# A SEARCH FOR MINI-CLUSTERS IN JAPAN-USSR JOINT EXPERIMENT AT PAMIR

JAPAN-USSR JOINT EXPERIMENT (II)

Abstract

A search for mini-clusters, very collimated shower clusters of hadrons and electromagnetic particles, is made for the hadron and gamma families observed by Japan-USSR joint carbon chamber at Pamir. The existence of anomalous correlation between hadrons and electromagnetic particles is found. The decascading method is applied to the families and it is found that 11 clusters which include hadrons as members have smaller spread, <Er> < 3.5 GeV.m and larger lateral spread, $E^*R^*$ > 100 GeV.m, from the family center. In the simulated events, we have found very rare such clusters. The results are compared with those of Chacaltaya experiment.

## 1. Introduction.

In the cosmic-ray nuclear interactions of incident particle energy $E_0$ > $10^{15}$ eV, there exist several kinds of exotic phenomena[1], Centauro is a typical one, which are not yet observed in the accelerator experiments. The characteristics of those exotic phenomena is seen in the composition and in the magnitude of transverse momentum of produced particles, that is, particles unaccompanied with pions are produced with large transverse momentum. Recently, the existence of a new shower phenomenon is reported from Chacaltaya experiment ,that is, there exist hadrons accompanied by electromagnetic showers in very close vicinity and those hadrons and electromagnetic showers form very collimated shower cluster, the mini-cluster[2]. And now, it is one of the most important problems to make clear the physical nature of the mini-cluster. The carbon chamber is thick enough to detect hadrons and is suitable to detect mini-clusters. Here we show the results of systematic analysis on hadron and gamma families observed in USSR-Japan joint carbon chamber[3] exposed at Pamir plateau, paying special attention to the mini-clusters.

## 2. Experimental procedure.

The chamber, so-called carbon chamber, consists of three parts, i.e., Γ-block of 6 cmPb, H-block of 6 cmPb and carbon layer of 60 cm thick between the two. The detail structure of the chamber and the method of energy determination is described in the separate paper[3].

Identification of hadrons The showers observed in H-block are those from local nuclear interaction in the carbon layer(C-jet), those from local nuclear interactions in the H-block itself(Pb-jet-H) and tails of showers from Γ-block. Thus almost all showers in H-block are hadronic origin. The showers observed in Γ-block are mixture of electromagnetic showers from the atmosphere and those from local nuclear interactions in Γ-block itself(Pb-jet-Γ). Among showers observed in Γ-block, we consider the shower as hadronic-origin when the shower continues to H-block and the darkness of the shower in H-block is far above the expected darkness in case of electromagnetic shower. The detail argument on the identification is described in the Ref.[4]. The above procedure for identification of hadrons in Γ-block can not pick up all hadrons interacted in -block, and also the threshold energy for them becomes 5 ∿10 TeV although the detection threshold energy of showers is around 2 TeV. The detection probability of hadrons with energy $E_h^{(\gamma)}$ greater than 2 TeV is estimated as $\sim$70 %.

Selection of the events The systematic measurement of gamma- and/or hadron- families is done in one section(24 $m^2$) of the joint chamber 'Pamir-2'[4], and we have about 110 unbiased events with total visible energy greater than 20 TeV. Among 52 families of total visible energy greater than 50 TeV, 21 events have hadrons in their member showers. Our main concern is to see correlations between hadrons and electromagnetic showers. Then we pick up only the events which have showers penetrating from Γ-block to H-block. Among 21 hadron and gamma families, 14 events have penetrating showers. In the following analysis, three high energy events( in the another section where systematic measurement is going on ) together with 14 events above mentioned are used.

## 3. Results.

Correlation between hadrons and electromagnetic showers 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 its nearest neighbouring shower in $X_{ij}(=\sqrt{E_iE_j}R_{ij})$-space,where $E_i$, $E_j$ are energies of showers and $R_{ij}$ is a relative distance between the two. Histogram in the figure shows a background distribution which is obtained by randomly changing azimuthal angle, $\phi$ , of hadrons in the observed events. As is seen in the figures, in contrast with that the background distribution is almost uniform, in the experiment there exists a peak, which is not seen in the background distribution, in small Rmin region, Rmin < 400 μm and in small Xmin region, Xmin < 2.2 GeV.m. We have 11 hadrons which accompany a shower in Rmin less than 400 μm and 9 hadrons which accompany a shower in Xmin less than 2.2 GeV.m. The number of those hadrons expected from the background distribution is $\sim$0.8 and $\sim$0.6 respectively. And the probability that the observed number of hadrons accompany showers in such small Rmin and Xmin is estimated $\sim 5\times10^{-10}$ and $\sim 8\times10^{-9}$. The result well agrees to that obtained in the Chacaltaya experiment[5], and the observed closeness in (energy-weighted) relative distance between hadrons and electromagnetic showers can not be simply accidental.

Mini-clusters Mini-cluster is a narrowly collimated shower cluster and it looks like pure young electromagnetic cascade in the atmosphere. The characteristic of mini-clusters different from pure electromagnetic cascade is its hadronic nature, that is, hadrons are included as members. Here we apply the decascading method[6] to the families in order to study cluster structure of hadrons and electromagnetic particles. Decascading method is a way to trace back to the original gamma-rays from the observed cluster of electromagnetic showers. The showers are amalgamated to one if $Z_{ij}=E_iE_jR_{ij}/(E_i+E_j)$ is less than a constant value k where $E_i$, $E_j$ are energies of showers and $R_{ij}$ is relative distance between the two. Here the decascading method is applied to all the members, including hadrons and electromagnetic particles, of the family, and we put parameter k=11 GeV.m(=$k_sX_0$), characteristic spread of electromagnetic cascade at Pamir altitude. In this case, the decascading method loses its original meaning but simply means 'clustering'. Fig.2a shows a correlation diagram on the energy-weighted lateral spread $E^*R^*$ of clusters with energy $E^*$ greater than 10 TeV and the average lateral spread, ⟨Er⟩ , of showers in the clusters, obtained by the above procedure. $E^*$, $R^*$ are the energy and the distance of the cluster from the family center. E and r are energy of shower in a cluster and distance of it from cluster center. In the figure, clusters which include hadrons as constituents are marked by triangles. For the comparison, the clusters with hadrons, obtained by the same procedure, in the Chacaltaya events are shown in the figures. Fig.2b shows the same diagram for the simulated events. Simulations are carried out under the assumption that the primary particles are protons with power energy spectrum. Two types of interaction model are assumed. One is fire-ball(H-quantum) model[7], Model-I, and the other is C-jet data model[8], Model-II, where C-jet events observed by Chacaltaya experiment are boosted to cosmic-ray energies. The above two interaction models can well reproduce results of accelerator experiment of ISR and SPS. As is seen in the figure, in the simulated events, too, there exist clusters which accidentally include hadrons as members. Those clusters which include hadrons, however, are distributed in the region of larger $\langle Er \rangle$ in the above diagram. The striking characteristics in the experiment is that there exist clusters including hadrons which have smaller $\langle Er \rangle$ and larger $E^*R^*$. For example, 11 among 16 clusters with hadrons in the events of joint chamber and 11 among 26 clusters in the Chacaltaya events are with $\langle Er \rangle < 3.5$ GeV.m and $E^*R^* > 100$ GeV.m, the region is indicated by broken lines in the figure, while in the simulated events almost all clusters with hadrons are distributed outside of the above region. Such smallness of $\langle Er \rangle$ of experimentally observed clusters with hadrons are coming from the anomalous closeness of hadrons and electromagnetic showers, discussed in the previous section. In Fig.2a we put special mark to the clusters which include hadrons with $R_{min} < 400\ \mu m$ and/or $X_{min} < 2.2$ GeV.m.

## 4.Conclusion.

We have observed 11 clusters, mini-clusters, of anomalously collimated hadrons and electromagnetic particles through the systematic analysis on 17 hadron and gamma families, with total observed energy greater than 50 TeV, observed by joint carbon chambers at Pamir. Though the structure of the chamber and the accuracy of measurement are different from the Chacaltaya chambers, we have obtained good agreement on the characteristics of mini-clusters between the two experiments.

Aknowledgement. The collaboration experiment is financially suppotred in part by Grant-in-Aid from the Ministry of Education and Waseda University, in Japan.

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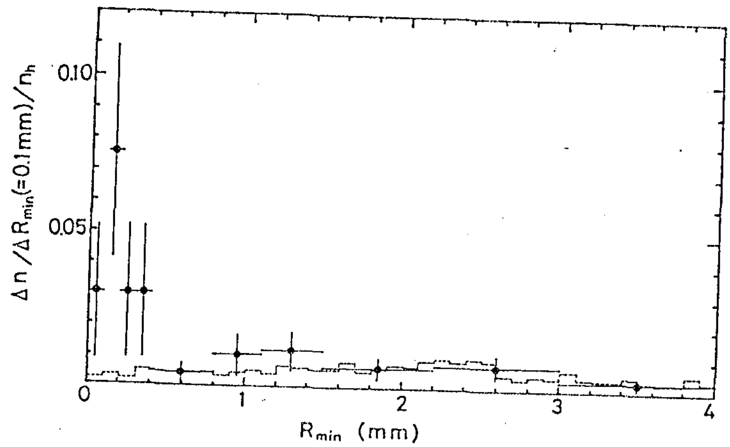


Fig.1a: Distribution of relative distance, Rmin, between a hadron and its nearest neighbouring shower. Histogram is a background distribution (see text).

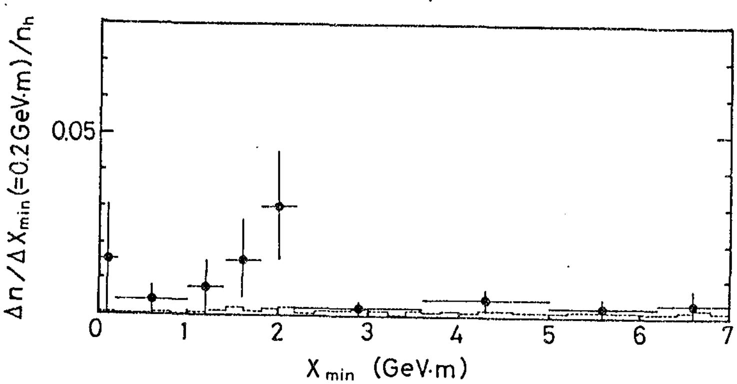


Fig.1b: Distribution of energy-weighted relative distance, Xmin, between a hadron and its nearest neighbouring shower in Xij-space.

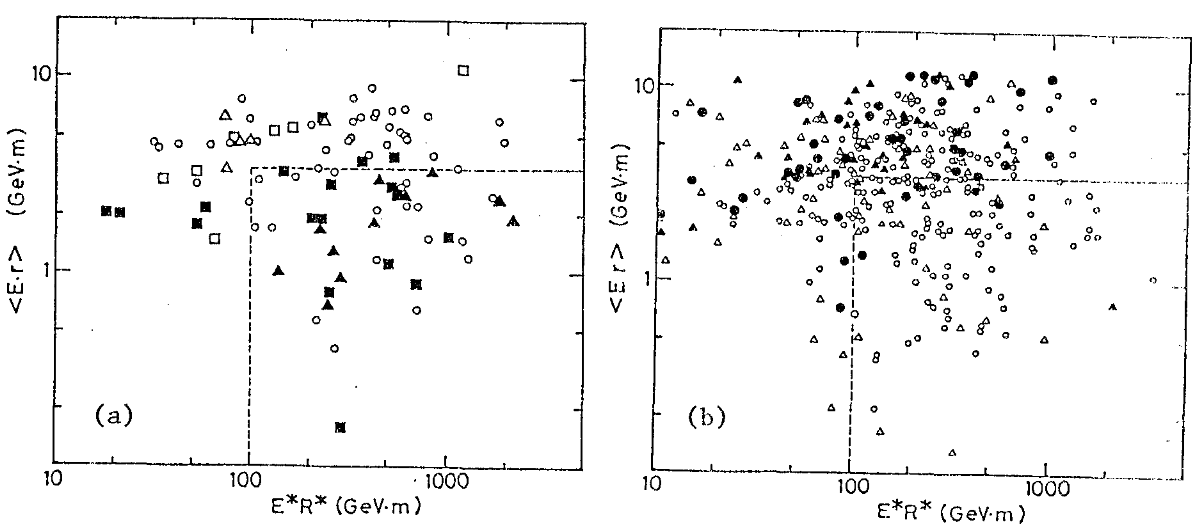


Fig.2a: Correlation diagram on energy-weighted lateral spread, E R of clusters and the average ⟨Er⟩ of showers in a cluster for the clusters with energy greater than 10 TeV.
○: clusters without hadrons, △: clusters which include hadrons,
▲: clusters which include hadrons with Rmin < 400 μm and/or Xmin < 2.2 GeV.m for the events of joint chamber.
□: clusters which include hadrons, ■: clusters which include hadrons with Rmin < 400 μm and/or Xmin < 2.2 GeV.m for the events of Chacaltaya chamber no.19.
Fig.2b: Same to Fig.2a for the simulated events. △, ▲: for Model-I and ○, ●: for Model-II. ▲, ●: clusters which include hadrons.