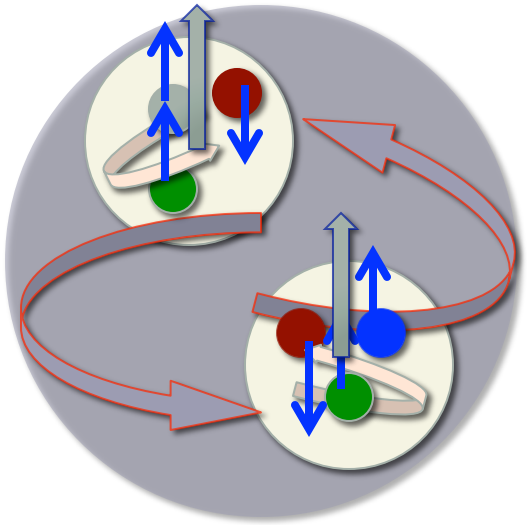
FLAVOR DEPENDENCE DETERMINATION OF TRANSVERSITY GPDS AND BSM INTERACTIONS

BNL WORKSHOP ON GPDS FOR EIC
JUNE 4TH, 2018

Simonetta Liuti
University of Virginia

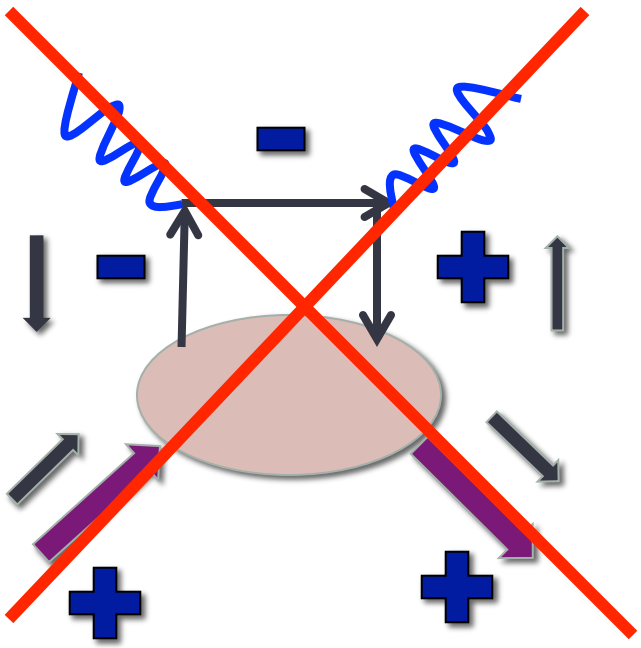


Outline

1. Introduction
2. Chiral Odd GPDs
3. Extraction from experiment: role of EIC
4. Impact on BSM searches
5. Conclusions and Outlook

1. INTRODUCTION

In a nutshell



- ✓ The tensor charge is not a fundamental property of strongly interacting matter within the Standard Model
- ✓ Chiral Odd constructs appear because of the composite structure of hadrons
- ✓ To detect chiral odd distributions we need another distinct hadronic blob

In 2009 we proposed

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Nucleon tensor charge from exclusive π^0 electroproduction

Saeed Ahmad, Gary R. Goldstein, and Simonetta Liuti
Phys. Rev. D **79**, 054014 – Published 25 March 2009

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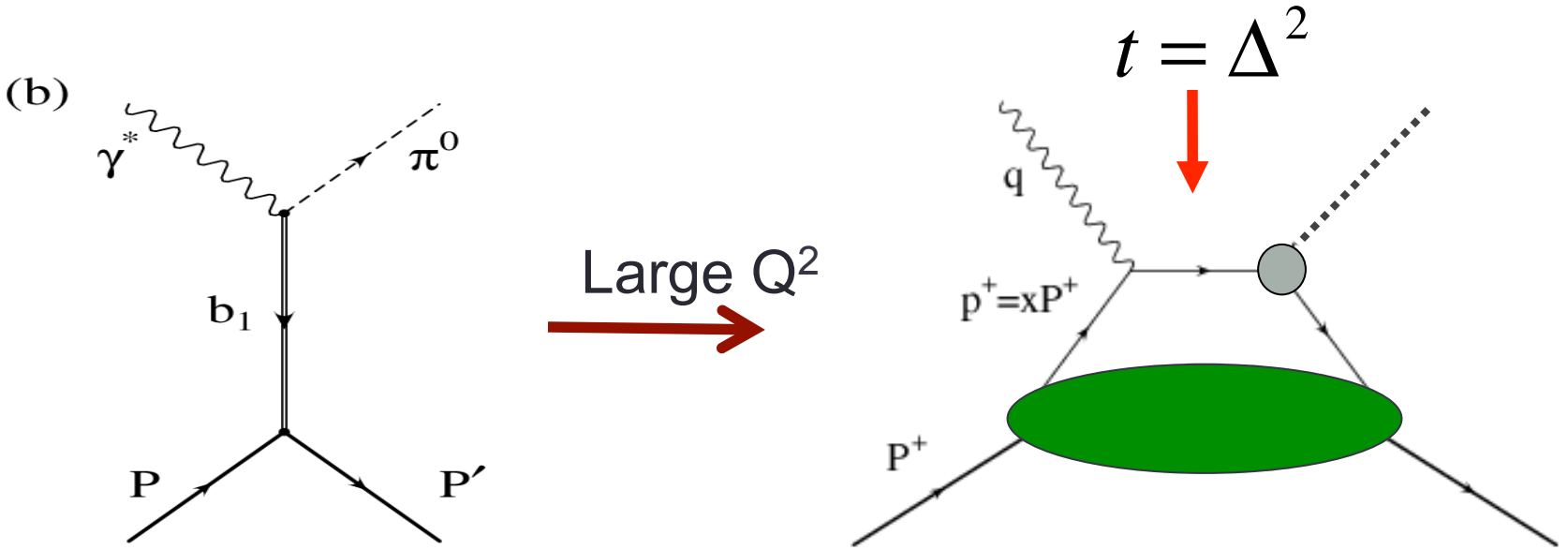
Flexible parametrization of generalized parton distributions: The chiral-odd sector

Gary R. Goldstein, J. Osvaldo Gonzalez Hernandez, and Simonetta Liuti
Phys. Rev. D **91**, 114013 – Published 8 June 2015

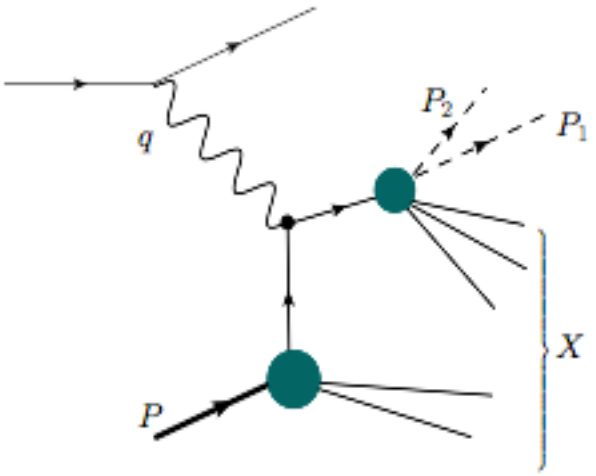
Dual Representation



$$f_{1,\Lambda;0,\Lambda'} = \sum_{\lambda,\lambda'} g_{1,\lambda;0,\lambda'} A_{\Lambda',\lambda';\Lambda,\lambda}$$

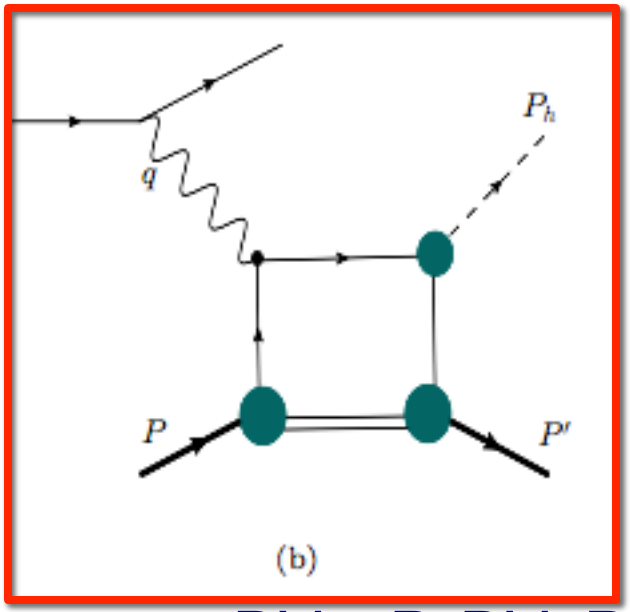
helicity amps.

Quark-Hadron Helicity Amplitudes



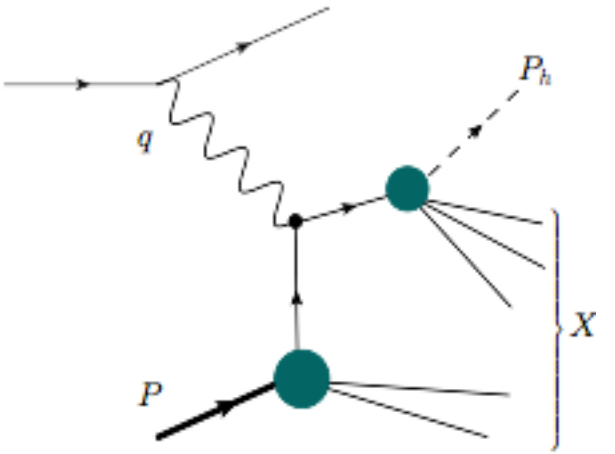
(a)

dihadron



(b)

DVπ°P, DVηP

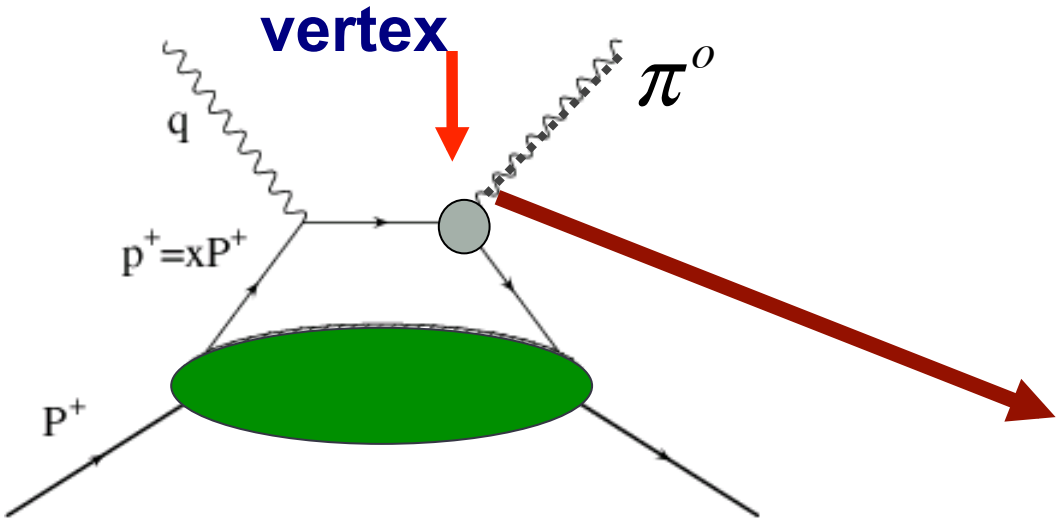


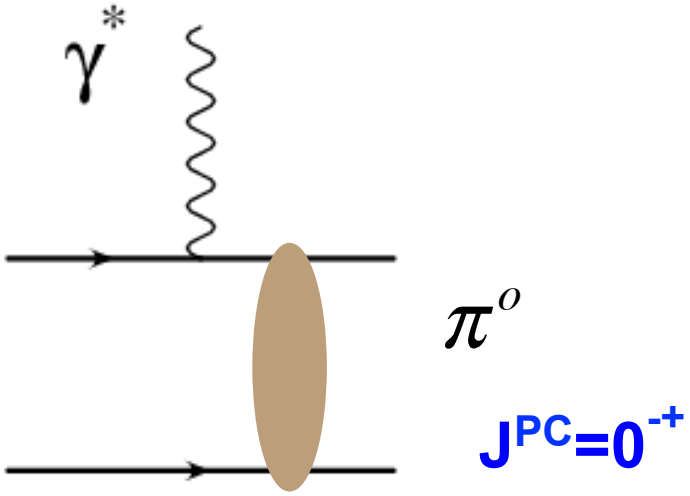
(c)

SIDIS

collinear

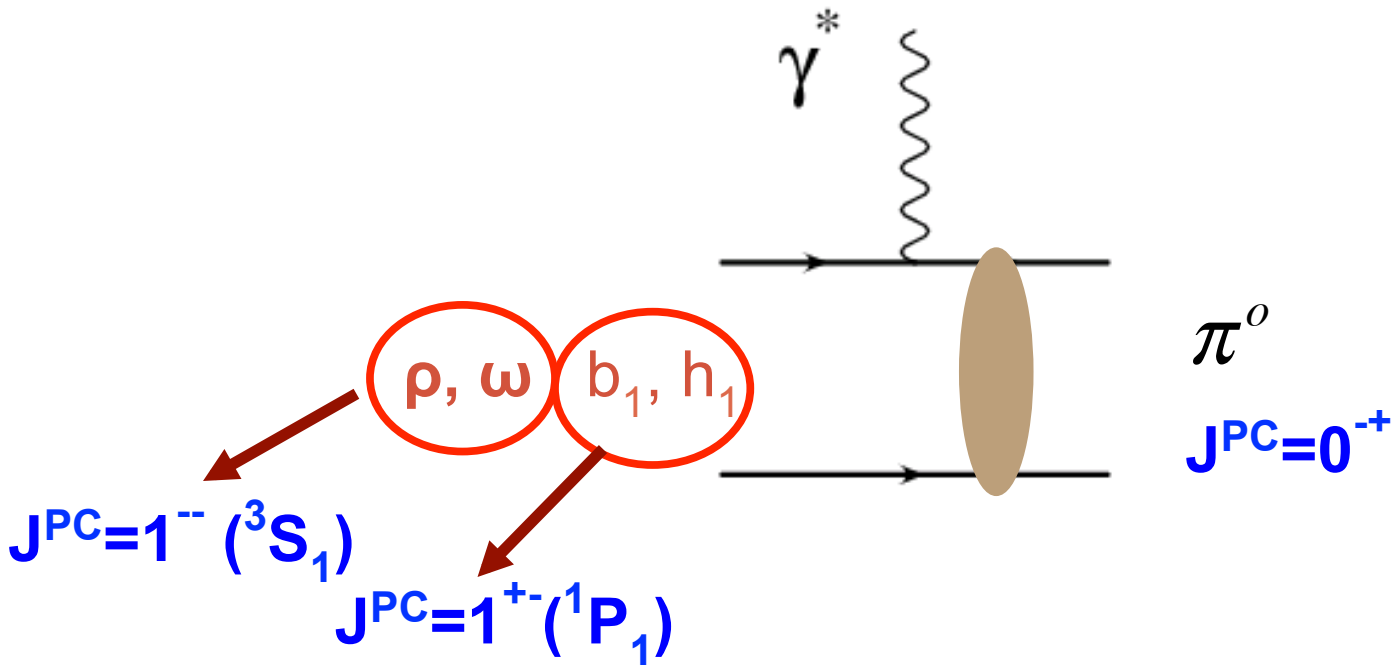
Issue: Q^2 dependence





Goloskokov and Kroll: γ_5 coupling is of twist 3

Our model: pseudoscalar-meson transition form factor



mesons quark content: $\frac{1}{\sqrt{2}}\left(u\bar{u} \pm d\bar{d}\right)$

ρ, ω (vector) and b_1,h_1 (axial-vector) exchanges

$J^{PC}=1^{--}$ → from ρ, ω (S=1 L=0) to π^o (S=0 L=0) **ΔL =0** no change in OAM

$J^{PC}=1^{+-}$ → from b_1,h_1 (S=0 L=1) to π^o (S=0 L=0) **ΔL =1** change 1 unit of OAM

$$F_{\gamma^* V\pi^o} = \int dx_1 dy_1 \int d^2\mathbf{b}\, \psi_V(y_1,b)\, \mathcal{C} K_o(\sqrt{x_1(1-x_1)Q^2}b)\, \psi_{\pi^o}(x_1,b)\, exp(-S)$$

$$F_{\gamma^* A\pi^o} = \int dx_1 dy_1 \int d^2\mathbf{b}\, \psi_A^{(1)}(y_1,b)\, \mathcal{C} K_o(\sqrt{x_1(1-x_1)Q^2}b)\, \psi_{\pi^o}(x_1,b)\, exp(-S)$$

Because of OAM axial vector transition involves Bessel J_1

$$\psi_A^{(1)}(y_1,b) = \int d^2k_T J_1(y_1 b)\psi(y_1,k_T),$$

This yields configurations of larger “radius” in b space (suppressed with Q^2)

Rewrite helicity amps. expressions using new GFFs

$$f_1 = f_4 = \frac{g_2}{\mathcal{C}_q} F_V(Q^2) \frac{\sqrt{t_0 - t}}{2M} \left[\widetilde{\mathcal{H}}_T + \frac{1-\xi}{2} \mathcal{E}_T + \frac{1-\xi}{2} \widetilde{\mathcal{E}}_T \right]$$

$$f_2 = \frac{g_2}{\mathcal{C}_q} [F_V(Q^2) + F_A(Q^2)] \sqrt{1-\xi^2} \left[\mathcal{H}_T + \frac{t_0 - t}{4M^2} \widetilde{\mathcal{H}}_T - \frac{\xi^2}{1-\xi^2} \mathcal{E}_T + \frac{\xi}{1-\xi^2} \widetilde{\mathcal{E}}_T \right]$$

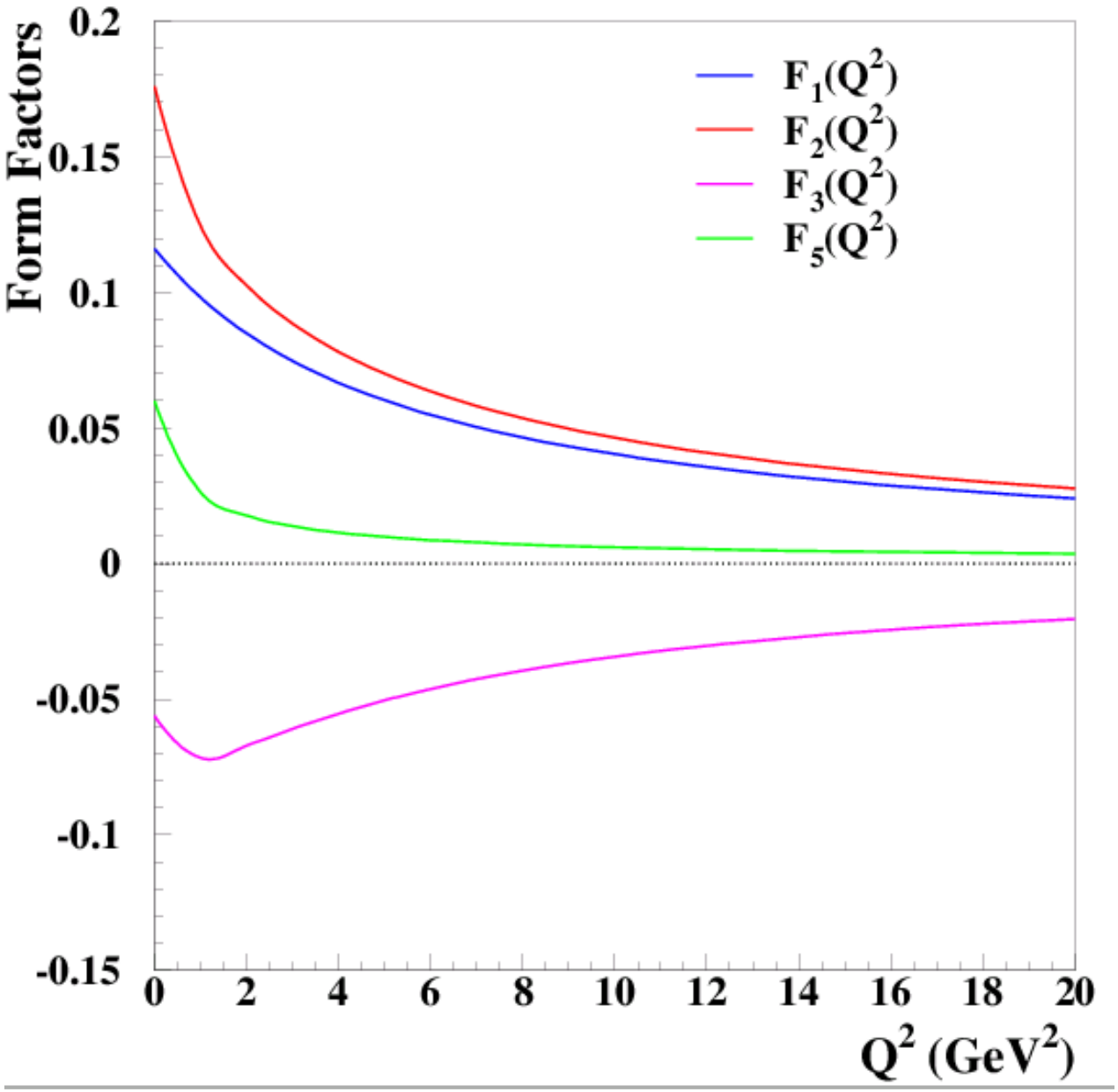
$$f_3 = \frac{g_2}{\mathcal{C}_q} [F_V(Q^2) - F_A(Q^2)] \sqrt{1-\xi^2} \frac{t_0 - t}{4M^2} \widetilde{\mathcal{H}}_T$$

$$f_5 = \frac{g_5}{\mathcal{C}_q} F_A(Q^2) \sqrt{1-\xi^2} \left[\mathcal{H}_T + \frac{t_0 - t}{4M^2} \widetilde{\mathcal{H}}_T - \frac{\xi^2}{1-\xi^2} \mathcal{E}_T + \frac{\xi}{1-\xi^2} \widetilde{\mathcal{E}}_T \right],$$

elementary subprocess

Q^2 dependent pion vertex

GFFs


Form Factors
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
0
2
4
6
8
10
12
14
16
18
20
Q^2 (GeV^2)
$F_1(Q^2)$
$F_2(Q^2)$
$F_3(Q^2)$
$F_5(Q^2)$

Does QCD factorization hold and how can we test it?

- ✓ Proof at twist two for longitudinal polarization given in
J. C. Collins, L. Frankfurt, and M. Strikman, Phys. Rev. D 56, 2982 (1997).

- ✓ No proof at twist three exists as of yet

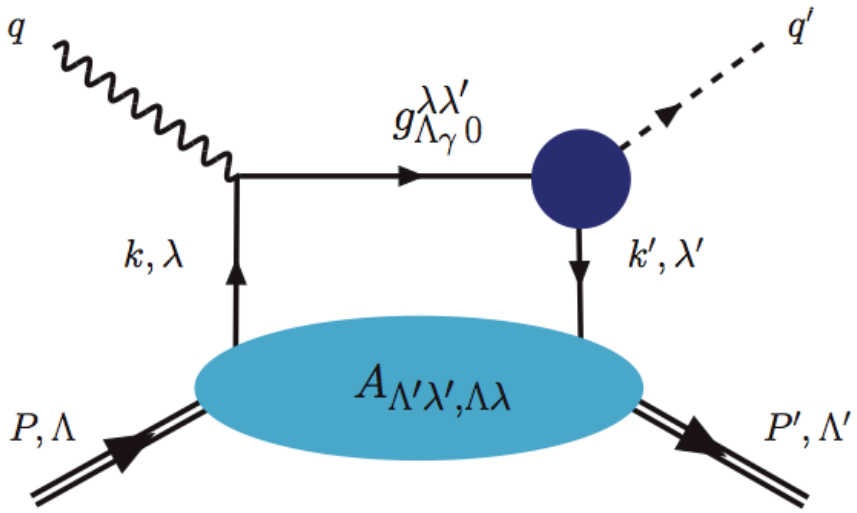
- ✓ A Q^2 "scan" at the EIC will be fundamental

2. CHIRAL ODD GPD'S

$$e\,p \rightarrow e'\,p'\,\pi^{o}$$

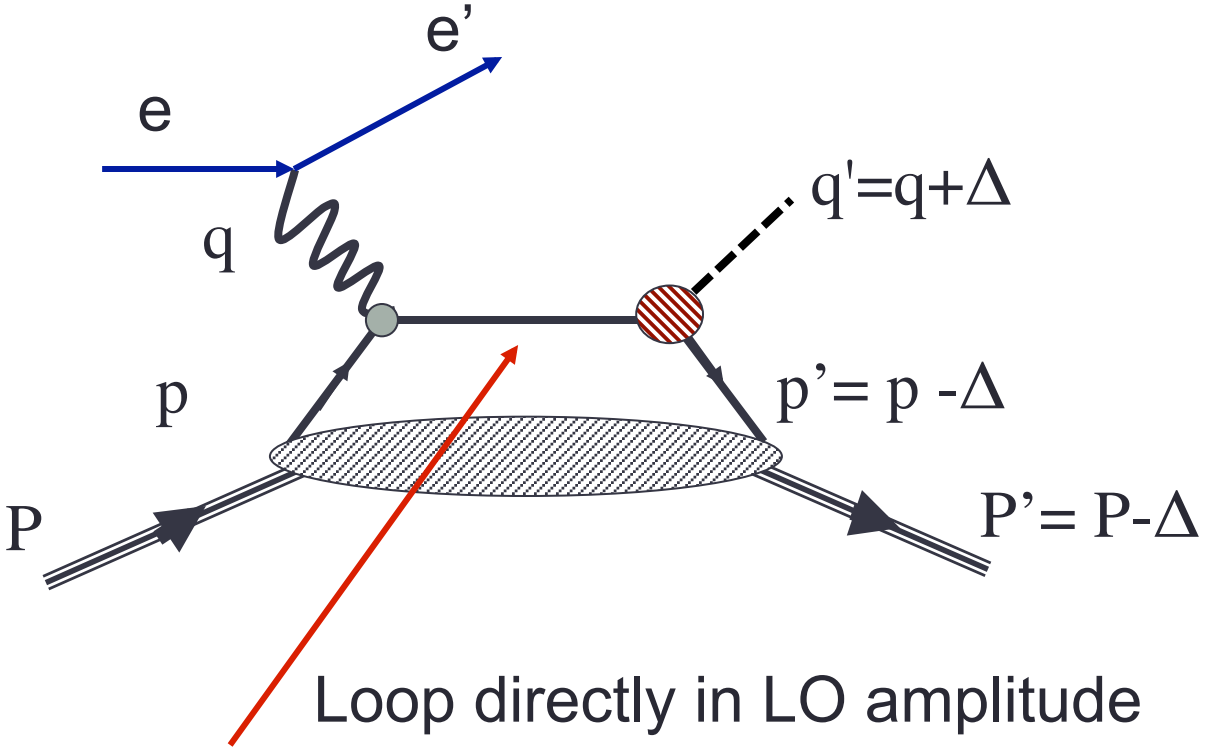
The non-local matrix elements probed are

$$\langle P'|\bar{u}(\xi)\sigma_{\mu\nu}\,u(0)|P\rangle$$



Ahmad et al. Phys.Rev. D79 (2009) 054014

Deeply virtual pseudoscalar meson production

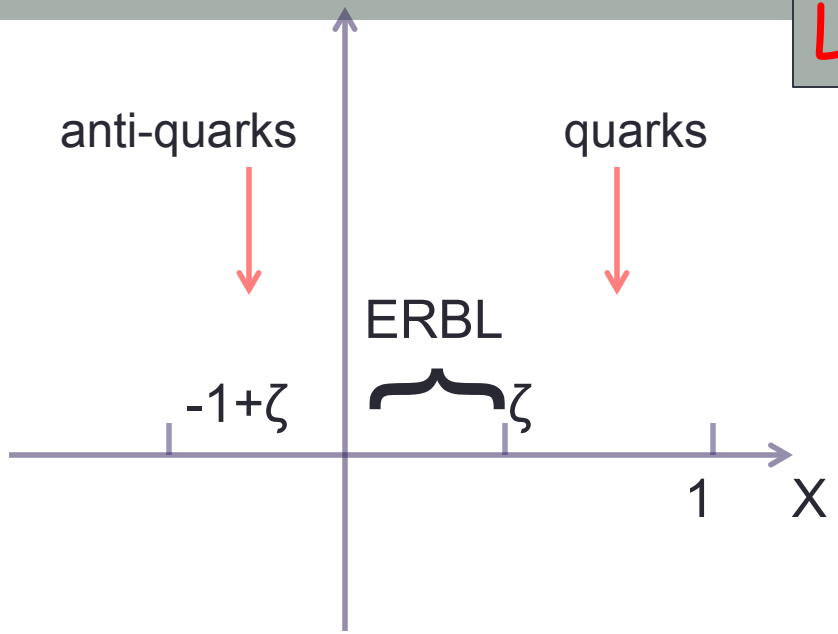


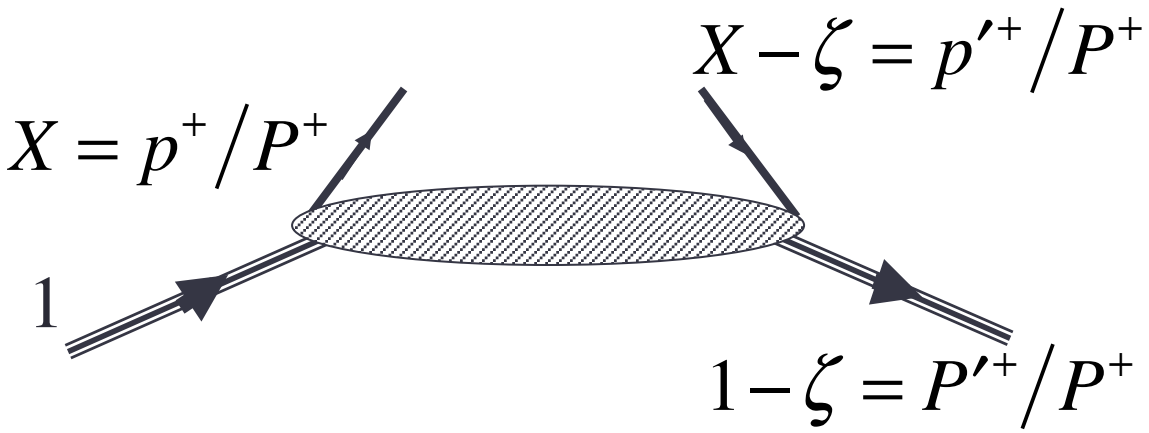
(1) $$\frac{1}{(p+q)^2 - m^2 + i\varepsilon} = PV\frac{1}{(p+q)^2 - m^2} - i\pi\,\delta((p+q)^2 - m^2)$$

Both Re and Im parts are present

(2) Quarks momenta and spins on LHS can be different from the RHS

Light Cone Variables

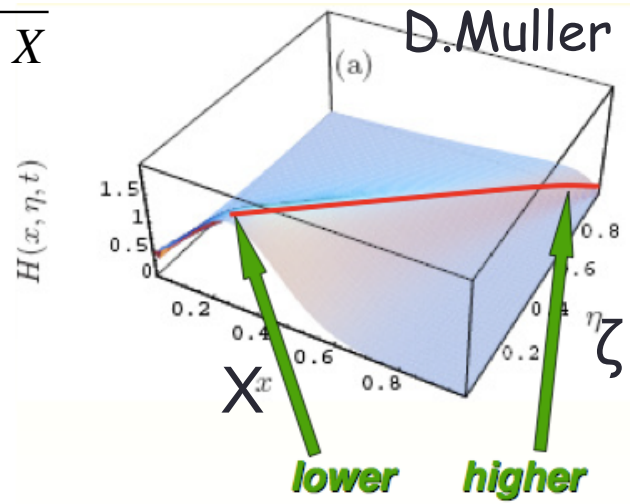




Asymmetry in kinematics on LHS and RHS of diagram

$$\frac{1}{(p+q)^2 - m^2 + i\varepsilon} = PV\frac{1}{(p+q)^2 - m^2} - i\pi\,\delta((p+q)^2 - m^2)$$

$$\rightarrow \frac{1}{-Q^2 + 2(pq) + i\varepsilon} \rightarrow \frac{1}{-Q^2\,/\,2(Pq) + (pq)\,/\,(Pq)} = \frac{1}{-\zeta + X}$$



Amplitude

$$\mathcal{F}_q = P.V.\int_{-1+\zeta} dX\, F_q(X,\zeta,t)\left[\frac{1}{\zeta - X} - \frac{1}{X}\right] + i\,\pi e_q^2 F_q(\zeta,\zeta,t)$$

GPD

Comptom Form Factor

GPD on “ridge”

Quark correlator in the chiral odd sector

$$W^{[i\sigma^{i+}\gamma_5]}_{\Lambda',\Lambda}(x,\xi,t) = \overline{U}(P',\Lambda')\left(i\sigma^{+i}H_T(x,\xi,t) + \frac{\gamma^+\Delta^i - \Delta^+\gamma^i}{2M}E_T(x,\xi,t)\right.$$
$$\left. + \frac{P^+\Delta^i - \Delta^+P^i}{M^2}\widetilde{H}_T(x,\xi,t) + \frac{\gamma^+P^i - P^+\gamma^i}{2M}\widetilde{E}_T(x,\xi,t)\right)U(P,\Lambda)$$

One to one relation with helicity amplitudes

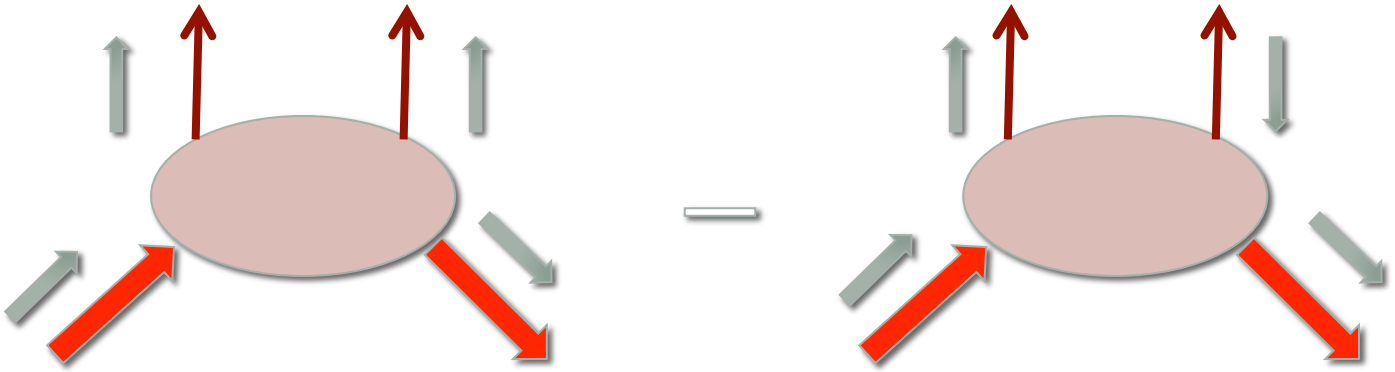
$$A_{++,--} = \frac{\sqrt{1-\zeta}}{1-\zeta/2}\left[H_T + \frac{t_0-t}{4M^2}\widetilde{H}_T + \frac{\zeta^2/4}{1-\zeta}E_T + \frac{\zeta/2}{1-\zeta}\widetilde{E}_T\right]$$

$$A_{+-,-+} = -\frac{\sqrt{1-\zeta}}{1-\zeta/2}\,\frac{t_0-t}{4M^2}\,\widetilde{H}_T$$

$$A_{++,+-} = \frac{\sqrt{t_0-t}}{2M}\left[\widetilde{H}_T + \frac{1-\zeta}{2-\zeta}E_T + \frac{1-\zeta}{2-\zeta}\widetilde{E}_T\right],$$

$$A_{-+,--} = \frac{\sqrt{t_0-t}}{2M}\left[\widetilde{H}_T + \frac{1}{2-\zeta}E_T + \frac{1}{2-\zeta}\widetilde{E}_T\right].$$

Chiral Even Quark-Proton Helicity Amplitudes



$$A_{\Lambda'\pm,\Lambda\pm} \Leftrightarrow H, E, \tilde{H}, \tilde{E}$$

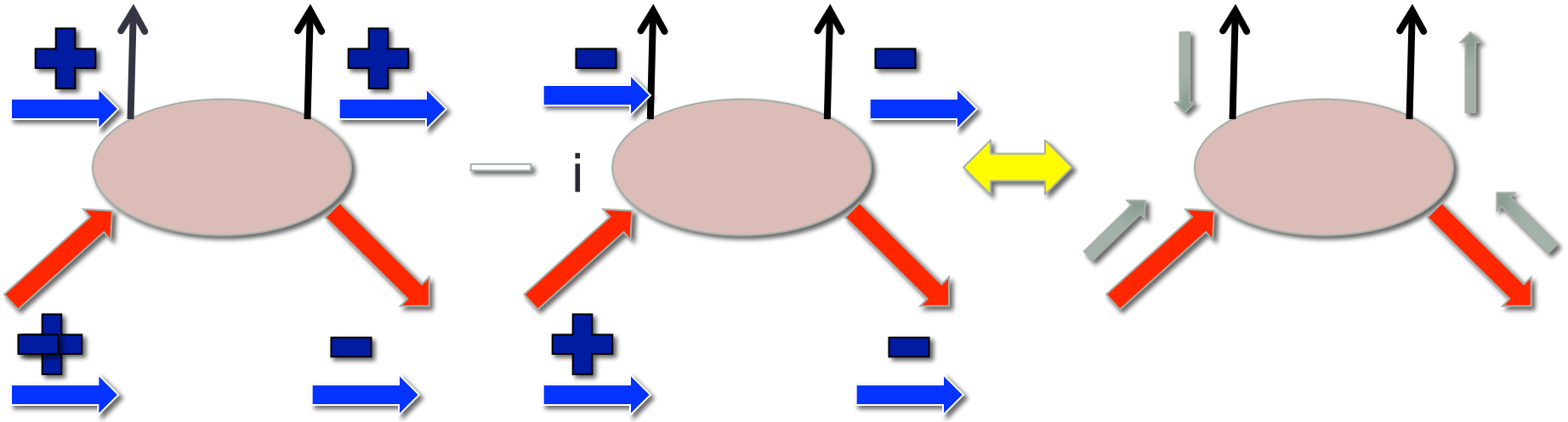
Net helicity of a quark in a longitudinally polarized proton:

$$g_1\left(x,Q^2\right) \Rightarrow \int_0^1 dx\, g_1\left(x,Q^2\right) = g_A$$

Chiral Odd Quark-Proton Helicity Amplitudes

$$\left|\uparrow\downarrow\right\rangle_Y = \left|\rightarrow\right\rangle \pm i\left|\leftarrow\right\rangle$$

$$A_{\Lambda'\pm,\Lambda\mp} \Leftrightarrow H_T, E_T, \tilde{H}_T, \tilde{E}_T$$

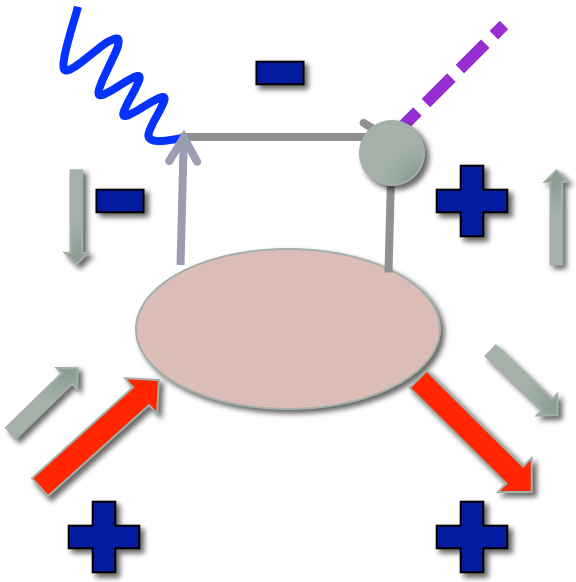


Net transverse polarization of a quark in a transversely polarized proton:

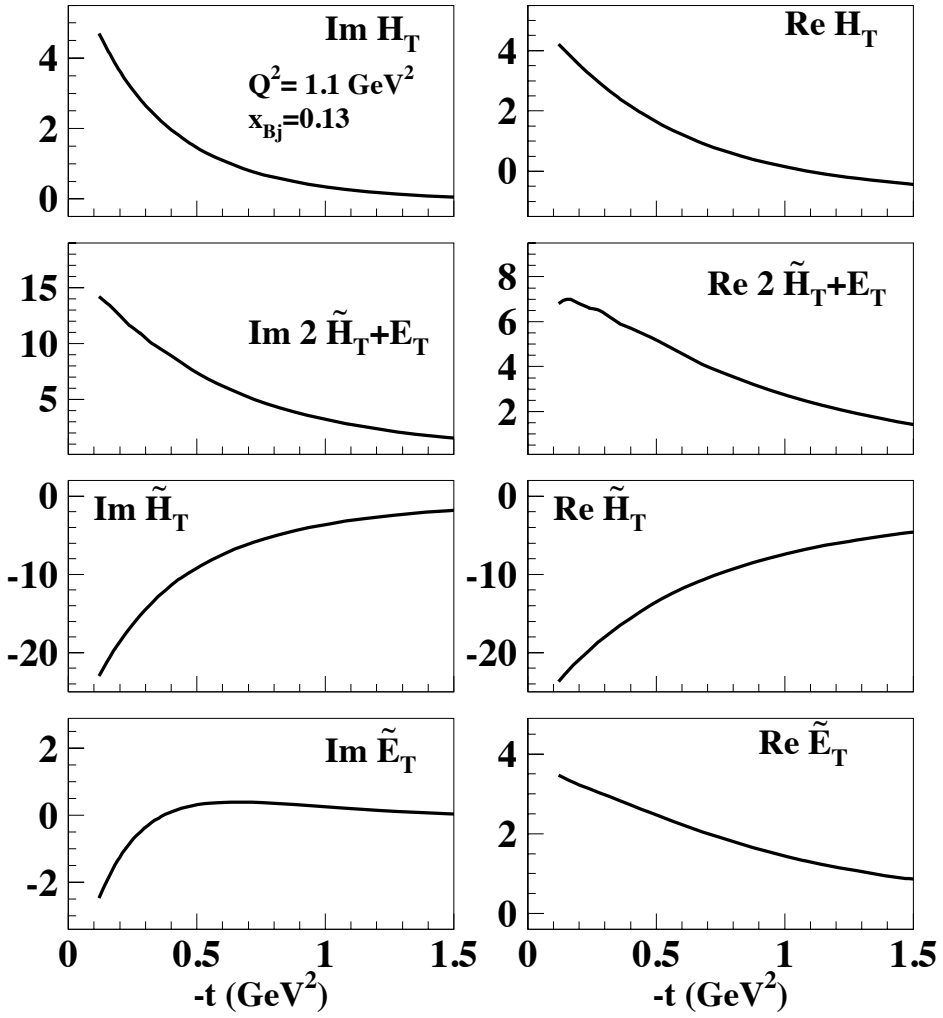
$$h_1\left(x,Q^2\right) \Rightarrow \int_0^1 dx\, h_1\left(x,Q^2\right) = \delta(Q^2)$$

In the helicity basis it is described in terms of non-diagonal/chirally-odd quark-proton helicity amplitudes.

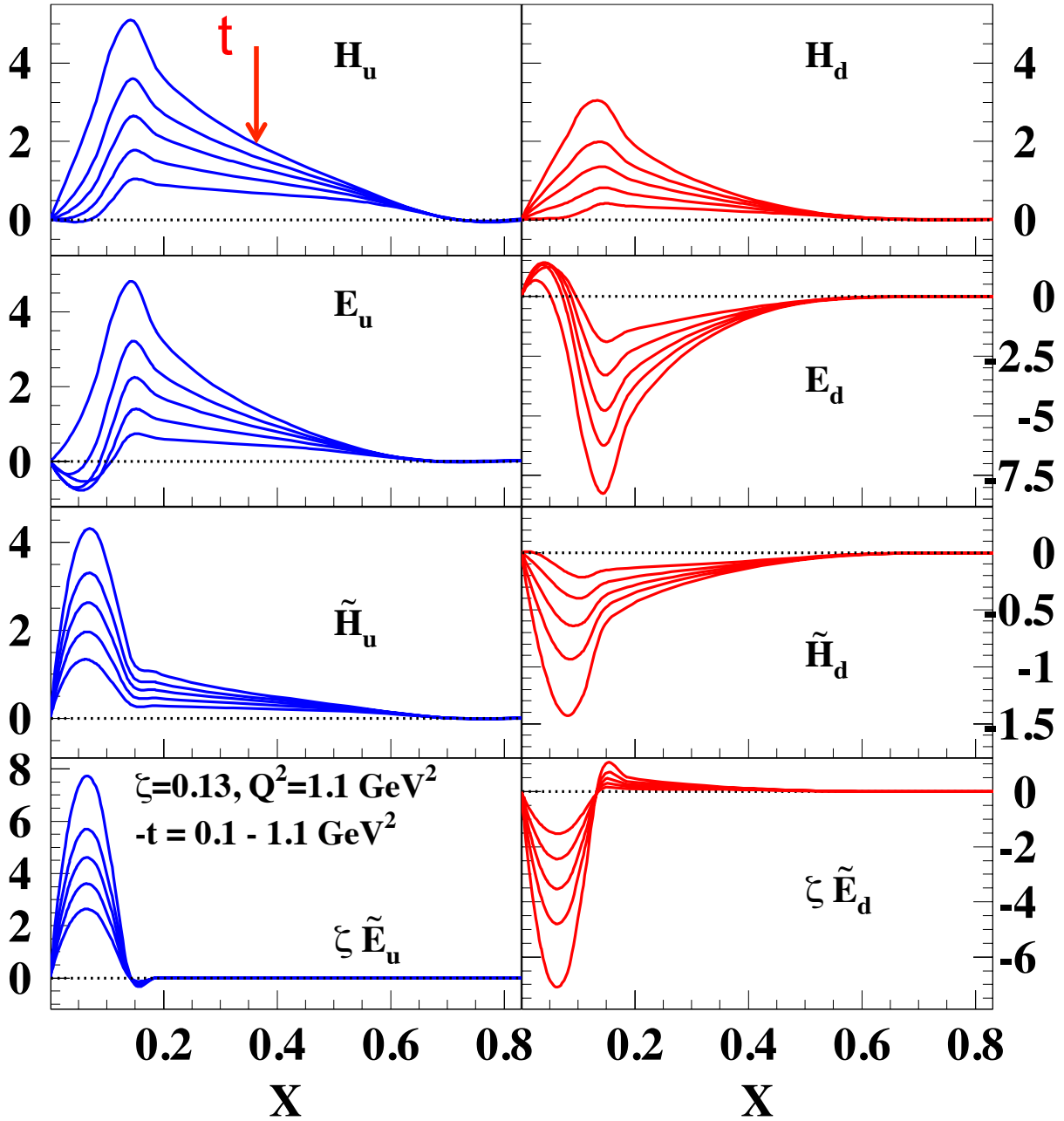
One can disentangle all four configurations, for example:



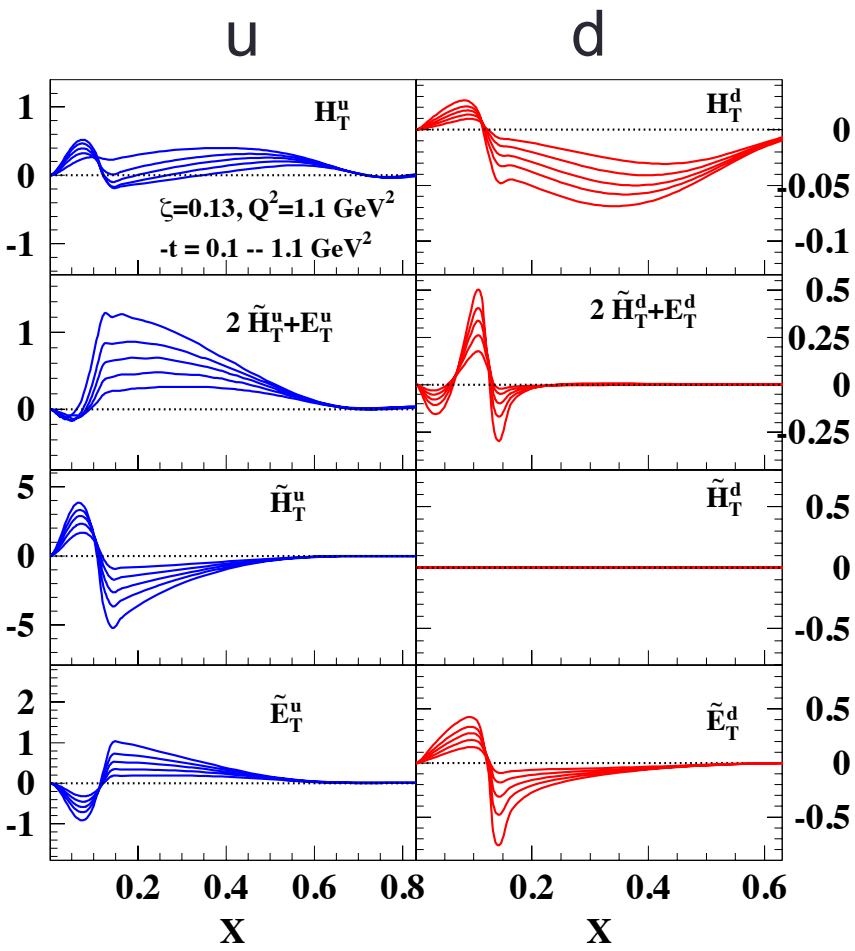
$A_{+-,++}$  $2\tilde{H}_T + E_T$


Im H_T
Q^2= 1.1 GeV^2
x_{Bj}=0.13
Re H_T
Im 2 $\tilde{H}_T$+E_T
Re 2 $\tilde{H}_T$+E_T
Im $\tilde{H}_T$
Re $\tilde{H}_T$
Im $\tilde{E}_T$
Re $\tilde{E}_T$
-t (GeV^2)
-t (GeV^2)

Chiral even GPDs



The Chiral Odd sector is vastly unexplored



G. Goldstein, O. Gonzalez-Hernandez, S.L., PRD(2015) arXiv:1311.0483

tensor charge

$$\int dx\, H_T^q(x,\zeta,t,Q^2) = \delta_q(t,Q^2)$$

tensor anomalous magnetic moment

$$\int dx\, [2\tilde{H}_T^q(x,\zeta,t,Q^2) + E_T^q(x,\zeta,t,Q^2)] = \kappa_q(t,Q^2)$$

(M. Burkardt, PRD66, 114005 (2002)

?

?

Predictions based on the reggeized diquark model

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Flexible parametrization of generalized parton distributions: The chiral-odd sector

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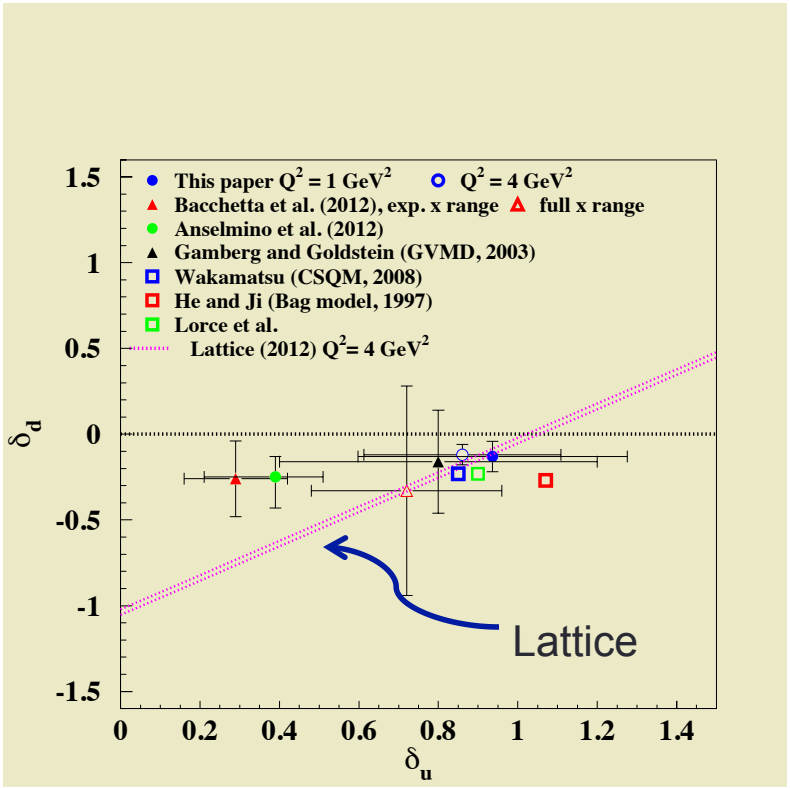
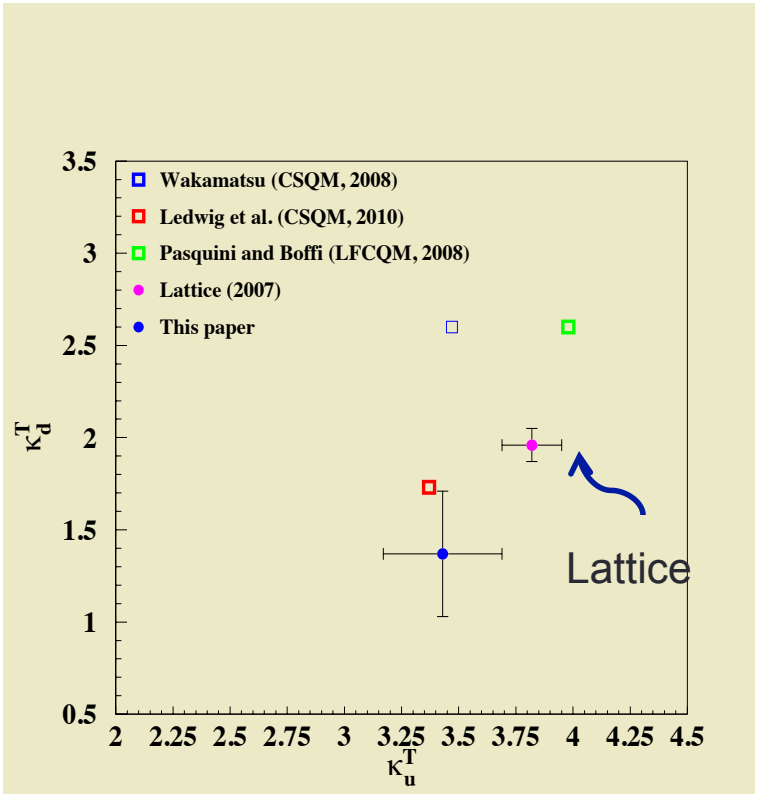
Phys. Rev. D **91**, 114013 – Published 8 June 2015

arXiv:1401.0438 [hep-ph]



J.~R.~Green, J.~W.~Negele, A.~V.~Pochinsky, S.~N.~Syritsyn, M.~Engelhardt and S.~Krieg, %``Nucleon Scalar and Tensor Charges from Lattice QCD with Light Wilson Quarks," Phys.\ Rev.\ D {\bf 86}, 114509 (2012)

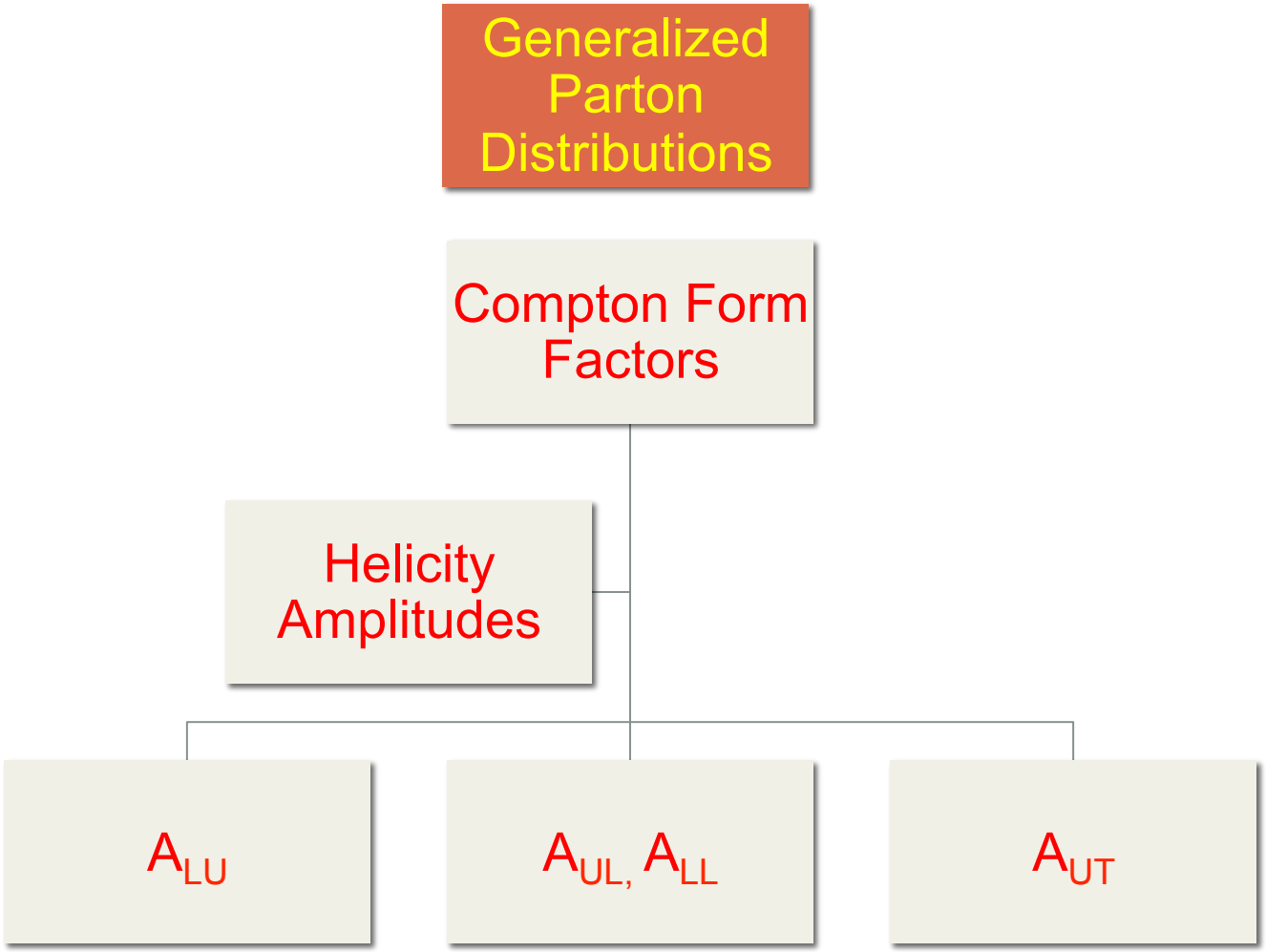


M. Gockeler et al. [QCDSF and UKQCD Collaborations], Phys. Rev. Lett. 98, 222001 (2007)

3. EXTRACTION FROM EXPERIMENT

Experiment: DVπ^{0}P, DVηP

(Hall B, H. Avakian et al, Hall A. F. Sabatie et al)



Cross Section Formulation

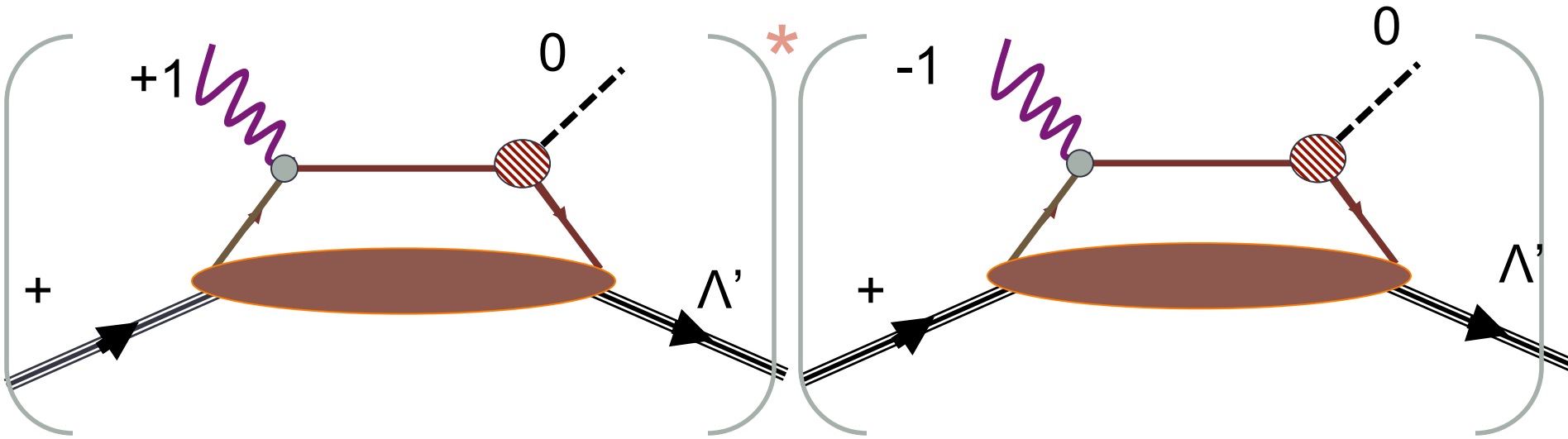
Goldstein, Gonzalez Hernandez, S.L. Phys.Rev. D91 (2015)

$$
\begin{aligned}
\frac{d^4\sigma}{dx_{Bj}dyd\phi dt} &= \Gamma\Big\{ F_{UU,T} + \epsilon F_{UU,L} + \epsilon\cos 2\phi F_{UU}^{\cos 2\phi} + \sqrt{2\epsilon(\epsilon+1)}\cos\phi F_{UU}^{\cos\phi} + h\sqrt{2\epsilon(1-\epsilon)}\sin\phi F_{LU}^{\sin\phi}\Big] \\
&+ S_{||}\Big[\sqrt{2\epsilon(\epsilon+1)}\sin\phi F_{UL}^{\sin\phi} + \epsilon\sin 2\phi F_{UL}^{\sin 2\phi} + h\left(\sqrt{1-\epsilon^2}F_{LL} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi F_{LL}^{\cos\phi}\right)\Big] \\
&+ S_{\perp}\Big[\sin(\phi-\phi_S)\left(F_{UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\right) + \epsilon\left(\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)} + \sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)}\right) \\
&+ \sqrt{2\epsilon(1+\epsilon)}\left(\sin\phi_S F_{UT}^{\sin\phi_S} + \sin(2\phi-\phi_S)F_{UT}^{\sin(2\phi-\phi_S)}\right)\Big] \\
&+ S_{\perp}h\Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\left(\cos\phi_S F_{LT}^{\cos\phi_S} + \cos(2\phi-\phi_S)F_{LT}^{\cos(2\phi-\phi_S)}\right)\Big]\Big\}
\end{aligned}
$$

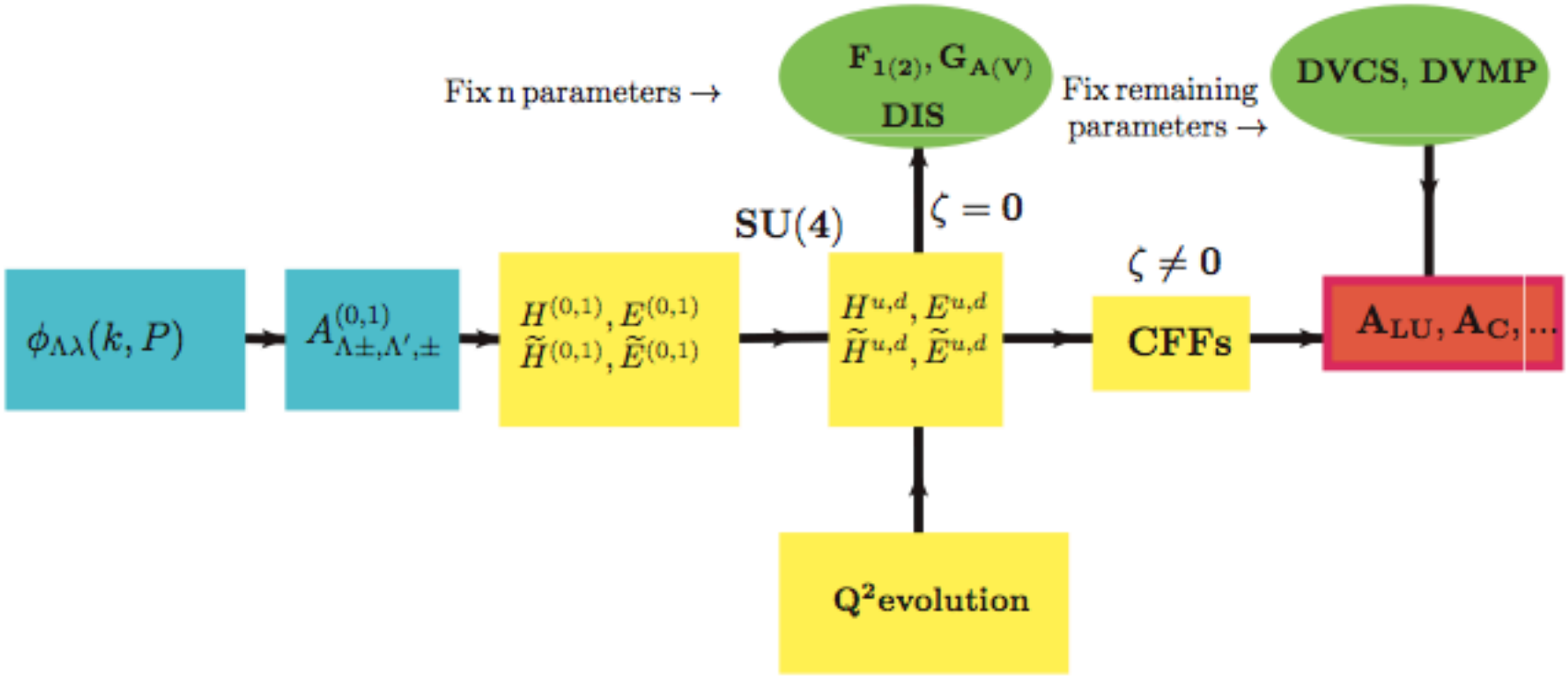
GPDs in helicity amplitudes

$$
\begin{aligned}
F_{UU,T} &= \mathcal{N}\left[|f_{10}^{++}|^2 + |f_{10}^{+-}|^2 + |f_{10}^{-+}|^2 + |f_{10}^{--}|^2\right] \\
F_{UU,L} &= \mathcal{N}\left[|f_{00}^{++}|^2 + |f_{00}^{+-}|^2\right] \\
F_{UU}^{\cos 2\phi} &= -\mathcal{N}\,2\Re e\left[(f_{10}^{++})^*(f_{10}^{--}) - (f_{10}^{+-})^*(f_{10}^{-+})\right] \\
F_{UU}^{\cos\phi} &= -\mathcal{N}\Re e\left[(f_{00}^{+-})^*(f_{10}^{+-} + f_{10}^{-+}) + (f_{00}^{++})^*(f_{10}^{++} - f_{10}^{--})\right] \\
F_{LU}^{\sin\phi} &= \mathcal{N}\Im m\left[(f_{00}^{+-})^*(f_{10}^{+-} + f_{10}^{-+}) + (f_{00}^{++})^*(f_{10}^{++} - f_{10}^{--})\right]
\end{aligned}
$$

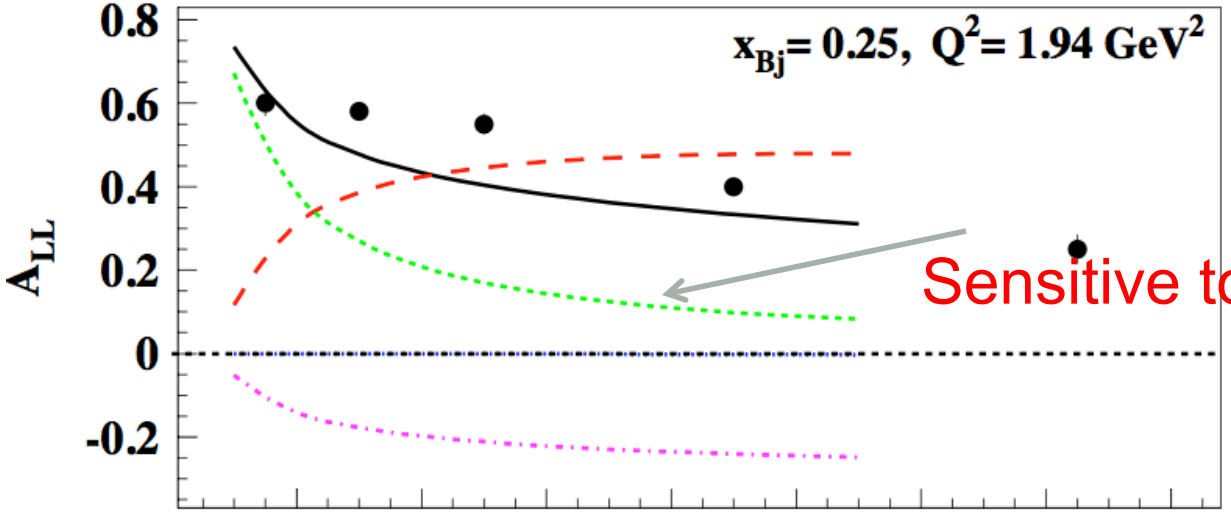
General form of structure function of a chiral odd term:



helicity amplitudes $$F^{++}_{1,-1} = \sum_{\Lambda'} \left(f^{+\Lambda'}_{10} \right)^* \left(f^{+\Lambda'}_{-10} \right)$$



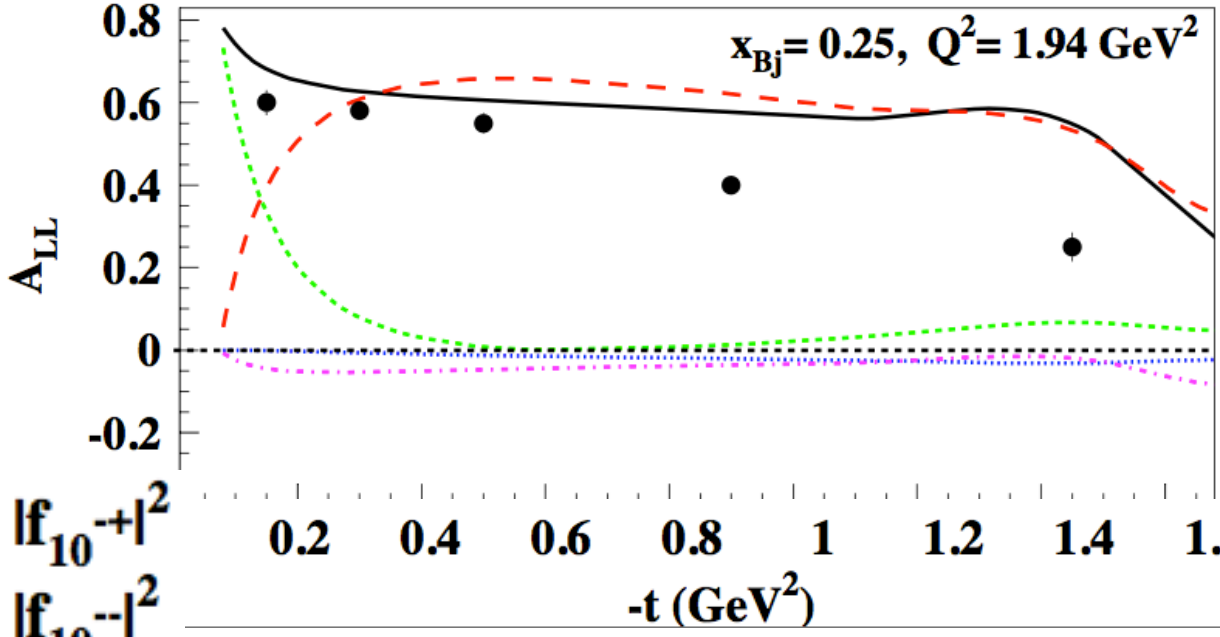
Goldstein, Gonzalez Hernandez, S.L. Phys.Rev. D91 (2015)



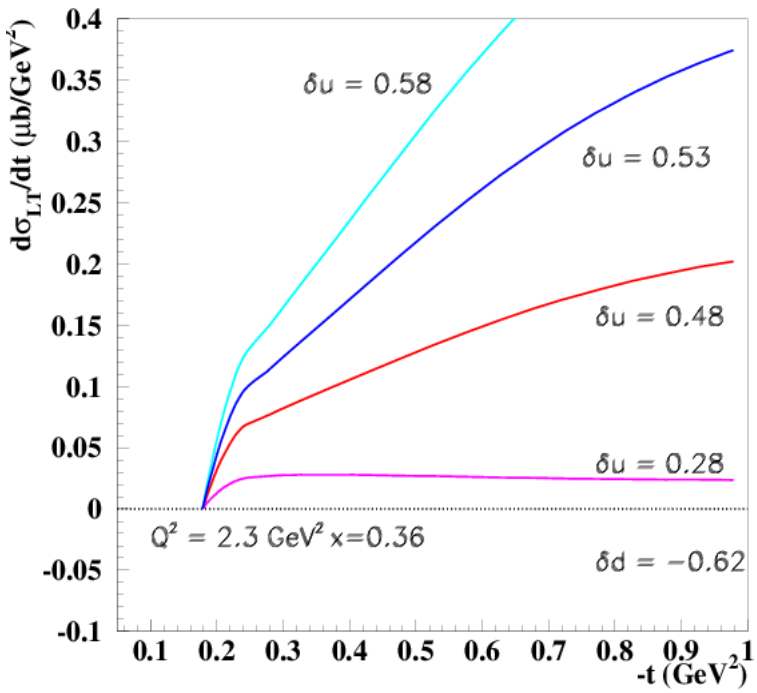
Andrey Kim, Harut Avakian et al., Jefferson Lab CLAS Collaboration

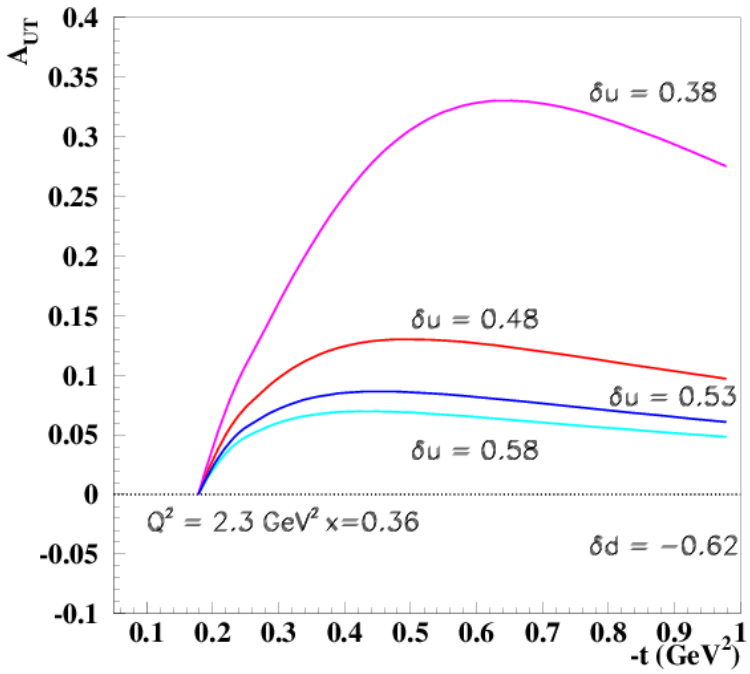
Sensitive to tensor charge

Role of parameters

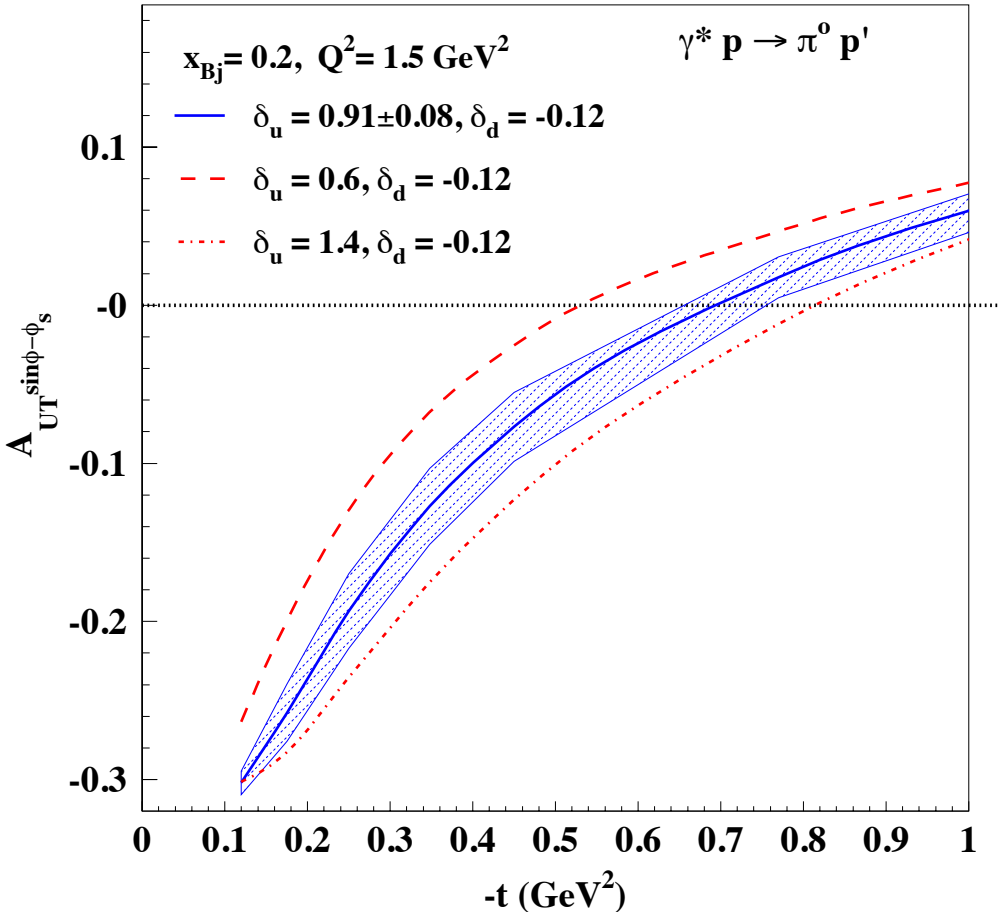


Tensor Charge and Anomalous Transverse Moment treated as free parameters to be extracted from data





Projections for transverse polarized target



4. IMPACT ON BSM SEARCHES

Based on

PHYSICAL REVIEW LETTERS

Highlights Recent Accepted Collections Authors Referees Search Press

Beyond-Standard-Model Tensor Interaction and Hadron Phenomenology

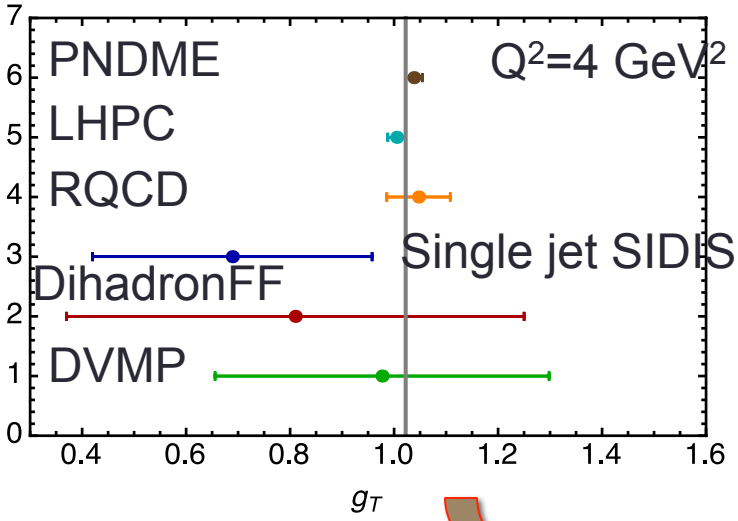
Aurore Courtoy, Stefan Baeßler, Martín González–Alonso, and Simonetta Liuti

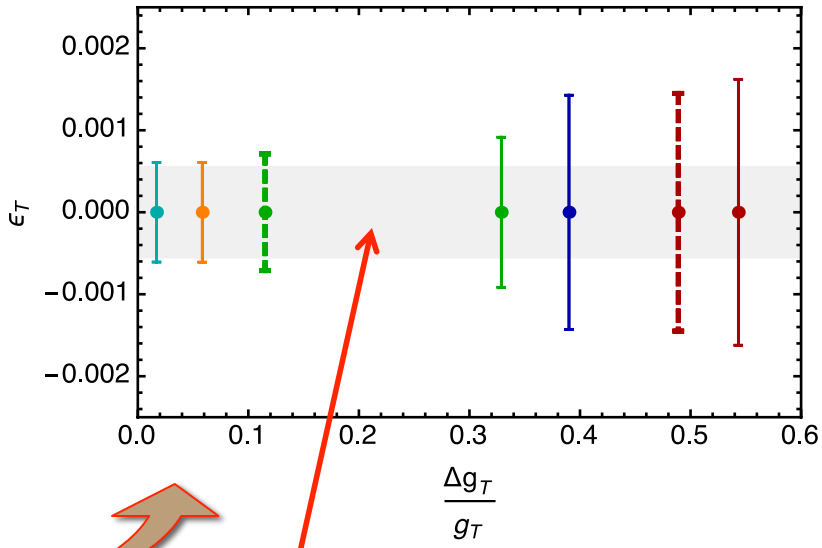
Phys. Rev. Lett. **115**, 162001 – Published 15 October 2015

Why is the tensor charge interesting?

- ✓ It describes a specific response of the nucleon to polarization but it is not a fundamental property ➔ composite structure
- ✓ It evolves in PQCD but it does not couple to gluons (valence-like structure)
- ✓ Because the anomalous dimensions do not vanish for the first Mellin moment, the tensor charge evolves with Q^2

Impact on BSM searches…



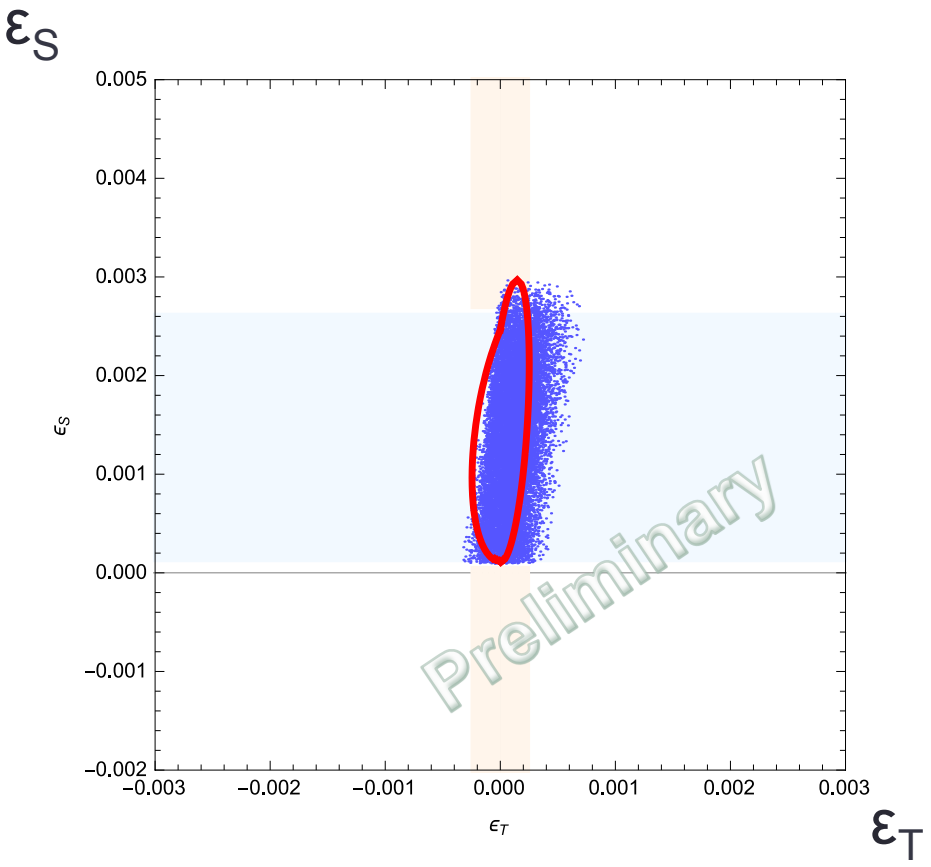


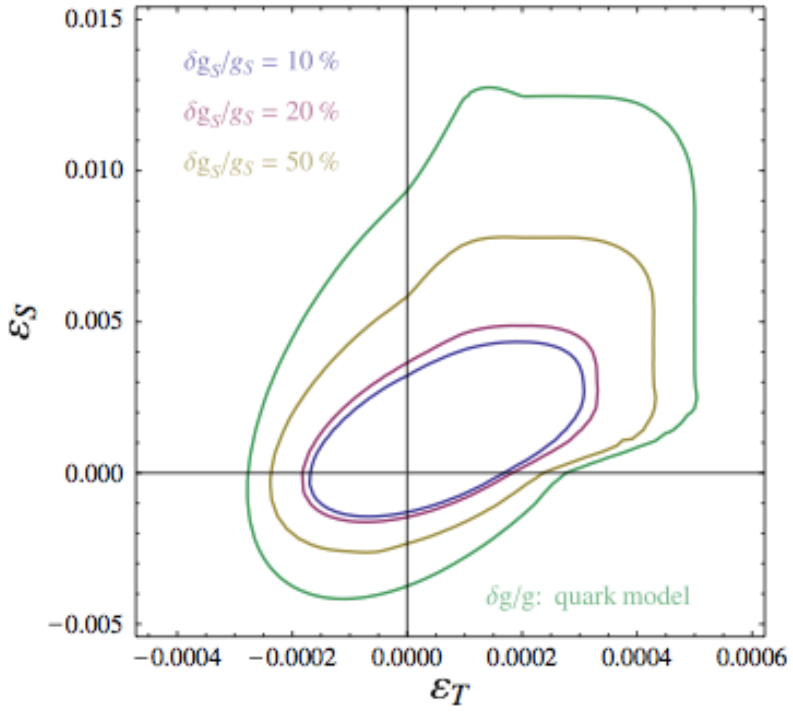
$|\varepsilon_T\, g_T| < 6.4 \times 10^{-4}$

Pattie et al, PRC88 (2013)

A. Courtoy, S.Baessler, M. Gonzalez-Alonso, S.L, arXiv:1503.06814

New Analysis (Pavia, UNAM, NMSU, Virginia)





Lattice Extraction

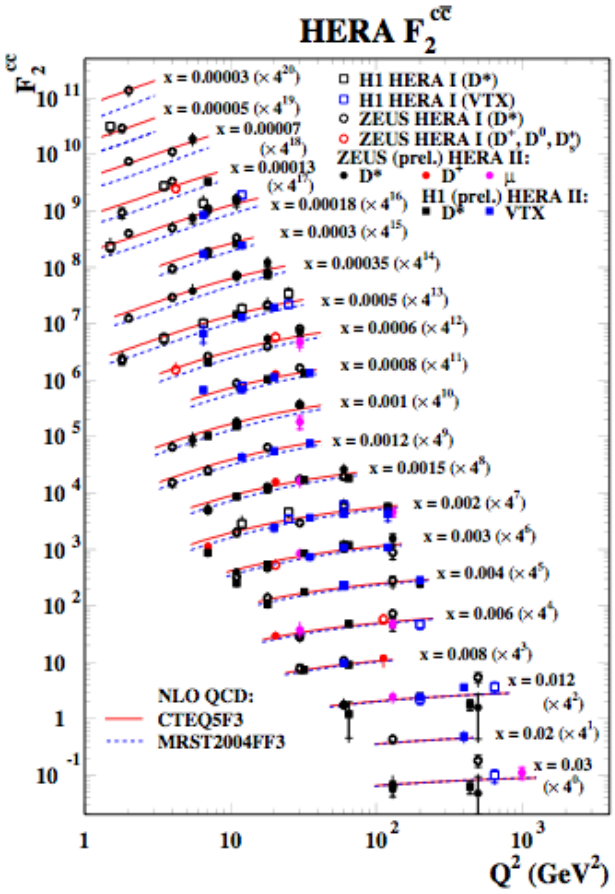
Bhattacharya et al., PRD85 (2012)

g_S from J. Martin-Camalich + M. Gonzalez-Alonso, PRL (2014)

Combined 90% confidence level in ε_S-ε_T plane

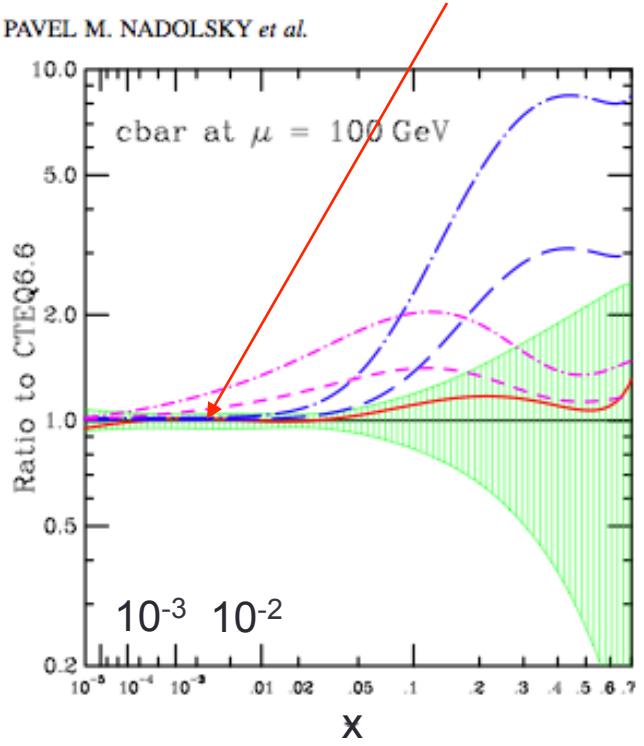
5. FUTURE DEVELOPMENTS

5.1 Deeply Virtual Exclusive Processes with Charm



Data are at very low x where they cannot discriminate whether Intrinsic Charm is there

IC/no-IC



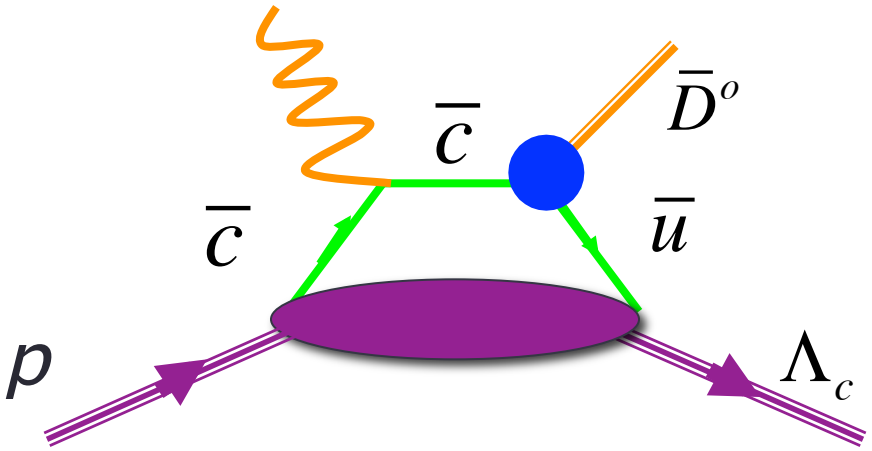
A window into heavy flavor production at the EIC

$$\gamma^* p \to \eta_c p'$$

η_c, D^o, and $\bar{D}^o$ exclusive production is governed by chiral-odd soft matrix elements (GPDs) which cannot evolve from gluons!

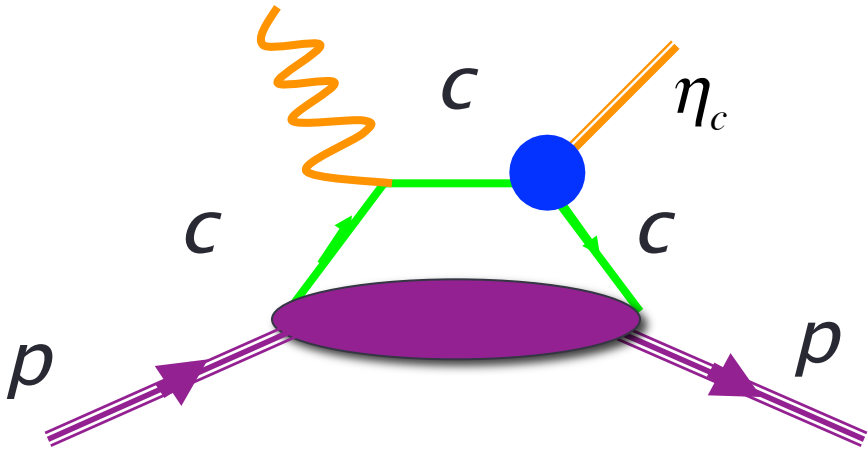
η_c, D^o, and $\bar{D}^o$ used as triggers of "intrinsic charm content"!

(1)



$$p \to c\bar{c}uud \to (\bar{c}u)cud$$

(2)



$$p \to c\bar{c}uud \to (\bar{c}c)uud$$

5.2 A program to study BSM physivs

$$\langle p(p')|\bar{u}\sigma_{\mu\nu}d|n(p)\rangle \equiv \bar{u}_p(p')\Big[g_T(q^2)\sigma^{\mu\nu} + g_T^{(1)}(q^2)(q^\mu\gamma^\nu - q^\nu\gamma^\mu) + g_T^{(2)}(q^2)(q^\mu P^\nu - q^\nu P^\mu) + g_T^{(3)}(q^2)(\gamma^\mu \not{q}\gamma^\nu - \gamma^\nu \not{q}\gamma^\mu)\Big]u_n(p),$$

Study the additional currents

- Potential impact in axial vector sector studied by S. Gardner and B.Plaster, PRC87(2013)
- Connection with new chiral-odd GPDs
- Impact on EDM measurements
- More…

Conclusions and outlook

A vast program ahead of us that can be explored only with an EIC

A global analysis will allow us to extract the tensor charge from measurements of hard electron proton scattering processes (DVMP, Dihadron electroproduction, single jet SIDIS). This program can be developed at the EIC!!!!

The possibility of obtaining the scalar and tensor form factors and charges directly from experiment with sufficient precision, gives an entirely different leverage to neutron beta decay searches

The error on ε_T , depends on both the central value of g_T as well as on the relative error, $\Delta g_T / g_T$, therefore, independently from the theoretical accuracy that can be achieved, experimental measurements are essential since they simultaneously provide a testing ground for lattice QCD calculations.

A unique probe of intrinsic charm

sl4y@virginia.edu