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New way for determination of the primary cosmic ray energy spectrum around the knee with the GAMMA array at Mt Aragats

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Abstract. Experimental data on EAS characteristics with $N_e \geq 10^5$ are used to calculate the value of so-called α parameter which is directly connected with the primary energy. It is shown that the distribution of showers selected by constant value of this parameter is isotropic and the measurement of the α spectrum is a direct way to obtain the primary energy spectrum. The obtained energy spectrum is compared with data from other experiments.

1 Introduction

Since the knee in the extensive air shower size spectrum was discovered, (G.V. Kulikov, 1958), the problem of the astrophysical origin of this phenomena is with us, with many conjectures, but not definitively explained due to insufficiency of experimental data. The importance of cosmic ray investigations around the knee was emphasized again at the recent meeting of cosmic ray physicists in Bolivia, (L.W. Jones, 2000). All models and conjectures towards an explanation do not only predict the shape of the spectrum and the position of the knee e.g., they imply also specific variations of the elemental composition of the primary cosmic rays. Thus the energy spectrum and mass composition of very high-energy cosmic rays are issues of utmost importance and actual interest. The investigation of detailed spectral shape and, in particular, of a conjectured variation of the mass composition of the knee region, are the objectives of a number of contemporary large-scale experiments, (M. Amenori, 1996; J.W. Fowler, 2001; G. Navarra, 1998; D.B. Kieda, 1999; K.H. Kampert, 1999). However, the results are still confusing and conflicting, since the characteristic difficulties of EAS observations have not been adequately accounted for. Some limitations and uncertainties originate from the increase of fluctuations in the shower development deeper in the atmosphere, in addition to insufficient experimental sampling of the lateral EAS extension. The GAMMA array located on 3250m a.s.l. (700 g/cm^2), also studies the energy region around the knee. Consisting of surface and underground scintillation detectors, the GAMMA array is able to measure electromagnetic and muon components of cosmic ray air showers. The investigation of the characteristics of these two components, expressed by a number of EAS observables, provides a basis for multi-parameter analyses. Such analyses more or less rely on the comparison of the experimental findings with results from Monte-Carlo simulations of the EAS development.

The phenomenological characteristics of the electron and muon components of EAS within the range $10^5 \leq N_e \leq 10^7$ obtained from GAMMA installation were presented in (V.S. Eganov et al., 2000). Now we present the energy spectra of primary cosmic radiation derived on the base of experimental data and supposition of the absence of the sharp change in the strong interaction picture.

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2 Parameter $\alpha(70)$ as the primary energy the estimator

There are many various approaches and methods for the estimation of primary particle energy generating EAS. In basic they depend on the construction of the experimental installation, used detectors and also the depth of the atmosphere on which the installation is located. An another method of energy estimation for experimental installations located at mountain altitudes was suggested, (J. Procureur, 1995). In further, this method was specially adapted for GAMMA array in view of all its features, (R.M. Martirosov, 1995).

The basic parameter used for the primary particle energy estimation is the so-called α-parameter determined by the formula:
$\alpha(70) = \rho_e(70)70^2/f_{NKG}(1, S)$
where $\rho_e(70)$ is the electron density on distance 70m from the shower axis;
$f_{NKG}(1, S)$ is the value of the NKG function at r=1m with given value of the age parameter S.

In figure 1, the simulated data of estimated energy dependence on $\alpha(70)$ are presented for the primary proton and iron nuclei. As this figure shows, this method allows a selection of showers generated by the primary particles with the same energy independently on primary mass. It is necessary to notice that the showers were simulated in the zenith angular interval $\theta \in [0, 30]^0$. The following dependence is obtained $:< E_0 >=$ K $\alpha(70)$, where K=5.18 10^3. Detailed description of this method as well as some simulation and experimental results are given in (V.S. Eganov , 2001).

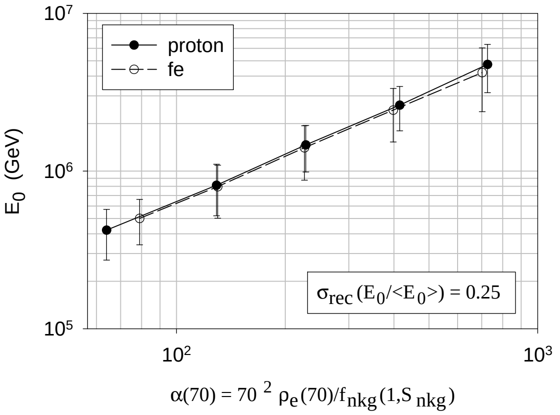

Fig. 1. The primary energy versus the $\alpha(70)$ parameter for proton and iron showers

3 Properties of EAS selected at given parameter $\alpha(70)$

If $\alpha(70)$ allows to pick up EAS with given primary energy E_0, such selected showers must be uniformly distributed into the used angular interval. This is a necessary requirement to any primary energy estimator and it would be interesting to test various energy estimators by this way. On this point,we would like to underline that showers selected by constant size N_e have no uniformly angular distribution and have steep angular dependence.

Figure 2 presents the experimental angular distributions of showers selected at given values of $\alpha(70)$, shower size N_e and number of muons Nμ. It can be seen that up to θ=30^0 the distribution of the showers selected by $\alpha(70) \geq$700 and $\alpha(70) \geq$1000 is close to be isotropic in contrast to distributions of showers selected at given values of shower size N_e or number of muons N_μ. This is the proof that the showers selected by fixed parameter $\alpha(70)$ have the same energy independently of mass of primary particles.

4 Primary energy spectra

The primary energy E_0 is obtained using the experimental values of $\alpha_{exp}(70)$ and coefficient K=5.18 10^3 derived from

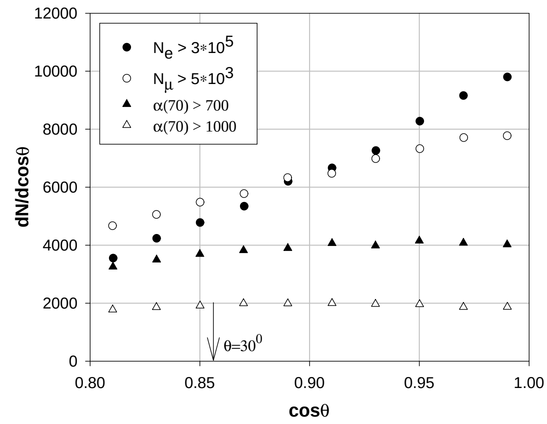

Fig. 2. Experimental angular distributions of N_e and N_μ for showers selected at given values of $\alpha(70)$

the data of figure 1. The errors of E_0 are the sum of errors of the method itself and of the experimental errors on the $\rho_e(70)$ and S determinations. The correctness of E_0 strongly depends on $\sigma(S)/S$, which decreases with N_e. The accuracy of the E_0 is $\sim$25% around the knee. Figure 3 presents primary energy spectra obtained with GAMMA array in comparison with schematic approximations of results from some other experiments. Before the knee our spectrum is steeper then others and its slope is in agreement with the most of them after with γ=3.2$\pm$0.1. It can be seen that our spectrum after the knee is very close to the data of the KASCADE experiment.

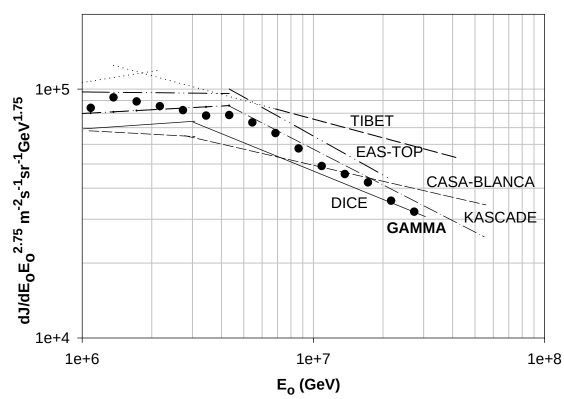

Fig. 3. Primary energy spectrum

5 Conclusion

In this way using the GAMMA array experimental data we have shown the applicability of a new primary energy estimator $\alpha(70)$ for the determination of the primary energy spectrum in the range 10^{15}-3 10^{16} eV. Obtained by this manner, the primary energy spectrum doesn't contradict results from other experiments.

The showers selected by $\alpha(70)$ criterion have isotropic angular distribution. The presented energy spectrum is the spectrum of all kind of primary particles (nucleus) and obtained without any hypothesis about the primary mass composition, but on the assumption of deficiency of the strong hadron-nuclei interaction sharp changes. As a next step we plan to estimate mass composition of the primary cosmic radiation in this energy region using the multi-parameter analysis of EAS components.

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