NUCLEAR EFFECTS ON THE NUCLEON STRUCTURE FUNCTION

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ABSTRACT

The structure function of nucleons inside nuclei is approximated by that of free nucleons, Δ isobars and pions in the combination given by nuclear studies. The EMC effect is well reproduced, the Q^2- and A-dependence is discussed.

I would like to report on the work done at the University of Nice in collaboration with Joanna Kubar and Guy Plaut+). It concerns the EMC effect[1], already presented and discussed in previous talks, from what one can call - 'the nuclear physics point of view'. Our aim is to describe an effective nucleon - i.e. a nucleon inside the nucleus applying some standard knowledge gained in nuclear studies. To be specific our main assumption approximates the deep inelastic scattering off nuclei by that off free nucleons, Δ isobars and pions. One sees that the appearance of nuclear forces and possible overlapping of nucleons is represented here by the presence of additional states (Δ, π) which undergo deep inelastic scattering.

We write the 'effective nucleon' structure function of an isoscalar nucleus A as[2,3]

$$F_2^{N/A}(x) = \int_x^A dz f^N(z) F_2^N(\tfrac{x}{z}) + \int_x^A dz f^\Delta(z) F_2^\Delta(\tfrac{x}{z}) + \int_x^A dz f^\pi(z) F_2^\pi(\tfrac{x}{z}) \quad (1)$$

where z is the (+) momentum fraction per nucleon of the interacting nucleon, Δ isobar or pion, $z = Ap_+/p_+^A$, $\alpha = N, \Delta, \pi$.
The distribution functions $f^\alpha(z)$ satisfy the sum rules

$$\int_0^A dz f^N(z) = 1 \qquad \int_0^A dz f^\Delta(z) = \langle n_\Delta \rangle \qquad \int_0^A dz f^\pi(z) = \langle n_\pi \rangle$$

where $\langle n_\Delta \rangle$ ($\langle n_\pi \rangle$) is the average number of Δ isobars (excess pions) per nucleon - as well as the momentum conservation law

$$\sum_{\alpha = N,\Delta,\pi} \int_0^A dz z f^\alpha(z) = 1$$

The convolution formula (1) holds in the large Q^2 limit when the nuclear interactions are 'frozen' during the hard photon-quark scattering. Its validity may be potentially questionable for the pionic contribution[4], we checked however that the shape of our pion distribution $f_\pi(z)$, which is equivalent to the distribution in the '+' momentum component, justifies the use of all three terms of the convolution formula (1).

Let me discuss each part of Eq. (1) separately.

<u>The nucleons</u>. Our main assumption requires the use of free nucleon structure functions as measured in deep inelastic μp and μd scattering (we prefer to stick to one set of data, and present here the results based only on the EMC data). The quark distributions

$$xu_v = 0.77x^{0.3}(1 - x)^3(1 + 4x),$$

$$xd_v = 1.23x^{0.5}(1 - x)^4,$$
$$x\bar{q} = 0.23(1 - x)^6.$$

describe well the aviable EMC data at $\langle Q^2 \rangle = 50$ GeV^2 5).

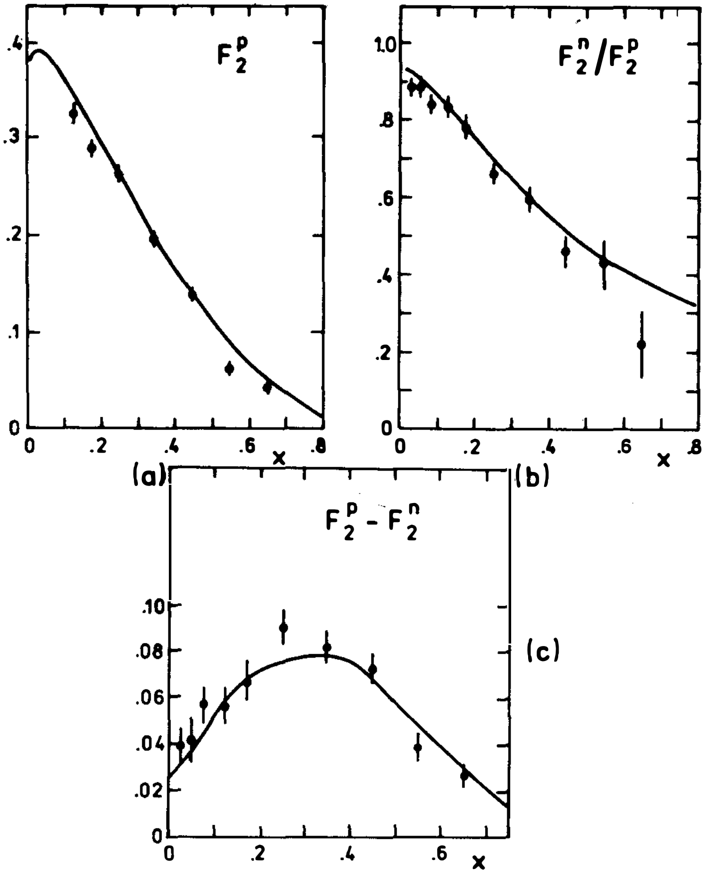

Fig. 1. The x dependence of (a) the proton structure function $F_2^p(x)$ at $Q^2 = 50$ GeV^2, (b) the ratio $F_2^n(x)/F_2^p(x)$ of the neutron to proton structure functions (c) the difference $F_2^p(x) - F_2^n(x)$

The Fermi momentum distribution $f^N(z)$ is taken to be that of a free, nonrelativistic Fermi gas:

$$f^N(z) = \frac{3}{4}\left(\frac{m_N}{k}\right)^3\left[\left(\frac{k_F}{m_N}\right)^2 - (z - \eta)\right]; -\frac{k_F}{m_N} \leq (z - \eta) \leq \frac{k_F}{m_N}$$

where m_N is the nucleon mass, k_F - the Fermi momentum and η - the average momentum carried by the nucleon ($\eta = 1$ in the absence of other components inside nuclei).

The Δ isobars. In the absence of direct measurement of the Δ structure function we base on a construction proposed in Ref. [6], which I recall briefly: one starts with writing the nucleon structure functions $F_2^p(x)$ and $F_2^n(x)$ in terms of the functions $A_I(x)$, $I = 0,1$, which represent the scattering off valence quarks with the spectator valence quarks in spin-isospin I state, and the sea contribution S(x)

$$F_2^p(x) = \frac{4}{9} A_o(x) + \frac{2}{9} A_1(x) + S(x)$$

$$F_2^n(x) = \frac{1}{9} A_o(x) + \frac{3}{9} A_1(x) + S(x)$$

Theoretical arguments as well as the data suggest $A_1(x)$ to decrease with x faster than $A_o(x)$, $A_1(x) \sim (1 - x)A_o(x)$ for large x. The Δ isobar structure function can be written remembering that the spectator valence quarks are always in spin-isospin 1 state (e.g. for Δ^-)

$$F_2^{\Delta^-}(x) = \frac{2}{9} A_1(x) + cS(x)$$

The Δ sea is assumed to be of the same shape as in the nucleons with the normalization fixed by the requirement that all charged partons carry the same fraction of momentum inside nucleons, Δ isobars and pions. The EMC effect is easily understood in the presence of Δ isobars. Any admixture of them increases the coefficient of the function $A_1(x)$ at the costs of $A_o(x)$ in the 'effective nucleon' structure function. An example with 10% of Δ isobars inside the iron nucleus is shown in Fig. 2 with (dashed line) and without (dotted line) the Fermi motion. One sees qualitatively right effect, however the amount of Δ isobars needed to explain the effect quantitatively (about 15%) seems to be too high according to present estimates.

The pions[3,7]. Here we follow essentially the approach of Ref. [3], differing in the parametrization of the pion structure function (and using the free nucleon structure function in the first term of Eq. (1)). The form

$$xq_v = 1.02x^{0.6}(1 - x)^{1.2}, \qquad xq^{sea}(x) = 0.39(1 - x)^6$$

fits well the pion structure function as known from massive lepton pair production[8]. The pion distribution function $f^{\pi}(z)$ is calculated by integration over transverse momenta of the pion distribution inside nucleus $\rho(k)$ obtained[9] by solving the many body Schrodinger equation with the potential which is a sum of pion exchange contribution and a phenomenological parametrization of short-range nucleon-nucleon interaction.

The presence of pions influences the ratio R(x) of structure functions in two ways. The enhancement above 1 at low x is mainly due to the pion structure function, the decrease below 1 at large x is essentially caused by the fact that baryons are slowed down when sharing momentum with pions.

Having explained all three terms of the convolution formula (1) I show the resulting ratio R(x) for iron where the amount of pions and Δ isobars is, according to the calculation of Ref. [9], 0.12/nucleon and 0.04/nucleon respectively. One sees (Fig. 2) quite good agreement with the data in a large range of x.

Let me finish with a few remarks concerning our approach:

- the predicted Q^2 dependence of the EMC effect is very weak. We evoluted our curve down to $Q^2 = 1.5$ GeV^2 with nearly no effect.

- the A dependence is given by the nuclear physics calculation of Ref. [9] where the amount of π's and Δ's is given for various nuclei. The A-dependence is generally weak, as an example I show in Fig. 3 the resulting curve for the aluminium.

- the errors come mainly from the parametrization of the free structure functions of nucleons and pions - particularly at low x - and from the estimates for $\langle n_\pi \rangle$ and $\langle n_\Delta \rangle$. One should not forget also about our main assumption of treating the nucleons, Δ isobars and pions as free states - it may receive corrections from possible interactions within nuclei[4)].

- we repeated the same analysis on the set of SLAC data[10)] parametrizing the ep and ed structure functions and drawing the EMC curve for iron. The results are of the same quality as above and will be presented with the results for other nuclei elsewhere.

To summarize: I presented a construction which is able to explain quantitatively all features of the EMC effect. It is based on what I called 'standard nuclear physics' and this we regard as an important advantage, since it does not produce unwanted side-effects in low energy nuclear physics. Such a potential danger is present in many other models based on new quark structures inside nuclei. It is possible however that these two approaches form two complementary descriptions in two different languages.

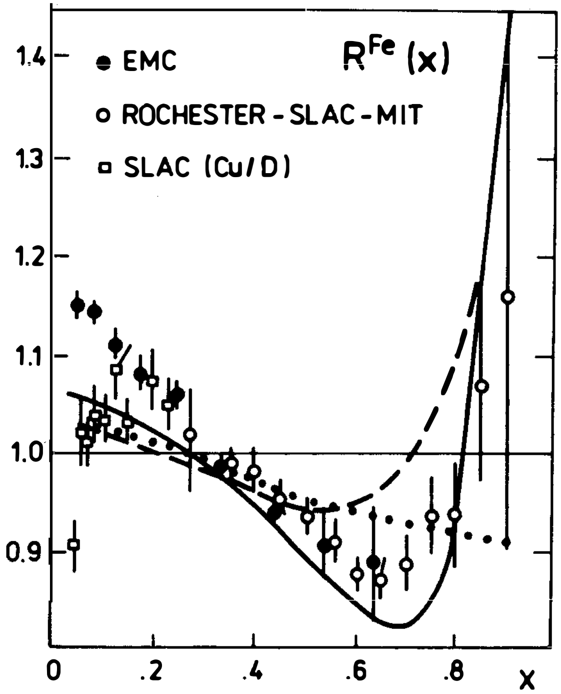

Fig.2

The ratio R(x) of the nucleon structure function in iron to that in deuetrium. The model calculations: 10% of Δ isobars with the Fermi motion included (dashed line), 10% of Δ isobars without the Fermi motion (dotted line), 4% of Δ isobars and 12% of pions with the Fermi motion (solid line)

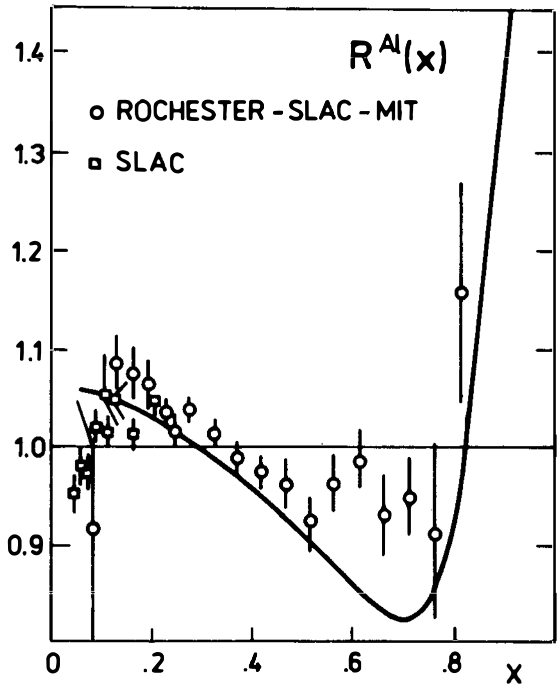

Fig.3

The ratio R(x) of the nucleon structure functions in aluminium and deuterium. The solid line shows the model calculation with 4% of Δ isobars and 11% pions and the Fermi motion included

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