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The Longitudinal and Transverse Response of the $^4He(e,e'p)$ Reaction in the Dip Region

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A study of the $(e,e'p)$ reaction on ^4He was carried out at the MAMI Microtron, Institut für Kernphysik in Mainz, Germany. The measurements were done in parallel kinematics on the high-energy side of the quasi-elastic peak. The $(e,e'p)$ cross section for ^4He was obtained as a function of missing energy and missing momentum, for three different virtual-photon polarizations, ϵ. A distorted spectral function and momentum distributions were extracted from the data using the de Forest $cc1$ prescription for the elementary $e-p$ cross section, which described well the L/T behaviour of the $(e,e'p)$ cross section. For $E_m = 50 - 100\ MeV$ the $(e,e'p)$ strength was dominated by the radiative tail from lower missing energies, and agreed well with the theoretical spectral function of Ref.[1].

The kinematical conditions selected for the experiment enhances the role of two-body currents in the $(e,e'p)$ cross section. This may lead to larger transverse strength than for pure quasi-free nucleon knockout, which dominates near the quasi-elastic (QE) peak. The role of two-body currents in the $(e,e'p)$ cross section was studied by looking into the longitudinal/transverse (L/T) cross-section behaviour for both two-body and continuum breakup channels, with the emphasis towards the high missing energies (E_m) in order to compare with earlier data (e.g. [2]), where unexpectedly large transverse strength was

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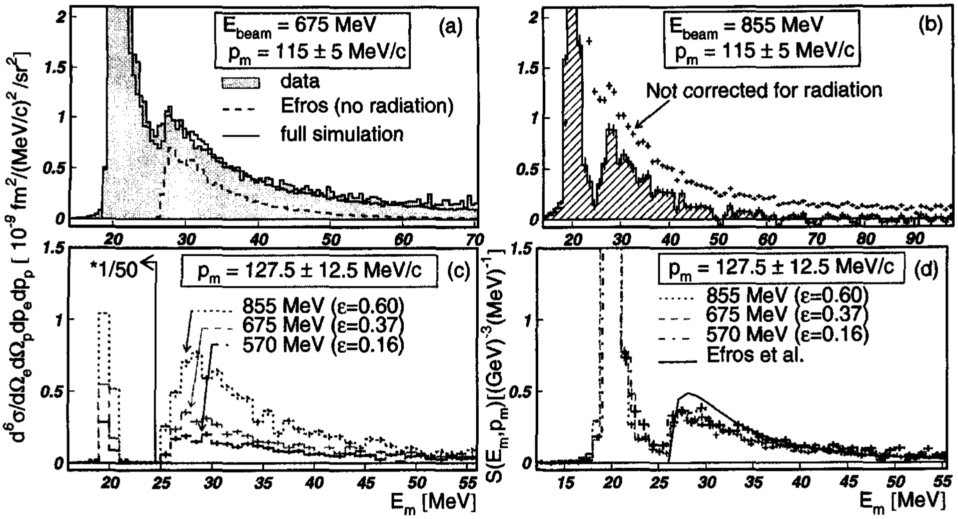

Figure 1. (a) Monte-Carlo simulation of the radiative effects [6].(b) Six-fold differential cross section. (c) Radiatively corrected six-fold differential cross section for the three values of ϵ. (d) Spectral function.

reported for the $(e, e'p)$ reaction at high E_m.

The current measurement was performed at the Mainz microtron, which is characterized by a high quality, 100 % duty factor electron beam. The high-resolution three-spectrometer system of the A1 collaboration [3] was used. The measurements were done at a central 3-momentum transfer of $|\vec{q}|$ = 685 MeV/c, and at a central energy transfer of ω = 334 MeV, corresponding to a value of the y-scaling variable of +140 MeV/c. Spectrometer A defined the electron arm of the reaction, Spectrometer B was used as the proton detector, and Spectrometer C was used as a luminosity monitor by detecting electrons in a fixed kinematical region. Three incident beam energies (570, 675 and 855 MeV) were used to study L/T cross-section behaviour. They correspond to a virtual-photon polarizations ϵ equal to 0.16, 0.37 and 0.60 respectively. Parallel kinematics were used, with protons being detected in the direction of $\vec{q}$. The helium target used was a high-pressure (17-20 bars), low-temperature (20-21 K) Al cell. A standard radiative unfolding procedure [4] using the RADCOR code (Mainz version) [5] was applied to correct for radiation in 2-D (E_m, p_m) space (see Fig. 1(b)). In addition, a theoretical PWIA cross-section model (based on [9] and [1]) was used to simulate radiative tails using a Monte-Carlo technique [6]. In Fig.1(a) the theoretical cross section was reduced by 25 % to account for distortions and match the measured two-body-breakup cross section at $p_m = 115\ MeV/c$.

The $(e, e'p)$ cross section for ^4He was obtained as a 2-D function of missing energy E_m and missing momentum p_m. The general structure of the radiatively-corrected missing-energy spectra is shown in Figs.1(b)-1(d). The two-body breakup peak is at 19.8 MeV, and the first continuum channel threshold is at 26.07 MeV. Strong cross-section dependence on the virtual-photon polarization, ϵ, is evident. To evaluate whether or not this ϵ-dependence can be described simply by the elementary $e - p$ cross section, the distorted spectral function – $S^{dist}(E_m, p_m)$ – was extracted from the data using de Forest's *cc1*

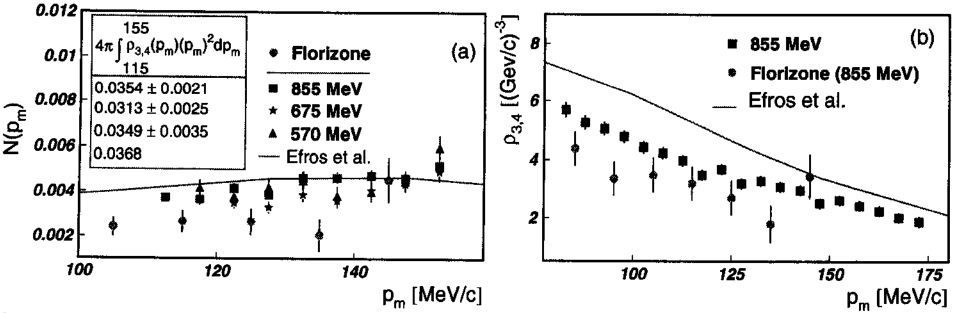

Figure 2. (a) $\langle N\rangle$ value for continuum reaction channels ($\omega = 334 \pm 23.6\ MeV$).(b) Proton-momentum distribution for the measurement at the highest ϵ value ($\epsilon = 0.60$; $\omega = 334 \pm 54\ MeV$)

prescription for the off-shell $e - p$ cross section (σ_{ep}) [7], using

$$S^{dist}(p_m, E_m) = \frac{1}{p_p^2 \sigma_{ep}} \frac{d^6\sigma}{d\Omega_e d\Omega_p dp_e dp_p} \quad . \tag{1}$$

The measured spectral function for the three virtual-photon polarizations is shown in Fig.1d together with a recent full calculation for the ^4He spectral function [1]. The experimental spectral function shows no ϵ-dependence, and agrees quite well with the theoretical prediction. This indicates that the L/T behaviour of the $(e, e'p)$ cross section for the continuum channels can be described by the $e - p$ cross section (in $cc1$ prescription). The difference in magnitude at low E_m values between the theoretical and measured spectral functions can be explained (at least partially) by final-state interaction (FSI) effects between the detected proton, and the undetected 3N system, since the effect of these distortions was not included in the calculations. The FSI may also cause re-distribution of the $(e, e'p)$ events towards the higher values of E_m and p_m, and thus increase the distorted spectral function values in this region (this can be seen in Fig 1d, 3c). The distorted proton-momentum distributions, $\rho_{3,4}(p_m) = \int_{25}^{45} S^{dist}(E_m, p_m) dE_m$, for the continuum channels were also obtained. They show no ϵ-dependence within the experimental uncertainties when compared in the same ω-range ($\omega = 334 \pm 23.6\ MeV$). The integral value $\langle N\rangle$ was used to estimate any remaining ϵ-dependence, where

$$\langle N\rangle = 4\pi \int_{p_m^{low}}^{p_m^{high}} dp_m\, p_m^2\, \rho_{3,4}(p_m) \quad . \tag{2}$$

It was also independent of ϵ when compared in the same ω-range (Fig.2(a)). Fig. 2(b) shows the proton-momentum distribution for the measurement at the highest ϵ value ($w = 334 \pm 54\ MeV$). The data and the theory prediction agreed better at higher p_m values, which can be an indication of re-distribution of $(e, e'p)$ strength due to FSI.

The distorted $p - t$ momentum distributions, $\rho_2(p_m) = \int_{17}^{25} S^{dist}(E_m, p_m) dE_m$, were also extracted, and compared to the theoretical calculations of Schiavilla *et al* [8] and Forest *et al.* [9], and to the earlier experimental results from NIKHEF [10] and from MAMI [4] (Fig. 3(b)). The integral value $\langle N\rangle$ was also calculated for comparison of the $p - t$ momentum distributions (using $\rho_2(p_m)$ instead of $\rho_{3,4}(p_m)$ in Eq. 2), as shown in Fig. 3(a). This shows some systematic ϵ-dependence, being 6.8 % larger for the lowest

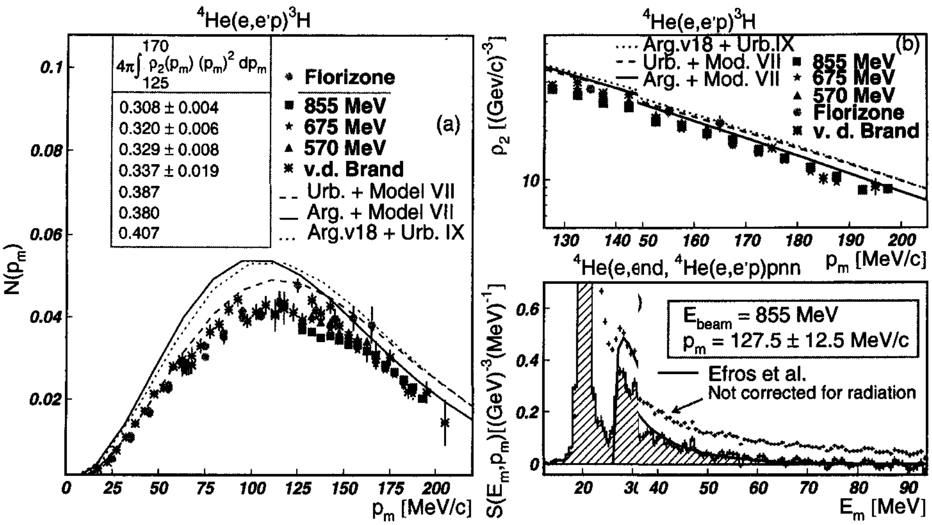

Figure 3. (a) $\langle N\rangle$ value for the two-body breakup channel ($\omega = 33423.6\ MeV$) (b)$p - t$ momentum distributions ($\omega = 334 \pm 23.6\ MeV$). (c) Spectral function.

virtual-photon polarization value ($\epsilon = 0.16$) compared to theaeasurements with $\epsilon = 0.60$. This is an indication that two-body currents must be tak into accout to explain the L/T behaviour of the two-body breakup cross section. Thexperimental $p - t$ momentum distributions were 15-25 % lower than those predicteoy the PWIA models. This difference in magnitude can be explained by the FSI effects the $p - t$ nuclear system.

In summary, measurements of the $^4He(e,e'p)$ cross secticin the dip region were performed with a systematic error of $\pm 2.2 - 2.4$ %. The dborted spectral function for $E_m \geq 50\,MeV$ was small and close to the theory predicti [1], as shown in Fig. 3(c). The large strength observed in the raw $(e,e'p)$ spectra atigh E_m was formed mostly by the radiative tails (Fig.1(a)-(b) and 3(c)). The majoritf the ϵ-dependence seen in the $(e,e'p)$ cross section was removed by division of the ementary σ_{cc1} cross section. However, some deviation of the L/T ratio from that for thquasi-free-nucleon knockout was observed for the two-body breakup reaction channel.

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