# Pion GPDs

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## Introduction

The factorized form of the valence meson light-front wavefunction is expressed as [1]

$$\varphi(x,\zeta,\theta) = e^{\iota L\theta} X(x) \frac{\Phi(\zeta)}{\sqrt{2\pi\zeta}}\,, \tag{1}$$

where $X(x)$ corresponds to the longitudinal part of the wavefunction, which is fixed by mapping the spacelike electromagnetic or gravitational form factor calculated in $AdS_5$ and in physical spacetime [1]. The light-front variable is defined as $\zeta = \sqrt{x(1-x)}\mathbf{b}_\perp$ with $\mathbf{b}_\perp$ being the transverse separation between quark and antiquark. The holographic Schödinger equation, which is derived in the semiclassical approximation to the light-front QCD, is assured by the transverse part of the holographic wave function and is given by [2, 3]

$$\left(-\frac{\mathrm{d}^2}{\mathrm{d}\zeta^2} - \frac{1-4L^2}{4\zeta^2} + U_{\rm eff}(\zeta)\right)\Phi(\zeta) = M^2\Phi(\zeta), \tag{2}$$

where $U_{\rm eff}$ is the effective confining potential and is uniquely fixed [1, 4].

After adding the dynamical spin effects, the pseudoscalar ($\mathcal{P}$) meson wavefunction is expressed as [5, 6]

$$\psi^{\mathcal{P}}_{h,\bar{h}}(x,\mathbf{k}_\perp) = \chi^{\mathcal{P}}_{h,\bar{h}}(x,\mathbf{k}_\perp)\,\varphi(x,\mathbf{k}_\perp^2)\,, \tag{3}$$

where $h$ and $\bar{h}$ are the helicities of quark and antiquark respectively. The Lorentz invariant spin structure ($\chi$) for the pseudoscalar meson is expressed by accounting the photon-quark-antiquark vertex [5, 6].

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GPDs being the function of quark longitudinal momentum fraction $x$, momentum transfer in longitudinal direction $\xi$ (also known as skewness) and total momentum transfer to the final state of hadron $t = q^2$, are responsible for unravelling the spatial tomography of partons inside the hadron. The 3D GPDs are unification of FFs and PDFs at $\xi = 0$. The $x$-integration of the GPDs lead to the FFs which conceal the location of partons inside the hadron. On the other hand, with the initial and final state hadron polarizations being equal, GPDs produce parton densities with $\xi = 0$, in the forward limit ($\mathbf{q}_\perp = 0$).

## GPDs

For the present calculations of valence quark GPDs, we restrict ourself to the DGLAP region $\xi < x < 1$, with $\xi = 0$. At leading twist, there are two independent GPDs for spin-zero hadrons. One of them is chirally-even and the other is chirally-odd. The chiral-even quark GPD, $H_{(\pi)}(x,\xi=0,t)$, which corresponds to the unpolarized quark in the pseudoscalar meson, is defined through the correlation function of the tensor current as [7]

$$H_{(\pi)}(x,0,t) = \int \frac{\mathrm{d}z^-}{2(2\pi)} e^{\iota k\cdot z} \times \langle \Psi(P')|\bar{\vartheta}(0)\gamma^+\vartheta(z)|\Psi(P)\rangle\Big|_{z^+=\mathbf{z}_\perp=0}\,, \tag{4}$$

whereas the chiral-odd GPD, $E_{T(\pi)}(x,\xi=0,t)$, corresponding to the transversely polarized quark in the pseudoscalar meson, is defined through the correlation function of the tensor current as [8]

$$\frac{\iota\epsilon_\perp^{ij} q_\perp^i}{M_\pi} E_{T(\pi)}(x,0,t) = \int \frac{dz^-}{2(2\pi)} e^{\iota k\cdot z} \times \langle \Psi(P')|\bar{\vartheta}(0)\iota\sigma^{j+}\gamma_5\vartheta(z)|\Psi(P)\rangle\Big|_{z^+=\mathbf{z}_\perp=0}\,. \tag{5}$$

We obtain the quark GPDs $H_{(\pi)}(x, 0, t)$ and $E_{T(\pi)}(x, 0, t)$ in the overlap form of LFWFs as

$$H_{(\pi)}(x,0,t) = \int \frac{\mathrm{d}^2\mathbf{k}_\perp}{2(2\pi)^3} \sum_{h,\bar{h}} \psi^{\pi *}_{h,\bar{h}}(x, \mathbf{k}_\perp + \bar{x}\mathbf{q}_\perp)\psi^{\pi}_{h,\bar{h}}(x,\mathbf{k}_\perp)\ , \quad (6)$$

$$\frac{\iota q_2}{M_\pi} E_{T(\pi)}(x,0,t) = \int \frac{\mathrm{d}^2\mathbf{k}_\perp}{2(2\pi)^3} \sum_{h,h',\bar{h}} \psi^{\pi *}_{h',\bar{h}}(x, \mathbf{k}_\perp + \bar{x}\mathbf{q}_\perp)\psi^{\pi}_{h,\bar{h}}(x,\mathbf{k}_\perp)\delta_{h,-h'}\ , \quad (7)$$

with $\bar{x} = (1 - x)$. Also, it is noticeable here that we choose the quark polarization along $x$-direction i.e. $j = 1$.

Substituting the spin-improved holographic wavefunctions in Eqs. (6) and (7), we get

$$H_{(\pi)}(x,0,t) = \int \frac{\mathrm{d}^2\mathbf{k}_\perp}{(2\pi)^3} \left( \frac{\mathbf{k}_\perp^2 + \bar{x}\mathbf{k}_\perp \cdot \mathbf{q}_\perp}{x^2\bar{x}^2} + \left(M_\pi + \frac{m}{x\bar{x}}\right)^2 \right) \varphi^*(x, \mathbf{k}_\perp + \bar{x}\mathbf{q}_\perp)\varphi(x,\mathbf{k}_\perp)\ , \quad (8)$$

$$E_{T(\pi)}(x,0,t) = \frac{M_\pi}{x} \int \frac{\mathrm{d}^2\mathbf{k}_\perp}{(2\pi)^3} \left(M_\pi + \frac{m}{x\bar{x}}\right) \times \varphi^*(x, \mathbf{k}_\perp + \bar{x}\mathbf{q}_\perp)\varphi(x,\mathbf{k}_\perp)\ , \quad (9)$$

with $\varphi(x, \mathbf{k}_\perp) \propto \frac{1}{\sqrt{x\bar{x}}} \exp\left(-\frac{\mathbf{k}_\perp^2 + m^2}{2\kappa^2 x\bar{x}}\right)$

We show the 3D graphical representation of the chiral-even GPD $H_{(\pi)}(x, 0, t)$ and the chiral odd GPD $E_{T(\pi)}(x, 0, t)$ for the case of pion in Fig. 1. We observe that as the momentum transferred to the pion is increased, the chiral-even distribution peak decreases in magnitude and shifts towards higher values of the quark longitudinal momentum fraction $x$. Unlike the unpolarized GPD $H$, the peak of the chiral-odd GPD $E_T$ in pion appears below the central value of $x$ when the momentum transfer is less. As expected, when the momentum transferred to the pion is zero, the unpolarized quark distribution in the pion with respect to the longitudinal momentum fraction $x$ is maximum at the central value ($x = 0.5$), and gives us the information about the quark density i.e. $H(x, 0, 0) = f(x)$.

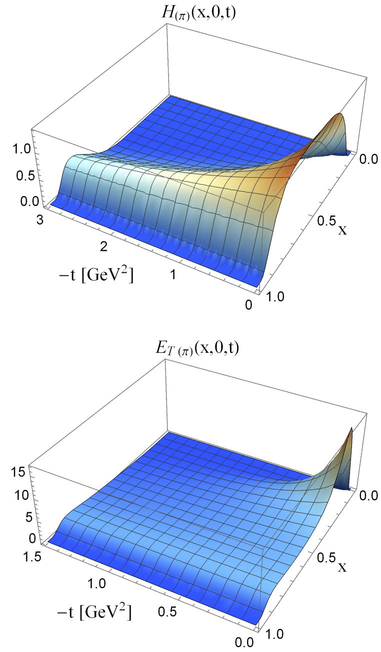


FIG. 1: The chiral-even and chiral-odd pion GPDs $H_{(\pi)}(x, 0, t)$ and $E_{T(\pi)}(x, 0, t)$ as a function of $-t$ (in GeV$^2$) and $x$ in the LF holographic model.

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## References


[1] S. J. Brodsky *et al.*, Phys. Rept. **584**, 1 (2015).

[2] S. J. Brodsky *et al.*, Phys. Rev. Lett. **96**, 201601 (2006).

[3] G. F. de Teramond *et al.*, Phys. Rev. Lett. **102**, 081601 (2009).

[4] S. J. Brodsky *et al.*, Phys. Lett. B **729**, 3 (2014).

[5] M. Ahmady *et al.*, Phys. Rev. D **95**, 074008 (2017).

[6] M. Ahmady *et al.*, Phys. Rev. D **98**, 034010 (2018).

[7] M. Diehl, Phys. Rept. **388**, 41 (2003).

[8] S. Meissner *et al.*, JHEP **08**, 038 (2008).