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Interpretation of Azimuthal Anisotropical Gamma-Family Events

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The azimuthal anisotropy of gamma-family events obtained by mountain emulsion chambers is studied. By using the D-ND and SD-SH models, the gamma-family phenomena are simulated with the anisotropical events with adequate frequency reproduced. The study indicates that the few-particle diffractive production in the fragmentation region mainly accounts for the azimuthal anisotropical events. The QCD jet production is considerably insignificant to the anisotropical effect.

1. INTRODUCTION

The Pamir collaboration group [1] reported that they found several collinear events in the observed gamma-families. Recently, such events have also been found in Mt. Kanbala emulsion chambers. The Pamir group introduced several parameters to describe the azimuthal anisotropy of gamma-families [1,2]. One of the parameters, Z, is very sensitive to the azimuthal anisotropy and is related to the linear correlation coefficient r:

$$r = \sum_i (x_i - \bar{x})(y_i - \bar{y}) \Big/ \left[\sum_i (x_i - \bar{x})^2 \sum_i (y_i - y)^2\right]^{1/2},$$

$$Z = 0.5\ln[(1 + |r|)/(1 - |r|)].$$

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where x_i and y_i are the coordinates of gammas in a family, $(\bar{x}, \bar{y})$ is the energy-weighted center. The Pamir group analysed the Z distribution of the gamma-families with the observed energies ΣE_γ = 100--400 TeV and rejuvenated multiplicity $n'_\gamma \geqslant 10$ [1]. They found that the ratio of the events with $Z > 1.6$ to the total events is $(12 \pm 3)\%$, which is much higher than $(3 \pm 2)\%$, the value predicted by the MJ model [3] (with moderate scaling violation in fragmentation region and including QCD jet production) [1]. Therefore, it is believed that besides the statistical fluctuation, there is a physical mechanism that accounts for the azimuthal anisotropy of gamma-families. In this paper, it is found that the azimuthal anisotropy can be quantitatively attributed to the diffractive dissociation, in terms of two statistical quantities.

2. MONTE-CARLO SIMULATION and STATISTICAL ANALYSES

Using the D-ND and SD-SH models [4], we have simulated the gamma-family phenomena with the Monte-Carlo method. It should be pointed out that both of these models can reproduce most experimental results of the multiparticle productions at collider energies, such as the pseudo-rapidity distribution, the average transverse momentum, etc, and can explain, in connection with proper composition of primary cosmic ray, most characteristics of the gamma-family events. The most significant feature of these two models is the inclusion and detailed treatment of the diffractive dissociation process in inelastic collisions. In the D-ND model, the inelastic interaction is devided into the diffractive (D) and the non-diffractive (ND) processes. The D-component is treated by the longitudinal phase space (LPS) method [5] and the ND-component is described by the approximation of Chou-Yang partition temperature model [6]. In the SD-SH model, the single diffractive (SD) part is also treated by the LPS method, while the non-single diffractive interaction (SH) is the combination of the soft process obeying Feynman scaling and hard parton scattering with large p_t jet described by perturbative QCD. Table 1 lists the key parameters of D and SD processes.

Monte-Carlo simulations for the interaction and propagation of the super-high energy cosmic ray particles in atmosphere have been carried out. Under the same conditions as in the experiments, we obtained gamma-family samples at Mt. Kanbala and Mt. Pamir altitudes. The families with the observed energies $\Sigma E\gamma$ = 100--400 TeV are selected and rejuvenated. The rejuvenating treatment [7] will reduce the influence of the lower energy particles produced in the electromagnetic cascade processes and clarify the characteritics of the particle production in the fragmentation region more efficiently. Analogous to the Feynman variable, x is defined as $x = 2p_{\parallel}/\sqrt{s}$. Similarly, it is defined that $f' = E_\gamma / \Sigma' E_\gamma$, and only $f' > f'_{\min}$ is retained as fragmentation particles, where $\Sigma' E_\gamma$ and n'_γ are the total energy and multiplicity of the rejuvenated family respectively.

TABLE 1 The Model Parameters of SD and DD Processes

Cross section (mb)	distribution of invariant mass $f(M^2)$	the nature of fragmentation	fragmentation multiplicity
SD: 7 DD: 4	$f(M^2)$ ~ 1, when $1 < M^2 \leq 2(\mathrm{GeV})^2$ ~ $1/M^2$, when $M^2 > 2(\mathrm{GeV})^2$	longitudinal phase space (lps) imposing $f(p_t) = p_t \cdot \exp(-4p_t)$	$a + b\ln M^2 + c\ln^2(M^2)$

TABLE 2 Average Z of Gamma-Family Events with ΣE_γ = 100--400 TeV and $n_\gamma \geq$ 10

incident primary		p	He	C. N. O	Fe
Mt. Kanbala	D-ND	0.91	0.63	0.47	0.44
	from D	1.32	0.54	0.46	0.45
	SD-SH	0.74	0.67	0.56	0.37
	from jet	0.63	0.75	0.53	0.31
Mt. Pamir	D-ND	0.91	0.58	0.46	0.41
	from D	1.10	0.51	0.41	0.43

3. RESULTS AND COMPARISONS WITH THE EXPERIMENTAL DATA

Under the Pamir experimental conditions, we have analysed the gamma-family events with f'_{min} = 0.04 and $n_\gamma \geq$ 10. The results are as follows:

(1) The distribution and average value of parameter Z of gamma-families are shown in Fig.1 and Table 2 respectively. It can be seen that, in the case of the proton primary incidence, the D-ND model can reproduce the Z distribution. The ratios of the events with Z > 1.6 to the total events for different models are listed in Table 3. It can be seen that the D-ND model can reproduce large anisotropy events with adequate frequency distribution.

(2) The azimuthal anisotropy of gamma-families induced by various primaries has also been analysed. We obtained the average Z for different primary incidences (see Table 2). Obviously, the azimuthal anisotropy of gamma-families is dependent on the primary composition. The proton induces the family with the highest Z. The heavier the incident primary, the less the azimuthal anisotrpy of families. For a moderate composition of primary incidences [8], the Z distribution has also been calculated and is shown in Fig.1. It can be seen that the result is compatible with the data.

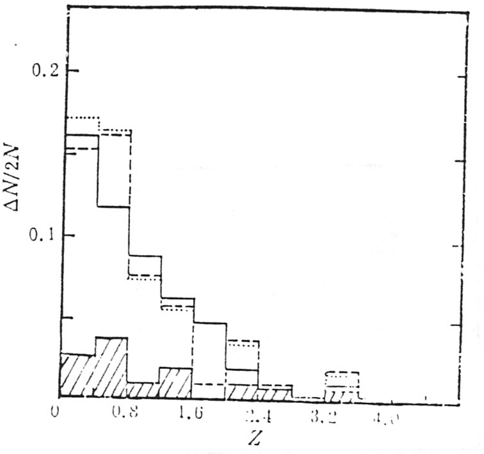

FIG. 1 Z distribution of gamma-families with ΣE_γ = 100--400 TeV and $n'_\gamma \geq$ 10. Simulation results and comparison with experiment data. Solid line denotes Pamir data, broken line denotes p-D-ND, dashed line denotes M-D-ND and shadow area stands for contribution of D-component.

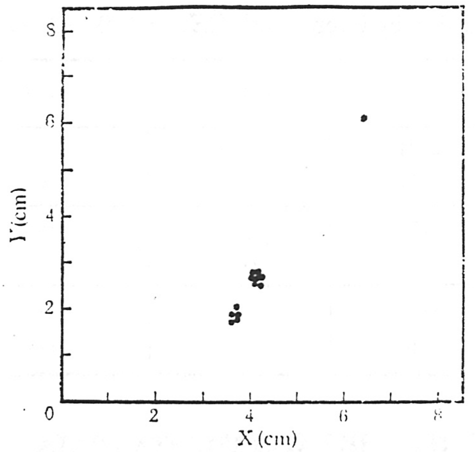

FIG.2 A collinear event found in simulation families. The three gammas are produced in a SD process. Mt. Kanbala, ΣE_γ = 125.8 TeV, n_γ = 15, n_γ = 13 and Z = 3.5.

(3) For the D-ND model, in the gamma-families observed, those that experience the diffractive dissociation process in their first collisions with air nuclei are about 25%. However, in the events with $Z > 1.6$, they are up to 40%. This indicates that the diffractive dissociation process not only plays an important role in the gamma-family production [9], but also accounts for the high anisotropy of these events. This point can also be seen from the average Z listed in Table 2.

(4) For the SD-SH model, the gamma-families whose members' ancestors took part in the hard scattering (no matter in which generation) are about 35% in the observed families. But in the events with $Z > 1.6$, they drop to 20%. From Table 2, it can also be seen that the average Z in the families with QCD jet particles is smaller. This fact implies that the azimuthal anisotropy is not attributed to QCD-jet production. This is the reason why the MJ model which contains the QCD-jet production but does not include the diffractive dissociation process would give too low frequency of $Z > 1.6$ events.

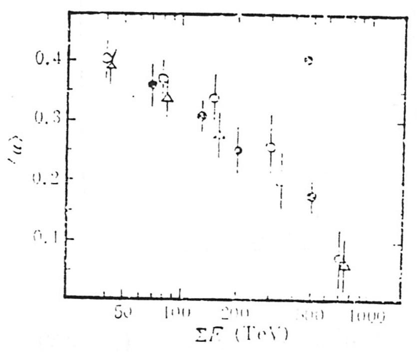

FIG.3 The variation of $<\alpha>$ with $\Sigma E\gamma$. The solid cycle stands for Pamir experimental result, open cycle denotes p-D-ND and triangle denotes M-D-ND.

TABLE 3 Ratio of Events with $Z > 1.6$ to All Family Events of ΣE_γ = 100--400 TeV and $n_\gamma \geq 10$ at Mt. Pamir Level, Model Prediction and Comparison with the Experimental Data

	Experiment	MJ	p-D-ND	He-D-ND	CNO-D-ND	Fe-D-ND
$\frac{N(Z>1.6)}{N(\text{total})} \times 100\%$	12±3	3±2	15±5	4±4	~0	~0

(5) Several collinear structure events have been found in ~ 700 samples of the simulated families. Fig.2 shows an example of such events. Investigating its history, it is found that the three collinear gamma clusters come from a single diffractive dissociation process, which produces three neutral pions, a few charged pions and one proton. The three neutral pions decay into photons and are recorded by emulsion chambers as three gamma clusters, while the charged pions and proton lose their energies and are not detected by the emulsion chambers due to their decays or successive nuclear interactions.

(6) Fig.3 presents another azimuthal anisotropical parameter <α> as a function of the observed energy ΣE_γ. For each family, α is defined as [10]: $\alpha = \sum_{i \neq j}^{n} \cos 2\varepsilon_{ij} / (n(n-1))$.

where, ϵ_{ij} is the angle between the momentum projections of i-th and j-th particles in the plane perpendicular to the incident direction and n is the shower number in an event. It can be seen that the simulation results are in agreement with the experimental data. The difference between the two models is insignificant. This indicates that <α> is less sensitive than Z.

4. CONCLUSION AND DISCUSSION

(1) The D-ND model successfully reproduces the gamma-family events with azimuthal anisotropy reported by the Pamir group. The <α>, the Z distribution of gamma-families and the frequency of $Z > 1.6$ events given by the Monte-Carlo simulation are all compatible with the data.

(2) The diffractive dissociation process plays an important role in the azimuthal anisotropy of gamma-families, especailly in the high anisotropical events. Since the particles produced in such process are few in number, high in energy and forward in angle distribution, they propagate more efficiently in atmosphere, thus, the probability of showing collinear configuration is enhanced. The QCD-jet production has opposite characters, and conseqently is not the main source of the azimuthal anisotropical gamma-families.

(3) The collinear event, in our opinion, might be related to the resonance production and charge exchange process in the fragmentation region, because in our simulation, the diffractive system is treated as two-body or three-body decay when the invariant mass is less than $\sqrt{2}$ GeV, which is similar to the resonance production and charge exchange process in the fragmentation region. Considering that the adopted value of the cross section of the diffractive dissociation process can yield adequate frequency of high Z events, it is estimated that the cross section of the resonance production and charge exchange process is in mb order.

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