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HIGHER TWIST QCD TERMS IN HIGH-P_T PION PRODUCTION

by

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HIGHER TWIST QCD TERMS IN HIGH-P_T PION PRODUCTION*

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ABSTRACT

We investigate the higher twist subprocesses $qG \rightarrow q\pi^{\pm}$ and $q\bar{q} \rightarrow G\pi^{\pm}$ in the framework of perturbative Quantum Chromodynamics (QCD). Cross sections for these processes are compared with the minimum twist QCD results for $q\bar{q} \rightarrow q\bar{q}$ and $qG \rightarrow qG$. The higher twist terms give sizeable corrections to the inclusive pion yields, particularly for $q\bar{q}$ initial states. We also examine the effects of higher twist QCD terms for the charge ratio, $N(\pi^- N \rightarrow \pi^- X)/N(\pi^- N \rightarrow \pi^+ X)$.

Most investigations of high-p_T hadron production in the framework of perturbative Quantum Chromodynamics (QCD) have involved a conventional hard-scattering formalism in which $2 \rightarrow 2$ quark/gluon cross sections are convoluted with non-perturbative structure functions and fragmentation functions. However, we now have reason to believe that this minimum-twist scenario is not the only important hadron production mechanism expected in QCD. It has been emphasized for some time that, in a hard-scattering expansion involving <u>hadrons</u>, a very significant role may be played by subprocesses involving "constituents" other than isolated quarks and gluons. Pairs of quarks or gluons from a given hadron may participate in a coherent fashion in a hard scattering process. Such higher-twist QCD mechanisms have been shown to be important in the Drell-Yan process and in semi-inclusive deep inelastic scattering. In this note, we summarize an extension of higher-twist physics to inclusive, high-p_T pion production in hadron-hadron collisions.[1]

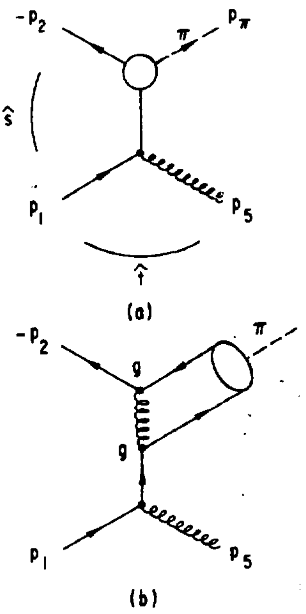

Fig.(1) (a) Quark-exchange amplitude for $q\bar{q} \rightarrow \pi G$.
(b) Hard-gluon approximation.

Our basic approach is illustrated in Fig.(1). In the single quark-exchange process sketched in Fig.(1.a), the pion emerges from an a priori complicated $q\bar{q}\pi$

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vertex. However, if we consider only high p_T^2 scattering, and if we view the pion as a $q\bar{q}$ bound state, then the large-p_T process in Fig.(1.a) probes the pion wave function with one of the constituents far off shell. We represent this large off-shell momentum dependence by the exchange of a single hard gluon, as shown in Fig.(1.b). The unshaded oval encompasses all soft binding effects, and can be described in terms of the pion weak decay constant f_π.

The results presented below are only the beginning of a more comprehensive program. Just as there are <u>many</u> 2 → 2 elementary processes involved in the conventional, minimum twist hard scattering expansion ($qq \to qq$, $qG \to qG$, etc.), there are many potentially important higher twist processes. We will examine the specific 2 → 2 processes

$$q_A\bar{q}_B \to \pi^\pm G \tag{1}$$

$$q_A G \to q_B \pi^\pm \tag{2}$$

where q_A, q_B are distinct quark flavors. In quark-quark or gluon-gluon scattering, 2 → 3 processes are required: $qq \to \pi qq$, $GG \to \pi q\bar{q}$. Our results thus provide a <u>lower bound</u> on the estimated size of higher-twist effects.

To construct amplitudes for $q\bar{q} \to \pi G$ and $qG \to q\pi$, we follow methods developed by Farrar and Jackson and extended by Brodsky and Lepage for exclusive hadronic reactions and electromagnetic form factors. The absolute normalization is determined in terms of the pion weak decay constant f_π. Our approach is consistent with that used by Berger and Brodsky for $\pi^- N \to \gamma^* X$, by Berger for $\nu N \to \mu^- \pi X$, and by Farrar and Fox in their study of $\pi q \to \pi q$. We write the total amplitude in the symbolic form

$$\langle q_A\bar{q}_B|\pi G\rangle = \langle q_A\bar{q}_B|q_A\bar{q}_B G\rangle\langle q_A\bar{q}_B|\pi\rangle \tag{3}$$

The first factor in Eq.(3) is the full 2 → 3 QCD amplitude (Fig.(1.b) and its four gauge invariance partners) with the following restrictions: (i) The final $q\bar{q}$ pair is constrained to the parallel configuration, $p(q_A) = z_1 p_\pi$, $p(\bar{q}_B) = z_2 p_\pi$. (ii) The final state $q\bar{q}$ pair is projected onto a pseudo-scalar, color singlet configuration. For the pion wave function in Eq.(3) we use the asymptotic form

$$\langle q_A\bar{q}_B|\pi\rangle = \sqrt{3}\, f_\pi z_1 z_2 \delta(1-z_1-z_2)dz_1 dz_2 \tag{4}$$

Evaluation of the resulting higher-twist cross sections is now quite straightforward; details are given in Ref.(1).

We write the elementary higher-twist cross sections in the form

$$\frac{d\sigma}{d\hat{t}}(ab \to c\pi) = \left(\frac{\pi\alpha_s^2}{\hat{s}^2}\right)\left(\frac{\alpha_s}{4\pi}\right)\left(\frac{s_0}{\hat{s}}\right) F(\cos\theta) \tag{5}$$

The fixed higher-twist scale is $s_0 = 16\pi^2 f_\pi^2$. The angular functions are

$$F(z;q\bar{q}\to\pi G) = \left(\frac{256}{81}\right)\left[\frac{1+z^2}{(1-z)^2(1+z)^2}\right] \qquad (6)$$

where $z = \cos(q,\pi)$.

$$F(z;qG\to q\pi) = \left(\frac{2}{27}\right)\left[1+\frac{4}{(1+z)^2}\right](1-z) \qquad (7)$$

with $z = \cos\theta(q,q)$.

It is worth noting that Eqs.(5)-(7) involve no arbitrary normalization parameters. The higher twist scale $s_0 = 16\pi^2 f_\pi^2$ is specified in a corresponding treatment of the pion form factor. Moreover, results numerically similar to Eqs.(6),(7) can also be obtained using a different, probabilistic approach in which a $2\to3$ QCD cross section is convoluted with a $q\bar{q}\to\pi$ recombination function. This suggests that our results are not strongly dependent on specific assumptions about the transition from $q\bar{q}$ to π.

Since we have not evaluated all important higher twist cross sections, it would be premature to use Eqs.(6),(7) to estimate the total high-p_T pion yield in actual hadronic processes. Instead,

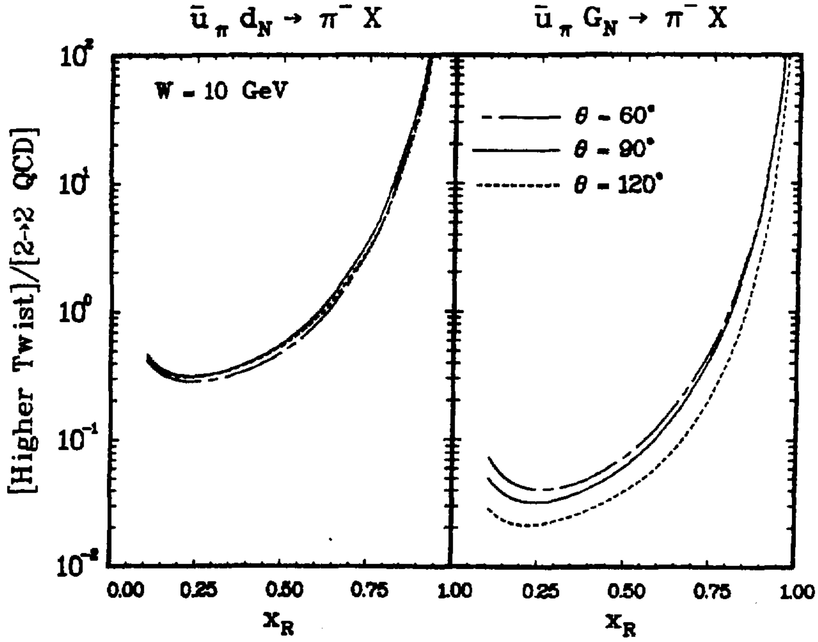

Fig.(2) Higher twist corrections to π^- production by $\bar{u}d$, $\bar{u}G$ initial states in $\pi^-N\to\pi^-X$.

we will view these results as corrections to minimum twist QCD for the specific initial states $\bar{u}_\pi d_N$ and $\bar{u}_\pi G_N$ in the hard scattering expansion for $\pi^- N\to\pi^- X$. In Fig.(2) we show results of such a comparison, using simple scaling parton densities and fragmentation functions. θ is the CM scattering angle between the initial and final pions and $x_R \equiv 2E_\pi/\sqrt{s}$. The curves in Fig.(2) scale as $s^{-1}\equiv W^{-2}$. We note that (i) the higher twist process $q_A\bar{q}_B\to\pi G$ provides a substantial correction to $q_A\bar{q}_B\to\pi X$, (ii) the higher twist corrections to $qG\to\pi X$ are about a factor of 5 less important than those for $q\bar{q}\to\pi X$, (iii) for both processes, the corrections are most important for large x_R (i.e., large p_T at fixed $\sqrt{s}$). Using simple, power-law parton densities it is easy to estimate

$$(\text{Higher Twist})/(\text{Minimum Twist}) \xrightarrow[x_R\to 1]{} (1-x_R)^{-3} \qquad (8)$$

Unfortunately, the large-x_R region is hard to reach experimentally.

It is also useful to examine the charge ratio

$$R(x_R) \equiv N(\pi^- N\to\pi^- X)/N(\pi^- N\to\pi^+ X)\ . \qquad (9)$$

The higher twist processes in Eqs.(1),(2) are maximally "charge-retaining" in that the final pions carry the quantum numbers of the incident quarks. Only $G_\pi u_N\to\pi^+\bar{d}$ contributes to $\pi^- N\to\pi^+ X$ (ignoring sea quarks). The higher twist charge ratio is thus enormous. However, these higher twist processes are corrections to minimum twist QCD, not alternatives. To the order we are working,

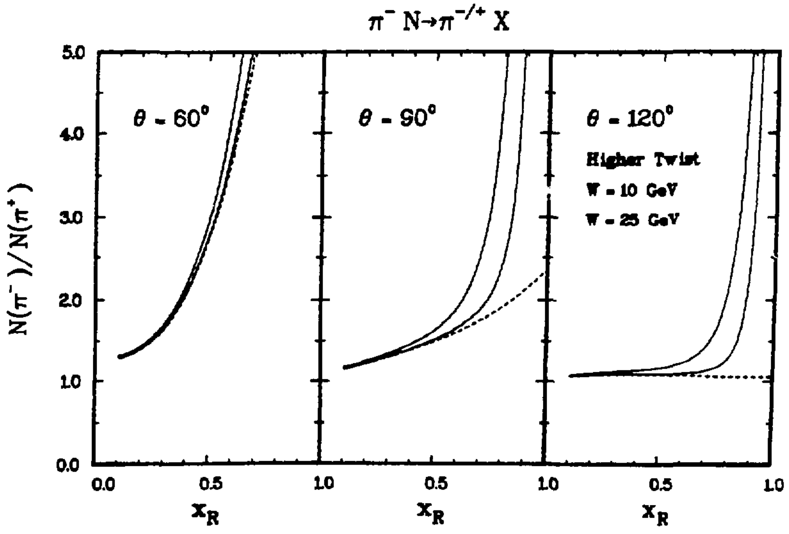

Fig.(3) $R(x_R)$ predictions, Eq.(10), for $\pi^- N\to\pi\ X$.

the total charge ratio can be written as

$$R(x_R) = \frac{A^-(x_R) + B^-(x_R)/s}{A^+(x_R) + B^+(x_R)/s} \tag{10}$$

where A,B describe minimum twist and higher twist respectively. Results for $R(x_R)$ are shown in Fig.(3); the dashed curves are the minimum twist results, A^-/A^+. We note that (i) for fixed s, the higher twist effects are unimportant for small x_R, but dominate for $x_R \to 1$, (ii) for fixed x_R, higher twist effects decrease with increasing s, roughly as s^{-1}. Presently available data do not extend to high enough x_R to see expected higher twist effects.

The 60° panel in Fig.(3) is interesting, primarily because preliminary data for this forward angle charge ratio are consistent with $R \simeq 1$, in marked contrast to the curves. The difficulties at 60° are not related to higher twist corrections to πN scattering but rather, reflect the strong charge retention properties of conventional, minimum twist fragmentation. Should the forward angle charge ratio data continue to differ substantially from the expectations of Fig.(3), a likely explanation might be that the empirical minimum twist fragmentation functions D(z) contain too much higher twist "contamination". The functions D(z) are deduced from minimum twist phenomenological fits to relatively low energy data (e.g., $\nu N \to \mu \pi^{\pm} X$ for $W \sim 4$ GeV). Higher twist effects in such data could well be sizeable. Removing expected higher twist effects from the data before extracting D(z) will soften the charge retention properties of the minimum twist fragmentation functions, thus lowering the dashed curves in Fig.(2).

To conclude, we note that there is a growing awareness of the relevance of higher twist phenomena in Quantum Chromodynamics. The results presented above must be combined with quantitative estimates of other higher twist effects (e.g., $qq \to qq\pi$) in order to obtain the full higher twist corrections to high-p_T observables. Collectively, these terms are likely to yield a non-trivial contribution to the full QCD hard-scattering description of high-p_T physics, particularly at large $x_T = 2p_T/\sqrt{s}$.

REFERENCE

1. E. L. Berger, T. Gottschalk, and D. Sivers, ANL-HEP-PR-80-58 (1980), submitted to Phys. Rev. D, and references therein.