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Measurement of the EAS muon characteristics in the knee region on the mountain level

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Abstract

The EAS muon component is studied in the energy range of 10^5 – 10^7 GeV with the GAMMA installation (Mt. Aragats, Armenia). Using the muon detector setup ($150 m^2$ effective area), the muon lateral distributions function and muon number dependence on shower size are obtained. The results are compared with the CORSIKA simulations and Tien-Shan experimental data.

1 Introduction:

One of the main goals of the GAMMA experiment is the study of the nature of the knee on the shower size spectrum. The most popular explanation of this knee is the existence of the knee in the primary cosmic ray energy spectrum at energy about $3*10^6$ GeV and change of the mass composition. At the same time, an alternative explanation could be some modifications of the EAS development in the upper part of the Earth atmosphere. The knee, first observed by the Moscow University group, (Kulikov and Khristiansen, 1959), continues to be the subject of the intensive studies.

In the energy range 10^5 – 10^7 GeV, one of the methods to determine the primary mass composition and strong interaction properties is the simultaneous analyses of the different EAS component characteristics. The GAMMA installation place on hillside of the Mt. Aragats in Armenia (3200 m a.s.l.) has been built for such a purpose. The description of this installation and its first results can be found in (Arzumanian *et al.*, 1995 and Chilingarian *et al.*, 1997).

Recently some essential changes were made in the method of the data treatment. It was mostly connected with the correct transfer from the scintillation detector response to the electron number. Of course, this has influenced measurements of the EAS electromagnetic and muon component characteristics. In the present work, the results of the EAS muon component study based on the analyses of ~ 10^5 showers with $N_e>10^5$, at the zenith angle $\theta \leq 30^0$, are presented.

2 Experimental Data:

The layout of the muon underground detector setup (150 m^2 effective area) is shown on figure 1. It has to be noted that the muon detectors are divided into 2 groups placed under different absorber thickness. It allows to study EAS muons with 2 different energy thresholds: $E_\mu>5$ GeV (Hall) and $E_\mu>2.5$ GeV (Tunnel). The disposition of muon detectors allows to determinate the lateral distribution up to 60 meters at $E_\mu>5$ GeV and up to 90 meters at $E_\mu>2.5$ GeV. These distributions for three shower sizes are shown in figure 2 (a, b). Figure 2a shows that, inside the experimental uncertainties, there is no essential difference in the shapes of the muon lateral distributions for the both muon energy thresholds. So, we can use the density correction

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factor $\rho_\mu(>2.5\ \mathrm{GeV})/\ \rho_\mu(>5\ \mathrm{GeV})=1.3$ to transfer density at $E_\mu>2.5$ GeV to density at $E_\mu>5$ GeV. Then, the muon flux lateral distribution with $E_\mu>5$ GeV in the full interval $6\mathrm{m}\leq r\leq 90\mathrm{m}$ can be obtained. It has to be noticed that data for small distances, (< 6m), are not taken into account because of the strong influence of the "punchthrough" particles. On figure 2(b), the lines are the Tien-Shan approximation for $E_\mu>5$GeV (Aseikin *et al.*, 1979) obtained by Stamenov:

$$\rho_\mu(r, N_e) = 0.95\ (N_e/10^5)^{0.8}\ r^{-0.75}\ \exp(-r/80) \qquad (1)$$

This approximation well describes experimental data up to $N_e \sim 5*10^6$. For larger sizes an agreement is worse.

Extrapolating ρ_μ till infinity, the total number of muons, N_μ, was obtained. For zenith angles $\theta\leq 30^0$, the dependence of N_μ versus the shower size, N_e is shown in figure 3. As usual, there is some uncertainty of the total muon number estimation because of the limited range of *r* in the complex array. This is depending on the type of approximation used for large distances. For example, the following to well known muon lateral distribution approximation proposed by Greisen (Greisen, 1956) describes correctly our experimental data.

$$\rho_\mu^{Gr}(r, N_e) = A\ N_e^{0.8}\ r^{-0.75}\ (1+r/180)^{-2.5} \qquad (2)$$

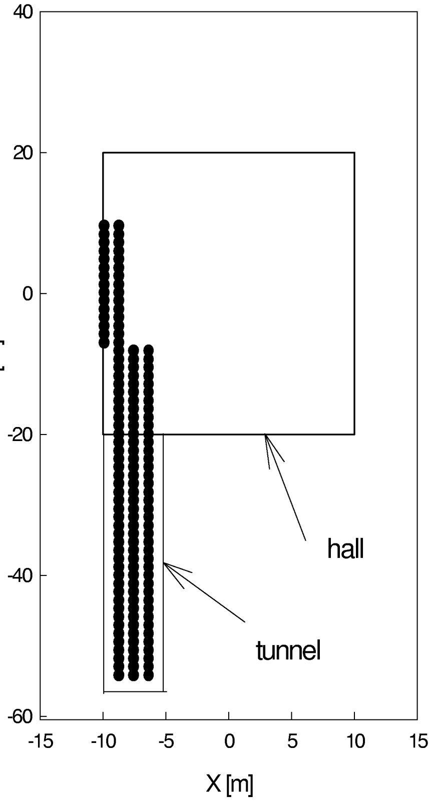

Figure 1: The layout of the muon underground detector

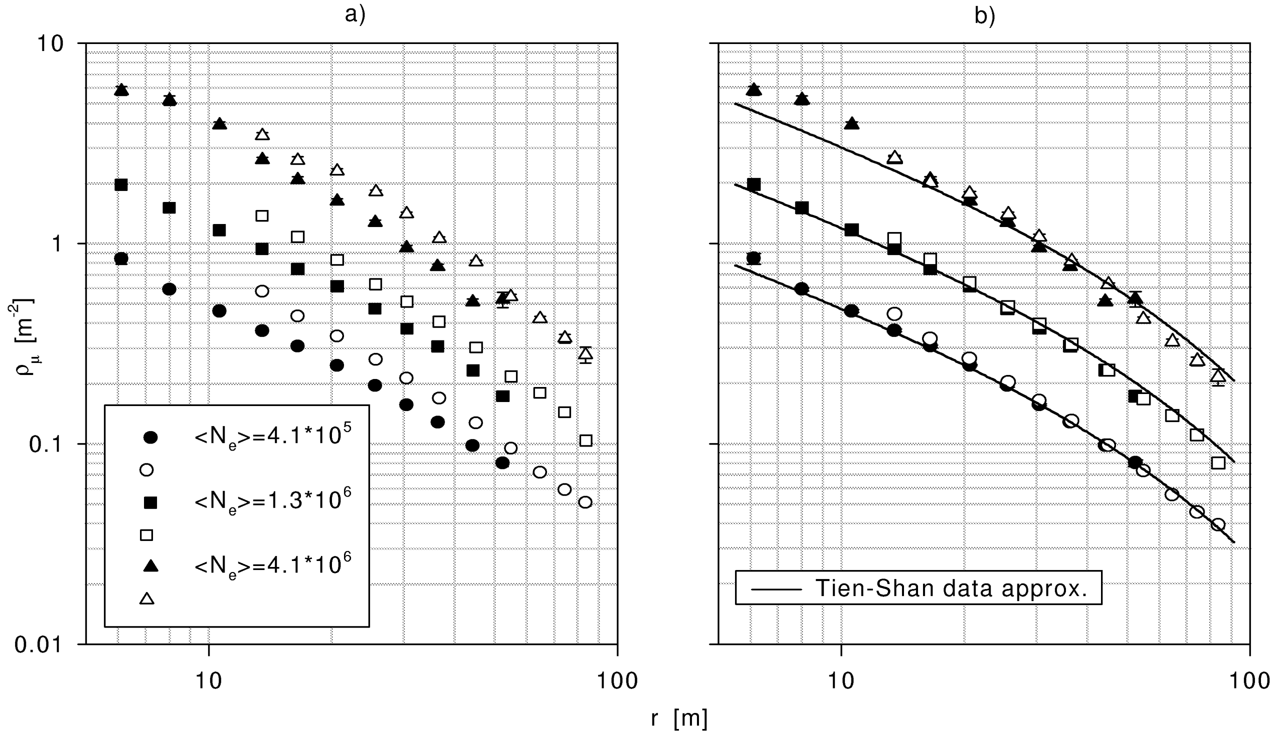

Figure 2: Muon lateral distribution: full points - $E_\mu>5$GeV, open points - $E_\mu>2.5$GeV.

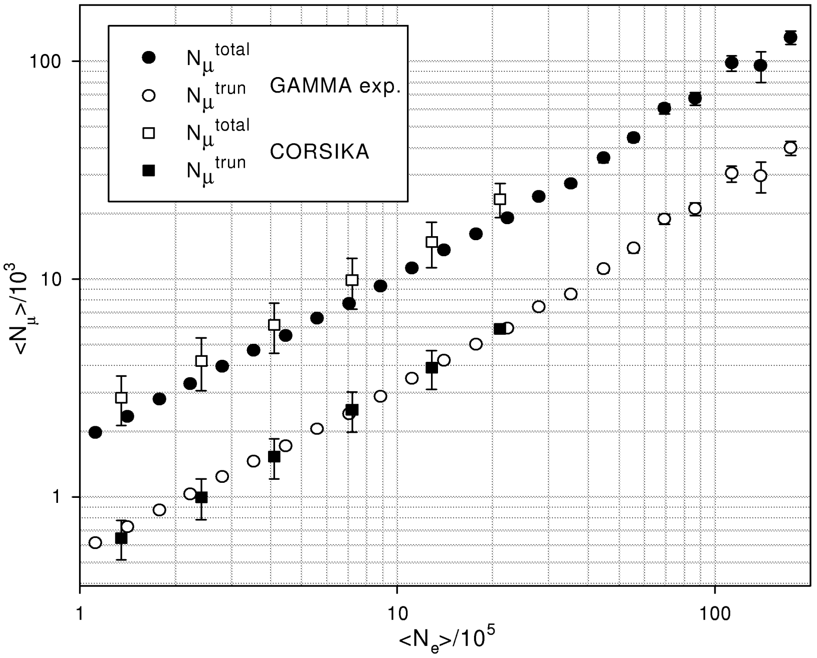

Figure 3: The dependence total and truncated muon numbers, N_μ^{tot} and N_μ^{tr} on shower size N_e.

However, these two formulas give different total muon numbers due to their divergence at distances *r*>90m:

$$N_\mu(\text{Greizen})/ N_\mu(\text{Stamenov}) \approx 1.8.$$

To avoid this problem, we have estimated the truncated muon number N_μ^{trun} for E_μ>5GeV in the limited distance interval (8-52)m. Figure 3 presents N_μ^{trun} dependence on the shower size. N_e To compare the present experimental data with model predictions, the CORSIKA code (Capdevielle *et al.*, 1992) has been used. Let us notice that CORSIKA has been used in version 4.50 including Venus mode for the hadronic cascades. Results from simulation are obtained for the normal mixed mass composition : proton : 40%, α-nuclei : 21%, light-nuclei (<A>=14): 14%, medium-nuclei (<A>=26):13% and heavy-nuclei

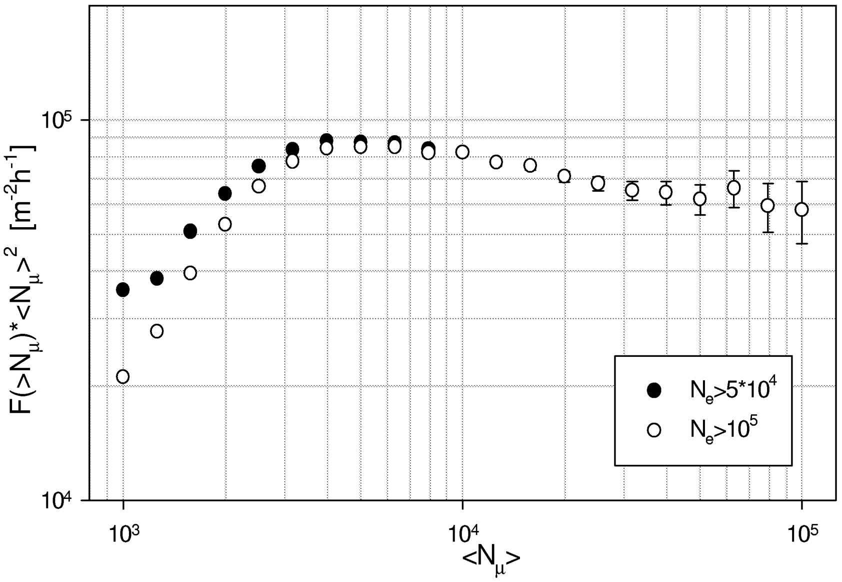

Figure 4: The integral muon size spectra

(<A>=56):12%. In figure 3, it is seen that the experimental results are in a good agreement with the correspondent CORSIKA simulation data.

At relatively small N_μ the spectrum is exposed to influence of the threshold effect caused by our limit $N_e>10^5$. The part of these showers produced mostly by heavy primaries, has $N_e<10^5$ and thus is discriminated. To clear up the undistorted spectrum range we compare two spectra obtained at different limits on N_e – $5{\cdot}10^4$ and 10^5 (fig. 4). These spectra coincide with accuracy better 4% at $N_\mu>10^3$. The muon size spectrum is not distorted at $N_\mu>4{\cdot}10^3$. The spectrum above $N_\mu>7{\cdot}10^3$ is well described by the power dependence $F(>N_\mu) \sim N_\mu^{-2.18}$. So, it is not possible yet to conclude about the knee of the integral muon size spectrum.

3 Conclusions:

The experimental EAS muon characteristics obtained by the GAMMA installation with a revised treatment method are in a good agreement with the Tien-Shan data and CORSIKA simulations. The data with $N_\mu>4{\cdot}10^3$ will be used**,** in the nearest future, for an unbiased determination of the mass composition.

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