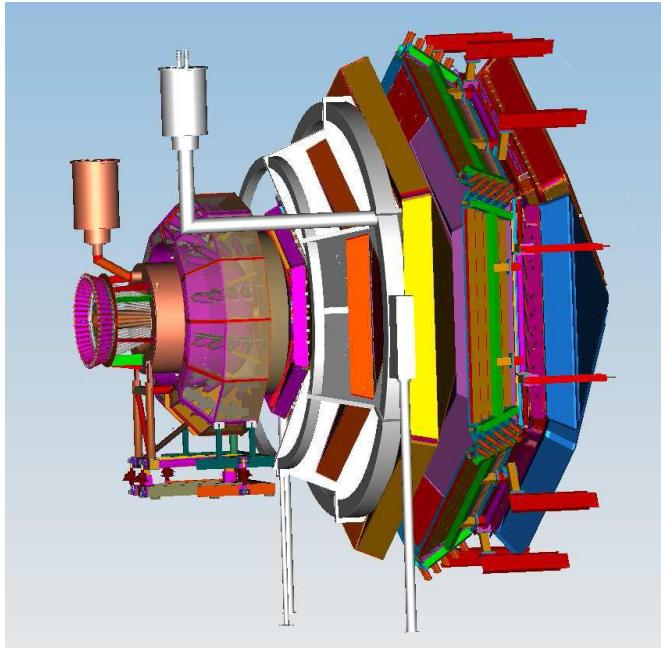
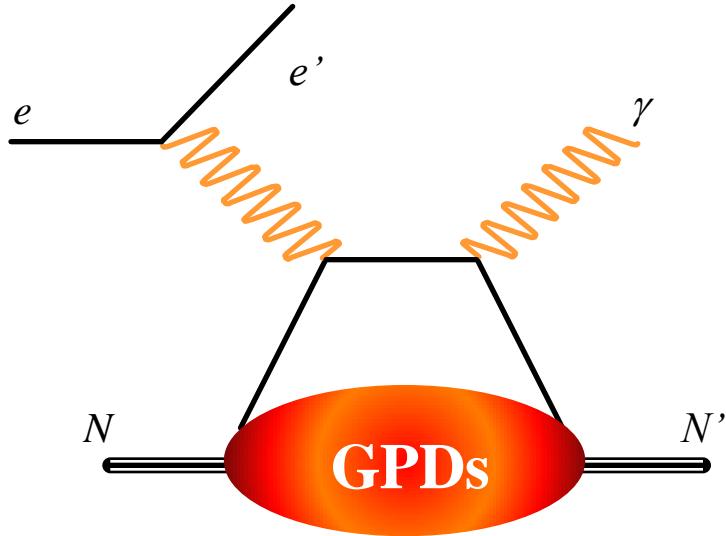


Experimental results on GPDs

*Silvia Niccolai, IPN Orsay
for the CLAS Collaboration*

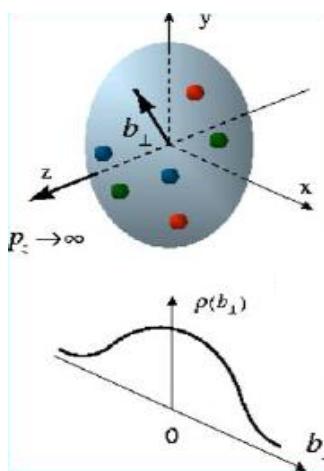
HIX2014, 20/11/2014, Frascati (Italia)



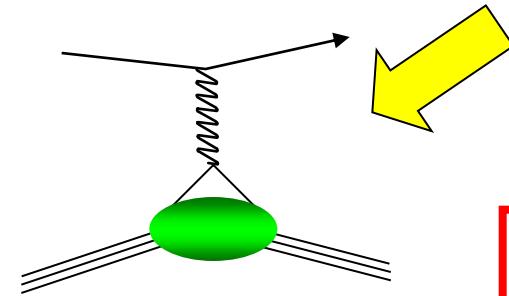
- Interest of GPDs
- GPDs and DVCS
- Recent DVCS results from Jefferson Lab
 - The JLab 12 GeV upgrade
 - Future experiments on DVCS



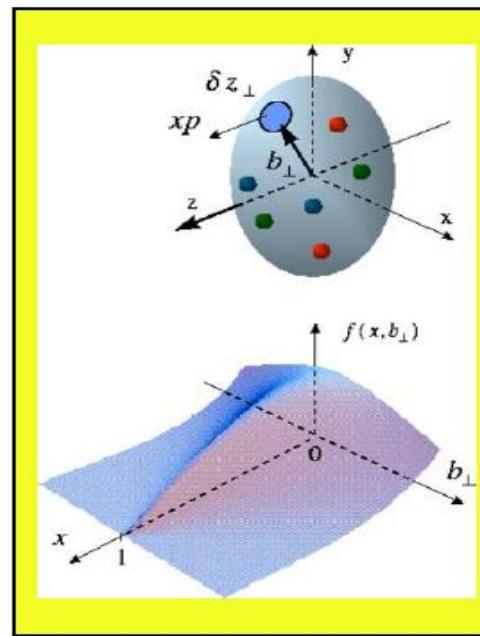
Electron-proton scattering to study nucleon structure



Form factors:
transverse quark distribution in coordinate space



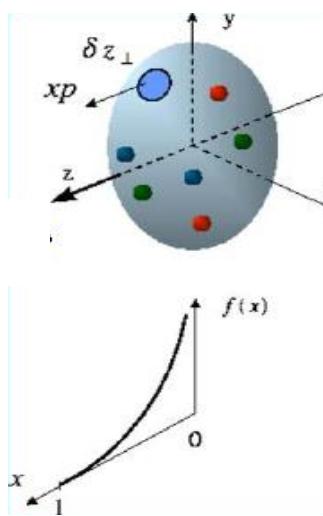
GPDs: $H, E, \tilde{H}, \tilde{E}$
Fully correlated quark distributions in both coordinate and momentum space



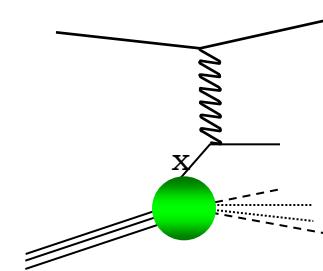
**Accessible in
hard exclusive processes**

$$\int H(x, \xi, t) dx = F_1(t) \quad (\forall \xi)$$

$$\int E(x, \xi, t) dx = F_2(t) \quad (\forall \xi)$$

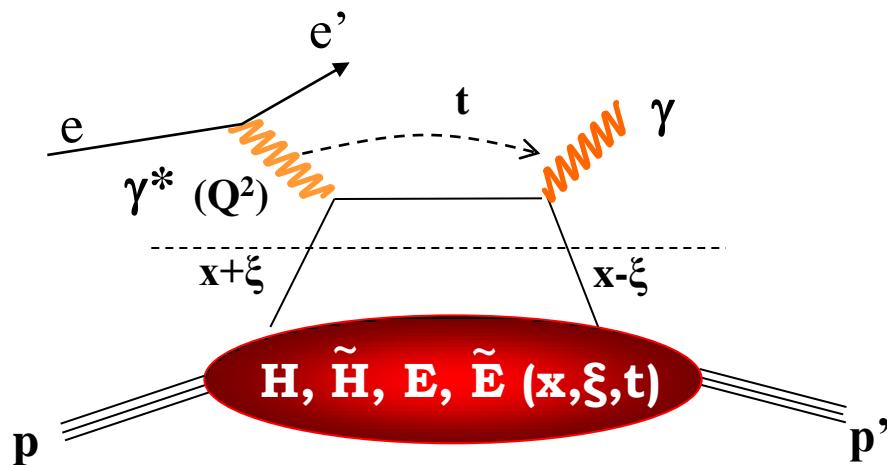


Parton distributions:
longitudinal quark distribution in momentum space



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

Deeply Virtual Compton Scattering and GPDs



- $Q^2 = -(\mathbf{e} - \mathbf{e}')^2$
- $x_B = Q^2/2Mv$ $v = E_e - E_{e'}$,
- $x + \xi, x - \xi$ longitudinal momentum fractions
- $t = (\mathbf{p} - \mathbf{p}')^2$
- $\xi \cong x_B / (2 - x_B)$

At leading order, leading twist, chiral-even,
quark sector
 $\rightarrow 4$ GPDs for each quark flavor

« Handbag » factorization valid
in the Bjorken regime:
high Q^2 , v (fixed x_B), $t \ll Q^2$

conserve nucleon spin

Vector: $H(x, \xi, t)$

Axial-Vector: $\tilde{H}(x, \xi, t)$

Tensor: $E(x, \xi, t)$

Pseudoscalar: $\tilde{E}(x, \xi, t)$

flip nucleon spin

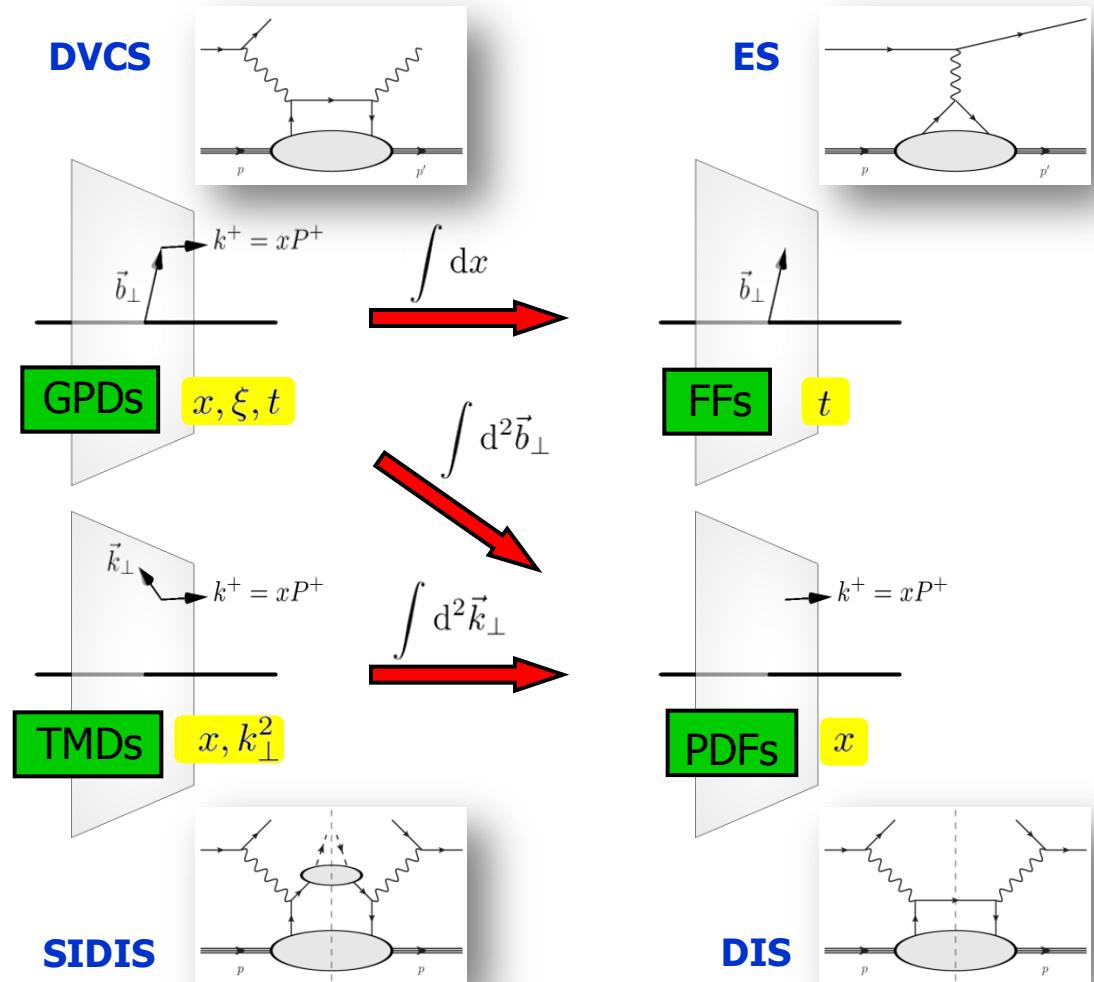
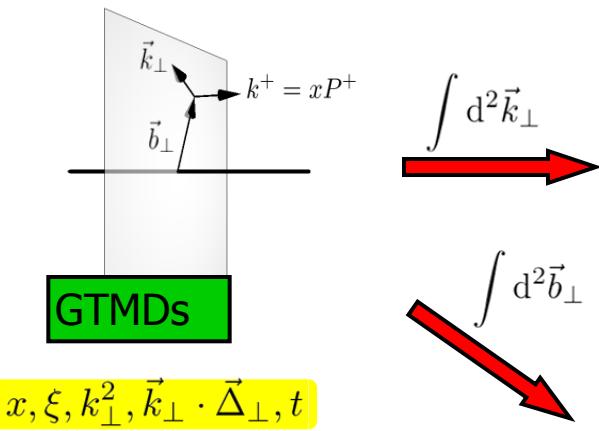
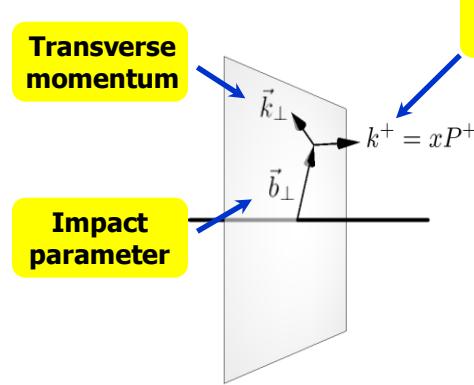
Quark angular momentum (Ji's sum rule)

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

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

«3D» quark/gluon
imaging of
the nucleon

Interplay between parton distributions and reaction channels



Thanks to C. Lorcé

Accessing GPDs through DVCS

$$\sigma(eN \rightarrow eN\gamma) = \left| \text{DVCS} + \frac{\text{Bethe-Heitler (BH)}}{2} \right|^2$$

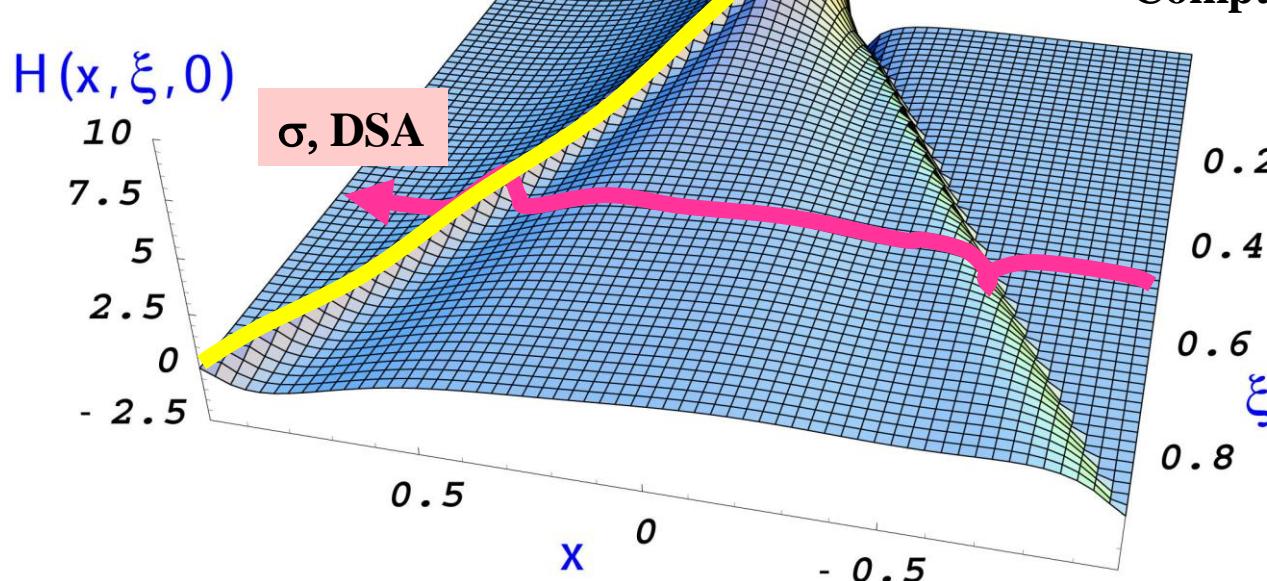
$\Delta\sigma = \sigma^+ - \sigma^- \propto I(\text{DVCS} \cdot \text{BH})$

$$A = \frac{\Delta\sigma}{2\sigma} \propto \frac{I(\text{DVCS} \cdot \text{BH})}{|\text{BH}|^2 + |\text{DVCS}|^2 + I}$$

$$T^{DVCS} \sim \int_{-1}^{+1} \frac{GPD(x, \xi, t)}{x \pm \xi + i\varepsilon} dx + \dots \sim P \int_{-1}^{+1} \frac{GPD(x, \xi, t)}{x \pm \xi} dx \pm i\pi GPD(\pm\xi, \xi, t) + \dots$$

$\Delta\sigma$

Real and imaginary parts of
Compton Form Factors

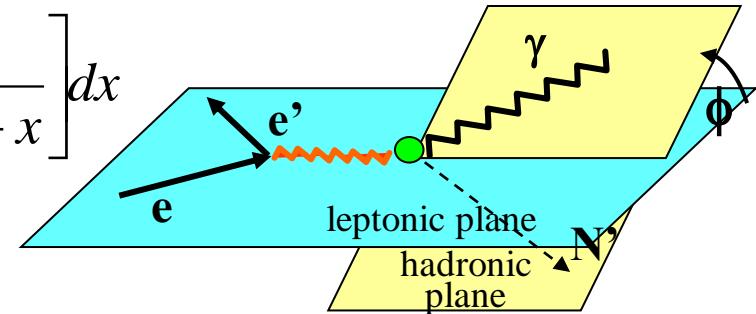


Only ξ and t
are accessible
experimentally

Sensitivity to GPDs of DVCS spin observables

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

$$Im\mathcal{H}_q = \pi e_q^2 \left[H^q(\xi, \xi, t) - H^q(-\xi, \xi, t) \right]$$

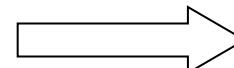


$$\xi = x_B / (2 - x_B) \quad k = -t / 4M^2$$

Proton Neutron

Polarized beam, unpolarized target:

$$\Delta\sigma_{LU} \sim \sin\phi \operatorname{Im}\{F_1 \mathcal{H} + \xi(F_1 + F_2) \tilde{\mathcal{H}} - kF_2 \mathcal{E}\} d\phi$$



$$\begin{aligned} & Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p, \mathcal{E}_p\} \\ & Im\{\mathcal{H}_n, \tilde{\mathcal{H}}_n, \mathcal{E}_n\} \end{aligned}$$

Unpolarized beam, longitudinal target:

$$\Delta\sigma_{UL} \sim \sin\phi \operatorname{Im}\{F_1 \tilde{\mathcal{H}} + \xi(F_1 + F_2)(\mathcal{H} + x_B/2\mathcal{E}) - \xi kF_2 \tilde{\mathcal{E}} + \dots\} d\phi$$

$$\begin{aligned} & Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\} \\ & Im\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\} \end{aligned}$$

Polarized beam, longitudinal target:

$$\Delta\sigma_{LL} \sim (A + B\cos\phi) \operatorname{Re}\{F_1 \tilde{\mathcal{H}} + \xi(F_1 + F_2)(\mathcal{H} + x_B/2\mathcal{E}) + \dots\} d\phi$$

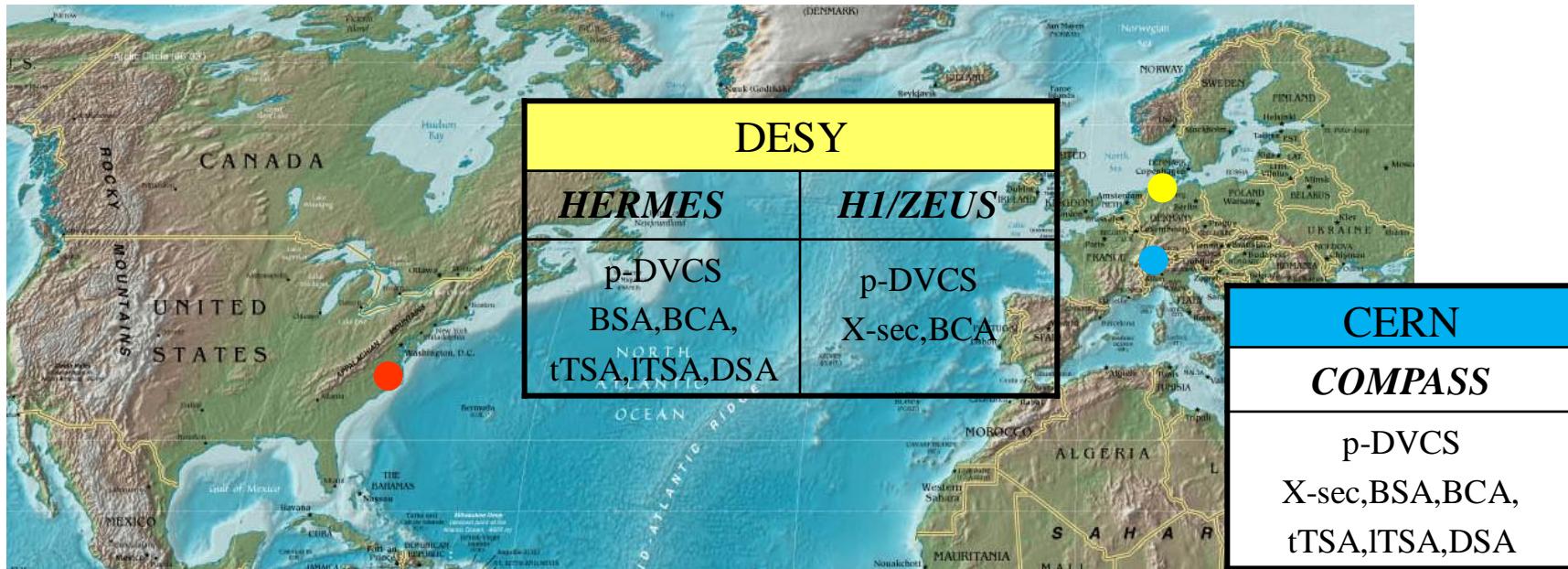
$$\begin{aligned} & Re\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\} \\ & Re\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\} \end{aligned}$$

Unpolarized beam, transverse target:

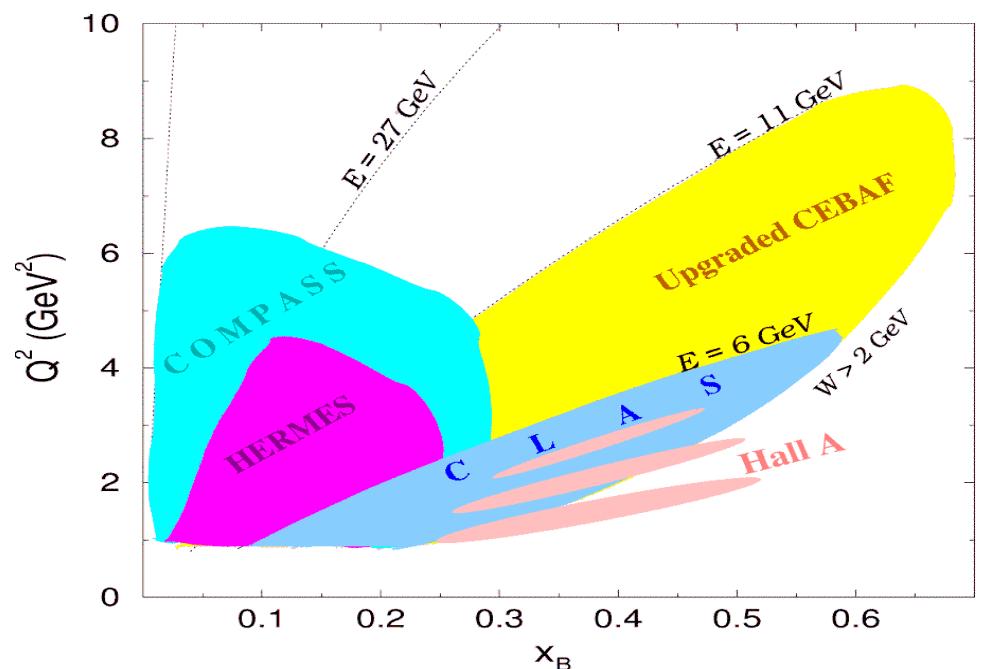
$$\Delta\sigma_{UT} \sim \sin\phi \operatorname{Im}\{k(F_2 \mathcal{H} - F_1 \mathcal{E}) + \dots\} d\phi$$

$$\begin{aligned} & Im\{\mathcal{H}_p, \mathcal{E}_p\} \\ & Im\{\mathcal{H}_n\} \end{aligned}$$

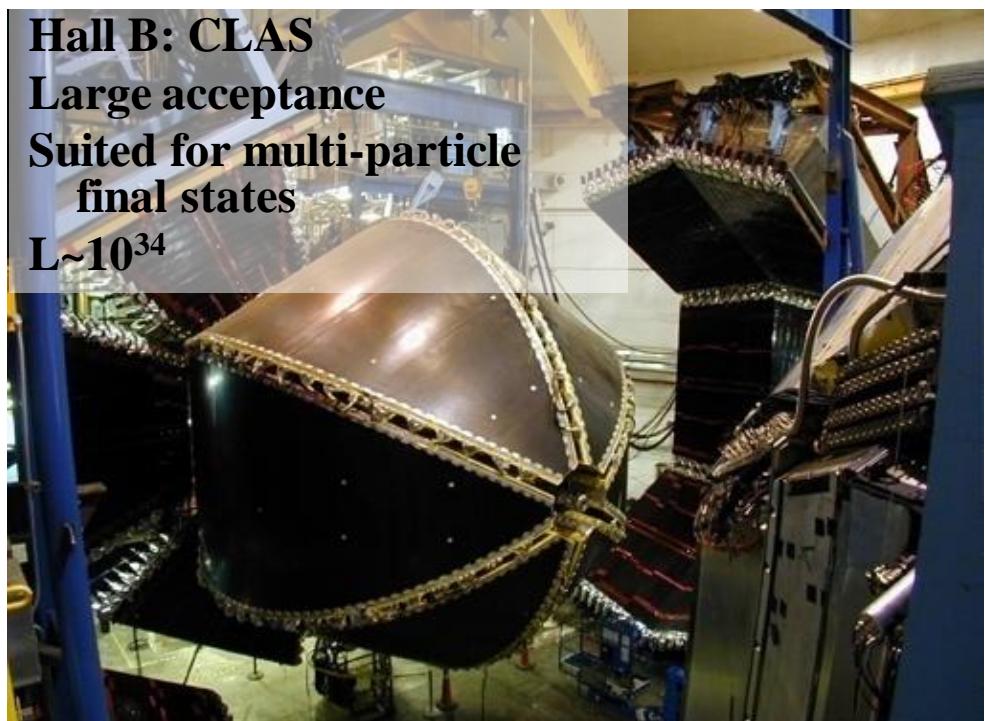
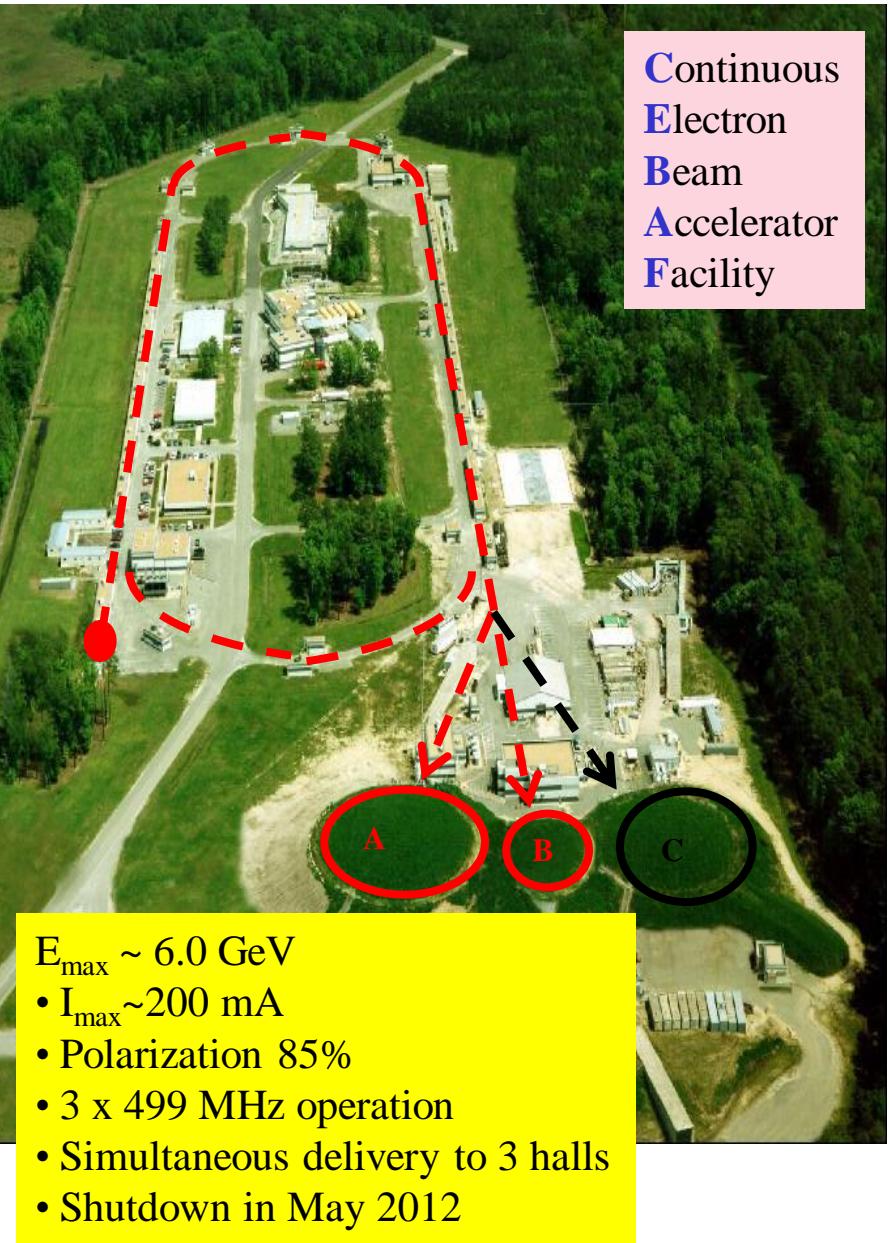
DVCS experiments worldwide



JLAB	
<i>Hall A</i>	<i>Hall B</i>
p,n-DVCS (Bpol.) X-sec	p-DVCS BSA,ITSA,DSA,X-sec



JLab@6 GeV

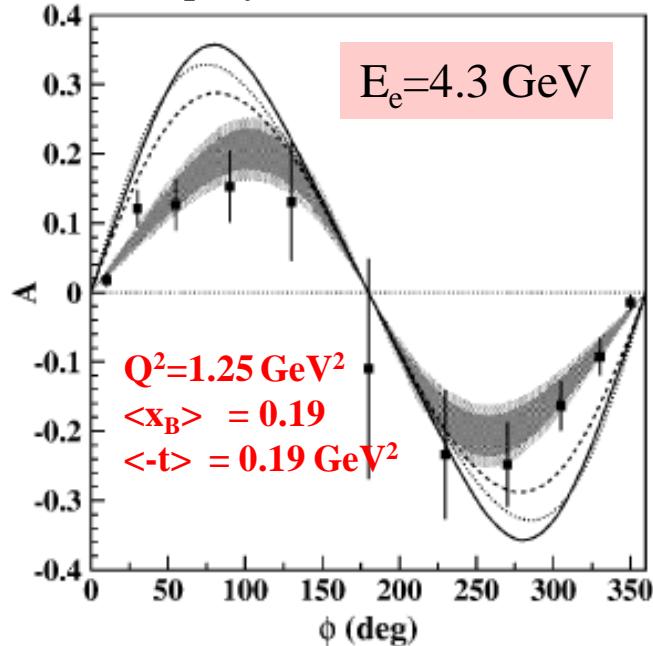


DVCS @ CLAS: first pioneering results

NON-DEDICATED experiments

$\text{ep} \rightarrow \text{epX}$

S. Stepanyan et al., PRL 87 (2001)



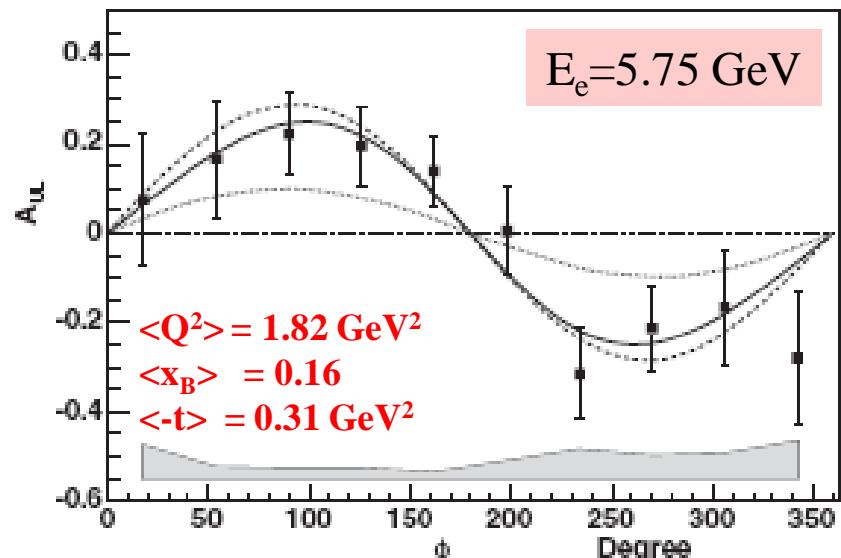
$$\text{BSA} \sim \text{Im}\{\mathcal{H}_p, \tilde{\mathcal{H}}_p, E_p\}$$

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

$\beta/\alpha \ll 1 \rightarrow \text{twist-2 (handbag) dominance}$

$\text{ep} \rightarrow \text{ep}\gamma$

S. Chen et al., PRL 97 (2006)



$$\text{TSA} \sim \text{Im}\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$$

**BSA, BCA and TSA (T & L) at HERMES:
handbag dominance confirmed**

Low statistics

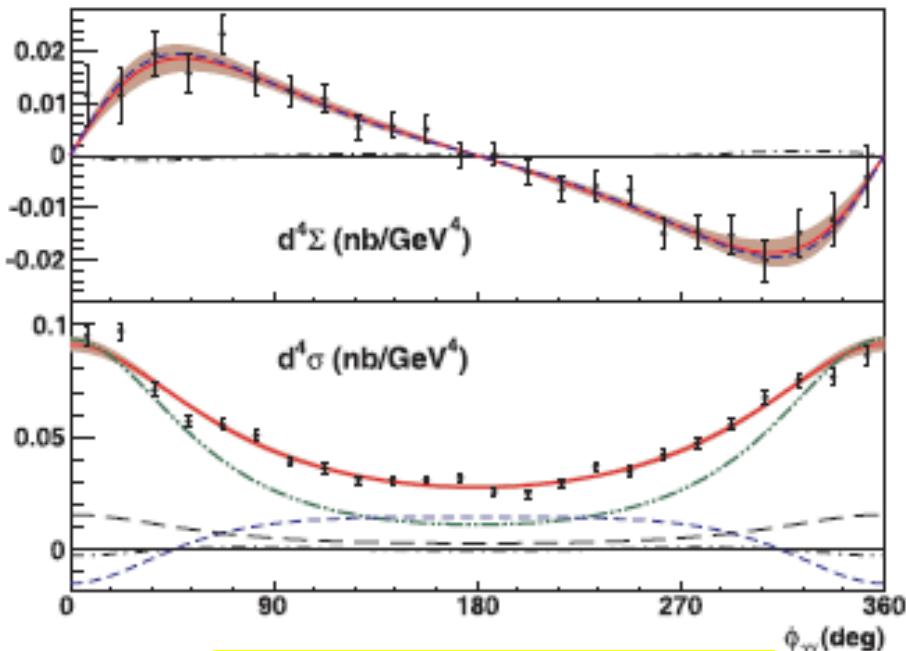
Limited kinematics

Uncertainties on determination of epy final state

Hall A (JLab): first dedicated DVCS experiment

$e p \rightarrow e \gamma X$

Polarized cross section difference



Unpolarized cross section

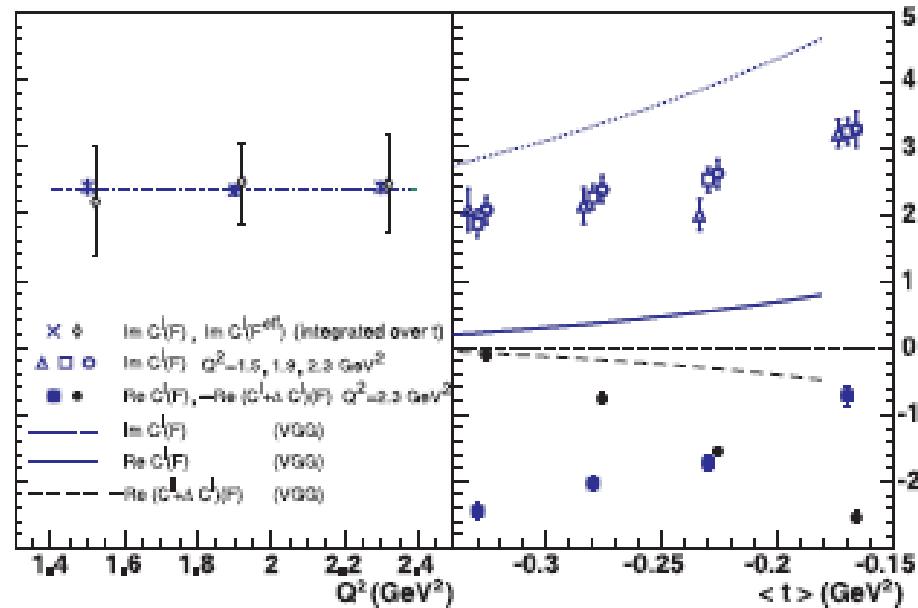
$$\langle Q^2, -t \rangle = (2.3, -0.28)$$

- Fit
- · — $|BH|^2$
- - - - Interference BH-DVCS

C.M. Camacho et al., PRL 97 (2006)

Q^2 evolution → evidence for scaling

(small Q^2 range)



Formalism of Belitsky, Mueller, Kirchner

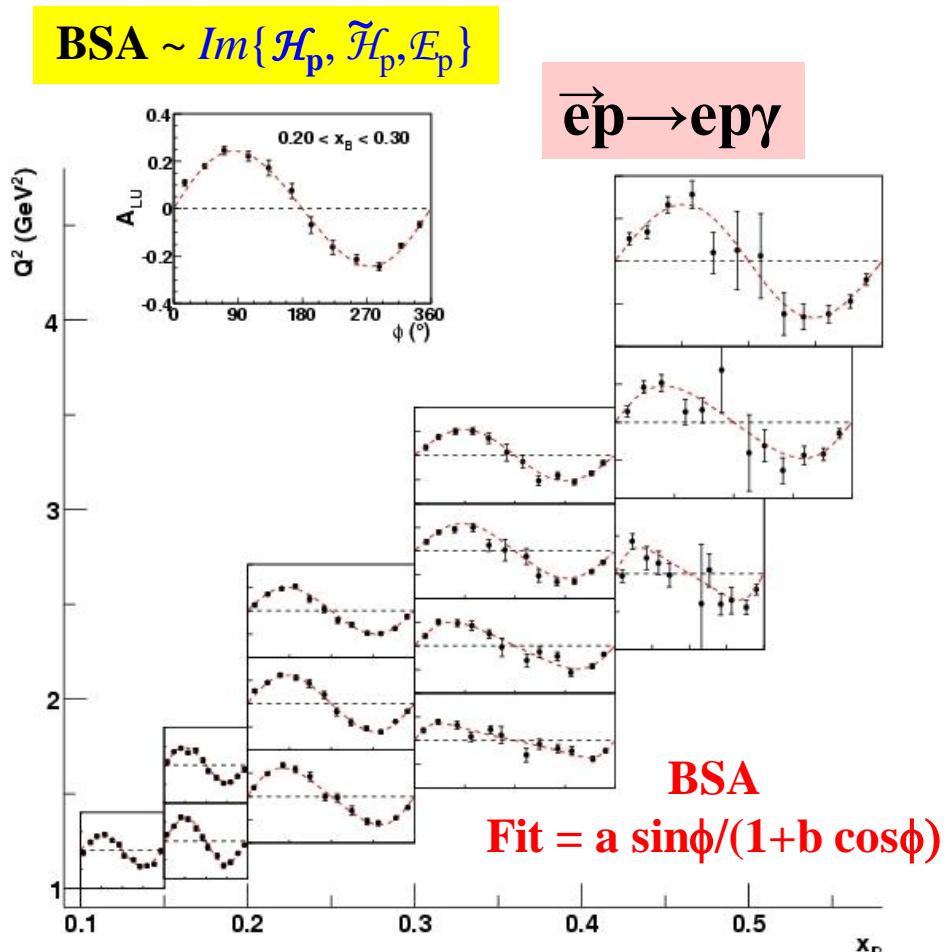
High resolution → exclusivity
High luminosity → precision
Limited phase space

The CLAS e1-DVCS experiment

Part 1 of the e1-DVCS experiment:

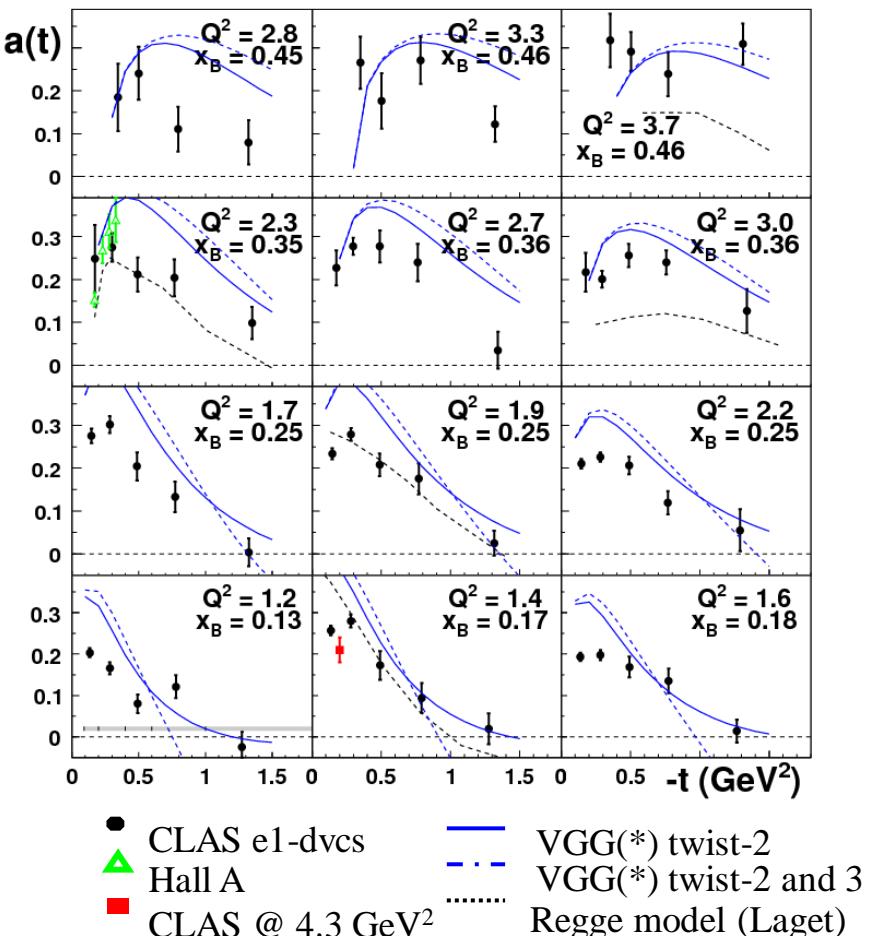
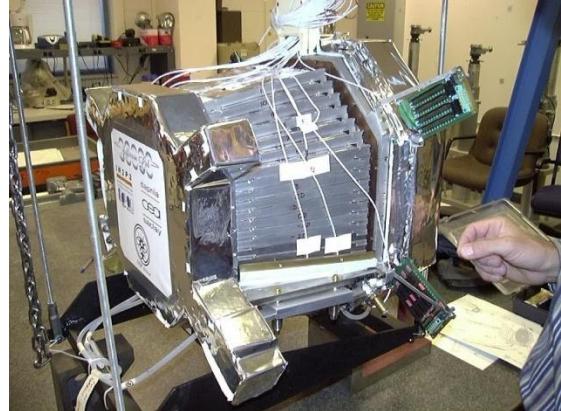
- Data taken in the spring **2005**
- Beam energy $\sim 5.75 \text{ GeV}$
- Beam polarization $\sim 80\%$
- Target **LH₂**

(More data taken in 2008, under analysis)

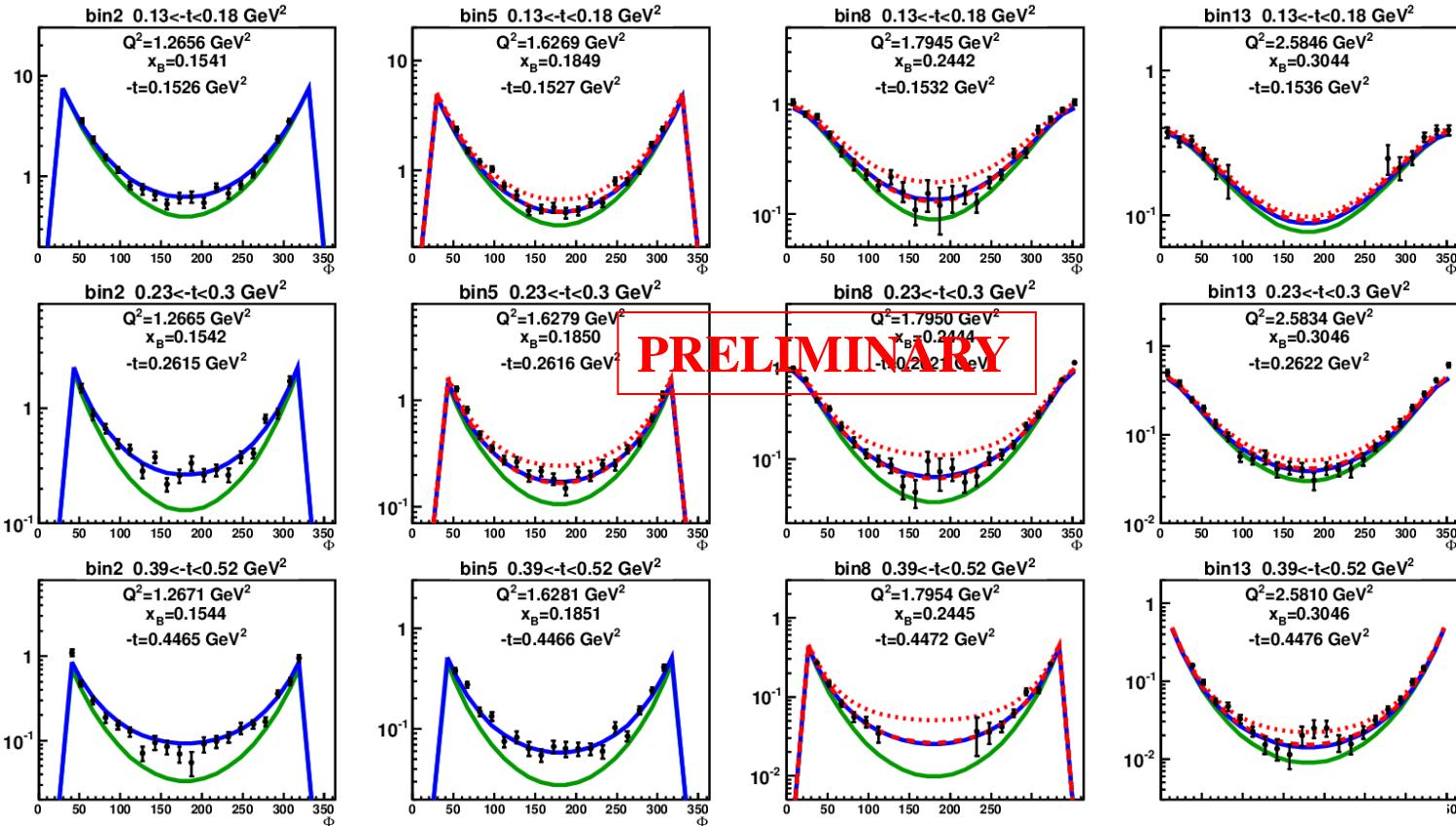


Added to the standard CLAS

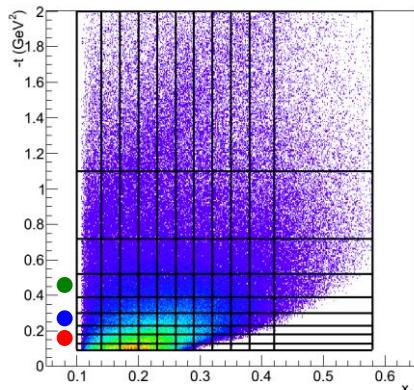
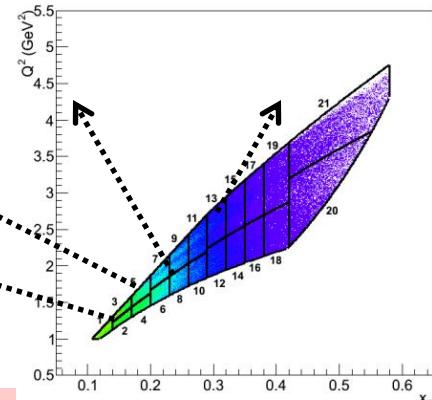
- ✓ Solenoid magnet +
- ✓ IC (inner calorimeter): 424 lead-tungstate crystals + APD readout



CLAS e1-dvcs: DVCS cross sections



$\bullet \frac{d^4\sigma_{ep \rightarrow ep\gamma}}{dQ^2 dx_B dt d\Phi} (\text{nb}/\text{GeV}^4)$
— BH — VGG (H only)
... KM10 --- KM10a

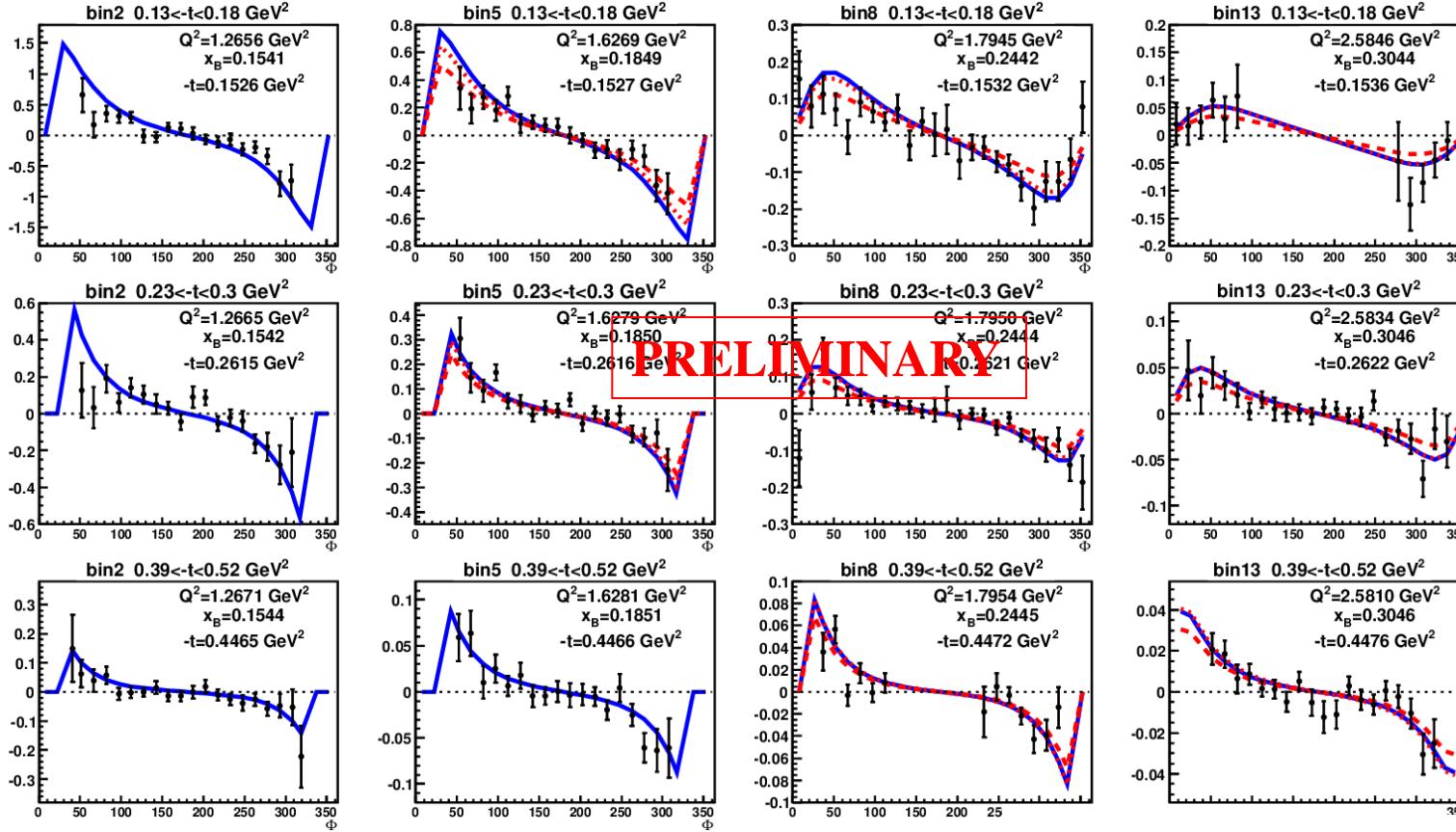


Same amount of statistics will come from e1-dvcs2

21 Q^2 - x_B bins, 9 t bins, 24 ϕ bins

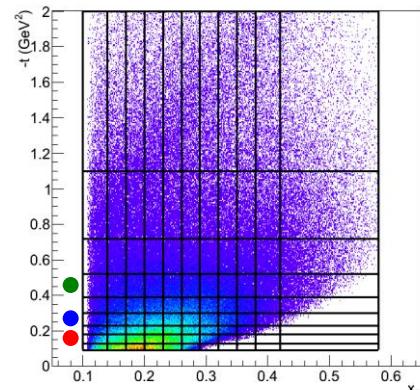
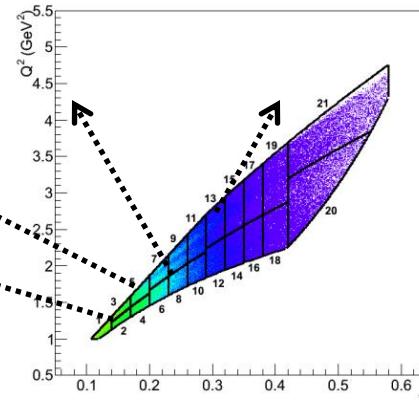
CLAS e1-dvcs: DVCS cross section differences

Work by H.S. Jo



$$\frac{d^4\sigma_{ep \rightarrow ep\gamma}}{dQ^2 dx_B dt d\Phi} (\text{nb}/\text{GeV}^4)$$

● BH — VGG (H only)
····· KM10 --- KM10a



$$\Delta\sigma_{LU} \sim \sin\phi \operatorname{Im}\{F_1 \mathcal{H} + \xi(F_1 + F_2) \tilde{\mathcal{H}} - kF_2 \mathcal{E}\} d\phi$$

Extraction of Compton Form Factors from DVCS observables

8 CFF

$$\left\{
 \begin{array}{l}
 \text{Re}(\mathcal{H}) = P \int_0^1 dx [H(x, \xi, t) - H(-x, \xi, t)] C^+(x, \xi) \\
 \text{Re}(E) = P \int_0^1 dx [E(x, \xi, t) - E(-x, \xi, t)] C^+(x, \xi) \\
 \text{Re}(\tilde{\mathcal{H}}) = P \int_0^1 dx [\tilde{H}(x, \xi, t) + \tilde{H}(-x, \xi, t)] C^-(x, \xi) \\
 \text{Re}(\tilde{E}) = P \int_0^1 dx [\tilde{E}(x, \xi, t) + \tilde{E}(-x, \xi, t)] C^-(x, \xi) \\
 \text{Im}(\mathcal{H}) = H(\xi, \xi, t) - H(-\xi, \xi, t) \\
 \text{Im}(E) = E(\xi, \xi, t) - E(-\xi, \xi, t) \\
 \text{Im}(\tilde{\mathcal{H}}) = \tilde{H}(\xi, \xi, t) - \tilde{H}(-\xi, \xi, t) \\
 \text{Im}(\tilde{E}) = \tilde{E}(\xi, \xi, t) - \tilde{E}(-\xi, \xi, t)
 \end{array}
 \right.$$

with $C^\pm(x, \xi) = \frac{1}{x - \xi} \pm \frac{1}{x + \xi}$

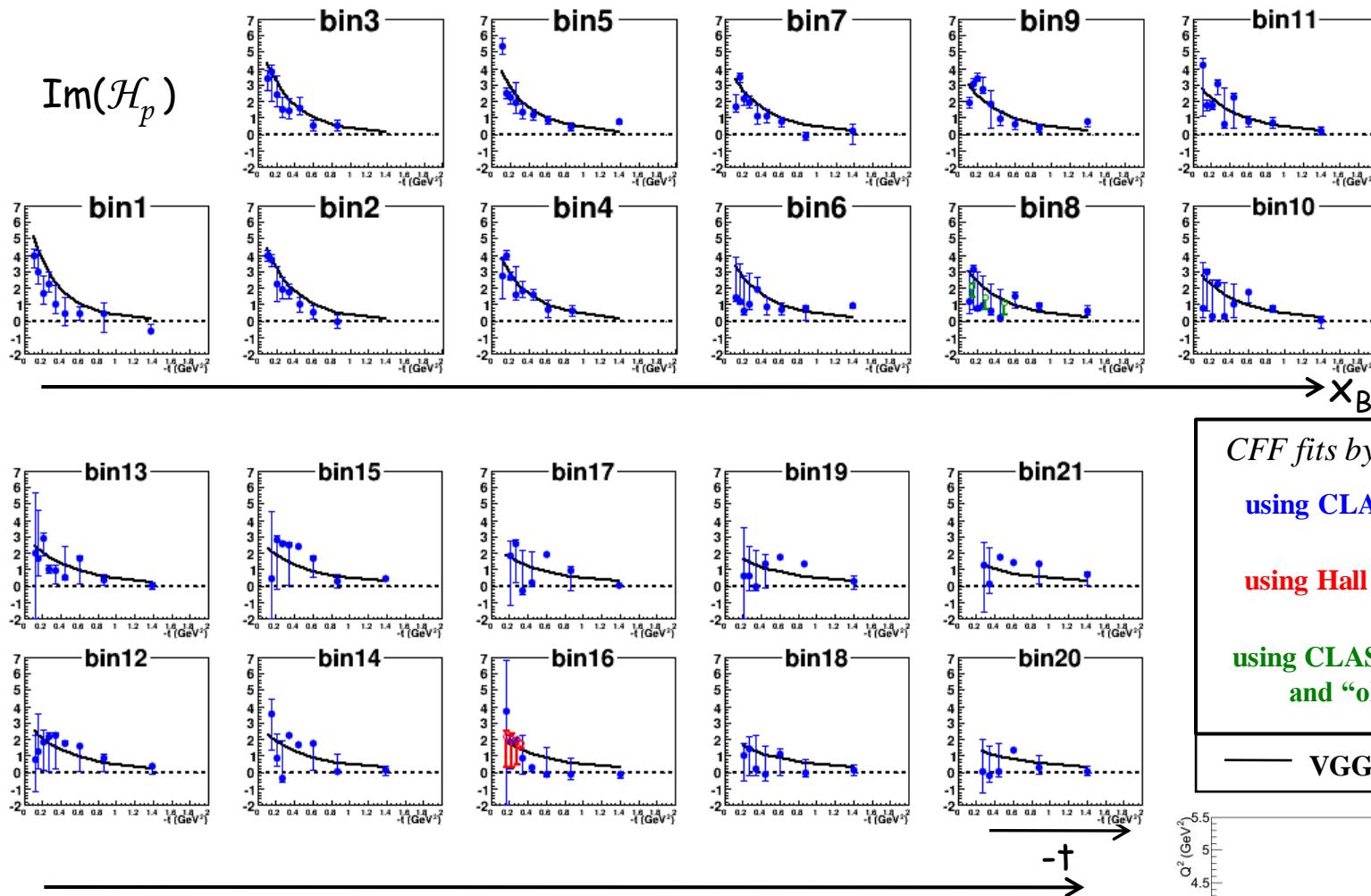
M. Guidal: **Model-independent fit**, at fixed Q^2 , x_B and t of DVCS observables

8 unknowns (the CFFs), non-linear problem, strong correlations

Bounding the domain of variation of the CFFs with model (5xVGG)

M. Guidal, Eur. Phys. J. A 37 (2008) 319

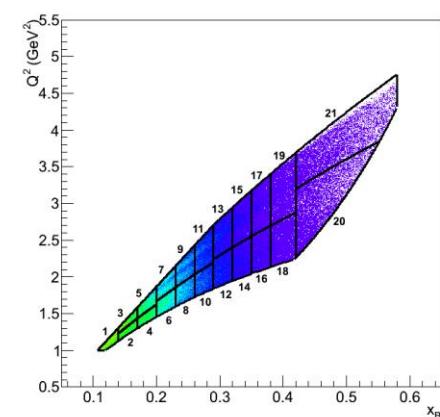
Extraction of CFF from CLAS DVCS pol. and unpol. cross sections



PRELIMINARY

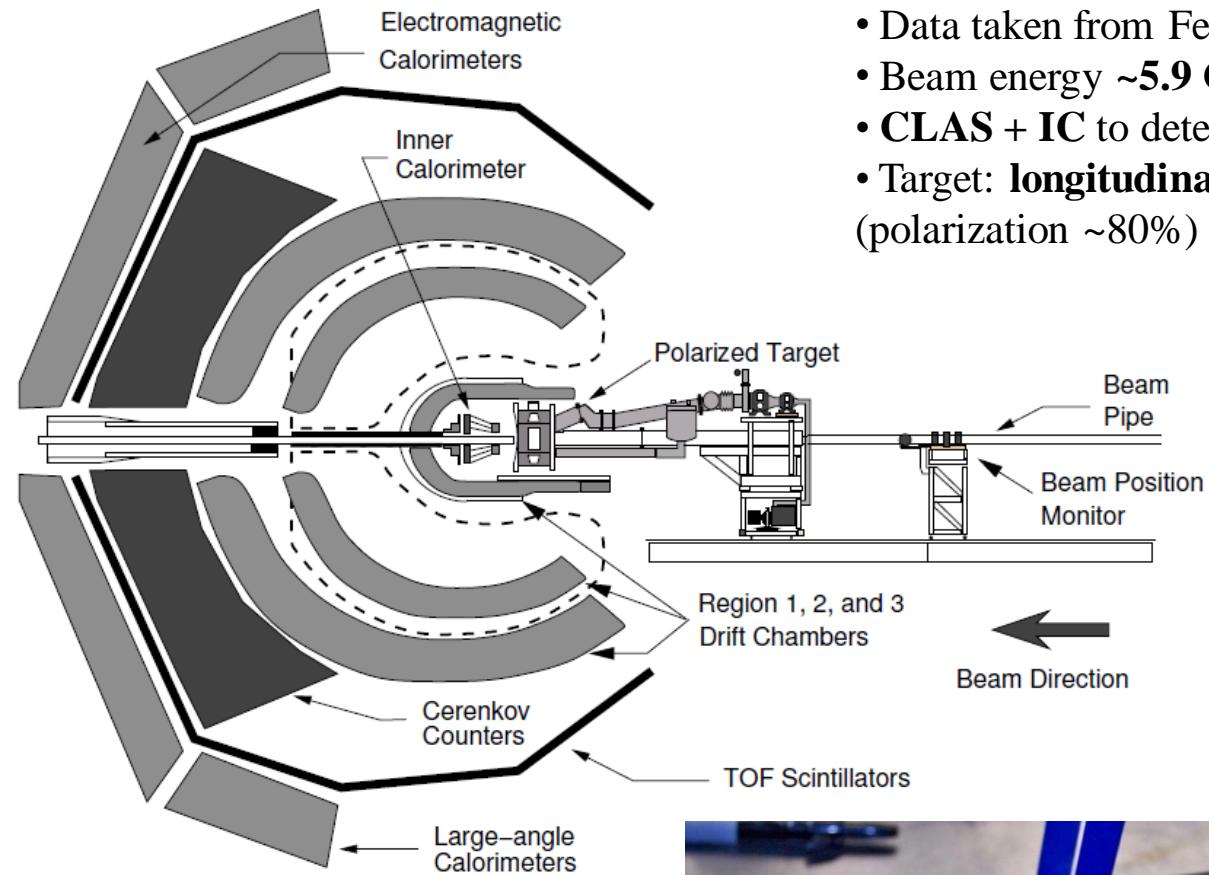
$\text{Im}(\mathcal{H}_p)$, flatter t slope at high x_B : faster quarks (valence) at the core of the nucleon, slower quarks (sea) at its periphery

*CFF fits by M. Guidal
using CLAS DVCS c.s.
using Hall A DVCS c.s.
using CLAS DVCS BSA
and “old” TSA
— VGG predictions*



The CLAS eg1-dvcs experiment

$\vec{e}\vec{p} \rightarrow e\gamma$



Analysis by:

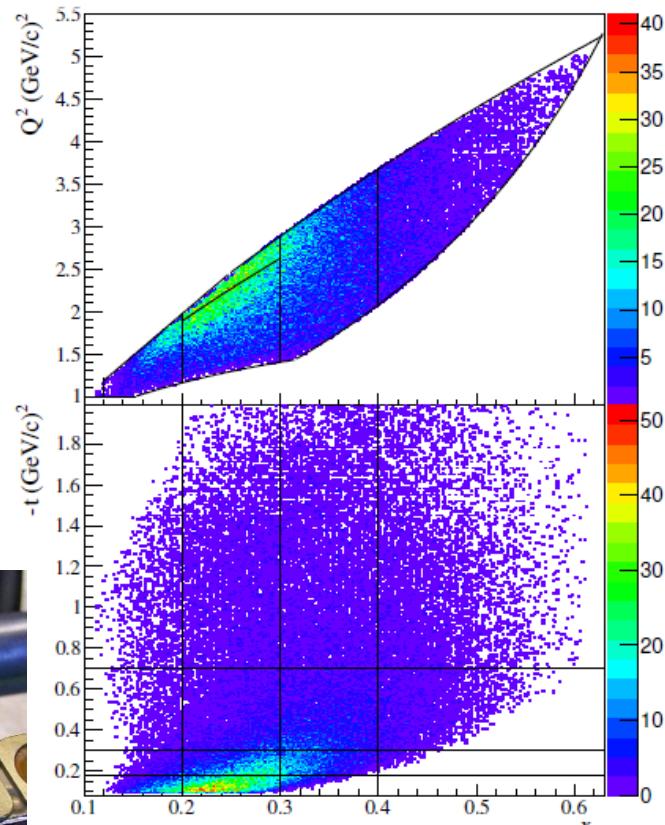
E. Seder, U Connecticut

S. Pisano, INFNFR

A. Biselli, Fairfield U

S. Niccolai, IPNO

- Data taken from February to September **2009**
- Beam energy ~ 5.9 GeV
- CLAS + IC to detect forward photons
- Target: **longitudinally polarized NH₃** (polarization $\sim 80\%$)



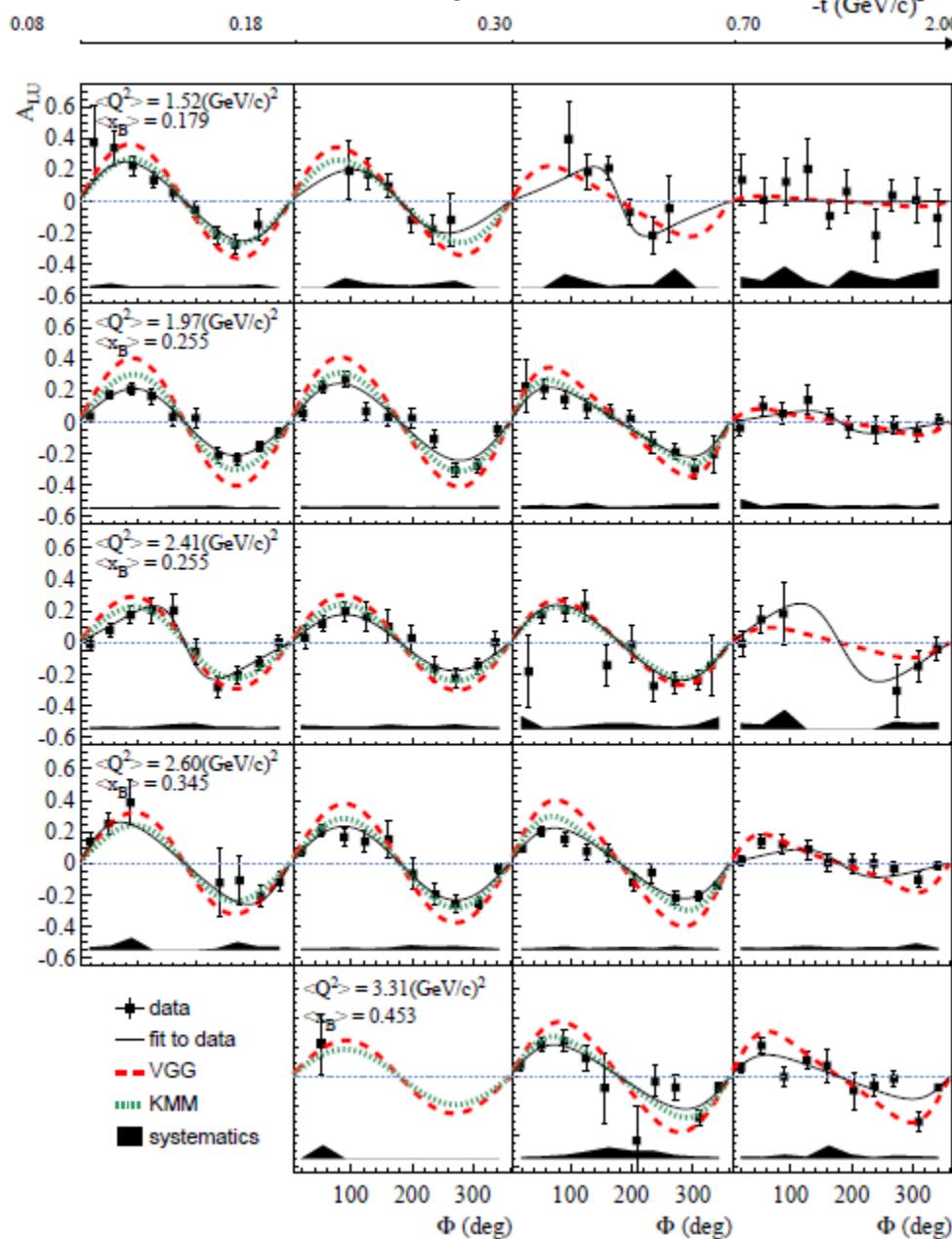
- 5 Q^2 - x_B bins
- 4 t bins
- 10 ϕ bins

Also: ongoing BSA and TSA for nDVCS

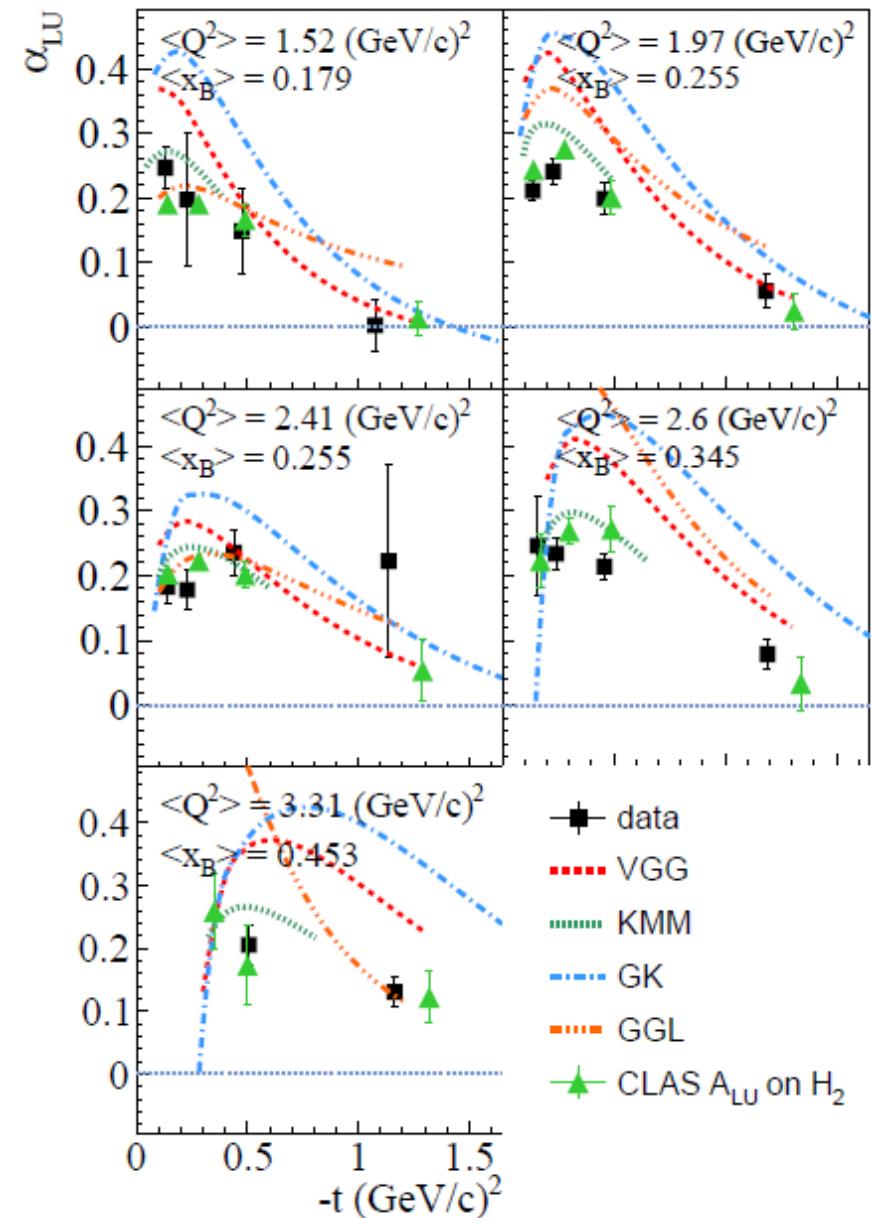
(D. Sokhan, Glasgow U)

Beam-spin asymmetry from the CLAS eg1-dvcs data

Fit: $\alpha_{LU} \sin\phi / (1 + \beta \cos\phi)$

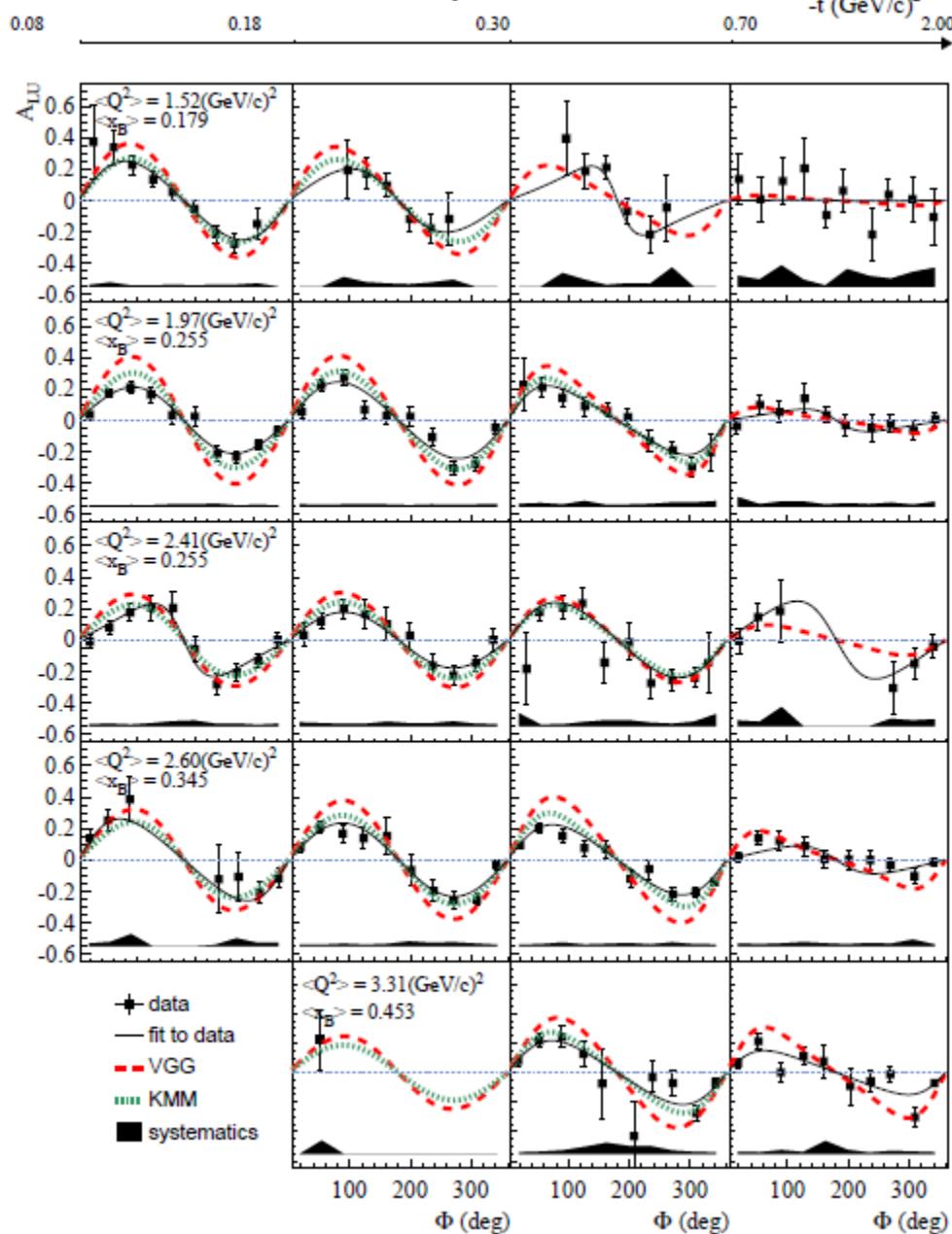


$$\alpha_{LU} \sim \text{Im}\{\mathcal{H}_p\}$$

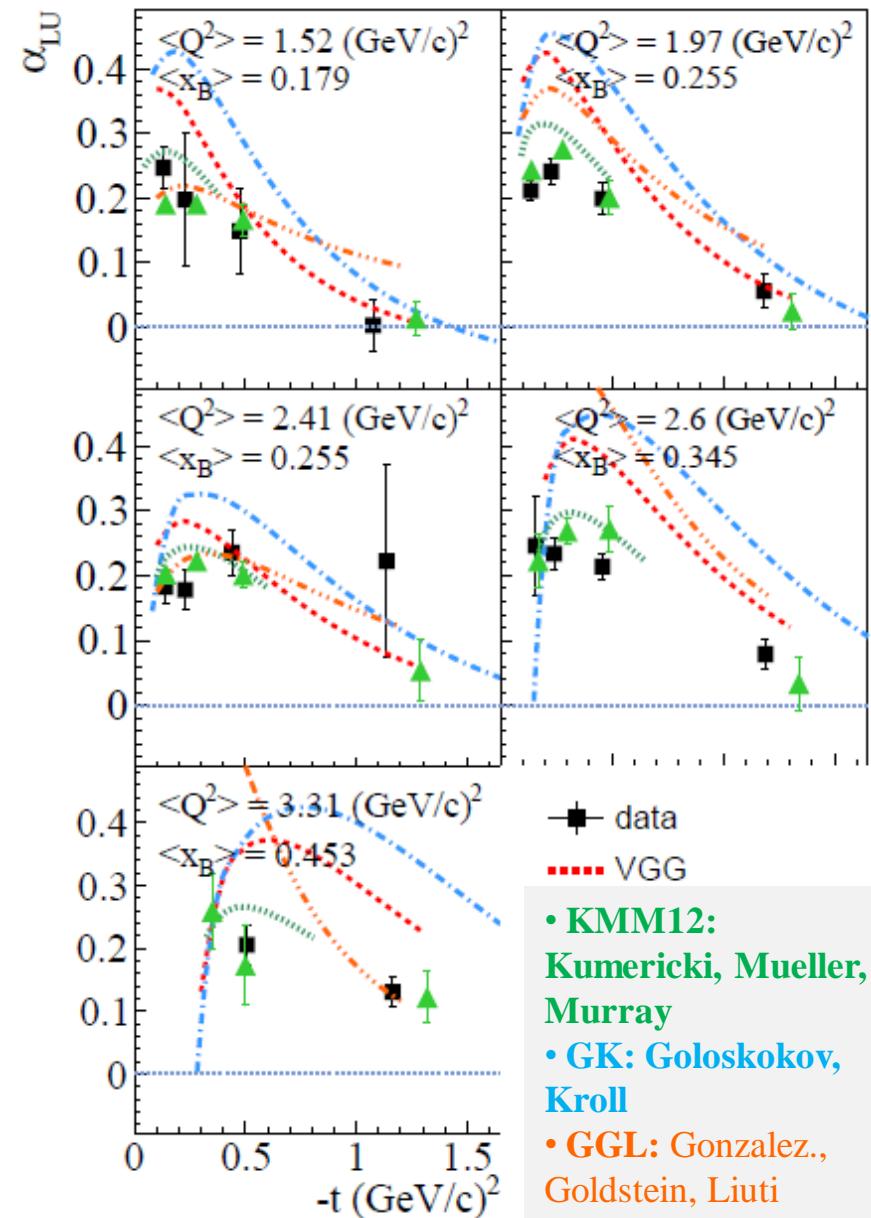


Beam-spin asymmetry from the CLAS eg1-dvcs data

Fit: $\alpha_{LU} \sin\phi / (1 + \beta \cos\phi)$



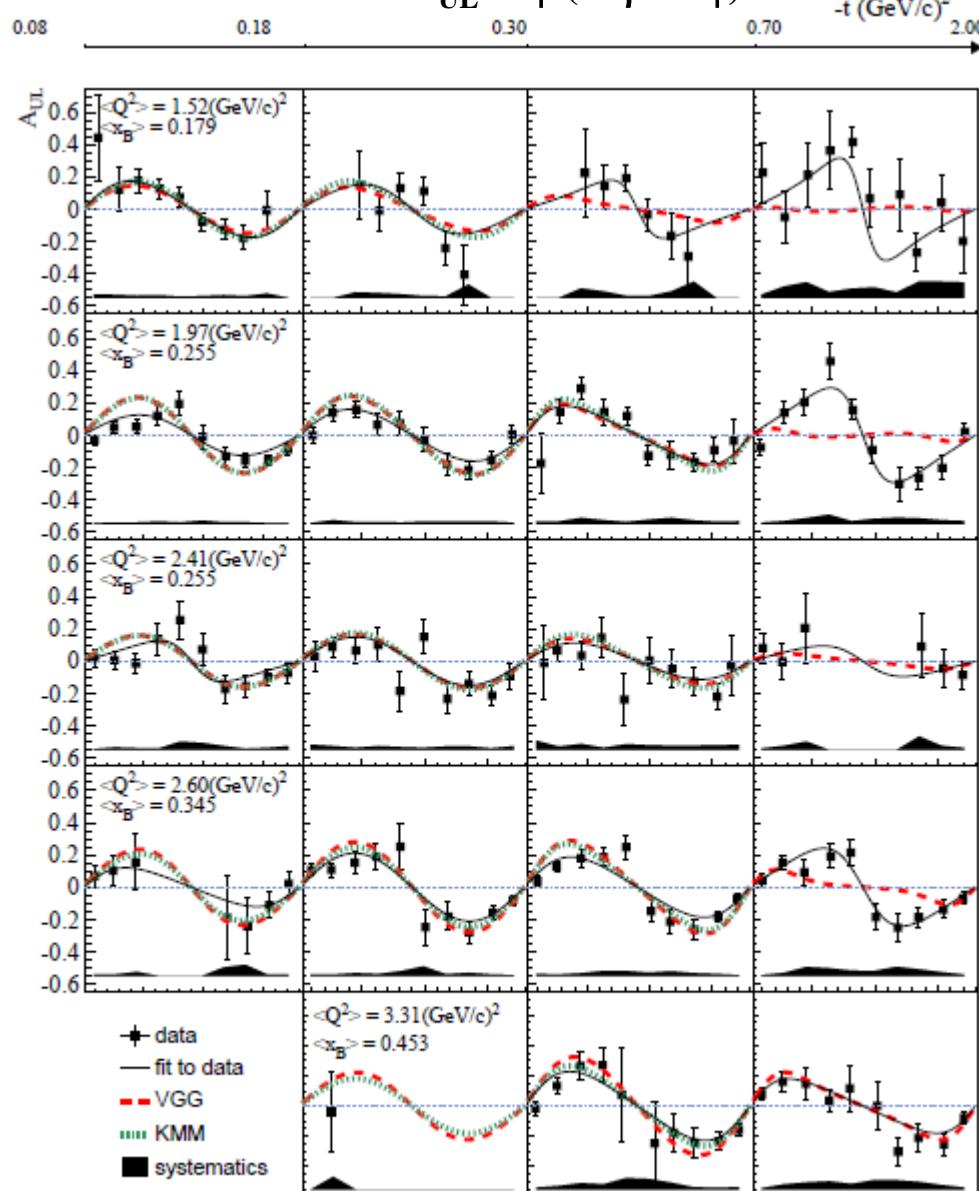
$$\alpha_{LU} \sim \text{Im}\{\mathcal{H}_p\}$$



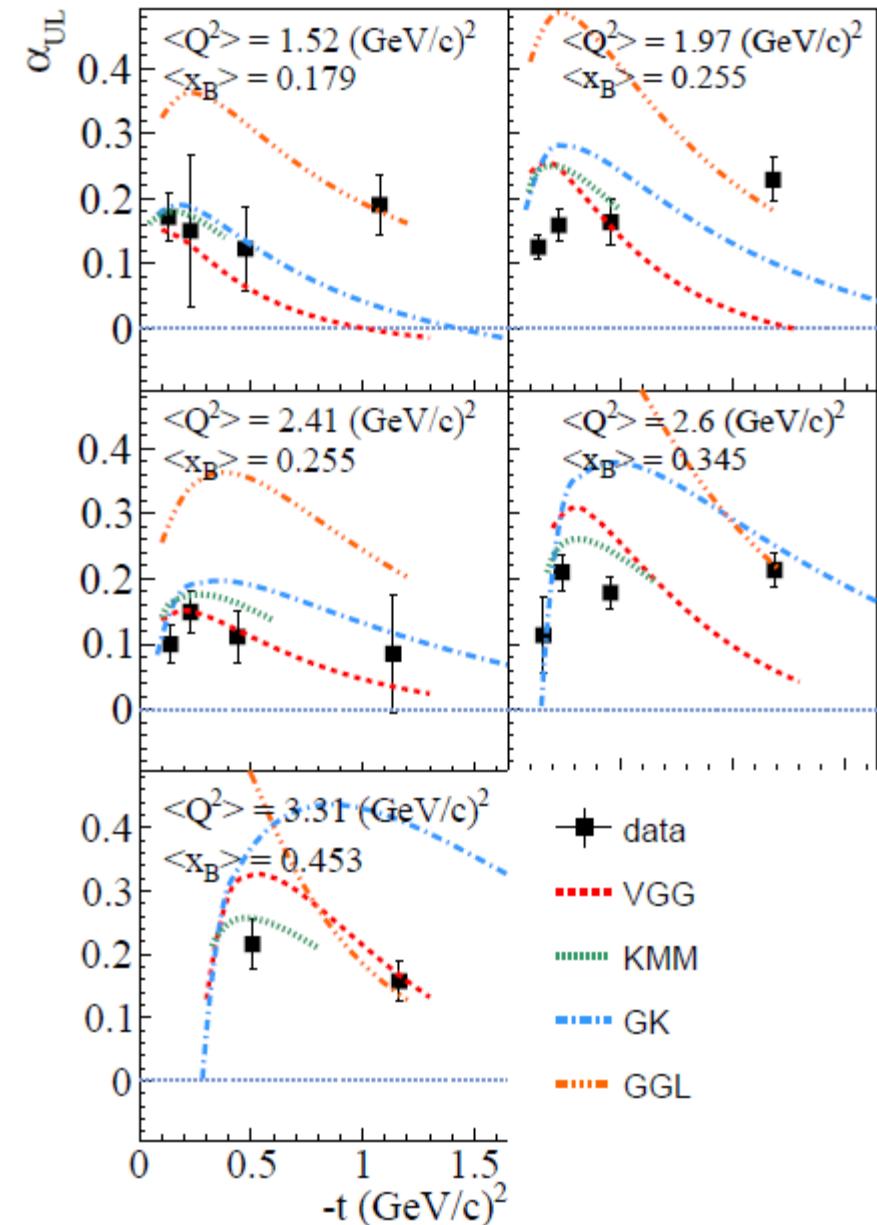
- **KMM12:** Kumericki, Mueller, Murray
- **GK:** Goloskokov, Kroll
- **GGL:** Gonzalez., Goldstein, Liuti

Target-spin asymmetry from the CLAS eg1-dvcs data

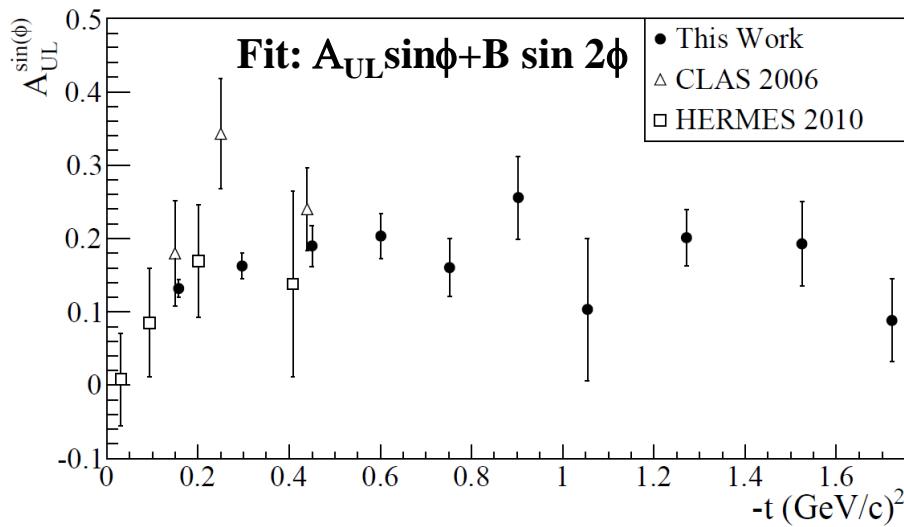
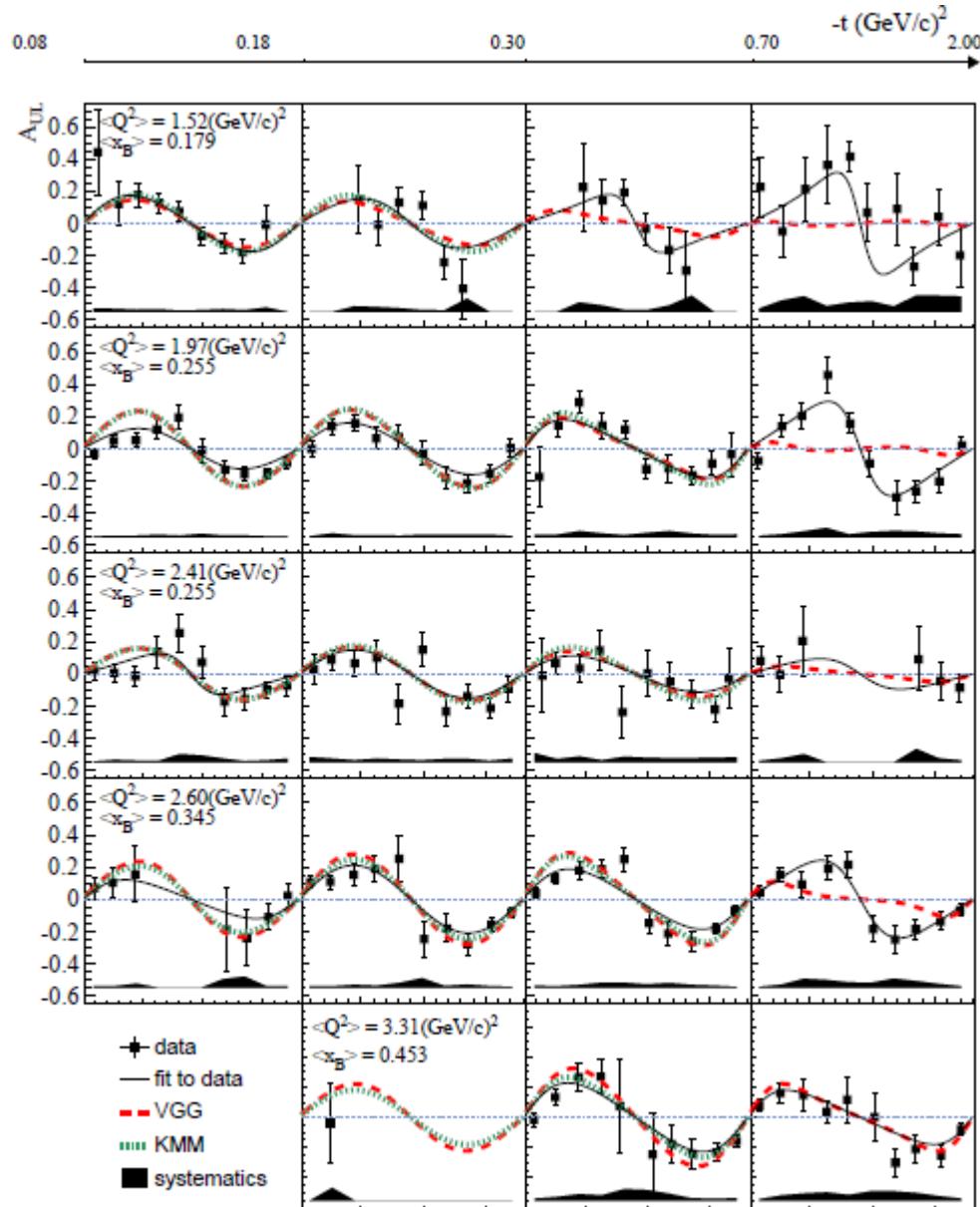
Fit: $\alpha_{UL} \sin\phi / (1 + \beta \cos\phi)$



$$\alpha_{UL} \sim \text{Im}\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$$



Target-spin asymmetry from the CLAS eg1-dvcs data



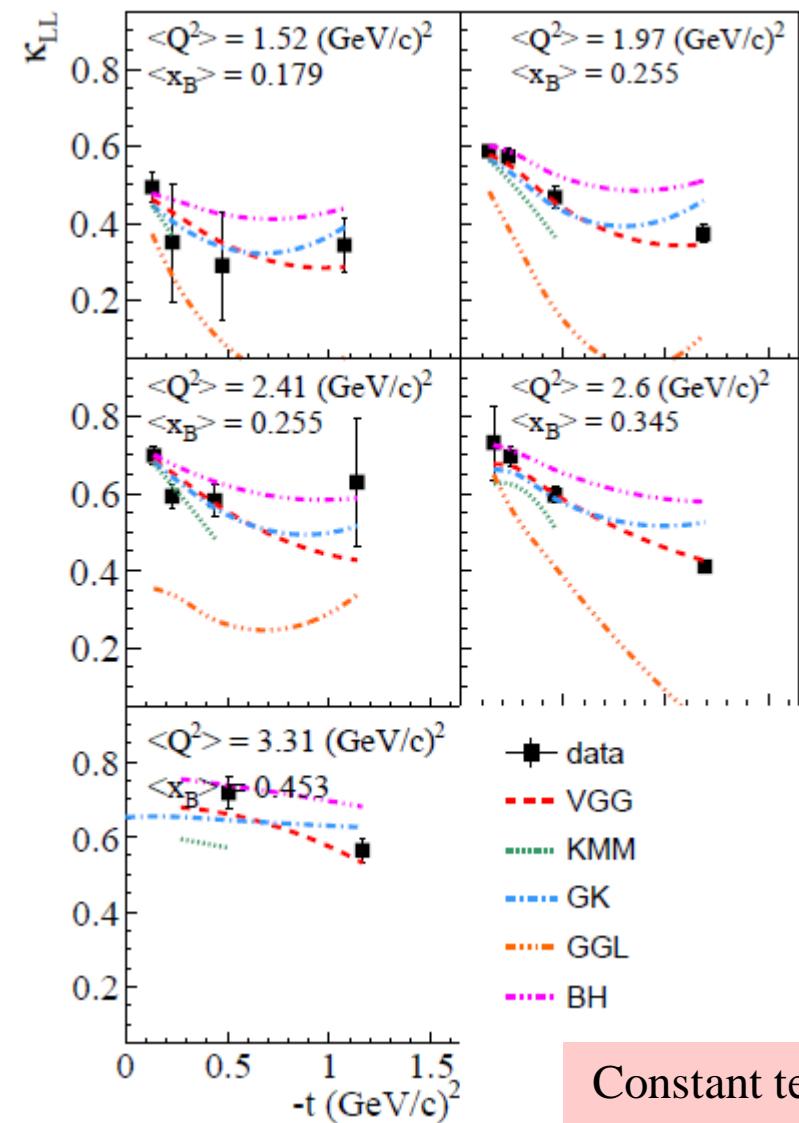
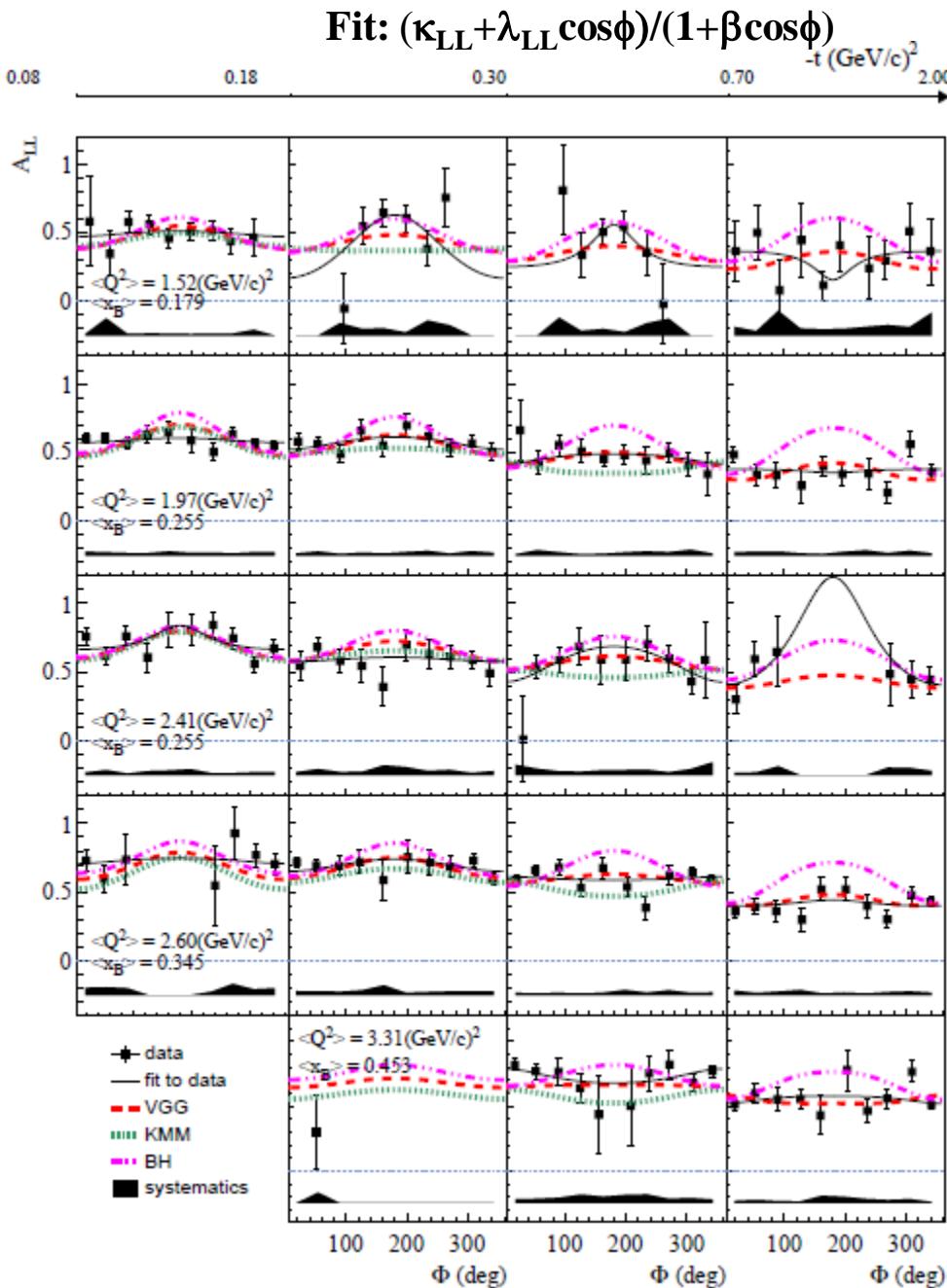
CLAS: $\langle Q^2 \rangle = 2.4 (\text{GeV}/c)^2, \langle x_B \rangle = 0.31$

HERMES: $\langle Q^2 \rangle = 2.459 (\text{GeV}/c)^2, \langle x_B \rangle = 0.096$

CLAS2006: $\langle Q^2 \rangle = 1.82 (\text{GeV}/c)^2, \langle x_B \rangle = 0.28$

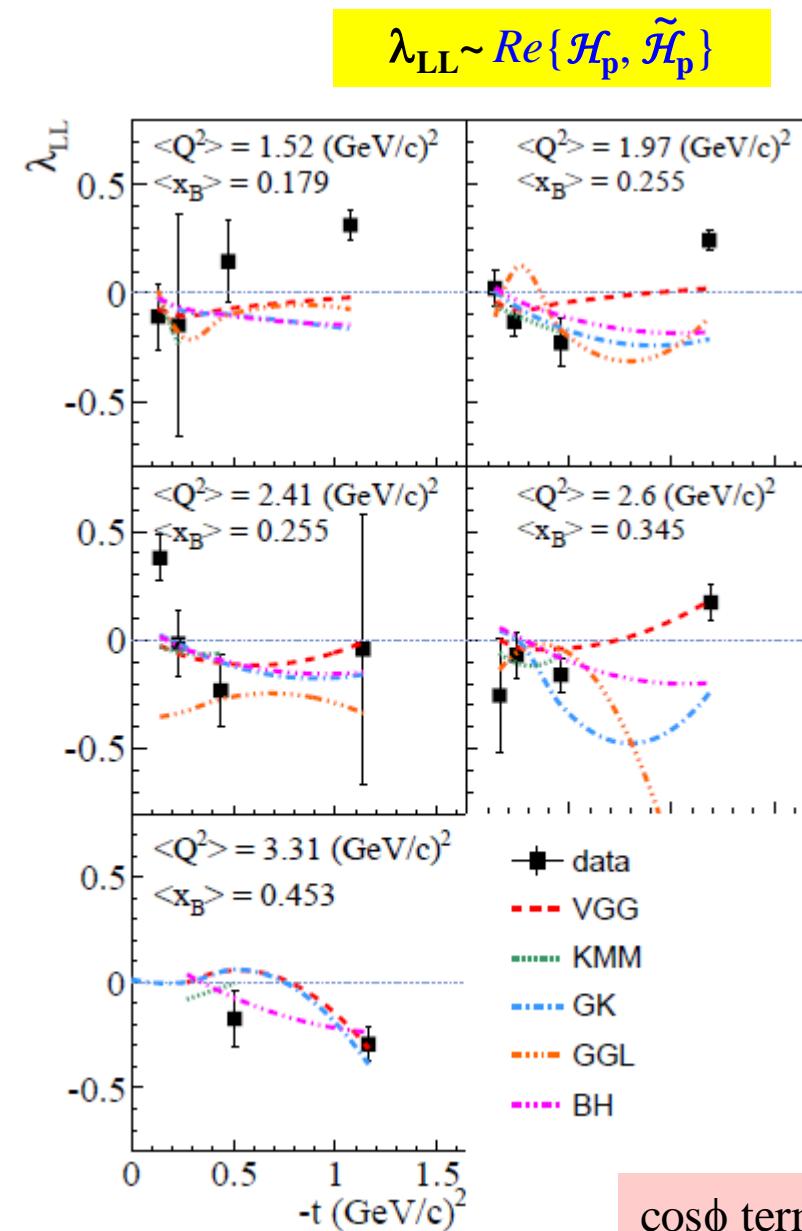
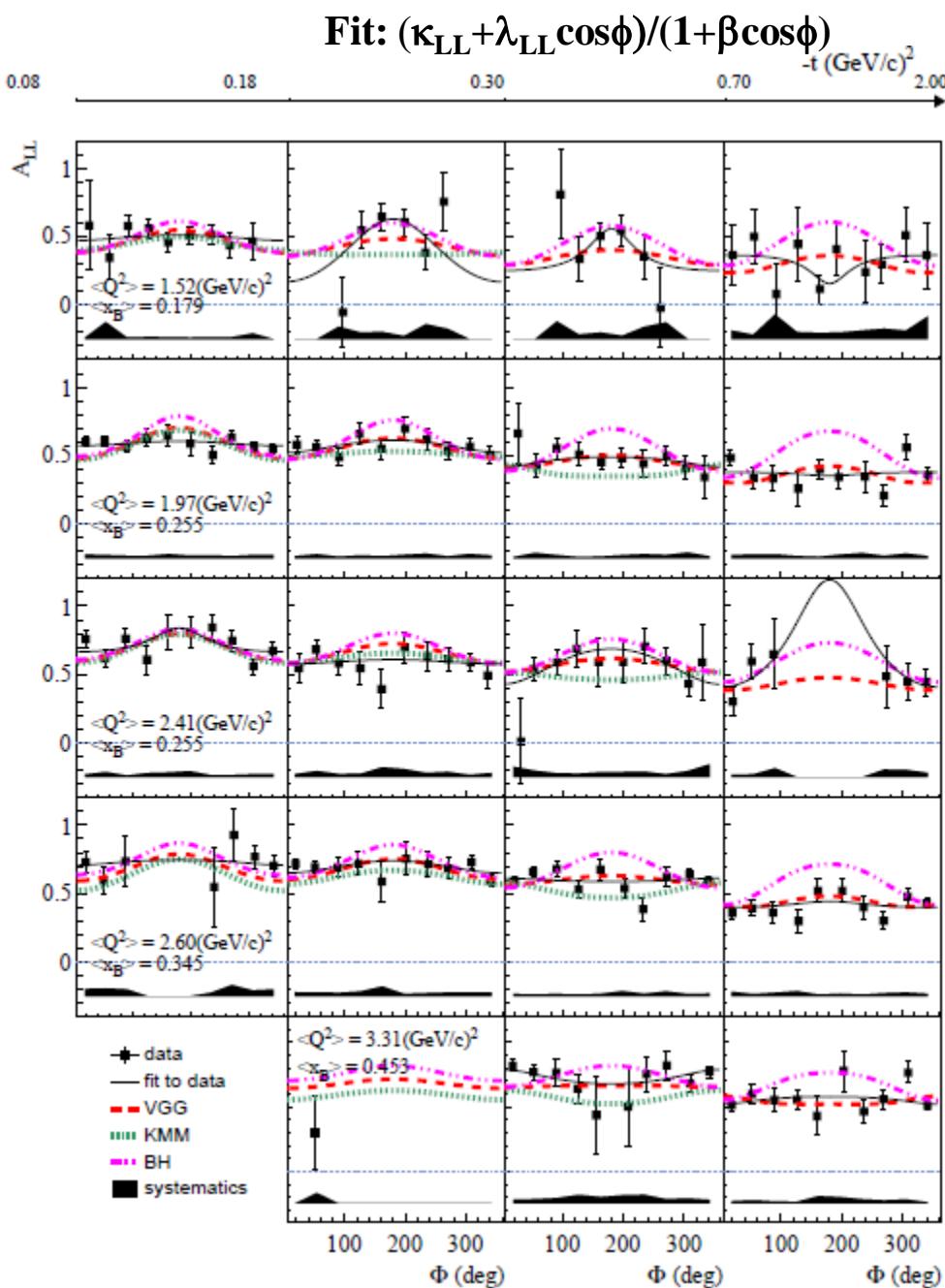
Agreement with world data
Improved statistics x10 at low $-t$
Extended kinematic coverage

Double-spin asymmetry from the CLAS eg1-dvcs data



Constant term
dominated
by BH

Double-spin asymmetry from the CLAS eg1-dvcs data



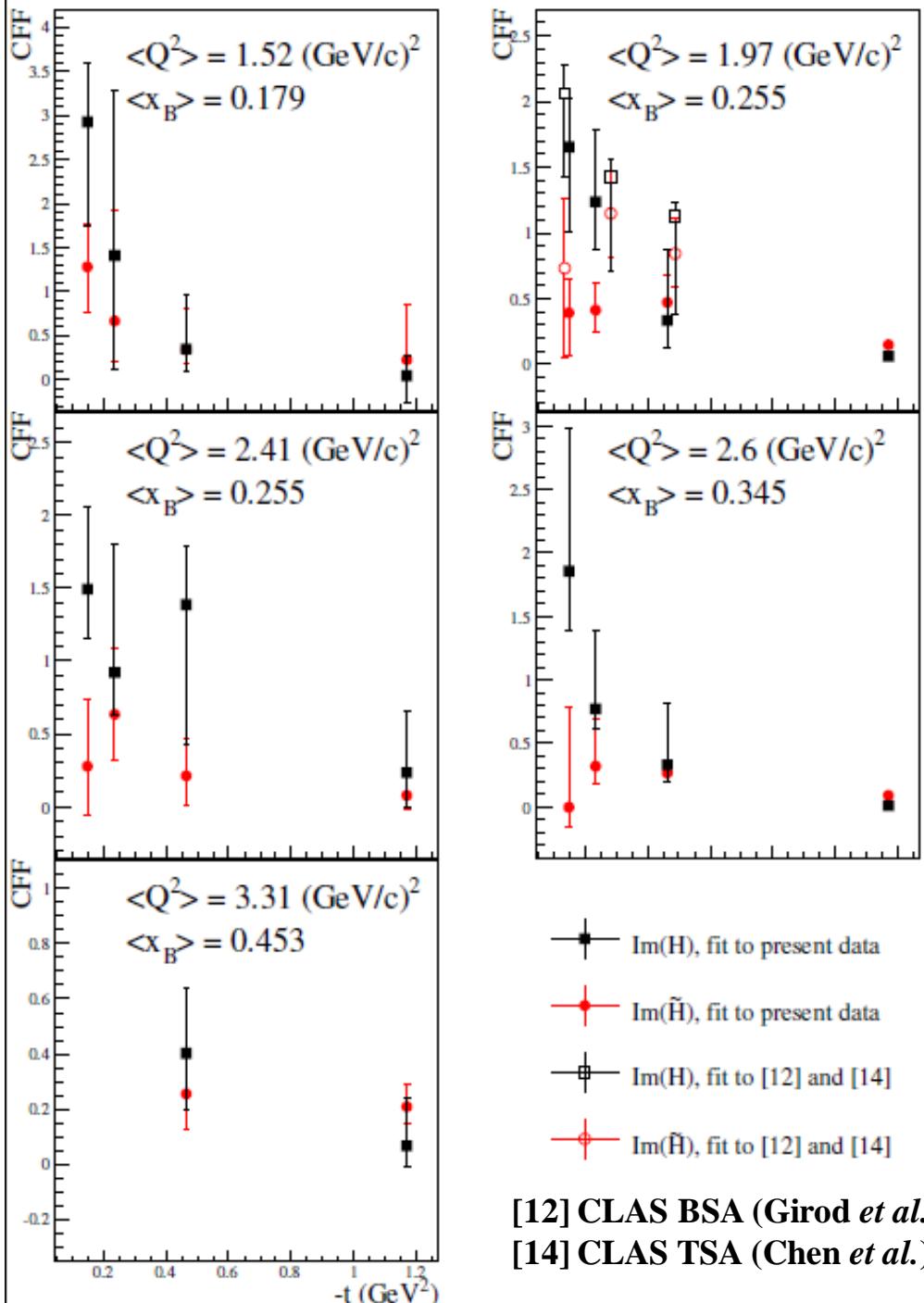
cosphi term
small

Extraction of CFF from DVCS TSA, BSA, DSA (CLAS eg1-dvcs)

$\text{Im}\mathcal{H}$ has steeper t-slope than $\text{Im}\tilde{\mathcal{H}}$: is axial charge more “concentrated” than the electromagnetic charge?

Some sensitivity to $\text{Re}\mathcal{H}, \text{Re}\tilde{\mathcal{E}}$ but with big uncertainties

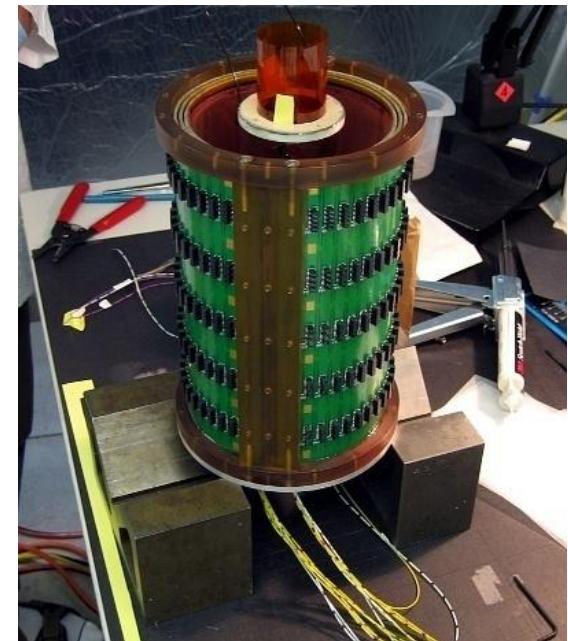
CFFs fitting code by M. Guidal



DVCS on nuclei: the CLAS eg6 experiment

- Data taken in the fall 2009
- Setup: CLAS+IC+RTPC+ ^4He target
- Beam energy $\sim \mathbf{6.065 \text{ GeV}}$
- Goals: coherent and incoherent DVCS
- Nuclear GPDs, EMC effect

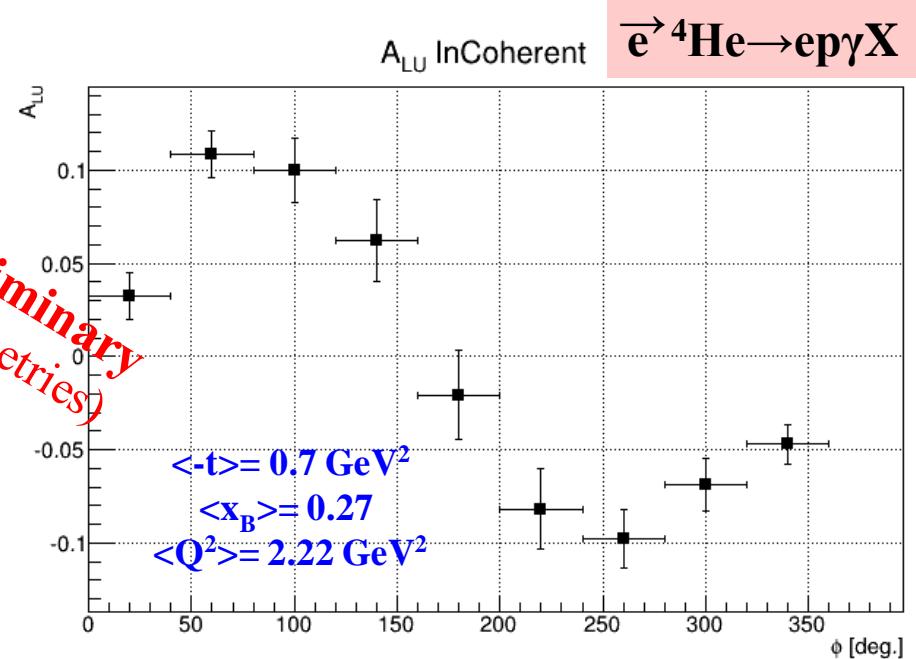
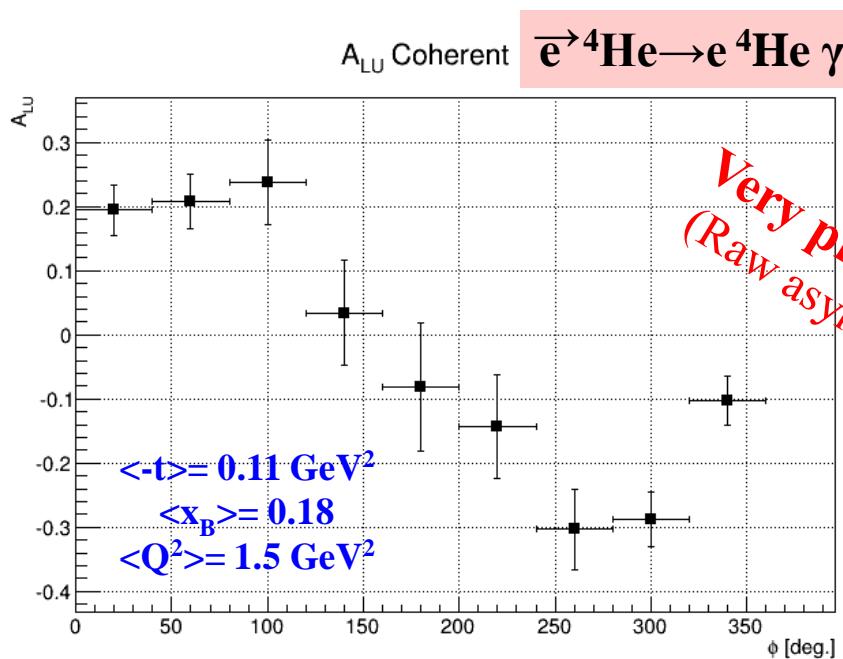
Radial
Time
Projection
Chamber



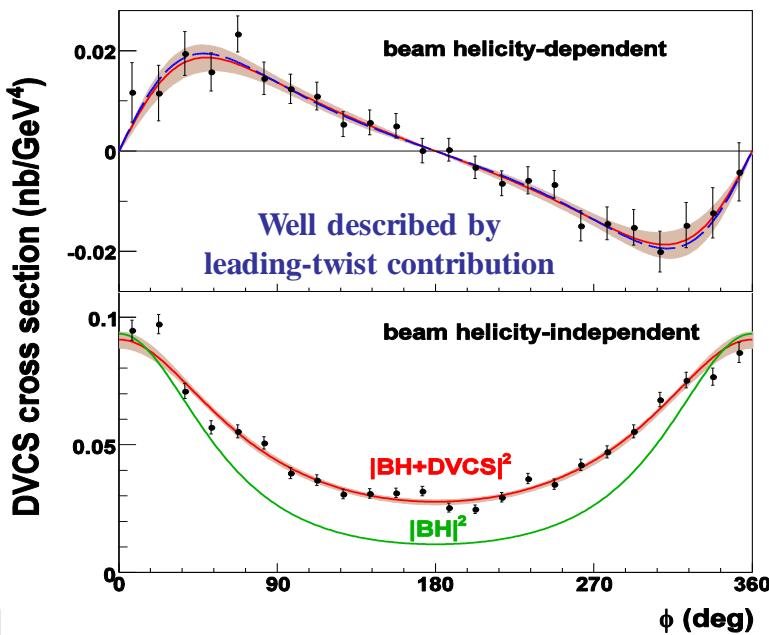
^4He spin 0 nucleus, at twist-2 **only one CFF** in DVCS BSA

$$A_{LU}^{^4\text{He}}(\phi) = \frac{\alpha_0(\phi) F_A(t) \Im[\mathcal{H}_A]}{\alpha_1(\phi) F_A^2(t) + \alpha_2(\phi) F_A(t) \Re[\mathcal{H}_A] + \alpha_3(\phi) \Re[\mathcal{H}_A]^2 + \alpha_3(\phi) \Im[\mathcal{H}_A]^2}$$

Work by M. Hattawy, IPNO



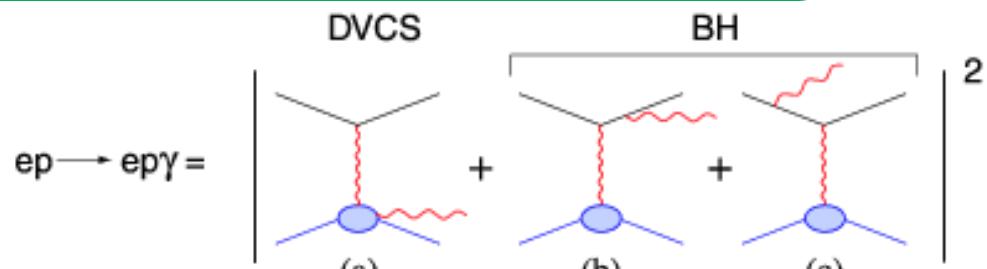
DVCS on the proton in Hall A



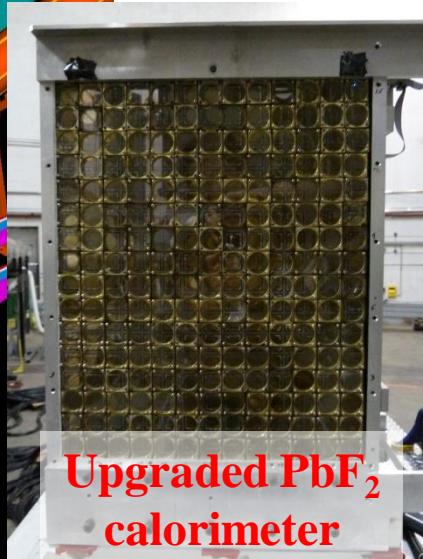
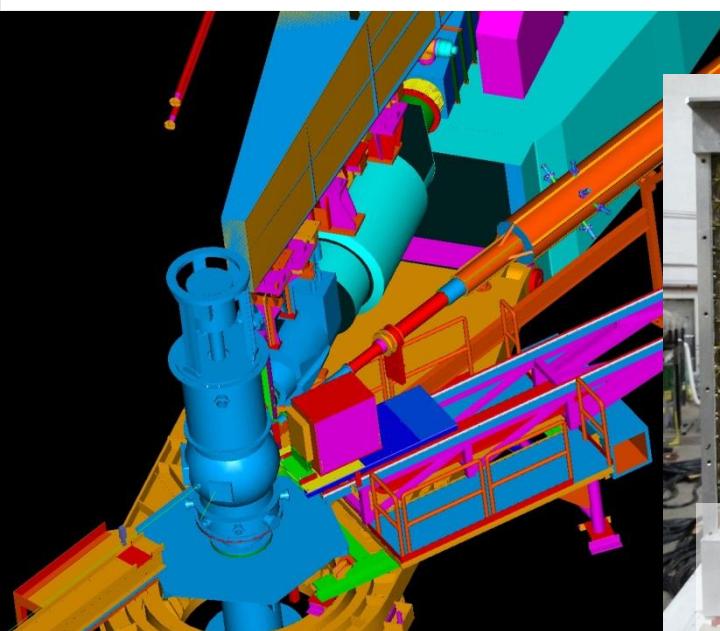
Results from E00-110

C. Munoz-Camacho et. al., PRL 97, 262002 (2006)

Significant deviation from Bethe-Heitler:
Both $I(BH \cdot DVCS)$ and $|DVCS|^2$ contribute
to the cross section



$$\sigma = |BH|^2 + I(BH \cdot DVCS) + |DVCS|^2$$
$$\sim E_b^3 \quad \sim E_b^2$$

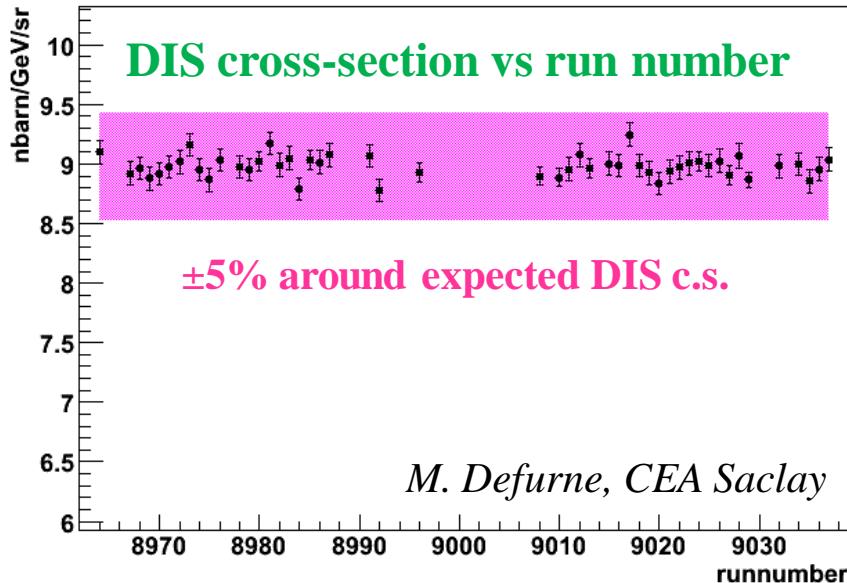


Upgraded PbF₂
calorimeter

Beam-energy separation
at constant Q^2 , x_B and t :
experiment E07-007

E07-007: Rosenbluth-like separation of DVCS

Ebeam=3.355GeV x=0.36 Q2=1.5GeV²



- Data taken in late 2010
- Release of preliminary results expected in the next few months

3 kinematic points:

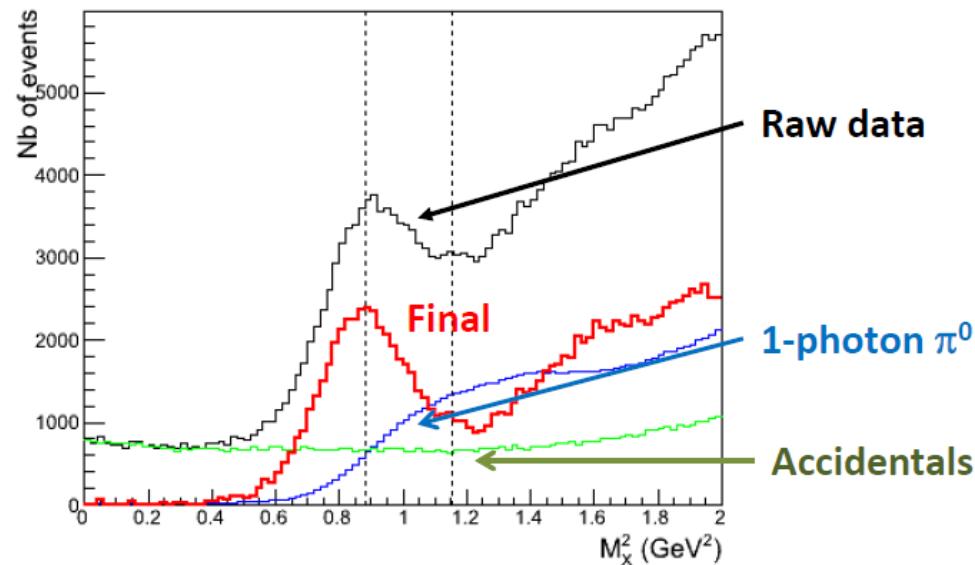
$x_B=0.36, Q^2=1.5, 1.75, 2.0 \text{ GeV}^2$

5 bins in t

2 beam energies per point

- Electron acceptance checks using DIS data
- Working on final global normalizations (multi-tracks, dead-time, radiative corrections)

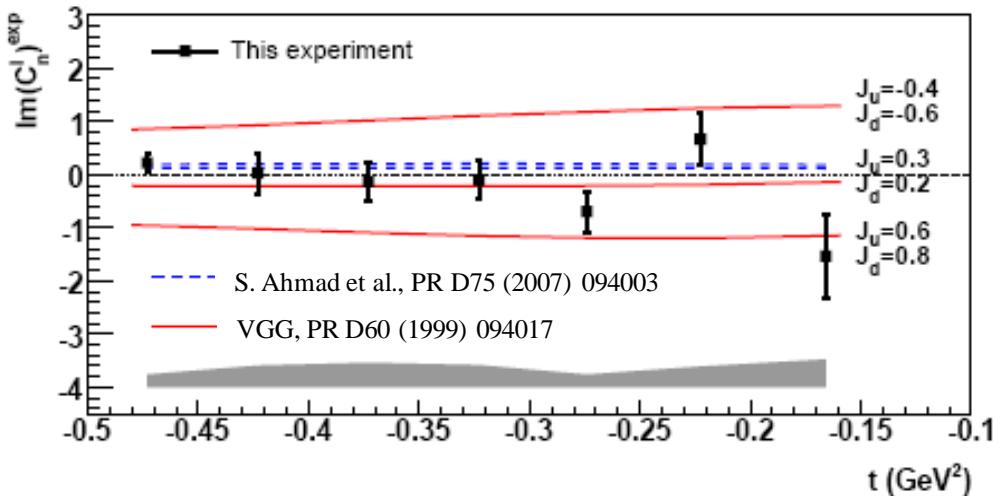
$ep \rightarrow e\gamma X$ missing mass squared



Analysis underway (A. Marti, IPNO & Valencia U)

DVCS on the neutron in Hall A

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



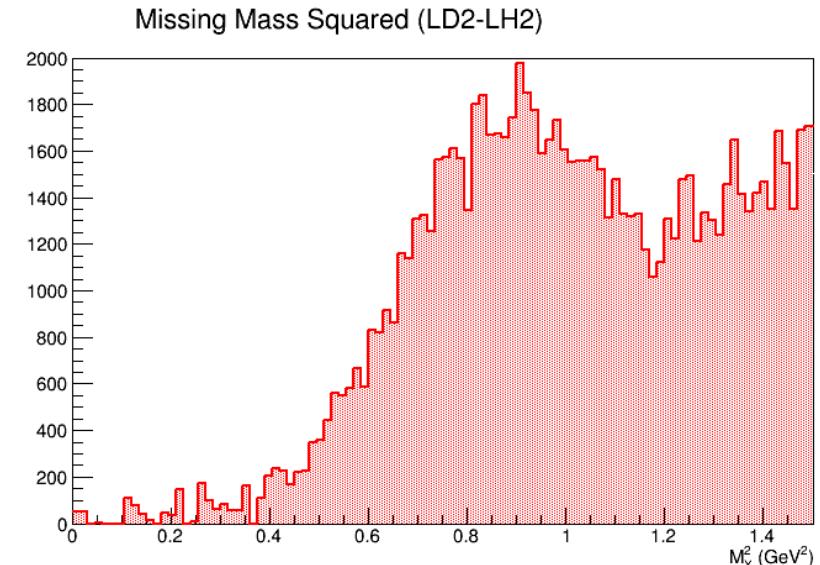
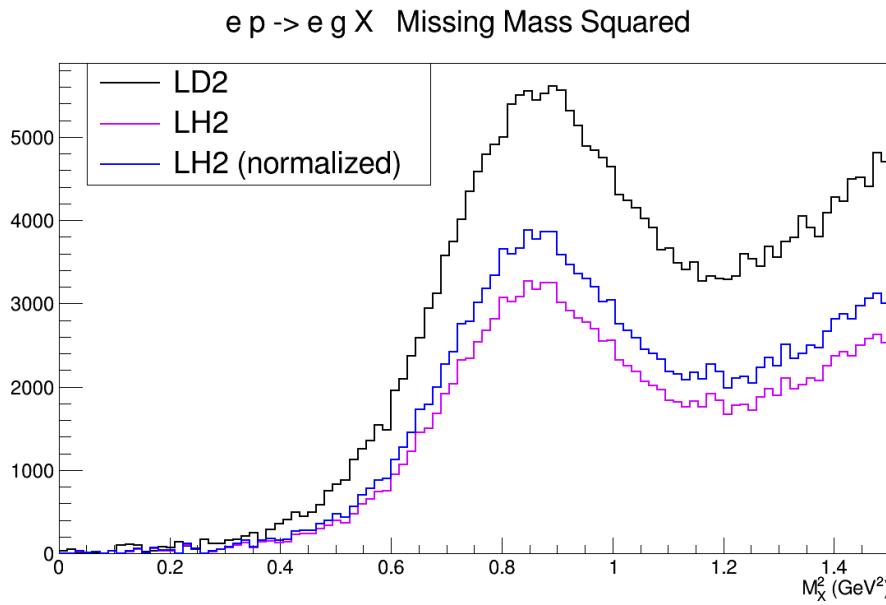
- **E08-025:** Beam-energy « Rosenbluth » separation off the neutron using an LD2 target
- Important contribution of $|\text{DVCS}|^2$ term expected in unpolarized cross section

Data taken in fall 2010 concurrently with E07-007

$$Q^2 = 1.75 \text{ GeV}^2, x_B = 0.36$$

E08-025, analysis ongoing:

- Calibrations completed
- Exclusive data isolated
- Cross section extraction underway



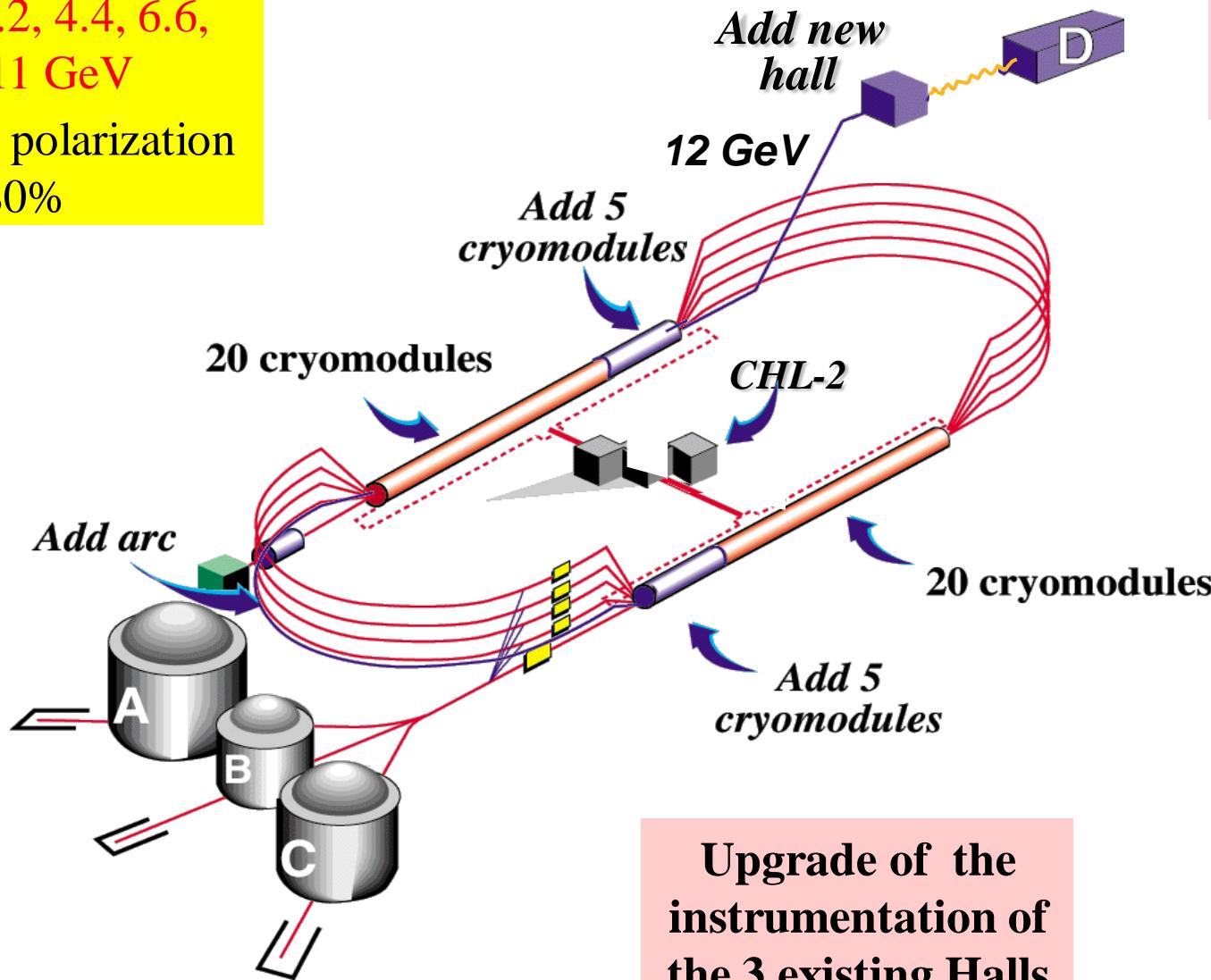
C. Desnault, IPNO

JLab upgrade to 12 GeV

Continuous
Electron
Beam
Accelerator
Facility

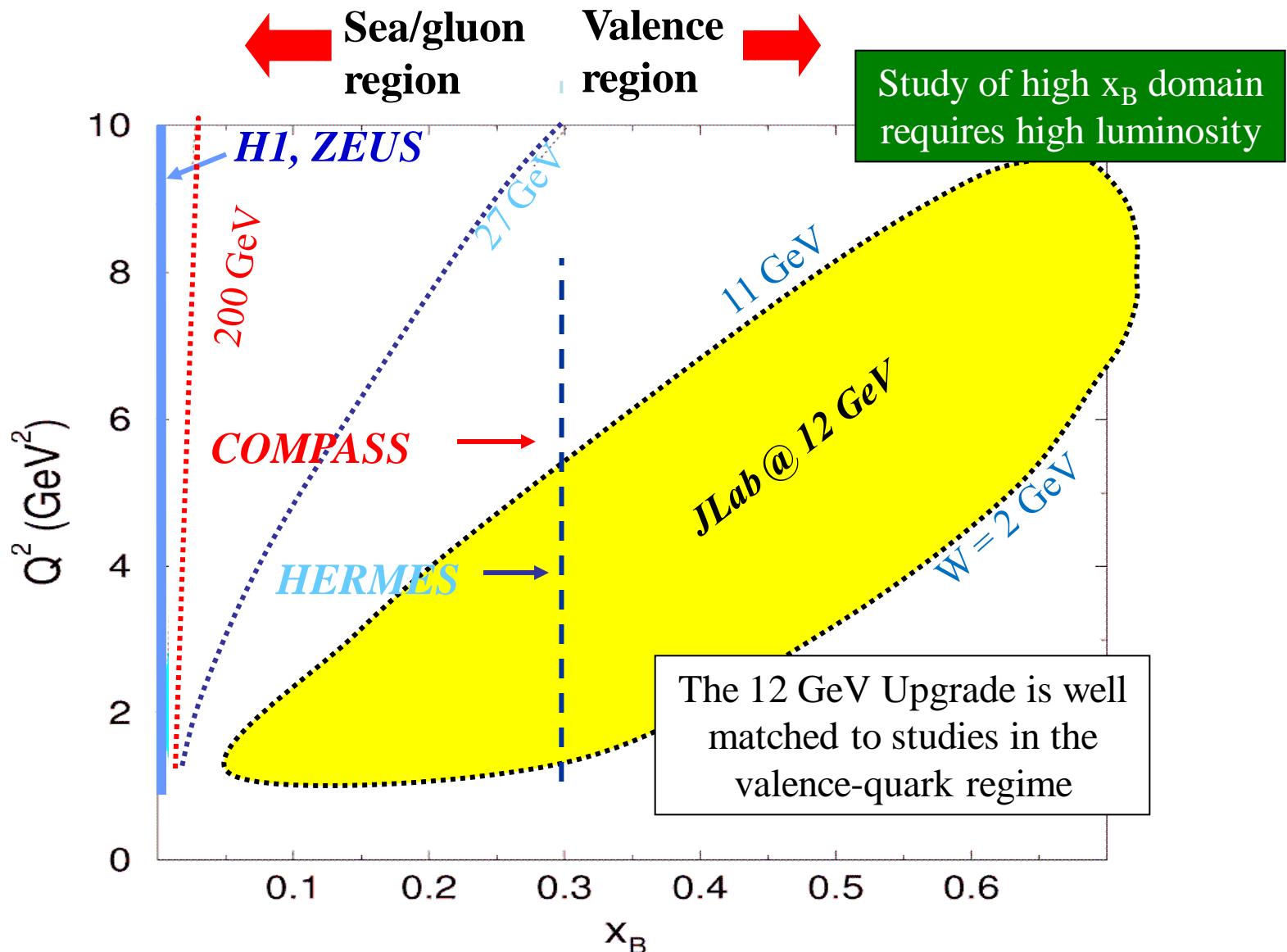
$E = 2.2, 4.4, 6.6,$
 $8.8, 11 \text{ GeV}$

Beam polarization
 $P_e > 80\%$

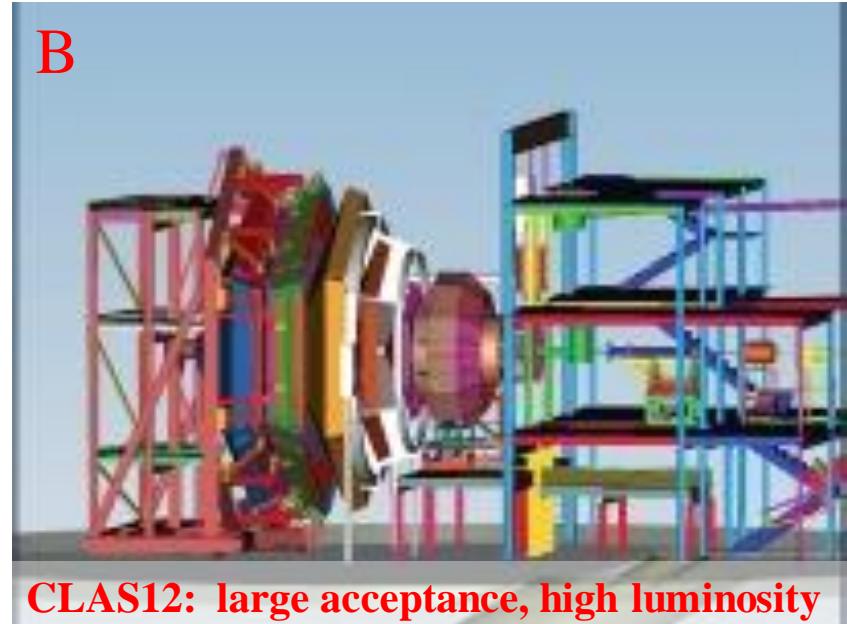


Upgrade of the
instrumentation of
the 3 existing Halls

Kinematic coverage for the 12-GeV upgrade



New capabilities in Halls A, B & C



DVCS experiments at 11 GeV have been approved for each of these **three halls**.

Complementary programs:

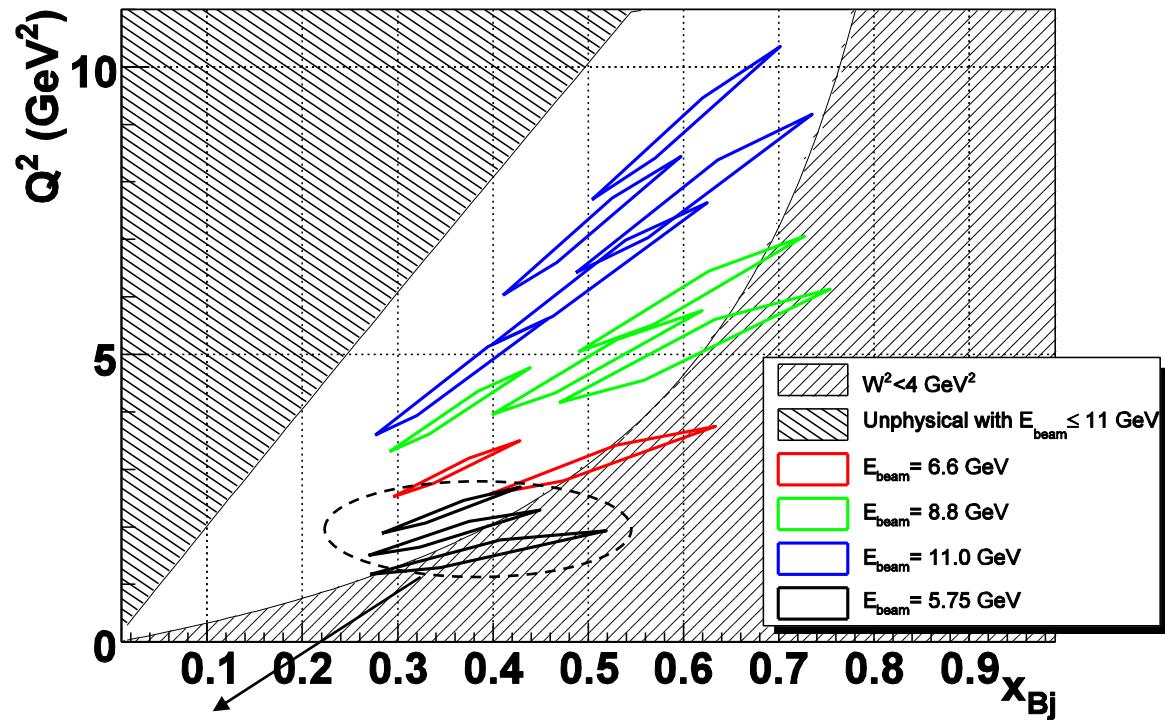
- different kinematic coverage
- different precisions/resolutions
- focus on different observables

E12-06-114: DVCS at 11 GeV in Hall A

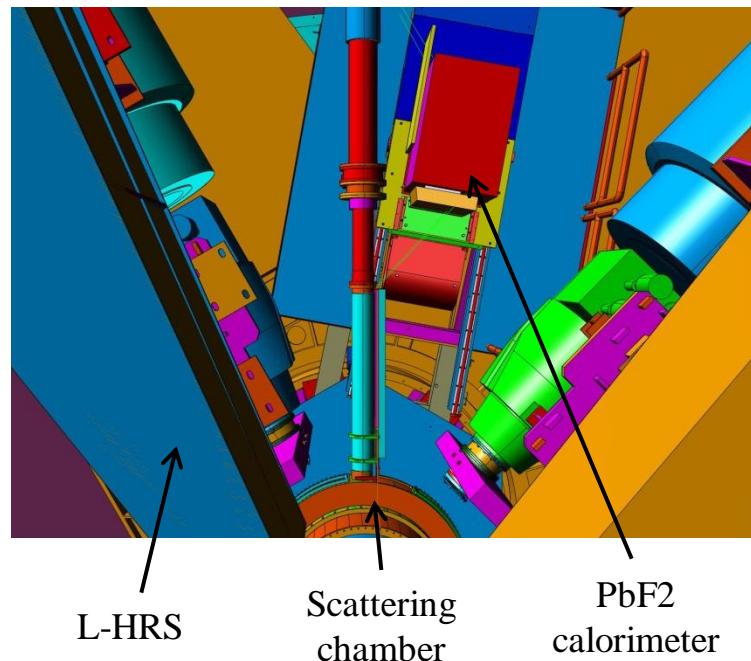
- Absolute cross-section measurements
- Test of scaling: Q^2 dependence of $d\sigma$ at fixed x_{Bj}
- Increased kinematical coverage

JLab12 with 3, 4, 5 pass beam (6.6, 8.8, 11.0 GeV)

DVCS measurements in Hall A/JLab



JLab @ 6 GeV



1st experiment to run after
the 12-GeV upgrade

Start in 2014
for 1 year of data taking

DVCS BSA and TSA with CLAS12 & 11 GeV beam

85 days of beam time

$P_{\text{beam}} = 85\%$

$L = 10^{35} \text{ cm}^{-2}\text{s}^{-1}$

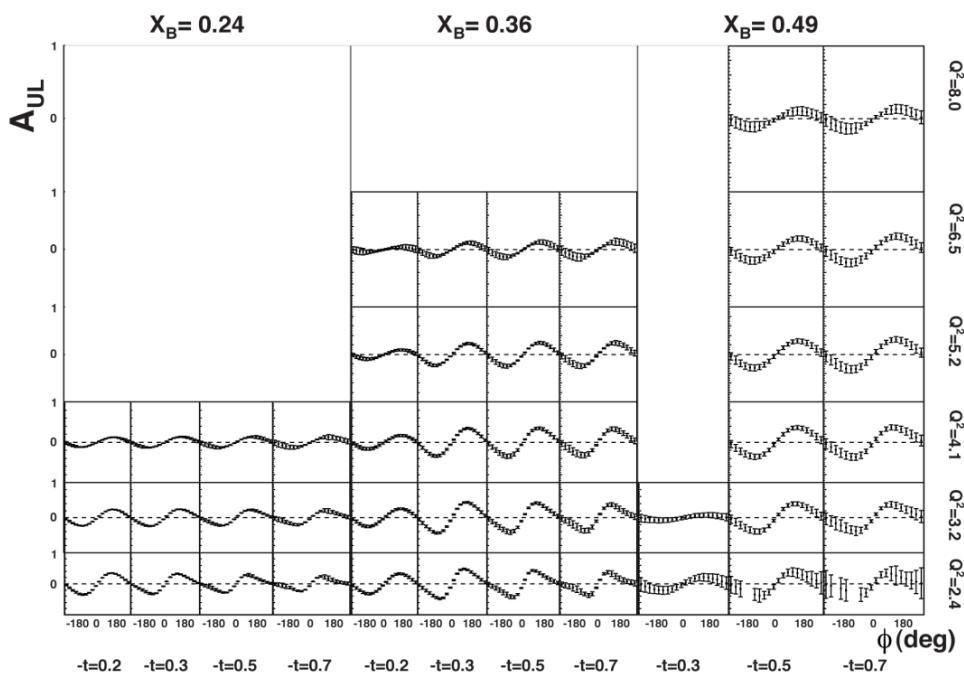
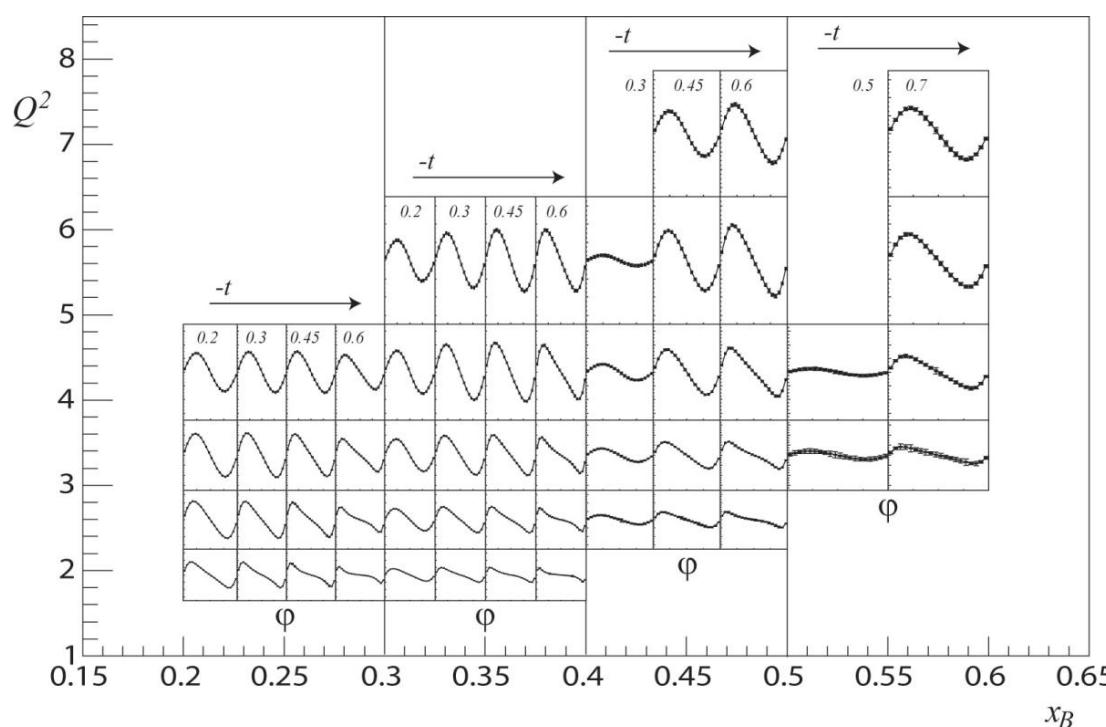
$1 < Q^2 < 10 \text{ GeV}^2$

$0.1 < x_B < 0.65$

$-t_{\min} < -t < 2.5 \text{ GeV}^2$

Statistical error: 1% to 10%
on $\sin\phi$ moments

Systematic uncertainties: ~6-8%



120 days of beam time

$P_{\text{beam}} = 85\%, P_{\text{target}} = 80\%$

$L = 2.10^{35} \text{ cm}^{-2}\text{s}^{-1}$

$1 < Q^2 < 10 \text{ GeV}^2$

$0.1 < x_B < 0.65$

$-t_{\min} < -t < 2.5 \text{ GeV}^2$

Statistical error: 2% to 15%
on $\sin\phi$ moments

Systematic uncertainties: ~6-8%

DVCS BSA and TSA with CLAS12 & 11 GeV beam

85 days of beam time

$P_{\text{beam}} = 85\%$

$L = 10^{35} \text{ cm}^{-2}\text{s}^{-1}$

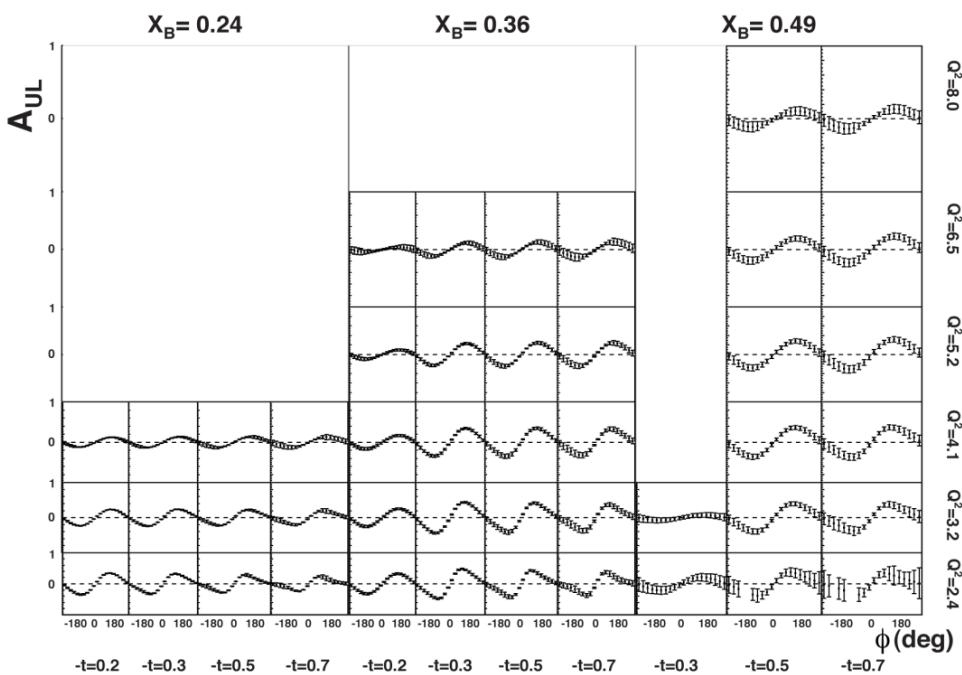
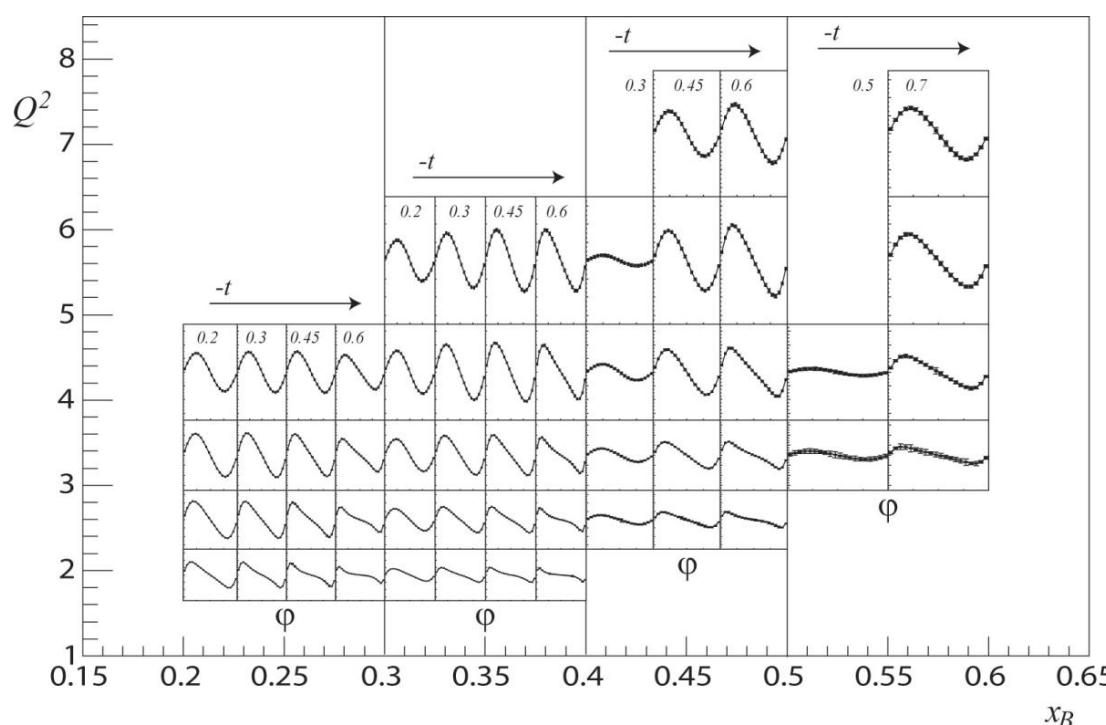
$1 < Q^2 < 10 \text{ GeV}^2$

$0.1 < x_B < 0.65$

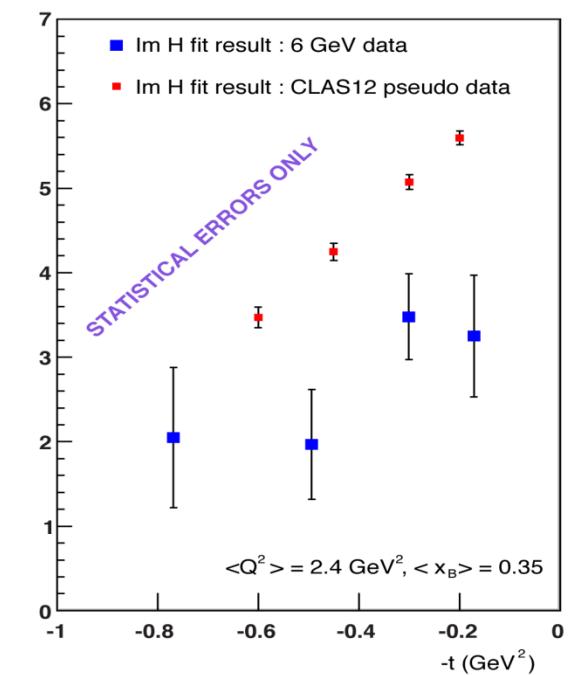
$-t_{\min} < -t < 2.5 \text{ GeV}^2$

Statistical error: 1% to 10%
on $\sin\phi$ moments

Systematic uncertainties: ~6-8%



Impact of
CLAS12
DVCS-BSA
data
on model-
independent
fit to extract
 $\text{Im}(H)$

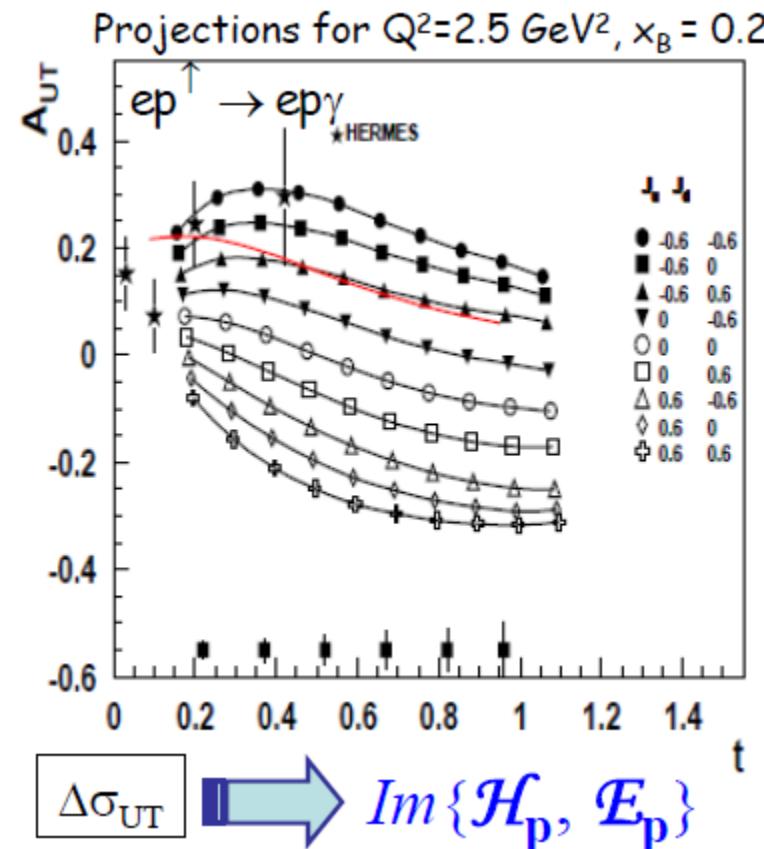


CLAS12: p-DVCS *transverse* target-spin asymmetry

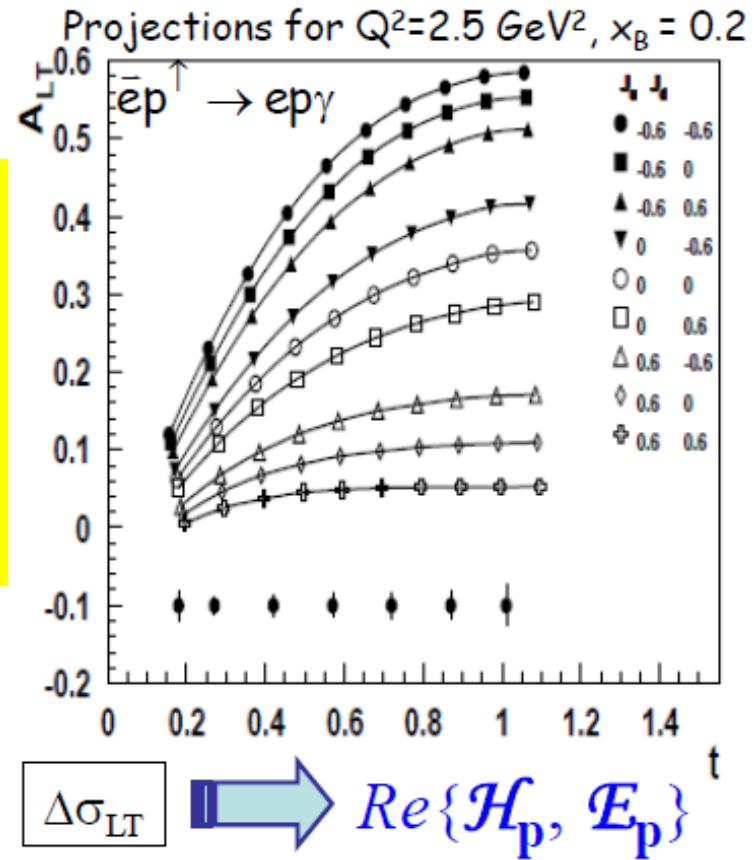
100 days of beam time

Beam pol. = 80% ; target pol. (HDIce) = 60% ; Luminosity = $5 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

$1 < Q^2 < 10 \text{ GeV}^2$, $0.06 < x_B < 0.66$, $-t_{\min} < -t < 1.5 \text{ GeV}^2$

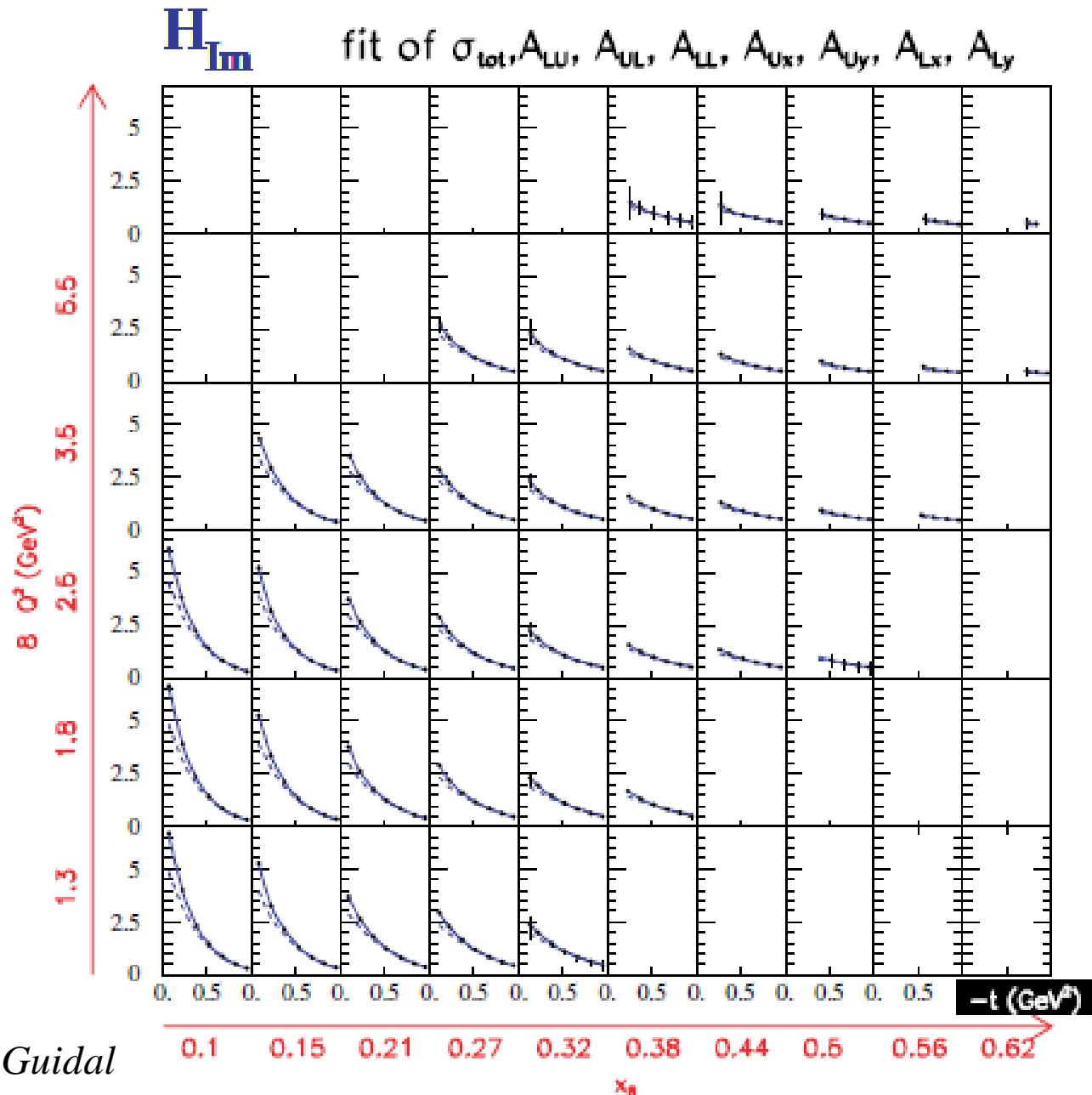


Transverse-target
spin asymmetry
for p-DVCS is
highly sensitive
to the **u-quark
contributions** to
proton spin.



Proposal conditionally approved by PAC39

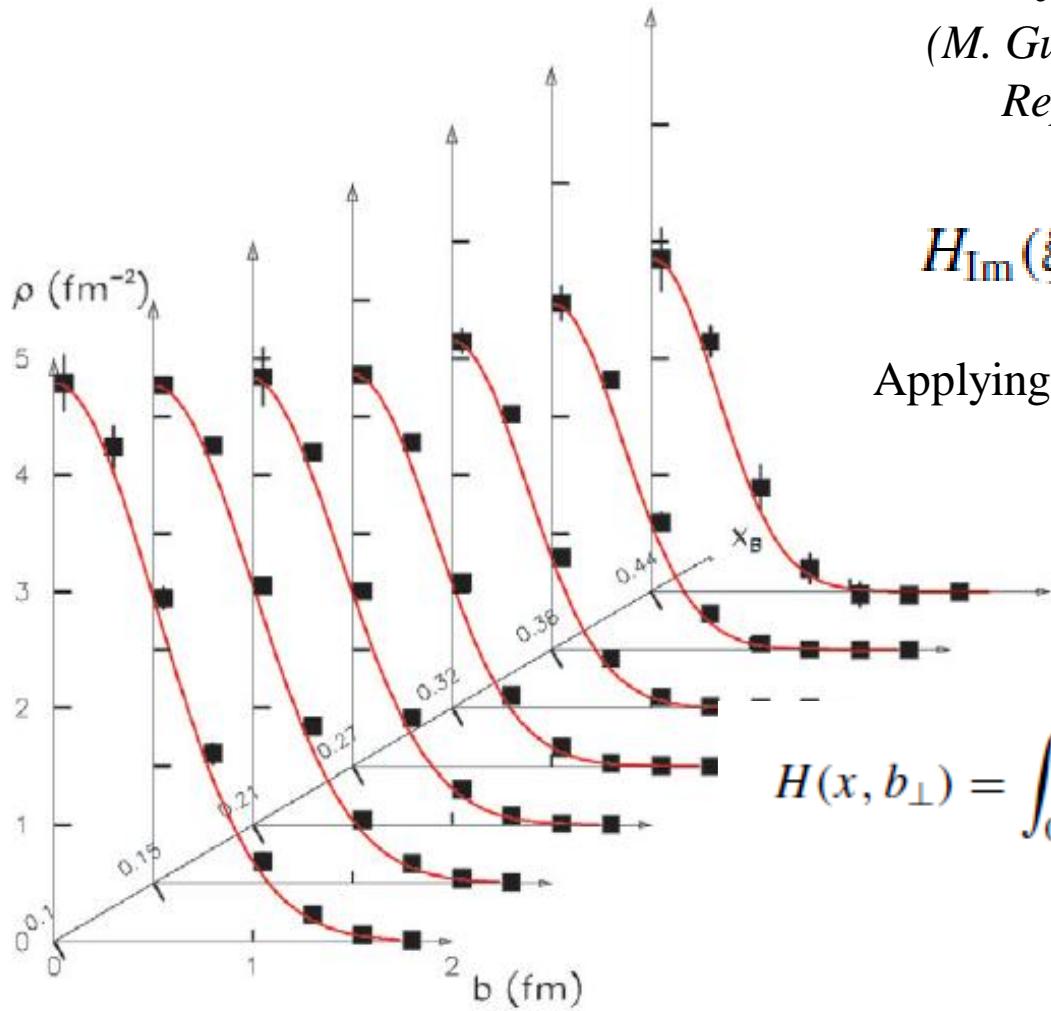
Projections for CLAS12 for H_{Im}



From CFFs to spatial densities

How to go from momentum coordinates (t)
to space-time coordinates (b) ?

(M. Guidal, H. Moutarde, M. Vanderhagen,
Rept.Prog.Phys. 76 (2013) 066202)



$$H_{\text{Im}}(\xi, t) \equiv H(\xi, \xi, t) - H(-\xi, \xi, t)$$

Applying a model-dependent “deskewing” factor:

$$\frac{H(\xi, 0, t)}{H(\xi, \xi, t)}$$

$$H(x, b_\perp) = \int_0^\infty \frac{d\Delta_\perp}{2\pi} \Delta_\perp J_0(b_\perp \Delta_\perp) H(x, 0, -\Delta_\perp^2)$$

Burkardt (2000)

Projections for CLAS12

BSA for DVCS *on the neutron* with CLAS12

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

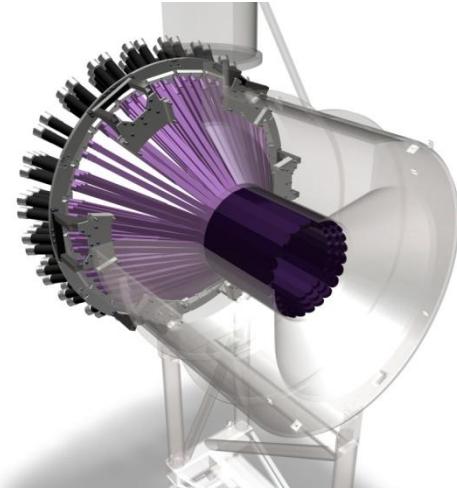
$$\Delta\sigma_{LU} \sim \sin\phi \operatorname{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\} d\phi$$

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

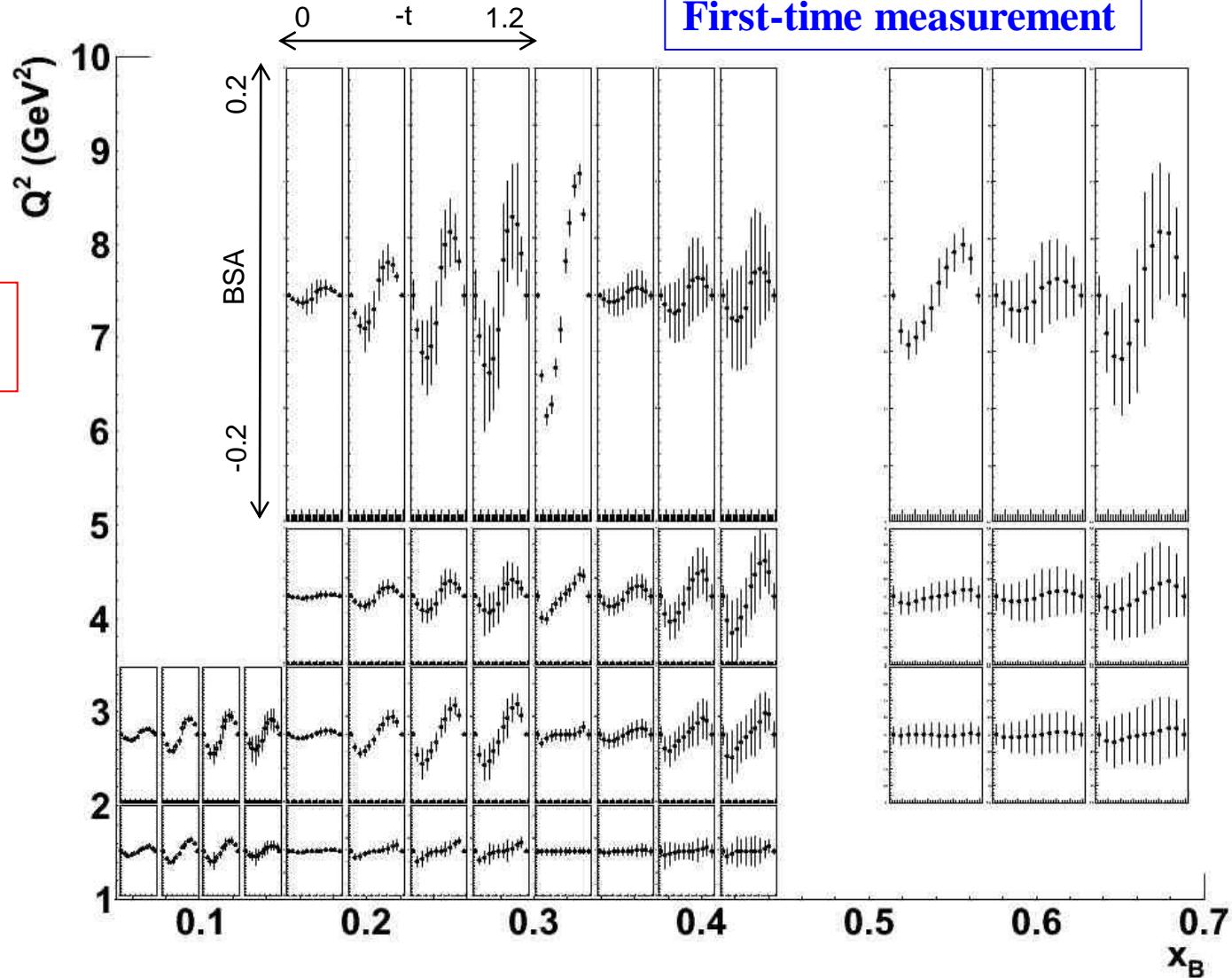
The most sensitive observable to the GPD **E**

$ed \rightarrow e(p)n\gamma$
 CLAS12 +
 Forward Calorimeter +
 Neutron Detector

80 days of data taking
 $L = 10^{35} \text{ cm}^{-2}\text{s}^{-1}/\text{nucleon}$



Final phases of construction
 at IPN Orsay



BSA for DVCS *on the neutron* with CLAS12

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

$$\Delta\sigma_{LU} \sim \sin\phi \operatorname{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\} d\phi$$

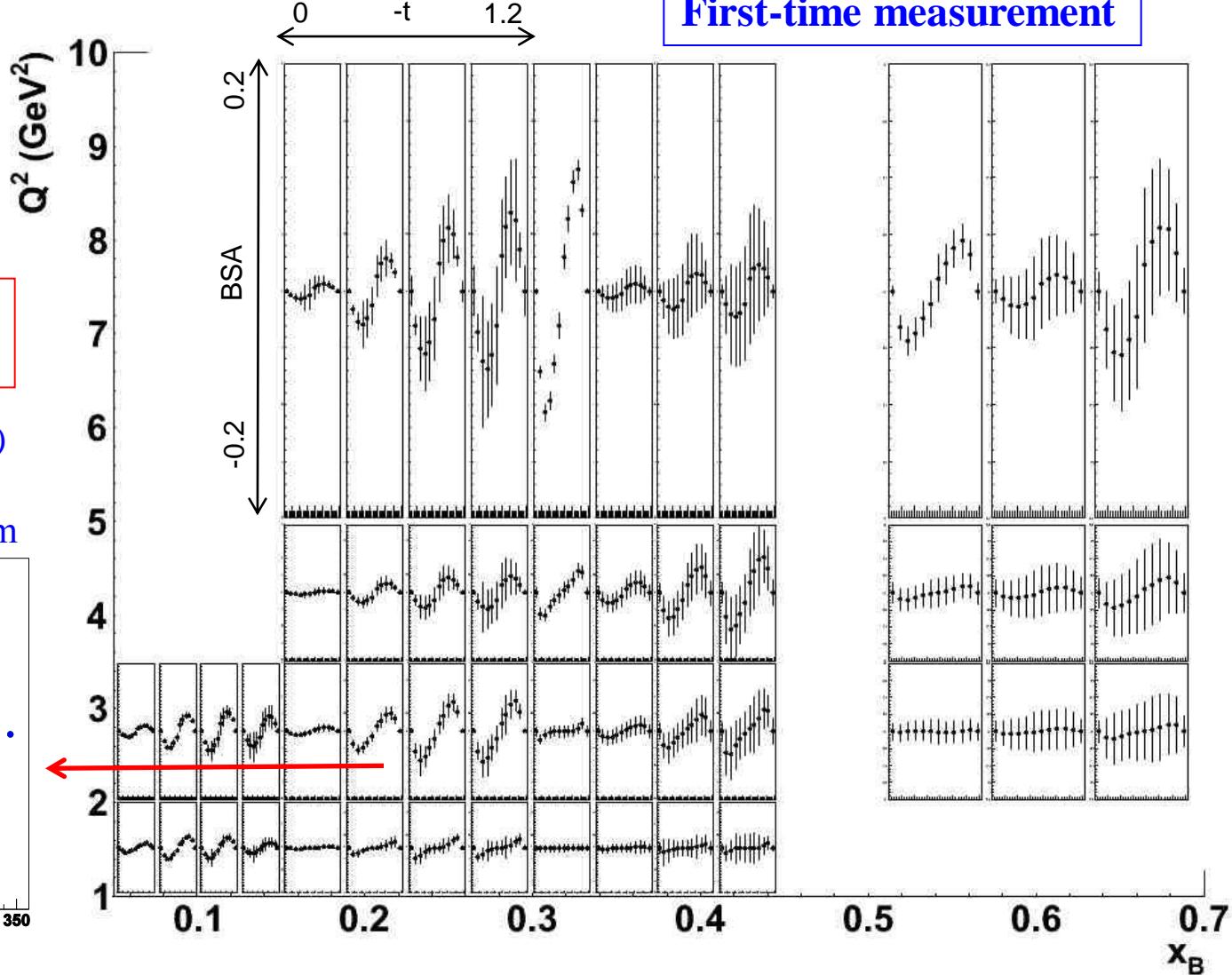
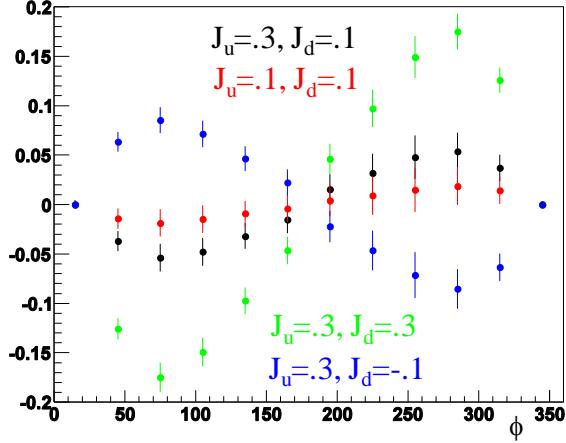
$$(H, E)_d(\xi, \xi, t) = \frac{9}{15} [4(H, E)_n(\xi, \xi, t) - (H, E)_p(\xi, \xi, t)]$$

The most sensitive observable to the GPD **E**

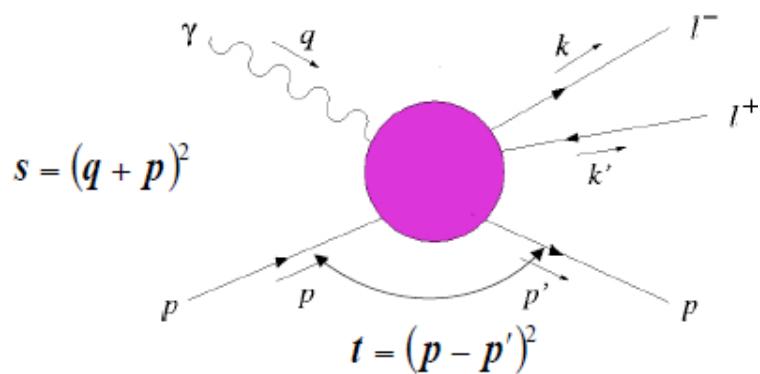
$ed \rightarrow e(p)n\gamma$
CLAS12 +
Forward Calorimeter +
Neutron Detector

80 days of data taking
 $L = 10^{35} \text{ cm}^{-2}\text{s}^{-1}/\text{nucleon}$

Model predictions (VGG)
for different values of
quarks' angular momentum

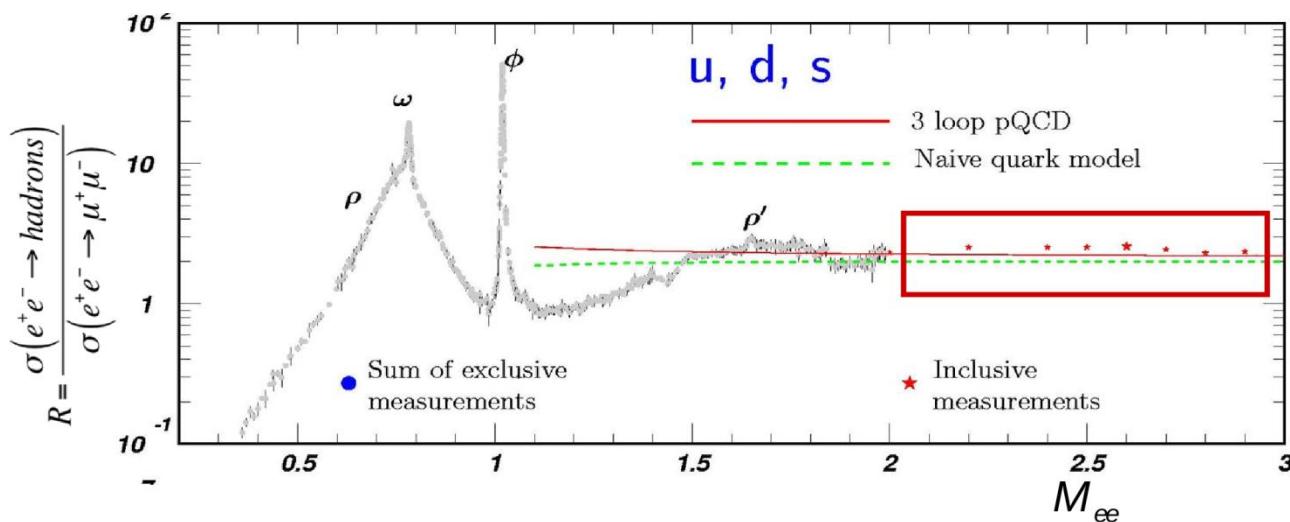


Timelike Compton Scattering with CLAS12



TCS: sensitivity to the **real part** of CFFs

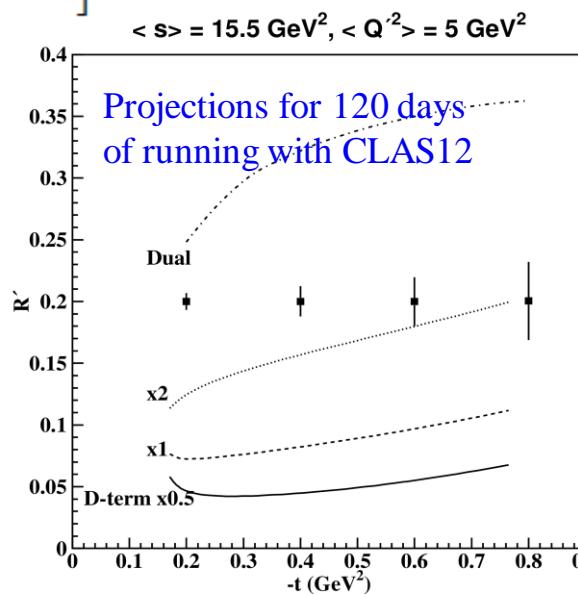
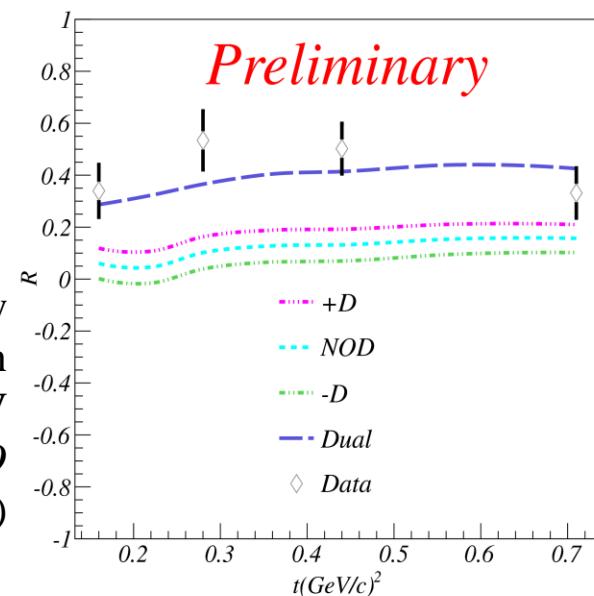
$$R = \frac{2 \int_0^{2\pi} d\phi \cos \phi \frac{dS}{dQ'^2 dt d\phi}}{\int_0^{2\pi} d\phi \frac{dS}{dQ'^2 dt d\phi}} \propto \tilde{M}^{--} = \frac{2\sqrt{t_0 - t}}{m} \frac{1-\eta}{1+\eta} \left[F_1 \mathcal{H} - \eta(F_1 + F_2) \tilde{\mathcal{H}} - \frac{t}{4m^2} F_2 \mathcal{E} \right]$$



$$Q'^2 = M_{l^+l^-}^2 = (k + k')^2$$

$$\eta = \frac{Q'^2}{2s - Q'^2}$$

Exploratory measurement with CLAS@6 GeV
(R. Paremuzyan, IPNO & Yerevan)

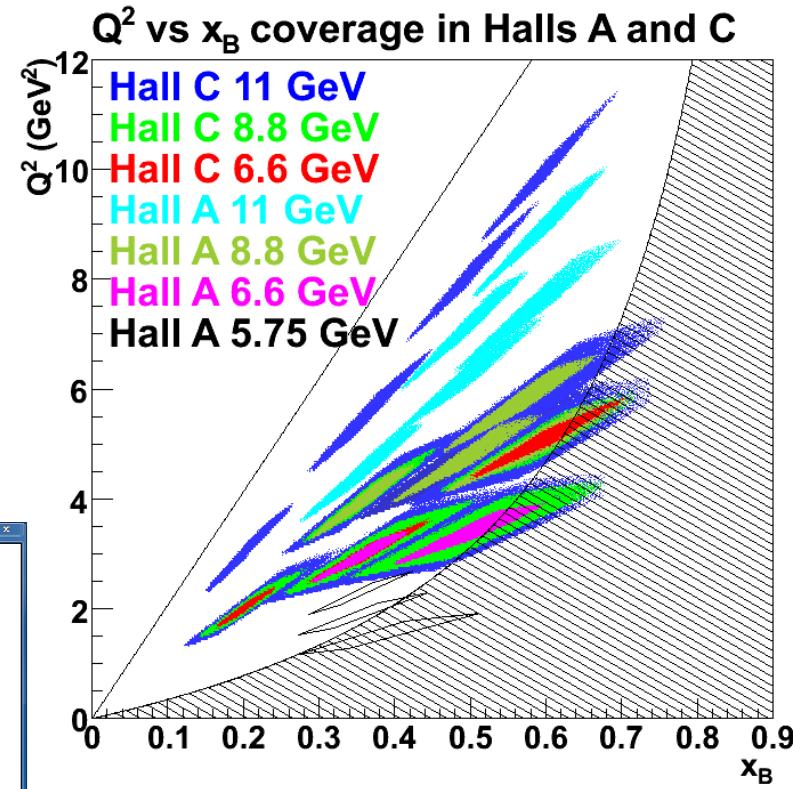
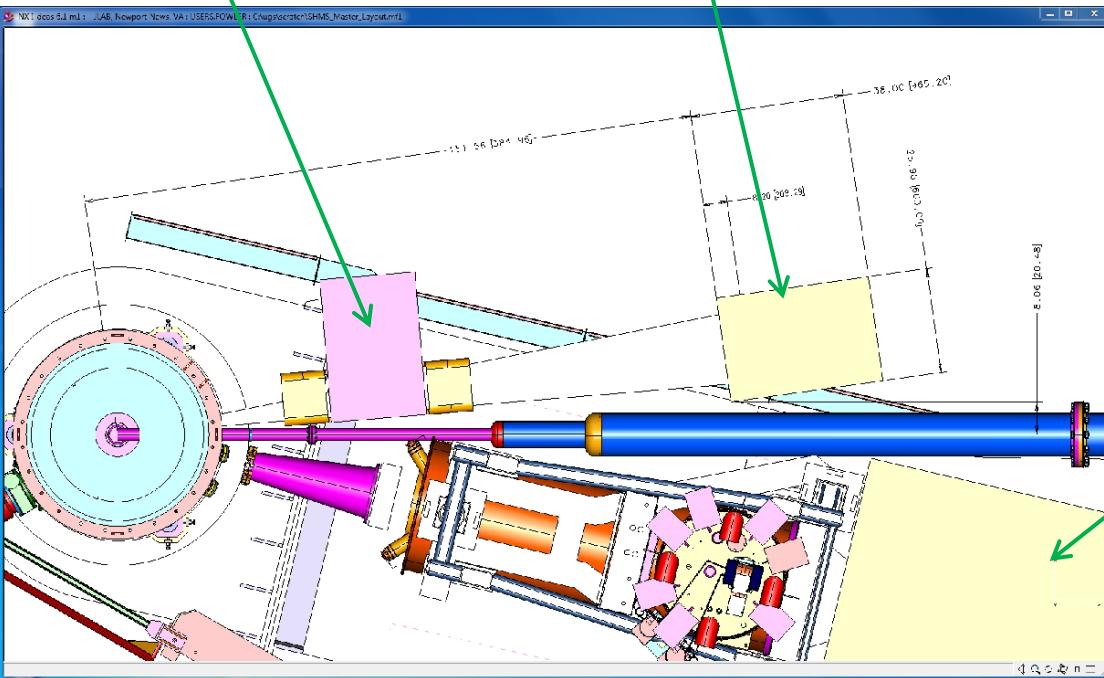


E12-13-010: DVCS at 11 GeV in Hall C

- Energy separation of the DVCS cross section
- Higher Q^2 : measurement of higher twist contributions
- Low- x_B extension (thanks to sweeping magnet)

Sweeping magnet

1116-block PbWO₄ calorimeter



Hall C
HMS

Tentative running:
~ 2019-20

Summary

- GPDs are a unique tool to explore the **internal landscape of the nucleon**:
 - **3D** quark/gluon **imaging** of the nucleon
 - **orbital angular** momentum carried by quarks
- Their extraction from experimental data is **very difficult**:
 - there are **4 GPDs for each quark flavor**
 - they depend on **3 variables**, only two (ξ, t) experimentally accessible
 - they appear as **integrals** in cross sections
- Recently-developed fitting methods allow to **extract CFFs from DVCS observables**
- We need to measure **several p-DVCS** and **n-DVCS observables** over a **wide phase space**
- A wealth of **new results** on various DVCS observables is coming from recent **CLAS and Hall-A experiments** (on the proton, deuterium and ${}^4\text{He}$ targets)
- The 12-GeV-upgraded JLab will be **the only facility** to perform DVCS experiments **in the valence region**, for Q^2 up to 11 GeV
- **DVCS experiments on both proton and deuterium targets (polarized and unpolarized) are planned for 3 of the 4 Halls at JLab@12 GeV**