Beam charge and beam helicity asymmetries arising from DVCS measured with kinematically complete event reconstruction

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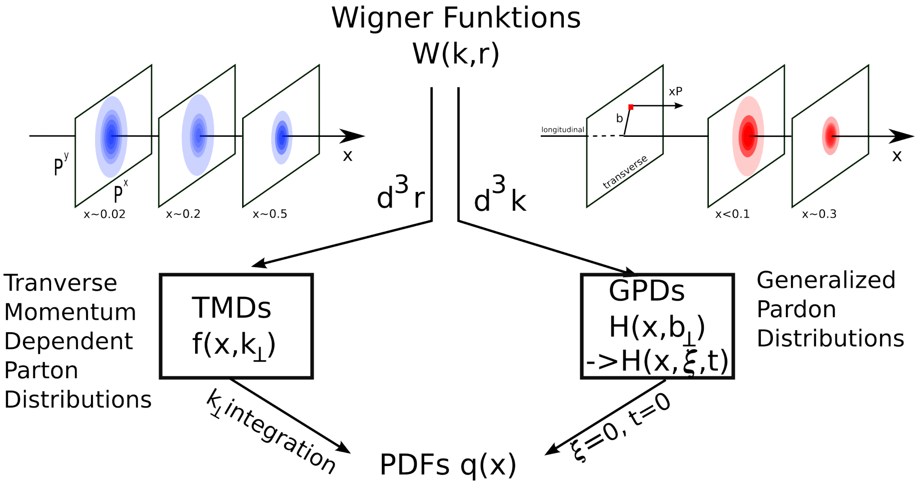
Outline of the Talk

1. Tomography on Nucleons
   - Tomography of the Nucleon?
   - From Wigner distributions to GPDs
   - Deeply Virtual Compton Scattering
2. DVCS at HERMES
   - HERMES @ DESY
   - HERMES Detector
   - Asymmetries from the unresolved data sample
3. HERMES Recoil Studies
   - Beam Spin Asymmetry with Recoil Detector

Nucleon tomography



Reducing Wigner distributions

Fast forward from the Wigner function to the GPD's

$$
\begin{aligned}
\hat{\mathcal{W}}_\Gamma(\vec{r}, k) &= Tr(\Gamma W(r,p)) \\
&\Downarrow \\
W_\Gamma(\vec{r},\vec{k}) &= \int \frac{dk^-}{(2\pi)^2} \hat{\mathcal{W}}_\Gamma(\vec{r},k) \\
&\Downarrow \\
\tilde{f}_\Gamma(\vec{r},k^+) &= \int \frac{d^2\vec{k}_\perp}{(2\pi)^2} W_\Gamma(\vec{r},\vec{k}) \\
&= \int \frac{d^3\vec{q}}{(2\pi)^3} e^{-i\vec{q}\vec{r}} F_\Gamma(x,\xi,t)
\end{aligned}
$$

Decomposition to GPDs

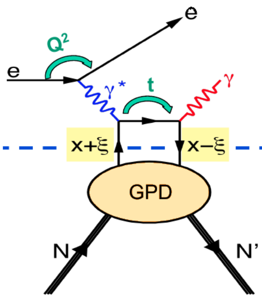
We select for the leading twist $\Gamma = \gamma^+, \gamma^+\gamma_5, \sigma^{+\perp}\gamma_5$. The decomposition introduces the generalized parton distributions (GPDs).

$$F_{\gamma^+}(x,\xi,t) = \frac{1}{2p^+}\overline{U}(\vec{q}/2)[H(x,\xi,t)\gamma^+ + E(x,\xi,t)\frac{i\sigma^{\nu}q_\nu}{2M}]U(-\vec{q}/2) \quad (1)$$

$$F_{\gamma^+\gamma_5}(x,\xi,t) = \frac{1}{2p^+}\overline{U}(\vec{q}/2)[\tilde{H}(x,\xi,t)\gamma^+ + \tilde{E}(x,\xi,t)\frac{i\sigma^{\nu}q_\nu}{2M}]U(-\vec{q}/2) \quad (2)$$

$$\begin{aligned} F_{\sigma^{+j}\gamma_5}(x,\xi,t) &= \frac{1}{2p^+}\overline{U}(\vec{q}/2)[H_T(x,\xi,t)\sigma^{+\mu}\gamma_5^+ + \tilde{H}_T(x,\xi,t)\frac{i\epsilon^{+j\mu\nu}q_\mu P_\nu}{M^2} \\ &+ E_T(x,\xi,t)\frac{i\epsilon^{+j\mu\nu}q_\mu\gamma_\nu}{2M} + \tilde{E}_T(x,\xi,t)\frac{i\epsilon^{+j\mu\nu}P_\mu\gamma_\nu}{M}]U(-\vec{q}/2) \end{aligned} \quad (3)$$

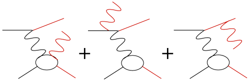
The DVCS process



Handbag diagram separates

- hard scattering process (QED & QCD) (NLO) and
- non-pertubative structure of the nucleon: GPD(x,ξ,t,Q^2)

Mixing of DVCS and BH

$\boldsymbol{\sigma}_{\gamma\gamma^*N} \sim \Big|$  $\Big|$

$$d\sigma \propto \mathcal{T}^2 = \mathcal{T}^2_{DVCS} + \mathcal{T}^2_{BH} + \underbrace{\mathcal{T}^*_{DVCS}\mathcal{T}_{BH} - \mathcal{T}^*_{BH}T_{DVCS}}_{\mathcal{I}}$$

For example For small x regions can be approximated

$$|\mathcal{T}_{\rm DVCS}|^2 \approx \frac{2(2-2y+y^2)}{y^2\mathcal{Q}^2}\left[({\rm Im}\mathcal{H}_1)^2 - \frac{\Delta^2}{4M^2}\left\{({\rm Im}\mathcal{E}_1)^2 + ({\rm Re}\mathcal{E}_1)^2\right\}\right] - \frac{4\lambda\Lambda(2-y)}{y\mathcal{Q}^2}\left({\rm Im}\mathcal{H}_1{\rm Im}\widetilde{\mathcal{H}}_1 + {\rm Re}\mathcal{H}_1{\rm Re}\widetilde{\mathcal{H}}_1\right).$$

and

Compton form factors (CFF) that are a convolution in t $\otimes \equiv \int dt$

$$\begin{pmatrix}\mathcal{H}_1\\ \mathcal{E}_1\end{pmatrix}(\xi, Q^2, \Delta^2) = T_1(t,\xi,Q^2,\mu^2) \otimes \begin{pmatrix}H\\ E\end{pmatrix}(t,\xi,\Delta^2,\mu^2)$$

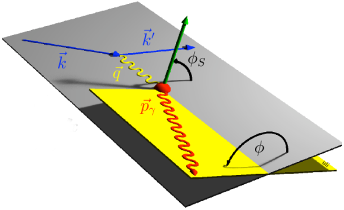
$$\begin{pmatrix}\tilde{\mathcal{H}}_1\\ \widetilde{\mathcal{E}}_1\end{pmatrix}(\xi, Q^2, \Delta^2) = T_1(t,\xi,Q^2,\mu^2) \otimes \begin{pmatrix}\widetilde{H}\\ \widetilde{E}\end{pmatrix}(t,\xi,\Delta^2,\mu^2)$$

Fourier Coefficients

$$|\mathcal{T}_{\rm BH}|^2 = \frac{K_{\rm BH}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left\{\sum_{n=0}^{2} c_n^{\rm BH}\cos(n\phi) + s_1^{BH}\sin(\phi)\right\}$$

$$|\mathcal{T}_{\rm DVCS}|^2 = K_{\rm DVCS}\left\{\sum_{n=0}^{2} c_n^{\rm DVCS}\cos(n\phi) + \sum_{n=1}^{2} s_n^{\rm DVCS}\sin(n\phi)\right\}$$

$$\mathcal{I} = -\frac{K_{\rm I} e_\ell}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left\{\sum_{n=0}^{3} c_n^{\rm I}\cos(n\phi) + \sum_{n=1}^{3} s_n^{\rm I}\sin(n\phi)\right\}$$



Longitudinally polarized target:

$$\left.\begin{aligned} c_n &= c_{n,unp} + \lambda\Lambda c_{n,LP} \\ s_n &= \lambda s_{n,unp} + \Lambda s_{n,LP} \end{aligned}\right\} \textbf{Spin - 1/2}$$

$$\left.\begin{aligned} c_n &= \frac{3}{2}\Lambda^2 c_{n,unp} + \lambda\Lambda c_{n,LP} + (1-\frac{3}{2}\Lambda^2)c_{n,LLP} \\ s_n &= \frac{3}{2}\lambda\Lambda^2 s_{n,unp} + \Lambda s_{n,LP} + (1-\frac{3}{2}\Lambda^2)\lambda s_{n,LLP} \end{aligned}\right\} \textbf{Spin - 1}$$

λ - Beam helicity

Λ - Target spin projection

e_ℓ - Beam charge

Transversely polarized target:

$$\left.\begin{aligned} c_n &= c_{n,unp} + \Lambda c_{n,UT} + \lambda\Lambda c_{n,LT} \\ s_n &= \lambda s_{n,unp} + \Lambda s_{n,UT} + \lambda\Lambda s_{n,LT} \end{aligned}\right\} \textbf{Spin - 1/2}$$

Accessing CFFs

Access through asymmetries A_{xy} x:beam polarization, y:target polarization

$$A_{LU}(\phi, e_l) = \frac{\sigma_{LU}(\phi, e_l, \lambda=+1) - \sigma_{LU}(\phi, e_l, \lambda=-1)}{\sigma_{LU}(\phi, e_l, \lambda=+1) + \sigma_{LU}(\phi, e_l, \lambda=-1)}$$

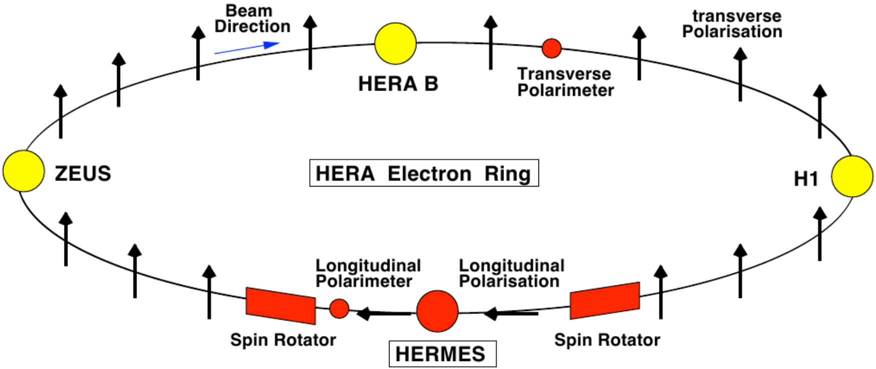
$$= \frac{1}{\sigma_{UU}(\phi, e_l)} \left[K_{DVCS} s_1^{DVCS} \sin\phi - e_l \frac{K_I \sum_{n=1}^{2} s_n^{\mathcal{I}} \sin(n\phi)}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \right]$$

and

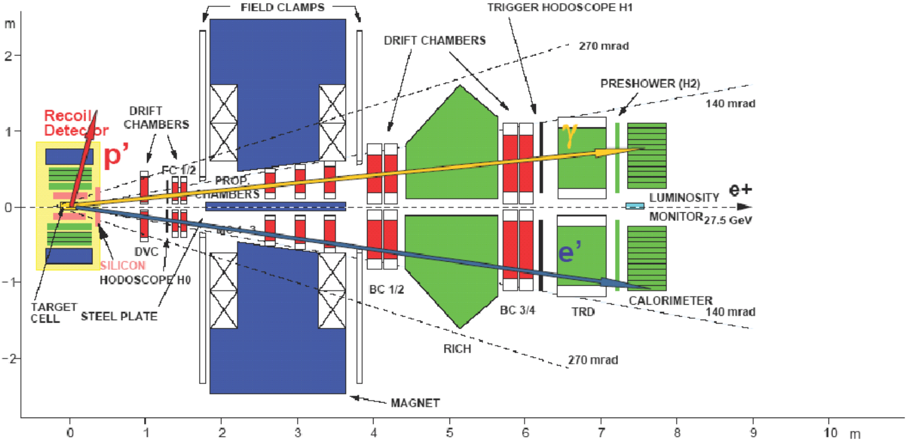
$$A_{LU}(\phi) \sim \pm \frac{x_B}{y} \frac{s_1^{\mathcal{I}}}{c_0^{BH}} \sin(\phi) \propto \mathfrak{Im} \left\{ F_1 \mathcal{H} + \frac{x_B}{2 - x_B}(F_1 + F_2)\tilde{\mathcal{H}} - \frac{\Delta^2}{4M^2} F_2 \mathcal{E} \right\} \sin(\phi)$$

HERA @ DESY

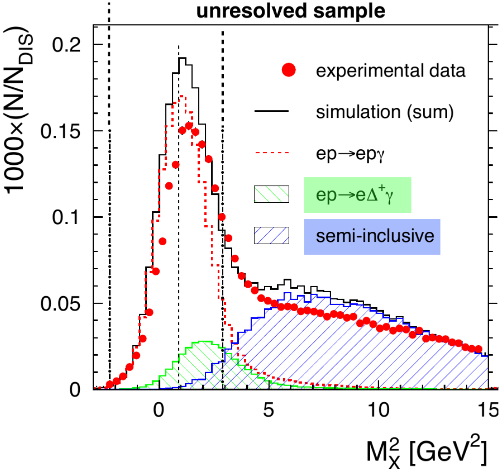
HERMES @ HERA


Beam
Direction
transverse
Polarisation
HERA B
Transverse
Polarimeter
ZEUS
HERA Electron Ring
H1
Longitudinal
Polarimeter
Longitudinal
Polarisation
Spin Rotator
HERMES
Spin Rotator

The HERMES Detector



The "traditional" Analysis

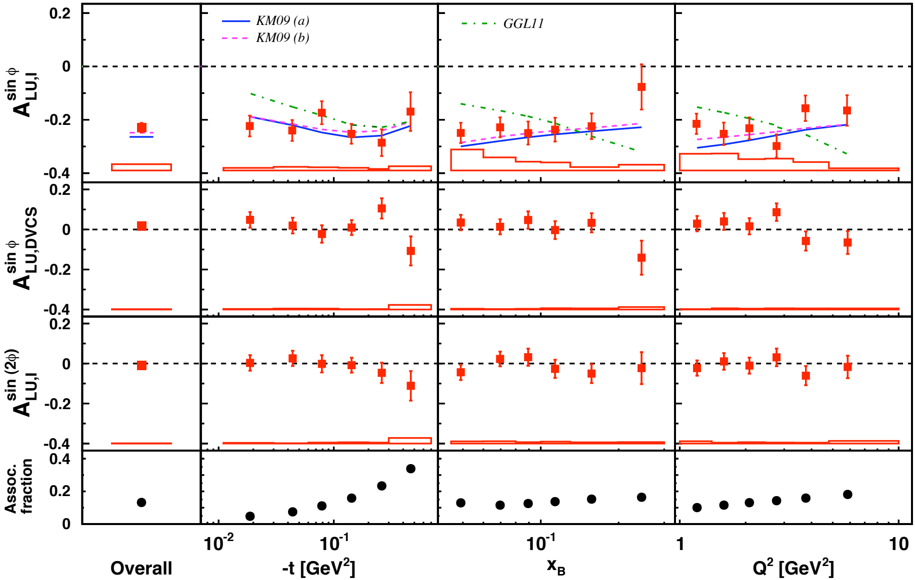


- Exactly one charged object tracked (lepton)
- Only one photon cluster in the calorimeter (photon)
- Missing Mass cut: $M_x^2 = (e + p - e' - \gamma)^2$

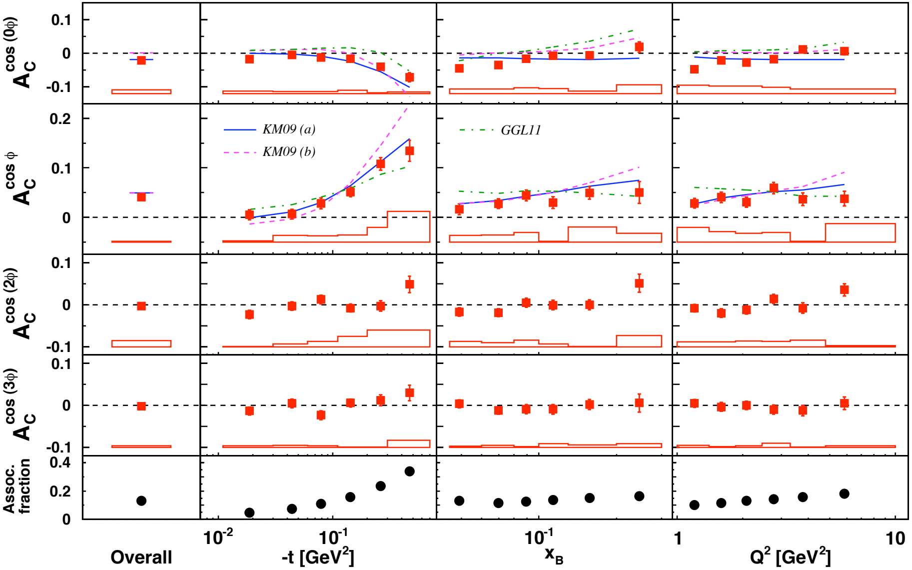
- Asymmetry fit performed by minimizing:

$$-ln\mathcal{L}_{ELM} = -\Sigma_i^N ln[1 + \eta_i A_C(x_i;\theta) + P_i A_{LU}^{DVCS}(x_i;\theta) + \eta_i P_i A_{LU}^{I}(x_i;\theta)] + \mathbb{N}(\theta)$$

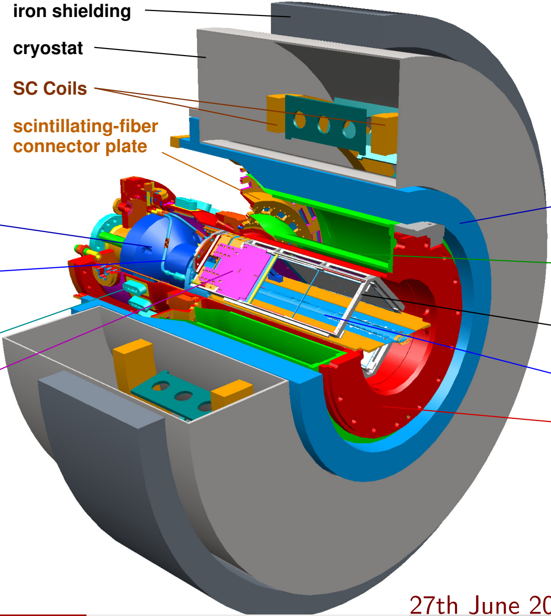
Beam helicity asymmetry



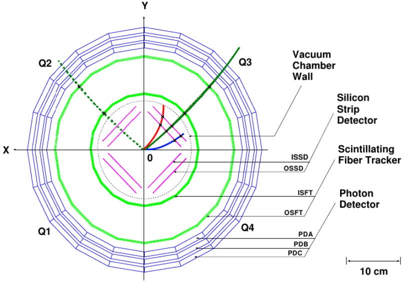
Beam charge asymmetry



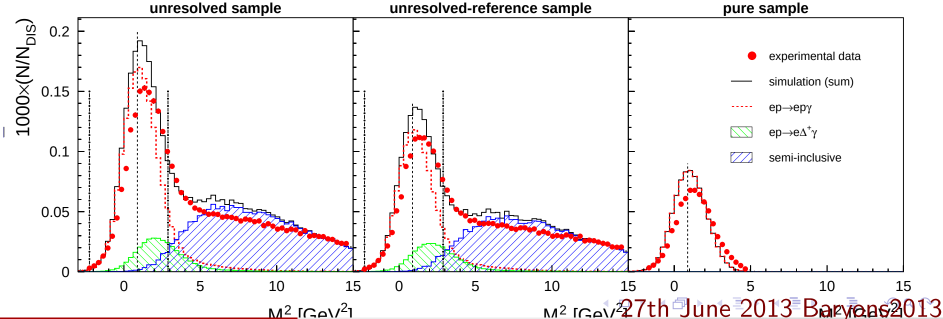
The Hermes Recoil detector



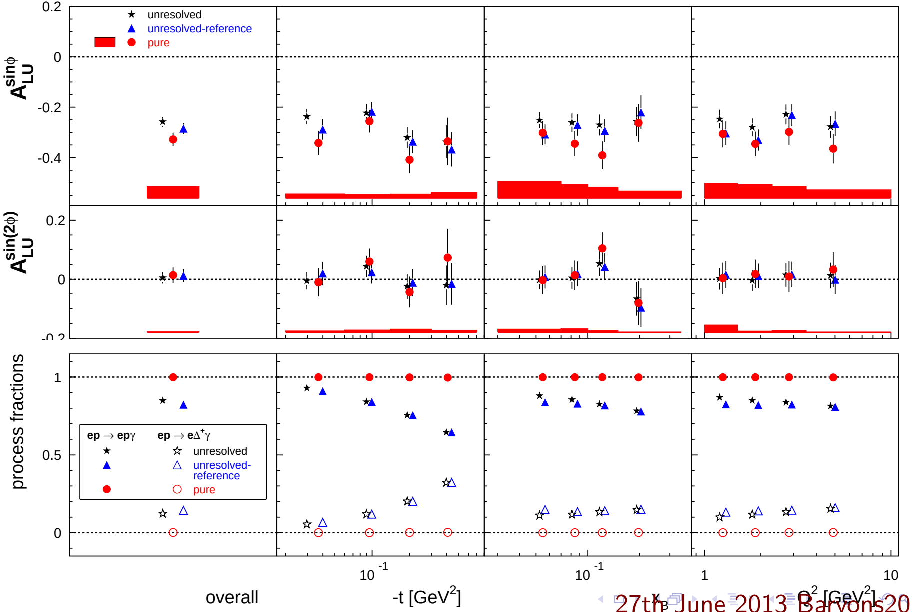
Advantages of the Recoil detector



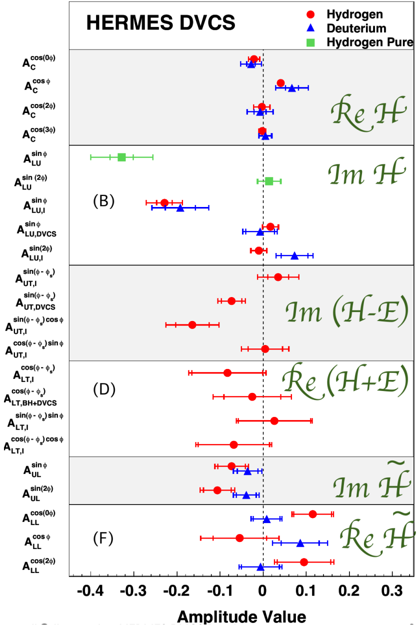
$$C_0 = p_{x,l} + p_{x,\gamma} + P_{x,P} = 0$$
$$C_1 = p_{y,l} + p_{y,\gamma} + P_{y,P} = 0$$
$$C_2 = p_{z,l} + p_{z,\gamma} + P_{z,P} - p_{\text{beam}} = 0$$
$$C_3 = E_l + E_\gamma + E_P - E_{\text{beam}} - m_P = 0$$



Beam helicity asymmetry



Asymmetries@Hermes



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