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Characteristics of gamma families simulated by QGSJET model

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Abstract

The characteristics of gamma families simulated by CORSIKA program with QGSJET model of nuclear interaction are shown. The comparison with MC0 program, used in Pamir collaboration is presented. The results of calculations are compared with experimental data of Pamir Experiment too.

1 Introduction:

Particles of the EAS cores are registered in the emulsion of X-ray calorimeter exposed at mountain altitudes. In the upper part of X-ray calorimeter gammas and electrons/positrons begin to create a cascade in the lead. This cascade can be seen with a naked eye film as a small dark dot of a diameter of a few tens microns in the X-ray film, providing that the mean energy of the particle above the chamber exceeded 2 TeV. For each cascade its energy and both zenith and azimuth angles were measured. A bunch of particles initiated by primary nucleus (or photon) has similar zenith and azimuth angles and is called a γ-family.

The calorimeter of the Pamir Experiment is exposed at 4370 m asl. Its chamber is described in (Baiburina S.G et.al. 1984). A γ-family is defined as a set of minimum 3 particles with similar zenith and azimuth angles and located within a circle of a fixed radius.

Results from the X-ray calorimeter cannot be compared directly with the accelerator data. In the emulsion chamber the event called a family is composed of the particles coming from a few interactions which occurred at different heights in the atmosphere. In order to make such a comparison with the accelerator data we make assumptions on primary spectra and nuclear interactions then simulate propagation of the EAS core through the atmosphere; then the products of such calculations are compared with experimental data. Therefore, the conclusions which concern the postulated assumptions are made indirectly.

2 Calculation:

The CORSIKA program (Heck D. et al.. 1998) was used to simulate development of the cores of extensive air showers in the air and the QGSJET model of nuclear interactions was taken into calculation. This model, according to (Heck D., et al. 1998), has the characteristics best fitted to the accelerator data, moreover, they are extrapolated to the energy ranges considered in this paper. The adopted cross sections for nuclear interactions were in agreement with the model.

Primary particles which entered the atmosphere were sampled with the spectrum $\approx E^{-\gamma}$ where $\gamma = -1.7$ in the range $5.10^{14} – 5.10^{15}$ eV and $\gamma = -2.2$ above 5.10^{15}eV. Zenith angles varied from 0 to 40^{o}. Hadrons

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in the air calculations were traced down to the energy 2 TeV and the same threshold was applied to gammas and electrons/positrons.

To fulfill the conditions for gamma families the particles were processed in the following way:

1. the particles with energies lower than the energy threshold (E_{thr}) of 4 TeV were rejected. The energy threshold of gammas and electrons (E_{thr}=4 TeV), used in the families, included consideration of the efficiency of particle registration in the calorimeter
2. the energy weighted center of a family was calculated,
3. the particles within the distance greater than 150 mm from the energy weighted center were cut off,
4. if multiplicity of the particles was not less than 3 and the sum of the energies of the particles was greater than the energy threshold for the family (ΣE_γ=100 TeV) then the family was taken into further calculations.

3 Results:

The number of calculated EAS cores for each kind of a primary (proton, alpha, nitrogen, iron) is shown in Table 1.

Table 1 The number of calculated cores of EAS for considered kinds of primaries (QGSJET-CORSIKA)

range of energy (eV)	proton	alpha	N	Fe
$5.10^{14} – 5.10^{15}$ eV	60000	22000	2000	1000
$>5.10^{15}$ eV	6000	2000	3000	3000

The ratio $N_{family}/N_{primaries}$ (the ratio of the number of families N_{fam} created by the number of primaries N_{prim} in consideration) is called efficiency or probability of γ-family production. As the cores of proton initiated EAS give the main contribution to the registered families, the efficiency of γ-family production for different intervals of primary proton energy is presented in Table 2. It is seen that almost 100% protons of energy exceeding 50 PeV produce a gamma family the energy of which is greater than 100 TeV. On the other hand only one per mille of protons of energy 0.5 – 1 PeV gives the contribution to the number of families at the observation level of Pamir Experiment.

Table 2 The amount of γ-families created by primary 1000 protons in various interval of primary proton energy (QGSJET-CORSIKA).

The energetic interval of primary protons (PeV)	0.5-1.0	1-2	2-5	5-10	10-20	20-50	50-100
N_{fam} of ΣE_γ >100 TeV *per*1000 primary proton	1	5	21	108	262	605	979

The percentage of gamma families that are "recorded" at the height of 4370 m asl according to the conditions described in subsection 2 ($E_{thr} \geq 4$ TeV, $n \geq 4$, $\Sigma E_\gamma > 100$ TeV, $R < 150$ mm), is presented in Table 3. This percentage is referred to a total amount of families created by primaries of considered kinds.

Table 3 The number of γ-families created (No of γ-families *per* 1000 primaries) by various kinds of primaries sampled according to the described spectra (QGSJET-CORSIKA).

proton	alpha	N	Fe
6.5	2.9	0.6	0.1

The errors vary and are of the order of 5 – 10 %. It can be seen, that the amount of the families registered in X-ray film of calorimeter and initiated by primary iron nucleus is very low in comparison to the proton initiated EAS. Alpha induced showers give only a small contribution to γ-families. The percentage of the families in the energy intervals referred to the total number of families is presented in Table 4. In the considered region a contribution of γ-families created by the primaries heavier than proton is rather small.

Table 4 The percentage of the number of families in intervals of energy referred to the total number of families i.e. normalized to 1.0 for ΣE_γ>100 TeV

ΣE_γ , TeV	proton	N	Fe
>100	1.00	1.00	1.00
100-200	0.61	0.66	0.81
200-400	0.25	0.23	0.19
400-700	0.09	0.06	<0.001

The following parameters of γ-families are used in the Pamir Experiment, basing on measurements of the coordinates and the energy of registered particles:

1. the mean multiplicity <n> of gamma and electrons,
2. the mean radius <R> of particles in the family (R, expressed in [mm] is measured from the energy weighted center),
3. the mean value of product of energy and radius of particles: <E·R> (expressed in TeV*mm).

In Table 5 the average values of multiplicity <n>, the radius <R> and the value <ER> of the simulated γ-families are presented. The <<R>> and <<ER>> notation means that these parameters are twice averaged: first the mean value of R in an individual family was calculated and then the average value over all considered families was found. The data obtained in the simulation of EAS with MC0 model are also shown in Table 4. Generally, the MC0 and MQ (by Dunayevski, A., 1988, modernized by S. Karpova) algorithms are based on a quark gluon string model of nuclear interaction.

Table 5 The average values of multiplicity <n>, radius <R> and <ER> of γ-families for various ranges of family energy. The following criteria are applied to choose the family: the threshold energy of gamma or electrons is greater than 4 TeV, ΣE_γ>100 TeV, the cut-off radius for the particles is 150 mm from the energy weighted center.

ΣE_γ,TeV	QGSJET (CORSIKA)				MC0 model				Pamir Exp.
	proton	alpha	N	Fe	proton	alpha	A:12-16	A:50-56	
	multiplicity of particles of energy threshold > 4 TeV in γ-family, <n>								
100-200	12 ± 1	13 ± 1	13 ± 2	15 ± 1	12.6 ± .2	13.1 ± .4	14 ± 1	15 ± 1	
200-400	20 ± 1	25 ± 2	28 ± 2	22 ± 3	21.8 ± .6	24 ± 1	35 ± 4	29 ± 2	
400-700	38 ± 2	47 ± 3	54 ± 3		41 ± 2	46 ± 4	49 ±4	51 ±4	
	mean value of radius of particle in γ-family, <<R>>, mm								
100-200	19 ± 1	23 ± 2	32 ± 2	46 ± 3	19.1 ± .5	26 ± 1	35 ± 2	45 ± 3	23 ± 1
200-400	13 ± 1	26 ± 2	29 ± 3	41 ± 6	16.8 ± .6	23 ± 2	36 ± 3	38 ± 3	22 ± 1
400-700	15 ± 1	19 ± 3	36 ± 4		15.7 ± .9	20 ± 3	30 ± 2	35 ± 2	18 ± 2

Table 5 *(cont.)*

ΣE_γ,TeV	QGSJET (CORSIKA)				MC0 model				Pamir Exp.
	proton	alpha	N	Fe	proton	alpha	A:12-16	A:50-56	
	mean value of E*R of particle in γ-family, <<ER>>, TeV*mm								
100-200	165 ± 10	193 ± 16	265 ± 20	346 ± 25	169 ± 5	220 ± 12	276 ± 17	370 ± 33	210 ± 10
200-400	132 ± 11	224 ± 16	223 ± 15	439 ± 98	156 ± 6	195 ± 13	276 ± 26	340 ± 37	220 ± 10
400-700	128 ± 11	182 ± 17	305 ± 50		138 ± 8	153 ± 21	255 ± 23	281 ± 21	210 ± 20

The details of the MC0 model can be found in (Mukhamedshin R.A., 1994). The MC0 model has been used by the Pamir Collaboration for a few years as a good model which describes many characteristics of the experimental data. We would like to point out that the calculated data did not take into account the detector response so only a general idea can be obtained from the comparison with the experiment.

In order to compare the results with other programs for different models of nuclear interaction we carried out calculations with the same initial assumptions and the same conditions for the choice of the families as presented in (Bielawska H. et al., 1997). In this case the exponent of the integral spectrum of entering particles is $\gamma = -1.7$ for all models, protons are sampled in the interval 1-10 PeV, the energy threshold of the particles in the family is assumed 2 TeV, the $\Sigma E_\gamma > 100$ TeV, $R_{cut\text{-}off} < 150$ mm.

In Table 6 the results of the comparison of the families calculated by the VENUS, QGSJET (CORSIKA), MC0 and MQ model are shown. As it can be seen, the last three models are in a good agreement. The existing differences, especially in lateral distributions, need further studies.

Table 6 The comparison of γ-family characteristics for different programs/models of nuclear interaction. The data for VENUS (CORSIKA) and MC0 models are taken from [5].

model ->	VENUS (CORSIKA)	MC0	QGSJET (CORSIKA)	MQ
<n>	36 ± 1	38 ± 1	38 ± 1	40 ± 3
<<R>>	45 ± 1	34 ± 1	28 ± 2	30 ± 2
<<ER>>	204 ± 5	144 ± 4	135 ± 8	130 ± 10

4 Conclusions:

The calculated characteristics of gamma families for the QGSJET (CORSIKA), MC0 and MQ models are very similar. All three models are based on quark gluon string model. Differences with the VENUS model confirm our hope that the Pamir Experiment can be helpful in rejecting some groups of nuclear interaction models. To get better understanding of the model of nuclear interaction or of the spectra of primary cosmic rays, a detector response program should be used to get the results which may be in better agreement with the experiment.

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