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CASCADE SHOWERS ORIGINATED IN JET SHOWERS

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ABSTRACT

Cascade showers originated in jet showers occured by 400 GeV proton beam in an emulsion chamber will be studied for their longitudinal development and lateral structure.

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ABSTRACT

Cascade showers originated in jet showers occured by 400 GeV proton beam in an emulsion chamber will be studied for their longitudinal development and lateral structure.

THE PURPOSE OF THE EXPERIMENT

The cascade showers originated in jet showers[1] are studied by using an emulsion chamber. The purpose of this experiment is to observe the longitudinal development and the lateral structure of the cascade showers originated in the jet shower in emulsion chamber.

The results can be compared with the pure electro-magnetic cascade showers initiated by electron, which is our other proposal #340. If the difference between the above two kinds of shower is made clear, we can discriminate them in cosmic-ray experiments. Also, we can discriminate the nuclear events from the bremsstrahlung event in muon experiment with emulsion chamber.

CONDITIONS REQUIRED IN THIS EXPERIMENT

1) Beam: parallel and mono-energetic proton beam
2) Energy: proton beam at 400 GeV
3) Amounts of irradiation: 10 to 10^2 particles/cm^2.

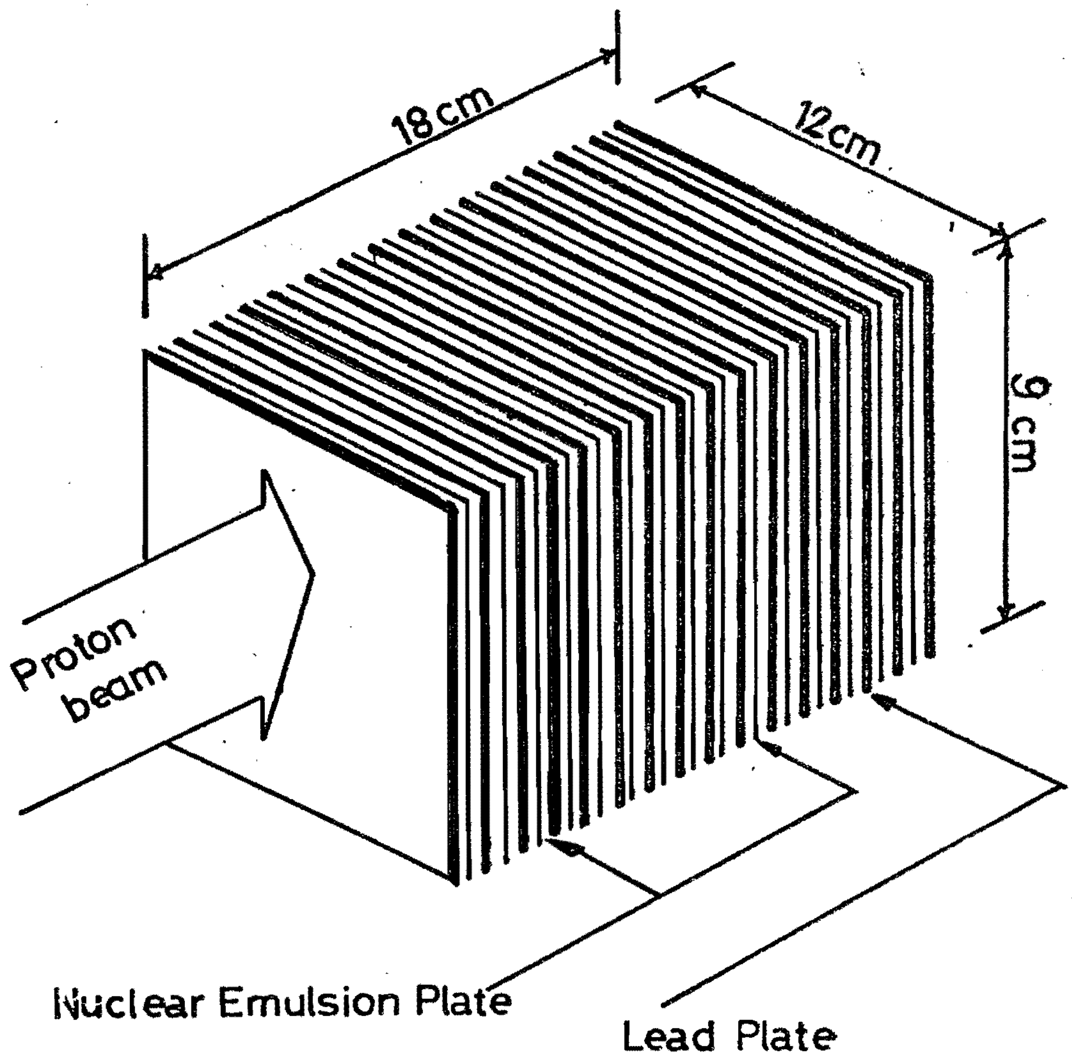
DETECTOR

The chamber is composed of nuclear emulsion plates and lead plates which are piled up alternatively. The schematic view of the detector is shown in the figure. The geometrical size of the detector is about 9 cm x 12 cm x 18 cm and the total thickness of lead absorber is 30 radiation lengths. Two or three chambers are scheduled to be exposed.

REFERENCE

[1]Cascade Shower Originated in Jet Shower, paper presented at 14th International Conference at München, HE6-47 (1975).

SCHEMATIC VIEW OF THE DETECTOR



Cascade Shower Originated in Jet Shower

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The transition curves and the lateral distributions of jet origin cascade shower in the uniform materials are calculated. As the type of the emission of secondary particles the C.K.P. model is adopted and the Nishimura-Kidd curves are also used for the lateral distribution of a single photon initiated cascade shower. It is found that the lateral distribution of shower electrons is fairly affected by the lateral spread of initial photons, that is, the decay products of neutral pions emitted from the jet. For the lateral distribution of shower electrons the result of calculation shows a good agreement with an observed P_b-jet origin shower in an emulsion chamber.

1. Introduction. In the experiments of emulsion chamber works, the initial energy of a photon or an electron is determined with a sufficient accuracy by comparing the number of electron tracks within a circle of radius R from the shower axis with the theoretical one which was given numerically by J. Nishimura and J. Kidd.[1)2)3)]

A group of photons as the decay products of neutral pions emitted from the jet shower in materials developes a cascade shower which should be called a jet origin cascade shower. But, the decay photons from the neutral pions have a large lateral spread originating from the transverse momentum of secondary pions as compared with the spread of shower particles in the electro-magnetic cascade process. And also, the energy spectrum of the decay photons is different from that of shower electrons and photons in the cascade process. Then, these two cascade showers give the different lateral distribution of shower electrons, even if they have a same total energy. For the jet origin cascade shower, we calculated the number of shower electrons within a circle of radius R from the shower axis at the depth t c.u. by using the C.K.P. model[4)5)] as the type of secondary particle emission in the jet. The calculation enable us to descrive the transition curves within a circle of an arbitrary radius and the lateral distributions of shower electrons at any depth. In this paper we report the results of calculation and attempt to compare them with a P_b-jet origin shower obtained in the emulsion chamber.

2. Calculation. According to the C.K.P. model, the energy distribution of the decay photons from the neutral pions is given by a following expression for E>>1 GeV, that is

$$n(E)dE = -\frac{A}{T}\, E_i\left(-\frac{E}{T}\right) dE, \qquad (1)$$

where E is the energy of a photon, T the average energy and A the multiplicity and $E_i(-z)$ means the exponential integral function which is defined by $E_i(-z) = -\int_z^\infty e^{-t}/t\,dt$. If the inelasticity in the jet is chosen to be 0.5, the multiplicity A of the decay photons is given as $A=(2c/3)\cdot(3\Sigma E_\gamma)^{1/4}$, where ΣE_γ (TeV) is the total energy of the decay photons and c=2.0 is a constant. Then the average energy T of the decay photons is given by $T=\Sigma E_\gamma/A=(3\Sigma E_\gamma)^{3/4}/2c$. In the C.K.P. model, the distribution of the transverse momentum $p_{t\gamma}$ of the decay photons is also given as

$$g(p_{t\gamma})dp_{t\gamma} = p_{t\gamma}(-E_i(-\frac{p_{t\gamma}}{p_{to}}))dp_{t\gamma}, \qquad (2)$$

where p_{to} is 0.2 GeV/c.

Assuming for the decay photons to be emitted from the jet in the materials according to the above C.K.P. model, we can calculate the number of shower electrons at the plane perpendicular to the jet axis. Here, we neglect the successive nuclear interactions of the survival nucleon or the secondary mesons. At first, we remark the cascade shower initiated by one of the decay photons with an energy E and a transverse momentum $p_{t\gamma}$. The lateral distribution of electrons of this cascade shower at the depth t c.u. from the starting point of the jet is given by the Nishimura-Kidd curves. Then we put the number of electrons as f(E,R,d,t) within a circle of radius R arround the jet axis which locates at the distance d from the axis of the cascade shower. The distance d between the two axes is given by $d = (p_{t\gamma}/E)tL$, where L is the thickness of 1 c.u., that is 5,700 μm in the pure lead or 7,180 μm in the expanded lead with the spacing factor 1.26. The total number of electrons within the above defined circle is given by the sum of the contribution of all initial decayed photons, that is, by the integral of the function $f(E,R,\frac{p_{t\gamma}}{E}tL,t)$ respect to E and $p_{t\gamma}$ as follows,

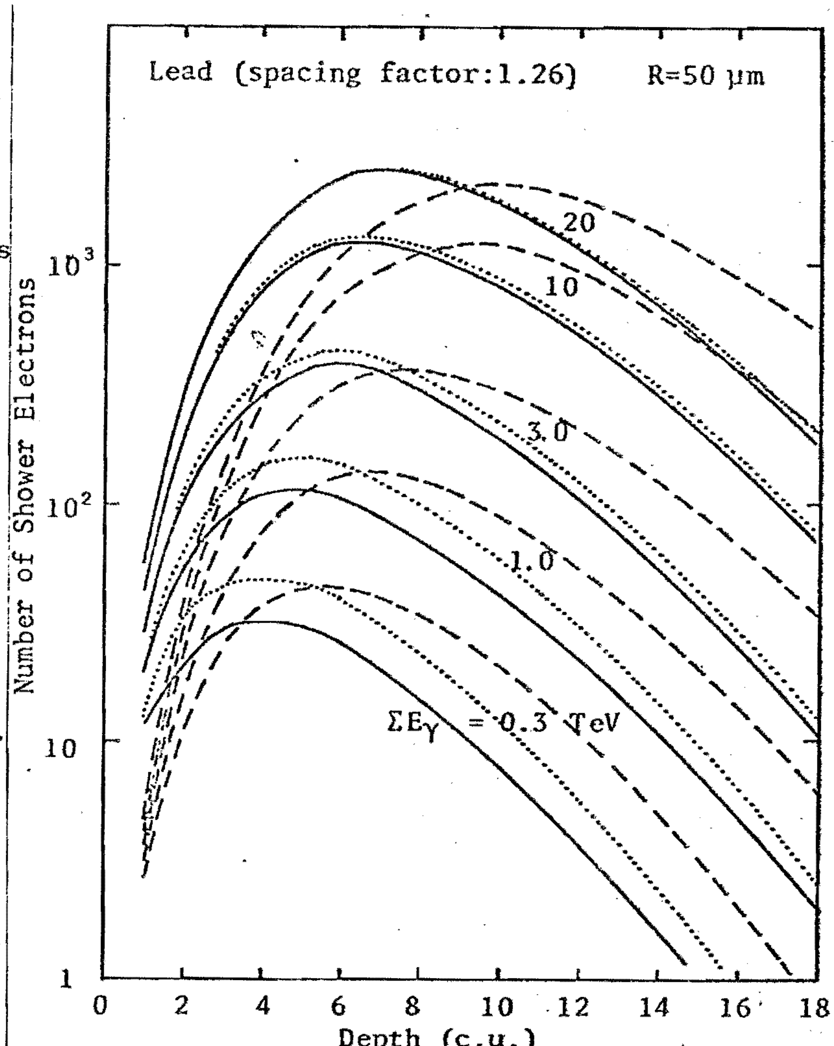

Fig. 1 Transition curves within the circle of radius 50 μm for the three types of cascade showers; C.K.P. jet origin with the lateral spread of initial photons (solid curves), C.K.P. jet origin without the spread (dotted curves) and single photon origin (dashed curves).

$$N_{js}(\Sigma E_\gamma,R,t) = \int\int f(E,R,\frac{p_{t\gamma}}{E}tL,t)\cdot n(E)\cdot g(p_{t\gamma})dEdp_{t\gamma}$$

$$\cong \int_0^\infty dE\frac{A}{T}\{-E_i(-\frac{E}{T})\}\int_0^\infty f(E,R,\frac{p_{t\gamma}}{E}tL,t)\{-E_i(-\frac{p_{t\gamma}}{p_{to}})\}p_{t\gamma}dp_{t\gamma}. \quad (3)$$

The numerical calculation of the double integral is carried out by the help of the Gauss integral as

$$N_{js}(\Sigma E_\gamma,R,t) = \sum_{k=1}^{n} w_k\{-E_i(-x_k)\}\sum_{\ell=1}^{n} f(TRx_k,\frac{p_{t\gamma}}{Tx_\ell}tL,t)x_\ell\{-E_i(-x_\ell)\}w_\ell, \quad (4)$$

where w_i and x_i ($i=1\sim n$) are the Gauss's factor of the integral in which the exponential function is involved and n=4 is used in this calculation.

3. Results. The transition curves for P_b-jet origin cascade shower within radius 50 μm are shown in Fig. 1 for various energies. The solid curves are the case with the lateral spread of initial photons according to the Eq. (2) with p_{to}=0.2 GeV/c and the dotted curves are without the lateral spread, that is, the zero transverse momentum. The difference between these two curves shows us the effect of lateral spread of the initial photons. Its effect fades away when the total energy of the initial photons (ΣE_γ) increases. The dashed curves indicate the transition curves for single photon initiated showers. Though the jet origin showers develop more rapidly than the single photon initiated showers, they show the similar shape in the transition curves. The differences between the two curves in the maximum electron numbers and in their positions vary with the initial total energy.

Fig. 2 shows the ratio of the number of electrons within the circle of radius R at the shower maximum of a jet origin cascade shower to that of a single photon initiated shower with a same total energy 1 TeV. The

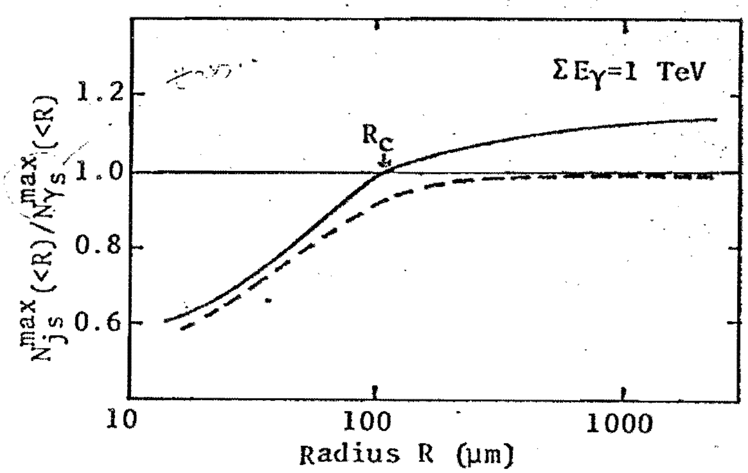

Fig. 2 Ratios of number (solid curve) and track-length (dashed curve) of shower electrons within the circle of radius R of jet origin shower to those of single photon initiated shower.

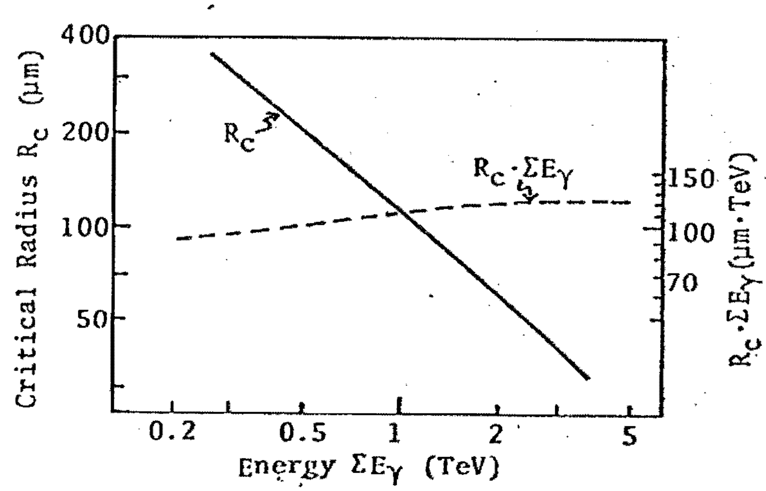

Fig. 3 Critical radius R_c and $R_c\cdot\Sigma E_\gamma$, where ΣE_γ indicates the initial total energy of photons or of single photon.

dotted curve shows the ratio of the total track length within radius R. It is noted that the energy of a jet origin cascade shower determined by using the transition curve for a single photon is underestimation for the radius smaller than the critical radius R_c, for an example $R_c \simeq 110$ μm for $\Sigma E\gamma = 1$ TeV, and is overestimation for $R > R_c$. The critical radius, in which the number of electrons coincide with each other for the two types of cascade showers, decreases with the initial total energy as shown in Fig. 3. On the other hand, the energy estimation by using the track length is always underestimation. These tendencies are characteristic for the jet origin cascade shower.

Moreover we obtain the lateral distribution of shower electrons by numerical differentiation of the transition curves with a parameter of radius R. Fig. 4 shows the lateral distributions of electrons in P_b-jet origin cascade shower with a fixed energy 1 TeV at the various depths. The solid curves indicate the case with the lateral spread of initial photons and the dotted curves the case without it. The effect of the lateral spread appears in the fact that the former case give the lower electron density than the latter case, especially near the jet axis. The dashed curves are the lateral distributions for single photon initiated showers with the same energy 1 TeV. Comparing the lateral distribution of the P_b-jet origin shower with the lateral spread at the depth t c.u. to that of the single photon initiated shower at the depth (t+2) c.u. (for $4 \leq t \leq 14$), we find that they have similar shape and value for $R > 50$ μm. The shift by 2 c.u. is consistent with that of transition curves as shown in Fig. 1. For $R < 50$ μm, the lateral curve of P_b-jet origin shower shows flatter distribution and its absolute value is smaller than those of the single photon initiated shower. However, such differ-

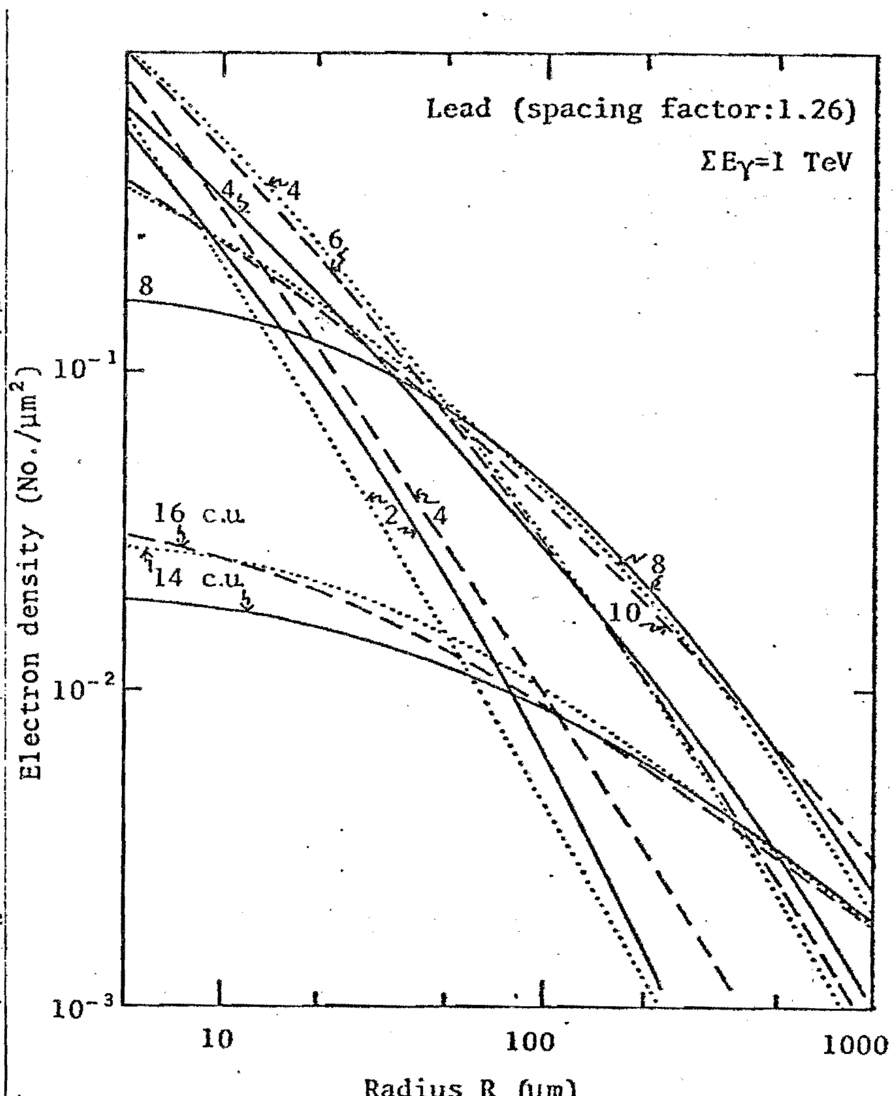

Fig. 4 Lateral curves for a C.K.P. jet origin cascade shower with $\Sigma E\gamma = 1$ TeV (solid curves: with the lateral spread of initial photons, dotted curves: without it) and dashed curves for a single photon initiated shower with $E\gamma = 1$ TeV. Numbers attached to the curves show the depths (c.u.) from the starting point of shower curve.

ence is not found between the P_b-jet origin shower without the lateral spread of initial photons and the single photon initiated shower.

Therefore, if we want to know whether a cascade shower found in the emulsion chamber originates from a single photon or a jet, we have to observe the lateral structure of electron density at the earlier stage of the cascade development. For, we cannot decide it from only the shape of transition curve, as the starting point of jet origin shower is not observed in the ordinary emulsion chambers.

4. Comparison with experment. Now we compare the calculation with an experimental data. An example of cascade shower in emulsion chamber experiment at Mt. Norikura is shown in next two figures. Fig. 5 shows the numbers of the shower electrons within the circle of R=50 μm at the depths 10.5 c.u. (layer A) and 14.0 c.u. (layer B) from the chamber top. Fig. 6 shows the lateral distributions of shower electrons at both layers. At these depths, P_b-jet origin shower is found with a comparable probability to that of single photon initiated shower at Mt. Norikura. In the Fig. 5 the energy of the cascade shower is estimated ΣE_γ=3.5 TeV by the solid curve for P_b-jet origin shower and also E_γ=3.6 TeV by the dashed curve for single photon initiated shower. If the observed shower is originated from the P_b-jet, the interaction point of the jet is estimated to be 7.2 c.u. from the chamber top, so that the depth of the observation layer A is lead to be t_1=3.3 c.u. from the interaction point of the jet and that of B is t_2=6.8 c.u.. On the other hand, if it is a cascade shower initiated by a single photon, t_1 is estimated to be 5.0 c.u. and t_2 is 8.5 c.u.. In the Fig. 6, the solid curves are the theoretical lateral distributions for P_b-jet origin shower with energy ΣE_γ=3.5 TeV at the layer A (t_1=3.3 c.u.) and layer B (t_2=6.8 c.u.), and the dashed curves are for single photon initiated shower with E_γ=1 TeV at the layer A(t_1=5.0 c.u.) and layer B(t_2=8.5 c.u.). It is found from this figure the experimental lateral distribution shows better fit to that of jet origin shower than that of single photon intiated shower. Thus, we can know this shower to be not a single photon initiated shower but a P_b-jet origin shower.

As the method of the calculation has been

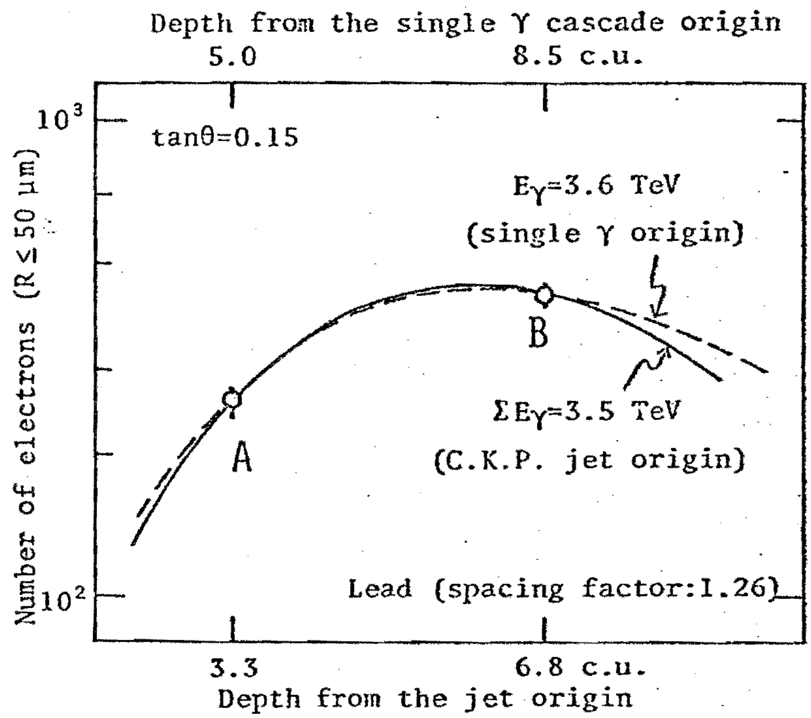

Fig. 5 Fitting the theoretical transition curves (solid curve: jet origin shower with the lateral spread, dashed curve: single photon initiated shower) to the experimental data observed in an emulsion chamber. Sensitive layers A is located at the depth 10.5 c.u. and B is at 14.0 c.u. from the top of the emulsion chamber.

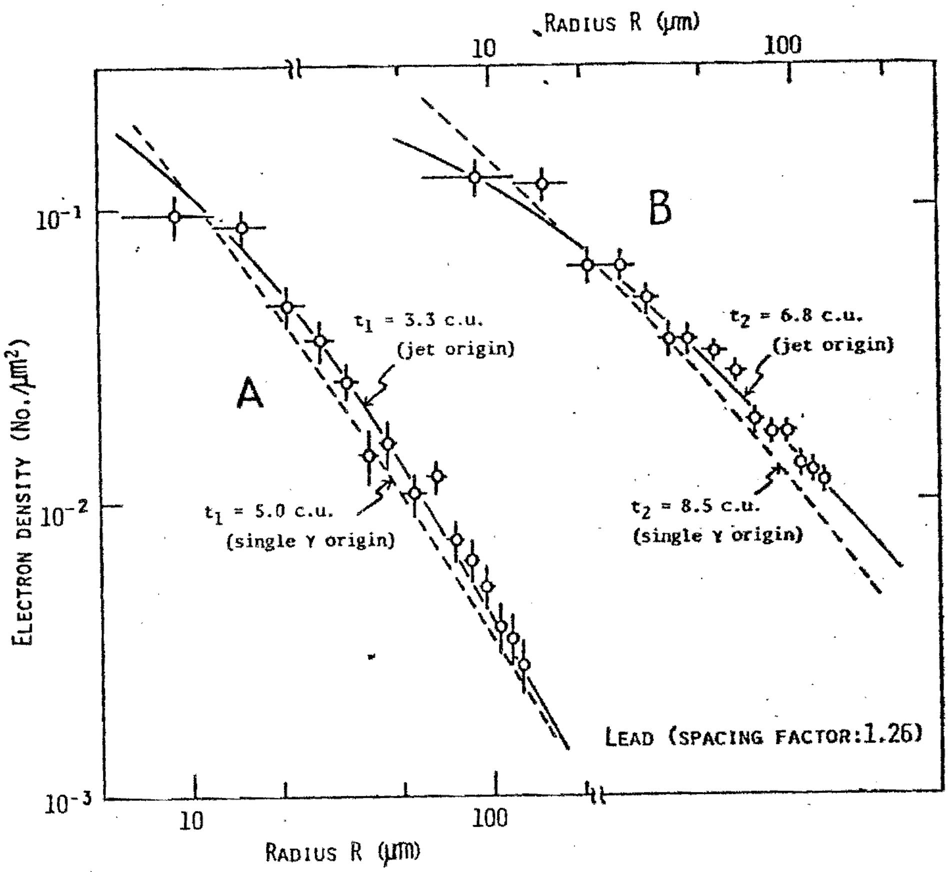

Fig. 6 Lateral distributions of the observed data at the layers A and B, and the theoretical curves (solid curves: jet origin shower with the lateral spread, dashed curves: single photon initiated shower).

established, we can easily obtain the result as mensioned above, under various kinds of jet model (scaling, two fire balls etc.) and in several materials (Air, Fe, Al and so on). And also, we have a plan of the calculation in which the successive nuclear interactions are taken into consideration by using the results of the above P_b-jet origin cascade shower. We can apply the results of calculation to the steep core of EAS and to the selection of the nuclear interaction of muons in the underground emulsion chamber.

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