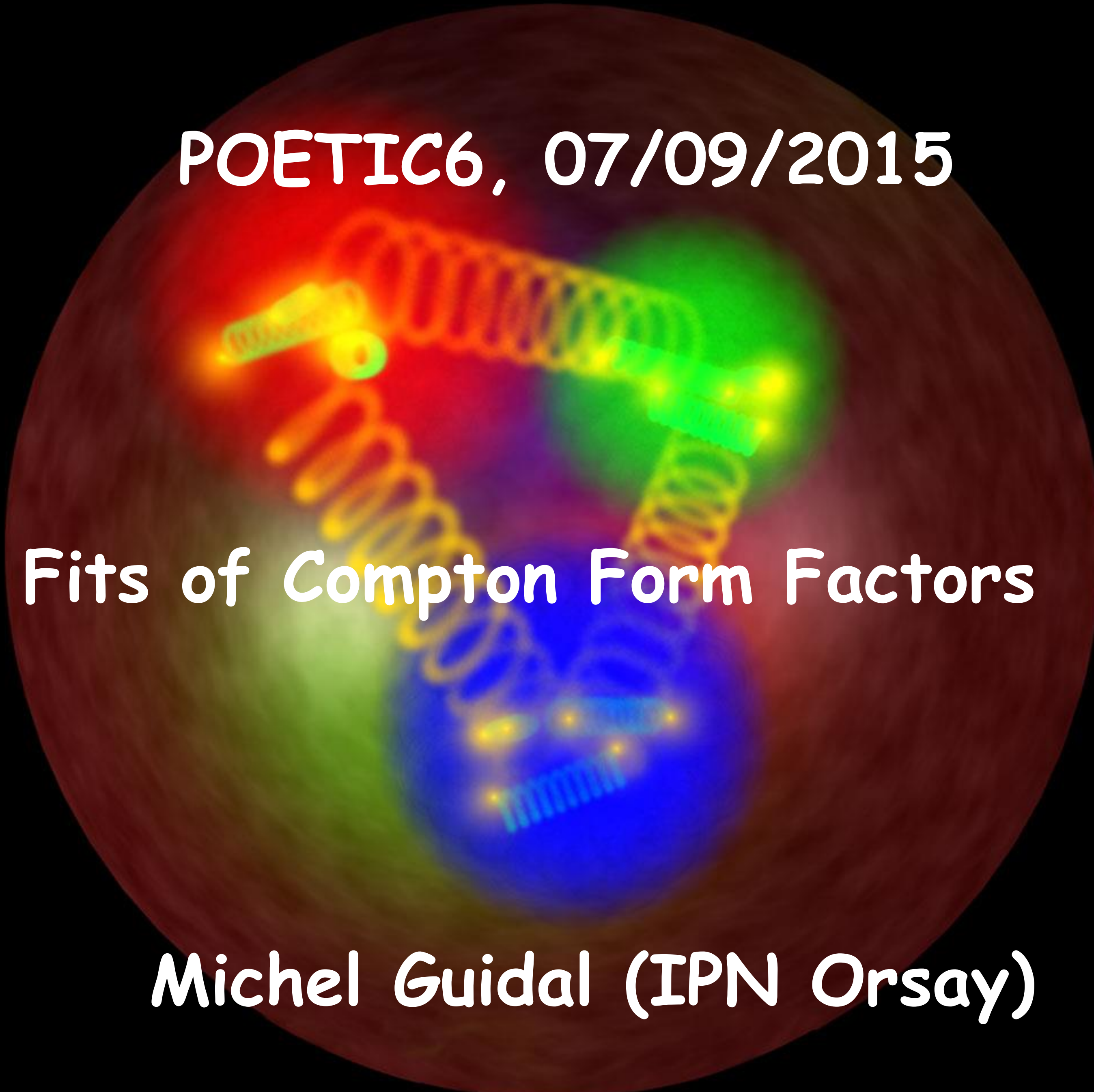
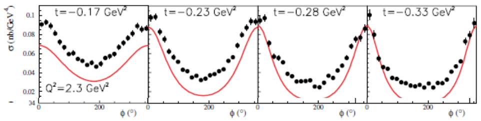
POETIC6, 07/09/2015



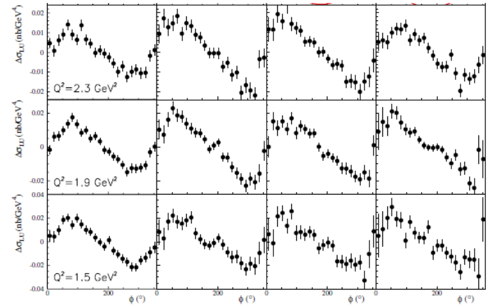
Fits of Compton Form Factors

Michel Guidal (IPN Orsay)

JLab Hall A



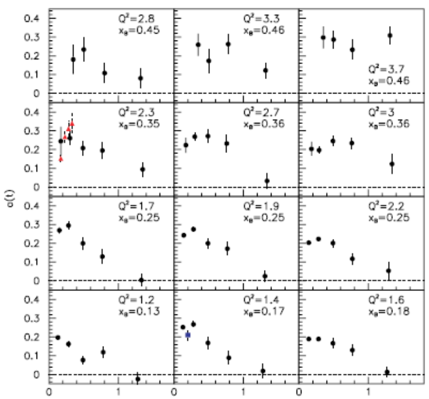
DVCS unpol. X-section

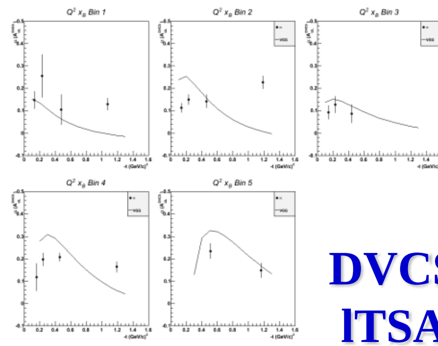


DVCS B-pol. X-section

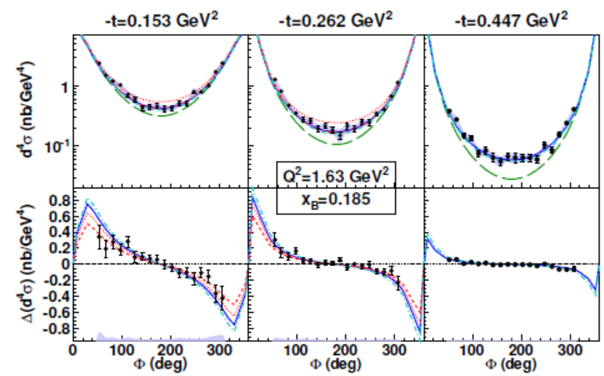
JLab CLAS

DVCS BSA



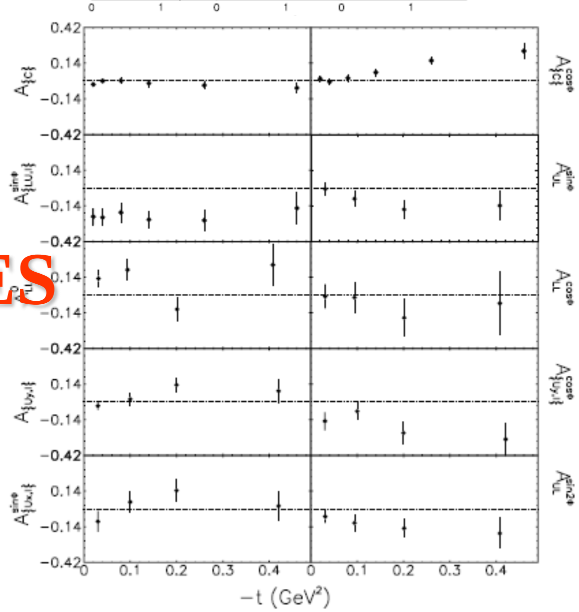


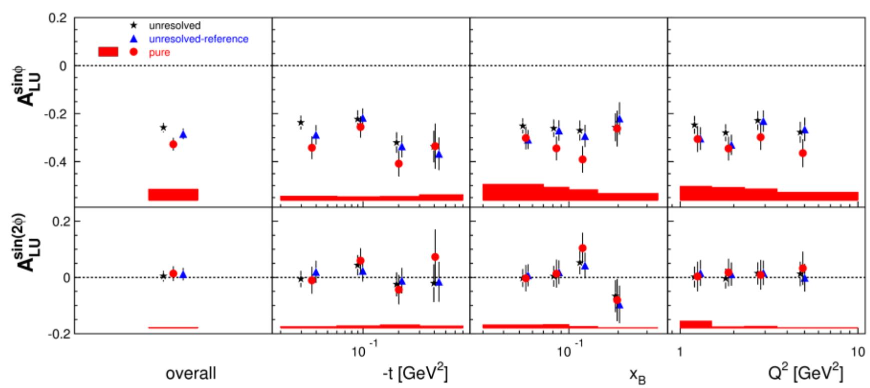
DVCS lTSA



DVCS unpol. and B-pol. X-sections

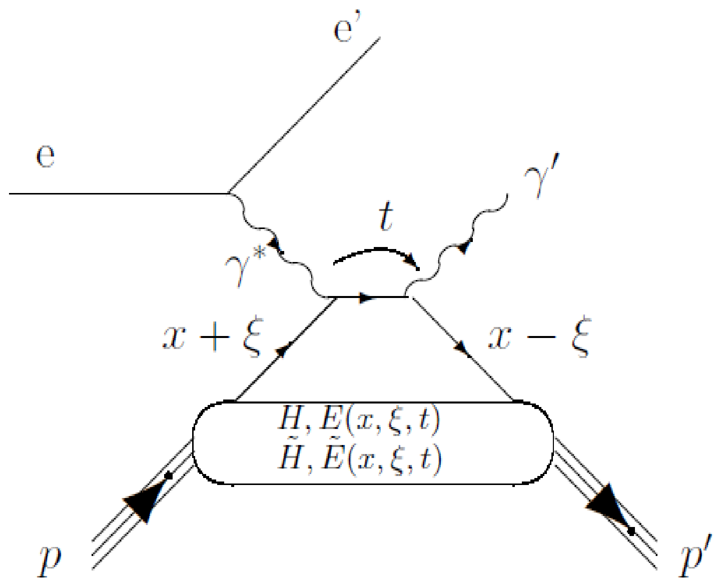
HERMES





DVCS BSA,lTSA,tTSA,BCA

$H^q(x,\xi,t)$ but only ξ and t experimentally accessible



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

In general, 8 GPD quantities accessible

(sub-)Compton Form Factors

$$H_{\mathrm{Re}}(\xi,t) \equiv \mathcal{P}\int_0^1 \mathrm{d}x\,[H(x,\xi,t) - H(-x,\xi,t)]\,C^{+}(x,\xi)$$

$$E_{\mathrm{Re}}(\xi,t) \equiv \mathcal{P}\int_0^1 \mathrm{d}x\,[E(x,\xi,t) - E(-x,\xi,t)]\,C^{+}(x,\xi)$$

$$\tilde{H}_{\mathrm{Re}}(\xi,t) \equiv \mathcal{P}\int_0^1 \mathrm{d}x\left[\tilde{H}(x,\xi,t) + \tilde{H}(-x,\xi,t)\right]C^{-}(x,\xi)$$

$$\tilde{E}_{\mathrm{Re}}(\xi,t) \equiv \mathcal{P}\int_0^1 \mathrm{d}x\left[\tilde{E}(x,\xi,t) + \tilde{E}(-x,\xi,t)\right]C^{-}(x,\xi)$$

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

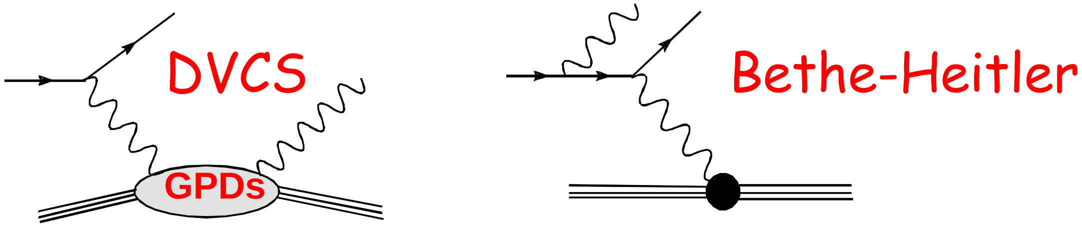
$$E_{\mathrm{Im}}(\xi,t) \equiv E(\xi,\xi,t) - E(-\xi,\xi,t)$$

$$\tilde{H}_{\mathrm{Im}}(\xi,t) \equiv \tilde{H}(\xi,\xi,t) + \tilde{H}(-\xi,\xi,t)$$

$$\tilde{E}_{\mathrm{Im}}(\xi,t) \equiv \tilde{E}(\xi,\xi,t) + \tilde{E}(-\xi,\xi,t)$$

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

Given the well-established LT-LO DVCS+BH amplitude



Can one recover the 8 CFFs from the DVCS observables?

Obs= Amp(DVCS+BH) $\otimes$ CFFs

Two (quasi-) model-independent approaches to extract, at fixed x_B, t and Q^2 (« local » fitting), the CFFs from the DVCS observables

1/ Mapping and linearization

If enough observables measured, one has a system of 8 equations with 8 unknowns

Given reasonable approximations (leading-twist dominance, neglect of some $1/Q^2$ terms,...), the system can be linear (practical for the error propagation)

$$\begin{pmatrix} A_{\mathrm{LU,I}}^{\sin(1\phi)} \\ A_{\mathrm{UL,+}}^{\sin(1\phi)} \\ A_{\mathrm{UT,I}}^{\sin(\varphi)\cos(1\phi)} \\ A_{\mathrm{UT,I}}^{\cos(\varphi)\sin(1\phi)} \end{pmatrix} \Rightarrow \Im\mathrm{m} \begin{pmatrix} \mathcal{H} \\ \widetilde{\mathcal{H}} \\ \mathcal{E} \\ \overline{\mathcal{E}} \end{pmatrix}, \quad \begin{pmatrix} A_{\mathrm{C}}^{\cos(1\phi)} \\ A_{\mathrm{LL,+}}^{\cos(1\phi)} \\ A_{\mathrm{LT,I}}^{\sin(\varphi)\sin(1\phi)} \\ A_{\mathrm{LT,I}}^{\cos(\varphi)\cos(1\phi)} \end{pmatrix} \Rightarrow \Re\mathrm{e} \begin{pmatrix} \mathcal{H} \\ \widetilde{\mathcal{H}} \\ \mathcal{E} \\ \overline{\mathcal{E}} \end{pmatrix}$$

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

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

K. Kumericki, D. Mueller, M. Murray Phys.Part.Nucl. 45 (2014) 4, 723

2/ «Brute force » fitting

χ^2 minimization (with MINUIT + MINOS) of the available DVCS observables at a given x_B, t and Q^2 point by varying the CFFs within a limited hyper-space (e.g. 5xVGG)

The problem can be (largely) underconstrained:
JLab Hall A: pol. and unpol. X-sections
JLab CLAS: BSA + TSA

⇨ 2 constraints and 8 parameters !

However, as some observables are largely dominated by a single or a few CFFs, there is a convergence (i.e. a well-defined minimum χ^2) for these latter CFFs.

The contribution of the non-converging CFF enters in the error bar of the converging ones. For instance (naive):

$3 = y + 0.001x$ If -10<x<10: $3 = y \pm 0.01$ (or $y = 3 \pm 0.01$)

2/ «Brute force » fitting

χ^2 minimization (with MINUIT + MINOS) of the available DVCS observables at a given x_B, t and Q^2 point by varying the CFFs within a limited hyper-space (e.g. 5xVGG)

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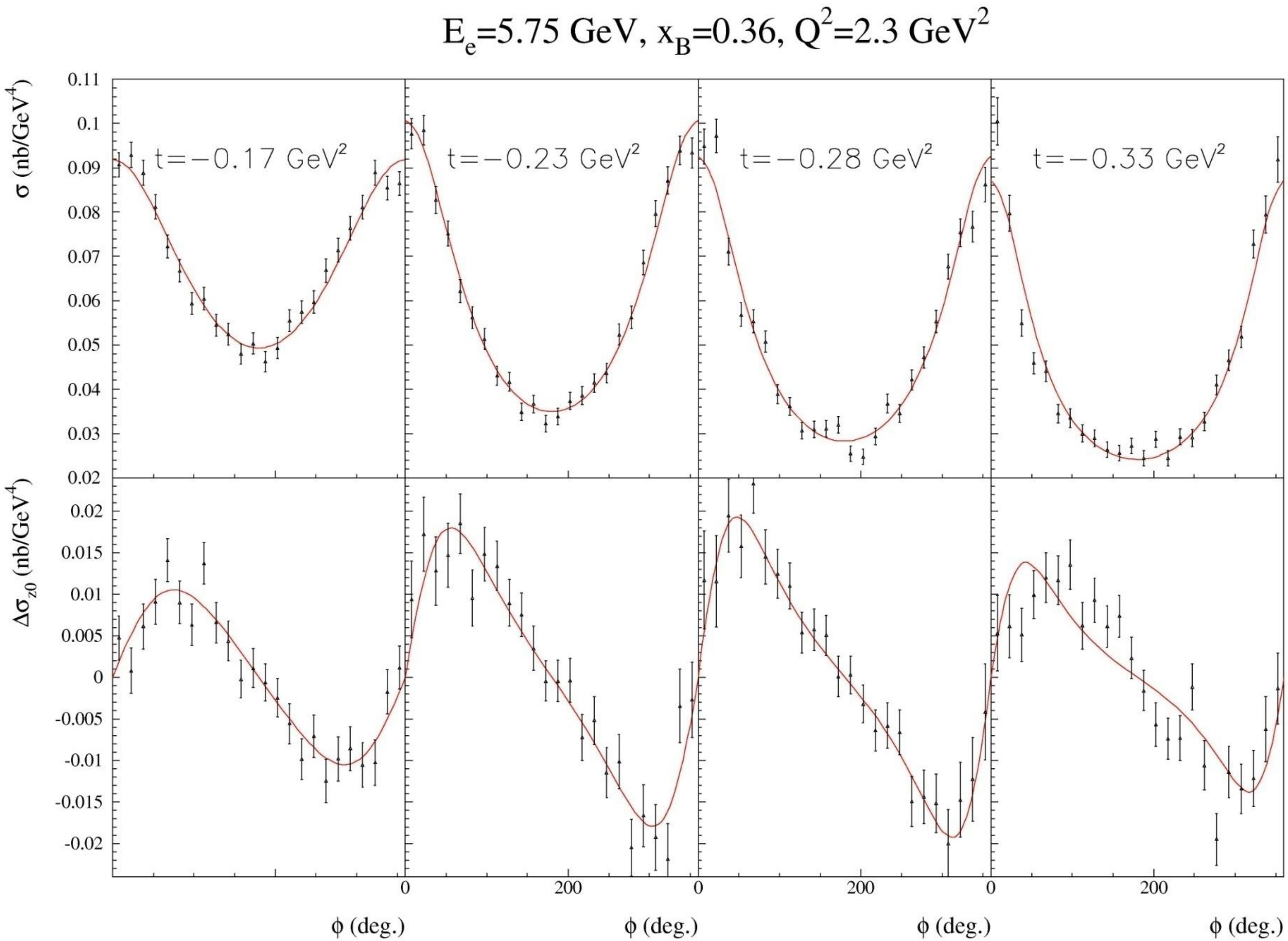
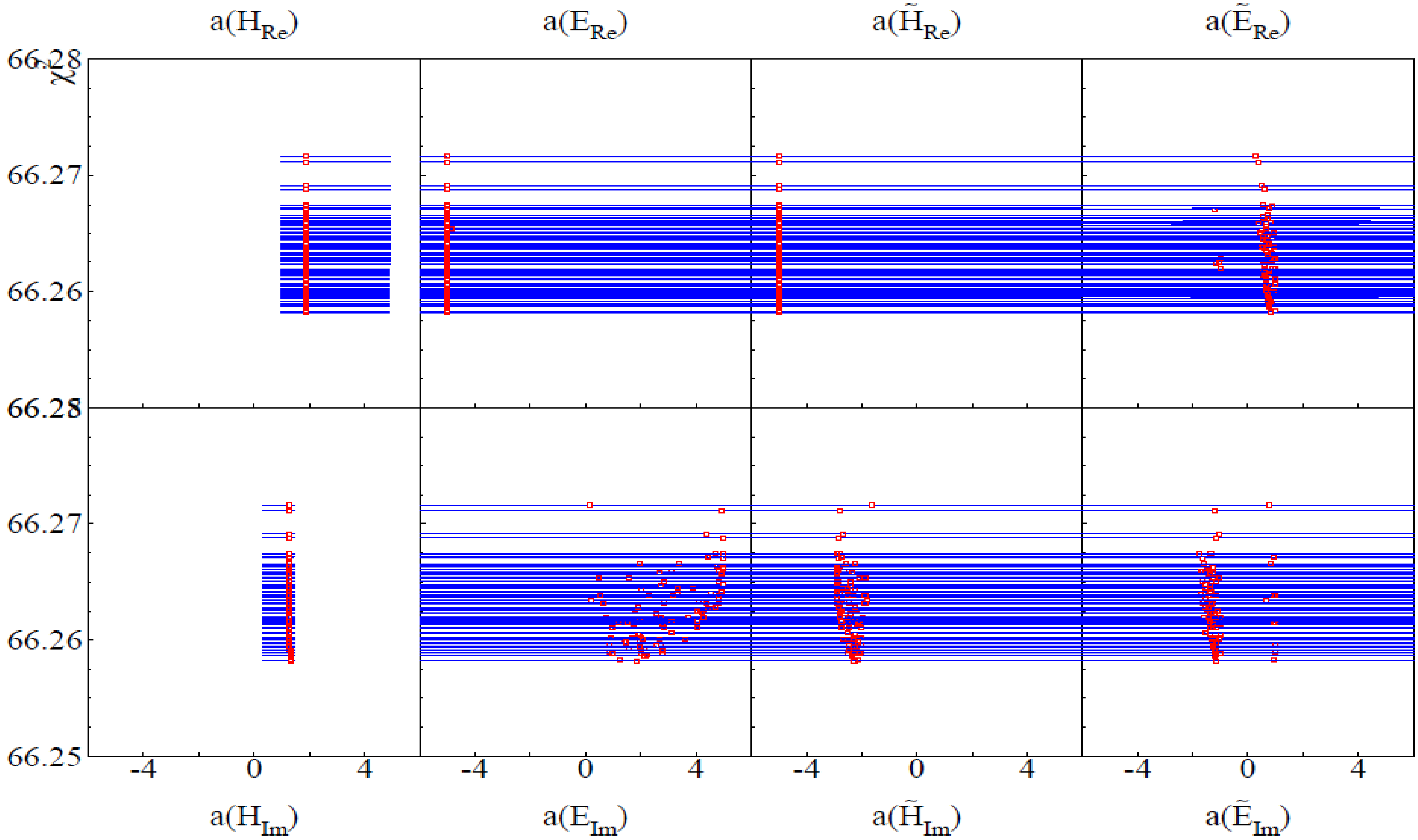
M.G. EPJA 37 (2008) 319 M.G. & H. Moutarde EPJA 42 (2009) 71

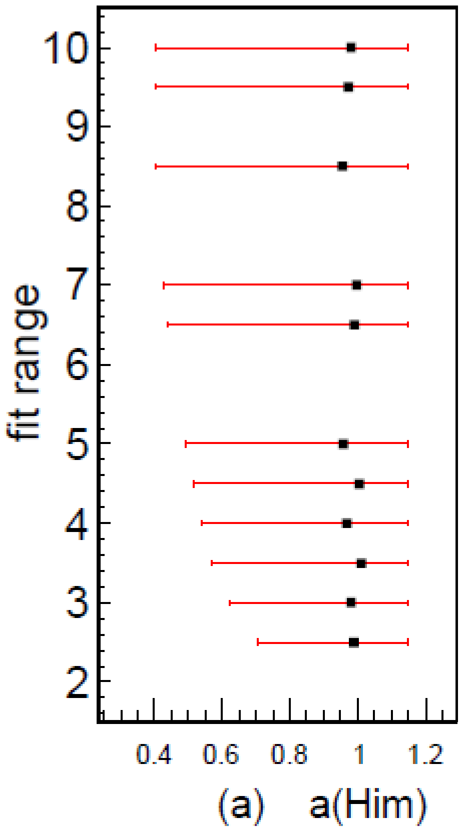
Hall A : σ & $\Delta\sigma_{LU}$, x_B=0.36,Q^2=2.3,t=.17,.23,.28,.33





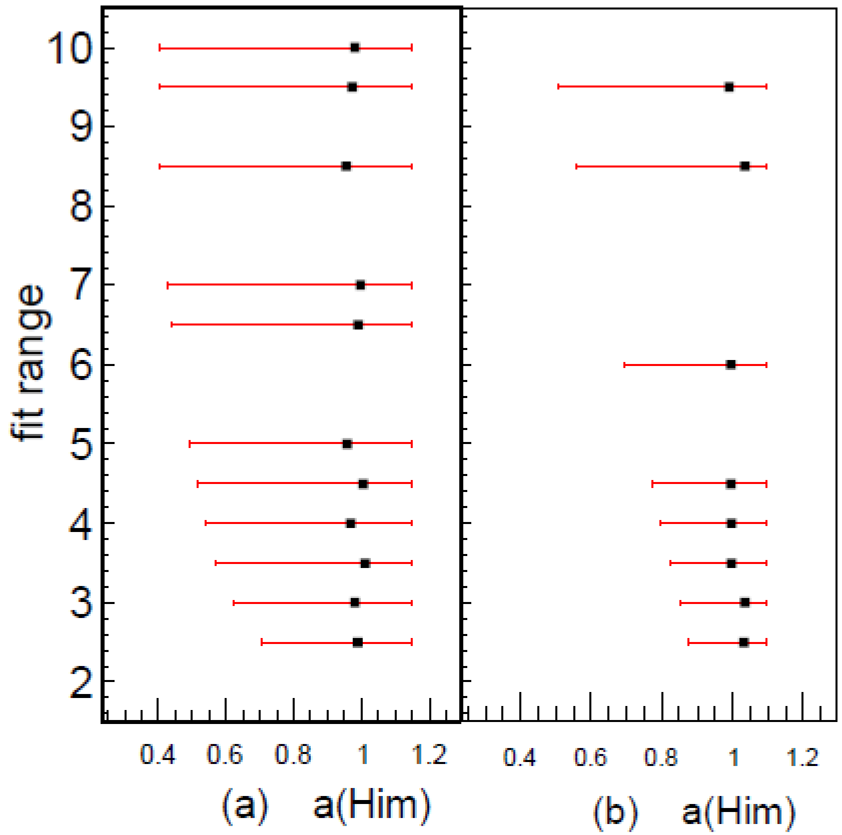
M. Boer, MG J.Phys. G42 (2015) 3, 034023

Figure 3. Result of the fits for the 8 CFF multipliers $a(\ldots)$ (central value in red and error bar in blue on the x-axis) and the corresponding χ^2 value (y-axis), for the first tens of several hundreds of trials differing only by the starting values of the 8 CFF multipliers. This example is for the third t-bin of the JLab Hall A data.



M. Boer, MG J.Phys. G42 (2015) 3, 034023

Figure 5. Results of fits based on simulations for the CFF multiplier $a(H_{Im})$ and its error bar (x-axis) for different maximum ranges of the domain of variation allowed for the CFFs (y-axis, in units of VGG CFFs) and for different sets of observables fitted: (a) the unpolarized cross section σ and the beam-polarized cross section $\Delta\sigma_{LU}$ (like the Hall A data), (b) σ, $\Delta\sigma_{LU}$ and $\Delta\sigma_{Uz}$, (c) σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{Uz}$, $\Delta\sigma_{Ux}$ and $\Delta\sigma_{Uy}$, (d) σ and all single and double polarization observables. The pseudo-data that were fitted were generated with the VGG values, so that the multipliers of all CFFs should be 1. In this example, the kinematics is approximately similar to the JLab Hall A data: xi=0.2, Q^2=3 GeV^2 and $-t$=0.4 GeV^2.



M. Boer, MG J.Phys. G42 (2015) 3, 034023

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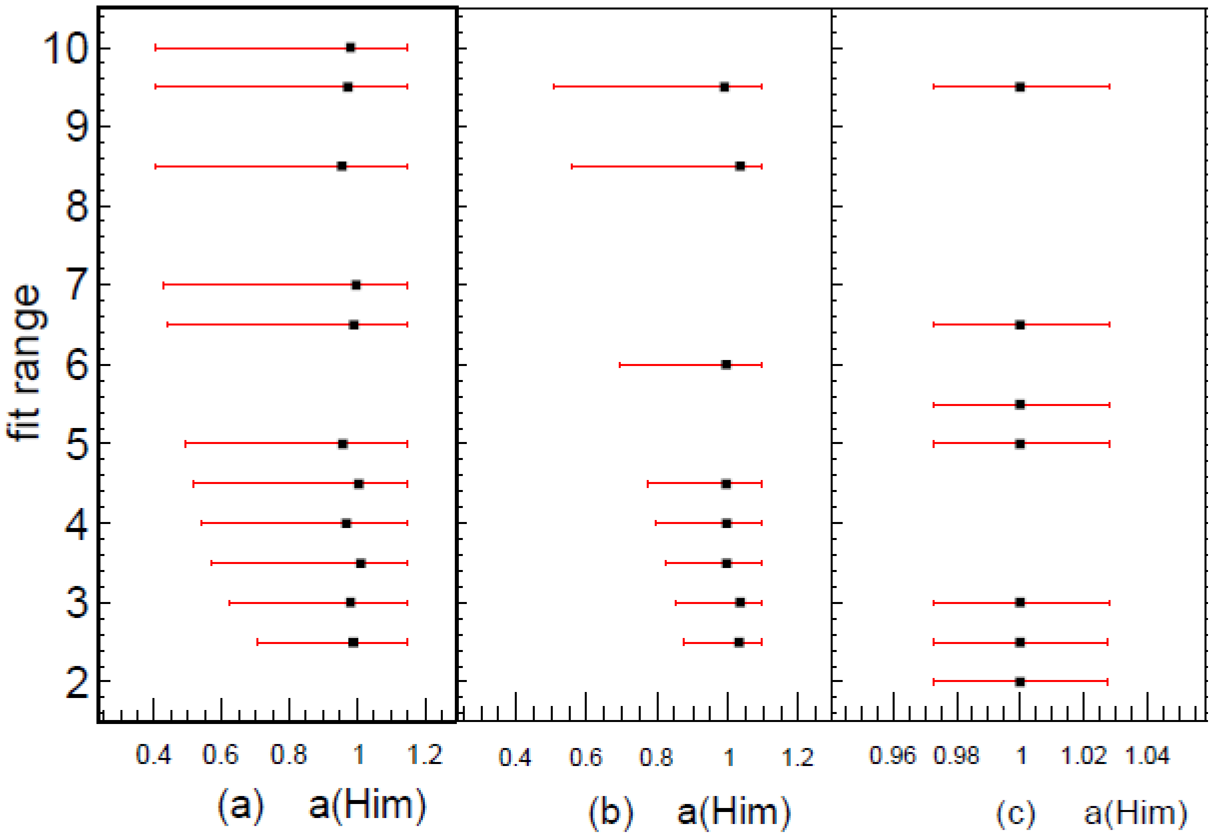

M. Boer, MG J.Phys. G42 (2015) 3, 034023

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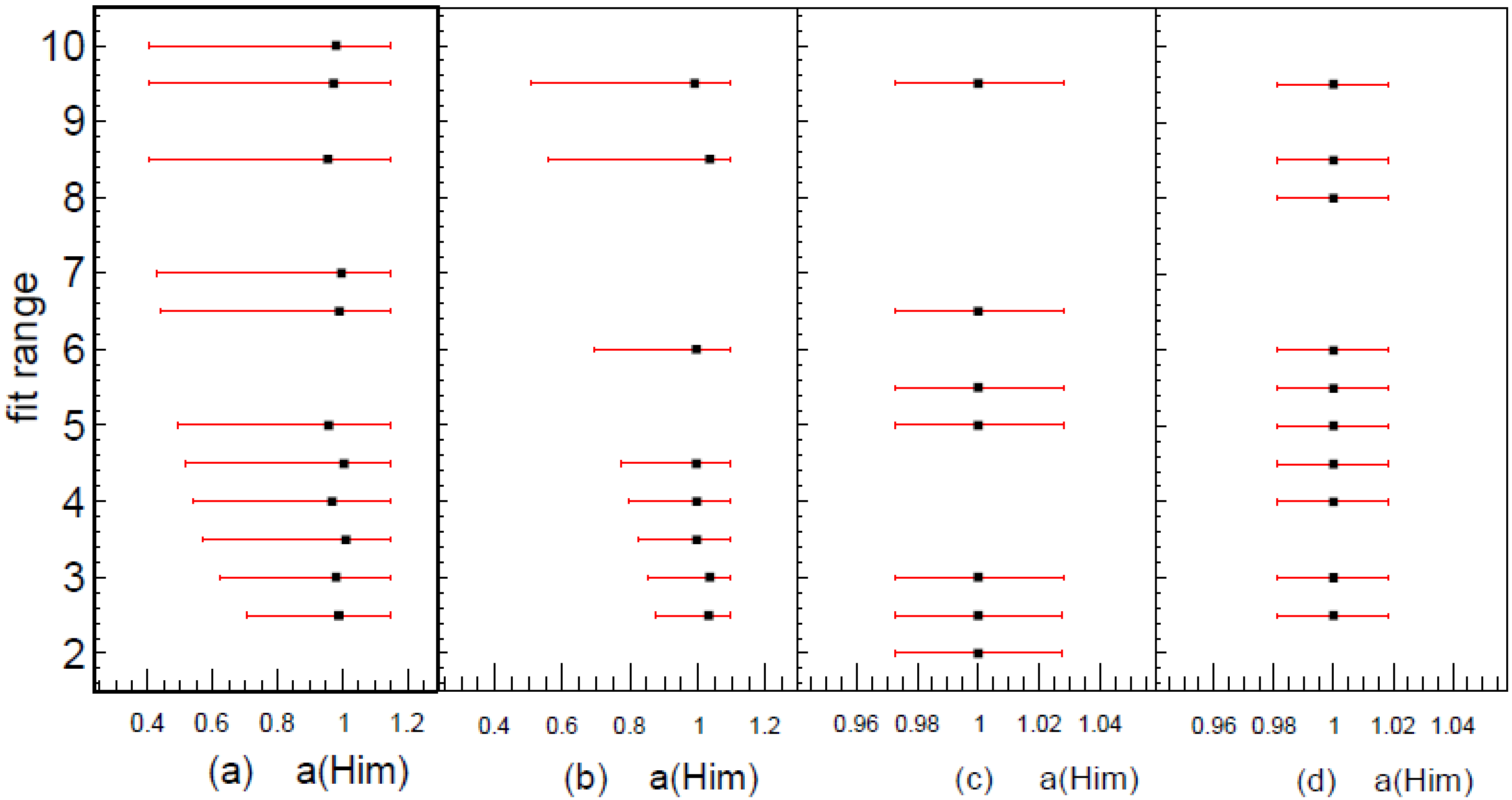

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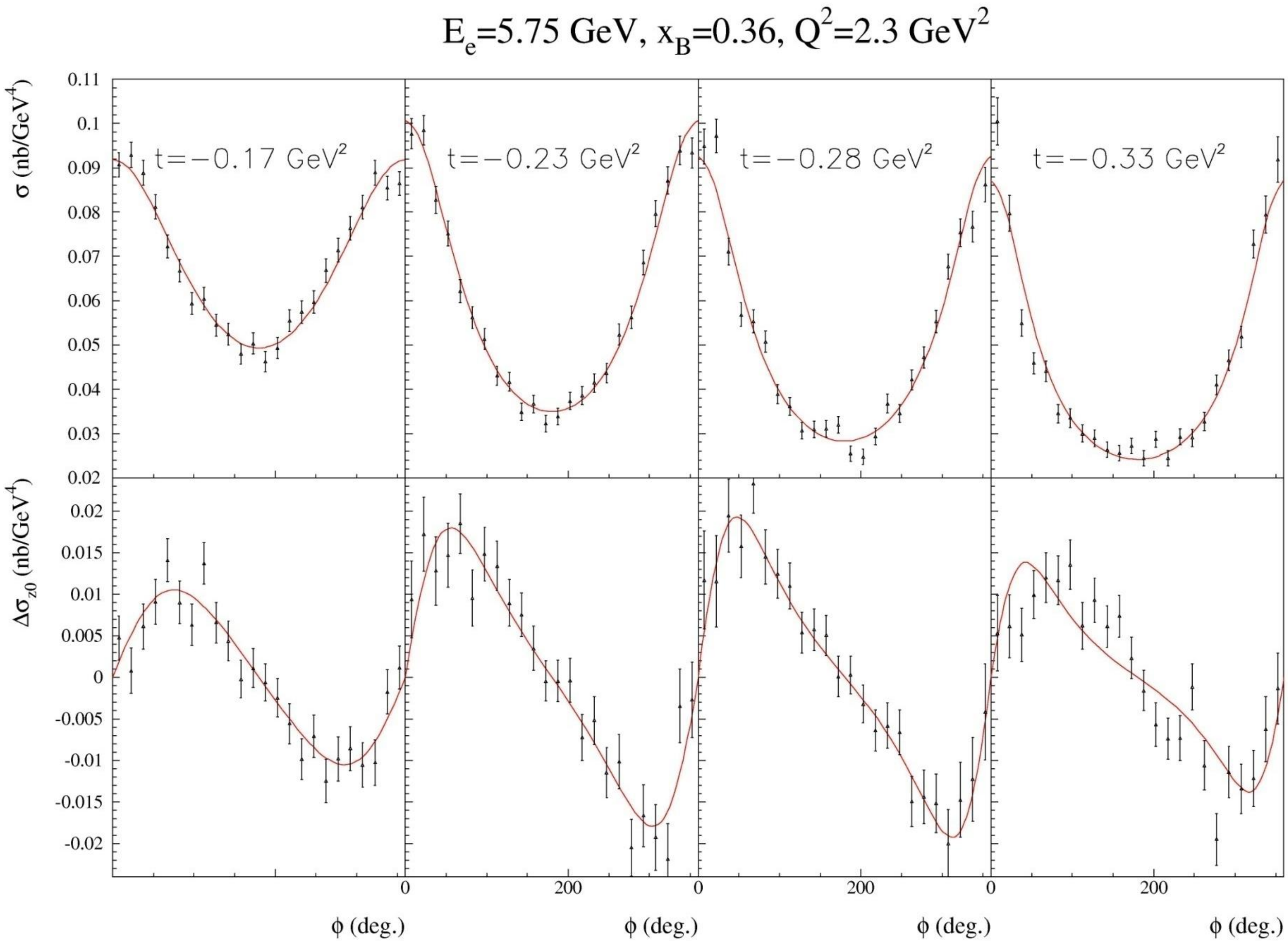
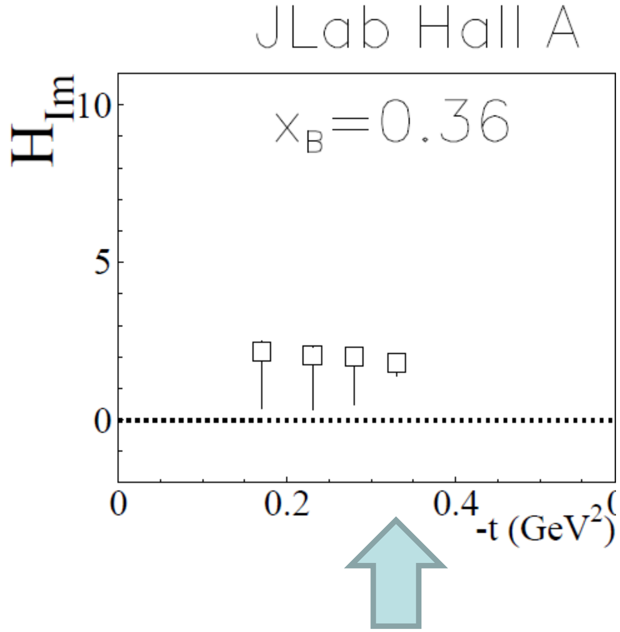


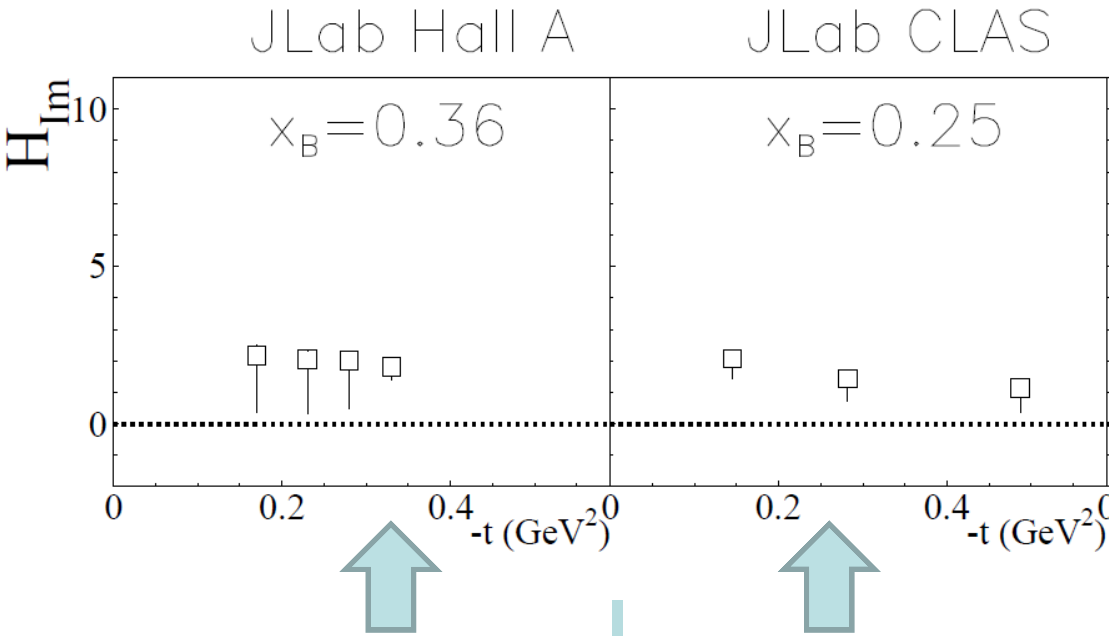


unpol.sec.eff.

+

beam pol.sec.eff.

- **χ^2 minimization**



unpol.sec.eff.

+

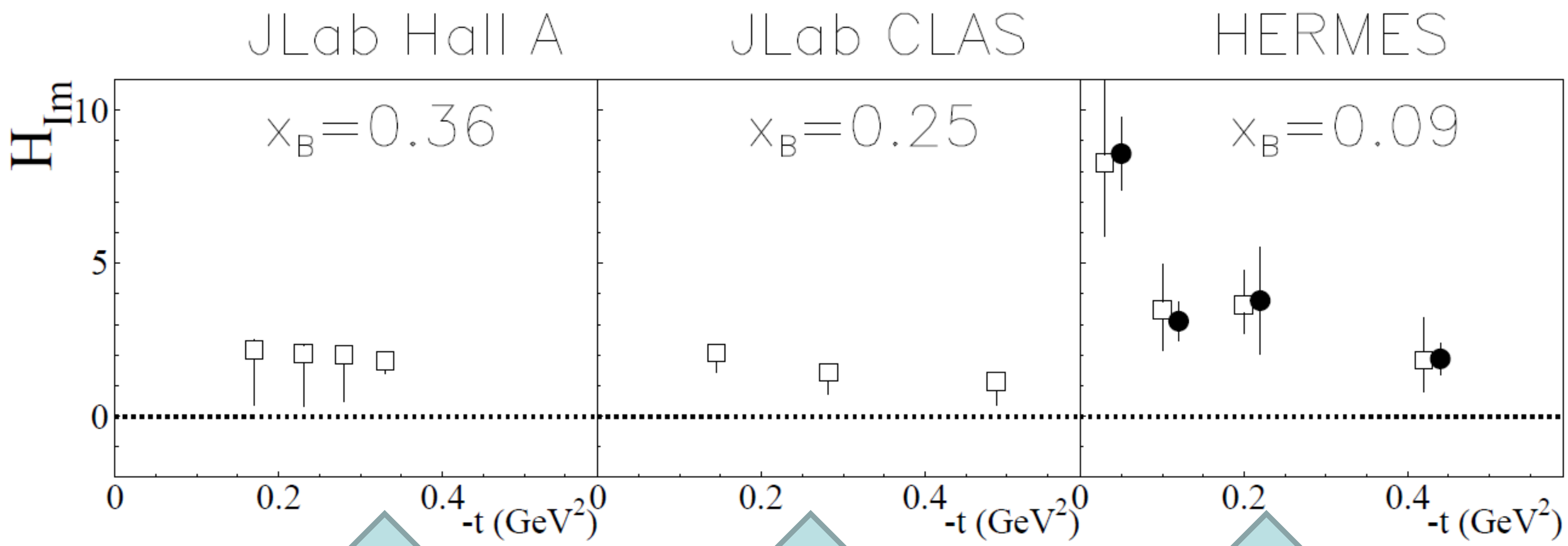
beam pol.sec.eff.

beam spin asym.

+

long. pol. tar. asym

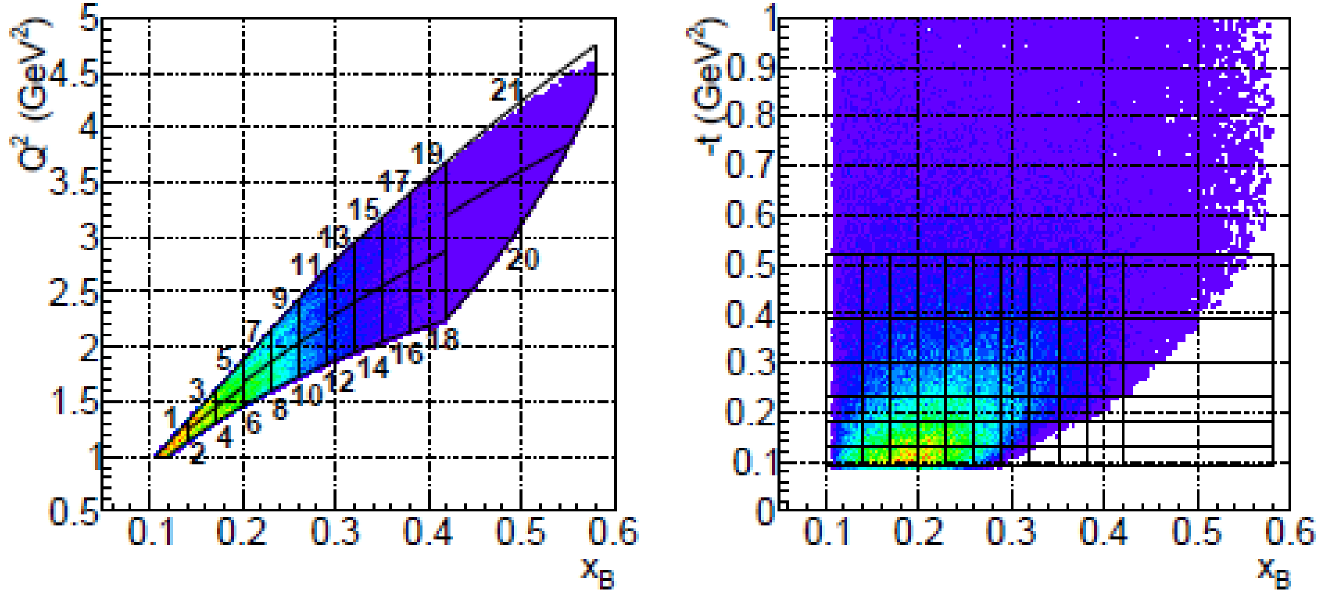
- **χ^2 minimization**



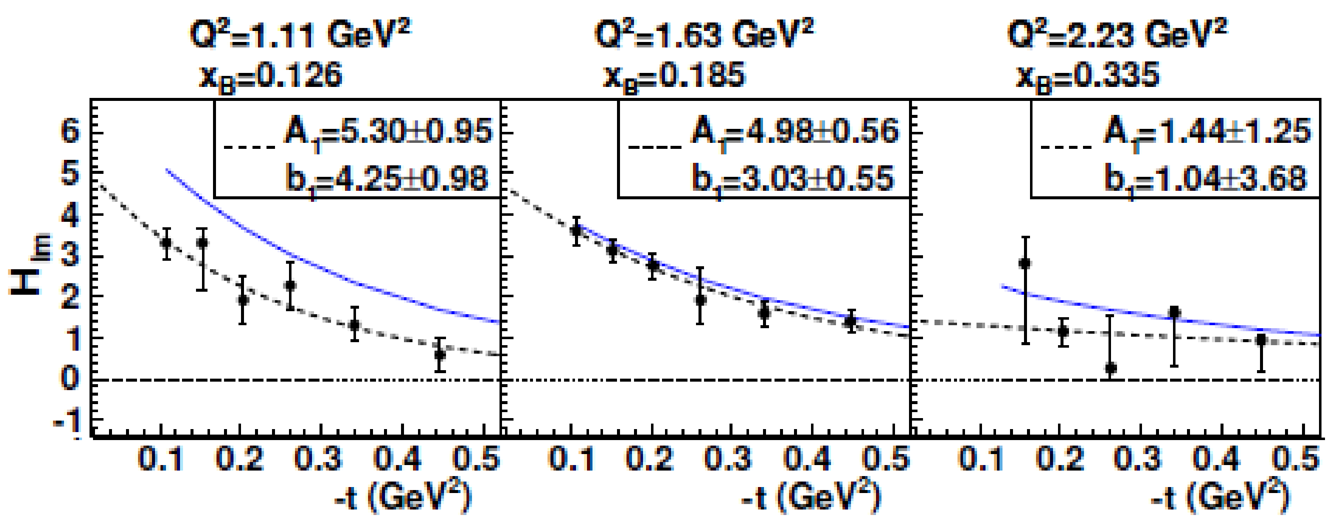
unpol.sec.eff.	beam spin asym.	beam charge asym.
+	+	+
beam pol.sec.eff.	long. pol. tar. asym	beam spin asym
		+
		…

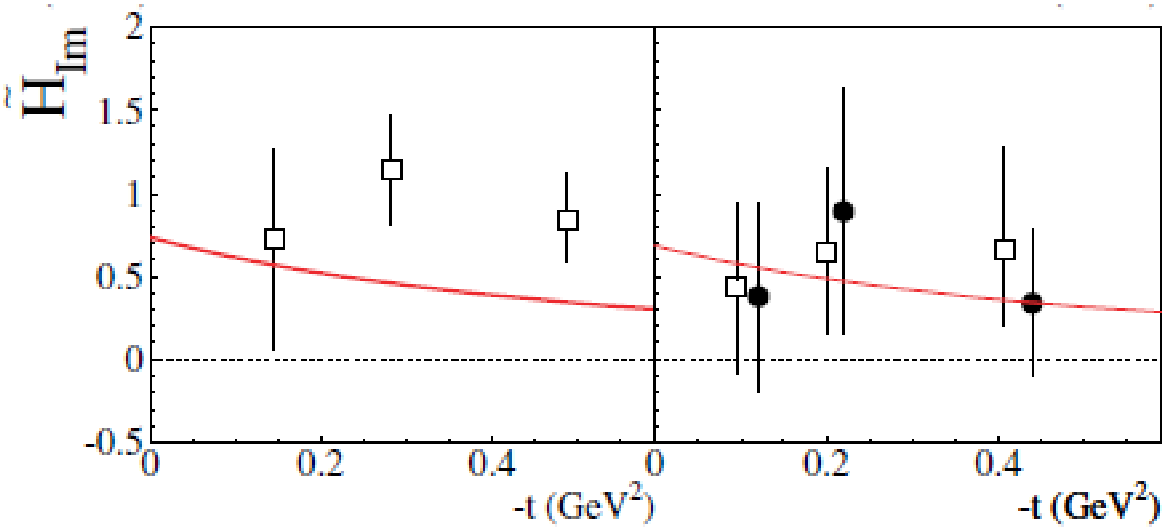
□ χ^2 minimization

● linearization



CLAS coll. arXiv:1504.02009 [hep-ex]

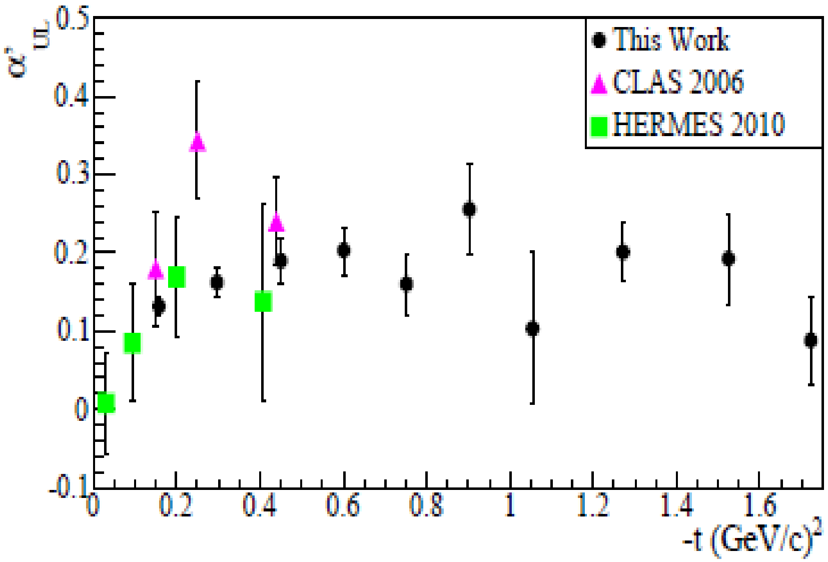


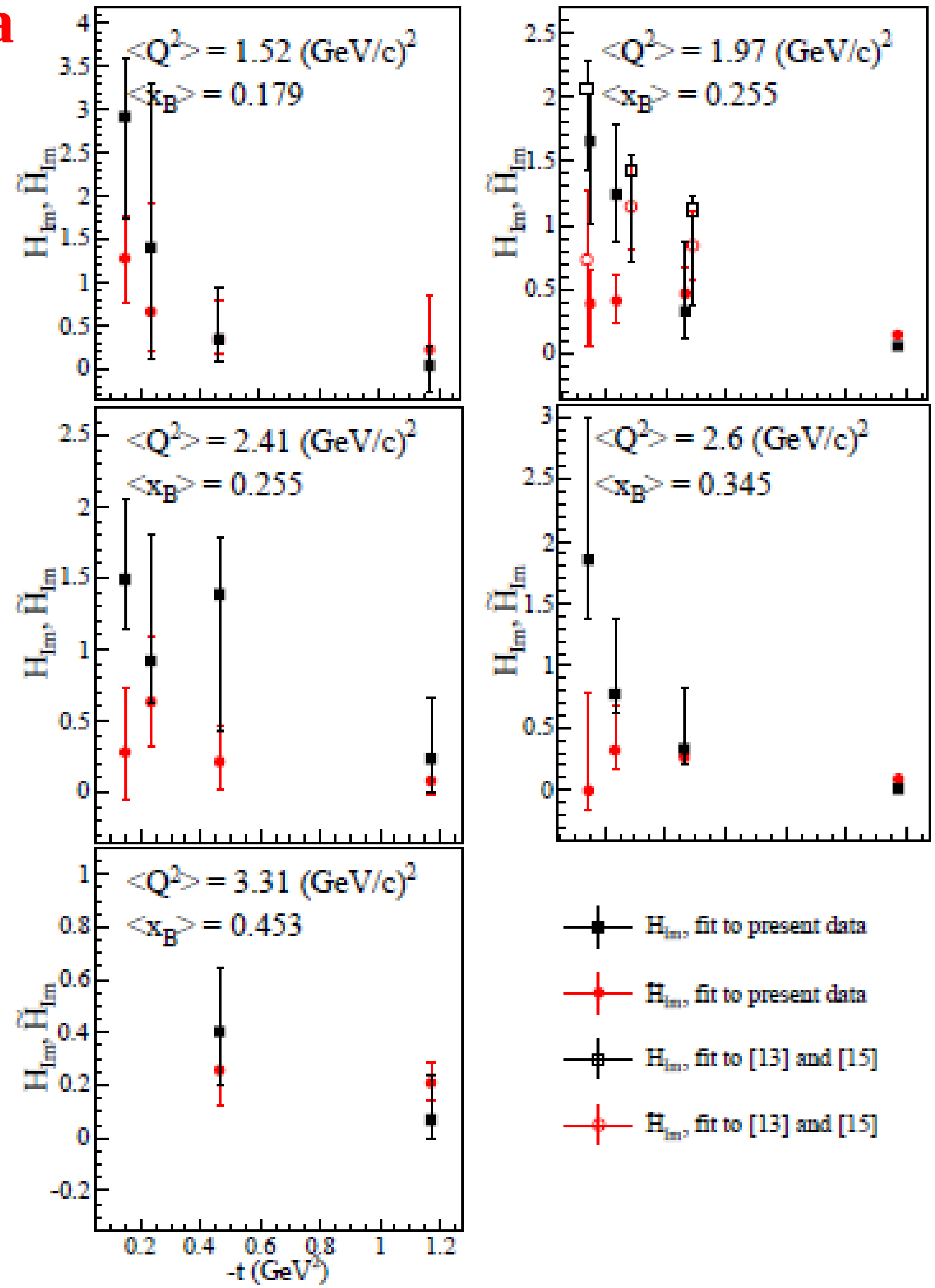


The axial charge (~$\tilde{H}_{im}$) appears to be more « concentrated » than the electromagnetic charge (~H_{im})

New A_UL and A_LL CLAS data

Phys.Rev. D91 (2015) 5, 052014





Confirms the apparent « x_B-independence » and flatter « t-dependence » of $\tilde{H}_{Im}$

From CFFs to spatial densities

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

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

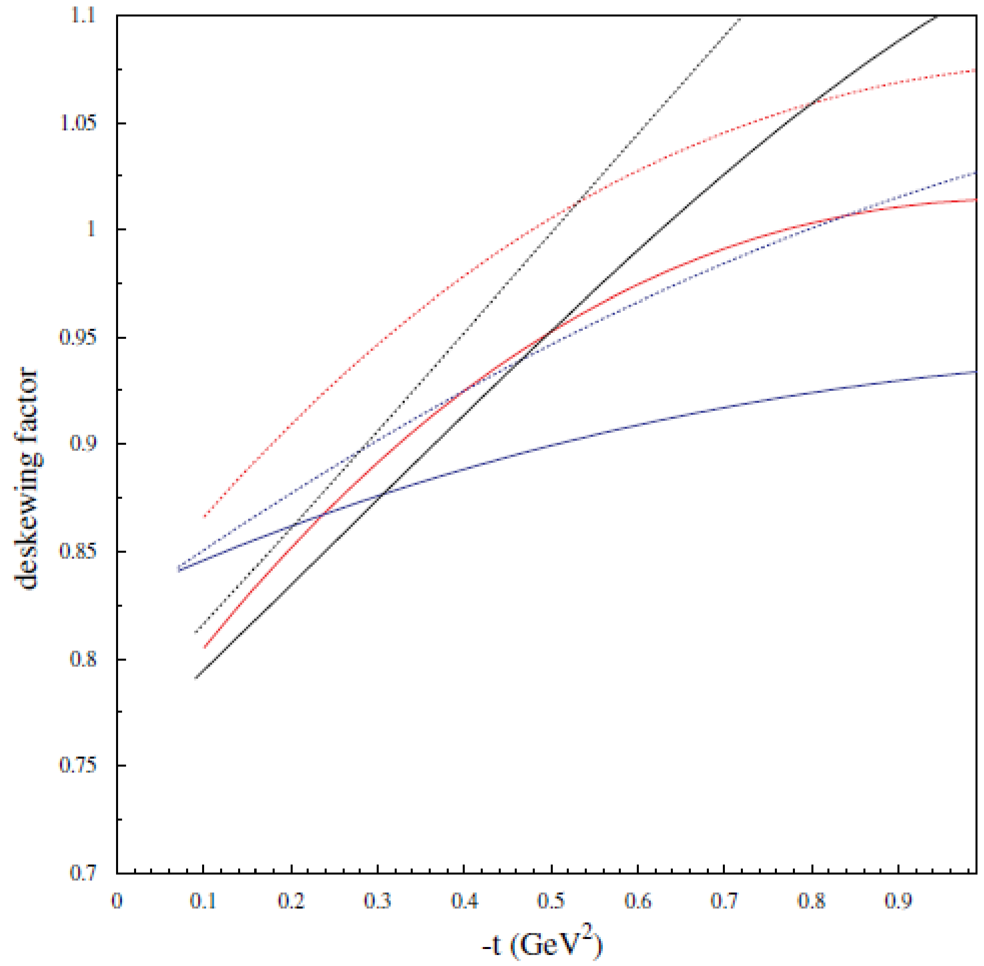
$$H(x, b_\perp) = \int_0^\infty \frac{\mathrm{d}\Delta_\perp}{2\pi} \Delta_\perp J_0(b_\perp \Delta_\perp) H(x, 0, -\Delta_\perp^2)$$

Burkardt (2000)

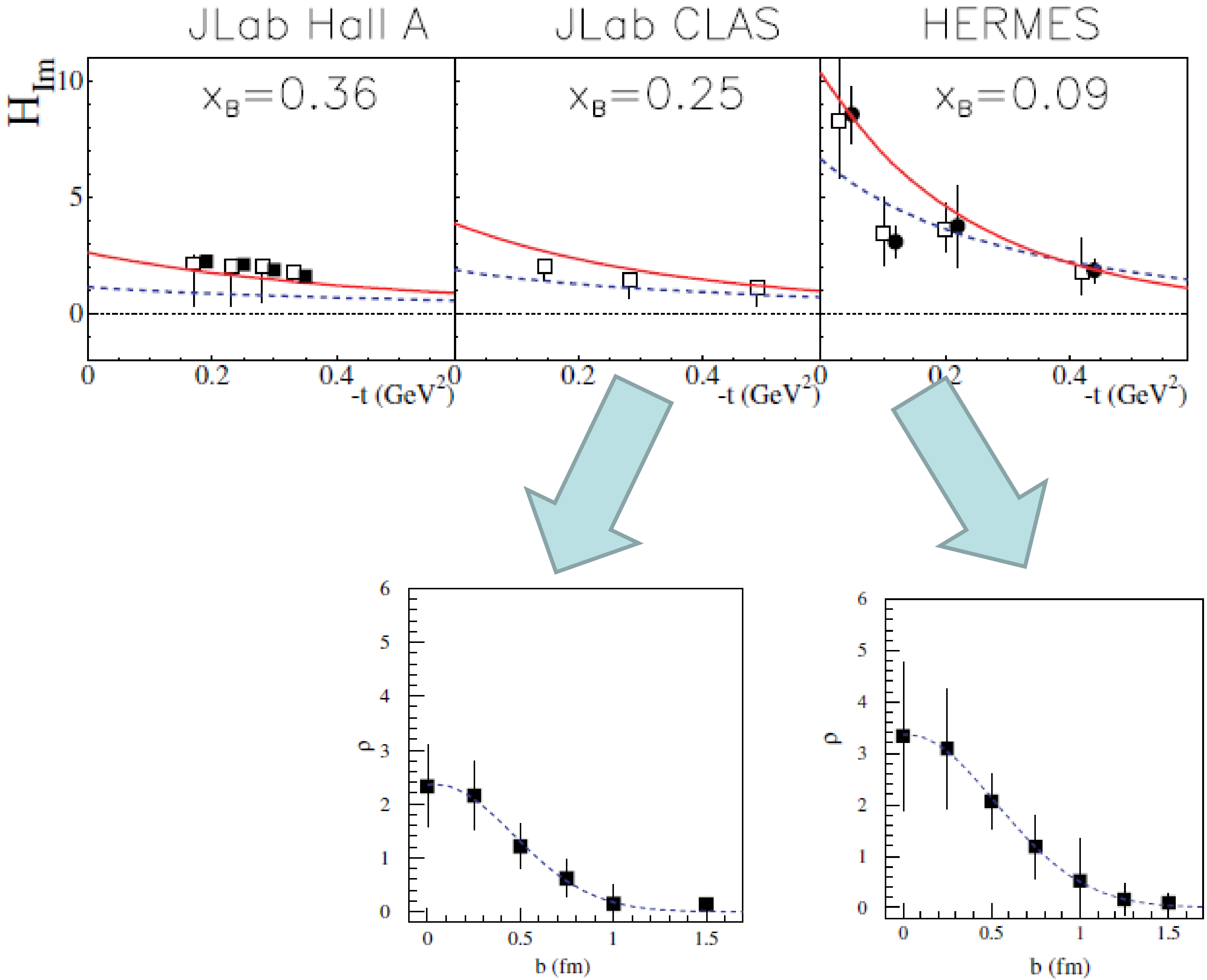
Applying a (model-dependent) “deskewing” factor:

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

and, in a first approach, neglecting the sea contribution

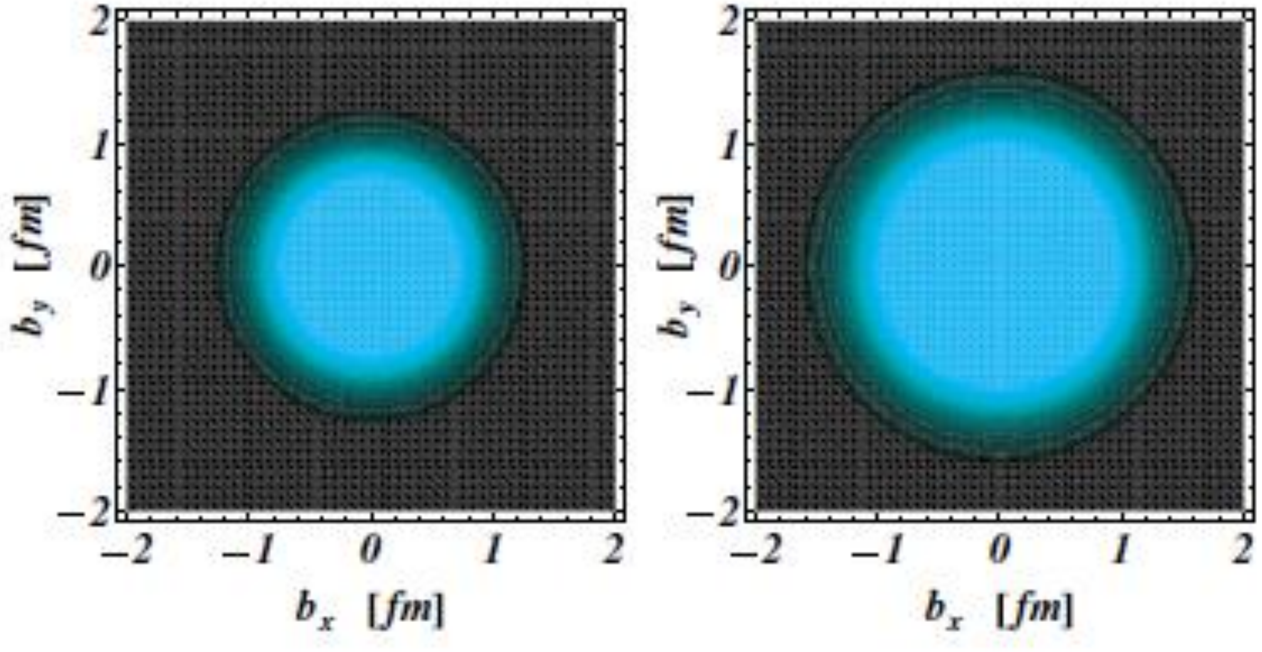


'Deskewing' factor $H(\xi, 0, t)/H(\xi, \xi, t)$ as a function of $-t$ for the VGG model (red curves), the GK model (blue curves) and the dual model (black curves). The solid curves correspond to $x_B = 0.1$ (HERMES kinematics) and the dashed ones to $x_B = 0.25$ (CLAS kinematics).

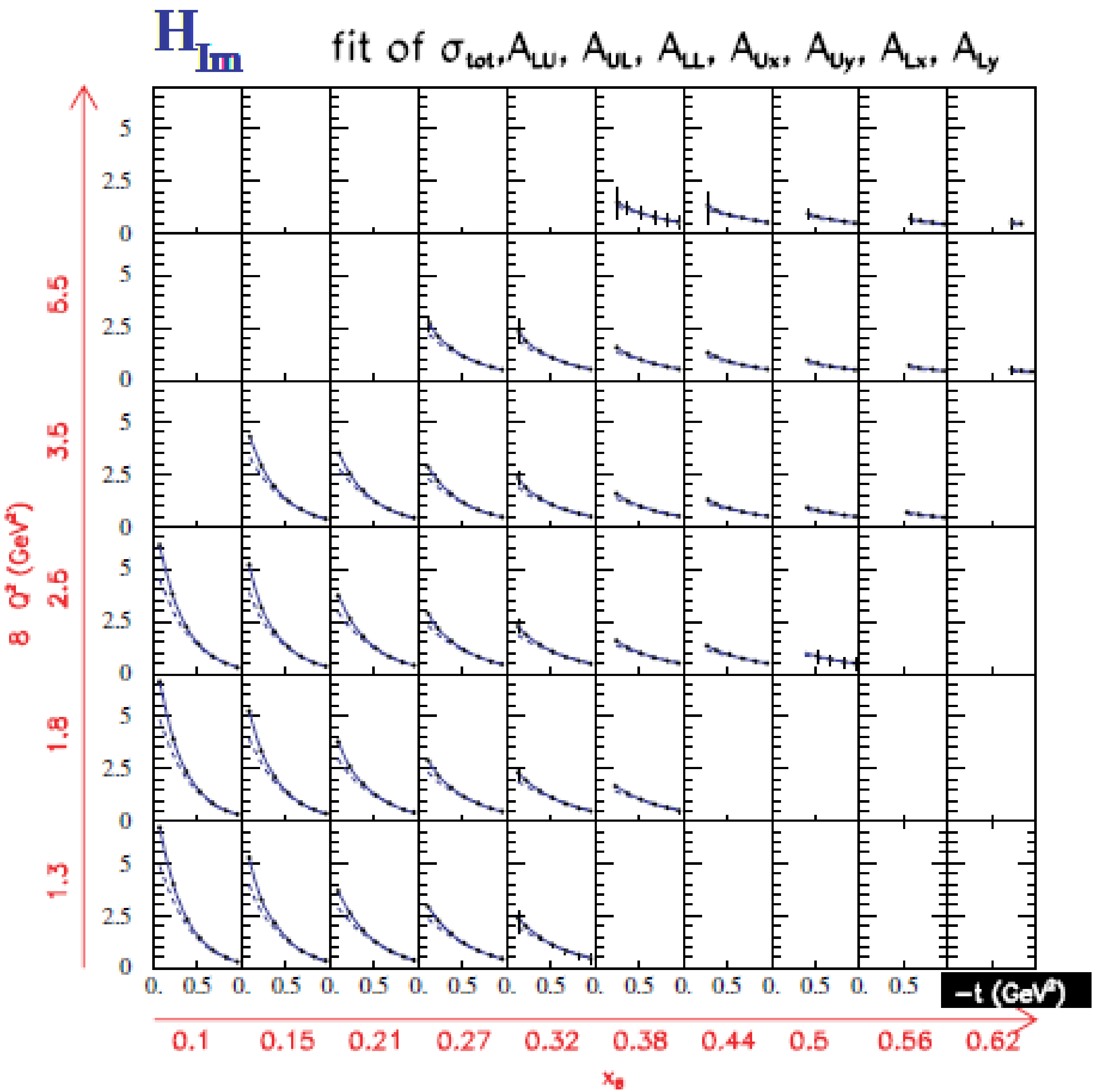


JLab Hall A
JLab CLAS
HERMES
H_{Im}
$x_B=0.36$
$x_B=0.25$
$x_B=0.09$
-t (GeV^2)
ρ
b (fm)

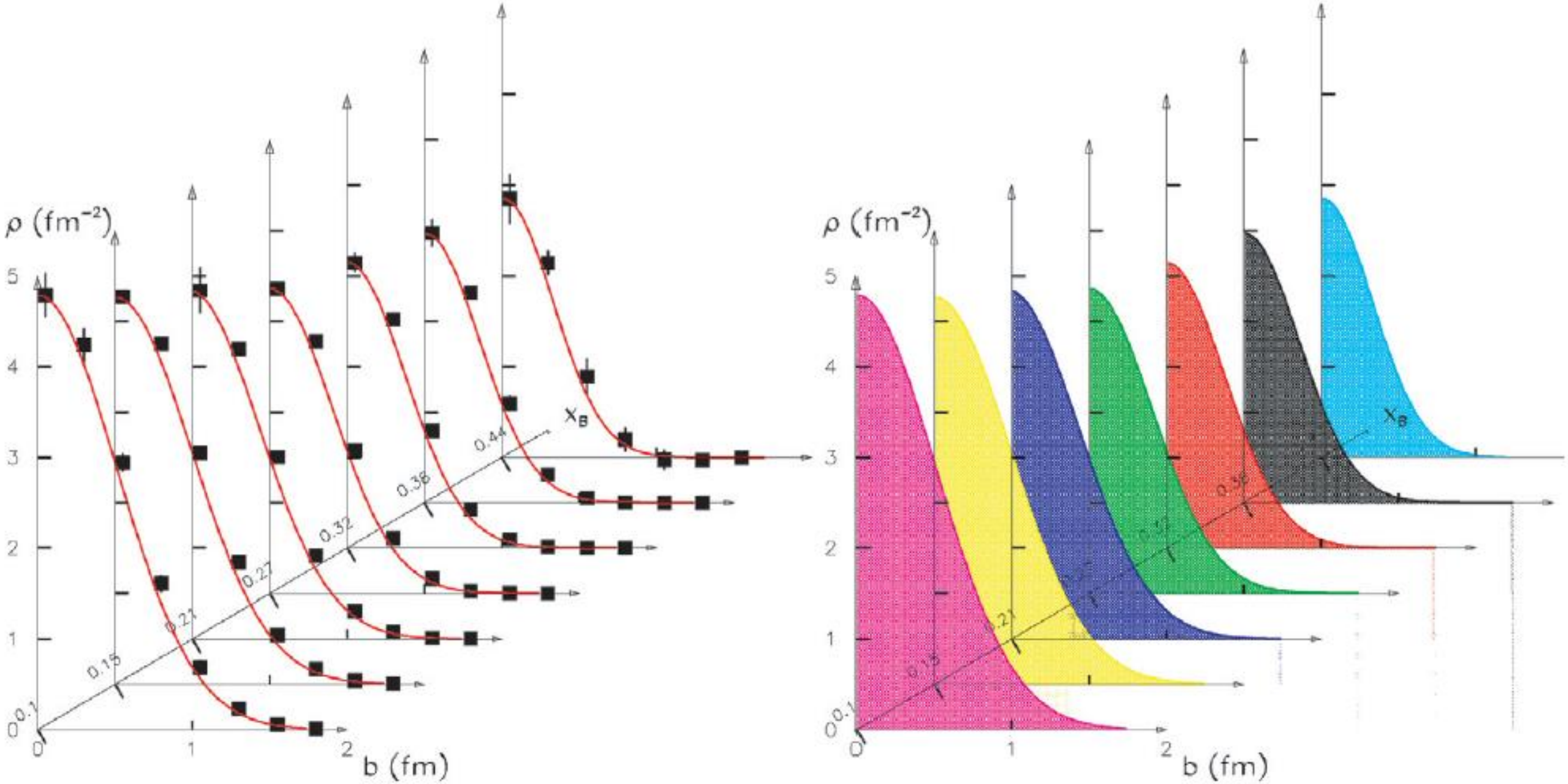
x_B=0.25 x_B=0.09

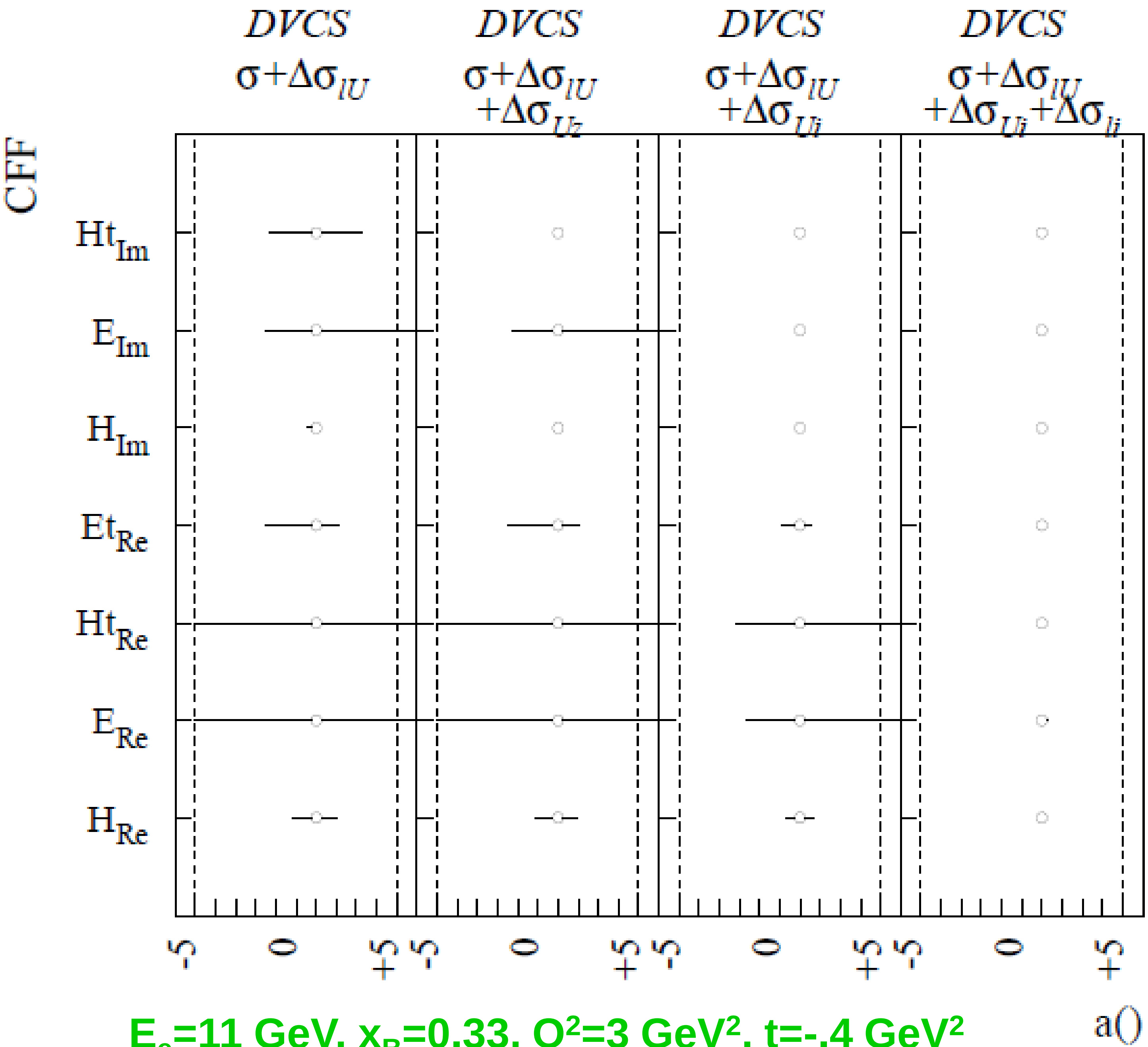


Projections for CLAS12 for H_{Im}

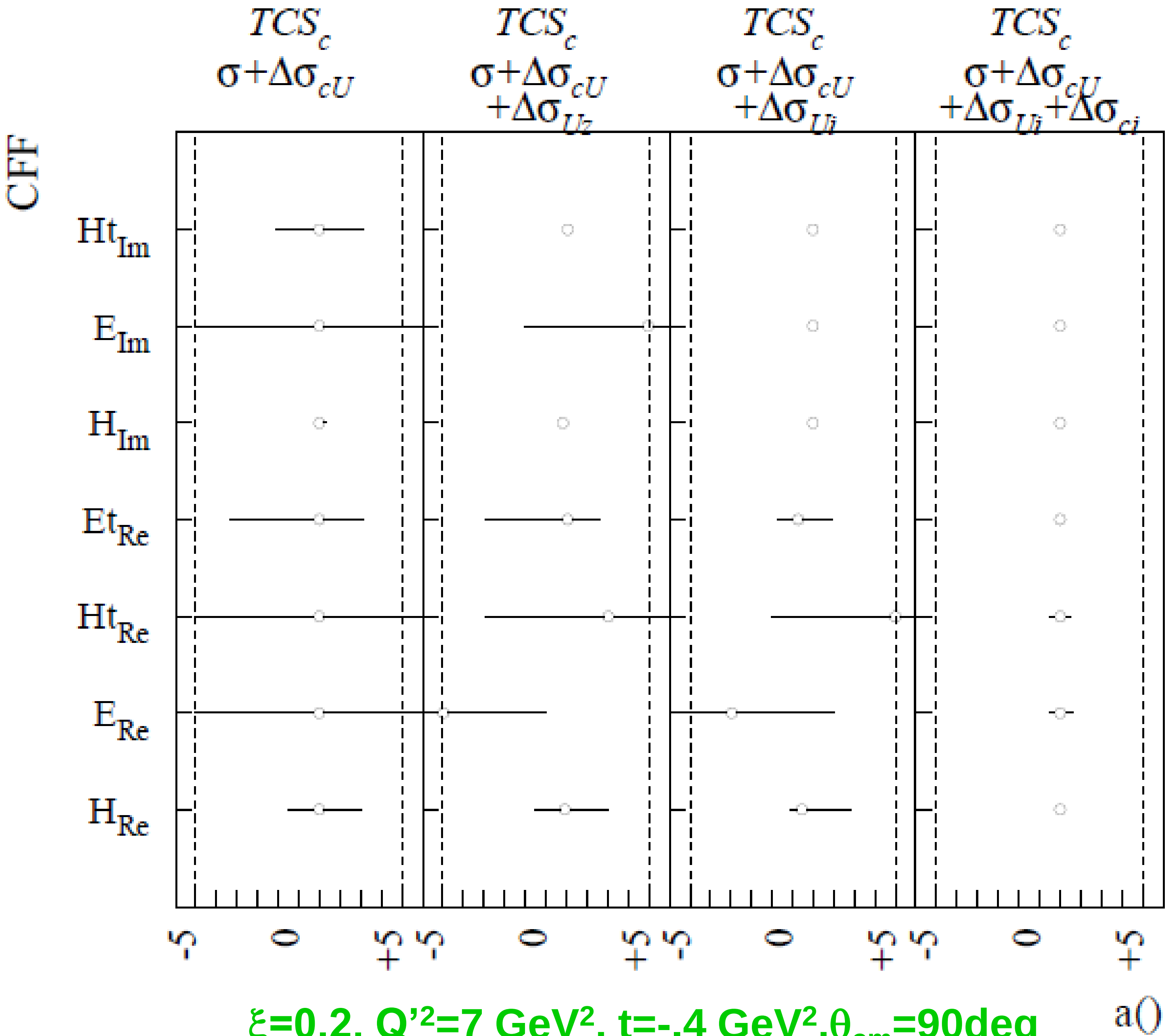


Corresponding spatial densities

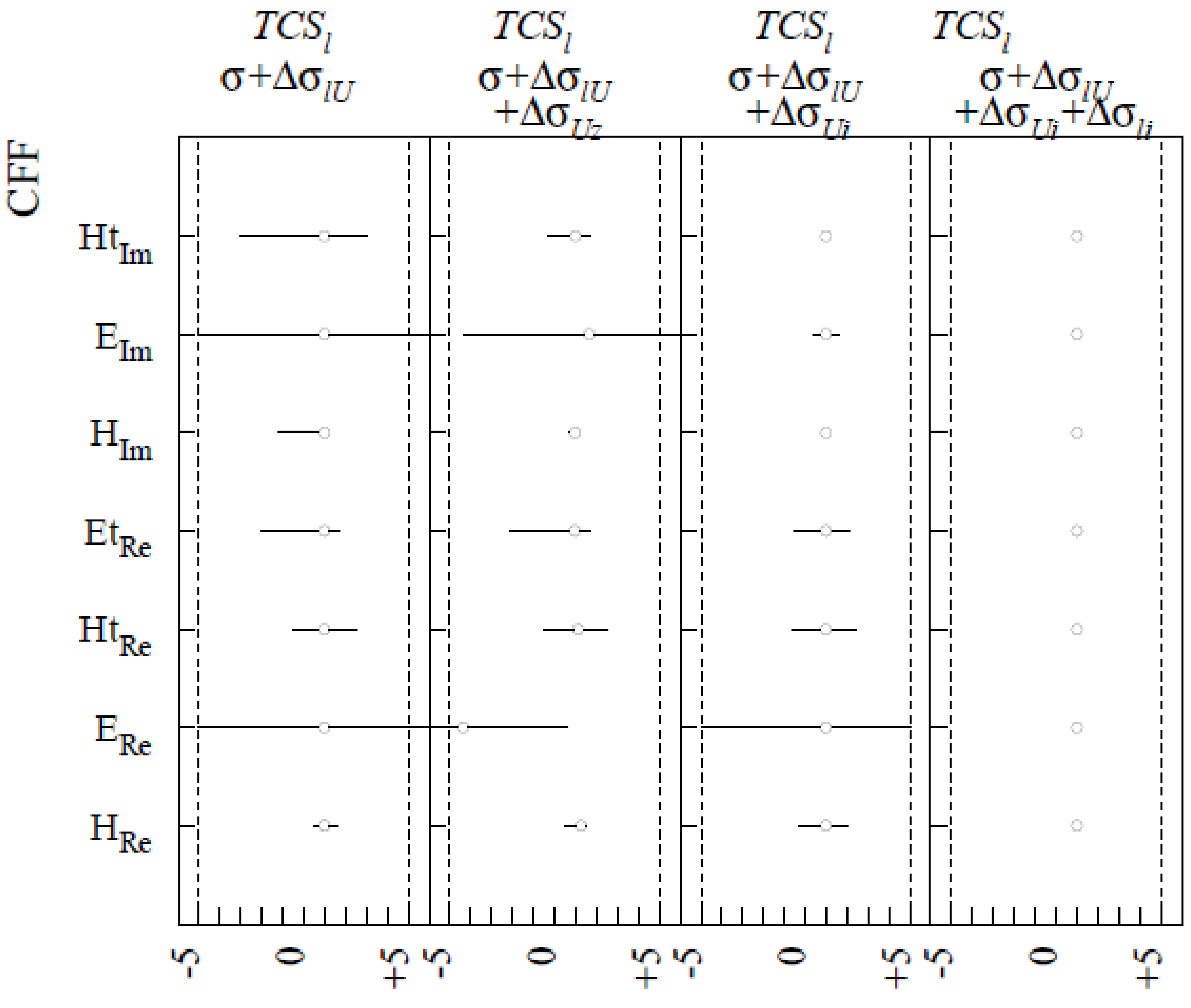




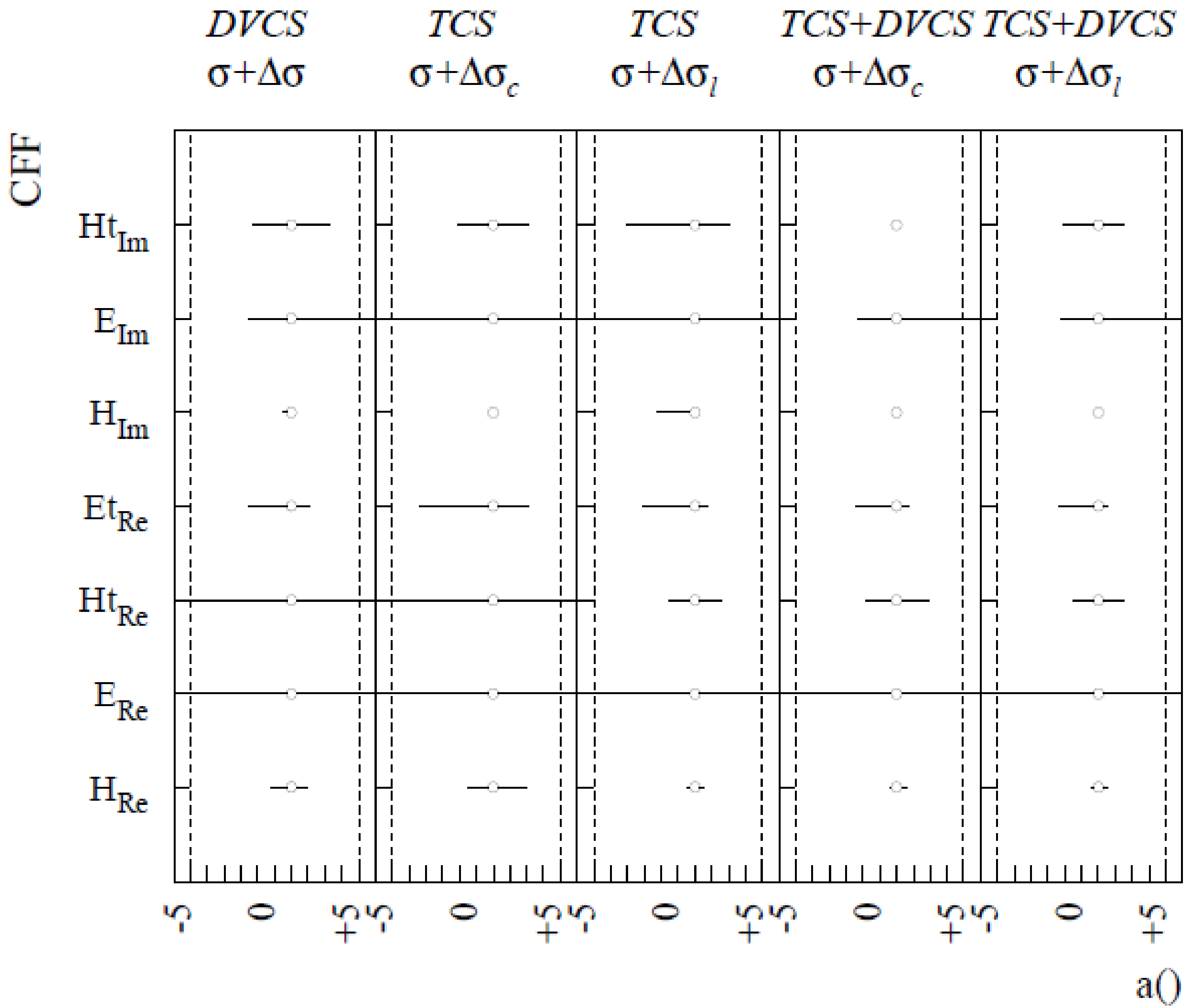
E_e=11 GeV, x_B=0.33, Q^2=3 GeV^2, t=-.4 GeV^2



ξ=0.2, Q'^{2}=7 GeV^2, t=-.4 GeV^2,θ$_{cm}$=90deg



ξ=0.2, Q'^2=7 GeV^2, t=-.4 GeV^2,θ_{cm}=90deg



DVCS
σ+Δσ
TCS
σ+Δσ_c
TCS
σ+Δσ_l
TCS+DVCS
σ+Δσ_c
TCS+DVCS
σ+Δσ_l
CFF
Ht_Im
E_Im
H_Im
Et_Re
Ht_Re
E_Re
H_Re
-5
0
+5
a()

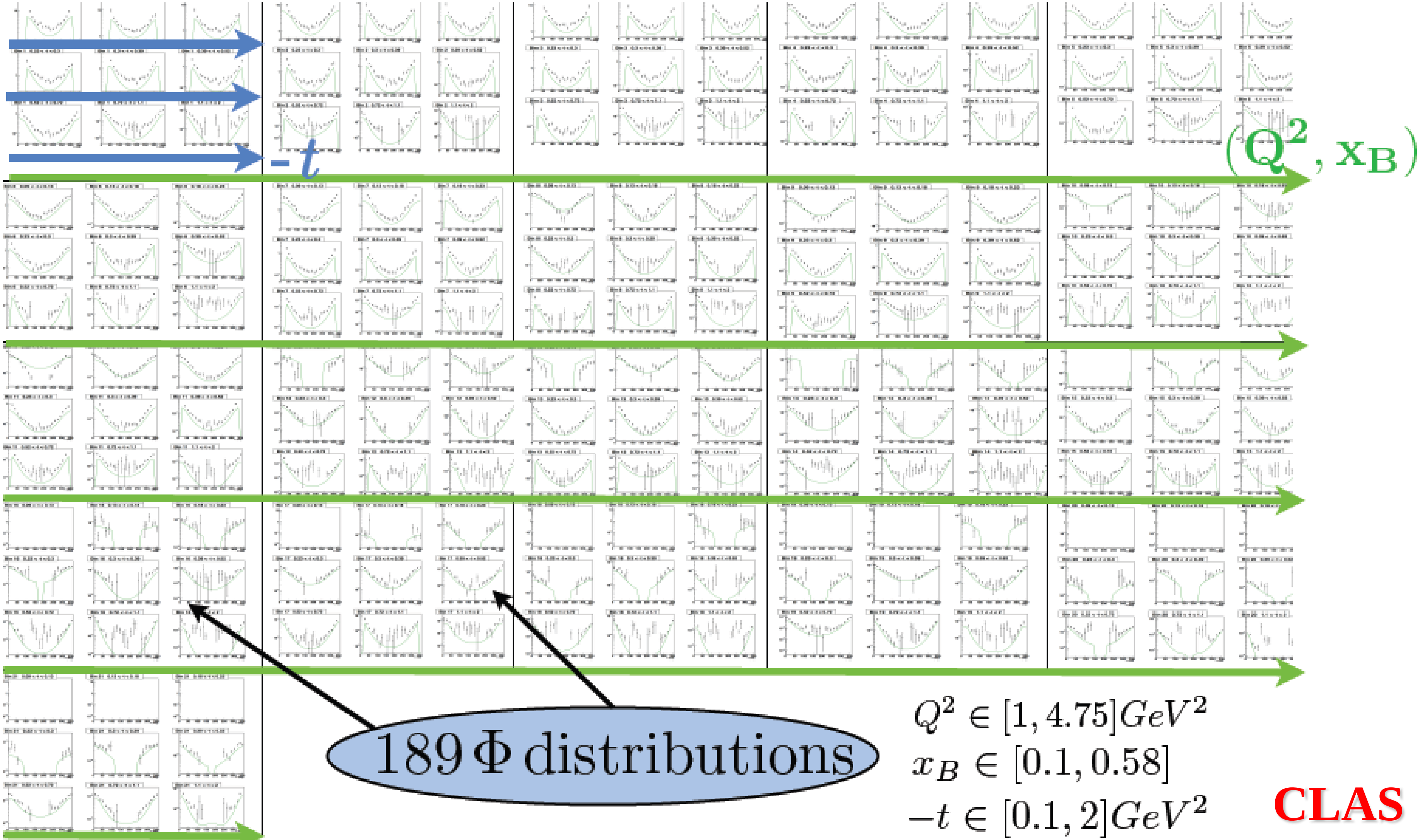
- **GPDs contain a wealth of information on nucleon structure and dynamics: space-momentum quark correlation, orbital momentum, pion cloud, pressure forces within the nucleon,…**

- **They are complicated functions of 3 variables x,ξ,t , depend on quark flavor, correction to leading-twist formalism,…: extraction of GPDs from precise data and numerous observables, global fitting, model inputs,…**

- **First new insights on nucleon structure already emerging from current data with new fitting algorithms**

- **Large flow of new observables and data expected soon (JLab6,JLab12,COMPASS) will allow a precise nucleon tomography in the valence region**

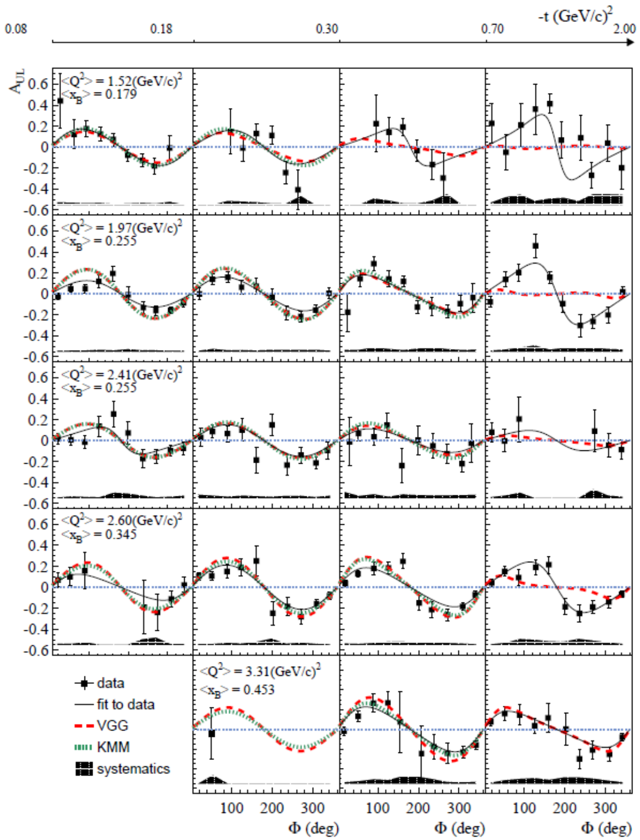
DVCS differential cross section



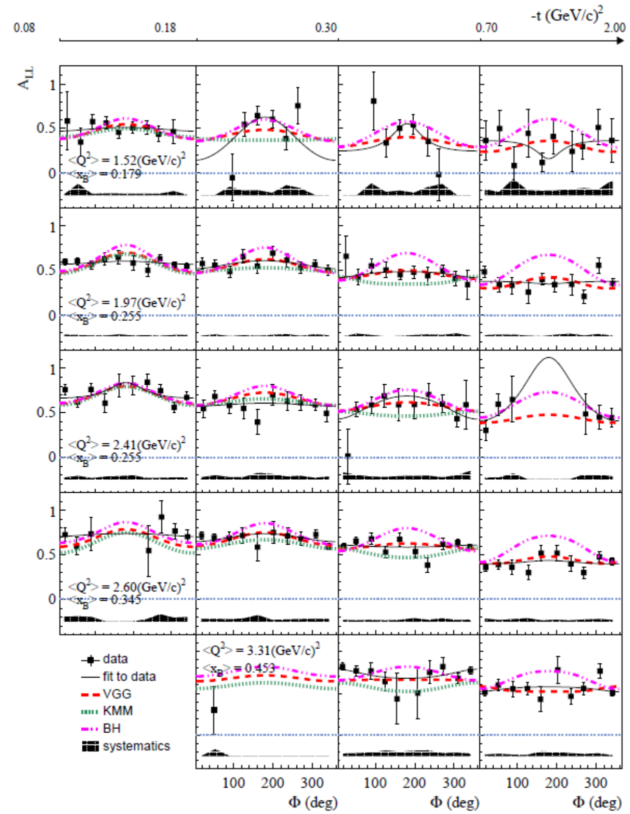
$Q^2 \in [1, 4.75] GeV^2$
$x_B \in [0.1, 0.58]$
$-t \in [0.1, 2] GeV^2$

CLAS
(courtesy H.S. Jo)

To be published in 2014



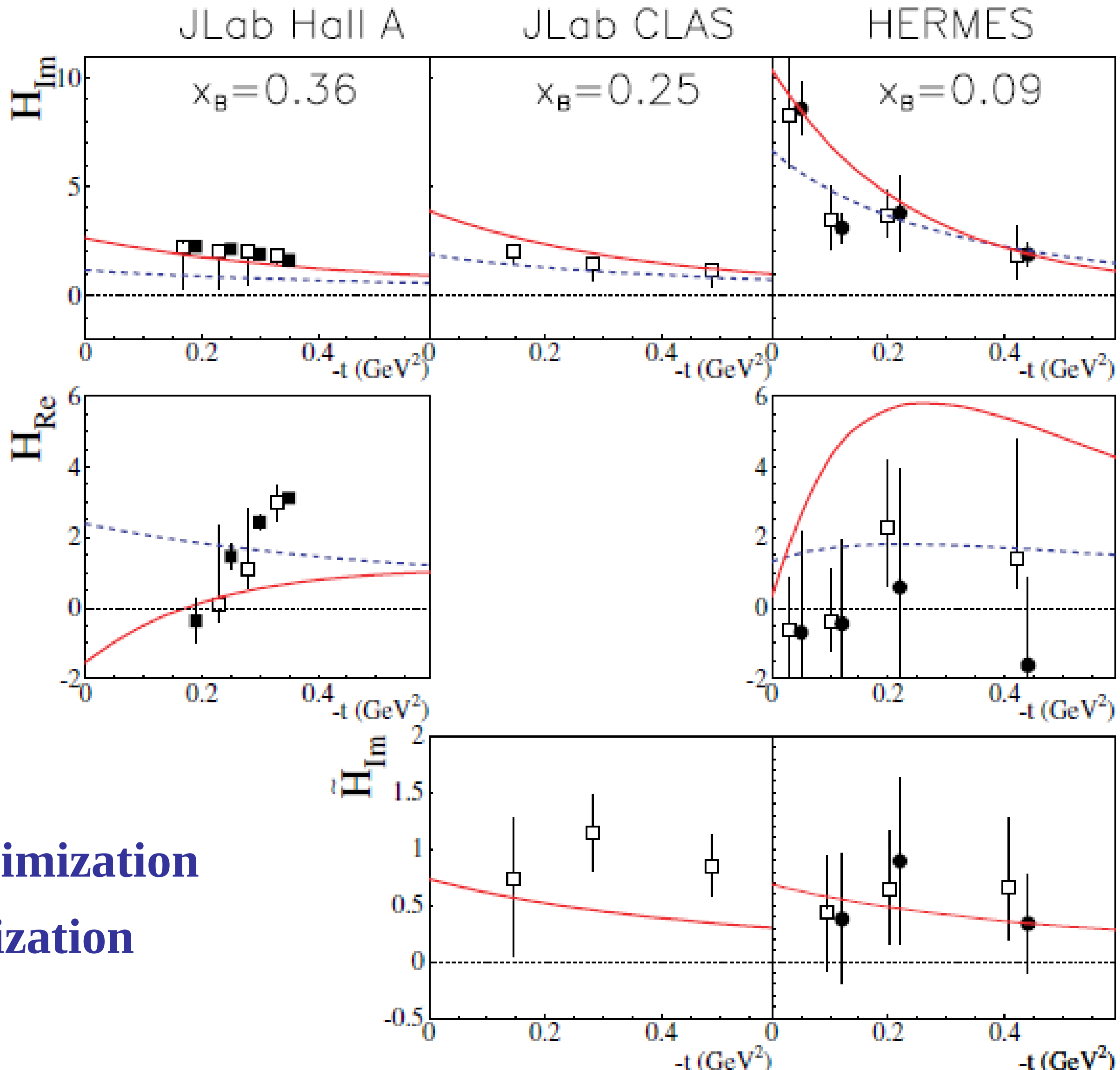
Long. target spin asym.



Double beam-target spin asym.

CLAS
(courtesy S. Niccolai)

To be published in 2014



□ χ^2 minimization

● linearization

VGG model

KM10 model/fit

■ Moutarde 10 model/fit

Other approach:

Assume a functionnal shape and fit some parameters

***D. Mueller & K. Kumericki**
***H. Moutarde**
***VGG by the HERMES and n-DVCS Hall A coll.**

(slide from K. Kumericki, Photons11)

$$\Im\mathrm{m}\mathcal{H}(\xi,t) = \pi\left[\frac{4}{9}H^{u_{\rm val}}(\xi,\xi,t) + \frac{1}{9}H^{d_{\rm val}}(\xi,\xi,t) + \frac{2}{9}H^{\rm sea}(\xi,\xi,t)\right]$$

- Valence quarks model:

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

- Fixed: n (from PDFs), $\alpha(t)$ (eff. Regge), p (counting rules)

$$\alpha^{\rm val}(t) = 0.43 + 0.85\, t/\mathrm{GeV}^2 \quad (\rho,\, \omega)$$

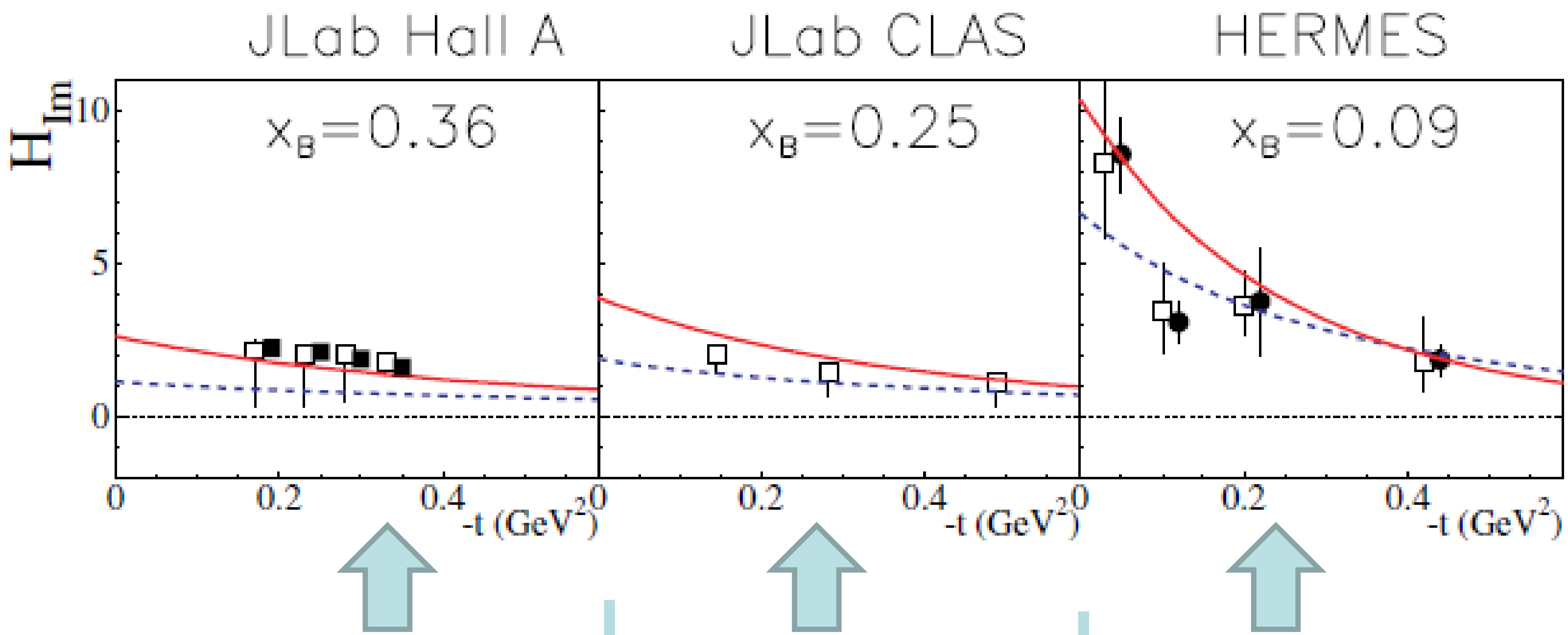
- Sea partons modelled in conformal moment space.

- $\Re\mathrm{e}\mathcal{H}$ determined by dispersion relations

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

- Typical set of free parameters:

$M_0^{\rm sea}$, $s_{\rm sea}$, s_G	sea[1] quarks and gluons H
$r^{\rm val}$, $M^{\rm val}$, $b^{\rm val}$	valence H
C, M_C	subtraction constant (H, E)
$(\tilde{r}^{\rm val}, \tilde{M}^{\rm val}, \tilde{b}^{\rm val})$	valence $\tilde{H}$ (if needed)



unpol.sec.eff. + **beam pol.sec.eff.**

beam spin asym. + **long. pol. tar. asym**

beam charge asym. + **beam spin asym** + …

□ χ^2 **minimization**

● **linearization**

■ **Moutarde 10 model/fit**

VGG model (red solid line)

KM10 model/fit (blue dashed line)