Analysis of one hadron rich event

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In this report it are presented arguments to classify this hadron rich event as an interaction event and the consequences of this statement, for instance the total invariant mass would be estimated as ≈ 61 GeV/c^2 and the pair of hadrons used for height estimation has invariant mass = 2.2 GeV/c^2. Besides, tables showing the parametric and non parametric analysis resulting in a criteria table and the resulting tables for the discrimination of γ or hadron induced showers were present at the 16^{th} ISVHECRI, held at Batavia, USA. As the main point of hadron rich and Centauro events is the identification of the nature of observed showers, this identification and energy determination of γ or hadron induced showers were done using 2 simulations. Complemented with observation of photosensitive material under microscope it was obtained that the event C16S086I037 would be classified as a hadron rich event. It were depicted 10 reasonable scenarios for γ/hadron discrimination and obtained that the event is composed by 25 γ's, 36 hadrons and 1 surviving and leading hadron. All these scenarios were reported at the 14^{th} ISVHECRI, held at Weihai, China and resulted in rather constant values of physical quantities, like mean transverse momentum of hadrons, $< P_{T_h} >$, mean inelasticity of γ-ray, $< k_\gamma >$. Assuming that the most energetic shower is the surviving particle of an interaction and the tertiary produced particles are from normal multiple pion production, the characteristics of the interaction are: Energy of primary particle $E_0 = 1,061$ TeV, Inelasticity of collision K = 0.81, Mean inelasticity of γ-ray $< k_\gamma >= 0.27$, Hadron induced showers energy/Total energy $Q'_h = 0.90 \approx Q_h = 0.71$, Rapidity density $N_h/\Delta Y = (8.56 - 9.89)$, Mean energy of secondary hadrons $< E_h >= (21.5 \pm 4)$ TeV, Mean transverse momentum $< P_{T_h} >= (1.2 \pm 0.2)$ GeV/c, Upper bound of partial cross section $\sigma \leq (0.32 - 0.85)mb$ and life time $\tau \leq 10^{-12}$ s.

1. Introduction

Brazil-Japan Collaboration of Chacaltaya emulsion chamber experiment (B-J Collaboration) exposed 25 detectors of cosmic-ray particles at a 540 g/cm^2 level, geomagnetic coordinates $4^0 50' 40''$ South and $0^0 50' 20''$ East. These detectors consists of multi-layered envelopes containing typically 2 or 3 X-ray films and 1 Nuclear emulsion plates, inside a barrier bag, all having an area of 40cmx50cm and tickness of 200 μm and 1,550 μm, respectively [1]. The envelops are inserted between lead plates and the last 11 chambers have two-storey structure as a main detector.

Since the observation of an unusual event of cosmic ray interaction, nicknamed as Centauro event, attempts to explain it were under way. The pionner event showed behaviour different of an usual interaction events, that is, it shows more particle in the lower part of the detector, then the nickname. Consequently an empirical interpretation was that it produces charged particles, without π^0's, for instance. After the observation of this event, search for new Centauro candidates was carried out in the posterior experiments. Unfortunatelly all of these candidates doesn't show the visual aspect of the pionner one, that is upper block of photosensitive detectors less fired than the lower block, but one of these candidates, hereafter nicknamed Centauro V, presents the most relevant feature, mean transverse momentum of charged hadrons, $< P_{T_h} > \approx 1.0$ GeV/c.

The showers of the first event seen only in the lower chamber were classified as hadrons, due to the small probability (exp[-8]) to be of electromagnetic origin. The same feature in another event (C22I019) was observed. The notation used here means that the concerned chamber is C22 (exposed during the period April/86-May/88 and I019 identifies the lower chamber block no.019. In the case of this event, the identification of hadrons is much more clear due to the absence of showers in the upper chamber. Most of other hadron rich events does not have this remarkable feature. Therefore a crucial aspect is the identification of hadrons and some other criteria was used, with emphasis in a comparison with simulated showers. B-J Collaboration classifies events as hadron-rich for those that has more than 50% of total observed energy in hadronic origin showers. Previously, [2] B-J Collaboration showed that there are only 2 other hadron-rich events compatible with the pioneer one (C15S055I012, exposed during the period October/69-July/70). The most straighforward way of knowing interaction height of an atmospheric event is a geometrical way to measure changes in relative distance of cascade showers along the depth, called triangulation method. This method was succesfully done in one of these events, C16S086I037, because it have 7 hadronic induced showers with coincidence of showers in both parts of chamber, showing unambiguously the continuation of showers. Moreover all showers are consistently produced in one interaction point, as could be verified using the algorithms reported at ICRC2001 [3].

2. Description of the event C16S086I037

The concerned event was observed in the 16th chamber experiment exposed during the period March/71 - April/72 (383 days of exposure time) and observed 15+7 events with total electromagnetic energies $\Sigma E_{\gamma} \geq 23$ TeV and $\Sigma E_{\gamma} \geq 20$ TeV, respectively and the 7 events are observed only in the part of chamber below the carbon target. This chamber has optimized solid angle design and their tickness is $\approx 1.9\ \lambda$, therefore a deep starting shower may be detected. At the location of this event has (3+11) Nuclear Emulsion plates, (6+15) RR-type and (12+31) X-ray N-type X-ray films, inserted between lead plates (12+20) r.l. The numbers means the quantity in (86th upper + 37th lower) blocks, respectively. In total it presents 65 showers (numbered #1 to #66, with the absence of #14 that has a different azimuthal angle),the zenithal angle $\theta = 12.6^0$ and the azimuthal is $\phi = 30^0$ incident from Northeastern to Southwest direction. As some pairs of showers are close enough and sufficiently isolated from other showers, to analyse this event we considered 6 showers amalgamated into 3 clusters (#4+#5, #43+#44 and #47+#55), therefore the total of individual showers analized is 62, distributed as (45+7+13) in upper, penetrating from upper to lower and observed only in lower parts of the chamber, respectively. The 7 showers (#8,#10,#11,#20,#27,#37 and #40) traversing from upper to lower detectors and the 13 showers (#54 to #66) observed only after traversing all the upper part, that is after more than 12 r.l. were interpreted as hadronic origin. The pair (#47+#55) is observed in (upper+lower) parts of the chamber, and so interpretable as clusters of one secondary particle of the interaction. Identification of showers using the Nuclear Emulsion plates, both types of X-ray films and best fitting procedures got from simulations were reported already in some conferences and symposia, the last one at the 14th ISVHECRI, held at Weihai, China [4]

From 2 showers (#20 and #27), both showing (5upper+2lower)cores and (5upper+3lower)cores we determined the interaction point as H=(478^{+188}_{-106})m at the X-ray RR-type films and H=(500^{+206}_{-113}) m in Nuclear emulsion plates. Considering 4 paired combinations of 4 showers, that is avoiding 2 negative relative distances, we determined mean height H=(412^{+327}_{-126}) m in Nuclear emulsion plates. Considering all 6 combinations and the absolute values of relative distances, the mean height we got is H=(552^{+199}_{-126}) m, that the value of interaction height seem to span in the interval [300,750].

Figure 1 shows the map of C16S086I037 projected in a plane perpendicular to their incident direction and the showers amalgamated into 3 clusters are identified.

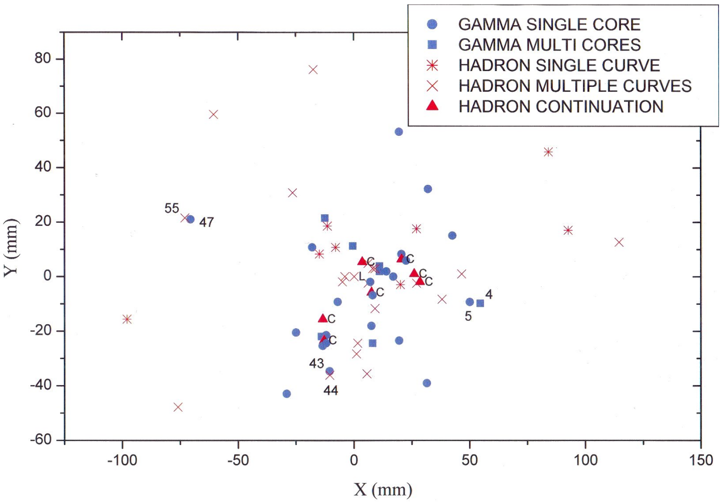

Figure 1: Map of event C16S086I037

3. Analysis results

Energy determination was done using a simulation carried out by T.Shibata et al.[5],[6] and M.Tamada[7], this one under computer code Corsika with a QGS-jet interaction model applied only for upper chamber blocks. Another use of these simulations is to identify hadronic showers through the best fitting procedure that provides statistical parameters like σ and $\chi 2$. Some cluster showers are better fitted using double transition curves, therefore these showers may be identified as hadron induced ones. To identify these showers as hadron induced shower more confidently, other criterion such as observation of multi-core structure was used.

For single showers the main tool for γ or hadron induced shower recognition is the comparison with simulated events, using σ and $\chi 2$ of fitting to the data of darkness of the showers in the X-ray films. Some of identified hadrons by the Shibata's simulation has aspect of double peaks in the shower development inside the chamber. As even a γ-shower may have this kind of development, through Landau-Pomeranchuk-Migdal effect, in spite of σ_{min} for these showers, we complemented the beforehand mentioned statistical parameters with others criteria such as observation of multicoared structure in Nuclear Emulsion plates and constructed a score table from where we selected the γ-hadron samples which have at least two of the adopted criteria, beeing the most important the both statistical parameters.

To classify this event as product of interaction and not of fragmentation it were used the algorithms before mentioned [3], obtaining: i) A correlation

$$R = \frac{[\Sigma E_i][\Sigma E_i(\Gamma\theta_i)^2]}{[\frac{4}{\pi}\Sigma E_i(\Gamma\theta_i)]^2} \qquad (1)$$

ii) From the correlation

$$mDW = \frac{1}{4M\Gamma}[\Sigma E_i + \frac{4}{\pi}\Sigma E_i(\Gamma\theta_i) + \Sigma E_i(\Gamma\theta_i)^2 + \frac{4}{3\pi}\Sigma E_i(\Gamma\theta_i)^3] \quad (2)$$

we obtain the angular coeficient s=1.66, rather different from 2.0 that is for isotropic decay of the secondaries of the interaction. iii) A correlation, known as Peyrou plot [8] shows a big dispersion in the longitudinal, but not in the transverse momentum, even calculated from Center of Mass of only hadrons or Center of Mass of all showers.

The shower (#62) was not observed in the upper block and it interacts twice in lower chamber. It has 16% of total energy much more than the second highest energy shower (#27) that has 8%, and so we can identify it as the surviving hadron, legitimately. This identification permits to calculate K, $< k_\gamma >$, E_0 and Q'_h, that is, the inelasticity of the nuclear collision, the γ-ray inelasticity, energy of primary particle and a fraction of hadron-induced showers energy to total energy.

The correlation Mean Transverse Momenta - Rapidity density is shown in the figure 2 where we observe that this event analysed as not γ induced showers event, but considering as effectively hadronic showers it is in a region above the data of accelerator experiments.

Concerning to the cross section we did a estimation based in a expression used in accelerator experiments [9], assuming that the chamber is a detector of cosmic rays accelerated particles. The figures got from is σ_{normal}=[16-43]mb and $\sigma_{hadron-rich}$=[0.32-0.85]mb. And assuming Breit-Wigner cross section to a interaction $p + N \rightarrow$ c16s086i037 $\rightarrow hadrons + \gamma$'s it was obtained $\Delta T_{C16s086i037} < 10^{-12}$ s for the mean life time.

density.jpg

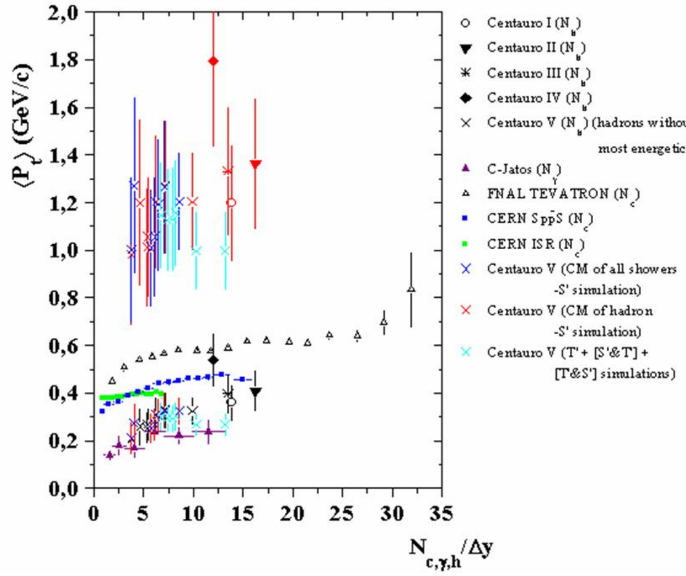

Figure 2: Mean P_T - rapidity density correlation. The cross marks are for this event under various scenarios of hadrons identification

4. Conclusions and discussions

i)Four figures presented at the symposium suggests that the event is a product of interaction or of a unusual fragmentation. Additional suggestion for this interpretation comes from the diference between the center of momenta of all showers and the center of hadronic showers without the shower #62 is small (Δr_{max} = $4mm$ implying in $\Delta\theta_{max}$ = 8×10^{-6} rad), but not zero. ii)Two other figures indicates that the shower # 62 is a leading energy and surviving hadronic induced shower. iii) A ratio between the maximum darkness of the first peak (d_1) to the sum (d_1 + d_2) is 0.37 and their corresponding energy ratio is 0.31. Another similar estimations are the energy ratio between surviving hadron to all hadrons = 0.26 and the ratio between surviving hadron energy to total observed showers energy = 0.24. Then we used $< k_\gamma >= 1/3$ in the conservation laws of energy and linear momentum and got the values listed in a table presented at the symposium. iv) The analysis shows that this event presents high energy content in hadronic showers (Q=0.71)and ($Q^{'}$ = 0.90), characterizing hadron-rich event and that it is above the region of accelerator data,as shown in figure 2. v) Using the interaction height (vertex), we obtained for the invariant mass of the pair of hadrons (#20 and #27) the value $2.2GeV/c^2$. Almost same value ($2.9GeV/c^2$) we obtained assuming that the transverse momentum of primary cosmic ray particle express the invariant mass, assumption that is correct in a thermodinamical model for interaction. vi) The mean height obtained from a kinematical coupling of 2 $\gamma^{'}s$ induced showers to π^0 has the value around 780 m, that is this heigth is compatible with the mean height gotten from triangulation of all pairs of hadronic induced showers (764 m). This analysis is preliminary and not completed yet. vii)The obtained value for $< k_\gamma >= 0.27$ is also consistent with charge independence for the Multiple Meson Production, considering the $25\gamma^{'}s$ coupled to $12\pi^{0'}$s and $36\pi^{\pm}$. viii)A comparison of this event with other similar was done in [2]. There it were showed that it is compatible with Centauro I and with Centauro IV. As the particles of Centauro I are spread covering an area of ≈1.2 cm of radius (≈ 10% radius of this event(=10.8 cm)), it is plausible that the Centauro I has its vertex located near to 50 m. above the chamber, as previously gotten. ix) Centauro IV is analysed by M.Tamada [10] showing that the fractionally energy spectrum has slope similar with the corresponding spectrum of Centauro I, so is similar indirectly with this event and also with the 4 other events containing a halo in the center.[11].

Then, the results of our observations and analysis are compatible with the assumption that this hadron-rich event is the result of a collision of a hadron with energy $E_0 \approx 1,000 TeV$ at H=(500^{+206}_{-113}) m above the chamber, with mean transverse momenta $< p_t > \approx 1 GeV/c$, that is this event is an authentic Centauro event producing ≈ 70-90 hadrons at the interaction point.

We dedicate this analysis to pionners of Brazil-Japan Collaboretion, Professors Y.Fujimoto, S.Lasegawa and C.M.G.Lattes and homage our late friend of Cistor experiment, Professor Aris Angelis also enthusiast of Centauro events.

5. Acknowledgment

We have pleasure in acknowledging our indebtedness to the financial support from CBPF, CNEN, CNPq, FAEPEX-UNICAMP, FAPESP, FINEP'in Brazil and Aoyama Gakuin University, University of Tokyo, Wasedi University, Ministry of Education in Japan. We are also glad to IIF-UMSA in Bolivia, host of the experiments, for the help in many occasions. The authors wishes to acknowledge to all members of B-J Collaboration, for the free use of the data. Two of us (SLCB and EHS) are keen to express their gratitude to A.Ohsawa,M.Tamada and T.Shibata for the simulated events that we used in this and previous reports. One of us, SLCB, wish to acknowledge the funding agency FAPESP for support (contract no. 01/04150-0).

References

[1] M.Luksys, A.Ohsawa, E.H.Shibuya, Nucl.Inst.& Meth. B82 (1983),549-556
[2] C.R.A.Augusto, S.L.C.Barroso, P.C.Beggio, A.O.Carvalho, M.J.Menon, C.E.Navia, R.Oliveira, E.H.Shibuya, Proc.27^{th}ICRC (2001),1537-1510
[3] ibidem,1422-1425
[4] S.L.C.Barroso, P.C.Beggio, A.O.Carvalho, J.A.Chinellato, A.Mariano, R.Oliveira, E.H.Shibuya, Nucl.Phys.B(Proc.Suppl.)175-176 (2008),131-136
[5] M.Okamoto and T.Shibata, Nucl.Inst.&Meth. A257 (1987),155-176
[6] T.Fujinaga, M.Ichimura, Y.Niihori and T.Shibata, Nucl.Inst.&Meth. A276 (1989),317-339
[7] M.Tamada and A.Ohsawa, Nucl.Phys. B581 (2000),73-90
[8] S.Brandt, Ch.Peyrou, R.Sosnowski and A.Wroblewski, Phys.Lett.12, n.1 (1964),57-60
[9] J.Garvey, Rep.Prog.Phys. 50 (1987),1311-1385
[10] M.Tamada, Nuovo Cim.41B, N.1 (1977),245-265
[11] S.L.C.Barroso, P.C.Beggio, A.O.Carvalho, J.A.Chinellato, A.Mariano, R.Oliveira, E.H.Shibuya, Nucl.Phys.B(Proc.Suppl.)175-176 (2008),182-185