Studies of 3D PDFs with CLAS12

Transversity GPDs from Deeply Virtual Meson Production

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on behalf of CLAS collaboration

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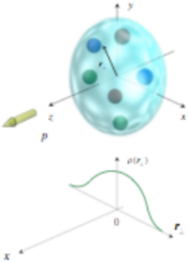
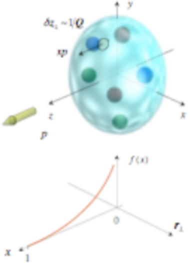
D. Müller, X. Ji, A. Radyushkin



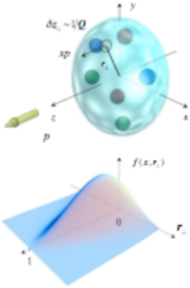
Nucleon Form Factors

transverse charge and current densities



Parton Distributions

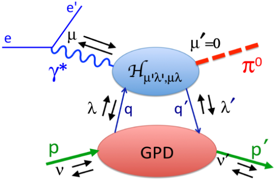
quark longitudinal momentum distributions



Generalized Parton Distributions (GPDs)

correlated quark momentum distirbutions in transverse space

GPDs in Deeply Virtual Meson Production



- $\langle F\rangle = \sum_\lambda \int_{-1}^{1} dx \mathcal{H}_{0\lambda,\mu\lambda}\left(x,\xi,Q^2,t\right) F\left(x,\xi,t\right)$

Generalized Form Factor $\langle F\rangle$ is a convolution of hard subprocess with GPD F

- 4 parton helicity conserving (chiral even) GPDs: H, $\tilde{H}$, E, $\tilde{E}$
- 4 parton helicity flip (chiral odd) GPDs: H_T, $\tilde{H}_T$, E_T, $\tilde{E}_T$
- functions of three kinematic variables: x, ξ and t

Generalized Parton Distributions

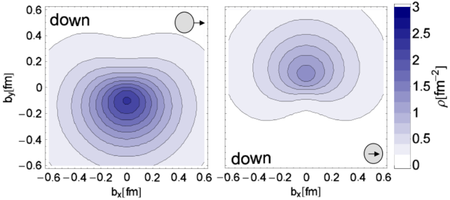
		Quark polarization		
		U	L	T
Nucleon polarization	U	H		$\bar{E}_T$
	L		$\tilde{H}$	
	T	E		$H_T,\ \tilde{H}_T$

Chiral even GPDs:

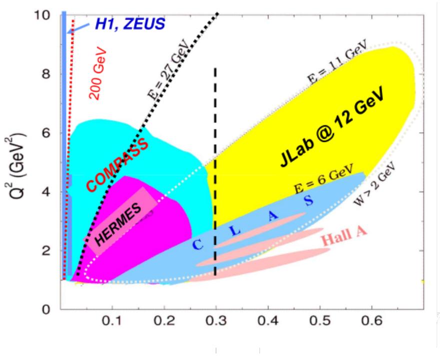
- DVCS on unpolarized and polarized targets with polarized beam by HERMES, JLAB and COMPASS

Chiral-odd GPD results:

- Deeply virtual meson production
- Lattice QCD by Göckeler *et al*

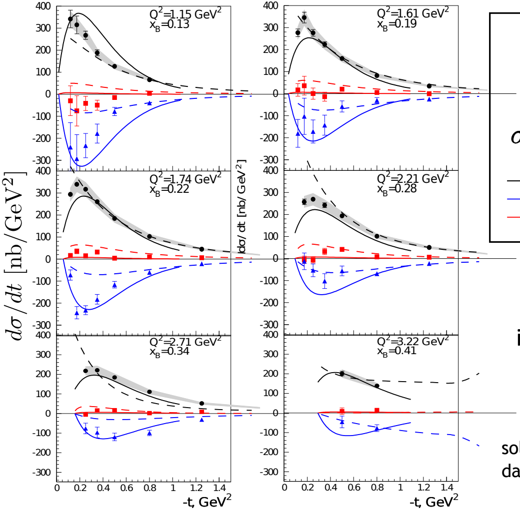


Roadmap: from 6 GeV to 12 GeV



- Early results (2001) from non-dedicated experiment with CLAS (DVCS target spin asymmetry)
- First round of dedicated experiments in Halls A/B at JLab 2004/2005
- Second round of dedicated experiments 2008/2010
- Strong exclusive program at 12 GeV, CLAS12 first experiment is ongoing

π^0 structure functions



Inclusion of the Chiral-odd GPDs brings theoretical calculations into moderate agreement with the data.

$$\sigma_T \sim (1-\xi^2)|H_T|^2 - \frac{t'}{8m^2}|\bar{E}_T|^2$$

— $\sigma_0 = \sigma_T + \epsilon\sigma_L$
— σ_{TT}
— σ_{LT}

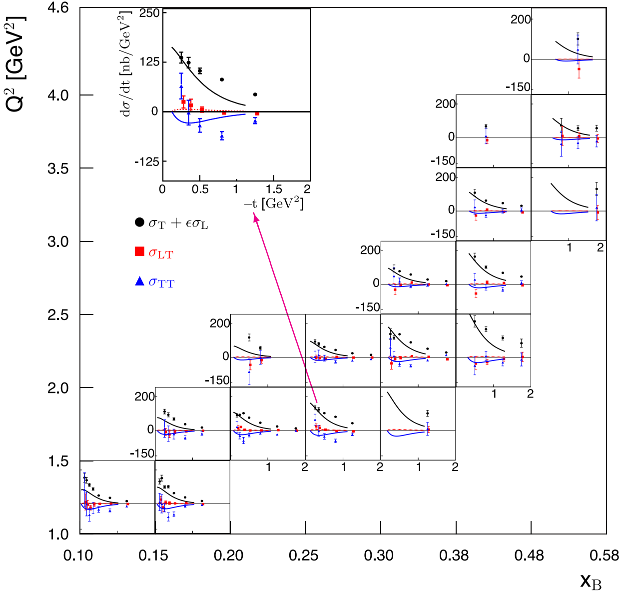
$$\sigma_{TT} \sim \frac{t'}{8m^2}|\bar{E}_T|^2$$

π^0 electroproduction
is uniquely sensitive process to access
transversity GPDs.

solid: P.Kroll & S.Goloskokov
dashed: G.R. Goldstein, J.O. Gonzalez & S.Liuti

PRL109:112001 (2012) I. Bedlinskiy et al. (CLAS collaboration)

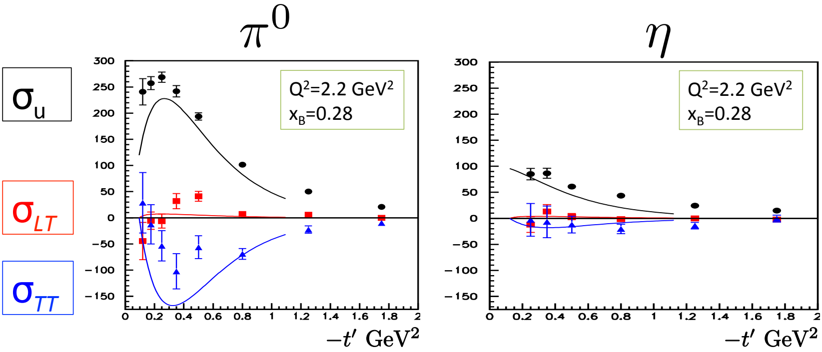
η structure functions



PRL95: 035202 (2017)

I. Bedlinsky et al. (CLAS)

Comparison of π^0 and η



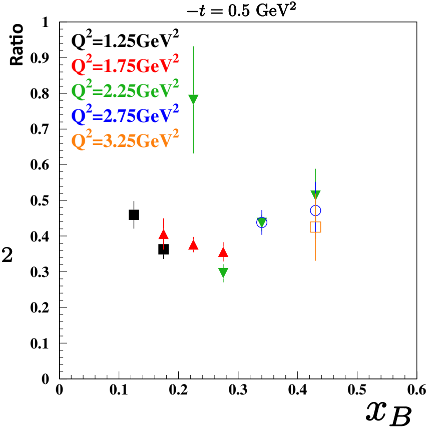
- $\sigma_U = \sigma_T + \epsilon\sigma_L$ drops by a factor of 2.5 for η
- σ_{TT} drops by a factor of 10
- Theoretical model calculations (GK model) follows the experimental measurements

Ratio of π^0 and η

$$F_i^{\pi^0} = \frac{(e_u F_i^u - e_d F_i^d)}{\sqrt{2}}$$

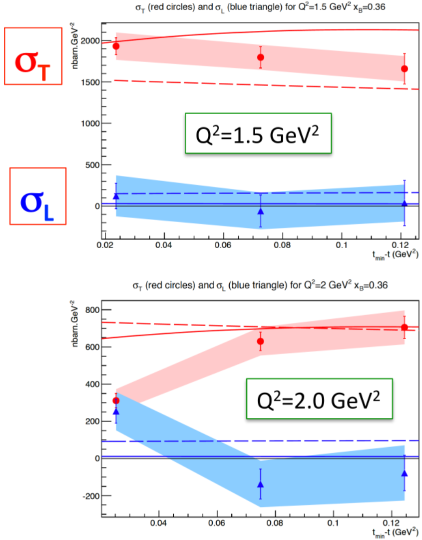
$$F_i^{\eta} = \frac{(e_u F_i^u + e_d F_i^d)}{\sqrt{6}}$$

$$\frac{d\sigma(\eta)}{d\sigma(\pi^0)} \simeq \left(\frac{f_\eta}{f_\pi}\right)^2 \frac{1}{3} \left|\frac{2\langle F_T^u\rangle - \langle F_T^d\rangle}{2\langle F_T^u\rangle + \langle F_T^d\rangle}\right|^2$$



- Theoretical calculations based on chiral odd GPDs predict this ratio to be around 1/3 at CLAS kinematics

Rosenbluth separation of σ_T and σ_L at Hall A



- 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 collaboration, PRL 117: 262001 (2016)

Access to transverse GPDs

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

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

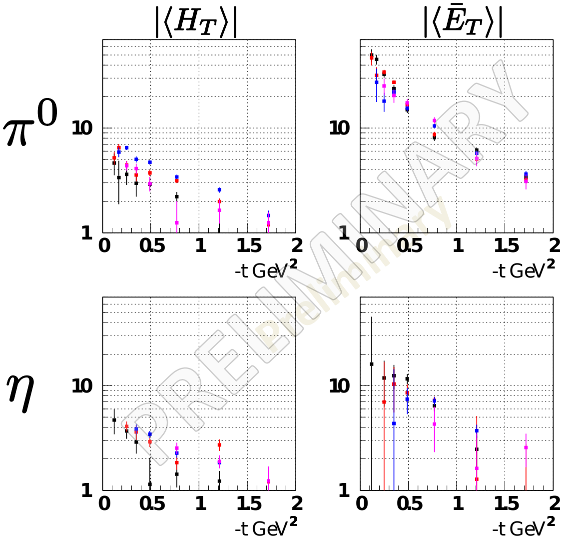
Goloskokov, Kroll
Transversity GPD model

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

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

- No separation of σ_T and σ_L
- However, in the approximation of transversity GPDs dominance, supported by JLab data, $\sigma_L << \sigma_T$ and can be neglected

Generalized Form Factors



V. Kubarovsky, arXiv:1601.04367

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 both π^0 and η
- t-dependence is steeper for $\bar{E}_T$

Flavor decomposition

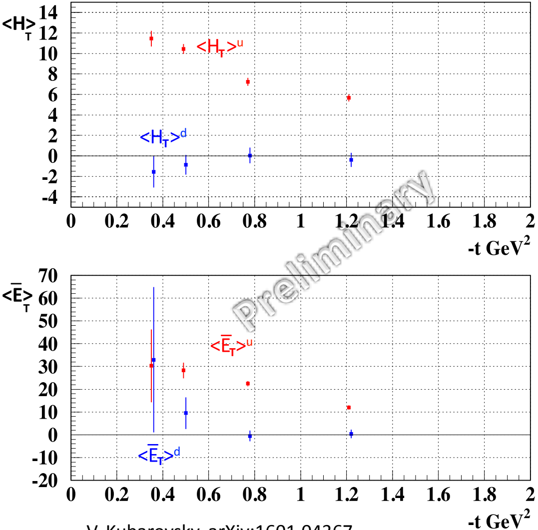
$$F^{\pi} = \frac{1}{3\sqrt{2}}\left[2F^u + F^d\right]$$
$$F^{\eta} = \frac{1}{3\sqrt{6}}\left[2F^u - F^d\right]$$

$$\Downarrow$$

$$\frac{1}{18}\left|2\langle H_T\rangle^u + \langle H_T\rangle^d\right|^2 = |\langle H_T\rangle^{\pi}|^2$$
$$\frac{1}{54}\left|2\langle H_T\rangle^u - \langle H_T\rangle^d\right|^2 = |\langle H_T\rangle^{\eta}|^2$$

- GPDs appear in different flavor combinations for π^0 and η
- **Combined datasets of π^0 and η channels** allow flavor decomposition for GPDs H_T and $\bar{E}_T$
- To attempt flavor decomposition an assumption on the relative phase between u and d quark GPDs was made to be either 0 or 180 degrees.

First attempts at flavor decomposition



V. Kubarovsky, arXiv:1601.04367

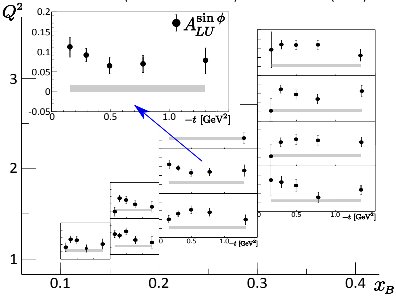
$Q^2 = 1.8$ GeV^2
x_B=0.22

- $\langle H_T \rangle^u$ and $\langle H_T \rangle^d$ have opposite signs in accordance with transversity function h_1 (Anselmino *et al.*)
- $\langle E_T \rangle^u$ and $\langle E_T \rangle^d$ have the same signs

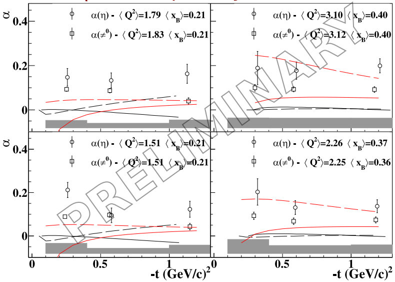
Spin asymmetry variables

π^0 Beam Spin Asymmetries

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

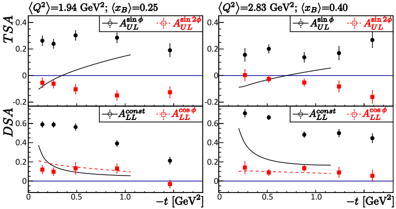


η Beam Spin Asymmetries



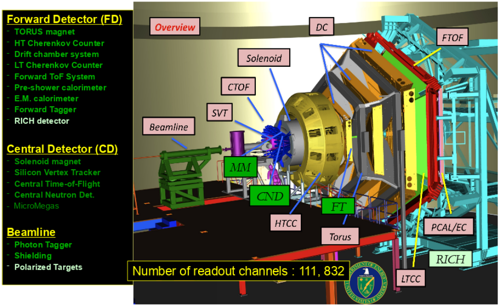
π^0 Target and Double Spin Asymmetries

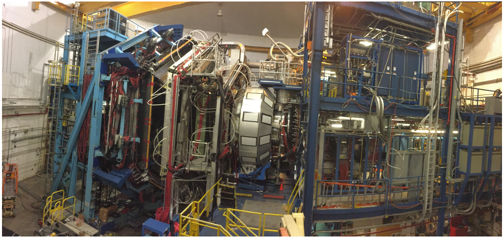
A. Kim et al. (CLAS) PLB768, 168-173 (2017)



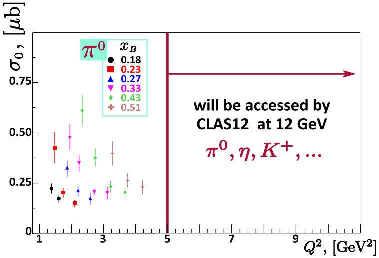
- Large number of single and double spin asymmetries were measured over wide kinematic range
- Asymmetries are much harder to interpret since they involve convolutions of chiral even and chiral odd GPDs

12 GeV upgrade and CLAS12

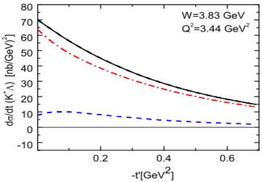


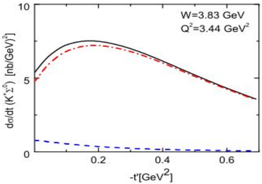


- DVCS/DVMP(π^0,η. . .):
  - at 6.6, 8.8 and 11 GeV
  - on proton and neutron at 11 GeV

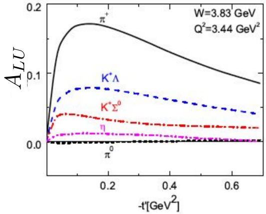


Exclusive kaon production

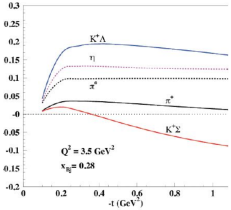




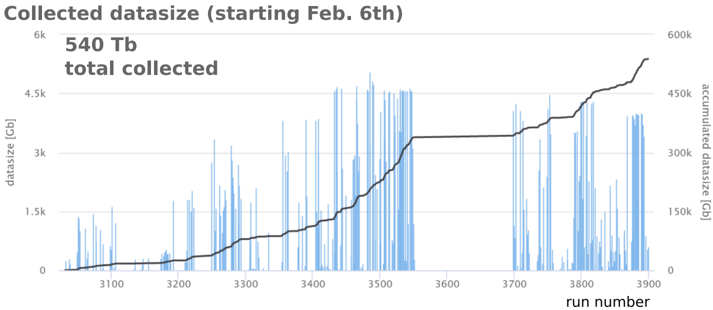
Goloskokov and Kroll



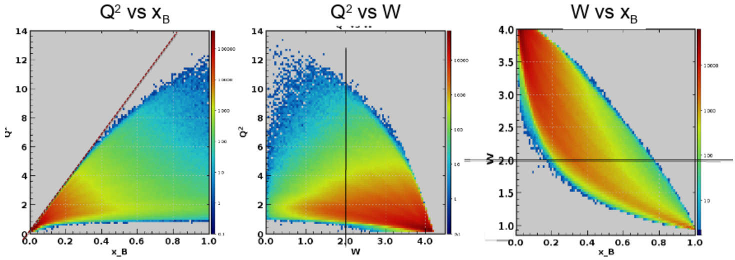
Goldstein, Hernandez and Liuti



- Kaon production is expected to be an attractive alternative to neutral meson production in the studies of transversity GPDs
- It is expected to be dominated by transversity GPDs with small kaon pole contribution



Collected datasize (starting Feb. 6th)
540 Tb
total collected
datasize [Gb]
accumulated datasize [Gb]
0
1.5k
3k
4.5k
6k
150k
300k
450k
600k
3100
3200
3300
3400
3500
3600
3700
3800
3900
run number



Q² vs x_B
Q² vs W
W vs x_B
x_B
W
Q²

Summary

- Deeply virtual π^0 and η electroproduction are sensitive to the chiral odd GPDs
- The measured structure function are directly connected to the generalized form factors $\langle H_T \rangle$ and $\langle \bar{E}_T \rangle$
- The global analysis of π^0 and η production as well as data with neutron target, and inclusion of kaon production, will allow the flavor decomposition of transversity GPDs
- Awaiting new results at wider kinematic range from CLAS12 first experiment