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SOME PHYSICAL ASPECTS OF HIGHER TWIST*

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ABSTRACT

A brief description of some of the physical origins of higher twist terms and their possible relevance to data are given.

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The purpose of this brief talk is to review the physical basis for the higher twist contributions in QCD. By higher twist I shall simply mean a power law nonscaling contribution to a process (such as to a structure function, etc.). It is often remarked that QCD is the <u>only</u> candidate for a theory of the strong interactions. This is true, but do we fully appreciate what an insult this is to theorists and their imagination! In any case, since it is the only serious game in town, one should be even more critical and careful in comparing QCD with experiment.

At the present time, the "most rigorous" predictions of QCD are perturbative in origin[1] - and this requires that both the coupling constant $\alpha(Q^2)$ and its derivative with respect to $\ln(Q^2/\Lambda^2)$ be small. In comparing with data, however, one normally includes the low Q^2 region (i.e. Q^2 near Λ^2) among the "successes" of QCD even though in this regime the coupling is large and rapidly varying. At low Q^2, higher twist terms can play an important role and they have been ignored for the most part.[2]

As an example of higher twist contributions, consider a structure function written as

$$F(x,Q^2) \cong F^0(x,L) + F^1(x,L)/Q^2 + F^2(x,L)/Q^4 + \ldots ,$$

where $L = \ln(Q^2/\Lambda^2)$ and $x = x_{bj}$. In almost all comparisons with data one either neglects all terms beyond the first or one tries to sum up their effect by changing variables from x to the Nachtmann[3] variable $\xi = \xi(x,Q^2/M^2)$. This variable includes the effects of initial state masses but neglects the final state mass effects. Since their effects tend to cancel, the use of ξ may tend to overcorrect for mass effects. [This is the origin of the difficulties that are normally handled[4] by chanting "duality" even though this has not been shown to hold in QCD - thus adding an external assumption to the test of QCD.]

Finally let us note that exclusive scattering is pure higher twist - no self-respecting theory can afford to ignore this type of behavior. The old "classic" CIM theory[5] was an attempt to classify such terms and to give simple counting rules to allow a prediction of their kinematic behavior. In the original discussion, logarithms were ignored and only power laws were retained. This "bare" power law behavior can be modified by radiative corrections that depend on the details of the basic theory.

Very important progress in describing exclusive reactions in QCD has been made by Brodsky and Lepage.[6] They have shown that a typical exclusive amplitude (such as a form factor, or an elastic amplitude) behaves in leading log as

$$M \sim \left(\frac{\alpha(s)}{s}\right)^N M_0(\ell n\, s/\Lambda^2) ,$$

where M_0 is (hopefully) a slowly varying function of energy and in many cases sums up to give a typical anomalous dimension type of power behavior on $\ell n s/\Lambda^2$. In comparing with data, the nuclear form factor and especially pp elastic scattering demand a small value of Λ^2, much smaller than those commonly used to fit the structure functions. Also, this behavior gives an effective power behavior on s that behaves as

$$n_{eff}(s) = n(1 + 1/\ell n\, s/\Lambda^2) .$$

However, the data requires that $n_{eff}(s)$ decrease as s decreases, in contradiction to the above. Thus probably there are even higher twist contributions at lower s. The result of Brodsky and Lepage is just as fundamental a prediction of QCD as is the more familiar structure function analysis. It may yield the most restrictive constraint on the value of Λ^2 that we have available. If the value of Λ^2 is indeed small, how do we then fit the nonscaling behavior of the structure functions that seem to require a much larger value of Λ^2?

Now let us turn to higher twist terms in the structure functions given in our first equation. In Figure 1, these contributions are written in terms of the number of recoil quarks[7,8] that carry a finite fraction of Q. In part (a), the single quark term scales and then radiative corrections will yield the familiar $\log(Q^2/\Lambda^2)$ behavior of $F^0(x,L)$. In part (b), the two quark recoil term will fall as $1/Q^2$ (in the matrix element) and hence will produce the $F^1(x,L)$ term by interference with (a) and the $F^2(x,L)$ term.

The $F^1(x,L)$ term is very difficult to compute or to estimate. It contains mass effects of both the initial and final states as well as final state phase interference. We will assume, as a working hypothesis, that this term is extremely small and proceed to $F^2(x,L)$. This term has mass and interference terms but has a parton-type term which is the square of the contribution of type (b).

Should one expect that there will be diquark type terms in the nucleon wave function? If so, in what x-range should it be important?

In order to explore the physics of such correlations, let us turn to an example that we understand (presumably) and for which the parton model should work.[9] In Figure 2, the production of pions off of carbon by protons is shown as a function of x_F. This cubic behavior, in fact, holds all the way up to ISR energies. Now let us consider an incident deuteron beam as shown in Figure 3. The power increases to 9 because of the additional nucleon beam spectator (1 spectator yields $\sim$ 6 powers). In Figure 4, the distribution for an alpha beam is given and again we see that the power of $(1-x_F)$ increases with about 6 powers/spectator.

Now let us ask if there are coherent (or clustering) effects present in the nucleus. In Figure 5, several yields are given for carbon-carbon scattering. We see that in addition to the protons, one finds deuterons, tritons, etc., and that these are more likely to have a larger fraction of the beam momentum than the smaller clusters as one would expect.

Thus we are led to expect a priori that there will be diquark structure in the nucleon and that it will peak at large x ($x \sim 2/3$). The diquark, of course, need not exist as a strongly bound system. If a diquark does absorb a photon and is scattered into the photon fragmentation region it will produce a different type of final state from a single quark recoil. Two obvious differences[7] that should be looked for experimentally are

(a) Hard baryons in the photon fragmentation region with a $\sim$ $(1-z)$ spectrum.

(b) The p_T-distribution of mesons in the fragmentation region should be narrower for a diquark (because of its finite radius) than for a quark ($\sim$ factor of 2).

Very roughly, if the single quark scaling term vanishes as $(1-x)^3$ for large x, the diquark term behaves as $(1-x)/Q^4$. Thus for any value of Q^2, it dominates as $x \to 1$. A detailed fit of such a model to the SLAC-MIT data was carried out some time ago by I. A. Schmidt and myself.[7] We also developed a relativistic treatment of the deuteron so that an analysis of the neutron structure function could be performed. The results for the proton and neutron are given in Figure 6. The top graph is the scaling term and the lower graph is the coefficient of the Q^{-4} term. We see that it does peak in the neighborhood of $x = 2/3$ as expected for a diquark.

Also we see that at large x the ratio of the scaling amplitudes for the proton/neutron is quite close to 3/2, as expected from the average square of the quark charges. The nonscaling terms have a ratio close to the value of 3/1, as expected from the average square of the diquark charges.

Furthermore, the presence of diquark correlations in the nucleon wave function will introduce effective bosons into the constituent structure and break the Callan-Gross relation[10)] (but at the expense of extra $1/Q^2$ factors but fewer (1-x) factors). This effect was used by Abbott, Berger, Kane, and myself[11)] to explain the large value of $R = \sigma_L/\sigma_T$ measured at large x. We found that the data could be fit in a reasonable manner by (with spinor quarks and spin zero diquark)

$$\sigma_T = A(x)(1-x)^3 + d_T x^2 F^3(Q^2)$$

$$\sigma_L = d_L x^2 (1-x)^2 F^2(Q^2) \ ,$$

where $$F = (1 + Q^2/M^2)^{-1} \ ,$$

and $$d_T/d_L = < k_T^2 >/2 \ .$$

For details of the fit, see Refs. 7 and 11 and Figure 7. Very roughly, for $0.3 < x < 1$, R behaves as

$$R \sim Q^{-4}(1-x)^{-1} \quad \text{or} \quad Q^{-4}(1-x)^{-2},$$

which is quite different from the "QCD inspired" form that has been frequently discussed and used

$$R \sim Q^{-2}(1-x) \ .$$

For small x, one again finds experimentally a large value of R which indicates that further mechanisms may be playing a role, such as electro-pion production ($q\bar{q}$) or heavy quark production near threshold. A finite fraction of the rise in the structure functions at small x should be due to charm production. These points deserve further attention, especially in any quantitative fit to the data (to determine Λ^2, for example).

These correlations show up in other reactions. Berger and Brodsky[12)] have shown that in $\pi N \to e^+e^-X$, the Drell-Yan process, there are important and striking angular distribution effects that do not scale and that show up near x = 1. Berger[13] has shown that there are "anomalous" (1-y) terms in the reaction $\ell N \to \ell' \pi X$.

The study of correlation effects in the hadronic wave function is for the most part a nonperturbative problem that is going to require a long time to solve but must be settled before a true quantitative test of QCD can be carried out. At the present time, it is (almost) consistent with the available data to claim that Λ^2 is so small that there are no observable effects due to gluon radiative corrections, the coupling constant is constant, and all observed nonscaling behavior is due to higher twist terms and heavy quark production. It will be interesting to see if this statement can be repeated at next year's Moriond.

References

1) H. D. Politzer, Phys. Rev. Lett. 26, 1346 (1973); D. J. Gross and F. Wilczek, Phys. Rev. Lett. 26, 1343 (1973) and Phys. Rev. D8, 3633 (1973) and D9, 980 (1974); A. Zee, F. Wilczek and S. B. Treiman, Phys. Rev. D10, 2881 (1974); H. Georgi and H. D. Politzer, Phys. Rev. D9, 416 (1974); S. Weinberg, Phys. Rev. Lett. 31, 494 (1973).

2) For a fuller description of this point, see L. F. Abbott and R. M. Barnett, Report No. SLAC-PUB-2325 (May 1979), to be published in Annals Phys.; W. B. Atwood, SLAC-PUB-2428 (to appear in the Proceedings of Summer Institute on Particle Physics, SLAC, 1979).

3) O. Nachtmann, Nucl. Phys. B63, 237 (1973).

4) A. De Rújula, H. Georgi and H. D. Politzer, Ann. Phys. 103, 315 (1977); H. D. Politzer, Nucl. Phys. B122, 237 (1977).

5) R. Blankenbecler, S. J. Brodsky, and J. F. Gunion, Phys. Rev. D6, 2652 (1972). See also D. Sivers, S. J. Brodsky, and R. Blankenbecler, Phys. Rep. 23C, No. 1 (1976).

6) G. Peter Lepage and S. J. Brodsky, Phys. Rev. Lett. 43, 545 (1979), and Phys. Lett. 87B, 359 (1979).

7) I. A. Schmidt and R. Blankenbecler, Phys. Rev. D16, 1318 (1977).

8) See also H. D. Politzer, preprint March 1980, CALT-68-765, "Power Corrections at Short Distances."

9) I. A. Schmidt and R. Blankenbecler, Phys. Rev. D15, 3321 (1977). The data is from J. Papp *et al.*, Phys. Rev. Lett. 34, 601 (1975).

10) C. G. Callan and D. J. Gross, Phys. Rev. Lett. 22, 156 (1969).

11) L. F. Abbott, E. L. Berger, R. Blankenbecler and G. L. Kane, Phys. Lett. 88B, 157 (1979).

12) E. L. Berger and S. J. Brodsky, Phys. Rev. Lett. 42, 940 (1979).

13) E. L. Berger, Argonne preprint, 1980.

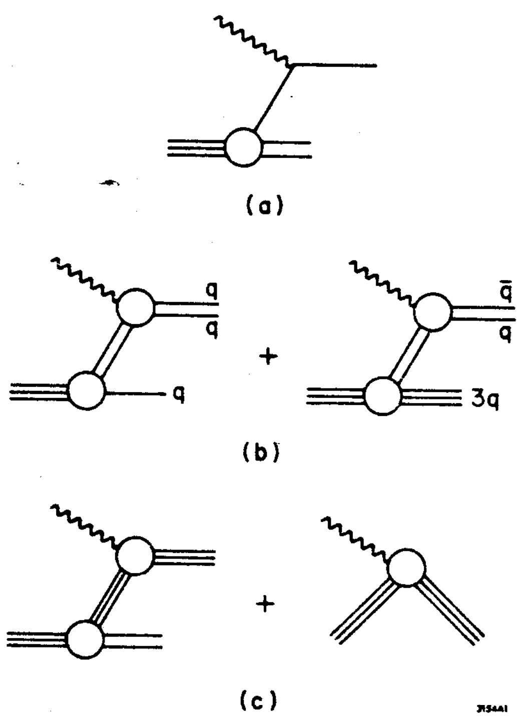

Fig. 1. Classification of some simple final states for structure functions.

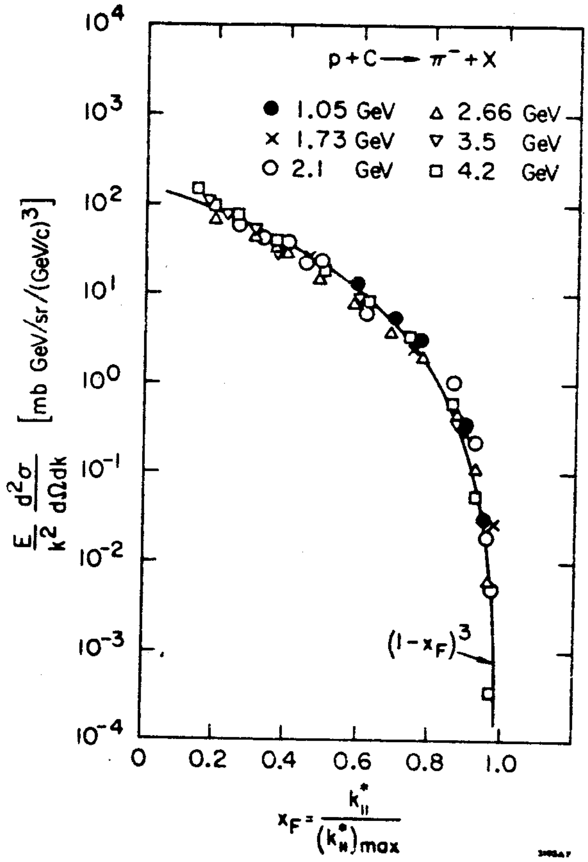

Fig. 2. Basic longitudinal spectrum for pion production.

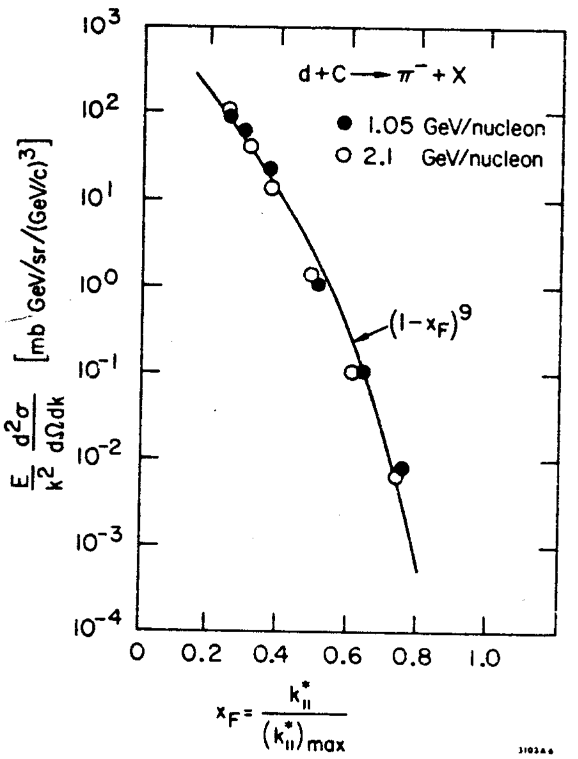

Fig. 3. Longitudinal pion spectrum for deuteron beam.

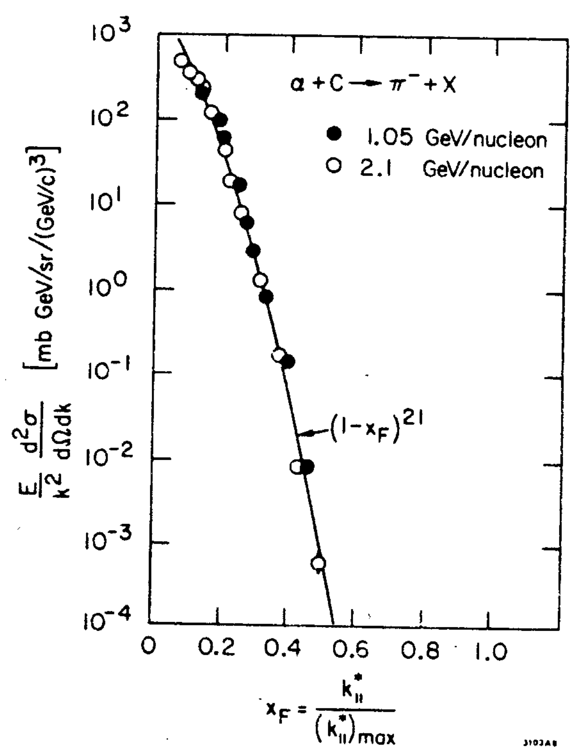

Fig. 4. Longitudinal pion spectrum for alpha beam.

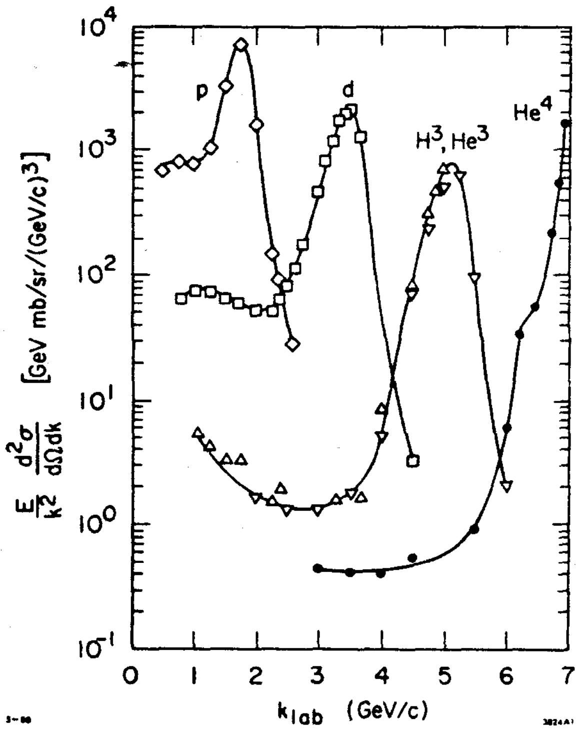

Fig. 5. Coherent clusters out of the incident beam.

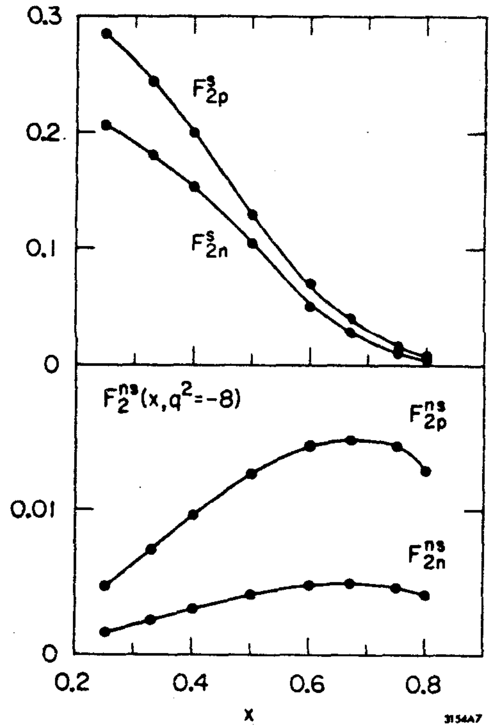

Fig. 6. Scaling and nonscaling parts of structure functions for proton and neutron.

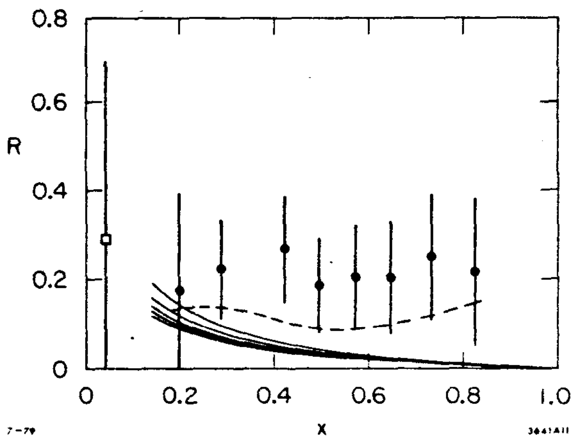

Fig. 7. Compatison of experimental R with standard QCD (solid curve and diquark higher twist term (dashed curve).