Future Transversity Measurements at HERMES

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- Transversity
- How to measure ? $\Longrightarrow$ Collins effect
- Analysis method:
  - proton target: u-quark
  - deuteron target: u- and d- quarks
- Polarized fragmentation function
- Summary:

  HERMES can measure $\delta u(x)$ for the first time

Twist-2 Quark Distributions

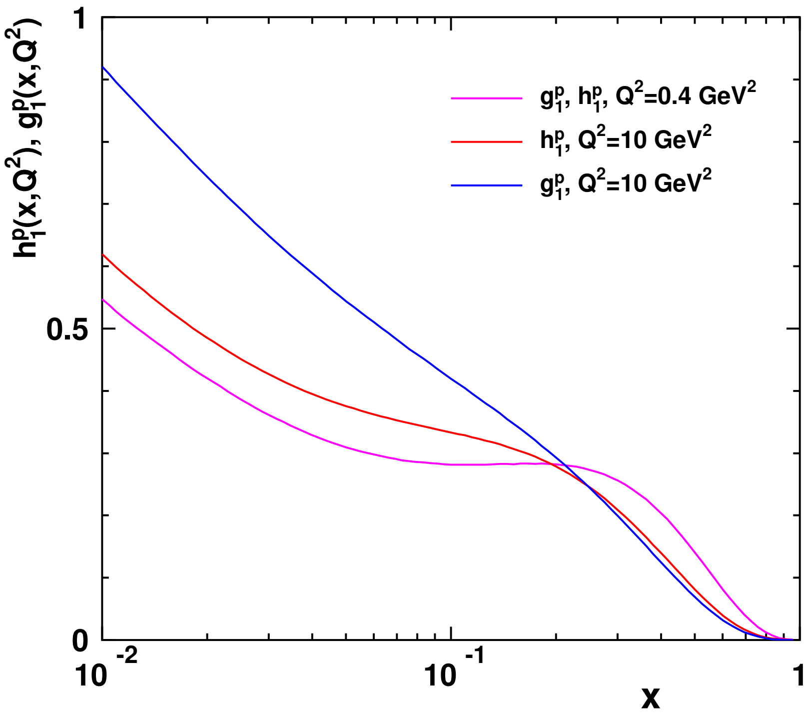
Three twist-2 quark distributions:

- quark number density distribution $q(x, Q^2)$
- quark helicity distribution $\Delta q(x, Q^2)$
- quark transversity distribution $\delta q(x, Q^2)$

For non-relativistic quarks: $\delta q(x) = \Delta q(x)$.

No transversity distribution for gluons. $\Longrightarrow$ $\delta q(x, Q^2)$ does not mix with gluons under QCD evolution.

QCD-evolution of $\delta q(x, Q^2)$ is well established theoretically.
Example for LO evolution of proton structure functions
$g_1(x, Q^2) = \frac{1}{2}\sum_i e_i^2 \Delta q_i(x, Q^2)$ and $h_1(x, Q^2) = \frac{1}{2}\sum_i e_i^2 \delta q_i(x, Q^2)$



Possible methods to measure $\delta q(x)$

DY in doubly transversely polarized pp collisions.

$$A_{TT} \sim \sum e_i^2 \delta q_i(x) \delta \bar{q}_i(x)$$

SIDIS off transversely polarized nucleons:

i) Twist-3 pion production [Jaffe, Ji, 93]

ii) Measurement of the transverse polarization of Λ's in the current fragmentation region [Baldracchini,82 Jaffe,96]

iii) Measurement of correlation between the transverse spin vector of the target nucleon and the normal to the two-meson plane [Jaffe et al.,97]

iv) 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].

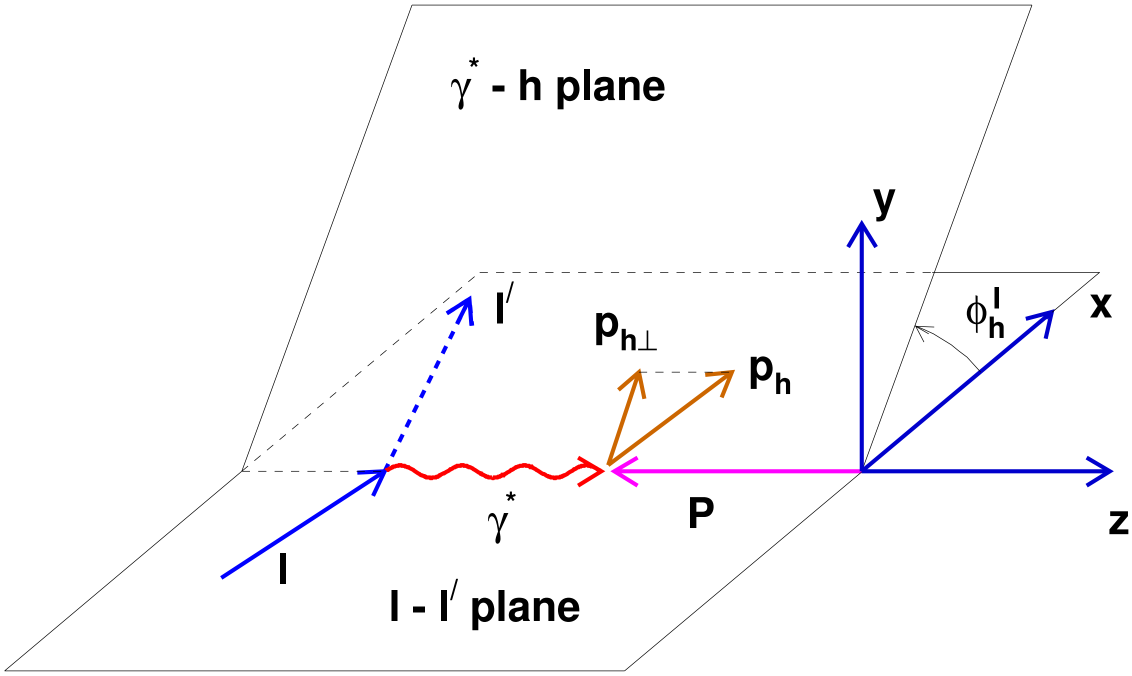
$$A \sim \sum_i e_i^2 \delta q_i(x) H_i(z)$$

Methods ii) - iv) rely on POLARIMETRY of the scattered transversely polarized quark

Measurement of $\delta q(x)$ via the Collins effect

Weighted asymmetry [Mulders, Tangermann 96, Kotzinian, Mulders 97]

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



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.

u-quark Dominance in π^+ Production

i) 70÷90% of π^+ originate from the fragmentation of struck u-quark for a proton target (only slightly smaller for a deuteron target);

ii) Sum rule for T-odd fragmentation functions [Schäfer, Teryaev, 99] $\rightarrow$ contributions from non-leading parton fragmention is expected to be severely suppressed:

$$\frac{H_1^{\perp(1)d\rightarrow\pi^+}(z)}{D_1^{d\rightarrow\pi^+}(z)} = \frac{H_1^{\perp(1)\bar{u}\rightarrow\pi^+}(z)}{D_1^{\bar{u}\rightarrow\pi^+}(z)} = 0$$

iii)

$$\frac{\Delta q_{sea}(x)}{q_{sea}(x)} \ll \frac{\Delta q(x)}{q(x)}$$

Assume

$$\frac{\delta q_{sea}(x)}{q_{sea}(x)} \ll \frac{\delta q(x)}{q(x)}$$

Then

$$A_p^{\pi^+}(x,y,z) = P_T \cdot D_{nn} \cdot \frac{\delta u(x)}{u(x)} \cdot \frac{H_1^{\perp(1)}(z)}{D_1(z)}$$

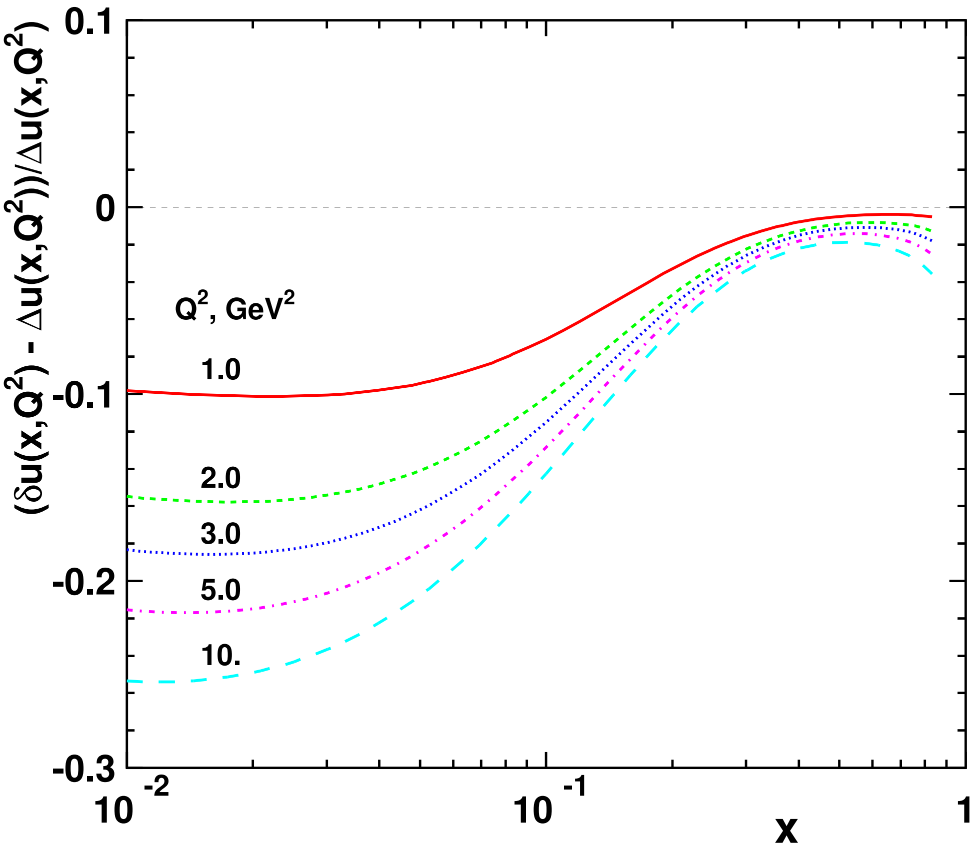
$$A_d^{\pi^+}(x,y,z) = f_D \cdot P_T \cdot D_{nn} \cdot \frac{\delta u(x)+\delta d(x)}{u(x)+d(x)} \cdot \frac{H_1^{\perp(1)}(z)}{D_1(z)}$$

where $f_D = 1 - \frac{3}{2}\omega_D$, $\omega_D = 0.05$

Normalization Ambiguity

The factorized form with respect to x and z allows the simultaneous reconstruction of the SHAPE for both $\delta u(x)$ and $H_1^{\perp(1)}(z)/D_1(z)$, while the relative normalization cannot be fixed without a further assumption.

Use the expectation that $\delta q(x)$ coincides with $\Delta q(x)$ at small Q^2.



The differences are expected to be smallest for intermediate and large x. Hence the assumption

$$\delta q(x_0) = \Delta q(x_0)$$

at $x_0 = 0.25$ was made to resolve the normalization ambiguity.

Polarized Fragment. Function $H_1^{\perp(1)q}(z)$

Experimental indications that $H_1^{\perp(1)q}(z)$ is non-zero:

i) azimuthal correlations between particles from opposite jets in Z decay at DELPHI [A.Efremov et al., 99]

ii) a single target-spin asymmetry measured at HERMES [DESY 99-149, subm. to PRL]

Analyzing power in transversely polarized quark fragmentation (Collins guess):

$$A_C(z,k_T) \equiv \frac{|k_T| H_1^{\perp q}(z, z^2 k_T^2)}{M_h D_1^q(z, z^2 k_T^2)} = \frac{M_C\,|k_T|}{M_C^2 + |k_T^2|},$$

$M_C \simeq 0.3 \div 1.0$ GeV

Gaussian parameterization for the quark transverse momentum dependence in the unpolarized fragmentation function

$$D_1^q(z, z^2 k_T^2) = D_1^q(z)\,\frac{R^2}{\pi\, z^2}\,\exp(-R^2 k_T^2),$$

leads to

$$H_1^{\perp(1)q}(z) = D_1^q(z)\frac{M_C}{2M_h}\left(1 - M_C^2 R^2 \int_0^\infty dx\,\frac{\exp(-x)}{x + M_C^2 R^2}\right).$$

$R^2 = z^2/b^2$

In the following $M_C = 0.7$ GeV and $b^2 = 0.25$ GeV^2
Consistent with the HERMES and DELPHI measurements.

Transversity Analysis at HERMES

$$ep^{\uparrow}(d^{\uparrow}) \to e'\pi^+X, \;\; E = 27.5 \text{ GeV}, \;\; P_T = 0.75$$

Statistics expected for 2002+: $7 \cdot 10^6$ reconstructed DIS events

$$Q^2 > 1 \text{ GeV}^2, \quad W > 2 \text{ GeV}, \quad 0.02 < x < 0.7, \quad y < 0.85.$$

From HERMES Monte-Carlo program: pion distributions, acceptance.

Cuts for the kinematic variables of the pion:

$$x_F > 0., \quad z > 0.1, \quad P_{h\perp} > 0.05 \text{ GeV} .$$

To simulate A_T, the approximation $\delta q(x) = \Delta q(x)$ was used; this is ok because of the relatively low Q^2-values at HERMES.

$Q^2 = 2.5$ GeV^2 (average value for the HERMES)

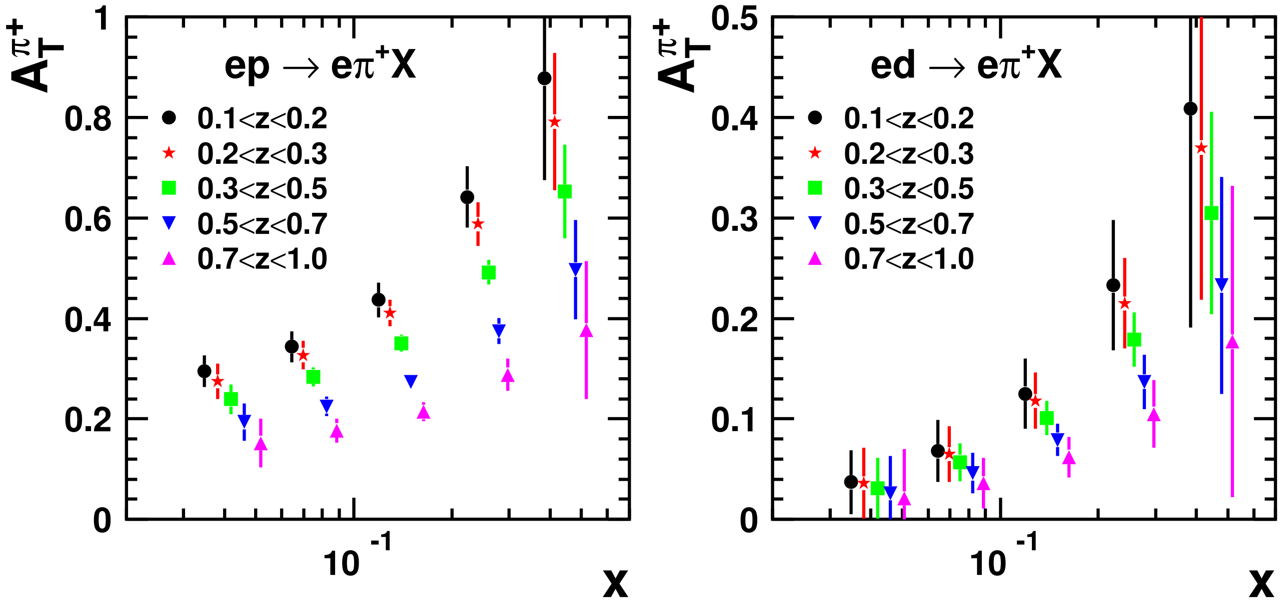
GS LO parameterization for $\Delta q(x)$
GRV94LO parameterization for $q(x)$

The projected accuracies for the asymmetry were estimated by

$$\delta A = \left\langle \left(\frac{P_{h\perp}}{z m_\pi} \sin(\phi_s^\ell + \phi_h^\ell) \right)^2 \right\rangle^{\frac{1}{2}} \cdot \frac{1}{\sqrt{N_\pi}}$$

Single Target-Spin Asymmetry

The simulated data were divided into 5x5 bins in (x, z).



The experimental data consist of 25 measured values, as opposed to 9 unknown function values:

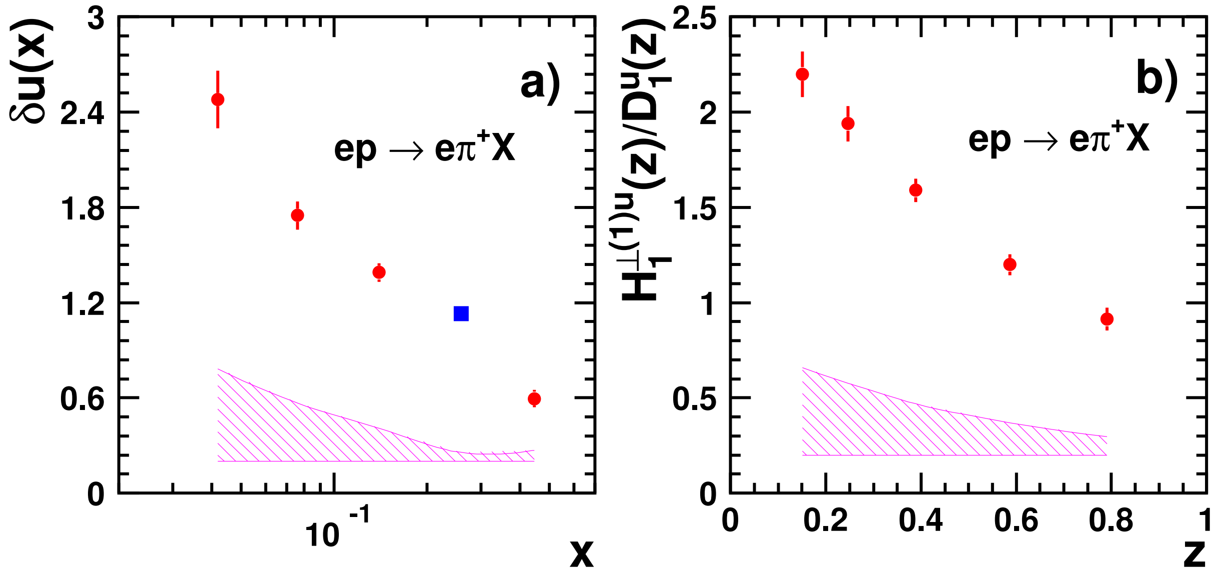
4 values for $\delta u(x_i)$ $[\delta u(x_i) + \delta d(x_i)]$ and

5 values for $H_1^{\perp(1)u}(z_j)/D_1^u(z_j)$

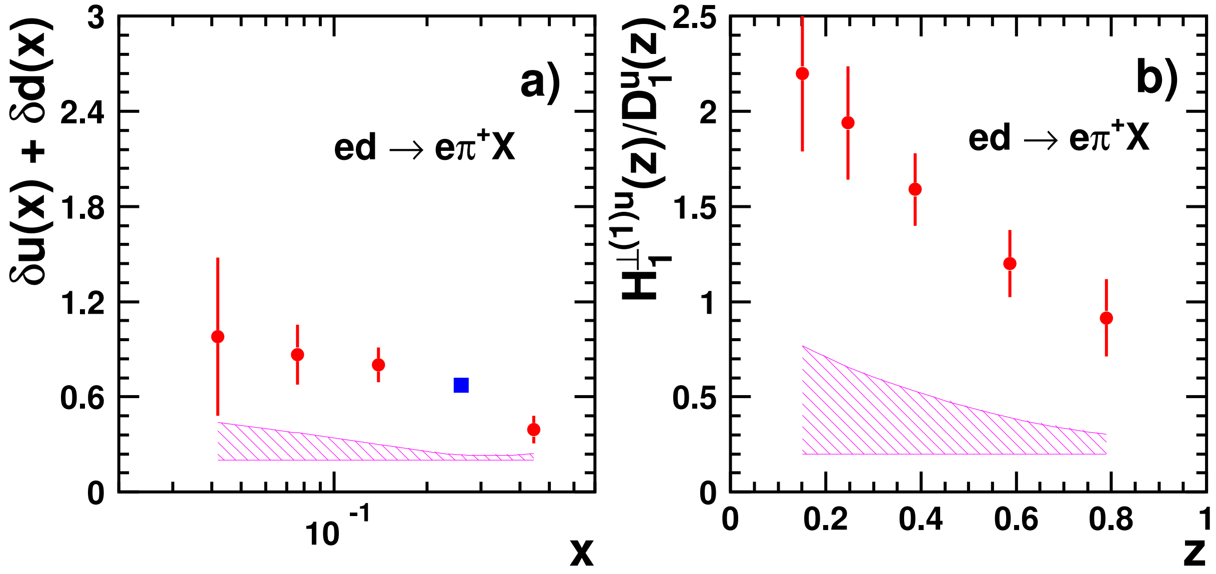
The standard procedure of χ^2 minimization was applied to reconstruct the values for both $\delta u(x)$ $[\delta u(x_i) + \delta d(x_i)]$ and $H_1^{\perp(1)u}(z)/D_1^u(z)$ and to evaluate their projected statistical accuracies.

Projections for Statistical Accuracy

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



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



Summary

- No experimental data on quark transversities yet

- Quark transversities are important pieces of the complete angular momentum "map" of the nucleon

- HERMES can make a statistically rather precise first measurement of $\delta u(x)$ and of the polarized fragmentation function $H_1^{\perp(1)u}(z)$ with a transversely polarized proton target in 2002+

- We need new high luminosity experiments to complete the angular momentum "map" of the nucleon

  $\Longrightarrow$ eN@TESLA

  (http://www.ifh.de/hermes/future/)