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FERMILAB-CONF-77-179-E

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THE ELECTROMAGNETIC CASCADE SHOWERS IN LEAD ABSORBER

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In order to study the three dimensional behaviour of electromagnetic cascade showers in lead absorber, thirteen emulsion chambers were exposed at Fermi National Accelerator Laboratory for the monoenergetic electron beams with energies 50 GeV, 100 GeV and 300 GeV. The transition curves decrease faster than the theoretical ones after the maximum development. At such depths the lateral distributions show steep slopes. The spacing effect between both sides of acryl base of emulsion plate is measured. The similarity law seems to hold at the maximum development in energy range 100 GeV ~ 300 GeV.

1. Introduction.

In many experiments using emulsion chambers or stacks in which the cascade shower initiated by a photon or an electron is detected, the initial energy of the cascade shower has been estimated by fitting the counting data of the shower tracks to the theoretical transition curves of three dimensional cascade showers calculated by J.Nishimura and J.Kidd(1). The theoretical curve itself has never been directly checked by photon or electron beam of an exactly known energy. However, the method of energy estimation by this theory has been approved because of its consistency with energy estimated from a kinematical relation in the $\pi^0 \rightarrow 2\gamma$ decay(2) or from scattering method applied to shower electrons(3) in cosmic ray experiment. Today, it has become to be able to check directly the three dimensional cascade theory by exposures of emulsion chambers to monoenergetic beams made from the 400 GeV proton beam at Fermi National Accelerator Laboratory.

With the above purpose, thirteen emulsion chambers were exposed to the electron beams with energies 50 GeV, 100 GeV and 300 GeV in Octorber 1976 at Fermi laboratory. The preliminary results obtained from the analysis of a few chambers are described in this paper.

2. Chamber design, beams and events.

The emulsion chamber has a simple

structure composed from sensitive layers and lead plates which are stacked alternately except for the two top emulsion plates. The face area of each plate is 10 cm x 10 cm. The sensitive layer is 50 μm emulsion, coated on both sides of 800 μm or 1500 μm thick acryl base. The thickness of lead plates are 2.5 mm or 5.0 mm. Our emulsion chambers have four spacing factors according to the four types of combination of lead plate and acryl base as given in Table 2, where the spacing factor p is defined by the ratio of the repeat distance of emulsion plate versus the thickness of the unit lead plate. Eight chambers, as shown in Fig. 1a, were exposed with right angle to the electron beams with energies 50 GeV, 100 GeV and 300 GeV as summarized in Table 1. Two chambers were exposed with dip angle θ to 300 GeV electrons as shown in Fig. 1b. The other three chambers, having complex structures with mixed spacing factors, are used for practical purpose of energy calibration in another experiment.

Table 1. List of emulsion chambers.

Dip angle of incident electrons ($\tan\theta$)	Energy (GeV)	50			100			300		
	Spacing factor (p)	Chamber	Emulsion	Lead	Chamber	Emulsion	Lead	Chamber	Emulsion	Lead
			layers	cm		layers	cm		layers	cm
0	1.18	C1	9	3.5	C2	11	5.0	C3	16	7.0
	1.32							D	16	7.0
	1.36				A2	20	4.5	A3	30	7.0
	1.64	A1	14	3.0				B	30	7.0
0.5	1.36							A4	26	6.9
1.0	1.36							A5	22	7.1

Table 2. Combination of emulsion plates and lead plates.

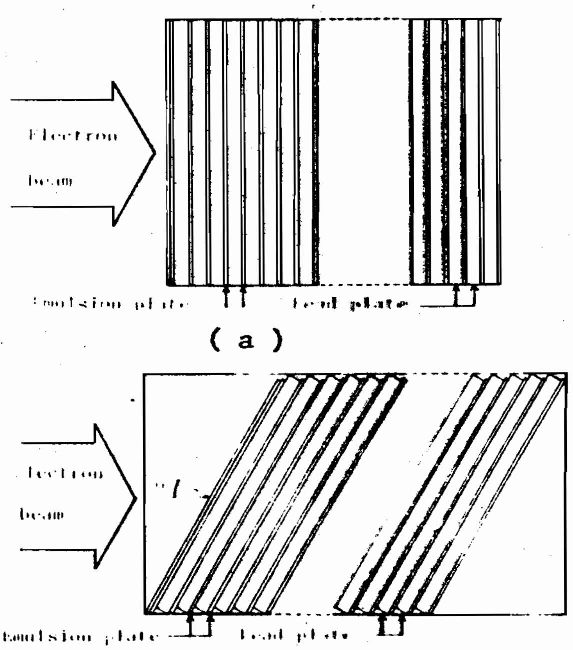
Spacing factor (p)	Thickness of lead plate	Thickness of acryl base	Thickness of emulsion
1.18	5.0 mm	800 μm	50+50 μm
1.32	5.0	1500	
1.36	2.5	800	
1.64	2.5	1500	

The electron beam was expected to irradiate each chamber with beam density $5 \sim 7$ /cm^2. However, the density of shower events found by general scanning under microscope is in a range $1 \sim 5$ /cm^2 except for the two chambers exposed to the 50 GeV electrons, in which only a few events have been found. In each chamber exposed to 100 GeV and 300 GeV electrons $50 \sim 100$ showers have been found. Out of these events $30 \sim 60$ showers are useful for our purpose, for some closed events located at a mutual distance within 2000 μm should be put out of analysis. Moreover, there are some contaminations, *i.e.* jet showers induced by π^- mesons and cascade showers initiated by photons which are generated in the plastic scintillator (1 cm thickness) located at 30 cm in front of the emulsion chamber. The former contamination is distinguished by finding the large angle hadron tracks at the starting point of the shower and/or by deep start in the lead absorber of the chamber. The latter is also excluded by the lack of corresponding single track in the two top emulsion plates. Up to date $10 \sim 40$ showers in each of a few chambers have been analyzed.

3. Method of analysis.

The following three methods are employed for counting the shower tracks,

a) direct eye counting of shower tracks in microscope,
b) sketching the shower tracks in microscope,
c) tracing the enlarged image of shower tracks on micro-projector.



(a)

(b)

Fig.1(a) and (b). Illustrations of chamber construction.

In the method a) the numbers of shower tracks within a circle of radius 50 μm and 100 μm are counted. From our experience the method b) gives the most reliable and detailed data, then the data obtained by the other two methods are checked and calibrated to the data by the method b). The method c) is good enough for showers with track density less than $50 \sim 60$ tracks within a circle of radius 100 μm.

4. Transition curves and lateral distributions.

The preliminary results obtained from the chamber A3, A5 shown in Table 1 for 300 GeV electrons and the chamber C2 for 100 GeV electrons are as follows.

Chamber A3 : (300 GeV, $\tan\theta = 0$, $p = 1.36$, 800 μm base)

51 events have been found by general scanning on two layers at the depths 4.0 cm and 4.5 cm in lead. Out of them about 30 events will serve for our analysis. The average transition curves of 10 events, whose analysis has been finished by the method b) described in section 3, are shown in Fig.2 for shower tracks within circles of radii 12.5 μm, 25 μm, 50 μm and 100 μm. The number of shower tracks on the back side (closed circles) of the emulsion plate are smaller than the data on the front side (open circle), especialy at the layers subsequent to the maximum development. This is due to the spacing effect of the 800 μm base. The experimental data on the front side are surprisingly consistent with the theoretical curves before the maximum development. On the layers subsequent to the maximum development the experimental data show smaller track numbers than the theoretical curves, especialy in the case that the radius is larger than 50 μm. This means that the experimental lateral distribution is steeper than the theoretical one. Fig.3, the average lateral distribution, shows actually this tendency. The back side data are small in the absolute value but their slopes rather fit to the theoretical curves.

Chamber A5 : (300 GeV, $\tan\theta = 1$, $p = 1.36$, 800 μm base)

Out of 70 events, found by the general scanning at the effective depth 2.5 cm and 4.6 cm in lead, 39 showers have been analyzed by the method a) described in section 3. Fig.4 shows the average transition curves of 39

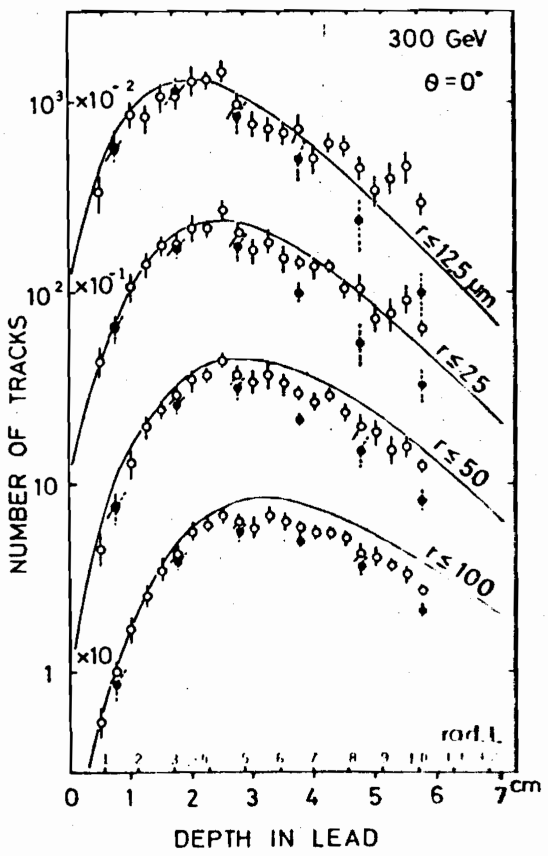


Fig. 2. Average transition curves of 10 events in the chamber A3. Open circles: front side data of the emulsion plate, closed circles: back side data. Solid curves are the theoretical ones.

showers. On the layers previous to the maximum development the front side data show comparatively good agreement with the theory but also show fast drop after the maximum development similarly to the chamber A3. The great reduction of the back side data shown in this figure is due to an increase of effective thickness of acryl base for the inclined electron beam.

In cosmic-ray experiments using emulsion chambers in which X-ray films and shielding papers or poly-ethylene films are ordinary interposed between the lead plate and the emulsion plate, the spacing effect is essential. Such emulsion chambers seem to give lower values of cascade energy for inclined showers.

Chamber C2 : (100 GeV, $\tan\theta = 0$, $p = 1.18$, 800 μm base)

The general scanning was carried out on the layers at the depths 2.0 cm and 2.5 cm in lead and about 80 events have been found. About 50 events will serve our purpose. Out of them 20 showers have been analyzed by the method c) in section 3 on the front side and 10 showers by the method b) on the back side. In the average transition curves shown in Fig.5 the experimental data show fast rising and slightly early and large maximum development. After the maximum the number of shower tracks decreases faster than the theoretical curve

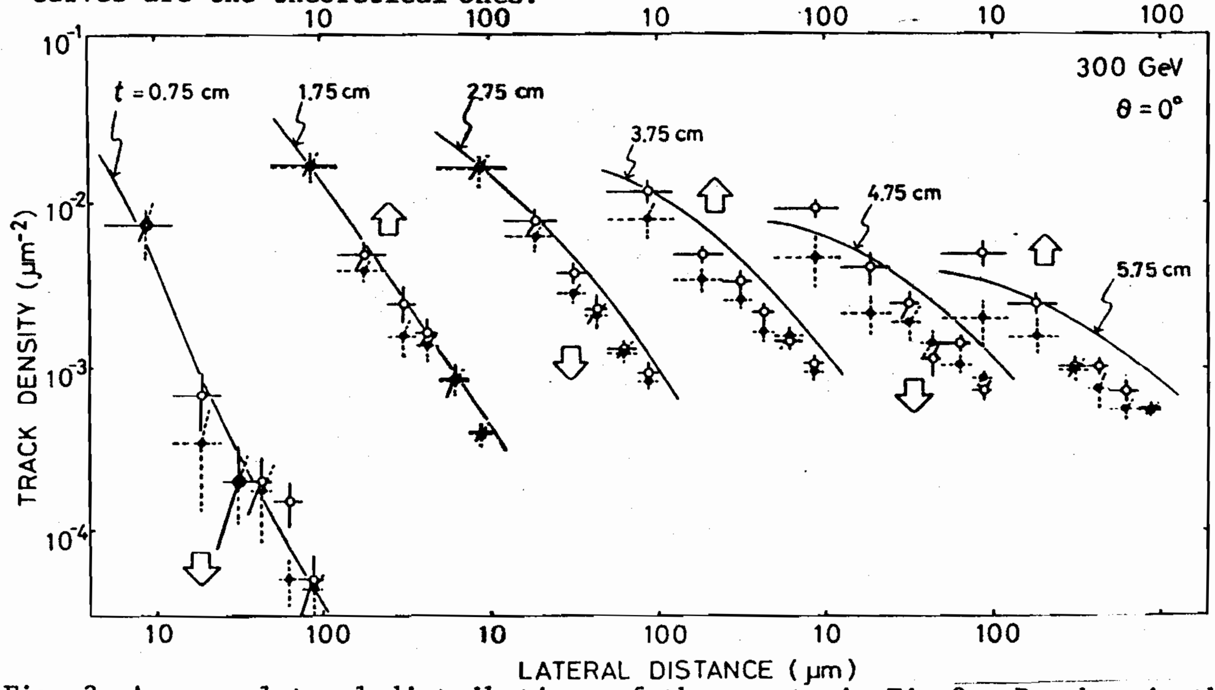


Fig. 3. Average lateral distributions of the events in Fig.2. Depth t is the thickness of lead from the chamber top. Solid curves: the theoretical ones.

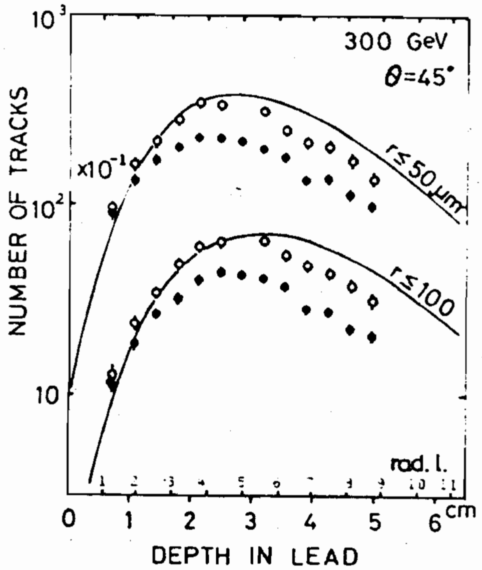


Fig. 4. Average transition curves of 39 events in the chamber A5.

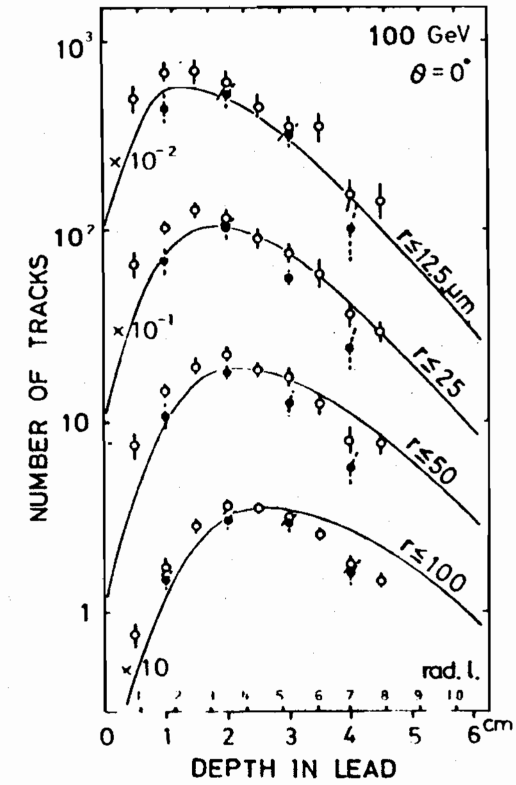


Fig. 5. Average transition curves of 20 events in the chamber C2. (10 events for back side data.)

especially at large distance from shower axis as like as in the data of the chambers A3 and A5. The average lateral distribution shown in Fig.6 also exhibits steep slopes at the deep layers in the emulsion chamber.

In general the location of shower center is diffcult to be determined at the layers far behind the maximum development. On such layers the local high density of shower tracks sometimes attracts our eyes, then we accidentally make an error in location of the shower center. This error might be a cause of steep lateral distribution at the deep layers.

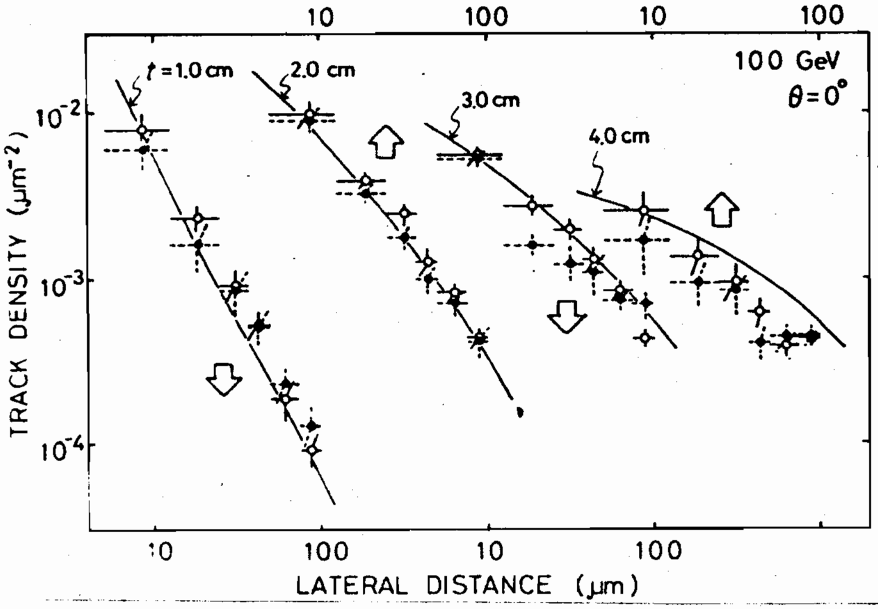


Fig. 6. Average lateral distributions of the events in Fig. 5.

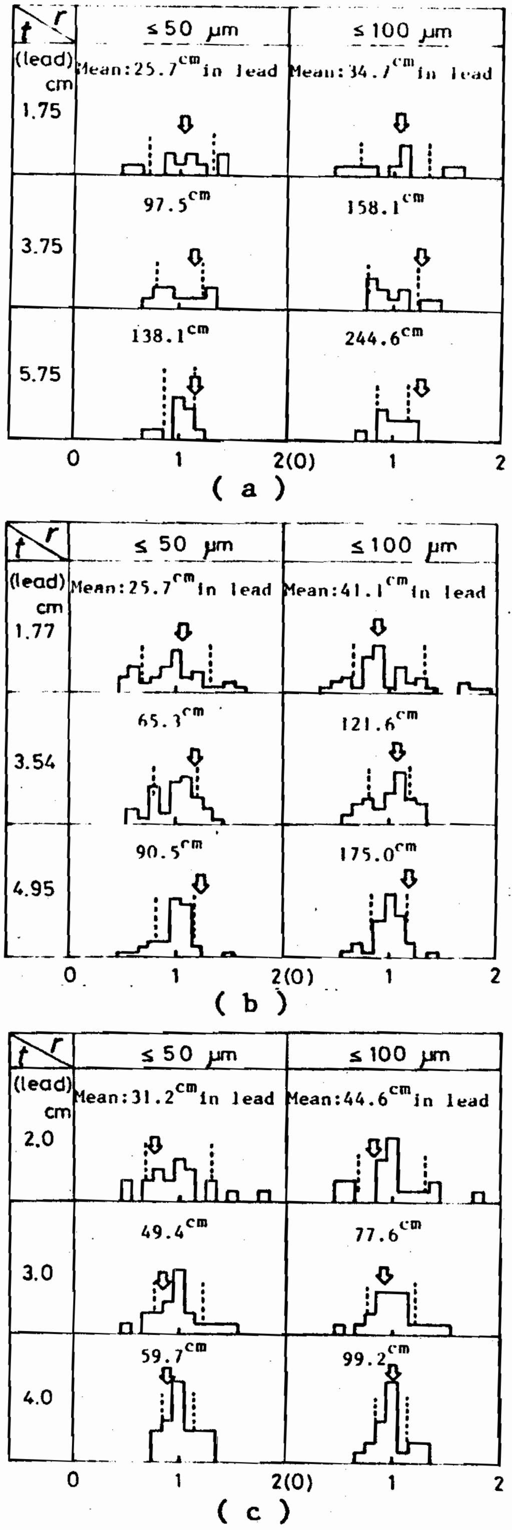


Fig. 7. Track length distributions. (a): the chamber A3, (b): the chamber A5 and (c): the chamber C2.

5. Track length distribution.

The respective transition curves for each events are widely distributed around the average curve. Therefore, in order to get the incident energy as accurately as possible, we consider the track length, $L(\leq r,\ t)$, of shower particles within a cylinder of radius r till the depth t in lead :

$$L(\leq r, t) = t_0 \sum_{i=3}^{k} n_i(\leq r) \qquad (\text{cm in lead}),$$

where t_0 is the thickness (cm) of a lead plate, $t = (k-2)t_0$ and $n_i(\leq r)$ is the number of shower tracks within a circle of radius r on the front side of i-th emulsion plate from the chamber top.

The track length distributions for shower events in the chambers A3, A5 and C2 are ahown in Fig.7a,b,and c, respectively. In each of them the distributions are shown at the three sensitive layers for the cylinders of radii 50 um and 100 um. The mean value in every distribution is normalized to unity and a range of one standard deviation is indicated by two dotted lines. The arrow mark means the theoretical value deduced from the theoretical transition curves according to the above definition equation. Although the mean values of the experimental data do not always agree with the theoretical ones, the distribution becomes apparently narrower as the depth t of the cylinder increases. Furthermore, it is a noticeable point, the dispersion in the track length distribution has little dependence on the radius of the cylinder. It may possibly get more accurate cascade energy by the track length within a cylinder of a small radius than the conventional method of fitting the experimental data to the theoretical transition curves, for we have often met with shower events showing ill-fitting to the theoretical curves in the cosmic-ray or accelerator experiments.

6. Other indications.

In order to check the similarity law in the three dimensional cascade theory, we compare the data of the chambers A3 and C2. The number of shower tracks within a circle at the maximum development is plotted in Fig.8 for a few values of radius. Though the value of the spacing factor p is different between the two chambers, the quantity $p \cdot n^{\max}(\leq r)$ is nearly independent of p according to the theoreti-

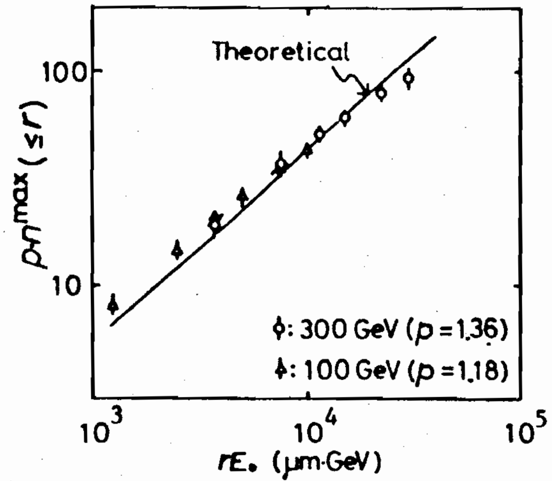


Fig. 8. $r \cdot E_o$ - plot at the maximum development for the data of the chambers A3 and C2.

cal curves. The experimental data of these two chambers do not completely fit to the theoretical curve in Fig. 8, but they show a good agreement with each other. Therefore, we can tell that the similarity law seems to hold at the maximum development, at least, in the energy region 100 GeV and 300 GeV.

7. Acknowledgements. The authors would like to express their gratitudes to Drs. P. Garbincius, S. Mori, B. Cox, L. Voyvodic, T. Nash, and T. Yamanouchi in Fermi National Accelerator Laboratory for making successful exposure of emulsion to electron beams. The authors also wish to express their thanks to Professor J.J. Lord and Dr. J. Wilkes in Washington University for kind facility for successful processing of the emulsion.

8. References.

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