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III-4-28. Fine Structure of the Core of Extensive Air Showers

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Fine structure of the core of extensive air showers (EAS) was studied with a device named the neon hodoscope. Considerable fluctuation of the structure was found within 3 m from the axis. In particular, those cores are noted whose lateral distribution is definitely steeper than $1/r$ as close as 10 cm to the axis. As the implication of these cores, it is inferred that the majority of the transferred energy may be concentrated to one or a few γ-ray (or π^0-mesons) in some high energy interactions of the order of 10^{14} ev.

Three remarkable multi-core events have been observed. From the energy of the separate steep core and its distance from the main axis of the EAS, the transverse momentum is estimated to be more than 5 Gev/c in each case, assuming that the separate core is due to the nuclear interaction within a few Km above sea level. Frequency comparison would suggest that the large transverse momentum might be related to unusual concentration of the transferred energy into one or a few γ-rays.

The lateral distribution has been studied with 14 scintillation counters of 1 m^2 each, whose arrangement will be found in the report III-4-1. The result found, is that the lateral distribution is almost unique at a distance greater than 3 to 5 m, regardless of the size.[1] On the other hand, the lateral structure within 3 m was confirmed to fluctuate considerably from shower to shower.

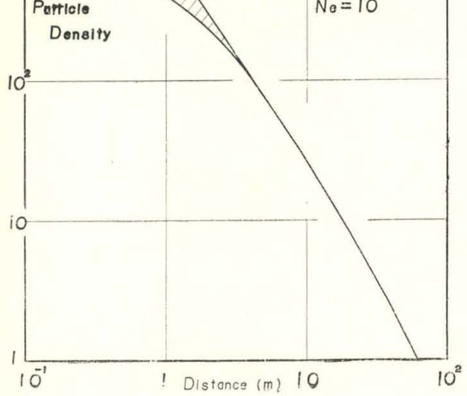

Fig. 1.

The fine structure in this region was studied with a device named the neon hodoscope. This was a lattice array of 5000 neon-filled tubes of 7 m^2.[2] It has been extended to 12m^2 area at present with much smaller size tubes. From the photograph of the neon hodoscope, the axis of the core can be located as accurately as 10 cm in favorable cases.

Suppose we look at the cores of extensive air showers with the size greater than $5 \cdot 10^4$. If the lateral distribution of the core is expressed by an inverse power of the radius, r^{-n}, the exponent n is found to be distributed from almost 0 to more than 1, as shown by the hatched zone in Fig. 1.

However, about 90 percent of the showers has a rather flat core, one typical example of which can be seen in Fig. 2. Therefore,

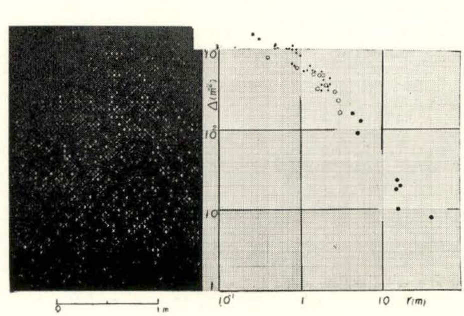

Fig. 2.

in what follows, these cores will be referred to as ordinary cores. In the showers with size of the order of 10^4 or smaller, there exist some much steeper cores whose exponents are even as great as 2, one example of which is shown in Fig. 3.

Since the majority of the cores has a distribution much flatter than $1/r$ within a few meters from the axis regardless of the size, the following interpretation may be plausible. γ-rays of energies less than several times 10^{11} ev are supposed to be common and rather abundant for all air showers at an altitude of a few Km above sea level. These γ-rays will lead to a spread of a core of a few meters at sea level, assuming that the transverse momentum has a value of about 300 Mev/c.

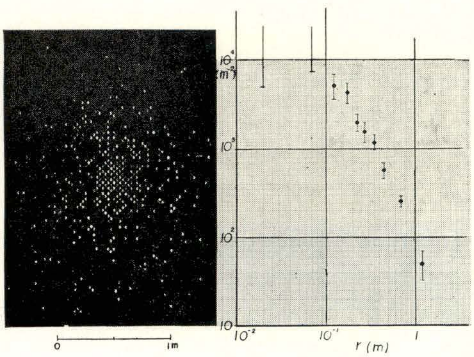

Fig. 3.

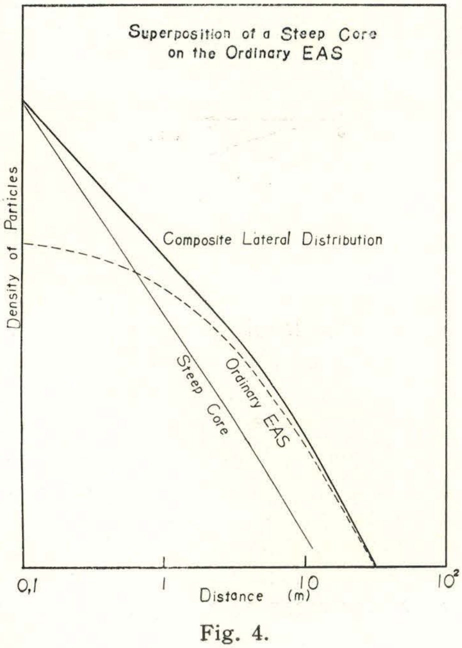

Fig. 4.

On the other hand, the γ-ray spectrum is supposed to fall off beyond several times 10^{11} ev by some possible variation of the production spectrum. Some evidence for this variation may be seen in the same energy region in the results with the emulsion cloud chamber in Japan.

Thus, the fluctuation of the structure within a few meters from the axis can be understood in terms of the presence or absence of such high energy γ-rays. The schematic diagram in Fig. 4 represents that obtained when young cascade showers initiated by these high energy γ-rays are superposed on the ordinary core. Then, the composite lateral distribution would become steeper much closer to the axis. In fact, there are cases where one can clearly distinguish a steep core superposed on the flat portion of an ordinary core. Therefore, upon subtracting the basic lateral distribution of the ordinary air shower, the remainder may represent the steep core due to the high-energy cascade shower.

The energies of these steep cores have been directly measured by two kinds of energy detectors. One kind is eight lead-shielded scintillation counters of each 0.25 m² area while the other is eleven lead-glass Cerenkov counters of each 0.22 m² area. Their arrangement is shown in Fig. 5. In cases where the core did not strike these detectors, the energy is empirically estimated, comparing with the cases of direct measurement.

At a frequency of about 5 percent that of

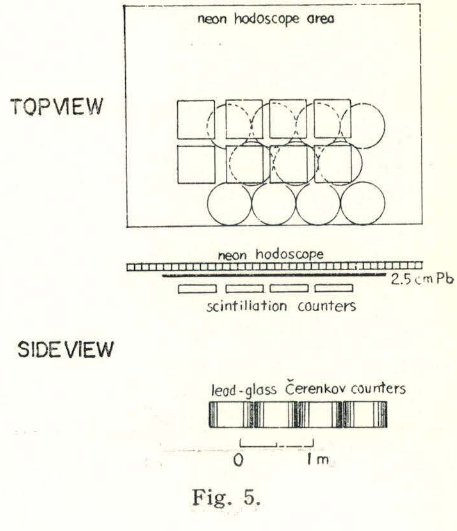

Fig. 5.

the air showers of size greater than 5.10^4 whose cores strike the neon hodoscope, there appear steep cores having a spread no more than 10 cm. These appear either as a single core or superposed on an ordinary air shower core, and the energy of these steep cores is estimated to be greater than or about equal to 10^{13} ev. An example of such event is shown in Fig. 6.

Moreover, the lateral distribution corresponding to these steep cores are definitely steeper than $1/r$ in some cases. This may imply the following condition. If such steep cores are composed of several cascade showers originated from secondary neutral pions of a nuclear interaction, at least one neutral pion of about 10^{13} ev should be included among them in order to keep the minimum spread of the core to be less than 10 cm, on the assumption that the altitude of initiation is about $3\sim4$ Km above sea level, and that the value of the transverse momentum is at least equivalent to the neutral pion mass, 140 Mev/c.

Furthermore, according to the general consideration, the composite lateral distribution cannot be steeper than $1/r$, regardless of the altitude of initiation. This statement is based on the assumption that neutral pions are emitted according to the energy spectrum generally expressed by $E^{-2}dE$ which is known to be satisfied in ordinary jets. In other words in order to achieve the lateral distribution which is much steeper than $1/r$, an entirely different energy spectrum which is very rich in higher energy mesons should be necessary. Therefore, it is likely that there arises a considerable probability that the transferred energy is preferentially concentrated into one or a few γ-rays, in the nuclear interactions with energy as high as 10^{14} ev.

So far, we have observed three remarkable multi-core events. Two examples are shown in Figs. 7 and 8. In each of them, a steep core, corresponding to a cascade shower of more than 10^{13} ev, can be seen at a separation of more than 1 m from the main axis of the extensive air shower.

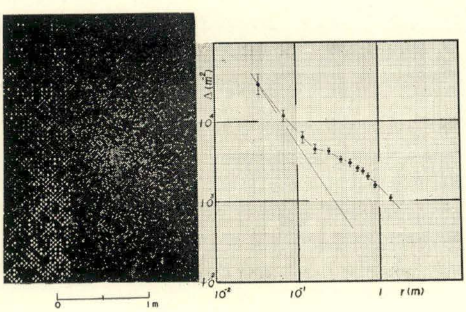

Fig. 6.

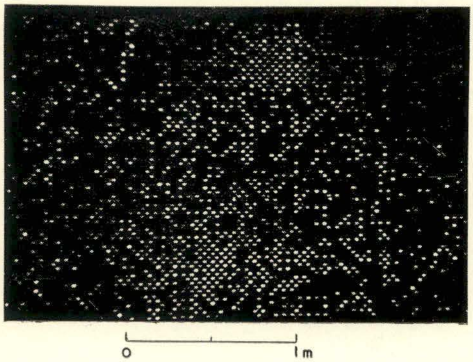

Fig. 7.

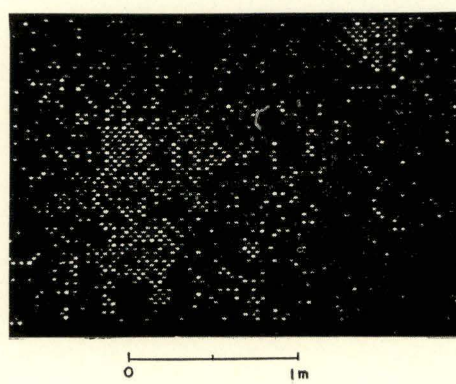

Fig. 8.

If one assumes that these cascade showers are initiated at some altitude no higher than 4 Km above sea level, as the result of a nuclear interaction, their transverse momenta turn out to be more than 5 Gev/c. This seems to be much larger than the generally accepted value of the transverse momentum.

Each of these steep cores which is responsible for the large transverse momentum has a distribution definitely steeper than $1/r$ as close as 10 cm to the axis. Therefore, the energy of the steep core might be concentrated into one or a few γ-rays, according to the same argument mentioned above.

On the other hand, during the same period of observation, we have observed eight steep cores which are comparable to those three steep cores in double core events, either as a single core or superposed on an ordinary air shower core.

This frequency comparison might suggest the following possibility. Let us assume again that the double core events are produced within a few Km from sea level, because the lateral distribution is very steep. Then, there seems to be a considerable tendency that those particular events in which the majority of energy is concentrated into one or a few γ-rays, are likely to be produced with an unusually large transverse momentum. This large transverse momentum, then, is carried either by a single γ-ray or a group of γ-rays as a whole by some process.

References

1) S. Fukui, H. Hasegawa, T. Matano, I. Miura, M. Oda, K. Suga, G. Tanahashi and Y. Tanaka: Progr. Theor. Phys. Suppl. **16** (1961) 1.
2) S. Fukui: Jour. Phys. Soc. Japan **16** (1961) 604.

Discussion

McCusker, C. B. A.: I would like to make a comment on four observations. First, some cloud chamber pictures we have support some of Dr. Tanaka's results. One, which I call to mind, was, in two cloud chambers 1.3 m apart densities of respectively 2000 and 200 p/m^2. Secondly, in jet work P_T values at least as high as 6 Bev/c have been seen although the interpretation is in doubt. Thirdly, the flattening of the core and the steepening of our density spectrum seen are in good agreement. Fourthly, Dr. Ueda and I have used a theory which includes the contribution of hyperons to get rather good agreement with several features of air shower work.

Zatsepin, G. T.: These multiple core events are observed by Soviet group with mosaic ionization chambers. But what is the nature of these core? Are they generated by single primary nucleon, or by heavy nuclei?

Tanaka, Y.: According to the slope of the lateral distribution, they could be most reasonably interpreted as young energetic cascade showers.

I cannot exclude the possibility that the double core events are due to heavy primaries. However, in order to explain the observed separation of the cores, one should again assume the large P_T for the individual nucleon at the disintegration of the heavy nuclei.

McCusker: Typical transverse momenta of pions is 400 Mev/c. From heavy primary break up P_T might well be a factor of ten less than this.

Tanaka: I agree with you. Therefore, if this is the case, the separation of the two cores is too large to be accounted for by the break up of heavy nuclei.

Millar, D. D.: Can these sharp cores be produced by μ-meson knock-on showers produced at low altitude above the neon hodoscope? A large number of μ-mesons must be incident on the neon hodoscope in all of these events.

Tanaka: Since the size of the EAS, with which the double core event was associated, was less than or as great as 10^5. The number of μ-mesons of above 10^{13} ev is very small. Therefore, taking into account the very small probability of radiation process for μ-mesons, your point seems unlikely.

Zatsepin: In our experiments reported in 1959 multiple core were observed in not less than 30% of shower core. So it can not be produced by μ-mesons or some other spurious cause.

Ueda, A: I would like to ask some people including you. Dr. Kameda told me rather unusual events observed in cloud chamber which consist of a bundle of cascade showers but do not accompany any high-energy nuclear particle. In connection with Dr. Zatsepin pointing out that the existence of multiple core could be due to EAS initiated by heavy nuclei, have you got a similar evidence or not?

Tanaka: We are not quite sure about such experimental evidences.