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Exclusive neutrino production of a charmed vector meson and transversity gluon generalized parton distributions

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We calculate at the leading order in α_s the QCD amplitude for exclusive neutrino production of a D^* or D_s^* charmed vector meson on a nucleon. We work in the framework of the collinear QCD approach where generalized parton distributions (GPDs) factorize from perturbatively calculable coefficient functions. We include $O(m_c)$ terms in the coefficient functions and the $O(m_D)$ term in the definition of heavy meson distribution amplitudes. The show that the analysis of the angular distribution of the decay $D^*_{(s)} \to D_{(s)}\pi$ allows us to access the transversity gluon GPDs.

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I. INTRODUCTION

The now well-established framework of collinear QCD factorization [1–3] for exclusive reactions mediated by a highly virtual photon in the generalized Bjorken regime describes hadronic amplitudes using generalized parton distributions (GPDs) which give access to a three-dimensional analysis [4] of the internal structure of hadrons. Neutrino production is another way to access (generalized) parton distributions [5–7]. Although neutrino induced cross sections are orders of magnitude smaller than those for electroproduction and neutrino beams are much more difficult to handle than charged lepton beams, they have been very important to scrutinize the flavor content of the nucleon, and the advent of new generations of neutrino experiments will open new possibilities.

In Ref. [7], we showed that exclusive neutrino production of a charmed scalar D^+ meson allows us to access the transversity chiral-odd quark GPDs. In this paper, we complement that study and consider the exclusive production of a vector $D^*(2010)$ or $D_s^*(2112)$ meson through the reactions

$$\nu_l(k)p(p_1,\lambda) \to l^-(k')D^{*+}(p_D,\varepsilon_D)p'(p_2,\lambda'), \quad (1)$$

$$\nu_l(k)n(p_1,\lambda) \to l^-(k')D^{*+}(p_D,\varepsilon_D)n'(p_2,\lambda') \quad (2)$$

in the kinematical domain where collinear factorization leads to a description of the scattering amplitude in terms of gluonic [8] GPDs and the D^*- or D_s^*-meson distribution amplitude, with the hard subprocess ($q=k-k', Q^2=-q^2$),

$$W^+(q)g \to D^{*+}g, \quad (3)$$

described by the handbag Feynman diagrams of Fig. 1.

Here, we show that neutrino production of D^* mesons may help to measure the gluon transversity GPDs, the phenomenology of which is presently restricted to angular asymmetries in deeply virtual Compton scattering (DVCS) [9], which turn out to be quite difficult to access experimentally. The charmed vector meson $D^*(2010)$ has been produced and studied in deep inelastic electroproduction at HERA [10]. Its main decay channel is known to be

$$D^*(2010) \to D(1870)\pi, \quad (4)$$

and we will demonstrate that one may use the angular distribution of the final pion to disentangle various helicity amplitudes for D^* production. The case of $D_s^*(2112)$ is also interesting. It was already stressed by Ref. [5] that the amplitude for $D_s(1968)$-neutrino production is enhanced by the large value of the Cabibbo-Kobayashi-Maskawa (CKM) matrix element V_{sc} and is dominated by the contribution of gluon GPDs; its main decay channel is

$$D_s^*(2112) \to D_s(1968)\gamma, \quad (5)$$

but it turns out to be more difficult to use this decay channel to disentangle various helicity amplitudes.

II. D^*- AND D_s^*-MESON DISTRIBUTION AMPLITUDES

In the collinear factorization framework, the hadronization of the quark-antiquark pair is described by a distribution amplitude (DA) which obeys a twist expansion and evolution equations. Much work has been devoted to this subject [11]. The charmed meson distribution amplitudes are less known than the light meson ones. Here, we shall restrict ourselves to a leading twist description of the D^*-meson DA but including the M_D term in the definition of the correlator. Omitting the path-ordered gauge link, the relevant distribution amplitudes read for the D^* vector meson case in the longitudinal or transverse polarization state

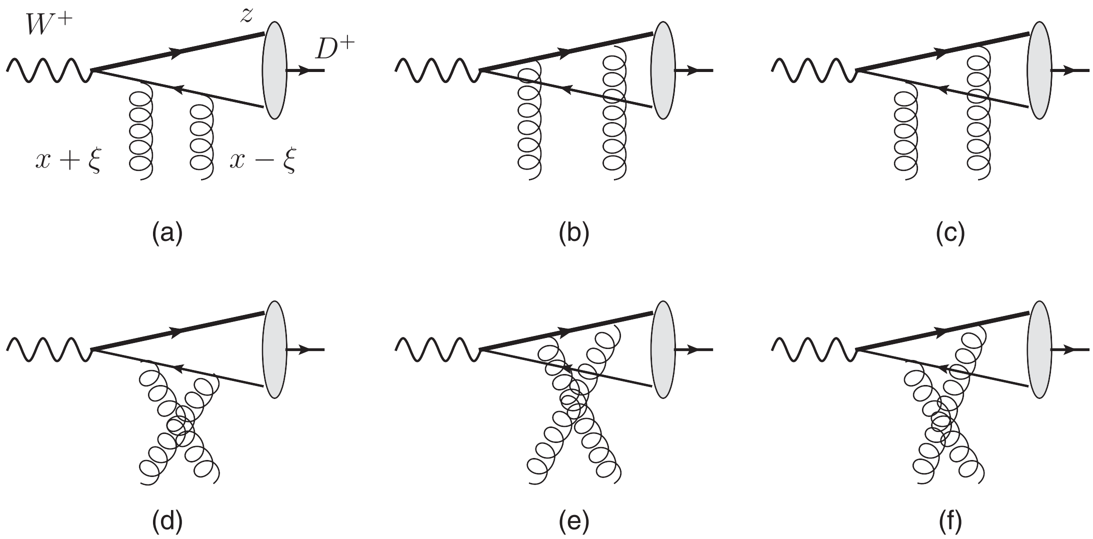

FIG. 1. Feynman diagrams for the factorized amplitude for the $W^+N \to D^{*+}N'$ process involving the gluon GPDs; the thick line represents the heavy quark. The three other diagrams are obtained through the transformation $(x \to -x; \mu \to \nu)$.

$$\langle D^{*+}(P_D, \varepsilon_L)|\bar{c}_\beta(y)d_\gamma(-y)|0\rangle = \frac{f_L}{4}\int_0^1 dz e^{i(z-\bar{z})P_D\cdot y}[\hat{P}_D - M_D]_{\gamma\beta}\phi_D(z), \quad (6)$$

$$\langle D^{*+}(P_D, \varepsilon_T)|\bar{c}_\beta(y)d_\gamma(-y)|0\rangle = \frac{f_T}{4}\int_0^1 dz e^{i(z-\bar{z})P_D\cdot y}[(\hat{P}_D - M_D)\hat{\varepsilon}_T]_{\gamma\beta}\phi_D(z), \quad (7)$$

where $\int_0^1 dz\phi(z) = 1$. It has been argued that a heavy-light meson DA is strongly peaked around $z_0 = \frac{m_c}{M_D}$. We will parametrize $\phi_D(z)$ in a very crude way, i.e. $\phi_D(z) = \delta(z - \frac{m_c}{M_D})$.

III. TRANSVERSITY GLUON GPDS

The four transversity gluon GPDs are defined in Ref. [12] as

$$-\frac{1}{P^+}\int \frac{dz^-}{2\pi} e^{ixP^+z^-}\langle p', \lambda'|\mathbf{S}F^{+i}\left(-\frac{1}{2}z\right)F^{+j}\left(\frac{1}{2}z\right)|p, \lambda\rangle\Big|_{z^+=0, \mathbf{z}_T=0}$$
$$= \mathbf{S}\frac{1}{2P^+}\frac{P^+\Delta^j - \Delta^+P^j}{2mP^+}\bar{u}(p', \lambda')\left[H_T^g i\sigma^{+i} + \tilde{H}_T^g\frac{P^+\Delta^i - \Delta^+P^i}{m^2} + E_T^g\frac{\gamma^+\Delta^i - \Delta^+\gamma^i}{2m} + \tilde{E}_T^g\frac{\gamma^+P^i - P^+\gamma^i}{m}\right]u(p, \lambda), \quad (8)$$

where $\mathbf{S}$ is an operator that symmetrizes a tensor and subtracts its trace: $\mathbf{S}t^{ij} = (t^{ij} + t^{ji})/2 - \delta^{ij}/2 * t^{kk}$. $\mathbf{S}$ may be written with the help of the $\tau^\perp_{\mu\nu;\rho\sigma}$ tensor defined as

$$\tau^\perp_{\mu\nu;\rho\sigma} = \frac{1}{2}[g^\perp_{\mu\rho}g^\perp_{\nu\sigma} + g^\perp_{\mu\sigma}g^\perp_{\nu\rho} - g^\perp_{\mu\nu}g^\perp_{\rho\sigma}], \quad (9)$$

which appears in the Fierz decomposition of the Lorentz structure describing the two transverse gluons entering the coefficient function

$$g^\perp_{\mu\mu'}g^\perp_{\nu\nu'} = \frac{1}{2}g^\perp_{\mu\nu}g^\perp_{\mu'\nu'} + \frac{1}{2}\epsilon^\perp_{\mu\nu}\epsilon^\perp_{\mu'\nu'} + \tau^\perp_{\mu\nu;\rho\sigma}\tau^\perp_{\mu'\nu';\rho\sigma}. \quad (10)$$

As is obvious from Eq. (8), these transversity GPDs always appear accompanied by a factor Δ_T (at least) in an amplitude. To be consistent with the collinear factorization procedure, we calculate the coefficient function at zero Δ_T. When computing a hadronic cross section, we restrict to lowest order in Δ_T, which means that we neglect all Δ_T effects in the definition of the polarization of the produced vector meson and in the definition of its decay angles.

There is no known parametrization for the four transversity gluon GPDs [13], and we shall not propose here a model for them. Since they do not have a forward nonzero limit, they cannot easily be constructed from a double distribution ansatz. Some inequalities have been derived [14] based on positivity constraints [15].

IV. SCATTERING AMPLITUDE

A. Kinematics

Our kinematical notations are as follows (m and M_D are the nucleon and D^*-meson masses),

$$q = k - k'; \qquad Q^2 = -q^2; \qquad P = \frac{p_1 + p_2}{2};$$
$$\Delta = p_2 - p_1; \qquad \Delta^2 = t;$$
$$p_1^\mu = (1+\xi)p^\mu + \frac{1}{2}\frac{m^2}{1+\xi}n^\mu;$$
$$p_2^\mu = (1-\xi)p^\mu + \frac{1}{2}\frac{m^2 - \Delta_T^2}{1-\xi}n^\mu + \Delta_T^\mu;$$
$$q^\mu = -2\xi' p^\mu + \frac{Q^2}{4\xi'}n^\mu;$$
$$p_D^\mu = 2(\xi - \xi')p^\mu + \frac{M_D^2 - \Delta_T^2}{4(\xi - \xi')}n^\mu - \Delta_T^\mu, \tag{11}$$

with $p^2 = n^2 = 0$ and $p.n = 1$. Momentum conservation leads to the relation

$$\frac{Q^2}{\xi'} - \frac{2(m^2 - \Delta_T^2)}{1-\xi} = \frac{M_D^2 - \Delta_T^2}{\xi - \xi'}. \tag{12}$$

As in the double deeply virtual Compton scattering case [16], it is meaningful to introduce two distinct momentum fractions:

$$\xi = -\frac{(p_2 - p_1).n}{2}, \qquad \xi' = -\frac{q.n}{2}. \tag{13}$$

Neglecting the nucleon mass and Δ_T, the approximate values of ξ and ξ' are

$$\xi \approx \frac{Q^2 + M_D^2}{4p_1.q - Q^2 - M_D^2}, \qquad \xi' \approx \frac{Q^2}{4p_1.q - Q^2 - M_D^2} \tag{14}$$

so that $\frac{Q^2}{\xi'} = \frac{Q^2+M_D^2}{\xi}$. We note $\kappa = p\cdot p_D = \frac{M_D^2}{4(\xi-\xi')} = \frac{M_D^2+Q^2}{4\xi}$.

B. Coefficient function

The coefficient function is calculated from the Feynman diagrams of Fig. 1 (the three diagrams (d, e, and f) are obtained from (a, b, and c) by a $(x \to -x; \mu \to \nu)$ operation. Since we use a simple $\delta(z - m_c/M_D^*)$ form for the D^* distribution amplitude, we put $z = m_c/M_D^*$ to simplify these coefficient functions.

1. Diagrams a and d

The vector part of the diagrams of Fig. 1 (a and d) contributes to the longitudinal amplitude and produces a longitudinally polarized D^* meson,

$$G_L^{ad} = \frac{-8M\bar{z}[\epsilon_D\cdot\epsilon_W(\kappa(x-3\xi)+M^2\bar{z})+2\xi(x+\xi)p\cdot\epsilon_D p\cdot\epsilon_W]}{D_1(x,\xi)D_2(x,\xi)} + (x\to -x). \tag{15}$$

It also contributes to the transverse amplitude producing a transversally polarized D^* meson,

$$G_T^{ad} = \frac{-8M\bar{z}\epsilon_D\cdot\epsilon_W(\kappa(x-3\xi)+M^2\bar{z})}{D_1(x,\xi)D_2(x,\xi)} + \{x\to -x\}, \tag{16}$$

and to the transverse scattering amplitude via the ϵ^{ijpn} part of the coefficient function, which is convoluted with $\tilde{H}$ and $\tilde{E}$ gluon GPDs,

$$\tilde{G}_T^{ad} = \frac{-8M\bar{z}\epsilon^{np\epsilon_D\epsilon_W}(M^2\bar{z}+\kappa(x-3\xi))}{D_1(x,\xi)D_2(x,\xi)} - \{x\to -x\}. \tag{17}$$

The axial part [17] of the diagrams of Fig. 1 (a and d) contributes with the $H(x,\xi)$ and $E(x,\xi)$ GPDs to the transverse amplitude and gives

$$G_{5T}^{ad} = \frac{8iM\bar{z}\kappa(x+\xi))\epsilon^{pn\epsilon_D\epsilon_W}}{D_1(x,\xi)D_2(x,\xi)} + \{x\to -x\}. \tag{18}$$

It also contributes with the $\tilde{H}(x,\xi)$ and $\tilde{E}(x,\xi)$ GPDs to the longitudinal amplitude

$$\tilde{G}_{5L}^{ad} = \frac{8iM\bar{z}p\cdot\epsilon_W p\cdot\epsilon_D(M^2(\xi - x - 2\xi z) + 4\kappa\xi(x-\xi))}{\kappa D_1(x,\xi)D_2(x,\xi)} - \{x\to -x\} \tag{19}$$

and to the transverse amplitude

$$\tilde{G}_{5T}^{ad} = \frac{8iM_D\bar{z}\kappa(x+\xi)\epsilon_D\cdot\epsilon_W}{D_1(x,\xi)D_2(x,\xi)} - \{x\to -x\}. \tag{20}$$

2. Diagrams b and e

The vector part of Fig. 1 (b and e) gives a contribution to the longitudinal amplitude,

$$G_L^{be} = -16\frac{\kappa zM(x-\xi)\epsilon\cdot\epsilon_W}{D_3(x,\xi)D_4(x,\xi)} + \{x\to -x\}, \tag{21}$$

and to the transverse amplitude,

$$G_T^{be} = -16\frac{\kappa zM(x-\xi)\epsilon\cdot\epsilon_W}{D_3(x,\xi)D_4(x,\xi)} + \{x\to -x\}, \tag{22}$$

but not to the transverse scattering amplitude via the ϵ^{ijpn} part of the coefficient function, which is convoluted with $\tilde{H}$ and $\tilde{E}$ gluon GPDs,

$$\tilde{G}_T^{be} = \frac{16\kappa Mz(\xi - x)\epsilon^{np\epsilon\epsilon_W}}{D_3(x,\xi)D_4(x,\xi)} - \{x\to -x\} = 0. \tag{23}$$

The axial part of Fig. 1 (b and e) gives a zero contribution to the amplitude.

3. Diagrams c and f

The vector part of Fig. 1 (c and f) gives a contribution to the longitudinal amplitude,

$$G_L^{cf} = -\frac{4M(x-\xi)p\cdot\epsilon_W(p\cdot\epsilon_D(-M^2\bar{z}+4\kappa(x+\xi))+2\kappa^2\bar{z}n\cdot\epsilon_D)}{\kappa D_4(x,\xi)D_2(-x,\xi)} + \{x\to -x\}, \tag{24}$$

and to the transverse-transverse (TT) amplitude (to be convoluted with transversity GPDs),

$$G_\tau^{cf} = 4\kappa M(x-\xi)\bar{z}\frac{\epsilon_W^\alpha\epsilon^\beta+\epsilon^\alpha\epsilon_W^\beta-g_T^{\alpha\beta}\epsilon\cdot\epsilon_W}{D_4(x,\xi)D_2(-x,\xi)} + \{x\to -x\}, \tag{25}$$

but not to the transverse amplitude,

$$G_T^{cf} = 0. \tag{26}$$

Moreover, it does not give any contribution to the ϵ^{ijpn} part of the amplitude which is convoluted with $\tilde{H}$ and $\tilde{E}$ gluon GPDs.

$$\tilde{G}_T^{cf} = 0. \tag{27}$$

The axial part of Fig. 1 (c and f) convoluted to the $\tilde{H}$ and the $\tilde{E}$ GPDs gives a contribution to the longitudinal amplitude,

$$\tilde{G}_{5L}^{cf} = -\frac{8iM(x-\xi)p\cdot\epsilon_D p\cdot\epsilon_W(-M^2\bar{z}+2\kappa(x+\xi))}{\kappa D_4(x,\xi)D_2(-x,\xi)} - \{x\to -x\}. \tag{28}$$

It does not give any contribution to the transverse amplitude. Its contribution to the transversity GPD part of the TT amplitude reduces after using the fact that only the symmetric part in (α,β) contributes, to

$$G_{5\tau}^{cf} = \frac{-4iM\kappa\bar{z}(x-\xi)(\epsilon_D^\alpha\epsilon^{\beta pn\epsilon_W}+\epsilon_W^\beta\epsilon^{\alpha pn\epsilon_D})}{D_4(x,\xi)D_2(-x,\xi)} + \{x\to -x\}. \tag{29}$$

The denominators of the quark propagators are given by

$$\begin{aligned} D_1(x,\xi) &= -\bar{z}[zM_D^2+Q^2]+i\epsilon,\\ D_2(x,\xi) &= \bar{z}(Q^2+M_D^2)\frac{x-\xi+\bar{z}\alpha\xi}{2\xi}+i\epsilon\\ &= 2\bar{z}\tau(x-\xi+\bar{z}\alpha\xi)+i\epsilon,\\ D_3(x,\xi) &= -z[M_D^2+Q^2]+i\epsilon = -4\xi\tau z+i\epsilon,\\ D_4(x,\xi) &= z[M_D^2+Q^2]\frac{x-\xi}{2\xi}+i\epsilon = 2z\tau(x-\xi)+i\epsilon, \end{aligned} \tag{30}$$

where $\alpha = \frac{2M_D^2}{Q^2+M_D^2}$.

These computations show that there are five nonzero $(W\to D^*)$ helicity amplitudes:

(i) a longitudinal (W) to longitudinal (D^*) amplitude $\mathcal{M}_{00}$, originated from $G_L = G_L^{ad}+G_L^{be}+G_L^{cf}$ and from $\tilde{G}_L = \tilde{G}_{5L}^{ad}+\tilde{G}_{5L}^{cf}$;

(ii) a left (W) to left (D^*) and a right (W) to right $((D^*)$ amplitude, $\mathcal{M}_{LL}$ and $\mathcal{M}_{RR}$, originated from $G_T = G_T^{ad}+G_{5T}^{ad}+G_T^{be}$ and from $\tilde{G}_T = \tilde{G}_T^{ad}+\tilde{G}_{5T}^{ad}$;

(iii) a left (W) to right (D^*) and a right (W) to left (D^*) amplitude, $\mathcal{M}_{LR}$ and $\mathcal{M}_{RL}$, originated from $G_\tau^{\alpha\beta} = G_\tau^{cf}+G_{5\tau}^{cf}$, which are proportional to transversity gluon GPDs.

These amplitudes read

$$\mathcal{M}_{00} = \frac{iC_g}{2}\int_{-1}^1 dx\frac{-1}{(x+\xi-i\epsilon)(x-\xi+i\epsilon)}\int_0^1 dz f_L\phi_{D^*}(z) \cdot\left[\bar{N}(p_2)\left[H\hat{n}+E\frac{i\sigma^{n\Delta}}{2m}\right]N(p_1)G_L+\bar{N}(p_2)\left[\tilde{H}\,\hat{n}\,\gamma^5+\tilde{E}\frac{\gamma^5 n.\Delta}{2m}\right]N(p_1)\tilde{G}_L\right], \tag{31}$$

$$\mathcal{M}_{RR} = \mathcal{M}_{LL} = \frac{iC_g}{2}\int_{-1}^1 dx\frac{-1}{(x+\xi-i\epsilon)(x-\xi+i\epsilon)}\int_0^1 dz f_T\phi_{D^*}(z) \cdot\left[\bar{N}(p_2)\left[H\hat{n}+E\frac{i\sigma^{n\Delta}}{2m}\right]N(p_1)G_T+\bar{N}(p_2)\left[\tilde{H}\,\hat{n}\,\gamma^5+\tilde{E}\frac{\gamma^5 n.\Delta}{2m}\right]N(p_1)\tilde{G}_T\right], \tag{32}$$

$$\mathcal{M}_{LR} = iC_g \int_{-1}^{1} dx \frac{-1}{(x+\xi-i\epsilon)(x-\xi+i\epsilon)} \int_0^1 dz f_T \phi_{D^*}(z) G_\tau^{\alpha\beta} \mathbf{S} \frac{P\cdot n\Delta^\beta - \Delta\cdot nP^\beta}{2m}$$
$$\cdot \left[\bar{N}(p_2)\left[H_T i\sigma^{n\alpha} + E_T \frac{\hat{n}\Delta^\alpha - \Delta\cdot n\gamma^\alpha}{2m} + \tilde{H}_T \frac{P\cdot n\Delta^\alpha - \Delta\cdot nP^\alpha}{m^2} - \tilde{E}_T \frac{P\cdot n\gamma^\alpha - \hat{n}P^\alpha}{m}\right] N(p_1)\right] \tag{33}$$

$$\mathcal{M}_{RL} = \mathcal{M}_{LR}^*, \tag{34}$$

with $T_f = \frac{1}{2}$, and the factor $\frac{-1}{(x+\xi-i\epsilon)(x-\xi+i\epsilon)}$ comes from the conversion of the strength tensor to the gluon field. $C_g = T_f \frac{\pi}{3}\alpha_s V_{dc}$ for D^* production and $C_g = T_f \frac{\pi}{3}\alpha_s V_{sc}$ for D_s^* production.

V. OBSERVABLES

The differential cross section for neutrino production of a charmed meson is written as [18]

$$\frac{d^4\sigma(\nu_l N \to l^- N' D^*)}{dy dQ^2 dt d\varphi} = \bar{\Gamma}\left\{\frac{1}{2}(\sigma_{RR}^{(X)} + \sigma_{LL}^{(X)}) + \varepsilon\sigma_{00}^{(X)} - \varepsilon\cos(2\varphi)\mathcal{R}e\sigma_{RL}^{(X)} + \varepsilon\sin(2\varphi)\mathcal{I}m\sigma_{RL}^{(X)}\right.$$
$$- \sqrt{\varepsilon(1+\varepsilon)}\cos\varphi\mathcal{R}e(\sigma_{R0}^{(X)} - \sigma_{L0}^{(X)}) + \sqrt{\varepsilon(1+\varepsilon)}\sin\varphi\mathcal{I}m(\sigma_{R0}^{(X)} + \sigma_{L0}^{(X)})$$
$$- \sqrt{1-\varepsilon^2}\frac{1}{2}(\sigma_{RR}^{(X)} - \sigma_{LL}^{(X)}) + \sqrt{\varepsilon(1-\varepsilon)}\cos\varphi\mathcal{R}e(\sigma_{R0}^{(X)} + \sigma_{L0}^{(X)})$$
$$\left. - \sqrt{\varepsilon(1-\varepsilon)}\sin\varphi\mathcal{I}m(\sigma_{R0}^{(X)} - \sigma_{L0}^{(X)})\right\}. \tag{35}$$

Here, $\sigma_{RR} = \sigma_{LL}$. When integrated over the leptonic azimuthal angle φ, this yields

$$\frac{d^4\sigma(\nu N \to l^- N' D^*)}{dy dQ^2 dt} = 2\pi\bar{\Gamma}\{\sigma_{LL} + \varepsilon\sigma_{00}\}, \tag{36}$$

with $y = \frac{p\cdot q}{p\cdot k}$, $Q^2 = x_B y(s-m^2)$, $\varepsilon \approx \frac{1-y}{1-y+y^2/2}$, and

$$\bar{\Gamma} = \frac{G_F^2}{(2\pi)^4}\frac{1}{16y}\frac{1}{\sqrt{1+4x_B^2 m_N^2/Q^2}}\frac{1}{(s-m_N^2)^2}\frac{Q^2}{1-\epsilon},$$

where the "cross sections" $\sigma_{lm} = \epsilon_l^{*\mu} W_{\mu\nu}\epsilon_m^\nu$ are the product of amplitudes for the process $W(\epsilon_l)N \to D^* N'$, averaged (summed) over the initial (final) nucleon polarizations.

The D^* meson decays preferably through the $D\pi$ channel. The azimuthal distribution of this $D\pi$ final state (in the D^* rest system) is obtained from the helicity matrix elements of the D^* [19,20] related to the amplitudes for the production of a D^* with definite helicity. The cross section integrated over the leptonic azimuthal angle but not over the (θ_D, φ_D) decay angles thus reads ($B^{D^*\to X}$ is the branching ratio for the particular decay mode)

$$\frac{d^5\sigma(\nu N \to l^- N' D\pi)}{dy dQ^2 dt d\theta_D d\varphi_D} = 2\pi\bar{\Gamma} B^{D^*\to D\pi}\frac{3}{8\pi}\{\varepsilon\sigma_{00} 2\cos^2\theta_D + \sigma_{LL}\sin^2\theta_D(1 - \alpha\cos 2\varphi_D + \beta\sin 2\varphi_D)\}, \tag{37}$$

with

$$\alpha = \frac{2\mathcal{R}e[\mathcal{M}_{RR}\mathcal{M}_{RL}^*]}{\sigma_{LL}}, \qquad \beta = \frac{2\mathcal{I}m[\mathcal{M}_{RR}\mathcal{M}_{RL}^*]}{\sigma_{LL}}. \tag{38}$$

The fact that $\mathcal{M}_{LR}$ and thus α, β are linear in the transversity GPDs allows direct access to them through the moments

$$\langle\cos 2\varphi_D\rangle = \frac{\int d\varphi_D \cos 2\varphi_D \frac{d^5\sigma(\nu N\to l^- N' D\pi)}{dy dQ^2 dt d\theta_D d\varphi_D}}{\int d\varphi_D \frac{d^5\sigma(\nu N\to l^- N' D\pi)}{dy dQ^2 dt d\theta_D d\varphi_D}}, \tag{39}$$

$$\langle\sin 2\varphi_D\rangle = \frac{\int d\varphi_D \sin 2\varphi_D \frac{d^5\sigma(\nu N\to l^- N' D\pi)}{dy dQ^2 dt d\theta_D d\varphi_D}}{\int d\varphi_D \frac{d^5\sigma(\nu N\to l^- N' D\pi)}{dy dQ^2 dt d\theta_D d\varphi_D}}. \tag{40}$$

The D_s^* meson decays preferably through the $D_s\gamma$ channel. The azimuthal distribution of such a pseudoscalar meson + photon state is model dependent [21], and we shall not discuss it further. The suppressed decay $D_s^* \to D_s\pi$ may be treated in the same way as above.

VI. CONCLUSION

We have derived a new way to get access to the transversity gluon GPDs, the knowledge of which would shed new light on the deep structure of the nucleons. D^* mesons are produced in a medium energy neutrino experiment, at least in their longitudinal modes, at a rate comparable to the pseudoscalar D mesons [7]. We, however, believe that it is too premature to work on the phenomenology of the proposed reaction. On the one hand, neutrino experiments have not yet demonstrated their ability to analyze exclusive production of a charmed meson, even a simple pseudoscalar D meson. Analysing precisely the angular distribution of the decay products of the D^* meson is likely to be a formidable task since neutrino experiments cannot pretend to as precise energy reconstruction as electroproduction experiments. On the other hand, the nonexistence of a reasonable model for transversity gluon GPDs would nullify any effort to predict the size of the angular modulation present in Eq. (37).

Although planned high energy neutrino facilities [22] which have their scientific program oriented toward the understanding of neutrino oscillations should allow some important progress in the realm of hadronic physics, we cannot claim that the experimental measurement of the observables proposed here will be feasible.

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