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NN CORRELATIONS AND FINAL-STATE INTERACTIONS IN (e,e′NN) REACTIONS

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After a brief overview of relevant studies on one-nucleon knockout, showing the importance of quantitatively understanding the origin of the quenched spectroscopic factors extracted from data, attention is focussed on two-nucleon emission as a suitable tool to investigate nucleon-nucleon correlations inside complex nuclei. In particular, direct (e,e′pp) and (e,e′pn) reactions are discussed, and the role of final-state interactions is studied. The influence of the mutual interaction between the two outgoing nucleons is shown to depend on the kinematics and on the type of the considered reaction.

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1. *Introduction and motivations*

Electron scattering has been used for many years as a clean tool to explore nuclear structure. In the one-photon-exchange approximation, where the incident electron exchanges a photon of momentum $\boldsymbol{q}$ and energy ω with the target, the response of atomic nuclei as a function of $Q^2 = |\boldsymbol{q}|^2 - \omega^2$ and ω can nicely be separated because the electromagnetic probe and its interaction are well under control. In addition, in direct one- and two-nucleon emission, one may access the single-particle properties of nuclei and nucleon-nucleon (NN) correlations, respectively (see, e.g., Ref. [1]).

In plane-wave impulse approximation (PWIA), i.e. neglecting final-state interactions (FSI's) of the ejected particle, the coincidence (e,e′p) cross section in the one-photon exchange approximation is factorized [1, 2] as a product of the (off-shell) electron-nucleon cross section σ_{eN} and the nuclear spectral density,

$$S(\boldsymbol{p}, E) = \sum_{\alpha} S_{\alpha}(E) |\phi_{\alpha}(\boldsymbol{p})|^2. \tag{1}$$

For each removal energy E, the $\boldsymbol{p}$ dependence of $S(\boldsymbol{p}, E)$ is given by the momentum distribution of the quasi-hole states α produced in the target nucleus at that energy and described by the (normalized) overlap functions ϕ_{α} between the target (A-particle) nucleus ground state and the $(A-1)$-particle states of the residual nucleus. The spectroscopic factor S_{α} gives the probability that such a quasi-hole state α be a pure hole state in the target nucleus. In an independent-particle shell model (IPSM), ϕ_{α} are just the single-particle states of the model, and $S_{\alpha} = 1$ (0) for occupied (empty) states. In reality, the strength of a quasi-hole state is fragmented over a set of single-particle states due to correlations, and $0 \leq S_{\alpha} < 1$.

Complications arise in the theoretical treatment when considering FSI's because such a factorization in the cross section is no longer possible [2]. Still, the shape of the experimental momentum distribution at each excitation energy of the residual nucleus can be described to a high degree of accuracy in a wide range of kinematical conditions in terms of quasi-hole states, and the normalization factor needed to adjust the theoretical result to data is interpreted as the value of the spectroscopic factor extracted from experiment.

Two major findings came out of these studies. First, the valence quasi-hole states ϕ_{α} almost overlap the IPSM functions with only a slight ($\sim 10\%$) enlargement of their rms radius. Second, a systematic suppression of the single-particle strength of valence states as compared to IPSM has been observed all over the periodic table. A quenching of spectroscopic factors is naturally conceived in nuclear many-body theory in terms of nucleon-nucleon correlations. However, model calculations produce spectroscopic factors S_{α} much larger than those extracted in low-energy (e,e′p) data. As an example, for the p-shell holes in ^{16}O, a Green-function approach to the spectral density [3] gives $S_{\mathrm{p}_{1/2}} = 0.890$ and $S_{\mathrm{p}_{3/2}} = 0.914$, while from experiment one has $S_{\mathrm{p}_{1/2}} = 0.644$ and $S_{\mathrm{p}_{3/2}} = 0.537$. In contrast, at higher energy and momentum transfer, much larger spectroscopic factors are extracted, i.e. $S_{\mathrm{p}_{1/2}} = 0.73$ and $S_{\mathrm{p}_{3/2}} = 0.71$ in Ref. [4], and $S_{\mathrm{p}_{1/2}} = 0.72$ and $S_{\mathrm{p}_{3/2}} = 0.67$ in Ref. [5]. This was confirmed in the reanalysis of the ^{12}C(e,e′p) data [6] where at $Q^2 \leq 0.3$ GeV^2, the s- and p-shell strength has been found quite substantially reduced by the factor 0.57 ± 0.02. In contrast, for $Q^2 \geq 1$ GeV^2, the same analysis gives a strength approximating the IPSM value. A possible Q^2 dependence of spectroscopic factors, jumping from values around 0.6–0.7 at low Q^2 to unity at $Q^2 \geq 1$ GeV^2, simply means that something is not under control in either experiment or theory or both.

In fact, the most general form of the coincidence cross section in the one-photon-exchange approximation is the contraction of the lepton tensor $L_{\mu\nu}$ with the hadron tensor $W^{\mu\nu}$. The latter is a bilinear form of the hadron current J^μ, i.e.

$$J^\mu = \int \mathrm{d}\boldsymbol{r} \; \langle \Psi_\mathrm{f} |\, j^\mu(\boldsymbol{r}) \,| \Psi_\mathrm{i} \rangle e^{\mathrm{i}\boldsymbol{q}\cdot\boldsymbol{r}}, \tag{2}$$

where the charge-current operator $j^\mu(\boldsymbol{r})$ is responsible for the transition from an initial state $|\Psi_\mathrm{i}\rangle$ (describing the motion of the ejected nucleon in its initial bound state) to a final state $|\Psi_\mathrm{f}\rangle$ with the ejectile undergoing FSI's with the residual nucleus. In the nonrelativistic PWIA approach, the representation of $|\Psi_\mathrm{i}\rangle$ is identified with $[S_\alpha]^{1/2}\phi_\alpha(\boldsymbol{r})$ and $|\Psi_\mathrm{f}\rangle$ becomes a plane wave.

In order to get reliable information in a comparison between theory and data, all sources of theoretical uncertainties must be under control and treated consistently. Under quasi-free kinematics, $j^\mu(\boldsymbol{r})$ is reliably approximated by a one-body operator. Ambiguities arising from its off-shell behaviour [7] have been studied and shown to give a small effect [8–10]. The relevance of genuine relativistic effects has recently been investigated [11] in a consistent comparison between nonrelativistic and relativistic calculations within the distorted-wave impulse approximation (DWIA). Significant relativistic effects, especially in the transverse responses, are found already for a proton kinetic energy as low as 100 MeV. As a consequence, a satisfactory description of ^{16}O data at low and high Q^2 is obtained with (extracted) spectroscopic factors of about 0.7.

Most important is the treatment of FSI's as much of the quenching of the extracted spectroscopic factor depends on the loss of flux introduced by FSI's in the observed channel. A systematic analysis of the effects of FSI's is highly desirable also in view of the debated problem of hadron propagation in the nuclear medium and nuclear transparency. In fact, the role of genuine attenuation of FSI's with increasing energy must be understood before studying other mechanisms, such as, e.g., colour transparency.

Here, great help comes from the measurement of the recoil proton polarization P^N normal to the scattering plane of the polarized incident electrons. Without FSI's, $P^\mathrm{N} = 0$. Therefore, P^N is a good candidate to look at when studying nuclear transparency, as its Q^2 dependence reflects the energy dependence of FSI's. Relativistic DWIA results are indeed sensitive to the model used to simulate FSI's [11].

In principle, the absorption of the ejectile is due to the same (energy-dependent) mean field producing the quasi-hole state. The relevant quantity is the self-energy which is obtained from a self-consistent calculation of the nucleon spectral function. In this way, it is then possible to analyse data at different values of Q^2 with the same quasi-hole wave functions and a correspondingly consistent treatment of FSI's [12, 13]. It is remarkable that with this approach, the same spectroscopic factors used to describe the data at low Q^2 also describe data at high Q^2. Thus the puzzle on the Q^2 dependence seems to be solved.

The problem remains to understand quantitatively the quenching of spectroscopic factors with respect to IPSM and to have a handle to discriminate between different contributions to NN correlations, i.e. long/short range, central/tensor correlations, etc. (see, e.g., Refs. [14, 15]). There is accumulating evidence for enhanced (e,e′p) transverse strength of non-single particle origin at high missing energies [16–18]. However, one-nucleon emission is only an indirect tool for such a purpose. It is by now well established that better information on NN correlations can be obtained with exclusive two-nucleon emission. In this paper, a review of the present status of such a type of reactions on complex nuclei is presented with particular attention to the recent work on improving the treatment of FSI's [19, 20].

2. *Two-nucleon emission*

Exclusive two-nucleon emission by an electromagnetic probe has been proposed long time ago [21] to study NN correlations. Data with real photons are available [22–25] confirming the validity of the direct mechanism for low values of the excitation energy of the residual nucleus. Due to the difficulty of measuring exceedingly small cross sections in triple coincidence, only with the advent of high-duty-cycle electron beams a systematic investigation of (e,e′NN) reactions has become possible. At present, only a few pioneering measurements have been carried out [26–29], but the prospects are very encouraging.

The general theoretical framework involves the two-hole spectral density [30,31,1], whose strength gives the probability of removing two nucleons from the target, leaving the residual nucleus at some excitation energy. Integrating the two-hole spectral density over the energy of the residual nucleus, one obtains the two-body density matrix incorporating NN correlations. The triple-coincidence cross section is again a contraction between a lepton and a hadron tensor. It contains the two-hole spectral density through bilinear products of hadron currents J^μ of the type (2) suitably adapted to this type of reaction, i.e.,

$$J^\mu = \int \mathrm{d}\boldsymbol{r}\ \langle \psi_\mathrm{f} |\, j^\mu(\boldsymbol{r})\, | \psi_\mathrm{i} \rangle e^{\mathrm{i}\boldsymbol{q}\cdot\boldsymbol{r}}, \tag{3}$$

where $|\psi_\mathrm{i}\rangle$ is the two-nucleon overlap function between the ground state of the target and the final state of the residual $(A-2)$ nucleus, and $|\psi_\mathrm{f}\rangle$ is the scattering wave function of the two ejected nucleons. The nuclear current operator $j^\mu(\boldsymbol{r})$ is the sum of a one- and a two-body part. The one-body part consists of the usual charge operator and the convection and spin currents. The two-body part consists of the nonrelativistic meson exchange currents (pionic seagull and pion-in-flight contributions) and intermediate isobar contributions such as the Δ-isobar.

A consistent treatment of FSI would require a genuine three-body approach for the interaction of the two emitted nucleons and the residual nucleus, which represents a challenging task never addressed up to now in complex nuclei. A crucial assumption adopted in the past was the complete neglect of the mutual interaction between the two outgoing nucleons. Thus FSI is simply described by an attenuated flux of each ejectile due to an optical model potential. However, this apparently reasonable assumption has to be checked. In the following subsections, first steps towards a complete description of FSI are presented and discussed.

Even without FSI, the two-hole spectral density is not factorized in the triple-coincidence cross section. Therefore, it is difficult to extract information on correlations from data, and to investigate suitable kinematic conditions where the cross section is particularly sensitive to correlations, one must use models. A priori, one may envisage that two-nucleon knockout is due to one- and two-body currents. Of course, one-body currents are only effective if correlations are present so that the nucleon interacting with the incident electron can be knocked out together with another (correlated) nucleon. In contrast, typically due to the meson exchanges and isobar configurations, two-body currents lead naturally to the two-nucleon emission even in an independent-particle shell model.

Two-body currents are mainly transverse and preferentially involve a proton-neutron pair. Thus reactions like (γ,pn) and (e,e$'$pn) are particularly sensitive to their effects. In this respect, (e,e$'$pp) reactions, where the two-body currents play a minor role, are better suited to look for correlations. Resolution of discrete final states has been shown to provide an interesting tool to discriminate between contributions of different mechanisms responsible for two-nucleon emission [32].

2.1. NN correlations

The shape of the angular distribution of the two emitted nucleons mainly reflects the momentum distribution of their c.m. total angular momentum L inside the target nucleus [30]. When removing, e.g., two protons from the ^{16}O ground state, the relative $^1S_0$ wave of the two protons is combined with $L = 0$ or 2 to give 0^+ or 2^+ states of the residual ^{14}C nucleus, respectively, while the relative ^{3}P waves always occur combined with a $L = 1$ wave function giving rise to $0^+, 1^+$and 2^+ states. Combining the reaction description of Ref. [31] with the many-body calculation of the two-particle spectral function in ^{16}O of Ref. [33], the cross section for the 0^+ ground state, and to a lesser extent also for the first 2^+ state of ^{14}C, was shown in Ref. [32] to receive a major contribution from the ^{1}S$_0$ knockout. Such transitions are, therefore, most sensitive to short-range correlations. This is indeed the case, as seen in two exploratory studies performed at NIKHEF [26, 27], and confirmed in Ref. [28]. As the calculations are sensitive to the treatment of correlations, precise data could give important constraints when modelling the off-shell behaviour of the NN potential.

Superparallel kinematics has been preferred at Mainz [29], with one proton ejected along the virtual photon direction and the other in the opposite direction. In this kinematics only the pure longitudinal (L) and pure transverse (T) structure functions occur in the cross section, and a Rosenbluth L/T separation becomes possible in principle. The effect of two-body currents is further suppressed by looking at the longitudinal structure function that is most sensitive to short-range correlations. The data are still preliminary and require further analysis before a fully reliable comparison with calculations can be done. Nevertheless, they show distinctive features predicted by calculations [32, 34].

Tensor correlations are expected to play a major role in (e,e$'$pn) reactions where, however, the proton-neutron pair is ejected by a much more complicated mechanism involving two-body currents. In the superparallel kinematics of the proposed Mainz experiment [35] with an incident electron energy of 855 MeV, $\omega = 215$ MeV and $q = 316$ MeV/c, the predicted cross sections for (e,e′pn) are about one order of magnitude larger than the corresponding cross sections for (e,e′pp) reactions [36]. This enhancement is partly due to meson-exchange currents and partly to tensor correlations. Quite different results are predicted depending on these correlations being included or not. An accurate determination of the two-hole spectral density is thus most desirable in order to disentangle the effects of two-body currents from those of nuclear correlations.

Experimentally, additional and precise information will come from measurements of the recoil polarization of the ejected proton in either (e,e′pp) or (e,e′pn). Resolving different final states is a precise filter to disentangle and separately investigate the different processes due to correlations and/or two-body currents. The general formalism is available [37] and has been extended to study polarization observables also in the case of two nucleons emitted by a real photon [38].

2.2. Final-state interactions

The relevant diagrams for electromagnetic two-nucleon knockout on a complex nucleus are depicted in Fig. 1. In the simplest approach, any interaction between the two nucleons and the residual nucleus is neglected, and a plane-wave (PW) approximation is assumed for the two outgoing nucleons. In the more sophisticated approach of Ref. [32], the interaction between each of the outgoing nucleons and the residual nucleus is considered in the distorted-wave (DW) approximation by using a complex phenomenological optical potential V^{OP} for nucleon-nucleus scattering which contains a central, a Coulomb and a spin-orbit term [39] (see diagram (a) in Fig. 1). Only very recently the mutual NN interaction V^{NN} between the two

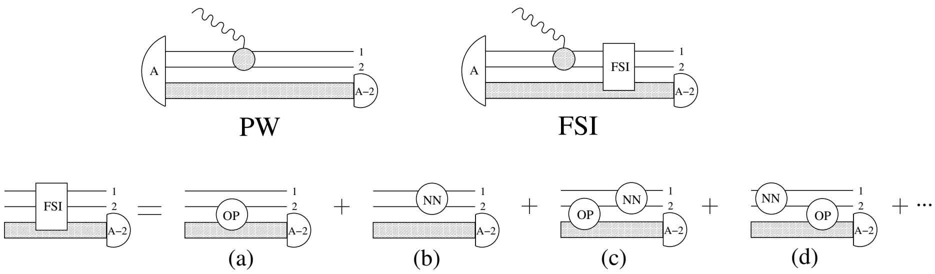

Fig. 1. The relevant diagrams for electromagnetic two-nucleon knockout on a complex nucleus. The two diagrams on top depict the plane-wave approximation (PW) and the distortion of the two outgoing proton wave functions by the final state interaction (FSI). Below, the relevant mechanisms of FSI are depicted in detail, where the open circle denotes either a nucleon-nucleus interaction given by a phenomenological optical potential (OP) or the mutual interaction between the two outgoing nucleons (NN). Diagrams which are given by an interchange of nucleon 1 and 2 are not depicted.

outgoing nucleons (NN-FSI) has been taken into account [19, 20] (diagram (b) in Fig. 1). Multiscattering processes, like those described by diagrams (c) and (d) of Fig. 1, are still neglected and left for future work. The present treatment of incorporating NN-FSI is denoted as DW-NN. We denote as PW-NN the treatment where only V^{NN} is considered and V^{OP} is switched off.

Denoting by $|\boldsymbol{q}_i\rangle$ a plane-wave state of the ejectile i with momentum $\boldsymbol{q}_i$ and by $|\phi^{\mathrm{OP}}(\boldsymbol{q}_i)\rangle$ its state distorted by the optical potential, the corresponding final states in these different approximations are given by

$$|\psi_{\mathrm{f}}\rangle^{\mathrm{PW}} = |\boldsymbol{q}_1\rangle\,|\boldsymbol{q}_2\rangle, \tag{4}$$

$$|\psi_{\mathrm{f}}\rangle^{\mathrm{DW}} = |\phi^{\mathrm{OP}}(\boldsymbol{q}_1)\rangle\,|\phi^{\mathrm{OP}}(\boldsymbol{q}_2)\rangle, \tag{5}$$

$$|\psi_{\mathrm{f}}\rangle^{\mathrm{PW-NN}} = |\boldsymbol{q}_1\rangle\,|\boldsymbol{q}_2\rangle + G_0(z)\,T^{\mathrm{NN}}(z)\,|\boldsymbol{q}_1\rangle\,|\boldsymbol{q}_2\rangle, \tag{6}$$

where the NN-scattering amplitude T^{NN} is given by

$$T^{\mathrm{NN}}(z) = V^{\mathrm{NN}} + V^{\mathrm{NN}} G_0(z)\,T^{\mathrm{NN}}(z), \tag{7}$$

with

$$G_0(z) = \frac{1}{z - H_0(1) - H_0(2)}, \tag{8}$$

$H_0(i)$ denoting the kinetic energy operator for particle i, and $z = \boldsymbol{q}_1^2/(2m) + \boldsymbol{q}_2^2/(2m) + \mathrm{i}\epsilon$. The full approach, including diagrams (a) and (b) in Fig. 1 gives

$$|\psi_{\mathrm{f}}\rangle^{\mathrm{DW-NN}} = |\phi^{\mathrm{OP}}(\boldsymbol{q}_1)\rangle\,|\phi^{\mathrm{OP}}(\boldsymbol{q}_2)\rangle + G_0(z)\,T^{\mathrm{NN}}(z)\,|\boldsymbol{q}_1\rangle\,|\boldsymbol{q}_2\rangle. \tag{9}$$

2.3. Results

Results are presented in this section for the specific case of two-nucleon knockout by electron scattering off ^{16}O. Calculations have been done in the same kinematic conditions as in previous experiments performed at Mainz [29] and NIKHEF [26, 27], but here only the superparallel kinematic conditions adopted at Mainz [29] will be discussed. The differential cross sections of the ^{16}O(e,e$'$pp) reaction to the 0^+ ground state of ^{14}C and of the ^{16}O(e,e$'$pn) reaction to the 1^+ ground state of ^{14}N, calculated with the different approximations (4) – (6) and (9), are displayed in the left and right panels of Fig. 2, respectively.

The inclusion of the optical potential leads, in both reactions, to an overall and substantial reduction of the calculated cross sections (see the difference between the PW and DW results). This effect is well known and it is mainly due to the imaginary part of the optical potential that accounts for the flux lost to inelastic channels in the nucleon-residual nucleus elastic scattering. The optical potential gives the dominant contribution of FSI's for recoil-momentum values up to $p_{\mathrm{B}} \simeq 150$ MeV/c. At larger values, NN-FSI gives an enhancement of the cross section that increases

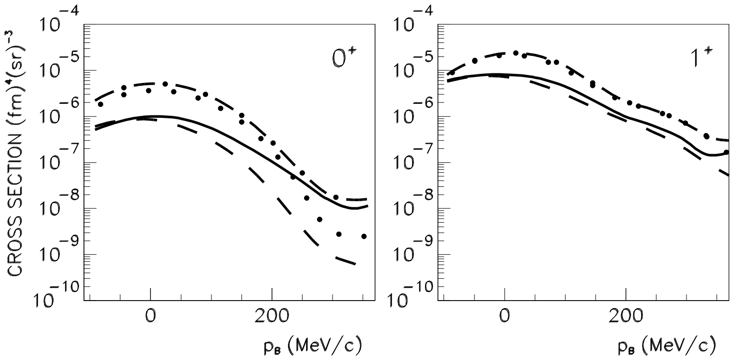

Fig. 2. The differential cross section of the ^{16}O(e,e$'$pp) *reaction to the* 0^+ *ground state of* ^{14}C *(left panel) and of the* ^{16}O(e,e$'$pn) *reaction to the* 1^+ *ground state of* ^{14}N *(right panel) in superparallel kinematics with an incident electron energy* $E_0 = 855$ MeV, *an electron scattering angle* $\theta_e = 18°$, *energy transfer* $\omega = 215$ MeV *and* $q = 316$ MeV/c. *In* ^{16}O(e,e$'$pn) *the proton is ejected parallel and the neutron antiparallel to* $\boldsymbol{q}$. *Different values of* $p_{\rm B}$ *are obtained changing the kinetic energies of the outgoing nucleons. Positive (negative) values of* $p_{\rm B}$ *refer to situations where* $\boldsymbol{p}_{\rm B}$ *is parallel (anti-parallel) to* $\boldsymbol{q}$. *Line convention: PW (dotted), PW-NN (dash-dotted), DW (dashed), DW-NN (solid).*

with $p_{\rm B}$. In (e,e$'$pp), this enhancement goes beyond the PW result and amounts to roughly an order of magnitude for $p_{\rm B} \simeq 300$ MeV/c. In (e,e$'$pn), this effect is still sizeable but much weaker. We note that in both cases the contribution of NN-FSI is larger in the DW-NN than in the PW-NN approximation.

In (e,e$'$pp), NN-FSI produces a strong enhancement of the Δ-current contribution for all values of $p_{\rm B}$ (left panel of Fig. 3). Up to about 100-150 MeV/c, however, this effect is completely overwhelmed by the dominant contribution of the one-body current, while for larger values of $p_{\rm B}$, where the one-body current is less important in the cross section, the increase of the Δ-current is responsible for the substantial enhancement in the final result. The effect of NN-FSI on the one-body current is much weaker but anyhow sizeable, and it is responsible for the NN-FSI effect at lower values of $p_{\rm B}$.

The combined role of FSI and the different partial waves in the initial relative state of the two emitted protons in the ^{16}O(e,e$'$pp) reaction is shown in the right panel of Fig. 3. The effect of NN-FSI is more important on the ^{1}S$_0$ initial state and gives in practice almost the full contribution of NN-FSI. The role of NN-FSI on the ^{3}P initial relative states is of special relevance for the transition to the 1^+ excited state of ^{14}C, where only ^{3}P components are present and the ^{1}S$_0$ relative partial wave cannot contribute [19].

In the NIKHEF kinematics [26, 27], the effect of NN-FSI is also sizeable, although not as strong as in the superparallel kinematics [19]. Moreover, whereas in the superparallel kinematics the relative effect of NN-FSI increases for decreasing cross section, in the NIKHEF kinematics NN-FSI is maximal when also the cross section is maximal, i.e. when $|\boldsymbol{p}_B| \approx 0$ MeV/c. This result clearly shows that the role of NN-FSI is strongly dependent on the kinematics and no general statement can be drawn with respect to its relevance.

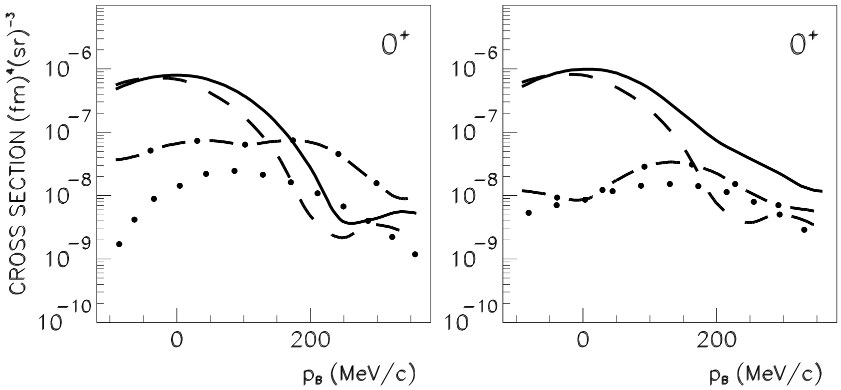

Fig. 3. The differential cross section of the $^{16}O(e,e'pp)$ reaction to the 0^+ ground state of ^{14}C in the same superparallel kinematics as in Fig. 2. Line convention for the left panel: DW with the Δ-current (dotted), DW-NN with the Δ-current (dash-dotted), DW with the one-body current (dashed), DW-NN with the one-body current (solid). In the right panel the dashed (solid) curve shows the separate contribution of the $^1S_0$ relative partial wave in a DW (DW-NN) calculation. The dotted (dash-dotted) curve shows the separate contribution of the $^3P_1$ relative partial wave in a DW (DW-NN) calculation.

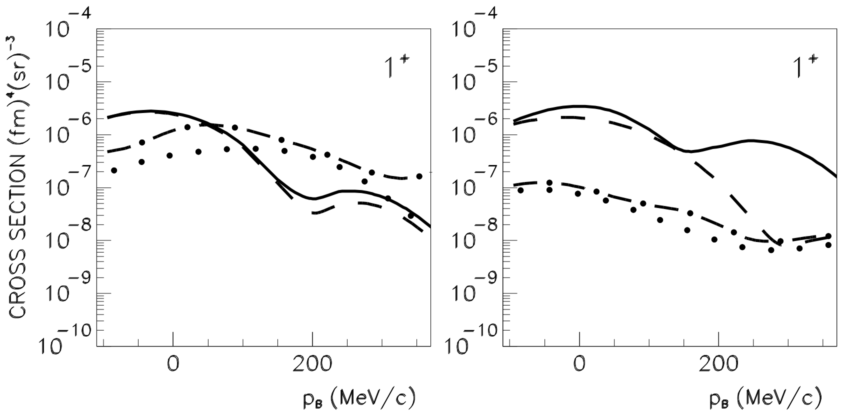

Fig. 4. The differential cross section of the $^{16}O(e,e'pn)$ reaction to the 1^+ ground state of ^{14}N in the same superparallel kinematics as in Fig. 2. Line convention in the left panel: DW with the Δ-current (dotted), DW-NN with the Δ-current (dash-dotted), DW with the one-body-part (dashed), DW-NN with the one-body-part (solid). Line convention in the right panel: DW with the pion-in-flight-current (dotted), DW-NN with the pion-in-flight–current (dash-dotted), DW with the seagull-current (dashed), DW-NN with the seagull-current (solid).

Different effects of NN-FSI on the various components of the current are shown for the (e,e′pn) reaction in Fig. 4. Also in this case, NN-FSI affects more the two-body than the one-body current. A sizeable enhancement is produced on the Δ-current, at all values of p_{B}, and a huge enhancement on the seagull current at large momenta. In contrast, the one-body current is practically unaffected by NN-FSI up to about 150 MeV/c. A not very large but visible enhancement is produced at larger momenta, where, however, the one-body current gives only a negligible contribution to the final cross section. The role of the pion-in-flight term, both in the DW and DW-NN approaches, is practically negligible in the cross section. Thus, a large effect is given by NN-FSI on the seagull and the Δ-current. The sum of the two terms, however, produces a destructive interference that leads to a partial cancellation in the final cross section. The net effect of NN-FSI in Fig. 2 is not large but still non negligible. Moreover, the results for the partial contributions in Fig. 4 indicate that in pn-knockout, NN-FSI can be large in particular situations and, therefore, should in general be included in a careful evaluation.

3. *Conclusions*

The advent of high-energy continuous electron beams coupled to high-resolution spectrometers has opened a new era in the study of basic nuclear properties such as single-particle behaviour and NN correlations by means of one- and two-nucleon emission. Concurrently, new theoretical approaches have been developed. For one-nucleon knockout, relativistic effects have been shown to be most important and to affect the interpretation of data even at moderate energies of the emitted particles. In addition, a consistent treatment of the initial and final states in terms of the same (energy-dependent) Hamiltonian seems to avoid the striking feature coming from previous analyses of (e,e′p) world data with an apparent Q^2 dependence of the extracted spectroscopic factors. The problem remains, however, concerning the discrepancy between calculated and observed spectroscopic factors. This is clearly tight to NN correlations, their theoretical treatment and the possibility of finding observables sensitive to them.

Exclusive experiments with direct two-nucleon emission by an electromagnetic probe have been suggested long time ago as good candidates to study correlations. In electron scattering, they require triple coincidences with three spectrometers. This is now possible and the first experiments have been performed. By an appropriate selection of the kinematic conditions and specific nuclear transitions, it has been shown that data are sensitive to nuclear correlations. In turn, they strictly depend on the NN potential. Therefore, two-nucleon emission is a promising field deserving further investigation both experimentally and theoretically in order to solve a longstanding problem in nuclear physics.

In particular, FSI's must be carefully treated. A consistent evaluation of FSI's would require a genuine three-body approach, for the two nucleons and the residual nucleus, by summing up an infinite series of contributions in the NN-scattering amplitude and in the interaction of the two nucleons with the residual nucleus

(Fig. 1). So far, only the major contribution of FSI's, due to the interaction of each of the two outgoing nucleons with the residual nucleus, was taken into account in the different models. The guess was that the mutual interaction between the two outgoing nucleons (NN-FSI) could be neglected since they are mainly ejected back to back.

Results have been presented here with a first estimate of the role of NN-FSI in the case of the ^{16}O(e,e′pp) and ^{16}O(e,e′pn) reactions. In general, the optical potential gives an overall and substantial reduction of the calculated cross sections. This important effect represents the main contribution of FSI's and can never be neglected. In most of the situations considered here, NN-FSI gives an enhancement of the cross section. The effect is in general non negligible, it depends strongly on the kinematics [19], on the type of reaction [20] and on the final state of the residual nucleus [19]. NN-FSI affects in a different way the various terms of the nuclear current, usually more the two-body than the one-body terms and is sensitive to various theoretical ingredients of the calculation. This makes it difficult to make predictions about the role of NN-FSI in a particular situation. In general, each specific situation should be separately investigated.

Extension of the same NN-FSI approach to the real-photon-induced reactions will be presented elsewhere [20]. The solution of the full three-body problem of the final state is in progress.

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NN KORELACIJE I MEĐUDJELOVANJA U KONAČNOM STANJU U (e,e′NN) REAKCIJAMA

Nakon kratkog pregleda istraživanja izbacivanja jednog nukleona, koji ukazuje na važnost kvantitativnog razumijevanja uzroka malih spektroskopskih faktora dobivenih iz mjernih podataka, pažnja se usmjerava na dvonukleonsku emisiju koja je pogodan proces za istraživanje korelacija nukleon-nukleon u kompleksnim jezgrama. Posebno se raspravljaju izravne (e,e′pp) i (e,e′pn) reakcije i proučava uloga međudjelovanja u konačnom stanju. Pokazuje se da uzajamno djelovanje među izlaznim nukleonima ovisi o kinematici i vrsti ispitivane reakcije.