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CHARGED LEPTON-NUCLEUS INELASTIC SCATTERING AT HIGH ENERGIES

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The composite model is made to describe inelastic high-energy scattering of muons and taus in standard rock. It involves photonuclear interactions at low Q^2 as well as moderate Q^2 processes and the deep inelastic scattering (DIS). In the DIS region the neutral current contribution is taken into consideration. Approximation formulas both for the muons and tau energy loss in standard rock are presented for wide energy range.

Keywords: muon inelastic scattering off nuclei; tau-lepton energy loss

1. Introduction

The muon inelastic scattering off nuclei contributes noticeably to the energy loss of cosmic rays muons. The influence of this interaction on the shape of ultra-high energy muon spectra at the great depth of a rock/water is still unknown in detail. The tau-lepton energy loss is of interest in view of ability of atmospheric or extraterrestrial muon neutrinos to transform to tau neutrinos which may produce taus in νN interactions. The validity of the well known model of photonuclear interactions,[1] employed over a long period in computations of the cosmic rays muon energy loss and the muon depth-intensity relation (see, e.g., Refs. 2, 3, 4), is not apparent at very high energies. Certainly low Q^2 processes give dominant contribution to the scattering, nevertheless the large Q^2 may contribute significantly at very high energies. Recently the high momentum transfer in high-energy lepton-nucleon interactions was taken into account by diverse ways.[5–7] Unlike Refs. 5, 7, in Ref. 6 the Z^0-exchange processes were taken into consideration but only scattering of muons was involved there. Present computation is close to the former differing however from that in some points:

i) very low Q^2 are considered separately from moderate Q^2;
ii) calculations are performed for wider range of lepton energies, $E = 10^3 - 10^9$ GeV;
iii) both muon and tau lepton energy loss spectra are calculated.

2. The model

The three-component model (3-model) is made to describe inelastic high-energy scattering of muons and taus in standard rock, involves photonuclear interactions at low momentum transfer squared as well as moderate Q^2 processes and the deep inelastic scattering (DIS). For low Q^2 (< 0.1 GeV^2) the structure function (SF) parameterization[1] based on the GVDM model was used. The Regge based model CKMT[8] was applied for moderate values of Q^2, $0.1 < Q^2 < 5$ GeV^2. In the DIS region electroweak nucleon SFs and lepton-nucleus cross sections are computed with the CTEQ6[9] set of parton distributions. Also considered is the two-component version (2-model) that consists of the CKMT model and the DIS calculations. For the scattering off nuclei effects of the nucleon shadowing, anti-shadowing as well as EMC effect are taken into account according to Ref. 6. The energy loss spectra for a lepton passing through a substance with nuclear weight A can be derived from the differential cross-section:

$$\frac{N_A}{A} y \frac{d\sigma^{\ell A}}{dy} = \frac{N_A}{A} y \int_{Q^2_{min}}^{Q^2_{max}} \frac{d^2\sigma^{\ell A}}{dQ^2 dy} dQ^2, \qquad y = \frac{E - E'}{E} = \frac{\nu}{E}. \tag{1}$$

The energy loss due to lepton-nucleus interactions is defined with the integral

$$b_N^{(\ell)}(E) \equiv -\frac{1}{E}\frac{dE}{dh} = \frac{N_A}{A} \int_{y_{min}}^{y_{max}} y \frac{d\sigma^{\ell A}}{dy} dy. \tag{2}$$

3. Results

Two top panels of Fig. 1 show the energy loss spectra of muons (left panel) and taus (right panel) in standard rock at the energy $E = 10^8$ GeV. The result of the 2-model (solid line) differs visibly from that of the 3-model (dash-dotted) only in small y range. Dotted lines show spectra calculated with the "nonperturbative part" approximation,[7] dashed lines present our calculation with the parameterization.[1] One can conclude that for not too large energies ($E < 10^5$ GeV) all these spectra differ significantly only at low y.

Predictions for the energy loss of muons and taus in standard rock are shown in the bottom panels of Fig. 1. Circles show calculations with the 3-model in which the nuclear effects for low-Q^2 component (BB) were taken into account after Ref. 6 instead of those in Ref. 1. Apparently the difference between the 2-model and 3-model appears because of nuclear effects, the anti-shadowing, EMC-effect and Fermi motion, which were not taken into consideration in Ref. 1. The energy dependence of the calculated muon and tau energy loss in standard rock can be approximated with the formula ($\ell = \mu, \tau$):

$$b_N^{(\ell)}(E) = (c_0 + c_1\eta + c_2\eta^2 + c_3\eta^3 + c_4\eta^4) \times 10^{-6}\ \mathrm{cm}^2/\mathrm{g}, \quad \eta = \lg(E/1\ \mathrm{GeV});$$

$$\mu: \quad c_0 = 0.98711,\ c_1 = -0.56840,\ c_2 = 0.17677,\ c_3 = -0.02114,\ c_4 = 0.00112;$$

$$\tau: \quad c_0 = 0.33247,\ c_1 = -0.22283,\ c_2 = 0.06811,\ c_3 = -0.00873,\ c_4 = 0.00048.$$

4. Summary

(i) The low Q^2 contribution to spectra of the muon and tau energy loss predicted by BB is close to the CKMT one except the small-y region. (ii) The nucleon anti-shadowing and

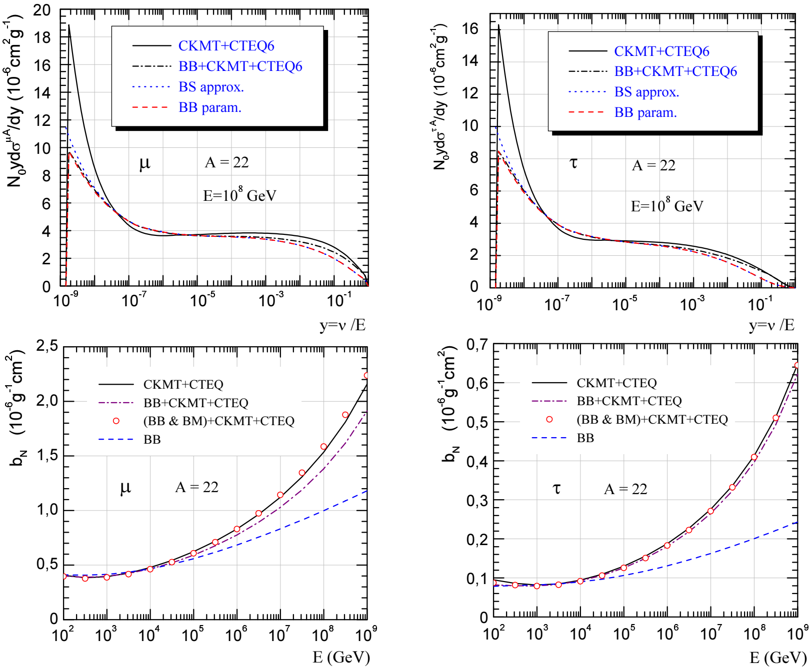

Fig. 1. **Top panels**: spectra of the lepton energy loss in standard rock ($Z = 11, A = 22$) at $E = 10^8$ GeV. **Bottom panels**: muon and tau lepton energy loss in the standard rock.

EMC effect influence visibly on muon energy loss. (iii) No apparent the neutral current part in the energy loss of muons and taus was found up to 10^9 GeV. (iv) There is noticeable discrepancy between this work prediction for high-energy behavior of the muon energy loss, $b_N^{(\mu)}(E)$, and that of Ref. 7, likely due to diverse ways in considering of high Q^2 processes and nuclear effects.

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