Deeply Virtual Meson Production at Jefferson Lab

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Jefferson Lab

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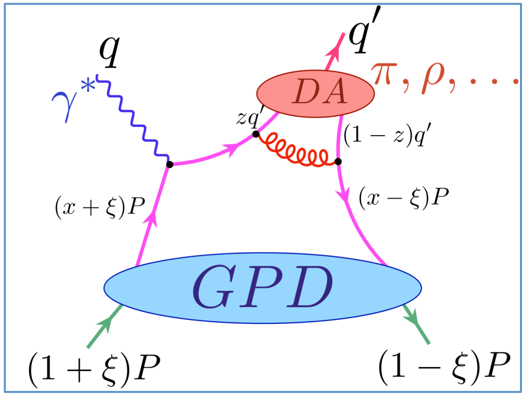
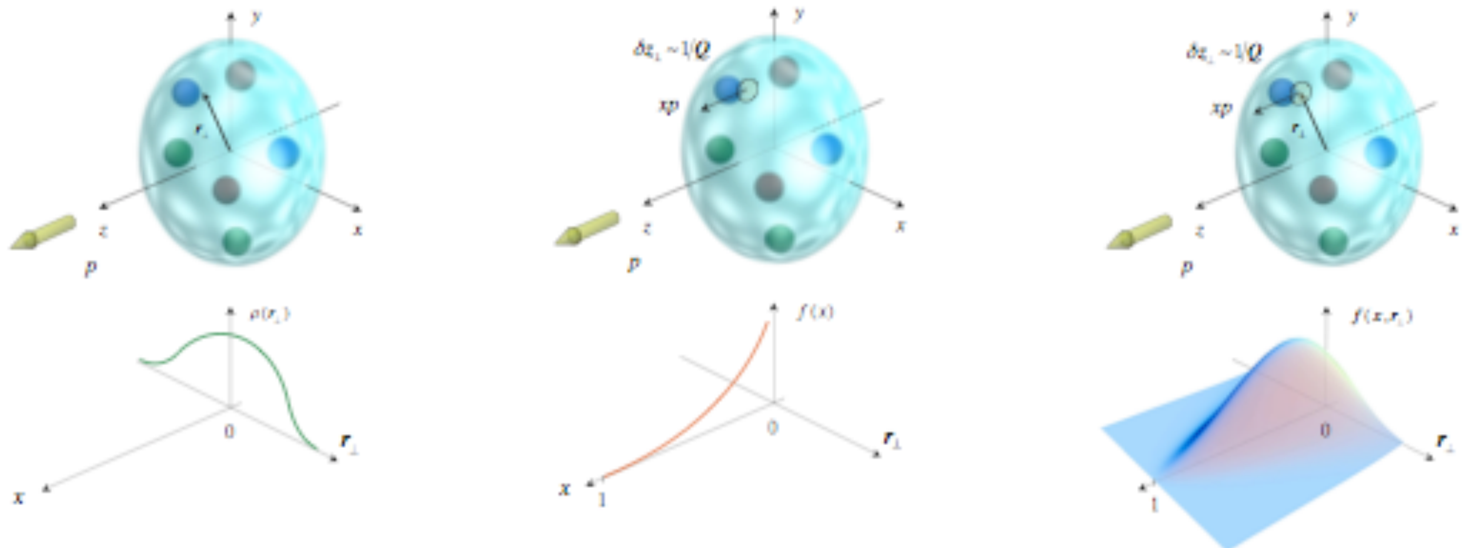
Outline



- Physics motivation
- CLAS data on pseudoscalar meson electroproduction
- Transversity GPD and structure functions
- Flavor decomposition of the Transversity GPDs
- Conclusion

Description of hadron structure in terms of GPDs

D. Mu¨ller ’,X. Ji, A. Radyushkin

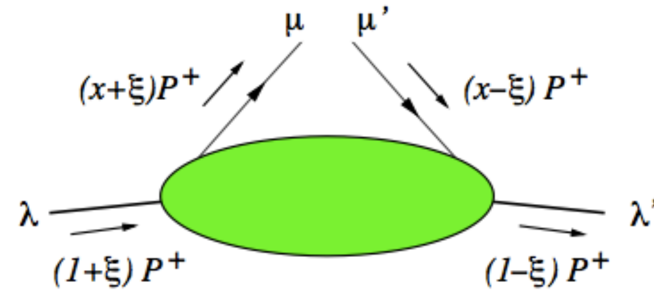


Nucleon form factors
transverse charge & current densities
Nobel prize 1961- R. Hofstadter

Structure functions
quark longitudinal momentum (polarized and unpolarized) distributions
Nobel prize 1990 –J.Friedman, H. Kendall, R. Taylor

GPDs
correlated quark momentum distributions (polarized and unpolarized) in transverse space

Generalized Parton Distributions



- GPDs are the functions of three kinematic variables: x, ξ and t
- There are 4 chiral even GPDs where partons do not flip helicity $H, \tilde{H}, E, \tilde{E}$
- 4 chiral odd GPDs flip the parton helicity

  $H_T, \tilde{H}_T, E_T, \tilde{E}_T$
- The chiral-odd GPDs are difficult to access since subprocesses with quark helicity-flip are suppressed

Chiral-odd GPDs

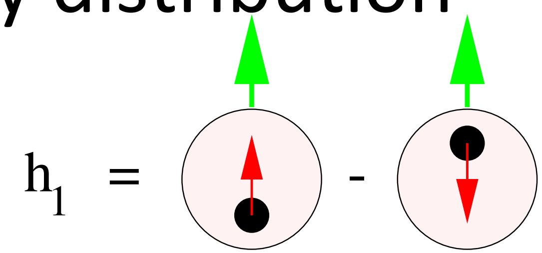
- Very little known about the chiral-odd GPDs
- Anomalous tensor magnetic moment

$$\kappa_T = \int_{-1}^{+1} dx\ \bar{E}_T(x,\xi,t=0)$$

- (Compare with anomalous magnetic moment)

$$\kappa = \int_{-1}^{+1} dx\ E(x,\xi,t=0) = F_2(t=0)$$

- 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

$ep \to ep\pi^0$

Structure functions and GPDs

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

Leading twist σ_L

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

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)

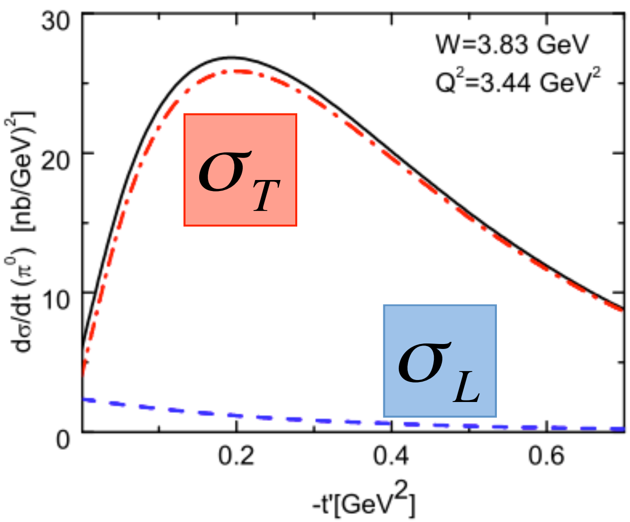
$ep \to ep\pi^0$

Structure functions and GPDs

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

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

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



Transversity GPD model

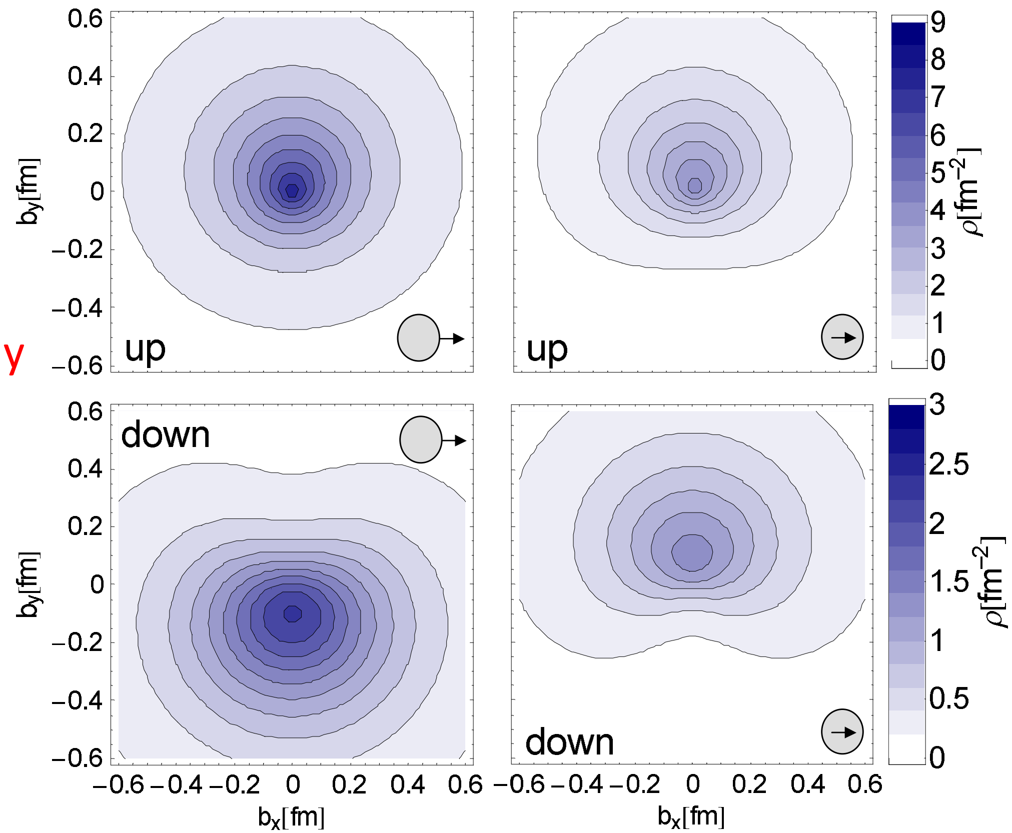
S. Goloskokov and P. Kroll

S. Liuti and G. Goldstein

- $\sigma_L \ll \sigma_T$
- t-dependence at $t=t_{min}$ is determined by the interplay between H_T and $\bar{E}_T = 2\tilde{H}_T + E_T$

Transverse Densities for u and d Quarks in the Nucleon

Strong distortions for unpolarized quarks in transversely polarized nucleon



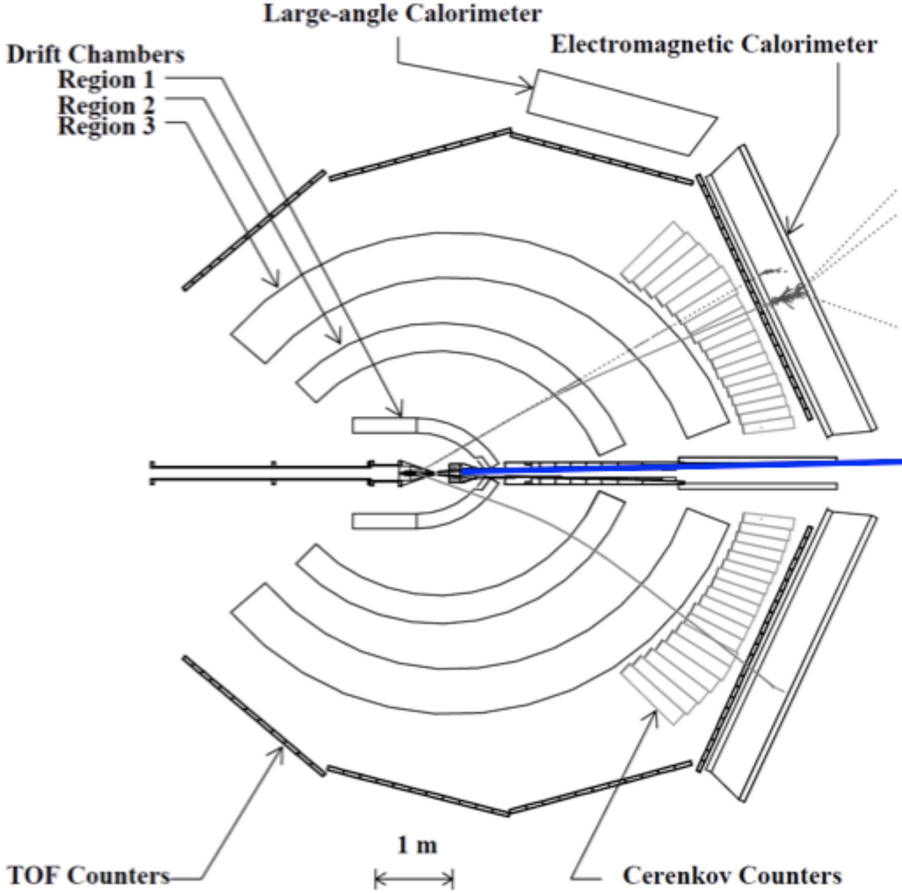
Strong distortions for transversely polarized quarks in an unpolarized nucleon

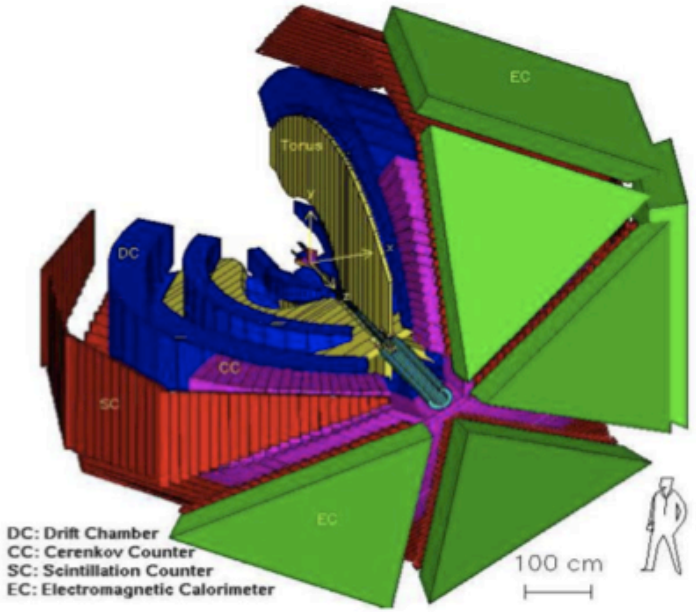
Described by E

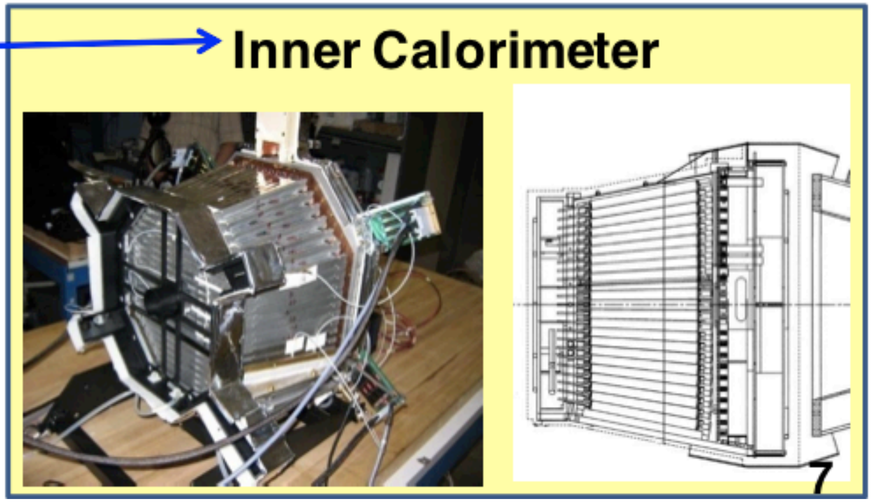
Described by $\bar{E}_T = 2\tilde{H}_T + E_T$

Gockeler et al, hep/lat/0612032

CEBAF Large Acceptance Spectrometer CLAS







CLAS Lead Tungstate Electromagnetic Calorimeter

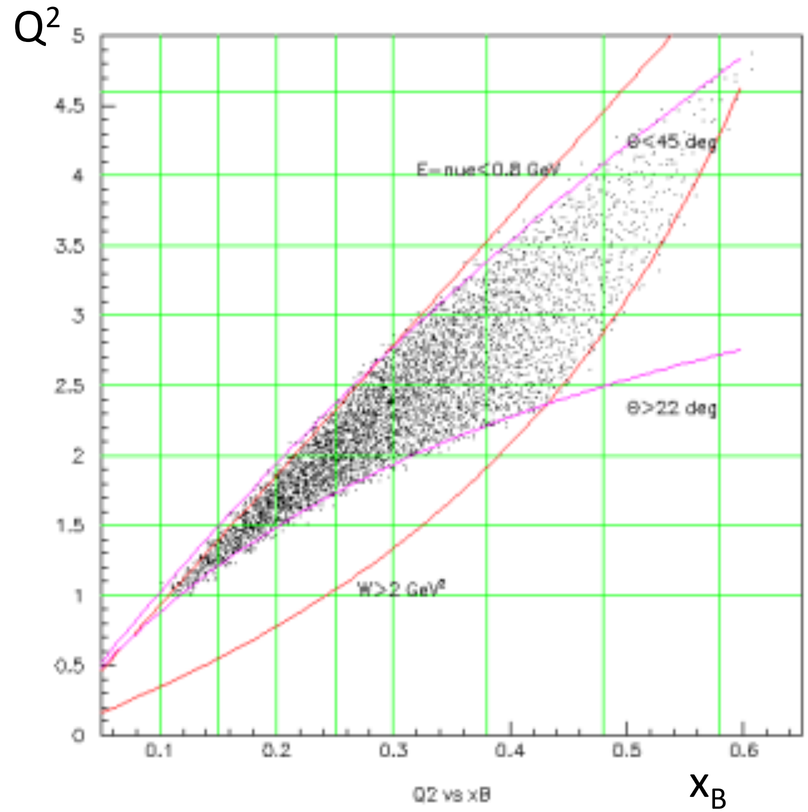
424 crystals, 18 RL,
Pointing geometry,
APD readout

4 Dimensional Grid

$$ep \rightarrow ep\pi^0$$

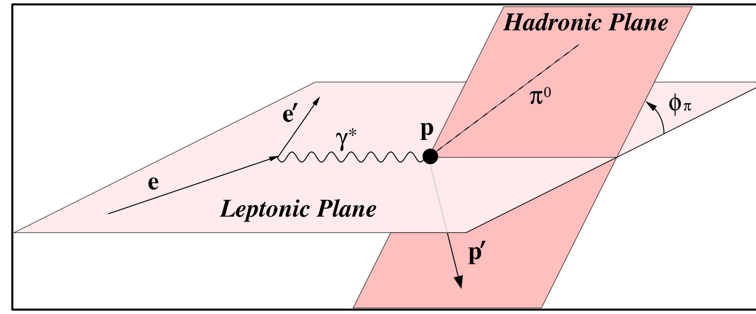
Rectangular bins are used.

- Q^2 7 bins(1.-4.5GeV^2)
- x_B 7 bins(0.1-0.58)
- t 8 bins(0.09-2.0GeV)
- ϕ 20 bins(0-360°)
- π^0 data ~2000 points
- η data ~1000 points

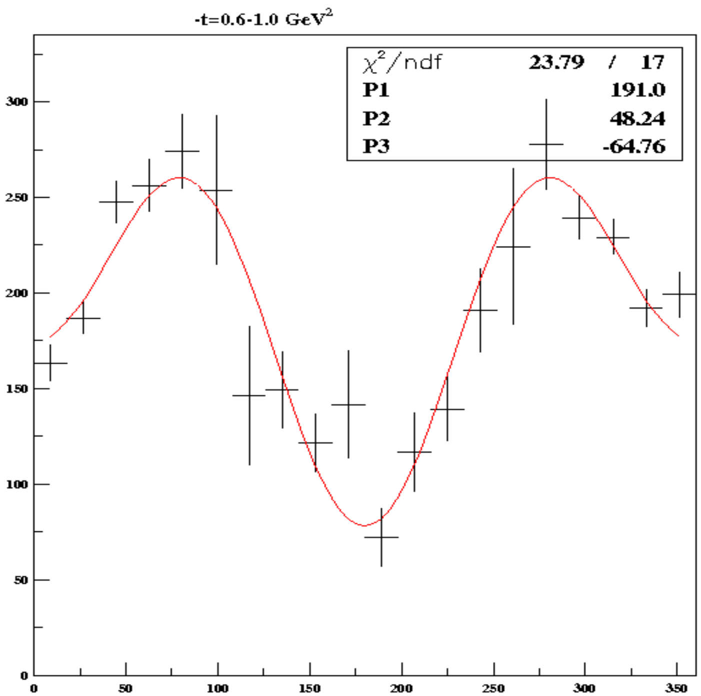


Structure Functions

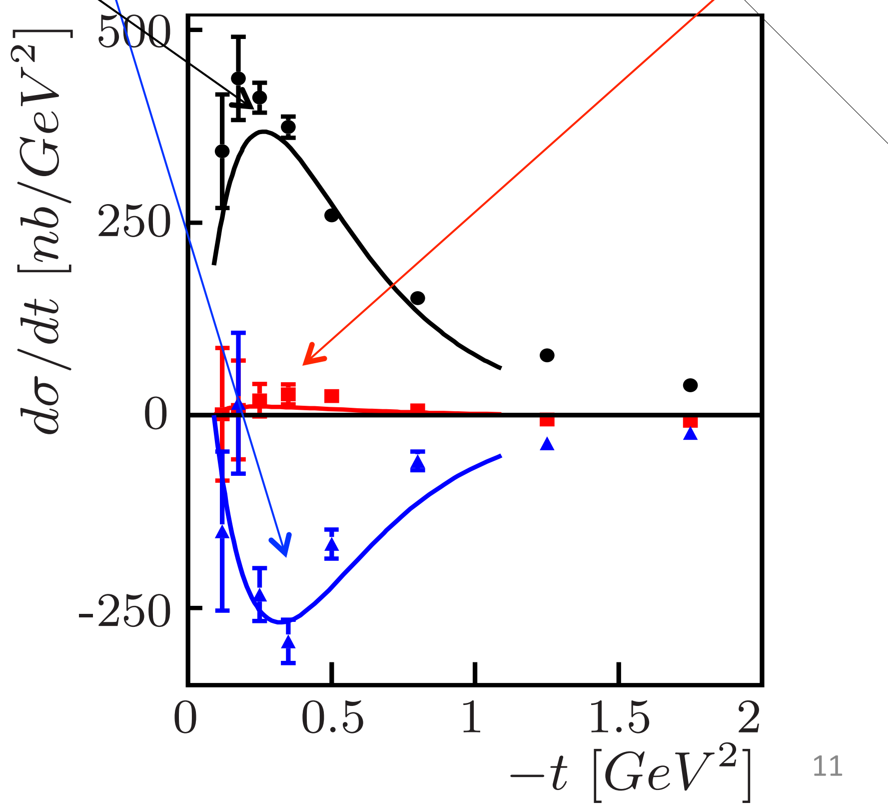
$\sigma_U = \sigma_T + \varepsilon \sigma_L \quad \sigma_{TT} \quad \sigma_{LT}$



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



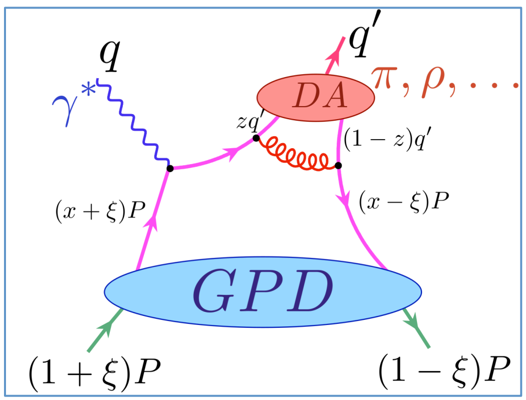
ϕ distribution

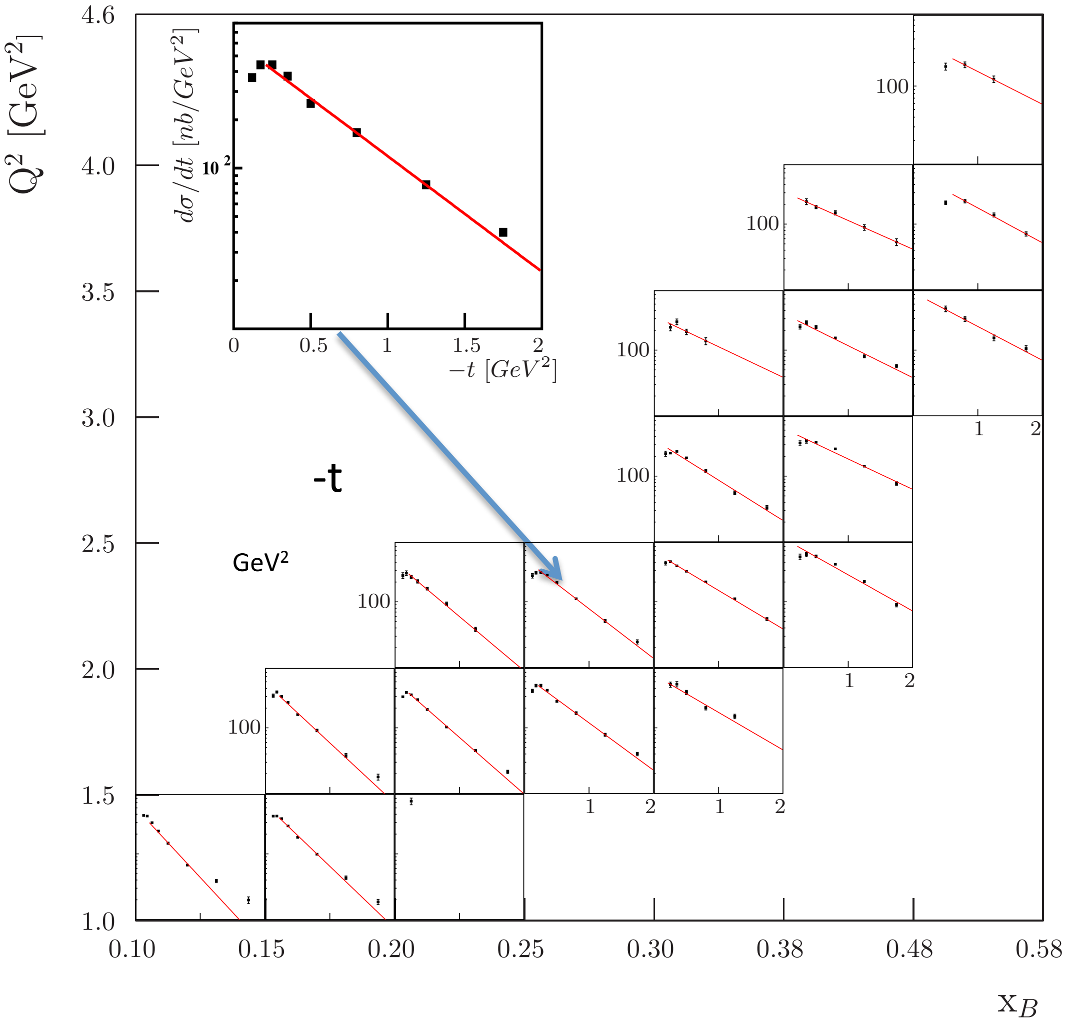


-t

$d\sigma_U/dt$

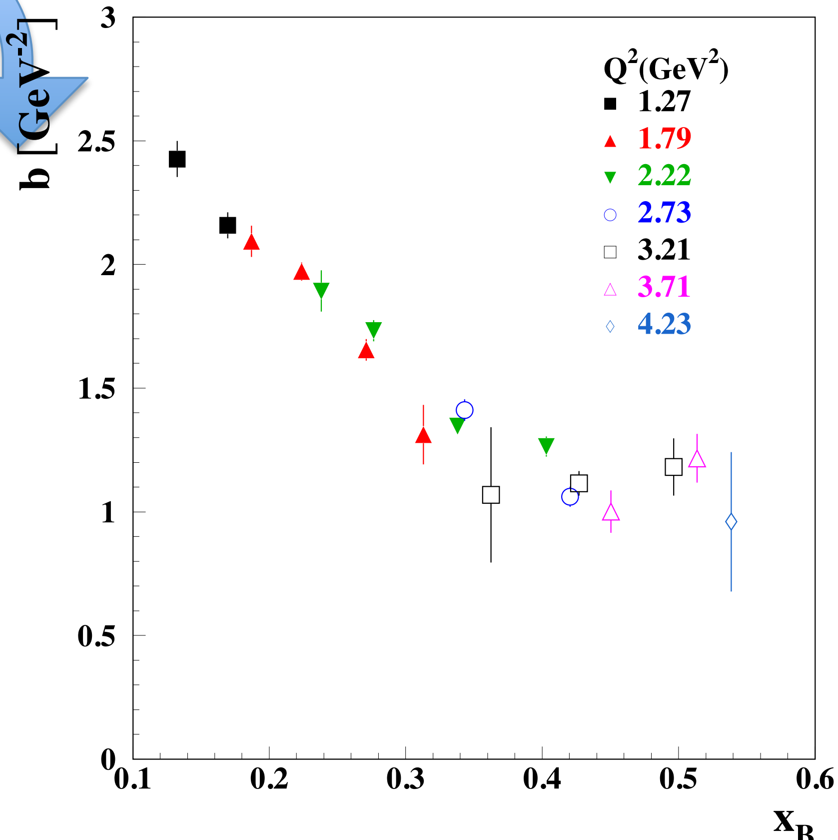
$$\frac{d\sigma}{dt}(\gamma^* p \to ep\pi^0) \propto e^{bt}$$





t-slope parameter: x_B dependence

$$\frac{d\sigma}{dt} \propto e^{bt}$$

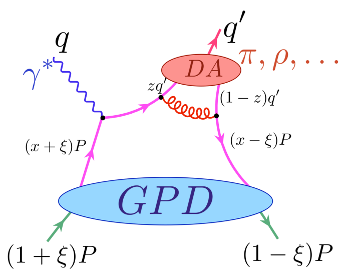


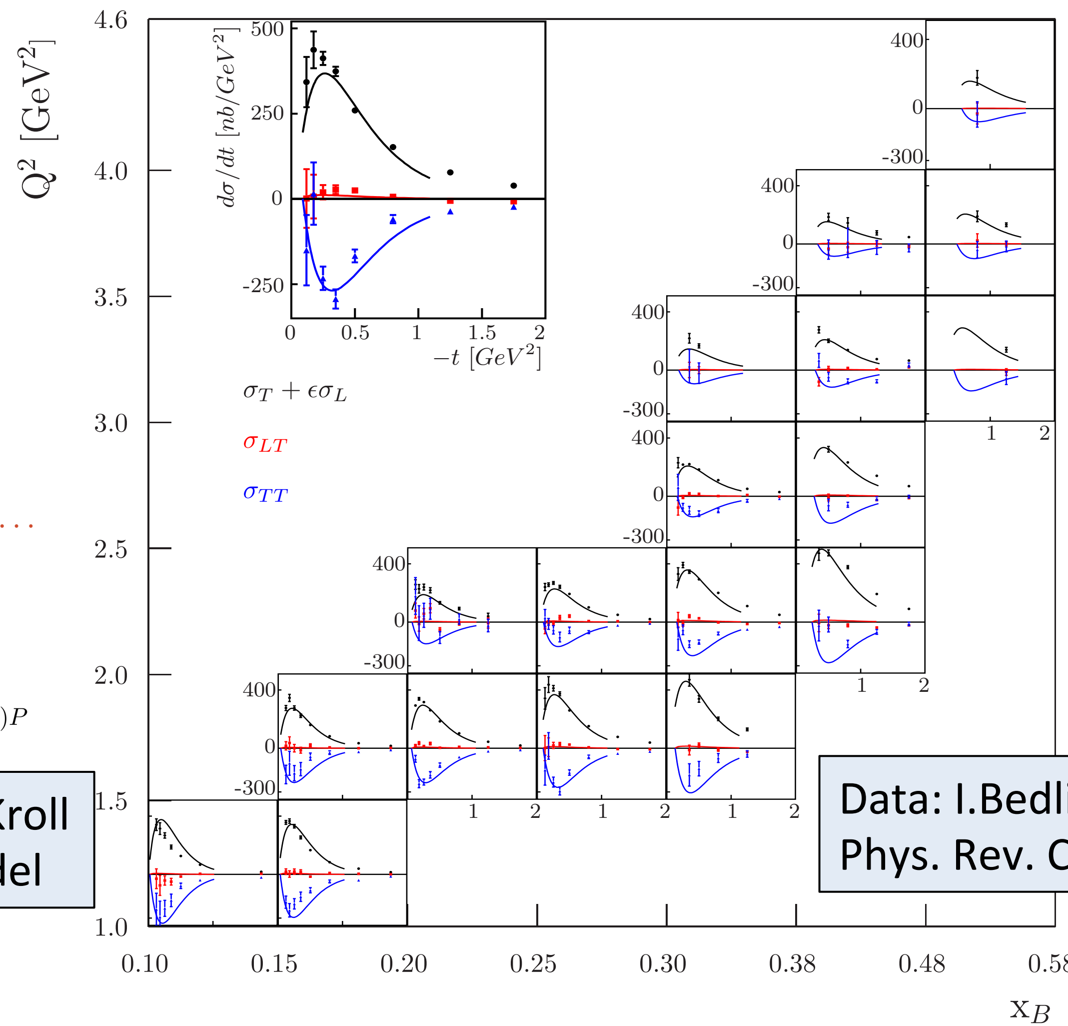
The slope parameter is decreasing with increasing x_B. The Q^2 dependence is weak. Looking to this picture we can say that the perp width of the partons with x→1 goes to zero.

Structure Functions

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

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





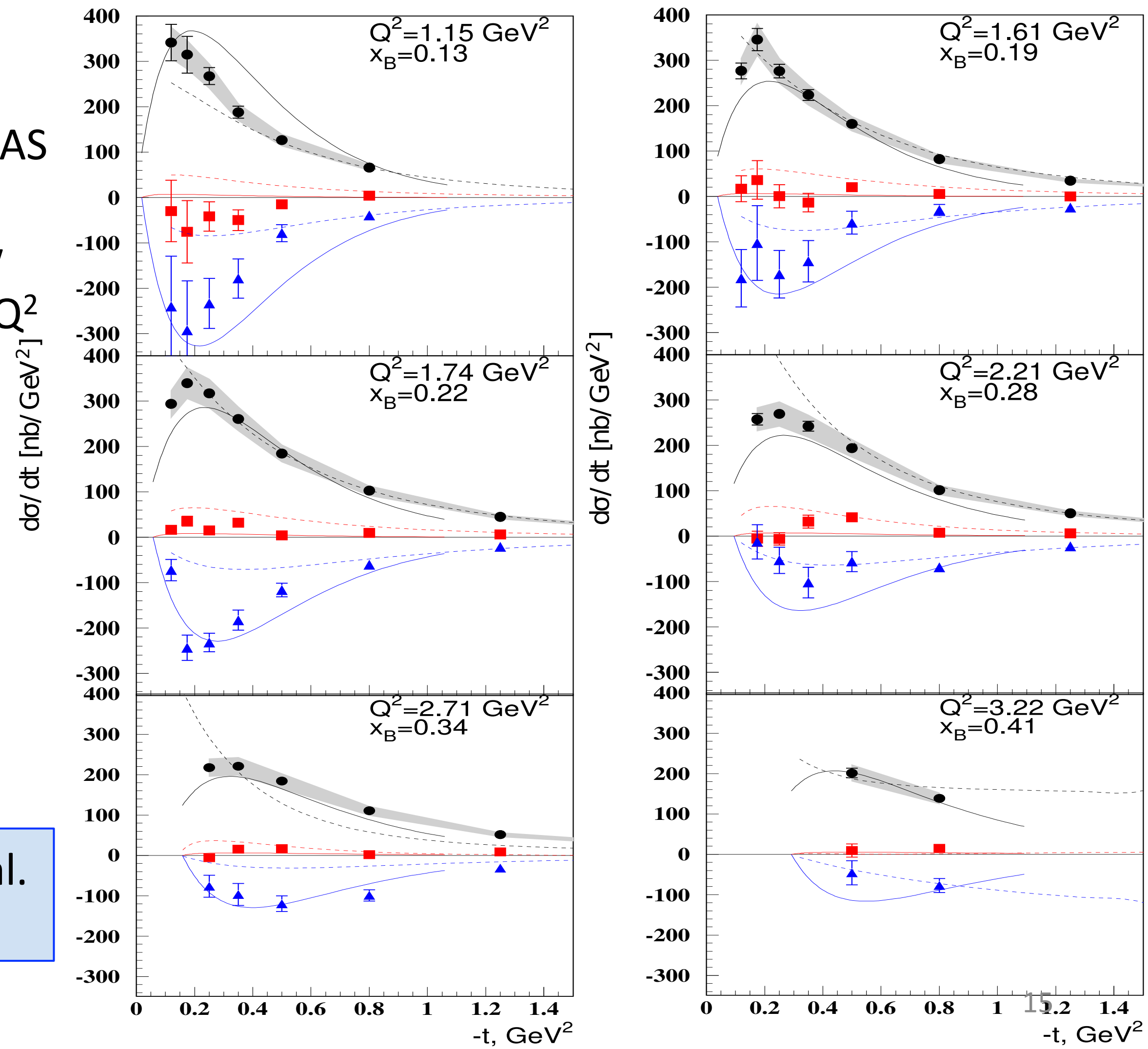
Curves: Goloskokov, Kroll
Transversity GPD model

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

CLAS data and GPD theory predictions

Solid: S. Goloskokov and P. Kroll
Dots: S. Liuti and G. Goldstein

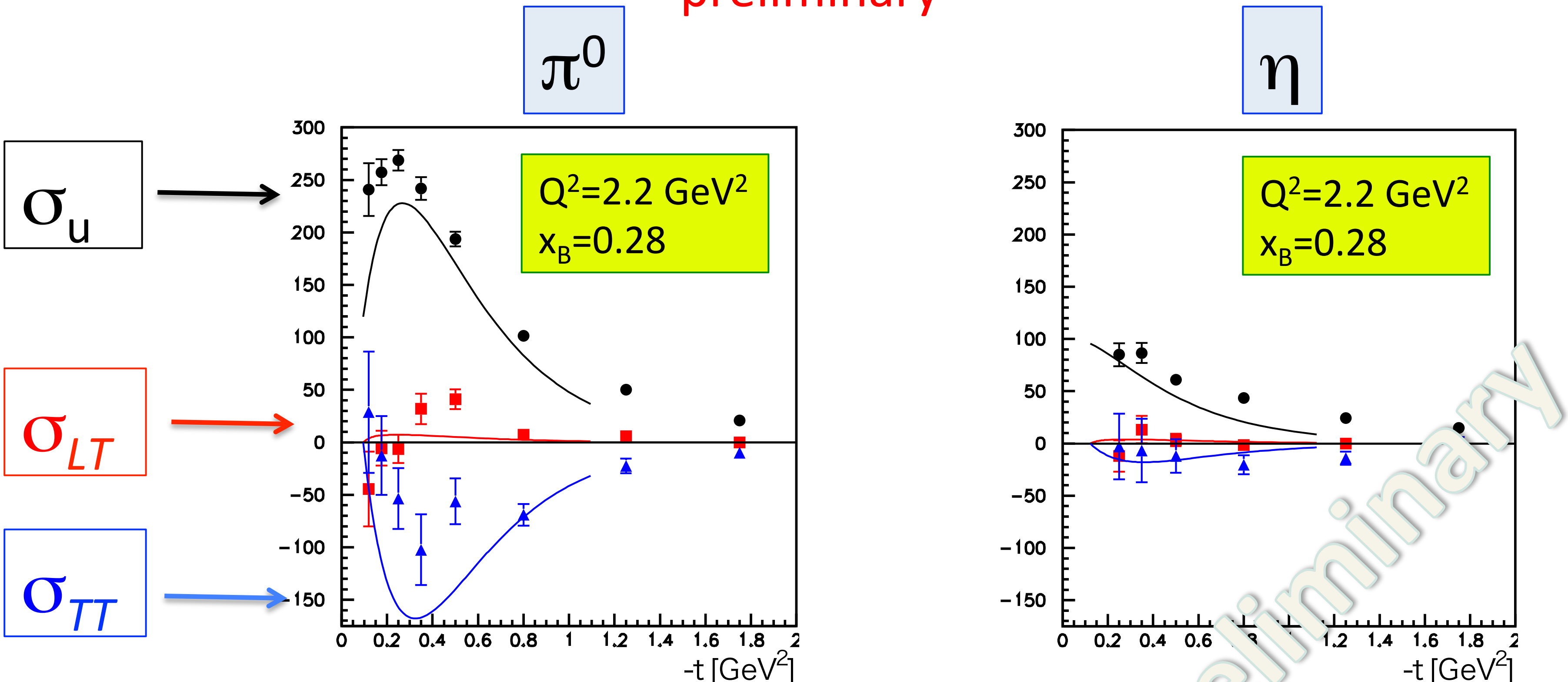
- ***Transversity* GPDs** H_T and $\bar{E}_T = 2\tilde{H}_T + E_T$ dominate in CLAS kinematics.
- The model was optimized for low x_B and high Q^2. The corrections t/Q^2 were omitted
- The model successfully describes CLAS data even at low Q^2
- Pseudoscalar meson production [provides unique possibility to access the transversity GPDs.]()



CLAS collaboration. I Bedlinskiy et al. Phys.Rev.Lett. 109 (2012) 112001

Comparison π^0/η

preliminary

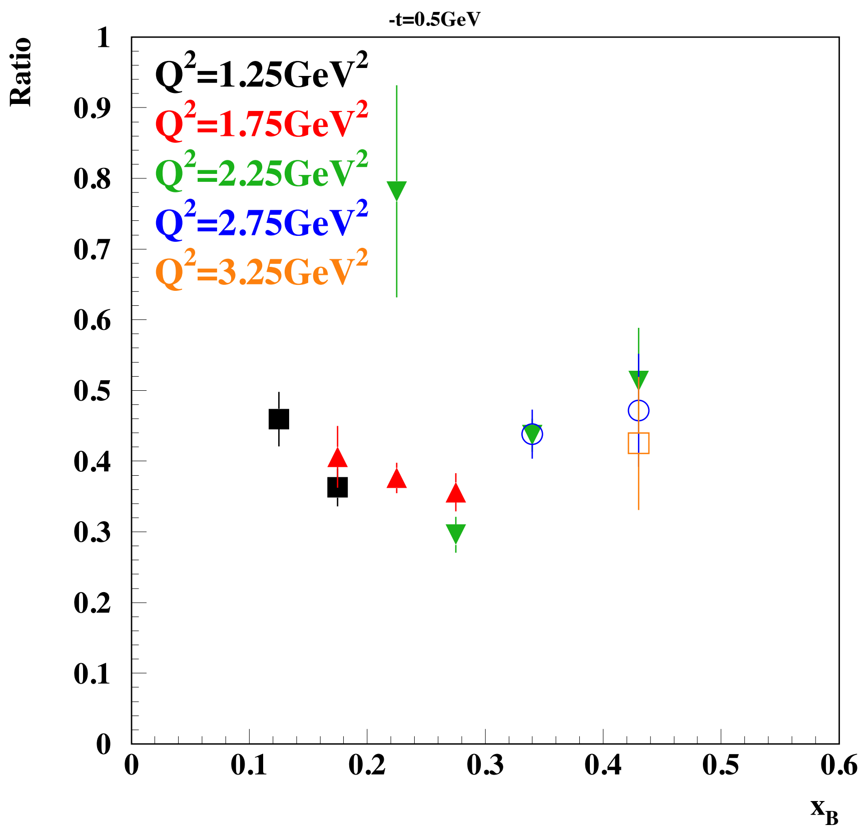


- $\sigma_U=\sigma_T+\varepsilon\sigma_L$ drops by a factor of 2.5 for η
- σ_{TT} drops by a factor of 10
- The GK GPD model (curves) follows the experimental data
- The statement about the transversity GPD dominance in the pseudoscalar electroproduction becomes more solid with the inclusion of η data

η/π^0 ratio

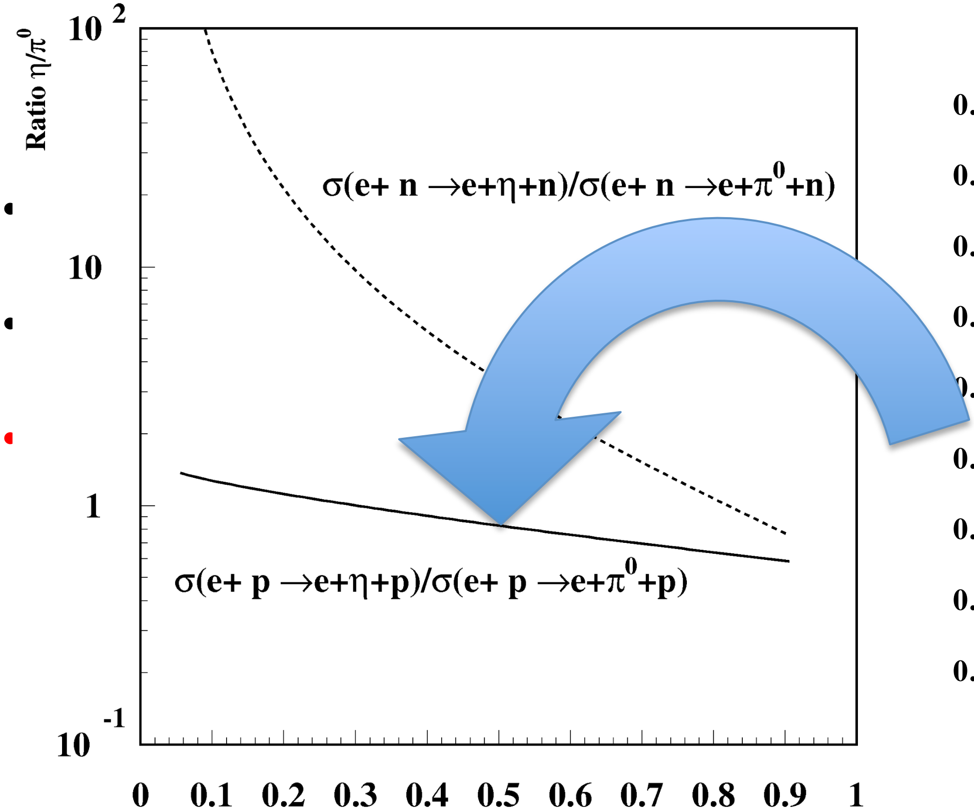
$$\frac{\sigma(ep \to ep\eta)}{\sigma(ep \to ep\pi^0)}$$

- The dependence on x_B and Q^2 is very weak.
- Chiral odd GPD models predict this ratio to be ~1/3 at CLAS kinematics
- Chiral even GPD models predict this ratio to be around 1 (at low –t).

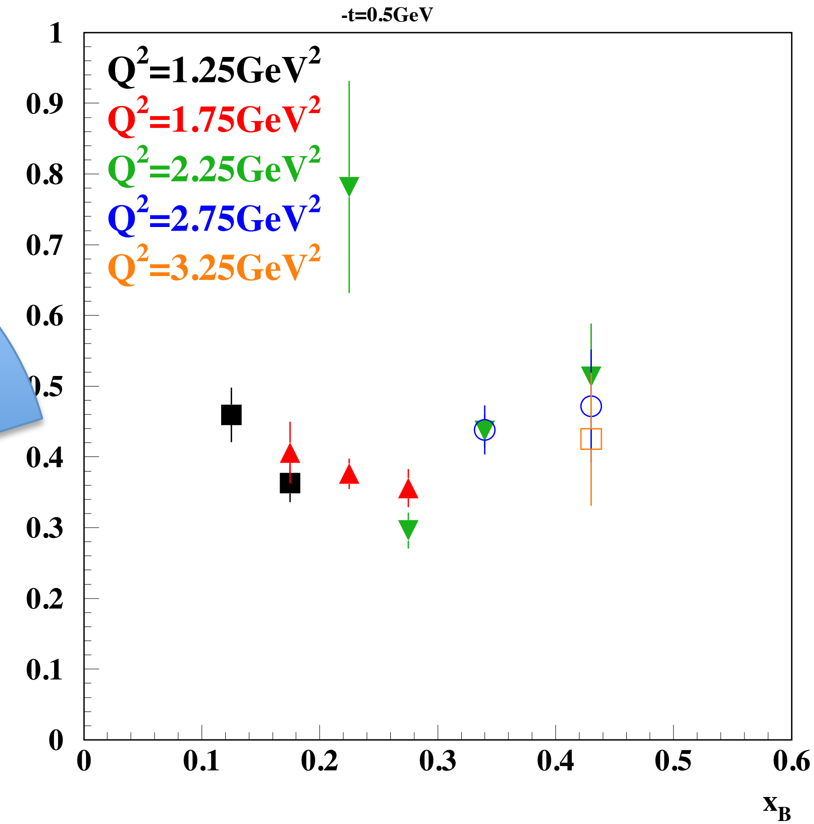


η/π^0 ratio

$$\frac{\sigma(ep \to ep\eta)}{\sigma(ep \to ep\pi^0)}$$



Theoretical prediction R=1 for the Chiral-even GPD models ($\sigma_L >> \sigma_T$)



Structure functions and GPDs

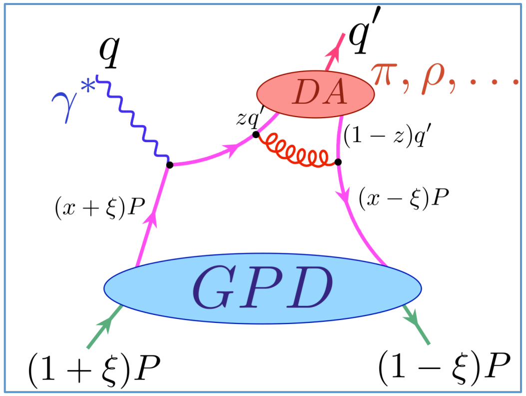
$$\frac{d\sigma_T}{dt} = \frac{4\pi\alpha}{2k'}\frac{\mu_P^2}{Q^8}\left[(1-\xi^2)\left|\langle H_T\rangle\right|^2 - \frac{t'}{8m^2}\left|\langle \bar{E}_T\rangle\right|^2\right]$$

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

Goloskokov, Kroll
Transversity GPD model

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

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



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

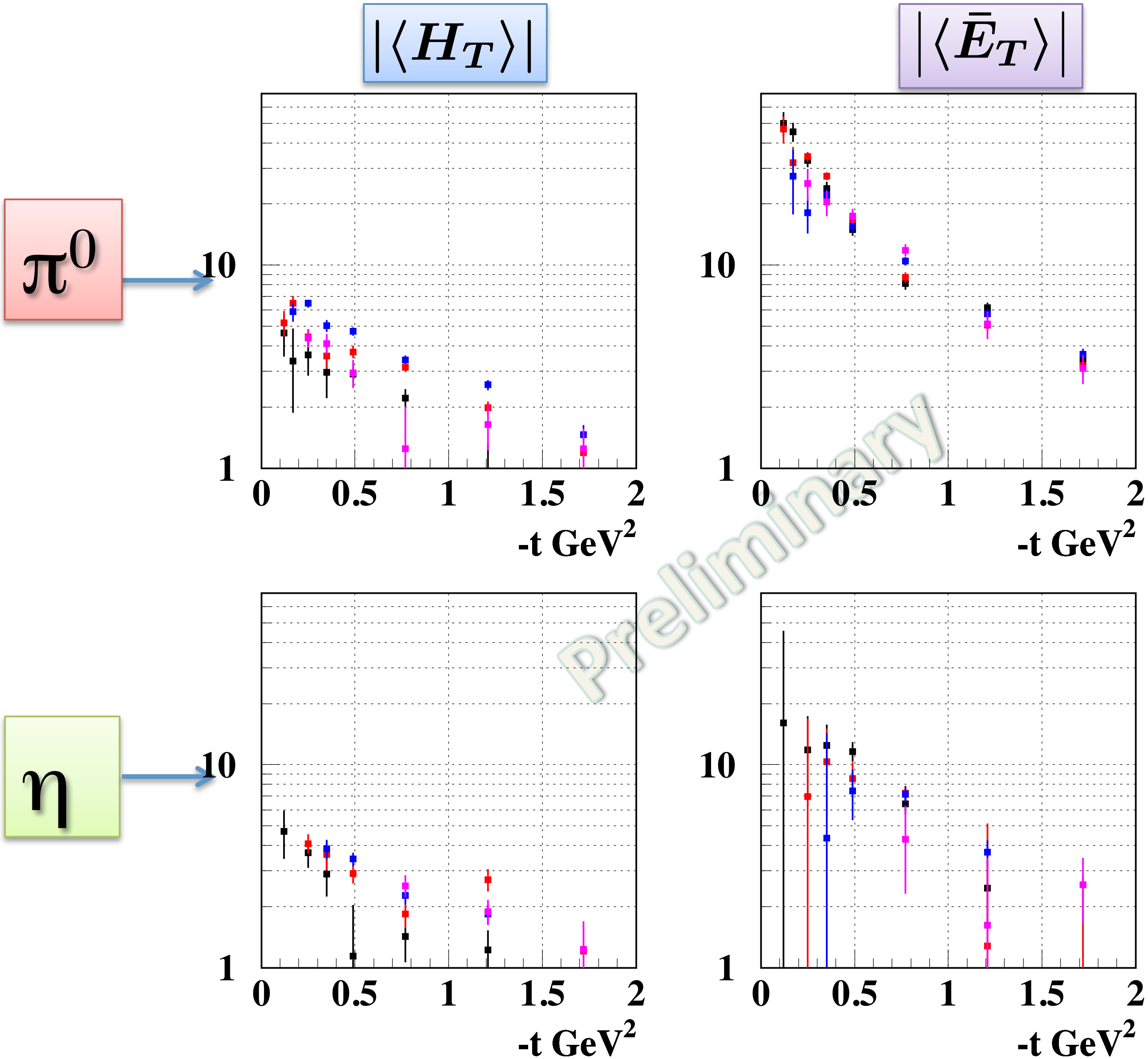
$$\langle \bar{E}_T\rangle = \Sigma_\lambda \int_{-1}^{1} dx M(x,\xi,Q^2,\lambda) \bar{E}_T(x,\xi,t)$$

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

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

- We did not separate σ_T and σ_L
- However *in the approximation* of the transversity GPDs dominance, that is supported by CLAS data, $\sigma_L \ll \sigma_T$ we have direct access to the generalized form factors for π and η production.

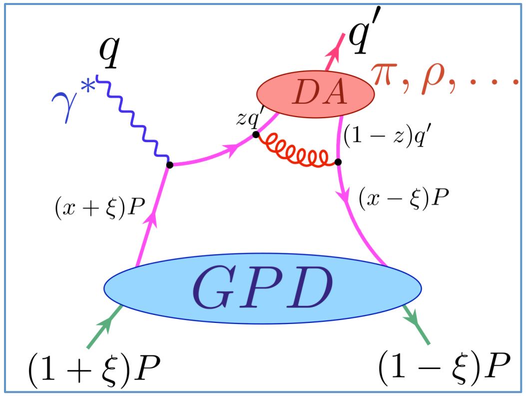
Generalized Form factors

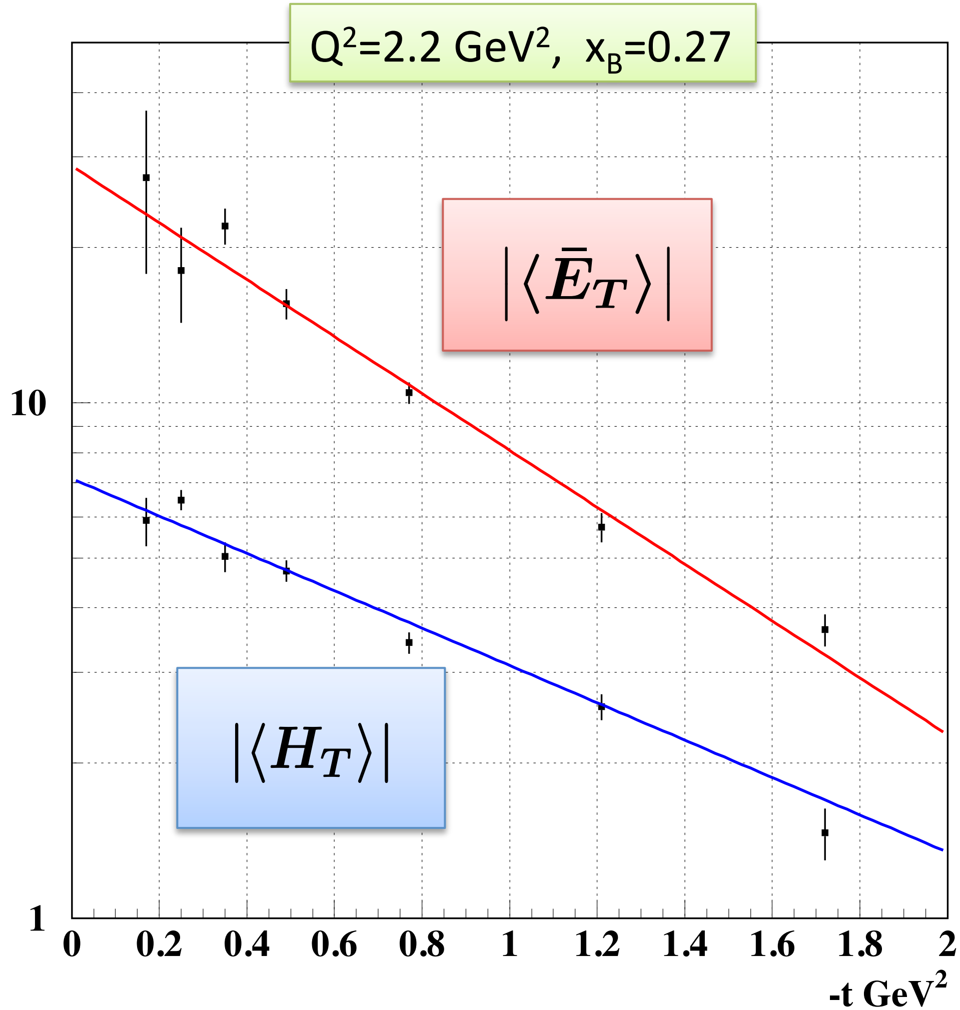


Q^2 GeV²	x_B
1.2	0.15
1.8	0.22
2.2	0.27
2.7	0.34

- $\bar{E}_T > H_T$ for π^0 and η
- t-dependence is steeper for $\bar{E}_T$ than for H_T
- Estimation of the systematic uncertainties connected with the used approximation is in progress

π^0 Generalized Form Factors





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

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

Preliminary

GPD Flavor Decomposition

$$H_T^\pi = \frac{1}{3\sqrt{2}}[2H_T^u + H_T^d]$$
$$H_T^\eta = \frac{1}{\sqrt{6}}[2H_T^u - H_T^d]$$

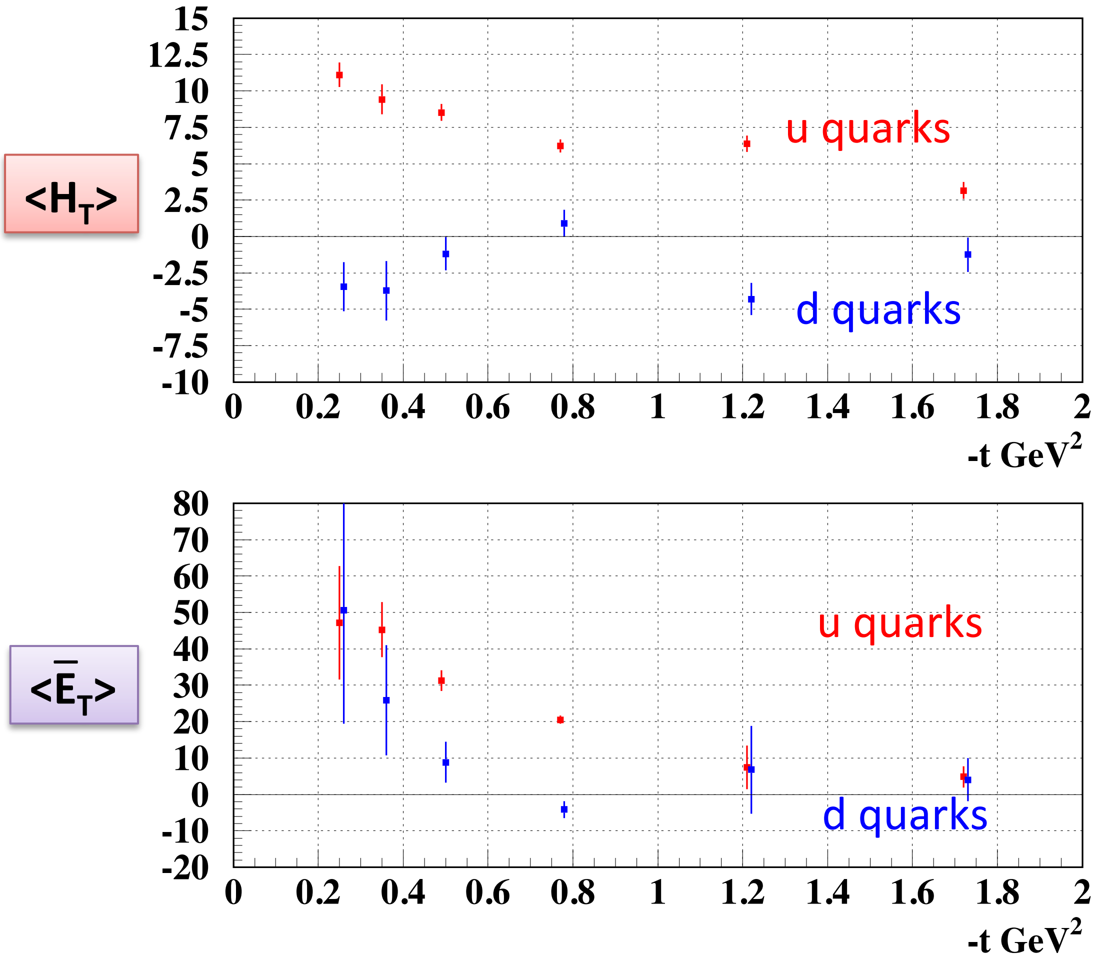
↓

$$H_T^u = \frac{3}{2\sqrt{2}}[H_T^\pi + \sqrt{3}H_T^\eta]$$
$$H_T^d = \frac{3}{\sqrt{2}}[H_T^\pi - \sqrt{3}H_T^\eta]$$

Similar expressions for $\bar{E}_T$

- 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 $\bar{E}_T$
- The u/d decomposition was done under simple assumption that the relative phase between u and d is 0 or 180 degrees.

Flavor Decomposition of the Transversity GPDs



Q^2=1.8 GeV^2, x_B=0.22

- $\langle H_T \rangle^u$ and $\langle H_T \rangle^d$ have different signs for u and d-quarks in accordance with the transversity function h_1 (Anselmino et al.)
- $|\langle \bar{E}_T \rangle|^d$ and $|\langle \bar{E}_T \rangle|^u$ seem to have the same signs
- Decisions shown with positive values of u-quark's GPDs only

Preliminary

Summary

- The discovery of Generalized Parton Distributions has opened up a new and exciting avenue of hadron physics that needs exploration in dedicated experiments

- CLAS π^0 and η data supports the dominance of the transversity GPDs H_T and $\bar{E}_T$ in the processes of the pseudoscalar meson electroproduction

- The generalized form factors $<H_T>$ and $<\bar{E}_T>$ are directly connected to the structure functions σ_T and σ_{TT} within handbag approach

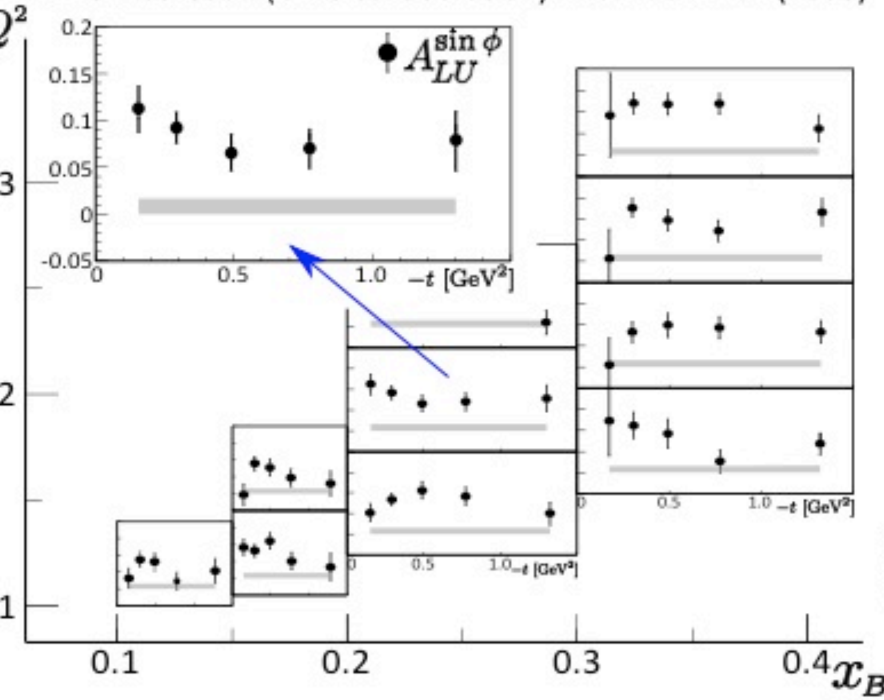
- The combined π^0 and η data will provide the way for the flavor decomposition of transversity GPD

END

$ep \to ep\pi^0$: spin asymmetries

❖ Beam Spin Asymmetries

R. De Masi *et al.* (CLAS collaboration) PRC**77:** 042201 (2008)



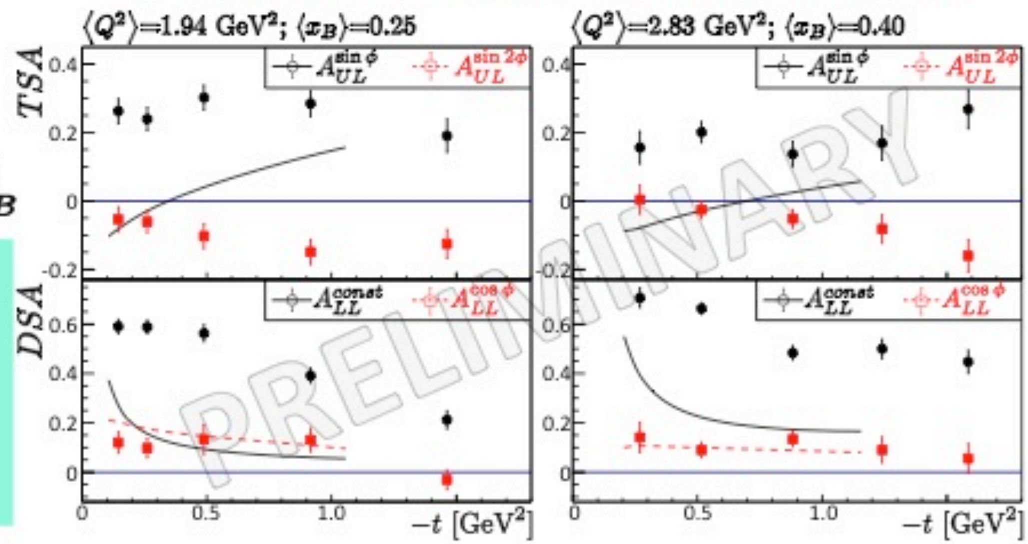
$$A_{LU}^{\sin\phi}\sigma_0 \sim \ \mathrm{Im}\left[\langle H_T\rangle^*\langle\tilde{E}\rangle\right]$$

$$A_{UL}^{\sin\phi}\sigma_0 \ \sim \ \mathrm{Im}\left[\langle\bar{E}_T\rangle^*\langle\tilde{H}\rangle + \xi\langle H_T\rangle^*\langle\tilde{E}\rangle\right]$$

$$A_{LL}^{const}\sigma_0 \sim \ |\langle H_T\rangle|^2$$

$$A_{LL}^{\cos\phi}\sigma_0 \ \sim \ \mathrm{Re}\left[\langle\bar{E}_T\rangle^*\langle\tilde{H}\rangle + \xi\langle H_T\rangle^*\langle\tilde{E}\rangle\right]$$

❖ Target and Double Spin Asymmetries



Dominated by transverse virtual photons contribution

⇓

Unique sensitivity
for constraining the chiral-odd GPDs