Experimental Study of Nuclear Few Body Systems at Jefferson Lab

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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 ^3He , 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 ^3He has also been investigated 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 ^4He have focussed on specific kinematic regions and there are plans to extend them over kinematic ranges similar to the ^3He investigation.

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

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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 ⁴He. 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 Q² 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 experiment³, 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 ³He 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 parallel and perpendicular kinematics with full in-plane separation of the response functions.

In the D(e,e'p) experiment¹, the effective momentum distribution was mapped out to 600 MeV/c in missing momentum in perpendicular kinematics. In a presently run experiment on the Deuterium², the Bjorken x distribution of the cross section at various values of missing momenta (200 MeV/c, 400 MeV/c and 500 MeV/c) are being mapped out to look for Color Transparency effects.

In a recently approved experiment on ⁴He⁴, a detailed study will be made through (e,e'p) measurements at high momentum transfers in kinematics similar in range and scope to the ³He(e,e'p)d³ study.

Figure 1. Shown are the preliminary cross section results for the reaction ${}^3\text{He}(e,e'p)d$ 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 $\phi = 180^\circ$. The theory curves show a PWIA calculation using Salme's spectral function along with the latest calculations of J.M. Laget.

3 Results

The preliminary cross section results of the in ${}^3\text{He}(e,e'p)d$ reaction³ 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. Laget⁵. There is good agreement of Laget's full calculation 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} (≤ 50 MeV/c) and this is presently be-

Figure 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 along with a preliminary results of J. Udias⁵. 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.

ing 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: $\sigma(\phi = 0^\circ)$ and $\sigma(\phi = 180^\circ)$. The curves in Fig. 2 show the latest calculation of J.M. Laget as well as preliminary and rough calculations of J. Udias⁵. 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. J. Udias is now working on making a full calculation of the cross sections and A_{TL} using a realistic potential.

With the cross section analysis of the perpendicular kinematics now nearly finished, the process of making the response function separations is now underway and should be available soon.

Figure 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.

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 Q^2 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.

We have made good progress in the analysis of the continuum region. Fig. 4 shows the missing energy spectra at a p_{miss} value centered around 425 MeV/c.

Figure 4. The missing energy spectra at a p_{miss} value centered around 425 MeV/c. The bump at $e_{miss} = 45$ MeV is at the location of the knockout of a quasi-deuteron within the ${}^3\text{He}$ nucleus..

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Experiment E94-004¹ performed the $d(e,e'p)n$ reaction and the results are presented in Fig. 5. The data was taken in perpendicular kinematics analogous to the ${}^3\text{He}(e,e'p)$ kinematics but at a lower value of $Q^2 = 0.665 \text{ (GeV/c)}^2$. The data show the same characteristics as the ${}^3\text{He}$ data described above with lowering of the cross section with respect to the PWIA calculation in the p_{miss} region around 200 MeV/c and enhancement over the PWIA calculation in the region around $p_{miss} = 400$ MeV/c due to final state interactions. The full calculations are from Arenhovel⁷.

4 Conclusions

The Jefferson Lab E89-044 ${}^3\text{He}(e,e'p)$ experiment has been successfully completed and preliminary results are starting to become available. From the preliminary cross section results along with the A_{TL} asymmetry we can already

Figure 5. The $d(e,e'p)$ data was taken in perpendicular kinematics at $Q^2 = 0.665$ (GeV/c) 2 . The data show the same characteristics as the ^3He data described earlier with lowering of the cross section with respect to the PWIA calculation in the p_{miss} region around 200 MeV/c and enhancement over the PWIA calculation in the region around $p_{miss} = 400$ MeV/c due to final state interactions. The full calculations are from Arenhovel⁷.

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 than 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 $^4\text{He}(e,e'p)$ experiment will be run in Hall A and will provide a valuable investigation of the 4-body system.

5 Acknowledgments

I would like to acknowledge the hard work and dedication of the doctoral students working on the experiment. Marat Rvachev with M.I.T. has done the perpendicular analysis. Emilie Penel-Nottaris with Grenoble is working on the parallel analysis and Fatiha Benmokhtar with Rutgers University is analyzing the continuum data for her doctoral research.

Also, I would also like to thank my experimental co-spokespersons, Marty Epstein and Eric Voutier, for their hard work and dedication along with both the Hall A and the E89-044 collaboration. Special thanks also to Doug Higinbotham for taking an active role in the analysis of the data and the management of the collaboration and to Paul Ulmer for the $d(e,e'p)$ results.

The Southeastern Universities Research Association (SURA) operates the Thomas Jefferson National Accelerator Facility under DOE Contract No. DE-AC05-84ER40150.

References

1. M. Jones and P.E. Ulmer, In-Plane Separations and High momentum Structure in $D(e,e'p)n$, Jefferson Lab Experiment 94-004.
2. W. Boeglin, M. Jones, A. Klein, P. Ulmer and E. Voutier, $(e,e'p)$ Studies of the Deuterium at High Q^2 , Jefferson Lab Experiment 01-020.
3. M. Epstein, A. Saha, and E. Voutier, Selected Studies of the ^3He and ^4He Nuclei through Electrodisintegration at High Momentum Transfer, Jefferson Lab Experiment 89-044.
4. K. Aniol, D.W. Higinbotham, S. Gilad, and A. Saha, Detailed Study of the ^4He Nuclei Through Response Function Separations at High Momentum Transfers, Jefferson Lab Experiment 01-108.
5. J.M. Laget, Phys. Rev. D579 (1994) 333.
6. J. Udias, private communication.
7. W. Fabian and H. Arenhovel, Nucl. Phys. A314 (1979) 253.