FLAVOR STRUCTURE OF THE NUCLEON AS REVEALED AT HERMES

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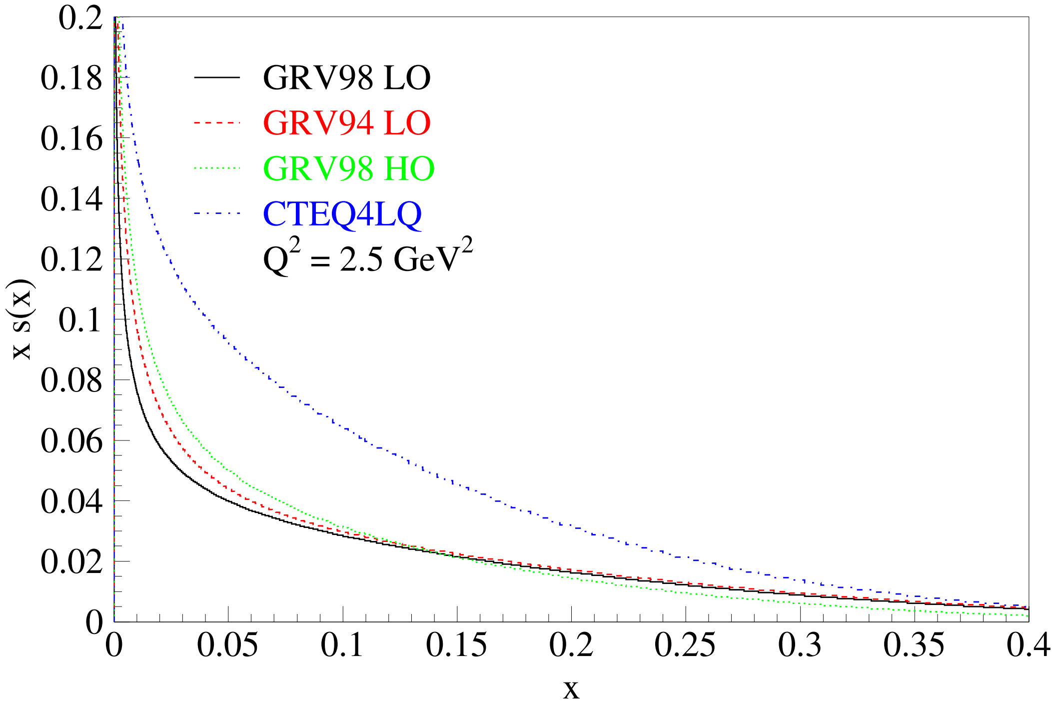
On behalf of the HERMES Collaboration

Outline:

1. Introductory remarks on parton distributions (PDF's).
2. Some models of PDF's in DIS.
3. The HERMES experiment.
4. Flavor tagging and purity analysis.
5. Experimental results.
6. Discussion and conclusions.

Unpolarized Parton Distributions

- Parton distributions (PDF's) are the basis for description of the flavor structure of the nucleon - $q(x,Q^2) \Rightarrow$ mass structure; $\Delta q_f(x,Q^2) \Rightarrow$ spin structure.
- A new CTEQ6 generation of parton distributions(PDF's) is available - The fit to data is very impressive. Study carried out mainly in the $\overline{MS}$ scheme. Improved error treatment, but new PDF's do not differ much from CTEQ5.
- Outstanding problems - $q_f(x)'s$ as $x \to 1$, x dependence of $\overline{d}/\overline{u}$, and data on $s(x), \overline{s}(x)$.
- From HERMES point of view - a serious problem with s(x) remains - unresolved discrepencies between dimuon ν data and results from charge and neutral current structure functions. CTEQ assumes $s = \overline{s} = 0.2(\overline{u} + \overline{d})$ at Q_0
- s(x) still poorly known:

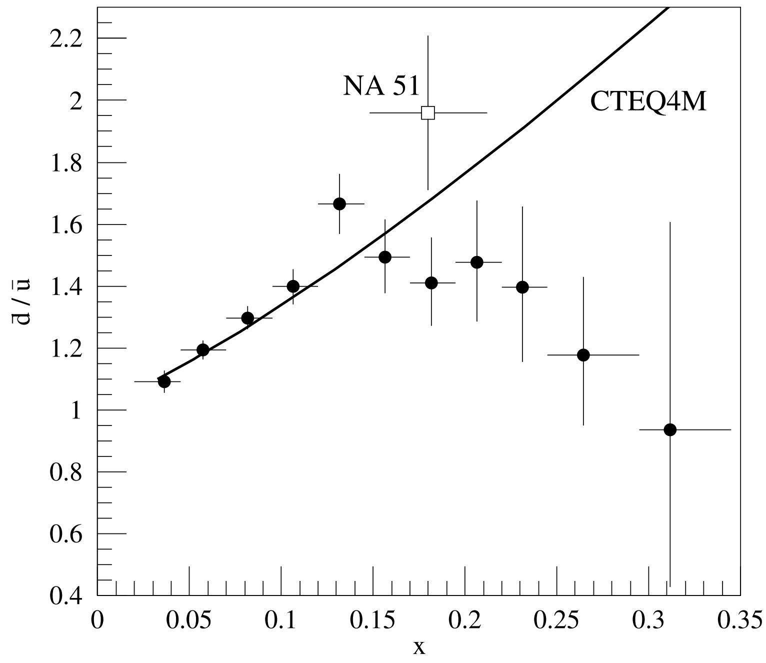


Flavor Asymmetry of Light Sea

The Gottfried sum rule :

$$I_G = \int_0^1 [F_2^p(x) - F_2^n(x)]\frac{dx}{x} = \frac{1}{3} - \frac{2}{3}\int_0^1 [\bar{d}_p(x) - \bar{u}_p(x)]dx$$

NMC(exp NA51): $I_G = 0.235 \pm 0.026 \neq \frac{1}{3}$



The ratio of $\frac{\bar{d}}{\bar{u}}$ in the proton as a function of x extracted from Drell Yan cross sections in FNAL E866.

Important features of the data can be explained by a number of theoretical models:

- Chiral Quark Soliton Model (χQSM)
- Statistical Model
- Virtual pion models

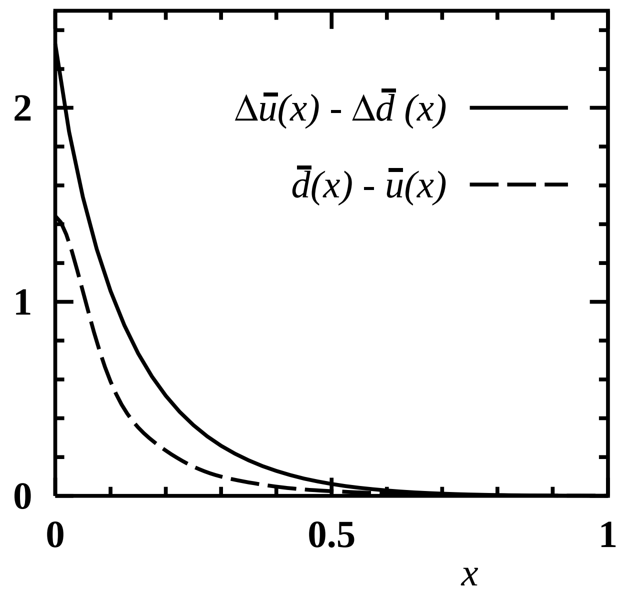
According to these models, the flavor asymmetry observed for the light sea puts important constraints on the flavor asymmetry for the the polarization of the light sea.

Flavor Asymmetry in the χQSM

B. Dressler et al., Eur. Phys. J. **C14**, 147

- Starting point is QCD calculation of PDF's in the large-N$_c$ limit. Theory makes a strong prediction about
$$\Delta\overline{u} - \Delta\overline{d}.$$
- The quantities $u(x) + d(x)$, $\Delta\overline{u}(x) - \Delta\overline{d}(x)$, and $\Delta u(x) - \Delta d(x)$ are L. O., i.e. $\approx N_c^2 f(N_c, x)$ in $1/N_c$-expansion.
- Parametrically - $\Delta\overline{u}(x) - \Delta\overline{d}(x) > |\overline{u}(x) - \overline{d}(x)|$.
- Calculations at low scale - large N$_c$ limit with effective field theory description of chiral symmetry breaking give:

Isovector antiquark distributions at low normalization point, as obtained from the chiral quark soliton model.



- Theory also gives(with SU(3) symmetry) an estimate of polarized octet strength:
$$\Delta\overline{u}(x) + \Delta\overline{d} - 2\Delta\overline{s}(x) = \frac{3F - D}{F + D}[\Delta\overline{u}(x) - \Delta\overline{d}(x)]$$

Statistical Model of PDF's

Bourrely,Soffer, and Buccella, Eur. Phys. J. **C23**, 487

- Objective - generate $q_i, \Delta q_i, \overline{q}_i, \Delta\overline{q}_i, G, \Delta G$ distributions using a very small number of parameters

- Assumptions:
  - Nucleon = a gas of massless partons
  - Particle density for partons has form:

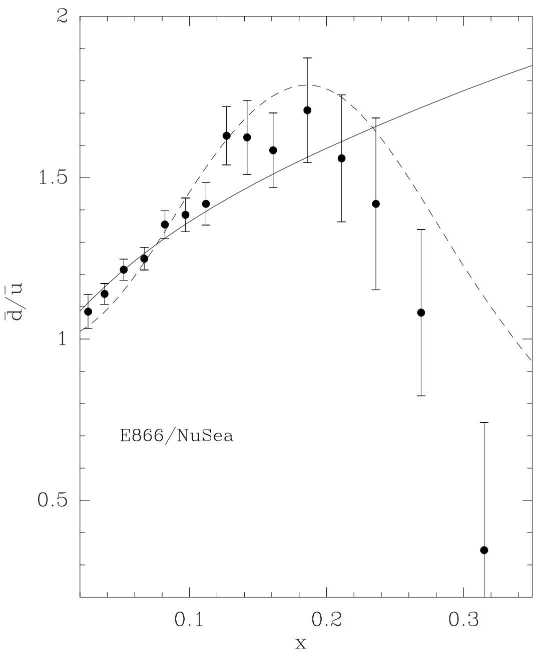
$$[exp(x - X_{0p})/\overline{x} \pm 1]^{-1}$$

- From chiral structure of QCD & features of u(x) and d(x) known from DIS:

$$\overline{d}(x) > \overline{u}(x);\ \Delta\overline{u}(x) > 0;\ \ \Delta\overline{d}(x) < 0;$$

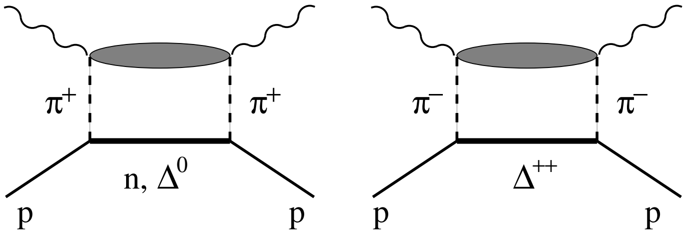
$$\Delta\overline{u}(x) - \Delta\overline{d}(x) \sim \overline{d}(x) - \overline{u}(x)$$

- Impressive agreement with global data base for $F_2^p(x,Q^2)$,$F_2^d(x,Q^2)$, and, $G(x,Q^2)$

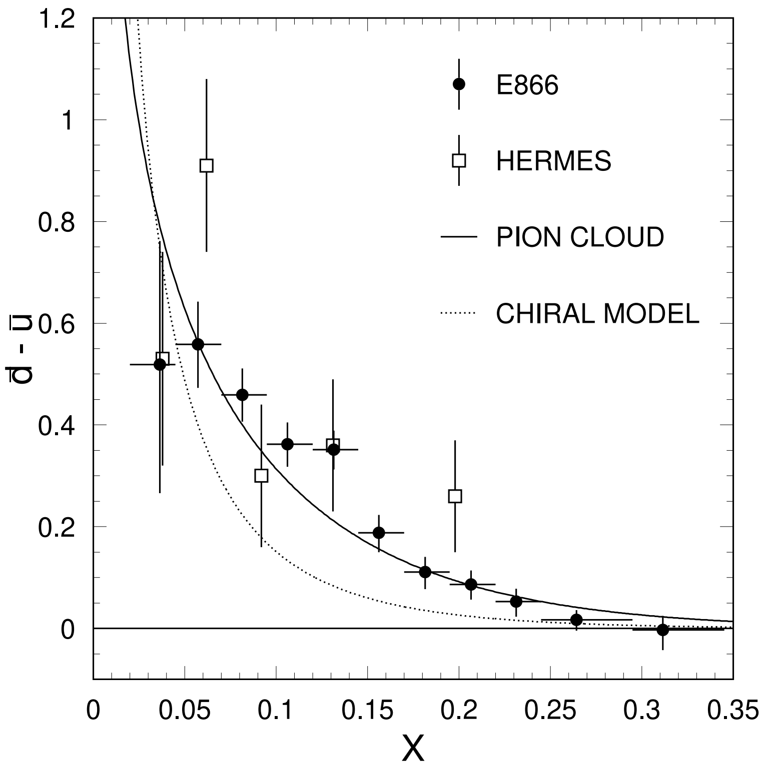


Meson Cloud Picture of DIS

- Physical proton is a coherent sum of virtual meson-baryon states: $p = (1-\alpha)p_0 + \alpha\pi N$ where p_0 is a proton with a symmetric sea.
  A. W. Thomas, Phys. Lett. **B126**, 97
- "The Sullivan process" generates an antiquark asymmetry through processes:



- With some tuning of cutoff parameters for πNN and $\pi\Delta N$ coupling, the virtual pion model works:
  Hawker, et al.,
  Phys. Rev Lett. **80**, 3715



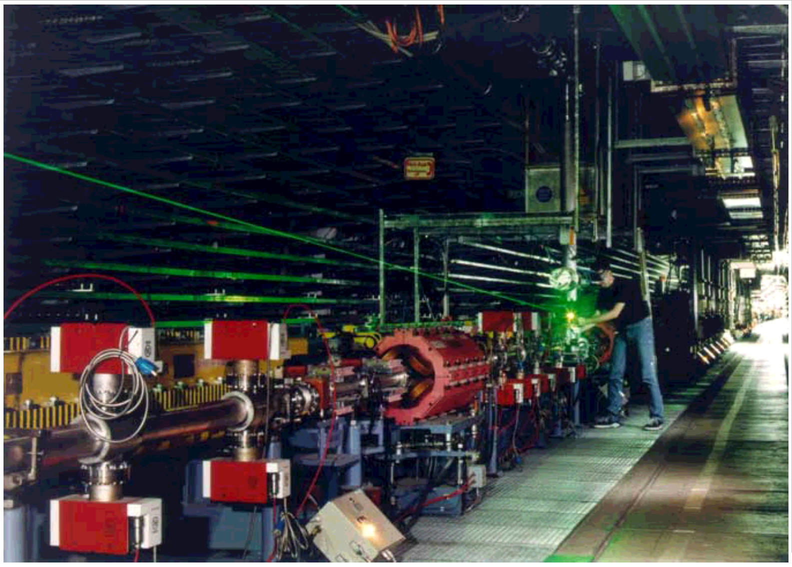
- Important implication of this model - for a light sea generated by a pion cloud plus a symmetry sea generated by gluon splitting:

$$\Delta\overline{u} - \Delta\overline{d} \approx 0$$

- Light sea flavor asymmetry a good test of models!

Latest from HERMES
on Nucleon Flavor Structure

Laser polarimeter in the HERA tunnel
HERMES uses the polarized electrons from HERA to find out how the different quarks and gluons account for the "spin" (the intrinsic angular momentum) of the protons. During HERA operation, the green laser beam is directed inside the beam pipe against the electron beam, to observe to what extent the electrons are polarized, i.e. how their spins are aligned preferring a forward or backward direction. In this picture, the laser beam is outside the beam pipe for adjustment.

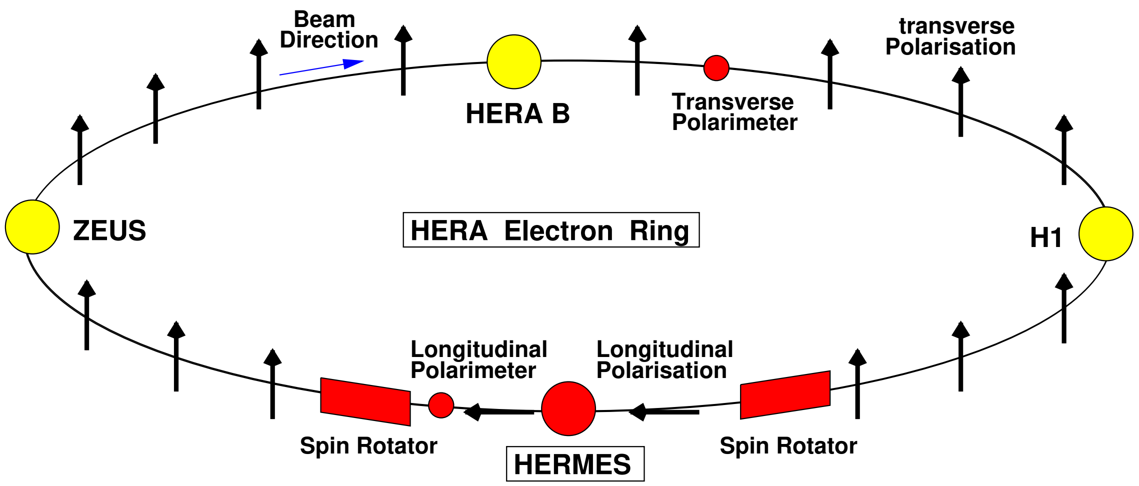


hermes

A second generation experiment designed to study the spin structure of the nucleon at HERA

Alberta
Argonne
Bari
Beijing
Colorado
DESY-Hamburg
DESY-Zuethen
Erlangen
Ferrara
Freiburg
Gent
Glasgow
Geissen
Illinois
INFN-Frascati
INFN-Rome
JINR-Dubna
Liverpool
Marburg
MIT
Moscow
MPI-Heidelberg
Munich
NIKHEF
Protvino
Regensburg
St. Petersburg
Tokyo
TRIUMF
Warsaw
Yerevan

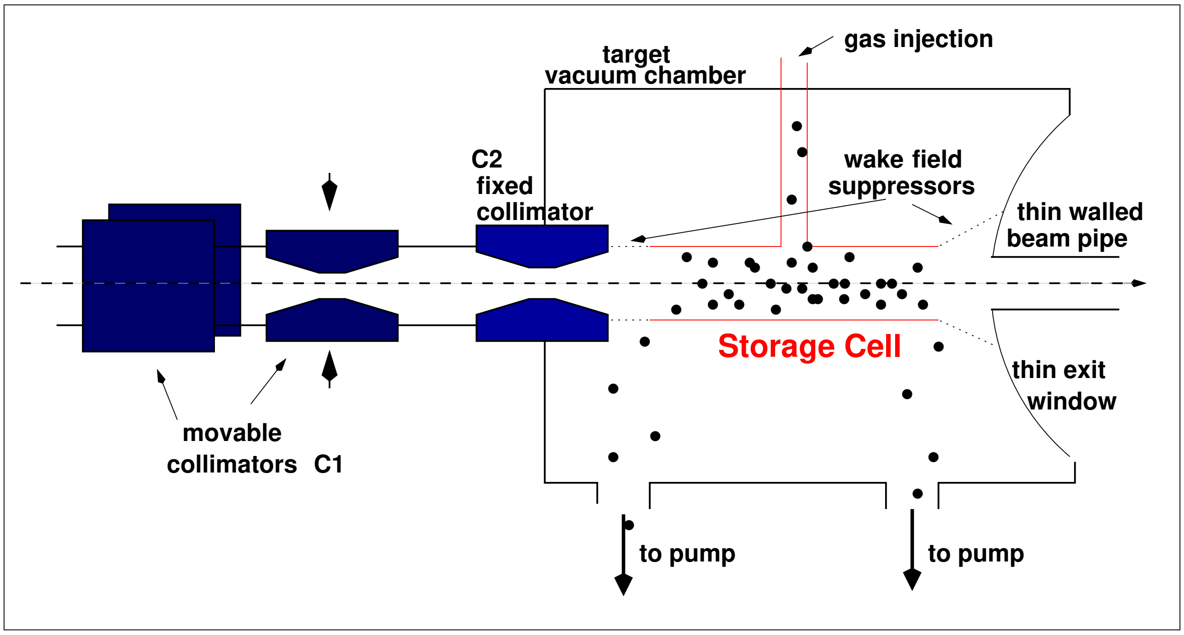
POLARIZED ELECTRONS in HERA



Polarization measured by two Compton Polarimeters.

$$\langle P \rangle = (55 \pm 2_{sys})\%$$

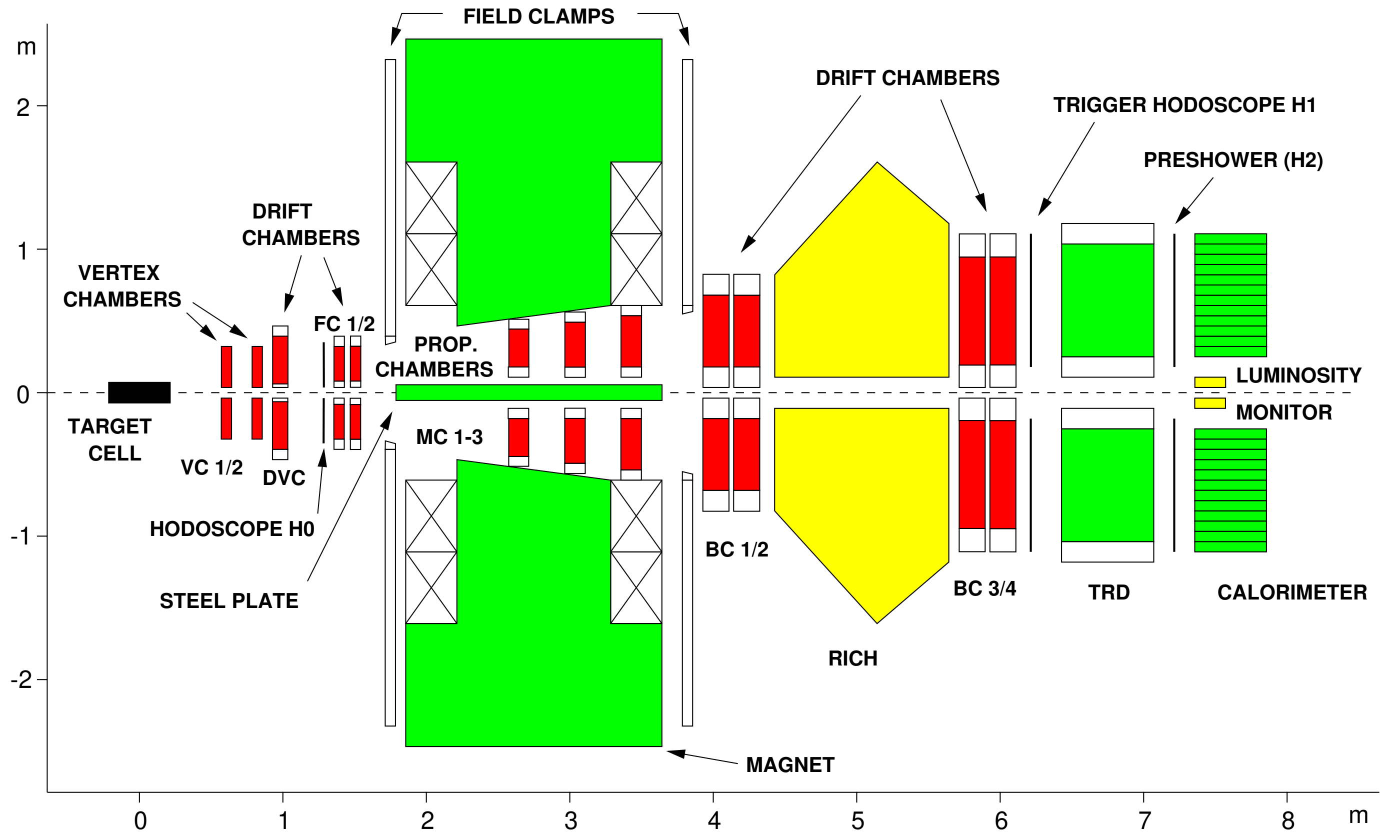
INTERNAL POLARIZED GAS TARGET



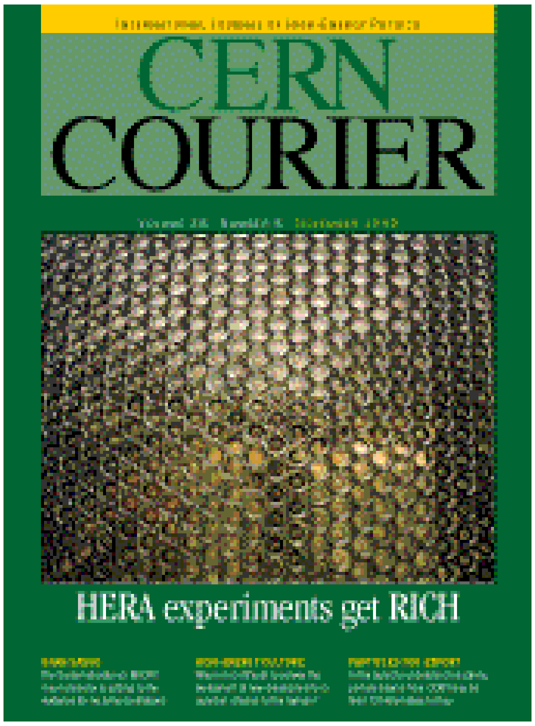
H,D target - Cell filled by Atomic beam source.

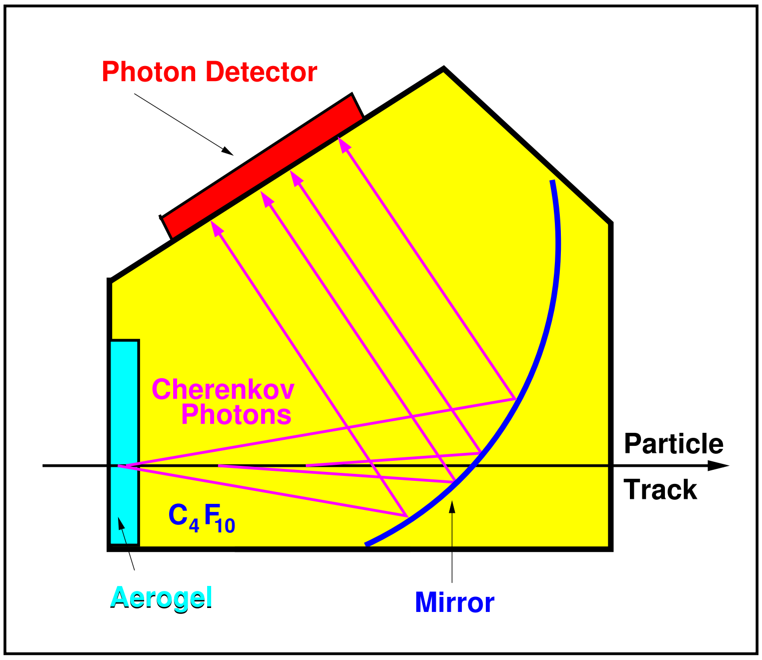
$\rho = 7.6 \cdot 10^{13}$ atoms/cm^2 $\quad \langle P \rangle = (82 \pm 4_{sys})\%$

SPECTROMETER



The RICH Detector





Installed in 1998, - π, K, p separation for $1 < p < 15$ GeV.

POLARIZATION OF THE QUARK SEA

The flavor decomposition of the polarized quark distributions, Δq_f, is one of the major missions of HERMES.

From early analysis of $\int g_1(x, Q^2)dx$ by SMC,SLAC:

$$\Delta u = +0.78 \pm 0.06$$
$$\Delta d = -0.47 \pm 0.06$$
$$\Delta s = -0.19 \pm 0.06$$

A NLO analysis of all inclusive proton data gives:

$$a_s = -0.07 \pm 0.04$$

D. Adams et al., Phys. Rev **D56**, 5330

With flavor tagging in DIS, individual spin contributions, $\Delta q_f(x)$ can be determined directly from the spin asymmetries

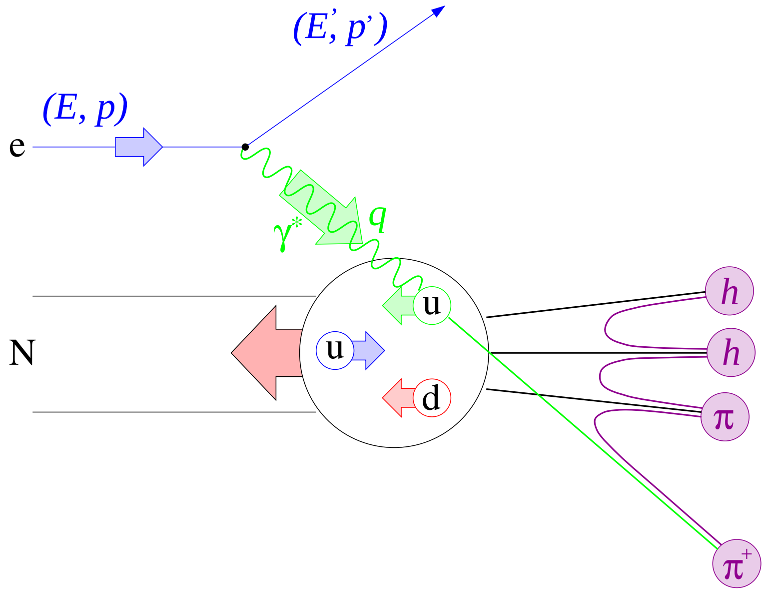
$$A_{\parallel}^{(h)} = \frac{N_{(h)}^{\uparrow\downarrow} - N_{(h)}^{\uparrow\uparrow}}{N_{(h)}^{\uparrow\downarrow} + N_{(h)}^{\uparrow\uparrow}}, \quad A_1^h = \frac{A_{\parallel}^h}{D(1+\eta\gamma)}$$

Can rewrite in terms of a purity matrix:

$$A_1^h(x,z) = \sum_q P_q^h(x,z)\frac{\Delta q(x)}{q(x)}$$

Polarized Semi-Inclusive DIS

In semi-inclusive DIS a hadron h is detected in coincidence with the scattered lepton



$$Q^2 = 4EE'sin^2(\Theta/2)$$
$$\nu = E - E'$$
$$x = Q^2/2M\nu$$

Typical Kinematics:
$E_{e^+} = 27.5GeV$
$x > 0.02,\ W^2 > 10GeV^2$
$1.0GeV^2 < Q^2 < 15GeV^2$
$\nu < 24GeV$

Cuts for Current fragmentation:
$z = E_h/\nu > 0.2$
$x_F \approx 2p_{\|}/W > 0.1$

Flavor Tagging

The flavor content of the final state hadrons is related to the flavor of the struck quark through the agency of the fragmentation functions $D_q^h(z, Q^2)$. In LO QCD:

$$A_1^h(x, Q^2) = \frac{\int_{z_{min}}^1 dz \sum_q e_q^2 \Delta q(x, Q^2) \cdot D_q^h(z, Q^2)}{\int_{z_{min}}^1 dz \sum_{q'} e_{q'}^2 q'(x, Q^2) \cdot D_{q'}^h(z, Q^2)}$$

Purity Analysis of Asymmetries

- Perform a simultaneous global analysis of all $A_1^h(x,z)'s$

- The photon-nucleon Asymmetry is

$$A_1^h(x,z) = \frac{\int_{z_{min}}^1 dz \sum_q e_q^2 q(x) \cdot D_q^h(z)}{\int_{z_{min}}^1 dz \sum_{q'} e_{q'}^2 q'(x) \cdot D_{q'}^h(z)} \cdot \frac{\Delta q(x)}{q(x)}$$

$$= \sum_q P_q^h(x,z) \frac{\Delta q(x)}{q(x)}$$

- The hadron quark-purity $P_q^h(x,z)$ is the probability that a quark q was struck in an event $l + N \longrightarrow l' + X$

- Purities are spin-independent quantities

- Define

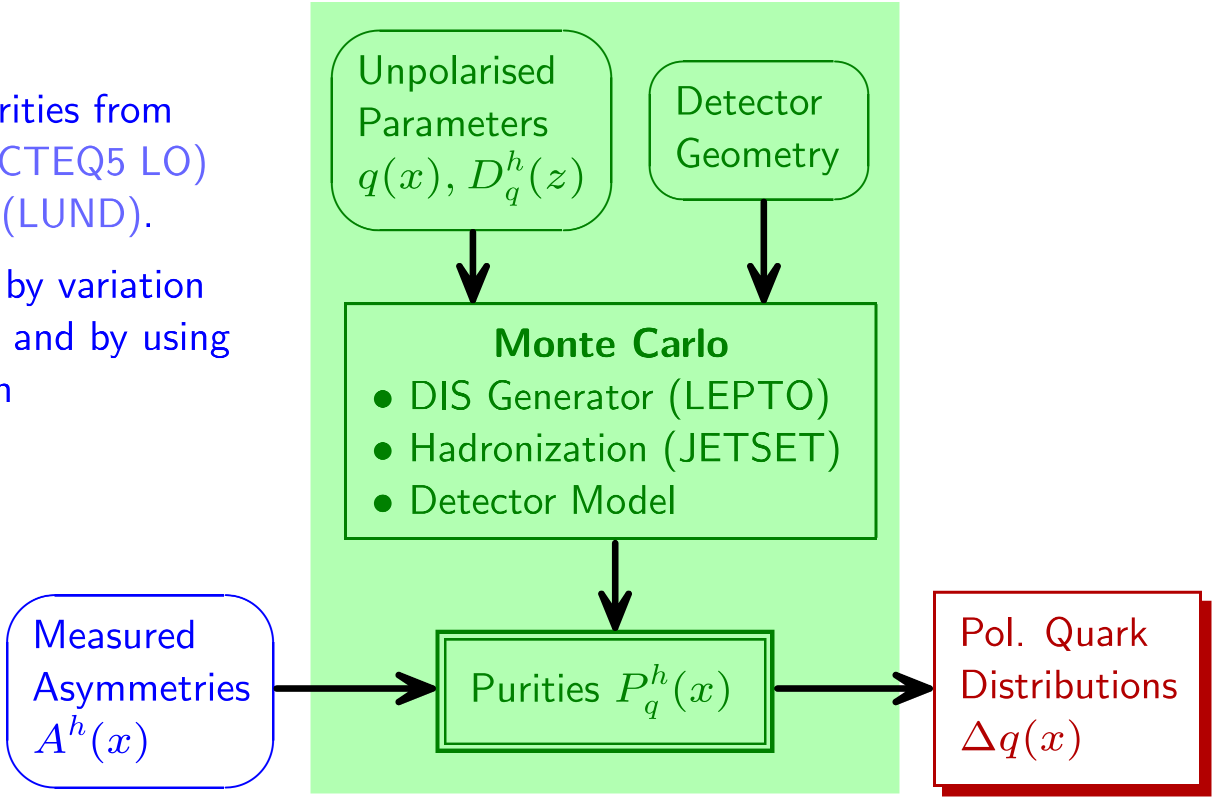
$$\vec{A} = \begin{pmatrix} A^{h_1}(x) \\ \dots \\ A^{h_n}(x) \end{pmatrix}, \vec{Q} = \begin{pmatrix} \Delta q_1(x)/q_1(x) \\ \dots \\ \Delta q_n(x)/q_n(x) \end{pmatrix}, P = [P_q^h(x)]$$

Determine quark polarizations by inverting

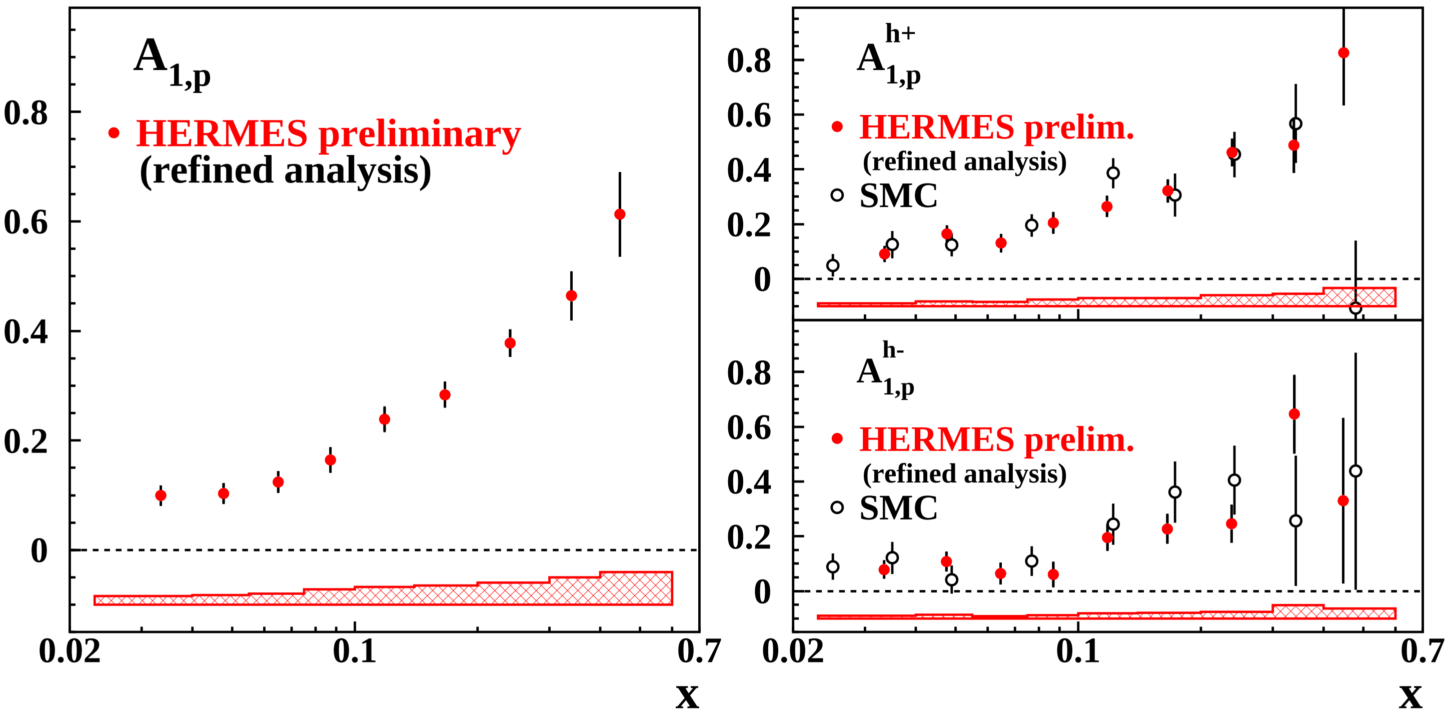
$$\vec{A} = P\vec{Q}$$

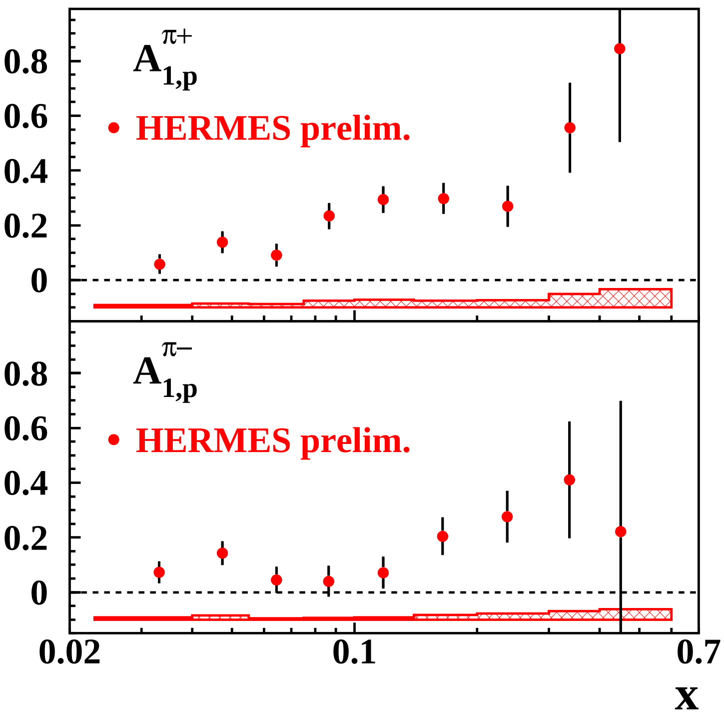
How Do We Obtain the Purities?

- ▷ 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).



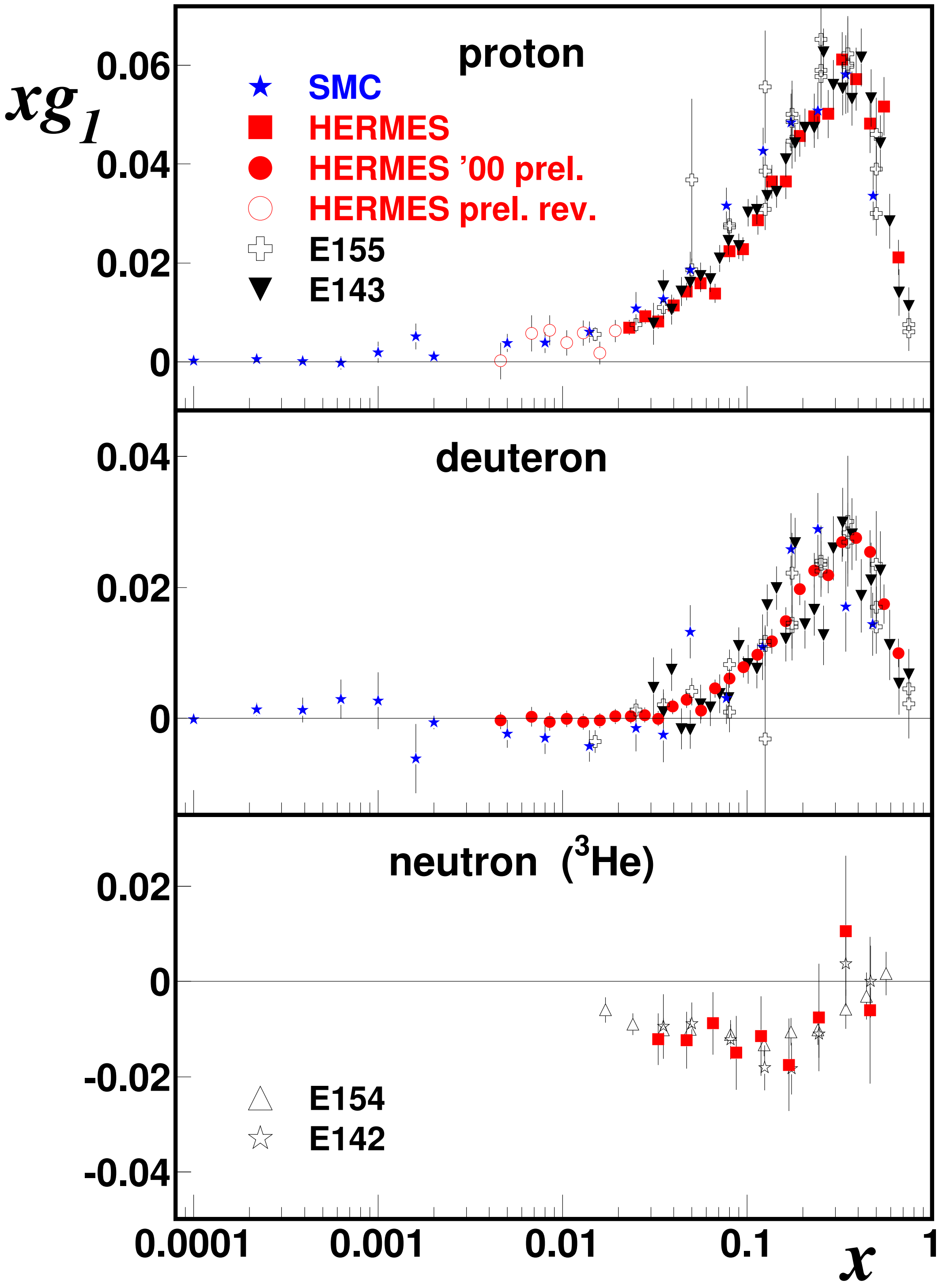
Measured Semi–Inclusive Asymmetries on a Proton Target



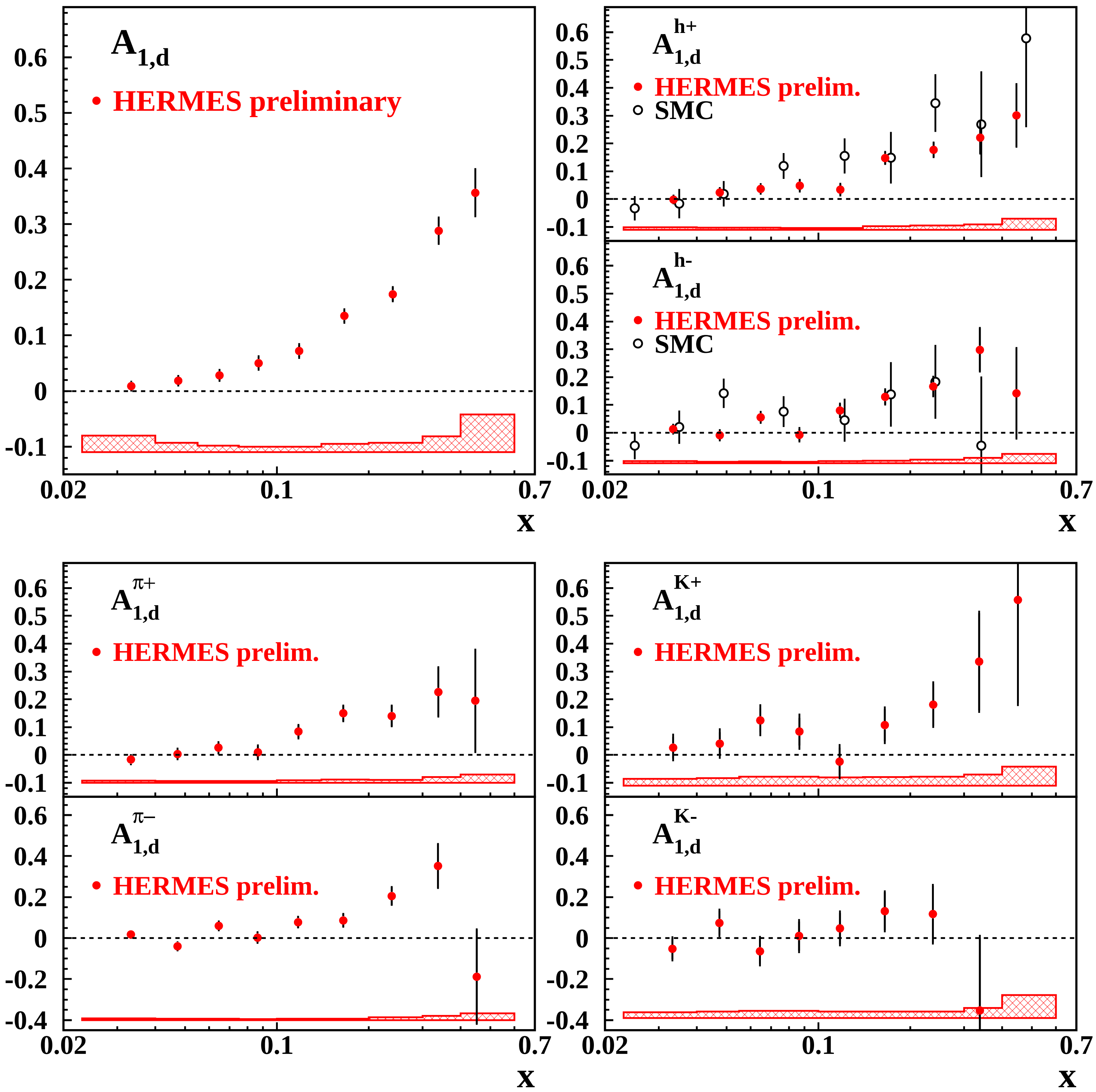


- ▷ Increased statistical uncertainties due to unfolding procedure
- ▷ Revised target polarisation value $\langle P_T \rangle = 0.82 \pm 0.05$ (prelim.) compared to published value $\langle P_T \rangle = 0.86 \pm 0.04$ [HERMES Coll., PL **B464** (1999) 123.]

Comparison of Data for $g_1(x)$



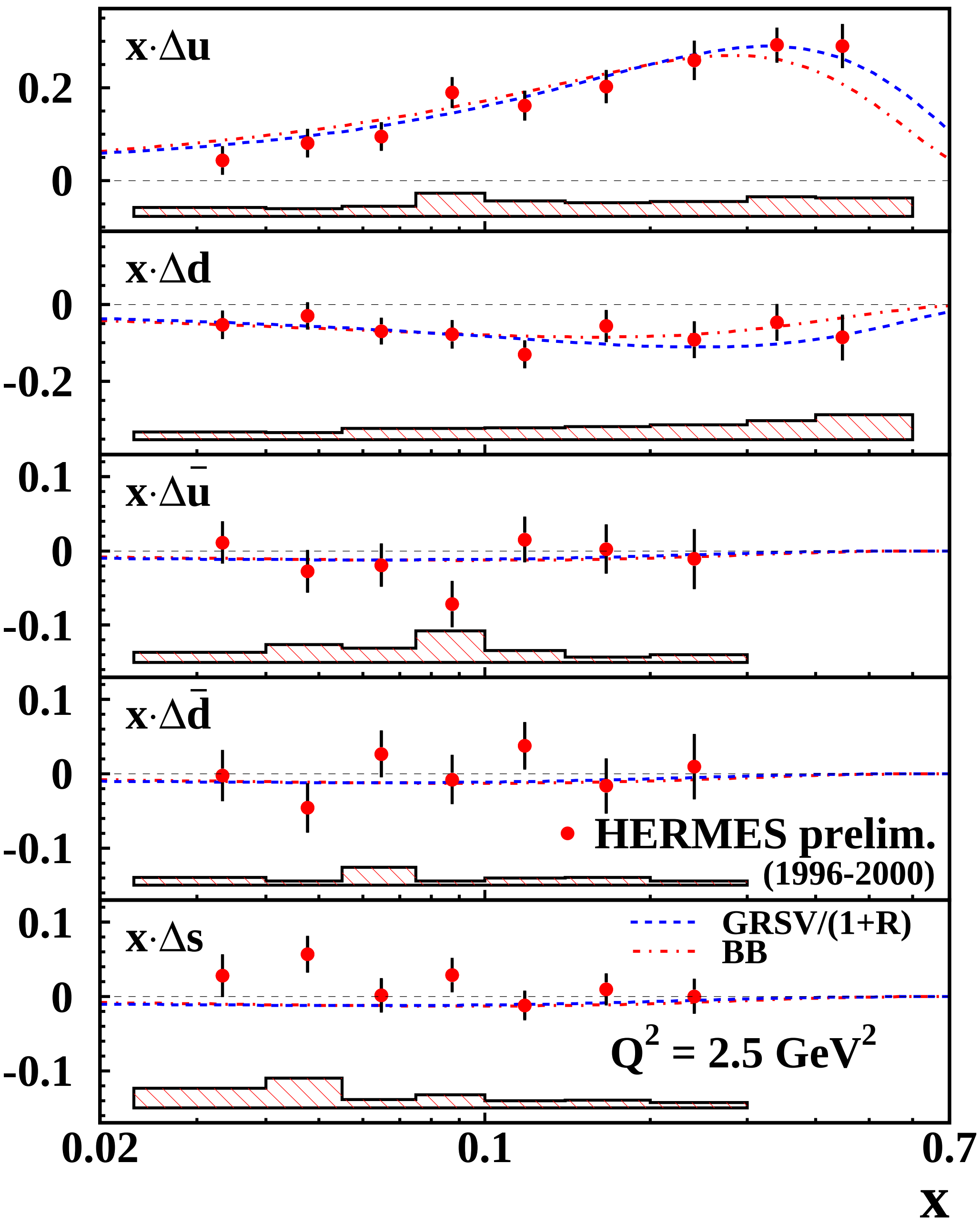
Measured Semi–Inclusive Asymmetries on a Deuterium Target



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

HERMES Flavor Decomposition

For the first time, a five component, $\Delta u, \Delta\overline{u}, \Delta d, \Delta\overline{d}, \Delta s = \Delta\overline{s}$, decomposition using $\pi's, K's, p's$:



- No evidence for significant polarization of nonstrange sea.
- The strange sea appears to be positively polarized

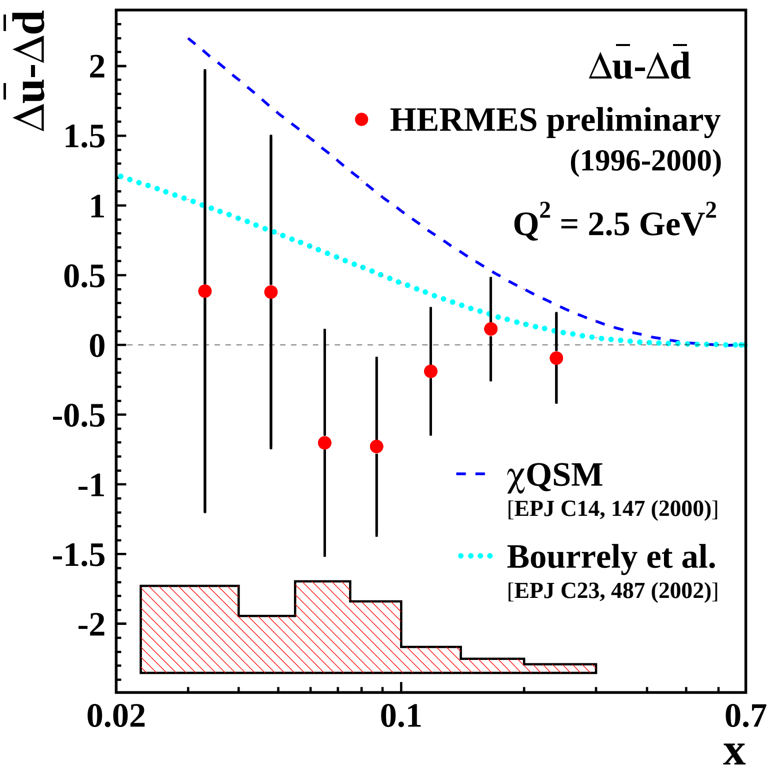
Remarks and Conclusions

- This is the first "direct" 5 component decomposition of quark helicity distributions using flavor tagging.

- The helicity distributions for u, d, and the nonstrange sea show trends similar to those inferred from inclusive measurements, i.e. $\Delta u >> 0$, $\Delta d < 0$, and $\Delta\overline{u} = \Delta\overline{d} \approx 0$.

- Result $\Delta(s + \overline{s}) > 0$ is unexpected. A challenge to understand since if sea results from gluon splitting, one would expect also $\Delta\overline{u} \approx \Delta\overline{d} > 0$.

- No strong breaking of the flavor symmetry of the light sea.



Remarks and Conclusions(cont'd)

- The singlet strength, $\Delta q_3 = \Delta u - \Delta d$, agrees to within 1σ with the Bjorken sum rule which states

$$\Delta q_3 = \int_0^1 \Delta q^{NS}(x)dx = |\frac{g_a}{g_v}| \times C_{QCD} = 1.01 \pm 0.05$$

- Can make a measurement of Δs using $A_1^D(x)$ and $A_{1,D}^{K^+ + K^-}$:
  - Use fragmentation functions from e^+e^- collider exp's.
  - Provides an independent check on strange polarization result.
  - Two component analysis also shows $\Delta s > 0$.

- Analysis will continue with a comparison of $\Delta q_8 = \Delta u + \Delta d - 2\Delta s$ with predictions of SU(3) symmetry, i.e.

$$\Delta q_8 = (3F - D) \times C_{QCD} = 0.46 \pm 0.03$$

.

- The hypothesis of a large negative strange sea polarization as an explanation for the violation of the Ellis-Jaffe sum rule in inclusive scattering is ruled out.