



Gravitational form factors of baryons in a spectator diquark model

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Outline

- 1 *Energy momentum tensor*
- 2 *Generalized parton distributions*
- 3 *Results and discussion*

Energy momentum tensor

BARYONS are composite systems of partons.
To interpret the complex partonic dynamics

- Spin structure,
- Intrinsic motion of partons and
- Spin-orbit correlations.

Insight into these aspects is provided by

- Energy-momentum tensor (EMT),
- Gravitational form factors (GFFs) and
- Gravitational lens into baryon structure.

“There is no direct way to measure the GFFs, as it would require measurements of the graviton-proton interaction”

Energy momentum tensor

The energy-momentum tensor for a quark

$$T_q^{\mu\nu} = \bar{\psi}_q \gamma^\mu i D^\nu \psi_q$$

Matrix element of the EMT operator allows one to study

- mass
- spin as well as
- mechanical properties.

If γ^μ is replaced by $\sigma^{\lambda\mu}\gamma_5$, then the non-forward matrix elements of energy-momentum tensor can be parameterized

$$\begin{aligned} \langle p' | \bar{\psi} \sigma^{\lambda\mu} \gamma_5 i \overleftrightarrow{D}^\nu \psi | p \rangle &= \bar{u} \sigma^{\lambda\mu} \gamma_5 u \bar{p}^\nu A_{T20}(t) + \frac{\epsilon^{\lambda\mu\alpha\beta} \Delta_\alpha \bar{p}_\beta \bar{p}^\nu}{M^2} \bar{u} u \bar{A}_{T20}(t) \\ &+ \frac{\epsilon^{\lambda\mu\alpha\beta} \Delta_\alpha \bar{p}^\nu}{M^2} \bar{u} \gamma_\beta u B_{T20}(t) + \frac{\epsilon^{\lambda\mu\alpha\beta} \bar{p}_\alpha \Delta^\nu}{M^2} \bar{u} \gamma_\beta u \bar{B}_{T21}(t) \end{aligned}$$

Phys. Lett. B **774**, (2017)

EMT and measurable parton distributions

No fundamental probe coupling to $T_{q5}^{\lambda\mu\nu}$ is known in particle physics.

It is however possible to relate the corresponding GFFs to specific moments of measurable parton distributions.

$$A_{T20}^{X_q}(t) = \int dx x H_T^{X_q}(x, \xi, t),$$

$$\tilde{A}_{T20}^{X_q}(t) = \int dx x \tilde{H}_T^{X_q}(x, \xi, t)$$

$$B_{T20}^{X_q}(t) = \int dx x E_T^{X_q}(x, \xi, t),$$

$$-2\xi \tilde{B}_{T21}^{X_q}(t) = \int dx x \tilde{E}_T^{X_q}(x, \xi, t)$$

Phys. Rev. D **72**, 094020 (2005)

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2 *Generalized parton distributions*

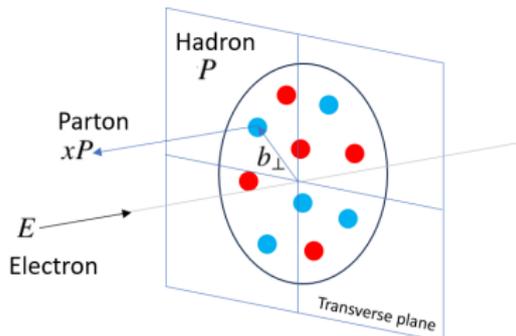
3 *Results and discussion*

Generalized Parton Distributions

$$F_{\lambda\lambda'}^{\Gamma} = \frac{1}{2} \int \frac{dz^-}{2\pi} e^{ik \cdot z} \langle p', \lambda' | \bar{\psi}\left(\frac{-z}{2}\right) \Gamma \psi\left(\frac{z}{2}\right) | p, \lambda \rangle \Big|_{z^+=0, \mathbf{z}_\perp=0}$$

with

- $\lambda(\lambda')$: Initial (final) state helicity.
- $P = \frac{p+p'}{2}$, average momentum.
- $\Delta = p' - p$, momentum transfer.
- Impact parameter space, $\Delta_\perp \leftrightarrow b_\perp$ via FT.
- Γ basis $[1, \gamma_5, \gamma^\mu, \gamma^\mu \gamma_5, \sigma^{\mu\nu}]$.



JHEP 08, 056 (2009)

Generalized Parton Distributions

$$F_{\lambda\lambda'}^{[i\sigma^{+i}\gamma^5]} = \frac{1}{2P_X^+} \bar{U}(P', \lambda') \left[H_T(x, \xi, -t) \sigma^{+i} \gamma_5 + \tilde{H}_T(x, \xi, -t) \frac{\epsilon^{+j\alpha\beta} \Delta_\alpha P_\beta}{M^2} \right. \\ \left. + E_T(x, \xi, -t) \frac{\epsilon^{+j\alpha\beta} \Delta_\alpha \gamma_\beta}{2M} + \tilde{E}_T(x, \xi, -t) \frac{\epsilon^{+j\alpha\beta} P_\alpha \gamma_\beta}{M} \right] U(P, \lambda)$$

Eur. Phys. J. A 52 (2016) 163.

quark pol.

		U	L	T	
nucleon pol.	U	H		$E_T + 2\tilde{H}_T$	
	L		\tilde{H}	\tilde{E}_T	
	T	E	\tilde{E}	H_T	\tilde{H}_T

$\Gamma = \gamma^+ : H \text{ \& } E$
unpolarized

$\Gamma = \gamma^+ \gamma^5 : \tilde{H} \text{ \& } \tilde{E}$
longitudinal polarized

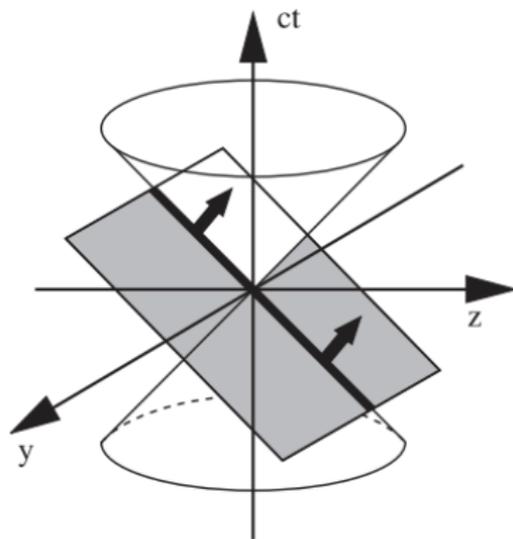
$\Gamma = i\sigma^{+i}\gamma^5 : H_T, E_T, \tilde{H}_T \text{ \& } \tilde{E}_T$
transversely polarized

Partonic interpretation

A generic four Vector x^μ in light-cone coordinates is describe as $x^\mu = (x^-, x^+, x_\perp)$.

- $x^+ = x^0 + x^3$ is called as **light-front time**.
- $x^- = x^0 - x^3$ is called as **light-front longitudinal space variable**.
- $x^\perp = (x^1, x^2)$ is the **transverse variable**.

Similarly, we can define the longitudinal momentum $p^+ = p^0 + p^3$ and light-front energy $p^- = p^0 - p^3$.



The front form

arXiv:hep-ph/9612244 [hep-ph]

Spectator diquark model

The instant form wave function of proton

$$|p\rangle^{\uparrow,\downarrow} = \frac{1}{\sqrt{2}} |u \, s(ud)\rangle^{\uparrow,\downarrow} - \frac{1}{\sqrt{6}} |u \, a(ud)\rangle^{\uparrow,\downarrow} + \frac{1}{\sqrt{3}} |d \, a(uu)\rangle^{\uparrow,\downarrow}$$

Probabilistic weight among

- scalar isoscalar $s(ud)$
- vector isoscalar $a(ud)$
- vector isovector $a(uu)$ comes out to be 3:1:2.

Similarly,

$$|\Sigma^+\rangle^{\uparrow,\downarrow} = \frac{1}{\sqrt{2}} |u \, s(us)\rangle^{\uparrow,\downarrow} - \frac{1}{\sqrt{6}} |u \, a(us)\rangle^{\uparrow,\downarrow} + \frac{1}{\sqrt{3}} |s \, a(uu)\rangle^{\uparrow,\downarrow},$$

$$|\Xi^0\rangle^{\uparrow,\downarrow} = \frac{1}{\sqrt{2}} |s \, s(us)\rangle^{\uparrow,\downarrow} + \frac{1}{\sqrt{6}} |s \, a(us)\rangle^{\uparrow,\downarrow} - \frac{1}{\sqrt{3}} |u \, a(ss)\rangle^{\uparrow,\downarrow}.$$

Phys. Rev. C **93**, 065209 (2016)

Spectator diquark model

Light-cone wave function for scalar diquark

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

Light-cone wave function for axial-vector diquark

$$\psi_{\lambda_q \lambda_a}^{\lambda}(x, \mathbf{k}_{\perp}) = \sqrt{\frac{k^+}{(P-k)^+}} \frac{1}{k^2 - m_q^2} \bar{u}(k, \lambda_q) \epsilon_{\mu}^*(P-k, \lambda_a) \cdot \mathcal{Y}_a^{\mu} U(P, \lambda).$$

- \mathcal{Y}_s - contribution of scalar vertex
- \mathcal{Y}_a^{μ} - contribution of axial-vector vertex
- λ - baryon helicity
- λ_q - quark helicity
- λ_a - axial-vector diquark helicity
- $\epsilon_{\mu}^*(P-k, \lambda_a)$ - four-vector polarization of spin-1 diquark
- $u(k, \lambda_q)$ - spin $-\frac{1}{2}$ Dirac spinor of active quark with momentum k
- $U(P, \lambda_q)$ - spin $-\frac{1}{2}$ Dirac spinor of baryon with momentum P

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

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Baryon		p_u	Ξ_u^0
$g_T^{X_q}$	This work	1.249	-0.313
	χ QSM	1.08	-0.32
	HYP model	0.97	-
	HO model	1.17	-
	Relativistic model	1.008	-
	LFQM	1.167	-
	Chiral soliton model	1.12	-
	MIT bag model	1.105	-
	Lattice QCD	0.84	-
	Lattice QCD	0.791 ± 0.053	-
	Meson electroproduction	0.876	-
	BLFQ	1.251	-
	Data analysis	$0.39^{+18}_{-0.12}$	-
	Data analysis	$0.39^{+16}_{-0.20}$	-
Data analysis	0.39 ± 0.15	-	

Table 1: Comparison of tensor charge $g_T^{X_q}$ for u quark flavor of non-strange and strange baryons with available data.

Phys. Rev. D **112**, 074024 (2025), Phys. Rev. D **82**, 034022 (2010), Phys. Rev. D **72**, 094029 (2005), Phys. Rev. D **94**, 114030 (2016), Phys. Lett. B **407**, 331-334 (1997), Phys. Lett. B **387**, 577 (1996), Phys. Rev. D **11**, 3309 (1975), Phys. Rev. D **56**, 433-436 (1997), Phys. Rev. D **93**, 039904 (2016), Eur. Phys. J. A **47**, 112 (2011), Phys. Rev. D **109**, 014015 (2024), Phys. Rev. D **87**, 094019 (2013), Phys. Rev. D **93**, 014009 (2016), JHEP **05**, 123 (2015)

Baryon		p_u	Ξ_u^0
κ_T^{Xq}	This work	3.64	2.489
	HYP model	1.98	-
	HO model	3.60	-
	BLFQ	3.208	-
	Relativistic model	4.065	-
	Reggeized model	3.43 ± 0.26	-

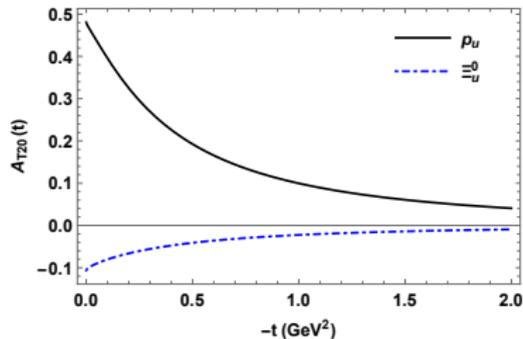
Table 2: Comparison of anomalous tensor magnetic moment κ_T^{Xq} quark flavor of non-strange and strange baryons with available data.

Phys. Rev. D **112**, 074024 (2025),
 Phys. Rev. D **72**, 094029 (2005),
 Phys. Rev. D **109**, 014015 (2024),
 Phys. Rev. D **94**, 114030 (2016),
 arXiv:1401.0438 [hep-ph]

Chiral-odd GPD $H_T(x, 0, t)$

By taking second moment of chiral-odd GPD H_T , we have GFF A_{T20}

$$A_{T20}(t) = \int dx x H_T(x, \xi, t)$$

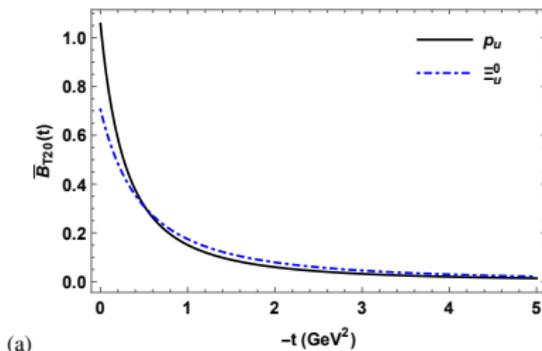


- For the case of proton, BLFQ predicts $A_{T20}^{p_u}(0) = 0.445$, comparable with our model result $A_{T20}(0) = 0.480$
- Ξ_u^0 has negative values.
- For the case of Ξ^0 , $A_{T20}^{\Xi_u^0}(0) = -0.106$.
- Contribution of u quark flavor for the case of Ξ^0 comes out to be smaller than p .

Chiral-odd GPD $E_T(x, 0, t) + 2\tilde{H}_T(x, 0, t)$

By taking second moment of chiral-odd GPD \tilde{H}_T and E_T , we have GFF \bar{B}_{T20}

$$\bar{B}_{T20}(t) = \int dx x (2\tilde{H}_T(x, \xi, t) + E_T(x, \xi, t))$$



- For the case of proton, BLFQ predicts $\bar{B}_{T20}^{p_u}(0) = 0.802$, discrepancy with our model result $\bar{B}_{T20}(0) = 1.057$.
- For the case of Ξ^0 , $A_{T20}^{\Xi^0}(0) = 0.706$.
- Contribution of u quark flavor for the case of Ξ^0 comes out to be smaller than p .

Quark transverse asymmetry $\langle \delta^x J_u^x \rangle$

- These GFFs are used to provide a decomposition of the quark angular momentum w.r.t. quarks of definite transversity.
- According to Burkardt, this quantity is one half of the expectation value of the transversity asymmetry
- Comparison with available model predictions

$$\langle \delta^x J_q^x \rangle = \frac{A_{T20}(0) + 2\bar{A}_{T20}(0) + B_{T20}(0)}{2}$$

$\langle \delta^x J_u^x \rangle$	This work	LF χ QSM	LFCQM	BLFQ	HO
p	0.768	0.745	0.737	0.62	0.68
Ξ^0	0.30	-	-	-	-

Phys. Lett. B **774**, 435-440 (2017),
 Phys. Rev. D **79**, 014033 (2009),
 Phys. Rev. D **72**, 094029 (2005) and
 Phys. Rev. D **109**, 014015 (2024).

Summary

u quark flavor of Ξ^0

- shows **complementary roles** in proton and Ξ^0 in case of GFF A_{T20} , owing to the flavor dependence of transversity distributions.
- has **smaller values** of GFFs at zero momentum transfer.
- The **expectation value of the transversity asymmetry** of u quark flavor comes out to be **61% less** compared to its corresponding value in the proton

Thank You!

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