Iso-scalar extraction of ΔS in the nucleon at HERMES from semi-inclusive DIS

L. A. Linden Levy
(On behalf of the HERMES collaboration)
lindenle@uiuc.edu

University of Illinois at Urbana-Champaign
1110 W. Green Street Urbana, IL 61801

25th February 2006

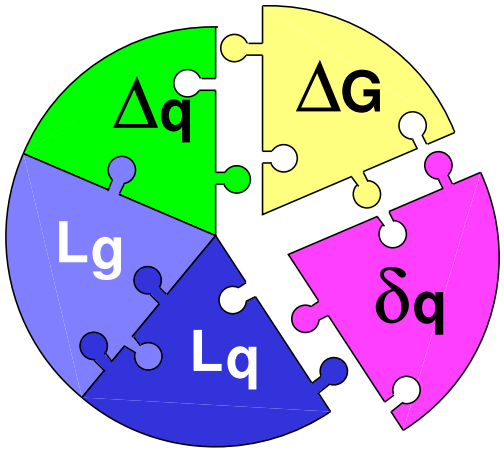
Outline

1. Introduction
   - Partonic structure of the proton
   - Polarized semi-inclusive deep inelastic scattering (SIDIS)
   - HERMES experiment
2. HERMES SIDIS results for ΔS
   - 5-flavor purity extraction
   - New analysis: iso-scalar extraction from ^2H
3. Expectations for ΔS
   - g_1 NLO inclusive analysis & hyperon β decay
4. Conclusions

A brief history of the proton spin puzzle

- (1927) Denisson discovers that the proton is a spin $1/2$ fermion
- (1933) Estermann & Stern measure protons anomalous magnetic moment
- (1960s) SLAC discovery of scaling
- (1980s) EMC ("Spin Crisis")

$$\boxed{\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + J_g}$$



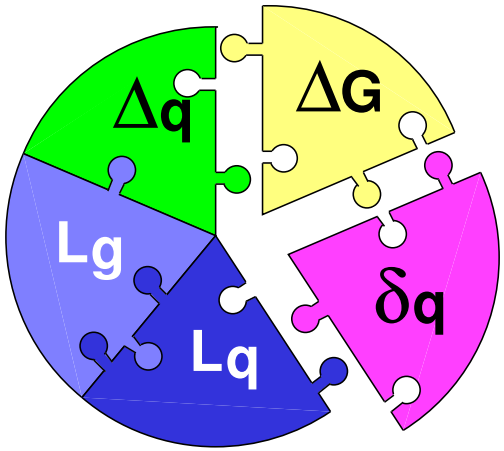
- (1990s) SMC, HERMES, SLAC measure inclusive structure function ("Spin Puzzle")
- (2001) HERMES 5-flavor extraction of Δq
- New analysis of strange quark polarization

A brief history of the proton spin puzzle

- (1927) Denisson discovers that the proton is a spin $1/2$ fermion
- (1933) Estermann & Stern measure protons anomalous magnetic moment
- (1960s) SLAC discovery of scaling
- (1980s) EMC ("Spin Crisis")

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + J_g$$

Quark spin



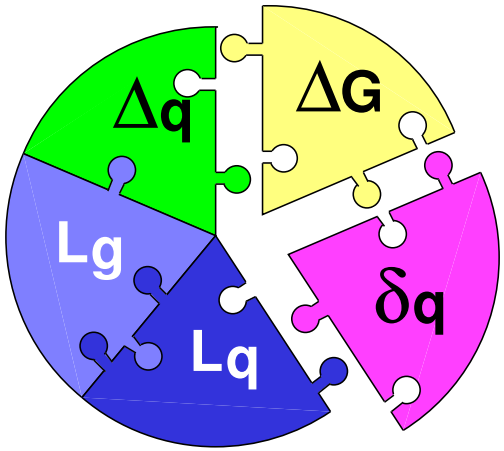
- (1990s) SMC, HERMES, SLAC measure inclusive structure function ("Spin Puzzle")
- (2001) HERMES 5-flavor extraction of Δq
- New analysis of strange quark polarization

A brief history of the proton spin puzzle

- (1927) Denisson discovers that the proton is a spin $1/2$ fermion
- (1933) Estermann & Stern measure protons anomalous magnetic moment
- (1960s) SLAC discovery of scaling
- (1980s) EMC ("Spin Crisis")

$$\boxed{\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + J_g}$$

Quark orbital angular momentum



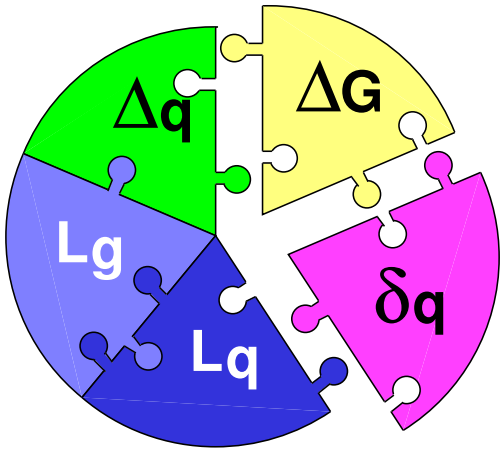
- (1990s) SMC, HERMES, SLAC measure inclusive structure function ("Spin Puzzle")
- (2001) HERMES 5-flavor extraction of Δq
- New analysis of strange quark polarization

A brief history of the proton spin puzzle

- (1927) Denisson discovers that the proton is a spin $1/2$ fermion
- (1933) Estermann & Stern measure protons anomalous magnetic moment
- (1960s) SLAC discovery of scaling
- (1980s) EMC ("Spin Crisis")

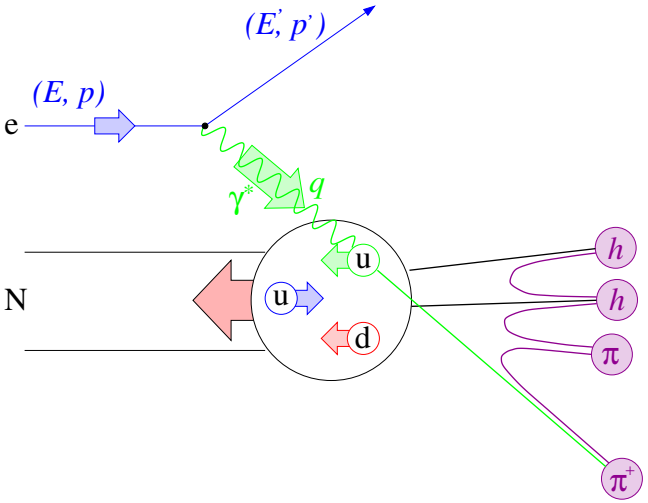
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + J_g$$

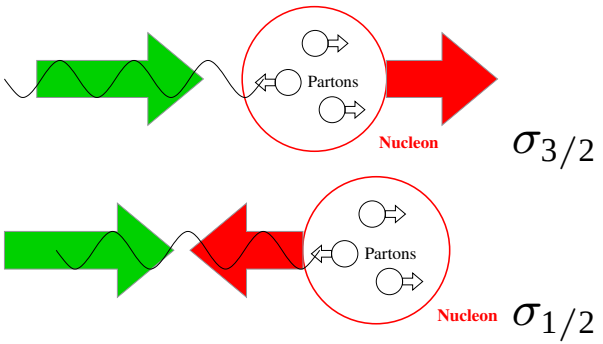
Gluon angular momentum



- (1990s) SMC, HERMES, SLAC measure inclusive structure function ("Spin Puzzle")
- (2001) HERMES 5-flavor extraction of Δq
- New analysis of strange quark polarization

Quark Parton Model Formalism

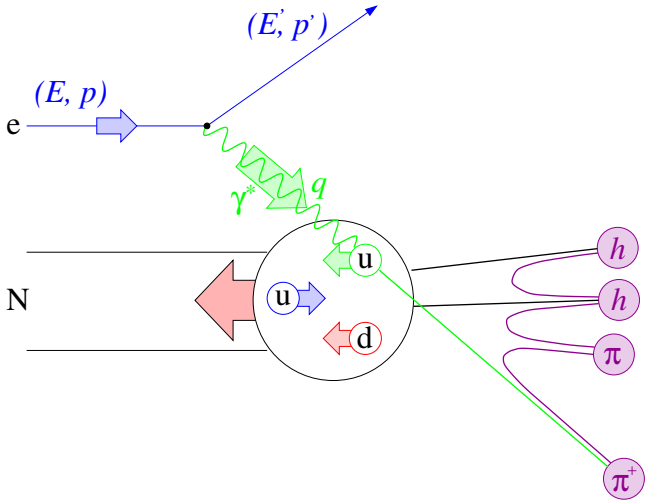


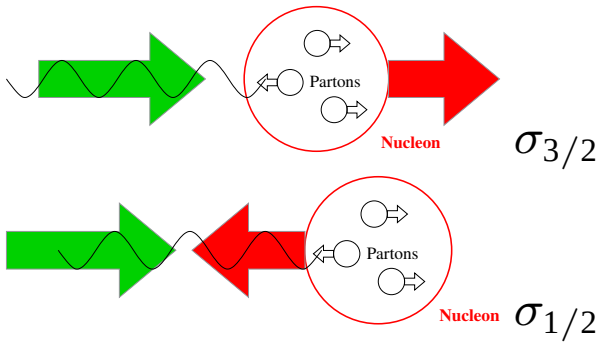


- DIS requirements: $Q^2 > 1.0$, $W^2 > 10$
- Virtual photon probe reveals the partonic substructure of the nucleon
- Hadron provides flavor tag for struck parton ($x_F > 0.1$, $0.2 < z < 0.8$)
- Angular momentum conservation connects parton spin to polarized target
- Asymmetry can be recast in terms of a completely inclusive quantity (purity)

$$\frac{d^3\sigma^h_{1/2(3/2)}}{dxdQ^2dz} \propto \Sigma_q e_q^2 q(x,Q^2)^{+(-)} D_q^h(z,Q^2)$$

Quark Parton Model Formalism

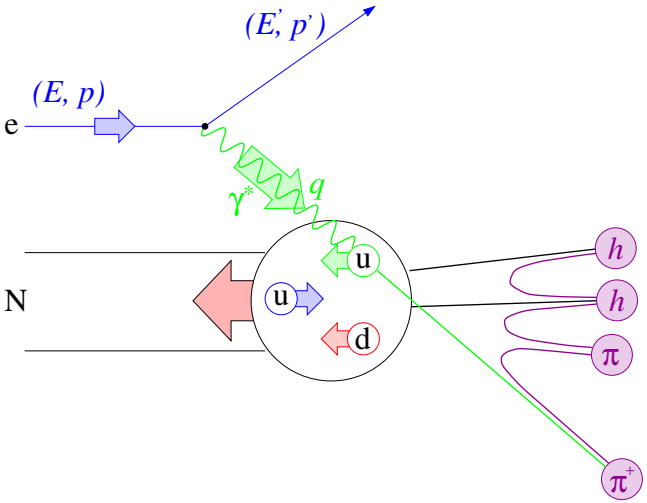


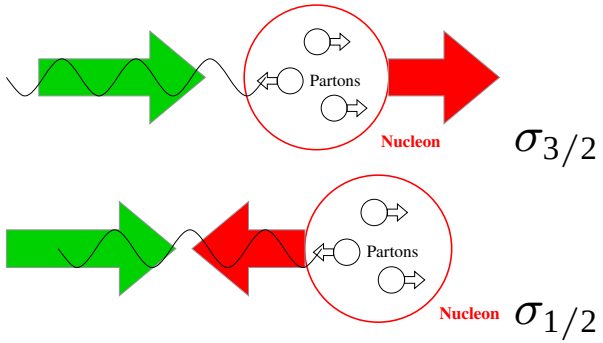


- DIS requirements: $Q^2 > 1.0$, $W^2 > 10$
- Virtual photon probe reveals the partonic substructure of the nucleon
- Hadron provides flavor tag for struck parton ($x_F > 0.1$, $0.2 < z < 0.8$)
- Angular momentum conservation connects parton spin to polarized target
- Asymmetry can be recast in terms of a completely inclusive quantity (purity)

$$A_1^h(x,Q^2) = \frac{1}{\langle P_b P_t \rangle} \frac{\sigma_{1/2}^h - \sigma_{3/2}^h}{\sigma_{1/2}^h + \sigma_{3/2}^h} \overset{g_2=0}{\approx} \frac{\Sigma e_q^2 \Delta q(x,Q^2) \bar{D}_q^h}{\Sigma_q q(x,Q^2) \bar{D}_q^h}$$

Quark Parton Model Formalism

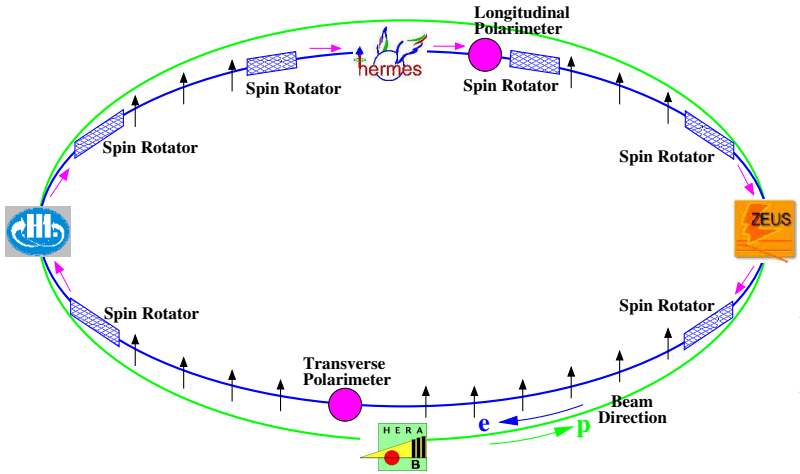


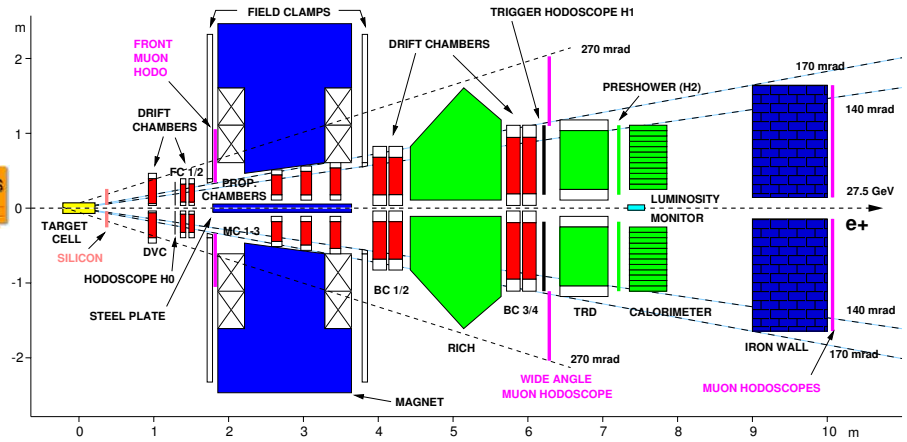


- DIS requirements: $Q^2 > 1.0$, $W^2 > 10$
- Virtual photon probe reveals the partonic substructure of the nucleon
- Hadron provides flavor tag for struck parton ($x_F > 0.1$, $0.2 < z < 0.8$)
- Angular momentum conservation connects parton spin to polarized target
- Asymmetry can be recast in terms of a completely inclusive quantity (purity)

$$A_1^h(x,Q^2) = \frac{1}{\langle P_b P_t \rangle} \frac{\sigma_{1/2}^h - \sigma_{3/2}^h}{\sigma_{1/2}^h + \sigma_{3/2}^h} \overset{g_2=0}{\approx} \Sigma_q P_q^h(x,Q^2) \frac{\Delta q(x,Q^2)}{q(x,Q^2)}$$

Experimental Details





- Polarized lepton beam of the HERA ring $< P_B > \approx 54\%$
- Polarized gas (ABS) target $< P_T > \approx 85(-84)\%$
- Open geometry forward spectrometer
- 98% lepton identification with $< 1\%$ hadron contamination
- Excellent separation of π, K and p via ring imaging Cherenkov (RICH)

Published 5-flavor purity extraction

$$\vec{A}_1 = P \cdot \vec{Q}$$

$$\vec{A}_1 = \begin{pmatrix} A_{1,p} \\ A_{1,p}^{\pi^+} \\ A_{1,p}^{\pi^-} \\ A_{1,d} \\ \vdots \\ A_{1,d}^{K^-} \end{pmatrix}$$

$$P_q^h(x) \equiv \frac{e_q^2 q(x) \int dz D_q^h(z)}{\Sigma_{q'} e_{q'}^2 q'(x) \int dz D_{q'}^h(z)}$$

Measured

$$\vec{Q} = \begin{pmatrix} \Delta u/u \\ \Delta d/d \\ \Delta \bar{u}/\bar{u} \\ \Delta \bar{d}/\bar{d} \\ \Delta s/s \end{pmatrix}$$

- Inclusive purities extracted from LUND string model MC simulation (LEPTO+JETSET) tuned to HERMES unpolarized data
- System of asymmetries and purities solved through χ^2 minimization of polarizations

Published 5-flavor purity extraction

$$\vec{A}_1 = P \cdot \vec{Q}$$

$$\vec{A}_1 = \begin{pmatrix} A_{1,p} \\ A_{1,p}^{\pi^+} \\ A_{1,p}^{\pi^-} \\ A_{1,d} \\ \vdots \\ A_{1,d}^{K^-} \end{pmatrix} \qquad P_q^h(x) \equiv \frac{e_q^2 q(x) \int dz D_q^h(z)}{\Sigma_{q'} e_{q'}^2 q'(x) \int dz D_{q'}^h(z)} \qquad \vec{Q} = \begin{pmatrix} \Delta u/u \\ \Delta d/d \\ \Delta \bar{u}/\bar{u} \\ \Delta \bar{d}/\bar{d} \\ \Delta s/s \end{pmatrix}$$

Simulated

- Inclusive purities extracted from LUND string model MC simulation (LEPTO+JETSET) tuned to HERMES unpolarized data
- System of asymmetries and purities solved through χ^2 minimization of polarizations

Published 5-flavor purity extraction

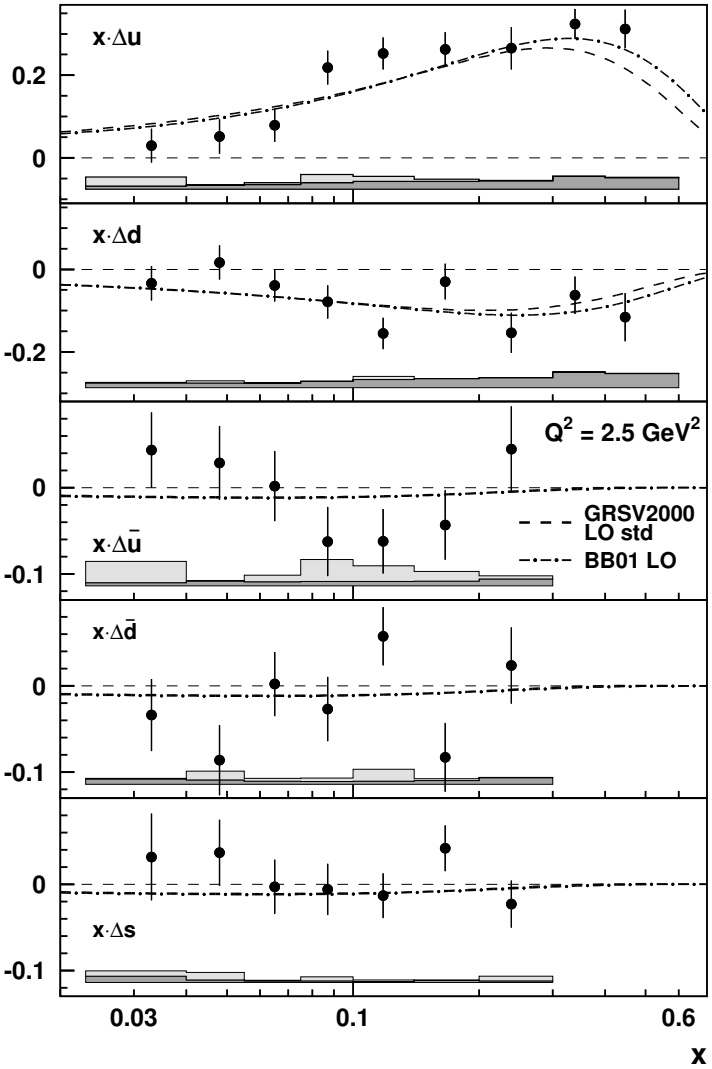
$$\vec{A}_1 = P \cdot \vec{Q}$$

$$\vec{A}_1 = \begin{pmatrix} A_{1,p} \\ A_{1,p}^{\pi^+} \\ A_{1,p}^{\pi^-} \\ A_{1,d} \\ \vdots \\ A_{1,d}^{K^-} \end{pmatrix} \qquad P_q^h(x) \equiv \frac{e_q^2 q(x) \int dz D_q^h(z)}{\Sigma_{q'} e_{q'}^2 q'(x) \int dz D_{q'}^h(z)} \qquad \vec{Q} = \begin{pmatrix} \Delta u/u \\ \Delta d/d \\ \Delta \bar{u}/\bar{u} \\ \Delta \bar{d}/\bar{d} \\ \Delta s/s \end{pmatrix}$$

Extracted

- Inclusive purities extracted from LUND string model MC simulation (LEPTO+JETSET) tuned to HERMES unpolarized data
- System of asymmetries and purities solved through χ^2 minimization of polarizations

Published 5-flavor purity extraction



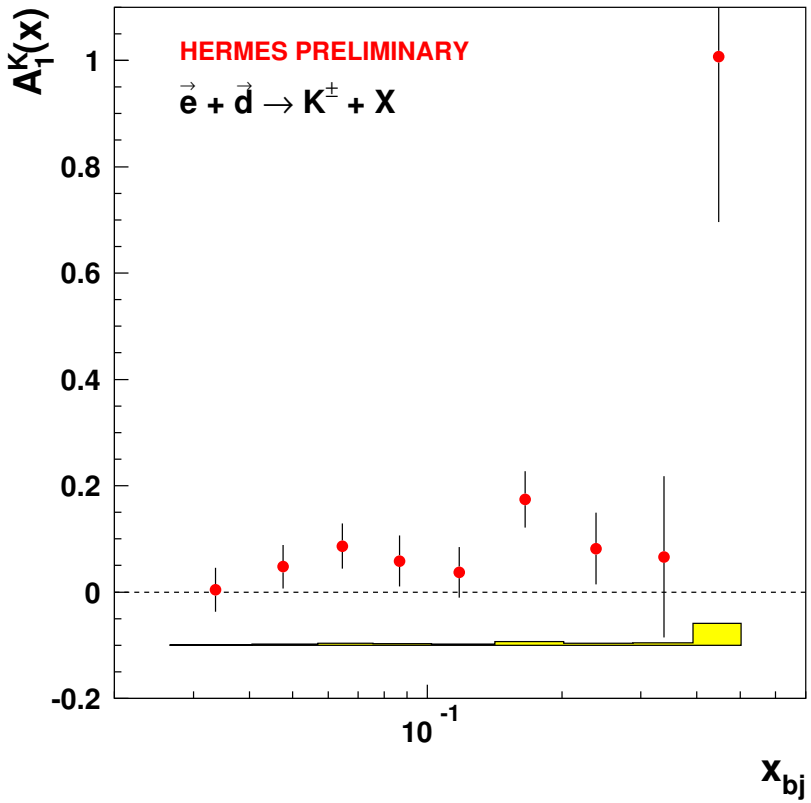
- Only 5-flavor Δq extraction
- $\Delta s = \Delta \bar{s}$ only flavor symmetry assumption
- Δu, Δd in good agreement with LO & NLO inclusive fits
- Sea quark polarizations all consistent with 0
- First moment: $\Delta^{(1)}s = 0.028 \pm 0.033 \pm 0.009$ in measured region

New Analysis: Iso-scalar formalism

Using only deuteron target (iso-scalar) and kaon asymmetries allows alternative extraction of $\Delta s/s$

$$A_1(x) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

$$A_1^K(x) = \frac{\sigma^K_{1/2} - \sigma^K_{3/2}}{\sigma^K_{1/2} + \sigma^K_{3/2}}$$



- From charge conjugation invariance.($D_q^{h^+ + h^-} = D_{\bar{q}}^{h^+ + h^-}$)
- CTEQ6 LO used to fit fragmentation function constants.
- No dependence on MC simulation.

New Analysis: Iso-scalar formalism

Using only deuteron target (iso-scalar) and kaon asymmetries allows alternative extraction of $\Delta s/s$

$$A_1(x) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

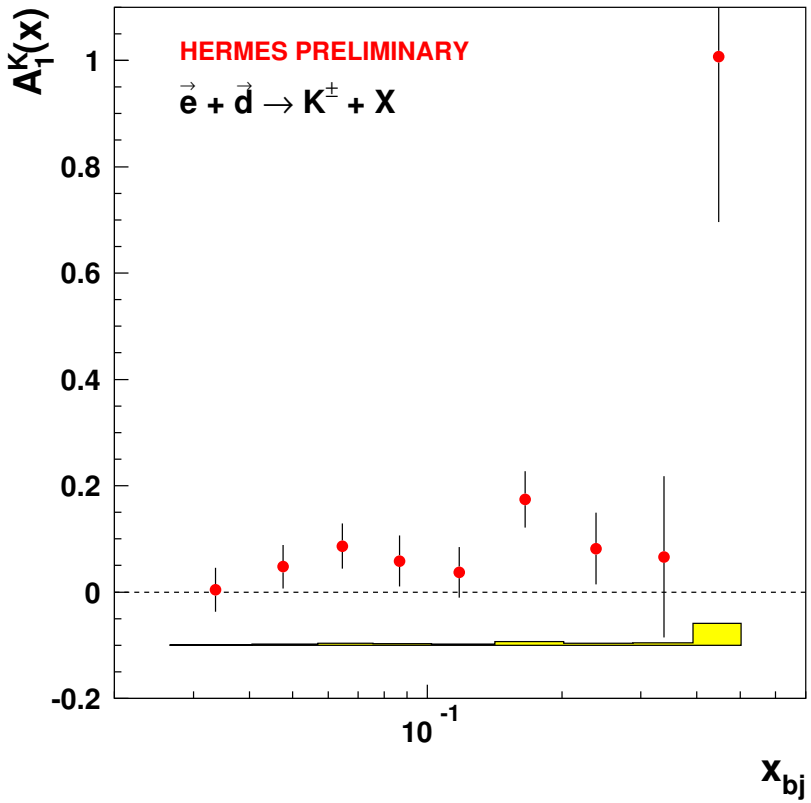
$$A_1^K(x) = \frac{\sigma^K_{1/2} - \sigma^K_{3/2}}{\sigma^K_{1/2} + \sigma^K_{3/2}}$$

$$\mathbb{D}_Q^K \equiv \int dz \left(4D_u^{K^+ + K^-} + D_d^{K^+ + K^-}\right)$$

$$\mathbb{D}_S^K \equiv \int dz \; D_s^{K^+ + K^-}$$

$$\Delta Q(x) \equiv \Delta u(x) + \Delta \bar{u}(x) + \Delta d(x) + \Delta \bar{d}(x)$$

$$\Delta S(x) \equiv \Delta s(x) + \Delta \bar{s}(x)$$



- From charge conjugation invariance.($D_q^{h^+ + h^-} = D_{\bar{q}}^{h^+ + h^-}$)
- CTEQ6 LO used to fit fragmentation function constants.
- No dependence on MC simulation.

New Analysis: Iso-scalar formalism

Using only deuteron target (iso-scalar) and kaon asymmetries allows alternative extraction of $\Delta s/s$

$$A_1(x) = \frac{5\Delta Q + 2\Delta S}{5Q(x) + 2S(x)}$$

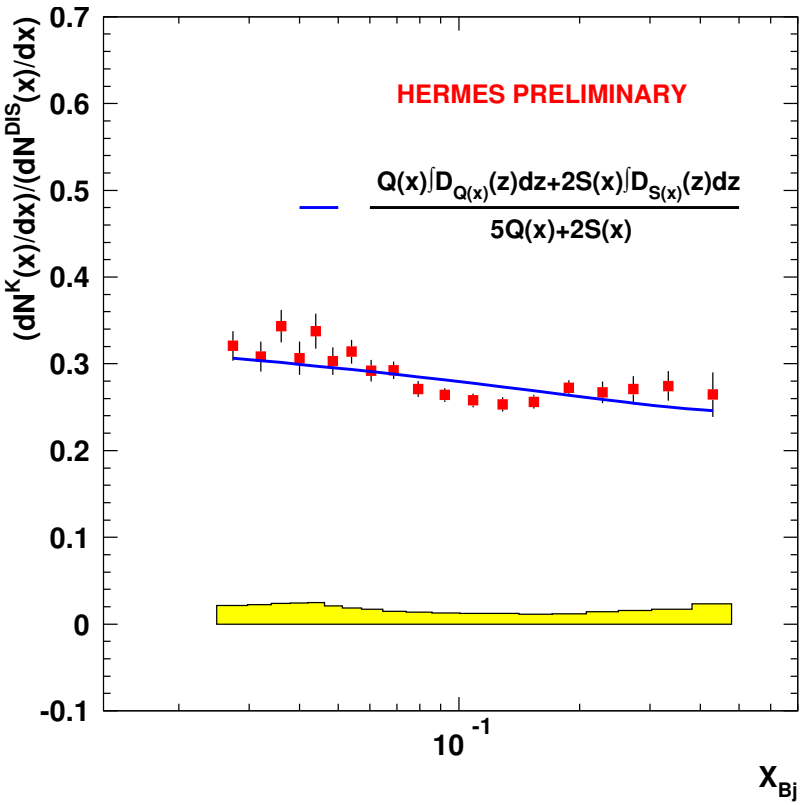
$$A_1^K(x) = \frac{\Delta Q \mathbb{D}_Q^K + 2\Delta S \mathbb{D}_S^K(z)}{Q(x)\mathbb{D}_Q^K + 2S(x)\mathbb{D}_S^K}$$

$$\mathbb{D}_Q^K \equiv \int dz \left(4D_u^{K^+ + K^-} + D_d^{K^+ + K^-}\right)$$

$$\mathbb{D}_S^K \equiv \int dz \; D_s^{K^+ + K^-}$$

$$\Delta Q(x) \equiv \Delta u(x) + \Delta \bar{u}(x) + \Delta d(x) + \Delta \bar{d}(x)$$

$$\Delta S(x) \equiv \Delta s(x) + \Delta \bar{s}(x)$$



- From charge conjugation invariance.($D_q^{h^+ + h^-} = D_{\bar{q}}^{h^+ + h^-}$)
- CTEQ6 LO used to fit fragmentation function constants.
- No dependence on MC simulation.

New Analysis: Iso-scalar formalism

Using only deuteron target (iso-scalar) and kaon asymmetries allows alternative extraction of $\Delta s/s$

$$A_1(x) = \frac{5\Delta Q + 2\Delta S}{5Q(x) + 2S(x)}$$

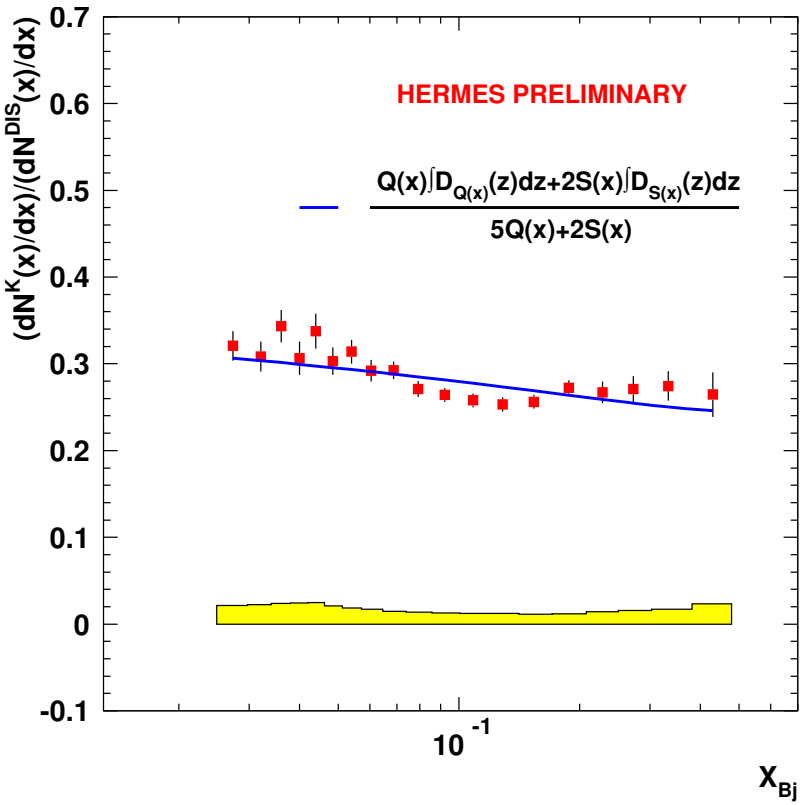
$$A_1^K(x) = \frac{\Delta Q \mathbb{D}_Q^K + 2\Delta S \mathbb{D}_S^K(z)}{Q(x)\mathbb{D}_Q^K + 2S(x)\mathbb{D}_S^K}$$

$$\mathbb{D}_Q^K \equiv \int dz \left(4D_u^{K^+ + K^-} + D_d^{K^+ + K^-}\right)$$

$$\mathbb{D}_S^K \equiv \int dz \; D_s^{K^+ + K^-}$$

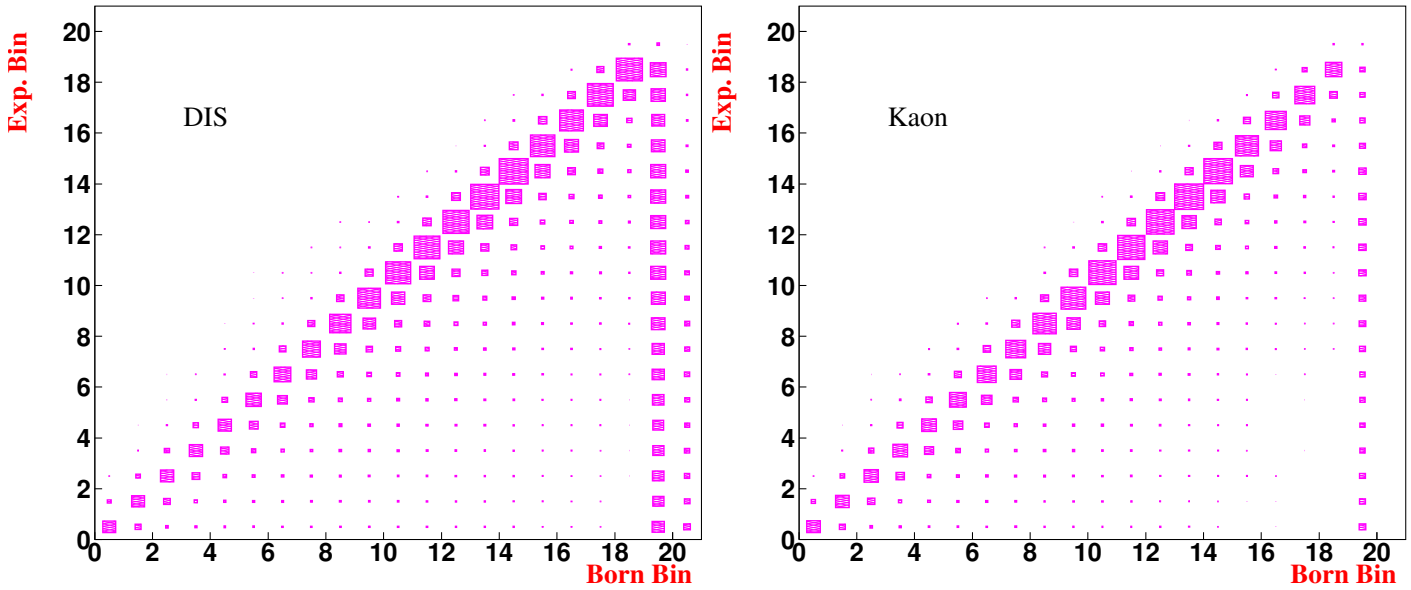
$$\Delta Q(x) \equiv \Delta u(x) + \Delta \bar{u}(x) + \Delta d(x) + \Delta \bar{d}(x)$$

$$\Delta S(x) \equiv \Delta s(x) + \Delta \bar{s}(x)$$



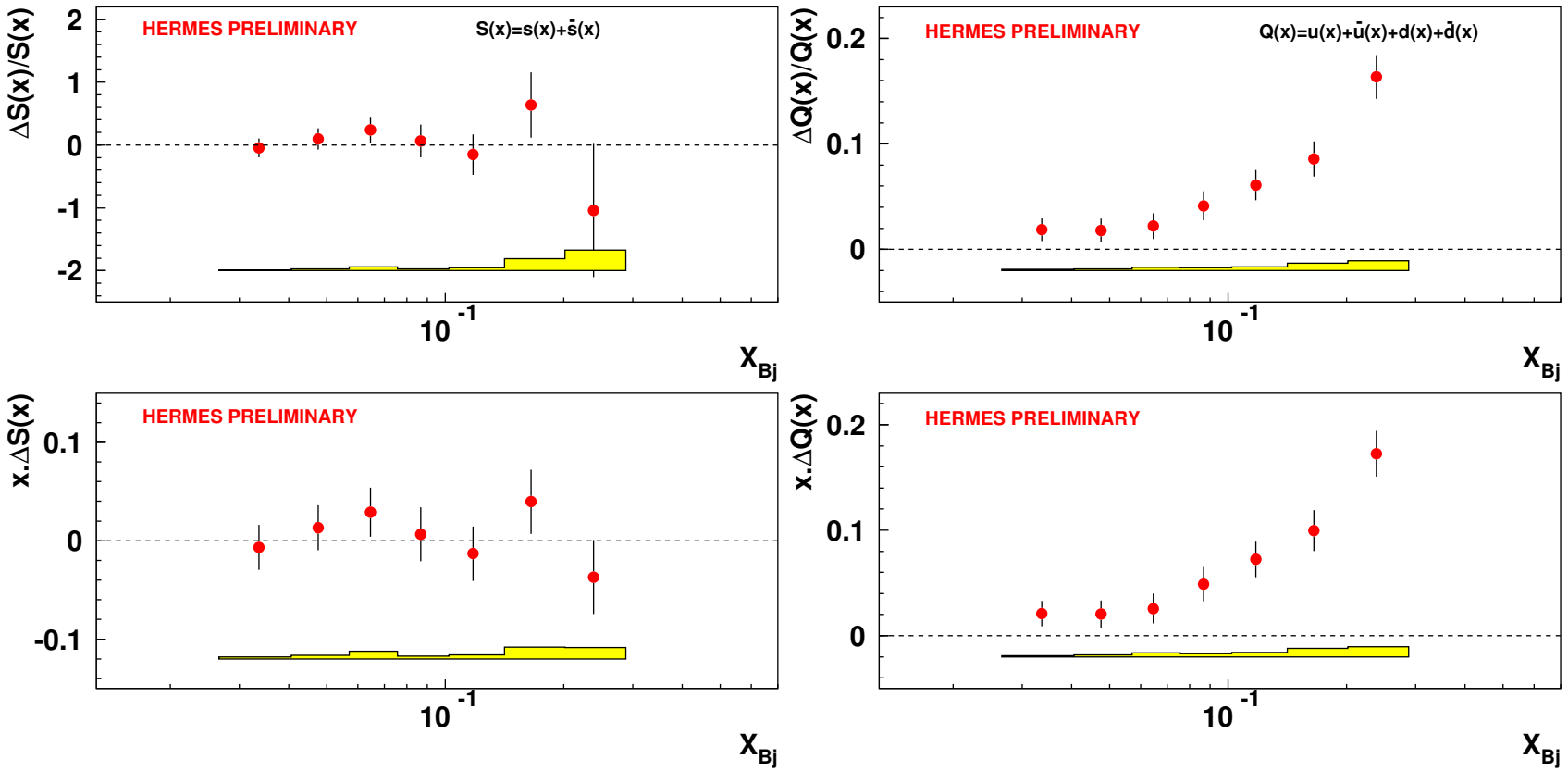
- From charge conjugation invariance.($D_q^{h^+ + h^-} = D_{\bar{q}}^{h^+ + h^-}$)
- CTEQ6 LO used to fit fragmentation function constants.
- No dependence on MC simulation.

Data corrections



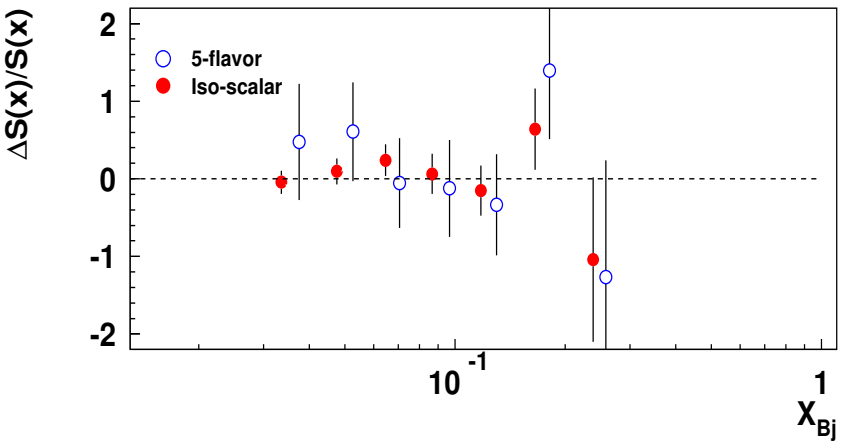
- Charge symmetric background correction. (pair production, neutral pion decay)
- RICH efficiency is momentum dependent, unfold misidentification
- Radiative correction that takes into account bin migration using detector and radiative corrections simulation (GEANT3 + RADGEN)
- Vector meson decays contamination in hadron signal estimated (PYTHIA) and removed

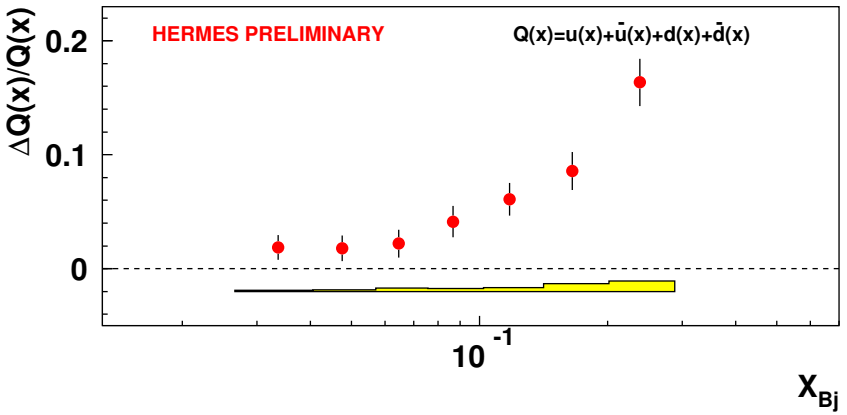
Results of iso-scalar extraction method

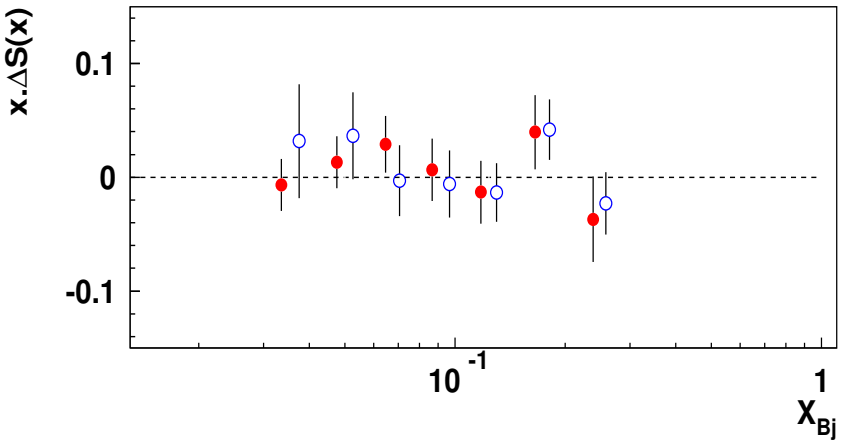


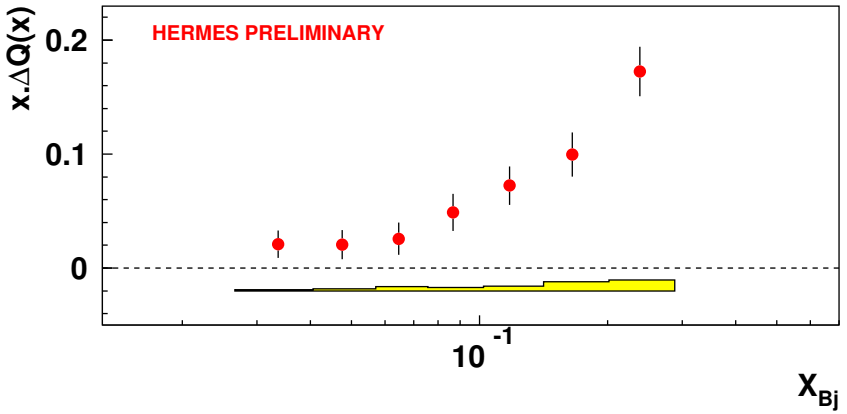
Result consistent with zero and...

Results of iso-scalar extraction method









...with previously published extraction.

QCD inclusive structure function fitting

$$g_1^{p(n)} = \frac{1}{9}\left(C_{NS} \otimes \left[\pm\frac{3a_3}{4} + \frac{a_8}{4}\right] + C_S \otimes a_0 + 2N_f C_g \otimes \Delta^{(1)} g\right)$$

- One would like to extract the moments directly from the differing Q^2 dependences. (c.f. F_1)
- The lack of kinematic coverage for g_1 makes the use of polarized hyperon β data necessary. (a_8)

$$a_3 \equiv F + D \equiv \Delta^1 u - \Delta^1 d$$
$$a_8 \equiv 3F - D \equiv \Delta^1 u + \Delta^1 d - 2\Delta^1 s$$
$$a_0 \equiv \Delta^1 \Sigma \equiv \Delta^1 u + \Delta^1 d + \Delta^1 s$$

- All inclusive analyses tend to favor $\Delta^{(1)} s < 0$.
- But these depend on SU(3) flavor symmetry for the hyperon octet, which must be violated at some level.

Can this be reconciled?

- SU(3) flavor asymmetry breaking of $\approx 20\%$ (supported by KTeV) for hyperon beta decay can give $(0.47 < a_8 < 0.70)$ [1]
  - Use SMC first moment of g_1
  - Then $\Delta^1 s = 0$ requires $a_8 = 0.089(0.197)$
  - From this effect alone it seems implausible to have a vanishing moment.
- How much flexibility exists in the NLO QCD fits to g_1? (extensive studies during 5-flavor analysis) [2]
  - Study of the flexibility in global QCD fit similar to BB LO
  - Artificially offset parameters of fit to assess change in moments
  - Both modified and unmodified fits were consistent with HERMES result
- Extrapolation into the unknown x regions can have a major effect.
  - A drastic turnover where $\Delta s \approx -5$ for $x < 0.023$ is not impossible as $s(x) \approx 20 - 300$ for $0.01 > x > 0.001$ [3]
- Exciting new physics for $\Delta s(x < 0.02)$!!

Can this be reconciled?

- SU(3) flavor asymmetry breaking of $\approx 20\%$ (supported by KTeV) for hyperon beta decay can give ($0.47 < a_8 < 0.70$) [1]
  - Use SMC first moment of g_1
  - Then $\Delta^1 s = 0$ requires $a_8 = 0.089(0.197)$
  - From this effect alone it seems implausible to have a vanishing moment.
- How much flexibility exists in the NLO QCD fits to g_1? (extensive studies during 5-flavor analysis) [2]
  - Study of the flexibility in global QCD fit similar to BB LO
  - Artificially offset parameters of fit to assess change in moments
  - Both modified and unmodified fits were consistent with HERMES result
- Extrapolation into the unknown x regions can have a major effect.
  - A drastic turnover where $\Delta s \approx -5$ for $x < 0.023$ is not impossible as $s(x) \approx 20 - 300$ for $0.01 > x > 0.001$ [3]
- Exciting new physics for $\Delta s(x < 0.02)$!!

Can this be reconciled?

- SU(3) flavor asymmetry breaking of $\approx 20\%$ (supported by KTeV) for hyperon beta decay can give ($0.47 < a_8 < 0.70$) [1]
  - Use SMC first moment of g_1
  - Then $\Delta^1 s = 0$ requires $a_8 = 0.089(0.197)$
  - From this effect alone it seems implausible to have a vanishing moment.
- How much flexibility exists in the NLO QCD fits to g_1? (extensive studies during 5-flavor analysis) [2]
  - Study of the flexibility in global QCD fit similar to BB LO
  - Artificially offset parameters of fit to assess change in moments
  - Both modified and unmodified fits were consistent with HERMES result
- Extrapolation into the unknown x regions can have a major effect.
  - A drastic turnover where $\Delta s \approx -5$ for $x < 0.023$ is not impossible as $s(x) \approx 20 - 300$ for $0.01 > x > 0.001$ [3]
- Exciting new physics for $\Delta s(x < 0.02)$!!

Can this be reconciled?

- SU(3) flavor asymmetry breaking of $\approx 20\%$ (supported by KTeV) for hyperon beta decay can give $(0.47 < a_8 < 0.70)$ [1]
  - Use SMC first moment of g_1
  - Then $\Delta^1 s = 0$ requires $a_8 = 0.089(0.197)$
  - From this effect alone it seems implausible to have a vanishing moment.
- How much flexibility exists in the NLO QCD fits to g_1? (extensive studies during 5-flavor analysis) [2]
  - Study of the flexibility in global QCD fit similar to BB LO
  - Artificially offset parameters of fit to assess change in moments
  - Both modified and unmodified fits were consistent with HERMES result
- Extrapolation into the unknown x regions can have a major effect.
  - A drastic turnover where $\Delta s \approx -5$ for $x < 0.023$ is not impossible as $s(x) \approx 20 - 300$ for $0.01 > x > 0.001$ [3]
- Exciting new physics for $\Delta s(x < 0.02)$!!

References


Elliot Leader and Dimiter B. Stamenov.
Can the polarization of the strange quarks in the proton be positive?
Phys. Rev., D67:037503, 2003.


A. Airapetian et al.
Quark helicity distributions in the nucleon for up, down, and strange quarks from semi-inclusive deep-inelastic scattering.
Phys. Rev., D71:012003, 2005.


Stephen F. Pate.
Don't forget to measure delta(s).
Eur. Phys. J., A24S2:67–70, 2005.