

The Development of Air Shower in the Iron Absorber

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ABSTRACT

The iron open-sandwich experiments to observe one dimensional development of individual air showers were carried out at Akeno Observatory. One dimensional energy flow, incident energy and production height of shower is estimated using the data of size and age obtained from the above experiment and simple calculation.

1. Introduction.

In order to study the total development of individual air showers, two general methods to observe at different altitudes or to catch the generation gap of air showers from the difference of their arrival directions at the same altitude, have been used. But it is impossible to observe the longitudinal development of a shower and only able to grasp its average features.

The experiments to measure the particle density of each generation of a shower using the multiple detectors set top and bottom sandwiching some materials such as water, iron, lead etc. as absorber between them and arranged over the range of 3 - 7 m, mainly to study the longitudinal development of the central parts of an air shower, have been carried out. (1-4) But the cost of experiment increases when the sandwich type arrangement mentioned above is adopted to observe the total longitudinal development of individual air shower, because the whole range of lateral spread of an air shower must be covered with the detectors.

Now, the new observation method so called "open sandwich" has been proposed as follows. Some different kinds of air

shower arrays are arranged over the range enough to observe whole features of air shower.

The types of air shower array are classified by the thickness of the substance piled on the scintillation counter. The transition of the particle densities of an air shower is known when it passes through a substance by comparing the particle densities obtained from some different kinds of air shower arrays, and in the result the total longitudinal development of an air shower can be observed by the smaller number of detectors.

2. Experimental procedure.

Iron open sandwich experiment was carried out at station in Akeno Observatory (920g/cm²) for three months (December 1980 - March 1981). The array consists of 100 scintillation counters which covered an area of 50x50m², they are 30 counters, on which 5 iron plates are laid (4.5cm iron thick and called 2Fe array), 28 counters 10 iron plates (9cm thick, 4Fe array) and 42 counters non iron plate (0Fe array) in which 4 counters to detect arrival direction are included. The unit area of 96 scintillation counters is 0.5m x 0.5m and of 4 detectors for arrival directions is 1m x 1m.

The air shower array was triggered by the condition of any six fold coincidence out of central eight scintillation counters discriminating of 6 particles per counter. Thus 12,070 air showers were obtained in the above observation period.

3.1 Analysis of air showers.

The coordinates of shower axis (X_c, Y_c) and the set of the parameters size N_0 and age S_0 (N_0, S_0) on top of the iron plate, where S_0 denotes lateral spread of air shower, are determined by fitting lateral density distribution curve obtained from 0Fe data to the theoretical lateral curves (NKG lateral structure function) by means of the least square method.

Another two sets of size and age (N_2, S_2) and (N_4, S_4) for the axis of 0Fe array are also obtained by the same method as above using the data from 2Fe and 4Fe array respectively. The arrival direction (zenith angle θ) is determined by the difference of time arriving at the 4 counters to detect zenith angle.

1,308 air showers whose axes hit near the central part of the array and the parameters sizes and ages are determined with high precision, which are suitable for analysis, are selected and analyzed. They satisfy the following conditions:

$\theta < 30^\circ$, $r = \sqrt{X_c^2 + Y_c^2} < 8.0 \text{ m}$, $\sqrt{\sum dN_0(i)^2/42} < N_0$,
 $\sqrt{\sum dN_2(i)^2/30} < N_2$, $\sqrt{\sum dN_4(i)^2/28} < N_4$, where $dN_0(i)$, $dN_2(i)$ and $dN_4(i)$ are the difference between the number of particles detected by the i -th detector of 0Fe, 2Fe, or 4Fe array and one estimated as the value of i -th detector from the sets of parameters (N_0, S_0), (N_2, S_2) or (N_4, S_4) respectively.

3.2 Models, energy and production height of air shower.

An air shower starts from the gamma rays decayed from neutral pi mesons which are produced when a primary cosmic ray interacts with an air nucleus. The number of gamma rays and the energy distribution of the gamma rays are assumed as follows.

In 1-gamma ray model (e1) 1 gamma ray is emitted and in CKP model (e2) the number and the energy of gamma ray follow CKP distribution. One third of incident energy transfers to electromagnetic cascade in both models. The age parameter of an air shower S_1 , which denotes longitudinal development of air shower, can not to be measured directly.

From the experimental results that in electromagnetic cascade the age for lateral development agrees with the one for longitudinal development when they are measured in the range one Molliele unit, which presents order of lateral spread of air shower and about 91 m at Akeno, S_1 is substituted for S_0 in usual. However, they are essentially different to each other, then following two models about age parameter of individual air shower are assumed as $S_1 = S_0 \dots (sa)$ and $S_1 = S_0 + 0.2 \dots (sb)$.

The combination of 2 models for energy distribution and 2 models for age makes the 4 models; (e1-sa), (e2-sa), (e1-sb) and (e2-sb) called model A, B, C and D respectively. The primary energy E_0 and production height T of the air shower were determined by selecting the set of (E_0, T) which corresponds to the set of (N_0, S_1) obtained from calculation of electro magnetic cascade depending on models mentioned above, and yet agrees with experimental value.

3.3 Determination of energy flow.

The calculation for energy flow of the air shower has been carried out by the assumption that the electromagnetic component consists of electrons only because it has been difficult to know the energy distribution of gamma rays.

Now, new attempt to estimate the energy flow of electron or gamma ray individually has been made by giving each energy distribution based on electromagnetic cascade theory, and the age for electron or gamma rays is also determined separately. The energy distribution of electron or gamma ray composed of the shower, on top of the iron plate, is given by electromagnetic cascade theory respectively as follows,

$$N_e dE = A_e E^{-(1+S_e)} dE \quad \text{and}$$

$$N_g dE = A_g E^{-(1+S_g)} dE.$$

Where, age S_e is substituted for S_1 assumed above, and age for gamma ray S_g is given by the set of (E_0, T) determined above.

4. Results and discussions

The energy determination of air shower ever been used is to multiply size N_0 by the average energy which is obtained some simulations. (5) Age is taken into account as well as size

in this method. The present results agree with those published before in model A and B. (5) The average value of the ratio E_0 to N_0 and one of energy flow per electron E_f are in Table 1. The values of E_f are consistent with ones of other works. (6) The ratio N_4/N_2 correlates with age S_0 as shown in Fig. 1. Fig. 2 shows the correlation of mean energy per shower electron or total energy flow to S_0 at Akeno altitude. The correlation between the ratio of total energy flow to incident energy E_f/E_0 and S_0 is shown in Fig. 3.

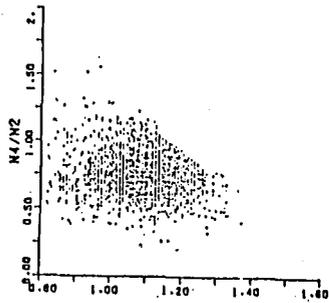


Fig. 1

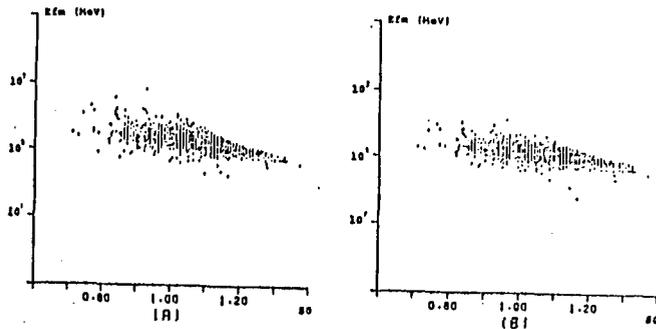


Fig. 2

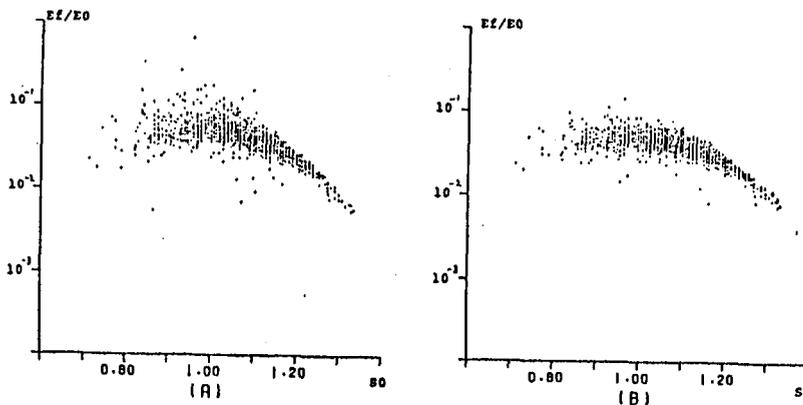


Fig. 3

model	$\langle E_0/N_0 \rangle$ (Gev)	$\langle E_f \rangle$ (Mev)
A	4.27	140
B	3.33	117

Table-1

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