$D(e,ep)N^*$ Reaction and the NN^*-Structure of the Deuteron

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Abstract

The differential cross section of the D(e,ep)N* reaction has been calculated in the framework of spectator mechanism using Light Front Dynamics (LFD). It has been shown that the p-wave behaviour of momentum distribution of N* isobar of negative parity in the deuteron expected in nonrelativistic approximation does not appear in the relativistic approach . The contribution of deexcitation processes $eN^* \rightarrow ep$ into cross section is negligible in comparison with $ep \rightarrow ep$ transitions.

1. Introduction

The presence of excited six quark configurations in the deuteron established by microscopic calculations in 6q-dynamics [1] results in the admixture of NN^* and N^*N^* components in the deuteron wave function [2]. So, the genealogical expansion of s^4p^2 configuration wave function

$$|s^4p^2>= C_{NN}|s^3>|s^3>\varphi_{2S} + C_{N^{**}N}|sp^2>|s^3>\varphi_{0S}+$$
$$C_{N^*N}|s^2p>|s^3>\varphi_{1P} + C_{N^*N^*}|s^2p>|s^2p>\varphi_{0S} + \ldots \quad (1)$$

determines relative motion in the channels $D \rightarrow N^* + N^*$ and $D \rightarrow N^{**} + N$ as s-wave type and in the $D \rightarrow N^* + N$ channel as p-wave one. Here φ_{nS} and φ_{1P} are the wave functions of relative motion of three- quark clusters, $|s^3>$ is the nonexcited nucleon state, $|s^2p>$ is the negative parity nucleon state (N* isobar), $|sp^2>$ is the positive parity state (N**), C_{BB} is the corresponding genealogical coefficient. It was suggested in Ref.[1] to use the quasi-elastic knock-out reaction $D(e,ep)N^*$ as experimental test of this picture by analogy with physics of excited nucleon clusters in atomic nuclei and corresponding spectroscopic factors $S_D^{NN^*}$ were calculated .

However, there is an essential difference between the reaction under discussion and ordinary nonrelativistic nuclear physics problems of excited nucleon clusters [3]. It is caused by large binding energy in the channel $D \rightarrow N + N^*$ which is comparable with nucleon mass ,i.e. ε=500-600 MeV. In this case one has to use a relativistic approach instead of Shcrödinger equation even at low momenta of spectator [4].

In [5] an analysis of relativistic structure factors $D \to N + N^*$ for the $D(e,ep)N^*$ reaction was performed. Two different approaches were used - the Light Front Dynamics (LFD) without angular condition (i.e. Infinite Momentum Frame approach) Ref.[6] and Faddeev type relativistic equations for the three-body problem [7]. The problem of deriving electromagnetic current for composite system in relativistic dynamics is not solved in general case at present. Therefore these two approaches give some estimation for relativistic effects in the desintegration reaction $D(e,ep)N^*$ only. In the limit of high energies $\sqrt{s} \to \infty$ both approaches give the same results, but at intermediate energies they are different. In this work we use the LFD approach in order to estimate the differential cross section of the reaction because in this approach the matrix elements of *ep*- and *eN*-interaction potentials are direct related to corresponding differential cross section of *ep*- and *eN*-scatterings.

2. Elements of Formalism

In the one-photon approximation the spin overaged square of the amplitude is

$$\overline{|M(eD \to epN^*)|^2} = \frac{e^2}{q^4} L_e^{\mu\nu} L_{\mu\nu}^h, \tag{2}$$

where

$$L_{\mu\nu}^h = \frac{1}{2J_D + 1} \sum_{\lambda_D \lambda_p \lambda_N} J_\mu^h \left(J_\nu^h\right)^* \tag{3}$$

is the hadronic tensor, J_μ^h is the hadronic electromagnetic current for $D \to N + N^*$ transition. $L_e^{\mu\nu}$ is the well known leptonic tensor ($e^2 = 1/137$). Here λ_j is the helicity of the j-th particle, J_D is the deuteron angular momentum. In order to construct the current J_μ^h we use the one particle approximation for the six-quark model of the deuteron in the LFD approach. The "+" component of the electromagnetic current has a form

$$J_+^h = (2\pi)^3 \delta^{(2)}(\mathbf{p}_{D\perp} + \mathbf{q}_\perp - \mathbf{p}_{N\perp} - \mathbf{p}_{p\perp}) \delta(p_{D-} + q_- - p_{N-} - p_{p-}) \sum_{p'\lambda_p'} \frac{p_{D-}}{p_{p-}}$$

$$\times \Psi_{\lambda_D}^{\lambda_p' \lambda_N}(\mathbf{k}_\perp, \xi) 2p_{p-} < p\lambda_p(\mathbf{p}) | j_+^N(p' \to p) | p'\lambda_p'(\mathbf{p}') >, \tag{4}$$

here p_{i-} and $\mathbf{p}_{\mathbf{i}\perp}$ are the "-" and transversal components of the 4-momentum of the i-th particle, respectively; $\mathbf{k}_\perp$ and $\xi = p_{N-}/p_{D-}$ are the internal light-cone variables of the deuteron and $\Psi(\mathbf{k}_\perp, \xi)$ is its internal wave function, j_+^N is the "+"-component of nucleon electromagnetic current for the $p' \to p$ transition. The summation on internal states of nucleon p' (including N^*, N^{**}) takes the place in Exp.(4). The deuteron wave function $\Psi_{\lambda_D}^{\lambda_p' \lambda_N}$ is constructed in the LFD on the base of Melosh transformation for the canonical wave function Ψ_D^c which corresponds to the nonrelativistic scheme of angular momenta composition [8]

$$\Psi_{\lambda_D}^{\lambda'_p\lambda N}(\mathbf{k}_\perp,\xi) = \sum_{\lambda_1\lambda_2} < \lambda_N|R_M^+(\xi,\mathbf{k}_\perp,m_N)|)\lambda_1 >< \lambda_p|R_M^+(1-\xi,-\mathbf{k}_\perp,m_p)|\lambda_2 >$$

$$\times\Psi_{\lambda_D}^c(\mathbf{k},\lambda_1,\lambda_2). \qquad (5)$$

In the quasi-elastic peak region $p_N^* \le 0.3-0.4$ GeV/c, where p_N^* is the N^* spectator momentum in the lab. system, the hadronic tensor $L_{\mu\nu}^h$ can be presented in the separable form

$$L_{\mu\nu}^h = \frac{2J'_p+1}{4\pi}\left(\frac{1}{1-\xi}\right)^2\varphi_{nl}^2(k)L_{\mu\nu}^N, \qquad (6)$$

where $L_{\mu\nu}^N$ is the nucleon tensor corresponding to the $ep'\to ep$ transition,J'_p is the angular momentum of intermediate nucleon p'. The radial wave function $\varphi_{nl}(k)$ is normalized according to

$$\frac{1}{2J_D+1}\sum_{\lambda_D\lambda_p\lambda_N}\int\frac{d^2\mathbf{k}_\perp d\xi}{(2\pi)^3 2\xi(1-\xi)}|\Psi_{\lambda_D}^{\lambda_N\lambda_p}(\mathbf{k}_\perp,\xi)|^2$$

$$= N_S\int_0^\infty\frac{\epsilon_p(k)+\epsilon_N(k)}{2\epsilon_p(k)\epsilon_N(k)(2\pi)^3}\varphi_{nl}^2(k)k^2dk = S_D^{pN}, \qquad (7)$$

where $\epsilon_i(k) = \sqrt{\mathbf{k}^2+m_i^2}$, S_D^{pN} is the deuteron spectroscopic factor in corresponding channel. In order to calculate the $L_{\mu\nu}^h$ we take the current $J^N(p'\to p)$ in Exp.(4) in the same form as for the free processes $eN(1/2^+)\to ep(1/2^+)$ and $eN^*(1/2^-)\to ep(1/2^+)$ [9,10]. Keeping one term in the summation on p' in Exp.(4) we have the following form for the differential cross section of the $D(e,ep)N^*$ reaction in the lab. system

$$\frac{d^5\sigma}{dE_e d\Omega_e d\Omega_p} = \frac{(2J'_p+1)}{64(2\pi)^6 m_D}\frac{\mathbf{p}_p^2}{|R_o|\mathbf{p}_p|-|\mathbf{R}|E_p\cos\theta_{\mathbf{pR}}|}\left(\frac{1}{1-\xi}\right)^2$$

$$\times\varphi_{nl}^2(k)\overline{|M(ep'\to ep)|^2}. \qquad (8)$$

Here$\overline{|M(ep'\to ep)|^2}$ is the spin overaged amplitude square for the free reaction $ep'\to ep$ [11], $R_0 = E_0+m_D-E_e$, $\mathbf{R} = \mathbf{p}_0-\mathbf{p}_e$; E_p and $\mathbf{p}_p$ are the energy and momentum of final proton, $E_p,\mathbf{p}_0$ and $(E_e,\mathbf{p}_e)$ are the same for initial (final) electron. Because of energy nonconservation in the quasi free process $ep'\to ep$ the post- and prior- forms of kinematic are different but in the LFD approach this difference goes to zero at $\sqrt{s}\to\infty$. We use the post form. In order to suppress the $N\overline{N}$-pair creation from vacuum it is sufficiently to take the following condition [4,10]

$$q^+ = 0 \qquad (9)$$

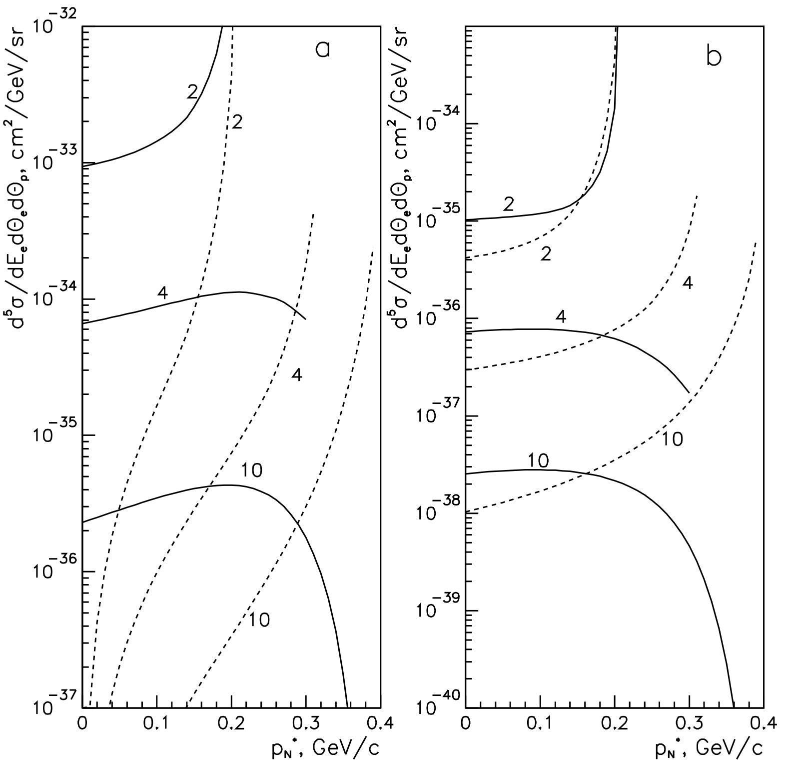

Figure 1: The calculated differential cross section $d^5\sigma/dE_e d\Omega_e d\Omega_p$ of the $D(e,ep)N^*$ $(1/2^-, 1535)$ reaction at the scattering angles $\vartheta_e = 37^o$ and $\vartheta_N = 127^o$ as a function of the N^*-spectator momentum p_N^* in the laboratory system in the LFD approach (—) and nonrelativistic one (− − −−): a -the contribution of the $ep \to ep$ transition, b - the contribution of deexcitation processes $eN^* \to ep$. The numbers near the curves are the initial energies in GeV.

(q is the 4-momentum transferred by electron). According to [4] we take the oz-axis direction on the surface of the cone Exp.(9) in such a way to obtain the minimum for the k^2 value. This prescription is not consistent in the LFD approach and it used here as an approximation for the spectator mechanism. There is not ambiguity for the z-axis direction at the point $p_N^* = 0$.

3. Results and Discussion

Numerical calculations are performed at initial energies of 4 -10 GeV in complanar kinematic with backward going N^*-isobar in the final state. The photon absorption on virtual N^*-isobar ($\gamma N^* \to \gamma N^*$) omitted in Exp.(4) is suppressed in this kinematic. The relativistic bound state problem $D = p + N^*$ has been solved in this work in order to find the wave functions $\varphi_{nl}(k)$. Deep attractive potentials for the NN^* interaction are used according to [12]. The results of numerical calculations for transitions onto the $N^*(1/2^-, 1535)$ state are shown in Fig.1. One can see from Fig.1,a that relativistic results differ from nonrelativistic ones drastically. Namely, the p-wave character of momentum distribution in the channel $D \to p + N^*$ does not appear in the LFD approach. It follows from Fig.1,b, that in the LFD approach the contribution of deexcitation processes $eN^* \to ep$ is smaller by 3 order of magnitude in comparison with that for the $ep \to ep$ processes. According to the nonrelativistic predictions of Ref.[1] these contributions are comparable one with other. Such considerable difference between relativistic and nonrelativistic results can be explained by the following way. It follows from the LFD conservation lows $\mathbf{p}_{D\perp} = \mathbf{p}_{p\perp} + \mathbf{p}_{N\perp}$ and $p_{D-} = p_{p-} + p_{N-}$ that at the point $p_N^* = 0$ the intermediate proton p' has non-zero z-component of its momentum

$$p_z = \frac{m_{p'}^2 - (m_D - m_N)^2}{2(m_D - m_N)}. \tag{10}$$

From Exp.(10) we have $p_z = 1.1$GeV/c for the $D \to p + N^*$ transition ($m_p' = 0.94$ MeV) and $p_z = 3.2$GeV/c for the $D \to N^* + N^*$ transition ($m_p' = m_N = 1.5$GeV). As a result the argument in the wave function $\varphi_{nl}(k)$ is k=0.54 GeV/c and k=1 GeV/c for the processes $ep \to ep$ and $eN^* \to ep$, respectively instead of nonrelativistic value $k = p_N^* = 0$.

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