Exotic Interactions among C-jets and Pb-jets

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ABSTRACT

Systematic survey of C-jets and Pb-jets is carried out on
the part of Chacaltaya Emulsion Chamber No.19 amounting to
an exposure of 28.8 m^2yr. 198 C-jets with two or more con-
stituent shower cores and with $\Sigma E_\gamma \geq 5$ TeV are adopted and
analysed. It is shown that the adopted events make up an
unbiased sample of C-jets for $\Sigma E_\gamma \geq 7$ TeV. Among the adopt-
ed events, 16 are found to be pinaught-less. Fluctuation
of ordinary multi-pion production can account for only a
small fraction of them. Mini-Centauro interaction gives
the most natural explanation for the eight pinaught-less C-
jets with three or more constituent shower core. Out of
the eight double-cored pinaught-less events, three are found
to have visible invariant masses > 1.8 GeV/c , which strong-
ly reminds us of the event "Castor-Pollux", the first clear
example of a Geminion interaction.
In addition, three Pb-jets-lower are found to be composed of
double cores whose respective visible transverse momenta are
greater than 0.5 GeV/c, suggesting that they are of Geminion
origin or chiron origin.
The energies of the parent particles are estimated to be 100
to 200 TeV for all the above-mentioned three kinds of events.
    Discussions are made on the implications of this energy
estimate and of the frequency of observed exotic events.

1. Introduction.

    In mountain emulsion chamber experiments, several types of exotic nu-
clear interactions have been found among A-jets, i.e., nuclear interactions
occurring in the atmosphere above the chamber/1/2/. The decisive charact-
eristics common to all these exotic interactions are follows:
(i) they produce secondary particles with unusually large transverse mo-
     menta.
(ii) they are "pinaught-sterile", i.e., they produce pratically no pinaught.
    Some of the above-mentioned exotic interactions were expected to occur
at the CERN $\bar{p}$-p collider, but the search met with no success.
    The present work is the report on a least biased systematic survey of
the local nuclear interactions occuring within the emulsion chamber, aiming
at making a guess on the threshold energy for the exotic interactions.

2. Experimental Procedure.

    C-jets and Pb-jets-lower recorded in the two-storeyed Chacaltaya Emul-
sion Chamber No.19 are detected and analysed. The chamber consists of the
upper chamber(area 44m^2, thickness 6cmPb), nuclear interaction producer
(area 44m^2, thickness 23 cm asphalt), air gap(1.5m) and the lower chamber
(area 33m^2, thickness 7cmPb). C-jets and Pb-jets-lower are the local nu-
clear interactions occuring in the producer and in the lower chamber, res-
pectively. The chamber contains nuclear plates and N-type X-ray films under
1.5cm, 2cm, 2.5cm, 3cm, 4cm and 6cm of Pb. It was exposed for 667 days to
cosmic rays at Chacaltaya(540 gr/cm^2). It is worth remarking that all the
nuclear plates maintained excellent and uniform level of sensitivity even
after this long exposure. 16m^2 of the lower chamber has been used in the

present work, which amounts to the exposure 28.8 m^2yr.

Scanning of C-jets and Pb-jets-lower are made in the same way as the previous works, and so is the energy measurement of their constituent showers/4/.

An electron shower satisfying one of the following criteria is identified as of a hadronic origin:

  (i) It becomes observable only in greater depths, typically under at least 6 c.u.

 (ii) The change with depth of electron number deviates significantly from that of a pure electron-photon cascade shower.

(iii) Clear multi-core structure is observed and traced at two or more successive layers.

3. Quality of Experimental Data

215 C-jets with $n \geq 2$ are found, where n denotes the number of constituent showers. Out of them 198 have visible energy $\Sigma E \geq 5$ TeV, of which 155 are isolated and 43 are accompanied by γ-hadron families (i.e., bundle of parallel γ-rays and hadrons). These 198 events are adopted and used for analysis.

The 145 C-jets with $n \geq 2$ and $\Sigma E_\gamma \geq 7$ TeV yield quite consistent and reasonable results for ΣE_γ-distribution, the zenith angle distribution and the vertical flux. This shows that the event detection has been made in the way free from any serious biases.

As for constituent showers, the detection efficiency turns out to be nearly uniform down to $E_\gamma \simeq 0.2$ to 0.3 and up to $r = 1.5$ to 2.0 mm. Also the invariant mass distribution of all possible γ-ray pairs has quite a reasonable shape. This shows, firstly, that the present experimental method is free from any serious systematic errors and, secondly, that the overwhelming part of the C-jets in the present experiment are due to ordinary multi-hadron production.

4. Morphology of Pinaught-less C-jets

Eight events with n=2 and another eight with n≳3 are found to be "pinaught-less", i.e., every pair out of the constituent showers either has visible invariant mass M(ij) > 200 MeV/c , or contains at least one identified Pb-jet-lower.

As ΣE_γ of all the above 16 events are rather small(< 30 TeV), the question arises whether they are accounted for as the fluctuation tail of usual C-jets. In order to answer the question, simulation C-jets are constructed and compared with experiment. 200 Mirim-type C-jets (scaling multi-pion production via H-quanta) and 200 Acu-type C-jets (scale-breaking multi-hadron production via SH-quanta) are constructed. The rest masses of an H-quantum and an SH-quantum are assumed to be 2.3 GeV/c^2 and 18 GeV/c^2, respectively. For simplicity, SH-quanta are assumed to decay exclusively into pions in the present simulation.

Fig. 1 shows the E_1/E_2 vs. n plot of the observed and the simulated pinaught-less events, where E_1 and E_2 stand for the highest and the second highest, respectively, energies of the constituent showers.

Firstly one observes that the simulation produce only n=2 and n=3 events, while about one-third of the observed events have $n \geq 4$.

Secondly, only two Mirim-type C-jets (one double-cored and the other triple-cored), out of the 18 simulated pinaught-less events, are observed to reproduce the experiment. The remaining 16 yield E_1/E_2 far too large to be reconciled with experiment.

The conclusion is that a minor part of pinaught-less C-jets might represent the fluctuation tail of Mirim-type ordinary C-jets, but that the main part is of genuinely different origin.

5. Nature of n≥3 Pinaught-less C-jets

Fig. 2 shows the superposed integral $p_T(\gamma)$-distribution of the constituent showers of the eight pinaught-less C-jets with $n\geq3$, where $p_T(\gamma)$ denotes the observed part of the shower transverse momentum with respect to the respective energy-weighted center of each event. Also shown in the figure by a solid line is the same distribution of Event Centauro I. Both agree well with each other, giving

$$<p_T(\gamma)> = 0.35 \pm 0.05 \text{ GeV/c},$$

which, at the same time, coincides with that of Mini-Centauro interactions.

Fig. 1. E_1/E_2 vs. n plot

Fig. 3 shows the superposed fractional energy distribution of the constituent showers of the same eight events in an integral form. It fits well with an exponential form, and extrapolation down to zero energy gives

$$<m> = 6 \pm 1 \text{ /event},$$

as the average observed multiplicity of cores.

Now let us assume that the events are due to bundle of non-rapid-gamma-decaying hadrons having the same nuclear mean free path as nucleons. Then the correction for escaping hadrons gives

$$<m_0> = 18 \pm 3$$

as the average multiplicity of hadrons produced in the parent interaction. Again this is in good agreement with
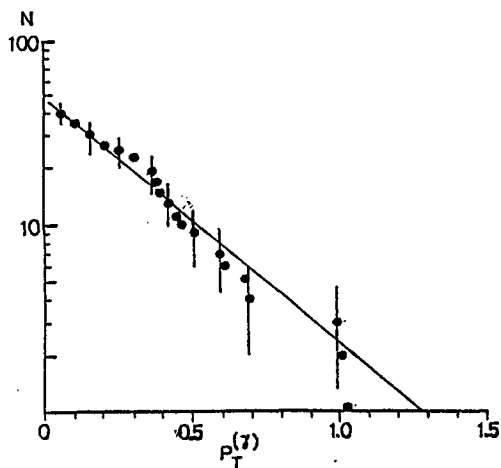
$$<m_0> = 15 \text{ to } 20$$

Fig. 2. Integral $p_T(\gamma)$-distribution.

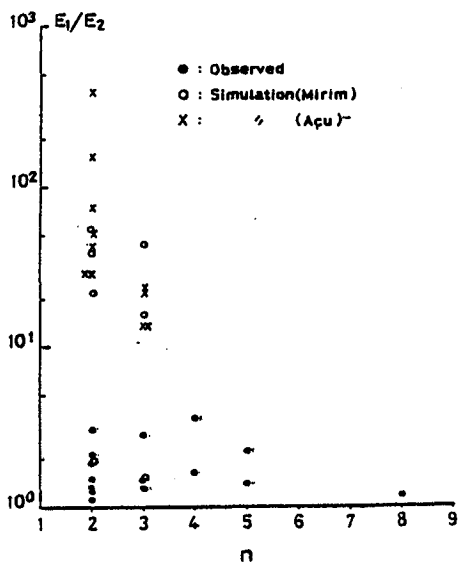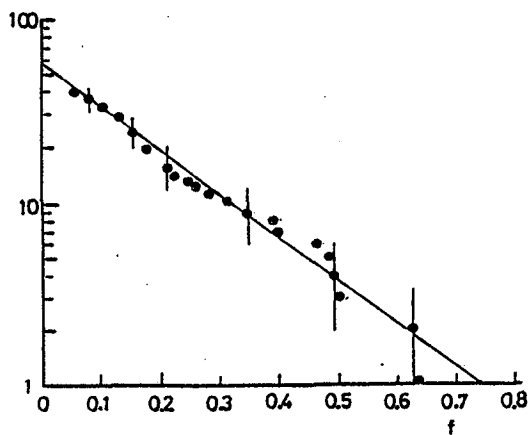Fig. 3. Fractional energy distribution in the integral form.

of the Mini-Centauro interaction.

In view of the above results for $<p_T(\gamma)>$ and $<m_0>$, the Mini-Centauro interaction seems to be the most natural explanation of the pinaught-less C-jets with $n \geq 3$.

Now the average energy of the parent particle responsible to these C-jets, $<E_0>$, is estimated by $<E_0> = <\Sigma E_h(\gamma) / (<K><f><k_\gamma>)$, where $<E_h(\gamma)>$ is the average observed energy sum of the hadron bundle, $<K>$ the average inelasticity at a Mini-Centauro interaction, $<f>$ the energy fraction of the released energy given to the detected hadrons, and $<k_\gamma>$ the average fraction of the energy released to γ-rays at a successive interaction in Pb. Assumption $<K> \sim 1/2$, $<f> = 1/3$ to 1, $<k_\gamma> = 1/5$ to 1/4 yields

$<E_0> \simeq 100$ to 400 TeV.

6. Double-cored Pinaught-less C-jets.

Out of the eight double-cored pinaught-less C-jets, three has striking features. The constituent shower-core pairs yield quite large visible invariant masses, M(1-2): 3.3 GeV/c^2, 1.85 GeV/c^2 and 2.9 GeV/c^2. They strongly remind us of the Geminions, whose first clear example is the "Castor-Pollux" with M(1-2)=5.8 GeV/c^2. The event with M(1-2)=3.3 GeV/c^2 has still another striking feature. Its constituent showers originate from a point in the air gap, indicating a decay of some unknown matter.

Now, the assumption that the constituent showers are due to ordinary hadrons gives an estimate $<E_0> \simeq 100$ to 200 TeV. The remaining five events have M(1-2) falling between 0.2 GeV/c^2 and 1.0 GeV/c^2, and can be explained either as the fluctuation of Mini-Centauros or as that of Mirim-type C-jets.

7. Pb-jets-lower with High-p_T Double Cores.

Three Pb-jets-lower are found to be composed of two shower cores whose mutual opening angles are large enough to be measured. Their M(1-2) are 3.3 GeV/c^2, 2.77 GeV/c^2 and 1.1 GeV/c^2. They again strongly remind us of Geminions. Here also the "ordinary hadron assumption" gives an estimate $<E_0> \sim 100$ TeV.

8. Summary and Discussions.

1) A least-biased systematic study of C-jets is made in Chacaltaya Emulsion Chamber No.19. It is found out that 5-10 % of the C-jets with $\Sigma E_\gamma \geq 5$ TeV are genuine exotic events. This corresponds to an estimated incident frequency of ~ 1 exotic-interactable particle per m^{2}yr at Chacaltaya.
2) Average energy of the parent particles responsible to the above exotic events are estimated to be 100 to 200 TeV, irrespective of types.
3) If a nuclear collision of ordinary hadrons can produce an exotic interaction directly, either the versioned-up CERN SPS Collider or the coming FNAL TEVATRON must produce one.
4) On the other hand, if we assume that only the secondary particles from a chiron interaction can produce exotic interactions[3], the upper bound of the threshold energy for chiron production will be estimated, from flux consideration, as $E_0 \sim 10^{16}$ eV.

References

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