Extraction of the Transversity GPDs Parameters

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DVMP Meeting at MIT

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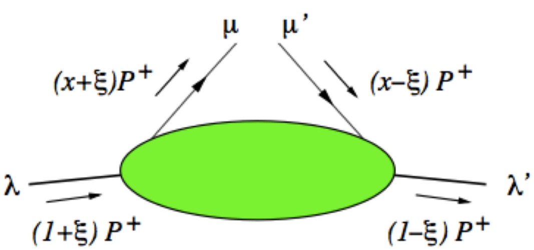
Generalized Parton Distributions

- A wealth of information on the nucleon structure is encoded in the Generalized Parton Distributions.
- GPDs are the functions of three kinematic variables: x, ξ and t
- They admit a particularly intuitive physical interpretation at zero skewness $\xi=0$, where after a Fourie transform GPDs describe the spatial distribution of quarks with given longitudinal momentum in the transverse plane.



In the quark sector

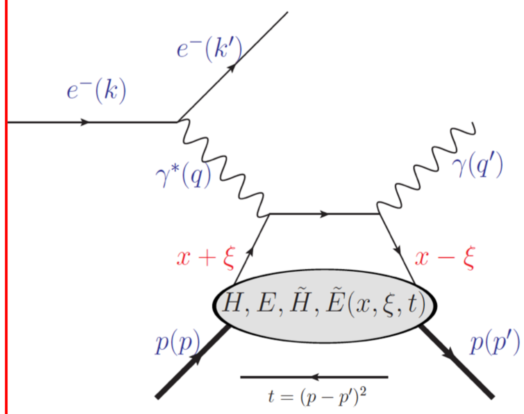
- 4 chiral even GPDs where partons do not flip helicity $H^q, \tilde{H}^q, E^q, \tilde{E}^q$
- 4 chiral odd $H_T^q, \tilde{H}_T^q, E_T^q, \bar{E}_T^q = 2\tilde{H}_T^q + E_T^q$

DVCS

- Deeply Virtual Compton Scattering is the cleanest way to study GPDs
- GPDs appear in the DVCS amplitude as Compton Form Factor (CFF)

$$\mathcal{H} = \int_{-1}^{1} H(x,\xi,t)\Big(\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon}\Big)dx$$

- DVCS accesses only chiral-even GPDs due to suppression of the helicity flip amplitude
- Flavor separation is difficult



DVCS at leading order

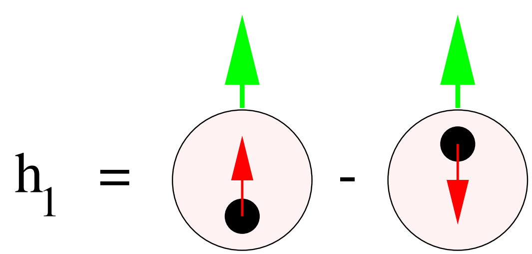
$$\xi = \frac{x_B}{2 - x_B}$$

$$t = (p - p')^2$$

$x\ is\ not\ experimentally\ accessible$

Chiral-odd GPDs

- The chiral-odd GPDs are difficult to access since subprocesses with quark helicity-flip are usually strongly suppressed
- Very little known about the chiral-odd GPDs
- Transversity distribution $H_T^q(x,0,0) = h_1^q(x)$

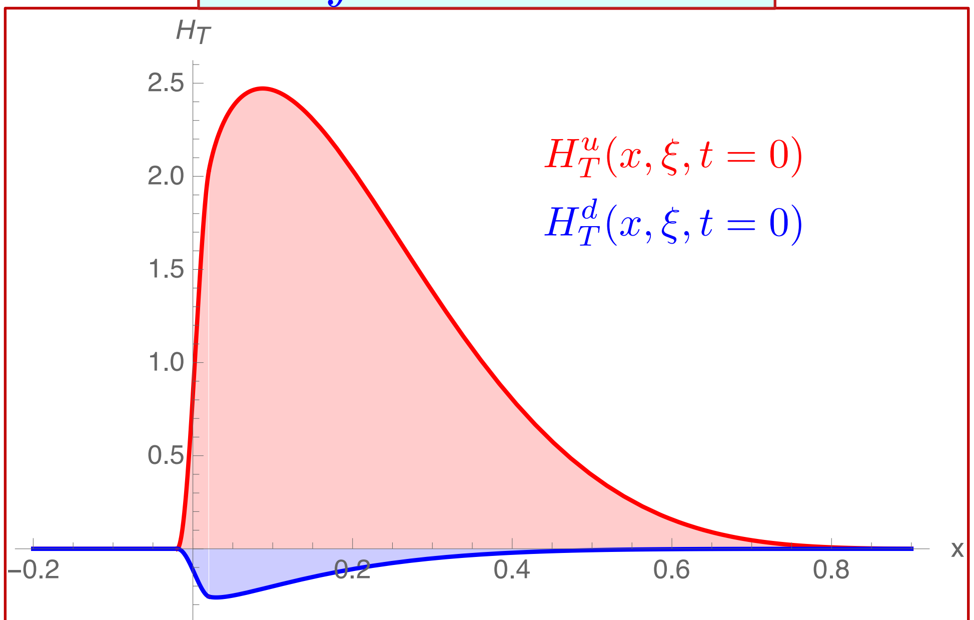


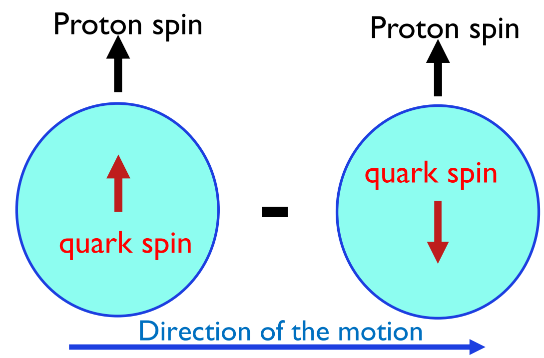
The transversity describes the distribution of transversely polarized quarks in a transversely polarized nucleon

Proton Tensor Charge

$$\delta_T^u = \int dx H_T^u(x, \xi, t = 0)$$

$$\delta_T^d = \int dx H_T^d(x, \xi, t = 0)$$





The tensor charge measures the net distribution of transversely polarized quarks inside a transversely polarized proton

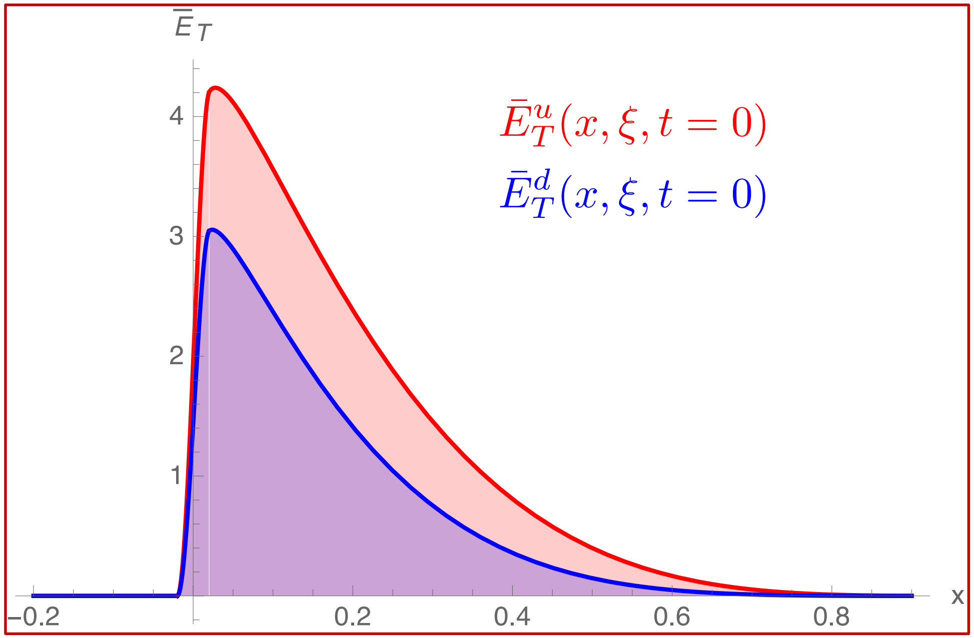
$$\langle P(k,\sigma)|\bar{q}\sigma_{\mu\nu}|P(k,\sigma)\rangle = \delta_T^q \bar{u}(k,\sigma)\sigma_{\mu\nu}u(k,\sigma)$$

The nucleon tensor charge is a fundamental property of the nucleon and its determination is among the main goals of existing and future experiments.

Proton Anomalous Tensor Magnetic Moment

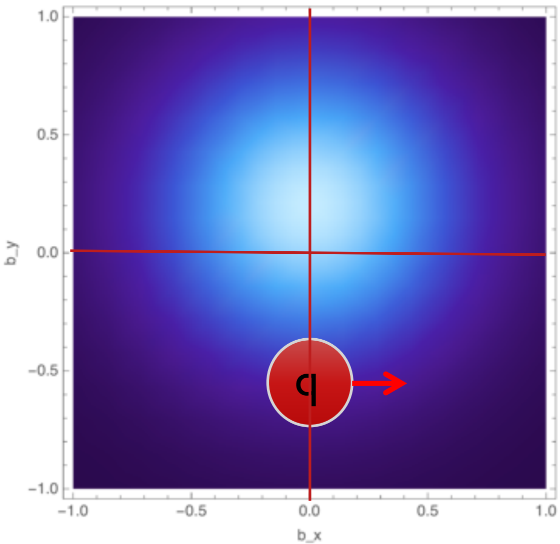
$$\kappa_T^u = \int dx \bar{E}_T^u(x, \xi, t=0)$$

$$\kappa_T^d = \int dx \bar{E}_T^d(x, \xi, t=0)$$



Anomalous tensor magnetic moment induces a sideways shift of the quark density in the transverse to the nucleon motion plane.

Density of Transversely Polarized Quarks in an Unpolarized Proton in the Transverse Plane



$\bar{E}_T$ is related to the distortion of the polarized quark distribution in the transverse plane for an unpolarized nucleon

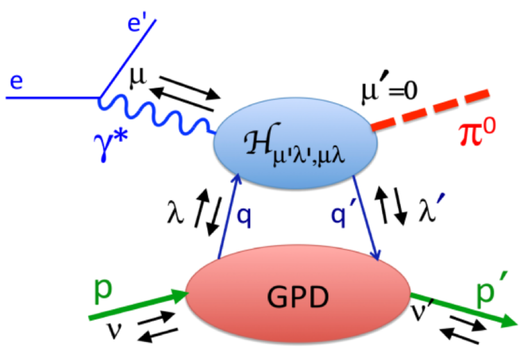
$$\delta(x,\vec{b}) = \frac{1}{2}[H(x,\vec{b}) - \frac{b_y}{m}\frac{\partial}{\partial b^2}\bar{E}_T(x,\vec{b})]$$

$$ep \to ep\pi^0$$

DVMP Leading Twist

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi_\pi} = \Gamma(Q^2, x_B, E)\frac{1}{2\pi}(\sigma_T + \epsilon\sigma_L + \epsilon\cos 2\phi_\pi \sigma_{TT} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_\pi \sigma_{LT})$$

$$\sigma_L = \frac{4\pi\alpha_e}{\kappa Q^2}[(1-\xi^2)|\langle\tilde{H}\rangle|^2 - 2\xi^2 Re(\langle\tilde{H}\rangle|\langle\tilde{E}\rangle) - \frac{t}{4m^2}\xi^2|\langle\tilde{E}\rangle|^2]$$



$$\sigma_L \sim \frac{1}{Q^6}$$

$$\frac{\sigma_T}{\sigma_L} \sim \frac{1}{Q^2}$$

$$Q^2 \to \infty, \quad x_B, t\ fixed$$

The brackets <F> denote the convolution of the elementary process with the GPD F (generalized form factors)

J.C. Collins, L. Frankfurt, and M. Strikman
Factorization for hard exclusive electroproduction of mesons in QCD
Phys. Rev. D **56**, 2982 (1997)

Leading Twist Failed to describe data

$ep \to ep\pi^0$

Leading twist σ_L – dominance, no ϕ modulation

$$\sigma_L = \frac{4\pi\alpha_e}{\kappa Q^2}\left[(1-\xi^2)|\langle\tilde{H}\rangle|^2 - 2\xi^2 Re(\langle\tilde{H}\rangle|\langle\tilde{E}\rangle) - \frac{t}{4m^2}\xi^2|\langle\tilde{E}\rangle|^2\right]$$

σ_L suppressed by a factor coming from:

$$\tilde{H}^\pi = \frac{1}{3\sqrt{2}}[2\tilde{H}^u + \tilde{H}^d]$$

$\tilde{H}^u$ and $\tilde{H}^d$ have opposite signes

S. Goloskokov and P. Kroll
S. Liuti and G. Goldstein

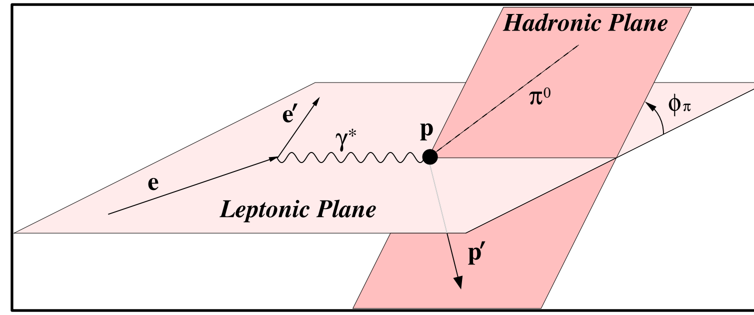
$$\langle\tilde{H}\rangle = \sum_\lambda \int_{-1}^{1} dx M(x,\xi,Q^2,\lambda)\tilde{H}(x,\xi,t)$$

$$\langle\tilde{E}\rangle = \sum_\lambda \int_{-1}^{1} dx M(x,\xi,Q^2,\lambda)\tilde{E}(x,\xi,t)$$

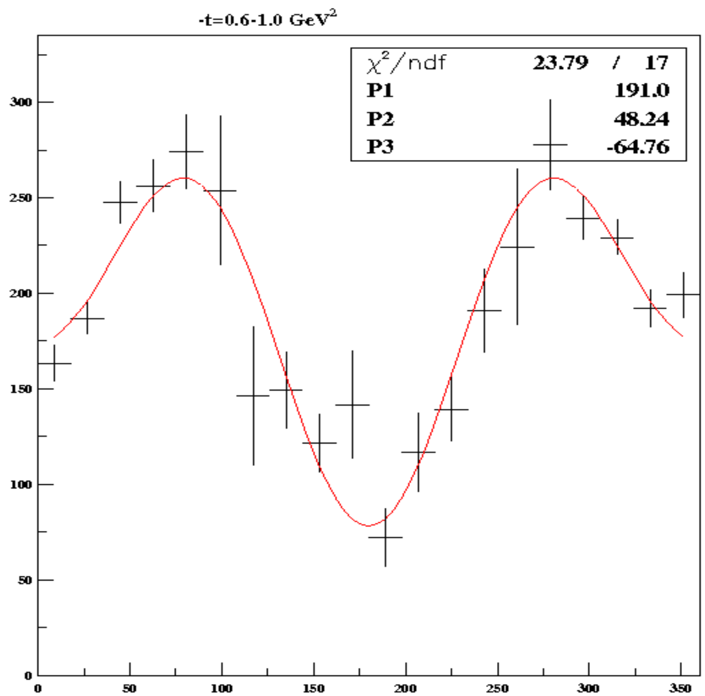
The brackets <F> denote the convolution of the elementary process with the GPD F (generalized form factors)

Structure Functions

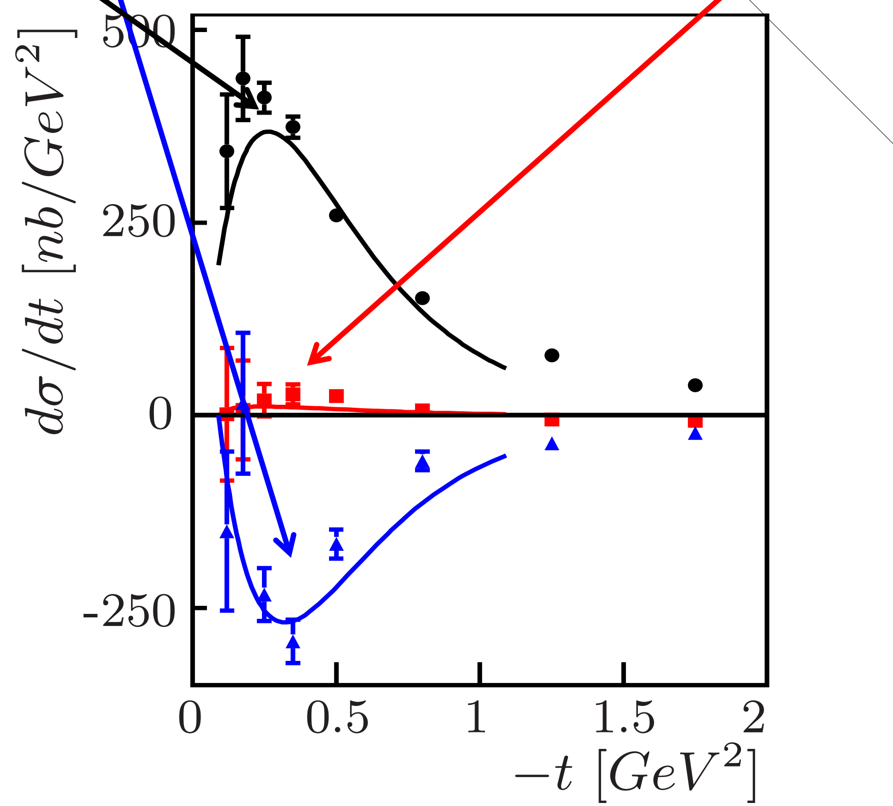
$\sigma_U = \sigma_T + \varepsilon\sigma_L \quad \sigma_{TT} \quad \sigma_{LT}$



$$\frac{d\sigma}{dt\,d\phi}(Q^2,x,t,\phi) = \frac{1}{2\pi}\left(\left(\frac{d\sigma_T}{dt} + \varepsilon\frac{d\sigma_L}{dt}\right) + \varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi + \sqrt{2\varepsilon(\varepsilon+1)}\,\frac{d\sigma_{LT}}{dt}\cos\phi\right)$$



φ distribution

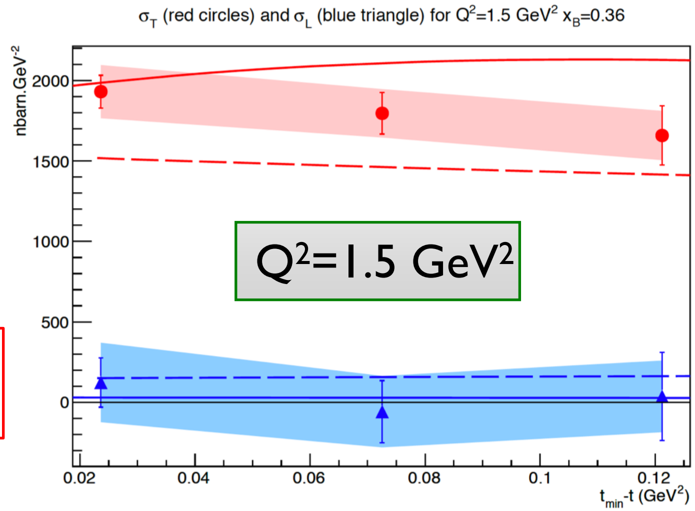


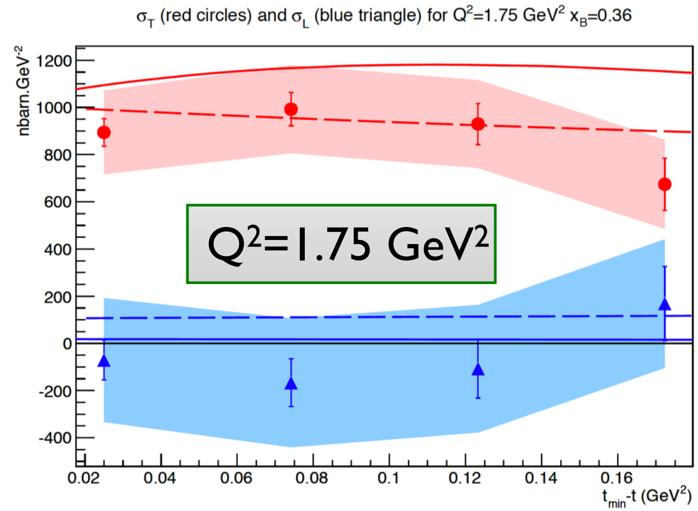
-t

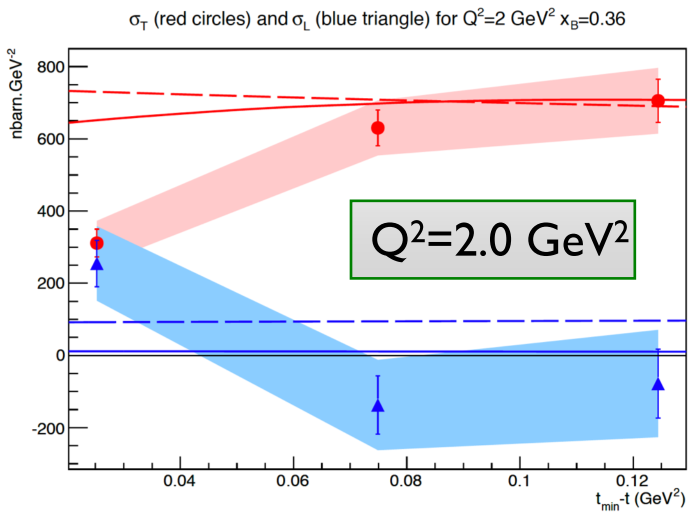
Rosenbluth separation σ_T and σ_L Hall-A Jefferson Lab

σ_T

σ_L







- Experimental **proof** that the transverse π^0 cross section is dominant!
- It opens the direct way to study the transversity GPDs in pseudoscalar exclusive production

- Hall-A, PRL, 118, 222002 (2017)

$$ep \to ep\pi^0$$

Structure functions and GPDs

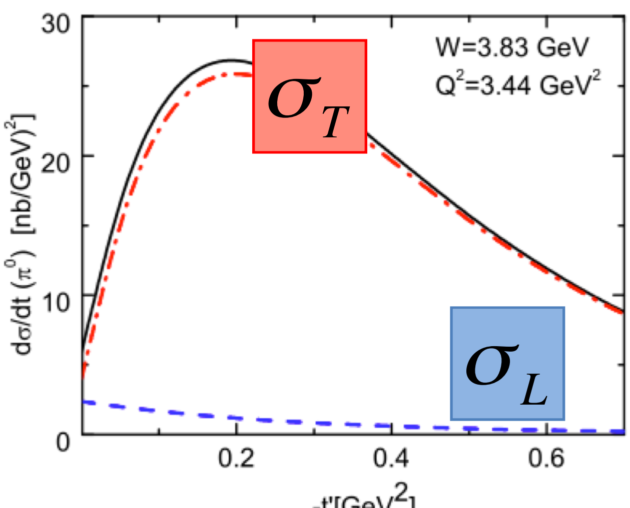
$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi_\pi} = \Gamma(Q^2, x_B, E)\frac{1}{2\pi}(\sigma_T + \epsilon\sigma_L + \epsilon\cos 2\phi_\pi \sigma_{TT} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_\pi \sigma_{LT})$$

$$\sigma_T = \frac{4\pi\alpha_e}{2\kappa}\frac{\mu_\pi^2}{Q^4}\left[(1-\xi^2)|\langle H_T\rangle|^2 - \frac{t'}{8m^2}|\langle \bar{E}_T\rangle|^2\right]$$

$$\sigma_{TT} = \frac{4\pi\alpha_e}{2\kappa}\frac{\mu_\pi^2}{Q^4}\frac{t'}{8m^2}|\langle \bar{E}_T\rangle|^2$$

$$\langle \bar{E}_T\rangle = \sum_\lambda \int_{-1}^{1} dx M(x,\xi,Q^2,\lambda)\bar{E}_T(x,\xi,t)$$

$$\langle H_T\rangle = \sum_\lambda \int_{-1}^{1} dx M(x,\xi,Q^2,\lambda)H_T(x,\xi,t)$$



<u>Transversity GPD model</u>

S. Goloskokov and P. Kroll

S. Liuti and G. Goldstein

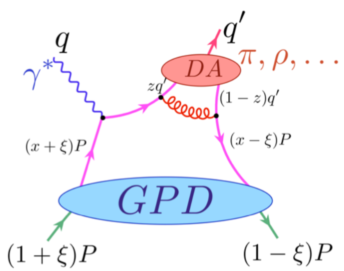
- $\sigma_L << \sigma_T$

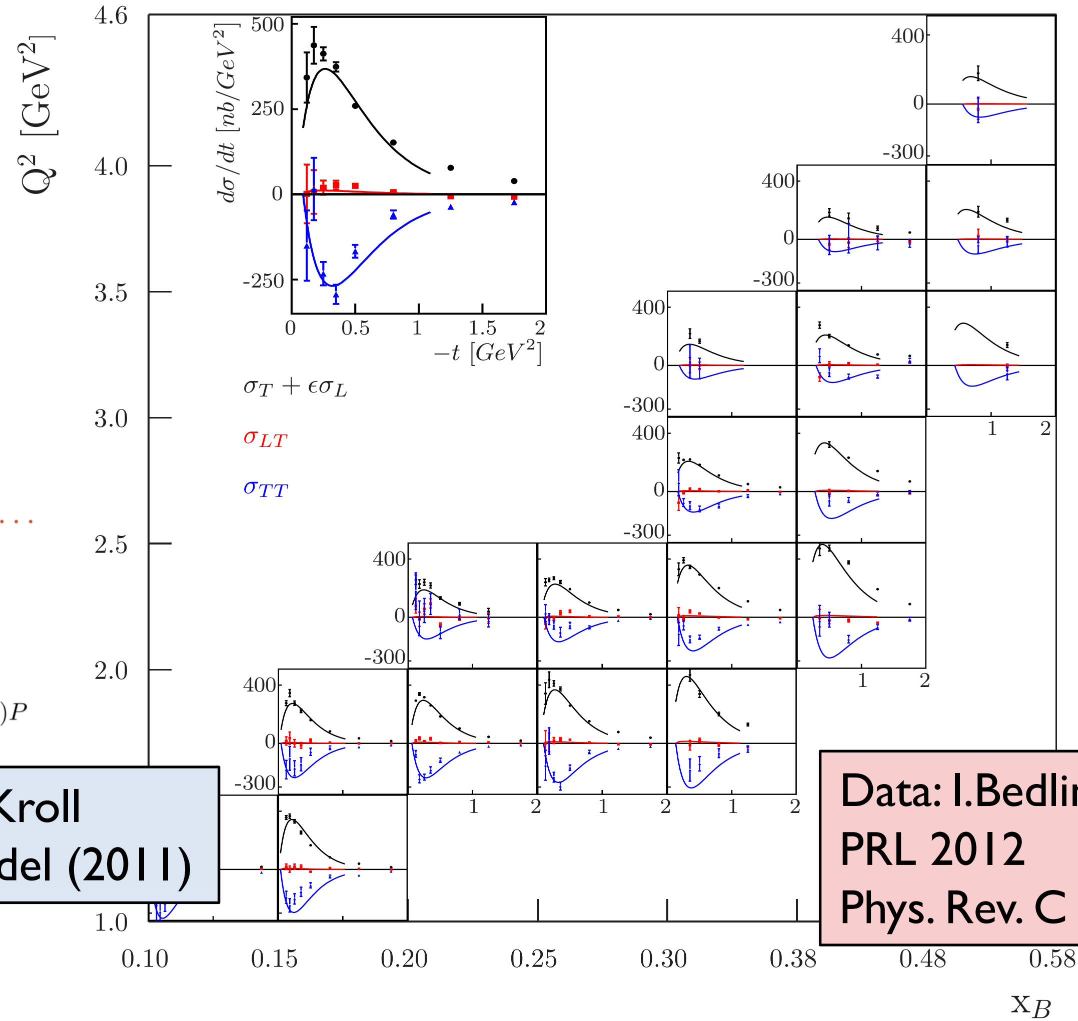
The brackets <F> denote the convolution of the elementary process with the GPD F (Generalized Form Factors, GFF)

CLAS: π^0 Structure Functions

$(\sigma_T + \varepsilon\sigma_L)$ σ_{TT} σ_{LT}

$$\gamma^* p \rightarrow p\pi^0$$





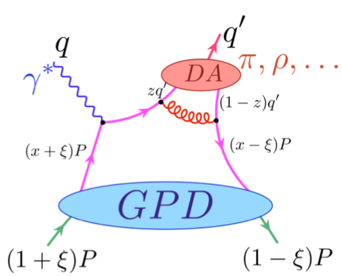
Curves: Goloskokov, Kroll
Transversity GPD model (2011)

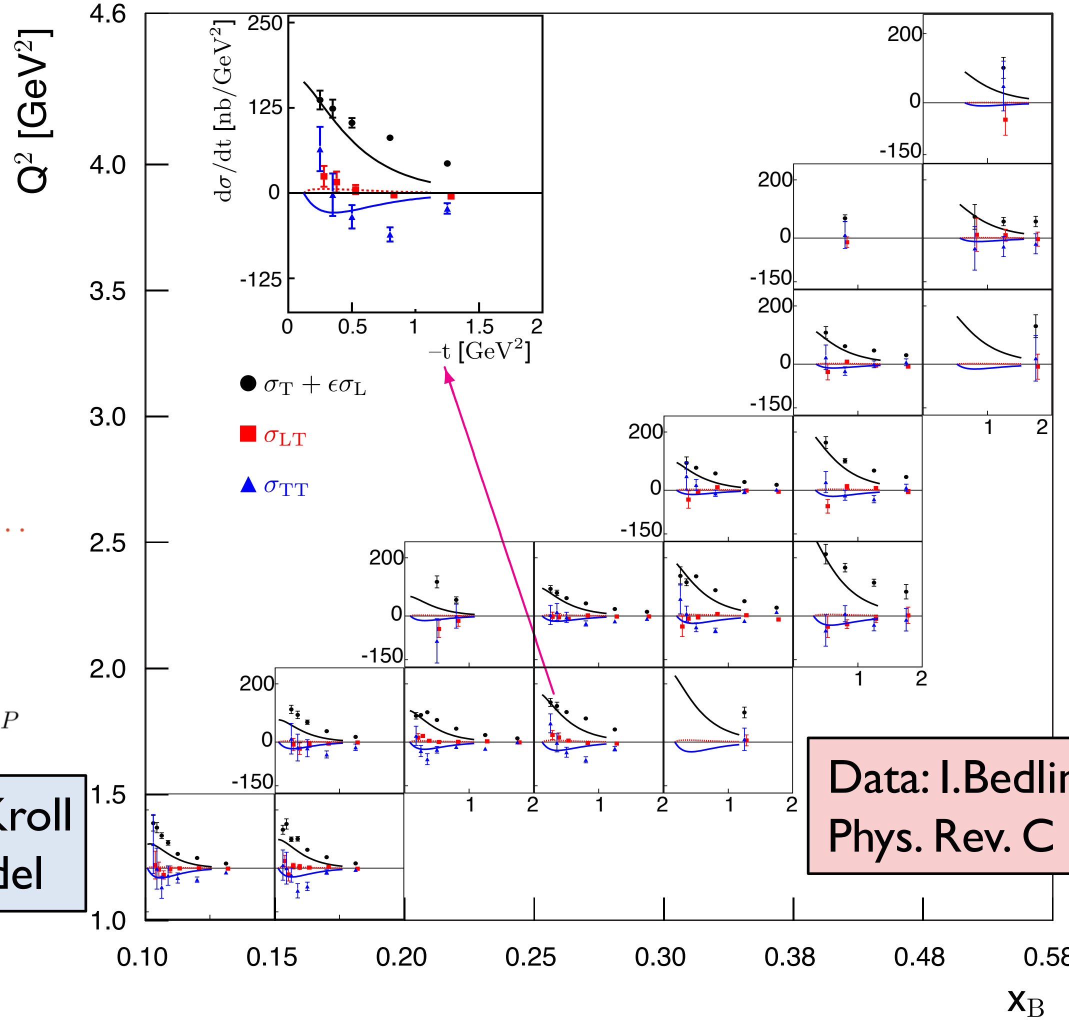
Data: I.Bedlinskiy et al. (CLAS)
PRL 2012
Phys. Rev. C 90, 039901 (2014)

CLAS: η Structure Functions

$(\sigma_T + \varepsilon\sigma_L)$ σ_{TT} σ_{LT}

$\gamma^* p \to p\eta$





Curves: Goloskokov, Kroll
Transversity GPD model

Data: I.Bedlinskiy et al. (CLAS)
Phys. Rev. C **95**, 035202 (2017)

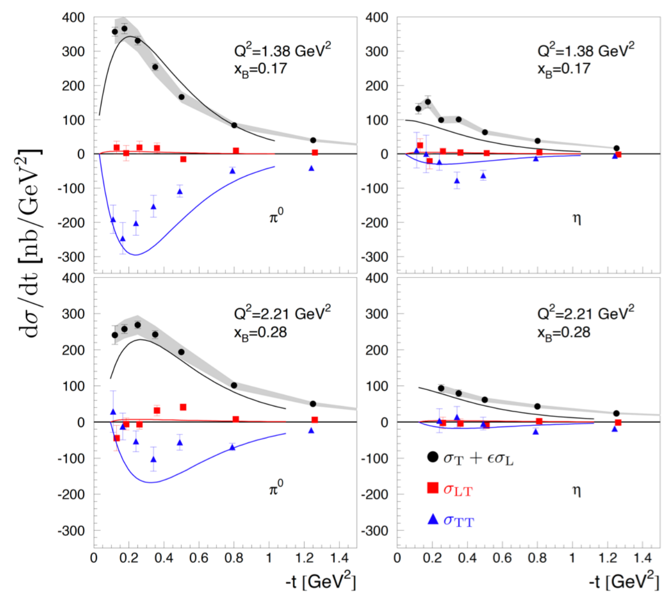
CLAS: π^0/η Comparison

π^0 η

σ_u

σ_{LT}

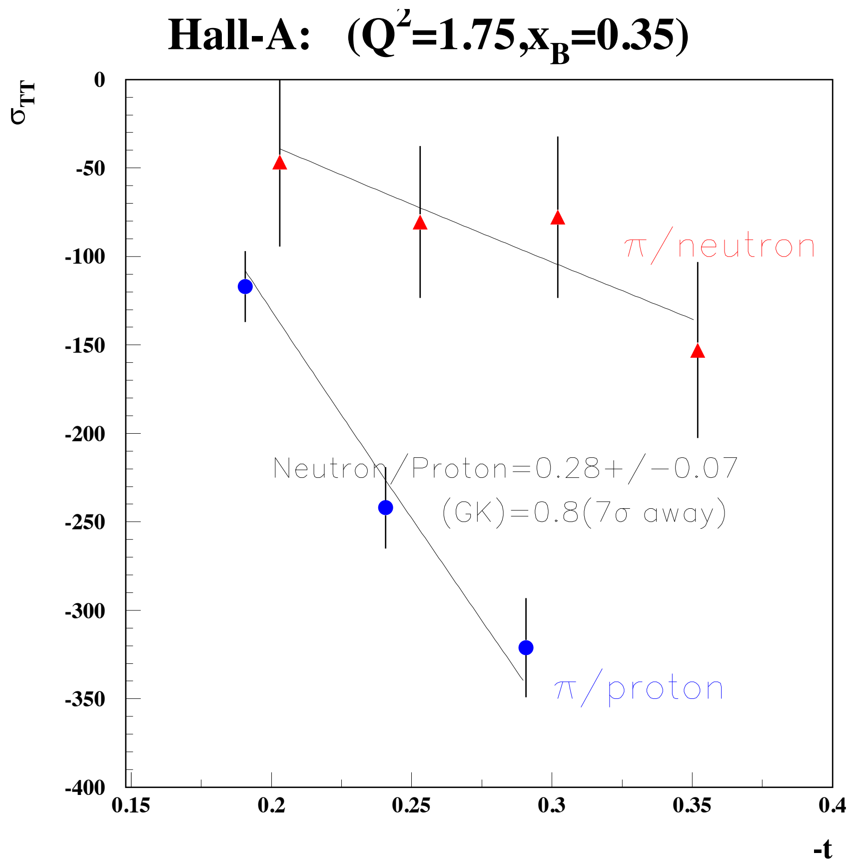
σ_{TT}



CLAS-Phys.Rev.C95(2017)

- σ_{TT} drops by a factor of 10
- The GK GPD model (curves) follows the experimental data

Hall-A: σ_{TT} π^0 out of proton and neutron



$$\sigma_{TT} = \frac{4\pi\alpha_e}{2\kappa}\frac{\mu_\pi^2}{Q^4}\frac{t'}{8m^2}|\langle\bar{E}_T\rangle|^2$$

$$\bar{E}_T^{\pi/proton} = \frac{1}{3\sqrt{2}}(2\bar{E}_T^u + \bar{E}_T^d)$$

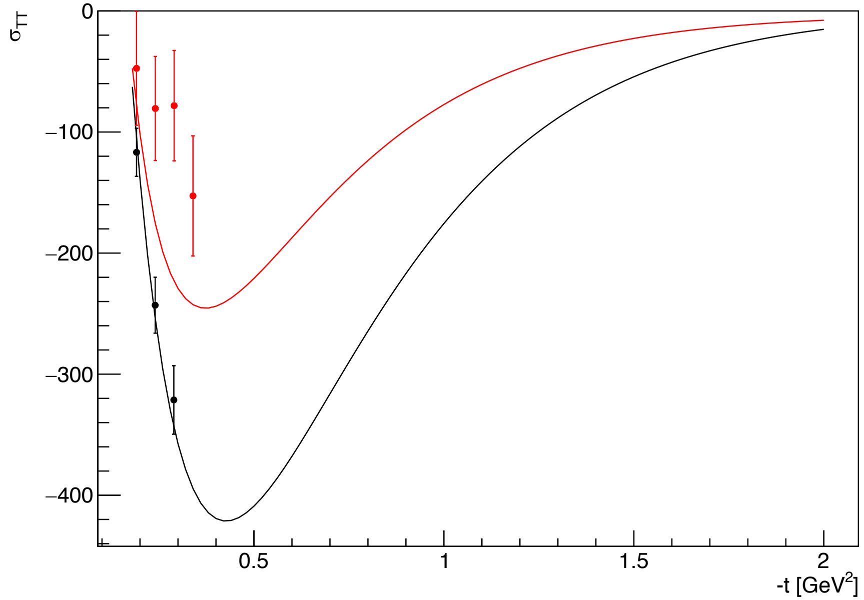
$$\bar{E}_T^{\pi/neutron} = \frac{1}{3\sqrt{2}}(\bar{E}_T^u + 2\bar{E}_T^d)$$

$$\bar{E}_T^{\eta/proton} = \frac{1}{3\sqrt{6}}(2\bar{E}_T^u - \bar{E}_T^d)$$

Hall-A, PRL, **117**,262001(2016)
Hall-A, PRL, 118, 222002 (2017)

GK exact calculation of σ_{TT}

pi0 on proton (black) and neutron (red)



- Neutron/proton = 0.28
- GK model ~ 0.6
- Model parameters needed adjustment
- Global fit is in progress

$$\bar{E}_T^u(x, \chi = 0, t) = N^u \cdot e^{bt} \cdot x^{\alpha_0 + \alpha' t} \cdot (1-x)^4$$

$$\bar{E}_T^d(x, \chi = 0, t) = N^d \cdot e^{bt} \cdot x^{\alpha_0 + \alpha' t} \cdot (1-x)^5$$

COMPASS arXiv:1903.12030, 28 Mar,2019

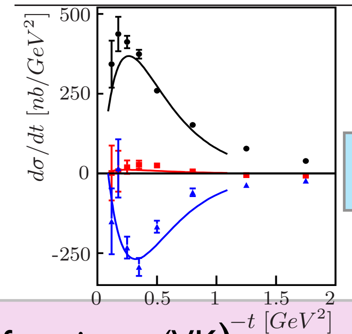
- 160 GeV/c polarized μ^+ and μ^- beams of the CERN SPS
- Data taken in 2012, within 4 weeks
- **$\langle Q2 \rangle = 2.0$ GeV^2**
- **$\langle xB \rangle = 0.093$**
- $\langle -t \rangle = 0.256$ GeV^2

- 0.08 GeV^2 < $|t|$ < 0.64 GeV^2
- 1 GeV^2 < Q2 < 5 GeV^2
- 8.5 GeV < ν < 28 GeV

COMPASS-Jlab comparison

- **<Q2>=2.0 GeV²**
- **<xB>=0.093**
- <-t>=0.256 GeV²
- **<ν>=12.8 GeV**

COMPASS data (5 points)

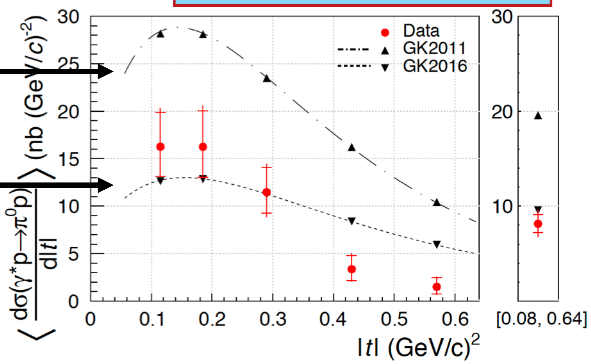


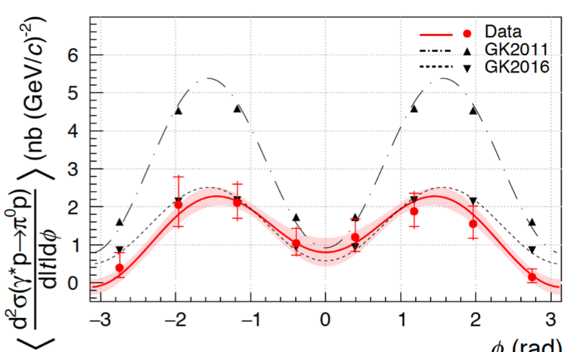
CLAS 2000 points

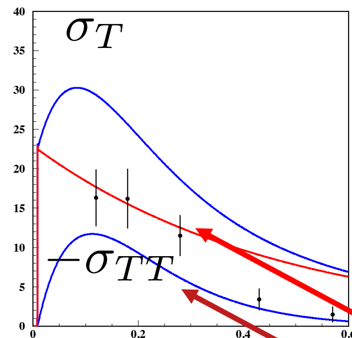
CLAS structure functions (VK)

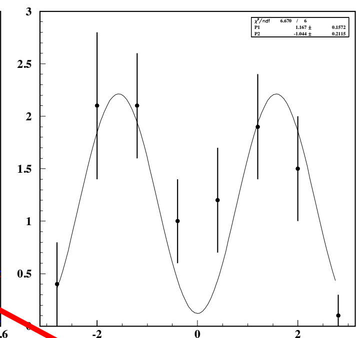
GK2011

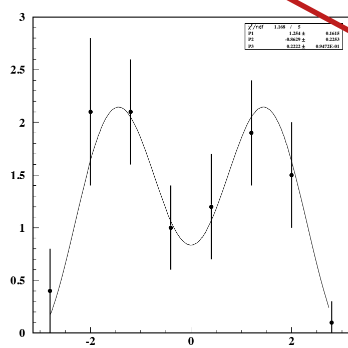
GK2016











$\langle H_T \rangle$

$\langle \bar{E}_T \rangle$

- Factor of two difference between GK2011 and GK2016
- Factor of two difference between COMPAS and CLAS

From Structure functions to Generalized Formfactors

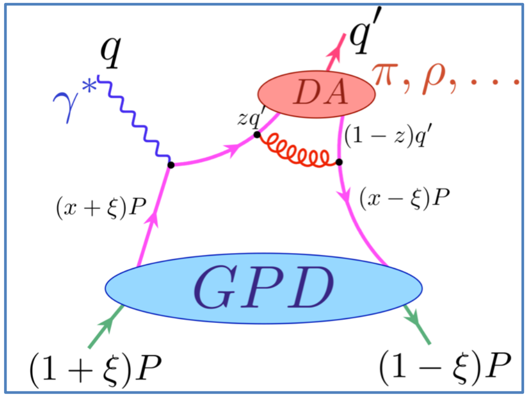
$$\frac{d\sigma_T}{dt} = \frac{4\pi\alpha}{2k'}\frac{\mu_P^2}{Q^8}\left[(1-\xi^2)\,|\langle H_T\rangle|^2 - \frac{t'}{8m^2}|\langle \bar{E}_T\rangle|^2\right]$$

$$\frac{d\sigma_{TT}}{dt} = \frac{4\pi\alpha}{k'}\frac{\mu_P^2}{Q^8}\frac{t'}{16m^2}|\langle \bar{E}_T\rangle|^2$$

$$|\langle \bar{E}_T\rangle^{\pi,\eta}|^2 = \frac{k'}{4\pi\alpha}\frac{Q^8}{\mu_P^2}\frac{16m^2}{t'}\frac{d\sigma_{TT}^{\pi,\eta}}{dt}$$

$$|\langle H_T\rangle^{\pi,\eta}|^2 = \frac{2k'}{4\pi\alpha}\frac{Q^8}{\mu_P^2}\frac{1}{1-\xi^2}\left[\frac{d\sigma_T^{\pi,\eta}}{dt} + \frac{d\sigma_{TT}^{\pi,\eta}}{dt}\right]$$

$\bar{E}_T = 2\tilde{H}_T + E_T$

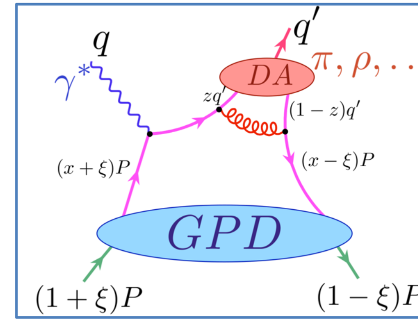


$$\langle H_T\rangle = \Sigma_\lambda \int_{-1}^{1} dx M(x,\xi,Q^2,\lambda) H_T(x,\xi,t)$$

$$\langle \bar{E}_T\rangle = \Sigma_\lambda \int_{-1}^{1} dx M(x,\xi,Q^2,\lambda) \bar{E}_T(x,\xi,t)$$

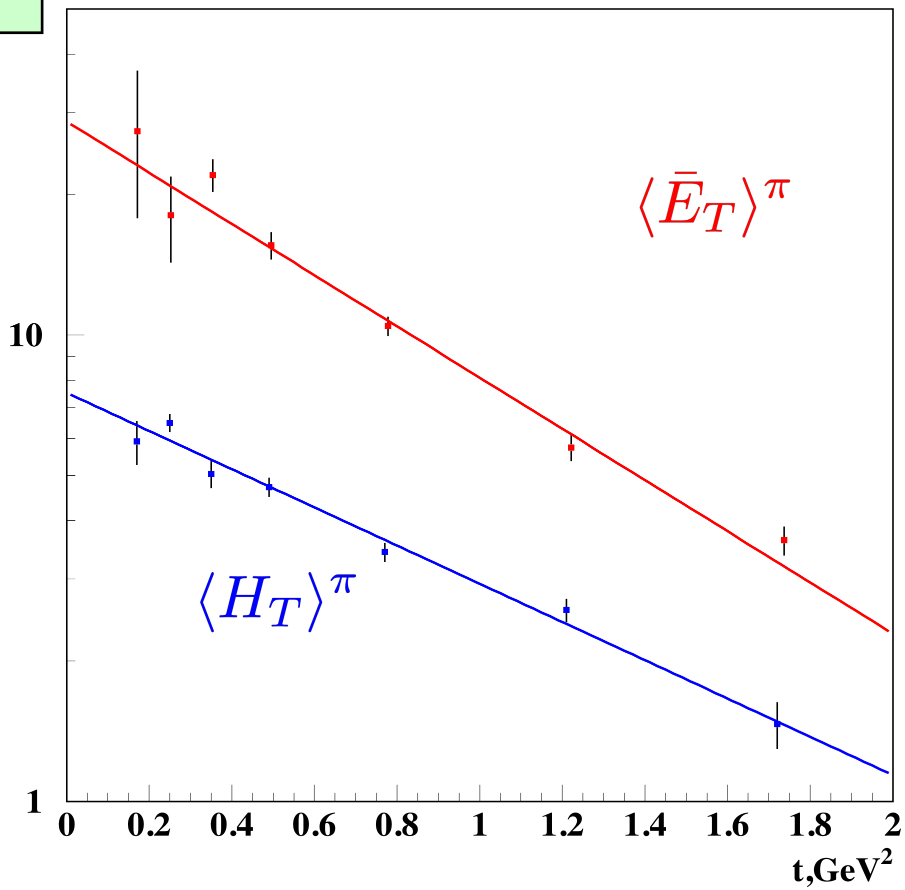
The brackets <F> denote the convolution of the elementary process with the GPD F (generalized form factors)

π^0 Generalized Form Factors



$$\frac{d<F>}{dt} \propto e^{bt}$$

Q^2=2.2 GeV^2, x_B=0.27



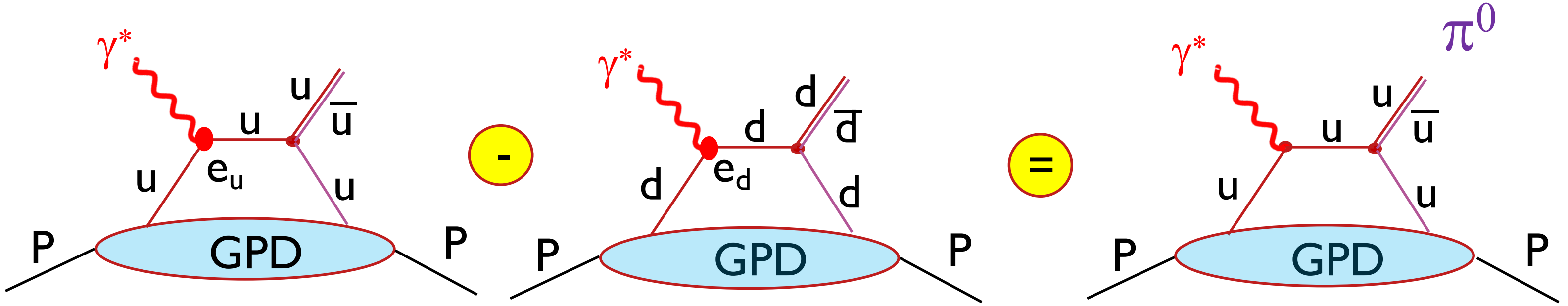
- $\bar{E}_T$ > H_T
- t-dependence is steeper for $\bar{E}_T$ than for H_T

- $|<E_T,H_T>|\sim\exp(bt)$
- $b(E_T)$=1.27 GeV^{-2}
- $b(H_T)$=0.98 GeV^{-2}

VK, arXiv:1601.04367

Handbag graph for π^0 electroproduction

$$\left|\pi^0\right\rangle = \frac{\left|u\bar{u}\right\rangle - \left|d\bar{d}\right\rangle}{\sqrt{2}}$$



$$\bar{E}_T^{\pi} = \frac{1}{\sqrt{2}}(e_u\bar{E}_T^u - e_d\bar{E}_T^d) = \frac{1}{3\sqrt{2}}(2\bar{E}_T^u + \bar{E}_T^d)$$

Flavor Decomposition

$$\bar{E}_T^{\pi/proton} = \frac{1}{3\sqrt{2}}(2\bar{E}_T^u + \bar{E}_T^d)$$

$$\bar{E}_T^{\pi/neutron} = \frac{1}{3\sqrt{2}}(\bar{E}_T^u + 2\bar{E}_T^d)$$

$$\bar{E}_T^{\eta/proton} = \frac{1}{3\sqrt{6}}(2\bar{E}_T^u - \bar{E}_T^d - 2\cancel{\bar{E}_T^s})$$

- GPDs appear in different flavor combinations for π^0 and η
- The combined π^0 and η data permit the flavor (u and d) decomposition for GPDs H_T and $\bar{E}_T$
- Contribution from sea quarks is cancelled out

Experimental observables

$$\sigma_T = \frac{4\pi\alpha_e}{2\kappa}\frac{\mu_\pi^2}{Q^4}\left[(1-\xi^2)|\langle H_T\rangle|^2 - \frac{t'}{8m^2}|\langle \bar{E}_T\rangle|^2\right]$$

$$\sigma_{TT} = \frac{4\pi\alpha_e}{2\kappa}\frac{\mu_\pi^2}{Q^4}\frac{t'}{8m^2}|\langle \bar{E}_T\rangle|^2$$

$\bar{E}_T(x,t,\xi)$ Global fit

status report

<u>Data</u>

- CLAS π^0/η (2012–2018)
- Hall-A π^0 (2011, 2016)
- Hall-A π^0 out of neutron
- COMPASS π^0 (coming soon)
- $\bar{E}_T(x,t,\xi)$ parameters only

- Fit *ONLY* σ_{TT} data $\boxed{\sigma_{TT} = \frac{4\pi\alpha_e}{2\kappa}\frac{\mu_\pi^2}{Q^4}\frac{t'}{8m^2}|\langle\bar{E}_T\rangle|^2}$

Goloskokov-Kroll GPDs Model

- The GPD ansatz has an exponential t behavior with x-dependent width specified by profile function f(x).

$$\bar{E}_T(x,t) = g(x) \cdot e^{t \cdot f(x)}$$

- The profile function f(x) defines the shape of the quark distribution in the impact parameter plane

$$\bar{E}_T(x,\vec{b}) = \int \frac{d^2\vec{\Delta}}{(2\pi)^2} e^{-i\vec{b}\vec{\Delta}} \bar{E}_T(x, t=-\Delta^2, \xi=0) \longrightarrow \bar{E}_T(x,\vec{b}) = \frac{1}{4\pi}\frac{q(x)}{f(x)} e^{-\frac{\vec{b}^2}{4f(x)}} \longrightarrow \left\langle \vec{b}^2 \right\rangle = 4f(x)$$

- The parametrization of the profile function follows the Regge prescriptions with the dominance of a single pole

$$\bar{E}_T^u(x,t,\xi=0) = N^u \cdot x^{-\alpha_0^u}(1-x)^4 e^{(b^u - \alpha'^u \ln(x))t}$$

$$\bar{E}_T^d(x,t,\xi=0) = N^d \cdot x^{-\alpha_0^d}(1-x)^5 e^{(b^d - \alpha'^u \ln(x))t}$$

This forward limit was used as input to the double distribution ansatz

$$f_{val} = \bar{E}_T(\beta,t)\frac{3}{4}\frac{(1-\beta)^2-\alpha^2}{1-\beta^2}\Theta(\beta)$$

Radyushkin(2000)

$$\bar{E}_T(x,t,\xi) = \int_{-1}^{1} d\beta \int_{-1+|\beta|}^{1-|\beta|} d\alpha \delta(\beta+\xi\alpha-x) f_{val}(\beta,\alpha,t)$$

Goloskokov-Kroll GPDs Model

$$\bar{E}_T^u(x,t,\xi) = N^u \cdot e^{b^u t} \sum_{j=0}^{2} c_j^u \cdot \mathcal{D}(\frac{j}{2}, x, \xi)$$

$$\bar{E}_T^d(x,t,\xi) = N^d \cdot e^{b^d t} \sum_{j=0}^{4} c_j^d \cdot \mathcal{D}(\frac{j}{2}, x, \xi)$$

$$\mathcal{D}(i,x,\xi) = \frac{3}{2\xi^3(1+i-k)(2+i-k)(3+i-k)}\{(\xi^2 - x)$$
$$\left(\left(\frac{x+\xi}{1+\xi}\right)^{2+i-k} - \left(\frac{x-\xi}{1+-xi}\right)^{2+i-k}\right)$$
$$+\xi(1-x)(2+i-k)\left(\left(\frac{x+\xi}{1+\xi}\right)^{2+i-k} + \left(\frac{x-\xi}{1+-xi}\right)^{2+i-k}\right)\}$$

$$\mathcal{D}(i,x,\xi=0) = x^{i-k}(1-x)^3$$
$$k = \alpha_0 + \alpha' t$$

ξ=0 Limit

$$\bar{E}_T^u(x,t,\xi) = N^u \cdot e^{b^u t} \sum_{j=0}^{2} c_j^u \cdot \mathcal{D}(\frac{j}{2}, x, \xi)$$

$$\bar{E}_T^d(x,t,\xi) = N^d \cdot e^{b^d t} \sum_{j=0}^{4} c_j^d \cdot \mathcal{D}(\frac{j}{2}, x, \xi)$$

$$\xi \to 0$$

$$\bar{E}_T^u(x,t,\xi=0) = N^u \cdot x^{-\alpha_0^u}(1-x)^4 e^{(b^u - \alpha'^u \ln(x))t}$$

$$\bar{E}_T^d(x,t,\xi=0) = N^d \cdot x^{-\alpha_0^d}(1-x)^5 e^{(b^d - \alpha'^u \ln(x))t}$$

ξ=0 Limit

$$\bar{E}_T^u(x,t,\xi) = N^u \cdot e^{b^u t} \sum_{j=0}^{2} c_j^u \cdot \mathcal{D}(\frac{j}{2}, x, \xi)$$

$$\bar{E}_T^d(x,t,\xi) = N^d \cdot e^{b^d t} \sum_{j=0}^{4} c_j^d \cdot \mathcal{D}(\frac{j}{2}, x, \xi)$$

$$\downarrow \quad \xi \to 0$$

$$\bar{E}_T^u(x,t,\xi=0) = N^u \cdot x^{-\alpha_0^u}(1-x)^4 e^{(b^u - \alpha'^u \ln(x))t}$$

$$\bar{E}_T^d(x,t,\xi=0) = N^d \cdot x^{-\alpha_0^d}(1-x)^5 e^{(b^d - \alpha'^u \ln(x))t}$$

Fit Versions

The table of GK model fit to CLAS6 data with different set of parameters.

name:	v0.p5	v1.p5	v2.p6	v3.p8
datasets:	a) clas: all t b) clas: -t<1 c) clas+hallA2011: all t d) clas+hallA2011: -t<1	a) clas: all t b) clas: -t<1 c) clas+hallA2011: all t d) clas+hallA2011: -t<1	a) clas: all t b) clas: -t<1 c) clas+hallA2011: all t d) clas+hallA2011: -t<1	a) clas: all t b) clas: -t<1 c) clas+hallA2011: all t d) clas+hallA2011: -t<1 e) clas+hallA2011+neutron: all t f) clas+hallA2011+neutron: -t<1 g) clas+hallA2011+neutron+hallA2016: all t h) clas+hallA2011+neutron+hallA2016: -t<1 i) clas+hallA2011+neutron: -t<1, initial pars from 'd' j) clas+hallA2011+neutron+hallA2016: -t<1, initial pars from 'd' k) clas+hallA2011+neutron: -t<1, initial pars from 'd', limit: b>0 l) clas+hallA2011+neutron+hallA2016: -t<1, initial pars from 'd', limit: b>0

- CLAS π^0/η (2012–2018)
- Hall-A π^0 (2011, 2016)
- Hall-A π^0 out of neutron
- COMPASS π^0 (coming soon!)

Fit Parameters

	GK model	CLAS HA2011	CLAS HA2011 Neutron	CLAS HA2011 Neutron HA2016	+/-
N^u	4.82	9.91	17.3	16.7	3.5
b^u	0.5	0.17	0.76	0.71	0.35
$\alpha_0{}^u$	0.3	0.04	-0.067	-0.058	0.06
α'^u	**0.45**	0.46	0.36	0.38	0.11
N^d	3.57	24.7	4.1	4.2	3.5
b^d	0.5	0.96	-1.33	-1.22	1.6
$\alpha_0{}^d$	0.30	**-0.07**	0.43	0.42	0.18
α'^d	**0.45**	1.21	1.81	1.79	0.47

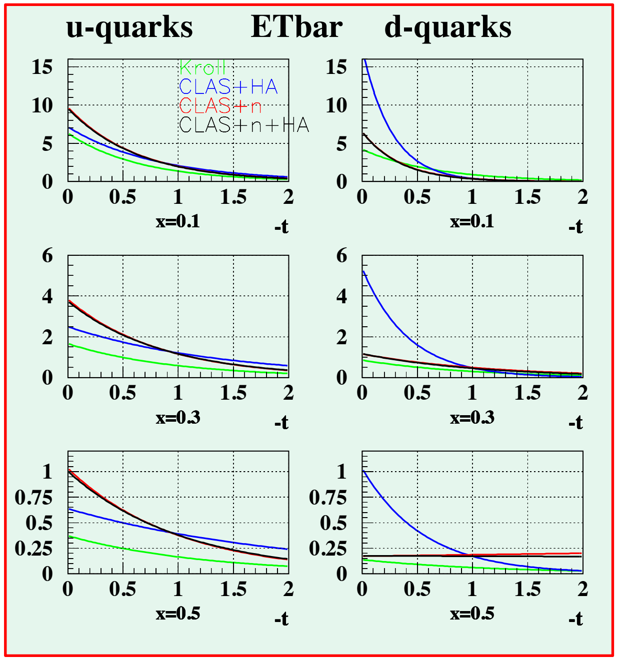
$$\bar{E}_T^u(x,t,\xi=0) = N^u \cdot x^{-\alpha_0^u}(1-x)^4 e^{(b^u - \alpha'^u \ln(x))t}$$

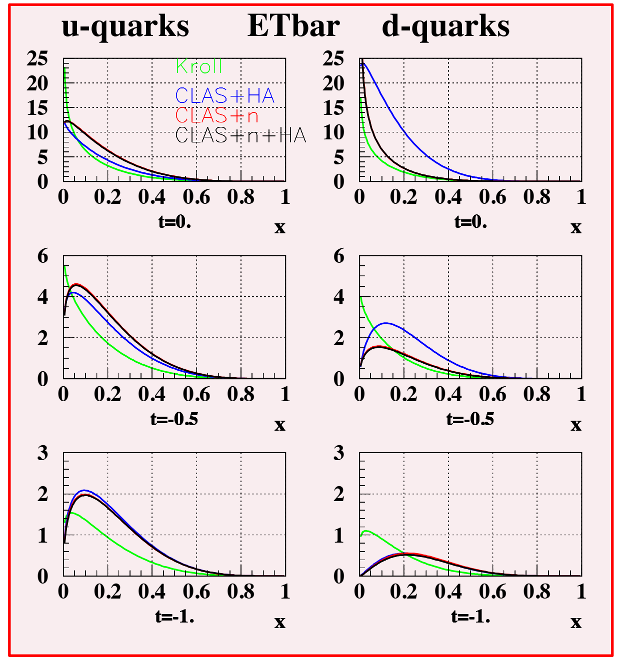
$$\bar{E}_T^d(x,t,\xi=0) = N^d \cdot x^{-\alpha_0^d}(1-x)^5 e^{(b^d - \alpha'^u \ln(x))t}$$

$\bar{E}_T({\color{red}x}, t, \xi = 0)$ x and t-distributions

$$\bar{E}_T^u(x,t,\xi=0) = N^u \cdot x^{-\alpha_0^u}(1-x)^4 e^{(b^u - \alpha'^u \ln(x))t}$$

$$\bar{E}_T^d(x,t,\xi=0) = N^d \cdot x^{-\alpha_0^d}(1-x)^5 e^{(b^d - \alpha'^u \ln(x))t}$$

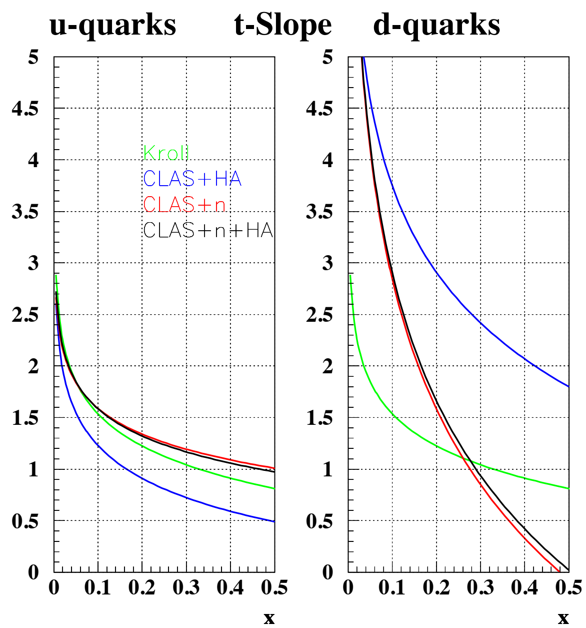




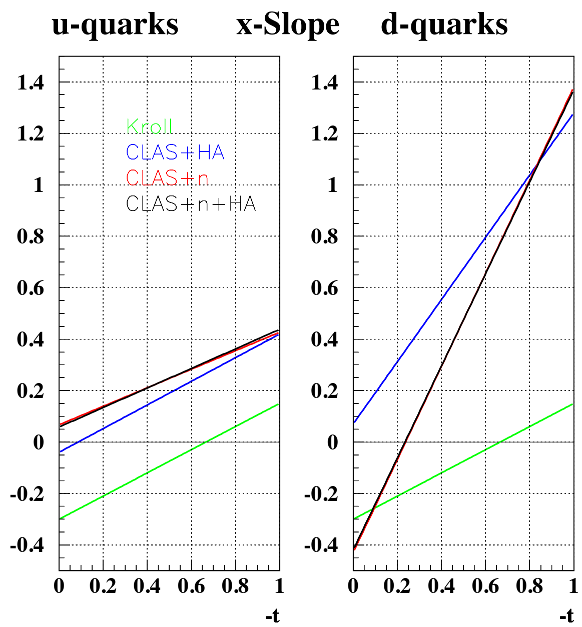
$$x^{-\alpha_0} e^{(b+\alpha' \ln(1/x))t}$$

$$x^{-(\alpha_0+\alpha' t)} e^{bt}$$

$\bar{E}_T(x, t, \xi = 0)$ x and t Slope Parameters



$$e^{(b+\alpha' \ln(1/x))t}$$



$$x^{-(\alpha_0+\alpha' t)}$$

Plan moving forward

- Four sets of data were used for a moment: CLAS (π^0 and η) and Hall-A (π^0) out of proton and neutron
- COMPASS released π^0 muon electroproduction out of proton
- Neutron data help with the flavor separation and COMPASS with energy dependence of GPDs (alpha)
- We are going to change the definition of t-min that is used in the c++ code from theoretical one to the exact expression

What $\bar{E}_T(x,t,\xi)$ will tell us about the nucleon structure?

The Fourier Transform of Generalized Parton Distribution

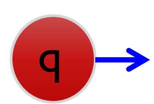
- The Fourier transforms of GPDs at $\xi = 0$ describe the distribution of partons in the transverse plane (M. Burkardt, 2002)
- It was shown that they satisfy positivity constraints which justify their physical interpretation as a probability density
- **H** is related to the impact parameter distribution of unpolarized quarks in an unpolarized nucleon
- $\tilde{\mathbf{H}}$ is related to the distribution of longitudinally polarized quarks in a longitudinally polarized nucleon
- **E** is related to the distortion of the unpolarized quark distribution in the transverse plane when the nucleon has transverse polarization.
- $\bar{\mathbf{E}}_T$ is related to the distortion of the polarized quark distribution in the transverse plane for an unpolarized nucleon

$$\mathcal{K}(x,\vec{b}) = \int \frac{d^2\vec{\Delta}}{(2\pi)^2} \exp^{-i\vec{b}\cdot\vec{\Delta}} K(x, t = -\Delta^2)$$

The Density of Transversely Polarized Quarks in an Unpolarized Proton

$\bar{E}_T$ is related to the distortion of the polarized quark distribution in the transverse plane for an unpolarized nucleon

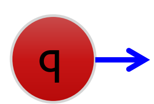
$$\boxed{\delta(x,\vec{b}) = \frac{1}{2}\left[H(x,\vec{b}) - \frac{b_y}{m}\frac{\partial}{\partial b^2}\bar{E}_T(x,\vec{b})\right]}$$



The Density of Transversely Polarized Quarks in an Unpolarized Proton

$\bar{E}_T$ is related to the distortion of the polarized quark distribution in the transverse plane for an unpolarized nucleon

$$\delta(x,\vec{b}) = \frac{1}{2}[H(x,\vec{b}) - \frac{b_y}{m}\frac{\partial}{\partial b^2}\bar{E}_T(x,\vec{b})]$$

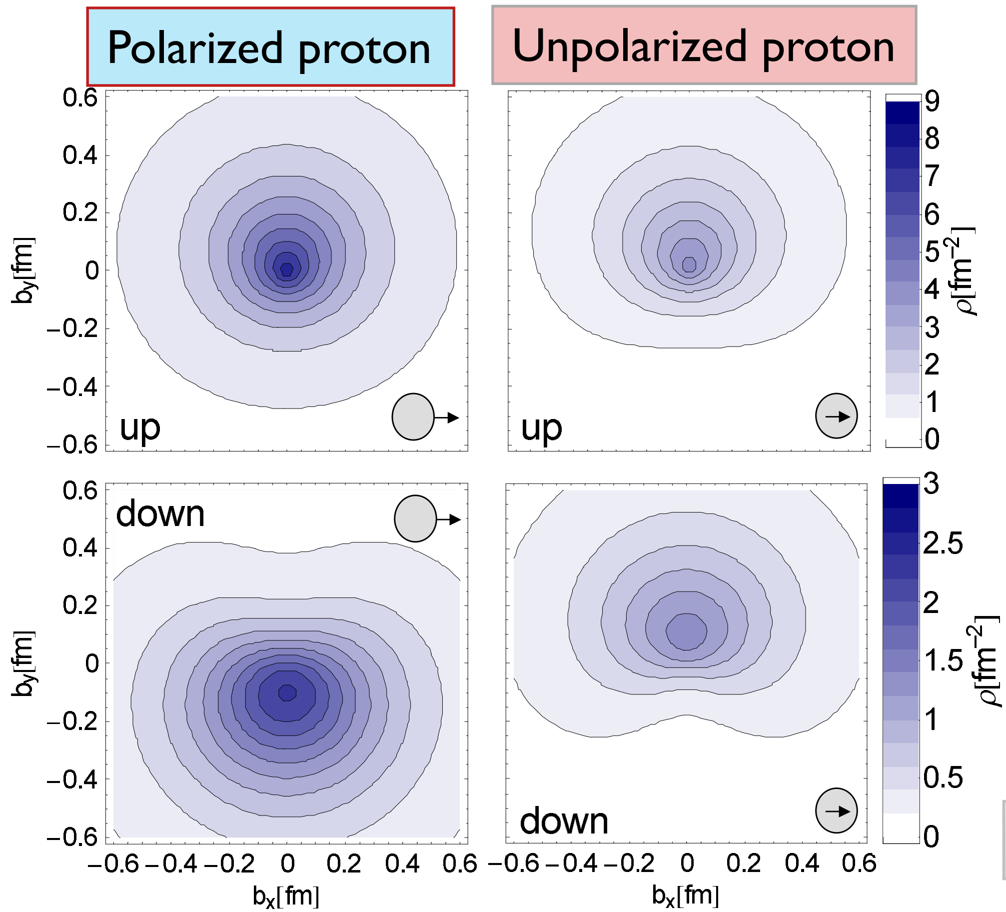


Integrated over x Transverse Densities for u and d Quarks in the Proton

u quarks

d quarks

Strong distortions for unpolarized quarks in transversely polarized proton



Controlled by E

Controlled by $\bar{E}_T = 2\tilde{H}_T + E_T$

Strong distortions for transversely polarized quarks in an unpolarized proton

Lattice calculations

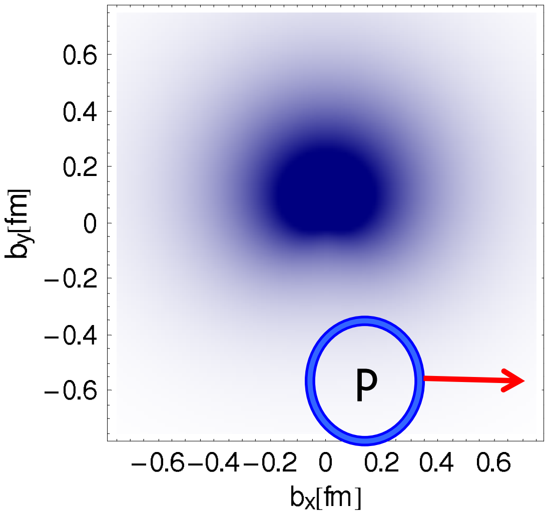
Gockeler et al, Phys. Rev. Lett. 98, 222001 (2007), lattice

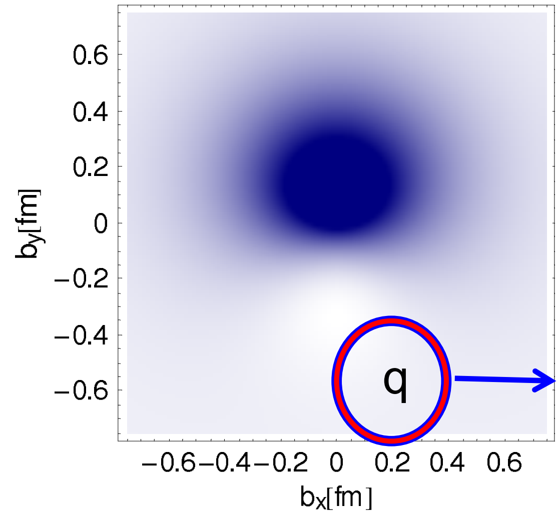
GPD model: integrated over *x* Impact Parameter Density for u-quarks

Polarized proton

Unpolarized proton

u quarks

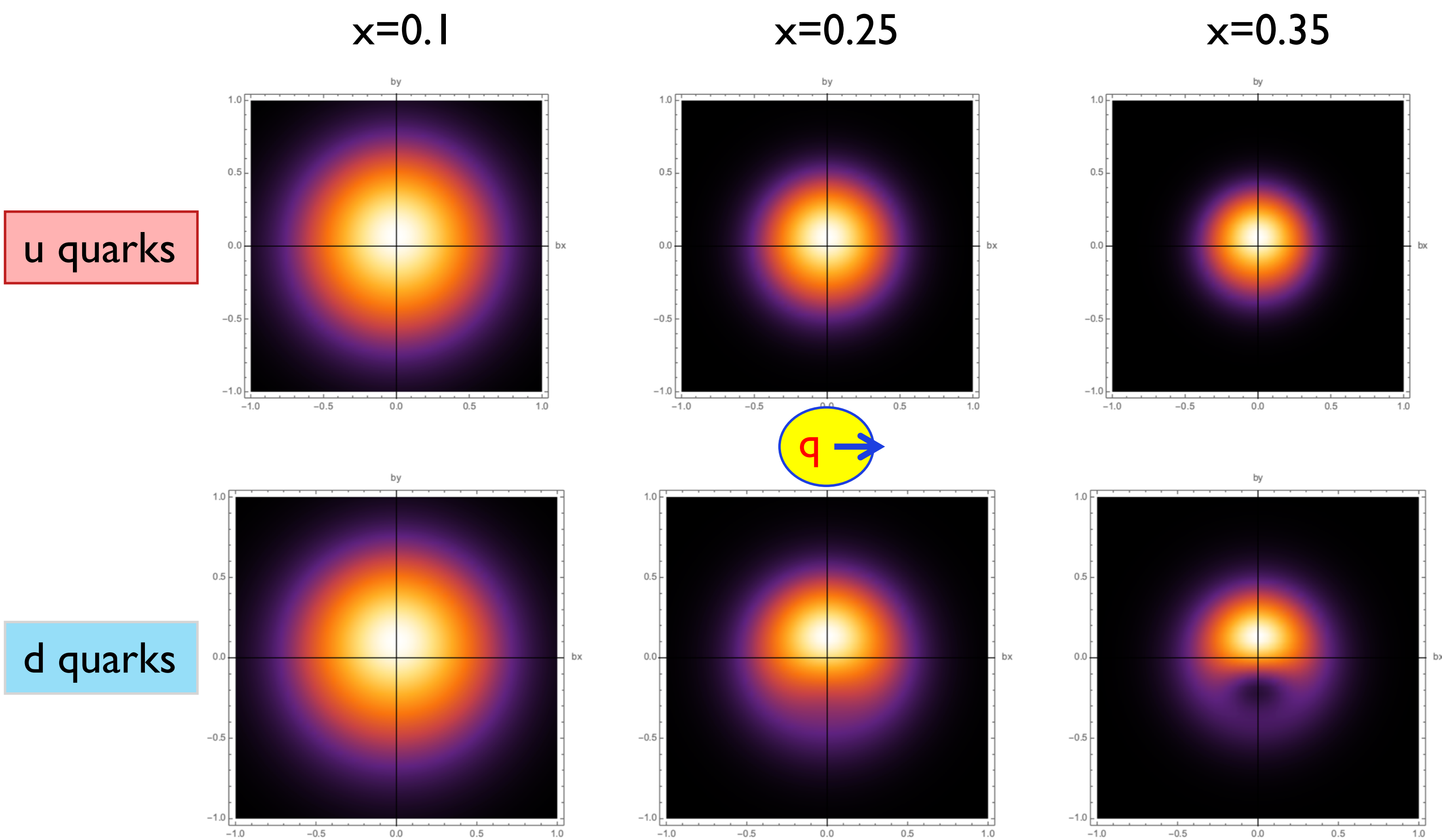




- **Left:** unpolarized u-quarks in a proton with transverse spin vector.
- **Right**: the distribution of u-quarks with transverse spin vector in an unpolarized proton.

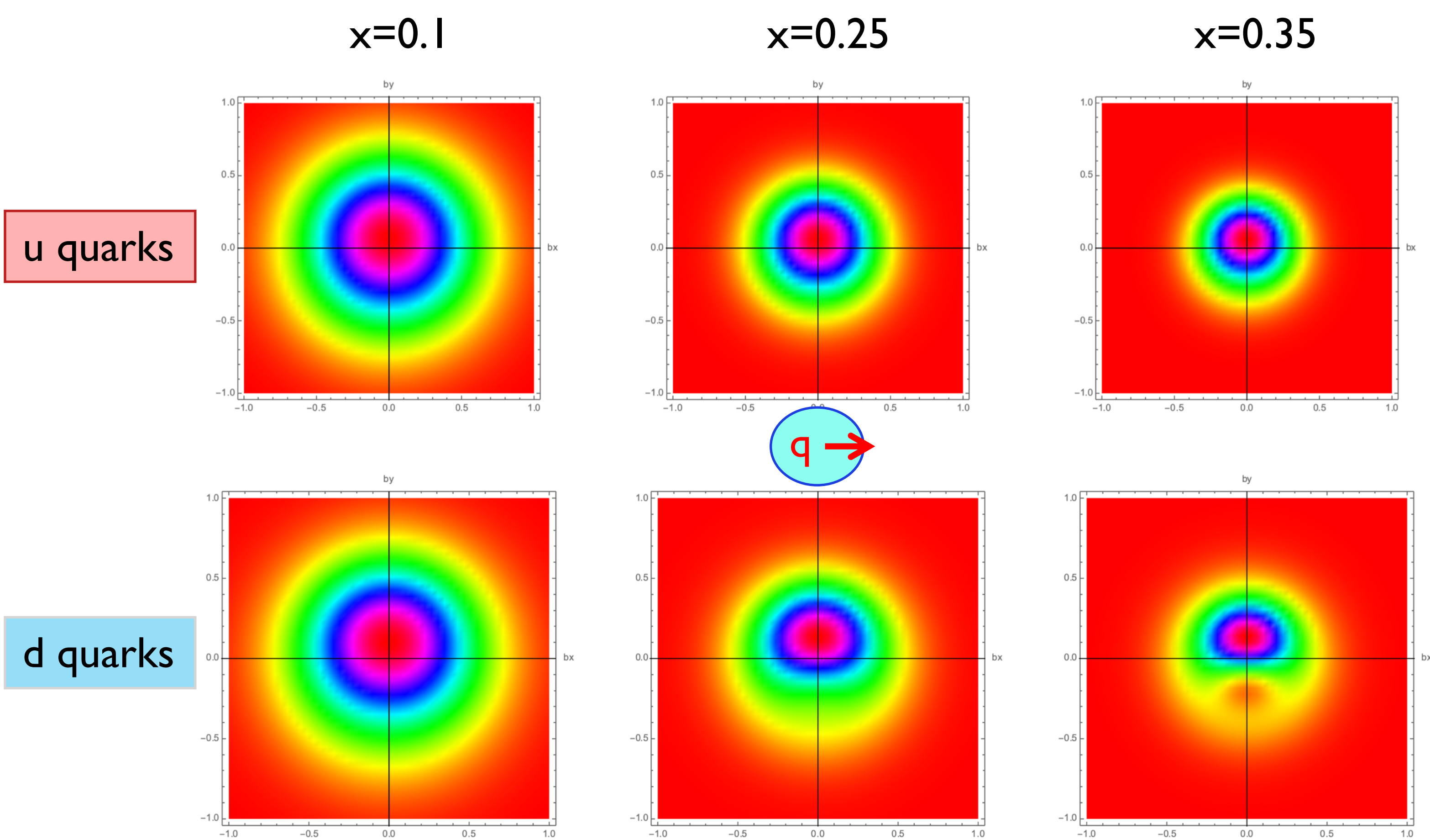
M. Diehl and Ph Hagler (2005) GPD model with “some reasonable ” parameters.

Transverse Densities for Polarized Quarks in Unpolarized Proton



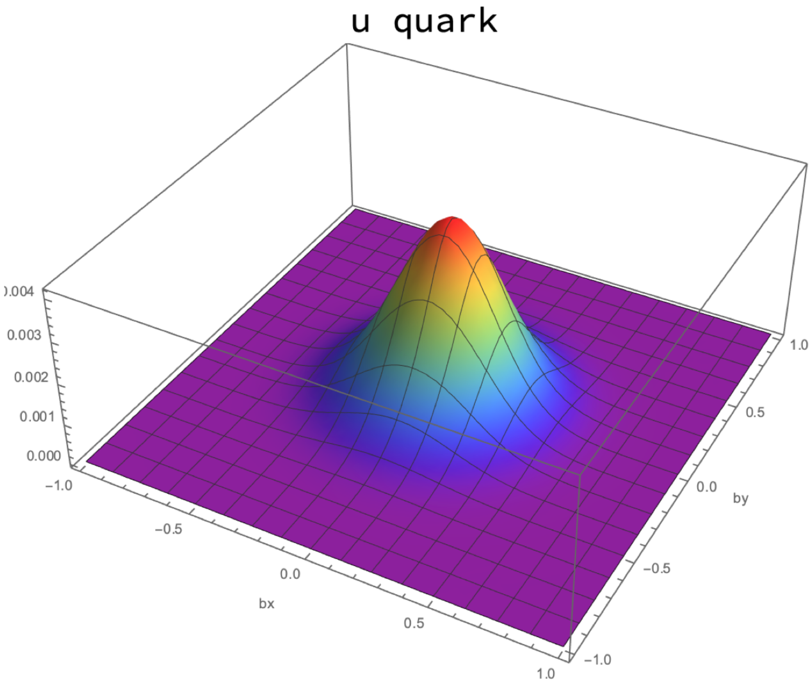
Note distortions for transversely polarized u and d quarks.

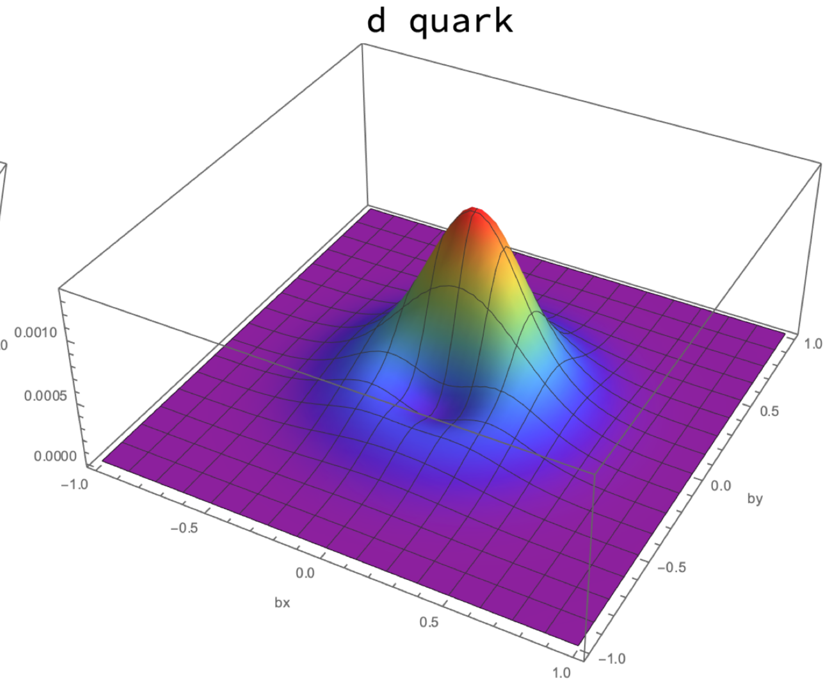
Transverse Densities for Polarized Quarks in Unpolarized Proton

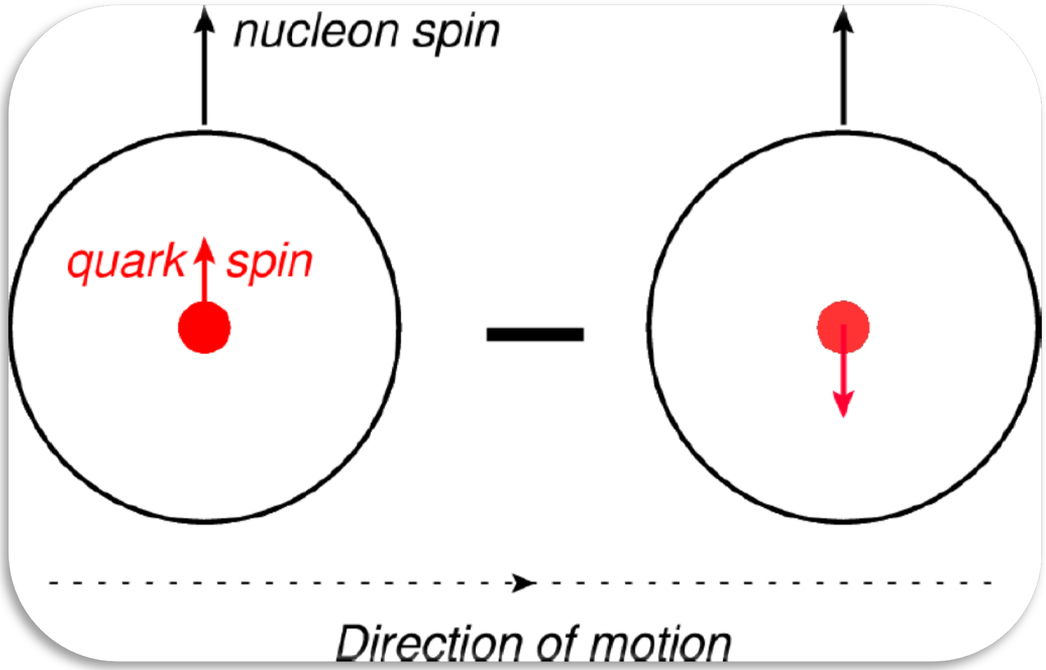


Transverse Densities for Polarized Quarks in Unpolarized Proton

x=0.35







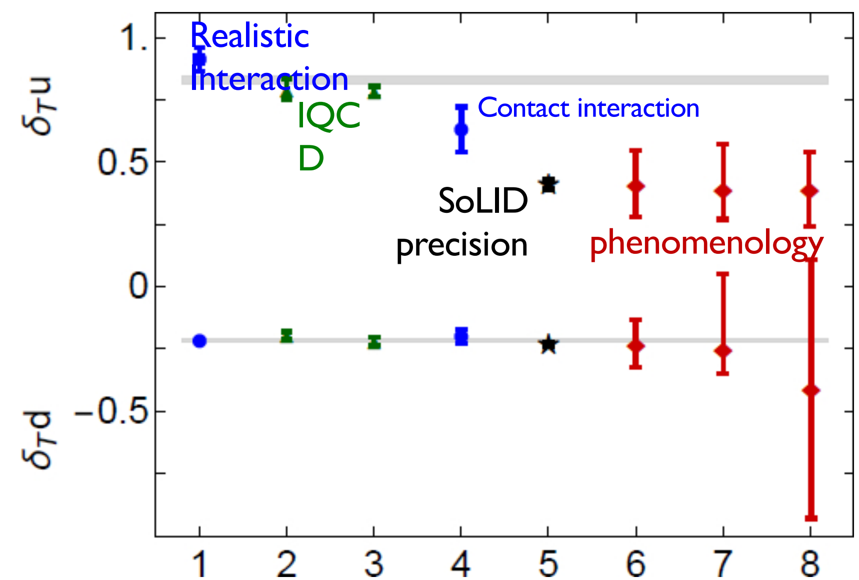
Proton's Tensor Charge

Proton tensor charges from a Poincaré-covariant Faddeev equation, Qing-Wu Wang, S.-X. Qin, C.D. Roberts and S. M. Schmidt, arXiv:1806.01287 [nucl-th], Phys. Rev. D **98** (2018) 054019/1-10

Proton's Tensor Charges

- Faddeev equation predictions
- $\delta_T d$: Theory and Phenomenology agree
  - $\delta_T d \equiv 0$ in models that suppress axial-vector diquark correlations
- $\delta_T u$: Increasing tension between theory and phenomenology
- Theory average

$$\delta_T u = 0.912^{(42)}_{(47)}\,, \qquad \delta_T d = -0.218^{(4)}_{(5)}\,,$$
$$g_T^{(1)} = 1.130^{(42)}_{(47)}\,, \qquad g_T^{(0)} = 0.694^{(42)}_{(47)}$$

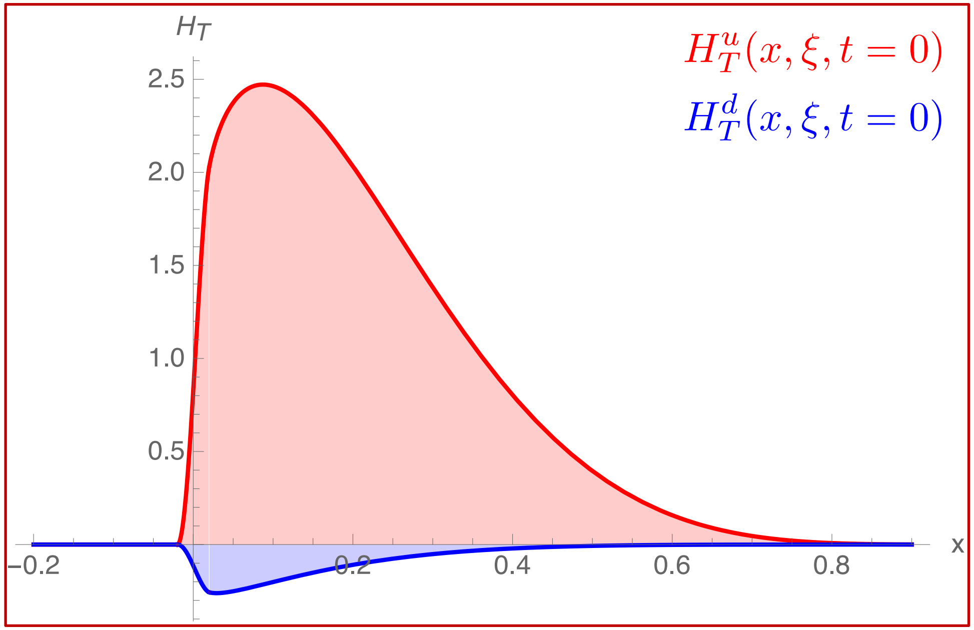


$$\overline{\delta_T u} = 0.803(17)\,,\ \overline{\delta_T d} = -0.216(4)$$

Proton Tensor Charge

$$\delta_T^u = \int dx H_T^u(x,\xi,t=0) = \ 0.830$$

$$\delta_T^d = \int dx H_T^d(x,\xi,t=0) = -0.052$$



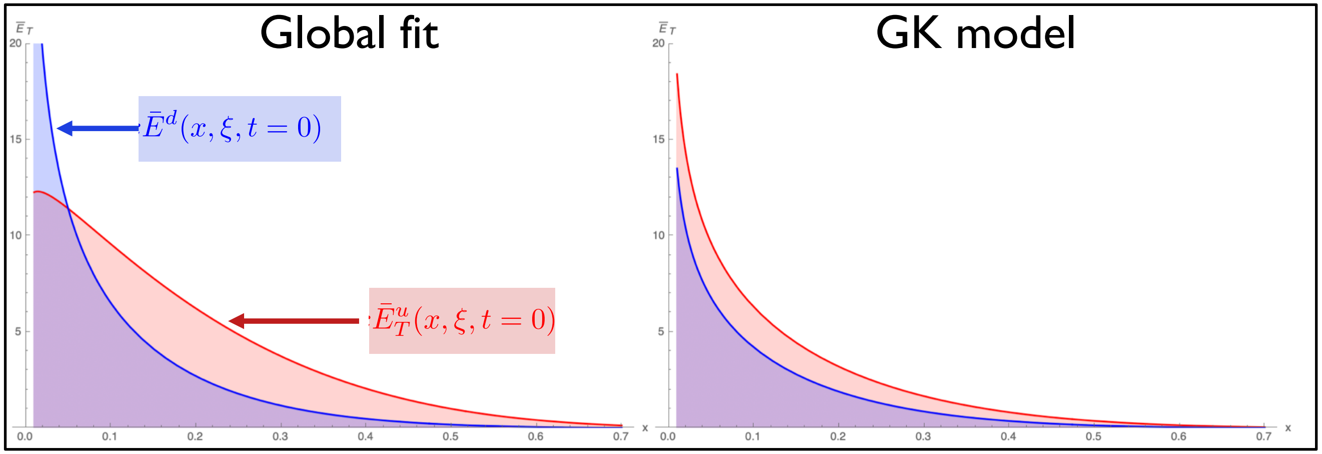
Theory average $\overline{\delta_T u} = 0.803(17)\,,\ \overline{\delta_T d} = -0.216(4)$

Proton Anomalous Tensor Magnetic Moment

$$\kappa_T^u = \int dx \bar{E}_T^u(x,\xi,t=0)$$

$$\kappa_T^d = \int dx \bar{E}^d(x,\xi,t=0)$$

	GK model Lattice	Global Fit	Chiral Soliton model
κ_T^u	2.07	2.93	3.56
κ_T^d	1.35	2.32	1.83



Future developments

- Asymmetries, Cross section at different beam energies: RGA, RGB, RGK

- Cross sections:
  - $ep \to ep(\pi^0, \eta)$
  - $en \to en(\pi^0, \eta)$
  - $ep \to e\pi^+ n$
  - $ep \to eK^+ \Lambda$

- Asymmetries:
  - $\mathcal{A}_{LU}$ – *beam spin*
  - $\mathcal{A}_{UL}$ – *target spin*
  - $\mathcal{A}_{LL}$ – *beam target*

Summary

- The study of deeply virtual exclusive pseudoscalar meson production uniquely connected with the transversity GPDs, and has already begun to access their underlying polarization distributions of quarks in the nucleon.
- The combined π^0 and η, proton and neutron data analysis provide the way for the flavor decomposition of transversity GPD
- The global analysis of the full data set from CLAS, Hall-A and COMPASS is underway with main goal to get the transversity GPD parameters with flavor decomposition
- The brand new CLAS12 detector successfully took data with proton and deuteron targets data with 10.6, 10.2, 7.5 and 6.5 GeV electron beam. The analysis of these data will significantly increase the kinematic coverage and robustness of the accessing the Transversity GPDs.