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D(e,e′p) data

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Abstract. One hopes to learn about the short range structure of the deuteron by measuring the D(e,e′p)n cross section at large nucleon momenta. The problems of previous experiments are discussed and a recent Hall A experiment at Jefferson Lab is presented.

PACS. 25.10.+s Nuclear reactions involving few nucleon systems – 25.30.-c Lepton-induced reactions – 25.30.Fj Inelastic electron scattering to continuum

1 Introduction

The understanding of the short-range structure of the bound two-nucleon system – the deuteron, is fundamentally important for the advancement of the understanding of nuclear matter at short distances. One has to investigate configurations where the two nucleons come very close together and are strongly overlapping in order to probe the short-range properties of the deuteron . The ultimate goal of these studies is to find the validity limit of the picture of two nucleons at large relative momenta.

The most direct way to study high nucleon momenta is to investigate the quasi-elastic electro-disintegration of the deuteron via the D(e,e′p)n reaction at high missing momenta p_{miss} . Within the Plane Wave Impulse Approximation (PWIA), p_{miss} corresponds to the initial momentum of the target nucleon before the interaction. Thus the strategy in these studies is to probe the cross section at as large as possible missing momenta . However, depending on the selected kinematics, the reaction is dominated by inelastic (meson and Δ-isobar) channels. This has been confirmed by early experiments at low/intermediate energies of scattered electrons [1]. Also, more recent experiments [3,2] at higher energies and momentum transfers found that in the regime of large p_{miss} medium/long range (soft) two-body currents such as meson-exchange currents and isobar contributions significantly dominate the cross section. This is illustrated in figure 1 where the measured D(e,e′p)n cross section [3] as a function of missing momentum is shown.

Figure 2 shows the ratio between the experimental and the PWIA cross section together with the ratio of various calculations to the PWIA. The momentum transfer for these data ranged from $Q^2 = 0.33$ for low p_{miss} to $Q^2 = 0.12(GeV/c)^2$ for high p_{miss} values. Large contributions from final state interaction (FSI) are found for missing momenta between 200 and $400 MeV/c$ and above $750 MeV/c$. For p_{miss} values between 400 and

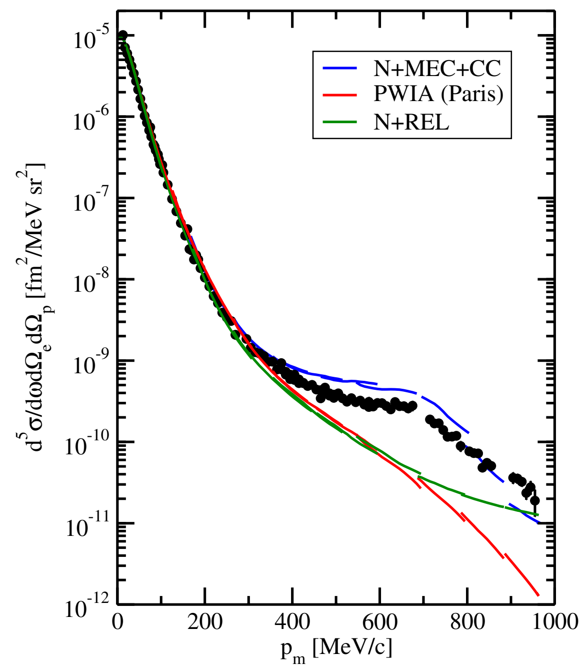

Fig. 1. Experimental D(e,e′p)n cross section from the Mainz experiment [3] compared to calculations by Arenhövel

$750 MeV/c$ the reaction is dominated by meson exchange currents (MEC) and isobar configurations (IC). Large contributions of FSI have also been found in the most recent D(e,e′p)n experiment at Jefferson Lab [4] where the D(e,e′p)n cross section has been measured for missing (recoil) momenta up to $550 MeV/c$ at a momentum transfer of $Q^2 = 0.665(GeV/c)^2$.

In order to study short range phenomena one has to suppress processes due to large inter-nucleon distances while enhancing contributions of reaction mechanisms which probe the short-distance structure of the deuteron. One hopes that this can be achieved when the trans-

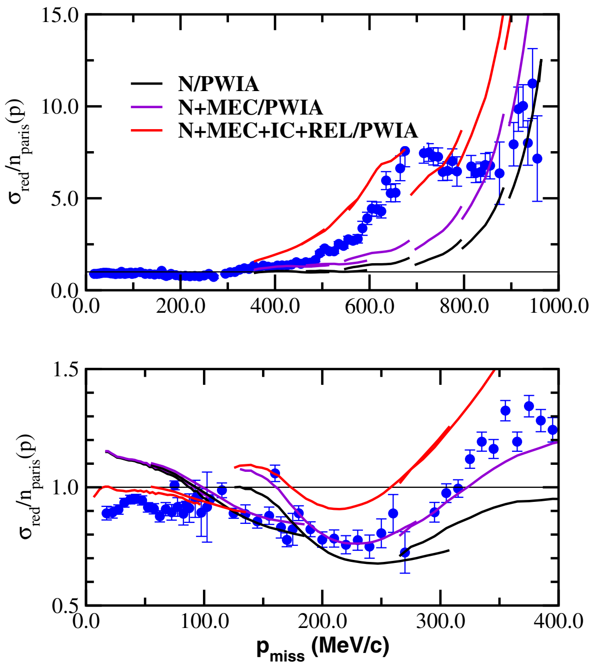

Fig. 2. Experimental D(e,e′p)n cross section divided by the PWIA cross section for the Mainz experiment [3] compared to calculations by Arenhövel

fered momentum in the reaction is typically larger than 1 GeV/c.

The problem in using large momentum transfers is that large particle energies are involved. In this case the nucleon-nucleon interaction is increasingly inelastic and "classical" methods for treating final state interactions by solving the Schödinger equation become ineffective. The solution to this problem is to use models based on the Glauber approximation which has been very successfully applied in high energy nucleon nucleon scattering. A representative of this method is the generalized eikonal approximation [5,6](GEA). Within this model, final state interactions are described as a series of small angle rescatterings of the stuck nucleon with spectator nucleons. In contrast to the original Glauber approximation the GEA also takes the motion of the bound nucleon into account. GEA is expected to be valid at high momentum transfers (and consequently at high neutron-proton relative energies in the final state) but no quantitative studies have been carried out so far.

2 Jefferson Lab Hall A experiment E01-020

In order to test Glauber based models quantitatively, we have completed a D(e,e′p)n experiment in Hall A at Jefferson Lab (experiment E01-020). Coincidence cross sections for the electro-disintegration of the deuteron at four momentum transfers of $Q^2 = 0.8$, 2.1 and 3.5 $(\mathrm{GeV/c})^2$ and at missing momenta of $p_{miss} = 0.2$, 0.4 and 0.5 GeV/c have been measured. These data allow us to study in detail several important aspects of the D(e,e′p)n reaction.

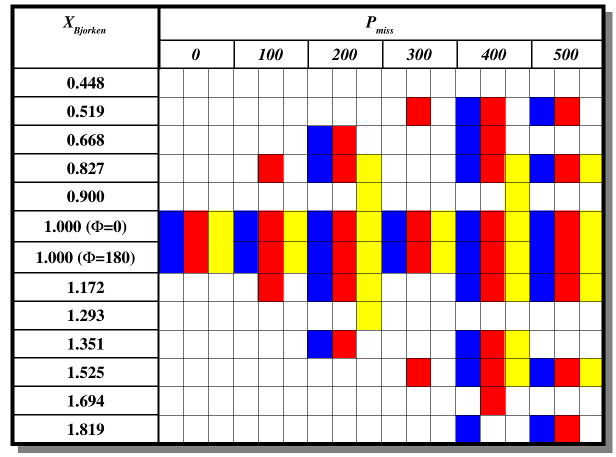

Fig. 3. Kinematic settings measured. The various colors represent the Q^2-values. $Q^2 = 0.8(GeV/c)^2$ $(blue)$, $Q^2 = 2.35(GeV/c)^2$ (red) and $Q^2 = 3.5(GeV/c)^2$ $(yellow)$

Figure 3 gives an overview of all the kinematic settings measured in this experiment.

For protons detected along **q** each kinematic setting is chosen to emphasize different aspects of the reaction mechanism. For energy transfers below the quasi-free peak ($x > 1$), non-nucleonic effects (IC and MEC) are expected to be minimized since the energy transfer is relatively low. For protons detected along **q**, FSI are also expected to be minimized since they would shift strength predominantly from high to low recoil momentum and the one-body response falls off sharply with recoil momentum. Therefore, these kinematics are expected to be mainly sensitive to aspects of the deuteron's short-range structure.

A separation of the R_{LT} interference response function will be performed in quasi-free kinematics over a large range of Q^2 and recoil momenta to test the validity of relativistic models. Proper treatment of relativity is essential at kinematics where we will probe the deuteron's short-range structure.

According to models based on the Glauber approximation, the angular distribution of recoiling neutrons (for fixed Q^2 and recoil momentum) is expected to exhibit very different behavior depending on the magnitude of the recoil momentum compared to the PWIA where FSI have been neglected. At small recoil momenta ($p_{miss} < 0.1$ GeV/c) it is expected to be very close to the PWIA prediction. For p_{miss} values around 0.2 GeV/c a reduction of the cross section is expected for recoil angles around 80° and for $p_{miss} = 0.4$ GeV/c and above a large increase in the D(e,e′p)n cross section around 80° is expected. This behavior can be understood if one assumes that the amplitude for re-scattering is dominated by its imaginary part and its magnitude is increasing relative to the direct term with increasing p_{miss} . Figure 4 shows the ratio between the D(e,e′p)n cross section including final state interactions and the plane wave impulse approximation cross section. Note that the peak location is very different for the generalized eikonal approximation as compared to the prediction of a conventional Glauber calculation.

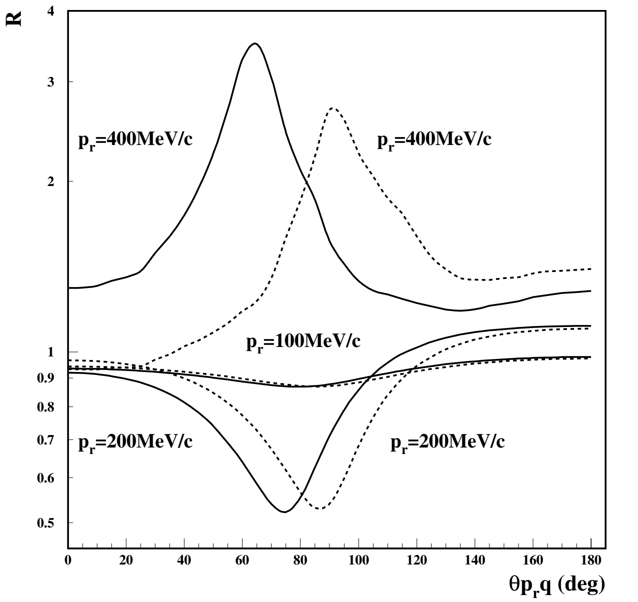

Fig. 4. The angular dependence of R, the ratio of the D(e,e′p)n cross section calculated including PWIA and FSI terms to the cross section which includes PWIA term only: GEA (*solid line*) and according to the conventional Glauber approximation (*dashed line*)

From a first pass analysis of the data we extracted angular distributions that allow a first, qualitative test. Using the Hall A montecarlo program MCEEP we calculated the yield for each kinematic setting including radiative effects. The experimental data have been corrected for computer dead time and charge normalized. As an additional normalization factor, that takes into account an overall efficiency, we took the ratio between the observed yield and the one calculated in PWIA for low missing momenta ($p_{miss} < 100MeV/c$)). Finally, we calculated the ratio between the corrected observed yields and the calculated one. The result corresponds to the ratio between the experimental cross section and the PWIA prediction which then can be compared to a theoretical prediction for this ratio. These results are clearly very preliminary and we are currently analyzing the normalization data and the detector efficiencies. Therefore the results presented here should be used *only at the qualitative level*.

Figure 5 shows the VERY PRELIMINARY result of this analysis for the angular distribution at Q^2=3.5 (GeV/c)^2 for $p_{miss} = 0.2$ and $p_{miss} = 0.5$ GeV/c. The following bin sizes (full width) have been used: $\Delta\theta_{nq} = 5°$, $\Delta Q^2 = 0.5(GeV/c)^2$ and $\Delta p_{miss} = 0.04GeV/c$. The missing energy spectrum has been integrated from -5 MeV to 10 MeV.

One can clearly see the reduction in cross section for $p_{miss} = 0.2$ GeV/c and a strong enhancement for $p_{miss} = 0.5$ GeV/c. Both the minimum and the maximum occur at a recoil angle between 70° and 80° . This indicates that a conventional Glauber approximation calculation does not satisfactorily describe FSI in the D(e,e′p)n reaction.

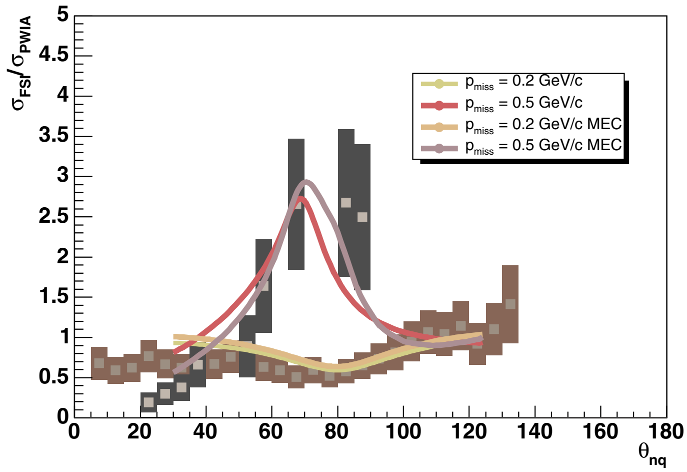

Fig. 5. The angular dependence of the ratio between the *very preliminary* experimental yield and the PWIA yield for $Q^2 = 3.5$ (GeV/c)^2. The curves have been calculated by J.M. Laget [8] and include MEC within his model. The boxes indicate the systematic uncertainty of our very preliminary analysis (20%)

We are currently in the process of finishing up our calibrations and will start a next pass at the physics analysis of the data. This will considerably reduce the uncertainty in the first data presented here.

3 Conclusion/Summary

Data at $Q^2 < 0.6(GeV/c)^2$ show large contributions of FSI especially for p_{miss} above $200MeV/c$. At large values of p_{miss} and small momentum transfers there are also large contributions due to MEC and IC. New data obtained at large Q^2-values qualitatively confirm predictions by models based on the eikonal approximation. A more refined comparison and interpretation needs further analysis of the data. These measurements will help our understanding of the D(e,e′p)n reaction at large Q^2 and enable us to extract information on the short range structure of the two nucleon system.

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