Study of kaon GTMDs in light-cone quark model

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Abstract

We investigate the generalized transverse momentum-dependent quark and anti-quark distributions (GTMDs) for kaon in light-cone quark model. The leading twist GTMDs are evaluated from the quark-quark correlator by considering the unpolarized, longitudinally-polarized and transversely-polarized quark/anti-quark in unpolarized kaon. For the evaluation of GTMDs, the overlap representation of light-cone wavefunctions is used. We observe the variation of GTMDs with longitudinal momentum fraction (x) at different values of quark/anti-quark transverse momentum and momentum transfer.

Introduction

One of the main goals of hadron physics is to understand the distribution of partons inside the hadron in both position and momentum space. Quantum Chromodynamics (QCD) describes the formation of hadron by including the strong interrelation between quarks, antiquarks and gluons. The parton distribution is the key to expose the relationship between hadron and its constituents. The generalized transverse momentum-dependent parton distributions (GTMDs) describe the complete picture of hadron at the level of its constituents. The Fourier transform of GTMDs lead to the Wigner distributions : the quantum phase-space distributions.

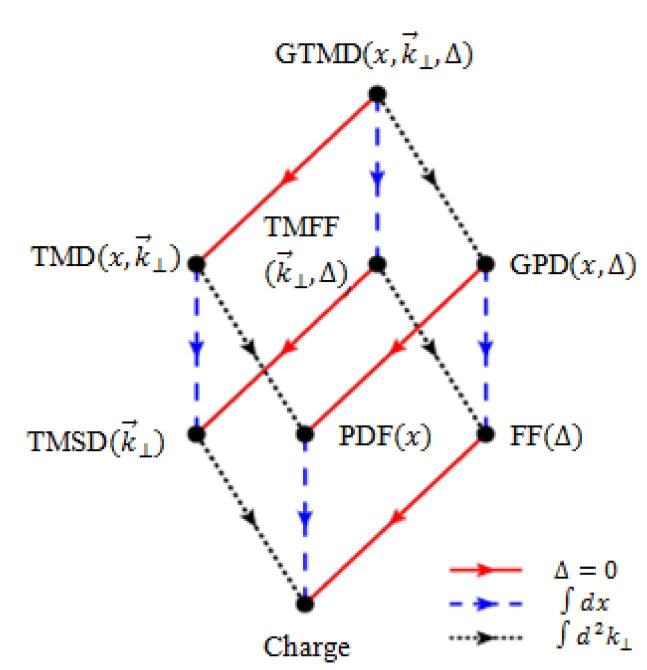

Figure 1: Representation of the projections of GTMDs into various parton distributions [1].

Light-cone quark model

We use the frame where the general four-vector $A = [A^+, A^-, \mathbf{A}_\perp]$ components are described as $A^\pm = A^0 \pm A^3$, $\mathbf{A}_\perp = (A^1, A^2)$ and $A^2 = A^+A^- - \mathbf{A}_\perp^2$.

The initial and final four-momenta of meson in symmetric frame are taken as

$$P' = \left[(1+\zeta)P^+, \frac{M^2 + \mathbf{\Delta}_\perp^2/4}{(1+\zeta)P^+}, \frac{\mathbf{\Delta}_\perp}{2}\right], \quad (1)$$

$$P'' = \left[(1-\zeta)P^+, \frac{M^2 + \mathbf{\Delta}_\perp^2/4}{(1-\zeta)P^+}, -\frac{\mathbf{\Delta}_\perp}{2}\right]. \quad (2)$$

The two-particle Fock state expansion for meson ($n = 2$) can be expressed as [2]

$$|M(P)\rangle = \sum_{\lambda_1,\lambda_2} \int \frac{dx d^2\mathbf{k}_\perp}{\sqrt{x(1-x)}16\pi^3} |x, \mathbf{k}_\perp, \lambda_1, \lambda_2\rangle \psi_{S_z}^{\lambda_1,\lambda_2}(x, \mathbf{k}_\perp). \quad (3)$$

Here λ_1 and λ_2 describe the helicities of quark and anti-quark in meson respectively.

The light-cone wavefunctions $\psi_{S_z}^{\lambda_1,\lambda_2}(x, \mathbf{k}_\perp)$ for kaon with $S = 0$ are defined as

$$\psi_0^{\uparrow,\uparrow}(x, \mathbf{k}_\perp) = -\frac{1}{\sqrt{2}} \frac{k_1 - ik_2}{\sqrt{\mathbf{k}_\perp^2 + l^2}} \varphi(x, \mathbf{k}_\perp),$$

$$\psi_0^{\uparrow,\downarrow}(x, \mathbf{k}_\perp) = \frac{1}{\sqrt{2}} \frac{(1-x)m_1 + xm_2}{\sqrt{\mathbf{k}_\perp^2 + l^2}} \varphi(x, \mathbf{k}_\perp),$$

$$\psi_0^{\downarrow,\uparrow}(x, \mathbf{k}_\perp) = -\frac{1}{\sqrt{2}} \frac{(1-x)m_1 + xm_2}{\sqrt{\mathbf{k}_\perp^2 + l^2}} \varphi(x, \mathbf{k}_\perp),$$

$$\psi_0^{\downarrow,\downarrow}(x, \mathbf{k}_\perp) = -\frac{1}{\sqrt{2}} \frac{k_1 + ik_2}{\sqrt{\mathbf{k}_\perp^2 + l^2}} \varphi(x, \mathbf{k}_\perp), \quad (4)$$

with

$$l^2 = (1-x)m_1^2 + xm_2^2 - x(1-x)(m_1 - m_2)^2. \quad (5)$$

The momentum-space wavefunction $\varphi(x, \mathbf{k}_\perp)$ is described as [3]

$$\varphi(x, \mathbf{k}_\perp) = A \exp\left[-\frac{\frac{\mathbf{k}_\perp^2 + m_1^2}{x} + \frac{\mathbf{k}_\perp^2 + m_2^2}{1-x}}{8\beta^2} - \frac{(m_1^2 - m_2^2)^2}{8\beta^2\left(\frac{\mathbf{k}_\perp^2 + m_1^2}{x} + \frac{\mathbf{k}_\perp^2 + m_2^2}{1-x}\right)}\right]. \quad (6)$$

The numerical values of parameters used for the calculations are as follows:
$m_1 = 0.25\ GeV$, $m_2 = 0.5\ GeV$ (with the u-quark on-shell), $\beta = 0.393\ GeV$ and $A = 74.2$.

Twist-2 GTMDs

The Wigner operator or correlator at fixed light-cone time $z^+ = 0$ is defined by

$$\hat{W}^{[\Gamma]}(\Delta_\perp, \mathbf{k}_\perp, x) = \frac{1}{2} \int \frac{dz^- d^2 z_\perp}{(2\pi)^3} e^{ik\cdot z} \left\langle M(P'') \middle| \bar{\psi}\left(-\frac{z}{2}\right) \Gamma \mathcal{W}_{[-\frac{z}{2},\frac{z}{2}]} \psi\left(\frac{z}{2}\right) \middle| M(P') \right\rangle \Big|_{z^+=0} \quad (7)$$

By using the Eq. (3) in Eq. (7), we get the Wigner correlation operator $\hat{W}^{[\Gamma]}$ for $\Gamma = \gamma^+, \gamma^+\gamma_5, i\sigma^{j+}\gamma_5$ in the overlap form as

$$\hat{W}^{[\gamma^+]}(\mathbf{\Delta}_\perp, \mathbf{k}_\perp, x) = \frac{1}{16\pi^3} \sum_{\lambda_1',\lambda_1,\lambda_2} \psi^{*\lambda_1'\lambda_2} \chi_{\lambda_1'}^\dagger \chi_{\lambda_2} \psi^{\lambda_1,\lambda_2},$$

$$\hat{W}^{[\gamma^+\gamma_5]}(\mathbf{\Delta}_\perp, \mathbf{k}_\perp, x) = \frac{1}{16\pi^3} \sum_{\lambda_1',\lambda_1,\lambda_2} \psi^{*\lambda_1'\lambda_2} \chi_{\lambda_1'}^\dagger \sigma_3 \chi_{\lambda_2} \psi^{\lambda_1,\lambda_2},$$

$$\hat{W}^{[i\sigma^{j+}\gamma_5]}(\mathbf{\Delta}_\perp, \mathbf{k}_\perp, x) = \frac{1}{16\pi^3} \sum_{\lambda_1',\lambda_1,\lambda_2} \psi^{*\lambda_1'\lambda_2} \chi_{\lambda_1'}^\dagger \sigma_j \chi_{\lambda_2} \psi^{\lambda_1,\lambda_2}. \quad (8)$$

The twist-2 GTMDs related to unpolarized pseudoscalar meson with spin-0 are connected with Wigner correlator or operator as [4]

$$\hat{W}^{[\gamma^+]} = F_1, \quad (9)$$

$$\hat{W}^{[\gamma^+\gamma_5]} = \frac{i\epsilon_\perp^{ij} k_\perp^i \Delta_\perp^j}{M^2} \tilde{G}_1, \quad (10)$$

$$\hat{W}^{[i\sigma^{j+}\gamma_5]} = \frac{i\epsilon_\perp^{ij} k_\perp^i}{M} H_1^k + \frac{i\epsilon_\perp^{ij} \Delta_\perp^i}{M} H_1^\Delta, \quad (11)$$

Since, the distributions have the support interval $-1 < x < 1$, we restrict ourselves in the DGLAP regions ($-1 < x < -\zeta$) for the anti-quark and for the ($\zeta < x < 1$) quark.

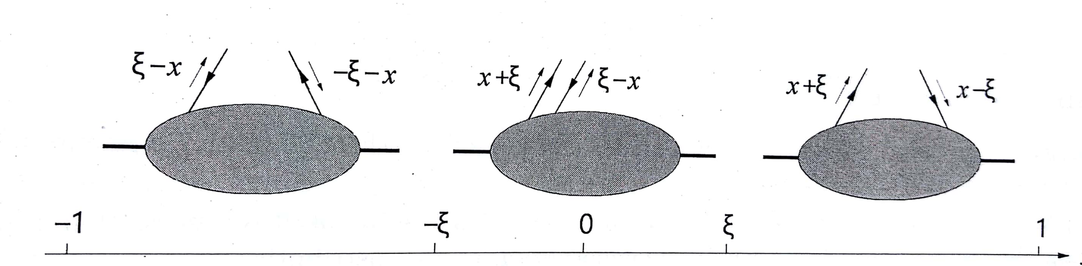

Figure 2: Regions of quark/anti-quark longitudinal momentum fraction i.e. x [1]

The $\bar{s}$ quark GTMDs in kaon are related to the u quark distributions as

$$F^u(x, \zeta, \mathbf{k}_\perp^2, \mathbf{k}_\perp.\mathbf{\Delta}_\perp, \mathbf{\Delta}_\perp^2, m_1, m_2) = -F^{\bar{s}}(-x, \zeta, \mathbf{k}_\perp^2, -\mathbf{k}_\perp.\mathbf{\Delta}_\perp, \mathbf{\Delta}_\perp^2, m_2, m_1). \quad (12)$$

Results

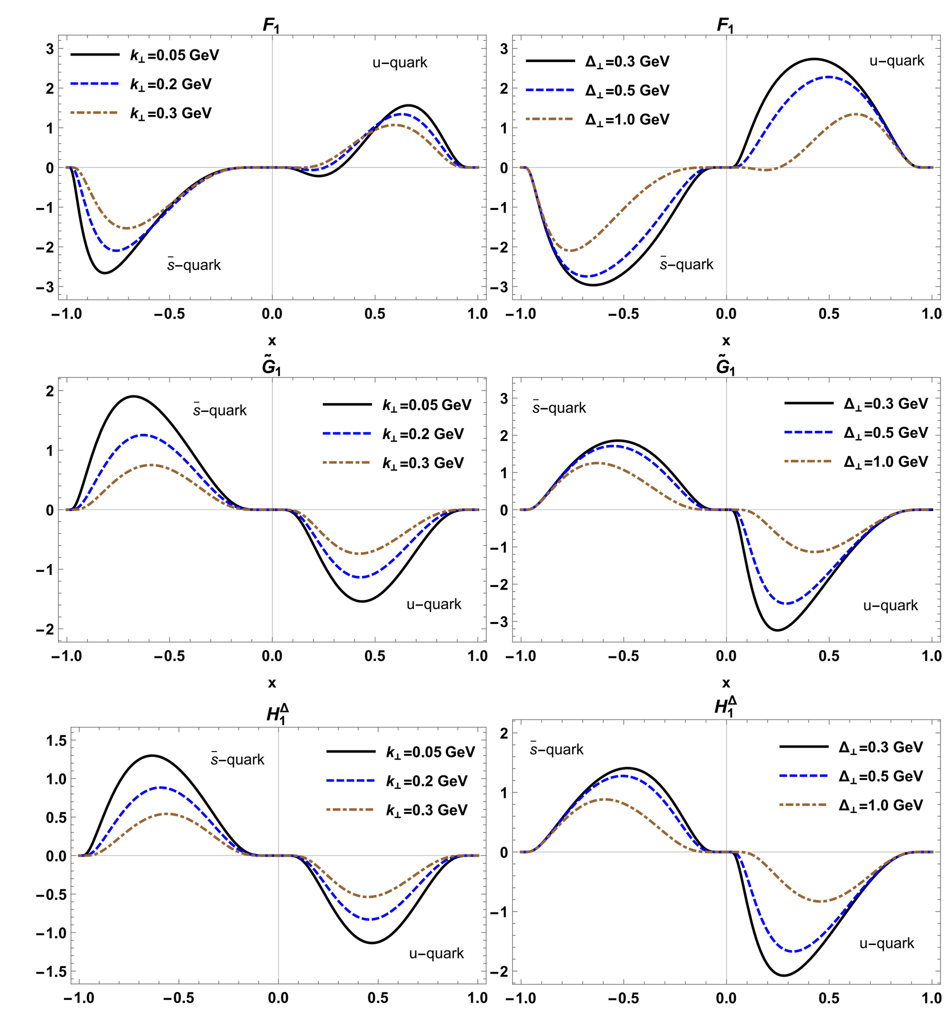

Figure 3: Plots of GTMDs F_1, $\tilde{G}_1$, H_1^Δ w.r.t x for u and $\bar{s}$ quarks (i) at different values of $\mathbf{k}_\perp$ with fixed $\mathbf{\Delta}_\perp = 1\ GeV$, and (ii) at different values of $\mathbf{\Delta}_\perp$ with fixed $\mathbf{k}_\perp = 0.2\ GeV$.

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