Muon Groups Underground and Primary Cosmic Ray Mass Composition

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Abstract

CORSIKA based Monte-Carlo simulations have been performed to simulate Baksan experiment on muon groups study underground. Comparison with experimental data as well as with previously made analytical calculations is presented. Some discrepancies with analytical calculation were obtained.

1. Introduction

An experiment for studying of muon groups underground is carried out in Baksan Underground Scintillator Telescope (BUST) for a long time of about 20 years. Experimental data for different depths from 850 hg/cm^2 to 5000 hg/cm^2 were obtained by selecting of inclined tracks in BUST [1-3].
Theoretical base for the phenomenon of muon groups (bundles) underground has been put by A.E.Chudakov in 1979 [4]. In a frame of 2 simple suppositions, namely: i) existence of scaling in the fragmentation region and ii) the number of muons similar to that of parent pions and kaons in Extensive Air Shower (EAS) follows a power low dependence of a type: $< N_\mu > \sim E_0{}^\delta$, where $\delta \approx 0.73$, he has obtained that muons should follow power low energy spectrum with integral index $\gamma \approx 1.7$, i.e. flatter by 1 than that for single muons, and also, he was first who has said that muon multiplicity spectrum should follow in asymptotic a power low with integral index $\beta = \gamma/\delta \approx 1.7 / 0.73 = 2.3$. Later this approach was successfully used in another works [1-3,5,6,8]. Note that such an approach is correct only in a case of absence of the pole in muon lateral distribution and when $E_\mu << E_0$ and so, both energy and multiplicity muon spectra shape do not depend on primary energy E_0.

2. Experimental set-up and calculations

The calculations were performed in 3 steps. First, we have made banks of artificial showers from different primaries, such as proton, He and Fe simulated by CORSIKA (version 6.012, HDPM model) for fixed primary energies and with zenith angle cut-off equal to 30 degrees. Second, we simulated banks of showers

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with power low spectrum index of –2.7 starting from 1 TeV per nucleon. Then, these showers were applied to real experimental set-up [7]. Standard HDPM model was used for hadron interactions and observation altitude level was chosen 1700 m a. s. l. in accordance with Baksan array location. The BUST is situated at a depth of 850 hg/cm^2 , it consists of 3200 liquid scintillator detectors (150 l each) and has outer dimensions equal to 11 x 16.7 x 16.7 m^3. It has spatial resolution equal to 0.7 m and angular resolution equal to 2°. Muon threshold energy is equal to 220 GeV. That is equal to 250 GeV for vertical direction.

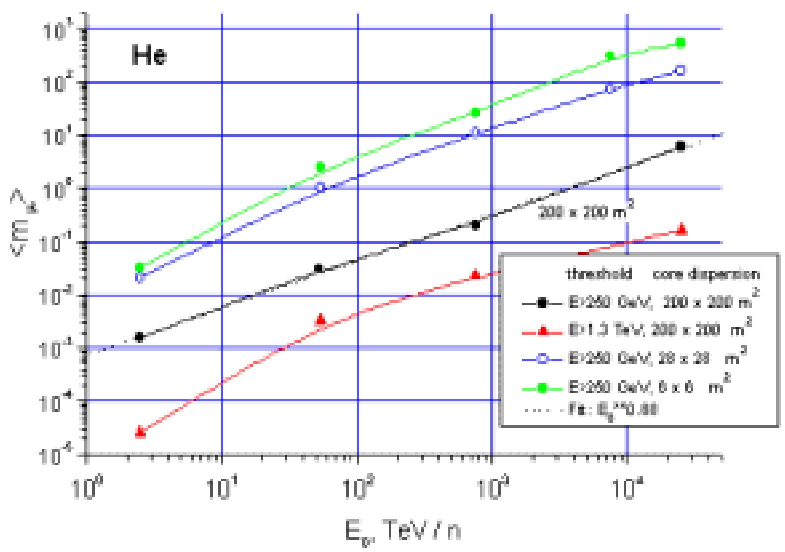

Fig. 1. Mean muon multiplicity in BUST as a function of primary He energy for various core dispersions.

Result for muon threshold energy 1.3 TeV is also shown (△) for comparison.

3. Results

Main results are shown in Fig.1 and Fig.2 [9]. Fig.1 shows expected mean muon number in BUST for various core dispersion area, as a function of primary energy E_0 for He originated EAS. As one can see, it rises with primary energy more rapidly than ${E_0}^{0.73}$. Dashed curve fitted the data for 200m core dispersion has a slope equal to 0.88. So, expected multiplicity spectrum should be flatter than $m^{-2.33}$ and is expected to be $\sim m^{-1.9}$. Fig.2 displays this. There are shown experimental data[2] and results of analytical calculations from [1] along with present Monte-Carlo simulations. Fig.3 shows a comparison of current calculations with BUST data taken from [1, 2] for low and medium multiplicity and from [10] for the highest observed multiplicity.

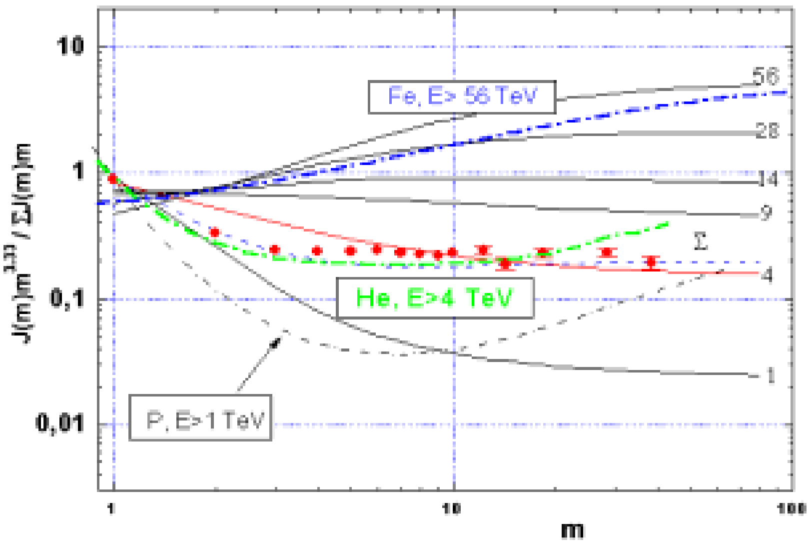

Fig. 2. Experimental and calculated multiplicity spectra in BUST for muons with energy above 250 GeV.

Dashed lines – our M-C simulation for various primary nuclei with energy above 1 TeV/nucleon. Solid lines marked by the mass number show the old analytical calculations[1,2]. • – experimental data from [2].

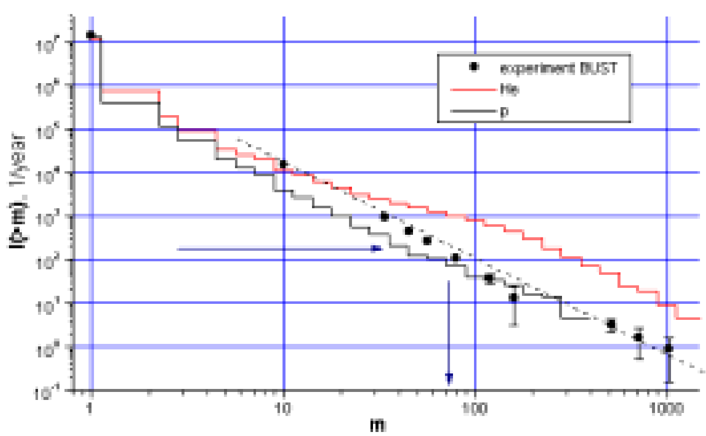

Fig. 3. Absolute integral muon groups intensity in BUST.

Histograms – calculations for primary p and He. Experimental data (•) from [2,8,10]. Arrows show the "knee" position obtained from the expected intensity.

4. Conclusion

As it can be seen from Fig.2, our results are in contradiction with previous analytical calculations. Asymptotical behavior of multiplicity spectra at least for light primaries, differs from that expected from analytical calculations. The reason could be probably found in the limitations and simplifications made in previous calculations, namely that muon energy spectrum does not depend on primary energy. In fact, the density of high energy muons has a pole at the EAS core and depends on primary energy more strongly than $E^{0.73}$. This results in flatter muon multiplicity spectrum in a detector of limited dimensions. Our result for muon multiplicity spectum observing in BUST can be fitted in asymptotic by a power law with integral index of $\sim$1.9. The experimental points corresponding to the highest multiplicity are lower of our expectations. On our opinion this could be caused by poor statistics in the M-C simulations or by methodical reasons: underestimation of real flux due to problem with event identification for large muon multiplicity in BUST. It is also seen in fig.3, that introduction of the "knee" in primary spectrum will not help to agree the data: experimental points lie more or less on a strait line.

Acknowledgements

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