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Energy Distributions of Hadrons in the Chosen Zenith Angles Registered in the Pamir Experiment

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The energy and zenith angles distributions of hadrons registered in the carbon emulsion chambers of the Pamir experiment have been published [1, 2].

The energy distributions for hadrons registered in the chosen zenith angle intervals are presented in this paper. It is interesting, if a stream of the registered high energy hadrons (tens of TeV) recalculated to the vertical stream changes with the change of zenith angle.

The comparison of the experimental data with the calculated spectra enables a statement about the mass composition of the primary cosmic ray below the "knee".

Introduction

Basic characteristics for hadrons registered in the carbon emulsion chambers of the Pamir experiment at the altitude of 4300 m. a.s.l. (i.e. 600 g/cm^2) have been published in former papers [1–4].

A preliminary analysis of the distributions of hadrons registered for various zenith angles has been presented in paper [5]. The anomalies in some distributions of zenith angles and their inconsistency with theoretical forecasts were inspiration to conduct the following analysis. A more detailed explanation can be found in paper [5].

Experimental Results

The distributions of energy of hadrons registered in carbon emulsion chambers for the chosen intervals of zenith angles: 0 – 15°, 15 – 90°, and for 0 – 25° and 25 – 90° have been made. Received differential spectra E_h have been described with the power law function.

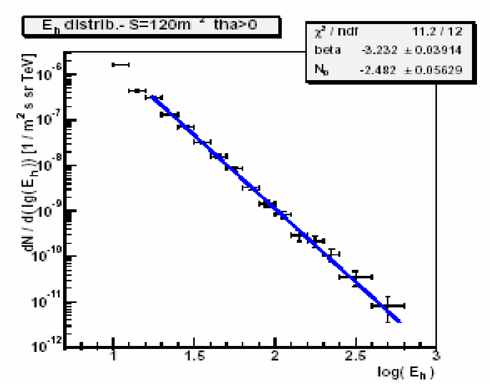

Figure 1.

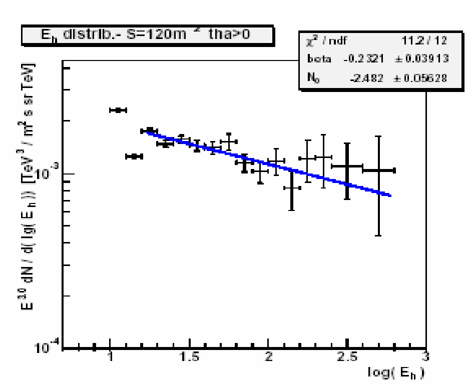

Figure 2.

Experimental Spectra of Hadrons: for Zenith Angle θ > 0°; the same data, various scale

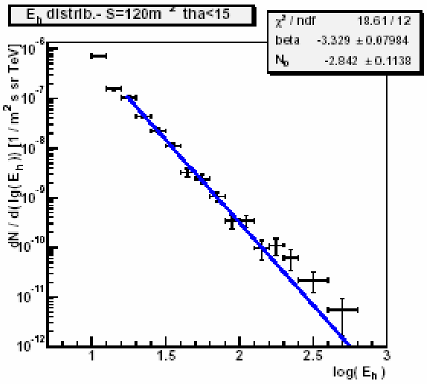

Figure 3. Experimental Spectra of Hadrons for Zenith Angle θ < 15°

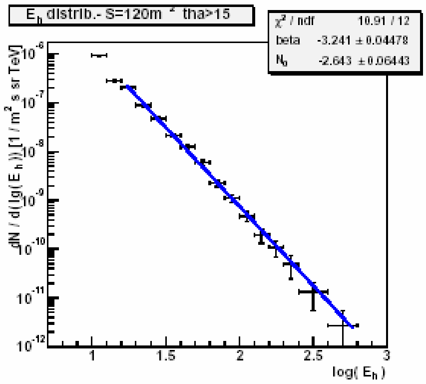

Figure 4. Experimental Spectra of Hadrons for Zenith Angle θ > 15°

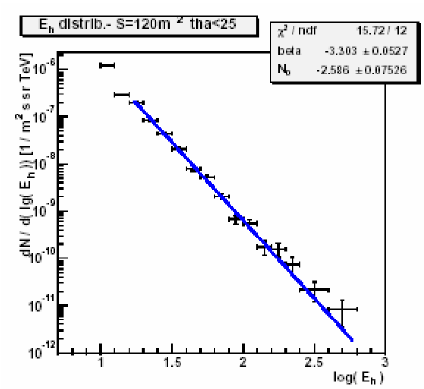

Figure 5. Experimental Spectra of Hadrons for Zenith Angle θ < 25°

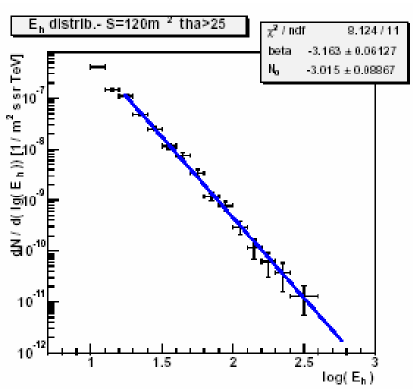

Figure 6. Experimental Spectra of Hadrons for Zenith Angle θ > 25°

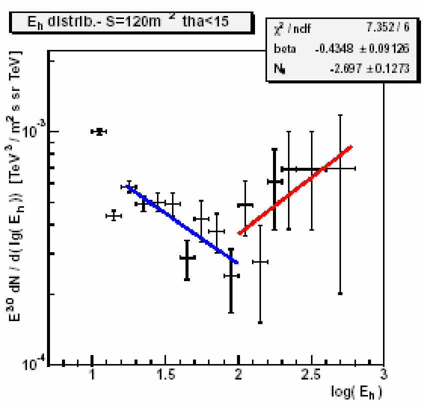

Figure 7. Experimental Spectra of Hadrons for Zenith Angle θ < 15°

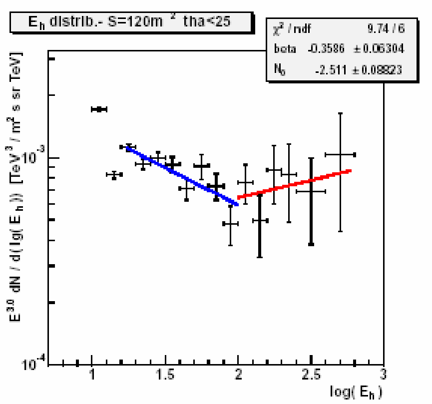

Figure 8. Experimental Spectra of Hadrons for Zenith Angle θ < 25°

Figures 1 – 8 present received experimental E_h distributions at the mountain level for the intervals of zenith angles θ given above. The parameters of fitting with the power law function have been shown in Table 1. It can be seen from Figure 3 that the experimental E_h distribution for small θ cannot be described with one power function. Chi-square test of goodness of fit of the power function with the data in the whole energy interval E_h (only for hadrons with small zenith angles) gives χ^2 values above 1.5 for one freedom degree.
Two functions with energy intervals of 17 – 100 TeV and 100 – 600 TeV give good fits. Remaining distributions can be described with one power law function. The result of fitting is unexpected. The exponent of differential spectrum is very small 2.5 for small θ angles and increases up to ~3.24 for large θ angles. The exponents of the power functions that best describe the distributions presented in Figures 3 – 8 in the chosen zenith angles intervals have been presented in Table 1.

Table 1. The Exponents of the Power Law Function - Fits of Energy Distributions of Hadrons Registered in the Experiment; χ^2 and ndf in Parenthesis

for θ [deg] fit in ΔE [TeV]	> 0	< 15	>15	< 25	> 25
17 – 600	3.23 ± 0.04 (11.2 / 12)	3.33 ± 0.08 (18.6 / 12)	3.24 ± 0.05 (10.9 / 12)	3.30 ± 0.05 (15.7 / 12)	3.16 ± 0.06 (8.1 / 11)
17 – 100		3.43 ± 0.09 (7.4 / 6)		3.36 ± 0.06 (9.7 / 6)	
100 – 600		2.51 ± 0.36 (2.8 / 4)		2.83 ± 0.36 (2.3 / 4)	

Calculations

The same procedure of the analysis of energy distributions as for the experimental data has been applied to the calculation data. The assumptions regarding the calculations simulating the penetration of primary cosmic ray particles through the Earth atmosphere to the detection level have been described in detail in papers [4, 6] (the CORSIKA program).
The following assumptions about the mass composition of primary cosmic ray have been made in the calculations: light, around 60% He + p and 12 – 14% Fe, and the heavy one, 23% He + p and 62% Fe. After conducting the simulation, the mass distributions of hadrons at the depth of 600 g/cm^2 in the atmosphere have been made. The received distributions have been presented in Figures 9 – 12. These distributions have been fitted with the power function. The parameters of the power functions that best describe the analysed distributions have been presented in Table 2.

Table 2. The Exponents of Power Law Function - Fits of Energy Distributions of Hadrons Received in the Calculations; χ^2 and ndf in Parenthesis

for θ [deg] mass cmp.	> 0	< 15	>15	< 25	> 25
light	3.07 ± 0.02 (18.7 / 13)	3.08 ± 0.03 (6.8 / 13)	3.07 ± 0.02 (16.6 / 13)	3.06 ± 0.02 (17.2 / 13)	3.16 ± 0.03 (34.2 / 13)
heavy	3.11 ± 0.02 (19.0 / 13)	3.12 ± 0.03 (8.6 / 13)	3.11 ± 0.02 (16.9 / 13)	3.10 ± 0.02 (15.8 / 13)	3.19 ± 0.03 (39.2 / 13)

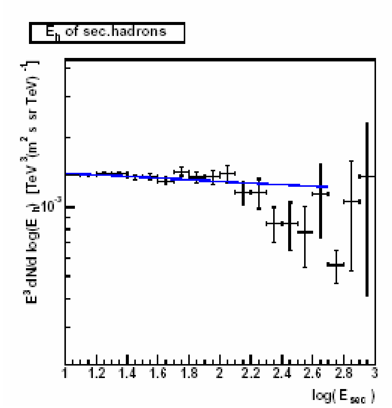

Figure 9. Simulation Spectra of Hadrons for Zenith Angle θ > 0° - for Light Mass Composition

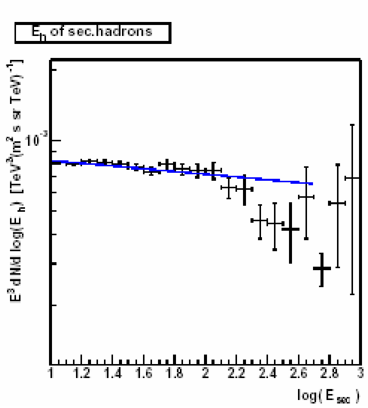

Figure 10. Simulation Spectra of Hadrons for Zenith Angle θ > 0°- for Heavy Mass Composition

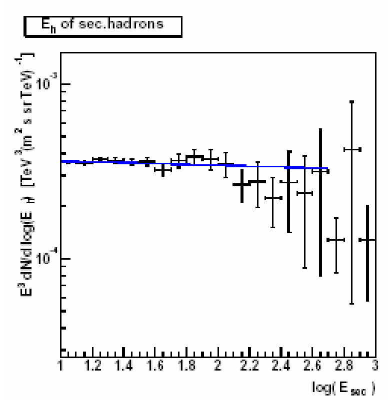

Figure 11. Simulation Spectra of Hadrons for Zenith Angle θ < 15° for Light Mass Composition

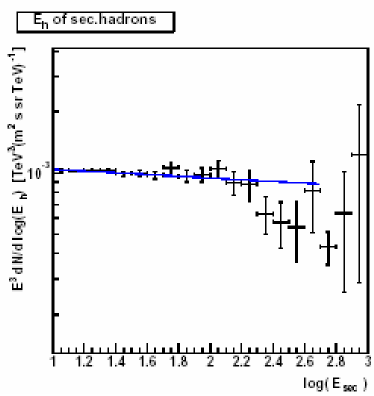

Figure 12. Simulation Spectra of Hadrons for Zenith Angle θ > 15° for Light Mass Composition

Conclusions

It can be concluded from the calculations that the energy distributions are different for different assumptions regarding mass composition of primary cosmic ray, what has been analysed in papers [4, 6]. The distributions of calculated energy of hadrons coming with small and large angles do not differ significantly from each other for any of the assumptions made. The comparison of the results of these calculations with the experiment shows the differences in the shapes of energy distributions. The slope of experimental distribution for small zenith angle is greater than the calculation one. The differences observed in the distributions indicate that the intensity of protons and light nuclei in primary spectrum is other than we assumed in the hundreds TeV region.

References

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[4] J. Malinowski, Proc. of the 28th ICRC, Tsukuba, HE–1.1, 135 – 138 (2003).
[5] J. Malinowski et al., Proc. of the 28th ICRC, Tsukuba, HE–1.1, 21 – 24 (2003).
[6] J. Malinowski, Proc. of the 28th ICRC, Pune, HE–1.2 (2005).