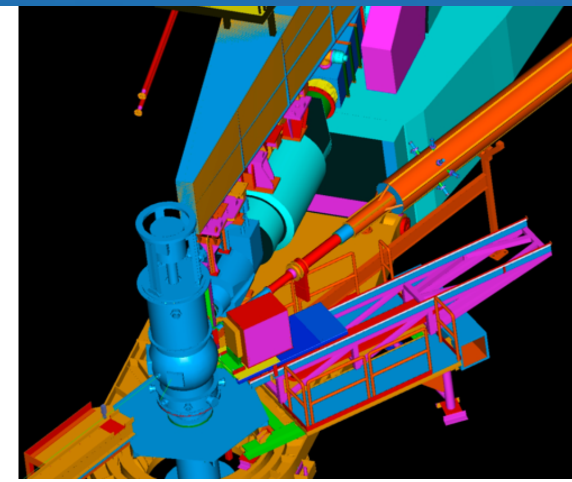
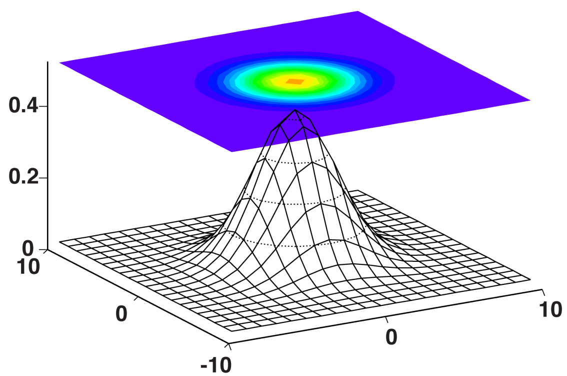


DVCS phenomenology

Franck Sabatié
CEA Saclay

In collaboration with :
P. Kroll, C. Mezrag, H. Moutarde, B. Pire, L. Szymanovski, J. Wagner



- Theoretical framework
- Deeply Virtual Compton Scattering
- A test of Universality
- Beyond leading-order, RDDA, leading twist
- Strategies for fitting GPDs
- Conclusion and outlook

November 12th 2012

GPDs : matrix elements of bi-local twist-2 operators

Full analogy with PDF definition :

$$F^q = \frac{1}{2}\int \frac{dz^-}{2\pi} e^{ixP^+z^-} \langle p' \left| \bar{q}\left(-\frac{z}{2}\right)\gamma^+ q\left(\frac{z}{2}\right)\right| p\rangle_{z^+=0, z_\perp=0}$$

$$= \frac{1}{2P^+}\left[H^q \bar{u}(p')\gamma^+ u(p) + E^q \bar{u}(p')\frac{i\sigma^{+\alpha}\Delta_\alpha}{2M}u(p)\right]$$

$$\tilde{F}^q = \frac{1}{2}\int \frac{dz^-}{2\pi} e^{ixP^+z^-} \langle p' \left| \bar{q}\left(-\frac{z}{2}\right)\gamma^+\gamma_5 q\left(\frac{z}{2}\right)\right| p\rangle_{z^+=0, z_\perp=0}$$

$$= \frac{1}{2P^+}\left[\tilde{H}^q \bar{u}(p')\gamma^+\gamma_5 u(p) + \tilde{E}^q \bar{u}(p')\frac{\gamma^5\Delta^+}{2M}u(p)\right]$$

… and equivalent expressions for gluons

+ another set for chiral-odd GPDs (with parton helicity flip)

GPD properties

- Forward limit

$$H^q(x,0,0) = q(x)$$

- Sum rules (including Ji's)

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

- Polynomiality

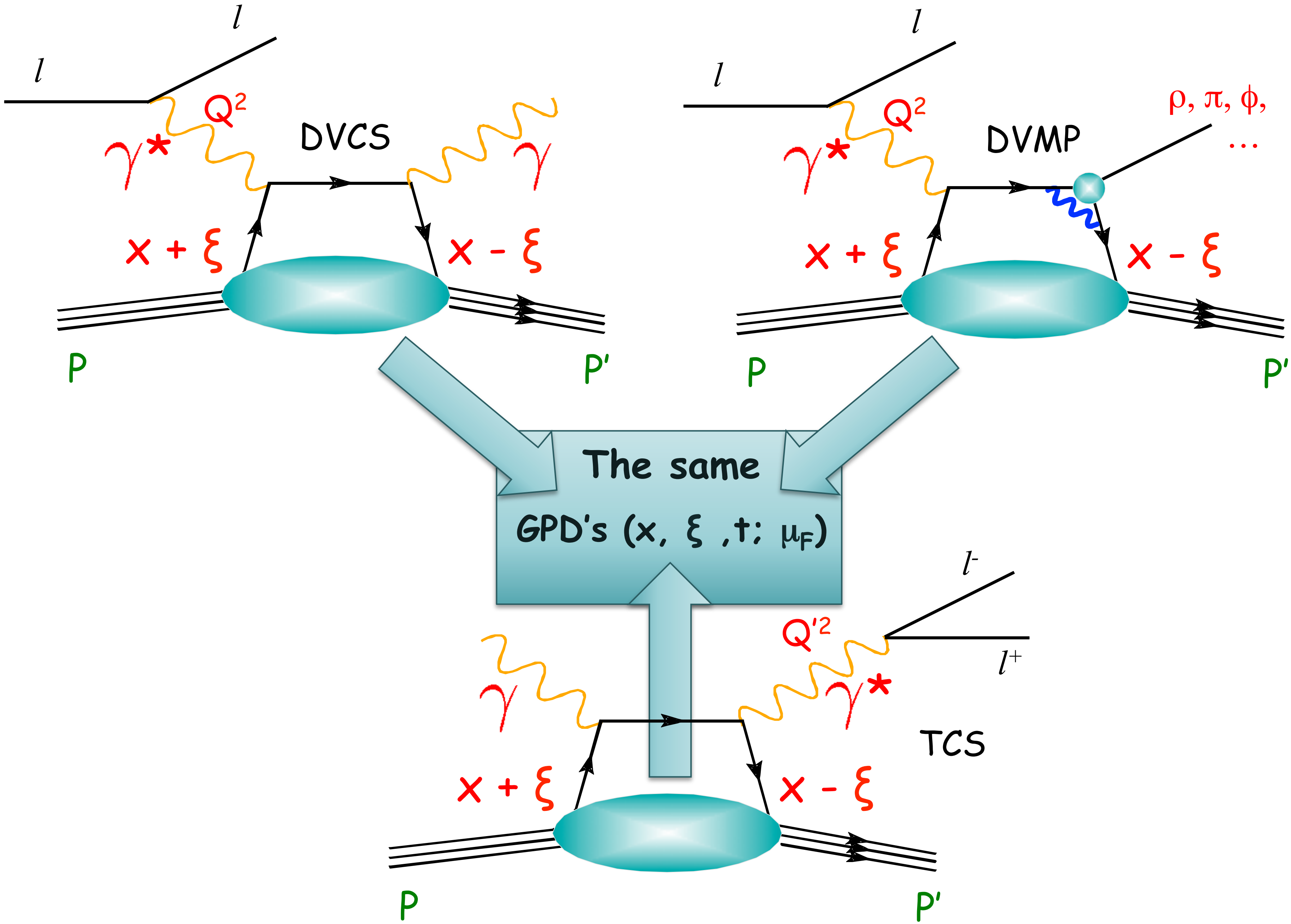
$$\int_{-1}^{+1} dx\, x^n H^q(x,\xi,t) = \text{polynomial in } \xi$$

- Impact parameter interpretation

$$\rho(x, b_\perp, \lambda, \lambda_N) = \frac{1}{2}\left[H(x, b_\perp^2) + \frac{b_\perp^j \epsilon_{ji} S_\perp^i}{M} \frac{\partial E}{\partial b_\perp^2}(x, b_\perp^2) + \lambda\lambda_N \tilde{H}(x, b_\perp^2) \right]$$

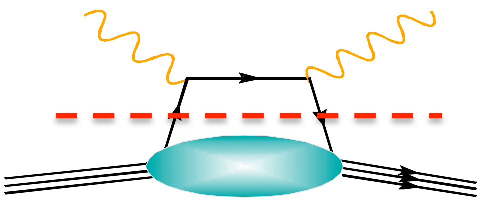
- Universality …

Generalized Parton Distributions are Universal !



Factorization and Universality

The partonic interpretation of all these hard exclusive processes relies on collinear factorization theorems valid in the Bjorken limit of large Q^2 and W, fixed $x_B \approx 2\xi / (1+\xi)$



The GPD's then depend on an arbitrary factorization scale μ_F

GPD's should be the same for DVCS, DVMP, TCS, … :

Not only is **Universality an essential property**

But we need it to **Explore the whole GPD landscape**

(different dependences on the GPDs and flavors)

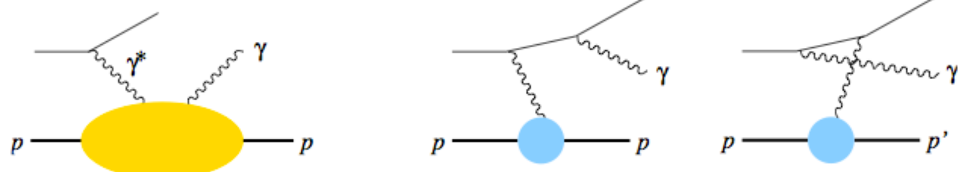
Different Hard Processes : different advantages

Deeply Virtual Compton Scattering

- Theory is under control : up to α_S^2, twist-3, target mass corrections, etc Müller et al, Braun et al
- Sensitive to the quark combination : $\frac{4}{9}u + \frac{1}{9}d + \frac{1}{9}s$
- At JLab/HERMES energies, mostly sensitive to valence and sea quarks
- Sensitive to gluon GPDs through Q^2 evolution at NLO or beyond

Direct access to the Re and Im part of Compton Form Factors $\mathcal{H}$, …

through interference with known Bethe-Heitler process Diehl, Gousset, Pire, Ralston, …



Hard Meson Electroproduction

- Many channels available for flavor separation (ρ^0, ρ^+, π^0, π^+, ϕ, …)
- J/Ψ and ϕ are especially interesting to access gluon GPDs (H and even E)
- Theory less under control : convolution with (unknown) meson WF, large power and NLO corrections

GPDs enter DVCS through Compton Form Factors

GPD's

$$\mathcal{F}(\xi, t, \mu_F, Q^2) = \int_{-1}^{1} dx\, C\left(x, \xi, \alpha_S(\mu_F), \frac{Q}{\mu_F}\right) F(x, \xi, t, \mu_F)$$

Compton Form Factor (CFF)
CFF are *complex* functions !

Integration Kernels have been worked out up to NLO

$$+O\left(\frac{1}{Q^2}\right)$$

Higher twist,
Power corrections

Definition of DVCS observables

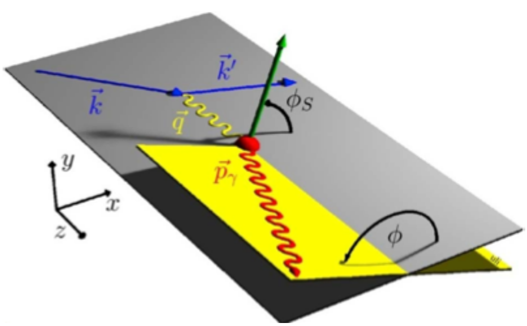
In the one-photon exchange approximation of QED,
the BH, DVCS and interference parts of the $ep \to ep\gamma$ cross section read :

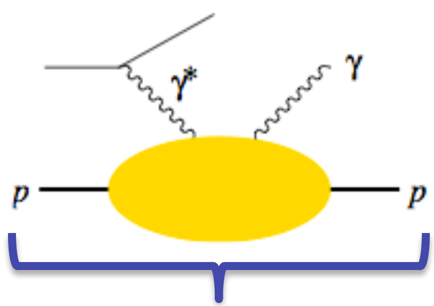
Diehl et al

$$|\mathcal{M}_{\mathrm{BH}}|^2 \propto \frac{1}{|t|}\frac{1}{P(\cos\phi)}\sum_{n=0}^{3}\left[c_n^{\mathrm{BH}}\cos(n\phi)+s_n^{\mathrm{BH}}\sin(n\phi)\right]$$

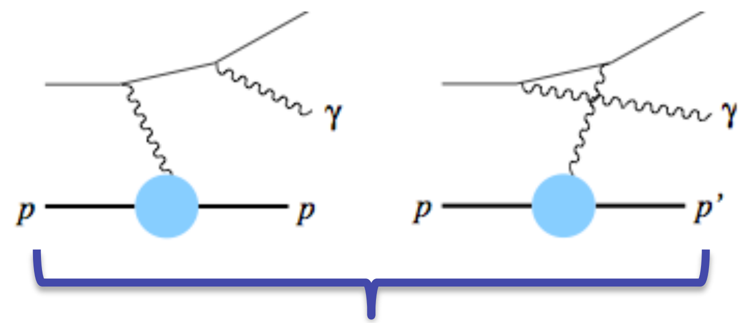
$$|\mathcal{M}_{\mathrm{DVCS}}|^2 \propto \sum_{n=0}^{3}\left[c_n^{\mathrm{DVCS}}\cos(n\phi)+s_n^{\mathrm{DVCS}}\sin(n\phi)\right]$$

$$\mathcal{M}_{\mathrm{I}} \propto \frac{1}{|t|}\frac{1}{P(\cos\phi)}\sum_{n=0}^{3}\left[c_n^{\mathrm{I}}\cos(n\phi)+s_n^{\mathrm{I}}\sin(n\phi)\right]$$





DVCS



Bethe-Heitler

Definition of DVCS observables

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Diehl et al

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$$|\mathcal{M}_{\mathrm{DVCS}}|^2 \propto \sum_{n=0}^{3}\left[c_n^{\mathrm{DVCS}}\cos(n\phi)+s_n^{\mathrm{DVCS}}\sin(n\phi)\right]$$

$$\mathcal{M}_{\mathrm{I}} \propto \frac{1}{|t|}\frac{1}{P(\cos\phi)}\sum_{n=0}^{3}\left[c_n^{\mathrm{I}}\cos(n\phi)+s_n^{\mathrm{I}}\sin(n\phi)\right]$$

IN SOME APPROXIMATIONS (like BMK) a (1/Q) expansion of the leptonic tensors is performed, and they retain only the leading and sub-leading terms.

In JLab6 (or 12) kinematics, it is *not* legitimate !

Definition of DVCS observables

In the one-photon exchange approximation of QED,
the BH, DVCS and interference parts of the $ep \to ep\gamma$ cross section read :

Diehl et al

$$|\mathcal{M}_{\mathrm{BH}}|^2 \propto \frac{1}{|t|}\frac{1}{P(\cos\phi)}\sum_{n=0}^{3}\left[c_n^{\mathrm{BH}}\cos(n\phi) + s_n^{\mathrm{BH}}\sin(n\phi)\right]$$

$$|\mathcal{M}_{\mathrm{DVCS}}|^2 \propto \sum_{n=0}^{3}\left[c_n^{\mathrm{DVCS}}\cos(n\phi) + s_n^{\mathrm{DVCS}}\sin(n\phi)\right]$$

$$\mathcal{M}_{\mathrm{I}} \propto \frac{1}{|t|}\frac{1}{P(\cos\phi)}\sum_{n=0}^{3}\left[c_n^{\mathrm{I}}\cos(n\phi) + s_n^{\mathrm{I}}\sin(n\phi)\right]$$

All the observables' evaluations in this talk are achieved using an exact treatment of all contributions apart from the OPE in the hadronic tensor, done at leading twist (only twist-2 GPD's are considered)

Guichon, Vanderhaeghen

Definition of DVCS observables

The $lp \rightarrow lp\gamma$ cross section on an unpolarized target for a given beam charge e_l and beam helicity $h_l/2$ can be written as :

$$d\sigma^{h_l,e_l}(\phi) = d\sigma_{\mathrm{UU}}(\phi)\left[1 + h_l A_{\mathrm{LU,DVCS}}(\phi) + e_l h_l A_{\mathrm{LU,I}}(\phi) + e_l A_{\mathrm{C}}(\phi)\right]$$

If one has access to both different beam charges and helicities, one can extract :

$$A_{\mathrm{C}}(\phi) = \frac{1}{4d\sigma_{\mathrm{UU}}(\phi)}\left[\left(d\sigma^{\stackrel{+}{\rightarrow}} + d\sigma^{\stackrel{+}{\leftarrow}}\right) - \left(d\sigma^{\stackrel{-}{\rightarrow}} + d\sigma^{\stackrel{-}{\leftarrow}}\right)\right]$$

$$A_{\mathrm{LU,I}}(\phi) = \frac{1}{4d\sigma_{\mathrm{UU}}(\phi)}\left[\left(d\sigma^{\stackrel{+}{\rightarrow}} - d\sigma^{\stackrel{+}{\leftarrow}}\right) - \left(d\sigma^{\stackrel{-}{\rightarrow}} - d\sigma^{\stackrel{-}{\leftarrow}}\right)\right]$$

$$A_{\mathrm{LU,DVCS}}(\phi) = \frac{1}{4d\sigma_{\mathrm{UU}}(\phi)}\left[\left(d\sigma^{\stackrel{+}{\rightarrow}} - d\sigma^{\stackrel{+}{\leftarrow}}\right) + \left(d\sigma^{\stackrel{-}{\rightarrow}} - d\sigma^{\stackrel{-}{\leftarrow}}\right)\right]$$

If one only has access to different beam helicities, one can extract :

$$A_{\mathrm{LU}}^{e_l}(\phi) = \frac{d\sigma^{\stackrel{e_l}{\rightarrow}} - d\sigma^{\stackrel{e_l}{\leftarrow}}}{d\sigma^{\stackrel{e_l}{\rightarrow}} + d\sigma^{\stackrel{e_l}{\leftarrow}}} = \frac{e_l A_{\mathrm{LU,I}}(\phi) + A_{\mathrm{LU,DVCS}}(\phi)}{1 + e_l A_{\mathrm{C}}(\phi)}$$

(equivalent expressions for polarized target case)

Definition of DVCS observables

Finally, experiments sometimes prefer to publish Fourier Harmonics of the asymmetries which are linked to the CFF's.
Taking the charge asymmetry for instance, it is evaluated this way :

$$A_C^{\cos(n\phi)} = N \int_0^{2\pi} d\phi A_C(\phi) \cos(n\phi)$$

N is $1/2\pi$ in the case $n = 0$ and $1/\pi$ for $n \geq 1$

In the BMK approximation, a few different harmonics read :

$$A_C^{\cos\phi} \propto \mathrm{Re}\left[\boxed{F_1\mathcal{H}} + \xi(F_1+F_2)\tilde{\mathcal{H}} - \frac{t}{4m^2}F_2\mathcal{E}\right],$$

$$A_{LU,I}^{\sin\phi} \propto \mathrm{Im}\left[\boxed{F_1\mathcal{H}} + \xi(F_1+F_2)\tilde{\mathcal{H}} - \frac{t}{4m^2}F_2\mathcal{E}\right],$$

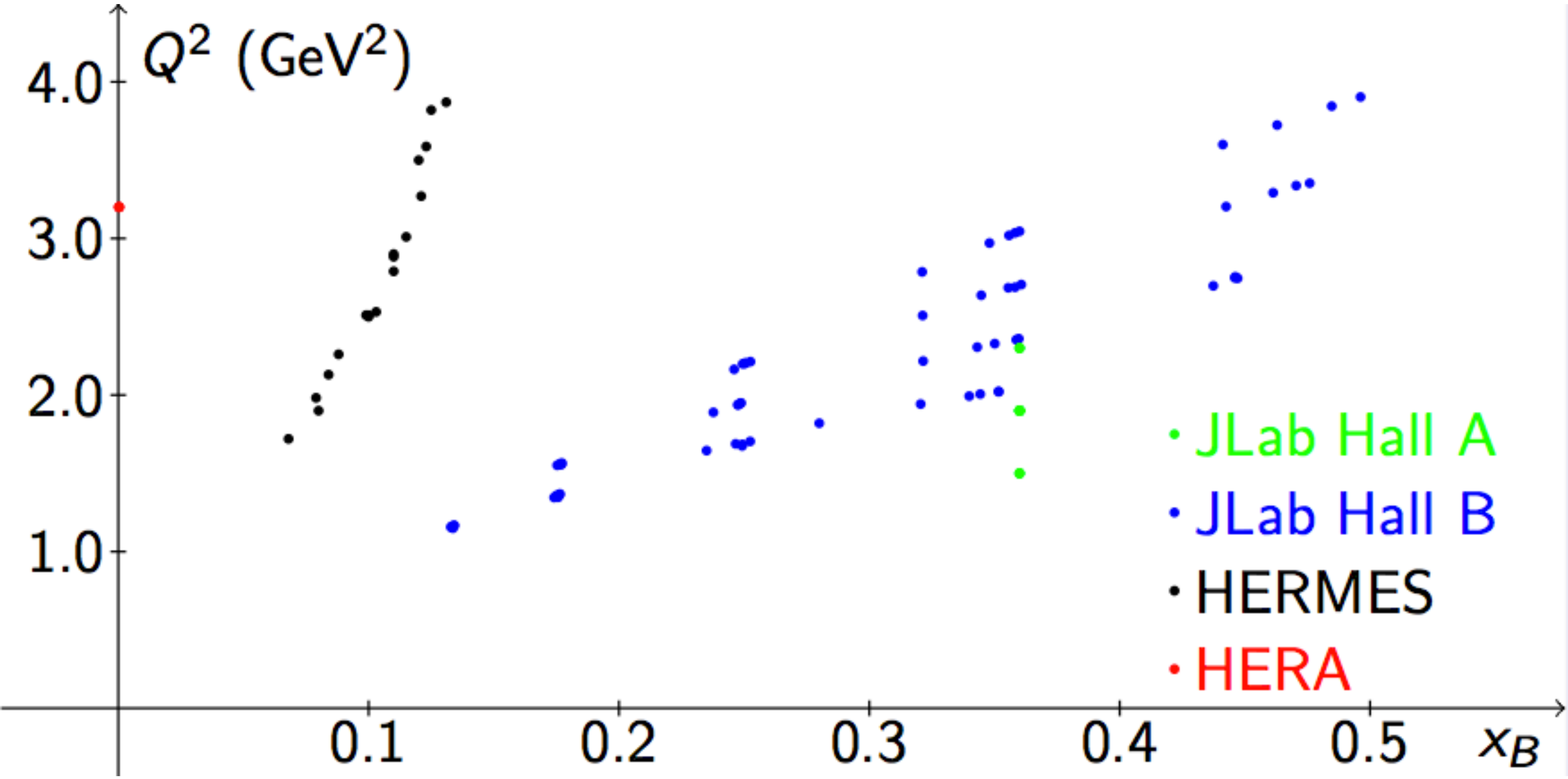
$$A_{UL,I}^{\sin\phi} \propto \mathrm{Im}\left[\xi(F_1+F_2)(\mathcal{H} + \frac{\xi}{1+\xi}\mathcal{E}) + \boxed{F_1\tilde{\mathcal{H}}} - \xi(\frac{\xi}{1+\xi}F_1 + \frac{t}{4M^2}F_2)\tilde{\mathcal{E}}\right]$$

$$A_{LL,I}^{\cos\phi} \propto \mathrm{Re}\left[\xi(F_1+F_2)(\mathcal{H} + \frac{\xi}{1+\xi}\mathcal{E}) + \boxed{F_1\tilde{\mathcal{H}}} - \xi(\frac{\xi}{1+\xi}F_1 + \frac{t}{4M^2}F_2)\tilde{\mathcal{E}}\right]$$

DVCS data worldwide

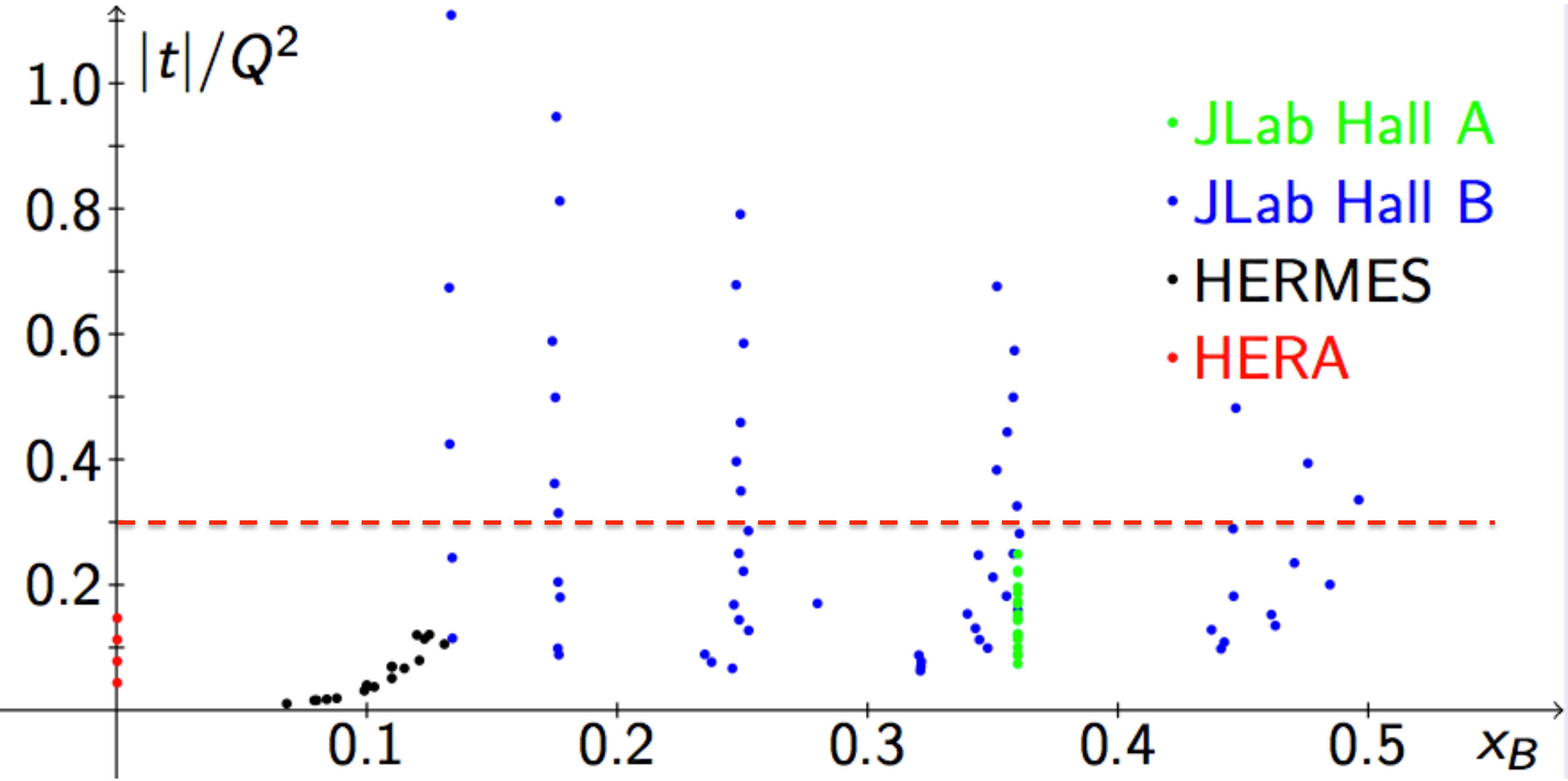
Experiment	
HERMES	Various asymmetries with beam helicity, charge and target L and T polarizations
CLAS	Various asymmetries with beam helicity and target L polarization
HALL A	Helicity-dependent cross sections
HERA	DVCS cross sections and charge asymmetry

DVCS data kinematics



- ❑ DVCS data cover complementary kinematical regions

DVCS data kinematics



- DVCS data cover complementary kinematical regions
- Warning : $|t|/Q^2$ is not always small

DVCS data and their sensitivity to CFF's

Experiment	Observable	Normalized CFF dependence
HERMES	$A_{\mathrm{C}}^{\cos 0\phi}$	$\mathrm{Re}\mathcal{H} + 0.06\mathrm{Re}\mathcal{E} + 0.24\mathrm{Re}\widetilde{\mathcal{H}}$
	$A_{\mathrm{C}}^{\cos \phi}$	$\mathrm{Re}\mathcal{H} + 0.05\mathrm{Re}\mathcal{E} + 0.15\mathrm{Re}\widetilde{\mathcal{H}}$
	$A_{\mathrm{LU,I}}^{\sin \phi}$	$\mathrm{Im}\mathcal{H} + 0.05\mathrm{Im}\mathcal{E} + 0.12\mathrm{Im}\widetilde{\mathcal{H}}$
	$A_{\mathrm{UL}}^{+,\sin \phi}$	$\mathrm{Im}\widetilde{\mathcal{H}} + 0.10\mathrm{Im}\mathcal{H} + 0.01\mathrm{Im}\mathcal{E}$
	$A_{\mathrm{UL}}^{+,\sin 2\phi}$	$\mathrm{Im}\widetilde{\mathcal{H}} - 0.97\mathrm{Im}\mathcal{H} + 0.49\mathrm{Im}\mathcal{E} - 0.03\mathrm{Im}\widetilde{\mathcal{E}}$
	$A_{\mathrm{LL}}^{+,\cos 0\phi}$	$1 + 0.05\mathrm{Re}\widetilde{\mathcal{H}} + 0.01\mathrm{Re}\mathcal{H}$
	$A_{\mathrm{LL}}^{+,\cos \phi}$	$1 + 0.79\mathrm{Re}\widetilde{\mathcal{H}} + 0.11\mathrm{Im}\mathcal{H}$
	$A_{\mathrm{UT,DVCS}}^{\sin(\phi-\phi_S)}$	$\mathrm{Im}\mathcal{H}\mathrm{Re}\mathcal{E} - \mathrm{Im}\mathcal{E}\mathrm{Re}\mathcal{H}$
	$A_{\mathrm{UT,I}}^{\sin(\phi-\phi_S)\cos\phi}$	$\mathrm{Im}\mathcal{H} - 0.56\mathrm{Im}\mathcal{E} - 0.12\mathrm{Im}\widetilde{\mathcal{H}}$
CLAS	$A_{\mathrm{LU}}^{-,\sin \phi}$	$\mathrm{Im}\mathcal{H} + 0.06\mathrm{Im}\mathcal{E} + 0.21\mathrm{Im}\widetilde{\mathcal{H}}$
	$A_{\mathrm{UL}}^{-,\sin \phi}$	$\mathrm{Im}\widetilde{\mathcal{H}} + 0.12\mathrm{Im}\mathcal{H} + 0.04\mathrm{Im}\mathcal{E}$
	$A_{\mathrm{UL}}^{-,\sin 2\phi}$	$\mathrm{Im}\widetilde{\mathcal{H}} - 0.79\mathrm{Im}\mathcal{H} + 0.30\mathrm{Im}\mathcal{E} - 0.05\mathrm{Im}\widetilde{\mathcal{E}}$
HALL A	$\Delta\sigma^{\sin \phi}$	$\mathrm{Im}\mathcal{H} + 0.07\mathrm{Im}\mathcal{E} + 0.47\mathrm{Im}\widetilde{\mathcal{H}}$
	$\sigma^{\cos 0\phi}$	$1 + 0.05\mathrm{Re}\mathcal{H} + 0.007\mathcal{H}\mathcal{H}^*$
	$\sigma^{\cos \phi}$	$1 + 0.12\mathrm{Re}\mathcal{H} + 0.05\mathrm{Re}\widetilde{\mathcal{H}}$
HERA	σ_{DVCS}	$\mathcal{H}\mathcal{H}^* + 0.09\mathcal{E}\mathcal{E}^* + \widetilde{\mathcal{H}}\widetilde{\mathcal{H}}^*$

Our framework

arXiv:1210.6975

GPD's we used are from Goloskokov-Kroll model (fit to DVMP, PDF, FF data)

GPD's H and $\tilde{H}$ evolutions are therefore done through PDF's at $\mu_F=Q$

GPD's were not adjusted using DVCS data

Kernel is calculated at Leading-Order of α_S

Leading-Twist (in the hadronic tensor OPE)

No D-term (not needed for low-x_B data)

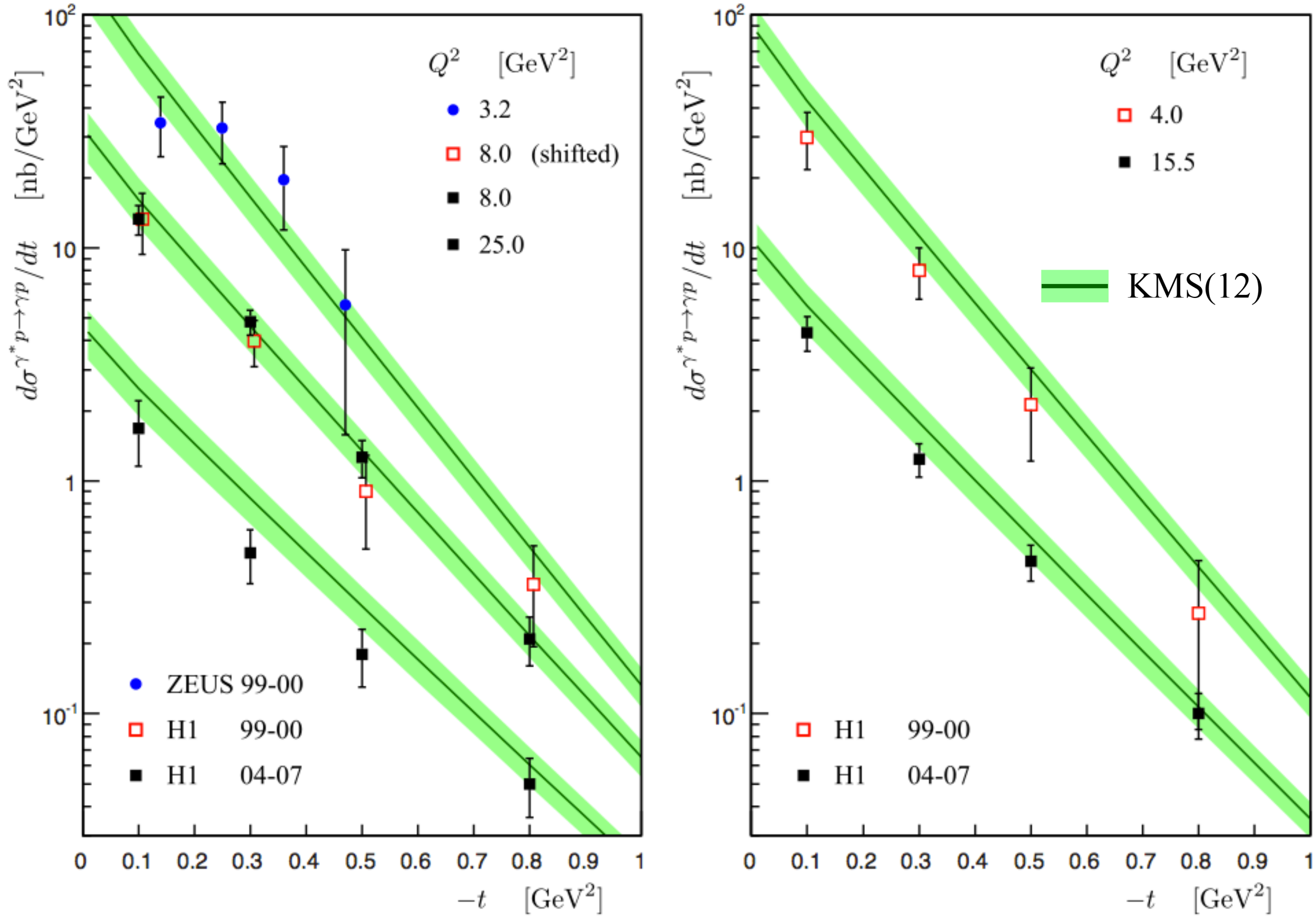
No finite-t or target-mass corrections (Braun et al. recent work)

Exact calculation of all leptonic parts (no 1/Q expansion as in BMK, DS)

Error bands are evaluated using polarized and unpolarized PDF errors

Article on the arXiv

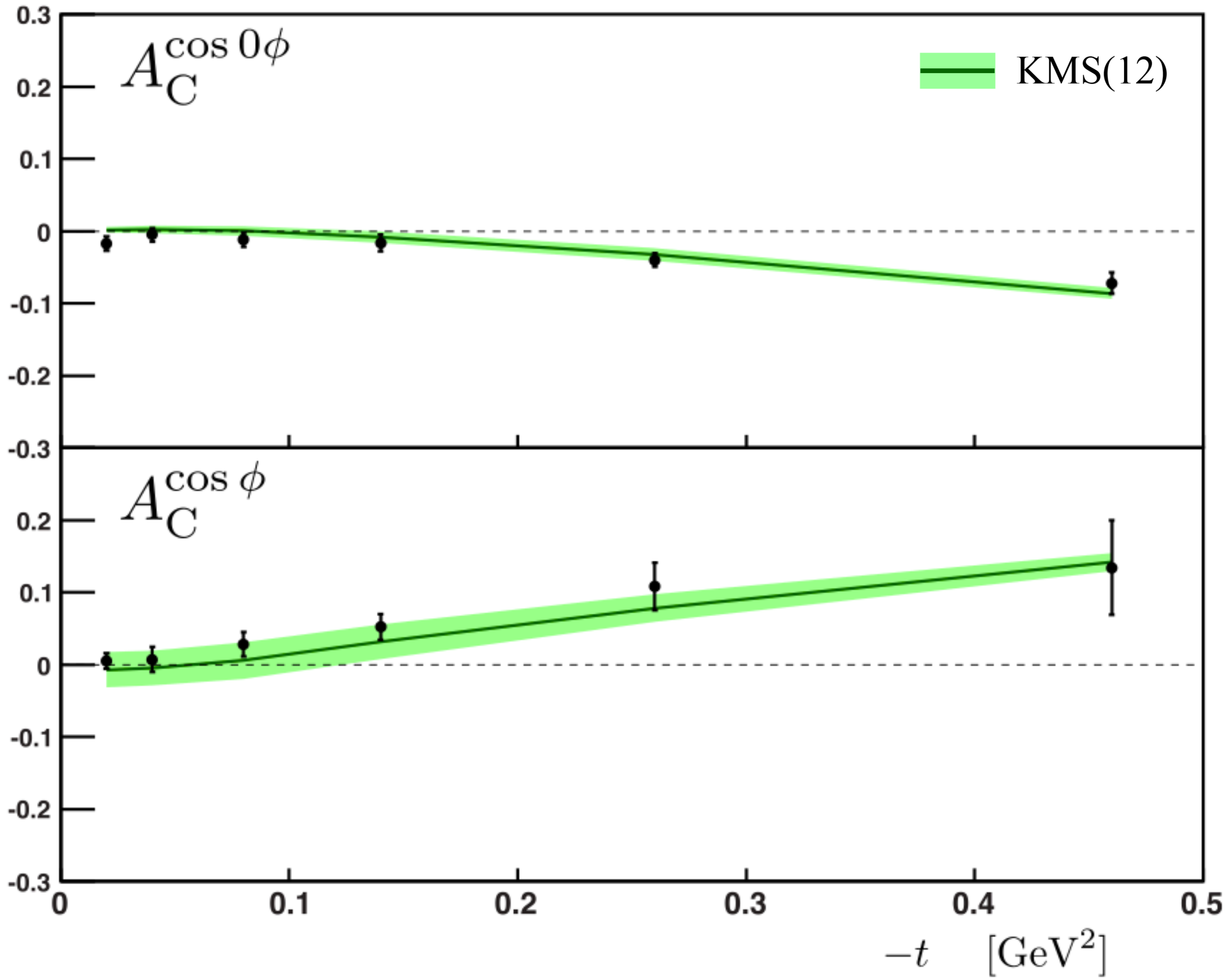
Low-x_B DVCS cross sections (HERA)



- ❑ Dominated by ImH of sea quarks
- ❑ Important evolution effects (Q^2 from 3 to 25 GeV^2)
- ❑ Reasonable agreement over the whole data range

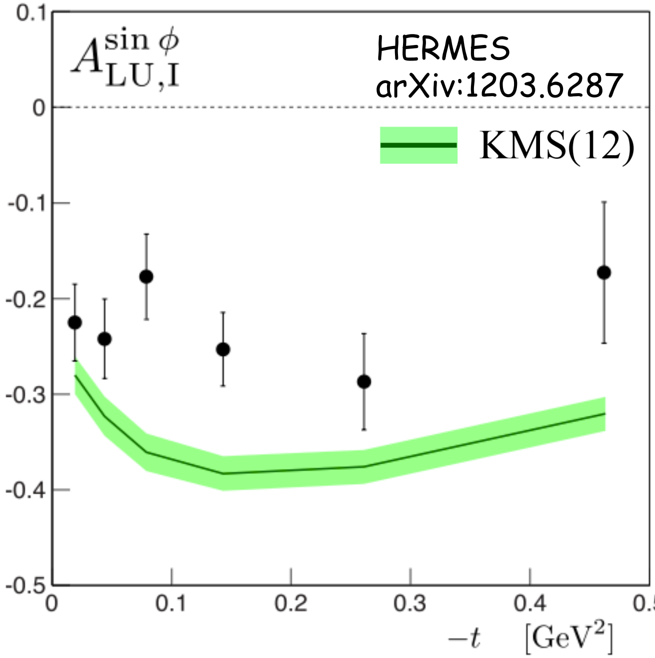
DVCS Charge Asymmetry (HERMES)

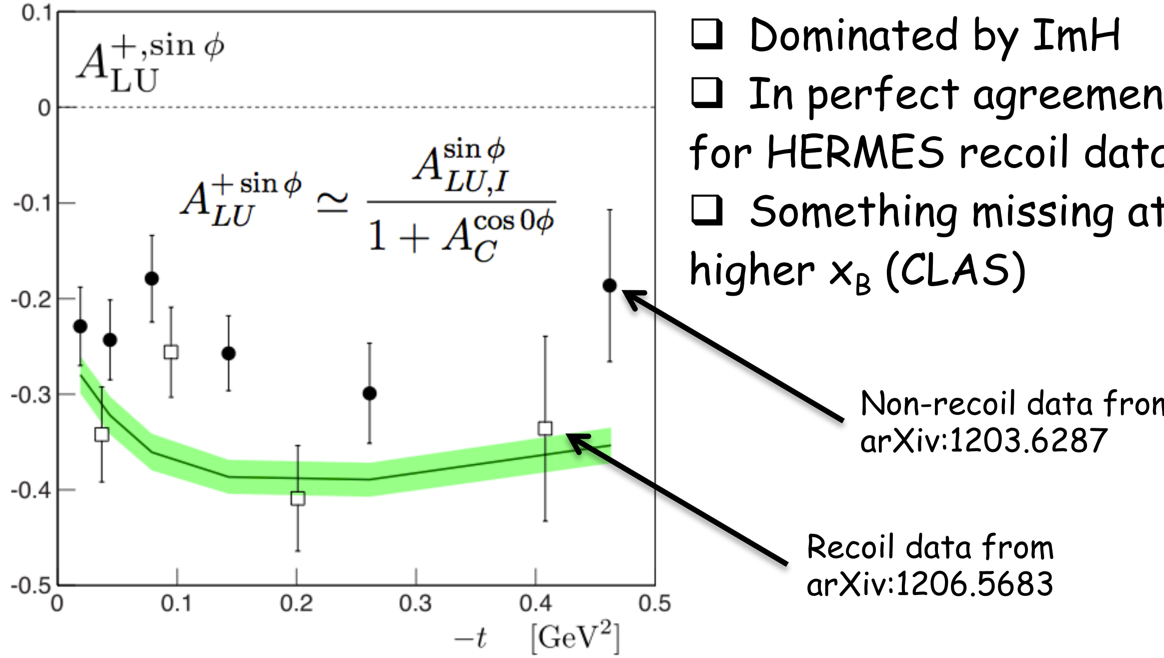
arXiv:1203.6287



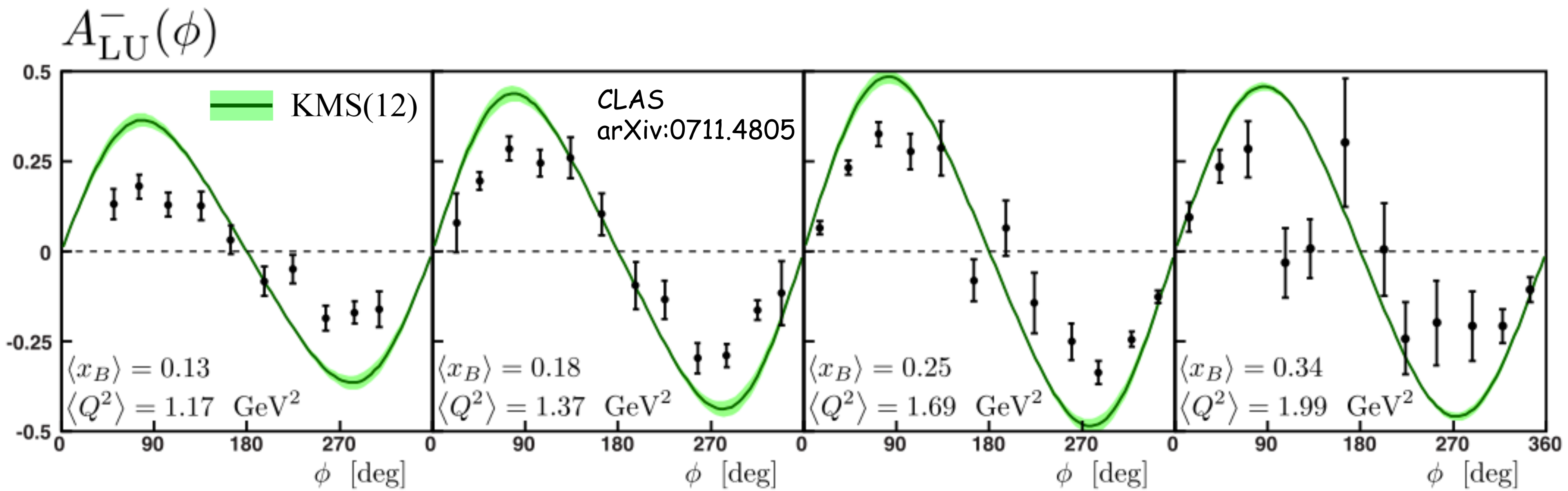
- ❑ Dominated by ReH
- ❑ In perfect agreement over the whole t-range

DVCS Beam Spin Asymmetries (HERMES, CLAS)



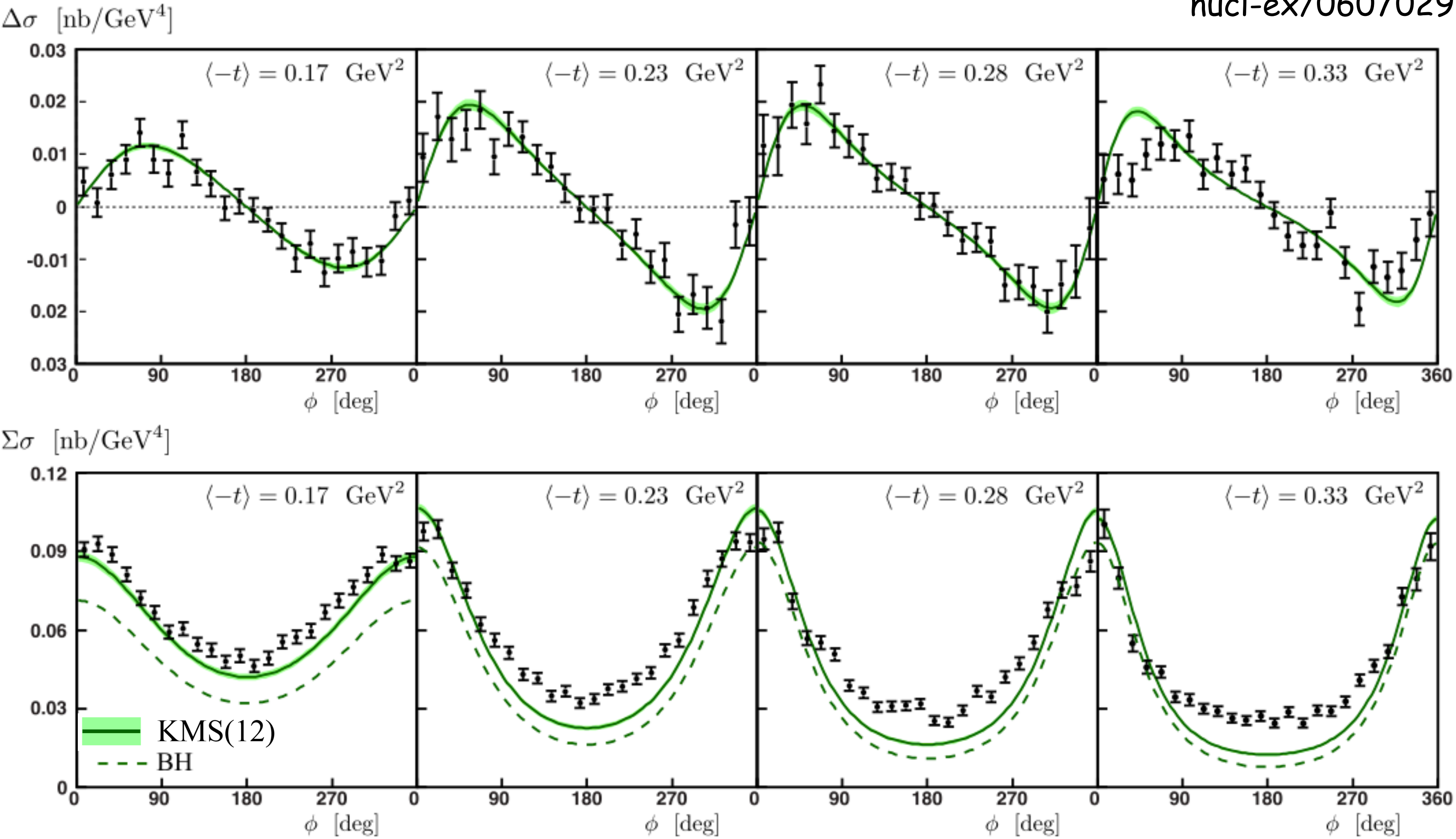


- Dominated by ImH
- In perfect agreement for HERMES recoil data
- Something missing at higher x_B (CLAS)



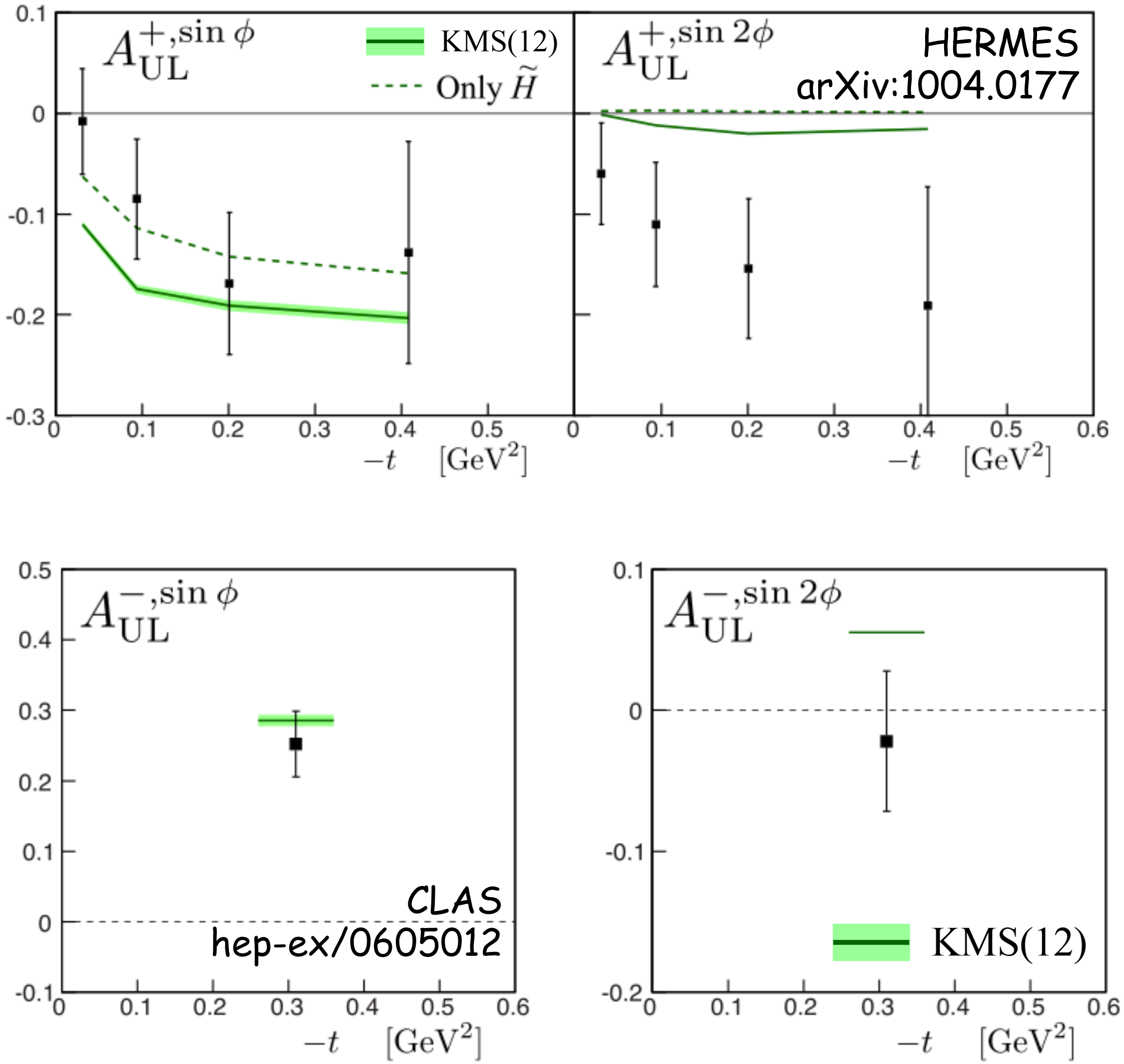
DVCS helicity-dependent cross sections (Hall A)

nucl-ex/0607029



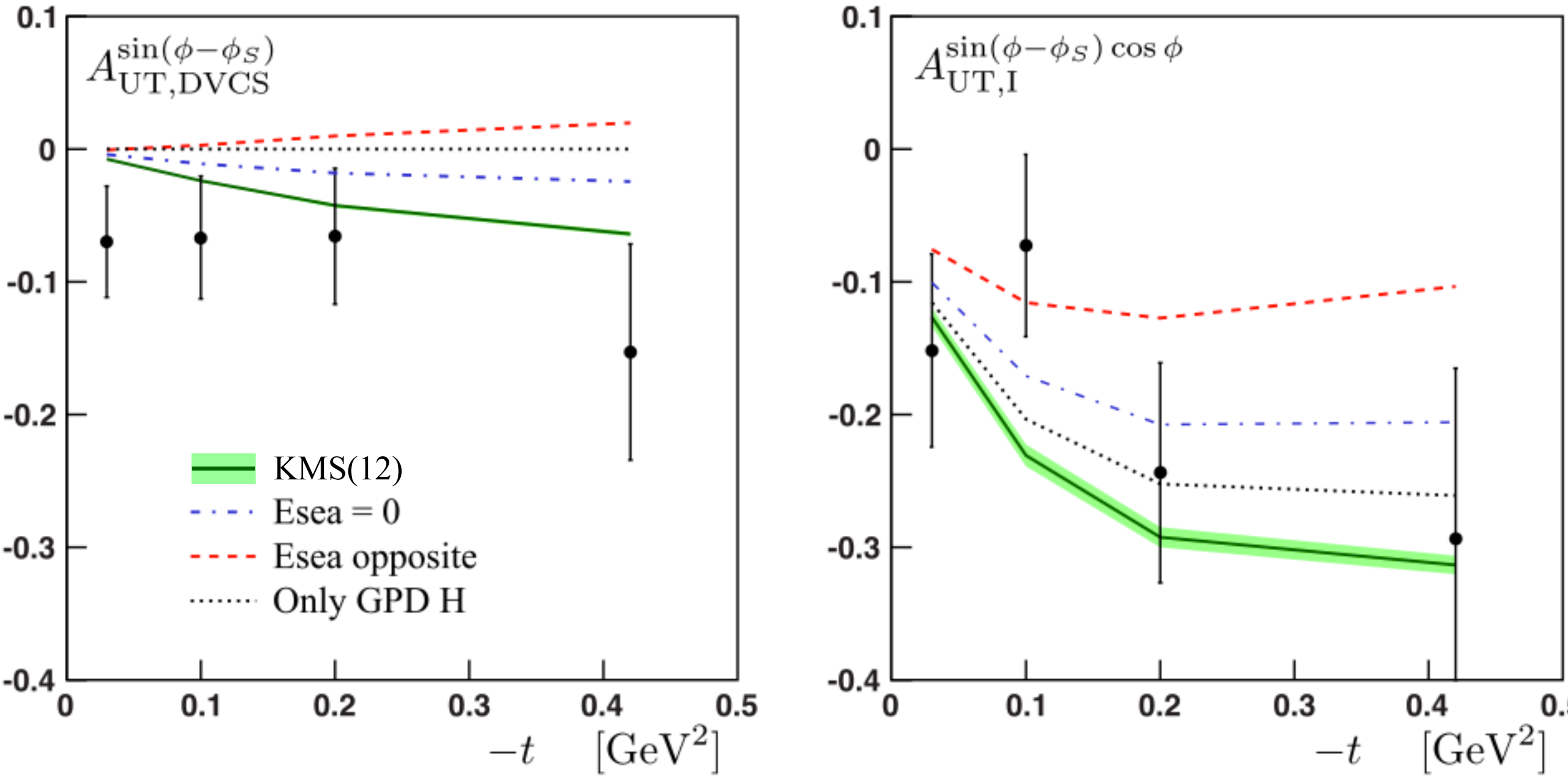
- ❑ $\Delta\sigma$ dominated by ImH, in perfect agreement
- ❑ Total cross section more challenging (disclaimer: high-x_B !)

DVCS L-Target Spin Asymmetries (HERMES, CLAS)



- ❑ Dominated by Im$\tilde{H}$
- ❑ sinϕ harmonic in good agreement
- ❑ HERMES sin2ϕ unexpectedly large

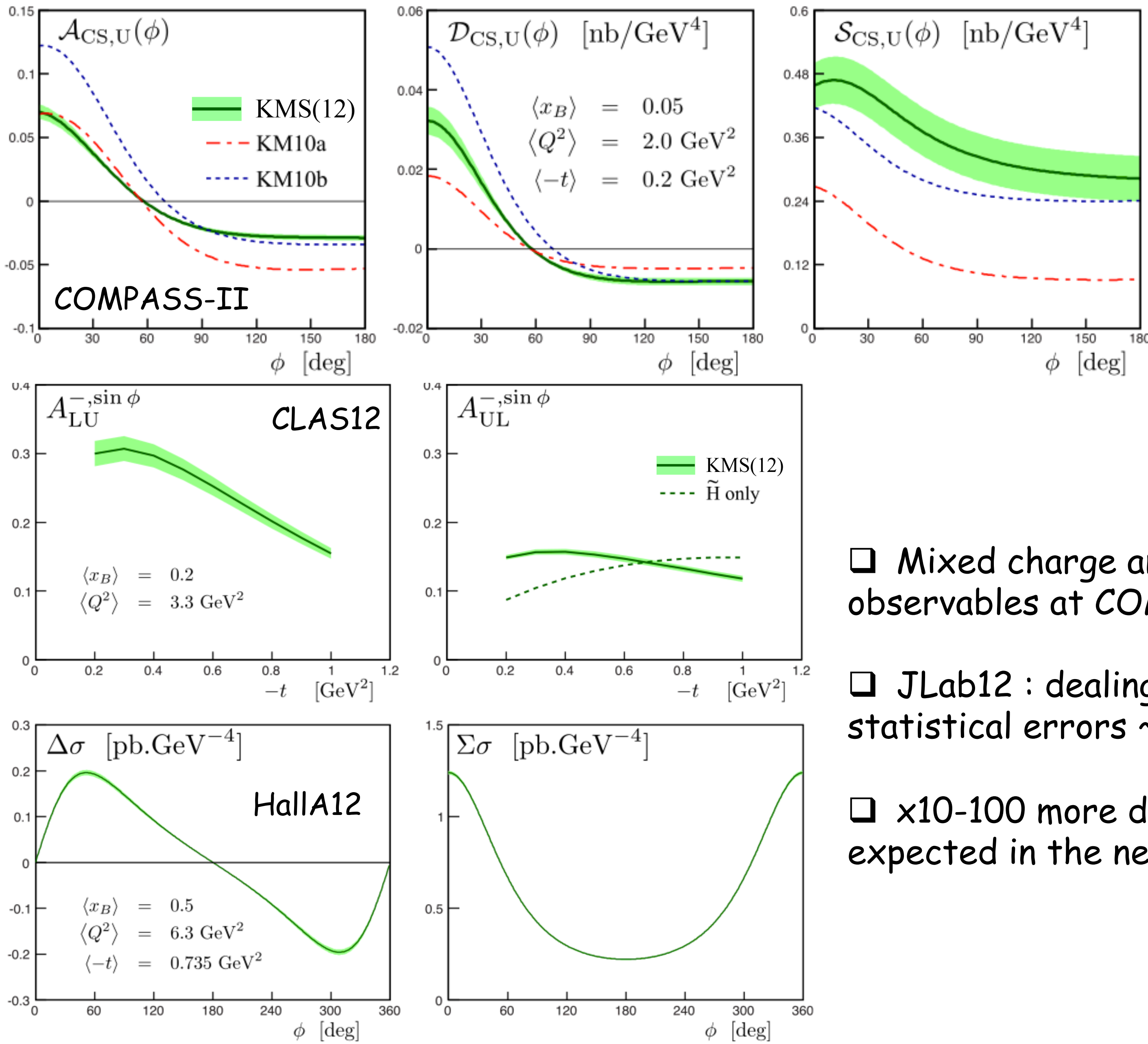
DVCS T-Target Spin Asymmetries (HERMES)



- ImE_{sea} clearly non-zero

… and most likely negative and large

Near future : COMPASS-II and JLab12



- ❑ Mixed charge and spin observables at COMPASS-II
- ❑ JLab12 : dealing with statistical errors ~1%
- ❑ x10-100 more data expected in the next few years

So, what did we learn ?

- ❑ Using GPD's fit to low-to-mid-x_B DVMP data (+PDF, FF) we evaluated DVCS observables at Leading-Order and Leading-Twist

- ❑ Agreement with data is good for HERA and HERMES, fair for JLab

<u>Possible improvements:</u>

- ❑ NLO kernel + NLO GPD evolution

(Moutarde, Pire, Sabatié, Szymanowski, Wagner, in preparation)

- ❑ Modification of the profile function, D-term for high-x_B

(Mezrag, Moutarde, Sabatié, in preparation)

- ❑ Finite-t and target mass corrections

(New developments from Braun. Et al)

- ❑ And … of course, of upmost importance, add more data :

COMPASS-II, CLAS 6 & 12, Hall A 6 & 12 and … EIC

Next-to-leading order studies

Quark and gluon coefficient functions up to NLO are well known :

$$
\begin{aligned}
C_0^q(x,\xi) &= -e_q^2 \frac{1}{x+\xi-i\varepsilon}\,, \\
C_1^q(x,\xi) &= \frac{e_q^2\alpha_S C_F}{4\pi}\frac{1}{x+\xi-i\varepsilon}\left[9-3\frac{x+\xi}{x-\xi}\log(\frac{x+\xi}{2\xi}-i\varepsilon)-\log^2(\frac{x+\xi}{2\xi}-i\varepsilon)\right], \\
C_{coll}^q(x,\xi) &= \frac{e_q^2\alpha_S C_F}{4\pi}\frac{1}{x+\xi-i\varepsilon}\left[-3-2\log(\frac{x+\xi}{2\xi}-i\varepsilon)\right], \\
C_1^g(x,\xi) &= \frac{\Sigma e_q^2\alpha_S T_F}{4\pi}\frac{1}{(x+\xi-i\varepsilon)(x-\xi+i\varepsilon)}\times \\
&\left[2\frac{x+3\xi}{x-\xi}\log\left(\frac{x+\xi}{2\xi}-i\varepsilon\right)-\frac{x+\xi}{x-\xi}\log^2\left(\frac{x+\xi}{2\xi}-i\varepsilon\right)\right], \\
C_{coll}^g(x,\xi) &= \frac{\Sigma e_q^2\alpha_S T_F}{4\pi}\frac{2}{(x+\xi-i\varepsilon)(x-\xi+i\varepsilon)}\left[-\frac{x+\xi}{x-\xi}\log\left(\frac{x+\xi}{2\xi}-i\varepsilon\right)\right],
\end{aligned}
$$

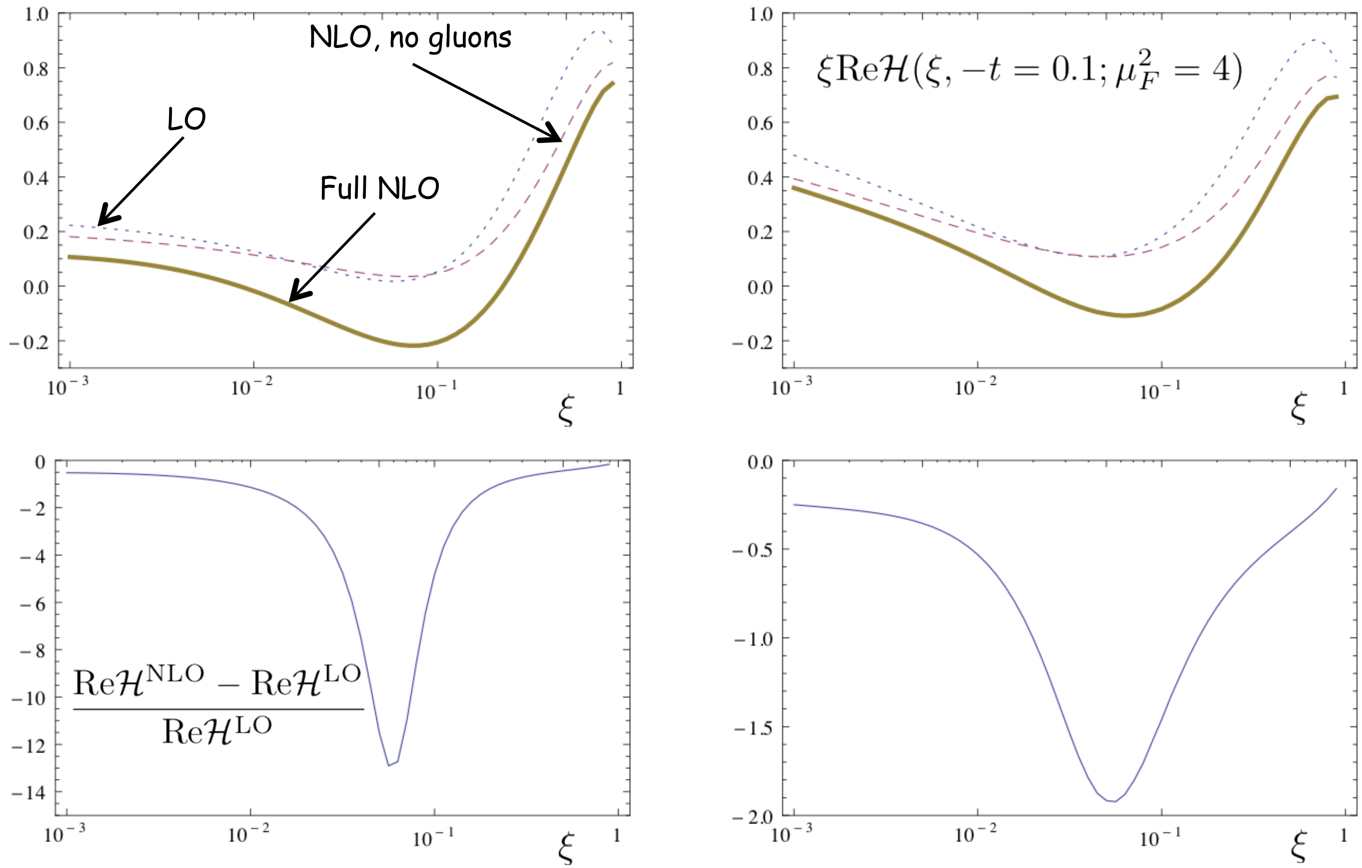
Main differences : - gluon GPDs contribute to DVCS at NLO

- factorization scale dependence of the kernel at NLO
- extra logs in the kernel, integrals even trickier to evaluate

Next-to-leading order studies : ReH

Goloskokov-Kroll

RDDA using MSTW08

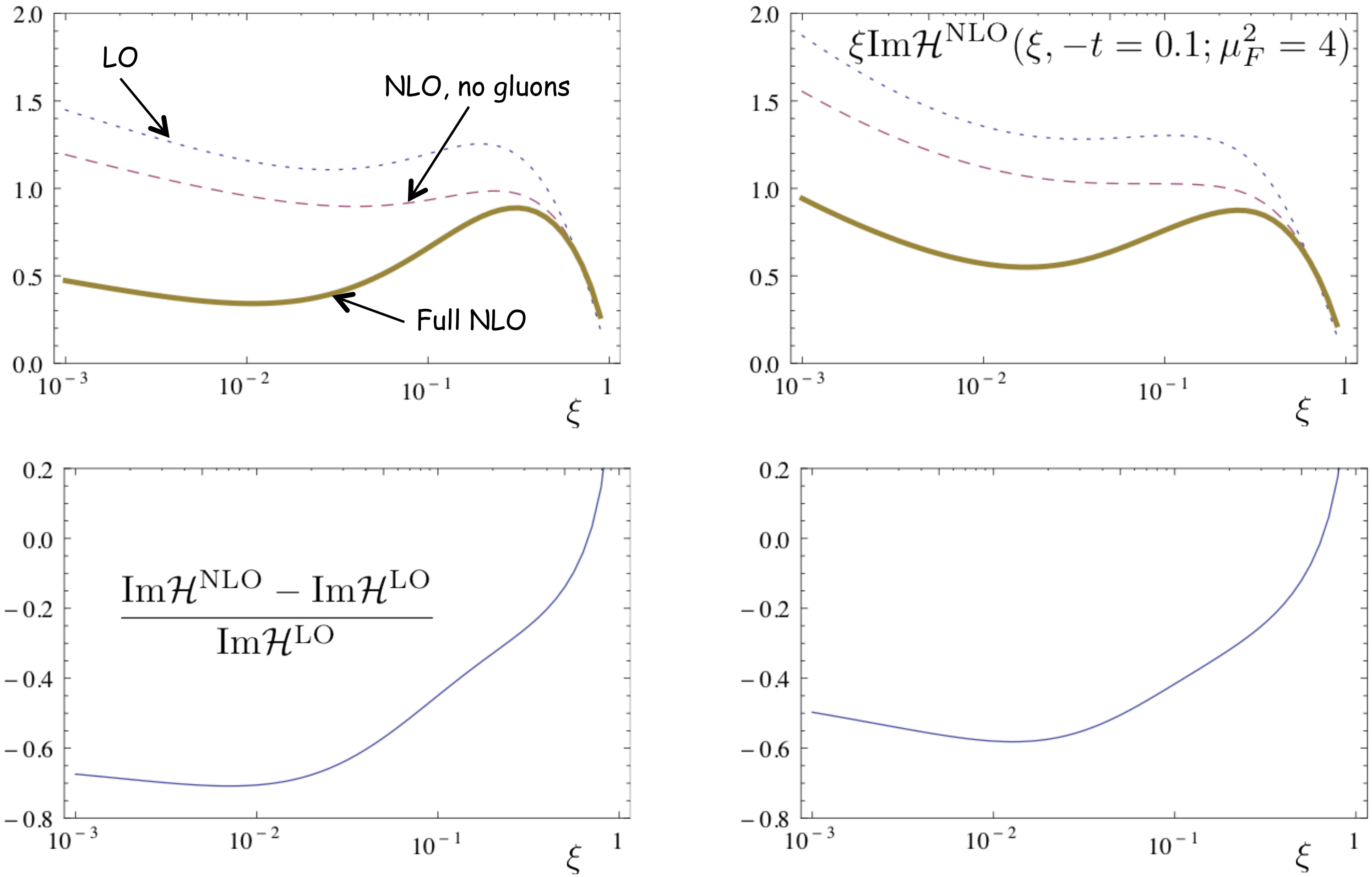


Significant corrections for quarks

Very large/huge (model-dependent) corrections from gluons

NLO correction peaks in the COMPASS-II kinematical range

Next-to-leading order studies : ImH



Significant corrections for quarks

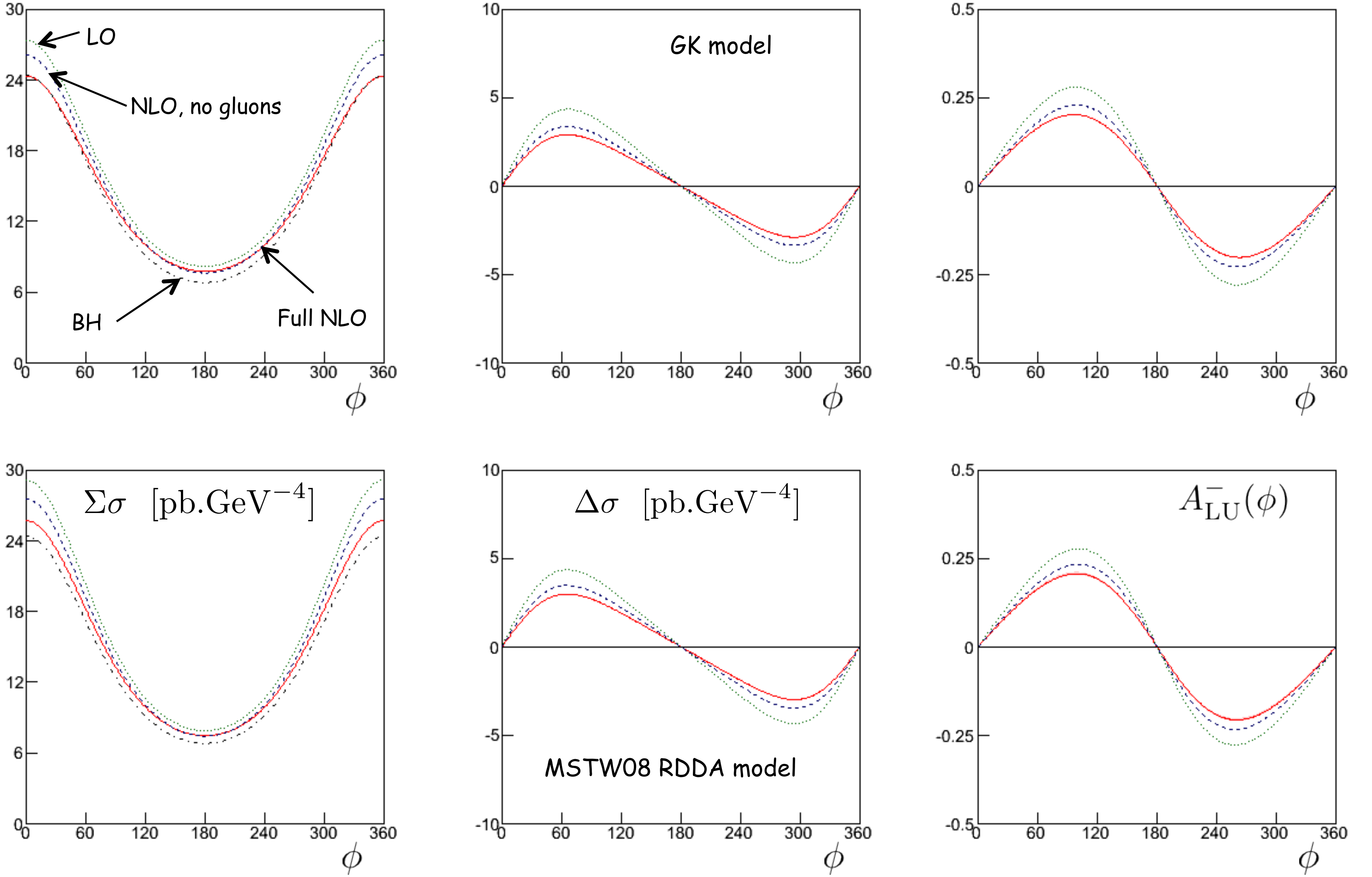
Large corrections from gluons, less model dependence than for the Re part

The good : large sensitivity to gluon GPDs even at moderate/large x_B

The bad : a quantitative extraction of GPDs at LO is not legitimate

Effect on observables at E_{beam}=11 GeV

$\xi = 0.2, -t = 0.2 \quad \mathrm{GeV}^2, Q^2 = \mu_F^2 = 4 \quad \mathrm{GeV}^2$



Extending Double Distribution-based models

C. Mezrag, H. Moutarde, F.S.
work in progress

One of the popular ways to modelise GPDs : « DD+D » which involves :

> One double-distribution (DD) factorised into a PDF and a profile function
> A largely unknown D-term often expended on a Gegenbauer polynomial basis

$$H_{\mathrm{DD+D}}(x,\xi) = \int_{\Omega} \left[f(\beta)h(\beta,\alpha) + \xi D(\alpha)\delta(\beta)\right]\delta(x-\beta-\alpha\xi)d\beta d\alpha$$

2011 : New model of GPD by A. Radyushkin using « single DD » formalism in which the previous external D-term is no more needed to get the right degree in ξ of GPD Mellin moments.

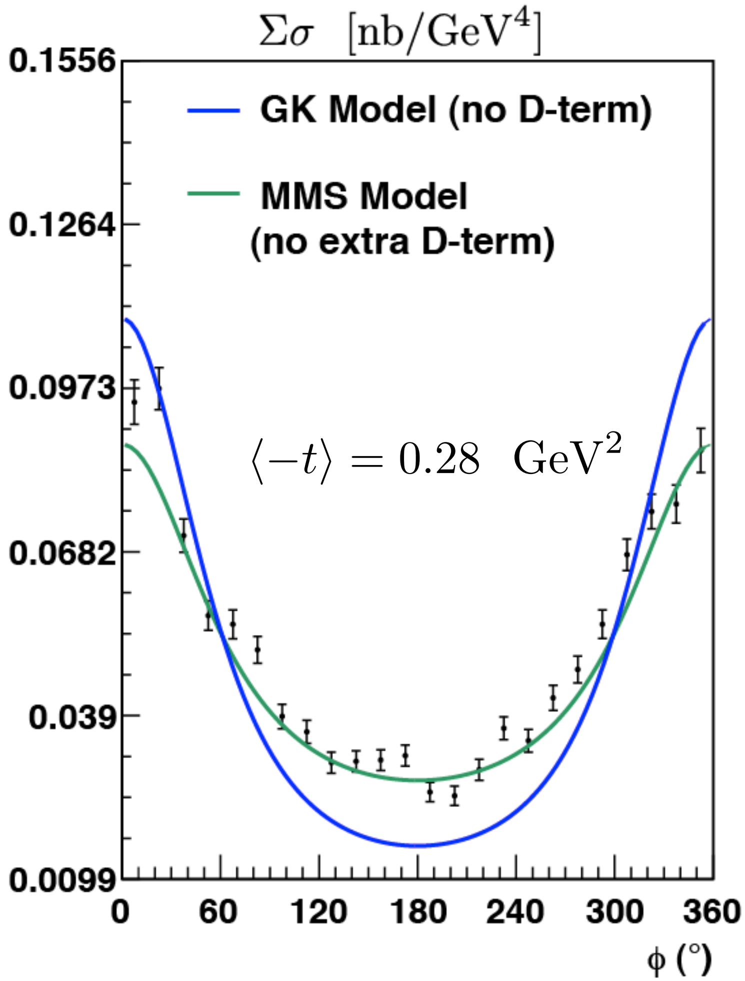
arXiv:1101.2165

$$H_{\mathrm{sDD}}(x,\xi) = x\int_{\Omega} \frac{f(\beta)}{\beta} h_N(\beta,\alpha)d\beta d\alpha$$

2012 : We're developping a realistic model based on Radyushkin sDD and the Goloskokov-Kroll fundations, fitted on JLab Hall A data.

« Single DD » to the rescue of the total cross-section

C. Mezrag, H. Moutarde, F.S.
work in progress



Higher-twist & Power corrections

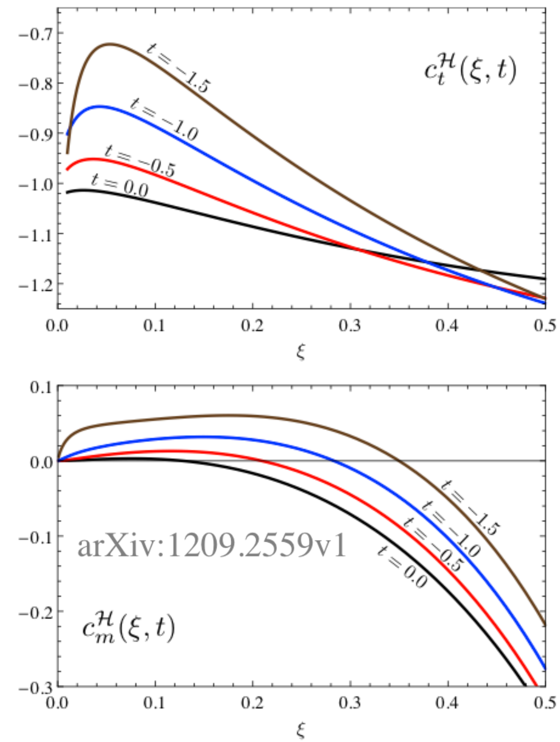
Dynamical/geometrical/genuine/… twist: - a work in progress, very few phenomenology results about this,

- will be needed for quantitative GPD extraction

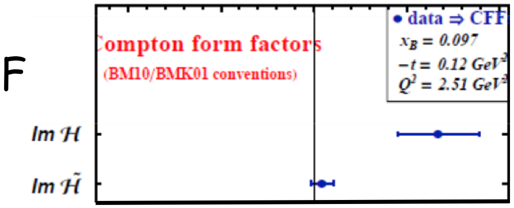
A recent example (Braun et al., 2012):

Finite-t and target mass corrections are potentially sizeable

$$\frac{\mathrm{Im}\mathcal{F} - \mathrm{Im}\mathcal{F}^{LO}}{\mathrm{Im}\mathcal{F}^{LO}} = \frac{t}{Q^2} c_t^{\mathcal{F}}(\xi,t) + \frac{m^2}{Q^2} c_m^{\mathcal{F}}(\xi,t)$$

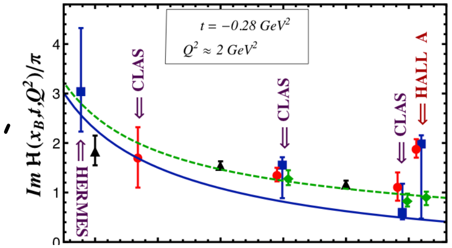


GPD fitting strategies, so far



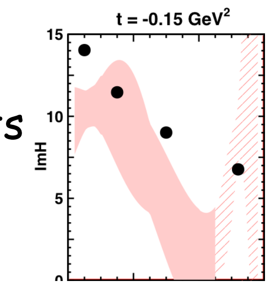
Local fits : treat each kinematic bin independantly, fit CFF

BMK, Hall A, Guidal, Moutarde, Mueller, Murray



Global fits : Take all kinematic bins at once (either low-x_B or high-x_B), Use a parametrization of GPDs (or CFFs).

Kumericki, Mueller

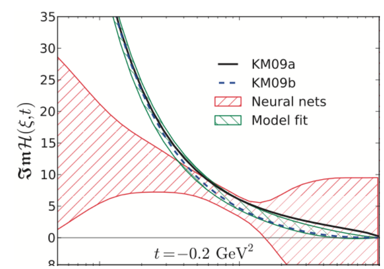


Hybrid fits : Start from local fits and … connect the dots

Moutarde

Neural Network fits : same technique as for PDF, better for error estimate of extrapolated areas

Kumericki, Mueller, Schäfer



Four methods, one thing in common : A LOT OF WORK IS NEEDED

> Either many d.o.f. or too few. Very rough hypothesis. For now, gives at best a qualitative estimate of some CFFs in specific kinematic regimes.

Conclusion : what did we learn ?

> Dominance of twist-2, validity of a GPD analysis of DVCS data

> Within hypothesis, Im$\mathcal{H}$ well known, Re$\mathcal{H}$ poorly constrained for now

> Some of those hypothesis are « rough » : Leading Order, Leading-twist, H-dominance

> In order to get better than 20-30% accuracy, a lot of work is needed

For now, GPD/CFF extraction accuracy is actually completely dominated by limitations stemming from theory and phenomenology, not by data accuracy. (for JLab data especially)

Backup Slides

Typical kinematics of experimental data sets

Experiment	**Kinematics**		
	x_B	Q^2 [GeV^2]	t [GeV^2]
HERMES	0.09	2.50	-0.12
CLAS	0.19	1.25	-0.19
HALL A	0.36	2.30	-0.23
HERA	0.001	8.00	-0.30

Goloskokov-Kroll GPD model

A typical RDDA model fit to DVMP, PDF and FF data (no DVCS):

$$
\begin{aligned}
H_i(x,\xi,t) &= \int_{|\alpha|+|\beta|\leq 1} d\beta d\alpha\, \delta(\beta+\xi\alpha-x) f_i(\beta,\alpha,t) \\
f_i(\beta,\alpha,t) &= e^{b_i t} \frac{1}{|\beta|^{\alpha' t}} h_i(\beta) \pi_{n_i}(\beta,\alpha) \\
\pi_{n_i}(\beta,\alpha) &= \frac{\Gamma(2n_i+2)}{2^{2n_i+1}\Gamma^2(n_i+1)} \frac{(1-|\beta|)^2-\alpha^2]^{n_i}}{(1-|\beta|)^{2n_i+1}}
\end{aligned}
$$

$$
\begin{aligned}
h_g(\beta) &= |\beta| g(|\beta|) & n_g &= 2 \\
h^q_{\mathrm{sea}}(\beta) &= q_{\mathrm{sea}}(|\beta|)\mathrm{sign}(\beta) & n_{\mathrm{sea}} &= 2 \\
h^q_{\mathrm{val}}(\beta) &= q_{\mathrm{val}}(\beta)\Theta(\beta) & n_{\mathrm{val}} &= 1
\end{aligned}
$$

What data to be expected in the future?

Short-term (2012-2013) :

JLab CLAS: Finalized analysis of DVCS cross sections (1^{st} run)
JLab CLAS: Updated results with 2^{nd} half of DVCS run
JLab CLAS: Finalized analysis of NH_3 and ND_3 data on DVCS
JLab Hall A: Rosenbluth separation of DVCS cross section (+ π^0)
HERMES: Finalized analysis of recoil detector data

Mid-term (2014-2020+) :

JLab CLAS12: Approved DVCS program (LH2, LD2, NH3) + more to come
JLab Hall A: Approved DVCS program with up to 11 GeV beam
COMPASS-II: Short DVCS run in 2012, then 2015 (also DVMP)

Long-term (2025+)

EIC : DVCS and DVMP, see R. Ent's talk on Friday morning

Conclusion

A sizeable data set to be used for phenomenology

> H1, ZEUS, HERMES, Jlab CLAS + Hall A, COMPASS and more

What we know **experimentally** (with constraints from theory usually !)

> Reasonable idea of the size of H (gluons, sea, valence)

> Rough idea of the size of $\tilde{H}$ and E for valence

> Some limited clues on the size of $\tilde{H}$ and E for sea

> Almost nothing on $\tilde{E}$ and the chiral-odd GPDs, but some progress !

What's next? **Going from a "rough" to a "good" knowledge !**

Clearly, **accurate** data on **cross sections** are needed in the next stage
Progress in theory and phenomenology is also needed (corrections, fits, etc)

> COMPASS-II and JLab12 will provide essential new data
> EIC is the ultimate tool for 3D nucleon imaging (and much more)