Two-nucleon photoabsorption mechanisms and quasielastic $(e,e'p)$ reactions from nuclei

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We assess the global effect of central and tensor correlations, meson-exchange and isobar currents upon the cross sections for quasielastic $(e,e'p)$ reactions from nuclei by presenting calculations for the ^{16}O target. Four-momenta in the range $0.1 \leqslant Q^2 \leqslant 1$ GeV^2 are addressed. We observe that for Q^2 values exceeding 0.2 GeV^2, quasielastic conditions and missing momenta below the Fermi momentum, the ground-state correlations and two-body currents do not dramatically alter the magnitude of the $(e,e'p)$ cross sections as they are obtained in the impulse approximation. Moreover, the deviations from the impulse approximation induced by the two-nucleon photoabsorption mechanisms considered here, exhibit a rather modest Q^2 dependence.

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I. INTRODUCTION

Electron scattering experiments have made it possible to probe the deep interior of nuclei. A profound and systematic investigation of coincidence $(e,e'p)$ reactions with nuclear targets which started back in the seventies, has provided a wealth of information about the dynamics of protons in nuclei with unprecedented precision. In particular, the $(e,e'p)$ work of the last three decades provided one of the most direct proofs for the existence of independent-particle motion (IPM) in nuclei, at the same time pointing towards the limitations of such a model [1]. The limitations of the IPM are primarily inferred from the magnitude of the measured $(e,e'p)$ cross sections suggesting rather small occupation numbers for the quasiparticles which are the constituents in an independent-particle description of nuclei.

The process of extracting physical information from measured $A(e,e'p)$ data involves some theoretical modeling. A more than satisfactory description of the available $(e,e'p)$ data sets, which cover target nuclei from ^{4}He up to ^{208}Pb, is given with model calculations performed within the context of the ''distorted-wave impulse approximation'' (DWIA). The basic ingredients underlying this approach are summarized in a number of review papers [2,3]. Basically, the DWIA is a single-particle approach to the $A(e,e'p)$ reaction. The input required to describe the hadronic interactions of the ejectile in the exit channel is provided by global optical-potential fits to elastic proton-nucleus scattering data. The key element of the DWIA approach, though, is the impulse approximation (IA), a term which covers a combination of several presumptions. First, the ejectile is supposed to be the very same hadron which was struck by the virtual photon. Second, and most importantly, the quasiparticles that fill the atomic nucleus are presumed to have the same static properties as bare nucleons. As a matter of fact, in the DWIA the vertex function that models the interaction of quasiparticles with virtual photons, is directly derived from its free $p(e,e')p'$ counterpart. Consequently, the current operators that are used in the DWIA are manifestly of one-body nature.

In Ref. [4] we have developed a nonrelativistic dynamical model for calculating exclusive $A+\vec{e}\rightarrow A-1+e'+\vec{p}$ observables which accounts for two-nucleon meson-exchange and Δ-isobar currents. In this paper, we report on progress that we have made in extending the model to include also the dynamical effect of central and tensor correlations in the photonucleus absorption. All of the aforementioned ingredients introduce two-nucleon mechanisms in the photoabsorption process that are usually neglected in the IA. By comparing cross sections obtained in the IA with predictions that account for two-body photoabsorption mechanisms, one can assess the importance of mechanisms beyond the IA and evaluate to what extent they may affect the quantities extracted from a DWIA analysis of measured $A(e,e'p)$ cross sections.

In Sec. II we briefly review the basic ingredients of our $A(e,e'p)$ model, including the model assumptions with respect to the bound and scattering states, as well as the nuclear current operators. The numerical results of the ^{16}O$(e,e'p)$ calculations are given in Sec. III. Special attention is paid to the possible role of two-nucleon photoabsorption mechanisms for the extraction of spectroscopic factors and the Q^2 evolution that they may be subject to. A brief summary is given in Sec. IV.

II. TWO-BODY PHOTOABSORPTION MECHANISMS

The differential cross sections for exclusive $e+A(\text{g.s.}) \rightarrow e'+A-1(E_x)+p(\vec{k}_p m_s)$ processes are determined by an amplitude of the type

$$\langle \vec{k}_p m_s ; A-1(E_x) | J_{\mu=0,\pm 1}(\vec{q}) | A(\text{g.s.}) \rangle, \qquad (1)$$

where J_μ is the spherical component of the hadron electromagnetic current and $|\vec{k}_p m_s\rangle$ the scattering wave function of the ejected proton. In the IA, the current operator is approximated by a one-body operator $J_\mu \overset{\text{IA}}{\rightarrow} \Sigma_{i=1}^{A} J_\mu^{[1]}(i;\vec{q})$. After introducing the quasihole wave function $\psi_{E_x ljm}$

$$\psi_{E_x ljm}(x) \equiv \langle A-1(E_x) | (-1)^{j+m} a_{lj-m}(x) | A(\text{g.s.}) \rangle, \qquad (2)$$

the transition amplitude of Eq. (1) reduces to

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$$\int dx \chi^{\dagger}_{\vec{k}_p m_s}(x) J^{[1]}_{\mu}(x;q) \psi_{E_x ljm}(x). \tag{3}$$

This amplitude is the basic quantity which is evaluated in a conventional DWIA $(e,e'p)$ model. Both initial and final-state correlations, pion and Δ degrees-of-freedom can give rise to multinucleon mechanisms in the photoabsorption process, effects which are commonly discarded in the standard relativistic and nonrelativistic DWIA approaches.

In our model, we implement the effect of central and tensor correlations beyond the mean-field approximation through the introduction of the following correlated wave functions:

$$|\tilde{\Psi}\rangle \equiv \hat{\mathcal{G}}|\Phi\rangle, \tag{4}$$

where Φ is a Slater determinant and the correlation operator $\hat{\mathcal{G}}$ reads

$$\hat{\mathcal{G}} = \mathcal{S}\left[\prod_{i<j=1}^{A}\left(1 - g_c(r_{ij}) + f_{t\tau}(r_{ij})\widehat{S_{ij}}\vec{\tau}_i\cdot\vec{\tau}_j\right)\right], \tag{5}$$

where $\mathcal{S}$ is the symmetrizing operator. It is worth emphasizing that central and tensor correlations are considered in both the initial and the final state. It is assumed that both are governed by the same correlation functions. Unlike the Slater determinant $|\Phi\rangle$, the correlated wave function $|\tilde{\Psi}\rangle$ is no longer normalized to unity and special care has to be taken in evaluating the transition matrix elements [7]. This implies that in order to ensure proper normalization the following quantities are to be evaluated

$$\langle \tilde{\Psi}_f | J_{\pm 1,0}(\vec{q}) | \tilde{\Psi}_i \rangle = \frac{\langle \Phi_f | \hat{\mathcal{G}}^{\dagger}(J_{\pm 1,0}(\vec{q}))\hat{\mathcal{G}}|\Phi_i\rangle}{\langle \Phi_i|\hat{\mathcal{G}}^{\dagger}\hat{\mathcal{G}}|\Phi_i\rangle} \times \sqrt{\frac{\langle \Phi_i|\hat{\mathcal{G}}^{\dagger}\hat{\mathcal{G}}|\Phi_i\rangle}{\langle \Phi_f|\hat{\mathcal{G}}^{\dagger}\hat{\mathcal{G}}|\Phi_f\rangle}}. \tag{6}$$

In evaluating this expression one usually relies on cluster expansion techniques based on Mayer-like diagrams [6,7]. It can be shown that a proper cluster expansion leads to an exact cancellation of the unlinked diagrams in the numerator and denominator. In our calculations, all two-point diagrams in the cluster expansion are retained. This procedure has been explained in detail in Ref. [8], where also the explicit expressions for the matrix elements are given. As explained for example in Ref. [7], in the lowest order expansion the exact normalization in the limit $|\vec{q}|\to 0$ can only be imposed by including both two-point and three-point diagrams. The three-point diagrams give rise to three-body operators and an enormous computational load when including the tensor correlations. For that reason, they have been neglected in the present study. Three-point diagrams have the tendency to reduce the effect of the two-point diagrams. In the light of this, the effect of the central and tensor correlations upon the $A(e,e'p)$ cross sections predicted in this work should be considered as an upper limit [5].

For the sake of completeness, we mention that calculating the effect of the central short-range and tensor correlations in the nuclear wave functions upon $(e,e'N)$ cross sections eventually amounts to computing the matrix elements of the following two-body current operator:

$$[J^{[1]}_{\mu}(1;q) + J^{[1]}_{\mu}(2;q)][-g_c(r_{12}) + f_{t\tau}(r_{12})\widehat{S_{12}}\vec{\tau}_1.\vec{\tau}_2] + \text{H.c.}, \tag{7}$$

between uncorrelated Slater determinant wave functions. Here, g_c and $f_{t\tau}$ are the central (or, Jastrow) and tensor correlation function. Apart from the terms contained in Eq. (7), the ground-state correlations have extra spin terms, for example of the spin-orbit type. The central and tensor terms, though, are by far the most important ones [9]. The g_c corrects the relative motion of nucleon pairs for the short-range repulsion at short distances, a peculiar effect that falls beyond the independent-particle model. Triple-coincidence reactions of the type $(e,e'pp)$ can, in principle, discriminate amongst the different model predictions for the central correlation function g_c [10]. In the calculations we use the central correlation function from a *G*-matrix calculation of Gearhart and Dickhoff. With this correlation function, our model calculations can reasonably describe the existing ^{12}C$(e,e'pp)$ and ^{16}O$(e,e'pp)$ data [10,11]. The central correlation function that came out of the *G*-matrix calculations falls in between the class of "hard" and "soft" correlation functions. Of all effects beyond the IA considered here, the tensor correlations are the most tedious ones to implement numerically. As of now, the radial internucleon dependence of the tensor correlation function $f_{t\tau}$ is not too well constrained. The $(e,e'pn)$ research program which is conducted at the electron accelerators in Mainz and Jefferson Lab is expected to improve this situation in the near future. For the results presented here, we have used the tensor correlation function from the Monte Carlo calculations by Pieper, Wiringa, and Pandharipande that are based on a realistic nucleon-nucleon force [12]. This calculation predicts a rather soft central correlation function. The analysis of ^{12}C$(e,e'pp)$ data presented in Ref. [10] preferred harder correlation functions.

The two-body photoabsorption mechanisms lead to contributions to the transition amplitude which read

$$\sum_{\alpha} \int dx \int dy \chi^{\dagger}_{\vec{k}_p m_s}(x)\psi^{\dagger}_{\alpha}(y) J^{[2]}_{\mu}(x,y) \times [\psi_{E_x ljm}(x)\psi_{\alpha}(y) - \psi_{E_x ljm}(y)\psi_{\alpha}(x)], \tag{8}$$

where the sum over α extends over all occupied single-particle states in the target nucleus. Apart from the operator (7), the $J^{[2]}_{\mu}(x,y)$ includes meson-exchange currents (MEC) from pion exchange and Δ-isobar currents (IC). The MEC and IC operators are not any different from the ones which are commonly used in deuteron [16] and helium calculations. Hereby, the meson-exchange currents are derived through performing minimal substitution in the one-pion exchange potential. Our Δ-current operator is nonstatic. In addition to the πN decay width, an extra density-dependent width in the

Δ propagators was introduced. More details regarding the MEC and IC operators used in our calculations can be found in Sec. II C of Ref. [17].

Over the last number of years accumulated two-nucleon knockout data have resulted in an improved knowledge about meson-exchange and isobar currents in nuclei. Experiments such as $(\vec{\gamma},NN)$ have put the two-body meson-exchange and isobar current models to a stringent test, thereby pointing for example to sizeable but controllable medium effects in the isobar current operators [13,14]. All two-body currents used here, have been tested in $(e,e'pN)$ and (γ,pN) calculations and the agreement with the existing data is acceptable.

In evaluating the matrix elements we use nonrelativistic quasihole wave functions as obtained from a Hartree-Fock calculation with an effective Skyrme force. Also the scattering states $\chi_{\vec{k}_p m_s}$ are obtained by solving the Hartree-Fock Hamiltonian in the continuum. While, perhaps not representing the most realistic description of the final-state interactions, our approach neither violates orthogonality and unitarity conditions, nor does it require any empirical input. When utilizing an optical potential to generate the continuum wave functions, the amplitudes suffer from an orthogonality defect. Detailed investigations have shown that these defects are not a serious problem for $(e,e'p)$ calculations which are performed in the IA [15]. In contrast, the lack of orthogonality of the bound and continuum states poses serious problems when it comes to calculating the higher-order multinucleon amplitudes. The contribution from the central correlations, for example, is highly sensitive to spurious contributions from nonorthogonality defects. As there is no unique way to remedy this, for the presented calculations the bound and continuum states are generated by the same Hamiltonian. After all, this letter deals with the role of two-nucleon effects *relative* to the contribution of the single-nucleon (IA) term in the hadron-nucleus vertex. The $^{16}O(e,e'p)$ results reported in Ref. [18] are indicating that the impact of the MEC and IC on the transverse response σ_T is rather insensitive to the model utilized to describe final-state interactions.

III. TWO-NUCLEON PHOTOABSORPTION AND QUASIELASTIC $^{16}O(E,E'P)$

In order to minimize the role of mechanisms beyond the IA, the bulk of the experimental $(e,e'p)$ research was conducted in quasielastic kinematics. Given the overall success of DWIA approaches in reproducing the shapes of the effective momentum distributions one may be tempted to dismiss the many-body effects in the photon-nucleus vertex as unimportant. We have made a systematic study of $(e,e'p)$ differential cross sections for knockout from the different shells in ^{16}O in quasielastic kinematics and Q^2 values in the range $0.1 \leqslant Q^2 \leqslant 1$ GeV^2. We started from the IA and gradually added the two-body photoabsorption mechanisms related to central and tensor correlations, meson-exchange and isobar configurations, described above. A typical example of such a calculation is displayed in Fig. 1. As is commonly done, the $A(e,e'p)$ results are displayed as a reduced cross section

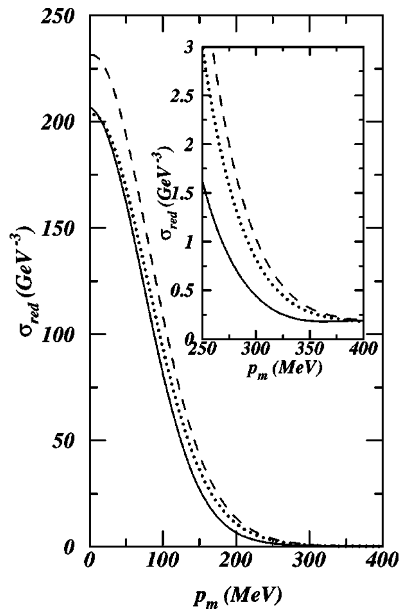

FIG. 1. Reduced cross section versus missing momentum for knockout from the $1s_{1/2}$ orbit in ^{16}O at $T_p = 125$ MeV and an initial electron energy of 2 GeV. The dotted line is the IA calculation, the dashed line includes also tensor and central correlations. Finally, the solid line is the full calculation including correlations, meson-exchange and isobar currents. The coverage in missing momentum was achieved by varying the polar angle of the ejectile.

$\sigma_{\rm red}$ and plotted versus missing momentum $p_m = |\vec{k}_p - \vec{q}|$. In the limit of vanishing final-state interactions, p_m is the momentum of the proton at the time that it is hit by the virtual photon, and $\sigma_{\rm red}$ is the squared quasihole wave function $\psi_{E_x ljm}$ in momentum space. For missing momenta below the Fermi momentum ($k_F \approx 250$ MeV), inclusion of the two-body effects in the hadron-nucleus vertex brings about only modest changes in the shape of the cross sections as they are computed in the IA. Hence, the mere observation that the DWIA calculations nicely reproduce the p_m dependence of the measured $(e,e'p)$ data does not exclude any sizeable contributions from mechanisms that fall beyond the IA. This conjecture is particularly pertinent in view of the fact that the bulk of the $(e,e'p)$ data covers the p_m range below the Fermi momentum k_F. As becomes clear from the inset in Fig. 1 quite a different picture for the role of two-body mechanisms emerges at higher missing momenta. In this kinematical domain the relative importance of the MEC and IC grows and the validity of the IA is clearly at stake.

To proceed we turn to the question of how the effect of two-nucleon components in the electron-nucleus vertex evolves with four-momentum transfer and how they manifest themselves in the separated longitudinal and transverse $(e,e'p)$ response. Intuitively, one may expect that the two-nucleon effects in the photonucleus vertex are subject to some distance scale dependence. In Figs. 2, 3 we show the Q^2 evolution of the relative contributions attributed to mechanisms beyond the IA for knockout from the various orbits in ^{16}O. These results were obtained in parallel kinematics (the ejectile is detected along the direction of the vir-

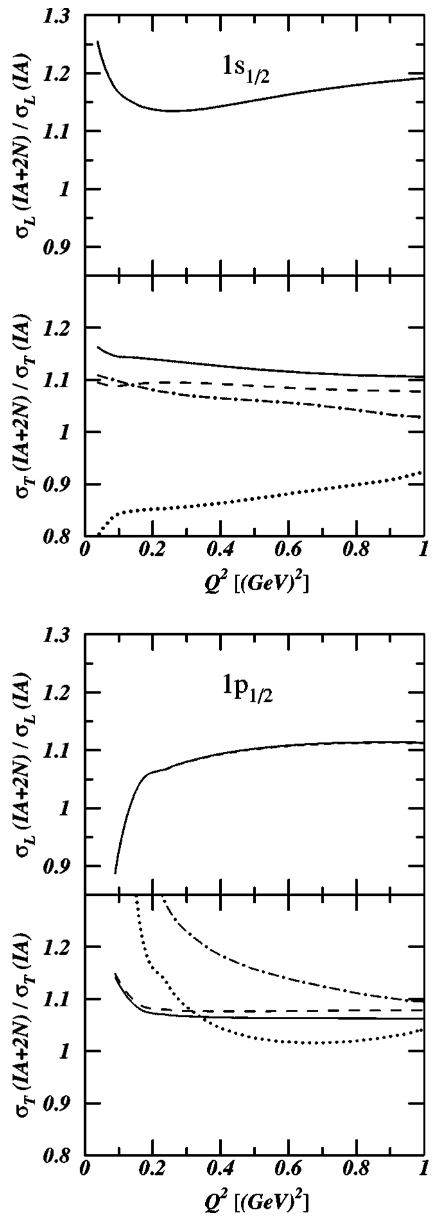

FIG. 2. Sensitivity of the longitudinal and transverse ^{16}O$(e,e'p)$ strength to two-nucleon photoabsorption effects. The curves show the ratio of the calculated response including various combinations of two-body effects to the corresponding value obtained in the IA. Parallel kinematics ($\vec{p}_p \| \vec{q}$) and quasielastic conditions were imposed. The dashed line includes only central correlations, whereas the solid curve also includes tensor correlations. The dot-dashed calculation accounts only for MEC, whereas the dotted line includes MEC, IC, central, and tensor correlations.

tual photon's momentum). Furthermore, for each specific shell we consider electron kinematics corresponding with the peak of the IA predictions (i.e., $p_m = 0$ and 100 MeV for *s*-shell and *p*-shell knockout, respectively). The quasielastic condition was imposed by requiring that $q \equiv k_p - p_m$. In parallel kinematics, the differential $(e,e'p)$ cross section is determined by the sum of only two structure functions $v_T\sigma_T + v_L\sigma_L$, where the v's are functions of the electron kinematics and the σ's contain all information on the hadron dynamics in the electron-scattering process.

In our framework, only two sources of strength beyond the IA are affecting the longitudinal response σ_L. As becomes obvious from the upper panels of Fig. 2, in σ_L only central correlations play a significant role and tensor correlations are only marginally contributing (note that the dashed and solid lines in the upper panels of Fig. 2 nearly coincide). A more complex picture emerges in the transverse response σ_T. The σ_T is affected by central and tensor correlations, as well as MEC and IC. In contrast to what is observed in σ_L, the effect of tensor correlations is substantial. The effect of MEC, while being extremely important at lower momentum transfer, gradually fades out as Q^2 increases. Whereas the ground-state correlations and the MEC tend to increase the magnitude of the cross sections, a strong destructive interference with the isobar contribution is observed. The overall effect of the ground-state correlations is an increase of the cross sections. Such behavior is known from transparency studies [19,20]. Indeed, central correlations effectively reduce the range over which the ejectile is subject to final-state interactions, thereby increasing the cross sections in the exclusive channels. A striking feature of the results contained in Fig. 2 is the dramatic shell dependence. Indeed, knockout from the interior of the nucleus ($1s_{1/2}$ state) is subject to substantially larger deviations from the IA than knockout from states that are more surface peaked ($1p_{1/2}$ state). An exception made for the lowest Q^2 regions, the effect of the ground-state correlations is relatively constant throughout the four-momentum range considered.

One of the physical quantities extracted from $(e,e'p)$ measurements is the so-called quasihole normalization factor z_{lj}, often referred to as the *spectroscopic strength*. The z_{lj}'s are obtained by scaling the height of the calculated $(e,e'p)$ cross sections to the measured ones and are a measure for the occupation of the quasi-hole state carrying the quantum numbers lj in the ground state of the target nucleus. Systematically, remarkably low values for z_{lj} were obtained with analyses based on DWIA calculations. This is one of the key results of $(e,e'p)$ research, indicating the limitations of the concept of independent particle motion for modeling nuclei. In a recent paper [21], Lapikás and collaborators presented a DWIA analysis of the ^{12}C$(e,e'p)$ world data, thereby covering a Q^2 range from roughly 0.1 to several GeV^2. This analysis suggested a Q^2 dependence for the quasihole normalization factors z_{lj} in ^{12}C. Indeed, up to momentum transfers of 0.6 GeV^2 the derived z_{lj} exhaust a mere 50% of the sum rule value. At higher momentum transfers, on the other hand, larger values of z_{lj} approaching the sum-rule value are extracted. This phenomenon is being referred to as "single-particle strength restoration" [22]. A possible explanation for this intriguing situation is that effects beyond the impulse approximation induce large corrections on the values of the extracted z_{lj}'s and that these corrections exhibit a strong Q^2 evolution. To present in a more quantitative manner the effect of two-nucleon photoabsorption effects upon the magnitude of the calculated $(e,e'p)$ cross sections we calculated the ratio $[v_L\sigma_L(\mathrm{IA}+2N)+v_T\sigma_T(\mathrm{IA}+2N)]/[v_L\sigma_L(\mathrm{IA})+v_T\sigma_T(\mathrm{IA})]$ in parallel and quasielastic kinematics. This number is a measure for $z_{lj}(\mathrm{IA})/z_{lj}(\mathrm{IA}+2N)$, where $z_{lj}(\mathrm{IA})$

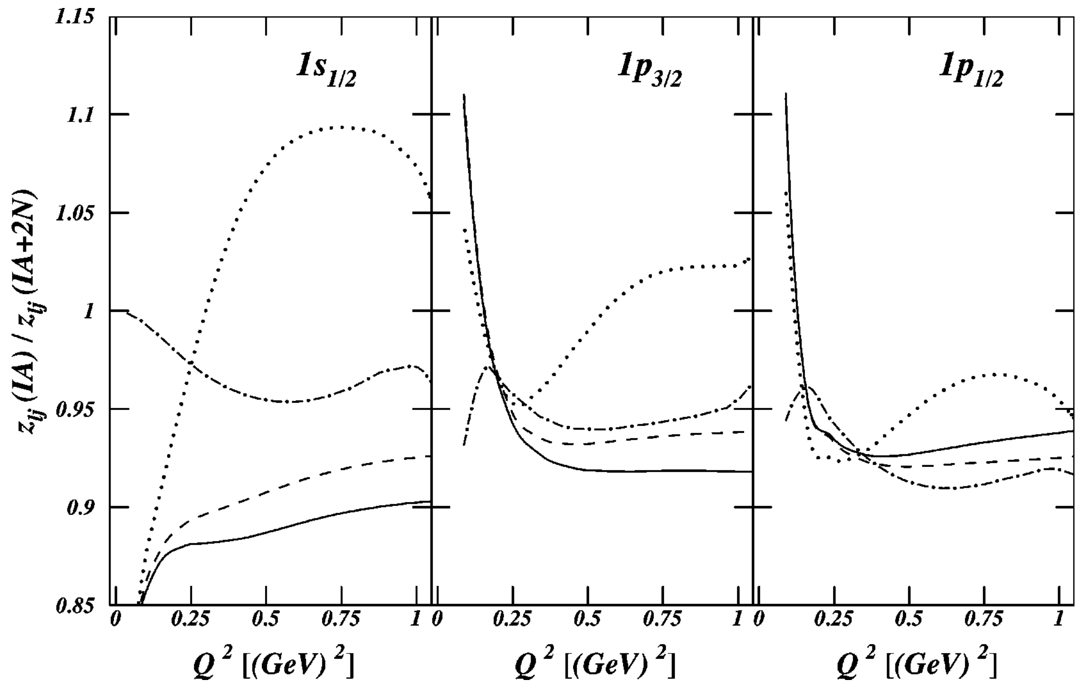

FIG. 3. Predicted sensitivity of the extracted spectroscopic factors to two-nucleon photoabsorption effects. Same line conventions as in Fig. 2. The initial electron energy is 2 GeV.

is the deduced spectroscopic strength in the impulse approximation, whereas $z_{lj}(\mathrm{IA}+2N)$ provides the same number but now extracted from a model that accounts also for the two-nucleon absorption effects related to ground-state correlations beyond IPM, meson exchange, and isobar currents. For vanishing two-nucleon effects the ratio $z_{lj}(\mathrm{IA})/z_{lj}(\mathrm{IA}+2N)$ would be one. In that respect, the deviations from one provide a measure for the importance of two-nucleon photoabsorption effects or, the error made by adopting the IA. The strongest deviations from the IA are observed for knockout from the interior of the nucleus ($1s_{1/2}$ state). Here, the predicted variation in the z_{lj} as one moves from the lowest to the highest Q^2 is about 25%. For knockout from the valence p shell the estimated error on the extracted z_{lj}'s attributed to the limitations of the IA is of the order 5–10 %.

IV. CONCLUSION

In conclusion, we have performed exclusive $^{16}\mathrm{O}(e,e'p)$ calculations that account for central and tensor correlations, as well as meson-exchange and Δ-isobar currents. For four-momentum transfers beyond $Q^2 \geqslant 0.2$ GeV^2 and quasielastic kinematics, the global effect of the two-nucleon photoabsorption mechanisms on the magnitude and shape of the differential $A(e,e'p)$ cross sections is rather moderate as long as low missing momenta are probed. This result is not so surprising in the light of the success of y-scaling analyses of inclusive $A(e,e')$ data which heavily rely on the reliability of the IA.

The uncertainty on the extracted values for the spectroscopic factors induced by mechanisms that fall beyond the IA is computed to be of the order of 5–10 %. In any case, it appears that two-nucleon photoabsorption mechanisms stemming from mesons and Δ-isobar currents and the dynamical effects of ground-state correlations cannot be invoked neither to explain the very low spectroscopic factors extracted from $(e,e'p)$ experiments at low Q^2 nor to explain the Q^2 (or, scale) dependence that they might be subject to (Ref. [21]). As a final remark, we wish to stress that for some specific interference response functions or polarization observables, the effect of two-nucleon photoabsorption mechanisms can be large even at small missing momenta, not to mention the high-missing momentum conditions where they are always sizable.

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[1] V.R. Pandharipande, I. Sick, and P.K.A. deWitt Huberts, Rev. Mod. Phys. **69**, 981 (1997).
[2] J.J. Kelly, Adv. Nucl. Phys. **23**, 75 (1996).
[3] S. Boffi, C. Giusti, and F.D. Pacati, Phys. Rep. **226**, 1 (1993).
[4] J. Ryckebusch, D. Debruyne, W. Van Nespen, and S. Janssen, Phys. Rev. C **60**, 034604 (1999).
[5] J.E. Amaro, A.M. Lallena, G. Co', and A. Fabrocini, Phys. Rev. C **57**, 3473 (1998).

[6] S. Fantoni and V.R. Pandharipande, Nucl. Phys. **A473**, 234 (1987).
[7] G. Co' and A.M. Lallena, Ann. Phys. (N.Y.) **287**, 101 (2001).
[8] S. Janssen, J. Ryckebusch, W. Van Nespen, and D. Debruyne, Nucl. Phys. **A672**, 285 (2000).
[9] O. Benhar and V.R. Pandharipande, Rev. Mod. Phys. **65**, 817 (1993).
[10] K.I. Blomqvist *et al.*, Phys. Lett. B **421**, 71 (1998).
[11] R. Starink *et al.*, Phys. Lett. B **474**, 33 (2000).
[12] S.C. Pieper, R.B. Wiringa, and V.R. Pandharipande, Phys. Rev. C **46**, 1741 (1992).
[13] I.J.D. MacGregor *et al.*, Phys. Rev. Lett. **80**, 245 (1998).
[14] S. Franczuk *et al.*, Phys. Lett. B **450**, 332 (1999).
[15] J.I. Johannson, H.S. Sherif, and F. Ghoddousi, Nucl. Phys. **A665**, 403 (2000).
[16] H. Arenhövel, Nucl. Phys. **A384**, 287 (1982).
[17] J. Ryckebusch, V. Van der Sluys, K. Heyde, H. Holvoet, W. Van Nespen, M. Waroquier, and M. Vanderhaeghen, Nucl. Phys. **A624**, 581 (1997).
[18] J.E. Amaro, A.M. Lallena, and J.A. Caballero, Phys. Rev. C **60**, 014602 (1999).
[19] O. Benhar, A. Fabrocini, S. Fantoni, V.R. Phandharipande, and I. Sick, Phys. Rev. Lett. **69**, 881 (1992).
[20] L.L. Frankfurt, E.J. Moniz, M.M. Sargsyan, and M. Strikman, Phys. Rev. C **51**, 3435 (1995).
[21] L. Lapikás, G. van der Steenhoven, L. Frankfurt, M. Strikman, and M. Zhalov, Phys. Rev. C **61**, 064325 (2000).
[22] L. Frankfurt, M. Strikman, and M. Zhalov, Phys. Lett. B **503**, 73 (2001).