Higher-twist effects in semi-inclusive $\tilde{\nu}N \to \mu^+ h^- X$ reactions

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A y-z correlation has been observed for semi-inclusive $\tilde{\nu}N \to \mu^+ h^- X$ reactions in the current fragmentation region in an antineutrino experiment carried out with the Fermilab 15-foot bubble chamber. This correlation can be explained as an effect of higher twists. When the kinematic effect is ignored, the parameter $\langle P_T^2 \rangle$, which determines the magnitude of the higher-twist contribution, is estimated to be 0.18 ± 0.06 (GeV/c)^2.

The scaling violation which is observed in the structure functions and fragmentation functions can be described satisfactorily by quantum chromodynamics.[1] The validity of a comparison of experimental data with the predictions of quantum chromodynamics, however, depends to a large extent on the contribution of higher twists,[2] which is expected to fall off with increasing value of the square of the momentum (Q^2) transferred from the lepton to the hadrons or with increasing value of the square of the invariant mass (W^2) of the hadron system.

Experiments on the higher-twist effect in semi-inclusive lepton-nucleon processes have recently been reported.[3,4] The semi-inclusive cross section for the production of negative hadrons (h^-) in the reaction $\tilde{\nu}N \to \mu^+ h^- X$ can be written[4,5]

$$d^3\sigma/dx\,dy\,dz \sim (x/z)\{[q(x)(1-y)^2 + \bar{q}(x)]$$

$$\times (1-z)^2 + (4/9)((1-y)/Q^2)(q(x)+\bar{q}(x))\langle P_T^2 \rangle\}.$$

Here $x = Q^2/2mE_H$, $y = E_H/E_\nu$, $z = E_h/E_H$, E_ν is the antineutrino energy, E_H is the energy transferred to hadrons, E_h is the hadron energy, m is the mass of the nucleon, the parameter $\langle P_T^2 \rangle$ determines the higher-twist contribution, and xq and $x\bar{q}$ represent the momentum distributions of the quarks and antiquarks in the nucleon. This expression was derived in the approximation of zero masses, small transverse momenta of the hadrons, and large z. For the production of positive hadrons (h^+) in the reaction $\nu N \to \mu^- h^+ X$, the corresponding expression for the cross section is found through the interchange $q \leftrightarrow \bar{q}$. The term that violates the scaling in this expression ($\sim 1/Q^2$) arises from the higher-twist contribution and is significant at moderate values of Q^2.

At large values of x, where the contribution of antiquarks may be ignored, the higher-twist effect has a simple consequence: the z distribution for $h^+(h^-)$ for $\nu N(\tilde{\nu}N)$

interactions becomes harder (softer) at small values of y than at large values of y. The y-z correlation in the νN ($\tilde{\nu}N$) interaction should not be present for "nonleader" h^-(h^+) hadrons. Our purpose in the present study was to determine the y-z correlation in the reaction $\tilde{\nu}N \to \mu^+ h^- X$.

Mazzanti *et al.*[6] have pointed out that the y-z correlation observed in νN interactions for h^+ is of a kinematic nature and can be reproduced satisfactorily by the model of a longitudinal phase space. In this model, the reason for the correlation is simple: Events with low multiplicities are dominant at small values of y. The probability for a hadron to have a large value of z is thus high. Consequently, taking the higher-twist effect into account for h^+ in the νN scattering leads to the same y-z correlation as does the kinematic effect. On the other hand, the higher-twist effect for h^- in $\tilde{\nu}N$ interactions is opposite the kinematic effect. We thus conclude that $\tilde{\nu}N$ scattering is the only possibility for studying the higher-twist effect.

The statistical base of our experimental analysis is $\sim$155 000 photographs obtained from the Fermilab 15-foot bubble chamber, filled with a heavy neon-hydrogen mixture (64% Ne atoms). The experimental procedure and the procedure for selecting events are described in more detail in Refs. 7 and 8. In this study, the energy of the antineutrinos was corrected individually for each event.[9] After imposing the cutoffs $P_\mu > 4$ GeV, $E_\nu > 10$ GeV, $Q^2 > 1$ (GeV/c)^2, and $W > 2$ GeV we are left with $\sim$3900 $\tilde{\nu}N$ interactions which occur through a charged current. For these events we have $\langle Q^2 \rangle = 6.3$ (GeV/c)^2 and $\langle W^2 \rangle = 22$ GeV^2. For the analysis we used only those particles for which the relative error in the momentum satisfied $\Delta P/P < 30\%$. The loss of poorly measured tracks was taken into account by appropriate corrections.[10] A sample of positive mesons, for which no higher-twist effect is expected, was used for a normalization; this procedure made it possible to cancel the identical kinematic dependences and to bring out the effect of interest in its pure form. The contribution of unidentified protons (with momenta greater than 1 GeV/c) in the sample of h^+ hadrons was analyzed by the method of Ref. 11. The results show that at $z > 0.4$ and with the cutoffs listed above these protons can be ignored. For the correlation analysis we considered only the hadrons moving into the forward hemisphere in the hadron center-of-mass frame.

To reliably distinguish the higher-twist contribution we selected events with $x > 0.15$, thereby suppressing the contribution of the interactions of antineutrinos with antiquarks. To study the Q^2 dependence of the higher-twist effect, we carried out an analysis for two Q^2 regions: $1 < Q^2 < 8$ (GeV/c)^2 [$\sim$1900 events, $\langle Q^2 \rangle = 3.9$ (GeV/c)^2] and $8 < Q^2 < 50$ (GeV/c)^2 [$\sim$790 events, $\langle Q^2 \rangle = 16.2$ (GeV/c)^2].

Figure 1 shows the z dependence of the ratio of the average values of y, $\langle y \rangle_{h^-} / \langle y \rangle_{h^+}$, for negative and positive hadrons in these two Q^2 regions. The experimental data are compared here with the predictions of the Field-Feynman fragmentation model.[12] We see that the experimental data show an excess of $\langle y \rangle_{h^-}$ over $\langle y \rangle_{h^+}$ at large values of z for small values of Q^2, in agreement with the behavior expected from the higher-twist contribution.

The y-z correlation can be seen most clearly in a comparison of the shapes of the y distributions for the h^+ and h^- hadrons which have been distinguished. Figure 2 shows the y distributions of the ratio of these hadrons for two regions along z ($z < 0.4$

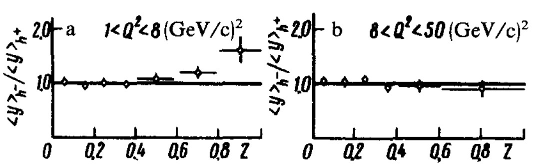

FIG. 1. The z dependence of the ratios of the average values of y, $\langle y\rangle_{h^-}/\langle y\rangle_{h^+}$, for h^+ and h^- hadrons in the reaction $\tilde{\nu}N\to\mu^+h^-(h^+)X$ at $W>2$ GeV. a—$1<Q^2<8$ (GeV/c)^2; b—$8<Q^2<50$ (GeV/c)^2. The solid lines are the predictions of the Field-Feynman model.

and $z>0.4$) and for small and large values of Q^2. The solid lines are the predictions of the Field-Feynman model. We see that the y distribution of h^- is harder than that of h^+ only at $z>0.4$ and at small values of Q^2.

The observed behavior of the y-z correlation is thus consistent with a higher-twist effect on the reaction $\tilde{\nu}N\to\mu^+h^-X$.

For a quantitative estimate of the higher-twist contribution, we make use of that dependence of the fraction of particles with large values of $z(z>a)$ on y which is caused by the y-z correlation. Following Refs. 4 and 5, we find

$$D^{h^-}(z>a)=\int_a^1 D^{h^-}(z)\,dz=\int_a^1 (1/N_{\mathrm{int}})(dN^{h^-}/dz)\,dz$$

$$=A\int_a^1 (1-z)^2/z\,dz+AR\langle P_T^2\rangle\int_a^1 (1/z)\,dz,$$

where

$$R=(4/9)\,(q(x)+\bar{q}(x))/\,(q(x)(1-y)^2+\bar{q}(x))\,(1-y)/Q^2,$$

and A is a normalization constant. The higher-twist contribution is more sensitive to

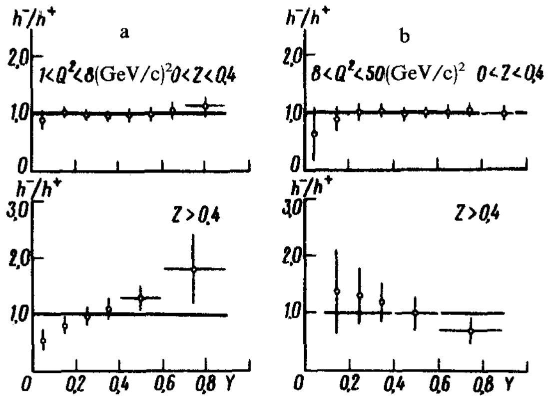

FIG. 2. The y distribution of the ratio of h^+ and h^- hadrons in two regions along z, $z<0.4$ and $z>0.4$, for the reaction $\tilde{\nu}N\to\mu^+h^-(h^+)X$ at $W>2$ Gev. a—$1<Q^2<8$ (GeV/c)^2; b—$8<Q^2<50$ (GeV/c)^2. The solid lines are the predictions of the Field-Feynman model.

the parameter R as defined here than it is to y. If the scaling violation is caused exclusively by the higher-twist effect, then $\langle P_T^2 \rangle$ can be estimated from the parameters of the straight line

$$D^{h^-}(z > a) = b + cR,$$

which describes the R dependence of $D^{h^-}(z > a)$. We find $b = A \int_a^1((1-z)^2/z)dz$ and $c = A \langle P_T^2 \rangle \int_a^1(1/z)dz$. At $Q^2 > 1$ (GeV/c)^2, for $W > 2$ GeV, for all values of x, and for $a = 0.4$, we find the value [1)] $\langle P_T^2 = 0.18 \pm 0.06$ (GeV/c)^2. The estimate of $\langle P_T^2 \rangle$ is insensitive to the x cutoff. Since the kinematic effect partially cancels the higher-twist effect, this estimate of $\langle P_T^2 \rangle$ is on the low side.

It follows from this analysis that the reaction $\tilde{\nu}N \to \mu^+ h^- X$ exhibits a y-z correlation in the current fragmentation region at $1 < Q^2 < 8$ (GeV/c)^2. The observed correlation agree with the effect expected from the higher-twist contribution.

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[1)]In determining R for the momentum distributions of the quarks and the antiquarks in the nucleon, we used the parametrizations of Field and Feynman,[13] which give a good description of our experimental data.[8]

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