Flavor Separated Quark Polarizations at HERMES

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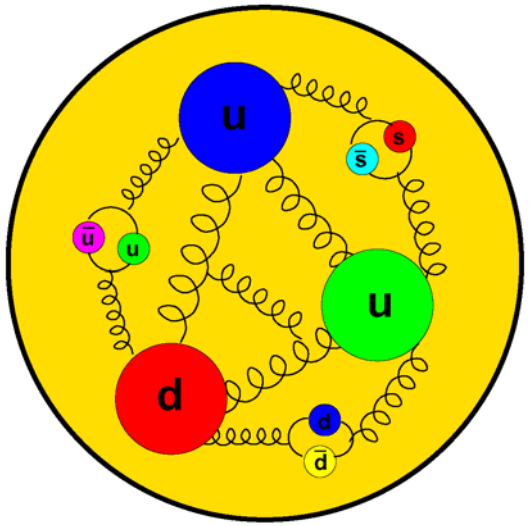
Collaboration

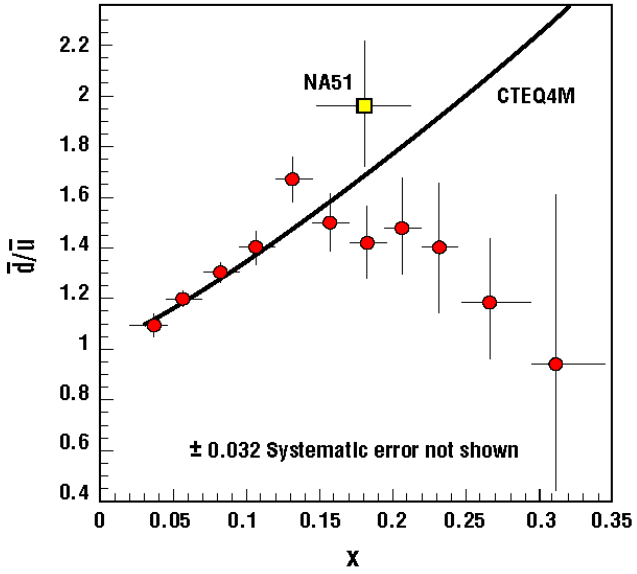
28 May 2003

- Flavor structure of proton – some phenomenological models
- Flavor tagging and purity analysis
- Experimental results
- Summary and Outlook …

Flavor Structure of the Proton



E866: $\bar{d} > \bar{u}$



- Constituent Quark Model

  Pure valence description: proton = 2u + d

- Perturbative Sea

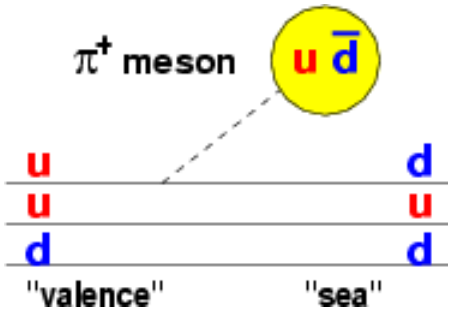
  sea quark pairs from $g \rightarrow q\bar{q}$

  should be flavor symmetric: $\bar{u} = \bar{d}$

Flavor Structure of the Proton - II

Non-perturbative models: alternate d.o.f.

Meson Cloud Models



Quark sea from cloud of 0^- mesons:

→ $\bar{d} > \bar{u}$

Chiral-Quark Soliton Model

- quark d.o.f. in a pion mean-field
- nucleon = chiral soliton
- one parameter: dynamically generated quark mass
- expand in $1/N_c$:

→ $\bar{d} > \bar{u}$

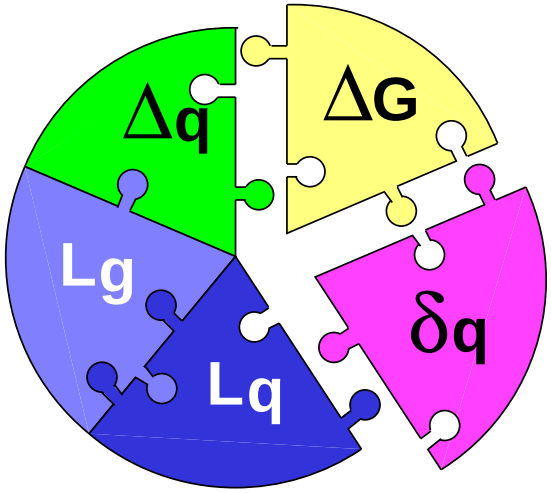
Statistical Model

- nucleon = gas of massless partons
- few parameters: generate parton distribution functions
- input: QCD: chiral structure DIS: u(x) and d(x)

→ $\bar{d} > \bar{u}$

$\Rightarrow$ important constraints on flavor asymmetry for polarization of light sea

Spin Structure of the Proton



$$\tfrac{1}{2} = \tfrac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

"You think you understand something?
Now add spin …" -R. Jaffe

- Constituent Quark Model

  pure valence description of constituent quarks:

  $\Delta u = +4/3, \Delta d = -1/3 \longrightarrow \boxed{\Delta\Sigma = 1}$

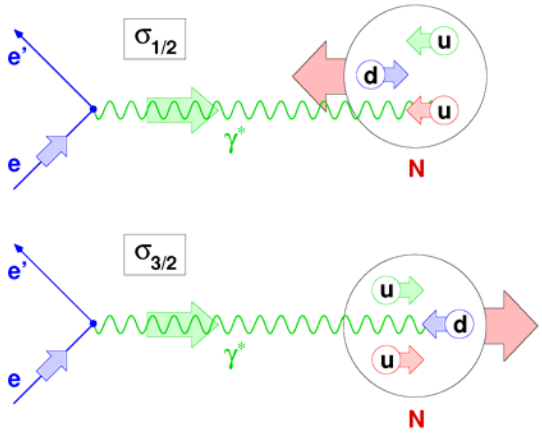
- Relativistic Quark Model

  relativistic current quarks with light masses: orbital angular momentum is important, and accounts for the deficit of $\Delta\Sigma$.

  $\boxed{\Delta\Sigma \simeq 0.60 - 0.75}$ $\quad L_q = \tfrac{1}{2}(1-\Delta\Sigma)$

- QCD?

Polarized Deep-Inelastic Scattering



$$\sigma_{1/2} \sim q^{+} \qquad \sigma_{3/2} \sim q^{-}$$

$$F_1 = \frac{1}{2}\sum_q e_q^2 q \qquad g_1 = \frac{1}{2}\sum_q e_q^2 \Delta q$$

$$q := q^{+} + q^{-} \quad \text{and} \quad \Delta q := q^{+} - q^{-}$$

Note: inclusive DIS is sensitive only to e_q^2

There are no neutrino DIS measurements on polarized targets (yet!)

$\Rightarrow$ inclusive DIS cannot distinguish quark from anti-quark

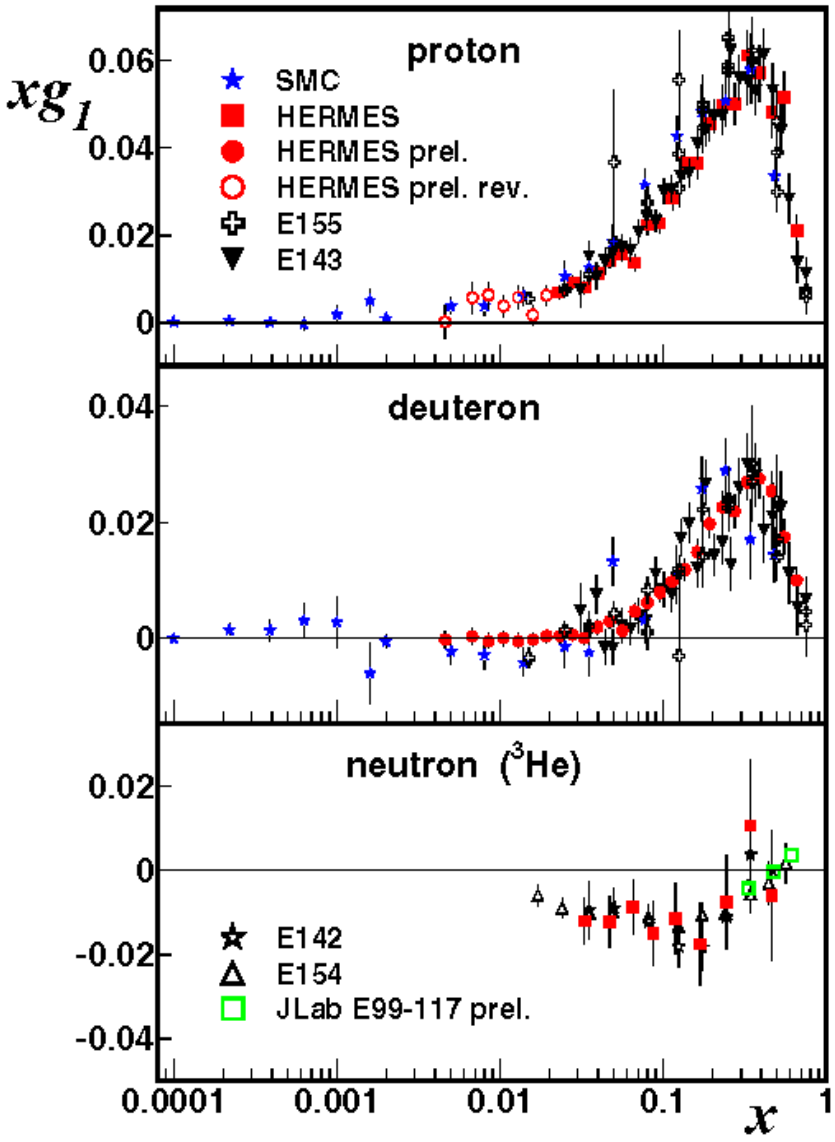
$\Rightarrow$ $\Delta q := \Delta(q + \bar{q})$

One measures double spin asymmetries: $A_1 = \dfrac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$

In QCD Parton Model:

$$A_1(x,Q^2) \overset{g_2=0}{\simeq} \frac{g_1(x,Q^2)}{F_1(x,Q^2)} = \frac{\sum_q e_q^2 \Delta q(x,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

Comparison of Data for $g_1(x)$



- From NLO-QCD analysis of inclusive DIS measurements…

SMC, PRD 58 (1998) 112002

(in AB scheme)

$\Delta\Sigma = 0.38$ $\Delta G = 1.0\ ^{+1.9}_{-0.6}$

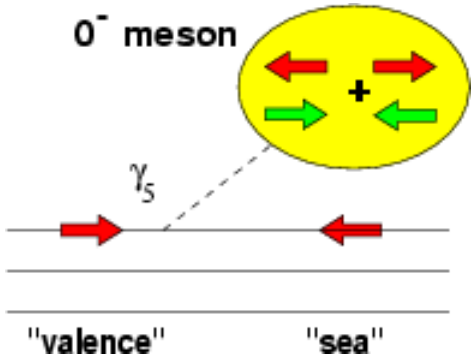
$\Delta s = -0.02$ to -0.15 (model dependent)
→ slight neg. sea-quark polarization?

What about $\Delta\bar{q}$? (inclusive DIS gives no answer)

Anti-quark Spin in the Proton

Meson Cloud Models

Li, Cheng, hep-ph/9709293



→ $\Delta q_{valence} > 0$

→ $\Delta q_{sea} < 0$, but …

⇒ $\boxed{\Delta\bar{q} = 0}$

"higher-order" cloud of vector mesons can generate a small polarization.

Chiral-Quark Soliton Model

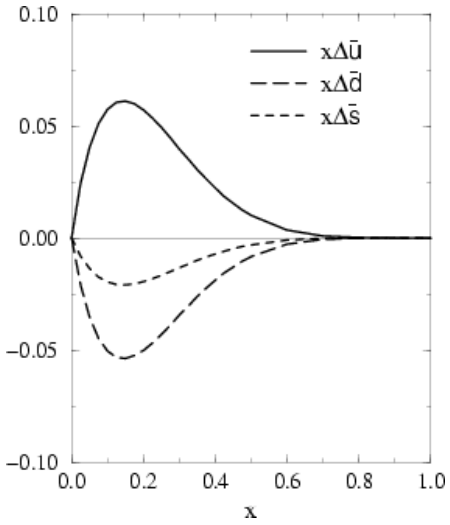
Goeke at al, NPA 680 (2000) 397

Light sea quarks polarized:

$$\boxed{\Delta\bar{u} \simeq -\Delta\bar{d} > 0}$$

with …

$\Delta\bar{u}(x) - \Delta\bar{d}(x) > \bar{d}(x) - \bar{u}(x)$



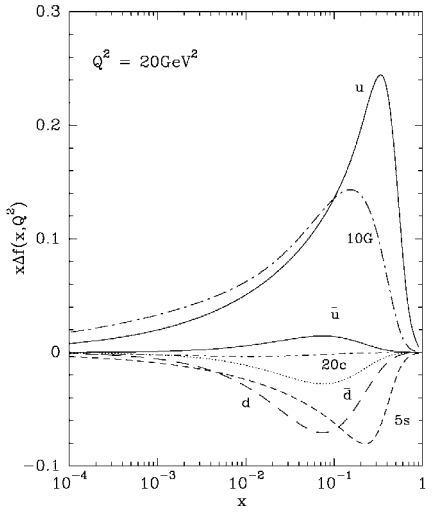
Statistical Model

Bourelly et al, EPJ C23, (2002) 487

$$\boxed{\Delta\bar{d} < 0, \quad \Delta\bar{u} > 0}$$

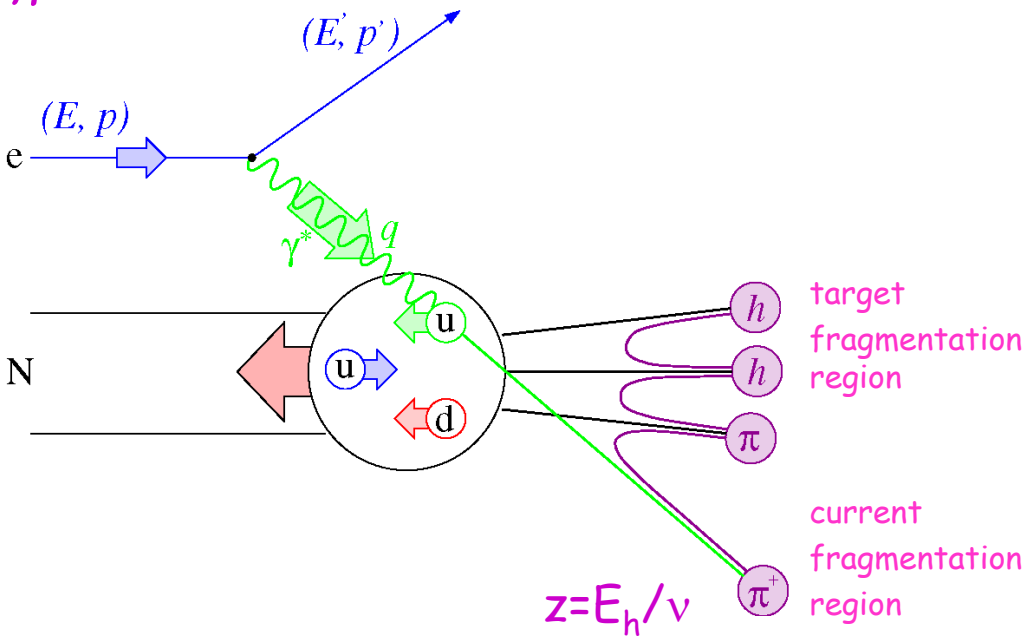
but …

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



Quark Polarization from Semi-Inclusive DIS

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



Goal: Flavor Separation

of quark and anti-quark helicity distributions

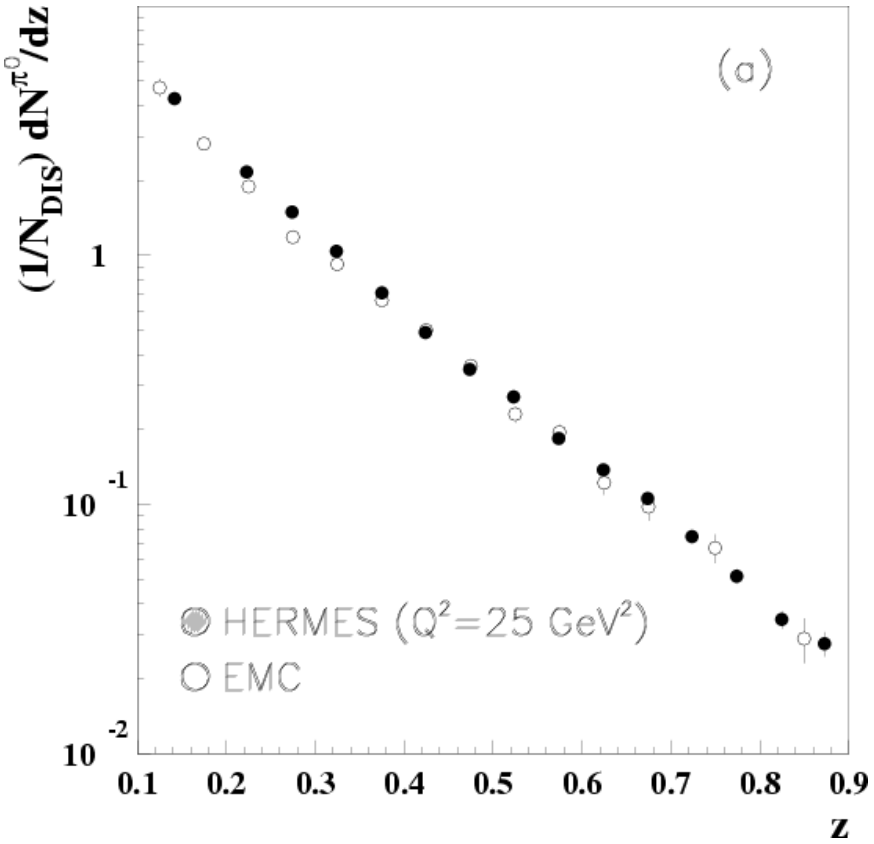
Technique: Flavor Tagging

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

$$\frac{d\sigma_h^{\uparrow\downarrow}}{dz} - \frac{d\sigma_h^{\uparrow\uparrow}}{dz} = \sum_{q=u,\bar{u},\ldots} e_q^2 \Delta q(x,Q^2) \cdot D_q^h(z,Q^2)$$

Is HERMES Fragmentation "Universal"?

Compare pion multiplicities: HERMES vs EMC (both at Q^2=25 GeV^2)



Assumptions for flavor tagging (in LO QCD):

- factorization (DIS, fragmentation)
- fragmentation functions exhibit scaling

Good agreement, despite order of magnitude difference in energy

Purity Analysis of Asymmetries

- Perform a simultaneous global analysis of all $A_1^h(x,Q^2)$'s
- The photon-nucleon asymmetry is:

$$A_1^h(x,Q^2) = \frac{\sum_q e_q^2 \Delta q(x,Q^2) \int_{z_{\min}}^{z_{\max}} D_q^h(z,Q^2)dz}{\sum_q e_q^2 q(x,Q^2) \int_{z_{\min}}^{z_{\max}} D_q^h(z,Q^2)dz} \times c$$

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

F_L contribution to unpolarizaed PDF's:

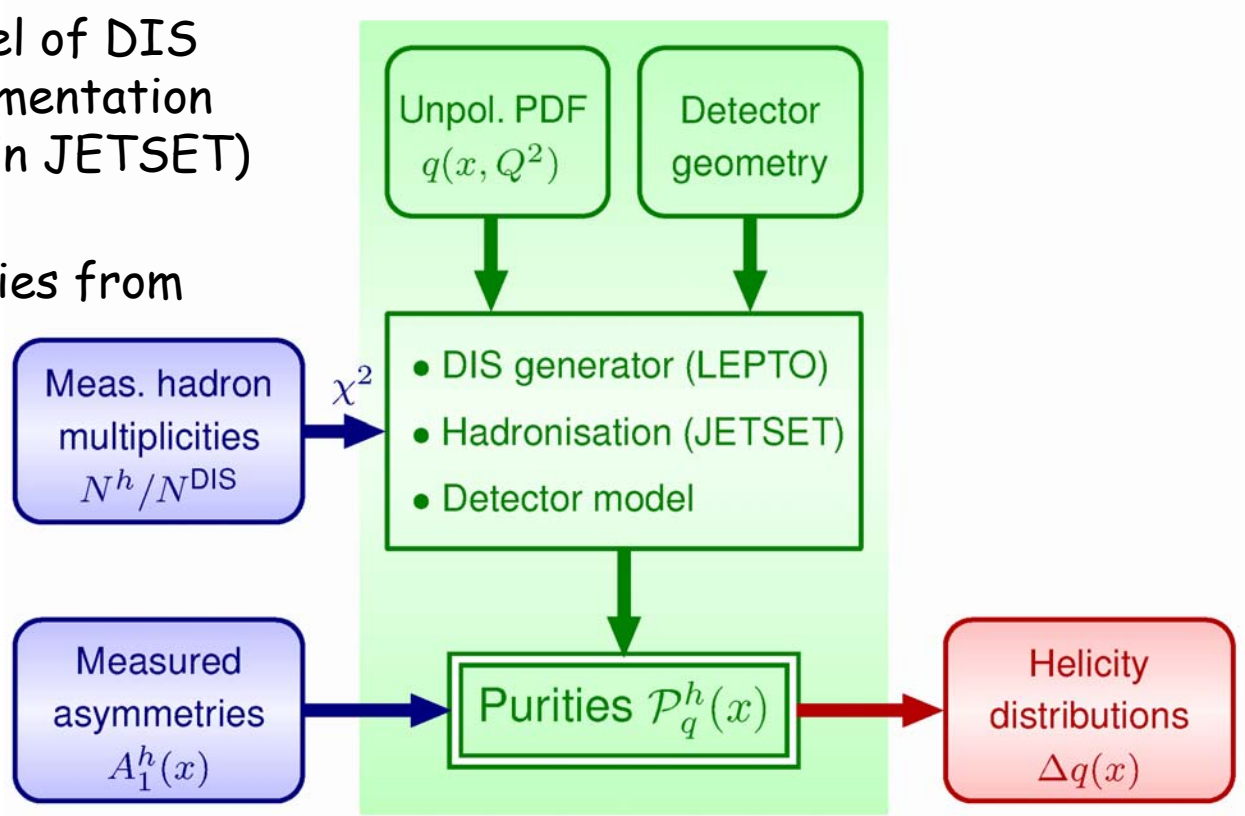
$$c = \frac{1+R(x,Q^2)}{1+\gamma^2}$$

- The hadron quark purity $P_q^h(x,Q^2)$ is the probability that a quark q was struck in an event e+N → e'+h+X
- Need at least six independent asymmetry sets $A_1^h(x)$ to determine six unknown helicity distributions $\Delta u(x),\ \Delta\bar{u}(x),\ \Delta d(x),\ \Delta\bar{d}(x),\ \Delta s(x),\ \Delta\bar{s}(x)$
- Purity equations are generally under determined → add symmetry assumptions

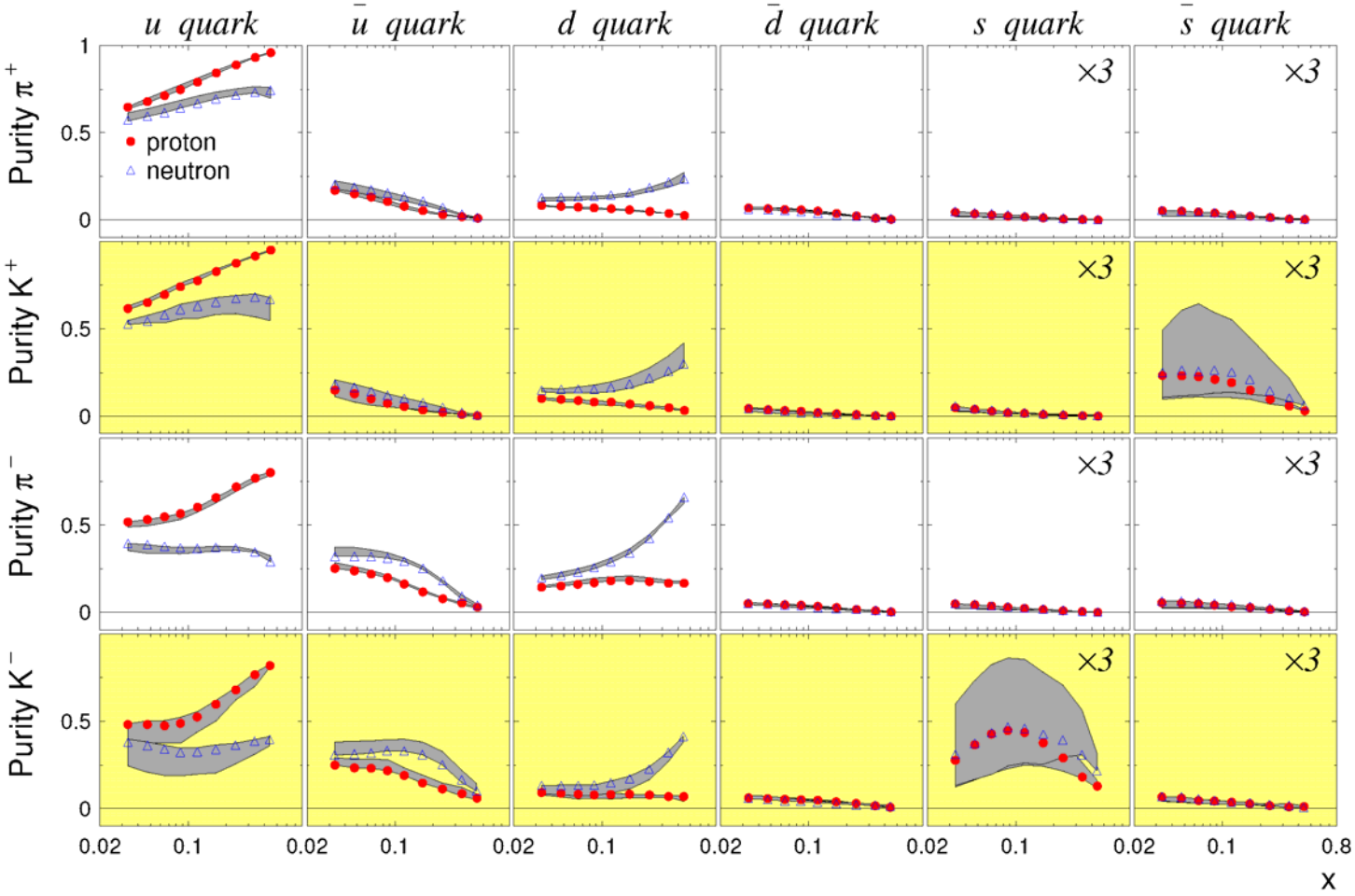
$$\frac{\Delta s(x)}{s(x)} = \frac{\Delta\bar{s}(x)}{\bar{s}(x)}$$ (HERMES 2002)

Generation of Purities

- Use Monte Carlo model of DIS process (LEPTO), fragmentation process (LUND model in JETSET) and detector
- Systematic uncertainties from
  - Variation of fragmentation parameters
  - Use of alternative PDF set GRV98LO vs. CTEQ5L



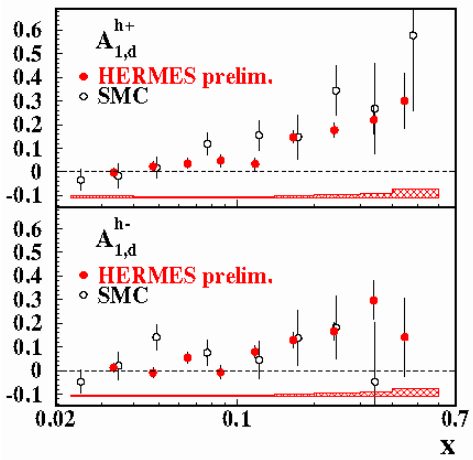
Purities

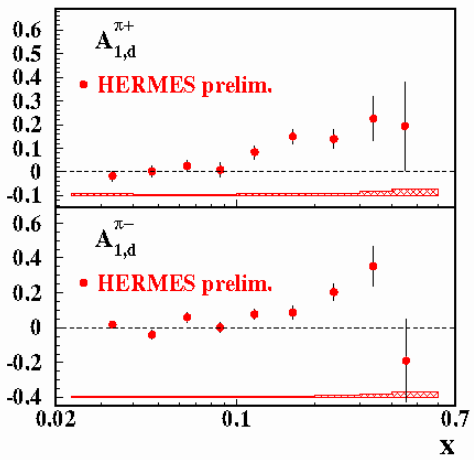


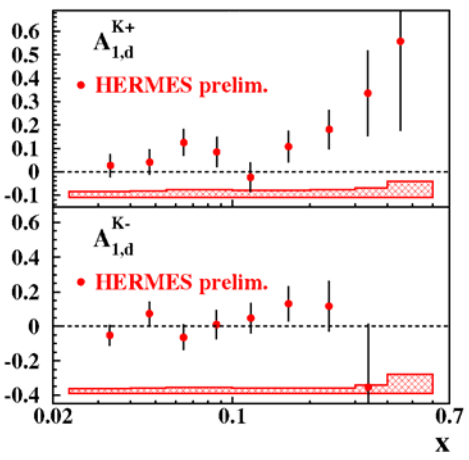
Syst. uncertainties from PDF sets (GRV98LO, CTEQ5L) and LUND parameters

Semi-Inclusive Asymmetries

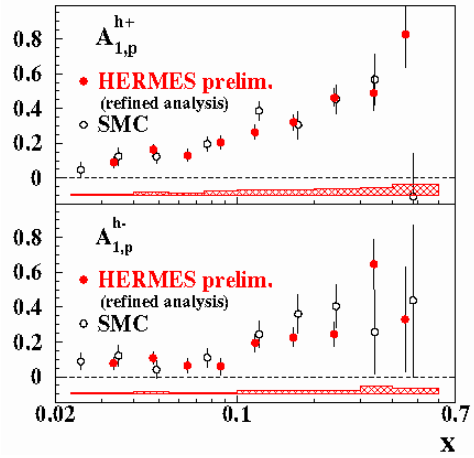
1998-2000
(RICH)

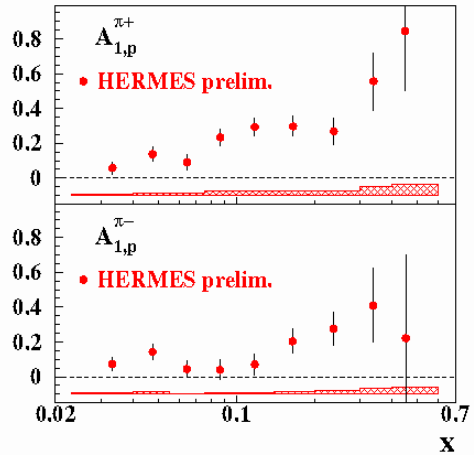






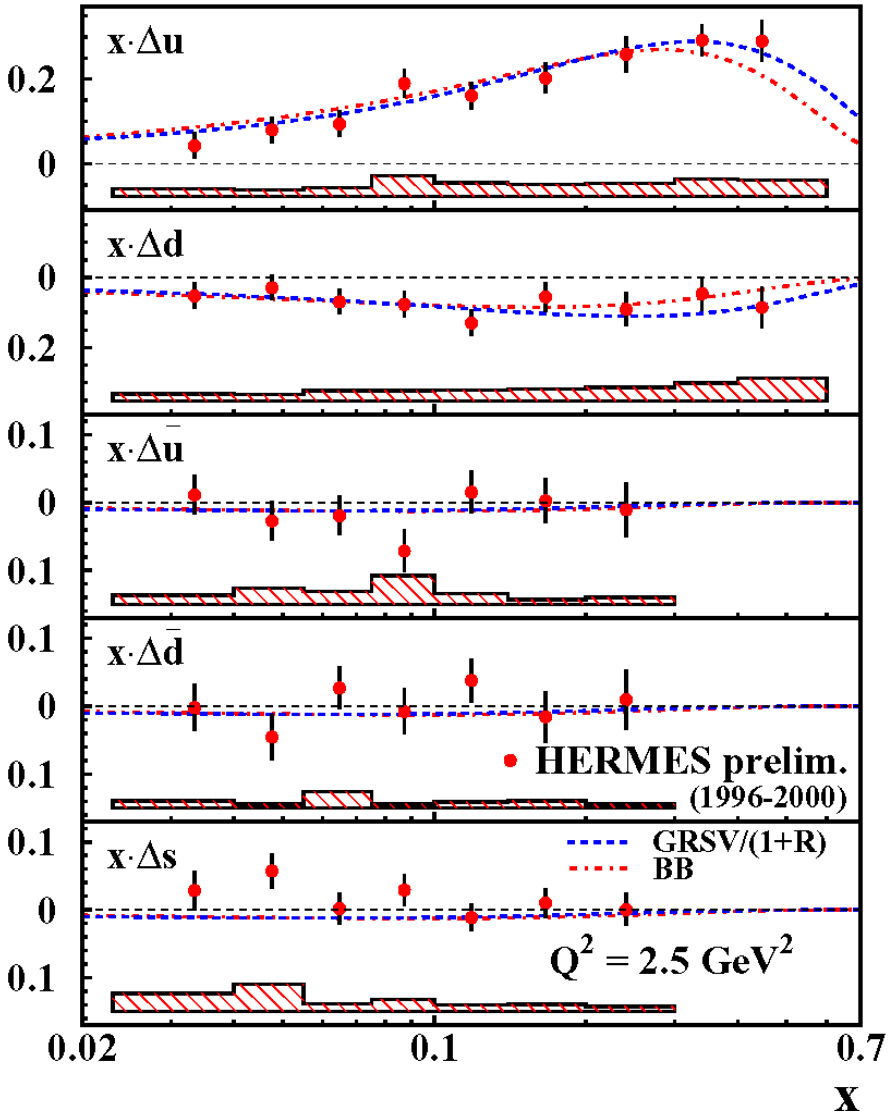
1996-97
(Cerenkov)





- $A_1^{K^-}(x) \approx 0$
- $K^- = (\bar{u}s)$ is an all-sea object
- Covered range:
  $0.023 \leq x \leq 0.6$
  $0.2 \leq z \leq 0.7$ $x_F > 0.1$
- Asymmetries are independent of z in this range

Latest Δq Results from HERMES



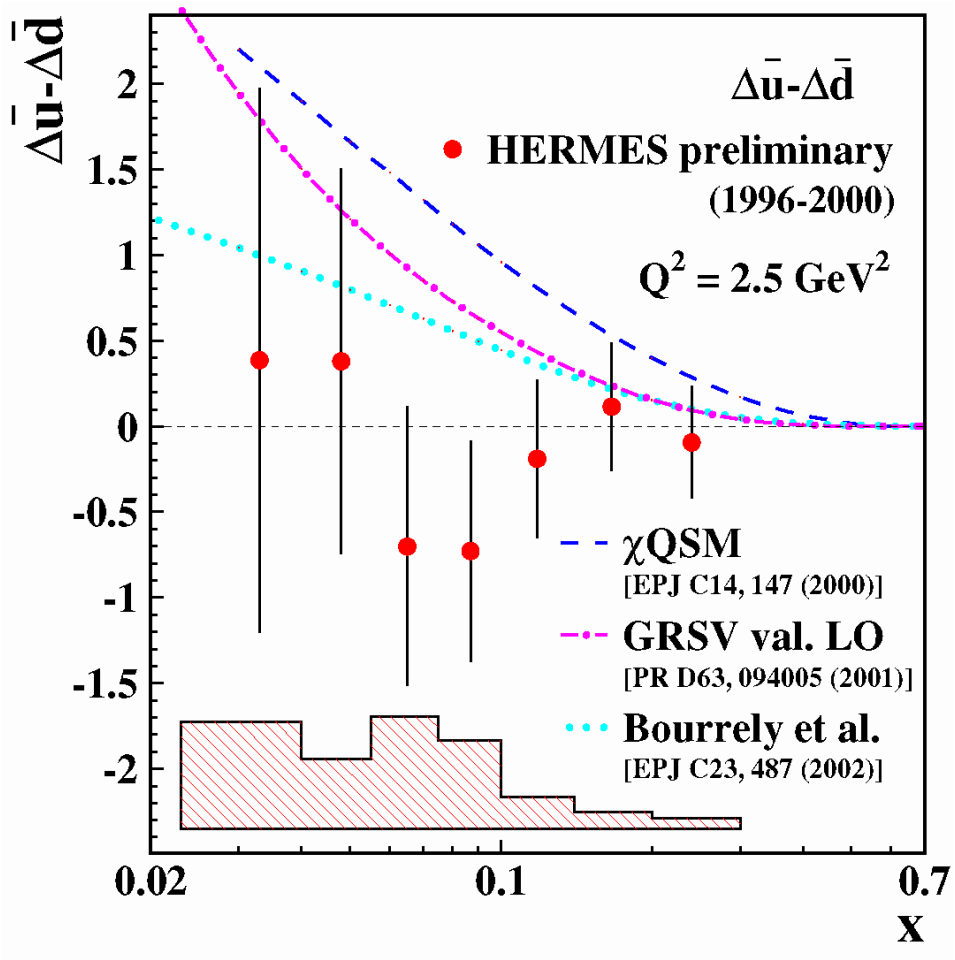
First 5-flavor fit to Δq(x)

$(\Delta s(x)/s(x) = \Delta\bar{s}(x)/\bar{s}(x)$ assumed)

Results show:

- u-quark positively polarized
- d-quark negatively polarized
- light sea quark polarization small
- s-quark polarization somewhat positive (1σ)

(A)symmetry of Polarized Light Quark Sea



- no strong breaking of flavor asymmetry in light sea
- data disfavor χQSM of Dressler *et al.*
- statistical model consistent with $\Delta\bar{u} = \Delta\bar{d} \approx 0$ BUT…
- meson cloud model seems to describe data best

Isoscalar Extraction of Δs

- A_1^K provide largest sensitivity to Δs: $K^+ = (u\bar{s})$ and $K^- = (\bar{u}s)$
  - but: large systematic uncertainties on P_s^K
- Alternative approach:
  - use only total kaon flux $K^+ + K^-$ on deuterium target (isoscalar)
  - $\Delta s' = \Delta s + \Delta\bar{s}$ is also isoscalar quantity
- Can measure Δs using inclusive $A_{1,d}(x)$ and semi-inclusive $A_{1,d}^{K^+ + K^-}$
  - use fragmentation functions from e^+e^- collider experiments, $D_{q+\bar{q}}^{K^+ + K^-}(z, Q^2)$
    $\rightarrow$ directly compute purities P_s^K (no MC model needed)
- Provides independent check on strange polarization result
- Two component analysis also favors positive Δs

Summary and Outlook

- First 5-flavor separation from HERMES
  - helicity distributions confirm inclusive DIS results: $\Delta u \gg 0,\ \Delta d < 0$
  - light sea in unpolarized: $\Delta\bar{u} = \Delta\bar{d} \approx 0$
  - no indication for $\Delta(s + \bar{s}) < 0$
- The Next Round of Experiments
  - COMPASS: complementary results at higher energy
  - RHIC: polarized W production
    - $\Delta\bar{u}(x)$ vs $\Delta\bar{d}(x), \Delta\bar{s}(x)$ sensitivity
    - largely improved precision
- HERMES Run 2 with transverse target
  - focus on transversity