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Detailed study of the few nucleon systems with (e,e'p) reactions

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Abstract. In a new and detailed experimental program carried out at Jefferson Laboratory, the few nucleon systems has been studied via electrodisintegration of Deuterium and the Helium nuclei. Interesting new results probing the high momentum structure have been studied via the (e,e'p) reaction using the two high resolution spectrometers in Hall A and various kinematic regions have been investigated. Detailed and precise information on the effective bound state momentum distributions have been measured for the first time up to missing momenta of 1 Gev/c in ^{3}He, exhibiting significant strength at these high momenta which standard nuclear calculations fail to explain and could be an indication of the onset of non-nucleonic degrees of freedom. The continuum region in ^{3}He has also been invsetigated in great detail looking for nuclear correlations and quasi-deuteron strength. Response function separations have been carried out to extract details of the few body structure and relativistic dynamics. Measurements made so far on D and ^{4}He have focussed on specific kinematic regions and there are plans to extend them over kinematic ranges similar to the ^{3}He investigation.

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1 Introduction

Electron quasi-elastic scattering is a powerful tool for the study of nuclear structure. In particular, (e,e'p) reactions have provided a wealth of information such as the effective nucleon momentum distributions in nuclei as well as separated response function distributions. In addition, these measurements provide information on ground state short-range correlations, final state interactions, meson exchange contributions and relativistic effects in the few body wave function. At JLab, this is being accomplished by extending the domain of momentum transfers towards higher values where short-range effects and possibly the internal structure of the nucleons are manifested, by exploring nuclear structure in its extreme conditions, and by investigating the high momentum part of the wave function. We will also increase the knowledge of the nuclear structure by separating the response functions associated with different polarization states of the virtual photon.

At Jefferson Lab a series of (e,e'p) measurements have been performed on the Deuterium [1,2] and Helium [3,4] isotopes designed to exploit these new possibilities. Deuteron is the simplest nuclear system where exact calculations can be performed and its structure can be investigated in great detail. Next to the deuteron, the A=3 and A=4 nuclei are the simplest systems in which all basic ingredients of a complex nucleus exist. Sophisticated methods to solve the many-body Schrödinger equation almost exactly have been applied to the A=3 nuclei and have been extended to ^{4}He. Microscopic calculations of FSI and MEC contributions have been developed and applied to reactions on few-nucleon systems. The data provided by these experiments test the validity of these models in the high Q^2 and high missing momentum regime. In this paper the preliminary results of the experiments will be presented and discussed with special emphasis on the e89044 experiment.

2 The experiments

In the e89044 experiment [3], different kinematics regions were studied to exploit various aspects of the nuclear structure and reaction mechanisms. In constant (q,ω) kinematics, also known as perpendicular kinematics, a constant q = 1.5 GeV/c and ω = 0.845 GeV was maintained. In this kinematics the single nucleon structure of ^{3}He was studied with special emphasis on high momenta up to p_{miss} = 1 GeV/c. We also did a complete in-plane separation of the response functions R_{TL}, R_T, and the combination of R_{L+TT} up to missing momenta of 0.55 GeV/c.

In parallel kinematics, the q dependence of the reaction was determined by performing an R_L/R_T (longitudinal/transverse) Rosenbluth separation for protons emitted along **q** (in parallel kinematics), up to q = 3 GeV/c. This was performed in both quasi free kinematics ($p_m = 0$) and for q = 1 and 2 GeV/c at $p_m \pm 0.3$ GeV/c.

Also, the continuum region was studied in order to search for correlated nucleon pairs. This was done in both

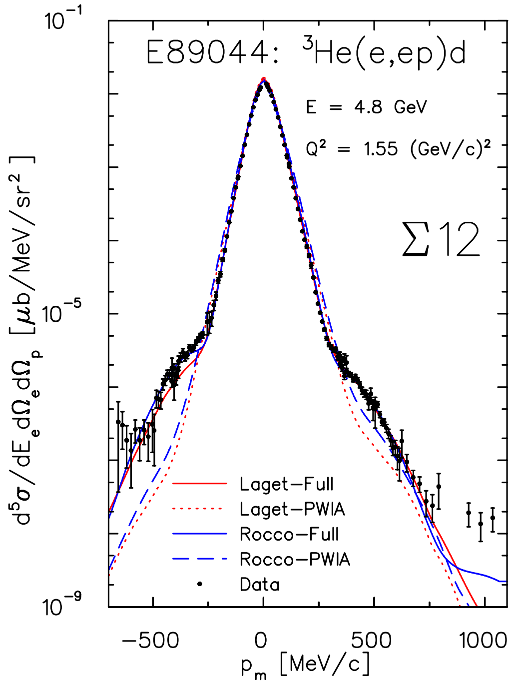

Fig. 1. Shown are the preliminary cross section results for the reaction ^{3}He(e,e'p)d as a function of missing momentum with a beam energy of 4807 MeV and with a fixed $\mathbf{q} = 1500$ MeV/c and $\omega = 840$ MeV with $\phi = 180°$. The *theory curves* show the latest calculations of J.M. Laget and R. Schiavilla

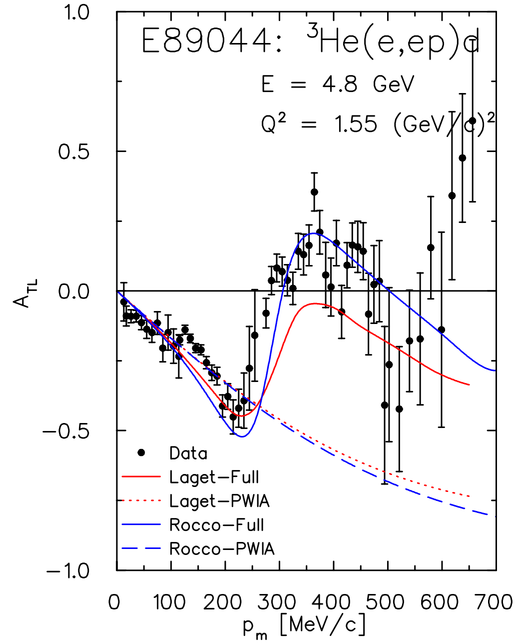

Fig. 2. Shown is the preliminary A_{TL} data. This result is obtained by taking the sum over the difference of the two forward kinematics. The *curves* show the latest calculation of J.M. Laget and R. Schiavilla. At lower missing momentum the theories are most sensitive to relativistic effects, while at the larger missing momentum the theories become sensitive to FSI effects

parallel and perpendicular kinematics with full in-plane separation of the response functions.

In a recently approved experiment on 4He [4], a detailed study will be made through (e,e'p) measurements at high momentum transfers in kinematics similar in range and scope to the ^{3}He(e,e'p)d [3] study.

3 Results

The cross section results of the in ^{3}He(e,e'p)d reaction [3] in perpendicular kinematics are shown in Fig. 1 for the forward kinematics. It has generated considerable theoretical interest. The curves show the most recent calculations of J.M. Laget [5] and R. Schiavilla [6]. There is good agreement of the full calculations with the data up to 750 MeV/c. One sees that in the region between 0 and 200 MeV/c in p_{miss} there is good agreement with the PWIA calculation except at the very low values of p_{miss} ($\leq$50 MeV/c) and this is presently being investigated more thoroughly. In the region between 200 MeV/c and 400 MeV/c, the data lies below the PWIA calculation and this is due to the interference between the PWIA and the rescattering amplitudes - also referred to as Glauber screening. In the region between 400 MeV/c and 750 Mev/c most of the enhancement in the strength of the data over the PWIA calculation is due to final state interactions (FSI). There is as yet no clear indication as to what is causing the cross section at the largest missing momentum at around 1 GeV/c to be nearly an order of magnitude greater than predicted.

The A_{TL} response function is a sensitive tool to study the details of the theoretical inputs. It is obtained by taking the sum over the difference of the two forward kinematics: $\sigma(\phi = 0°)$ and $\sigma(\phi = 180°)$ and shown in Fig. 2. At lower missing momentum the theories are most sensitive to relativistic effects, while at the larger missing momentum the theories become sensitive to final state interaction effects.

The results of the analysis of the perpendicular kinematics is now been submitted for publication [7].

In parallel kinematics, in Fig. 3 we show the results of the forward (high epsilon) kinematics for Q^2 values of 0.8, 1.5, 2.2 and 4.1 $(GeV/c)^2$. The PWIA results of Laget are also shown and they agree with the data at the low $Q2$ values. Once the backward angle kinematics (low epsilon) data are analysed we shall have the R_L/R_T (longitudinal/transverse) Rosenbluth separation done. This will enable us to probe the electromagnetic properties of the proton embedded in the nucleus and see if they are modified from those of the free nucleon.

The experimental data for the continuum region [8] are both much higher in statistics and more extensive in kinematic coverage than any previous measurement. Figure 4 shows the effective momentum density distribution, obtained by integrating the theory and cross section data over missing energy from threshold to 140 MeV.The continuum density distribution (also referred to as the 3bbu – the 3-body breakup channel)tends to have a much larger

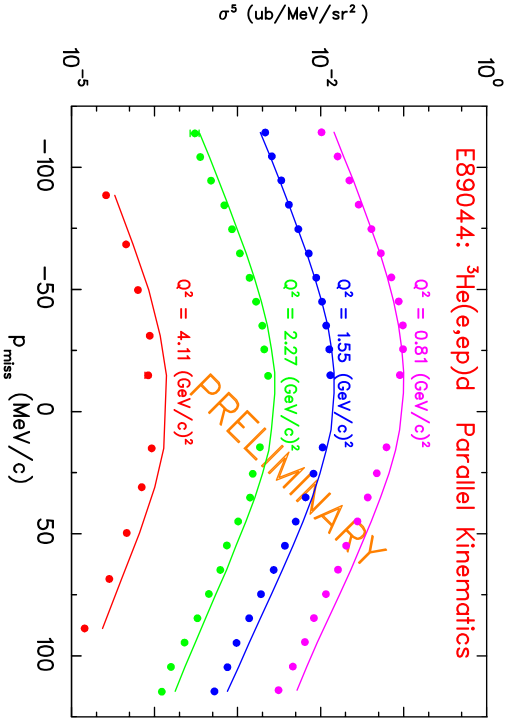

Fig. 3. The forward (high epsilon) kinematics for Q^2 values of 0.8, 1.5, 2.2 and 4.1 $(GeV/c)^2$ in parallel kinematics. The PWIA results of Laget are also shown

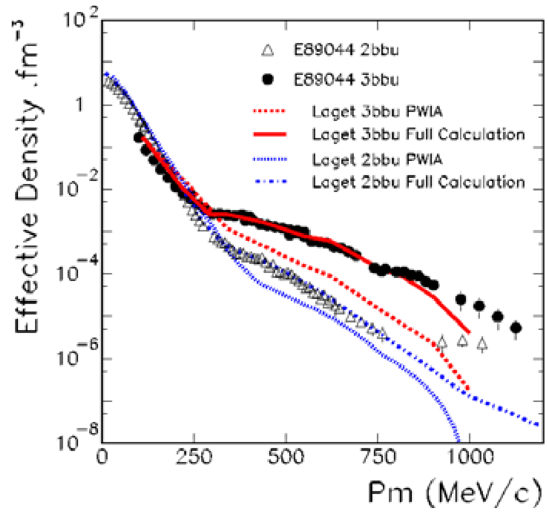

Fig. 4. Proton effective momentum density distributions in ^{3}He extracted from ^{3}He(e,e'p)pn (*filled black circles*) and ^{3}He(e,e'p)d (*open black triangles*), compared to calculations from Laget. The 3bbu integration covers E_M from threshold to 140 MeV

relative strength for high missing momentum, suggesting an important role for correlations. The generally good agreement of the full calculations shown in Fig. 4 indicates that, at this level of comparison, there is no need for correlations beyond those already present in a modern conventional nuclear physics model.

The Jefferson Lab E89-044 ^{3}He(e,e'p) experiment has been successfully completed and results are in the process of being published. From the cross section results along with the A_{TL} asymmetry we can already see regions where the theoretical models clearly predicted the experimental results, such as the rise in the cross section at 300 MeV/c in Fig. 1. Also seen are the deficiencies in the theories, as indicated by much larger then expected cross section at extremely large missing momentum in Fig. 1 and by the A_{TL}. As the analysis now continue with the response function separations, it should become clear what effects are causing the discrepancies between theory and experiment, and allow a significant improvement in our understanding of the three-body system. In the coming years, the E01-108 ^{4}He(e,e'p) experiment will be run in Hall A and will provide a valuable investigation of the 4-body system.

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