Fermi National Accelerator Laboratory

FERMILAB-Pub-88/59-E
[E-745]

A New Method to Investigate the Nuclear Effect in Leptonic Interactions*

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May 12, 1988

*Submitted to Phys. Lett. B

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Abstract

High energy neutrino interactions in a heavy liquid bubble chamber were classified by the presence or absence of dark tracks at the interaction vertices. Quark distribution, $\sigma(x)$, was compared in the two groups of data. Those with dark tracks, presumably indicative of interaction with a deeply bound nucleon, show an enhanced EMC effect.

Since the discovery of the EMC effect[1], various experiments have followed. These experiments include muon scattering studies by EMC and BCDMS[2], electron scattering data from SLAC[3], and deep inelastic neutrino experiments[4-7] at CERN and FNAL. All of these experiments obtained the ratio of the deep inelastic structure functions, $F_2(x)$, or equivalently of the cross section, $\sigma(x)$, for interactions with a heavy nucleus relative to deuterium. The common features of these data are a small excess of the ratio in the region ($x<0.3$), a dip in the middle region ($0.3<x<0.7$) and a sharp rise for ($0.8<x$). The latter feature has been explained by the Fermi motion of nucleons[8]. Although many theoretical interpretations of this effect[9] have been advanced, it would appear that a final resolution of its underlying cause will require either more detailed information or, perhaps, experimental data of a different kind. In this

paper we present a new experimental approach to the study of the nuclear effect.

The basis of our idea is that a nucleus is not uniform for this effect. The more loosely bound surface nucleons may be considered quasi-free while the more tightly bound nucleons experience motion which is strongly correlated with other nucleons, and the EMC effect may be due to interactions involving nucleons of the latter type.

Interactions with the above two categories of nucleons can presumably be differentiated by the nuclear debris such as dark tracks from an interaction vertex in the bubble chamber pictures. It is clear that this procedure will not result in a perfect separation, i.e. some interactions with quasi-free nucleons will result in proton emission while the interaction with deeply bound nucleons does not guarantee visible proton emission. Nevertheless, to first order, we shall assume that events with dark tracks are predominantly interactions with deeply bound nucleons while events without dark tracks are primarily interactions with quasi-free surface nucleons. If these assumptions are adequate, we should be able to demonstrate the EMC effect by comparing the two groups of data from a given target nucleus. Furthermore, this should result in a larger effect than is seen in conventional experiments since the latter, perforce, include a large fraction of quasi-free interactions.

In this paper we demonstrate this method qualitatively with data from a neutrino experiment using a heavy liquid bubble chamber. However, the method should be applicable to deep inelastic interactions generally. In FNAL experiment E745, the Tohoku 1.4m High Resolution Freon Bubble Chamber Hybrid System was exposed to the wide band neutrino beam generated by 800 GeV protons from the TEVATRON. The bubble chamber has a holographic camera in addition to the three normal stereo-optic cameras. Details of this experiment will be described elsewhere. This paper is based on our initial sample of the neutrino charged current events. In this experiment the Freon liquid is a mixture of R116, C_2F_6 (27% in weight), and R115, $C_2C\ell F_5$ (73%). The ratio of the number of atoms is:

$$^{12}C : {}^{19}F : {}^{35}C\ell : = 0.25 : 0.66 : 0.09.$$

The average A is 18.7 so that the average target nucleus is quite close to ^{19}F.

The separation of events into two groups, those with or without dark tracks, is affected by the sensitivity of the detector to the observation of short dark tracks, ℓ_{min}. The data from the holographic sample have a sensitivity $\ell_{min} \sim 0.5$mm in space and $P_{min} \sim 0.09$ GeV/c. Since the analysis of the holograms is time consuming, in this preliminary report we include the data which is based on the results from normal pictures. In this case, $\ell_{min} \sim 4$ mm in space and $P_{min} \sim 0.17$ GeV/c.

The analysis of events was made in the standard way for bubble chamber neutrino events. The neutrino energy of an event, E_ν, was calculated from the momentum balance of the visible tracks,

$$E_\nu = P_\parallel^{\mu} + P_\parallel^{h,vis} + (p_\perp^{h,Miss}).p_\parallel^{h,vis}/p_\perp^{h,vis},$$

and the other kinematical quantities, Q^2, ν, $x=Q^2/2M\nu$, $y=\nu/E_\nu$, were deduced. Neutrino charged current events were selected by a kinematical method. The muon was kinematically defined[10] and the cut, $P_{TR}>2.5$ GeV/c, was applied to ensure the rejection of neutral current events and hadron events, where P_{TR} is the transverse muon momentum relative to the sum of visible hadron momenta. Having defined the charged current sample thusly, we separate the events into two groups. Our final sample, utilizing a conservative fiducial volume, consisted of 553 events without any dark tracks ($n_D=0$) and 532 events with ($n_D\geqq 1$), where n_D is the number of dark tracks at the primary vertex in an event. Our assumption is that the presence of dark tracks is the signature of a strong correlation between the interacting nucleon and its neighbors and that it is relatively independent of the various quantities in each ν-nucleon deep inelastic interaction. If the dark tracks were to result from a rescattering of secondary particles, the probability of finding dark tracks should be proportional to the light track multiplicity. Such a circumstance would enrich the large W events in the dark track ($n_D\geqq 1$) group and could result in a bias in the ratio of $\sigma(x)$. However, the observed fraction of ($n_D\geqq 1$) events as a function of the number of light track, n_L, in Fig.1 is independent of n_L, except for $n_L>10$. It is estimated that dark track events resulting from rescattering constitute less than 3% of our sample, i.e. the bias due to this type of dark tracks is negligibly small. Alternatively one could consider small Q^2 events as a preferential source of the ($n_D=0$) group. This can be rejected because the fraction of events below $Q^2=2(GeV/c)^2$ is found to be the same within errors, 0.15±0.02 in the ($n_D=0$) group and 0.18±0.03 in the ($n_D\geqq 1$) group.

In order to obtain the ratio of $\sigma(x)$, the directly measured dN/dx distribution in the two groups are used without any Monte Carlo correction. Fig.2a shows the ratio of the $\sigma(x)$ distributions for ($n_D\geqq 1$) and ($n_D=0$) groups, $R(x)=\sigma(x)^{n_D\geq 1}/\sigma(x)^{n_D=0}$. The EMC effect is clearly seen. The two groups are segregated merely by the presence or absence of dark tracks at primary vertices, so that the experimental bias in the ratio is minimal. To obtain the ratio, areas of dN/dx were normalized for all x regions. This corresponds to the assumption that the total cross section per nucleon is the same in the two groups. If the n/p ratios are different in the two groups, a correction is required. However, the correction is less than 2% the of ratio at $x=0.5$ for all reasonable assumptions.

In Fig.2b,c,d we compare the data of the present experiment with data from a previous FNAL ν-D experiment, E545[11]. This latter experiment contains 13,106 charged current events which permit better statistical accuracy in the ratios in these comparisons. The ν-D events were measured and analysed by substantially the same method as in the present experiment. However, differences in the experimental condition and in the charged current selection could cause some bias, especially in the small x region. Therefore, the normalization was made for $x>0.1$ in the comparison with deuterium. Fig.2b shows the standard EMC plot for our full data ν-^{19}F, ($n_D=0+n_D\geqq 1$), relative to the deuterium data. Fig.2c represents the ratio $\sigma(x)^{n_D=0}/\sigma(x)^{\nu D}$ which shows that the effect is very weak for these events. By contrast, Fig.2d shows $\sigma(x)^{n_D\geq 1}/\sigma(x)^{\nu D}$ where a strong effect is seen. It is clear that the effect seen in Fig.2a is primarily in ($n_D\geq 1$) group.

The A dependence of the EMC effect in previous data[3c] is such that the effect increases as A increases. We can qualitatively understand this if the strength of the effect is nearly constant among the deeply bound nucleons. The decrease in the fraction of the quasi-free nucleons (surface/volume ratio) as A increases will mainly explain the data.

The most reasonable conclusion from our results is that the dark track events involve interactions with deeply bound nucleons and show a neat nuclear effect while events without dark tracks are dominated by interactions of quasi-free nucleons.

The authors wish to thank to Prof.G.Snow and Dr.S.Kunori of Maryland University for their valuable discussions. This Research is supported by the US-Japan Cooperation Program on High Energy Physics between the Ministry of Education, Science and Culture, Japan, and the Department of Energy, U.S.A.. Also, this work is partly supported by the National Science Foundation of U.S.A.. We thank them for their support.

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Figure captions

Fig.1 Fraction of ($n_D \gtrsim 1$) events vs. light track multiplicity, n_L. The dash line shows the average.

Fig.2 The ratio of $\sigma(x)$, $R(x) = \sigma(x)^{I}/\sigma(x)^{II}$;

(a) $I=(n_D \gtrsim 1)$ and $II=(n_D=0)$,

(b) $I=(n_D \gtrsim 1+n_D=0)$ and $II=(\nu-D)$; the standard EMC plot, $\sigma(x)^{\nu F}/\sigma(x)^{\nu D}$.

(c) $I=(n_D=0)$ and $II=(\nu-D)$,

(d) $I=(n_D \gtrsim 1)$ and $II=(\nu-D)$

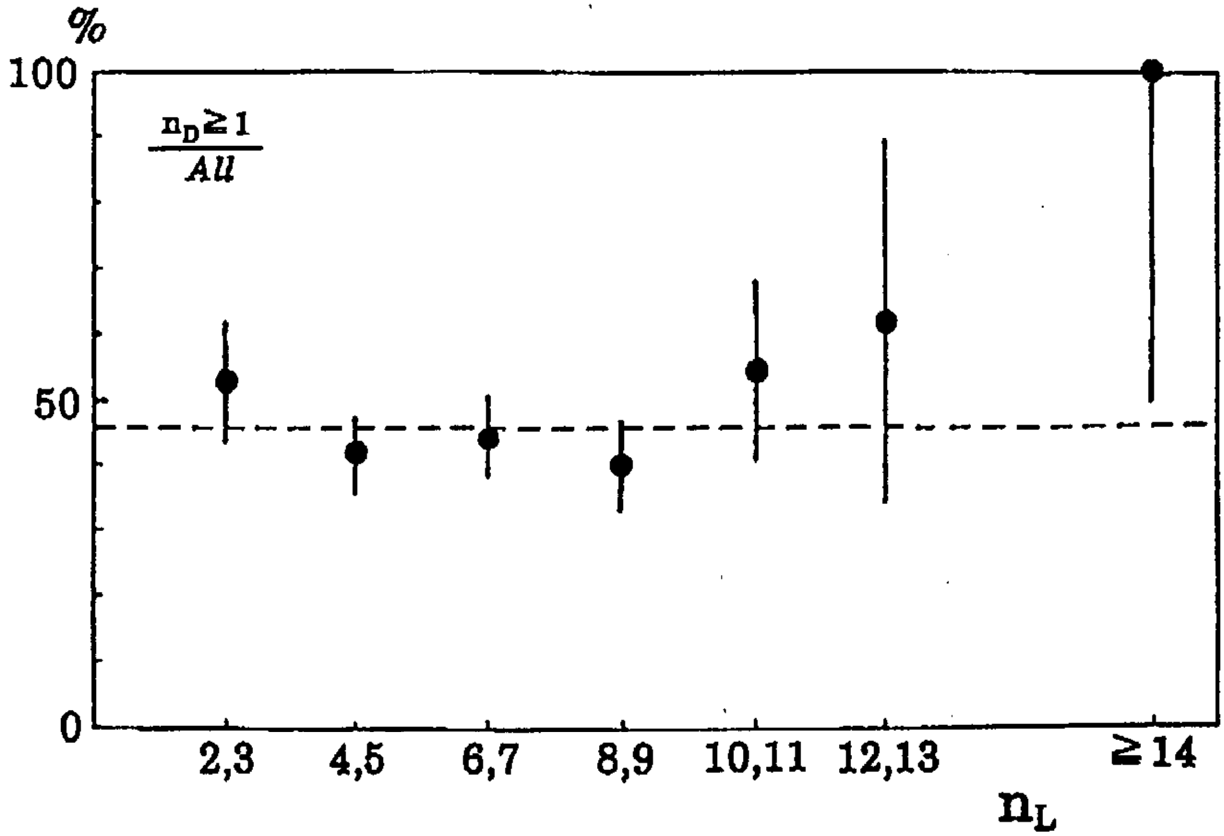

Fig.1 Fraction of ($n_D \geq 1$) vs n_L

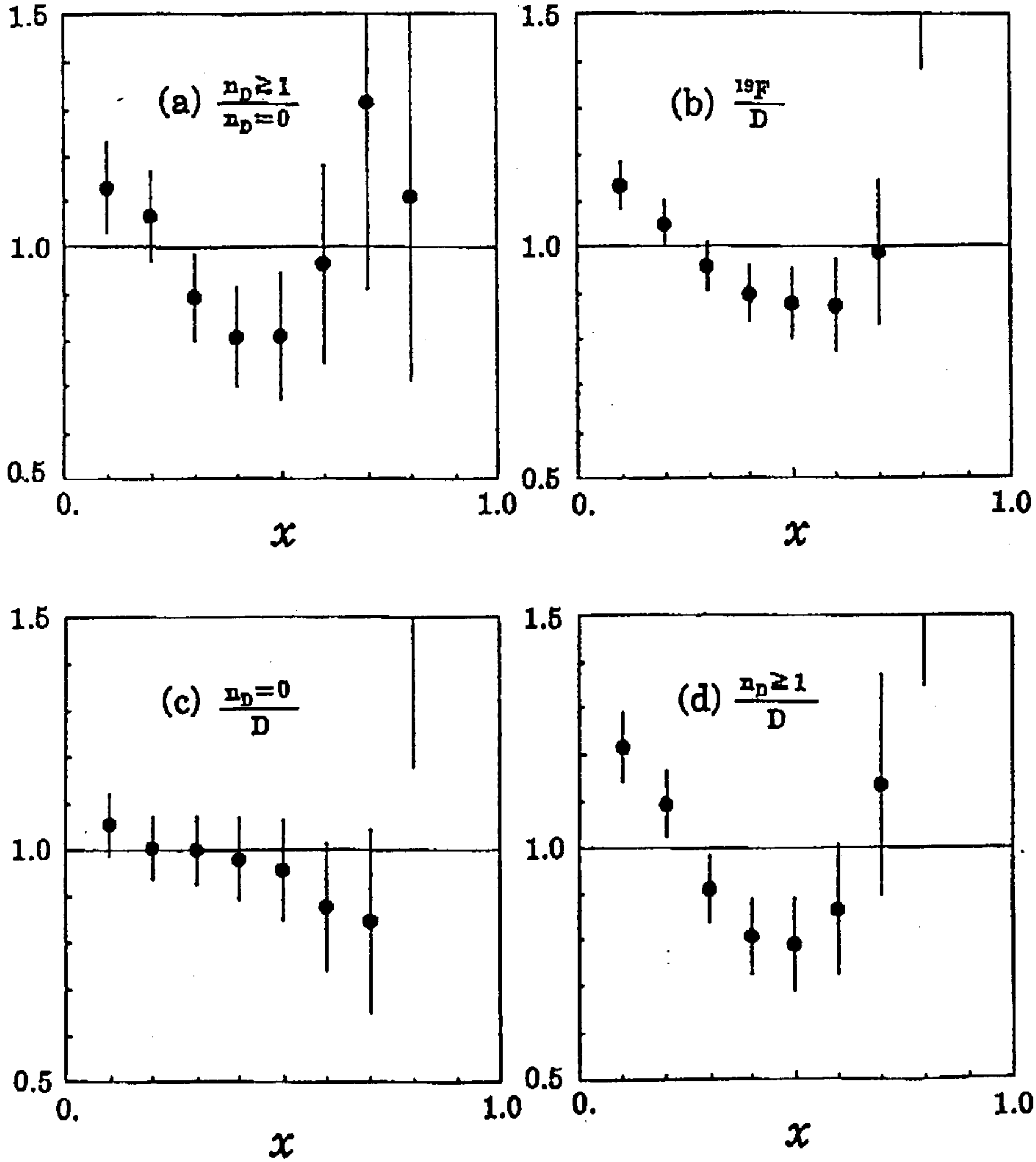
1.5
1.0
0.5
0.
1.0
x
(a) $\frac{n_D \geq 1}{n_D = 0}$
(b) $\frac{^{19}F}{D}$
(c) $\frac{n_D = 0}{D}$
(d) $\frac{n_D \geq 1}{D}$

Fig.2 R(x)