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New energy estimates of the giant air showers

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Abstract

The c^2 procedure was used to interpret data in terms of the QGS model at the array plane with the geomagnetic field taken into account of the standard method (so called experimental method) adopted at Yakutsk and Akeno. As no model and some assumptions involved into calculations can be completely trusted at superhigh energies the normalization of some shower calculated parameters was suggested to fit the results of the calorimetry method and other available data. As a result some energy estimates increased by 1.5–2 times. Thus the number of the giant air showers with energies above 10^{20} *eV* may be larger than it was assumed. Indeed 3 more showers observed at the Yakutsk array may have energies above 10^{20} *eV*. The energy of the most giant shower observed at the Yakutsk array is estimated as *3´*10^{20} *eV*

1 Introduction:

The problem how to interpret the experimental data on the giant air showers has to be solved. The standard procedure adopted both at the Yakutsk and AGASA arrays seems to be rather complicated. It includes also several approximations. First the arrival direction of a giant shower should be estimated in terms of any suitable model. The accuracy depends much on the model involved (e.g. see Antonov et al., a, 1999). Next step to be executed is estimating of the specific parameter $r(600,q)$ suggested by Hillas et al. 1971 – the charged particle density at distance $R=600$ *m* from the showers axis – in terms of adopted symmetrical function of particle lateral distribution. Some assumptions are utilized at this step. Instead of the array plane the experimental data should be regarded in the shower plane which is perpendicular to the shower axis. The recalculations of the data may be followed by induced errors. Besides in case of inclined showers the lateral structure function of charged particles may be not symmetrical due to the possible deflection of muons by the geomagnetic field (e.g. see Antonov et al., 1998). Fig. 1 illustrates this deflection for the most giant air shower observed at the Yakutsk array. To display the picture more clearly only one half of calculated lateral structure function is shown. What is shown as a waved grid is the ratios of muon densities calculated with and without the geomagnetic field. The plane $z=1$ is naturally representing the lateral structure function with no geomagnetic field taken into account, the points show the experimental data also divided by the

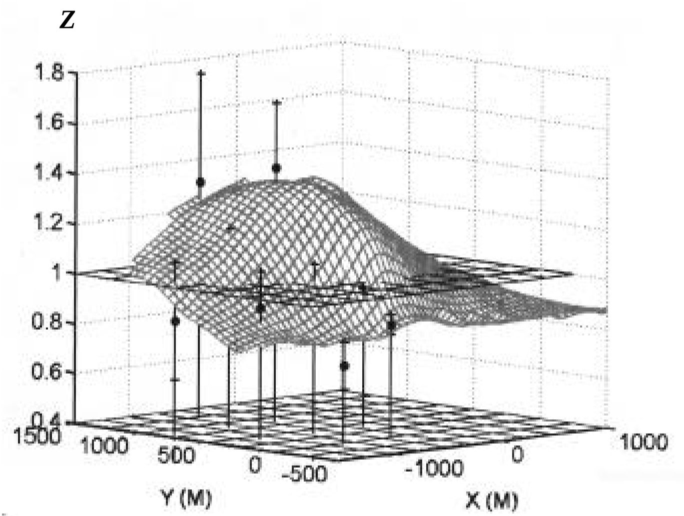

Fig 1. The muon lateral structure function. Only one half of the picture is shown. The waved grid – calculations with the geomagnetic field taken into account. Points – data. The plane *z=1* – no geomagnetic field involved.

calculated densities with no geomagnetic field involved. Fig. 1 shows clearly the local minimum of muon density at the point where shower axis strikes the detector plane. But instead of the only one maximum at this point two new maxima are formed quite aside from this point (only one is shown on Fig.1). It is also clearly seen that the calculated densities with the geomagnetic field taken into account fit the data very well. Indeed the possibility to regard the data with no geomagnetic field involved is nearly 0.03% (Antonov et al., 1998). Thus the assumption of the symmetrical lateral structure function may be not correct.

Other step is estimating of the parameter $r(600,0°)$ – particle density at $R=600$ *m* for a vertical shower. This step involves also a suggestion that the absorption of charged particles is exponential. Actually this assumption may not be correct. Fig.2 shows how the parameter $r(600,q)$ depends on the zenith angle q. The curves 1 and 2 are the results of calculations for the NKG (Greisen, 1956) and the modified NKG (e.g. see Dedenko et al., 1975) approximations and the line 3 represents the exponential absorption adopted at the Yakutsk array. In fact the real absorption in the particular individual shower should be estimated. This problem is rather complicated (e.g. see Dedenko, 1975). So the hypothesis about the simple exponential absorption may induce some additional errors. At last the estimate of the primary particle energy E_0 in terms of any model involved may also not be correct. Some energy calibration method such as the Cherenkov light measurements (Glushkov et al., 1987) or the fluorescent light observation as it was adopted at the Fly's Eye array is needed to normalize this estimate.

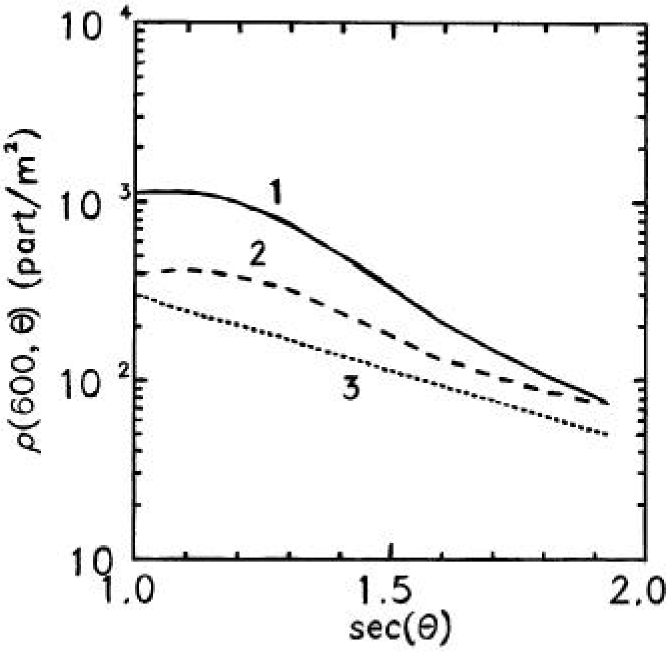

Fig 2. Dependence of the $r(600,q)$ on the zenith angle q.

1- the NKG assumption;
2- the modified NKG assumption;
3- the exponential absorption.

2 Method and Results:

Instead of the standard procedure described above the new method is suggested to interpret data observed at the array plane in terms of the QGS model normalized according to the calorimetry results (Dedenko, 1991). So we have to minimize

$$c_{n-3}^{2} = \sum_{i=1}^{n} \left(\frac{r_e - r_t}{s} \right)^2 , \qquad (1)$$

where n is a number of hit detectors, r_e and r_t are experimental and calculated densities of the charged particles in the array plane, and s is a standard deviation. Some normalization of calculated densities was used to produce the correct muon to electron ratio and a density of charged particles at the fixed primary energy estimated by the calorimetry method (Glushkov et al., 1987).

Approximately 20 most energetic showers observed at the Yakutsk array were tried by the suggested procedure (1). Only 10 showers were selected to adjust the criterion of minimal errors. As a result 3 more showers observed at the Yakutsk array have probably energies above 10^{20} *eV*. As for the most energetic shower calculations with geomagnetic field taken into account showed its energy as high as $3´10^{20}$ *eV* (Antonov et al., b, 1999). It should also be mentioned that standard formula (Glushkov et al., 1991)

$$E = a r^{a} (600) \qquad (2)$$

may be applied but with the exponent $a=1.07$ (instead of $a=1$ in the standard case) and a coefficient *a=4.55´10*^{17} *eV*. If the energy of shower is increasing the maximum of shower development approaches the level of observation. So at very high energies the exponent a should increases because only part of the energy of the primary particle is released. If this formula with the exponent a=1.07 is applied then the energy estimates would also become higher.

Thus at least 4 showers observed at the Yakutsk array may have energies above 10^{20} *eV* and one shower has the energy of *3´*10^{20} *eV.*

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