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THE ELECTROMAGNETIC POLARIZABILITY
AND THE SWELLING OF NUCLEONS IN THE NUCLEUS

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A B S T R A C T

We discuss the modifications of the e.m. polarizability and of the charge radius of a nucleon embedded in the nuclear medium. For a free nucleon these structure constants are influenced by the pion cloud. The distortion of this cloud by the nuclear environment produces an appreciable enhancement of the two constants. The implications for the deep inelastic ee' experiments is discussed.

The experiments on deep inelastic ee' scattering on nuclei have revealed an unsuspected feature⁽¹⁾. The Coulomb sum rule, extracted from the longitudinal response is too small, by a factor of nearly two, at momenta $q \approx 600$ MeV/c in medium weight nuclei (Ca, Fe). In order to interpret this result Noble⁽²⁾ has suggested a modification of the electric form factor of the nucleon, with a swelling effect for nucleons inside the nuclear medium. This hypothesis was related to the rescaling one proposed⁽³⁾ for EMC, which is associated with a change in the length scale by the nuclear surrounding.

The necessity of a modification of the nucleon electric form factor in order to account for the sum rule has also been checked at the level of the frequency dependence of the longitudinal response⁽⁴⁾. Indeed no reasonable fit of the $lplh$ response can be achieved without some drastic assumption such as the modification of the electric form factor. The corresponding radius of the nucleon has to be increased by more than 20%⁽⁴⁾.

The swelling of nucleons inside the nucleus has generally been thought of as originating from deep QCD effects, with a partial deconfinement of the quarks. Although this swelling is not yet a fully established fact, we propose in this letter the possibility of a different interpretation belonging to traditional nuclear physics and based on the dynamics of pions in nuclei. In this language a modification of the nucleon radius appears quite natural.

Our viewpoint is inspired by a similarity between the electromagnetic (e.m.) polarizability and the nucleon radius. The e.m. polarizability α determines the leading frequency dependence of the forward (spin averaged) Compton amplitude

$$f(\omega) = f(0) + \alpha \omega^2 + \dots \quad (1)$$

in the same way as the charge radius gives the leading t dependence of the electric form factor

$$G_E(t) = G_E(0) \left[1 + \frac{t \langle r^2 \rangle}{6} + \dots \right] \quad (2)$$

On the other hand both quantities are linked to the internal structure of the nucleon. In fact they are both strongly influenced by the peripheral part of the nucleon structure, i.e. by the pion cloud, as discussed below.

Thus a change in the pion cloud, more precisely a change in the pion charge density, by the proximity of the other nucleons is directly reflected as a modification of these two structure constants. The problem of the e.m. polarizability is easier to handle as this quantity is directly linked to the measured photo-absorption cross section. The corresponding treatment for the radius requires an analytic continuation of cross sections that is beyond the scope of this work. We limit ourselves to a semi-quantitative estimate. We first discuss the charge radius and the e.m. polarizability of a free proton and then turn to their modification in the nuclear medium.

I Free proton

Our starting point is the following observation. The isovector charge radius of the proton arises to a great extent from the exchange of two uncorrelated pions as has been stressed by Höhler et al.⁽⁵⁾ and by Oset et al.⁽⁶⁾. This can be seen from a dispersion relation for the charge form factor which gives the radius $\langle r^2 \rangle^{1/2}$ as⁽⁵⁾

$$\langle r^2 \rangle_p = \frac{6}{\pi} \int_{4m_\pi^2}^{\infty} dt \frac{\text{Im } G(t)}{t^2} \quad (3)$$

where $G(t)$ is the spectral function which follows from unitarity with a dominance of two pion intermediate states with

$$\text{Im } G(t) = \frac{1}{m} \frac{q_t^3}{\sqrt{t}} |F_\pi(t)| |f_-^1(t)| \quad (4)$$

Here $F_\pi(t)$ is the pion form factor and $f_-^1(t)$ the p wave helicity amplitude for $N\bar{N} \rightarrow \pi\pi$. The denominator $1/t^2$ in the expression (3) strongly favours states near the pseudophysical threshold, $t=4m_\pi^2$, i.e. 2π exchange in the continuum (see Figure 1). The direct coupling to the nucleon of the 2π resonance, the ρ meson, which occurs at $t \approx 30m_\pi^2$ is less important. According to Oset et al.⁽⁶⁾ the pion cloud gives most of the proton radius with $\langle r^2 \rangle_{\text{pion}} \approx 0.5 \text{ fm}^2$ as compared to the total value $\langle r^2 \rangle_p = 0.65 \text{ fm}^2$.

Thus we find a situation very similar to that encountered⁽⁷⁾ for the e.m. polarizability a_N given by the dispersion relation

$$a_N = \alpha + \beta = \frac{1}{2\pi^2} \int_{m_\pi}^{\infty} d\omega \frac{\sigma(\omega)}{\omega^2} \quad (5)$$

Here α and β are the electric and magnetic polarizabilities and σ is the total δp cross section. In spite of the dominance of the Δ resonance the weighted sum rule (5) favours the threshold region, where the electric dipole (contact term and pion pole) dominates⁽⁷⁾. The main excitations in the polarizability are therefore the non resonant πN states, as was inferred by Ericson and Rfner⁽⁸⁾. This statement means that the polarizability is mainly due to the pion cloud, corresponding to the graphs of Figure 2. An evaluation of the contribution of these graphs gives⁽⁷⁾

$$a_N = \int d^3q \, b(q) \quad \text{with} \quad b(q) = \frac{e^2 \beta^2}{3\pi^2 m_\pi^2} \frac{q^2}{(q^2 + m_\pi^2)^3} \left[1 - \frac{4q^2 m_\pi^2}{3(q^2 + m_\pi^2)^2} \right] \quad (6)$$

which leads to the numerical value $a_N = 1.4 \times 10^{-3} \text{ fm}^3$. This coincides with the experimental value and emphasizes the role of the pion cloud in the e.m. polarizability. Notice that it also implies that the electric contribution dominates over the magnetic one, which is experimentally verified.

II Nucleon inside the nuclear medium.

We discuss now what modifications of the quantities a_N and $\langle r \rangle^2$ are expected in the nuclear surrounding, starting with the polarizability a_N .

E.m polarizability

One can approach this problem from two different directions. The first one is theoretical. It analyzes the polarizability graphs of Figure 2 to infer the possible modifications by the nuclear medium. The second one is phenomenological. The delicate point in this second approach is the extraction of the nucleon polarizability inside the nucleus. At this point the theoretical approach can be used as a guiding principle.

The graphs of Figure 2 immediately suggest the modifications which naturally should be expected in the nucleus. The first one is the Pauli blocking effect, since the intermediate nucleon has to be above the Fermi sea. The single nucleon graphs of Figure 2 become the many body graphs of Figure 3. The consequence of Pauli blocking is readily evaluated. In the expression (6) $b(q)$ is replaced for $q < 2 p_F$ by

$$b(q) \rightarrow b(q) \left[\frac{3}{2} \frac{q}{2p_F} - \frac{1}{2} \left(\frac{q}{2p_F} \right)^3 \right]$$

This results⁽⁷⁾ in a quenching of a_N by $\approx 20 \%$.

An additional modification arises as follows. In the expression (6) the integrand is strongly convergent with the relevant momenta in the range $1 \lesssim q \lesssim 3 \text{ fm}^{-1}$. This is precisely the region for which an enhancement of the pion field is expected due to the scattering of the virtual pion (see Figure 4). This should be reflected as an enhancement of the polarizability.

We now turn to the phenomenological approach and show how the enhancement manifests itself. For this we consider the integral relation for the nuclear polarizability a_A

$$a_A = \frac{1}{2\pi^2} \int_0^\infty d\omega \frac{\sigma_A(\omega)}{\omega^2} \quad (7)$$

where σ_A is the total π nucleus cross section. We must now separate out and retain in the cross section σ_A or in the polarizability a_A the contribution of the nucleons inside the nucleus as distinguished from surface effects.

The cross section σ_A displays at low energies the strong giant dipole resonance (GDR). Its position varies with the mass number A as $\omega_{\text{GDR}} \approx 80 A^{-1/3} \text{ MeV}$.

At high energy, $\omega \approx 300 \text{ MeV}$, the Δ resonance shows up. Between these two resonances the cross section does not vanish but shows a plateau. The striking feature of the experimental cross sections is their universality. Above the GDR region the cross section per nucleon is practically the same, from very light nuclei (Be) to very heavy ones (Pb and U). This indicates the volume character of this part of the cross section, allowing its identification with an individual nucleon contribution. Indeed if the nuclear and nucleonic excitations were well separated, with the nuclear ones well below $\omega = m_\pi$ and the nucleonic ones above $\omega = m_\pi$, then the nucleonic polarizability inside the nucleus, $\tilde{a}_N$, could easily be separated out. It would be given by a dispersive integral analogous to (5)

$$\tilde{a}_N = \frac{1}{2\pi^2} \int_{m_\pi}^\infty d\omega \frac{\sigma_A(\omega)/A}{\omega^2} \quad (8)$$

but now with the nuclear photoabsorption cross section per nucleon. The comparison between the free polarizability and the one inside the nucleus would amount to a comparison between the nucleon and the nuclear photoabsorption cross sections, σ and σ_A/A , above $\omega = m_\pi$. The presence of the plateau between the GDR and the pion threshold makes this separation more subtle. The microscopic understanding of the origin of this intermediate region sheds light

on this problem. In this region the absorption of the photon is a two-nucleon process which occurs on correlated np pairs. It is the so called quasi-deuteron region where the cross section has been parametrized as

$$\sigma_{QD}(\omega) = \left[62.5 L' \frac{ZN}{A} \frac{\omega - 2.2}{\omega^{5/2}} \right] e^{-80/\omega} \quad (9)$$

with σ in mb and ω in MeV. The bracket represents the deuteron cross section scaled with the Levinger factor L' . The exponential $e^{-80/\omega}$ produces a strong damping at small ω values. Its origin lies in the Pauli blocking effect which forces the two emitted nucleons to be above the Fermi sea. Note that the quasi-deuteron cross section overlaps with the GDR and extends above the pion threshold. Microscopically the 2p2h excitations by the photon is at low energy an electric dipole process. It occurs mostly ⁽⁹⁾ through the contact term (Figure 5a) or the pionic current one (Figure 5b) shown in Figure 5. These contributions are the dominant ones up to $\omega \approx 140$ MeV as in the free deuteron case. The correlation terms (Figure 5c) also plays some role in the quasi-deuteron cross section.

Although the quasi-deuteron cross section is not a single nucleon mechanism, its volume character suggests that it should contribute to the nucleon polarizability but that it concerns a modified nucleon with its polarization cloud. This interpretation is further supported by the remark that the graphs of Figure 5 responsible for the quasi-deuteron cross section follow from the rescattering graphs of the polarizability when the nucleon lines are cut through (see Figure 4a). The quasi-deuteron cross section can thus be seen as a manifestation of the modification of the pion cloud. The consequence for the e.m. polarizability of the nucleon inside the nucleus is now discussed quantitatively.

Let us define the nucleon polarizability in the nucleus as

$$\tilde{\alpha}_N = \frac{1}{2\pi^2} \int_0^\infty d\omega \frac{\sigma'_A(\omega)/A}{\omega^2} \quad (10)$$

where σ'_A refers only to the volume contribution of the cross section, i.e. the GDR has been separated out. Before discussing the numerical result it is instructive to trace in the cross section σ'_A the different modifications of the polarizability mentioned previously and first the Pauli blocking effect. In order to relate these effects in the polarizability to those in the cross section we have to perform a cut in the polarizability graphs of Figure 3 and 4.

The cut of the Pauli blocking graphs of Figure 3 gives the photoproduction of a real pion, through a quasi free mechanism, by the contact or pion pole term. Indeed the Pauli blocking effect appears also in the cross section near threshold where it should produce a strong quenching effect discussed by Mac Donald et al⁽¹⁰⁾. No sizeable quenching is observed however. Near threshold the nuclear cross section per nucleon is close to the free nucleon one. The reason is believed to be the distortion effect of the emitted pion. It changes the energy momentum relation for the pion, thus bringing the nuclear response into a different kinematical domain and producing an enhancement which counterbalances the Pauli blocking effect.

The distortion term arises from the cut on the scattering graphs of Figure 4 through the pion line. Thus the modifications expected for the nucleon polarizability, namely that due to the Pauli blocking and that due to the modification of the pion cloud, can be traced back into corresponding effects in the cross section and there is a consistency between the two descriptions. In fact a detailed understanding of the nuclear cross section σ_A' is not needed for the evaluation of $\tilde{a}_N$ from the dispersion relation (9) but it is useful at the conceptual level. Note that the virtual Δ excitation is essential for the suppression of the Pauli blocking effect, as the p wave scattering of physical pions, mainly responsible for the pion distortion, occurs via Δ excitation. Numerically we find in lead (with the Levinger factor $L'=10$) $\tilde{a}_N = 4.5 \times 10^{-3} \text{ fm}^3$. This value is about three times larger than the free nucleon value $a_N = 1.4 \times 10^{-3} \text{ fm}^3$.

The reason for this large enhancement is the appearance of low lying 2p2h excitations: above $\omega = m_\pi$ the free nucleon cross section and the nuclear cross section per nucleon are close and the enhancement of $\tilde{a}_N$ comes from the integral between 0 and m_π over the quasi-deuteron cross section, strongly favoured by the weighting factor $1/\omega^2$. This factor also introduces a large sensitivity to the low energy behavior of the quasi-deuteron cross section. As this is uncertain below $\approx 30 \text{ MeV}$ (in Pb) where the GDR dominates, we have introduced to test this sensitivity a sharp low energy cut-off, starting the integral of eq.(10) at $\omega = 30 \text{ MeV}$. With this we find a smaller value $\tilde{a}_N = 3.4 \times 10^{-3} \text{ fm}^3$. The precise value of $\tilde{a}_N$ is therefore uncertain but

the existence of a large enhancement in spite of the Pauli blocking effect is beyond doubts. Note that the enhancement of $\tilde{a}_N$ corresponds nearly entirely to a modification of the nucleon electric polarizability α .

Charge radius

We turn now to the charge radius. The nuclear radius is given by a dispersion relation similar to (1) where the helicity amplitude refers to nuclei: $A \bar{A} \rightarrow \pi\pi$. The nucleonic contribution to the radius should be separated out, which is not an easy task. The following things can be said. The spectral function above $t = 4 m_\pi^2$ is expected to be modified by two effects: i) the Pauli blocking of the intermediate nucleon state ii) the distortion of the pion which modifies its energy-momentum relation. In addition the low lying 2p2h excitations should contribute to the spectral function below $t = 4 m_\pi^2$, as for the photoabsorption process. It is plausible that these combined effects increase the proton radius inside the nucleus. However we do not know enough about the behavior of the spectral function in nuclei to attempt a determination by this method.

On the other hand we can get an insight using the following image of a pion bound to a nucleon through a potential. For a two particle system interacting via a potential the mean square charge radius is simply related to the photoabsorption cross section by the "Bremsstrahlung weighted sum rule"

$$\langle r^2 \rangle = \frac{3}{e^2 \pi^2} \int_0^\infty d\omega \frac{\sigma_{\text{dip}}(\omega)}{\omega} \quad (11)$$

where σ_{dip} is the unretarded electric dipole cross section. This result holds true in any potential (central, tensor, etc...) In particular this sum rule is well verified in the deuteron case.

This relation can be compared to the expression of the electric polarizability

$$\alpha = \frac{1}{2\pi^2} \int_0^\infty d\omega \frac{\sigma_{\text{dip}}(\omega)}{\omega^2} \quad (12)$$

It gives the following approximate relation between the mean radius squared and the electric polarizability

$$\langle r^2 \rangle \approx \frac{3}{2e^2} \langle \omega \rangle \alpha \quad (13)$$

where $\langle \omega \rangle$ is a typical E1 excitation energy. Thus an increase in the polarizability by the medium effects implies an increase in the radius.

It is worth pointing out that eq.(11) gives a fairly reasonable idea of the charge radius of the free proton itself arising from the pion cloud. With the value of the electric polarizability of the free proton, $\alpha = 10^{-3} \text{ fm}^3$ and an average energy $\langle \omega \rangle \approx 200 \text{ MeV}$, relevant for the πN continuum, eq. (11) gives $\langle r^2 \rangle_{\text{pion}} \approx 0.8 \text{ fm}^2$ while the value given by Oset et al ⁽⁶⁾ for this quantity is $\approx 0.5 \text{ fm}^2$. This gives us some confidence that we can use the expressions (10) or (11) to relate the increase in the charge radius of the proton to the modification of the polarizability, i.e. to the quasi deuteron cross section.

The proton radius in the nucleus is obtained from eq. (11) with the nuclear electric dipole cross section per nucleon. It gets a contribution from the region above the pion threshold and another one from the region below. The first contribution gives practically the free nucleon radius since the nuclear cross section per nucleon and the free nucleon one are close. The region below

$\omega = m_\pi$ gives an excess radius

$$\Delta \langle r^2 \rangle_p \approx \frac{3}{e^2 \pi^2} \int_0^{m_\pi} d\omega \frac{\sigma_{\text{EO}}(\omega)/A}{\omega} \quad (14)$$

which gives in lead : $\Delta \langle r^2 \rangle_p \approx 0.5 \text{ fm}^2$, nearly doubling the free value

$\langle r^2 \rangle_p = 0.65 \text{ fm}^2$. The sensitivity of $\Delta \langle r^2 \rangle$ to the low energy behavior of $\sigma_{\text{EO}}(\omega)$ is large, although not as large as that of the polarizability. With a sharp cut-off which completely eliminates the contribution from the region below $\omega = 30 \text{ MeV}$, we obtain $\Delta \langle r^2 \rangle_p \approx 0.4 \text{ fm}^2$.

The quantity $\Delta \langle r^2 \rangle_p$ represents a "quasi-deuteron" contribution to the proton radius, the distance over which the proton charge is spread, being transmitted to the neighbouring neutrons or to the pion cloud. The question then arises: how can this spreading be tested? In particular can it show up in the deep inelastic ee' experiments and be responsible for the missing strength? The answer to this question is not obvious. Our estimate for the radius increase happens to be close to the one empirically needed to account for the missing strength which is, in Ca and Fe, $\Delta \langle r^2 \rangle_p \approx 0.4 \text{ fm}^2$ ⁽⁴⁾. However at present no firm conclusion can be drawn from this coincidence. Our evaluation for the radius is made in the long wavelength and static limit while the ee' experiments concern photons of momentum ranging from $q \approx 1$ to 3 fm^{-1} and frequencies from 0 to 200 MeV. It is not clear whether the considerations developed in this work fully apply under those circumstances.

We plan to pursue this investigation by a study of our effect under those

experimental conditions, with an explicit evaluation of the graphs that generate it. These represent the renormalization in the nuclear medium of the πNN vertex, more precisely of its 2π exchange part, by the Pauli blocking for the intermediate nucleon and by the scattering of the virtual pion. For the quasi elastic response these graphs are represented in Figure 6 and 7.

The introduction of these graphs allows to relate our work to previous investigations. The Pauli blocking graph of Figure 6 represents the meson exchange corrections which have been considered by Kohno and Ohtsuka⁽¹¹⁾. They found them to be negligible at small q and to reach a 10% level at $q = 2 \text{ fm}^{-1}$. Their q dependence is normal for a radius modification but the sign of their effect is opposite to our expectations. Since Pauli blocking quenches the e.m. polarizability it should decrease the radius and hence enhance the response, while they find a quenching. This point should be cleared up. In addition to the effect of Pauli blocking we have considered the influence of pion scattering. We have done this in terms of the quasi deuteron cross section which also incorporates the correlation graphs of Figure 7c. These last graphs are the same as those introduced by Bertsch and Hamamoto⁽¹²⁾ in their study of the Gamow-Teller response. Here for the charge response, we believe that the dominant effect does not come from the correlation graphs but from those graphs of Figure 7a and 7b where the photon attaches to a πNN vertex or to a pion line. We remind that in the process of photo- or electrodisintegration of the deuteron the two body meson exchange current of Figure 8 (pair term and pion current term) play a very important role. It is then normal that they should also show up in the quasi elastic response through the graphs of Figure 7a and 7b.

Finally we want to make some remarks about the experimental consequences of this picture. The change in the radius has an isovector character. Therefore it does not show up in the elastic charge form factor for a nucleus with equal number of protons and neutrons. An incoherent process instead, such as the quasi elastic ee' scattering, is sensitive to this increase in the isovector radius. This should lead to a suppression of the isovector component in the longitudinal response, which could be detected as follows. In an RPA framework the isovector and isoscalar components of the longitudinal response are split by the ph force. The suppression should then be more visible in the high

region of the response which concentrates the isovector strength. In fact the suppression of the isovector component has been proposed by Stroth et al⁽¹³⁾ on empirical grounds.

Moreover the isovector nature of the change has repercussions for the coupling of the photon to a neutron, proportional to $G_s(t) - G_v(t)$, where G_s and G_v are the isoscalar and isovector form factors. The change in the isovector radius makes G_v appreciably different from its free value and hence from G_s at finite t . Thus the coupling of the photon to the neutron becomes much larger than its free value, which is small. The nuclear response which is proportional to $Z (G_s + G_v)^2 + N (G_s - G_v)^2$ becomes sensitive to the neutron excess. This may be at the origin of the experimental finding⁽¹⁾ of a difference between the longitudinal responses of ^{40}Ca and ^{48}Ca .

We have examined in this work the influence of the modification of the pion cloud on the charge form factor of the nucleon inside the nucleus. A similar investigation should be performed for the magnetic form factor. Both the magnetic moment and the magnetic radius receive a contribution from the pion cloud. The modification of this cloud by the nuclear environment should not lead to consequences in conflict with data. The influence on the magnetic moment has been discussed by Noble⁽¹⁴⁾. For what concerns the radius, we remind that in the transverse response there is apparently no need for a modification of the magnetic radius. Moreover a specific quasi-elastic ee' experiment whose aim was a test of the nucleon radius in the nucleus has put stringent limits on the maximum possible increase⁽¹⁵⁾. Under the kinematical conditions of this experiments which probed mostly the transverse response this limit applies essentially to the magnetic radius.

In conclusion we have studied here how the e.m. polarizability and the charge radius of the nucleon are affected by the nuclear environment. For a free nucleon these quantities are strongly influenced by the pion cloud, i.e. by the peripheral structure of the nucleon which is the one most sensitive to the presence of other nucleons. In the photoabsorption process by nuclei, the distortion of the pion cloud shows up in the γ -nucleus total cross section by the appearance of the quasi-deuteron cross section. This extends below the pion threshold where it has essentially an electric dipole character. The excess

cross section below $\omega = m_\pi$ is linked by a dispersion relation to the modification of the e.m. polarizability where it produces a large enhancement. In the same way the modification of the charged pion cloud around a proton implies that the proton in the nucleus acquires an effective charge radius different from the free one: part of the charge has been transferred to the periphery of the proton, i.e. to the neighbouring neutrons or to the pion cloud which becomes denser in the nuclear medium. A semi quantitative estimate leads to an increase in the mean square radius: $\Delta \langle r^2 \rangle = \langle r^2 \rangle_{\text{eff}} - \langle r^2 \rangle_p \approx 0.4 \text{ to } 0.5 \text{ fm}^2$. In our picture the swelling of the nucleon in the nucleus is a meson exchange effect which pertains to the traditional nuclear physics.

In connection with our suggestion more work is needed. In particular the change in the radius must be evaluated more accurately. The interest of this problem is such that it is worth a serious effort. We remind in this connection that the EMC effect has revealed that the quark structure of the nucleons is affected by the nuclear surrounding. Two schools of thought have emerged to interpret this result. One links it to some deep QCD effects with a partial deconfinement of the quarks. The other sees a manifestation of traditional nuclear physics, expressed in terms of nuclear binding or pion excess. In the second language there is no genuine deconfinement since only colour singlets (mesons) are allowed to be exchanged. Our study of the polarizability of the nucleon in the nuclear medium is in favour of the existence of a modification of the charged pion cloud by the nuclear environment. In turn this modification gives rise to an effective charge radius, larger than the free value. We suggest that this effect may be at the origin of the missing strength problem in ee' scattering. If our suggestion proves to be right it would be a strong support in favour of the second school of thought to interpret the EMC effect.

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FIGURE CAPTIONS

- Fig. 1 The two-pion exchange contribution to the proton radius. The $\gamma 2\pi$ vertex incorporates ρ exchange.
- Fig. 2 The contribution of the pion cloud to the polarizability of a free nucleon.
- Fig. 3 The same as Fig. 2 for a nucleon inside the nuclear medium. Only the Pauli blocking effect is included.
- Fig. 4 The same as Fig. 3 with in addition the inclusion of the pion scattering (not all graphs are shown). The dot-dashed lines represent examples of a cut which puts intermediate states on-shell.
- Fig. 5 The graphs responsible for the 2p2h excitations by a photon through a) the contact term, b) the pion current term c) the correlation term.
- Fig. 6 The meson exchange correction to the quasi-elastic lph response. Only the Pauli blocking effect is included.
- Fig. 7 The same as Fig. 6 with in addition the inclusion of the pion scattering.
- Fig. 8 Two-body meson exchange current.

Fig.1

a

b

c

Fig.2

Fig.3

a

b

c

Fig.4

a

b

c

c

Fig.5

Fig.6

Fig.7

Fig.8