Probing Nucleon Strangeness with Neutrino Scattering

Outline:
- Nucleon structure - strange quarks, spin
- Neutrinos as probes of strange spin - $G_A^s$, $\Delta s$
- An experiment to measure $G_A^s$ via neutrino neutral current scattering
Nucleon Structure: strange quarks

Net strangeness of the nucleon is zero. However, QCD: valence ud quarks + sea of qqbar pairs.

mass:
\[ \frac{2 \langle N | \bar{s}s | N \rangle}{\langle N | \bar{u}u + \bar{d}d | N \rangle} \approx 0.2 \]

\pi\text{-}N scattering data -> strange quarks contribute \sim 20% to nucleon mass

spatial distributions:
PV e\text{-}scattering (e.g. SAMPLE, HAPPEX, G0, PVA4) looks for strange-quark contributions to the proton magnetic moment (\( \mu_s \)) and radius (\( r_s \)).
Results consistent with small strange quark contribution.
Nucleon Structure: strange quarks

momentum:
The CCFR and NuTeV experiments measure strange-sea distributions via $\nu$ and $\bar{\nu}$ DIS dimuon production.

$$\nu_\mu + s \rightarrow \mu^- + c ; \ c \rightarrow \mu^+ + \nu_\mu + s$$
$$\bar{\nu}_\mu + s \rightarrow \mu^+ + \bar{c} ; \ \bar{c} \rightarrow \mu^- + \nu_\mu + \bar{s}$$

$$\frac{2 \int_0^1 [s + \bar{s}] dx}{\int_0^1 [u + \bar{u} + d + \bar{d}] dx} \approx 0.35 \pm 0.04$$

and spin: ....

NuTeV, PRD 64, 112006
Nucleon Structure: strange quark spin \(\Delta s\)

- Polarized Lepton Deep Inelastic Scattering (DIS) experiments; e.g. SLAC (ESA), CERN(EMC,SMC); have extracted the quark contributions to the spin (\(\Delta q\)) of the nucleon via the axial structure function: \(g_1^{p,n}(x,Q^2)\).

Requires:
- integration over \(x\) \(\Gamma_1^{p(n)} \equiv \int_0^1 g_1^{p(n)}(x)\,dx\)
- use of nucleon/hyperon decay data (assumes SU(3)\(_f\) symmetry)

<table>
<thead>
<tr>
<th></th>
<th>“Regge”</th>
<th>QCD fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta u)</td>
<td>0.84 (\pm) 0.06</td>
<td>0.80 (\pm) 0.06</td>
</tr>
<tr>
<td>(\Delta d)</td>
<td>-0.42 (\pm) 0.06</td>
<td>-0.46 (\pm) 0.06</td>
</tr>
<tr>
<td>(\Delta s)</td>
<td>-0.08 (\pm) 0.06</td>
<td>-0.12 (\pm) 0.06</td>
</tr>
</tbody>
</table>

\[\Delta \Sigma = \Delta u + \Delta d + \Delta s\]
\[\Delta q = q^\uparrow - q^\downarrow + \bar{q}^\uparrow - \bar{q}^\downarrow\]
Nucleon Structure: strange quark spin $\Delta s$...

- In addition, recent results from HERMES in semi-inclusive scattering of polarized positrons from polarized deuterium allow for the extraction of sea-quark helicities:

$$\Rightarrow \ "\Delta s" = 0.03 \pm 0.03 \pm 0.01 \ (0.023 < x < 0.30)$$

Note:
- Limited x range
- Is the (meson-quark) factorization robust?

- A measurement of neutrino-nucleon elastic-scattering can determine $\Delta s$ directly via a measurement of the neutral-current axial form factor. This method requires:
  - no extrapolation to $x=0$
  - no assumptions of SU(3) symmetry
\(\nu N \rightarrow \nu N\) scattering and \(\Delta s\)

- Axial part of Nucleon Neutral Weak Current:

\[
\langle N | A_\mu^Z | N \rangle = -\left[ \frac{G_F}{\sqrt{2}} \right]^{1/2} \langle N | \frac{1}{2} \{ \bar{u} \gamma_\mu \gamma_5 u - \bar{d} \gamma_\mu \gamma_5 d - \bar{s} \gamma_\mu \gamma_5 s \} | N \rangle
\]

\[
= -\left[ \frac{G_F}{\sqrt{2}} \right]^{1/2} \langle N | \frac{1}{2} \{ -G_A(Q^2) \gamma_\mu \gamma_5 \tau_z + G_A^s(Q^2) \gamma_\mu \gamma_5 \} | N \rangle
\]

- \(G_A\) (non-strange, \(\Delta u-\Delta d\)) known (from n \(\beta\)-decay)

- \(G_A^s(Q^2 = 0) = \Delta s\)

- At low \(Q^2\), (NC elastic) cross section in most-sensitive to axial part (unique to neutrino scattering):

\[
\frac{d\sigma}{dQ^2}(\nu p \rightarrow \nu p) \propto (-G_A + G_A^s)^2
\]

- Therefore, a measurement of \(\nu N\) NC scattering (at low \(Q^2\)) yields \(\Delta s\)
A ratio method to extract $\Delta s$

A measurement of $R_{\nu}(NC/CC)$ reduces

- experimental systematics (e.g. flux, efficiencies, etc.)

- nuclear effects

- other form factor uncertainties (e.g. $M_A$)

\[
R_{\nu}(NC/CC) &= \frac{\sigma(\nu_{\mu} p \to \nu_{\mu} p)}{\sigma(\nu_{\mu} n \to \mu p)} \\
\bar{R}_{\nu}(NC/CC) &= \frac{\sigma(\bar{\nu}_{\mu} p \to \bar{\nu}_{\mu} p)}{\sigma(\bar{\nu}_{\mu} p \to \mu n)}
\]

sensitivity of $R(NC/CC)$ to $\Delta s$
A “rigorous sum rule” for NC nu scattering

From A. Thomas (hep-ex/0311029):
- measured in DIS:

\[ \int_0^1 dx \, g_1^P(x, Q^2) = \left( \frac{1}{12} g_A^{(3)} + \frac{1}{36} g_A^{(8)} \right) C_{NS}(Q^2) + \frac{1}{9} g_A^{(0)} |_{\text{inv}} C_S(Q^2) + O\left( \frac{1}{Q^2} \right) . \]

- measured in n-decay: \( g_A^{(3)} \)
- measured in hyperon-decay: \( g_A^{(8)} \)
- measured in nu NC scattering:

\[ 2 g_A^{(Z)} = (\Delta u - \Delta d - \Delta s)_{\text{inv}} + \mathcal{P} (\Delta u + \Delta d + \Delta s)_{\text{inv}} + O(m_t^{-1}), \]

small correction (Phys.Rev. D66 (2002) 031901) (= -0.02)

- then the relation of quark to axial charges

\[ (\Delta u - \Delta d - \Delta s)_{\text{inv}} = g_A^{(3)} + \frac{1}{3} g_A^{(8)} - \frac{1}{3} g_A^{(0)} |_{\text{inv}}. \]

- becomes a “rigorous sum rule” relating DIS to 3 low-energy observables

- need nu NC measurement of NC axial charge, \( g_A^{(Z)} \), to test this...
NC neutrino scattering: BNL E734

BNL E734: \( \nu p, \bar{\nu} p \) elastic scattering

170 ton segmented detector

@ \( E_\nu \sim 1.2 \text{ GeV} \), \( (Q^2 = 0.4 \rightarrow 1.1 \text{ GeV}^2) \)

(Ahrens et al., PRD 35, 785, '87.)

BNL734 detector

BNL734 data (PRD 35, 785, '87):

- 951 \( \nu p \) events
- 776 \( \bar{\nu} p \) events
NC neutrino scattering: BNL E734

- A fit to the $\nu p, \bar{\nu} p$ elastic scattering diff xsection yielded: $\Delta s = -0.15\pm0.09$ (Ahrens et al., PRD 35, 785, '87.)

- This data has generated much interest...

and several reanalyses:

- (Garvey et al., PRC48, 761, 1993): more realistic values for vector form factors, $Q^2$ evolution → $\Delta s = -0.21\pm0.10\pm0.10$

- (Alberico et al., Nucl. Phys. A651, 277, 1999), considered ratios of NC,CC cross sections → $\Delta s$ consistent with above

- (Pate, PRL 92, 082002, '04): combines E734 data with eN data from HAPPEX, yields $G_A^s(Q^2=0.5 \text{ GeV}^2)$, but data not close enough to $Q^2=0$ → no $\Delta s$ extraction.

- The BNL734 data is not accurate enough for an extraction of $\Delta s$ with sufficiently small errors (i.e. to be competitive with DIS measurements)

- This data set may be improved in a new experiment...

  - with more events (~10k NCp events, ~x10 E734)
  - with lower background
  - at lower $Q^2$ (down to 0.2 GeV$^2$)
  - with a ratio method: $R(\text{NC}/\text{CC})$
FINeSSE experiment

Physics Motivation:
- A measurement of $\Delta s$
- Intermediate-energy cross sections

Experiment:
- at a near (~100m) location on an intense $\nu$ source
- 2 part detector:
  - 10 ton liquid-scintillator/fiber vertex detector
  - muon rangestack

Possible locations:
- FNAL: 8GeV booster $\nu$ source
- BNL: AGS $\nu$ source
- JPARC: T2K beam

FINeSSE collaboration

Columbia University, Nevis Labs, Irvington, New York

S. Brice, D. Finley, R. Stefanski
Fermi National Accelerator Laboratory, Batavia, Illinois

J. C. Peng
University of Illinois, Urbana-Champaign, Illinois

Indiana University Cyclotron Facility, Bloomington, Indiana

C. Green, G. T. Garvey, W. C. Louis, G. McGregor, H. Ray, R. Van de Water
Los Alamos National Laboratory, Los Alamos, New Mexico

W. Metcalf, M. Wascko
Louisiana State University, Baton Rouge, Louisiana

V. Papavassiliou, S.F. Pate
New Mexico State University, Las Cruces, New Mexico

A. Curioni, B. T. Fleming*
Yale University, New Haven, Connecticut

*spokespersons
Neutrino Flux

- $\nu/\bar{\nu}$ flux at 80m location on FNAL (8 GeV) booster $\nu$ beamline
- $\nu$: $<E> \sim 700\text{MeV}$, $\nu$ frac = 7%
- $\bar{\nu}$: flux $\sim 60\%(\nu$ flux), $<E> \sim 600\text{MeV}$, $\nu$ frac = 16%
- similar fluxes may be obtained from AGS, T2K
Event Rates:
- with these $\nu/\bar{\nu}$ fluxes, and with...
- 1 yr $\nu$ running and 2 yr $\bar{\nu}$ and a 9 ton (fiducial) detector...

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$\nu_\mu$ (RS) $10^{20}$ POT 1 ton</th>
<th>$\nu_\mu$ (WS) $10^{20}$ POT 1 ton</th>
<th>$\nu_\mu$ (RS) $2 \times 10^{20}$ POT 9 ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC quasi-elastic</td>
<td>10,107</td>
<td>181</td>
<td><strong>181,930</strong></td>
</tr>
<tr>
<td>NC elastic</td>
<td>4,126</td>
<td>78</td>
<td><strong>74,275</strong></td>
</tr>
<tr>
<td>CC resonant $1\pi^+$</td>
<td>4,990</td>
<td>0</td>
<td><strong>59,827</strong></td>
</tr>
<tr>
<td>CC resonant $1\pi^-$</td>
<td>0</td>
<td>42</td>
<td>0</td>
</tr>
<tr>
<td>CC resonant $1\pi^0$</td>
<td>928</td>
<td>13</td>
<td><strong>16,704</strong></td>
</tr>
<tr>
<td>NC resonant $1\pi^0$</td>
<td>1,301</td>
<td>19</td>
<td><strong>23,414</strong></td>
</tr>
<tr>
<td>NC resonant $1\pi^+$</td>
<td>458</td>
<td>8</td>
<td><strong>8,237</strong></td>
</tr>
<tr>
<td>NC resonant $1\pi^-$</td>
<td>357</td>
<td>5</td>
<td><strong>6,422</strong></td>
</tr>
<tr>
<td>CC DIS</td>
<td>253</td>
<td>2</td>
<td><strong>4,550</strong></td>
</tr>
<tr>
<td>NC DIS</td>
<td>91</td>
<td>0</td>
<td><strong>1,542</strong></td>
</tr>
<tr>
<td>NC coherent $1\pi^0$</td>
<td>365</td>
<td>14</td>
<td><strong>6,566</strong></td>
</tr>
<tr>
<td>CC coherent $1\pi^+$</td>
<td>603</td>
<td>0</td>
<td><strong>10,858</strong></td>
</tr>
<tr>
<td>CC coherent $1\pi^-$</td>
<td>0</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td>other (multi-$\pi$, etc.)</td>
<td>621</td>
<td>18</td>
<td><strong>11,174</strong></td>
</tr>
<tr>
<td>total</td>
<td>24,200</td>
<td>403</td>
<td><strong>435,600</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$\bar{\nu}_\mu$ (RS) $10^{20}$ POT 1 ton</th>
<th>$\bar{\nu}_\mu$ (WS) $10^{20}$ POT 1 ton</th>
<th>$\bar{\nu}_\mu$ (RS) $4 \times 10^{20}$ POT 9 ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC quasi-elastic</td>
<td>2,219</td>
<td>787</td>
<td><strong>79,892</strong></td>
</tr>
<tr>
<td>NC elastic</td>
<td>922</td>
<td>323</td>
<td><strong>33,179</strong></td>
</tr>
<tr>
<td>CC resonant $1\pi^+$</td>
<td>0</td>
<td>470</td>
<td>0</td>
</tr>
<tr>
<td>CC resonant $1\pi^-$</td>
<td>419</td>
<td>0</td>
<td><strong>15,092</strong></td>
</tr>
<tr>
<td>CC resonant $1\pi^0$</td>
<td>130</td>
<td>93</td>
<td><strong>4,666</strong></td>
</tr>
<tr>
<td>NC resonant $1\pi^0$</td>
<td>230</td>
<td>118</td>
<td><strong>8,294</strong></td>
</tr>
<tr>
<td>NC resonant $1\pi^+$</td>
<td>83</td>
<td>43</td>
<td><strong>2,996</strong></td>
</tr>
<tr>
<td>NC resonant $1\pi^-$</td>
<td>59</td>
<td>35</td>
<td><strong>2,132</strong></td>
</tr>
<tr>
<td>CC DIS</td>
<td>3</td>
<td>30</td>
<td><strong>116</strong></td>
</tr>
<tr>
<td>NC DIS</td>
<td>2</td>
<td>11</td>
<td><strong>58</strong></td>
</tr>
<tr>
<td>NC coherent $1\pi^0$</td>
<td>184</td>
<td>30</td>
<td><strong>6,624</strong></td>
</tr>
<tr>
<td>CC coherent $1\pi^+$</td>
<td>0</td>
<td>51</td>
<td>0</td>
</tr>
<tr>
<td>CC coherent $1\pi^-$</td>
<td>298</td>
<td>0</td>
<td><strong>10,714</strong></td>
</tr>
<tr>
<td>other (multi-$\pi$, etc.)</td>
<td>157</td>
<td>93</td>
<td><strong>5,644</strong></td>
</tr>
<tr>
<td>total</td>
<td>4,706</td>
<td>2,086</td>
<td><strong>169,402</strong></td>
</tr>
</tbody>
</table>
$\nu N \rightarrow \nu N$ scattering and $\Delta s$

Differential xsections, ratios for $\nu N$, $\bar{\nu} N$
CC and NC
(quasi-) elastic scattering
- with different
values of $\Delta s$

$\Delta s=-0.1$
$\Delta s=0.0$
$\Delta s=+0.1$

- flux-weighted
(8 GeV flux)

- assuming dipole for
$Q^2$ dep. of $G_A$, $G_A^s$:

$$G_A^s = \frac{\Delta s}{(1 + Q^2/M_A^2)}$$

R. Tayloe, IU
$\nu N \rightarrow \nu N$ scattering and $\Delta s$

- sensitivity of $R(\nu)$, $R(\bar{\nu} \bar{\nu})$ to $\Delta s$ is large
- actually larger for $R(\bar{\nu} \bar{\nu})$
- $Q^2$ dep of $R(\nu)$, $R(\bar{\nu} \bar{\nu})$ is different => good systematic check...

![Graph showing the relationship between $R(\nu NC/\nu CC)$ and $Q^2$ for neutrinos and antineutrinos with $Q^2 = 0.25, 0.45, 0.65$ GeV$^2$.](image)

$R = \kappa (S \Delta s + 1)$

$\sigma(\Delta s) = \frac{1}{|S|} \sigma(R)$

$S$ is “sensitivity” of $R$ to $\Delta s$

$S = \text{slope of this plot}$

![Graph showing sensitivity of $R(\nu NC/\nu CC)$ and $R(\bar{\nu} NC/\bar{\nu} CC)$ over $Q^2$.](image)
Detector Requirements

To precisely measure $\Delta s$, need a precise measurement of $R(\text{NC}/\text{CC})$ (to ~5%)

Also need to measure $R(\text{NC}/\text{CC})$ as function of $Q^2(=2m_p T_p)$ down to 0.2 GeV$^2$

Need:
- A ~10 ton (fiducial) detector capable of:
  - proton energy measurement
    (independently of muon energy)
    down to $T_p \sim 100$MeV ($R \sim 10$cm)
  - particle ID for NC/CC/background separation
  - muon ID/tracking capability

- Need a large, low-threshold, tracking "vertex" detector
- with a muon “rangestack”

GEANT-generated events in scintillator:
$Q^2 = 0.2$ GeV$^2$, $E_v = 800$MeV
$T_p \sim 100$ MeV, $T_\mu \sim 600$ MeV
FINeSSE Detector

The Vertex Detector...
- to precisely track low-energy protons (and muons, pions, electrons)
- $(2.5\text{m})^3$ active liquid scintillator volume
- 19200 (80x80x3) 1.5 mm WLS fibers on 3cm spacing with 3 orientations
- no optical separation between fibers (“scibath” method)

The Muon Rangestack...
- to track and measure the energy of muons

WLS fibers in vertex detector


Simulation of R(NC/CC) measurement
- high purity/low background
for NC and CCQE events has
been shown

\[ \nu \text{NC}: \nu_\mu p \rightarrow \nu_\mu p \]

\[ \nu \text{CC}: \nu_\mu n \rightarrow \mu^- p \]

400k reconstructed MC events

<table>
<thead>
<tr>
<th>reaction channel</th>
<th>NCp cuts</th>
<th>NCn</th>
<th>NCπ</th>
<th>CCQE</th>
<th>CCπ</th>
</tr>
</thead>
<tbody>
<tr>
<td>raw events</td>
<td>39098</td>
<td>37544</td>
<td>35500</td>
<td>184032</td>
<td>100630</td>
</tr>
<tr>
<td>passed events</td>
<td>5668</td>
<td>483</td>
<td>131</td>
<td>203</td>
<td>24</td>
</tr>
<tr>
<td>efficiency (%)</td>
<td>14.5</td>
<td>1.3</td>
<td>0.4</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>fid. eff. (%)</td>
<td>21.3</td>
<td>1.9</td>
<td>0.5</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>purity (%)</td>
<td>87.1</td>
<td>7.4</td>
<td>2.0</td>
<td>3.1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>reaction channel</th>
<th>NCp cuts</th>
<th>NCn</th>
<th>NCπ</th>
<th>CCQE</th>
<th>CCπ</th>
</tr>
</thead>
<tbody>
<tr>
<td>raw events</td>
<td>39098</td>
<td>37544</td>
<td>35500</td>
<td>184032</td>
<td>100630</td>
</tr>
<tr>
<td>passed events</td>
<td>84</td>
<td>7</td>
<td>285</td>
<td>10090</td>
<td>1789</td>
</tr>
<tr>
<td>efficiency (%)</td>
<td>0.2</td>
<td>0.0</td>
<td>0.8</td>
<td>5.5</td>
<td>1.8</td>
</tr>
<tr>
<td>fid. eff. (%)</td>
<td>0.3</td>
<td>0.0</td>
<td>1.2</td>
<td>8.0</td>
<td>2.6</td>
</tr>
<tr>
<td>purity (%)</td>
<td>0.7</td>
<td>0.1</td>
<td>2.3</td>
<td>82.0</td>
<td>14.5</td>
</tr>
</tbody>
</table>
Simulation of $R(\text{NC/CC})$ measurement..

A fit to the simulated data was performed to estimate the precision of $\Delta s$ extracted from a measurement of the neutrino NC/CC ratio (1 yr nu run):

$$R_v(\text{NC/CC}) = \frac{\sigma(\nu_\mu p \rightarrow \nu_\mu p)}{\sigma(\nu_\mu n \rightarrow \mu p)}$$

Included the effects of:
- statistical errors
- systematic errors due to...
- NCn ($\nu n \rightarrow \nu n$) scattering misid
- scattering from free protons
- uncertainties in efficiencies
- $Q^2$ reconstruction

Experimental (stat + sys) error:

$$\sigma(\Delta s) = \pm 0.025$$
Simulation of $R$(NC/CC) measurement..

A similar exercise was performed for a 2 yr antinu run:

$$R_v(\text{NC/CC}) = \frac{\sigma(\bar{\nu}_\mu p \rightarrow \bar{\nu}_\mu p)}{\sigma(\bar{\nu}_\mu p \rightarrow \mu n)}$$

Experimental (stat + sys) error:

$$\sigma(\Delta s) = \pm 0.04$$

measured ratio (stat & total errors)
Another idea..

- group from Japan (N. Saito, et al) are looking into NC measurement at J-PARC

- extract nNC measurement on free protons by using scintillators with different H/C ratio

\[ N_{NC}^H \text{ extraction using BC501A and BC533} \]
NC neutrino scattering: some (theoretical) details

- $Q^2$ evolution of form factors, sensitivity to $M_A$ uncertainties
  - Will actually measure $G_A^s(Q^2)$ for $Q^2 = 0.2$-0.9 GeV$^2$
  - $Q^2$ evolution uncertainties are reduced in ratio

- The NC/CC ratio depends upon other (unknown) strange form factors ($F_{1,2}^s$).
  - Sensitivity to $F_{1,2}^s$ is much smaller than to $G_A^s$
  - $F_{1,2}^s$ has been measured (G0, Happex, SAMPLE, PVA4)
  - measure nu and antinu ratios, combine with PVe data
    (see talk by S. Pate)

- A real-world neutrino experiment will use a nuclear target (e.g. CH$_2$) with
  bound nucleons.
  - This problem has been studied by many groups. While the correction is
    sizable for absolute cross sections, the uncertainty in a ratio is small.

- (in-medium) meson exchange correlations (MECs)
  - effects have been shown to be small in light-nuclei
    (eg: hep-ph/0511204, PRL 74, 4993)
NC neutrino scattering: some (experimental) details

- Need neutron detection to measure nubar ratio: $R(\bar{\nu}\text{NC}/\bar{\nu}\text{CC})$
  - This is possible (with correct detector) via $n p \rightarrow d \gamma (2.2\text{MeV})$

- "Dirt neutrons" are an important background
  - Simulations CC/NC interactions in dirt produce neutral particles that are recon'd as NC p/n events in detector
  - Simulations show they are small in 8GeV beam with FINeSSE detector (50cm thick active veto)

- Final state interactions in nucleus will modify $R$(NC/CC).
  - (eg $pn \rightarrow np$ in nucleus)
  - A simultaneous measurement of CC inclusive vs exclusive will enable a correction
Summary

- A neutrino NC scattering experiment to measure $\Delta s$ would yield important information on nucleon spin structure.

- Calculated sensitivities for FINeSSE at FNAL:

From neutrinos (1y run at FNAL):
$$\sigma(\Delta s) = \pm 0.025 \text{ (exp. stat. and sys.)}$$
$$\pm 0.02 \text{ (f. f. systematic)}$$

From antineutrinos (2y run at FNAL):
$$\sigma(\Delta s) = \pm 0.04 \text{ (exp. stat. and sys.)}$$
$$\pm 0.02 \text{ (f. f. systematic)}$$

- We are continuing work to make it happen.

More info:
- http://www-finesse.fnal.gov

Recall:
BNL E734:
$$\Delta s = -0.15 \pm 0.09 \text{ (\pm f.f. systematics)}$$
polarized DIS:
$$\Delta s = -0.12 \pm 0.06$$
$$-0.08 \pm 0.06$$