CORE STRUCTURE OF EAS IN 10^{15}ev TO 10^{17}ev

T.Hara, Y.Hatano, N.Hayashida, T.Kifune, M.Nagano and G.Tanahashi

Institute for Cosmic Ray Research, University of Tokyo
Tanashi, Tokyo, 188 Japan

ABSTRACT

With use of Akeno calorimeter, the attenuation of particles in concrete is analized as the function of the shower size of 10^5 to 10^7. The attenuation length does not depend much on the shower size but depends a little on the shower age. The average value is ~150gcm^{-2} for s=0.5-0.85 and ~140gcm^{-2} for s=0.85-1.15. These values and their fluctuations are consistent with the equi-intensity curves of EAS.

1. Introduction

Akeno calorimeter has an area of about 10mx10m and has the proportional counter arrays at 5 different depths(0, 115, 230, 345 and 633gcm^{-2} in concrete) with 10cm resolution in one dimension(1). We report the preliminary result of energy flow or the attenuation length measurement with use of the calorimeter. In this paper the attenuation length(Λ) is defined as

$$\text{Energy flow}=\beta\int_{x_0}^{\infty}N(x)dx=\beta\, N(x_0)\int_{x_0}^{\infty}\exp(-x/\Lambda)dx$$

where β ; the energy loss/particle. unit mass
N(x) ; shower size in the depth x
xo ; observation depth, 930gcm^{-2} in Akeno

The data are of the latter half of 1982, and about 13,000 vertical showers are analyzed whose sizes are between 10^5 and several times of 10^7. Only 3 shower cores hit the calorimeter area above the size of 10^7.

2. Average attenuation length of EAS

The analysis is only for the vertical showers with secθ=1.0-1.1. EAS data are sorted in the shower size(N) bin of $10^{5.0-5.5}$, $10^{5.5-6.0}$, $10^{6.0-6.5}$, $10^{6.5-7.0}$ and $>10^{7.0}$, and also in the age(s) bin of 0.50-0.85, 0.85-1.15 and 1.15-1.50. The average lateral distribution of particles and the shower sizes in each concrete depth are determined in every combinations of the above sorting. Fig.1 shows the average local attenuation lengths as the function of core distance in N=$10^{6.0-6.5}$ and in all s. They are defined in 1 replacing N(x) by Δ(x), the particle density in a unit of 10 proportional counters(5mx1m). The average shower sizes in each concrete depth are obtained by integrating Δ(x) over the core distance. They are shown in Fig.2. A systematic difference of the particle densities measured by the scintillation counters and by the proportional counters are corrected in the figure, that is Δpc/Δ sc is about 1.5 at Δ=10, 1.3 at Δ=10^2 and 1.15 at Δ=10^3. The shower sizes are normalized within eacn size bin. The error bars only show the uncertainty due to the threshold of the counter output, and in most cases the true values are considered to be rather close to the lower limit. The data of size=10^7 and age=0.85-1.15 are not reliable because of the poor statistics of the core events.

The attenuation lengths from these transition data are 150±10gcm^{-2} for s=0.50-0.85 and 140±10gcm^{-2} for s=0.85-1.15, and not much depend on the shower size. These values are smaller than ~180gcm^{-2} predicted for the proton showers of the standard interaction, and also for the iron showers as shown in Fig.3(2), where "standard" means the increasing cross section as $\sigma \propto E^{0.06}$, Feynman scaling and the extrapolation of the known central energy distribution to the higher energies.

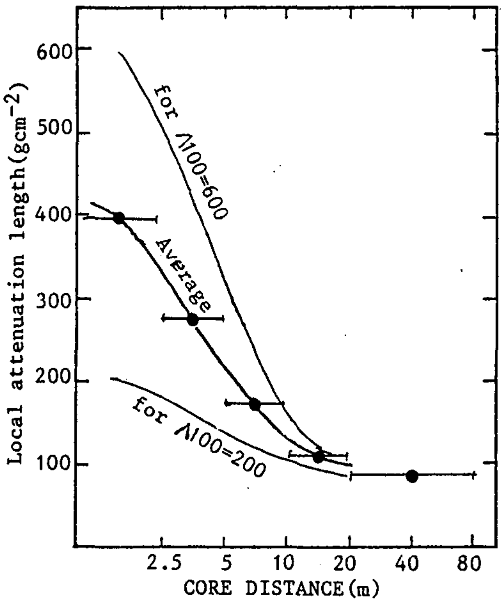


Fig.1

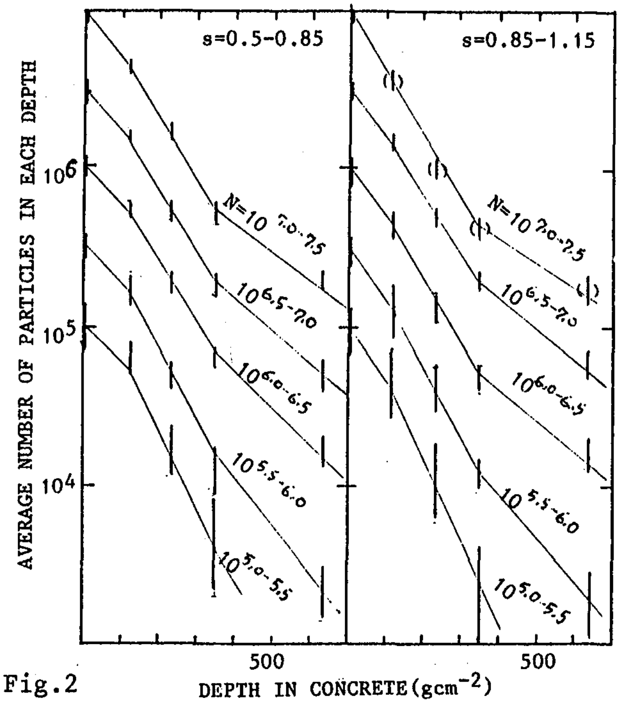


Fig.2

3. Relation of 3 attenuation lengths, ΛE, ΛI, ΛN

To see the consistency of the result with others, three attenuation lengths are taken into account. Their definitions are as follows.

(i) ΛE of the fixed energy shower

ΛE is obtained from the shower calculation of the fixed energy, and in the case of the simulation, the average value of many showers is used. ΛE is about 180gcm^{-2} in 10^{16}ev and in >950gcm^{-2} for the standard proton showers(Fig.3).

(ii) ΛI of equi-intensity cut

ΛI is obtained from the equi-intensity cut of the size spectra in the different depths. The experimental value is 160-170gcm^{-2}(3) in 10^{16}ev to 10^{17}ev and >950gcm^{-2}.

(iii) ΛN of the fixed size in the fixed level

The attenuation length obtained in the calorimeter experiment is ΛN. The experimental value is 140-150gcm^{-2} as described in 2.

In what follows we make a simple calculation of these Λs to see how the cosmic ray composition affects these values. The composition is assumed to be two components, the proton and the heavy nuclei. Each shower curve is to be the exponential form, say $Np.\exp(-x/\Lambda p)$ for proton and $Nh.\exp(-x/\Lambda h)$ for heavy nuclei. $Np=Nh=10^9$, $\Lambda p=180$gcm^{-2} and $\Lambda h=140$gcm^{-2} in 10^{16}ev as shown in Fig.3. The reason to adopt the small value of Λh is that the usual models of heavy nuclei shower can not give a appreciably smaller attenuation than the proton's. The fluctuations of the longitudinal development are ignored. The integral energy spectrum is to be E^{-2}, and the intensity ratio at the same energy $k=Ih/Ip$ is to be a parameter of the calculation. ΛE, ΛI and ΛN are given as follows.

$\Lambda=(x2-x1)/\ln(N1/N2)$

for ΛE, $N1/N2=(ex1p+k.ex1h)/(ex2p+k.ex2h)$

for ΛI, $N1/N2=((ex1p^2+k.ex1h^2)/(ex2p^2+k.ex2h^2))^{0.5}$

for ΛN, $N1/N2=(ex1p^2+k.ex1h^2)/(ex1p.ex2p+k.ex1h.ex2h)$

where N1 and N2 are the shower size at the depth of x1 and x2 respectively and $ex1p=\exp(-x1/\Lambda p)$, $ex1h=\exp(-x1/\Lambda h)$, $ex2p=\exp(-x2/\Lambda p)$, $ex2h=\exp(-x2/\Lambda h)$.

The relations between k and Λs are shown in Fig.4. It is seen that ΛN has almost the same value as ΛI in the whole range of k. This means that the difference of ΛI(160-170gcm^{-2}) and ΛN(140-150gcm^{-2}) can not be explained by means of the different response of proton and heavy nuclei showers.

The other possible explanation is to attribute it to the fluctuation of the shower development. Fig.5 shows two distributions of simulated attenuation lengths of fixed energy and of fixed size for the proton showers. The positions of the distribution maximum are almost the same, but the average value of the fixed energy one is larger than that of the fixed size. As the attenuation length of fixed energy is nearly equal to that of the equi-intensity cut in single component showers, this can explain the difference provided that the primary cosmic rays contain a proper amount of protons.

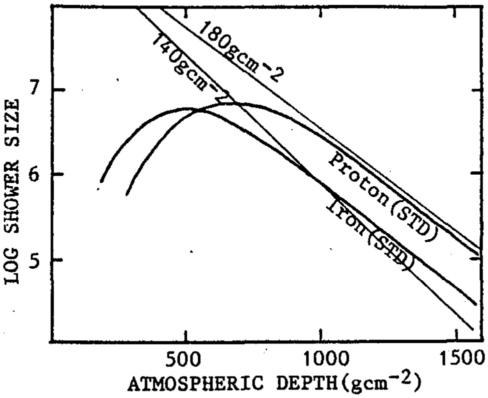


Fig.3

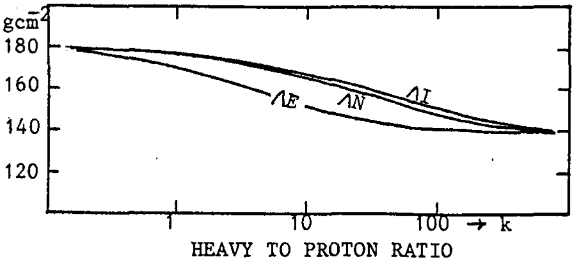


Fig.4

4. Fluctuation of the attenuation length

The attenuation length of each shower can not be directly obtained from the data, and only "the attenuation length within 10mx10m(Λ100)" are obtained. The histogram in Fig.6 shows the Λ100 distribution(bottom side scale) of the showers which hit the central part(5mx5m) of the calorimeter. This kind of fluctuation decreases with the core distance, and gets remarkably smaller beyond 15m down to 80-90gcm^{-2}. So, for the core hitting showers, we can convert Λ100 to the attenuation length assuming the local attenuation lengths are continuous between 5m and 20m.

The conversion depends on how to interpolate the attenuation between 5m and 20m. The most gentle one is that the local attenuation lengths fluctate around the average in proportion to the central Λ100 in the region above 80-90gcm^{-2} like the two curves in Fig.1. The attenuation lengths obtained with use of this conversion are shown in the top side scale of Fig.6. In the same figure, the distribution of the attenuation length is compared with the one simulated for proton showers(the same one in Fig.5). The observed distribution does not agree with the prediction. Some part of the disagreement may be the contribution of the heavy nuclei showers, but the further discussion needs the further detailed analysis, especially the improvement of Λ100 conversion to the attenuation length.

Fig.5

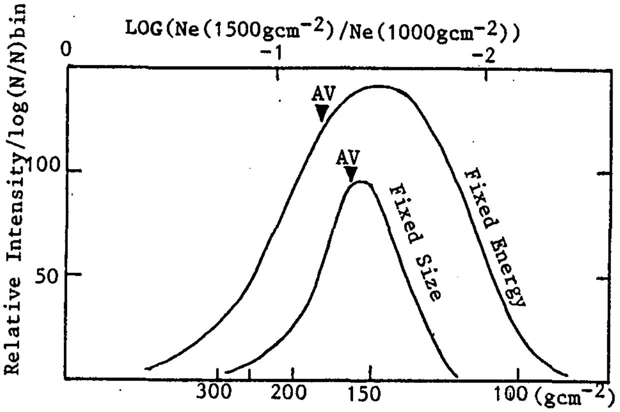
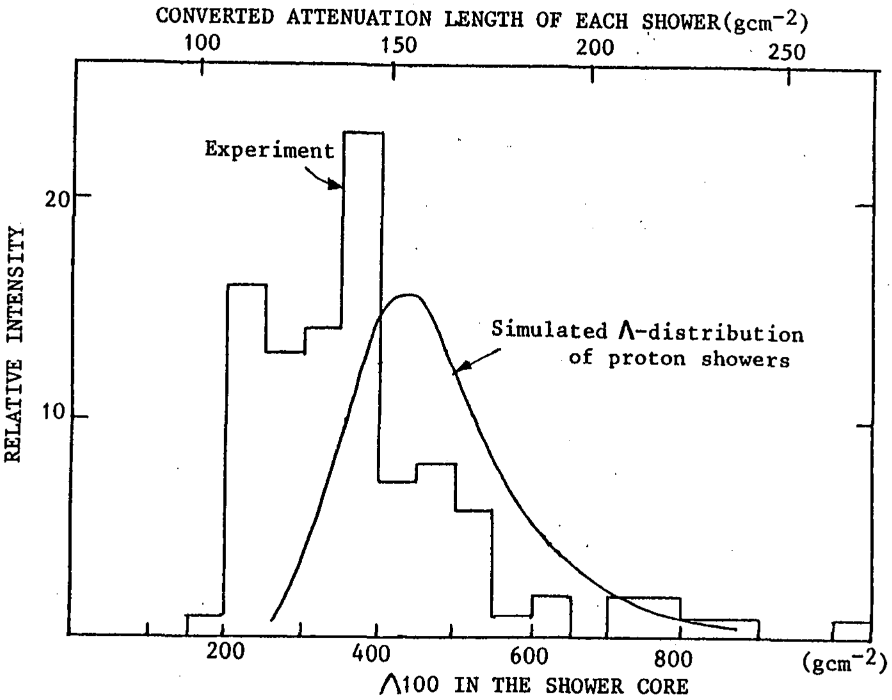


Fig.6



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