Recent Results on the Helicity Structure of the Nucleon

from hermes

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DESY, Hamburg

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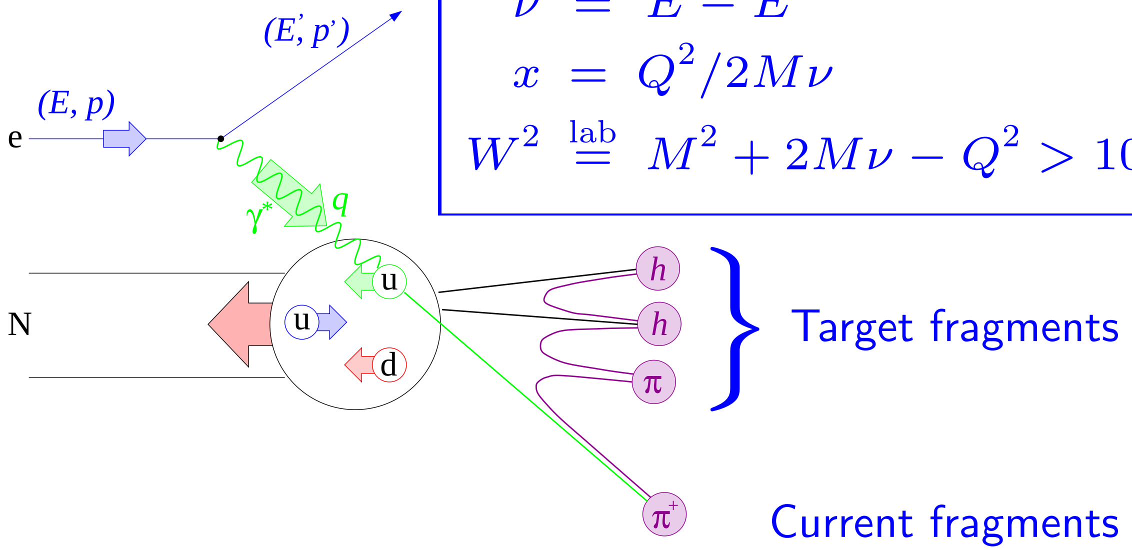
Outline:

- 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

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



- ▷ Hadrons from the current fragmentation:

  $0.8 > z = E_h/\nu > 0.2$

  $x_F \simeq 2p_\parallel/W > 0.1$

- ▷ 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

$$A_{\parallel}^{h} = \frac{1}{\langle P_B \, P_T \rangle} \cdot \frac{(N^h/L)^{\overleftarrow{\rightarrow}} - (N^h/L)^{\overrightarrow{\rightarrow}}}{(N^h/L)^{\overleftarrow{\rightarrow}} + (N^h/L)^{\overrightarrow{\rightarrow}}} \, ,$$

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:

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

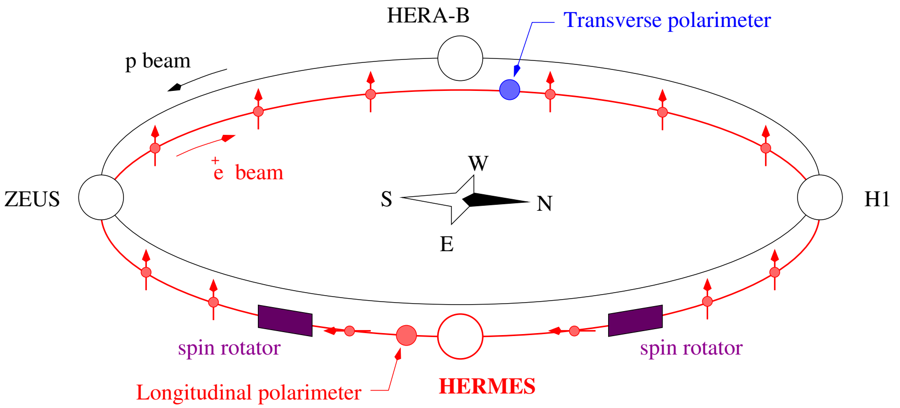
$$\boxed{2x \, F_1 = F_2 \cdot \frac{1 + \gamma^2}{1 + R}}$$

▷ In LO QCD:

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

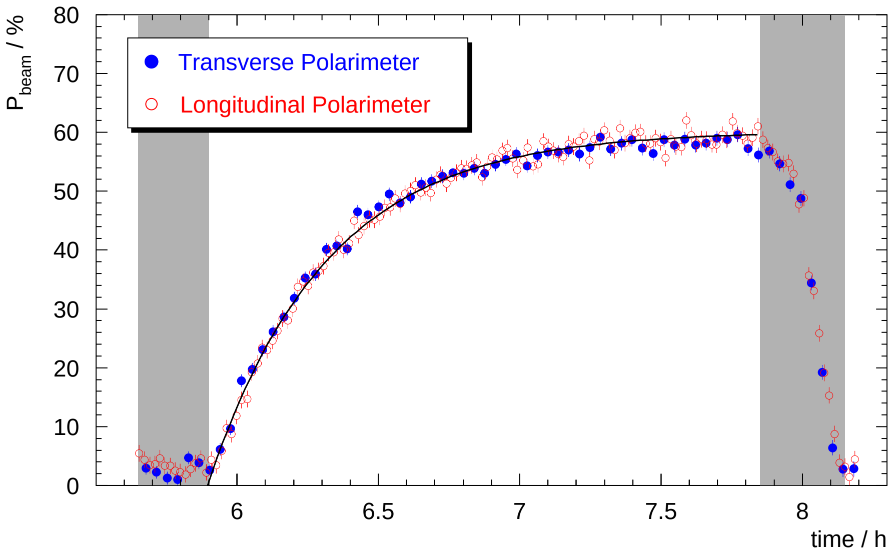
The HERMES Experiment at HERA

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

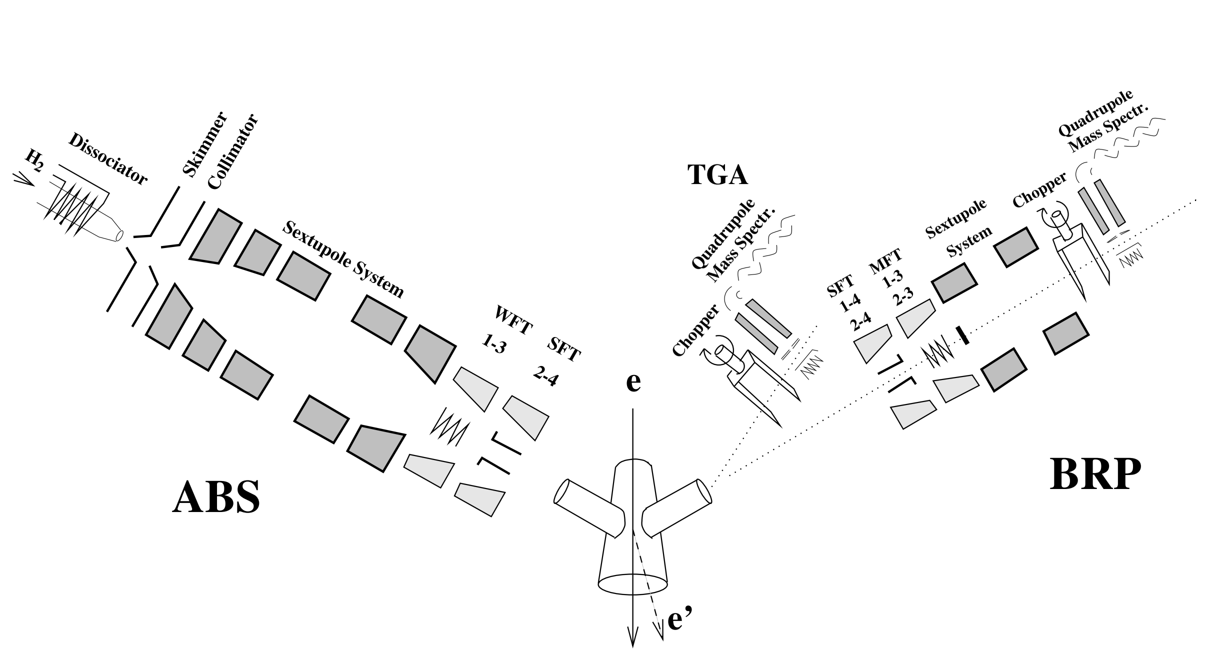


- ▷ Asymptotic build–up of transverse positron polarisation in HERA through the emission of synchrotron radiation ("Sokolov–Ternov mechanism")
- ▷ Longitudinal positron spin polarisation at HERMES

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

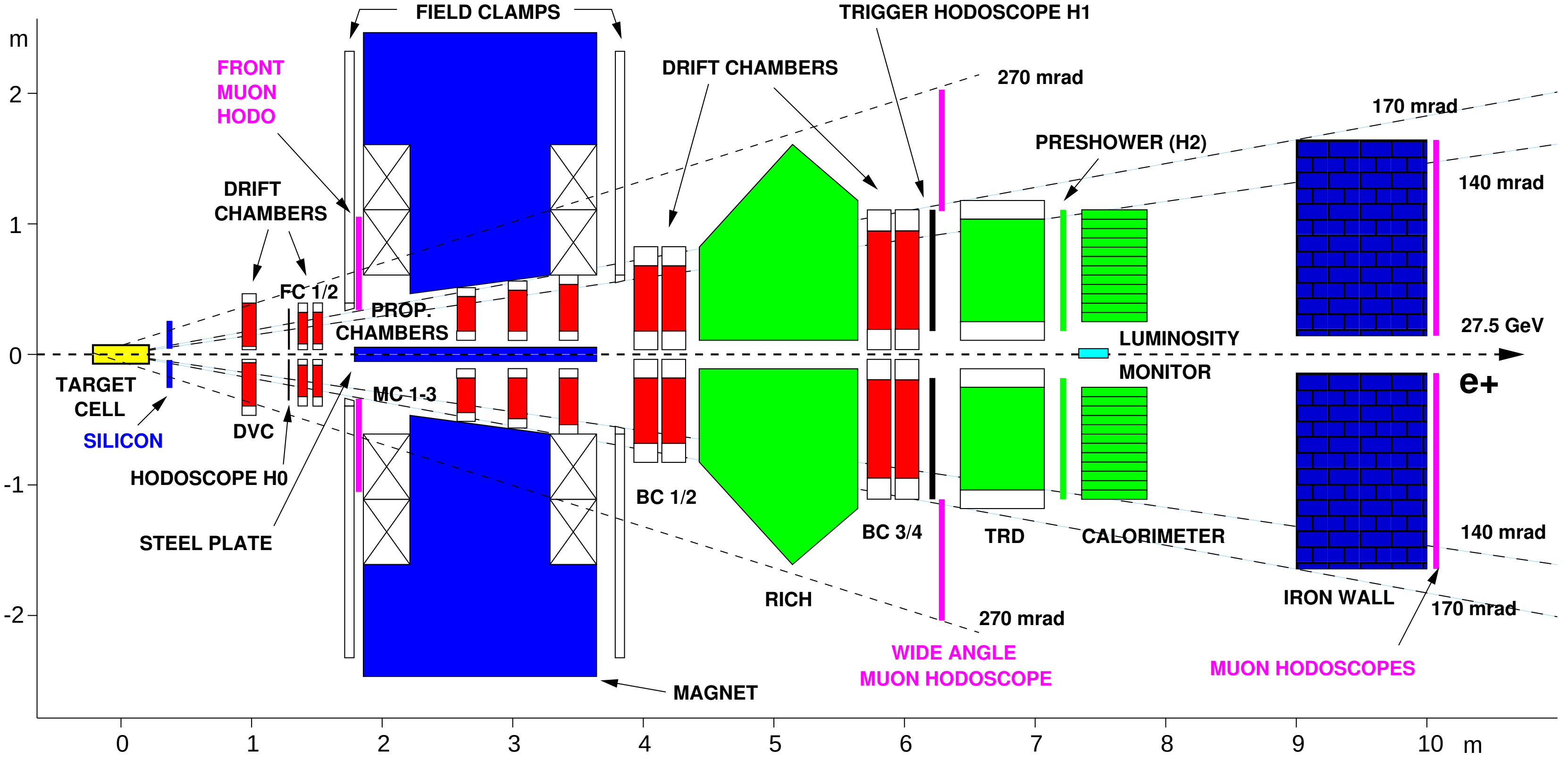


- ▷ Polarised, windowless gas target (ABS) internal to the HERA beam line vacuum



H_2
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 $\pi^{\pm}, K^{\pm}, p, \bar{p}$

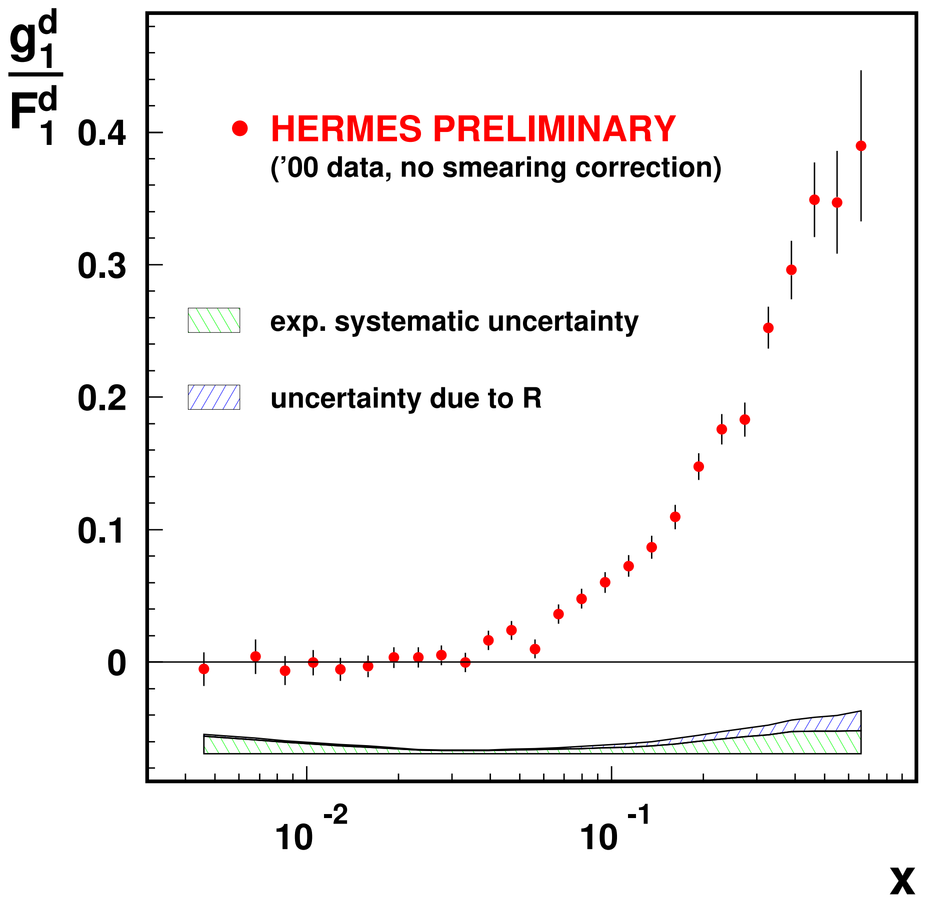
Data Samples

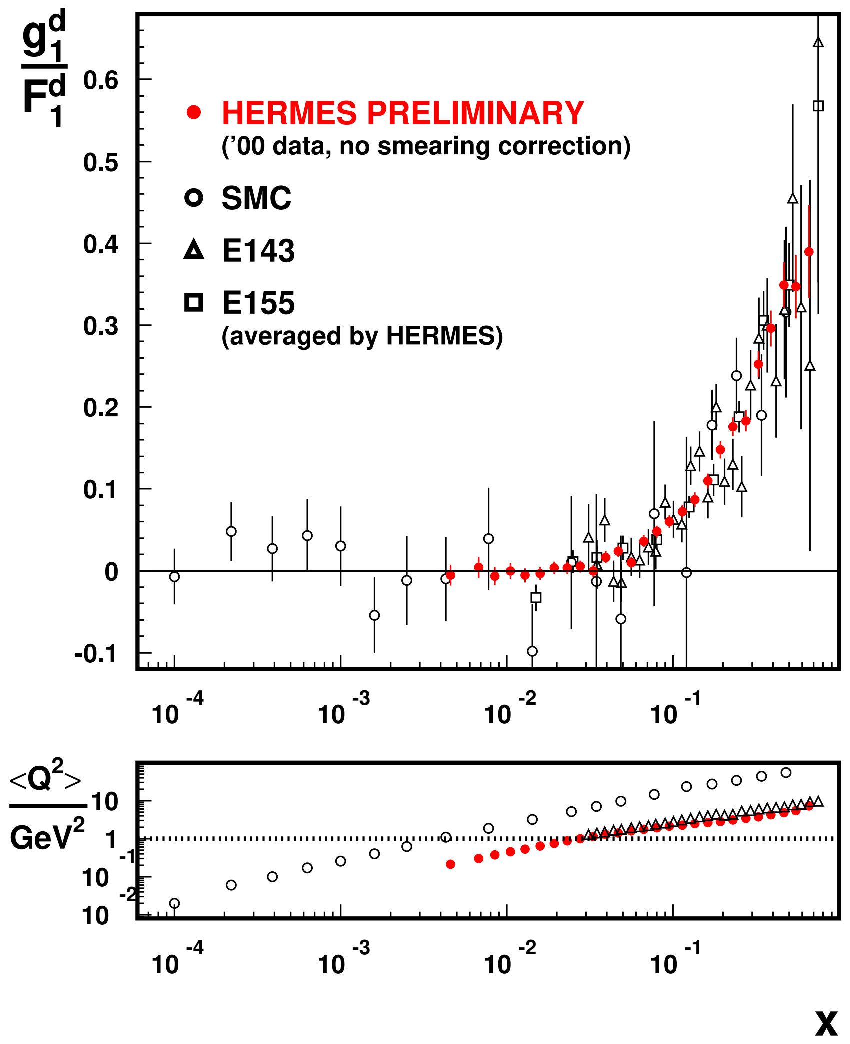
▷ Summary of the HERMES data taking program on polarised targets from 1996 until 2000:

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**

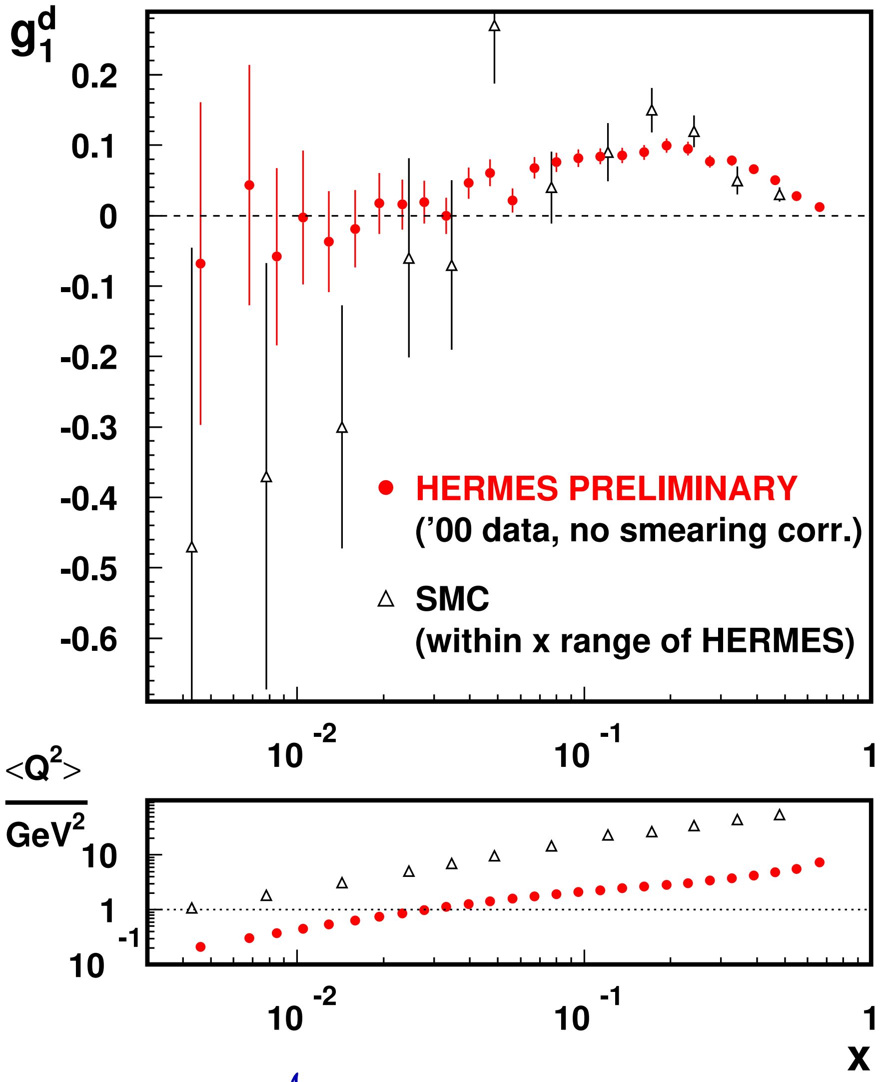
(All numbers after data quality and kinematic cuts)

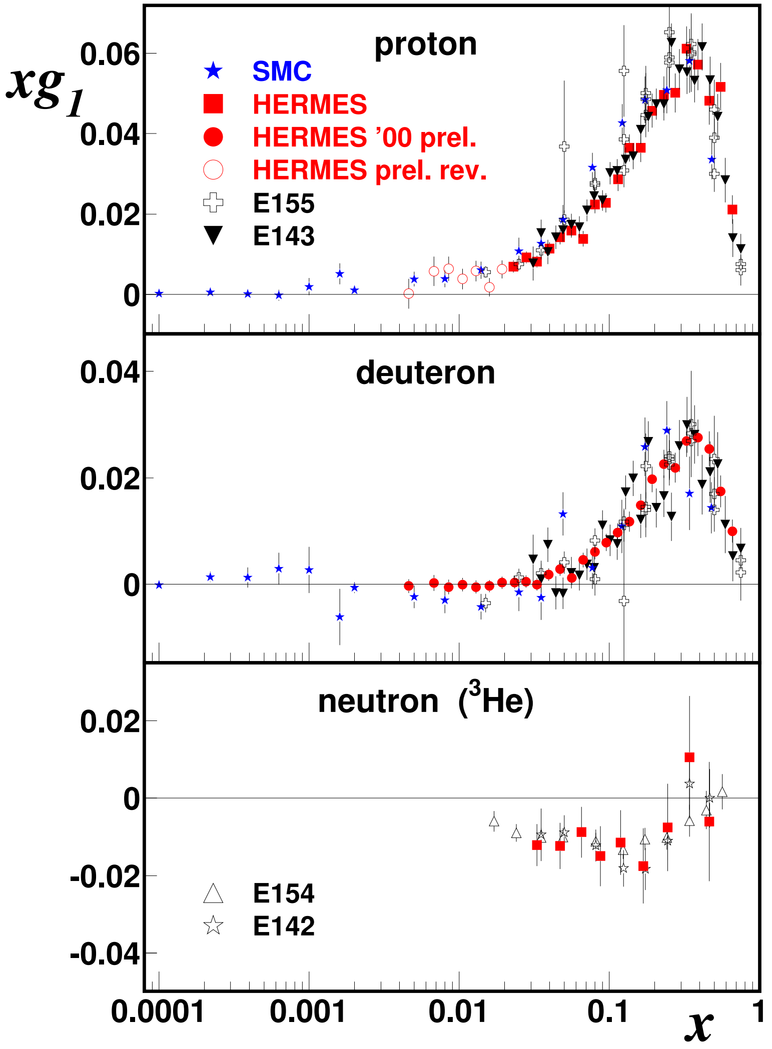
Measured Inclusive Asymmetry on a Deuterium Target





Results on the Polarised Structure Function g_1





Unfolding of Born Asymmetries

Unfolding algorithm to derive Born asymmetries from measured data

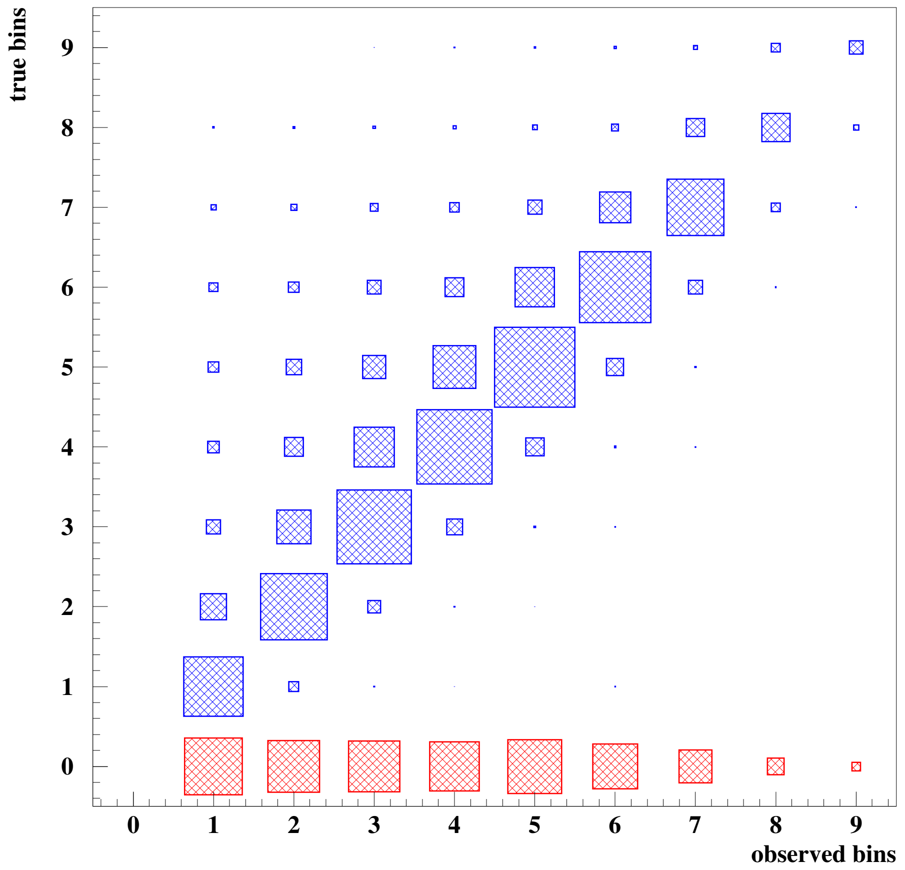
- Compute smearing matrix from Monte Carlo data:

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

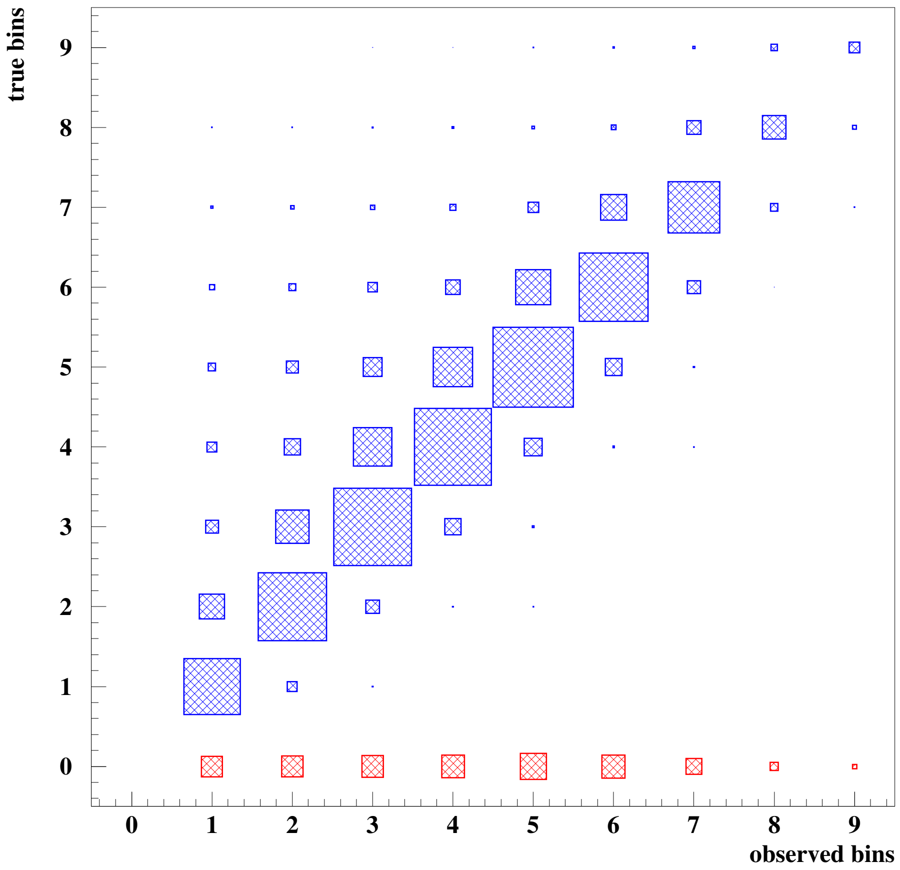
  in measured bins $i = 1, \ldots, n_{\mathrm{meas}}$ and bins for the Born asymmetry $j = 1, \ldots, n_{\mathrm{Born}}$
- Matrix $S_{\pm}(i,j)$ includes effects from QED radiative corrections and from detector smearing
- Obtain Born asymmetry from measured data using inverted smearing matrix $[S_{\pm}]^{-1}$ $[\ldots]$
- 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



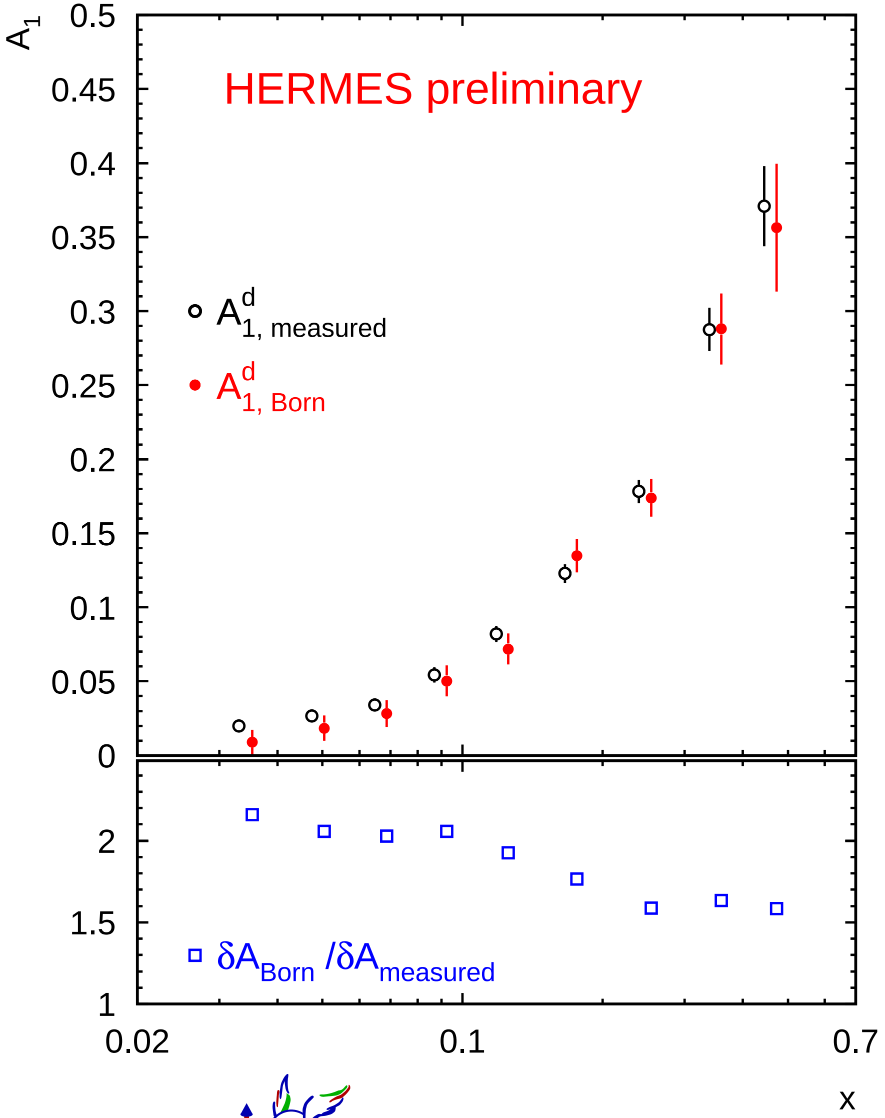
SIDIS positive hadrons



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

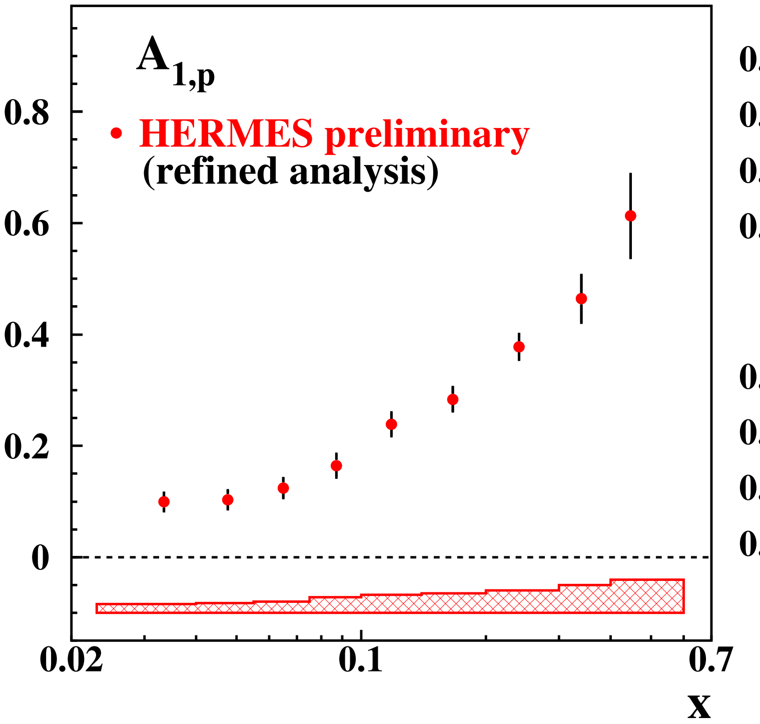
true bin $\neq 0$: Event smearing within acceptance

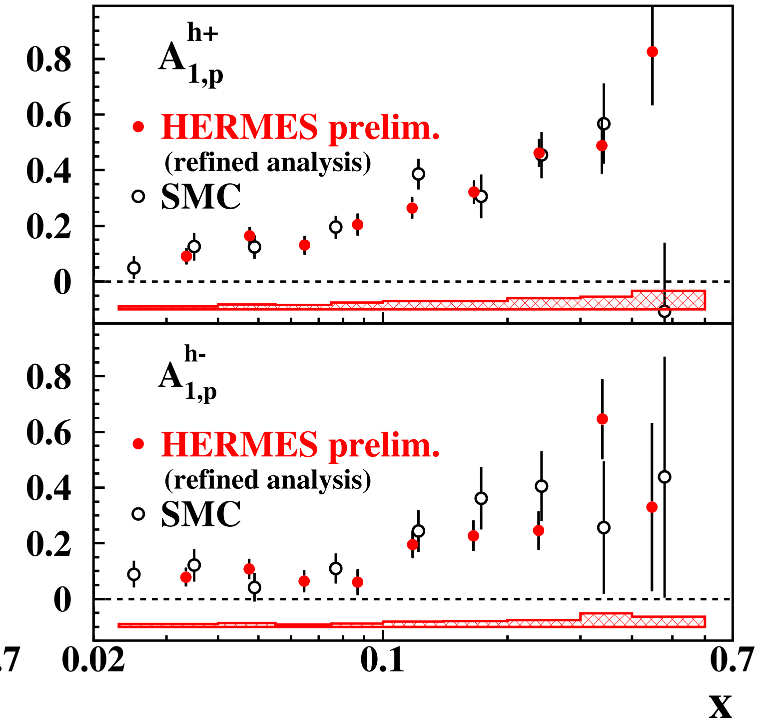
Results of the Unfolding Procedure

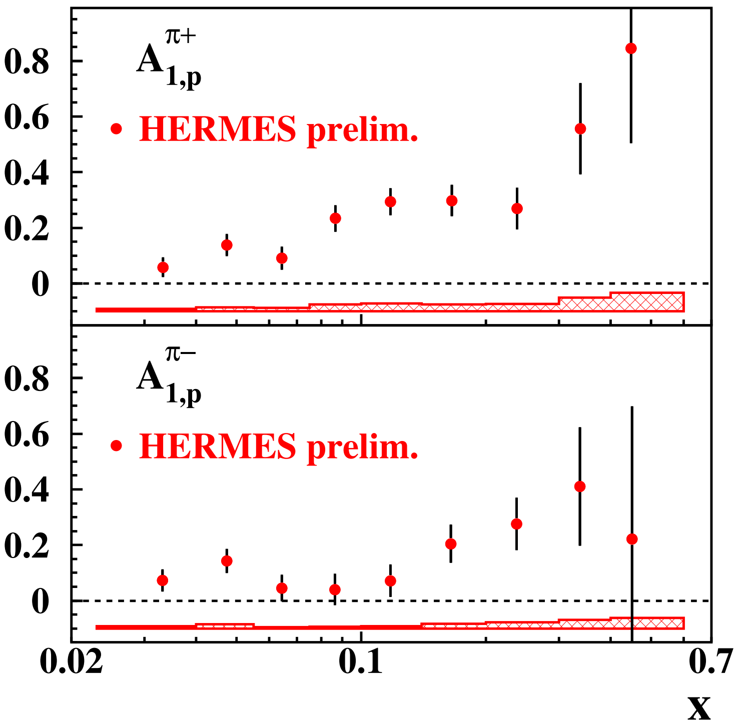


- ▷ Enlargement of statistical uncertainties dominated by
  - ∘ QED radiative effects $(x \lesssim 0.1)$
  - ∘ detector smearing effects $(x \gtrsim 0.1)$
- ▷ Resulting statistical uncertainties are uncorrelated between bins

Measured Semi–Inclusive Asymmetries on a Proton Target

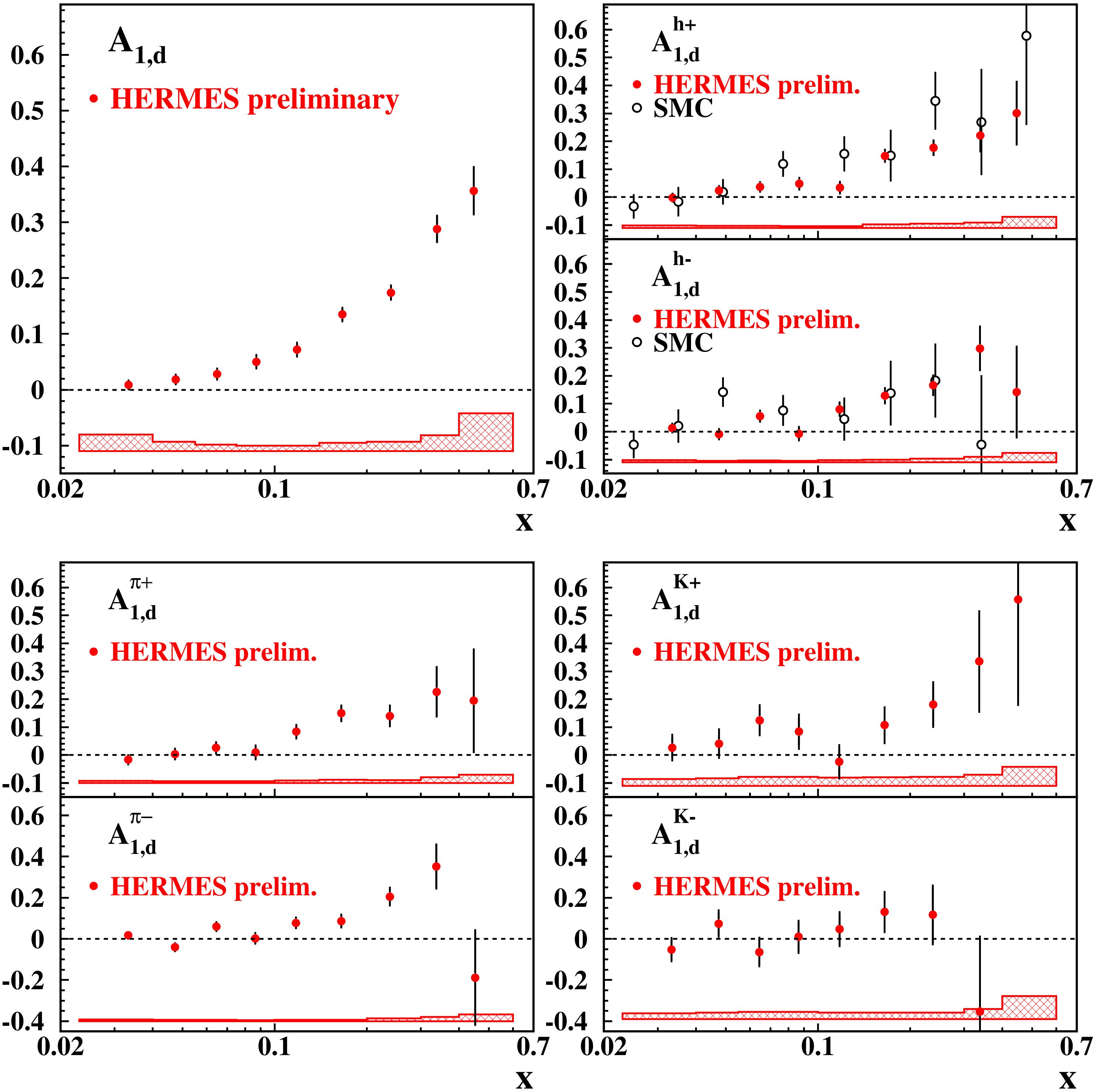






- ▷ Increased statistical uncertainties due to unfolding procedure
- ▷ Revised target polarisation value $\langle P_T \rangle = 0.82 \pm 0.05$ (prelim.) compared to published value $\langle P_T \rangle = 0.86 \pm 0.04$ [HERMES Coll., PL **B464** (1999) 123.]

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

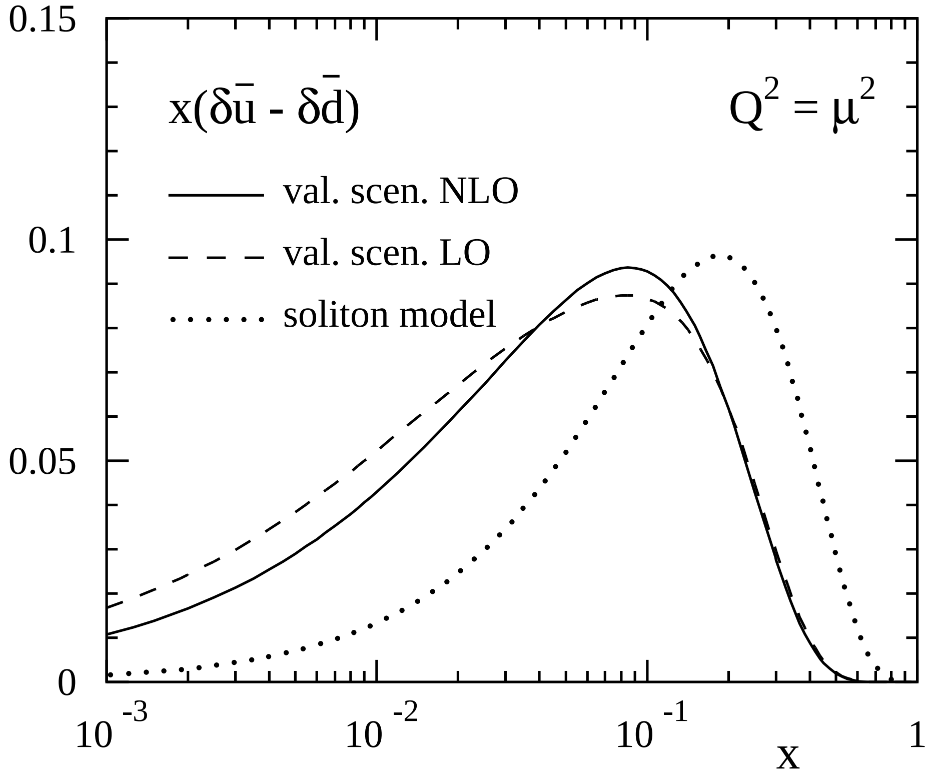
$$\vec{Q} = \left(\frac{\Delta u}{u}, \frac{\Delta d}{d}, \frac{\Delta \bar{u}}{\bar{u}}, \frac{\Delta \bar{d}}{\bar{d}}, \frac{\Delta s + \Delta \bar{s}}{s + \bar{s}} \right) \; .$$

Models for Polarised Sea Quark Distributions

Various models for polarised sea quark distributions with broken $SU(3)_f$ symmetry $\Delta\bar{u}(x) \neq \Delta\bar{d}(x) \neq \Delta s(x)$ are existing

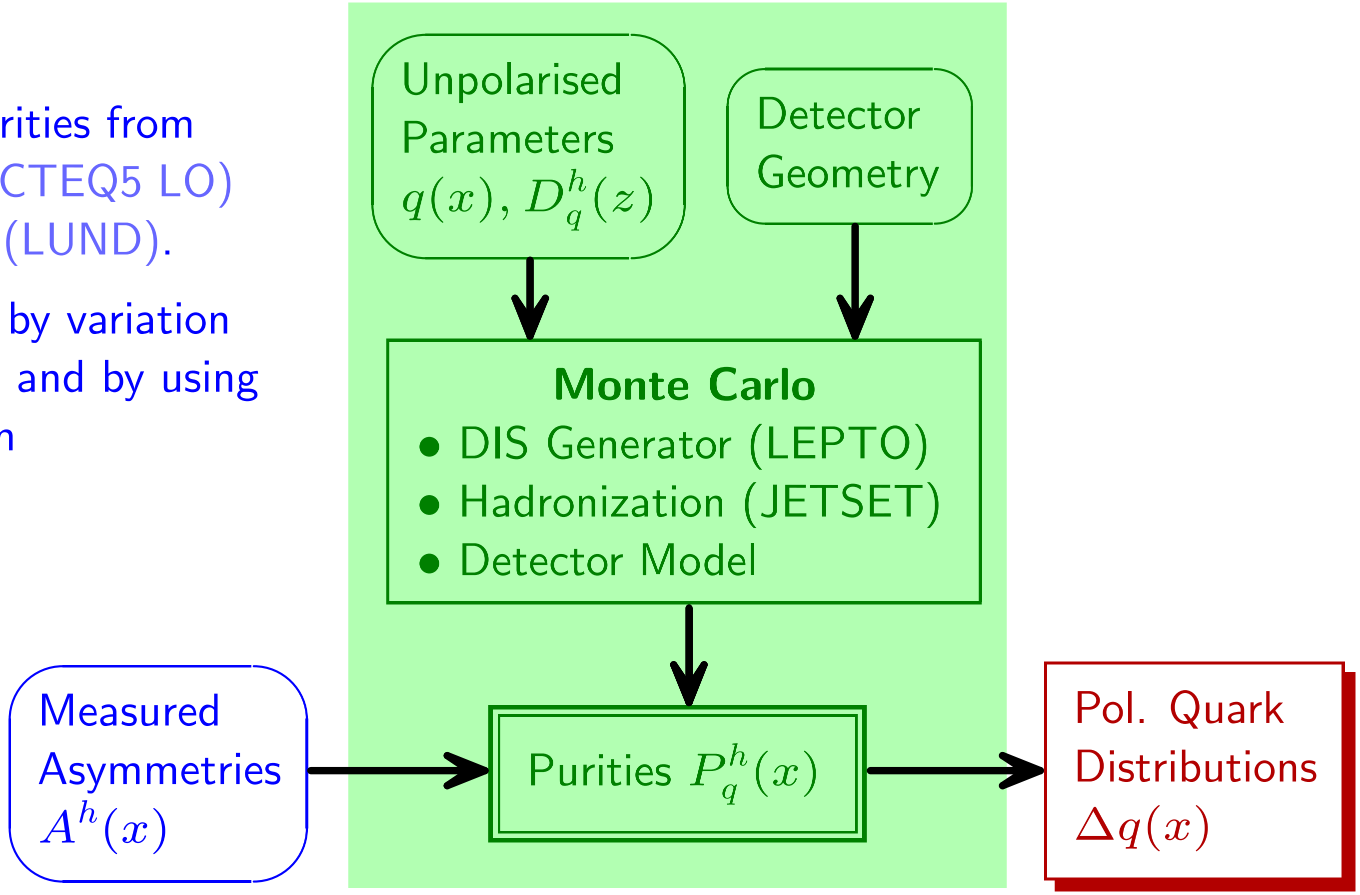
- ▷ Chiral Quark–Soliton–Model (χQSM)
  [Dressler et al., EPJ C14 (2000) 147]
- ▷ Pauli–Blocking Ansatz
  [Glück et al., PRD 63 (2001) 094005]

  ⋮



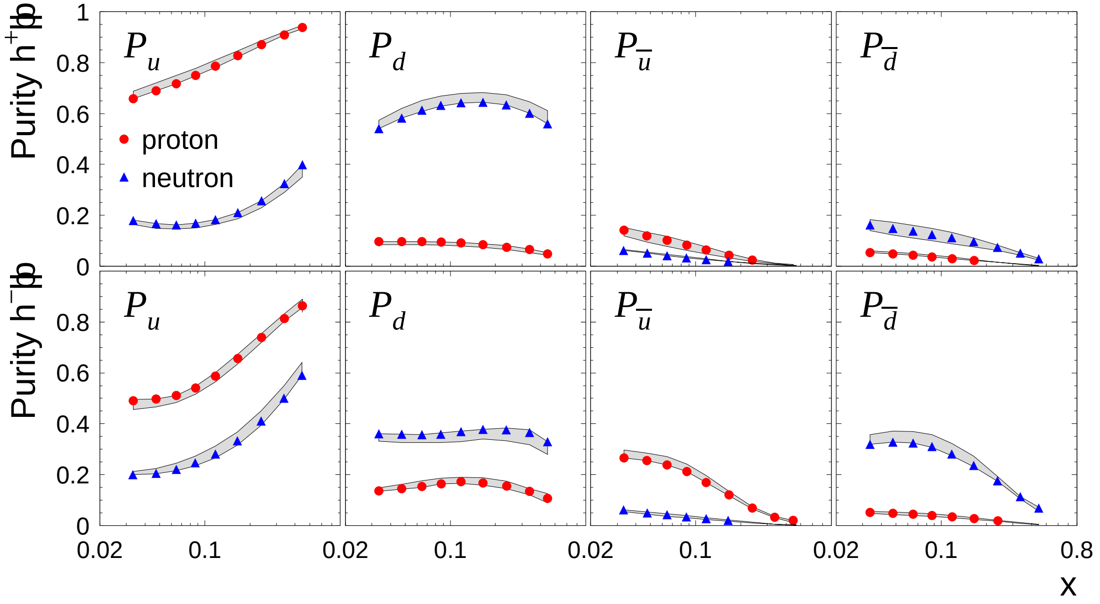
How Do We Obtain the Purities?

- ▷ 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

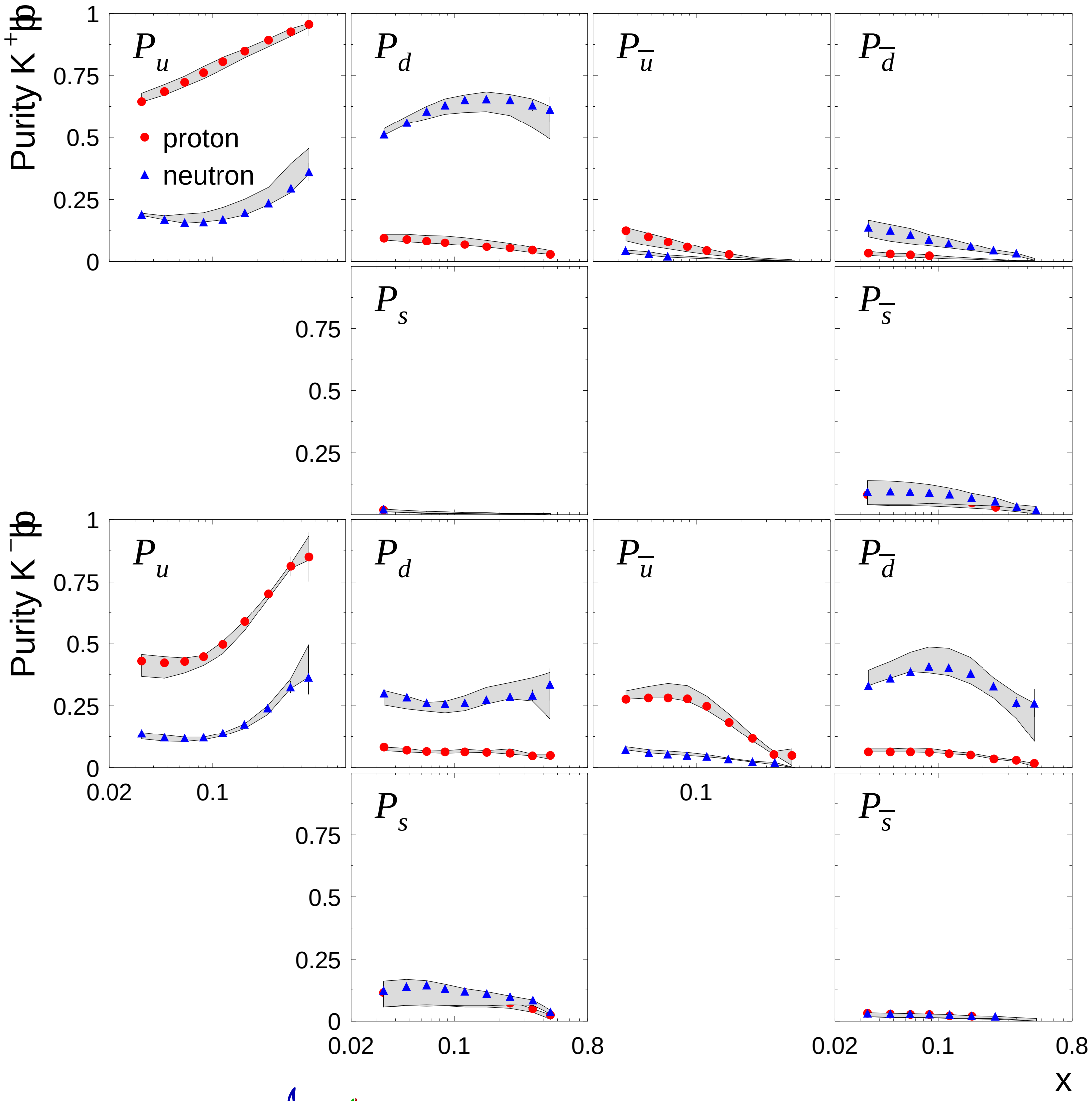
▷ Semi–inclusive hadron asymmetries $h^\pm$ on the proton dominated by $\Delta u(x)$.

▷ 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 $x \leq 0.2$.

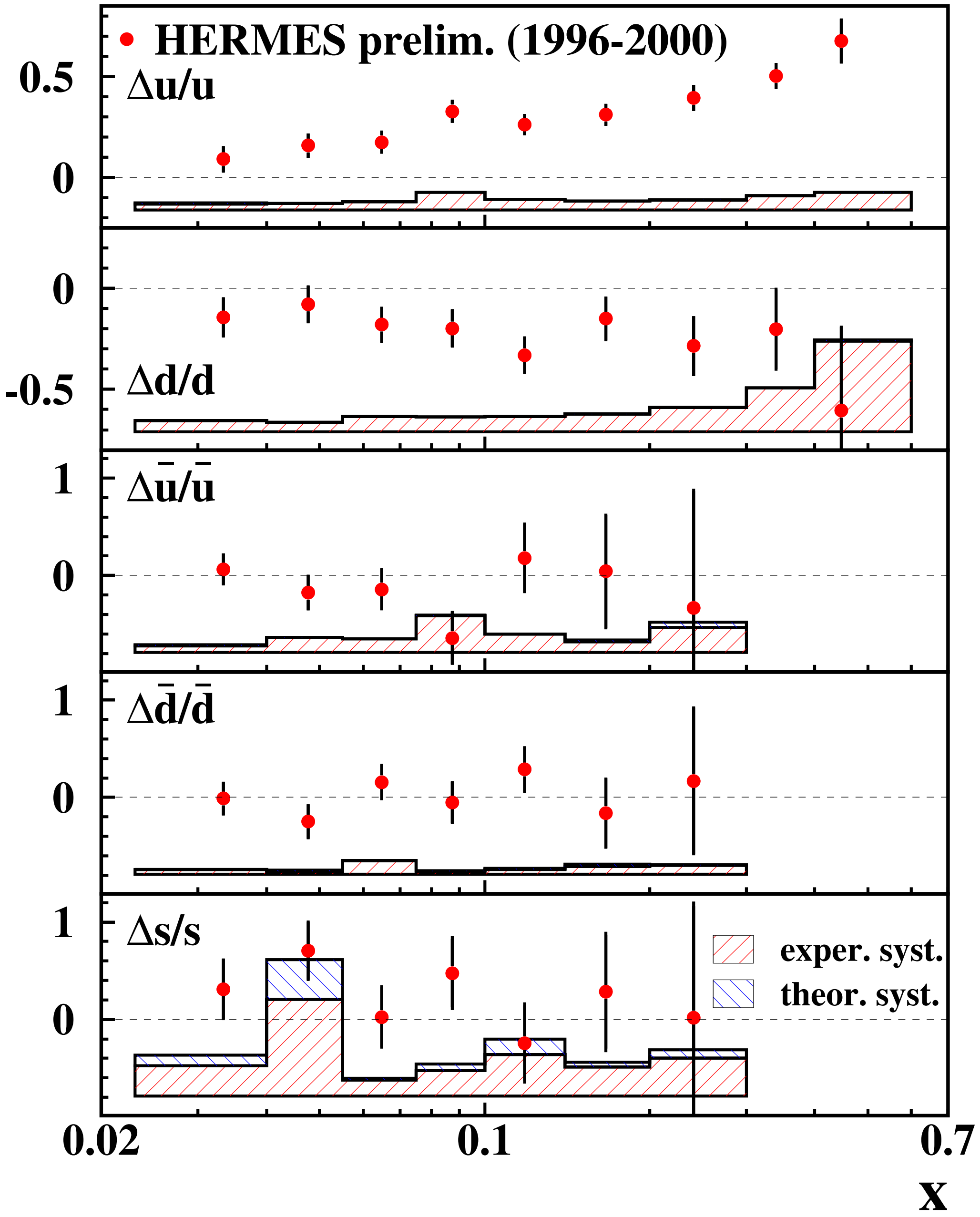
⇒ Data on proton– and "neutron targets" (Deuterium, ^{3}He) have to be combined in order to extract other sea quark flavour polarisations than $\Delta\bar{u}(x)$.

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

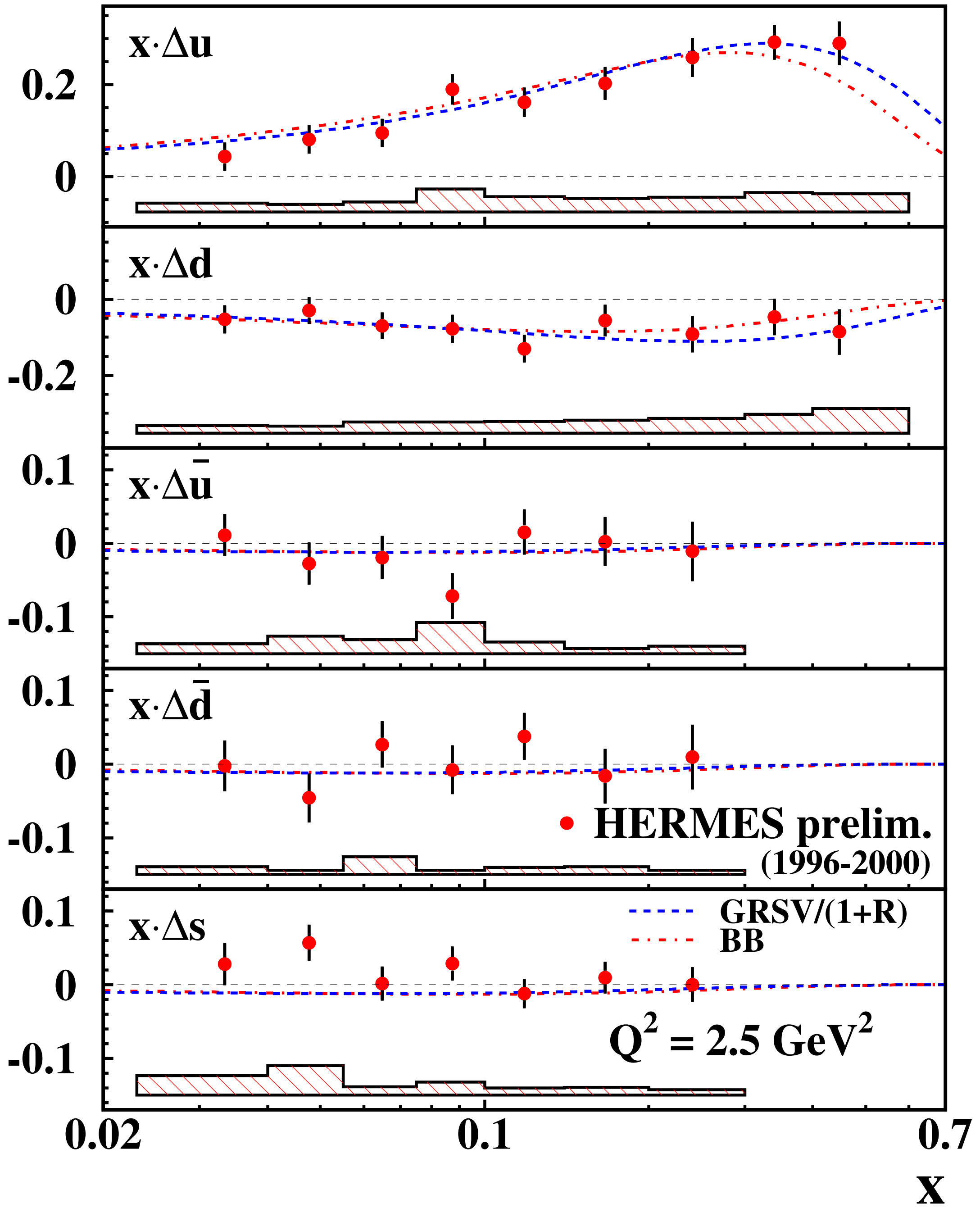


▷ Only remaining symmetry assumption:

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

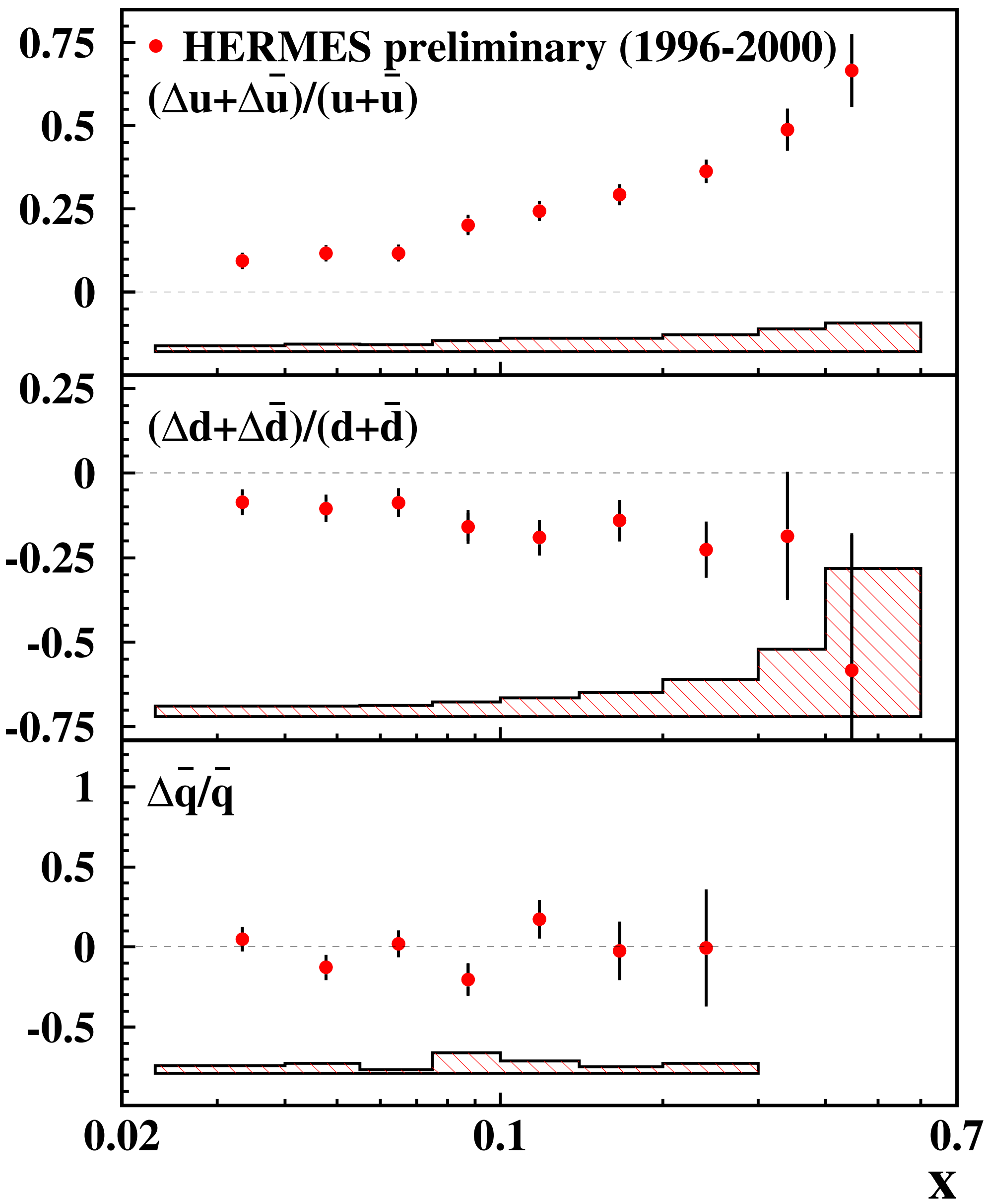
▷ Systematic uncertainty for the sea flavours dominated by the fragmentation model uncertainty.

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

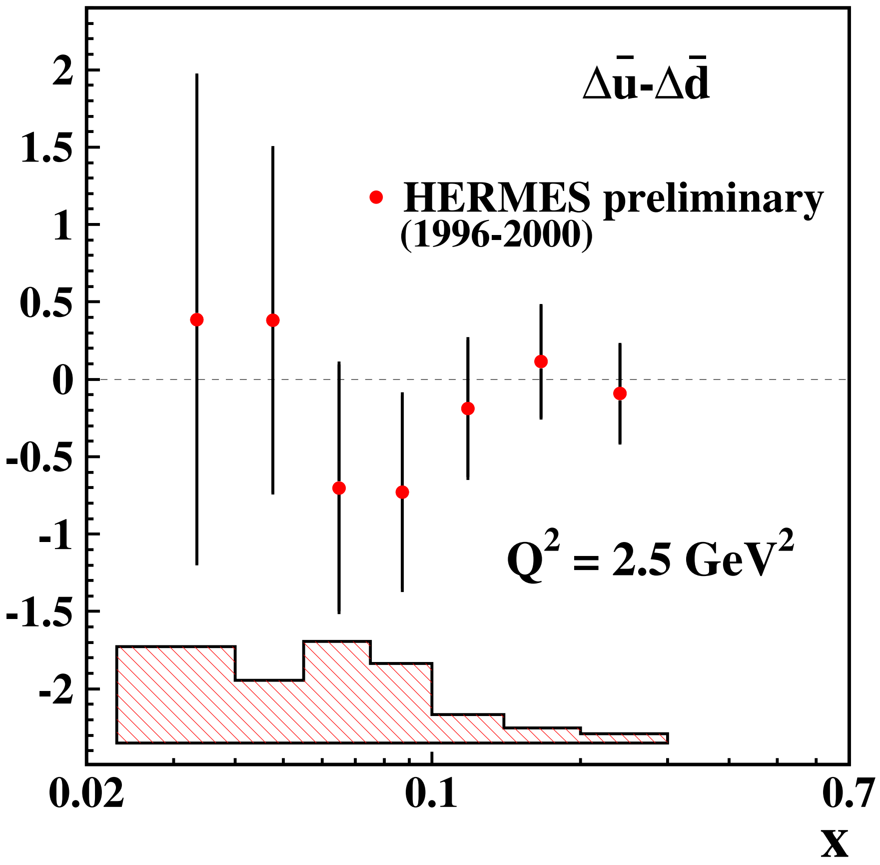


▷ Symmetry assumptions:

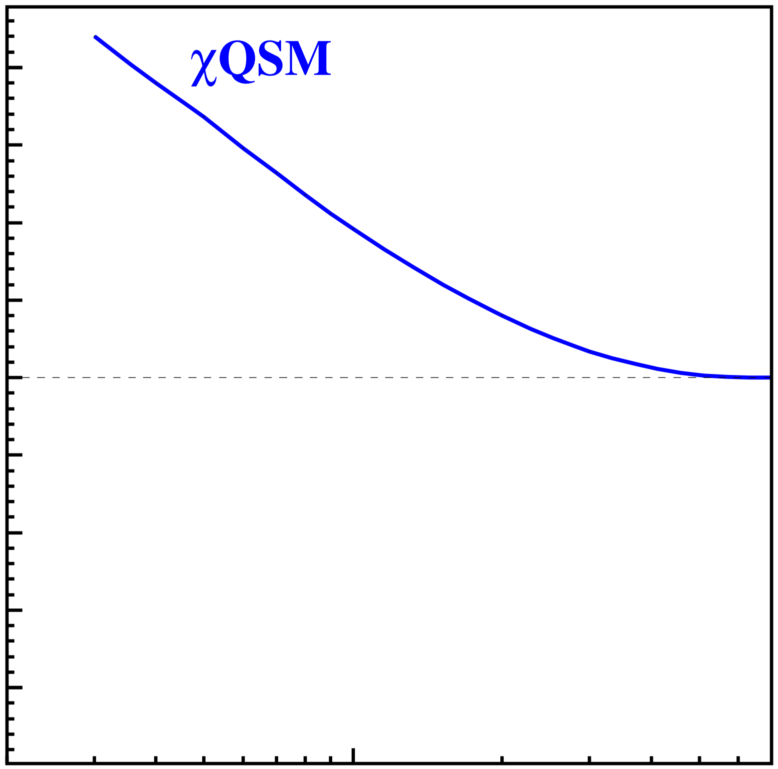
$$\frac{\Delta\bar{q}(x)}{\bar{q}(x)} \equiv \frac{\Delta\bar{u}}{\bar{u}} = \frac{\Delta u_s}{u_s} = \frac{\Delta\bar{d}}{\bar{d}} = \frac{\Delta d_s}{d_s} = \frac{\Delta s}{s} = \frac{\Delta\bar{s}}{\bar{s}}$$

▷ $\Delta\bar{q}(x)/\bar{q}(x)$ 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 χQSM [Dressler et al., EPJ **C14** (2000) 147.]


χQSM

Summary & Outlook

- ⊕ Polarised quark distributions from a LO QCD analysis of 1.8×10^6 (6.5×10^6) 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 Δs.
- ⊕ 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.