Polarized lepton–nucleon scattering at HERMES

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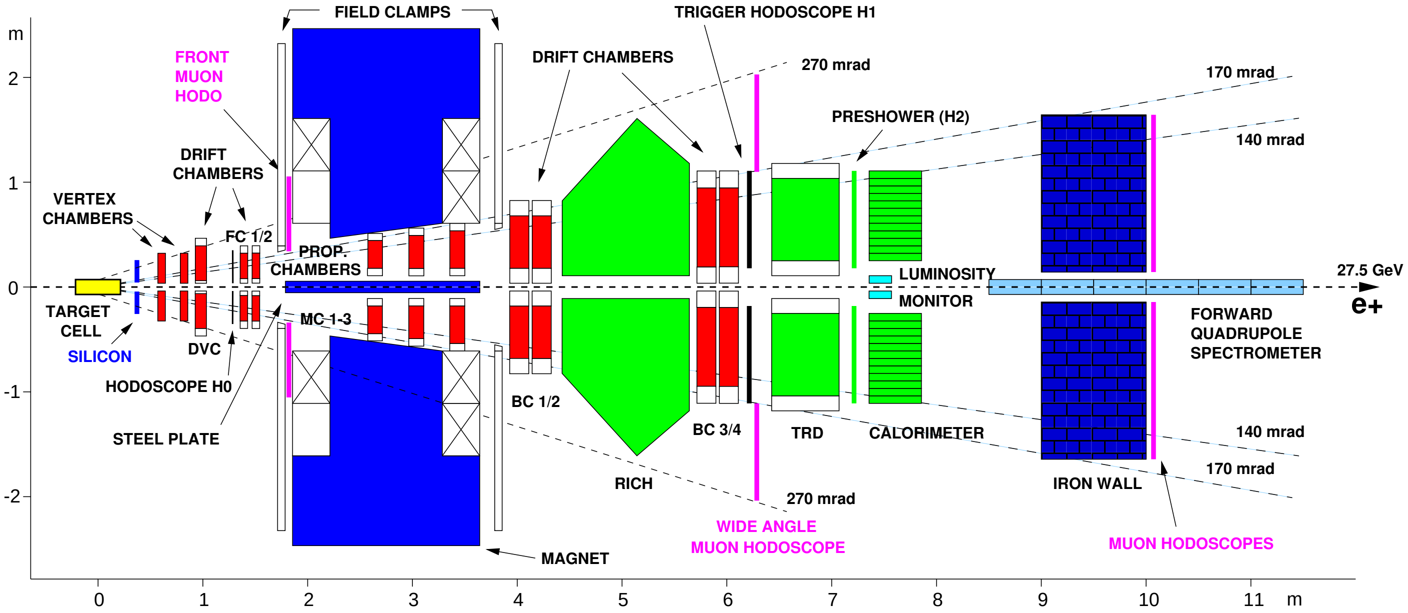
Outline

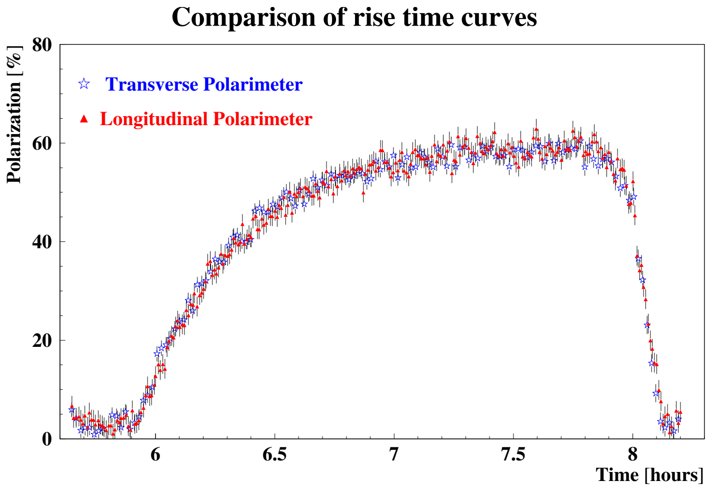
- Inclusive measurement of the spin structure function g_1
- Semi–inclusive extraction of the quark helicity distributions Δq
- Deeply Virtual Compton Scattering (DVCS)
- HERMES Run II (2002-2006)

The HERMES Experiment at HERA

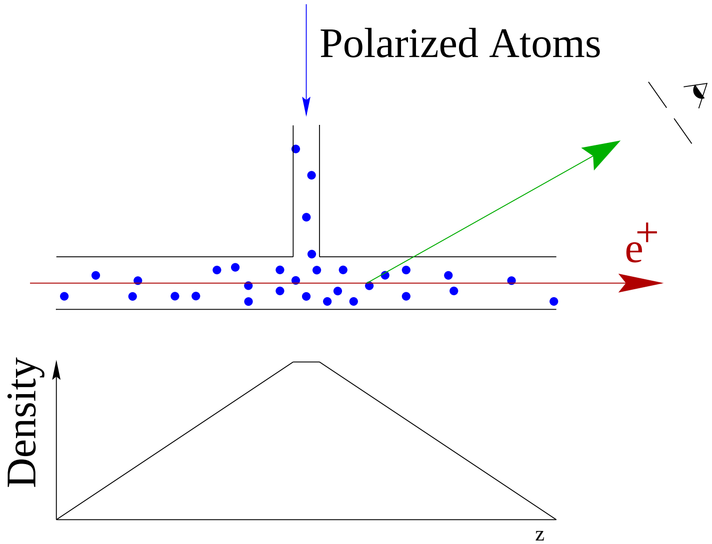


- Kinematic Range: $0.02 \leq x \leq 0.8$ at $Q^2 \geq 1\mathrm{GeV}^2$ and $W \geq 2\mathrm{GeV}$
- Acceptance: 40mrad$\leq |\theta_{vertical}| \leq$140 mrad and $\theta_{horizontal} \leq$ 170 mrad
- Reconstruction: $\delta p/p$ 0.7 - 1.3%, $\delta\Theta \leq$ 0.6mrad
- Particle ID: TRD, Preshower, Calorimeter
  lepton identification efficiency: ~98%   hadron contamination: $\leq$ 1%
- 95-97: Threshold Čerenkov   1998+: RICH and Muon-ID

Polarized HERA and the HERMES target



- 27 GeV positrons and electrons
  $\longrightarrow$ Also collected 12 GeV data
- Self–Polarized (Sokolov-Ternov effect)
- Average beam polarization $< P_b > \approx 55$ %
- Spin rotators for long. polarization including helicity reversal

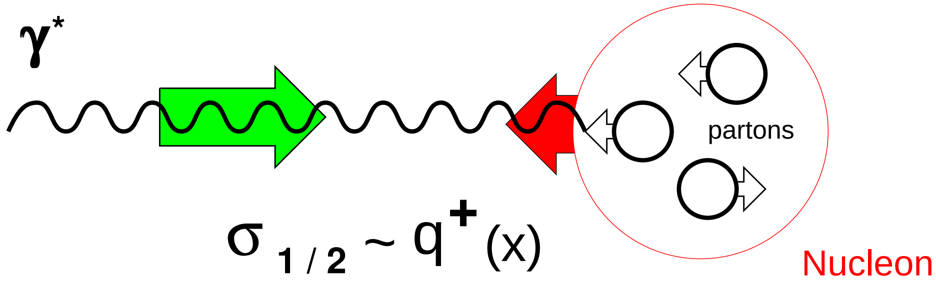


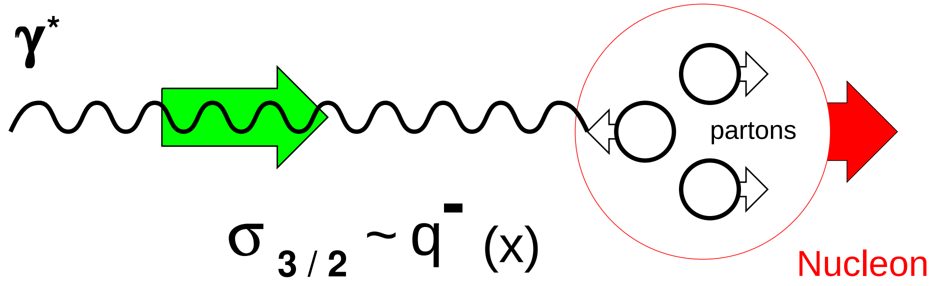
- Internal storage cell gas target
- $\overrightarrow{He}$, $\overrightarrow{D}$, $\overrightarrow{H}$: unpol: H_2, D_2, He, N_2, Ne, Kr
- Polarization: $< \mathrm{P_{He}} >= 0.46 \pm 0.05$
  $< \mathrm{P_H} >= 0.88 \pm 0.04$ and $< \mathrm{P_D} >= 0.84 \pm 0.03$
- Density: He^3 10^{15}nucl/cm^2, H/D 10^{14} (Unpolarized 10^{16}nucl/cm^2)
- Total $\int$lumi=1fb^{-1} (1/3 long. polarized)

Virtual Photon Scattering

Conservation of angular momentum

Spin–1 + Spin–$\frac{1}{2}$ $\rightarrow$Spin–$\frac{1}{2}$





$$F_1(x) = \frac{1}{2}\sum_i e_i^2 (q_i^+(x) + q_i^-(x)) = \frac{1}{2}\sum_i e_i^2 q_i(x)$$

$q(x)$ quark number density

$$g_1(x) = \frac{1}{2}\sum_i e_i^2 (q_i^+(x) - q_i^-(x)) = \frac{1}{2}\sum_i e_i^2 \Delta q_i(x)$$

$\Delta q(x)$ quark helicity distribution

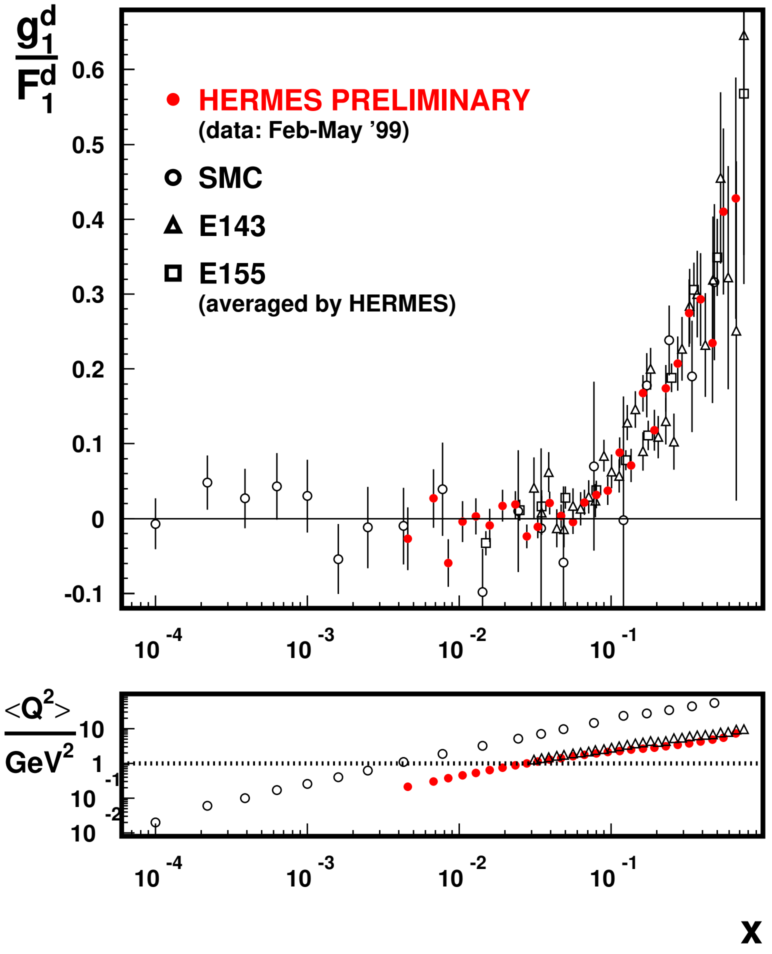
Measured Inclusive Asymmetries

$$A_{||} = \frac{\sigma^{\stackrel{\rightarrow}{\Leftarrow}} - \sigma^{\stackrel{\rightarrow}{\Rightarrow}}}{\sigma^{\stackrel{\rightarrow}{\Leftarrow}} + \sigma^{\stackrel{\rightarrow}{\Rightarrow}}} = D(A_1 + \eta A_2)$$

$$A_1 = \frac{\sigma_{\frac{1}{2}} - \sigma_{\frac{3}{2}}}{\sigma_{\frac{1}{2}} + \sigma_{\frac{3}{2}}} = \frac{g_1 - \gamma^2 g_2}{F_1}$$

$$D = \frac{y(2-y)}{y^2 + 2(1-y)(1+R)} \quad \eta = \frac{2(1-y)\sqrt{Q^2}}{y(2-y)E}$$

World data on g1(x)



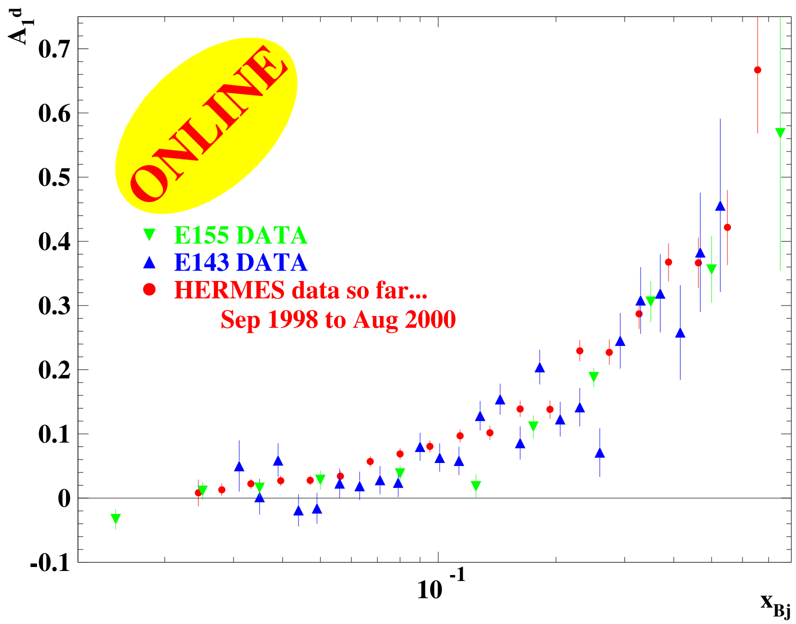
Status:

Indication of scaling violation of g_1

- NLO QCD fit $\rightarrow \Delta G > 0$

On Going:

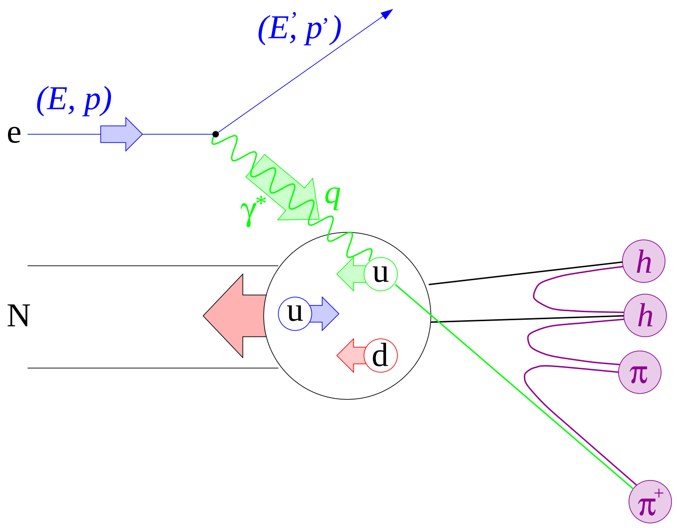
7 M Deut. still being analyzed



New:

1 M Tensor pol. deut. $\rightarrow b_1$

Semi-inclusive DIS



Flavor Tagging

Hadron Production Cross Section in LO QCD

$$\frac{1}{\sigma_{tot}} \frac{d\sigma^h(x,Q^2,z)}{dz} = \frac{\sum_f e_f^2 q_f(x,Q^2) D_f^h(z,Q^2)}{\sum_f e_f^2 q_f(x,Q^2)}$$

- z **Fraction γ energy carried by hadron**
- $q_f(x,Q^2)$ **Quark Distribution Function**
- $D_f^h(z,Q^2)$ **Fragmentation Functions**

Long. Polarized Lepton – Long. polarized Target

$$A_1^{\mathrm{h}}(x,Q^2) = \frac{\sigma^h_{1/2} - \sigma^h_{3/2}}{\sigma^h_{1/2} + \sigma^h_{3/2}} = C \cdot \frac{\sum_f e_f^2 \Delta q_f(x,Q^2) \int dz D_f^{\mathrm{h}}(z,Q^2)}{\sum_f e_f^2 q_f(x,Q^2) \int dz D_f^{\mathrm{h}}(z,Q^2)}$$

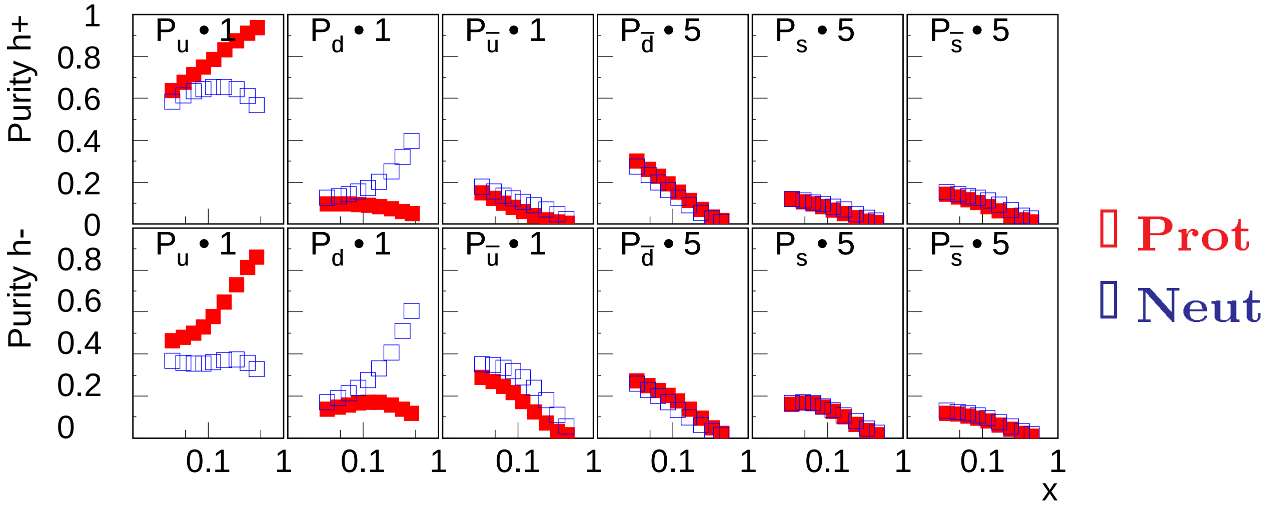
$$\mathbf{C} = \frac{1+R(x,Q^2)}{1+\gamma^2}$$

Extraction of Δq

$$A_1^{\mathrm{h}}(x) = C \cdot \sum_f \underbrace{\frac{e_f^2 q_f(x) \int dz D_f^{\mathrm{h}}(z)}{\sum_{f'} e_{f'}^2 q'_f(x) \int dz D_{f'}^{\mathrm{h}}(z)}}_{P_f^h(x)} \frac{\Delta q_f(x)}{q_f(x)}$$

$P_f^h(x)$ **Purity: Probability that a quark q_f was struck if a hadron h is detected.**

Purely Unpol. Quantities ↔ Determine from MC



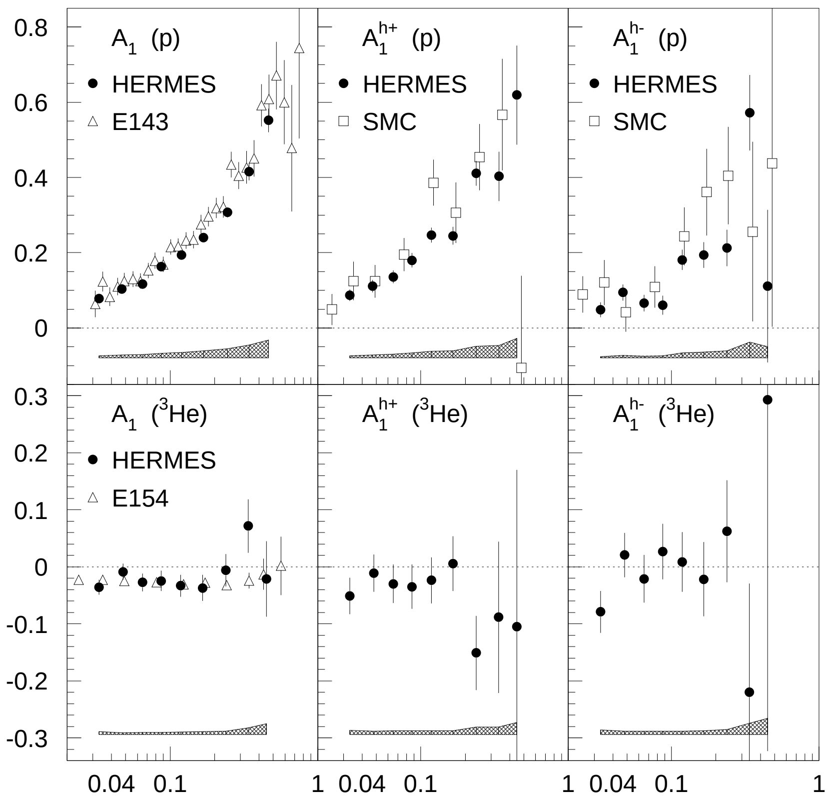
Neutron PDF is Isospin rotated Proton PDF

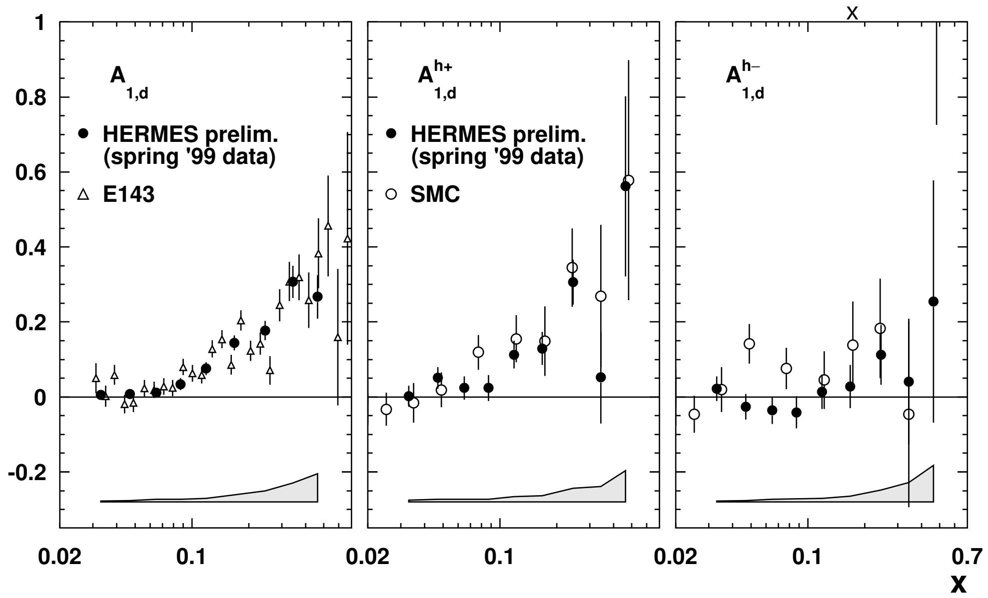
$$\vec{A} = \begin{pmatrix} A_{1,p}(x) \\ A_{1,p}^{h^+}(x) \\ A_{1,p}^{h^-}(x) \\ \dots \\ A_{1,d}^{h^-}(x) \end{pmatrix} : \vec{Q} = \begin{pmatrix} \Delta q_1(x)/q_1(x) \\ \dots \\ \Delta q_n(x)/q_n(x) \end{pmatrix} : \mathcal{P} = C \cdot \left[P_f^h(x) \right]$$

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

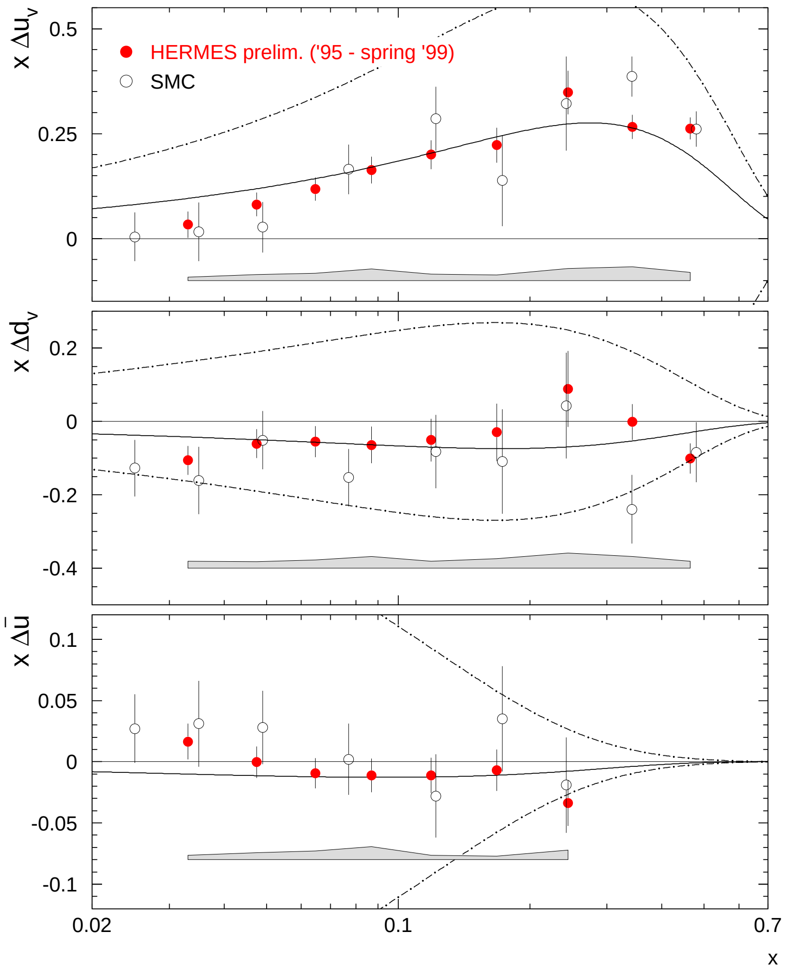
To measure the Quark Polarizations invert!

Semi–Inclusive Measurements





Quark Polarizations at LO



Dashed: Positivity limit   Solid: GRSV

First moments at $Q^2 = 2.5$

$\Delta\Sigma = 0.30 \pm 0.04 \pm 0.09$

$\Delta q_s = -0.01 \pm 0.03 \pm 0.03$

PL B464 ('99) 123 ('95-'97)

- **Result is insensitive to choice of sea assumption:**

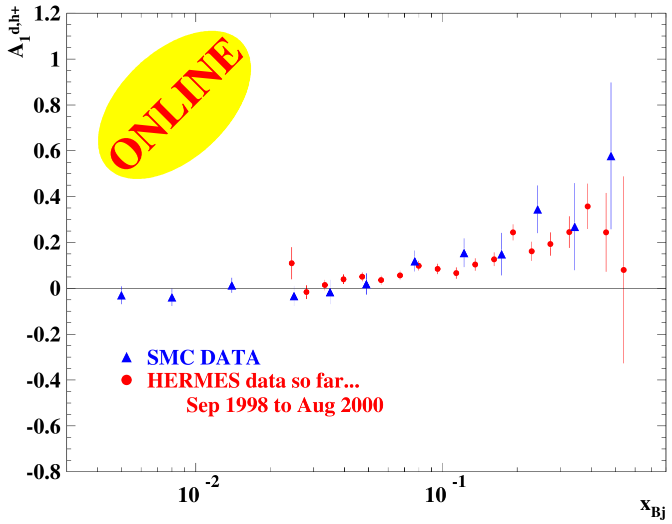
$$\frac{\Delta q_s}{q_s} \equiv \frac{\Delta u_s}{u_s} = \frac{\Delta d_s}{d_s} = \frac{\Delta s}{s} = \frac{\Delta \bar{u}}{\bar{u}} = \frac{\Delta \bar{d}}{\bar{d}} = \frac{\Delta \bar{s}}{\bar{s}}$$

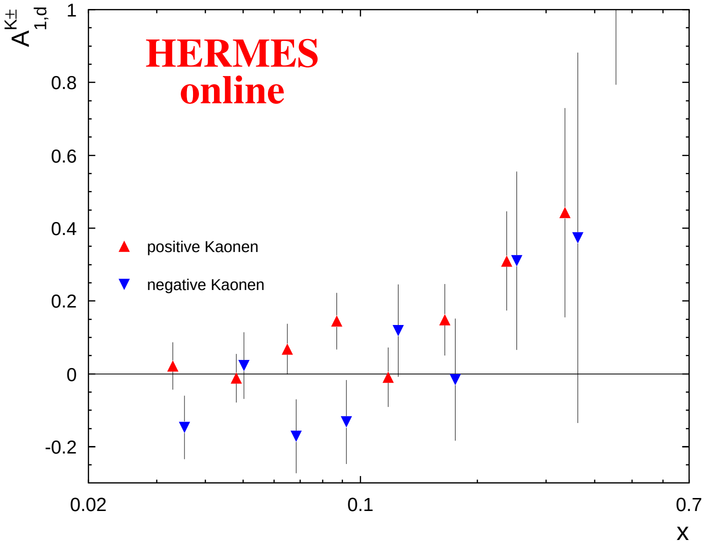
$$\Delta q_s \equiv \Delta u_s = \Delta d_s = \Delta s = \Delta \bar{u} = \Delta \bar{d} = \Delta \bar{s}$$

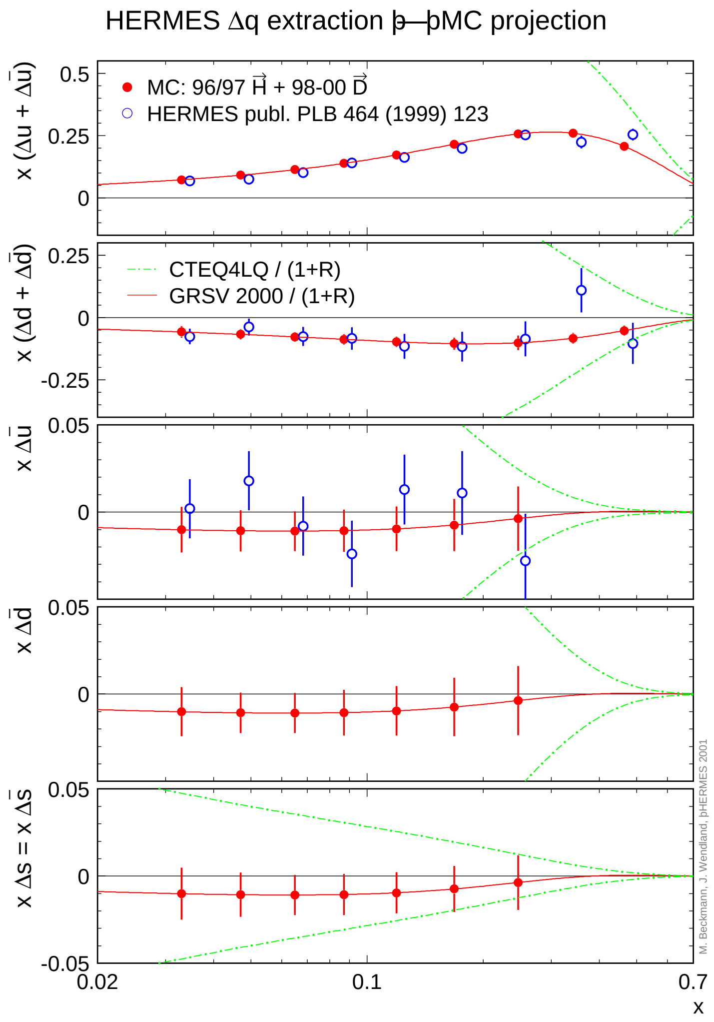
- **Agreement with Gehrmann, Stirling fit to inclusive data (Gluon A, LO)**

- **Conclusion on sea must await final analysis of the HERMES complete ^{2}D data set with kaon PID**

The Future of Hadron Asymmetries and Δq



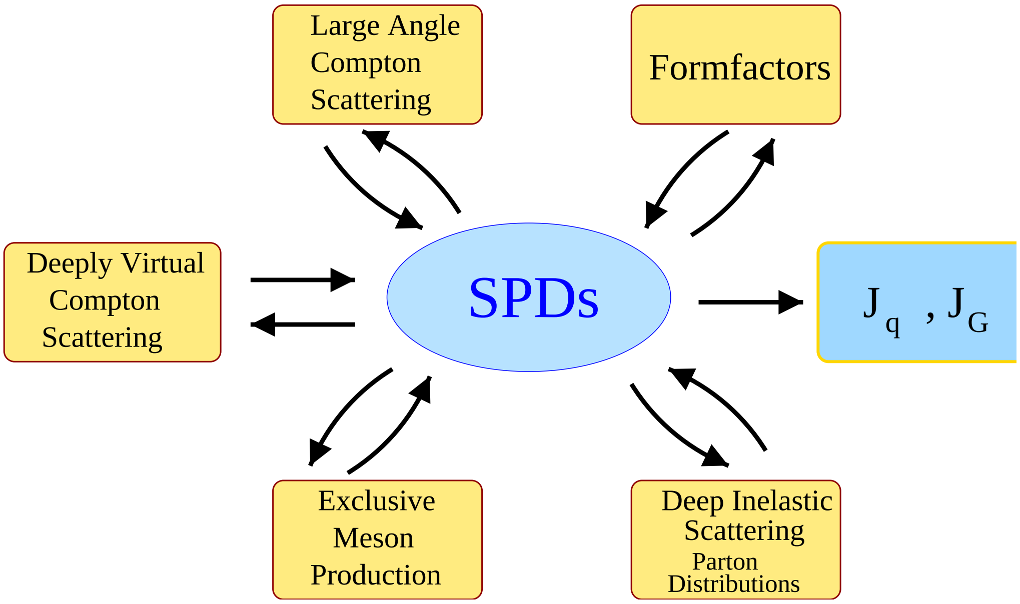


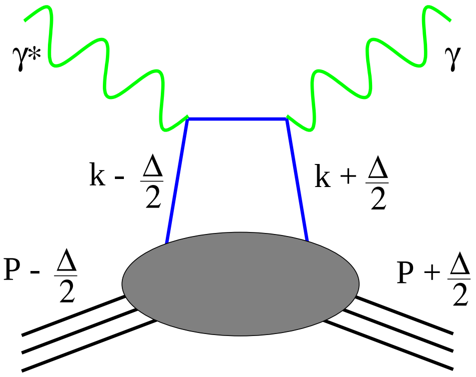


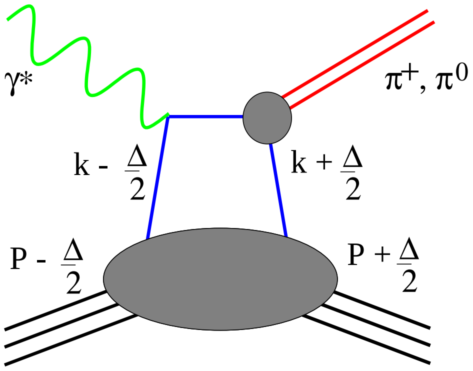
Based on HERMES data on tape

$A_D^{K^\pm}$ corresponds to 1 x 10^6 DIS

Exclusive Physics and SPDs







- DVCS
- Exclusive Data

New class of parton distributions $H, \tilde{H}, E, \tilde{E}$

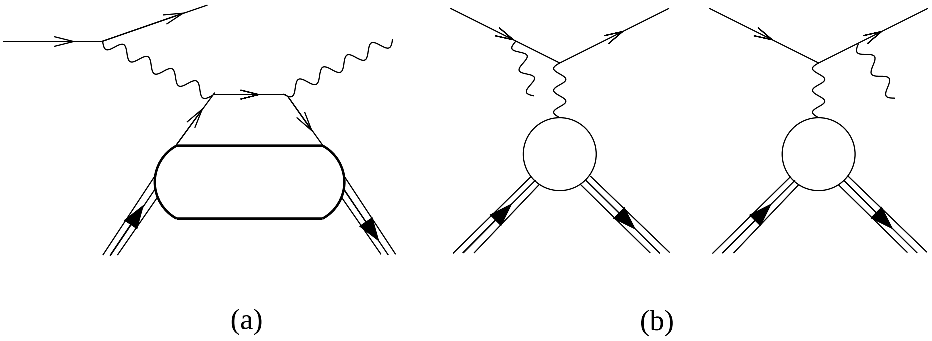
- PDF $q(x) = H^q(x, \xi = 0, t = 0)$ $\quad \Delta q(x) = \tilde{H}^q(x, \xi = 0, t = 0)$
- First moments are the Elastic Formfactors
- 2nd moments H^q $\quad E^q$: possible access to J^q

  † $t = \Delta^2$, ξ long. fraction of momentum transfer

HERMES Data: DVCS, Exclusive ρ and π production.

Deeply Virtual Compton Scattering

$$e + p \longrightarrow e + p + \gamma$$



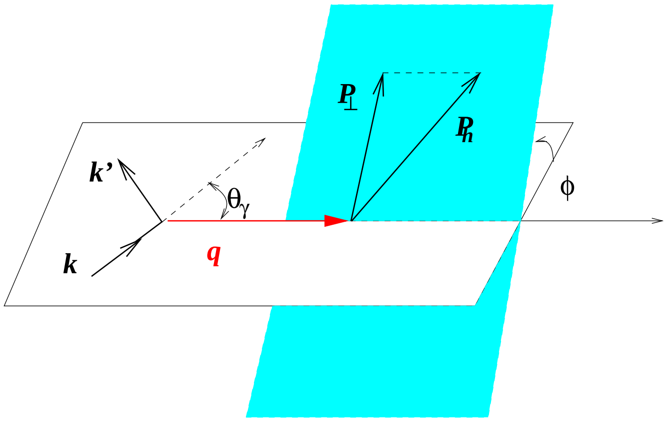
(a) Compton Scattering (b) Bethe–Heitler

$$\frac{d^4\sigma}{d\phi dt dQ^2 dx} = \frac{xy^2}{32(2\pi^4)Q^4} \frac{|\tau_{BH}+\tau_{DVCS}|^2}{(1+4x^2m^2Q^2)^{\frac{1}{2}}}$$

Helicity Dep. LO term: A. Belitsky et.al. Nucl Phys B593,289

$$\tau^*_{BH}\tau_{DVCS} + \tau^*_{DVCS}\tau_{BH} \sim$$
$$e_l P_l sin(\phi) Im \left[F_1\mathcal{H}_1 + \frac{x}{2-x}(F_1+F_2)\tilde{\mathcal{H}}_1 - \frac{\Delta^2}{4M^2}F_2\mathcal{E}_1 \right]$$

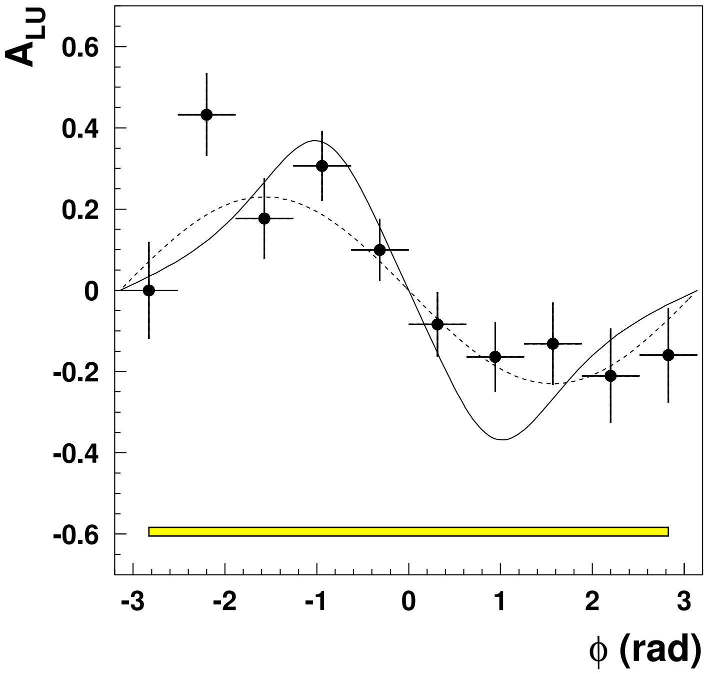
Depends on Lepton charge e_l and helicity P_l and:



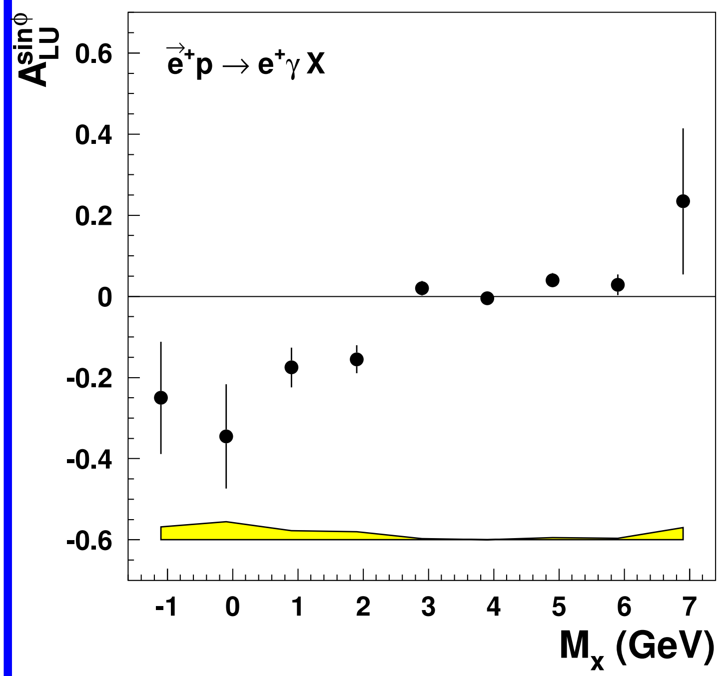
Access $\mathrm{Im}H_1$ and $Im\tilde{\mathcal{H}}_1$

$\mathcal{E}_1$ is suppressed

Single Spin Asymmetry in DVCS



- Exclusive Data
- $A_{LU} =$
  $\frac{1}{<|P_l|>} \cdot \frac{(N^{+}(\phi)-N^{-}(\phi))}{(N^{+}(\phi)+N^{-}(\phi))}$
- $+$ $-$ Beam Helicity
- $-1.5 < \mathrm{M_x} < 1.7\mathrm{GeV}$
- Dashed $P_1 sin\phi$ $P_1 = 0.23$
- Solid Kivel et.al. PRD 63



- Helicity Avg. $A_{LU} = 0$
- $A_{LU}^{sin\phi} = \frac{2}{N} \sum_{i=1}^{N} \frac{sin(\phi_i)}{(P_l)_i}$
  $N = N^{+} + N-$
- Electroprod. of γ ~10%
- π^0 contam. ~8.5%
- M_x resolution 0.77GeV for Exclusive γ data

- 1996-1997 proton data $\leftrightarrow$ $104 pb^{-1}$
- hep-ex/0106068

Future of Exclusive Physics at HERMES

DVCS:

- Analyze 98-00 data set
  - 8M hydrogen and 12 deuterium on tape
- Charge asymmetry $\rightarrow$ access ReH_1 and $Re\tilde{\mathcal{H}}_1$
  - 1M e^- 98 data
  - Collect charge symmetric data set
- Continue collecting end–of–fill unpol data.

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

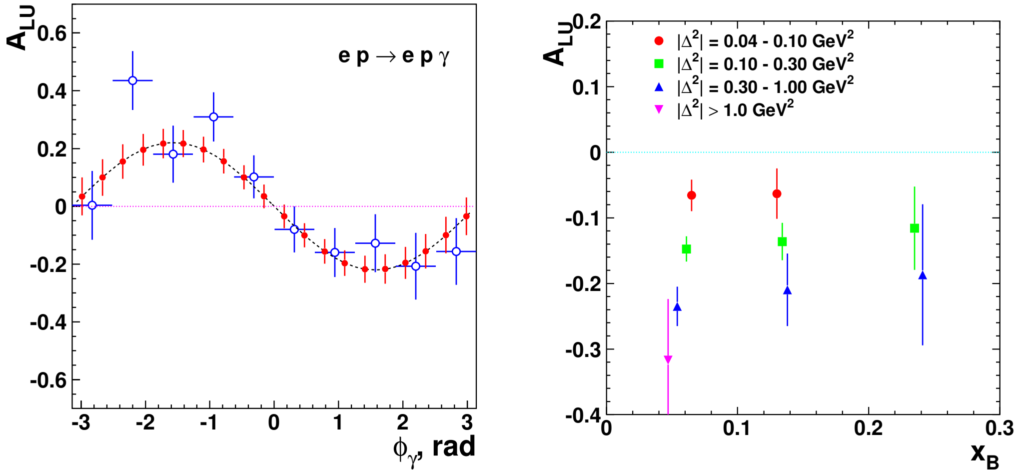
Hermes RECOIL DETECTOR

Design Goals:

- Measure exclusive $\gamma, \pi^0, \pi^+, \rho \ldots$
- Decrease non–exclusive background
- Improve t resolution
- Design underway

Install 2003/2004

Monte Carlo Projection 2fb^{-1} ($\approx$1yr)
DVCS with recoil detector



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Transversity and HERMES Run II

There are 3 independent twist–2 density distributions for the nucleon:

$q(x)$ quark number density – chiral even

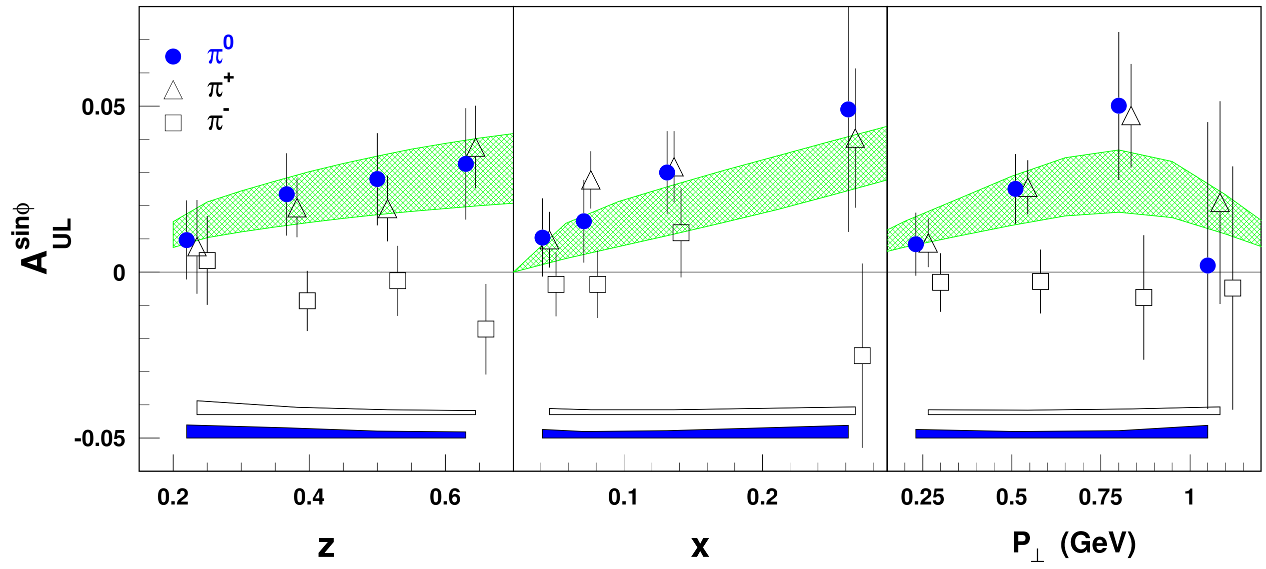
$\Delta q(x)$ Helicity distribution – chiral even

$\delta q(x)$ transversity distribution – chiral odd

$\delta q(x)$ cannot be measured in Inclusive DIS

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

$H_1^{\perp(1)q}(z)$ Collins fragmentation function



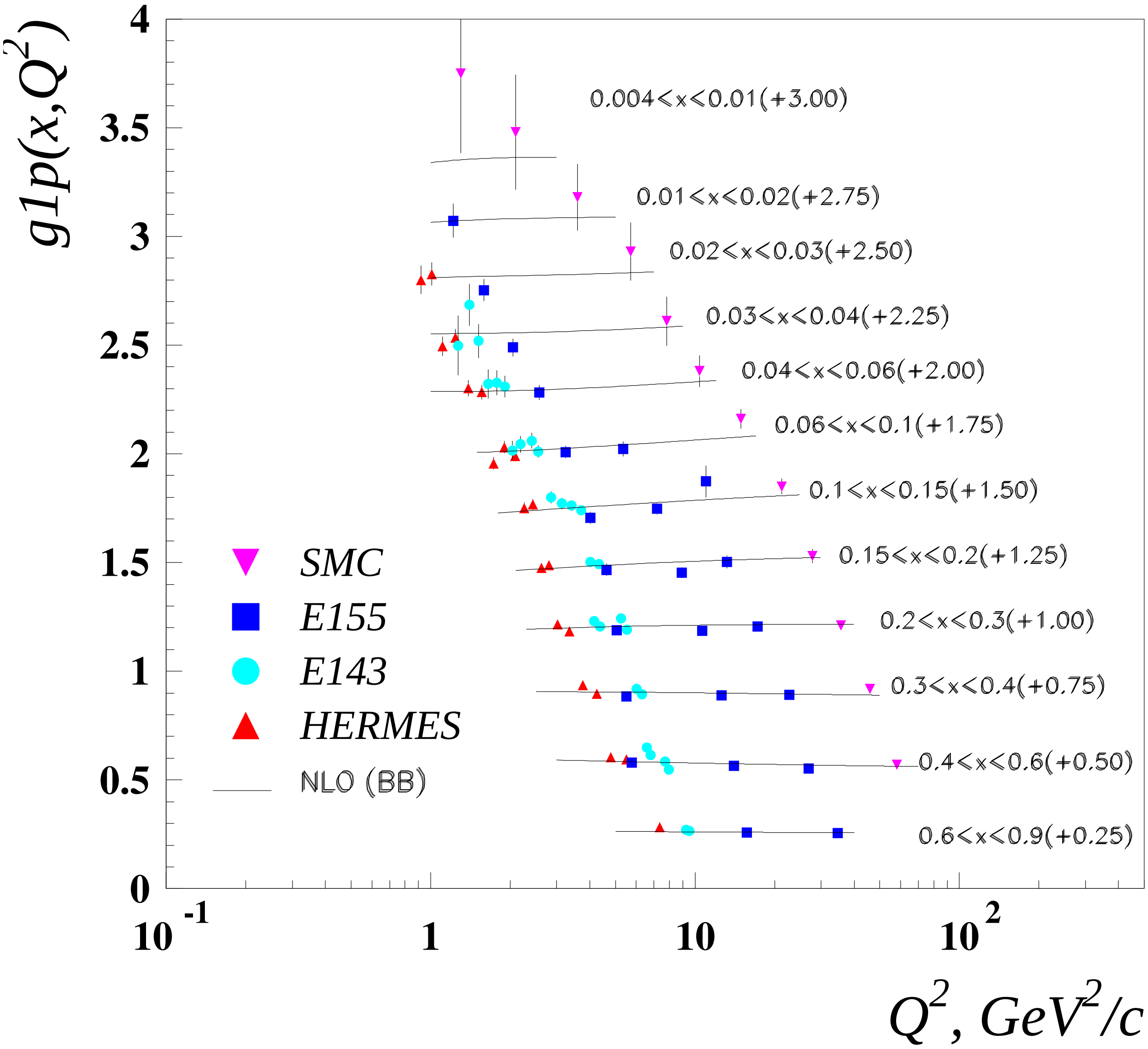
Hermes SSA indicate that $H_1^{\perp(1)q}(z)$ is not small!

HERMES RUN II

Transverse polarized physics 2002-2004

Possibly 1 yr Longitudinal Polarized Hydrogen

Exclusive physics run 2004-2006



$g1p(x,Q^2)$
0.004<x<0.01(+3.00)
0.01<x<0.02(+2.75)
0.02<x<0.03(+2.50)
0.03<x<0.04(+2.25)
0.04<x<0.06(+2.00)
0.06<x<0.1(+1.75)
0.1<x<0.15(+1.50)
0.15<x<0.2(+1.25)
0.2<x<0.3(+1.00)
0.3<x<0.4(+0.75)
0.4<x<0.6(+0.50)
0.6<x<0.9(+0.25)
SMC
E155
E143
HERMES
NLO (BB)
Q^2, GeV^2/c