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REACTIONS PROBING EFFECTS OF QUARK CLUSTERS IN NUCLEI

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ABSTRACT

We study signatures of quark clusters in reactions which probe quarks in nuclei. We examine the EMC effect and use physical arguments to establish features of valence and ocean parton distributions in multiquark clusters. We predict from these distributions ratios of structure functions and cross sections measured with neutrino, antineutrinos and proton beams. It appears that a unique determination of the source of the EMC effect will be possible.

INTRODUCTION

A recent experiment[1] by the EMC group showed that the ratio $R(A/D)$ of structure functions measured in deep inelastic scattering on nuclear target A to that on a deuterium target D is less than unity in the small parton momentum fraction region, $x \lesssim 0.1$. Their earlier measurements[2] of this quantity showed conclusively that $R(A/D) \neq 1$ for most x so charged partons in nuclei behave differently than they do in free nucleons. The source of this difference has become an interesting area of theoretical study; undoubtedly, a number of effects contribute to the overall deviation of R from unity. In this study we focus on contributions of clusters of quarks to this deviation, including for now only the $6q$ cluster additional to the nucleon ($3q$). Although we believe pions are also present, various effects must be explored individually first to gain enough understanding to combine all contributions. Overall, calculations[3] including the effects of clusters have had considerable success in explaining unusual nuclear effects, independent of the interpretation of how the momentum fraction should be scaled[4] from nucleon to cluster.

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CLUSTER CONTRIBUTIONS TO THE EMC EFFECT

The EMC group concluded[1] that the effect they measure must be explained at the parton level. In the quark cluster model (QCM) the deviation of R from unity is caused by the valence and sea (ocean) quarks contributing in different regions of z, the fraction of the total cluster momentum, as compared to the corresponding nucleon quantities. For a generic N quark cluster we take

$$O_N(z) = A_N(1-z)^{a_N}, \quad V_N(z) = B_N z^{1/2}(1-z)^{b_N}, \quad G_N(z) = C_N(1-z)^{c_N},$$

for ocean, valence and gluon distributions. The normalization parameters come from: (i) normalization to N valence quarks, (ii) momentum conservation $z(O) + z(V) + z(G) = 1$ and (iii) by examining data for $N = 2$ and $N = 3$, where $z(O)/Z(G)$ is 0.2 independent of N so we can extrapolate to larger N. The $(1-z)$ powers are fixed mainly by examining $N = 2$ and 3 values along with keeping $a_N > b_N$, leading to $13 \gtrsim a_6 \gtrsim 11$. For simplicity, we take the fraction of $6q$ clusters in Fe to be that of Ref. 3. Then, we can examine the value of R and the slope dR/dx at $x = 0$ to find that the powers for a and b from this analysis automatically leads to $R(x = 0) < 1$, with positive slope. The predicted value of R vs. x, for three slightly different powers of $(1-z)$ in cluster distributions, compared with data are shown in Fig. 1. Further details can be found in Ref. 5.

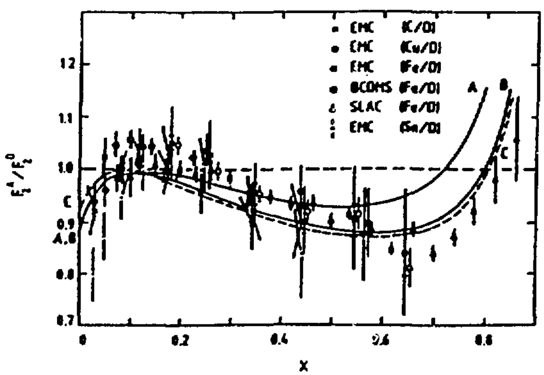

FIG. 1. Structure function ratio R vs. x for various nuclear targets. The curves are identifiable by a set of $(1-z)$ powers A(3,9,9,11), B(3,9,10,11), C(3,9,10,13), where (b_3, a_3, b_6, a_6) are in parentheses.

NEUTRINO, ANTINEUTRINO CHARGED CURRENT RATIOS

These interactions look into the nucleus with a charged W-boson probe. The cross sections are determined by two structure functions $F_2(\nu,\bar{\nu})$ and $xF_3(\nu,\bar{\nu})$ where the former is analogous to the F_2 of DIS, as measured by the EMC group, and the latter comes from the parity violating part of the weak interaction. The CDHS group has separated out the F_2 contribution and their data[6] for the ratio $F_2(\mathrm{Fe})/F_2(H_2)$ analogous to R plotted above is shown in Fig. 2 compared with the curves A, B, C predicted by QCM. These curves are the same for ν and $\bar{\nu}$ beams.

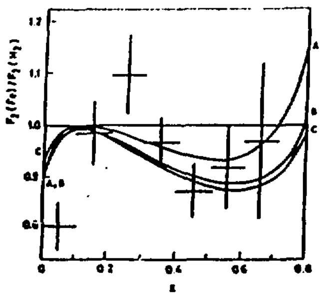

FIG. 2. Predictions from QCM for the ratio of F_2 structure functions for iron and hydrogen compared with the measurements of the CDHS group with neutrino and antineutrino beams. The curves labelled A, B, C have the same meaning as in Fig. 1.

The cross section predictions for ν and $\bar{\nu}$ beams are different because of the sign change in the parity violating contributions. This indicated clearly that these various probes emphasize different components of the cluster's constituents and with better (very near) future data.the source of the EMC effects should be pinned down rather precisely. The neutrino and antineutrino cross section ratios for neon and deuterium targets are shown in Fig. 3. The predictions for cases A and C (solid and dashed lines) for an incident ν beam are compared with the dots representing case A for the $\bar{\nu}$ beam. These are seen to be rather different, with the $\bar{\nu}$ results showing considerable antishadowing in the QCM model for $0.1 < x < 0.4$. The data[6] indeed appear to suggest that this difference is real.

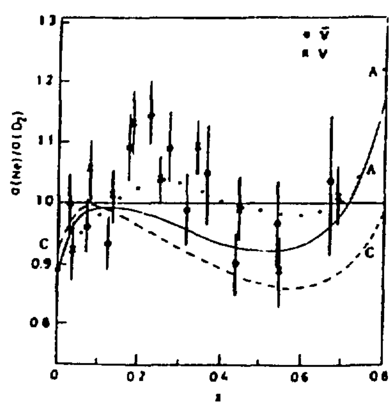

FIG. 3. Cross section ratios on neon and deuterium targets for incident neutrino and antineutrino beams as given by the quark cluster model compared with data. The curve given by spaced dots represents case A for $\bar{\nu}$ beams. The solid and dashed curves represent cases A and C for incident ν beams.

DRELL-YAN PRODUCTION OF MU PAIR ON NUCLEI

It is anticipated that experiment E-772 will produce a large sample of mu pairs by bombarding protons on nuclear targets. At high momentum fraction x_1 of the annihilating parton in the incident proton, the u quark is expected to provide the dominant hard component. However, when statistics are low and it is necessary to average events over a range of x, so that the peak regions of the valence quark distributions contribute, the data cannot hope to discriminate predictions of the QCM from other models or among predictions of cases A, B, C. The majority of events will then indeed be at small x, and the dominant contributions to the averaging is given by curves such as those shown in Fig. 4 for case B and C. A (being similar to B) is dropped for clarity. Also, we note that through $R < 1$ at $x_2 = 0$, if an experiment cannot study R for values of $x_2 < 0.05$, nothing significant can be said with low statistics on shadowing as seen by EMC. Finally, we note that our detailed Drell-Yan results will be published elsewhere with Harindranath and Vary.

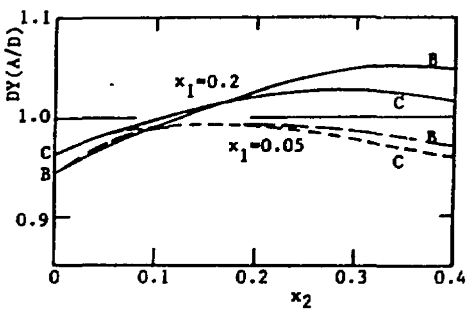

FIG. 4. Calculated ratios of the Drell-Yan mu pair production cross sections on iron to that on deuterium as a function of x_2 for x_1 fixed at 0.05 and 0.2. the curve for case A is similar to B so is not shown. The dashed curve shows the ratio for $x_1 = 0.05$ for B and C and the solid curves show the corresponding results for $x_1 = 0.20$.

CONCLUSIONS

Different reactions emphasize different x regions so the relative importance of valence and ocean quark distributions in nuclei can be "tuned". This feature will aid in allowing the true explanation of the EMC effect to be found.

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