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SOME CONSEQUENCES OF A SCALE BREAKING MODEL IN ELECTRON AND NEUTRINO DEEP INELASTIC SCATTERING*

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ABSTRACT

We analyze electron and neutrino deep inelastic processes, extending a simple parton model explanation of the approach to scaling observed in electroproduction at large x. The model is successful in fitting the present experimental data without any explicit effects from asymptotic freedom or new quarks. This model has a large q^2 behavior which is quite different from that expected in asymptotic freedom (AF) theories and comparisons to data can be used to sharpen any experimental demonstration of AF effects. Of course, the model is consistent with AF and both effects could be present.

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Recently a simple parton-model explanation of the approach to scaling observed in electroproduction at large x (Bjorken scaling variable) was proposed.[1] The purpose of this note is to extend that analysis to all values of x and also to charged current neutrino processes. We will show that it is possible to fit the data in terms of this simple parton model with no explicit asymptotic freedom effects (AF).[2,3] A combination of these models should also work, and only more extensive data can determine the right proportions.

In Ref. 1 it was shown that in the framework of the ordinary parton model, it is possible to identify and to parametrize terms that do not scale. They correspond physically to more than one quark absorbing the momentum of the virtual photon. Specifically a term with two quarks sharing that momentum can account for the bulk of the scaling violations observed (for large x) in electroproduction. This explanation does not rule out possible logarithmic corrections due to AF effects, but they should then vary more slowly with q^2.

First we want to extend the parametrization that was given in Ref. 1 for the electroproduction structure function $F^e_{2p}(x, q^2)$ of the proton to the small x region.[4,5] For this purpose we write:

$$F^e_{2p}(x, q^2) = F^v_{2p}(x) + F^d_{2p}(x, q^2) + F^{sea}_{2p}(x, q^2) \quad , \tag{1}$$

where the first two terms dominate at large x.

$F^v_{2p}(x)$ corresponds to the usual (scaling) parton model diagram in which one quark absorbs the virtual photon, and is given by

$$F^v_{2p}(x) = A_v(x)(1-x)^3 \tag{2}$$

where our fitting yields

$$A_v(x) = \begin{cases} 1.58\, x^{0.6} & (0 \lesssim x \lesssim 1/3) \\ 1.58\, x^{0.6}(0.93 - 0.85|x-2/3| - 1.15(x-2/3)) & (1/3 \lesssim x \leq 1) \end{cases} .$$

This expression has the (1-x) dependence predicted by dimensional counting rules[6] (two spectator quarks), and explicitly exhibits Regge behavior at small x. Note that $\int \frac{dx}{x} F^{v}_{2p}(x) \simeq 1$, as expected in the parton model for the valence quarks.

The term $F^{d}_{2p}(x, q^2)$ is the scale breaking contribution at large x, in which two quarks share the momentum of the photon. In this case we have one spectator quark, so it has the form[1]

$$F^{d}_{2p}(x, q^2) = 2.5\, x^2 (1-x)\, F^2_d(q^2) \quad , \tag{3}$$

where

$$F_d(q^2) = \frac{1}{(1-q^2/2)}$$

is the form factor for the diquark system.

The last term $F^{sea}_{2p}(x, q^2)$ is only important at small x, and can be identified with contributions from quark-antiquark pairs in the parton sea. Since the number of spectator quarks for this case is four, it must vanish as $(1-x)^7$ for $x \to 1$. We have parametrized it in the form

$$F^{sea}_{2p}(x, q^2) = (.6 - \sqrt{x})(1-x)^7 \left(1 - F^2_d(q^2)\right)^2 . \tag{4}$$

for $x \leq .36$, and zero otherwise. We have considered only the region $(-q^2) \gtrsim 2\ (\mathrm{GeV})^2$.

Adding these three contributions, we get the total structure function F^{e}_{2p}. Fits to the experimental data[4,5] are shown in Fig. 1, for different values of q^2.

Since experimentally the first moment of the total structure function is virtually independent of q^2 in the range $2 \leq (-q^2) \leq 30\ (\mathrm{GeV})^2$,[5] we have chosen the same function F_d as in the diquark term to parametrize the q^2 behavior of this sea contribution. Notice that this particular form makes F^{e}_{2p} increase with

q^2 for small values of x,[7] while the diquark term makes it decrease for large x, as seen experimentally.[4,5] In fact, we have calculated the first moment using our parametrization, and obtained $\int_0^1 F^e_{2p}\,dx \simeq 0.17$, constant for $q^2 \gtrsim 5\ (\mathrm{GeV})^2$. As expected, this result agrees very well with the data.[5] At this point we should mention that the AF prediction with respect to this first moment is a logarithmic falloff.[2]

The rise with q^2 of the structure function at small x can be explained in our model if we consider quark mass effects. Take, for example, the valence contribution. We explicitly calculated this term for a certain choice of wave function, and found a power-law rise with q^2 (which matched $F^2_d(q^2)$) for $x \gtrsim 1/3$ and a falloff for $x \lesssim 1/3$, where the valence peak is at $x \sim 1/3$. Physically this effect comes from the condition that the missing mass has to be greater than the sum of the masses of the interacting and spectator quark systems, and is independent of the particular choice of wave function. For higher configurations of quarks, in which we have N quark-antiquark pairs, the maximum in x is going to be around $1/(2N+3)$. The rise with q^2 is then going to extend to the small x region for large N.

The above discussion gives a clear picture of the behavior of $F_2(x,q^2)$ in the different regions of x. At large x only the diquark and valence terms are important, and the falloff with q^2 of the diquark contribution overcomes the rise of the valence part, giving the experimentally observed overall falloff. At small x, on the other hand, the diquark term is negligible and the dominant contributions have N large. Thus a rise with q^2 is obtained.

Let us now turn to neutrino processes. Our main assumption will be that the structure functions for electroproduction and charged weak interactions (off an isoscalar target) are proportional $\left(F_2^e \propto F_2^\nu\right)$. This result can be obtained in the parton model by making the approximation that the number of strange quarks in the nucleon is negligible, and/or on more general grounds, using properties of the electromagnetic and weak currents (see Ref. 9).

The spin of each of the contributions (valence, diquark, sea) to the structure functions fixes the y dependence of that particular term. For example, the spin-1/2 valence will have a $(1-y)^2$ behavior for antineutrinos and a constant behavior for neutrinos. The diquark term is more complicated since it can have both spin zero or one. However, in our range of energies its magnitude is very small, so for simplicity we will consider only the spin zero part. This means a (1-y) dependence for neutrinos and antineutrinos, but our results are quite insensitive to this choice. Finally, the sea contribution was divided evenly between quarks and antiquarks, which means that the y dependence of this term is $(1+(1-y)^2)/2$ for both neutrinos and antineutrinos.

We obtain with these assumptions:

$$\frac{1}{E}\frac{d\sigma^{\bar{\nu}}}{dxdy} \propto (1-y)^2 F_2^v(x) + (1-y) F_2^d(x,q^2) + \frac{1}{2}\left[1+(1-y)^2\right] F_2^{sea}(x,q^2)$$

$$\frac{1}{E}\frac{d\sigma^{\nu}}{dxdy} \propto F_2^v(x) + (1-y) F_2^d(x,q^2) + \frac{1}{2}\left[1+(1-y)^2\right] F_2^{sea}(x,q^2) \qquad (6)$$

These results can now be used to calculate several quantities of interest. In Fig. 2 we show $\langle y\rangle$, $\langle x\rangle$ and $\langle xy\rangle$, for neutrinos and antineutrinos, as a function of the incident energy. The agreement with the antineutrino data[10] is quite good. From the graphs one concludes that in comparing a specific theoretical prediction with experimental data, it is important to consider the cuts made on that data, since their effect can be quite large.

We have also calculated the ratio of antineutrino to neutrino total cross sections, and find $\left(\sigma^{\bar{\nu}}/\sigma^{\nu}\right) \simeq 0.38$, essentially constant over our energy range ($20 \leq E \leq 150$ (GeV)). This result was obtained without using any cuts. If some typical set of cuts were included, the number would increase somewhat (to $\simeq .40$ for a cut $x < 0.6$). See Fig. 3.

In this note we have shown that the simple parton model used to explain and fit the approach to scaling in electroproduction at large x, gives good results when applied to neutrino processes[11] (at least for all the comparisons with experimental data that we have made). The large x nonscaling behavior is easily interpreted in the model as due to diquark effects, and the nonscaling of the sea can be interpreted as due to wave function effects. The main conclusion, as far as both electroproduction and neutrino experiments is concerned, is that we can have a simple physical picture of these processes without any need for AF effects and/or new quarks[12] (at least in our energy range). As we have mentioned before, additional logarithmic corrections due to AF could still be present even in this model, and only further experimental data can determine the right combination.

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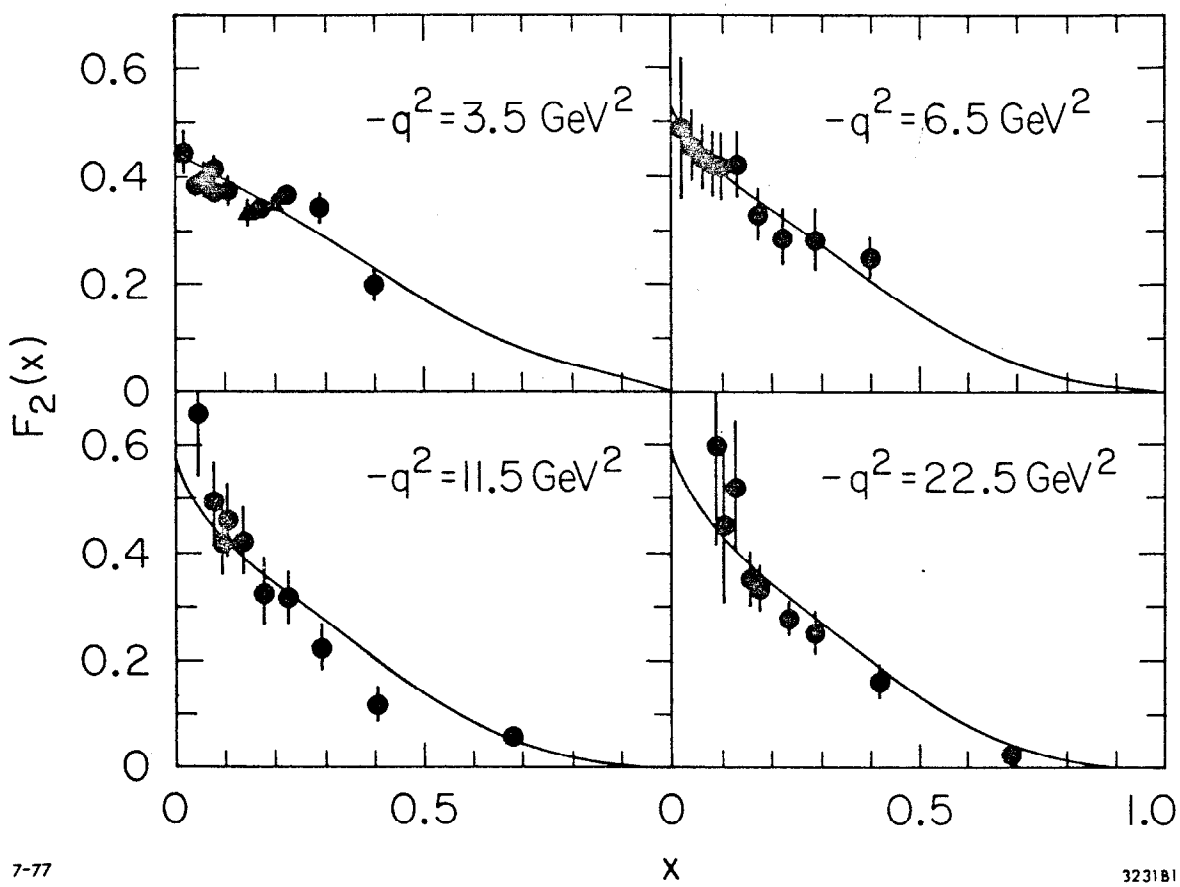
FIGURE CAPTIONS

1. Fits to the proton structure function, for different values of q^2 (see Eq. (1)). Data shown is from Ref. 5. For detailed fits at large x see Ref. 1.
2. Predictions for $\langle y \rangle$, $\langle x \rangle$ and $\langle xy \rangle$, for antineutrinos and neutrinos, and for two different cuts in the y-variable. Antineutrino data is from Ref. 10.
3. Prediction for the antineutrino/neutrino cross section ratio, for the HPWF cuts ($x < .6$, $-q^2 > 1$ GeV^2, $E > 4$ GeV, $\theta < .225$ rad).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0.4
0.2
0
$F_2(x)$
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$-q^2 = 6.5\ GeV^2$
$-q^2 = 11.5\ GeV^2$
$-q^2 = 22.5\ GeV^2$
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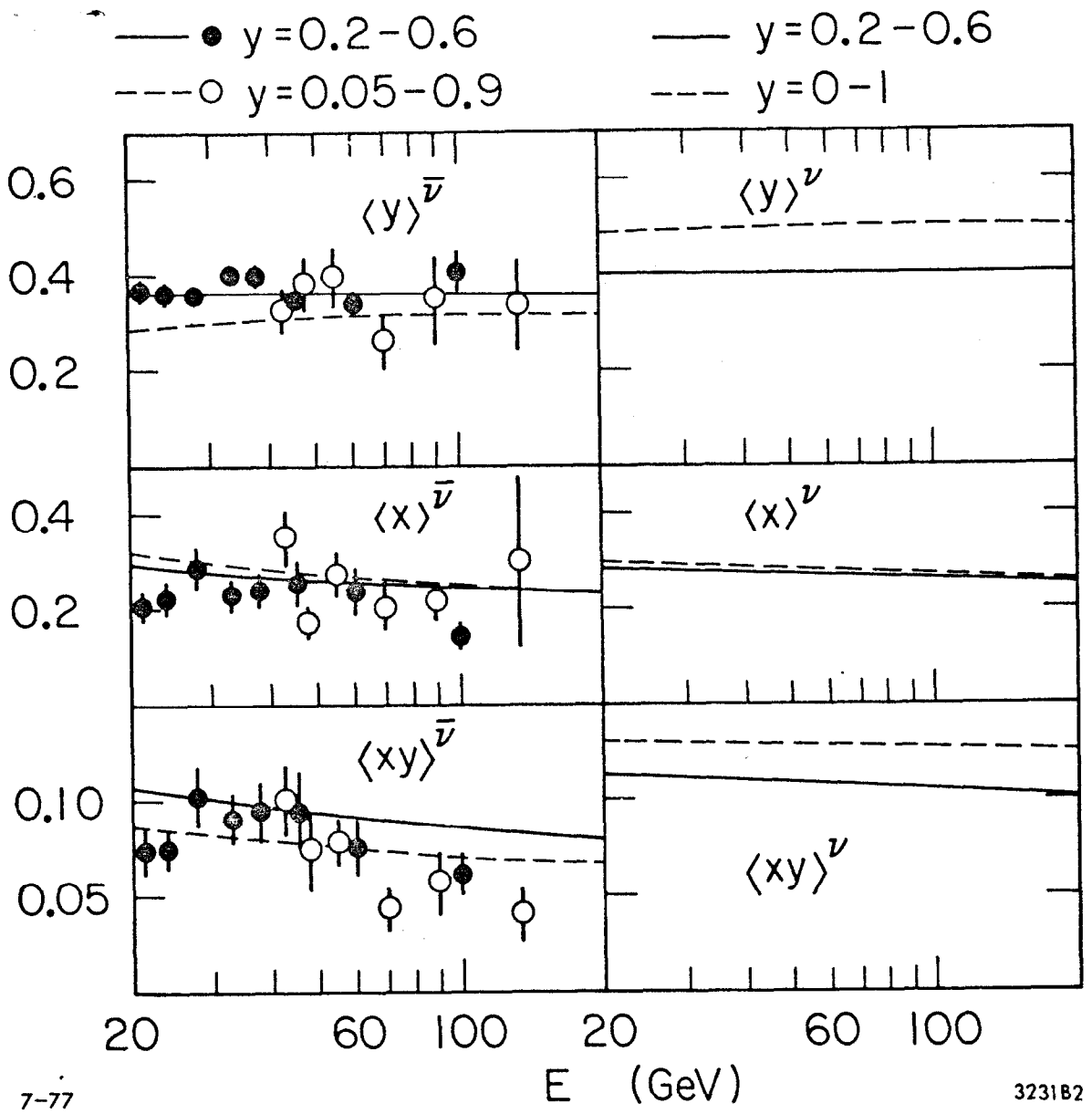
0.5
0
0.5
1.0
x
7-77
3231B1

Fig. 1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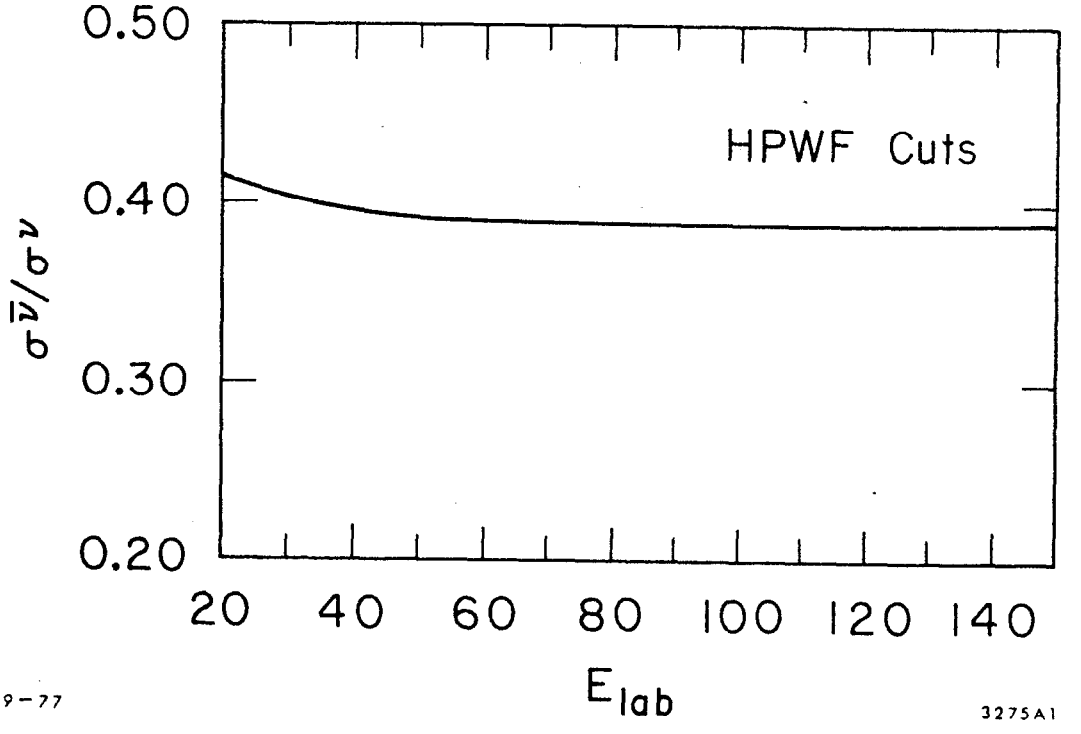
⟨y⟩$^{\nu}$
0.4
0.2
⟨x⟩$^{\bar{\nu}}$
⟨x⟩$^{\nu}$
0.10
0.05
⟨xy⟩$^{\bar{\nu}}$
⟨xy⟩$^{\nu}$
20
60
100
20
60
100
E (GeV)
7-77
3231B2

Fig. 2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0.40
0.30
0.20
$\sigma^{\bar{\nu}}/\sigma^{\nu}$
HPWF Cuts
20
40
60
80
100
120
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E_{lab}
9-77
3275A1