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Bound Nucleon Properties through ^{3}He(e,e′p) at High Q^2

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Electron scattering cross-sections for the reaction ^{3}He(e,e′p)d have been measured in parallel kinematics for three values of the recoil momentum (0 and ±300 MeV/c) and for different values of the virtual photon squared mass Q^2 up to 4.1 GeV^2. The goal is to probe the electromagnetic properties of the proton when embedded in a nucleus, by studying the Q^2 dependence of the longitudinal and transverse response functions.

1. INTRODUCTION

Electron scattering on ^{3}He is of great interest to further our understanding of few body systems [1]; it can also be used to study the interaction on a bound proton and get insight onto its structure.
In Plane Wave Impulse Approximation (PWIA), the ^{3}He(e,e′p)d reaction is described by the diagram on Fig. 1: only one photon is exchanged (Born Approximation) with the detected proton and the incident and scattered particles are described by plane waves. Such a model leads to a factorized cross-section [2] as follows:

$$\frac{d^5\sigma}{d\Omega_e d\Omega_p dE'} = k\ \sigma_{ep}(Q^2)\ S(P_{miss})$$

where k is a kinematical factor, σ_{ep} the electron-bound proton elastic scattering cross-section and $S(P_{miss})$ the proton spectral function for ^{3}He, which is the probability for forming a final deuteron by removing one proton with momentum P_{miss} from the ^{3}He nucleus. The range of the photon momentum transfer q available in this experiment (up to 3 GeV/c) should allow to test the electromagnetic properties of bound protons at a scale smaller than the proton radius.

The more general expression for the Born Approximation cross-section in terms of longitudinal and transverse response functions allows one to account for additional reaction mechanisms such as final state interactions (FSI) and meson exchange currents (MEC):

$$\frac{d^5\sigma}{d\Omega_e d\Omega_p dE'} = k'\ (\sigma_T + \epsilon(\sigma_L + \sigma_{TT}\cos 2\Phi) + \sqrt{\epsilon(\epsilon+1)}\ \sigma_{TL}\cos\Phi)$$

where $\epsilon = (1 + \frac{2q^2\tan^2\theta/2}{Q^2})^{-1}$ is the virtual photon polarization. In parallel kinematics, the interference response functions σ_{LT} and σ_{TT} vanish and the longitudinal and transverse

*http://hallaweb.jlab.org/physics/experiments/E89-044/index.html

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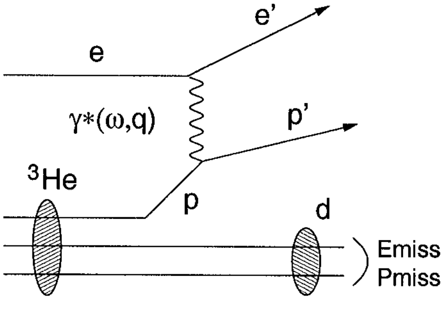

Figure 1. PWIA diagram of ^{3}He(e,e'p)d.

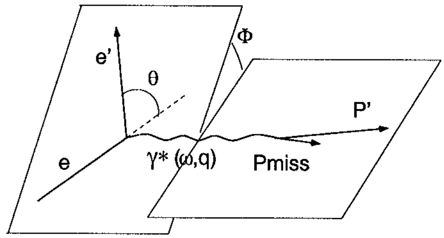

Figure 2. Schematic of the parallel dinematics.

terms can be separated by the Rosenbluth technique. This separation should allow the study of the competing reaction mechanisms as well as the bound nucleon charge and current distributions as a function of Q^2.

2. HALL A EXPERIMENTAL SET UP

Data were taken from December 1999 to April 2000 in Hall A of the Jefferson Laboratory. The accelerator delivered continuous electron beams with energies from 845 MeV up to 4.8 GeV and currents up to 130 μA.

Hall A is equiped with two high resolution spectrometers having momenta acceptances of ± 5 % and horizontal and vertical angle apertures of ± 30 mrad and ± 60 mrad that provide large Q^2 and P_{miss} acceptances. They allow a final 10^{-4} resolution on momentum that leads to a missing energy σ-width of 0.8 MeV. To achieve this resolution, transport parameters of the particles through the spectrometers were optimized using elastic scattering data on carbon and aluminium foils.

On each arm, the detector packages are composed of two planes of scintillators that trigger data acquisition, four planes of vertical drift chambers that allow track reconstruction, providing vertex positions and momentum vectors. For particle identification in the electron arm, a gas Cerenkov detector and a set of preshower and shower detectors are used. The density of the high pressure (110 psi) low temperature (6.3 K) ^{3}He gas target was monitored using both pressure and temperature sensors and elastic scattering data linked to single arm rate monitoring. This should allow us to get accurate normalization of cross-sections, hopefully at the level of 2-3 %.

Parallel kinematics were selected at different values of Q^2 from 0.5 GeV^2 to 4.1 GeV^2, and for three values of P_{miss} : P_{miss} = 0 MeV/c and $P_{miss} = \pm 300$ MeV/c. Table 1 summarizes the selected kinematics.

One of the main objectives of this experiment is to provide the large ϵ lever arm, needed to achieve an accurate separation of the longitudinal and transverse response function.

Table 1
Parallel kinematics for longitudinal-transverse separation of cross-sections.

P_{miss} (MeV/c)	Q^2 (GeV^2)	q (GeV/c)	$\epsilon_{forward} - \epsilon_{backward}$
0	0.80	1.00	0.966 – 0.247
0	1.54	1.50	0.943 – 0.200
0	2.27	1.94	0.899 – 0.314
0	4.10	3.00	0.719 – 0.180
+300	0.94	1.00	0.968 – 0.338
-300	0.52	1.01	0.924 – 0.523
-300	1.45	1.94	0.891 – 0.204

3. DATA ANALYSIS AND FORWARD CROSS-SECTIONS

The first step of the data analysis is the selection of (e,e′p) events, which means rejecting π^- in the electron arm using the Cerenkov and shower detectors (Fig. 3), and π^+, deuterons and accidental protons in the hadron arm by making use of the coincidence time between the two arms and cuts on vertex position (Fig. 4).

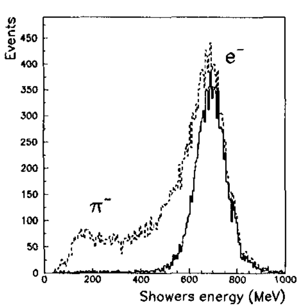

Fig. 3: π^- rejection in shower detectors.

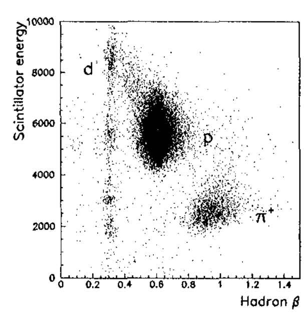

Fig. 4: π^+, deuterons and protons in the scintillators.

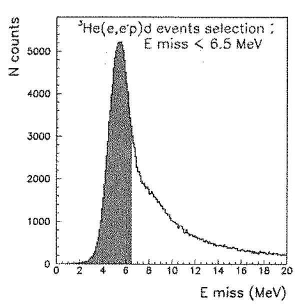

Fig. 5: Experimental missing energy spectrum.

In ^{3}He, the 2-body-break-up (e,e′p)d peak appears at 5.5 MeV in the missing energy spectrum, while the 3-body-break-up (e,e′p)pn begins at 7.7 MeV: in order to separate them a cut is applied on E_{miss} at 6.5 MeV (Fig. 5). The correction for the events lost due to resolution and the radiative tails is obtained from calculations: a Monte-Carlo simulation (MCEEP software [5]) is performed, in which detector and tracking resolutions have been fitted to ^{3}He(e,e′) elastic and ^{12}C(e,e′p) data. The phase-space cuts are then adjusted to match experimental phase-space.

Preliminary results are presented for forward kinematics at $P_{miss} = 0$ MeV/c (Fig. 6). The present absolute cross-section normalization does not take into account elastic scattering measurements for target density: ^{3}He density is currently obtained from P and T sensors and may differ from the final value by 10 to 15 %.
Experimental results are compared to a plane wave model integrated over the spectrom-

eter acceptance: k $\sigma_{cc1} \cdot S(P_{miss})$ with the De Forest σ_{cc1} prescription [3] and a spectral function from Salme [4]. These PWIA calculations tend to agree with the anti-parallel ($P_{miss} < 0$) part and disagree with the parallel ($P_{miss} > 0$) part of the cross section, leading to a parallel/anti-parallel assymmetrical behaviour particularly flagrant at low Q^2 ($Q^2 = 0.8$ GeV^2). As Q^2 increases, the difference between experimental data and calculations at $P_{miss} = 0$ MeV/c increases, suggesting a different Q^2 evolution of the cross section: such kinematics were previously unattainable and have never been investigated.

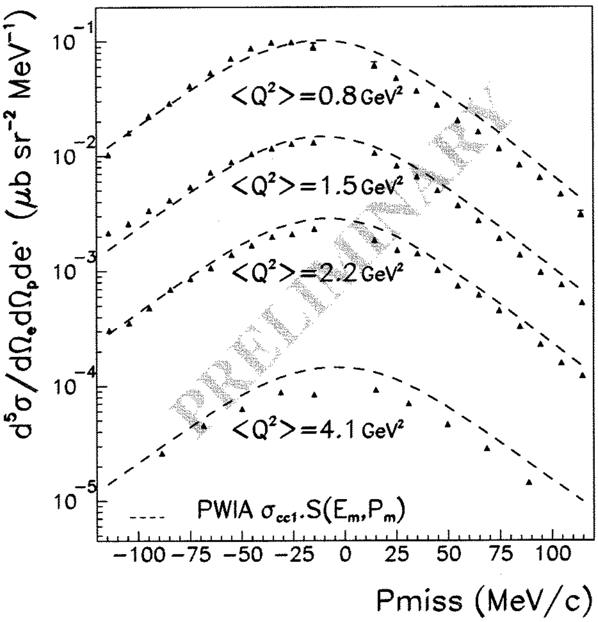

Fig. 6: ^{3}He(e,e'p)d cross-sections for $P_{miss} = 0$ MeV/c kinematics; error bars are only statistics.

4. CONCLUSION

The preliminary results for the measurement of ^{3}He(e,e'p)d cross-sections in parallel kinematics have been presented and discussed. The general trend seems to indicate a parallel/anti-parallel assymetrical behaviour when compared to PWIA calculations. The on-going analysis of backward cross-sections is necessary to further our understanding of these results, particularly the Q^2 behaviour of the cross-section.

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