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# THE SPECTRUM OF COSMIC RAY MUONS OBTAINED WITH 100-TON SCINTILLATION DETECTOR UNDERGROUND AND THE ANALYSIS OF RECENT EXPERIMENTAL RESULTS

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ABSTRACT

The vertical muon spectrum up to 15 TeV obtained with the underground installation is presented. Recent experimental data dealing with horizontal and vertical cosmic ray muon spectra are analyzed and discussed.

1. Results. The 100-ton scintillation detector /1/ has been used to obtain the final results on cosmic ray muon spectrum up to 15 TeV. The spectrum is measured at the depth of 570 m.w.e. in the salt mine. It has been determined by detecting the energy releases of electromagnetic cascades.

About 70% of cascade energy (for the energy range 0.1 ÷ 6 TeV) are detected by the installation. The electromagnetic cascades were obtained after the separation of nuclear cascades from electromagnetic ones by different number of neutrons in them.

A total of 16235 electromagnetic cascade events was obtained during 13188 hours of installation operation. The range of observed energy releases, $\varepsilon$, extends from 0.07 to 4 TeV. It corresponds to the muon energies at the depth, $E_{\mu}$, from 0.26 to 10 TeV and the muon energies at sea level, $E_{\mu_0}$, from 0.6 to 15 TeV.

The power index of $\pi$ - and K-meson spectrum has been determined as follows. We used the muon spectrum at sea level in the form as presented in /2/ with various values of $\gamma_{\pi,K}$. To calculate the muon spectrum at our depth we have applied the solution of kinetic equation for the muons passing through the material, the fluctuations being taken into account /3/. The spectrum of energy releases was obtained analytically and by Monte Carlo simulation. For both cases salt-scintillator transition effect was allowed for. The cascade curves for the various scintillator thicknesses were obtained in /4/. The nonuniformity of light collection and its fluctuations in the detector were taken into account in Monte Carlo simulation. The calculations had shown the energy releases detected to be a little greater than the energy releases without light collection fluctuations. Analitical and Monte Carlo spectra are of the same shape, the latter being 15 % higher in absolute intensity. Taking into account the surface topology, the index of calculated spectra is somewhat increased ( $\Delta\gamma \approx 0.05$).

To compare the experimental data with the calculations the $\chi^2$-test has been used. The best fit is obtained for $\gamma_{\pi,K} = 2.75 \pm 0.08$, however $\gamma_{\pi,K} = 2.65$ for $E_{\mu_0} < 1$ TeV and $\gamma_{\pi,K} = 2.85$ for $E_{\mu_0} > 1$ TeV don't contradict our results.

<u>2. Discussion.</u> The cosmic ray muon spectra in energy range $0.3 \div 20$ TeV were measured in the experiments with magnetic spectrometers (DEIS/5/, MUTRON /6/, MARS /7,8/, Kiel /9,10/, Nottingham /22/), X-ray emulsion chambers /11,12/, ionization calorimeters /13-16/ and depth-intensity curve method /17,18/. The spectral index of muon parents, $\gamma_{\pi,K}$, obtained with magnetic spectrometer DEIS and MUTRON (horisontal direction of incident muons) is $2.71 \div 2.74$ for $E_{\mu_0} > 0.3$ TeV. The depth-intensity curve gives $\gamma_{\pi,K} = 2.60 \div 2.75$, $\gamma_{\pi,K}$ following the X-ray chamber experiments being $2.75 \div 2.85$. The data of ionization calorimeters/13-15/ agree with cascade spectrum index $\gamma_{cascade} = 2.1 \div 2.3$. To explain these results some speculations have been proposed: the existence of an hypothetic particle /19/, an anomalous interaction of muons with heavy atoms ($A \geqslant 100$) or with polycrystals /20/. Even the authors of these works believe the cascade spectrum flatness not to refer to the muon spectrum. Fig.1 shows the vertical muon spectra at sea level presented in various papers. The full points are derived from our energy release spectrum. The horizontal spectra of MUTRON and DEIS were reconstructed to the vertical direction using the approximate formulae from /6/. Use was made of approximate formulae from /2/ with $\gamma_{\pi,K} = 2.65$ for $E_{\mu_0} < 0.3$ TeV and $\gamma_{\pi,K} = 2.75$ for $E_{\mu_0} > 0.3$ TeV to draw the solid curve in Fig.1. One can see the bulk of data for $E_{\mu_0} > 0.3$ TeV doesn't contradict $\gamma_{\pi,K} = 2.75$, the range of small energies being well described by $\gamma_{\pi,K} = 2.65$. The spectrum of muon parents seems to be approximated by the power law with index varying from 2.65 to 2.75. The cause of this variation is difficult to determine unambiguously.

The errors of primary spectrum measurements are too great to compare $\gamma_{\pi,K}$ with $\gamma_p$ of primary spectrum. To illustrate, the JACEE collaboration gives $\gamma_p = 2.81 \pm 0.13$ for $E_p = (1 \div 100)$TeV /21/. The $\gamma_p \sim 2.65$ up to 1000 TeV follows from the EAS experiments /23-26/. The discrepancy between this value and $\gamma_{\pi,K}$ from muon spectrum may be interpreted as the weak violation of scaling in the fragmentation region.But as there are some experiments giving the $\gamma_p$ for $E_p > 1$ TeV more greater

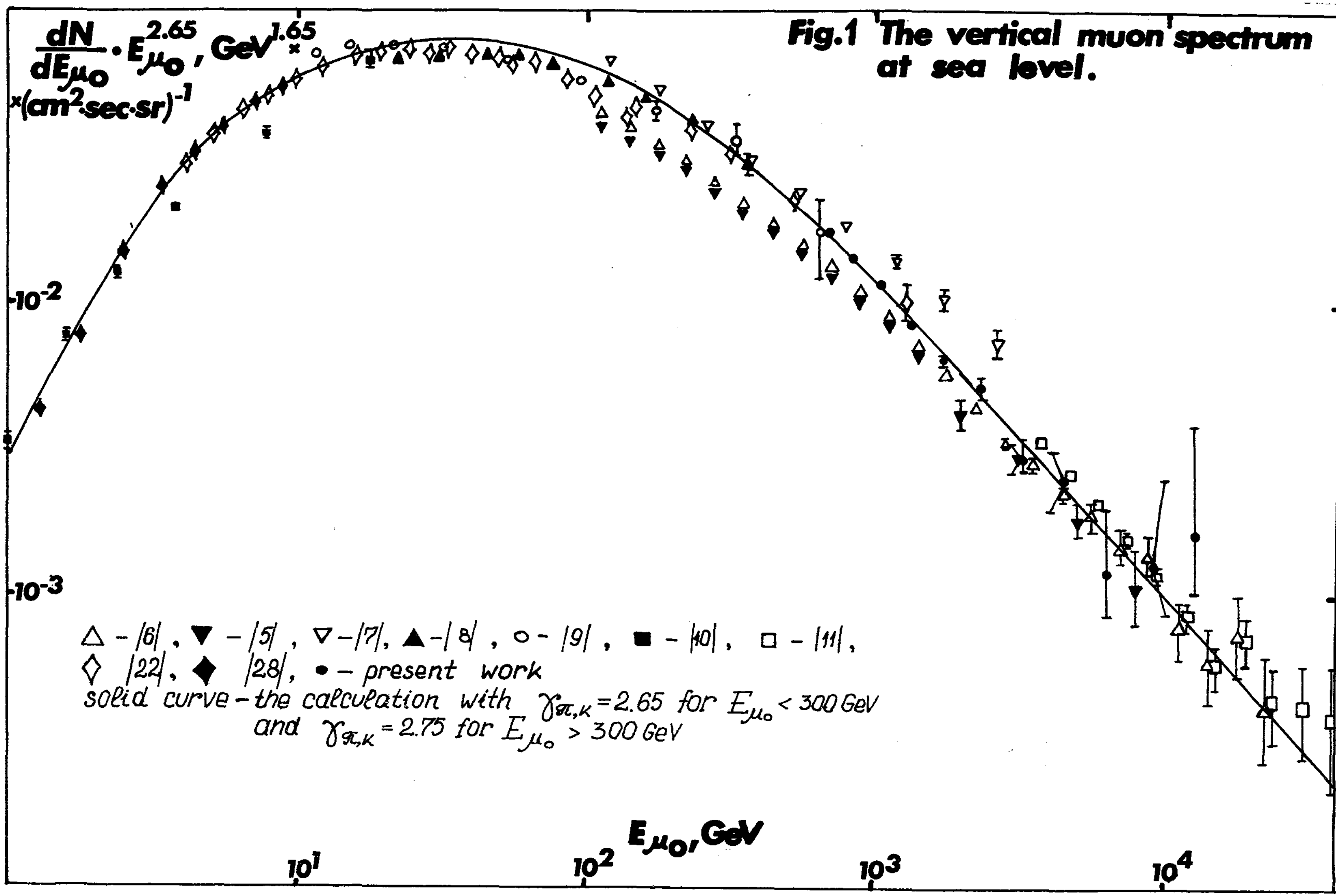


**Fig.1 The vertical muon spectrum at sea level.**

than 2.65 /21,27/ as we can not exclude the steepening of primary spectrum.

Thus the existence of small steepening of $\pi$- and K-meson spectra can be explained by either the steepening of primary spectrum or the scaling violation, or both the former and the latter.

## References

1. R.I.Enikeev et al. Proc.16th ICRC, Kyoto, 10,214(1979)
R.I.Enikeev et al. Proc.17th ICRC, Paris,10, 329 (1981)
2. L.A.Kuzmichev , L.V.Volkova, G.T.Zatsepin. Sov.J.Nucl. Physics, 29,1252(1979)
3. V.I.Gurentsov, E.D.Mikhalchi, G.T.Zatsepin. Sov.J.Nucl. Phys., 5,101(1976)
4. T.A.Chuykova . Proc.18th ICRC, Bangalore,5,316 (1983)
5. O.C.Allkofer et al. Proc.17th ICRC, Paris, 10,321(1981)
6. S.Matsuno et al. Phys.Rev.D29,1(1984)
7. M.G.Thompson et al. Prpc. 15th ICRC, Plovdiv,6,21(1977)
8. C.A.Ayre et al. J.Phys.G.,1, 584(1975)
9. O.C.Allkofer et al. Phys.Lett.,36B,425(1971)
10. O.C.Allkofer et al. Nuovo Cim.Lett.,12,107(1975)
11. M.A.Ivanova et al. Proc.19th ICRC, La Jolla (1985)
12. M.Ichiju et al. Proc.17th ICRC, Paris, 7,27(1981)
13. Yu.N.Bazhutov et al. Proc.17th ICRC, 7,59(1981)
14. A.D.Erlykin et al. Proc.13 ICRC, Denver,3,1803(1973)
15. V.A.Aglamazov et al.Proc.17th ICRC, Paris,7, 63(1981)
16. K.Mitsui et al.J.Phys.G., 9, 573(1983)
17. M.R.Krishnaswamy et al. Proc.15th ICRC, Plovdiv, 5,85 (1977)
18. L.Bergamasco et al. Nuovo Cimento,6C,569(1983)
19. Yu.N.Bazhutov et al. Izv.AN SSSR, ser.phys.,46,2425 (1981)
20. A.P.Chubenko et al. Proc.17th ICRC, Paris,7,98(1981)
21. I.C.Gregory et al.Phys.Rev.Lett.,51,1010(1983)
22. B.C.Rastin. J.Phys.G., 10,1609(1984)
23. I.N.Kirov et al. Proc.17th ICRC, Paris,2,109(1981)
24. B.S.Acharya et al.Proc.17th ICRC, Paris,9,162(1981)
25. T.Hara et al.Proc.18th ICRC, Bangalore, 9,198(1983)
26. G.B.Khristiansen et al. Proc.18th ICRC, Bangalore,9, 195 (1983)
27. V.G.Abulova et al. Proc.18th ICRC, Bangalore, 9 , 179 (1983).
28. A.I.Barbouti, B.C.Rastin. J.Phys.G., 9, 573 (1983)