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Comparison between experimental and simulated data for the GAMMA experiment, (Armenia)

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Abstract. The phenomenological experimantal characteristics of the EAS electron component with sizes 3 $10^5 \leq N_e \leq 10^7$ at the observation level 700 $g.cm^{-2}$ are obtained with the help of the GAMMA array at the Mt. Aragats in Armenia. These results are in a agreement with the carried out simulation data using the CORSIKA code.

On the other hand, a new method to select showers generated by primaries with different masses having the same primary energy is proposed and applied with good agreement between experimental and simulated results.

1 Introduction

Some basic questions of the cosmic radiation are in lack of distinct answer. One of them is the reason of the change of the primary energy spectrum structure around 3 10^6 GeV (*knee*) and, as a possible consequence, the determination of the mass composition in this energy range. At present the analysis of the experimental data for an unbiased determination of the primary radiation for given energies is not ready yet. Indeed, as usual showers are classified due to some fixed parameters (e.g. the shower size). It is obvious that such showers are generated by primaries with different masses as well with different energies. Thus the obtained mass composition is only the *observed* composition (for the given sizes) and not the *exact* determination, (Chatelet et al., 1991). That is why it is necessary to suggest a new method able to select showers generated by primaries with different masses having the same energy. Such kind of work was done by one of the co-authors for mountain altitude (Procureur et al., 1995) and especially adapted to the altitude of the GAMMA array (Aghadjanian et al., 1987). In this work we present the comparison of the EAS charge and muon component characteristics, observed by the GAMMA experiment, with corresponding results obtained from simulation using the CORSIKA code version 5.20, QGSJET model (Heck et al., 1998). In order to compare the simulation data with experimental results the normal mixed composition was used, i.e. proton: 40%, α: 21%, light-nuclei ($<A>$=14): 14%, medium-nuclei ($<A>$=26): 13% and heavy-nuclei ($<A>$=56): 12%.

2 Present status of the GAMMA EAS array

The GAMMA array (Aghadjanian et al., 1987) was proposed and realized as a part of the ANI project (Danilova et al., 1983) in attempt to continue the experimental studies of the phenomenological EAS characteristics. The existence of large effective area of the muon detectors (150m^2) lets to determine the mass composition around the *knee* and select the muon poor EAS events initiated by primary gamma-quanta with energies $10^2 - 10^4$ TeV (Martirosov et al., 1995) . The altitude of the array is 3200m a.s.l., detector energy threshold for charged EAS particles is 9.5 MeV. The muon detectors are placed in the hall and in the tunnel of the GAMMA array underground part with threshold 2.5 and 5 GeV respectively. After some years spent to enlarge the effective area of the muon detectors, to elaborate methodical studies of the detector parameters, to investigate detector response properly as well the expected precision of the shower parameter estimations, the GAMMA experiment is now effectively running with sufficient statistic.

The detailed description of the GAMMA array and the results of the electromagnetic and muon EAS components can be found in ref. (Eganov et al., 2000).

3 Selection of showers with given energy

As we noticed in the introduction, it is important to avoid systematic biases to be able to pick up EAS generated by primaries with different masses and with the same energy. With the aim of this, we suggested (Procureur et al., 1995) to select showers with constant values of parameter $\alpha_e\,(70) =$

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$70^2\frac{\rho_e(70)}{f_{nkg}(10,S_{5-70})}$, were $\rho_e(70)$ is the density of charged particles measured at 70m from the shower axis, f_{nkg} is the well known Nishimura-Kamata-Greisen function (Cocconi et al., 1961) and S_{5-70} is the local age measured at 5 - 70m from the shower axis. In fact this result was modified comparing its stability at different simulation codes (Brankova et al., 1998). It has been shown that the definition of α_e parameter slightly depends on the models and the chosen CORSIKA code (Heck et al., 1998). The selection parameter was redefined as $\alpha_e(135) = 135^2\frac{\rho_e(135)}{f_{nkg}(3,S_{25-135})}$. However, it is important to note that this definition was obtained taking into account the simulated data only. When it was applied to the shower selection using GAMMA experimental data, there appeared two difficulties . The first one is the large fluctuations of densities of the charged particles measured at 135m from the shower axis. Indeed, in spite of the existence of enough large effective detector area (20m^2) this distance from the shower axis involves bad accuracy of the $\alpha_e(135)$ measurement. Another source of uncertainty was observed for the local age measurement S_{25-135}, which was defined using densities measured at 25 - 135m from the shower axis. Weak error in determination of the shower axis location is inducing an additional error in the measurement of S_{25-135} and, consequently, in the α_e evaluation. That is why, it was decided to include the well known and easily measurable S_{nkg} in the definition of α_e. Indeed, S_{nkg} is obtained fitting the charge particle densities for different distances from the shower axis and can be defined with rather proper precision for all individual showers. In this case the α_e parameter was defined as: $\alpha_e(70) = 70^2\frac{\rho_e(70)}{f_{nkg}(1,Snkg)}$. The dependence of the primary energy versus $\alpha_e(70)$ using S_{nkg} is shown in figure 1. It can be seen that showers with same values of $\alpha_e(70)$ are in the meantime with the same energy irrespective of the primary mass. In this and the following figures the reception condition of the array such as $\sigma_{rec}(K_\alpha) = 0.25$ with $K_{\alpha_e} = \frac{\alpha_e(70)}{<\alpha_e(70)>}$ and $\sigma_{total}(K_{\alpha_e}) = \sqrt{\sigma^2(K_{\alpha_e}) + \sigma^2_{rec}(K_{\alpha_e})}$ was taken into account. In order to verify the consistency of showers selected with fixed values of $\alpha_e(70)$ and showers simulated with fixed primary energies, we have drawn $N_e = f(E_0)$ and $N_e = f(\alpha_e(70))$ in the same graph (figure 2). These results are given for the normal primary mass composition defined in the introduction. The identity of these dependences is very good and standard deviations are quite reasonable.

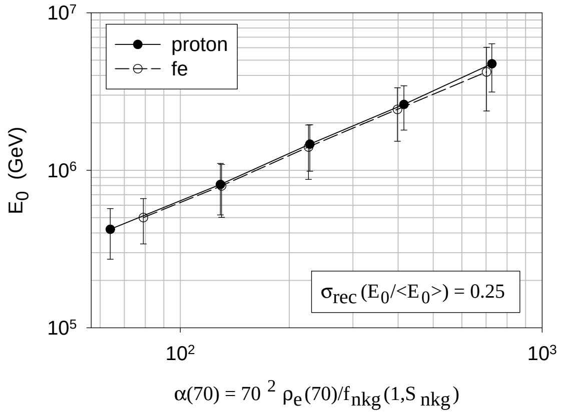

Fig. 1. The primary energy versus the $\alpha(70)$ parameter for proton and iron showers

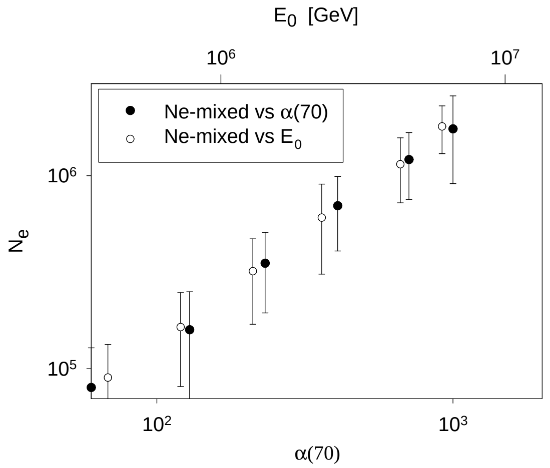

Fig. 2. The shower size, N_e, versus the primary energy, E_0, and the $\alpha(70)$ parameter for the normal mixed composition

4 Results

4.1 Selection of showers with the fixed size

Taking into account the experimental conditions, the size threshold was taken as 3 10^5 particles. Figure 3 shows the dependence of the age parameter, S_{nkg} versus the shower size. S$_{nkg}$ has been determined fitting the lateral distribution of charged particles by the Nishimura-Kamata-Greisen formula between 10 and 120m from the shower axis. Open and full dots are respectively experimental and simulated data respectively. The number of muons observed by the GAMMA experiment is the truncated number N_μ^{trunc}, i.e. the muons with energies larger than 5 GeV detected between 8 and 53m from the shower axis. Figure 4 shows the size dependence of N_μ^{trunc} for experimental (full dotted) and simulated (open dotted) data. For these two curves one can see good agreement between experimental and simulated data. As it was noted in the previous section, we claim that it is possible to define new parameter $\alpha_e(70)$ to select the showers generated by primaries with different masses having the same energy. The dependence of $\alpha_e(70)$ versus the measured sizes is shown in figure 5. In this figure full points are simulated data and open points are experimental data measured by the

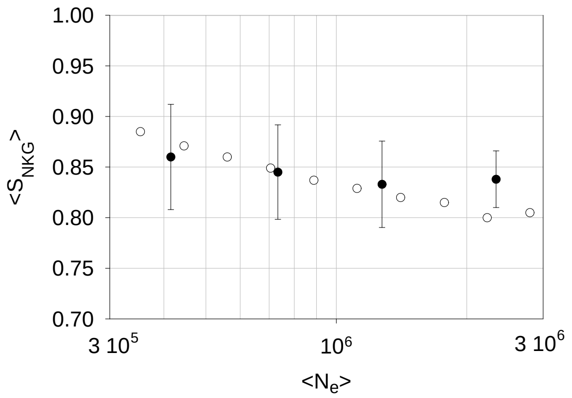

Fig. 3. Comparison of the experimental, (open points), and simulated, (full points), age parameters for showers with fixed sizes

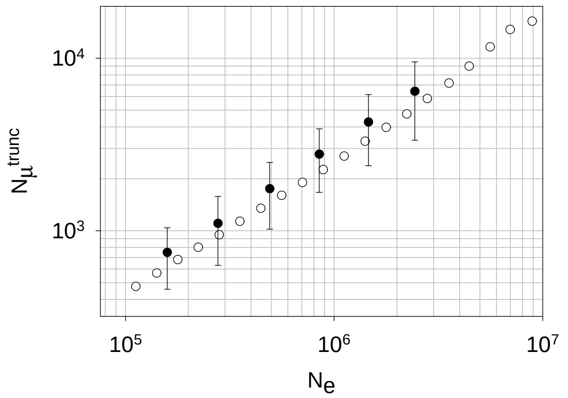

Fig. 4. Comparison of the experimental, (open points), and simulated, (full points), truncated muon numbers for showers with fixed sizes

GAMMA array. Good agreement between experimental and simulated values is again observed.

4.2 Selection of showers with the fixed $\alpha_e(70)$

In many applications it is necessary to define EAS characteristics for given primary energies. Up to now such parameters were often defined for fixed sizes and determined for fixed energies using the poor studied correlation ”$size \longleftrightarrow energy$”. One of the natural ways to obtain information for given energy is the selection of showers with the same values of the $\alpha_e\,(70)$ parameter. In figure 6 we have drown the dependence of the shower size versus $\alpha_e\,(70)$. Using normal mixed composition simulated data are obtained. Taking into account that the experimental values of $\alpha_e\,(70)$ are not observed directly but they are obtained from the measurement of the lateral density of charges particles at 70m from the shower axis $\rho_e\,(70)$ and from the Nishimura-Kamata-Greisen age S_{nkg}, the agreement between experimental and simulated values is quite reasonable.

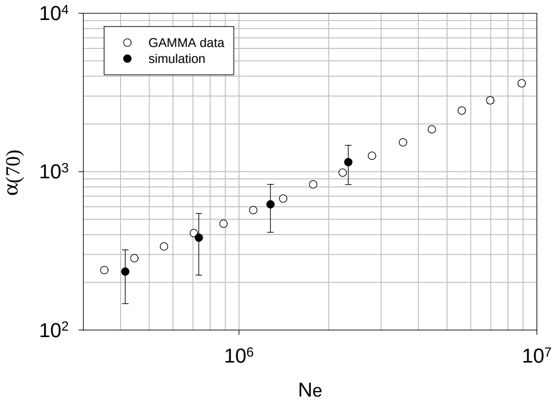

Fig. 5. Comparison of the experimental, (open points), and simulated, (full points), $\alpha_e(70)$ parameters for showers with fixed sizes

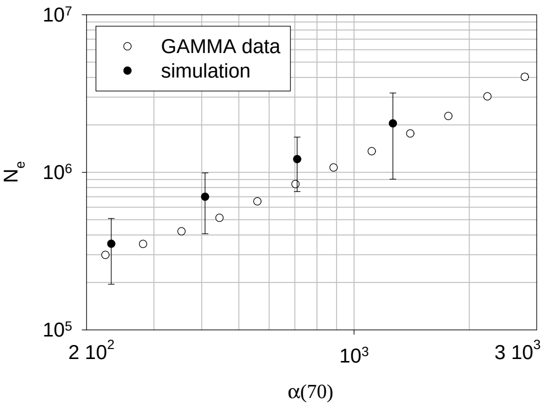

Fig. 6. Comparison of the experimental, (open points), and simulated, (full points), shower sizes for showers selected with given $\alpha(70)$, (i.e. for given energy)

5 Conclusion

The main advantages of the GAMMA experiment are as follows:
- its situation in altitude of (3200 a.s.l.) which reduces a lot of the undesirable parameter fluctuations;
- the possibility to select directly the showers generated by primaries with different masses having the same energy. Such shower selection is new and avoids usual biases in the primary energy determination;

- the large effective area of muon detectors (150 m^2) which allows to determine mass composition for given energies close to the *knee* region;
- as the showers are selected taking into account only their energy, it will be possible to determine specific parameters to pick up showers generated by primary photons with energy around 10^6 GeV. These parameters will be based both on the electromagnetic and muon components.

The present work is the first stage of this program.

Experimental data for the charged and muon component characteristics are shown and compared with the corresponding simulated values (code CORSIKA 5.20). A good agreement between experiment and simulation is obtained. Selected showers with given values of the parameter $\alpha_e(70)$ corresponding to the given energies in the range $3\ 10^5 - 10^7$ GeV and $N_e = f(\alpha_e(70))$, obtained from experiment and from simulation, was compared. Once again a good agreement is observed.

This work shows:

- the good coherence between experimental and simulated values of the main EAS characteristics;
- the possibility to select showers with respect to their energies. This possibility has to be used to define directly from the measured $\alpha_e\,(70)$ spectrum the primary spectrum for given energies around the *knee*. On the other hand, the study of fluctuation of the specified parameters (as the truncated muon number) gives possibility to determine directly the mass composition for given energies around and above the *knee*.

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