A Binocular-type Atmospheric Interaction Generating Sequential Exotic Features

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Abstract A cosmic-ray induced nuclear event is presented, which is of clear binocular-type and contains several exotic features through its passage in the atmosphere and the emulsion chamber.

1. Introduction

Brasil-Japan Collaboration has observed some exotic events (Centauro family) in the high-energy cosmic-ray interactions, and they are classified into four categories as (original-) Centauro, Mini-Centauro, Geminion and Chiron according to their multiplicity and average p_T./1,2/ Their common feature is a lack of γ-ray emission in their interactions, and they are regarded as phenomena quite distinct from the normal pion production.

In this paper, we present a very special event which shows several exotic features in three generations of interactions.

2. Experiment

The event was observed in the 19th emulsion chamber at Chacaltaya. The chamber is two-storied, which consists of an upper chamber, a lower chamber and a target layer in-between. The chamber is multi-layered sandwiches of lead plates and photo-sensitive materials. In the unit block where the present event was detected, nuclear emulsion plates were inserted with N-type X-ray films at 6,8 and 12 cu in the upper chamber and 3,4,5,6,10 and 12 cu in the lower chamber. At 4 and 10 cu in the upper chamber and at 8 cu in the lower chamber, only X-ray films were inserted. Thanks to the high spatial resolution of nuclear emulsion, we can study a fine structure of shower cores in detail which is quite powerful to pick up and examine the exotic features.

3. Results

As the event was observed in the unit block 109 in the upper chamber and in the block 69 in the lower chamber, we name this event as CH19 S109 I69. In the following, the results corrected on the incident zenith angle (15 degrees) will be presented.

Fig.1 shows the target diagram of the event, which already visualizes the first impressive feature, i.e., a clear double-core structure. In the group A, 83.7 TeV is observed in the form of electro-magnetic cascade showers,and

51.3 TeV in the group B. The relative distance between A and B is 22 cm, and the value $\chi(A,B) = R(A,B)\cdot\sqrt{E(A)E(B)}$ is 1440 TeV·cm. We notice how large the spread of this event is, comparing the average value ~650 TeV·cm of the binocular-type events observed by the Brasil-Japan Collaboration./1,2/

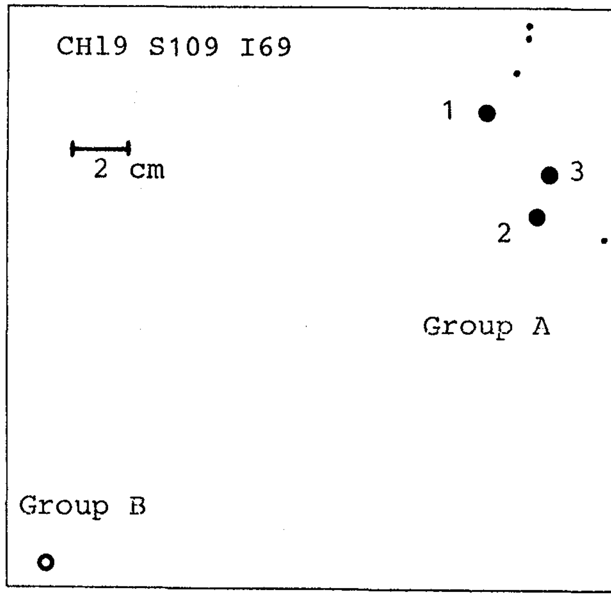

Fig.1 The target diagram of the event CH19 S109I69.

3-1. Group A The group A contains 3 high energy hadrons and 4 low energy showers as shown in Fig.1 and Table 1.

	Energy (TeV)	Comments
A1	16.3	A-jet
A2	31.5	Pb-jet-upper
A3	20.0	Pb-jet-lower
A4-7	15.9	A-jet
B	51.3	A-jet

Table 1 Groups A and B.

(#A1) #A1 has two cores in the upper chamber (10.5 TeV and 5.8 TeV with the relative distance 152 μ), and continues into the lower chamber where five weak and diffused showers and one very new core are observed inside the radius ~400 μ. Thus we can know that one of the two cores observed in the upper chamber or another hadron interacted to produce the showers observed in the lower chamber.

(#A2) #A2 starts to appear at 12 cu in the upper chamber as a very collimated core which can be realized only in the emulsion plate, and appears in the lower chamber as a multi-core event inside the radius 114 μ. The energy was determined for each of the 7 cores, and π°-coupling confirms that they were born in a normal pion production at the lower part of the upper chamber. Outside the multi-cores, one new core of 8 TeV starts to appear at 10 cu in the lower chamber, its distance from the multi-cores being 187 μ. But we can not test whether it came from the emission point of the multi-cores or from the atmosphere. In case of the former, the electro-magnetic component of p_T of this hadron with respect to the emitted direction of the multi-cores is 0.80 MeV/c.

(#A3) #A3 starts to appear at 3 cu in the lower chamber as a single core, but at 4,5 and 6 cu as double cores, their energies being 17 TeV and 3 TeV. The relative distance between the two cores increases gradually at the deeper layers as shown in Fig.2. The convergence shows that #A3 is an interaction in lead plate in the lower chamber, and that the

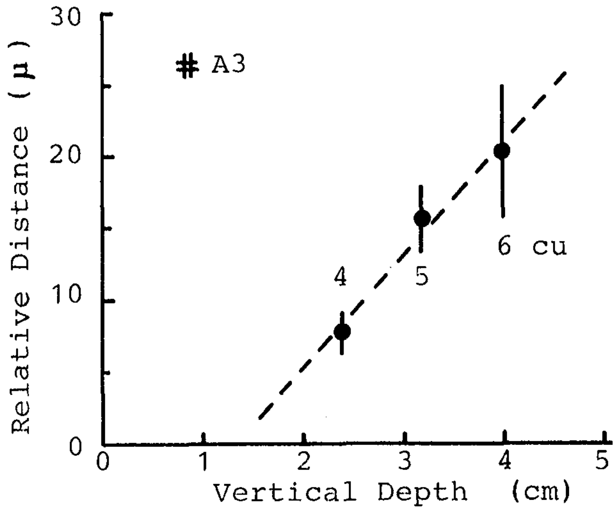

Fig.2 Variation of relative distances in #A3 at 4,5 and 6 cu.

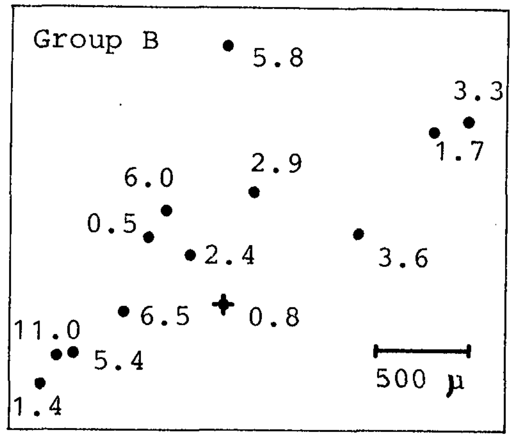

Fig.3 The target diagram of B. + stands for a hadron.

opening angle is $(7.6 \pm 1.8)\cdot 10^{-4}$ rad.. Their invariant mass is calculated only for the electro-magnetic component to be 5.4 GeV/c^2.

(#A4-7) #A4-7 are observed in the upper chamber as normal low energy showers.

The triangulation method was applied to determine the interaction height of the group A by measuring the relative distances between the higher energy core of #A3 and one of the multi-cores of #A2 at 3,4,5,6 and 10 cu in the lower chamber and between the higher energy core of #A3 and the new core of #A1 at 4 and 5 cu in the lower chamber. Within the error, the measurements on both pairs are consistent with parallelism, so we can say that the interaction height of the group A is higher than the limit of accuracy on the height determination, ~500 m above the chamber.

3-2. Group B The group B contains 13 shower cores with a quite small lateral spread; the average spread is 745 μ which is ~1 % of the average of atmospheric interactions. The target diagram of B is shown in Fig.3. One core indicated by the cross in Fig.3 appears at 6 cu as a very collimated shower core whose starting-point of cascade is estimated to be 2.2 cm·Pb, which is identified as a hadron.

4. Discussions and Conclusion

The event S109 I69 is of clear binocular-type consisting of two groups of particles well separated to each other. In the view-point of Centauro family, this event can be a Geminion-type. Using the average mass of Geminion ($k_\gamma M \sim 5$ GeV/c^2), the production height is calculated to be ~3 km.

In the group A, the fraction of the energy sum of hadrons over the total visible energy is 81 %. This large fraction satisfies the criteria/3/ that the event can be of Mini-Centauro type. Using the average p_T of Mini-Centauro ($k_\gamma p_T \sim$

0.35 GeV/c), the interaction height is calculated as ~1 km.

#A1 is an atmospheric interaction. If we assume that the two cores observed are decay-products of $\pi^0 \rightarrow 2\gamma$, the height is 8.8 m. If we assume that they are from mini-cluster/2,4/ with p_T = 20 MeV/c, the height is ~30 m above the chamber.

#A2 is an interaction in the upper chamber. If the hadronic core came from the same emission point of the multi-cores, #A2 can be a normal pion production in the chamber. If the hadronic core came from the atmosphere with another hadron producing the multi-cores, #A2 can be of mini-cluster. Using p_T = 20 MeV/c, the height is ~60 m.

#A3 is an interaction in the lower chamber, in which two cores are well separated with a very large transverse momentum ($k_\gamma p_T$ ~ 1.9 GeV/c). #A3 can be a Geminion.

#A4-7 may be products of normal pion production in the atmosphere.

The group B is an atmospheric interaction very near the chamber. If we assume that the interaction is of normal pion production with $\langle p_{T\gamma} \rangle$ = 200 MeV/c, the height is 15 m. If we assume a mini-cluster, the height is 150 m.

Summarizing the results and discussions on the event CH19 S109 I69 whose total visible energy is 135 TeV, our conclusion is as follows:

- S109 I69 (Geminion) ~3 km
  - Group A (Mini-Centauro) ~1 km
    - A1 (Mini-cluster, 30 m or Pion Production, 8.8 m)
    - A2 (Pion Production, 0 m or Mini-cluster, 60 m)
    - A3 (Geminion, 0 m)
    - A4-7 (Pion Production, ~500 m)
  - Group B (Mini-cluster, 150 m or Pion Production, 15 m)

Sequential appearance of exotic features in this event can be well understood by the hypothesis on genetic relation/4/ that an exotic interaction is generated by an exotic particle produced out of the exotic interactions.

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