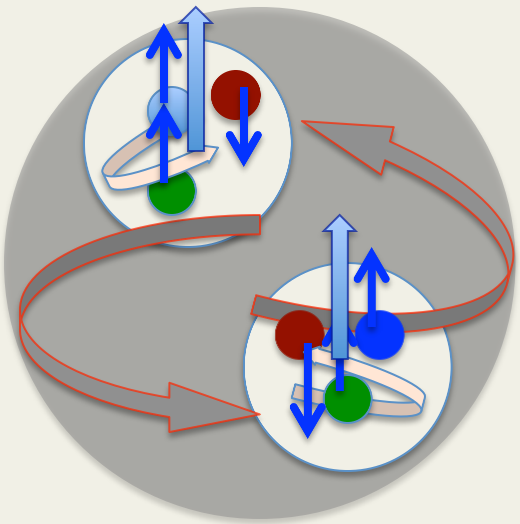
BSM Tensor Interaction and Hadron Phenomenology

Simonetta Liuti, University of Virginia



Workshop on "Intersections of BSM Phenomenology and QCD for New Physics Searches"

October 5th, 2015

Institute of Nuclear Theory, University of Washington

Work in collaboration with: S. Baessler, A. Courtoy, M. Gonzalez-Alonso

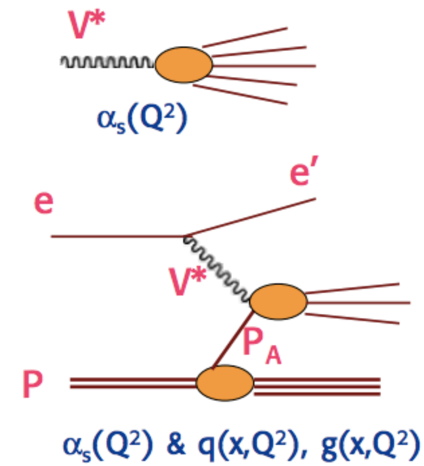
Week 3 of the Workshop covered different areas of progress, to date, on the role of QCD in Searches for New Physics

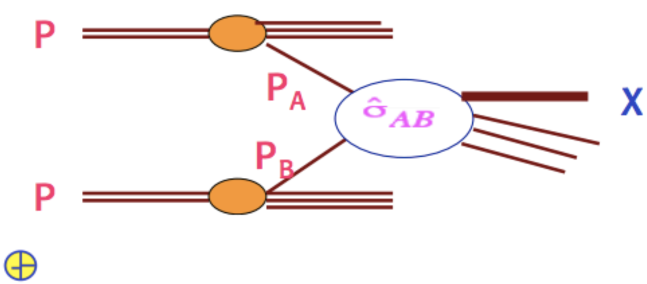
✓ QCD impacts the extraction of several of the 19 (28) fundamental parameters in the SM

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

1. The fine structure constant α (1)
2. The Weinberg angle or weak mixing angle θ_W (2)
3. The strong interaction coupling constant α_S (3)
4. The electroweak symmetry breaking energy scale (or the Higgs potential vacuum expectation value, v.e.v.) v (4)
5. The Higgs potential coupling constant λ /the Higgs mass m_H (5)
6. 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 (9)
7. The Yukawa coupling constants that determine the masses of the 6 quarks. (15)
8. … + 3 charged leptons (18)
9. Strong CP parameter (19)

“The proton pdfs uncertainties govern the theoretical errors on crucial processes including Higgs production”





The basic experimental set ups for accelerator particle physics:

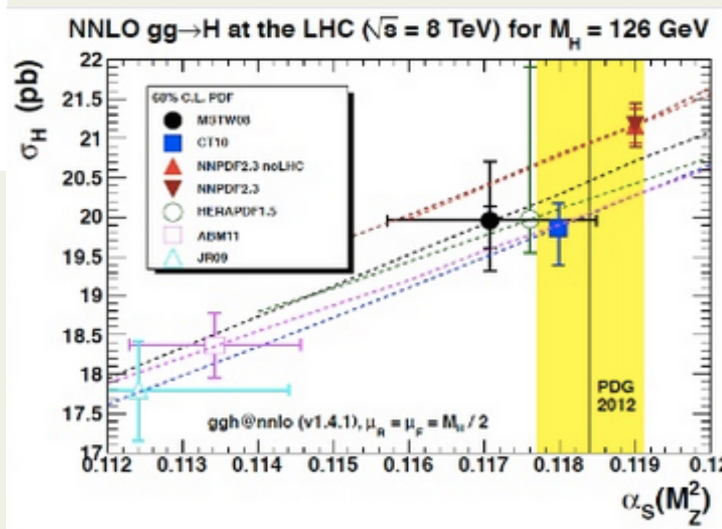
- no initial hadron (....LEP, ILC, CLIC)
- 1 hadron (....HERA, LHeC)
- 2 hadrons (Tevatron, LHC, FCC)

The pdf are defined in DIS

The theory of inclusive DIS is crystal clear

Thru the factorization “theorem” the pdf’s and α_s determine the hadron collider rates

G. Altarelli, LHeC Meeting, CERN June 2015



Large PDF uncertainties

✓ QCD affects also 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. .....

It is important to emphasize that "the strong interactions issues" in all of these examples are outstanding questions that require a deeper understanding of the structure of hadrons

1. Longitudinal and transverse spin structure: spin crisis, role of orbital angular momentum …
2. Running of α_S
3. QCD factorization for the transverse momentum distributions of quark and gluons
4. …

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…

The role of spin dependent observables → @LHC

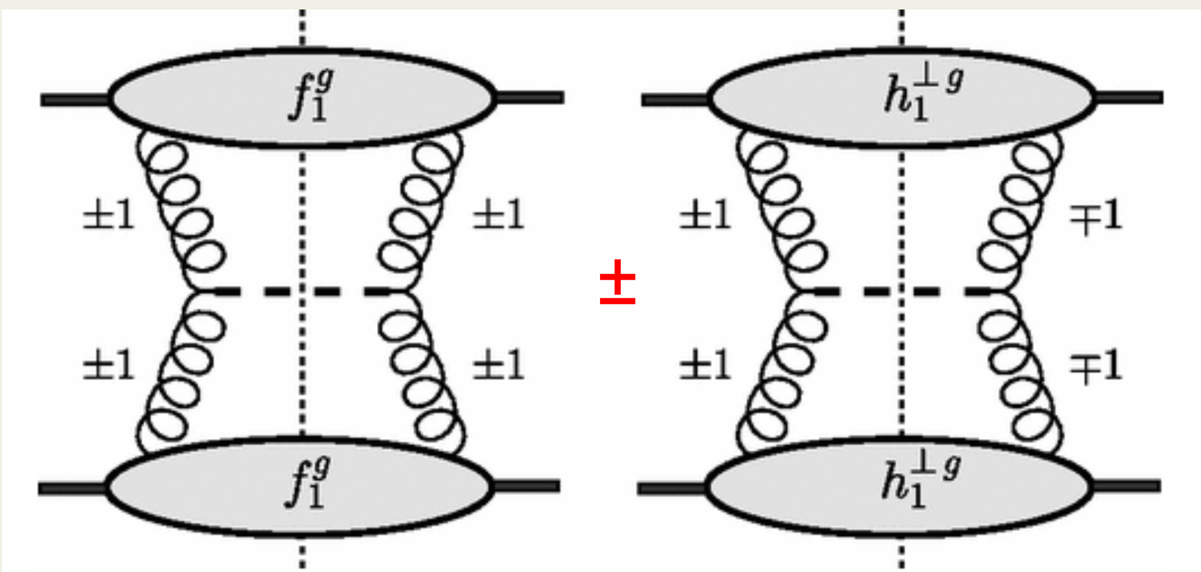
✓ Higgs, η_c (heavy pseudoscalar quarkonia) and top production are sensitive to the polarization of gluons

$pp \to H + jet + X$

D. Boer and C. Pisano, PRD 91, 074024 (2015)

$$\frac{d\sigma}{dy_H\, dy_j\, d^2\boldsymbol{K}_\perp\, d^2\boldsymbol{q}_T} = \frac{\alpha_s^3}{144\,\pi^3\, v^2}\, \frac{1}{x_a x_b s^2} \left[A(\boldsymbol{q}_T^2) + B(\boldsymbol{q}_T^2)\cos 2\phi + C(\boldsymbol{q}_T^2)\cos 4\phi \right],$$

sensitive to linearly polarized gluon TMDs



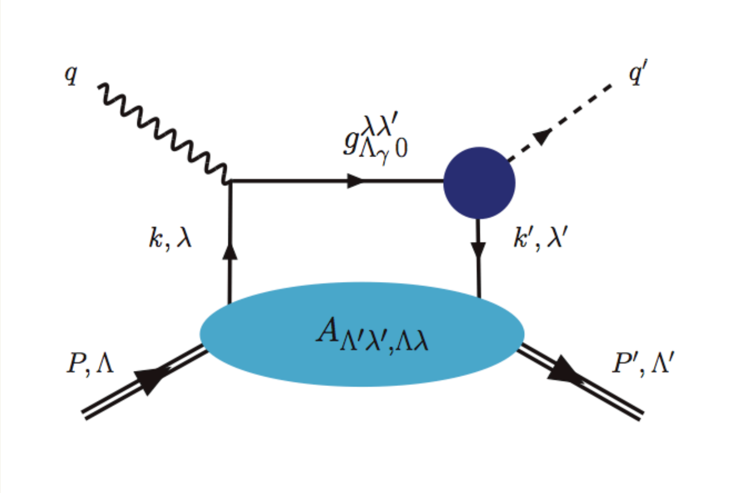
unpolarized linearly polarized

The sign of the polarized gluons term determines the parity of the Higgs boson

The role of spin dependent observables → in neutron beta decay, EDM, ..

Polarized hard scattering processes measurable at Jlab @12 GeV and at Electron Ion Collider (EIC) give us 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

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 decay

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

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

Bhattacharya et al., PRD85 (2012)

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

Fierz term

These terms can contain tensor corrections

A more specific look…

$$b = \frac{2}{1+3\lambda^2}\left[g_S\epsilon_S - 12 g_T\epsilon_T\lambda\right]$$

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

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

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

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:

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

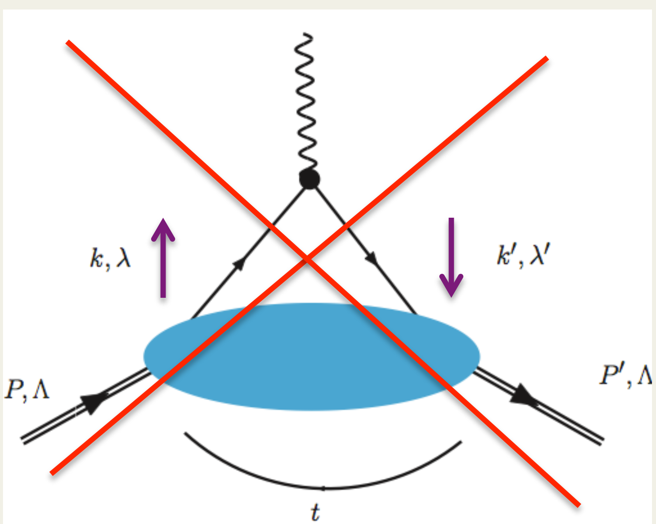
$$\langle p'_p, S_p | \bar{u}\sigma_{\mu\nu}u - \bar{d}\sigma_{\mu\nu} d | p_p, S_p\rangle = g_T(-t)\overline{U}(p'_p, S_p)\sigma_{\mu\nu}U(p_p, S_p),$$

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

Nucleon Tensor Charge and Chiral Odd GPDs

- 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** $\bar{\Psi}\gamma_\mu\gamma_5\Psi$

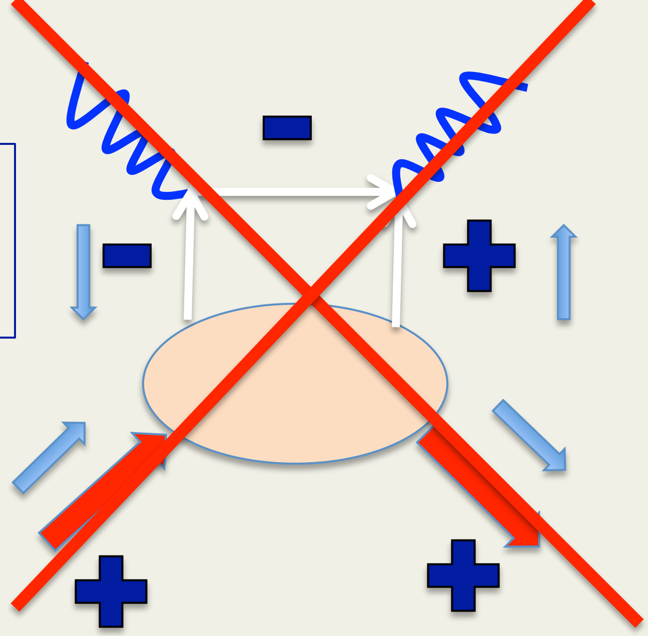
- The tensor charge is therefore not "fundamental"
- A "tensor form factor" cannot be measured in elastic scattering type processes mediated by either one or two photons

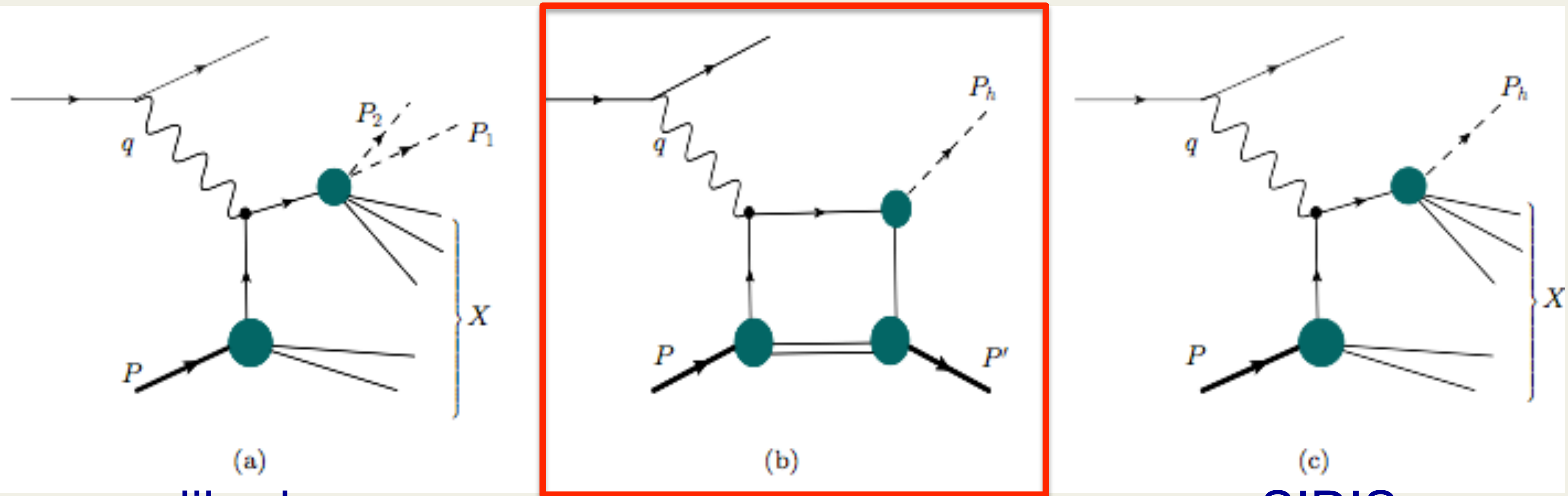


$$\langle p', \Lambda' \mid \pm i\bar{\psi}(0)\left(\sigma^{+1} \pm i\sigma^{+2}\right)\psi(0) \mid p, \Lambda\rangle$$

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

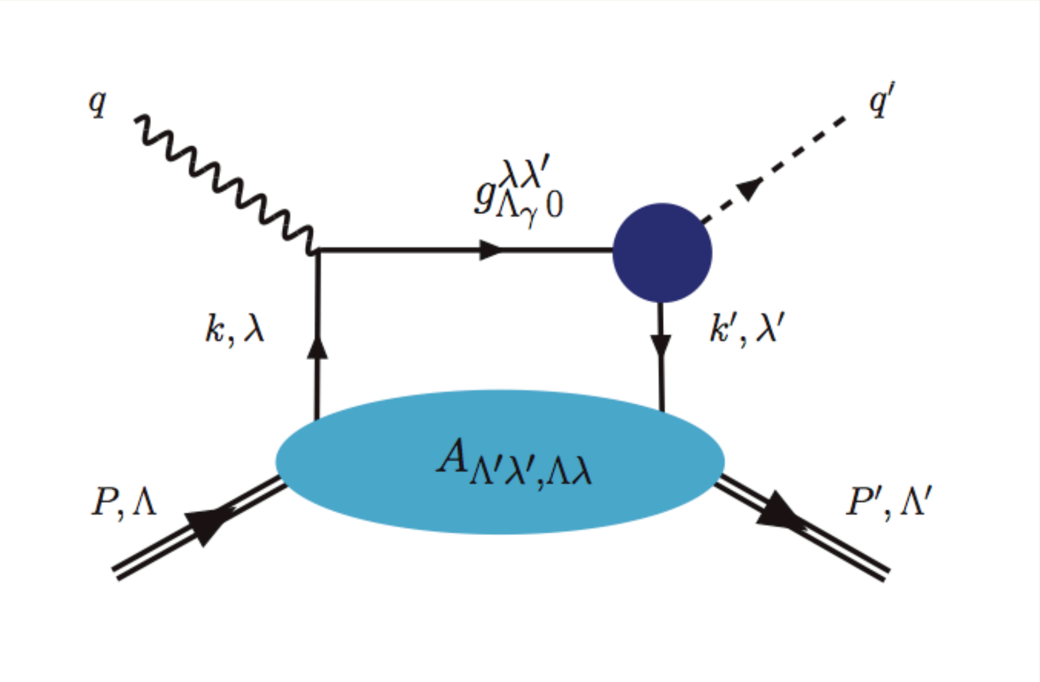
collinear

Dihadron

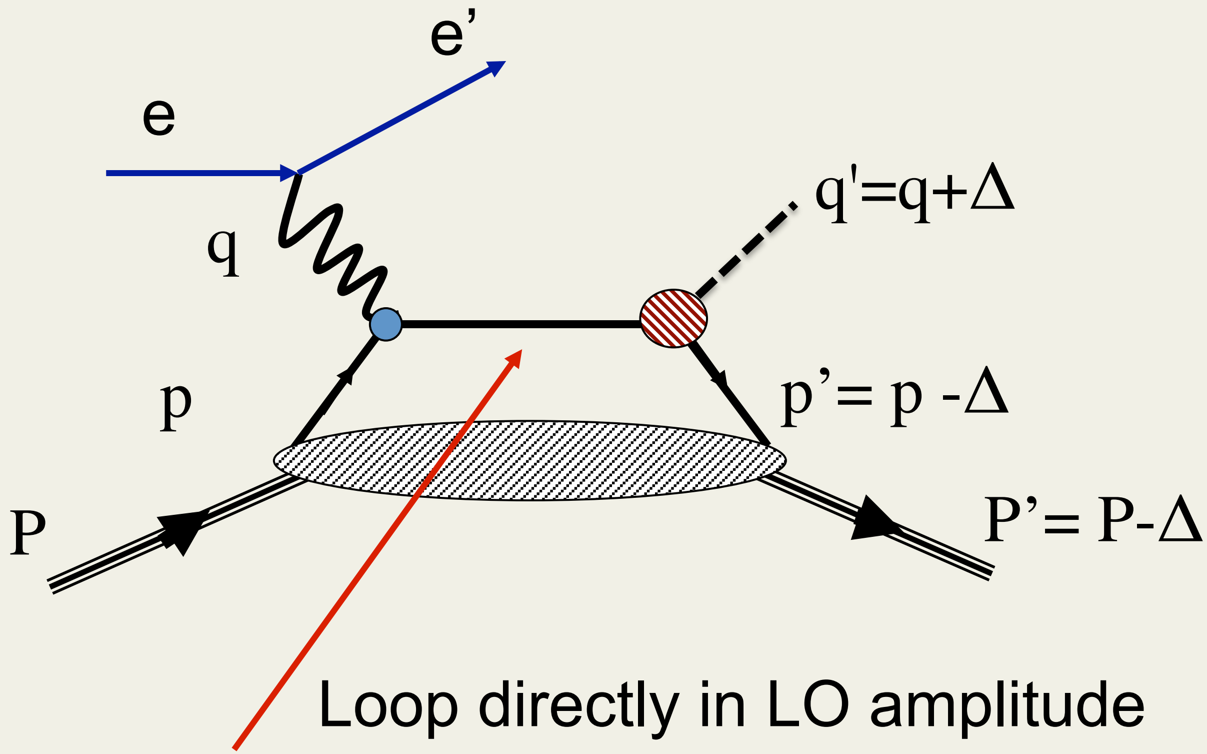
$$e\,p \rightarrow e'p'\pi^o$$

Non-local matrix elements like the ones probed in deeply virtual type experiments

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



Off forward Parton Distributions (GPDs) are embedded in the soft matrix elements for deeply virtual exclusive experiments

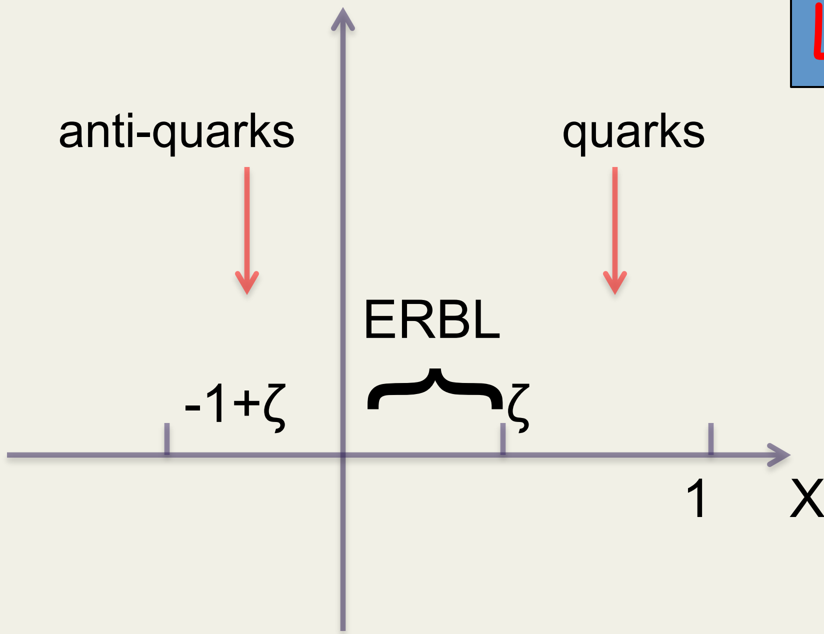


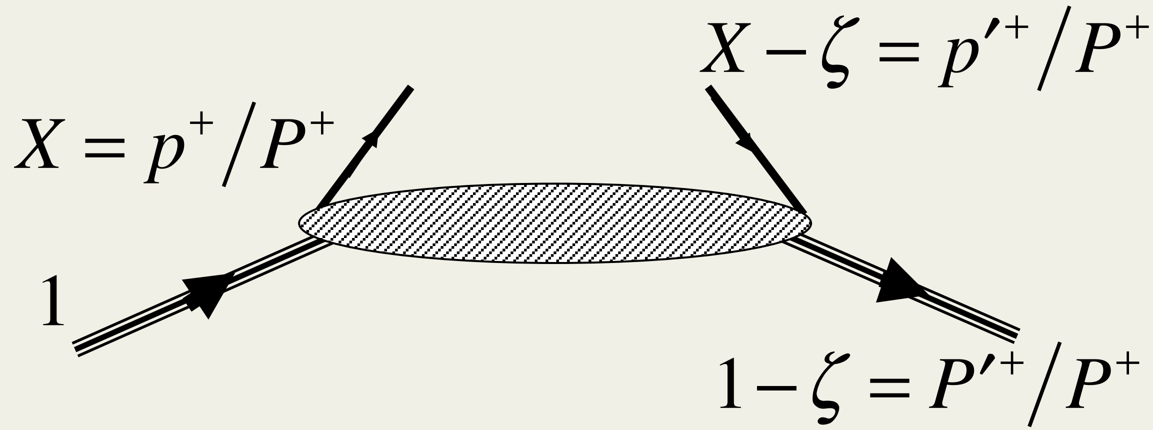
Loop directly in LO amplitude

(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

Limits of GPDs

- DIS

$$H_q(x,0,0) = q(x), \quad \tilde{H}_q(x,0,0) = \Delta q(x)$$

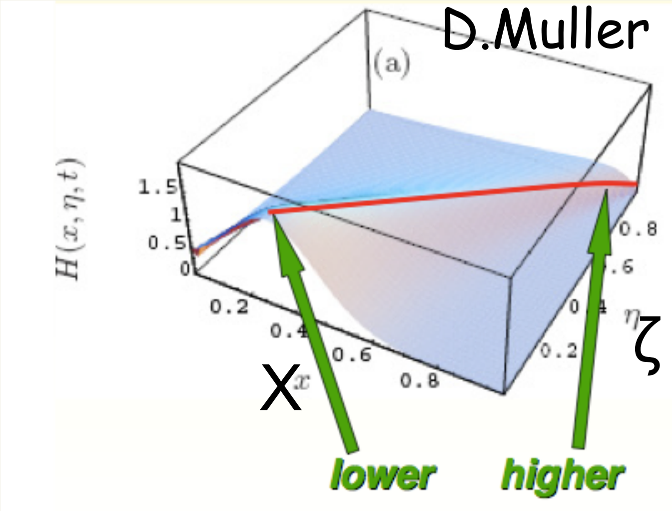
- Nucleon Form Factors

$$\int dx\, H_q(x,\xi,t) = F_1(t), \quad \int dx\, E_q(x,\xi,t) = F_2(t)$$

$$\int dx\, \tilde{H}_q(x,\xi,t) = G_A(x), \quad \int dx\, \tilde{E}_q(x,\xi,t) = G_P(x)$$

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

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



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”

In more detail…

$$\mathcal{F}^S_{\Lambda,\Lambda'}(\zeta,t) = \int_{-1+\zeta}^{1} dX \left(\frac{1}{X-\zeta+i\epsilon} + \frac{1}{X-i\epsilon}\right) \times F^S_{\Lambda,\Lambda'}(X,\zeta,t), \quad (7)$$

$$\mathcal{F}^A_{\Lambda,\Lambda'}(\zeta,t) = \int_{-1+\zeta}^{1} dX \left(-\frac{1}{X-\zeta+i\epsilon} + \frac{1}{X-i\epsilon}\right) \times F^A_{\Lambda,\Lambda'}(X,\zeta,t), \quad (8)$$

$$F^S_{\Lambda,\Lambda'}(X,\zeta,t) = \frac{1}{2\overline{P}^+}\left[\overline{U}(P',\Lambda')\left(\gamma^+ H(X,\zeta,t) + \frac{i\sigma^{+\mu}(-\Delta_\mu)}{2M}E(X,\zeta,t)\right)U(P,\Lambda)\right],$$

$$F^A_{\Lambda,\Lambda'}(X,\zeta,t) = \frac{1}{2\overline{P}^+}\left[\overline{U}(P',\Lambda')\left(\gamma^+\gamma_5\widetilde{H}(X,\zeta,t) + \gamma_5\frac{-\Delta^+}{2M}\widetilde{E}(X,\zeta,t)\right)U(P,\Lambda)\right].$$

Quark correlator in the chiral odd sector

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

$$\left. + \frac{P^+\Delta^i - \Delta^+P^i}{M^2}\widetilde{H}_T(x,\xi,t) + \frac{\gamma^+P^i - P^+\gamma^i}{2M}\widetilde{E}_T(x,\xi,t)\right)U(P,\Lambda)$$

One to one relation with helicity amplitudes

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

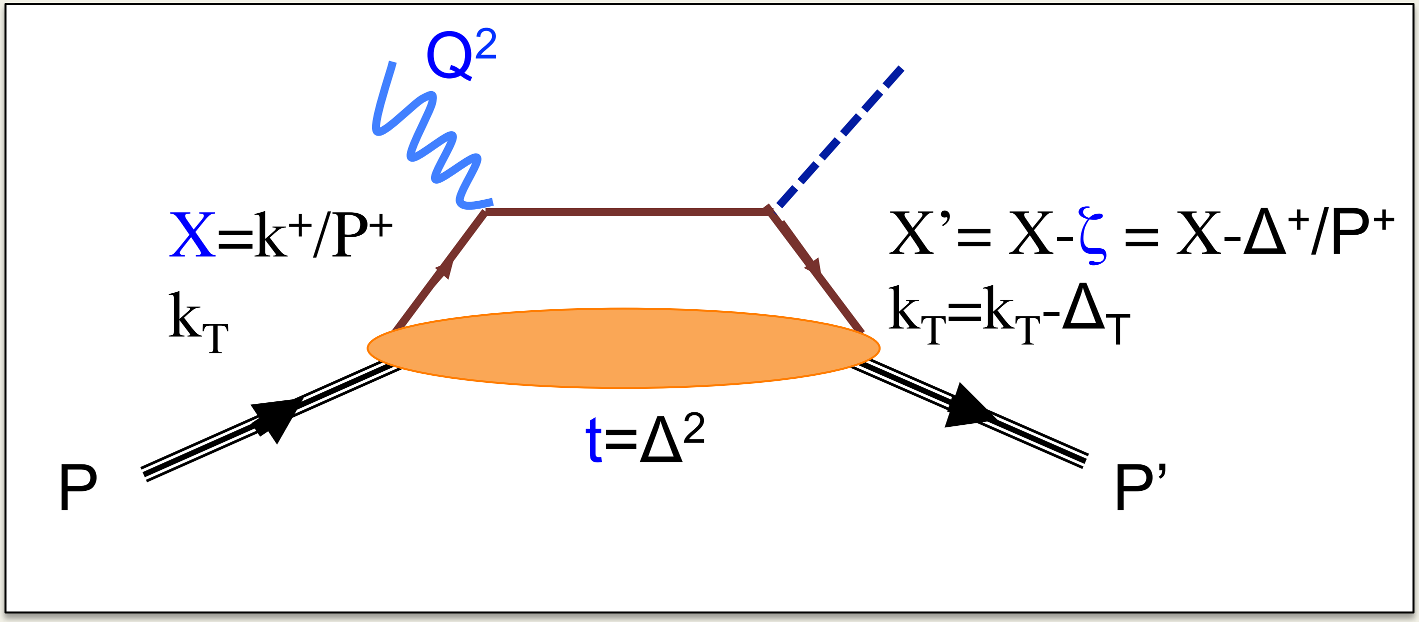
$$A_{+-,-+} = -\frac{\sqrt{1-\zeta}}{1-\zeta/2}\,\frac{t_0-t}{4M^2}\,\widetilde{H}_T$$

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

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

Summary so far:

GPDs are hybrids of PDFs and "elastic" form factors: H(X, ζ, t,Q^2)



$$W_{\Lambda\Lambda'}^{\sigma^{i+}\gamma_5} = \int \frac{d^2 z_T d^2 z^-}{(2\pi)^3} e^{ixP^+z^- - i\vec{k}_T\cdot\vec{z}_T} \langle P',\Lambda' | \bar{\psi}(0) i\sigma^{i+}\gamma_5 \psi(z) | P,\Lambda \rangle \Big|_{z^+=0}$$

non-local like PDF

$t=\Delta^2$ like form factor

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

Chiral Even

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

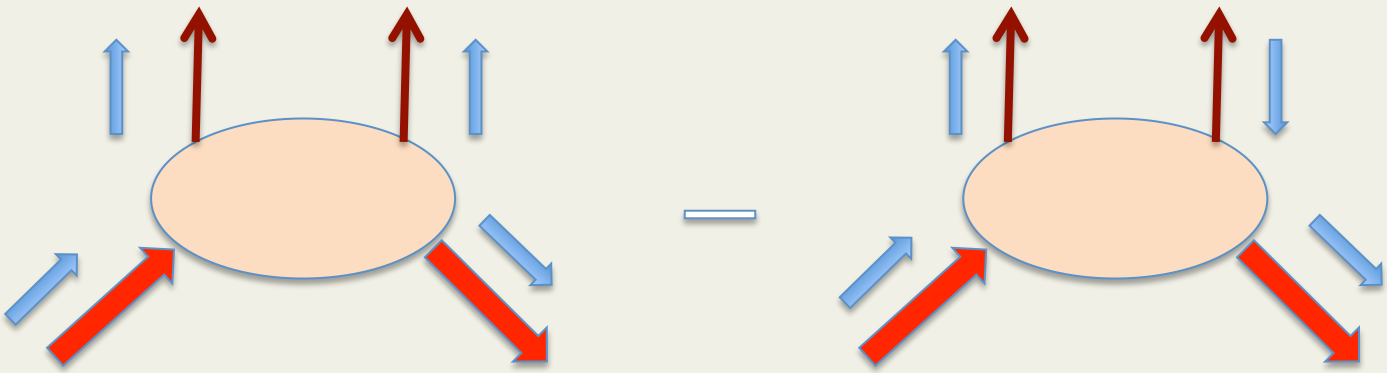
Chiral Odd

Compton Form Factors: convolutions of hard and soft parts

$$\mathcal{H}(\xi,t;Q^2) = \int dx \left[\frac{1}{x-\xi-i\varepsilon} \mp \frac{1}{x+\xi-i\varepsilon} \right] H(x,\xi,t;Q^2)$$

$$\rightarrow \left(P.V. \int dx \frac{H(x,\xi,t;Q^2)}{x-\xi} + i\pi H(\xi,\xi,t;Q^2) \right) \mp (symm.term)$$

Chiral Even Quark-Proton Helicity Amplitudes



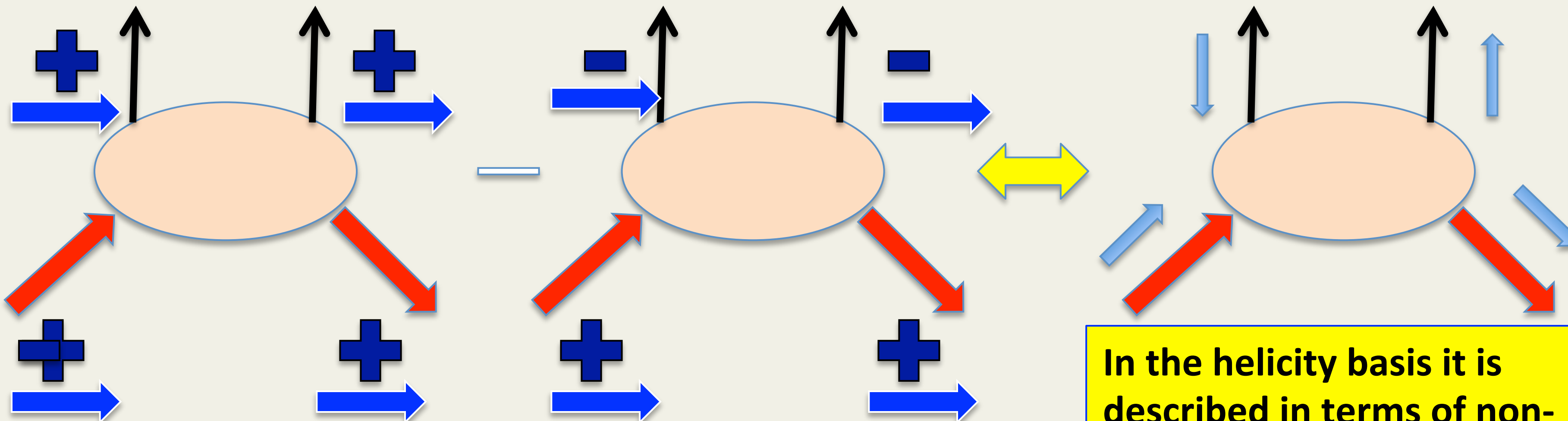
- (# quarks with momentum fraction x and spin parallel to the proton's) –
  (# quarks with the same x and spin antiparallel)

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

… take transverse polarization, or in transverse basis: $\left|\uparrow\downarrow\right\rangle_Y = \left|\rightarrow\right\rangle \pm i\left|\leftarrow\right\rangle$



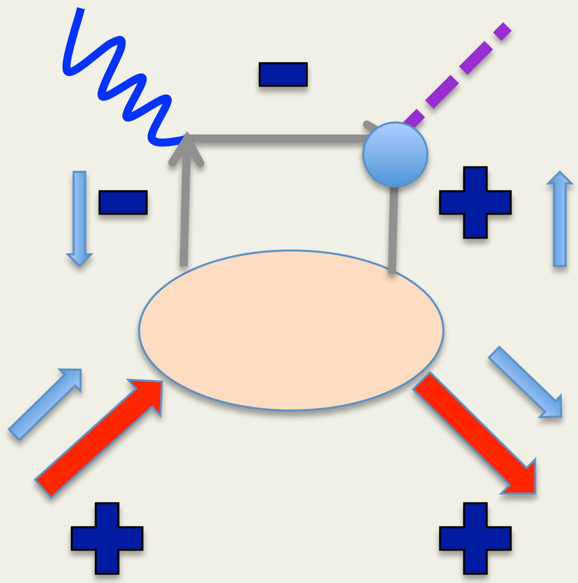
In the helicity basis it is described in terms of non-diagonal/chirally-odd quark-proton helicity amplitudes.

- #quarks with momentum fraction x and polarization parallel to the proton's –
  # number of quarks with the same x and polarization antiparallel

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

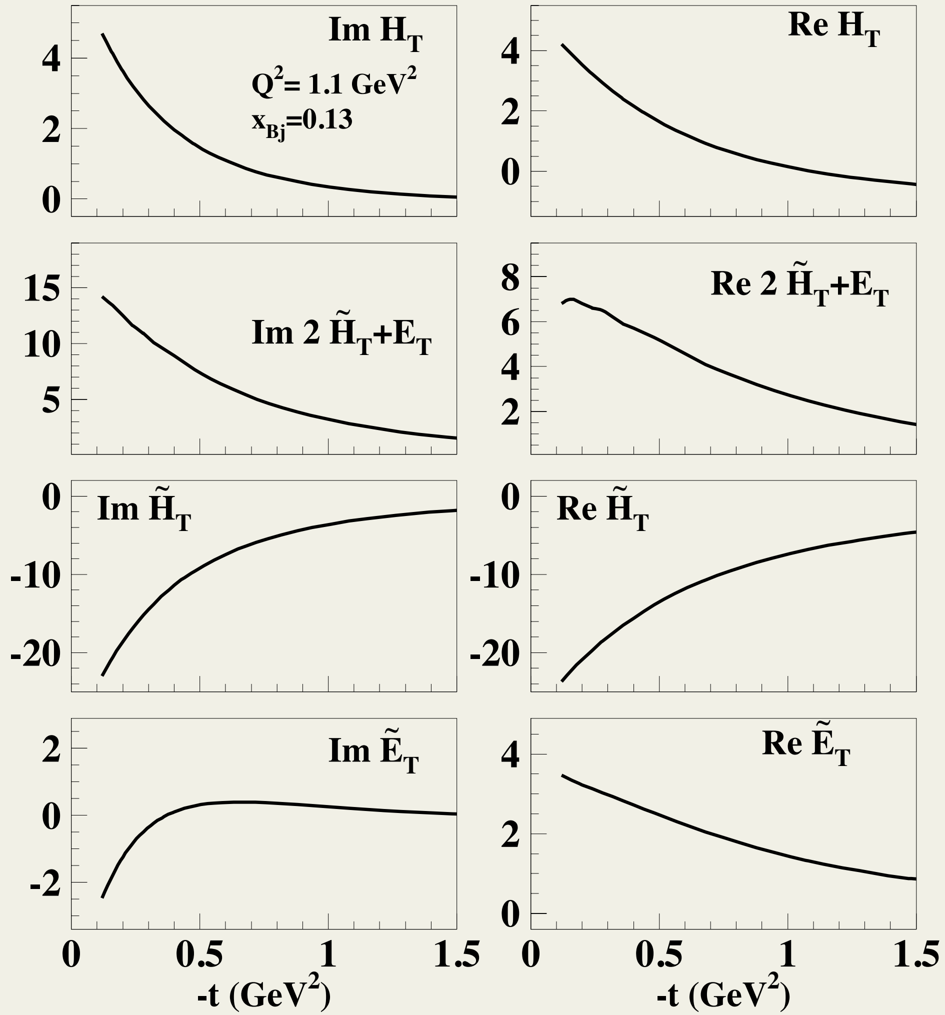
$$h_1\left(x,Q^2\right) \Rightarrow \int_0^1 dx\, h_1\left(x,Q^2\right) = \delta(Q^2)$$

For example:

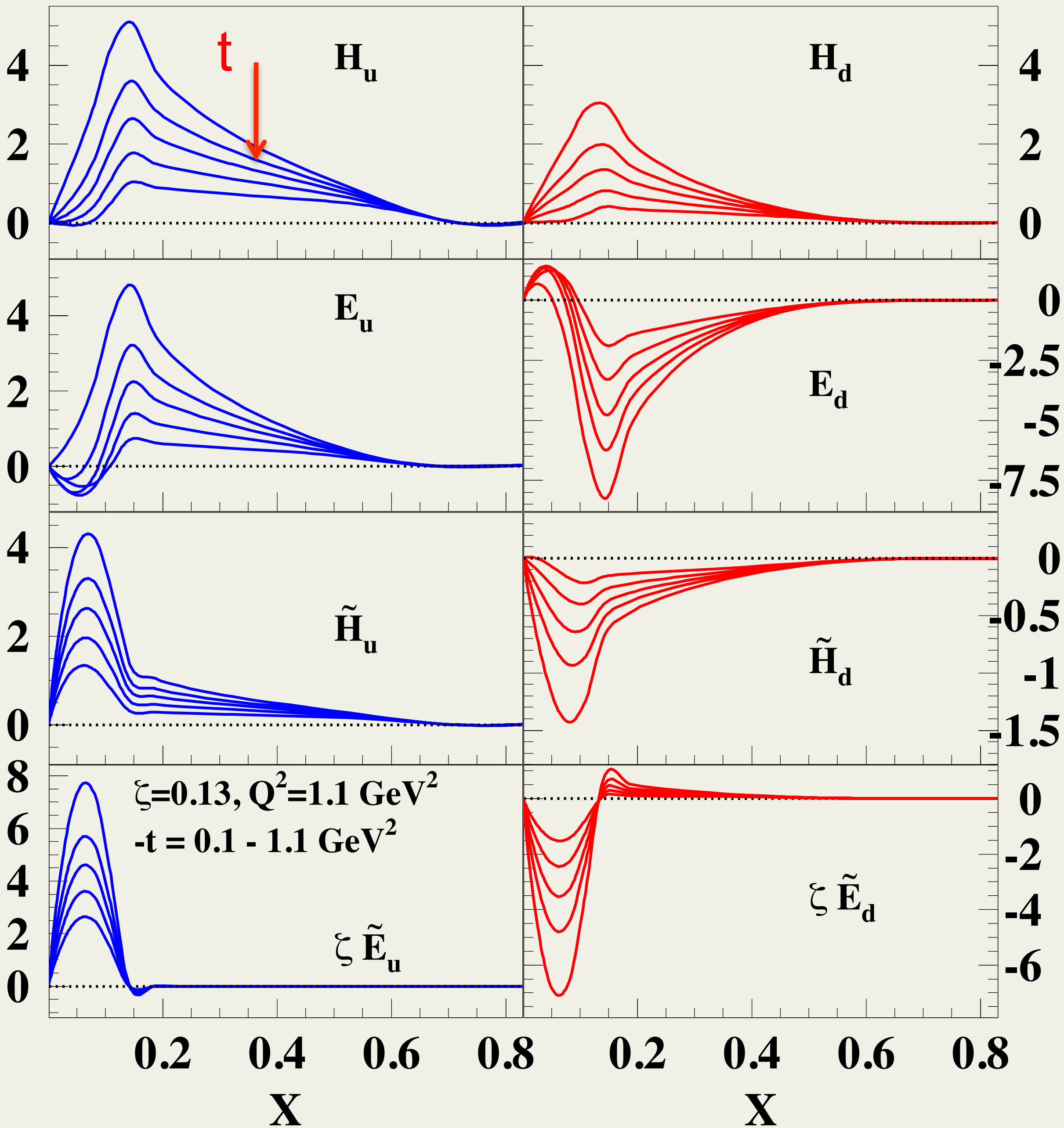


$A_{+-,++}$ $\Rightarrow$ $2\tilde{H}_T + E_T$

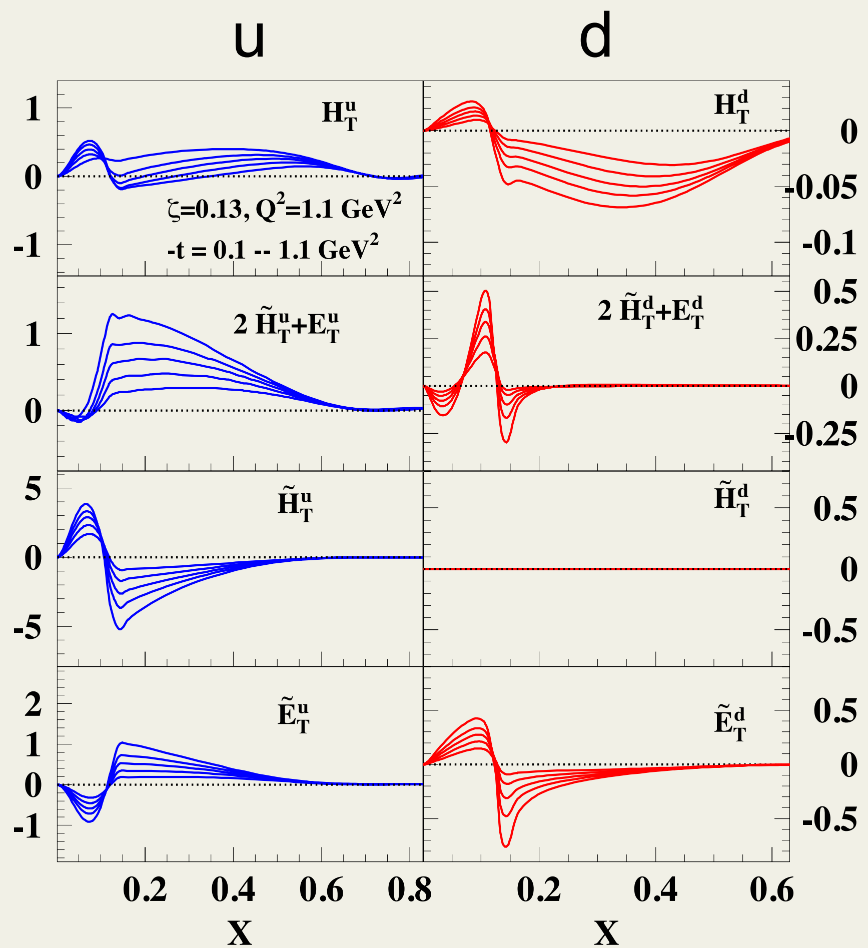
Compton form factors



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

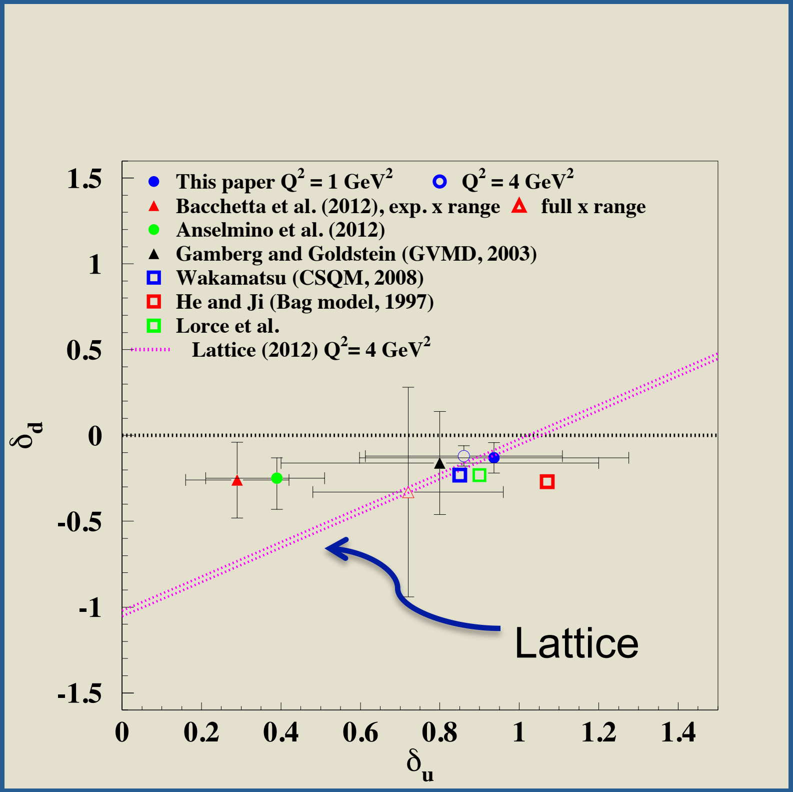
$$\int dx\, [2\tilde{H}_T^q(x,\zeta,t,Q^2) + E_T^q(x,\zeta,t,Q^2)] = \kappa_q(t,Q^2)$$

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

?

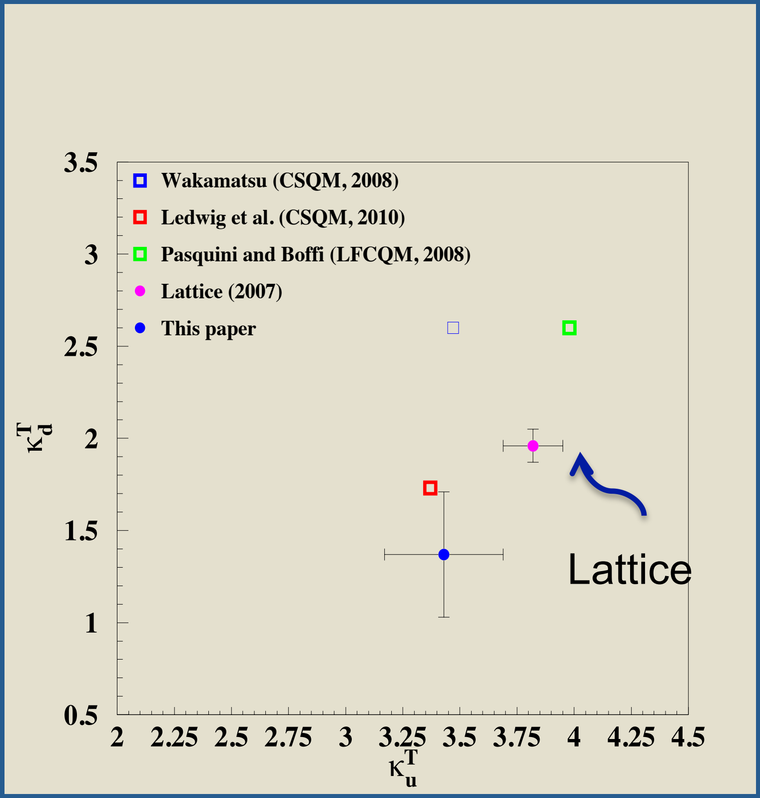
?

Flavor separated tensor charge



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)

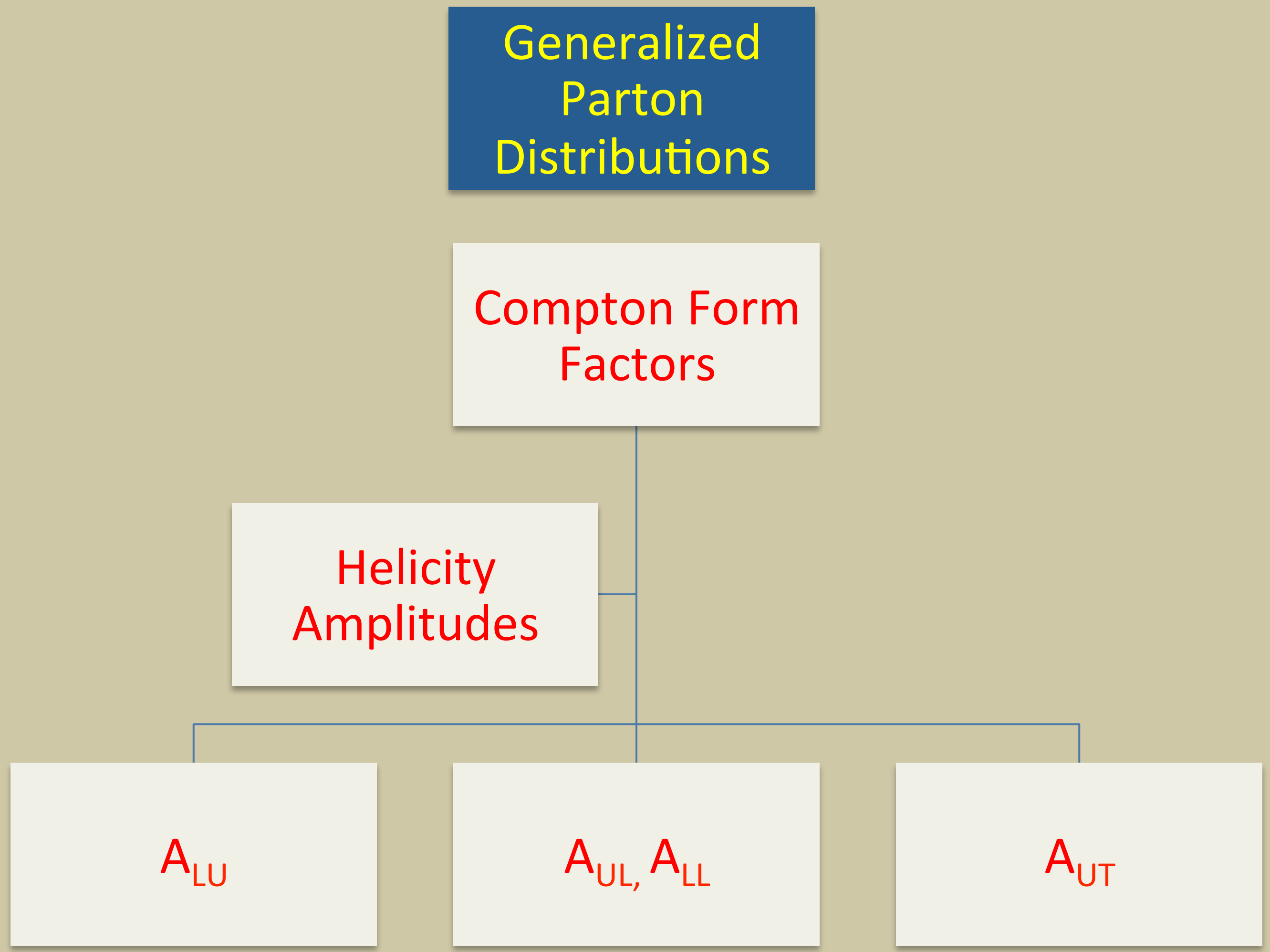
Tensor anomalous magnetic moment



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

Experiment: DVπ^{o}P, DVηP

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



Compare with DIS cross section

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{4\pi\alpha}{2xQ^4}\left[\left(1+(1-y)^2\right)F_2(x,Q^2) - y^2 F_L(x,Q^2)\right]$$

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

GPDs in helicity amplitudes

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

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

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

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

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

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

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

$$+ S_{\perp}\Big[\sin(\phi-\phi_S)\Big(F_{UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\Big) + \epsilon\Big(\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)} + \sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)}\Big)$$

$$+ \sqrt{2\epsilon(1+\epsilon)}\Big(\sin\phi_S F_{UT}^{\sin\phi_S} + \sin(2\phi-\phi_S)F_{UT}^{\sin(2\phi-\phi_S)}\Big)\Big]$$

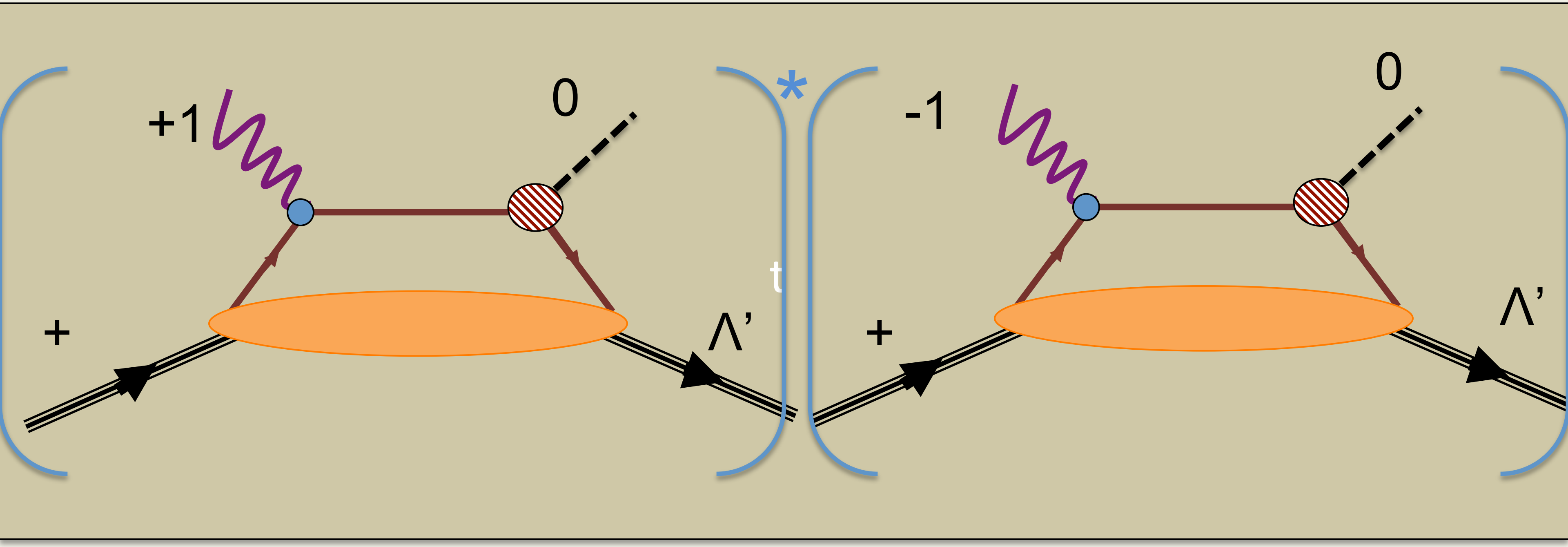
$$+ S_{\perp}h\Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\,\Big(\cos\phi_S F_{LT}^{\cos\phi_S} + \cos(2\phi-\phi_S)F_{LT}^{\cos(2\phi-\phi_S)}\Big)\Big]\Big\}$$

$$A_{LU} = \sqrt{\epsilon(1-\epsilon)}\,\frac{F_{LU}^{\sin\phi}}{F_{UU,T} + \epsilon F_{UU,L}}$$

$$A_{UL} = \frac{N_{s_z=+} - N_{s_z=-}}{N_{s_z=+} + N_{s_z=-}} = \frac{\sqrt{\epsilon(\epsilon+1)}\sin\phi F_{UL}^{\sin\phi}}{F_{UU,T} + \epsilon\, F_{UU,L}} + \frac{\epsilon\sin 2\phi F_{UL}^{\sin 2\phi}}{F_{UU,T} + \epsilon\, F_{UU,L}}$$

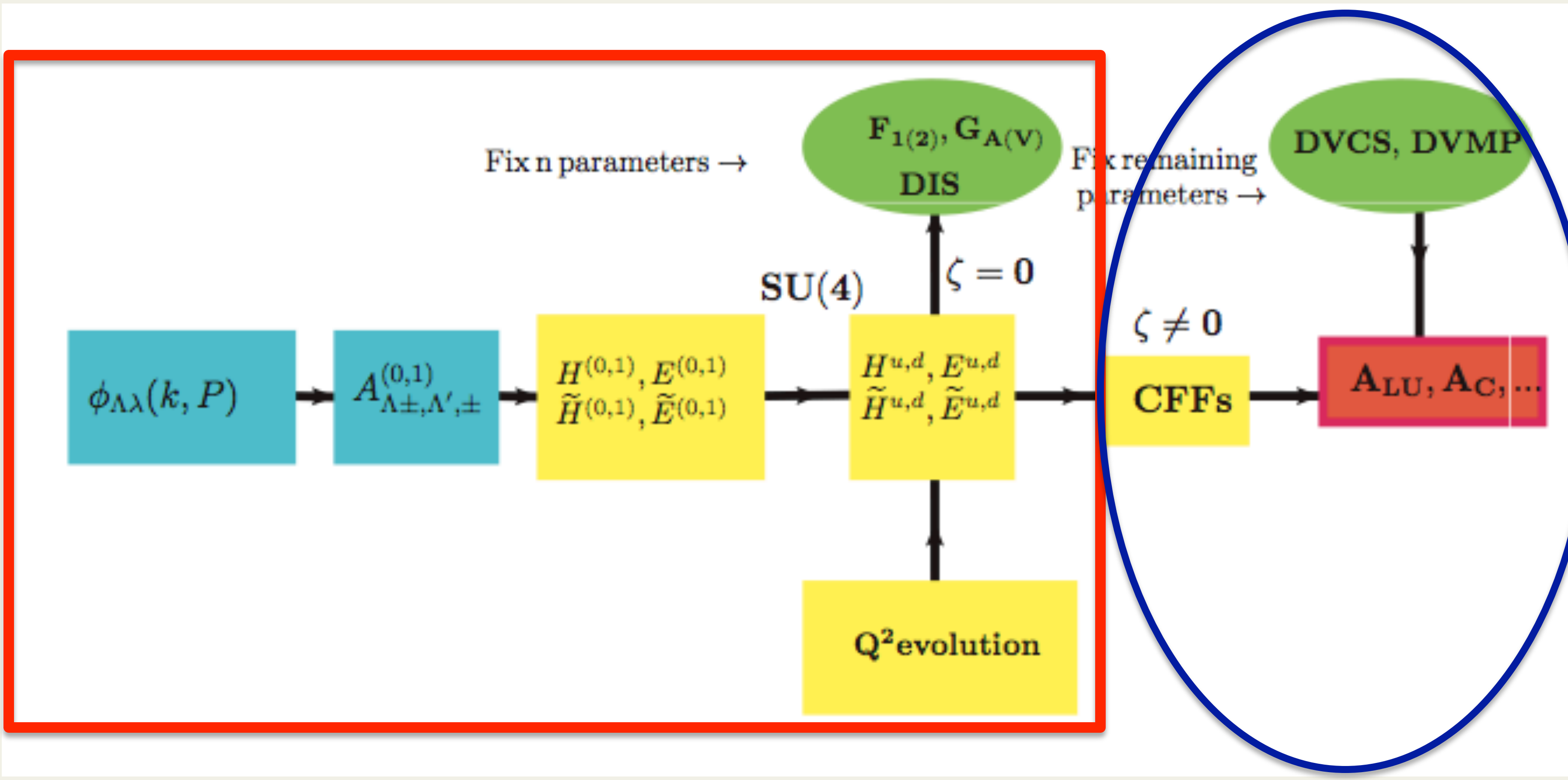
$$A_{LL} = \frac{N^{\rightarrow}_{s_z=+} - N^{\rightarrow}_{s_z=-} + N^{\leftarrow}_{s_z=+} - N^{\leftarrow}_{s_z=-}}{N_{s_z=+} + N_{s_z=-}} = \frac{\sqrt{1-\epsilon^2}\;F_{LL}}{F_{UU,T} + \epsilon F_{UU,L}} + \frac{\sqrt{\epsilon(1-\epsilon)}\;\cos\phi\,F_{LL}^{\cos\phi}}{F_{UU,T} + \epsilon F_{UU,L}}$$

General form of structure function of a chiral odd term:

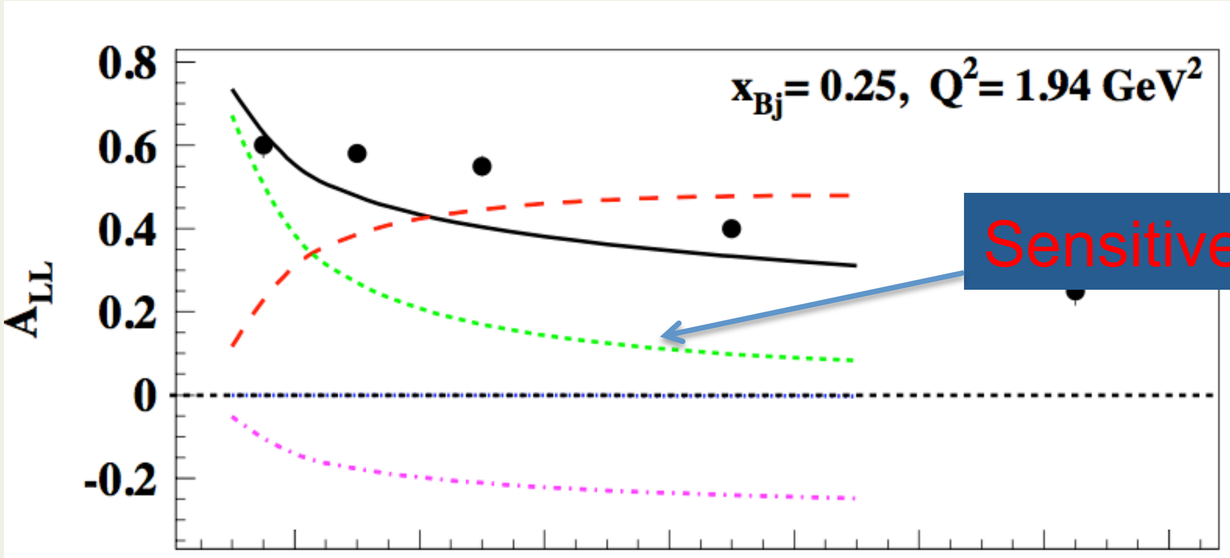


helicity amplitudes

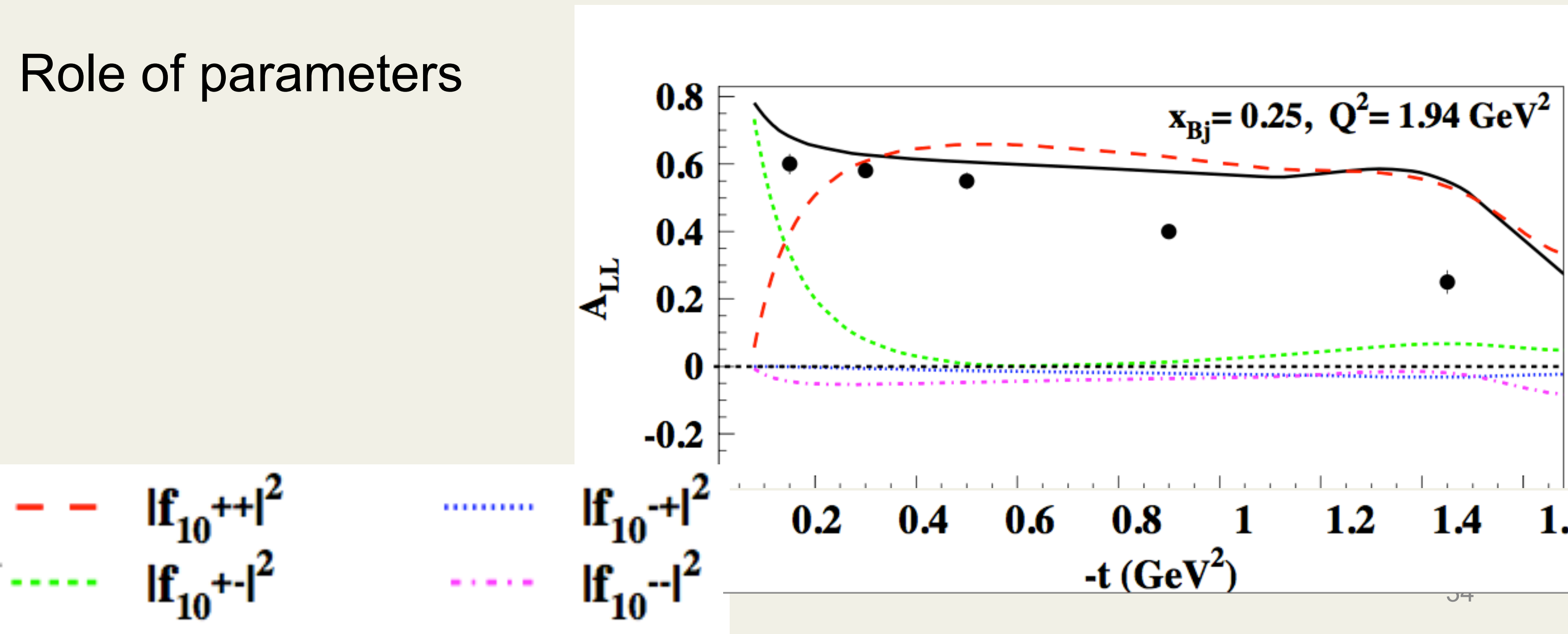
$$F^{++}_{1,-1} = \sum_{\Lambda'} \left(f^{+\Lambda'}_{10}\right)^{*} \left(f^{+\Lambda'}_{-10}\right)$$


$\mathbf{F_{1(2)}, G_{A(V)}}$
DIS
Fix n parameters →
Fix remaining parameters →
DVCS, DVMP
SU(4)
$\zeta = 0$
$\zeta \neq 0$
$\phi_{\Lambda\lambda}(k, P)$
$A^{(0,1)}_{\Lambda\pm,\Lambda',\pm}$
$H^{(0,1)}, E^{(0,1)}$
$\widetilde{H}^{(0,1)}, \widetilde{E}^{(0,1)}$
$H^{u,d}, E^{u,d}$
$\widetilde{H}^{u,d}, \widetilde{E}^{u,d}$
CFFs
$\mathbf{A_{LU}, A_C, ...}$
$\mathbf{Q^2}$evolution

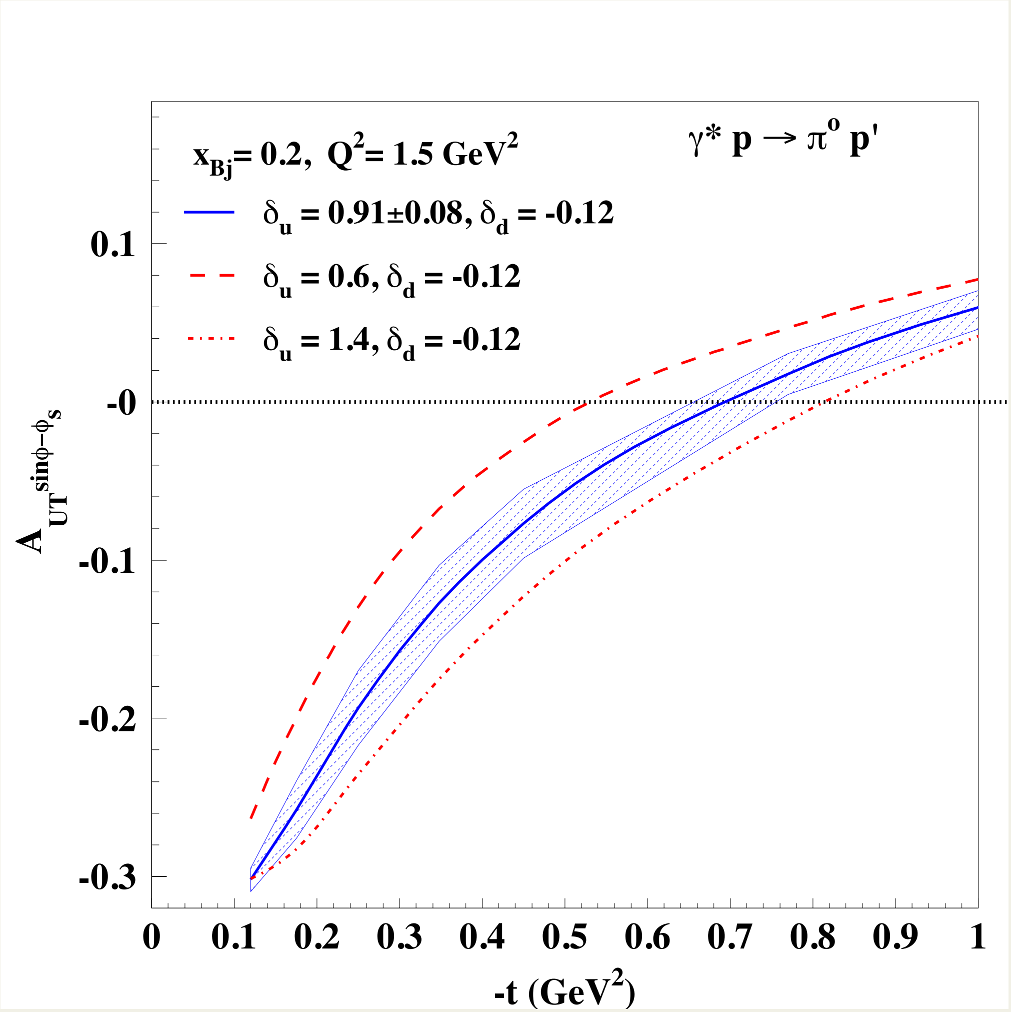
Andrey Kim, Harut Avakian et al., Jefferson Lab CLAS Collaboration



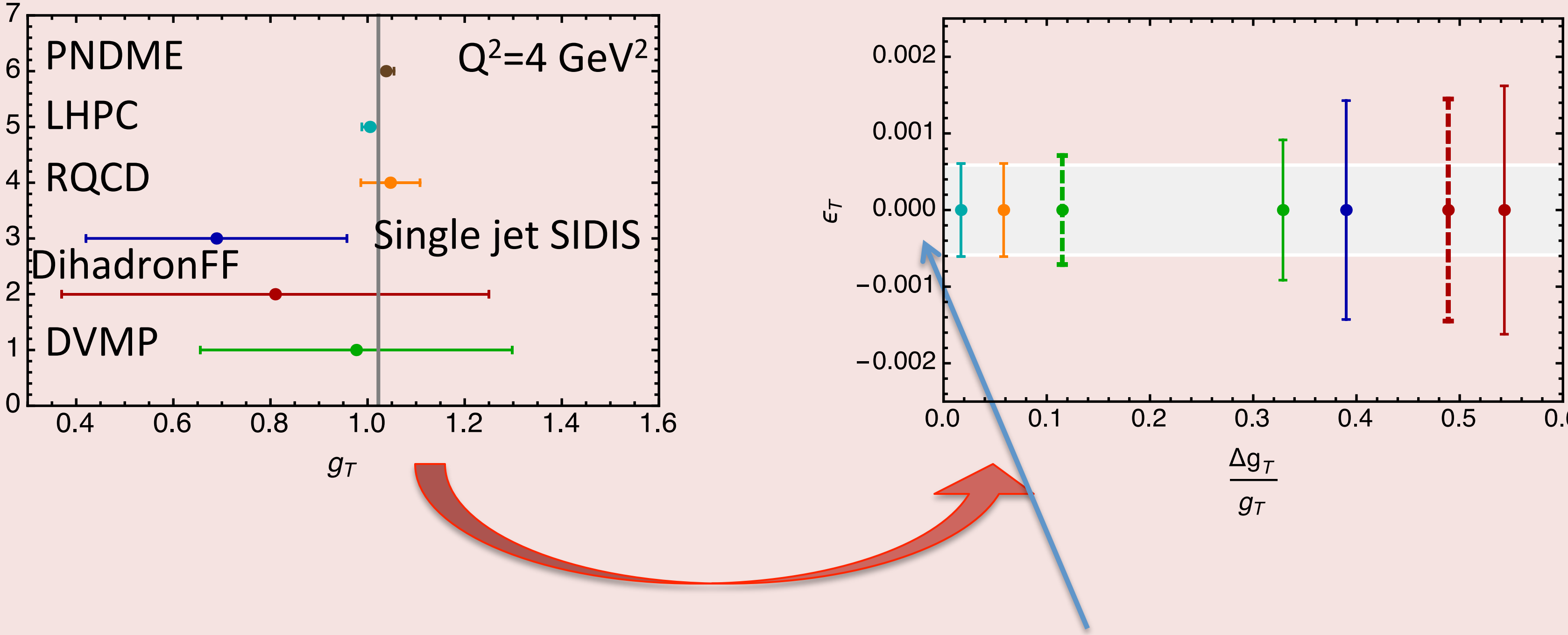
Role of parameters



Projections for transverse polarized target



Impact on BSM searches…



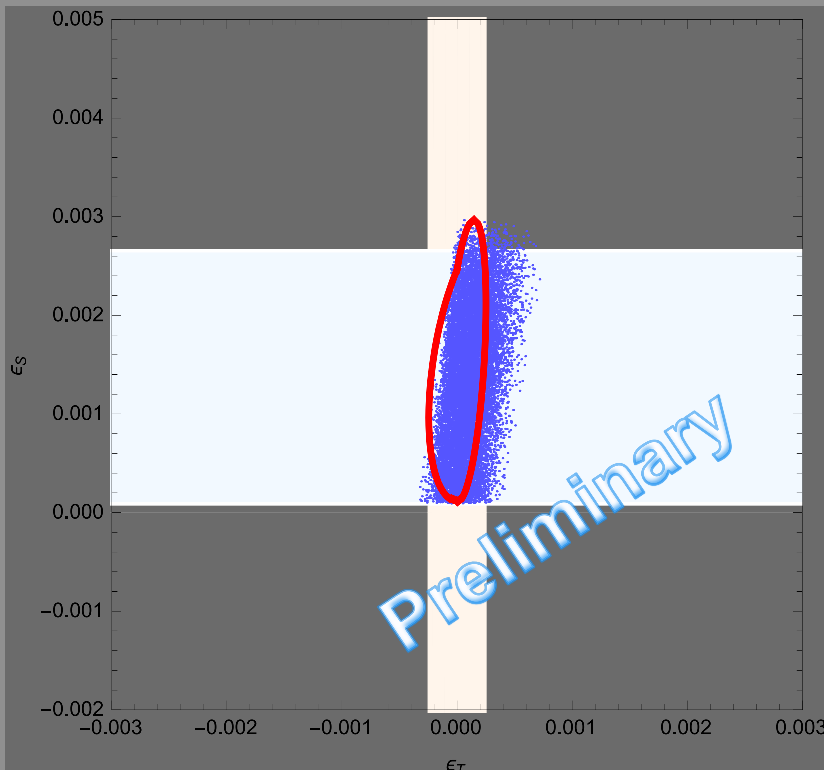
$|\varepsilon_T \, g_T| < 6.4 \times 10^{-4}$

Pattie et al, PRC88 (2013)

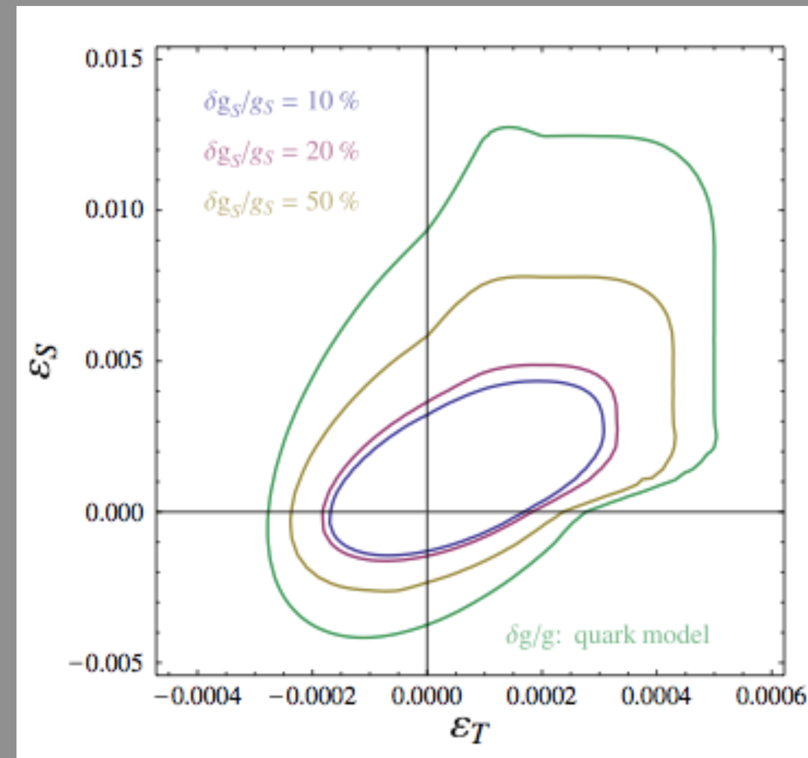
A. Courtoy, S.Baessler, M. Gonzalez-Alonso, S.L, arXiv:1503.06814

Combined 90% confidence level in ε_S-ε_T plane

ε_S



ε_T



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

Bhattacharya et al., PRD85 (2012)

Future developments

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

Study the additional currents

- Potential impact in axial vector sector studied by S. Gardner and B.Plaster, PRC87(2013)

- Coonection with new chiral-odd GPDs

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).

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.

sl4y@virginia.edu

Back up