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JUN 27 1977
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CASCADE SHOWERS INDUCED BY 400 GeV PROTONS IN THE EMULSION CHAMBER

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The cascade showers originated from P_b-jets show a fast rising in their development and a steep lateral structure. They hardly fit to the theoretical curves of single γ-ray origin cascade showers but rather fit to those of multiple γ-ray origin showers. The distribution of partial inelasticity of electromagnetic component (K_γ) lies between theoretical curves deduced from the flat and Gaussian distributions of total inelasticity including all secondary particles.

1. Introduction. In order to investigate the longitudinal development and the lateral structure of cascade showers originated from the jet showers, three emulsion chambers were exposed at Fermi laboratory for 400 GeV proton beam.

The distinctive points of the jet origin cascade shower from an electromagnetic cascade shower initiated by an electron or a photon are as follows. The jet origin cascade shower is initiated by multiple γ rays which have an energy spectrum according to that of hadrons. The multiple γ rays are emitted from the interaction point with transverse momenta whose average value is about 0.2 GeV/c. Therefore, the cascade energy is determined by fitting the theoretical transition curves given in our previous paper (Dake S. et al. 1975), in which the CKP jet model is used for the emission mechanism of secondary hadrons, to the experimental data.

2. Design, beam and number of events analyzed. The emulsion chambers have a face area of 9.5 cm × 12 cm and a total thickness of 6 cm lead. Two chambers of which analyses are proceeding have a same construction as illustrated in Fig. 1. They are composed of 16 sensitive layers (each is 50 μm emulsion coated on both sides of 800 μm acryl base) and 12 lead plates of each 2.5 mm thickness which are gilted by silver.

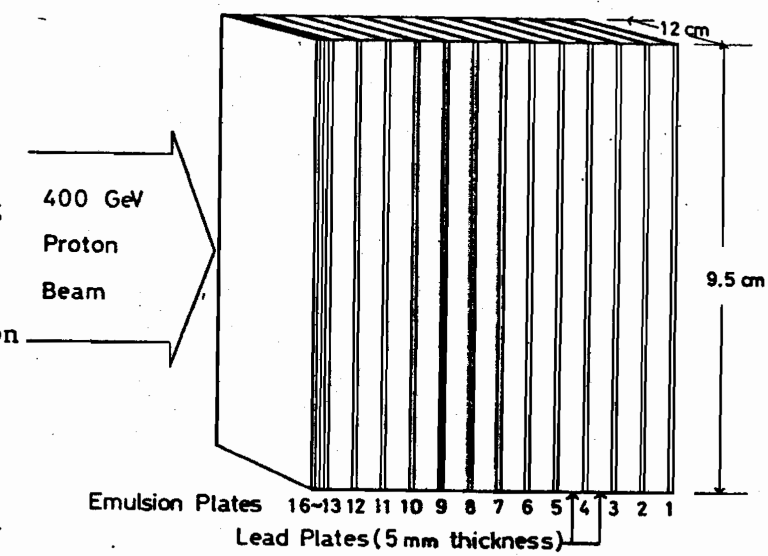

Fig. 1. Emulsion chamber.

The proton beam of density 300 ~ 600 per cm^2 was irradiated at a richt angle to the face of the chamber. The general scanning was performed in the 7th emulsion plate which is located at the depth of 3 cm lead from the chamber top. Only the events which have ten tracks at least within a circle of radius 100 μm from the shower axis were analyzed in detail. Thus, 55 events have been obtained in an area about 2 cm^2 of one chamber and 16 events in about 1 cm^2 of another chamber.

3. Transition and lateral curves. When we fit the theoretical transition curves to the experimental data, we define the starting point of the best fit curve as that of the cascade shower. The distribution of the starting points is shown in Fig. 2 for two cases, *i.e.* when the experimental data are fitted to *a*) the transition curves of single γ-ray origin showers and *b*) those of multiple γ-ray origin showers in the CKP jet model without lateral spread ($p_{T\gamma}$ =0). The distribution of the starting points is clearly unnatural for the single γ-ray origin showers but reasonable for the multiple γ-ray origin showers. This means a fact that the P_b-jet origin cascade showers show the faster rising in their development than the single γ-ray origin cascade showers.

The theoretical transition curves and the experimental points of showers whose energies are estimated to lie between the theoretical curves are shown in Fig. 3. Although the experimental points of individual events are widely distributed, the average numbers of shower tracks, shown by crosses in this figure, are fairly

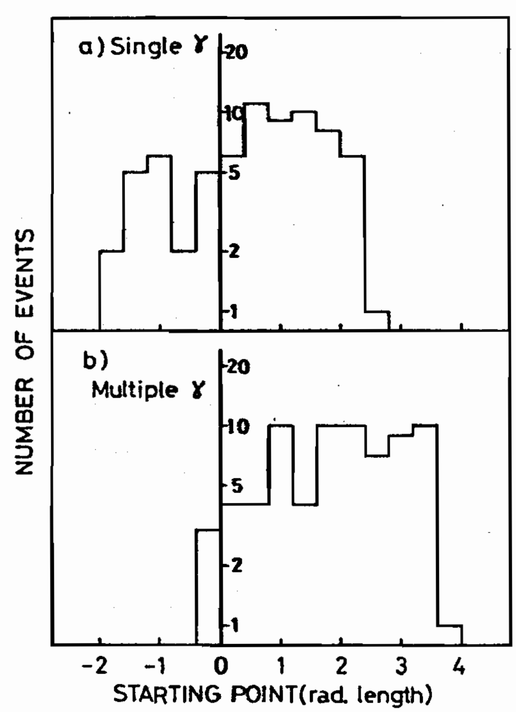

Fig. 2. Depth distribution of the starting points.

suitable for the theoretical cyrves.

The average lateral density distributions of the observed cascade showers are shown in Fig. 4 together with the theoretical curves of the multiple γ-ray origin showers under the CKP jet model without lateral spread. The experimental data are taken at the layer of mean depth 3.0 rad. length from starting points defined above. However, they hardly fit to the theoretical curves at the depth 3.0 rad. length but rather fit to those of 2.5 rad. length. This is a newly found feature of the P_b-jet origin cascade showers of which the cause must be inquired.

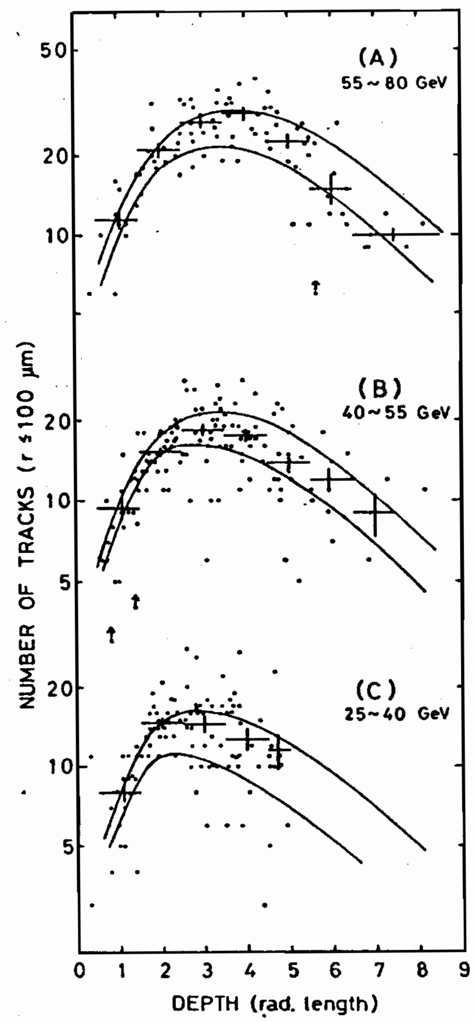

Fig. 3. Superposed transition curves for events with ΣE_γ= (A) 55~80 GeV, (B) 40~55 GeV and (C) 25~40 GeV. Solid curves are the theoretical ones for multiple γ-ray origin cascade showers without lateral spread.

__4. Cascade energy and detection bias.__ In the last section the cascade energy is estimated by using the theoretical transition curves without lateral spread of the initial γ rays. The energy thus obtained is a low estimation because these γ rays must be emitted with a transverse momentum of 0.2 GeV/c on an average. The lateral spread of the initial γ-rays has a similar effect to a spacing effect in material which decreases the number of shower tracks within a circle of a certain radius. Moreover, the effect due to the lateral spread is more essential in the lower energy region different from the spacing effect because of the constancy of the average transverse momentum. Therefore, we make a correction of the cascade energy obtained in section 3 by using the CKP jet model with lateral spread of the initial γ rays. The correction factor is shown by a thick solid curve in Fig. 5. Hereafter, we use the cascade energy corrected by this curve.

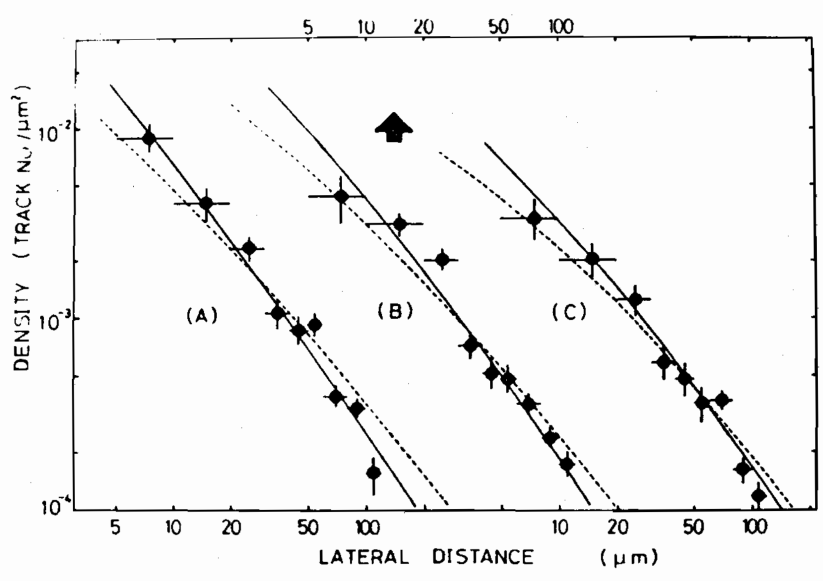

Fig. 4. Superposed lateral curves of the same events as in Fig. 3. Solid curves: at the depth 2.5 rad. length, dashed curves: 3.0 rad. length for mean cascade energy (A) 72 GeV, (B) 46 GeV and (C) 34 GeV.

In Fig. 6 is plotted the correlation of the cascade energy and the number of tracks, n, within a circle of radius r=100 μm in the 7th layer of emulsion plate. The solid line n=10 is a detection bias and the solid curve indicates a relation of the cascade energy and the maximum number of tracks of the theoretical transition curves. The experimental points show a fluctuation around this curve and the points far under from this curve indicate the events at the early stages of their development. The most (95%) of the experimental points are involved within the area between the two dashed curves in Fig. 6. Therefore, the energy spectrum shown in Fig. 7 is given with a 95% confidence for detection bias in the energy region above ΣE_γ= 150 GeV.

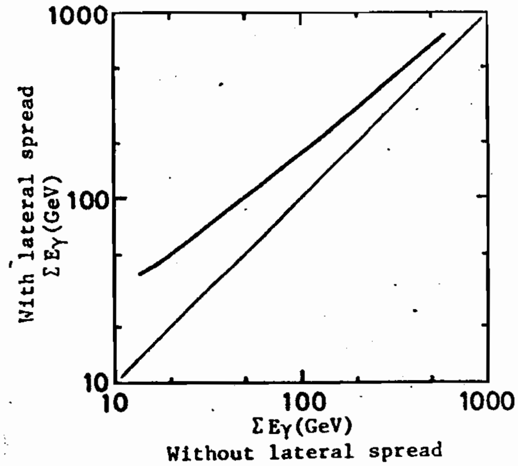

Fig. 5. Conversion factor of cascade energy from the CKP jet model without lateral spread of initial γ rays to that with it.

The cascade shower is contaminated by hadrons generated in the jet among the cascade electrons and positrons. Most of the secondary hadrons have energies less than 50 GeV in jets induced by 400 GeV protons. As these hadrons go out of a circle of radius 100 μm except for a few initial emulsion plates before the maximum development, the contamination of few energetic hadrons around the maximum development does not mislead the cascade energy.

On the other hand, the successive interaction of the survival nucleon or of the energetic secondary hadrons does not occur so frequently, because the emulsion chamber is mainly composed of lead absorber in which the collision mean free path of nucleon or pion is much longer than rad. length. Never-

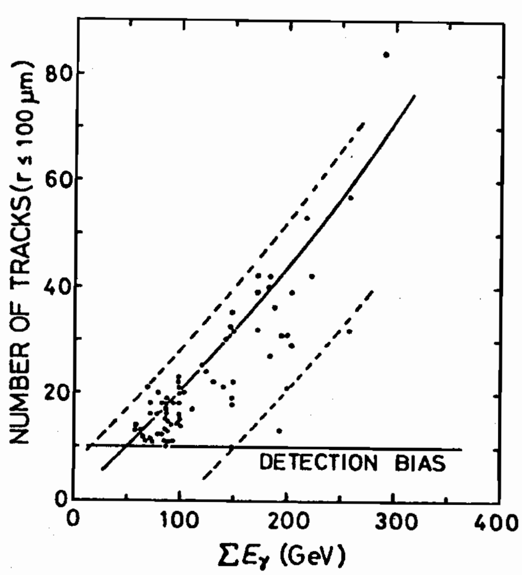

Fig. 6. Diagram of cascade energy and number of tracks at the layer of general scanning.

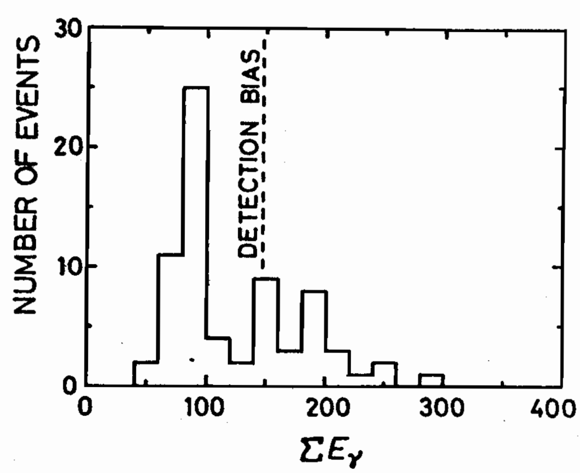

Fig. 7. Distribution of cascade energy.

theless, several events of adjacent successive interaction have been found, which are now under analysis. Only the part of the cascade shower induced by the first interaction in these events is presented in this paper.

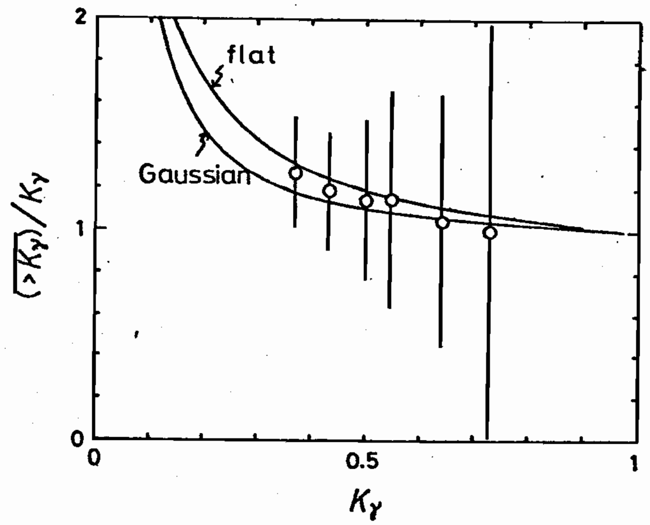

Fig. 8. K_γ dependence of $(\overline{\geq K_\gamma})/K_\gamma$.

5. Inelasticity distribution of electromagnetic component. The cascade energy obtained in section 4 is equal to the total energy of the initial γ rays at the interaction point. Therefore, a partial inelasticity of electromagnetic component (K_γ), *i.e.* an energy fraction carried by the initial γ rays out of the incident proton energy (400 GeV), can be given for each cascade event.

Using K_γ distribution function $f(K_\gamma)$, we define a quantity as

$$\overline{(\geq K_\gamma)} = \frac{\int_{K_\gamma}^{1} K'_\gamma f(K'_\gamma)\,dK'_\gamma}{\int_{K_\gamma}^{1} f(K'_\gamma)\,dK'_\gamma} .$$

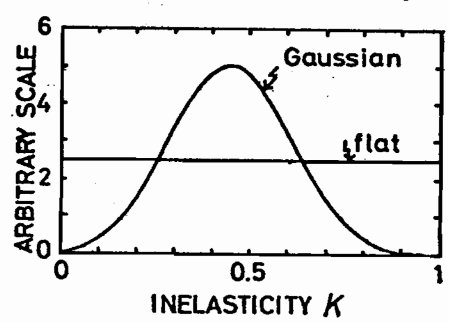

Fig. 9. Two assumed distributions of total inelasticity.

The quantity $\overline{(\geq K_\gamma)}$ implies the average K value in the region of the K_γ distribution greater than K_γ. The ratio $\overline{(\geq K_\gamma)}/K_\gamma$ obtained in this experiment is plotted in Fig. 8. The curves drawn in this figure are the theoretical ones deduced from assumed K distribution (K is a total inelasticity for all secondary particles). Two types of K distribution are assumed. One is a flat type and another is a Gaussian type as shown in Fig. 9. Assumption of charge independence of the interaction and the KNO scaling (Koba Z. et al. 1972) are used in the calculation. As shown in Fig. 8 the experimental result lies between the curves deduced from the flat and Gaussian K distributions for jets induced by 400 GeV protons in lead. However, the both distributions are within statistical errors of the experimental points.

6. Acknowledgements. The authors would like to express their gratitudes to the members of the Fermi National Accelerator Laboratory for making successful exposure of emulsion to accelerator beams.

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