PROCEEDINGS OF SCIENCE

Spatial and Transverse structure of Heavy B- and D-mesons

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We have investigated the unpolarized valence quark generalized parton distribution functions (GPDs) and parton distribution functions (PDFs) for heavy spin-0, B- and D-mesons in the light-front quark model (LFQM). PDFs have been extracted from unpolarized $f_1(x, \mathbf{k}_\perp^2)$ transverse momentum-dependent parton distribution functions (TMDs). We have solved the quark-quark correlation function to have an unpolarized $H(x, \zeta, t)$ GPD. The unpolarized GPDs at zero skewness ($\zeta = 0$) lead to describing the electromagnetic form factors (EMFFs) ($F_M(t)$) and gravitational form factors (GFFs)($A_M(t)$) of the mesons.

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1. Introduction

Distribution functions (DFs) [1] have been widely used to describe the multidimensional structure of the elementary particles. In this context, TMDs [2] and GPDs [3] play an important role to understand the distributions of constituents inside the mesons. The GPDs provides the information about spatial structure (ζ, t) and longitudinal momentum fraction (x), while the TMDs carry the information about transverse momenta $(\mathbf{k}_\perp)$ of the quark along with x. GPDs are accessed through the deeply virtual compton scattering (DVCS) and deeply virtual meson production (DVMP) processes. TMDs can be extracted from the deep inelastic scattering (DIS) processes, Drell-Yan processes and semi-inclusive deep inelastic scattering (SIDIS) processes. In this present work, we have discussed the unpolarized TMD and GPD for heavy mesons using the light-front quark model.

2. Light-Front Quark Model

The light-front (LF) minimal Fock-state representation for mesons with momentum P is

$$|M(P, S_Z)\rangle = \sum_{\lambda_i,\lambda_j} \int \frac{\mathrm{d}x \mathrm{d}^2\mathbf{k}_\perp}{\sqrt{x(1-x)}16\pi^3} \Psi_{S_Z}(x, \mathbf{k}_\perp, \lambda_i, \lambda_j)|x, \mathbf{k}_\perp, \lambda_i, \lambda_j\rangle. \tag{1}$$

Here $x = \frac{k^+}{P^+}$ and $\mathbf{k}_\perp$ are the longitudinal momentum fraction and transverse momentum of the active quark respectively. $\Psi_{S_Z}(x, \mathbf{k}_\perp, \lambda_i, \lambda_j)$ is the LF meson wave function with different spin and helicity projections λ. It can be expressed as

$$\Psi_{S_z}(x, \mathbf{k}_\perp, \lambda_i, \lambda_j) = J_{S_z}(x, \mathbf{k}_\perp, \lambda_i, \lambda_j)\psi^M(x, \mathbf{k}_\perp). \tag{2}$$

Here $J_{S_z}(x, \mathbf{k}_\perp, \lambda_i, \lambda_j)$ and $\psi^M(x, \mathbf{k}_\perp)$ are the spin and momentum space wave functions of the mesons respectively. The momentum space wave function in Eq. 2 can be expressed using Brodsky-Huang-Lepage (BHL) [4] as

$$\psi^M(x, \mathbf{k}_\perp) = A \exp\left[-\frac{\frac{\mathbf{k}_\perp^2+m_q^2}{x} + \frac{\mathbf{k}_\perp^2+m_{\bar{q}}^2}{1-x}}{8\beta^2} - \frac{(m_q^2 - m_{\bar{q}}^2)^2}{8\beta^2\left(\frac{\mathbf{k}_\perp^2+m_q^2}{x} + \frac{\mathbf{k}_\perp^2+m_{\bar{q}}^2}{1-x}\right)}\right], \tag{3}$$

where $m_{q(\bar{q})}$ is the masses of quark (anti-quark) of the meson. A and β are the normalization constant and harmonic scale parameter of the respective mesons respectively. The input parameters have been taken from Ref. [5].

The spin wave function for pseudoscalar mesons ($S_z = 0$) with different helicites is expressed as [4]

$$\begin{cases} J_P^{(S_z=0)}(x, \mathbf{k}_\perp, \uparrow, \uparrow) = \frac{1}{\sqrt{2}}\omega^{-1}(-k^L)(M + m_q + m_{\bar{q}}), \\ J_P^{(S_z=0)}(x, \mathbf{k}_\perp, \uparrow, \downarrow) = \frac{1}{\sqrt{2}}\omega^{-1}((1-x)m_q + xm_{\bar{q}})(M + m_q + m_{\bar{q}}), \\ J_P^{(S_z=0)}(x, \mathbf{k}_\perp, \downarrow, \uparrow) = \frac{1}{\sqrt{2}}\omega^{-1}(-(1-x)m_q - xm_{\bar{q}})(M + m_q + m_{\bar{q}}), \\ J_P^{(S_z=0)}(x, \mathbf{k}_\perp, \downarrow, \downarrow) = \frac{1}{\sqrt{2}}\omega^{-1}(-k^R)(M + m_q + m_{\bar{q}}), \end{cases} \tag{4}$$

with $\omega = (M + m_q + m_{\bar{q}})\sqrt{x(1-x)[M^2 - (m_q - m_{\bar{q}})^2]}$ and $k^{L(R)} = k_x \pm k_y$. M is the mass of hadrons expressed as

$$M^2 = \frac{m_q^2 + \mathbf{k}_\perp^2}{x} + \frac{m_{\bar{q}}^2 + \mathbf{k}_\perp^2}{1-x}. \tag{5}$$

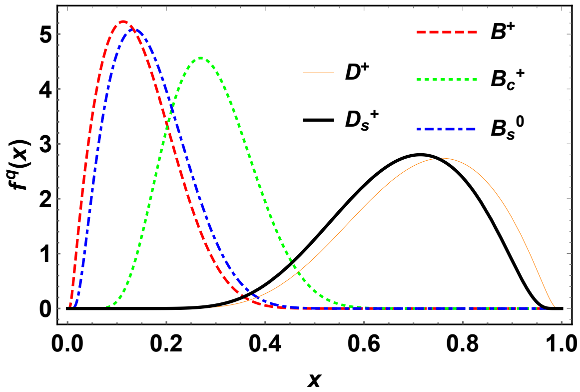

Figure 1: Comparison of PDFs for B- and D-mesons.

3. Transverse momentum-dependent parton distributions

In case of the pseudo-scalar mesons, the leading twist unpolarized TMD is expressed through the quark-quark correlation function is defined as [3]

$$f^{q\,[+]}_1(x, \mathbf{k}_\perp^2) = \frac{1}{2}\int \frac{\mathrm{d}z^- \mathrm{d}^2\vec{z}_\perp}{2(2\pi)^3} e^{i\mathbf{k}\cdot z}\langle M|\bar{\Psi}(0)\gamma^+\mathcal{W}(0,z)\Psi(z)|M\rangle|_{z^+=0}. \tag{6}$$

The unpolarized $f_1^q(x, \mathbf{k}_\perp^2)$ TMD in the form of wave function is found to be

$$\begin{aligned} f_1^q(x, \mathbf{k}_\perp^2) \quad &= \quad \frac{1}{16\pi^3}\Big[\ |\ \psi(x, \mathbf{k}_\perp, \uparrow, \Uparrow)\ |^2 + |\ \psi(x, \mathbf{k}_\perp, \downarrow, \Downarrow)\ |^2 + |\ \psi(x, \mathbf{k}_\perp, \downarrow, \Uparrow)\ |^2 \\ &\quad + |\ \psi(x, \mathbf{k}_\perp, \uparrow, \Downarrow)\ |^2\ \Big]. \end{aligned} \tag{7}$$

The unpolarized PDF is given by

$$f^q(x) = \int_0^\infty d\mathbf{k}_\perp^2 f_1^q(x, \mathbf{k}_\perp^2). \tag{8}$$

All the PDFs obey the sum rule

$$\int_0^1 dx f^q(x) = 1\,. \tag{9}$$

4. Generalized Parton Distributions

The unpolarized GPD correlation function at leading twist with initial momentum P'' and final momentum P' is expressed as [3]

$$H(x, \zeta, t) \quad = \quad \int \frac{dz^-}{4\pi} e^{ik^+z^-/2}\langle M(P'')|\bar{\Psi}(0)\gamma^+\Psi(z)|M(P')\rangle|_{z^+=\mathbf{z}_\perp=0}. \tag{10}$$

At $\zeta = 0$, $H(x, 0, t)$ is found to be

$$\begin{aligned} H(x, 0, t) = \int \frac{d^2\mathbf{k}_\perp}{16\pi^3}\big[&\psi^*(x, \mathbf{k}''_\perp, \uparrow, \Uparrow)\psi(x, \mathbf{k}'_\perp, \uparrow, \Uparrow) + \psi^*(x, \mathbf{k}''_\perp, \uparrow, \Downarrow)\psi(x, \mathbf{k}'_\perp, \uparrow, \Downarrow) \\ &+\psi^*(x, \mathbf{k}''_\perp, \downarrow, \Uparrow)\psi(x, \mathbf{k}'_\perp, \downarrow, \Uparrow) + \psi^*(x, \mathbf{k}''_\perp, \downarrow, \Downarrow)\psi(x, \mathbf{k}'_\perp, \downarrow, \Downarrow)\big], \end{aligned} \tag{11}$$

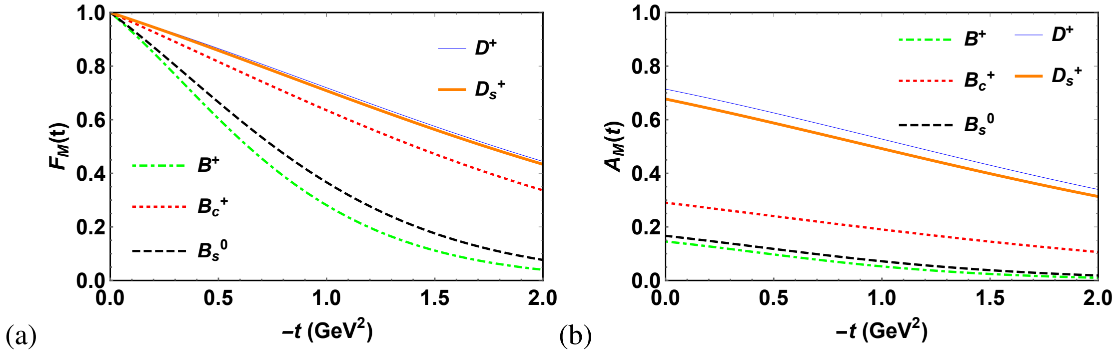

Figure 2: Comparison of electromagnetic and gravitational form factors for B- and D-mesons

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with quark final and initial momenta,

$$\mathbf{k}''_\perp = \mathbf{k}_\perp - (1-x)\frac{\Delta_\perp}{2}, \mathbf{k}'_\perp = \mathbf{k}_\perp + (1-x)\frac{\Delta_\perp}{2}, \tag{12}$$

where $t = \sqrt{-\Delta_\perp}$. The electromagnetic form factors $F_M(t)$ and the gravitational form factors $A_M(t)$ are expressed in the form of GPD as [6]

$$F_M(t) = \int_0^1 dx H(x,0,t), \quad A_M(t) = \int_0^1 dx x H(x,0,t). \tag{13}$$

5. Conclusion

We have solved the quark-quark correlation function to get the unpolarized GPD and TMD for spin-0 heavy mesons. The TMDs provide the information about PDFs, which have been plotted for different particles in Fig. 1. The EMFFs and GFFs are extracted from $H(x,0,t)$ GPD. The EMFFs and GFFs have been plotted with transverse momentum differences t in Fig. 2.

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