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Study on Alignment of High Energy γ-Hadron Family Events with Iron Emulsion Chambers

L.Xue[1], Z.Q.Dai[1], J.Y.Li[1], X.Y.Zhang[1], Y.Fu[1], J.Li[1], P.Y.Cao[1], N.J.Zhang[1], M.He[1] C.R.wang[1] J.R.Ren[2] and S.L.Lu[2]

[1] *High Energy Physics Group, Shangdong University, Jinan, 250100,China*

[2] *Institute of High Energy Physics, The Chinese Academy of Sciences, Beijing, 100039, China*

Abstract

The alignment of energetically distinguished cores both in a part of family events observed by Kanbala iron emulsion chambers and the simulated family events given by COSMOS code is analyzed. The results obtained in this work are basically in agreement with those of Pamir Collaboration.

1 Introduction:

The alignment phenomenon of high energy families was first found by Pamir Collaboration when they studied the multi-core halo events[1].Afterwards continual researches had been done by Pamir Collaboration on this phenomenon[2-8]. The Pamir Collaboration accumulated over one thousand family events, obtained reliable experiment results, engaged in theoretical exploration of the alignment phenomenon and put forward many models (such as MSF、MJ、SHDID、MC0) for simulations.

A large-scale iron emulsion chambers were installed by Kanbala Collaboration in 1980's[9]. The iron emulsion chambers have unique advantage in the study of super-high energy hadronic interactions, due to their higher efficiency for hadron detection[10]. In present work the propagation of cosmic rays in atmosphere is simulated by using the EAS simulation code of COSMOS with heavy-nuclei-dominant primary spectrum. The secondary particles arriving at observation level are processed according to the experimental conditions of Kanbala iron emulsion chambers. 1,814 simulation family events are obtained. The alignment of energetically distinguished cores (EDC) in both simulation family events of COSMOS and experimental family events observed by Kanbala K0-K7 iron emulsion chambers is analyzed in this paper. The analysis results of this work are basically in agreement with those of Pamir Collaboration.

2 Monte Carlo Simulation:

The simulation code of COSMOS, we have used, was developed by K.kasahara[11]. It is basically based on a phenomenological multicluster model which is under the assumption of an approximate Feynman scaling in the fragmentation region of hadronic interactions, and the inelastic interaction cross section is assumed to increase with energy as $E^{0.08}$. In our simulations the heavy-nuclei-dominant primary spectrum is used and the primary particles are divided into seven groups: (1)proton, (2)helium, (3)light nuclei(Li,Be,B), (4)medium nuclei(C,N,O), (5)heavy nuclei(Z~12), (6)very heavy nuclei(Z~17) and (7)Fe. At energy $E=10^{16}$eV the fractions of each group(%) are 9.7, 12.1, 0.5, 18.1, 15.2, 7.9, 36.5 respectively.

The simulation data of COSMOS are processed according to the experimental conditions of Kanbala iron emulsion chambers. The following conditions are taken into account: the limited area of emulsion chamber, efficiency of hadron detection, space resolution and influence of inclined incidence. The inelasticity coefficient of projectile particles are sampled randomly between 0.1—0.9; The secondary particles generated in chamber are assumed as π mesons and of which π^0、π^+、π^- are one-third respectively. The free path of interactions in absorber of emulsion chambers are assumed as an exponential distribution: P(x)=$\frac{1}{\lambda}e^{-\frac{x}{\lambda}}$ (λ:mean free path of interaction).

3 Analytical technique of family events:

3.1 Separating criterion of γ-rays and hadrons: In emulsion chamber experiments the correct identification of γ-rays and hadrons is the prerequisite to study cosmic ray morphology and superhigh energy hadronic interactions. Traditionally, the depth of starting point Δt=6c.u. was taken as the criterion to separate γ-rays and hadrons, i.e., if the showers with the starting point less than 6c.u. and they show no successive interaction structure they are refered to γ-rays, otherwise they are regarded as hadrons.

The nuclear interaction length of hadron (λ_I) in iron is shorter than that in lead (Fe:λ_I≈9.5c.u., Pb:λ_I≈30c.u.). If we take 6c.u. as the criterion of separating γ-rays and hadrons for iron emulsion chambers, , a lot of hadrons will be mixed in γ rays. In present work a statistic method is used to calculate the fraction of mutual admixture of γ-rays and hadrons under different criteria of selection. The results are listed in Table 1.

As shown in Table 1, if we take 6c.u. as the selection criterion, the fraction of hadrons mixing in γ rays is 53.5%and it decreases to 39.5%if 4c.u. is taken, meanwhile the fraction of γ mixing in hadrons is only 3.1%. So in our work the depth of starting point Δt=4c.u. is taken as the selection criterion to separate γ-rays and hadrons.

Table 1. The fraction of mutual admixture of γ and hadron events under different criteria of selection

Separating criterion of γ-rays and hadrons	γ-rays mixed into hadrons	hadrons mixed into γ-rays
6.0 c.u.	0.6%	53.5%
5.5 c.u.	0.9%	50.3%
5.0 c.u.	1.3%	46.8%
4.5 c.u.	2.0%	43.1%
4.0 c.u.	3.1%	39.5%

3.2 Electromagnetic decascading and nuclear clusterization procedure: The electromagnetic components in family events recorded by emulsion chambers, except a little come from the decay of π^0 mesons, mainly are generated in electromagnetic cascades above chambers. In order to study the possible mechanism which governs the production of coplanar high energy particles , it is necessary to reconstruct the electromagnetic and nuclear cascading in atmosphere by means of electromagnetic decascading and nuclear clusterization procedures. Firstly, the particles coming from the same initial γ-ray should be combined together, this is “decascading” ; Then the particles generated in an ‘air jet’ should be coupled, this is “clusterization” .

In decascading, we take parameter

$$Z_{ij}=\sqrt{E_i \cdot E_j} \cdot R_{ij} \leqslant Z_0$$

as the transverse spread between ith and jth particle which have energies E_i and E_j, R_{ij} is the geometrical distance between them. The selection of critical value Z_0 is based on the fact that cascading particles with energy E spread within the space r~2·E_s·X_0/E, where E_s is the scattering energy (≈20MeV), X_0 is the radiation length of γ-ray in atmosphere (≈600m at elevation of Kanbala). So we may take Z_0= 2.4TeV·cm.

In clusterization we employ

$$Z_{ij}^{*}=\frac{E_i^{*}\cdot E_j^{*}}{E_i^{*}+E_j^{*}}\cdot R_{ij}^{*}\leqslant X_c^{*}$$

to describe the transverse spread of particles originated from a jet. The clusterization constant $X_c^*=P_{t,\gamma}\cdot H$, where $P_{t,\gamma}$ is the mean transverse momentum of the particles produced in the same nuclear interactions(P_t=0.4 and 0.2GeV/c are assumed for hadrons and γ-rays respectively), H is the production height of interaction above the emulsion chamber. In our work we calculate the height H by using COSMOS. The result is illustrated in Figure 1. The mean generating height of particles is about 500m. So we select the X_c^* =10TeV·cm for the electromagnetic components. After the final clusterization the low-energy clusters with energy $E_c < 10$TeV were rejected.

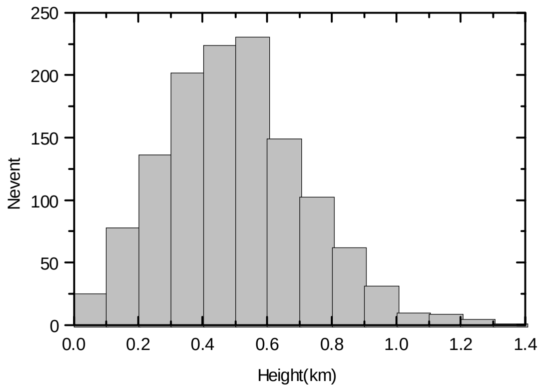

Fig. 1 The distribution of production height of family events

3.3 Selection criterion of alignment: For quantitatively describing the asymmetry of high energy γ-h family events we employ the following parameter as an alignment criterion which is introduced by Pamir Collaboration:

$$\lambda_N=\sum_{i\neq j\neq k}^{N}\cos 2\phi_{ijk}\Big/N(N-1)(N-2)$$

Where N is the number of EDCs, ϕ_{ijk} is the angle between straight lines connecting ith and jth core with kth core. The parameter λ_N reaches 1 in the case of complete alignment of N cores along one straight line and tends to -1/(n-1) for isotropic distribution of cores in a plane. An event is considered as aligned one if its $\lambda_N>0.8$.

4 Results and discussions:

The decascading and clusterization procedures are carried out to process the family events observed with Kanbala K0—K7 iron emulsion chambers and given by COSMOS code. The alignment of EDCs with energy above 10TeV in these families is analyzed and discussed. The selection criteria of family events are as follows:

(1)The total visible energy $\sum E_{vis}$=100—3000TeV;

(2)The energy threshold of showers is 4 TeV for E_γ and $E_h^{(\gamma)}$;

(3)Number of showers $N\geq4$ and number of hadrons $N_h\geq1$.

Under these selection criteria, 1814 simulation families and 47 experimental families are selected for further analysis.

The fractions of simulation events with alignment in different energy regions are presented in Table 2. It is seen that the alignment frequency shows energy independent in the case of clusterization analysis of family events. In the cases N_{EDC}=3 and 4, the alignment fractions are about 20-25％ and 5-6％ which are both slightly higher than background values(the background values are about 15％and 3％as N_{EDC}=3 and 4[4]). The results are basically in agreement with those given by MC0 code of Pamir Collaboration [8].

Table 2: The frequency of alignment family events given by COSMOS simulation (%)

$\sum E_{vis}$(TeV)	100—300	300—500	500—1000	1000—3000
λ_3>0.8	20.6±0.6	23.7±1.5	18.0±1.6	21.5±2.4
λ_4>0.8	5.0±0.2	5.7±0.4	4.5±0.4	5.1±0.6

The frequency of experimental family events with alignment observed with Kanbala K0—K7 iron emulsion chambers is shown in table 3. Because the experimental family events with higher energies are too few to achieve enough statistic, only the case of three-EDCs alignment is presented and the two sets of data at energy regions of 500—1000TeV and 1000—3000TeV are merged as one set to be analyzed.

It can be seen in Table 3 that the fraction of alignment increases with energy in the case of clusterization analysis of γ-h family events. At the region of 500—3000TeV the fraction comes to 50.0±20.4％which is more than three times higher than background value. The tendency of our data is in good agreement with the results of Pamir Collaboration. From the comparison of experimental data with the simulation ones, one can reach a conclusion that traditional models could not interpret this specific characteristics — the fraction of alignment increases with energy.

Table 3: The frequency of alignment family event given by Kanbala iron emulsion chamber experiment (%)

$\sum E_{vis}$(TeV)	100—300	300—500	500—3000
λ_3>0.8	20.7±3.8	22.2±7.4	50.0±20.4

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