COSMIC RAYS WITH ENERGY ABOVE $10^{17}$ eV

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The energy spectrum of primary cosmic rays with ultra–high energies based on the Yakutsk EAS Array data is presented. For the largest events values of $S_{600}$ and axis coordinates have been obtained using revised lateral distribution function. The affect of the arrival time distribution at several axis distance on estimated density for Yakutsk and AGASA is considered.

1. Introduction

Research into the cosmic rays above $10^{17}$ eV spectrum shape and into intensity in the region of cutoff near $10^{20}$ eV predicted by Greisen, Zatsepin and Kuzmin are of great importance for their sources detection. Results obtained in various experiments differ from each other by factor 2 and more in absolute intensity, but their shapes are similar. At energies greater than the GZK–cutoff results are inconsistent. At the Yakutsk array after recent analysis have been carried out, there is only one event with energy estimated to be greater than $10^{20}$ eV. To explain this contradiction with AGASA, A. Watson assumed that at the Yakutsk array such showers are skipped due to inadequate small integration time for large distances from the axis. In this work we have studied the affect of particle arrival time distribution at different distances on estimated density for Yakutsk and AGASA. We provided core location with adjusted LDF for the largest events, which in average led to increase of $S_{600}$.

2. Density Measurement At Large Distances From The Axis

At the Yakutsk array and at AGASA a nearly similar RC–convertors are used. At the Yakutsk array for an event to be treated, a coincidence of signals from both detectors within 2 mcsec is required. Herewith input of convertors is closed in 2 mcsec after coincidence. In the case when shower front is wide, this may result in underestimation of the density. These circumstances have been pointed out by Watson in his report. At AGASA input is constantly open and in the case of wide signal this may lead to density overestimation due to convertor's features. To examine the
influence of the effects mentioned above, we have provided simulation for response of detectors at distances $R = 1050, 1500$ and $2000$ m, based on the particle distribution approximation obtained at AGASA. A coefficient $K_R$ was considered — a ratio between density estimated with RC–convertor and the one set with program. For the Yakutsk array, in the case of detectors with large area, registering large particle densities we have following values: $K_{1050} = 1.05$, $K_{1500} = 0.994$, $K_{2000} = 0.76$. Same points for AGASA: $K_{1050} = 1.065$, $K_{1500} = 1.11$, $K_{2000} = 1.2$. At $2000$ m distance for Yakutsk — $25\%$ underestimation, for AGASA — $20\%$ overestimation.

For the real experiment for the shower with $E_0 = 10^{20}$ eV at $R = 2000$ m about 2 particles per detector is expected. Simulation indicated, that in this case underestimation is much less than $K_{2000} = 0.92$. It is connected with the fact that conversion starts only after the first particle hit and at low density the effective thickness of the shower front decreases. Probability of that the station doesn’t operate due to gap between operating of two separate detectors is more than $2$ mcsec is $8.5\%$ and it is lower by factor $3$ than those due to Poisson fluctuations at this density.

Simulation showed no significant underestimation of particle density for distances up to $2000$ m for density measurement system at the Yakutsk array. In the case of AGASA, when input of RC–convertor is constantly open, besides wide distribution, there is an afterpulse contribution to density overestimation from delaying particles (probably neutrons) together with casual additives from background muons. One can conclude from the data in paper that delaying neutrons can overstate the density by factor $1.37$ already at $500$ m and further. Background muons may cause distortions in wide range of axis distances. If one such particle hits within last $10$ mcsec of RC–circuit discharge, then resulting density can be overestimated by factor $2$ and more independently of the real density. The effects mentioned above are excluded at the Yakutsk array thanks to blocking of convertor’s input in $2$ mcsec.

3. Energy Spectrum Summary

Events selection was provided as described in paper. Showers with $\theta < 60^\circ$ were used. For determination of the intensity for showers with $E_0 > 4 \cdot 10^{19}$ eV, an extended area together with efficient zone outside the array was used. It was shown that for showers with energy greater than $10^{19}$, LDF used in standard procedure of axis determination badly corresponded with experimental data at $R > 1000$ m from the axis. A modified approximation similar to AGASA’s was proposed. In this work we provided axes coordinates determination with this adjusted LDF. As a result, in average estimated $S_{600}$ values increased: $10\%$ — for showers with axes lying within array area and $20\%$ on border.

For energy estimation we used adjusted formulas of $S_{300}$ and $S_{600}$. On Fig. the differential energy spectra obtained at the Yakutsk array, AGASA and HiRes are presented. Results obtained in different experiments correspond quite well in
shape but differ in intensity. The data from the Yakutsk array near $10^{19}$ eV are higher by factor $\simeq 2.5$ than HiRes data and $\simeq 30\%$ than AGASA’s. This rather is connected with the difference in estimation of the showers energy. In the region of ultra–high energies the results from Yakutsk and AGASA approach. There are 4 events registered in Yakutsk with adjusted estimated energy exceeding $10^{19.9}$ eV. Relative errors in energy estimation in these individual showers amount from 32% to 46%. If the energy is reduced by one standard error then it slightly exceeds the $10^{20}$ eV threshold only in one event. Therefore the relic cutoff of the spectrum cannot be rejected based on Yakutsk EAS data. Similar experimental errors are observed at AGASA. According to work 7 their averaged value is about 20%. Taking into account this circumstance a conclusion was made that yet there are too few events recorded to approve the spectrum cutoff absence. Besides, estimations of the energy at AGASA depend on model conclusions. The affects of observed densities mentioned above are also not considered yet.

**Acknowledgements**

This work is supported by INTAS grant #03–51–5112, Federal Agency of Science and Innovations grant #748.2003.2, RFBR grants #02–02–16380, #03–02–17160 and the program #01–30.

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