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High energy particles coplanar emission and spatial characteristics of gamma-families with energies $\Sigma E_\gamma = 100 - 2000$ TeV.

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Abstract. The paper presents the experimental data obtained by large-scale X-ray emulsion chambers of "Pamir" experiment. Azimuthal effects and alignment of the most energetic particles in γ-families with energies $\sum E_\gamma = 100-2000$ TeV are considered. Experimental dependences of the azimuthal and alignment parameters on family spatial characteristics are compared with MCO Quark-Gluon String Model.

1 Introduction

Pamir Collaboration have observed the coplanar emission of the most energetic secondary particles (alignment effect) and the azimuthal anisotropy of the families, that has unusual peculiarities (Slavatinsky S.A., 1997; Yuldashbaev T.S., 1994; Yuldashbaev T.S. et. al., 1999). There is no consistent theoretical interpresetation of alignment and azimuthal peculiariaties up to now, though some attempts are made (Muchamedshin R.A., 1995; Roysen I.I., 1994). For the understanding these phenomena is of great interest to study the correlation of alignment λ and anisotropy α parameters with different gamma family spatial characteristics, the dependence of exotic events appearence on primary energy in the region $E_0 = 4 - 100$ PeV.

These parameters are defined by following expressions:

$$\alpha = \frac{\sum_{i\neq j}^{n_\gamma} Cos2\varepsilon_{ij}}{n_\gamma(n_\gamma - 1)},$$

where n_γ - number of family particles, ε_{ij} - angle between projections of i-th and j-th particles in azimuthal plane, $0 < \varepsilon_{ij} < \pi$, $i \neq j$. A value of $\alpha_{max} \sim 1$ is reached for coplanar events and $\alpha \sim 0$ for the isotropic distribution of azimuthal angles.

$$\lambda_n = \frac{\sum_{i\neq j\neq k}^{n} Cos2\phi_{ij}^k}{n(n-1)(n-2)},$$

where ϕ_{ij}^k is the angle between two straight lines connecting the k-th centre with i-th and j-th, n is the number of the most energetic particles, $n = 4$. The parameter $\lambda_n = 1$ for the case of n particles aligned along straight line. Families with $\lambda_4 \geq 0,8$ are referred to as aligned events.

Usually are used for analysis the spatial characteristics of gamma families: $\overline{R}_\gamma = \frac{\sum R_\gamma}{n_\gamma}$ (lateral spread) and $\overline{E_\gamma R_\gamma} = \frac{\sum E_\gamma R_\gamma}{n_\gamma}$, where R_γ is a distance from γ-quantum to an energy weighted center in the family, E_γ is the particle energy.

Tashkent group has revealed the azimuthal correlation increasing effect for the "wide" families with large lateral spreads $\overline{R}_\gamma$ that can not be described by models based on the smooth extrapolatiom of interaction characteristics obtained in the accelerator experiments (Yuldashbaev T.S., 1994).

2 New spatial characteristics

The different selection criteria for the analysis it is used: the particles placed on the maximal distance $R_0 = 15$ cm or $R_0 = 30$ cm from centre are included in the family. Sometimes the criterion $R_0 = 15$ cm uses in order to avoid possible loss of the quanta plaed on the considerable distances from family centre. However, the particles with large transverge momentum situated on the distances above 15 cm can be losed. Therefore it is used also criterion $R_0 = 20$ cm or 30 cm.

In the paper it is proposed the new spatial characteristics sensitive to strong interaction mechanism:

$$R_{1E}\ and\ \rho = \frac{R_{1E}}{\overline{R}},$$

where R_{1E} - is the distance of particle with the highest energy from family centre.

The value R_{1E} correspond to the transverse momentum of leading particle at the definite height H of family production ($P_T^L = \frac{E_{max} R_{1E}}{H}$). Parameter ρ is normalized to lateral

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spread $\overline{R}_\gamma$ value R_{1E} and insensitive to the H and Cosmic Rays (CR) mass composition.

As it can see from fig. 1a, a strong difference between R_{1E} distributions for families produced by proton-nucleus PA and nucleus-nucleus AA interactions is observed. On the other hand, the difference between parameter ρ distributions for families induced by PA (P-family) and AA (A-family) interactions is rather small (fig. 1b). While the average value of $\overline{R}^A_{1E}$ for A-family higher in 1.8 time than $\overline{R}^P_{1E}$ for P-family the difference between ρ for such events small (about 20%).

3 Experimental results

It is analysed $N_0 = 803$ gamma-famlies of Pamir experiment with visible energies $\sum E_\gamma = 100 - 2000$ TeV, number of particles $n_\gamma \geq 4$ with minimal energies $E_\gamma \geq 4$ TeV selected within a cricle of radius $R_0 = 20$ cm. These events are subjected to the "decascating" procedure using paramener Z_{ik} between i-th and k-th quanta in a family defined as,

$$Z_{ik} = \frac{E_i E_k R_{ik}}{(E_i + E_k)},$$

where E_i and E_k are the respective energies and R_{ik} their mutual distance. If $Z_{ik} < Z_0 = 10$ TeV·mm, the quantum pair decascades into a single "initial" quantum with energy $E_i + E_k$ at the position of the energy centre of the two. Repeating the process of joining the two over all possible pair of quanta the observed γ-families transformed to the initial one with number of particles n_{in}.

The initial families are further subjected to "rejuvenation" procedure that allows us to select the high energy quanta from fragmentation region of the incident particle. Only the quanta satisfied the condition

$$f' = \frac{E_{in}}{\sum E_\gamma} \geq 0.04,$$

where E_{in} - energy of the initial quanta are included in family. The number of such initial, "rejuvenated" quanta is denoted by n'_{in}.

Experimental results are compared with MCO Quark-Gluon String Model (Muchamedshin R.A., 1995). Energy E_{est} of primary particles was founded on using correlation relation with number of initial quanta

$$\lg E_{est} = A + B\, lg\,(n_{in}),$$

where the coefficient A and B were derived from comparison with MCO-model.

While the spatial characteristics $\overline{R}_{in}$, R_{1E} and ρ were evaluated for the initial families with $n_{in} \geq 4$ produced by primary particles with energies $E_{est} = 4 - 70$ PeV, the anisotropy parameter α'_{in} were obtained for $n'_{in} \geq 4$ initial, "rejuvenated" γ-quanta and alignment parameter $\lambda'_4 \geq 0.8$ - for the four the most energetic family particles.

According to fig. 1c and fig. 1d the excess of experimental events with large value $R_{1E} > 14$ mm and $\rho \geq 0.3$ in comparison with MCO-model is observed.

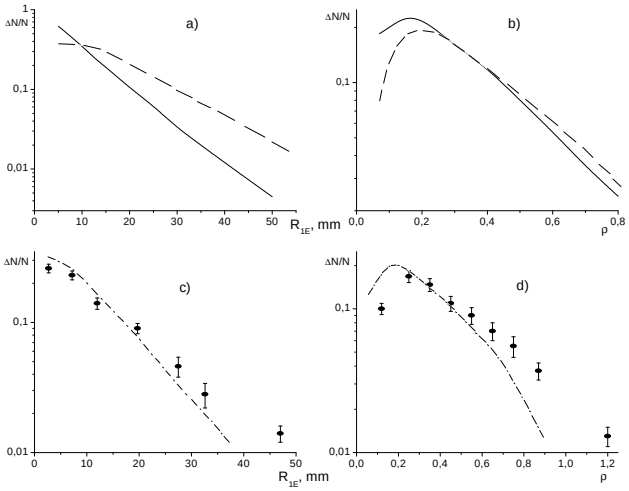

Fig. 1. The distribution of parameters R_{1E} and ρ —— - primary protons, – – - primary nucleus, –·– - normal composition, ● - experiment

As it can see from fig. 2a, fig. 2b azimuthal correlations increase in the large $R_{1E} > 14$ mm, $\rho \geq 0.3$ region is not reproduced by MCO-model. On the other hand, according to fig. 2c, fig. 2d experimental average values of $\overline{R}_{1E}$ and $\overline{\rho}$ are much more than for the model in the whole region $\sum E_\gamma = 100 - 2000$ TeV.

Table presents the dependences of fraction: "unusual" events P_{un} and aligned families between events with large $\rho \geq 0.3$ - P_λ for the experiment and model on the primary energies $E_{est} = 4 - 70$ PeV. Values

$$P_{un} = \frac{\Delta N_{un}(\alpha'_{in} > 0.13,\ \rho \geq 0.3)}{N}$$

$$P_\lambda = \frac{\Delta N_\lambda(\lambda_4 \geq 0.8)}{N_\rho}$$

where ΔN_{un} - number of "unusual" events with $\alpha'_{in} > 0.13$, $\rho \geq 0.3$, ΔN_λ - number of aligned families, N - number of events in given energy region, N_ρ - number of event with $\rho \geq 0.3$

As can see from table, at the energies E_{est} above 30 PeV considerable excess of experimental "unusual" events and aligned families between events with large $\rho \geq 0.3$ in comparison with model is observed. At that, fraction of aligned families between "unusual" events $P^\lambda_{un} = \Delta N_\lambda \,/\, \Delta N_{un}$ is much more in experiment (0.22 ± 0.08), than in MCO-model (0.07 ± 0.03) at the energies $\overline{E}_{est} \sim 40$ PeV.

$\overline{E}_{est}$	10 PeV	20 PeV	40 PeV
P^{exp}_{un}	0.32 ± 0.03	0.30 ± 0.05	0.30 ± 0.05
P^{mod}_{un}	0.24 ± 0.01	0.17 ± 0.02	0.14 ± 0.02
P^{exp}_{λ}	0.06 ± 0.01	0.08 ± 0.03	0.15 ± 0.04
P^{mod}_{λ}	0.08 ± 0.01	0.07 ± 0.02	0.06 ± 0.02

4 Conclusion

The new spatial characteristics of gamma-families R_{1E} and $\rho = R_{1E} / \overline{R}_{in}$ sensetive to strong interaction mechanism are proposed. At that parameter ρ almost independent on suppositions about primary CR mass composition.

At the energies above 10 PeV considerable excess of experimental event fraction with large values R_{1E}, ρ in comparison with MCO-model is observed. Azimuthal correlations increase at the large values of R_{1E}, ρ and considerable rise of aligned family fraction between "unusual" events at the superhigh energies $E_{est} > 30$ PeV are not reproduced by MCO-model.

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