Penetrative nature of high energy showers observed in Chacaltaya Emulsion chamber

Y. Funayama and M. Tamada

Science and Engineering Research Laboratory,
Waseda University, Tokyo 162, JAPAN

ABSTRACT

It is shown that about thirty percent of single core showers with $E^{(\gamma)} > 10$ TeV , which have been observed in the air families with $\Sigma E^{(\gamma)} > 100$ TeV , have stronger penetrating power than that expected from electromagnetic showers (e,γ). On the other hand, their starting points of cascades in the chamber are found to be as shallow as those of (e,γ) components. Then, we can consider that those showers are very collimated bundles of hadron and (e,γ) component. Otherwise, we must accept that the collision mean free path of those showers in the chamber is shorter than that of hadron with geometrical value.

1. Introduction

Chacaltaya experiment has reported the existence of mini-cluster, which has been observed as the daughter product of the exotic interaction, such as Chiron[1] and Geminion[2]. This is the shower bundle observed as nallowly collimated cluster structure and looks like an early stage of (e,γ) cascade showers in the upper chamber. But, we can identify at least one hadron in it, and then we must consider that this is the collimated bundle of hadrons and electromagnetic showers.

On the other hand, we have often observed a number of showers in these families penetrating strongly through the whole chamber, although they are found to start at the shallower depth in lead of the upper chamber.

Here, we discuss the characteristics of those penetrating showers with $E^{(\gamma)} > 10$ TeV, observed as single core structure in the upper chamber.

2. Experimental apparatus and method

2.-1 chamber

Chacaltaya E.C. no.19 has two storey structure and consists of four parts, the upper chamber of 6 cm thick in lead, the target layer of 23 cm pitch, the air gap of 158 cm and the lower chamber of 8.4 cm thick in lead. Both the upper and the lower chamber are multi-layered sandwiches of lead plates and photo-sensitive materials (nuclear emulsion plates and X-ray films).

2.-2 selection of families

We here select 19 air families with $\Sigma E^{(\gamma)} > 100$ TeV, which have been

obtained by the systematic study of Chacaltaya E.C. no.19 (Japan part, ~30 m^2.yr). They have at least two showers which are detected both in the upper chamber and in the lower chamber.

2.-3 measurement of showers

In the present analysis, we pick up only single core showers with penetrative nature. Here, the penetrating shower means that it has at least two layers where its spot darkness on X-ray films is greater than 0.1 in the lower chamber. The spot darkness is measured by microphotometer with 200 μm x 200 μm square slit. The energy of shower with maximum darkness 0.1 is about 1 TeV, and it is the threshold energy obtained by X-ray film. We call showers as ' single core showers ' which accompany no showers within 1 mm around them. The energy measurement of each shower is also carried out by the track-counting method on nuclear emulsion plates.

3. Results

3.-1 (e,γ)-like behaviour of penetrating showers

Fig.1 is the integral energy distribution of observed single core showers (O) and those with penetration (●). That of simulated gamma-rays is also shown in the same figure. (—; all showers, -----; with penetration). Statistics of calculations is about 10 times larger than that of observed showers. Here, we consider the only showers with $E_\gamma > 10$ TeV, because the penetration probability of gamma-ray with $E_\gamma < 10$ TeV is found to be negligible small by the same calculations.
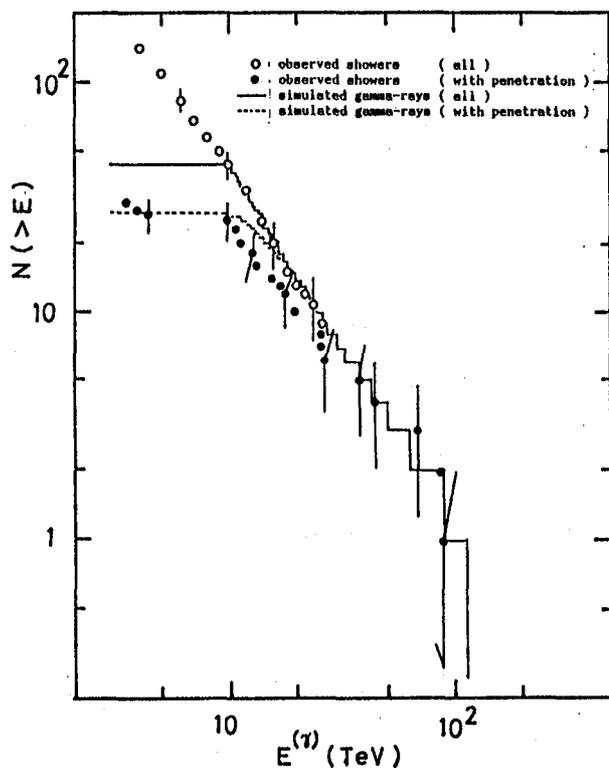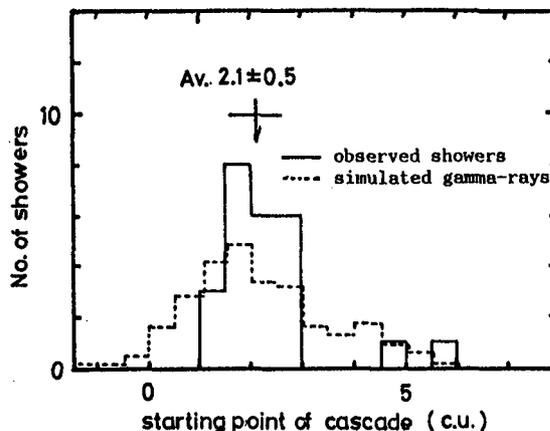
Fig.1 Integral energy distribution

Fig.2 Starting point distribution of cascade in the chamber for penetrating showers $E^{(\gamma)} > 10$ TeV

Simulation calculation is constructed by T.Shibata et.al.[3]   The exact structure of E.C. no.19, L.P.M. effect and spacing effect are taken into account.   Fig 2. is the starting point distribution of cascades in the chamber only for penetrating showers with $E^{(\gamma)} > 10$ TeV (———; experiment, -----; simulated gamma-ray).   We can see from these figures that the observed showers with $E^{(\gamma)} > 10$ TeV show the (e,γ)-like behaviour on the penetration probability and the starting point of cascades.

3.-2 hadron-like behaviour of penetrating showers
    In order to investigate the penetrating power of showers, we define the quantity n_i at the i-th layer in the lower chamber, and introduce Σn_i as follows. (Fig.3)

$$\Sigma n_i = \Sigma (\log D_i - \log \langle D \rangle_i) / \log \sigma_i$$

    D_i denotes the observed spot darkness on X-ray films at the i-th layer in the lower chamber.   For each shower, we fit the observed spot darkness in the upper chamber to the transition curve, using the least square method.   Here, the transition curve is constructed by the simulated (e,γ) cascade showers of electron pair origins in the chamber without air gap of 158 cm. $\langle D \rangle_i$ and σ_i is the average darkness and its one standard deviation at the i-th layer in the lower chamber, respectively, estimated from the above fitted curve. Σ means summing up of the quantity n_i only for the layers in the lower chamber where the spot darkness D_i is greater than 0.1.   We assume $n_i = 0$ if $D_i < \langle D \rangle_i$. Then, it is considered that the showers with larger Σn_i have long tails with strongly penetrative nature.
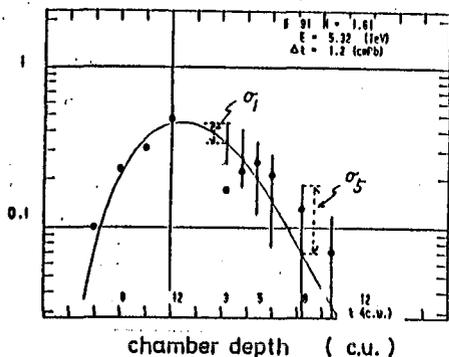
chamber depth   (c.u.)

Fig.3   Procedure of calculating Σn_i

We get $< D >_i$ and σ_i at the i-th layer in the lower chamber from the fitted curve and calculate Σn_i.

where,
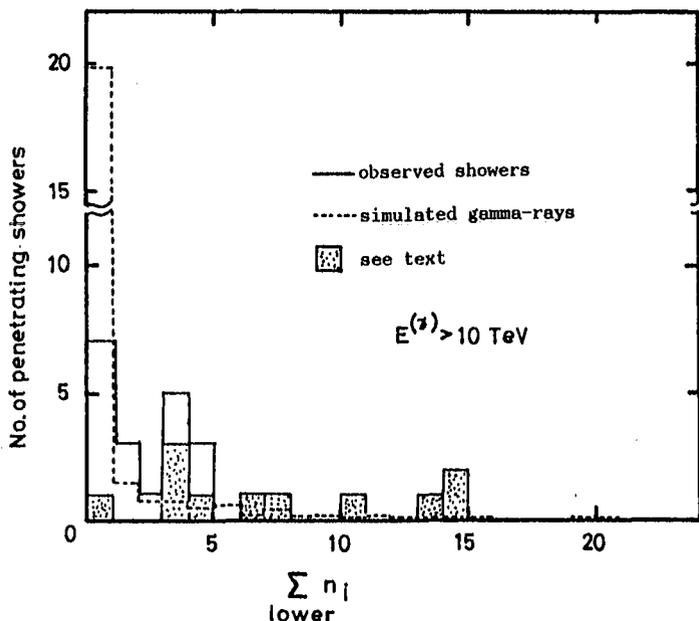$n_i = 0$ (at $D_i < 0.1$
                    or $D_i < < D >_i$)
$n_i = (\log D_i - \log < D >_i)$
        $/ \log \sigma_i$
                    (otherwise)
    (see text.)

In this case,
$n_1 = n_2 = n_6 = n_7 = n_8 = 0$
$n_3 = 0.40$, $n_4 = 0.55$, $n_5 = 0.66$

then, $\Sigma n_i = 1.61$

Fig.4 Σn_i distribution of penetrating showers

——observed showers

------simulated gamma-rays

▨ see text

$E^{(\gamma)} > 10$ TeV

No.of penetrating showers

Σn_i
lower

Σ n$_i$ distribution is shown in Fig.4 (——;experiment, ------;simulated gamma-rays). That for simulated gamma-rays is obtained by applying the same method. We can expect that the showers with larger Σ n$_i$ have the new shower cores in the lower chamber, which make this quantity bigger. Thus, the showers, which were identified to have these new cores in the lower chamber under the microscopic observation, are shown by the ⊠ marks.

As is seen from this figure, about one half of observed penetrating showers with $E^{(\gamma)} >$ 10 TeV, that is, about thirty percent of observed single core showers with this energy region, have long tails of cascade developments in the lower chamber, which cannot be explained by the fluctuation of (e,γ) showers.

4. Conclusion and Discussion

About 30 % of single core showers with $E^{(\gamma)} >$ 10 TeV, which have been observed in the families with $\Sigma E^{(\gamma)} >$ 100 TeV detected by Chacaltaya E.C. no.19, start at the shallower depth in the upper chamber like (e,γ) components, but they penetrate strongly into the lower chamber like hadron components. This suggests that they consist of very collimated a gamma-ray and a hadron, the distance between the two is $< 100 \mu m \sim 200 \mu m$. That is, the gamma-ray starts cascade development in the upper chamber and the hadron interacts in the target layer, so that they look like just continuing single core shower, because there is an uncertainty of about $100 \mu m \sim 200 \mu m$ in the geometrical position when we identify the showers observed in the lower chamber with the continuation of the shower in the upper chamber. Then, when the hadron happen to interact in the upper chamber, we might recognize those showers as mini-clusters. Otherwise, from the argument on the detection probability of hadrons in the chamber, the collision mean free path of these showers is about one third of that of hadron with geometrical value [4].

References

[1] Brazil-Japan collaboration ; Proc. of Workshops on Cosmic-Ray Interactions High Energy Results, La Pas Rio de Janeiro (1982) 319 S.Hasegawa ; Proc. of Int. Sympo. on Cosic Rays and Particle Physics, Tokyo (1984) 319
[2] Brazil-Japan collaboration ; AIP Conf. Proc. no.49 (1979) 145
[3] M.Okamoto and T.Shibata ; Conf. Paper, 17th Cosmic Ray Conf.,Paris 5 (1981) 214,218
[4] Y.Funayama and M.Tamada ; to be published.