Momentum-Space Tomography of the Proton in a Quark-Diquark Picture

Navpreet Kaur

working under the supervision of

Prof. Harleen Dahiya

Dr. B. R. Ambedkar National Institute of Technology Jalandhar (144008), Punjab, India

Theoretical Motivations and Empirical Evidence for Diquark Correlations in Hadrons, ECT*







Oct 19, 2026

Outline

1 Transverse Momentum-Dependent Parton Distributions

2 EMT in Momentum-Space

3 Quark-Diquark Model

4 Results

- The hadronic tensor in terms of the bi-local operator

$$2MW^{\mu\nu} \sim \int d^4x\, e^{iq\cdot x} x^{\lambda} \sigma_{\mu\lambda\nu\rho} \langle P,S|\, O_V^{\rho}(x,0)\, |P,S\rangle\,.$$

- Performing the Fourier transform, the coefficient functions are proportional to $\left(\frac{M}{Q}\right)^{t-2}$.

- Twist:2 | Leading order | Q^0 | Single parton distributions.
- Twist:3 | Subleading order | $1/Q$ | Quark-gluon correlations and spin-dependent effects.
- Twist:4 | Sub-subleading order | $1/Q^2$ | Multiparton correlations.

https://inspirehep.net/literature/1493030

Distribution functions

Distribution functions	**GTMDs**	**TMDs**	**GPDs**
Longitudinal momentum fraction	✓	✓	✓
Transverse momentum	✓	✓	✗
Momentum transfer	✓	✗	✓
Same Initial & final state	✗	✓	✗
Processes	Double Drell-Yan	Deep inelastic scattering	DVCS and DVMP

Table 1: Variables on which different distribution functions depend and experimental source of their respective measurement.

JHEP 08, 056 (2009)

TMDs

Quark-quark correlator

$$\Phi_q^{[\Gamma]} = \frac{1}{2}\int \frac{dz^- d^2\mathbf{z}_\perp}{(2\pi)^3} e^{ik\cdot z}\ \langle P,\lambda|\,\bar{\Psi}\left(\frac{-z}{2}\right)\Gamma\mathbb{W}\left(\frac{-z}{2},\frac{z}{2}\middle|n\right)\Psi\left(\frac{z}{2}\right)|P,\lambda\rangle\Big|_{z^+=0}.$$

Γ basis $[1, \gamma_5, \gamma^\mu, \gamma^\mu\gamma_5, \sigma^{\mu\nu}]$.

Polarization	Twist 2	Twist 3
U	$\gamma^+ : f_1$	$\gamma^\alpha : f^\perp;\quad i\gamma_5 : h;\quad \mathbf{1} : e$
L	$\gamma^+\gamma_5 : g_1$	$\gamma^\alpha : f_L^\perp;\quad i\sigma^{+-}\gamma_5 : h_L;\quad \mathbf{1} : e_L$
T	$i\sigma^{\alpha+}\gamma_5 : h_1$	$\gamma^\alpha\gamma_5 : g_T;\quad i\sigma^{\alpha\beta}\gamma_5 : h_T;\quad i\gamma_5 : f_T$

Table 2: Hadron-polarization labelling of collinear quark PDFs in terms of the Dirac current Γ.

JHEP **08**, 056 (2009)

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- The quark bilocal gic EMT operator

$$T^{\alpha\beta}_{q,gic}(r,k) = k^{\beta}\int \frac{d^4z}{(2\pi)^4} e^{ik\cdot z}\,\bar{\Psi}\Big(r-\frac{z}{2}\Big)\gamma^{\alpha}\,\mathbb{W}\Big(r-\frac{z}{2},r+\frac{z}{2}\Big|n\Big)\,\Psi\Big(r+\frac{z}{2}\Big).$$

(pure-gauge covariant derivatives commute, eliminating gauge-dependent ambiguities in the bilocal operator)

- The forward matrix elements of the operator $T^{\alpha\beta}_{q,gic}(r,k)$ is expressed as

$$\Theta^{\alpha\beta}_{q}(P,k,N,\lambda;\eta) = \frac{1}{2}\,\langle P,\lambda|\,T^{\alpha\beta}_{q,gic}(0,k)\,|P,\lambda\rangle\,.$$

- The integration over the light-front energy of an active quark leads to the 3D EMT in momentum-space

$$\begin{aligned}\mathbb{T}^{\alpha\beta}_{q}(P,x,\mathbf{k}_{\perp},N,\lambda;\eta) &= \int dk^{-}\,\Theta^{\alpha\beta}_{q}(P,k,N,\lambda;\eta)\\ &= \frac{1}{2}\int \frac{dz^{-}d^2\mathbf{z}_{\perp}}{(2\pi)^3}e^{ik\cdot z}\,i\partial^{\beta}_{z}\,\langle P,\lambda|\,\bar{\Psi}\Big(\frac{-z}{2}\Big)\gamma^{\alpha}\mathbb{W}\Big(\frac{-z}{2},\frac{z}{2}\Big|n\Big)\Psi\Big(\frac{z}{2}\Big)|P,\lambda\rangle\Big|_{z^{+}=0}.\end{aligned}$$

Phys. Lett. B **91**, 062001 (2003),
Phys. Rev. D **85**, 114006 (2012)

Using the complete set of independent rank-2 tensors $g_T^{\alpha\beta}$, $\epsilon_T^{\alpha\beta}$, P^α, N^α and k_T^α,
EMT in momentum space is expressed as

$$\begin{aligned}\mathbb{T}_q^{\alpha\beta} = \frac{1}{P^+}\Big[&P^\alpha P^\beta a_1 + N^\alpha N^\beta a_2 + k_T^\alpha k_T^\beta a_3 + P^\alpha N^\beta a_4 + N^\alpha P^\beta a_5 + P^\alpha k_T^\beta a_6 + k_T^\alpha P^\beta a_7 + N^\alpha k_T^\beta a_8 \\ &+ k_T^\alpha N^\beta a_9 + M^2 g_T^{\alpha\beta} a_0 - \frac{\epsilon^{k_T S_T}}{M}\Big\{P^\alpha P^\beta a_{1T}^\perp + N^\alpha N^\beta a_{2T}^\perp + k_T^\alpha k_T^\beta a_{3T}^\perp + P^\alpha N^\beta a_{4T}^\perp + N^\alpha P^\beta a_{5T}^\perp \\ &+ P^\alpha k_T^\beta a_{6T}^\perp + k_T^\alpha P^\beta a_{7T}^\perp + N^\alpha k_T^\beta a_{8T}^\perp + k_T^\alpha N^\beta a_{9T}^\perp + M^2 g_T^{\alpha\beta} a_{0T}^\perp\Big\} - M\{P^\alpha \epsilon_T^{\beta S_T} a_{1T} + P^\beta \epsilon^{\alpha S_T} a_{2T} \\ &+ N^\alpha \epsilon_T^{\beta S_T} a_{3T} + N^\beta \epsilon_T^{\alpha S_T} a_{4T} + k_T^\alpha \epsilon_T^{\beta S_T} a_{5T} + k_T^\beta \epsilon_T^{\alpha S_T} a_{6T}\} - \lambda\{P^\alpha \epsilon_T^{\beta k_T} a_{1L} + P^\beta \epsilon_T^{\alpha k_T} a_{2L} \\ &+ N^\alpha \epsilon_T^{\beta k_T} a_{3L} + N^\beta \epsilon_T^{\alpha k_T} a_{4L} + k_T^\alpha \epsilon_T^{\beta k_T} a_{5L} + k_T^\beta \epsilon_T^{\alpha k_T} a_{6L}\}\Big],\end{aligned}$$

– a_{0-9} : unpolarization,
– $a_{0-9T}^\perp$ and a_{1-6T} : transverse polarization and
– a_{1-6L} : longitudinal polarization.

Phys. Lett. B **843**, 138016 (2023)

EMT and TMD

3D EMT in momentum-space

$$\begin{aligned}\mathbb{T}_q^{\alpha\beta}(P,x,\mathbf{k}_\perp,N,\lambda;\eta) &= \int dk^- \Theta_q^{\alpha\beta}(P,k,N,\lambda;\eta),\\ &= \frac{1}{2}\int \frac{dz^- d^2\mathbf{z}_\perp}{(2\pi)^3} e^{ik\cdot z} i\partial_z^\beta \langle P,\lambda|\bar{\Psi}\Big(\frac{-z}{2}\Big)\gamma^\alpha \mathbb{W}\Big(\frac{-z}{2},\frac{z}{2}\Big|n\Big)\Psi\Big(\frac{z}{2}\Big)|P,\lambda\rangle\Big|_{z^+=0},\\ &= k^\beta\ \Phi_q^{[\gamma^\alpha]}(P,x,\mathbf{k}_\perp,N,\lambda;\eta).\end{aligned}$$

For $\beta \neq -$

$$\boxed{\mathbb{T}_q^{\alpha\beta}(P,x,\mathbf{k}_\perp,N,\lambda;\eta) = k^\beta \Phi_q^{[\gamma^\alpha]}(P,x,\mathbf{k}_\perp,N,\lambda;\eta)}$$

Phys. Lett. B **843**, 138016 (2023)

TMDs from Dirac projections γ^+, γ^i_T and γ^- are parametrized in terms of respective twist-2, twist-3 and twist-4 as

$$\Phi_q^{[\gamma^+]} = f_1^q - \frac{\epsilon_T^{k_T S_T}}{M} f_{1T}^{\perp(q)},$$

$$\Phi_q^{[\gamma^i_T]} = \frac{M}{P^+}\left[\frac{k_T^i}{M} f^{\perp(q)} - \epsilon_T^{iS_T} f_T^{\prime(q)} - \lambda_l \frac{\epsilon^{ik_T}}{M} f_L^{\perp(q)} - \frac{k_T^i k_T^j - \frac{1}{2}k_T^2 g_T^{ij}}{M^2} \epsilon_{Tjs_T} f_T^{\perp(q)}\right],$$

$$\Phi_q^{[\gamma^-]} = \left(\frac{M}{P^+}\right)^2\left[f_3^q - \frac{\epsilon_T^{k_T \cdot S_T}}{M} f_{3T}^{\perp(q)}\right].$$

The expression of $f_T^{\pm(q)}$ TMD is

$$f_T^{\pm(q)} = f_T^{\prime(q)} \pm \frac{\mathbf{k}_\perp^2}{2M^2} f_T^{\perp(q)}.$$

J. High Energy Phys. **02** 093, (2007)

Relations between gravitational TMDs and ordinary TMDs

$$\mathbb{T}_q^{\alpha\beta}(P, x, \mathbf{k}_\perp, N, \lambda; \eta) = k^\beta \Phi_q^{[\gamma^\alpha]}(P, x, \mathbf{k}_\perp, N, \lambda; \eta)$$

For $\beta = +$,

- $a_1 = x\, f_1$
- $\frac{1}{2} a_1 + a_5 = x\, f_3$
- $a_7 = x\, f^\perp$
- $a_{2L} = x\, f_L^\perp$
- $a_{1T}^\perp = x\, f_{1T}^\perp$
- $\frac{1}{2} a_{1T}^\perp + a_{5T}^\perp = x\, f_{3T}^\perp$
- $a_{7T}^\perp = x\, f_T^\perp$
- $a_{2T} = x\, f_T^+$

For i,

- $a_3 = f^\perp$
- $\frac{1}{2} a_6 + a_8 = f_3$
- $a_6 = f_1$
- $a_{6L} = f_L^\perp$
- $a_{3T}^\perp = f_T^\perp$
- $\frac{1}{2} a_{6T}^\perp + a_{8T}^\perp = f_{3T}^\perp$
- $a_{6T}^\perp = f_{1T}^\perp$
- $a_{6T} = f_T^+$

Phys. Lett. B **843**, 138016 (2023)

EMT components

$\mathbb{T}_q^{++}$ and $\mathbb{T}_q^{+i}$ give the corresponding longitudinal and transverse quark momentum densities from the EMT as

$$\mathbb{T}_q^{++} = xP^+\Phi_q^{[\gamma^+]} = \left(f_1^q - \frac{\epsilon_T^{k_T S_T}}{M} f_{1T}^{\perp(q)}\right) xP^+,$$

$$\mathbb{T}_q^{+i} = k_T^i \Phi_q^{[\gamma^+]} = \left(f_1^q - \frac{\epsilon_T^{k_T S_T}}{M} f_{1T}^{\perp(q)}\right) k_T^i.$$

$\mathbb{T}_q^{i+}$ is written as

$$\mathbb{T}_q^{i+} = xP^+\Phi_q^{[\gamma_T^i]} = \left(xf^{\perp(q)} - \frac{\epsilon_T^{k_T S_T}}{M} xf_T^{\perp(q)}\right) k_T^i - M\epsilon_T^{iS_T} xf_T^{+(q)} - \lambda_l \epsilon_T^{ik_T} xf_L^{\perp(q)}.$$

On decomposition of $\epsilon_T^{iS_T}$ into the parallel and orthogonal components to the k_T

$$\mathbb{T}_q^{i+} = \left(xf^{\perp(q)} - M\frac{\epsilon_T^{k_T S_T}}{k_T^2} xf_T^{-(q)}\right) k_T^i - \left(\lambda_l xf_L^{\perp(q)} + \frac{M(k_T \cdot S_T)}{k_T^2} xf_T^{+(q)}\right) \epsilon_T^{ik_T}.$$

$\mathbb{T}_q^{\alpha\beta}$ gives the transverse pressure σ^q and shear force Π^q distributions in the momentum space

$$\mathbb{T}_q^{ij} = -g_T^{ij}\sigma^q + \left(\frac{1}{2}g_T^{ij} - \frac{k_T^i k_T^j}{k_T^2}\right)\Pi^q + \frac{k_T^i \epsilon_T^{jk_T} + k_T^j \epsilon_T^{ik_T}}{2k_T^2}\Pi_S^q + \epsilon_T^{ij}\Pi_A^q,$$

which is analogous to the representation of 2D spatial distributions of pressure and shear force. Considering the TMD EMT, we have

$$\begin{aligned}\mathbb{T}_q^{ij} &= k_T^j\,[\Phi^{\gamma_T^i}] \\ &= \frac{1}{P^+}\left[\left\{f^{\perp(q)} - \frac{M\epsilon_T^{k_T S_T}}{k_T^2} f_T^{-(q)}\right\}k_T^i k_T^j - \left\{\lambda_l f_L^{\perp(q)} + \frac{M(k_T\cdot S_T)}{k_T^2} f_T^{+(q)}\right\}\epsilon^{ik_T} k_T^j\right],\end{aligned}$$

with

$$\begin{aligned}2\sigma^q &= -\frac{1}{P^+}\left[k_T^2\, f^{\perp(q)} - M\epsilon_T^{k_T S_T} f_T^{-(q)}\right], \\ 2\Pi_A^q &= -\frac{1}{P^+}\left[\lambda_l\, k_T^2\, f_L^{\perp(q)} + M(k_T\cdot S_T) f_T^{+(q)}\right].\end{aligned}$$

Phys. Lett. B **843**, 138016 (2023)

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Quark-Diquark Picture

– The proton's spin-flavor structure: isoscalar-scalar diquark singlet $|u\ \mathfrak{s}(ud)\rangle$, isoscalar-vector diquark $|u\ \mathfrak{a}_u(ud)\rangle$, and isovector-vector diquark $|d\ \mathfrak{a}_d(uu)\rangle$

$$|P;\pm\rangle = \sum C_{\mathfrak{d}}|q\ \mathfrak{d}\rangle^{\pm},$$

where $\mathfrak{d} = (\mathfrak{s}, \mathfrak{a}_u, \mathfrak{a}_d)$ denotes the different types of diquarks.
– LFWFs for the respective scalar diquark $\mathfrak{s}$ with mass $m_{\mathfrak{s}}$ and axial-vector diquarks $\mathfrak{a}$ with mass $m_{\mathfrak{a}}$ are expressed as

$$\psi^{\lambda}_{\lambda_q}(x,\mathbf{k}_\perp) = \sqrt{\frac{k^+}{(P-k)^+}}\frac{1}{k^2-m_q^2}\bar{u}(k,\lambda_q)\,\mathcal{Y}_{\mathfrak{s}}\,U(P,\lambda),$$

$$\psi^{\lambda}_{\lambda_q\lambda_{\mathfrak{a}}}(x,\mathbf{k}_\perp) = \sqrt{\frac{k^+}{(P-k)^+}}\frac{1}{k^2-m_q^2}\bar{u}(k,\lambda_q)\epsilon^*_\mu(P-k,\lambda_{\mathfrak{a}})\cdot\mathcal{Y}^\mu_{\mathfrak{a}}\,U(P,\lambda),$$

with scalar and axial-vector vertex $\mathcal{Y}_{\mathfrak{s}} = ig_{\mathfrak{s}}(k^2)\mathbf{1}$ and $\mathcal{Y}^\mu_{\mathfrak{a}} = ig_{\mathfrak{a}}(k^2)\gamma^\mu\gamma_5/\sqrt{2}$, sequentially.

Phys. Rev. D **78**, 074010 (2008)

Parametrization of the leading and higher-twist TMDs $\Phi_q^{\gamma^\alpha}$ for different combinations of λ in initial and final state ($\Uparrow\Uparrow, \Uparrow\Downarrow, \Downarrow\Downarrow, \Downarrow\Uparrow$)

γ^α	$\Phi^{[\gamma^\alpha](\Uparrow\Uparrow)}_{q\mathfrak{s}(\mathfrak{a})} + \Phi^{[\gamma^\alpha](\Downarrow\Downarrow)}_{q\mathfrak{s}(\mathfrak{a})}$	$\Phi^{[\gamma^\alpha](\Uparrow\Uparrow)}_{q\mathfrak{s}(\mathfrak{a})} - \Phi^{[\gamma^\alpha](\Downarrow\Downarrow)}_{q\mathfrak{s}(\mathfrak{a})}$	$\Phi^{[\gamma^\alpha](\Downarrow\Uparrow)}_{q\mathfrak{s}(\mathfrak{a})} + \Phi^{[\gamma^\alpha](\Uparrow\Downarrow)}_{q\mathfrak{s}(\mathfrak{a})}$	$\Phi^{[\gamma^\alpha](\Downarrow\Uparrow)}_{q\mathfrak{s}(\mathfrak{a})} - \Phi^{[\gamma^\alpha](\Uparrow\Downarrow)}_{q\mathfrak{s}(\mathfrak{a})}$
γ^+	$2f_1^q$	$\cdots$	$\frac{-2ik_y}{M} f_{1T}^{\perp}(q)$	$\frac{2k_x}{M} f_{1T}^{\perp}(q)$
γ_T^1	$\frac{2k_x}{P^+} f^{\perp}(q)$	$\frac{-2ik_y}{P^+} f_L^{\perp}(q)$	$\frac{2ik_xk_y}{MP^+} f_T^{\perp}(q)$	$\frac{-2M}{P^+}\left(f_T'(q) + \frac{k_x^2}{M^2} f_T^{\perp}(q)\right)$
γ_T^2	$\frac{2k_y}{P^+} f^{\perp}(q)$	$\frac{2ik_x}{P^+} f_L^{\perp}(q)$	$\frac{2iM}{P^+}\left(f_T'(q) + \frac{k_y^2}{M^2} f_T^{\perp}(q)\right)$	$\frac{-2k_xk_y}{MP^+} f_T^{\perp}(q)$
γ^-	$\frac{2M^2}{(P^+)^2} f_3^q$	$\cdots$	$\frac{-2ik_yM}{(P^+)^2} f_{3T}^{\perp}(q)$	$\frac{2k_xM}{(P^+)^2} f_{3T}^{\perp}(q)$

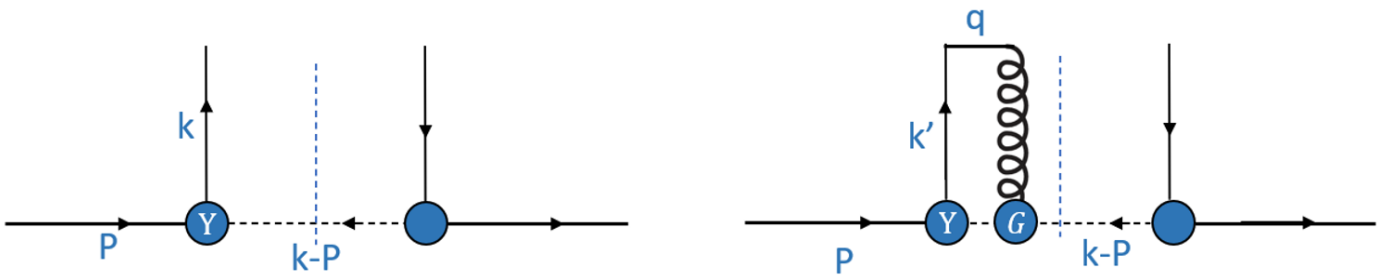
For T-even TMDS, the quark-quark correlator can be expressed as overlaps of the LFWFs

$$\Phi_{q\mathfrak{s}}^{[\gamma^\alpha](\lambda,\lambda')} = \frac{1}{16\pi^3} \sum_{\lambda_q} \sum_{\lambda_q'} \psi^{\lambda_q'}_{\lambda_q'}(x,\mathbf{k}_\perp)\, \psi^{\lambda}_{\lambda_q}(x,\mathbf{k}_\perp) \frac{\bar{u}(k,\lambda_q')\gamma^\alpha u(k,\lambda_q)}{2xP^+},$$

$$\Phi_{q\mathfrak{a}}^{[\gamma^\alpha](\lambda,\lambda')} = \frac{1}{16\pi^3} \sum_{\lambda_q} \sum_{\lambda_\mathfrak{a}} \sum_{\lambda_q'} \psi^{\lambda_q'}_{\lambda_q'\lambda_\mathfrak{a}}(x,\mathbf{k}_\perp)\, \psi^{\lambda}_{\lambda_q\lambda_\mathfrak{a}}(x,\mathbf{k}_\perp) \frac{\bar{u}(k,\lambda_q')\gamma^\alpha u(k,\lambda_q)}{2xP^+}.$$

Prog. Theor. Exp. Phys. **2024**, 103B05 (2024)

Tree-level diagrams for T-even and T-odd TMDs, with P, k and $k-P$ as proton, active quark and spectator diquark momentum



For T-odd TMDS, the quark-quark correlator can be expressed as overlaps of the LFWFs

$$\Phi_{q\mathfrak{s}}^{[\gamma^\alpha](\lambda,\lambda')} = i\int \frac{d^2\mathbf{q}_\perp}{16\pi^3}\sum_{\lambda_q}\sum_{\lambda_q'}\psi^{\lambda_q'}_{\lambda_q'}(x,\mathbf{k}_\perp)G(x,\mathbf{q}_\perp)\psi^{\lambda}_{\lambda_q}(x,\mathbf{k}'_\perp)\,\frac{\bar{u}(k,\lambda_q')\gamma^\alpha u(k',\lambda_q)}{2xP^+},$$

$$\Phi_{q\mathfrak{a}}^{[\gamma^\alpha](\lambda,\lambda')} = i\int \frac{d^2\mathbf{q}_\perp}{16\pi^3}\sum_{\lambda_q}\sum_{\lambda_\mathfrak{a}}\sum_{\lambda_q'}\psi^{\lambda_q'\lambda_\mathfrak{a}}_{\lambda_q'\lambda_\mathfrak{a}}(x,\mathbf{k}_\perp)G(x,\mathbf{q}_\perp)\psi^{\lambda}_{\lambda_q\lambda_\mathfrak{a}}(x,\mathbf{k}'_\perp)\,\frac{\bar{u}(k,\lambda_q')\gamma^\alpha u(k',\lambda_q)}{2xP^+},$$

where $G(x,\mathbf{q}_\perp)$ kernel: encodes the ISI/FSI in the gauge-link structure of the quark correlator.

Phys. Rev. D **78**, 074010 (2008),
Prog. Theor. Exp. Phys. **2024**, 103B05 (2024)

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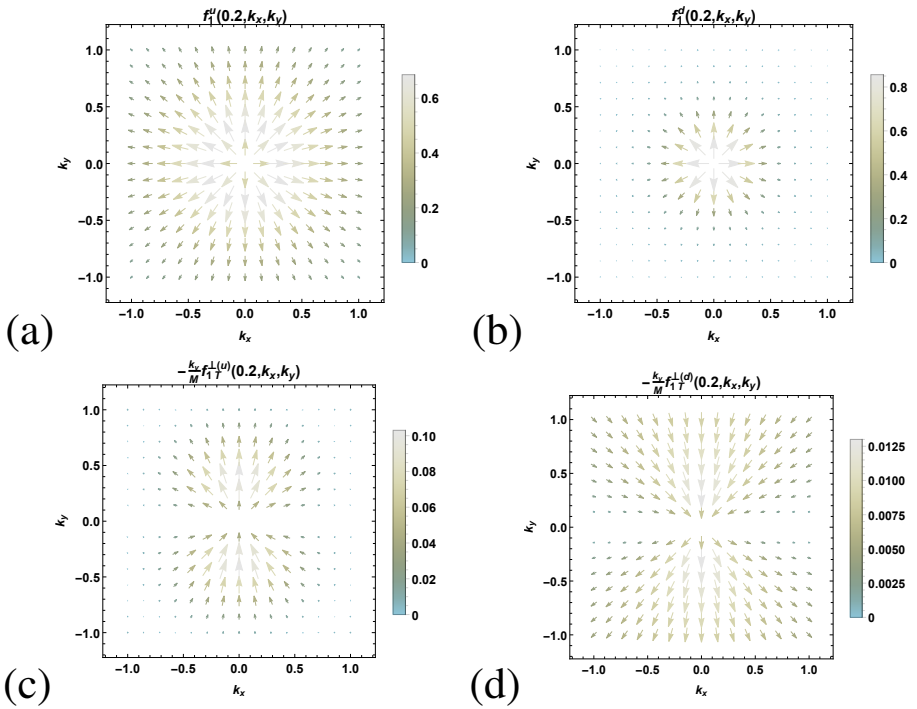
Quark longitudinal and transverse momentum densities

Components of the TMD EMT T^{++} for the u- and d-quark flavors of the proton in the transverse momentum $(k_x - k_y)$ plane

$$\mathbb{T}_q^{++} = xP^+\Phi_q^{[\gamma^+]} = \left(f_1^q - \frac{\epsilon_T^{k_T S_T}}{M} f_{1T}^{\perp(q)}\right) xP^+,$$

$$\mathbb{T}_q^{+i} = k_T^i \Phi_q^{[\gamma^+]} = \left(f_1^q - \frac{\epsilon_T^{k_T S_T}}{M} f_{1T}^{\perp(q)}\right) k_T^i.$$

- Term 1: unpolarized
- Term 2: hedgehog



Phys. Rev. D **114**, 014056 (2026)

Transverse flux of inertia

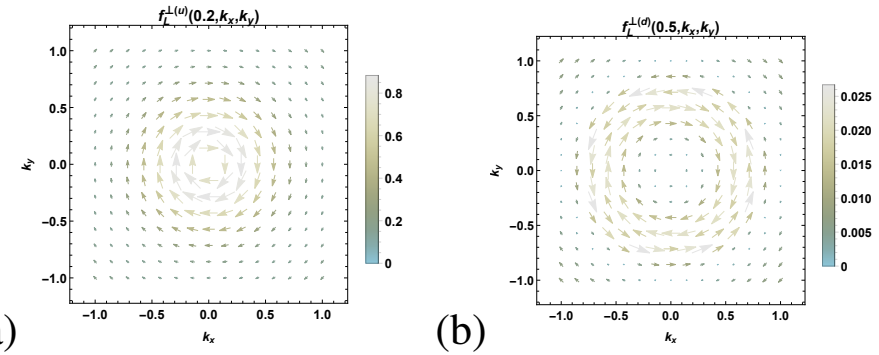
– Light-front longitudinal momentum plays the role of inertia in the transverse plane

$$v_i^{\perp} = \frac{\mathbb{T}_q^{i+}}{\mathbb{T}_q^{++}}$$

$$\mathbb{T}_q^{i+} = \left(x f^{\perp(q)} - M \frac{\epsilon_T^{k_T S_T}}{k_T^2} x f_T^{-(q)}\right) k_T^i - \left(\lambda_l x f_L^{\perp(q)} + \frac{M(k_T \cdot S_T)}{k_T^2} x f_T^{+(q)}\right) \epsilon_T^{ik_T} .$$

– Third component of the TMD EMT T^{i+}, $f_L^{\perp(q)}$, for (a) u- and (b) d-quark flavors of the proton in the transverse momentum $(k_x - k_y)$ plane

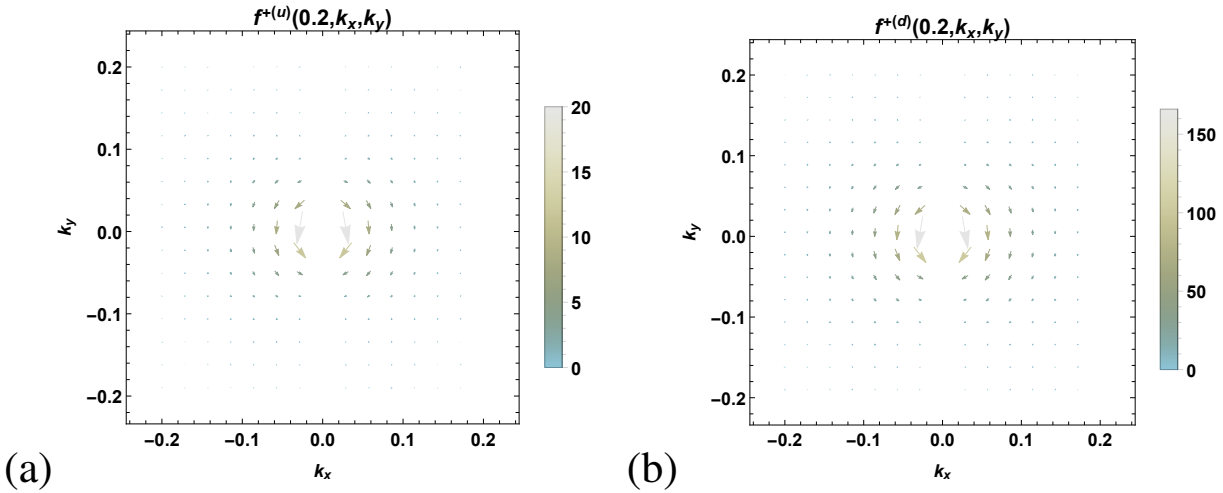
- Term 3 and 4: new ones in $\mathbb{T}_q^{i+}$
- Term 3: vortex like structure



(a) (b)

Phys. Rev. D **114**, 014056 (2026)

Fourth component of the TMD EMT T^{i+}, $f^{+(q)}$, for (a) u- and (b) d-quark flavors of the proton in the transverse momentum $(k_x - k_y)$ plane



- The rotational symmetry is partially broken and
- a dipole like pattern emerges near the central region
  due to its angular dependence with respect to the transverse spin direction

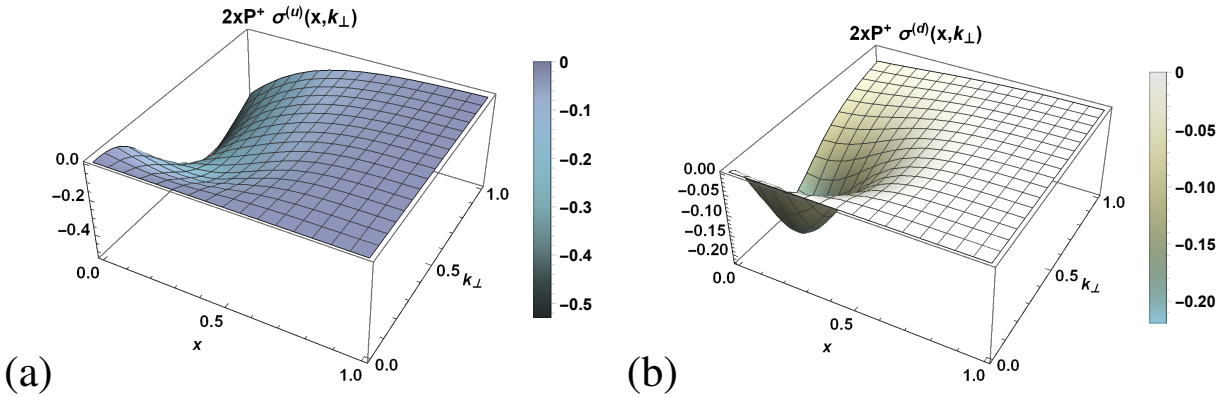
Phys. Rev. D **114**, 014056 (2026)

Pressure and Shear force distributions

$$2\sigma^q = -\frac{1}{P^+}\left[k_T^2\, f^{\perp(q)} - M\epsilon_T^{k_T S_T} f_T^{-(q)}\right],$$

– Here, $2\sigma^q = \Pi_q$

Pressure distribution for (a) u- and (b) d-quark flavors of the proton in the momentum-space



- u- quark distribution covers the wide range of $\mathbf{k}_\perp$
- Negative distribution: Attractive contribution

Phys. Rev. D **114**, 014056 (2026),
Phys. Lett. B **879**, 140686 (2026)

Summary

- Higher-twist parton distributions
  usually treated as power correction within the QCD factorization framework
  also carry important information about the gravitational TMD structure of hadrons
- Along with quark longitudinal and transverse momentum densities
  gets an information of transverse flux of inertia and mechanical properties
- Pressure (or shear force) | Twist-3 contribution only | negative distribution | Model dependent
- Future Prospect: Diquark Correlations in Hadron Structure

Acknowledgement
ECT*, Trento (Italy) and CSIR Foreign Travel Grant (India) for supporting participation in this workshop

Thank you !