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

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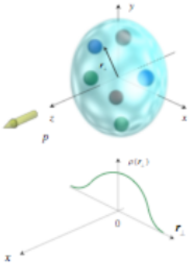
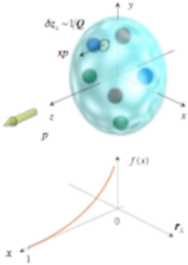
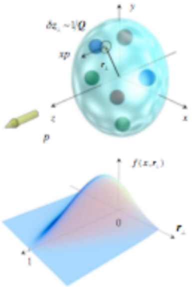
8th Workshop of the APS Topical Group on Hadronic Physics
April 11, 2019

Description of hadron structure

D. Müller, X. Ji, A. Radyushkin







<u>Nucleon Form Factors</u>

transverse charge and current densities

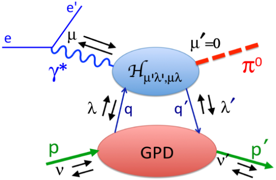
<u>Parton Distributions</u>

quark longitudinal momentum distributions

<u>Generalized Parton Distributions (GPDs)</u>

correlated quark momentum distirbutions in transverse space

GPDs in Deeply Virtual Exclusive Reactions



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

Generalized Form Factor (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, ξ 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):
$$J^q = \int x dx \left[H^q(x,\xi,0) + E^q(x,\xi,0)\right]$$

Tensor charge

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

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

- 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 δq through GPD in the forward limit:

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

Generalized Parton Distributions

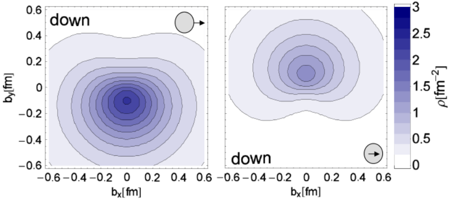
		Quark polarization		
		U	L	T
Nucleon polarization	U	H		$\bar{E}_T$
	L		$\tilde{H}$	
	T	E		$H_T,\ \tilde{H}_T$

Chiral 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*



Goloskokov-Kroll model

Eur. Phys. J. A (2011) **47**: 112
DOI 10.1140/epja/i2011-11112-6

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Theoretical Physics

Transversity in hard exclusive electroproduction of pseudoscalar mesons

S.V. Goloskokov[1,a] and P. Kroll[2,3,b]

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

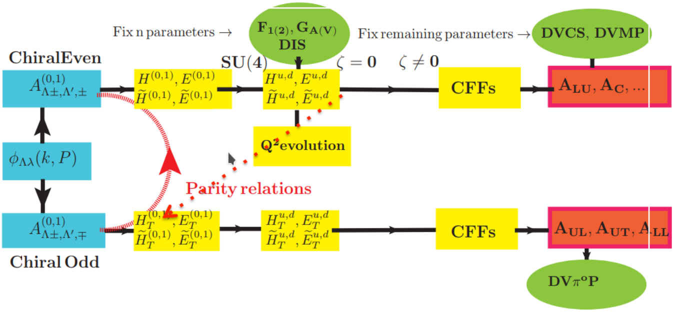
PHYSICAL REVIEW D **84**, 034007 (2011)

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

Gary R. Goldstein,[1,*] J. Osvaldo Gonzalez Hernandez,[2,†] and Simonetta Liuti[2,‡]
[1]*Department of Physics and Astronomy, Tufts University, Medford, Massachusetts 02155, USA*
[2]*Department of Physics, University of Virginia, Charlottesville, Virginia 22901, USA*

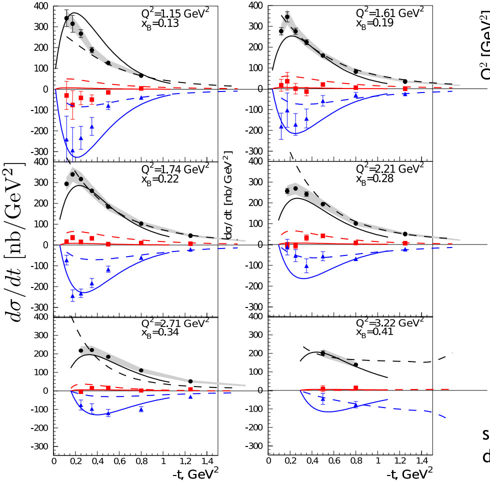
(Received 16 February 2011; published 5 August 2011)

- 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.



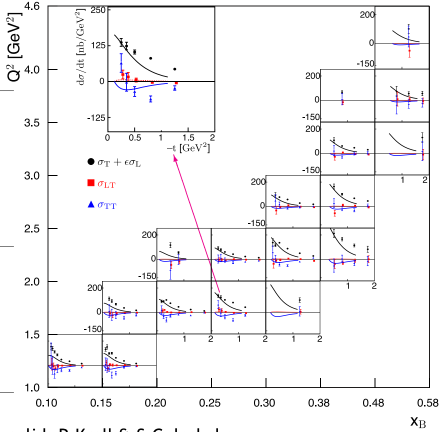
π^0 measurements

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



η measurements

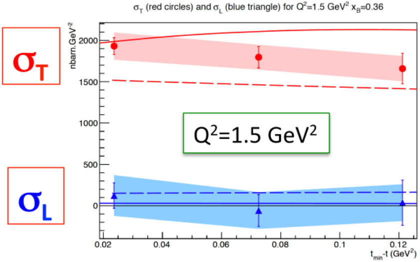
PRL95: 035202 (2017) I. Bedlinsky et al. (CLAS)

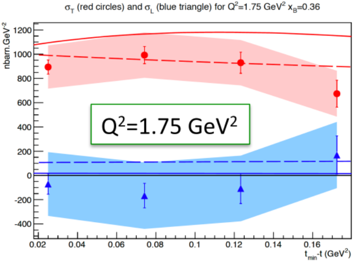


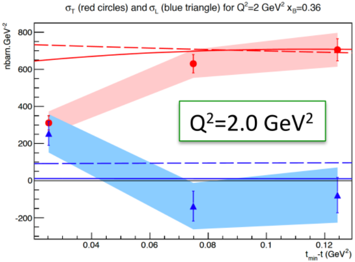
solid: P.Kroll & S.Goloskokov

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

Rosenbluth separation of σ_T and σ_L at Hall A







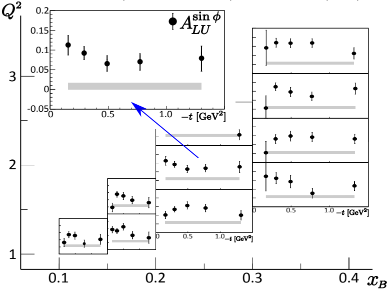
- Experimental **proof** that the transverse π^0 cross section is dominant!
- It opens the direct way to study the transversity GPDs in pseudoscalar exclusive production

Hall A collaboration, PRL 117: 262001 (2016)

Spin asymmetry variables

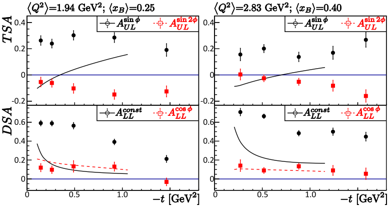
π^0 Beam Spin Asymmetries

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

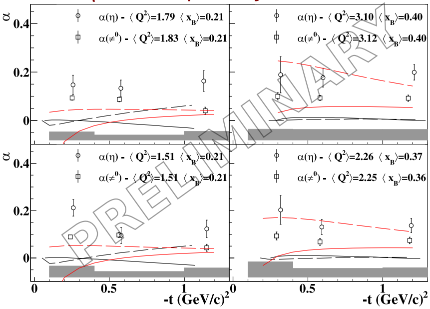


π^0 Target and Double Spin Asymmetries

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

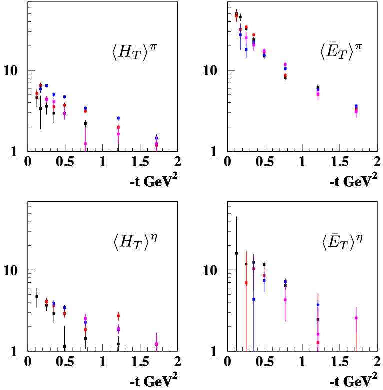


η Beam Spin Asymmetries

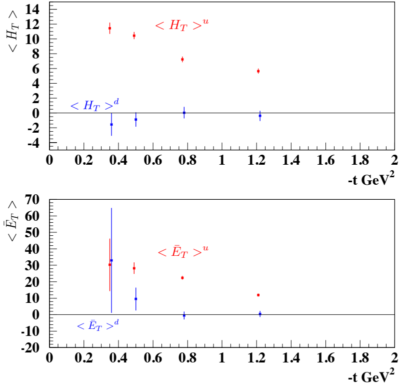


- Large number of single and double spin asymmetries were measured over wide kinematic range
- Asymmetries are much harder to interpret since they involve convolutions of chiral even and chiral odd GPDs

Generalized Form Factors



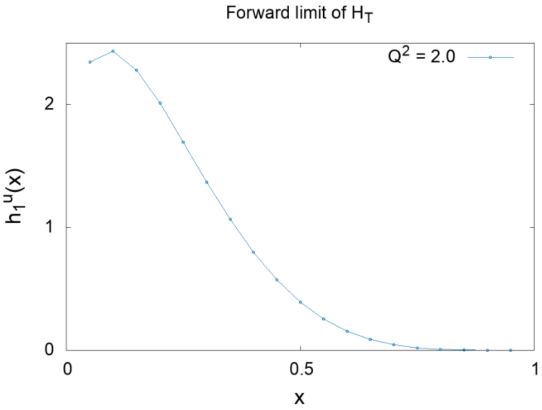
Quark flavor decomposition



Valery Kubarovsky, arXiv:1601.04367

HepGen

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



GPD parameterizations

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

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

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

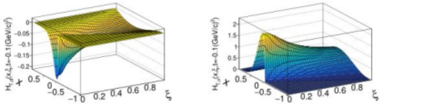


Figure 6.3: The transversity GPD H_T for d quarks on the left and u quarks on the right.

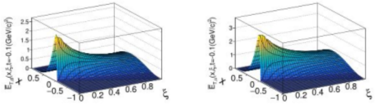


Figure 6.4: The transversity GPD combination $\bar{E}_T$ for d quarks on the left and u quarks on the right.

Technical details

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 π^0 data

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

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

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

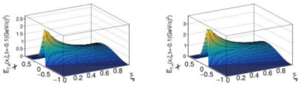
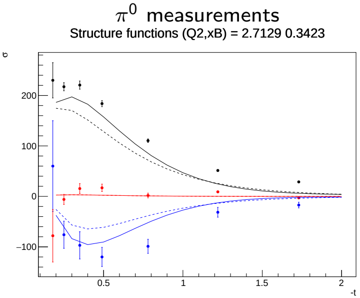
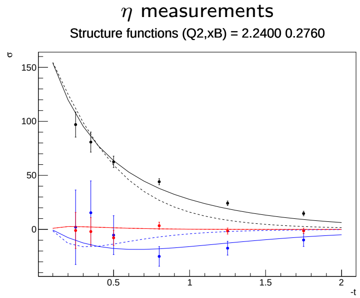


Figure 6.4: The transversity GPD combination $\bar{E}_T$ for d quarks on the left and u quarks on the right.

- 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 π^0 and η data to constrain $\bar{E}_T$ parameterizations of u and d quarks
- Free 8 coefficients

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





- Unpolarized π^0 structure function measurements
- σ_0, σ_{TT}, σ_{LT} at 96 $Q^2, xB, -t$ kinematic bins, 18 Q^2, xB bins
- Free 8 coefficients in $\bar{E}_T$ parameterization
- Minimization of $\chi^2 = \sum \frac{(\sigma_{GK} - \sigma_{CLAS})^2}{\Delta\sigma^2}$

σ_0, σ_{TT}, σ_{LT}
Solid line - after the fit
Dashed - before the fit

Summary

- 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 π^0 and η data from CLAS and CLAS12, as well as data on proton and neutron from Hall A, using GPD model parameterizations
- The combined π^0 and η 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 π^0/η channel from CLAS12 data
- Chiral-odd GPD extractions using CLAS/CLAS12 data

STAY TUNED FOR NEW RESULTS!