Extraction of the Compton Form Factor $\mathcal{H}$ from recent DVCS measurements at JLab

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(Phys. Rev. **D79**, 094021 (2009))

Compton Form Factors.

At leading twist, DVCS cross sections are described by 4 **complex** functions.

- Example : GPD H

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

- Integration yields **real** and **imaginary** parts to H :

$$Re\mathcal{H} = \mathcal{P} \int_{-1}^{+1} dx \, H(x,\xi,t) \left(\frac{1}{\xi - x} - \frac{1}{\xi + x} \right)$$

$$Im\mathcal{H} = \pi \Big(H(\xi,\xi,t) - H(-\xi,\xi,t) \Big)$$

- Relation between $Im\mathcal{H}$ and $Re\mathcal{H}$ **weakly constrained** by dispersion relations. See however

K. Kumericki and D. Müller, arXiv:0904.0458

G. Goldstein and S. Liuti, arXiv:0908.2215

Selected JLab data : recent DVCS measurements.

Fine kinematic binning and large kinematic coverage.

Hall A : helicity-dependent and independent cross sections

C. Muñoz Camacho et al., Phys. Rev. Lett. **97**, 262002 (2006)

- 12 bins : 1 value of x_B, 3 values of Q^2 and 4 values of t.
- Each kinematic bin contains 24 ϕ-bins.
- Statistical uncertainties :
  - helicity-dependent : at least 20 %
  - helicity-independent : $\simeq$ 5 %

Hall B : Beam Spin Asymmetries

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

- 62 bins : 5 value of x_B, 4 values of Q^2 and 5 values of t.
- Each kinematic bin contains (at most) 12 ϕ-bins.
- Statistical uncertainties : $\simeq$ 25 %

Analytic $ep \to ep\gamma$ cross sections.

Interference between Bethe-Heitler and VCS processes treated exactly.

Example : DVCS helicity-dependent cross section at twist 2

- BMK formalism :

$$C_1 \ \sin \ \phi \ Im \ \left(\mathcal{H} + \frac{x_B}{2 - x_B}\left(1 + \frac{F_2}{F_1}\right)\tilde{\mathcal{H}} - \frac{t}{4M^2}\frac{F_2}{F_1}\mathcal{E}\right)$$

A.V. Belitsky, D. Mueller and A. Kirchner
Nucl. Phys. **B629**, 323 (2002)

- GV formalism :

$$C_2 \ \sin\phi \ Im\left(\mathcal{H} + \ c_{\mathcal{E}} \ \ \mathcal{E} + \ c_{\tilde{\mathcal{H}}} \ \ \tilde{\mathcal{H}} + \ c_{\tilde{\mathcal{E}}} \ \ \tilde{\mathcal{E}}\right)$$

P.A.M. Guichon and M. Vanderhaeghen, unpublished

Analytic $ep \to ep\gamma$ cross sections.

Interference between Bethe-Heitler and VCS processes treated exactly.

Example : DVCS helicity-dependent cross section at twist 2

- BMK formalism : coefficients do not depend on Q^2

$$C_1 \;\sin\;\phi\; Im\;\left(\mathcal{H} + \frac{x_B}{2 - x_B}\left(1 + \frac{F_2}{F_1}\right)\tilde{\mathcal{H}} - \frac{t}{4M^2}\frac{F_2}{F_1}\mathcal{E}\right)$$

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- GV formalism : coefficients depend on Q^2

$$C_2\;\sin\phi\; Im\left(\mathcal{H} + \underbrace{c_{\mathcal{E}}}_{20\ \%}\,\mathcal{E} + \underbrace{c_{\tilde{\mathcal{H}}}}_{20\ \%}\,\tilde{\mathcal{H}} + \underbrace{c_{\tilde{\mathcal{E}}}}_{30\ \%}\,\tilde{\mathcal{E}}\right)$$

P.A.M. Guichon and M. Vanderhaeghen, unpublished

Main assumptions.

Expectation : extraction of $\mathcal{H}$ with $\geq$ 40 % total uncertainty.

- **Twist 2 accuracy**
  - Early Q^2-scaling was observed in Hall A.

    C. Muñoz Camacho et al.
    Phys. Rev. Lett. **97**, 262002 (2006)
  - Test of twist 3 contribution left for future work.
- ***H*-dominance**
  - Dramatically decreases the number of degrees of freedom in the fits.
  - Theoretical expectations : systematic error between 20 and 50 %.
  - Systematic error $\lesssim$ 25 % from direct test of hypothesis with VGG model.

Local fits.

Fits on each kinematic bin to twist 2 expressions.

- Keep bins with $\frac{|t|}{Q^2} < \frac{1}{2}$.
- Low model dependence (H-dominance, twist 2).
- But fits may still be underconstrained.
- **Estimation** of systematic errors caused by ***H*-dominance hypothesis** by fitting data with subdominant GPDs set to 0 or to their VGG value.

Global fit.

Fit to a parametrization from the dual model.

- DVCS cross sections depend on singlet combination H_+ :

$$H_+(x, \xi, t, Q^2) = H(x, \xi, t, Q^2) - H(-x, \xi, t, Q^2)$$

- Dual model parametrization of H_+ :

$$2 \sum_{n=0}^{\infty} \sum_{l=0}^{n+1} B_{nl}(t, Q^2) \theta \left(1 - \frac{x^2}{\xi^2}\right) \left(1 - \frac{x^2}{\xi^2}\right) C_{2n+1}^{\frac{3}{2}} \left(\frac{x}{\xi}\right) \quad P_{2l} \left(\frac{1}{\xi}\right)$$

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- Dual model parametrization of H_+ :

$$2 \sum_{n=0}^{\infty} \sum_{l=0}^{n+1} B_{nl}(t, Q^2) \underbrace{\theta \left(1 - \frac{x^2}{\xi^2}\right)}_{\text{Support : Resummed}} \left(1 - \frac{x^2}{\xi^2}\right) C_{2n+1}^{\frac{3}{2}}\left(\frac{x}{\xi}\right) \quad P_{2l}\left(\frac{1}{\xi}\right)$$

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- Dual model parametrization of H_+ :

$$2 \sum_{n=0}^{\infty} \sum_{l=0}^{n+1} \underbrace{B_{nl}(t, Q^2)}_{\text{Model t-dep.}} \theta \left(1 - \frac{x^2}{\xi^2}\right) \left(1 - \frac{x^2}{\xi^2}\right) C_{2n+1}^{\frac{3}{2}} \left(\frac{x}{\xi}\right) \quad P_{2l} \left(\frac{1}{\xi}\right)$$

with $B_{nl}(t, Q^2) = \left(\ln \frac{Q_0^2}{\Lambda^2} / \ln \frac{Q^2}{\Lambda^2}\right)^{\frac{\gamma_p}{\beta_0}} B_{nl}(t, Q_0^2)$.

Global fit.

Fit to a parametrization from the dual model.

- DVCS cross sections depend on singlet combination H_+ :

$$H_+(x,\xi,t,Q^2) = H(x,\xi,t,Q^2) - H(-x,\xi,t,Q^2)$$

- Dual model parametrization of H_+ :

$$2\sum_{n=0}^{N}\sum_{l=0}^{n+1} \underbrace{B_{nl}(t,Q^2)}_{\text{Model t-dep.}} \theta\left(1-\frac{x^2}{\xi^2}\right)\left(1-\frac{x^2}{\xi^2}\right) C_{2n+1}^{\frac{3}{2}}\left(\frac{x}{\xi}\right) \quad P_{2l}\left(\frac{1}{\xi}\right)$$

with $B_{nl}(t,Q^2) = \left(\ln\frac{Q_0^2}{\Lambda^2} / \ln\frac{Q^2}{\Lambda^2}\right)^{\frac{\gamma_p}{\beta_0}} \quad \frac{a_{nl}}{1+b_{nl}(t-t_0)^2}$.

- Non-trivial correlation between x and t.
- a_{nl} and b_{nl} are fitted. t_0 is chosen prior to the fits.

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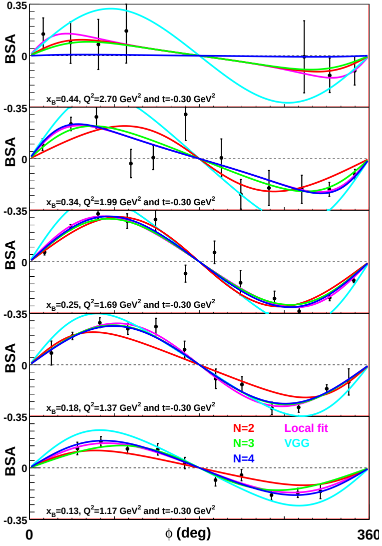
Global fit.

Iterative fitting procedure and systematic uncertainties.

- Keep bins with $\frac{|t|}{Q^2} < \frac{1}{2}$ (1001 ϕ-bins fitted).
- $\frac{N(N+3)}{2}$ fitted coefficients for a given truncation N.
  - Restrict to low values of N.
  - 10, 18 and 28-parameter fits for $N = 2$, 3 and 4.
  - **Estimation** of the **truncation error** by comparison of the results of these 3 fits.
- Iterative fitting procedure to handle large number of parameters.
- **Estimation** of systematic errors caused by *H*-**dominance hypothesis** by fitting data with subdominant GPDs set to 0 or to their VGG value.
- Purpose : smooth parametrization of data. **No extrapolation** outside the domain of the fit.

Effect of the truncation of the series.

Hall B data.



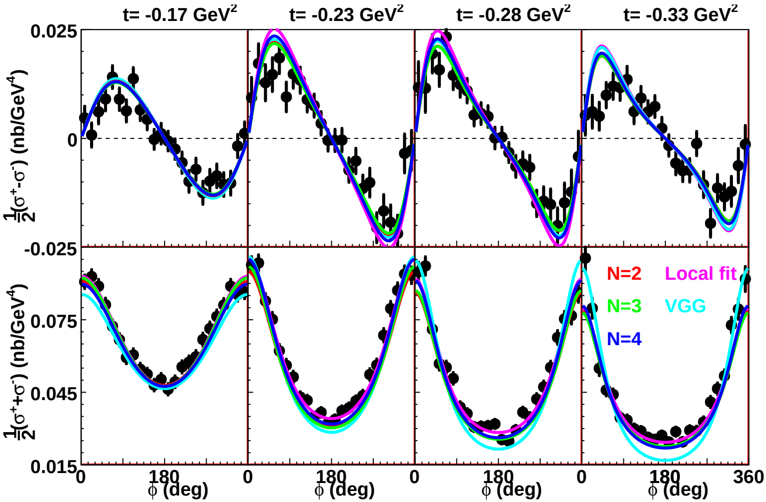
- 3 global fits qualitatively similar :

N	$\chi^2/\mathrm{d.o.f.}$
2	1.73
3	1.61
4	1.78

- No differences on Hall A data (next slide).
- N=2 fails to reproduce BSAs at small ξ.
- N=3 always good and close to local fits.
- N=4 is uncontrolled at large ξ.

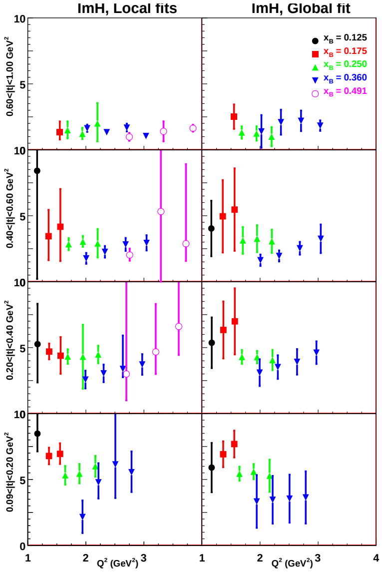
Effect of the truncation of the series.

Hall A data.



$Im\mathcal{H}$ on Hall B kinematics.

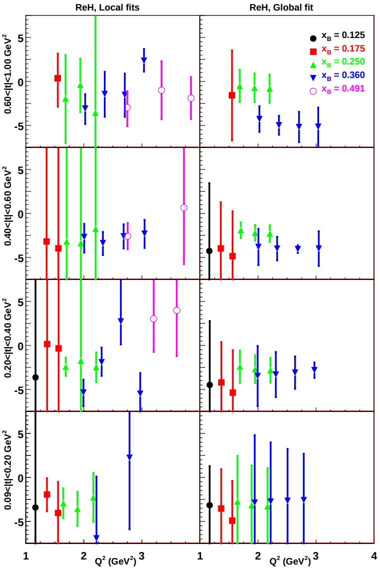
Q^2-dependence.



- Compatible results of local and global fits : **strong consistency check**.
  - local fits : fluctuations but model-independent.
  - global fit : no fluctuations but truncation effect.
- **Realistic estimation of systematic uncertainties** :
  - Comparable accuracy from local and global fits.
  - Accuracy in agreement with expectations.
- Restricted kinematic region **suitable for GPD-analysis**.

$Re\mathcal{H}$ on Hall B kinematics.

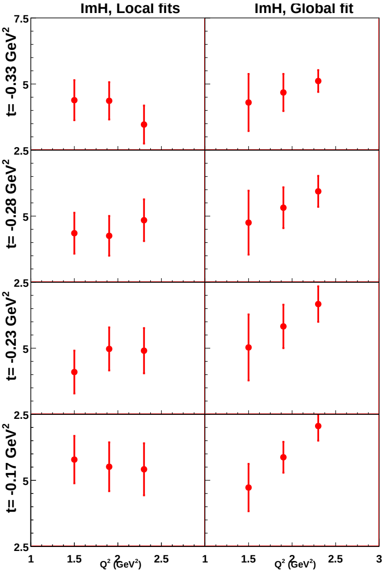
Q^2-dependence.



- **Large fluctuations in** $Re\mathcal{H}$ from local fits. Global fit is smoother.
- Unreliable extraction of $Im\mathcal{H}$ or $Re\mathcal{H}$ at large ξ.
- $Re\mathcal{H}$ **weakly constrained**.

$Im\mathcal{H}$ on Hall A kinematics.

t-dependence.



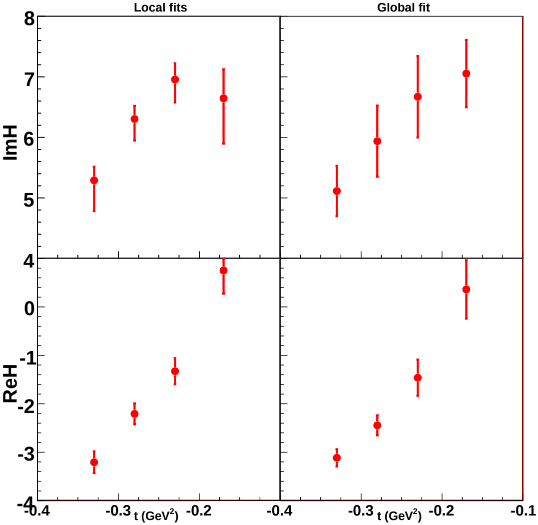
- Good agreement between results of local and global fits but...
- Discrepancy seems to be larger at small $|t|$!
- Sizeable scaling deviation for t = -0.17 GeV^2.
- Noticeable deviations if

$$\xi = x_B \frac{1 + \frac{t}{2Q^2}}{2 - x_B + \frac{x_B t}{Q^2}} \rightarrow \frac{x_B}{2 - x_B}$$

- Call for a **twist 3 analysis** !

$Im\mathcal{H}$ and $Re\mathcal{H}$ on Hall A kinematics.

t-dependence.



Comparison with other studies (Hall A data).

Several approaches : BMK, BMK + "hot fix", GV, VGG.

- First extraction : BMK formalism without "hot fix".

  C. Muñoz Camacho et al.
  Phys. Rev. Lett. **97**, 262002 (2006)

- Model-dependent prediction. Fit in progress.

  S. Ahmad *et al.*, arXiv:0708.0268

- VGG fitter code.

  M. Guidal, EPJA 37, 319 (2008)

- "Hot fix" : restoration of power suppressed contributions in BMK.

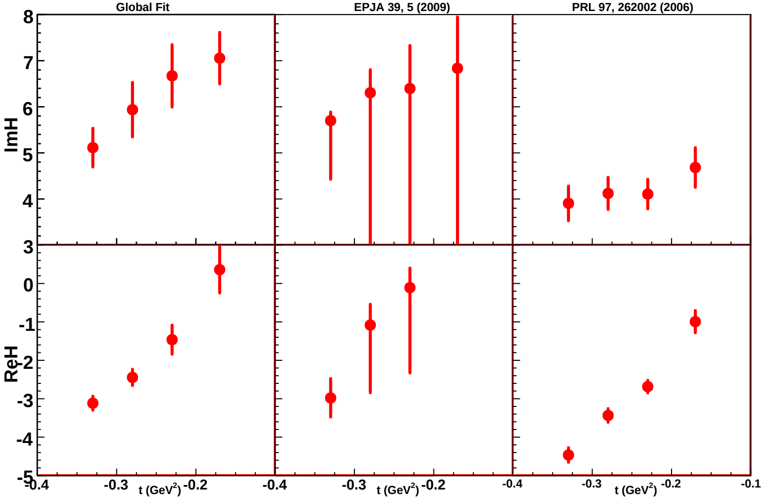
  A. Belitsky and D. Müller, PRD79, 014017 (2009)

- Global fit for unpolarized proton target with BMK + "hot fix".

  K. Kumericki and D. Müller, arXiv:0904.0458

Comparison with previous studies (Hall A data).

Significant deviations to a BMK extraction without "hot fix".



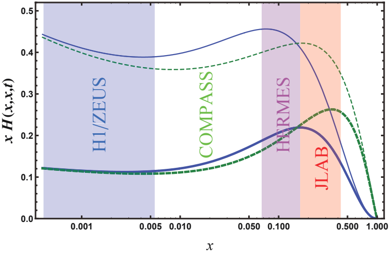
- Agreement with model-independent approach at twist 2.

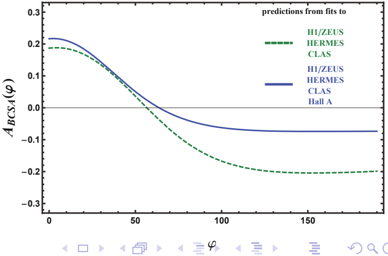
Comparison with previous studies (Hall A data).

Agreement with a BMK extraction with "hot fix".

- Extractions in agreement on Hall A and Hermes kinematics.

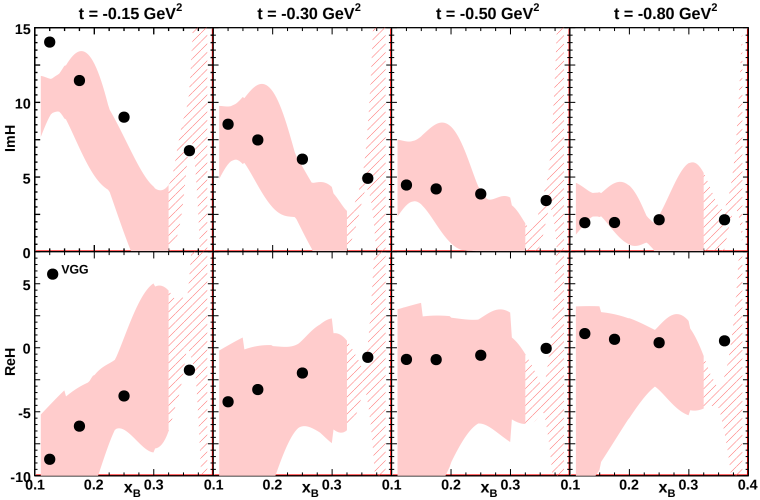
  M. Guidal and H. M., arXiv0905.1220, to appear in EPJA
- Comparison still to be done on Hall B kinematics.
- Agreement on qualitative features :
  - $Im\mathcal{H}$ is the best determined quantity.
  - H-dominance is a questionable assumption.





Comparison to the VGG model.

Similar x_B-dependence but loss of information during the extraction.



Conclusions.

Extraction of GPDs from measurements is a challenge to phenomenology.

- JLab DVCS measurements are already a **strong constraint on phenomenological interpretation** and will remain a reference in the near future.
- $Im\mathcal{H}$ extracted **with 20 to 50 % accuracy on a wide kinematic range**.
- Realistic first estimation of systematic errors.
- Plausible **early Q^2-scaling** but twist 3 study necessary.
- Working without H-dominance hypothesis ?
- More generally, a fitting strategy allowing an extrapolation outside the domain of the extraction is still missing.