Revealing CFFs and GPDs from DVCS measurements

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- *photon leptoproduction observables*
- *mapping HERMES asymmetries to CFFs*
- *GPD models and their uses in fits*
- *GPD studies for EIC*

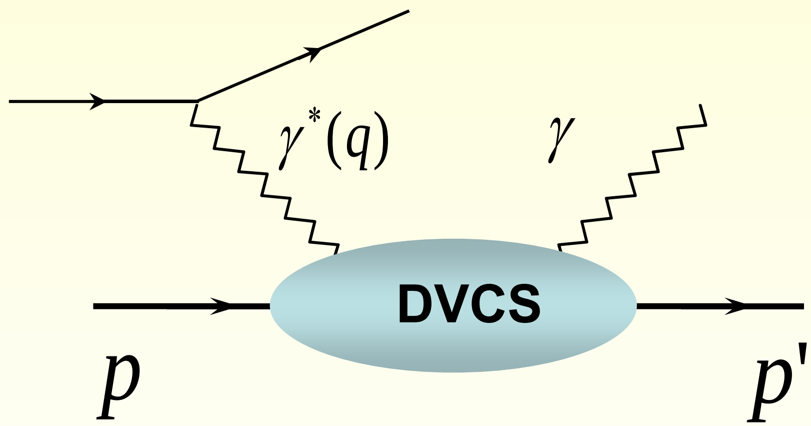
in collaboration with
K. Kumerički and M. Murray (HERMES studies)
E. Aschenauer , S. Fazio, and K. Kumerički (EIC studies)

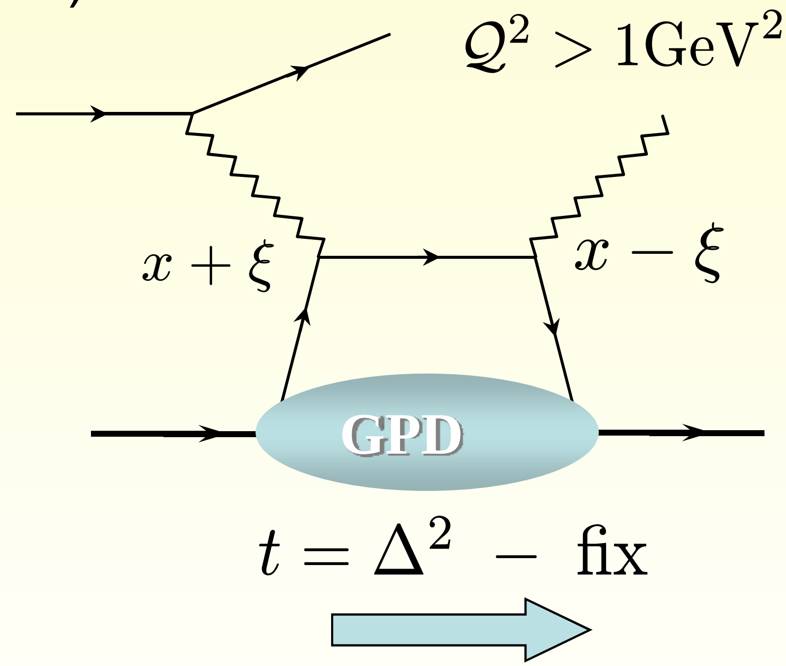
GPDs embed non-perturbative physics

[DM et. al (90/94)
Radyushkin (96)
Ji (96)]

GPDs appear in various hard exclusive processes,

e.g., hard electroproduction of photons (DVCS)





$$\mathcal{F}(\xi, \mathcal{Q}^2, t) = \int_{-1}^{1} dx\, C(x, \xi, \alpha_s(\mu), \mathcal{Q}/\mu) F(x, \xi, t, \mu) + O(\tfrac{1}{\mathcal{Q}^2})$$

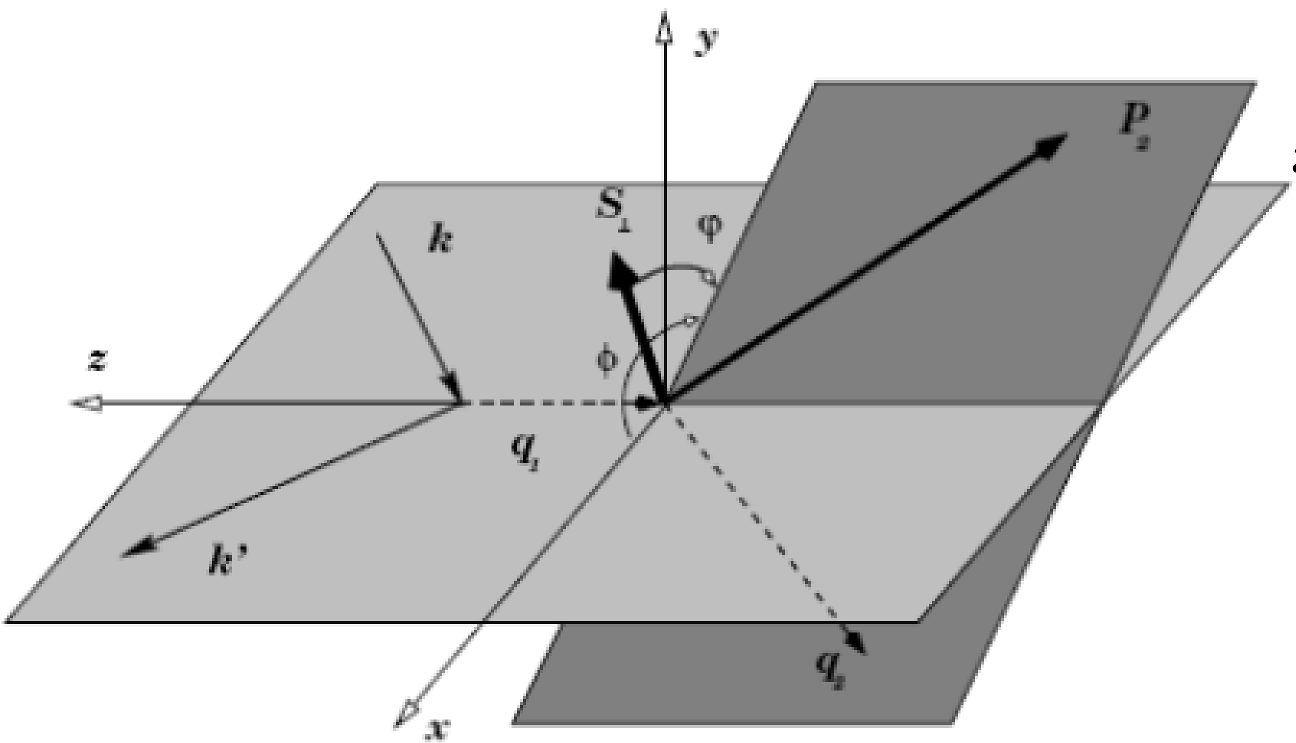
CFF	**hard scattering part**	**GPD**	**higher twist**
Compton form factor observable	perturbation theory (our conventions/microscope)	universal (conventional)	depends on approximation

Photon leptoproduction $e^{\pm} N \to e^{\pm} N \gamma$

measured by ***H1, ZEUS, HERMES, CLAS, HALL A*** collaborations

planed at ***COMPASS, JLAB@12GeV***, perhaps at ?? EIC,

$$\frac{d\sigma}{dx_{\mathrm{Bj}}\,dy\,d|\Delta^2|\,d\phi\,d\varphi} = \frac{\alpha^3 x_{\mathrm{Bj}} y}{16\,\pi^2\,\mathcal{Q}^2}\left(1+\frac{4M^2x_{Bj}^2}{\mathcal{Q}^2}\right)^{-1/2}\left|\frac{\mathcal{T}}{e^3}\right|^2,$$



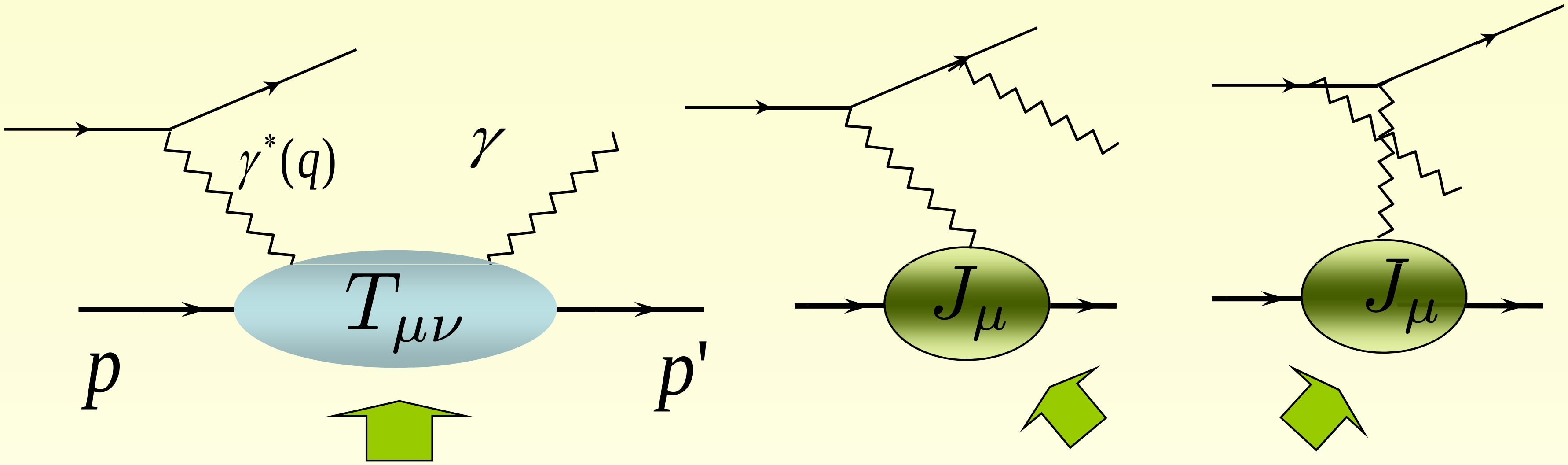
$$x_{\mathrm{Bj}} = \frac{\mathcal{Q}^2}{2P_1\cdot q_1} \approx \frac{2\xi}{1+\xi},$$

$$y = \frac{P_1\cdot q_1}{P_1\cdot k},$$

$$\Delta^2 = t \quad (\text{fixed, small}),$$

$$\mathcal{Q}^2 = -q_1^2 \quad (>1\mathrm{GeV}^2),$$

interference of *DVCS* and *Bethe-Heitler* processes



12 Compton form factors $\mathcal{H}, \mathcal{E}, \widetilde{\mathcal{H}} \ldots$ elastic form factors F_1, F_2

(helicity amplitudes)

$$|\mathcal{T}_{\rm BH}|^2 = \frac{e^6(1+\epsilon^2)^{-2}}{x_{\rm Bj}^2 y^2 \Delta^2 \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ c_0^{\rm BH} + \sum_{n=1}^{2} c_n^{\rm BH} \cos(n\phi) \right\},$$

exactly known (LO, QED)

$$|\mathcal{T}_{\rm DVCS}|^2 = \frac{e^6}{y^2 \mathcal{Q}^2} \left\{ c_0^{\rm DVCS} + \sum_{n=1}^{2} \left[c_n^{\rm DVCS} \cos(n\phi) + s_n^{\rm DVCS} \sin(n\phi) \right] \right\},$$

harmonics ⇕ **1:1** helicity ampl.

$$\mathcal{I} = \frac{\pm e^6}{x_{\rm Bj} y^3 \Delta^2 \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ c_0^{\mathcal{I}} + \sum_{n=1}^{3} \left[c_n^{\mathcal{I}} \cos(n\phi) + s_n^{\mathcal{I}} \sin(n\phi) \right] \right\}.$$

harmonics ⇕ helicity ampl.

access of CFFs (conventionally defined) from measurements:

sector		harmonics in $\mathcal{I}$				extraction	P of	$\Delta_\perp^l$ behavior	
twist	$\mathcal{C}$'s	unp	LP	TP_x	TP_y	of CFFs	Q^{-P}	unp, LP	TP
two	$\Re\mathrm{e}\,\mathcal{C}(\mathcal{F})$, $\Delta\mathcal{C}(\mathcal{F})$	c_1, c_0	c_1, c_0	c_1, c_0	s_1, -	over compl.	1,2	1,0	0,1
	$\Im\mathrm{m}\,\mathcal{C}(\mathcal{F})$, $\Delta\mathcal{C}(\mathcal{F})$	s_1, -	s_1, -	s_1, -	c_1, c_0	over compl.	1,2	1,0	0,1
three	$\Re\mathrm{e}\,\mathcal{C}(\mathcal{F}^{\mathrm{eff}})$	c_2	c_2	c_2	s_2	complete	2	2	1
	$\Im\mathrm{m}\,\mathcal{C}(\mathcal{F}^{\mathrm{eff}})$	s_2	s_2	s_2	c_2	complete	2	2	1
two	$\Re\mathrm{e}\,\mathcal{C}_T(\mathcal{F}_T)$	c_3	-	-	-	$1 \times \Re\mathrm{e}$ of 4	1	3	2
	$\Im\mathrm{m}\,\mathcal{C}_T(\mathcal{F}_T)$	-	s_3	s_3	c_3	$3 \times \Im\mathrm{m}$ of 4	1	3	2

three possible nucleon polarizations + electron/positron beam +
neglecting transversity allows to access imaginary and real part of

$$\mathcal{F} = \{\mathcal{H}, \mathcal{E}, \widetilde{\mathcal{H}}, \widetilde{\mathcal{E}}\}$$

$$\mathcal{F}^3 = \{\mathcal{H}^3, \mathcal{E}^3, \widetilde{\mathcal{H}}^3, \widetilde{\mathcal{E}}^3\}$$

twist-three offers access to quark-gluon-quark correlations
transversity arises at NLO from gluons at twist-two or at LO as a twist-four effect

$$\mathcal{F}_T = \mathcal{O}(\alpha_s, 1/\mathcal{Q}^2)$$

Can one `measure' GPDs?

- ***CFF*** given as ***GPD*** **convolution**:

$$\mathcal{H}(\xi,t,Q^2) \stackrel{\rm LO}{=} \int_{-1}^{1} dx \left(\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon}\right) H(x,\eta=\xi,t,Q^2)$$

$$\stackrel{\rm LO}{=} i\pi H^-(x=\xi,\eta=\xi,t,Q^2) + {\rm PV}\int_0^1 dx \frac{2x}{\xi^2 - x^2} H^-(x,\eta=\xi,t,Q^2)$$

- $H(x,x,t,Q^2)$ viewed as **"spectral function"** (s-channel cut):

$$H^-(x,x,t,Q^2) \equiv H(x,x,t,Q^2) - H(-x,x,t,Q^2) \stackrel{\rm LO}{=} \frac{1}{\pi}\Im{\rm m}\mathcal{F}(\xi=x,t,Q^2)$$

[Frankfurt et al (97)
Chen (97)
Terayev (05)
KMP-K (07)
Diehl, Ivanov (07)]

- ***CFFs*** satisfy `**dispersion relations**'
(not the physical ones, threshold ξ_0 set to 0)

$$\Re{\rm e}\mathcal{F}(\xi,t,Q^2) = \frac{1}{\pi}{\rm PV}\int_0^1 d\xi' \left(\frac{1}{\xi-\xi'} \mp \frac{1}{\xi+\xi'}\right)\Im{\rm m}\mathcal{F}(\xi',t,Q^2) + \mathcal{C}(t,Q^2)$$

[Terayev (05)]

access to the ***GPD*** on the **cross-over line** $\eta = x$ (at LO)

DVCS data and perspectives

existing data

including longitudinal and transverse polarized proton data

new data

HERMES
(recoil detector data)

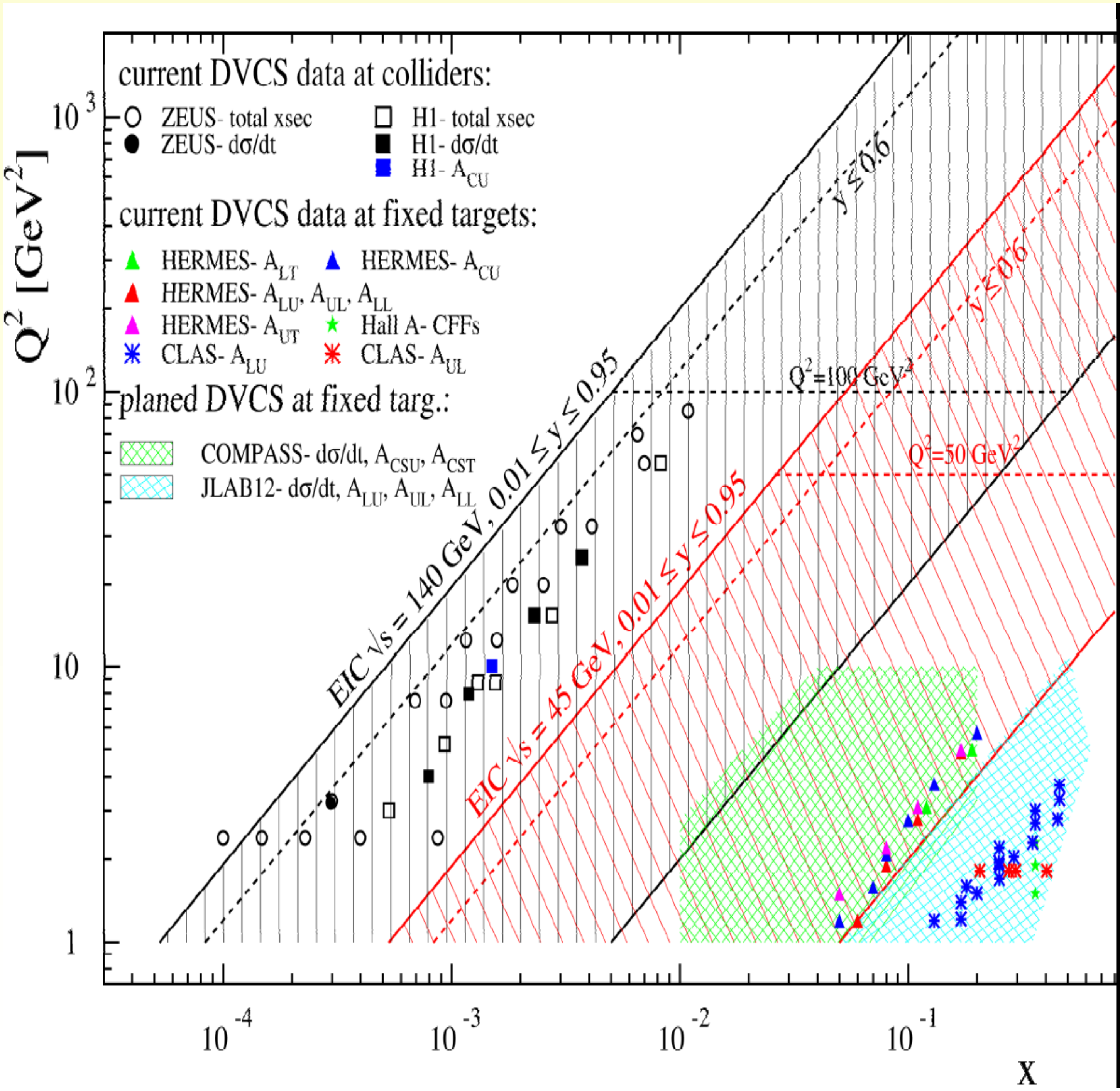
JLAB
(longitudinal TSA, cross sections)

planned

COMPASS II, JLAB 12

proposed

EIC



Strategies to analyze DVCS data

(ad hoc) modeling: **VGG** code [**Goeke et. al (01)** based on **Radyuskin's** DDA]
BKM model [**Belitsky, Kirchner, DM (01)** based on RDDA]
`aligned jet' model [**Freund, McDermott, Strikman (02)**]
Goloskokov/Kroll (05) based on RDDA (pinned down by DVMP)
`dual' model [**Polyakov,Shuvaev 02;Guzey,Teckentrup 06;Polyakov 07**]
" -- " [**KMP-K (07)** in MBs-representation]
polynomials [**Belitski et al. (98), Liuti et. al (07), Moutarde (09)**]

dynamical models: not applied **[Radyuskin et.al (02); Tiburzi et.al (04); Hwang DM (07)]…**
(respecting Lorentz symmetry)

flexible models: any representation by including ***unconstrained*** degrees of freedom
(for fits) **KMP-K (07/08)** for H1/ZEUS in MBs-integral-representation

CFFs (real and imaginary parts) and GPD fits/predictions

i. CFF extraction with formulae (local) **[BMK (01), HALL-A (06)]** and **[KM, Murray]**
least square fits (local) **[Guidal, Moutarde (08...)]**
neural networks – a start up **[KMS (11)]**
ii. `dispersion integral' fits **[KMP-K (08),KM (08...)]**
iii. flexible GPD modeling **[KM (08...)]**
vi. model comparisons **VGG code, however also BMK01 (up to 2005)**
& predictions **Goldstein et al. (11)** (no sea, giving up polynomiality)
Goloskokov/Kroll (07) model based on RDDA

DVCS HERMES data to CFFs

➢ **?** 1:1 map of charge odd asymmetries (interference term) to CFFs

toy example DVCS off a scalar target

➢ for the first step we use twist two dominance hypothesis
(neglecting twist-three and transversity associated CFFs)

- linearized set of equations (approximately valid)

$$A_{\rm LU,I}^{\sin(1\phi)} \approx N c_{\mathfrak{Im}}^{-1} \mathcal{H}^{\mathfrak{Im}} \quad \text{and} \quad A_{\rm C}^{\cos(1\phi)} \approx N c_{\mathfrak{Re}}^{-1} \mathcal{H}^{\mathfrak{Re}}$$

- normalization *N* is bilinear in CFFs

$$0 \lesssim N(\boldsymbol{A}) \approx \frac{1}{1+\frac{k}{4}|\mathcal{H}|^2} \approx \frac{\int_{-\pi}^{\pi} d\phi\, \mathcal{P}_1(\phi)\mathcal{P}_2(\phi) d\sigma_{\rm BH}(\phi)}{\int_{-\pi}^{\pi} d\phi\, \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)\left[d\sigma_{\rm BH}(\phi) + d\sigma_{\rm DVCS}(\phi)\right]} \lesssim 1$$

- cubic equation for *N* with two non-trivial solutions

$$N(\boldsymbol{A}) \approx \frac{1}{2}\left(1 \pm \sqrt{1 - k\, c_{\mathfrak{Im}}^2 \left(A_{\rm LU,I}^{\sin(1\phi)}\right)^2 - k\, c_{\mathfrak{Re}}^2 \left(A_{\rm C}^{\cos(1\phi)}\right)^2}\right)$$

+ BH regime
- DVCS regime

- standard error propagation

(**NOTE:** that the philosophy of CFF extraction has been questioned)

- mathematical generalization to nucleon case is straightforward
- HERMES provided an *almost* complete measurement

• having a look to the twist-two sector

$$\boldsymbol{\mathcal{F}}^{\mathfrak{Im}} = \mathfrak{Im}\begin{pmatrix}\mathcal{H}\\ \widetilde{\mathcal{H}}\\ \mathcal{E}\\ \hat{\mathcal{E}}\end{pmatrix} \quad \text{and} \quad \boldsymbol{\mathcal{F}}^{\mathfrak{Re}} = \mathfrak{Re}\begin{pmatrix}\mathcal{H}\\ \widetilde{\mathcal{H}}\\ \mathcal{E}\\ \hat{\mathcal{E}}\end{pmatrix}, \quad \text{where } \hat{\mathcal{E}} = \frac{x_{\mathrm{B}}}{2-x_{\mathrm{B}}}\widetilde{\mathcal{E}}$$

• rotatedata $A^{\sin(1\phi)}_{\mathrm{UL},+} \to\approx A^{\sin(1\phi)}_{\mathrm{UL,I}}, A^{\cos(1\phi)}_{\mathrm{LL},+} \to\approx A^{\cos(1\phi)}_{\mathrm{LL,I}}, A^{\cos(0\phi)}_{\mathrm{LL},+} \to\approx A^{\cos(0\phi)}_{\mathrm{LL,I}} + A^{\cos(0\phi)}_{\mathrm{LL,DVCS}}$

$$\boldsymbol{A}^{\sin} = \begin{pmatrix} A^{\sin(1\phi)}_{\mathrm{LU,I}} \\ A^{\sin(1\phi)}_{\mathrm{UL,I}} \\ A^{\sin(\varphi)\cos(1\phi)}_{\mathrm{UT,I}} \\ A^{\cos(\varphi)\sin(1\phi)}_{\mathrm{UT,I}} \end{pmatrix} \quad \text{and} \quad \boldsymbol{A}^{\cos} = \begin{pmatrix} A^{\cos(1\phi)}_{\mathrm{C}} \\ A^{\cos(1\phi)}_{\mathrm{LL,I}} \\ A^{\sin(\varphi)\cos(0\phi)}_{\mathrm{UT,DVCS}} \\ A^{\cos(0\phi)}_{\mathrm{LL,I}} + A^{\cos(0\phi)}_{\mathrm{LL,DVCS}} \end{pmatrix}$$

6 x linear constraints

2 x quadratic constraints

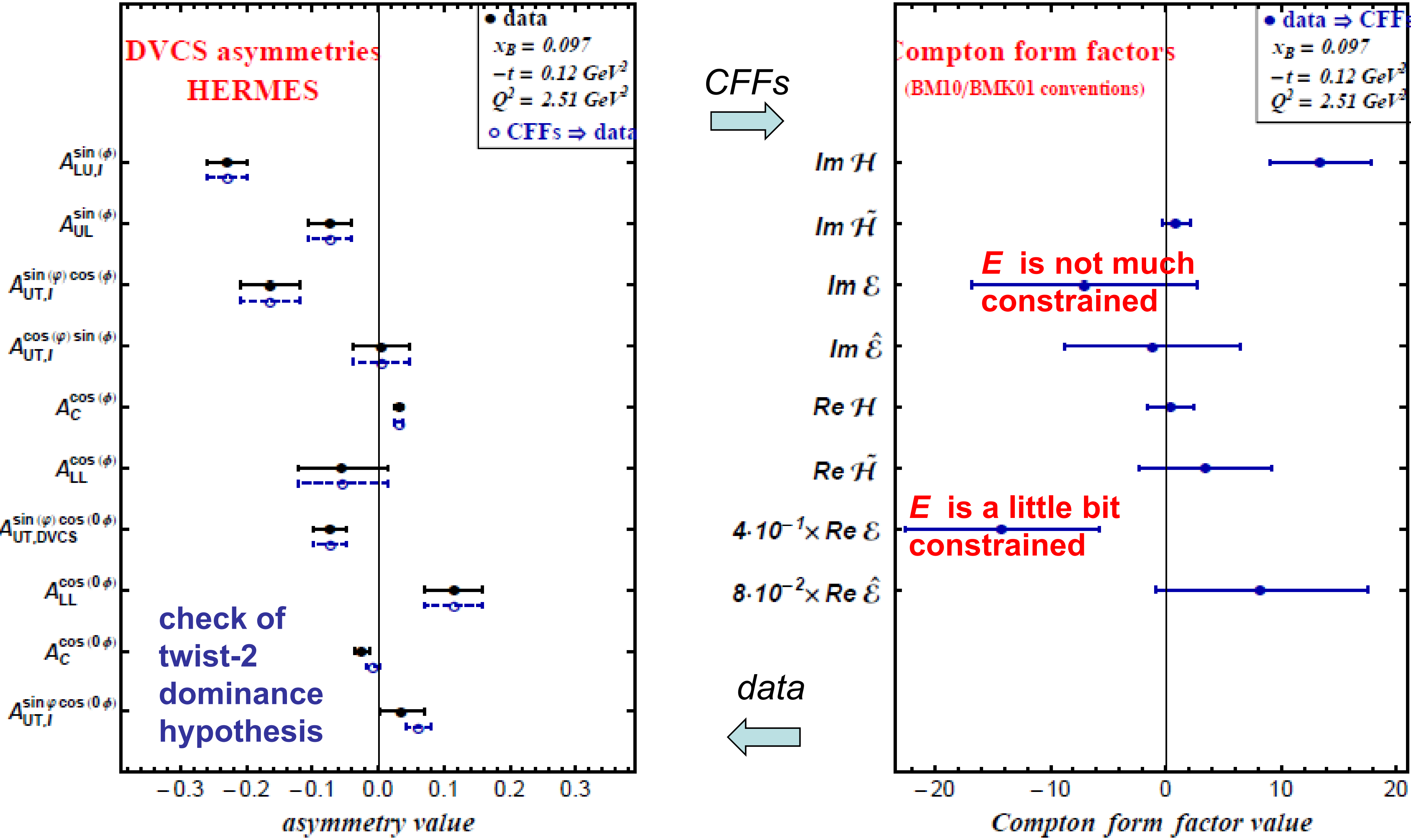
• non-linear solution may be written as

$$\begin{pmatrix}\mathfrak{Im}\,\mathcal{F}\\ \mathfrak{Re}\,\mathcal{F}\end{pmatrix} = \frac{1}{N(\boldsymbol{A})}\begin{pmatrix}\mathbf{c}_{\mathfrak{Im}} & \mathbf{0}_{4\times4}\\ \mathbf{0}_{4\times4} & \mathbf{c}_{\mathfrak{Re}}(\boldsymbol{A}|N(\boldsymbol{A}))\end{pmatrix}\cdot\begin{pmatrix}\boldsymbol{A}^{\sin}\\ \boldsymbol{A}^{\cos}\end{pmatrix}$$

imaginary parts needed to evaluate real parts

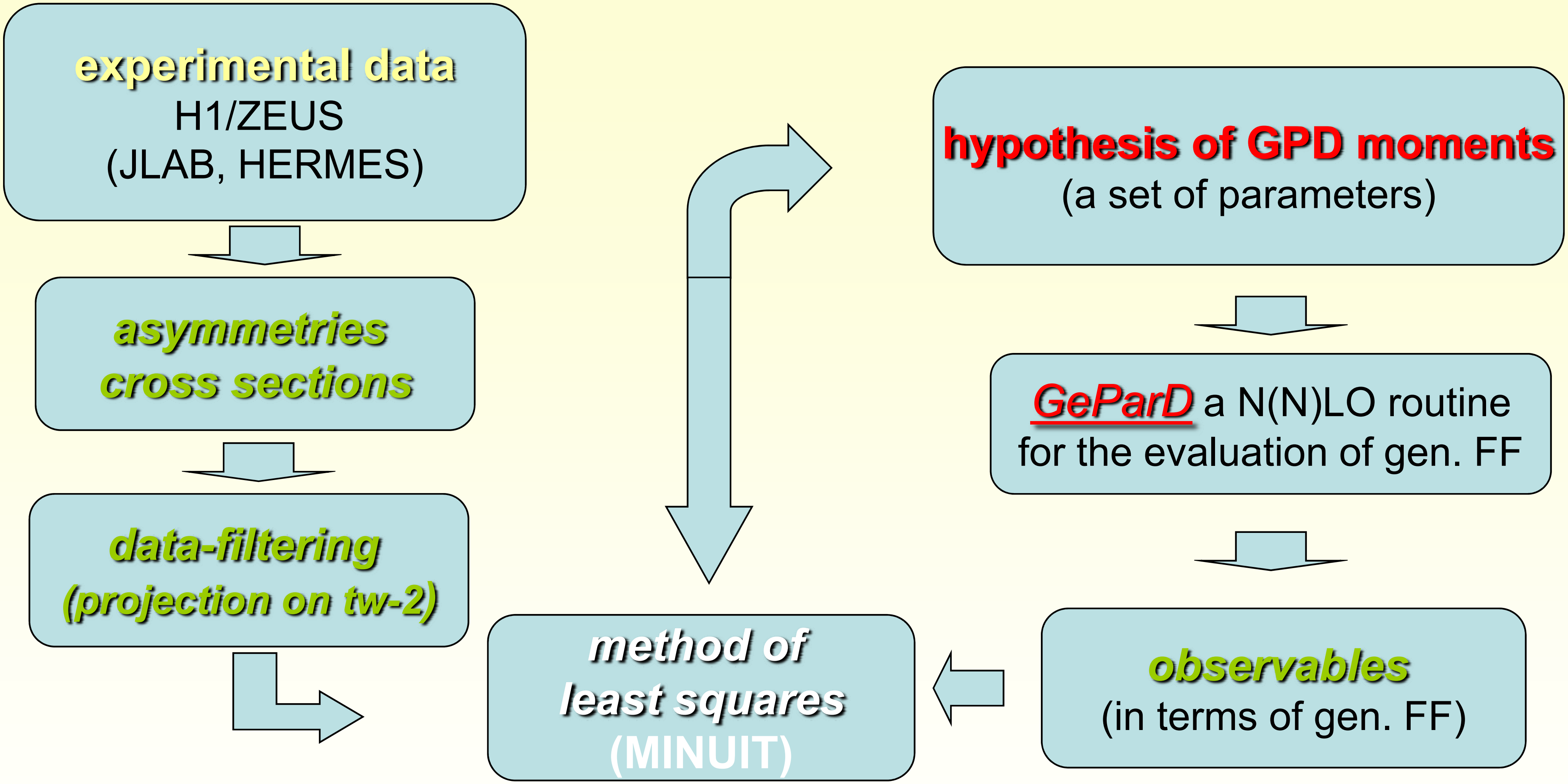
$$\mathrm{cov}(\boldsymbol{\mathcal{F}}) = \left[\frac{\partial\boldsymbol{\mathcal{F}}}{\partial\boldsymbol{A}}\right]\cdot\mathrm{cov}\left(\boldsymbol{A}\right)\cdot\left[\frac{\partial\boldsymbol{\mathcal{F}}}{\partial\boldsymbol{A}}\right]^{\mathsf{T}}$$

DVCS to CFF map for $\frac{\int_{-\pi}^{\pi} d\phi\, \mathcal{P}_1(\phi)\mathcal{P}_2(\phi) d\sigma_{\mathrm{BH}}(\phi)}{\int_{-\pi}^{\pi} d\phi\, \mathcal{P}_1(\phi)\mathcal{P}_2(\phi) \left[d\sigma_{\mathrm{BH}}(\phi) + d\sigma_{\mathrm{DVCS}}(\phi)\right]} \approx 0.84$



NOTE: three combinations of CFFs are (very) well constrained

Ready for flexible GPD model fits?



YES for small x and ***we don`t use it*** for fixed target kinematics

- reasonable well motivated hypotheses of GPDs (moments) must be known first
- many parameters, intricate data set – Is a least square fit an appropriate strategy?

GPDs in phenomenology

- double distribution representation (is not unique), e.g., one may use

$$\left\{\begin{matrix} H \\ E \\ \widetilde{H} \\ \widetilde{E} \end{matrix}\right\}(x,\eta,t) = \int_0^1 dy \int_{-1+y}^{1-y} dz\, \delta(x-y-\eta z) \left\{\begin{matrix} h+(x-y)e \\ (1-x)e \\ \widetilde{h} \\ \widetilde{e}+(1-y-z/\eta)\, e \end{matrix}\right\}(y,z,t)$$

(consistent diquark models for transversity GPDs see **[Hwang, DM 1108.3869]**)

- Mellin-Barnes integral representation (is also not unique)

(conformal) GPD moments

$$F(x,\eta,t) = \frac{i}{2}\int_{c-i\infty}^{c+i\infty} dj\, \frac{1}{\sin(\pi j)} p_j(x,\eta)\, F_j(\eta,t)$$

(``dual'' parameterization can be easily realized in this representation)

- perhaps in future: overlap representations (polynomiality is not explicit)

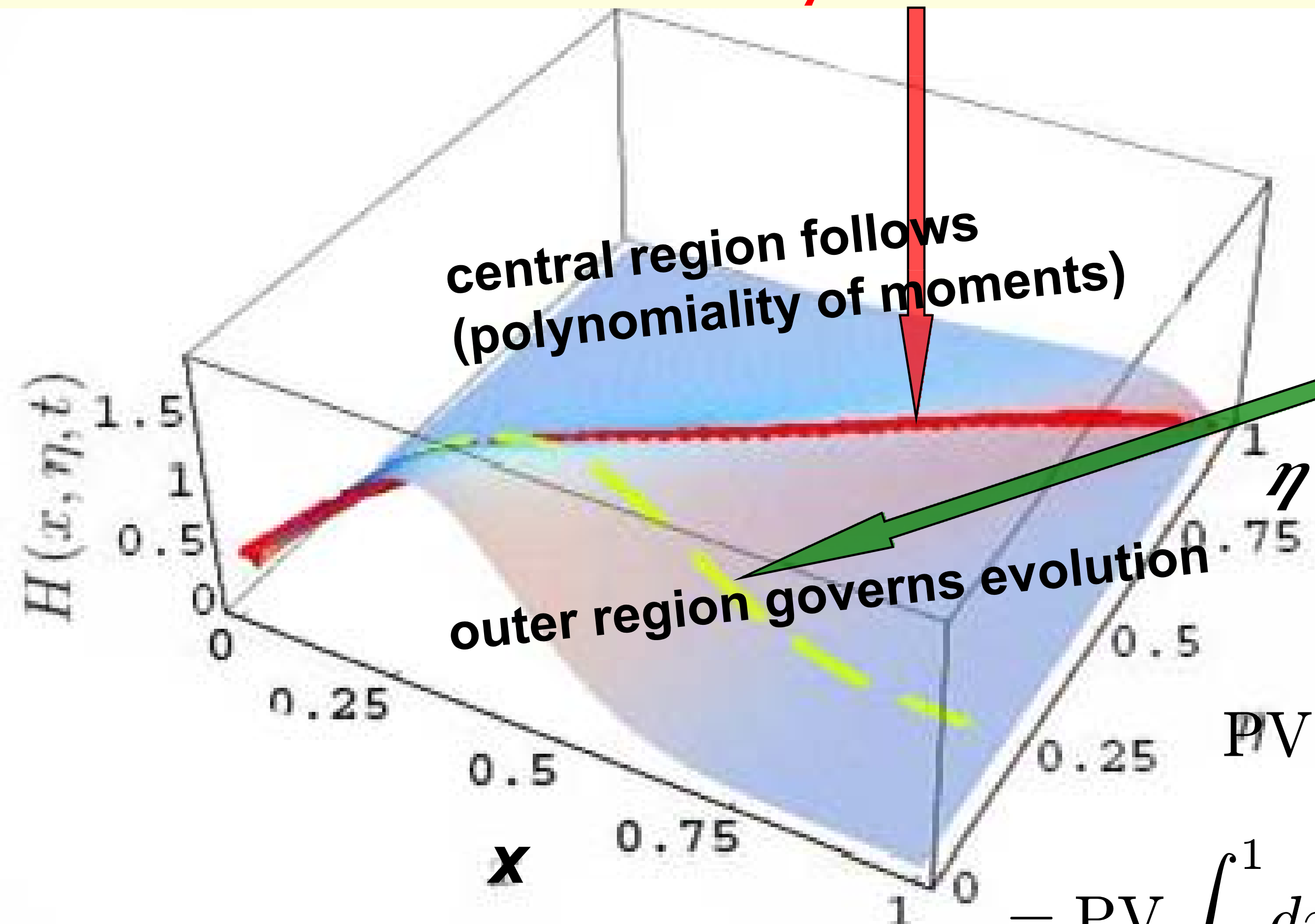
respect underlying Lorentz symmetry and one can work with effective two-body LCWFs make such LCWF models flexible **[Hwang, DM]**

Modeling & Evolution

outer region governs the evolution at the cross-over line

$$\mu^2 \frac{d}{d\mu^2} H(x,x,t,\mu^2) = \int_x^1 \frac{dy}{x} V(1, x/y, \alpha_s(\mu)) H(y,x,\mu^2)$$

GPD at $\eta = x$ is `measurable' (LO)



net contribution of outer + central region is governed by a sum rule:

$$\mathrm{PV}\int_0^1 dx\, \frac{2x}{\eta^2 - x^2} H^-(x,\eta,t)$$

$$= \mathrm{PV}\int_0^1 dx\, \frac{2x}{\eta^2 - x^2} H^-(x,x,t) + C(t)$$

Cross-overline GPD modeling

- model of GPD *H(x,x,t) within DD motivated ansatz at* $Q^2=2$ GeV^2

fixed: *rules* — *PDF normalization*, *eff. Reage pole*, *large t-counting*

$$H(x,x,t) = \frac{n\,r\,2^{\alpha}}{1+x}\left(\frac{2x}{1+x}\right)^{-\alpha(t)}\left(\frac{1-x}{1+x}\right)^{b}\frac{1}{\left(1-\frac{1-x}{1+x}\frac{t}{M^2}\right)^{p}}\,.$$

free: — *r-ratio at small x*, *large x-behavior*, *p-pole mass*

sea quarks (taken from LO fits)

$$n=0.68,\quad r=1,\quad \alpha(t)=1.13+0.15t/\mathrm{GeV}^2,\quad m^2=0.5\mathrm{GeV}^2,\quad p=2$$

valence quarks

$$n=1.0,\quad \alpha(t)=0.43+0.85t/\mathrm{GeV}^2,\quad p=1$$

flexible parameterization of subtraction constant

$$\mathcal{D}(t)=\frac{-C}{(1-t/M_c^2)^2}$$

+ pion-pole contribution

KM10 fits to (unpolarized) DVCS

- a hybrid model: three effective SO(3) PWs for sea quarks/gluons
  dispersion relations for valence
  flexible pion pole contribution
  still *E* GPD is neglected (only D-term)
- framework

leading order, including evolution for sea quarks/ gluons
twist-two dominance hypothesis within CFF convention **[BM10]**

- data selection (taking moments of azimuthal angle harmonics)

i. neglecting,
ii. ii. forming ratios of moments, or
iii. iii. original HALL-A data
neglecting large –*t* BSA CLAS data

15 parameter fit, e.g.,
including all HALL-A data

175 data points
$\chi^2/d.o.f. = 132/165$

```
------------------------------------
MO2S  =  0.51  +-  0.02
SECS  =  0.28  +-  0.02
SECG  = -2.79  +-  0.12
THIS  = -0.13  +-  0.01
THIG  =  0.90  +-  0.05
  Mv  =  4.00  +-  3.33  (edge)
  rv  =  0.62  +-  0.06
  bv  =  0.40  +-  0.67
   C  =  8.78  +-  0.98
  MC  =  0.97  +-  0.11
 tMv  =  0.88  +-  0.24
 trv  =  7.76  +-  1.39
 tbv  =  2.05  +-  0.40
 rpi  =  3.54  +-  1.77
 Mpi  =  0.73  +-  0.37
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```
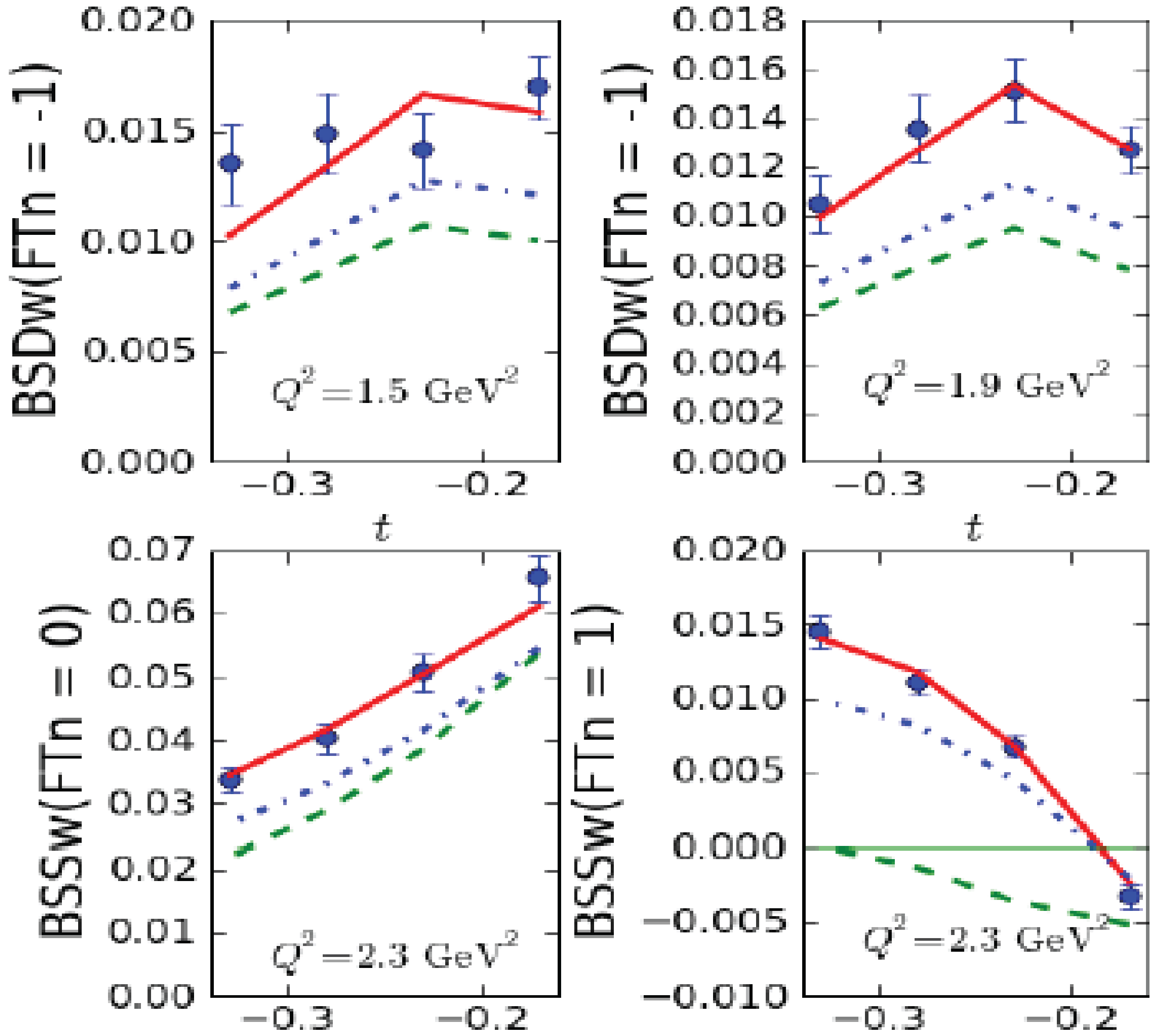

- results are given as **xs.exe** on ***http://calculon.phy.hr/gpd/***



HALL-A data:

neglected at all

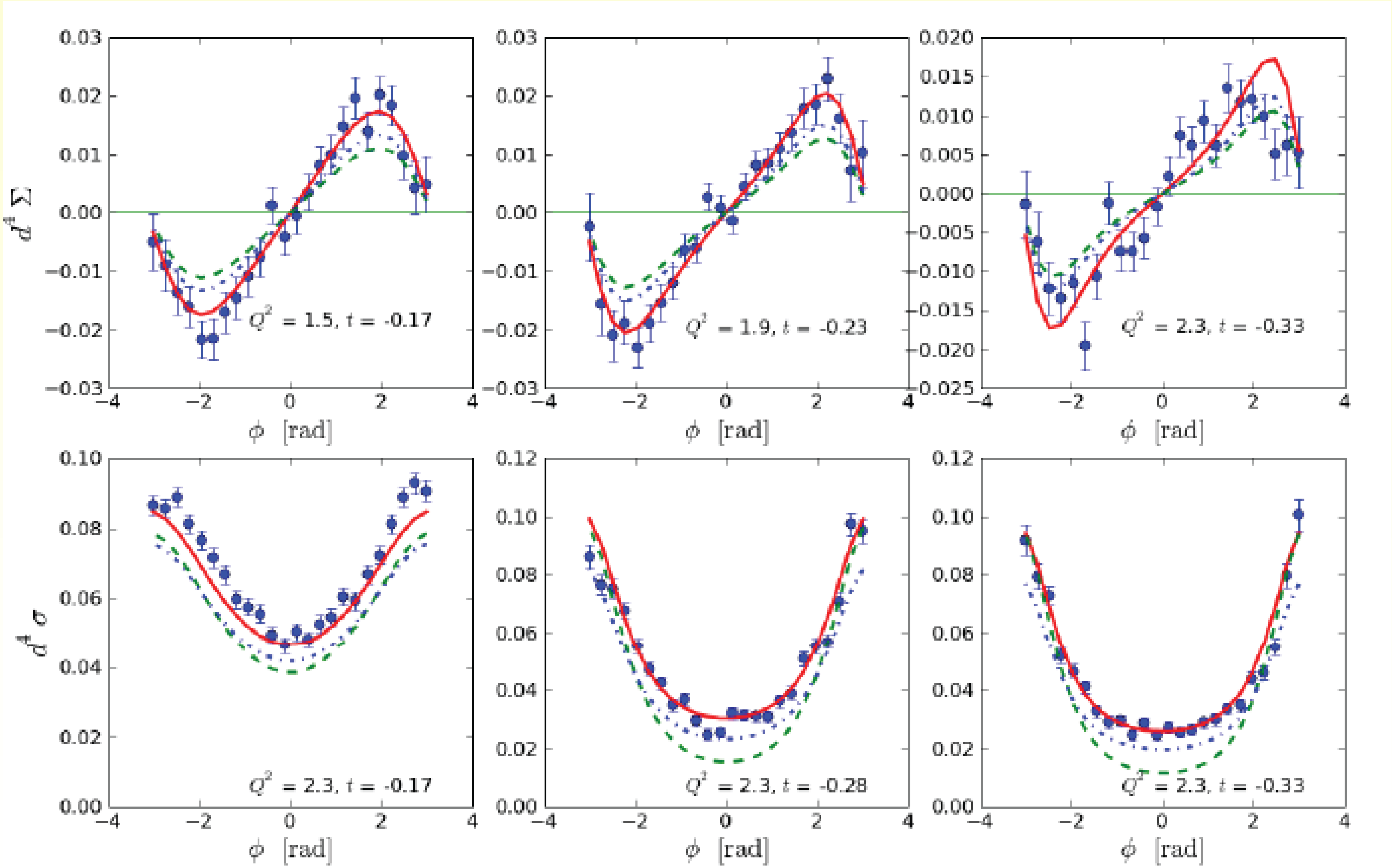
ratios of moments

cross sections

- fits to HALL A harmonics are fine for unexpected large Ĥ or Ě contribution
- large Ĥ KM09 scenario is excluded from longitudinal TSA (HERMES, CLAS)
- large pion pole scenario might look reasonable (cf. **[Goloskokov and Kroll (10)]**)

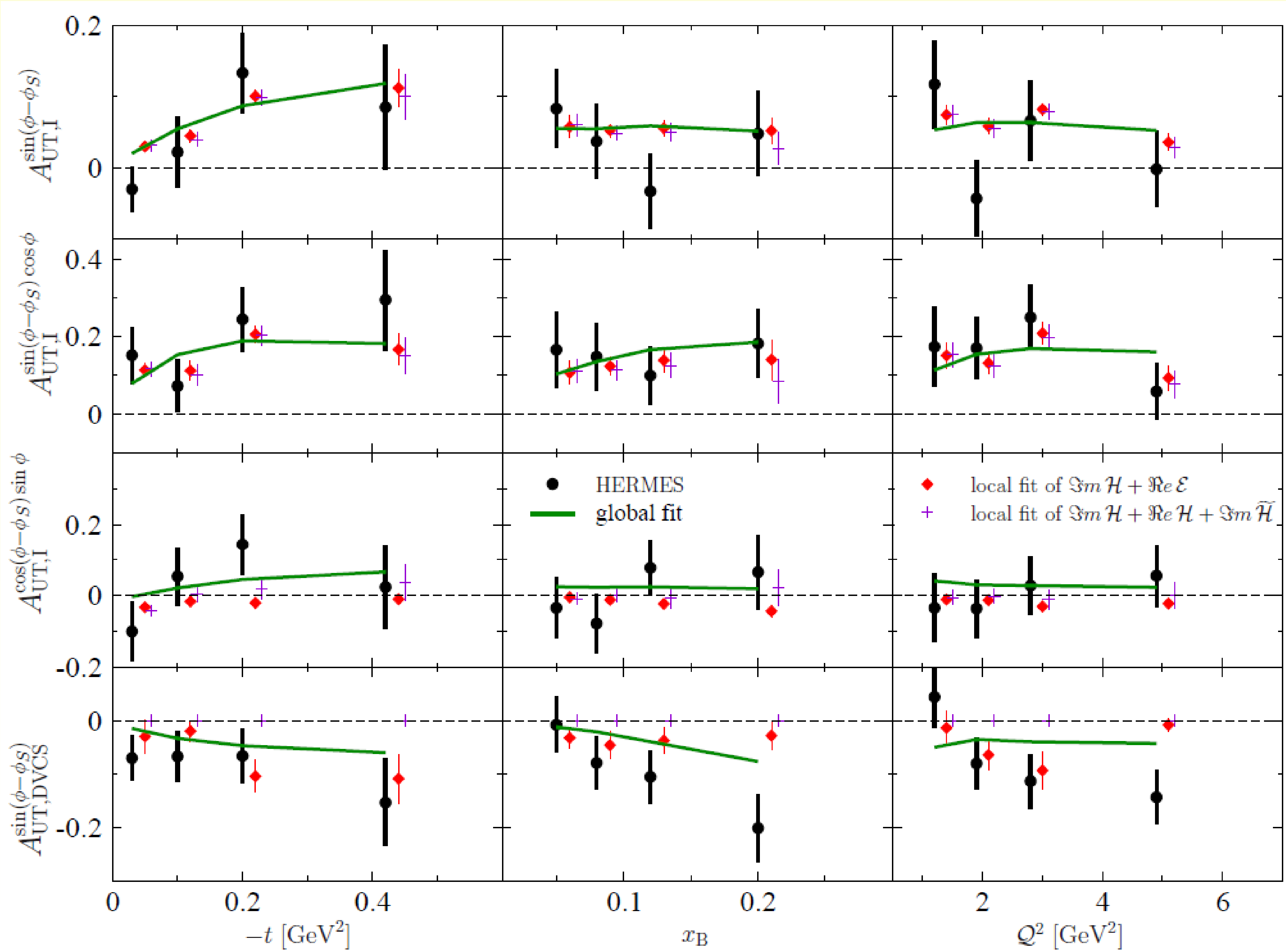
HALL A φ-dependence

- φ-dependence is described (if we fit to it)



• KM... model works also if we include polarized target data

(a new global fit, e.g., transverse polarized HERMES asymmetries looks as)



DVCS fits to H1 and ZEUS data

DVCS cross section measured at small $x_{\mathrm{Bj}} \approx 2\xi = \frac{2Q^2}{2W^2+Q^2}$

predicted by

$$\frac{d\sigma}{dt}(W,t,\mathcal{Q}^2) \approx \frac{4\pi\alpha^2}{\mathcal{Q}^4}\frac{W^2\xi^2}{W^2+\mathcal{Q}^2}\left[|\mathcal{H}|^2 - \frac{\Delta^2}{4M_{\mathrm{p}}^2}|\mathcal{E}|^2 + \left|\widetilde{\mathcal{H}}\right|^2\right](\xi,t,\mathcal{Q}^2)\Big|_{\xi=\frac{\mathcal{Q}^2}{2W^2+\mathcal{Q}^2}}$$

suppressed contributions *<<0.05>>* relative *O(ξ)*

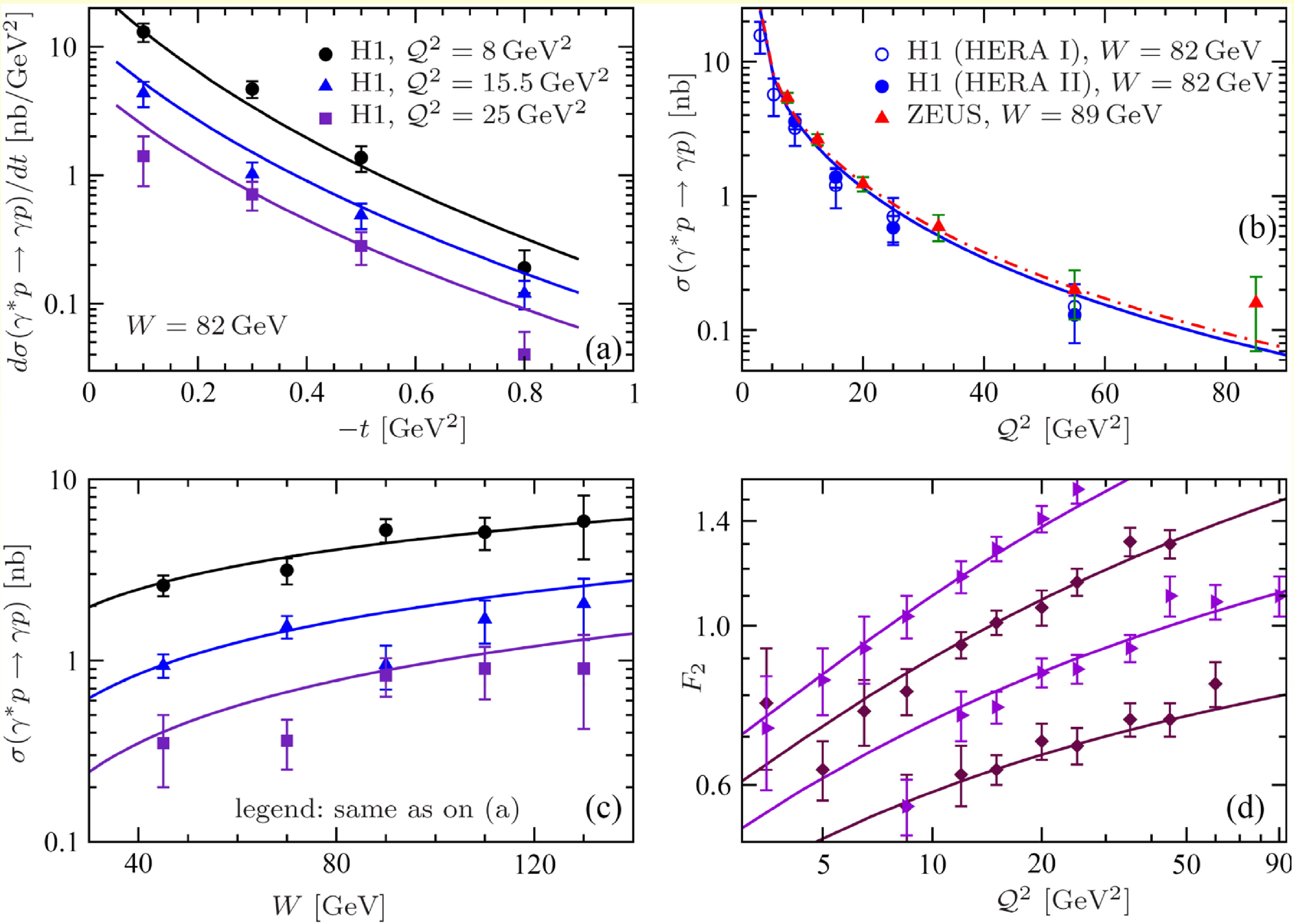
- LO data could not be described before **2008** (only if you break polynomiality)
- NLO works with ad hoc GPD models **[Freund, McDermott (02)]**
  (! Q^2 evolution of *t*-dependency is put in by hand – has to come from GPD evolution**)**

results strongly depend on employed PDF parameterization

⇒ ***do a simultaneous fit to DIS and DVCS*** **[KMP-K (07)]**

⇒ ***use flexible GPD models in a two-step fit*** **[KM (09)]**

good DVCS fits at LO, NLO, and NNLO with flexible GPD ansatz



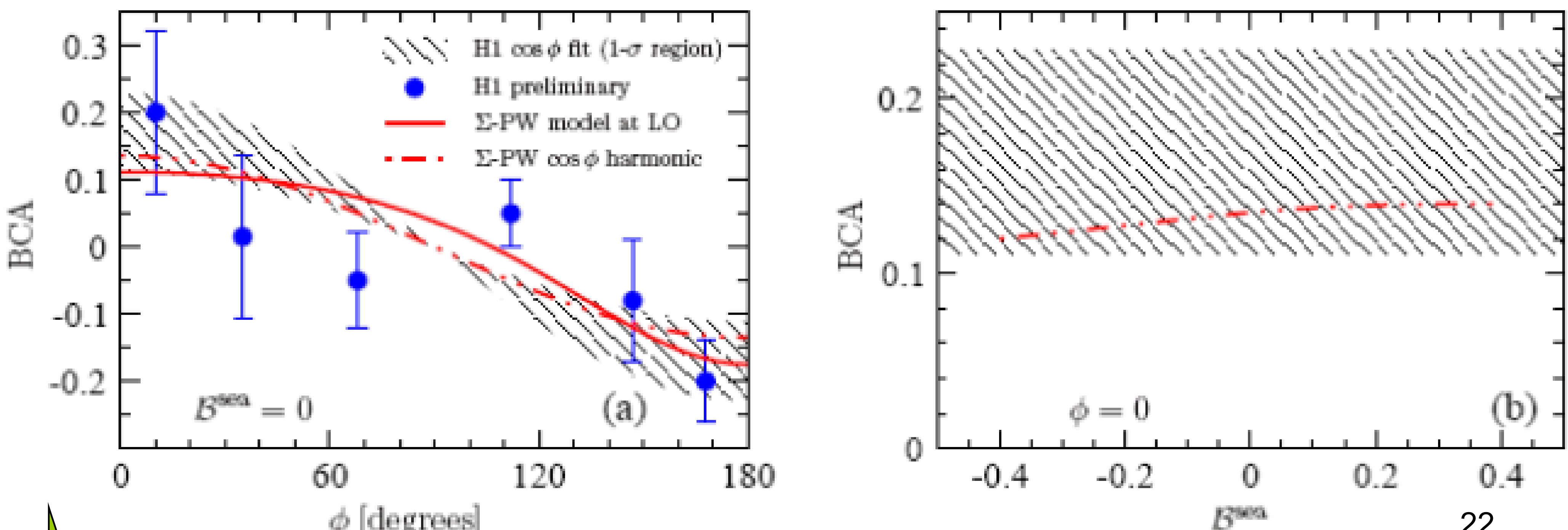
Beam charge asymmetry

$$BCA = \frac{d\sigma_{e^+} - d\sigma_{e^-}}{d\sigma_{e^+} + d\sigma_{e^-}} = \frac{\mathcal{T}_{\mathrm{Interference}}}{|\mathcal{T}_{\mathrm{BH}}|^2 + |\mathcal{T}_{\mathrm{DVCS}}|^2}$$

$$\propto F_1(t)\Re\mathrm{e}\mathcal{H} + \frac{|t|}{4M^2} F_2(t)\Re\mathrm{e}\mathcal{E}$$

the unknown in Ji's nucleon spin sum rule

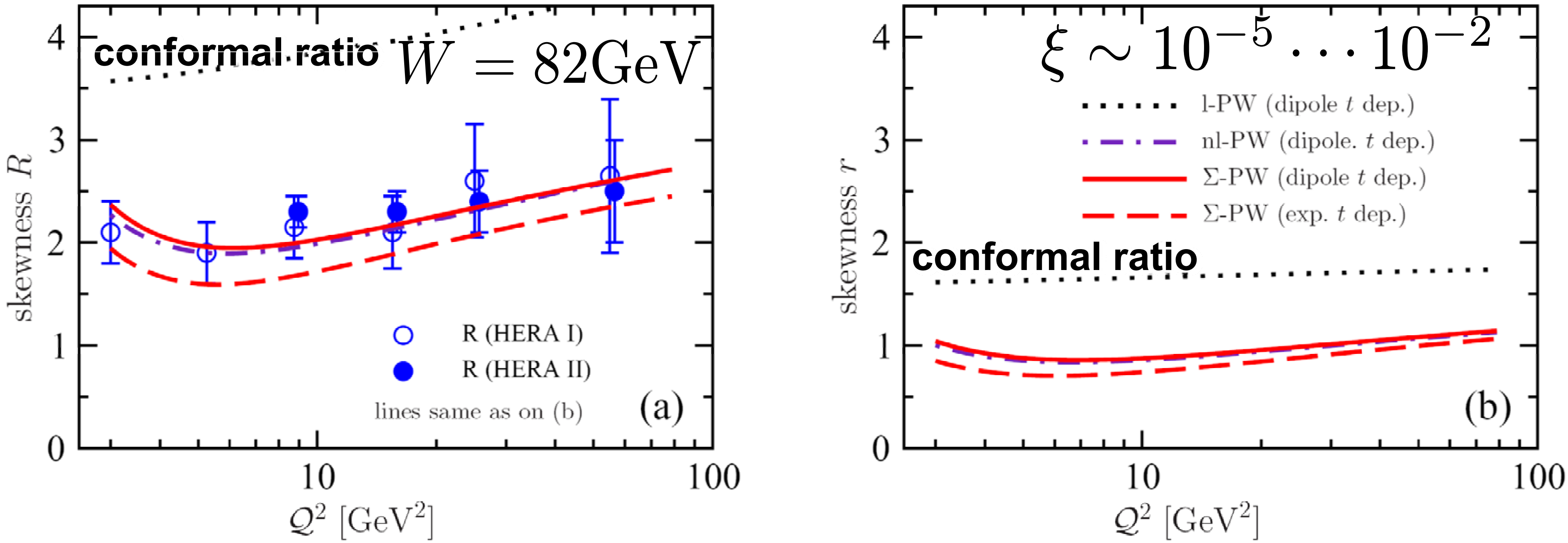
- set $E_{\mathrm{sea}} \propto H_{\mathrm{sea}}$, use *anomalous gravitomagnetic moment* $B_{\mathrm{sea}} = \int_0^1 dx\, x E_{\mathrm{sea}}$ as parameter



unfortunately, H1 data do not allow to access B_{sea}

quark skewness ratio from DVCS fits @ LO

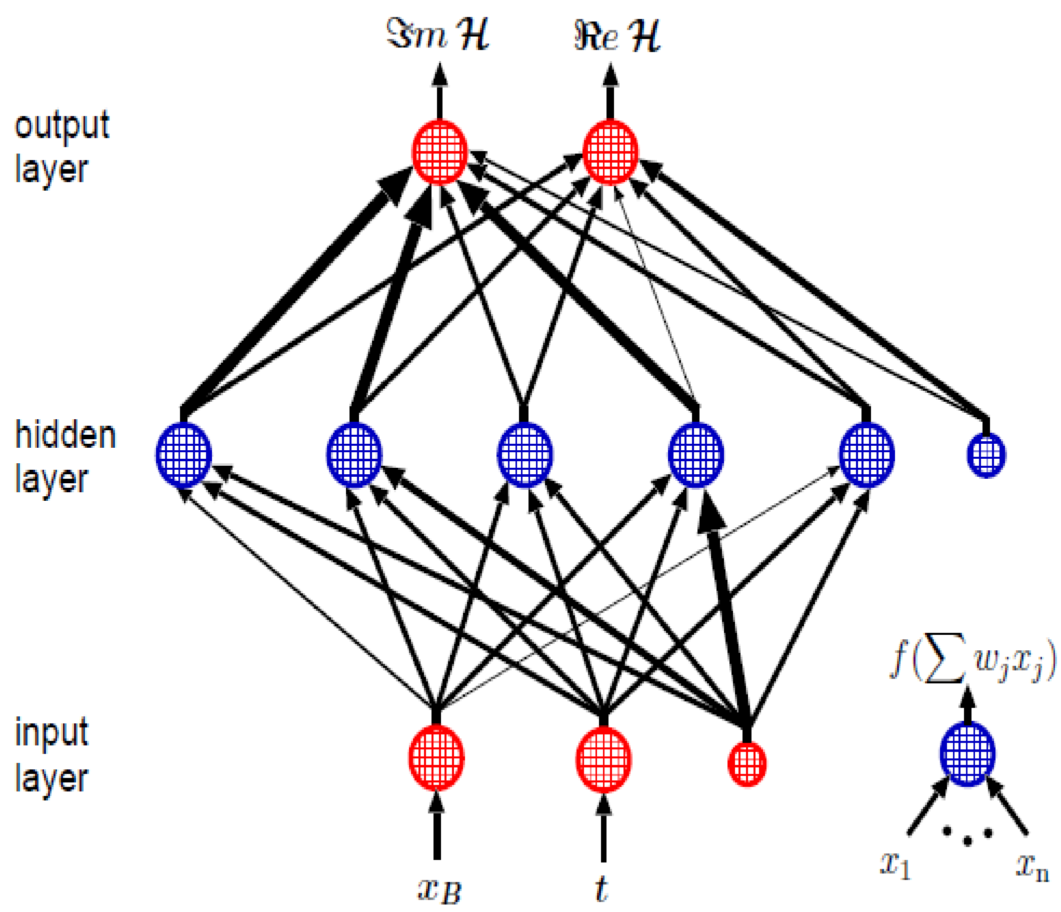
$$R = \frac{\Im\mathrm{m}\mathcal{A}_{\mathrm{DVCS}}}{\Im\mathrm{m}\mathcal{A}_{\mathrm{DIS}}} \stackrel{LO}{=} \frac{H(\xi,\xi)}{H(2\xi,0)} \approx 2^{\alpha} r \qquad r = \frac{H(\xi,\xi)}{H(\xi,0)}$$



- @LO the conformal ratio $r_{\mathrm{con}} = \frac{2^{\alpha}\Gamma(3/2+\alpha)}{\Gamma(3/2)\Gamma(2+\alpha)}$ is ruled out for sea quark GPD
- a generically zero-skewness effect over a large Q^2 lever arm
- scaling violation consistent with pQCD prediction
- this zero-skewness effect is non-trivial to realize in conformal space (SO(3) sibling poles are required)

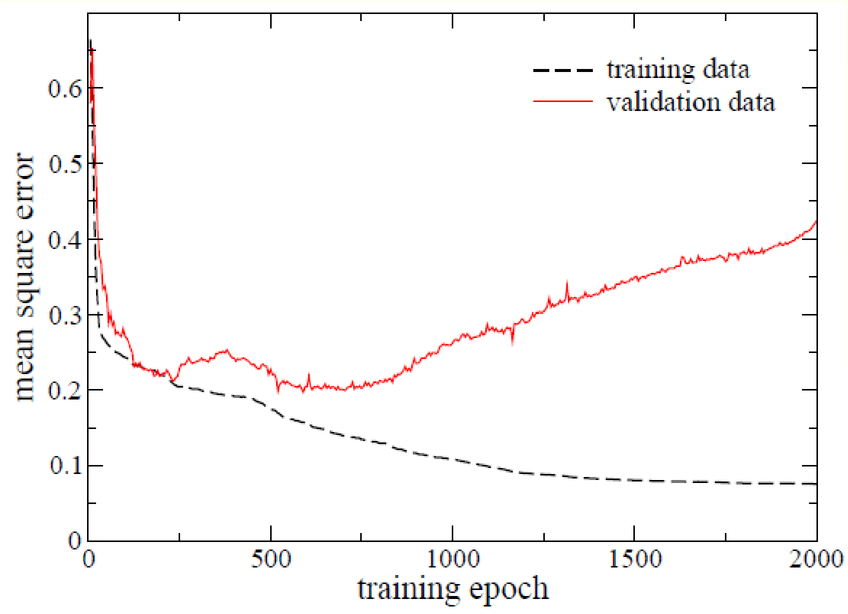
Neural Networks

- kinematical values are represented by the input layer
- propagated trough the network, where weights are set randomly
- random values for *Im*$\mathcal{H}$ and *Re*$\mathcal{H}$
- calculation of χ^2
- backwards propagation (PyBrain)
- adjusting weights so that error decreases
- repeat procedure
- taking next kinematical point



Monte Carlo procedure to propagate errors, i.e., generating a replica data set

avoiding over fitting (fitting to noise), dividing data set, taking a control example if error increases after decreasing – one stops

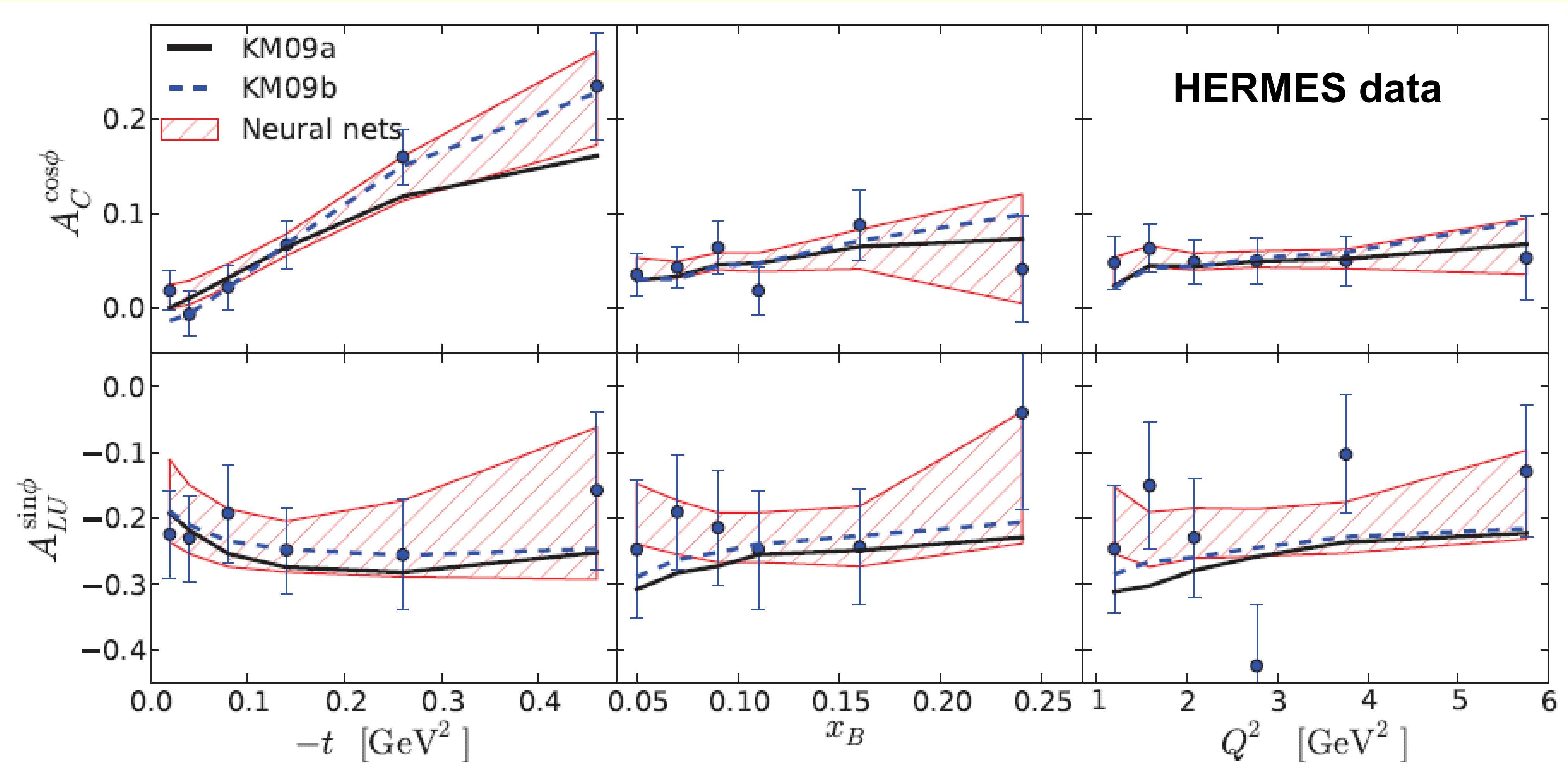


A first use of neural network fits

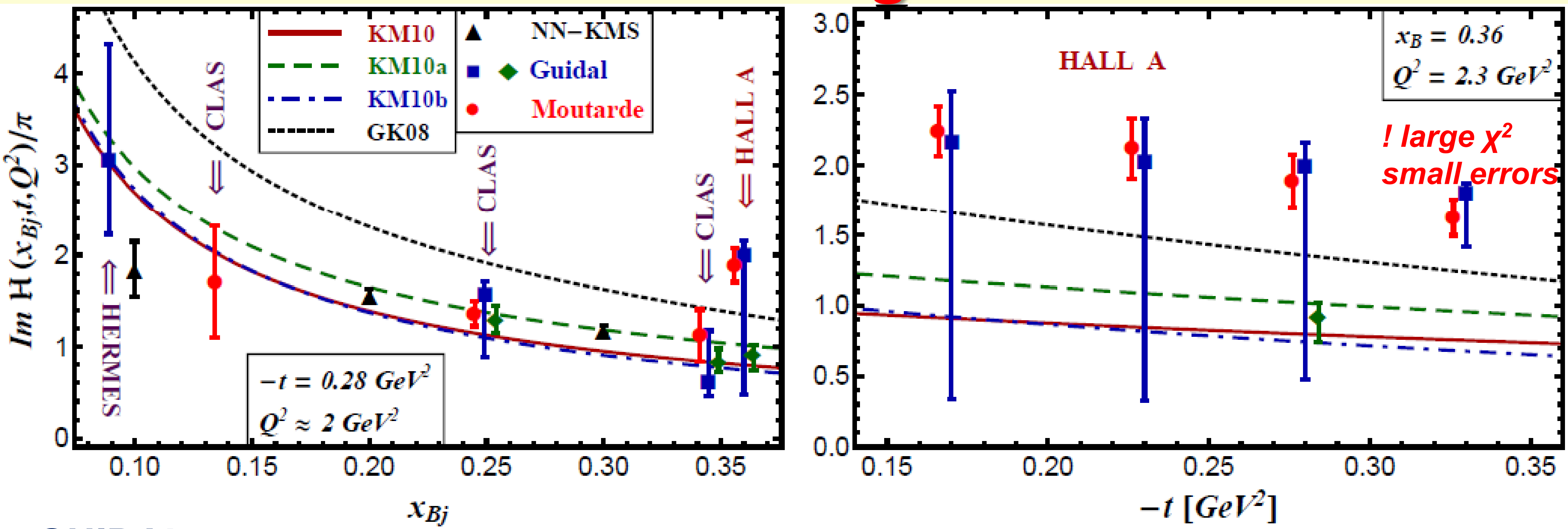
(ideal) tool for error propagation and quantifying model uncertainties

used to access real and imaginary part of $\mathcal{H}$ CFF from HERMES

results are compatible to model fits



KM... versus CFF fits & large-x "model" fit



GUIDAL	twist-two dominance hypothesis 7 parameter fit to all harmonics of unpolarized cross section propagated errors + "theoretical" error estimate
GUIDAL	same + longitudinal TSA
Moutarde	H dominance hypothesis within a smeared polynomial expansion propagated errors + "theoretical" error estimate
NN	neural network within H dominance hypothesis green (blue) [red] curves (KM10...) without (with) HALL A data (ratios)
GK08	black curve GPDs (based on RDDA) obtained from handbag approach to DVMP

- reasonable agreement for HERMES and CLAS kinematics
- large *x*-region and real part remains unsettled

EIC potential for DVCS

to address angular momentum (GPD E), 3D picture, (effective) nucleon wave function within the GPD framework new DVCS experiments with

large kinematical coverage, high luminosity, and dedicated detectors are needed to quantify CFFs and GPDs on the cross-over line (and outer region)

- disentangling CFFs at small(er) *x*
  cross sections
  beam spin, target spin, and double spin flip experiments

$$BSA \propto y\left\{F_1(t)H(\xi,\xi,t,\mathcal{Q}^2) - \tfrac{t}{4M^2}F_2E(\xi,\xi,t,\mathcal{Q}^2)\right\}$$

$$TSA_T \propto \tfrac{\sqrt{-t}}{4M^2}\left\{F_1(t)E(\xi,\xi,t,\mathcal{Q}^2) - F_2(t)H(\xi,\xi,t,\mathcal{Q}^2)\right\}$$

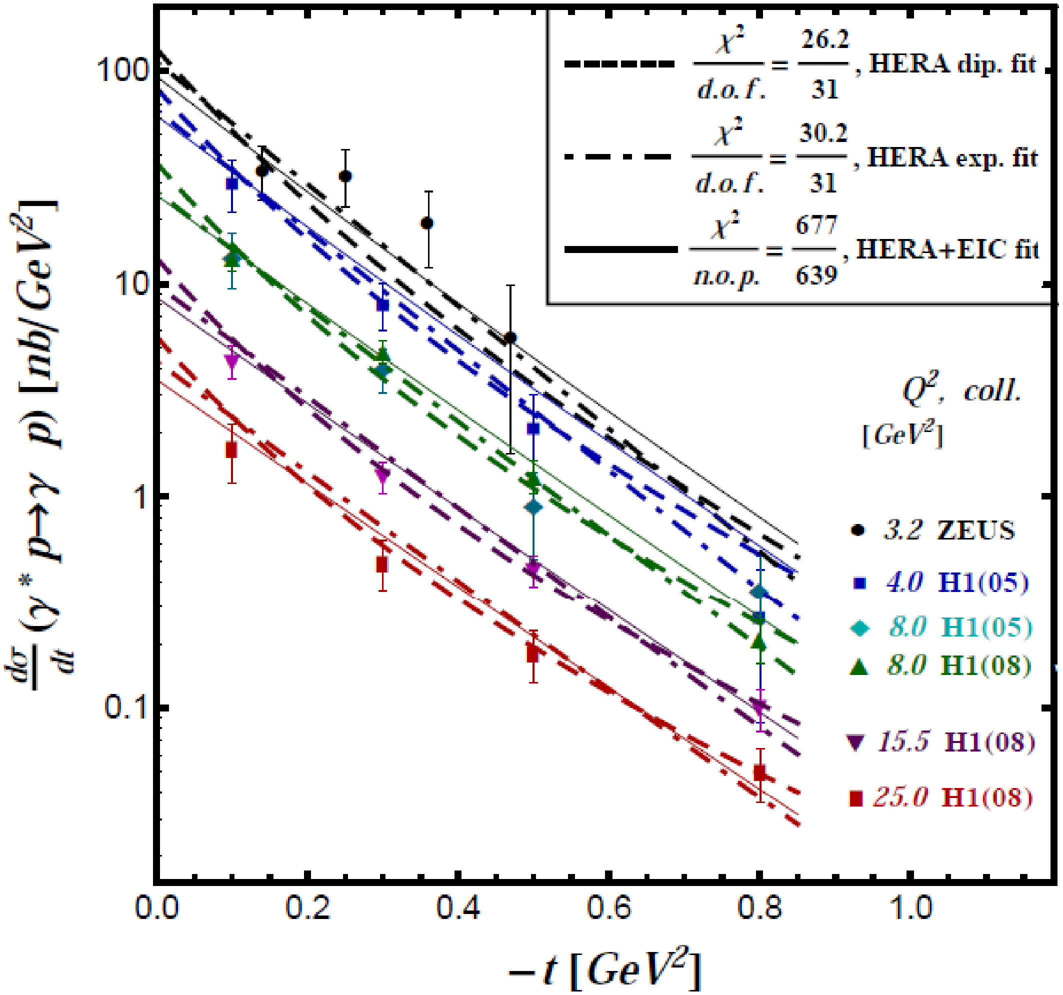
$$TSA_L \propto \left\{F_1(t)\widetilde{H}(\xi,\xi,t,\mathcal{Q}^2) + \xi(F_1+F_2)(t)H(\xi,\xi,t,\mathcal{Q}^2)\right\}$$

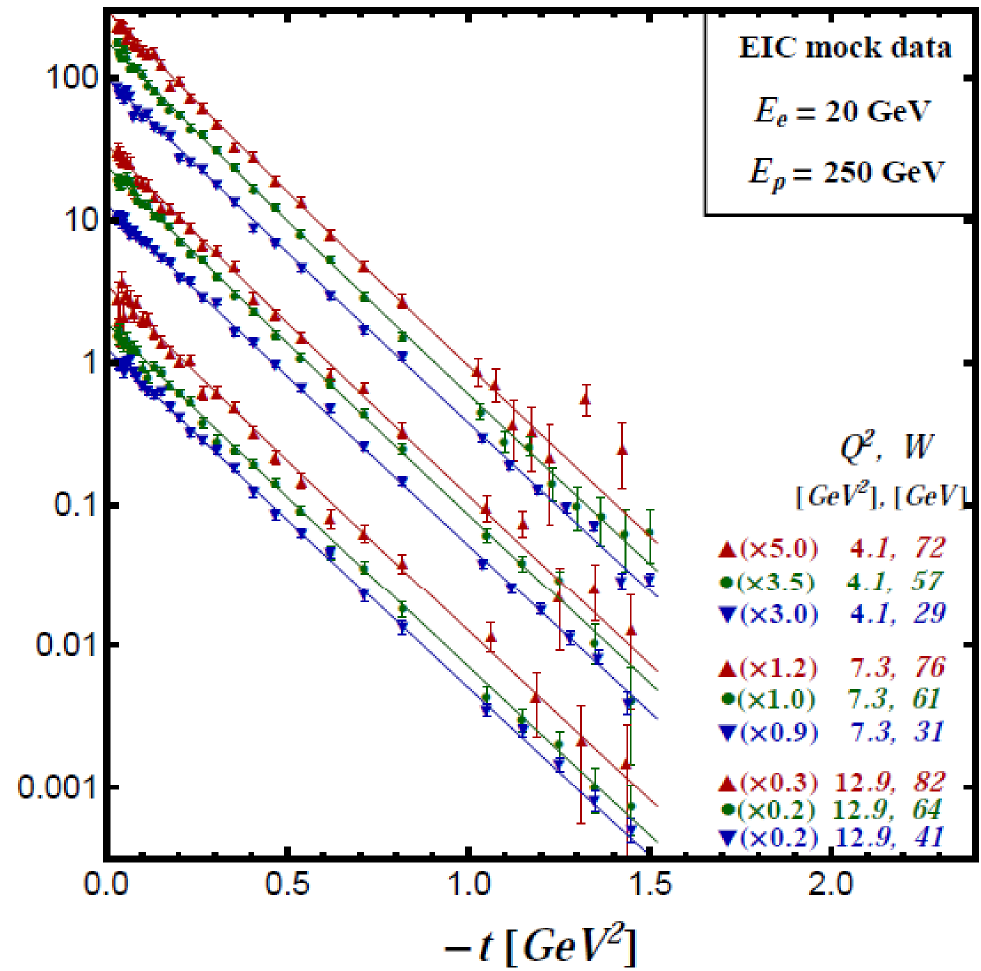
- off neutron another possibility to access GPD E
- separation of twist-2 and twist-3 induced harmonics requires positron beam
- time-like region (a new field to study)
- off nuclei (has its own interest)

Impact of EIC data to extract GPD H

two simulations from S. Fazio for DVCS cross section ~ 650 data points
$-t <$ ~0.8 GeV^2 for ~ 10/fb
1 $\text{GeV}^2 < -t < 2$ GeV^2 for ~ 100/fb (cut: $-t < 1.5$ GeV^2, 4 $\text{GeV}^2 < Q2$ to ensure $-t < Q^2$)

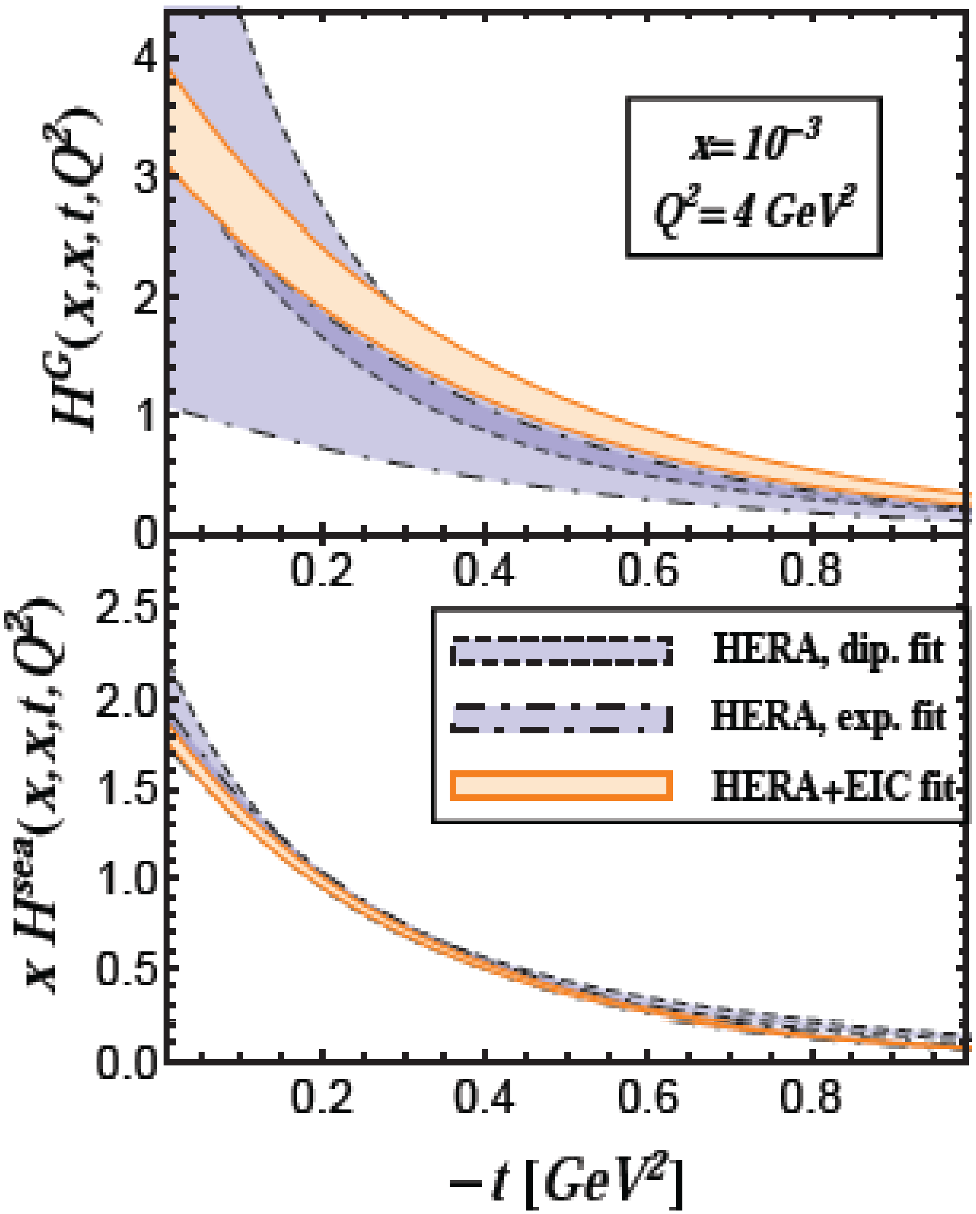
pseudo data are re-generated with GeParD
statistical errors rescaled
5% systematical errors added in quadrature, 3% Bethe-Heitler uncertainty





Imaging (probabilistic interpretation)

$$q(x,\vec{b},\mu^2) = \frac{1}{4\pi}\int_0^\infty d|t|\, J_0(|\vec{b}|\sqrt{|t|})H(x,\eta=0,t,\mu^2)$$



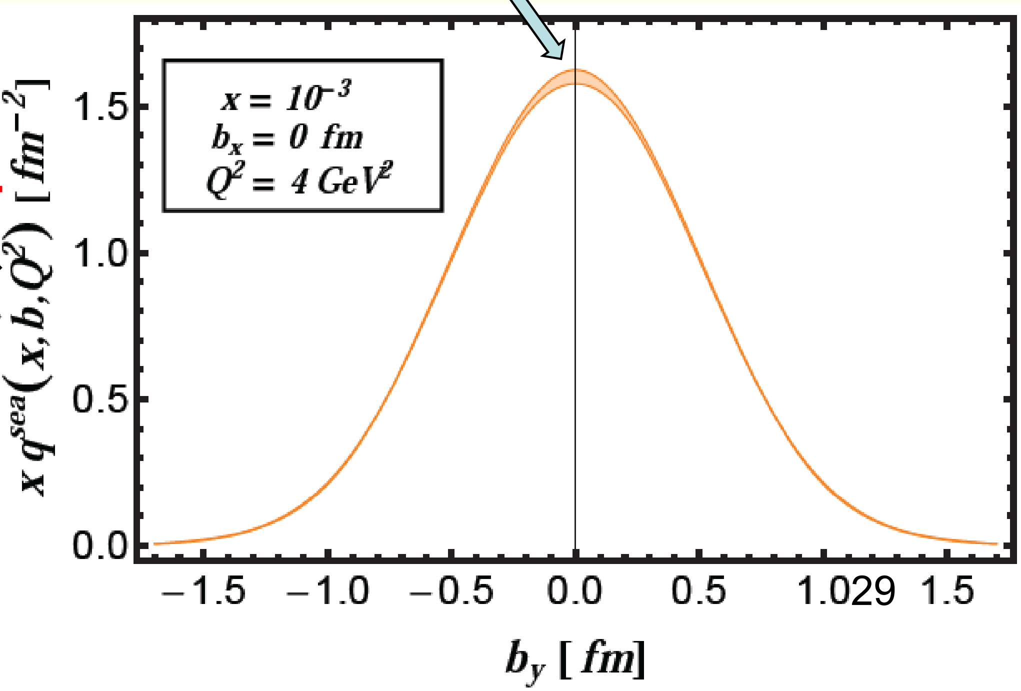
skewness effect vanishes (s_2 , $s_4 \rightarrow 0$)

- reduce fit uncertainties
- increase model uncertainties

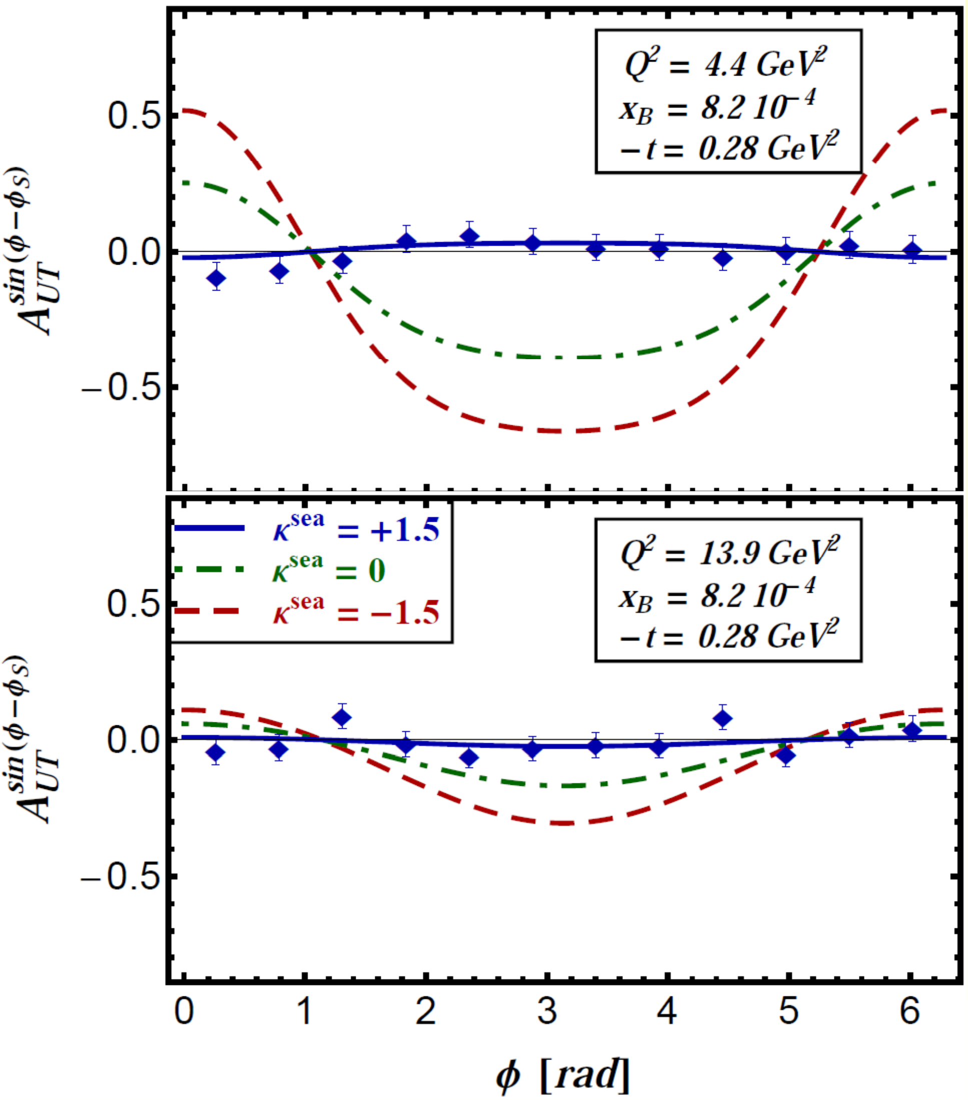
extrapolation errors for $-t \rightarrow 0$
(large b uncertainties – small effect)

extrapolation errors into $-t > 1.5$ GeV^2
(small b uncertainties)

FT



Single transverse target spin asymmetry

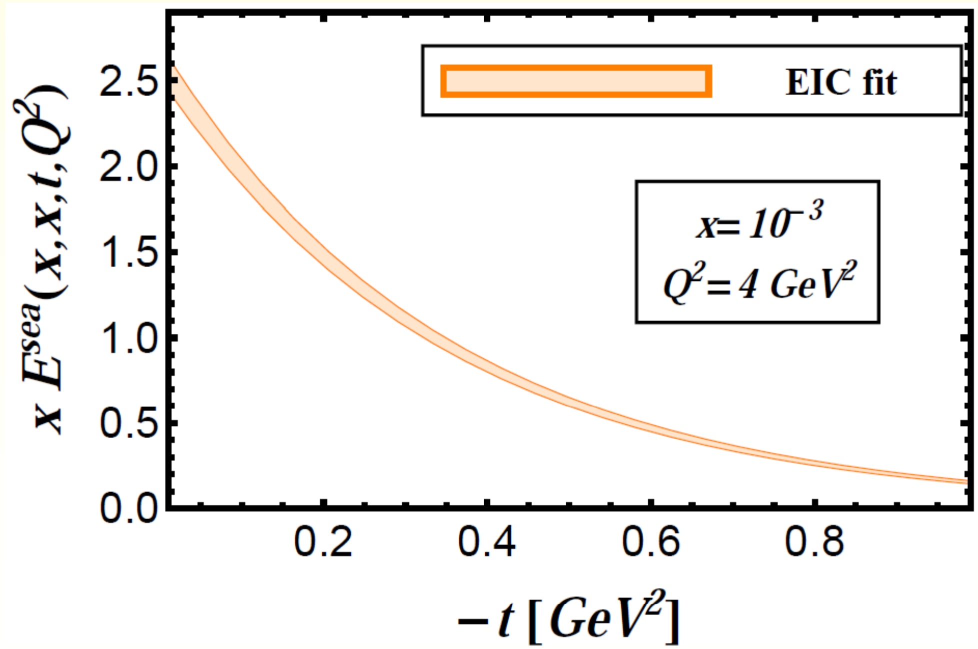


20x250 2x5/fb mock data
(~1200 data points with statistical errors
+ 5% systematics at cross section level)

flexible GPD model for E^{sea} and E^G

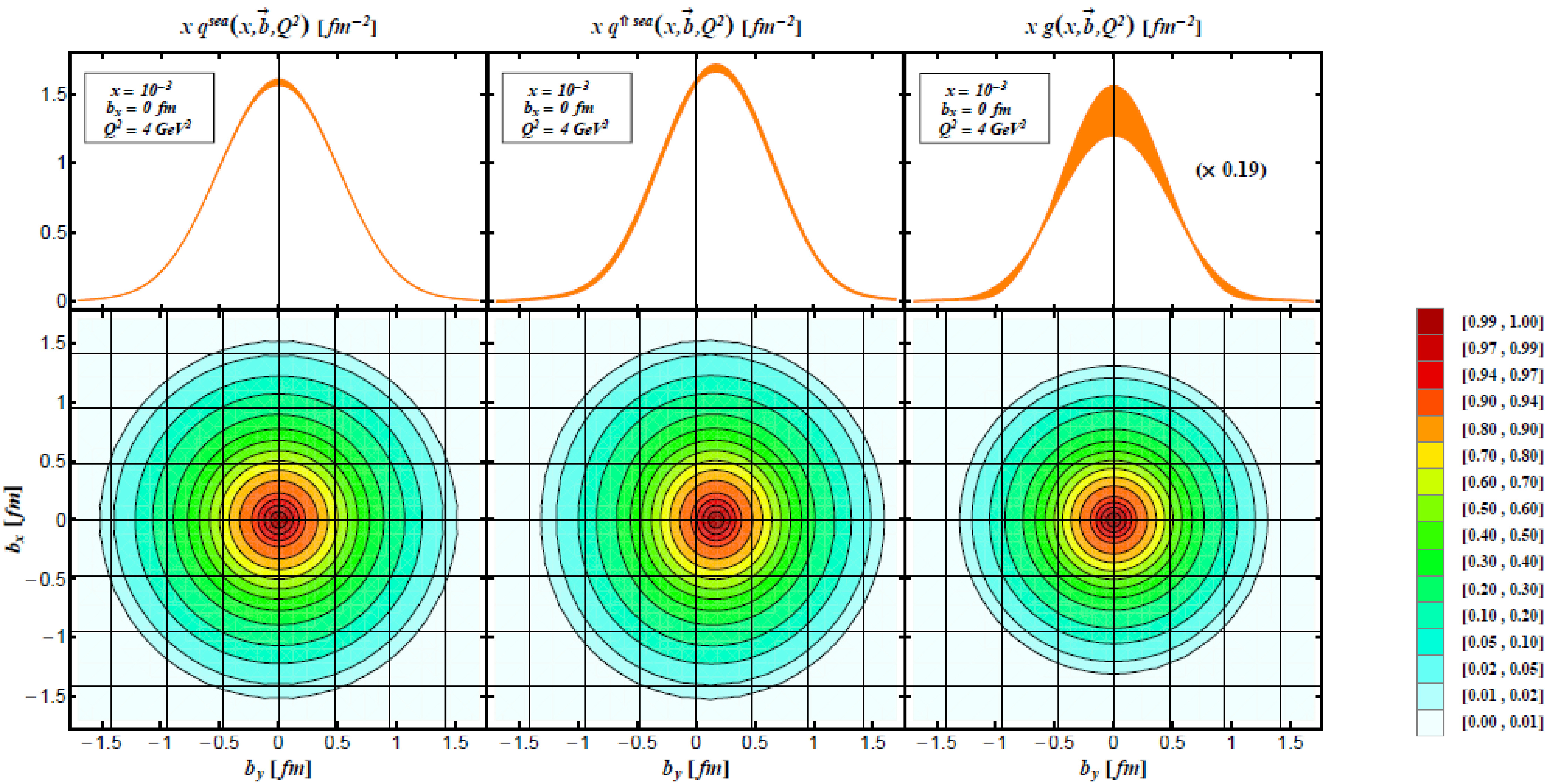
normalization (and *t*-dependency) of E^{sea} is reasonable constraint

E^G is essentially unconstraint



EIC goals for GPD phenomenology

- revealing GPDs at small *x*, tomography seems possible
- qualitative insight on the orbital angular momentum of sea quarks



Summary

GPDs are intricate and (thus) a promising tool

- to reveal the transverse distribution of partons
- to address the spin content of the nucleon
- providing a bridge to LCWFs modeling & non-perturbative methods (lattice)

hard exclusive leptoproduction

- DVCS is widely considered as a theoretical clean process
- it is elaborated in NLO and offers a new insight in QCD
- possesses a rich structure, allowing to access various CFFs/GPDs
- new experiments (high luminosity machines and dedicated detectors) are desired to quantify exclusive (and inclusive) QCD phenomena

technology

software tools for global GPD fits have been developed for demonstration

? global QCD fits (inclusive + exclusive)