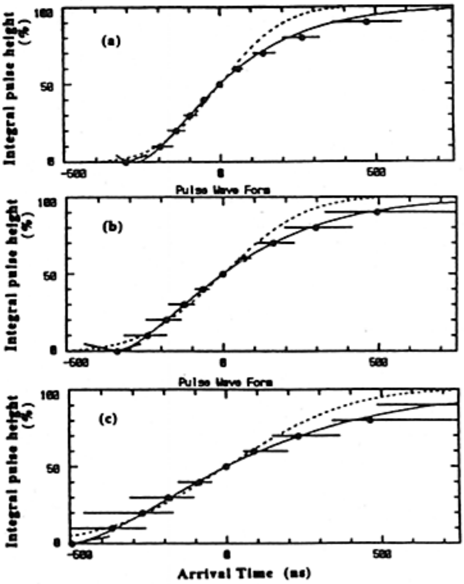

Fig. 1: The average integral pulse height of the arrival time distribution for typical three core distances about the event above 10 particles. The integral arrival time distribution is normalized with all particles . The arrival time is normalized 0 ns at 50% of all particle. The dot line and the line in figures are fitting gaussian shape and the shape of equation (1). (a) 501m < R < 562m, 134 events, (b) 707m < R < 794m, 210 events, (c) 1000m < R < 1122m, 76 events

The average arrival time distribution is fitted by the function (1) better than Gaussian for core distances investigated. The values of $t_0(R)$ in these figures are 168ns at R=534m, 212ns at 750m and 311ns at 1050m, respectively. This function fits to rise time very well, however, some discrepancy remains in fall time of the signal. The deviations become larger with increasing core distance. The investigation of individual event will be discussed elsewhere.

In the following, we introduce a parameter T_{15}, the rise time from 10% to 50% of the integrated signal, since this parameter is not affected by the delayed signals and has less fluctuation compared to $T_{10\%-90\%}$ or $T_{20\%-80\%}$ and the time dispersion (Honda *et al*,1991).

The density dependence of T_{15} is shown in Fig. 2 for four different core distances. The rise time is almost independent of the density if there are enough incident particles. In the following, only events with more than 10 particles are used in all core distances. The scatter plots of T_{15} as a function of the core distance are shown in Fig. 3 (a). Since lot of signals at R < 300m are saturated and hence excluded, there is bias within 500m. The average value of T_{15} are shown in Fig. 3(b) and strongly depend on R. Also the deviation of the distributions as a function of the core distance rapidly increase at R >1000m. Events of small value of T_{15} appear at R>700m. Since the counting rate of >10 particles/$30m^2$ is about 20/sec and the gate width is $16\mu s$, the accidental rate is only 3×10^{-4}. Therefore these events are not accidental. It is necessary to examine these events whether they are collimated in the small area of detector.

Next, we discuss the dependence of T_{15} on the zenith angle and the primary energy. Fig. 4 shows the value of T_{15} as a function of sec θ for four different core distances. The solid line is the least square fitted line. The value of T_{15} is weakly dependent of the zenith angle. The dependence is fitted to $T_{15} = a \times 10^{bx \sec\theta}$ and the values of the slope b are -0.303, -0.320, -0.553 and -0.857 at R=568m, 707m,882m and 1107m, respectively. The effect of densities has not been examined for the large zenith angles. The dependence on the primary energy is shown in Fig. 5 for same different core distances. The values of slope d fitted to $T_{15} = c \times E_0^d$ are 0.116, 0.146, 0.219 and 0.199 at R=568m, 707m,882m and 1107m, respectively. The value of T_{15} depends weakly both on the zenith angle and the primary energy.

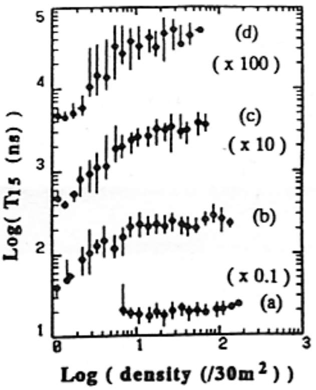

Fig. 2 : The values of T_{15} as a function of the densities per $30m^2$ for four different core distances.
(a) 501m < R < 630m, $T_{15} \times 0.1$
(b) 630m < R < 794m
(c) 794m < R < 1000m, $T_{15} \times 10$
(d) 1000m < R < 1258m, $T_{15} \times 100$

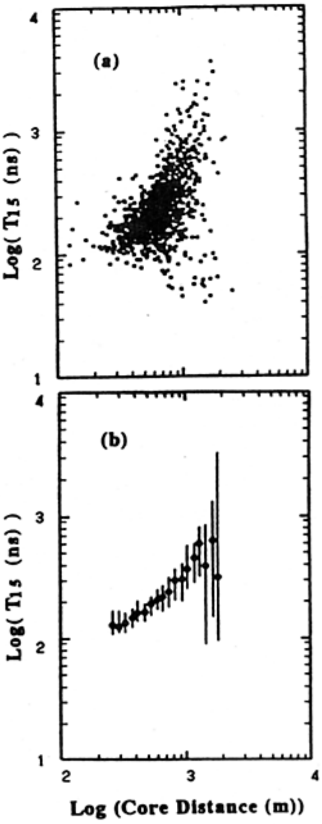

Fig. 3 : The value of T_{15} as a function of the core distance for 1.0 < sec θ < 1.4 .
(a) the scatter plot, 1462 events
(b) the median T_{15} for each core distances above 5 events.

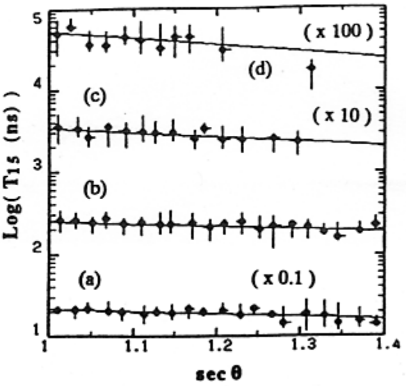

Fig. 4 : The value of T_{15} as a function of sec θ for four different core distances.

(a) 501m < R < 630m, T_{15} x 0.1
(b) 630m < R < 794m
(c) 794m < R < 1000m, T_{15} x 10
(d) 1000m < R < 1258m, T_{15} x 100

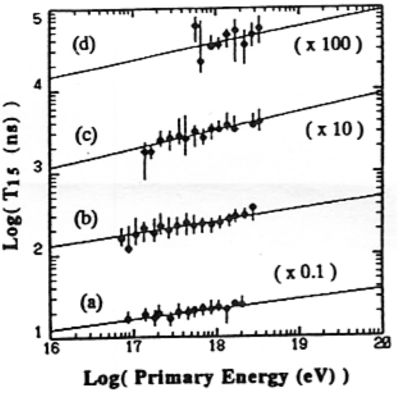

Fig. 5 : The value of T_{15} as a function of the primary energy for four different core distances.

(a) 501m < R < 630m, T_{15} x 0.1
(b) 630m < R < 794m
(c) 794m < R < 1000m, T_{15} x 10
(d) 1000m < R < 1258m, T_{15} x 100

This can be understood as evidence of the reflection of the longitudinal development and will be discussed in some detail elsewhere.

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