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Arrival Time Distribution Computation for Particles of the E.M. Component in E.A.S.

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Particles of the E.M. component in an extensive air shower may be delayed with respect to one another at the plane of observation because of different energy and nature and statistical ways of interaction.

It is well known that at any time most particles of the shower are concentrated in a disk-shaped region of space simmetric about the shower axis and that the instantaneous spatial density distribution $\sigma(R, Z, S)$, (where Z is the distance measured along the shower axis, R is the radial distance from the axis, and S is the time) changes as the shower propagates downward.

Rossi (1) has calculated the normalized probability distribution $F(R, Z, S)$ for the time of arrival of the first particle at a counter struck by a shower, assuming that the time dependence of the $\sigma(R, Z, S)$ is exponential: $\sigma(S) = \exp[-S/\lambda]$.

In the present note we calculate the behaviour of $\sigma(R, Z, S)$ with the Monte Carlo method. The details of the calculation, which take into account multiple diffusion, pair production, energy loss for ionization and radiation (B approximation), have been described in our previous work (2).

The air density at different heights is given by experimental measurements of the N.A.S.A. (3).

The three-dimensional calculation, carried out on a IBM 7040 computer, gives the e^+e^- density distribution as a function of the radial distance R from the axis and of the time S computed from the arrival time of the first particle at the plane of observation.

We simulate vertical showers originated by γ of energy $E_0 = 10^{12}$, 10^{13} eV at the height of 15 km above sea level. Particles are neglected when their energy becomes less than 10 MeV. The planes of observation are fixed at heights of 8.5 and 3.5 km above sea level.

In order to obtain a check for our calculations we also made a calculation with γ of $E_0 = 10^{11}$ eV and the planes of observation at heights of 3.5, 8.5, 11.5 km above sea level, in which e^+e^- are neg-

(1) P. Bassi, G. Clark and B. Rossi: *Phys. Rev.*, **92**, 441 (1953).

(2) C. Castagnoli, M. A. Locci, P. Picchi and G. Verri: *A calculation on the Čerenkov light in* $(10^{12} \div 10^{14})$ eV *E.A.S.*, *Nucl. Phys.* (in press).

(3) N.A.S.A.: Standard atmosphere 1962.

lected only when their kinetic energy becomes less than 0.1 MeV.

The values $N(E_0, t)$ of the longitudinal shower development so obtained, compared with theoretical curves, are shown in Fig. 1. In Fig. 2 our results on the lateral distribution Δ of the shower at the height of 3.5 km above sea level (where $s = 1.4$) are compared with the results obtained by NISHIMURA and KAMATA (4).

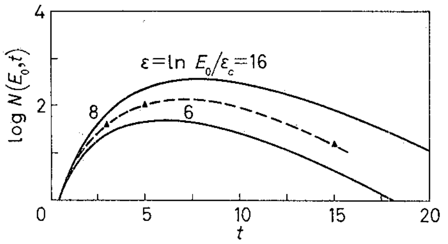

Fig. 1. – Total number of electrons $N(E_0, t)$ as a function of the thickness t of air in radiation units (37.7 g cm^{-2}) for showers initiated by single photons of various energies according to SNYDER. ▲ our results, $\varepsilon = 7.07$.

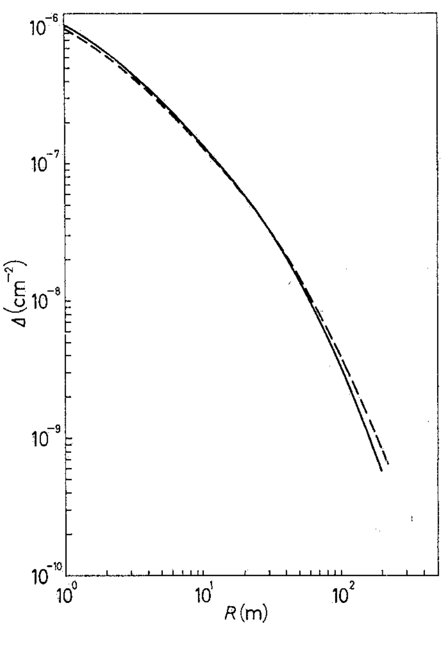

Fig. 2. – Lateral density distribution Δ of particles as a function of the distance R from the axis of the shower, $E_0 = 10^{11}$ eV, $Z = 3.5$ km: ——— our results, – – – NISHIMURA and KAMATA.

The good agreement in this comparisons provides us a good test for our calculation.

In Fig. 3*a*, *b* are given the $\sigma(R, Z, S)$ with $Z = 3.5$ km and $R = 1, 5, 15, 25, 35$ m.

In Fig. 4*a*, *b* are given the $\sigma(R, Z, S)$ with $Z = 8.5$ km and $R = 1, 5, 15, 25, 35$ m.

We note that:

1) only for small values of R and sizeable values of Z the $\sigma(R, Z, S)$ is rather well approximated by an exponential line;

2) as far as Z decreases and R increases the slope of the $\sigma(R, Z, S)$ decreases and the maximum of the curve shifts to greater times;

3) the function $\sigma(R, Z, S)$ depends on the energy E_0 of the primary photon.

We can compare experimental data calculating the s.d. (standard deviation relative to the mean) of the arrival times of single electrons measured in an imaginary plane normal to the shower axis.

In Fig. 5 is plotted the s.d. as a function of the thickness t of air in radiation units for $E_0 = 10^{12}, 10^{13}$ eV. The s.d. calculated for $Z = 11.5$ km ($t = 2$), 8.5 km ($t = 5$), 3.5 km ($t = 15$) has been extrapolated till 22.5 t ($Z = 0$).

The obtained data are in good agreement with Rossi's and De Benedetti's (5) ones considering the detector arrangement and for Rossi's device the part of the observed dispersion which is due

(4) J. NISHIMURA and K. KAMATA: *Progr. Theor. Phys.*, **7**, 185 (1952).

(5) R. SUGARMAN and S. DE BENEDETTI: *Phys. Rev.*, **102**, 857 (1956).

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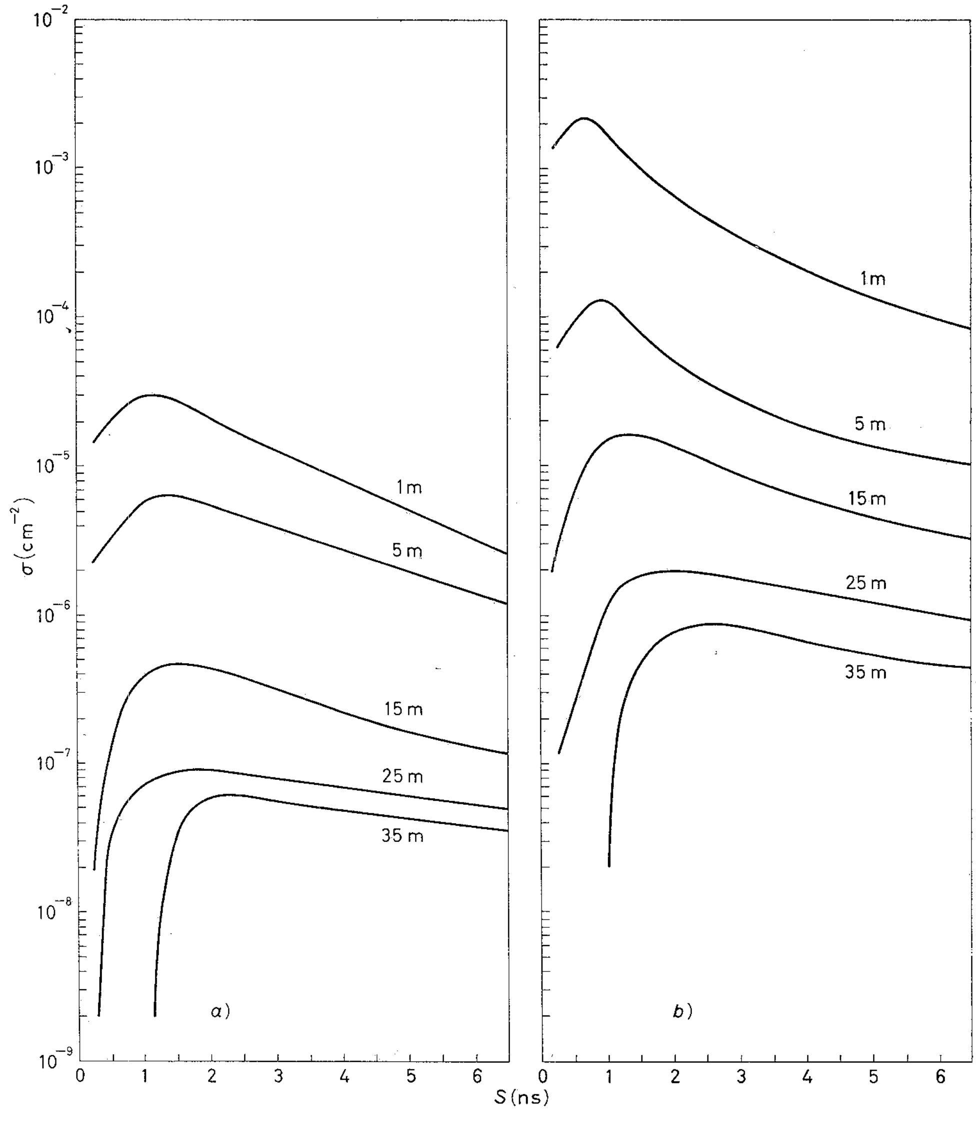

Fig. 3. – Density distribution σ of particles as a function of the time S for a given distance R(1, 5, 15, 25, 35 m) at the height $Z = 3.5$ km: *a*) $E_0 = 10^{12}$ eV; *b*) $E_0 = 10^{13}$ eV.

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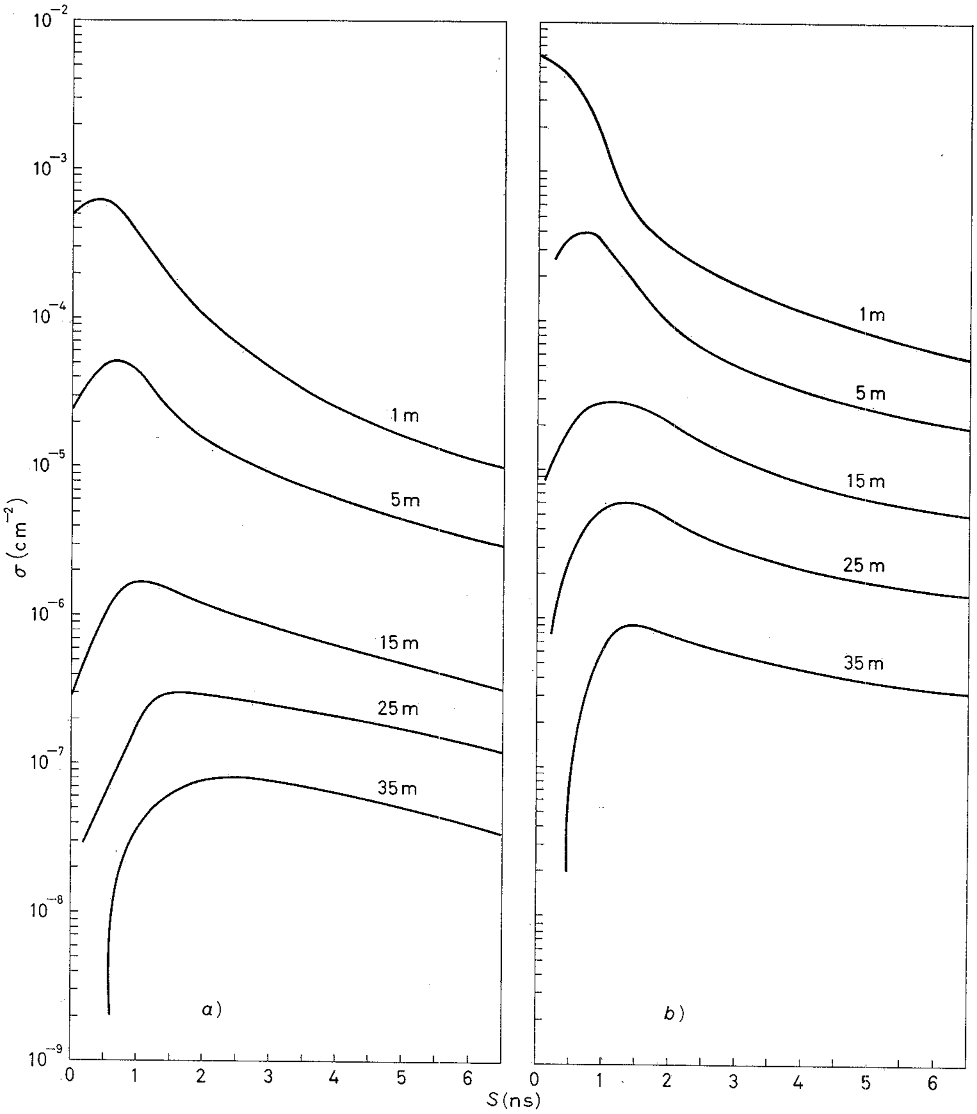

Fig. 4. – Density distribution σ of particles as a function of the time S for a given distance R(1, 5, 15, 25, 35 m) at the height $Z = 8.5$ km: *a*) $E_0 = 10^{12}$ eV; *b*) $E_0 = 10^{13}$ eV.

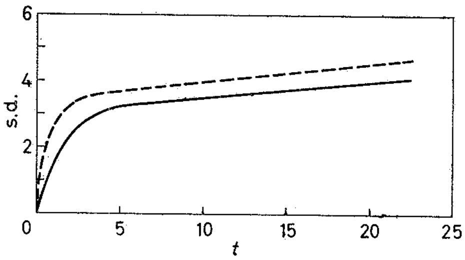

Fig. 5. – s.d. (standard deviation relative to the mean) of the arrival times of single electrons measured in an imaginary plane normal to the shower axis as a function of the thickness t of air in radiation units (37.7 g cm^{-2}): – – – $E_0 = 10^{12}$ eV; —— $E_0 = 10^{13}$ eV.

to the inclination of the shower axis.

In conclusion we have found that at a given instant most electrons with energies $E \geqslant 10$ MeV lie in a disk of thickness between 1 and 2 m.

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