NEW ANALYSIS OF NUCLEAR INTERACTION OBSERVED BY MT. KANBARA EMULSION CHAMBER EXPERIMENT

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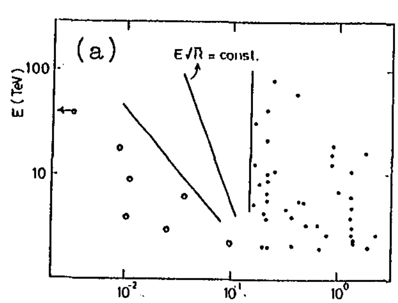
1. Introduction. Up to date, the analysis of air cascade family has been performed mainly by using a full Monte Carlo simulation, because of the large fluctuation of the air cascade. Recently it has become clear, however, that it is difficult to draw a definite conclusion about the interaction mechanism by using only this kind of simulation, due to too many assumptions in relation to the amount of information.

On the other hand, some attempts to reproduce the original γ-ray at the interaction point, for example `decascading[1]', have also been made. This kind of method makes it possible to observe the interaction directly and to analyze the data from various angles. All of these methods, however, assume the constant ER in cascade shower, where E is energy and R is the distance from the center of cascade shower. This character is all-inclusive and changes according to the energy and the interaction height of original γ-ray. It is impossible, therefore, to reproduce the exact interaction height and energy by these methods. This work adopts a quite different way from the ER constant method; that is, a relative method in separating one cascade shower from others. This new method makes it possible to estimate the interaction height and energy by using information about the lateral spread of the cascade shower.

2. New method. Fig.1 (a) shows the correlation between E and R of γ-rays in a simulated family event. Open circle and closed circle represent the γ-ray produced by one original γ-ray and other original γ-rays, respectively. In this figure, we can find an energy gap at the boundary between groups of cascade shower γ-rays. The new method is nothing but a way to classify one cascade shower group from others by using of this energy gap.

We make a classification of each cascade shower according to the following procedure.



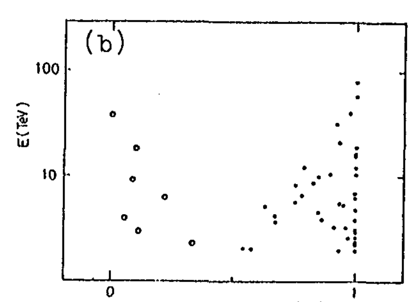


Fig.1 (a) Correlation between E and R in a simulated family event. Open and closed circle represent the γ-ray produced by one original γ-ray and othe γ-rays, respectively. (b) Transformed figure of (a) in order to represent the energy gap symmetrically.

1) Take the i-th γ-ray as a temporary center of a cascade shower group. The selection of the i-th γ-ray is performed according to size of energy, because a high energy γ-ray should be located near the true center.
2) Calculate the following quantity Sij representing a spread between the i-th γ-ray of a temporary center and all other γ-rays (j= 1~n),

$$Sij = (Ei+5)Rij\sqrt{E}j/15 \qquad (1)$$

where Rij is a length between the i-th and j-th γ-rays. As is seen in Fig.1 (a), a straight line of $R\sqrt{E}$ = constant has a mean inclination between the line of ER=constant and R=constant.
3) Caluculate the energy density for the following quantity Wj,

$$Wj = 1-\exp(-Sj) \qquad (2)$$

for fixed i. Wj ranges from 0 to 1 and is effective to search for an energy gap impartially among various cases. The correlation between E and W is shown in Fig. 1 (b) for the same sample as in (a). We can see a symmetrical valley of energy in this Figure.

The energy density is defined as

$$Pj = \sqrt[3]{Ej \cdot Ej_{+1} \cdot Ej_{+2}}/(Wj_{+2}-Wj) \qquad (3)$$

The boundary is set up the position Wmin where Pj has the minimum value.
4) Select candidates, which satisfy the following criteria, as members of the same cascade shower with the i-th γ-ray.

$$Wj < Wmin \quad \text{and} \quad Ej < Ei$$

5) Proceed to the next γ-ray to be set as a temporary center. The γ-rays which have been already selected in (4) are excluded as new centers.
6) When a γ-ray is selected as a candidate of more than two groups, it is decided to belong the group which gives the smallest distance from its center.

3. Estimation of energy and production height. The energy and production height of γ-ray are estimated by using the mean spread of clusterized γ-ray as members of a cascade shower. The mean lateral spread <R> is defined as,

$$\langle R\rangle = \Sigma R/N \quad (cm) \qquad (4)$$

where R is a distance from the energy weighted center and N is the number of γ-rays in a cluster. Close investigation of the simulation data drew the estimation formula of energy Ees and interaction height Hes at Mt. kanbara height (5500m) as follows,

$$Ees = \Sigma E \cdot 10^{2.5\langle R\rangle} \quad (TeV) \qquad (5)$$

$$Hes = 17000 \cdot \langle R\rangle^{1.5} \quad (m) \qquad (6)$$

4. Check of new analysis method. Reproducibility by the new method was checked by using artificial data in a full Monte Carlo simulation. For the purpose of checking, only the standard model simulation was necessary. An outline of the simulation[2] is as follows.

(1) Proton primary with energy spectrum as

$$I(E)dE \propto E^{-\beta-1}dE \quad (\beta=1.7)$$

(2) Particle production spectrum is scaling law

$$f(X)dX \propto (1-X)^{3.5}/XdX$$

where $X=E/E_0$, E and E_0 are secondary and primary energy, respectively.

(3) Interaction mean free path

$$\lambda = \begin{cases} 80\ g/cm^2 & \text{for proton} \\ 96\ g/cm^2 & \text{for secondary pion} \end{cases}$$

(4) Mean transverse momentum

$$\langle Pt \rangle = \begin{cases} 330\ MeV/c & \text{for secondary particle} \\ 500\ MeV/c & \text{for leading particle} \end{cases}$$

For the investigation of large Pt, the double value $\langle Pt \rangle$=660 MeV/c was also used.

All of the clusterized groups have not always one to one correspondence to the expected one. In the case of no one to one correspondence, the original γ-ray which gives the highest energy ratio within the cluster is selected as corresponding γ-ray and used for checking.

Fig.2 (a) shows the distribution of Nes/N_0, where Nes is the number of γ-rays in an actual clusterized group and N_0 is the expected number in the corresponding cascade shower. The peak at $Nes/N_0=2$ is due to the case of $N_0=1$. Figure shows fairly strong agreement and the validity of the new method was confirmed.

Fig.2 (b) and (c) show the comparison of estimated energy Ees and estimated interaction height Hes of original γ-ray with expected true ones E_0 and H_0, respectively. Fig. (c) for interaction height shows broad distribution. This is due to mainly the fluctuation in the traveling distance of the original γ-ray from the interaction point to the first pair creation point. We need the statistical analysis for the interaction height.

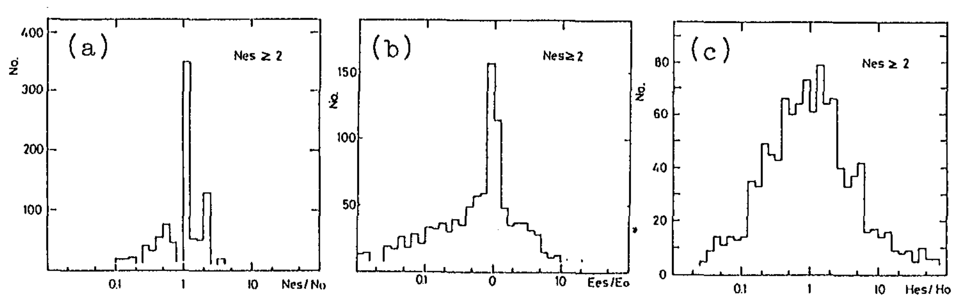


Fig.2. Comparison of the estimated value by new method with the expected one (a) Number of γ-rays in a clusterized shower (b) energy and (c) interaction height of original γ-ray

Fig.3 shows the reproducibilty of the transverse momentum Pt distribution, (a) for normal Pt and (b) for double Pt. The full and broken lines represent the distribusions of the estimated Pt and of the expected Pt of all γ-rays at the interaction point. The estimated and expected distribtion does not necessarily coincide because of the detection bias and the error of estimated value. The positions of peak, however, coincide with each other, and the estimated distribution for normal Pt and for large Pt reproduce just a double difference. It is worth notice that the estimated Pt distribution has a large error but is independent of the interaction model.

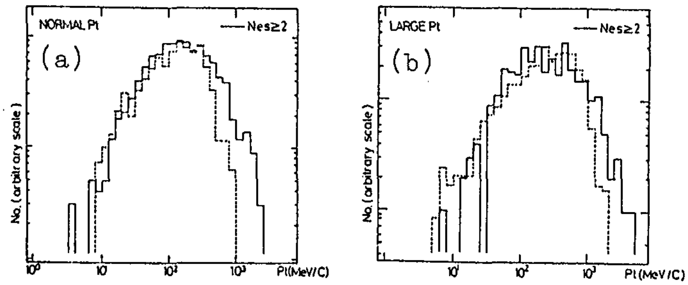


Fig.3 The transverse momentum Pt distribution of reproduced γ-ray for (a) normal Pt (b) double Pt, compared with the distribution of all γ-rays produced by the interaction (broken line).

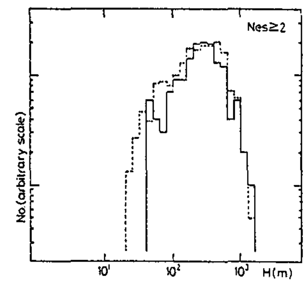


Fig.4 The interaction height distribution, compared with the simulated data(broken line)

5. Results. In Fig.4, is shown the result of the interaction height of the reproduced original γ-ray by the experimental data of the Mt. Kambara emulsion chamber experiment, compared with the result of simulated data (broken line). The experimental data does not contradict the prediction of the simulation.

Fig.5 shows the lateral spread R distribution, where R is the distance between an energy weighted center of a family and of γ-rays in a cluster. Smoothed curves represent the distribution of the simulated data in the case of normal Pt and double Pt.

Fig.6 shows the transverse momentum Pt distribution by Mt.Kanbara experiment, compared with the simulated data. Smoothed curves in the figure are also the simulated distribution for normal Pt and double Pt.

Though the statistics of experimental data are not enough to reach a definite conclusion, the both results in Fig.5 and Fig. 6 prefer large Pt (<Pt> ~ 600 MeV/c) rather than normal Pt.

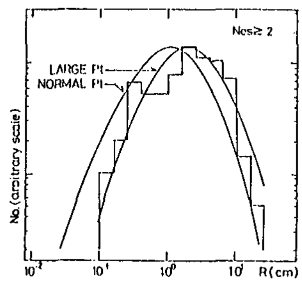


Fig.5 The lateral spread distribution of original γ-ray. Smoothed curves represent the simulated data for normal Pt and large Pt.

6. Acknowledgments. The author would like to express his thanks to the members of the Mt. Kanbara group for allowing the use of experimental data. He is much indebted to Dr. Shibata of Yokohama National University for using the Monte Carlo simulation method. The auther thanks Mr. Y. Noto of Hirosaki University for help in calculation of the simulation.

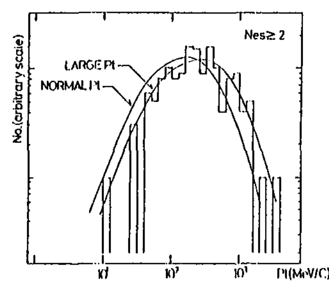


Fig.6 The transverse momentum Pt distribution of reproduced original γ-ray, compared with the simulated distribution for normal Pt (<Pt>=330 MeV/c) and large Pt (660 MeV/c)

References

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