

The ${}^4\text{He}(e, e'p)$ Cross Section at Large Missing Energy

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The $(e, e'p)$ reaction on ${}^4\text{He}$ nuclei was studied in kinematics designed to emphasize effects of nuclear short-range correlations. The measured cross sections display a peak in the kinematical regions where two-nucleon processes are expected to dominate. Theoretical models incorporating short-range correlation effects agree reasonably with the data.

1. Introduction

The Independent-Particle Shell Model (IPSM) of nuclei has been very successful in providing understanding of many of the observed properties of nuclei in the ground state and low-lying excited states. Over the last decade, the IPSM has been extensively tested by the results of $(e, e'p)$ experiments, which probe the Fourier transform of individual nucleon wavefunctions [1,2]. The data indicate that the shell model provides good understanding of the nucleon wavefunctions, but that states that in the IPSM are fully occupied, can be depleted by as much as 35%. Recent theoretical studies also seem to have converged on such a picture [3]. The depletion comes about since nucleons are undergoing violent pairwise collisions which cause a portion of their wavefunction to be quite different than that predicted by the IPSM.

These $(e, e'p)$ experiments first concentrated on measurements in kinematics where the residual $A - 1$ nuclear systems had low recoil momenta and excitation energies, since this

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is where the IPSM predicts nucleon strength to reside. The remaining strength is theoretically predicted to be found at energies(momenta) above the Fermi energy(momentum). Signatures of this strength can be found by performing $(e, e'p)$ experiments that probe the regions of large p_m and E_m . This paper describes a measurement of the ${}^4\text{He}(e, e'p)$ reaction over a wide range of (E_m, p_m) aimed at investigating the effects of short-range correlations as well as other two-nucleon processes originating from meson-exchange currents (MEC) and Δ -isobar currents (IC).

2. Kinematics

In an $(e, e'p)$ experiment, the incoming and outgoing electron four-vectors k_i and k_f determine the energy and momentum transferred to the nuclear target:

$$q = k_i - k_f = (\omega, \vec{q}). \quad (1)$$

If final-state interactions and many-body currents are ignored, we can assume that all of the momentum \vec{q} is transferred to a single nucleon. Then if this nucleon is detected with momentum \vec{p}_f , its original momentum was $\vec{p}_i = \vec{p}_f - \vec{q} = -\vec{p}_m$.

If a pair of nucleons is undergoing a strong, short-range interaction, we expect the nucleons to have high momenta — one can think of the Fourier transform of a short-range pair wavefunction, which must have large components at high momenta. Due to angular-momentum constraints, we also expect the momenta of the two nucleons to be roughly equal in magnitude and opposite in direction. Thus if we strike one member of this pair which has momentum \vec{p}_i , the other will have momentum $-\vec{p}_i$ and will require an energy $p_i^2/2M$ to be put on shell. The missing energy for a two-nucleon knockout reaction, of which only one nucleon is detected, then reads [4,5] as:

$$E_m \sim \frac{A-2}{A-1} \frac{p_m^2}{2M} + E_{\text{thr}}, \quad (2)$$

recalling that $|\vec{p}_m| = |\vec{p}_i|$. Thus Eq. 2 determines where in (E_m, p_m) space one should look to find effects of short-range correlations. It should be noted that Eq. 2 is appropriate for all processes in which two nucleons are knocked out, hence the strength from two-body hadronic currents will also follow this relation. Such currents include MEC, or Δ excitation followed by $\Delta N \rightarrow NN$.

3. Experiment

The experiment was performed at NIKHEF in Amsterdam. The electron beam was provided by the AmPS ring and had an energy of 525 MeV. This beam impinged on a cryogenic high-pressure helium cell. Scattered electrons were detected in the QDQ magnetic spectrometer of the EMIN end station, with central values of the energy and momentum transfer $(\omega, q) = (215 \text{ MeV}, 400 \text{ MeV}/c)$. Ejected protons were detected in the HADRON4 detector. This is a highly-segmented, large-solid-angle (550 msr) device based on plastic scintillators. It had a proton energy acceptance of 65–185 MeV, which was determined by the Pb shielding (5.2 mm thick) placed in front of the detector to reduce the counting rate in the frontmost scintillators. Its angular acceptance is $40 \times 40 \text{ deg}^2$.

The large acceptances of HADRON4 enabled acquisition of an enormous amount of data in a relatively short time. Data was obtained over the range $0 < E_m < 140$ MeV, $20 < p_m < 690$ MeV/c using four angular settings of HADRON4.

4. Results

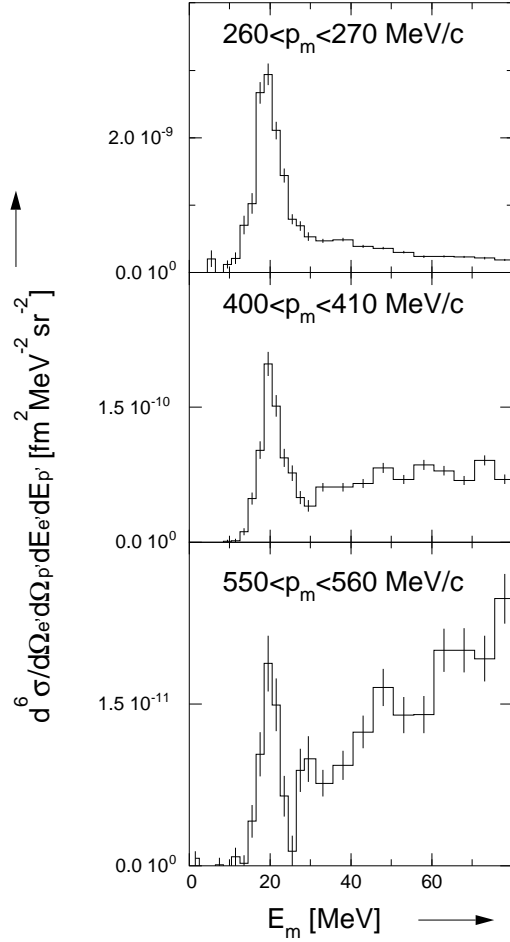


Figure 1: Differential cross sections *vs.* E_m for three consecutive bins in p_m .

Fig. 1 shows sample data from the experiment. Differential cross sections are displayed *vs.* E_m for three consecutive bins in p_m . The peak at $E_m \sim 20$ MeV is due to the two-body breakup channel ${}^4\text{He}(e, e'p){}^3\text{H}$; an analysis of this portion of the data has been previously reported [6,7]. The relative importance of the continuum obviously increases as p_m increases. This is in keeping with the observations noted in Sec. 1 that cross sections for knockout to low- E_m states of the $(A-1)$ system peak at low values of the recoil momentum, while short-distance phenomena will involve relatively larger momenta, and thus generate strength which peaks at large E_m and p_m in accordance with Eq. 2.

Fig. 2 shows the same data now plotted for three consecutive bins of proton emission angle γ_{pq} (relative to \vec{q}). The two-body breakup peak has been removed for clarity. The curves are calculations by Laget. They include effects from MEC and IC in addition to the normal one-body hadronic currents. The ${}^4\text{He}$ wavefunction was computed with a realistic NN interaction, so SRC effects are implicitly included in the one-body hadronic current. FSI are approximately accounted for by single-step rescattering diagrams. The dashed curve shows the results of calculations in which only one-body currents are taken into account. They may be considered as a qualitative indication for the

importance of short-range correlations to the differential cross section.

Several features are worth noting in these plots. The broad bump in the experimental strength is well-reproduced by the calculation, and changes with p_m in a way consistent with expectations from Eq. 2. This is direct evidence of the dominance of two-nucleon knockout. At small values of the angle γ_{pq} (near parallel kinematics) the effect of hadronic two-body currents is small and the cross sections may be largely attributed to the effect of short-range correlations. At larger values of γ_{pq} the role of the hadronic two-body currents gradually increases.

Fig. 2 also shows that for the lowest values of γ_{pq} a large fraction of the cross section at the high- E_m side cannot be accounted for by the calculation. It has been recently suggested [8] that this tail is due to multistep $(e, e'N)(N, p)$ processes, where the struck nucleon knocks out one or more additional nucleons as it exits the nucleus. This conjecture is supported by at least one calculation [9].

The data have been compared to predictions by Simula [5,10]. Comparable agreement to what is shown for Laget's calculations is obtained near parallel kinematics, but the agreement deteriorates with γ_{pq} , which is attributed to the neglect of MECs in Simula's calculations.

5. Conclusions

An experiment has been performed studying the $(e, e'p)$ reaction on ${}^4\text{He}$ in kinematics which emphasize effects related to two-body processes in the nucleus. The measured cross sections peak at the predicted location, and reasonably quantitative agreement is achieved with theories including SRC effects and two-body currents.

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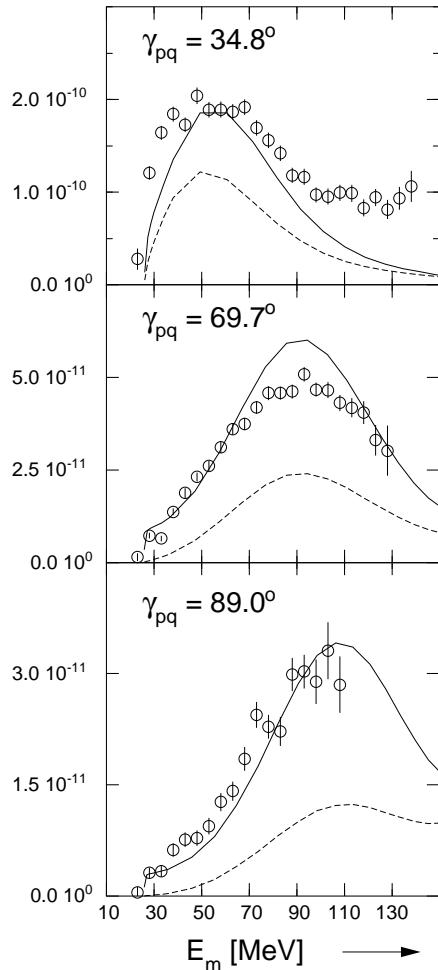


Figure 2: Continuum $(e, e'p)$ differential cross sections vs. E_m for three values of the proton emission angle relative to \vec{q} . Dashed: without MEC or IC. Solid: full.