A Contradiction in The Concept of Shower Age

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Abstract

It is found that the longitudinal local age and the lateral local age of the EAS are two different concepts. The lateral local age increases with axial distance, but the longitudinal local age decreases with distance if the local density instead of the shower size is used as a measure of the age. Hence, they can not be expressed simply to be s (r) = $s_{//}$(r) - ä as some previous work suggested for the age of the whole shower.

The shower age was introduced primarily to describe the development of the electromagnetic cascade. It was found that the lateral distribution of shower particles, generally, related to the shower age as [Kamata and Nishimura 1958, Greisen 1960]

$$\rho(R) = C \frac{N}{R_0^2} \left(\frac{R}{R_0}\right)^{s-2} \left(1+\frac{R}{R_0}\right)^{s-4.5}$$

where *r*(R) is the particle density at distance R, N is the total number of shower secondaries, C is the normalization constant, R. is the Moliere unit and s is the shower age. This is so called NKG function. Later on, it was found that the longitudinal development age (longitudinal age) and the lateral age (age parameter used to describe the lateral distribution) are not identical for hadron primary showers though most of the secondaries can be classified into electromagnetic cascade and mesons. This is due to the differences in the interaction length and the transverse momentum between hadron and electromagnetic component. Some recent results expressed the difference as $s_{=}$ $s_{//}$ - ä (Stamenov 1987], where s is the lateral age, $s_{//}$ is the longitudinal age, ä 0.2. Since 70's, many authors have pointed out that the NKG function with a single age is not adequate to describe the lateral distribution at all distances (Kristiansen 1971, Kawaguchi 1975, Chudakov 1979, Nagano 1983), this means that lateral age varies with the axial distance.

Linsley has proposed a double parameter function, characterized by á and ç [[Linsley 1977], to replace the NKG function, expressed as

$$\rho(R) = C(\alpha, \eta) \frac{N}{R_0^2} \left(\frac{R}{R_0}\right)^{-\alpha} \left(1+\frac{R}{R_0}\right)^{-(\eta-\alpha)}$$

when R approaches 0, the distribution is determined by á, whereas at by ç. This function was proved to be better than the NKG function when used to describe the lateral distribution.

From NKG function, we got

[d ln *r* (r)] / [d ln r] = (s – 2) + (s – 4.5) r / (1 + r)

and

[d ln *r* (r)] / [d ln r] = -(á + rç) / (l + r)

from Linsley's function, where r-R/R To make two functions effectively equal, s should satisfy:

(s – 2) + (s – 4.5) r / (1 + r) = -(á + rç) / (1 + r)

Therefore, the effective age (lateral age) varies with distance r as

s (r) = [2 – á + (6.5 – ç) r] / (1 + 2r) Adopting á = 1.25, ç = 3.7 (Linsley 1977], the ages at different distances are listed in Table 1.

Table 1. Effective lateral ages at different distances [Linsley 1977]

r	0.1	0.2	0. 5	1.0	2.0	5.0	10.0
s (r)	0.86	0.94	1.08	1.18	1.27	1.34	1.37

This means that the lateral age increases with distance r. Figs.1 [tiara et al 1979] are the data from Akeno which display such tendency.

Kiel group had used the age parameter to select the ã showers [Samorski and Stamm 1983]. But if the detector span is ununiform, there is danger of selecting showers from larger span area unless precautions are taken.

Now we turn to the longitudinal age. Conventionally, the longitudinal age is determined by the transition curve of the shower size. Here we introduce the concept of local longitudinal age with the help of local density transition curve.

According to the electromagnetic cascade theory, the shower age

S = 3t / (t + 2y + 2x), where y = ln(W_0 / ª), x = ln (r),

W_0 is the primary energy, ª = 81MeV, is the critical energy, t is the air depth in unit of radiation length. We found s decreases as r increases. For t = 25, $W_0 = 10^{15}$ eV, in the region of 0.1 < r < 10, s varies from 1.41 to 1.20.

For the hadron initiated showers, according to a Monte Carlo calculation about the relative density fluctuation at different axial distances [Dai et al 1988], the optimum axial distance (where the relative density fluctuation is minimum) increases with incident angle (Figs.2, the simulation only considers the longitudinal development fluctuation and the observation level is set at 920g / cm^2). It is reasonable to assume that the optimum distance is related to the maximum development of *r* (r). We know at a fixed observation level, the maximum density is near the shower core. But for the density at a fixed axial distance r_i, *r* (r_I) reaches its maximum at some special observation level t_i, t_i varies with r_i. Therefore, in Fig.2, the optimum distances correspond to the axial distances where the local density reaches its maximum at the observation levels 920sec 6 g/cm^2 (secθ -1.0, 1.1, 1.2, ...) respectively. We define s (r) = 1 when *r* (r) is at its maximum development, before this level s (r) < 1, and s (r) > 1 after. Hence Fig.2 means the smaller the axial distance, the less the air density needed for the *r* (r) reaches s (r) = 1. In other words, the inner part is always elder than the out. Such a picture can be imaged as 'the sweetlization of the watermelon' if we define the s (r) > 1 region as 'the sweet region' (Fig.3), since the watermelon matured from the inner to the out gradually.

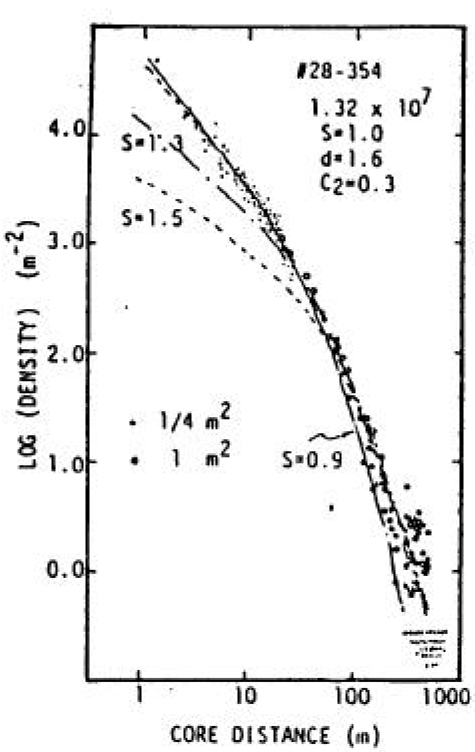

Fig. 1a An example of lateral distribution of a large shower.

(Hare 1977)

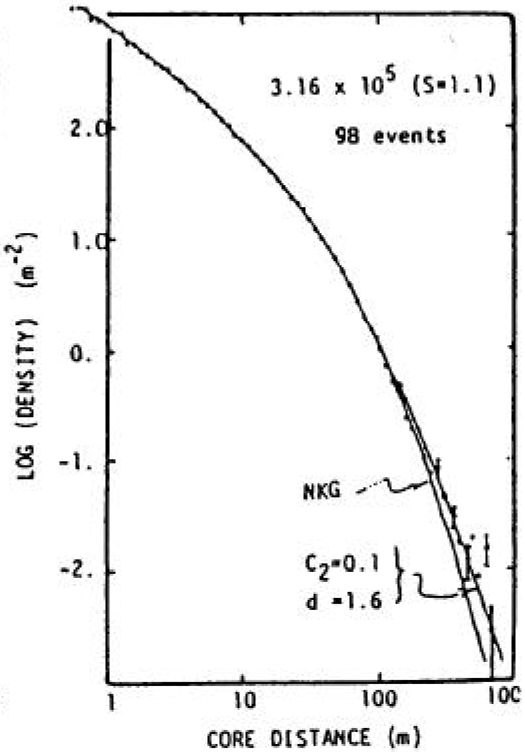

Fig. 1b An example of average lateral distribution of showers assigned to ã = 3.16x10^{5} and S = 1.1.

(Hara 1977)

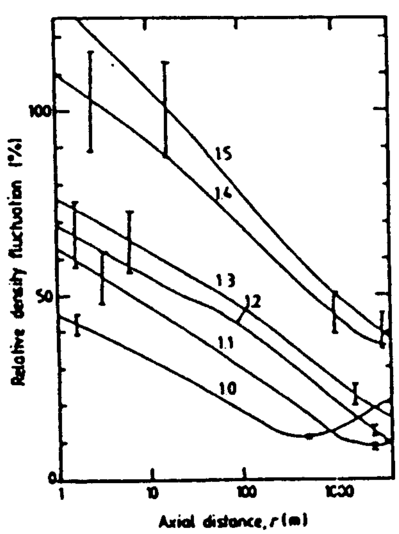

Figure 2a Relative density fluctuation plotted against distance r. The numbers for each line indicate sec θ (proton primary 10^{17} eV). The error bars are calculated according to ó = ós (2 (n - 1) -1/2

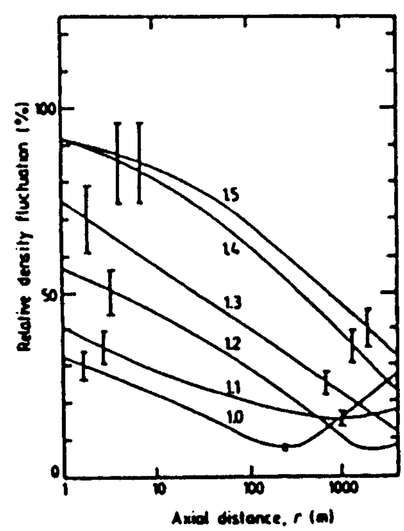

Figure 2b Same as figure 5. but for 10^{18} eV primary.

As discussed above, we conclude that:

Both longitudinal local age and lateral local age varies with axial distance, the lateral age increases with distance, but the longitudinal age decreases with distance. They can not be expressed simply as s (r) = $s_{//}$(r) – ä. The quantitative description and the possible physical explanation still need careful model calculations.

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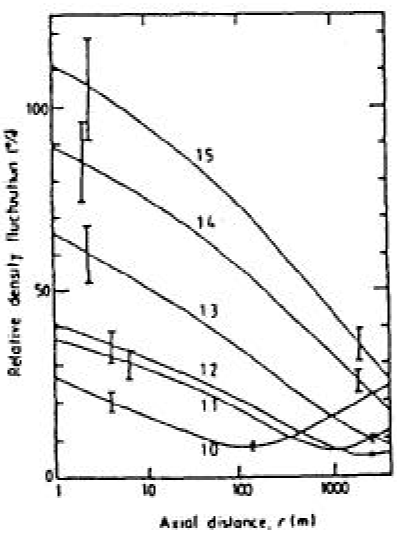

Fig. 2C Same as figure 5. but for 10^{19} eV primary.

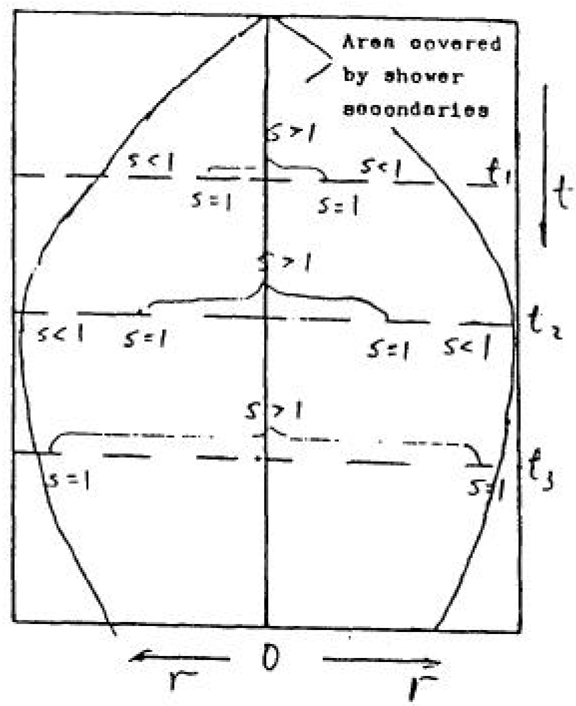

Fig. 3 Local longitudinal ago at different air depths.