Timelike Compton scattering on a deuteron target

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In collaboration with Jing Han, Prof. Bo-Qiang Ma and Prof. Bernard Pire

Outline

- Puzzle in tensor-polarized structure of deuteron
- GPDs and three-dimensional partonic structure of deuteron
- Deuteron timelike Compton scattering

Spin parameters for spin-1 hadrons

Spin parameters for spin-1 hadrons

- Vector polarization S (3 parameters): same as the case of proton
- Tensor polarization T (5 Parameters): unique in spin-1 hadrons

Covariant form of the matrix T:

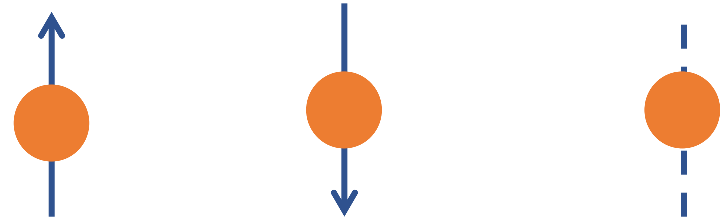
$$T^{\mu\nu} = \frac{1}{2}\left[\frac{4}{3}S_{LL}\frac{(P^+)^2}{M^2}\bar{n}^\mu\bar{n}^\nu - \frac{2}{3}S_{LL}(\bar{n}^{\{\mu}n^{\nu\}} - g_T^{\mu\nu}) + \frac{1}{3}S_{LL}\frac{M^2}{(P^+)^2}n^\mu n^\nu \right.$$
$$\left. + \frac{P^+}{M}\bar{n}^{\{\mu}S_{LT}^{\nu\}} - \frac{M}{2P^+}n^{\{\mu}S_{LT}^{\nu\}} + S_{TT}^{\mu\nu}\right],$$

$$n^\mu = \frac{1}{\sqrt{2}}(\,1,\,0,\,0,\,-1\,),\quad \bar{n}^\mu = \frac{1}{\sqrt{2}}(\,1,\,0,\,0,\,1\,)$$

A. Bacchetta and P. Mulders, PRD 62, 114004 (2000)

Spin parameters of tensor polarization

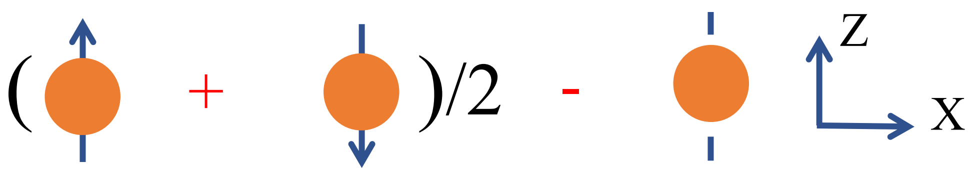
Three spin projections along z axis for spin-1 hadrons:



spin up spin down spin projection of 0

In comparison with a spin-1 hadron, the spin projection of a spin-1/2 hadron can not be 0, thus, one can infer that the tensor polarization must be related to the state with a spin projection of 0.

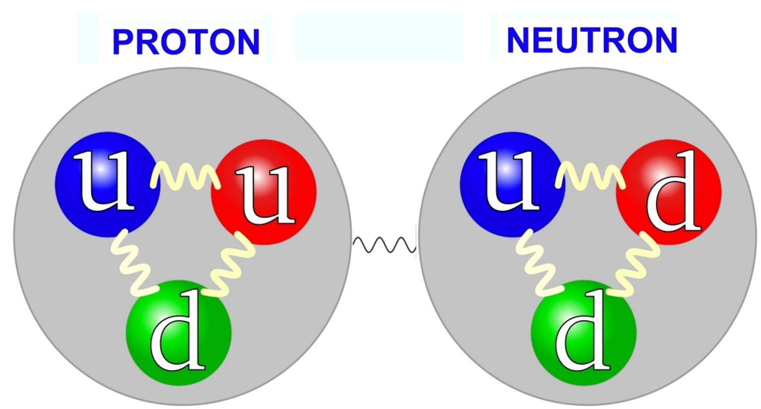
$S_{LL} =$



A. Bacchetta and P. Mulders, PRD 62, 114004 (2000)

Tensor polarized structure of a spin-1 deuteron

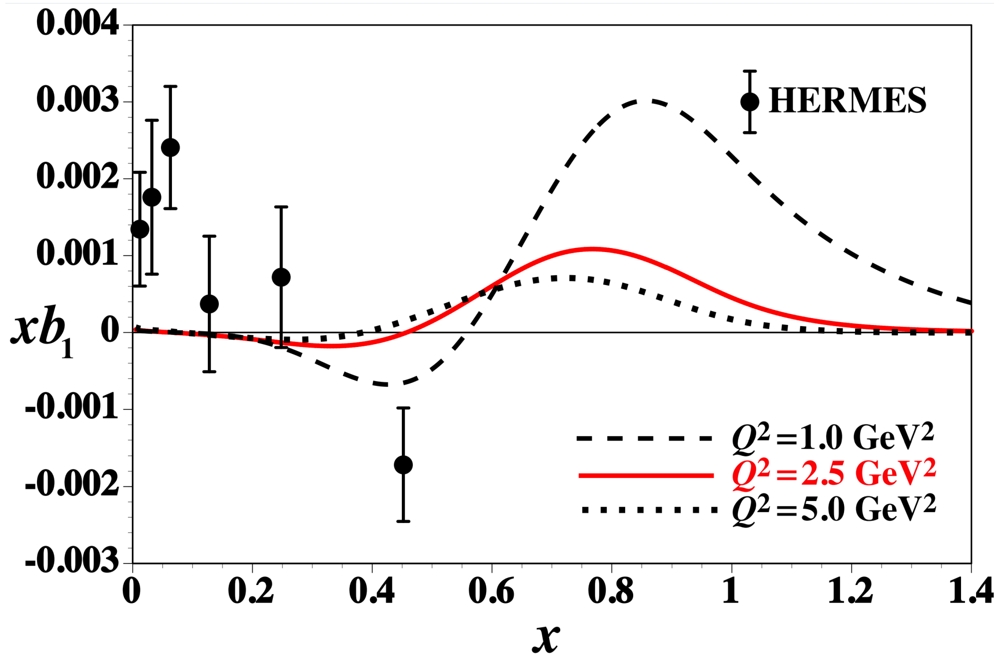
Standard model of deuteron: a loosely bound state of proton and neutron, s wave is dominant, d-wave component is tiny.



deuteron

First experimental measurement of b_1

Hermes measurements of b_1 are much larger than the theoretical predictions based on that deuteron is a S-D mixture.



H.Khan and P. Hoodhoy, PRC 44 (1991) 1219.
A. Y. Umnikov, PLB 391(1997), 177-184.
W. Cosyn, *et al* PRD 95 (2017), 074036.
A. Airapetian *et al.* (HERMES), PRL 95 (2005) 242001.

The large b_1 could indicate the existence of non-nucleonic components such as six-quark and hidden-color components in deuteron.

$$|6q\rangle = \sqrt{1/9}|N^2\rangle + \sqrt{4/45}|\Delta^2\rangle + \sqrt{4/5}|CC\rangle$$

G. A. Miller, PRC 89(2014), 045203.

Future measurements on tensor-polarized structure of deuteron

To solve this puzzle, b_1 will be measured at Jlab (DIS) and Fermilab (Drell-Yan process) in the near future!

PR12-13-011

Full approval in 2023

The Deuteron Tensor Structure Function b_1

A Proposal to Jefferson Lab PAC-40
(Update to PR12-11-110)

For the future b_1 experiment, there is a tensor meeting everyweek at JLab. In 2023, the first conference of "Tensor spin observables" was held at ECT*, Italy

E1039 experiment at Fermilab: Drell-Yan process with unpolarizd 120 GeV proton beam and tensor-polarized deuteron target.

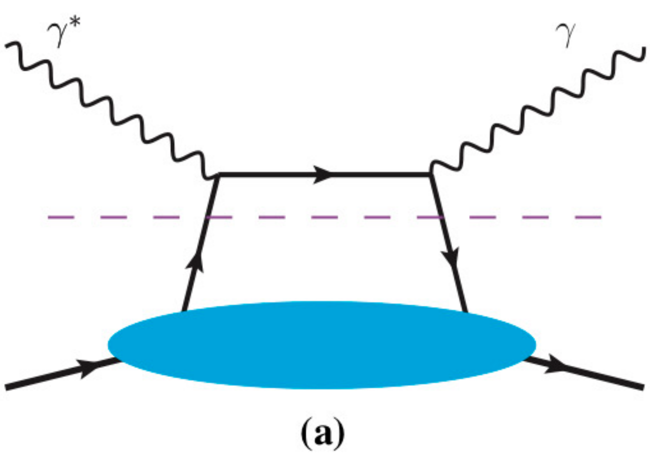
The SpinQuest Collaboration, arXiv:2205.01249v1.
D. Keller, D. Crabb, and D. Day, Nucl. Instrum. Meth. A 981(2020), 164504.
J. Clement and D. Keller, Nucl. Instrum. Meth. A 1050 (2023), 168177

GPDs and three-dimensional partonic structure of deuteron

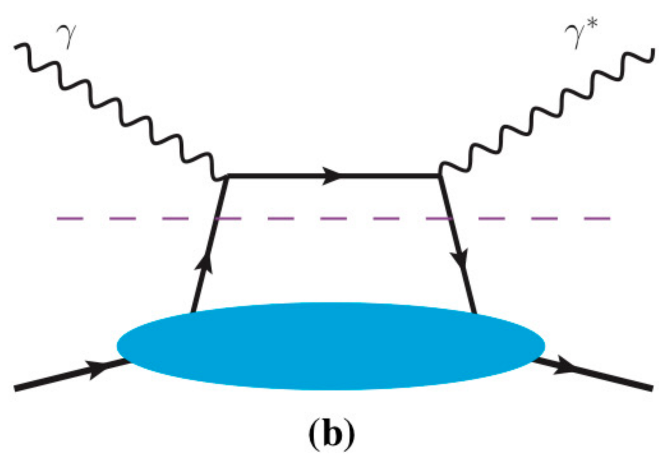
Puzzle in deuteron structure ⟷ Three-dimensional GPDs.

Three golden channels to access the hadron GPDs:

- DVCS: $\gamma^* + h \to \gamma + \mathrm{h}$
- Timelike Compton scattering (TCS) : $\gamma + h \to \gamma^* + \mathrm{h}$
- DVMP: $\gamma^* + h_1 \to \mathrm{M} + \mathrm{h}_2$



DVCS



TCS

See the talks of Prof. Zhihong Ye, Guang Tang, Zheyu Wang and Yaopeng Zhang.

Studies on deuteron GPDs

Theoretically studies on deuteron GPDs using effective models:

F. Cano and B.Pire, NPA721 (2003), 789-792.
A. Kirchner and D. Müller, EPJC 32 (2006) 347–375.
Y. Dong and C. Liang, JPG 40 (2013), 025001.
S. Mamedov, M. Allahverdiyeva and N.Akbarova, EPJC 85(2025), 361.
….

Experimental measurements on deuteron DVCS:

HERMES, NPB 829 (2010), 1-27.
M. Benali, et al., Nature Physics 16 (2020) no.2, 191-198.

Experimental measurements on deuteron DVMP ($\gamma^* + \mathrm{d} \to \pi^0 + \mathrm{d}$):

Jefferson Lab Hall A, PRL 118 (2017) 22, 222002.

The study of deuteron TCS still remain lacking. In contrast, JLab has recently reported the first measurement on proton TCS.

P. Chatagnon et al. [CLAS], PRL 127 (2021), 262501.

We will mainly discuss the deuteron TCS in this talk, both theoretical formalisms and numerical estimate will be provided for the cross section.

Kinematics of deuteron TCS

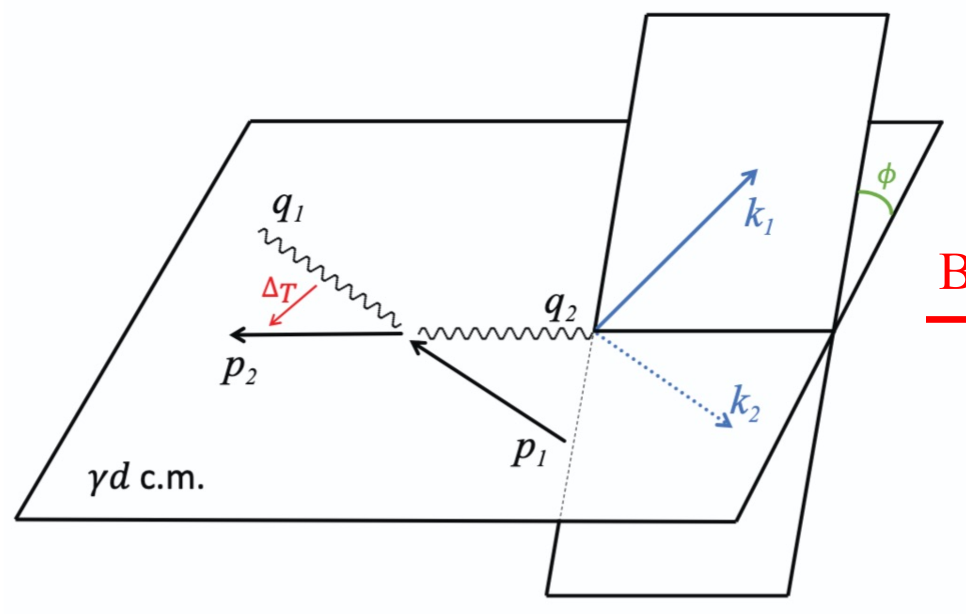
$$\gamma(q_1) + d(p_1) \to \gamma^*(q_2) + d(p_2) \to e^-(k_1)e^+(k_2) + d(p_2)$$

$$(q_2)^2 = (k_1 + k_2)^2 = Q^2, \quad t = \Delta^2 = (p_1 - p_2)^2, \quad P = p_1 + p_2, \quad q = \frac{1}{2}(q_1 + q_2)$$

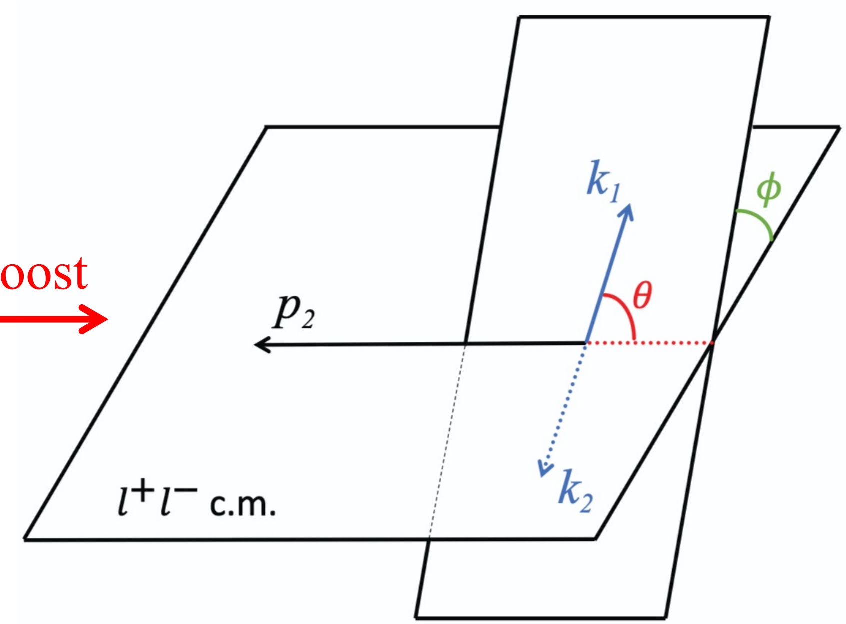
$$(q_1)^2 = 0, \quad \xi = -\frac{q^2}{P \cdot q}, \quad \eta = -\frac{\Delta \cdot q_1}{P \cdot q_1}, \quad \tau = \frac{Q^2}{2p_1 \cdot q_1},$$

η is the skewness parameter that characterizes the longitudinal momentum transfer in the limit $Q^2 \gg t$:

$$\eta = -\xi = \frac{(p_1 - p_2)^+}{(p_1 + p_2)^+}$$



Boost



γd c.m. frame

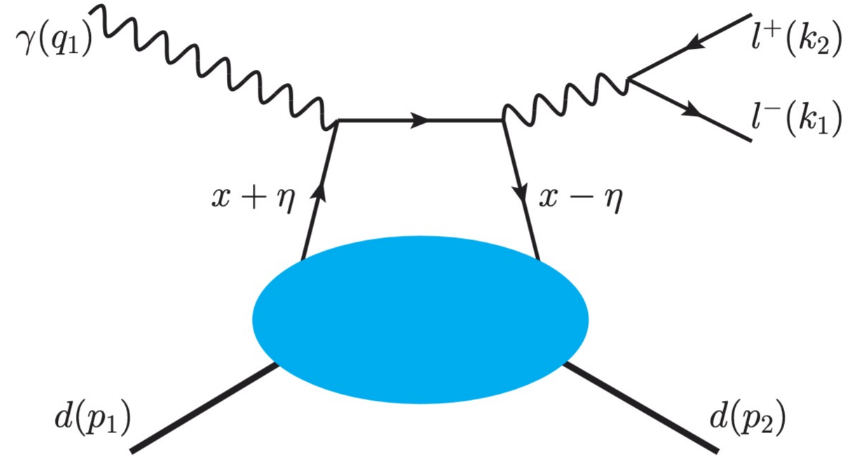
c.m. frame of lepton pair

Deuteron TCS

The reaction $\gamma + d \to e^{-}e^{+} + d$ receives contributions from two subprocesses.

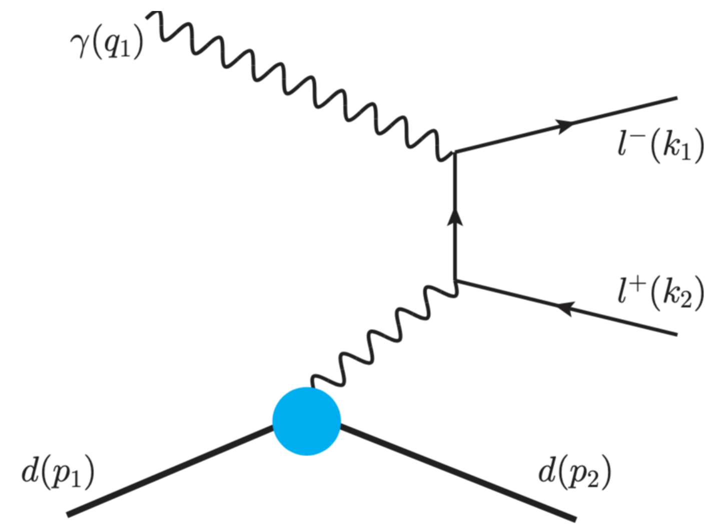
(1) TCS subprocess:

The TCS amplitude involves deuteron GPDs within QCD collinear factorization.



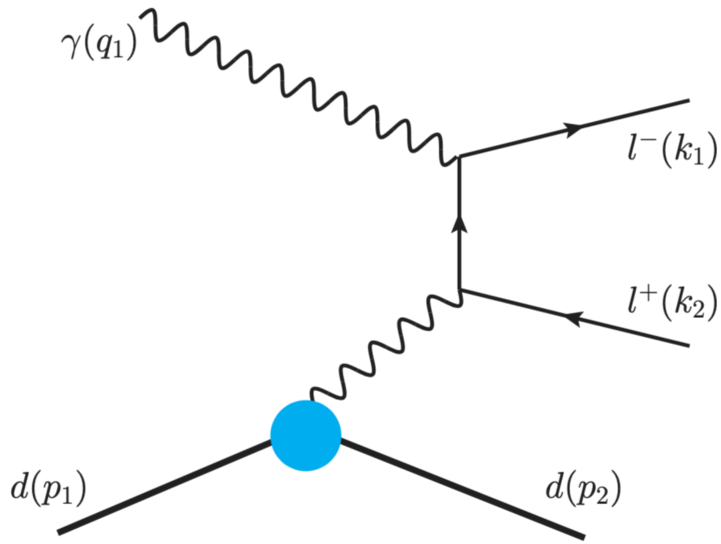
(2) Bethe–Heitler (BH) subprocess:

The $\gamma^* d \to d$ vertex is described by the deuteron EM FFs.



The deuteron EM FFs will be needed for the extraction of GPDs, which have been parameterized in literature.

Bethe–Heitler contribution



Bethe–Heitler (BH) subprocess：

EM FFs of deuteron:

$$J_\mu = -G_1(\epsilon_2^* \cdot \epsilon_1)P_\mu + G_2\left[\epsilon_{1\mu}(\epsilon_2^* \cdot P) + \epsilon_{2\mu}^*(\epsilon_1 \cdot P)\right] - G_3(\epsilon_1 \cdot P)(\epsilon_2^* \cdot P)\frac{P_\mu}{2m^2}$$

Electric FF, magnetic FF, and quadrupole FF (reflects the D-wave component of the deuteron).

BH cross section:

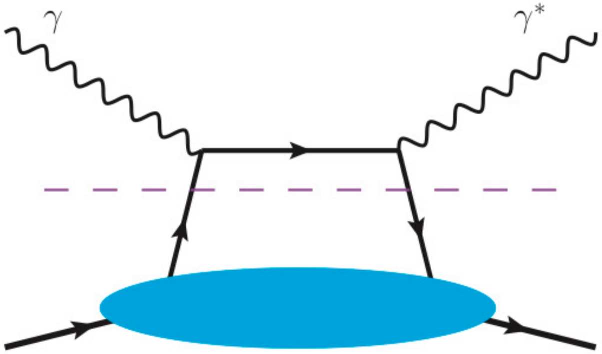
$$\frac{d\sigma_{\rm BH}}{d\tau dt d\cos\theta d\phi} = \frac{\alpha_{\rm em}^3}{12\pi s}\frac{1}{-t}\frac{1+\cos^2\theta}{\sin^2\theta}\Bigg\{ -4(\delta-1)|G_2|^2 - \frac{\Delta_T^2}{\tau^2 t}\Big[4\Big(4(\delta-1)\delta+3\Big)|G_1|^2 + 8(2\delta-1)\delta|G_2|^2$$
$$+16(\delta-1)^2\delta^2|G_3|^2 - 16(2\delta-1)\delta(G_1G_2) - 16\big(1+\delta(2\delta-3)\big)\delta(G_1G_3)$$
$$+32(\delta-1)\delta^2(G_2G_3)\Big)\Big]\Bigg\}$$

TCS contribution

Hadronic tensor at leading twist and leading order

$$T_1^{\mu\nu} = \boxed{-g_T^{\mu\nu} V} + \boxed{i\varepsilon_T^{\mu\nu} A}$$

Vector part Axial-vector part



(b)

$$V = -(\epsilon_2^* \cdot \epsilon_1)\,\mathcal{H}_1 + \frac{(\epsilon_1 \cdot q_1)(\epsilon_2^* \cdot P) + (\epsilon_2^* \cdot q_1)(\epsilon_1 \cdot P)}{P \cdot q_1}\mathcal{H}_2 - \frac{(\epsilon_1 \cdot P)(\epsilon_2^* \cdot P)}{2M^2}\mathcal{H}_3 + \frac{(\epsilon_1 \cdot q_1)(\epsilon_2^* \cdot P) - (\epsilon_2^* \cdot q_1)(\epsilon_1 \cdot P)}{P \cdot q_1}\mathcal{H}_4 + \left[4m^2\frac{(\epsilon_1 \cdot q_1)(\epsilon_2^* \cdot q_1)}{(P \cdot q_1)^2} + \frac{1}{3}(\epsilon_2^* \cdot \epsilon_1)\right]\mathcal{H}_5$$

$$A = i\frac{\varepsilon_{q_1\epsilon_2^*\epsilon_1 P}}{P \cdot q_1}\widetilde{\mathcal{H}}_1 - i\frac{\varepsilon_{q_1\Delta P\gamma}}{P \cdot q_1}\frac{\epsilon_1^\gamma(\epsilon_2^* \cdot P) + \epsilon_2^{*\gamma}(\epsilon_1 \cdot P)}{m^2}\widetilde{\mathcal{H}}_2 - i\frac{\varepsilon_{q_1\Delta P\gamma}}{P \cdot q_1}\frac{\epsilon_1^\gamma(\epsilon_2^* \cdot P) - \epsilon_2^{*\gamma}(\epsilon_1 \cdot P)}{m^2}\widetilde{\mathcal{H}}_3 - i\frac{\varepsilon_{q_1\Delta P\gamma}}{P \cdot q_1}\frac{\epsilon_1^\gamma(\epsilon_2^* \cdot q_1) + \epsilon_2^{*\gamma}(\epsilon_1 \cdot q_1)}{P \cdot q_1}\widetilde{\mathcal{H}}_4$$

The nine Compton FFs (CFFs) $\mathcal{H}_i$ are defined as

deuteron GPD

$$\mathcal{H}_i = \sum_q \int dx (e_q)^2 \left(\frac{1}{\eta - x + i\varepsilon} - \frac{1}{\eta + x + i\varepsilon}\right)\boxed{H_i^q}$$

TCS contribution

The TCS cross section can be expressed in terms of nine CFFs

$$\frac{d\sigma_{\mathrm{TCS}}}{d\tau dt d\cos\theta d\phi} = \frac{\alpha_{\mathrm{em}}^3}{24\pi s Q^2}(1+\cos^2\theta)\Bigg\{\frac{1}{2}\big[4(\delta-1)\delta+3\big]|\mathcal{H}_1|^2 - 2\delta(2\delta-1)\mathrm{Re}(\mathcal{H}_1\mathcal{H}_2^*)$$
$$-2\delta(\delta-1)(2\delta-1)\mathrm{Re}(\mathcal{H}_1\mathcal{H}_3^*) - 2(\delta-1)(2\delta-1)\eta\mathrm{Re}(\mathcal{H}_1\mathcal{H}_4^*)$$
$$+\frac{1}{3}\Big[\big(9-4(\delta-1)\delta\big)\eta^2 + 2\delta(5-2\delta)(1-\eta^2)\Big]\mathrm{Re}(\mathcal{H}_1\mathcal{H}_5^*) + 4(\delta-1)\delta^2$$
$$\times\mathrm{Re}(\mathcal{H}_2\mathcal{H}_3^*) + 4\delta(\delta-1)\eta\mathrm{Re}(\mathcal{H}_2\mathcal{H}_4^*) + \frac{2}{3}(\delta-2)(2\delta+3\eta^2)\mathrm{Re}(\mathcal{H}_2\mathcal{H}_5^*)$$
$$+\big[-\eta^2+2\delta^2-\delta(1-\eta^2)\big]|\mathcal{H}_2|^2 + 2\delta^2(\delta-1)^2|\mathcal{H}_3|^2 + 4(\delta-1)^2\delta\eta$$
$$\times\mathrm{Re}(\mathcal{H}_3\mathcal{H}_4^*) + \frac{2}{3}\Big[(2\delta-1)\big((\delta-1)\delta-3\big)\eta^2 + \delta\big(2(\delta-3)\delta+1\big)(1-\eta^2)\Big]$$
$$\times\mathrm{Re}(\mathcal{H}_3\mathcal{H}_5^*) + \frac{2}{3}\eta\Big[(\delta+1)(2\delta-5)\eta^2 + 2\big((\delta-3)\delta-1\big)(1-\eta^2)\Big]\mathrm{Re}(\mathcal{H}_4\mathcal{H}_5^*)$$
$$+\Big[\big(2(\delta-2)\delta+1\big)\eta^2 - \delta(1-\eta^2)\Big]|\mathcal{H}_4|^2 + \frac{1}{18}\big[4\delta^2 - 4\delta\eta^2 - 16\delta(1-\eta^2)$$
$$+9\eta^4 - 36\eta^2 + 6\big]|\mathcal{H}_5|^2 + \frac{\Delta_T^2}{m^2}(1+\eta)^2\big[-2(\delta-1)\mathrm{Re}(\widetilde{\mathcal{H}}_1\widetilde{\mathcal{H}}_2^*) + \frac{1}{2}\mathrm{Re}(\widetilde{\mathcal{H}}_1\widetilde{\mathcal{H}}_4^*)$$
$$-2\delta\mathrm{Re}(\widetilde{\mathcal{H}}_2\widetilde{\mathcal{H}}_4^*) + 4\delta(\delta-1)|\widetilde{\mathcal{H}}_2|^2 + 2(\delta-1)\eta\mathrm{Re}(\widetilde{\mathcal{H}}_3\widetilde{\mathcal{H}}_4^*) + 4\delta(\delta-1)|\widetilde{\mathcal{H}}_3|^2$$
$$+\frac{1}{4}(1+\eta^2)|\widetilde{\mathcal{H}}_4|^2\big] + (1-\delta)(1-\eta^2)|\widetilde{\mathcal{H}}_1|^2\Bigg\}$$

Interference contribution

The interference contribution between the TCS and BH subprocesses:

$$\frac{d\sigma_{\rm INT}}{d\tau dt d\cos\theta d\phi} = \frac{\alpha_{\rm em}^3}{3\pi}\frac{\Delta_T}{Q^3 t}\left(\frac{1+\cos^2\theta}{\sin\theta}\cos\phi\right){\rm Re}\Bigg\{\frac{1}{2}\mathcal{H}_1\Big[\Big((4(\delta-1)\delta+3)G_1 - 2\delta(2\delta-1)\big(G_2+(\delta-1)G_3\big)\Big)\Big]$$
$$+\delta\mathcal{H}_2\Big[\big(-(2\delta-1)G_1+(2\delta-1)G_2+2\delta(\delta-1)G_3\big)\Big]+(\delta-1)\delta\mathcal{H}_3\Big[\Big(-(2\delta-1)G_1+2\delta$$
$$\times\left(G_2+(\delta-1)G_3\right)\Big)\Big]+(\delta-1)\eta\mathcal{H}_4\Big[\Big(-(2\delta-1)G_1+2\delta\big(G_2(\delta-1)G_3\big)\Big)\Big]-\frac{1}{3}\mathcal{H}_5$$
$$\times\Big[\Big(\frac{1}{2}(4(\delta-1)\delta-9)\eta^2+(2\delta-5)\delta(1-\eta^2)\Big)G_1-((\delta+1)(2\delta-3)\eta^2+2(\delta-2)\delta(1-\eta^2))$$
$$\times G_2-\Big((2\delta-1)\big((\delta-1)\delta-3\big)\eta^2+\delta\big(2(\delta-3)\delta+1\big)(1-\eta^2)\Big)G_3\Big]+\eta G_2\Big[(\delta-1)\widetilde{\mathcal{H}}_1$$
$$-4(\delta-1)\delta\widetilde{\mathcal{H}}_2+\delta\widetilde{\mathcal{H}}_4\Big]\Bigg\}$$

The interference term depends on both the deuteron CFFs and EM FFs.

Because the lepton pair has opposite charge-conjugation parity in the two subprocesses, the interference term can be isolated by the transformation $(\theta,\varphi)\to(\pi-\theta,\pi+\varphi)$

$$d\sigma_{\rm BH}\to d\sigma_{\rm BH},\quad d\sigma_{\rm TCS}\to d\sigma_{\rm TCS},\quad d\sigma_{\rm INT}\to -d\sigma_{\rm INT}$$

Forward-backward asymmetry

We further define the forward–backward asymmetry (AFB), which has recently been measured in proton TCS.

PRL 127 (2021), 262501.

$$A_{FB}(\theta) = \frac{\int_{\pi/2}^{3\pi/2} d\phi \frac{d\sigma(\theta,\phi)}{d\cos\theta\ d\phi} - \int_{3\pi/2}^{2\pi} d\phi \frac{d\sigma(\pi-\theta,\phi)}{d\cos\theta\ d\phi} - \int_{0}^{\pi/2} d\phi \frac{d\sigma(\pi-\theta,\phi)}{d\cos\theta\ d\phi}}{\int_{\pi/2}^{3\pi/2} d\phi \frac{d\sigma(\theta,\phi)}{d\cos\theta\ d\phi} + \int_{3\pi/2}^{2\pi} d\phi \frac{d\sigma(\pi-\theta,\phi)}{d\cos\theta\ d\phi} + \int_{0}^{\pi/2} d\phi \frac{d\sigma(\pi-\theta,\phi)}{d\cos\theta\ d\phi}}$$

The numerator of A_{FB} is expressed as

$$\begin{aligned}
\frac{d\sigma_{\mathrm{FB}}}{d\tau dt d\cos\theta} = &-\frac{4\alpha_{\mathrm{em}}^3}{3\pi}\frac{\Delta_T}{Q^3 t}\Big(\frac{1+\cos^2\theta}{\sin\theta}\Big)\mathrm{Re}\Big\{\frac{1}{2}\mathcal{H}_1\Big[\Big(\big(4(\delta-1)\delta+3\big)G_1 - 2\delta(2\delta-1)\big(G_2+(\delta-1)G_3\big)\Big)\Big] \\
&+\delta\mathcal{H}_2\Big[\Big(-(2\delta-1)G_1+(2\delta-1)G_2+2\delta(\delta-1)G_3\Big)\Big]+(\delta-1)\delta\mathcal{H}_3\Big[\Big(-(2\delta-1)G_1+2\delta \\
&\times\big(G_2+(\delta-1)G_3\big)\Big)\Big]+(\delta-1)\eta\mathcal{H}_4\Big[\Big(-(2\delta-1)G_1+2\delta\big(G_2(\delta-1)G_3\big)\Big)\Big]-\frac{1}{3}\mathcal{H}_5 \\
&\times\Big[\Big(\frac{1}{2}\big(4(\delta-1)\delta-9\big)\eta^2+(2\delta-5)\delta(1-\eta^2)\Big)G_1-\big((\delta+1)(2\delta-3)\eta^2+2(\delta-2)\delta(1-\eta^2)\big) \\
&\times G_2-\Big((2\delta-1)\big((\delta-1)\delta-3\big)\eta^2+\delta\big(2(\delta-3)\delta+1\big)(1-\eta^2)\Big)G_3\Big]+\eta G_2\Big[(\delta-1)\widetilde{\mathcal{H}}_1 \\
&-4(\delta-1)\delta\widetilde{\mathcal{H}}_2+\delta\widetilde{\mathcal{H}}_4\Big]\Big\}
\end{aligned}$$

Numerical estimate for deuteron TCS

BH contribution:

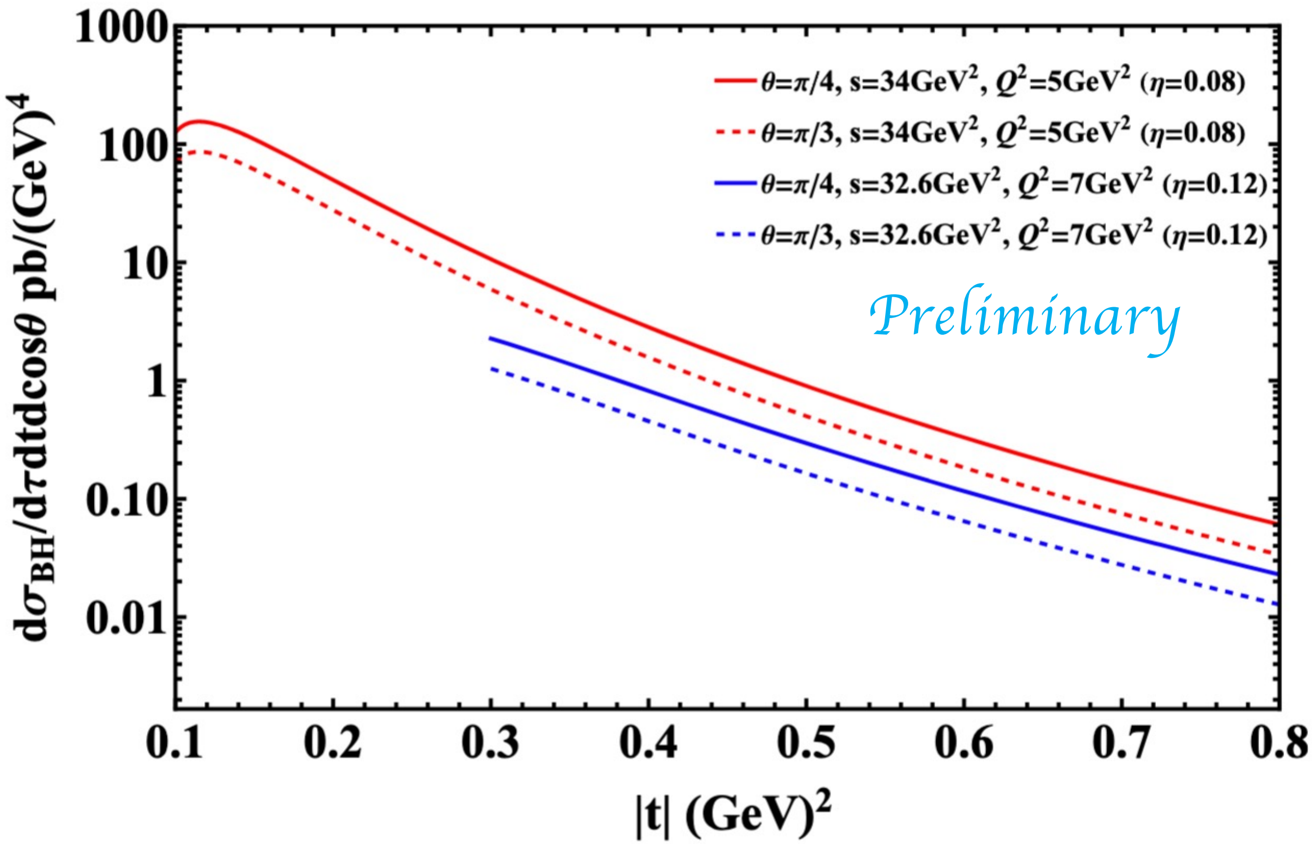
The parameterization of deuteron EM FFs are taken from PRD 91, 114001 (2015).

E_γ=7-9 GeV for proton TCS measurements at JLab.

P. Chatagnon et al. [CLAS], PRL 127 (2021), 262501.

→ Kinematics of deuteron TCS $\begin{cases} s \sim 30\ \mathrm{GeV}^2 \\ \eta \sim 0.1 \end{cases}$

Numerical estimate for BH contribution:



Numerical estimate of TCS cross section

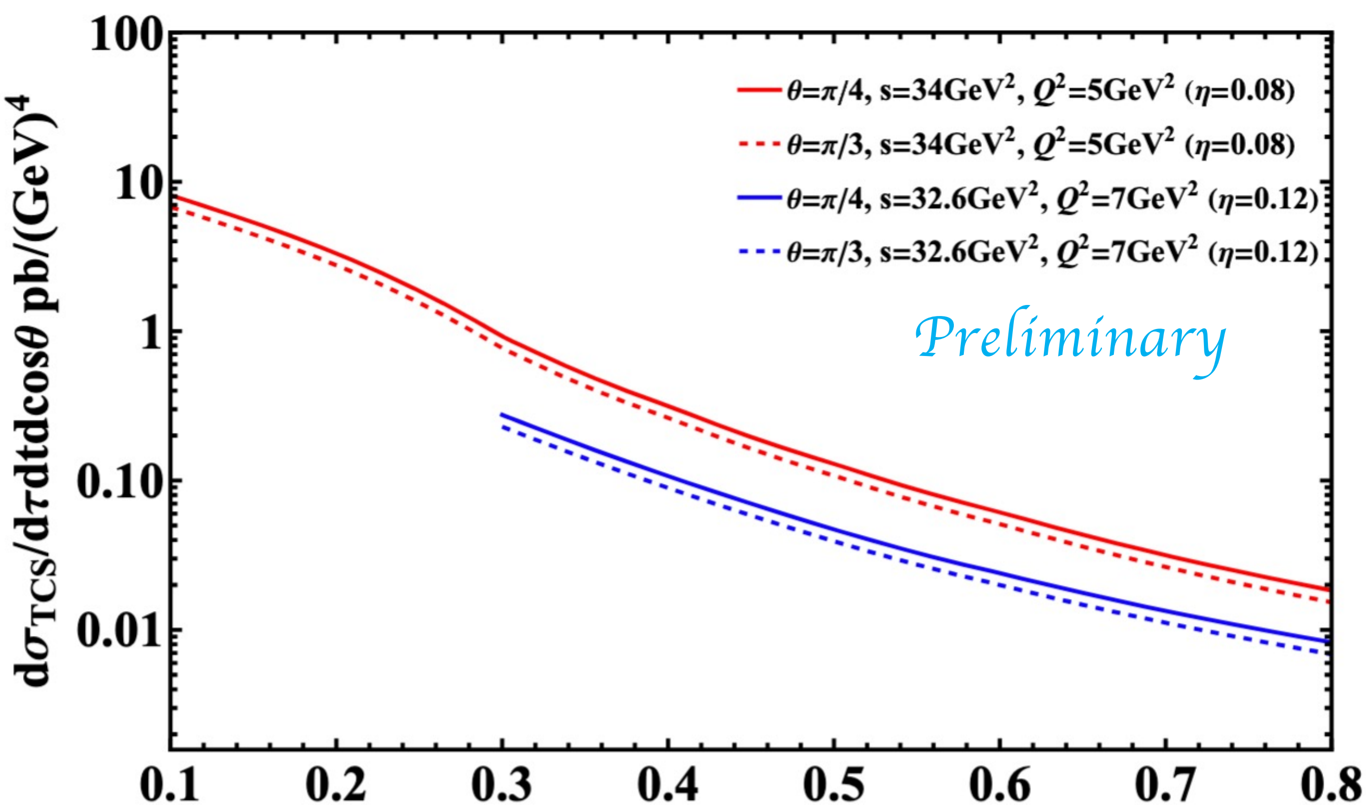
The deuteron GPDs are calculated using the convolution model developed by Prof. Wim Cosyn.

deuteron GPDs= nucleon GPDs $\otimes$ deuteron wavefunction

Goloskokov and Kroll GPD model

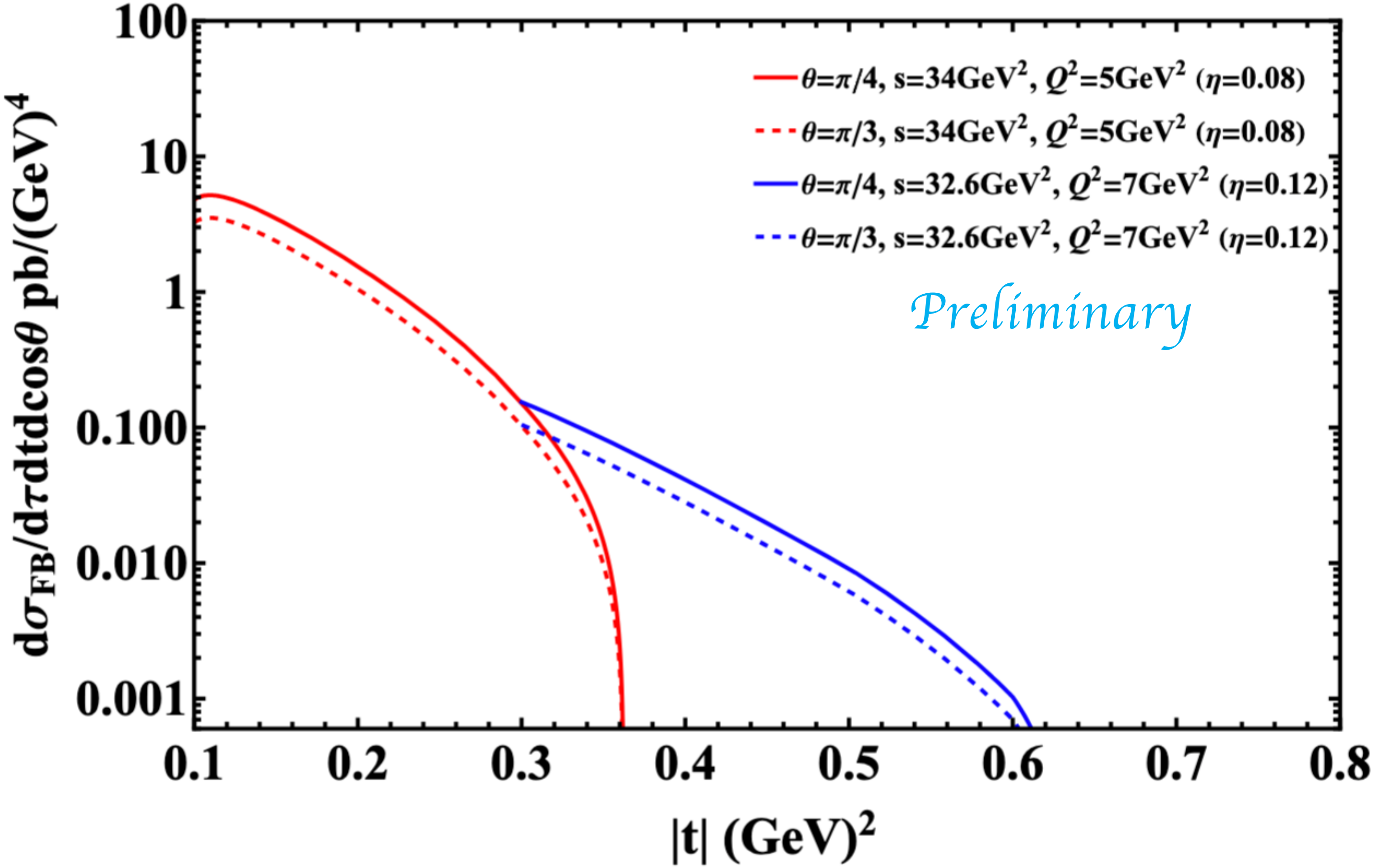
R. Wiringa, V. Stoks, and R. Schiavilla, PRC 51, 38 (1995).

TCS cross section:



Numerical estimate of forward-backward asymmetry

Estimating the interference contribution through the forward–backward asymmetry:



The interference contribution is comparable in magnitude to the TCS contribution.

NLO correction (in progress)

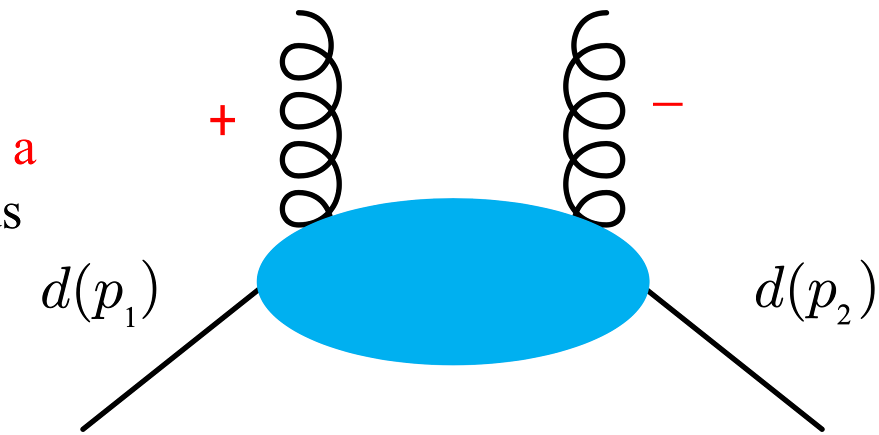
New term

Hadronic tensor: $$T^{\mu\nu} = -g_T^{\mu\nu} V - i\varepsilon_T^{\mu\nu} A + \boxed{T^{\mu\nu}_{\Delta\lambda=2}}$$

$$T_2^{\mu\nu} = \tau_T^{\mu\nu;\alpha\beta}\left\{(\Delta + 2\eta\bar{P})^\alpha \frac{(\epsilon_2^* \cdot q_1)\epsilon_1^\beta - \epsilon_2^{\beta *}(\epsilon_1 \cdot q_1)}{\bar{P}\cdot q_1}\mathcal{H}_1^{gT} + \ldots\right\}$$

$$\tau_T^{\mu\nu;\alpha\beta} = \frac{1}{2}(g_T^{\mu\alpha} g_T^{\nu\beta} + g_T^{\nu\alpha} g_T^{\mu\beta} - g_T^{\mu\nu} g_T^{\alpha\beta})$$

The gluon transversity GPDs will introduce a new term in the hadronic tensor, which leads to new angular dependence in the cross section .



Gluon transversity GPDs

There is no model calculation for gluon transversity GPDs in the deuteron, thus, a numerical estimate of the NLO corrections is currently not possible.

Summary

- The existing measurements of tensor-polarized PDFs may indicate the presence of non-nucleonic components in the deuteron.

- In principle, the non-nucleonic components can be investigated using deuteron GPDs. We present the theoretical formalism together with numerical estimates of the deuteron TCS cross section.

- Our results will be useful for future measurements of deuteron TCS at Jefferson Lab and other facilities.

Thank you very much

Backup：

Measurements of deuteron DVCS ($\gamma^* + d \rightarrow \gamma + d$)

NATURE PHYSICS ARTICLES

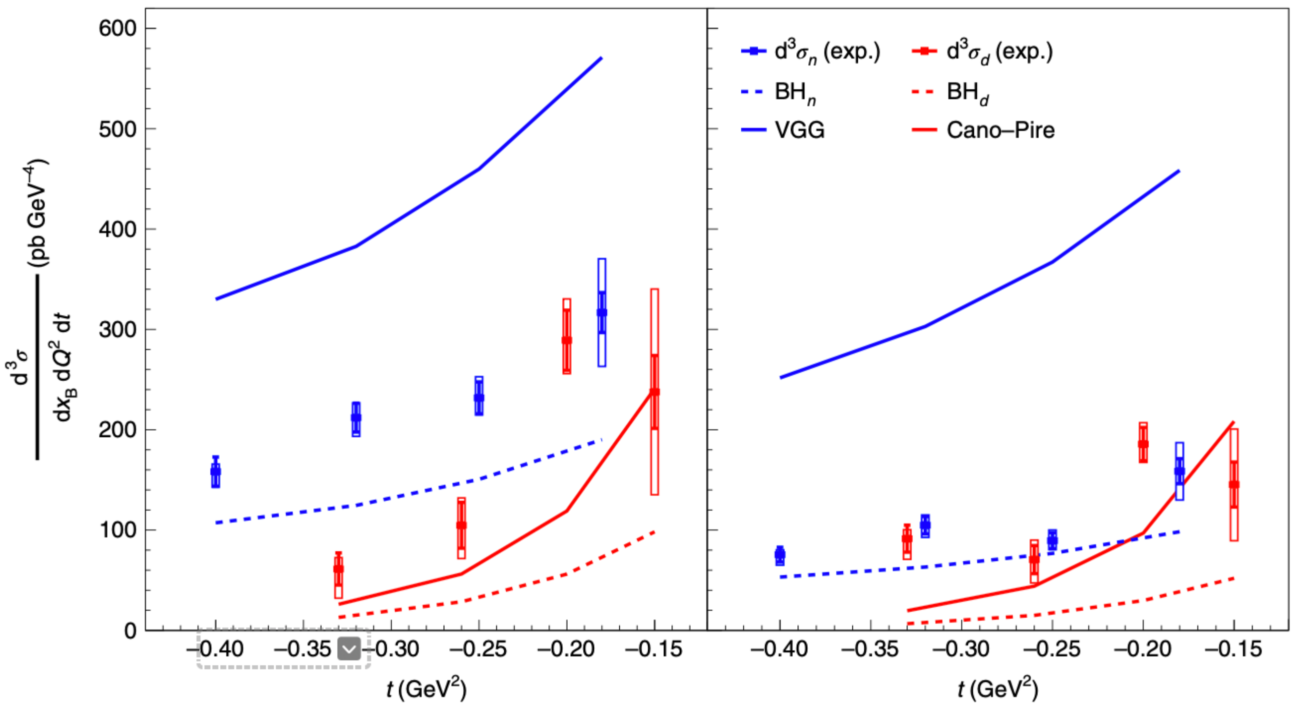
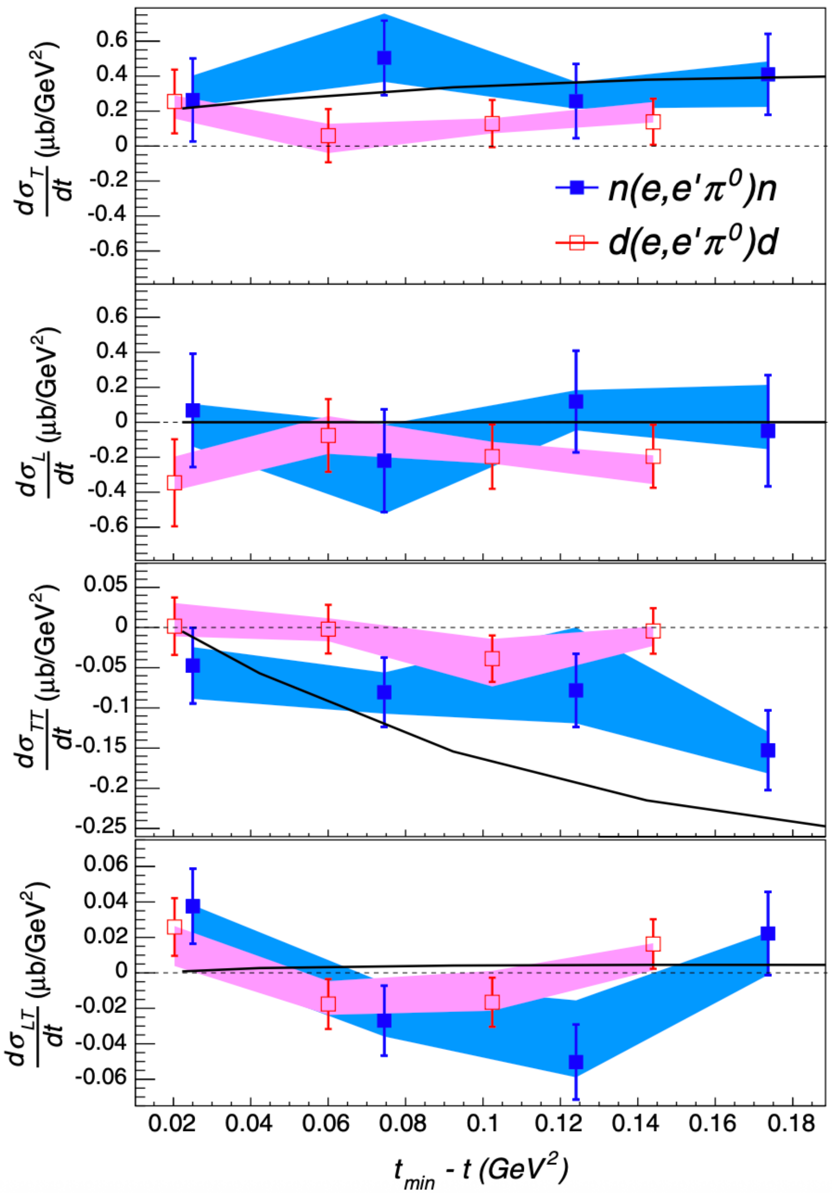


Fig. 4 | Neutron and deuteron cross-sections integrated over ϕ. The blue (red) points correspond to the $en \rightarrow en\gamma$ ($ed \rightarrow ed\gamma$) experimental cross-sections $d^3\sigma_{n(d)}/dQ^2\, dx_B\, dt$ for beam energy $E = 4.45$ GeV (left) and $E = 5.55$ GeV (right). The error bars show the s.d. statistical uncertainty and the boxes around the points show the total s.d. systematic uncertainty. Respective BH contributions are shown by the dashed lines, whereas the Vanderhaeghen–Guichon–Guidal model[49,50] for the neutron and Cano–Pire model[48] for the deuteron are represented by the solid curves.

M. Benali, et al., Nature Physics 16 (2020) no.2, 191-198.

Measurements of deuteron DVMP ($\gamma^* + \mathrm{d} \rightarrow \pi^0 + \mathrm{d}$)



Jefferson Lab Hall A, PRL 118 (2017) 22, 222002.

First experimental measurement of b_1

Hermes data show that b_1 (f_{1LL}) is not as small as the theoretical predictions based on that deuteron is a S-D mixture.

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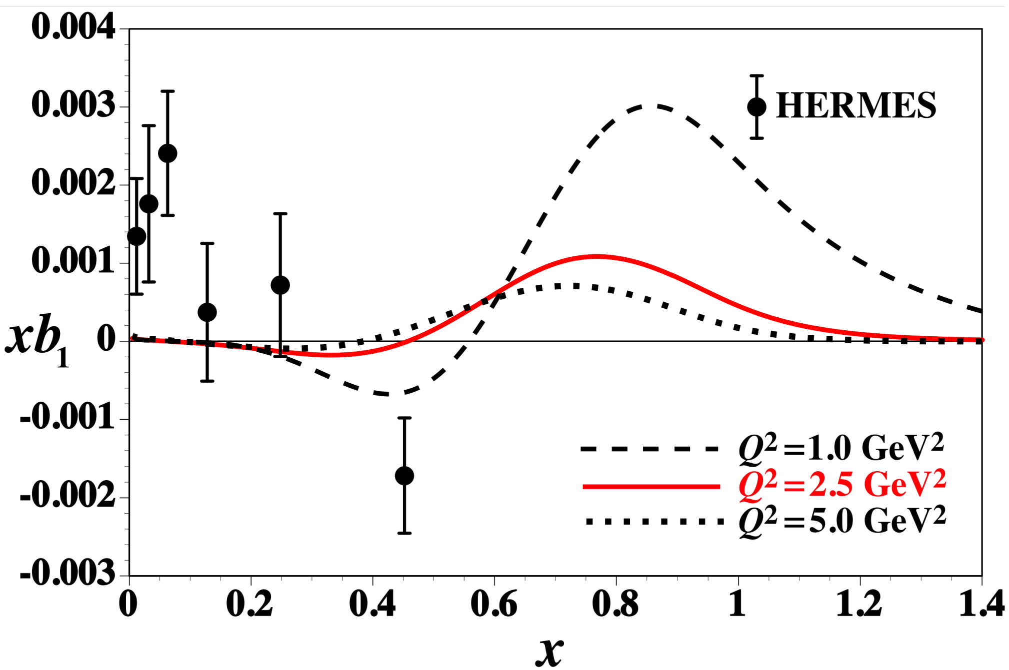
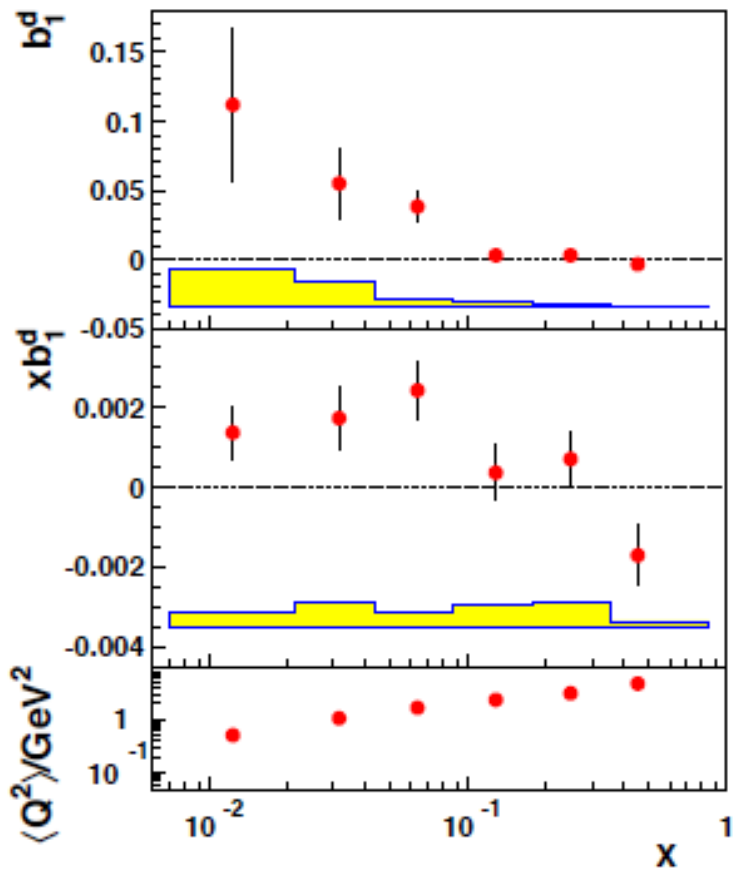
A. Y. Umnikov, PLB 391(1997), 177-184.
A. Airapetian *et al.* (HERMES), PRL 95 (2005) 242001.
W. Cosyn, *et al* PRD 95 (2017), 074036.





Hermes measurements of b_1

Hermes measurements are much larger than theoretical predictions.

The large b_1 could indicate the existence of exotic structures such as six-quark and hidden-color components in deuteron.

G. A. Miller, PRC 89(2014), 045203.