Some Aspects of Superhigh Energy Cosmic Ray Investigation

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Abstract

Some aspects of primary cosmic ray investigation at energies greater 10^{18} eV are considered. The problem of response detector fluctuations for different array geometry and for different primary energy ranges is discussed.

1 Introduction

One of the prime objectives of cosmic ray investigation is the precise measurements of primary cosmic ray (PCR) energy spectrum at energies above 10^{18} eV. Of course,the problem of the black-body cut-off is the most attractive puzzle and it is very essential to either validate or disprove the existence of cosmic rays with energies above 10^{20} eV. But it would be unwise to pay no attention to the region of more moderate energies where also really interesting phenomena can take place.

Experimental data of the EAS MSU array (Fomin et al., 1996) show the predominance of heavy nuclei at energies $\sim 10^{17}$ eV. This conclusion is in a good agreement with the Fly's Eye data (Bird et al., 1993). According to (Bird et al., 1993), the primary mass composition changes in the region 10^{17}–10^{19} eV in such a way that the abundance of protons begins to rise after 10^{18} eV. The quantitative details of that rise depend on a hadron interaction model adopted (see, for example, Kalmykov et al., 1997) but the main conclusion remains intact. The nature of a proton predominance at energies $\sim 10^{19}$ eV is to be solved. As was pointed out in (Zirakashvili et al., 1995), one has to choose between extragalactic or galactic cosmic rays. In the latter case the increasing proton abundance is due to the termination of cosmic ray diffusion and reflects the mass composition existing in the source. Of course, it is a point open to a question whether our Galaxy can produce cosmic rays up to the highest energies, but, admittedly, the problem of extragalactic sources is also a considerable challenge.

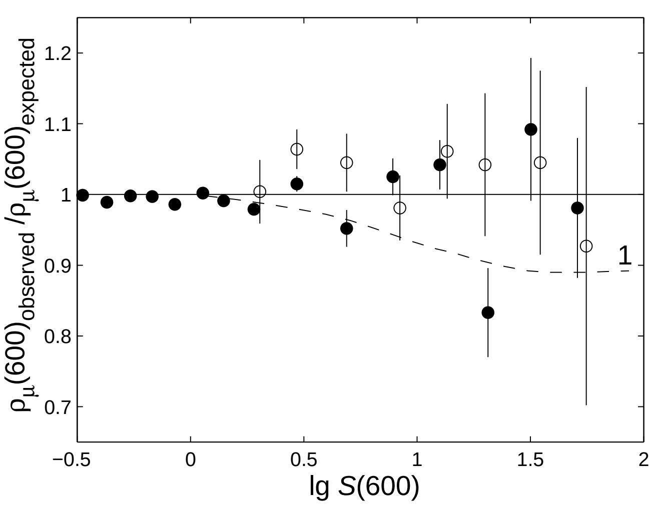

Figure 1: Ratio of the observed muon density to the expected one vs. charged particles density at 600 m from EAS axis. Experimental data of Akeno array: filled circles — 1 km^2, open circles — 20–100 km^2. Curve 1 — our calculations in assumptions that reproduce Fly's Eye data.

Mention should be made of the Akeno group results (Hayashida et al, 1995), which seem to be contrary to the conclusion of the Fly's Eye group. Indeed, the investigation of the ratio $\rho_\mu(600)_{\rm observed}/\rho_\mu(600)_{\rm expected}$ as a function of $S(600)$ that was carried out by the Akeno group, showed that the mass composition does not change with primary energy in the region 10^{17}–10^{19} eV. In (Hayashida, 1995) $\rho_\mu(600)_{\rm expected}$ was defined as a result of an extrapolation of experimental data from energies $< 10^{17}$ eV to the highest energies. According to our calculations (see Fig. 1) this ratio does not exibit a strong dependence on $S(600)$ but nevertheless noticeably differs from unity. We must emphasize that calculations presented in Fig. 1 were carried out exactly in the same manner as in (Kalmykov et al., 1997) where the results of the Fly's Eye group were successfully reproduced. The estimations made in (Hayashida, 1995) predicted more pronounced variations of the ratio in question. So the exact determination of the primary mass composition in the region 10^{17}–10^{19} eV presents a problem for the next generation of EAS arrays. These arrays should also provide sufficiently accurate data on cosmic ray anisotropy at ultra-high energies which is very essential for primary composition studies.

2 Estimations of New Array Possibilities

To accomplish mass composition studies at energies 10^{18}–10^{19} eV an array should include systems of electron–photon, muon, and Cherenkov light (or fluorescence) detectors (Khristiansen et al., 1989; Cronin et al., 1992). Cherenkov light detectors allow measurements of the primary energy and shower maximum depth whereas other detectors enable one to obtain some additional information concerning the primary mass composition. Our calculations carried out in the framework of the QGSJET model (Kalmykov et al., 1997) have showed that the total number of particles correlates strongly with the EAS maximum depth while the muon number is practically independent of it. So a promising approach to tackle the problem of mass composition measurements is to analyze the joint distribution of the shower maximum depth $X_{\rm max}$ and number of muons in the detector N_μ. In (Fomin et al., 1998) we have investigated the possibility of the primary mass composition reconstruction using a "quasi"-experimental sampling of 3000 showers with primary energy 10^{18} eV. The approach employed may be described as a comparison of the simulated distribution with five standard distributions corresponding to the traditionally used groups of nuclei (protons, α-particles, M ($\langle A\rangle = 15$), H ($\langle A\rangle = 28$) and VH (or Fe) groups). The details of the technique can be found in (Fomin et al., 1996). Calculations were carried out in the framework of the QGSJET model and certain assumptions concerning methodical errors were made. It was shown that there exist good possibilities to reconstruct the primary composition with realistic methodical errors (~ 20 g/cm^2 for $X_{\rm max}$ and 5–10% for N_μ). Relative errors of this reconstruction are about 20%.

As the energy region 10^{18}–10^{19} eV is of essential interest, it is very expedient to construct new arrays aimed at ultra-high energies in such a way that could provide reliable results not only above 10^{19} eV but also at energies 10^{18}–10^{19} eV. So the spacing between detectors should not be very large. Fig. 2 shows the charged particle numbers in detectors with spacing of 500 m and 1500 m respectively.

Our estimations correspond to the average lateral distribution function (LDF) obtained with AGASA array (Dai et al., 1995). The shower axis is assumed to fall onto the central detector. The account for LDF fluctuations would lead to the impairment of the response picture for arrays with large spacing.

Fig. 3 presents fluctuations of muon and total charged particle numbers calculated in the framework of the QGSJET model for primary energy 10^{19} eV. The essential enhancement of fluctuations at large distances (due to poissonian fluctuations) is quite evident for muons.

3 Conclusion

EAS giant arrays of new generation with small spacing are the necessary stage of quantitative investigation of ultra-high energy cosmic rays.

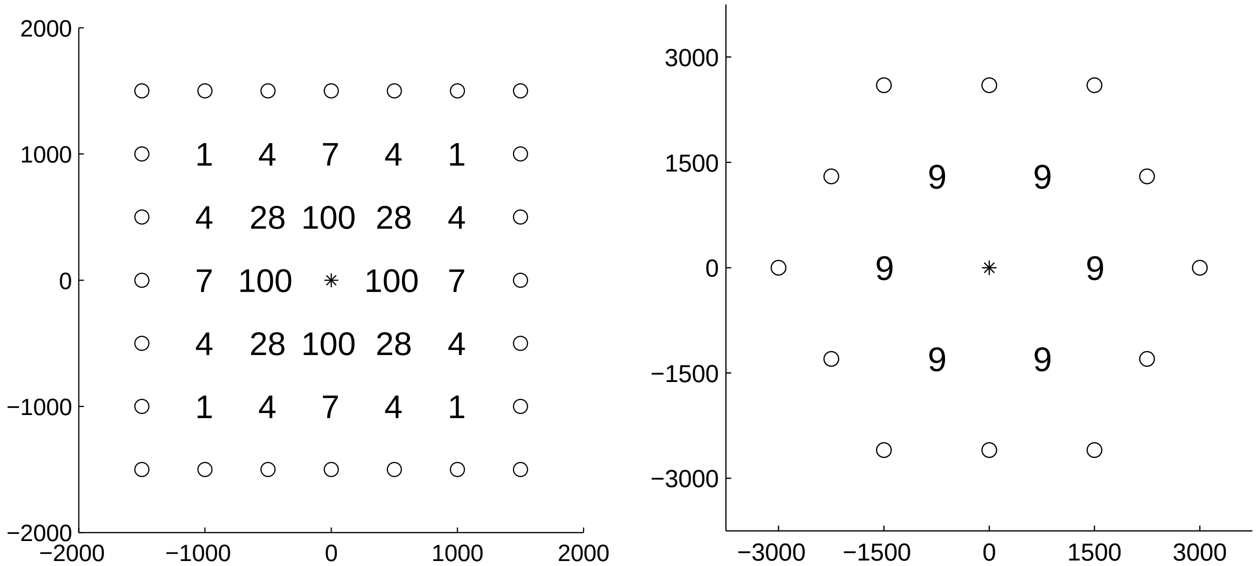

Figure 2: Responce of detectors for different spacings: left—spacing 500 m and detector area 1 m^2, right—spacing 1500 m and detector area 10 m^2.

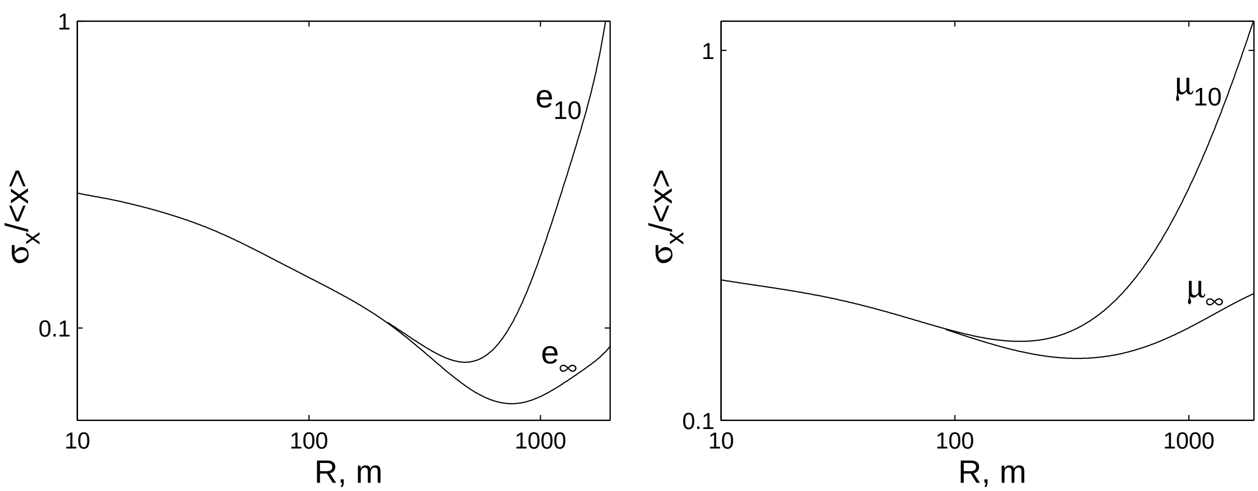

Figure 3: Fluctuations of charged particle (left) and muon (right) densities vs. radial distance. Calculations are made for detectors with area 10 m^2 and ∞ respectively.

Acknowledgments

This work was done with financial support of The Federal Scientific-Technical Program for 1996–2000 years "Research and Design in the Most Important Directions of Science and Techniques for Civil Applications", subprogram "High Energy Physics", INTAS–RFBR grant 95-0301 and RFBR grants 96-15-96783 and 99-02-16250.

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