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Attenuation length of γ-families derived from Pamir data

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Attenuation length λ_{att} of γ-families in the atmosphere registered in X-ray emulsion chambers (XREC) at a mountain altitude (520 g/cm^2, 600 g/cm^2, 690 g/cm^2) is analyzed by model simulations MC0 code which is based on most of accelerator results and includes also a quark-gluon string model. It is shown that: 1. Values of λ_{att} obtained from angular distributions of gamma-families and from their vertical intensities at different altitudes are near the same; 2. λ_{att} slowly depends on the atomic number of primary cosmic rays (PCR). The results of calculations are compared with experimental data of Pamir Experiment.

1. Introduction

Attenuation length of γ-families, λ_{att}, reflects the PCR energy dissipation during their penetration through the Earth's atmosphere. The λ_{att} depends on strong interaction characteristics, namely, a particle interaction cross-section σ_{NN}, inelasticity coefficient and primary particles composition and as well as PCR atomic composition and energy spectra. A reliable experimental λ_{att} quantity limits a possible parameter modification range in used model to match with the experimental data obtained in XREC and allows us to make some conclusions about PCR spectra and a composition. A value of λ_{att} can be obtained in two ways: 1) from a γ-family flux attenuation with a depth in the atmosphere; and 2) from a γ-family angular distribution at the given observation depth.

Experimental values of λ_{att} obtained in the different experiments by the different methods significantly differ: from the λ_{att} ~70-80 g/cm^2 [1], to λ_{att} ~ 100-120 g/cm^2 [2, 3]. This discrepancy forced us to examine λ_{att} and γ-family intensity by the various versions of the MC0 code [4], developed in Pamir Experiment, to prove of the identity of these two methods of a λ_{att} calculation, a possible relation of a measured value of λ_{att} with an altitude observation, dependence on threshold energy E_{thr} of γ-rays, which are selected in γ-families, and also a dependence on the PCR nature, which the investigated γ-families originate from. The values of λ_{att} derived from the simulations are compared with experimental date in Pamir Experiment.

2. Model and simulation.

Gamma-families with $\Sigma E\gamma$>100TeV was simulated by Model MC0 for $E_0=2\cdot10^{14} - 2\cdot10^{18}$ eV for these examinations in several variants. Only a composition, a primary particles spectrum kind or an altitude H, at that γ-families are recorded, are varied in this model; a hadron interaction features are not change. We used the following assumptions of PCR integral energy spectrum: 1) In the standard MC0 model all primary particles have the same energy spectra index γ=1.65 up to primary particle energy $E_0=3\cdot10^{15}$ eV, and beginning from $E_0=3\cdot10^{15}\cdot Z$ eV (Z-is atomic number) a spectrum index increases on Δγ=0.4; 2) In MCWK model the spectra indexes of all particles have the value γ=1.65 in the whole range of $E_0=2\cdot10^{14}–2\cdot10^{18}$eV; 3)

In MCPHe model the spectrum indexes of of all particles besides P and nucleus He are the same as in MC0. Spectra indexes for P at $E_0=3\cdot10^{15}$ eV and for He at $E_0=6\cdot10^{15}$ eV increase on $\Delta\gamma=2.0$. So P and He nucleus virtually disappear from this range of E_0 energy; 4). In the frame of standard model MC0 γ-families were simulated for altitudes H= 520 g/cm^2 (the Kambala), 600 g/cm^2 (the Pamirs) and 690 g/cm^2 (the Tien Shan), for two version:1) Primary particles incident angle $\theta=0^o$; 2) Incident angles θ = (0-0.9) rad. A restriction of incident angle value at $\theta=51^o$ is used because there are no γ-families with $\theta\geq51^o$ in an experiment and in models. For each of the pointed version about 2000 γ-families were simulated.

3. Experiment Pamir data.

To calculate value of λ_{att} and intensity I_{vert} of γ-families in Pamir Experiment 1096 γ-families were selected with ΣEγ>100 TeV, where Eγ is the energy of a selected γ-quantum at the threshold energy E_{thr}=4 TeV and at a distance R≤15см from energy-weighted γ-family center. The value of λ_{att} was calculated from γ-family angle distribution and is equal λ_{att}=(77±3) g/cm^2. From this value of λ_{att} the γ-families solid angle Ω for recorded γ-families was evaluated and Ω=0.60±0.02. Vertical intensity I_{vert} of γ-families with ΣEγ>100 TeV at the Pamir's altitude I_{vert}=0.54±0.04 fam/(m^2 year ster)$^{-1}$ in which γ-rays overlapping effect was taken into account.

4. Intensities of γ-families with ΣEγ≥100TeV in different models and in the experiment.

To evaluate the vertical intensities I_{vert} of γ-families we used simulated γ-families with $\theta=0^o$. Then $N_p= I^p_{vert}\cdot ST$, where N_p- a number of PCR particles, S- square and T- time exposition, I^p_{vert} –intensity of primary particles. Therefore ST= N_p/ I^p_{vert}. And a vertical intensity of γ-families $I_{vert}= N_f/ST$, где N_f –number of a simulated γ-families, which survived at given atmosphere depth. This simulated data were used for calculation λ_{att} by the method of a family intensity attenuation with an atmosphere depth.

In Figure1 the vertical intensities of γ-families with ΣEγ≥100TeV are shown for standard MC0 (○) at θ = 0–0.9 rad and for the different threshold energy selection E_{thr} of the γ-rays in the families that is at E_{thr}=4 TeV, 6 TeV, 8 TeV and 10 TeV.

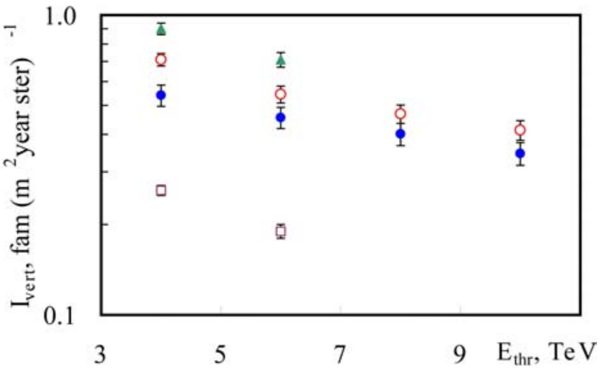

Figure1. Dependence of I_{vert} for experiment Pamir (•), MC0 (○), MCWK(▲) and MCPHe (□) models.

Figure1 shows also the intensities of γ-families in MCPHe (□) model, where P and He-nucleus primary energy spectra become very sharp at $E_0 > 3*10^{15}$ eV, and also the intensities in MCWK(▲) model, where all particles primary energy spectra have the same index $\gamma=1.65$ for all range of E_0 . Pamir experiment data (•) are shown for E_{thr}=4 TeV, 6 TeV, 8 TeV and 10 TeV.

The intensities in MC0 coincide with the experimental ones better than intensities in two another models. In this picture the experimental intensities are less than ones in MC0 at all threshold selections, but the difference between the experimental and this model intensity values is small.

The intensities in MCWK are some higher than ones in MC0 and then the intensities in Pamir experiment (in 1.6 times). In MCPHe model the intensities of γ-families are much less than MC0 or Pamir intensities, at least more than two times. So small family intensity in MCPHe originates from a lack of P and He in this E_0 region because of namely P and only P in this region (E_0=3 10^{15}--10^{17} eV) can form γ-families with $\Sigma E\gamma \geq 100$TeV at a mountain level. The nucleus efficiencies to form that γ-families are small at these primary energies. And a sharp decreasing of P и He (as it is in MCPHe) results in to the family intensity are strongly reduced and so Pamir Experiment data excludes this possibility.

5. Attenuation length λ_{att} of γ-families in MC0 models and in Pamir experiment.

In table 1 and 2 the attenuation length λ_{att} of γ-families are given. The attenuation length λ_{att} values were calculated from the γ-families vertical intensity at a different altitudes at ($\theta=0^o$)-table 1 and from γ-family angular distribution at the different altitudes-table 2. As can be seen from the tables 1 and 2 these two methods give the values of λ_{att}, which coincidence in limits of mean-square errors.

Table 1 Values of λ_{att} derived from I_{vert} on different altitudes.

ΔH, g/cm²	λ_{att} , g/cm², E_{thr}=4 TeV
596-520	87.5± 3.0
690-520	91.6±1.6
690-596	95.3±4.0
690, 596, 520	91.6±1.6

The experimental and MC0 model attenuation length λ_{att} were derived from the angular distribution and are shown in Table 3 at different threshold energies E_{thr} . Values of λ_{att} for MC0 are some more the experimental λ_{att} at different energies E_{thr}. The quantities of these λ_{att} do not change with an increasing E_{thr}. Hence an attenuation length λ_{att} calculated on an angular distribution do not depend on a selection on E_{thr}.

Table 2 Attenuation lengths derived from an angular distribution.

H, g/cm²	520	596	690
λ_{att} , g/cm²	89.7±2.9	86.4±3.0	84.0±2.5

This difference between experimental and simulated data means that it is necessary to change some parameters in MC0 so as a primary particle energy dissipation degree would be more than in MC0 model.

Table 3 Dependence value of λ_{att} from E_{thr}.

	λ_{att} , g/cm²		
E_{trh}	4 TeV	6 TeV	8 TeV
Pamir	76.5 ± 3.2	76.9 ± 3.6	78.9 ± 3.9
MC0	86.4 ± 3.0	86.6 ± 3.7	86.1 ± 4.0

The attenuation lengths in MCWK and MCPHe obtained from on angular distribution of γ-families are equal λ_{att} =(103.4±3.0) g/cm^2 and λ_{att} =(80.7±2.4) g/cm^2 accordingly. Hence, an attenuation length is sensitive to a kind of spectrum or a nature of a primary particle.

So we investigated a possible dependence of λ_{att} on a nature of PCR particle inducing γ-families. In table 4 the attenuation lengths for several PCR particles are shown. The values λ_{att} were calculated from an angular distribution of families simulated for each primary particle at H=600 g/cm^2.

Table 4 Attenuation lengths for different primary particles

Particle	N_{fam}	λ_{att} , g/cm^2
P	1618	88±4
He	1062	87±4
0	943	85±4
Si	1034	89±4
Fe	950	89±5

Thus, the values of λ_{att} coincide within mean-square errors for P all PCR particles in model MC0 at the taken kind of primary spectrum, when the spectrum slopes are the same for all primary particles before and after the knee. But the knee energy is a different for all particles. However, the value of λ_{att} can be changed by means some modification of the PCR spectra as it takes place in MCWK and MCPHe versions.

6. Discussion and conclusions.

Our analysis shows: 1) two methods of λ_{att} calculation give a coincident values of λ_{att} within mean-square errors; 2) The calculation of λ_{att} at different altitudes from an angle distribution of γ-families gives the compatible values of λ_{att} also. Therefore the different methods of calculation of λ_{att} and a difference of altitudes, where γ-families are recorded, do not lead to a difference in λ_{att} as in experiments with XREC at the mountains; 3) an attenuation length calculated from an angular distribution is independent of E_{thr} selection. Hence λ_{att} calculated from the angle distributions in the different experiments can be compare even if E_{thr} differs; 4) MC0 model where spectrum exponent is γ=1.65 up to E_0=3 10^{15} eV and then changes on Δγ=0.4 for each PCR particles coincides with the experimental data on I_{vert} and λ_{att} better than MCWK and MCPHe models; 5) the attenuation lengths of γ-families induced by P and other PCR primary particles have the same value of λ_{att} at similar PCR particle spectra.

It seems that the differences of a value λ_{att} in the experiments is due to a poor statistics in them. To correlate MC0 model data on I_{vert} and λ_{att} with the Pamir experimental ones it is necessary to slightly increase an energy dissipation of PCR particles at their penetration through the atmosphere.

References

[1] A.S. Borisov et al., Nuclear Physics B (Proc Suppl.) 97, 116-117 (2001).
[2] M. Akashi et al. Phys. Rev. D24, 2353. (1981).
[3] Brasilia-Japan Collaboration, ICR-report-1, Tokyo, ICRR 12-83-6(1983).
[4] G.F. Fedorova and R.A. Mukhamedshin, Bull. Soc. Sci. Lettr. Lodz, Ser. Rech. Def. V. XVI, p. 137 (1994).