FLUCTUATIONS AND ENERGY MEASUREMENTS OF CASCADE SHOWERS INDUCED BY FNAL ELECTRON BEAMS

N. Hotta[1], H. Munakata[1], M. Sakata[1], Y. Yamamoto[1],
S. Dake[2], H. Ito[2], M. Miyanishi[2], K. Kasahara[3], T. Yuda[3],
K. Mizutani[4] and I. Ohta[5].

[1]Department of Physics, Konan University, Kobe
[2]Department of Physics, Kobe University, Kobe
[3]Institute for Cosmic Ray Research, University of Tokyo, Tanashi
[4]Department of Physics, Saitama University, Urawa
[5]Faculty of Education, Utsunomiya University, Utsunomiya.

ABSTRACT

Emulsion chambers with lead absorber, exposed with a right angle to the 100 GeV and 300 GeV electron beams at Fermi National Accelerator Laboratory, were analysed. The number distribution of shower tracks within a certain radius show the narrowest one around the depth of the maximum number of tracks inside the radius, but it is about twice broader than the Poissonian distribution. The fluctuation of track length distribution until a certain depth decreases monotonically with depth and it becomes much smaller than that of number of tracks at deep layers. For the finite radius (50 μm) the maximum number of tracks of each cascade gives the largest ambiguity in the energy measurement and the track length gives the smallest one. The other energy measurements by fitting of transition curves are between them.

1. Introduction

To study the electromagnetic cascade showers the emulsion chambers were exposed to mono-energetic electron beams at Fermilab. The average behaviors of the longitudinal and lateral developments were reported at the 15th ICRC[1)] for 100 GeV and 300 GeV showers. Using same data and some data added thereafter, here are described the fluctuation in the cascade process and the ambiguity in the estimation of cascade energy.

The theoretical cascade function of a single electron primary near the core has never been published. Then, our data are compared with that of a pair electron primary[2)] which has been usually employed for estimation of the cascade energy. Dashed curve in Fig.1 is a transition curve of the theoretical cascade function within a radius 50 μm (fixed in this paper) for the pair just with the beam energy and the solid curve means a half of the function with twice beam energy. From a simple consideration it is understood that the cascade function of single electron primary should take an intermediate value between above two curves at depths after the maximum development and it will fit to the latter curve (half of pair curve) before the maximum. Surely, the experimental data fit very well to the half of pair curve before the maximum development, but they show somewhat steeper decrese after the maximum than expected. Anyway, the half of pair curve is employed when the theoretical curve is needed in this paper.

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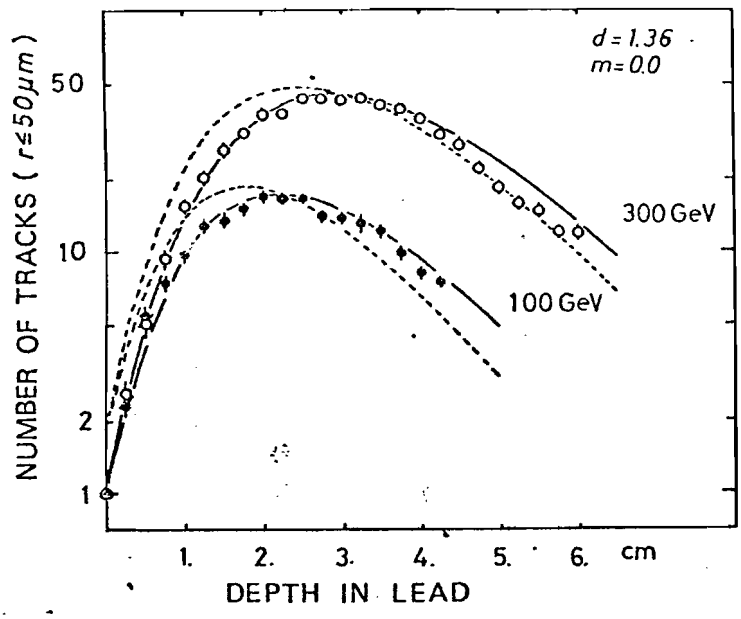

Fig. 1. The average transition curves of showers initiated by 100 GeV and 300 GeV single electrons. The dashed curves are the theoretical ones for pair elctron initiated showers with energies 100 GeV and 300 GeV, respectively. The solid curves are halves of pair electron initiated showers with energies 200 GeV and 600 GeV, respectively.

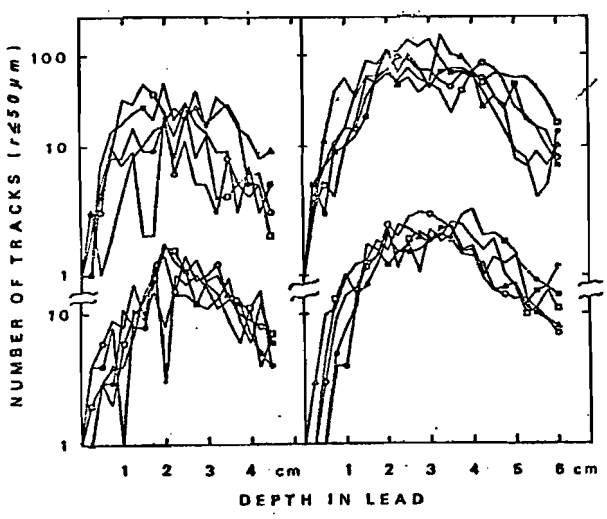

Fig. 2. Some examples of experimental transition curves for 100 GeV (left) and 300 GeV (right).

2. Experimental Method

Chamber design The emulsion chambers are composed of lead plate (2.5mm) and emulsion plate (50 μm emulsion coated on both sides of 800 μm thick acryl base) of face area 10cm x 10cm. These plates are alternately stacked except for top two emulsion plates. The geometrical dilution facter is 1.36.

Electron beam The electron beams of intensity 2~5/cm² were irradiated with a right angle to the chamber face. The beam energies were 100 GeV and 300 GeV. The energy resolution was ~2%[3].

Scanning of Cascade events The general scanning was carried out at one or two layers of each chamber under a microscope with an object lens of power 20. Cascade showers realy induced by a single electron were analysed. We omitted some contaminations such as showers induced by γ rays or π^- and also omitted closed incident events. The number of events analysed are 49 and 31 showers for 100 GeV and 300 GeV, respectively.

Track counting The shower tracks were sketched under a microscope with an object lens of power 60. Out of these tracks, after once sketched, only those with angles less than 10° against the beam axis were counted as the cascade electrons. The shower axis was taken on each plate so the number of shower tracks within a radius 50 μm as to be maximum.

3. Results

The average transition curves fit well to the theoretical curves (see

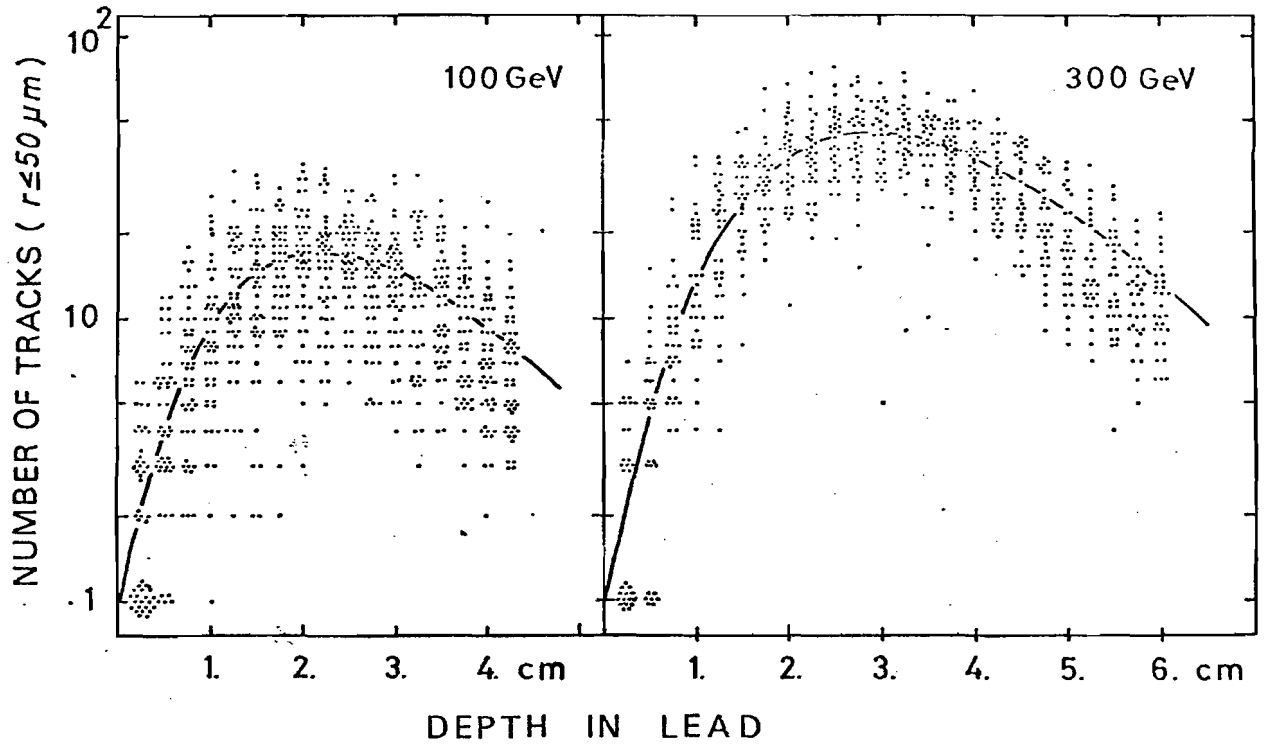

Fig. 3. Superposition of number of tracks inside a disk of radius 50 μm. The solid curves are the theoretical ones (half of pair curve).

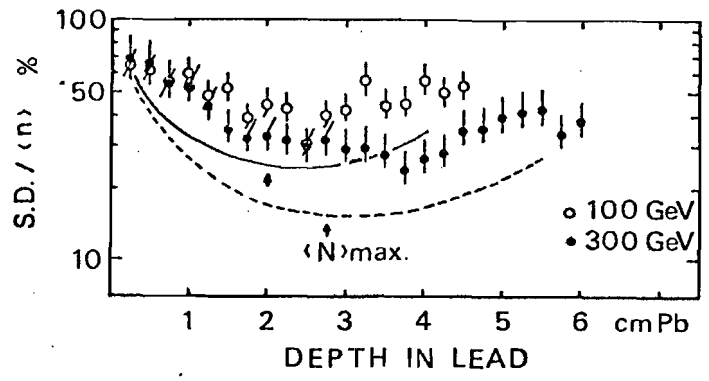

Fig. 4. Depth dependence of one standard deviation of distribution of track number inside a disk of radius 50 μm. The solid and dashed curves are for the Poissonian distribution with 100 GeV and 300 GeV, respectively. The arrows indicate the depth of maximum of the average experimental transition curve.

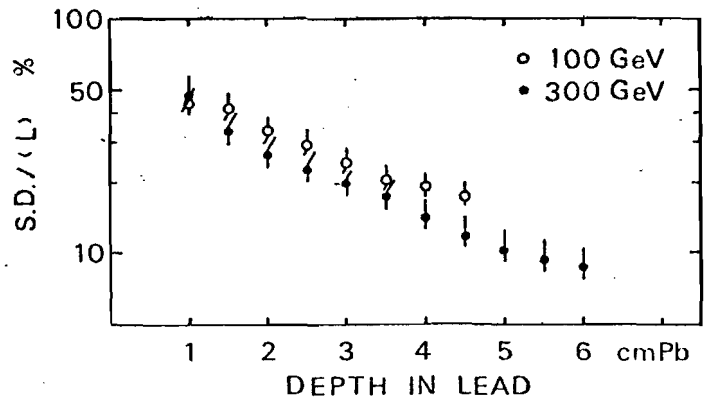

Fig. 5. The depth dependence of one stansard deviation of track length distribution inside a cylinder of radius 50 μm.

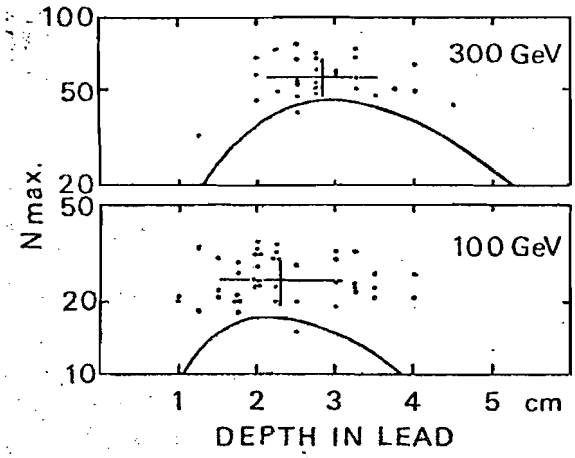

Fig. 6. The distribution of Nmax of each shower. The crosses mean the one standard deviation of Nmax, 23% and 20%, and of depth t, 33% and 25%, for 100 GeV and 300 GeV, respectively.

Fig.1), but the number of electrons on each layer shows a large fluctuation (see Fig.2). Fig.3 shows the superposition of number of electrons of each shower. The solid curves are the theoretical one, the half of pair curve, described in section 1. The spreading of number distribution at each depth is shown in Fig.4. The vertical axis means one standard deviation devided by the mean value. The spreading is smallest around the depth of maximum development and increases towards either side. Its absolute value, however, is about twice larger than that of Poissonian distribution at most depth*. We can see that the spreading of the distribution decreases with the increasing initial energy.

The track length inside a cylinder of radius r till a certain depth t in lead is defind in this paper by

$$L(\leq r,t) = t_o \cdot \sum_{i=3}^{k} n_i(\leq r) \qquad \text{(cm in lead)},$$

where t_o is the thickness of a lead plate, $t=(k-2)\cdot t_o$ and n_i is the number of tracks inside a disk of radius r at the front side of i-th emulsion plate from

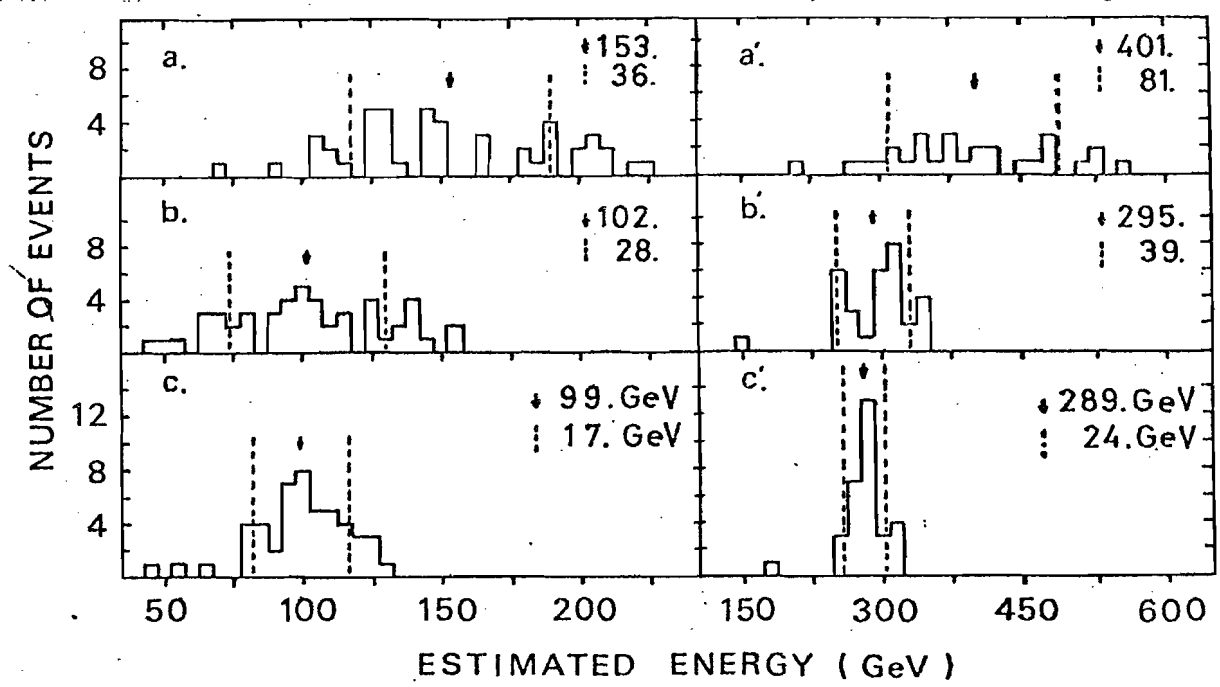

Fig. 7. The distribution of estimated cascade energies using Nmax (a and a'), transition curve (b and b') and track length (c and c') for 100 GeV (left) and 300 GeV (right). The dashed lines show one standard deviation and the arrows indicate the mean values.

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* For the total number of electrons the spreading is expected to be Poissonian at the depth of the maximum development[4].

the chamber top. As shown in Fig.5 (the vertical axis is same as Fig.4) the spreading of track length distribution contracts monotonically with the depth in lead. Its slope seems to depend on the electron's initial energy, i.e., the larger is the energy the faster the spreading decreases.

On the other hand, *N*max of each shower is almost always larger than the theoretical value (see Fig.6). Though one standard deviation of *N*max distribution for 100 GeV is nearly equal to Poissonian distribution, that for 300 GeV is not so small as expected.

Now, let us make a comparision between the known beam energy and the cascade energies estimated from the data by fitting to the theory (see Fig.7). The largest ambiguity in the energy estimation is given for using the data of *N*max (a and a') and the smallest one is for the track length (c and c'). The case using the four layers' data with each 1 cm thick lead interval, centered at the maximum development, gives an intermediate ambiguity (b and b') rather near the case for the track length.

4. Conclusions

The distribution of number of tracks within a radius 50 μm shows the narrowest spreading around the depth of the maximum track number, but it is about twice larger than the Poissonian distribution at any depth. The distribution of track length from top to a certain depth is, in general, smaller than that of number of tracks at the depth for the disk of the same radius. And the former decreases monotonically with the depth.

In the energy estimation of an incident electron the track length gives the smallest ambiguity, 17 % for 100 GeV and 8 % for 300 GeV. These results are consistent with other authors[5]. The maximum number of tracks in each shower gives not only a large ambiguity but also too high incident energy in an average. When the data at the four points of depth around the maximum are employed for the practical use, the ambiguity is larger than that of track length, 28 % for 100 GeV and 13 % for 300 GeV, but the average estimated energy shows a good agreement with the incident beam energy within 2 %.

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