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Content

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New Clean Example of Centauro Species, Observed by Chacaltaya Emulsion Chamber Experiment

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I. Introduction.

The present report describes a low energy family made of only hadrons without association of γ-rays, observed in a Chacaltaya chamber of Brasil-Japan Collaboration. Although the hadron multiplicity is small, this event has, in its essence, a similar appearance with that of the original Centauro I found in 1972 (Lattes,1980). Centauro, which is characterized by large imbalance between the hadron component and the γ-ray component, has been a puzzle to us for so many years.

II. Chacaltaya Chamber 22.

The concerned event was found in Chamber 22 exposed at Chacaltaya station (5200 m or 540 g/cm^2, Bolivia) for about 2 years. The chamber structure is given in Table 1.

The chamber, both upper and lower, is a multiple sandwich of lead plates and photosensitive layers made of X-ray films. Some layers contain nuclear emulsion plates, too. The chamber records an electron shower as a dark spot in X-ray films, or a bundle of tracks in nuclear emulsion plates. Through the observation over successive layers, we are able to obtain the shower transition curve and the shower energy can be measured from its comparison with the standard cascade curves.

Table 1 Structure of Chamber 22

	Area (m^2)	Thickness	Layers* (†)
Upper chamber	44.2	7 cm Pb	5 (3)
Target layer	45.0	30 cm CH$_2$	—
Space	—	237 cm	—
Lower chamber	32.0	11 cm Pb	10 (4)

* No. of sensitive layers.

† Those with nuclear emulsion plates.

III. Observational Data on New Event.

The concerned event was found in Block 19 of the lower chamber. Fig. 1 presents the target diagram of the event where we see a family of 31 showers. The total observed energy there is 57.4 TeV.

What is particular of this event is that there can be found no corresponding part of the family in the upper chamber. Since we know location and arrival direction of the family in the lower chamber, we are able to estimate the location in the upper chamber. The scanning for a shower with the same arrival direction was made around the expected region in the upper chamber, but with the negative result. Before arriving at the conclusion of absence of the upper chamber showers, we made the following consideration and check.

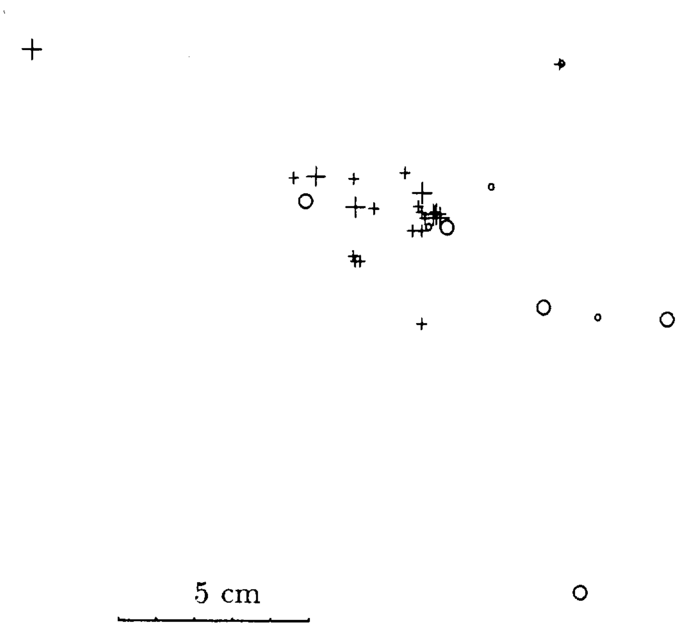

Fig. 1. Target diagram of the event in lower chamber. Large and small marks represent the showers with the visible energy above and below 1 TeV, respectively. The open circles are those identified as Pb-jet-lower. (See Table 2.)

1) Geometrical configuration of the event in the chamber is presented in Fig. 2. Since the arrival direction is near vertical, the location estimation at the upper chamber can be made with error less than 10 cm. The expected location is about 1.2 m inside the nearest edge of the upper chamber, the arrival direction of the event passed through the upper chamber and the carbon target layer, too, without leaving a record of showers there.

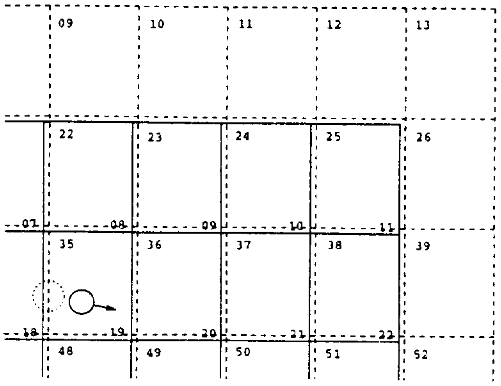

Fig. 2. Geometrical position of the event in the chamber. The blocks (40 cm × 50 cm each) of the upper and lower chambers are shown by dotted lines and solid lines, respectively. The solid circle is the location of the event in the lower chamber (with the direction of the event), and the dotted circle is the expected location which the event passes in the upper chamber.

2) The record on Chacaltaya expedition tells that the lower chamber was constructed only after the upper chamber was completed, and disassembled first while the upper chamber was kept untouched. There is no period during which the lower chamber was left alone for cosmic ray exposure. This is our routine way in Chacaltaya work.

3) The chamber is made of a number of blocks with registered numbers. The geometrical configuration of blocks was checked twice during construction and disassembly. The upper-lower geometrical correspondence of the chamber was confirmed by observing other families penetrating through the whole chamber.
4) Some showers can be missed in a gap between blocks. Size of the gap can be about 1 cm depending on cases. We may think that the whole showers in the family can not be missed by the gaps between blocks.

In summary, in spite of the evidences that the event passed through the upper chamber, we cannot find any shower in the upper chamber. And, we cannot find any trivial reasons for the fact that no shower is observed in the upper chamber.

IV. Arrival of Hadron Bundle.

The only interpretation we can think of is that the present event shows arrival of a hadron bundle without association of γ-rays above the detection threshold. Among showers in the lower chamber produced by a hadron, we make three class depending on location of the shower-initiating nuclear interaction in the chamber, as shown in Table 2.

Table 2 Classification of Observed Hadrons

Class	Location of interaction	Shower characteristics
Pb-jet-upper	upper chamber	diffuse shower starting from top
C-jet	carbon target layer	narrow bundle of showers
Pb-jet-lower	lower chamber	starting deep in lower chamber

From the chamber structure shown in Table. 1, we can expect different shower characteristics for different classes. For example, we find in the target map shown in Fig. 1 several shower clusters which are to be identified to class of C-jets. Table 3 shows the result of hadron identification through this classification.

Table 3 Classification of the showers of the event (preliminary)

Hadron class	No. of hadrons	Energy sum (TeV)	Effective thickness*
Pb-jet-upper	See "Unidentified".		0.38 λ
C-jet	5	10.9	0.38 λ
Pb-jet-lower	5	30.8	0.49 λ
Unidentified	3	10.5	—

* λ_{inel} = 18.5 cm Pb is assumed.

In conclusion, the family is made of 13 (preliminary) hadrons, with energy exceeding 1 TeV, without presence of γ-rays.

V. Discussion.

Fig. 3 shows the $N_h - Q_h$ plot of the present event, together with those of the simulation families based on the UA5 model of nuclear interaction. We see that the event is possible though with small probability. But this leaves the puzzle of Centauro I unsolved.

Suppose the event is not the fluctuation of ordinary family, there are left other possibilities to be discussed. Our working hypothesis for Centauro search has been to assume that this exotic family comes from an atmospheric interaction with emission of "Centauro fire-ball". From the data of Centauro I, the Centauro fire-ball is with large rest energy, 200 $\sim$ 300 GeV, decaying into 50 $\sim$ 100 hadrons without neutral pions (hence, maybe, decaying into nucleons and anti-nucleons). Because of such high mass, the yield of Centauro fire-ball will be rapidly increasing with collision energy. Thus the Centauro search has been directed towards families of larger energy, beyond 100 TeV.

Now comes discussion on the present hadron family. The event is hard to find a place under the Centauro fire-ball hypothesis, because of its rather low visible energy and rather large lateral spread. Since the observed energy is only one quarter or less of the case of Centauro I, we expect only a small yield of Centauro fire-ball. The collision energy here will be within the collider energy range, where the search in accelerator experiments has given very small upper limit for the yield (Alpgard,1982; Arnison,1983), which is equivalent to zero in the cosmic-ray studies. At the moment, there are left three choices for interpretation of the event.

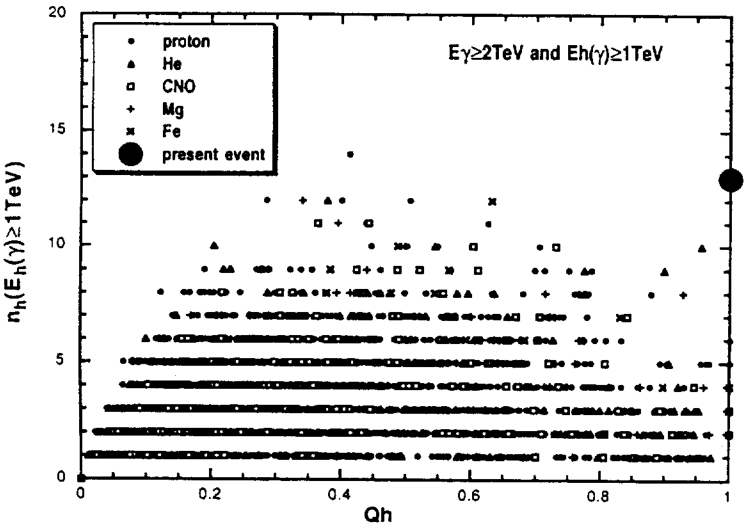

Fig. 3 $N_h - Q_h$ diagram, where N_h is the number of hadrons and $Q_h = \sum E_h^{(\gamma)} / \sum(E_h^{(\gamma)} + E_\gamma)$. The threshold energies for γ-rays and hadrons are set to be 2 TeV and 1 TeV, respectively. The events by the simulation are shown together.

We point out that the event shows a similar appearance to Mini-Centauro events in its hadron multiplicity and its energy spectrum (Lattes,1980). But this choice must describe why Mini-Centauro events are not detected by accelerator experiments.

The second is to assume (Hasegawa,1984) that a Centauro fire-ball is not directly produced in the atmospheric nuclear interaction, but is a decay product of a progenitor particle produced in it. Here, at present, one may expect an accelerator-transcending threshold of collision energy for observing a Centauro family of even a modest visible energy.

The third is to remind ourselves of the several past proposals which tried to interpret Centauro I event as a fragmentation of a heavy primary particle penetrating deep into the atmosphere. The "heavy primary particle" here must have much larger nuclear mean free path than that of an ordinary nucleus, in order to ensure its survival down close to the mountain altitudes. There are suggestions that the particle might be a quark glob (Bjorken,1979). Here a Centauro will have no production threshold, nor will it be produced in accelerator experiments.

The present report is a preliminary one based on the X-ray film information only. The complete data, based on the information from both X-ray films and nuclear emulsion plates, will be presented at the conference.

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