Prospects for HERMES Run II

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DIS 2001

Bologna, April 30, 2001

The 3 MAIN PHYSICS OBJECTIVES for HERMES running in the years 2001+ are:

(1) Measurement of transversity distributions δq

Hitherto unmeasured

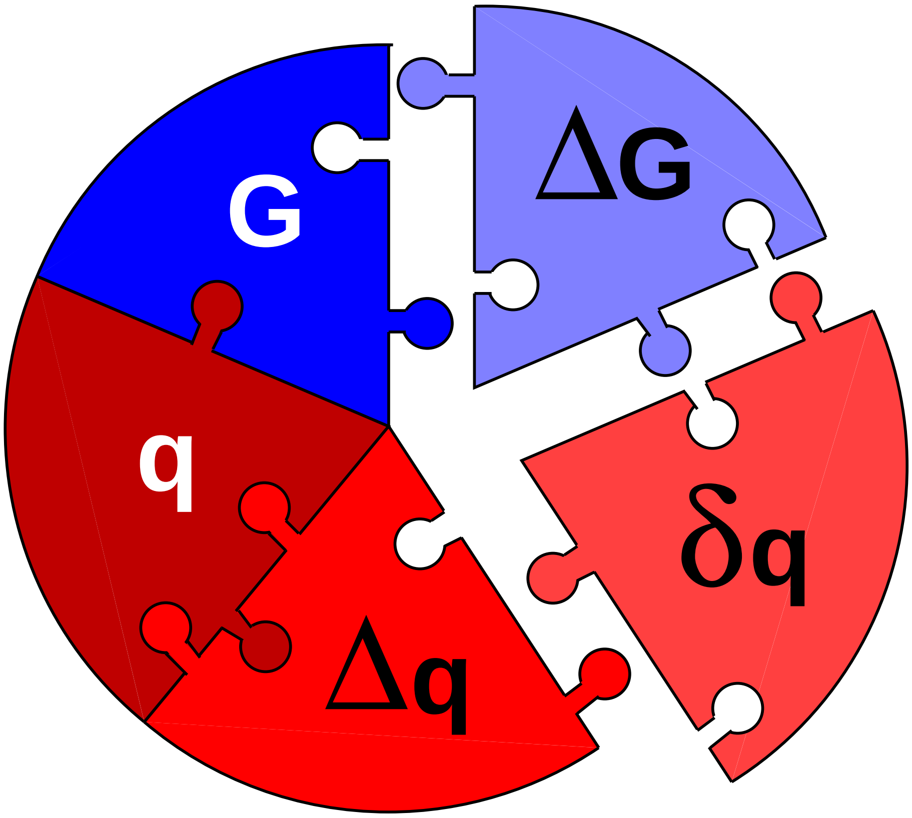
(2) Improved measurement of helicity distributions Δq

Present status: M. Beckmann, spin session

(3) Measurement of exclusive reactions to access Skewed Parton Distributions

Present status: J. Volmer, spin session

Twist-2 Parton Distributions



$q(x, Q^2)$	QUARK NUMBER DENSITY DISTRIBUTION (f_1^q)
$\Delta q(x, Q^2)$	QUARK HELICITY DISTRIBUTION (g_1^q)
$\delta q(x, Q^2)$	QUARK TRANSVERSITY DISTRIBUTION (h_1^q)
$G(x, Q^2)$	GLUON NUMBER DENSITY DISTRIBUTION
$\Delta G(x, Q^2)$	POLARIZED GLUON DISTRIBUTION

Transversity

- AS CHIRAL-ODD OBJECT NOT ACCESSIBLE IN DIS
  since qγ- and qg-couplings preserve chirality
- BUT ACCESSIBLE IN SIDIS
  in combination with a chiral-odd fragmentation function
  $\rightarrow$ extraction is NOT straightforward

Transversity at HERMES

Measure $\delta q(x)$ in SIDIS at HERMES via

(1) Twist-3 pion production in SIDIS (Jaffe, Ji, 93)

(2) Measurement of the transverse polarization of Λ's in the current fragmentation region (Baldracchini,82 Jaffe,96)

(3) Observation of the Collins effect in quark fragmentation (through the measurement of pion single target-spin asymmetries) (Collins,93, Kotzinian, 95, Mulders et al,96)

(4) Measurement of a correlation in 2-meson production (between transverse spin vector of target nucleon and normal to the two-meson plane) (Jaffe et al.,97)

(5) Measurement of spin-1 hadron production in SIDIS (Bacchetta, Mulders, 00)

Note: Methods (2)-(5) require a transversely polarized target only

Projections for $ep^{\uparrow}(d^{\uparrow}) \to e'\pi X$

$E = 27.5$ GeV, $P_T = 0.75$

Statistics expected for 2001+: $7 \cdot 10^6$ reconstr. DIS events

DIS cuts: $Q^2 > 1$ GeV^2, $W > 2$ GeV,
$0.02 < x < 0.7$, $y < 0.85$

From HERMES MC: pion distributions, acceptance

Cuts for pion kinematics:
$x_F > 0.$, $z > 0.1$, $P_{h\perp} > 0.05$ GeV

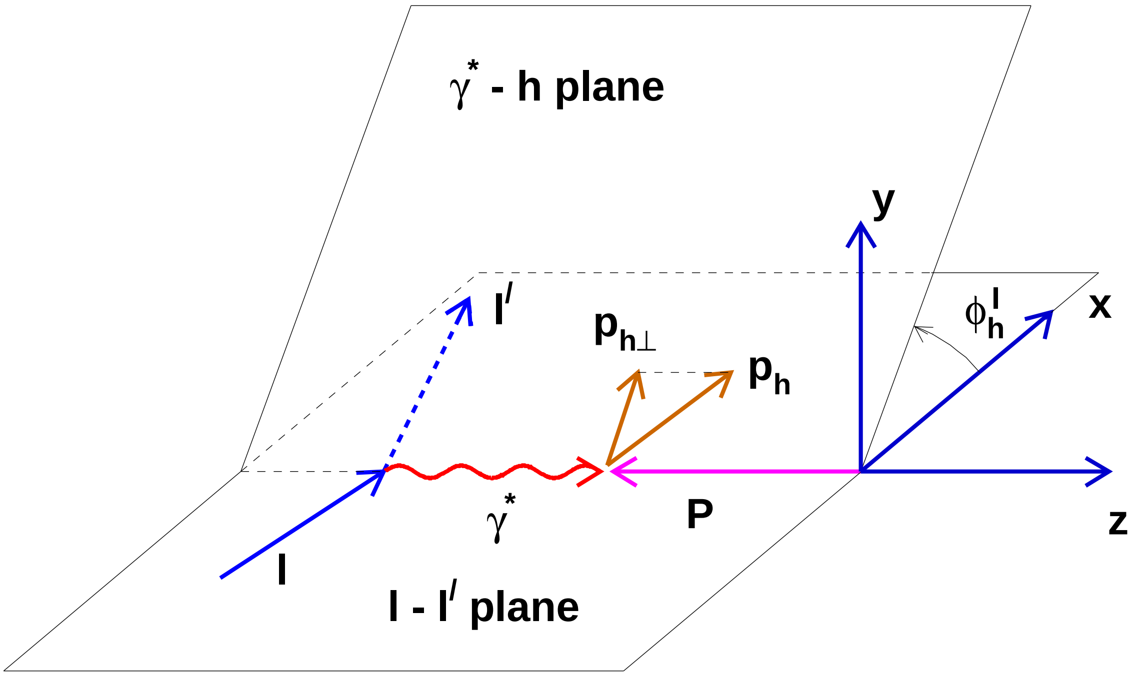
Transversity through the Collins Effect: Method

weighted asymmetry

[Mulders, Tangermann 96, Kotzinian, Mulders 97]

$$A_T(x,y,z) \equiv \frac{\int d\phi^\ell \int d^2P_{h\perp} \frac{|P_{h\perp}|}{zM_h} \sin(\phi_s^\ell + \phi_h^\ell)\ (d\sigma^\uparrow - d\sigma^\downarrow)}{\int d\phi^\ell \int d^2P_{h\perp}(d\sigma^\uparrow + d\sigma^\downarrow)}$$

ϕ_s^l is azimuthal angle of target spin vector w.r.t. γ^* axis



Factorization w.r.t. x and z:

$$A_T(x,y,z) = f \cdot P_T \cdot D_{nn} \cdot \frac{\sum_q e_q^2\ \delta q(x)\ H_1^{\perp(1)q}(z)}{\sum_q e_q^2\ q(x)\ D_1^q(z)}$$

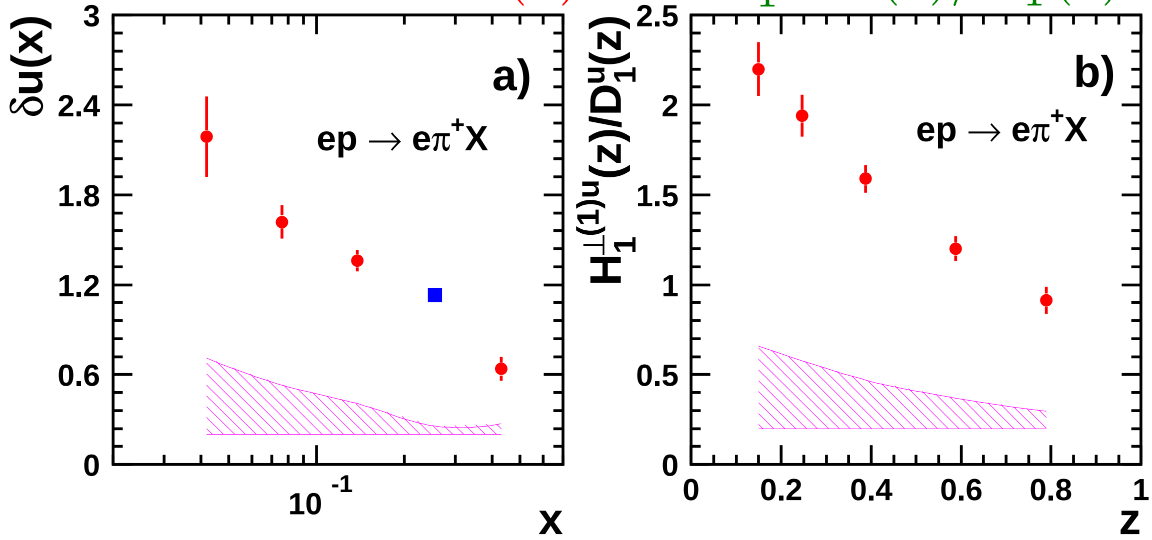
$D_{nn} = (1-y)/(1-y+y^2/2)$: transverse spin transfer coefficient

NOTE: $H_1^{\perp(1)q}$ accessible from e^+e^- data (LEP,Belle)

Transversity through the Collins Effect: Prospects [1]

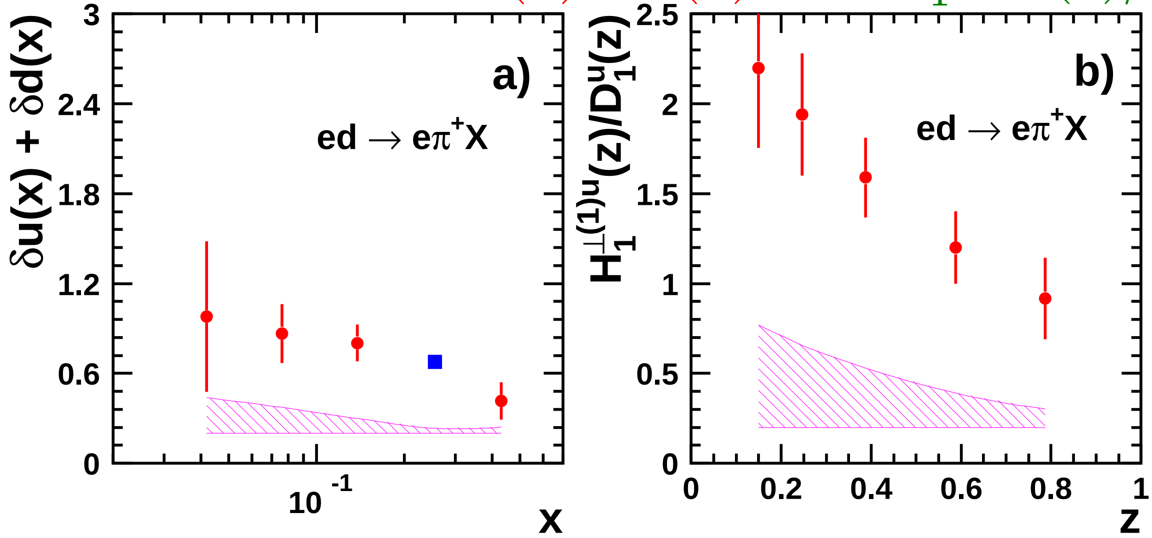
OPTION 1: proton target

Projections for $\delta u(x)$ and $H_1^{\perp(1)u}(z)/D_1^u(z)$



OPTION 2: deuteron target

Projections for $\delta u(x)+\delta d(x)$ and $H_1^{\perp(1)u}(z)/D_1^u(z)$



$\Rightarrow$ HERMES chose option 1 for 2001+

NOTE: δd extraction possible by adding option 2
(→ combined analysis)

[1] [V.Korotkov, W.-D.N.,K.Oganessyan, EPJC 18, 639 (2001)]

Δq-Extraction

- rewrite photon-nucleon asymmetry

$$A_1^h(x,z) = \sum_q \left[\underbrace{\frac{e_q^2\ q(x)\cdot D_q^h(z)}{\sum_{q'} e_{q'}^2\ q'(x)\cdot D_{q'}^h(z)}}_{P_q^h(x,z)} \right] \cdot \frac{\Delta q(x)}{q(x)}$$

- Purity $P_q^h(x,z)$ gives probability that a quark $q(x)$ was struck when a hadron $h(z)$ is detected

- Purities are spin-independent quantities (fragmentation process spin-independent for longitudinal quark polarization)

- Define

$$\vec{A} = \begin{pmatrix} A_1^{h_1(x)} \\ \ldots \\ A_1^{h_m(x)} \end{pmatrix} \quad \mathcal{P} = \left[P_q^{h_j}(x) \right]_{mn} \quad \vec{Q} = \begin{pmatrix} \Delta q_1(x)/q_1(x) \\ \ldots \\ \Delta q_n(x)/q_n(x) \end{pmatrix}$$

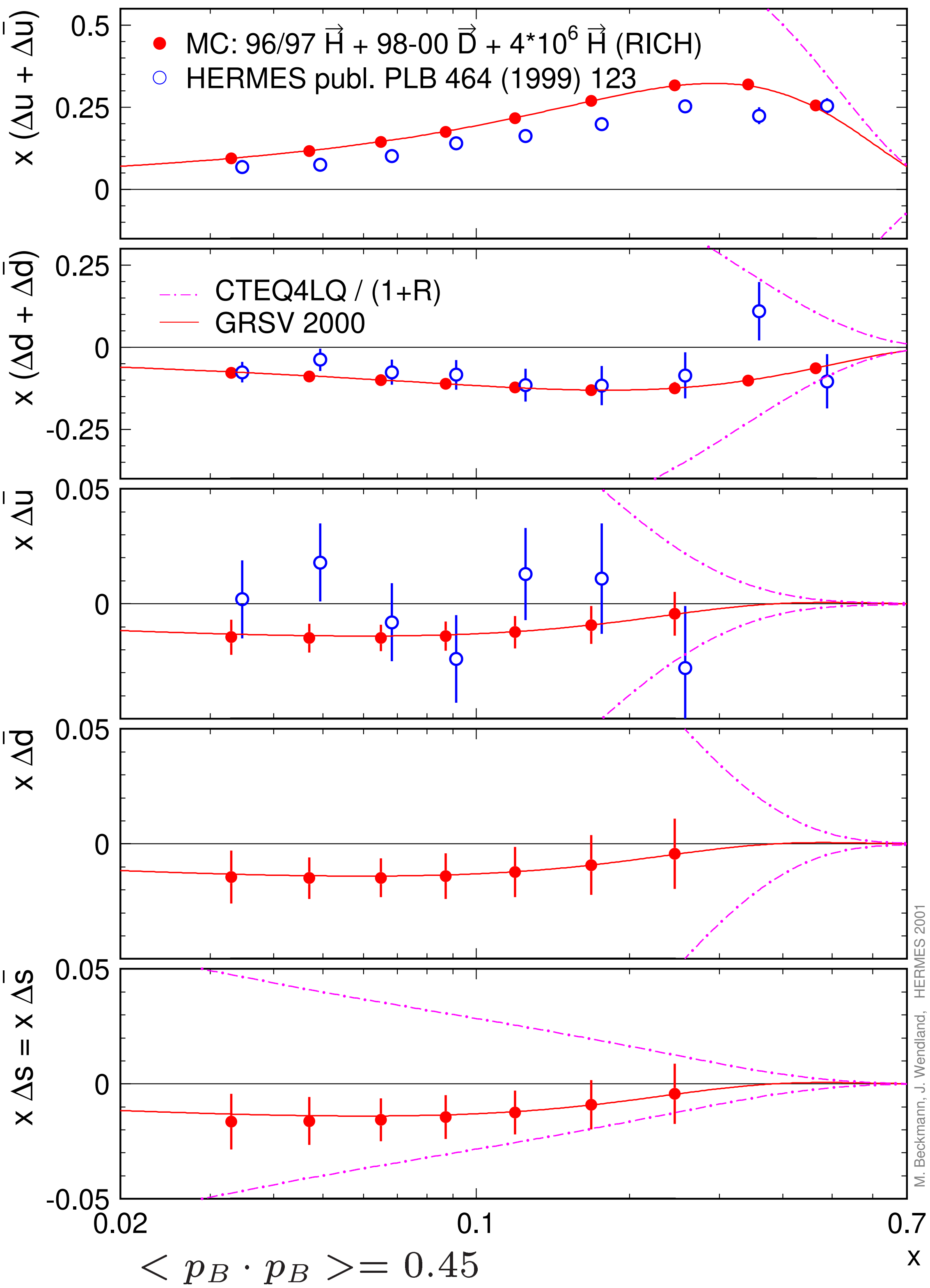
where $P_q^h(x) = \int_{z_{min}}^1 P_q^h(x,z)\ dz$

- to extract quark polarizations solve

$$\vec{A} = \mathcal{P}\vec{Q}$$

Δq-Extraction – Projections [2]

HERMES Δq extraction — MC projection



$< p_B \cdot p_B >= 0.45$

[2][M.Beckmann, J.Wendland, priv. comm.]

Skewed Parton Distributions and DVCS

Skewed (or Generalized, or off-forward)
Parton
Distributions:

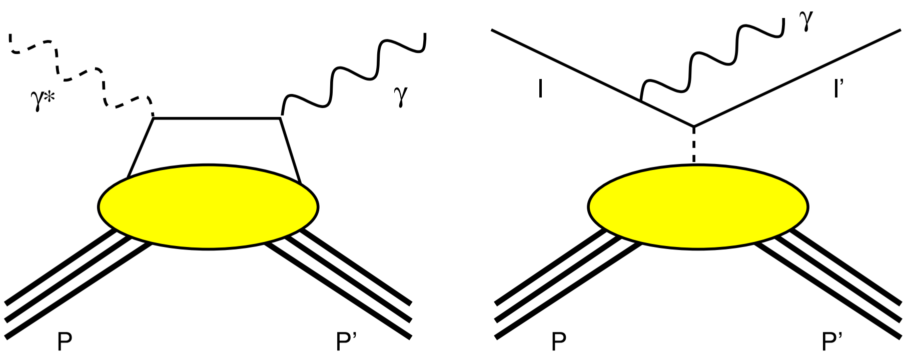
Unified theoretical description of inclusive and (hard) exclusive processes

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

Consider $\gamma^* p$ in Bjorken limit $\Longrightarrow$
Deeply Virtual Compton Scattering

- Highly virtual quark in γ^* scattering
  $\longrightarrow$ propagates perturbatively
- Simplest (and dominating) QCD mechanism to form Compton final state: quark radiates real γ and falls back to nucleon ground state
  ('hand-bag' subprocess in pQCD)

$\Downarrow$



DVCS

Bethe-Heitler $\Rightarrow$ p.t.o.

$\Rightarrow$ Interference gives access to DVCS amplitudes

DVCS and Bethe-Heitler

Bethe-Heitler (BH):

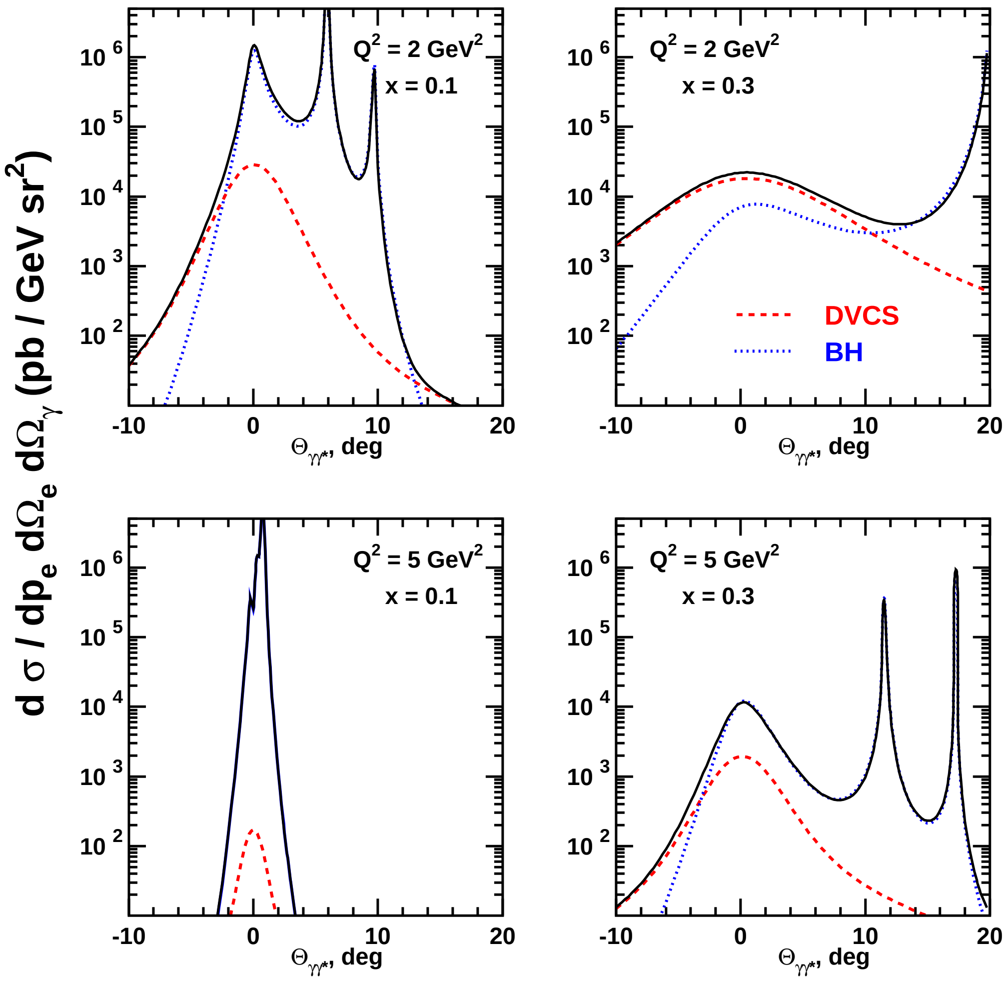
(Elastic lepton-proton scattering with γ radiation by lepton in initial or final state)

Interfering process leading to same final state

Can be exactly calculated when Dirac and Pauli form factors known

Cross sections at E=27.5 GeV (HERMES):

'In-plane' cross section: scattering plane = reaction plane (see below)



DVCS dominated by BH in most of kin. region !

DVCS-BH interference:

$\Longrightarrow$ Use BH as a vehicle to study DVCS !

SPDs and DVCS (II)

- Skewed Parton Distributions:
  generalization of usual Parton Distributions and nucleon form factors
- Usual parton distributions (PDs): probability to find a parton in the nucleon with momentum fraction x
- SPDs: interference of 2 wave functions:
  parton with $x + \xi$ emitted from nucleon,
  parton with $x - \xi$ falls back
  (SPDs sensitive to momentum correlations)

Variables:

- Parton long. momentum fractions x and ξ
- $\gamma^* \to \gamma$ mom. transfer $\Delta^2 = (p_{\gamma^*} - p_\gamma)$ (or t)

In DVCS: 4 different quark SPDs (per flavor)

$H^q(x, \xi, \Delta^2)$, $\widetilde{H}^q(x, \xi, \Delta^2)$ conserve nucleon helicity

$E^q(x, \xi, \Delta^2)$, $\widetilde{E}^q(x, \xi, \Delta^2)$ flip nucleon helicity

$\Downarrow$ $\Downarrow$

unpolarized polarized SPDs

In the limit $\Delta^\mu = 0$ (i.e. $\xi = 0$):

$$H^q(x, 0, 0) = q(x), \quad \widetilde{H}^q(x, 0, 0) = \Delta q(x)$$

$q(x)$ and $\Delta q(x)$: quark distr. and quark helicity distr.
(no 'usual' PD equivalents for E^q and $\widetilde{E}^q$)

SPDs and DVCS (III)

1st MOMENTS connected via sum rules to form factors.

2nd MOMENT of unpolarized SPDs in limit $\Delta^2 = 0$:

$\Longrightarrow$ total quark angular momentum [X.Ji]:

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

Real and imaginary parts of DVCS amplitudes $\mathcal{H}_1, \widetilde{\mathcal{H}}_1, \mathcal{E}_1, \widetilde{\mathcal{E}}_1$ can be expressed through SPDs $H, \widetilde{H}, E, \widetilde{E}$. ($P$ denotes Cauchy's principal value):

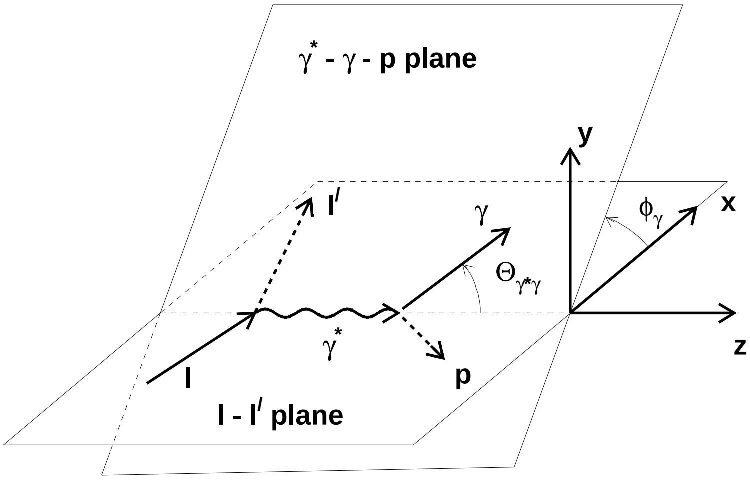
$$\begin{aligned}
\mathrm{Im}\, \mathcal{H}_1 &= -\pi \sum_q e_q^2 \left(H(\xi, \xi, \Delta^2) - H(-\xi, \xi, \Delta^2) \right) \\
\mathrm{Im}\, \widetilde{\mathcal{H}}_1 &= -\pi \sum_q e_q^2 \left(\widetilde{H}(\xi, \xi, \Delta^2) + \widetilde{H}(-\xi, \xi, \Delta^2) \right) \\
\mathrm{Re}\, \mathcal{H}_1 &= \sum_q e_q^2 \left[P \int_{-1}^{+1} H(x, \xi, \Delta^2) \left(\frac{1}{x - \xi} + \frac{1}{x + \xi} \right) dx \right] \\
\mathrm{Re}\, \widetilde{\mathcal{H}}_1 &= \sum_q e_q^2 \left[P \int_{-1}^{+1} \widetilde{H}(x, \xi, \Delta^2) \left(\frac{1}{x - \xi} - \frac{1}{x + \xi} \right) dx \right]
\end{aligned}$$

Analogous expressions for amplitudes $\mathcal{E}_1$, $\widetilde{\mathcal{E}}_1$.

$\Longrightarrow$ Extraction of SPDs will be a complex task

ϕ-DEPENDENCE OF ASYMMETRIES

DVCS KINEMATICAL CONFIGURATION:



ϕ_γ: azimuthal angle between scattering and reaction plane.

ϕ_γ: ASYMMETRIES SHOW DIFFERENT CHARACTERISTICS

A) MEASURE LEPTON CHARGE ASYMMETRY:

unpolarized beam, unpolarized target (A_{ch})

$$\Delta_{\text{ch}} d\sigma^{\text{unpol}} \equiv d\sigma(e^+p) - d\sigma(e^-p)$$

$$\sim \cos(\phi_\gamma) \times \text{Re}\left\{F_1\mathcal{H}_1 + \frac{x_B}{2-x_B}(F_1+F_2)\widetilde{\mathcal{H}}_1 - \frac{\Delta^2}{4M^2}F_2\mathcal{E}_1\right\}$$

$\Rightarrow$ ACCESS TO REAL PART OF $\mathcal{H}_1, \widetilde{\mathcal{H}}_1$

B) MEASURE LEPTON HELICITY ASYMMETRY:

long. polarized beam, unpolarized target (A_{LU})

$$\Delta d\sigma \equiv d\sigma(\overrightarrow{e}^+p) - d\sigma(\overleftarrow{e}^+p)$$

$$\sim \sin(\phi_\gamma) \times \text{Im}\left\{F_1\mathcal{H}_1 + \frac{x_B}{2-x_B}(F_1+F_2)\widetilde{\mathcal{H}}_1 - \frac{\Delta^2}{4M^2}F_2\mathcal{E}_1\right\}$$

$\Rightarrow$ ACCESS TO IMAGINARY PART OF $\mathcal{H}_1, \widetilde{\mathcal{H}}_1$

HERMES Measurements with a Recoil Detector, Projections (i)

- ▷ SPDs modeled according to
  [M.Vanderhaeghen, P.Guichon, M.Guidal, PRD 60 (99) 094017]
  Most simple ansatz is to neglect ξ dependence.
  Then e.g.

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

  similar expressions for $H^{q/p} \to \widetilde{H}^{q/p}$.

- ▷ $u(x)$ and $d(x)$:
  usual unpolarized quark distributions

- ▷ proton and neutron el.magn. form factors used to construct flavor-dependent Dirac and Pauli form factors

- ▷ annual integrated luminosity: $2\ fb^{-1}$
  (unpolarized target)

- ▷ HERMES acceptance taken in account for all involved particles

- ▷ kinematical cuts

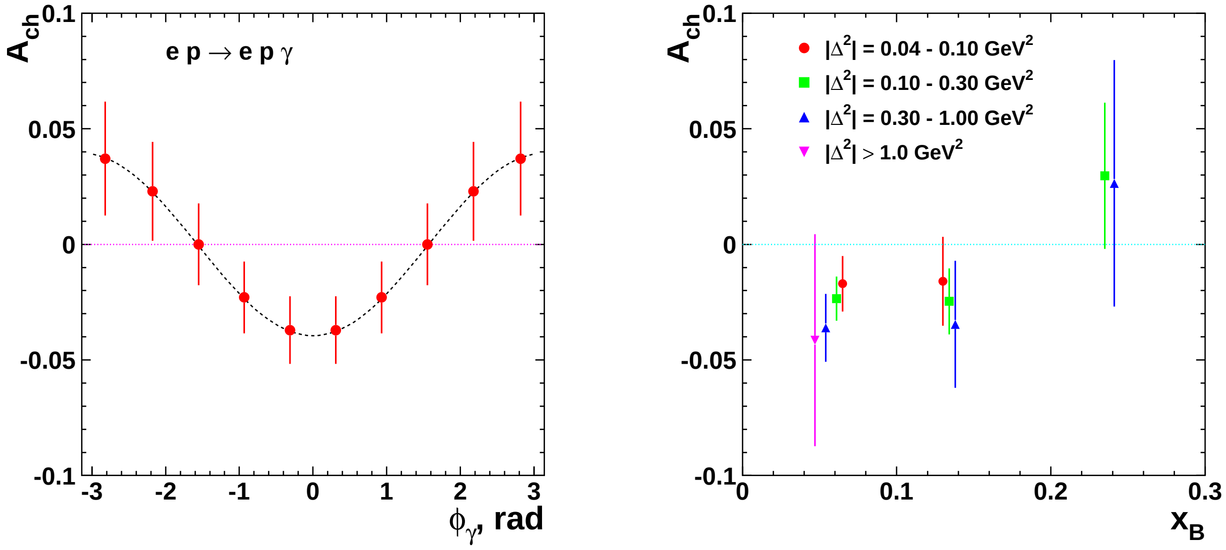
$E_e > 3.5\ GeV$ $\quad E_\gamma > 1\ GeV$ $\quad P_p > 0.2\ GeV$

$W^2 > 4\ GeV^2$ $\quad Q^2 > 1\ GeV^2$ $\quad 15 < \Theta_{\gamma\gamma^*} < 70\ mrad$

HERMES Measurements with a Recoil Detector, Projections[3] (ii)

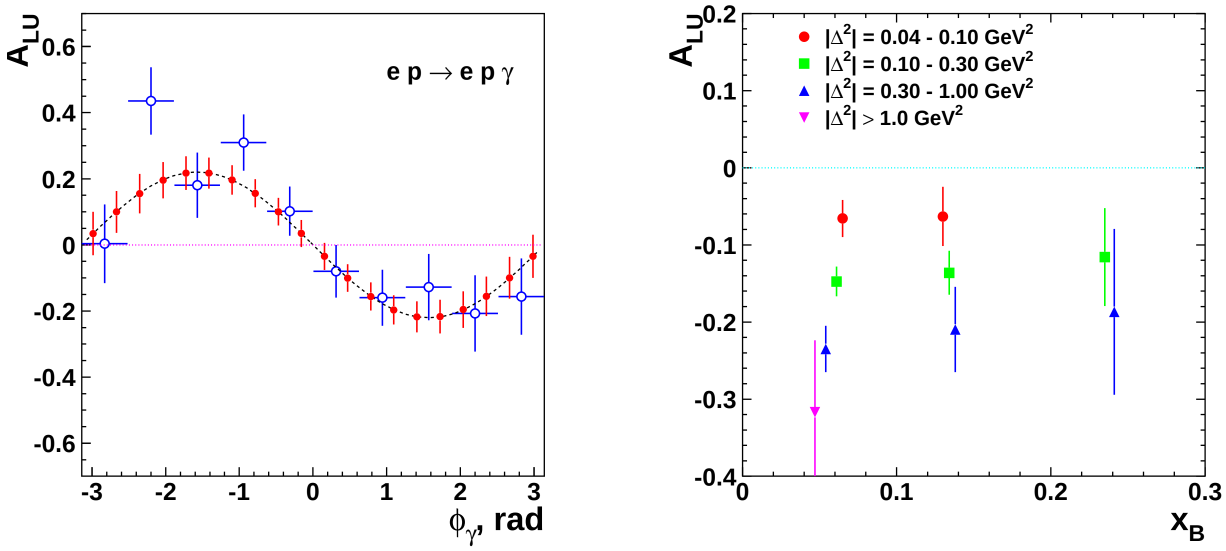
A) Measure lepton charge asymmetry in DVCS:

unpolarized beam, unpolarized target



B) Measure lepton helicity asymmetry in DVCS:

polarized beam, unpolarized target

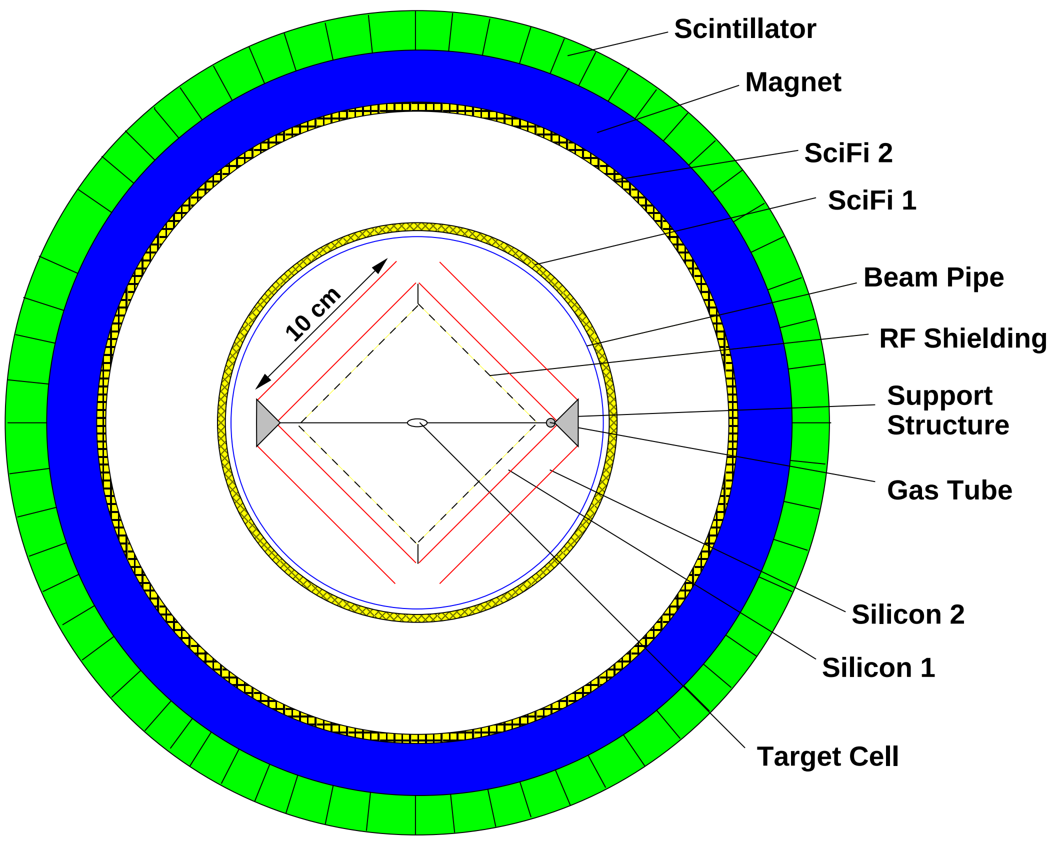


Open circles in left panel: HERMES PRELIMINARY (1996/97 data)

[3] [V.Korotkov, W.-D.N., in prep.]

A new Recoil Detector for Hard Exclusive Reactions

DVCS	$\gamma^* p$	$\longrightarrow$	$\gamma\ p$	$\mathbf{H}\ \tilde{\mathbf{H}}\ \mathbf{E}\ \tilde{\mathbf{E}}$
exclusive pseudoscalar meson production	$\gamma^* p$	$\longrightarrow$	$\pi^0\ p$	$\tilde{\mathbf{H}}\ \ \tilde{\mathbf{E}}$
	$\gamma^* p$	$\longrightarrow$	$\pi^+\ n$	
exclusive vector meson production	$\gamma^* p$	$\longrightarrow$	$\rho^0\ p$	$\mathbf{H}\ \ \mathbf{E}$
	$\gamma^* p$	$\longrightarrow$	$\omega\ p$	
	$\gamma^* p$	$\longrightarrow$	$\phi\ p$	



Schematic cross section

Long-term Objectives

Once J_q will have been determined from (a variety of) SPD measurements with acceptable accuracy, two remaining major unknowns in the nucleon spin puzzle get into reach:

L_q: quark orbital angular momentum, through

$$J_q = \frac{1}{2}\Delta\Sigma + L_q$$

since quark contribution to the nucleon spin, $\Delta\Sigma$, well measured already now.

L_g: gluon orbital angular momentum, through

$$\frac{1}{2} = J_q + J_g \; ; \qquad J_g = \Delta G + L_g$$

since gluon contribution to the nucleon spin, ΔG, expected to be well measured in a few years [COMPASS, RHIC]

$\Longrightarrow$ Strong motivation for future Lepton-Nucleon scattering experiments in

- U.S. (JLab, EIC)
- Europe (ELFE/TESLA-N at DESY)

  [cf. talk by D. Ryckbosch]

SUMMARY

- A TRANSVERSELY POLARIZED PROTON TARGET WILL ALLOW THE DETERMINATION OF THE UNMEASURED u-QUARK TRANSVERSITY DISTRIBUTION IN CONJUNCTION WITH A POLARIZED FRAGMENTATION FUNCTION

- A NEW RECOIL DETECTOR IN COMBINATION WITH AN UNPOLARIZED PROTON TARGET WILL LEAD TO SIGNIFICANT IMPROVEMENTS IN RESOLUTION AND STATISTICS IN MEASURING HARD EXCLUSIVE REACTIONS (DVCS, PSEUDOSCALAR AND VECTOR MESON PRODUCTION) TOWARDS AN EXTRACTION OF SKEWED PARTON DISTRIBUTIONS

- A LONGITUDINALLY POLARIZED PROTON TARGET MAY AGAIN BE USED TO SIGNIFICANTLY IMPROVE THE SEPARATION OF THE u-, d- AND s-QUARK HELICITY DISTRIBUTIONS

- A LARGE VARIETY OF HIGHLY INTERESTING FURTHER PHYSICS TOPICS COME 'FOR FREE' WHEN REALIZING THE ABOVE PROGRAM