

## Mini-clusters

## Brasil-Japan Collaboration of Chacaltaya Emulsion Chamber Experiment

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## Abstract

Experimental result of 'mini-clusters' observed in Chacaltaya emulsion chamber no.19 is summarized. The study was made on 54 single core shower upper and 91 shower clusters of  $E(\gamma) > 10$  TeV from 30 families which are visible energy greater than 80 TeV and penetrate through both upper and lower detectors of the two-storey chamber. The association of hadrons in mini-cluster is made clear from their penetrative nature and microscopic observation of shower continuation in lower chamber. Small  $p_t(\gamma)$  of hadrons in mini-clusters is remained in puzzle.

## 1. Introduction.

The new shower phenomena named "mini-cluster" was first found through the study of shower clusters associated with families of large spread called Chiron type in Chacaltaya emulsion chamber no.19[1]. Chacaltaya chamber no.19 is one of the series exposure of two-storey structure and what is special for no.19 is that the whole area of the upper chamber,  $44 \text{ m}^2$ , is covered with three layers of nuclear emulsion plates as well as the lower chamber,  $33 \text{ m}^2$ , with seven layers of nuclear emulsion plates[1]. It allowed us to study the behaviour of shower cores in fine resolution under the microscopic observation.

A mini-cluster is a narrowly collimated shower core bundle ; so narrow that, in many cases, it gives a single dark-spot in X-ray films, and it reveals itself a very closely distanced shower core cluster under the microscopic observation in nuclear emulsion plates. The characteristic dimension of lateral spread is of the order of a few GeV.m, the same as the spread of young atmospheric cascade showers. The difference is seen in the strong penetrative nature of mini-cluster, showing the shower cluster is not of simple electromagnetic nature but hadrons must be inside. The present paper describes the summary of study on mini-clusters in Chacaltaya chamber no.19 of 677 days exposure.

## 2. Statistics of families.

30 families with  $\Sigma E(\gamma) > 80$  TeV are selected under the following

criteria.

- i) A family penetrates through both upper and lower chambers.
- ii) A family has wide spread ;  $\langle ER \rangle > 180 \text{ GeV.m}$  after the decascading procedure with constant  $Kc=6 \text{ GeV.m}$ .

### 3. Shower core observation under microscope.

Every dark spots in X-ray films in the upper chamber are studied in nuclear emulsion plates under microscope, especially asking whether a dark spot in X-ray films is single core structure or closely distanced multiple cores. The track counting method is applied to all individual shower cores for their energy determination with radius  $r=25$  and/or  $50 \mu\text{m}$ .

### 4. High energy showers ( $E(\gamma) > 10 \text{ TeV}$ ) in the upper chamber.

The high energy showers show the following characteristics.

(1) About one third of high energy showers are of single core structure. More than 60% of them penetrate into the lower chamber, indicating the majority are of hadron origin showers in the chamber materials.

(2) The rest are of multi-core clusters spreading over area  $0.1 \sim$  a few mm of radius. About one half of them are penetrative into lower chamber, indicating they all are not pure electromagnetic cascade in the atmosphere.

Table 1 gives the summary of observation of high energy shower-upper.

	no. of shower	no. of penetrative showers	%
single core	54	35	$65 \pm 12$
mini-clusters	91	41	$45 \pm 8$

Fig.1 shows the average transition curve of spot darkness in X-ray films (measured by slit size  $200 \times 200 \mu\text{m}^2$ ) for 37 single core and 57 mini-clusters. The results of simulation calculations are drawn together for pure electromagnetic cascades of gamma-ray incidence with energies 10 and 20 TeV, respectively, since the average energies of single core shower-upper and the highest one in mini-clusters are 20 and 15 TeV, respectively. One sees qualitatively different behaviour between the two, especially in the deepest region in the lower chamber ; that is, experimental results have much larger and longer tail for both single and mini-cluster cases than the case of pure electromagnetic cascades in the chamber materials.

### 5. Mini-clusters.

5-1. Multiplicity Fig.2 gives the distribution of number of shower cores,  $m$ , for 91 mini-clusters ( $E > 10 \text{ TeV}$ ). We see most of mini-clusters are ranging  $m =$  a few  $\sim 10$ . There are observed mini-clusters with extreme large multiplicity, say  $m \sim 30$ , for which we put the name "Giant-mini-cluster" and we shall discuss specially the properties of those huge shower clusters in details in the separate paper[2].

5-2. Small pt of mini-clusters It is expected  $p_t(\gamma)$  of shower cores at the mini-cluster formation must be small from their very small lateral spread. Fig.3 gives the scatter plots between the spread of 91 mini-clusters,  $\langle ER \rangle$ , versus that of parent Chiron family,  $\langle ER \rangle$ , measured by high energy showers ( $> 10 \text{ TeV}$ ) by mark (O). The broken lines show the cases where the ratio of both spreads are  $1/1000$ ,  $1/300$  and  $1/100$ ,

respectively. Most of them are distributed in the region smaller than  $1/100$  and the average is given by  $\sim 1/300$ . If we accept  $\langle p_t(\gamma) \rangle$  of parent Chiron interaction is  $2 \sim 3$  GeV/c, the  $\langle p_t(\gamma) \rangle$  of mini-cluster formation is obtained  $10 \sim 20$  MeV/c. In the same figure, we present the relation of spreads on binocular families by mark (●). We see the same small ratio in more than half of clusters from binocular families as in the case of Chiron families. The large pt nature at the geminon interaction,  $\langle p_t(\gamma) \rangle = 2 \sim 3$  GeV/c, the same order of magnitude with the Chiron interaction, is suggesting that there might work the similar dynamics for secondary particle production.

5-3. Hadrons in mini-clusters Mini-clusters show strong penetrative nature than expected from pure electromagnetic cascades from X-ray film observation as shown in Table 1 and Fig.1. Table 2 gives the results of microscopic observation of shower continuation in the lower chamber for mini-clusters as well as single core shower-upper of  $E(\gamma) > 10$  TeV.

Table 2                      Microscopic observation of shower continuations  
in lower chamber.

	Pb-jet-upper	C-jets	Pb-jet-lower	any	not studied	sum
single-core	14	7	3	7	4	35
mini-clusters	22	8	5	6		41

Hadrons in mini-clusters are studied in much detail by observing the core configuration and by comparing transitions of electron number in individual shower cores with the expected behaviour of pure electromagnetic cascades of single gamma-ray incidence on the basis of a large number of simulation calculations by T. Shibata. The results show there are not small cases where mini-clusters include plural hadrons[3]. A study on hadron association in mini-clusters are made from the side of correlation analysis by M. Tamada[3]. Using 19 families of Japanese part of the chamber no.19, the distribution of the relative distance (and energy-weighted relative distance) between detected hadrons and the nearest shower in each family is constructed and compared with the one of random background (Fig.4). The anomalous correlation was found in the range  $R \lesssim 1$  mm which show the probability is nearly equal or less than  $10^{-6}$  if the hadrons and electromagnetic particles are produced without any correlation.

## 6. Discussions.

A systematic search of mini-clusters was carried in the first carbon chamber at Pamir by USSR-Japan joint exposure[4]. There are found 11 penetrative mini-clusters among 17 families with energy greater than 50 TeV in  $\sim 24$  m<sup>2</sup>year exposure. There was a report on study of penetrative cascade showers in Pamir carbon chamber, giving the consistent results[5]. Exotic behaviour of secondary particles of Chiron-type families is remarkable when one consider the small collision mean free path ( $1/2 \sim 1/3 \lambda_{geo.}$ ) and small pt of hadrons and electron/gamma-rays seen in the mini-clusters.

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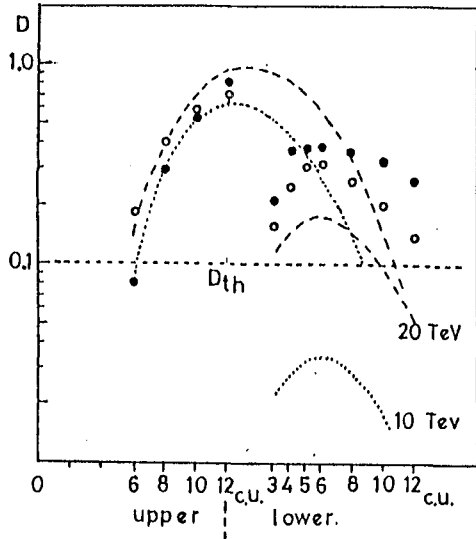


Fig.1 Penetrative nature of high energy( $E > 10$  TeV) single shower-upper and mini-clusters.  
 ● : single shower-upper  
 ○ : mini-clusters  
 Dth means threshold darkness of shower spot in X-ray films.

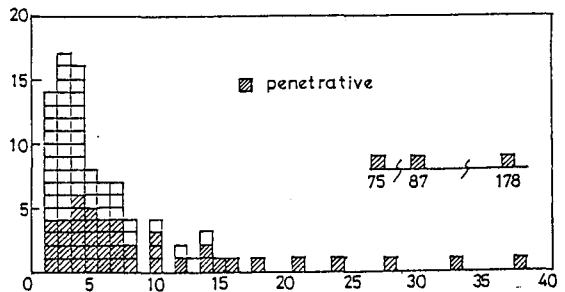


Fig.2 Histogram of shower core number in a mini-cluster.

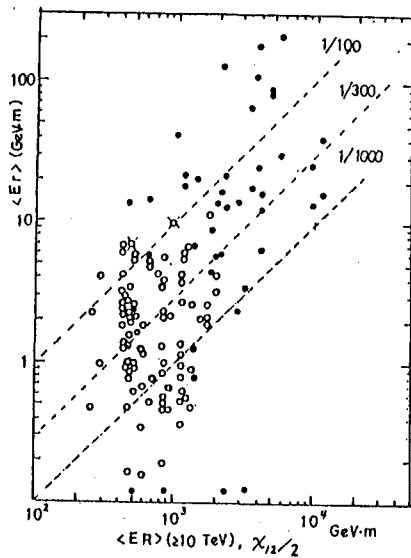


Fig.3 Scatter plot between two spread,  $\langle Er \rangle$  of individual shower clusters and family spread, of Chirons and binocular families.  
 ○ ; Chirons  
 ● ; binocular families.

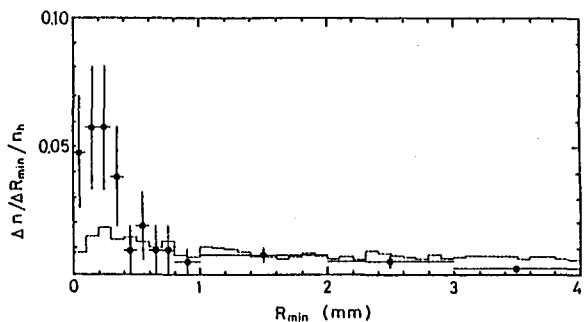


Fig.4 Distribution of relative distance,  $R_{min}$ , between a hadron and its nearest neighbouring shower. Histogram is background distribution obtained by changing randomly azimuthal angle,  $\phi$ , of hadrons in the observed events.