Status and Results From Recent CLAS 6 DVCS Experiments

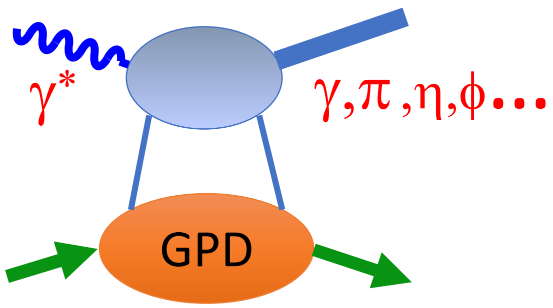
Carrying coals to Newcastle

1996 Introduction of GPD formalism for exclusive reactions

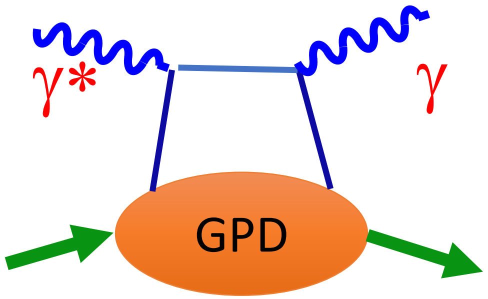
Lots of experimental and theoretical activity
Spate of theory articles:

Ji, Radyushkin, Mueller, Burkardt, VGG

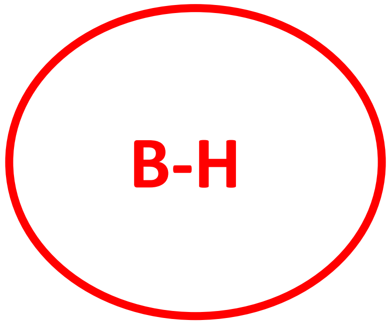
Experimental collaborations: Hermes and Jlab



DVCS in some ways most attractive at JLab kinematics
- γ perturbative.
- Sensitive to GPD H – charge distribution.

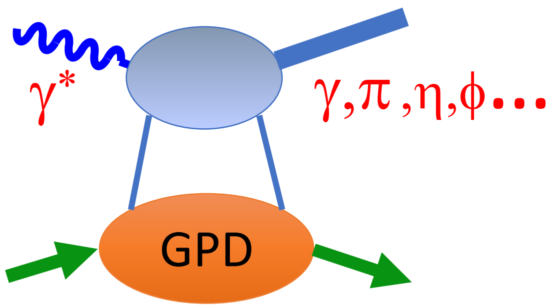


But, BH dominates cross sections.
Need polarization variables



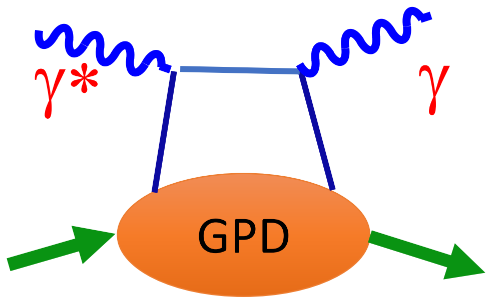
1996 Introduction of GPD – handbag formalism for exclusive reactions

Many experiments conducted
at Jlab for γ,π,η,ϕ final states



Focus on DVCS.
Sensitive to GPD H – charge distribution.

But, very large Bethe-Heitler interference



Experiments Performed at CLAS 6

1. Unpolarized cross section:

$$\sigma_{unp} \propto |\mathcal{M}_{BH}|^2 + 2\mathcal{M}_{BH} Re(\mathcal{M}_{DVCS}) + |\mathcal{M}_{DVCS}|^2$$

2. Polarization measurements, *either beam or target*,
   eliminate most of $|\mathcal{M}_{BH}|^2$

$$\Delta\sigma_{pol} = \sigma_+ - \sigma_- \sim 2\mathcal{M}_{BH} \mathrm{Im}(\mathcal{M}_{DVCS})$$

3. Asymmetry measurements $A \propto \Delta\sigma_{pol}/\sigma_{unp}$

(A_{UL} , A_{LU} , A_{LL})

A_{LU} least difficult. First experiments measured A_{UL}.

Experiments do not directly measure GPDs
but **Compton Form Factors**

DVCS $H, \widetilde{H}$

	DVCS	DVMP π, η
GPDs:	$F = H, \widetilde{H}, E, \tilde{E}$	$F_T = H_T, \widetilde{H_T}, E_T, \widetilde{E_T}$
Form Factors:	$\mathcal{F} = \mathcal{H}, \widetilde{\mathcal{H}}, \mathcal{E}, \tilde{\mathcal{E}}$	$\mathcal{F}_T = \mathcal{H}_T, \widetilde{\mathcal{H}_T}, \mathcal{E}_T, \widetilde{\mathcal{E}_T}$

$$\mathcal{F} \propto \int dx F(x,\xi,t) \left[\frac{1}{x-\xi+i\varepsilon} + \frac{1}{x+\xi+i\varepsilon}\right]$$

$$Re\mathcal{F} \propto P \int dx F(x,\xi,t) \left[\frac{1}{x-\varepsilon} + \frac{1}{x+i\varepsilon}\right]$$

$$Im\mathcal{F} = -\pi[F(\xi,\xi,t) \mp F(-\xi,\xi,t)]$$

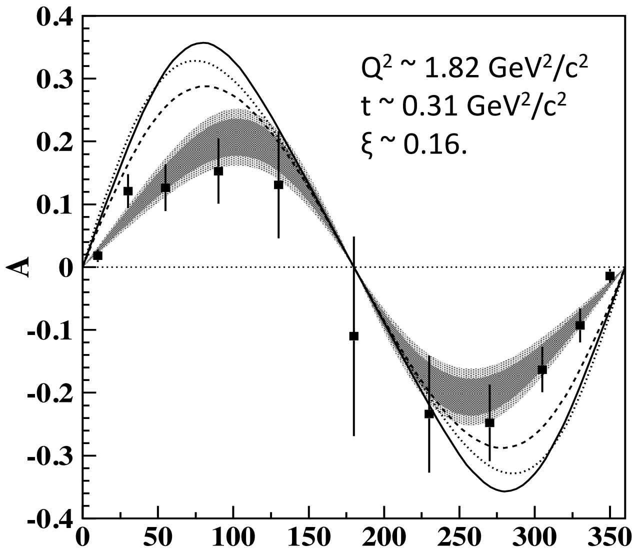
Different observables sensitive
to different CFFs

	Sensitivity
$\sigma_{unp} = \sigma^{\rightarrow} + \sigma^{\leftarrow}$	$\propto \mathcal{H}_{Re}$
$\sigma_{pol} = \sigma^{\rightarrow} - \sigma^{\leftarrow}$	$\propto \mathcal{H}_{Im}$
$\mathcal{A}_C$	$\propto \mathcal{H}_{Re}$
$\mathcal{A}_{LU}$	$\propto \mathcal{H}_{Im}$
$\mathcal{A}_{UL}$	$\propto \mathcal{H}_{Im}, \tilde{\mathcal{H}}_{Im}$
$\mathcal{A}_{LL}$	$\propto \mathcal{H}_{Re}, \tilde{\mathcal{H}}_{Re}$

First CLAS DVCS experiments

Beam Spin Asymmetry

S. Stepanyan et al.,
Phys. Rev. Lett. 87, 182002 (2001)

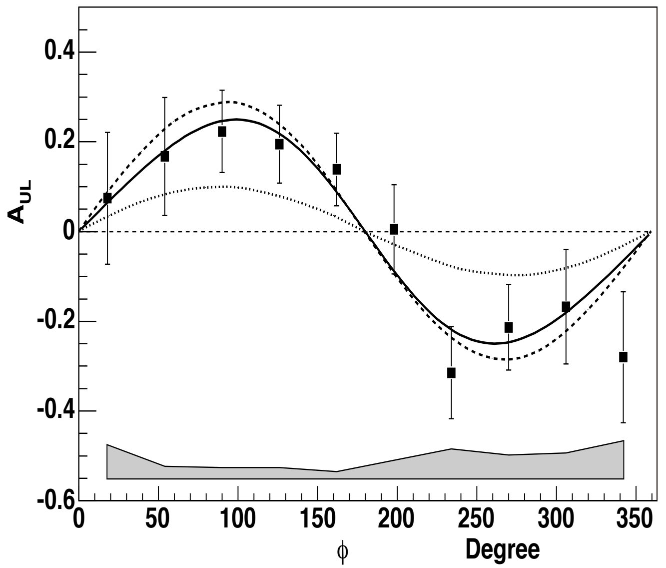


$$A(\phi) = \alpha \sin\phi + \beta \sin 2\phi.$$

$$\alpha \sim 0.20 \quad \beta \sim -0.02$$

Target Spin Asymmetry

S. Chen et al. ,
Phys. Rev. Lett. 97, 072002 (2006).



Consistent with dominance of leading order (twist 2)
in expansion: $A = \Sigma\, a_n \sin(n\phi)$

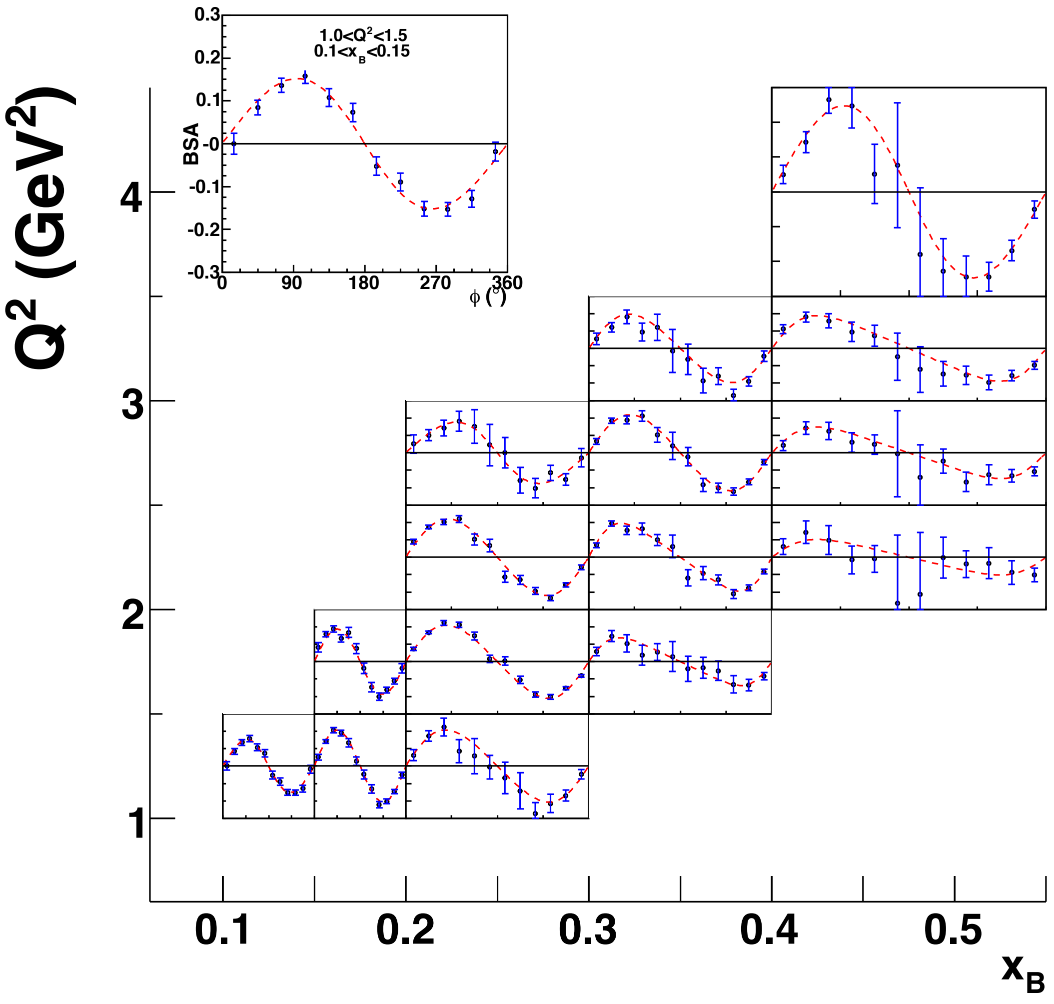
CLAS 6 GeV large kinematic acceptance experiments

CLAS 6 GeV - Run 2005 - A_{LU}

FX Girod et al. Phys. Rev. Lett. 100, 162002 (2008).

Beam spin asymmetries. Integrated over all t

(Thesis FX Girod - 2006)



Expansion: $A = \Sigma\, a_n \sin(n\phi)$

Leading order twist 2:

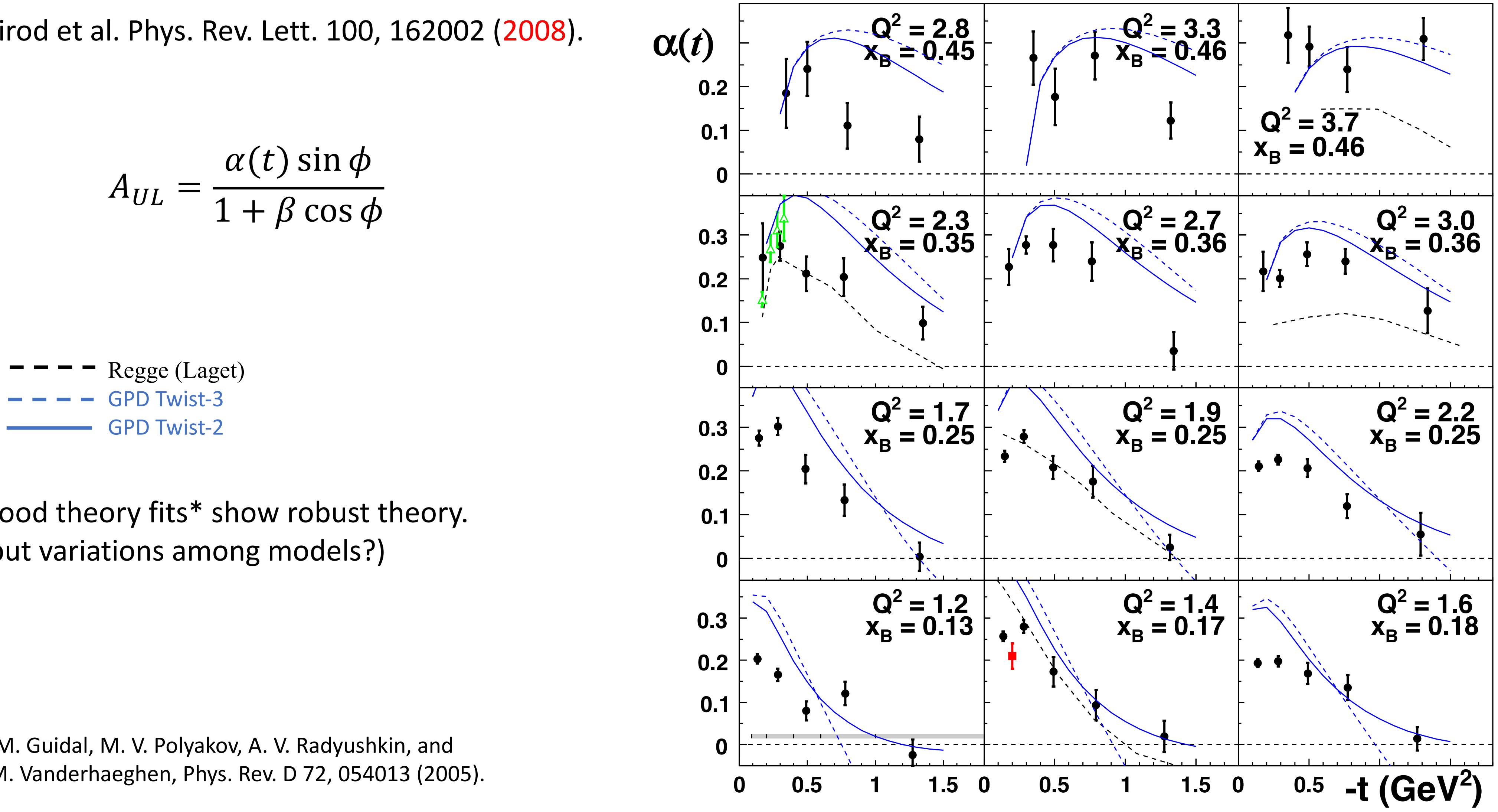
$$A = \frac{\alpha \sin\phi}{1+\beta\cos\phi}$$

"Whether integrated in t or in each t -bin, the ϕ- distributions were always found to be compatible with leading-twist dominance"

First CLAS 6 GeV - Run 2005 $\mathbf{A_{LU}}$

FX Girod et al. Phys. Rev. Lett. 100, 162002 (2008).

$$A_{UL} = \frac{\alpha(t)\sin\phi}{1+\beta\cos\phi}$$



Good theory fits* show robust theory.
(but variations among models?)

*M. Guidal, M. V. Polyakov, A. V. Radyushkin, and M. Vanderhaeghen, Phys. Rev. D 72, 054013 (2005).

Polarized beam and target - 2009

Beam, Target and Double beam/target asymmetry

Different geometry and beam conditions

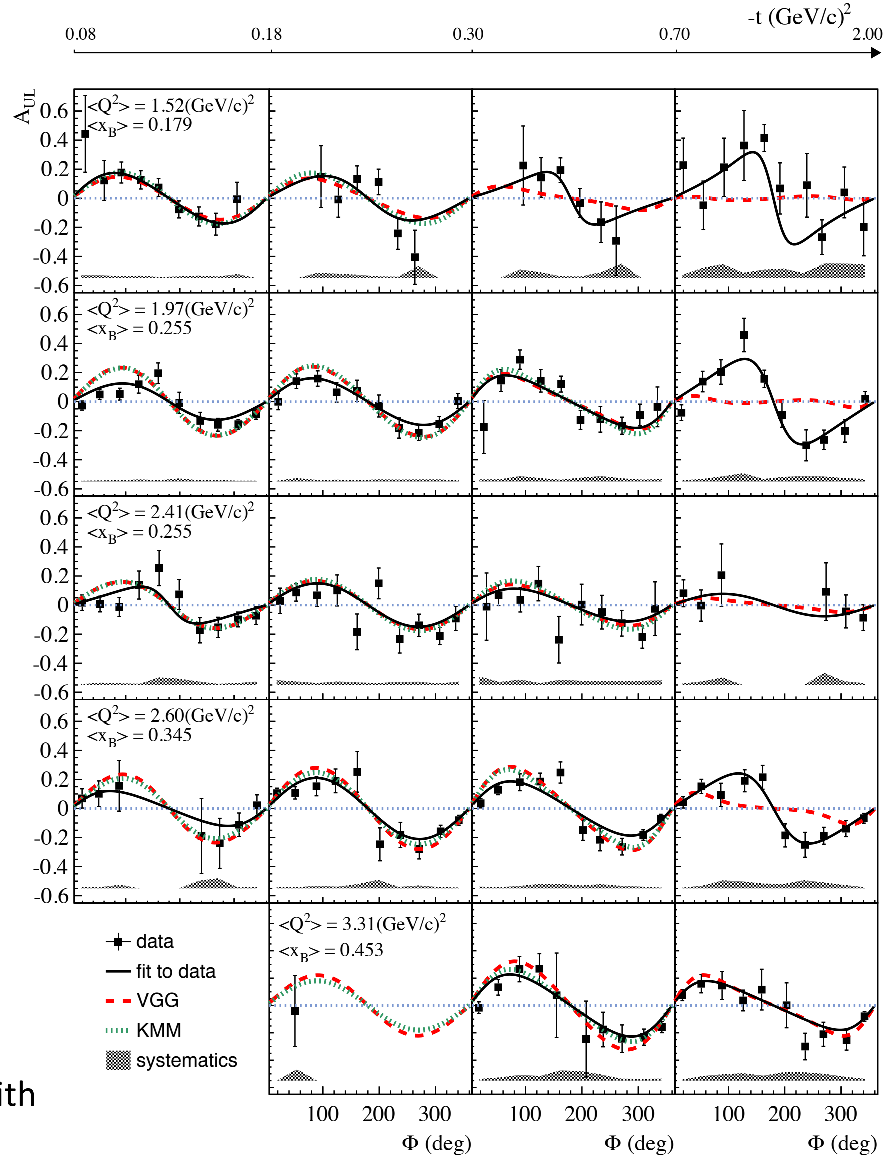
A_{UL} - E. Seder et al. Phys. Rev. Lett. 114, 032001 (2015)

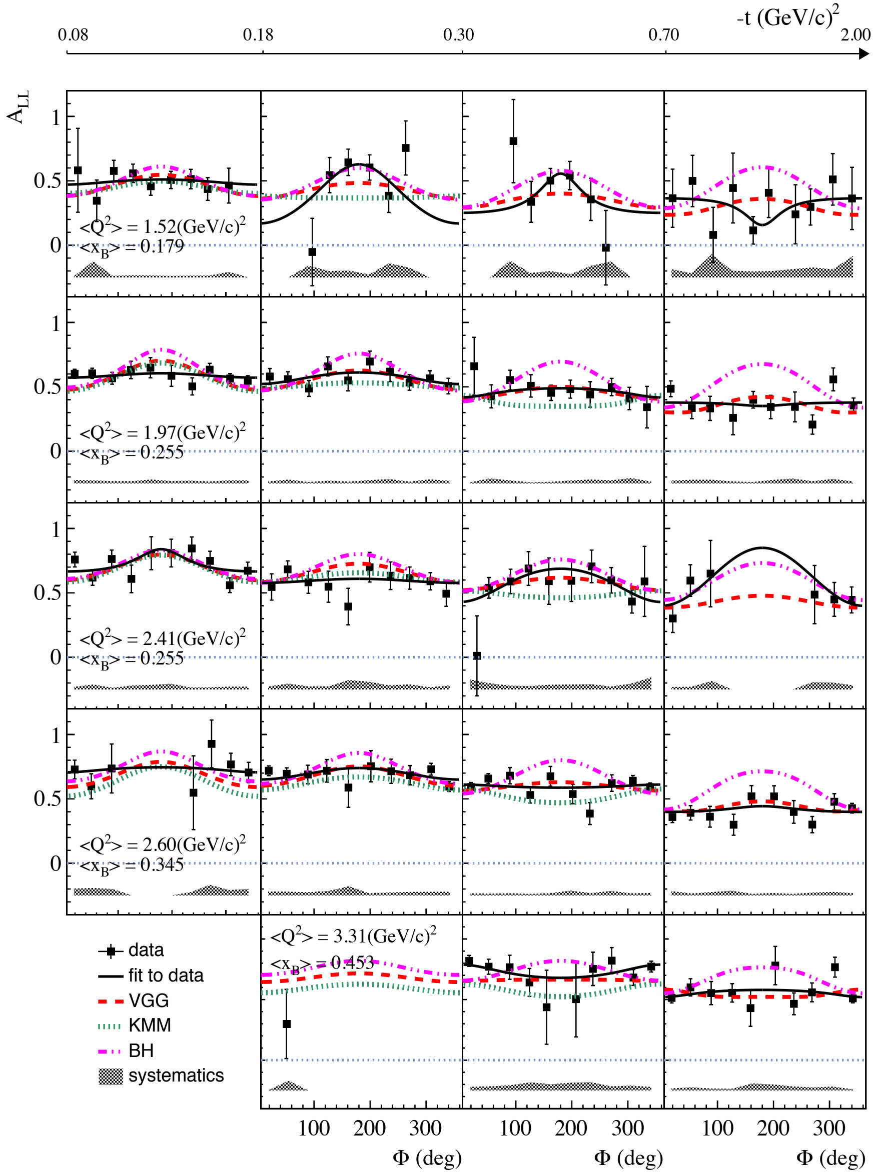
Full Article, A_{UL}, A_{LU} A_{LL} – S. Pisano et al, Phys.Rev. D91 (2015)

Target Spin Asymmetry $A_{UL} = \dfrac{\alpha_{UL} \sin\phi}{1 + \beta \cos\phi}$

Double Spin Asymmetry $A_{LL} = \dfrac{\kappa_{LL} + \lambda_{LL} \cos\phi}{1 + \beta \cos\phi}$

A_{UL}: $\sin\phi$ dominance in $\sin(n\phi)$ expansion → twist 2 region.





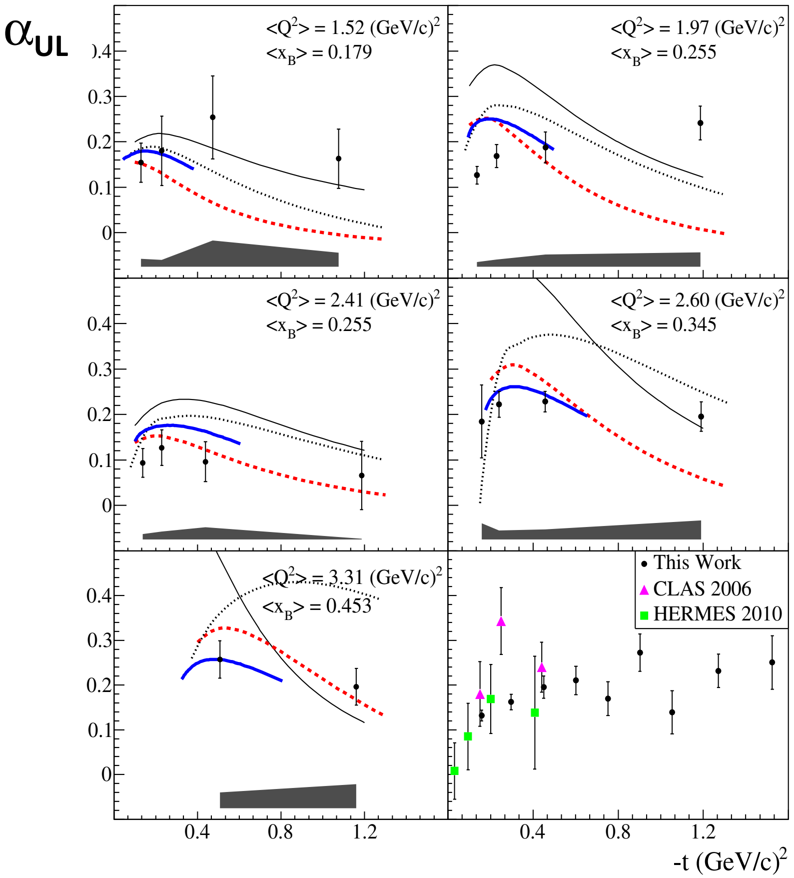
A_{LL}: flat Distribution → $\kappa_{LL} - BH$ dominance

- data
- fit to data
- VGG
- KMM
- BH
- systematics

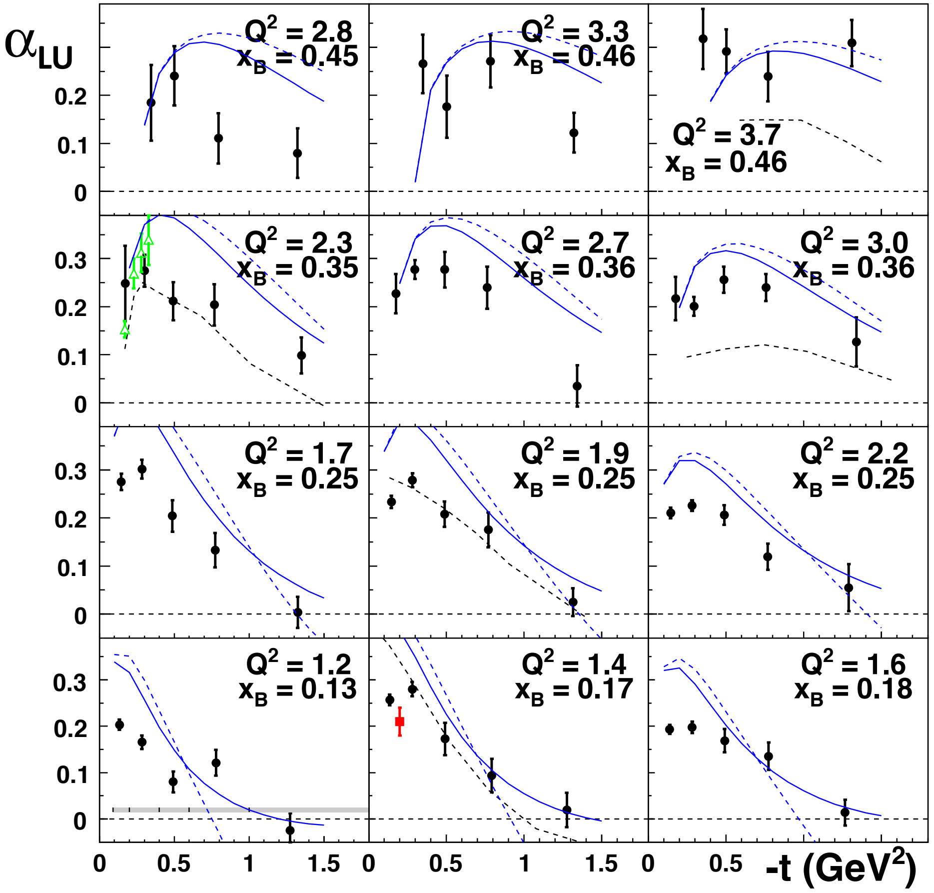
Fit based on VGG with CFF allowed to vary

Compare target spin asymmetry with beam spin asymmetry

TSA Sensitive to $\mathcal{H}$ and $\widetilde{\mathcal{H}}$



BSA Sensitive to $\mathcal{H}$



Smaller t slope in α_{UL} than α_{LU}

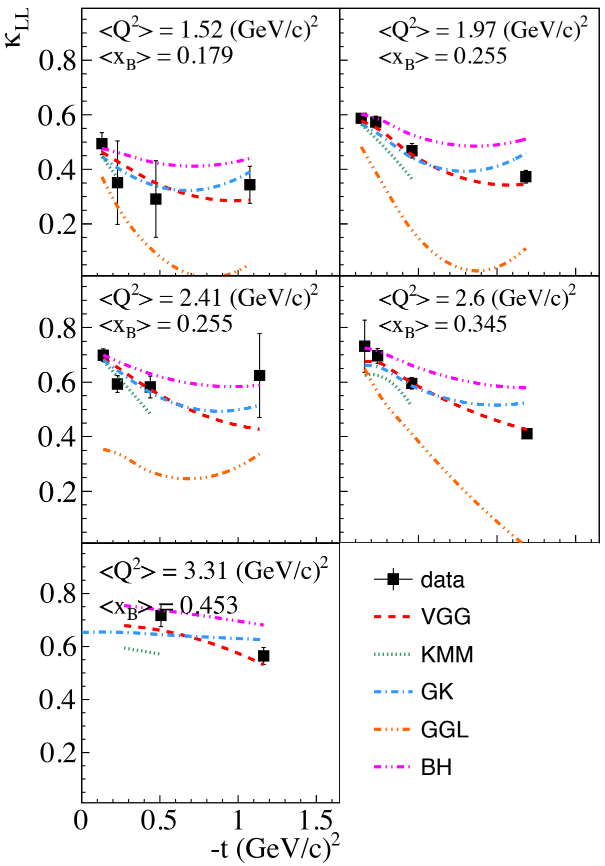
Axial charge radius is smaller than charge radius.

Agrees with axial form factor measurements involving π^0 and ν.

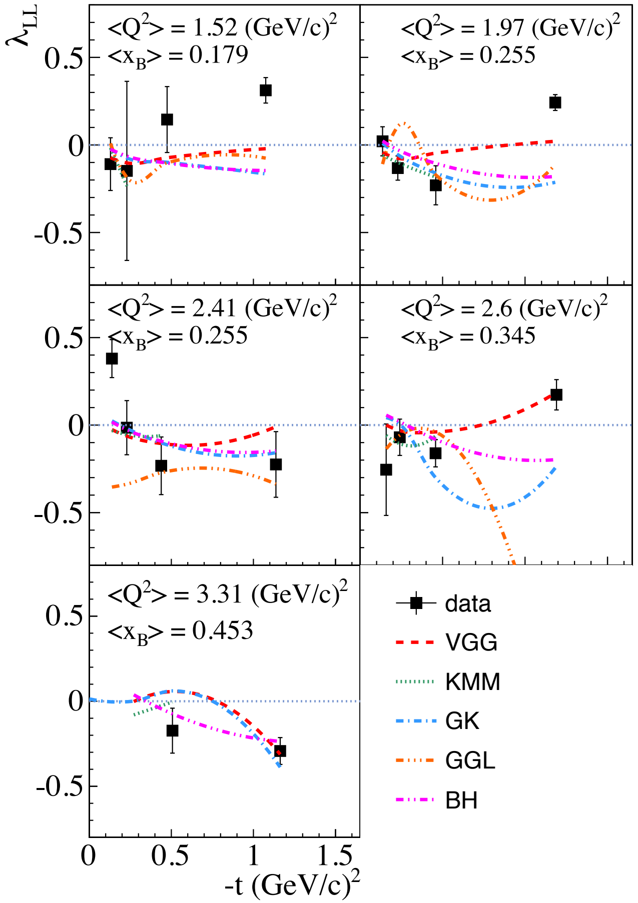
Double Spin Asymmetry

$$A_{LL} = \frac{\kappa_{LL} + \lambda_{LL} \cos\phi}{1 + \beta \cos\phi}$$

$\mathcal{K}_{\mathbf{LL}}$



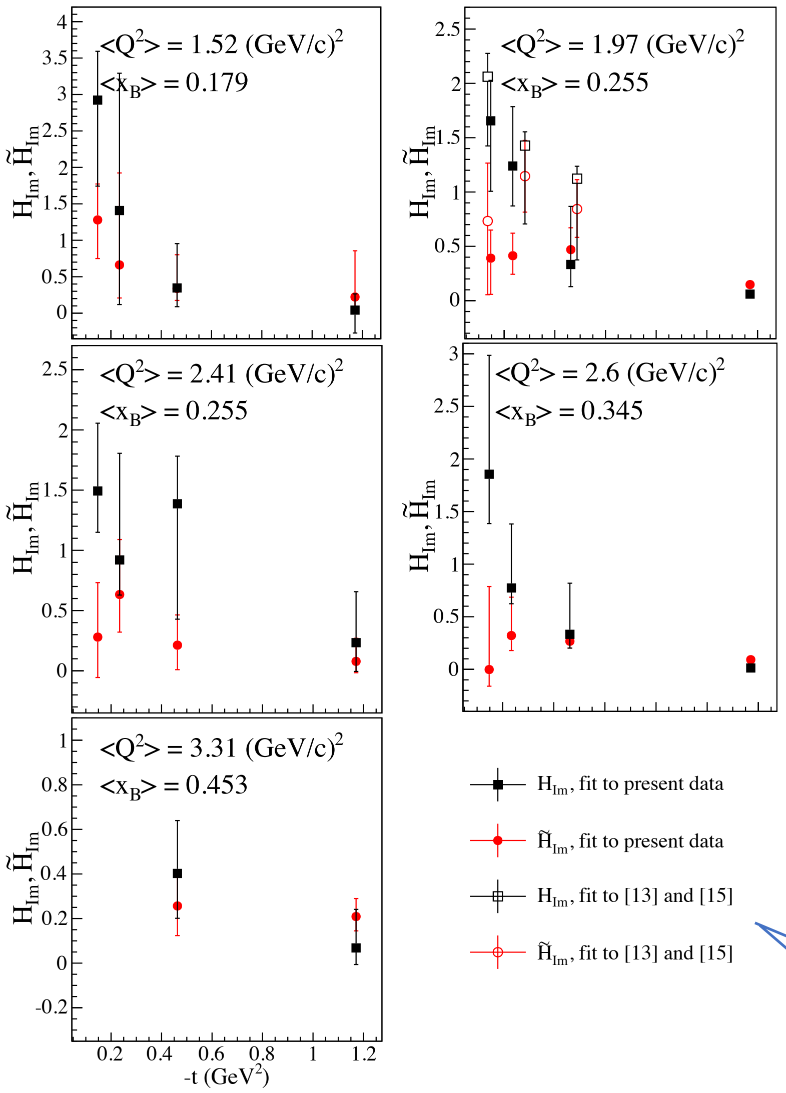
$\lambda_{\mathbf{LL}}$



Agreement on BH dominance – but A_{LL} data cannot constrain DVCS

Pisano et al

Extraction of $\mathcal{H}_{IM}$ and $\widetilde{\mathcal{H}}_{IM}$



For all data
$\mathcal{H}_{IM}$ falling faster than $\widetilde{\mathcal{H}}_{IM}$.

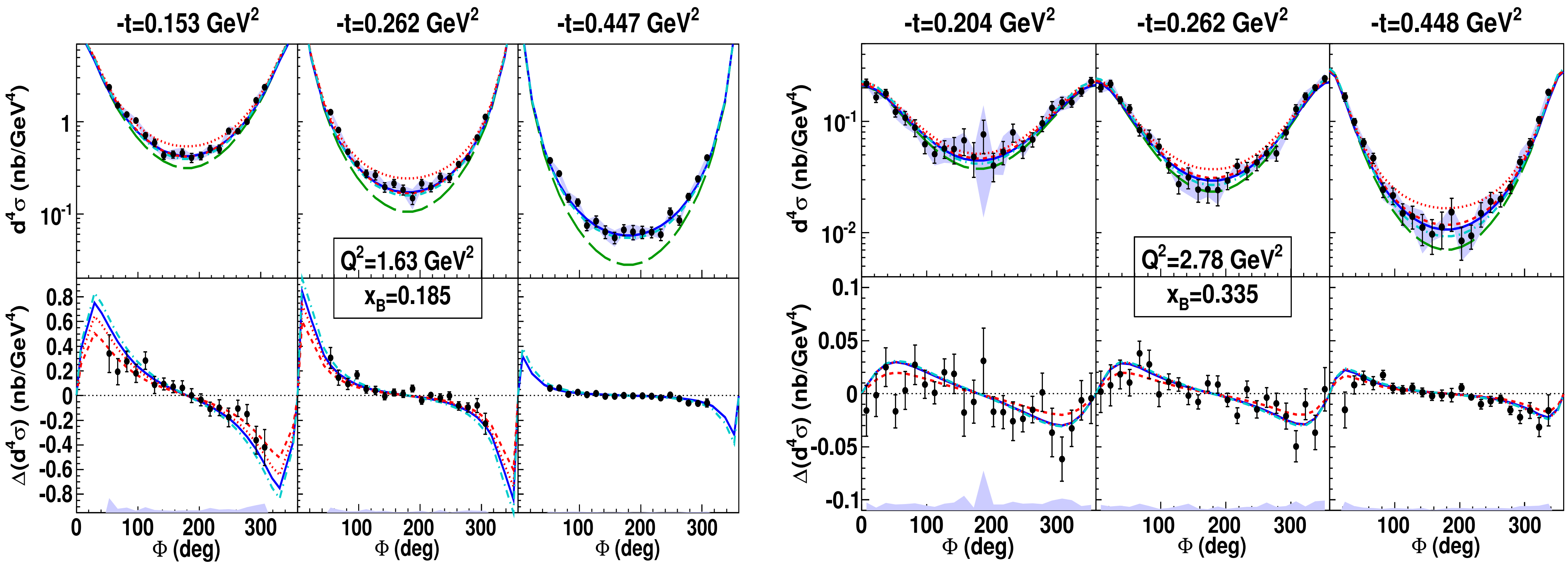
F.-X. Girod et al. (CLAS Collaboration), Phys. Rev. Lett. 100, 162002 (2008)

S. Chen et al. (CLAS Collaboration), Phys. Rev. Lett. 97, 072002 (2006).

Absolute Cross Section σ and Δσ measurements.

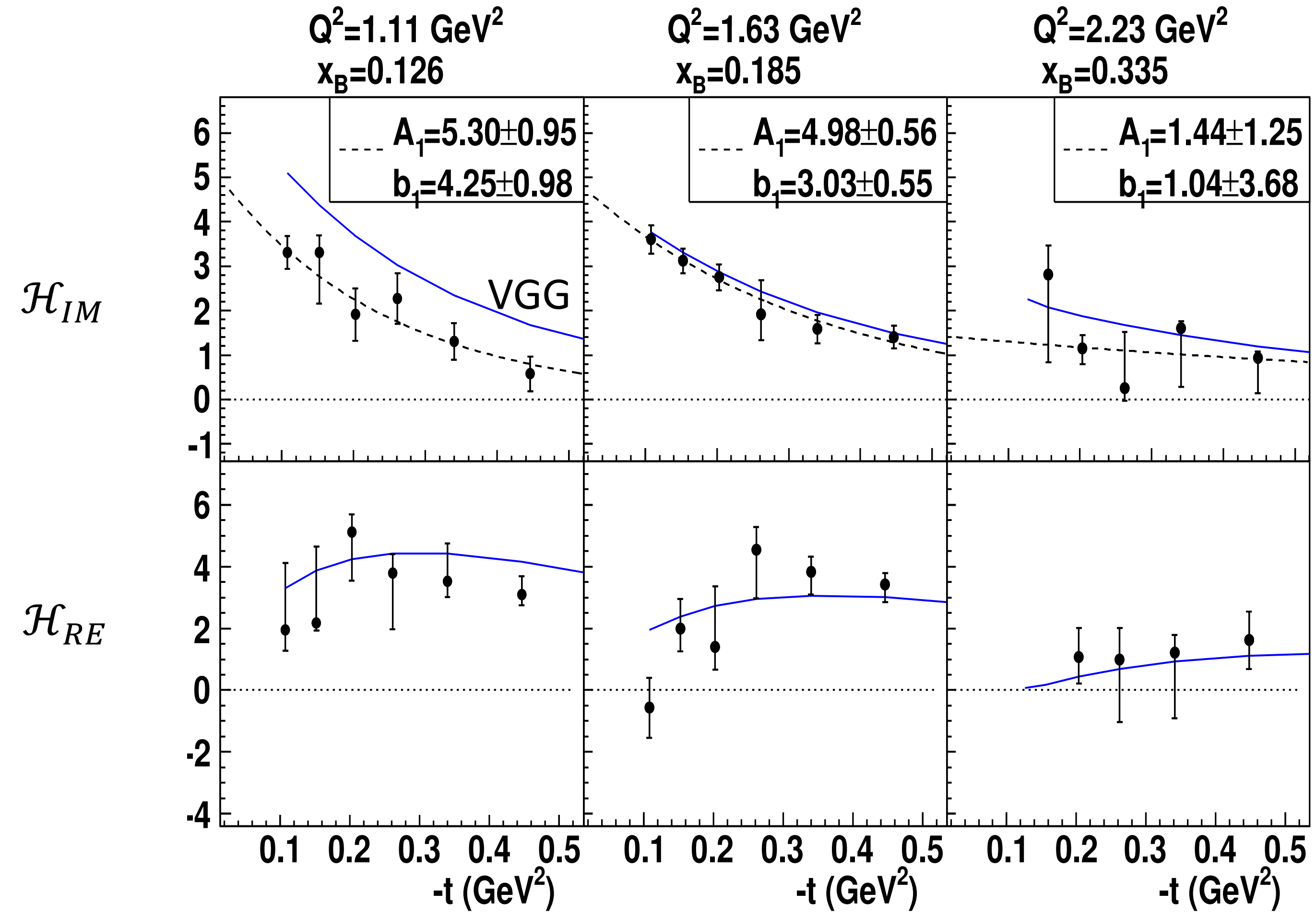
DVCS1 **Run: March to May 2005**

J. S. Jo et al. Phys. Rev. Lett. 115, 212003 (2015). **21 bins in x_B, Q^2, t**



-VGG -BH, .. KM10 KMS

CFF extracted assuming only $\mathcal{H}$ and $\widetilde{\mathcal{H}}$.



$\mathcal{H}_{IM}$ is a measure of density of partons at $x=\xi$

Fit to data $\mathcal{H}_{IM} = ae^{bt}$

$\mathcal{H}_{RE}$ is more complicated

$$Re\mathcal{H} \propto P \int \mathrm{d}x H(x,\xi,\mathrm{t}) \left[\frac{1}{x-\varepsilon} + \frac{1}{x+i\varepsilon}\right]$$

a and b increase, in a systematic way, with decreasing x_B

⇒ The size of the nucleon increases as lower momentum fractions.

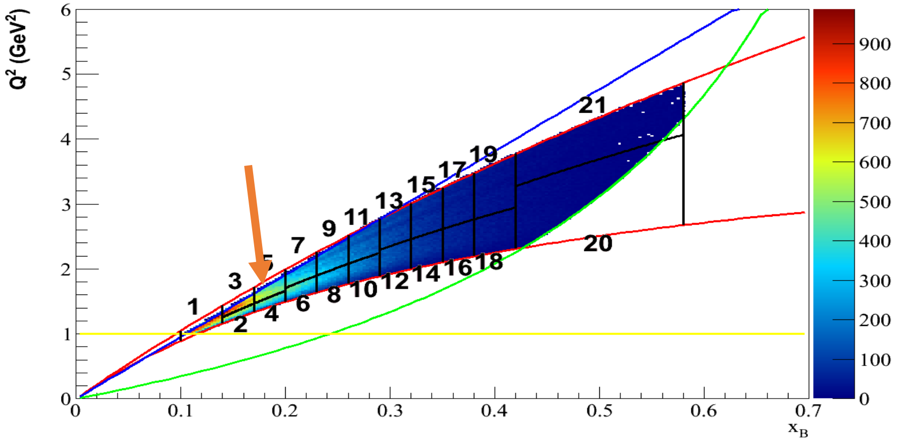
⇒ Increase of the partonic content of the nucleon as lower x_B

Last result: DVCS2 run 2008-2009

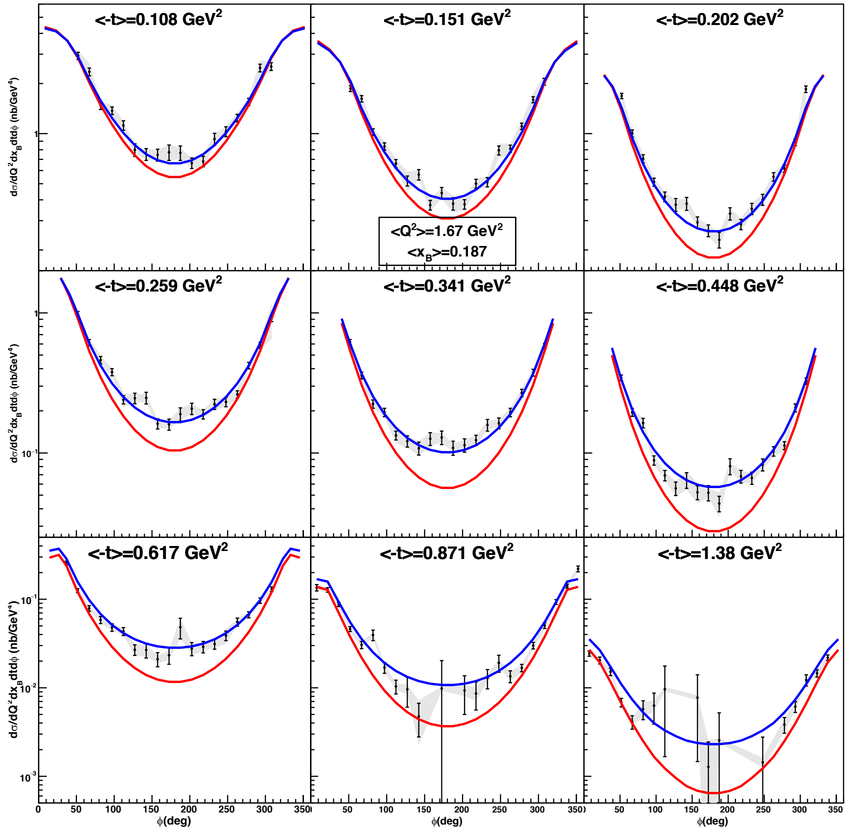
Theses, B. Guegan and N. Saylor

Final edits of PR article in progress

Bin5



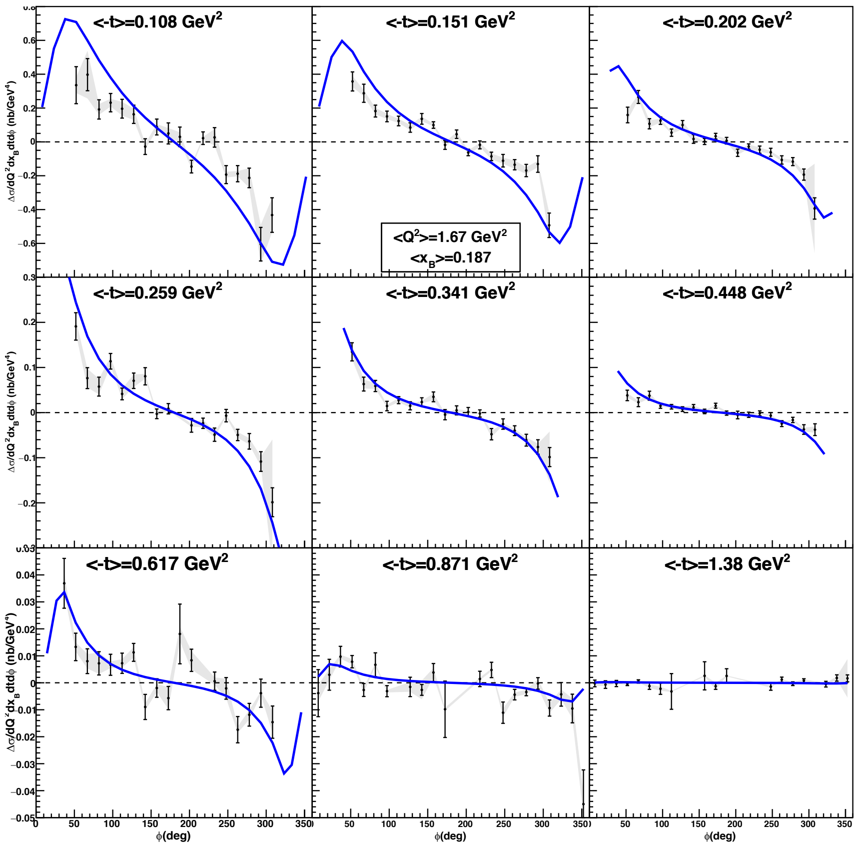
Q^2 (GeV^2)
x$_B$



<-t>=0.108 GeV^2
<-t>=0.151 GeV^2
<-t>=0.202 GeV^2
<Q^2>=1.67 GeV^2
<x$_B$>=0.187
<-t>=0.259 GeV^2
<-t>=0.341 GeV^2
<-t>=0.448 GeV^2
<-t>=0.617 GeV^2
<-t>=0.871 GeV^2
<-t>=1.38 GeV^2
ϕ(deg)

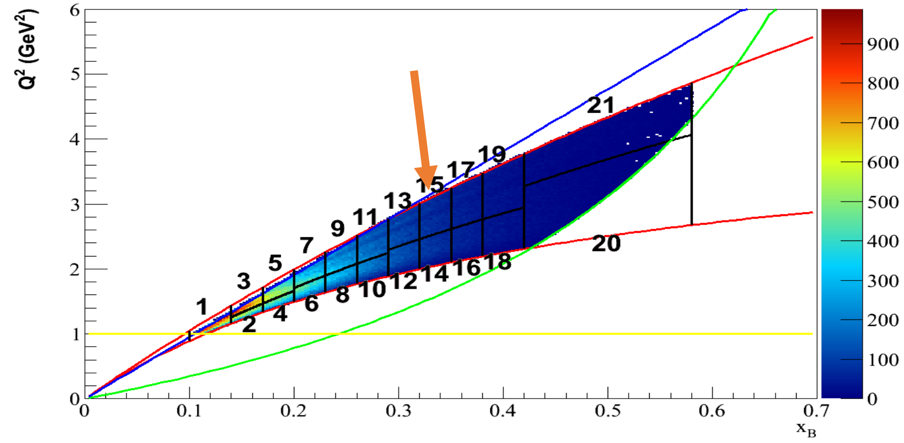
VGG

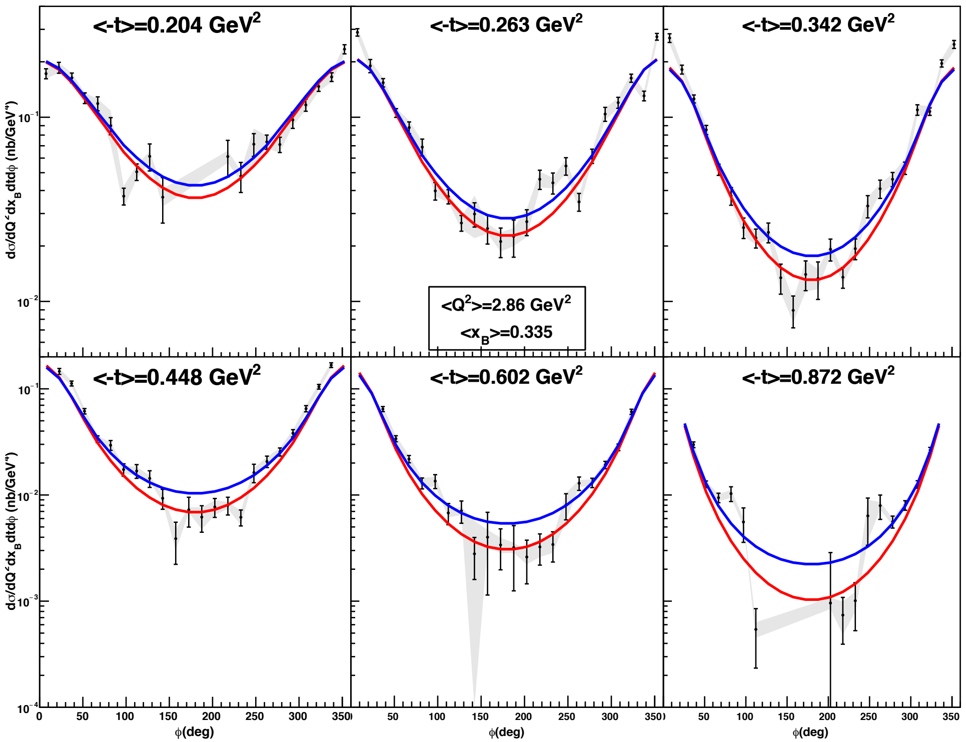
BH



<-t>=0.108 GeV^2
<-t>=0.151 GeV^2
<-t>=0.202 GeV^2
<Q^2>=1.67 GeV^2
<x$_B$>=0.187
<-t>=0.259 GeV^2
<-t>=0.341 GeV^2
<-t>=0.448 GeV^2
<-t>=0.617 GeV^2
<-t>=0.871 GeV^2
<-t>=1.38 GeV^2
ϕ(deg)

Bin15

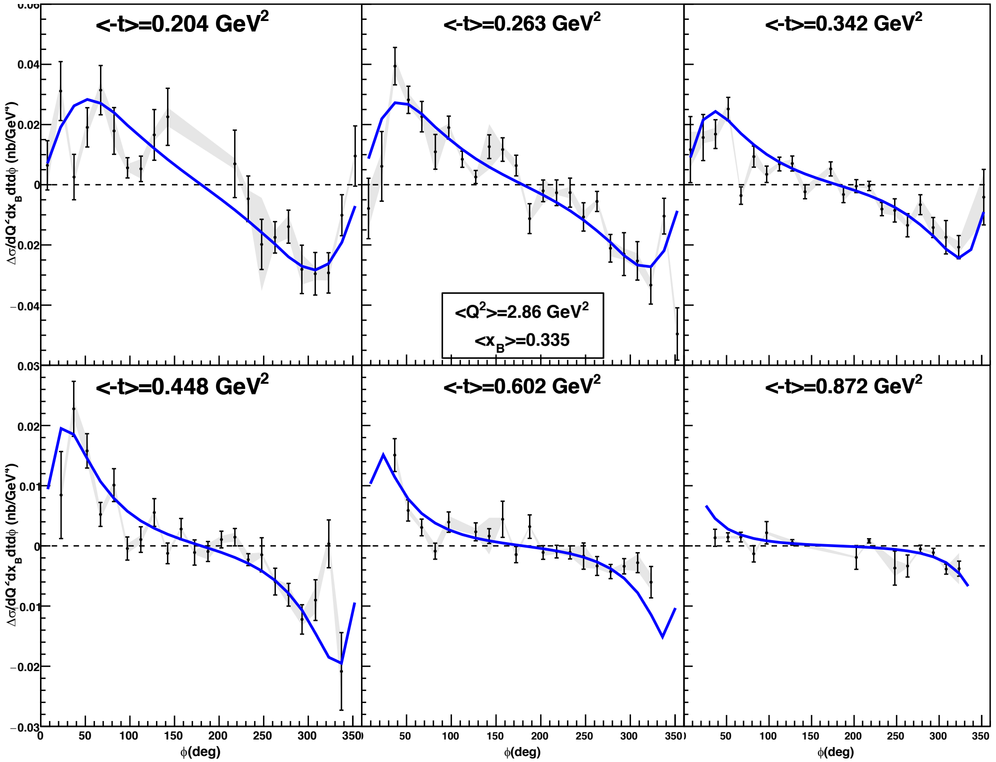




VGG

BH

BH+DVCS



Comparison between DVCS2 and DVCS1

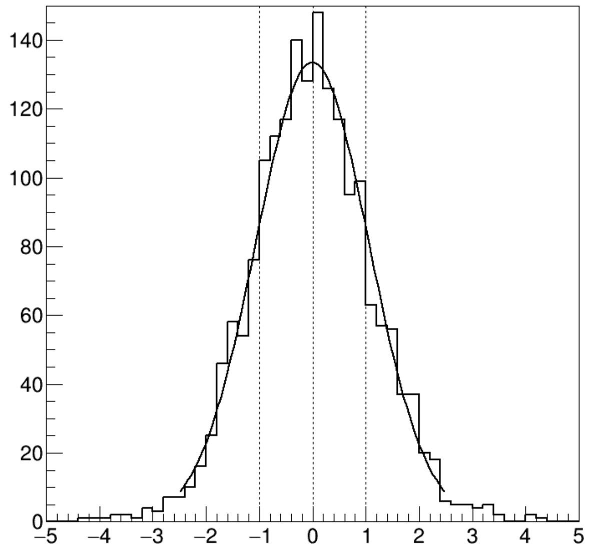
Different
- beam energy: 5.88 vs 5.75
- target length: 1.5 vs 4 cm
- target position: 3 cm
- solenoid/target offset

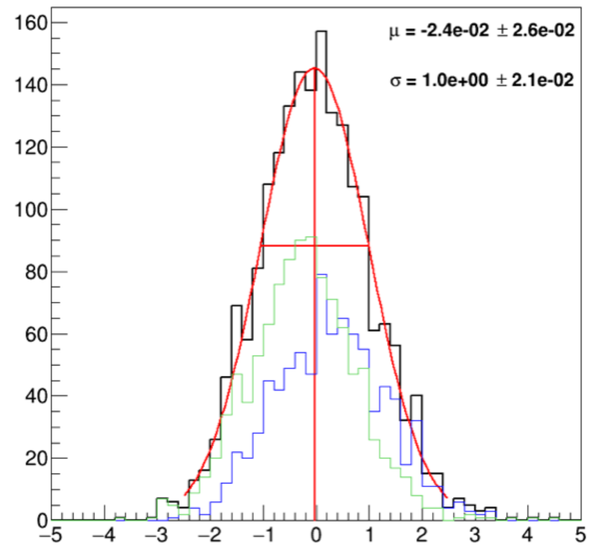
FX Girod: careful studies and extrapolate expected variations in σ

Ratio of cross section differences and errors added in quadrature

$$\delta_i = \frac{\sigma 1_i - \sigma 2_i}{\sqrt{\Delta\sigma 1_i^2 + \Delta\sigma 2_i^2}}$$

$\mu = 2\text{x } 10^{-2}$
$\Delta\delta = 1.0$





Major issue for cross section measurements –elastic normalization

Example of analysis of Jlab DVCS data and Proton Tomography

R. Dupre, M. Guidal, S. Niccolai, M. Vanderhaeghen

Eur.Phys.J. A53 (2017) no.8, 171

arXiv: 1704.07330v1 [hep-ph]

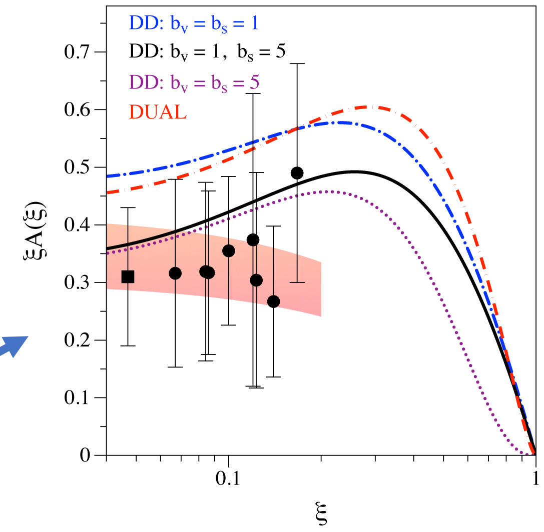
Fitting procedures based on VGG and developed over the years in various publications.

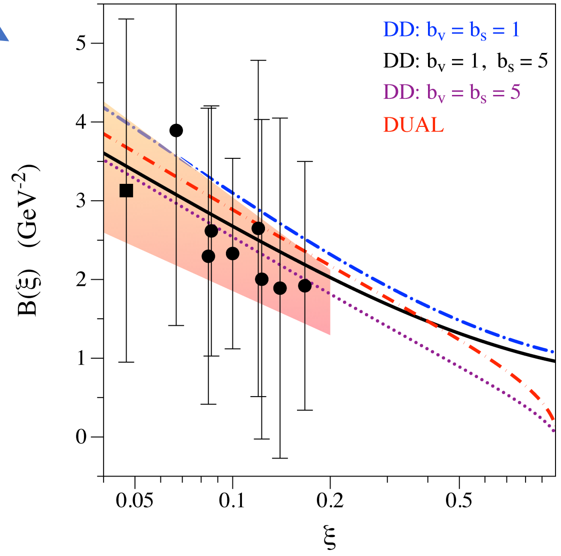
Data on $\mathcal{H}_{Im}(\xi, t)$ generated by fitting all CLAS and Hall A data.

1.For each x and Q^2 bin fit ξ dependence BY.

$$\mathrm{H}_{\mathrm{Im}}(\xi, t) = A(\xi)e^{B(\xi)t}$$

2. Plot all fit points in A & B vs ξ for all fits for all kinematics.





3. Fit all these A & $\boldsymbol{B}$ with Where and B have following functional form

$$\mathrm{H}_{\mathrm{Im}}(\xi, t) = A(\xi)e^{B(\xi)t}$$

$$A(\xi) = a_A(1-\xi)/\,\xi$$

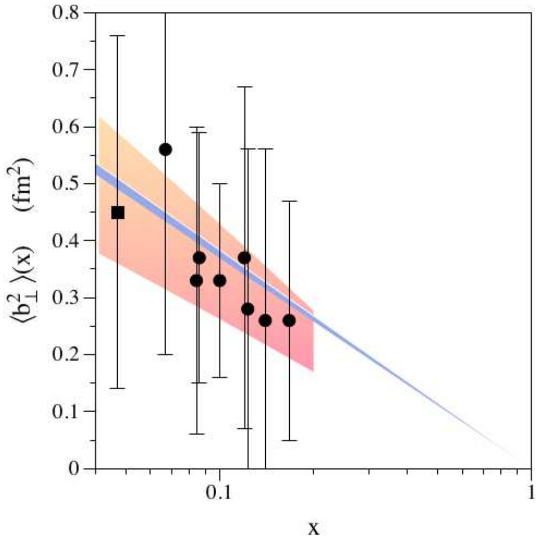
$$B(\xi) = a_B ln(1/\,\xi)$$

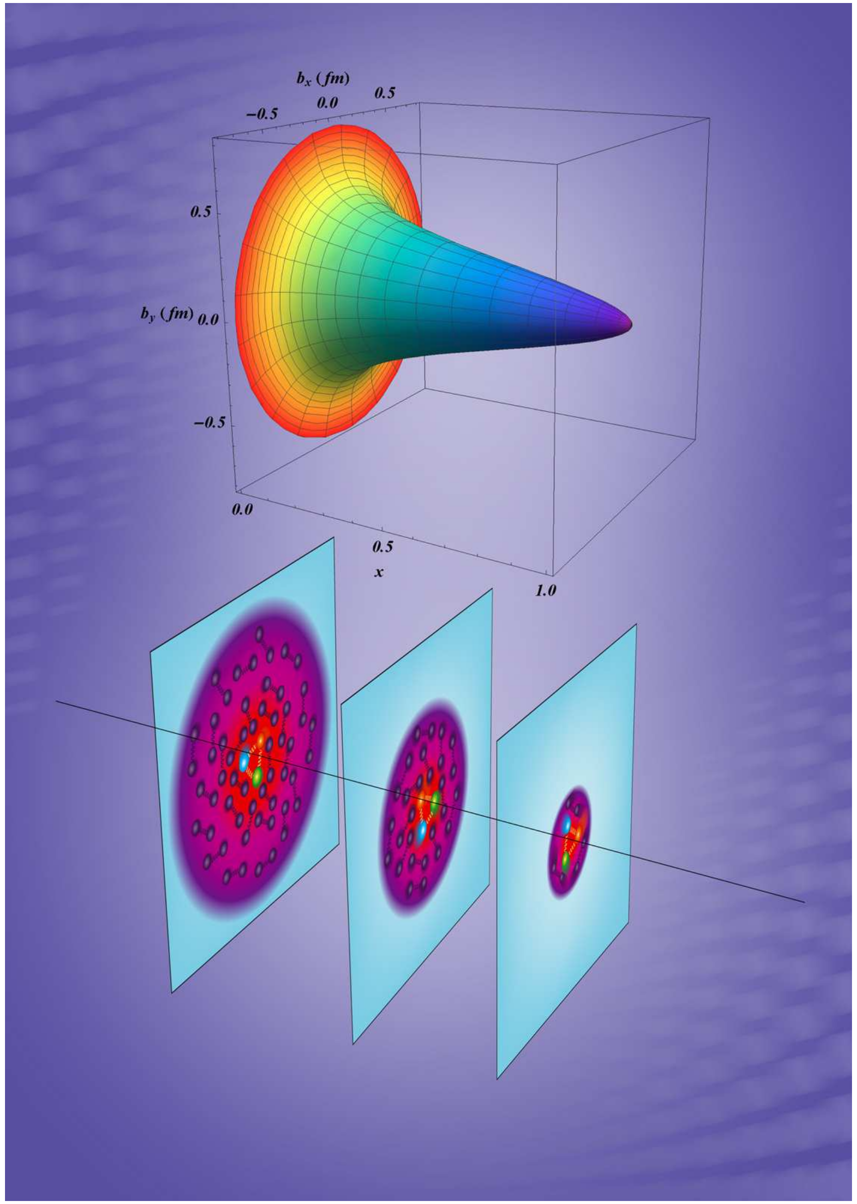
$H_{\mathrm{Im}}(\xi, t) \equiv H_{+(}\xi, \xi, t),$

$H_{+}(\xi, \xi, t) = H^{q}(x, \xi, t) - H^{q}(-x, \xi, t)$

$B \to \langle b_\perp^2 \rangle$

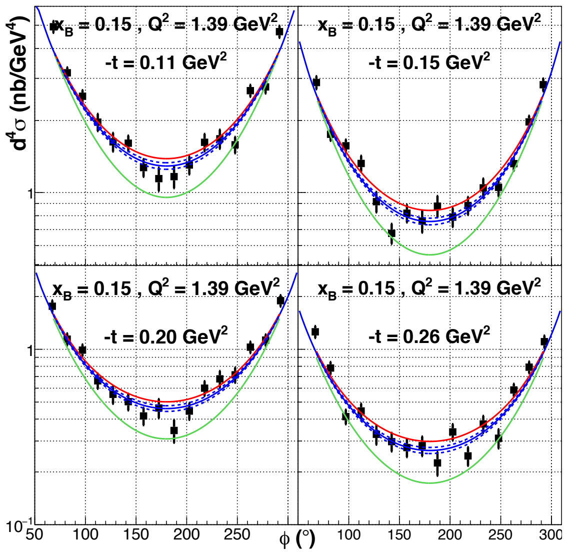
Relate B to the number density of quarks of quarks with longitudinal momentum fraction x at a given transverse distance $b_\perp$

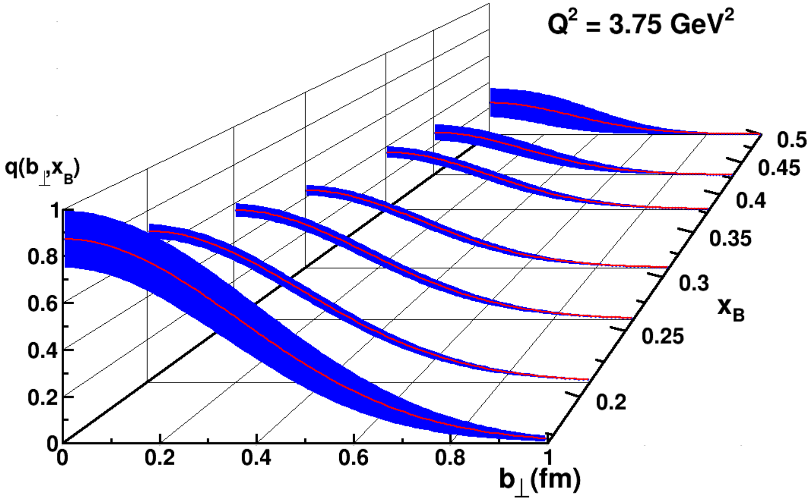


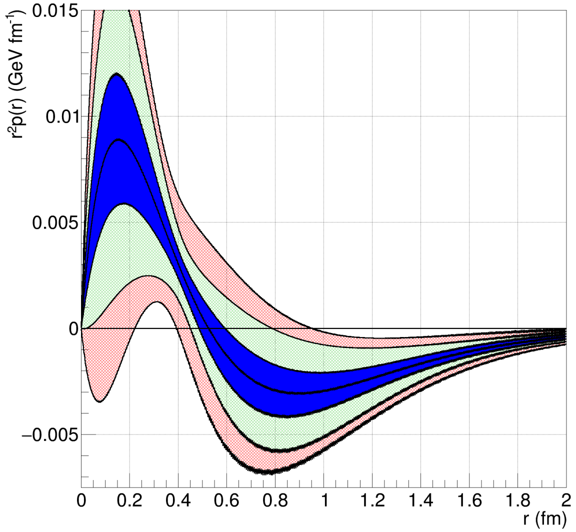


Outlook for CLAS 12:

See F-X Girod talk in March 2017 Collaboration meeting







Next step – publish DVCS2 data

Run experiments at 12 GeV during first run period