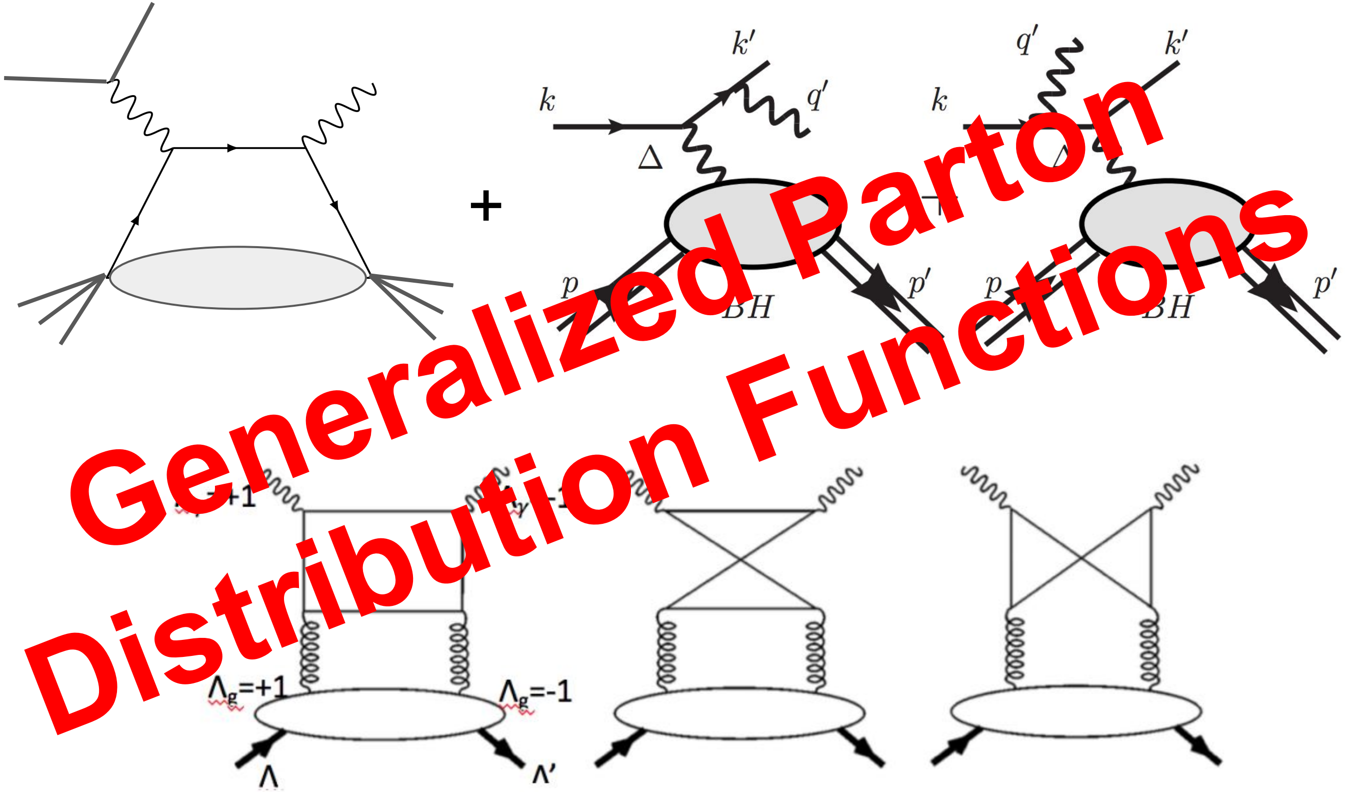
Extraction of Twist-3 Observables from DVCS

QCD Evolution 2019

B. Kriesten

5/14/2019

Deeply Virtual Compton Scattering Observables



Lorentz Invariance Relation (LIR) for OAM

GTMD GPD

$$\frac{d}{dx}\int d^2k_T \frac{k_T^2}{M^2} F_{1,4} = H + E + \widetilde{E}_{2T} + \mathcal{A}_{F_{14}}$$

Twist-2 **Twist-3** **LIR breaking**

Can we disentangle the Twist-3 GPDs from data?

Rajan, Englehardt, Liuti arXiv:1709.05770 Rajan, Courtoy, Englehardt, Liuti arXiv:1601.06117

Mechanical Properties of the Proton

Energy Momentum Tensor

$$\langle p'|T^{\mu\nu}|p\rangle = \overline{U}(P')\Big[A(t)\gamma^{(\mu}P^{\nu)} + B(t)P^{(\mu}i\sigma^{\nu)\alpha}\Delta_\alpha/2M + C(t)(\Delta^\mu\Delta^\nu - g^{\mu\nu}\Delta^2)/M + \widetilde{C}(t)g^{\mu\nu}M\Big]U(p)$$

$$\begin{bmatrix} T^{00} & T^{01} & T^{02} & T^{03} \\ T^{10} & T^{11} & T^{12} & T^{13} \\ T^{20} & T^{21} & T^{22} & T^{23} \\ T^{30} & T^{31} & T^{32} & T^{33} \end{bmatrix}$$

$$\int dx\, xH(x,\xi,t) = A(t) + \xi^2 C(t)$$

$$\int dx\, xE(x,\xi,t) = A(t) - \xi^2 C(t)$$

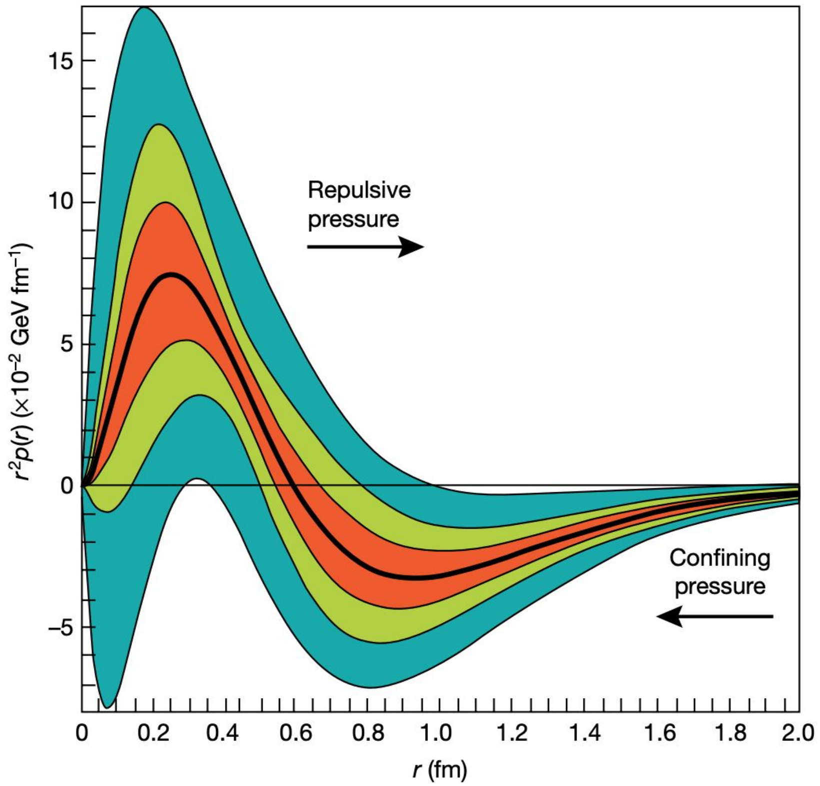
D - term

Ji arXiv:hep-ph/9603249

Mechanical Properties of the Proton

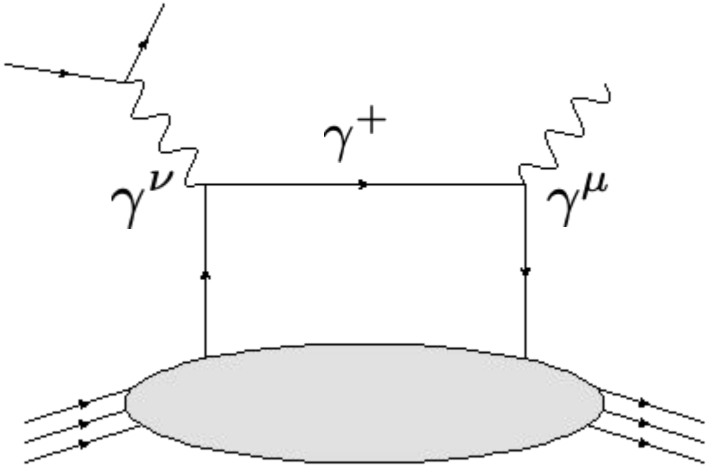
Pressure Distribution

$$\begin{bmatrix} T^{00} & T^{01} & T^{02} & T^{03} \\ T^{10} & T^{11} & T^{12} & T^{13} \\ T^{20} & T^{21} & T^{22} & T^{23} \\ T^{30} & T^{31} & T^{32} & T^{33} \end{bmatrix}$$



Burkert, L. Elouadrhiri, Girod *Nature* volume 557, pages 396–399 (2018)

DVCS



Twist - 2 (blue)
Twist - 3 (green)

$$W^{\mu\nu} \propto \gamma^\mu \gamma^+ \gamma^\nu = \begin{bmatrix} \gamma^- & \gamma^1 - i\gamma^2\gamma_5 & \gamma^2 + i\gamma^1\gamma_5 & i\gamma^-\gamma_5 \\ \gamma^1 + i\gamma^2\gamma_5 & \gamma^+ & i\gamma^+\gamma_5 & -\gamma^1 - i\gamma^2\gamma_5 \\ \gamma^2 - i\gamma^1\gamma_5 & -i\gamma^+\gamma_5 & \gamma^+ & -\gamma^2 + i\gamma^1\gamma_5 \\ -i\gamma^-\gamma_5 & -\gamma^1 + i\gamma^2\gamma_5 & -\gamma^2 - i\gamma^1\gamma_5 & \gamma^- \end{bmatrix}$$

Kinematics

$$x_{Bj} = \frac{Q^2}{2(pq)} \approx \frac{2\xi}{1+\xi}$$

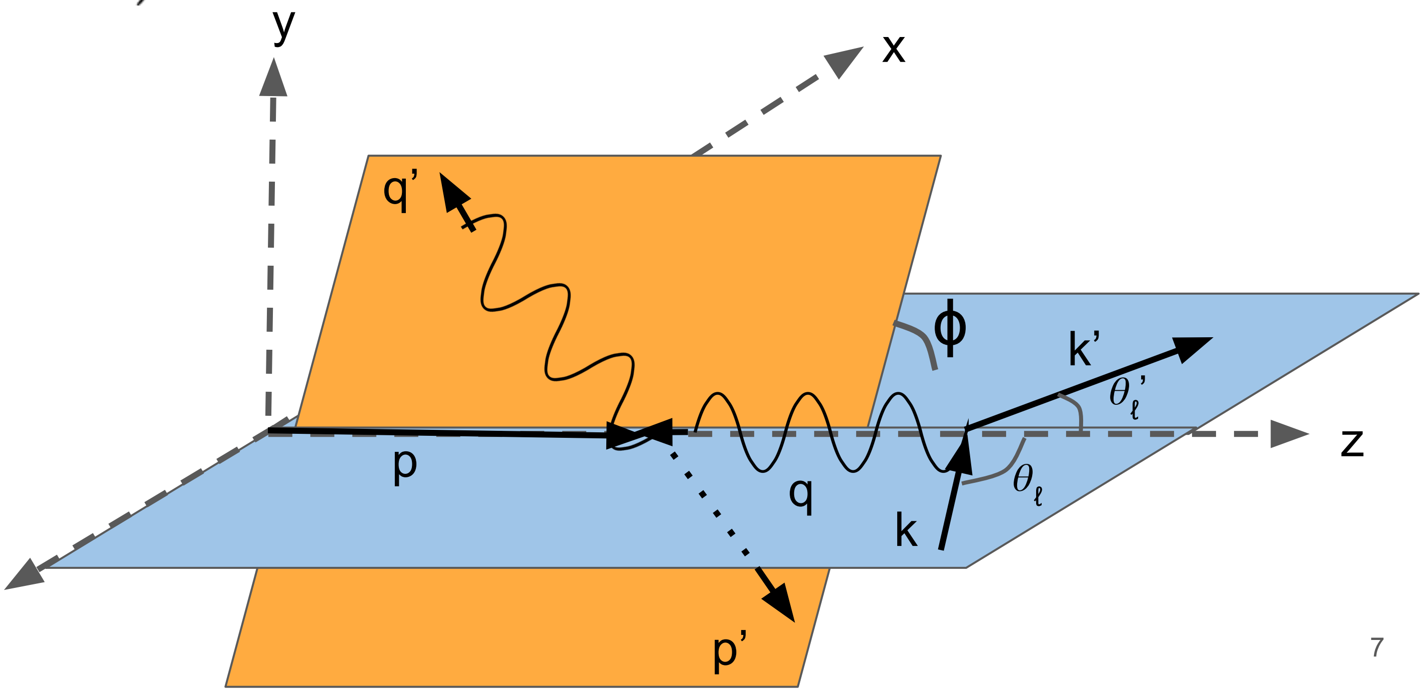
$$\frac{d^5\sigma}{dx_{Bj}dQ^2d|t|d\phi d\phi_S} = \Gamma|T|^2$$

$$Q^2 = -q^2 = -(k-k')^2$$

$$\xi = -\frac{\Delta^+}{2P^+}$$

$$P = \frac{p+p'}{2}$$

$$\Delta = p' - p$$



B.K., S.L., et. al. arXiv:1903.05742

$$\frac{d^5\sigma_{DVCS}}{dx_{Bj}dQ^2d|t|d\phi d\phi_S} = \frac{\alpha^3}{16\pi^2(s-M^2)^2\sqrt{1+\gamma^2}}|T_{DVCS}|^2$$

Unpolarized

$$= \frac{\Gamma}{Q^2(1-\epsilon)}\Big\{\Big[F_{UU,T} + \epsilon F_{UU,L} + \epsilon\cos 2\phi F_{UU}^{\cos 2\phi} + \sqrt{\epsilon(\epsilon+1)}\left[\cos\phi F_{UU}^{\cos\phi} + \sin\phi F_{UU}^{\sin\phi}\right]$$

LU polarized

$$+ (2h)F_{LU} + (2h)\sqrt{2\epsilon(1-\epsilon)}\sin\phi F_{LU}^{\sin\phi} + (2h)\sqrt{2\epsilon(1-\epsilon)}\cos\phi F_{LU}^{\cos\phi}\Big]$$

UL polarized

$$+ (2\Lambda)\left[F_{UL} + \sqrt{\epsilon(\epsilon+1)}\sin\phi F_{UL}^{\sin\phi} + \sqrt{\epsilon(\epsilon+1)}\cos\phi F_{UL}^{\cos\phi} + \epsilon\sin 2\phi F_{UL}^{\sin 2\phi}\right]$$

LL polarized

$$+ (2h)\sqrt{1-\epsilon^2}F_{LL} + 2(2h)\sqrt{\epsilon(1-\epsilon)}\cos\phi F_{LL}^{\cos\phi} + 2(2h)\sqrt{\epsilon(1-\epsilon)}\sin\phi F_{LL}^{\sin\phi}\Big]$$

UT polarized

$$+ |\vec{S}_\perp|\Big[\sin(\phi-\phi_S)\left(F_{UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\right) \epsilon\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\left(\sin\phi_S F_{UT}^{\sin\phi_S} + \sin(2\phi-\phi_S)F_{UT}^{\sin(2\phi-\phi_S)}\right)\Big]$$

LT polarized

$$+ (2h)|\vec{S}_\perp|\Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S} + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S)F_{LT}^{\cos(2\phi-\phi_S)}\Big]\Big\}$$

B.K., S.L., et. al. arXiv:1903.05742

$$
\begin{aligned}
\frac{d^5\sigma_{DVCS}}{dx_{Bj}dQ^2d|t|d\phi d\phi_S} &= \frac{\alpha^3}{16\pi^2(s-M^2)^2\sqrt{1+\gamma^2}}|T_{DVCS}|^2 \\
&= \frac{\Gamma}{Q^2(1-\epsilon)}\left\{\left[F_{UU,T} + \epsilon F_{UU,L} + \epsilon\cos 2\phi F_{UU}^{\cos 2\phi}\right.\right. \\
&+ \sqrt{\epsilon(\epsilon+1)}\left[\cos\phi F_{UU}^{\cos\phi} + \sin\phi F_{UU}^{\sin\phi}\right] \\
&+ (2h) F_{LU} + (2h)\sqrt{2\epsilon(1-\epsilon)}\sin\phi F_{LU}^{\sin\phi} + (2h)\sqrt{2\epsilon(1-\epsilon)}\cos\phi F_{LU}^{\cos\phi}\Big] \\
&+ (2\Lambda)\Big[F_{UL} + \sqrt{\epsilon(\epsilon+1)}\sin\phi F_{UL}^{\sin\phi} + \sqrt{\epsilon(\epsilon+1)}\cos\phi F_{UL}^{\cos\phi} + \epsilon\sin 2\phi F_{UL}^{\sin 2\phi} \\
&+ (2h)\sqrt{1-\epsilon^2}F_{LL} + 2(2h)\sqrt{\epsilon(1-\epsilon)}\cos\phi F_{LL}^{\cos\phi} + 2(2h)\sqrt{\epsilon(1-\epsilon)}\sin\phi F_{LL}^{\sin\phi}\Big] \\
&+ |\vec{S}_\perp|\Big[\sin(\phi-\phi_S)\left(F_{UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\right) \\
&\quad \epsilon\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)} \\
&\quad +\sqrt{2\epsilon(1+\epsilon)}\left(\sin\phi_S F_{UT}^{\sin\phi_S} + \sin(2\phi-\phi_S)F_{UT}^{\sin(2\phi-\phi_S)}\right)\Big] \\
&+ (2h)|\vec{S}_\perp|\Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S} \\
&\quad +\sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S)F_{LT}^{\cos(2\phi-\phi_S)}\Big]\Big\}
\end{aligned}
$$

B.K., S.L., et. al. arXiv:1903.05742

— Twist - 2

$$
\begin{aligned}
\frac{d^5\sigma_{DVCS}}{dx_{Bj}dQ^2d|t|d\phi d\phi_S} &= \frac{\alpha^3}{16\pi^2(s-M^2)^2\sqrt{1+\gamma^2}}|T_{DVCS}|^2 \\
&= \frac{\Gamma}{Q^2(1-\epsilon)}\Big\{F_{UU,T}+\epsilon F_{UU,L}+\epsilon\cos 2\phi F_{UU}^{\cos 2\phi} \\
&+ \sqrt{\epsilon(\epsilon+1)}\left[\cos\phi F_{UU}^{\cos\phi}+\sin\phi F_{UU}^{\sin\phi}\right] \\
&+ (2h)F_{LU}+(2h)\sqrt{2\epsilon(1-\epsilon)}\sin\phi F_{LU}^{\sin\phi}+(2h)\sqrt{2\epsilon(1-\epsilon)}\cos\phi F_{LU}^{\cos\phi}] \\
&+ (2\Lambda)\left[F_{UL}+\sqrt{\epsilon(\epsilon+1)}\sin\phi F_{UL}^{\sin\phi}+\sqrt{\epsilon(\epsilon+1)}\cos\phi F_{UL}^{\cos\phi}+\epsilon\sin 2\phi F_{UL}^{\sin 2\phi}\right. \\
&+ (2h)\sqrt{1-\epsilon^2}F_{LL}+2(2h)\sqrt{\epsilon(1-\epsilon)}\cos\phi F_{LL}^{\cos\phi}+2(2h)\sqrt{\epsilon(1-\epsilon)}\sin\phi F_{LL}^{\sin\phi}] \\
&+ |\vec{S}_\perp|\left[\sin(\phi-\phi_S)\left(F_{UT,T}^{\sin(\phi-\phi_S)}+\epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\right)\right. \\
&\quad \epsilon\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)}+\epsilon\sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)} \\
&\quad \left.+\sqrt{2\epsilon(1+\epsilon)}\left(\sin\phi_S F_{UT}^{\sin\phi_S}+\sin(2\phi-\phi_S)F_{UT}^{\sin(2\phi-\phi_S)}\right)\right] \\
&+ (2h)|\vec{S}_\perp|\left[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)}+\sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S}\right. \\
&\quad \left.\left.+\sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S)F_{LT}^{\cos(2\phi-\phi_S)}\right]\right\}
\end{aligned}
$$

B.K., S.L., et. al. arXiv:1903.05742

$$
\begin{aligned}
\frac{d^5\sigma_{DVCS}}{dx_{Bj}dQ^2d|t|d\phi d\phi_S} &= \frac{\alpha^3}{16\pi^2(s-M^2)^2\sqrt{1+\gamma^2}}|T_{DVCS}|^2 \\
&= \frac{\Gamma}{Q^2(1-\epsilon)}\Big\{F_{UU,T} + \epsilon F_{UU,L} + \epsilon\cos 2\phi F_{UU}^{\cos 2\phi} \\
&+ \sqrt{\epsilon(\epsilon+1)}\left[\cos\phi F_{UU}^{\cos\phi} + \sin\phi F_{UU}^{\sin\phi}\right] \\
&+ (2h) F_{LU} + (2h)\sqrt{2\epsilon(1-\epsilon)}\sin\phi F_{LU}^{\sin\phi} + (2h)\sqrt{2\epsilon(1-\epsilon)}\cos\phi F_{LU}^{\cos\phi}] \\
&+ (2\Lambda)\left[F_{UL} + \sqrt{\epsilon(\epsilon+1)}\sin\phi F_{UL}^{\sin\phi} + \sqrt{\epsilon(\epsilon+1)}\cos\phi F_{UL}^{\cos\phi} + \epsilon\sin 2\phi F_{UL}^{\sin 2\phi}\right. \\
&+ (2h)\sqrt{1-\epsilon^2}F_{LL} + 2(2h)\sqrt{\epsilon(1-\epsilon)}\cos\phi F_{LL}^{\cos\phi} + 2(2h)\sqrt{\epsilon(1-\epsilon)}\sin\phi F_{LL}^{\sin\phi}] \\
&+ |\vec{S}_\perp|\left[\sin(\phi-\phi_S)\left(F_{UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\right)\right. \\
&\quad \epsilon\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)} \\
&\quad \left.+\sqrt{2\epsilon(1+\epsilon)}\left(\sin\phi_S F_{UT}^{\sin\phi_S} + \sin(2\phi-\phi_S)F_{UT}^{\sin(2\phi-\phi_S)}\right)\right] \\
&+ (2h)|\vec{S}_\perp|\left[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S}\right. \\
&\quad \left.\left.+\sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S)F_{LT}^{\cos(2\phi-\phi_S)}\right]\right\}
\end{aligned}
$$

Twist - 2

Twist - 3

B.K., S.L., et. al. arXiv:1903.05742

$$\frac{d^5\sigma_{DVCS}}{dx_{Bj}\,dQ^2\,d|t|\,d\phi\,d\phi_S} = \frac{\alpha^3}{16\pi^2(s-M^2)^2\sqrt{1+\gamma^2}}|T_{DVCS}|^2$$

$$\begin{aligned}
= \frac{\Gamma}{Q^2(1-\epsilon)} \Big\{ & F_{UU,T} + \epsilon F_{UU,L} + \epsilon \cos 2\phi\, F_{UU}^{\cos 2\phi} \\
+ & \sqrt{\epsilon(\epsilon+1)} \left[\cos\phi\, F_{UU}^{\cos\phi} + \sin\phi\, F_{UU}^{\sin\phi}\right] \\
+ & (2h) \Big[F_{LU} + (2h)\sqrt{2\epsilon(1-\epsilon)}\sin\phi\, F_{LU}^{\sin\phi} + (2h)\sqrt{2\epsilon(1-\epsilon)}\cos\phi\, F_{LU}^{\cos\phi}\Big] \\
+ & (2\Lambda)\Big[F_{UL} + \sqrt{\epsilon(\epsilon+1)}\sin\phi\, F_{UL}^{\sin\phi} + \sqrt{\epsilon(\epsilon+1)}\cos\phi\, F_{UL}^{\cos\phi} + \epsilon\sin 2\phi\, F_{UL}^{\sin 2\phi} \\
+ & (2h)\sqrt{1-\epsilon^2}F_{LL} + 2(2h)\sqrt{\epsilon(1-\epsilon)}\cos\phi\, F_{LL}^{\cos\phi} + 2(2h)\sqrt{\epsilon(1-\epsilon)}\sin\phi\, F_{LL}^{\sin\phi}\Big] \\
+ & |\vec{S}_\perp|\Big[\sin(\phi-\phi_S)\left(F_{UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\right) \\
& \epsilon\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)} \\
& +\sqrt{2\epsilon(1+\epsilon)}\left(\sin\phi_S F_{UT}^{\sin\phi_S} + \sin(2\phi-\phi_S)F_{UT}^{\sin(2\phi-\phi_S)}\right)\Big] \\
+ & (2h)|\vec{S}_\perp|\Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S} \\
& +\sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S)F_{LT}^{\cos(2\phi-\phi_S)}\Big]\Big\}
\end{aligned}$$

Twist - 2

Twist - 3

$\mathcal{O}\left(\frac{1}{Q^2}\right)$

Photon/Proton Structure Functions and Phase

Definition of a Helicity Amplitude →

$$f_{\Lambda\Lambda'}^{\Lambda_{\gamma*}\Lambda'_{\gamma}}(\theta,\phi) = e^{-i(\Lambda_{\gamma*}-\Lambda-\Lambda'_{\gamma}+\Lambda')\phi}\,\tilde{f}_{\Lambda\Lambda'}^{\Lambda_{\gamma*}\Lambda'_{\gamma}}(\theta),$$

$$e^{i(\Lambda_{\gamma*}^{(1)}-\Lambda_{\gamma*}^{(2)})\,\phi}\,F_{\Lambda\Lambda'}^{\Lambda_{\gamma*}^{(1)}\Lambda_{\gamma*}^{(2)}} = e^{i(\Lambda_{\gamma*}^{(1)}-\Lambda_{\gamma*}^{(2)})\,\phi}\sum_{\Lambda_{\gamma'}}\left(\tilde{f}_{\Lambda\Lambda'}^{\Lambda_{\gamma*}^{(1)}\Lambda'_{\gamma}}\right)^{*}\tilde{f}_{\Lambda\Lambda'}^{\Lambda_{\gamma*}^{(2)}\Lambda'_{\gamma}} = \sum_{\Lambda_{\gamma'}}\left(f_{\Lambda\Lambda'}^{\Lambda_{\gamma*}^{(1)}\Lambda'_{\gamma}}\right)^{*} f_{\Lambda\Lambda'}^{\Lambda_{\gamma*}^{(2)}\Lambda'_{\gamma}}$$

Enter the observables in your cross section.

$$e^{i(\Lambda_{\gamma*}^{(1)}-\Lambda_{\gamma*}^{(2)}-2\Lambda)\,\phi}\,F_{T,\Lambda\Lambda'}^{\Lambda_{\gamma*}^{(1)}\Lambda_{\gamma*}^{(2)}} = \sum_{\Lambda_{\gamma'}}\left(f_{\Lambda\Lambda'}^{\Lambda_{\gamma*}^{(1)}\Lambda'_{\gamma}}\right)^{*} f_{-\Lambda\Lambda'}^{\Lambda_{\gamma*}^{(2)}\Lambda'_{\gamma}} = e^{i(\Lambda_{\gamma*}^{(1)}-\Lambda_{\gamma*}^{(2)}-2\Lambda)\,\phi}\sum_{\Lambda_{\gamma'}}\left(\tilde{f}_{\Lambda\Lambda'}^{\Lambda_{\gamma*}^{(1)}\Lambda'_{\gamma}}\right)^{*}\tilde{f}_{-\Lambda\Lambda'}^{\Lambda_{\gamma*}^{(2)}\Lambda'_{\gamma}}$$

B.K., S.L., et. al. arXiv:1903.05742

Jakob, Wick Annals Phys 7, 404 (1959)

Photon/Proton Structure Functions and Phase

Definition of a Helicity Amplitude →

$$f^{\Lambda_{\gamma*}\Lambda'_{\gamma}}_{\Lambda\Lambda'}(\theta,\phi) = e^{-i(\Lambda_{\gamma*}-\Lambda-\Lambda'_{\gamma}+\Lambda')\phi}\,\tilde{f}^{\Lambda_{\gamma*}\Lambda'_{\gamma}}_{\Lambda\Lambda'}(\theta),$$

$$e^{i(\Lambda^{(1)}_{\gamma*}-\Lambda^{(2)}_{\gamma*})\,\phi}\,F^{\Lambda^{(1)}_{\gamma*}\Lambda^{(2)}_{\gamma*}}_{\Lambda\Lambda'} = e^{i(\Lambda^{(1)}_{\gamma*}-\Lambda^{(2)}_{\gamma*})\,\phi} \ldots$$

Gives access to higher twist terms

$$e^{i(\Lambda^{(1)}_{\gamma*}-\Lambda^{(2)}_{\gamma*}-2\Lambda)\,\phi}\,F^{\Lambda^{(1)}_{\gamma*}\Lambda^{(2)}_{\gamma*}}_{T,\Lambda\Lambda'} =$$

$$\sum_{\Lambda_{\gamma'}}\left(f^{\Lambda^{(1)}_{\gamma*}\Lambda'_{\gamma}}_{\Lambda\Lambda'}\right)^{*} f^{\Lambda^{(2)}_{\gamma*}\Lambda'_{\gamma}}_{-\Lambda\Lambda'} = e^{i(\Lambda^{(1)}_{\gamma*}-\Lambda^{(2)}_{\gamma*}-2\Lambda)\,\phi}\sum_{\Lambda_{\gamma'}}\left(\tilde{f}^{\Lambda^{(1)}_{\gamma*}\Lambda'_{\gamma}}_{\Lambda\Lambda'}\right)^{*}\tilde{f}^{\Lambda^{(2)}_{\gamma*}\Lambda'_{\gamma}}_{-\Lambda\Lambda'}$$

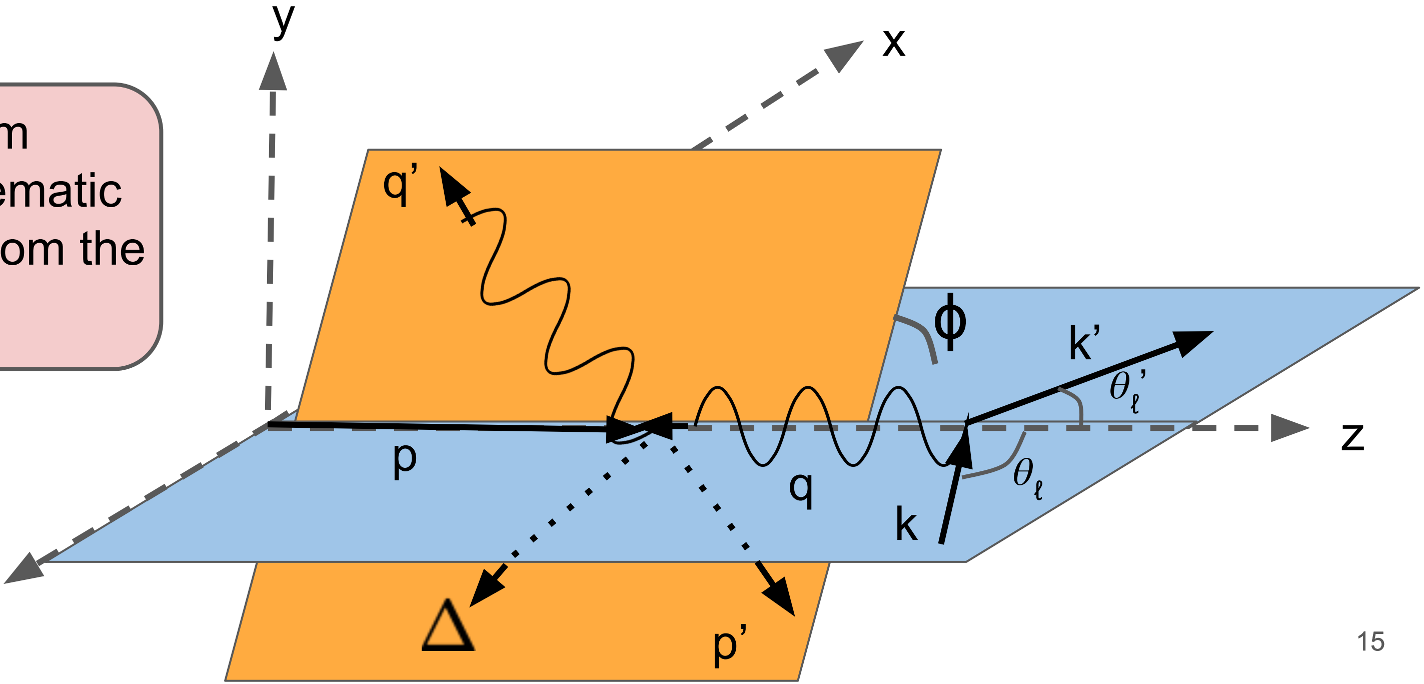
B.K., S.L., et. al. arXiv:1903.05742

Kinematic Dependence

$$(k\Delta) \propto \cos\phi$$

Not to be confused with the phase arising from the helicity amplitude which determines the Twist.

Our formalism disentangles kinematic phi-dependence from the phase.



B.K., S.L., et. al. arXiv:1903.05742

Twist-2 Observables

$$
\begin{aligned}
\frac{d^5\sigma_{DVCS}}{dx_{Bj}dQ^2d|t|d\phi d\phi_S} &= \frac{\alpha^3}{16\pi^2(s-M^2)^2\sqrt{1+\gamma^2}}|T_{DVCS}|^2 \\
&= \frac{\Gamma}{Q^2(1-\epsilon)}\Big\{F_{UU,T} + \epsilon F_{UU,L} + \epsilon\cos 2\phi F_{UU}^{\cos 2\phi} \\
&+ \sqrt{\epsilon(\epsilon+1)}\left[\cos\phi F_{UU}^{\cos\phi} + \sin\phi F_{UU}^{\sin\phi}\right] \\
&+ (2h)\Big[F_{LU} + (2h)\sqrt{2\epsilon(1-\epsilon)}\sin\phi F_{LU}^{\sin\phi} + (2h)\sqrt{2\epsilon(1-\epsilon)}\cos\phi F_{LU}^{\cos\phi}\Big] \\
&+ (2\Lambda)\left[F_{UL} + \sqrt{\epsilon(\epsilon+1)}\sin\phi F_{UL}^{\sin\phi} + \sqrt{\epsilon(\epsilon+1)}\cos\phi F_{UL}^{\cos\phi} + \epsilon\sin 2\phi F_{UL}^{\sin 2\phi}\right. \\
&+ (2h)\sqrt{1-\epsilon^2}F_{LL} + 2(2h)\sqrt{\epsilon(1-\epsilon)}\cos\phi F_{LL}^{\cos\phi} + 2(2h)\sqrt{\epsilon(1-\epsilon)}\sin\phi F_{LL}^{\sin\phi}\Big] \\
&+ |\vec{S}_\perp|\Big[\sin(\phi-\phi_S)\left(F_{UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\right) \\
&\quad \epsilon\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)} \\
&\quad +\sqrt{2\epsilon(1+\epsilon)}\left(\sin\phi_S F_{UT}^{\sin\phi_S} + \sin(2\phi-\phi_S)F_{UT}^{\sin(2\phi-\phi_S)}\right)\Big] \\
&+ (2h)|\vec{S}_\perp|\Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S} \\
&\quad +\sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S)F_{LT}^{\cos(2\phi-\phi_S)}\Big]\Big\}
\end{aligned}
$$

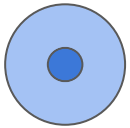
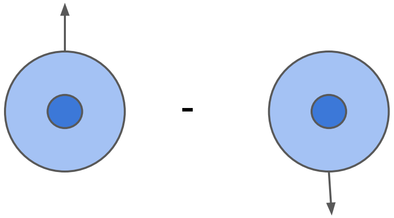
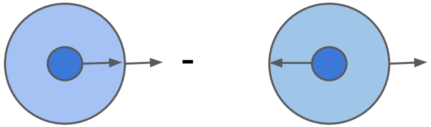
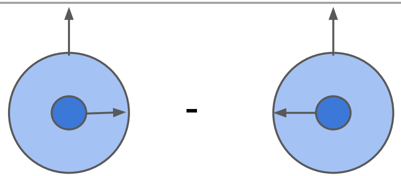
Twist-2 Observables

$$F_{UU,T} = 4\Big[(1-\xi^2)\Big(|\mathcal{H}|^2 + |\tilde{\mathcal{H}}|^2\Big) + \frac{t_o - t}{2M^2}\Big(|\mathcal{E}|^2 + \xi^2|\tilde{\mathcal{E}}|^2\Big) - \frac{2\xi^2}{1-\xi^2}\Re\mathrm{e}\Big(\mathcal{H}\mathcal{E} + \widetilde{\mathcal{H}}\widetilde{\mathcal{E}}\Big)\Big]$$

$$F_{LL} = 2\Big[2(1-\xi^2)\ |\mathcal{H}\widetilde{\mathcal{H}}| + 4\xi\frac{t_o - t}{2M^2}\ |\mathcal{E}\widetilde{\mathcal{E}}| + \frac{2\xi^2}{1-\xi^2}\Re\mathrm{e}\Big(\mathcal{H}\widetilde{\mathcal{E}} + \widetilde{\mathcal{H}}\mathcal{E}\Big)\Big]$$

$$F_{UT,T}^{\sin(\phi-\phi_S)} = -\frac{\sqrt{t_0-t}}{2M}\Big[\Re e\Big(\widetilde{\mathcal{H}} - \tfrac{\xi^2}{1-\xi^2}\widetilde{\mathcal{E}}\Big)\Im m\mathcal{E} - \xi\Re e\Big(\mathcal{H} - \tfrac{\xi^2}{1-\xi^2}\mathcal{E}\Big)\Im m\widetilde{\mathcal{E}}$$
$$- \Im m\Big(\widetilde{\mathcal{H}} - \tfrac{\xi^2}{1-\xi^2}\widetilde{\mathcal{E}}\Big)\Re e\mathcal{E} + \xi\Im m\Big(\mathcal{H} - \tfrac{\xi^2}{1-\xi^2}\mathcal{E}\Big)\Re e\widetilde{\mathcal{E}}\Big]$$

B.K., S.L., et. al. arXiv:1903.05742

GPD	Phase	Helicity Composition
H	1	
$\Delta_T E$	$e^{i\phi}$	
$\widetilde{H}$	1	
$\xi \Delta_T \widetilde{E}$	$e^{i\phi}$	

B.K., S.L., et. al. [arXiv:1903.05742](https://arxiv.org/abs/1903.05742)

Twist-3 Observables

$$
\begin{aligned}
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&= \frac{\Gamma}{Q^2(1-\epsilon)}\Big\{\Big[F_{UU,T} + \epsilon F_{UU,L} + \epsilon\cos 2\phi F_{UU}^{\cos 2\phi} \\
&+ \sqrt{\epsilon(\epsilon+1)}\left[\cos\phi F_{UU}^{\cos\phi} + \sin\phi F_{UU}^{\sin\phi}\right] \\
&+ (2h) F_{LU} + (2h)\sqrt{2\epsilon(1-\epsilon)}\sin\phi F_{LU}^{\sin\phi} + (2h)\sqrt{2\epsilon(1-\epsilon)}\cos\phi F_{LU}^{\cos\phi}\Big] \\
&+ (2\Lambda)\Big[F_{UL} + \sqrt{\epsilon(\epsilon+1)}\sin\phi F_{UL}^{\sin\phi} + \sqrt{\epsilon(\epsilon+1)}\cos\phi F_{UL}^{\cos\phi} + \epsilon\sin 2\phi F_{UL}^{\sin 2\phi} \\
&+ (2h)\sqrt{1-\epsilon^2} F_{LL} + 2(2h)\sqrt{\epsilon(1-\epsilon)}\cos\phi F_{LL}^{\cos\phi} + 2(2h)\sqrt{\epsilon(1-\epsilon)}\sin\phi F_{LL}^{\sin\phi}\Big] \\
&+ |\vec{S}_\perp|\Big[\sin(\phi-\phi_S)\left(F_{UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\right) \\
&\quad \epsilon\sin(\phi+\phi_S) F_{UT}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S) F_{UT}^{\sin(3\phi-\phi_S)} \\
&\quad + \sqrt{2\epsilon(1+\epsilon)}\left(\sin\phi_S F_{UT}^{\sin\phi_S} + \sin(2\phi-\phi_S) F_{UT}^{\sin(2\phi-\phi_S)}\right)\Big] \\
&+ (2h)|\vec{S}_\perp|\Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S) F_{LT}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S} \\
&\quad + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S) F_{LT}^{\cos(2\phi-\phi_S)}\Big]\Big\}
\end{aligned}
$$

B.K., S.L., et. al. [arXiv:1903.05742]

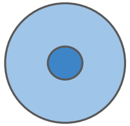
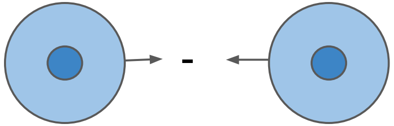
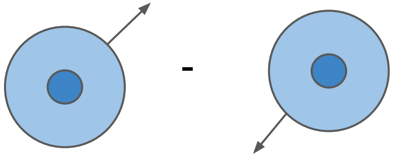
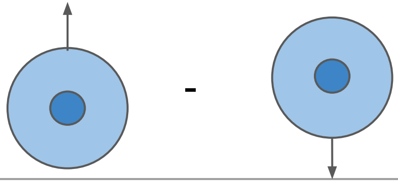
Twist-3 Observables

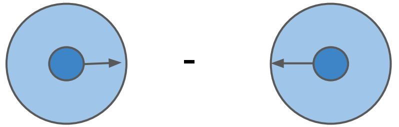
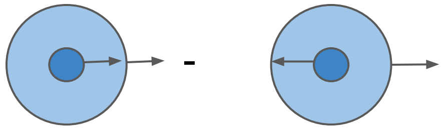
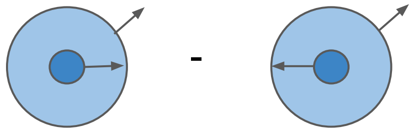
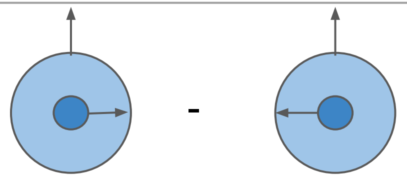
$$F_{UU}^{\cos\phi} = -2\,(1-\xi^2)\Re\mathrm{e}\Big[\Big(2\widetilde{\mathcal{H}}_{2T} + \mathcal{E}_{2T} + 2\widetilde{\mathcal{H}}'_{2T} + \mathcal{E}'_{2T}\Big)\Big(\mathcal{H} - \frac{\xi^2}{1-\xi^2}\mathcal{E}\Big) - 2\xi\Big(\widetilde{\mathcal{E}}_{2T} + \widetilde{\mathcal{E}}'_{2T}\Big)\Big(\widetilde{\mathcal{H}} - \frac{\xi^2}{1-\xi^2}\widetilde{\mathcal{E}}\Big) + \frac{t_0 - t}{16M^2}\Big(\widetilde{\mathcal{H}}_{2T} + \widetilde{\mathcal{H}}'_{2T}\Big)\Big(\mathcal{E} + \xi\widetilde{\mathcal{E}}\Big) + \Big(\mathcal{H}_{2T} + \mathcal{H}'_{2T} + \frac{t_0 - t}{4M^2}\Big(\widetilde{\mathcal{H}}_{2T} + \widetilde{\mathcal{H}}'_{2T}\Big) + \frac{\xi}{1-\xi^2}\Big(\widetilde{\mathcal{E}}_{2T} + \widetilde{\mathcal{E}}'_{2T}\Big) - \frac{\xi^2}{1-\xi^2}\Big(\mathcal{E}_{2T} + \mathcal{E}'_{2T}\Big)\Big)\Big(\mathcal{E} - \xi\widetilde{\mathcal{E}}\Big)\Big]$$

What are these linear combinations of CFFs?

$$F_{LU}^{\sin\phi} = -2\,(1-\xi^2)\Im\mathrm{m}\Big[\Big(2\widetilde{\mathcal{H}}_{2T} + \mathcal{E}_{2T} + 2\widetilde{\mathcal{H}}'_{2T} + \mathcal{E}'_{2T}\Big)\Big(\mathcal{H} - \frac{\xi^2}{1-\xi^2}\mathcal{E}\Big) - 2\xi\,\Big(\widetilde{\mathcal{E}}_{2T} + \widetilde{\mathcal{E}}'_{2T}\Big)\Big(\widetilde{\mathcal{H}} - \frac{\xi^2}{1-\xi^2}\widetilde{\mathcal{E}}\Big) + \frac{t_0 - t}{16M^2}\Big(\widetilde{\mathcal{H}}_{2T} + \widetilde{\mathcal{H}}'_{2T}\Big)\Big(\mathcal{E} + \xi\widetilde{\mathcal{E}}\Big) + \Big[\Big(\mathcal{H}_{2T} + \mathcal{H}'_{2T} + \frac{t_0 - t}{4M^2}\Big(\widetilde{\mathcal{H}}_{2T} + \widetilde{\mathcal{H}}'_{2T}\Big) + \frac{\xi}{1-\xi^2}\Big(\widetilde{\mathcal{E}}_{2T} + \widetilde{\mathcal{E}}'_{2T}\Big) - \frac{\xi^2}{1-\xi^2}\Big(\mathcal{E}_{2T} + \mathcal{E}'_{2T}\Big)\Big)\Big(\mathcal{E} - \xi\widetilde{\mathcal{E}}\Big)\Big]$$

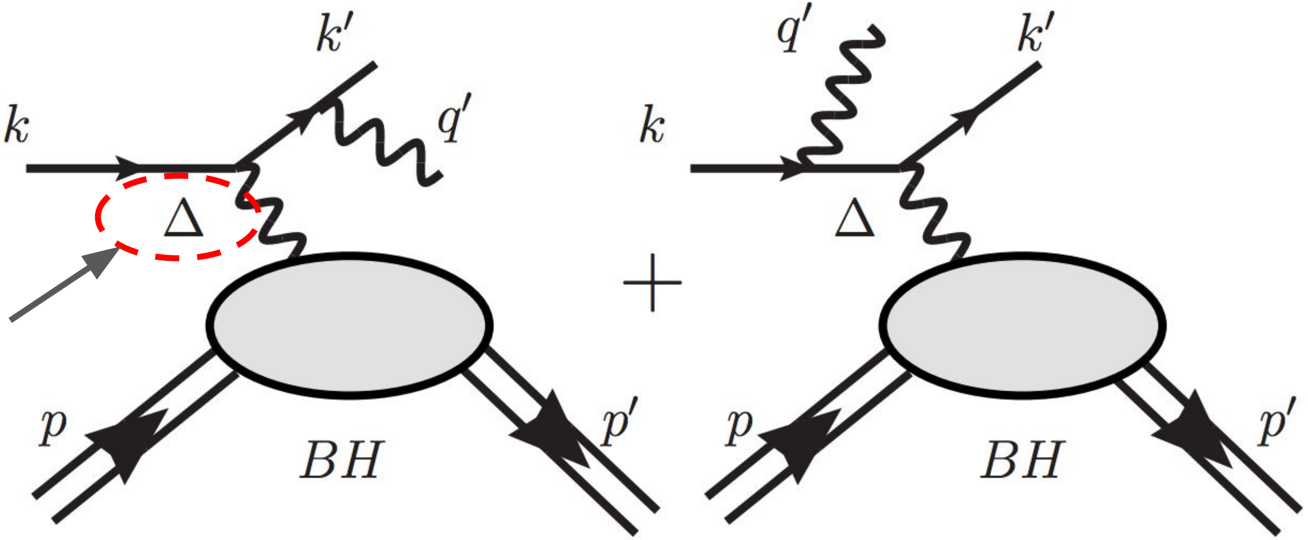
Get access to 8 Compton Form Factors from DVCS alone.

GPD		Phase	Helicity Composition
H	$2\widetilde{H}_{2T} + E_{2T}$	$e^{i\phi}$	
OAM	$\widetilde{E}_{2T}$	$e^{i\phi}$	
T OAM	$\widetilde{H}_{2T}$	$e^{2i\phi}$	
E	$H_{2T} + \frac{\Delta_T^2}{4M^2}\widetilde{H}_{2T}$	1	

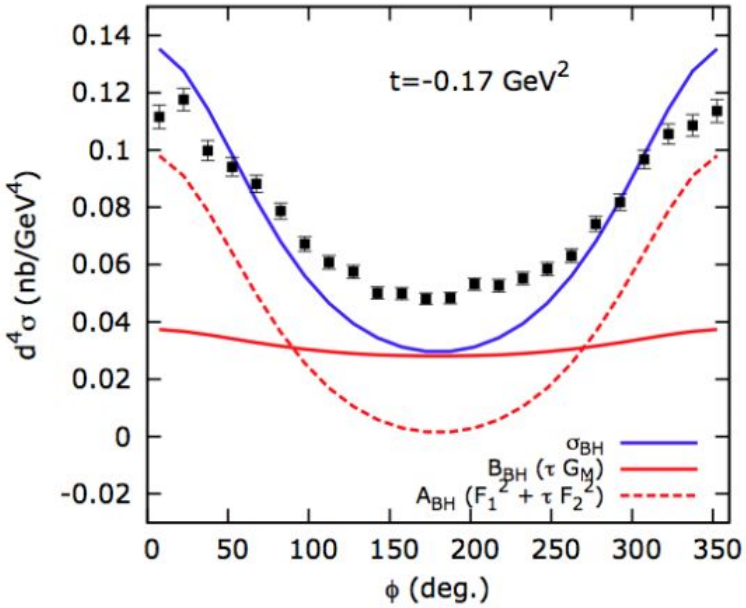
GPD		Phase	Helicity Composition
$\widetilde{H}$	$\widetilde{E}'_{2T}$	$e^{i\phi}$	
Spin Orbit	$E'_{2T} + 2\widetilde{H}'_{2T}$	$e^{i\phi}$	
T Spin Orbit	$\widetilde{H}'_{2T}$	$e^{2i\phi}$	
$\widetilde{E}$	$H'_{2T} + \frac{\Delta_T^2}{4M^2}\widetilde{H}'_{2T}$	1	

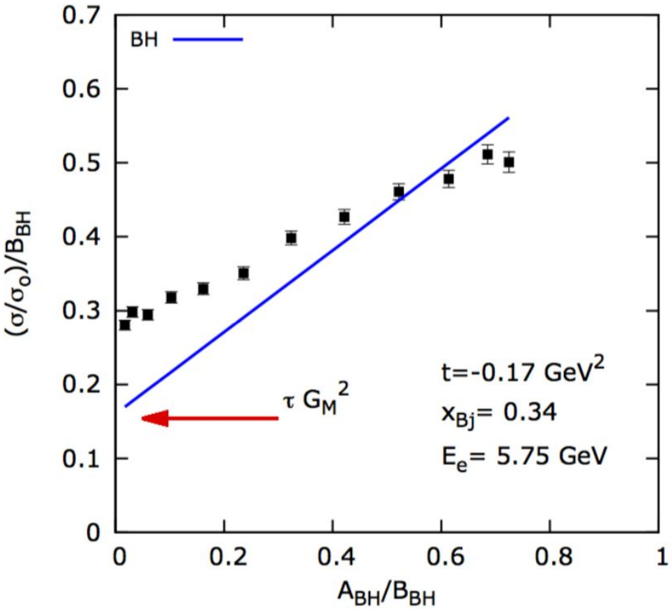
Bethe-Heitler

Different hard scale due to the radiation.



$$\frac{d^5\sigma^{BH}_{unpol}}{dx_{Bj}dQ^2d|t|d\phi d\phi_S} = \frac{\Gamma}{t^2}\left[A_{BH}(F_1^2+\tau F_2^2) + B_{BH}\tau G_M^2\right]$$





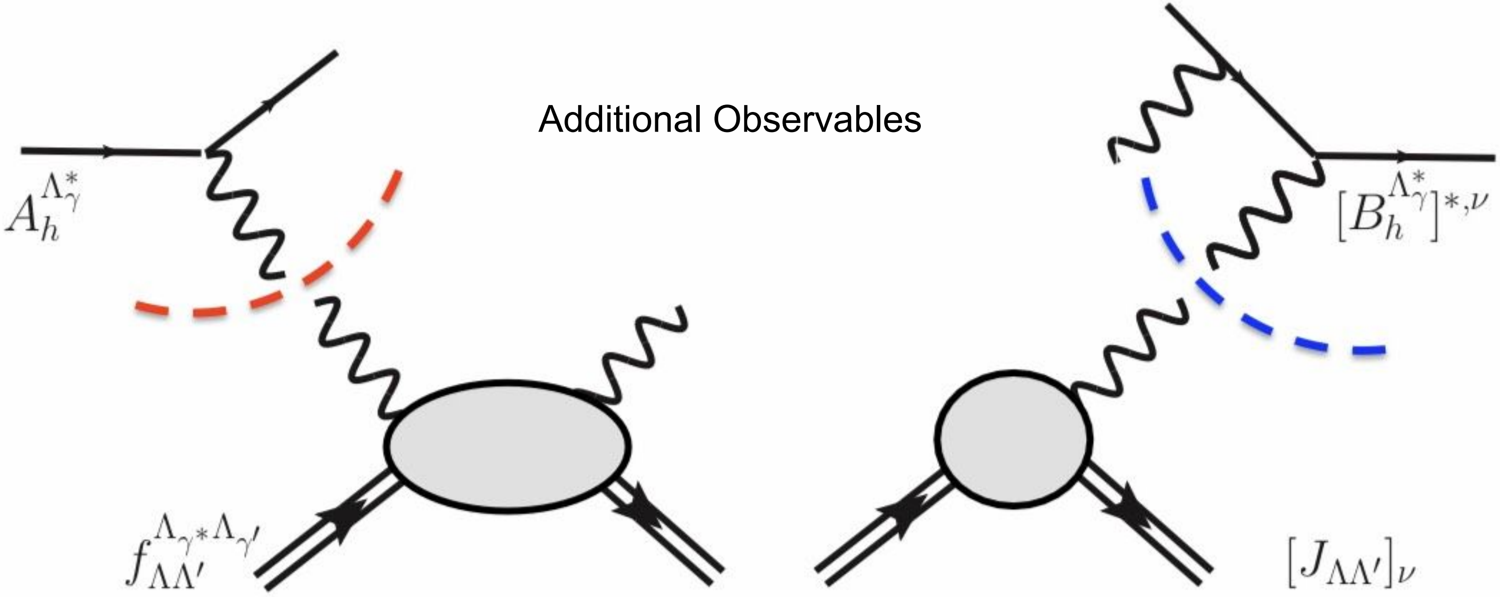
B.K., S.L., et. al. arXiv:1903.05742

DVCS/BH Interference

$$|T|^2 = |T_{\rm BH} + T_{\rm DVCS}|^2 = |T_{\rm BH}|^2 + |T_{\rm DVCS}|^2 + \mathcal{I}\ .$$

$$\mathcal{I} = T^*_{BH} T_{DVCS} + T^*_{DVCS} T_{BH}.$$

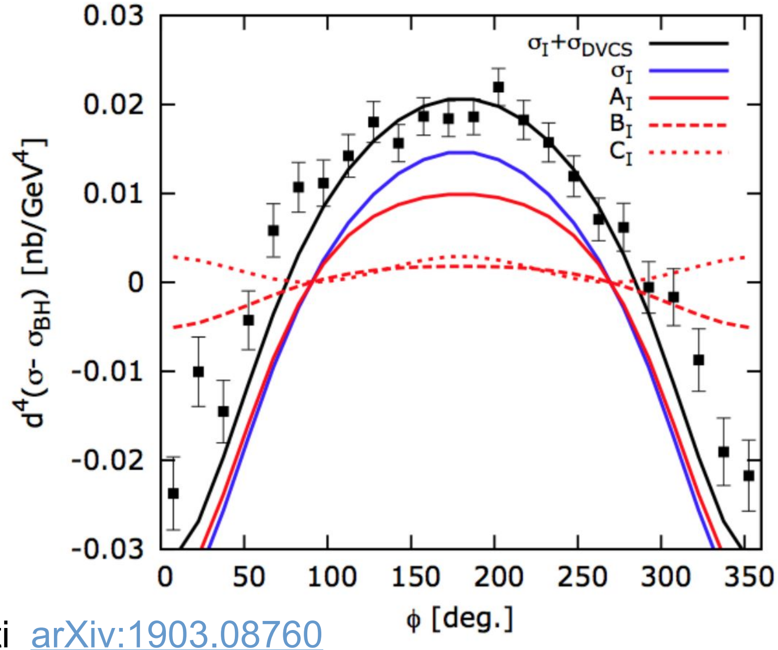
Additional Observables

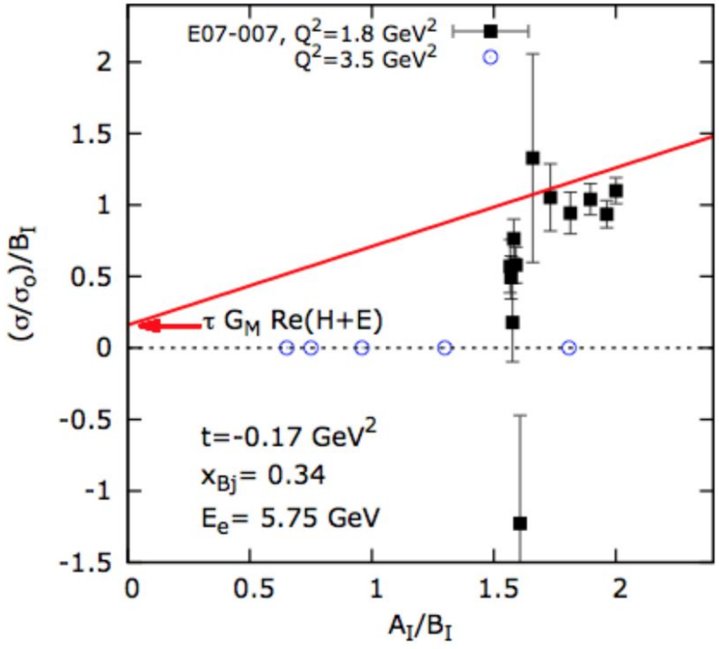


Rosenbluth-like Separation

Angular Momentum

$$F_{UU}^{\mathcal{I},tw2} = A_{UU}^{\mathcal{I}} \Re e\Big(F_1\mathcal{H} + \tau F_2 \mathcal{E}\Big) + B_{UU}^{\mathcal{I}} G_M \Re e(\mathcal{H}+\mathcal{E}) + C_{UU}^{\mathcal{I}} G_M \Re e\widetilde{\mathcal{H}}$$



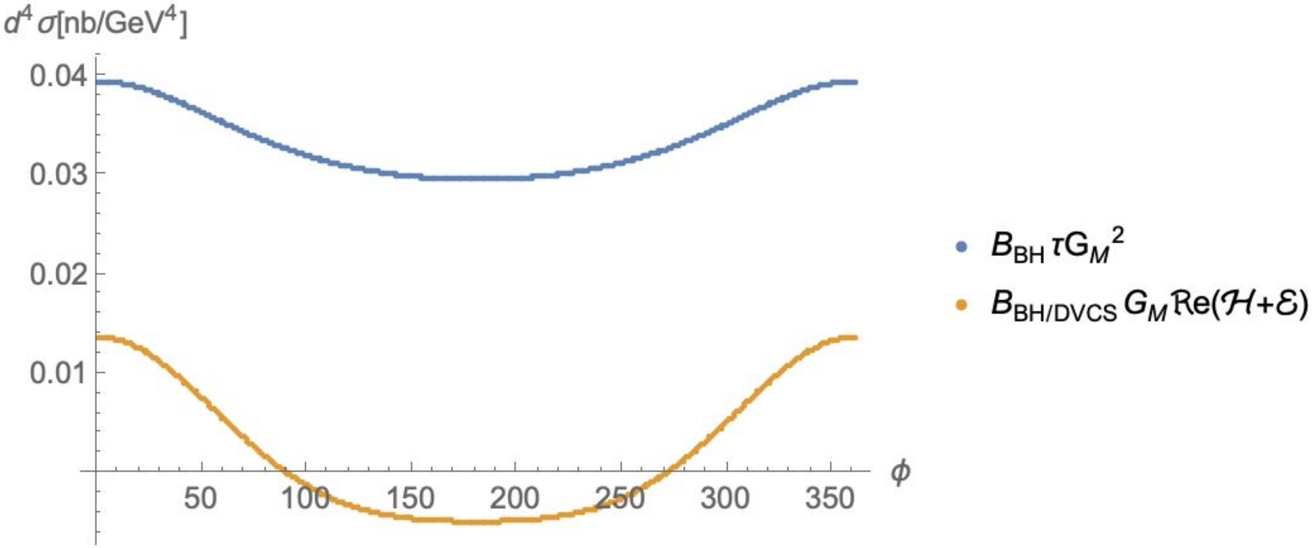


S. Liuti arXiv:1903.08760

Rosenbluth-like Separation

Angular Momentum

$$F_{UU}^{\mathcal{I},tw2} = A_{UU}^{\mathcal{I}} \Re e\left(F_1\mathcal{H} + \tau F_2\mathcal{E}\right) + B_{UU}^{\mathcal{I}} G_M \Re e(\mathcal{H} + \mathcal{E}) + C_{UU}^{\mathcal{I}} G_M \Re e\widetilde{\mathcal{H}}$$

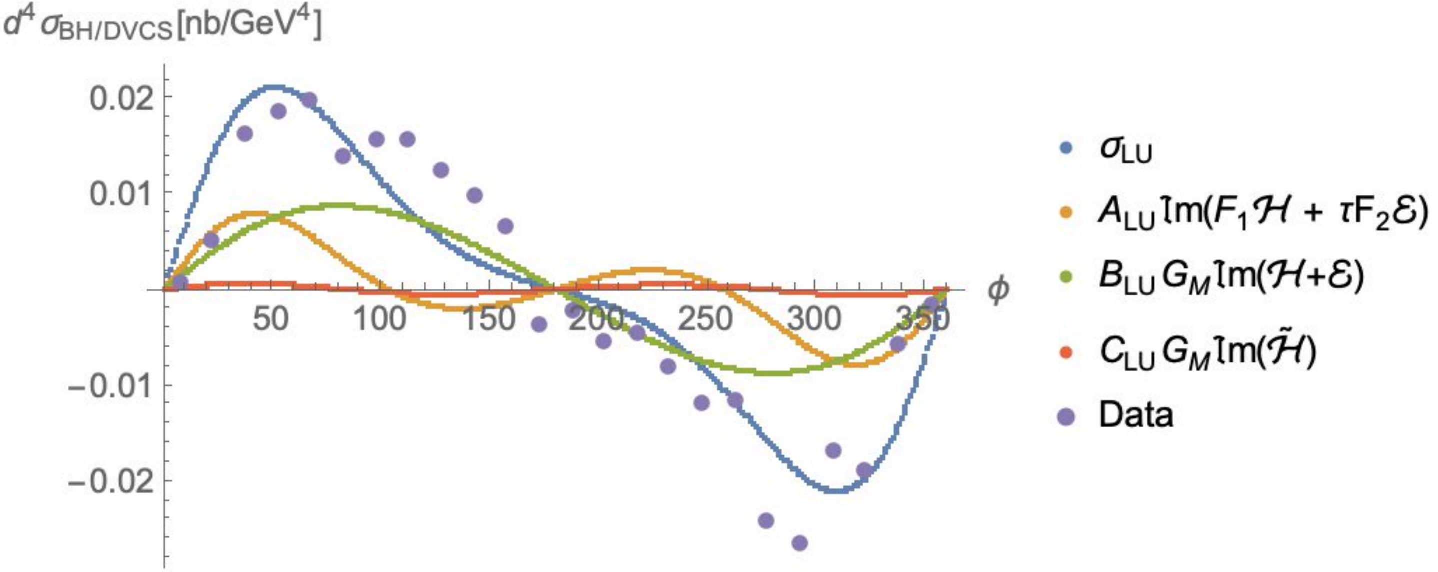


S. Liuti [arXiv:1903.08760]

Preliminary

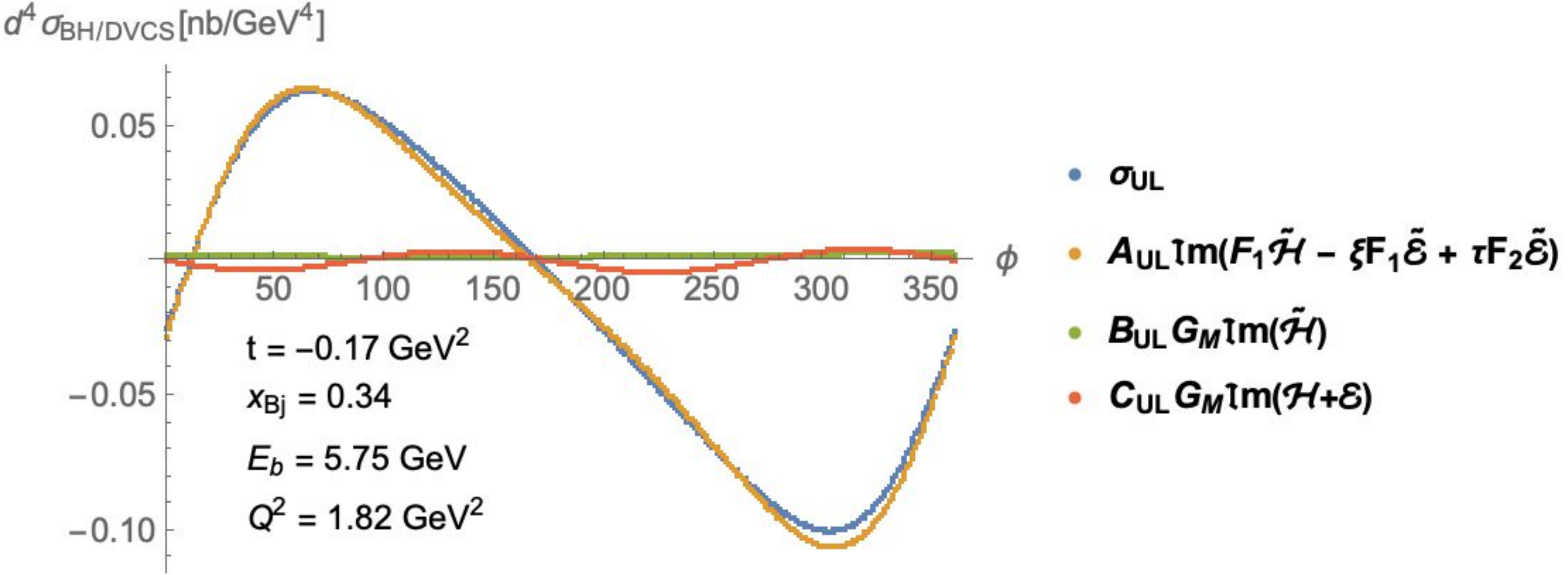
Angular Momentum

$$F_{LU}^{\mathcal{I},tw2} = A_{LU}^{\mathcal{I}} \Im m\Big(F_1\mathcal{H} + \tau F_2\mathcal{E}\Big) + B_{LU}^{\mathcal{I}} G_M \Im m(\mathcal{H} + \mathcal{E}) + C_{LU}^{\mathcal{I}} G_M \Im m\widetilde{\mathcal{H}}$$



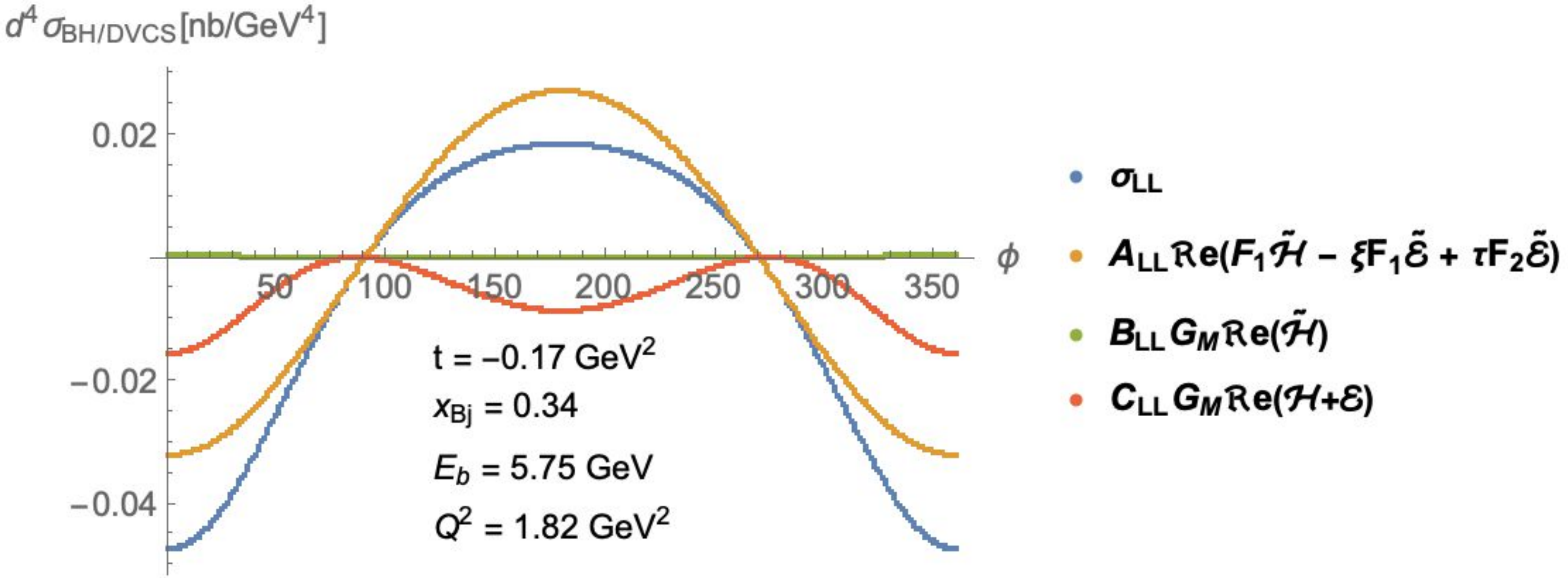
Preliminary

$$F_{UL}^{\mathcal{I},tw2} = A_{UL}^{\mathcal{I}} \Im m\Big(F_1(\widetilde{\mathcal{H}} - \xi\widetilde{\mathcal{E}}) + \tau F_2\widetilde{\mathcal{E}}\Big) + B_{UL}^{\mathcal{I}} G_M \Im m\widetilde{\mathcal{H}} + C_{UL}^{\mathcal{I}} G_M \Im m(\mathcal{H} + \mathcal{E})$$



Preliminary

$$F_{LL}^{\mathcal{I},tw2} = A_{LL}^{\mathcal{I}} \Re e\Big(F_1(\widetilde{\mathcal{H}} - \xi\widetilde{\mathcal{E}}) + \tau F_2\widetilde{\mathcal{E}}\Big) + B_{LL}^{\mathcal{I}} G_M \Re e \widetilde{\mathcal{H}} + C_{LL}^{\mathcal{I}} G_M \Re e(\mathcal{H} + \mathcal{E})$$



Twist-3 Coefficients (Preliminary)

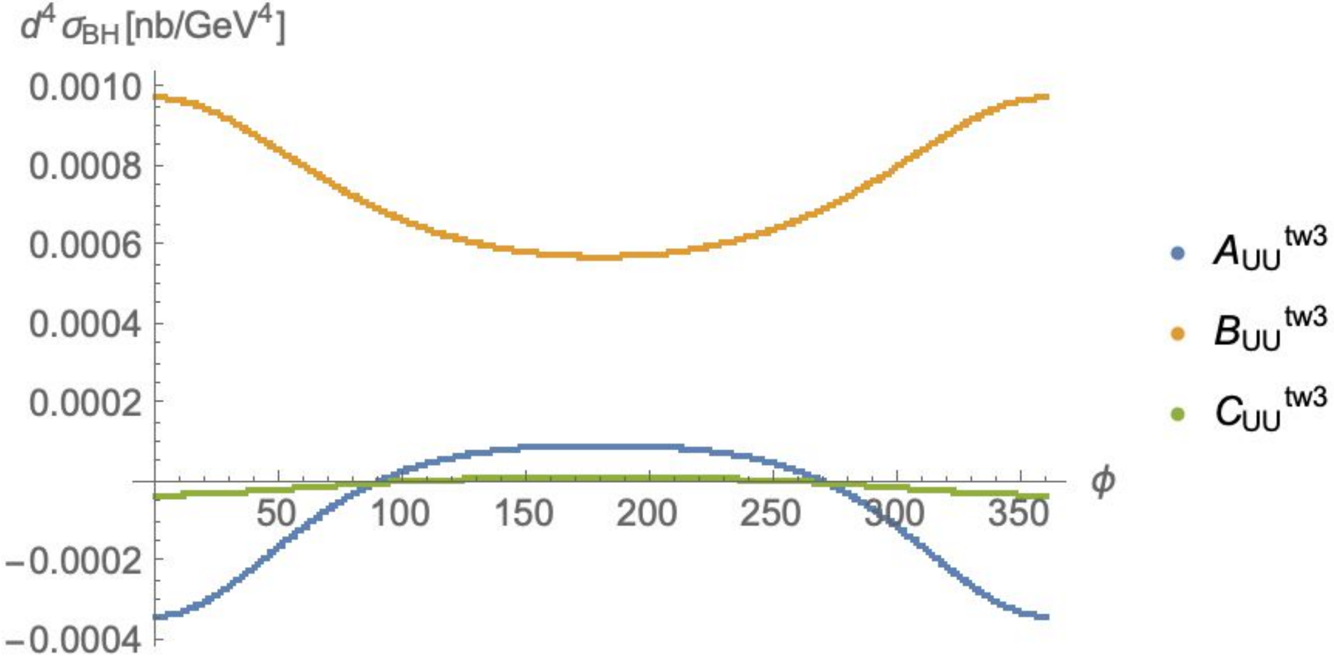
$$F_{UU}^{\mathcal{I},tw3} = \Re e\left\{ A_{UU}^{(3)\mathcal{I}}\left[F_1(2\widetilde{\mathcal{H}}_{2T} + \mathcal{E}_{2T}) + F_2(\mathcal{H}_{2T} + \tau\widetilde{\mathcal{H}}_{2T})\right]\right.$$

$$\left. +B_{UU}^{(3)\mathcal{I}} G_M\, \widetilde{E}_{2T} + C_{UU}^{(3)\mathcal{I}} G_M \left[2\xi H_{2T} - \tau(\widetilde{E}_{2T} - \xi E_{2T})\right]\right\}$$

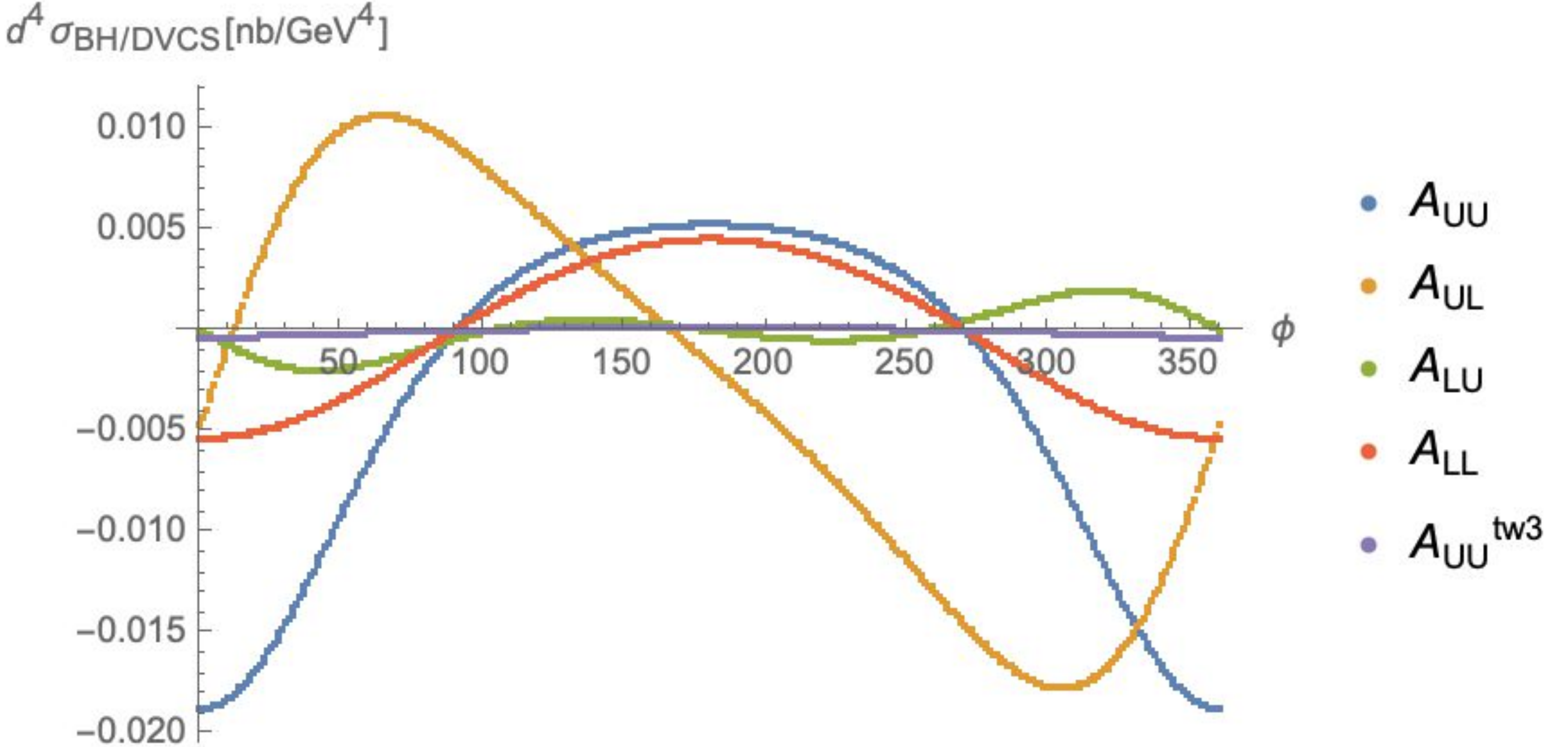
$$+ \Im m\left\{ \widetilde{A}_{UU}^{(3)\mathcal{I}}\left[F_1(2\widetilde{H}'_{2T} + E'_{2T}) + F_2(H'_{2T} + \tau\widetilde{H}'_{2T})\right]\right.$$

$$\left. +\widetilde{B}_{UU}^{(3)\mathcal{I}} G_M \widetilde{E}'_{2T} + \widetilde{C}_{UU}^{(3)\mathcal{I}} G_M \left[2\xi H'_{2T} - \tau(\widetilde{E}'_{2T} - \xi E'_{2T})\right]\right\}$$

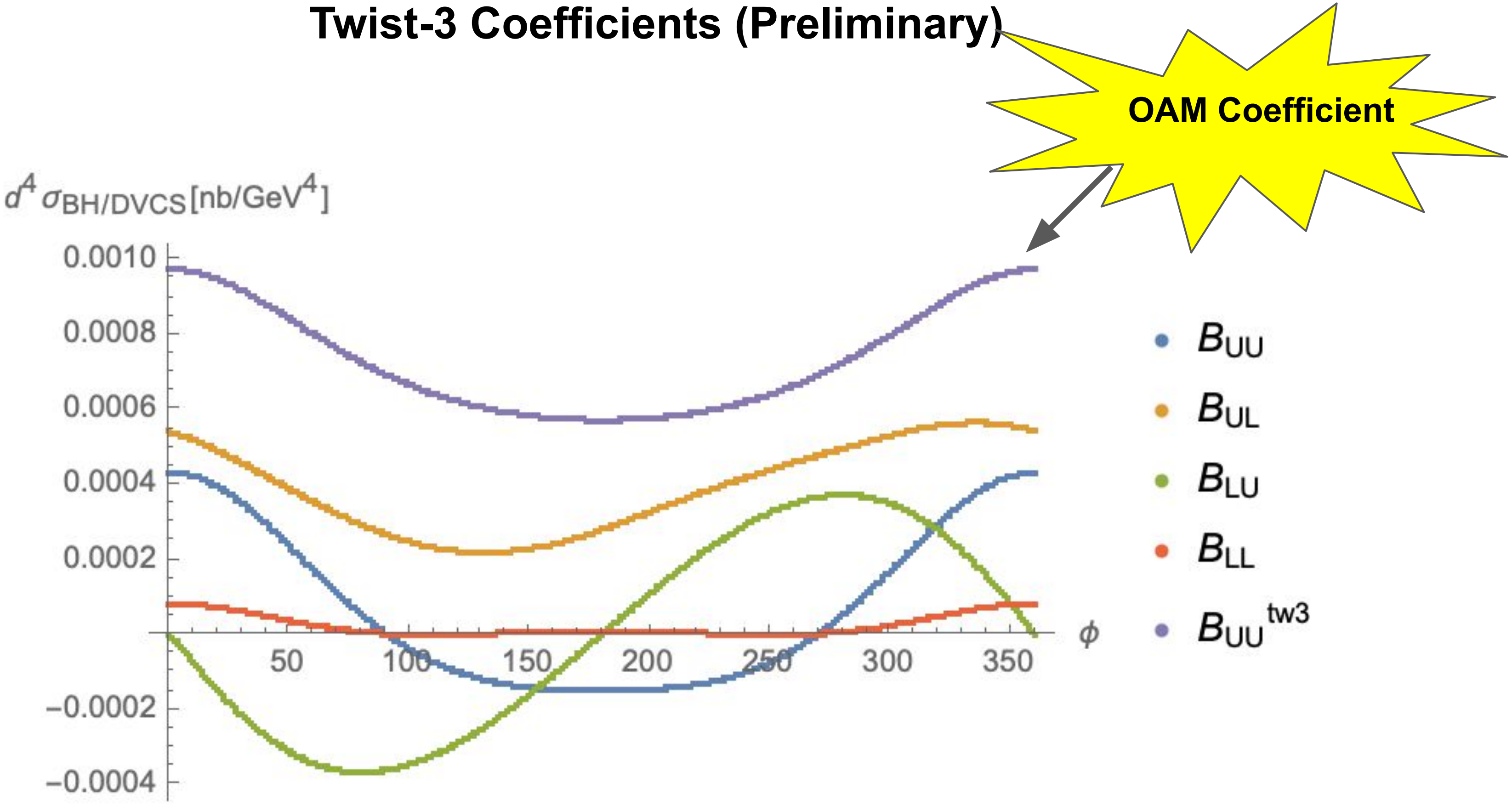
Twist-3 Coefficients (Preliminary)



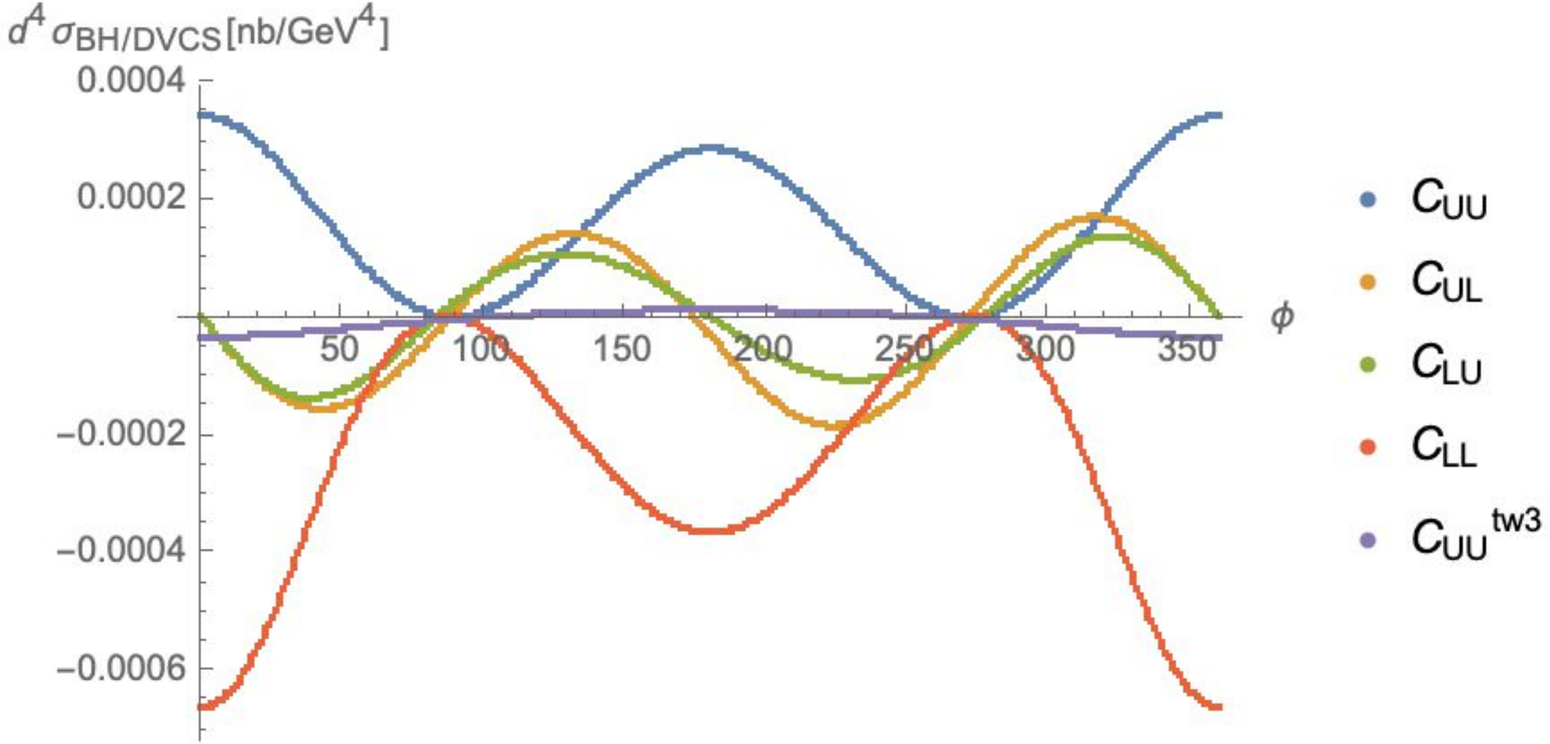
Twist-3 Coefficients (Preliminary)



Twist-3 Coefficients (Preliminary)

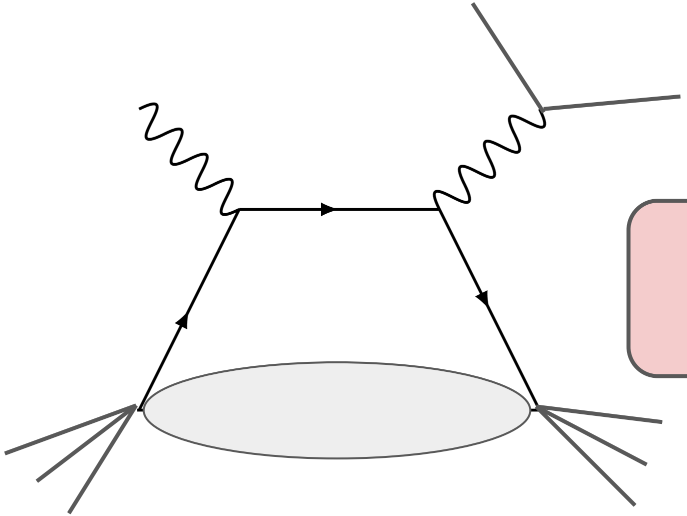


Twist-3 Coefficients (Preliminary)



TCS

Do we gain access to the other 8 Form Factor combinations?



Formalism for TCS is being developed!

Twist - 2

Twist - 3

$$W^{\mu\nu} \propto \gamma^\mu \gamma^+ \gamma^\nu = \begin{bmatrix} \gamma^- & \gamma^1 - i\gamma^2\gamma_5 & \gamma^2 + i\gamma^1\gamma_5 & i\gamma^-\gamma_5 \\ \gamma^1 + i\gamma^2\gamma_5 & \gamma^+ & i\gamma^+\gamma_5 & -\gamma^1 - i\gamma^2\gamma_5 \\ \gamma^2 - i\gamma^1\gamma_5 & -i\gamma^+\gamma_5 & \gamma^+ & -\gamma^2 + i\gamma^1\gamma_5 \\ -i\gamma^-\gamma_5 & -\gamma^1 + i\gamma^2\gamma_5 & -\gamma^2 - i\gamma^1\gamma_5 & \gamma^- \end{bmatrix}$$

DVCS from Spin-1 Deuteron

Angular momentum sum rule for a spin-½ nucleon.

$$J_q = \frac{1}{2}\int dx x \left[H_q(x,0,0) + E_q(x,0,0)\right]$$

Using the Spin-1 Energy Momentum Tensor, a similar formula has been developed for the Spin-1 deuteron

$$J_q = \frac{1}{2}\int dx x H_2^q(x,0,0)$$

Can we identify the observable for the Spin-1 Angular Momentum from DVCS off a spin-1 Deuteron formalism?

S. Taneja, K. Kathuria, S Liuti, and G.R. Goldstein [arXiv:1101.0581]

DVCS from Spin-1 Deuteron

$$2\int dx\, x\left[H_1(x,\xi,t) - \frac{1}{2}H_5(x,\xi,t)\right] = \mathcal{G}_1(t) + \boxed{\xi^2\mathcal{G}_3(t)}$$

$$2\int dx\, x H_3(x,\xi,t) = \mathcal{G}_2(t) + \boxed{\xi^2\mathcal{G}_4(t)}$$

$$-4\int dx\, x H_4(x,\xi,t) = \xi\mathcal{G}_6(t)$$

$$\int dx\, x H_5(x,\xi,t) = -\frac{t}{8M_D^2}\mathcal{G}_6(t) + \frac{1}{2}\mathcal{G}_7(t)$$

S. Taneja, K. Kathuria, S Liuti, and G.R. Goldstein **PRD86(2012)**

Summary

- Complete covariant description of DVCS cross section and its background process
- Helicity Composition of Twist-3 combinations of GPDs
- Calculations of Polarized and Unpolarized Cross Sections (prelim)
- Calculation of Twist-3 Coefficients

Future Work

- Formalism of TCS is being developed for possible additional Compton Form Factors

- DVCS off Spin-1 deuteron, verify sum rules, understand 2 D-terms

- Spin Asymmetry Calculations

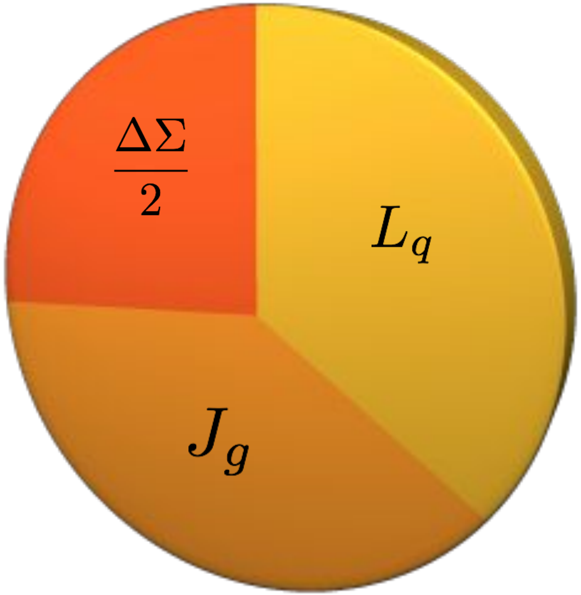
- Twist-3 Calculation of Cross Section

Thank you!

Backup Slides

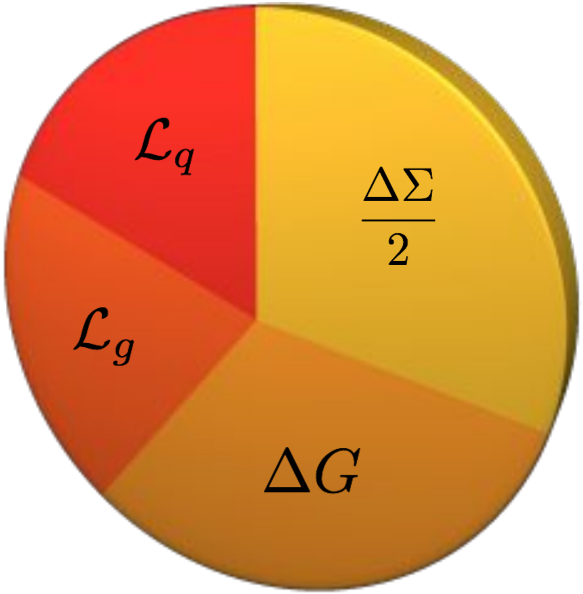
How to define OAM?

Ji



$$\frac{1}{2} = \frac{\Delta\Sigma}{2} + L_q + J_g$$

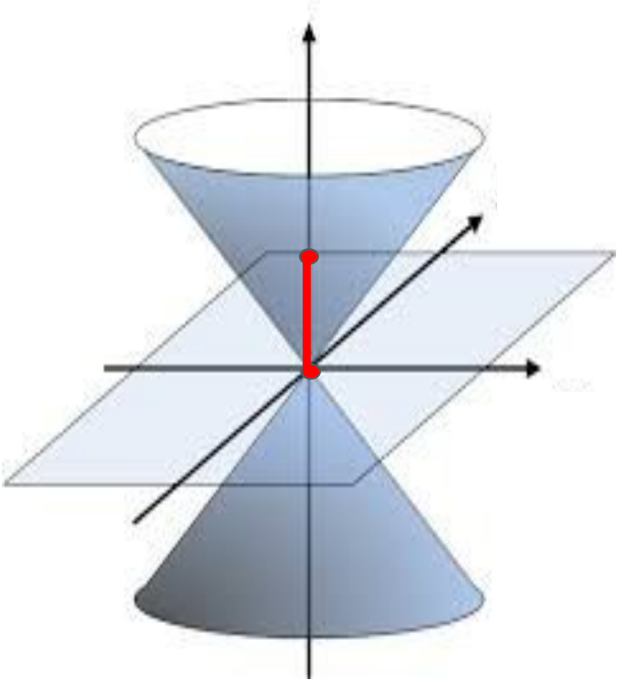
Jaffe Manohar



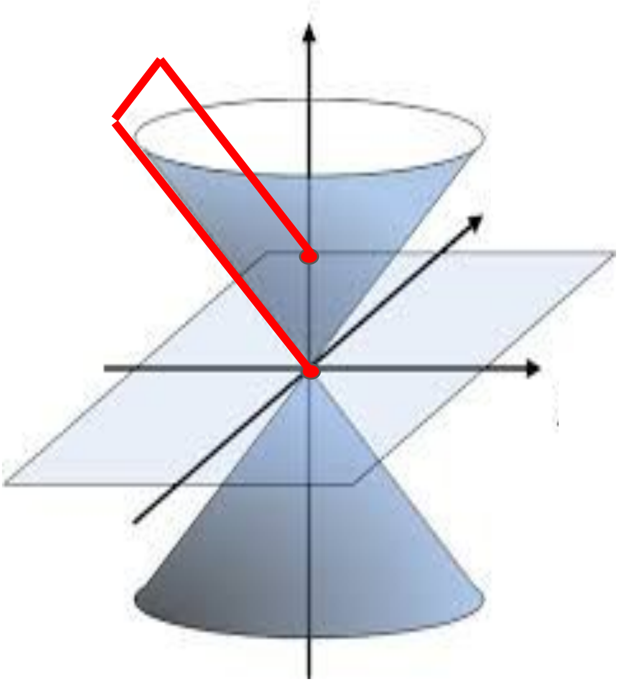
$$\frac{1}{2} = \frac{\Delta\Sigma}{2} + \mathcal{L}_q + \Delta G + \mathcal{L}_g$$

How to define OAM?

Ji



Jaffe Manohar



$$L_q = \int d^3r \langle P', \Lambda' | \overline{\psi}\, \gamma^+ \left(\vec{r} \times i\vec{D} \right) \psi | P, \Lambda \rangle$$

$$\mathcal{L}_q = \int d^3r \langle P', \Lambda' | \overline{\psi}\, \gamma^+ \left(\vec{r} \times i\vec{\partial} \right) \psi | P, \Lambda \rangle$$

Lorce, Pasquini arXiv:1106.0139

How do we describe the orbital angular momentum of the partons?

$$\vec{L} = \vec{r} \times \vec{p}$$

Classically

$$L_z^q = -\left(k_T \times b_T\right)_z^q$$

Partonic

b_T Relative average transverse position from the center of momentum of the system

k_T Relative average transverse momentum

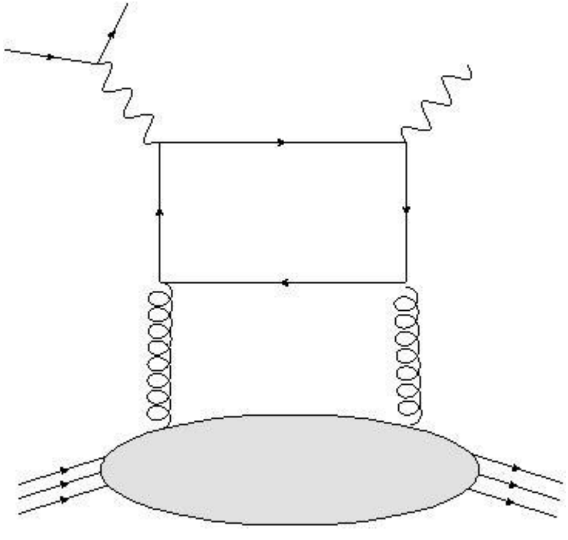
$$l_z^q = \int dx d^2k_T d^2b_T \left(b_T \times k_T\right)_z^q \rho^{[\gamma^+]}(b_T, k_T, x)$$

$$l_z^q = -\int dx d^2k_T \frac{k_T^2}{M^2} F_{1,4}^q$$

Observable?

Jaffe, Manohar Phys. Lett. B223 (1989)

A glimpse at the gluons



B.K., S.L., et. al. arXiv:1903.05742

Gluon GPD Observables

$$F_{UL}^{\sin 2\phi} = -2\frac{\alpha_S}{2\pi}\sum_q e_q^2\sqrt{1-\xi^2}\frac{t_0-t}{4M^2}\,\Im\mathrm{m}\Bigg[\sqrt{1-\xi^2}\left(\widetilde{\mathcal{H}}_T^g+(1-\xi)\frac{\mathcal{E}_T^g+\widetilde{\mathcal{E}}_T^g}{2}\right)\left(\mathcal{H}+\widetilde{\mathcal{H}}-\frac{\xi^2}{1-\xi^2}(\mathcal{E}+\widetilde{\mathcal{E}})\right)^*$$
$$+\sqrt{1-\xi^2}\left(\widetilde{\mathcal{H}}_T^g+(1+\xi)\frac{\mathcal{E}_T^g-\widetilde{\mathcal{E}}_T^g}{2}\right)\left(\mathcal{H}-\widetilde{\mathcal{H}}-\frac{\xi^2}{1-\xi^2}(\mathcal{E}+\widetilde{\mathcal{E}})\right)^*$$
$$+\frac{\sqrt{t_0-t}}{2M}\left(\widetilde{\mathcal{H}}_T^g+(1+\xi)\frac{\mathcal{E}_T^g-\widetilde{\mathcal{E}}_T^g}{2}\right)\left(\mathcal{E}+\xi\widetilde{\mathcal{E}}\right)^*$$
$$-\sqrt{1-\xi^2}\left(\mathcal{H}_T^g+\frac{t_0-t}{M^2}\widetilde{\mathcal{H}}_T^g-\frac{\xi^2}{1-\xi^2}\mathcal{E}_T^g+\frac{\xi}{1-\xi^2}\widetilde{\mathcal{E}}_T^g\right)\left(\mathcal{E}-\xi\widetilde{\mathcal{E}}\right)^*\Bigg]$$

$$F_{UT}^{\sin(3\phi-\phi_S)} = -4\frac{\alpha_S}{2\pi}\sum_q e_q^2\sqrt{1-\xi^2}\frac{\sqrt{t_0-t}^{\,3}}{8M^3}\,\Im m\Bigg[(1-\xi^2)\left(\widetilde{\mathcal{H}}_T^g\right)\left(\mathcal{H}-\widetilde{\mathcal{H}}-\frac{\xi^2}{1-\xi^2}(\mathcal{E}-\widetilde{\mathcal{E}})\right)^*$$
$$+\left(\widetilde{\mathcal{H}}_T^g+(1-\xi)\frac{\mathcal{E}_T^g+\widetilde{\mathcal{E}}_T^g}{2}\right)\left(\mathcal{E}-\xi\widetilde{\mathcal{E}}\right)^*\Bigg]$$

	PDFs	FFs
GPD	$\Delta \to 0$	$\int_{-1}^{1} dx$
H	$q(x)$	F_1
E	0	F_2
$\widetilde{H}$	$\Delta q(x)$	g_A
$\widetilde{E}$	0	g_P

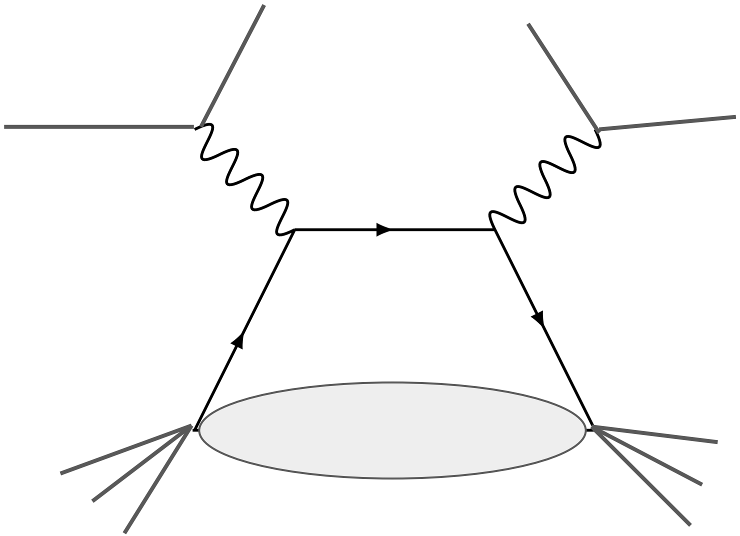
$\mathcal{O}\left(\frac{1}{Q^2}\right)$ Observables

$$F_{UU,L} = \frac{1}{(P^+)^2}\Bigg[2\left|\widetilde{\mathcal{H}}'_{2T} - \widetilde{\mathcal{H}}_{2T}\right|^2 + \frac{(1+\xi)^2}{4}\left|\mathcal{E}'_{2T} - \mathcal{E}_{2T} + \widetilde{\mathcal{E}}_{2T} - \widetilde{\mathcal{E}}'_{2T}\right|^2$$
$$+ \frac{(1-\xi)^2}{4}\left|\mathcal{E}'_{2T} - \mathcal{E}_{2T} - \widetilde{\mathcal{E}}_{2T} + \widetilde{\mathcal{E}}'_{2T}\right|^2 + (1+\xi)\Re e\left(\widetilde{\mathcal{H}}'_{2T} - \widetilde{\mathcal{H}}_{2T}\right)\left(\mathcal{E}'_{2T} - \mathcal{E}_{2T}\right)$$
$$+ (1+\xi)\Im m\left(\widetilde{\mathcal{H}}'_{2T} - \widetilde{\mathcal{H}}_{2T}\right)\left(\mathcal{E}'_{2T} - \mathcal{E}_{2T}\right)\Bigg]$$

The $\mathcal{O}\left(\frac{1}{Q^2}\right)$ observables are constructed from Twist-3 GPDs. This is because the DVCS process cannot access the Twist-4 sector of the hadronic tensor.

B.K., S.L., et. al. **arXiv:1903.05742**

DDVCS



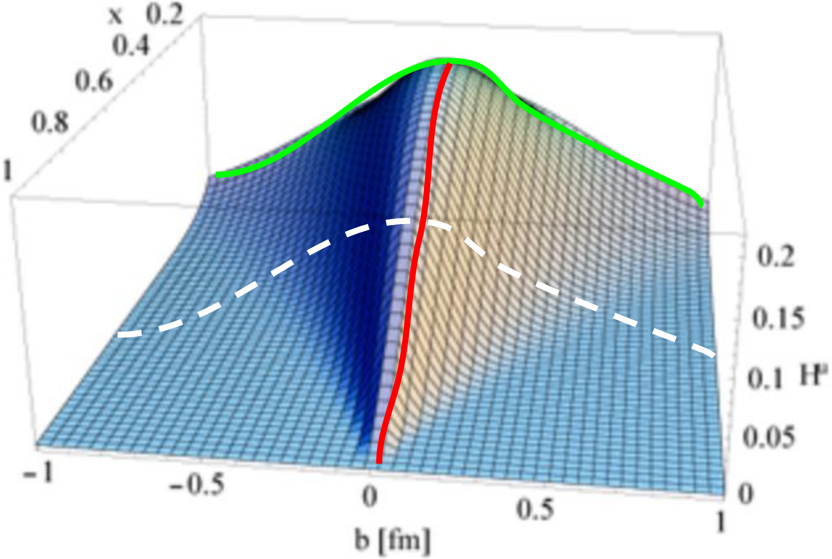
Twist - 2 (blue)
Twist - 3 (green)
Twist - 4 (magenta)

Isolate OAM directly through a singular process?

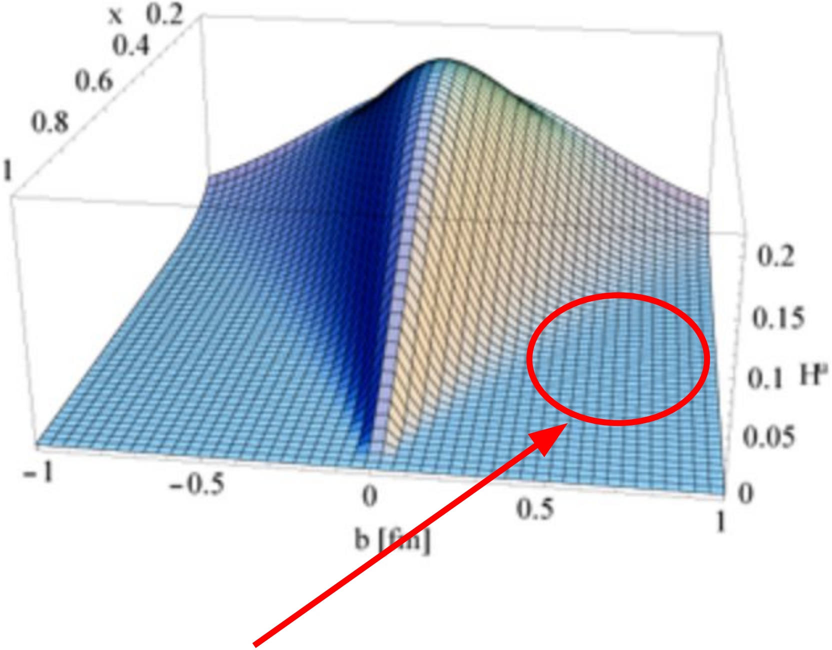
Developed formalism through GPDs to isolate OAM.

$$W^{\mu\nu} \propto \gamma^{\mu}\gamma^{+}\gamma^{\nu} = \begin{bmatrix} \gamma^{-} & \gamma^{1} - i\gamma^{2}\gamma_{5} & \gamma^{2} + i\gamma^{1}\gamma_{5} & i\gamma^{-}\gamma_{5} \\ \gamma^{1} + i\gamma^{2}\gamma_{5} & \gamma^{+} & i\gamma^{+}\gamma_{5} & -\gamma^{1} - i\gamma^{2}\gamma_{5} \\ \gamma^{2} - i\gamma^{1}\gamma_{5} & -i\gamma^{+}\gamma_{5} & \gamma^{+} & -\gamma^{2} + i\gamma^{1}\gamma_{5} \\ -i\gamma^{-}\gamma_{5} & -\gamma^{1} + i\gamma^{2}\gamma_{5} & -\gamma^{2} - i\gamma^{1}\gamma_{5} & \gamma^{-} \end{bmatrix}$$

DVCS



DDVCS



"Lever arm" can take
you off of the ridge, $x = \xi$