Hall A Polarized ^{3}He Collaboration Meeting, July 22, 2005.

PR05-112: The Δd Experiment

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Semi-inclusive deep-inelastic scattering (SIDIS) experiments with polarized targets will provide precision data on nucleon's spin-flavor structure. Jefferson Lab Hall A, with its high luminosity polarized ^{3}He target is the best place in the world to pin down Δd.

- Spin-flavor decomposition in polarized SIDIS at JLab. And how to obtain information on $\Delta u_v(x) - \Delta d_v(x)$.
- The combined asymmetry $A_{1N}^{\pi^+-\pi^-}$ on $\vec{p}$, $\vec{d}$ and ^{3}He ($\vec{n}$) targets: "The Δd Experiment" in Hall A and the semi-SANE experiment in Hall C.
- Accessing the polarized sea asymmetry $\Delta\bar{u}(x) - \Delta\bar{d}(x)$.
- Next-to-leading order global QCD fit to both DIS and SIDIS data constrain moments of $\Delta\bar{u}$, $\Delta\bar{d}$, Δs and indirectly on Δg.

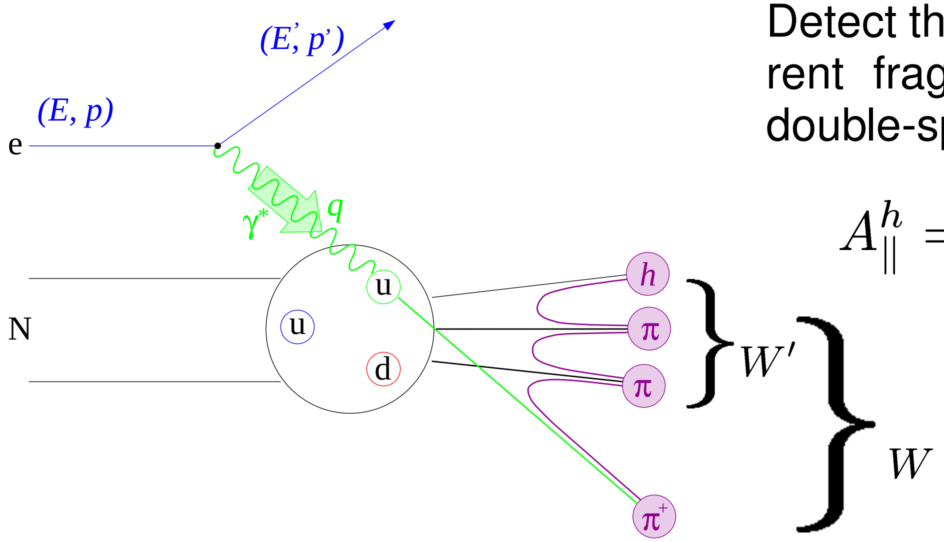
Inclusive experiments treat quark and anti-quark on the same footing therefore, are not sensitive to the quark flavor structure.

Since the inclusive cross sections:

$$\sigma(x, Q^2) \propto \sum_f e_f^2 \cdot q_f(x, Q^2).$$

Access only to $q(x) + \bar{q}(x)$ in inclusive reactions.

Flavor Tagging in Semi-Inclusive DIS



$z = E_\pi/\nu$

Detect the leading hadron from the current fragmentation and measure the double-spin asymmetry:

$$A_{\parallel}^{h} = f^{h} P_B P_T \cdot \mathcal{P}_{kin} \cdot A_{1N}^{h}$$

Two energy scales are involved. Assuming the leading order naive x-z factorization:

$$A_{1N}^{h}(x, Q^2, z) \equiv \frac{\Delta\sigma^{h}(x, Q^2, z)}{\sigma^{h}(x, Q^2, z)} = \frac{\sum_f e_f^2 \Delta q_f(x, Q^2) \cdot D_f^h(z, Q^2)}{\sum_f e_f^2 q_f(x, Q^2) \cdot D_f^h(z, Q^2)}.$$

Each asymmetry measurement provides an independent constrain on Δq_f.

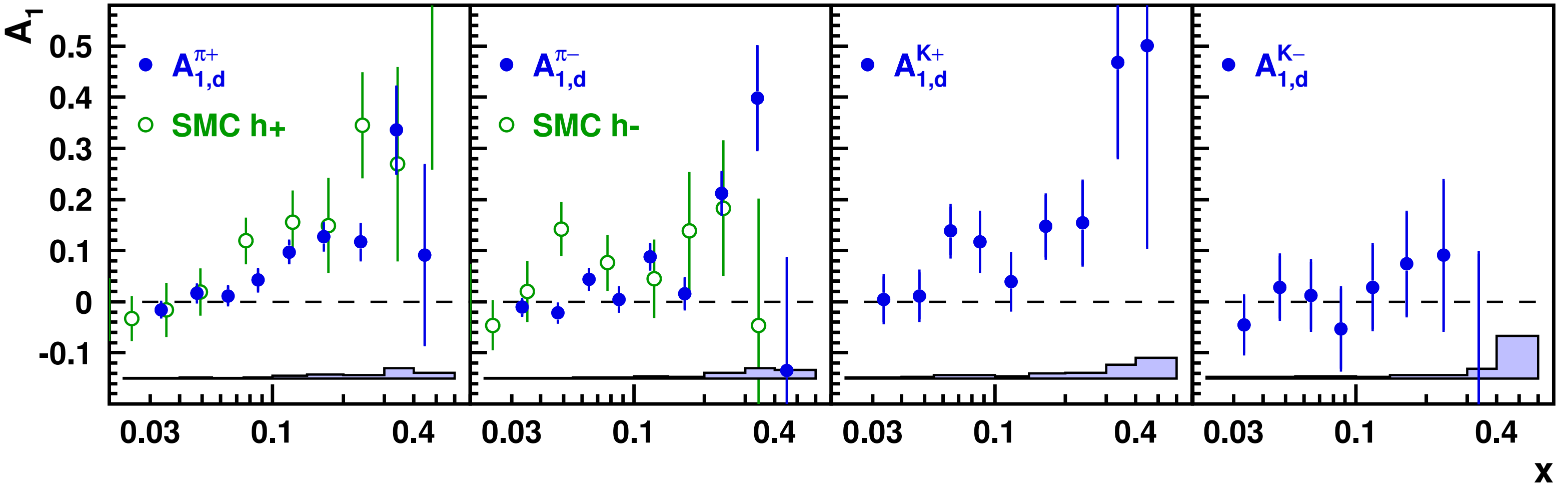
HERMES Flavor Decomposition: $\vec{A} = \mathcal{P}_f^h(x) \cdot \vec{Q}$

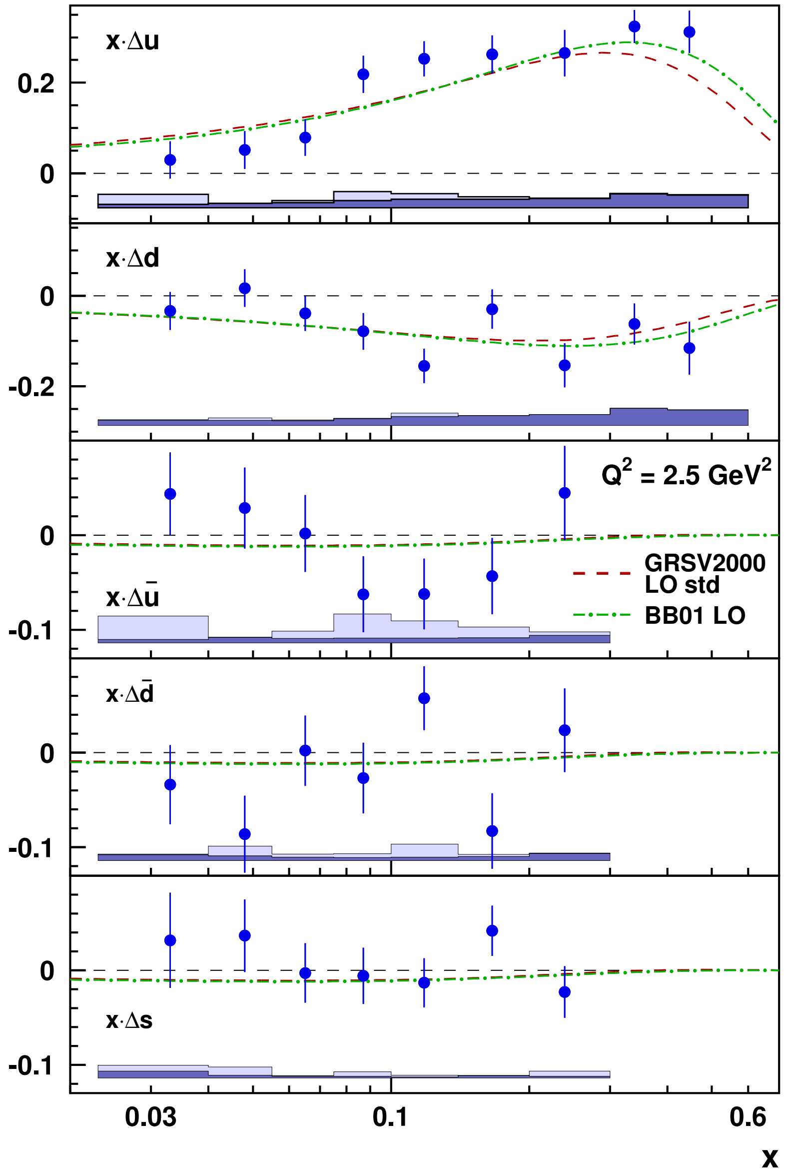
From measurements: $\vec{A} = \left(A_{1p}^{\pi^+}, A_{1p}^{\pi^-}, A_{1d}^{\pi^+}, A_{1d}^{\pi^-}, A_{1d}^{K^+}, A_{1d}^{K^-}, A_{1p}, A_{1d} \right)$

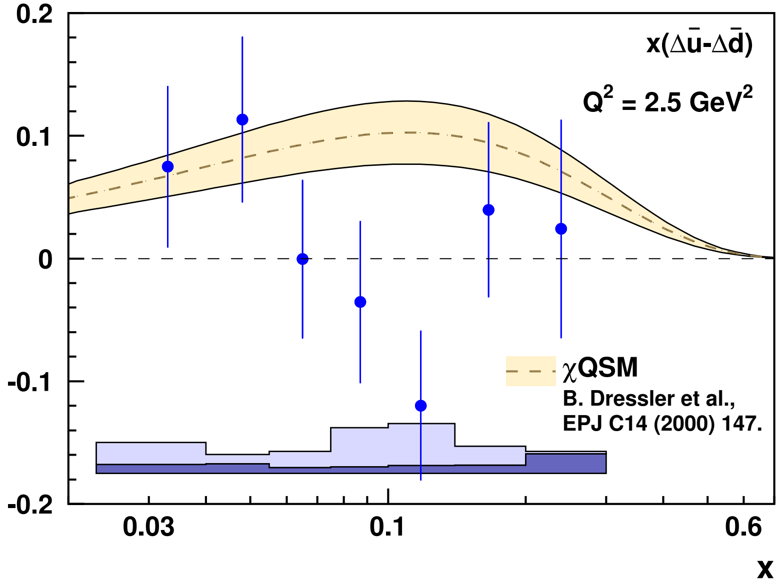
Solve for: $\vec{Q} = \left(x\Delta u, x\Delta d, x\Delta \bar{u}, x\Delta \bar{d}, x\Delta s \right)$.

Calculate "Purity" from a LUND based Monte Carlo:

$$\mathcal{P}_f^h(x) = \frac{e_f^2 q_f(x) \int_{0.2}^{0.8} dz D_f^h(z)}{\sum_i e_i^2 q_i(x) \int_{0.2}^{0.8} dz D_i^h(z)}$$







Assumes:

Leading order x-z factorization and current fragmentation.

Isospin symmetry and charge conjugation.

Purity from Monte Carlo.

Spin-Flavor Decomposition in SIDIS: Redefine the Goal

HERMES' goal of spin-flavor decomposition in SIDIS was to obtain Δu, Δd, $\Delta\bar{u}$, $\Delta\bar{d}$ and $\Delta s = \Delta\bar{s}$. However, if one is only interested in $\Delta\bar{u} - \Delta\bar{d}$, the strategy for experiments can be very different ...

Let's re-write an equation. At any QCD order, the flavor non-singlet is defined as:

$$\Delta q_3(x) = [\Delta u(x) + \Delta\bar{u}(x)] - \left[\Delta d(x) + \Delta\bar{d}(x)\right].$$

Introduce valence densities $\Delta u_v = \Delta u - \Delta\bar{u}$ and $\Delta d_v = \Delta d - \Delta\bar{d}$, at any QCD order we have:

$$\Delta\bar{u}(x) - \Delta\bar{d}(x) = \frac{1}{2}\Delta q_3(x) - \frac{1}{2}\left[\Delta u_v(x) - \Delta d_v(x)\right].$$

If we know Δq_3 and $\Delta u_v - \Delta d_v$, automatically, we know $\Delta\bar{u} - \Delta\bar{d}$.

- Obtain $\Delta q_3(x)$ through inclusive measurements of $g_1^p(x)$ and $g_1^n(x)$.
- Obtain $\Delta u_v(x) - \Delta d_v(x)$ through SIDIS measurements on $\vec{p}$ and $\vec{n}$.

At the leading order:

$$\Delta q_3(x) = g_1^p(x) - g_1^n(x).$$

If we are only interested in $\Delta\bar{u}(x) - \Delta\bar{d}(x)$, the goal of SIDIS should be redefined as to obtain precision information on $\Delta u_v(x) - \Delta d_v(x)$.

$\Delta u_v(x) - \Delta d_v(x)$ at the Leading Order

E. Christova and E. Leader, NPB607,369 (2001):

$$A_{1p}^{\pi^+-\pi^-}(\vec{p}) = \frac{\Delta\sigma_p^{\pi^+} - \Delta\sigma_p^{\pi^-}}{\sigma_p^{\pi^+} - \sigma_p^{\pi^-}} = \frac{4\Delta u_v - \Delta d_v}{4u_v - d_v}$$

$$A_{1d}^{\pi^+-\pi^-}(\vec{p}+\vec{n}) = \frac{\Delta\sigma_d^{\pi^+} - \Delta\sigma_d^{\pi^-}}{\sigma_d^{\pi^+} - \sigma_d^{\pi^-}} = \frac{\Delta u_v + \Delta d_v}{u_v + d_v}$$

$$A_{1He}^{\pi^+-\pi^-}(\vec{n}+2p) = \frac{\Delta\sigma_{He}^{\pi^+} - \Delta\sigma_{He}^{\pi^-}}{\sigma_{He}^{\pi^+} - \sigma_{He}^{\pi^-}} = \frac{4\Delta d_v - \Delta u_v}{7u_v + 2d_v}$$

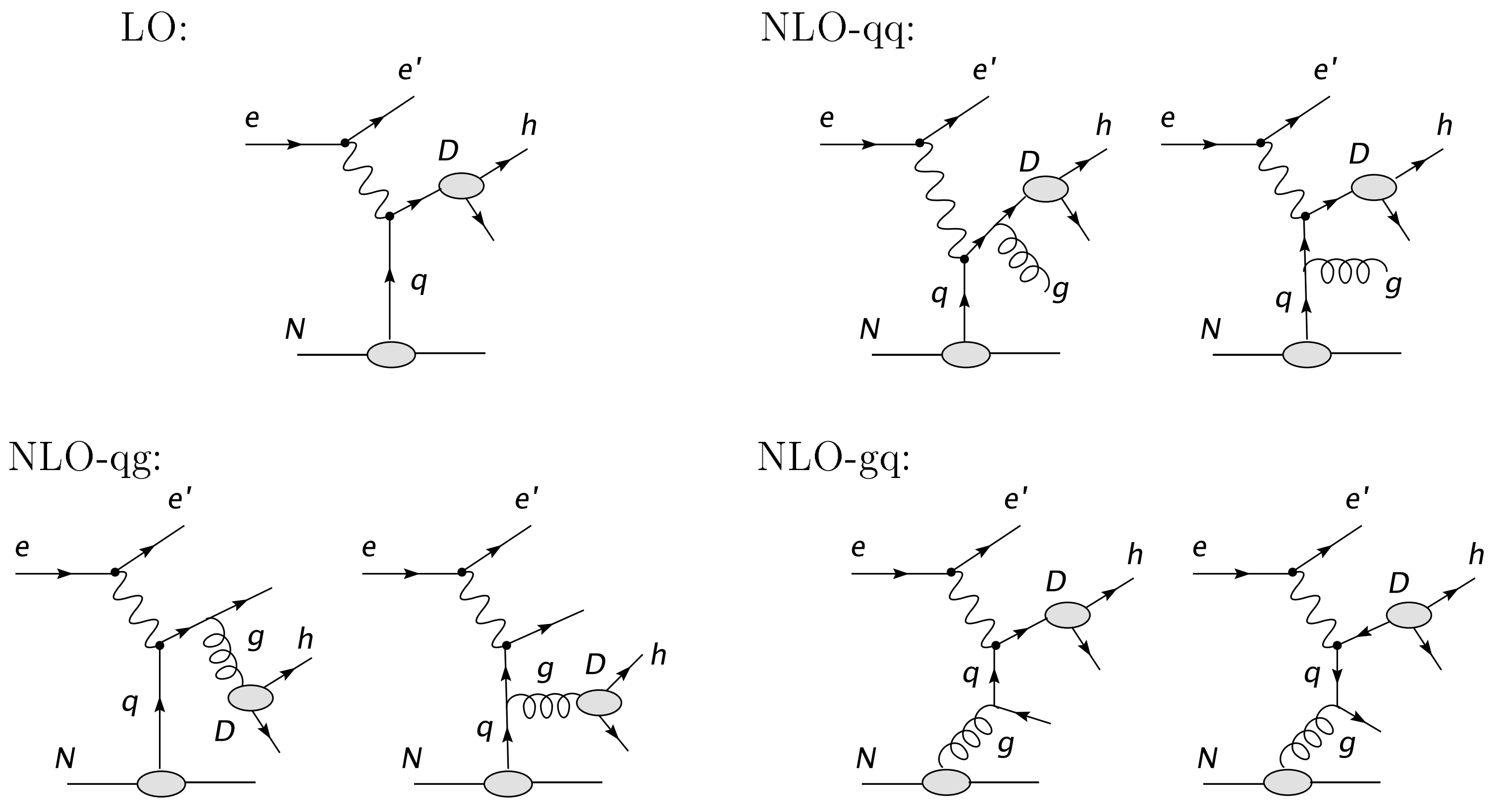
Measurements on three targets allow two different ways to obtain $\Delta u_v - \Delta d_v$.

$$(\Delta u_v - \Delta d_v)_{LO} = \frac{1}{5}\left[\left((4u_v - d_v)A_{1p}^{\pi^+-\pi^-} - (7u_v + 2d_v)A_{1He}^{\pi^+-\pi^-}\right)\right]$$

$$(\Delta u_v - \Delta d_v)_{LO} = \frac{1}{5}\left[2\left((4u_v - d_v)A_{1p}^{\pi^+-\pi^-} - 3(u_v + d_v)A_{1d}^{\pi^+-\pi^-}\right)\right]$$

Interpretation of SIDIS Beyond the Leading Order

What if the naive LO x-z factorization doesn't hold exactly ? Extended the interpretation of SIDIS beyond LO (Christova and Leader, NPB 607 (2001) 369, de Florian, Navarro and Sassot hep-ex/0504155 and PRD.)



- At NLO the naive x-z factorization is violated in a calculable way.

SIDIS Cross Sections at the Next-to-Leading-Order

$$q(x,Q^2)\cdot D(z,Q^2) \Rightarrow \int \frac{dx'}{x'}\int \frac{dz'}{z'} q\left(\frac{x}{x'}\right) C(x',z') D\left(\frac{z}{z'}\right) = q\otimes C\otimes D$$

C are well-known Wilson coefficients (D. Graudenz, NPB432, 351(1994)).

$$\begin{aligned}\Delta\sigma^h &= \sum_i e_i^2 \Delta q_i \left[1+\otimes\frac{\alpha_s}{2\pi}\Delta C_{qq}\otimes\right] D^h_{q_i} \\ &+ \left(\sum_i e_i^2\Delta q_i\right)\otimes\frac{\alpha_s}{2\pi}\Delta C_{qg}\otimes D^h_G + \Delta G\otimes\frac{\alpha_s}{2\pi}\Delta C_{gq}\otimes\left(\sum_i e_i^2 D^h_{q_i}\right)\end{aligned}$$

Isospin symmetry and charge conjugation: $D^h_G = D^{\bar{h}}_G$, $\sum_i e_i^2 D^h_{q_i} = \sum_i e_i^2 D^{\bar{h}}_{q_i}$.

Higher order terms which have gluons involved vanish in $\pi^+ - \pi^-$ observables to all orders of QCD. $A_{1N}^{\pi^+-\pi^-}$ is theoretically clean.

NLO $\Delta u_v(x)$ and $\Delta d_v(x)$ From $A_{1N}^{\pi^+-\pi^-}(x)$

E. Christova and E. Leader, NPB607,369 (2001):

$$\frac{\Delta\sigma_p^{\pi^+} - \Delta\sigma_p^{\pi^-}}{\sigma_p^{\pi^+} - \sigma_p^{\pi^-}} = \frac{(4\Delta u_v - \Delta d_v)\,[1 + \otimes(\alpha_s/2\pi)\Delta C_{qq}\otimes]\, D_u^{\pi^+-\pi^-}}{(4u_v - d_v)\,[1 + \otimes(\alpha_s/2\pi)C_{qq}\otimes]\, D_u^{\pi^+-\pi^-}}$$

$$\frac{\Delta\sigma_d^{\pi^+} - \Delta\sigma_d^{\pi^-}}{\sigma_d^{\pi^+} - \sigma_d^{\pi^-}} = \frac{(\Delta u_v + \Delta d_v)\,[1 + \otimes(\alpha_s/2\pi)\Delta C_{qq}\otimes]\, D_u^{\pi^+-\pi^-}}{(u_v + d_v)\,[1 + \otimes(\alpha_s/2\pi)C_{qq}\otimes]\, D_u^{\pi^+-\pi^-}}$$

$$\frac{\Delta\sigma_{He}^{\pi^+} - \Delta\sigma_{He}^{\pi^-}}{\sigma_{He}^{\pi^+} - \sigma_{He}^{\pi^-}} = \frac{(4\Delta d_v - \Delta u_v)\,[1 + \otimes(\alpha_s/2\pi)\Delta C_{qq}\otimes]\, D_u^{\pi^+-\pi^-}}{(7u_v + 2d_v)\,[1 + \otimes(\alpha_s/2\pi)C_{qq}\otimes]\, D_u^{\pi^+-\pi^-}}$$

- Δu_v and Δd_v are non-singlets which do not mix with gluon and sea densities.
- Data from two targets are needed to extract Δu_v and Δd_v. Measurements on the third target provide extra constrains.
- Proton data are mostly sensitive to Δu_v, neutron data (^{3}He) are mostly sensitive to Δd_v.

A New Tool: NLO Global Fit to DIS and SIDIS Data

(hep-ph/0504155 and PRD, de Florian, Navarro, Sassot.)

- Fit inclusive and semi-inclusive DIS data at the same time.
- To the next-to-leading order in PDFs and fragmentation functions.
- Different parameterization of FF (KRE and KKP).
- Gives error bands on polarized PDF and translate into error bands on asymmetry observables.
- Translate error bars from any new data set to overall constrains on moments of polarized PDFs.
- Preliminary CLAS EG1b data agrees with the NLO prediction.

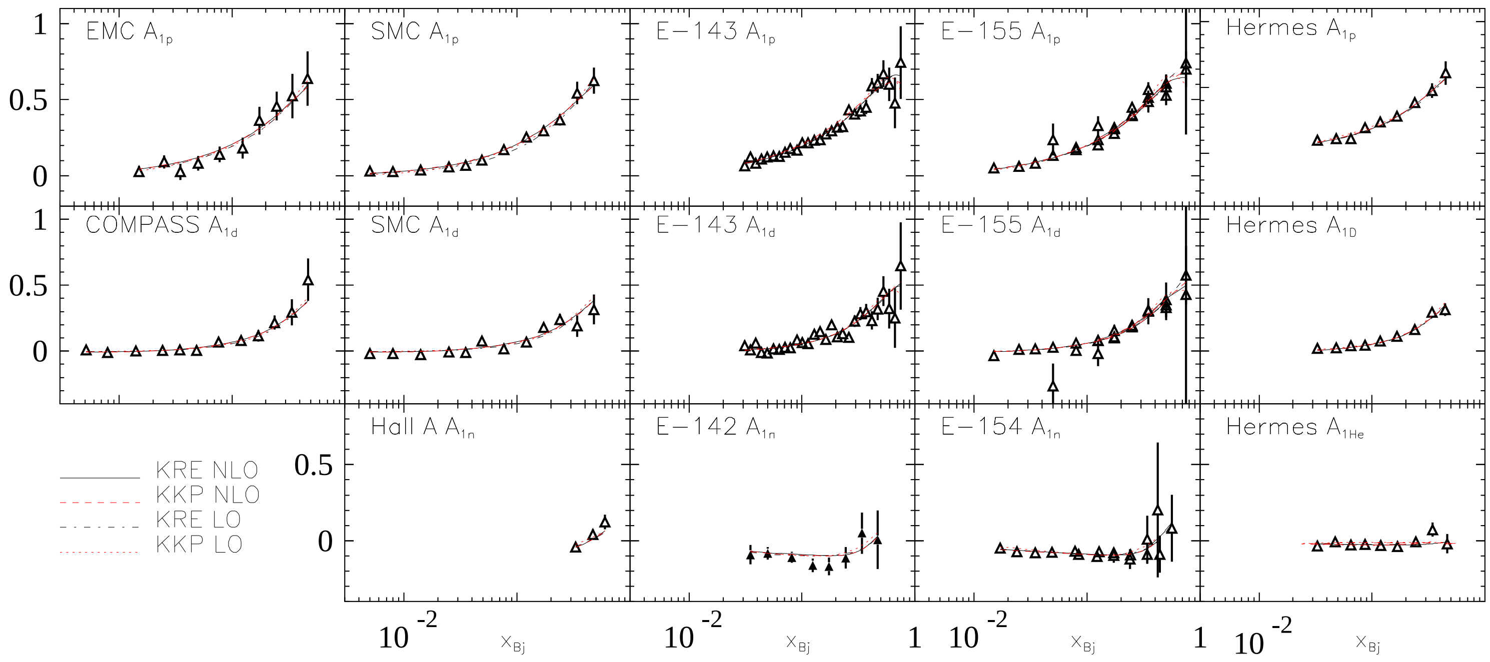
Fit to inclusive $g_1^p(x)$, $g_1^n(x)$ and $g_1^d(x)$:

$$
\begin{aligned}
g_1^N(x,Q^2) &= \frac{1}{2}\sum_{q,\bar{q}} e_q^2 \Bigg[\Delta q(x,Q^2) \\
&+ \frac{\alpha_s(Q^2)}{2\pi}\int_x^1 \frac{dz}{z}\left\{ \Delta C_q(z)\Delta q(\frac{x}{z},Q^2) + \Delta C_g(z)\Delta g(\frac{x}{z},Q^2) \right\}\Bigg].
\end{aligned}
$$

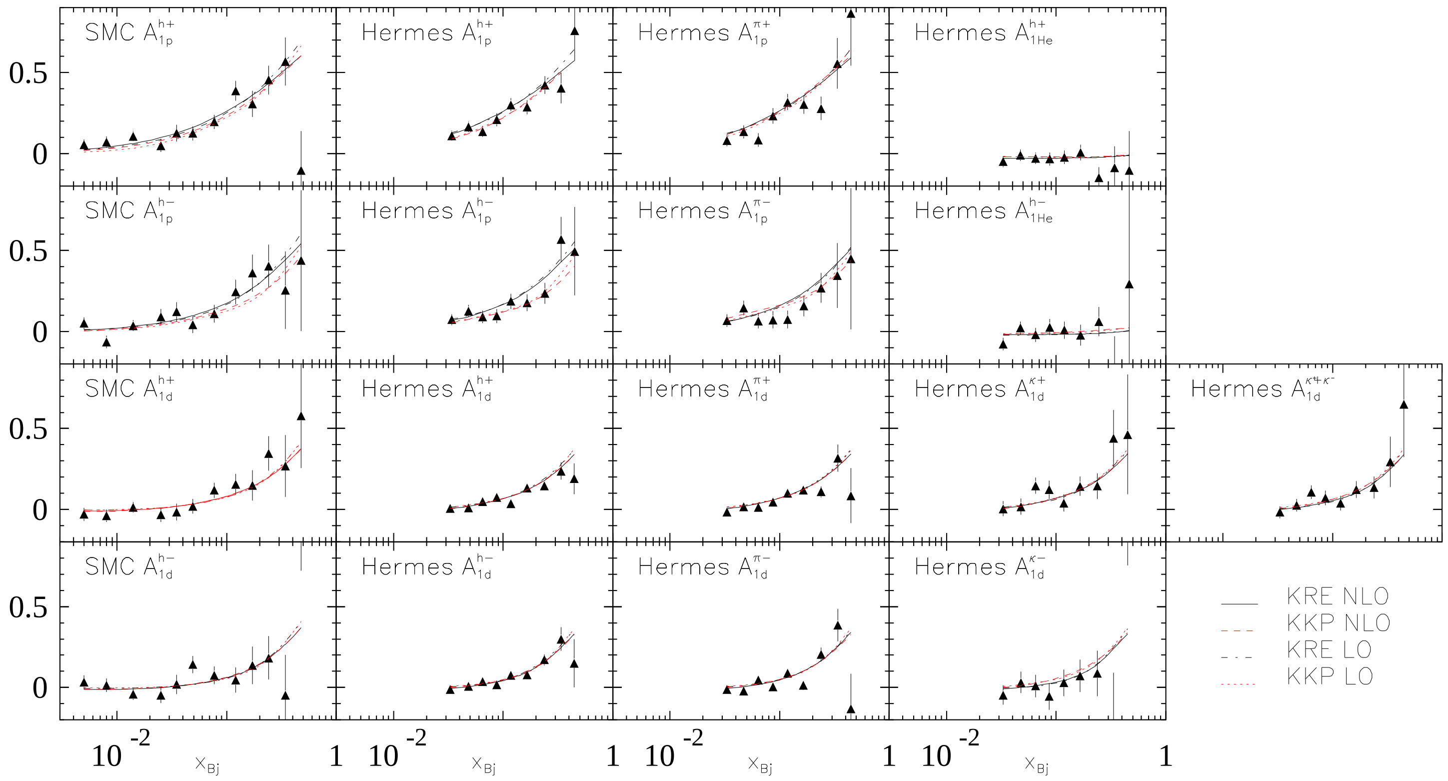
Fit to semi-inclusive $A_{1p}^h(x)$, $A_{1He}^h(x)$ and $A_{1d}^h(x)$:

$$
\begin{aligned}
\Delta\sigma_N^h(x,z,Q^2) &= A_{1N}^h(x,z,Q)\cdot\sigma_N^h(x,z,Q) \\
&= \frac{1}{2}\sum_{q,\bar{q}} e_q^2 \left[\Delta q\left(x,Q^2\right) D_q^H\left(z,Q^2\right)\right. \\
&+ \frac{\alpha_s(Q^2)}{2\pi}\int_x^1 \frac{d\hat{x}}{\hat{x}}\int_z^1 \frac{d\hat{z}}{\hat{z}}\left\{\Delta q\left(\frac{x}{\hat{x}},Q^2\right)\Delta C_{qq}^{(1)}(\hat{x},\hat{z},Q^2) D_q^H\left(\frac{z}{\hat{z}},Q^2\right)\right. \\
&+ \Delta q\left(\frac{x}{\hat{x}},Q^2\right)\Delta C_{gq}^{(1)}(\hat{x},\hat{z},Q^2) D_g^H\left(\frac{z}{\hat{z}},Q^2\right) \\
&+ \left.\left.\Delta g\left(\frac{x}{\hat{x}},Q^2\right)\Delta C_{qg}^{(1)}(\hat{x},\hat{z},Q^2) D_q^H\left(\frac{z}{\hat{z}},Q^2\right)\right\}\right]
\end{aligned}
$$

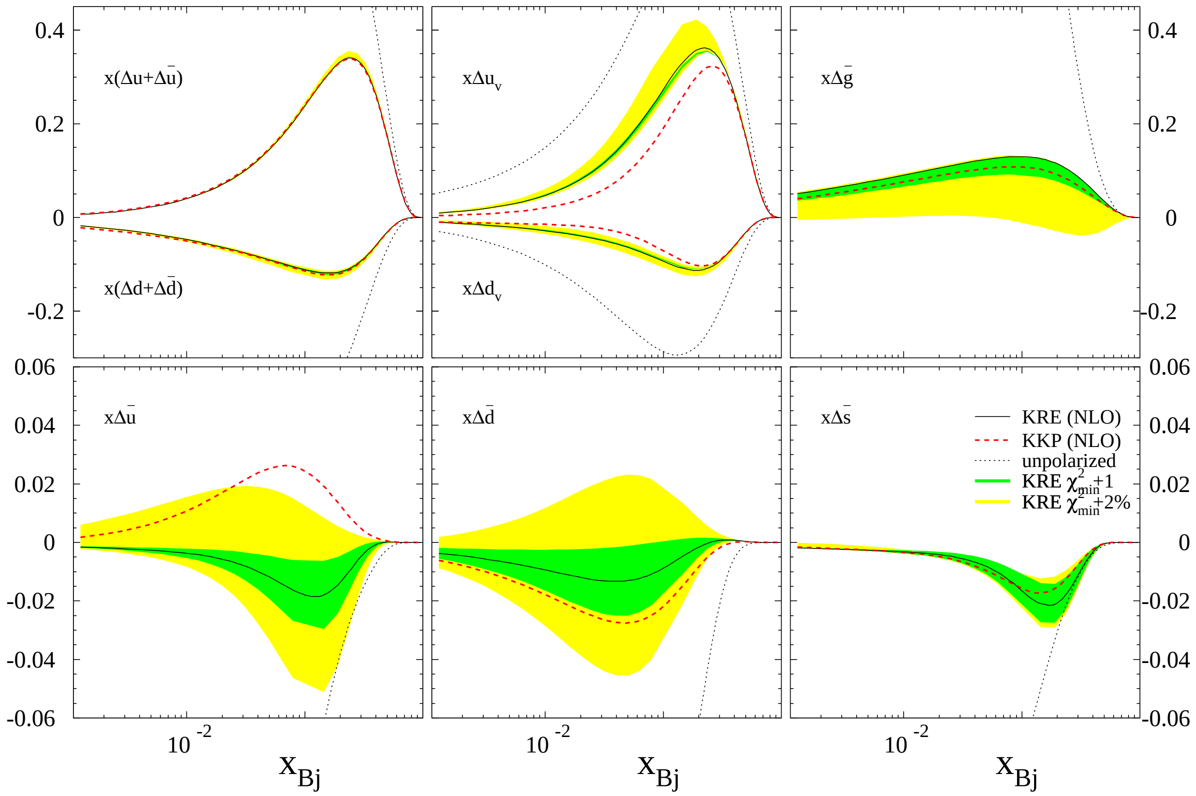
The Best Fit Compare with Inclusive Data:



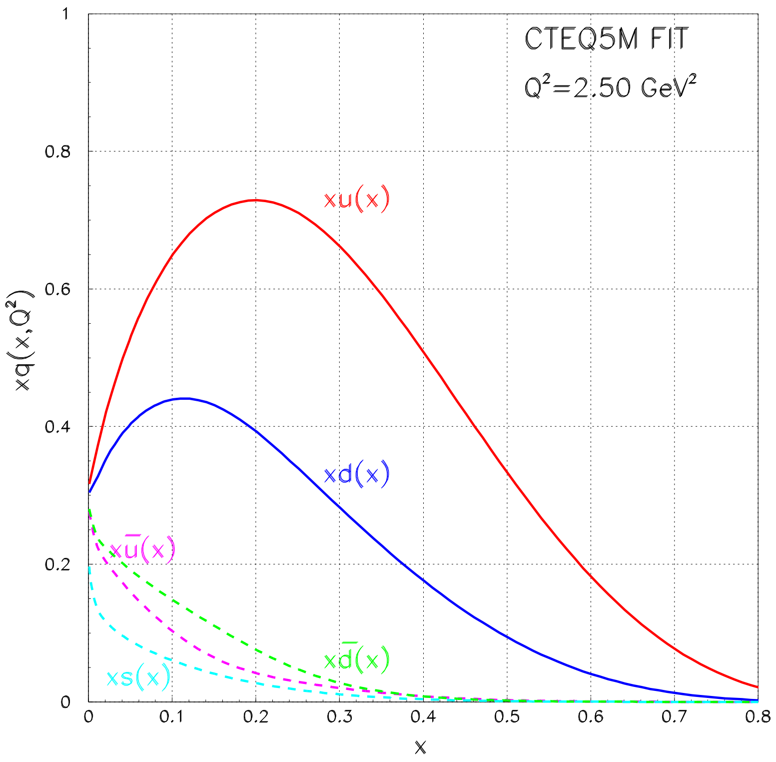
The Best Fit Compare with Semi-Inclusive DIS Data:



Error bands of NLO polarized PDF



Accessing Parton Distribution Through SIDIS



$\Leftarrow$ PDFs from CTEQ5M ($s = \bar{s}$).

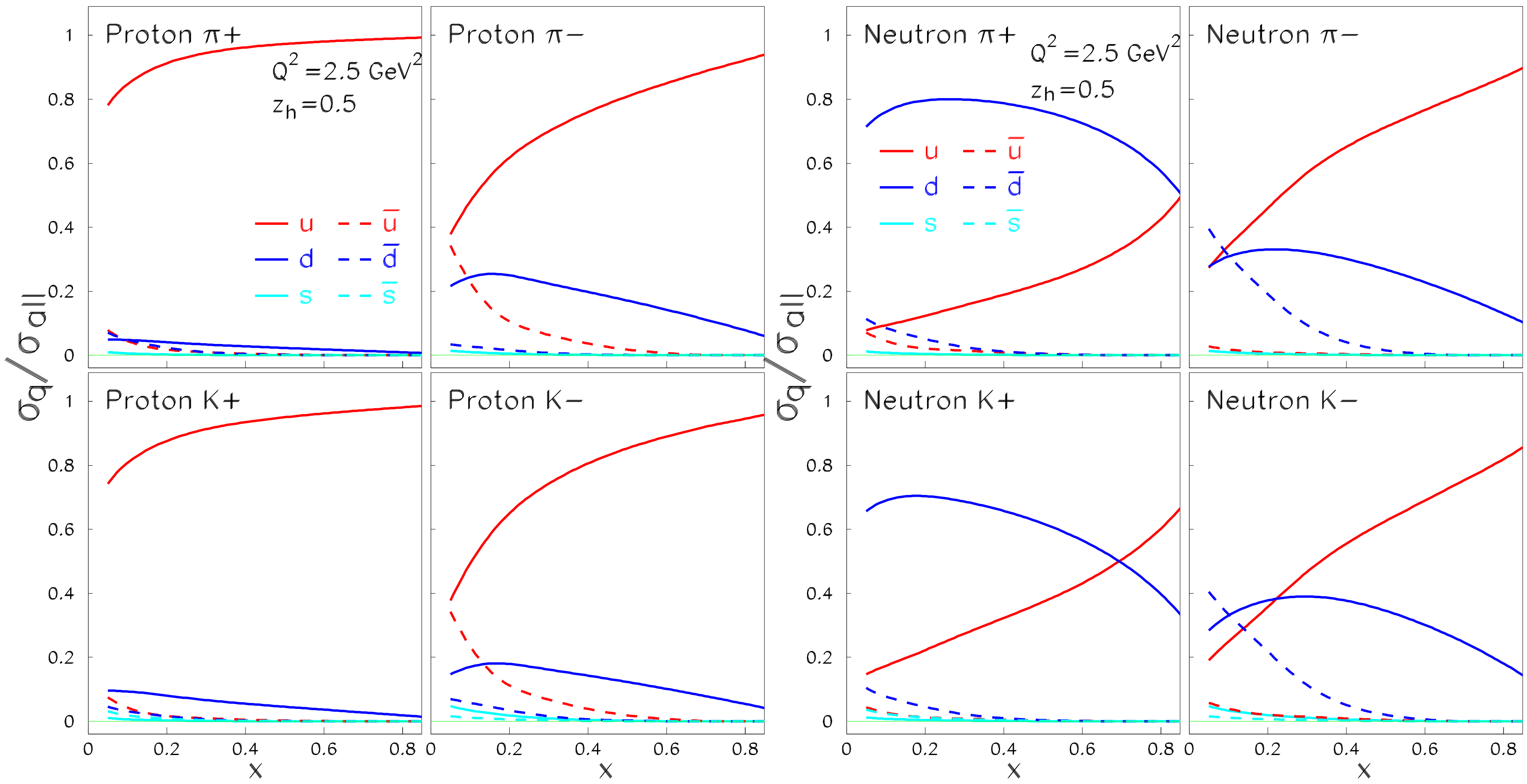
$\bar{q} \approx 0$ at $x \geq 0.4$.

In SIDIS, detect different h off different targets to enhence sensitivity to PDFs through the fragmentation functions D_q^h.

Contribution to SIDIS cross-section from parton $q_f(x)$ ("purity" at a fixed-z):

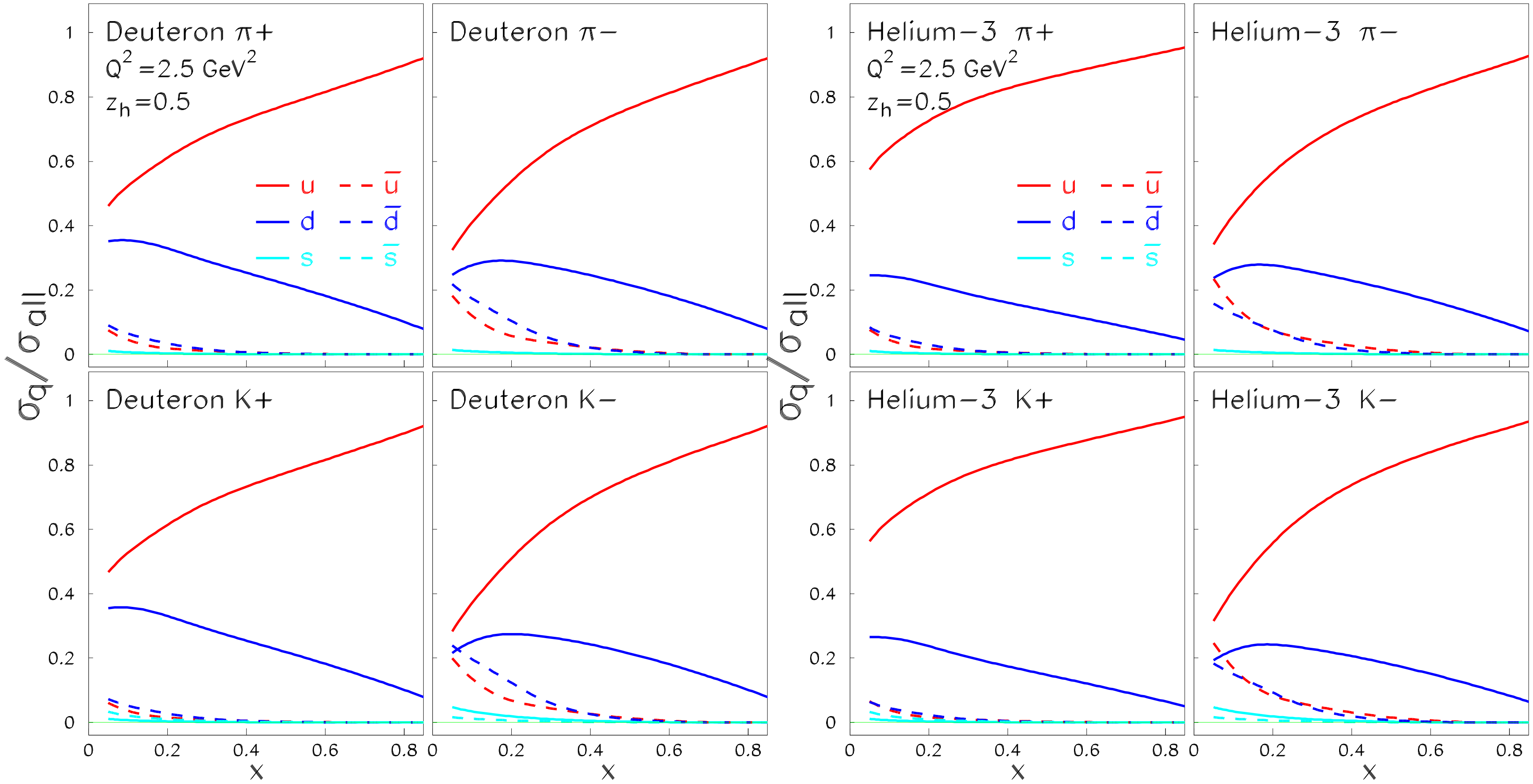
$$\sigma_q/\sigma_{all} = e_f^2 q_f(x) \cdot D_f^h(z) / \sum_i e_i^2 q_i(x) \cdot D_i^h(z).$$

Sensitivity to PDFs in Unpolarized Cross-Sections σ^h_{1N}



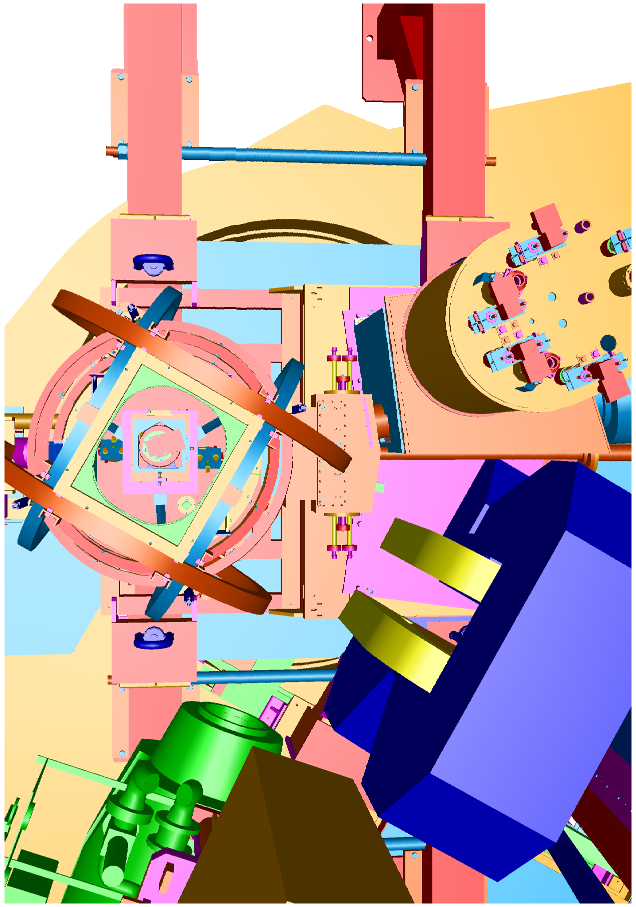
$$\sigma_q/\sigma_{all} = e_f^2 q_f \cdot D_f^h / \sum_i e_i^2 q_i \cdot D_i^h \qquad (@z_h = 0.5)$$

Sensitivity to PDFs: on Deuteron and ^{3}He Targets



$$\sigma_q/\sigma_{all} = e_f^2 q_f \cdot D_f^h / \sum_i e_i^2 q_i \cdot D_i^h$$

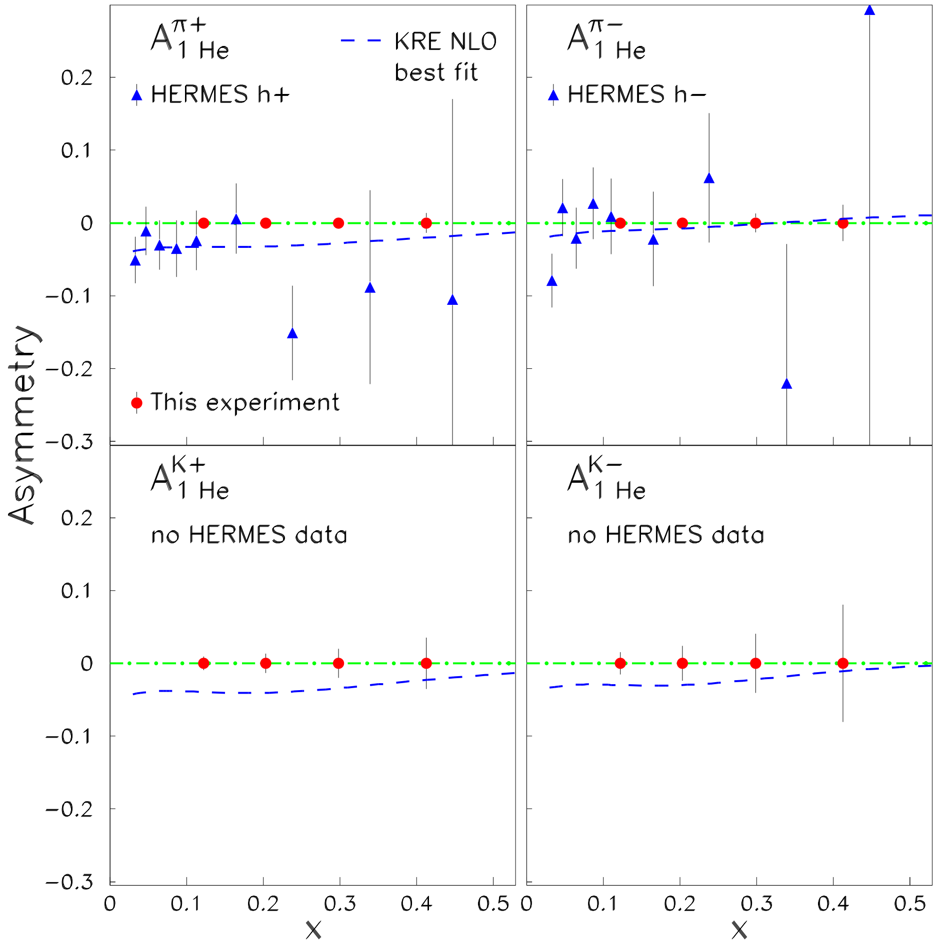
The Δd Experiment: SIDIS with Polarized ^{3}He



PR05-112 submitted to PAC28.
A^h_{LL} on polarized ^{3}He in Hall A.

- BigBite at 30° as e-arm. HRS+septum at 6° as h-arm, standard Hall A polarized ^{3}He target.
- All equipments exist in Hall A.
- Request for 24 days beam time.

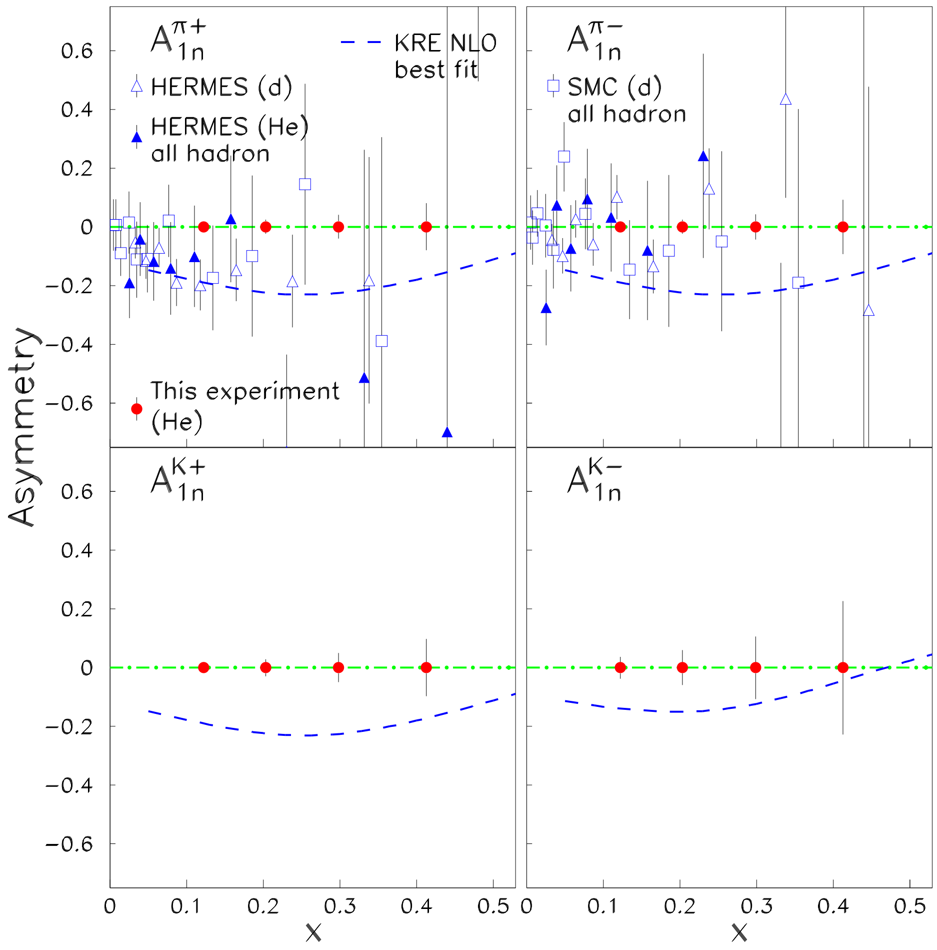
The Hall A Δd Experiment



A_{LL}^{h} on polarized ^{3}He in Hall A.

- A_{1He}^{h} are sensitive to Δd.
- Extract Δd_v (and Δu_v) from $A_{1He}^{\pi^+ - \pi^-}$.
- High precision constrains to the global NLO fit.

The Δd Experiment: Projected Uncertainties on A_{1n}^{h}

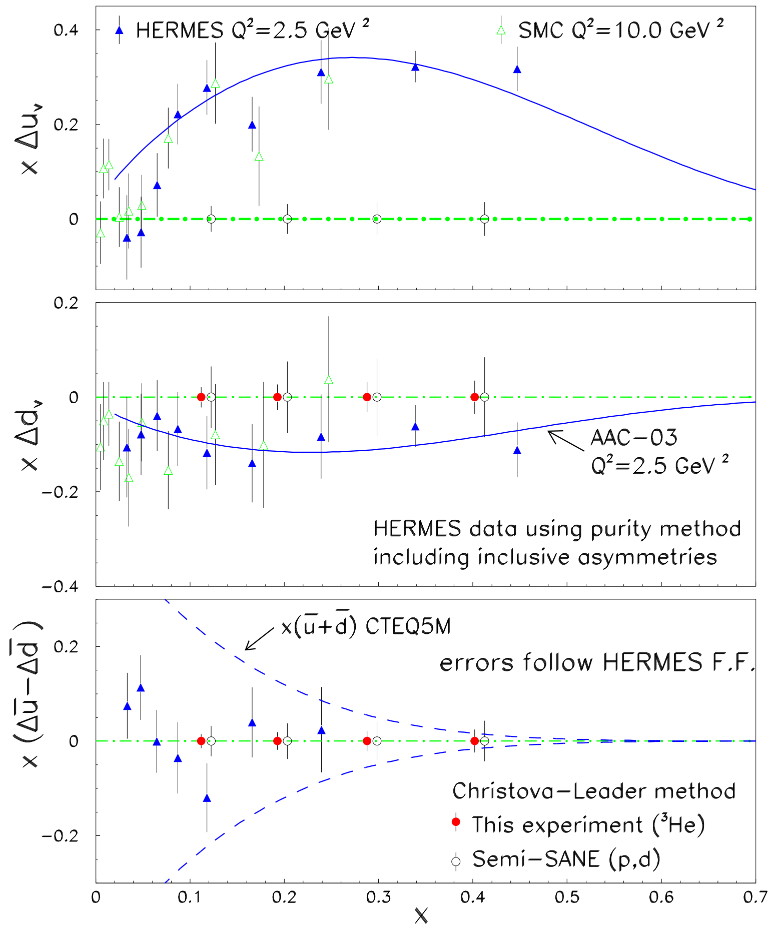


The high luminosity Hall A polarized ^{3}He target allows significant improvements over HERMES data.

- Hall A with a 6 GeV beam.
- $\langle Q^2 \rangle = 2.2$ GeV^2.
- 24 days of beam time.

Strong constraints on Δd_v. Improve accuracy on $\Delta \bar{u}(x) - \Delta \bar{d}(x)$.

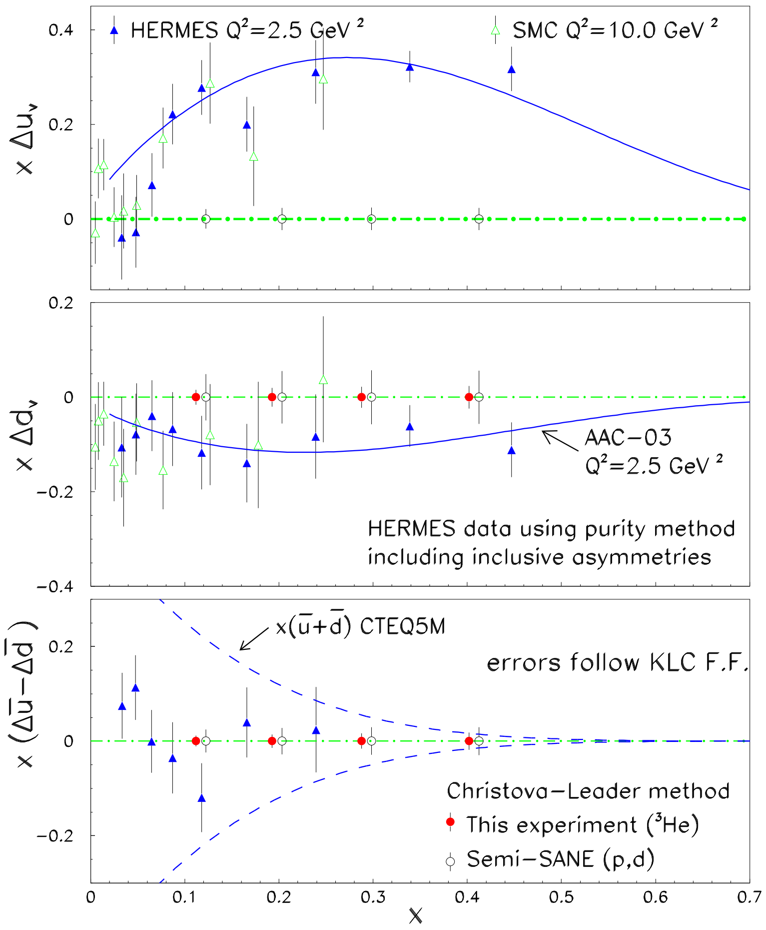
Projected Uncertainties on Δd_v (Following HERMES F.F.)



Error propagation is sensitive to the cross section ratios of $r = \sigma^{\pi^-}/\sigma^{\pi^+}$ which are related to the ratio of fragmentation functions.

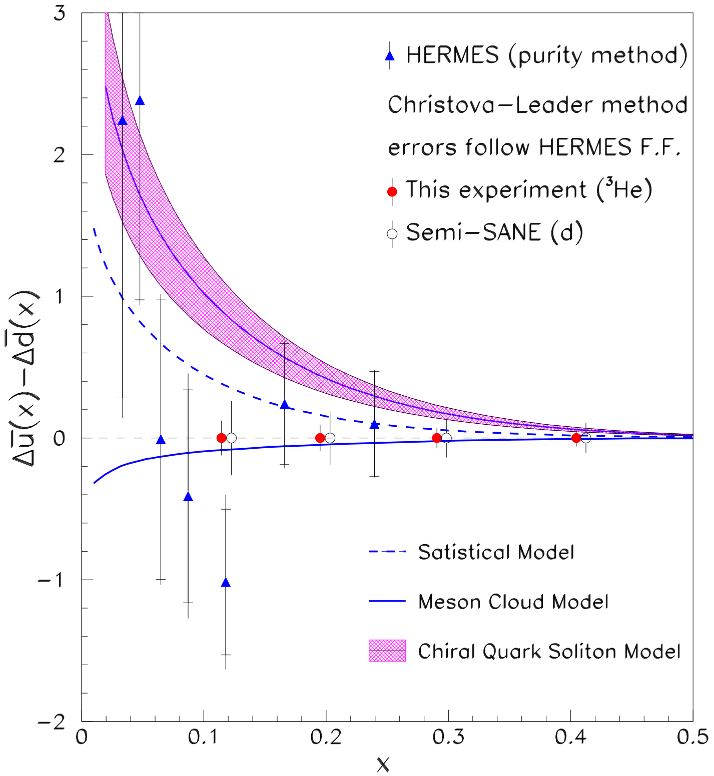
This plot is generated using the HERMES fragmentation function ratios.

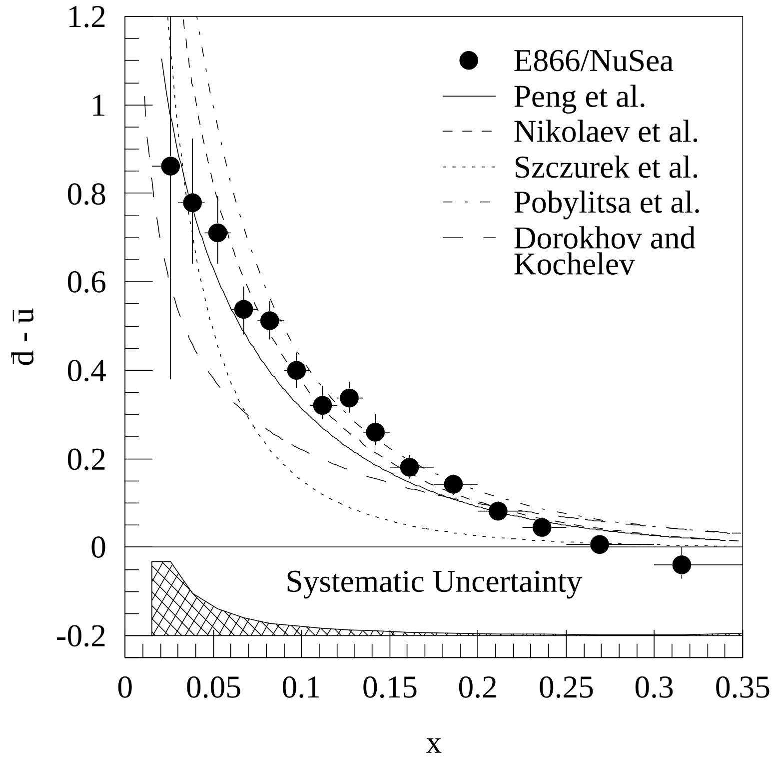
Projected Uncertainties on Δd_v (Following KLC F.F.)



This plot is generated using the KLC fragmentation function ratios.

$\Delta\bar{u} - \Delta\bar{d}$: Flavor Asymmetry in the Nucleon Sea



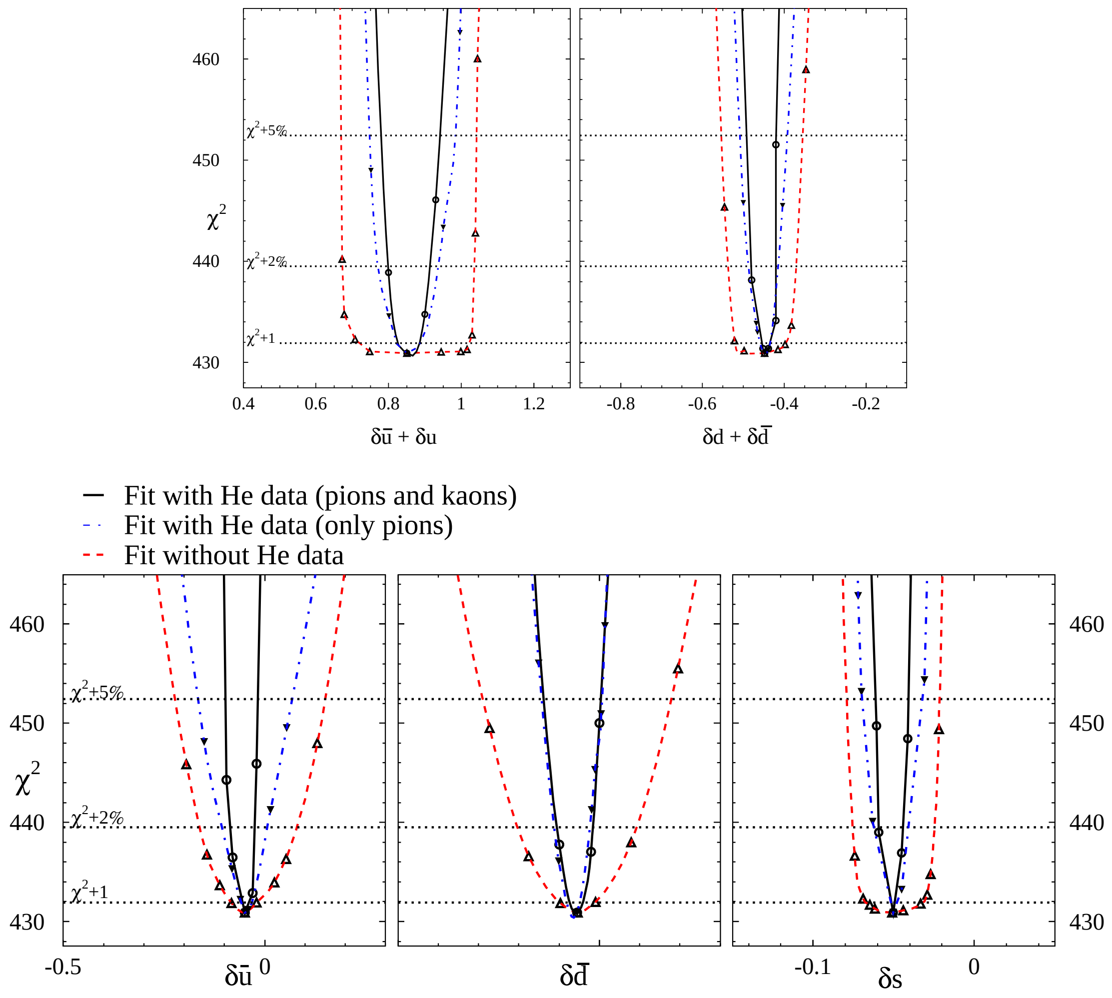


Many other model predicted large $\Delta\bar{u} - \Delta\bar{d}$. In Chiral-quark soliton model, $\Delta\bar{u} - \Delta\bar{d}$ appears in LO (N_c^2) while $\bar{d} - \bar{u}$ appears in NLO (N_c).

Fermilab $pp, pd \rightarrow \mu^+\mu^-$ data. Many models explain $\bar{d} - \bar{u}$, including the meson-cloud model (π) which predicts $\Delta\bar{u} = \Delta\bar{d} = 0$.

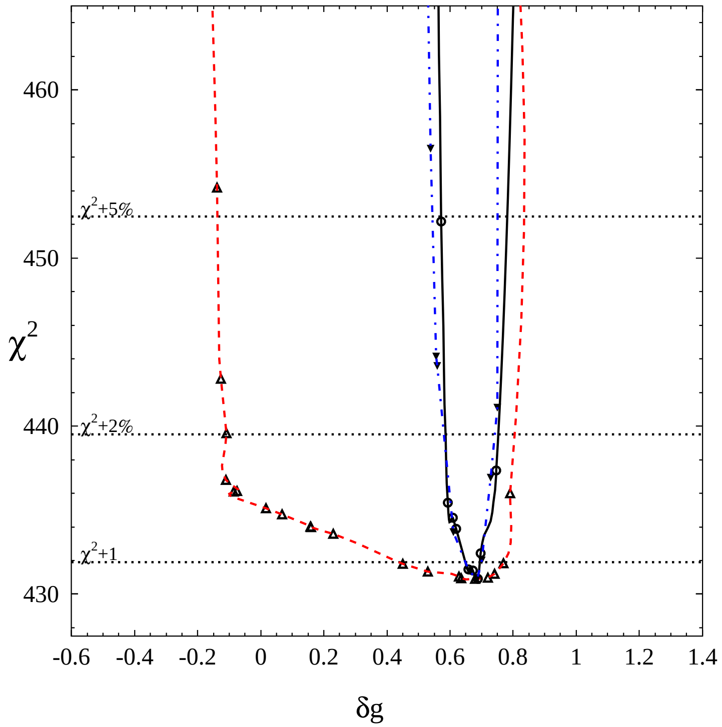
Pauli-blocking model: $\int_0^1 [\Delta\bar{u}(x) - \Delta\bar{d}(x)]dx = \frac{5}{3} \cdot \int_0^1 [\bar{d}(x) - \bar{u}(x)]dx \approx 0.2.$

Constraints on Moments of PDFs Through NLO Global Fit

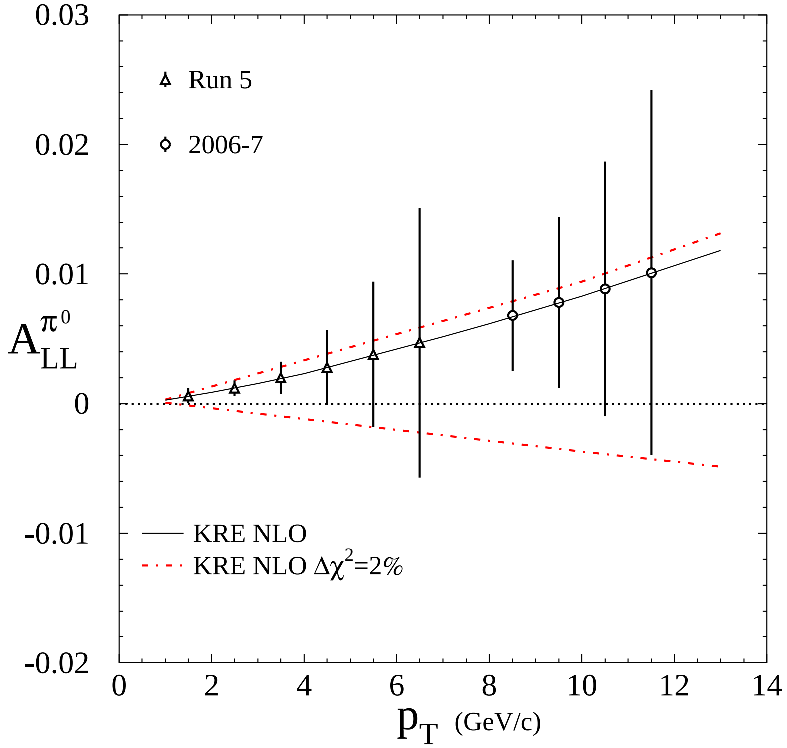


Limit the allowed range of Δq, $\Delta\bar{q}$ moments.

Indirectly Constrain the Gluon Polarization: ΔG



Shrink the allowed range of ΔG moment by a factor of four.



Compare with the projected RHIC-spin 2007 run. The two red dashed-lines corresponding to the existing $\chi^2 + 2\%$ constrain of ΔG.

Summary

Double-spin asymmetry measurements in SIDIS with polarized ^{3}He:

- Constrain Δd_v through SIDIS with polarized ^{3}He.
- Improved $\Delta u_v(x) - \Delta d_v(x)$ translate into sensitivity on $\Delta\bar{u} - \Delta\bar{d}$.
- High precision asymmetry data base for NLO global QCD analysis.
- Constrain moments of polarized PDF.
- Indirectly constrain moment of Δg, to the same level as in RHIC-II.

Standard equipments in Hall A, request 24 days at 6 GeV.

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