

STRUCTURE OF AIR SHOWER DISC NEAR THE CORE

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ABSTRACT

The longitudinal structure of air shower disc has been studied by measuring the arrival time distributions of air shower particles for showers with electron size in the range $3.2 \times 10^{5.5}$ to $3.2 \times 10^{7.5}$ in the Akeno air-shower array (930gcm^{-2} atmospheric depth). The average FWHM as a parameter of thickness of air shower disc is increasing with core distances at less than 50m. At present stage, it cannot be seen the dependence on electron size, zenith angle and air shower age. The average thickness of air shower disc within core distance of 50m is almost determined by electromagnetic cascade starting from lower altitude.

1. Introduction

The experiment to search for long-lived massive particles in extensive air showers has been carried out in the Akeno air-shower array, using twelve fast scintillation detectors at intervals of 5m, will be discussed in a separate paper (HE 6,2-10). The time profile of the signal from photomultiplier (PMT) reflects the arrival time distribution of air shower particles, namely the longitudinal structure of air shower disc. Hitherto, the lateral structure of air shower particles is rather well known through basically measurement of lateral density of air shower particles and also nuclear cascade theory. However, informations on the longitudinal structure near the core ($\leq 50\text{m}$) are not abundant in spite of recent improvement of recording apparatus and additive parts for nano second measurement. Only, C P Woidneck et al (1975) measured the longitudinal particle distribution from the time delay measurement, so far. It is interested in studying the thickness, the curvature of air shower disc and also their fluctuations in order to discuss the longitudinal development of air shower and primary compositions. The preliminary results on average thickness of air shower disc and its dependence on zenith angle and air shower age are presented in this paper.

2. Experimental

Twelve scintillation detectors were located at the S2 area in the Akeno air-shower array at intervals of 5m as described in separate paper (HE 6,2-10). The group A consisted of two 0.25m^2 scintillation detectors with 2" fast PMTs and a 1m^2 scintillation detector with 5"

fast PMT. Signals fed to an adding circuit through co-axial cables (11C4AF) with different length of 50m, 63m and 75m, and then added signals were recorded by a 100MHz storage oscilloscope. The group B and C were also same systems as mentioned above. The time response of the whole 0.25 m^2 scintillation detector system for single relativistic particle was 4.9ns in rise time (t_r : time from 10% to 90% of the maximum signal) and 10.6ns in Full Width at Half Maximum (t_w). That of the whole 1 m^2 scintillation detector system was also 6.2ns and 15.2ns in t_r and t_w , respectively.

The work was performed in conjunction with the air-shower array. Signals from each groups were stored in three storage oscilloscopes if the heights of three signals from the triggering detectors (A-1, B-1 and C-1) were higher than a given level and coincided in time with one another. The stored signals were read out to a floppy disk by simultaneous master pulse from the air-shower array.

3. Analysis and Result

Observation was made from May to October of 1984. Total running time was 88 days and the total number of events triggered was about 6300. The analysis was made on 2142 events recorded by B-2 detector. The arrival direction (Θ and φ), the electron size (N_e), the core location and the age parameter (s) of an air shower were determined according to the procedure adopted by the air-shower group of Institute for Cosmic Ray Research of the University of Tokyo. We excluded the signals whose peaks of some showers were out of the storage oscilloscope frame and also whose peaks were smaller than given level corresponding to four relativistic particles. In this paper, the arrival time distributions of air shower particles with N_e in the range $3.2 \times 10^{5.5}$ to $3.2 \times 10^{7.5}$ and sec Θ in the range 1.0 to 1.3 are reported.

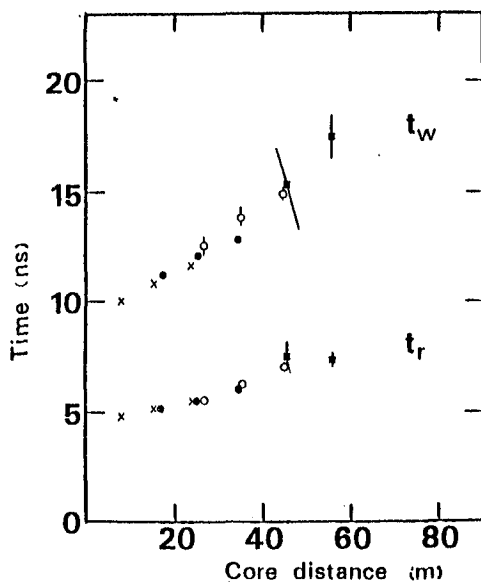


Figure 1. Average t_r s and t_w s against core distance for showers with sec Θ of 1.0-1.2 and N_e of $3.2 \times 10^{5.5}$ (\times), $1.0 \times 10^{6.0}$ (\times), $1.0 \times 10^{6.5}$ (\bullet), $3.2 \times 10^{6.5}$ (\bullet), $1.0 \times 10^{7.0}$ (\circ) and $1.0 \times 10^{7.0}$ (\circ), $3.2 \times 10^{7.5}$ (\blacksquare).

As is seen in this figure, both values increase with increase in core distances. On the other hand, dependence of these values on N_e cannot be seen from this figure. As often pointed out, average t_w s have some biases at core distances larger than those presented here in each N_e bins. They are caused by small number of incident particles (less than about ten particles), and consequently, average t_w s are estimated to be rather small values. We have been confirmed carefully unbiased regions of core distances in regard to each N_e bins.

The average values of t_r and t_w plotted against core distances are shown in figure 1. As is seen in this figure, both values increase with increase in core distances. On the other hand, dependence of these values on N_e cannot be seen from this figure. As often pointed out, average t_w s have some biases at core distances larger than those presented here in each N_e bins. They are caused by small number of incident particles (less than about ten particles), and consequently, average t_w s are estimated to be rather small values. We have been confirmed carefully unbiased regions of core distances in regard to each N_e bins.

Figure 2(a) shows the average values of t_w for showers with N_e in the range $3.2 \times 10^{6.5}$

to $1.0 \times 10^{7.0}$, core distances in the range 20m to 50m and sec Θ in the range 1.0 to 1.1, 1.1 to 1.2 and 1.2 to 1.3. Figure 2(b) shows dependence of average t_w on s for showers with sec Θ in the range 1.0 to 1.2, and same N_e and core distance bins as figure 2(a). Average number of incident particles to the detector in these three core distance bins is about 50, 25 and 12 for sec Θ in the range 1.0 to 1.2 and for s in the range 0.75 to 1.25. Average particle number adopted in figure 2(a), (b) is the same values within errors regardless of different s and sec Θ .

These quantities (t_r and t_w) derived from recorded signal shape are distorted due to the decay time of plastic scintillator, the transit time spread in PMT and the response in storage oscilloscope. Accordingly, the average signal shapes have to be reduced to a system with zero time response in order to discuss the true thickness of air shower disc. We assume the function V_e for the arrival time distribution of air shower particles as

$$V_e(t) = \exp(-a(t)) \times (1 - \exp(-b(t)))$$

The average signal shape derived from the recorded signals, V_o , can express as the convolution of the two functions V_e and V_s which is average shape corresponding to single relativistic particle.

$V_o(t) = \int_0^t V_s(t-t') \times V_e(t') dt'$ Here, V_o' is an expected signal shape. Calculation was made by two parameter (a and b) fit, and then determined these parameters giving the minimum value of $\sum (V_o'(t) - V_o(t))^2$. Figure 3 shows the corrected arrival time distributions of air shower particles for showers with sec Θ in the range 1.0 to 1.2, and different N_e and core distance bins as showed in figure caption. These distributions presented here are normalized their areas to be same value, namely to same number of incident particles. The distribution at core distance of 10m to 20m have a large ambiguity when correct to zero time response, because the average signal shape is as narrow as the average shape of single particle. In figure 4, corrected average t_w s are presented against core distances derived from the procedure mentioned above.

4. Discussion

The average thickness of air shower disc presented as the value of t_w is increasing with core distances. Apparently, the effects of multiple Coulomb scattering and transvers momenta of the particles contribute to broaden the thickness with increase in core distances. On the other hand, the contribution of high energy interaction and primary compositions through the longitudinal development of air shower particles to the value of t_w is not obvious as is seen in figure 2(a) and (b). It seems

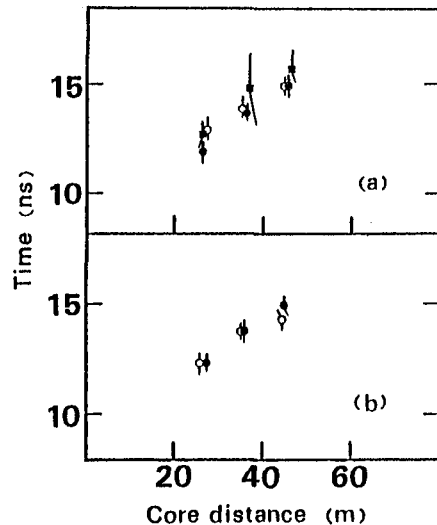


Figure 2. Average t_w s against core distance for showers with N_e of $3.2 \times 10^{6.5}$ $1.0 \times 10^{7.0}$. (a) shows the dependence of average t_w on sec Θ ; 1.0-1.1 (○), 1.1-1.2 (●) and 1.2-1.3 (■). (b) shows the dependence of average t_w on age parameter (s); 0.75-1.0 (○) and 1.0-1.25 (●).

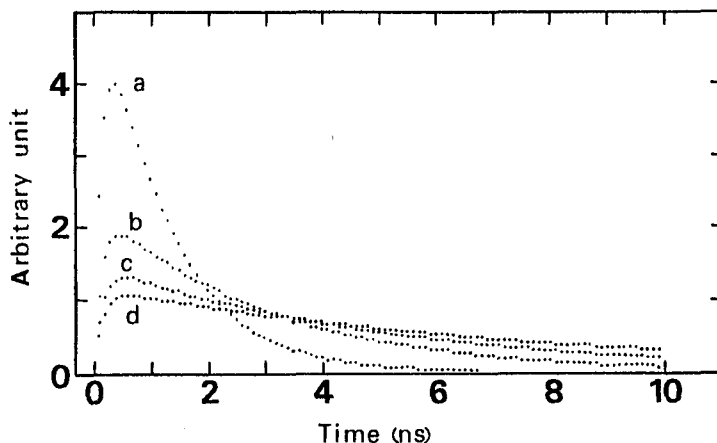


Figure 3. Corrected arrival time distributions of air shower particles for showers with sec θ of 1.0-1.2 and
 (a) N_e of $3.2 \times 10^{5.5}$ - $1.0 \times 10^{6.0}$ for core distances 10m-20m
 (b) N_e of $1.0 \times 10^{6.0}$ - $3.2 \times 10^{6.5}$ for core distances 20m-30m
 (c) N_e of $3.2 \times 10^{6.5}$ - $1.0 \times 10^{7.0}$ for core distances 30m-40m
 (d) N_e of $1.0 \times 10^{7.0}$ - $3.2 \times 10^{7.5}$ for core distances 40m-50m

that the thickness at core distance less than 50m is almost determined by electromagnetic cascade starting at lower atmosphere. However, the detailed discussions should be done after a comparison of the whole shape of arrival time distribution, especially on the part of tail and also those at larger core distances, which are seemed to include the information of upper atmosphere. Furthermore, it is necessary to compare with an elaborate three-dimensional shower simulation.

We are going to process the data obtained simultaneously in an air shower by twelve detectors in order to expect higher accuracy and also to study the uniformity of thickness.

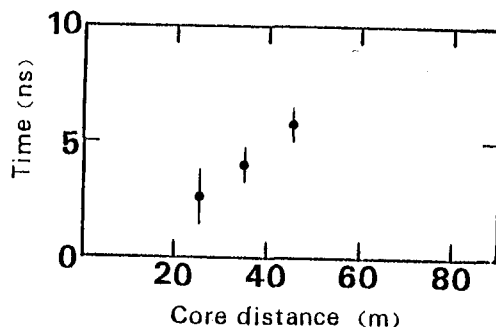


Figure 4. Corrected average $t_w s$ against core distance derived from the arrival time distributions shown in figure 3.

References

- Kawamoto, M. et al; HE 6,2-10 of this conference.
 Woidneck, C.P. et al: J.Phys. A:Math.Gen. 8(1975)997.