Twist-3 GPD $x\tilde{E}_{2T}^{\nu}$ of proton in LFQDM

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Introduction

Despite decades of theoretical and experimental efforts, the internal structure of the simplest baryon, the proton, remains not yet fully established. One of the primary approaches to understanding its internal structure, bound together by the mechanism of color confinement, is to examine the proton in terms of its constituent partons [1]. Depending on the type of experimental probe and the observables being measured, various distribution functions of parton can be accessed. A key tool in this exploration is the generalized parton distributions (GPDs), which provide detailed information on the partonic structure of the hadron, revealing both the longitudinal momentum fraction x carried by partons and the momentum transfer t during scattering processes. In the non-perturbative regime, a more refined understanding of the proton can be achieved through the twist expansion, allowing for the study of higher-order effects beyond the leading twist [1]. While the connection between higher-twist terms and experimentally measurable cross-sections is still an active area of research, significant progress has been made on the theoretical front. In this work, we investigate the sub-leading twist GPD $x\tilde{E}_{2T}^{\nu}$ within the framework of the light-front quark-diquark model (LFQDM), contributing to the ongoing development of this field.

LFQDM

In this study, we investigate the problem using the LFQDM [2], where the proton is modeled as a composite of an active quark and a diquark spectator with a well-defined mass. The proton is considered to have a spin-flavor SU(4) structure, composed of an isoscalar-scalar diquark singlet $|u\ S^0\rangle$, an isoscalar-vector diquark $|u\ A^0\rangle$, and an isovector-vector diquark $|d\ A^1\rangle$, represented as [2]

$$|P;\pm\rangle = C_S|u\ S^0\rangle^{\pm} + C_V|u\ A^0\rangle^{\pm} + C_{VV}|d\ A^1\rangle^{\pm}.$$

Here, S and A denote the scalar and vector diquark, respectively, with the isospin represented by the superscripts. The expansion of the two-particle Fock state for $J_z = \pm\frac{1}{2}$, for both scalar and vector diquarks, along with their associated light-front wave functions (LFWFs), has been elaborated in Ref. [2]. The generic ansatz of the LFWFs $\varphi_i^{(\nu)}(x, \mathbf{p}_\perp)$, derived from the soft-wall AdS/QCD predictions, takes the form:

$$\varphi_i^{(\nu)}(x, \mathbf{p}_\perp) = \frac{4\pi}{\kappa}\sqrt{\frac{\log(1/x)}{1-x}}\, x^{a_i^\nu}(1-x)^{b_i^\nu} \exp\left[-\delta^\nu \frac{\mathbf{p}_\perp^2}{2\kappa^2}\frac{\log(1/x)}{(1-x)^2}\right].$$

The parameters and coefficients C_i have been fitted to the model scale as described in Ref. [2]. The constituent quark mass m is taken to be 0.055 GeV [2].

Twist-3 GPDs

The unintegrated quark-quark GPD correlator for the proton can be defined as [3]

$$W^{\nu[\Gamma]}_{[\Lambda^{N_i}\Lambda^{N_f}]}(x, p_\perp, \Delta_\perp, \theta) = \frac{1}{2}\int \frac{dz^-}{(2\pi)}\frac{d^2 z_T}{(2\pi)^2} e^{ip.z} \langle P^f;\Lambda^{N_f}|\bar{\psi}(-z/2)\Gamma \mathcal{W}_{[-z/2,z/2]}\psi(z/2)|P^i;\Lambda^{N_i}\rangle.$$

Here, $|P^i;\Lambda^{N_i}\rangle$ and $|P^f;\Lambda^{N_f}\rangle$ represent the initial and final states of the proton, respectively, where Λ^{N_i} and Λ^{N_f} signify their helicities. we have considered the skewness parameter ξ to be zero i.e., $\xi = -\Delta^+/2P^+ = 0$. We have chosen Γ such that it takes the Dirac

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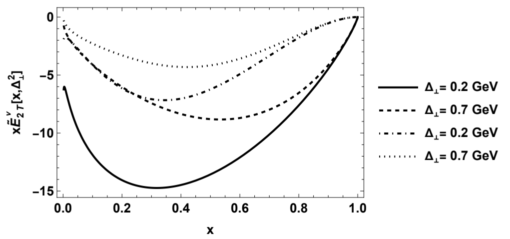

FIG. 1: The GPD $x\tilde{E}^{\nu}_{2T}$ has been plotted with respect to x at various fixed value of $\Delta_\perp$. The solid line and dashed line (dotted-dashed line and dotted line) are used for the representation of active u (d) quark scenario.

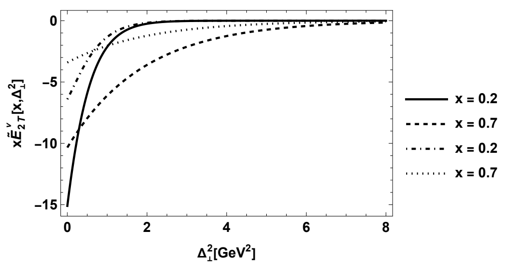

FIG. 2: The GPD $x\tilde{E}^{\nu}_{2T}$ has been plotted with respect to $\Delta_\perp$ at various fixed value of $\Delta_\perp$. The solid line and dashed line (dotted-dashed line and dotted line) are used for the representation of active u (d) quark scenario.

matrix structure corresponding to the subleading twist. We have taken the value of Wilson line W[0,z] to be 1. This ensures that the related bilocal quark operator has SU(3) color gauge invariance.

Results and discussion

The explicit expression of twist-3 chiral even GPD $x\tilde{E}^{\nu}_{2T}$ of proton can be given as [4]

$$x\tilde{E}^{\nu}_{2T} = \int \left[\frac{C_S^2 N_s^2}{16\pi^3} + \frac{C_A^2}{16\pi^3}\left(\frac{1}{3}|N_0^\nu|^2 - \frac{2}{3}|N_1^\nu|^2\right)\right] \left(-T_{11}^\nu + \left(\left(\mathbf{p}_\perp^2 - (1-x)^2\frac{\mathbf{\Delta}_\perp^2}{4}\right) - 2(1-x)\left(\frac{\mathbf{p}_\perp^2\mathbf{\Delta}_\perp^2 - (\mathbf{p}_\perp\cdot\mathbf{\Delta}_\perp)^2}{\mathbf{\Delta}_\perp^2}\right)\right)\frac{T_{22}^\nu}{x^2M^2}\right) d^2\mathbf{p}_\perp.$$

This GPD is plotted as a function of both x and $\Delta_\perp$ for the active u and d quarks in Figs. (1) and (2). The peaks of $x\tilde{E}^{\nu}_{2T}$ for the u and d quarks were observed in the low momentum transfer region, which is attributed to the presence of $\Delta_\perp$ in the denominator of expression of $x\tilde{E}^{\nu}_{2T}$. This behavior of the GPD aligns with the findings reported in Ref. [5]. The maxima of the plots for the u and d quarks occur at $x = 0.3$, suggesting that the longitudinal momentum fraction x is evenly distributed among the proton's three valence quarks. This GPD consists of the S-wave ($L_z = 0$), representing a scenario where there is no orbital angular momentum contribution, and the system is spherically symmetric in the transverse plane. It has been observed that the T_{11} term corresponds to the case where the spins of the active quark and the parent proton are aligned in a parallel configuration. In this case, the T_{11} term contributes negatively to the distribution, implying that this spin alignment reduces the overall amplitude in the distribution. On the other hand, for the anti-parallel spin alignment, the T_{22} term is relevant. Interestingly, this term contributes both negatively and positively to the distribution, indicating a more complex interplay between the spin states of the active quark and the parent proton. The positive contribution in this case suggests an enhancement of the amplitude in certain kinematic regions, possibly due to the interference effects arising from the anti-parallel spin states. This difference in behavior between T_{11} and T_{22} reflects the spin-spin correlations within the proton and highlights how the spin structure of the system influences the GPD in both parallel and anti-parallel configurations.

References

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