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

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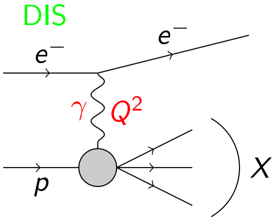
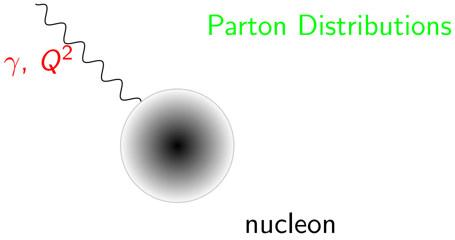
(Phys. Rev. **D79**, 094021 (2009))

(Generalized) Parton Distributions.

From Deep Inelastic Scattering to Deeply Virtual Compton Scattering.





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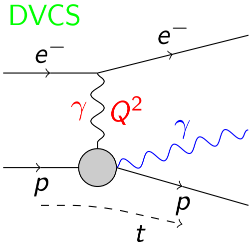

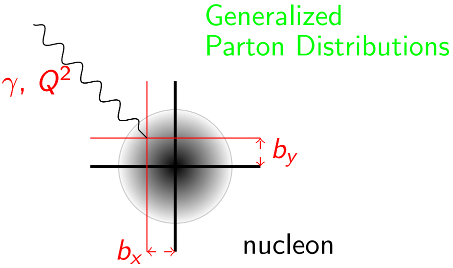

- Correlation of the **longitudinal momentum** and the **transverse position** of the struck quark.

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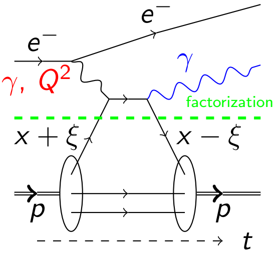

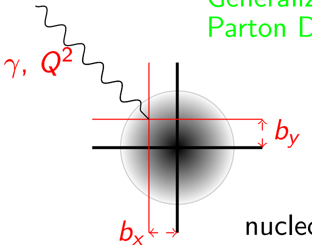

- Correlation of the **longitudinal momentum** and the **transverse position** of the struck quark.
- **3-dimensional** description of the nucleon.
- Insights on :
  - spin structure,
  - energy-momentum structure.

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 :

$$\begin{aligned} Re\mathcal{H} &= \mathcal{P} \int_{-1}^{+1} dx\, H(x, \xi, t) \left(\frac{1}{\xi - x} - \frac{1}{\xi + x} \right) \\ Im\mathcal{H} &= \pi \Big(H(\xi, \xi, t) - H(-\xi, \xi, t) \Big) \end{aligned}$$

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

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 $ep \rightarrow ep\gamma$ 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 ≥ 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_+ :

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

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_+ :

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

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.

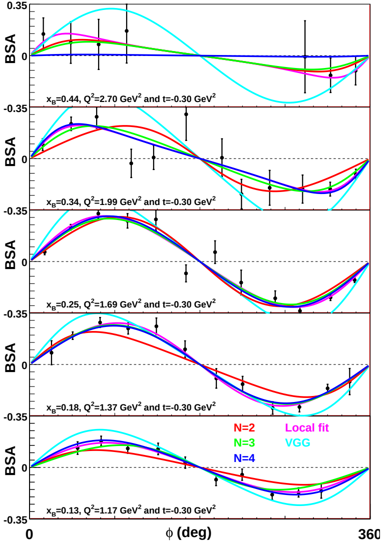
Global fit.

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.



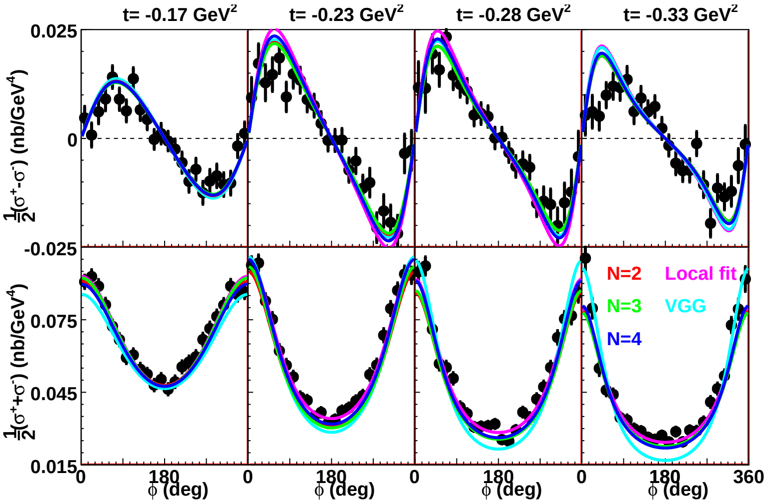
- 3 global fits qualitatively similar :

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.

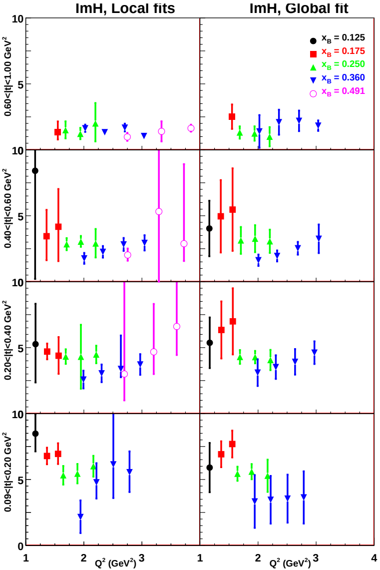
Effect of the truncation of the series.

Hall A data.



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

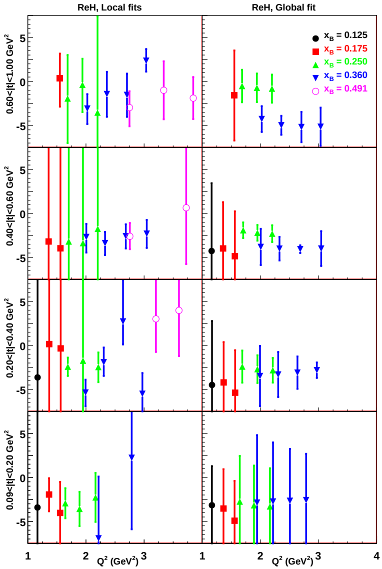
Q^2-dependence.



- 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.

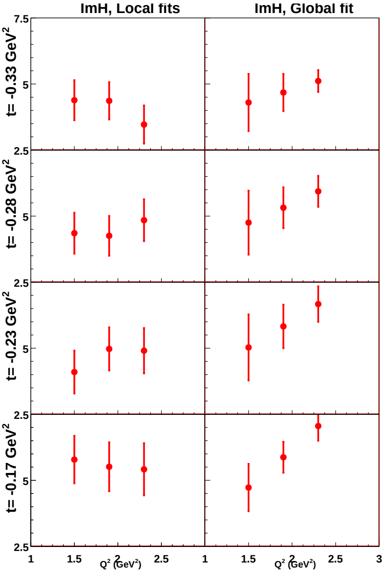
Q^2-dependence.



- **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.



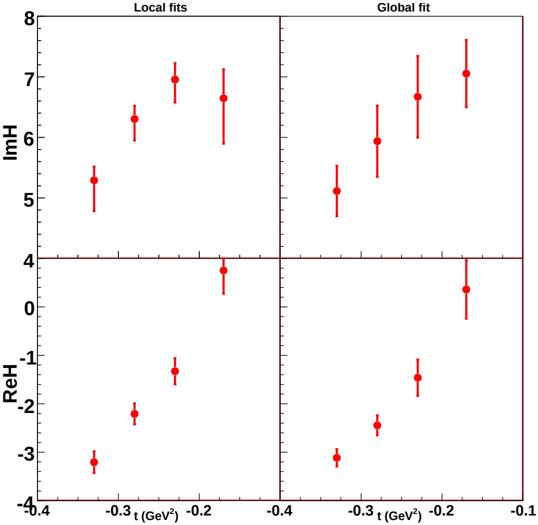
- Good agreement between results of local and global fits but. . .
- Discrepancy seems to be larger at small $|t|$!
- Sizeable scaling deviation for t = -0.17 GeV^2.
- Noticeable deviations if

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

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

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

t-dependence.



Extraction of $\mathcal{H}$ from DVCS

Preliminary analysis
- About GPDs
- Leading twist
- Selected data
- GV formalism
- Assumptions

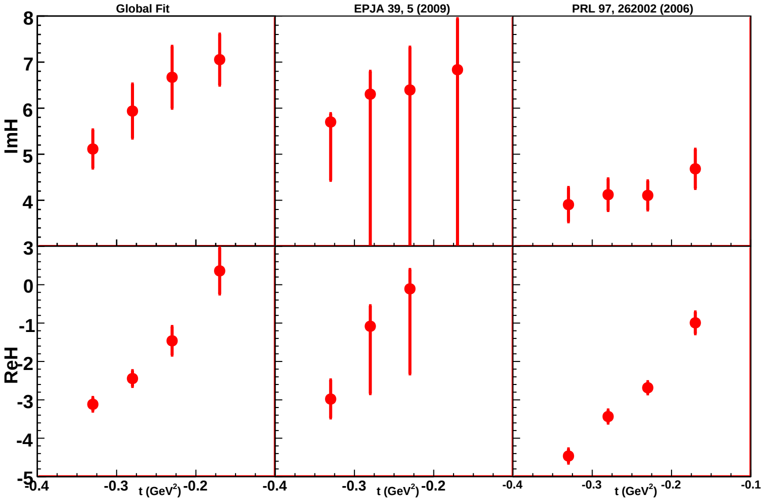
Fitting strategies
- Local fits
- Global fit

Results
- $Im\mathcal{H}$ and $Re\mathcal{H}$
- Discussion

Conclusions

Comparison with previous studies (Hall A data).

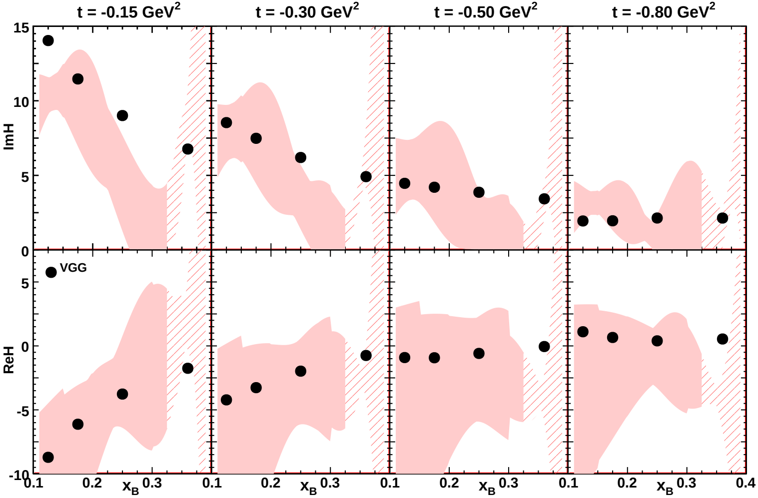
Significant deviations to an extraction with the BMK formalism.



- Agreement with model-independent approach at twist 2.

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.