FLAVOR DEPENDENCE DETERMINATION OF TRANVSRESITY GPDS AND BSM INTERACTIONS

HALL B COLLABORATION MEETING
MARCH 9, 2018
JEFFERSON LAB

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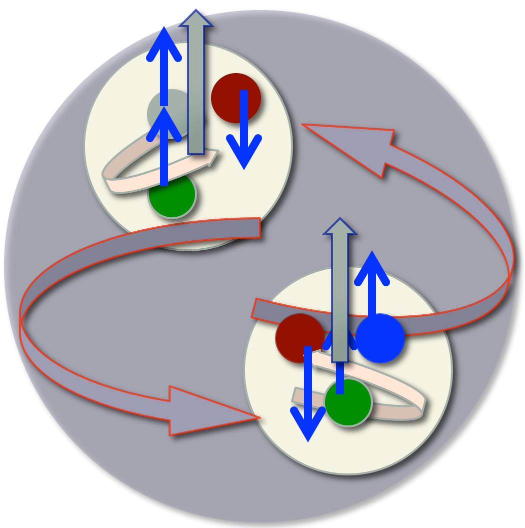


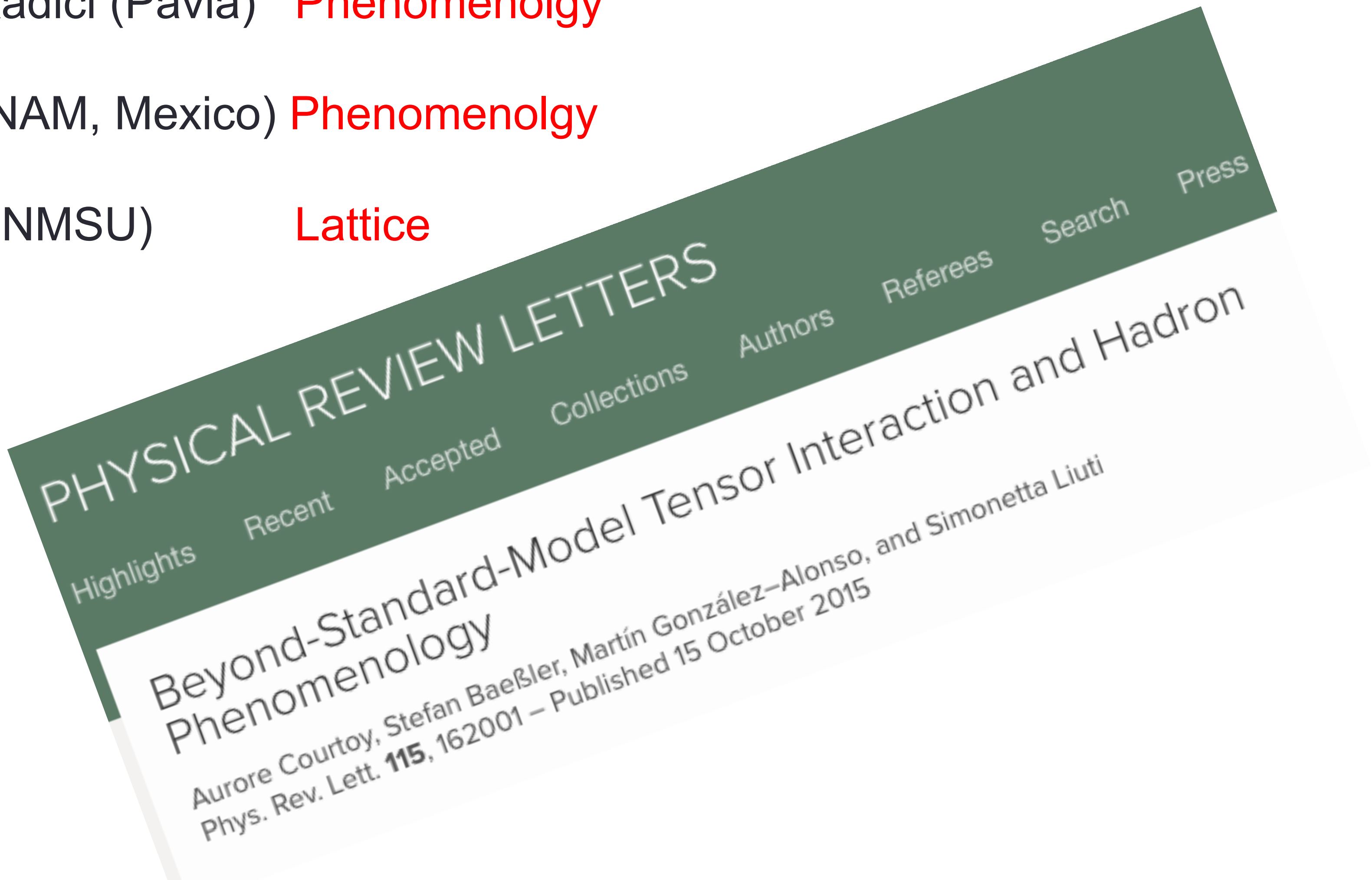
…newly formed groups:

Baessler, Liuti (Virginia) Experiment/Phenomenolgy

Bacchetta, Radici (Pavia) Phenomenolgy

Courtoy (UNAM, Mexico) Phenomenolgy

Engelhardt (NMSU) Lattice



….+ EIC BSM EFFORT LEAD BY
JULIA FURLETOVA AND SONNY MANTRY

General Motivation

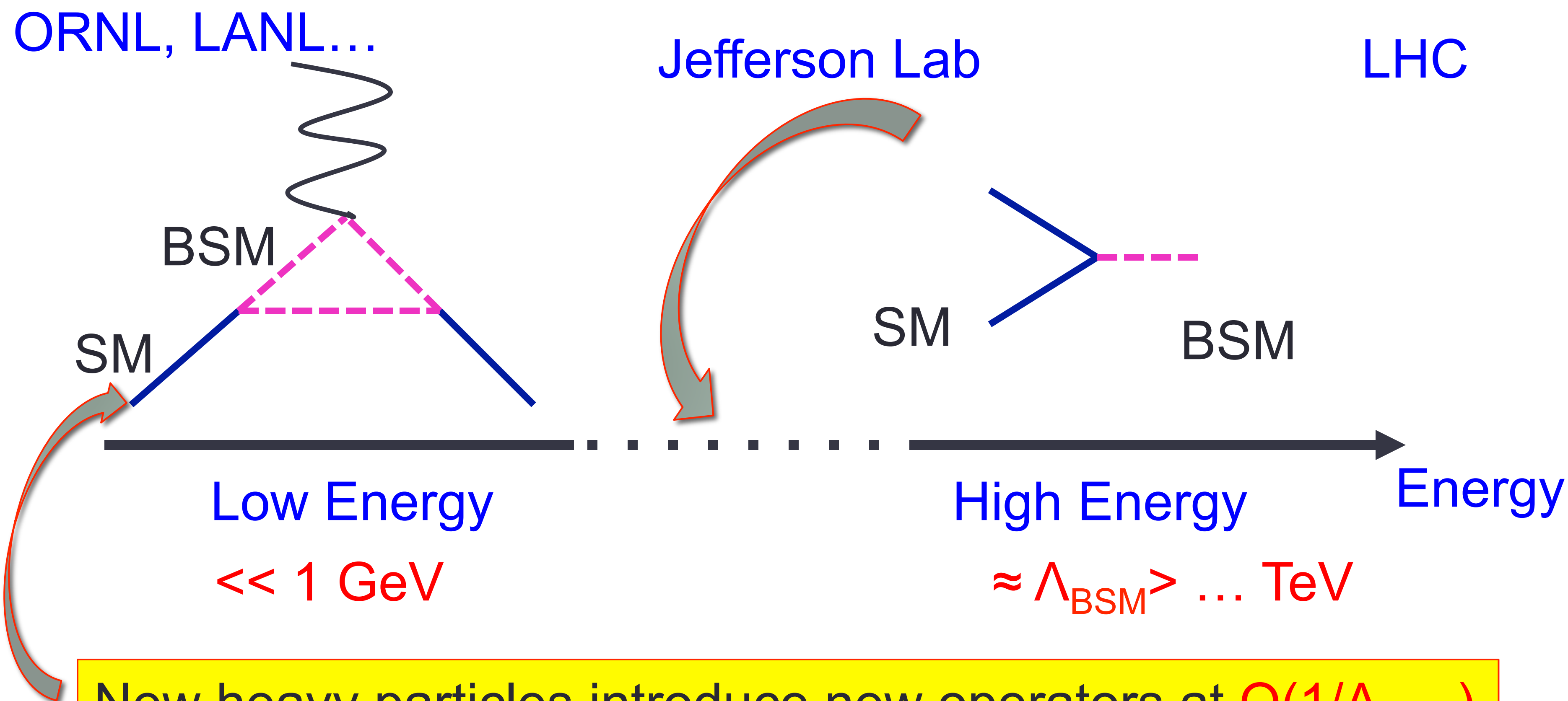
TENSOR AND SCALAR INTERACTIONS ARE NOT FUNDAMENTAL COMPONENTS OF THE SM LAGRANGIAN

A PRECISE DETERMINATION OF THE U AND D QUARKS TENSOR CHARGE AND TENSOR ANOMALOUS MAGNETIC MOMENT IMPACT SEARCHES OF PHYSICS BEYOND THE STANDARD MODEL

Intensity/Precision Frontier vs. Energy Frontier (collider expts.)

BSM particles appear in loops

BSM particles are produced directly



New heavy particles introduce new operators at $O(1/\Lambda_{BSM})$

Outline

1. Introduction
2. Role of spin dependent observables in low energy processes (neutron beta decay, EDM)
3. Chiral Odd GPDs
4. Extraction from experiment: role of EIC
5. Impact on BSM searches
6. Conclusions and Outlook

1. INTRODUCTION

ROLE OF QCD PHENOMENOLGY IN SEARCHES FOR NEW PHYSICS

…*rising new questions and challenges* trigger future developments for strong-interaction physics/QCD in the "post-discovery of the Higgs boson era" at the LHC.

QCD impacts the extraction of several of the 19 (28) fundamental parameters in the SM

1. The Weinberg angle or weak mixing angle θ_W
2. The strong interaction coupling constant α_S
3. The electroweak symmetry breaking energy scale (or the Higgs potential vacuum expectation value, v.e.v.) v
4. The Higgs potential coupling constant λ /the Higgs mass m_H
5. The three mixing angles θ_{12}, θ_{23} and θ_{13} and the CP-violating phase δ_{13} of the Cabibbo-Kobayashi-Maskawa (CKM) matrix
6. The Yukawa coupling constants that determine the masses of the 6 quarks.
7. … + 3 charged leptons
8. Strong CP parameter
9. The fine structure constant α (1)

In particular, we are interested in how QCD affects the low-energy regime in the indirect search for BSM physics:

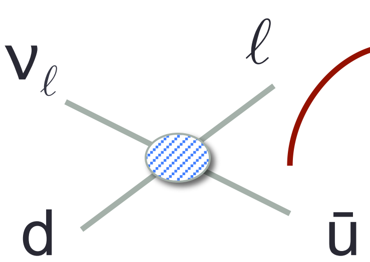
1. CP violation in *B* mesons decays
2. Permanent Electric Dipole Moment (EDM) in hadrons and nuclei
3. Anomalous magnetic moment of the muon
4. Neutrino physics
5. PVDIS
6. Non V-A contributions in nuclear, neutron and pion beta decay
7. …..

Precision Frontier

BSM Effective Lagrangian

V. Cirigliano, S. Gardner, B. Holstein, Prog.Nuc.Part. Phys. (2013)

$$\mathcal{L}_{CC} = -\frac{G_F^{(0)} V_{ud}}{\sqrt{2}}(1+\epsilon_L+\epsilon_R)$$
$$\times[\bar{\ell}\gamma_\mu(1-\gamma_5)\nu_\ell \cdot \bar{u}[\gamma^\mu - (1-2\epsilon_R)\gamma^\mu\gamma_5]d$$
$$+\bar{\ell}(1-\gamma_5)\nu_\ell \cdot \bar{u}[\epsilon_S - \epsilon_P\gamma_5]d$$
$$+\epsilon_T\bar{\ell}\sigma_{\mu\nu}(1-\gamma_5)\nu_\ell \cdot \bar{u}\sigma^{\mu\nu}(1-\gamma_5)d] + \mathrm{H.c.},$$



$$\varepsilon_{L,R,S,P,T} \approx \frac{m_W^2}{\Lambda_{BSM}^2}$$

Vector	$\bar{u}\gamma^\mu u$
Axial-Vector	$\bar{u}\gamma^\mu\gamma^5 u$
Pseudoscalar	$\bar{u}\gamma^5 u$
Scalar	$\bar{u}u$
Tensor	$\bar{u}\sigma^{\mu\nu} u$

The "strong interactions issues" in all of these examples are outstanding questions that stimulate a deeper understanding of the structure of hadrons

1. Spin structure: longitudinal and transverse spin, spin crisis, role of orbital angular momentum.
2. Running of α_S
3. Transverse Momentum Distributions: QCD factorization for quark and gluons
4. …

At the same time … understanding these issues gives us insights into strongly coupled gauge theories

- ✓ … from the high energy end: models for dark matter, BSM Higgs mechanism…
- ✓ … to the low energy end: description of lattices with QCD symmetry from cold atoms, Wigner distributions at the femtoscale…

2. ROLE OF SPIN DEPENDENT OBSERVABLES

A. Courtoy, S. Baessler, M. Gonzalez-Alonso and S. Liuti, arXiv: 1503.06814 [hep-ph], Phys ReV. Lett (2015).

Differential decay distribution for polarized neutron β decay

$$n \rightarrow p + e^- + \bar{\nu}$$

T.D. Lee, Chen-Ning Yang, Phys. Rev. 104 (1956)

$$\frac{d\Gamma}{dE_e d\Omega_e d\Omega_\nu} = \frac{(G_F^{(0)})^2 |V_{ud}|^2}{(2\pi)^5}(1+2\epsilon_L+2\epsilon_R) \times (1+3\tilde{\lambda}^2)\cdot w(E_e)\cdot D(E_e,\mathbf{p}_e,\mathbf{p}_\nu,\boldsymbol{\sigma}_n),$$

$$D(E_e,\mathbf{p}_e,\mathbf{p}_\nu,\boldsymbol{\sigma}_n) = 1 + c_0 + c_1\frac{E_e}{M_N} + \boxed{\frac{m_e}{E_e}\bar{b}} + \bar{a}(E_e)\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_eE_\nu} + \bar{A}(E_e)\frac{\boldsymbol{\sigma}_n\cdot\mathbf{p}_e}{E_e} + \boxed{\bar{B}(E_e)}\frac{\boldsymbol{\sigma}_n\cdot\mathbf{p}_\nu}{E_\nu} + \bar{C}_{(aa)}(E_e)\left(\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_eE_\nu}\right)^2 + \bar{C}_{(aA)}(E_e)\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_eE_\nu}\frac{\boldsymbol{\sigma}_n\cdot\mathbf{p}_e}{E_e} + \bar{C}_{(aB)}(E_e)\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_eE_\nu}\frac{\boldsymbol{\sigma}_n\cdot\mathbf{p}_\nu}{E_\nu}, \quad (9)$$

Fierz term

These terms can contain tensor corrections

A more specific look…

$$b = \frac{2}{1+3\lambda^2}\left[g_S\epsilon_S - 12\boxed{g_T\epsilon_T}\lambda\right]$$
$$b_\nu = \frac{2}{1+3\lambda^2}\left[g_S\epsilon_S\lambda - 4\boxed{g_T\epsilon_T}(1+2\lambda)\right],$$

g_T and g_S are the flavor non-singlet/isovector hadronic matrix elements

$$\langle p_p, S_p|\,\bar{u}d\,|p_n, S_n\rangle = g_S(-t)\,\overline{U}(p_p, S_p)U(p_n, S_n) \quad ,$$
$$\langle p_p, S_p|\,\bar{u}\sigma_{\mu\nu}d\,|p_n, S_n\rangle = g_T(-t)\,\overline{U}(p_p, S_p)\sigma_{\mu\nu}U(p_n, S_n),$$

… or by using isospin symmetry:

$$\langle p'_p, S_p|\,\bar{u}u - \bar{d}d\,|p_p, S_p\rangle = g_S(-t)\,\overline{U}(p'_p, S_p)U(p_p, S_p) \quad ,$$
$$\langle p'_p, S_p|\,\bar{u}\sigma_{\mu\nu}u - \bar{d}\sigma_{\mu\nu}d\,|p_p, S_p\rangle = g_T(-t)\,\overline{U}(p'_p, S_p)\sigma_{\mu\nu}U(p_p, S_p),$$

The precision with which ε_T can be measured depends on the uncertainty on g_T

The observable is always the product of the fundamental coupling times a hadronic matrix element

$$C_T = \frac{G_F}{\sqrt{2}} V_{ud} g_T \varepsilon_T$$

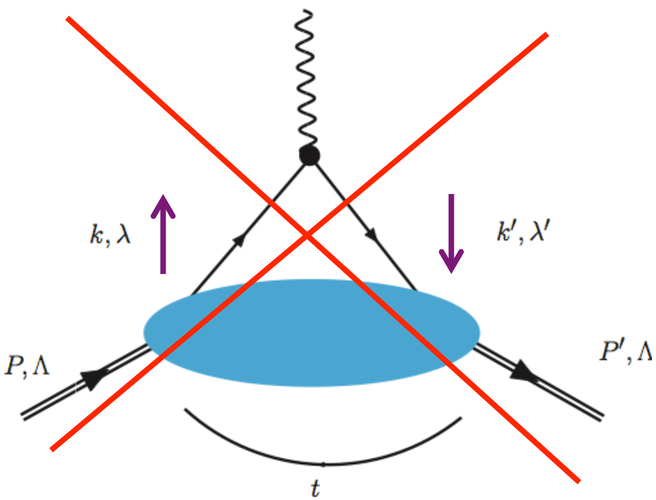
Lee-Yang effective coupling

Polarized hard scattering processes measurable at Jlab @12 GeV and at Electron Ion Collider (EIC) provide the hadronic matrix elements which are necessary to extract the possible BSM tensor, scalar and pseudo-scalar effective couplings entering the neutron beta decay cross section

The most general form of gauge interactions with the exchange of a spin-1 particle is a linear combination of

VECTOR $\bar{\Psi}\gamma_\mu\Psi$ and **AXIAL-VECTOR** $\bar{\Psi}\gamma_\mu\gamma_5\Psi$

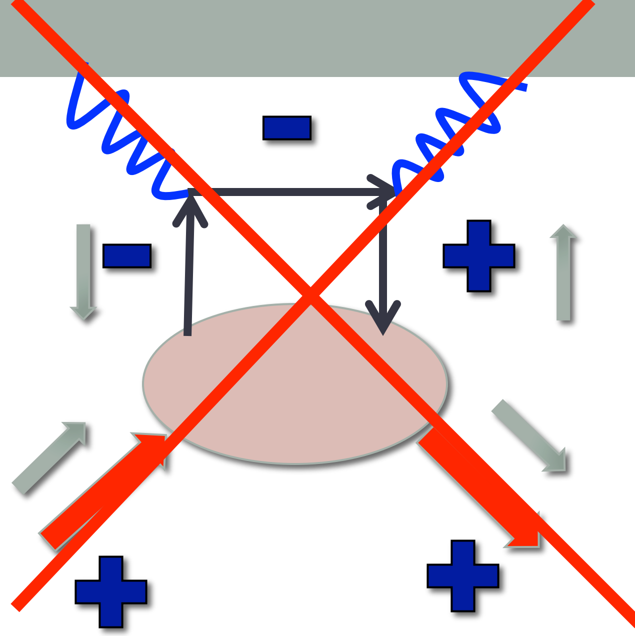
- ✓ The tensor charge is not "fundamental"
- ✓ A "tensor form factor" cannot be measured in elastic scattering type processes mediated by either one or two photons

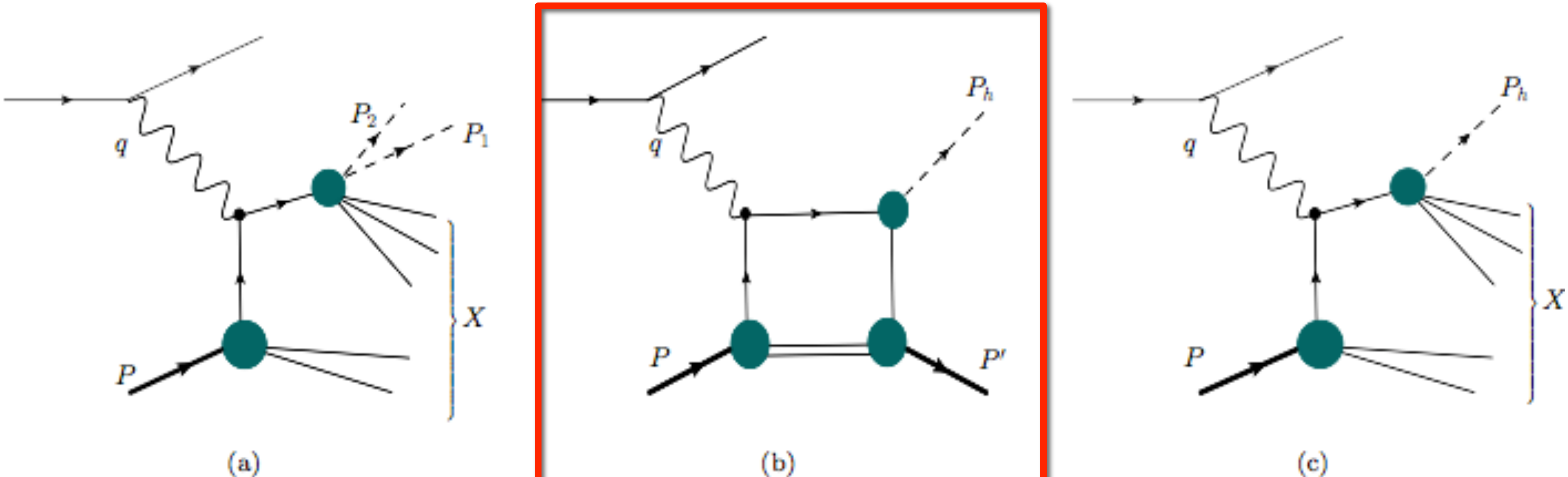


$$\langle p', \Lambda' \mid \pm i\bar{\psi}(0)\left(\sigma^{+1} \pm i\sigma^{+2}\right)\psi(0) \mid p, \Lambda\rangle$$

The operator is chiral-odd: only connects quarks with opposite helicity

To detect chiral odd distributions we need another distinct hadronic blob





dihadron

DVπ°P, DVηP

SIDIS

collinear

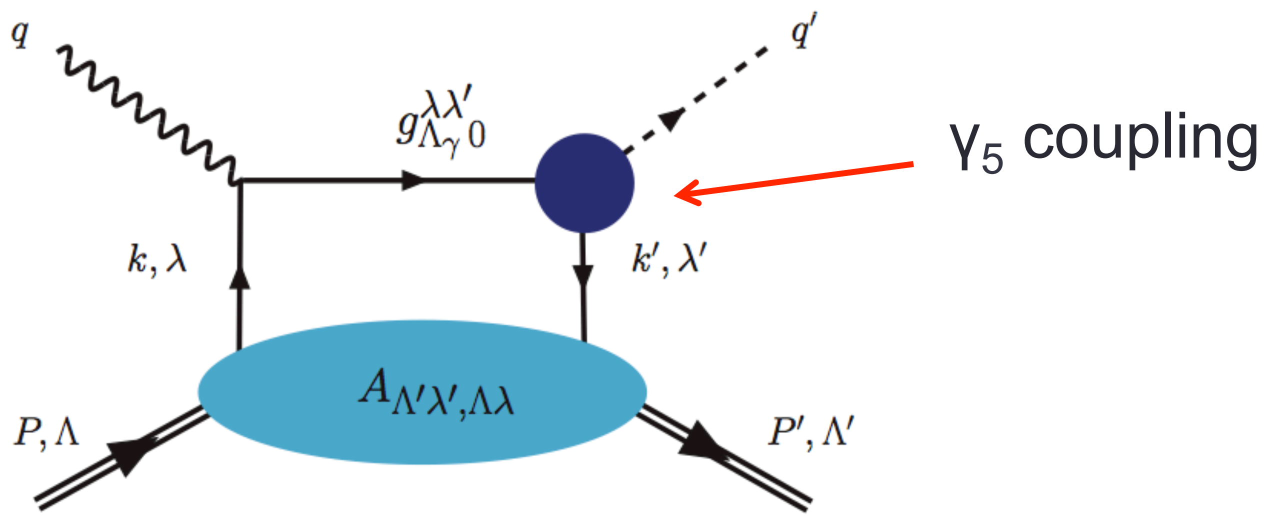
3. CHIRAL ODD GPD'S

A new way od accessing transversity GPDs was suggested in S. Ahmad et al. Phys.Rev. D79 (2009) 054014

The non-local matrix elements probed are

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

$$e\,p \to e'p'\pi^o$$



Quark correlator in the chiral odd sector: 4 distinct Lorentz structures/GPDs

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

One to one relation with helicity amplitudes

M. Diehl

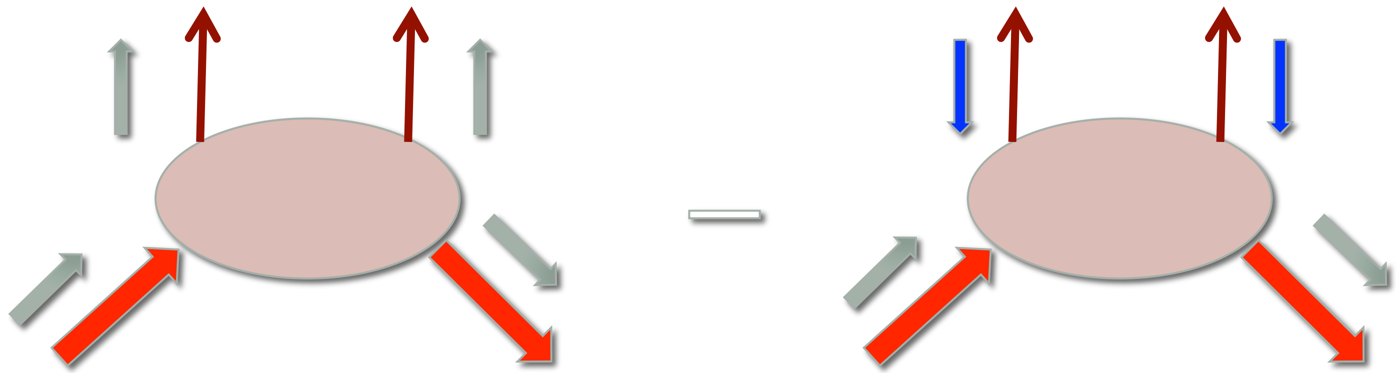
$$A_{++,--} = \frac{\sqrt{1-\zeta}}{1-\zeta/2}\left[H_T + \frac{t_0-t}{4M^2}\widetilde{H}_T + \frac{\zeta^2/4}{1-\zeta}E_T + \frac{\zeta/2}{1-\zeta}\widetilde{E}_T\right]$$

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

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

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

Chiral Even Quark-Proton Helicity Amplitudes



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

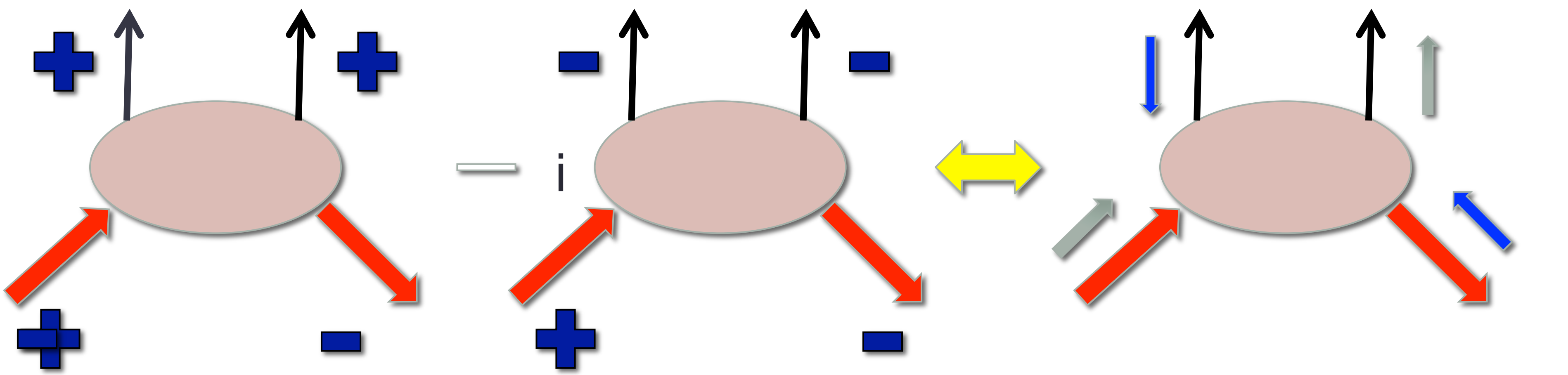
Net helicity of a quark in a longitudinally polarized proton:

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

Chiral Odd Quark-Proton Helicity Amplitudes

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

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

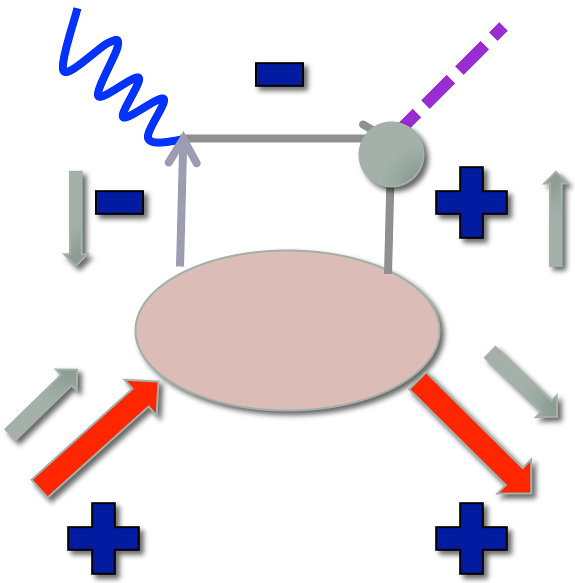


Net transverse polarization of a quark in a transversely polarized proton:

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

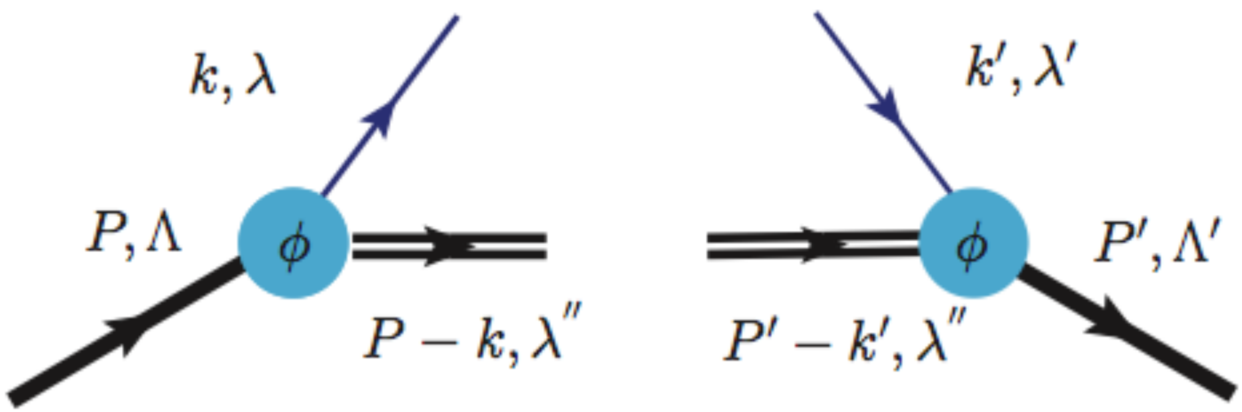
In the helicity basis it is described in terms of non-diagonal/chirally-odd quark-proton helicity amplitudes.

One can disentangle all four configurations, example:



$A_{+-,++}$ → $2\tilde{H}_T + E_T$

GPDs in Diquark/Spectator Model



λ"=0,1 ➔scalar or axial vector diquark

$$\phi_{\Lambda,\lambda}(k,P) = \Gamma(k)\frac{\bar{u}(k,\lambda)U(P,\Lambda)}{k^2 - m^2}$$

Diquark model allows to extract flavor dependence

Scalar diquark

$$A^{(0)}_{\Lambda'\lambda',\Lambda\lambda} = \int d^2k_\perp \phi^*_{\Lambda'\lambda'}(k',P')\phi_{\Lambda\lambda}(k,P),$$

Axial-vector diquark

$$A^{(1)}_{\Lambda'\lambda',\Lambda\lambda} = \int d^2k_\perp \phi^{*\mu}_{\Lambda'\lambda'}(k',P')\sum_{\lambda''}\epsilon^{*\,\lambda''}_{\mu}\epsilon^{\lambda''}_{\nu}\phi^{\nu}_{\Lambda,\lambda}(k,P),$$

Proton wave function using SU(4) (spin and flavor)

polarized

$$|\,p\uparrow\rangle = \sqrt{\frac{2}{1+a_S^2}}\left[\frac{a_S}{\sqrt{2}}\,|\,u\uparrow S_0^0\rangle + \frac{1}{3\sqrt{2}}\,|\,u\uparrow T_0^0\rangle - \frac{1}{3}\,|\,u\downarrow T_0^1\rangle - \frac{1}{3}\,|\,d\uparrow T_1^0\rangle + \frac{\sqrt{2}}{3}\,|\,d\downarrow T_1^1\rangle\right]$$

unpolarized

$$|\,p\rangle = \sqrt{\frac{2}{1+a_S^2}}\left[\frac{a_S}{\sqrt{2}}\,|\,u\,S_0\rangle - \frac{1}{\sqrt{6}}\,|\,u\,T_0\rangle + \frac{1}{\sqrt{3}}\,|\,d\,T_1\rangle\right].$$

$a_s=1$

Wave function is given by the overlap

unpolarized

$$F^u = \frac{2}{1+a_S^2}\left(\frac{3}{2}a_S^2F^{(0)} + \frac{1}{2}F^{(1)}\right)$$

$$F^d = \frac{2}{1+a_S^2}F^{(1)},$$

polarized

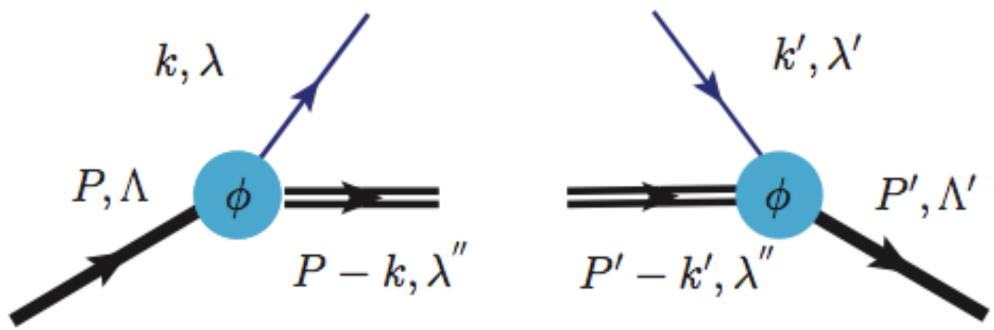
$$F^u_{pol} = \frac{2}{1+a_S^2}\left(\frac{3}{2}a_S^2F_T^{(0)} - \frac{1}{6}F_T^{(1)}\right)$$

$$F^d_{pol} = -\frac{2}{1+a_S^2}\frac{1}{3}F_T^{(1)},$$

How do the transversity GPDs look like?

- ✓ In the diquark model we can relate chiral-odd GPDs to chiral-even GPDs due to parity relations
- ✓ As a result, all 4 GPDs contribute (different from Kroll, Goloskokov model)

In the diquark model one can write parity relations among helicity amps



$$\phi_{-\Lambda-\lambda} = (-1)^{\Lambda-\lambda}\phi^*_{\Lambda\lambda}.$$

Scalar diquark

odd even

$$\widetilde{H}_T^{(0)} = -\frac{1}{F}\left(E^{(0)} - \frac{\zeta}{2}\widetilde{E}^{(0)}\right) \tag{70a}$$

$$E_T^{(0)} = \frac{2}{1-\xi^2}\left[E^{(0)} - \widetilde{H}_T^{(0)} - \xi^2 \widetilde{E}^{(0)}\right] = 2\,\frac{(1-\zeta/2)^2}{1-\zeta}\left[E^{(0)} - \widetilde{H}_T^{(0)} - \left(\frac{\zeta/2}{1-\zeta/2}\right)^2 \widetilde{E}^{(0)}\right] \tag{70b}$$

$$\widetilde{E}_T^{(0)} = \frac{2}{1-\xi^2}\left[\xi^2 E^{(0)} - \xi^2 \widetilde{H}_T^{(0)} - \widetilde{E}^{(0)}\right] = 2\,\frac{(1-\zeta/2)^2}{1-\zeta}\left[\left(\frac{\zeta/2}{1-\zeta/2}\right)^2 E^{(0)} - \left(\frac{\zeta/2}{1-\zeta/2}\right)^2 \widetilde{H}_T^{(0)} - \widetilde{E}^{(0)}\right] \tag{70c}$$

$$H_T^{(0)} = \frac{H^{(0)} + \widetilde{H}^{(0)}}{2} - \frac{\zeta^2/4}{1-\zeta}\,\frac{E^{(0)} + \widetilde{E}^{(0)}}{2} - \frac{\zeta^2/4}{(1-\zeta/2)(1-\zeta)} E_T^{(0)} + \frac{\zeta/4(1-\zeta/2)}{1-\zeta}\widetilde{E}_T^{(0)} - \frac{t_0 - t}{4M^2}\,\frac{1}{F}\left(E^{(0)} - \frac{\zeta}{2}\widetilde{E}^{(0)}\right) \tag{70d}$$

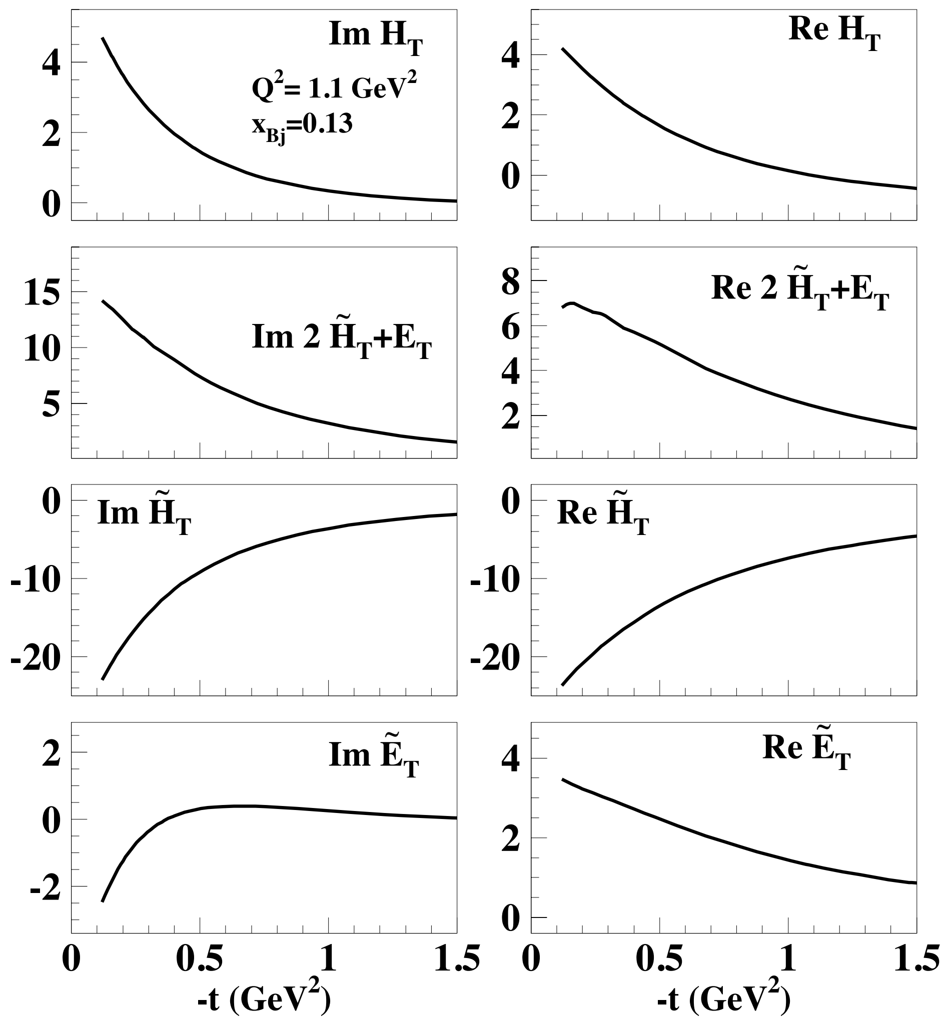
Soffer bound

Axial-vector diquark

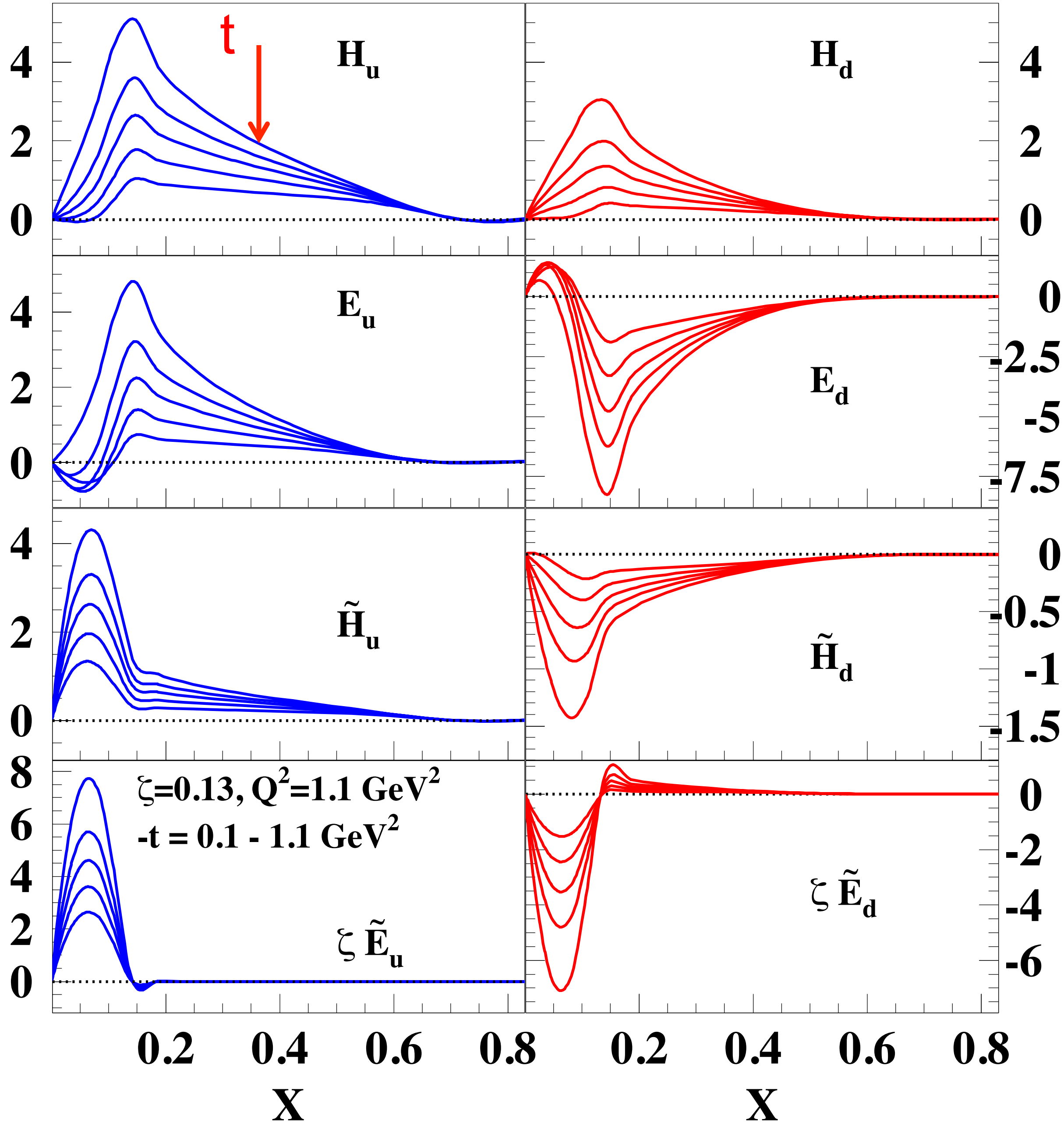
odd even

$$
\begin{aligned}
\widetilde{H}_T^{(1)} &= 0 \\
E_T^{(1)} &= \frac{1-\zeta/2}{1-\zeta}\left[\tilde{a}\left(E^{(1)} - \frac{\zeta/2}{1-\zeta/2}\widetilde{E}^{(1)}\right) + a\left(E^{(1)} + \frac{\zeta/2}{1-\zeta/2}\widetilde{E}^{(1)}\right)\right] \\
\widetilde{E}_T^{1} &= \frac{1-\zeta/2}{1-\zeta}\left[\tilde{a}\left(E^{(1)} - \frac{\zeta/2}{1-\zeta/2}\widetilde{E}^{(1)}\right) - a\left(E(1) + \frac{\zeta/2}{1-\zeta/2}\widetilde{E}^{(1)}\right)\right] \\
H_T^{(1)} &= G\left[\frac{H^{(1)} + \widetilde{H}^{(1)}}{2} - \frac{\zeta^2/4}{1-\zeta}\frac{E^{(1)} + \widetilde{E}^{(1)}}{2}\right] - \frac{\zeta^2/4}{1-\zeta}E_T^{(1)} + \frac{\zeta/4}{1-\zeta}\widetilde{E}_T^{(1)}
\end{aligned}
$$

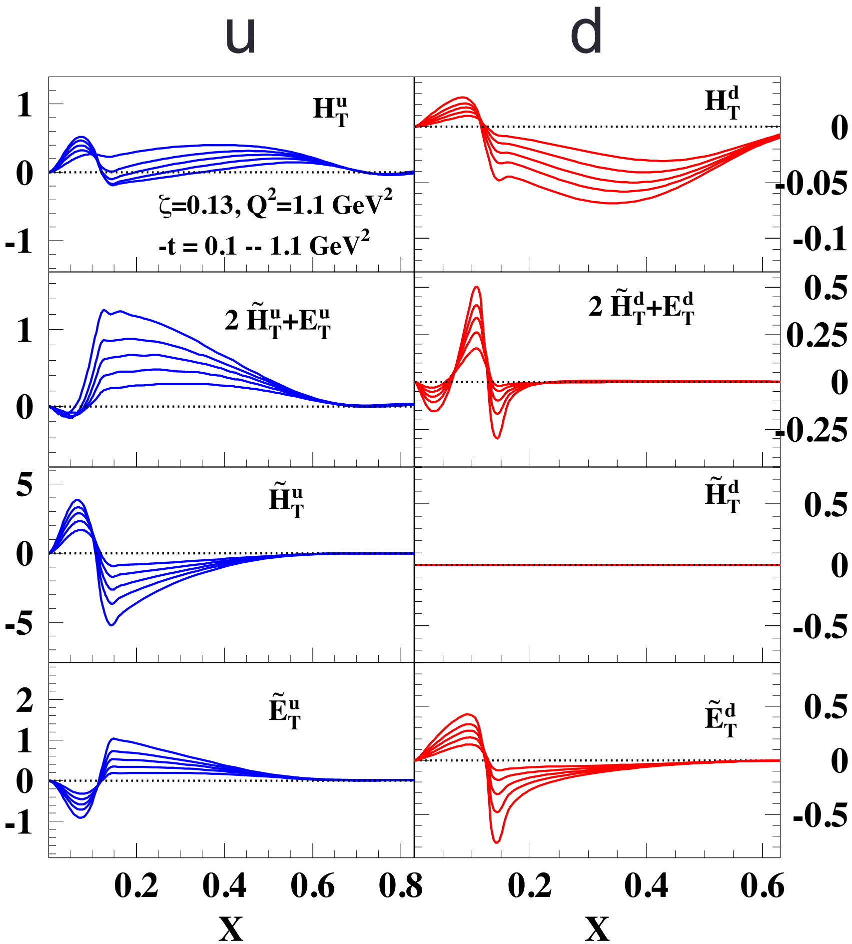
Soffer bound


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

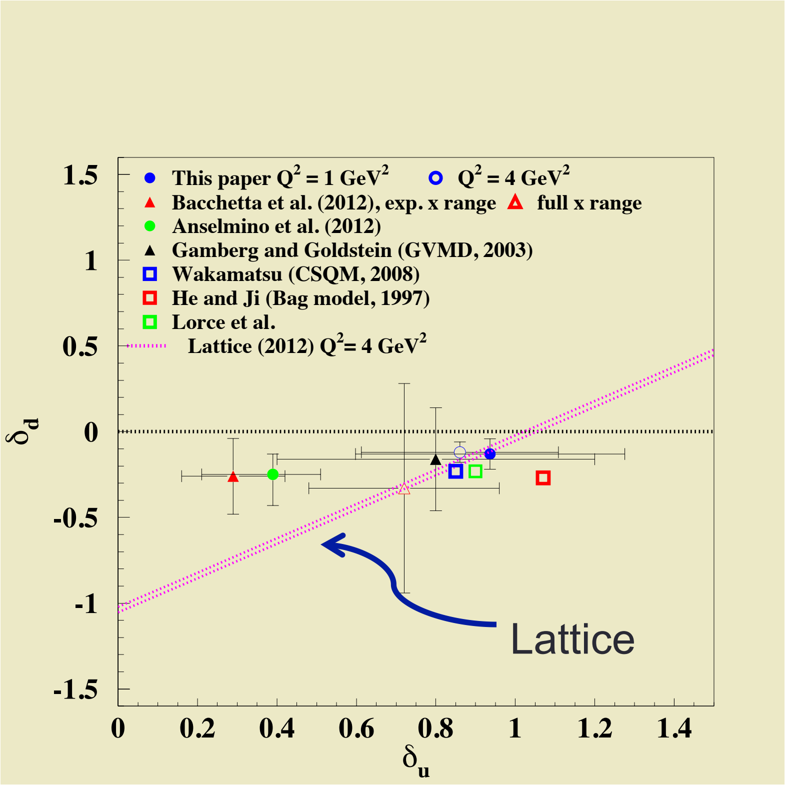
$$\int dx\, [2\tilde{H}_T^q(x,\zeta,t,Q^2) + E_T^q(x,\zeta,t,Q^2)] = \kappa_q(t,Q^2)$$

(M. Burkardt, PRD66, 114005 (2002))

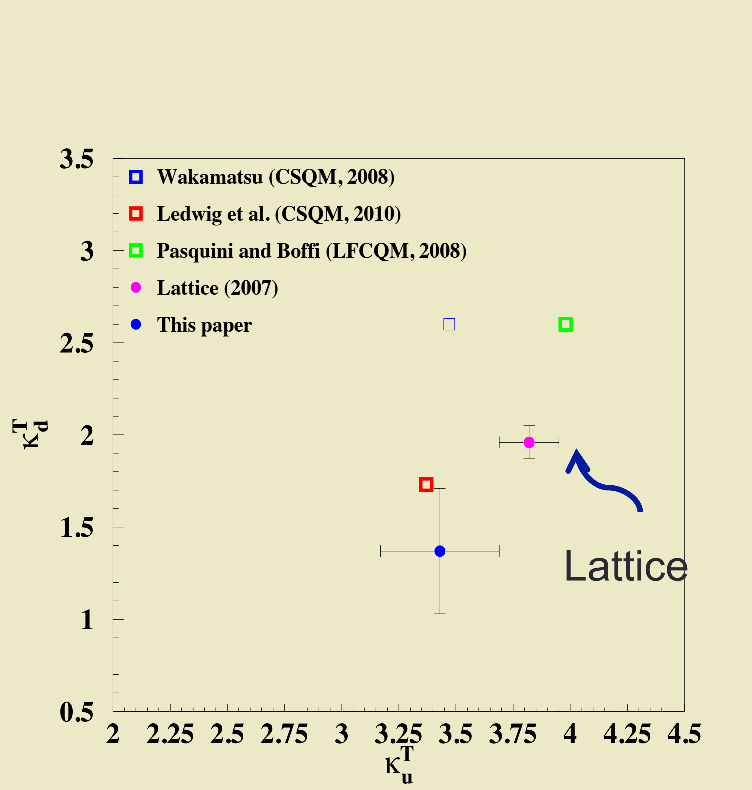
?

?

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)

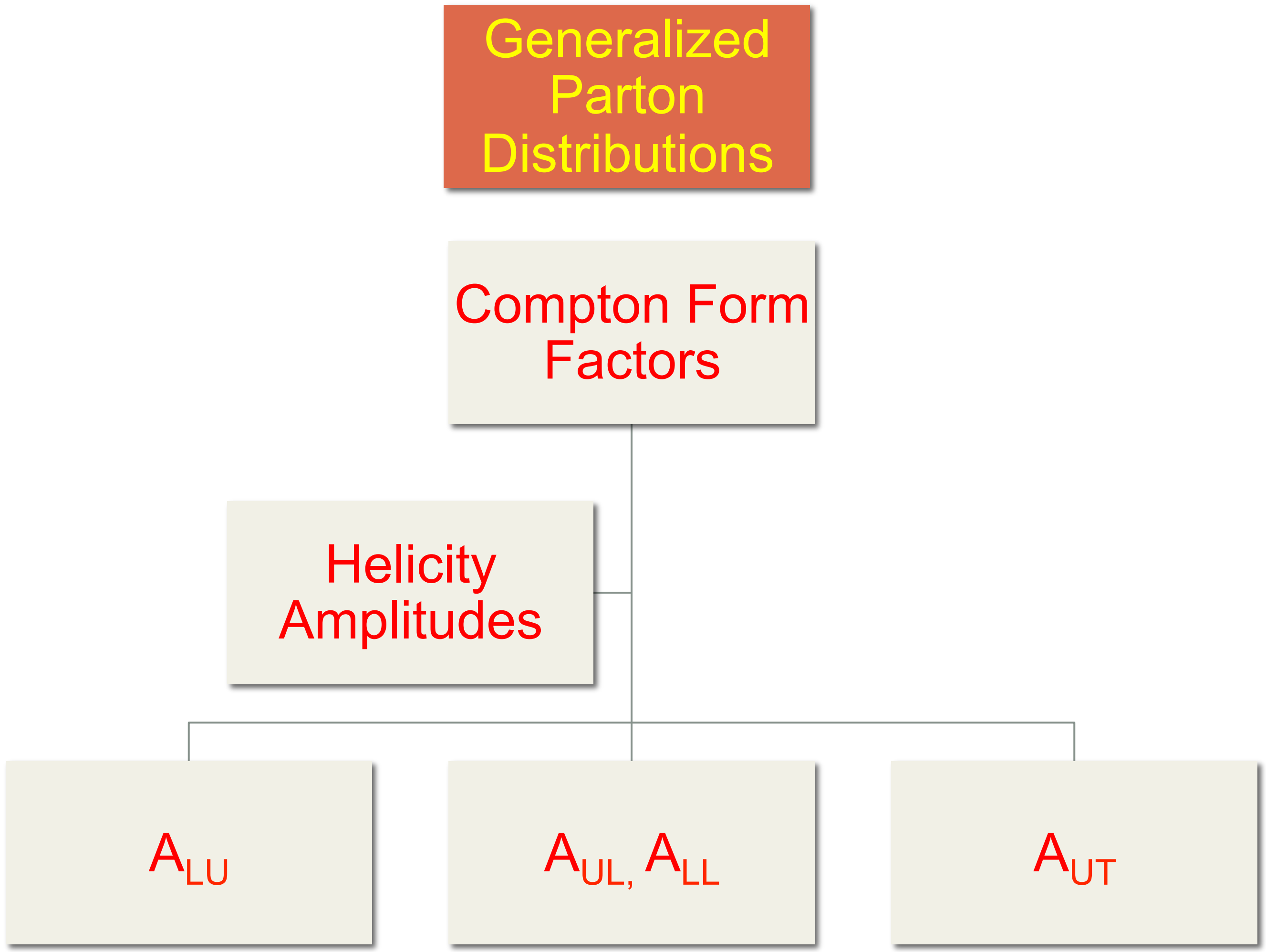
4. EXTRACTION FROM EXPERIMENT

Experiment: DVπ°P, DVηP

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

$$\mathcal{F}_T^{\pi^o} = \frac{1}{\sqrt{2}}(e_u \mathcal{F}_T^u - e_d \mathcal{F}_T^d)$$

$$\mathcal{F}_T^{\eta} = \frac{1}{\sqrt{6}}(e_u \mathcal{F}_T^u + e_d \mathcal{F}_T^d - 2e_s \mathcal{F}_T^s)$$


Generalized Parton Distributions
Compton Form Factors
Helicity Amplitudes
A_{LU}
A_{UL}, A_{LL}
A_{UT}

Cross Section Formulation

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

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

GPDs in helicity amplitudes →

$$F_{UU,T} = \mathcal{N} \left[\mid f_{10}^{++} \mid^2 + \mid f_{10}^{+-} \mid^2 + \mid f_{10}^{-+} \mid^2 + \mid f_{10}^{--} \mid^2 \right]$$

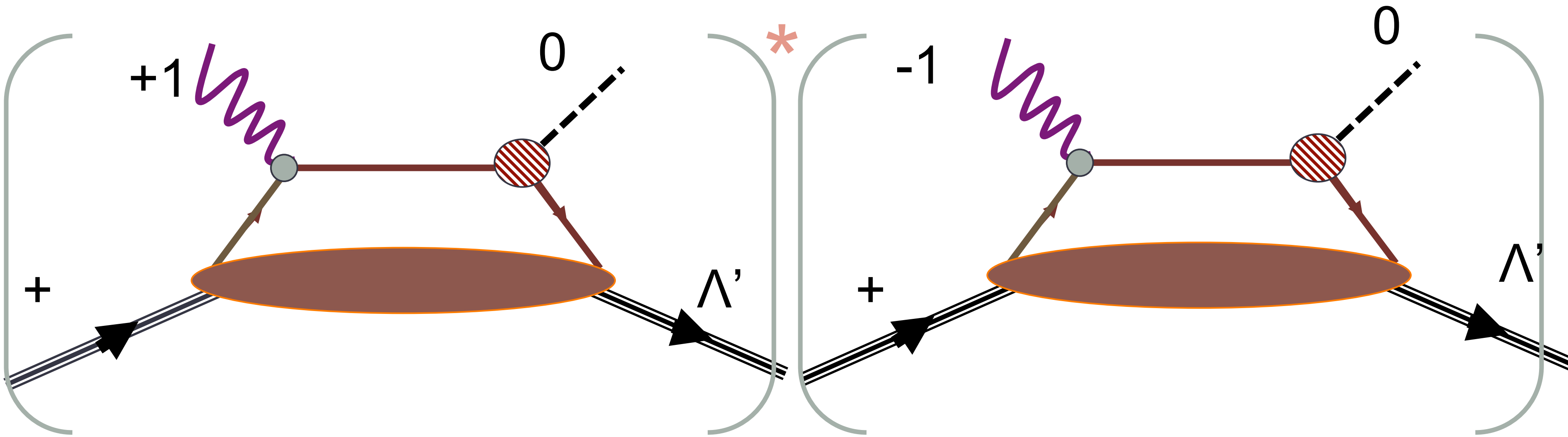
$$F_{UU,L} = \mathcal{N} \left[\mid f_{00}^{++} \mid^2 + \mid f_{00}^{+-} \mid^2 \right]$$

$$F_{UU}^{\cos 2\phi} = -\mathcal{N}\, 2\Re e \left[(f_{10}^{++})^* (f_{10}^{--}) - (f_{10}^{+-})^* (f_{10}^{-+}) \right]$$

$$F_{UU}^{\cos\phi} = -\mathcal{N} \Re e \left[(f_{00}^{+-})^* (f_{10}^{+-} + f_{10}^{-+}) + (f_{00}^{++})^* (f_{10}^{++} - f_{10}^{--}) \right]$$

$$F_{LU}^{\sin\phi} = \mathcal{N} \Im m \left[(f_{00}^{+-})^* (f_{10}^{+-} + f_{10}^{-+}) + (f_{00}^{++})^* (f_{10}^{++} - f_{10}^{--}) \right]$$

General form of structure function of a chiral odd term:

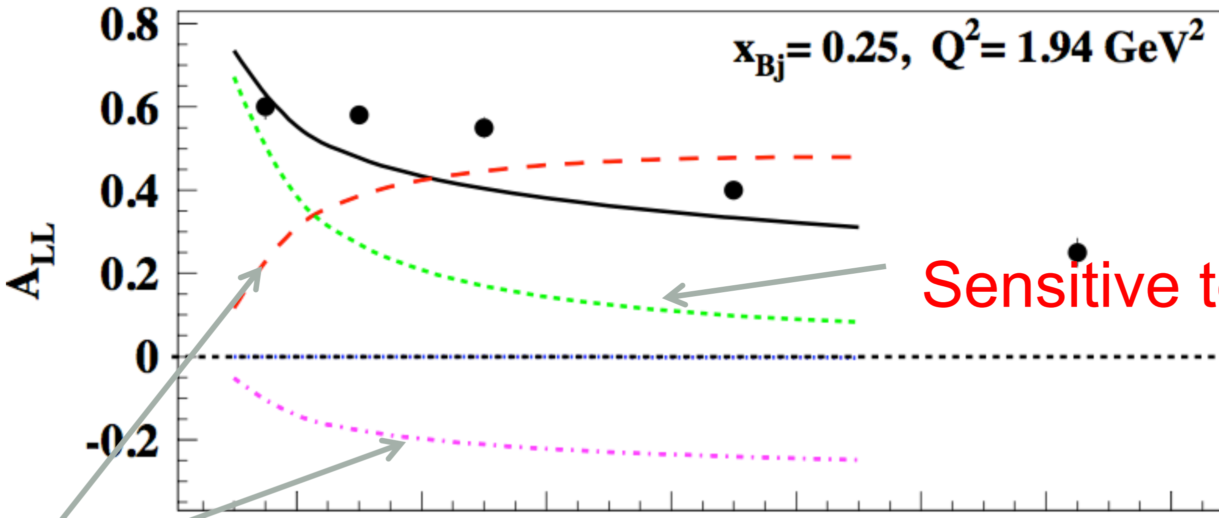


helicity amplitudes

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

$$
\begin{aligned}
f_{10}^{++} &\propto \sqrt{t_o - t}\left(2\widetilde{\mathcal{H}}_T + \mathcal{E}_T - \widetilde{\mathcal{E}}_T\right) \\
f_{10}^{+-} &\propto \mathcal{H}_T \\
f_{10}^{-+} &\propto (t_o - t)\,\widetilde{\mathcal{H}}_T \\
f_{10}^{--} &\propto \sqrt{t_o - t}\left(2\widetilde{\mathcal{H}}_T + \mathcal{E}_T + \widetilde{\mathcal{E}}_T\right),
\end{aligned}
$$

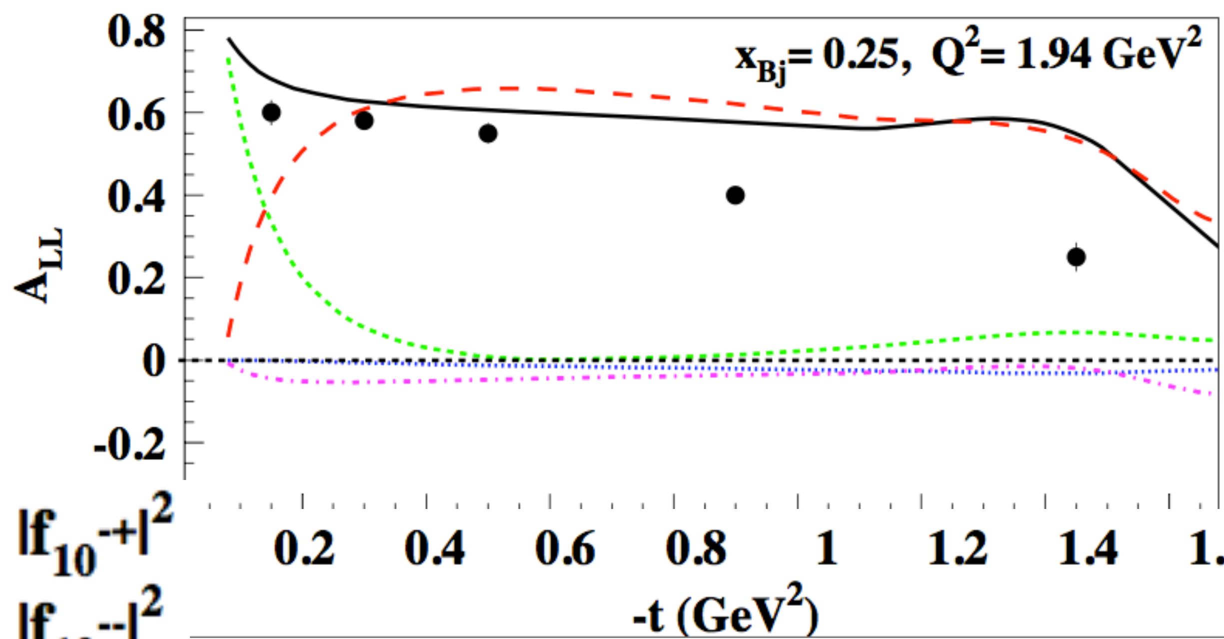
Andrey Kim, Harut Avakian et al., Jefferson Lab CLAS Collaboration

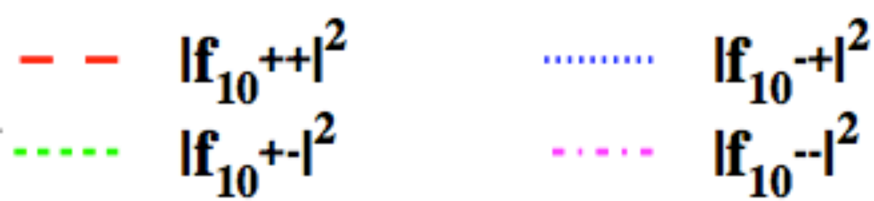


Sensitive to tensor charge

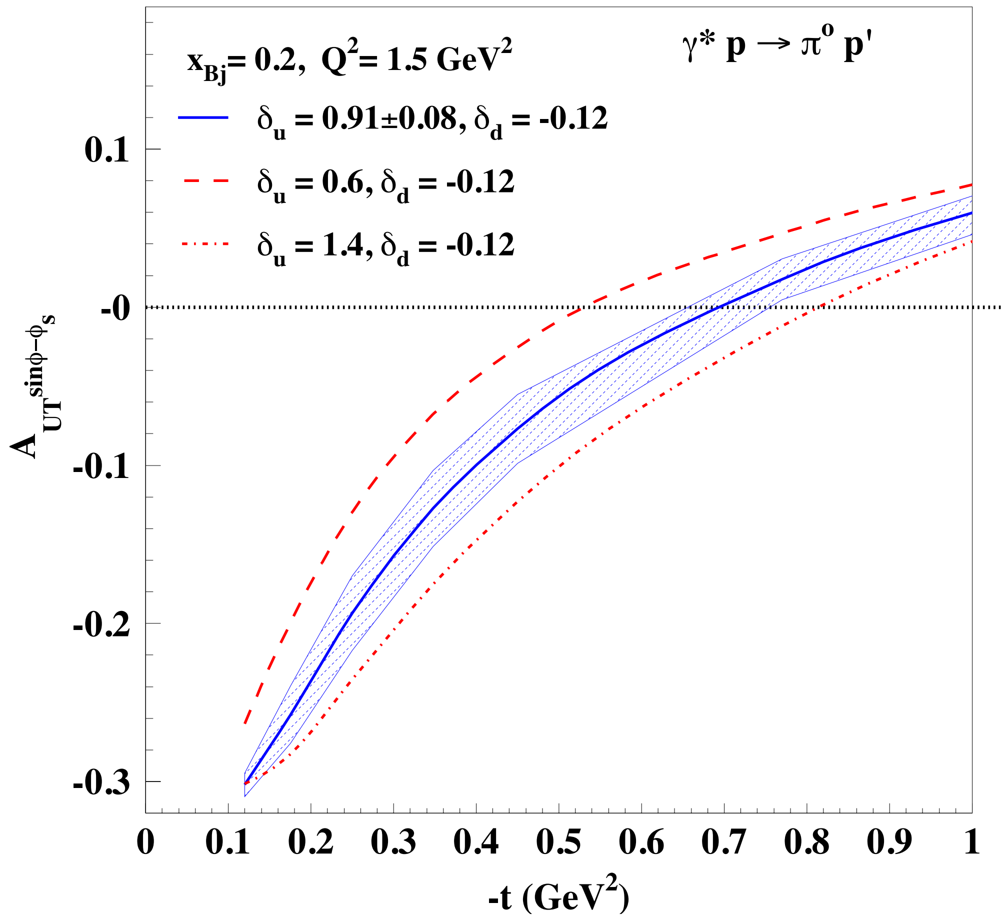
Sensitive to tensor an.mom.

Role of parameters



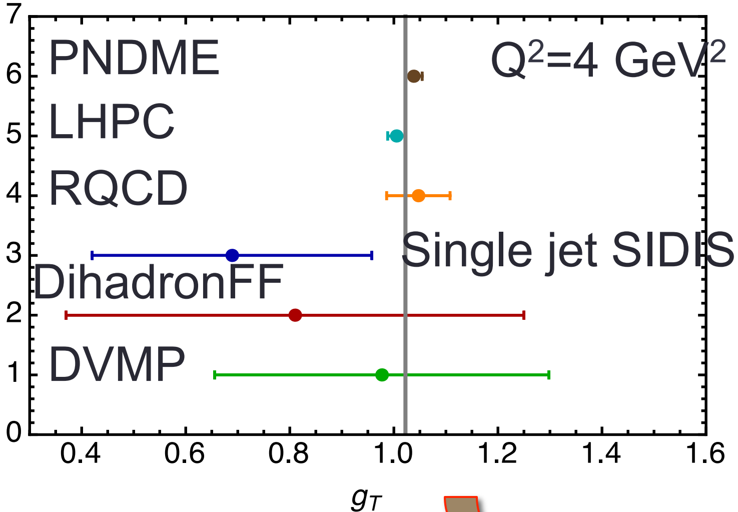


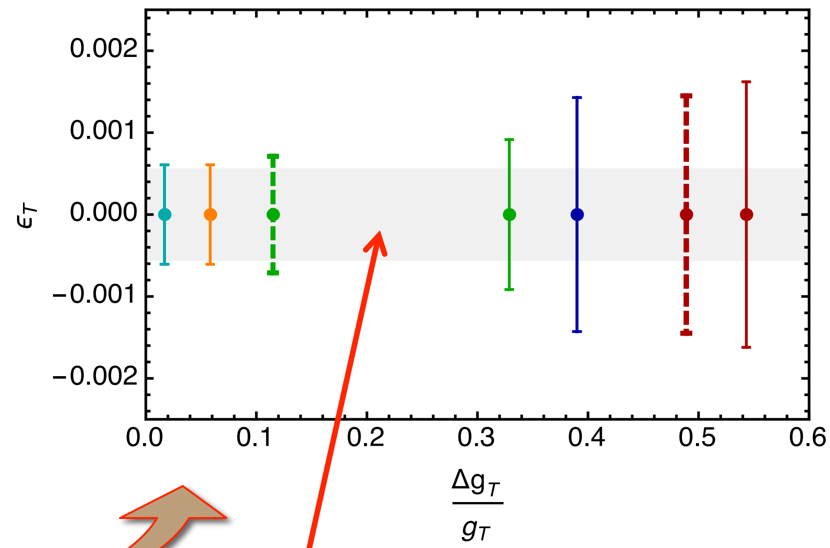
Projections for transverse polarized target



5. IMPACT ON BSM SEARCHES

Impact on BSM searches…





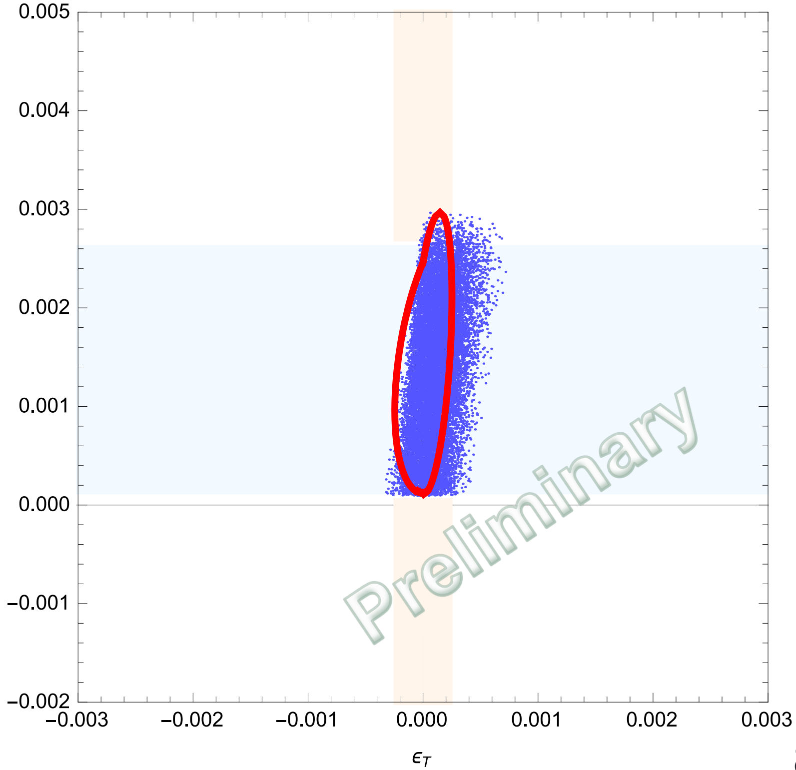
$|\varepsilon_T\, g_T| < 6.4 \times 10^{-4}$

Pattie et al, PRC88 (2013)

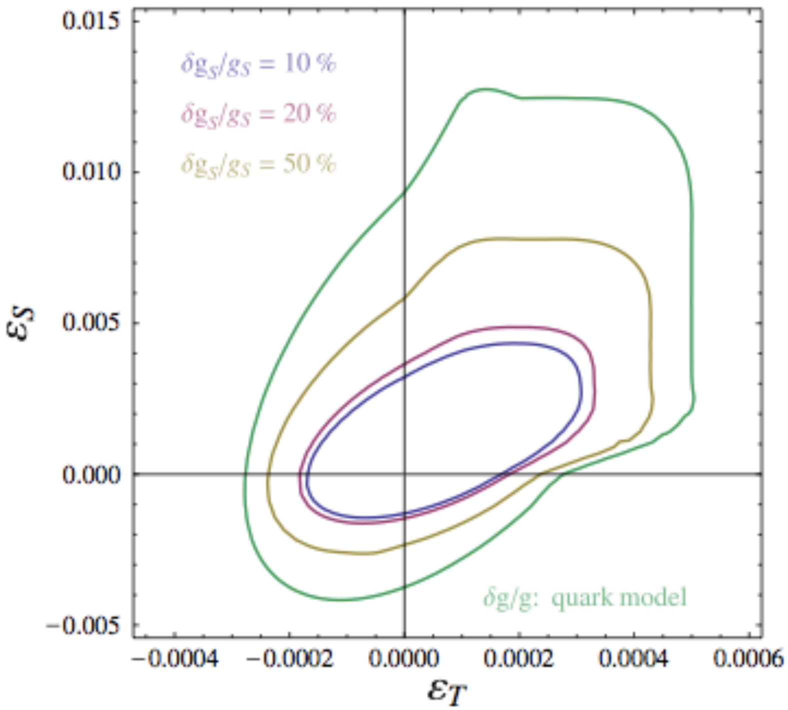
A. Courtoy, S.Baessler, M. Gonzalez-Alonso, S.L, arXiv:1503.06814

New Analysis (Pavia, UNAM, NMSU, Virginia)

ε_S



ε_T



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

Future developments

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

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

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

We outlined an approach 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 hadronic matrix element is the same which enters the DIS observables measured in precise semi-inclusive and deeply virtual exclusive scattering off polarized targets

However, 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.

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