MEDIUM EFFECTS IN A($\vec{E}, E'\vec{P}$) REACTIONS AT HIGH Q^2

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Medium dependencies of bound nucleons are studied in a fully relativistic and unfactorized framework for the description of exclusive A($\vec{e}, e'\vec{p}$) processes. The theoretical framework, which is based on the eikonal approximation, can accommodate both optical potential and Glauber approaches for the treatment of final state interactions. It is discussed how both approaches compare to one another. Calculations for ^{12}C($e, e'p$) nuclear transparencies are presented. The issue of measuring the predicted medium modifications for the bound nucleon's electromagnetic form factors is addressed by presenting ^{4}He($\vec{e}, e'\vec{p}$) results.

Exclusive A($\vec{e}, e'\vec{p}$) reactions at high Q^2 [$Q^2 \succeq 1$ (GeV/c)^2] are a tool to study several aspects of nuclear and nucleon structure in a region where one expects that both hadronic and partonic degrees-of-freedom may play a role. Amongst the physics issues which can be investigated with electromagnetically induced proton knockout reactions is the short-range structure of nuclei. Here, one wants to find out if there are any hadronic components in the nucleus that carry large momenta, or whether the high momentum components in the nuclear wavefunction are entirely governed by the partonic degrees-of-freedom. Exclusive A($\vec{e}, e'\vec{p}$) reactions can also provide stringent tests of constituent-quark models. Hereby, one is primarily addressing the question to what extent nucleons are modified in the medium. Closely related to this topic is the study of the nuclear transparency, where one searches for signatures for the onset of the predicted color transparency phenomenon.

The extraction of physical information from measured A($\vec{e}, e'\vec{p}$) observables involves some theoretical modeling of which the major ingredients are : the initial state of the struck nucleon, the electromagnetic electron-proton coupling, and the scattering state of the ejected nucleon. To model A($\vec{e}, e'\vec{p}$) processes we use a relativistic description with initial (bound state) wave functions from a mean-field approximation to the Walecka model. The scattering state is computed in the eikonal approximation which is based on the observation that high energy nucleon-nucleon elastic scattering occurs predominantly in a small cone centered about the incoming nucleon's momentum. For A($e, e'p$) processes, the relevance of the small-angle approximation requires that the incoming momentum transfer is much larger than the proton's initial momentum in the nucleus, $|\vec{q}| \gg |\vec{k}_i|$. Solving the relevant Dirac equation with scalar and vector potentials in this approach, leaves us with a wave function that ressembles a relativistic plane wave,

$$\phi^{(+)}_{\vec{k}_f,s} \sim \left[\begin{array}{c} 1 \\ \frac{1}{E+M+V_s-V_v} \vec{\sigma} \cdot \vec{p} \end{array} \right] e^{\imath \vec{k}_f \cdot \vec{r}} e^{\imath S(\vec{r})} \chi_{\frac{1}{2} m_s} \ . \quad (1)$$

but for two extra ingredients. First, there is the dynamical enhancement of the lower component through the presence of the scalar (V_s) and vector (V_v) potentials, and, second, there is the extra phase factor $\imath S(\vec{b}, z)$.

At higher energies the highly inelastic nature of pp and pn collisions makes that a potential based description of FSI effects appears no longer feasible and one can make use of the Glauber approach, which is a multiple-scattering extension of the eikonal approximation. In the Glauber model one assumes that the struck proton undergoes subsequent collisions with the spectator nucleons, and each of these collisions is then treated in the eikonal approximation. One assumes that spectator nucleons are frozen, and that only elastic or mildly inelastic collisions occur. The Glauber wave function can be formally written as

$$\phi^{(+)}_{\vec{k}_f,s} \sim \hat{\mathcal{S}} \left[\begin{array}{c} 1 \\ \frac{1}{E+M} \vec{\sigma} \cdot \vec{p} \end{array} \right] e^{\imath \vec{k}_f \cdot \vec{r}} \chi_{\frac{1}{2} m_s} \ , \quad (2)$$

with $\hat{\mathcal{S}}$ the Glauber phase shift function. The reader is referred to Refs.[1,2] for more details.

Within the context of exclusive A$(\vec{e}, e'\vec{p})$ reactions, color transparency stands for the suggestion that at sufficiently high values of Q^2 the struck proton may interact in an anomalously weak manner with the spectator nucleons in the target nucleus. The Q^2 and A dependence of the nuclear transparency can provide information about the non-hadronic, small-sized components in the nucleon, and is thus a direct measure for the occurence of color transparency. The nuclear transparency basically expresses the likelihood that a nucleon, after absorption of a virtual photon, escapes the nucleus. Results of relativistic calculations for the nuclear transparency in the ^{12}C$(e, e'p)$ reaction are shown in Fig. 1. Neither the data nor the model calculations give any evidence for the predicted onset of color transparency. At high Q^2 the nuclear transparency saturates at a value of 50-60 %.

A recent re-analysis of the world's ^{12}C$(e, e'p)$ database[5] resulted in spectroscopic factors of the order of 50-60% of the sum rule value for Q^2 values below 0.8 (GeV/c)^2. At higher values of Q^2, spectroscopic factors approaching the sum rule value were extracted. It should be stressed, though, that at low Q^2 an analysis based on optical potentials was used, whereas at high Q^2 a Glauber method was adopted. In view of the apparent discrepancy

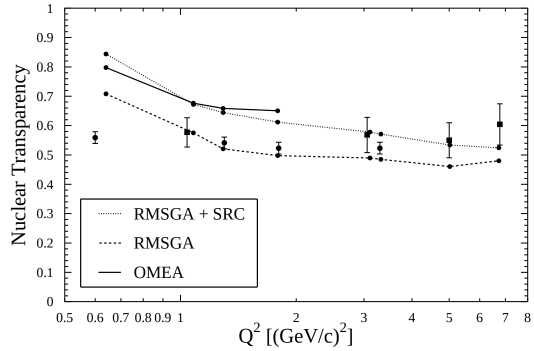

Figure 1. Nuclear transparency for $^{12}\mathrm{C}(e,e'p)$ as a function of Q^2. The curves are from relativistic calculations within the optical model eikonal approximation (OMEA) and the relativistic multiple-scattering Glauber approach (RMSGA) with or without short-range correlations (SRC). All calculations use the CC1 current operator in the Coulomb gauge. The displayed curves assume full occupancy of the single-particle levels. The data are from Refs.[3,4]

between the extracted spectroscopic factors at low and high Q^2, one may wonder whether a typical optical potential and Glauber approach actually lead to comparable spectroscopic factors when applied to the same $^{12}\mathrm{C}(e,e'p)$ data set. The summed spectroscopic factors for the s (S_{1s}) and p (S_{1p}) shell can be deduced from the transparency results of Fig. 1 through the following formula : $S_{^{12}C} \equiv (2S_{1s} + 4S_{1p})/6 \sim T_{exp}/T_{theo}$. From Fig. 1 one observes that at moderate values of Q^2 the optical potential calculations and correlated Glauber calculations produce similar nuclear transparencies, and, hence, similar summed spectroscopic factors. From this observation one may conclude that in the kinematical regime where both the Glauber and optical potential approach are plausible descriptions of FSI effects, there is a reasonably smooth transition from the low to the high Q^2 regime. The steady rise of the spectroscopic factors as a function of increasing Q^2, manifesting itself as an overshoot of the data at low values of Q^2, can also be inferred from this figure.

Recently, it has been suggested that the electric and magnetic form factors of a bound nucleon may deviate considerably from those of the free nucleon[6]. Double polarization experiments of the $\mathrm{A}(\vec{e},e'\vec{p})$ type provide excellent opportunities to probe these effects. We have compared our model calculations for the $^4\mathrm{He}(\vec{e},e'\vec{p})$ double polarization ratio at $\mathrm{Q}^2 \approx 0.4$ $(\mathrm{GeV/c})^2$ with data collected at Mainz. From the results displayed in Fig. 2 it can be seen that the inclusion of medium modified form factors has a considerable impact on the double ratio results. Implementing the effect of short-range correlations (SRC) only marginally affects the results. A study of the Q^2 dependence of this ratio, performed recently at JLab, confirms these findings[8].

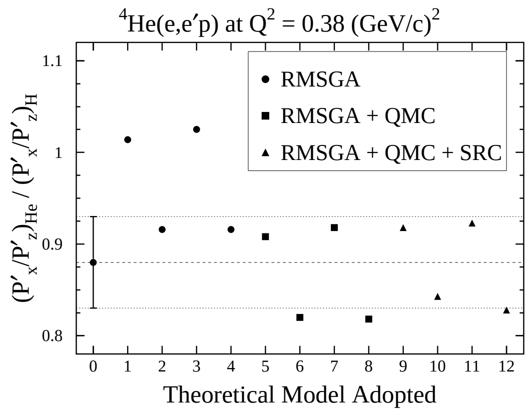

Figure 2. Double polarization ratio for the ^{4}He$(\vec{e}, e'\vec{p})$ reaction. Shown are calculations in the Glauber approach (RMSGA), with and without the effect of medium modification included (QMC), and with or without the inclusion of SRC. Each set of four calculations shows the results for the CC1 current operator, once in the Coulomb gauge, and once in the Weyl gauge, and for the CC2 operator, also in both gauges. Data are from Ref.[7]

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