BSM Tensor Interaction and Hadron Phenomenology

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QCD and Beyond Standard Model Physics

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

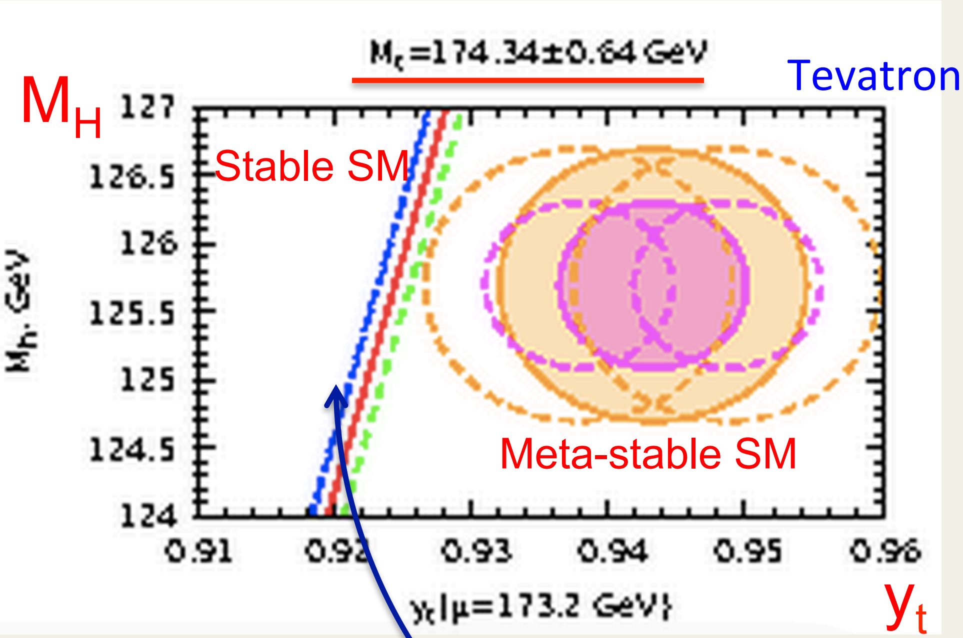
An era of *rising new questions*, *challenges* triggering future developments for strong-interaction physics/QCD after the discovery of the Higgs boson at the LHC.

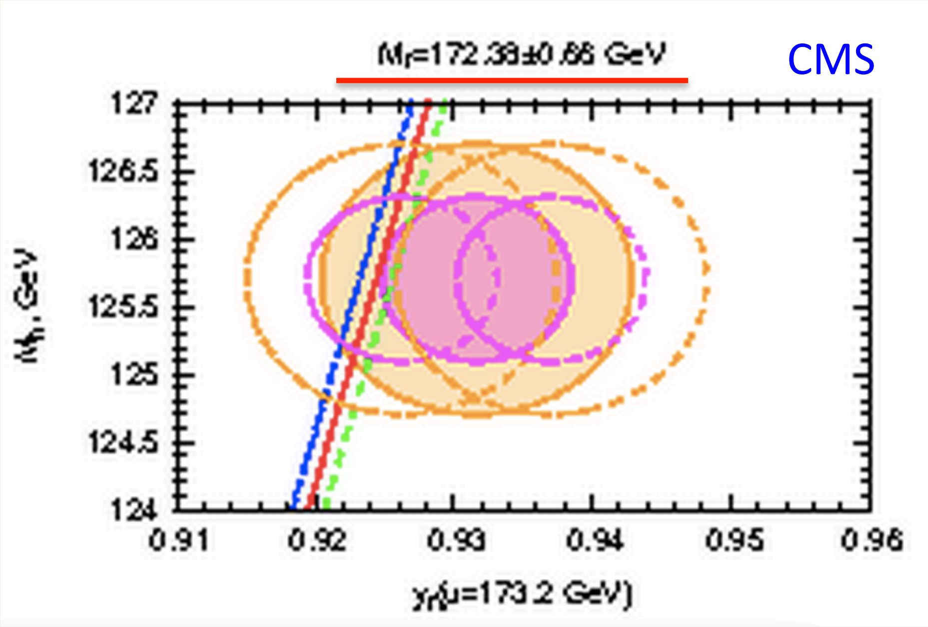
1. The fine structure constant α (1)
2. The Weinberg angle or weak mixing angle θ_W (2)
3. The strong interaction coupling constant α_S (3)
4. The electroweak symmetry breaking energy scale (or the Higgs potential vacuum expectation value, v.e.v.) v (4)
5. The Higgs potential coupling constant λ /the 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)

Outstanding questions

How do the quarks couple to the Higgs boson (what are their Yukawa couplings)?

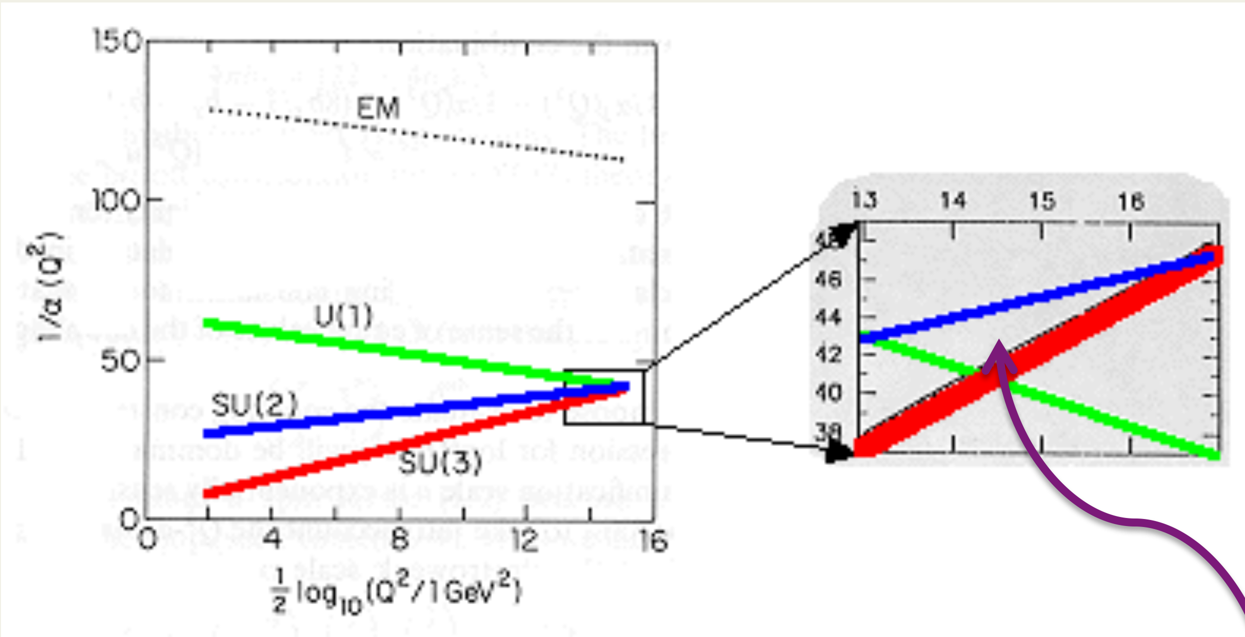
Bezrukov et al - arXiv:1411.1923





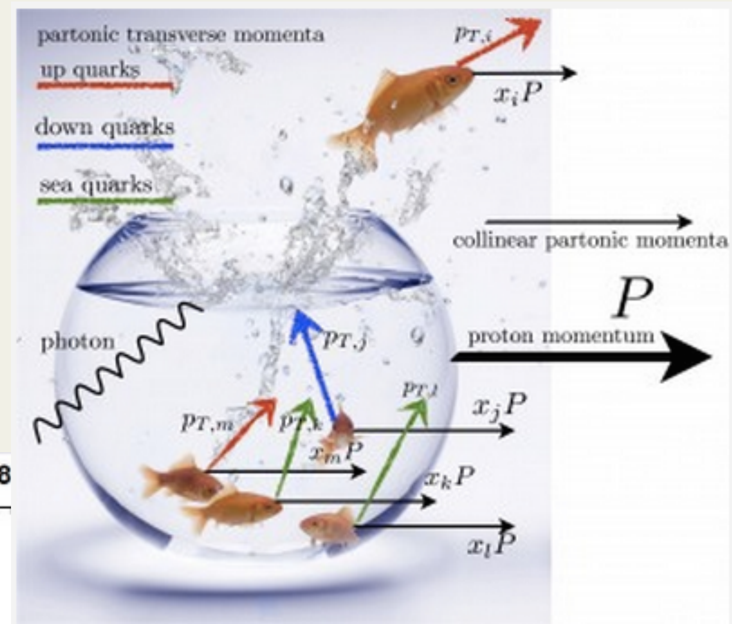
uncertainty in α_s

Does α_S unify with the other gauge couplings?

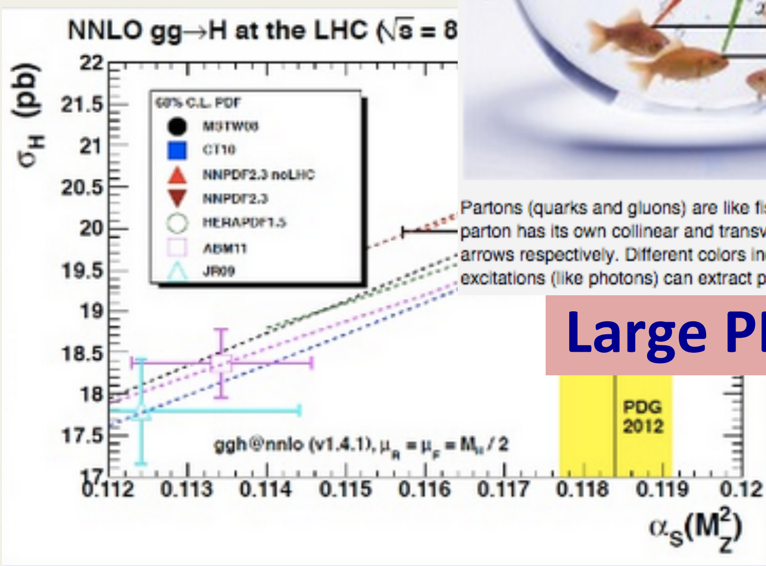


uncertainty on $1/\alpha_S$ determines the size of "triangle"=violation of unification

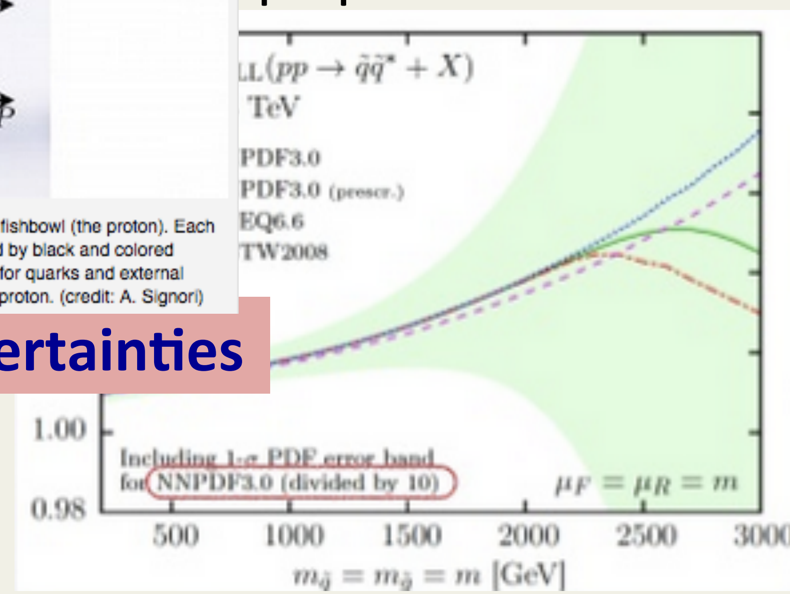
What are the quark and gluon distributions at very high energies?



Partons (quarks and gluons) are like fishes confined inside a fishbowl (the proton). Each parton has its own collinear and transverse velocity, indicated by black and colored arrows respectively. Different colors indicate different flavors for quarks and external excitations (like photons) can extract partons from inside the proton. (credit: A. Signori)



…k pair production



Large PDF uncertainties

Intensity frontier

✓ QCD affects also the low-energy regime in the indirect search for BSM physics:

1. CP violation in *B* 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

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

High Energy:

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

$pp \longrightarrow H + jet + X$

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

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

sensitive to linearly polarized gluons TMDs

Low Energy:

✓ Possible BSM tensor, scalar and pseudo-scalar contributions to neutron beta decay are constrained by polarized hard scattering processes

A.~Courtoy, S.~Baessler, M.~Gonzalez-Alonso and S.~Liuti, arXiv:1503.06814 [hep-ph].

Measurable at Jlab @12 GeV and at Electron Ion Collider, EIC

Neutron and pion beta decay…

- ✓ Neutron and pion beta decay can be used to investigate the existence of non-SM interactions:

$$1, \gamma_5, (\gamma_\mu + \gamma_\mu \gamma_5), \boxed{i\sigma^{j+}\gamma_5}$$

- ✓ Experiments using cold and ultra-cold neutrons [1–4], nuclei [5–8], and meson rare decays [9] can detect BSM deviations at the per-mil level or even higher precision.

- ✓ Effective field theory (EFT) allows one to connect low energy measurements and BSM effects generated at the TeV scale and beyond.

- ✓ The strength of the new interactions defined with respect to the strength of the known SM interaction is,

$$\mathrm{BSM}/\mathrm{SM} \approx (1/\Lambda^2_{\mathrm{BSM}}) \,/\, (1/m_W^2)$$

- ✓ The precision at which BSM elementary coupling is known determines a lower limit on the scale Λ_{BSM} where these effects can appear.

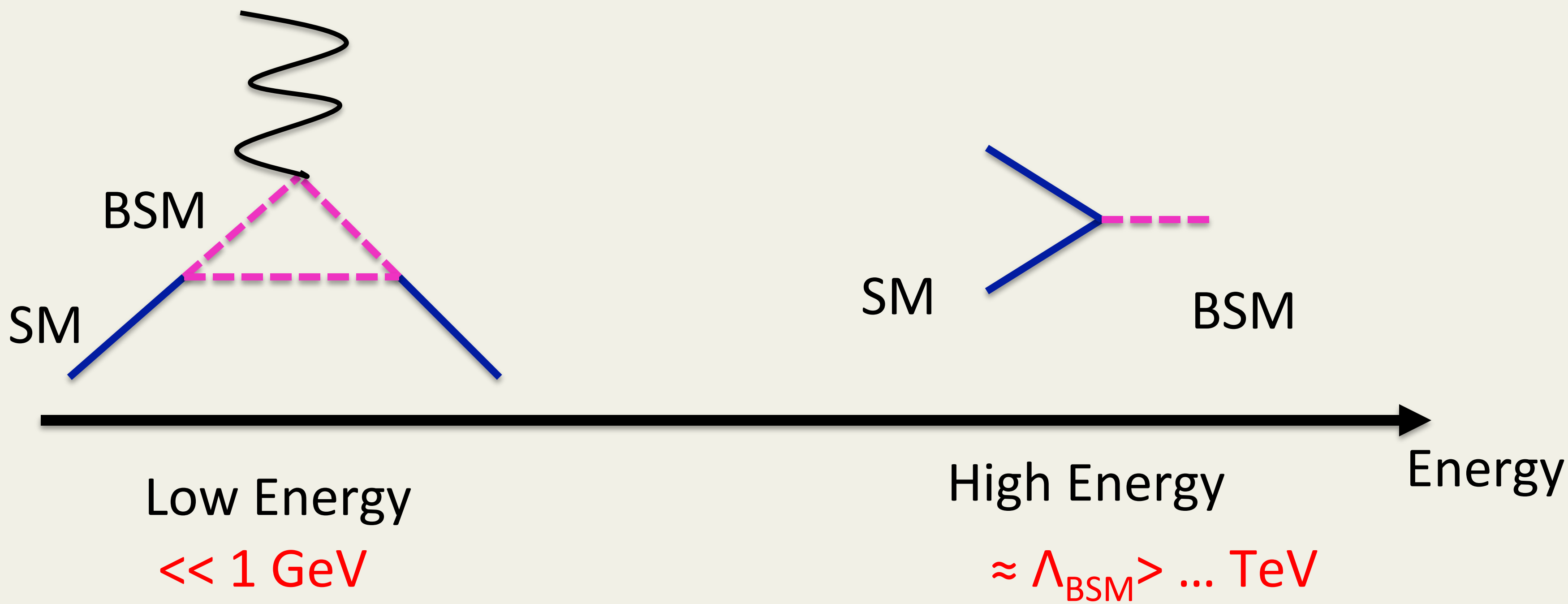
List of Experiments

1] H. Abele, Prog.Part.Nucl.Phys. 60, 1 (2008).
[2] J. S. Nico, J.Phys. G36, 104001 (2009).
[3] A. Young, S. Clayton, B. Filippone, P. Geltenbort, T. Ito,
et al., J.Phys. G41, 114007 (2014).
[4] S. Baessler, J. Bowman, S. Penttila, and D. Pocanic,
J.Phys. G41, 114003 (2014).
[5] O.Naviliat-CuncicandM.Gonza ́lez-Alonso,Annalen
Phys. 525, 600 (2013), 1304.1759.
[6] N. Severijns, J.Phys. G41, 114006 (2014).
[7] J. Hardy and I. Towner, J.Phys. G41, 114004 (2014),
1312.3587.
[8] J. Behr and A. Gorelov, J.Phys. G41, 114005 (2014).
[9] D. Pocanic, E. Frlez, and A. van der Schaaf, J.Phys. G41,
114002 (2014), 1407.2865.

Neutron beta decay vs. collider experiments

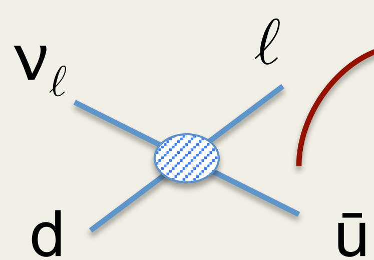
BSM particles appear in loops

BSM particles are produced directly



To describe low energy part here we use the BSM Effective Lagrangian from Cirigliano et al.

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



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

List of all possible couplings between quark fields

Vector $\bar{u}\gamma^{\mu}u$

Axial-Vector $\bar{u}\gamma^{\mu}\gamma^{5}u$

Pseudoscalar $\bar{u}\gamma^{5}u$

chiral-even

Scalar $\bar{u}u$

Tensor $\bar{u}\sigma^{\mu\nu}u$

chiral-odd

Differential decay distribution for polarized neutron decay

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

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

Bhattacharya et al., PRD85 (2012)

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

Fierz term

These terms can contain tensor corrections

A more specific look…

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

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

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

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

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

… or by using isospin symmetry:

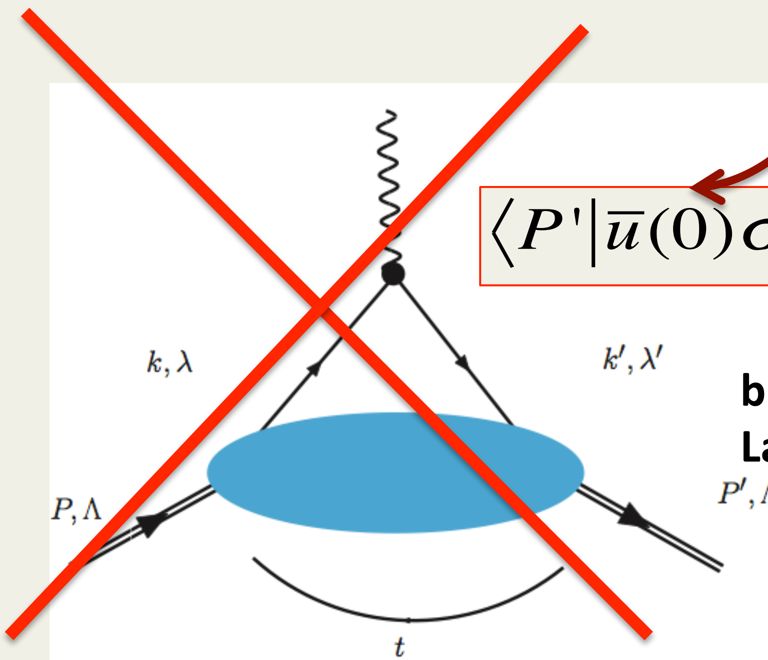
$$\begin{aligned}
\langle p_p, S_p | \bar{u}d | p_n, S_n\rangle &= g_S(-t)\,\overline{U}(p_p, S_p)U(p_n, S_n) \quad ,\\
\langle p_p, S_p | \bar{u}\sigma_{\mu\nu}d | p_n, S_n\rangle &= g_T(-t)\,\overline{U}(p_p, S_p)\sigma_{\mu\nu}U(p_n, S_n),
\end{aligned}$$

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

- 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



chiral-odd

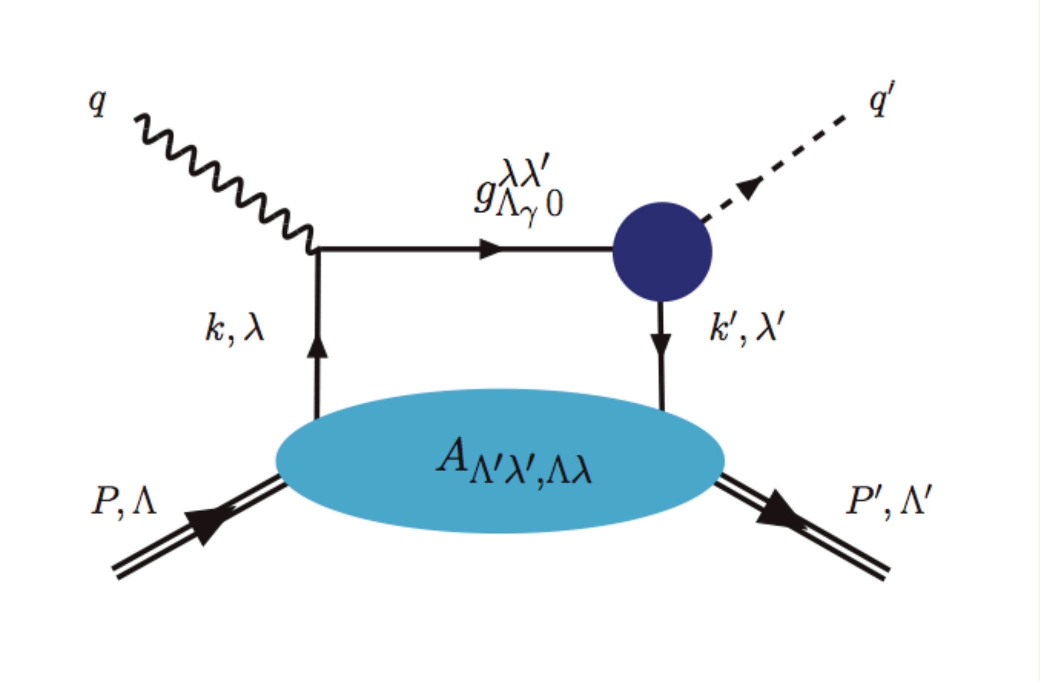
$$\boxed{\langle P' | \bar{u}(0)\sigma_{\mu\nu}\, u(0) | P\rangle}$$

but it can be calculated in Lattice QCD!

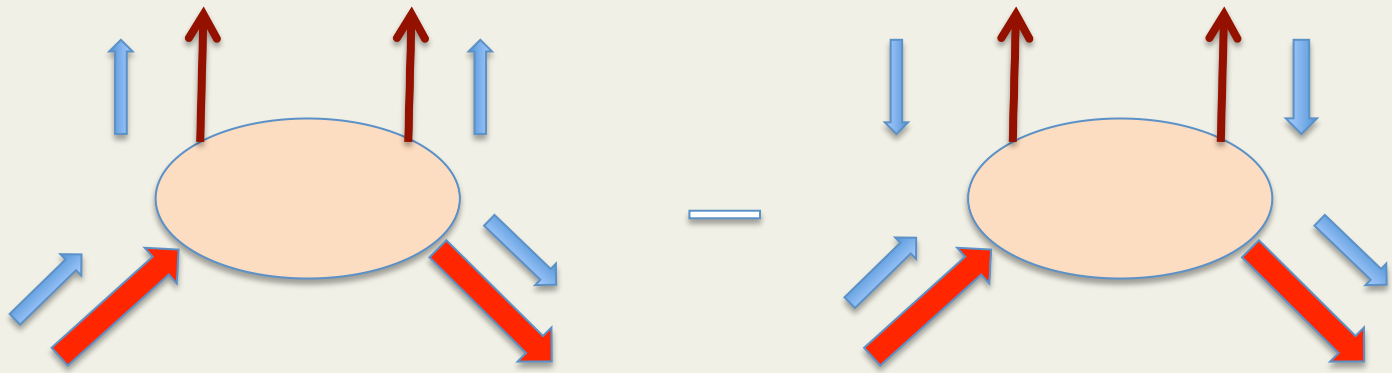
To access the tensor charge, we need more d.o.f.

Take non-local matrix elements like the ones probed in DIS type experiments

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



Chiral Even Quark-Proton Helicity Amplitudes



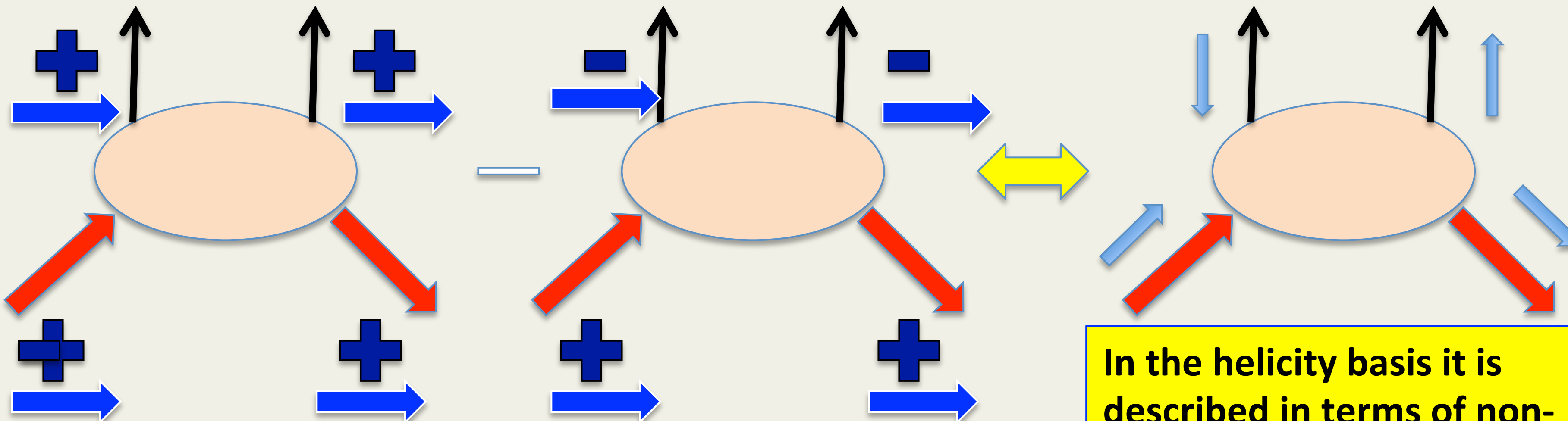
- (# quarks with momentum fraction x and spin parallel to the proton's) –
(# quarks with the same x and spin antiparallel)

Net helicity of a quark in a longitudinally polarized proton:

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

Chiral Odd Quark-Proton Helicity Amplitudes

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



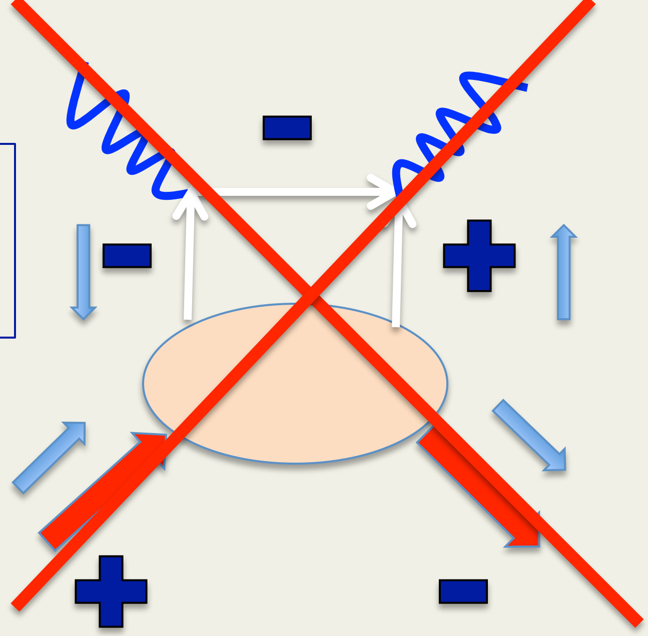
In the helicity basis it is described in terms of non-diagonal/chirally-odd quark-proton helicity amplitudes.

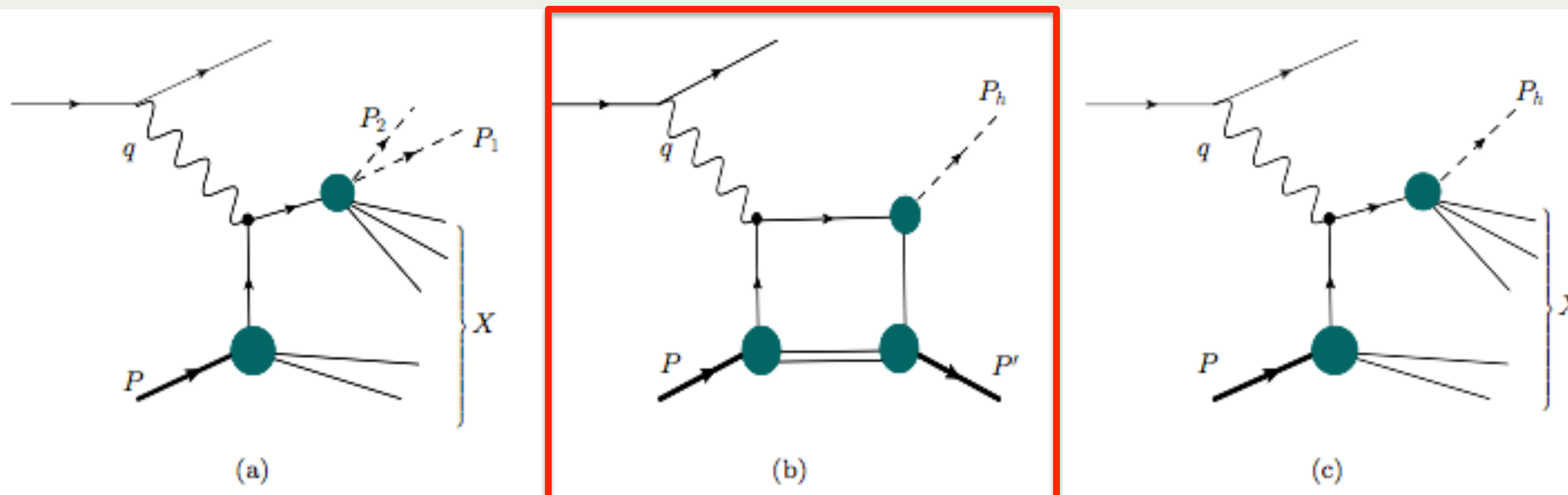
- #quarks with momentum fraction x and polarization parallel to the proton's – # number of quarks with the same x and polarization antiparallel

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

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

To detect chiral odd distributions we need another distinct hadronic blob





dihadron

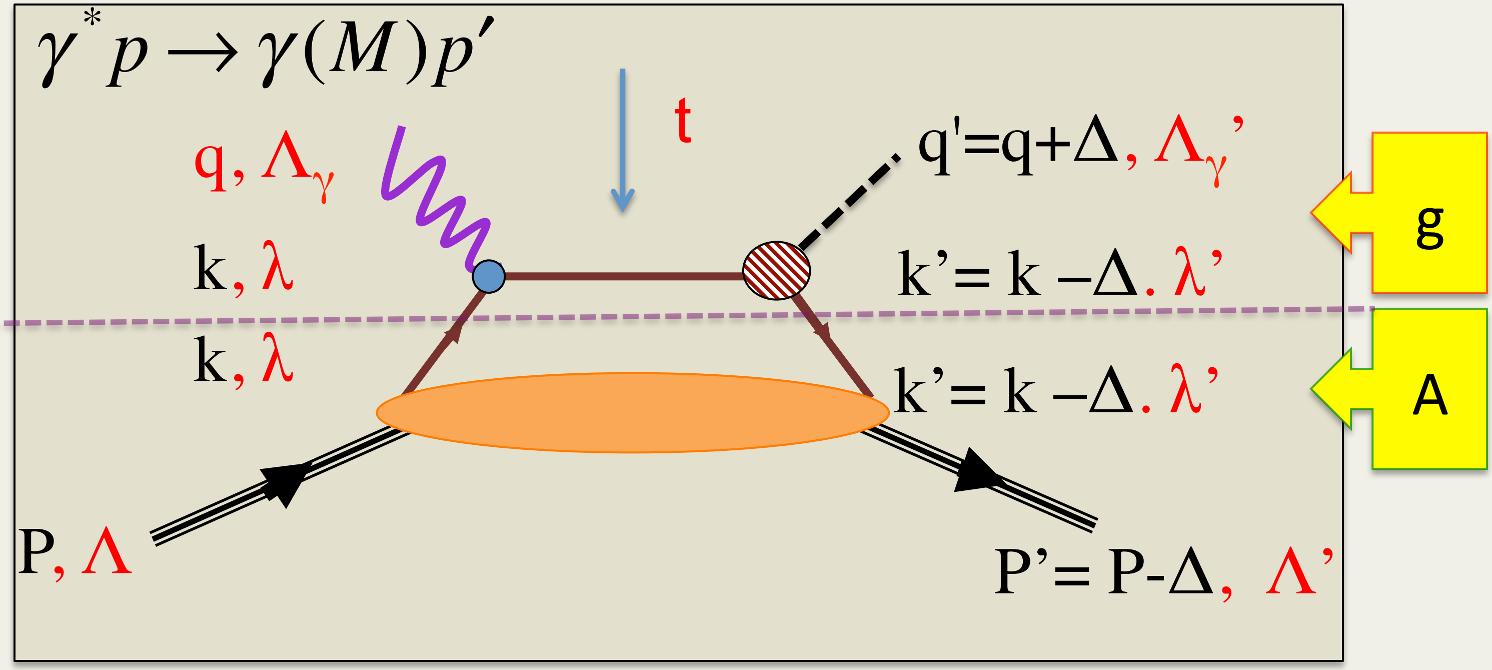
DVπ°P, DVηP

SIDIS

Dihadron

collinear

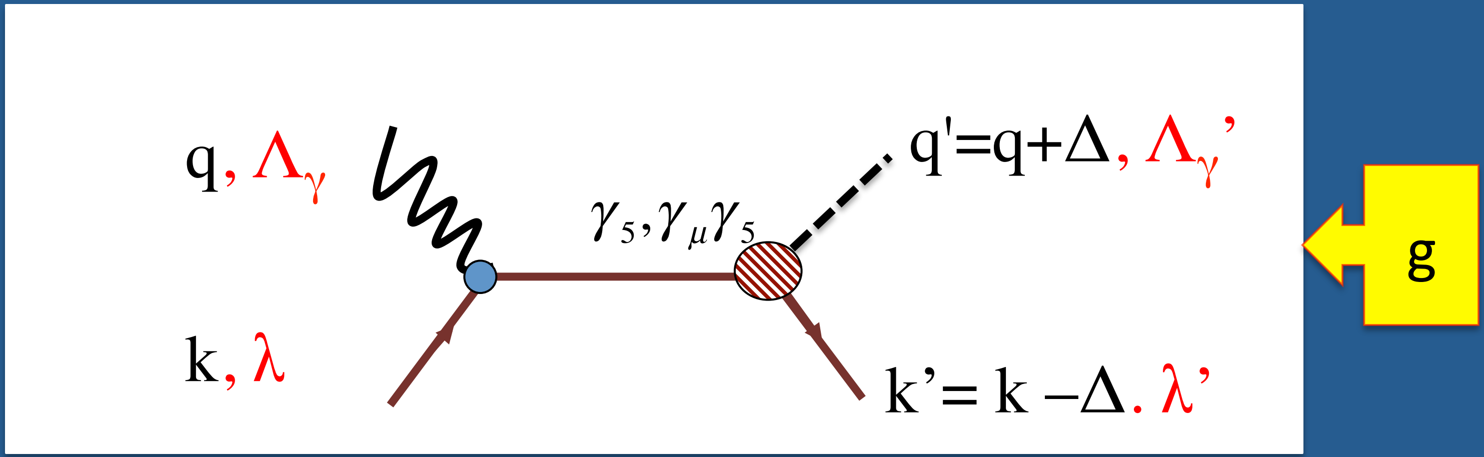
Factorization in deeply virtual exclusive processes: e p ➔ e' p' π^o



Convolution of "hard part" with quark-proton amplitudes

$$f_{\Lambda_\gamma,\Lambda;\Lambda'_\gamma,\Lambda'} = \sum_{\lambda,\lambda'} \boxed{g_{\lambda,\lambda'}^{\Lambda_\gamma,\Lambda'_{\gamma(M)}}(x,k_T,\zeta,t;Q^2)} \otimes \boxed{A_{\Lambda',\lambda';\Lambda,\lambda}(x,k_T,\zeta,t),}$$

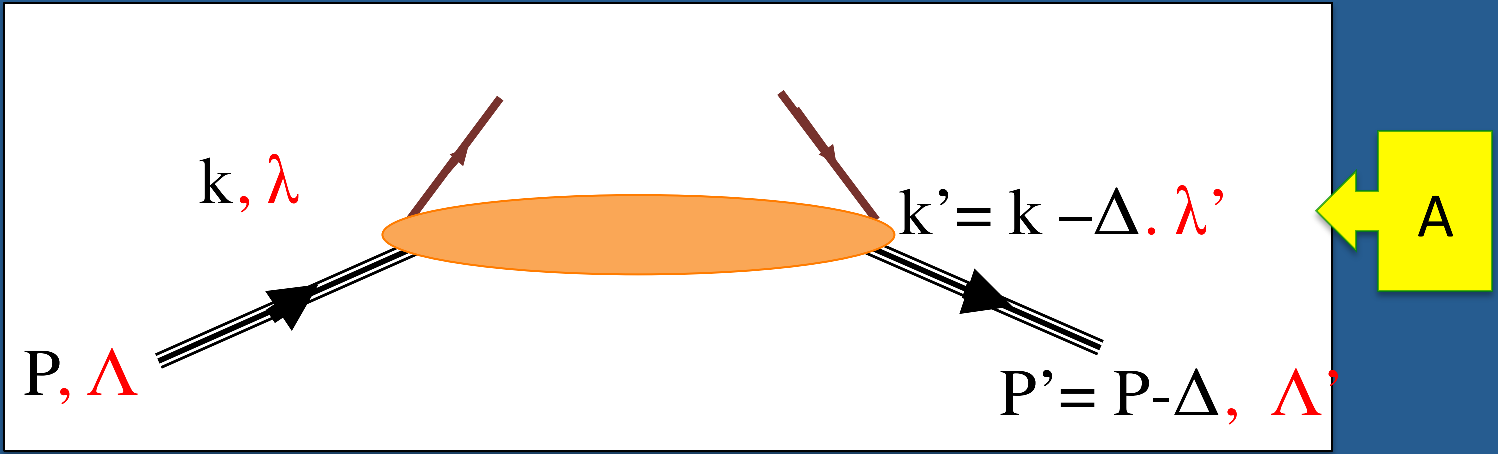
The type of amplitudes will depend on whether one has a chiral odd or even coupling



$$g_{\Lambda_\gamma 0}^{\lambda\lambda' \, (odd)} = \boxed{g_\pi^{V(A),odd}(Q^2)}\, q^- \left[\bar{u}(k',\lambda')\gamma^\mu\gamma^+\gamma_5 u(k,\lambda)\right] \epsilon_\mu^{\Lambda_\gamma} \left(\frac{1}{\hat{s}-i\epsilon} - \frac{1}{\hat{u}-i\epsilon}\right)$$

$$g_{\Lambda_\gamma 0}^{\lambda\lambda \, (even)} = \boxed{g_\pi^{even}(Q^2)}\, e_q\, q^- \left[\bar{u}(k',\lambda)\gamma^\mu\gamma^+\gamma^\nu\gamma_5 u(k,\lambda)\right] \times \epsilon_\mu^{\Lambda_\gamma}\, q'_\nu \left(\frac{1}{\hat{s}-i\epsilon} + \frac{1}{\hat{u}-i\epsilon}\right)$$

Quark-proton helicity amplitudes



$$
\begin{aligned}
f_{10}^{++} &= g_{10}^{+-} \otimes A_{+-,++} \\
f_{10}^{+-} &= g_{10}^{+-} \otimes A_{--,++} \\
f_{10}^{-+} &= g_{10}^{+-} \otimes A_{+-,-+} \\
f_{10}^{--} &= g_{10}^{+-} \otimes A_{++,+-} \\
f_{00}^{+-} &= g_{00}^{+-} \otimes (A_{--,++} - A_{+-,-+}) \\
f_{00}^{++} &= g_{00}^{+-} \otimes (A_{++,+-} - A_{+-,++}),
\end{aligned}
$$

$$
\begin{aligned}
f_{00}^{+-,\,even} &= \frac{\zeta}{\sqrt{1-\zeta}} \frac{1}{1-\zeta/2} \frac{\sqrt{t_o - t}}{2M} \widetilde{\mathcal{E}}, \\
f_{00}^{++,\,even} &= \frac{\sqrt{1-\zeta}}{1-\zeta/2} \widetilde{\mathcal{H}} + \frac{-\zeta^2/4}{(1-\zeta/2)\sqrt{1-\zeta}} \widetilde{\mathcal{E}},
\end{aligned}
$$

Observables: Generalized Parton Distributions (GPDs)

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

Chiral Even

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

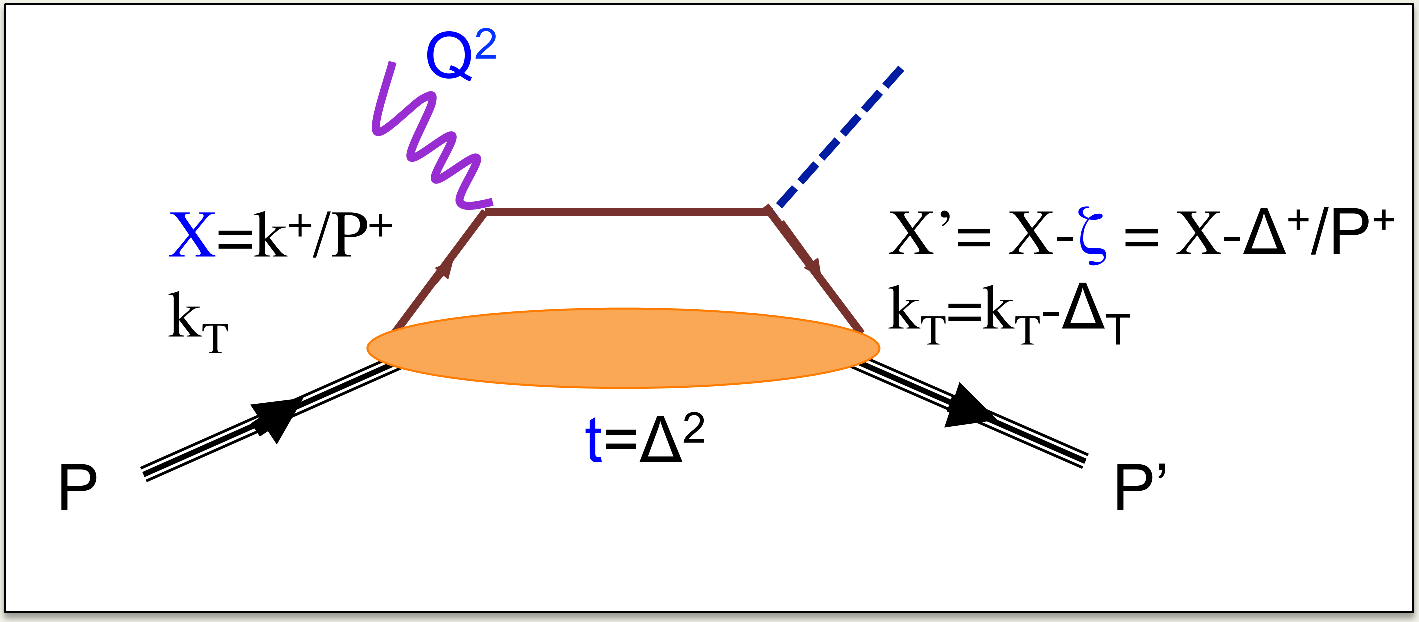
Chiral Odd

Compton Form Factors: convolutions of hard and soft parts

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

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

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



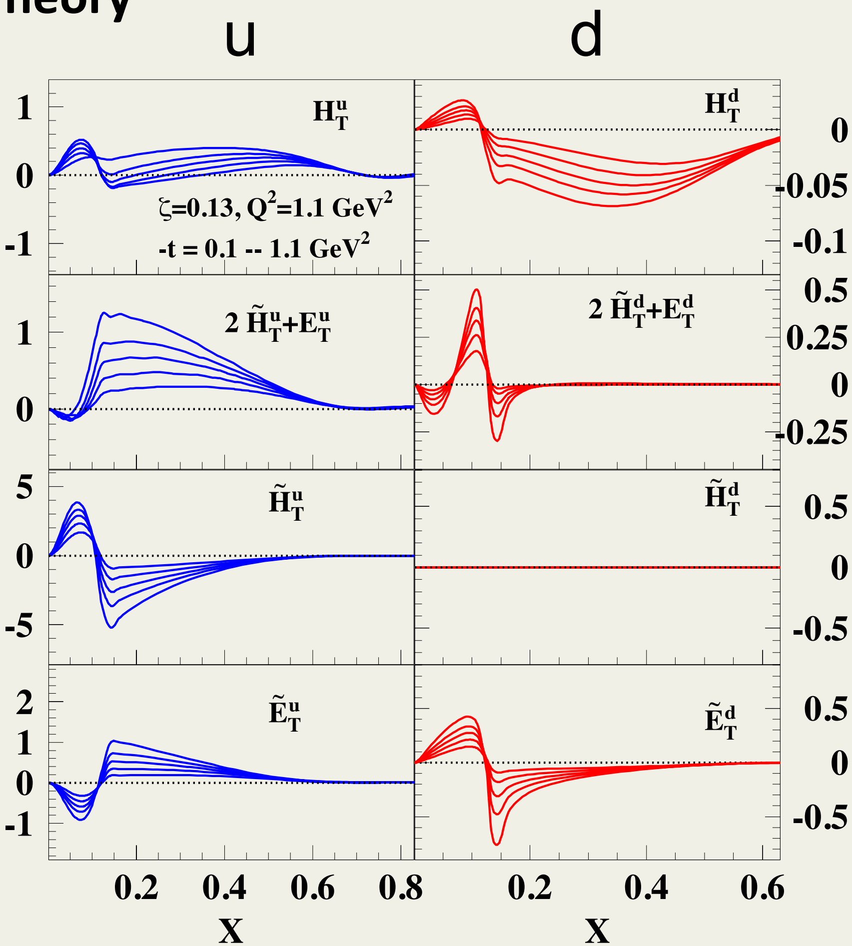
non-local like PDF

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

$t=\Delta^2$ like form factor

The Chiral Odd sector is vastly unexplored

Theory



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

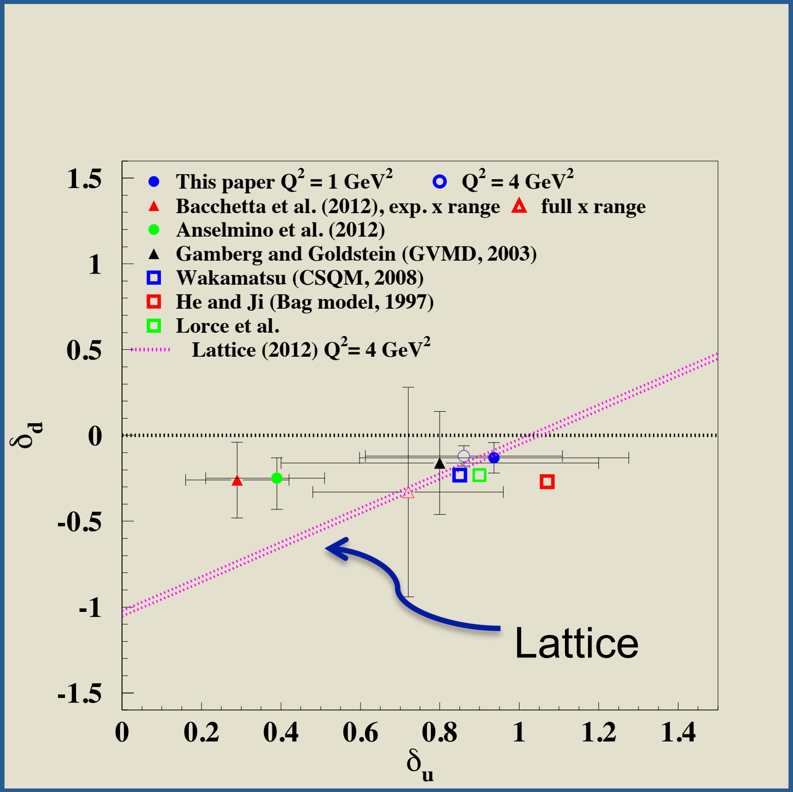
$$\int dx\, [2\tilde{H}_T^q(x,\zeta,t,Q^2) + E_T^q(x,\zeta,t,Q^2)] = \kappa_q(t,Q^2)$$

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

?

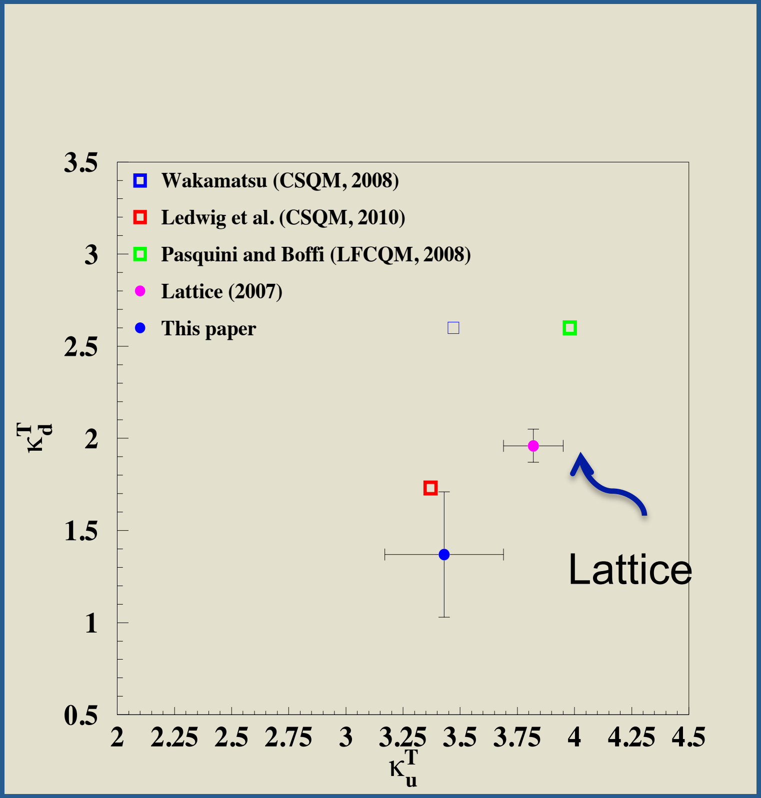
?

Flavor separated tensor charge



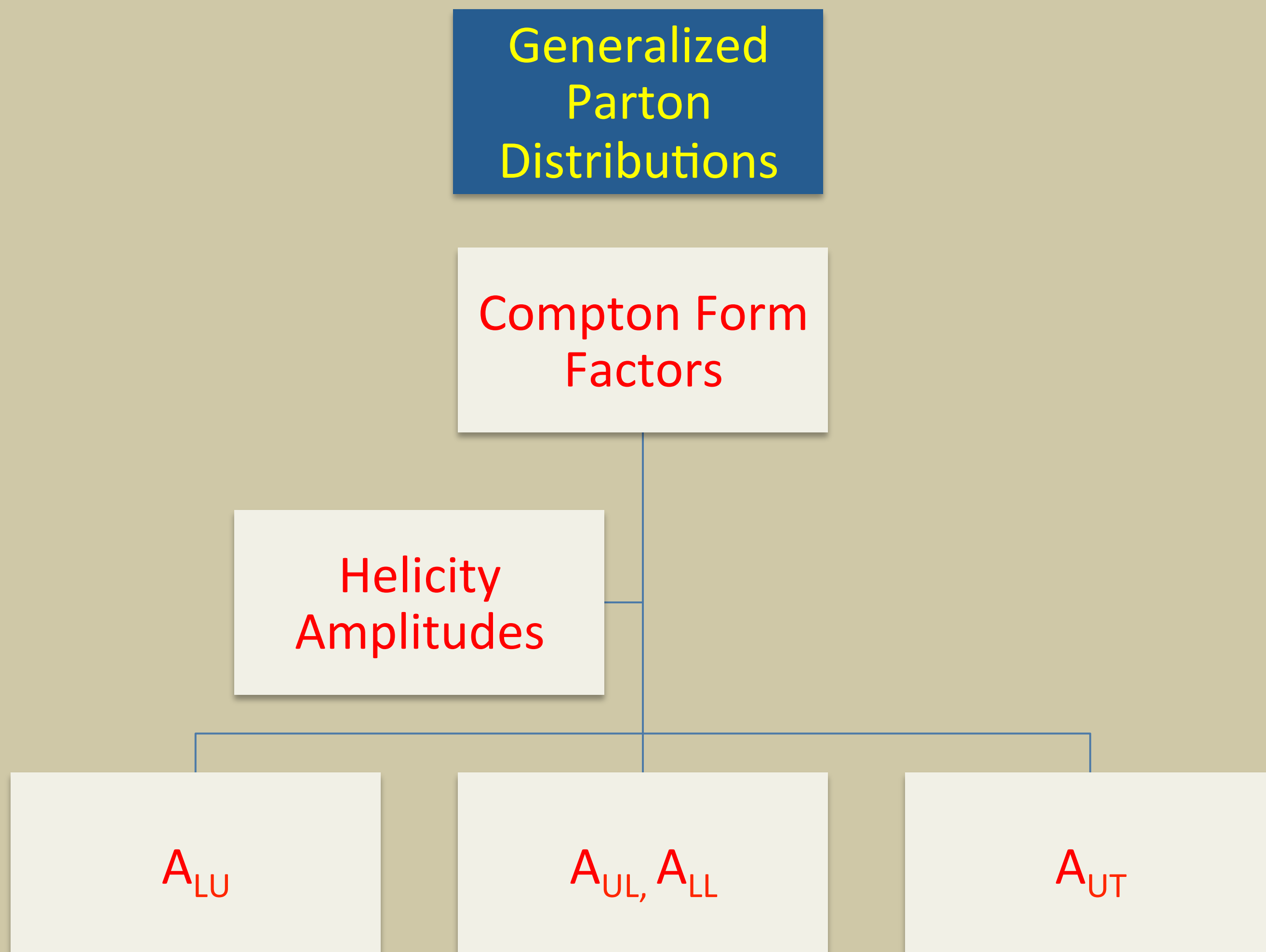
J.~R.~Green, J.~W.~Negele, A.~V.~Pochinsky, S.~N.~Syritsyn, M.~Engelhardt and S.~Krieg,
%``Nucleon Scalar and Tensor Charges from Lattice QCD with Light Wilson Quarks,''
Phys.\ Rev.\ D {\bf 86}, 114509 (2012)

Tensor anomalous magnetic moment



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

Experiment: DVπ^oP, DVηP
(Hall B, H. Avakian et al, Hall A. F. Sabatie et al)



Cross section

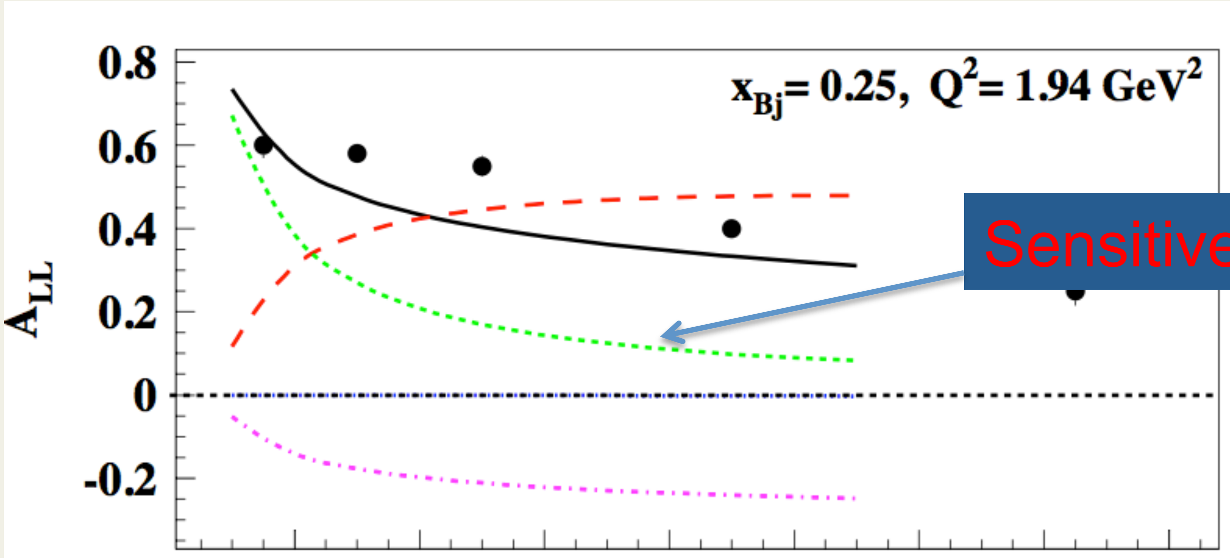
$$
\begin{aligned}
\frac{d^4\sigma}{dx_{Bj}\,dy\,d\phi\,dt} = \Gamma\Big\{ & \Big[F_{UU,T} + \epsilon F_{UU,L} + \epsilon\cos 2\phi F_{UU}^{\cos 2\phi} + \sqrt{2\epsilon(\epsilon+1)}\cos\phi F_{UU}^{\cos\phi} + \boxed{h\sqrt{2\epsilon(1-\epsilon)}\,\sin\phi F_{LU}^{\sin\phi}}\Big] \\
& + S_{||}\Big[\boxed{\sqrt{2\epsilon(\epsilon+1)}\sin\phi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

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

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

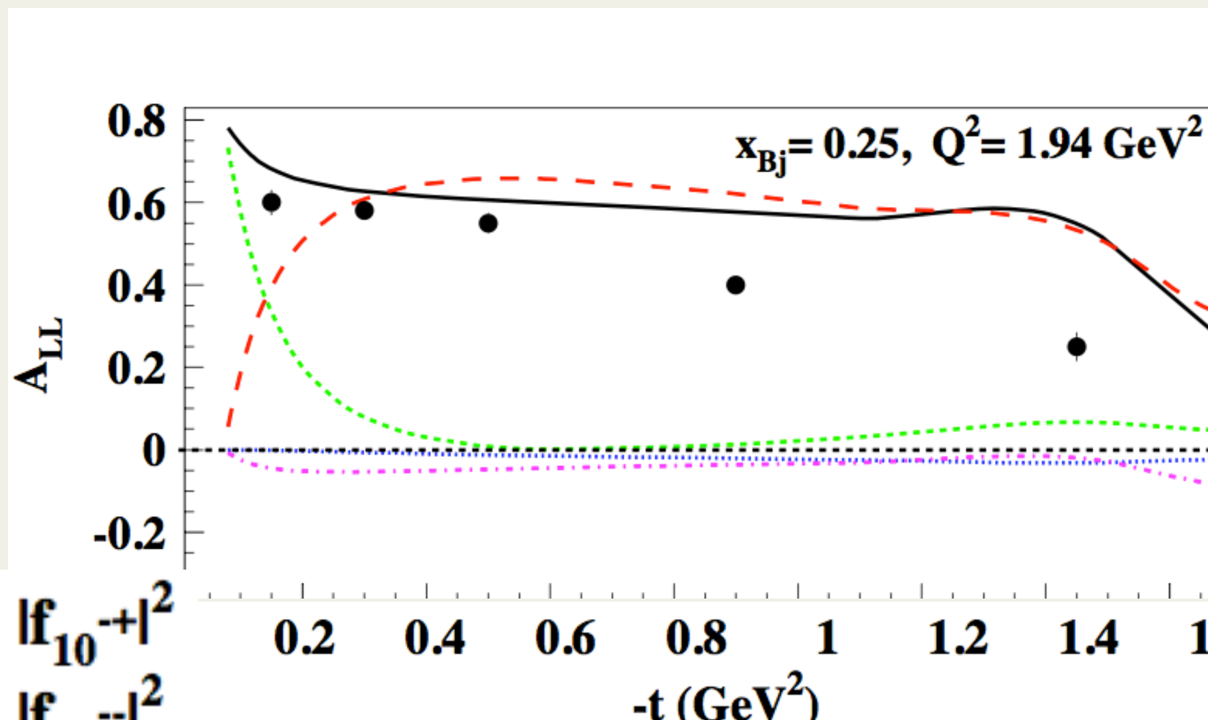
$$
A_{LL} = \frac{N^{\rightarrow}_{s_z=+} - N^{\rightarrow}_{s_z=-} + N^{\leftarrow}_{s_z=+} - N^{\leftarrow}_{s_z=-}}{N_{s_z=+} + N_{s_z=-}} = \frac{\sqrt{1-\epsilon^2}\;F_{LL}}{F_{UU,T}+\epsilon F_{UU,L}} + \frac{\sqrt{\epsilon(1-\epsilon)}\,\cos\phi\,F_{LL}^{\cos\phi}}{F_{UU,T}+\epsilon F_{UU,L}}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

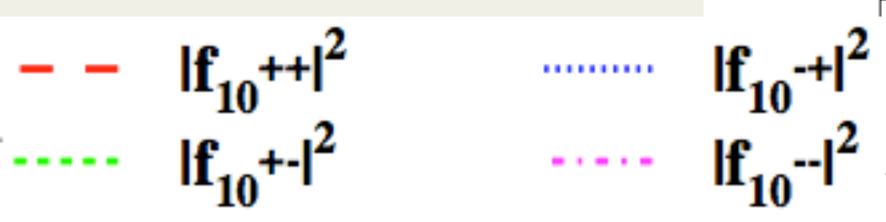
Andrey Kim, Harut Avakian et al., Jefferson Lab CLAS Collaboration



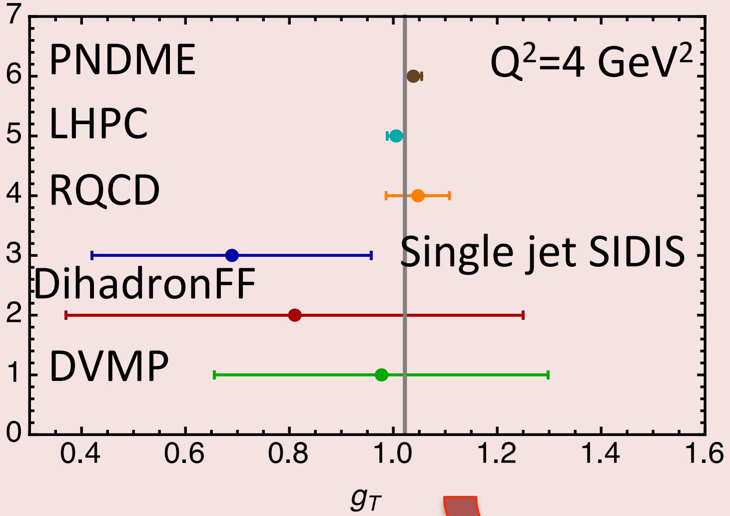
Sensitive to tensor charge

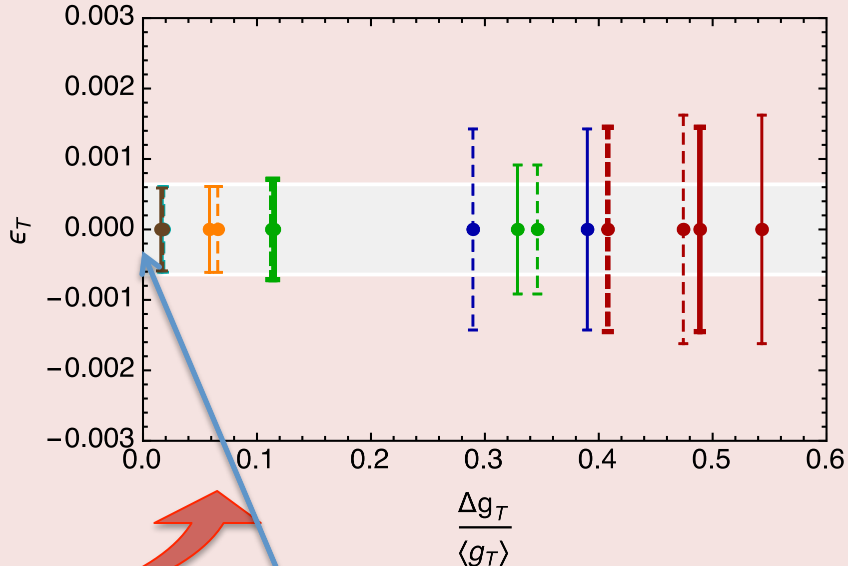
Role of parameters





Impact on BSM searches…



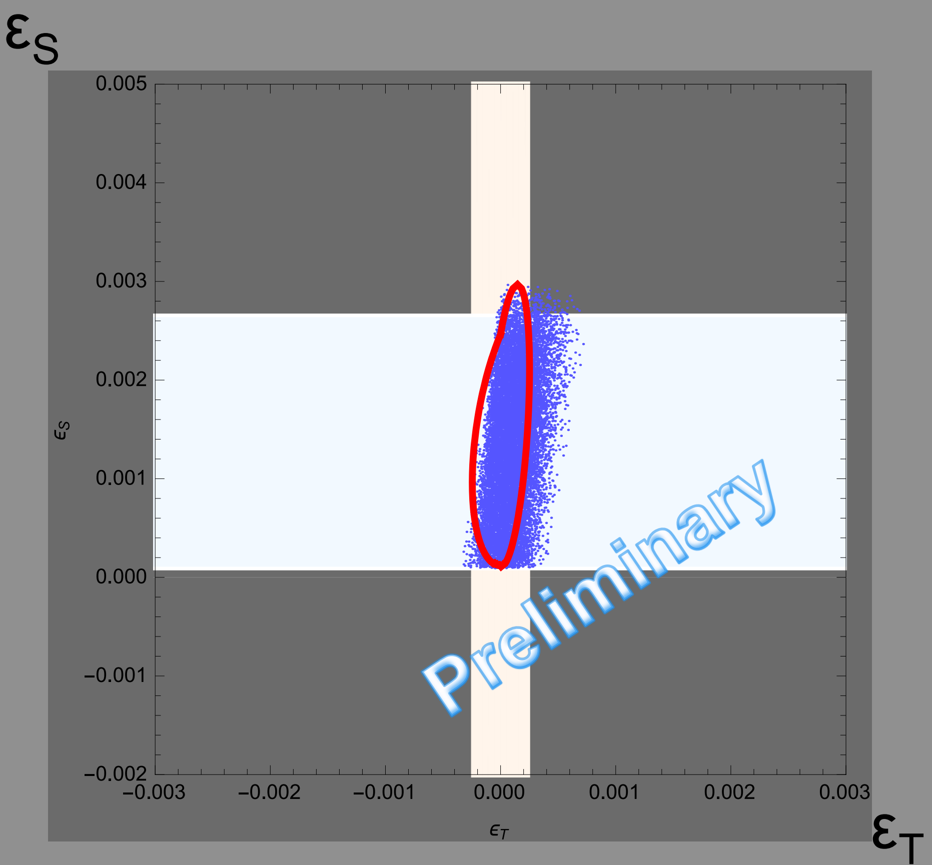


$|\varepsilon_T\ g_T|<6.4\text{x}10^{-4}$

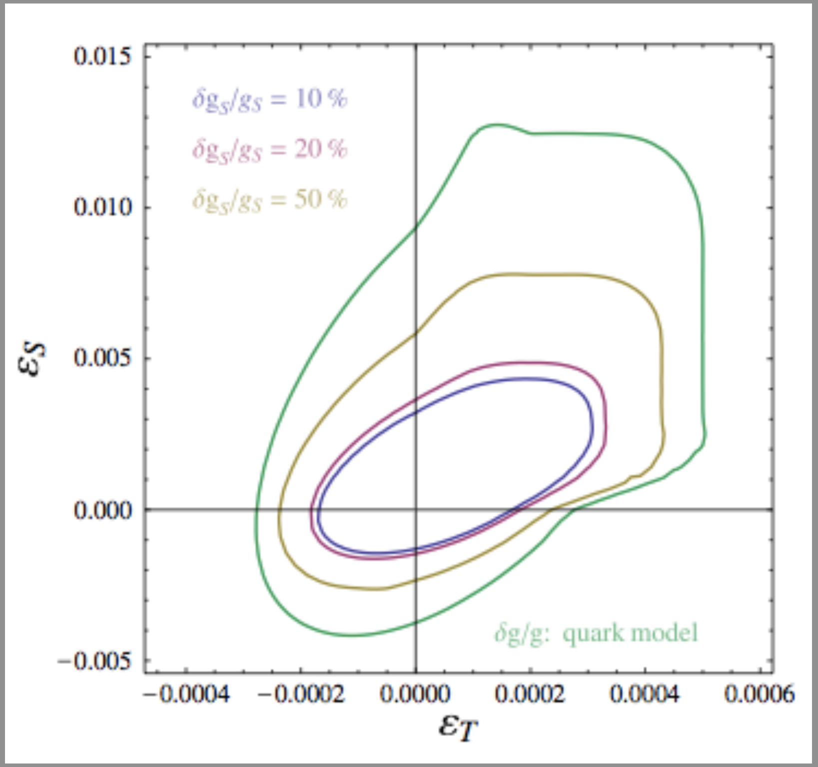
Pattie et al, PRC88 (2013)

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

Combined 90% confidence level in ε_S-ε_T plane



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



Bhattacharya et al., PRD85 (2012)

Future developments

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

Study the additional 2nd class currents

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

- Interplay 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.

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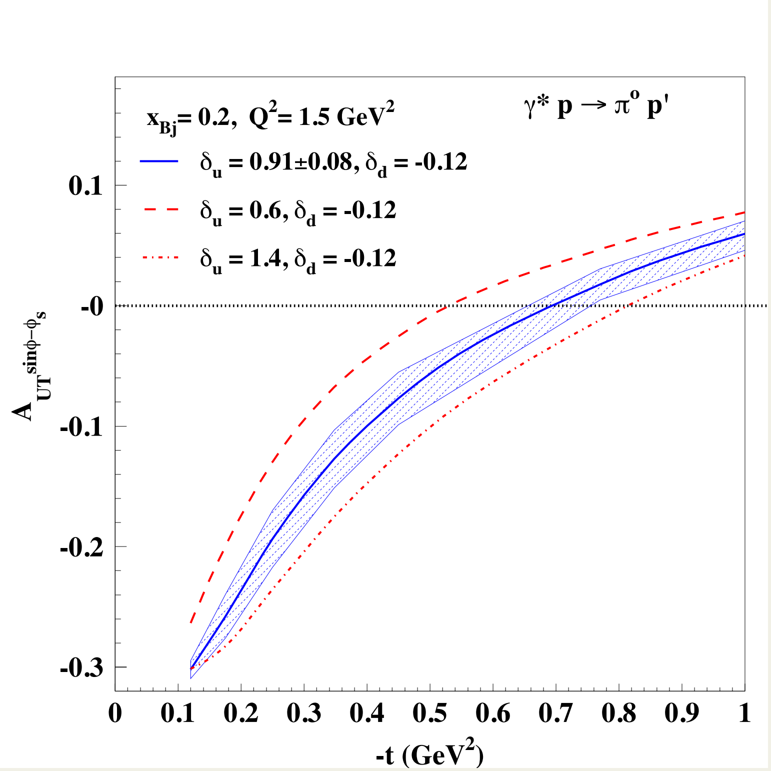
Back up



x_Bj= 0.2, Q^2= 1.5 GeV^2
γ* p → π^o p'
δ_u = 0.91±0.08, δ_d = -0.12
δ_u = 0.6, δ_d = -0.12
δ_u = 1.4, δ_d = -0.12
A_UT^sinφ−φs
0.1
-0
-0.1
-0.2
-0.3
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-t (GeV^2)