New results on Deeply Virtual Compton Scattering at HERA

Frank Ellinghaus

University of Colorado

for the H1, ZEUS and HERMES–Collaborations

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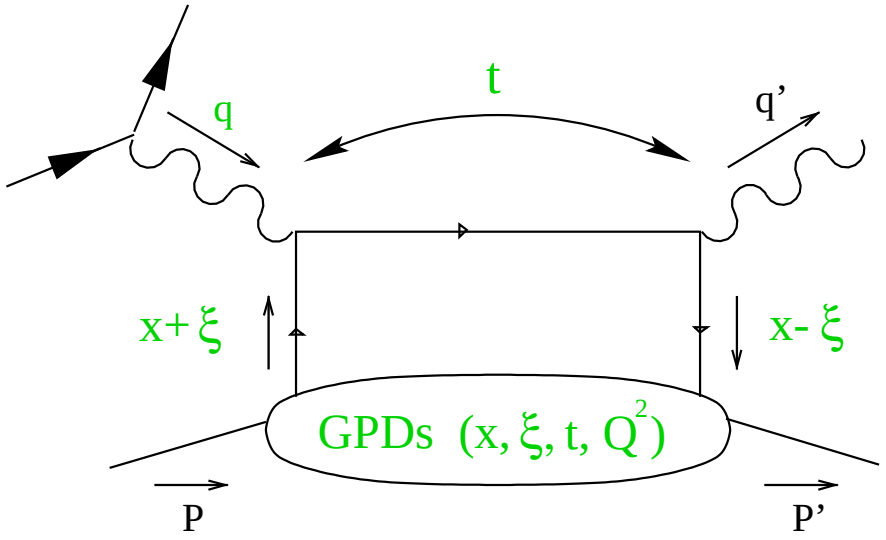
- Deeply Virtual Compton Scattering (DVCS)
- Generalized Parton Distributions (GPDs)
- DVCS Measurements at HERA
  - Cross Section Measurements at H1 and ZEUS
  - Azimuthal Asymmetries at HERMES
- Summary and Outlook

Deeply Virtual Compton Scattering (DVCS)

Simplest (hard exclusive) process: $\gamma^* p \to p' \gamma$

Deeply virtual photon generated by lepton scattering
$\Rightarrow e p \to e' p' \gamma$ (DVCS)



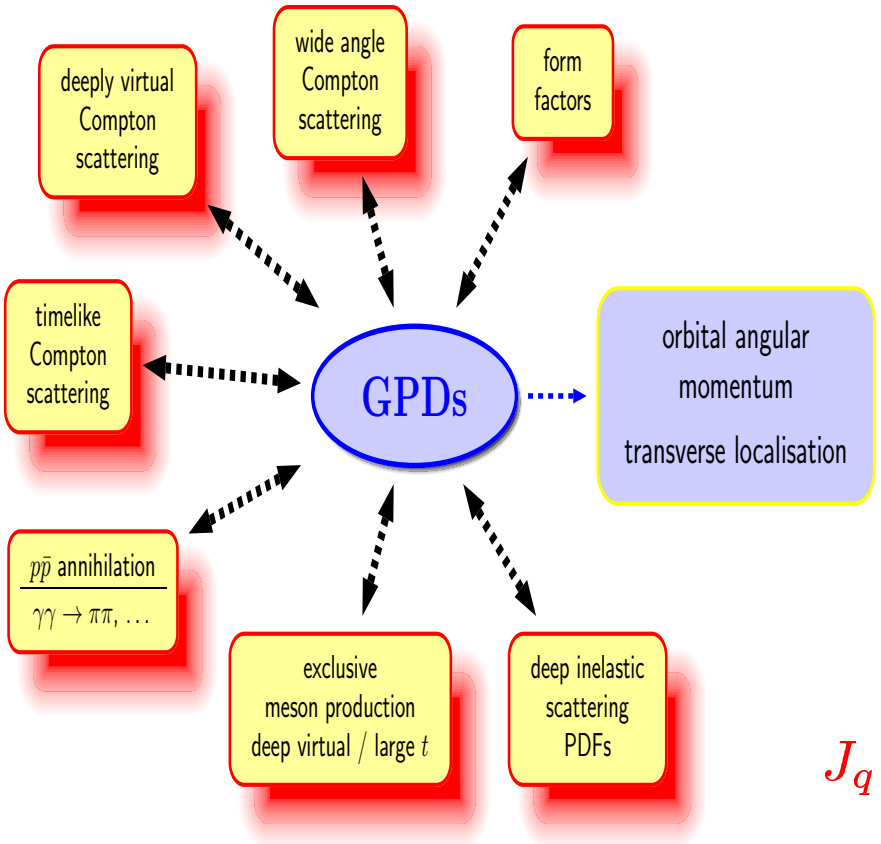
- Longitudinal momentum fractions:
  $x \in [-1, 1]$ (not accessible)
  $\xi \approx x_B/(2 - x_B)$
- $t = (q - q')^2$
  ($\gamma^* \to \gamma$ Momentum transfer)
- $Q^2 = -q^2$

DVCS-Amplitudes can be expressed in terms of GPDs

GPDs accessible in exclusive reactions $\Rightarrow$ Use the simplest one ...

GPDs $\longleftrightarrow$ Nucleon Structure

GPDs $(H, \tilde{H}, E, \tilde{E})$: Parameterization of the nucleon structure



Related to known quantities:

GPDs in the limit $t \to 0$:

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

First moments of GPDs:

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

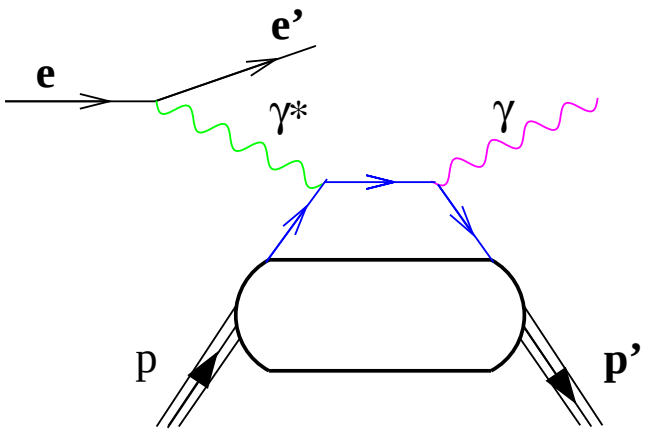
Only access to unknown quantities:

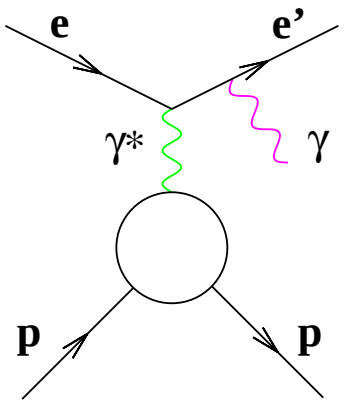
Second moments of GPDs:

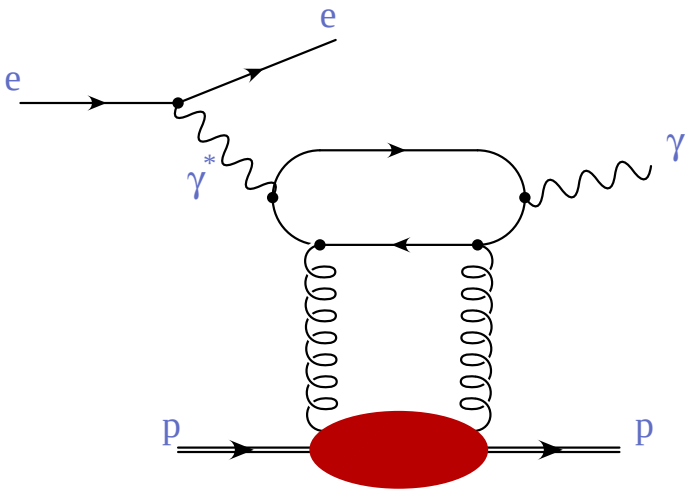
$$J_q = \lim_{t\to 0} \frac{1}{2} \int_{-1}^{1} dx\, x \left[H^q(x,\xi,t) + E^q(x,\xi,t) \right]$$

DVCS–BH Interference

DVCS final state $e + p \to e' + p' + \gamma$ is indistinguishable from the Bethe-Heitler Process (BH) $\to$ Amplitudes add coherently







H1, ZEUS, HERMES, CLAS

H1, ZEUS

Photon-Production cross section:

$$d\sigma \propto |\tau_{\mathrm{DVCS}} + \tau_{\mathrm{BH}}|^2 = |\tau_{\mathrm{DVCS}}|^2 + |\tau_{\mathrm{BH}}|^2 + \underbrace{(\tau^*_{\mathrm{DVCS}}\tau_{\mathrm{BH}} + \tau^*_{\mathrm{BH}}\tau_{\mathrm{DVCS}})}_{I}$$

DVCS Measurements at HERA

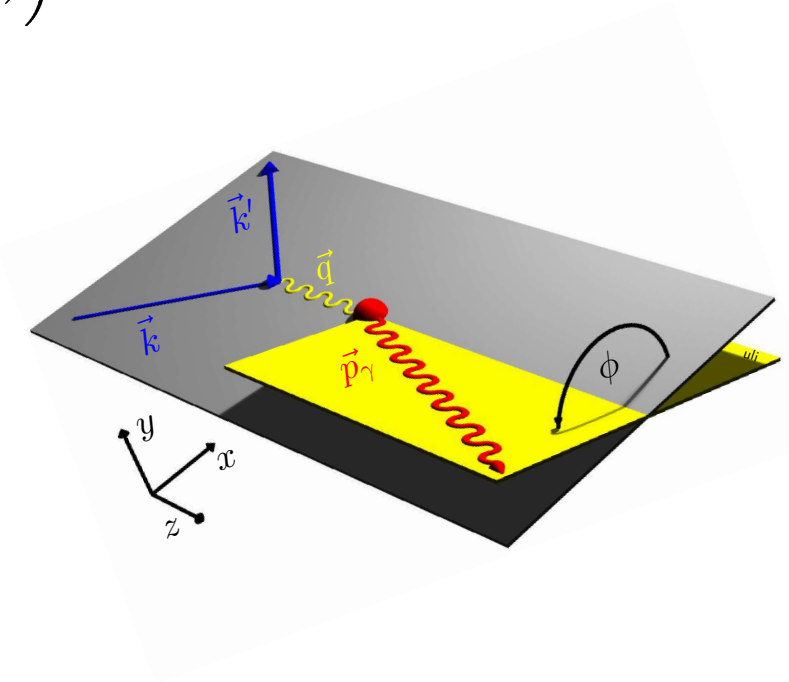
$$d\sigma \propto |\tau_{\mathrm{BH}}|^2 + \underbrace{(\tau^*_{\mathrm{DVCS}}\tau_{\mathrm{BH}} + \tau^*_{\mathrm{BH}}\tau_{\mathrm{DVCS}})}_{I} + |\tau_{\mathrm{DVCS}}|^2$$

$|\tau_{\mathrm{BH}}|^2$ calculable in QED with the knowledge of the form factors

$$I \propto \pm\left(c_0^I + \sum_{n=1}^{3} c_n^I \cos(n\phi) + \lambda \sum_{n=1}^{2} s_n^I \sin(n\phi)\right)$$

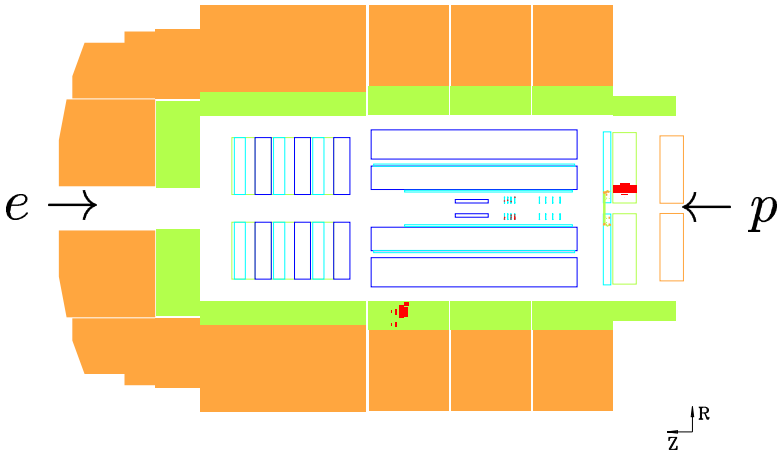
DVCS cross section (H1, ZEUS):
Measurement integrated over ϕ
$\rightarrow I = 0$ (at Twist–2), subtract $|\tau_{\mathrm{BH}}|^2$

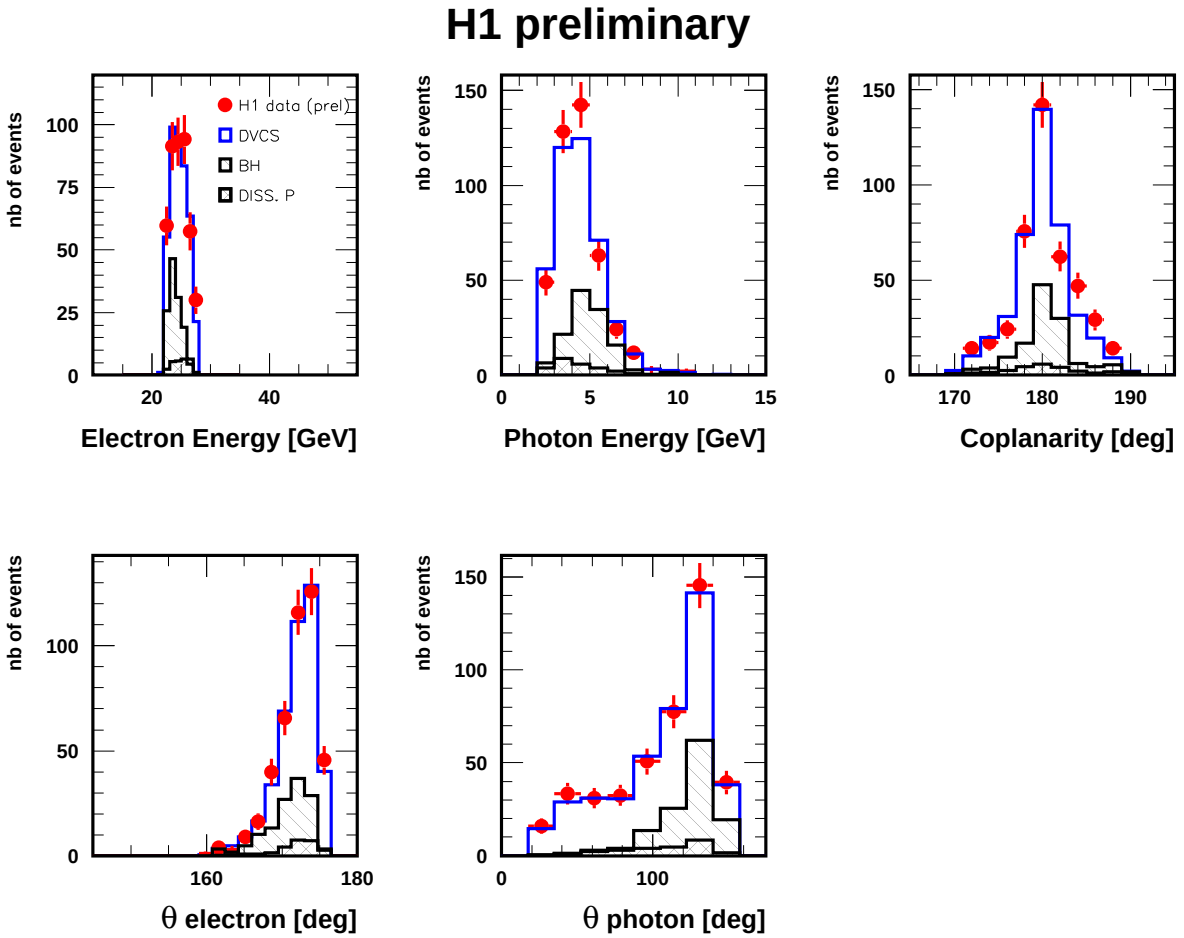
Azimuthal asymmetries (HERMES):
DVCS amplitudes directly accessible via I
(GPDs enter in linear combinations in amplitudes)



DVCS candidate sample

Collider:



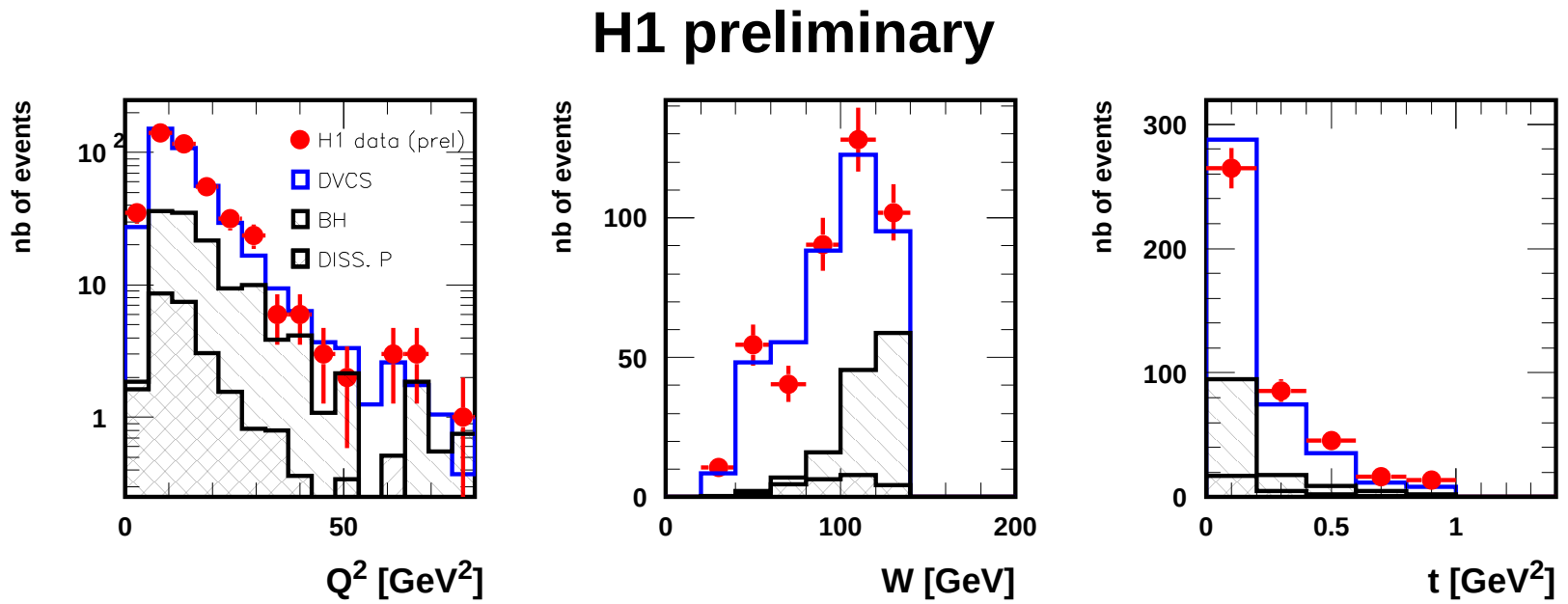


MC: LO Prediction by FFS at $t = t_{min}$

assume e^{bt}

with $b = 7$ GeV^{-2}

Cross Section Extraction



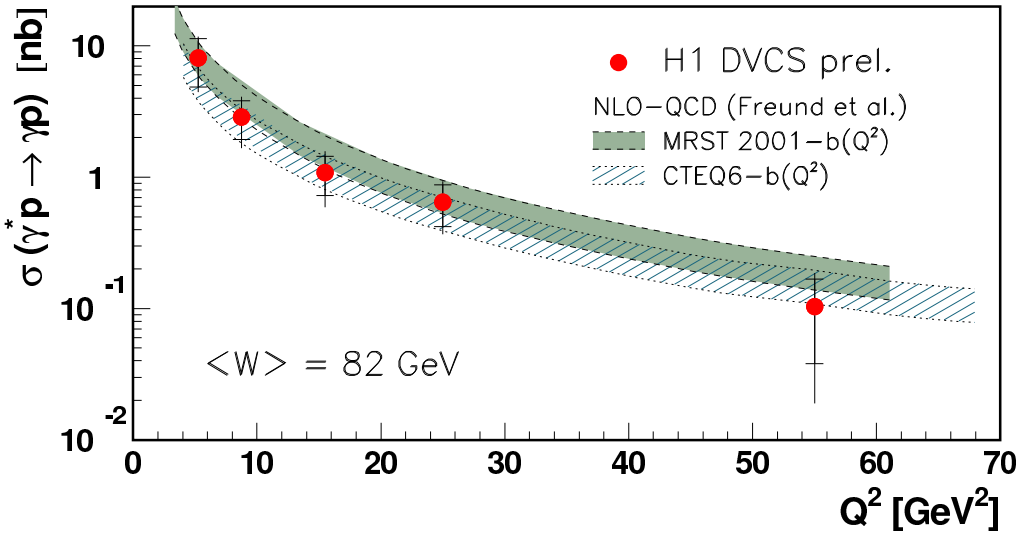
- $ep \to ep\gamma$ Total Cross section extraction:

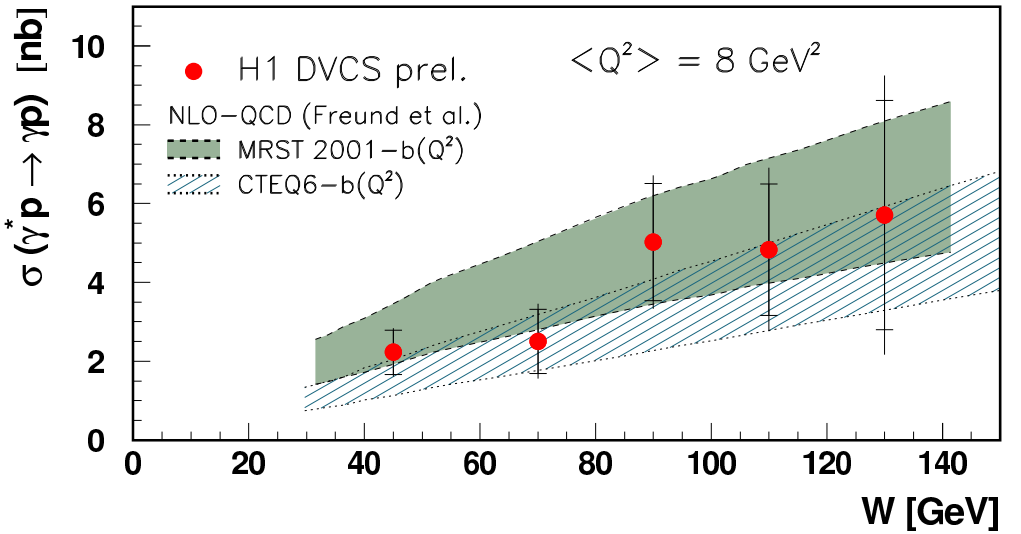
$$\frac{d\sigma_{bin}}{dQ^2} = \frac{N_{bin} - N_{backg.} - N_{diss.p}}{\epsilon\, A\, \Delta\, Q^2\, L}\,(1 + \delta_{rad})$$

- $ep \to ep\gamma$ DVCS Cross section extraction:
  $I \approx 0$, subtract BH

- $\gamma^* p \to p\gamma$ Cross section extraction: photon flux factor $\Rightarrow$

New Preliminary Result





NLO QCD predictions based on GPDs

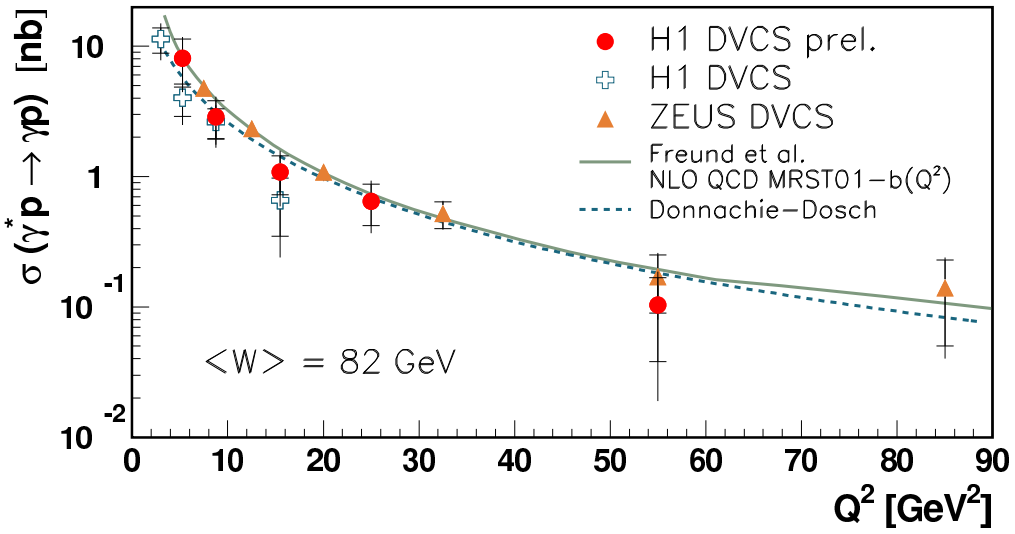
$b = b_0(Q^2)$

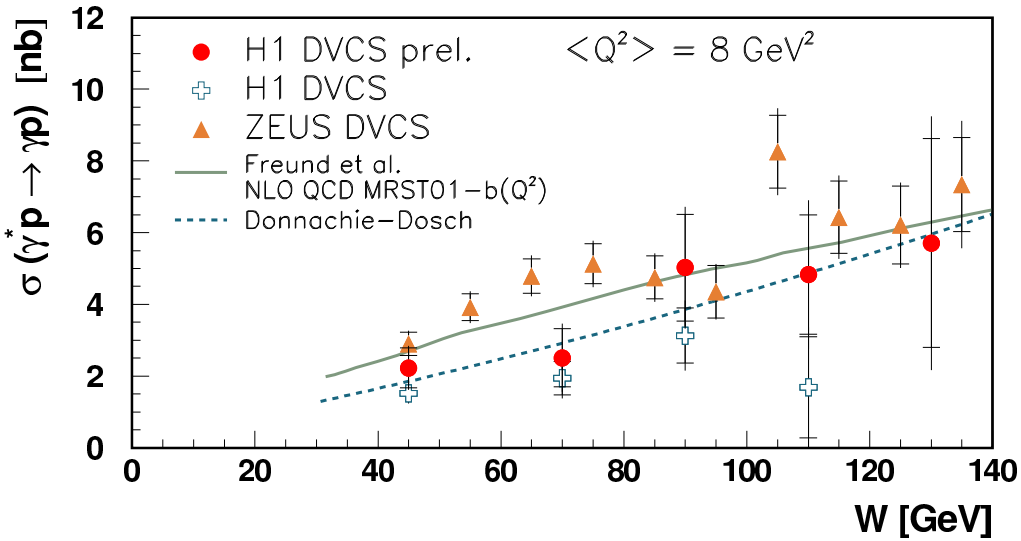
$5 < b_0 < 9$ GeV^{-2}

Models describe data, but normalization uncertainty

$\Rightarrow$ Measure t-dependence

ALL H1 AND ZEUS RESULTS





AT $b = 7$ GEV^{-2}:

COLOR DIPOLE MODEL DD (ALSO FAVART–MACHADO) AND GPD BASED MODEL DESCRIBE THE DATA

W^{δ} FIT:

H1 PREL: 0.98 ± 0.44

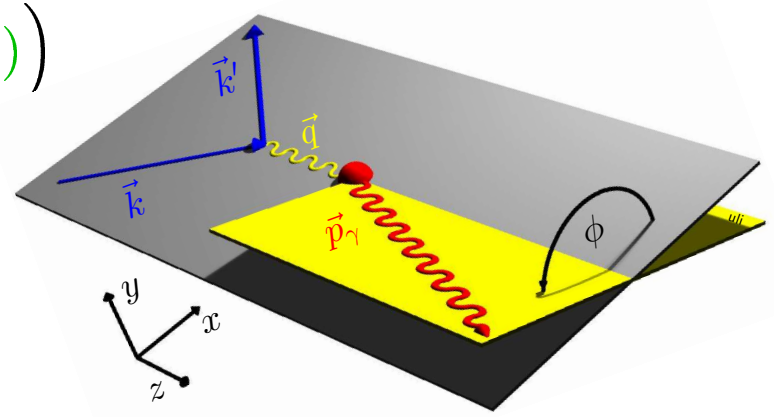
ZEUS e^+: $0.75 \pm 0.15^{+0.08}_{-0.06}$

$\Rightarrow$ INDICATES HARD REGIME

Azimuthal Asymmetries at HERMES

$$d\sigma \propto |\tau_{\mathrm{DVCS}}|^2 + |\tau_{\mathrm{BH}}|^2 + \underbrace{(\tau^*_{\mathrm{DVCS}}\tau_{\mathrm{BH}} + \tau^*_{\mathrm{BH}}\tau_{\mathrm{DVCS}})}_{I}$$

$$I \propto \pm\left(c_0^I + \sum_{n=1}^{3} c_n^I \cos(n\phi) + \lambda \sum_{n=1}^{2} s_n^I \sin(n\phi)\right)$$



Beam–Charge Asymmetry (BCA) and Beam–Spin Asymmetry (BSA) at leading twist:

$$\text{BCA}: \quad d\sigma(e^+p) - d\sigma(e^-p) \sim c_1^I \cos(\phi) \sim \cos(\phi) \times \mathrm{Re}\, M^{1,1}$$

$$\text{BSA}: \quad d\sigma(\overrightarrow{e^+}p) - d\sigma(\overleftarrow{e^+}p) \sim s_1^I \sin(\phi) \sim \sin(\phi) \times \mathrm{Im}\, M^{1,1}$$

$\Rightarrow$ Real and Imaginary Part of the helicity conserving amplitude $M^{1,1}$ can be accessed via Beam–Charge and Beam–Spin Asymmetry

(Other Amplitudes $\rightarrow \cos 2\phi,\ \cos 3\phi,\ \sin 2\phi$)

HERMES Event Selection

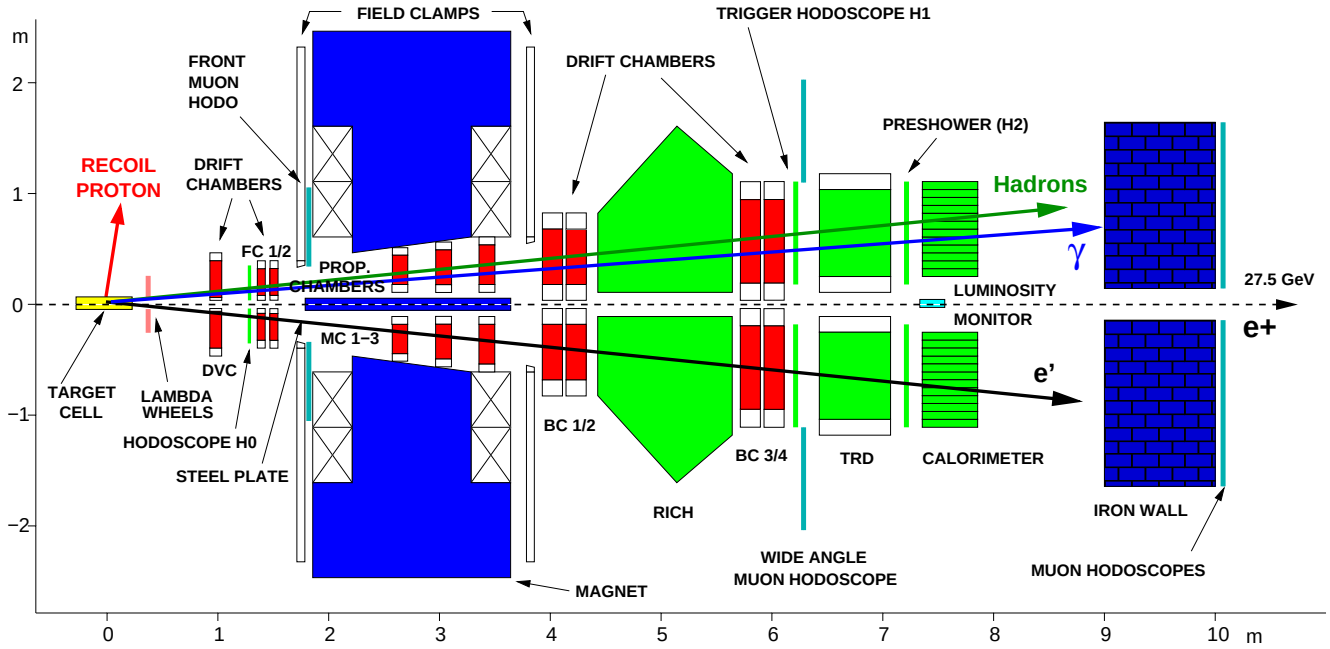
Fixed Target:

Beam:

27.6 GeV

e^+ and e^-

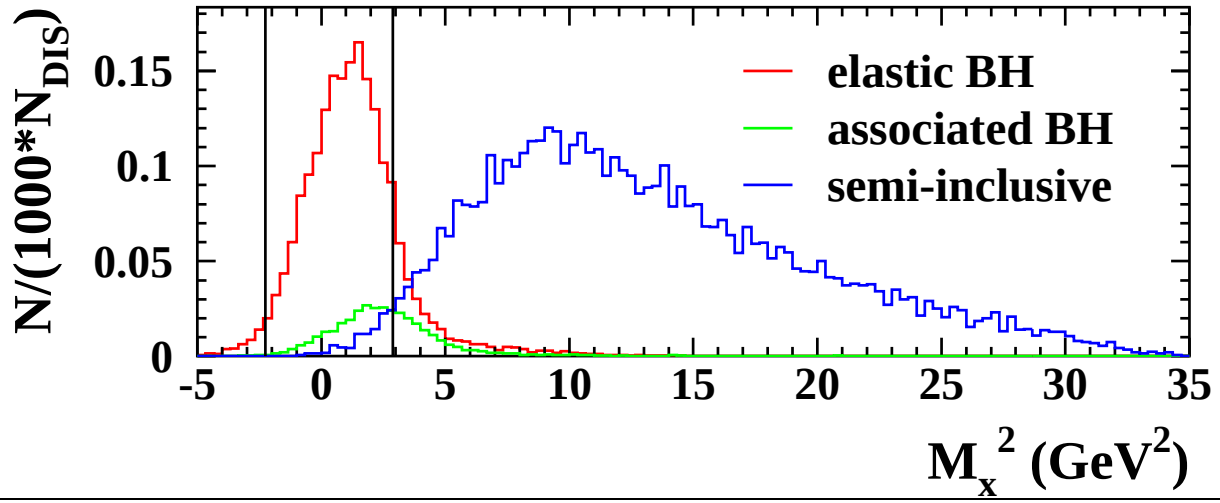
$\langle P \rangle \approx 55\%$



No recoil detection ⇒ Exclusivity via missing mass

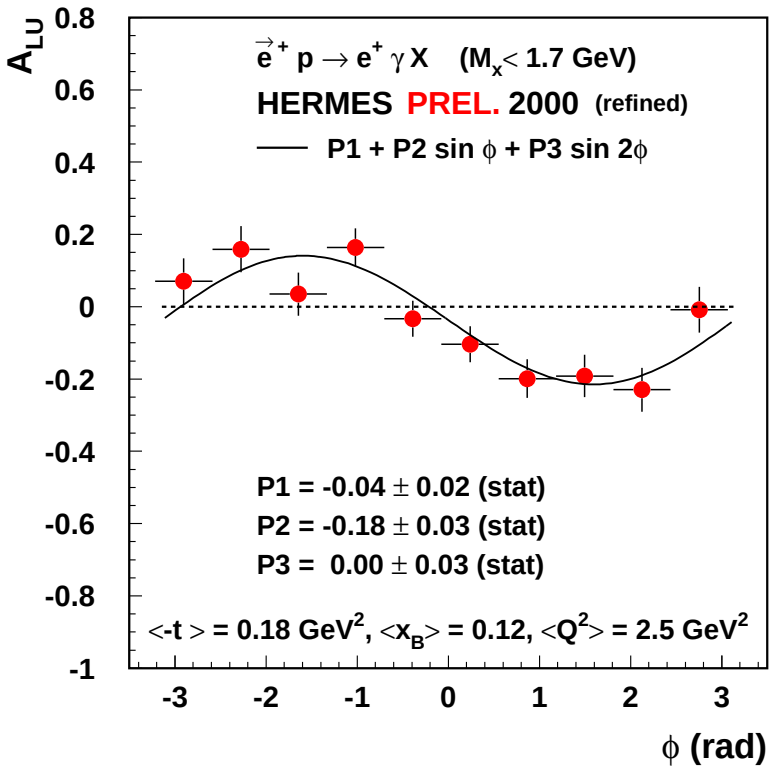
⇒ MC

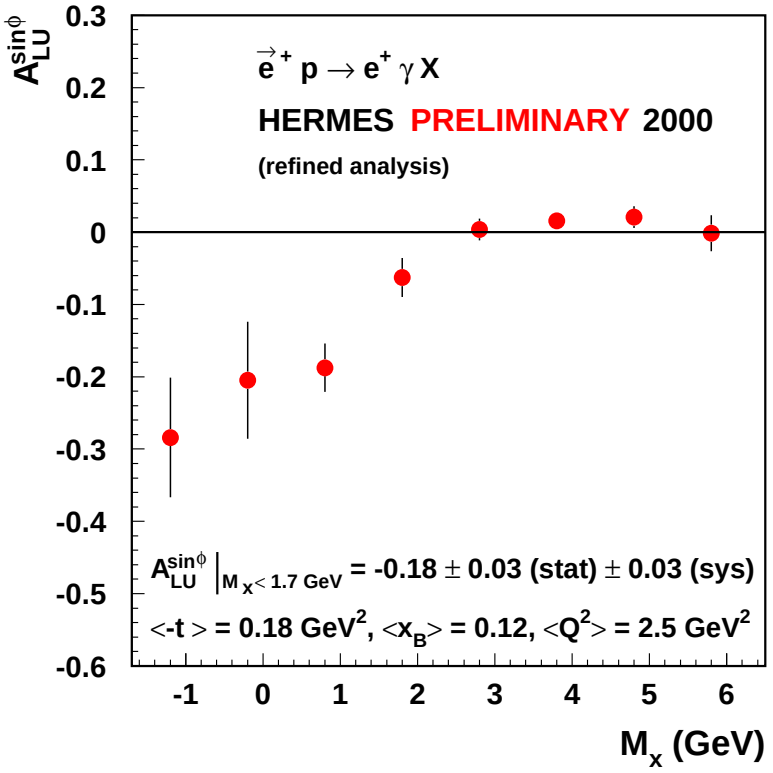
$(|\tau_{\mathrm{DVCS}}|^2 << |\tau_{\mathrm{BH}}|^2)$



Beam–Spin Asymmetry (BSA)

$$A_{\mathrm{LU}}(\phi) = \frac{1}{<|P_b|>} \frac{\overrightarrow{N}(\phi) - \overleftarrow{N}(\phi)}{\overrightarrow{N}(\phi) + \overleftarrow{N}(\phi)}$$





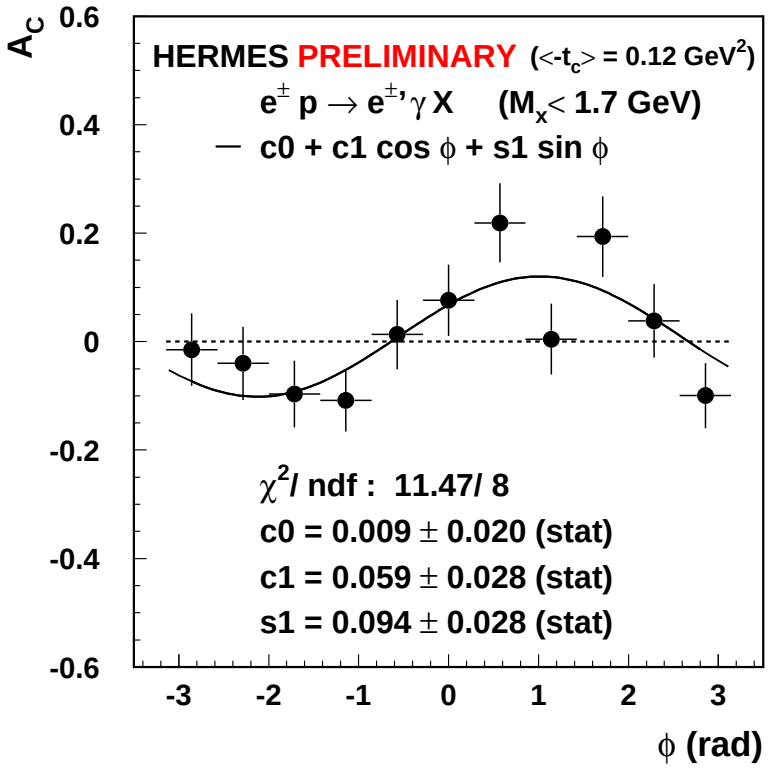
A_{LU} in exclusive bin: Expected $\sin(\phi)$ dependence $\Rightarrow$ Im $M^{1,1}$

$\sin(\phi)$–Moment in non–exclusive region: small and slightly positive $(\to \pi^0)$

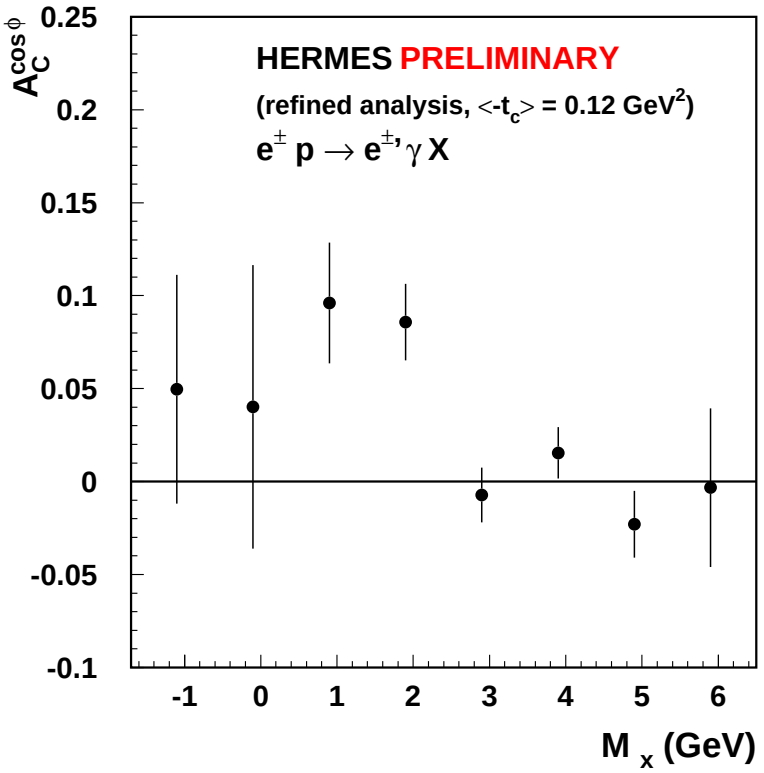
(Results from 1996/97 $\to$ PRL **87**, 182001 (2001))

Beam–Charge Asymmetry (BCA)

$$A_C(\phi) = \frac{N^+(\phi)-N^-(\phi)}{N^+(\phi)+N^-(\phi)} \propto I \propto \pm(c_0^I + \sum_{n=1}^{3} c_n^I \cos(n\phi) + \lambda \sum_{n=1}^{2} s_n^I \sin(n\phi))$$

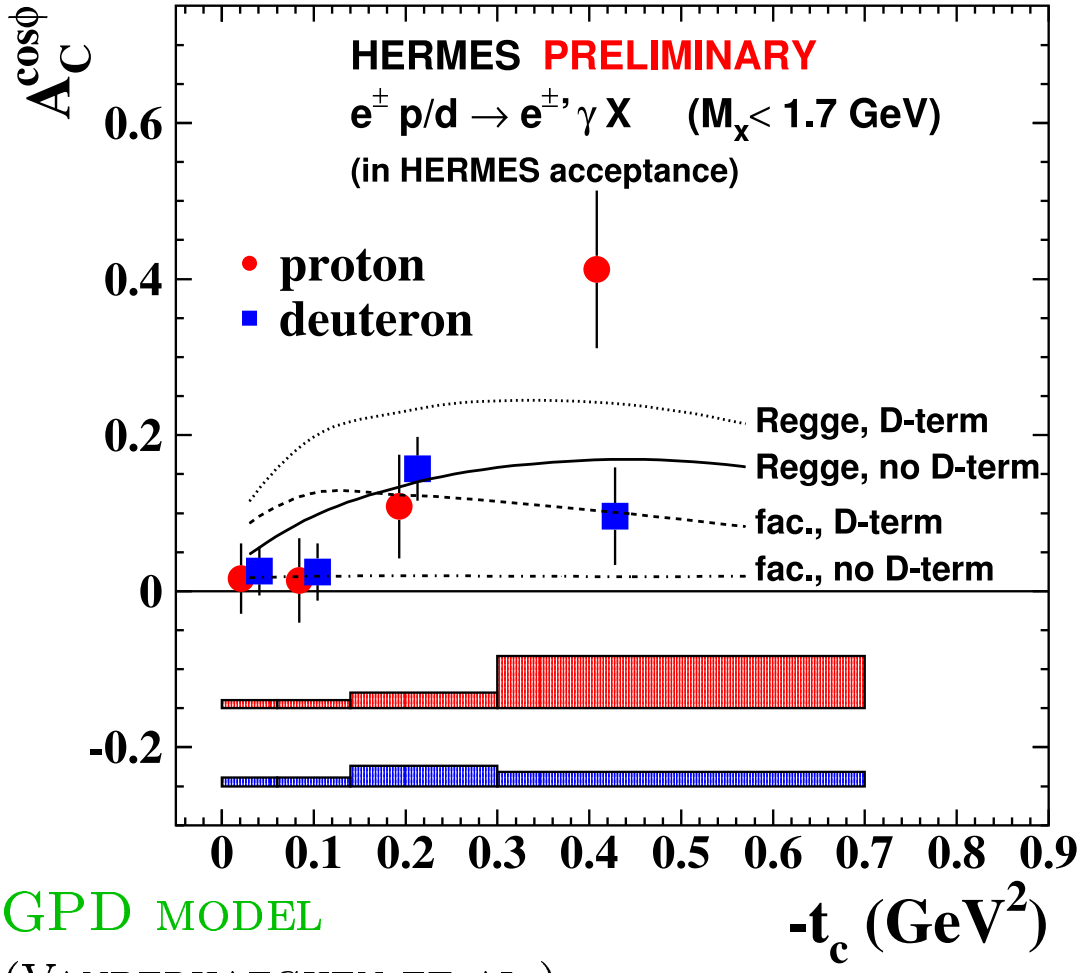


A_C in exclusive bin: Expected $\cos(\phi)$ dependence $\Rightarrow \mathrm{Re}\, M^{1,1}$ $\sin\phi$ due to polarized beam



$\cos(\phi)$–Moments zero at higher missing mass

The latest News! → BCA versus t



GPD model
(Vanderhaeghen et al.)

More:

First BCA on deuterium!

Coherent production only in first t-bin ($\approx 40\%$)
→ No effect seen
→ ≈ p-target

Difference in last bin (neutron resonances, neutron)

(BSA on deuterium, neon → hep–ex/0212019)

tiny $e^- p$ sample ($L \approx 10$ pb^{-1})
⇒ t–dependence of BCA has high sensitivity to GPD models!

Summary

- DVCS-Cross-Sections/Amplitudes $\Rightarrow$ GPDs
  $\Rightarrow$ Structure of Hadrons
- HERA: First measurements of cross-sections and azimuthal asymmetries
- HERA I: Results in agreement with different models
  $\rightarrow$ Basic Concept works $\rightarrow$ first constraints on models
- HERA II:
  - also asymmetry measurements at H1,ZEUS (spin rotators)
  - Ensure exclusivity $\rightarrow$ detect the proton
    (VFPS at H1, Recoil detector at HERMES)
  - statistics ...

  $\Rightarrow$ HERA (wide kinematic range, e^+/e^-, polarized beam) is the place to study DVCS/GPDs