Projections for DVCS measurements with unpolarized and polarized targets in the HERMES experiment

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- DVCS Cross Section
- Parameterization of GPDs
- HERMES experiment
- Projected Statistical Accuracy
- Summary

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DVCS Cross Section

We follow the paper

A.V. Belitsky, A. Kirchner, D. Muller, A. Schafer, Phys.Lett. B510, 117 (2001)

$e(k)p(P_1) \to e(k')p(P_2)\gamma(q_2)$

$$\frac{d\sigma}{dx_{\rm B}dyd|\Delta^2|d\phi} = \frac{\alpha^3 x_{\rm B} y}{8\,\pi\, Q^2}\left(1+\frac{4M^2x_{\rm B}^2}{Q^2}\right)^{-1/2}\left|\frac{\mathcal{T}}{e^3}\right|^2$$

$$\mathcal{T}^2 = |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{VCS}|^2 + \mathcal{I}$$

$q_1 = k - k'$, $Q^2 = -q_1^2$, $x_{\rm B} = -q_1^2/(2P_1\cdot q_1)$,
$y = P_1\cdot q_1/P_1\cdot k$, $\Delta^2 = (P_2 - P_1)^2$ and ϕ is the azimuthal angle between lepton and hadron scattering planes.

$$\mathcal{I} = \frac{1}{x_{\rm B} y^3 \mathcal{P}_1\mathcal{P}_2(-\Delta^2)}\left\{\frac{\Delta^2}{Q^2}c_0^{\mathcal{I}} + \sum_{m=1}^{2} K^m\left[c_m^{\mathcal{I}}\cos(m\phi) + \lambda s_m^{\mathcal{I}}\sin(m\phi)\right]\right\}$$

$$|\mathcal{T}_{\rm DVCS}|^2 = \frac{1}{y^2Q^2}\left\{c_0^{\rm DVCS} + K\left[c_1^{\rm DVCS}\cos(\phi) + \lambda\, s_1^{\rm DVCS}\sin(\phi)\right]\right\}$$

$c_1^{\mathcal{I}}$, $s_1^{\mathcal{I}}$, $c_0^{\rm DVCS}$ arise at the twist-two level.

$c_0^{\mathcal{I}}$, $c_2^{\mathcal{I}}$, $s_2^{\mathcal{I}}$, $c_1^{\rm DVCS}$, $s_1^{\rm DVCS}$ are given in terms of twist-two and twist-three GPDs.

DVCS Cross Section

For an unpolarized nucleon target:

$$
\begin{aligned}
c^{\mathcal{I}}_{1,\mathrm{unp}} &= -8(2-2y+y^2)\,\mathrm{Re}\,\mathcal{C}^{\mathcal{I}}_{\mathrm{unp}}\left(\mathcal{F}\right), \\
s^{\mathcal{I}}_{1,\mathrm{unp}} &= 8y(2-y)\,\mathrm{Im}\,\mathcal{C}^{\mathcal{I}}_{\mathrm{unp}}\left(\mathcal{F}\right), \\
c^{\mathcal{I}}_{2,\mathrm{unp}} &= -16\frac{2-y}{2-x_{\mathrm{B}}}\mathrm{Re}\,\mathcal{C}^{\mathcal{I}}_{\mathrm{unp}}\left(\mathcal{F}^{\mathrm{eff}}\right), \\
s^{\mathcal{I}}_{2,\mathrm{unp}} &= 16\frac{y}{2-x_{\mathrm{B}}}\mathrm{Im}\,\mathcal{C}^{\mathcal{I}}_{\mathrm{unp}}\left(\mathcal{F}^{\mathrm{eff}}\right).
\end{aligned}
$$

$\mathcal{F} \equiv \{\mathcal{H}, \mathcal{E}, \widetilde{\mathcal{H}}, \widetilde{\mathcal{E}}\}$ — twist-two Compton form factors.

$\mathcal{F}^{\mathrm{eff}} = -2\xi\left(\frac{1}{1+\xi}\mathcal{F} + \mathcal{F}^3_+ - \mathcal{F}^3_-\right)$ is an ‘effective’ twist-three GPD.

The Compton form factors are related to GPDs $F_i \equiv \{H_i, \ldots, \widetilde{E}_i\}$:

$$
\mathcal{F}(\xi, \Delta^2) = \sum_{i=u,d,\ldots} C_i^{(\mp)}(\xi, x) \otimes F_i(x, \xi, \Delta^2).
$$

The twist-two function

$$
\mathcal{C}^{\mathcal{I}}_{\mathrm{unp}}\left(\mathcal{F}\right) = F_1\mathcal{H} + \frac{x_{\mathrm{B}}}{2-x_{\mathrm{B}}}(F_1+F_2)\widetilde{\mathcal{H}} - \frac{\Delta^2}{4M^2}F_2\mathcal{E}
$$

In the following we set $\mathcal{F}^3_+ = 0$, $\mathcal{F}^3_- = 0$.

Parameterization of GPDs

Basically we follow the ansatz:

M. Vanderhaeghen, P.A.M. Guichon, M. Guidal, Phys.Rev. **D60**, 094017 (1999).
K. Goeke, M.V. Polyakov, M. Vanderhaeghen, hep-ph/0106012, 2001

Dependence on Δ^2 is taken in factorized form w.r.t. other variables.
A scale dependence of GPDs is neglected.

In a simplest approach GPDs — independent of the ξ.

$$\begin{aligned} H^u(x,\xi,\Delta^2) &= u(x)\ F_1^u(\Delta^2)\,/\,2\ , \\ H^d(x,\xi,\Delta^2) &= d(x)\ F_1^d(\Delta^2)\ , \\ H^s(x,\xi,\Delta^2) &= 0\ . \end{aligned}$$

$$\begin{aligned} \widetilde{H}^u(x,\xi,\Delta^2) &= \Delta u_V(x)\ g_A^u(\Delta^2)/g_A^u(0)\ , \\ \widetilde{H}^d(x,\xi,\Delta^2) &= \Delta d_V(x)\ g_A^d(\Delta^2)/g_A^d(0)\ , \\ \widetilde{H}^s(x,\xi,\Delta^2) &= 0 \end{aligned}$$

$F_1^u = 2F_1^p + F_1^n,\ F_1^d = F_1^p + 2F_1^n$
$g_A^u = \frac{1}{2}g_A + \frac{1}{2}g_A^0\,,\ g_A^d = -\frac{1}{2}g_A + \frac{1}{2}g_A^0\,,\ g_A^0 = \frac{3}{5}g_A.$

E and $\widetilde{E}$ have no definite limit at $\xi \to 0$.
E is taken in a form analogous to H:

$$\begin{aligned} E^u(x,\xi,\Delta^2) &= u(x)\ F_2^u(\Delta^2)\,/\,2\ , \\ E^d(x,\xi,\Delta^2) &= d(x)\ F_2^d(\Delta^2)\ , \\ E^s(x,\xi,\Delta^2) &= 0 \end{aligned}$$

Parameterization of GPDs

The function $\widetilde{E}$ is modelled to be due to the pion pole:

$$\widetilde{E}^u(x,\xi,\Delta^2) = -\widetilde{E}^d(x,\xi,\Delta^2) = \frac{1}{2}\,\widetilde{E}_{\pi-pole}(x,\xi,\Delta^2)\ ,$$

$$\widetilde{E}_{\pi-pole}(x,\xi,\Delta^2)\ =\ \theta\,(-\xi \le x \le \xi)\ h_A(\Delta^2)\,\frac{1}{\xi}\,\Phi\left(\frac{x}{\xi}\right)\ ,$$

$\Phi(z) = 3/4(1-z^2)$ — pion distribution amplitude
$h_A(\Delta^2) = \frac{4M^2 g_A}{m_\pi^2 - \Delta^2}$

To introduce a dependence of the GPDs on ξ, the DD formalism is used

D. Müller et al., Fortsch. Phys. **42**, 101 (1994)
A.V. Radyushkin, Phys.Rev. **D56**, 5524 (1997)

$$H^q_{DD}(x,\xi) = \int_{-1}^{1} dy \int_{-1+|y|}^{1-|y|} dt\ \delta(x-y-t\xi)\ h(y,t)\ q(y)\ .$$

$q(y)$ - ordinary quark distribution

$$h(y,t) = \frac{\Gamma(2b+2)}{2^{2b+1}\Gamma^2(b+1)}\ \frac{\left[(1-|y|)^2 - t^2\right]^b}{(1-|y|)^{2b+1}}\ ,$$

b — free parameter

Analogously for functions $\widetilde{H}$ and E.

Parameterization of GPDs

The contribution of the D-term

(M.V. Polyakov, C. Weiss, Phys.Rev. **D60**, 114017 (1999))

is taken according to the chiral quark soliton model calculation

(N. Kivel, M.V. Polyakov, M. Vanderhaeghen, Phys.Rev. **D63**, 114014 (2001)).

$$\begin{aligned} H^q(x,\xi) &= H^q_{DD}(x,\xi) + \theta(\xi - |x|)\,\frac{1}{N_f}\,D(\frac{x}{\xi})\,, \\ E^q(x,\xi) &= E^q_{DD}(x,\xi) - \theta(\xi - |x|)\,\frac{1}{N_f}\,D(\frac{x}{\xi})\,. \end{aligned}$$

$q(x)$ — MRST98 (at $Q^2 = 2$ GeV^2)
$\Delta q(x)$ — LSS98 (at $Q^2 = 1$ GeV^2)

Five versions of GPD models were tried:

A) $H(x,\xi)$, $\widetilde{H}(x,\xi)$, and $E(x,\xi)$ are ξ-independent.

B) The ξ dependence of $H(x,\xi)$, $\widetilde{H}(x,\xi)$, and $E(x,\xi)$ is generated through the DD formalism with $b = 1$.

C) same as B), but with the parameter $b = 3$.

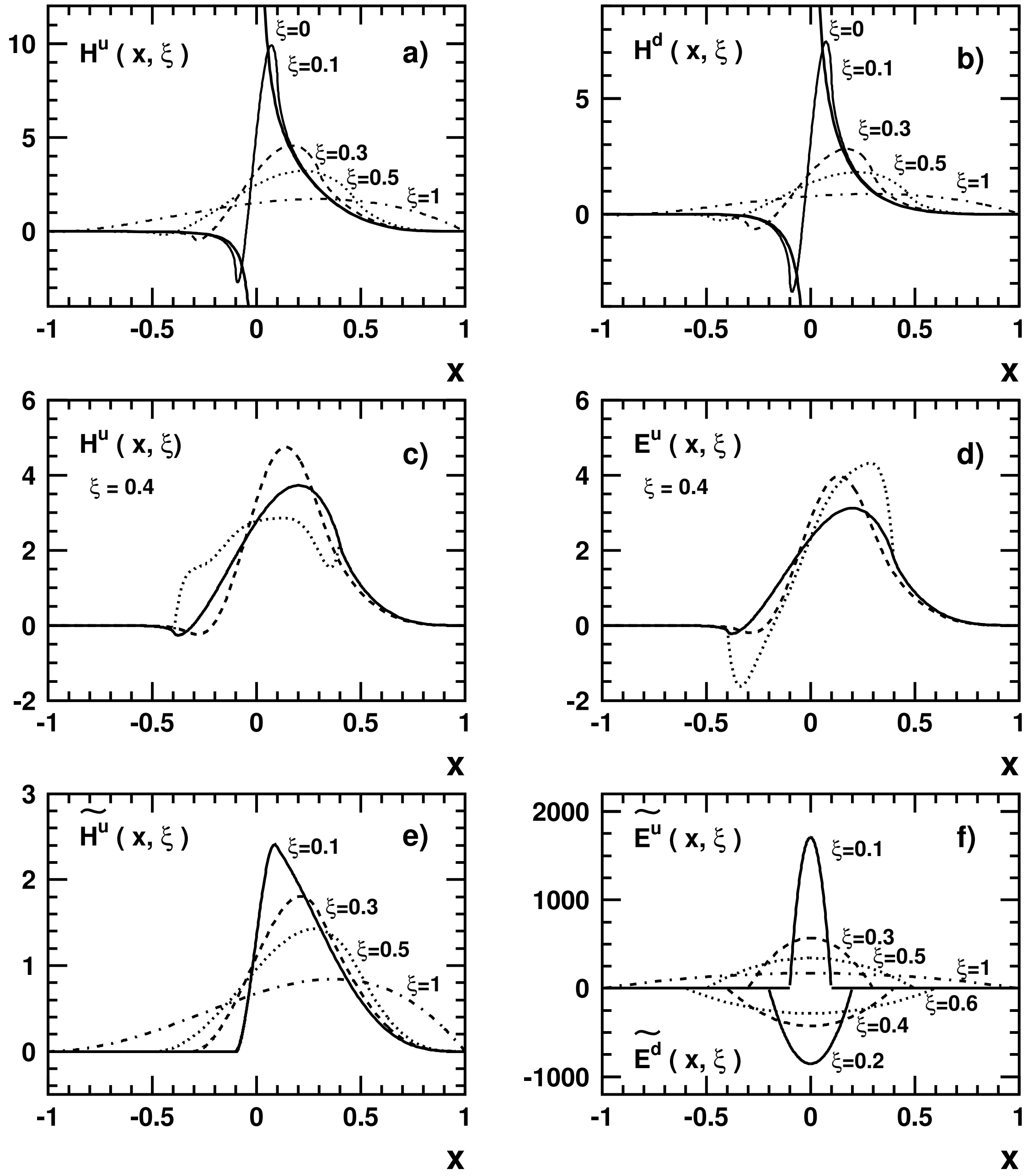
D) same as B), but the contribution of the D-term to $H(x,\xi)$ and $E(x,\xi)$ is included additionally.

E) same as D), but with the parameter $b = 3$.

For $\widetilde{E}(x,\xi)$ the pion pole expression is used for all versions.

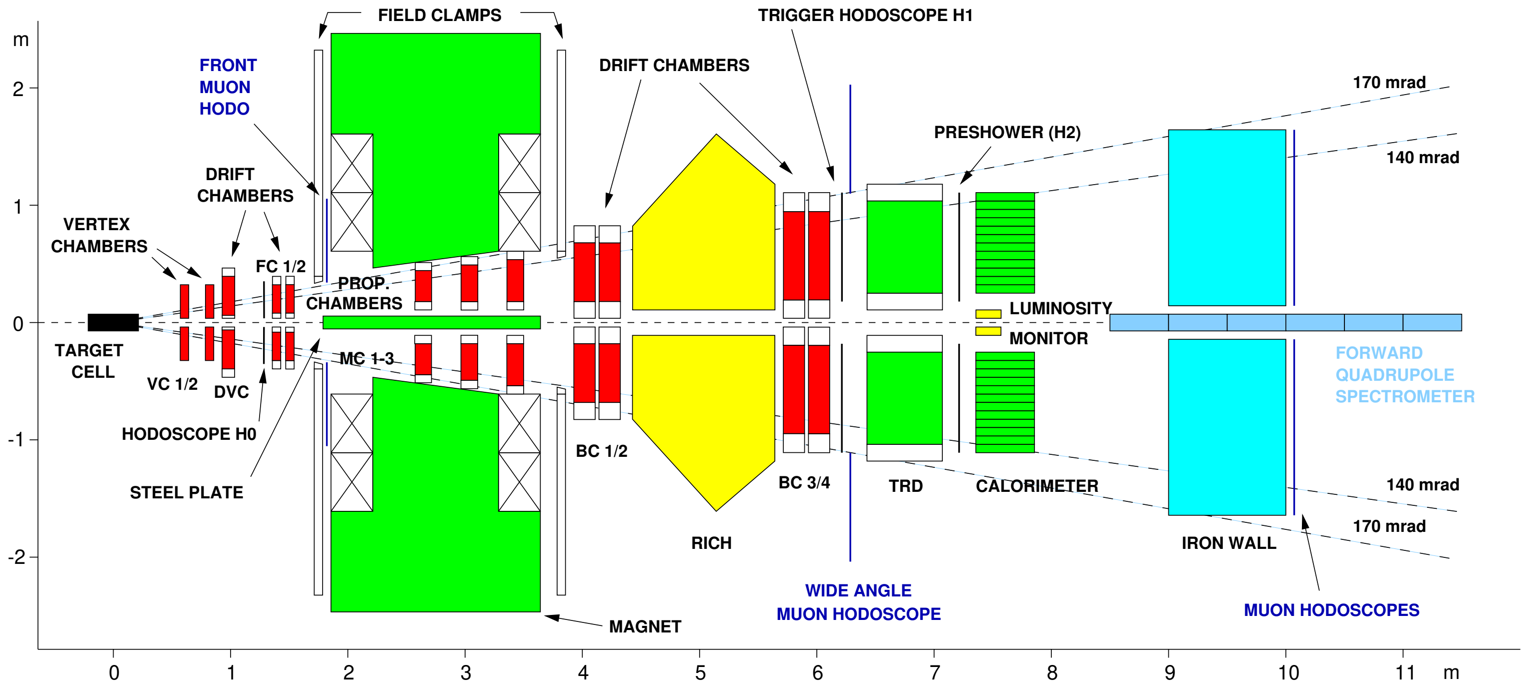
Parameterization of GPDs

Dependence of the GPDs on x and ξ (at $\Delta^2 = 0$).



a) $H^u(x,\xi)$ for different values of ξ in version B).
b) The same as a) but for d-quarks.
c) $H^u(x,\xi)$ at $\xi = 0.4$
solid line - version B), dashed line - version C), dotted line - version D).
d) The same as c) but for $E^u(x,\xi)$.
e) $\widetilde{H}^u(x,\xi)$ for different values of ξ in version B).
f) $\widetilde{E}^u(x,\xi)$ and $\widetilde{E}^d(x,\xi)$ for different values of ξ.

The HERMES Spectrometer



- Polarized positrons of energy 27.5 GeV in the HERA storage ring, $P_B = 0.55 \pm 0.02$

- Polarized internal hydrogen gas target, $P_T = 0.86 \pm 0.04$

- Forward spectrometer, $0.04 < \theta < 0.22$ rad.

- Particle ID: RICH (Threshold Čerenkov), TRD, Preshower, Lead Glass Calorimeter.

- Track reconstruction: $\delta P/P = 0.7 \div 1.3\%$, $\delta\theta \leq 0.6$ mrad.

Recoil Detector
Design

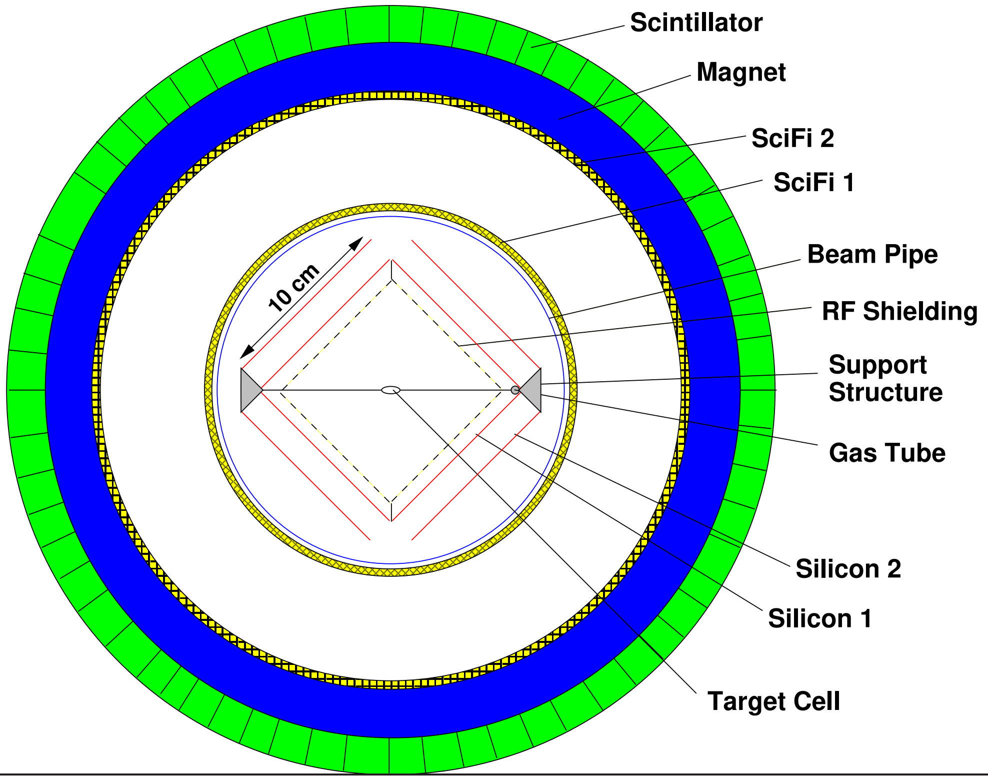
DESY PRC 01 - 01; HERMES 01-017

Design Requirements:

- identify recoil proton: momentum measurement in the range $100-1200$ MeV
- identify charged, neutral pions: $\Delta \to \pi N$ (requires charged-π, p separation)
- hermeticity

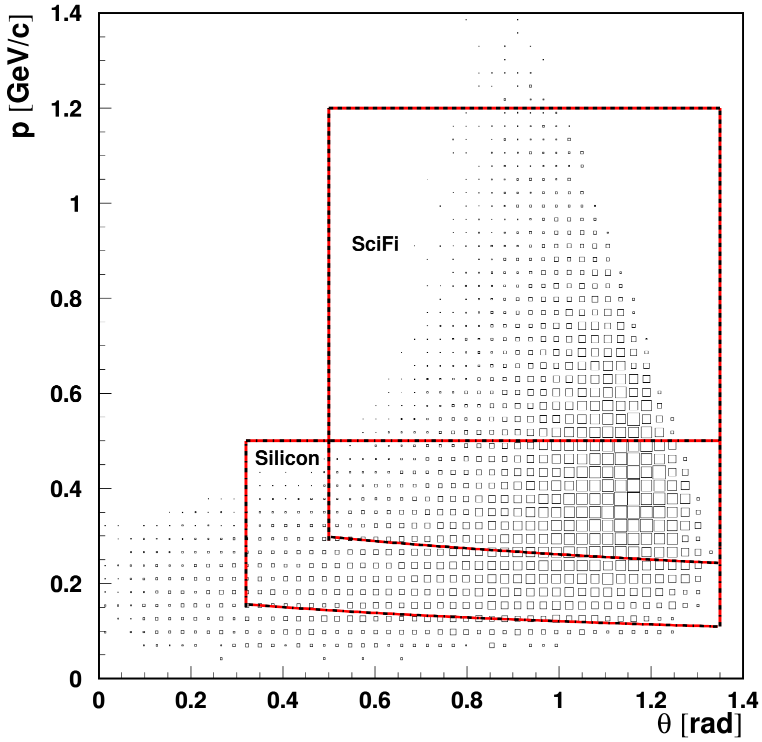
Detector Design:

- Two layers of silicon detectors around the target cell inside the beam pipe
- Two outer scintillating fiber trackers in a longitudinal magnetic field
- A layer of scintillating strips or pads for π^0 detection using return yoke as preshower material



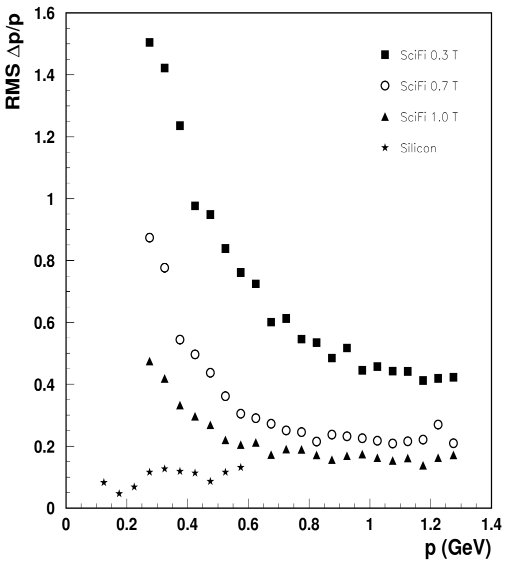
Recoil Detector
Acceptance and Resolution

85 % of recoil protons in the acceptance

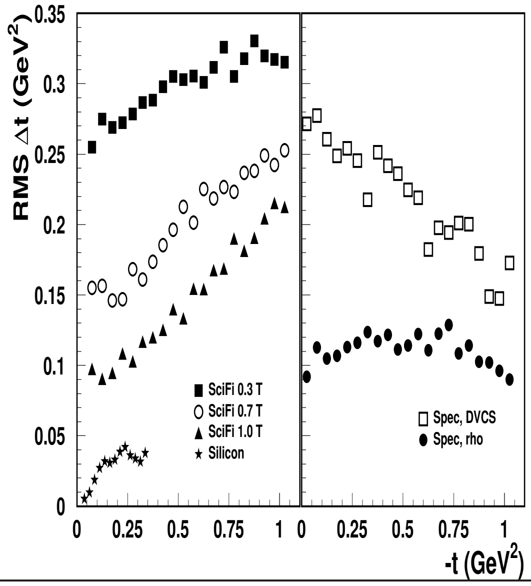


Expected Resolution

Momentum Resolution



Momentum Transfer Resolution



DVCS Projections
Unpolarized Proton Target

I) Lepton charge asymmetry

$$
\begin{aligned}
d\Delta\sigma_{ch} &\equiv d\sigma(e^{+}p) - d\sigma(e^{-}p) \sim \\
&\text{Re}\left\{ F_1\mathcal{H}_1 + \frac{x_B}{2-x_B}(F_1+F_2)\widetilde{\mathcal{H}}_1 - \frac{\Delta^2}{4M^2}F_2\mathcal{E}_1 \right\}
\end{aligned}
$$

II) Beam helicity asymmetry using a polarized positron beam:

$$
\begin{aligned}
d\Delta\sigma_{LU} &\equiv d\sigma(\overrightarrow{e^{+}}p) - d\sigma(\overleftarrow{e^{+}}p) \sim \\
&\text{Im}\left\{ F_1\mathcal{H}_1 + \frac{x_B}{2-x_B}(F_1+F_2)\widetilde{\mathcal{H}}_1 - \frac{\Delta^2}{4M^2}F_2\mathcal{E}_1 \right\}
\end{aligned}
$$

Future measurements of DVCS at HERMES:

$L = 2$ fb^{-1} , 1 year of running, $P_B = 50\%$.

Geometrical acceptance of the spectrometer.

Kinematical cuts:

$E_e > 3.5$ GeV, $W^2 > 4$ GeV^2, $Q^2 > 1$ GeV^2,

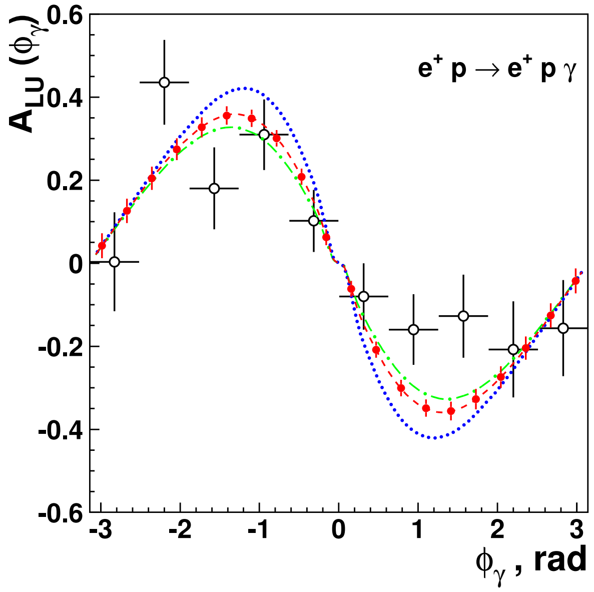
$E_\gamma > 0.8$ GeV, $P_p > 0.1$ GeV,

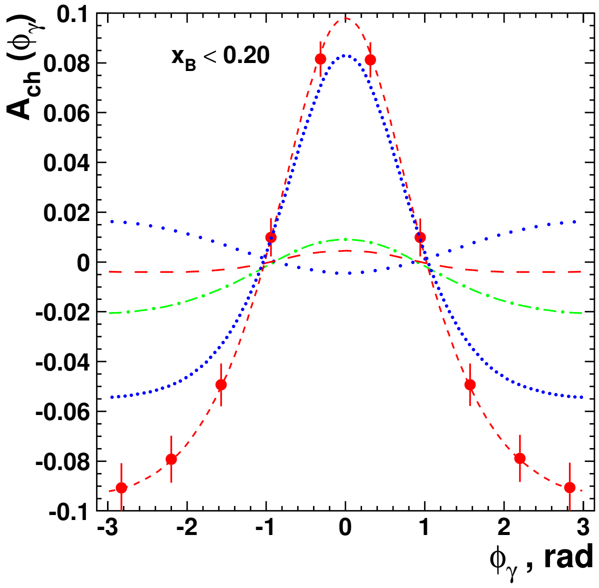
$0.35 < \theta_p^{lab} < 1.35$ rad, $15 < \Theta_{\gamma\gamma^*}^{lab} < 70$ mrad.

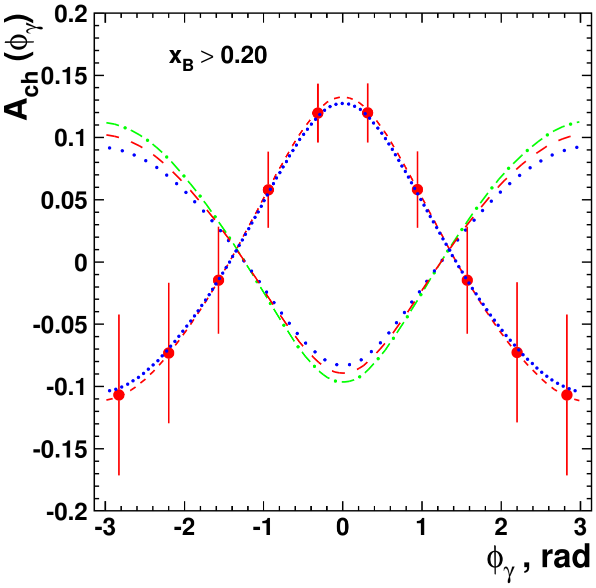
DVCS Projections
Asymmetry vs. Azimuthal Angle

Proton Target

A) - dash-dotted line
B) - long space dotted line
C) - long space dashed line
D) - dotted line
E) - dashed line





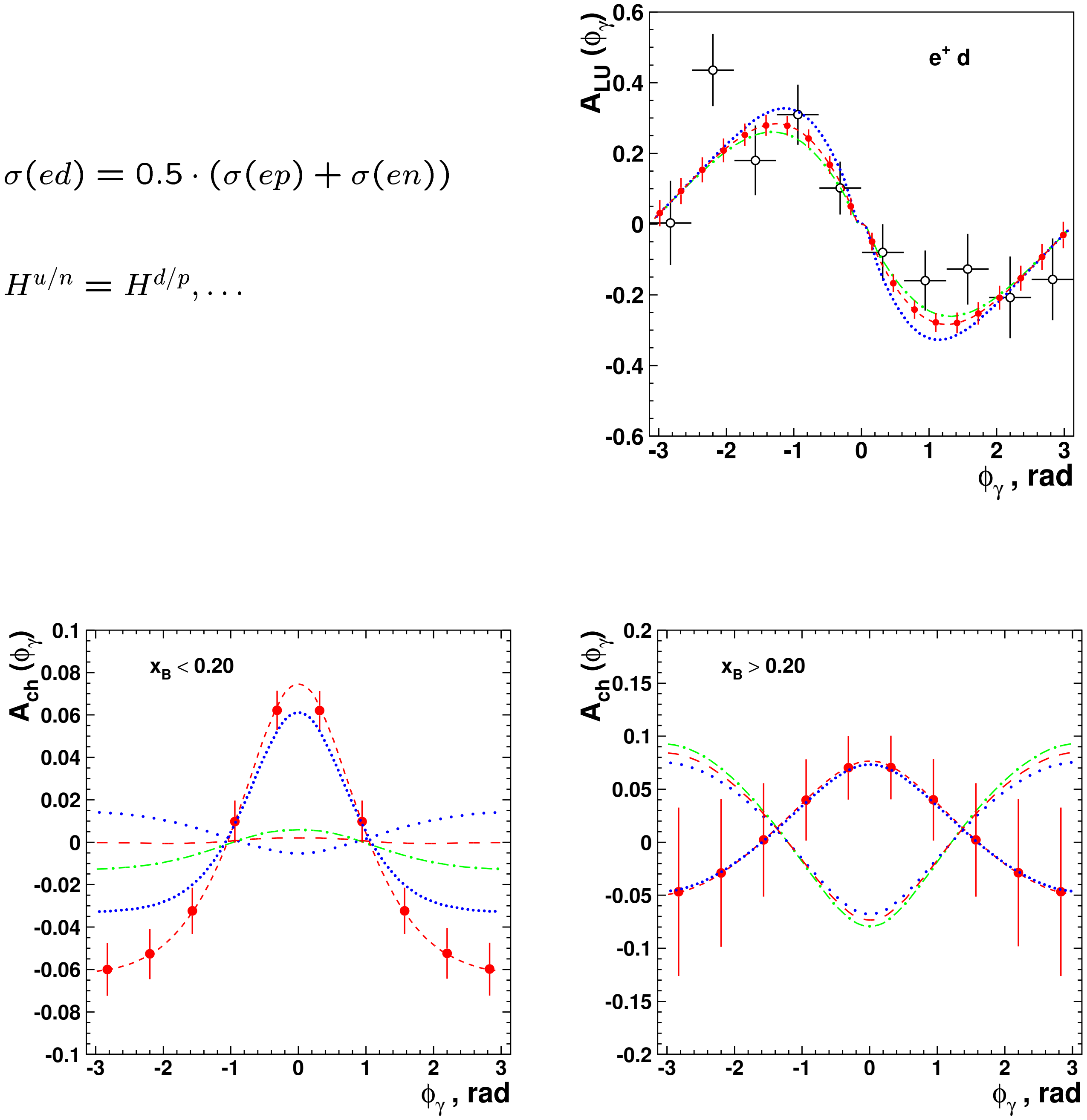


DVCS Projections
Asymmetry vs. Azimuthal Angle

Deuteron Target

$$\sigma(ed) = 0.5 \cdot (\sigma(ep) + \sigma(en))$$

$$H^{u/n} = H^{d/p}, \ldots$$

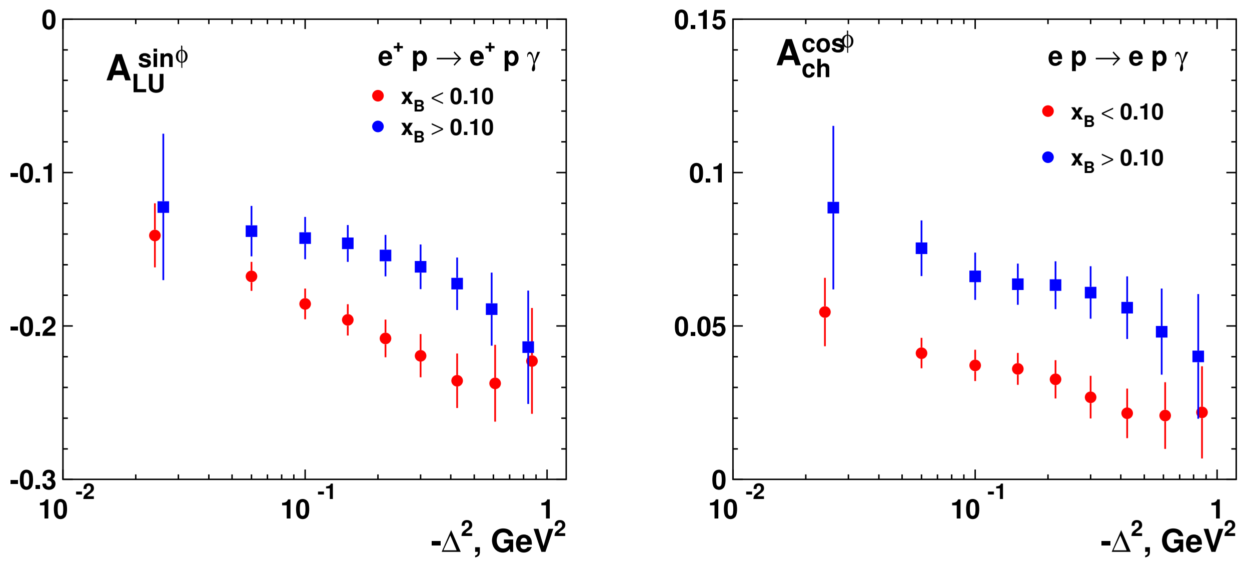


DVCS Projections

$\sin\phi$ / $\cos\phi$ Moments

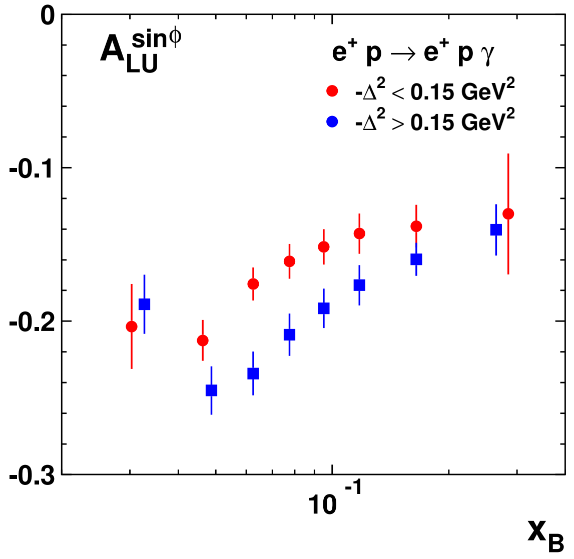
$$A_{LU}^{\sin\phi} = \frac{\int_0^{2\pi} d\phi\, \sin\phi \{d\sigma(e^{\uparrow}p)/d\phi \,-\, d\sigma(e^{\downarrow}p)/d\phi\}}{\int_0^{2\pi} d\phi\, \{d\sigma(e^{\uparrow}p)/d\phi \,+\, d\sigma(e^{\downarrow}p)/d\phi\}}$$

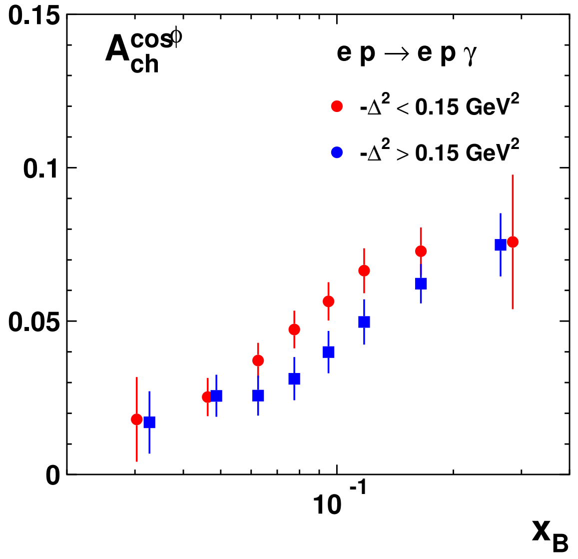
$$A_{ch}^{\cos\phi} = \frac{\int_0^{2\pi} d\phi\, \cos\phi \{d\sigma(e^{+}p)/d\phi \,-\, d\sigma(e^{-}p)/d\phi\}}{\int_0^{2\pi} d\phi\, \{d\sigma(e^{+}p)/d\phi \,+\, d\sigma(e^{-}p)/d\phi\}}$$

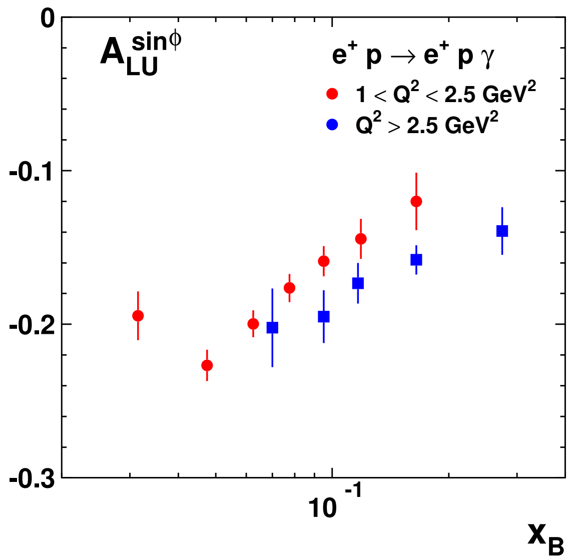


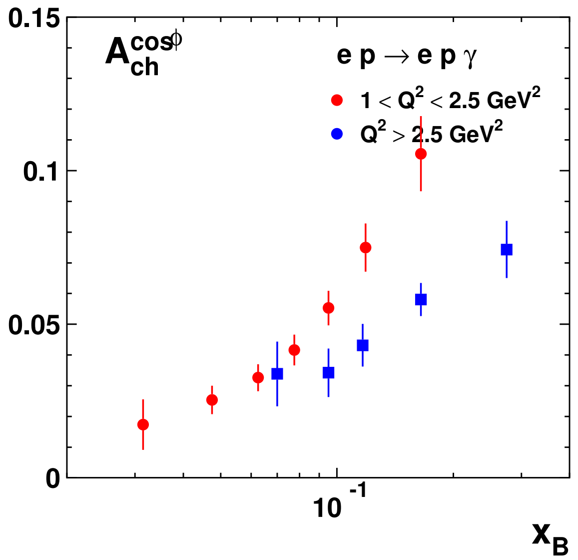
Asymmetry as a function of x_B and Δ^2 based upon GPDs version E).

DVCS Projections
$\sin\phi$ / $\cos\phi$ Moments





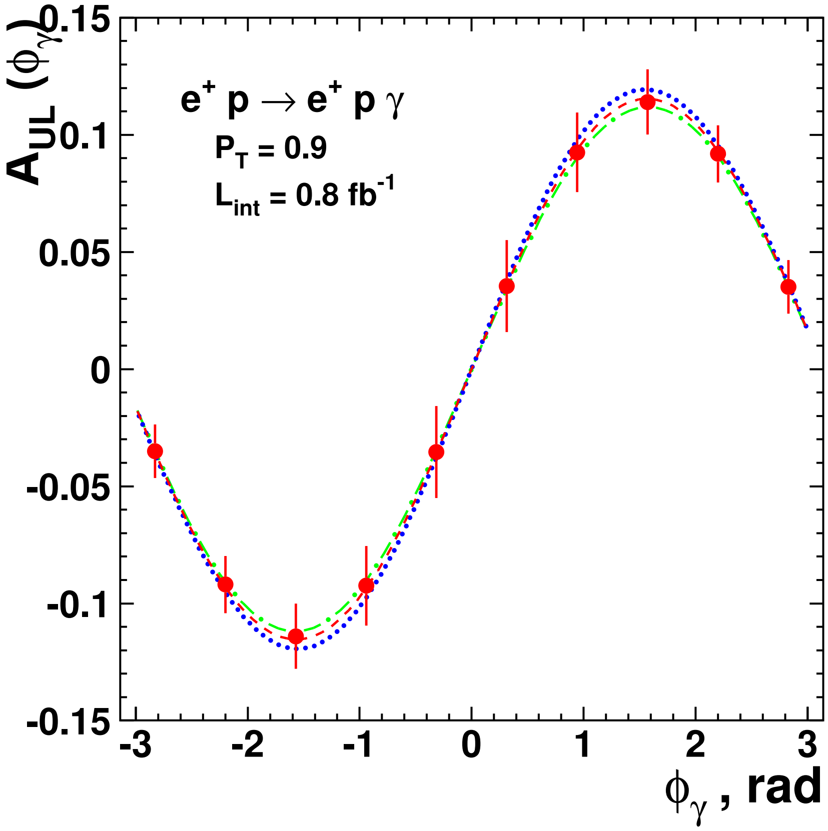




DVCS Projections
Long. Polarized Target

Unpolarized positron beam and longitudinally polarized target:

$$\Delta d\sigma \equiv d\sigma(e^+ \overrightarrow{p}) - d\sigma(e^+ \overleftarrow{p}) \sim$$
$$\text{Im} \left\{ \frac{x}{2-x}(F_1+F_2)\mathcal{H} + F_1\widetilde{\mathcal{H}} + \frac{x}{2-x}\left(\frac{x}{2}F_1 + \frac{\Delta^2}{4M^2}F_2\right)\widetilde{\mathcal{E}} \right\}$$



Assumptions:
i) Polarized target density by factor 2 high w.r.t. the present one.
ii) 3 years of running.

Summary

- HERMES has a plan to build a recoil detector and measure all particles produced in the DVCS.
- Prospects for future HERMES measurements are evaluated. Projected statistical accuracy in the beam helicity and lepton charge asymmetry measurements looks to be adequite to make a first comparison to GPD models.
- Measurements with polarised targets are possible but require increased target density.