Spin-1 unpolarized GPDs in light front formalism

Satyajit Puhan[1],* Narinder Kumar[1,2], and Harleen Dahiya[1]
[1] *Computational High Energy Physics Lab, Department of Physics, Dr. B R Ambedkar National Institute of Technology, Jalandhar, Punjab, India, 144008 and*
[2] *Computational Theoretical High Energy Physics Lab, Department of Physics, Doaba College, Jalandhar 144004, India*

1. Introduction

Understanding of three dimensional structure of hadron in both perturbative and non-perturbative limit is still a challenging task. Generalized parton distribution functions (GPDs) [1] and transverse momentum parton distribution function (TMDs) [2, 3] provide a complete description of a three dimensional hadron in terms of spatial and transverse distribution. The spatial structure of GPDs is expressed as function of longitudinal momentum fraction (x), skewness (ζ) and transverse momentum transfer ($t = -\Delta_\perp^2$). In case of spin-1/2 and 0, there have been a lot of work reported but very less work has been reported in case of spin-1 GPDs. There are total 5 leading twist unpolarized GPDs for the case of spin-1 mesons. In this work, we mainly focus on the $H_1(x, \zeta, t)$ unpolarized GPD at $\zeta = 0$ in light cone quark model (LFQM).

*Electronic address: puhansatyaji@gmail.com

2. Generalized parton distribution function

In case of spin-1 hadron, the unpolarized quark GPD is defined through the correlation function as [4]

$$V_{\Lambda',\Lambda}(x,\xi,t) = \int \frac{dz^-}{4\pi} e^{ixP^+z^-} \left\langle p',\Lambda' \left| \bar{\psi}(0)\gamma^+\psi\left(Z^-\right)\right| p,\Lambda \right\rangle .$$

Here p and p' are the four momenta of incoming and outgoing hadron with helicities Λ and $\Lambda' = 0, \pm1$ respectively. $P = (p' + p)/2$, $\Delta = p' - p$, $t = \Delta^2$ and skewness variable $\zeta = -\Delta^+/(2P^+)$ are the other notations used in the above equation. The unpolarized GPDs can be decomposed in the form of $V_{\Lambda',\Lambda}(x, \xi, t)$ as

$$V_{\Lambda',\Lambda}(x,\xi,t) = -(\epsilon'^* \cdot \epsilon)H_1 + \frac{(\epsilon\cdot n)(\epsilon'\cdot P) + (\epsilon'\cdot n)(\epsilon\cdot P)}{P\cdot n}H_2 - 2\frac{(\epsilon\cdot P)(\epsilon'^*\cdot P)}{M^2}H_3 + \frac{(\epsilon\cdot n)(\epsilon'\cdot P) - (\epsilon'^*\cdot n)(\epsilon\cdot P)}{P\cdot n}H_4 + \left\{M^2\frac{(\epsilon\cdot n)(\epsilon'^*\cdot n)}{(P\cdot n)^2} + \frac{1}{3}(\epsilon'^*\cdot\epsilon)\right\}H_5. \quad (1)$$

$\epsilon \equiv \epsilon(p, \Lambda)$ and $\epsilon' \equiv \epsilon(p', \Lambda')$ are the polarization vector for spin-1 mesons. M is the bound sate mass of ρ meson. For this work, we have chosen the Berit frame. The GPDs come out in the overlap form of $V_{\Lambda',\Lambda}$ as

$$H_1 = \frac{1}{3}[V_{0,0} - 2(\tau-1)V_{1,1} + 2\sqrt{2\tau}V_{1,0} + 2V_{1,-1}],$$
$$H_2 = 2V_{1,1} - \frac{2}{\sqrt{2\tau}}V_{1,0},$$
$$H_3 = -\frac{V_{1,-1}}{\tau},$$
$$H_4 = 0,$$
$$H_5 = V_{0,0} - (1+2\tau)V_{1,1} + 2\sqrt{2\tau}V_{1,0} - V_{1,-1},$$

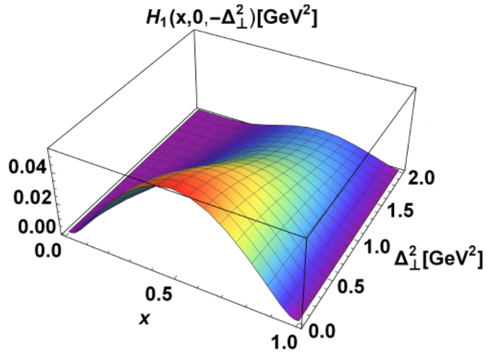

FIG. 1: Unpolarized $H_1(x,0,-\Delta_\perp^2)$ GPDs at zero skewness for ρ-meson.

with the abbreviation $H_i = H_i(x,0,t)$ and $V_{\Lambda',\Lambda} = V_{\Lambda',\Lambda}(x,0,t)$. In the Fock-state representation of mesons $V_{\Lambda',\Lambda}$ can be expressed

$$V_{\Lambda',\Lambda} = \sum_{\lambda_q,\lambda_{\bar{q}}} \int \frac{d^2\mathbf{k}_\perp}{2(2\pi)^3} \Phi^{\Lambda'*}_{\lambda_q,\lambda_{\bar{q}}}(x,\mathbf{k}^{\mathbf{f}}_\perp)\Phi^{\Lambda}_{\lambda_q,\lambda_{\bar{q}}}(x,\mathbf{k}^{\mathbf{i}}_\perp).$$

Here $\mathbf{k}^{\mathbf{f}}_\perp = \mathbf{k}_\perp + (\mathbf{1}-\mathbf{x})\frac{\mathbf{\Delta}_\perp}{\mathbf{2}}$ and $\mathbf{k}^{\mathbf{i}}_\perp = \mathbf{k}_\perp + -(\mathbf{1}-\mathbf{x})\frac{\mathbf{\Delta}_\perp}{\mathbf{2}}$ are the initial and final transverse momenta of the quark respectively.

3. Light-front quark model

The meson light front $\Phi^{\Lambda}_{\lambda_q,\lambda_{\bar{q}}}(x,\mathbf{k}_\perp)$ wave function in LFQM can be written as

$$\Phi^{\Lambda}_{\lambda_q,\lambda_{\bar{q}}}(x,\mathbf{k}_\perp) = \chi^{\Lambda}_{\lambda_q,\lambda_{\bar{q}}}(x,\mathbf{k}_\perp)\psi(x,\mathbf{k}^2_\perp),$$

$\chi^{\Lambda}_{\lambda_q,\lambda_{\bar{q}}}(x,\mathbf{k}_\perp)$ is the spin wave function [3]. $\psi(x,\mathbf{k}^2_\perp)$ is the momentum space wave function and can be written in the Brodsky-Huang-Lepage (BHL) prescription as

$$\psi(x,\mathbf{k}^2_\perp) = \mathcal{N}\exp\left[-\frac{\mathbf{k}^2_\perp + m_q^2}{8\beta^2 x(1-x)}\right]. \qquad (2)$$

4. Results

For this work, we have taken harmonic scale constat $\beta = 0.41$ GeV^2 and quark mass $m = 0.2$ GeV^2 for ρ meson. The unpolarized $H_1(x,0,-\Delta_\perp^2)$ and $H_5(x,0,-\Delta_\perp^2)$ GPD have been plotted with respect to longitudinal momentum fraction (x) and transverse momentum transfer ($\Delta_\perp^2$)) in Fig. 1 and 2. Both H_1 and H_5 distributions are symmetric about $x \leftrightarrow (1-x)$ at $\Delta_\perp = 0$. While with the increase in $\Delta_\perp$, the distribution shifts towards $x = 1$ for H_1. The maximum distributions of H_1 and minimum distribution of H_5 are obtained at $\Delta_\perp = 0$. Similar kind of observations has also been reported in Ref. [1]. The H_2 and H_3 GPDs are found to be more sensitive at $\Delta_\perp = 0$.

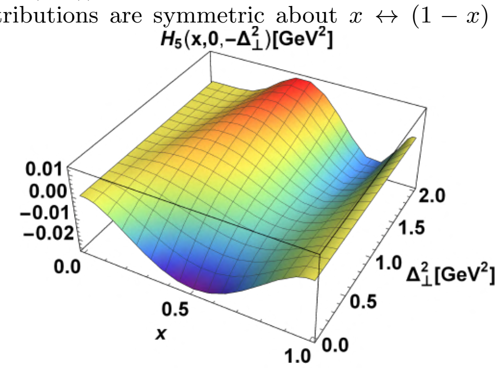

FIG. 2: Unpolarized $H_5(x,0,-\Delta_\perp^2)$ GPDs at zero skewness for ρ-meson.

References

[1] N. Kumar, Phys. Rev. D **99**, 014039 (2019).

[2] S. Puhan, S. Sharma, N. Kaur, N. Kumar and H. Dahiya, JHEP **02**, 075 (2024).

[3] S. Kaur, C. Mondal and H. Dahiya, JHEP **01**, 136 (2021).

[4] C. Shi, J. Li, P. L. Yin and W. Jia, Phys. Rev. D **107**, 074009 (2023).