Unpolarized TMDs of proton in the light-front quark-diquark model

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Introduction

Hadronic physics studies 3-dimensional (3D) hadronic structure in partonic degree of freedom. To acquire this knowledge, many experimental and theoretical attempts have been done in recent years. The generalized parton distributions (GPDs) and transverse momentum dependent parton distributions (TMDs) encode the hadronic structure. GPDs allow us to access partonic configurations with longitudinal momentum fraction and transverse position inside the hadron. TMDs provide a 3D representation of hadrons by taking the parton's inherent transverse momentum into account. Various scattering procedures, including Deep virtual compton scattering (DVCS), semi-inclusive deep inclusive scattering (SIDIS), and the Drell-Yan process, aid in measuring the GPDs and TMDs of hadrons. We have explored the unpolarized TMDs of proton using the light-front quark-diquark model (LFQDM) in this study.

1. Light-Front Quark-Diquark Model (LFQDM)

We examine the present problem by using the LFQDM [1] where the proton is described as an aggregate of active quark and a diquark spectator of definite mass [2]. The proton has spin-flavor $SU(4)$ structure and it has been stated as a composite of isoscalar-scalar diquark singlet $|u\ S^0\rangle$, isoscalar-vector diquark $|u\ A^0\rangle$ and isovector-vector diquark $|d\ A^1\rangle$ states as [1]

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

Here, S and $A = V, VV$ have been used to denote the scalar and vector diquark respectively. Their isospin has been represented by the superscripts on them. The expansion of the two particle Fock-state for $J^z = \pm 1/2$ for scalar as well as vector diquark, along with their light-front wave functions (LFWFs) have been given in in Ref. [3]. The generic ansatz of LFWFs $\varphi_i^{(\nu)}(x, \mathbf{p}_\perp)$ in Ref. [3] is derived from the soft-wall AdS/QCD prediction as

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

The parameters and the coefficients C_i have been fitted to the model scale in Ref. [1]. The constituent quark mass (m) has been taken to be 0.055 GeV [2].

Unpolarized TMDs

For SIDIS, the unintegrated quark-quark correlator can be defined as [3]

$$\Phi^{\nu[\Gamma]}(x, \mathbf{p}_\perp; S) = \frac{1}{2}\int \frac{dz^- d^2z_T}{2(2\pi)^3} e^{ip.z} \langle P; S|\overline{\psi}^\nu(0)\Gamma\mathcal{W}_{[0,z]}\psi^\nu(z)|P; S\rangle\Big|_{z^+=0}. \quad (3)$$

The momentum of proton, quark and diquark is $P \equiv (P^+, \frac{M^2}{P^+}, \mathbf{0}_\perp)$, $p \equiv (xP^+, \frac{p^2+|\mathbf{p}_\perp|^2}{xP^+}, \mathbf{p}_\perp)$ and $P_X \equiv ((1-x)P^+, P_X^-, -\mathbf{p}_\perp)$ respectively. If the proton's helicity is λ_N, its spin components are denoted as $S^+ = \lambda_N\frac{P^+}{M}$, $S^- = \lambda_N\frac{P^-}{M}$, and S_T. We have taken the value of Wilson line $\mathcal{W}_{[0,z]}$ to be 1. The unpolarized quark TMDs are projected in the form of Eq. (3) according to Ref. [4] as

$$\Phi^{\nu[\gamma^+]} = f_1^\nu - \frac{\epsilon_T^{ij}\boldsymbol{p}_{Ti}\boldsymbol{S}_{Tj}}{M} f_{3T}^{\perp\nu}, \quad (4)$$

$$\Phi^{\nu[1]} = \frac{M}{P^+}\left[e^\nu - \frac{\varepsilon_T^{ij}p_{\perp i}S_{Tj}}{M}e_T^{\perp\nu}\right], \quad (5)$$

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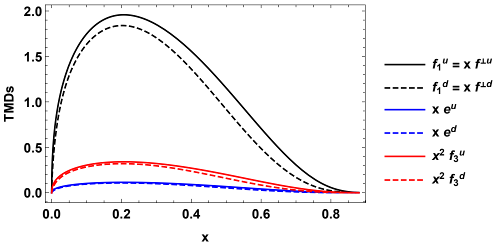

FIG. 1: The unpolarized TMDs ($f_1^\nu(x, \mathbf{p}_\perp^2)$, $xe^\nu(x, \mathbf{p}_\perp^2)$, $xf^{\perp\nu}(x, \mathbf{p}_\perp^2)$ and $x^2 f_3^\nu(x, \mathbf{p}_\perp^2)$) plotted with respect to x at $\mathbf{p}_\perp^2 = 0.15$ GeV^2.

$$\Phi^{\nu[\gamma^i]} = \frac{M}{P^+}\Big[\frac{p_\perp^i}{M}\Big(f^{\perp\nu} - \frac{\varepsilon_T^{jk} p_{\perp j} S_{Tk}}{M} f_T^{\perp'\nu}\Big)\Big]$$

$$+\frac{\varepsilon_T^{ij} p_{\perp j}}{M}\Big(\lambda\, f_L^{\perp\nu} + \frac{\vec{\mathbf{p}_\perp} \cdot \vec{S}_T}{M} f_T^{\perp\nu}\Big)\Big], \tag{6}$$

$$\Phi^{\nu[\gamma^-]} = \frac{M^2}{(P^+)^2}[f_3^\nu - \frac{\epsilon_T^{ij} \boldsymbol{p}_{Ti} \boldsymbol{S}_{Tj}}{M} f_{3T}^{\perp\nu}]. \tag{7}$$

Result and Discussion

The explicit expressions for unpolarized TMDs of proton is given by

$$f_1^\nu = \frac{M}{m} xe^\nu = xf^{\perp\nu} = \Big(\frac{M^2}{m^2 + p_\perp^2}\Big) x^2 f_3^\nu$$

$$= \frac{1}{16\pi^3}\Big(C_S^2 N_s^2 + C_A^2\Big(\frac{2}{3}|N_1^\nu|^2 + \frac{1}{3}|N_0^\nu|^2\Big)\Big)$$

$$\Big[|\varphi_1^\nu|^2 + \frac{p_\perp^2}{x^2 M^2}|\varphi_2^\nu|^2\Big]. \tag{8}$$

In Fig. 1, the unpolarized TMDs are plotted with respect to x at $\mathbf{p}_\perp^2 = 0.15$ GeV^2. As the value of longitudinal momentum fraction x increases the amplitude of TMDs first increases and then decreases to give a maxima at $x = 0.21$ ($x = 0.20$) for $u(d)$ quarks. In Fig. 2, the unpolarized TMDs are plotted with respect to $\mathbf{p}_\perp^2$ at $x = 0.3$. For TMDs f_1^ν, xe^ν and $xf^{\perp\nu}$, as the value of $\mathbf{p}_\perp^2$ increases the magnitude of TMDs decreases to meet the horizontal axis. For TMD $x^2 f_3^\nu$, the magnitude of TMD first increases and then decreases to meet the x axis, with increase in x. In Fig. 3, transverse momentum dependent parton distribution functions (TMDPDFs) have been plotted whose trend is similar to plot of TMDs versus x.

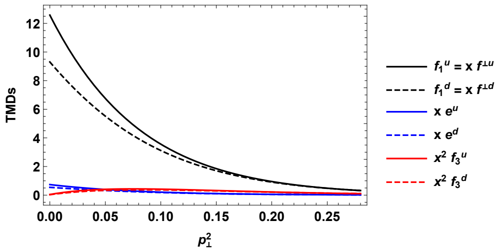

FIG. 2: The unpolarized TMDs ($f_1^\nu(x, \mathbf{p}_\perp^2)$, $xe^\nu(x, \mathbf{p}_\perp^2)$, $xf^{\perp\nu}(x, \mathbf{p}_\perp^2)$ and $x^2 f_3^\nu(x, \mathbf{p}_\perp^2)$) plotted with respect to $\mathbf{p}_\perp^2$ at $x = 0.3$.

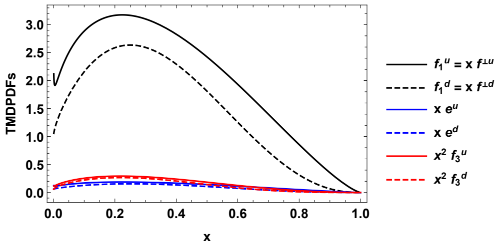

FIG. 3: The unpolarized integrated TMDs ($f_1^\nu(x)$, $xe^\nu(x)$, $xf^{\perp\nu}(x)$ and $x^2 f_3^\nu(x)$) plotted with respect to x.

In all figures, the magnitude of TMDs for u quarks is larger than that for d quarks. It should also been noted that as we go to higher twist, the amplitude of TMDs and TMDPDFs decreases.

Acknowledgments

N.K. and H.D. would like to thank the Science & Engineering Research Board, Government of India for providing Teacher Associateship Research Excellence Award, Grant No. TAR/2021/000157 for the financial support.

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