Observation of Penetrating Shower-clusters in Chacaltaya Two-storey Emulsion Chambers

M.Tamada
Faculty of Science and Engineering, Kinki University, Osaka 577-8502, Japan

Abstract

The penetrating nature of the cascade showers in the high-energy atmospheric families observed by Chacaltaya two-storey emulsion chambers are studied by comparing with those in the simulated events obtained by the full Monte Carlo calculation through the atmosphere and the detector. We find an excess of the number of penetrating showers over the expectations and these penetrating showers are mostly found as members of shower-clusters with small lateral spread.

1. Introduction

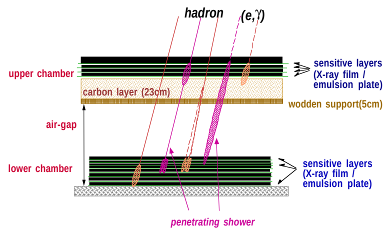
The existence of anomalous shower-clusters called "mini-cluster" has been reported in high energy events observed by the Chacaltaya two-storey emulsion chamber experiment.[1] Lateral spread of the "mini-cluster" is nearly same to that of simple atmospheric electromagnetic cascade, but we found a shower penetrating from the upper chamber down to the lower chamber among constituent showers. We consider the penetrating shower to be a hadron-induced shower because the shower became rejuvenated after passing through the target layer and air-gap.

In the experiment, we can study such penetrating nature using the showers observed in the events which have at least two penetrating showers, because an exact upper-lower correspondence is necessary to do the analysis and is possible only for those events. Here we perform full Monte-Carlo calculation of the atmospheric families throughout the atmosphere and the detector, and apply just the same procedure both to the experimental and simulational data in order to make possible a direct comparison between the two.[2]

2. Simulations

We use CORSIKA/QGSJET simulation code [3] for generating atmospheric families. 40,000 primaries of $E_0 \geq 10^{15}$ eV are sampled from the energy spectrum of 'normal chemical composition'. For (e, γ)-particles and hadrons, arriving upon the chamber, in the event with total energy larger than 100 TeV, we calculate further nuclear and electromagnetic cascade development inside the chamber taking into account exactly the structure of each chamber. The basic structure of the chamber is shown in Fig.1. We use QGSJET [4] model for hadron-nucleus interactions and the Monte-Carlo code formulated by Okamoto and Shibata [5] for electromagnetic cascade development in the chamber. We fi-

pp. 1591–1594 ©2003 by Universal Academy Press, Inc.



chamber	no.18	no.19	no.22
exposure (days)	570	677	749
upper chamber (44 m^2)			
thickness	7cmPb	8cmPb	7cmPb
sensitive layers	5 layers	4 layers	5 layers
target layer	pitch(23cm) + wood(5cm)		
air-gap	158 cm		230 cm
lower chamber (32 m^2)			
thickness	9.6cmPb	8.4 cmPb	11.3 cmPb
sensitive layers	9 layers	8 layers	10 layers

Fig. 1. Structure of Chacaltaya two-storey chambers.

nally obtain the spot darkness throughout the chamber for all the member showers ((e,γ)- and hadron-origin) in the simulated events. The experimental error in the measurement of spot darkness and also experimental space resolution of the shower observation are also taken into consideration. The visible (detectable) energy of each shower is re-estimated by applying fitting procedure just same to the experiment. For C-jets (hadron interaction in the carbon-layer), the energy is estimated by the sum of gamma-rays of $E_\gamma \geq 0.1$ TeV produced in the interaction, because each gamma-ray energy is estimated by track-counting method using nuclear emulsion plate in the experiment.

3. Selection of the events

We selects events for the analysis which satisfy the following conditions;
1) the total visible energy, E_{tot}, is in the interval between 100 TeV and 1,000 TeV where minimum shower energy is taken to be 2 TeV and
2) the event has at least two penetrating showers in which the spot darkness at the bottom two layers in the upper chamber and at two successive layers in the lower chamber is larger 0.1.

The second condition is necessary to confirm the exact upper-lower correspondence. In the observed events with $100 \leq E_{tot} < 1,000$ TeV in one half of the Chacaltaya chambers no.18, no.19 and no.22, 28 events ($\sim$ a half of the observed events) satisfy the second selection criterion. We apply just the same selection criteria also to the simulated events.

4. Penetrating cascade showers with excess energy

The observed high-energy showers in the events selected by the above two criteria are classified into the following three categories.
(a) showers observed only in the upper chamber (*non-penetrating showers*) defined as those which have no shower-spots of $D \geq 0.2$ in the lower chamber,
(b) those observed only in the lower chamber (C-jets, Pb-jets-lower) defined as showers which have no shower spots of $D \geq 0.2$ in the upper chamber and
(c) *penetrating showers* observed both upper and lower chambers.

Table 1. Number of high energy showers in the atmospheric families of $100 \leq E_{tot} < 1,000$ TeV with more than two penetrating showers observed in the Chacaltaya chambers no.18, no.19 and no.22.

chamber no.18		chamber no.19		chamber no.22		**total**	
exp.	sim.	exp.	sim.	exp.	sim.	**exp.**	**sim.**
number of events							
10		12		6		**28**	
(a) showers observed only in the upper chamber (non-penetrating), $E(\gamma) \geq 10$TeV							
42	39.6 ± 0.9 ($37.1\ e,\gamma$; $2.5\ h$)	41	42.5 ± 0.9 ($39.9\ e,\gamma$; $2.6\ h$)	35	28.8 ± 0.7 ($26.5\ e,\gamma$; $2.3\ h$)	**118 ± 11**	$\mathbf{110.9 \pm 1.5}$ (**103.5 e**, γ; **7.4 h**)
(b) showers observed only in the lower chamber, $E(\gamma) \geq 10$TeV							
8	10.0 ± 0.5	7	7.9 ± 0.4	7	5.1 ± 0.3	**22 ± 5**	**23.0 ± 0.7**
(c) penetrating showers with excess energy †							
19	14.5 ± 0.5 ($8.6\ e,\gamma$; $5.9\ h$)	36	15.6 ± 0.6 ($12.4\ e,\gamma$; $3.2\ h$)	9	8.2 ± 0.4 ($3.6\ e,\gamma$; $4.6\ h$)	**64 ± 8**	$\mathbf{38.3 \pm 0.9}$ (**24.6 e**, γ; **13.7 h**)
(d) clusters with penetrating showers†, $E_{cl} \geq 10$TeV							
11	6.1 ± 0.4 ($5.3\ e,\gamma$; $0.8\ h$)	20	7.9 ± 0.4 ($7.6\ e,\gamma$; $0.3\ h$)	6	2.8 ± 0.23 ($2.1\ e,\gamma$; $0.7\ h$)	**37 ± 6**	$\mathbf{16.8 \pm 0.6}$ (**15 e**, γ; **1.8 h**)
(e) penetrating showers of single-isolated †							
8	7.0 ± 0.4 ($2.3\ e,\gamma$; $4.7\ h$)	11	6.3 ± 0.3 ($3.7\ e,\gamma$; $2.6\ h$)	3	3.8 ± 0.3 ($0.9\ e,\gamma$; $2.9\ h$)	**22 ± 5**	$\mathbf{17.1 \pm 0.6}$ (**6.9 e**, γ; **10.2 h**)

Numerical values in the simulated events are normalized to the number of experimental events. Numerical values in the parenthesis are those of (e,γ)-induced and hadron-induced showers.
†) Penetrating showers are those with $N_{upper}(D \geq 0.2) \geq 2$ and excess energy in lower chosen irrespective of its energy.

Among the penetrating showers, we often observe showers in which spot darkness in the lower chamber is much larger than that expected from the data of the upper chamber, when we assume those showers are (e,γ)-origin. For those showers, we estimate excess energy, E_H, by using extra darkness in the lower chamber. Those penetrating showers with excess energy can be either hadron-induced cascade showers or (e,γ)-induced one with extreme fluctuation of cascade development, but is seen it is hard to discriminate hadron-induced showers from (e,γ)- induced ones.

We summarize in Table 1 the number of showers of the three categories in the above selected events together with those expected in the simulated events. Here the numerical values are normalized to the experimentally observed number of events in each chamber.

5. Clustering

We apply the decascading procedure to all the member showers, both (e,γ)- and hadron-origin, of a family. We calculate $Z_{ij} = E_iE_j/(E_i+E_j)R_{ij}$ for any pairs of showers, where R_{ij} is a relative distance between the two showers. If Z_{ij} is less than 1.2 TeV·cm, these two showers are amalgamated into one. The procedure is repeated until no member shower satisfies the above condition. If a cluster obtained above consists of only one shower, the shower is called "single-isolated shower". Some of the shower-cluster include penetrating showers as a member. In Table 1 we show also the number of clusters with penetrating showers and of single-isolated penetrating showers. Most of the clusters consist of only (e, γ)-induced ones in the simulated events.

6. Discussions

The table shows there exists a considerable excess of penetrating showers in the experimental data over the expectation. The excess amounts ~ 26 showers. Almost all of these 26 penetrating showers are found as a member of shower-clusters (excess number of the observed clusters with penetrating shower is ~ 20) and they look like as if they are (e, γ)-induced simple atmospheric cascades *. The ratio of the number of penetrating (e, γ)-showers to that of non-penetrating showers is given as $24.6/103.5 \sim 0.24$. (see Table 1), then we expect additional number of non-penetrating showers to be ~ 100, if we assume those 26 showers are (e, γ)-induced showers. This number is, however, too large compared to the observed excess of non-penetrating showers over expectation. On the contrary, if we assume those 26 penetrating showers are hadron-induced ones, we expect additional number of showers in lower (C-jets and Pb-jets-lower) to be ~ 40, using a number ratio ($13.7/23.0 \sim 0.6$) of the penetrating hadron-induced showers to showers in lower. The number again is too large compared to the observation. Thus we must look for another reason for the excess of the penetrating showers and penetrating clusters. One of the possible explanations is to assume the occurrence of extremely collimated pair of a γ-ray and a hadron. That is, if the mutual distance between a γ-ray and a hadron is extremely small, e.g., less than ~ 1 mm, and the γ-ray-induced shower is observed in the upper chamber and the hadron-induced shower is observed in the lower chamber, we would possibly misidentify those two as a penetrating shower. If a γ-ray makes electromagnetic interactions in the atmosphere, we can observe collimated several (e, γ)-particles and a hadron as a 'mini-cluster' which are often found in the exotic events.[1] Possible existence of extremely collimated hadron-bundles is also discussed in the analysis of transition curve of high-energy hadronic showers observed in the Pamir thick lead chamber [6]

1. Brasil-Japan collaboration, *Proc. AIP Conf.* No.85 (1981) 500
2. Tamada,M., *Proc. 27th ICRC, Hamburg* Vol.4 (2001) 1441
3. Heck,D. et al., *FZKA report 6019, Forschungszentrum, GmbH Karlsruhe* 1998
4. Kalmykov,N.N., Ostapchenko,S.S., & Pavlov, A.I., *Bull. Russ. Acad. Sci. (physics)* **58** (1994) 1966
5. Okamoto,M and Shibata,T., *Nucl. Instr. Meth.* **A257** (1987) 155
6. Tamada,M. and Ohsawa,A., *Nucl. Phys. B* **581** (2000) 73

---

*The penetrating probability depends on the chamber structure and the selection criterion 2), described in section 4, works in a different way in each chamber. Then the excess number depends on the structure of the chamber.