A new possibility to determine the mass composition around the knee with EAS observed in altitude (700 g.cm^{-2})

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Abstract

Showers registered at 700 g.cm^{-2} of the atmospheric depth are simulated using the CORSIKA code. After selection of showers generated by primaries with different masses but with the same primary energy we analyse the fluctuations of a new parameter to obtain an unbiased estimation of the mass composition of the primary radiation around the knee. This parameter for determination of the mass composition will be used at the GAMMA array, (Armenia, 3200m a.s.l.).

1. Introduction

The origin of the 'knee' in the energy spectrum of the primary cosmic rays is still open to discussion and the most valuable information for the solution of this problem could be extracted from the knowledge of the mass composition in the 'knee' region. The access to this information can only be obtained by indirect methods based on the study of different Extensive Air Shower (EAS) characteristics. Let us note that up to now such analysis gave quite controversial results. Two main reasons for this cacophony are the following: on the one hand these showers were not selected with respect to the primary energy. On the other hand, the shower characteristics are often imprecisely measured or not sensitive enough for determination of the primary particle mass. In the present work, we propose a new method for the primary mass determination available at mountain altitude using EAS directly selected with respect to their energy and defining a new parameter strongly correlated to the mass of the primary particles. All simulated showers are incident at zenith angle $\theta \leq 30^0$ and observed at the depth 700 g.cm^{-2}. Simulations have been performed using the CORSIKA code version 5.20 with the QGSjet model of hadronic interactions, [1], and with so-called 'normal mixed composition', [2]: p: 40%, α: 21%, medium nuclei (<M>=14): 14%, heavy nuclei (<M>=26): 13%, very heavy nuclei (<M>=56): 12%.

pp. 231–234

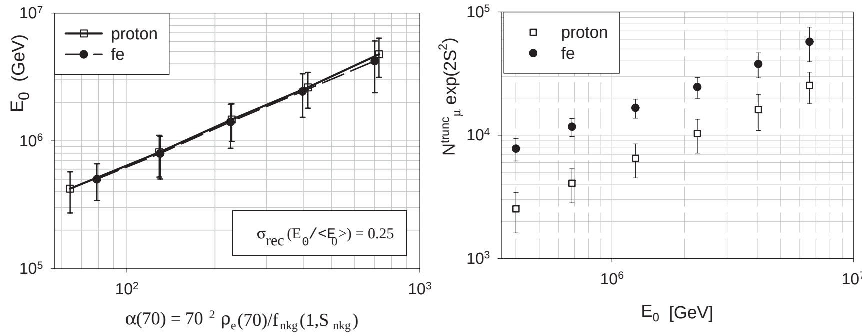

Fig. 1. a) Primary energies of proton and iron nuclei simulated EAS selected with given values of the parameter $\alpha_e(70)$. Errors are the standard deviations.
b) $N_\mu^{trunc} exp(2S^2_{NKG})$ versus the primary energy in simulated proton and iron showers selected with fixed primary energies. Errors are standard deviations.
Showers are vertical, $(\theta \leq 30^o)$ and registered at depth 700 g.cm^{-2}

2. Method of shower selection

In previous works we have defined a new method to select showers generated by primaries with different masses but with the same energy, which was applied to the GAMMA array at Mt. Aragats for determination of the primary energy spectrum (see for example Garyaka *et al.*, [3]). The selection parameter $\alpha_e(70)$ is, [3]: $\alpha_e(70) = 70^2 \rho_e(70)/f_{NKG}(1, S_{NKG})$
where: - $\rho_e(70)$ is the density of charged particles at 70 m from the shower axis, - f_{NKG} and S_{NKG} are the well-known Nishimura-Kamata-Greisen function and age parameter, respectively, [4]. Furthermore, we have taken into consideration the uncertainties caused by the specific conditions of the GAMMA experiment as $\sigma_{rec}(E_0)/ < E_0 >= 0.25$, [3]. The correlation between the proposed selection parameter, $\alpha_e(70)$, and primary energies is shown in figure 1a for simulated showers generated by protons and iron nuclei. The EAS muon component is more sensitive to the mass of the primary particles than the electromagnetic one. To optimise the shower selection with respect to the primary mass we combine S_{NKG} and N_μ^{trunc} to define the parameter $\chi = N_\mu^{trunc} exp(2S^2_{NKG})$, where N_μ^{trunc} is the number of muons between 8 and 52 meters from the shower axes. The sensitivity of this new parameter to the primary mass is shown in figure 1b for simulated showers. It can be seen in this figure that fluctuations of the parameter χ for EAS generated by primary protons or iron nuclei with fixed primary energies are without any overlap at the 4σ level.

In order to obtain not only the dependence of $\chi = N_\mu^{trunc} exp(2S^2_{NKG})$ on

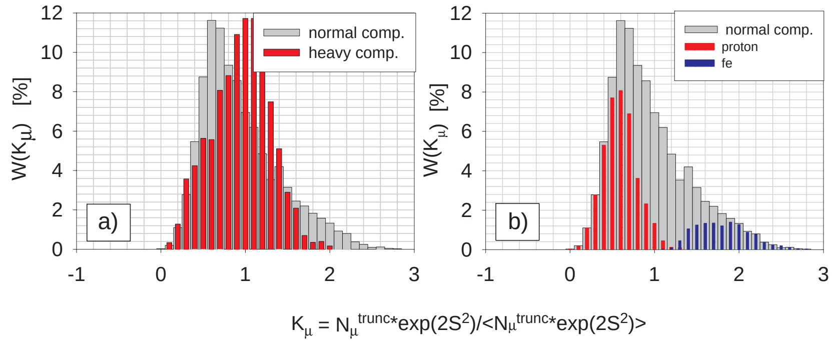

Fig. 2. Fluctuations of $K = \chi / < \chi >$ in showers with energy 6.86 10^5 GeV
a) for normal and heavy primary compositions.
b)in proton and iron showers for the normal compositions.

the primary masses but also to estimate the influence of the specificity of the primary composition we determined the fluctuations $W(K)$ of the relative value of this parameter, i.e.: $K = \chi / < \chi >$, for two different mass compositions, the normal one as defined previously and a heavy one, [5], defined as p: 16%, α: 8%, light nuclei (<M>=14): 10%, medium nuclei (<M>=26): 27%, heavy nuclei (<M>=52): 39%. Figure 2a shows clearly the influence of the light and heavy components in each composition. These histograms are for showers with the given primary energy E_0=6.86 10^5 GeV. In figure 2b quite separate contributions of proton and iron showers in the shape of $W(K)$ for the normal mixed composition are shown. This effect is used for the primary mass determination.

3. Determination of the primary mass composition around the knee

The aim of the present work is to show the possibility of determining the mass composition in the primary energy range [10^6-10^7] GeV using the characteristic parameter $\chi = N_\mu^{trunc} exp(2S_{NKG}^2)$. The first step is to obtain the experimental fluctuations of the parameter $K = \chi / < \chi >$ for showers registered at the GAMMA array and generated by primaries with fixed energy, (same value of the $\alpha_e(70)$ as shown above). This work is currently in progress. The second step is to simulate showers generated by primaries with masses belonging to the five classes already defined in this work. To demonstrate the feasibility of our method we constructed, using simulated data, the pseudo-experimental K fluctuations for a given primary energy for the normal and the heavy compositions, respectively. Our results are shown in table 1.

Table 1. : Determination of the mass composition of the primary radiation at energy 6.86 10^5 GeV. Two pseudo-experimental distributions are considered. In each case, our determination and corresponding errors are given inside brackets

	p	α	$M[14]$	$H[26]$	$VH[14]$
Composition					
Normal [2]	40%	21%	14%	13%	12%
answer	(40±2%)	(21±4%)	(14±3%)	(13±3%)	(12±3%)
Heavy [6]	16%	8%	10%	27%	39%
answer	(15±3%)	(7±3%)	(11±3%)	(29±5%)	(39±2%)

4. Conclusion

The aim of the present work is to show the possibility of obtaining an unbiased determination of the primary mass composition using EAS measurements at mountain altitudes, (GAMMA array, Armenia, 700 g.cm^{-2}), with the following procedure:
- selecting the vertical showers with specific values of one well-defined parameter $\alpha_e(70)$. Fixed values of $\alpha_e(70)$ are equivalent to fixed primary energies E_0, [3],
- simulating the fluctuations of $K = N_\mu^{trunc} exp(2S_{NKG}^2)/ < N_\mu^{trunc} exp(2S_{NKG}^2) >$, $W^{sim}(K)$, for primaries with different masses and the same energy E_0,
- determining the percentages of the primaries with different masses by minimization, fitting the best $W^{sim}(K)$ with the corresponding experimental distribution, $W^{exp}(K)$. This method is being applied to data of the GAMMA experiment, which is currently in progress.

5. References

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