# Recent Results on the Helicity Structure of the Nucleon

from hermes

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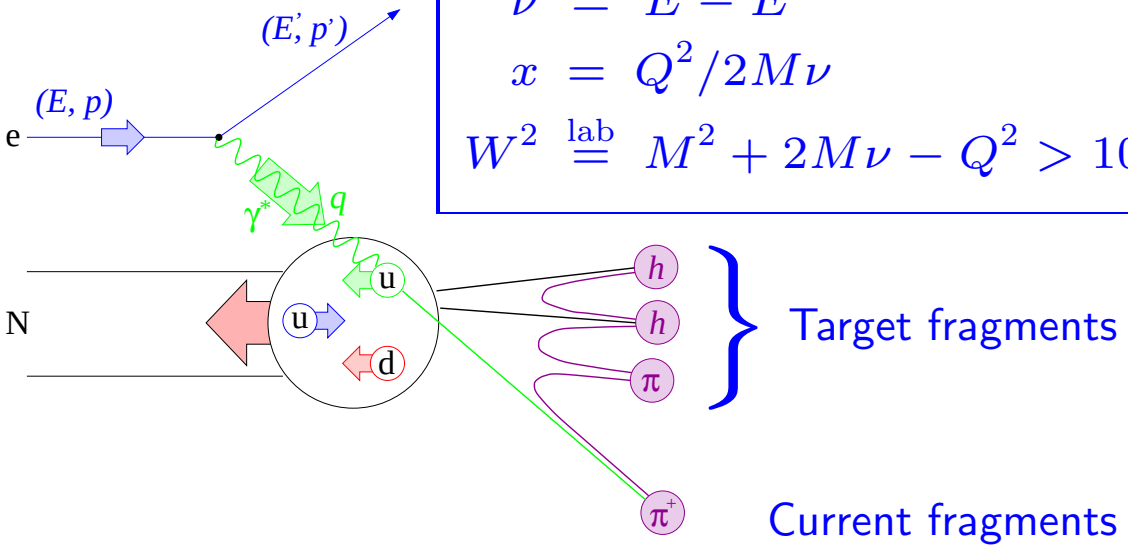
*"Testing QCD Through Spin Observables in Nuclear Targets"*,
University of Virginia,
Charlottesville, April 18–20, 2002.

Outline:

- Polarised Semi–Inclusive DIS
- The HERMES Experiment at HERA
- Results from Inclusive Measurements
- Measured Semi–Inclusive Asymmetries
- The Purity Formalism
- Results
  - The Flavour Separation of Quark Polarisations
  - The Symmetry of the Polarised Light Sea
- Summary

# Polarised Semi–Inclusive DIS




$$
\begin{aligned}
Q^2 &\overset{\text{lab}}{=} 4EE'\sin^2(\theta/2) > 1\ \text{GeV}^2 \\
\nu &\overset{\text{lab}}{=} E - E' \\
x &= Q^2/2M\nu \\
W^2 &\overset{\text{lab}}{=} M^2 + 2M\nu - Q^2 > 10\ \text{GeV}^2
\end{aligned}
$$

- ▷ Hadrons from the current fragmentation:
  $0.8 > z = E_h/\nu > 0.2$
  $x_{\text{F}} \simeq 2p_{\parallel}/W > 0.1$
- ▷ Correlation between flavour $q$ of the struck quark and the hadron type $h$ given by fragmentation functions $D_q^h(z, Q^2)$

Differential cross section for semi–inclusive deep inelastic scattering:

$$
\frac{\mathrm{d}^3\sigma^h}{\mathrm{d}x\,\mathrm{d}Q^2\,\mathrm{d}z} = \frac{\sum_q e_q^2\, q(x,Q^2)\, D_q^h(z,Q^2)}{\sum_q e_q^2\, q(x,Q^2)} \cdot \frac{\mathrm{d}^2\sigma^{\text{incl}}}{\mathrm{d}x\,\mathrm{d}Q^2}
$$

# Longitudinal Cross Section Asymmetries

▷ Measured longitudinal cross section asymmetries

$$A_{\parallel}^{h} \;=\; \frac{1}{\langle P_B\, P_T\rangle} \cdot \frac{\left(N^h/L\right)^{\rightleftarrows} - \left(N^h/L\right)^{\rightrightarrows}}{\left(N^h/L\right)^{\rightleftarrows} + \left(N^h/L\right)^{\rightrightarrows}} \,,$$

$N^h$ : Meas. number of DIS events (of type $h$)
$L$ : Dead–time corrected luminosity
$P_B, P_T$ : Beam and target polarisations

▷ Asymmetry $A_1$ in the virtual photon–nucleon system:

$$\frac{A_{\parallel}^{h}(x,Q^2)}{D(x,Q^2)[1+\eta\gamma]} \;=\; A_1^h(x,Q^2) \;\overset{g_2=0}{\simeq}\; \frac{g_1^h(x,Q^2)}{F_1^h(x,Q^2)}$$

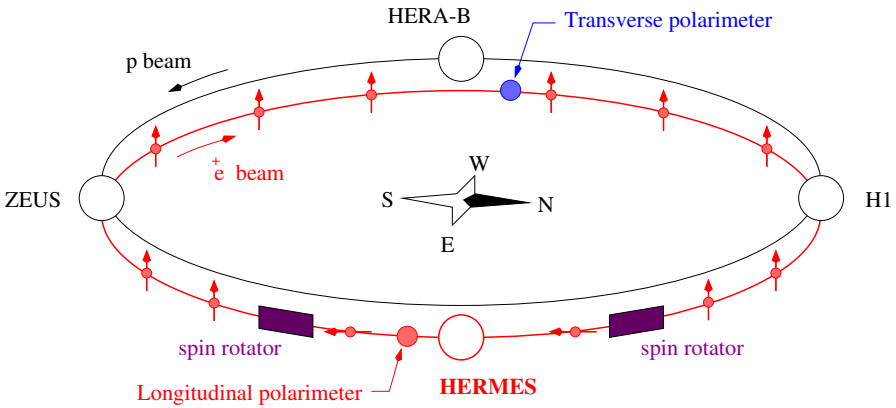
$$\boxed{2x\,F_1 \;=\; F_2 \cdot \frac{1+\gamma^2}{1+R}}$$

▷ In LO QCD:

$$A_1^h(x,Q^2) \;\overset{g_2=0}{\simeq}\; \frac{\sum_q e_q^2\,\Delta q(x,Q^2)\,\int_{z_{\min}}^{z_{\max}} \mathrm{d}z\; D_q^h(z,Q^2)}{\sum_q e_q^2\, q(x,Q^2)\,\int_{z_{\min}}^{z_{\max}} \mathrm{d}z\; D_q^h(z,Q^2)} \times \underbrace{\frac{1+R(x,Q^2)}{1+\gamma^2}}_{=:\,C}$$

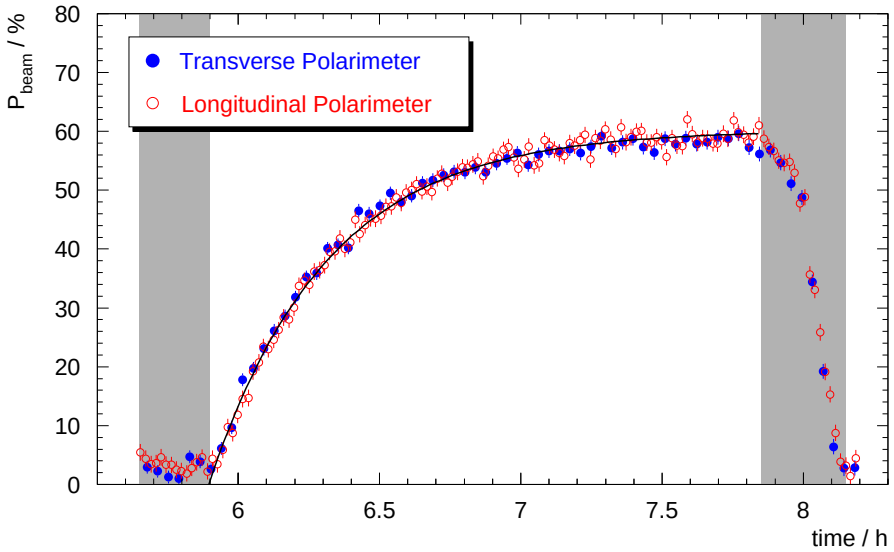
# The HERMES Experiment at HERA

- HERA–$e^{\pm}$: 27.6 GeV/$c$, $I = 40 \ldots 10$ mA
- The polarised $e^{\pm}$ beam at HERA:

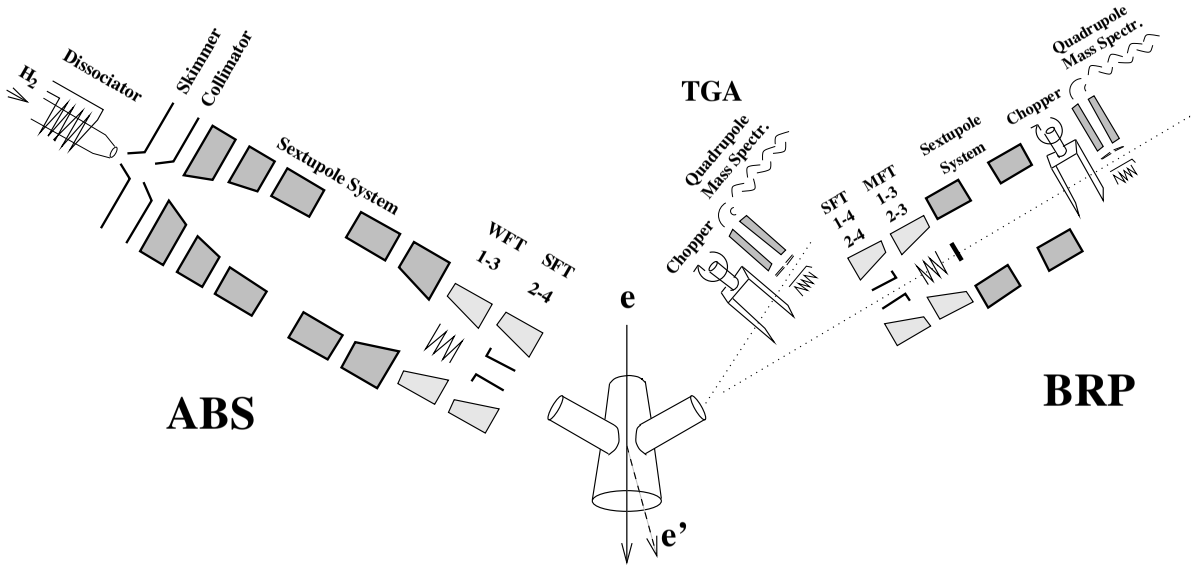



- Asymptotic build–up of transverse positron polarisation in HERA through the emission of synchrotron radiation ("Sokolov–Ternov mechanism")
- Longitudinal positron spin polarisation at HERMES

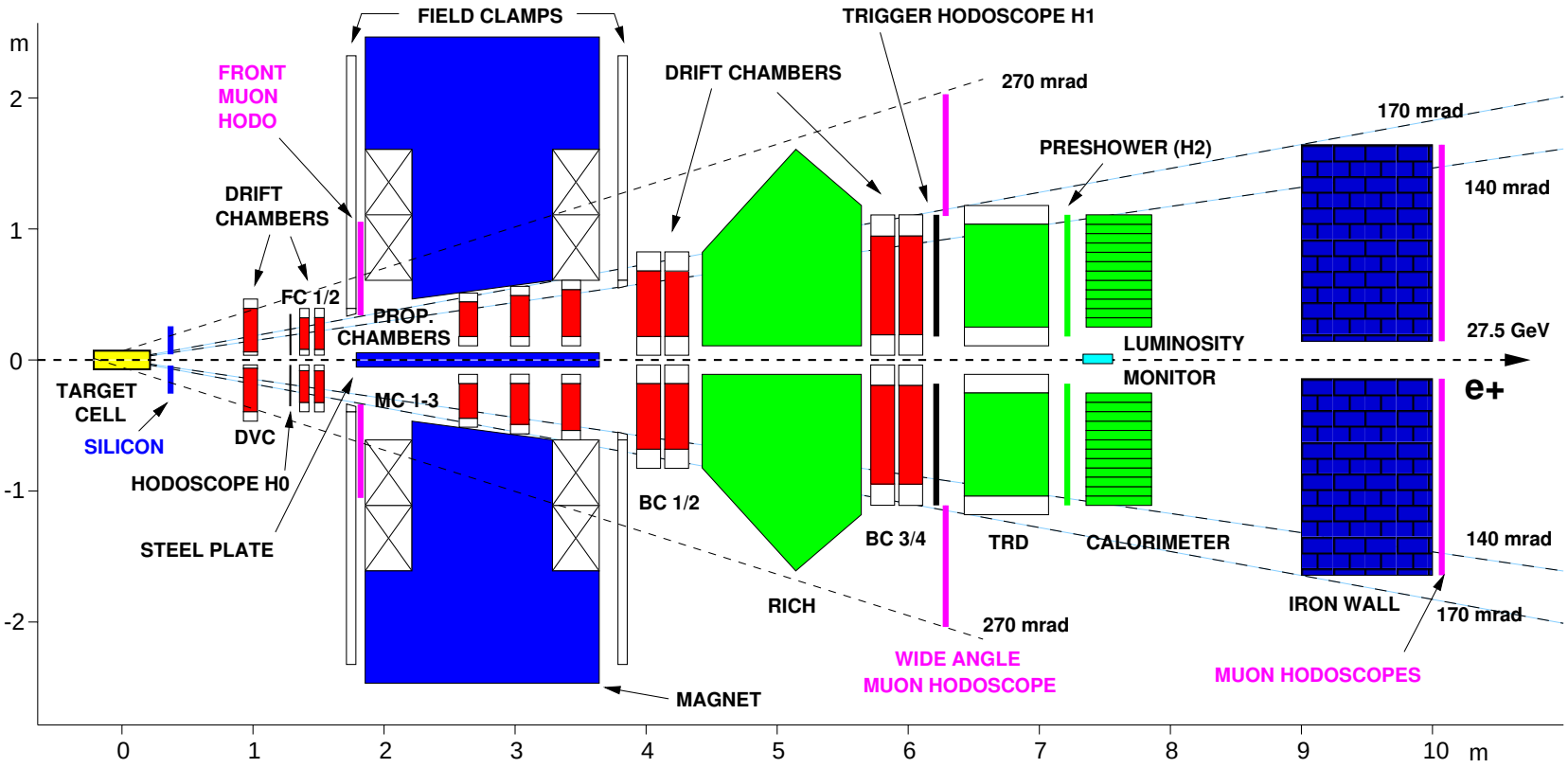
- Online measurement of the beam polarisation by two Compton backscattering polarimeters:




- Polarised, windowless gas target (ABS) internal to the HERA beam line vacuum


H2
Dissociator
Skimmer
Collimator
Sextupole System
WFT
1-3
SFT
2-4
ABS
e
e'
TGA
Quadrupole
Mass Spectr.
Chopper
SFT
1-4
2-4
MFT
1-3
2-3
Sextupole
System
Chopper
Quadrupole
Mass Spectr.
BRP

# The HERMES Spectrometer




- ▷ Angular resolution $\Delta\theta < 0.6$ mrad, momentum resolution $\Delta p/p = 0.7 \ldots 1.3\%$
- ▷ Good lepton identification (efficiency $\sim 98\%$) at small hadron contaminations ($\leq 1\%$)
- ▷ Threshold Čerenkov counter replaced by a RICH detector in 1998
  $\Rightarrow$ Identification of $\pi^{\pm}, K^{\pm}, p, \bar{p}$

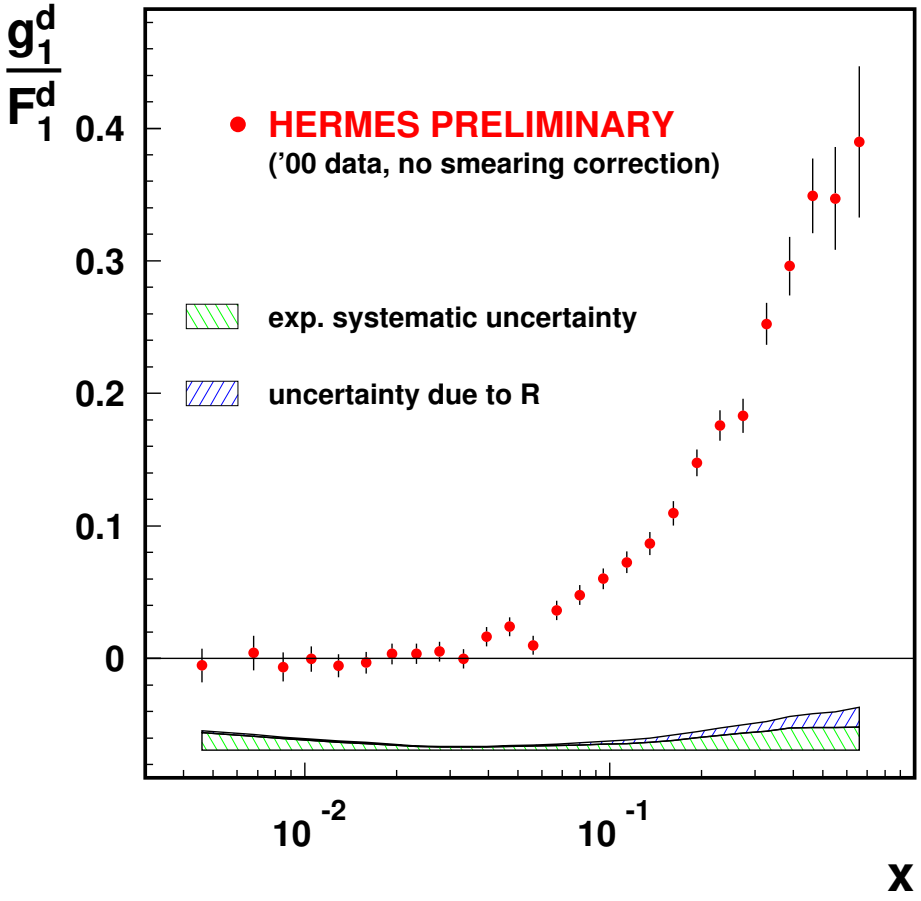
# Data Samples

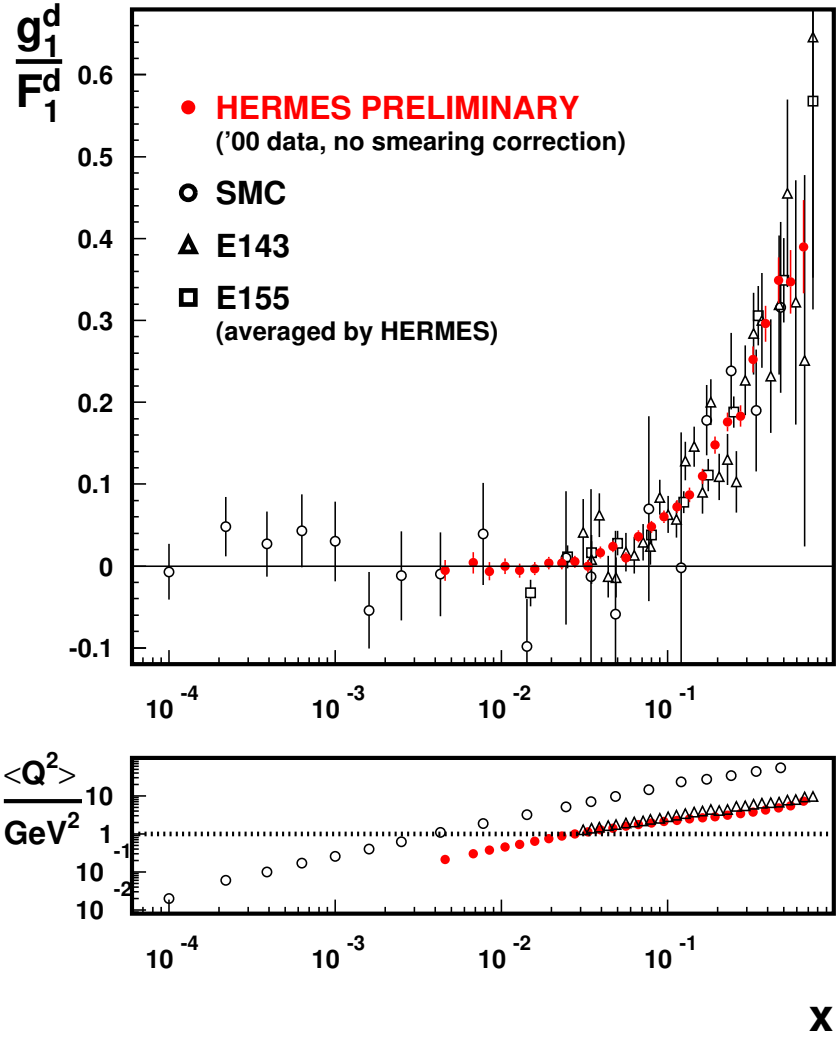
▷ Summary of the HERMES data taking program on polarised targets from 1996 until 2000:

| Year | 1996 | 1997 | **1996-97** | 1998 | 1999 | 2000 | **1998-2000** |
|---|---|---|---|---|---|---|---|
| Target | $\overrightarrow{\mathrm{H}}$ | | | $\overrightarrow{\mathrm{D}}$ | | | |
| DIS events ($\times 10^6$) | 0.49 | 1.28 | **1.77** | 0.75 | 0.92 | 4.81 | **6.48** |
| $\langle P_{\mathrm{B}} P_{\mathrm{T}} \rangle$ | 0.40 | 0.45 | **0.44** | 0.43 | 0.43 | 0.45 | **0.44** |

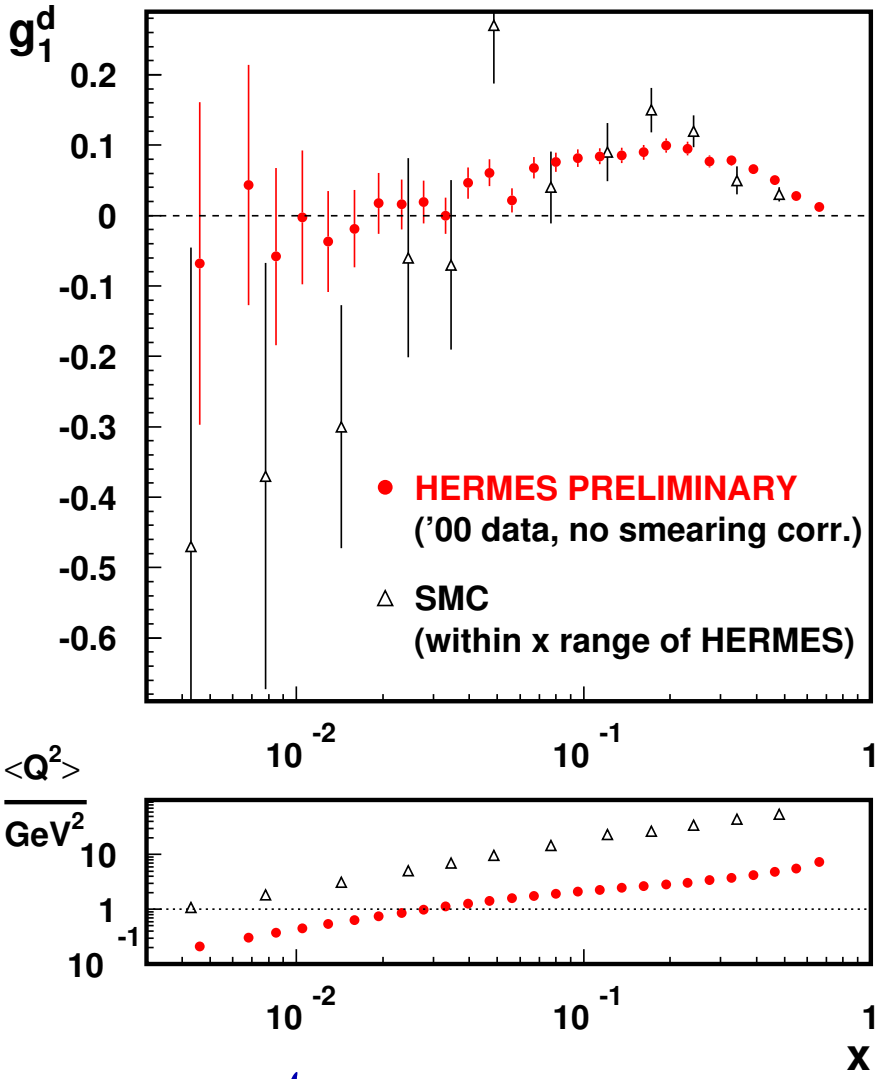
(All numbers after data quality and kinematic cuts)

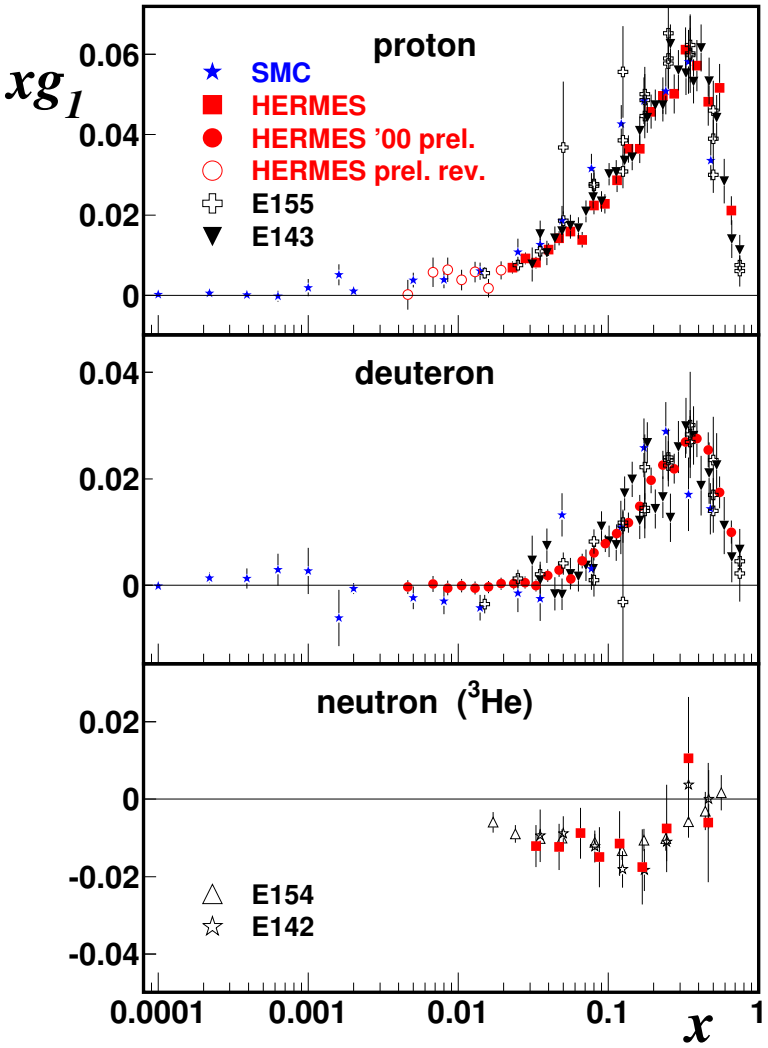
# Measured Inclusive Asymmetry on a Deuterium Target



# Results on the Polarised Structure Function $g_1$



# Unfolding of Born Asymmetries

Unfolding algorithm to derive Born asymmetries from measured data

▷ Compute smearing matrix from Monte Carlo data:

$$S_{\pm}(i,j) \;=\; \frac{\partial \sigma_{\pm}^{\mathrm{meas}}}{\partial \sigma_{\pm}^{\mathrm{Born}}} \;=\; \frac{\partial N_{\pm}^{\mathrm{meas}}}{\partial N_{\pm}^{\mathrm{Born}}} \;=\; \frac{N_{\pm}(i,j)}{N_{\pm}^{\mathrm{Born}}(j)}$$

in measured bins $i = 1, \ldots, n_{\mathrm{meas}}$ and bins for the Born asymmetry $j = 1, \ldots, n_{\mathrm{Born}}$

▷ Matrix $S_{\pm}(i,j)$ includes effects from QED radiative corrections and from detector smearing

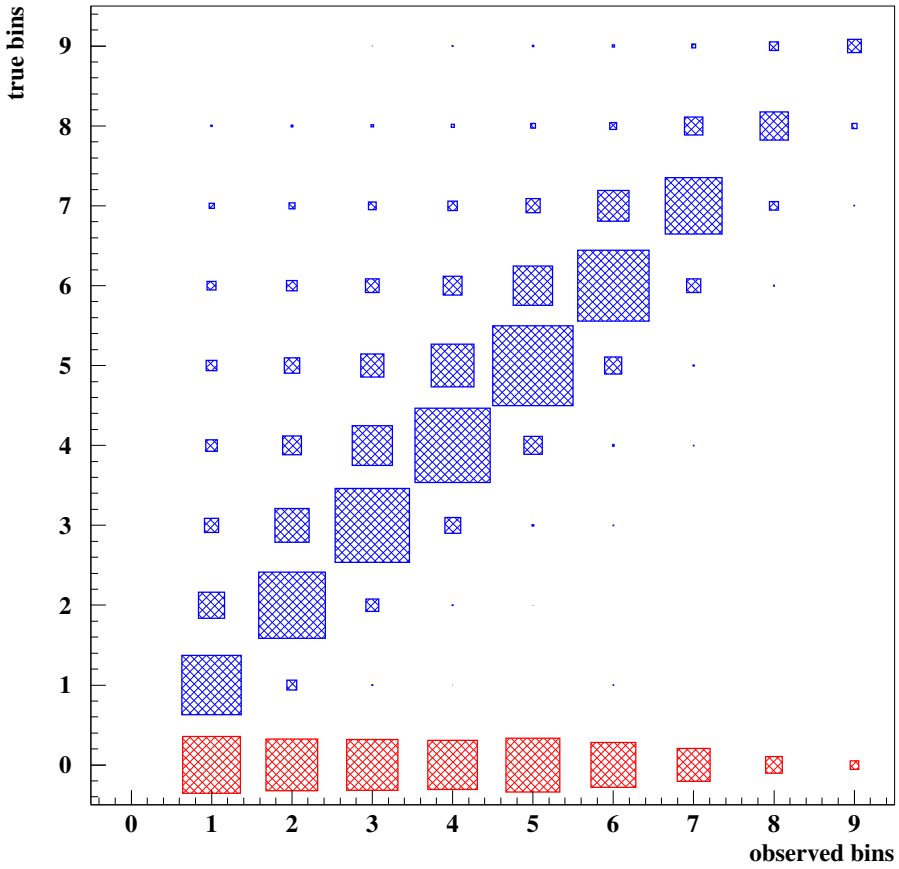
▷ Obtain Born asymmetry from measured data using inverted smearing matrix $[S_{\pm}]^{-1} \quad [\ldots]$

▷ Unfolding algorithm takes background and statistical correlations between all bins properly into account

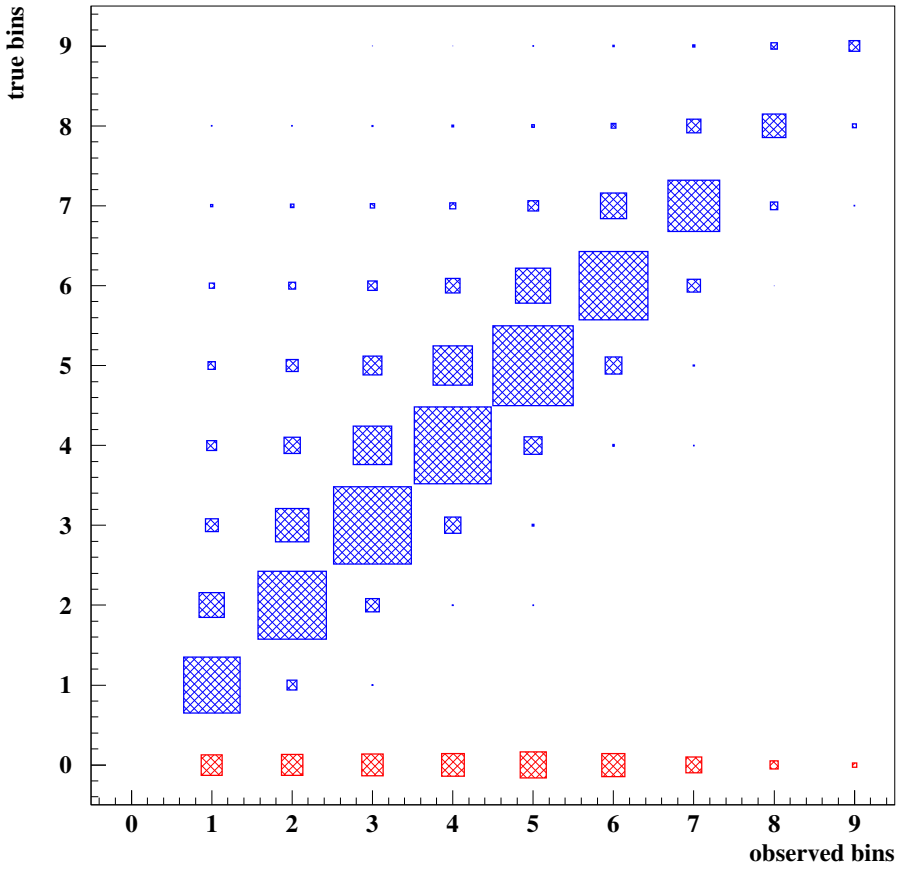
▷ Statistical uncertainties of unfolded asymmetries are enlarged

# Migration of Events over Bins

DIS positrons



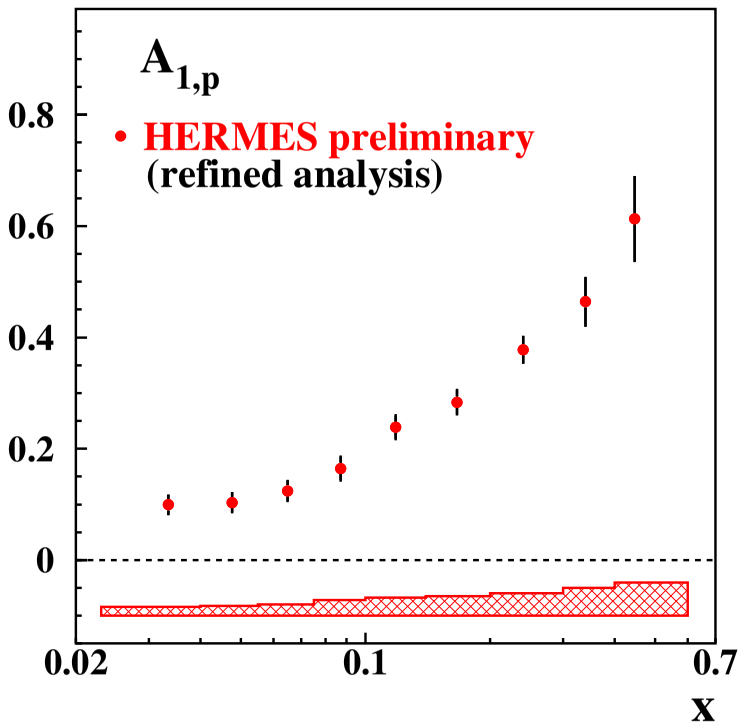

SIDIS positive hadrons

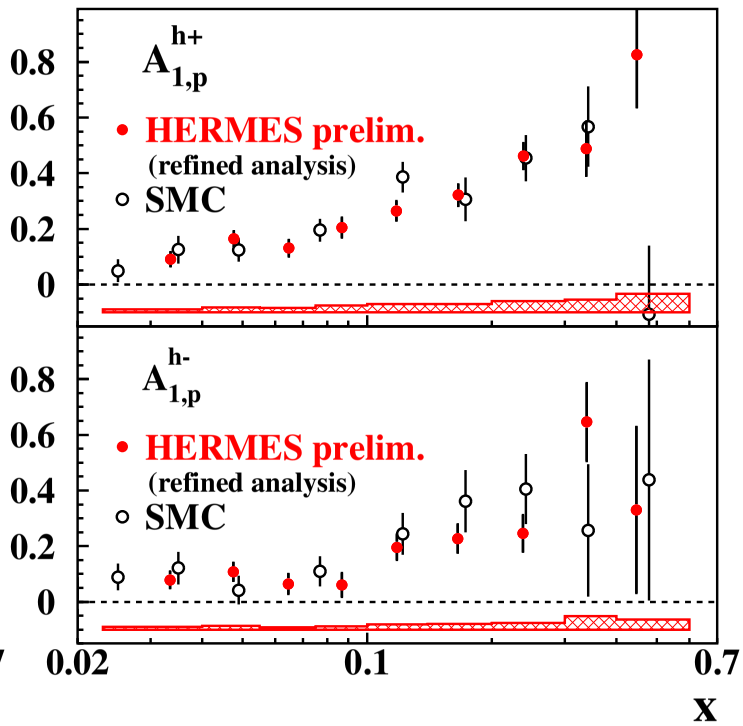


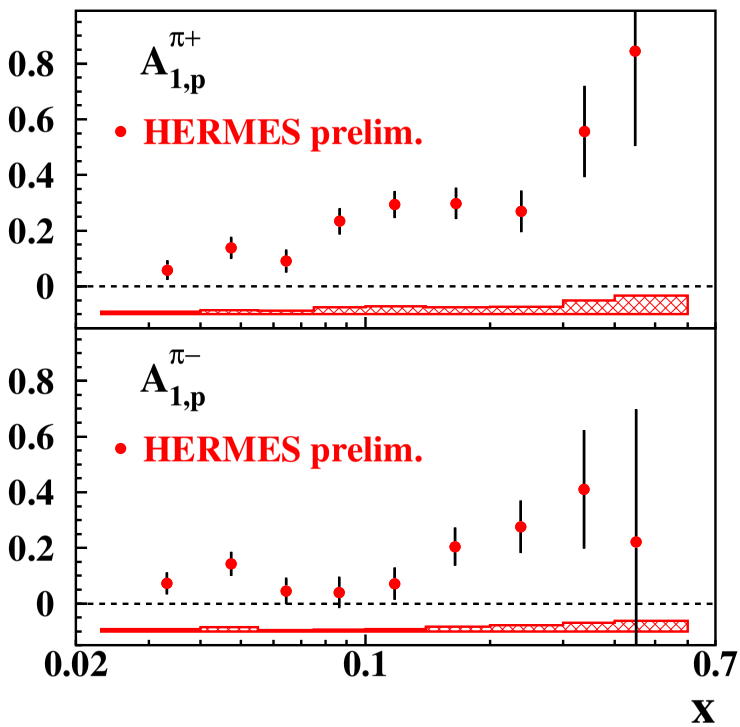

true bin $= 0$: Events smeared into kinematic and geometric acceptance

true bin $\neq 0$: Event smearing within acceptance

# Measured Semi–Inclusive Asymmetries on a Proton Target

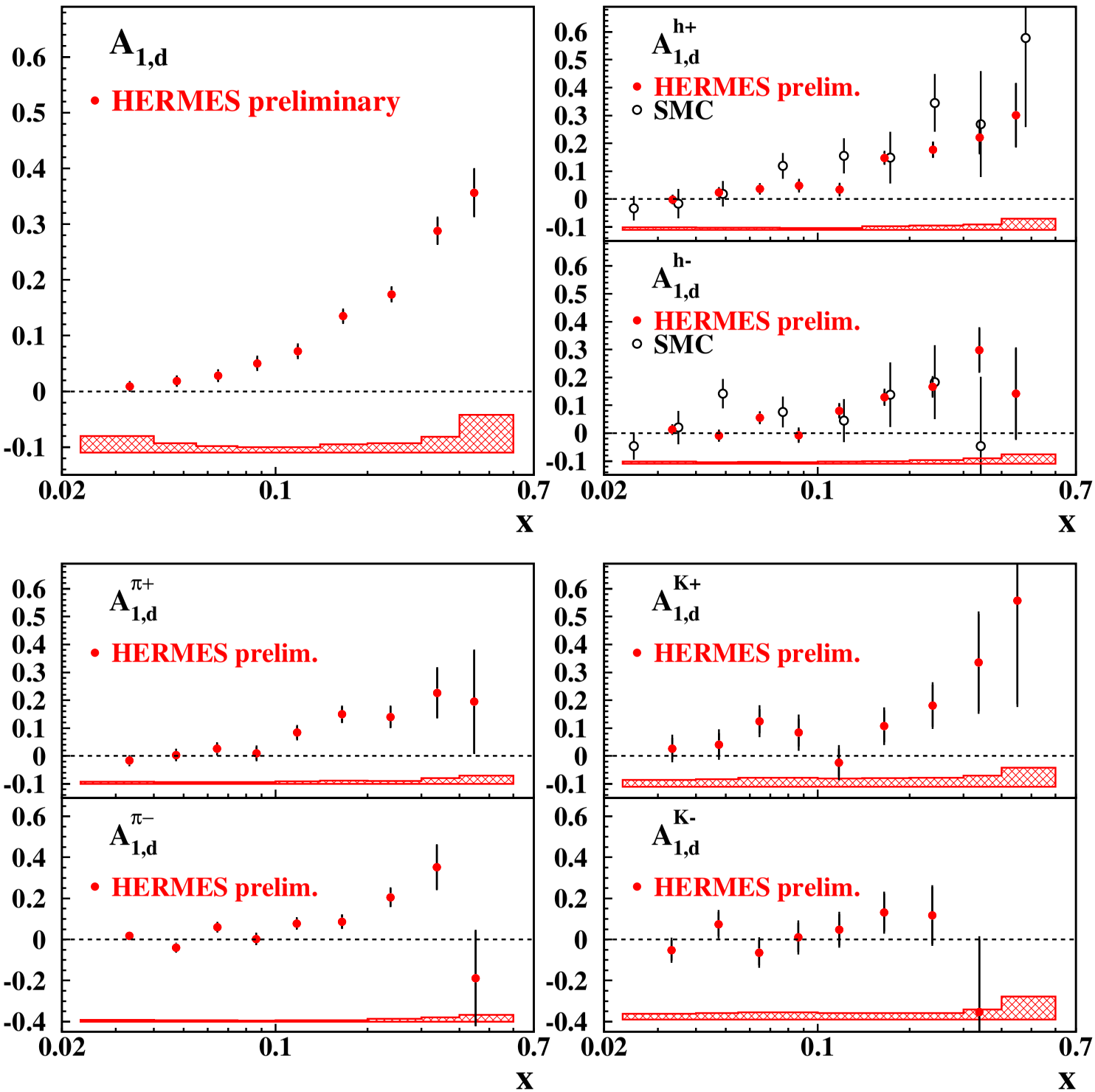



- ▷ Increased statistical uncertainties due to unfolding procedure
- ▷ Revised target polarisation value $\langle P_T \rangle = 0.82 \pm 0.05$ (prelim.) compared to published value $\langle P_T \rangle = 0.86 \pm 0.04$ [HERMES Coll., PL **B464** (1999) 123.]

# Measured Semi–Inclusive Asymmetries on a Deuterium Target




▷ RICH detector allows extraction of semi–inclusive $\pi^{\pm}$ and $K^{\pm}$ asymmetries

# The Purity Formalism

▷ Rewrite virtual photon–nucleon asymmetry as

$$A_1^h(x) \;=\; \mathcal{C} \cdot \sum_q \underbrace{\left( \frac{e_q^2\, q(x) \int_{z_{\min}}^{z_{\max}} D_q^h(z)\mathrm{d}z}{\sum_{q'} e_{q'}^2\, q'(x) \int_{z_{\min}}^{z_{\max}} D_{q'}^h(z)\mathrm{d}z} \right)}_{\equiv P_q^h(x)} \cdot \frac{\Delta q(x)}{q(x)}$$

▷ *Purity* $P_q^h(x) \equiv$ Probability that a hadron $h$ originated from scattering off a quark $q(x)$

▷ Solve system of linear equations $\vec{A}$

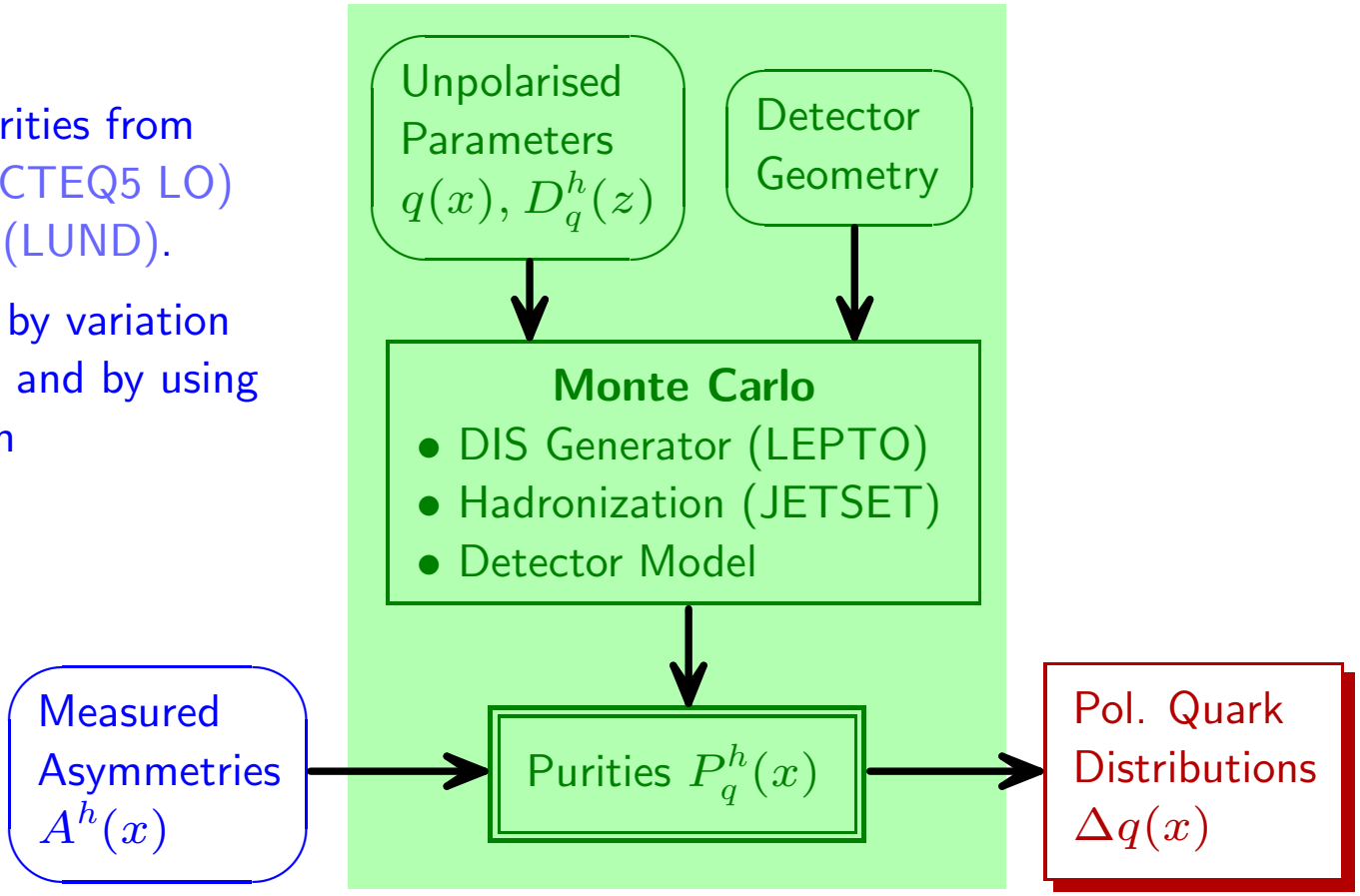
$$\vec{A}(x) \;=\; \mathcal{C} \cdot \mathbf{P}(x) \cdot \vec{Q}(x)$$

for vector of quark polarisations

$$\vec{Q} = \left( \frac{\Delta u}{u}, \frac{\Delta d}{d}, \frac{\Delta \bar{u}}{\bar{u}}, \frac{\Delta \bar{d}}{\bar{d}}, \frac{\Delta s + \Delta \bar{s}}{s + \bar{s}} \right) \;.$$

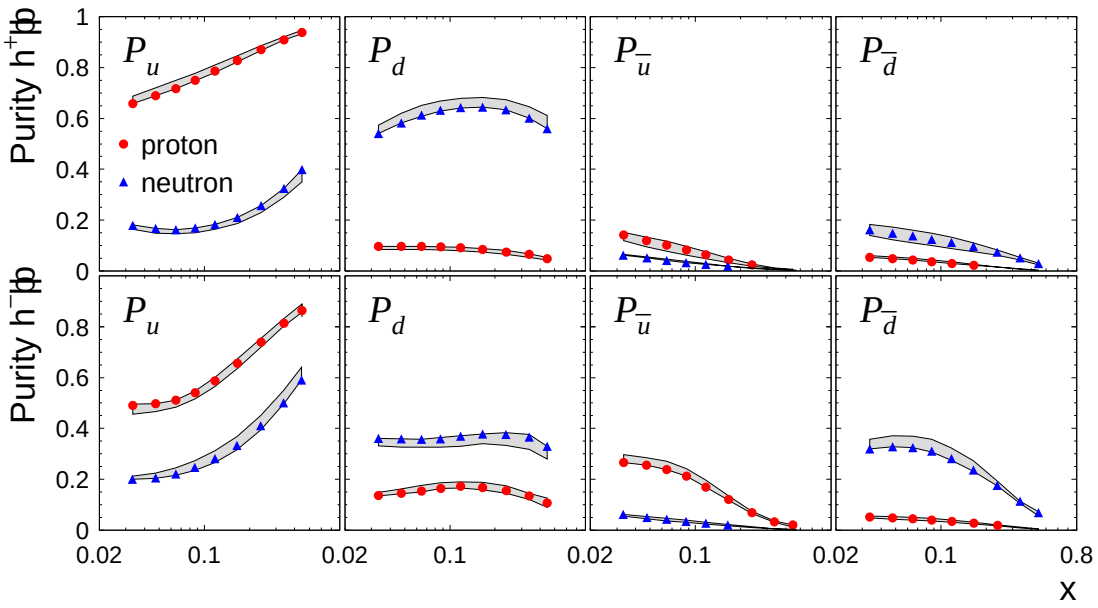
# How Do We Obtain the Purities?

- ▷ Use Monte Carlo to generate purities from parameterisations of $q(x, Q^2)$ (CTEQ5 LO) and tuned fragmentation model (LUND).
- ▷ Estimate systematic uncertainty by variation of the fragmentation parameters and by using alternative PDF parameterisation (GRV98 LO).



# Purities for Charged Hadrons

▷ Purities $P^{h^\pm}_{u,\bar{u},d,\bar{d}}$ for a proton and a neutron target:




Shaded bands indicate the systematic uncertainties

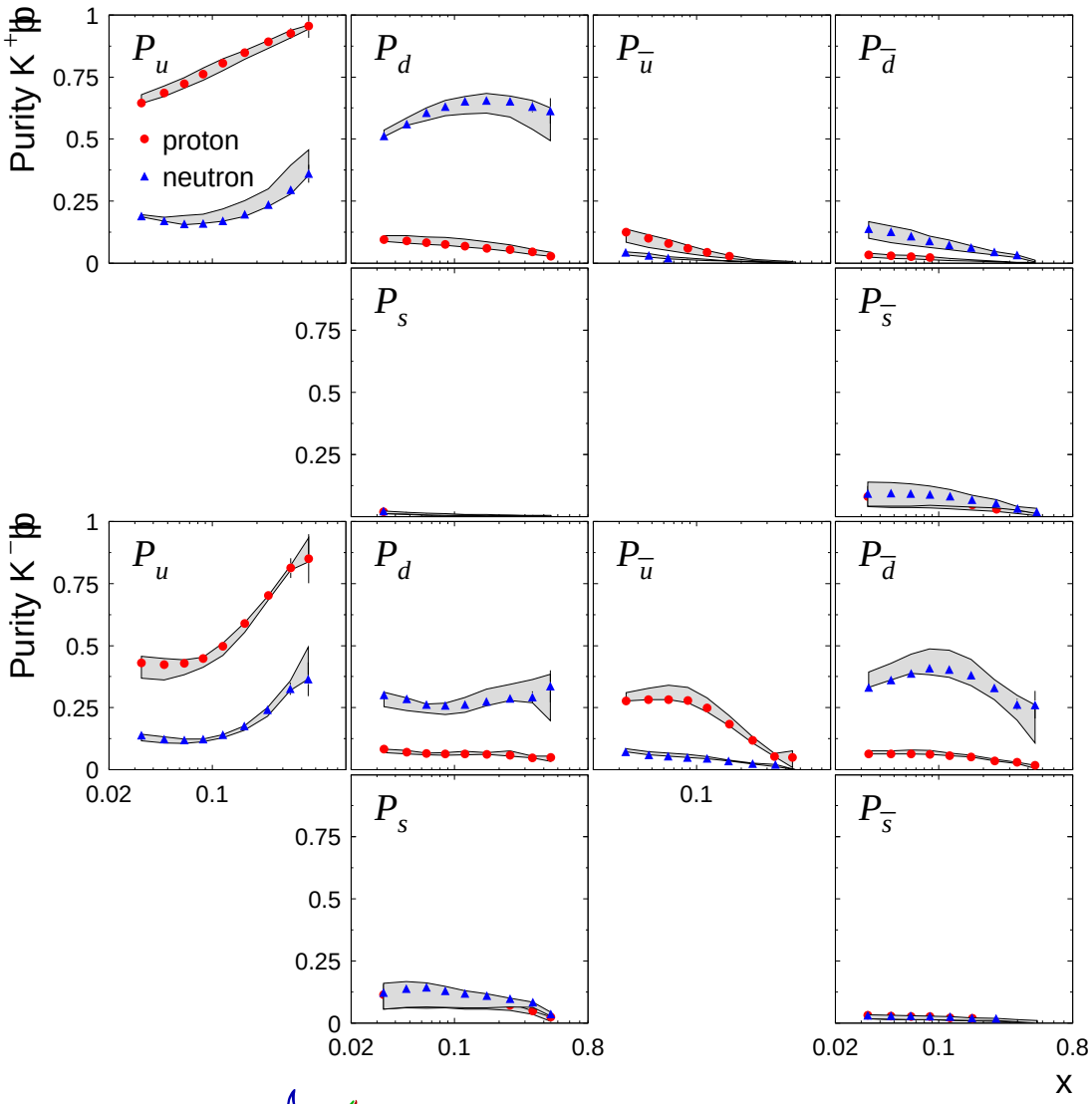
▷ Semi–inclusive hadron asymmetries $h^\pm$ on the proton dominated by $\Delta u(x)$.

▷ Semi–inclusive hadron asymmetries $h^\pm$ on the neutron sensitive to $\Delta d(x)$.

▷ Sensitivity on $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x) \gtrsim 10\%$ for $x \leq 0.2$.

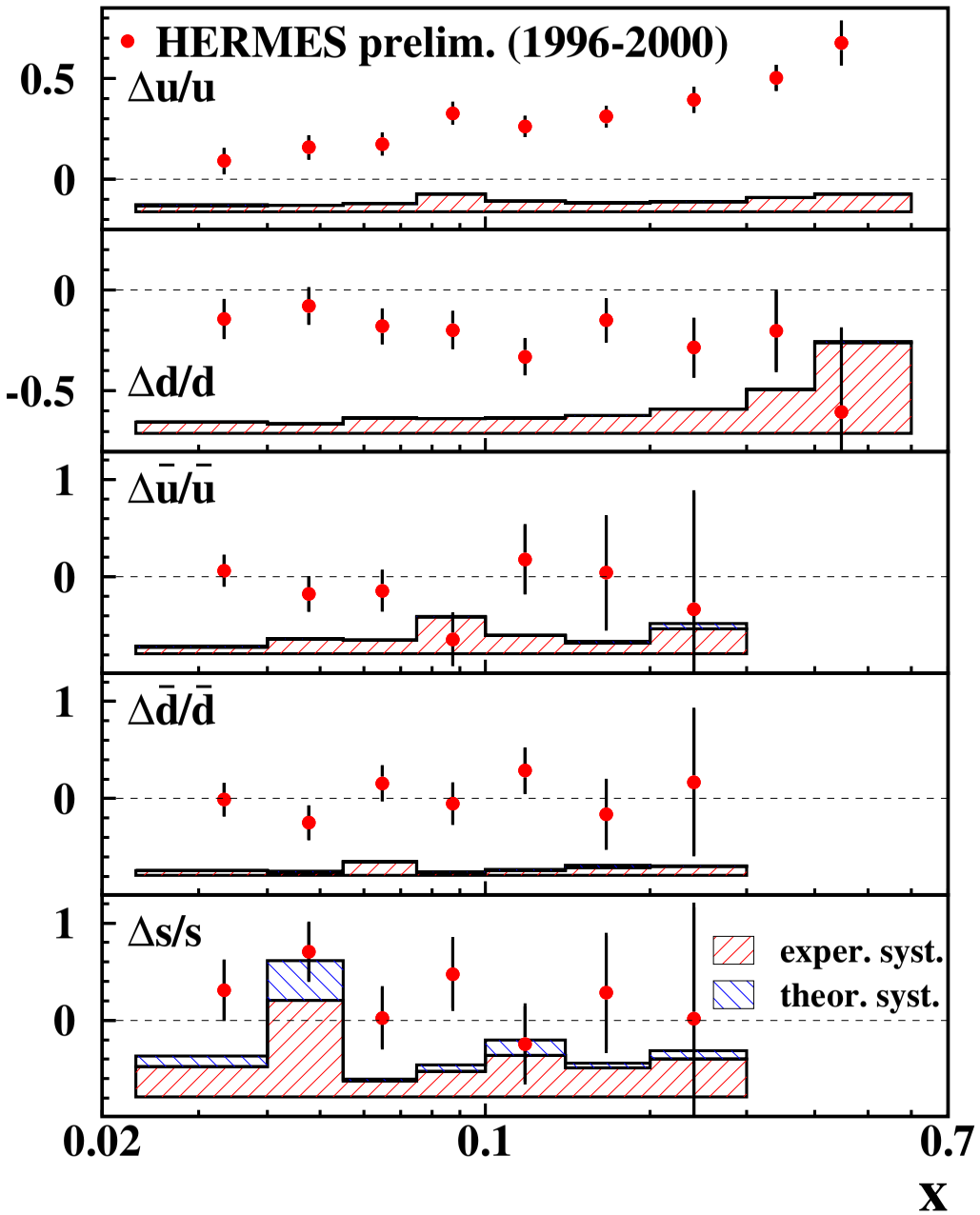
$\Rightarrow$ Data on proton– and "neutron targets" (Deuterium, $^3$He) have to be combined in order to extract other sea quark flavour polarisations than $\Delta\bar{u}(x)$.

# Purities for Charged Kaons




- Kaon samples provide sensitivity on $\Delta s(x), \Delta\bar{s}(x)$ for $x \lesssim 0.2$
- Systematic uncertainties on kaon purities dominated by fragmentation model and knowledge of unpolarised parton densities

# Extracted Quark Polarisations

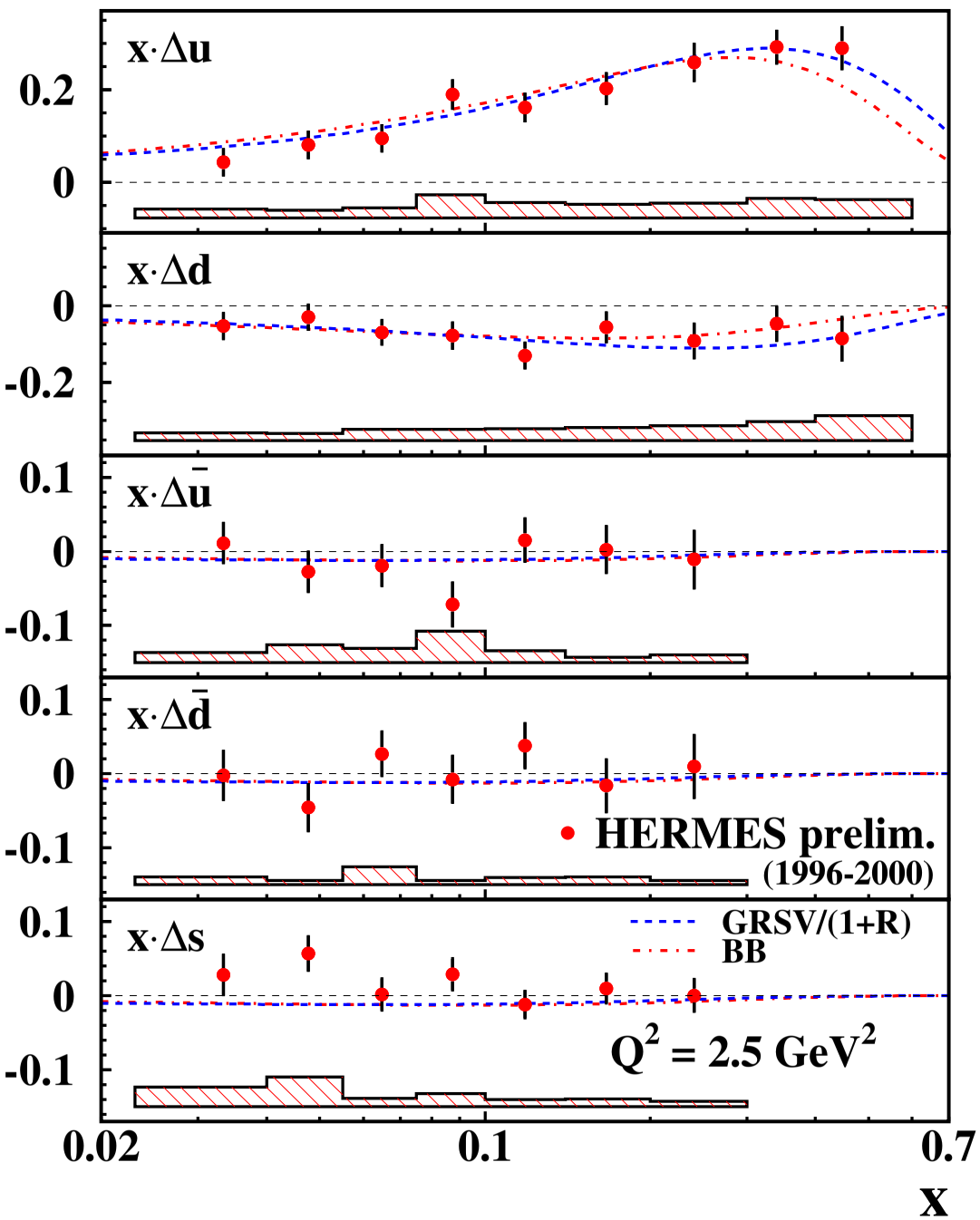



▷ Only remaining symmetry assumption:

$$\frac{\Delta s(x)}{s(x)} = \frac{\Delta \bar{s}(x)}{\bar{s}(x)}$$

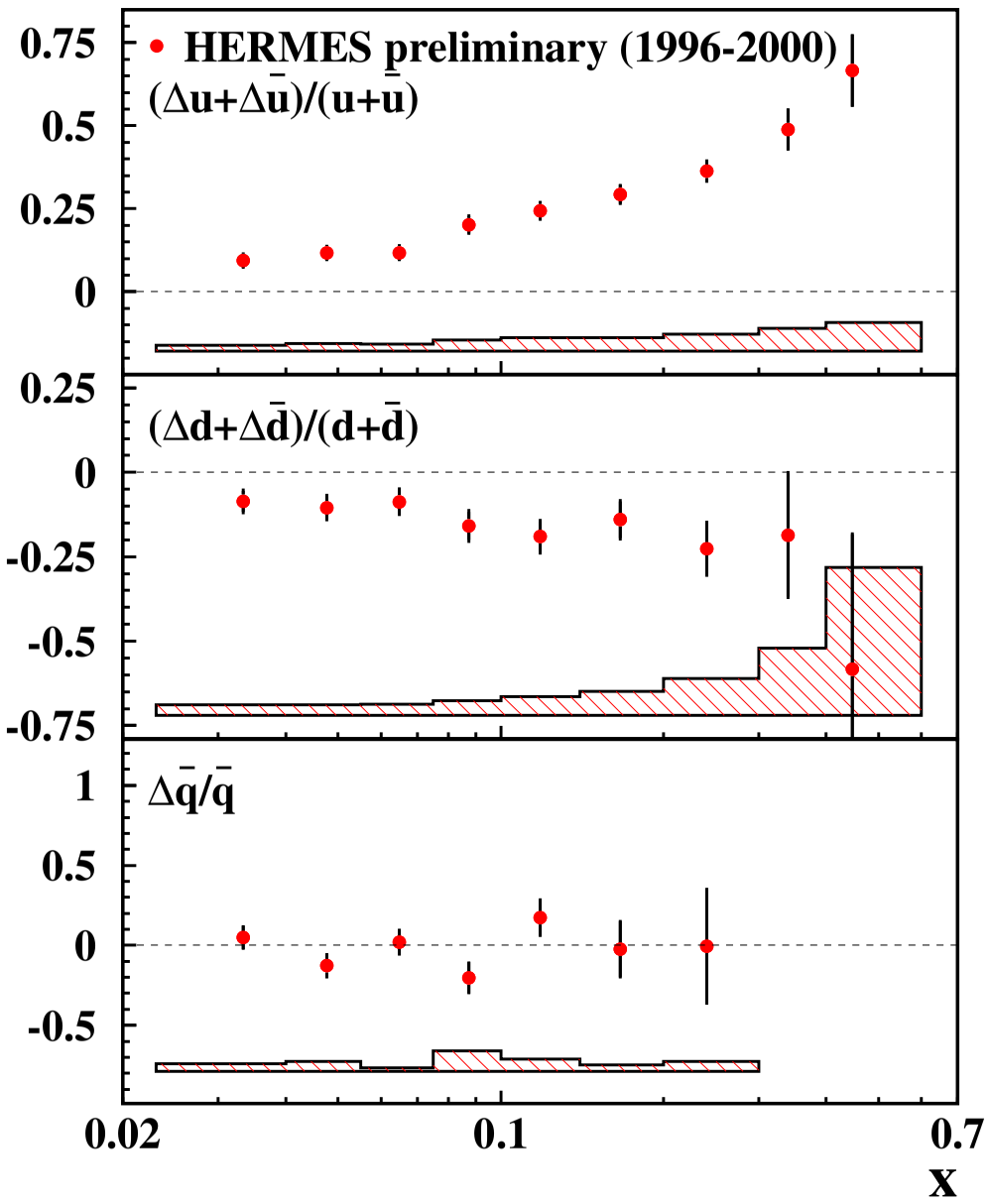
▷ Systematic uncertainty for the sea flavours dominated by the fragmentation model uncertainty.

# Polarised Quark Densities




- ▷ Use CTEQ5 LO unpolarised quark densities at $Q^2 = 2.5$ GeV$^2$
- ▷ No indication for a negative strange sea contribution

# Extracted Quark Polarisations

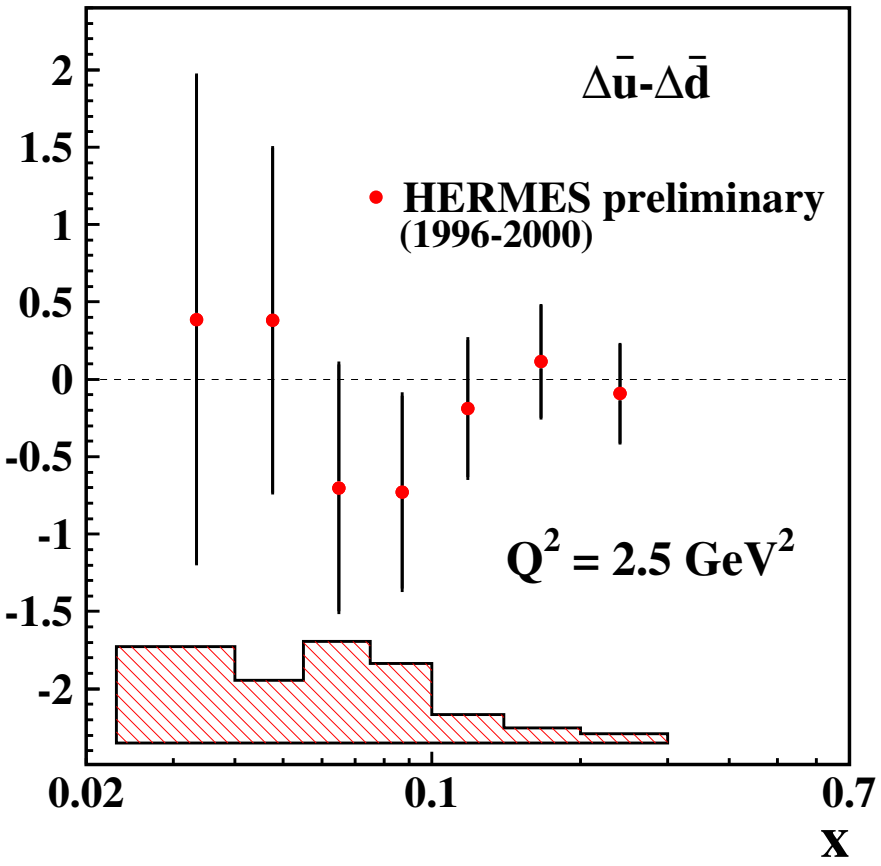



▷ Symmetry assumptions:

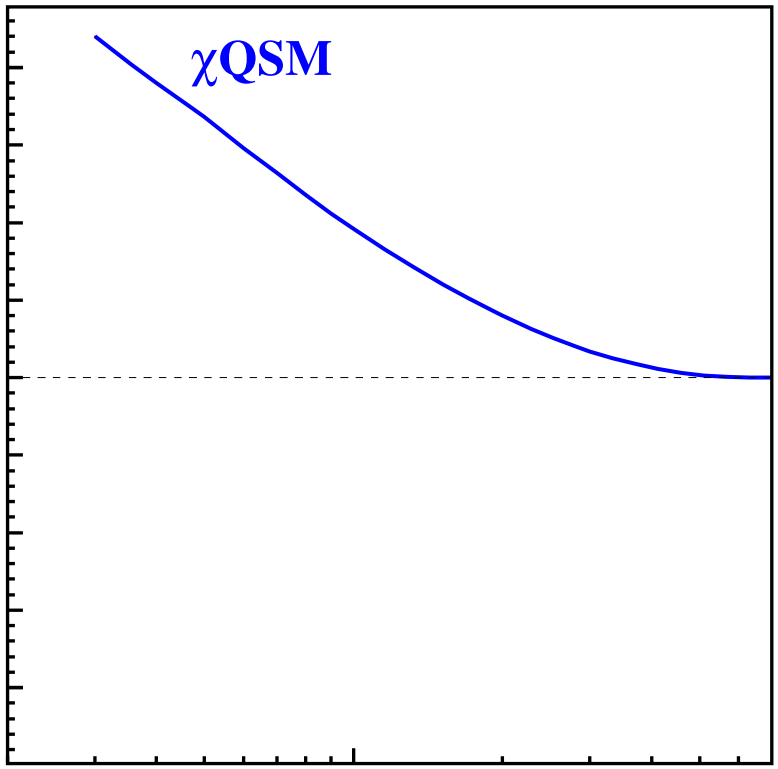
$$\frac{\Delta\bar{q}(x)}{\bar{q}(x)} \equiv \frac{\Delta\bar{u}}{\bar{u}} = \frac{\Delta u_s}{u_s} = \frac{\Delta\bar{d}}{\bar{d}} = \frac{\Delta d_s}{d_s} = \frac{\Delta s}{s} = \frac{\Delta\bar{s}}{\bar{s}}$$

▷ $\Delta\bar{q}(x)/\bar{q}(x)$ mainly reflects polarisation of $u_s$ and $\bar{u}$ quarks

# The Symmetry of the Polarised Light Sea




- ▷ No significant breaking of the flavour symmetry in the light sea observed. . .
- ▷ Data on $\Delta\bar{u}(x) - \Delta\bar{d}(x)$ do not favour predictions from the $\chi$QSM [Dressler et al., EPJ **C14** (2000) 147.]


χQSM

# Summary & Outlook

- ⊕ Polarised quark distributions from a LO QCD analysis of $1.8 \times 10^6$ $(6.5 \times 10^6)$ DIS events on a polarised $\overrightarrow{\mathrm{H}}\,(\overrightarrow{\mathrm{D}})$ target.
- ⊕ Identification of $\pi^{\pm}$ and $K^{\pm}$ mesons using a RICH detector.
- ⊕ Good consistency with earlier results at largely improved precision.
- ⊕ First determination of the individual polarised sea quark distributions without symmetry assumptions between them (except $\Delta s(x) = \Delta\bar{s}(x)$).
- ⊕ First extraction of the strange sea quark polarisation
  $\Rightarrow$ Favour slightly positive or zero first moment for $\Delta s$.
- ⊕ First measurement of $\Delta\bar{u} - \Delta\bar{d}$.

- ▷ Fragmentation functions **measured** at HERMES will help to reduce systematic uncertainties for the sea quark polarisations.