Studies of nucleon GPD properties at JLab

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PacificSpin2015 – October 6th, 2015.

The interactions of the nucleon

The nucleon is sensitive to all the interactions known so far

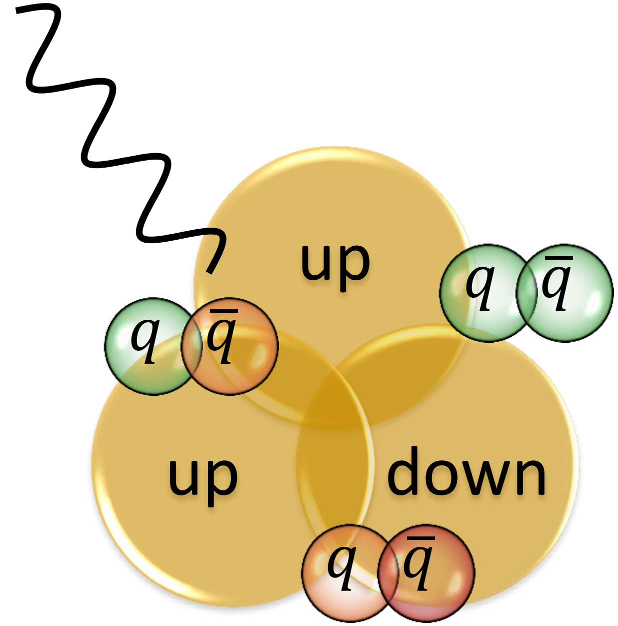
How the nucleon experiences a specific interactions is encoded in a ***charge*** → it depends on the nature of the operator describing the interaction

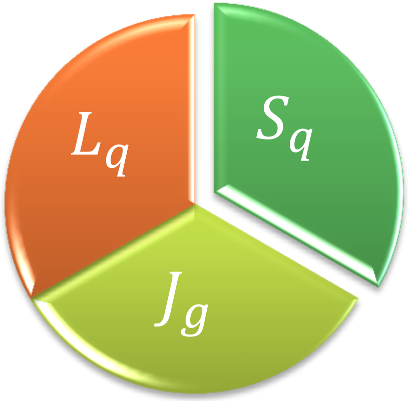
What is the spatial size of the nucleon?

And how its charges are distributed in its bulk?

What is the orbital angular momentum of the nucleon constituents?

And how its description relates to the full-QCD description encoded in lattice-based calculations?





GPDs & Deeply-Virtual Compton Scattering

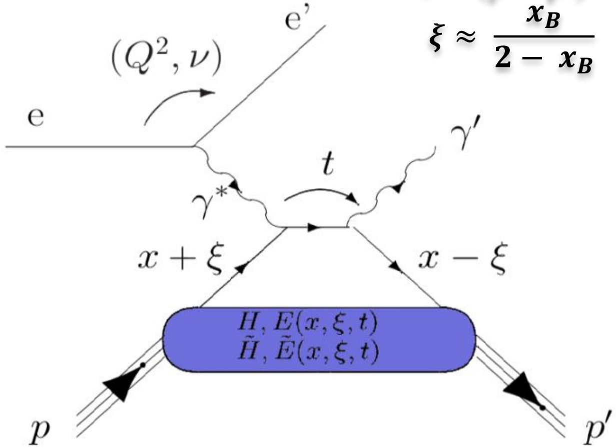
Generalized Parton Distributions → transverse spatial images of quarks and gluons as a function of their longitudinal momentum fraction.

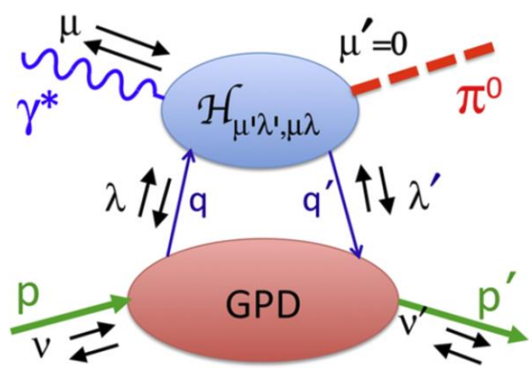
There are 4 *chiral-even* + 4 *chiral-odd* GPDs for any quark flavor

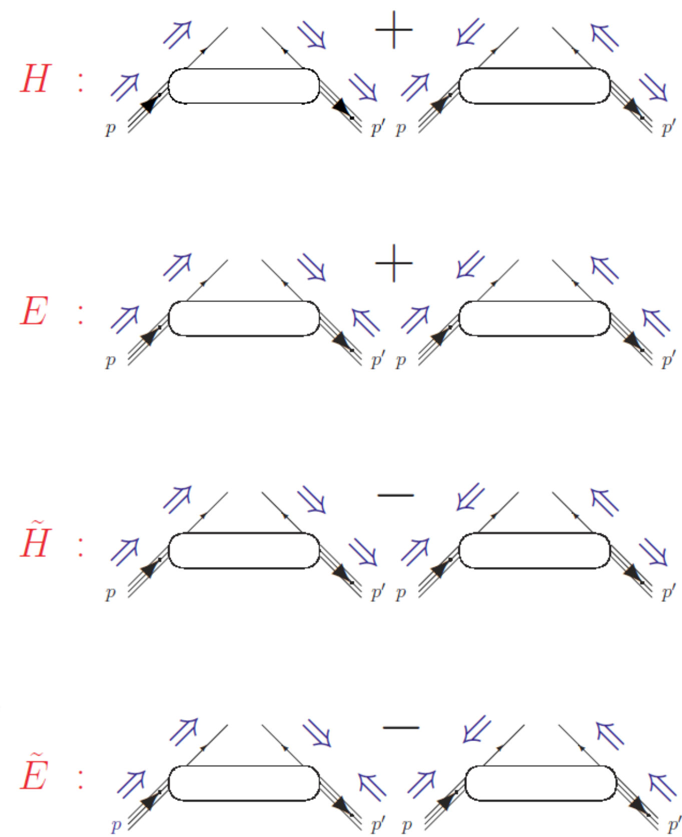
$$x$$

$$t = (p - p')^2$$

$$\xi \approx \frac{x_B}{2 - x_B}$$







$$H^q(x, 0, 0) = f_1(x)$$
$$\tilde{H}^q(x, 0, 0) = g_1(x)$$
$$H_T{}^q(x, 0, 0) = h_1(x)$$
(for x > 0; antiquark for x<0)

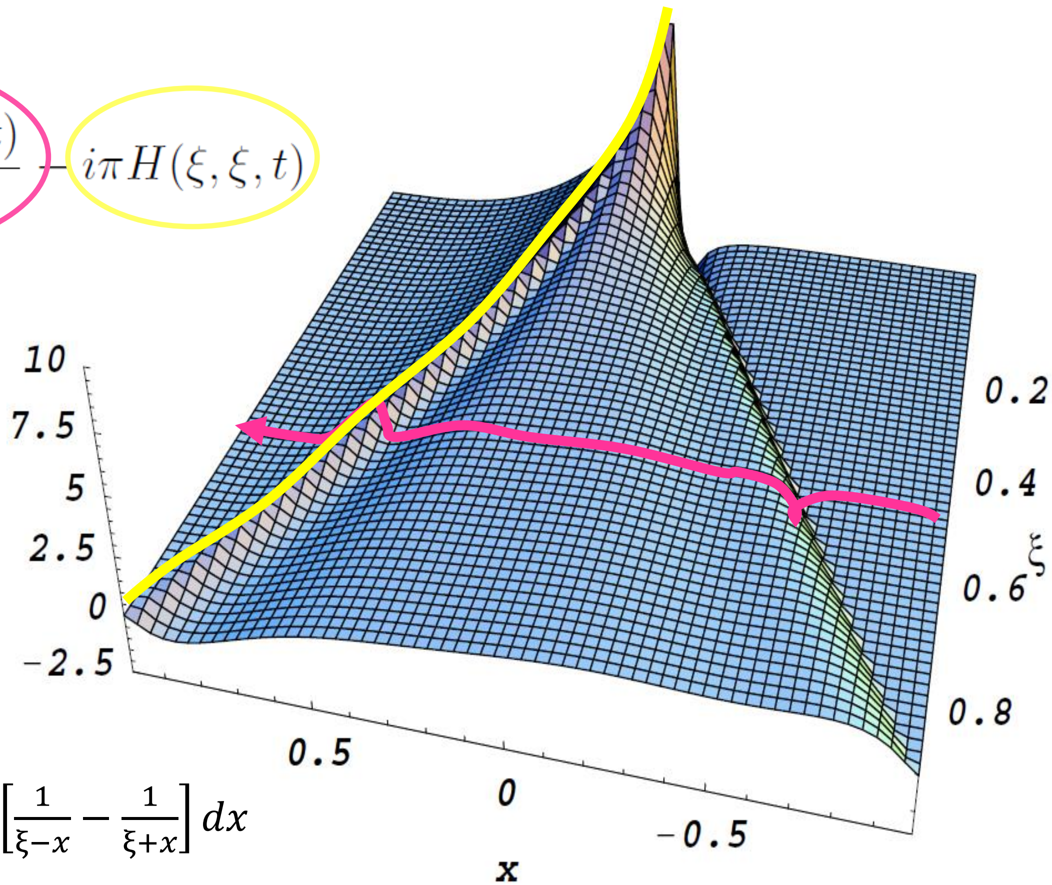
$$\int_{-1}^{+1} dx H^q(x, \xi, t) = F_1^q(t) , \quad \int_{-1}^{+1} dx E^q(x, \xi, t) = F_2^q(t)$$

$$\int_{-1}^{+1} dx \tilde{H}^q(x, \xi, t) = G_A^q(t) , \quad \int_{-1}^{+1} dx \tilde{E}^q(x, \xi, t) = G_P^q(t)$$

Sensitivity to GPDs in observables - Compton Form Factors

Only (ξ, t) are experimentally accessible, not x. GPDs will enter in the observables through

$$\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\epsilon} = \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi} - i\pi H(\xi,\xi,t)$$



The two parts will be accessible through observables sensitive to the *imaginary* (A_{LU}, A_{UL}) or the *real part* $(A_{LL}, A_{BeamCharge})$ of the amplitude.

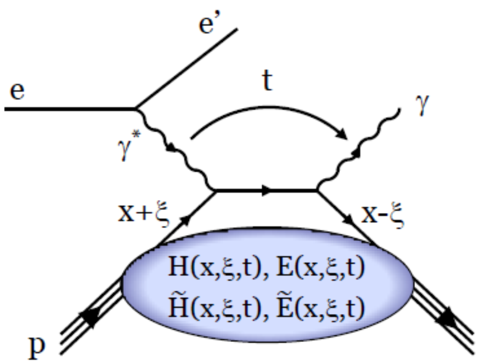
The following **Compton Form Factors** are introduced (experimentally observable):

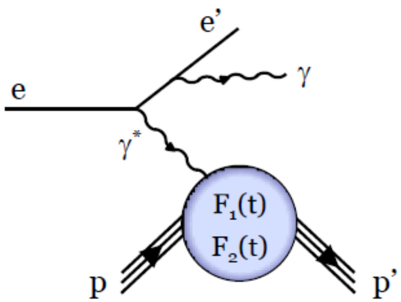
$$Re\mathcal{H}_q = e^2{}_q P\int_0^1 (H^q(x,\xi,t) - H^q(-x,\xi,t))\left[\frac{1}{\xi-x} - \frac{1}{\xi+x}\right] dx$$

$$Im\mathcal{H}_q = \pi e^2{}_q (H^q(\xi,\xi,t) - H^q(-\xi,\xi,t))$$

Accessing GPDs through DVCS observables

Different observables are sensitive to different combinations of Compton Form Factors and electromagnetic Form Factors:





1. **Beam-Spin Asymmetry**:
   $\Delta\sigma_{LU} \propto \sin\varphi\, Im\{F_1\mathcal{H} + \xi(F_1 + F_2)\widetilde{\mathcal{H}} + kF_2\mathcal{E}\}d\varphi$

2. **Target-Spin Asymmetry**:
   $\Delta\sigma_{UL} \propto \sin\varphi\, Im\{F_1\widetilde{\mathcal{H}} + \xi(F_1 + F_2)\mathcal{H} + kF_2\mathcal{E}\}d\varphi$

3. **Double-Spin Asymmetry**:
   $\Delta\sigma_{LL} \propto (A + B\cos\varphi)\, Re\left\{F_1\widetilde{\mathcal{H}} + \xi(F_1 + F_2)\left(\mathcal{H} + \frac{x_B}{2}\mathcal{E}\right)\right\}d\varphi$

4. **Transverse Target-Spin Asymmetry**:
   $\Delta\sigma_{UT} \propto \sin\varphi\, Im\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ \ldots\}d\varphi$

$$\sigma = |BH|^2 + I(BH \cdot DVCS) + |DVCS|^2$$

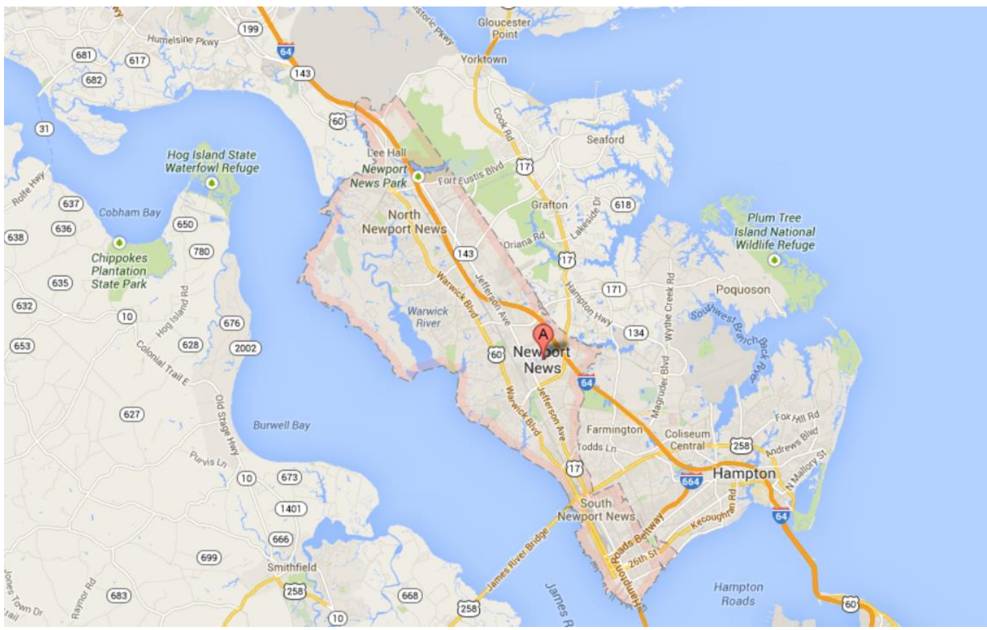
Access to LINEAR combinations of GPDs (instead of bilinear) thanks to the presence of Bethe-Heitler

Asymmetries identified as modulations in φ, the *angle between the leptonic and the hadronic plane*

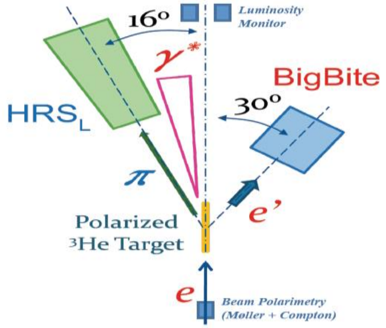
Thomas Jefferson National Accelerator Facility

The ***CEBAF (Continuous Electron Beams Accelerator Facility)*** operates in the Thomas Jefferson National Accelerator Facility (Newport News, VA, USA). The Cebaf:

- provides a continuous electron beam with a duty factor ~ 100%;
- with a beam energy up to 6 GeV;
- has a good energy resolution ($\frac{\sigma_E}{E} \sim 10^{-5}$);
- and the beam has a polarization ~ 85%

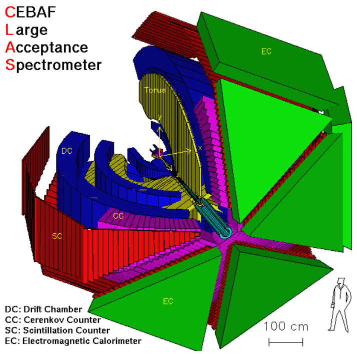


The three experimental Halls@JLab



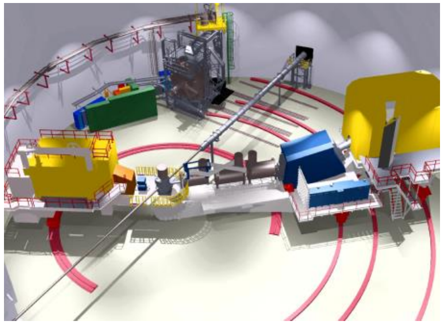
Hall-A: **High-resolution spectrometers ($^{\delta p}/_{p} \sim 10^{-4}$), measurements with well-defined kinematics at very-high luminosity**

NIM A 522, 294 (2004)



Hall-B: **high luminosity, Large acceptance, Multi-particle final state measurements**

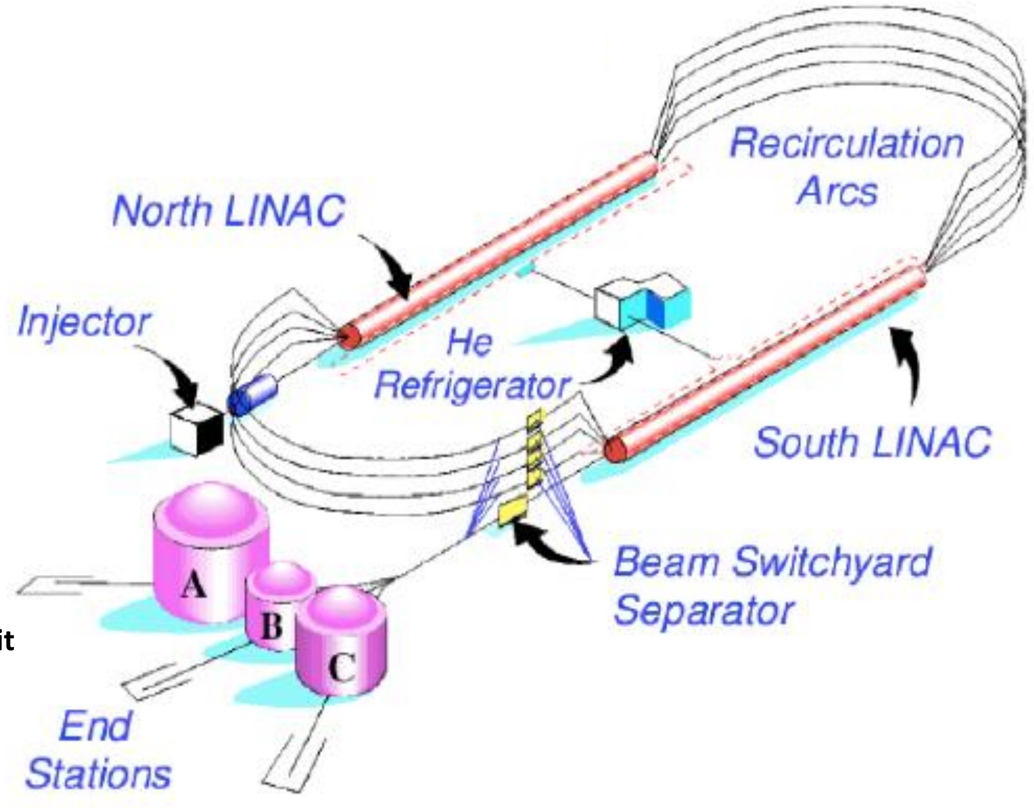
NIM A 503, 513 (2003)



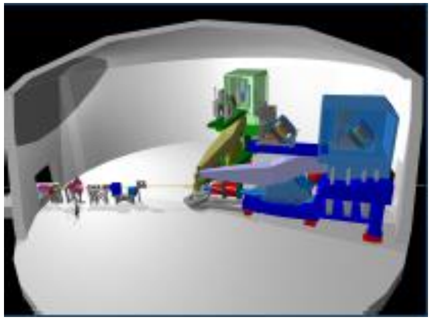
Hall C: **High momentum spectromer and Short Orbit Spectrometer—well-controlled acceptance for precise cross section measurements**

PRC 78, 045202 (2008)

The CEBAF provides longitudinally-polarized electrons to 3 experimental Halls, characterized by different and complementary characteristics.

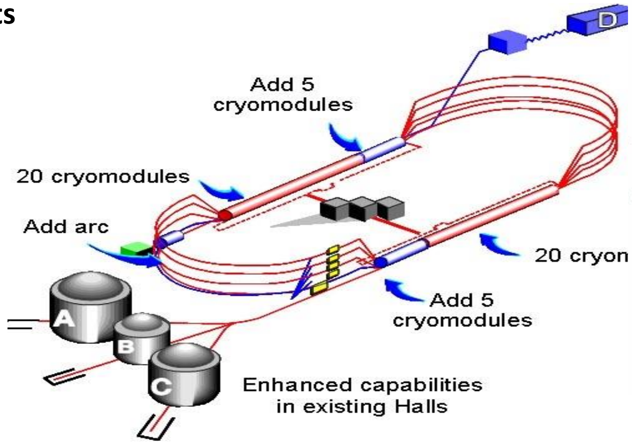


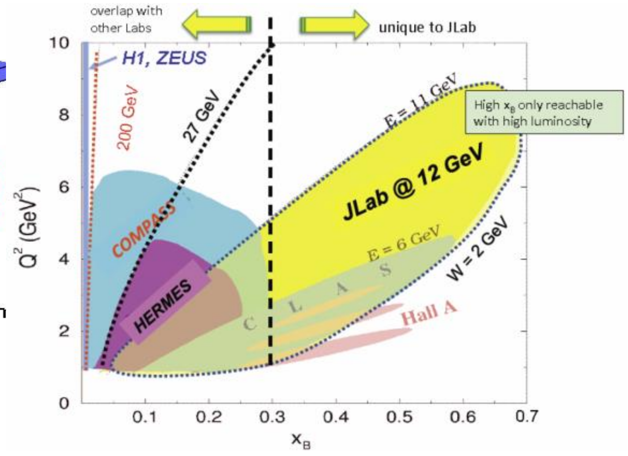
The 12-GeV upgrade

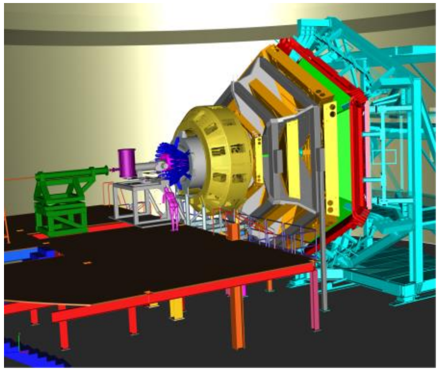


High Resolution Spectrometer (HRS) pair and specialized large installation experiments

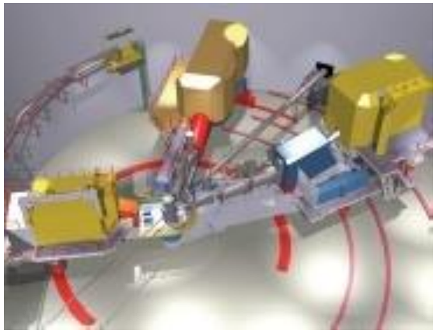
4 experimental halls with a longitudinally-polarized electron beam of E_e– up to 12 GeV.



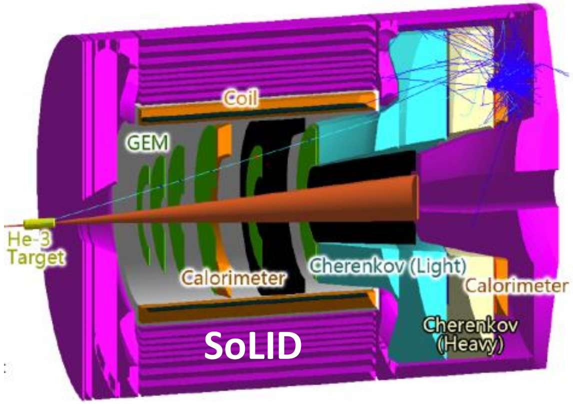


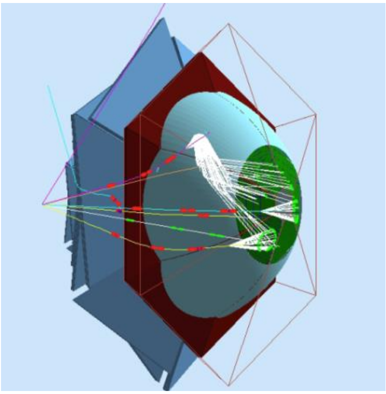


CLAS12: large acceptance, high luminosity



Super High Momentum Spectrometer (SHMS) at high luminosity and forward angles





RICH for CLAS12

Experiments and phase-space coverage

Different experiments (will) explore (-ed) different regions of the phase space

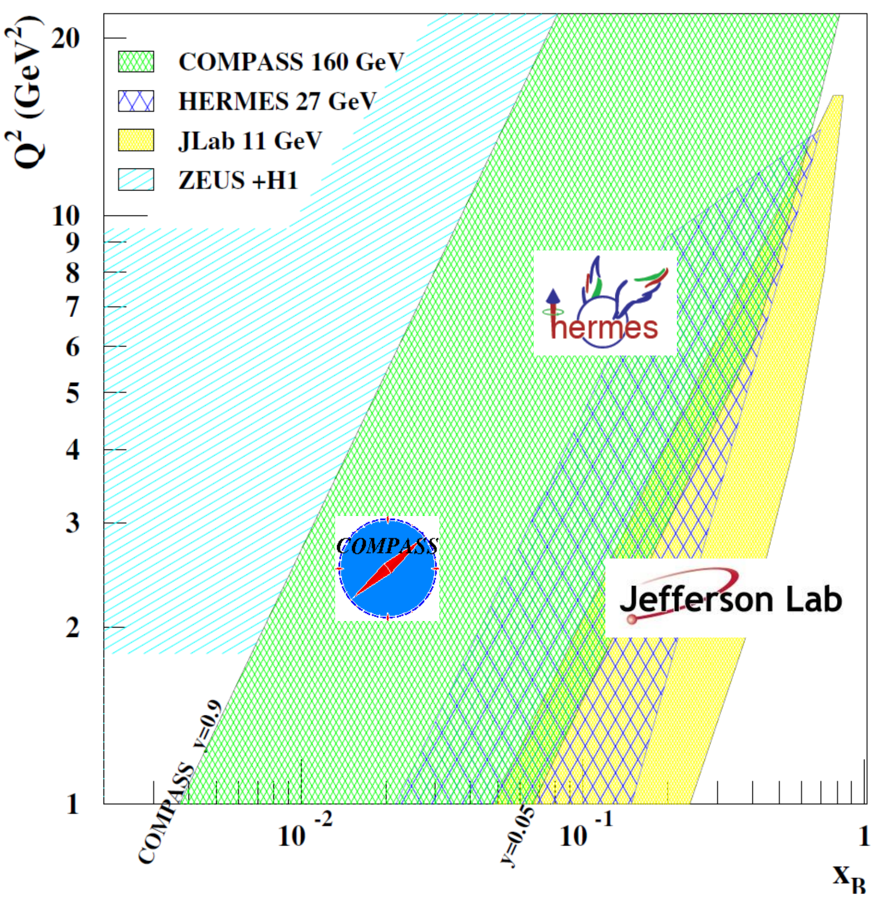
…ranging from the gluon-dominated domain of HERA to the quark valence region of JLab

Fixed-target experiments in the past:

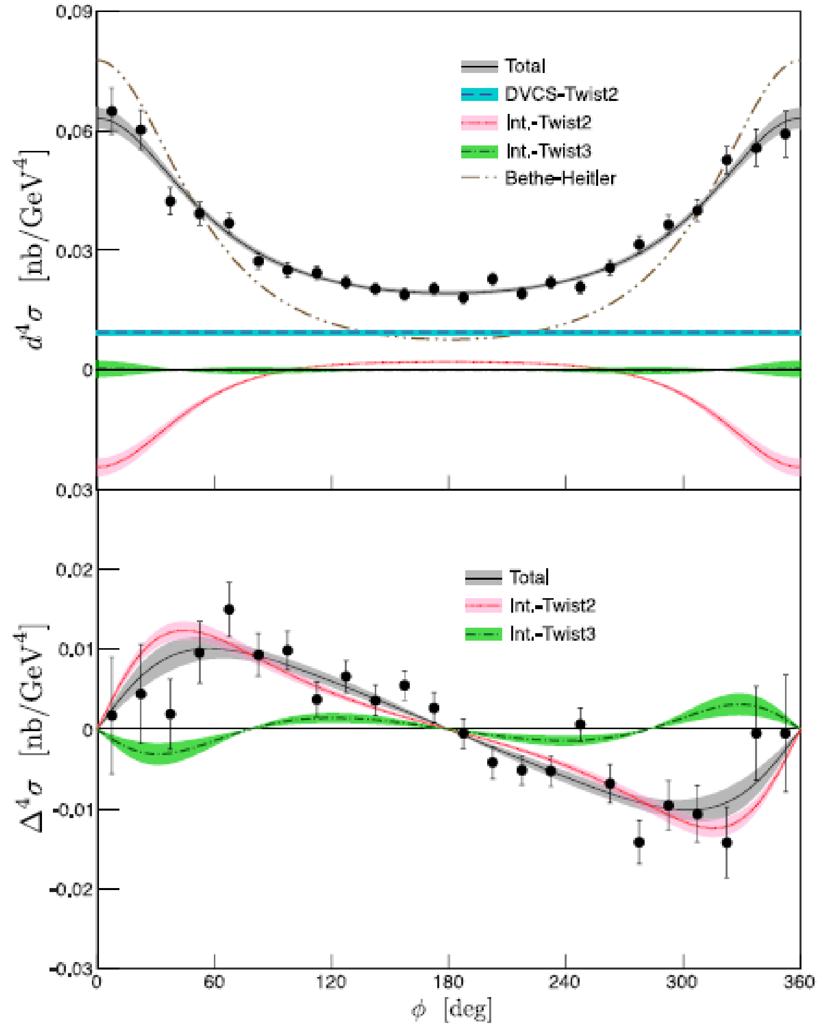
- HERMES@Desy: $e^{\pm}$ beam ($E_e = 27GeV$)
- Hall-A, CLAS@JLab: e^{-} beam ($E_e = 6GeV$)

Future experiments:

- Hall-A, CLAS12@JLab12: e^{-} beam ($E_e = 12GeV$)
- COMPASSII@CERN: $\mu^{\pm}$ beam ($E_e = 160GeV$)

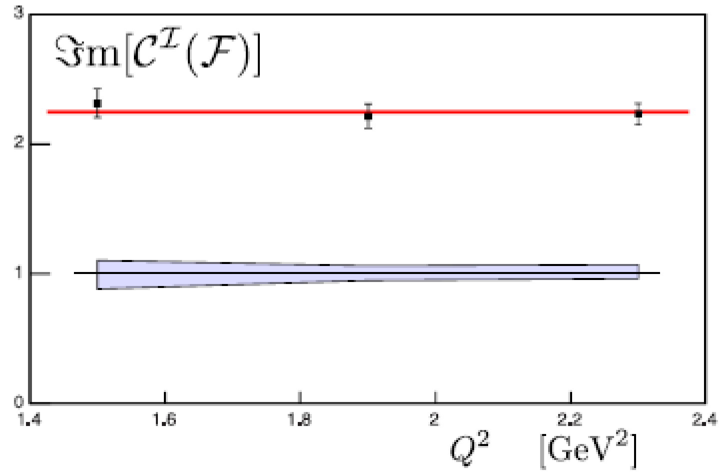


DVCS on the proton in Hall-A (E00-110)



$x_B = 0.37, Q^2 = 2.36\ GeV^2, -t = 0.32\ GeV^2$

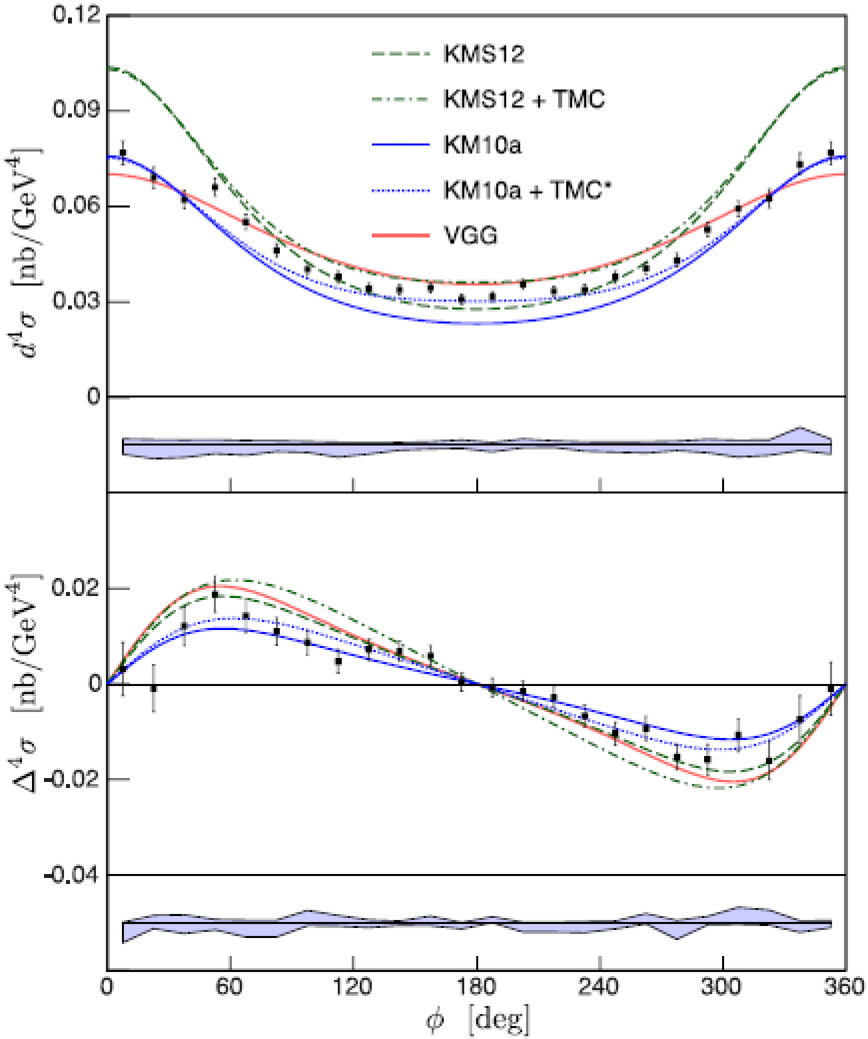
- Significan contribution from $|\mathcal{T}^{DVCS}|^2$ (φ-independent) and $\mathcal{T}^{int}$
- Clear deviation from BH-only behaviour around $\varphi = 180°$
- Helicity-dependent cross-section twist-2 dominated



- no Q^2 dependence visible in the CFFs (evolution effects negligible for the present Q^2 lever arm)

***M. Defurne et. al., hep-ex*:1504.05453**

DVCS on the proton in Hall-A (E00-110)



- Both Double-Distribution based models (VGG&KMS12) overestimate the helicity-dependence cross-section
- KMS12 tuned on vector-meson data at low-to-very-low x_B
- KM10a shows good agreement → model parameters already constrained from CLAS (Hall-B) asymmetry data on the same kinematical region.
- KM10a underestimates DVCS contribution around $\varphi = 180°$
- Lack of strength around $\varphi = 180°$ partly compensates by Target-Mass Corrections (TMS)
- Need a refit of KMS12 including valence data

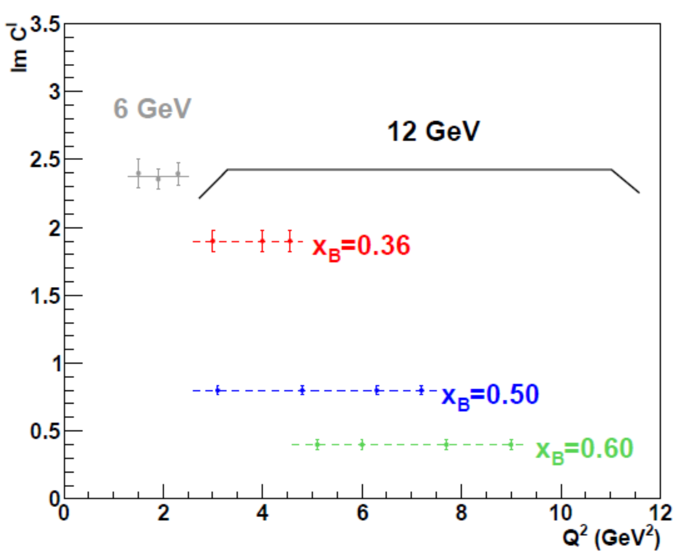
***M. Defurne et. al., hep-ex*:1504.05453**

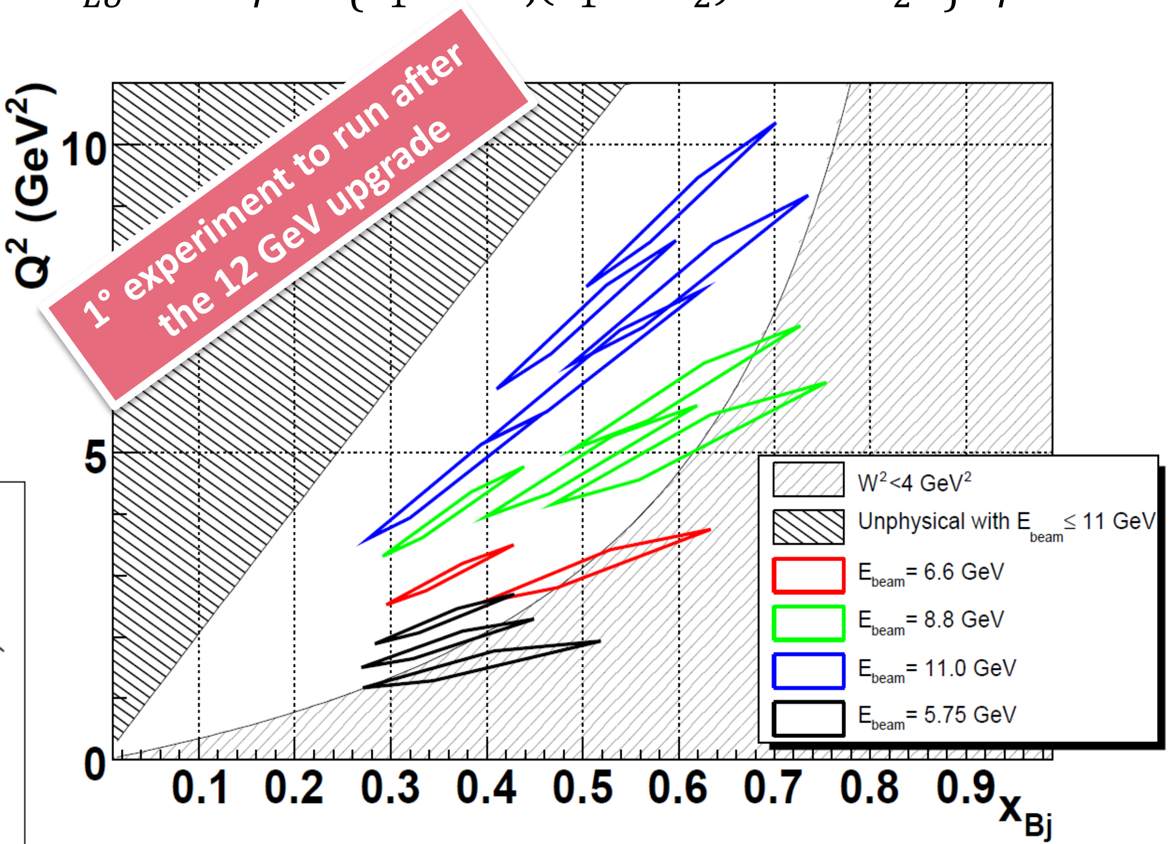
Hall-A@11 GeV: E12-06-114

$$\Delta\sigma_{LU} \propto \sin\varphi\, Im\{F_1\mathcal{H} + \xi(F_1 + F_2)\widetilde{\mathcal{H}} + kF_2\mathcal{E}\}d\varphi$$

Beam-polarized and unpolarized cross sections with high precision at three electron-beam energies to get:

- increased kinematic coverage
- Test of scaling → Q^2 dependence of $d\sigma$ at fixed x_B





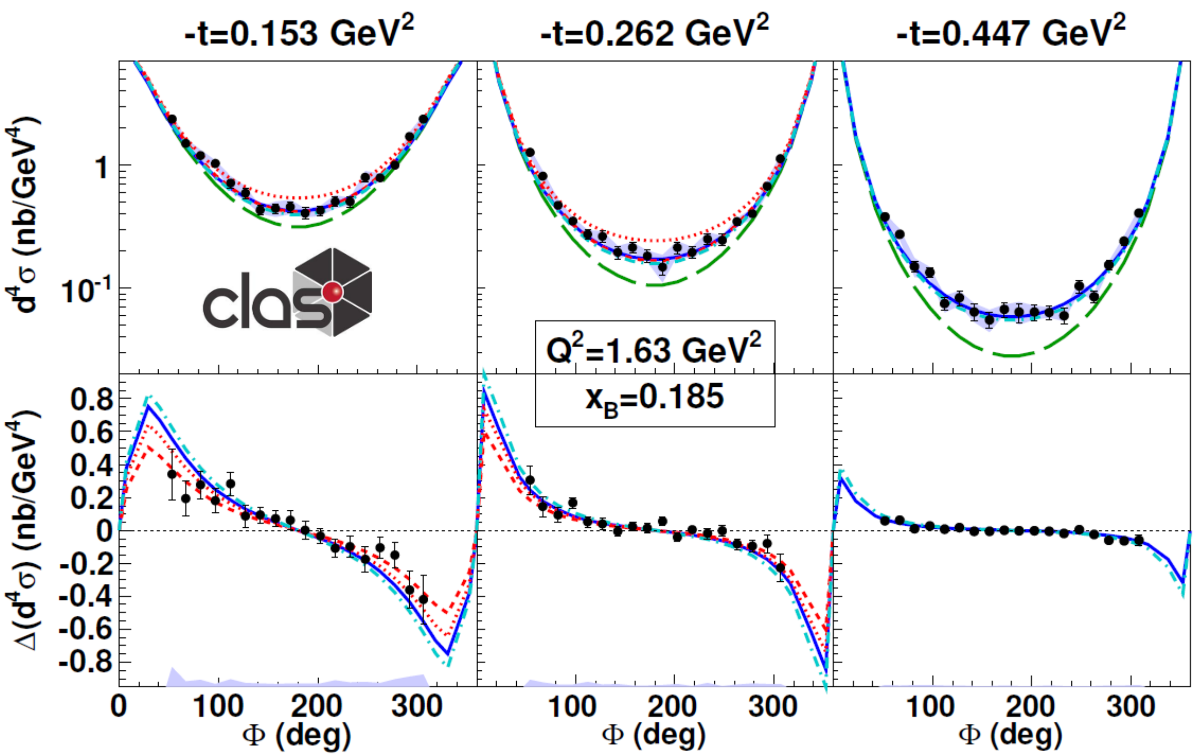
Large Q^2 region explored with high statistics

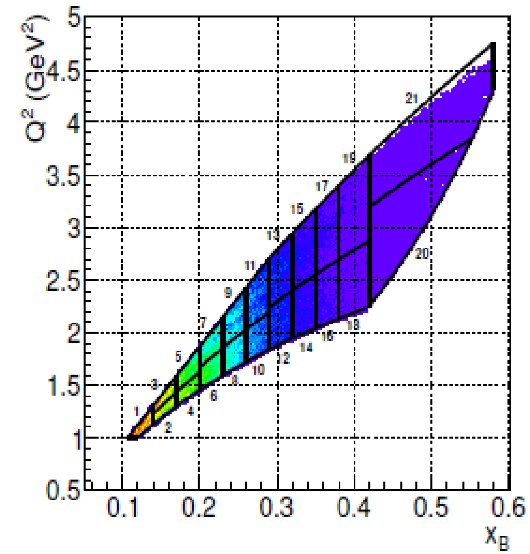
Hall-B: DVCS cross-section on the proton in Hall-B (E01-113)

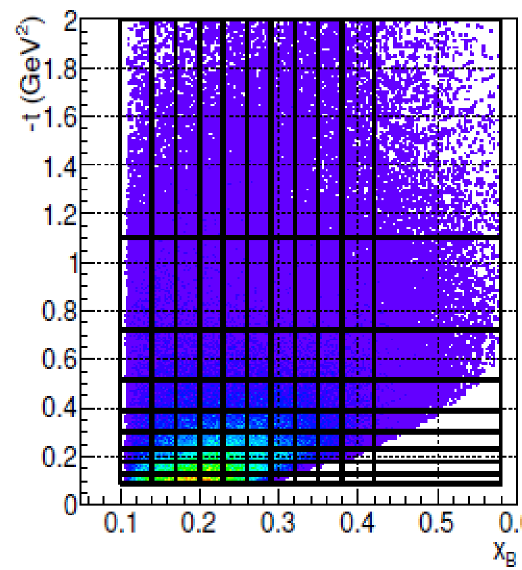
Extraction in a LARGE kinematic domain

$$\frac{d^4\sigma_{ep\to e'p'\gamma}}{dQ^2 dx_B dt d\varphi}$$

- BH only
- VGG (H only)
- KM10 (Kumericki, Mueller)
- KM10a
- KMS

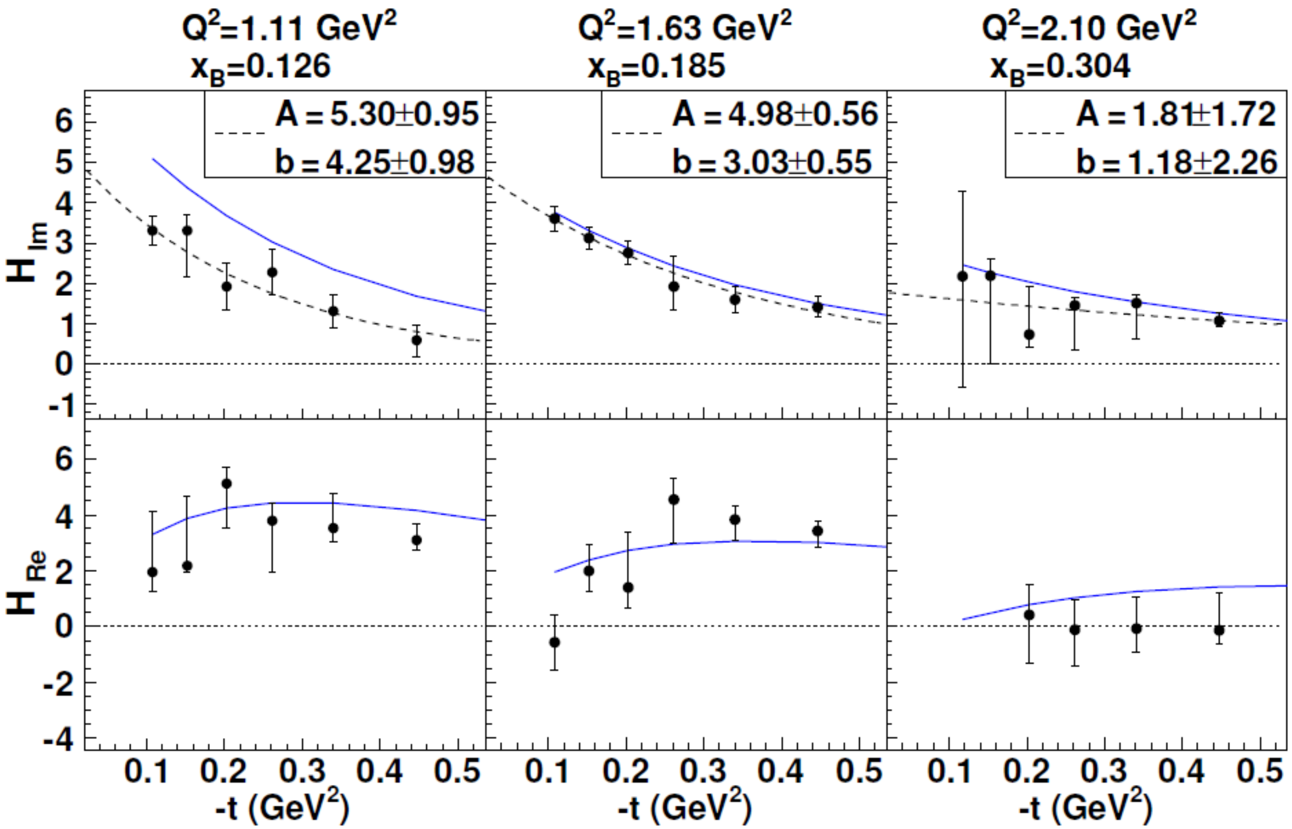






***H. S. Jo et. al., hep-ex*:1504.02009, accepted by PRL**

Hall-B: DVCS cross-section on the proton in Hall-B (E01-113)



- VGG model
- Ae^{bt}

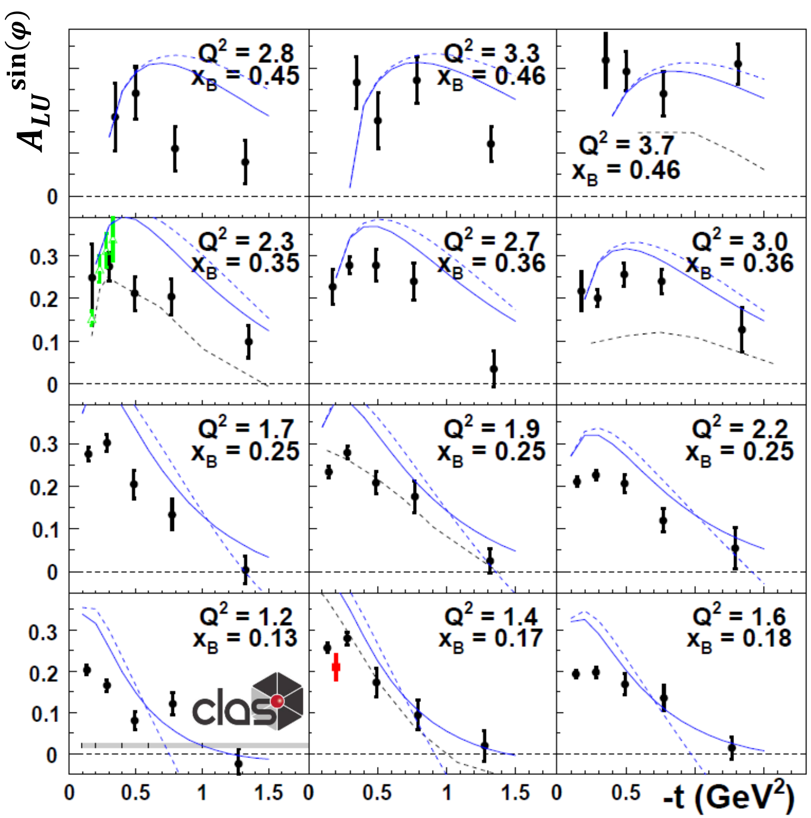
A, b increases with x_B

→ the partonic content of the nucleon increases when probing smaller x_B

***H. S. Jo et. al., hep-ex*:1504.02009, accepted by PRL**

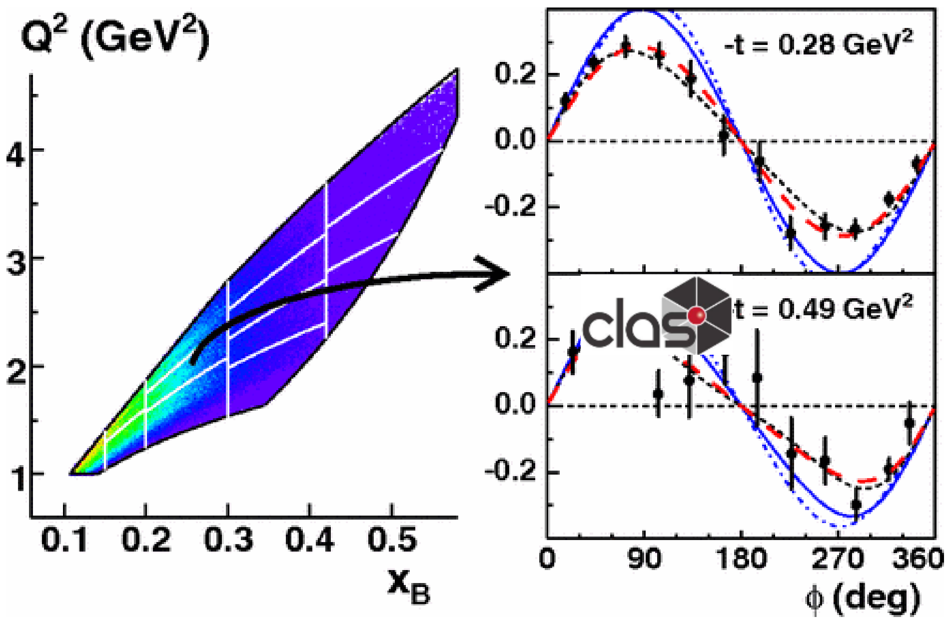
Mapping GPDs: Beam-spin asymmetries - $\mathcal{H}_{Im}$

First CLAS DVCS devoted experiment on unpolarized H_2



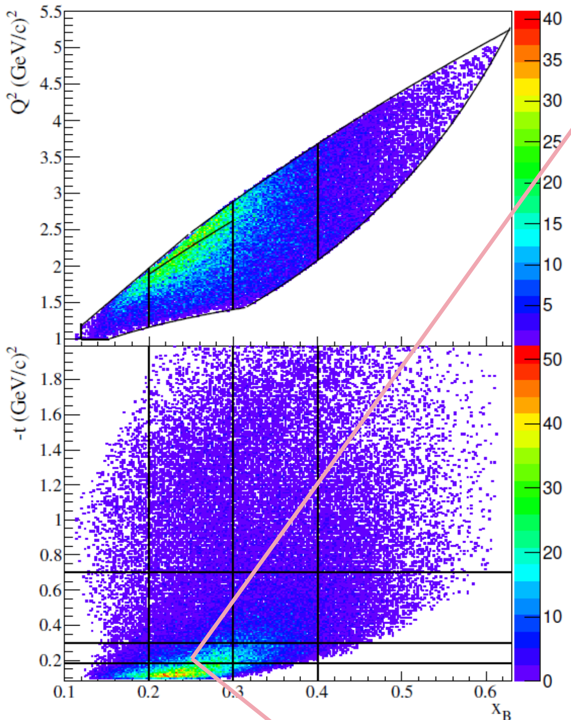
CLAS e1-dvcs
Hall A
CLAS @ 4.3 GeV^2
VGG(*) twist-2
VGG(*) twist-2 and 3
Regge model (Laget)

- - - $f = \frac{a \sin\phi}{1 + b\cos\phi}$
—— VGG twist-2
- - - VGG twist-3



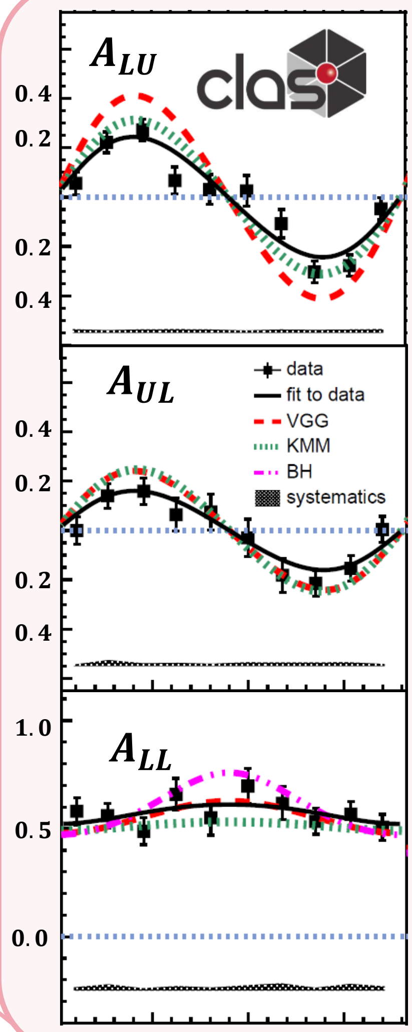
F. X. Girod et al., Phys. Rev. Lett. 100, 162002 (2008).

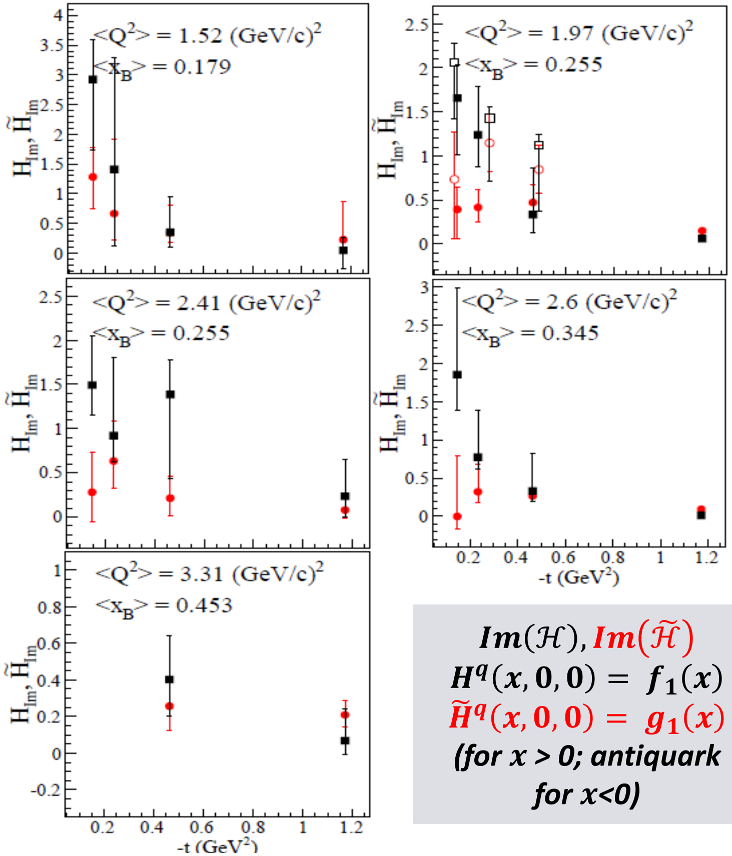
Comparing charge distributions: $A_{LU} \propto \mathcal{H}_{Im}$, $A_{UL} \propto \widetilde{\mathcal{H}}_{Im}$



High statistics extraction of Single and Double-Spin Asymmetries

→ *simultaneous CFF extraction from three observables in a common kinematics*



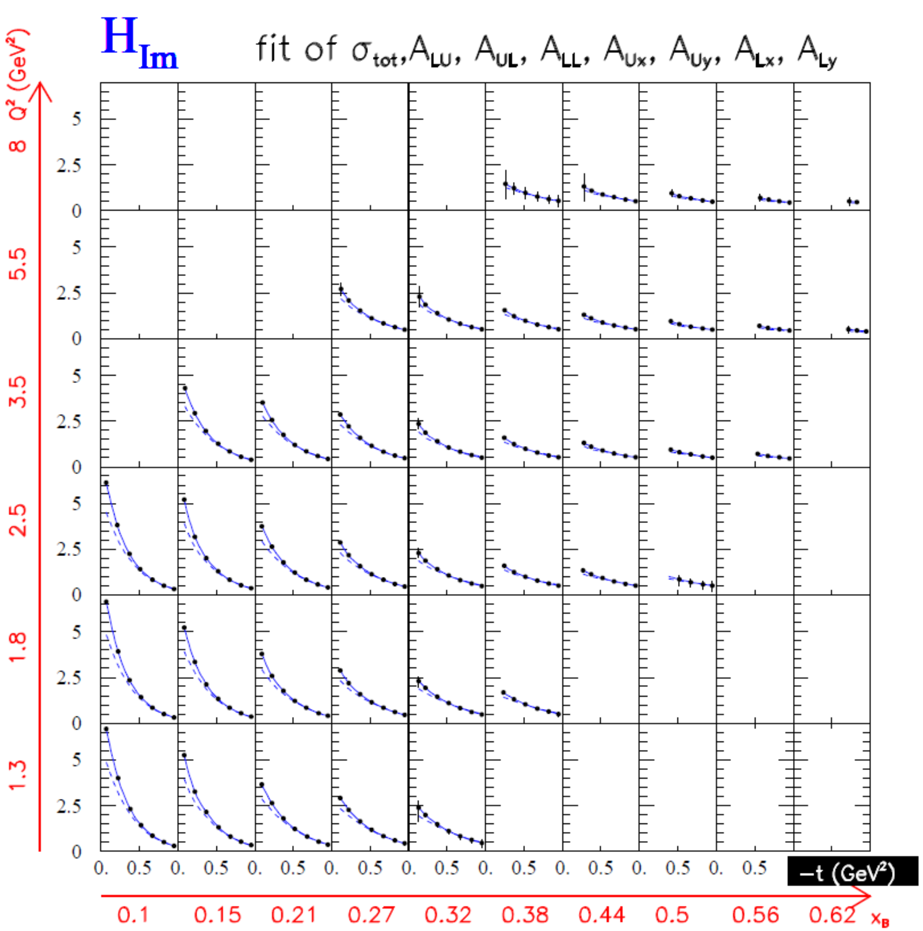


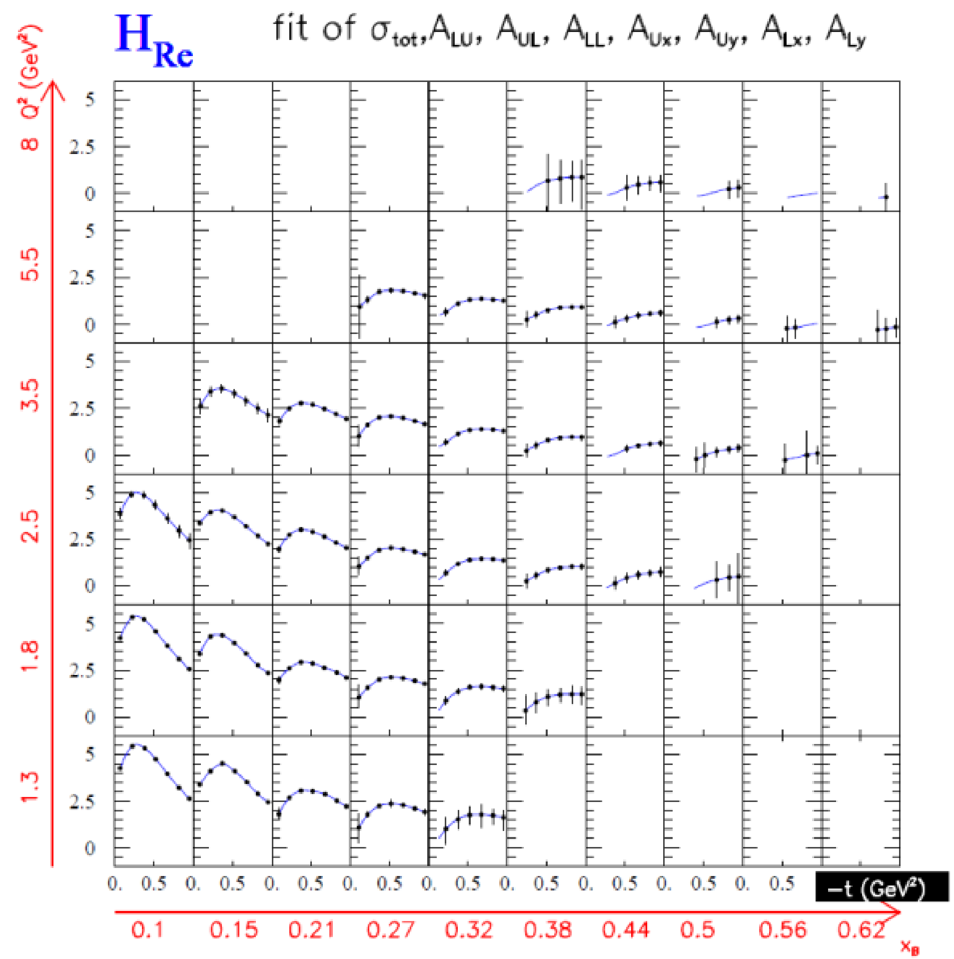
$Im(\mathcal{H}), Im(\widetilde{\mathcal{H}})$
$H^q(x,0,0) = f_1(x)$
$\widetilde{H}^q(x,0,0) = g_1(x)$
(for x > 0; antiquark for x<0)

→ axial charge is more concentrated in the nucleon centre than the electric charge

E. Seder et al, Phys. Rev. Lett. 114, 032001 (2015)
S.P. et al, Phys. Rev. D 91, 052014 (2015)

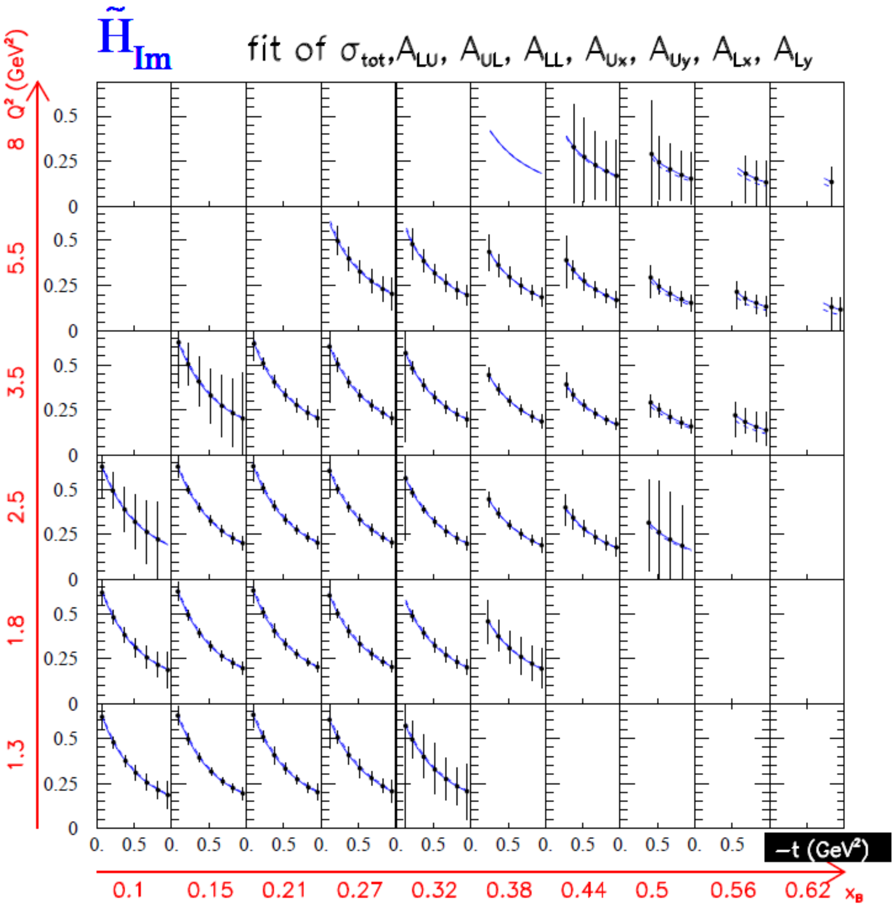
JLab 12 GeV data: impact on $\mathcal{H}$

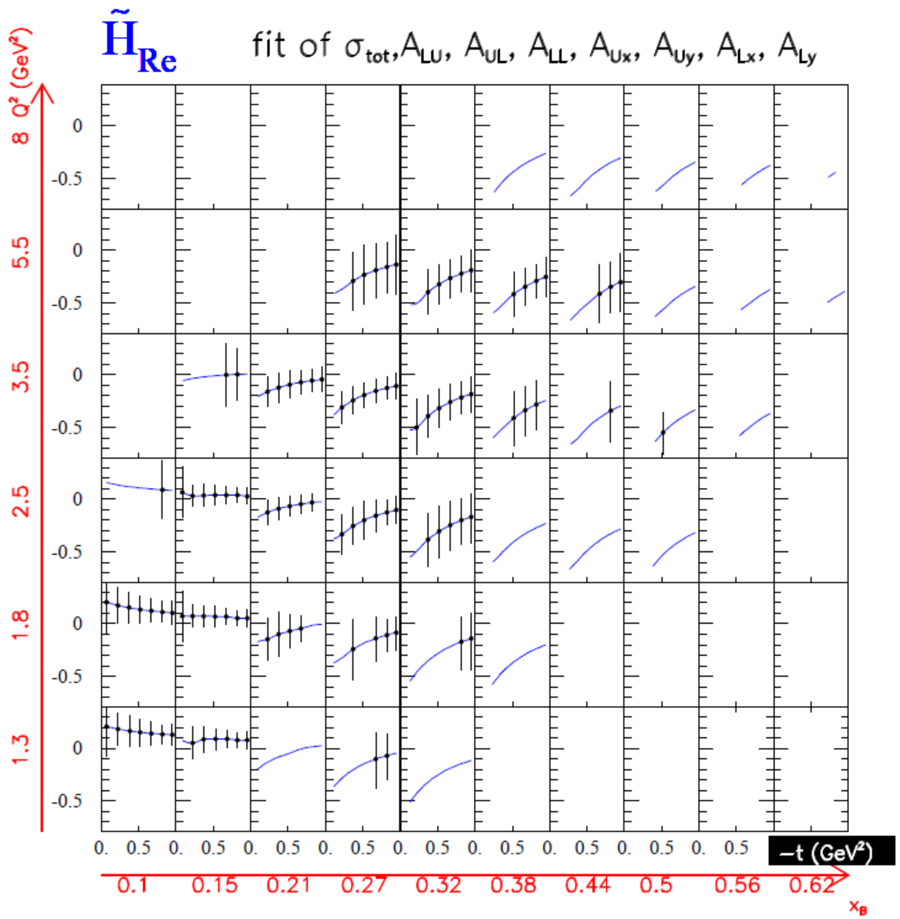




M. Guidal, H. Moutarde, M. Vanderhaeghen: hep-ph > arXiv:1303.6600

JLab 12 GeV data: impact on $\widetilde{\mathcal{H}}$





M. Guidal, H. Moutarde, M. Vanderhaeghen: hep-ph > arXiv:1303.6600

Quark orbital angular momentum

$$J_q = \frac{1}{2}\int_{-1}^{+1} dx\, x\, [H^q(x,\xi,t=0) + E^q(x,\xi,t=0)]$$

$$J_q = L_q + S_q$$

S_q → accessible through Inclusive Deep-Inelastic Scattering

Quark Orbital Angular Momentum can be extracted

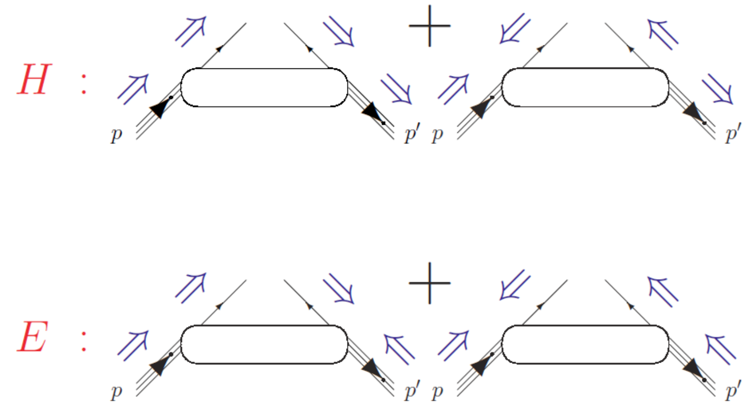
To access $E_u \& E_d$ both $E_p \& E_n$ are needed so to perform a *flavor separation*

$$(H,E)_u(\xi,\xi,t) = {}^{9}/_{15}\,[4(H,E)_p(\xi,\xi,t) - (H,E)_n(\xi,\xi,t)]$$

$$(H,E)_d(\xi,\xi,t) = {}^{9}/_{15}\,[4(H,E)_n(\xi,\xi,t) - (H,E)_p(\xi,\xi,t)]$$

Neutron GPD E_n: A_{LU} on the neutron

Proton GPD E_p: $\cos\varphi$ modulation in σ_{UT} on proton



Hall-B@12 GeV: Quark orbital angular momentum & GPD E

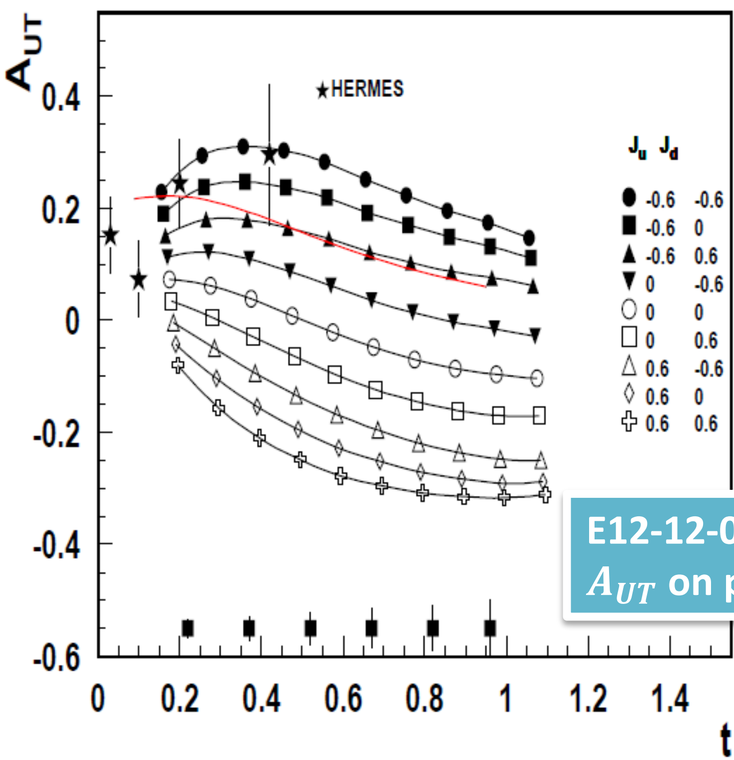
$$J_q = \frac{1}{2}\int_{-1}^{+1} dx\, x\, [H^q(x,\xi,t=0) + E^q(x,\xi,t=0)]$$

$$(H,E)_u(\xi,\xi,t) = {}^{9}/_{15}\left[4(H,E)_p(\xi,\xi,t) - (H,E)_n(\xi,\xi,t)\right]$$

To access $E_u \& E_d$ both $E_p \& E_n$ are needed.

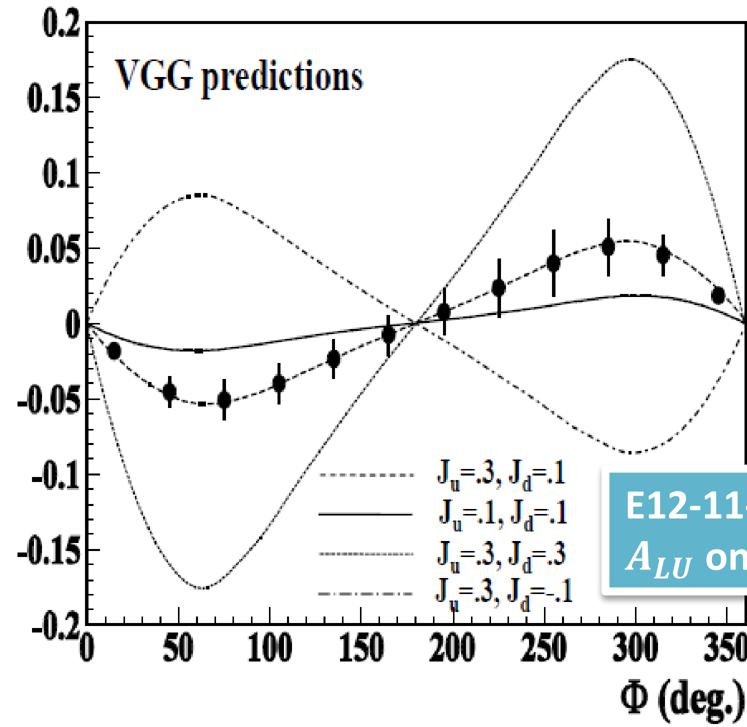
$$(H,E)_d(\xi,\xi,t) = {}^{9}/_{15}\left[4(H,E)_n(\xi,\xi,t) - (H,E)_p(\xi,\xi,t)\right]$$

Proton GPD E_p: $\cos\varphi$ modulation in σ_{UT} on proton



E12-12-010
A_{UT} on proton

Neutron GPD E_n: A_{LU} on the neutron



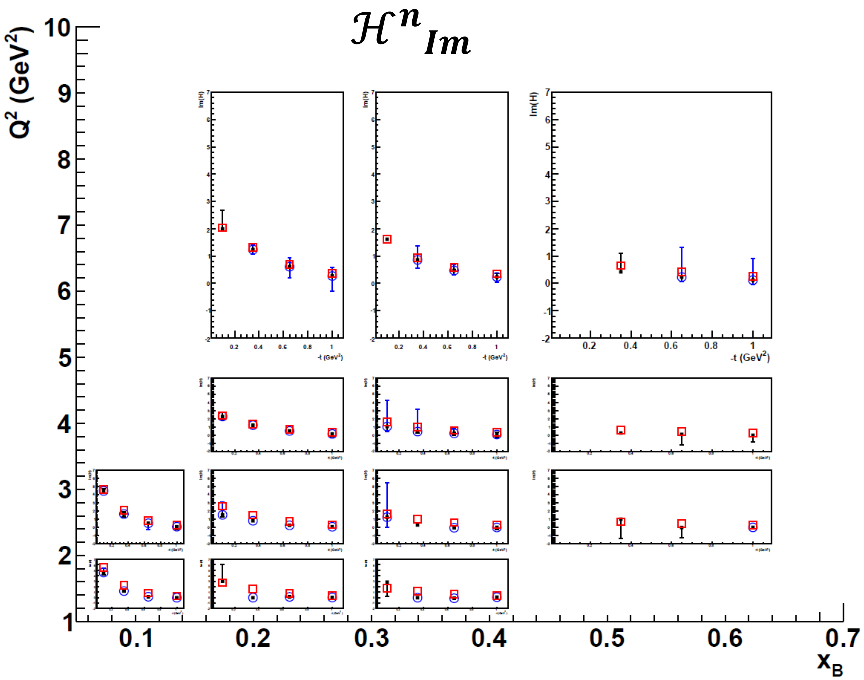
E12-11-003
A_{LU} on neutron

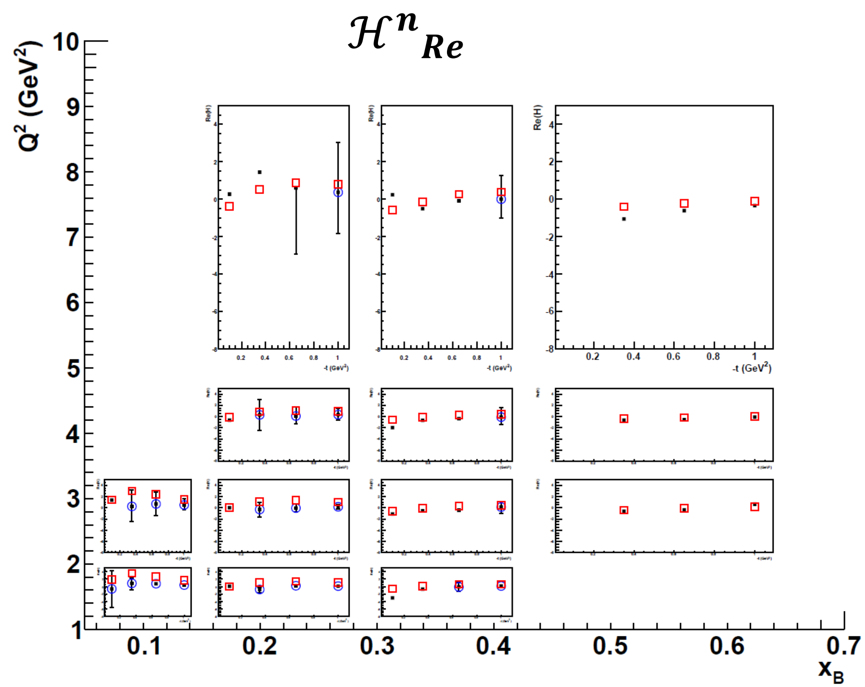
Exploring H_n in the valence region

New Research Proposal to Jefferson Lab PAC 43

→ to be (re-)submitted to **PAC44**

Deeply virtual Compton scattering on the neutron at 11 GeV with CLAS12 and a longitudinally polarized deuterium target





Conclusions

- Our knowledge of the nucleon structure has become richer in the last years thanks to GPD formalism and the experimental results of DVCS

- **combined measurement of several DVCS observables** in a vast kinematic space *to* disentangle the contributions of the various GPDs and their complex kinematic dependences

- Extracting both proton and neutron data is paramount if we want to ultimately perform a flavor decomposition of the GPDs

- Such a flavor separation is critical to access the elementary degrees of freedom of QCD and to connect them to macroscopic hadron properties such as mass or orbital angular momentum

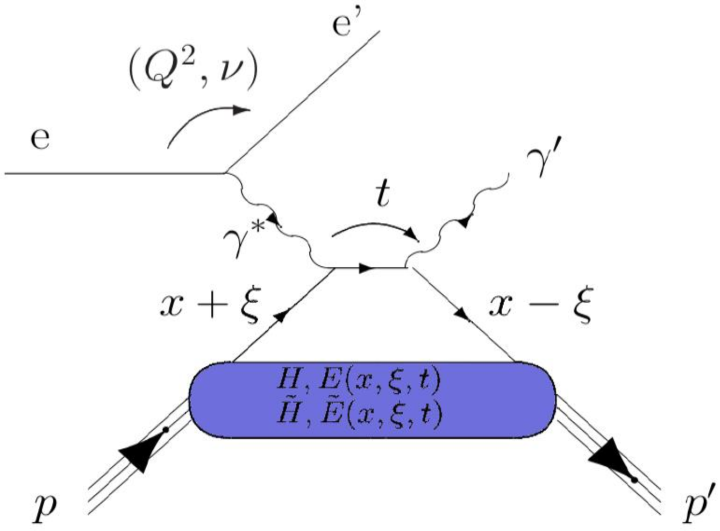
VOLUME 78, NUMBER 4 PHYSICAL REVIEW LETTERS 27 JANUARY 1997

It is important to comment on practical aspects of the experiment. First of all, from the cross section, one finds that E and H can be measured either in unpolarized scattering, or in electron single-spin asymmetry through interference with the Bethe-Heitler amplitude [12], or in polarized electron scattering on a transversely polarized target. A detailed examination of various possibilities, together with some numerical estimates will be published elsewhere [13]. Second, the DVCS cross section is down by an order of α_{em} compared with the deep-inelastic cross section, but has the same scaling behavior. So the cross section is appreciable, but statistics would be a challenging requirement. The ideal accelerator for the experiment is ~~ELFE [14]~~ JLab. Finally, the extrapolation of Δ^2 from order M^2 to 0 r... ersive study of the form factors of the tensor ...

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

backup

Generalized Parton Distributions *through* *DVCS & DVMP*



Hall-A: feasibility test at JLab kinematics & handbag description

PRL97: 262002 (2006), C. Munoz Camacho et al. (Hall A collaboration), **E12-06-114**

Hall-B: Pioneering single-spin asymmetry observations

A_{LU}: S. Stepanyan et al., Phys. Rev. Lett. 87, 182002 (2001)
A_{UL}: S. Chen et al., Phys. Rev. Lett. 97, 072002 (2006)

Hall-B: DVCS & DVMP cross-section measurements in a large kinematic domain

E01-113, H. Jo *et al.*, soon to be published
I. Bedlinskiy *et al.*, PRL109:112001 (2012)

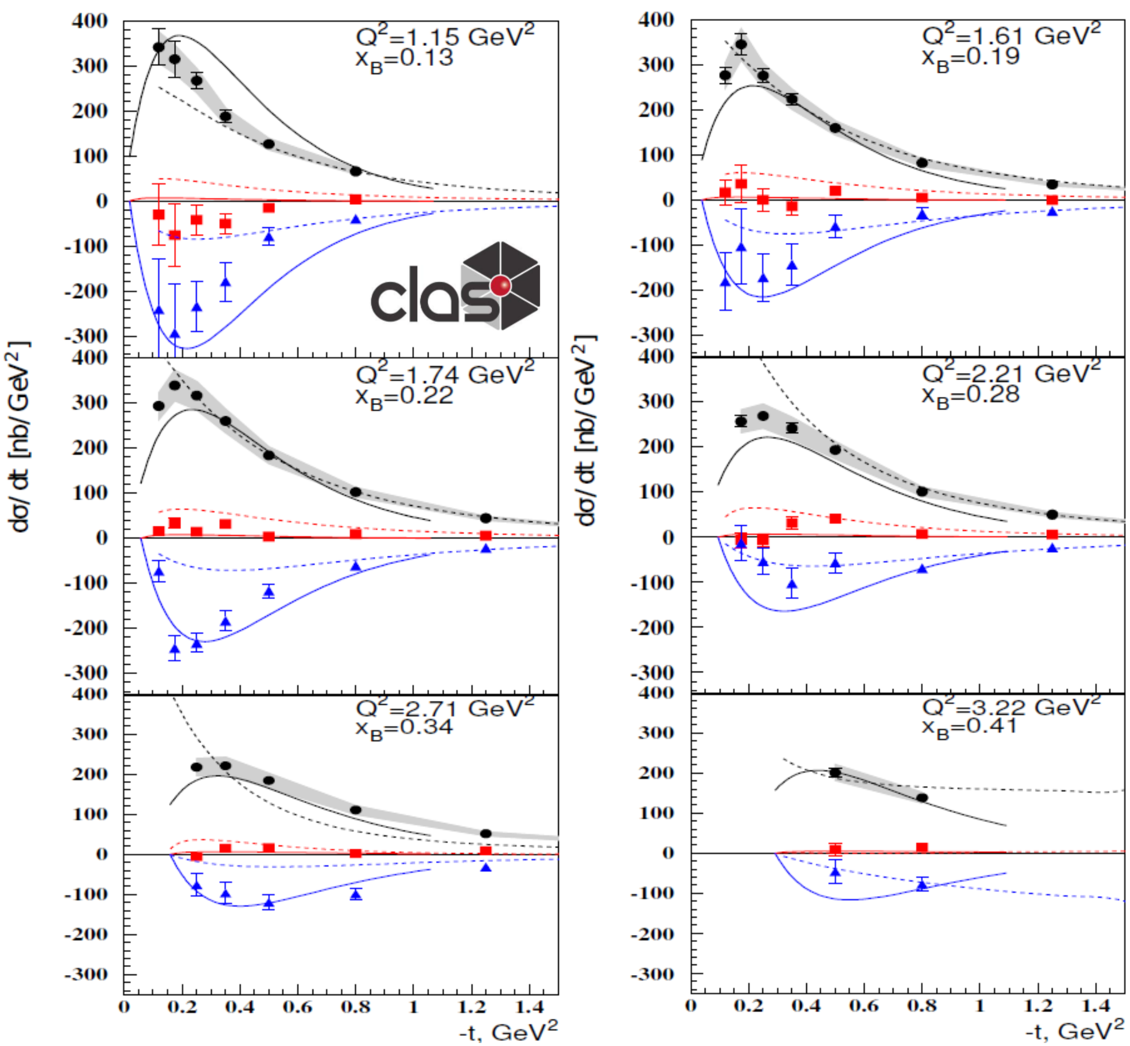
Hall-B: High-statistics extraction of Single- and Double Spin Asymmetries

A_{LU} for π^0 on H_2: R. de Masi *et al.*, PRC77:042201 (2008)
A_{LU} on H_2: PRL100: 162002 (2008) F.X. Girod *et al.*, E12-06-119
DVCS & DVπ^0P A_{LU}, A_{UL}, A_{LL} on NH_3: soon to be published

Hall-B Orbital Angular Momentum through GPDs

E12-12-010, A_{UT} on proton
E12-11-003, A_{LU} on neutron

DVπ^0P cross-section in Hall-B@JLab – tensor charge



π^0 electroproduction → sensitivity to *transversity* GPDs

$h_1(x)$ is related to the nucleon tensor charge → possible test of beyond-SM interactions of the nucleon (effects on beta decay)

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi_\pi} = \Gamma(Q^2, x_B, E)\frac{1}{2\pi}(\sigma_T + \epsilon\sigma_L + \epsilon\cos 2\phi_\pi \sigma_{TT} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_\pi \sigma_{LT}).$$

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

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

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

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

I. Bedlinskiy et al., PRL109:112001 (2012)

Quark orbital angular momentum

VOLUME 78, NUMBER 4 PHYSICAL REVIEW LETTERS 27 JANUARY 1997

Gauge-Invariant Decomposition of Nucleon Spin

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Center for Theoretical Physics, Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139
and Institute for Nuclear Theory, University of Washington, Seattle, Washington 98195
(Received 20 March 1996)

I introduce a gauge-invariant decomposition of the nucleon spin into quark helicity, quark orbital, and gluon contributions. The total quark (and hence the quark orbital) contribution is shown to be measurable through virtual Compton scattering in a special kinematic region where single quark scattering dominates. This deeply virtual Compton scattering has much potential to unravel the quark and gluon structure of the nucleon. [S0031-9007(96)02221-1]

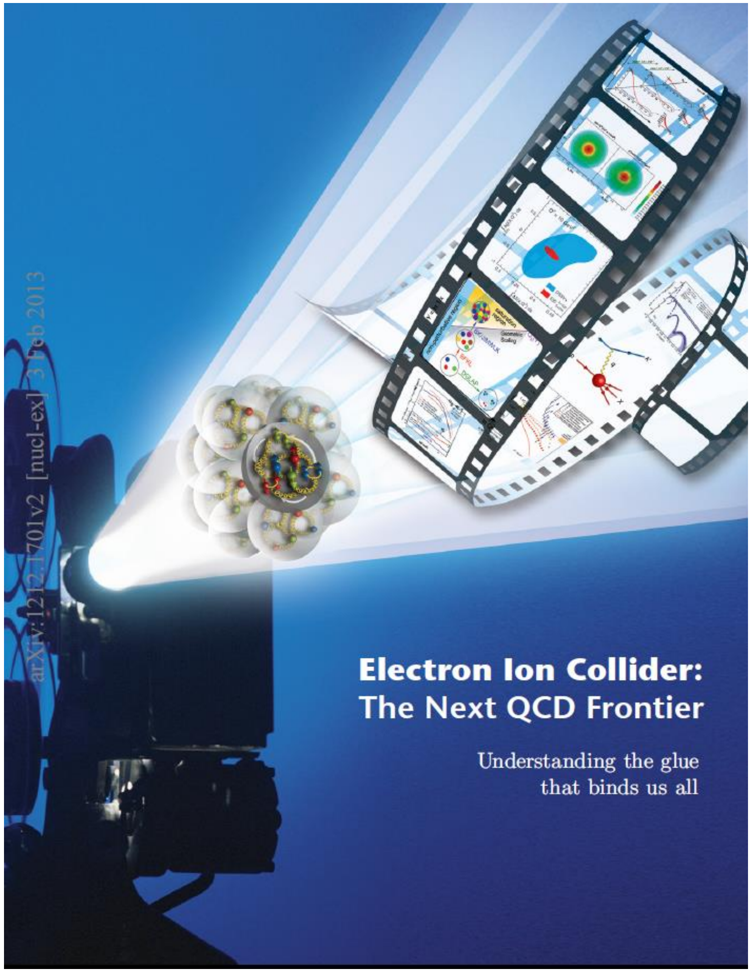
$$J_q = \frac{1}{2}\int_{-1}^{+1} dx\, x\, [H^q(x,\xi,t=0) + E^q(x,\xi,t=0)]$$

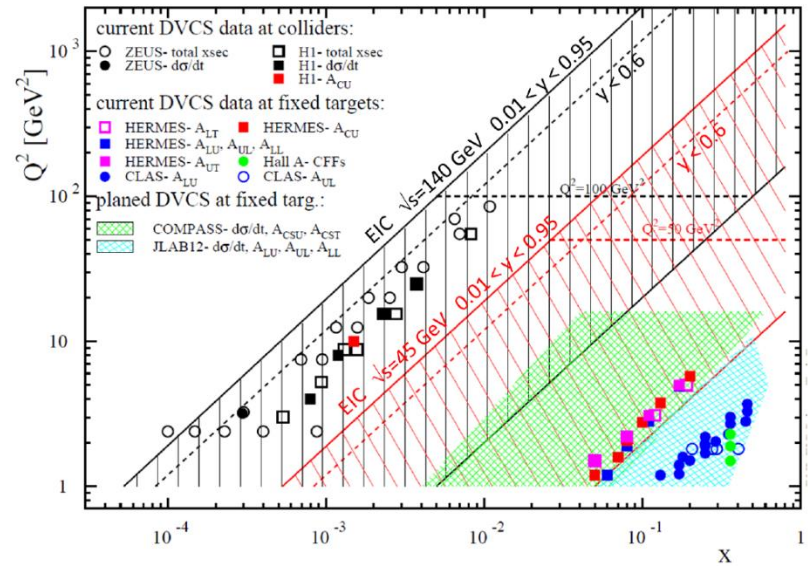
$$J_q = L_q + S_q$$

$S_q \rightarrow$ accessible through Inclusive Deep-Inelastic Scattering

Quark Orbital Angular Momentum can be extracted

Electron-Ion Collider





- A collider is needed to reach the gluon-saturated domain
- electron probe will provide the unmatched precision of the electromagnetic probes
- dynamical interplay between sea quarks & gluons through their distributions
- change of distributions when going from small to large x, to relate sea and valence quarks

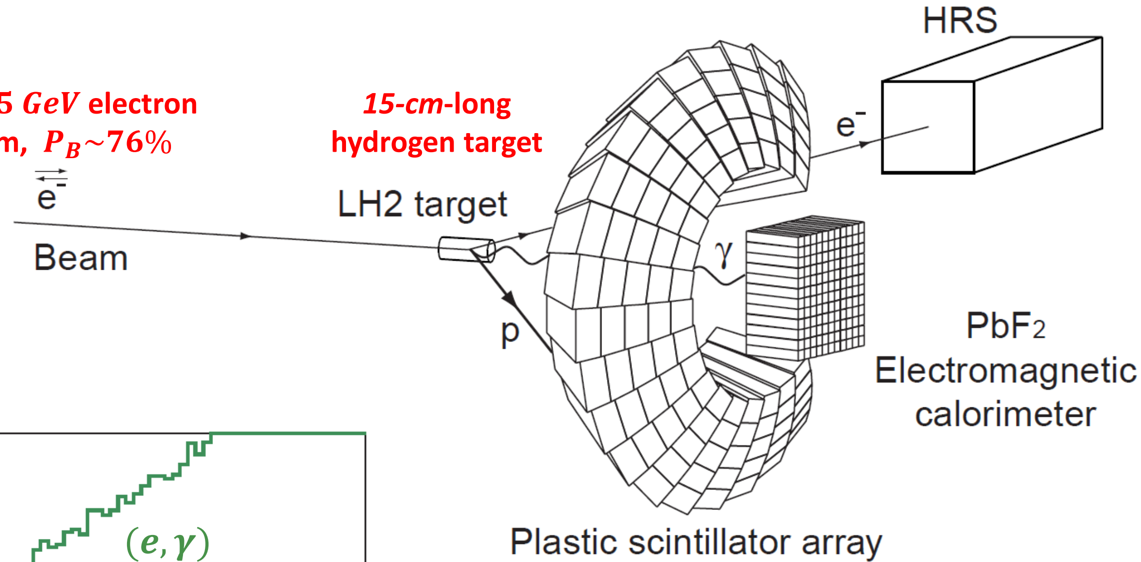
DVCS on the proton in Hall-A (E00-110)

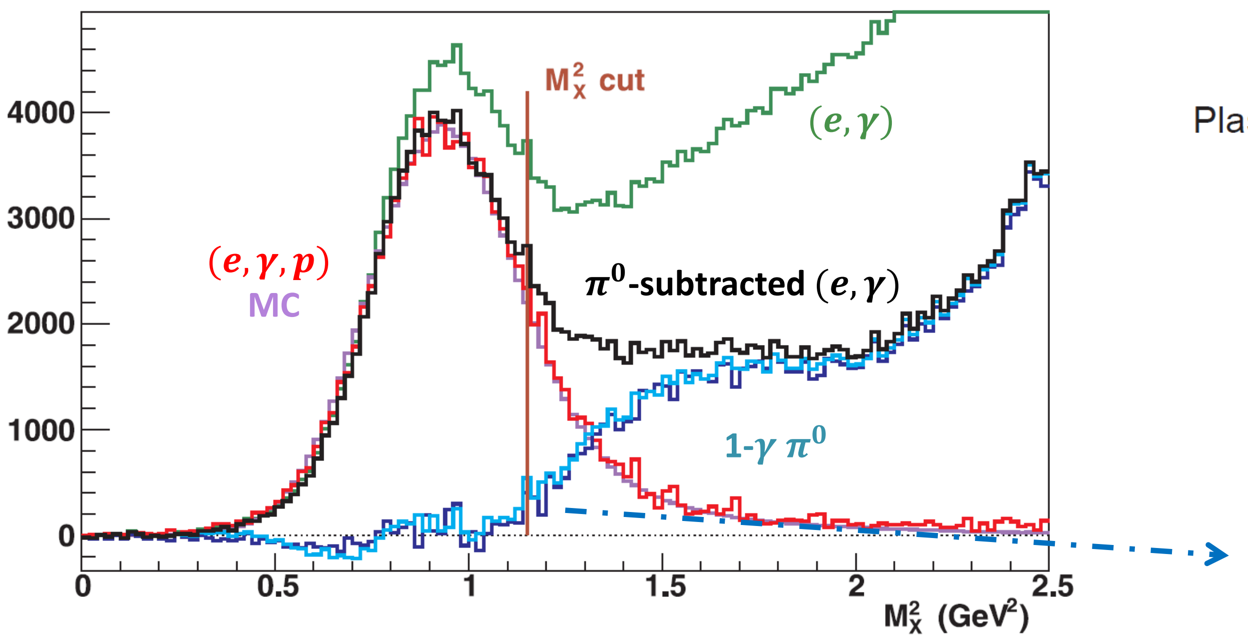
E00-110 → accurate cross section measurements at:

1. different Q^2 $(1.5 \div 2.3\ GeV^2)$
2. fixed $x_B = 0.36$

$5.75\ GeV$ electron beam, $P_B \sim 76\%$

15-cm-long hydrogen target



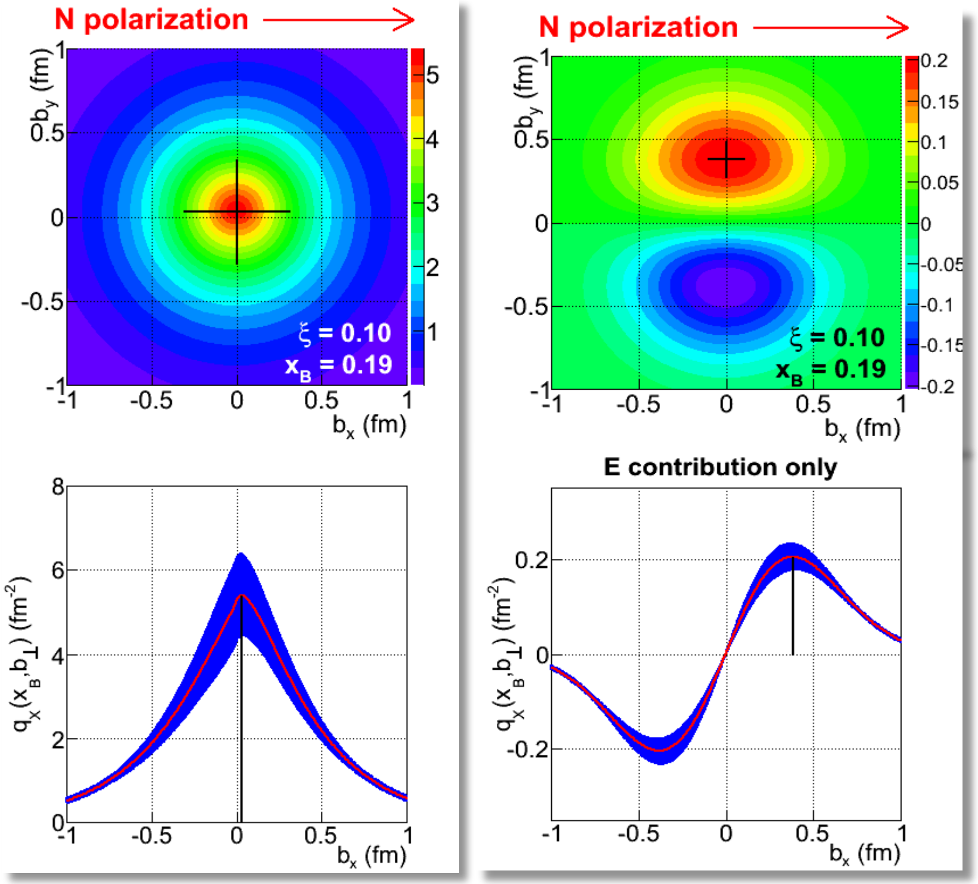


$10^{37} cm^{-2} s^{-1}$

Residual contamination < 3%

Projected quark densities in impact parameter

$$\rho_X(x, \vec{b}_\perp) = \int \frac{d^2\vec{\Delta}_\perp}{(2\pi)^2}\left[H(x,0,t) - \frac{E(x,0,t)}{2M}\frac{\partial}{\partial b_y}\right] e^{-i\vec{\Delta}_\perp \cdot \vec{b}_\perp}$$



Contribution of *H+E*

Contribution of *E*

- Fourier transform of GPDs to access quark densities in impact parameter space.
- GPD ***E*** probes the u- and d-quark separation in impact parameter space. Transversely polarized proton shows flavor dipole.

M. Burkardt
F.X. Girod

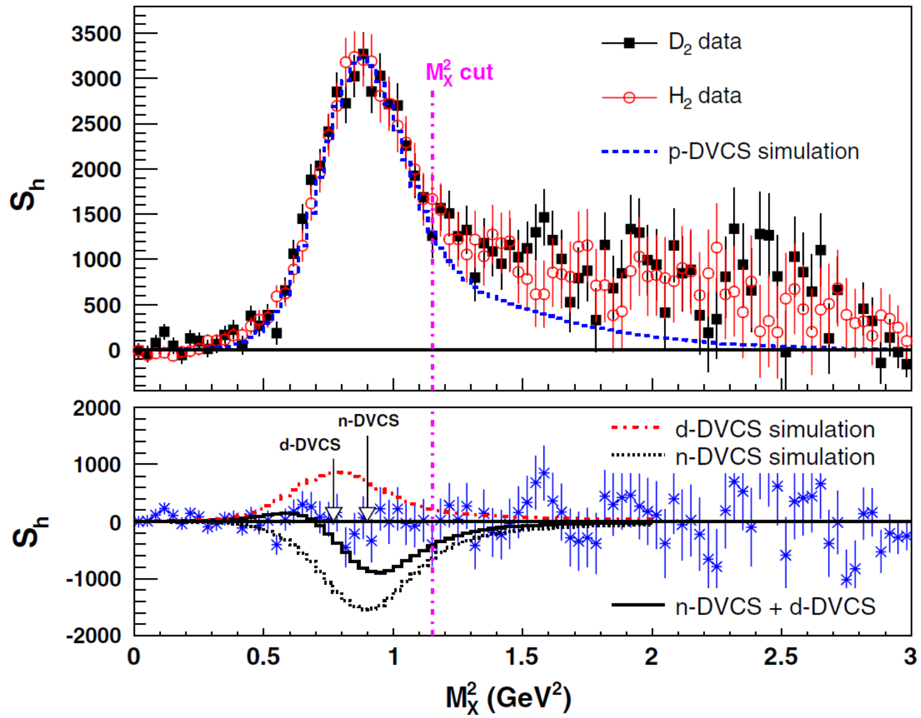
DVCS on the neutron in Hall-A (E03-106)

$(\vec{e}, e', \gamma)$ reaction on neutron off a deuterium target → decomposed into **elastic** (*d*-DVCS) and **quasi-elastic** (*p*-DVCS and *n*-DVCS) contributions.

$$\boldsymbol{D(\vec{e}, e', \gamma)X = d(\vec{e}, e', \gamma)d + n(\vec{e}, e', \gamma)n + p(\vec{e}, e', \gamma)p + \cdots}$$

From $D(\vec{e}, e', \gamma)X$ neutron events are obtained after the subtraction of the measured $p(\vec{e}, e', \gamma)X$ on hydrogen.

→ **Only twist-2 contributions are considered**

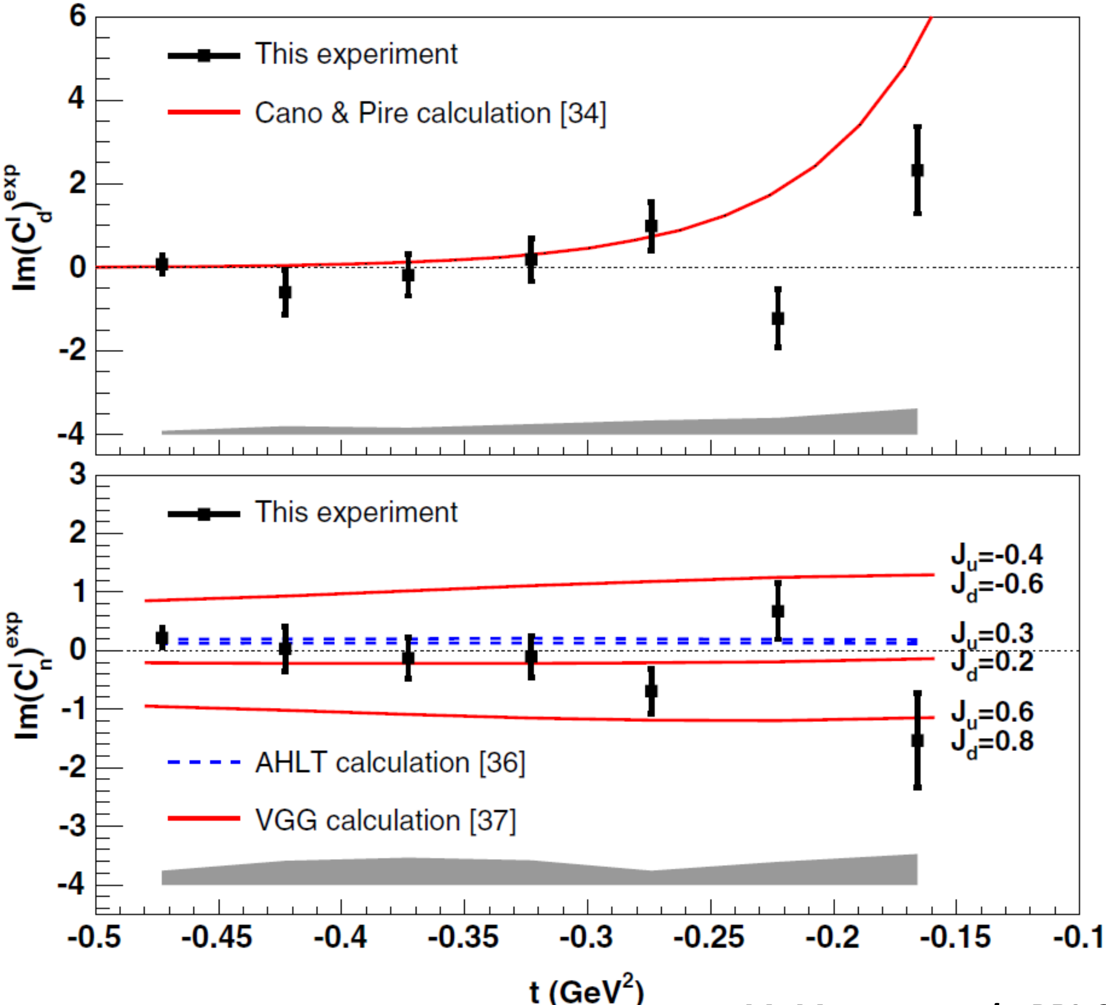


$$\frac{d^5\Sigma_{\mathrm{D-H}}}{d^5\Phi} = \frac{1}{2}\left(\frac{d^5\sigma^+}{d^5\Phi} - \frac{d^5\sigma^-}{d^5\Phi}\right) = (\Gamma_d^{\Im}\Im\mathrm{m}[\mathcal{C}_d^I]^{\exp} + \Gamma_n^{\Im}\Im\mathrm{m}[\mathcal{C}_n^I]^{\exp})\sin(\phi_{\gamma\gamma})$$

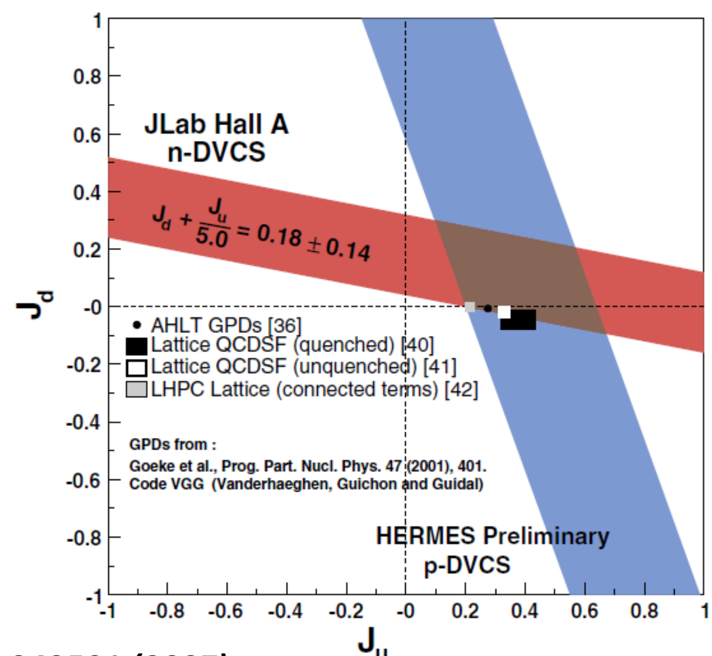
Sum of the *coherent* deuteron and *incoherent* neutron contributions

M. Mazouz et. al., PRL 99 242501 (2007)

DVCS on the neutron in Hall-A - results

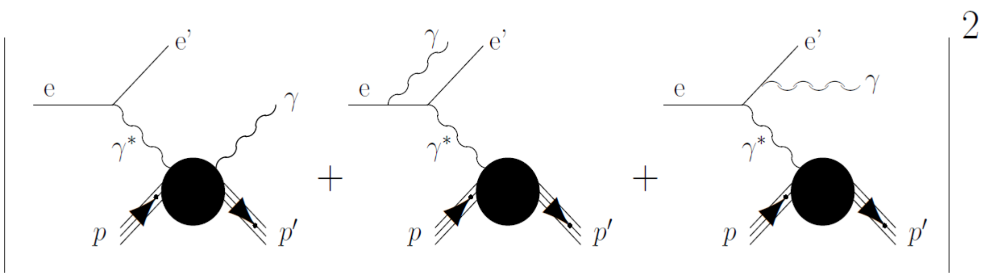


First experimental constraint on the parametrization of $E^q \rightarrow$ it is translated, whitin a model, in a constraint on the quark orbital angular momentum



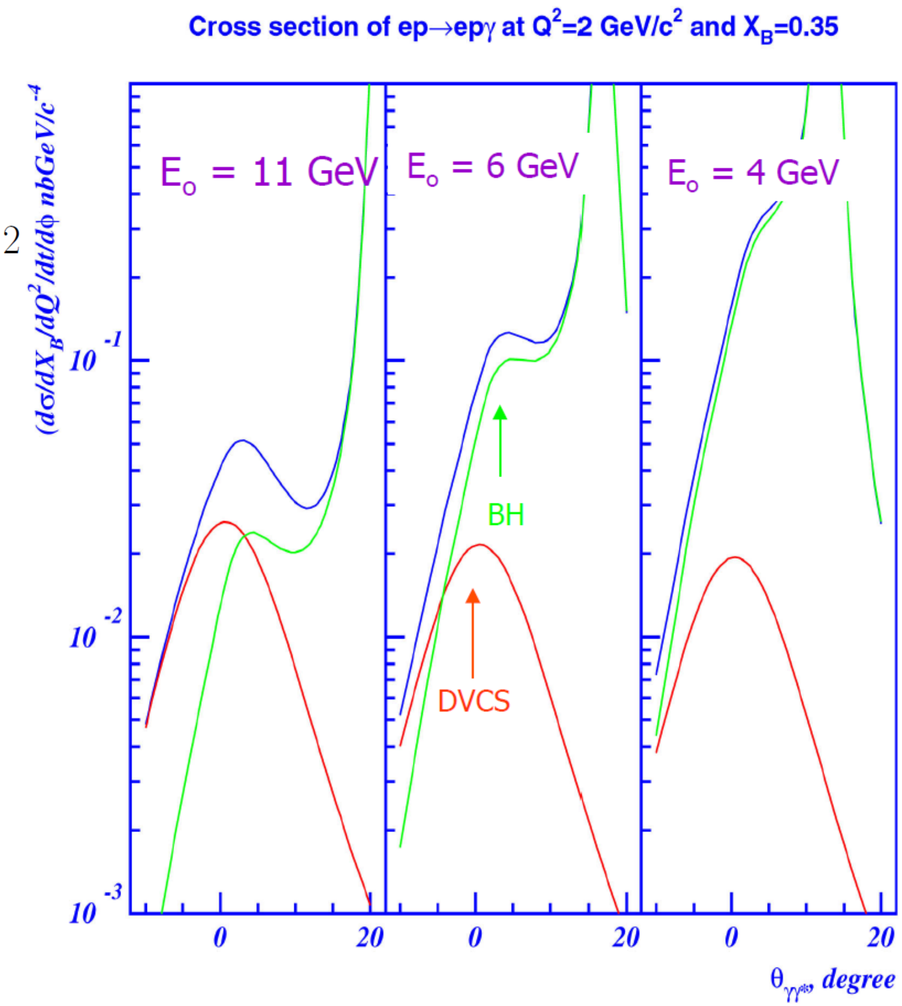
M. Mazouz et. al., PRL 99 242501 (2007)

Two processes contribute to the same (e, p, γ) final state: Bethe-Heitler and Deeply-Virtual Compton Scattering.



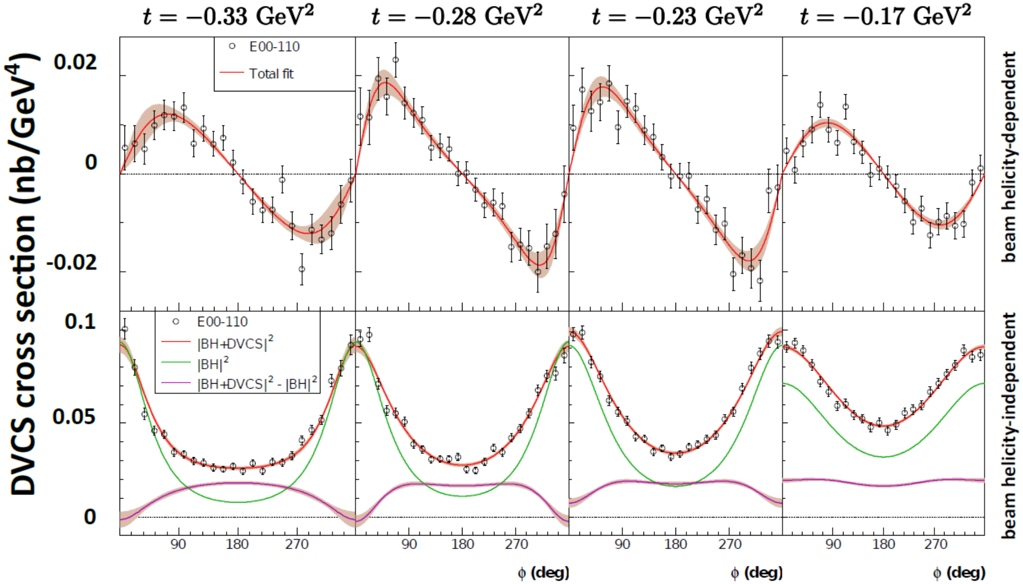
$$\sigma = |BH|^2 + I(BH \cdot DVCS) + |DVCS|^2$$

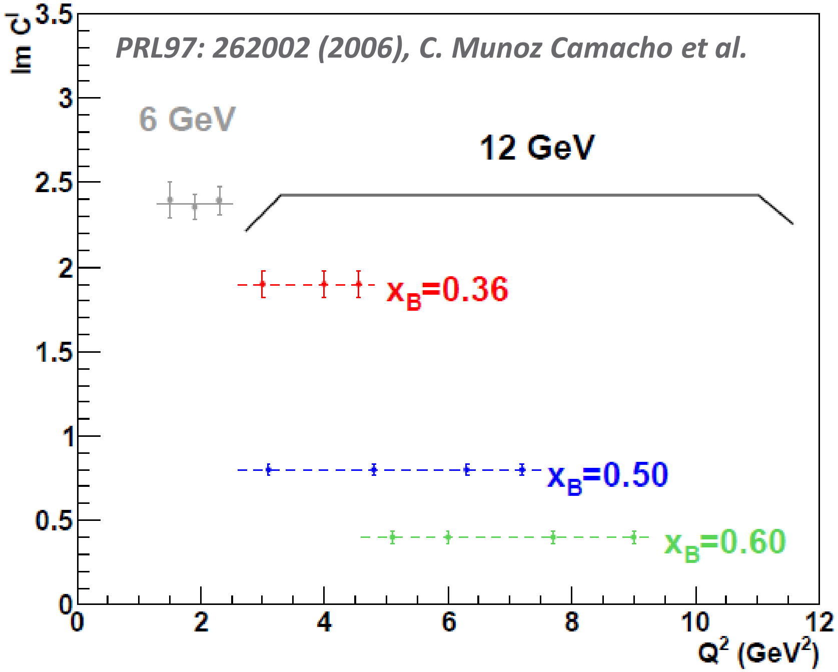
$I(BH \cdot DVCS)$ gives rise to spin asymmetries, which can be connected to combinations of GPDs



Test of the formalism: scaling in JLab/Hall-A (E00-110)

4-fold extraction at $x_B = 0.36$ of σ ($< Q^2 > = 2.3\ GeV^2$) & $\sigma^+ - \sigma^-$ ($< Q^2 > = 1.5, 1.9, 2.3\ GeV^2$) in 4 $-t$ bins



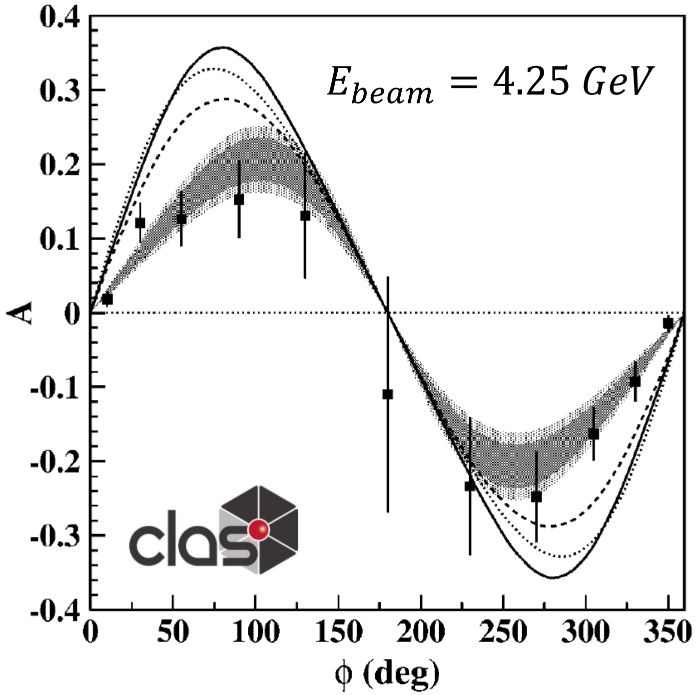


Significant deviation from pure BH → DVCS contribution to the cross section not negligible

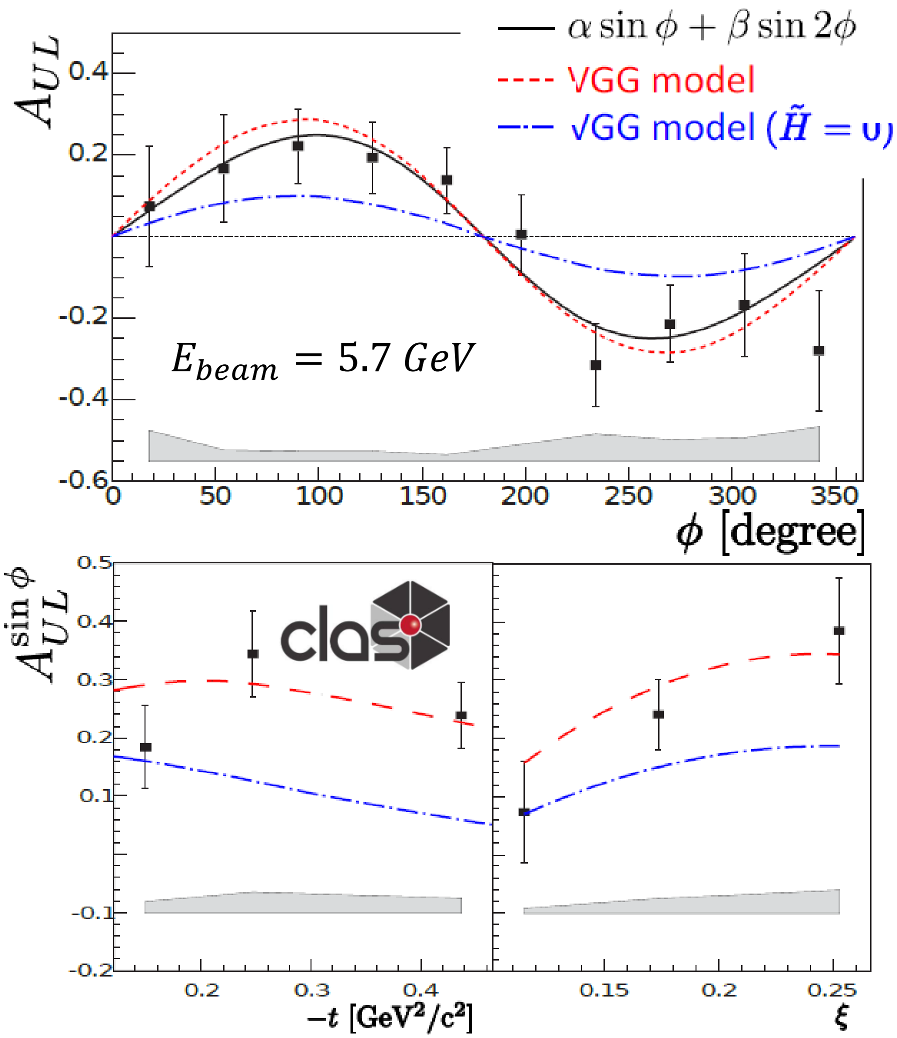
→ $\boldsymbol{Im(\mathcal{C}^I(\mathcal{F}))}$ independent of Q^2: no higher-order corrections enter → **perturbative QCD scaling in DVCS**

Hall-B/CLAS: First observations of A_{LU}& A_{UL}

→ *signal of the Bethe-Heitler and DVCS interference observed already at CLAS6 kinematics.*

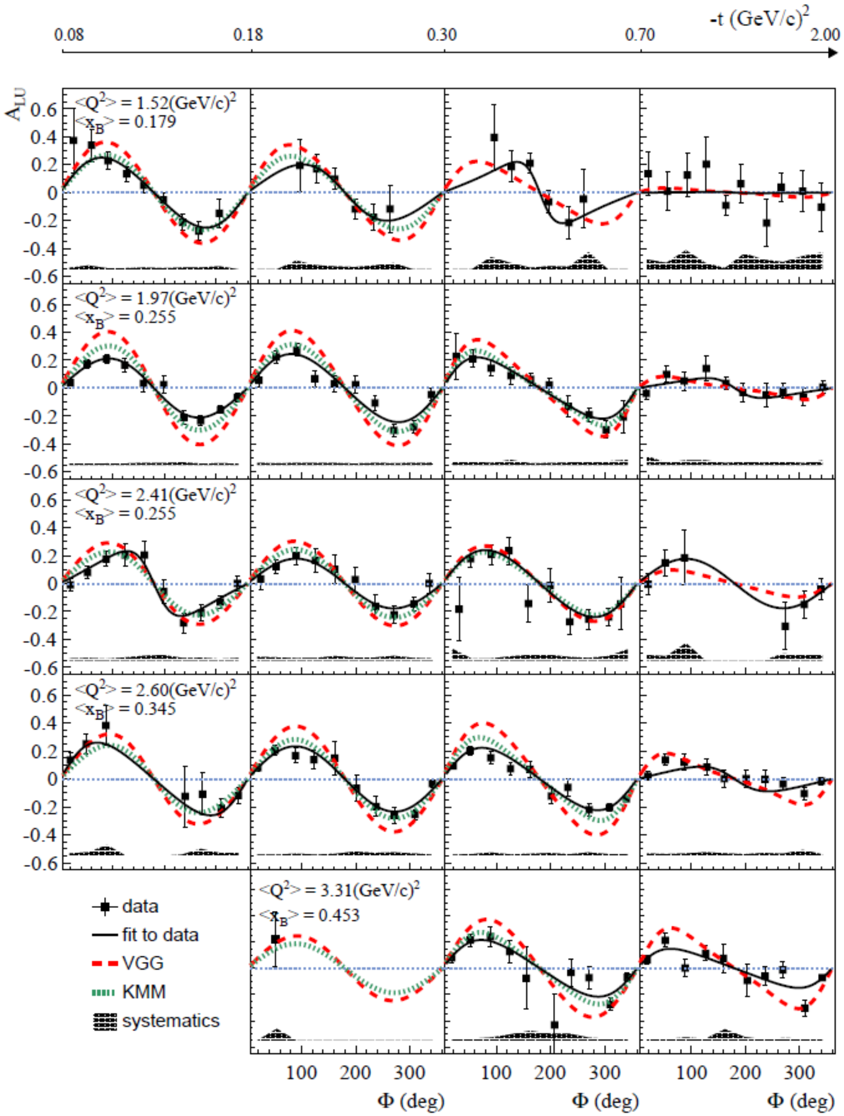


S. Stepanyan et al., Phys. Rev. Lett. 87, 182002 (2001).

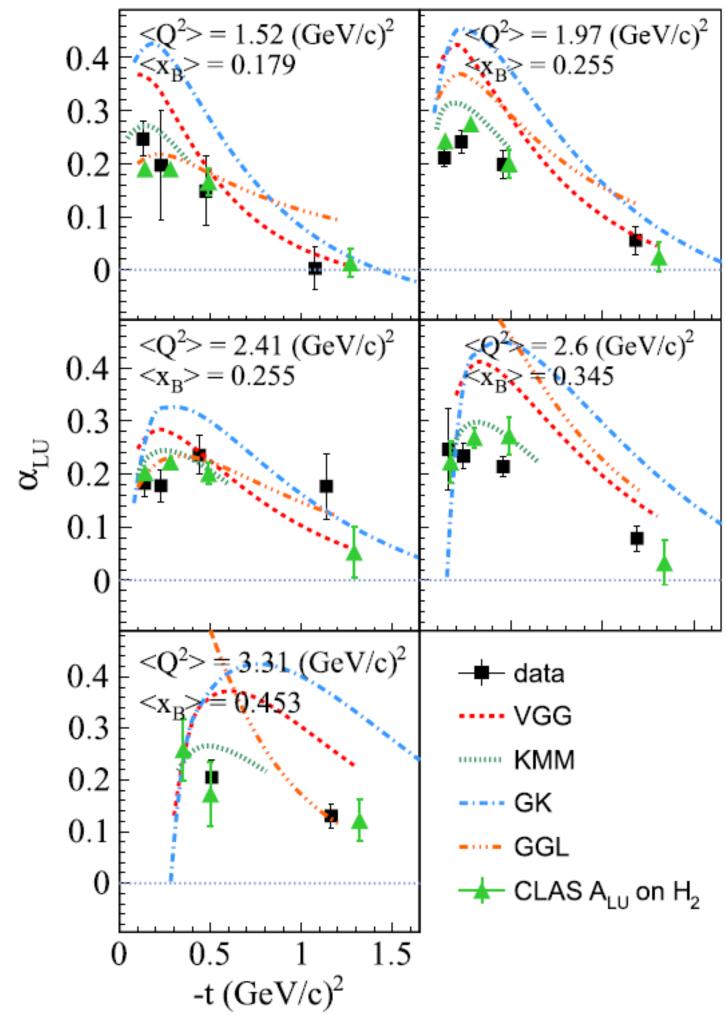


S. Chen et al., Phys. Rev. Lett. 97, 072002 (2006).

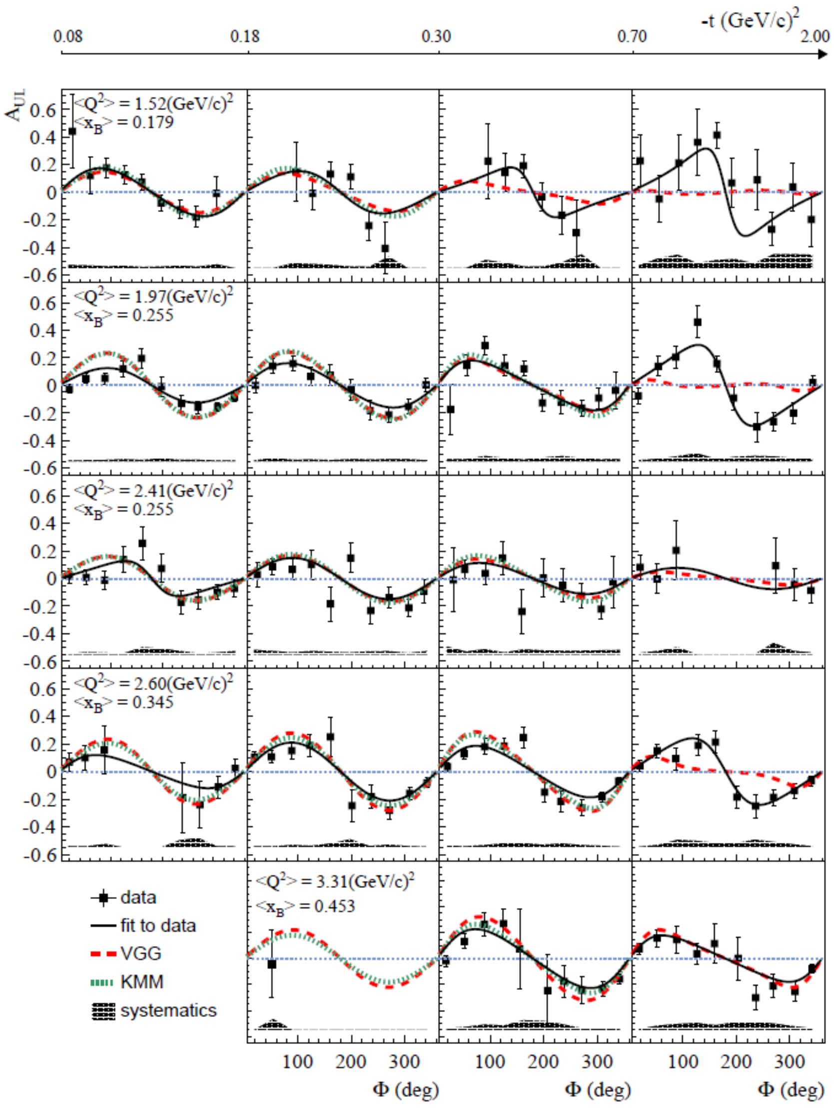
A_{LU} on NH_3



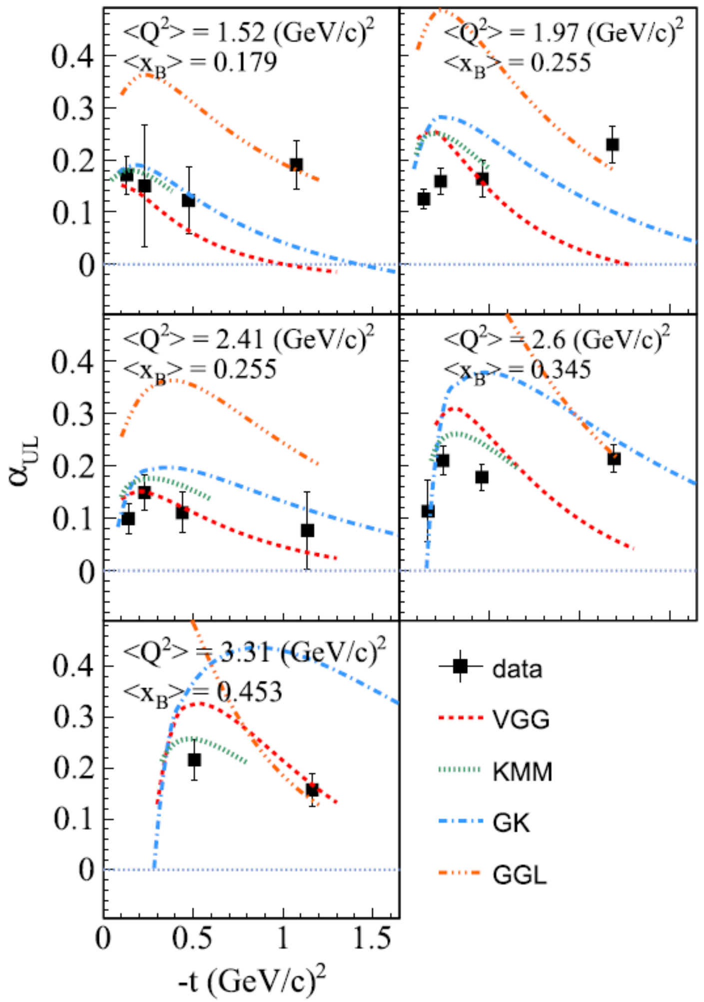
S.P. et al, Phys. Rev. D 91, 052014 (2015)



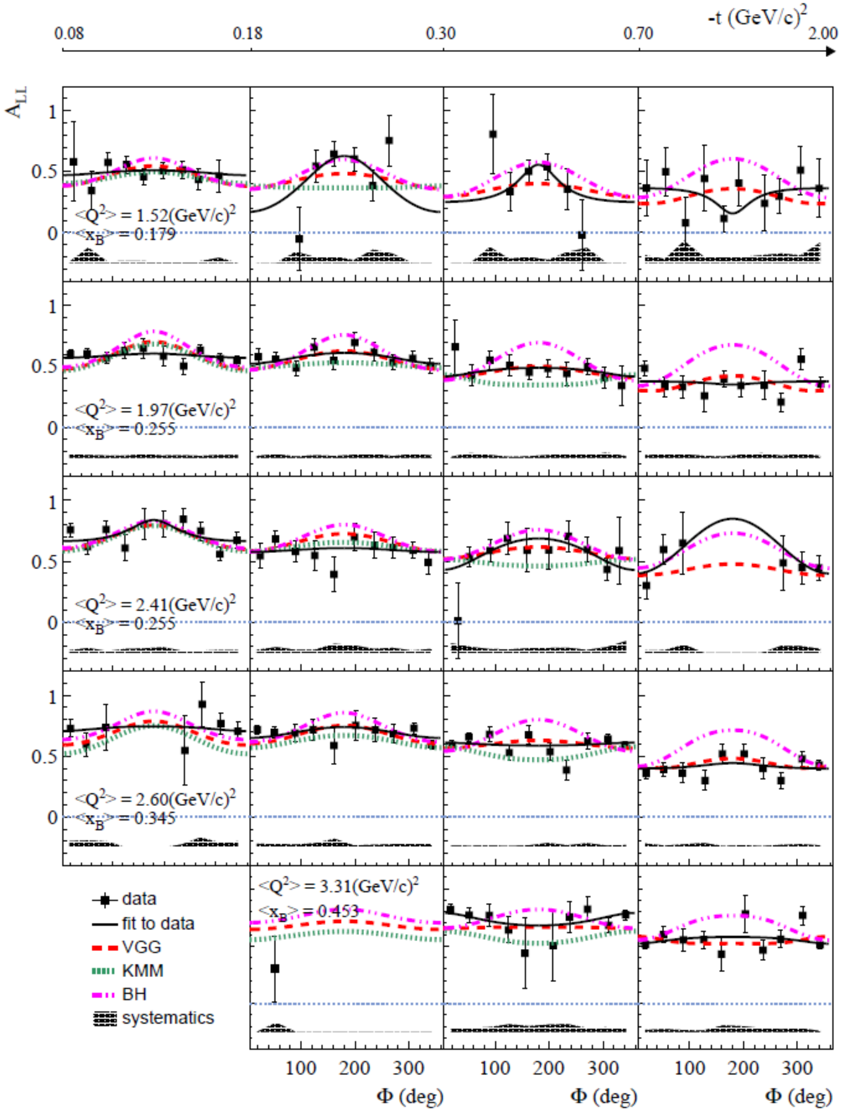
A_{UL} on NH_3



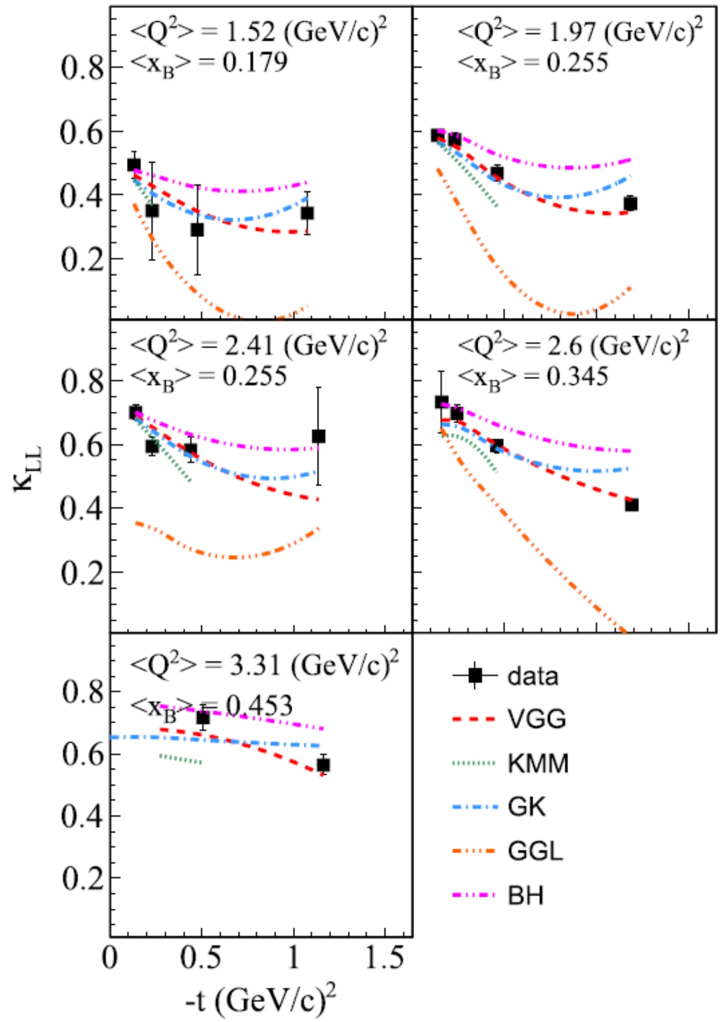
E. Seder et al, Phys. Rev. Lett. 114, 032001 (2015)
S.P. et al, Phys. Rev. D 91, 052014 (2015)



A_{LL} on NH_3



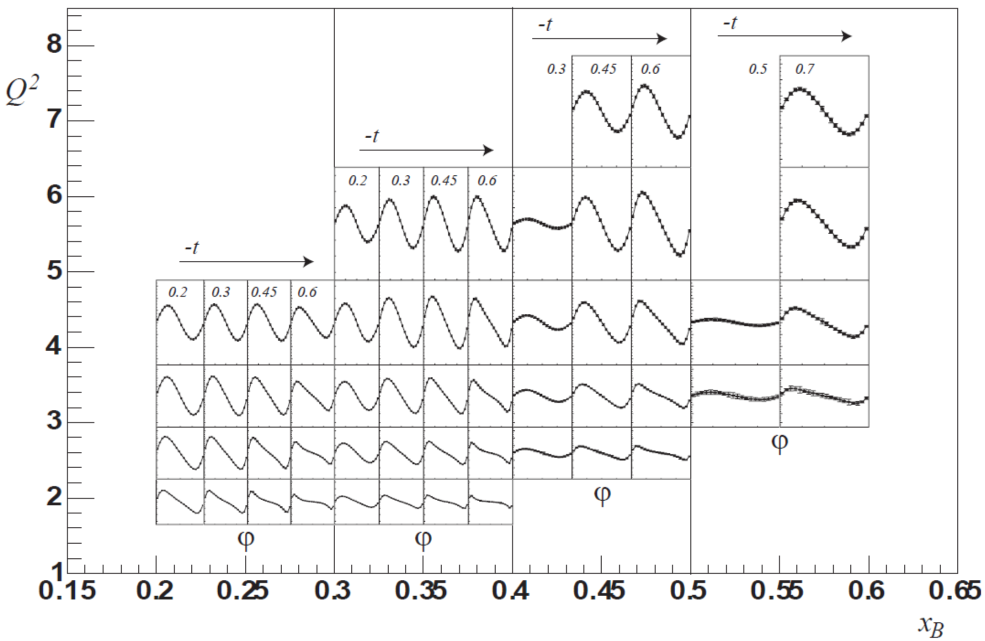
S.P. et al, Phys. Rev. D 91, 052014 (2015)

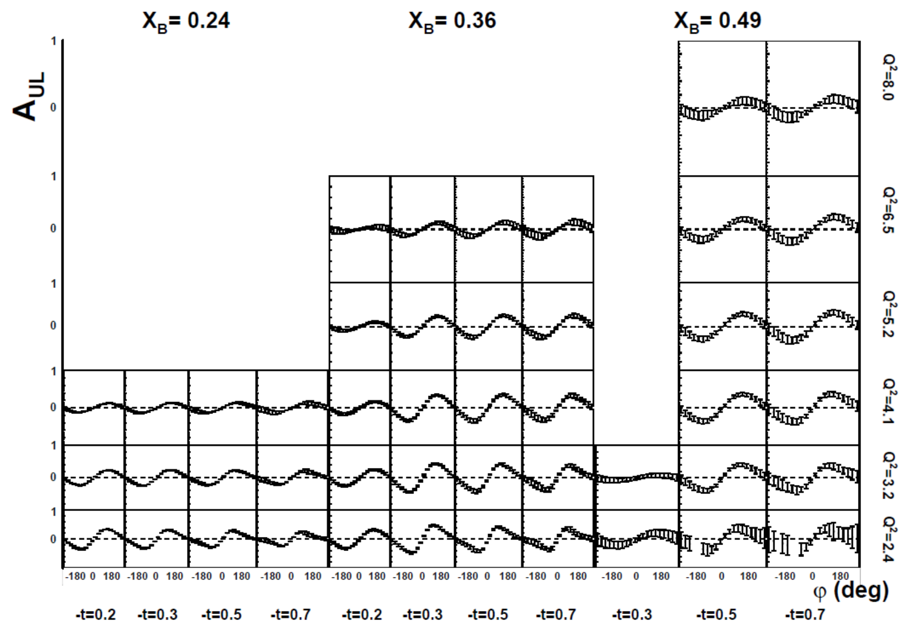


Hall-B/CLAS@12 GeV: High-statistics A_{LU}&A_{UL}- E12-06-119

$$\Delta\sigma_{LU} \propto \sin\varphi \, Im\{F_1\mathcal{H} + \xi(F_1 + F_2)\widetilde{\mathcal{H}} + kF_2\mathcal{E}\}d\varphi$$

$$\Delta\sigma_{UL} \propto \sin\varphi \, Im\{F_1\widetilde{\mathcal{H}} + \xi(F_1 + F_2)\mathcal{H} + kF_2\mathcal{E}\}d\varphi$$



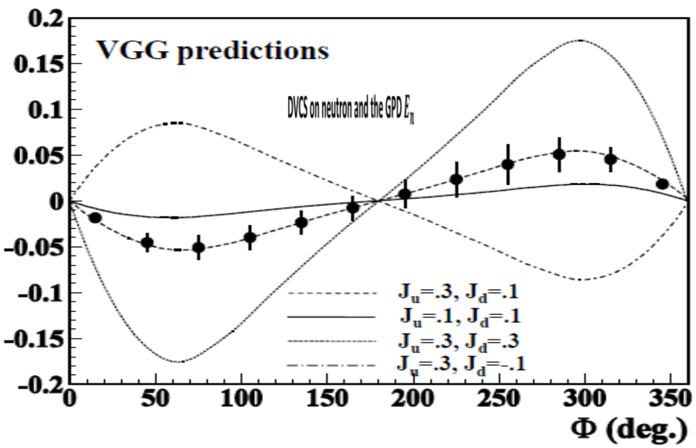


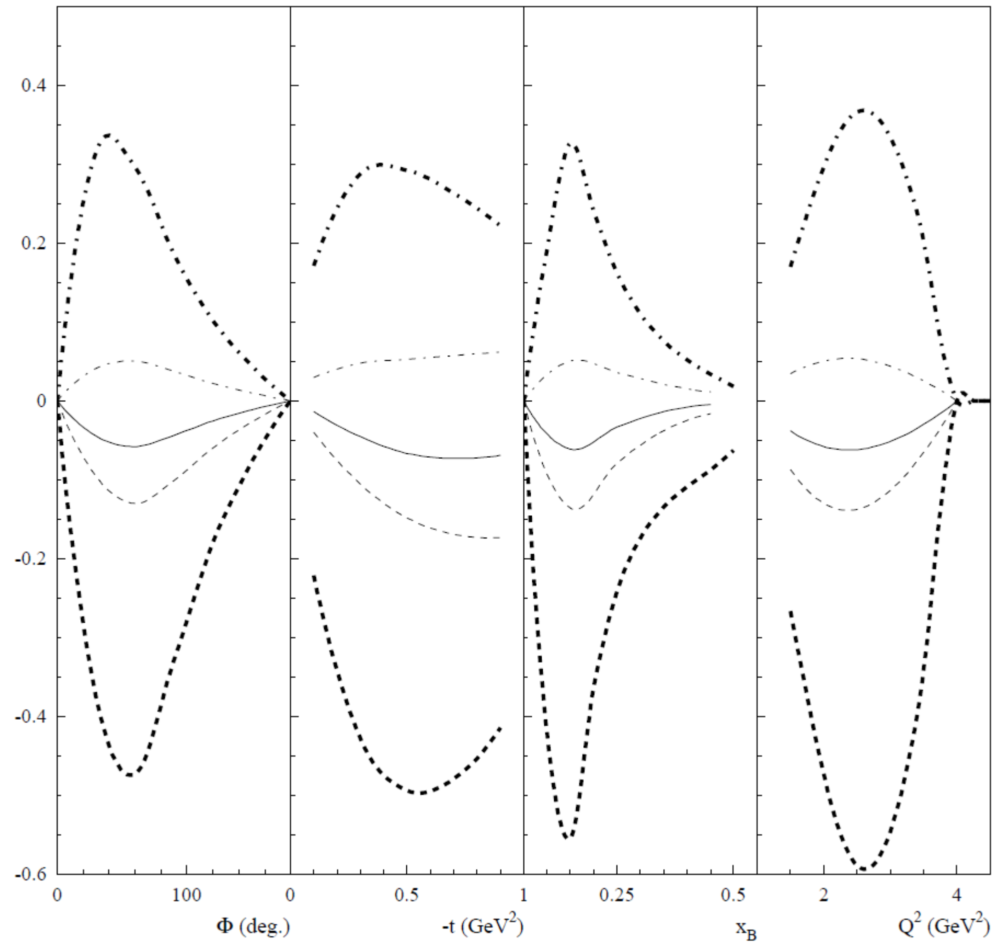
DVCS on neutron and the GPD E_n

Beam-Spin Asymmetry on the neutron highly sensitive to quark angular momentum

Different curves: VGG at $E_e = 11\ GeV, x_B = 0.17, Q^2 = 2\ GeV^2, -t = 0.4 GeV^2$ for

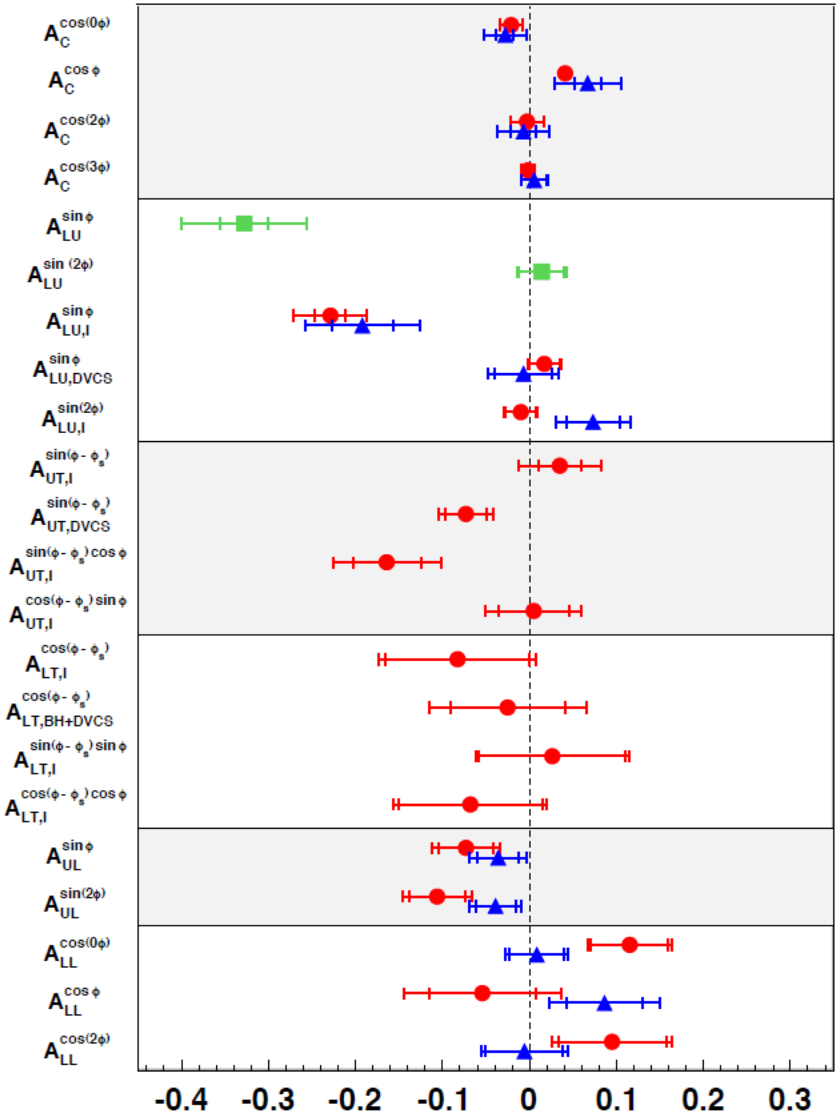
- $J_u = 0.3, J_d = 0.1$
---- $J_u = -0.5, J_d = 0.1$
- · - $J_u = 0.3, J_d = 0.8$
---- $J_u = 0.3, J_d = -0.5$





E12-11-003, A_{LU} on neutron

HERMES measurements



hydrogen

deuterium

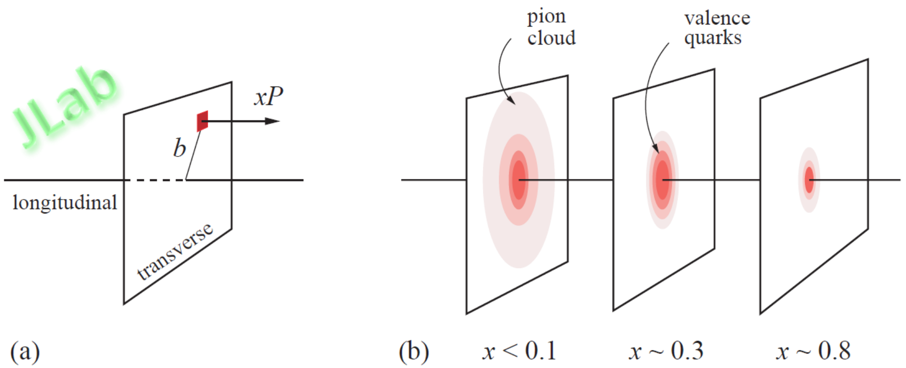
hydrogen pure

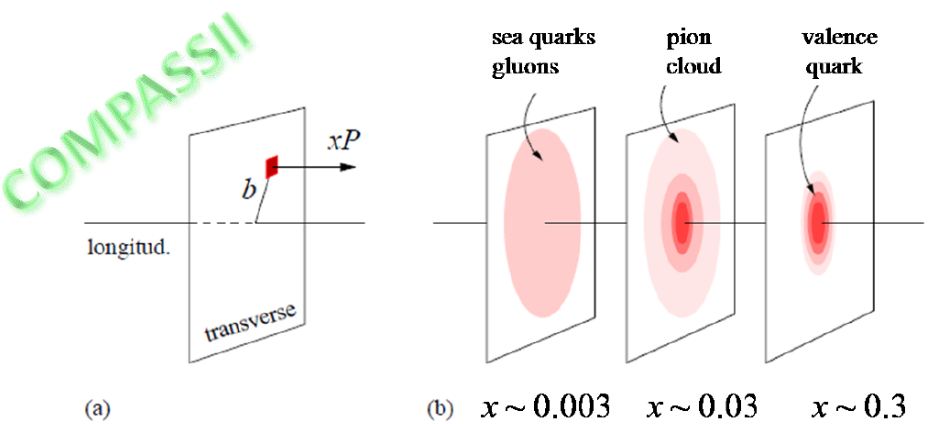
Nucleon transverse size

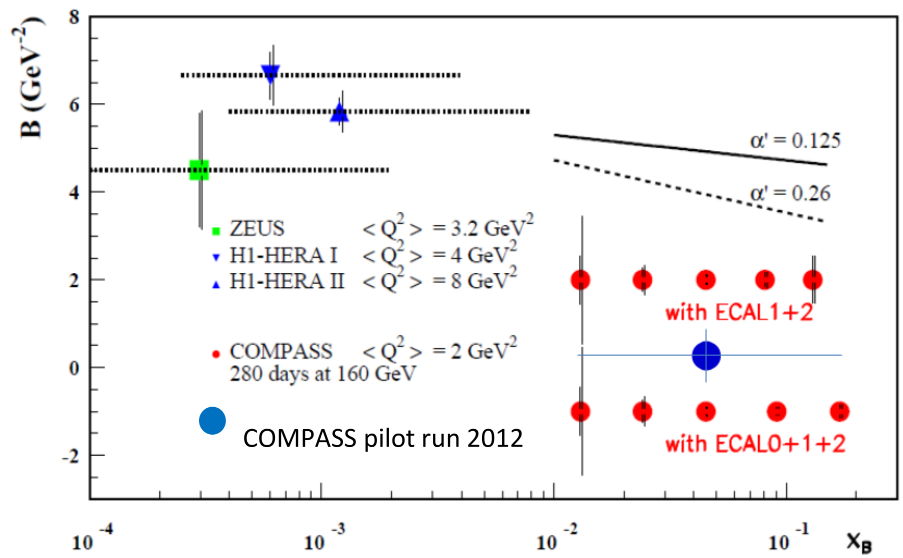
The distance $\langle r_\perp{}^2 \rangle$ between the struck quark and the spectator c.m. is given by the t-slope of the DVCS cross-section. Extracting it for different x_B values provides a tomographic picture of the nucleon, *i.e.* how its shape changes with x_B

$$\frac{d\sigma_0{}^{DVCS}}{dt} \propto exp(-B(x_B)|t|)$$

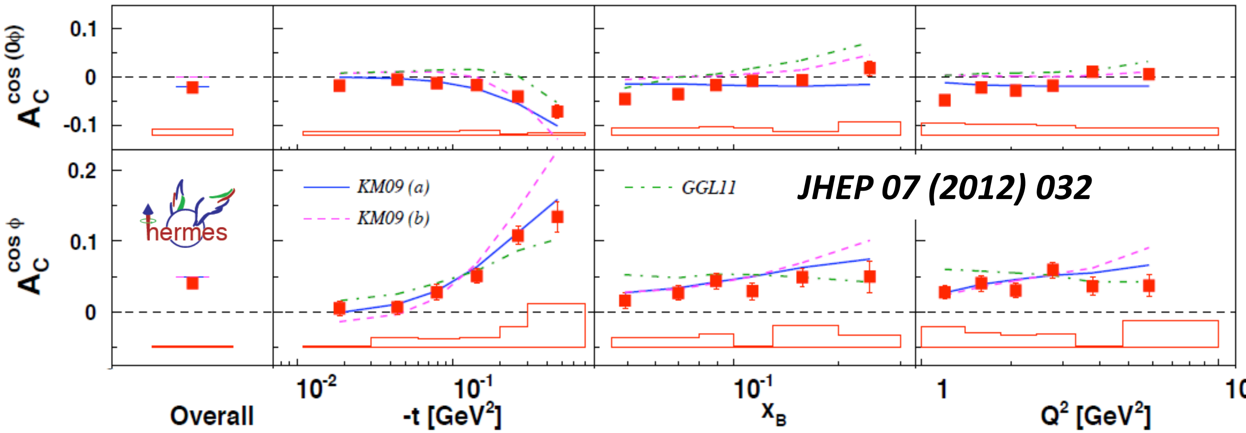
$$B(x_B) = B_0 + 2\alpha' log\left(\frac{x_0}{x_B}\right)$$

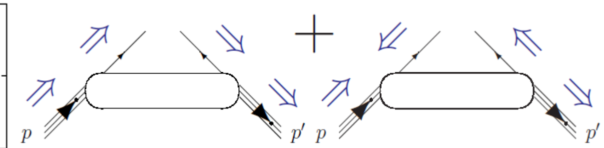




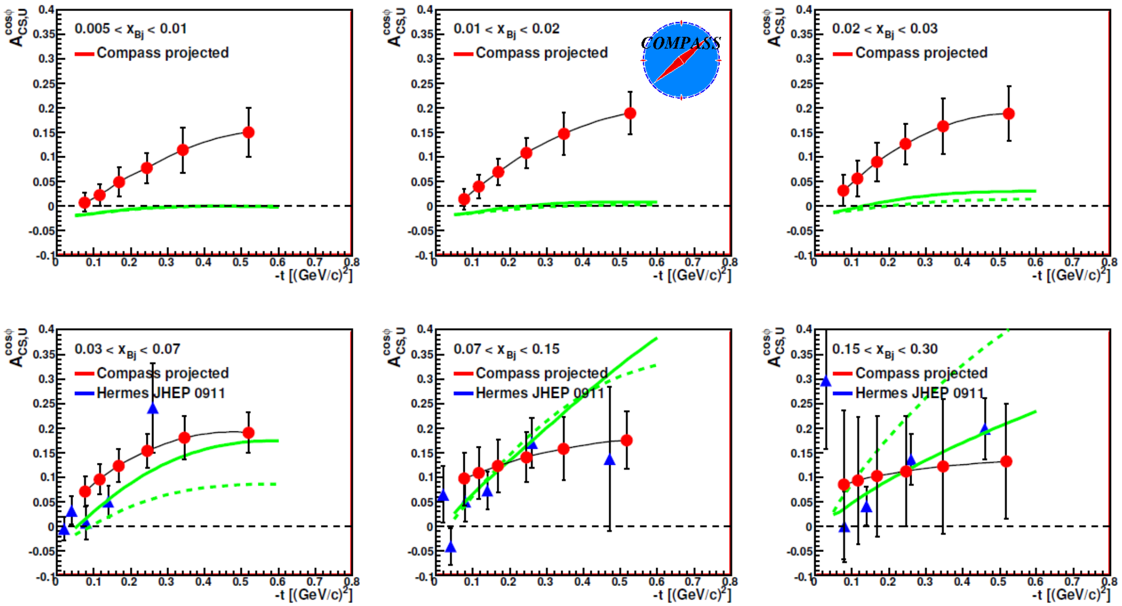


Mapping GPDs: Beam-charge asymmetries - $\mathcal{H}_{Re}$





Different beam charge in COMPASS and HERMES provides access to the Beam-Charge Asymmetry → mostly sensitive to the *real part of* $\mathcal{H}$



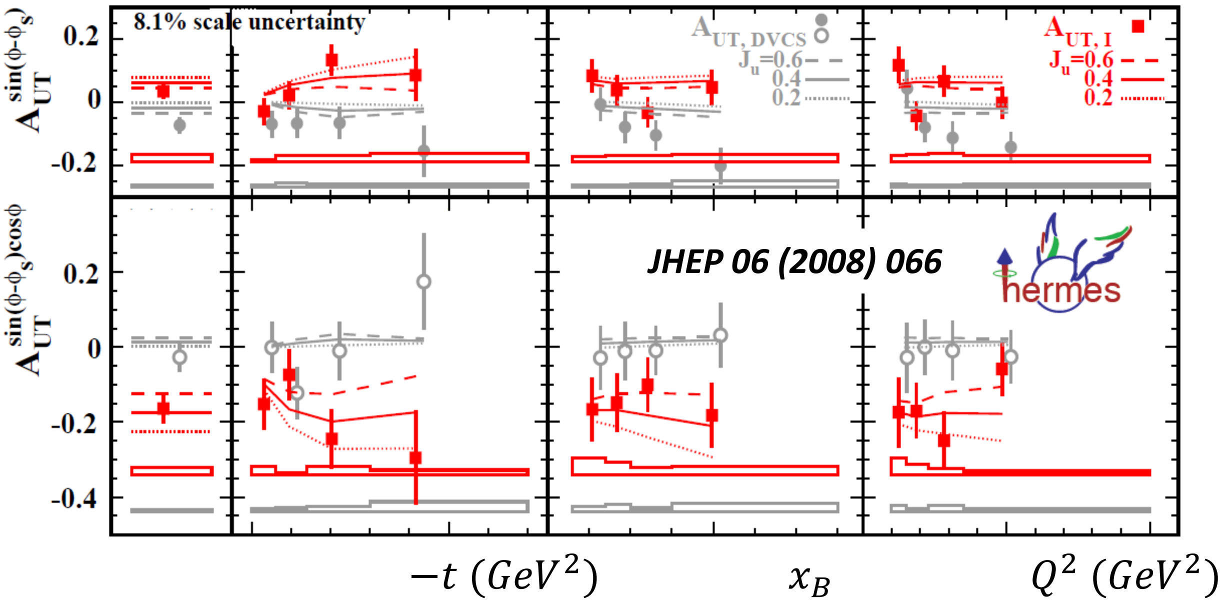
Asymmetry found significantly non zero in HERMES

Strong dependence on *-t*

COMPASSII measurement will extend HERMES measurement to lower-x_B

---- Fits by Kumericki, Mueller

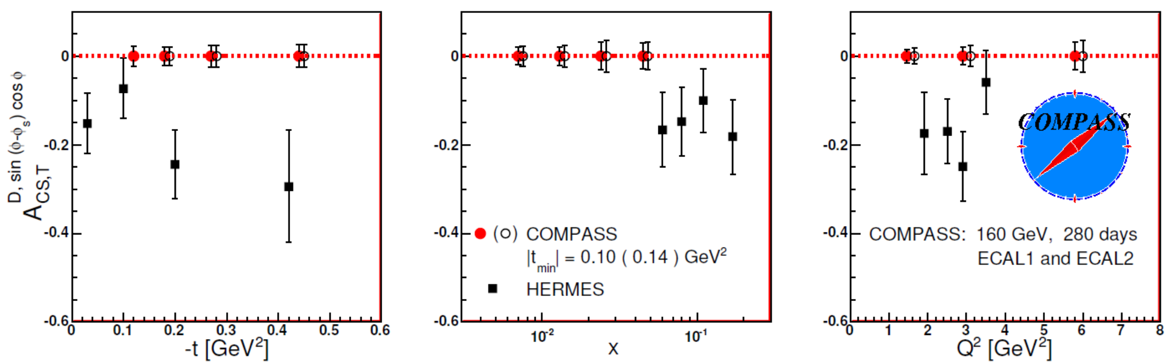
Exploring E_p in a wide kinematic range

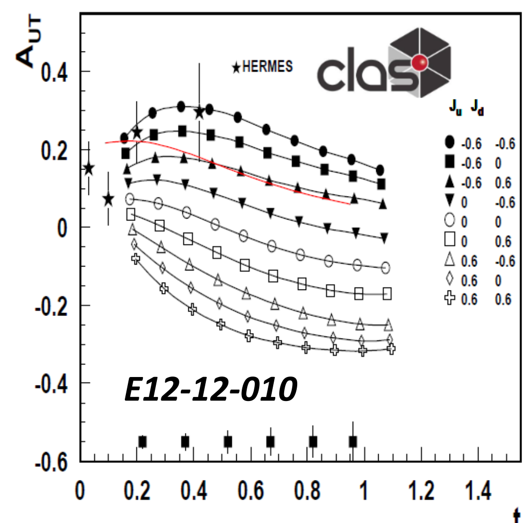


Coefficient accessible through A_{UT} modulations sensitive to E_p

→ observed significantly non-zero @HERMES

Different J_u values tested (with $J_d = 0$)





Higher-twist GPDs: $A_{UL}^{\sin 2\varphi}$

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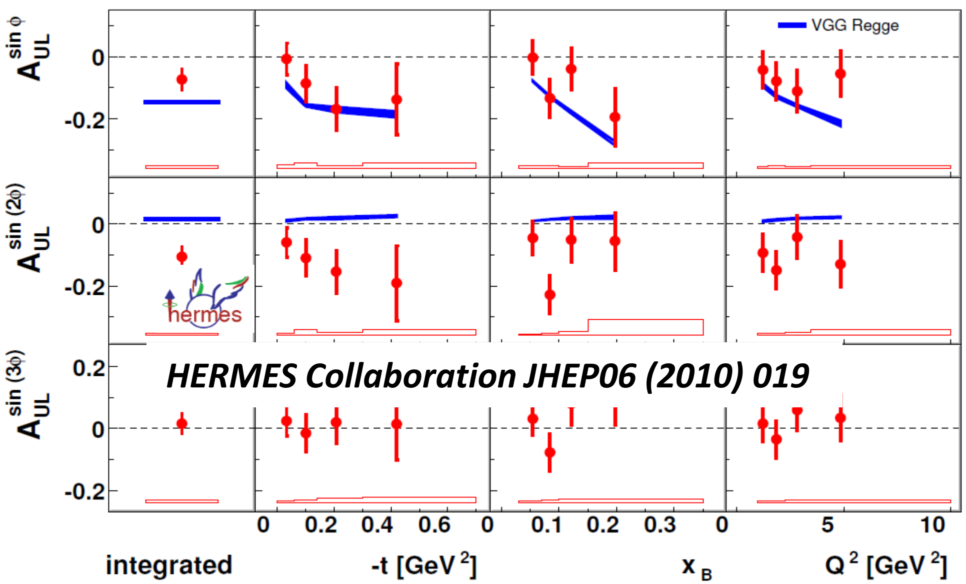
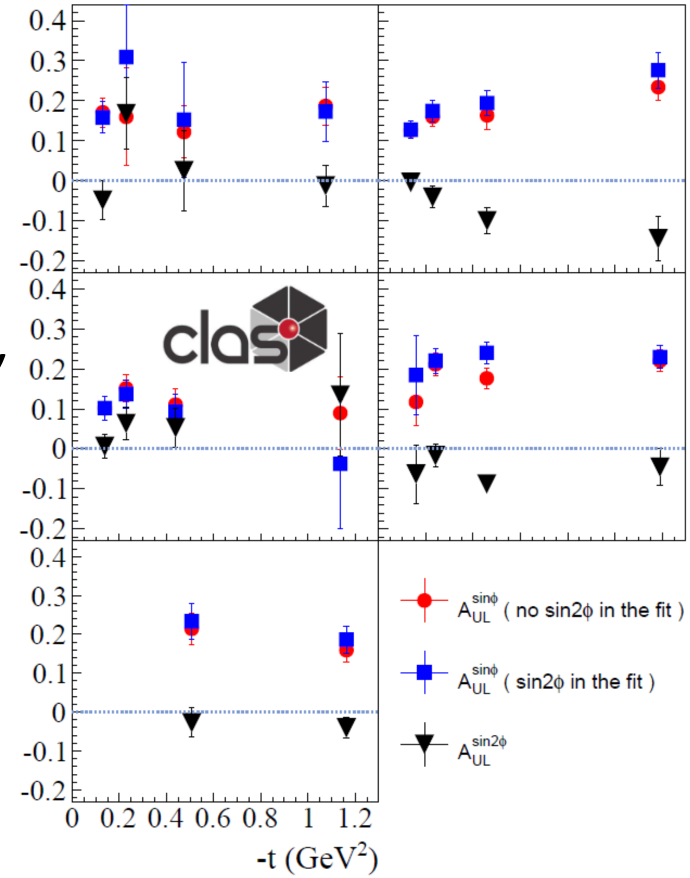
On the observability of the quark orbital angular momentum distribution

Aurore Courtoy[a,b], Gary R. Goldstein[c], J. Osvaldo Gonzalez Hernandez[d], Simonetta Liuti[e,b], Abha Rajan[e]

Higher-twist modulations of the ***longitudinal Target-Spin Asymmetry*** could provide access to the quark orbital angular momentum



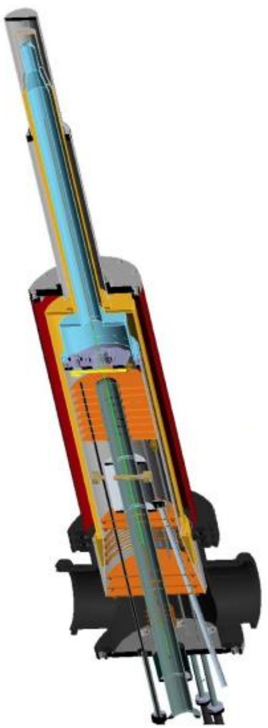
HERMES Collaboration JHEP06 (2010) 019



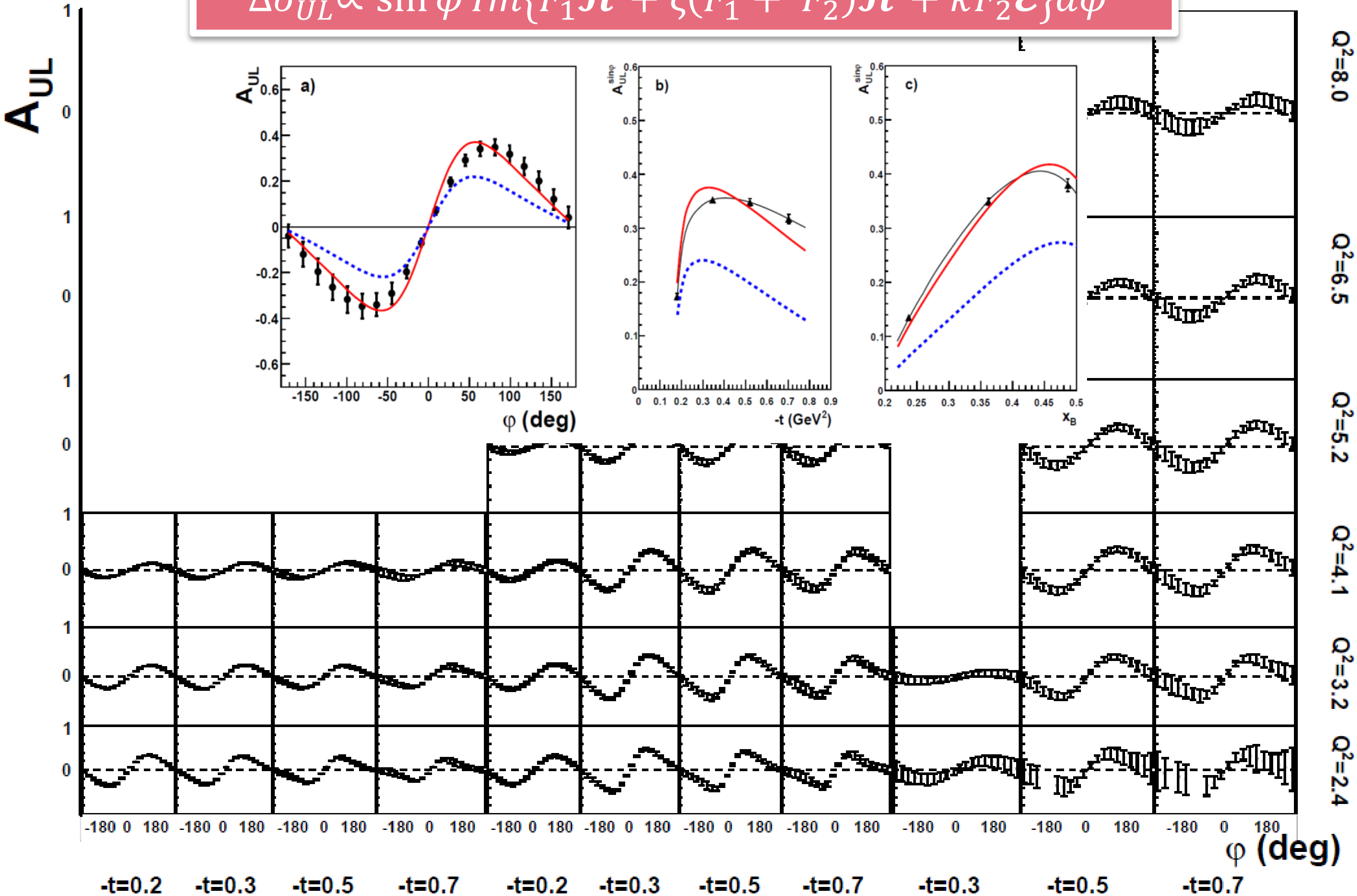
red: ***S.P. et al, PRD 91 052014 (2015)***
black: ***$\sin 2\varphi$ CLAS preliminary***

Longitudinal Target-Spin Asymmetry: E12-06-119

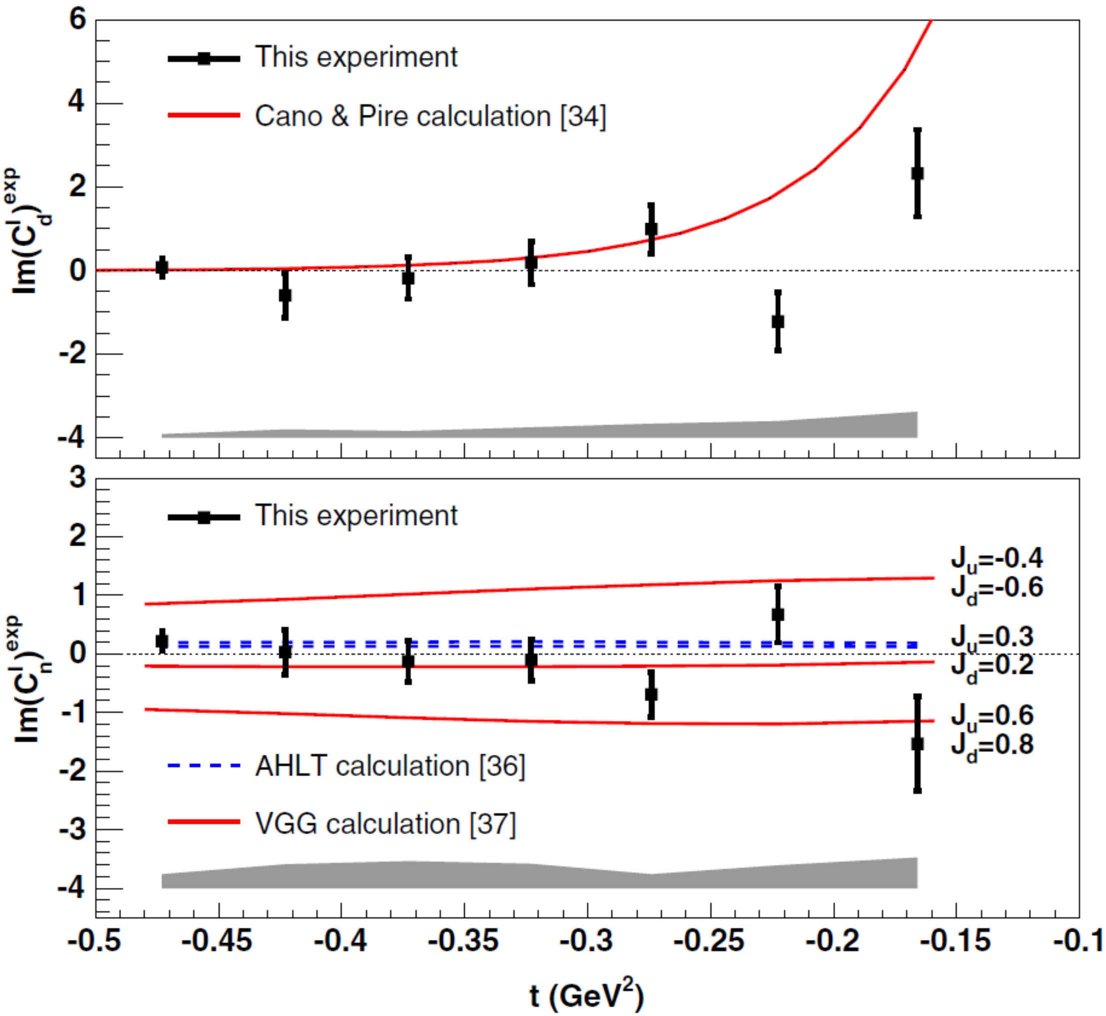
$$\Delta\sigma_{UL} \propto \sin\varphi \, Im\{F_1\widetilde{\mathcal{H}} + \xi(F_1 + F_2)\mathcal{H} + kF_2\mathcal{E}\}d\varphi$$



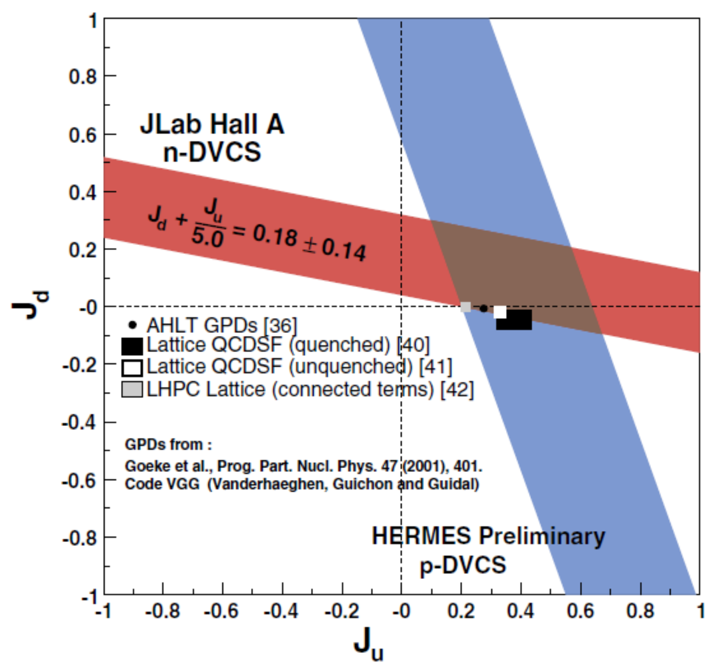
Dynamically-polarized NH_3 target



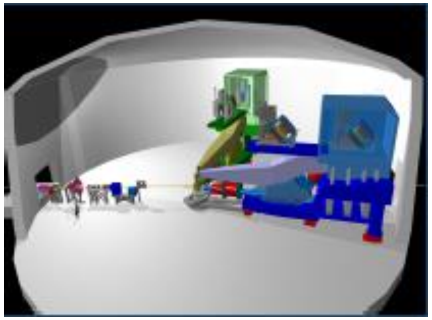
DVCS on the neutron in Hall-A - results



First experimental constraint on the parametrization of $E^q \rightarrow$ it is translated, whitin a model, in a constraint on the quark orbital angular momentum

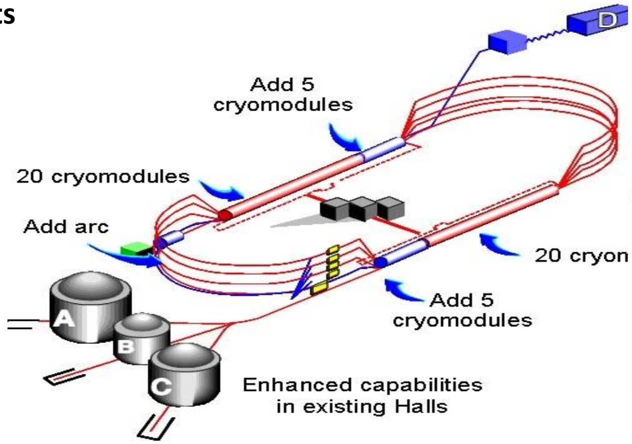


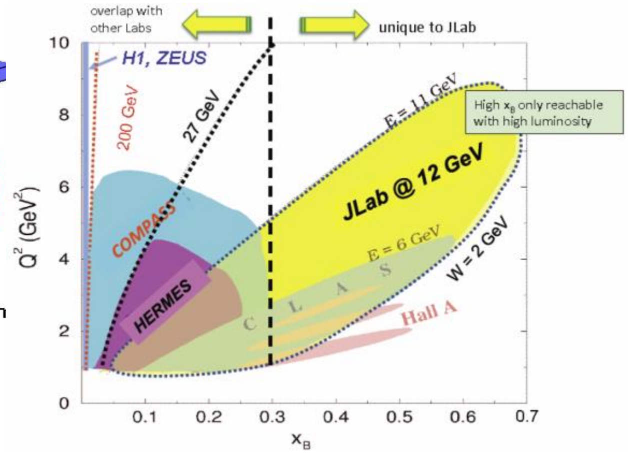
The 12-GeV upgrade

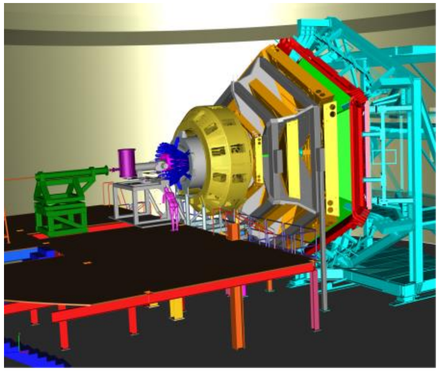


High Resolution Spectrometer (HRS) pair and specialized large installation experiments

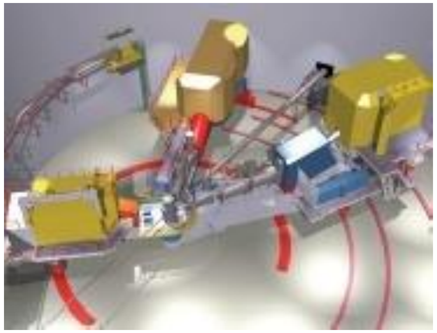
4 experimental halls with a longitudinally-polarized electron beam of E_e– up to 12 GeV.



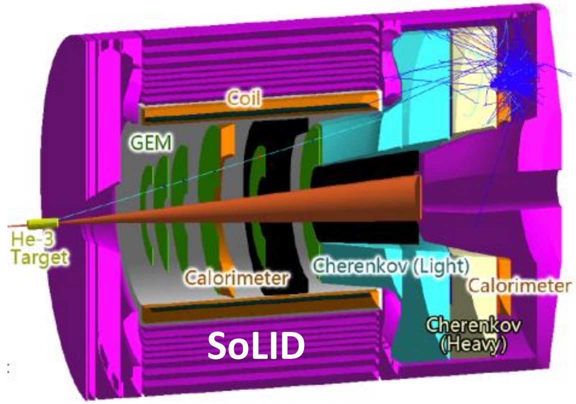


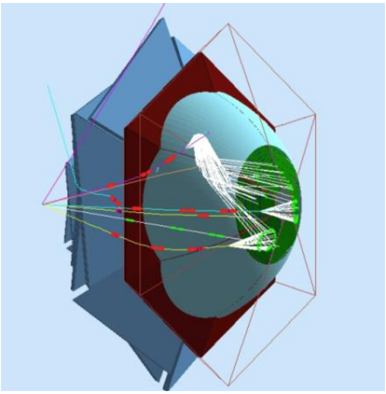


CLAS12: large acceptance, high luminosity



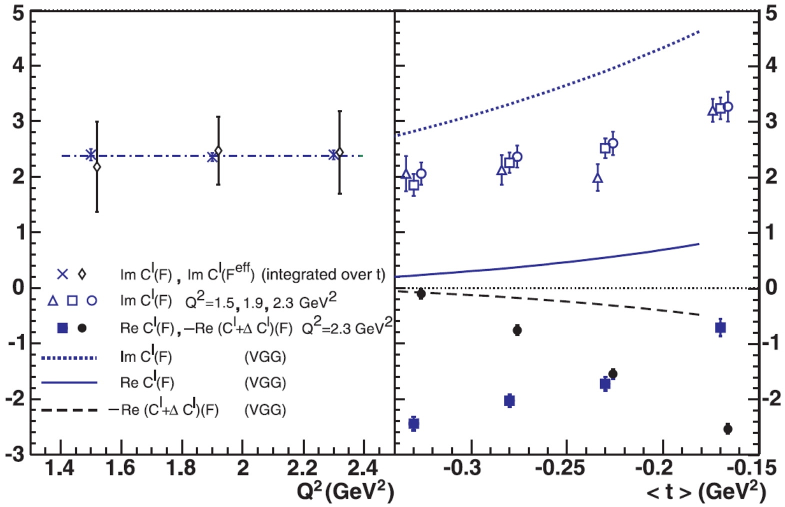
Super High Momentum Spectrometer (SHMS) at high luminosity and forward angles





RICH for CLAS12

Hall-A 1° cross section



→ twist-3 contributions smaller than twist-2

→ DVCS contribution to the cross-section not negligible

→ $\boldsymbol{Im}(\boldsymbol{\mathcal{C}^I}(\boldsymbol{\mathcal{F}}))$ independent of Q^2: no higher-order corrections enter **→ perturbative QCD scaling in DVCS**

1. **solid lines → total fit**
2. **dot-dash line → higher-twist contribution**
3. **dot-dot-dashed line → BH**
4. **short-dashed lines → fitted $Im(\mathcal{C}^I(\mathcal{F}))$ and $Re(\mathcal{C}^I(\mathcal{F}))$**
5. **long-dashed line → fitted $Re(\mathcal{C}^I + \Delta\mathcal{C}^I)(\mathcal{F})$**
6. **dot-dashed curves → fitted $Im(\mathcal{C}^I(\mathcal{F}^{eff}))$ and $Re(\mathcal{C}^I(\mathcal{F}^{eff}))$**

Conclusions 2

- Past experiments, both fixed target (JLab, HERMES, COMPASS) or active in colliders (ZEUS, H1), played a crucial role in proving the feasibility of a nucleon tomography through the formalism of the Generalized Parton Distributions
- Deeply-Virtual Compton Scattering emerged as the cleanest process to access GPDs (CFFs) through specific observables
- First constraints of the CFFs $\mathcal{H}, \widetilde{\mathcal{H}}$ through DVCS A_{LU}, A_{UL}, A_{LL} and cross-sections
- A good mapping of GPDs will describe how the different charges describing nucleon interactions are distributed inside its volume
- The observables can be compared to Lattice results → connection to pure QCD
- The (bright?) future will see a wide investigation ranging from the gluon/sea regime explored at COMPASSII to the valence region explored at JLab12

→ final goal (together with the TMDs): wide-coverage, high-statistics mapping of the 5D nucleon structure