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Most precise determination of arrival direction of the giant air showers

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Abstract

It was suggested to interpret data in terms of the calculated space-time structure of the shower front by various mathematical methods. It was shown that errors may be decreased up to nearly 0.5 degree in case of minimax procedure. It is very important for identification of estimated arrival direction of a giant air shower with the possible extra-galactic sources.

1 Introduction:

Since the first detection of the giant air shower by Linsley (1963) followed by observations at Haverah Park (Edge et al., 1973), Sydney (Bell et al., 1974), Yakutsk (Efimov et al., 1990), Akeno (Hayashida et al., 1994) and by the Fly's Eye array (Bird et al., 1995) it was shown that 6 more showers with energies above 10^{20} *eV* were observed at Akeno (Takeda et al., 1998) and possibly 3 showers detected at the Yakutsk array have also these tremendous energies (Antonov et al., a, 1999). So it is possible to claim the quite new phenomenon – the existence of the giant air showers with energies above 10^{20} *eV.*

The possible sources of the primary particles with these tremendous energies may be discovered if the arrival directions of giant air showers induced by these particles would be estimated. Thus it is of primary importance to decrease possible errors in the estimates of arrival directions of giant air showers.

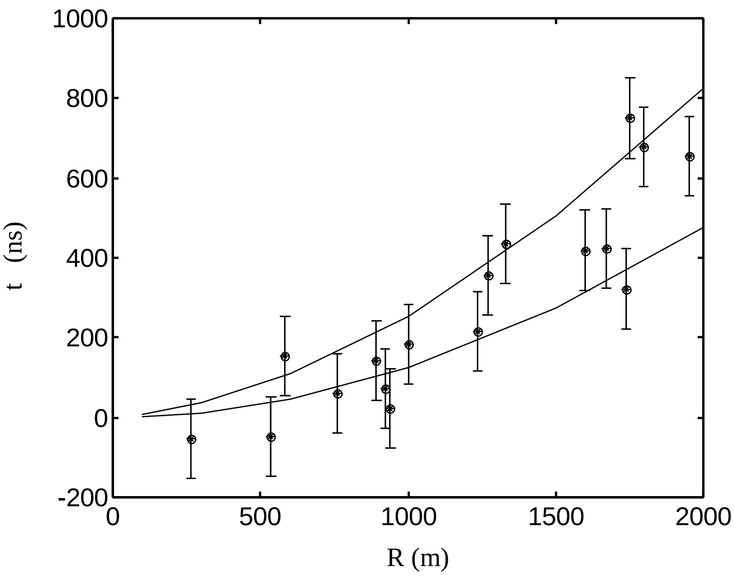

Fig 1. The space-time structure of a shower . Solid lines – calculated time front thickness; points with error bars – data.

To estimate the arrival direction of a giant air shower one has to have any model of its space-time structure. The simplest model of the space-time structure of a giant shower is a model of the flat front when all particles are located in this front plane. It was shown in the frame of this model (Antonov et al., b, 1999) that possible errors in estimates of the zenith and azimuthal angles which characterize the arrival direction of a giant air shower may be as large as 5° or even more. The χ^2 method gives very large values of χ_1^2. That means that this model of the flat front is inconsistent with the data. Much more realistic model of a shower time front was suggested by Linsly (1985). This model gives much better accuracy. But calculations by Anokhina et al. (1999) displayed that both the shower disk thickness and the average time delay depend on an energy of the primary particle and the kind of particles detected. So the calculated space-time structure of a giant air shower for both electrons and muons in terms of a realistic model (e.g. the quark-gluon string (QGS) model of hadron interactions suggested by Kaidalov, Ter-Martirosyan and Shabelsky (1986)) may fit the data and thus provide better accuracy.

Fig. 1 illustrates the comparison of the calculated shower time front thickness (solid curves) and data for the shower detected at the Yakutsk array. Though experimental errors are rather high the agreement seems to be satisfactory. So the space-time structure of giants shower calculated in terms of the QGS model will be utilized in our calculations.

The standard mathematical procedure to interpret data is the χ^2 method. This method leads to reasonable estimates of the zenith and azimuthal angles. Fig. 2 shows an example of application of this method. The calculated ratios of χ^2_{min} / χ^2 as a function of the zenith angle *q* and azimuthal angle *j* is shown. So the best estimates of *q* and *j* may be found at the point which corresponds to the maximum of the displayed surface. The possible errors may also be estimated by fixing the value of ratio χ^2_{min} / χ^2.

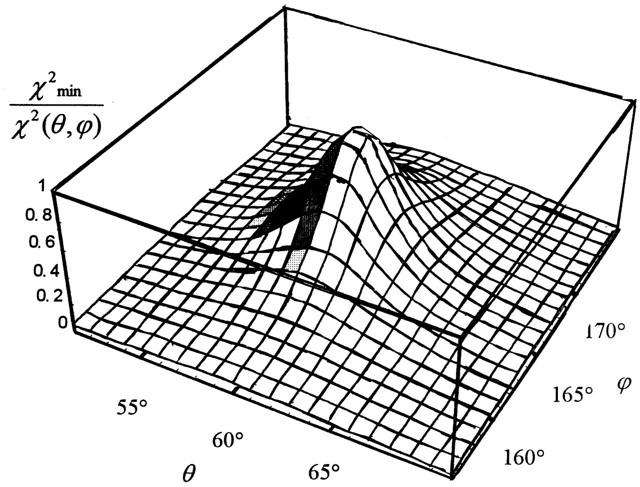

Fig. 2 The χ^2 fitting of data.

In some cases when the maximum value of an error in time measuring is known the minimax procedure (e.g. see Pyt'ev, 1991) may be utilized to interpret data. It was shown (see Antonov et al., b, 1999), that the possible error in estimates of the zenith and azimuthal angles may be decreased up to 0.5° if this minimax procedure is used.

The results obtained by the χ^2 method are presented in this paper.

2 Results and Discussion:

The simplest problem to be solved first is searching for specific direction on the sky sphere where the primary particles with tremendous energies may come from. So the distribution of the arrival directions of giant air showers may show on the possible sources of the primary particles.

Fig. 3 displays in the galactic coordinates this distribution of 20 giant air showers with energies above 10^{19} *eV* observed at the Yakutsk array. The dotted line shows the supergalactic plane. Though statistics is very low no evidence is found to prefer any directions. Of course one has to bear in mind that not all directions on the sky sphere may be observed by the Yakutsk array.

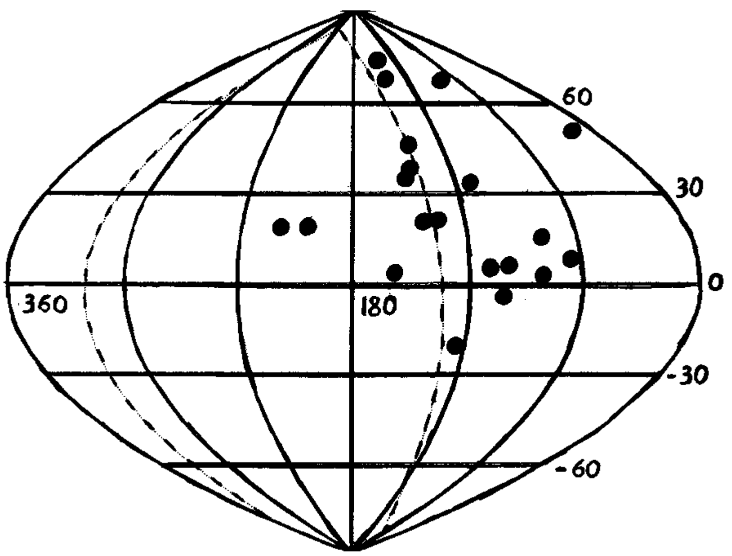

Fig. 3 A map of arrival directions distribution of giant air showers in the galactic coordinates.

Thus the isotropic distribution of the arrival directions of giant air showers with energies above 10^{19} *eV* seems to fit data. But the suggestion by Stanev et al. (1995) that the arrival directions of giant air showers exhibit a correlation with supergalactic plane may not be excluded.

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