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Comparison of the $^{12}C(e, e'p)$ Cross Sections at Low Momentum Transfer with Relativistic Calculations

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The $(e, e'p_0)$ cross section of ^{12}C previously measured using a 197.5 MeV continuous electron beam is compared with theoretical calculations based on the relativistic distorted-wave impulse approximation (RDWIA). The theoretical values overestimate the experimental ones by a factor of two. The contribution of meson exchange current (MEC) effects is important in the high missing momentum region.

We compared in a previous report [1] the reduced cross section obtained from the $^{12}C(e, e'p_0)$ experiment with results of a non-relativistic distorted-wave impulse approximation (DWIA). In this report, the reduced cross section is compared with theoretical calculations based on the relativistic distorted-wave impulse approximation (RDWIA) with and without MEC effects.

Recently the (e, e'p) and (γ, p) reactions have been investigated extensively in a fully relativistic DWIA (RDWIA) framework [2-8]. The relativistic calculations for the direct knock-out (DKO) mechanism appears to describe well measured (γ, p) cross sections in light nuclei at photon energies below 80 MeV, as well as the quasi-elastic (e, e'p) reaction. It means that the contribution of the MEC may not be large for the (γ, p) reaction in the relativistic framework. Actually, it was shown [8, 9] that the two-body contribution corresponding to the seagull term affects the (γ, p) cross section less than in non-relativistic calculations. The choice of the electromagnetic operator is a longstanding problem [7, 8]. Usually-used current-conserving operators (cc1, cc2, cc3) are equivalent each other for on-shell particles due to Gordon identity. However, for an off-shell nucleon, different choices of the prescriptions give very different (γ, p) cross sections.

In the plane-wave impulse approximation (PWIA) the (e, e'p) cross section can be factorized in the

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form;

$$\sigma_{e,e'p} \equiv \frac{d^3\sigma}{d\omega d\Omega_p d\Omega_p} = K\sigma_{e,p} S(E_m, p_m), \tag{1}$$

where K is a kinematic factor, and $\sigma_{e,p}$ is the off-shell electron-proton scattering cross section. In the PWIA the spectral function $S(E_m, p_m)$ is referred as a momentum distribution of the proton in the nucleus. From the measured coincidence cross section $\sigma_{e,e'p}$, the reduced cross section is defined by

$$\rho_{e,e'p}(p_m) = \frac{\sigma_{e,e'p}}{K\sigma_{e,p}}. \tag{2}$$

The reduced cross sections was obtained using the cc1 current [10]. The results with cc2 or cc3 currents are not different more than 2% from that with the cc1 prescription. The present data are compared with RDWIA calculations [11]. The RDWIA treatment is the same as in Refs. [7, 8]. The bound state wave function is calculated using parameters of the set NLSHT [12]. The relativistic bound state wave functions are solutions of a Dirac equation with scalar and vector potentials. The spectroscopic factor Z (p3/2) = 0.56 has been applied, which was obtained from the analysis [4] of the quasi-elastic (e, e'p_0) reaction. As the choice of the electromagnetic operator is, to some extent, arbitrary and no rigorous justification exists, three expressions (cc1, cc2, cc3) [7, 8, 10, 13] were used in the calculation in order to assess the effect. Figure 1 shows the calculations compared with the present data. The calculations overestimate the experimental data by about two times at low missing momenta. The enhancement factor is same to the (γ, p_0) reaction reported in Refs. [4, 6, 7]. A difference of the calculated results using different expressions of the current operator is larger than that in PWIA [10], and it becomes larger at high missing momenta. The measured cross section decreases a little slowly than the calculations with increasing missing momentum.

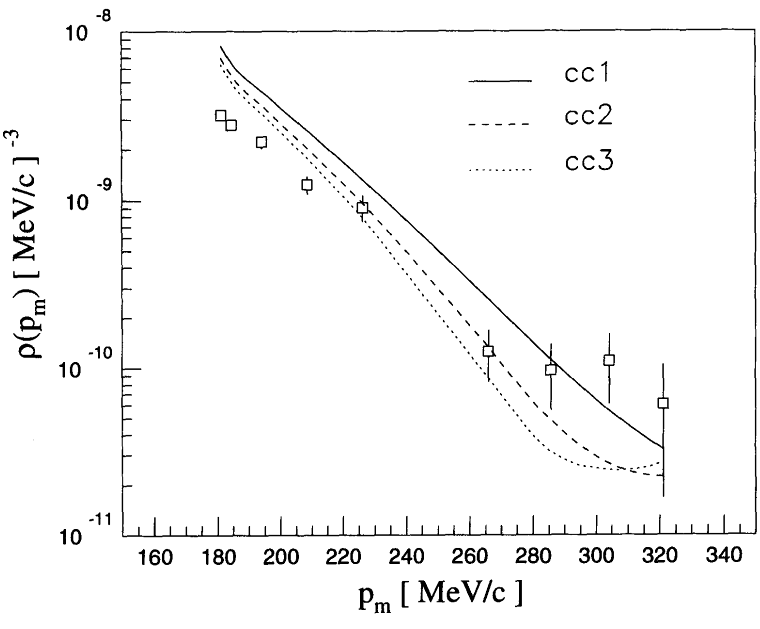

Fig.1. Reduced cross section of the present ^{12}C (e, e'p_0) measurement, compared with relativistic calculations including no MEC. Solid, dashed, and dotted lines represent the RDWIA results with cc1, cc2, and cc3 prescriptions for the one-body current, respectively.

In Fig.2 we compare the present data with the calculated results including the two-body seagull current [8, 14]. The calculations are multiplied by 0.5 in order to normalize them to the data at the lowest missing momentum. Although all of three calculations overestimate the data, the slope is similar to the data. The calculated result without the seagull term is also shown in Fig.2. It is clear that the calculation including the seagull term is in better agreement with the data at high missing momentums. The reduction factors for the cc2 and cc3 currents are almost same to that in the (γ, p_0) reaction. In the (γ, p_0) reaction the calculated result obtained with the cc1 current is enhanced above the data by an order of magnitude [7], while the overestimation is mild for the present (e, e'p_0) reaction. In the non-relativistic calculation for the (γ, p_0) reaction, a substantial reduction is obtained when the pion-in-flight diagram is added [8]. It is expected that the inclusion of the term may improve agreement between our data and calculations.

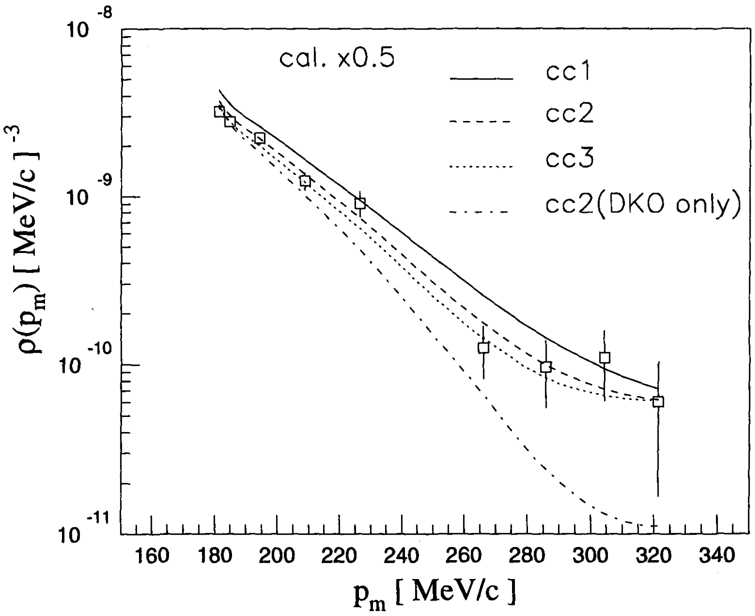

Fig.2. The reduced cross section compared with the RDWIA results calculated with the seagull contribution. Solid, dashed, and dotted lines represent the RDWIA result including the MEC, with cc1, cc2, and cc3 prescriptions for the one-body current, respectively. A dashed-dotted line shows the RDWIA result of the cc2 prescription without the MEC. Calculations are multiplied with a factor 0.5.

Any satisfactory theoretical model should simultaneously describe the (e, e'p) reaction in both of the quasi-elastic and low momentum transfer regions, and also (γ, p) and (γ, n) reactions. A consistent analysis of these reactions will disentangle the longstanding question about reaction mechanisms. The present investigation has firstly compared a relativistic calculation with the (e, e'p) reaction in the low momentum transfer region. The target nucleus of the present experiment, ^{12}C, is the one on which the RDWIA calculation overestimates the (γ, p_0) cross section at 60 MeV by a factor of 2. Obviously, successive investigations are needed on various nuclei such as ^{16}O and ^{40}Ca, for which the RDWIA calculation agrees well with the experiment in the (γ, p) reaction [4-9].

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