HE 3.1.14

Research of Absorption Curves of Muons in EAS with $E_0 > 3{\cdot}10^{17}$ eV

N.N. Efremov

Institute of Cosmophysical Research and Aeronomy,
31 Lenin Ave., 677891 Yakutsk, Russia

Abstract

The results of the new independent analysis of experimental data on the muon component of EAS registered at the Yakutsk array for 1974-1995 are presented. About 95 000 events according to several criteria have been selected. A new approximation of LDF for EAS muons suggested by the author in the analysis is used. An irregularity in behaviour of the number of muons has been confirmed. The zenith-angular dependence of muon component parameters in the region of primary energies 10^{18}-$3{\cdot}10^{19}$ eV has been considered. This dependence is of clearly expressed anomalous character at $E_0 > 2{\cdot}10^{18}$ eV. The gradual rise of this effect as the primary energy increases is traced. The unknown earlier anomaly in behaviour of the muons absorption curves has been found. The preliminary conclusion on the possible nonstandard behaviour of the interaction cross-section of leading protons is made.

Introduction

At present, the research of muons in extremely high energy EAS, above $3{\cdot}10^{17}$ eV, are performed only at two largest operating installations, AKENO in Japan and the Yakutsk array in Russia.

Irregular effects in behaviour of the muon component, for the first time, have been researched at the Yakutsk array, starting from 1990. With increasing massive of data and with improvement of algorithms of data treatment, the irregular behaviour of muons expressed itself more and more distinct (Efimov et al., 1990, 1991; Glushkov et al.,1994). At present , we can say about a possible detection, unknown earlier, phenomena in longitudinal development of cascades at superhigh energies. The AKENO group does not have sufficient statistical data of showers containing muon data, for confirmation the Yakutsk array results.

In present work, the results of alternative treatment of data obtained at the Yakutsk array are examined, zenith-angular dependencies of muon parameters in the range of primary energy $3{\cdot}10^{17}$-$3{\cdot}10^{19}$ eV are analyzed. A new approach to the modeling of irregular effects in EAS is suggested and the first preliminary results of modeling, illustrating one of the possible variation for explanation of discovered anomaly are presented.

We don't give here the description of the experiment on measurement of the muon component at the Yakutsk array because it was published in the work (Glushkov et al.,1994).

We suppose, that alternative, independent analysis of data is necessary in condition of a lack of external scientific competition and it in final outcome, would help to reach more reliable results.

Treatment of data

From all registrated data we selected about 95 000 showers with a probability of registration more than 0.7 and at zenith angles $\theta < 60°$. Events were classificated by the parameter $\rho_s(600)$ and grouped with intervals $\Delta \lg\rho_s(600) = 0.2$ and $\Delta\cos\theta = 0.1$. Then in each group fluctuational distributions of the muon density, normed to the level of expected density were built. For each distribution on average value and dispersion were calculated. Absolute values of average density were calculated by renorming on the expected average density of muons. The primary energy was calculated by a standard accepted for Yakutsk array (Glushkov et al.,1994).

To find the average of lateral distribution functions (LDF) of muons the best parameters for approximating function with the aid of non-linear fitting procedure were determined. As an approximating function we used the exponential function type

$$\rho(R) = \rho(0)\cdot\exp(-R)^{b} ,$$

where the parameter b characterizes simultaneously "curvature" of LDF (the degree of distinctivity from a simple exponent) and its slope. The evident advantages of the given approximation, in comparison with various modifications of well-known Greisen's approximation, is in absence of divergence in zero and in presence of only two varied parameters. Besides, this function has a natural steep behaviour at long distances from a core which elimimates a necessity of using additional multiplier as in the case with the Greisen's function (Glushkov et al.,1994; Shiba et al.,1992).

Results

In Fig.1 zenith-angular dependencies of the parameter $\rho_\mu(600)$ at fixed primary energies in the range of $5\cdot10^{17}$-$3\cdot10^{19}$ eV with a step $\Delta \lg E_0 = 0.1$ are shown which were obtained with the help of the above methods. From its of behavior $\rho_s(600)$ we make the preliminary conclusion that a clear anomaly, 'fission' of absorption curves and, moreover, the gradual rise of this effect is traced as the primary energy increases. The total number of muons has analogous behaviour. With the goal to find a reasonable explanation to this strange effect, we tried to search and test many variants, understanding, that these attempts have a preliminary exploring character and do not pretend to anything more.

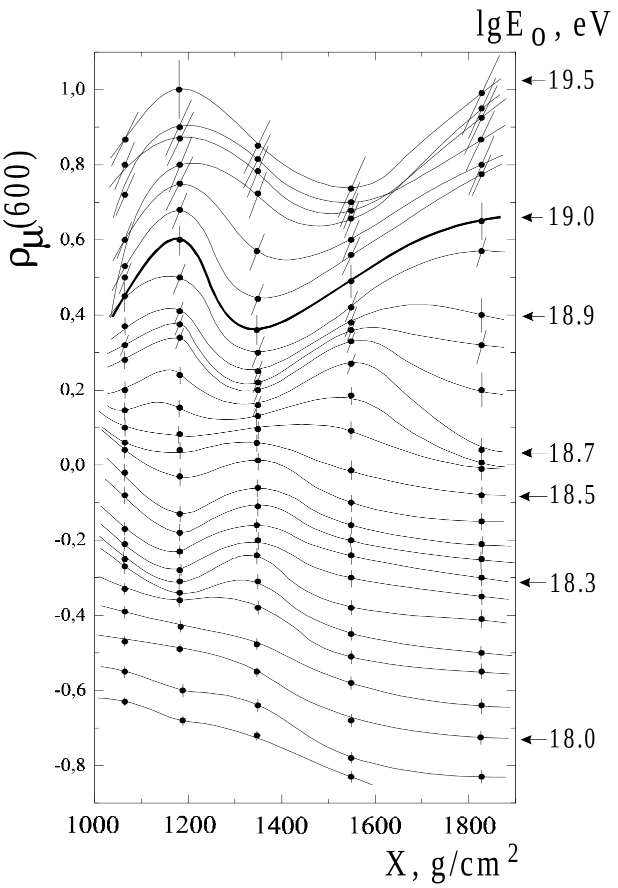

Fig. 1

Modeling and Interpretation

The main idea is in suggestion, that there is a fission of summary nuclear-electromagnetic cascade into series of partial cascades, initiated by leading particles. One of such possible reasons is a decrease of cross-section of interaction of primary and leading nucleons as E_0 increases. This decrease of cross-section has to correspond to the increase of the interaction length sufficient to shift hte beginning of partial cascades to the observation level, to form the observed fissioned cascade curve of muons and to increase the effect as E_0 rises.

The first attempts to realize this idea showed, ambiguous role of the classificational parameter $\rho_s(600)$ used at the Yakutsk array. Similar parameters are also used at other arrays, for example, AKENO (Hayashida et al.,1997). Parameter $\rho_s(600)$ acts in suggestion that there is the enough good logarithmic linear correlation with the primary energy. In the case, when the linear dependence $\rho_s(600)$ with E_0 is strongly distorted, then big problems of principle character appear.

The true estimation of the primary energy by a traditional method of logarithmic-linear recounting becomes practically impossible, if we only do not bear in mind the possibility of empirical estimation of energy in each shower event by Cerenkov radiation which also related to known problems.

Therefore, a single possibility to estimate a 'true' energy is the use of the nuclear-electromagnetic cascade model in which a mechanism of selection of shower events on $\rho_s(600)$ or an analogous parameter associated genetically with electromagnetic component is taken into account. Calculations show, that in order to describe the fission effect it is insufficiently to decrease the cross-section, it is also necessary to decrease the electromagnetic cascade width.

Strictly saying, one should distinguish the primary 'true' energy (the 'non-observed' value) and the energy calculated from the model $\rho_s(600)$ (the 'observed' primary energy E_{obs}). Fixing E_{obs} it is necessary to vary a the "true" energy controlling a behaviour of $\rho_\mu(600)$ or other 'observed' values of the model in order to reach the maximum coincidence with the experimental values by a step-by-step method. Generally, such a modeling method may be correct in that primary energy region where there isn't any information on a true character of processes and where the extrapolation of the accelerator data appears to be too arbitrary.

Taking into account the complexity of such a task, we intentionally chose the sufficiently simple model in order to minimize the computer time expenditure, to carry out multy-variant calculation with a variation of many parameters of our model and to obtain the approximate estimations of the 'fission' effect of muon absorption curves. The modeling results are given in Fig.2. Special attention must be given to the most important circumstance, namely, the 'humps' in the electron-photon component are transformed into the muon 'humps' at the selection on $\rho_s(600)$. Here the constrained linear ordering of the observed values $\lg E_0$ calculated from $\rho_s(600)$ is manifested. The similar linearization effect is evident and it practically takes place in any EAS experiment. Fig.3 demonstrates the supposed behaviour of nucleon cross-section and the relevant behaviour of interaction path lengths. The cross-section curve tends to the asymptotic limit ≈ 30 mb. Such a behaviour of the cross-section is necessary to describe the fission effect.

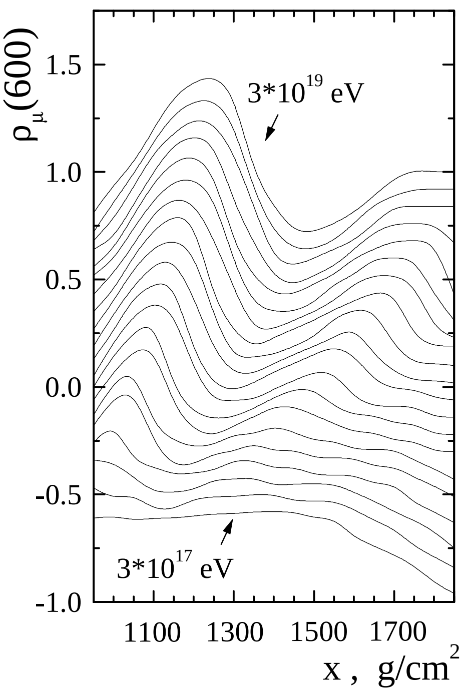

Fig. 2

EAS and Grand Unification

As to physical reasons of the 'fission' effect we risk to formulate and suggest the following hypothesis. According to theories of the grand unification, the constants of electromagnetic, weak and strong interactions are slowly approached and become the same at energies of ~10^{14}-10^{15} GeV (in the mass center system). If to suppose that interaction cross-sections in the first approach are proportional to interaction constants then the tendency of decreasing of 'strong' constant corresponds to the decrease of the nucleon interaction cross-section, in our case, and a growth of the 'electromagnetic' constant corresponds to the decrease of the electromagnetic cascade width (faster development of the cascade). At $E_0 > 3{\cdot}10^{18}$ eV the constants come closed as much as it is possible to observe the corresponding anomalies in EAS. It is worth noting that the cross-section becomes asymptotic already at ~10^{20}-10^{21} eV. By other words, the unification scale can be taken place much earlier (10^5-10^6 GeV in the mass center system). Some models, in which the group SU(5) with a scheme of the stable proton is used, predict such a small scale of unification (10^4 GeV) (Kuzmin, Shaposhnikov , 1981, 1983).

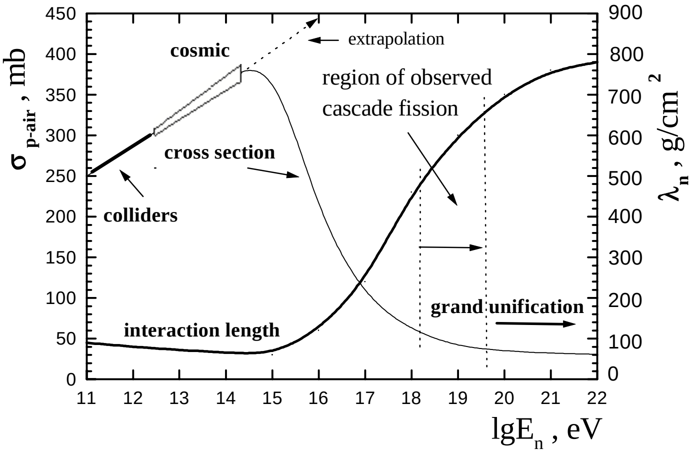

Fig. 3

Conclusions

A new approach to the modeling of non-linear effects in EAS at superhigh energies is of principal importance in our case. The model calculations carried out earlier and at present time didn't take into account the selection effects by classification parameters. It seemed to be self-evident that experimental parameters which are used for recalculation to the primary energy, depend linearly logarithmically on the primary energy. However, the analysis of the muon absorption curves in EAS clearly shows that it is not correct. Namely, realization of such an approach allowed to come to explanation of the muon cascade fission effect as a fission into partial electromagnetic cascades. And if the interaction constants become close to each other then this coming together in the region of EAS superhigh energies should be manifested in such a way as it was shown above or in an analogous way.

References

1. Efimov N.N. et al, 1990, Proc. of ICRR Int.Symp.'Astrophisical Aspects of the Most Energetic Cosmic Rays', Kofu, p.20
2. Efimov N.N. et al, 1991, Proc. 22-th ICRC, v.4, p.339
3. Glushkov A.V. et al, 1994, J.Nucl.Phys.Preprint
4. Shiba et al, 1992, Nucl. Instrum. Methods, A, **311**, 338
5. Hayashida N. et al, 1997, 'Summary of Akeno Experiments', University of Tokyo, p.225
6. Kuzmin V.A., Shaposhnikov M.E., 1981, Preprint IYaI P-02233, Phys.Lett., B, 1983