Recent Spin Physics Results from HERMES

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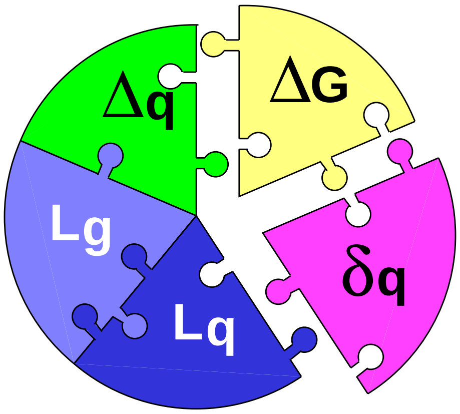
on behalf of the HERMES Collaboration



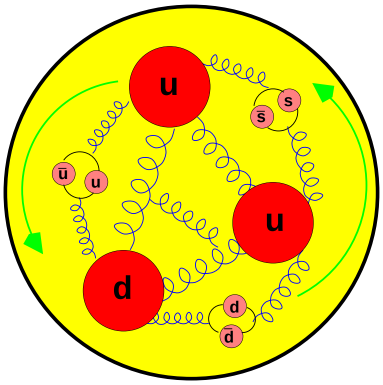
Outline

- Motivation
- The HERMES Spectrometer
- Inclusive and semi-inclusive polarised DIS
- Generalised Parton Distributions
- Deeply Virtual Compton Scattering
- Summary and Outlook

Motivation

the spin structure of the nucleon:

$$\langle S_z^{\mathrm{N}} \rangle = \frac{1}{2} = J_q + J_g$$
$$= \frac{1}{2}\Delta\Sigma + L_q + \Delta G + L_g$$



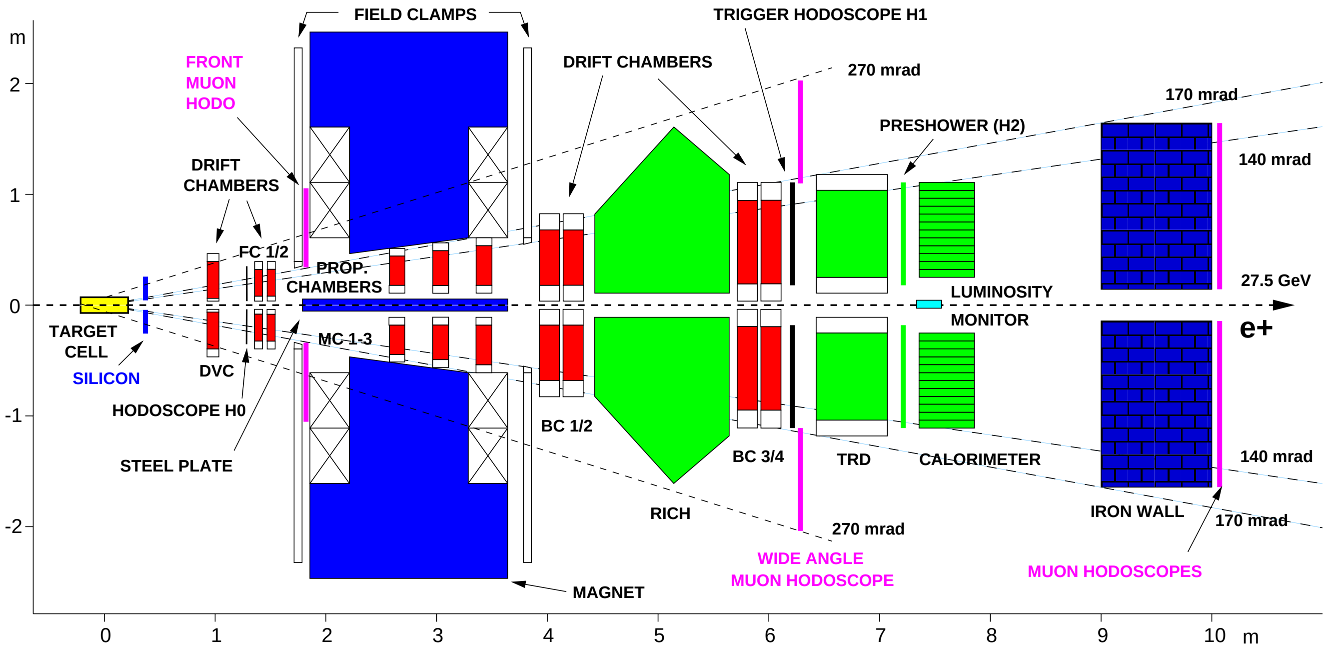
$\Delta\Sigma$ has been found to be small in inclusive DIS experiments

- 1988: EMC: *"spin crisis"* $\Delta\Sigma = 0.12 \pm 0.17 \approx 0$?
- 1988-2000: SLAC, CERN, DESY: $\Delta\Sigma \approx 0.2 \ldots 0.4 > 0$

possible contributions to $\langle S_z \rangle$ still unknown

- strange sea contribution Δs ?
- gluon contribution ΔG ? $\longrightarrow$ PGF
- orbital angular momentum $L_{q,g}$?

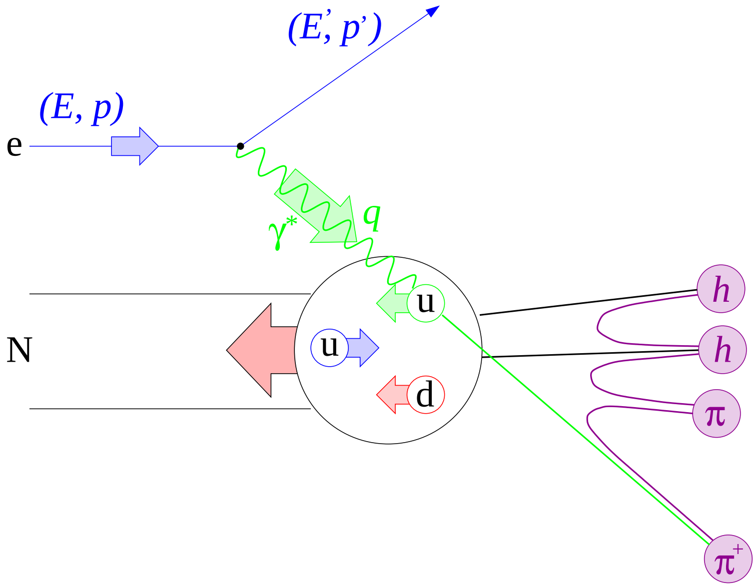
The HERMES Experiment at DESY



- targets $^3\vec{\mathrm{He}}$, $\vec{\mathrm{p}}$, $\vec{\mathrm{d}}$, p, d, Ne, Kr, ...
- e^+ (1998: e^-) at 27.5 GeV beam energy
- forward spectrometer with angular accept. $0.04 < |\Theta| < 0.22$ rad
- angular resol. $\Delta\Theta < 0.6$ mrad, momentum resol. $\Delta p/p = 0.7...1.3\%$
- energy resolution of e.m. calorimeter about 5%
- threshold Čerenkov detector replaced by a RICH detector in 1998
- lepton identification effic. $\sim$98%, low hadron contam. ($\leq 1\%$)

Polarised (Semi-)Inclusive Deep-Inelastic Scattering

in semi-inclusive DIS a hadron h is detected in coincidence with the scattered lepton:



kinematics:

$$\begin{aligned} Q^2 &\stackrel{\text{lab}}{=} 4EE'\sin^2(\Theta/2) \\ \nu &\stackrel{\text{lab}}{=} E - E' \\ x &\stackrel{\text{lab}}{=} Q^2/2M\nu \\ z &\stackrel{\text{lab}}{=} E_h/\nu \\ x_F &\simeq 2P^*_\parallel/W \end{aligned}$$

target fragments

current fragment

flavour tagging:

$\longrightarrow$ correlation between quark flavour q and type h of hadron via fragmentation function $D_q^h(z, Q^2)$

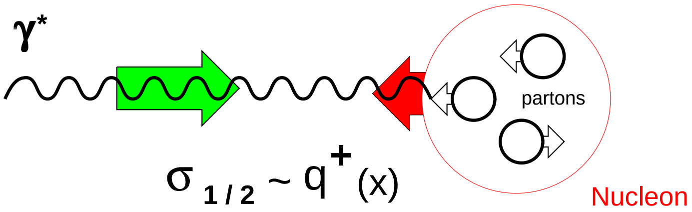
$\longrightarrow$ detection of hadrons from the current fragmentation:

$$z > 0.2$$
$$x_{\mathrm{F}} > 0.1$$

Spin Structure Functions in DIS

measure asymmetries w.r.t. orientation of beam and target spins

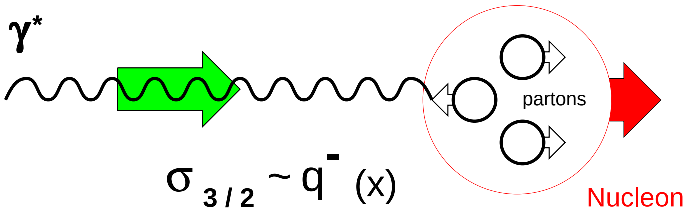
$$A_{\parallel} = \frac{\sigma^{\leftrightarrows} - \sigma^{\rightrightarrows}}{\sigma^{\leftrightarrows} + \sigma^{\rightrightarrows}}$$



relation to virtual photon asymmetries A_1 and A_2:

$$A_{\parallel} = D(A_1 + \eta A_2)$$

relation to structure functions g_1 and F_1:



$$A_1 \approx \frac{g_1}{F_1}$$

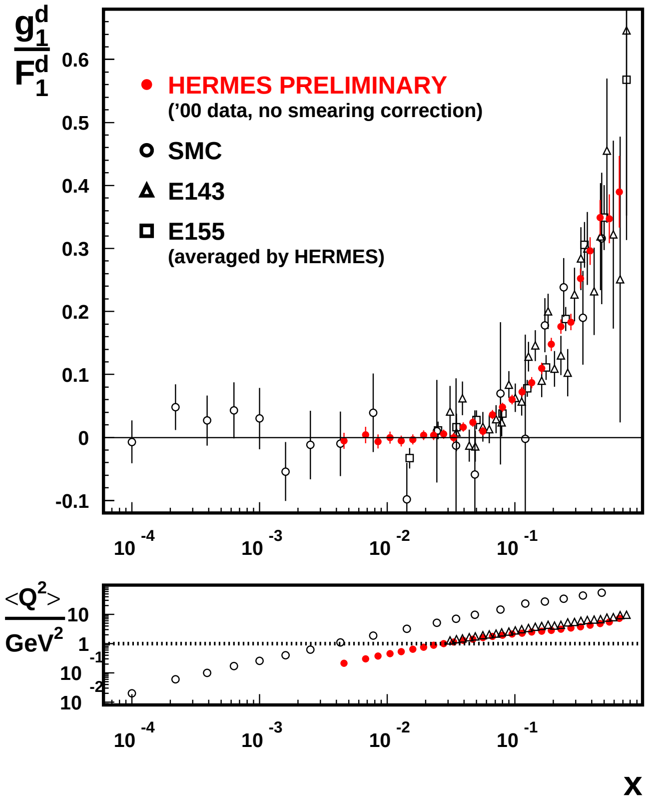
D: photon depolarization factor

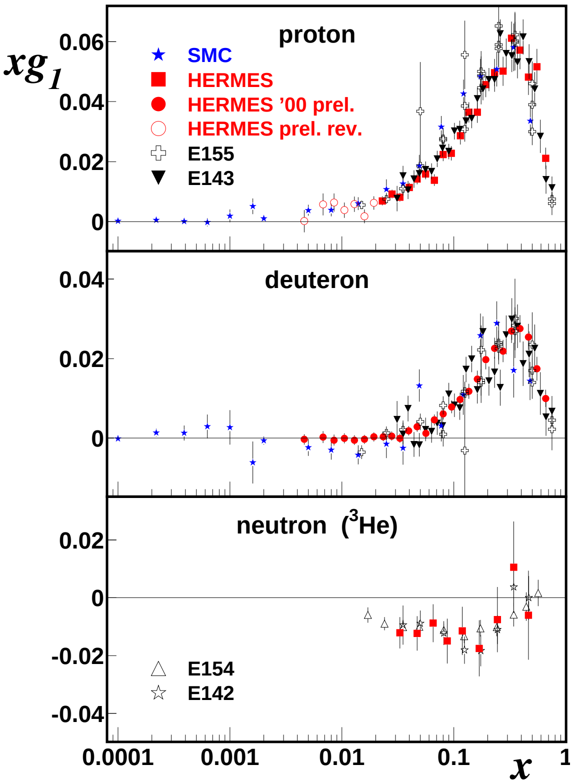
η: kinematic factor ($\eta \approx \stackrel{Q^2>>M^2}{\longrightarrow} 0$)

simple physical interpretation of g_1 and F_1 in terms of quark (helicity) distributions $q_f(x)$ and $\Delta q_f(x)$ (LO approach):

$$\begin{aligned} F_1(x) &= \frac{1}{2}\sum_f e_f^2 \quad q_f(x) = \frac{1}{2}\sum_f e_f^2 \left(q_f^+(x) + q_f^-(x)\right) \\ g_1(x) &= \frac{1}{2}\sum_f e_f^2 \Delta q_f(x) = \frac{1}{2}\sum_f e_f^2 \left(q_f^+(x) - q_f^-(x)\right) \end{aligned}$$

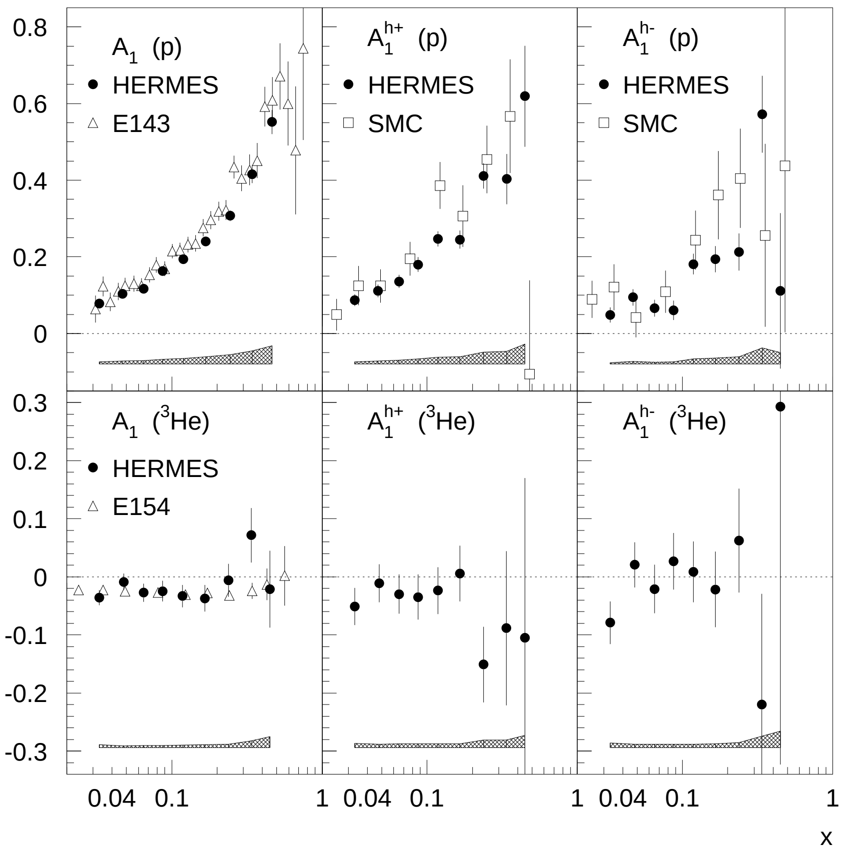
Spin Structure Functions - Measurement





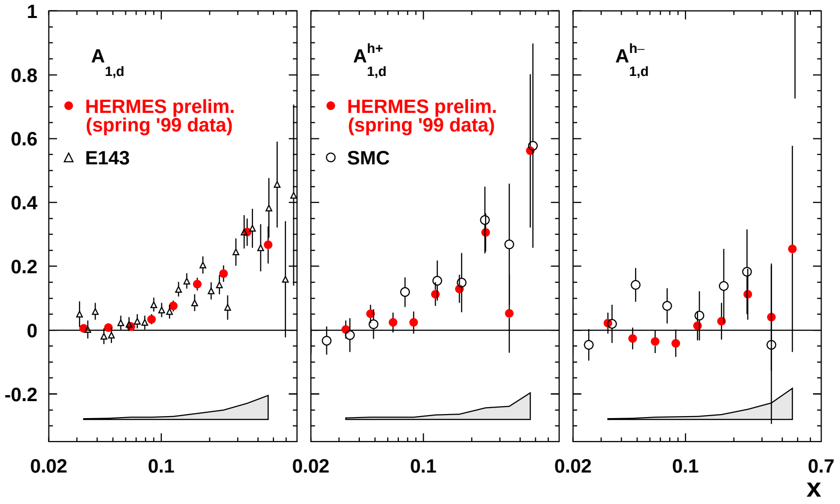
- $g_1^{\mathrm{d}}/F_1^{\mathrm{d}}$ based on 8 million DIS events
- $g_1^{\mathrm{d}}/F_1^{\mathrm{d}}$ independent of Q^2 in DIS region within uncertainties
- all data at measured values
- low-x proton data on xg_1 revisited
- 2000 data provide good statistics on xg_1 on deuterium target

Semi-Inclusive Asymmetries - Measurement



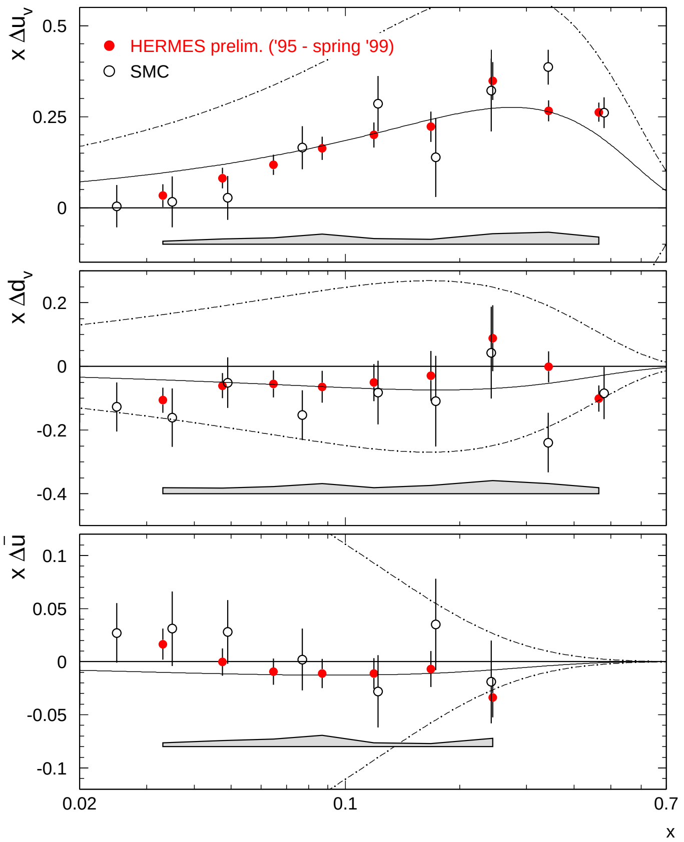
$A_1(h^{\pm})$ on p dominated by $\Delta u(x)$

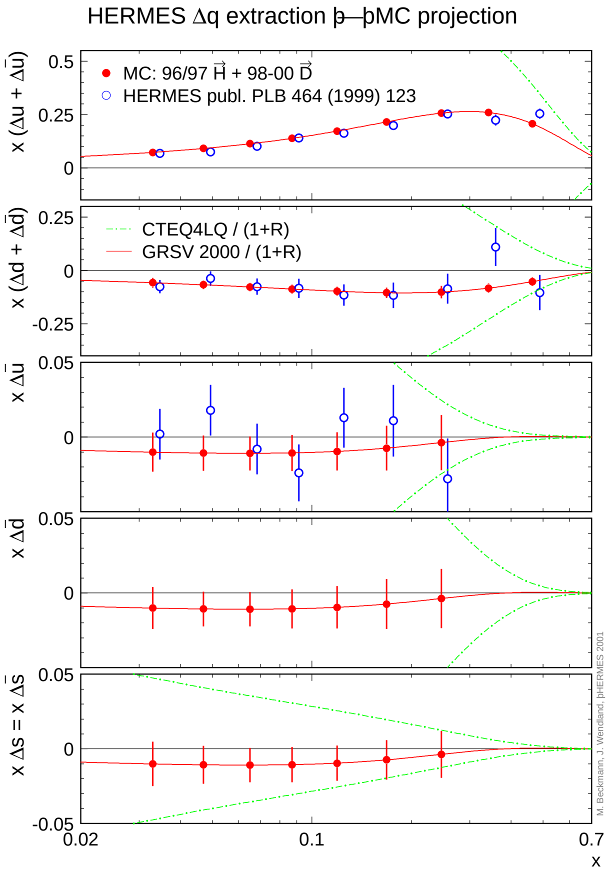
$A_1(h^{\pm})$ on n sensitive to $\Delta d(x)$



based on 1 million DIS events

Polarized Quark Distributions (LO)





solid lines: parametrization GRSV 96 (LO std.)

[Glück et al., PRD53(1996)4775]

dashed lines: positivity limits

sea quark pol. assumed to be flavour symmetric:

$$\frac{\Delta q_s}{q_s} \equiv \frac{\Delta u_s}{u_s} = \frac{\Delta \bar{u}}{\bar{u}} = \frac{\Delta d_s}{d_s} = \frac{\Delta \bar{d}}{\bar{d}} = \frac{\Delta s}{s} = \frac{\Delta \bar{s}}{\bar{s}}$$

projections based on full statistics

→ improvement in d quark sector

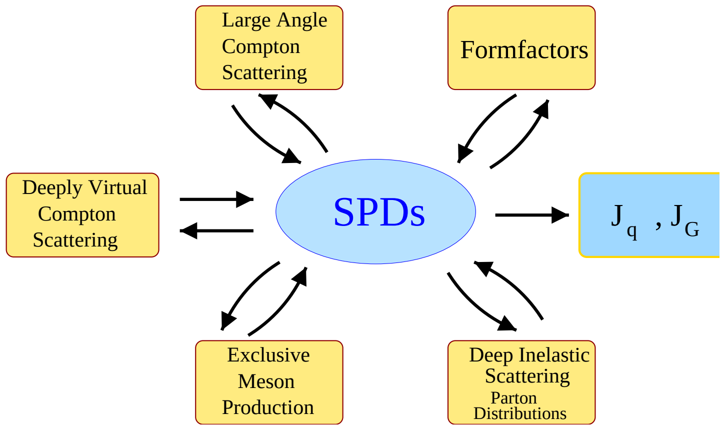
→ separation of sea quark flavours

$$\Delta\Sigma = 0.3 \pm 0.04 \pm 0.09$$

[HERMES, PLB464(1999)123]

polarized quark sea not yet separated

Generalized Parton Distributions and Hard Exclusive Processes

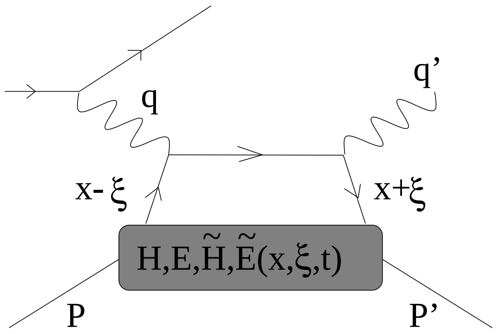


connection to angular momentum (Ji sum rule):

$$J_q = \frac{1}{2}\Delta\Sigma + L_q$$
$$= \frac{1}{2}\int_{-1}^{1} x\mathrm{d}x\,(H^q + E^q)$$

exclusive process:
all particles from process detected, or (e.g. via missing mass) identified

new observables in hard exclusive processes:
Generalized Parton Distributions:
$H, E, \tilde{H}, \tilde{E}(x, \xi, t)$
ξ: longitudinal momentum transfer, $(P' - P)^2 = t$

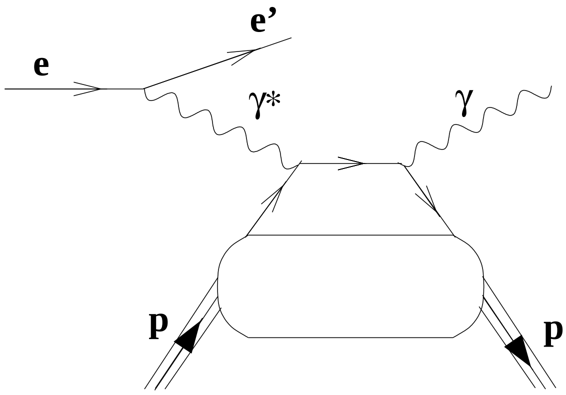


forward limit:
$$H^q(x,0,0) = q(x)$$
$$\tilde{H}^q(x,0,0) = \Delta q(x)$$

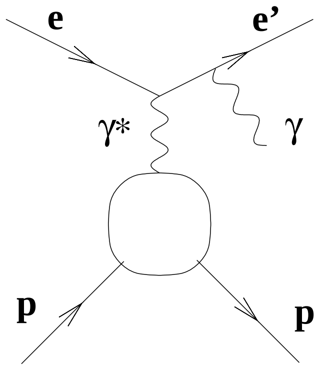
form factors
$$\int_{-1}^{+1} \mathrm{d}x H^q(x,\xi,t) = F_1^q(t)$$
$$\int_{-1}^{+1} \mathrm{d}x E^q(x,\xi,t) = F_2^q(t)$$
$$\int_{-1}^{+1} \mathrm{d}x \tilde{H}^q(x,\xi,t) = g_A^q(t)$$
$$\int_{-1}^{+1} \mathrm{d}x \tilde{E}^q(x,\xi,t) = h_A^q(t)$$

only polarized GPD's present in production of pseudoscalar mesons
only unpolarized GPD's present in production of vector mesons
All four GPD's present in Deeply Virtual Compton Scattering

Deeply Virtual Compton Scattering



DVCS process



Bethe-Heitler process

Amplitudes add up coherently, BH process dominant at HERMES kinematics

$\longrightarrow$ access to real and imaginary parts of amplitudes through interference by measuring asymmetries in ϕ_γ, the azimuthal angle between scattering plane and reaction plane

measurement of

beam charge asymmetry

$$\frac{\mathrm{d}\sigma\big(e^+p\big)-\mathrm{d}\sigma\big(e^-p\big)}{\mathrm{d}\sigma(e^+p)+\mathrm{d}\sigma(e^-p)}$$

real part of interference term

$\cos(\phi_\gamma)$ modulation

beam helicity asymmetry:

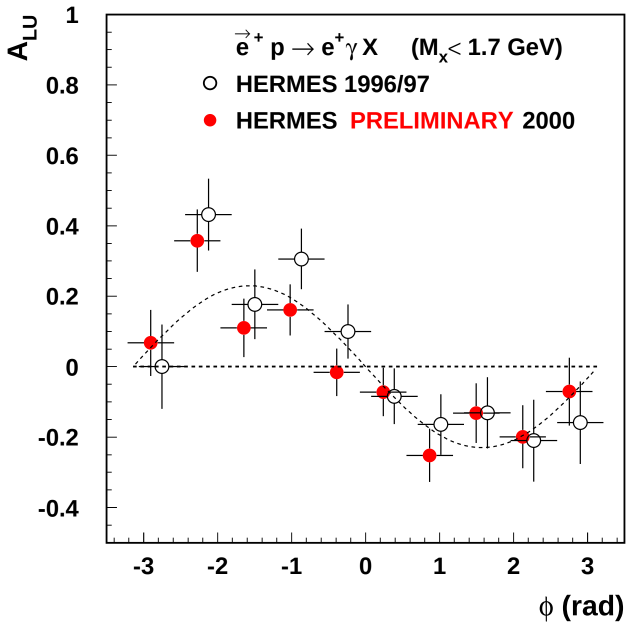
$$\frac{\mathrm{d}\sigma(\overrightarrow{e^+}p)-\mathrm{d}\sigma(\overleftarrow{e^+}p)}{\mathrm{d}\sigma(\overrightarrow{e^+}p)+\mathrm{d}\sigma(\overleftarrow{e^+}p)}$$

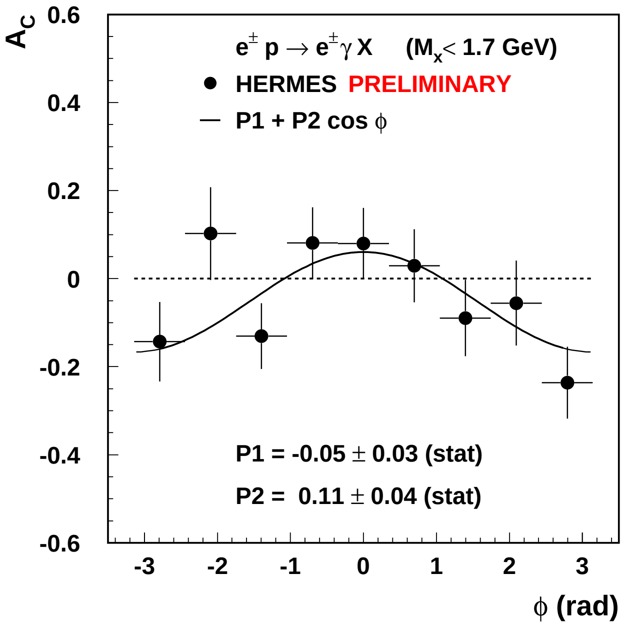
imaginary part of interference term

$\sin(\phi_\gamma)$ modulation

$\longrightarrow$ in principle use $\cos(\phi_\gamma)$ and $\sin(\phi_\gamma)$ moments to extract real and imaginary parts of DVCS amplitude

Deeply Virtual Compton Scattering
ϕ_γ Dependences





single spin asymmetry

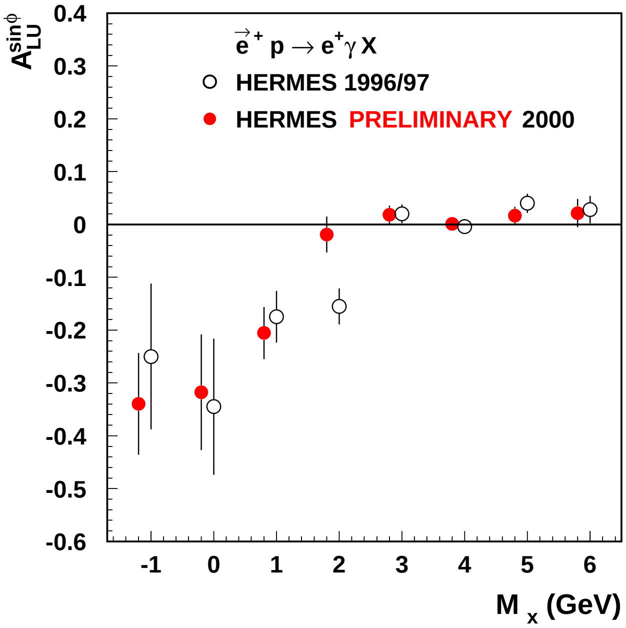
[96/97 data published in PRL87(2001)182001]

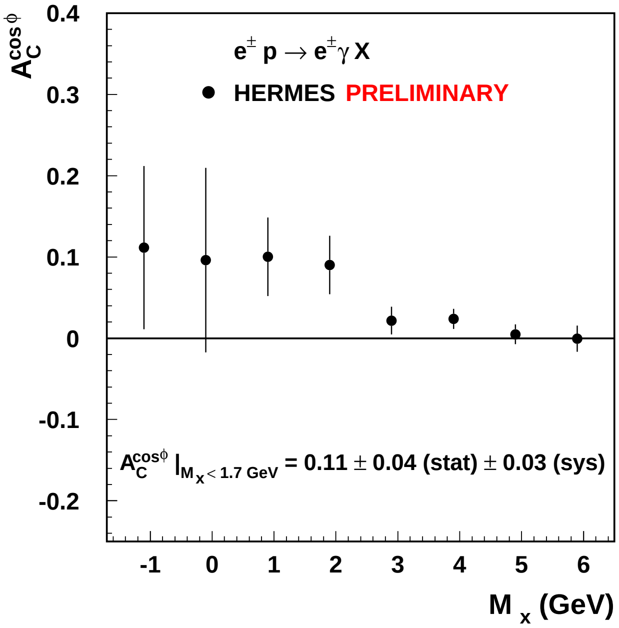
- statistical errors only
- each dataset based on about 5 million DIS events, and 4000 DVCS-type events
- average beam polarization 50%
- measured on polarized and unpolarized hydrogen

beam charge asymmetry

- statistical errors only
- e^+ and e^- datasets based on a total of about 5 million DIS events, and 4000 DVCS-type events
- measured on polarized (e^+, e^-) and unpolarized (e^+) hydrogen ($\rightarrow$ low e^- statistics)

Deeply Virtual Compton Scattering
Missing Mass Dependences





single spin asymmetry

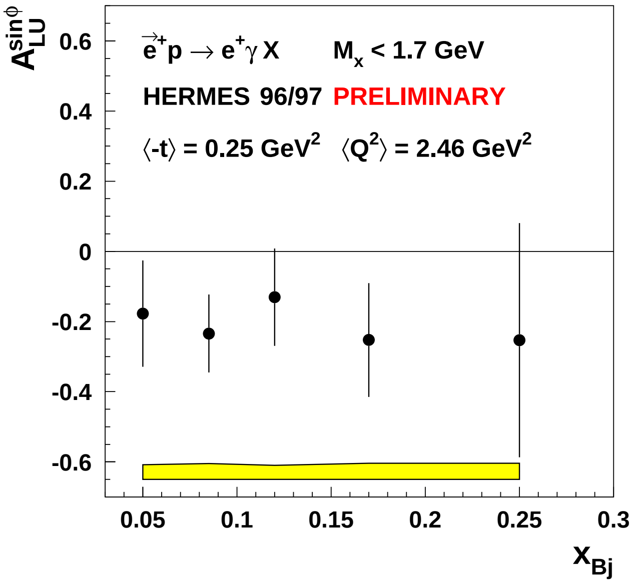
- statistical errors only
- $A_{\mathrm{LU}}^{\sin(\phi)} = -0.21 \pm 0.04(stat) \pm 0.04(syst)$
  (exclusive bin -1.5 GeV $< M_x <$ 1.7 GeV)

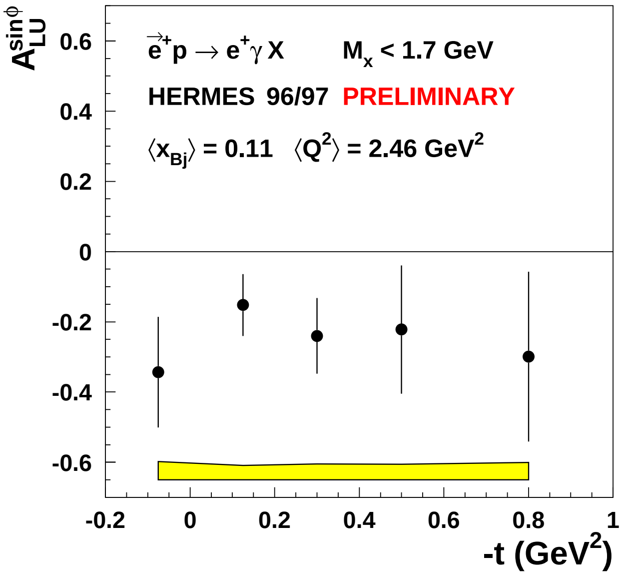
beam charge asymmetry

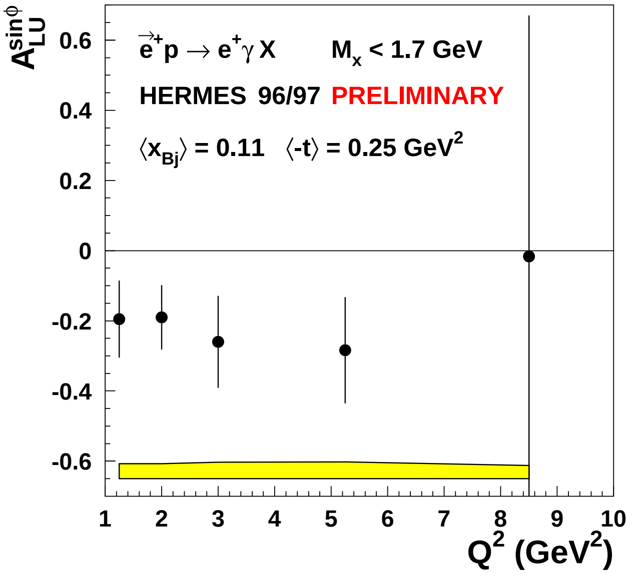
- statistical errors only
- $A_{\mathrm{C}}^{\cos(\phi)} = 0.11 \pm 0.04(stat) \pm 0.03(syst)$
  (exclusive bin: -1.5 GeV $< M_x <$ 1.7 GeV)

[96/97 data published in PRL87(2001)182001]

Deeply Virtual Compton Scattering SSA Kinematical Dependences







- ○ first kinematic dependences of DVCS single spin asymmetry
- ○ no significant kinematic dependences observed

Summary and Outlook

- spin physics is an exciting and rapidly developing field
- Δq:
  - extraction yields parallel (antiparallel) alignment of valence u-(d)-quarks with nucleon spin
  - sea quark contribution compatible with zero
  - more precise data will soon be available

    $\Rightarrow$ better separation of sea quark flavours
- DVCS:
  - first study of kinematical dependences of SSA
  - first measurement of beam charge asymmetry
  - new data will soon be available

    $\Rightarrow$ study of deuterium target data

    $\Rightarrow$ study of target spin asymmetry
- after 2002 HERA startup, running with transversely polarized hydrogen target $\longrightarrow$ transversity, δq