The Study of Elemental Species or the Primary Cosmic Rays at Energies $10^{13} - 10^{16}$ eV by the LVD Experiment

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Abstract

Distributions of distances between any muon pair in a cascade have been simulated with the help of CORSIKA code. In the knee region of the energy spectrum of the primary particles the very heavy mass composition is needed to fit data.

1. Introduction

The distributions of distances R between any muon pairs which strike the LVD detector [1] are of interest. These distributions depend on energy of the primary particles and the mass composition. Any change in the mass composition in the knee region of the energy spectrum would result in disturbances of these distributions. To interpret the experimental data correcrly a response for the LVD detestor should be simulated. The extensive Monte-Carlo simulations of cascades in the atmosphere were carried out with the help of CORSIKA code [2] in terms of the QGSJET model [3,4].

2. Methods

Monte-Carlo simulations. The table 1 shows numbers of possible distances between muon pairs in cascades for various elemental species and energy bins i. The statistics N for any kind of elemental spesies and energy interval i is also shown. Thus, nearby $0.7 \cdot 10^6$ cascades were simulated in the atmosphere. All muons have been transported through the rock. The profile of rock above the LVD detector was assumed as table 2 shows where depth of rock and the threshold energy of muons are displayed.

The continuous losses of muons have been accounted for as in [5]. The bremsstrahlung was considered as in [6] and the cross-section of the photonuclear

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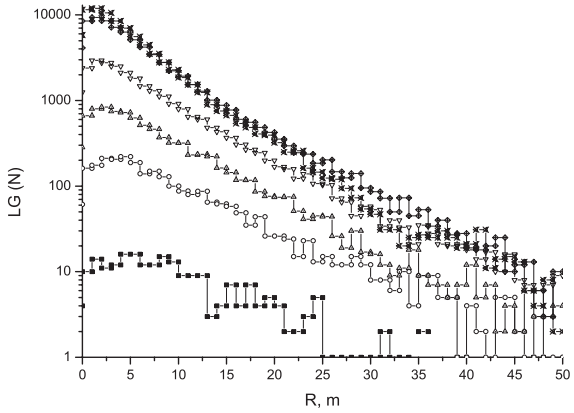

Fig. 1. Distributions of distance between various muon pairs in a cascade for different energy bins i for protons.

Table 1.

i	energy bins, eV	statistics, N	p	He	N	P	Fe
1	$10^{13} - 3.16 \cdot 10^{13}$	100000	262	40	-	-	-
2	$3.16 \cdot 10^{13} - 10^{14}$	50000	2699	2055	206	5	-
3	$10^{14} - 3.16 \cdot 10^{14}$	20000	8665	13437	8612	2675	427
4	$3.16 \cdot 10^{14} - 10^{15}$	10000	26504	47137	67211	69598	34074
5	$10^{15} - 3.16 \cdot 10^{15}$	5000	74019	138351	234748	314510	345681
6	$3.16 \cdot 10^{15} - 10^{16}$	1000	84857	143634	247379	385637	489561

interactions of muons have been taken from [7]. The Coulomb multiple scattering of muons in rock have also been taken into account. All muons which survive the transport procedure have been assigned weight w_i to estimate the particular contribution of the energy bin i. Final distribution $F(R)$ for any elemental species can be calculated as a sum:

$$F(R) = \sum_i w_i f_i(R) \tag{1}$$

The weights w_i were estimated according the following formula:

$$w_i = \frac{1}{W} \int_{E_i}^{E_{i+1}} E^{-\gamma} dE \tag{2}$$

where $W = \sum w_i$ and the exponent γ has a change at $3.16 \cdot 10^{15}$ eV. The energy spectrum was considered to be continious.

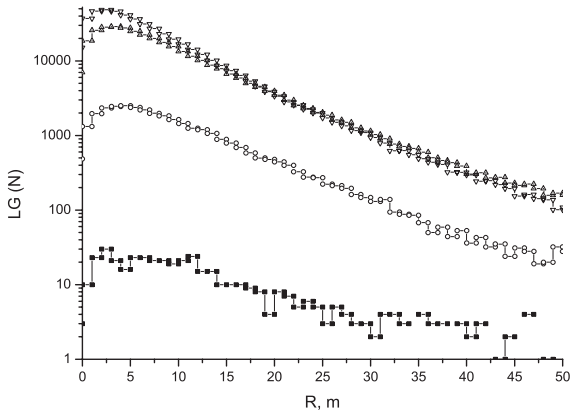

Fig. 2. Distributions of distance between various muon pairs in a cascade for different energy bins i for iron nuclei.

Table 2.

i	Depth of rock Z, m	Threshold energy, GeV
1	1000	1816
2	1500	2581
3	2000	3107
4	2500	3433
5	3000	4079

3. Results and discussion

The distributions of distances between various muon pairs in a cascade for different energy bins have been shown in Fig.1 for the primary protons and in Fig.2 for the primary iron nuclei.

The estimated mean values are decreasing from 12.1 m to 5.9 m for the primary protons and from 14.2 m to 8.3 m for iron nuclei though a distanse R can be as large as 50 m. With the help of weights w_i it is possible to calculate distributions F(R) for any elemental species. Assuming various mass composition one can see some differencies in calculated distributions. Fig.3 displays such distributions of distances between various muon pairs in a cascade for the primary protons (green), the primary iron nuclei (blue), and the standard mass composition (red). Data [1] are also shown as a histogram.

It can be seen that the peak values for protons and iron nuclei primaries differ by 2.5 m. Of couse, to fit the data [1] one should to estimate the response of the LVD detector to the passage of muon groups. This response is now calculated

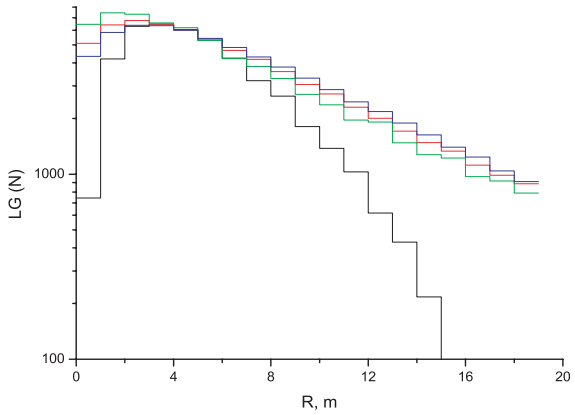

Fig. 3. Distributions of distance between various muon pairs in a cascade for the primary protons(green), iron nuclei(blue) and the standart mass composition(red). Data[1] are also shown as a histogram.

with the help of the simplest approach, described in other our paper [4].

4. Conclusion

Comparison with the LVD data shows some change towards the very heavy mass composition in the knee region of the energy spectrum of the primary particles.

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