EAS High Energy Muon Component Around the Knee: Simultaneous Surface and Underground Measurements at Baksan

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Abstract

A complex of installations of the Baksan Neutrino Observatory INR RAS consisting of Baksan Underground Scintillation Telescope (BUST) and shower array "Andyrchy" located above the first measure simultaneously high energy muon ($E_\mu \geq 230$ GeV) and electron-photon components of EAS. Shower size spectrum has been measured in the range $7 \cdot 10^5 - 2 \cdot 10^7$ and the knee is found to be at $N_e = 1.8 \cdot 10^6$. The dependence of the average number of high energy muons in EAS on Ne points out a heavier composition after the knee.

1. Introduction

The break in the shower size spectrum (the so called "knee") at about 10^6 particles was first observed by the MSU group more than 40 years ago [1], but its nature is still a puzzle. The astrophysical interpretation (the steepening of the primary cosmic ray spectrum) seems to be the most natural now. Reasons for such steepening can be found in acceleration processes as well as in propagation processes. For example, there is an energy limitation of the acceleration at the shock front in SNRs. And also, the containment of cosmic rays in the galaxy due to magnetic fields is decreasing with particles energy increasing. These processes lead to a heavier primary composition after the knee. The knee also can be a result of the nuclear fragmentation in the acceleration region. It leads to a lighter composition after the knee. Alternative interpretation could be a change in the hadronic interaction properties.

At present the situation around the knee is a very complicated one. To solve the problem requires accurate measurements of different EAS components in order to verify the main features of the hadronic physics as well as to measure the primary spectrum and composition variations with energy.

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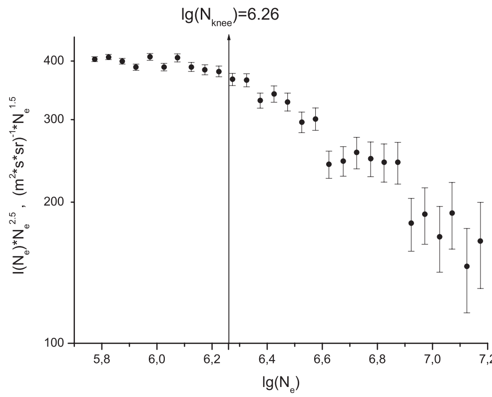

Fig. 1. Differential EAS size spectrum. The arrow indicates the knee position.

2. Apparatus

"Andyrchy" EAS array [2-4] is located on the slope of the mountain Andyrchy above BUST and consists of 37 plastic scintillation detectors of 1 m^2 each with the thickness of scintillator of 5 cm. The distance between the detectors is about 40 m in projection to the horizontal plane, and the overall area of the installation is $4.5 \cdot 10^4$ m^2. The central detector of the installation is just above the BUST at a distance of about 360 m and it is 2060 m above the sea level. The threshold of an individual detector is 5 MeV. Maximum energy release in the detector is about 10 GeV. The shower trigger condition of the installation requires four detectors to fire within 3 microseconds. Trigger's rate is about 9 s^{-1}.

BUST [5] is situated in an excavation at the effective depth 850 gg/sm^2. It is a four-flour building with $(16m \times 16m \times 11m)$ dimensions. 3150 liquid scintillator detectors cover entirely all four horizontal and four vertical layers of the installation. Each of the detectors has dimensions $0.7m \times 0.7m \times 0.3m$. The construction of the telescope allows to determine the number of the passing muons (1-200), their coordinates (with 0.7 m accuracy) and the direction of their arrival (with 1.5 degree accuracy). Coincidence trigger rate of BUST and "Andyrchy" is about 0.1 sec^{-1}. The threshold energy for muons for the directions considered in this work is 230 GeV.

3. The EAS Size Spectrum

The EAS parameters (shower core position, the slope of the lateral distribution function and shower size N_e) were determined in the standart way by a maximum likelihood method. In the following analysis we used EAS with the axis in the central part of the installation (at a distance not more than 50 m from the center) and with lg(N_e) in the range 5.75 - 7.2 (accuracy of reconstruction

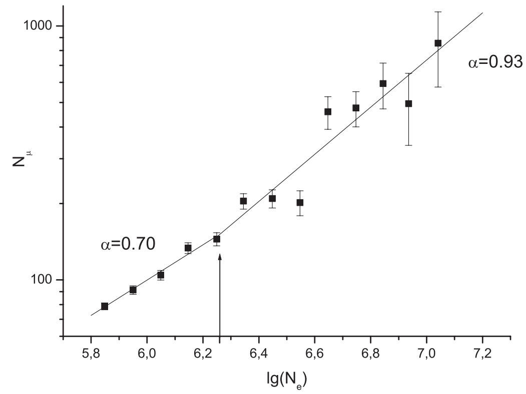

Fig. 2. Dependence of the mean number of EAS muons on N_e. The arrow indicates the knee position.

N_e is better than 12%) . Differential EAS size spectrum for the near vertical events ($\theta \leq 10°$, the mean atmospheric depth 805 g/sm^2) during the pure time of collection $9.3 \cdot 10^7$ s (1076.4 days) is given in Fig. 1. The knee in the spectrum is at $\lg(N_e) = 6.26$. The power law spectrum has exponents before and after the knee 2.56 ± 0.02 and 2.92 ± 0.04, respectively.

4. The $\overline{N}_\mu(N_e)$ dependence

As the underground telescope measures a part of the full number of muons in EAS, it is possible for our experiment to determine only the mean value of muons $\overline{N}_\mu$ for all the showers with given N_e. This method of $\overline{N}_\mu(N_e)$ determination is described in detail in [4,7]. The dependence $\overline{N}_\mu(N_e)$ obtained during the pure time $7 \cdot 10^7$ s (810.2 days) is in Fig.2. The points are experimental data (statistical errors are indicated), solid lines are fits of power law function $\overline{N}_\mu(N_e) \sim {N_e}^\alpha$ before and after the knee in the size spectrum. Power law indices are α=0.70 $\pm$ 0.06 and α=0.93 $\pm$ 0.09 before and after the knee, respectively.

5. Results

To compare the experimental data with the expected ones for different compositions of primary cosmic rays it is necessary to perform a transition from a primary energy E_0 and atomic number A to the mean values N_μ and N_e. The dependence of mean value of the number of charged particles in EAS on E_0 and A was obtained for the EAS-TOP [7] located almost at the same atmospheric depth (810 g/cm^2). The dependence of the mean value of high energy muons on E_0 and A was taken from [8]. The results of calculations for the three compositions of primary cosmic rays (primary protons, primary Fe nuclei and the Baksan composition [9]) are presented in Fig. 3 in comparison with the experimental

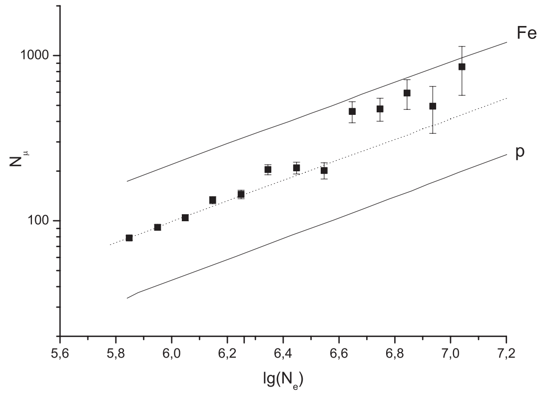

Fig. 3. Comparison of the experimental data with the calculated ones. The upper and the lower solid lines are primary protons and Fe nuclei, respectively. The dashed line shows the Baksan composition [10].

data.

In the approach used above the change in dependence of muon number on total number of particles could be interpreted as a composition of the primary cosmic radiation in the region after the knee becoming heavier.

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7. References

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