The Evidence for the Variation of the Mass Composition with Energy in the Region of the Knee by the LVD Experiment

LVD Collaboration, L.G. Dedenko,[1] G.F. Fedorova,[2] O.G. Ryazhskaya,[3] N.V. Khromina,[1] I.S. Krutsik,[1] T.M. Roganova[2]

(1) Department of Physics, M.V. Lomonosov Moscow State University, Moscow, Leninskie Gory 119992, Russia

(2) D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Leninskie Gory 119992, Russia

(3) Institute of Nuclear Research, Moscow, Russia

Abstract

Simulations of muon multiplicity distributions with the help of CORSIKA code show possible change in the mass composition in the knee region of the energy spectrum of the primary particles towards very heavy species.

1. Introduction

The scientific motivation was exploring the mass composition of the primary cosmic rays in the knee region using the LVD data [1] and extensive Monte-Carlo simulations. Calculations of a response for the LVD detector need a lot of the CPU time. To undestand how a signal is prodused some intermediate simulations were carried out. It has become customary to consider 5 elemental groups: protons (p), helium (He), the $C-N-O$ group (N), the heavy group (P) and the iron group (Fe). The energy spectrum over the range $3.16 \cdot 10^{12}$ to 10^{16} eV was considered separately for the equal intervals in the logarithmic scale. It was assumed that the energy spectrum of the primary particles has a form of $\sim A_i E^{-\gamma} dE$ for any group of particles with the exponent steeping from 2.7 to 3.1 at $3.16 \cdot 10^{15}$ eV. Of couse, other possibilities might be considered. Such differentiation of simulations allow us to see the particular contributions of any groups of the primary particles from every energy bin into the quantity of itrerest. In this paper this quantity is the muon multiplicity n which changes from 2 to ~ 70.

2. Methods

Monte-Carlo simulations. The basic simulations were carried out with the help of the CORSIKA code [2] and the QGSJET model [3]. For every cascade in the atmosphere energies E and coordinates x and y of muons were storaged.

pp. 1139–1142

Table 1.

i	energy bins, eV	statistics, N	p	He	N	P	Fe
1	$3.16 \cdot 10^{12} - 10^{13}$	100000	1044	-	-	-	-
2	$10^{13} - 3.16 \cdot 10^{13}$	100000	9484	2256	-	-	-
3	$3.16 \cdot 10^{13} - 10^{14}$	50000	16205	13348	8597	313	10
4	$10^{14} - 3.16 \cdot 10^{14}$	20000	16847	13348	8597	313	10
5	$3.16 \cdot 10^{14} - 10^{15}$	10000	2001	28311	3125*	30470	2134*
6	$10^{15} - 3.16 \cdot 10^{15}$	5000	4949	34250	8076*	51907	10519*
7	$3.16 \cdot 10^{15} - 10^{16}$	1000	11631	15870	18584	26210	30081

The table 1 shows the total numbers of muons with energies above 10^{12} eV in cascades for various energy bins and different groups of particles (* - statistics N=1000). Thus, nearby $0.7 \cdot 10^6$ cascades were simulated. As some examples Fig.1 for the primary protons and Fig.2 for the iron nuclei illustrate dependence of muon multiplicity n distributions on the number i of energy bin.

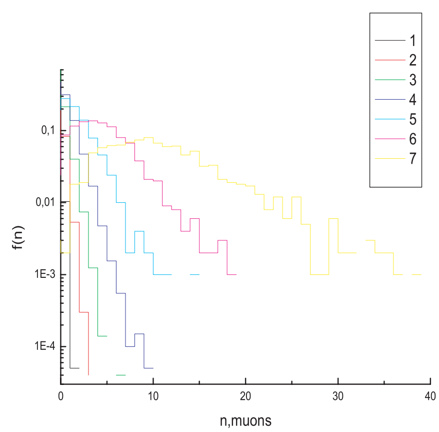

Fig. 1. The muon multiplicity n distribution normalized on statistics N for protons.

It is remarkable that for the last energy bin the muon multiplicity n distributions are very broad both for the protons and iron primaries. The dependes on the primary species is also seen: the peak value for the iron primaries is nearly 2.5 times larger than the peak value for protons. All muons generated in the atmosphere should be transported through the rock. The procedure of such transportation is considered in other our paper presented at this conference [4]. For every energy bin i muons which survive this transportations should be assigned the weight w_i to estimate the contribution of the particular muon multiplicity distribution $f_i(n)$ into the final distribution $F(n)$ for the whole energy

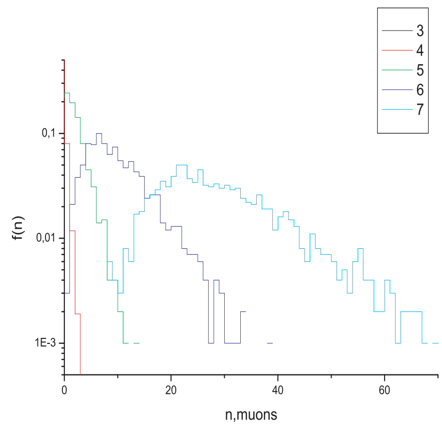

Fig. 2. The muon multiplicity n distribution for the iron nuclei

srectrum:

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

3. Results and discussion

Fig.3 displays the muon multiplicity n distributions for the primary protons (green histogram), the iron nuclei (blue histogram) and for the mass composition of 50% p and 50% Fe. The black histogram and line shows the LVD data [1].

The srtiking feature of the presented distributions is a different slope for the various primary species. To fit the LVD data data one needs to assume the increase of the mean mass from the light nuclei at low multiplicities (and also at low energies) up to very heavy mass (possibly the iron nuclei) at large multiplicities (and at large energies). Of couse, the response of the LVD detector should be taken into account to make the final conclusion. The simplest approach follows. Let us assume the size of a detector to be $a \times b$ and a diametr of a muon group d. Then we can consider the so called main area of $(d+a+d) \times (d+b+d)$. For every muon group the center of gravity can be estimated:

$$x_c = \sum_{i=1}^{n} x_i/n; \quad y_c = \sum_{i=1}^{n} y_i/n, \tag{2}$$

and coordinates $(x_i - x_c)$ and $(y_i - y_c)$ of muons relative to this center may be found. The center gravity should be randomly distributed inside the main area. If coordinates of muons happen to be inside the detector area of $a \times b$ then this case should be accepted. Thus acceptance coefficient c may be calculated:

$$c = k/N, \tag{3}$$

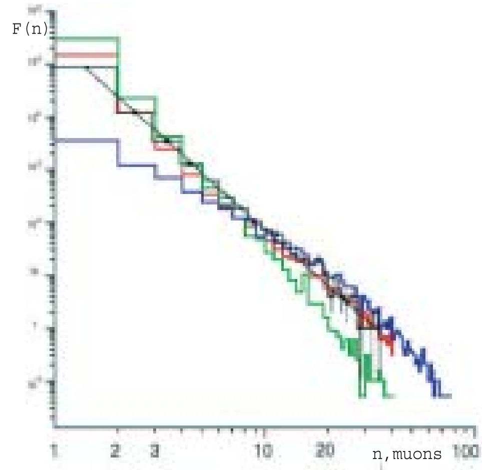

Fig. 3. The muon multiplicity n distribution for the primary protons (green histogram), the iron nuclei (blue), 50% p and 50% Fe (red), data [1] - black.

where k is the number of accepted events and N - the total number generated events. Such trials should be carried out for every muon group with various multiplicities n. It would be more correctly to take into account the real triggers used for the LVD detector. Muon multiplicity distributions estimated with the help of the approach suggested above are also calculated. The main conclusion is an evident change in the mass composition as it was discussed above.

4. Conclusion

Preliminary simulations with help of CORSIKA code display a change in the mass composition in the knee region of the energy spectrum of the primary particles towards very heavy species.

Aknolegement. We thank G.T. Zatsepin for useful discussions. The Russian Fund for fundamental investigations is thanked for support (Grant LSS-1782.2003.2, scientific school of G.T.Zatsepin).

1. Bari G. et al. (LVD collaboration), 1998, Nucl. Justr. and Meth., 277A, 11
2. Heck D. et al. 1998, FZKA 6019 Forschungszentrum, Karlsruhe
3. Kalmykov N.N. et al. 1997, Nucl. Phys. B (Proc. Suppl.) 52B, 17
4. Dedenko L.G. et al. 2003, Proc. of this conference