Influence of nonperturbative effects on the violation of scaling in neutrino interactions at $Q^2 = 2.0$–100.0 GeV^2

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The contributions of perturbative and nonperturbative effects to the violation of scaling are analyzed jointly for the structure functions of the nucleon measured in neutrino interactions at $2.0 < Q^2 < 100.0$ GeV^2. The value $\Lambda_{\overline{MS}} = 0.50 \pm 0.11$ GeV is found for the constant of quantum chromodynamics (the error is statistical). The contribution of the nonperturbative effects is negative, and its x dependence is described well by $x^2/(1-x)$.

The violation of scaling in lepton-nucleon processes is one of the major confirmations of perturbative quantum chromodynamics (QCD) as a theory of strong interactions. The values of the strong-interaction constant Λ which have been found experimentally in lepton-nucleon interactions, however, depend on the square of the 4-momentum transfer, Q^2, the square of the invariant mass of the hadronic system, W^2, and the scaling variable x (Ref. 1). This behavior is evidence that the violation of scaling may be caused by not only perturbative processes (of twist 2) but also dynamic nonperturbative processes (higher-twist effects). Among these processes, which are particularly important at moderate values of Q^2, are the scattering by bound quarks, the final-state interaction, and the effect of the transverse motion of quarks. So far, there has been little experimental[2] or theoretical[3,4] work on the effect of higher twists on the violation of scaling.

A power-law Q^2 dependence is generally accepted for the contribution of nonperturbative processes to the violation of scaling for structure functions:

$$F_i(x, Q^2) = F_i^{t=2}(x, Q^2)\left[1 + \frac{\mu_4(x)}{Q^2} + \frac{\mu_6(x)}{Q^4} + \ldots\right] \qquad (1)$$

where the functions $F_i^{t=2}$ determine the contributions of perturbative processes, and their Q^2 dependence is described by the Lipatov-Altarelli-Parisi equation.[5] The predicted x dependence of μ_i is[3,4] $\mu_i(x) \sim x^{\gamma}/(1-x)$.

In this leter we report the results of a joint analysis of perturbative and nonperturbative effects in the violation of scaling in an experiment on the inelastic scattering of (anti) neutrinos by an isoscalar target. The results of an analysis of the violation of scaling in perturabtive QCD were published in Ref. 6. The following values were found for the QCD scaling parameter in first and second orders in the coupling constant $\alpha_s(Q^2)$, corrected for the target mass over the range $2.0 < Q^2 < 100.00$ GeV^2:

$$\Lambda_{LO} = 0.16 \pm 0.07 \text{ (stat) } \pm 0.12 \text{ (syst) GeV },$$

$$\Lambda_{\overline{MS}} = 0.17 \pm 0.06 \text{ (stat) } \pm 0.12 \text{ (syst) GeV}.$$

These experiments were carried out at a 15-foot bubble chamber filled with a neon-hydrogen mixture (64% Ne atoms). The statistical base is 10 200 νN and 8265 $\tilde{\nu}N$ inelastic interactions of a charged current which meet the following requirements: The energy of the incident (anti) neutrino is greater than 10.0 GeV; the momentum of the muon is greater than 4.0 GeV; and the energy transfer from the lepton vertex to the hadronic system is greater than 0.5 GeV. The experiments and the criteria for selecting events are described in more detail in Ref. 7.

For a joint analysis of the perturbative and nonperturbative contributions to the violation of scaling, we used data on xF_3 over the interval $0.0 < x < 0.7$ and data on F_2 over the interval $0.3 < x < 0.7$ (the latter can be justified by the circumstance that the contribution of sea quarks to F_2 is small at $x > 0.3$). Data with $x > 0.7$ were excluded from the analysis, since the corrections for the experimental resolution in this region are large. The influence of nonperturbative effects on the violation of scaling was analyzed for the range $2.0 < Q^2 < 100.0$ GeV^2.

To study the x dependence of the higher-twist contribution, we fitted the structure functions to the experimental data, using expression (1). On the right side of expression (1) we retained only the term proportional to $1/Q^2$, and to describe perturbative processes, we used the QCD predictions in the $\overline{MS}$ scheme. The structure functions were parametrized in the form $F_i(x,Q_0^2) \sim x^\alpha(1-x)^\beta(1-\kappa x)$ at $Q^2 = Q_0^2 = 10.0$ GeV^2. The Lipatov-Altarelli-Parisi equation was solved by the method of Ref. 8.

Figure 1 shows the resulting x dependence of the higher-twist contribution. Shown for comparison here are data from neutrino experiment[9] WA59 and the results

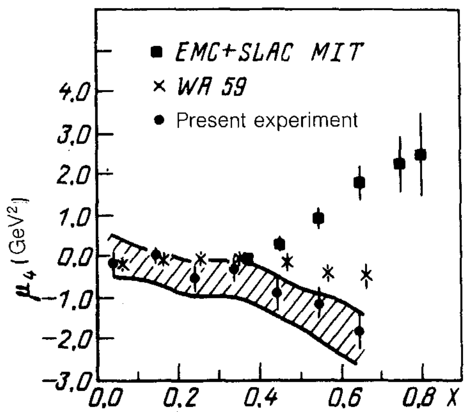

FIG. 1. The x dependence of the contribution of nonperturbative effects to the violation of scaling in the structure functions of the nucleon found in various experiments. The hatched region shows the systematic uncertainties in the determination of the parameter μ_4 for our experiment.

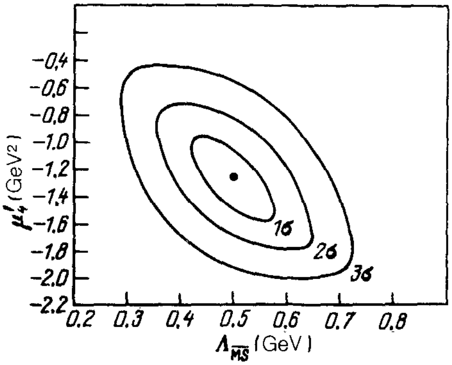

FIG. 2. Correlation between the parameters $\Lambda_{\overline{MS}}$ and μ_4' corresponding to the parametrization $\mu_4' x^2/(1-x)$ of the contribution of nonperturbative effects.

of a joint analysis of SLAC-MIT and EMC measurements.[10] It can be seen from our data that at $x > 0.4$ the higher-twist contribution becomes negative definite. The behavior of the data from neutrino experiment WA59 has a similar tendency, but not as pronounced. One possible reason is that in experiment WA59 it was assumed that higher-twist effects could be ignored even at $Q^2 > 4.0$ GeV^2 and $W^2 > 10.0$ GeV^2. We know[3] that the higher-twist contribution to the violation of scaling can be important up to $Q^2 = 100.0$ GeV^2.

It can be seen from this figure that the higher-twist contribution to the violation of scaling in the scattering of charged leptons by nucleons has a positive sign at $x > 0.4$. The possibility of such a behavior of the higher-twist contribution has been pointed out by Shuryak and Vainshtein.[11]

The behavior of the higher-twist contribution, shown in Fig. 1 for our data, is described best by the formula $\sim x^2/(1-x)/(\chi^2/NDF = 4.3/6)$.

The negative sign of the nonperturbative contribution to the violation of scaling results in a negative correlation between the QDC constant and the higher-twist constant. The situation is illustrated in Fig. 2. The higher-twist contribution has been parametrized in the form $\mu_4' x^2/(1-x)$. The best description of the data ($\chi^2/NDF = 66/73$) is reached with the values $\Lambda_{\overline{MS}} = 0.50 \pm 0.11$ GeV and $\mu_4' = -1.25 \pm 0.50$ GeV^2.

Incorporating nonperturbative effects in the analysis of our data substantially increases the contribution of perturbative effects to the violation of scaling for the structure functions. The constant Λ is approximately tripled. The higher-twist contribution in the neutrino interactions is negative, in contrast with the results found for the scattering of charged leptons.

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