PROPAGATION OF COSMIC RAYS THROUGH THE ATMOSPHERE IN THE QUARK-GLUON STRINGS MODEL.

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Quark-gluon strings model succeeds in the description of multiple hadron production in the central rapidity region of nucleon-nucleon interactions. This model has been developed for hadron-nucleus interactions and used for calculation of the cosmic ray propagation through the atmosphere. It is shown that at energies $10^{11}-10^{12}$ eV this model gives a satisfactory description of experimental data. But with the increase of the energy up to ~ 10^{14} eV results of calculations and of experiments begin to differ and this difference rises with the energy. It may indicate that the scaling violation in the fragmentation region of inclusive spectra for hadron-nucleus interactions is stronger than in the quark-gluon strings model.

Quark-gluon strings model (QGSM) describes successfully rather wide set of experimental data on the multiple hadron production in nucleon-nucleon collisions /1,2/. One of us (Yu.M.Sh.) developed this model for hadron-nucleus interactions. The weak scaling violation typical for that model becomes stronger after the transition from hp to hA collisions. In the fig.1 inclusive spectra of charged pions are shown. They were calculated according to QGSM with a magnitude of pomeron intercept Δ =0.14 for pN^{14}-collisions at energies 10^{11} and 10^{16} eV. It is seen that spectra become considerably softer in this energy range. For instance pion spectra at x=0.5 fall down by the factor 2,17. This model was used to calculate the penetration of cosmic rays through the atmosphere. The calculation routine was worked

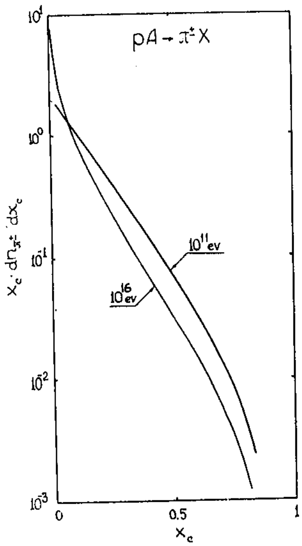

Fig.1.

out and used in papers /3,4/. Figures 2,3,4 demonstrate results of calculations compared with experimental data on energy spectra of muons at sea level, hadrons and gamma-quanta at different levels in the atmosphere. Energy spectrum and the mass composition of primaries were taken on the base of direct measurments at energies 10^{11}-10^{13} eV and small EAS data at energies 10^{13}-10^{15} eV /5/. These spectrum and the mass composition may be presented as

$$I(\geqslant E)=8.04\cdot 10^{-4}(E/0.1)^{-1.70}\left[B_p\cdot(1+6\cdot 10^{-4}\cdot E)^{-0.4}+\right.\qquad(1)$$

$$\left.+\sum_A' B_A(E/0.1)^{\Delta\gamma_A}(1+10^{-2}\cdot A^{-1}\cdot E)^{-0.4}\right]\ \mathrm{cm}^{-2}\cdot\mathrm{sec}^{-1}\cdot\mathrm{ster}^{-1}$$

where E - in TeV, B_p=0.41, B_4=0.22, B_{15}=0.13, B_{27}=0.14, B_{56}=0.10, $\Delta\gamma_4$ =0, $\Delta\gamma_{15}$ = $\Delta\gamma_{27}$ = $\Delta\gamma_{56}$ =0,04.

From the comparison of calculated and observed energy spectra of muons and hadrons at mountain level, which were measured by the most precise calorimetric method (fig.2,3), from similar comparison of mass and charge ratios of hadrons (data are not presented here due to the lack of space) one can conclude that QGSM gives a satisfactory agreement with experimental data at energies 10^{11}-10^{12} eV. Perhaps the only desirable improvement of this model at accelerator

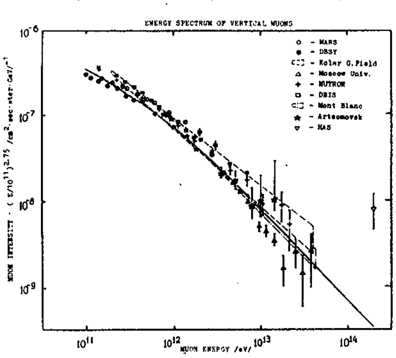

Fig. 2.

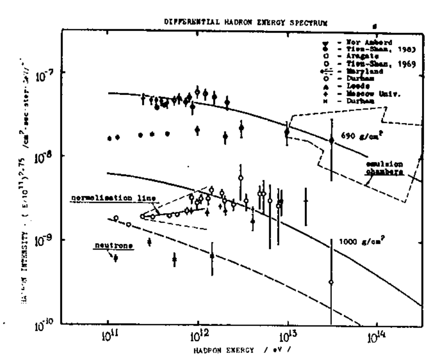

Fig. 3.

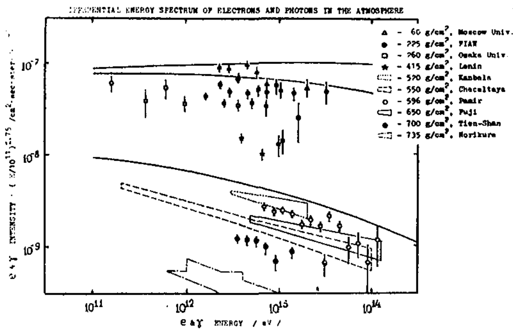

Fig.4. *)

energies is some reduction of the neutron flux, which influence on the muon charge ratio too.

Energy spectra of gamma-quanta are most sensitive to the high energy region. For gamma-quanta with energies 10^{13} eV at mountain level primary particles with energies above 10^{14} eV are responsible. It is seen in the figure 4 that calculation gives gamma-quanta intensities which exceed as a rule experimental values. This excess at mountain level is about the factor of 1.5. Uncertainties in the primary energy spectrum and mass composition could hardly explain the difference between calculations and experiments, since the spectrum (1) has the intensity at $\sim 10^{15}$ eV, which is at the lower end of the existing uncertainty. For example, spectra proposed by Nikolsky /6/ and by Maryland group /7/ give by ~ 1.4 higher intensities at this energy. It is not possible to vary the mass composition too, not coming to a contradiction with experimental data /8/. It is known that energy spectra of muons and gamma-quanta are most sensitive to the scaling violation in the fragmentation region of pion and kaon inclusive spectra. The observed excess of calculated intensities above experimental ones, the latter being stable in the future, indicates that the scaling violation for hadron-nucleus interactions is evidently stronger than in the present version of QGSM ($\Delta = 0,14$). This conclusion agrees with results of the analysis of lateral and energy characteristics of gamma families, according to which inclusive spectra in the fragmentation region go down not less than by the factor $3 \div 5$ when the collision energy increases from accelerator energies to 10^{16} eV /9/. Such a conclusion indicates possible directions of further improvement of this model at high energies.

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*) Upper full curve in the Fig.4 corresponds to calculations for the depth 60 g/cm^2, middle one - for 260 g/cm^2 and the lower one - for 600 g/cm^2.