

# Study of chiral-odd GPDs using pseudoscalar meson electroproduction with CLAS

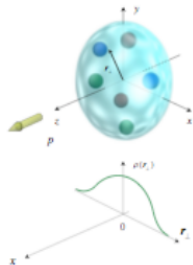
Andrey Kim

University of Connecticut

QCD Evolution 2019  
May 16, 2019

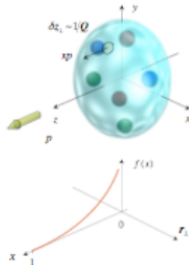
# Description of hadron structure

D. Müller, X. Ji, A. Radyushkin



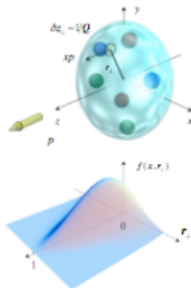
## Nucleon Form Factors

transverse charge and  
current densities



## Parton Distributions

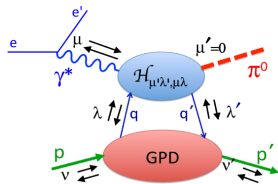
quark longitudinal  
momentum distributions



## Generalized Parton Distributions (GPDs)

correlated quark momentum  
distributions in transverse  
space

# GPDs in Deeply Virtual Exclusive Reactions



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

**Generalized Form Factor (GFF)**  $\langle F \rangle$  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:  $x, \xi$  and  $t$

# Link GPDs to PDF and Elastic Form Factors

PDFs:

in the forward limit

$$\xi = t = 0:$$

$$H^q(x, 0, 0) = q(x)$$

$$\tilde{H}^q(x, 0, 0) = \Delta q(x)$$

Form Factors:

$$\int dx H^q(x, \xi, t) = F_1(t)$$

$$\int dx E^q(x, \xi, t) = F_2(t)$$

$$\int dx \tilde{H}^q(x, \xi, t) = G_A(t)$$

$$\int dx \tilde{E}^q(x, \xi, t) = G_P(t)$$

X. Ji, Phys. Rev. Lett. 78, 610 (1997):

$$J^q = \int x dx [H^q(x, \xi, 0) + E^q(x, \xi, 0)]$$

- Jaffe and Ji have shown that the first Mellin moment of transversity PDF  $h_1^q(x)$  gives us the tensor charge  $\delta q$

$$\delta q = \int_{-1}^1 h_1^q(x) dx = \int_0^1 (h_1^q(x) - \bar{h}_1^q(x)) dx$$

- We can interpret tensor charge as the absolute magnitude of transversely polarized valence quarks inside a transversely polarized nucleon.
- Given the relations between transversity PDF  $h_1^q(x)$  and chiral-odd GPD  $H_T(x, \xi, t)$  one can obtain the tensor charge  $\delta q$  through GPD in the forward limit:

$$h_1^q(x) = H_T(x, \xi = 0, t = 0)$$

# Generalized Parton Distributions

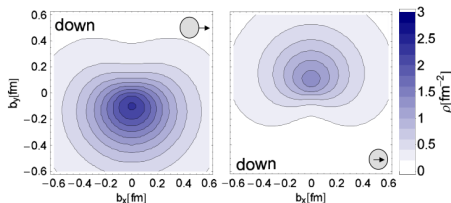
		Quark polarization		
		U	L	T
Nucleon polarization	U	$H$		$\bar{E}_T$
	L		$\tilde{H}$	
	T	$E$		$H_T, \tilde{H}_T$

Chiral-odd GPD results:

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

Chiral even GPDs:

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



## Transversity in hard exclusive electroproduction of pseudoscalar mesons

S.V. Goloskokov<sup>1,a</sup> and P. Kroll<sup>2,3,b</sup>

### GPDs parametrization:

$H_T$

tensor charge: T.Ledwig, A.Silva, H.C. Kim

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

transversity PDF: M.Anselmino

$$H_T(x, \xi = 0, t = 0) = h_1$$

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

Lattice QCD: M.Gockeler

$\bar{E}_T$  moments

- only  $H_T$  and  $\bar{E}_T$  chiral-odd GPDs have significant contribution to pseudoscalar meson electroproduction
- these two chiral-odd GPDs are data-driven and parameterized using Lattice QCD data and SIDIS data from HERMES and COMPASS collaborations

# Goldstein-Gonzalez-Liuti model

PHYSICAL REVIEW D 84, 034007 (2011)

## Flexible parametrization of generalized parton distributions from deeply virtual Compton scattering observables

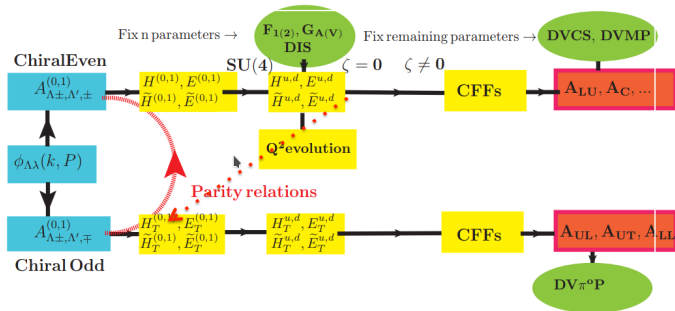
Gary R. Goldstein,<sup>1,\*</sup> J. Osvaldo Gonzalez Hernandez,<sup>2,†</sup> and Simonetta Liuti<sup>2,‡</sup>

<sup>1</sup>Department of Physics and Astronomy, Tufts University, Medford, Massachusetts 02155, USA

<sup>2</sup>Department of Physics, University of Virginia, Charlottesville, Virginia 22901, USA

(Received 16 February 2011; published 5 August 2011)

- In 2011 Goldstein, Hernandez and Liuti came up with a new model which allows flexible parameterization of GPDs.
- **Recursive fit:** DIS data, nucleon form factors, DVCS data.
- Relations between chiral-even and chiral-odd sectors through parity relations among helicity amplitudes.

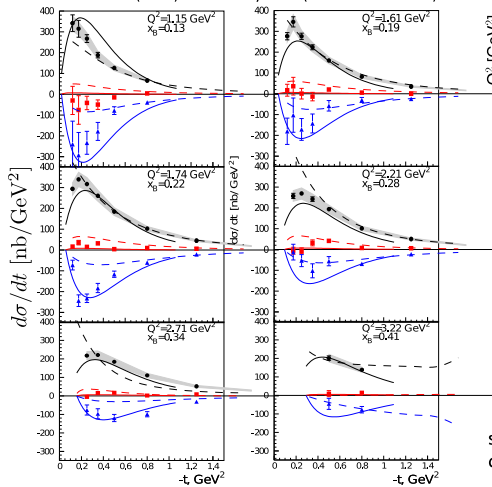




# CLAS measurements of pseudoscalar meson production

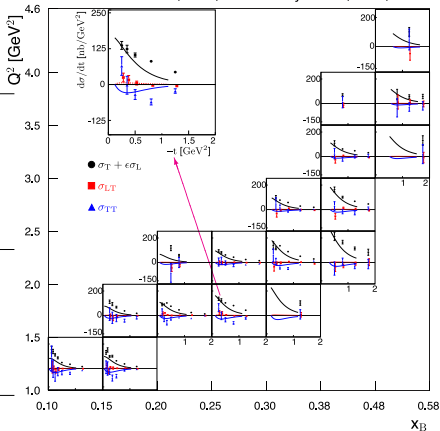
## $\pi^0$ measurements

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



## $\eta$ measurements

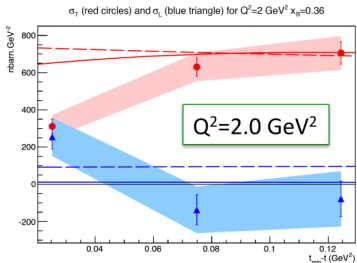
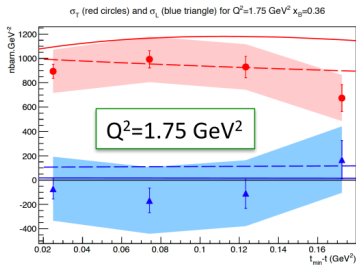
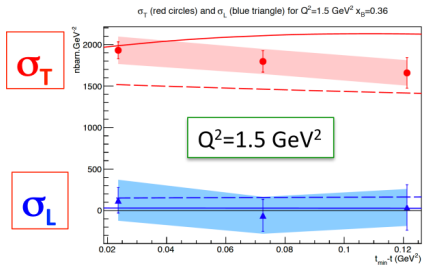
PRL95: 035202 (2017) I. Bedlinskiy et al. (CLAS)



solid: P. Kroll & S. Goloskokov

dashed: G.R. Goldstein, J.O. Gonzalez & S. Liuti

# Rosenbluth separation of $\sigma_T$ and $\sigma_L$ at Hall A



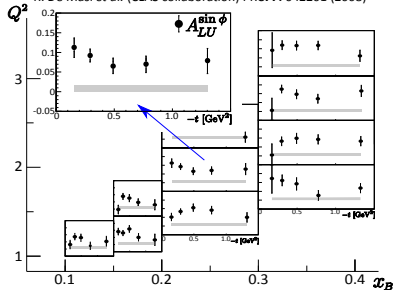
- Experimental **proof** that the transverse  $\pi^0$  cross section is dominant!
- It opens the direct way to study the transversity GPDs in pseudoscalar exclusive production

Hall A collaboration, PRL 117: 262001 (2016)

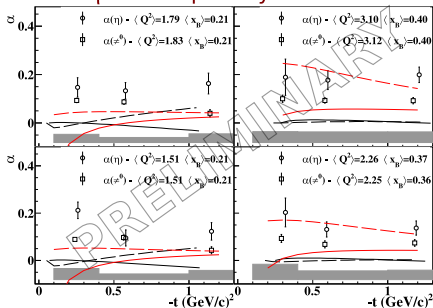
# Spin asymmetry variables

## $\pi^0$ Beam Spin Asymmetries

R. De Masi et al. (CLAS collaboration) PRC77: 042201 (2008)

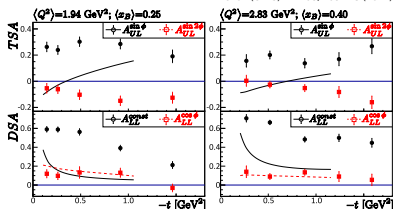


## $\eta$ Beam Spin Asymmetries



## $\pi^0$ Target and Double Spin Asymmetries

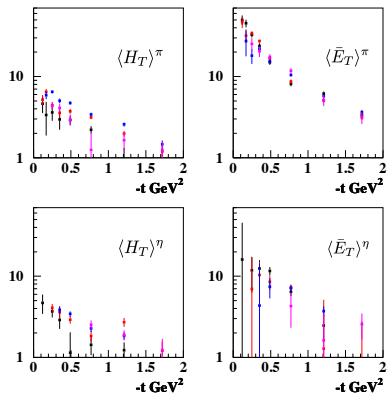
A. Kim et al. (CLAS) PLB768, 168-173 (2017)



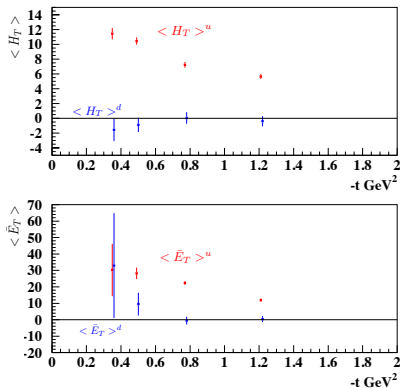
- Large number of single and double spin asymmetries were measured over wide kinematic range
- Asymmetries are much harder to interpret since they involve convolutions of chiral even and chiral odd GPDs

# First attempts at GPDs extraction

## Generalized Form Factors

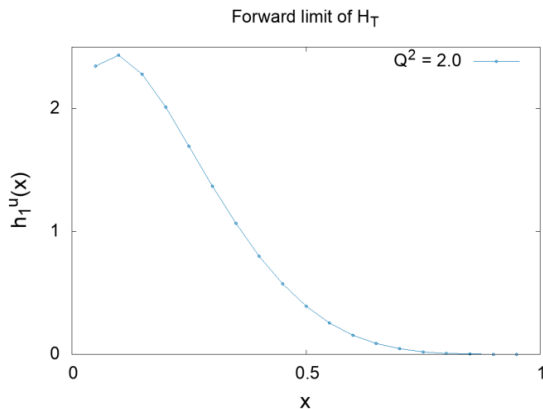


## Quark flavor decomposition



Valery Kubarovsky, arXiv:1601.04367

- HEPGen++ is an event generator for high energy exclusive meson / photon production:link
- Goloskokov-Kroll model has been implemented in HEPGen for  $\pi^0$  and  $\eta$  electroproduction by C. Regali in his thesis.
- HEPGen is capable to compute unpolarized cross sections of  $\pi^0$  and  $\eta$  electroproduction.
- In the forward limit for  $u$  quarks we get:



# GPD parameterizations

$$H_T(x, \xi, t) = N \exp[bt] \sum_{j=0}^5 c_j \cdot D\left(\frac{j}{2}, x, \xi\right)$$

Table 6.3: Used parameters for  $H_T$  [95].

Parameter	u	d
$c_0$	3.653	1.924
$c_1$	-0.583	0.179
$c_2$	19.807	-7.775
$c_3$	-23.487	3.504
$c_4$	-23.46	5.851
$c_5$	24.07	-3.683

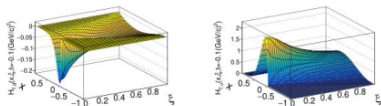


Figure 6.3: The transversity GPD  $H_T$  for d quarks on the left and u quarks on the right.

$$E_T^u(x, \xi, t) = N^u \exp[bt] \sum_{j=0}^2 c_j^u \cdot D\left(\frac{j}{2}, x, \xi\right)$$

Table 6.4: Power expansion coefficients used for  $\tilde{E}_T$  [95].

Parameter	u	d
$c_0$	1	1
$c_1$	0	0
$c_2$	-1	-2
$c_3$	0	0
$c_4$	0	1

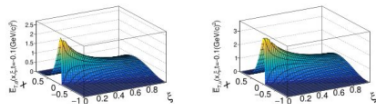


Figure 6.4: The transversity GPD combination  $\tilde{E}_T$  for d quarks on the left and u quarks on the right.

The agreement between experimental data and GK model results can be improved using CLAS experimental measurements to revise GPD parameterizations. However HEPGen is slow, calculation of one kinematic point takes a few minutes. Common gradient-based optimization is not going to work if approached head-on.

Possible solutions:

- Derivative free optimization methods: genetic algorithms, cross entropy method.
- Pre-calculated grid for subprocess amplitudes and interpolation for any kinematic point (implemented in libGK module of HEPGen).

# Fitting $\bar{E}_T$ GPD with CLAS unpolarized $\pi^0$ data

$$E_T^d(x, \xi, t) = N^d \exp[bt] \sum_{j=0}^4 c_j^d \cdot D\left(\frac{j}{2}, x, \xi\right)$$

$$E_T^u(x, \xi, t) = N^u \exp[bt] \sum_{j=0}^2 c_j^u \cdot D\left(\frac{j}{2}, x, \xi\right)$$

Table 6.4: Power expansion coefficients used for  $\bar{E}_T$  [95].

Parameter	u	d
$c_0$	1	1
$c_1$	0	0
$c_2$	-1	-2
$c_3$	0	0
$c_4$	0	1

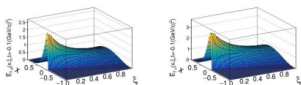


Figure 6.4: The transversity GPD combination  $\bar{E}_T$  for d quarks on the left and u quarks on the right.

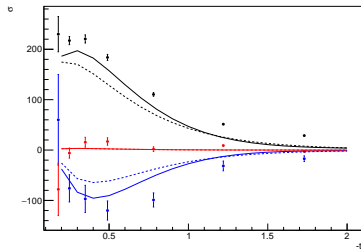
- $H_T$  is constrained using SIDIS data from HERMES and COMPASS
- $\bar{E}_T$  is only constrained by Lattice QCD results
- First step: we use only unpolarized  $\pi^0$  and  $\eta$  data to constrain  $\bar{E}_T$  parameterizations of  $u$  and  $d$  quarks
- Free 8 coefficients



# Fitting $\bar{E}_T$ GPD with CLAS unpolarized $\pi^0$ data

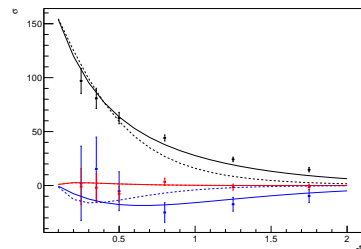
$\pi^0$  measurements

Structure functions ( $Q^2, xB$ ) = 2.7129 0.3423



$\eta$  measurements

Structure functions ( $Q^2, xB$ ) = 2.2400 0.2760



- Unpolarized  $\pi^0$  structure function measurements
- $\sigma_0, \sigma_{TT}, \sigma_{LT}$  at 96  $Q^2, xB, -t$  kinematic bins, 18  $Q^2, xB$  bins
- Free 8 coefficients in  $\bar{E}_T$  parameterization
- Minimization of 
$$\chi^2 = \sum \frac{(\sigma_{GK} - \sigma_{CLAS})^2}{\Delta\sigma^2}$$

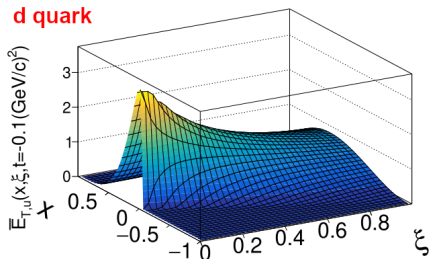
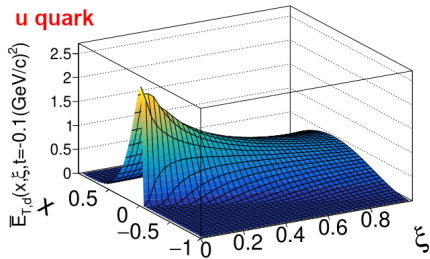
$\sigma_0, \sigma_{TT}, \sigma_{LT}$

Solid line - after the fit

Dashed - before the fit

# Very preliminary impact on GPD $\bar{E}_T$

constrained by Lattice QCD



constrained by CLAS data



- The access to GPDs through DVMP is indirect because cross section does not depend on GPDs but on GFFs, i.e. integrals of GPDs
- Develop the procedure to access GPDs by fitting  $\pi^0$  and  $\eta$  data from CLAS and CLAS12, as well as data on proton and neutron from Hall A, using GPD model parameterizations
- The combined  $\pi^0$  and  $\eta$  electroproduction on proton and neutron targets will provide the flavor decomposition of transversity GPDs
- CLAS12 pass0 cook is finished and we are starting to look at  $\pi^0/\eta$  channel from CLAS12 data
- Chiral-odd GPD extractions using CLAS/CLAS12 data

STAY TUNED FOR NEW RESULTS!