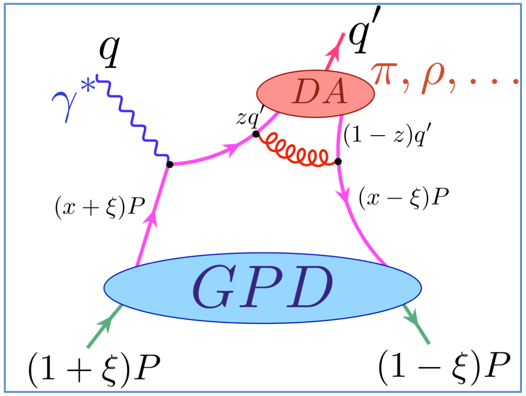
Tomographic transversity distributions and deeply exclusive meson production

Valery Kubarovsky

Jefferson Lab

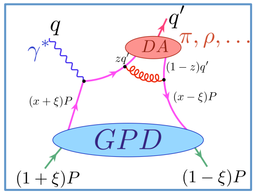
CLAS Collaboration Meeting
March 9, 2018

Outline



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

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



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:

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

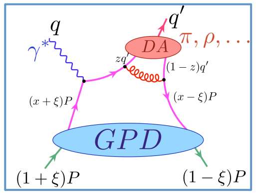
$\tilde{H}^u$ and $\tilde{H}^d$ have opposite signes

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

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

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

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



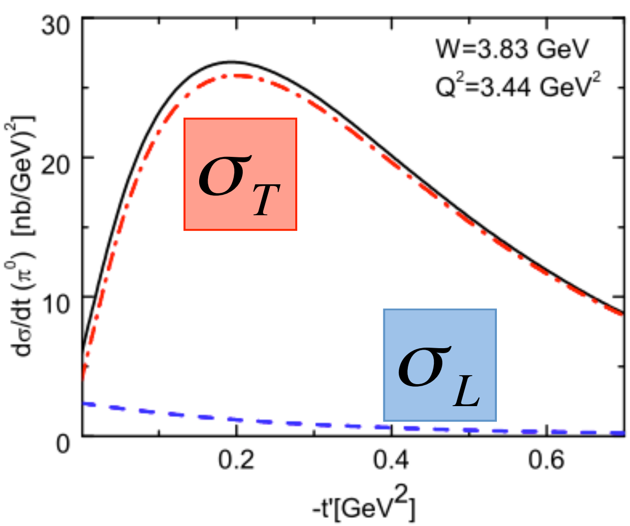
$ep \to ep\pi^0$

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

2012-2017

π^0/η Exclusive Electroproduction with CLAS

PRL **109,** 112001 (2012) PHYSICAL REVIEW LETTERS week ending 14 SEPTEMBER 2012

Measurement of Exclusive π^0 Electroproduction Structure Functions and their Relationship to Transverse Generalized Parton Distributions

I. Bedlinskiy,[22] V. Kubarovsky,[35,30] S. Niccolai,[21] P. Stoler,[30] K. P. Adhikari,[29] M. Aghasyan,[18] M. J. Amaryan,[29]
M. Anghinolfi,[19] H. Avakian,[35] H. Baghdasaryan,[39,41] J. Ball,[7] N. A. Baltzell,[1] M. Battaglieri,[19] R. P. Bennett,[29]

PHYSICAL REVIEW C **90**, 025205 (2014)

Exclusive π^0 electroproduction at $W > 2$ GeV with CLAS

I. Bedlinskiy,[19] V. Kubarovsky,[32,27] S. Niccolai,[18,12] P. Stoler,[27] K. P. Adhikari,[26] M. D. Anderson,[35] S. Anefalos Pereira,[15]
H. Avakian,[32] J. Ball,[6] N. A. Baltzell,[1,31] M. Battaglieri,[16] V. Batourine,[32,21] A. S. Biselli,[9] S. Boiarinov,[32] J. Bono,[10]

PHYSICAL REVIEW C **95**, 035202 (2017)

Exclusive η electroproduction at $W > 2$ GeV with CLAS and transversity generalized parton distributions

I. Bedlinskiy,[22] V. Kubarovsky,[36,31] P. Stoler,[31] K. P. Adhikari,[25] Z. Akbar,[12] S. Anefalos Pereira,[17] H. Avakian,[36] J. Ball,[7]
N. A. Baltzell,[36,34] M. Battaglieri,[18] V. Batourine,[36,24] A. S. Biselli,[10,5] S. Boiarinov,[36] W. J. Briscoe,[14] V. D. Burkert,[36]

PRL **109,** 112001 (2012) PHYSICAL REVIEW LETTERS week ending 14 SEPTEMBER 2012

Measurement of Exclusive π^0 Electroproduction Structure Functions and their Relationship to Transverse Generalized Parton Distributions

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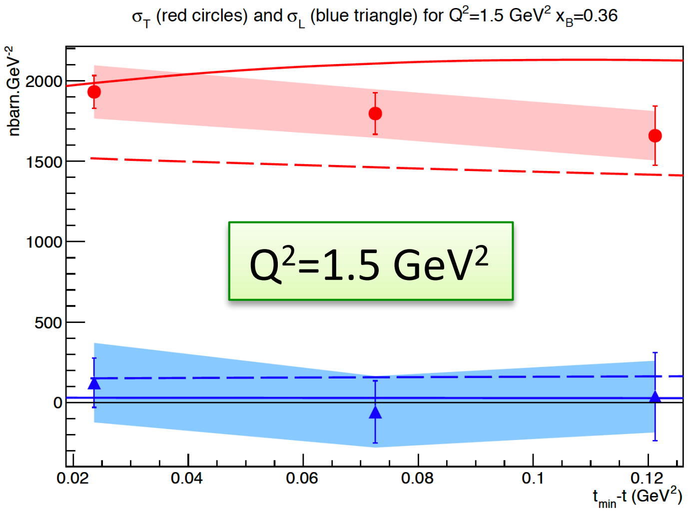
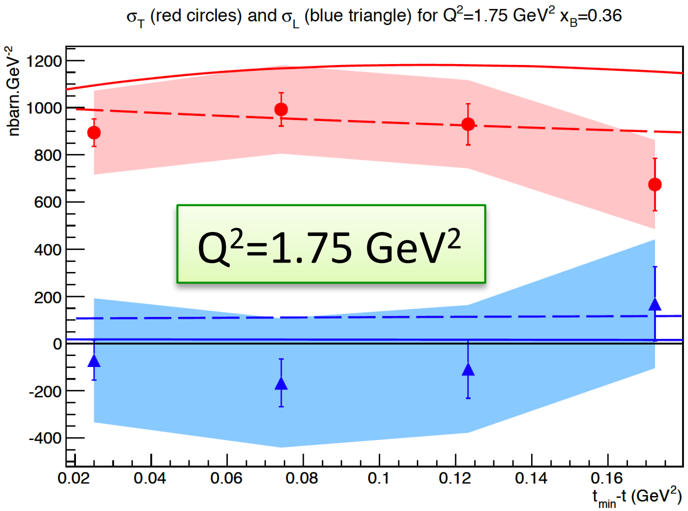
- The measured cross section of π^0 electroproduction is much larger than expected from leading-twist handbag calculation. This means that the contribution of the longitudinal cross section σ_L is small in comparison with σ_T. The same conclusion can be made in a almost model independent way from the comparison of the cross sections σ_U, σ_{TT} and σ_{LT}.

- The data appear to confirm the expectation that pseudoscalar and, in particular, π^0 electroproduction is a uniquely sensitive process to access the transversity GPDs E_T and H_T.

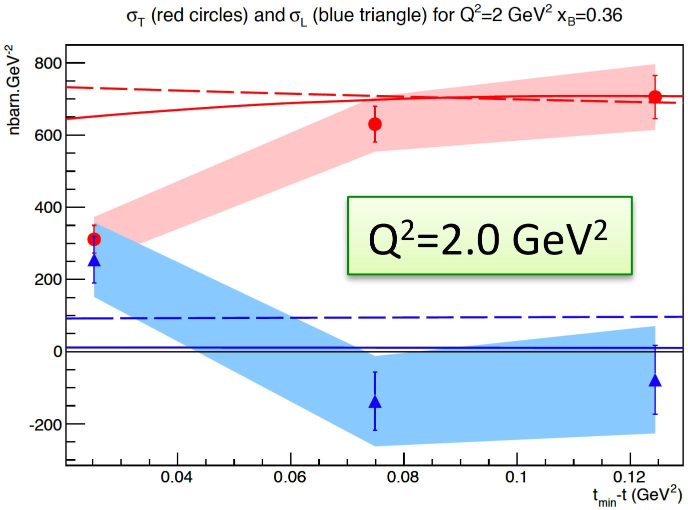
Rosenbluth separation σ_T and σ_L Hall-A Jefferson Lab

σ_T





σ_L

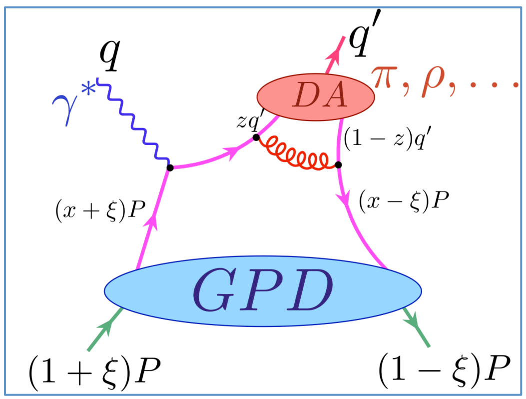


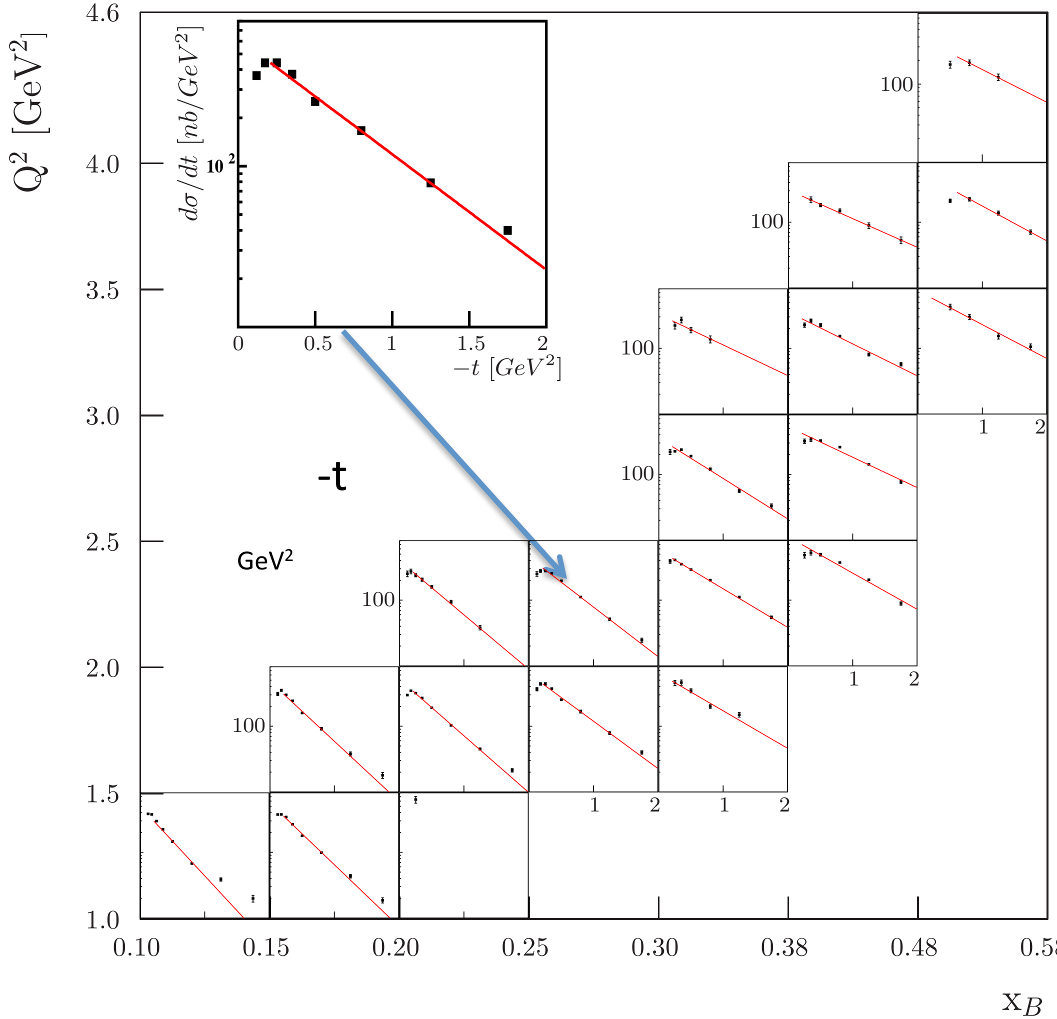
- Experimental **proof** that the transverse π^0 cross section is dominant!
- It opens the direct way to study the transversity GPDs in pseudoscalar exclusive production

Hall-A, Phys.Rev.Lett. **117**,262001(2016)

$d\sigma_U/dt$

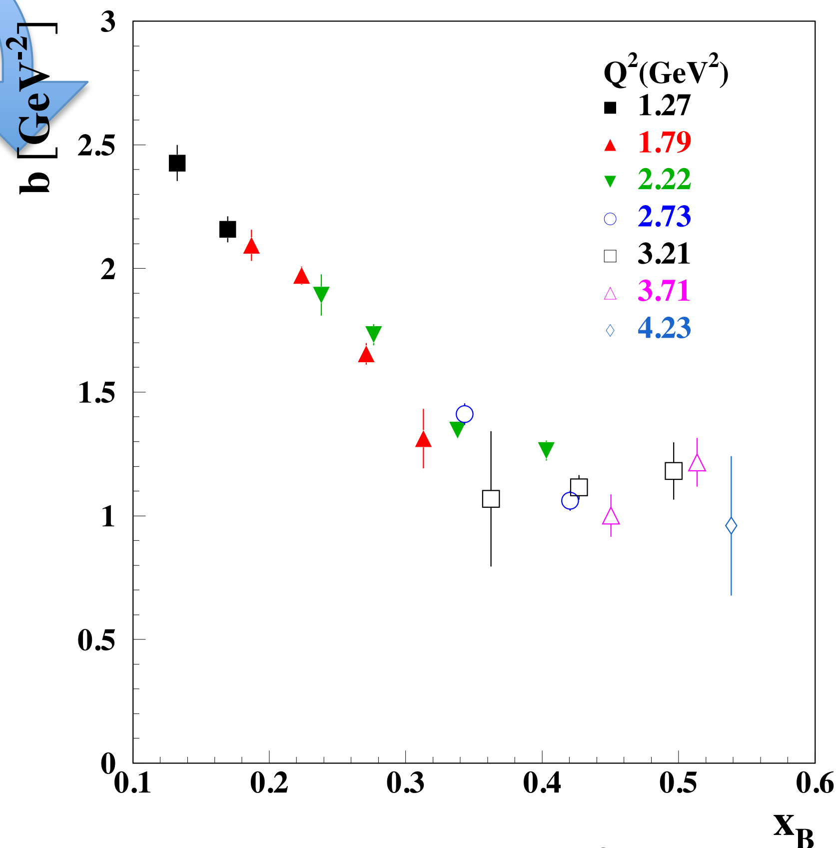
$$\frac{d\sigma}{dt}(\gamma^* p \rightarrow ep\pi^0) \propto e^{bt}$$





t-slope parameter: x_B dependence

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

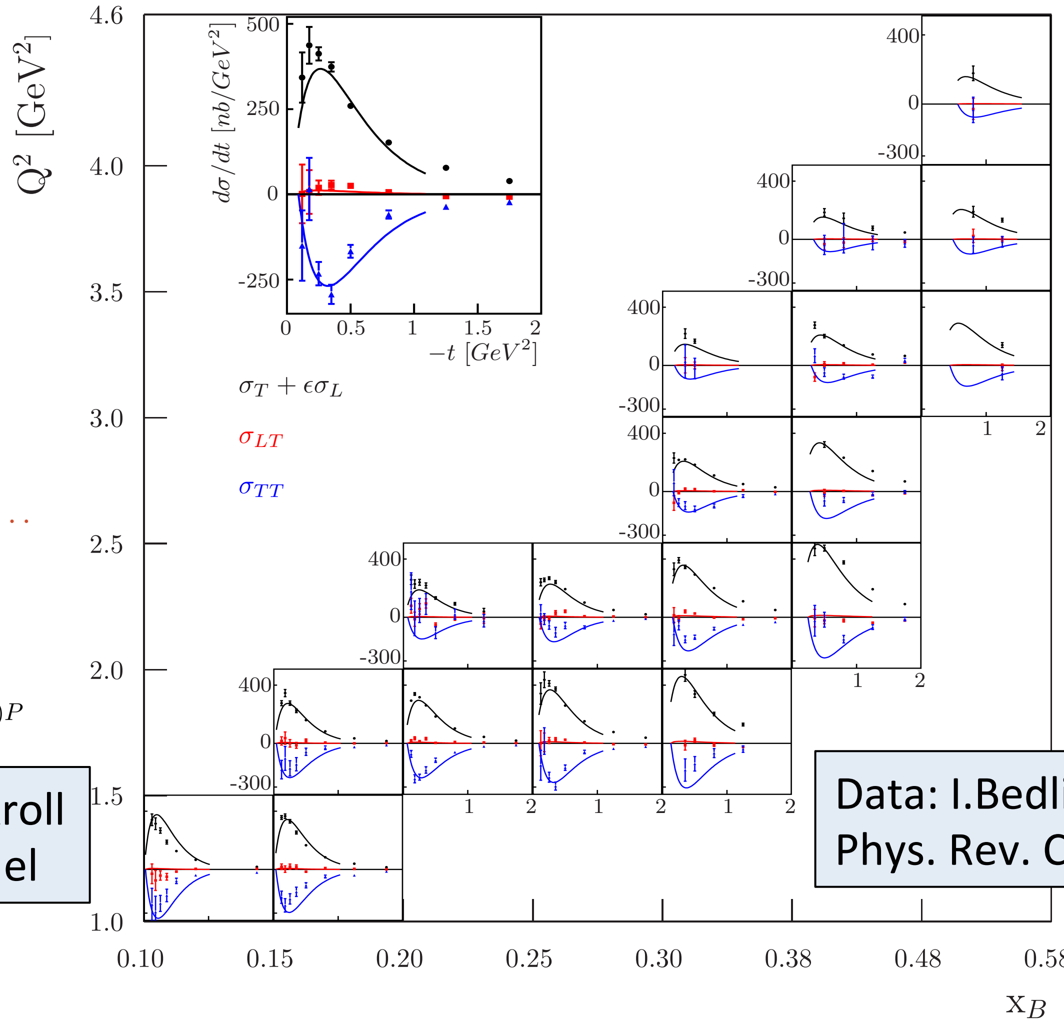


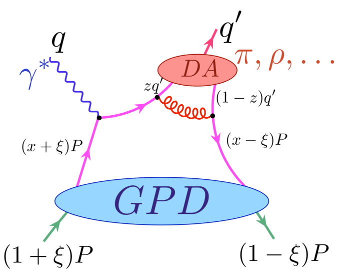
The slope parameter is decreasing with increasing x_B. The Q^2 dependence is weak. Looking to this picture we can say that the perp width of the partons with x→1 goes to zero.

Structure Functions

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

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





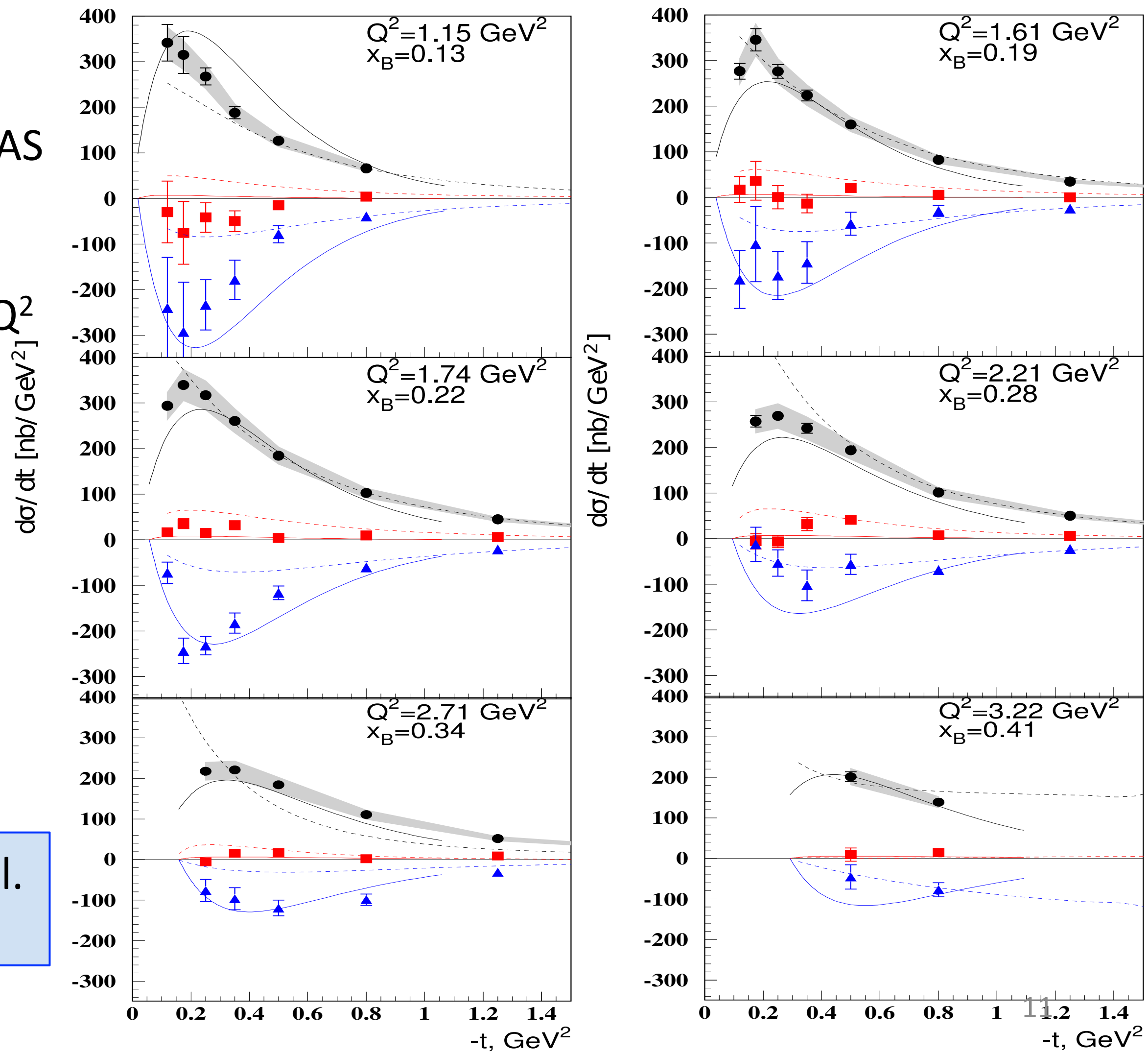
Curves: Goloskokov, Kroll
Transversity GPD model

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

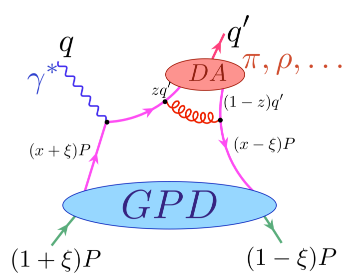
- ***Transversity* GPDs** H_T and $\bar{E}_T = 2\tilde{H}_T + E_T$ dominate in CLAS kinematics.
- The model was optimized for low x_B and high Q^2. The corrections t/Q^2 were omitted
- The model successfully describes CLAS data even at low Q^2
- Pseudoscalar meson production provides unique possibility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

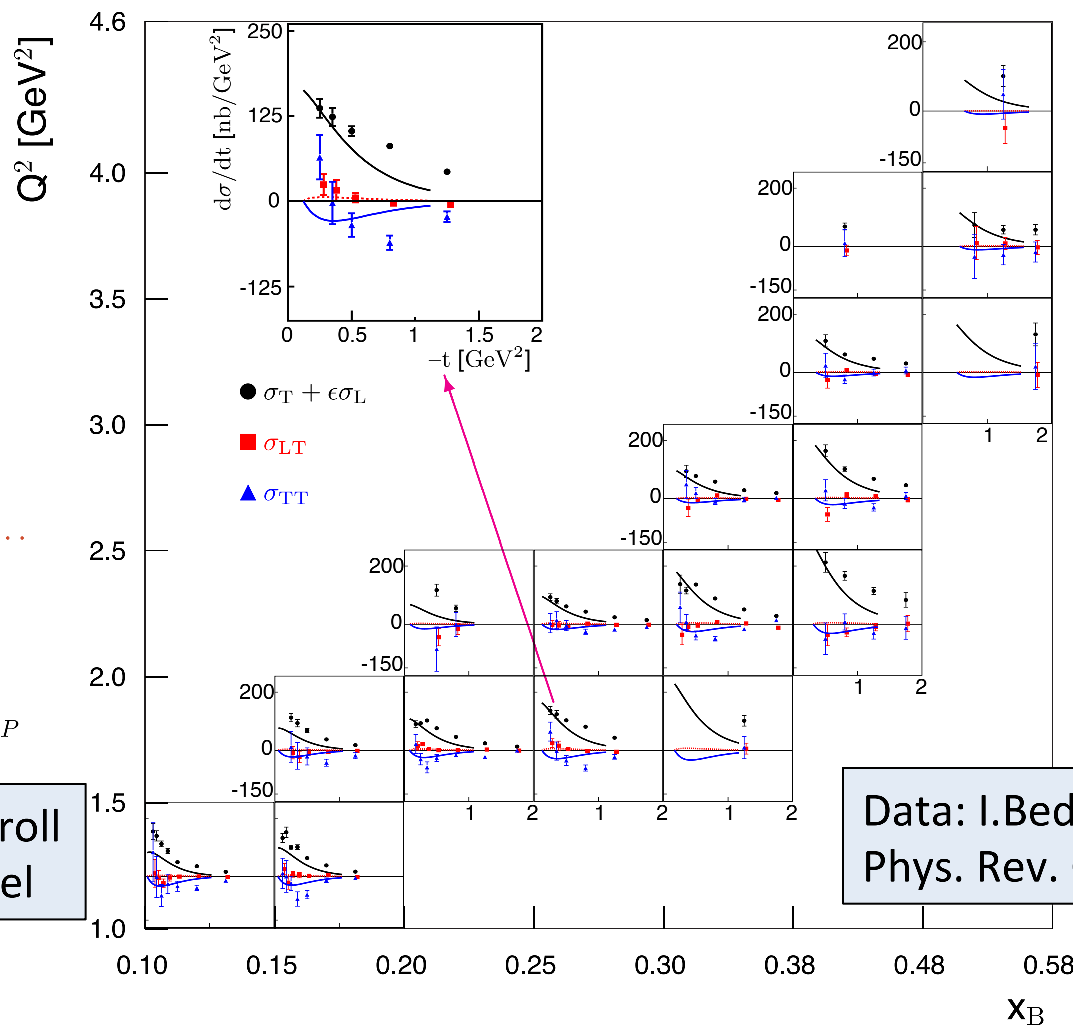


CLAS collaboration. I Bedlinskiy et al. Phys.Rev.Lett. 109 (2012) 112001

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

$\gamma^* p \rightarrow p\eta$

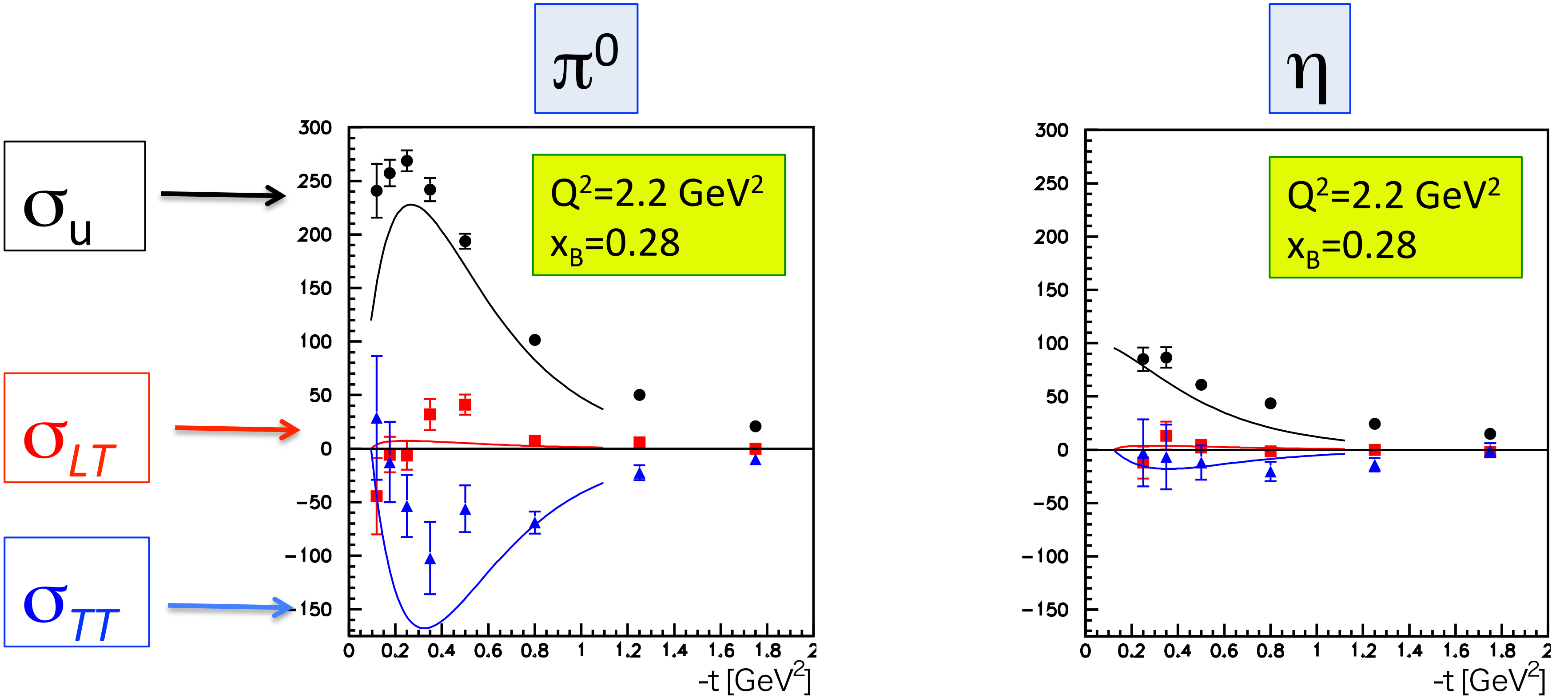




Curves: Goloskokov, Kroll
Transversity GPD model

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

Comparison π^0/η



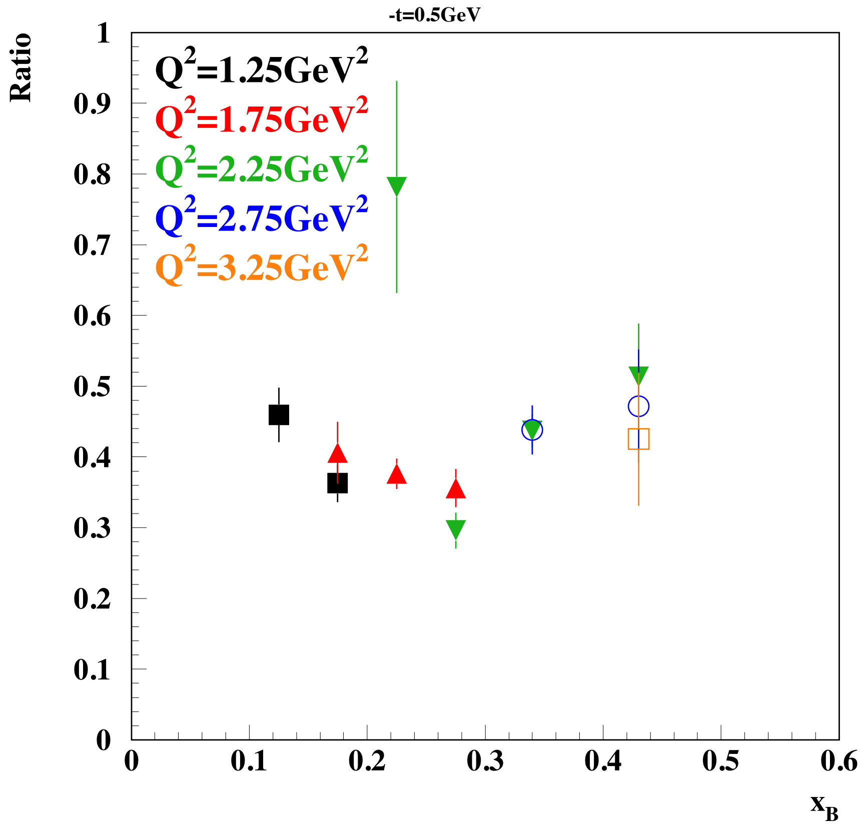
- $\sigma_U=\sigma_T+\varepsilon\sigma_L$ drops by a factor of 2.5 for η
- σ_{TT} drops by a factor of 10
- The GK GPD model (curves) follows the experimental data
- The statement about the ability of transversity GPD model to describe the pseudoscalar electroproduction becomes more solid with the inclusion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

CLAS-Phys.Rev.C95(2017)

η/π^0 ratio

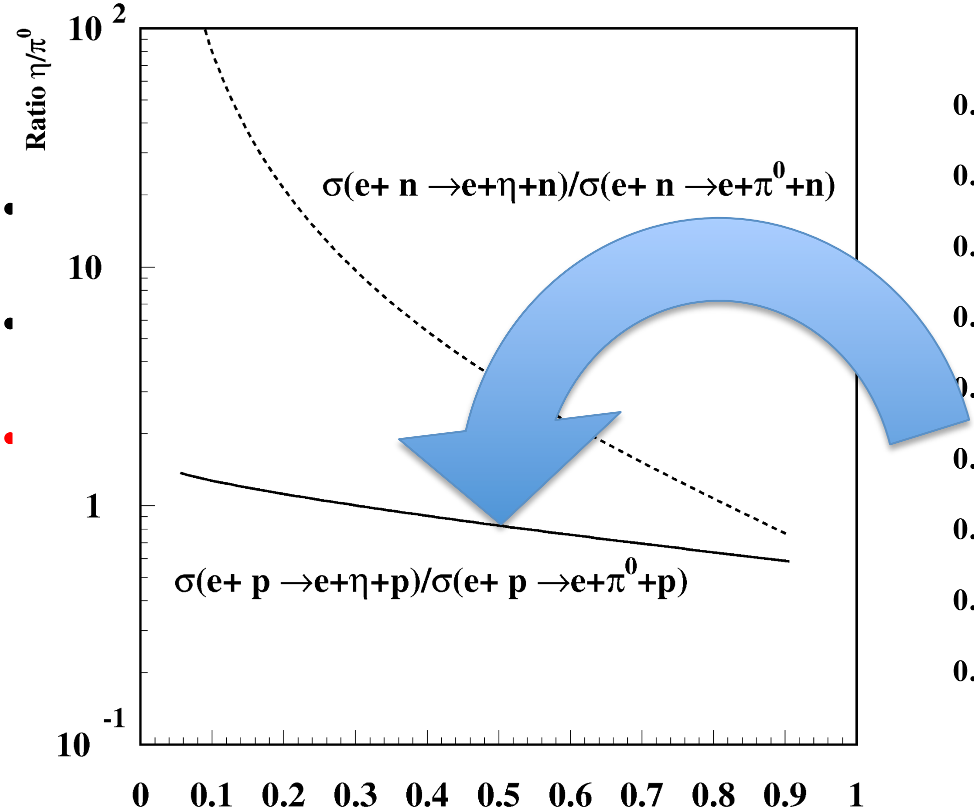
$$\frac{\sigma(ep \rightarrow ep\eta)}{\sigma(ep \rightarrow ep\pi^0)}$$

- 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).

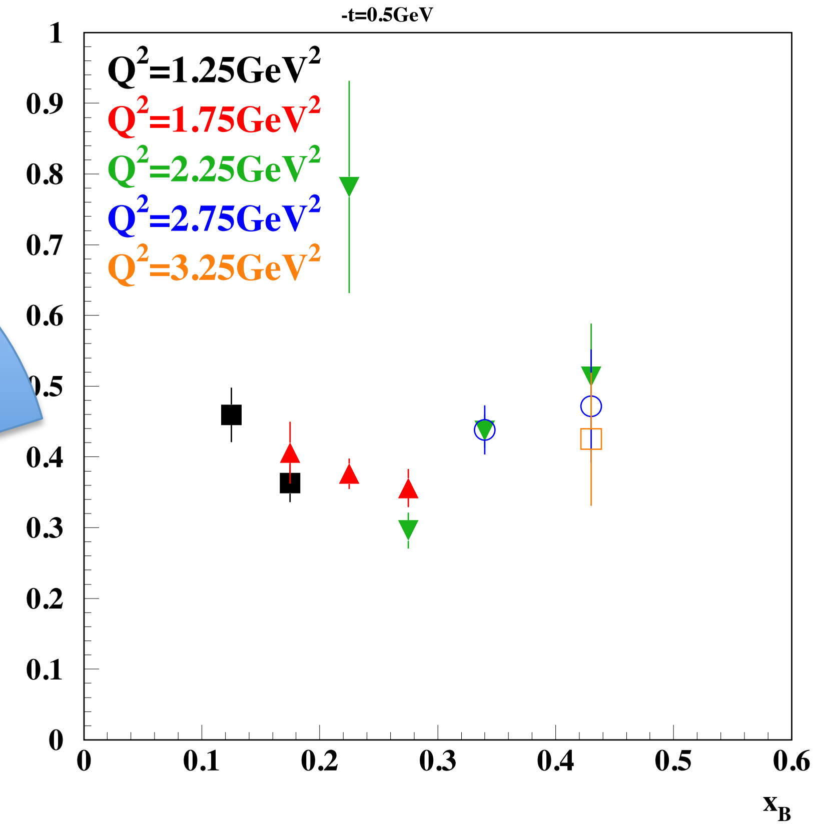


η/π^0 ratio

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



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

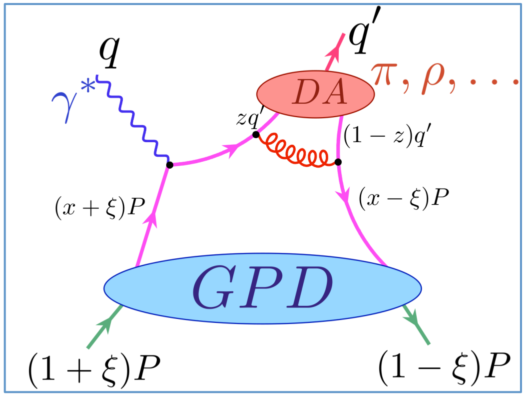


CLAS-Phys.Rev.C95(2017)

Structure functions and GPDs

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

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



Goloskokov, Kroll
Transversity GPD model

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

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

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

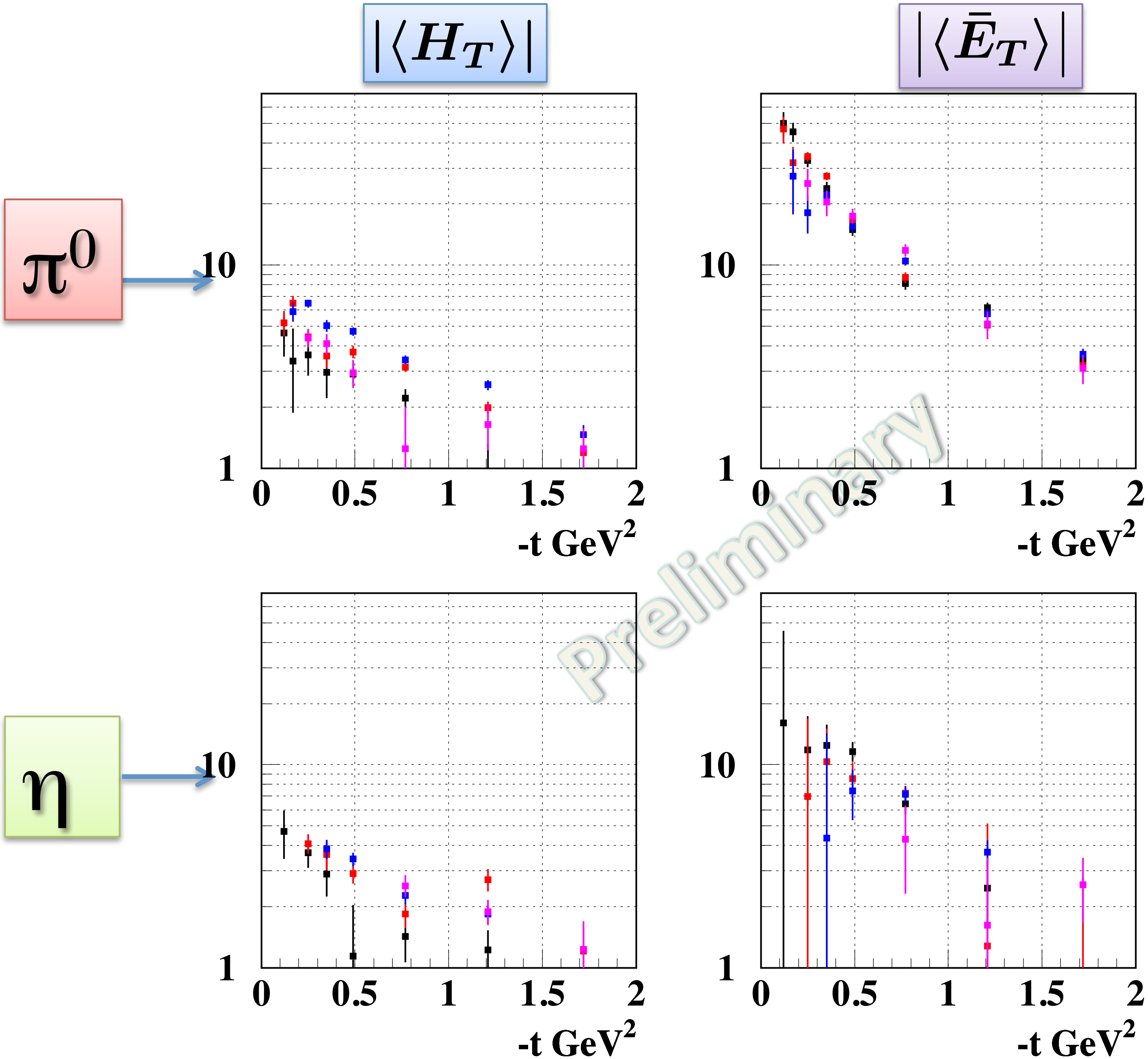
$$\langle \bar{E}_T\rangle = \Sigma_\lambda \int_{-1}^{1} dx M(x,\xi,Q^2,\lambda) \bar{E}_T(x,\xi,t)$$

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

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

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

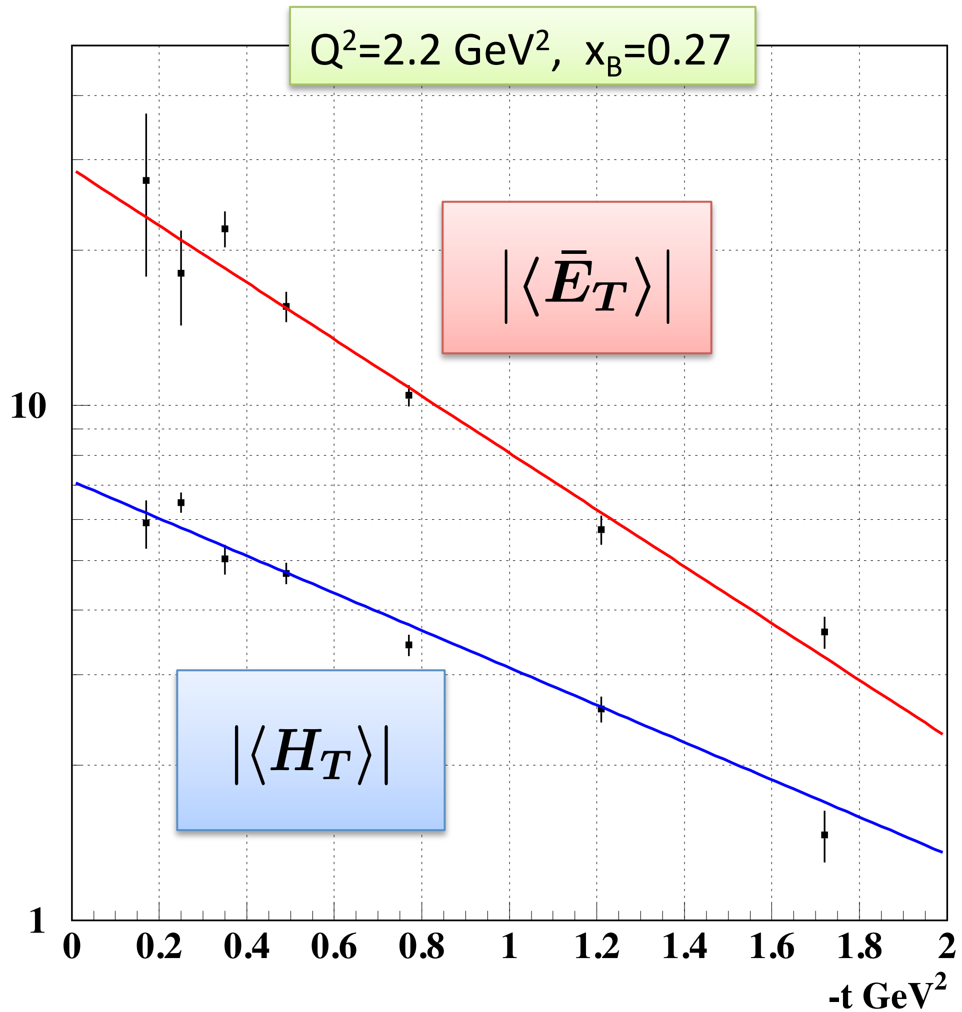
Generalized Form factors

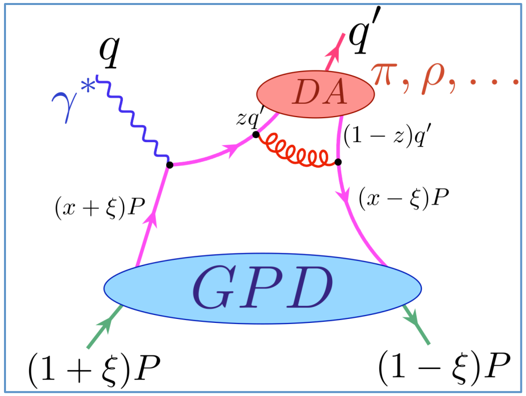


Q^2 GeV^2	x_B
1.2	0.15
1.8	0.22
2.2	0.27
2.7	0.34

- $\bar{E}_T$ > 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}

VK, arXiv:1601.04367

GPD Flavor Decomposition

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

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

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

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

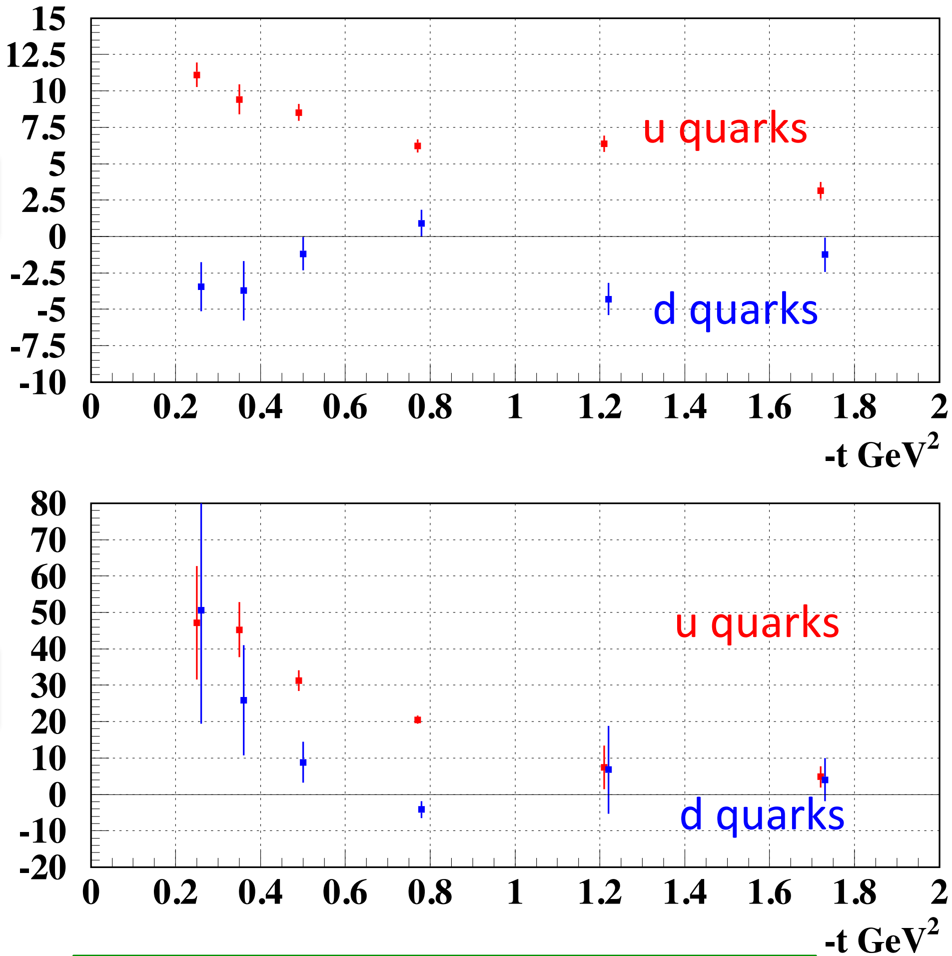
Similar expressions for $\bar{E}_T$

- 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

$\langle H_T \rangle$

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



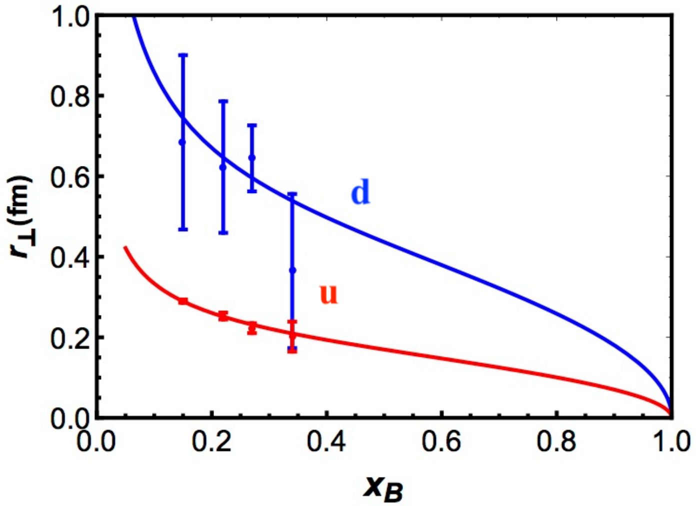
VK arXiv: 1601.04367 [hep-ex] 2016

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

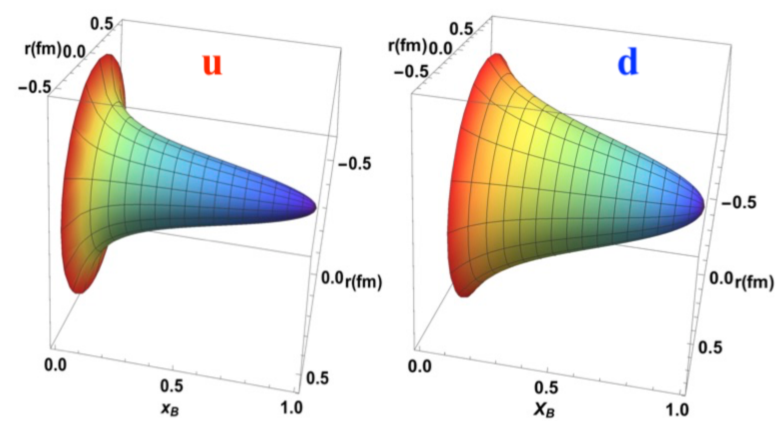
- $\langle H_T \rangle^u$ and $\langle H_T \rangle^d$ have different signs for u and d-quarks in accordance with the transversity function h_1 (Anselmino et al.)
- $|\langle \bar{E}_T \rangle|^d$ and $|\langle \bar{E}_T \rangle|^u$ seem to have the same signs
- Decisions shown with positive values of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

Impact parameter distributions for *u* and *d* quarks

Radius vs x_B



3D image



- u and d qurks spatial distributions are different
- u quarks are more compact in comparison with q quarks

π^0 Electroproduction off *Neutron*

Neutron

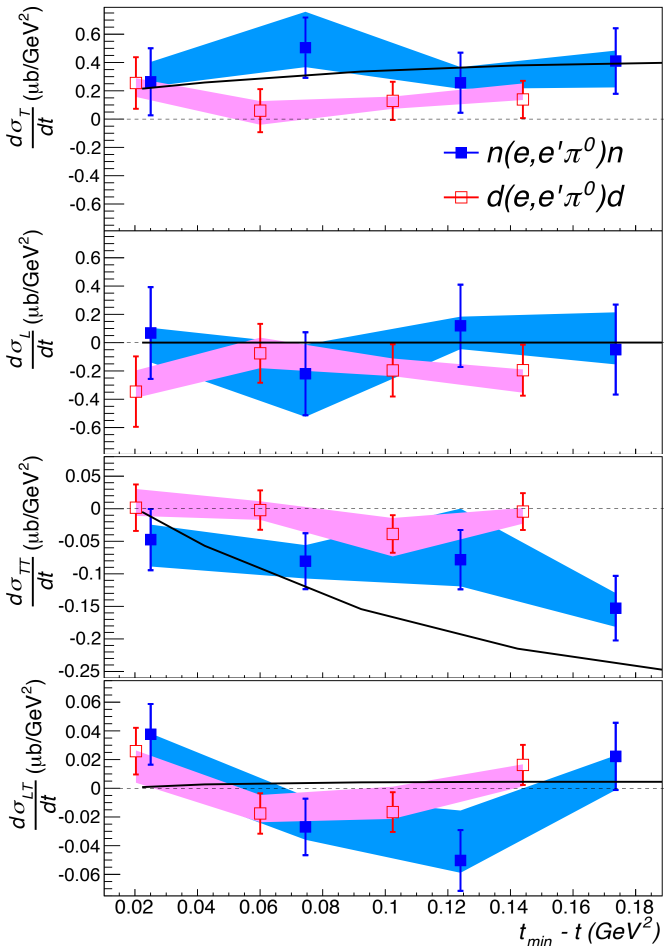
Deutron

σ_T

σ_L

σ_{TT}

σ_{LT}



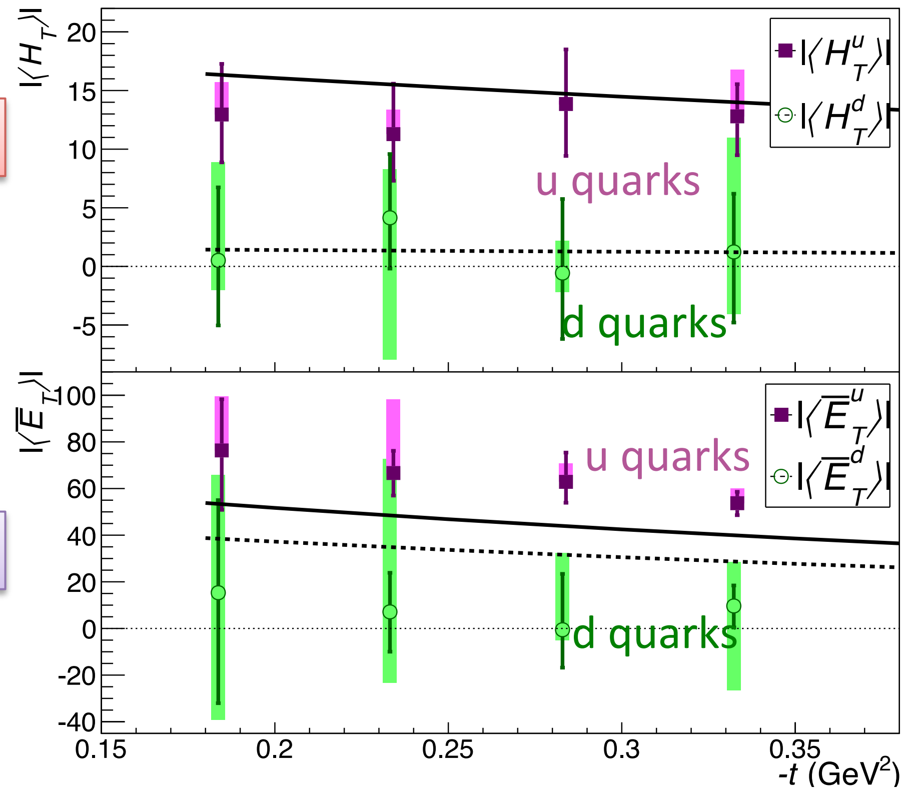
The neutron cross sections

- dominated by σ_T and σ_{TT}
- σ_L and σ_{LT} are compatible with zero
- It is in good agreement with the previous measurement off a proton
- The data are in a a fair agreement with the theoretical expectations based on the transversity GPDs

- Data, Hall-A Phys. Rev. Lett. 118,222002 (2017)
- Theory, S. Goloskokov and P. Kroll, Eur. Phys. J. A47, 112

Flavor decomposition:n and p

|<H$_T$>|



$$H_T^p = \frac{1}{3\sqrt{2}}(2H_T^u + H_T^d)$$

$$H_T^n = \frac{1}{3\sqrt{2}}(H_T^u + 2H_T^d)$$

|<E$_T$>|

$$H_T^p = \frac{1}{3\sqrt{2}}(2H_T^u + H_T^d)$$

$$H_T^n = \frac{1}{3\sqrt{2}}(H_T^u + 2H_T^d)$$

$$H_T^\eta = \frac{1}{\sqrt{6}}(2H_T^u - H_T^d)$$

Proton, neutron and η data
Will solve the problem of
unknown phase between u
and d GFF

- $< E_T^u >$ is larger than $< H_T^u >$
- Good agreement with GK model

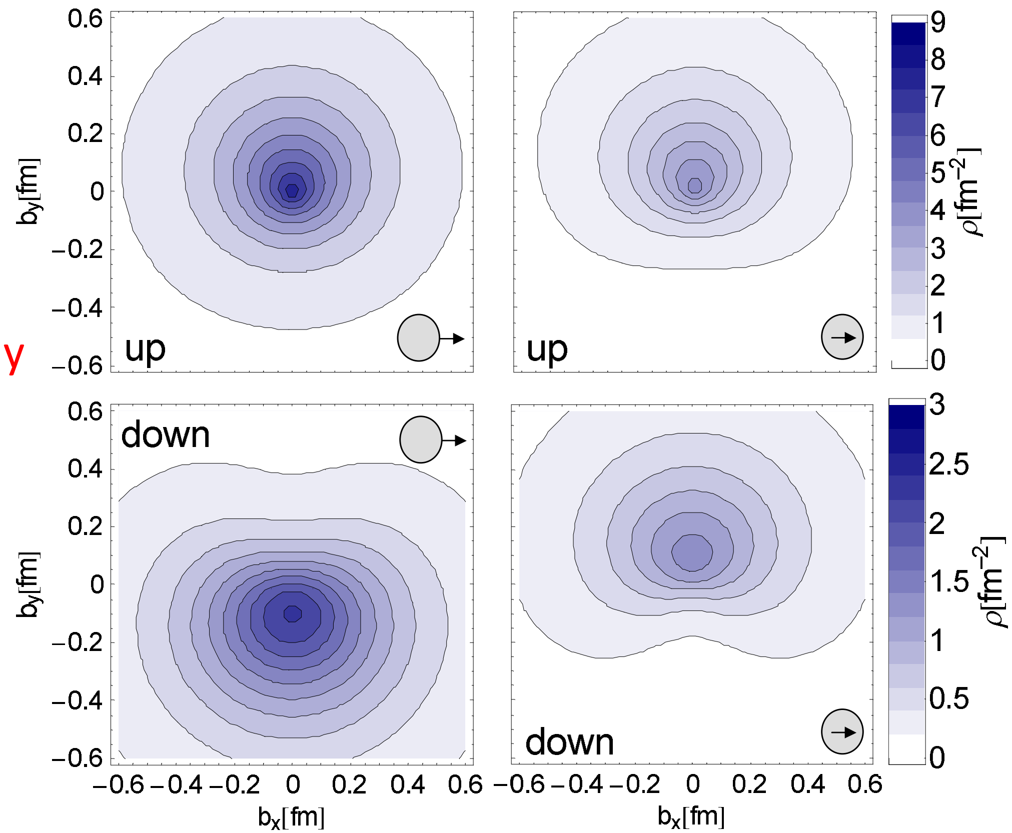
Q^2=1.75 GeV^2
x_B=0.36

From GFF to GPD

- The access to GPDs through DVMP is indirect because cross section does not depend on GPDs, but on Generalized Form Factors (GFFs), i.e. integrals of GPDs. Weighted
- GFF (or CFF in DVCS) form factors are an intermediate step towards GPD extraction
- The way to go is the global fit of experimental observables using GPD models with parameters. It may include DVCS and DVMP experimental data set.
- The DVCS community made an impressive steps in this direction. We can do similar attempts for the transversity GPDs.
- There are several models on the market that provide such a parameterization (PK,SL,SG,GG,CW..)
- The Jlab pseudoscalar electroproduction data(cross section on different target, asymmetries etc) gives the unique opportunity to access the critical parameters of the transversity GPDs.

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, Phys. Rev. Lett. 98, 222001 (2007), lattice

Future developments

- CLAS12 is taking data with proton target. Next in a queue – deuteron target.

- Cross sections:

$$ep \to ep(\pi^0, \eta)$$

$$en \to en(\pi^0, \eta)$$

- Asymmetries:

$$\mathcal{A}_{LU} \quad - \quad beam \ spin$$

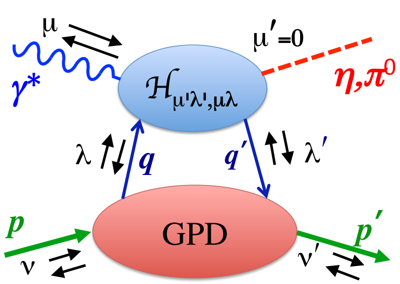
$$\mathcal{A}_{UL} \quad - \quad target \ spin$$

$$\mathcal{A}_{LL} \quad - \quad beam \ target$$

Summary

- Jlab 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 $\langle H_T \rangle$ and $\langle \bar{E}_T \rangle$ are directly connected to the structure functions σ_T and σ_{TT} within handbag approach
- The combined π^0 and η proton and neutron data will provide the way for the flavor decomposition of transversity GPD
- We are taking data with proton target. New CLAS12 data are around the corner. Stay tuned!
- The next generation of experiments will bring along data that will seriously constrain models and lead to GPD extraction with high reliability.

The End



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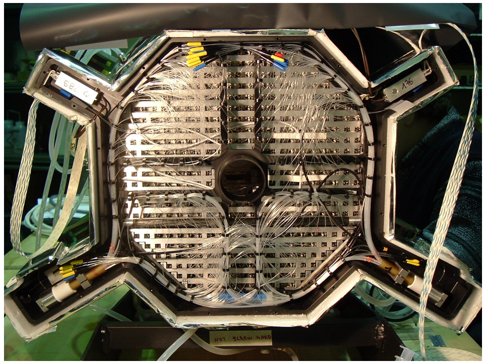

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