DETAILED STUDY OF THE ^{3}HE NUCLEUS THROUGH RESPONSE FUNCTION SEPARATIONS AT HIGH MOMENTUM TRANSFER

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In order to further our understanding of the few body system, a new series of measurements on the reaction ^{3}He(e,e'p) has been made at Jefferson Lab. Making use of beam energies as high as 4.8 GeV and of the two high resolution spectrometers in Hall A, kinematics which were previously unattainable have been investigated. In this paper the first preliminary results of this experiment will be presented.

1 Introduction

Coincidence experiments have proven to be very useful tools in studying specific aspects of the nucleus. In particular the (e,e'p) reaction has been used not only to study the single-nucleon structure of nuclei but also to study the behavior of nucleons embedded in the nuclear medium. 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 also will increase the specificity of the probe by separating the response functions associated with different polarization states of the virtual photon.

The Jefferson Lab E89-044 [1] and E01-108 [2] experiments are designed to exploit these new possibilities by undertaking a series of (e,e'p) measurements on the Helium isotopes. 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 E89-044 experiment will be presented and discussed.

2 Kinematics

The kinematics for the (e,e'p) reaction are shown in Fig. 1. The scattering plane is defined by the incoming electron, $e = (E_e, \mathbf{e})$, and the outgoing electron, $e' = (E'_e, \mathbf{e}')$. The four-momentum of the virtual photon is given by q^μ=(ω, $\mathbf{q}$) and the four-momentum of the outgoing proton is given by $p'^\mu = (E_p, \mathbf{p}')$. The four-momentum square, $Q^2 = q^2 - \omega^2$, is defined such that for electron scattering Q^2 is always positive. The missing momentum vector is defined as $\mathbf{p}_m = \mathbf{q} - \mathbf{p}'$.

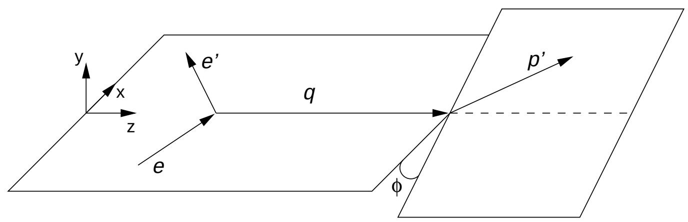

Figure 1. A schematic of the kinematics for the (e,e'p) reaction.

The form of the differential cross section for (e,e'p) reactions in the one-photon exchange approximation without polarization is:

$$\frac{d^6\sigma}{d\Omega_{e'} dE_{e'} d\Omega_{p'} dE_{p'}} = \frac{E_p p_p}{(2\pi)^3} \sigma_{Mott} [v_T R_T + v_L R_L + v_{TL} R_{TL} \cos\phi + v_{TT} R_{TT} \cos 2\phi], \quad (1)$$

with ϕ the angle between the plane defined by $\mathbf{e}$ and $\mathbf{e}'$ and the plane defined by $\mathbf{p}'$ and $\mathbf{q}$, σ_M is the Mott cross section,

$$\sigma_{Mott} = \frac{4\alpha^2 E_{e'}^2}{Q^4} \cos^2 \frac{\theta_e}{2}. \quad (2)$$

The kinematics factors v_L, v_T, v_{TL},and v_{TT} are:

$$v_L = \frac{Q^4}{q^4}, \quad (3)$$

$$v_T = \frac{Q^2}{2q^2} + \tan^2(\theta_e/2), \quad (4)$$

$$v_{TL} = \frac{Q^2}{q^2} \left[\frac{Q^2}{q^2} + \tan^2(\theta_e/2) \right]^{1/2}, \textit{and} \quad (5)$$

$$v_{TT} = \frac{Q^2}{2q^2}. \quad (6)$$

For the two body break-up channel, ^{3}He(e,e'p)^{2}H, the proton energy and angle with respect to $\mathbf{q}$ are correlated because the missing energy is fixed. In this case the differential cross is written as follows:

$$\frac{d^5\sigma}{d\Omega_{e'}d\Omega_{p'}dE_{e'}} = \frac{E_p P_p}{(2\pi)^3}\sigma_{Mott} f_{rec}^{-1}\left[v_T R_T + v_L R_L + v_{TL} R_{TL}\cos\phi + v_{TT} R_{TT}\cos 2\phi\right], \tag{7}$$

where f_{rec} is the recoil factor,

$$f_{rec} = \left[1 - \frac{E_{p'}}{E_t}\frac{\mathbf{p_m}\cdot\mathbf{p}'}{p'^2}\right]. \tag{8}$$

The response functions, R_L, R_T, R_{TL}, R_{TT} can be separated by a suitable choice of the kinematic parameters. In perpendicular in-plane kinematics, i.e. constant q and ω kinematics, one can separate R_T, R_{TL}, and a combination of the R_L and R_{TT} response functions, denoted in this proposal as R_{L+TT}. One can also measure the cross section asymmetry A_{TL} for a given $\mathbf{q}$ and ω. This asymmetry is defined as:

$$A_{TL} = \frac{\sigma(\phi=0) - \sigma(\phi=180)}{\sigma(\phi=0) + \sigma(\phi=180)}. \tag{9}$$

In parallel and anti-parallel kinematics, i.e. when the out-going proton is in the direction of $\mathbf{q}$, one can separate the R_L and R_T response functions. In parallel kinematics p_m points in the opposite direction as $\mathbf{q}$ with $x_B < 1$ while in anti-parallel kinematics p_m points in the same direction as $\mathbf{q}$ with $x_B > 1$ where

$$x_B = \frac{Q^2}{2M\omega} \tag{10}$$

is the Bjorken scaling variable. For $x_B > 1$, the region in ω between the quasi-elastic peak and the elastic peak is being probed; while for $x_B < 1$, the region ω towards the delta peak is being probed. The region in ω between the quasi-elastic peak and delta peak is often referred to as the dip region.

3 Measurements

In perpendicular kinematics, with a constant q = 1.5 GeV/c and ω = 0.845 GeV, the single nucleon structure of ^{3}He was studied with special emphasis on high momenta, up to 1 GeV/c in missing momentum. 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 quasifree 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.

Perpendicular Kinematics	q [GeV/c]	E_0 [GeV]	ω [GeV]	ϵ	p_m [GeV/c]
Kin01	1.50	4.80	0.837	0.943	0.00
Kin02	1.50	4.80	0.837	0.934	0.00
Kin03	1.50	1.25	0.837	0.108	0.00
Kin04	1.50	4.80	0.837	0.943	0.150
Kin05	1.50	4.80	0.837	0.943	0.150
Kin06	1.50	1.25	0.837	0.108	0.150
Kin07	1.50	4.80	0.837	0.943	0.300
Kin08	1.50	4.80	0.837	0.943	0.300
Kin09	1.50	1.25	0.837	0.108	0.300
Kin10	1.50	4.80	0.837	0.943	0.425
Kin11	1.50	4.80	0.837	0.943	0.425
Kin12	1.50	1.25	0.837	0.108	0.425
Kin13	1.50	4.80	0.837	0.943	0.550
Kin14	1.50	4.80	0.837	0.943	0.550
Kin15	1.50	1.25	0.837	0.108	0.550
Kin28	1.50	4.80	0.837	0.943	0.750
Kin29	1.50	4.80	0.837	0.943	1.00
Kin31	1.50	1.25	0.880	0.069	0.401
Kin32	1.50	1.25	0.880	0.069	0.509
Kin33	1.50	1.95	0.837	0.615	0.000
Kin34	1.50	1.95	0.837	0.615	0.150
Kin35	1.50	1.95	0.837	0.615	0.150

Table 1. *The perpendicular kinematics measured during the E89-044 experiment. The kinematics cover a range in missing momentum from 0 to 1000 MeV/c and span a range in ϵ from 0.108 to 0.934, all with a constant q and ω. From these cross section measurements, the response functions R_{TL}, R_T and a combination of R_L and R_{TT} can be extracted. Due to the large momentum acceptance of the Hall A spectrometers, data include both the two-body break-up, ^{3}He(e,e'p)d channel, and the continuum ^{3}He(e,e'p)pn channel out to missing energies of approximately 150 MeV/c.*

Parallel Kinematics	q [GeV/c]	E_0 [GeV]	ω [GeV]	ϵ	p_m [GeV/c]
Kin16	1.00	4.04	0.438	0.966	0.00
Kin17	1.00	0.845	0.438	0.221	0.00
Kin18	1.94	4.80	1.22	0.898	0.00
Kin19	1.94	1.95	1.22	0.314	0.00
Kin20	3.00	4.80	2.21	0.718	0.00
Kin21	3.00	2.90	2.21	0.180	0.00
Kin22	1.00	2.90	0.700	0.925	-0.300
Kin23	1.00	1.25	0.700	0.527	-0.300
Kin24	1.94	4.80	1.52	0.891	-0.300
Kin25	1.94	1.95	1.52	0.204	-0.300
Kin26	1.00	4.05	0.262	0.968	+0.300
Kin27	1.00	0.845	0.262	0.342	+0.300
Kin36	1.00	1.95	0.439	0.847	0.000

Table 2. *Shown here are the parallel kinematics measured during the E89-044 experiment. The kinematics include measurements made at 0 and 300 MeV/c missing momentum. The 300 MeV/c missing momentum data are taken with Bjorken x both greater and less than one. Due to the large momentum acceptance of the Hall A spectrometers, data include both the two-body break-up ^{3}He(e,e'p)d channel and the continuum ^{3}He(e,e'p)pn channel out to missing energies of approximately 150 MeV/c.*

4 Results

The preliminary cross section results of the in ^{3}He(e,e'p)d reaction in perpendicular kinematics are shown in Fig. 2, 3, and 4 have generated considerable theoretical interest. The curves show the most recent calculations of J.M. Laget [4]. The agreement of the theory to missing momentum of 750 MeV/c is striking. There is as yet no clear indication as to what is causing the cross section at the largest missing momentum to be much greater than predicted, though J.M. Laget is investigating the possibility that it is due to multiple rescattering which has not yet been included in his calculations.

J. Udias is also working on making theoretical calculations. He has already provided the collaboration with a rough A_{TL} calculation [5], shown in Fig. 5 and is now working on making a full calculation of the cross sections and A_{TL} using a realistic potential. R. Schiavilla and S. Jeschonnek are also planning to provide calculations for the collaboration.

With the cross section analysis of the perpendicular kinematics now nearly finished, the process of making the response function separations is now un-

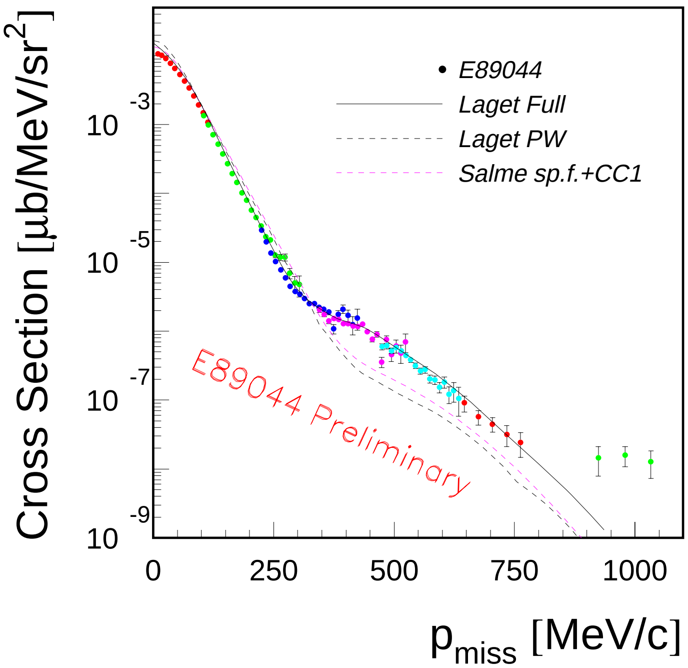

Figure 2. Shown are the preliminary cross section results for the reaction ^{3}He(e,e'p)d as a function of missing momentum with a beam energy of 4807 MeV and with a fixed $\mathbf{q}$ = 1500 MeV/c and ω = 840 MeV with $\phi = 180°$. The theory curves show a PWIA calculation using a spectral function a Salme along with the latest calculations of J.M. Laget. The enhancement in the cross section near 300 MeV/c and continuing to larger missing momentum is predominately due to final state interactions. There is no clear indication from theory what causes the enhancement of the cross section near 1000 MeV/c, though J.M. Laget is investigating the possibility that it is due to multiple rescattering which has not yet been included in his calculations.

derway and in early 2002 preliminary response function separations results should be available. Also next year the cross section and response function separations for the parallel kinematics and for the continuum data should be available.

5 Conclusion

The Jefferson Lab E89-044 ^{3}He(e,e'p) experiment has been successfully completed and preliminary results are starting to become available. From the pre-

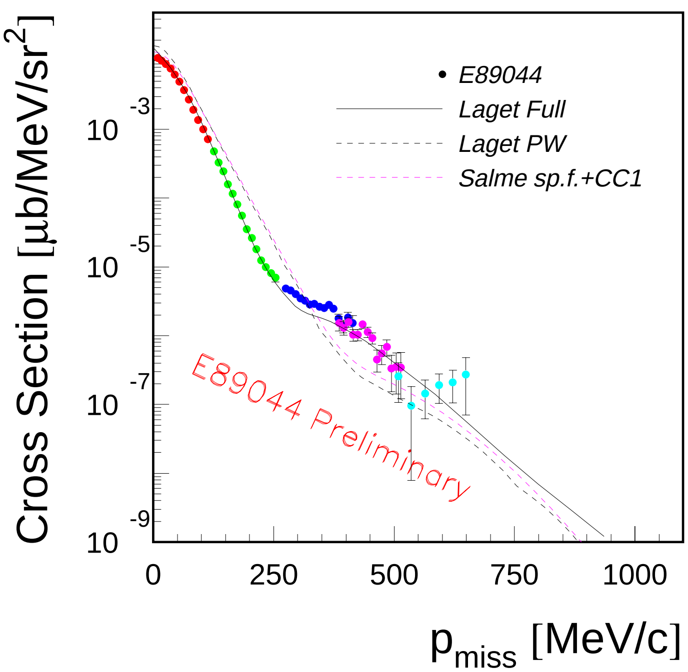

Figure 3. Shown are the preliminary cross section results for the reaction ^{3}He(e,e'p)d as a function of missing momentum with a beam energy of 4807 MeV and with a fixed $\mathbf{q} = 1500$ MeV/c and $\omega = 840$ MeV with $\phi = 0°$. When combined with the results shown in Fig. 2 this data can be used to extract the A_{TL} asymmetry and the R_{TL} response function.

liminary 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. 2. Also seen are the deficiencies in the theories, as indicated by much larger then expected cross section at extremely large missing momentum in Fig. 2 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 understand 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 four-body system.

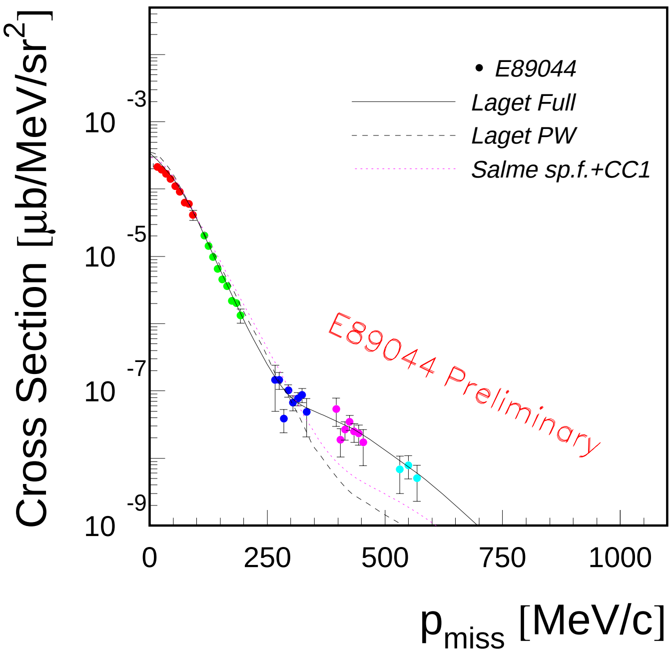

Figure 4. Shown are the preliminary cross section results for the reaction ^{3}He(e,e'p)d as a function of missing momentum with a beam energy of 1250 MeV and with a fixed $\mathbf{q}$ = 1500 MeV/c and ω = 840 MeV with $\phi = 180°$. This data, at an ϵ of 0.108, will be combined with the results shown in Fig. 2, at an ϵ of 0.943 to extract R_T and a combination of R_L and R_{TT}.

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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 and is responsible for the analysis shown in this work. Emilie Penel-Nottaris with Grenoble is working on the parallel analysis and plans to have results available next year and Fatiha Benmokhtar with Rutgers University is analyzing the continuum data for her doctoral research. Also, I would also like to thank the experimental spokespersons, Marty Epstein, Arun Saha, and Eric Voutier, for their hard work and dedication along with both the Hall A collaboration and the E89-044 collaboration. The Southeastern Universities Research Association (SURA) operates the Thomas Jefferson National Accelerator Facility under DOE Contract No. DE-AC05-84ER40150.

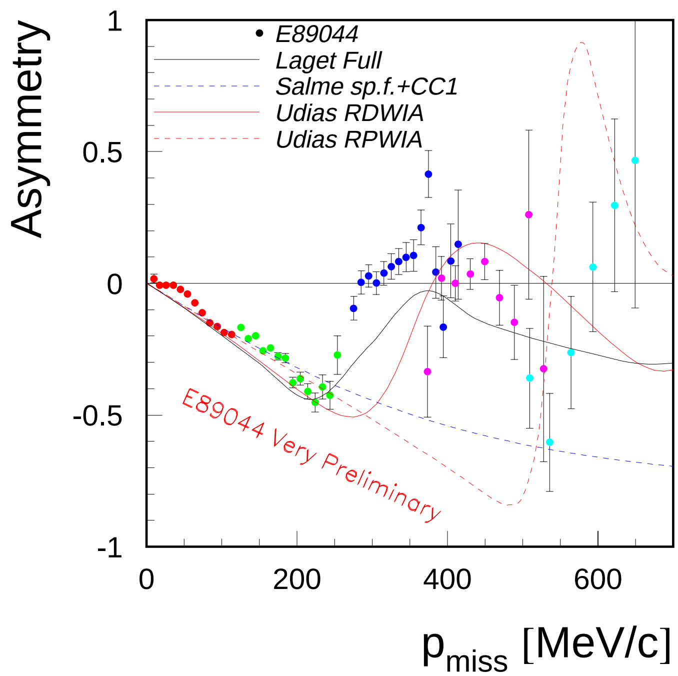

Figure 5. Shown is the preliminary A_{TL} data. This result is obtained by combining the taking the sum over the difference of the results shown in Fig. 2 and 3 (see Equation 9). The curves show the latest calculation of J.M. Laget along with a preliminary results of J. Udias. At lower missing momentum the theories are most sensitive to relativistic effects, while at the larger missing momentum the theories become sensitive to final state interactions effects.

References

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