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A peculiarity of high energy γ-quanta absorption in the atmosphere (EC data).

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Abstract. Experiment ”Hadron” data of the X-ray emulsion chamber at Tien-Shan level in comparision with other ones show that γ absorption in the atmosphere deviates from the simple exponential low. The resulting absorption curve has bump in the depth range $p \simeq 600 - 900$ g/cm^2. The increase of γ generation deep in the atmosphere can be connected with a new penetrating cosmic ray component, for example hypothetical strange quark matter, which is decayed at the fixed depth of the atmosphere $p \simeq 800$ g/cm^2.

1 Introduction

A simplified cascade theory predicts an exponential absorption of the primary CR (cosmic ray) nucleons in the atmosphere (Zatcepin, 1949, @):

$$I(E,p) = I(E,0)e^{-p/\lambda_a}, \quad (1)$$

where λ_a is an attenuation length.

An intensity of the secondary components, generated in the atmosphere by nucleons, have maximum for some depth $p = p_0^i$ $(i = \pi, \mu, e, \gamma)$ (Mursin and Sarytcheva, 1968, @). Above maximums an exponential absorption is also true.

Shape of the absorption curve more exact is deduced by means of Monte-Carlo simulation calculations, which show that variation of the model parameters results only in the change of λ_a value and don’t change the exponential shape of the absorption curves (see for example (Capdevielle et al., 1994, @; Ohsawa, 1991, @)).

The value of λ_a can be obtained by two ways, from Eq. (1) for the total vertical intensities $I^v(> E)$, and from intensities for different zenith angles θ:

$$-\frac{\partial I(> E)}{\pi\partial(\cos^2\theta)} = I_0 e^{-(p\sec\theta - p_0)/\lambda_a}, \quad (2)$$

where p is a detecting level.

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Both expressions must give the linear dependencies in the logarithmic scale with one the same slope $m = p/\lambda_a$.

The most plausible experimental data about absorption in the atmosphere were received for e,γ component (hereafter simple γ) by means of EC (X-ray emulsion chambers). The EC energy threshould is $E_\gamma > 1$ TeV and so γ, detected by EC, mainly are generated by decay $\pi^0 \to 2\gamma$.

It firstly is demonstrated in this work that γ absorption in the atmosphere is differed from simple exponential law. This conclusion mainly is founded on the new precise EC measurements in the experiment “Hadron” at Tien-Shan (685 g/cm^2), because the intensity deviation from a normal absorption is maximal for the atmosphere depth close to 700 g/cm^2.

Two kinds of EC events are analyzed in this work: γ and γ-families, which are differed by the total energy threshold ΣE_γ and γ multiplicity n_γ. The γ includes all events with $n_\gamma \geq 1$, $E_\gamma \geq 5$ TeV and $\Sigma E_\gamma \geq 5$ TeV. It consists mainly of the single γ and them pairs but includes a big $\gamma-$families too. The second one includes only $\gamma-$families with $n_\gamma \geq 3$, $E_\gamma \geq 4$ TeV and $\Sigma E_\gamma \geq 100$ TeV.

Table 1 lists the vertical intensities for different atmosphere depths p, which were received by means of high altitude balloons, airplanes and high mountain installations (Abraham et al., 1963 -...- Fukushima et al., 1987, @). The absorption curves for γ and γ-families are shown in Fig. 1.

A curve slope is decreased in the range $p \simeq 500 - 700$ g/cm^2 and becomes more steeper above this interval. The last conclusion is based on the five-fold distinction of the Tien-Shan and m. Noricura intensities ($\Delta p = 50$ g/cm^2). However, the m. Noricura points have a low statistical precision. So the Tien-Shan angular measurements were exploited to verify this result with better accuracy ($\sim$4500 events for γ). Although the m. Noricura intensity causes to more sharp effect, the angular distribution data support the general tendency for a slope increase in the range $p = 700 - 860$ g/cm^2.

The bump in the absorption curve for γ does not vary appreciably as the threshold energy of EC events is increased in case of the γ-families.

Table 1. The γ and $\gamma-$family vertical intensities I^v and angular slopes m for different atmosphere depths p.

P g/cm^2	m	$10^{10} \cdot I^v$ cm^{-2}sec^{-1}sr^{-1}
	$\gamma-$quanta	
106	~ 3.0	99 ± 5
225	2.1	40.8 ± 5.8
260		48 ± 10
400	5 ± 1	7.4 ± 0.7
455		3.2 ± 0.4
520	5.8 ± 0.9	2.1 ± 0.3
556		1.35 ± 0.08
600	5.8	1.45 ± 0.4
650	6.0 ± 0.3	1.1 ± 0.1
685	7.1 ± 0.2	0.85 ± 0.17
685	7.1	0.72 ± 0.03
735		0.16 ± 0.1
	$\gamma-$families	
225		0.6 ± 0.3
520		$(2.1 \pm 0.3) \cdot 10^{-2}$
540	7.5	$(1.9 \pm 0.2) \cdot 10^{-2}$
600	7.7	$(2.18 \pm 0.06) \cdot 10^{-2}$
650	5.8	$(0.68 \pm 0.03) \cdot 10^{-2}$
685	8.5	$(1.7 \pm 0.1) \cdot 10^{-2}$
735	7.5	$(0.4 \pm 0.2) \cdot 10^{-2}$

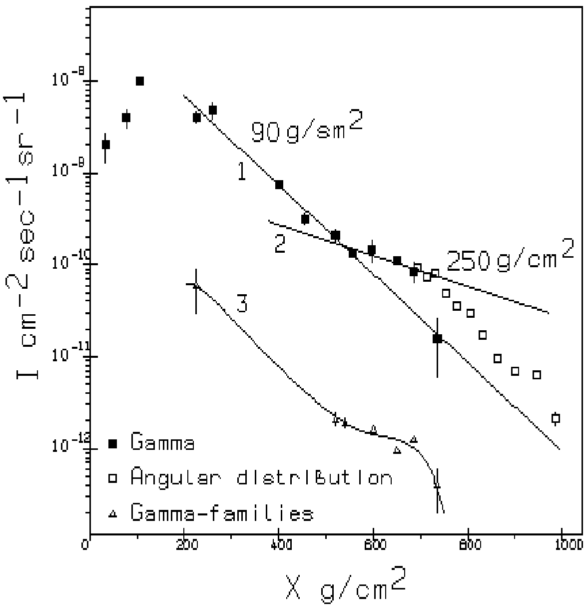

Fig. 1. The absorption curves for γ (squares) and γ-families (triangles). The intensities received from Tien-Shan angular distribution for γ are designated by empty squares. The straight lines 1 ($\lambda_a = 90$ g/cm^2) and 2 ($\lambda_a = 250$ g/cm^2) are drown through the experimental points in the intervals $p = 225 - 520$ g/cm^2 and $p = 520 - 685$ g/cm^2 consecutively. The curve 3 is approximation of the γ-family intensities by polinom.

A number of the corrections were introduced at the experimental data, which mainly decrease a value of the bump.

1) The experiment "Pamir" and "Hadron" intensities are reduced by 1.2 times in Table 1 after subtracting a hadron contribution in γ flow (Pamir collaboration, 1984, @). In otherwise cases the γ and hadrons were separated by the depth of cascade origin.

Two corrections were introduced in $\gamma-$family intensities at Fig. 1.

2) The intensities for "Pamir" and "Hadron" experiments were reduced by 1.35 times. An exposition of the joint EC at Pamir has shown that difference in Russian and Japanese methodics causes to the ratio $I^{RUS}/I^{JAP} = 1.35$ (Chacaltaya and Pamir collaborations, 1992, @).

3) The m. Fudji intensity is increased by 1.4 times. Because of the small statistic the authors of (Amenomori et al., 1983, @) use a value of the slope for γ angular distribution $m = -5.8$ when the family vertical intensity is determined. The linear interpolation of the Pamir and Tien-Shan data to m. Fudji level gives the value $m = -8.2$, that results in the intensity increas to 1.4 times.

Another reason for the bump overestimation may be connected with intensity errors. In individual cases only the statistical errors are included in Table 1. As our measurements have shown the total relative errors may comprise the values $\sigma_I/I \simeq 0.15 - 0.20$ because of differences in the emulsions, EC operating conditions and so on. It is properly accounted for the final results in this work.

The change of the absorption curve slope is characterized by the values of the absorption length λ_a in the Table 2.

The most emphatic value $\lambda_a = 252 \pm 29$ g/cm^2 is recived if the first three points of Tien-Shan angular distribution are added and intensity errors from Table 1 are used.

A conclusion about dissimilarity of γ absorption from the exponential law have their bases in quantitative evaluations of the agreement by χ^2 criterion. An agreement knowingly is bad when only a statistical errors are used: $P < 10^{-4}$ for the vertical intensities (solid squares in Fig. 1) above the maximum ($p > 200$ g/cm^2) and $P < 10^{-3}$ for a linear fit of the angular data only (open squares).

So probabilities of the agreement, collected in Table 3, were received with regard to methodical errors. Everywhere the errors were increased up to maximal value $\sigma = 0.2 \cdot I$.

Table 2. The λ_a values for γ and γ-families in different intervals of p. The intervals Δp, which include angular data, are symbolized by the stars. Two sets of λ_a are shown: with σ_{1i} - intensity errors from Table 1 and σ_{2i} - errors, increased up to value $\sigma_i = 0.2 I_i$.

Δp g/cm^2	σ_{1i}	σ_{2i}
	γ	
225-520	92 ± 5	89 ± 6
520-735*	252 ± 29	225 ± 47
$800 - 865^*$	50 ± 3	51 ± 13
	$\gamma-$families	
225-520	88 ± 14	88 ± 14
520-685	212 ± 34	252 ± 86
$685 - 730^*$	44 ± 8	44 ± 14

Table 3. The probabilities of the agreement between experimental intensities and linear approximations. P_1 - for all points. P_2 - for the points in range $p > 520$ g/cm^2 and extrapolation of an approximation in range $p = 220 - 520$ g/cm^2 ($\lambda_a = 90$ g/cm^2). $\sigma_i = 0.2 \cdot I_i$.

Events	P_1	P_2
γ	$< 5 \cdot 10^{-3}$	$< 10^{-5}$
γ with angular distribution	$< 10^{-5}$	$< 10^{-7}$
γ-families	$< 10^{-4}$	$< 10^{-6}$

The point deviations in range $p > 500$ g/cm^2 are not statistical but systematical ones. All these experimental points lay consistently higher than extrapolation of the "normal" absorption curves with $\lambda_a \simeq 90$ g/cm^2 from the range $p \simeq 200 - 500$ g/cm^2. The results of comparison with these extrapolations (P_2) are shown in Table 3 too. All deviations exceed 4σ in this case.

Agreements are bad both for γ and for γ-families, although the errors were increased. A value of $\lambda_a \simeq 100$ g/cm^2 in common use as usual is received without taking into account this discrepancy. A choice of the plane altitude point and any one of the points in interval $p > 500$ g/cm^2 as a second intensity for λ_a determination is little affected by the final result and give $\lambda_a = 90 - 120$ g/cm^2 (Cherdyntceva et al., 1999, @).

It may be argued, that the methodical distortions can't explain observed deviations. The five intensities of γ in Fig. 1 were received by approximately the same methodic, developed in (Baradzey et al., 1970, @). Three of them in the interval $p = 225 - 556$ g/cm^2 agree well with $\lambda_a = 90$ g/cm^2 value. An increase in λ_a for $p = 520 - 685$ g/cm^2 mainly is based on the comparison of the Pamir and Tien-Shan data, which were received by exactly the same methods (Cherdyntceva et al., 1999, @). Result about λ_a decrease for $p \simeq 800$ g/cm^2 is confirmed by the angular measurements.

It would be possible to explain the bump with an enhancement of the pions (muons) role in γ generation for the lower atmosphere or anything another changing of the interaction characteristics, but this kind effects must manifest itself in the simulation calculations. In all known cases the calculated curves are agreed with simple exponential law and the relatively small value of $\lambda_a = 70 - 120$ g/cm^2. It may be regarded as foundation for exotic explanation of the effect until it will be shown that the simulations with standard model are liable to give an essential change in λ_a with atmosphere depth.

So it only remains to speculate that some unknown penetrating component, which is capable to generate γ, manifests itself in the lower atmosphere. The situation closely parallels that in experiments with calorimeter at Tien-Shan (long flying component (Yakovlev, 1992, @)) and EC at Pamir (penetrating hadrons (Slavatinsky, 1988, @)), but has two new aspects.

As a penetrating effect is observed in the atmosphere, for this reason alone, a hypothesize of the leader charm (Yakovlev, 1992, @; Slavatinsky, 1988, @) can be excluded. The cross section of the charm particles generation in the air is significantly below then in the lead (calorimeter and EC). In addition a leader charm deposition in a formation of the γ flow for energies of order 100 TeV is negligible $< 10^{-2}$, as it must be proportional to the ratio l_{ch}/l_γ, where $l_{ch} \leq 10$ m - the charm decay interval and $l_\gamma \simeq 3000$ m - the depth of γ collection (Baradzey et al., 1964, @).

An additional point to emphasize is that an absorption is increased for $p > 700$ g/cm^2, but for sum of different exponents it only may be diminished with depth. An increase in absorption may becomes possible for example by a many-particle decay of the hypothetical hadron which carries a large part of the primary energy. It is of the prime interest that to receive the essential break in event intensity its decay must depend on an amount of the passed matter but not an lifetime of the particle. The hypothesis of QM (quark matter) particles (Bjorken and McLerran, 1979, @; Witten, 1984, @) is best suited to describe this shape of the absorption curve. Another, but similar, variant may be regarded, if QGP (quark-gluon plasma) is generated in interactions of the CR with air nuclei.

An absorption curve above the maximum in this case can be represented as sum of the exponent (the curve 1 at Fig. 1), which is associated with an absorption of CR nuclei, and the curve for QM deposition in the γ generation.

This work was made to verify one of the QM hypothesize predictions, which were received for CR data at (Shaulov, 1996, @). A central conclusion is that the γ absorption in the atmosphere appears as if the QM exists in CR. It don't agree with negative result of QM search by means of plastic track detectors (CR-39) (Price, 1982, @) and may signalled about QM small electric charge ($Z \leq 16$) when it pass through the atmosphere or a QGP generation by the CR heavy nuclei in the upper atmosphere.

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