Deeply Virtual Meson Production with CLAS12 and Impact on Chiral-odd GPD Models

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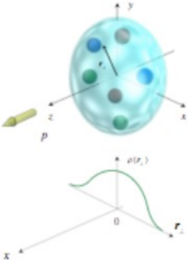
on behalf of CLAS collaboration

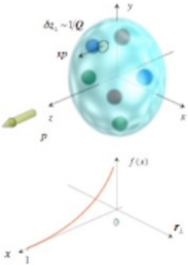
13th APCTP-BLTP JINR Joint Workshop :
"Modern Problems in Nuclear and Elementary Particle Physics"

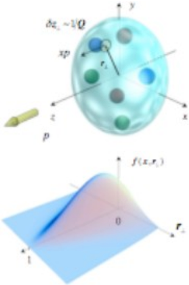
July 14-20, 2019

Description of hadron structure

D. Mu¨ller, X. Ji, A. Radyushkin







Nucleon Form Factors

transverse charge and current densities

Parton Distributions

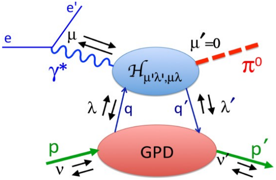
quark longitudinal momentum distributions

Generalized Parton Distributions (GPDs)

correlated quark momentum distirbutions in transverse space

GPDs in Deeply Virtual Exclusive Production

- 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



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

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

Generalized Parton Distributions

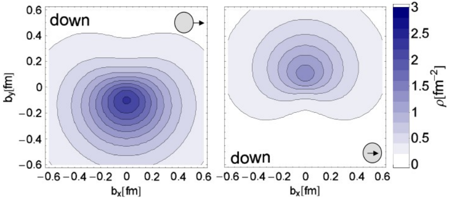
		Quark polarization		
		U	L	T
Nucleon polarization	U	H		$\bar{E}_T$
	L		$\tilde{H}$	
	T	E		$H_T,\ \tilde{H}_T$

Chiral-odd GPD results:

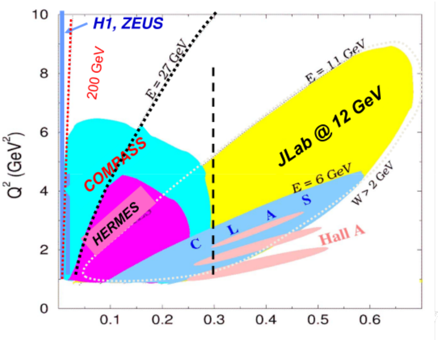
- Deeply virtual meson production
- Lattice QCD by G¨ockeler *et al*

Chiral even GPDs:

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

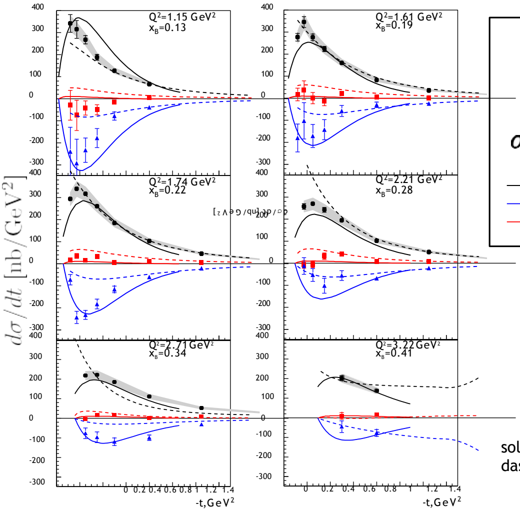


Roadmap: from 6 GeV to 12 GeV



- 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}

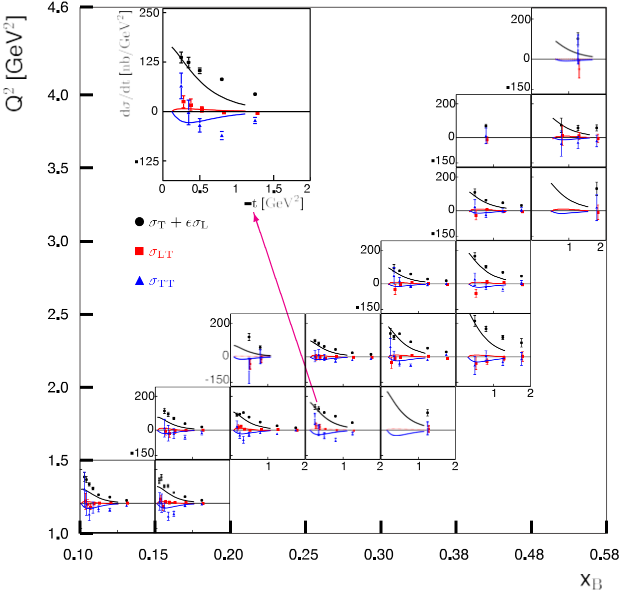
$$\sigma_{TT} \sim \frac{t'}{8m^2}|\bar{E}_T|^2$$

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



PRC 95: 035202 (2017)

I. Bedlinsky et al. (CLAS)

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

$$\delta q = \int_{-1}^{1} h_1^q(x) dx = \int_{0}^{1} \left(h_1^q(x) - \overline{h}_1^q(x) \right) dx$$

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:*

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

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 col- laborations

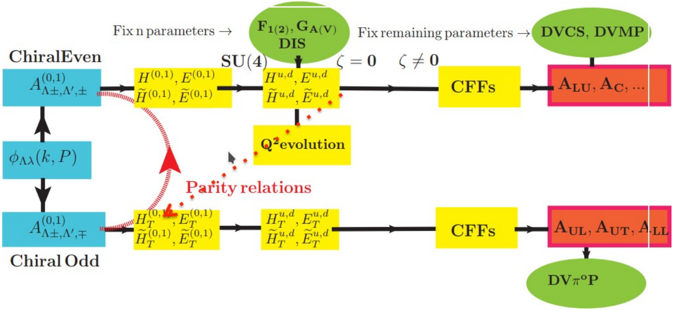
Goldstein-Gonzalez-Liuti model

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.



Goloskokov/Kroll(GK) Model and Goldstein/Liuti (GGL) Model

Both

Calculate the contributions fron the transverse virtual photon amplitudes using chiral-odd GPDs with $-t$ dependence, incorporated from Regge phenomenology, but differ in the GPD parametrisation methods.

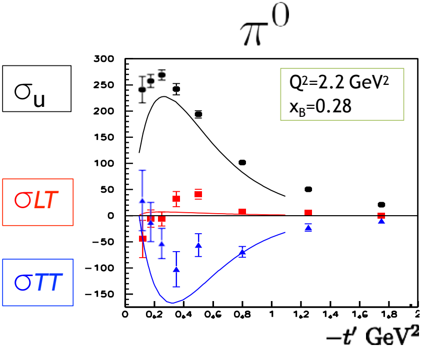
GK

Chiral-odd GPDs are constructed from double distributions and constrained using latest results from lattice QCD and transversely parton distribution functions.

GGL

Provides chiral-odd GPD Parametrisation via linear relations to chiral-even GDPs under parity and charge conjugation symmetries in a Reggeized diquark model

Comparison of π^0 and η



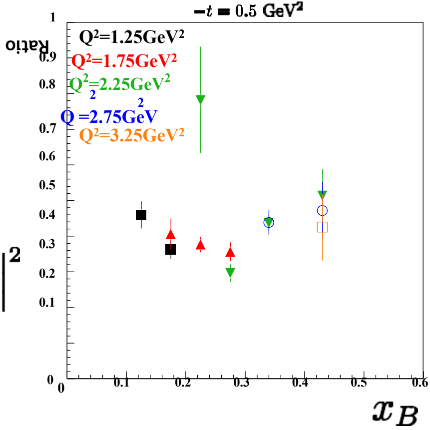
- $\sigma_U = \sigma_T + \varepsilon\sigma_L$ drops by a factor of 2.5 for η
- σ_{TT} drops by a factor of 10
- Theoretical model calculations (GK model) follows the experimental measurements

Ratio of π^0 and η

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

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

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

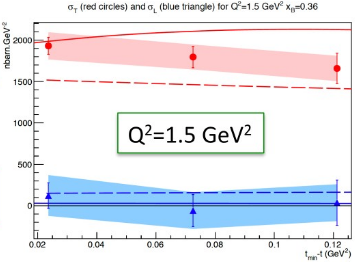


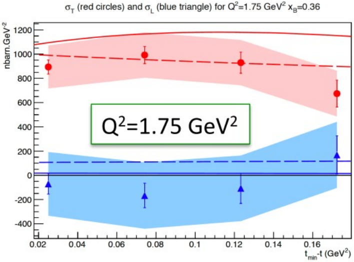
Theoretical calculations based on chiral odd GPDs predict this ratio to be around 1/3 at CLAS kinematics

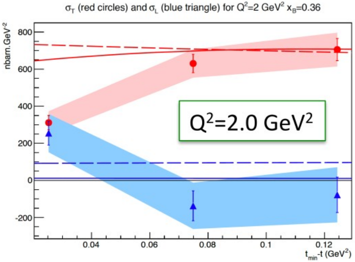
Rosenbluth separation of σ_T and σ_L at Hall A

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 collaboration, PRL 117: 262001 (2016)

Access to transverse GPDs

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

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

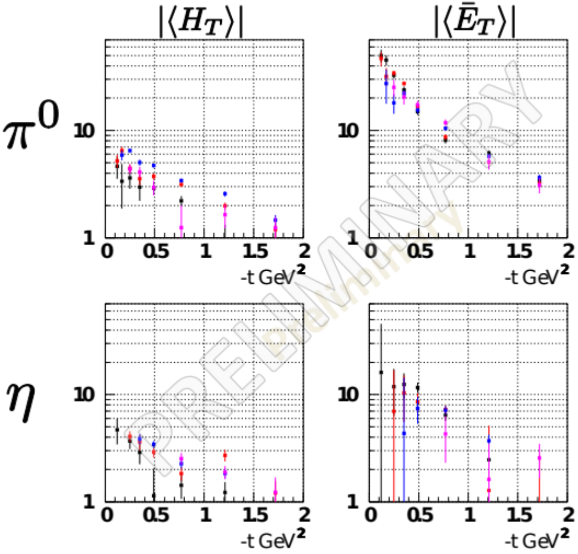
Goloskokov, Kroll
Transversity GPD model

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

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

- 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



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 $\bar{E}_T$

V. Kubarovsky, arXiv:1601.04367

Flavor decomposition

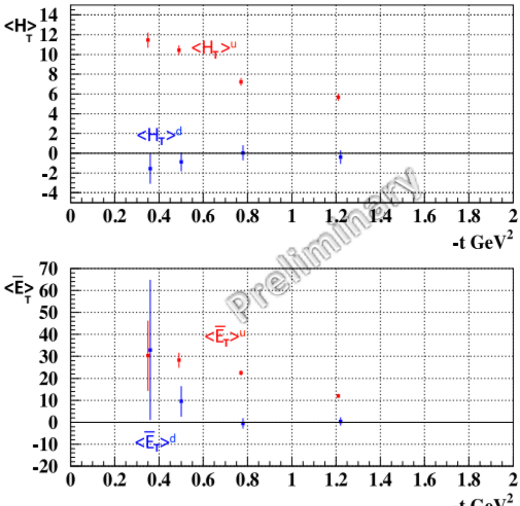
$$F^{\pi} = \frac{1}{3\sqrt{2}}\left[2F^{u} + F^{d}\right]$$
$$F^{\eta} = \frac{1}{3\sqrt{6}}\left[2F^{u} - F^{d}\right]$$

$$\Downarrow$$

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

- GPDs appear in different flavor combinations for π^0 and η
- **Combined datasets of π^0 and η channels** allow flavor decomposi- tion 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 have 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

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

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

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

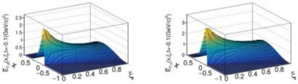


Figure 6.4: The transversity GPD combination $\bar{E}_T$ for d quarks on the left and u quarks on the right.

H_T is constrained using SIDIS data from HERMES and COMPASS

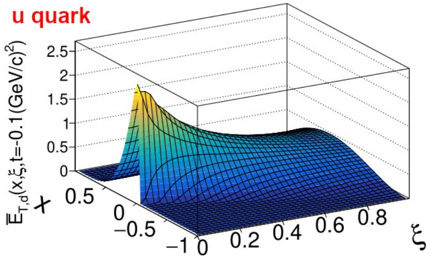
E_T is only constrained by Lattice QCD results

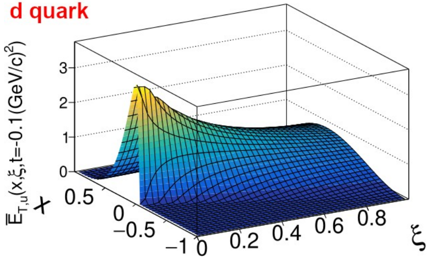
As a preliminary step: we use only unpolarized π^0 data to constrain $\bar{E}_T$ parameterizations of u and d quarks

Free 10 coefficients, 5 per eachquark

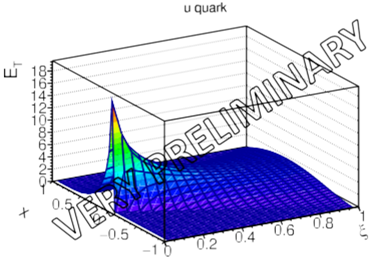
Very preliminary impact on GPD $\bar{E}_T$

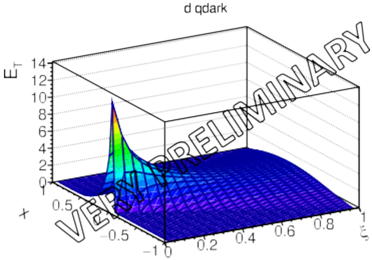
constrained by Lattice QCD





constrained by CLAS data

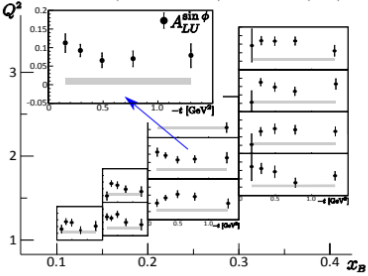




Spin asymmetry variables

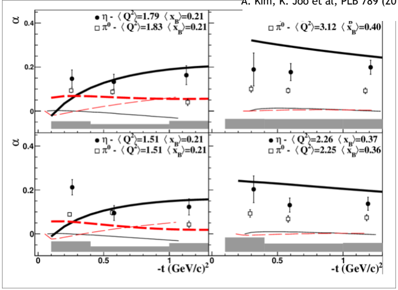
π^0 Beam Spin Asymmetries

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



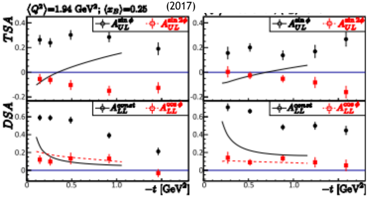
η Beam Spin Asymmetries

A. Kim, K. Joo et al, PLB 789 (2019)



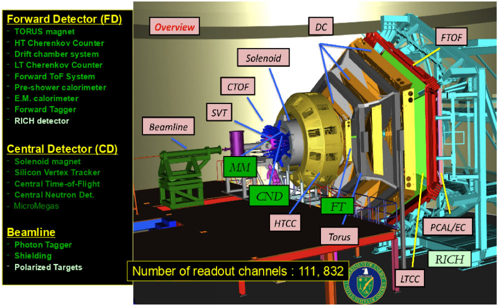
π^0 Target and Double Spin Asymmetries

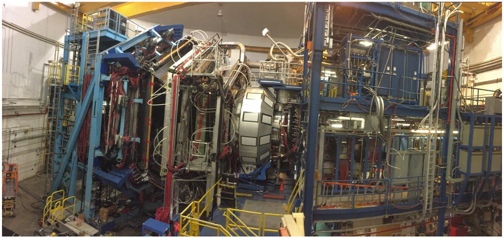
A. Kim, W. Kim et al(CLAS) PLB768, 168-173 (2017)



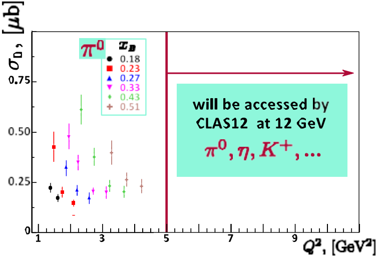
- Large number of single and double spin asymmetries were measured over wide kinematic range
- Asymmetries are much harder to interpret since they involve convolutions of chiral even and chiral odd GPDs

12 GeV upgrade and CLAS12

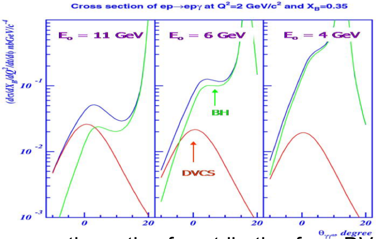




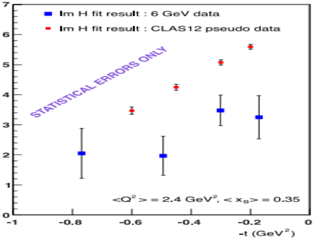
- DVCS/DVMP(π^0,η...):
- at 6.6, 8.8 and 11 GeV on proton and neutron
- at 11 GeV

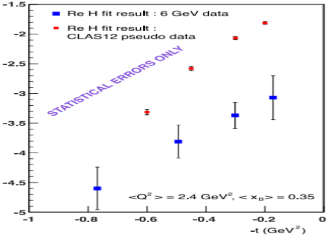


12 GeV Upgrade CLAS 12



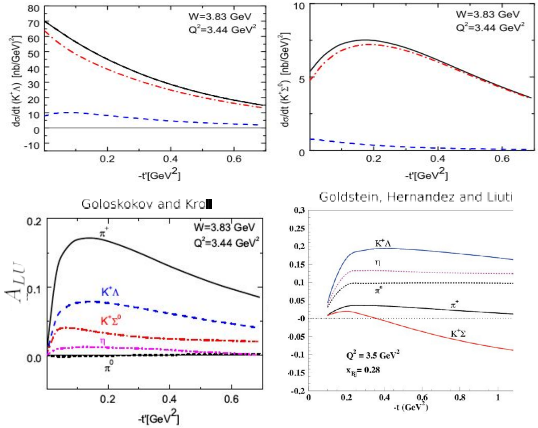
Relative cross section ratio of contribution from DVCS and BH
with increased electron beam energy





Imaginary part (left) and real part (right) of CFF H(t) extracted by H. Mourtarde for existing JLab 6 GeV data (blue squares) with CLAS12 pseudo-data (red squares).

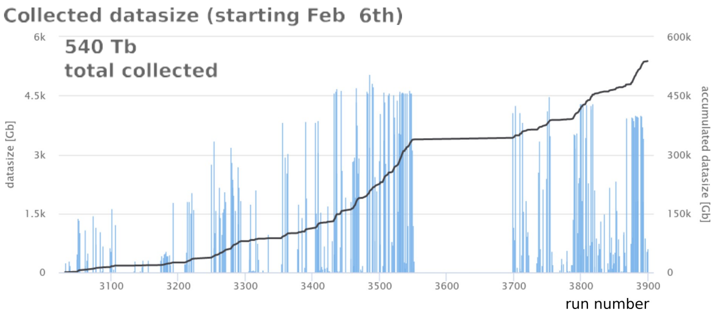
Exclusive kaon production

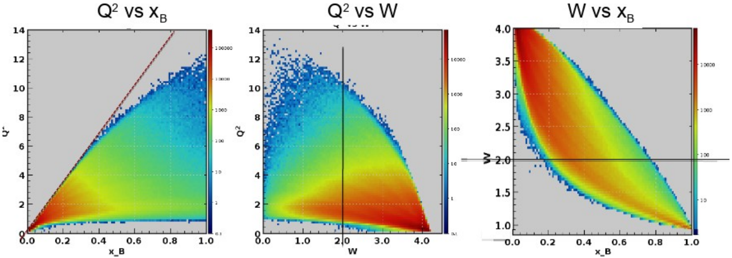


- Kaon production is expected to be an attractive alternative to neutral meson production in the studies of transversity GPDs

- It is expected to be dominated by transversity GPDs with small kaon pole contribution

Ongoing first experiment with CLAS12





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 $\langle \overline{E}_T \rangle$
- 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

STAY TUNED FOR 12 GeV DATA!

Beam spin asymmetry for deeply virtual η and π production as a function of -t

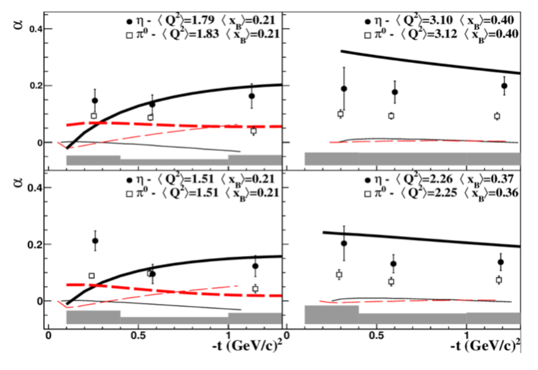


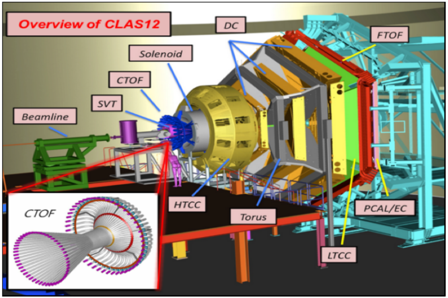
Fig. 2. Beam Spin Asymmetry for deeply virtual η (solid circles, solid lines) and η^0 (open squares, dashed lines) production as a function of -t for 4 kinematic bins in Q^2 and x_B. The curves are theoretical calculations from GK (thin lines) and GGL (thick) models.

$\eta(solid\ circles, solid\ line)$
$\pi^0: one\ squares, dashed\ lines$

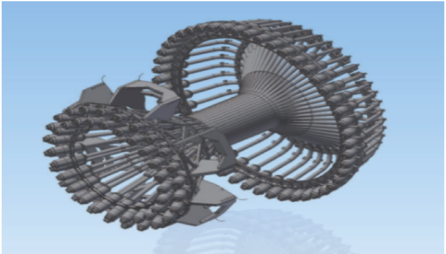
$GK: thin\ line$
$GGL: thick\ line$

CLAS12 and KNU contribution

R&D, Testing, and Installation of the hardware.



CLAS12 Detector at JLAB HALL B


Central TOF Detector of CLAS12

CTOF readout PMTs enclosed by magnetic shielding.