Chiral Odd GPDs from π^0 and η production

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With Gary Goldstein, J.Osvaldo Gonzalez Hernandez

Outline

1) How reliably can GPDs be measured? Towards a global fit: <u>models, parameters, theoretical errors, resolution</u>?
(GGL, PRD 2011)

2) Exclusive π^o electroproduction ➔ chiral odd sector
(Ahmad et al. PRD 2009, Goldstein et al., hep-ph/1201.6088)

Extraction of GPDs from experimental data

→ Define
"what type of information"

→ Define
"the way to access it"

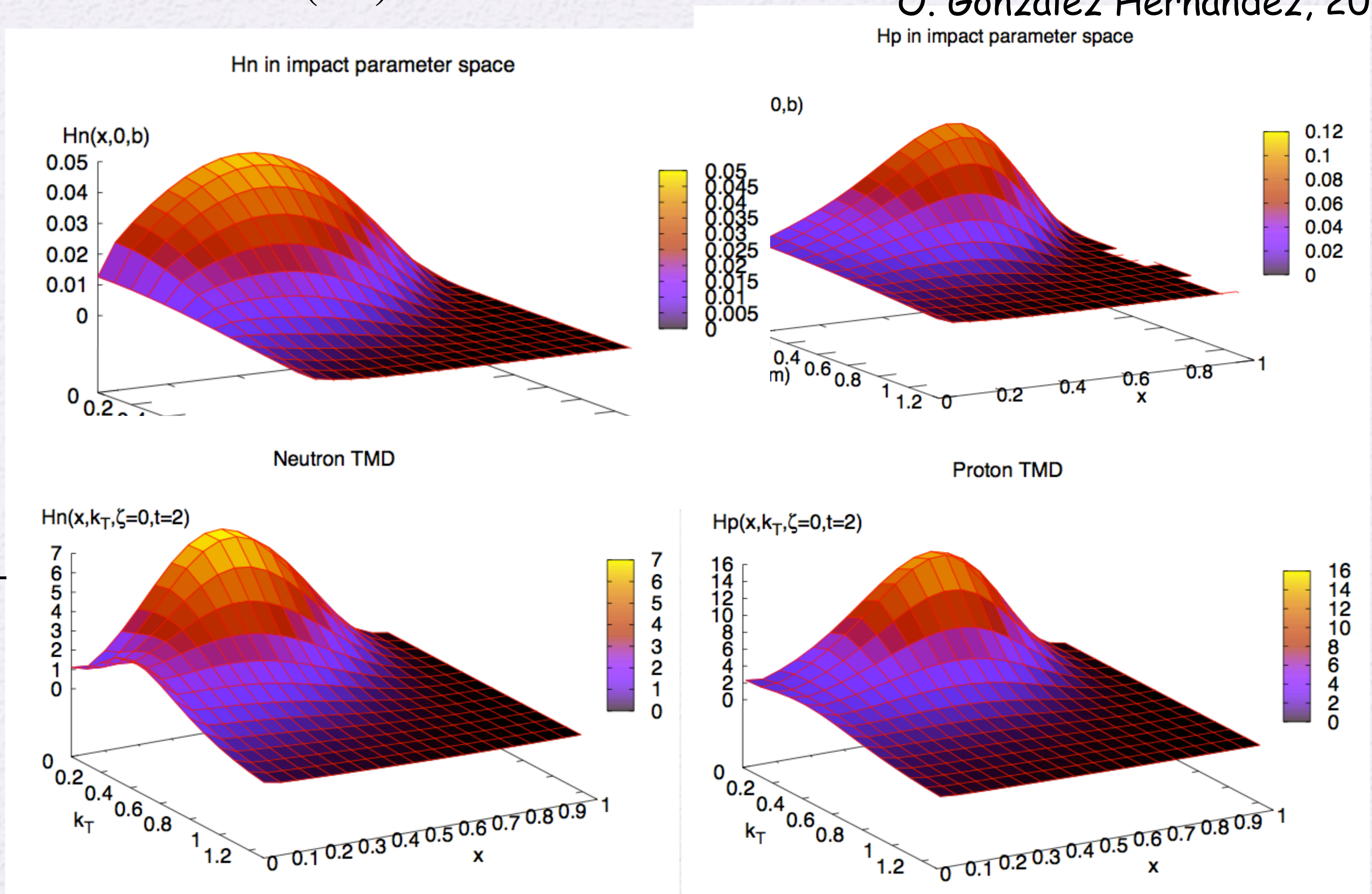
Wigner Dist'ns and OAM from Experiment????

$$F(X,b) = \int \frac{d^2\Delta_T}{(2\pi)^2}\, e^{-i\vec{\Delta}_T\cdot\vec{b}}\; F(X,0,t \equiv -\Delta_T^2)$$

O. Gonzalez Hernandez, 2011

b

k_T

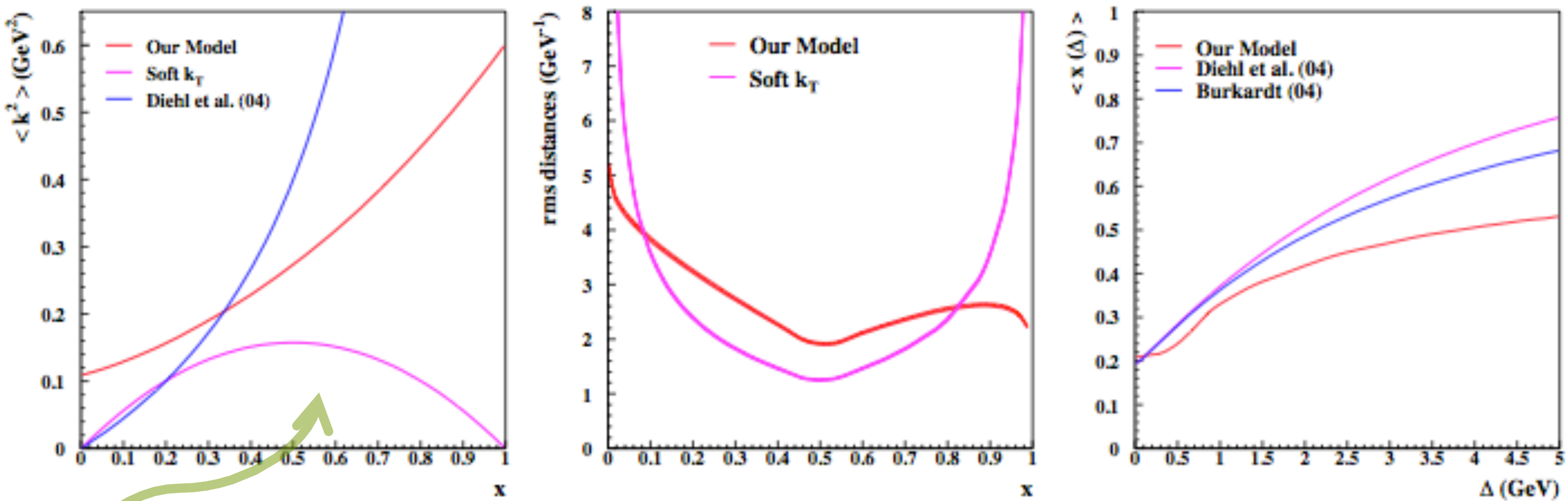


"Slices" of Wigner Distn's

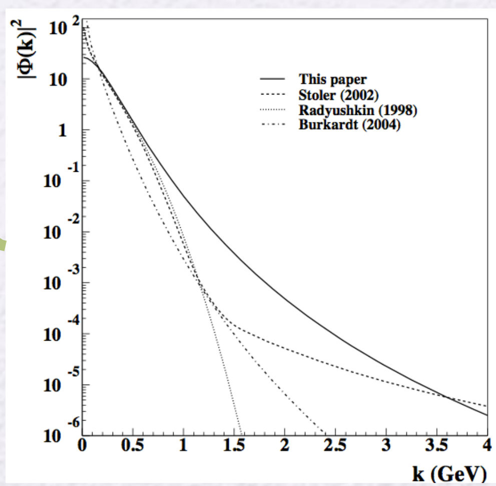
(S.L., S.Taneja, PRD'04)

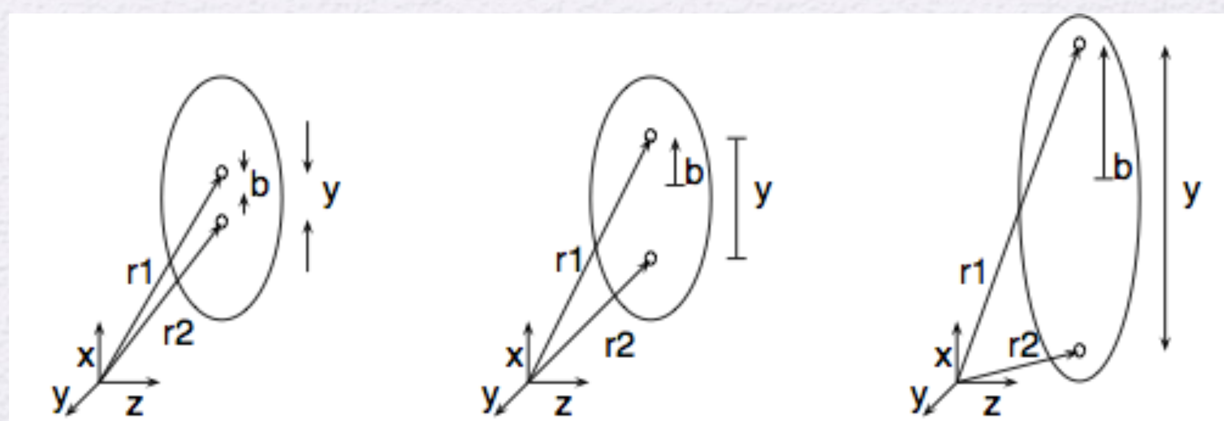
2 Simonetta Liuti: Study of Parton Interactions in Nuclei using Wigner Distributions

EIC Working Group, Editors: K. Hafidi et al.

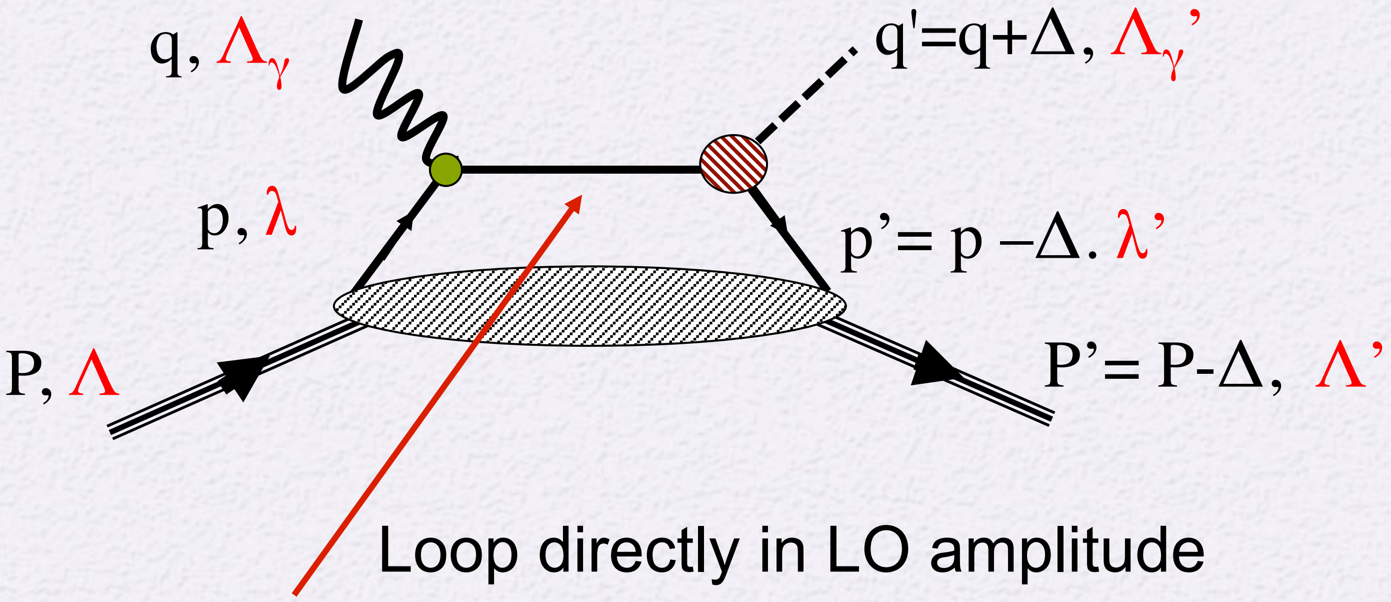


k_T r_T $X_{Bj}(t)$





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

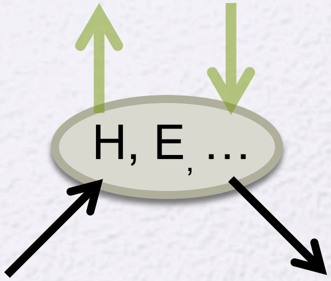


(1) $$\frac{1}{(p+q)^2 - m^2 + i\varepsilon} = PV\frac{1}{(p+q)^2 - m^2} - i\pi\,\delta((p+q)^2 - m^2)$$

Both Re and Im parts are present

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

Definitions



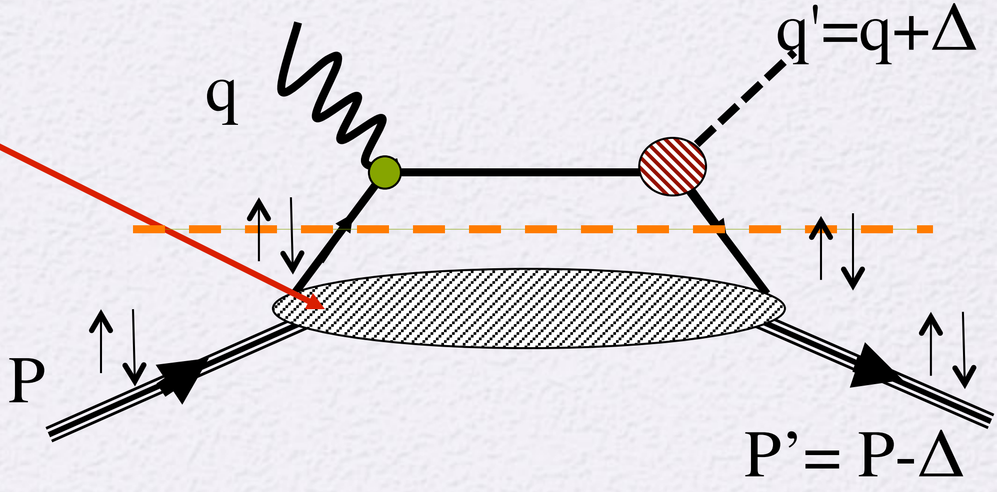
$$F^{S}_{\Lambda\Lambda'} = \int \frac{dy^-}{2\pi}\, e^{ixP^+y^-} \left\langle p',\Lambda' \right| \bar{\psi}\left(-\frac{y}{2}\right)\gamma^+\psi\left(\frac{y}{2}\right)\left| p,\Lambda \right\rangle \Big|_{y^+=y_\perp=0}$$

$$F^{S}_{\Lambda'\Lambda} = \sum_i \left[\bar{U}_\alpha(p',\Lambda')O^i_{\alpha\beta}U_\beta(p,\Lambda)\right] H_i(x,\xi,t)$$

$$H_1 = H, \quad H_2 = E, \quad O^1 = \gamma^+, O^2 = \frac{-i\sigma^{+\mu}\Delta_\mu}{2M}$$

Quark-Proton Helicity Amplitudes

$$
\begin{aligned}
f^S_{++} &= f_{++,++} + f_{-+,-+} \\
&= g^S_{++} \otimes (A_{++,++} + A_{-+,-+}) \\
f^A_{++} &= f_{++,++} - f_{-+,-+} \\
&= g^A_{++} \otimes (A_{++,++} - A_{-+,-+}) \\
f^S_{+-} &= f_{++,+-} + f_{-+,--} \\
&= g^S_{++} \otimes (A_{-+,++} + A_{++,-+}) \\
f^A_{+-} &= f_{++,+-} - f_{-+,--} \\
&= g^A_{++} \otimes (A_{-+,++} - A_{++,-+})
\end{aligned}
$$



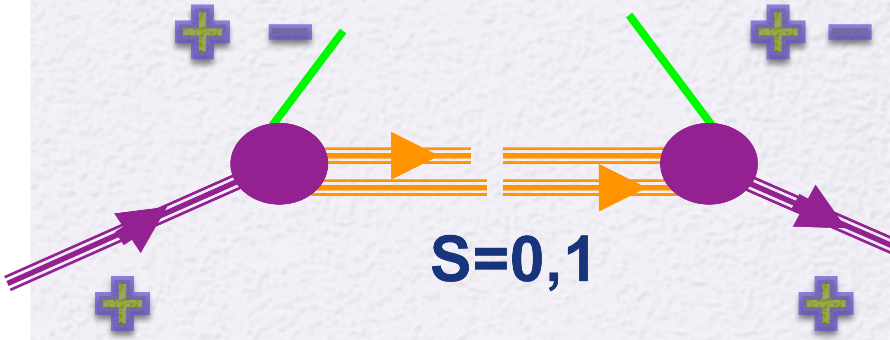
Diquark Model

$$A_{++,++} = \int d^2k_\perp \phi^*_{++}(k',P')\phi_{++}(k,P)$$

$$A_{+-,+-} = \int d^2k_\perp \phi^*_{+-}(k',P')\phi_{+-}(k,P)$$

$$A_{-+,++} = \int d^2k_\perp \phi^*_{-+}(k',P')\phi_{++}(k,P)$$

$$A_{++,-+} = \int d^2k_\perp \phi^*_{++}(k',P')\phi_{-+}(k,P).$$



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

$$\phi^*_{\Lambda'\lambda'}(k',P') = \Gamma(k')\frac{\overline{U}(P',\Lambda')u(k',\lambda')}{k'^2-m^2},$$

$$H = \mathcal{N}\frac{1-\zeta/2}{1-X}\int d^2k_\perp \frac{\left[(m+MX)\left(m+M\frac{X-\zeta}{1-\zeta}\right)+\mathbf{k}_\perp\cdot\tilde{\mathbf{k}}_\perp\right]}{(k^2-M_\Lambda^2)^2(k'^2-M_\Lambda^2)^2} + \frac{\zeta^2}{4(1-\zeta)}E,$$

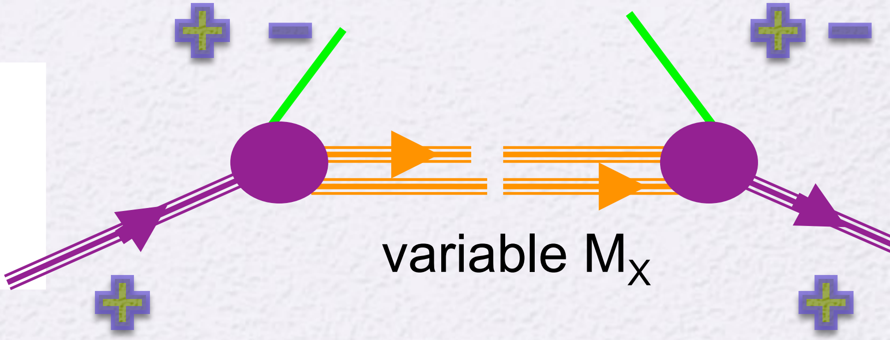
$$E = \mathcal{N}\frac{1-\zeta/2}{1-X}\int d^2k_\perp \frac{-2M(1-\zeta)\left[(m+MX)\frac{\tilde{k}\cdot\Delta}{\Delta_\perp^2}-\left(m+M\frac{X-\zeta}{1-\zeta}\right)\frac{k_\perp\cdot\Delta}{\Delta_\perp^2}\right]}{(k^2-M_\Lambda^2)^2(k'^2-M_\Lambda^2)^2}$$

$$\tilde{H} = \mathcal{N}\frac{1-\zeta/2}{1-X}\int d^2k_\perp \frac{\left[(m+MX)\left(m+M\frac{X-\zeta}{1-\zeta}\right)-\mathbf{k}_\perp\cdot\tilde{\mathbf{k}}_\perp\right]}{(k^2-M_\Lambda^2)^2(k'^2-M_\Lambda^2)^2} + \frac{\zeta^2}{4(1-\zeta)}\tilde{E}$$

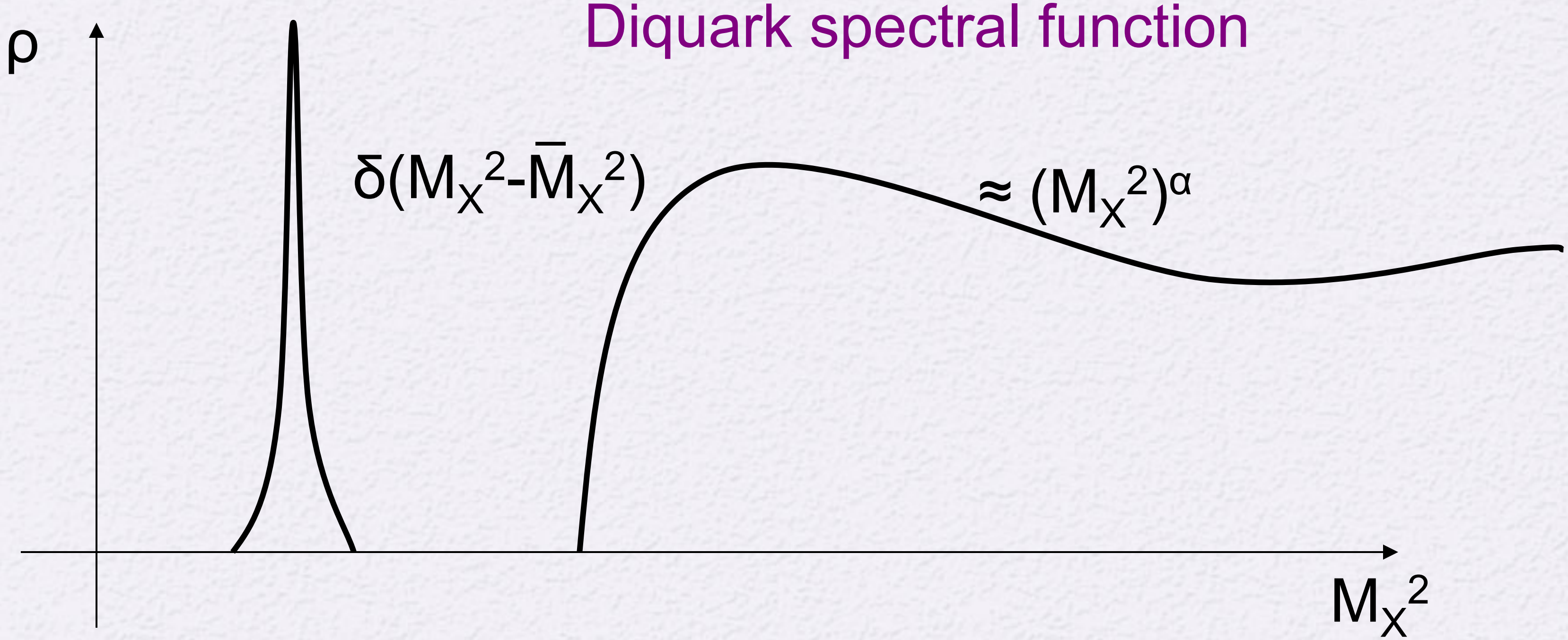
$$\tilde{E} = \mathcal{N}\frac{1-\zeta/2}{1-X}\int d^2k_\perp \frac{-\frac{4M(1-\zeta)}{\zeta}\left[(m+MX)\frac{\tilde{k}\cdot\Delta}{\Delta_\perp^2}+\left(m+M\frac{X-\zeta}{1-\zeta}\right)\frac{k_\perp\cdot\Delta}{\Delta_\perp^2}\right]}{(k^2-M_\Lambda^2)^2(k'^2-M_\Lambda^2)^2}$$

Reggeization

$$\int_0^\infty dM_X^2 \rho_R(M_X^2) H(X,0,0) \sim X^{-\alpha(0)-1},$$



Diquark spectral function

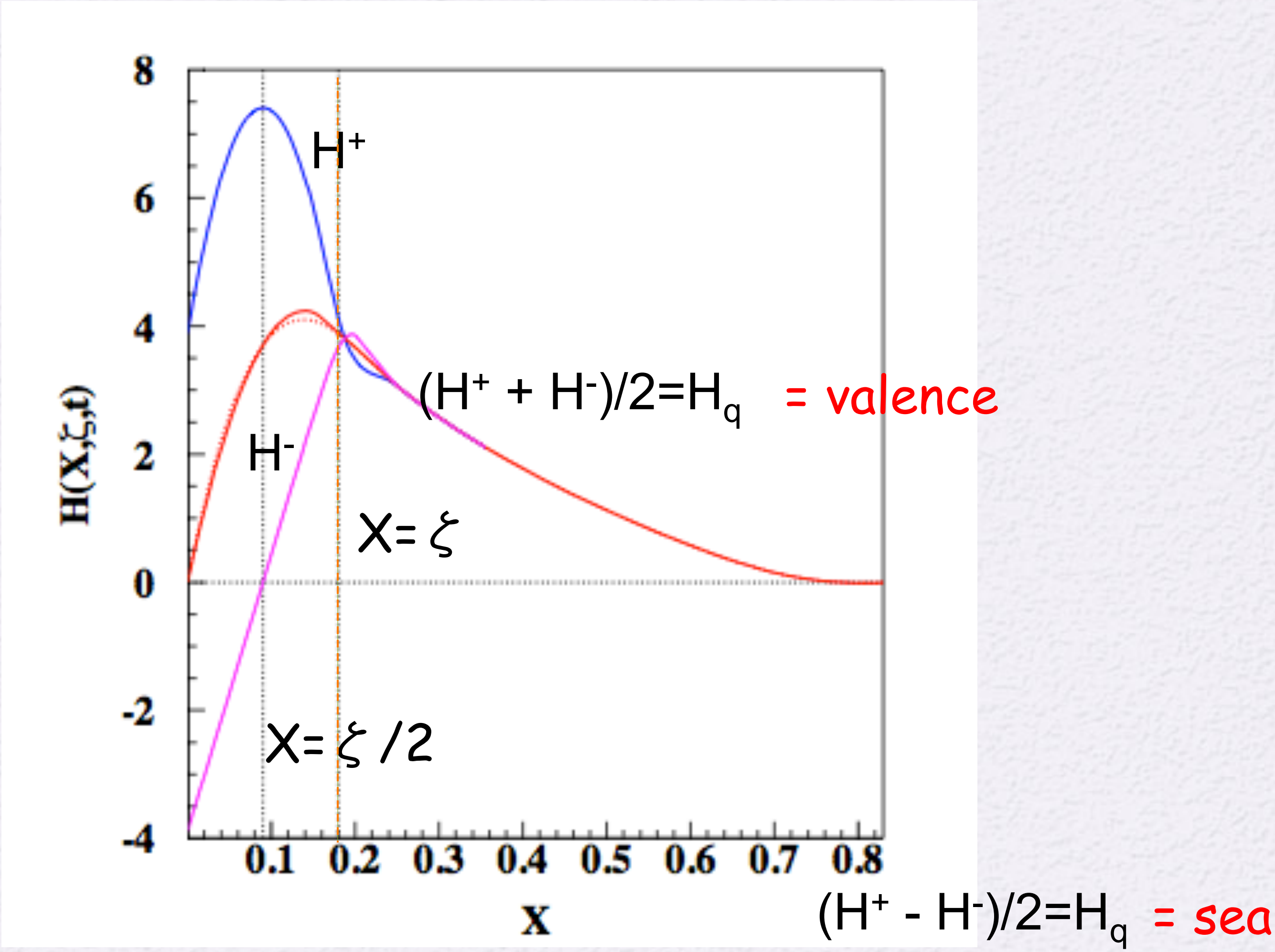


Brodsky, Close, Gunion ➔ DIS ('70s)

Gorshteyn & Szczepaniak (PRD, 2010)

Brodsky, Llanes, Szczepaniak arXiv:0812.0395

Crossing Symmetries



Parametric Form

$$F(X,\zeta,t) = \mathcal{N} G_{M_X,m}^{M_\Lambda}(X,\zeta,t)\, R_p^{\alpha,\alpha'}(X,\zeta,t)$$

Recursive fit, STEP 1

$$H^q(X,0,0,Q^2) \;=\; f_1^q(X,Q^2) \equiv q_v(X)$$
$$\widetilde{H}^q(X,0,0,Q^2) \;=\; g_1^q(X,Q^2) \equiv \Delta q_v(X)$$

Constraints from PDFs

Recursive fit, STEP 2

$$\int_0^1 H^q(X,\zeta,t) \;= F_1^q(t)$$
$$\int_0^1 E^q(X,\zeta,t) \;= F_2^q(t)$$
$$\int_0^1 \widetilde{H}^q(X,\zeta,t) \;= G_A^q(t)$$
$$\int_0^1 \widetilde{E}^q(X,\zeta,t) \;= G_P^q(t)$$

Constraints from FFs

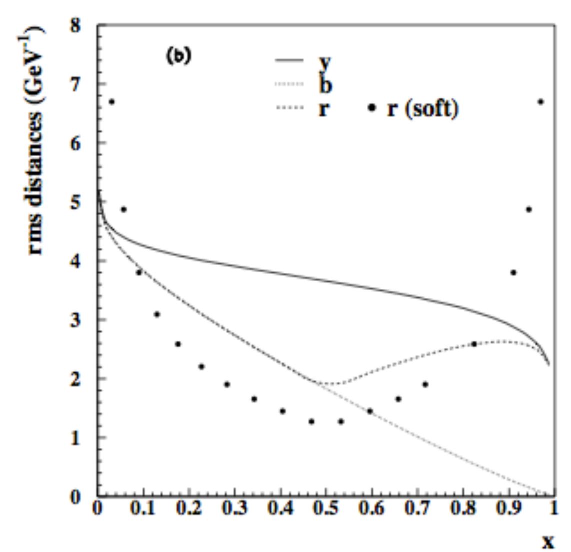
We asked the question: "What is the minimal number of parameters necessary to fit X and t ?" Can be addressed with Recursive Fit

Parameters	H	E	$\widetilde{H}$	$\widetilde{E}$
m_u (GeV)	0.420	0.420	2.624	2.624
M_X^u (GeV)	0.604	0.604	0.474	0.474
M_Λ^u (GeV)	1.018	1.018	0.971	0.971
α_u	0.210	0.210	0.219	0.219
α_u'	2.448 ± 0.0885	2.811 ± 0.765	1.543 ± 0.296	5.130 ± 0.101
p_u	0.620 ± 0.0725	0.863 ± 0.482	0.346 ± 0.248	3.507 ± 0.054
$\mathcal{N}_u$	2.043	1.803	0.0504	1.074
χ^2	0.773	0.664	0.116	1.98
m_d (GeV)	0.275	0.275	2.603	2.603
M_X^d (GeV)	0.913	0.913	0.704	0.704
M_Λ^d (GeV)	0.860	0.860	0.878	0.878
α_d	0.0317	0.0317	0.0348	0.0348
α_d'	2.209 ± 0.156	1.362 ± 0.585	1.298 ± 0.245	3.385 ± 0.145
p_d	0.658 ± 0.257	1.115 ± 1.150	0.974 ± 0.358	2.326 ± 0.137
$\mathcal{N}_d$	1.570	-2.800	-0.0262	-0.966
χ^2	0.822	0.688	0.110	1.00

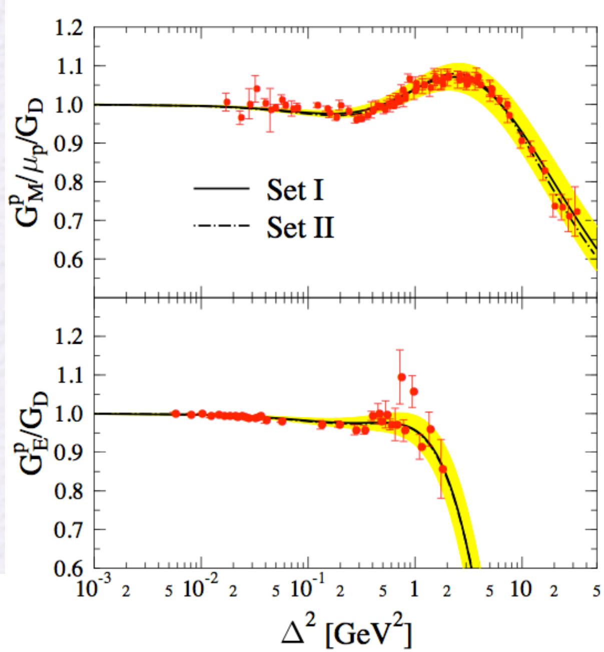
Flexible Model ('04-'07-'09'-'11-…)

S.Ahmad, H. Honkanen, S. Taneja –G.Goldstein, O.Gonzalez Hernandez

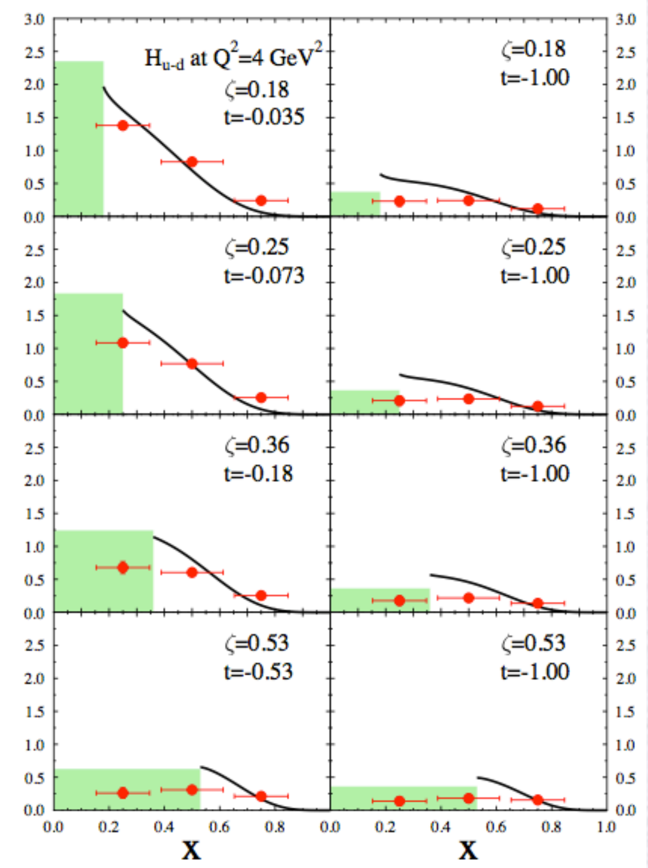
Radius=b/(1-x), PRD'04

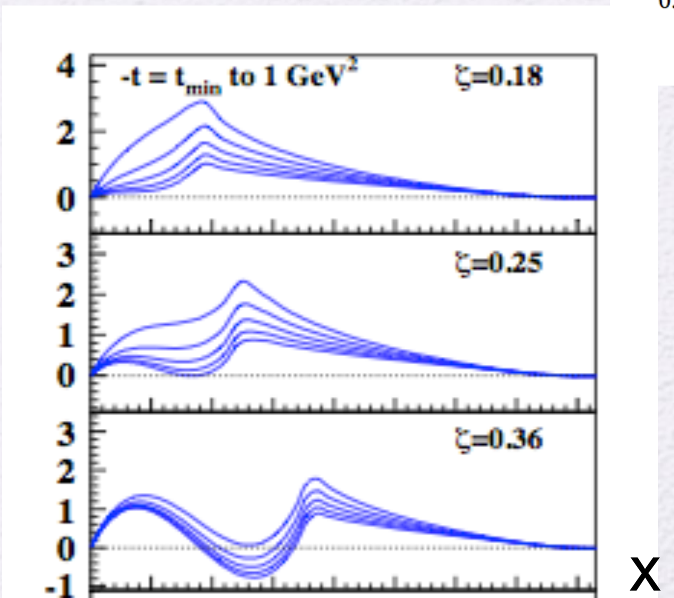


ξ=0, form factors, PRD'07



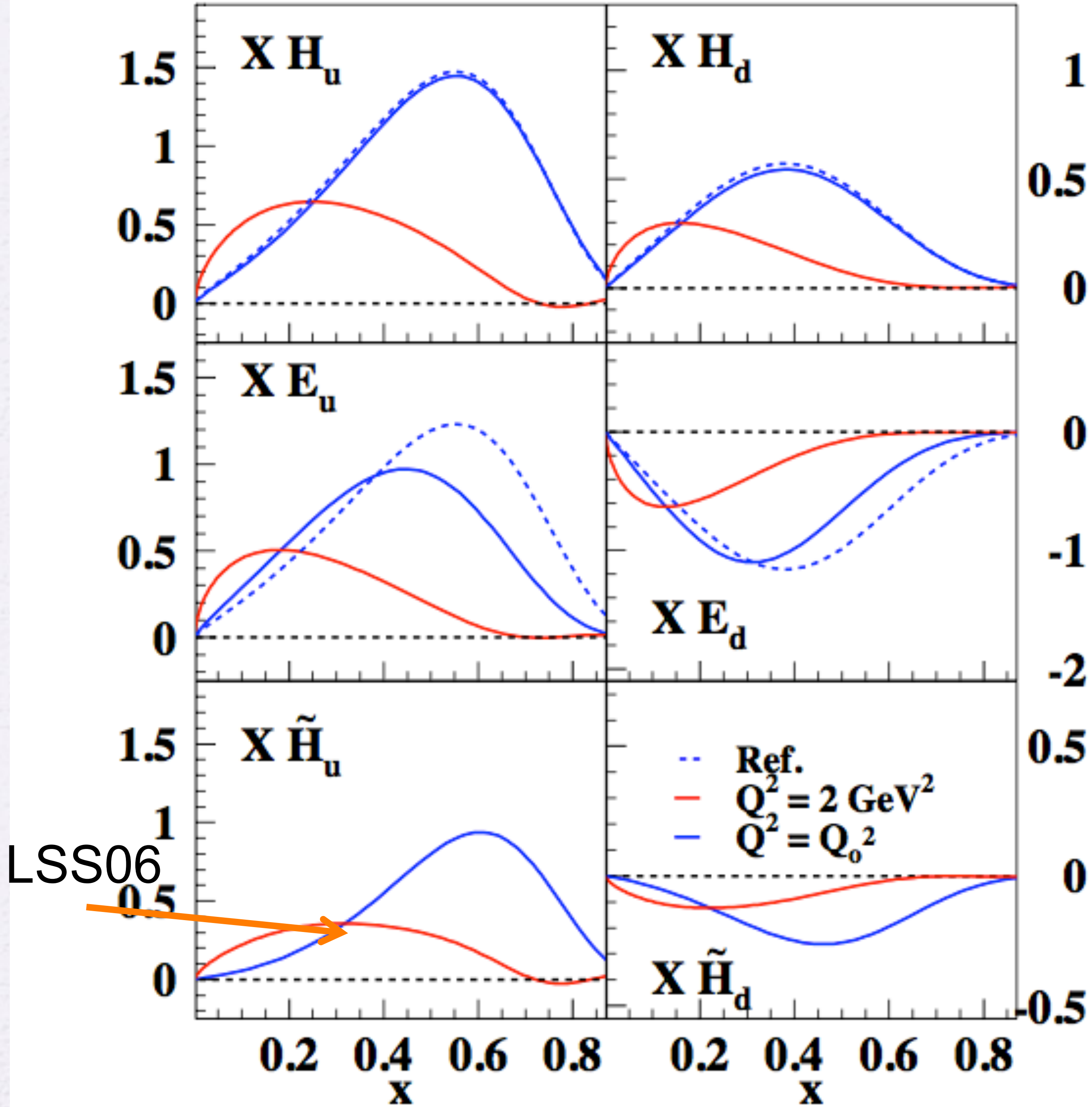
ξ≠0, lattice moments, EPJC'09





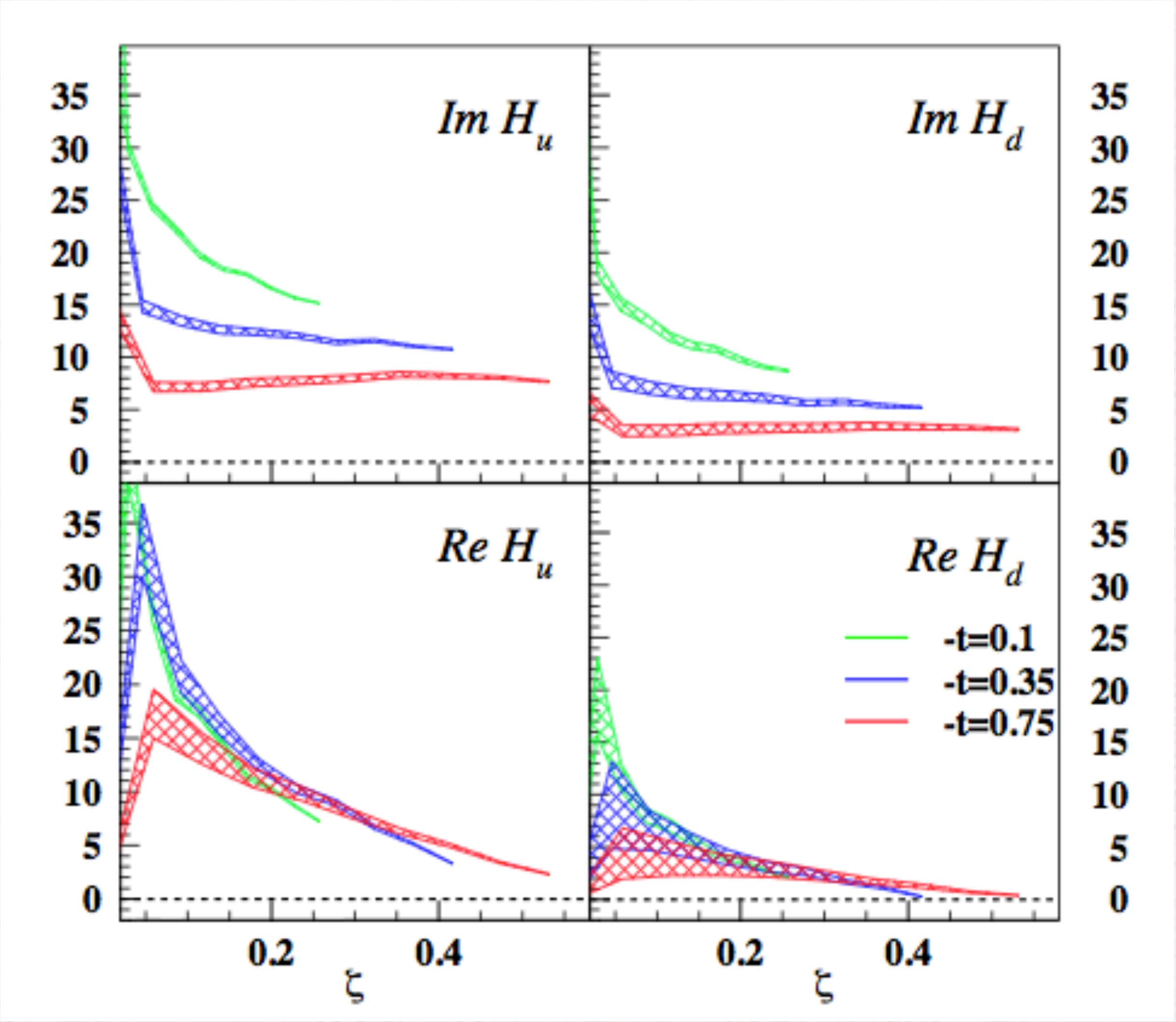
Extraction of GPDs from all data, PRD'11

Goldstein et al. arXiv:1012.3776



ξ=0, t=0

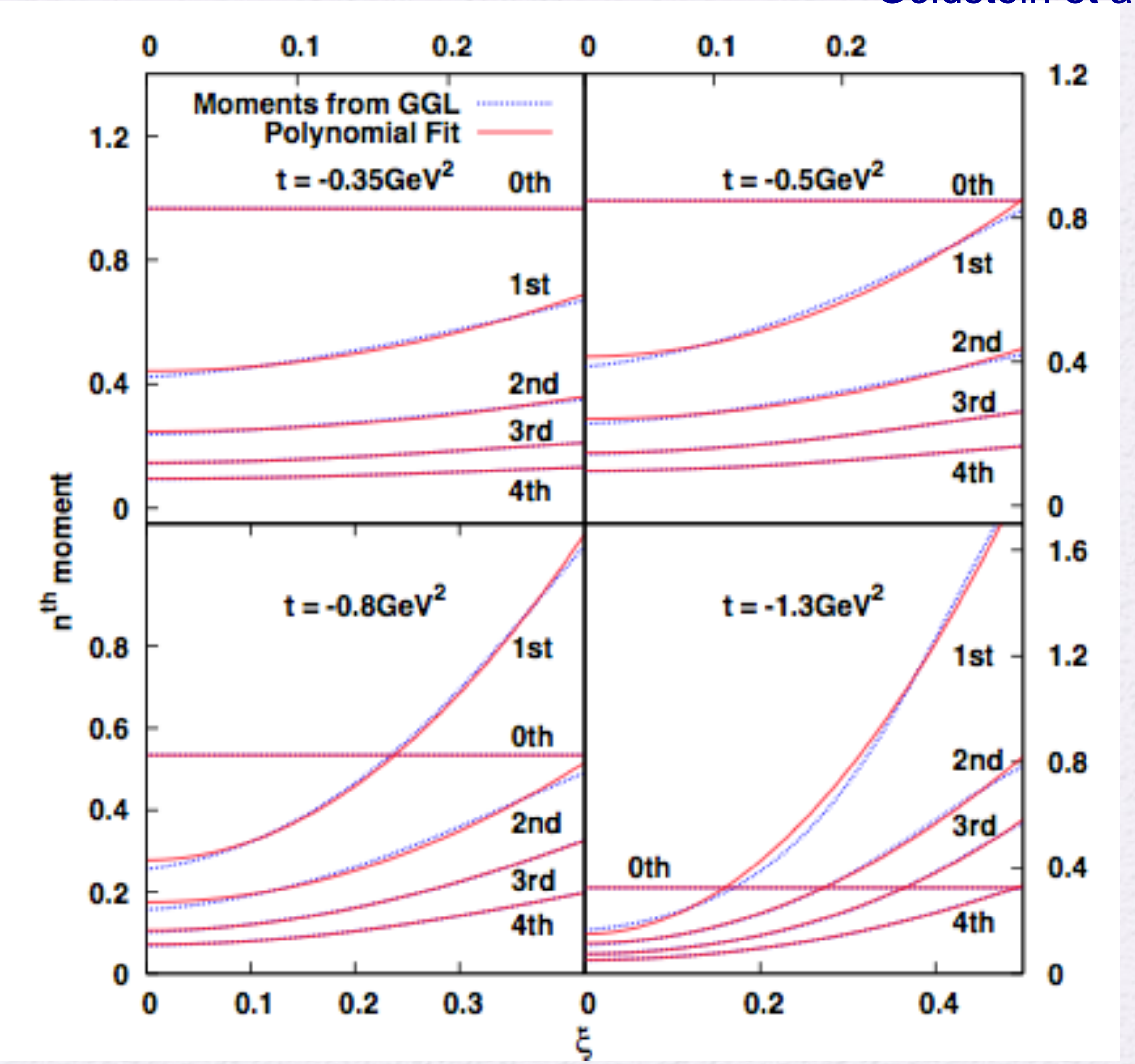
Compton Form factors vs. ζ



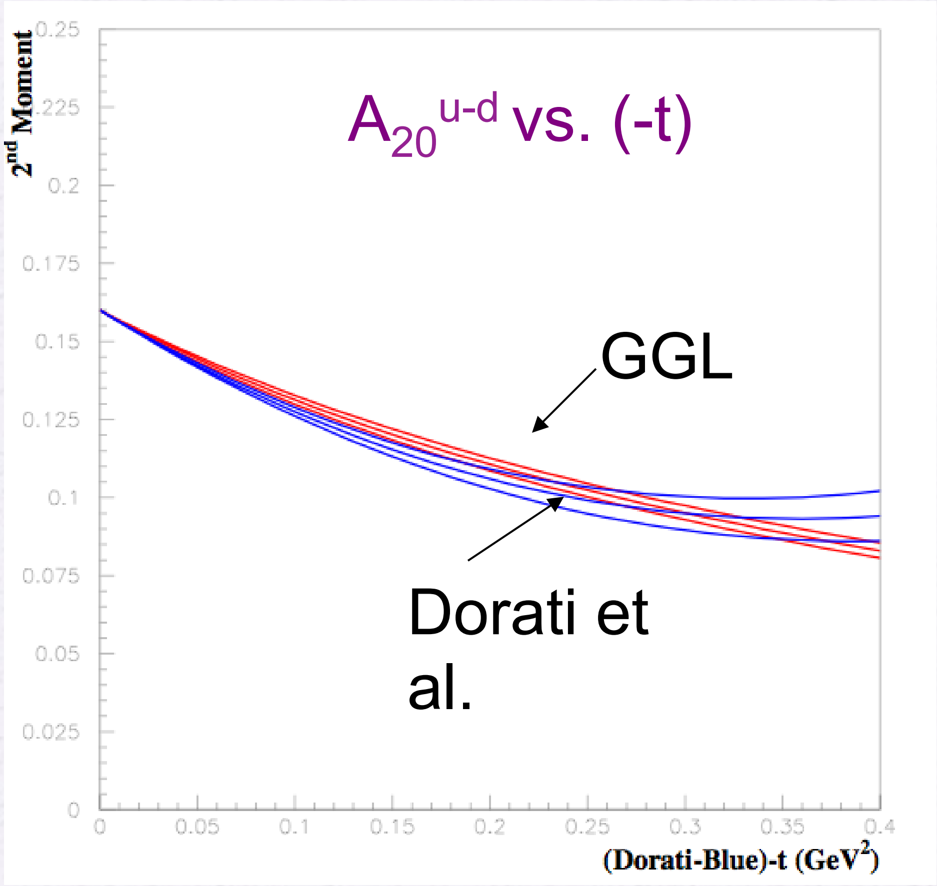
Q^2=2 GeV^2

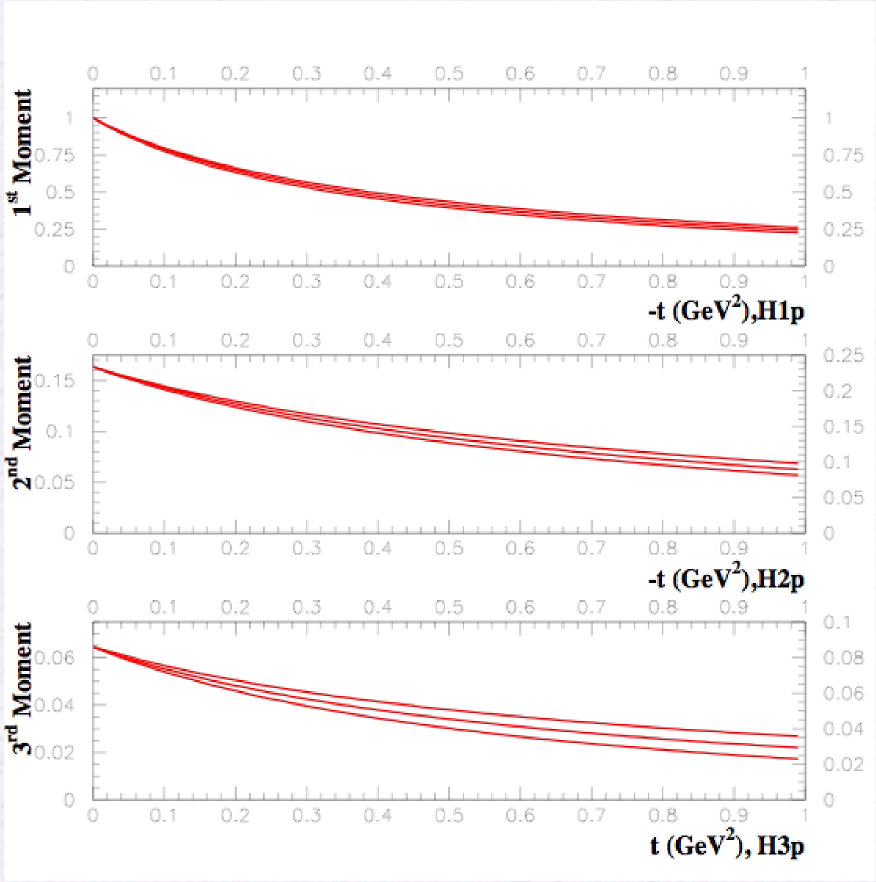
Polynomiality!

Goldstein et al. arXiv:1012.3776



Comparison with lattice

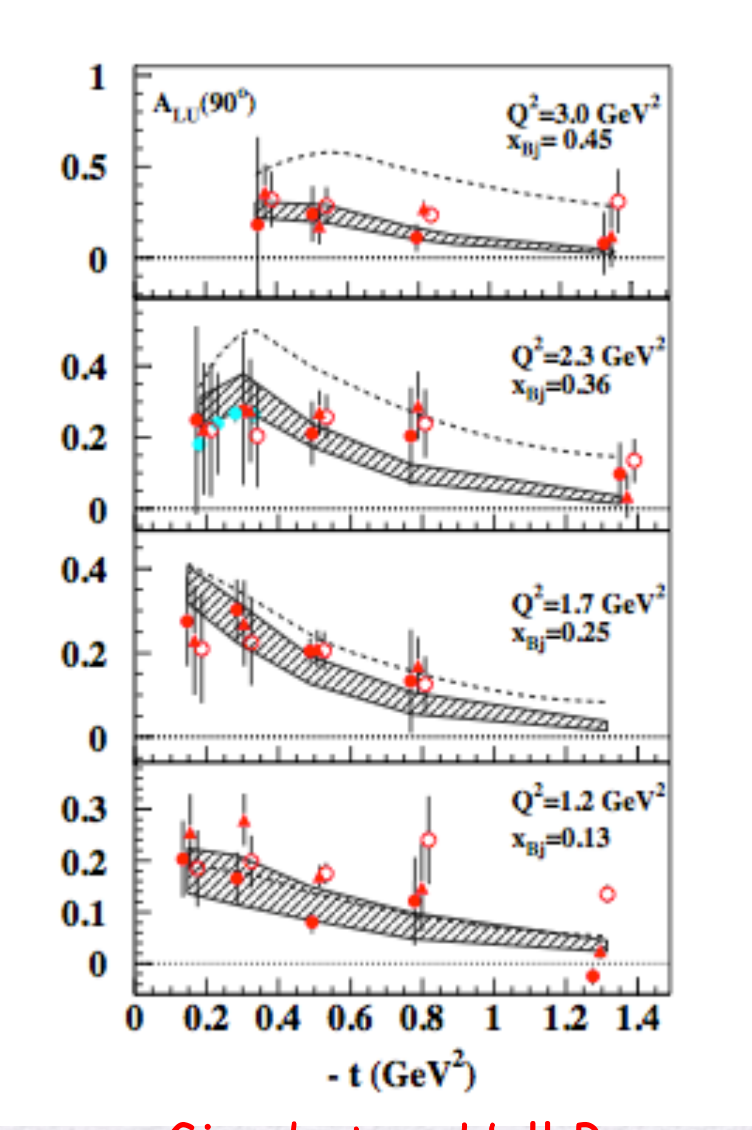




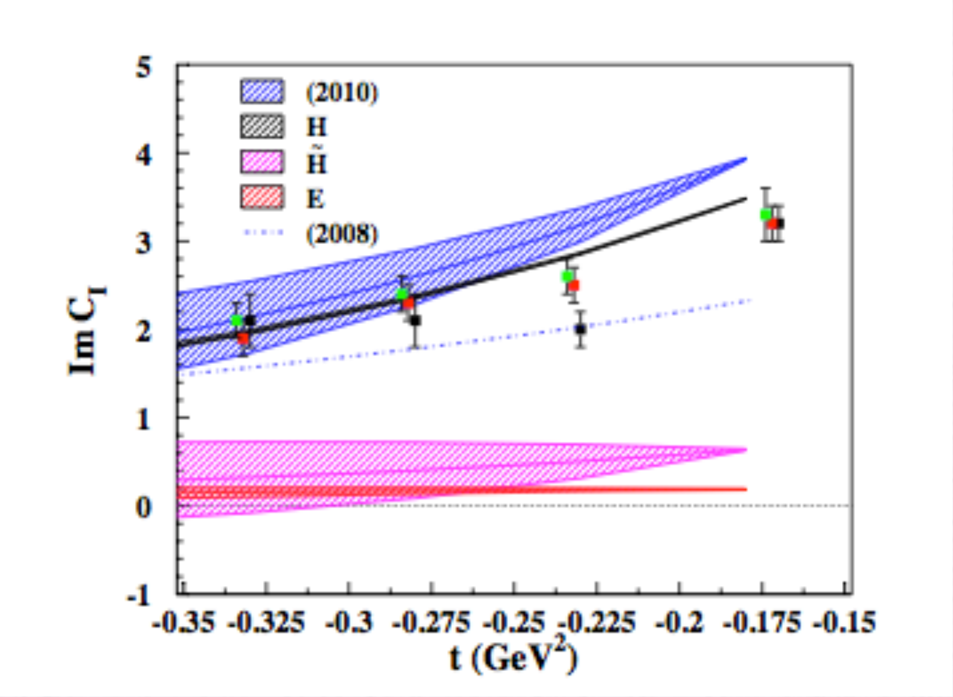
Implementing DVCS data...

$$R = X^{-[\alpha + \alpha'(X)t + \beta(\zeta)t]},$$

extra term



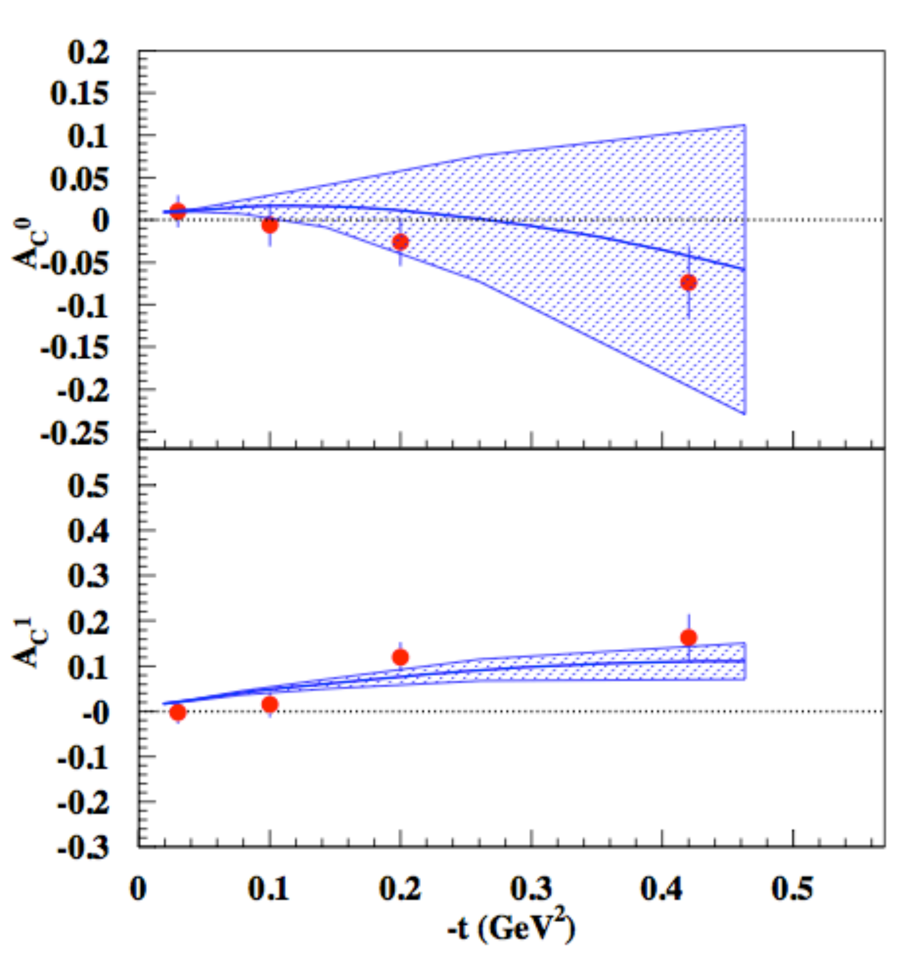
Girod et a., Hall B

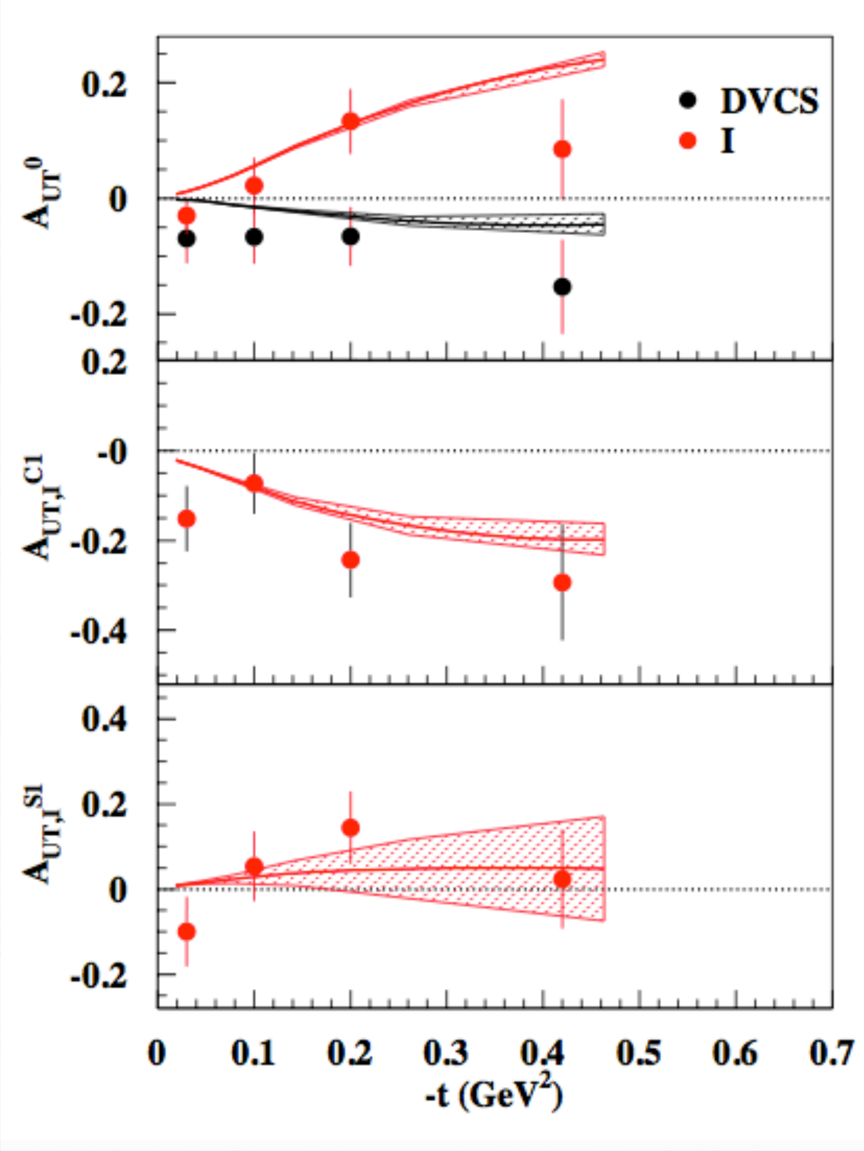


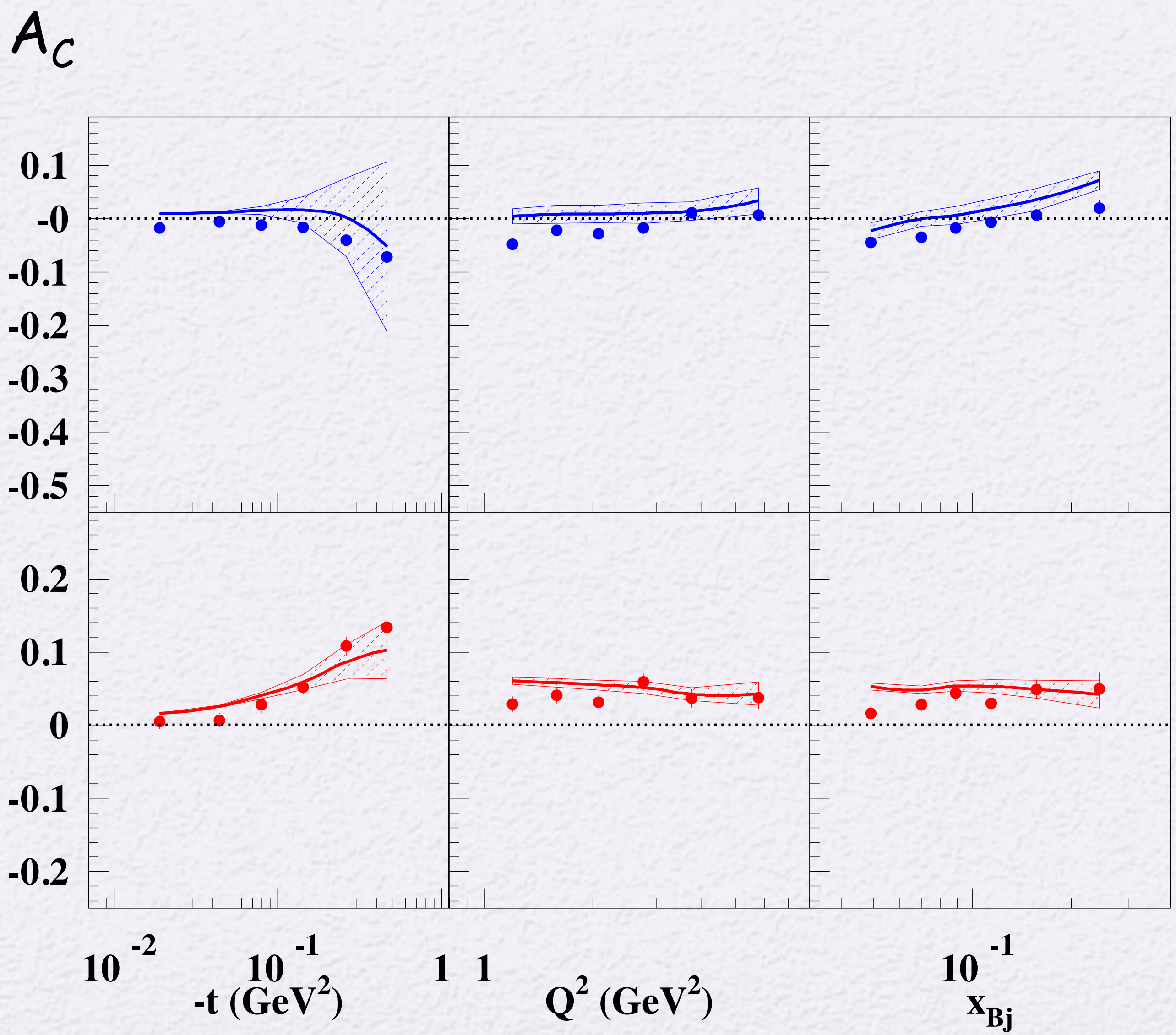
Hall A

Having fitted Jlab data, we predict Hermes

Goldstein et al. arXiv:1012.3776







A_C
0.1
-0
-0.1
-0.2
-0.3
-0.4
-0.5
0.2
0.1
0
-0.1
-0.2
10 -2
10 -1
1
1
10 -1
-t (GeV2)
Q2 (GeV2)
xBj

Pseudoscalar Mesons Electroproduction

π^o and η production probing the GPD chiral-odd sector

Goldstein et al., arXiv:hep-ph/1201.6088

Issue in a nutshell:

"Collinear factorization approach" for chiral-even process

$$g_{0,+;0,+} \approx \frac{1}{Q}\int d\tau \frac{\phi_\pi(\tau)}{\tau} C^+ \Rightarrow \frac{d\sigma_L^{even}}{dt} \propto \frac{1}{Q^6}$$

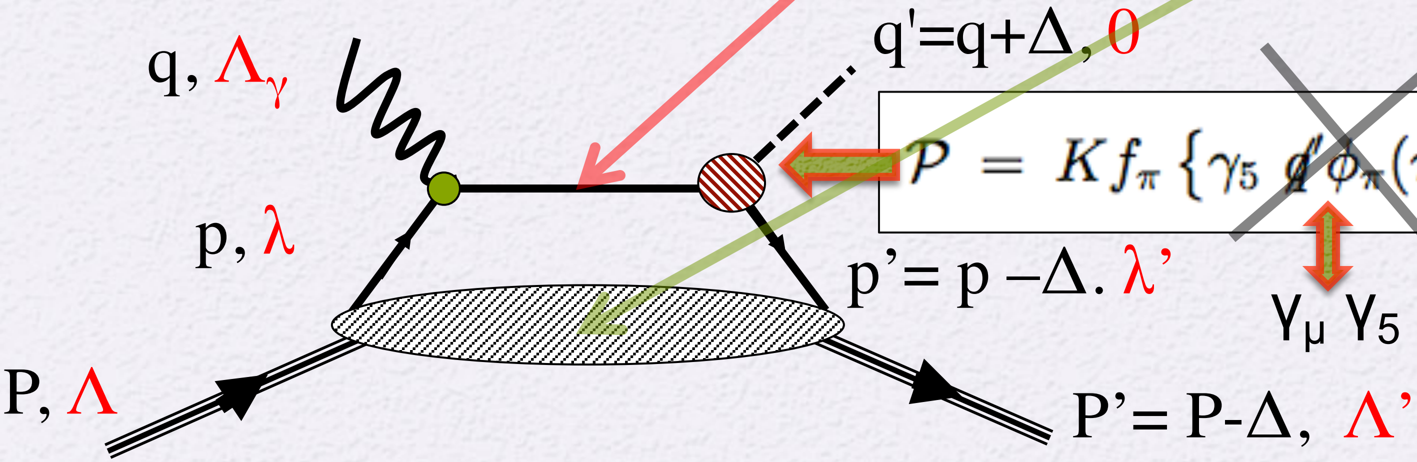
$$g_{1,+;0,+} \approx \frac{1}{Q^2}\int d\tau \frac{\phi_\pi(\tau)}{\tau} C^+ \Rightarrow \frac{d\sigma_T^{even}}{dt} \propto \frac{1}{Q^8}.$$

"Collinear factorization approach" for chiral-odd process

$$g_{0+,0-} \approx \frac{d\sigma_L^{odd}}{dt} \propto \frac{1}{Q^{10}} \qquad g_{1+,0-} \approx \frac{d\sigma_T^{odd}}{dt} \propto \frac{1}{Q^8}.$$

Transverse component seems to be larger than naively expected

$$f_{\Lambda_\gamma,\Lambda;0,\Lambda'}(\xi,t) = \sum_{\lambda,\lambda'}\int dx\, d^2k_\perp\; g_{\Lambda_\gamma,\lambda;0,\lambda'}(x,k_\perp,\xi,t)\; A_{\Lambda',\lambda';\Lambda,\lambda}(x,k_\perp,\xi,t)$$



$$\mathcal{P} = K f_\pi \left\{\gamma_5\, \not{q}'\, \phi_\pi(\tau) + \gamma_5 \mu_\pi \phi_\pi^{(3)}(\tau)\right\}$$

$\gamma_\mu\ \gamma_5$ $\qquad$ γ_5

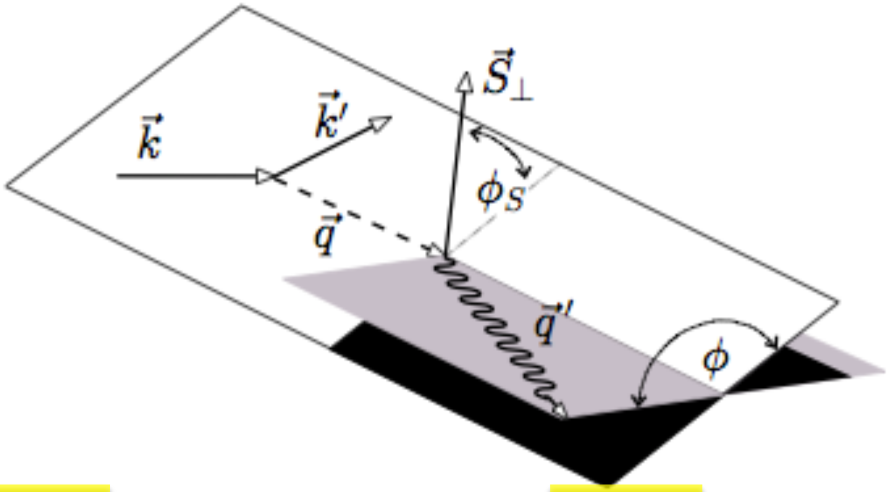
T
$$g_T = g_\pi^{odd}(Q)\left[\frac{1}{x-\xi+i\epsilon}+\frac{1}{x+\xi-i\epsilon}\right] = g_\pi^{odd}(Q)\, C^+$$

L
$$g_L = g_\pi^{odd}(Q)\sqrt{\frac{t_o-t}{Q^2}}\left[\frac{1}{x-\xi+i\epsilon}+\frac{1}{x+\xi-i\epsilon}\right] = g_\pi^{odd}(Q)\sqrt{\frac{t_o-t}{Q^2}}\, C^+,$$

T
$$f_1 = f_{1+,0+} = g_{1+,0-}\otimes A_{+-,++}$$
$$f_2 = f_{1+,0-} = g_{1+,0-}\otimes A_{--,++}$$
$$f_3 = f_{1-,0+} = g_{1+,0-}\otimes A_{+-,-+}$$
$$f_4 = f_{1-,0-} = g_{1+,0-}\otimes A_{--,-+},$$

L
$$f_5 = f_{0+,0-} = g_{0+,0-}\otimes A_{--,++}$$
$$f_6 = f_{0+,0+} = g_{0+,0-}\otimes A_{+-,++},$$

Cross Section



$$\frac{d^4\sigma}{d\Omega d\epsilon_2 d\phi dt} = \Gamma\left\{\frac{d\sigma_T}{dt} + \epsilon_L \frac{d\sigma_L}{dt} + \epsilon\cos 2\phi \frac{d\sigma_{TT}}{dt} + \sqrt{2\epsilon_L(\epsilon+1)}\cos\phi \frac{d\sigma_{LT}}{dt} + h\sqrt{2\epsilon_L(\epsilon-1)}\frac{d\sigma_{L'T}}{dt}\sin\phi\right\},$$

$$\frac{d\sigma_T}{dt} = \mathcal{N}\left(|f_1|^2 + |f_2|^2 + |f_3|^2 + |f_4|^2\right)$$

$$\frac{d\sigma_L}{dt} = \mathcal{N}\left(|f_5|^2 + |f_6|^2\right),$$

$$\frac{d\sigma_{TT}}{dt} = 2\mathcal{N}\,\Re e\left(f_1^* f_4 - f_2^* f_3\right).$$

$$\frac{d\sigma_{LT}}{dt} = 2\mathcal{N}\,\Re e\left[f_5^*(f_2 + f_3) + f_6^*(f_1 - f_4)\right].$$

$$\frac{d\sigma_{LT'}}{dt} = 2\mathcal{N}\,\Im m\left[f_5^*(f_2 + f_3) + f_6^*(f_1 - f_4)\right]$$

In terms of GPDs

$$\epsilon_T^\mu T_\mu^{\Lambda\Lambda'} = e_q \int_{-1}^{1} dx \, \frac{g_T}{2\overline{P}^+} \, \overline{U}(P',\Lambda') \left[i\sigma^{+i} H_T^q(x,\xi,t) + \frac{\gamma^+\Delta^i - \Delta^+\gamma^i}{2M} E_T^q(x,\xi,t) \right.$$

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

M. Diehl, 2001

$$\mathcal{H}_T, \mathcal{E}_T, \tilde{\mathcal{E}}_T, \bar{\mathcal{E}}_T$$

$$\frac{d\sigma_T}{dt} \approx \mathcal{N}^2[g_\pi^{odd}(Q)]^2 \frac{1}{(1+\xi)^4}\left[|\mathcal{H}_T|^2 + \tau\left(|\bar{\mathcal{E}}_T|^2 + |\tilde{\mathcal{E}}_T|^2\right)\right] \quad (11)$$

$$\frac{d\sigma_L}{dt} \approx \mathcal{N}^2[g_\pi^{odd}(Q)]^2 \frac{1}{(1+\xi)^4}\frac{2M^2\tau}{Q^2}|\mathcal{H}_T|^2 \quad (12)$$

$$\frac{d\sigma_{TT}}{dt} \approx \mathcal{N}^2[g_\pi^{odd}(Q)]^2 \frac{1}{(1+\xi)^4}\tau\left[|\bar{\mathcal{E}}_T|^2 - |\tilde{\mathcal{E}}_T|^2 + \Re e\mathcal{H}_T\frac{\Re e(\bar{\mathcal{E}}_T - \mathcal{E}_T)}{2} + \Im m\mathcal{H}_T\frac{\Im m(\bar{\mathcal{E}}_T - \mathcal{E}_T)}{2}\right] \quad (13)$$

$$\frac{d\sigma_{LT}}{dt} \approx \mathcal{N}^2[g_\pi^{odd}(Q)]^2 \frac{1}{(1+\xi)^4}\, 2\sqrt{\frac{2M^2\tau}{Q^2}}|\mathcal{H}_T|^2 \quad (14)$$

$$\frac{d\sigma_{L'T}}{dt} \approx \mathcal{N}^2[g_\pi^{odd}(Q)]^2 \frac{1}{(1+\xi)^4}\tau\sqrt{\frac{2M^2\tau}{Q^2}}\left[\Re e\mathcal{H}_T\frac{\Im m(\bar{\mathcal{E}}_T - \mathcal{E}_T)}{2} - \Im m\mathcal{H}_T\frac{\Re e(\bar{\mathcal{E}}_T - \mathcal{E}_T)}{2}\right] \quad (15)$$

$\tau = (t_0 - t)/2M^2$

Physical Interpretation of the various chiral-odd GPDs

Forward limit

$$H_T(x,0,0) = q_{\Uparrow}^{\uparrow}(x) - q_{\Uparrow}^{\downarrow}(x) = h_1(x)$$

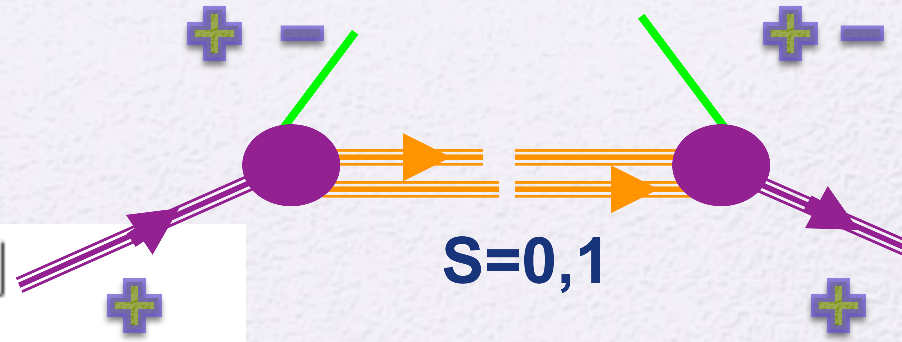
Form Factors

$$\int H_T(x,\xi,t)\, dx = \delta_T(t)$$

$$\int \bar{E}_T(x,\xi,t)\, dx = \int \left(2\tilde{H}_T + E_T\right) dx = \kappa_T(t)$$

$$\int \tilde{E}_T(x,\xi,t)\, dx = 0$$

No direct interpretation of E_T



$S=0$	$S=1$
$\phi^*_{\Lambda'\lambda'}\phi_{\Lambda\lambda}$	$\phi^{\mu}_{\Lambda'\lambda'}\left(\sum_{\lambda''}\epsilon^{*\lambda''}_{\mu}\epsilon^{\lambda''}_{\nu}\right)\phi^{\nu}_{\Lambda\lambda}$

In order to explain the working of Parity transformations, we write the LHS and RHS of Fig. 1

	RHS	LHS
$S=0$	$\phi^*_{\Lambda'\lambda'}$	$\phi_{\Lambda\lambda}$
$S=1$	$\phi^{\mu}_{\Lambda'\lambda'}\epsilon^{*\lambda''}_{\mu}$	$\epsilon^{\lambda''}_{\nu}\phi^{\nu}_{\Lambda\lambda}$

S=1

Odd Even

$$A^{(1)}_{++,--} = -\frac{X+X'}{1+XX'}\, A^{(1)}_{++,++}$$

$$A^{(1)}_{+-,-+} = 0$$

$$A^{(1)}_{++,+-} = -\sqrt{\frac{\langle \tilde{k}_\perp^2 \rangle}{X'^2 + \langle \tilde{k}_\perp^2 \rangle / P^{+2}}}\, A^{(1)}_{++,-+}$$

$$A^{(1)}_{+-,++} = -\sqrt{\frac{\langle k_\perp^2 \rangle}{X^2 + \langle k_\perp^2 \rangle / P^{+2}}}\, A^{(1)}_{-+,++},$$

S=0

Odd Even

$$A^{(0)}_{++,--} = A^{(0)}_{++,++}$$

$$A^{(0)}_{++,+-} = -A^{(0)}_{++,-+}$$

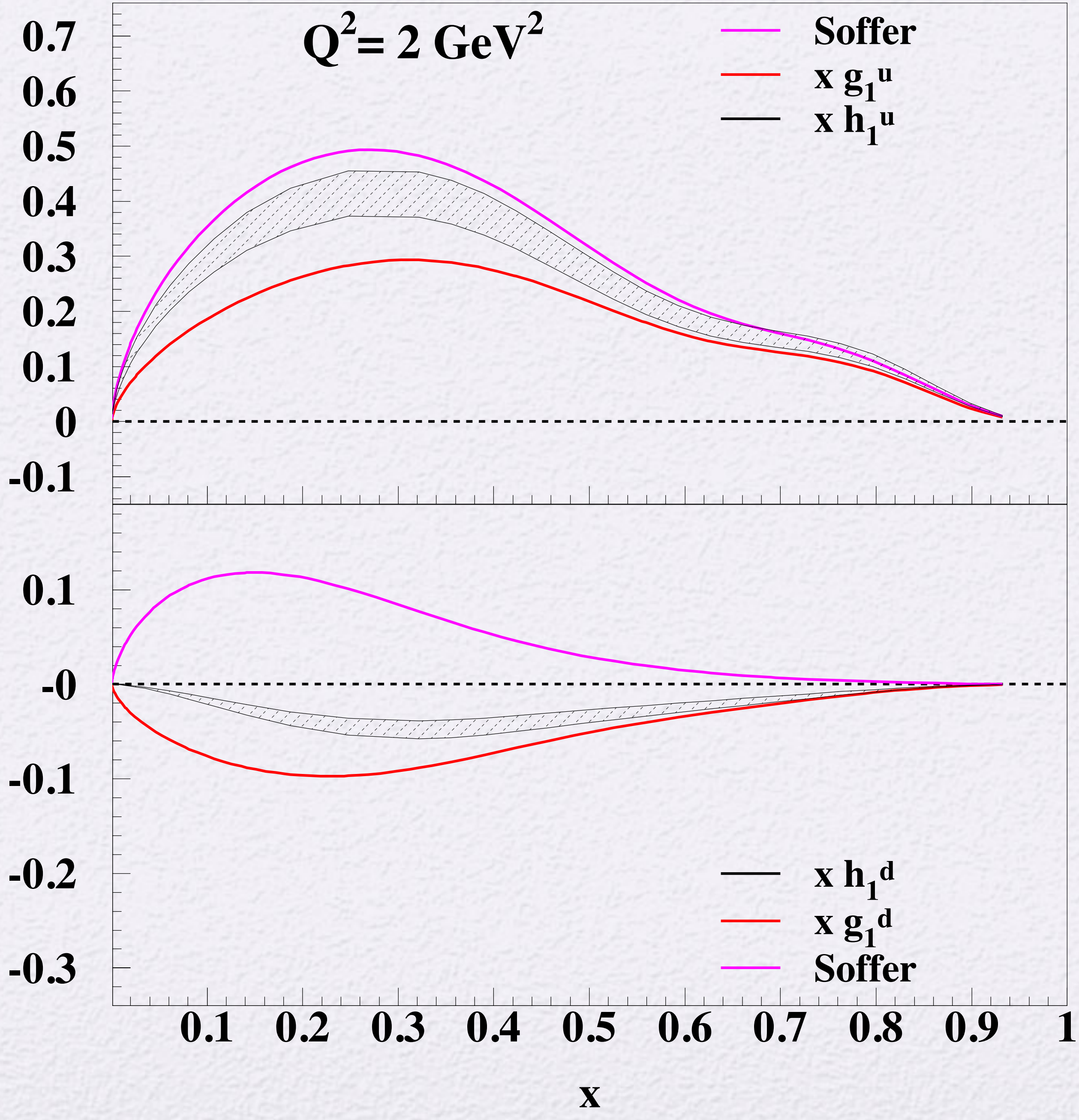
$$A^{(0)}_{+-,++} = -A^{(0)}_{-+,++},$$

$$A^{(0)}_{+-,-+} = \frac{t_0 - t}{4M} \frac{1}{\sqrt{1-\zeta}} \frac{1}{(1-\zeta/2)} \frac{\tilde{X}}{m + MX'} \left[E - (\zeta/2)\tilde{E}\right]$$

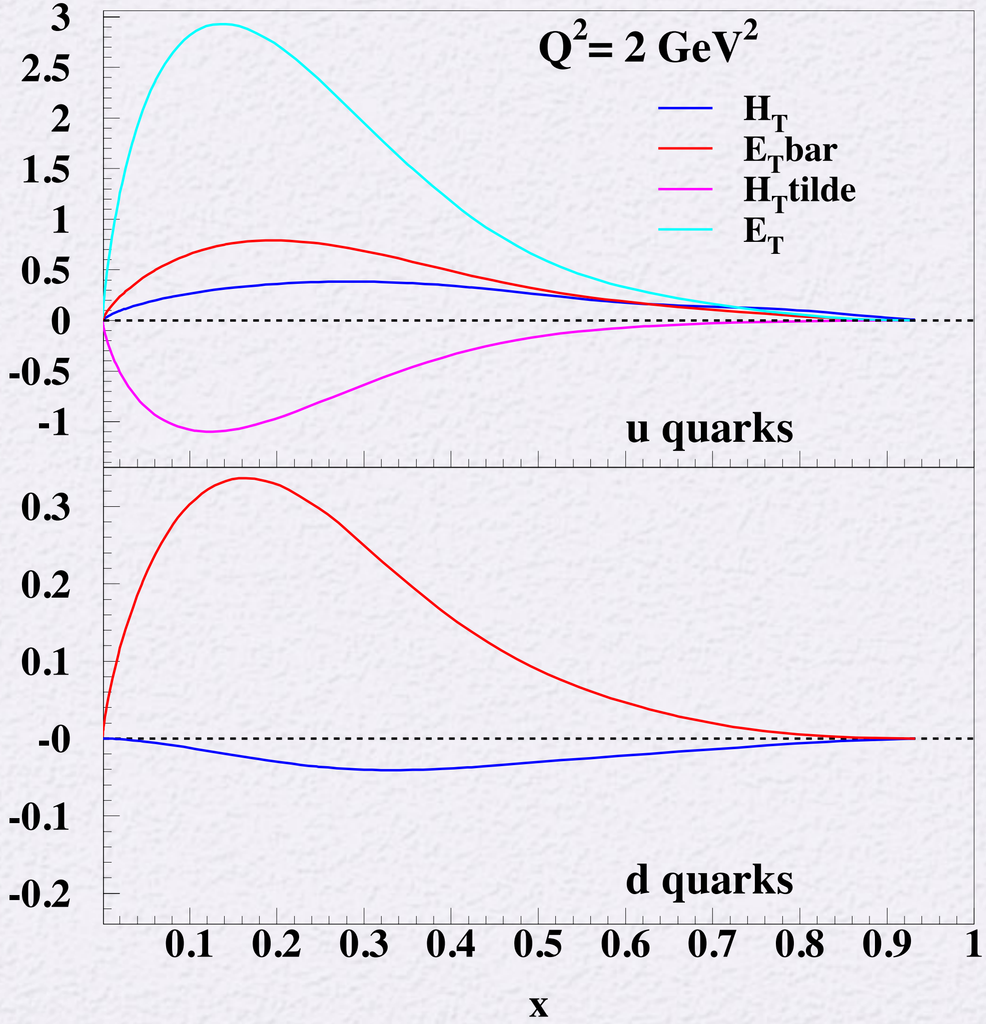
$$H_T^u = \frac{3}{2} H_T^{S=0} - \frac{1}{6} H_T^{S=1}$$

$$H_T^d = -\frac{1}{3} H_T^{S=1}$$

h_1, g_1



Q²= 2 GeV²
Soffer
x g₁ᵘ
x h₁ᵘ
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0
-0.2
-0.3
x h₁ᵈ
x g₁ᵈ
Soffer
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
x



Q^2= 2 GeV^2
H_T
$E_T$bar
$H_T$tilde
E_T
u quarks
d quarks
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0.3
0.2
0.1
-0
-0.1
-0.2
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
x

$$\sum_{\Lambda} \Im m\, F_{\Lambda+,\Lambda-} \propto h_1^{\perp}(x,k_T^2)$$

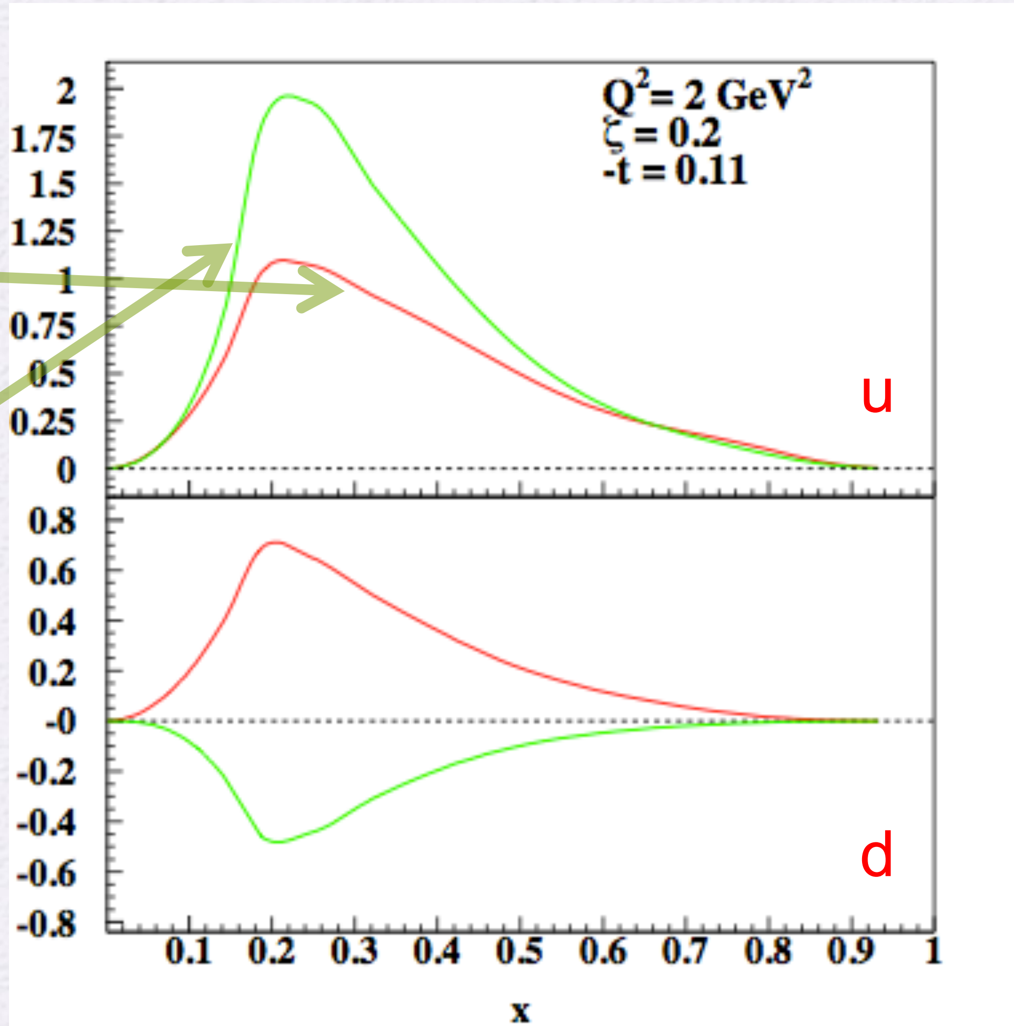
$$\sum_{\lambda} \Im m\, F_{+\lambda,-\lambda} \propto f_{1T}^{\perp}(x,k_T^2)$$

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

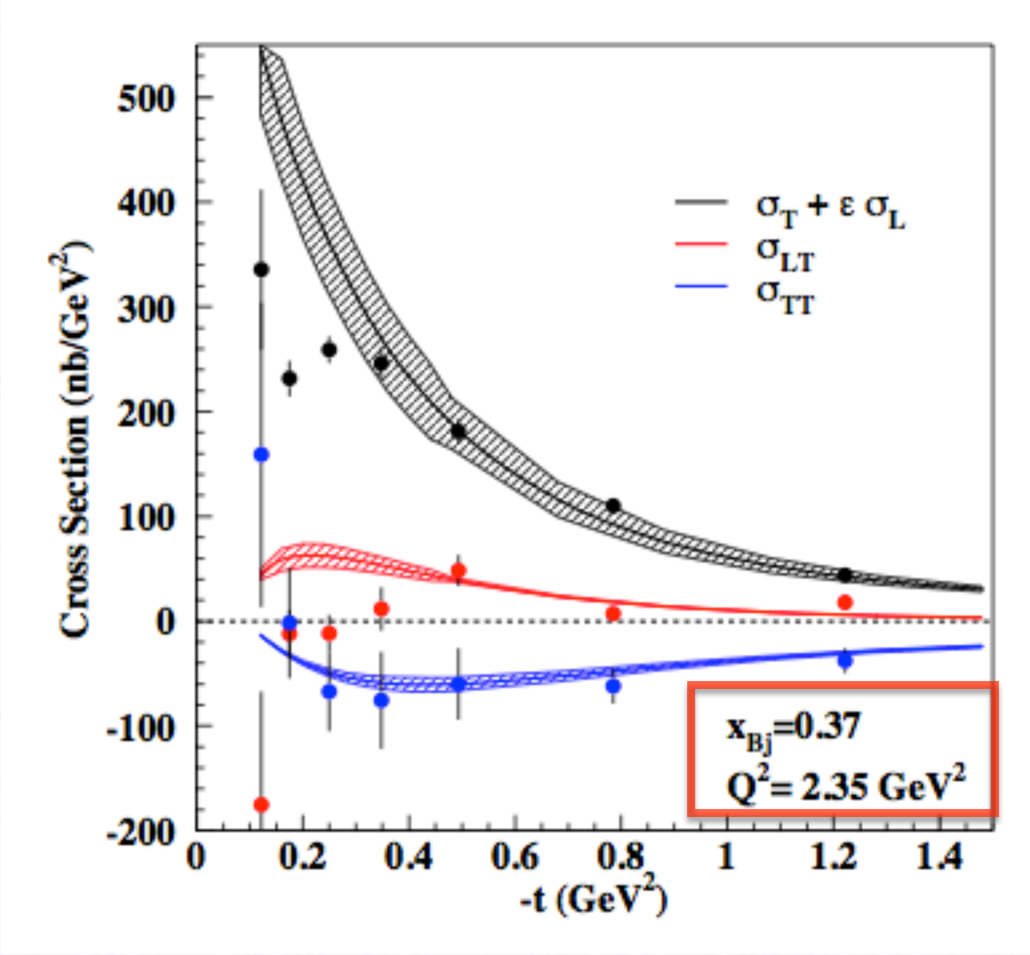
$$A_{++,-+} - A_{-+,++} \propto E$$

(h_1^T) $2\tilde{H}_T + E_T$

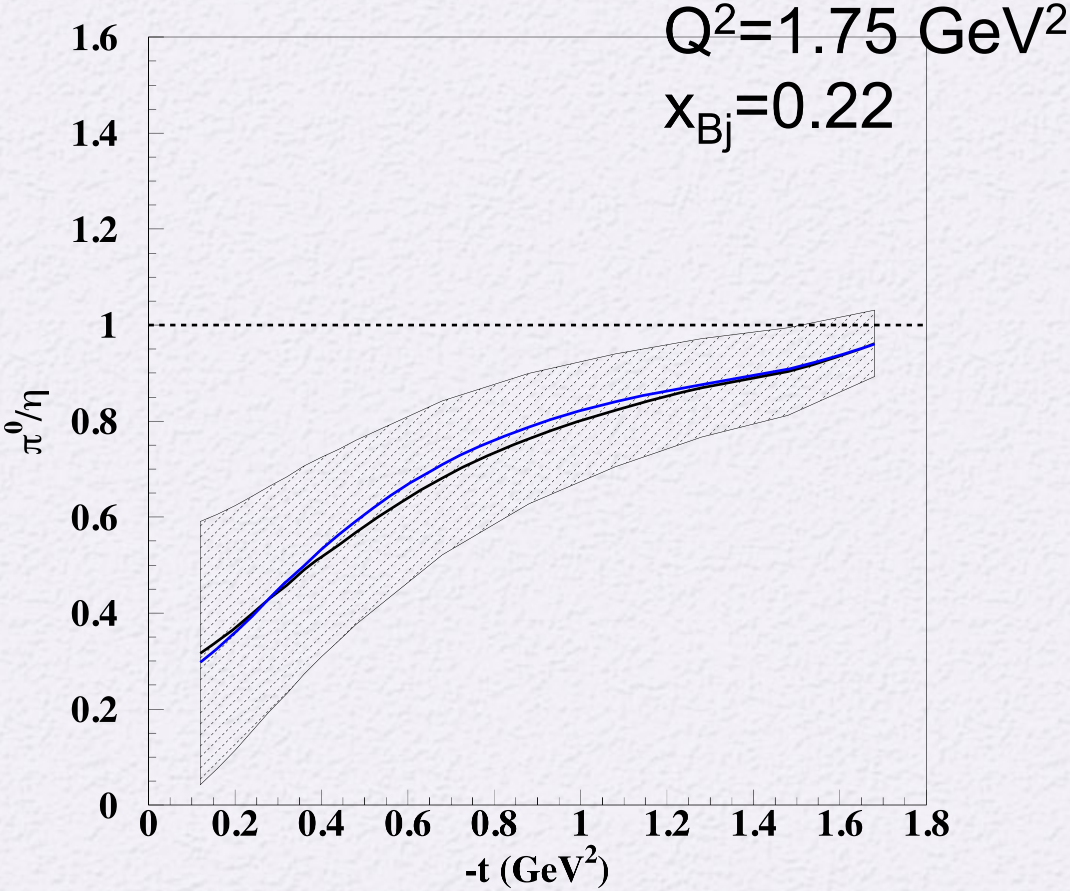
$\tilde{E}_T$



How well do the parameters fixed with DVCS data reproduce π^o electroproduction data?



Hall B data, Kubarovsky& Stoler, PoS ICHEP 2010



Q^2=1.75 GeV^2
x_{Bj}=0.22
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
π^0/η
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
-t (GeV^2)

Vary tensor charge as a parameter to see sensitivity of data

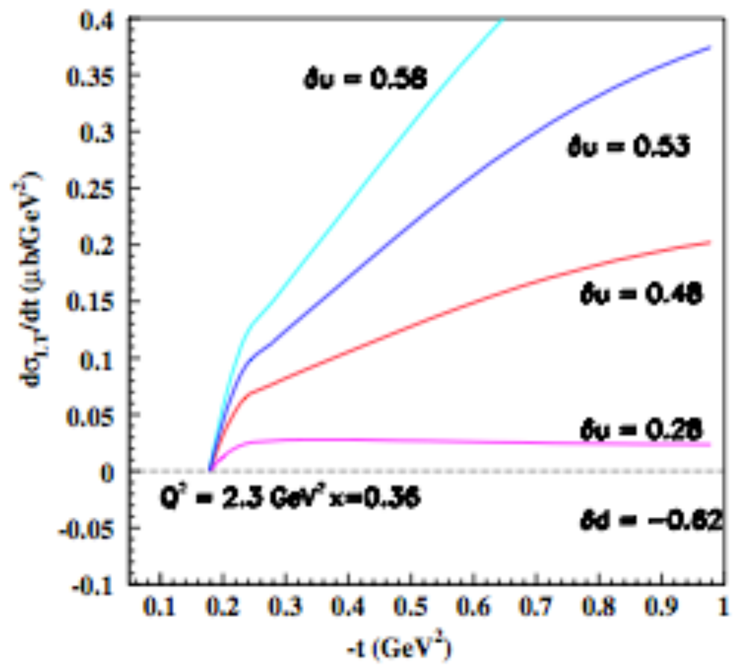


FIG. 9 (color online). (color online) Longitudinal/transverse interference term, $d\sigma_{LT}/dt$, Eq. (15), plotted vs $-t$ at $Q^2 = 2.3$ GeV^2, $x_{Bj} = 0.36$, for different values of the u quarks tensor charge, δu, used as a freely varying parameter in the GPD approach. The d quark component, δd was taken as $\delta d = -0.62$, i.e. equal to the central value extracted in the global fit of Ref. [44].

Q^2 dependence ➔obviously not predicted by collinear factorization

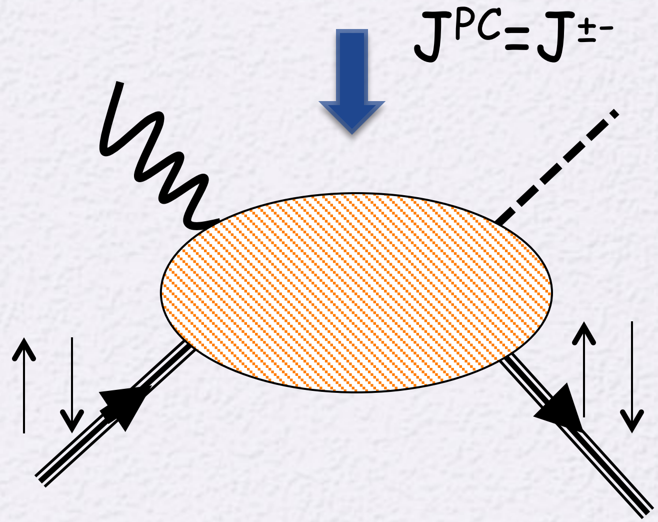
✓ Presence of a large transverse component

✓ "Anomalous" Pion Vertex behavior

Explain large T component

M.Diehl, Phys.Rep.(2003)

Chiral Even GPD	J^{PC}	
$H(x,\xi,t)-H(-x,\xi,t)$	$0^{++}, 2^{++}, \ldots$	$(S=1)$
$E(x,\xi,t)-E(-x,\xi,t)$	$0^{++}, 2^{++}, \ldots$	$(S=1)$
$\widetilde{H}(x,\xi,t)+\widetilde{H}(-x,\xi,t)$	$1^{++}, 3^{++}, \ldots$	$(S=1)$
$\widetilde{E}(x,\xi,t)+\widetilde{E}(-x,\xi,t)$	$0^{-+}, 1^{++}, 2^{-+}, 3^{++}, \ldots$	$(S=0,1)$
$H(x,\xi,t)+H(-x,\xi,t)$	$1^{--}, 3^{--}, \ldots$	$(S=1)$
$E(x,\xi,t)+E(-x,\xi,t)$	$1^{--}, 3^{--}, \ldots$	$(S=1)$
$\widetilde{H}(x,\xi,t)-\widetilde{H}(-x,\xi,t)$	$2^{--}, 4^{--}, \ldots$	$(S=1)$
$\widetilde{E}(x,\xi,t)-\widetilde{E}(-x,\xi,t)$	$1^{+-}, 2^{--}, 3^{+-}, 4^{--}, \ldots$	$(S=0,1)$



GGL, arXiv:hep-ph 1201.6088

Chiral Odd GPD	J^{-C}		J^{+C}	
$H_T(x,\xi,t)-H_T(-x,\xi,t)$	$2^{-+}, 4^{-+}, \ldots$	$(S=0)$	$1^{++}, 3^{++} \ldots$	$(S=1)$
$E_T(x,\xi,t)-E_T(-x,\xi,t)$	$2^{-+}, 4^{-+}, \ldots$	$(S=0)$	$1^{++}, 3^{++} \ldots$	$(S=1)$
$\widetilde{H}_T(x,\xi,t)-\widetilde{H}_T(-x,\xi,t)$			$1^{++}, 3^{++}, \ldots$	$(S=1)$
$\widetilde{E}_T(x,\xi,t)-\widetilde{E}_T(-x,\xi,t)$	$2^{-+}, 4^{-+}, \ldots$	$(S=0)$	$3^{++}, 5^{++} \ldots$	$(S=1)$
$H_T(x,\xi,t)+H_T(-x,\xi,t)$	$1^{--}, 2^{--}, 3^{--} \ldots$	$(S=1)$	$1^{+-}, 3^{+-} \ldots$	(S=0)
$E_T(x,\xi,t)+E_T(-x,\xi,t)$	$1^{--}, 2^{--}, 3^{--} \ldots$	$(S=1)$	$1^{+-}, 3^{+-} \ldots$	(S=0)
$\widetilde{H}_T(x,\xi,t)+\widetilde{H}_T(-x,\xi,t)$	$1^{--}, 2^{--}, 3^{--} \ldots$	$(S=1)$		
$\widetilde{E}_T(x,\xi,t)+\widetilde{E}_T(-x,\xi,t)$	$2^{--}, 3^{--}, 4^{--} \ldots$	$(S=1)$	$3^{+-}, 5^{+-} \ldots$	(S=0)

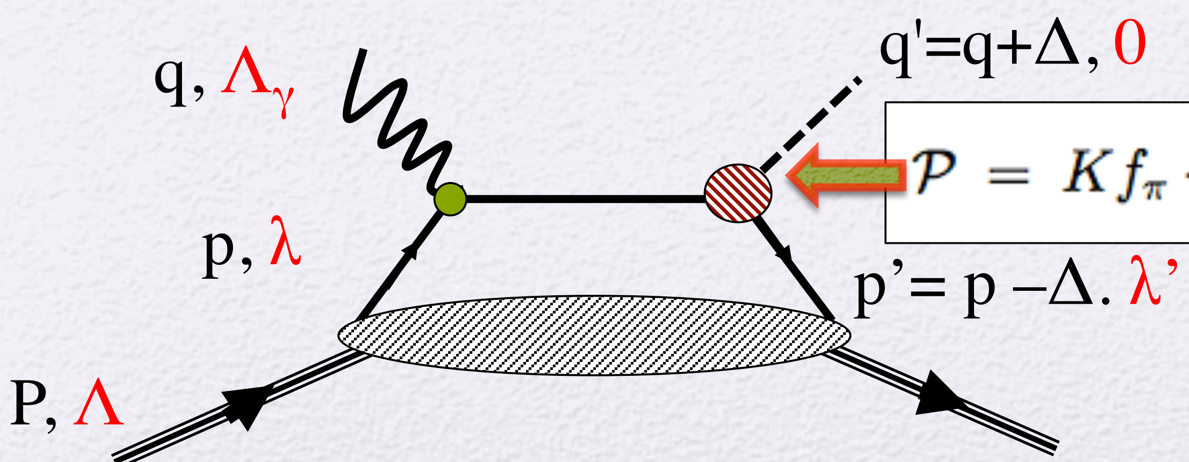
$\widetilde{H}(x,\xi,t)-\widetilde{H}(-x,\xi,t)$	$2^{--}, 4^{--}, \dots$	$(S=1)$
$\widetilde{E}(x,\xi,t)-\widetilde{E}(-x,\xi,t)$	$1^{+-}, 2^{--}, 3^{+-}, 4^{--}, \dots$	$(S=0,1)$

Polarized antiquarks

No!

All these combinations are possible, therefore…

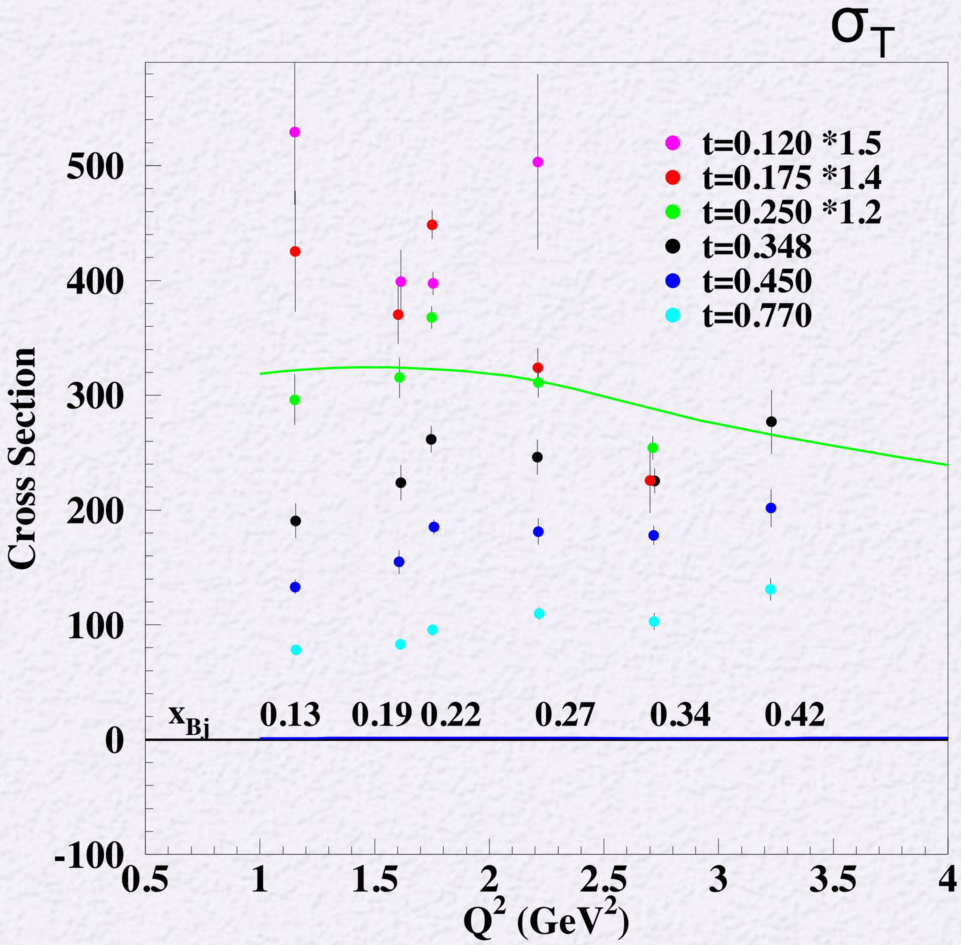
$H_T(x,\xi,t)+H_T(-x,\xi,t)$	$1^{--}, 2^{--}, 3^{--} \dots$	$(S=1)$	$1^{+-}, 3^{+-} \dots$	(S=0)
$E_T(x,\xi,t)+E_T(-x,\xi,t)$	$1^{--}, 2^{--}, 3^{--} \dots$	$(S=1)$	$1^{+-}, 3^{+-} \dots$	(S=0)
$\widetilde{H}_T(x,\xi,t)+\widetilde{H}_T(-x,\xi,t)$	$1^{--}, 2^{--}, 3^{--} \dots$	$(S=1)$		
$\widetilde{E}_T(x,\xi,t)+\widetilde{E}_T(-x,\xi,t)$	$2^{--}, 3^{--}, 4^{--} \dots$	$(S=1)$	$3^{+-}, 5^{+-} \dots$	(S=0)

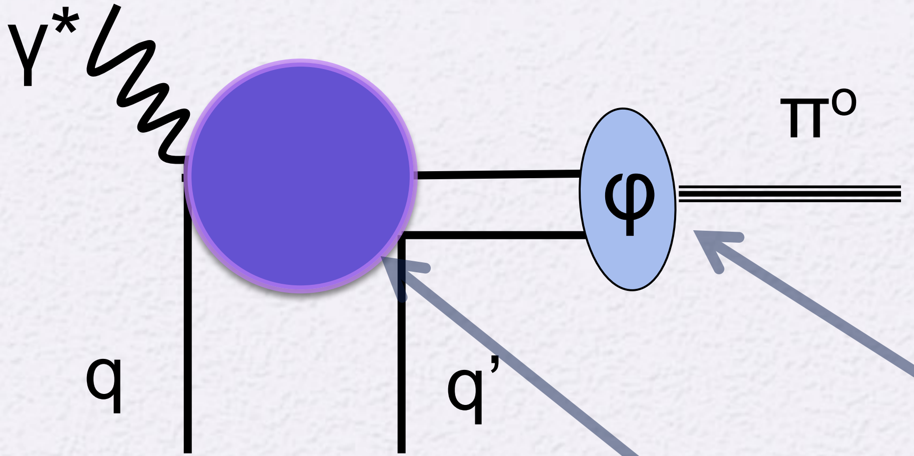


$$\mathcal{P} = K f_\pi \left\{ \gamma_5 \not{q}' \phi_\pi(\tau) + \gamma_5 \mu_\pi \phi_\pi^{(3)}(\tau) \right\}$$

$\gamma_\mu \gamma_5$ γ_5

Now that we have allowed for a large T component, explain the Q^2 dependence....



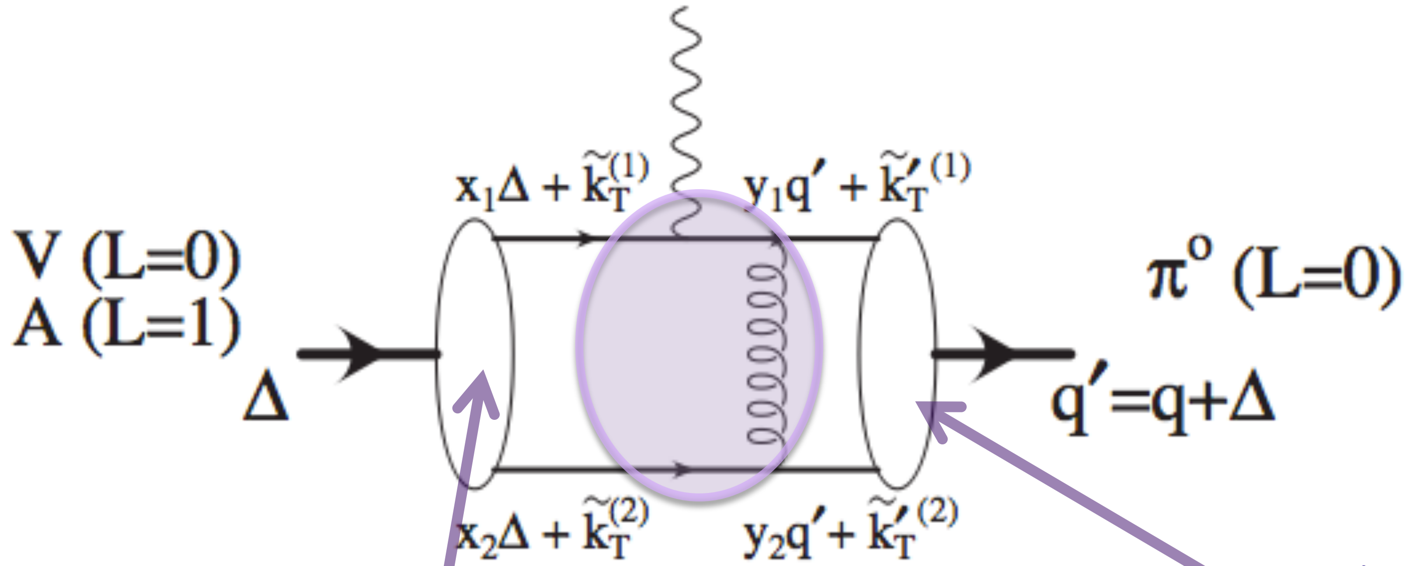


Take e.g. the modified perturbative approach

$$g_{\Lambda_{\gamma^*},\lambda;0,\lambda'} = \int d\tau \int d^2b\, \hat{\mathcal{F}}_{\Lambda_{\gamma^*},\lambda;0,\lambda'}(Q^2,\tau,b)\,\alpha_S(\mu_R)\,\exp[-S]\,\hat{\phi}_\pi(\tau,b)$$

Spin plays a role

LIUTI Ahmad et al., PHYSICAL REVIEW D **79**, 054014 (2009



"size matters"

twist 3

$$g^V_{\Lambda_{\gamma^*},\lambda;0,\lambda'} = \int dx_1 dy_1 \int d^2b\, \hat{\psi}_V(y_1,b)\, \hat{F}_{\Lambda_{\gamma^*},\lambda;0,\lambda'}(Q^2,x_1,x_2,b)\,\alpha_S(\mu_R)\exp[-S]\, \hat{\phi}_{\pi^o}(x_1,b)$$

$$g^A_{\Lambda_{\gamma^*},\lambda;0,\lambda'} = \int dx_1 dy_1 \int d^2b\, \hat{\psi}_A(y_1,b)\, \hat{F}_{\Lambda_{\gamma^*},\lambda;0,\lambda'}(Q^2,x_1,x_2,b)\,\alpha_S(\mu_R)\exp[-S]\, \hat{\phi}_{\pi^o}(x_1,b)$$

$V=1^{--}, 2^{--}, 3^{--}, \ldots$ $A=1^{+-}, 3^{+-}, \ldots$

Size of qqbar pair

We obtain a mixture of configurations of different "radii" (and different Q2 dependence)

✓ V ➔ π^o ➔ No change of OAM, $\Delta L=0$

✓ A ➔ π^o ➔ One unit change of OAM, $\Delta L=1$

Axial vector transition involves Bessel J_1

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

qqbar pair are more separated!

Summary of Q^2 dependence

✓ Twist 3 DA has a steeper dependence in the longitudinal variable “x” yields larger contribution

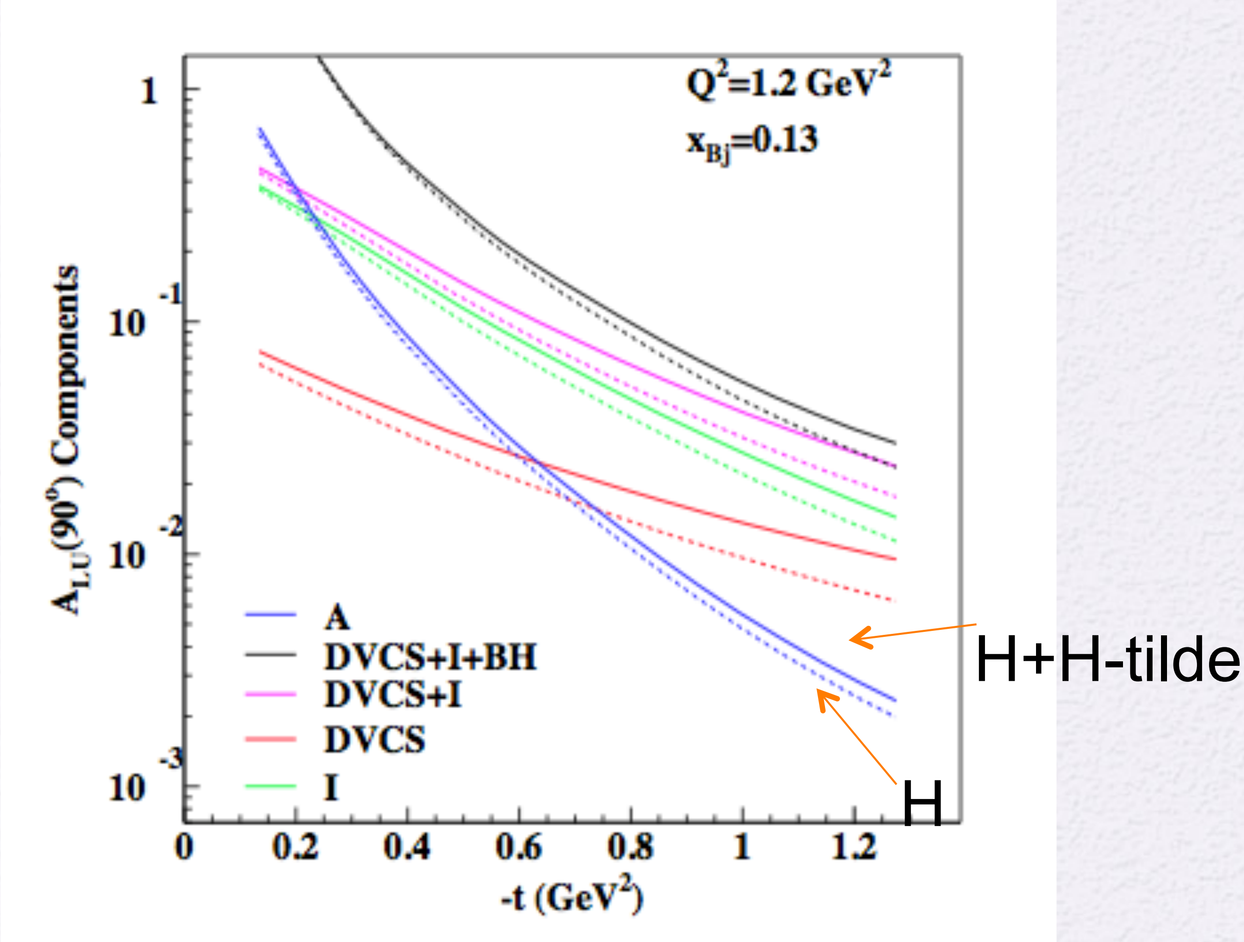
✓ This can compensate for the fall off in Q^2

✓ Spin plays a role

(A connection is possible with A. Radyushkin’s et al. interpretation of Babar data more channels including rho production need to be explored)

Back up

Role of BSA components: H and H-tilde



Goldstein et al. arXiv:1012.3776

Preliminary Results (PDFs)

(D. Perry, DIS 2010 and MS Thesis 2010, K. Holcomb, Exclusive Processes Workshop, Jlab 2010)

$Q^2 = 7.5\ GeV^2$