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SHADOWING IN DEEP INELASTIC SCATTERING
FROM A PARTON VIEWPOINT

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ABSTRACT

The dominance of the structure function at small x by pomeron exchange provides a natural mechanism for the reduction of the structure function at small x in a nuclear environment. A simple model of this reduction provides a quantitatively successful description of the shadowing in deep inelastic muon scattering. When coupled with x -rescaling, it is in good agreement with data on deep inelastic scattering on nuclei for $x \leq 0.5$.

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Shadowing is a well-known phenomenon for interactions between real photons and nuclei ⁽¹⁾, for which a quantitative explanation was provided ⁽²⁾ by the hypothesis of Vector Meson Dominance (VMD) ⁽³⁾. That shadowing should persist in deep inelastic electron or muon scattering was conjectured ⁽⁴⁾ on the basis of Generalized Vector Dominance (GVD) ⁽⁵⁾. Shadowing effects were indeed observed in inelastic electron scattering ⁽⁶⁾ below 20 GeV and at low values of Q^2 , and the effect was confirmed in a high energy muon experiment ⁽⁷⁾ which demonstrated strong shadowing for $Q^2 < 3 \text{ GeV}^2$ with some indication that it diminished at large Q^2 . Most recently the EMC collaboration ⁽⁸⁾ has conclusively demonstrated shadowing in the kinematic range of low x ($0.003 - 0.1$) and low Q^2 ($0.3 - 3.2 \text{ GeV}^2$). If these data are combined with those of earlier EMC results at appreciably higher values of Q^2 ⁽⁹⁾, there is strong evidence that the Q^2 -dependence of shadowing is weak.

Although GVD provides a reasonable description ⁽¹⁰⁾ of the data, it is natural to seek an explanation at the parton level. A partial step in this direction has been taken by Kwiecinski and Badelek ⁽¹¹⁾, in a model in which shadowing originates both from nuclear rescattering of vector mesons and from partonic mechanisms. A qualitative discussion at the purely parton level was given by Nicolaev and Zakharov ⁽¹²⁾, which indicated the possibility of antishadowing at intermediate values of x , as well as shadowing at small x . A much more comprehensive and quantitative discussion within the framework of QCD has been provided by Mueller and Qiu ⁽¹³⁾ and by Qiu ⁽¹⁴⁾. In the first of these papers it is argued that gluon recombination at small x in nuclei leads to a depletion of the gluon distribution, which then results in a lowering of the sea quark distribution. However the amount of shadowing expected is not quantified, and the emphasis is more on the Q^2 -evolution of nuclear structure functions and hence on the Q^2 -evolution of shadowing. Qiu ⁽¹⁴⁾ uses a simple parametrization to modify the nucleon structure functions to fit the nuclear data of Goodman et al. ⁽⁷⁾ at $Q^2 = Q_0^2 = 4 \text{ GeV}^2$. These are then evolved using the modified Altarelli-Parisi equations obtained by Mueller and Qiu ⁽¹³⁾ for a nuclear environment. This calculation demonstrates that at any fixed small value of x , nuclear shadowing disappears extremely slowly as Q^2 increases.

In this paper we propose a simple model of shadowing at the parton level. Our

starting point is the familiar one that the small- x limit of the structure function νW_2 is controlled by pomeron exchange ⁽¹⁵⁾, as in Fig.1. The structure function at small x is then proportional to $\beta_q \tilde{\beta}_q$ ⁽¹⁶⁾, where $\beta_q, \tilde{\beta}_q$ are respectively the effective couplings of the pomeron to the quark in the upper loop and to the lower quark in the nucleon. If the nucleon is not bound in a nucleus, then $\beta_q = \tilde{\beta}_q = \beta_0$ in the notation of ref. (16). We suggest that in a nuclear environment the effective coupling of the pomeron to a quark is suppressed i.e. $\tilde{\beta}_q < \beta_0$, and this suppression emanates itself as shadowing.

The suppression of the effective coupling of the pomeron comes about in the following manner. In a nuclear environment the nucleons overlap. The overlapping volume per nucleon, V_A , is large with V_A/V_N varying from 40 % for carbon to nearly 70 % for tin. Here V_N is the volume of a free nucleon. As a consequence the mean separation of the valence quarks to which the pomeron couples is decreased. It is generally agreed ⁽¹⁷⁾ that, to a good approximation, pomeron exchange is nothing but the exchange of a pair of gluons. If pomeron exchange is indeed gluon exchange then its coupling must be flavour blind, and total cross-sections should be flavour independent. The observed flavour dependence of total cross-sections is explained by the suggestion ^{(18),(19)} that the radius of a hadron (i.e. the spatial separation of the quarks) determines the strength of its coupling to the pomeron: the smaller the hadron (i.e. the less the quark-quark separation) the smaller is the effective coupling of the pomeron. Thus in a nuclear environment we expect the effective coupling of the pomeron to be reduced, the structure function at small x to be similarly reduced and shadowing to ensue.

The variation of total cross-sections with the radii of the hadrons involved has been quantified by Povh and Hufner ⁽²⁰⁾ who show that they are proportional to $R_{h_1}^2 R_{h_2}^2$, where R_{h_1} and R_{h_2} are respectively the radii of the two hadrons. As the total cross-section is also proportional to $\beta_{h_1} \beta_{h_2}$, where β_{h_1} and β_{h_2} are respectively the effective couplings of the pomeron, this means that the effective pomeron coupling is proportional to R^2 . Thus in a nuclear environment we expect the structure function at small x to be reduced by a factor of approximately $(1 - V_A/2V_N)^{2/3}$.

We have taken V_A/V_N from the calculation of Close et al. ⁽²¹⁾ who evaluate it for three choices of the nucleon correlation function in nuclear matter: no correlation, cor-

relation arising from treating the constituent nucleons as a Fermi gas, and correlations which follow from describing the two-nucleon force by the Reid soft-core potential. The first of these is not very realistic, so we do not consider it further. The other two are essentially the same and can be taken as one. The suppression factors for this set of values for V_A/V_N is given in the table.

To move away from the region of very small x we must now make a choice of nucleon structure functions and a choice of a rescaling scheme for the nuclear environment. For the former, we use the structure functions of Diemoz et al. ⁽²²⁾ at $Q^2 = 10 \text{ GeV}^2$ (which is, in fact, the starting point for their Q^2 -evolution). For the latter, it is most natural in our formalism to use x -rescaling ⁽²³⁾ rather than Q^2 -rescaling ⁽²¹⁾, although in the region of x in which we are interested (namely $x < 0.5$) the two approaches have been shown to be equivalent ⁽²⁴⁾. We assume that the sea quarks in the nucleus contribute to the momentum sum rule with the same relative strength as they do in the free nucleon. As the magnitude of the structure function at $x = 0$ is reduced in the nucleus, this requires that the sea-quark distributions in the nucleus are somewhat harder than those in the nucleon.

Specifically, the quark distributions in the free nucleon are given by

$$xu_v = 2.26x^{0.54}(1-x)^{2.52}[1 - 1.617(1-x) + 3.647(1-x)^2 - 1.998(1-x)^3]$$

$$xd_v = 0.57(1-x)xu_v$$

$$x\bar{u} = x\bar{d} = 0.25(1-x)^{8.5}[1 - 4.18x + 20.3x^2 - 15.3x^3]$$

$$xs = x\bar{s} = 0.4x\bar{u}$$

We take the valence quark distribution to be the same in a nuclear environment with the replacement of x by $x_c = x/z_0$. The relevant values of z_0 are given in the table ^{(23),(24)}. The coefficients of the sea quark distributions are reduced by the factors shown in the table, x is replaced by x_c and the powers of $(1-x_c)$ decreased to maintain the same fractional contribution to the momentum sum rule.

The model is now completely determined and we obtain the results shown in Fig.2. They provide a good description of the data, particularly the rate of increase of shadowing with increasing nuclear density and the rate of decrease of shadowing with increasing

x . Since the Q^2 - evolution of shadowing is expected to be small ⁽¹⁴⁾ our results for the ratio $F_2(A)/F_2(D)$ should be valid over a wide range of Q^2 and not just near $Q^2 = 10 \text{ GeV}^2$ where we have evaluated them. The turn -over into the EMC effect at $x > 0.25$ is, of course, a natural consequence of our use of the rescaling variable x_c . Without this our results for the ratio $F_2(A)/F_2(D)$ would simply go to the value of unity as x increases.

A different choice of initial structure function does not change the results qualitatively, although there are detectable quantitative changes. Structure functions with an initially harder sea component, such those of Martin et al. ⁽²⁵⁾ move the peak in the ratio $F_2(A)/F_2(D)$ to slightly larger x . On the other hand, the structure functions of Duke and Owens ⁽²⁶⁾ move the peak to lower x and give clear antishadowing. We do not show these explicitly, as it is our objective here to demonstrate the effect, rather than to seek a detailed fit to the data.

As an additional comment, it is obvious that our mechanism should apply to any reaction in a nuclear environment to which the pomeron is the dominant contribution. An example is provided by exclusive ρ -meson production in deep inelastic scattering ⁽²⁷⁾, from a target consisting mainly of nitrogen. Donnachie and Landshoff ⁽¹⁶⁾ have argued that the corresponding data on hydrogen ^{(28),(29)} are dominated by pomeron exchange, in which case there should be a difference in slope parameter between the nitrogen and hydrogen data. Following Povh and Hufner ⁽²⁰⁾, this difference can be estimated to be about 1.1. Experimentally ⁽²⁶⁾ the difference is 1.9 ± 0.86 at $Q^2 = 2 \text{ GeV}^2$ and 1.7 ± 1.2 at $Q^2 = 5 \text{ GeV}^2$.

We note that although we have used the language of pomeron exchange, the underlying content is qualitatively the same as the more formal QCD approach of Mueller and Qiu ⁽¹³⁾. We have estimated directly the reduction of the sea quark component of the structure function at small x in a nuclear environment, and this must be accompanied by a corresponding depletion of the gluon distribution. Insofar as the pomeron can be considered as underlying the gluon distribution as well as the sea quark distribution at small x this connection is direct. In the approach of Mueller and Qiu ⁽¹³⁾ the argument is reversed. They calculated a depletion of the gluon distribution which then results in

a lowering of the sea quark distributions, but in practical terms the effect is the same.

We make two final points on the consequences of shadowing being a parton-level phenomenon. Firstly, shadowing should be apparent in ν and $\bar{\nu}$ deep inelastic scattering. The data are inconclusive, but are certainly not inconsistent with this hypothesis ⁽³⁰⁾. Secondly, shadowing should not depend on the orientation of a deformed nucleus like Holmium ⁽³¹⁾. On the other hand, in the traditional GVD approach one would expect it to depend on the orientation. This experiment could be done as a test of our hypothesis.

In summary, we have proposed that shadowing is a parton phenomenon, due primarily to the overlapping of nucleons in a nucleus. This leads to a quantifiable depletion of the sea (and gluon) distribution at small x , which must consequently be harder to maintain the momentum sum rule. The detailed consequences of this hardening will be explored elsewhere. It is, of course, the same phenomenon of nucleon overlap which causes the EMC effect by softening the valence quark distribution, and the combination of the two effects produces the peak in the ratio $F_2(A)/F_2(D)$.

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TABLE

	$(1 - \frac{V_A}{2V_N})^{2/3}$	z_0
C	0.86	0.973
Ca	0.815	0.962
Cu/Fe	0.791	0.958
Sn	0.761	0.951

TABLE CAPTION

Suppression factors and x -rescaling factors used in the calculation of the curves in fig.2.

FIGURE CAPTIONS

- 1) Pomeron exchange in deep inelastic scattering at small x .
- 2) Comparison of our result for the ratio $F_2(A)/F_2(D)$ with data for (a) C; (b) Ca,Cu,Fe; (c) Sn. In (b) the solid line is Ca, the broken line is Cu/Fe. The dot-dash line in each figure shows the effect of decreasing z_0 as explained in the text.

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Fig. 1

Fig. 2