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CONTRIBUTIONS FROM HIGHER TWIST EFFECTS TO THE QUARK

FRAGMENTATION FUNCTIONS IN NEUTRINO DATA

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ABSTRACT

Quark fragmentation functions are studied with ~ 3500 charged current events induced in the bubble chamber Gargamelle by neutrinos of the SPS wide band beam, with $\langle E_\nu \rangle \simeq 25$ GeV. The Q^2 and W^2 regions covered by this experiment are $Q^2 \simeq 0-40$ GeV and $W^2 \simeq 1-100$ GeV, the mean values being $\langle Q^2 \rangle = 6.5$ GeV, $\langle W^2 \rangle = 22$ GeV². A correlation between the variables $z = E_\pi/E_H$ and $y = E_H/E_\nu$ is found in the data in the region $Q^2 = 1-10$ GeV, which can be explained in terms of higher twist effects. These effects reproduce the Q^2 evolution of the non-singlet moments of the fragmentation function without any need for logarithmic terms.

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Deviations from scaling have been observed [1] in the deep inelastic lepton scattering, and generally considered to provide support to quantum chromodynamics. The Q^2 evolution of structure functions predicted by QCD seems to agree with experiments but the applicability of these predictions depends critically on the size of the higher twist contributions [2,3,4]. A contribution which dies away as a negative power of Q^2 (higher twist) [3] must be taken into account in analysing the data [5]. The "low" Q^2 range say 2-40 GeV^2 , could give very important experimental information on the contributions of these terms to the scaling violation.

In this experiment, we looked for higher twist effects in the quark fragmentation functions $D_u^{h^\pm}$, where $h^\pm$ is a positive or negative hadron, most frequently a pion. About 3500 charged current neutrino interactions $\nu N \rightarrow \mu^- h^\pm X$ were analysed in the bubble chamber Gargamelle. In this analysis, all the positive tracks not identified as protons (a proton is identified up to about 800 MeV/c) are classified as pions. The chamber was filled with heavy liquid (90% C_3H_8 + 10% CF_3Br) and the beam was the wide band neutrino beam from the SPS at CERN, with $\langle E_\nu \rangle \approx 25 \text{ GeV}$. The μ^- was identified by an external muon identifier (EMI) made of 3 planes of MWPC described in [6], with an efficiency increasing from $\sim 40\%$ at $E_\mu = 2 \text{ GeV}$ to 100% at $E_\mu \approx 9 \text{ GeV}$. Events with muons with $E_\mu < 2 \text{ GeV}$ were rejected. In the selected charged current sample, the neutral current contamination is less than 1.5%. The determination of the neutrino energy E_ν was made by correcting the total measured hadronic energy (E_H) for the losses of neutral particles (γ , neutrons, neutral strange particles). The chamber being filled with a heavy liquid, these losses are not very important, and the total error on the hadronic energy is $\Delta E_H/E_H \approx 11\%$ in the range $E_H = 5-30 \text{ GeV}$. The Q^2 range covered by this experiment is 0 to 40 GeV^2 , with $\langle Q^2 \rangle \approx 6.5 \text{ GeV}^2$. The total invariant hadronic mass W^2 , which is the most relevant variable for the hadron vertex study, extends up to 100 GeV^2 , with an average value $\langle W^2 \rangle \approx 22 \text{ GeV}^2$. The acceptance in the plane (x, Q^2) where $x = Q^2/2m_N E_H$, is practically constant and greater than 90%. The acceptance in $y = E_H/E_\nu$ is 100% from 0 to 0.8 and is reduced to 0 at $y = 1$. by the EMI efficiency and the $E_\mu > 2 \text{ GeV}$ cut.

We define the variable z as:

$$z = \frac{\vec{P}_\pi \cdot \vec{P}_N}{\vec{Q} \cdot \vec{P}_N} = \frac{E_\pi}{E_H}.$$

Then,

$$D_u^{\pi^\pm}(z, Q^2) = \frac{1}{N_{ev}(Q^2)} \frac{dN^{\pi^\pm}(z, Q^2)}{dz}$$

is the multiplicity of charged secondary hadrons per unit of z , mainly due to the u quark fragmentation. The simple quark parton model predicts that D_q^π depends on z and Q^2 only, while quantum chromodynamics expects also a dependence on x [7,8] and predicts its Q^2 evolution [8]. In order to study the fragmentation functions and their Q^2 evolution, we retained for the analysis only those events which have $W^2 > 4 \text{ GeV}^2$ and $Q^2 > 2 \text{ GeV}^2$. This ensures the reduction of background due to non-identified protons, which can distort the z distribution over the overall range $z = 0-1$ [9]. In the region $W^2 > 4 \text{ GeV}^2$, it was found [9] that a small contamination of non identified protons remained at low z ($z < .5$), but it disappeared at high z ($z > .5$). Once these cuts are applied, the range of W covered by this experiment is $W \simeq 2-10 \text{ GeV}$ with $\langle W \rangle = 5.5 \text{ GeV}$ (which is still not a very high value). One should stress in fact that a clean separation of current and target fragmentation regions would be possible for $W \geq 5 \text{ GeV}$, and that below this value the separation is not completely efficient.

In Fig. 1 the fragmentation functions for π^+ and π^- are shown for different x , Q^2 (Fig. 1a) and y , Q^2 (Fig. 1b) regions. The data in Fig. 1b show a correlation between y and z for positive pions at low Q^2 . To study this further, we looked at the y distributions at fixed values of z_π ; for π^+ and π^- from $\nu N \rightarrow \mu^- \pi^\pm X$ separately. The behaviour of the data is shown in Fig. 2 for three different values of z . An additional cut on $x > 0.15$ has been applied to eliminate the sea contribution. The data are compared with Monte Carlo distributions obtained by applying the same cuts to the generated events as to the data, as well as a smearing due to measurement errors. Monte Carlo generates ν events with a flat y distribution as expected in the simple parton model. Fragmentation functions are of Feynman and Field type [10].

In Fig. 2 the agreement between the data and the Monte Carlo is good everywhere except for the π^+ sample with $z > 0.5$ for which the y distribution seems not to be flat anymore. Another way to see the effect is to compare directly the y distributions for π^+ and π^- . Assuming that the behaviour of π^- describes completely a flat distribution distorted by the detection efficiency functions and all possible kinematical effects at different z values, one can see from Fig. 3a that the y distributions are exactly the same for π^+ and π^- at low z values, but π^+ is different from π^- at $z > 0.5$ and it shows in that region a linear behaviour. Although the statistics is not large, we have to note that the probability that the distribution for $z > 0.5$ is flat, is of the order of 10^{-3} . If this trend was due to a phase space effect one should observe the same behaviour in the π^-/π^+ ratio in $\bar{\nu}$ interactions. We plot, just for comparison, this ratio which seems to behave in a different way (Fig. 3b)*.

In Ref. [11] it was predicted that a higher twist effect contributes a longitudinal term σ_L to the cross section, and that the y and z dependences are correlated:

$$\frac{d\sigma}{dz dy dQ^2} (\nu N \rightarrow \mu^- \pi^+ X) \propto (1-z)^2 + \frac{4}{9} (1-y) \frac{\langle K_T^2 \rangle}{Q^2} \quad (1)$$

The parameter $\langle K_T^2 \rangle$ is related to the primordial transverse momentum of the quark, but contains also all the mass terms which are neglected in the calculation of Ref. 11.

From (1) one may observe that the y distribution is not expected to be flat for $z \rightarrow 1$. Instead, as $z \rightarrow 1$, it is predicted to fall as $(1-y)$. This is qualitatively consistent with our π^+ data. In the case of $\bar{\nu}$, the effect should show up as an excess of events with a π^- of large z in the high y region, due to the comparison of $(1-y)^2$ behaviour with the $(1-y)$ one [11]. Furthermore, (1) indicates that the $(1-y)$ term should vary as $1/Q^2$. To examine this, we compare in Fig. 1b the two different Q^2 regions 1-10 GeV^2 and 10-80 GeV^2 . The effect is present in the 1-10 GeV^2 region, and it seems to die out above 10 GeV^2 , in agreement with (1). In the π^- case (Fig. 1b) no difference appears between the two Q^2 ranges. We fit the data at $z_{\pi^+} > 0.5$ with the expression (1) in order to determine the parameter K_T^2 . The fit gives $\langle K_T^2 \rangle = 1.5 \pm 0.4 \text{ GeV}^2$. Having determined the parameter $\langle K_T^2 \rangle$ in this way, we then ask whether the higher twist effect can account also for the Q^2 evolution of non-singlet moments of

* Private communication from the $\bar{\nu}$ Gargamelle collaboration

fragmentation functions. Using the calculation in Ref. 11, the fragmentation function $D_u^{\pi^+}$ has the form:

$$D_u^{\pi^+}(z, Q^2) \propto (1-z)^2 + \frac{2}{9} \frac{\langle K_T^2 \rangle}{Q^2} \quad (2)$$

containing a scaling violating term $\propto 1/Q^2$.

We measured the non-singlet moments, defined as:

$$M^{NS}(n, Q^2) = \int_{0.2}^1 z^{n-1} [D^{\pi^+}(z, Q^2) - D^{\pi^-}(z, Q^2)] dz \quad (3)$$

and compared their Q^2 evolution with an expression containing both logarithmic QCD $(\ln Q^2/\Lambda^2)^{d_n}$ and higher twist terms $1/Q^2$. This comparison is significant only for high moments, where large values of z weigh the most ((2) is only valid for $z > .5$). The n dependence of the higher twist term is deduced from (2), and the parameter K_T^2 as determined by the y distribution above.

Fig. 4 shows the result of the fit for moments $n = 3$ to 7. The χ^2 is 0.5/d.o.f, and there is no need for logarithmic terms to describe the Q^2 dependence of (3), i.e. Λ is compatible with 0. If instead of (2) the dependence on n were chosen to be linear for the higher twist contribution [3], then the value of Λ becomes $\Lambda < 200$ MeV (see Fig. 5). This seems to be in agreement with the small value of Λ ($\Lambda < 100$ MeV) determined in μ scattering [12] for high Q^2 values, where, according to our data, the higher twist effects are no longer important.

In this analysis we did not try to interpret the data in terms of higher order QCD corrections which predict [7] a (x, z) correlation. One should stress however that effects of higher order corrections could not explain the (y, z) correlation observed in Fig. 1b.

CONCLUSIONS

Semi-inclusive neutrino data $\nu N \rightarrow \mu^- \pi^+ x$ show a correlation between z and y in the region $Q^2 = 2-40$ GeV and $W = 2-10$ GeV. This correlation can be explained as an effect due to higher twist terms [11] and it can account for the Q^2 dependence of non-singlet moments without any need for

logarithmic scaling violating terms. This fact is not in conflict with QCD, but it indicates that the region of low Q^2 ($Q^2 < 10 \text{ GeV}^2$) and low W is not immuned from important $1/Q^2$ effects, and is not suitable for tests of $\ln Q^2$ scaling deviations.

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FIGURE CAPTIONS

Fig. 1 a) z distributions for positive and negative hadrons in two different Q^2 and x regions.

b) z distributions for positive and negative hadrons in two different Q^2 and y regions.

Fig. 2 y distributions at fixed z for π^+ and π^- . The curve is Monte Carlo predictions from a flat y distribution.

Fig. 3 Comparison between the shapes of y distributions of π^+ and π^- for fixed z values. a) π^+/π^- in interactions; b) π^+/π^- in $\bar{\nu}$ interactions. The data of Fig. b are from Gargamelle SPS $\bar{\nu}$ exposure.

Fig. 4 Fit of $M_n^{NS} = K_n / (1_n Q^2 / \Lambda^2)^{d_n} [1 + 0.31 (n+1)(n+2)/2 Q^2]$ where Λ and K_n are free parameters, to the non singlet moments of order $n = 3$ to 7. Only $n = 4, 5, 6$ are shown.

Fig. 5 Λ, B correlation determined by the fit to $M_n^{NS} = K_n / (1_n Q^2 / \Lambda^2)^{d_n} [1 + Bn/Q^2]$, taking all moments $n = 3 \dots 7$. The crossed area represents values of Λ determined by the value of B measured with the y distribution.

FIG. 1a

FIG. 1b

FIG. 2

Fig. 3

Fig. 4

Fig. 5