Anomalous correlation between hadron and electromagnetic particles in hadron and gamma-ray families

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Abstract

Correlations between hadrons and electromagnetic particles are studied in the hadron-gamma families observed in Chacaltaya emulsion chamber experiment. It is found that there exist a number of hadrons which associate electromagnetic showers in extraordinarily close vicinity. The probability to have such large number of hadrons associating electromagnetic showers, expected from background calculation, is found to be negligibly small, $\lesssim 10^{-5}$, and it means there exists anomalous correlation between hadrons and electromagnetic particles in the characteristic spread of atmospheric electromagnetic cascade.

1. Introduction.

Through the analysis on the structure of hadron and gamma-ray families, especially of the families with hadron-rich nature, we have noticed that there were a number of showers which penetrate through the hole chamber, the upper and the lower chamber. The core structure seen in the lower chamber tells us that considerable number of those penetrating showers are not simply pure electromagnetic cascades but are coming from nuclear interaction of hadrons in the chamber, that is, they are hadronic origin.[1][3] During studying on the core structure of those penetrating showers, we found some of showers which are considered as hadronic origin have separate multi-core structure in the upper chamber, not single core structure. That is, there exist hadron and electromagnetic showers which are located extraordinarily close each other, in the extreme case the relative distance between the two is $\sim 30\,\mu$m. Here we show how closely a hadron accompanies electromagnetic showers in its neighbourhood in the high energy hadron and gamma-ray families observed in Chacaltaya chamber no.19.

2. Experimental procedure.

Chacaltaya chamber no.19 The Chacaltaya chamber no.19 has two-storey structure with air-gap, that is, the upper chamber of 6 cmPb thick, target layer of 23 cm pitch, air-gap of 1.5 m and the lower chamber of 8.4 cmPb thick. The special character of the chamber no.19 different from the other chamber is that in all the area of the upper chamber nuclear emulsion plates together with X-ray films are inserted under 3, 4 and 6 cm lead plates. Then we can study very precisely on the core structure of showers, with accuracy of 10 μm, observed in the upper chamber as well as in the lower chamber.

The energy of each shower is estimated by track-counting method. Photometric measurement is also applied for high-energy showers.

Selection of the events Among the events observed in the chamber no.19 we pick up only the events which have at least one identified hadron and pass through the whole chamber, in order to get enough information on hadron component. In the Japanese part ($\sim$30 m^2year , a half of the total area) of the chamber no.19, we found 19 events with total observed energy greater than 100 TeV, incident energy $E_0 \sim 10^{15}$ eV, which satisfy the above criteria. The detection threshold energy is put to 2 TeV.

Identification of hadrons The showers in the lower chamber are those from local nuclear interactions in the target layer (C-jet with clean multi-core structure), those from local nuclear interactions in the lower chamber (Pb-jet-lower with clean single-core structure) and tails of showers from the upper chamber (with diffuse core structure). Thus almost all showers observed in the lower chamber are hadronic origin. The showers observed in the upper chamber are mixture of electromagnetic showers from the atmosphere and those from local nuclear interactions in the upper chamber itself (Pb-jet-upper). Among showers observed in the upper chamber, we consider the showers as hadrons when the showers can be seen only after 8 cascade unit of emulsion plate, that is, no electron shower track can be seen at the expected place of emulsion plate at 6 cascade unit, and/or when the showers continue to the lower chamber and new core can be seen in the lower chamber. The above procedure for identification of hadrons in the upper chamber can not pick up all hadrons interacted in the upper chamber, $20 \sim 30\%$ of them are left unidentified.

3. Results.

Here we study how closely hadrons accompany electromagnetic showers in their neighbourhood by comparing with background calculation where only azimuthal angle ϕ of observed hadrons are randomly chosen in the observed families. Fig.1a shows a distribution of relative distance, Rmin, between a hadron and its nearest neighbouring shower, and Fig.1b shows a distribution of energy-weighted relative distance, Xmin, between a hadron and a shower nearest neighbouring in X_{ij}-space for the events of Chacaltaya chamber no.19. X_{ij} is defined by $X_{ij} = \sqrt{E_i E_j} \times R_{ij}$ where E_i and E_j are visible energy of hadrons and of electromagnetic showers and R_{ij} is relative distance between the two. The distributions are compared with background calculation. As is seen in the figures, there exists a bump above the background distribution both in small Rmin region, Rmin < 400 μm and in small Xmin region, Xmin < 2 GeV.m. Figs.2a and 2b are the same distributions shown above in logR and in logX scale but here hadrons are divided into four parts depending on their distance Rh measured from energy-weighted center of a family. The background distribution in small Rmin and in small Xmin becomes negligibly small when distance Rh of hadrons becomes larger, in contrast to that in the experimental data there still exist hadrons which accompany a shower in very small Rmin and Xmin even when R_H is large. There exist two hadrons which accompany a shower in Rmin less than 160 μm and in Xmin less than 0.6 GeV.m for the case of Rh 5 cm where no hadrons are expected to accompany a shower in such small Rmin and Xmin region from the background calculation. The probability, p, that a hadron accompanies a shower at (energy-weighted) relative distance less than Rmin or Xmin is given by the background calculations. Then the probability Qn that at least n hadrons accompany a shower at (energy-weighted) relative distance less than Rmin or Xmin is given by a binomial formula,

$$Q_n = \sum_{r=n}^{n_h} {}_{n_h}C_r \; p^r (1-p)^{n_h - r} \qquad (1)$$

here n_h is the total number of observed hadrons. The observed number of hadrons which accompany a shower in small Rmin or Xmin is very large compared with background distributions and the probability that such large number of hadrons accompany a shower in such small Rmin or Xmin is negligibly small, for example, we have 21 hadrons which accompany a shower in Rmin less than 400 μm and 19 hadrons which accompany a shower in Xmin less than 2 GeV.m. The probability that these two cases are realized , expected from background calculation, is $\sim 8.3\times10^{-7}$ and $\sim 2.1\times10^{-5}$ respectively. Thus we can conclude that there exist hadrons which accompany electromagnetic showers extraordinarily close to them, and such closeness in relative distance Rmin and in energy-weighted relative distance X_{min} can not be reproduced simply by chance.

4. Discussions.

Those hadron and accompanied electromagnetic showers form isolated cluster of collimated showers, mini-cluster[2][3]. Then one may say that those cluster of showers are due to nuclear interaction at low altitude. However, if we interpret those clusters of showers as products of atmospheric nuclear interaction of normal type, $< p_t > \sim 350$ MeV/c, the interaction height of them always gives very small value, around several to several ten meters above the chamber. We can estimate the number of hadrons arriving at the chamber by the observed number of C-jet and Pb-jet-lower under the assumption of a collision mean free path of hadrons. Then we can estimate the number of atmospheric interactions at low altitude, H 50 m above the chamber for example. Table 2 shows a summary of the above argument for hadrons with visible energy, $E_h(\gamma)$,greater than 10 TeV. Almost all of shower clusters have their energy greater than 10 TeV. The estimated number of atmospheric interactions should be compared with the number of hadrons which accompany electromagnetic showers in the close vicinity of them. As one can see in the Table, the number of atmospheric interactions at such low altitude is very small compared with those hadrons unless we assume very short collision mean free path, $\sim 1/5\ \lambda_{geo.}$, of hadrons. The effect of the zinc roof of $\sim$ 1mm thick ($\lesssim 0.01\ \lambda_{geo}$) which is located 3m above the chamber is also negligible. Thus if we assume that those mini-clusters are due to nuclear interaction in the atmosphere, the interaction point should be much higher and the average transverse momentum of produced particles should be much smaller ($\sim$10 times smaller) than normal one. In many of mini-clusters, a hadron carries a large portion of energy of a cluster. This fact indicates that a hadron is a core of a cluster and electromagnetic showers are accompanied by unknown mechanism.

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References

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no. of hadrons with $R_{min} \leq 400$ μ m	number of 'single hadrons'			arriving number of hadrons expected from C-jet and Pb-jet-lower			
	Pb-jet-upper identified	C-jet	Pb-jet-lower	λ geo.	$1/2\lambda$ geo.	$1/3\lambda$ geo.	$1/5\lambda$ geo.
21	12	8	1	23± 7 (1.0± 0.3)	21± 7 (1.8± 0.6)	24± 8 (3.2± 1.1)	41± 14 (9.5± 3.2)

Figures in parenthesis are estimated number of atmospheric interactions at the heights less than 50 m above the chamber.

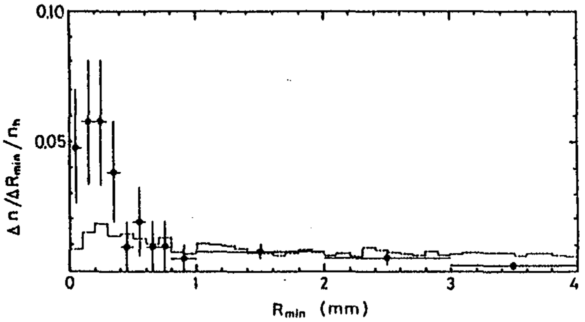

Fig.1a: Distribution of relative distance, Rmin, between a hadron and its nearest neighbouring shower. Histogram is a background distribution.

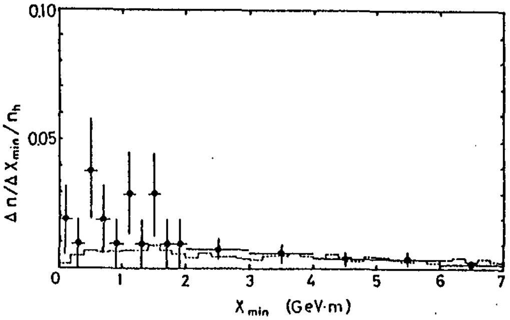

Fig.1b: Distribution of energy-weighted relative distance, Xmin, between a hadron and its nearest neighbouring shower in X_{ij}-space.

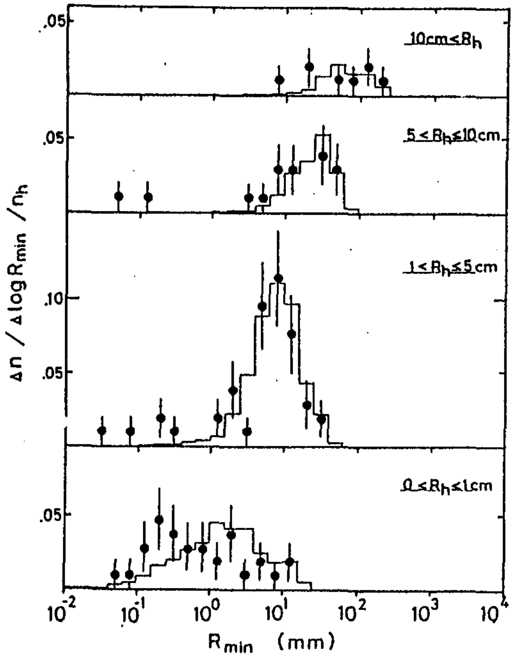

Fig.2a: Distribution of relative distance, Rmin, between a hadrons and its nearest neighbouring shower for four different intervals of distance R_h of hadrons measured from the energy-weighted center of the event. Histograms are bacnkground distributions.

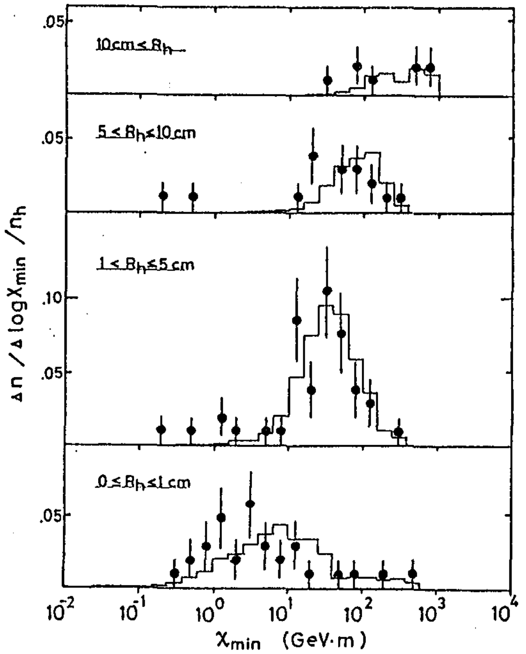

Fig.2b: Distribution of energy-weighted relative distance, Xmin, between a hadron and its nearest neighbouring shower in X_{ij}-space for four different intervals of distance R_h of hadrons.