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Longitudinal-momentum and Coulomb effects in inclusive deuteron breakup on hydrogen and carbon

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Inclusive zero-angle deuteron breakup probes the deuteron wave function and the short-distance reaction mechanism. We present a unified Glauber–Sitenko multiple-diffraction description of the $H(d,p)X$ and $^{12}C(d,p)X$ spectra. The formulation develops the diffraction approach used in our work with A. P. Kobushkin [1] and continues the MSDT treatment of few-nucleon-cluster breakup, including diffractive triton dissociation by incident protons [2]. In addition to the longitudinal transfer Q_z, we explicitly retain a nonzero transverse relative momentum of the final pn pair in the antilaboratory system: $k_\perp = p_\perp - Q_\perp/2 \neq 0$, while $k_z = p_3^*$.

For $H(d,p)X$, retaining small Q_z and transverse relative momentum changes the height and position of the quasifree maximum. Calculations with the multigaussian K2, AV18, and Nijm-I wave functions show that this refinement is essential for quantitative comparison with the spectrum and provides a controlled nucleonic baseline at large $|k_z|$ [3].

For $^{12}C(d,p)X$, the same kinematics is supplemented by the proton–nucleus electromagnetic interaction, Coulomb–nuclear interference, and the Coulomb correction to double pn rescattering [4]. An analytical Coulomb phase is obtained for a finite charge distribution, with its scale fixed by the measured ^{12}C charge radius. To first order in the Sommerfeld parameter,

$$\mathrm{F}_{\mathrm{tot}} = F_{\mathrm{str}} + \Delta F_{Cp} + \Delta F_{Cpn} + O(\eta^2),$$

where ΔF_{Cp} corrects the proton line and ΔF_{Cpn} corrects double pn rescattering. Thus Coulomb–nuclear interference is retained, and the two-dimensional rescattering term is reduced to a one-dimensional radial integral, extending earlier Coulomb treatments of $A(d,p)X$ breakup [1].

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Figure 1. Results for $^{12}C(d,p)X$. Left panel: K2 wave function with $\sigma_{pN} = 390$ mb, $\beta_p = 1.22$ fm^{-1}, $\mu = 0.25$ fm, $a = 1$, $k_x = 10^{-4}$ GeV/c, and $Q_z = -2.5 \times 10^{-3}$ GeV/c. Right panel: Nijm-I wave function with $\sigma_{pN} = 350$ mb, $\rho_{pN} = 10^{-4}$, $p_d = 9.1$ GeV/c, $\beta_p = 2.19$ fm, $\mu = 10^{-6}$, $a = \alpha_L = 1$, $k_x = -0.26$ GeV/c, $k_y = 0$, and $Q_z = -2.5 \times 10^{-3}$ GeV/c. The calculated grid is $-0.10 \leq k_z \leq 0.25$ GeV/c with $\Delta k_z = 0.0125$ GeV/c. Therefore, $k_\perp = 0.26$ GeV/c and is nonzero in the antilaboratory system. Red curve: strong MSDT; green curve: MSDT with Coulomb; blue points: 2019 data [5].

Both the K2 and Nijm-I calculations show that Coulomb–nuclear interference increases the narrow quasifree peak and improves its normalization, while becoming small at 0.3–0.5 GeV/c. Thus, Q_z and $k_\perp$ govern the kinematic displacement and broadening, whereas the finite-size Coulomb interaction mainly renormalizes the low-momentum peak. This provides a baseline for final-state interactions and for relativistic refinements not included here: invariant flux and phase-space Jacobians; Lorentz boosts between the antilaboratory and final-pn center-of-mass frames; a covariant or light-front deuteron wave function with spin rotations; D-wave and nonnucleonic components.

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