Proton spectrum in the deuteron fragmentation reaction

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The optimum position of the light-front surface must be determined in a calculation of the amplitudes of nuclear reactions in light-front dynamics. Taking this circumstance into account makes it possible to reconcile the theoretical cross section for fragmentation of the deuteron with the experimental cross section {V. G. Ableev *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **37**, 196 (1983) [JETP Lett. **37**, 233 (1981)]; Nucl. Phys. **A393**, 491 (1983)} without adding to the deuteron wave function a term interpreted as a contribution of a six-quark state.

Albeev *et al.*[1] have carried out some precise measurements of the proton distribution function in the deuteron fragmentation reaction $d + A \to p(0^0) + X$ at a deuteron momentum of 8.9 GeV/c. Preliminary results for a momentum of 9.3 GeV/c were published in Ref. 2. Analysis of this reaction by the method of Ref. 3, which is based on the Glauber approximation, with allowance for relativistic effects in the deuteron in light-front dynamics,[4] shows that the cross section is proportional to the square of the deuteron wave function. At proton momenta $p > 5.2$ GeV/c (corresponding in the rest frame of the deuteron to the emission of protons with momenta $p^* > 200$ MeV/c at an angle of 180° with respect to the incident nucleus) it was found[1,2] that the experimental data are significantly higher (by as much as 200–300%) than the calculations with the standard deuteron wave functions (the dashed line in Fig. 1). This effect was interpreted in Refs. 1 and 2 as a manifestation of a six-quark component of the deuteron, while in Ref. 5 it was interpreted as an effect of a rescattering of a pion emitted in an NA interaction.

We would like to call attention to the circumstance that in an approximate solution of the problem in light-front dynamics the accuracy of the approximation in the relativistic region depends strongly on the position of the light-front surface, and when the theory is formulated in a system with an infinite momentum it also depends on the direction of this infinite momentum. Consequently, the position of the light-front surface must be determined from the condition for optimization of the approximation that is used.[6] In the present letter we show that allowing for this circumstance eliminates the discrepancy between theory and experiment in a region in which we can generally expect the approach of Ref. 3 to be valid.

According to Refs. 1–4, the cross section for fragmentation into an angle of 0° can be written

$$E_p \frac{d^3\sigma}{d^3p} \equiv \sigma(p,\omega) = C_d\, \sigma_{NA}^{in}\, m F(p) \frac{\psi^2(\mathbf{q})}{2(1-x)}, \tag{1}$$

where we have ^{12}C $C_d \cong \sigma_{dA}^{in}/\sigma_{dA}^{tot} = 0.54$, $\sigma_{NA}^{in} = 265$ mb, for the ^{12}C nucleus. The function $F(p) = R_2(p)/R_2(p_d/2)$ reflects the vanishing of the phase volume $R_2(p)$ of

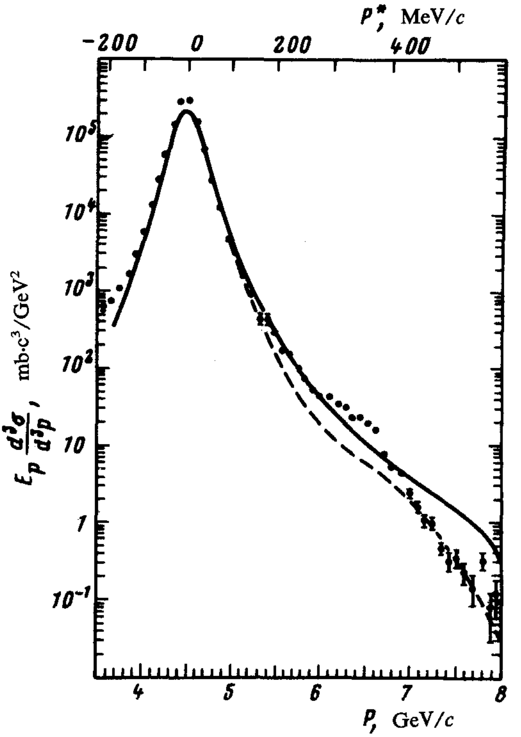

FIG. 1.

the ^{12}C nucleus and of the neutron at the kinematic boundary of the proton momentum. The analytic form of $F(p)$ differs from that in Refs. 1 and 2, but numerically the difference is not great. Relativistic effects are taken into account in the argument and normalization of the wave function in a very simple way in expression (1), in accordance with Refs. 1, 2, and 4. The square of the argument of the wave function (for $\mathbf{p}_\perp = 0$) is

$$\mathbf{q}^2 = \frac{m^2}{4x(1-x)} - m^2 . \tag{2}$$

The wave function in (1) is normalized by

$$m \int \psi^2(\mathbf{q}) \frac{d^3q}{E_q} = m \int \frac{\psi^2(\mathbf{q})}{2(1-x)} \frac{d^3p}{E_p} = 1. \tag{3}$$

We will identify $\psi(\mathbf{q})$ with the Paris wave function[1)] (Ref. 7).

For x it is convenient to use the invariant expression[8]

$$x = \omega p / \omega p_d , \tag{4}$$

where ω is a 4-vector which specifies the surface of the light front, $\omega_0 t - \vec{\omega}\,\mathbf{x} = 0$ ($\omega^2 = 0$), on which the wave function is defined. In the formulation of the theory of an infinite-momentum system, the unit vector $\vec{\omega}/\omega_0$ specifies the direction of motion of the infinite-momentum system (the observer is moving in this direction). The calculations in Refs. 1, 2, and 4 were carried out with $\vec{\omega}\| -\mathbf{p}_d$ in the laboratory frame, corresponding to the following value of x:

$$x = \frac{E_p + |\mathbf{p}|}{E_d + |\mathbf{p}_d|} . \tag{5}$$

It can be seen from Eqs. (1)–(4) that the cross section in (1) depends explicitly on the 4-vector ω. This dependence reflects, in particular, the contribution of many-particle intermediate states, which has been ignored. Clearly, the exact amplitude depends on only the 4-momenta of the particles and cannot depend on ω. The exact cross section can therefore be written

$$\sigma^{\text{exact}}(p) = \sigma(p, \omega) + \Delta\sigma(p, \omega), \tag{6}$$

where $\sigma^{\text{exact}}(p)$ does not depend on ω, and $\sigma(p,\omega)$ is given by (1). Restricting the discussion to the contribution $\sigma(p,\omega)$, we need to determine ω (i.e., express ω in terms of the 4-momenta of the particles) in order to minimize the contribution $\Delta\sigma(p,\omega)$, which is ignored here. A direct analysis of the functional dependence of $\Delta\sigma(p,\omega)$ on ω is possible only in the case of very simple mechanisms.[6] In the case at hand, in contrast, we are forced to draw conclusions about the dependence of $\Delta\sigma(p,\omega)$ on ω from the behavior of $\sigma(p,\omega)$ [under the condition that we know the sign of $\Delta\sigma(p,\omega)$]. Comparison of results calculated from Eqs. (1), (2), and (5) (the dashed curve in Fig. 1) with the data of Ref. 1 reveals $\Delta\sigma > 0$. Consequently, a minimum of $\Delta\sigma$ corresponds to a maximum of the cross section $\sigma(p,\omega)$. It is easy to verify that the maximum value of $\sigma(p,\omega)$ is reached in the case $\vec{\omega}\|\mathbf{p}_d$. For the ω we find from (4) an expression different from (5):

$$x = \frac{E_p - |\mathbf{p}|}{E_d - |\mathbf{p}_d|} . \tag{7}$$

The solid line in Fig. 1 is calculated from Eqs. (1), (2), and (7). At $p < 6.9$ GeV/c ($p^* < 0.42$ GeV/c) the results of this calculation agree with both the experimental data and the calculations of Ref. 1, which incorporate a $6q$ admixture in the deuteron. The points in the "overflow" in the interval $p = 6$–6.7 GeV/c were not used in the determination of the $6q$ admixture in Ref. 1. There was no such overflow in Ref. 2. At $p > 6.9$ GeV/c we find a discrepancy between theory and experiment, but in this region, near the kinematic boundary, the Glauber approximation is not applicable (the neutron momentum tends toward zero, off-shell effects intensify, and the mechanism of Ref. 5 comes into play). At the kinematic boundary as $\mathbf{p}_d \to \infty$, $\mathbf{p} \to \infty$ we formally find the following limiting values from (7) and (2): $x = 1/4$ and $q = m/\sqrt{3}$. Since expression (1) obviously does not apply near the kinematic boundary, we should not interpret these values as fundamental limits on the momenta of the nucleons coming from the deuteron in the fragmentation reaction.

We wish to emphasize that although ω has been determined by fitting the data of Ref. 1 in this case, the 4-vector ω is not an adjustable parameter, since the uncertainty which we are discussing here is exclusively a matter of a double-valuedness of ω. The source of the uncertainty [aside from the corrections of (1)] might be the extrapolation of the nonrelativistic wave function into the relativistic region. However, it was shown in Refs. 9 that incorporating relativistic effects in light-front dynamics with the Paris wave function[7] in the reaction *ed*→*enp* (with a suitable definition of ω, based in this case on theoretical considerations) also eliminates the discrepancy between theory and experiment. The wave function can thus be assumed to have been determined from the reaction *ed*→*enp*.

All the experimental data on the electrodisintegration and fragmentation of the deuteron can thus be described in a common way in light-front dynamics. We perceive the data of Ref. 1 as an important independent confirmation that the Paris wave function does in fact describe the two-nucleon sector in the deuteron in the relativistic region. It would be interesting to reproduce this entire empirical wave function (rather than make corrections to it) in the quark approach with a $6q$ admixture in the deuteron.

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[1)]We think it would be more systematic to not introduce a factor of E_q/m in expression (1) (in contrast with the approach of Refs. 1, 2, and 4), while retaining it in normalization integral (3).

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