$ECT^\star$ Partonic Structure Workshop 2005

Spin-Flavor Decomposition through SIDIS at Jefferson Lab with 6 and 12 GeV Beam

Xiaodong Jiang (Rutgers University), May. 12, 2005.

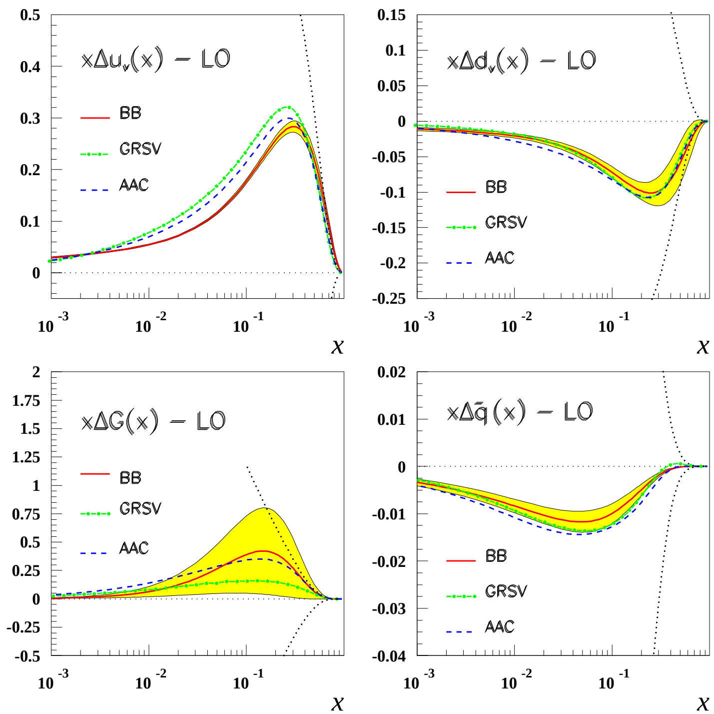
High precision asymmetry data in SIDIS will become available from Jefferson Lab in the next few years.

- Double-spin asymmetry A_{1N}^{h} and the combined asymmetry $A_{1N}^{h\pm\bar{h}}$ for $\vec{p}$, $\vec{d}$ and polarized ^{3}He targets.
- Δu_v, Δd_v from $A_{1N}^{\pi^+-\pi^-}$ at LO and NLO can be extracted.
- Tools of NLO global for DIS and SIDIS become available.
- (A brief discussion on the neutron transversity experiment at JLab Hall A.)
- SIDIS program to be expanded with the 12 GeV energy upgrade at JLab.

Two points of discussion:

- Measurements of g_{1T} will be rather interesting in the near future.
- Currently designed SIDIS experiments have little sensitivity to Δs.

Nucleon Spin Structure — in Flavor

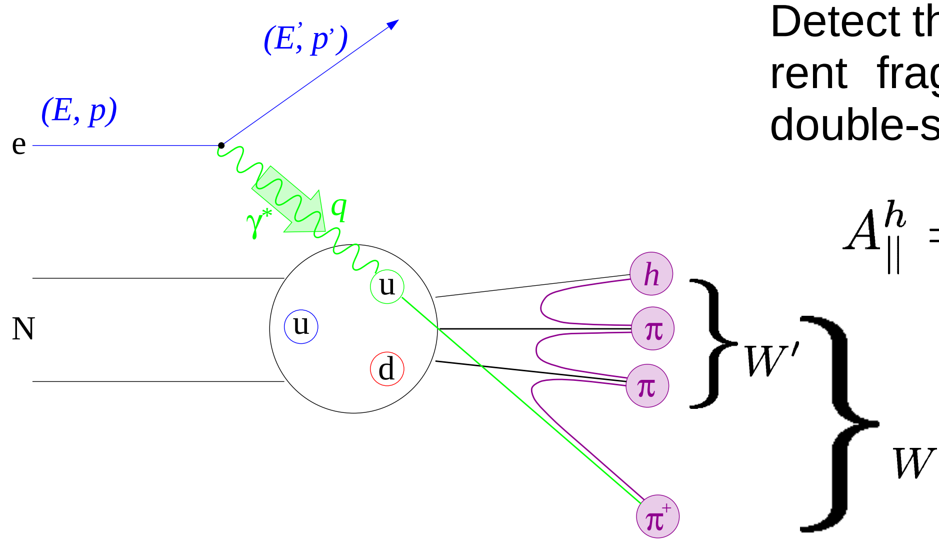


Global QCD fits to the inclusive DIS data.

- Have to assume the sea behavior. As in BB: $\Delta\bar{q} = \Delta\bar{u} = \Delta\bar{d} = \Delta\bar{s}$.
- Inclusive data can not distinguish between q and $\bar{q}$ since $\sigma = \sum_f e_f^2 q_f$.
- Only one flavor non-singlet accessible: $\Delta q_3 = (\Delta u + \Delta\bar{u}) - (\Delta d + \Delta\bar{d})$.
- Can not access $\Delta\bar{u} - \Delta\bar{d}$.

Semi-inclusive deep inelastic scattering (SIDIS) offers extra handle of q vs $\bar{q}$ due to flavor tagging. Provide access to the valence and the sea structure of the nucleon spin.

Flavor Tagging in Semi-Inclusive DIS



$$z = E_\pi / \nu$$

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

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

Assume the leading order naive x-z factorization (name invented by Ji, Ma and Yuan):

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

Each asymmetry measurement provides an independent constrain on Δq_f.

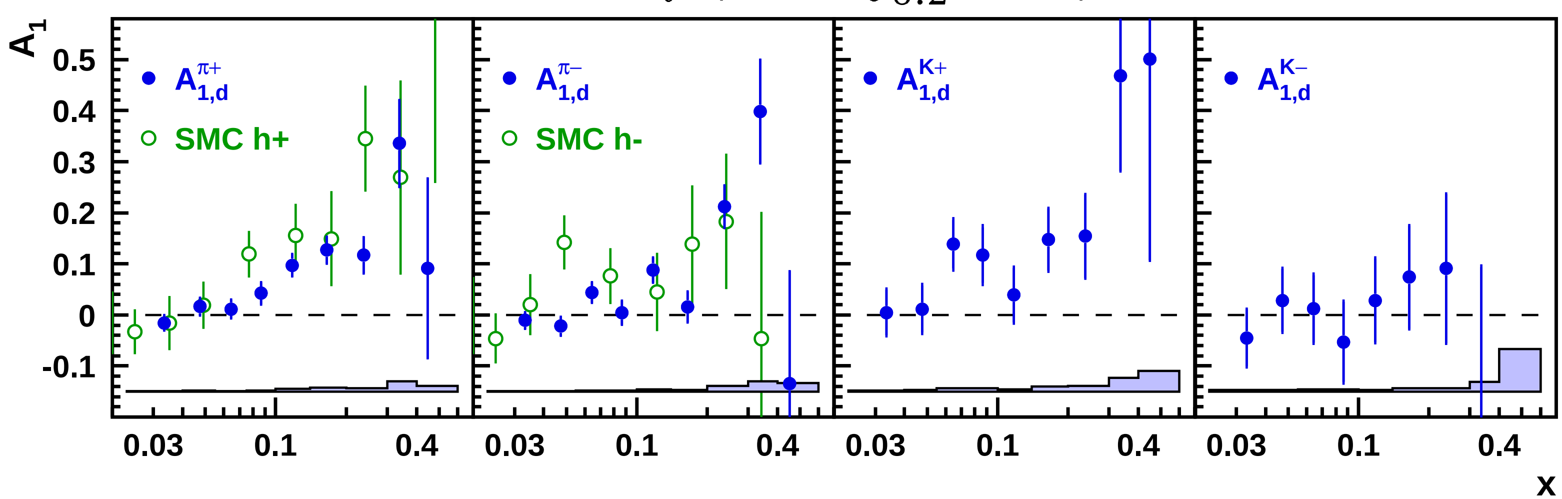
HERMES Flavor Decomposition: $\vec{A} = \mathcal{P}_f^h(x) \cdot \vec{Q}$

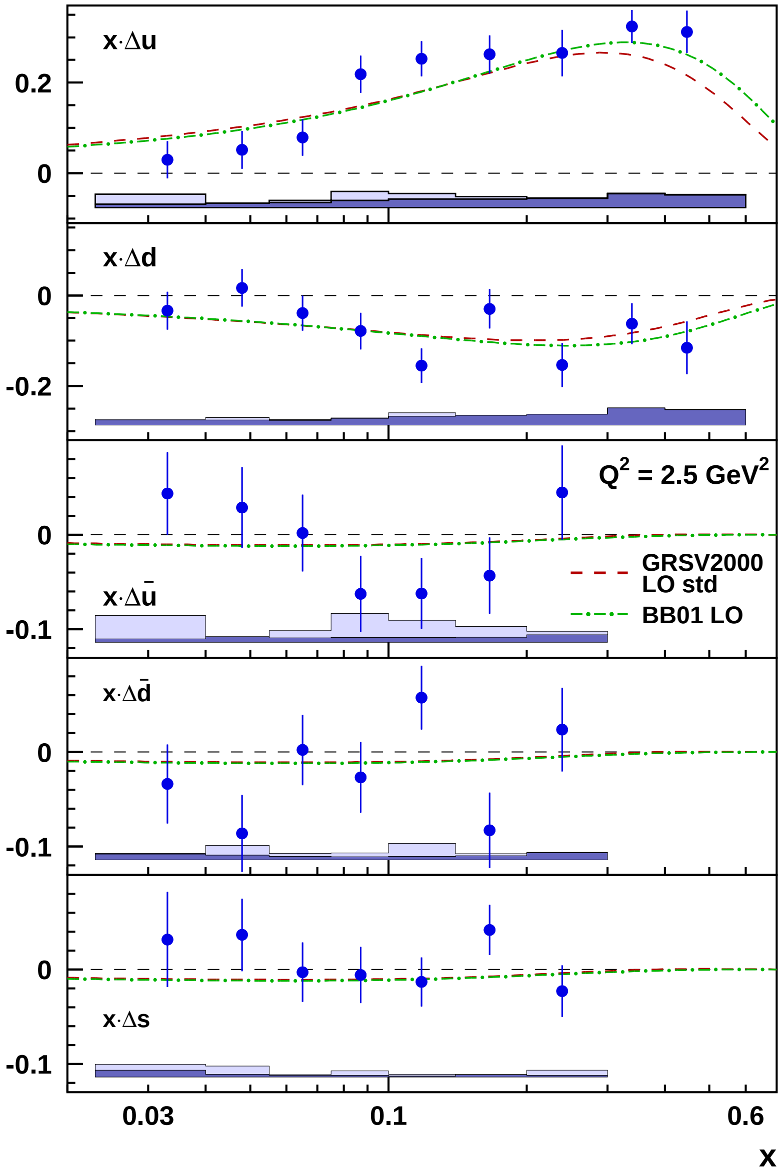
From measurements: $\vec{A} = \left(A_{1p}^{\pi^+}, A_{1p}^{\pi^-}, A_{1d}^{\pi^+}, A_{1d}^{\pi^-}, A_{1d}^{K^+}, A_{1d}^{K^-}, A_{1p}, A_{1d}\right)$

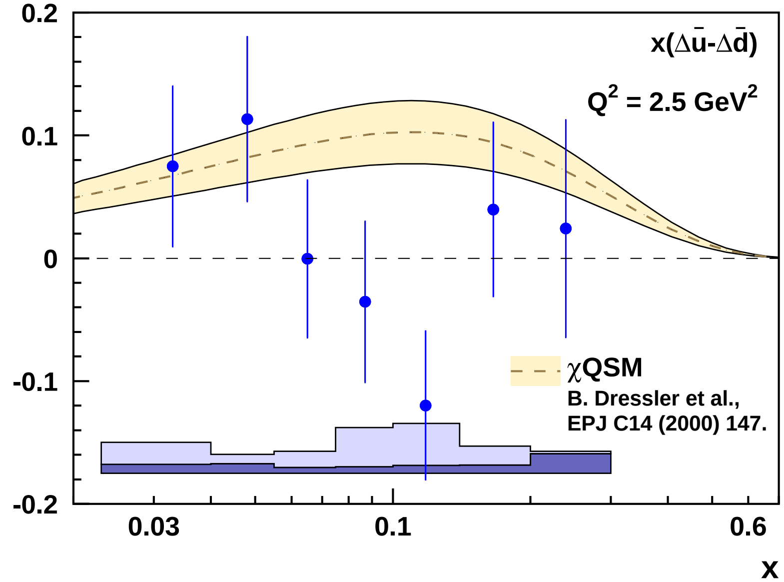
Solve for: $\vec{Q} = \left(x\Delta u, x\Delta d, x\Delta \bar{u}, x\Delta \bar{d}, x\Delta s\right)$.

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.

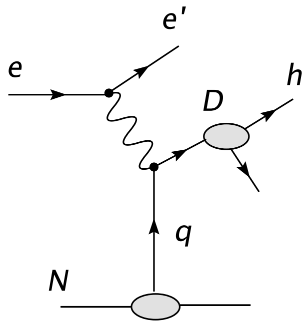
Isospin symmetry and charge conjugation.

Purity from Monte Carlo.

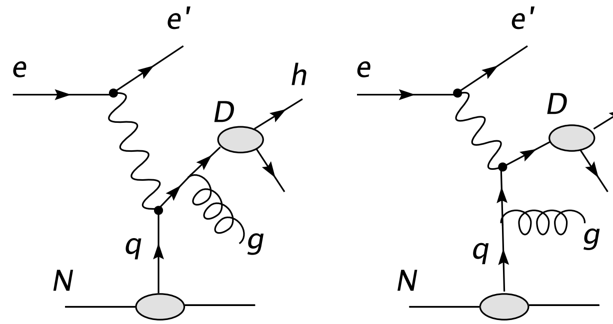
Interpretation of SIDIS Beyond the Leading Order

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.)

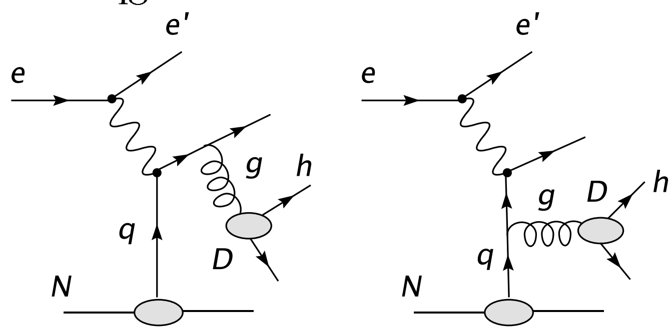
LO:



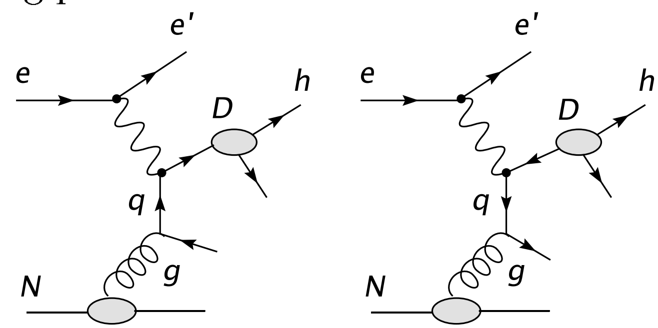
NLO-qq:



NLO-qg:



NLO-gq:



- 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)).

$$\Delta\sigma^h = \sum_i e_i^2 \Delta q_i \left[1+\otimes\frac{\alpha_s}{2\pi}\Delta C_{qq}\otimes\right] D_{q_i}^h$$
$$+ \left(\sum_i e_i^2 \Delta q_i\right)\otimes\frac{\alpha_s}{2\pi}\Delta C_{qg}\otimes D_G^h + \Delta G\otimes\frac{\alpha_s}{2\pi}\Delta C_{gq}\otimes\left(\sum_i e_i^2 D_{q_i}^h\right)$$

Isospin symmetry and charge conjugation: $D_G^h = D_G^{\bar{h}}$, $\sum_i e_i^2 D_{q_i}^h = \sum_i e_i^2 D_{q_i}^{\bar{h}}$.

The last two terms, which are related to gluon, vanish in $\pi^+ - \pi^-$ type observables. $A_{1N}^{\pi^+-\pi^-}$ is theoretically cleaner.

From $A_{1N}^{\pi^+-\pi^-}$ to Δu_v, Δd_v and $\Delta\bar{u}-\Delta\bar{d}$

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

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

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

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

Δu_v and Δd_v are non-singlets do not mix with the other quark and gluon densities.

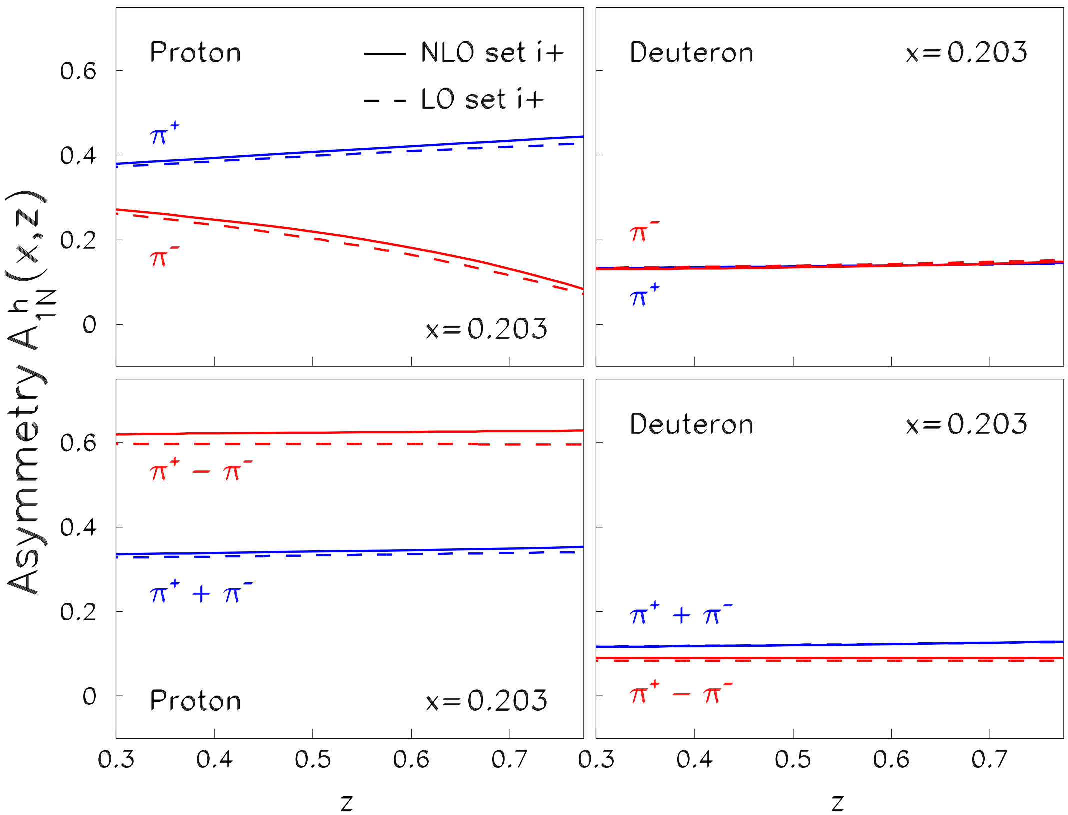
$$(\Delta\bar{u}-\Delta\bar{d})|_{LO} = \frac{1}{2}(\Delta q_3+\Delta d_v-\Delta u_v)|_{LO}$$

where $\Delta q_3=\Delta u+\Delta\bar{u}-\Delta d-\Delta\bar{d}=6(g_1^p-g_1^n)$ from inclusive data.

"Bjorken-type Sum Rule" links the moments at all orders of QCD (Sissakian *et al.* PRD68, 031502 (2003)).

$$2\int_0^1(\Delta\bar{u}-\Delta\bar{d})dx+\int_0^1(\Delta u_v-\Delta d_v)dx=|\frac{g_A}{g_V}|=1.2670\pm 0.0035$$

LO and NLO Predictions of $A^h_{1N}(x,z)$



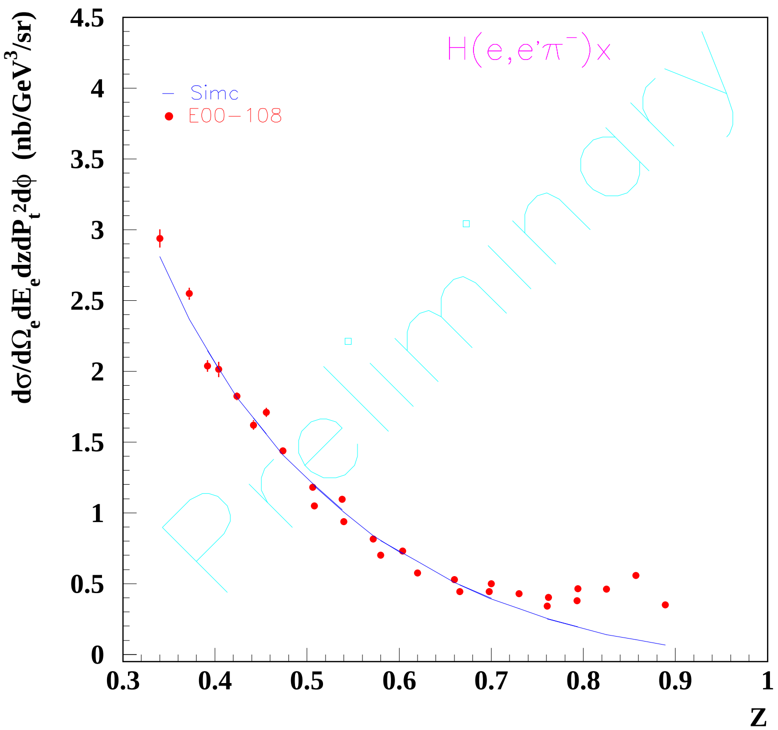
LO and NLO curves are close:

$A^{\pi^+}_{1p}$ and $A^{\pi^-}_{1p}$ depend on z.

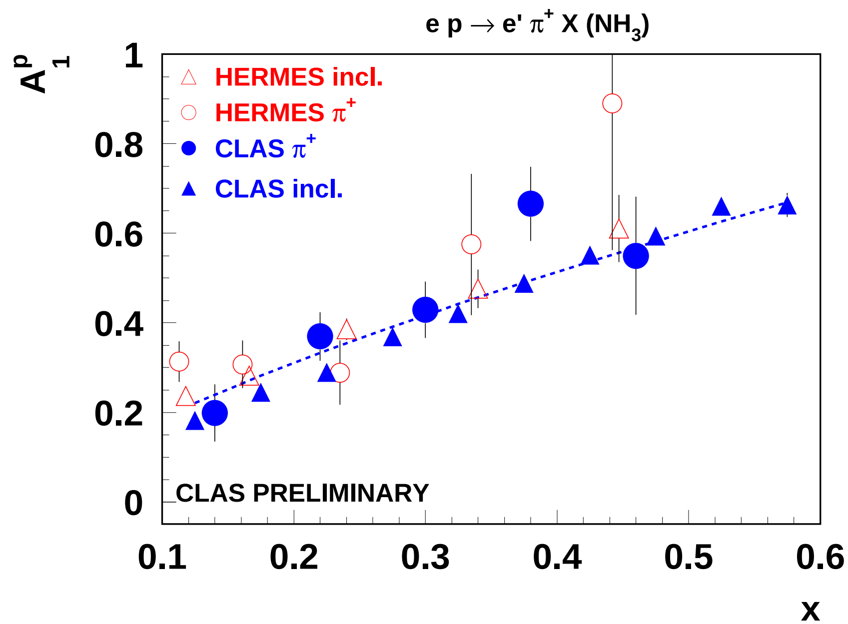
A^h_{1d} and $A^{\pi^+ \pm \pi^-}_{1N}$ are almost z-independent.

G. Navarro and R. Sassot private communications (2004), D. de Florian and R. Sassot, PRD 62, 094025(2000)

Leading-Order Naive x-z Factorization at JLab 6 GeV ?



Hall C E00-108 preliminary. Cross section reproduced by a Monte Carlo based on LO x-z factorization.

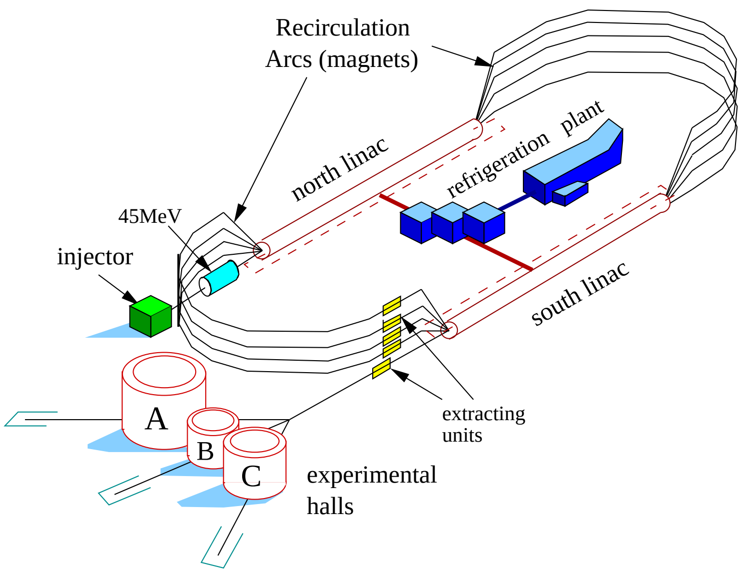


Hall B eg1b: semi-inclusive asymmetry $A_{1p}^{\pi^+}$ agree with HERMES, SMC, fall on the same curve of inclusive A_{1p}. No clear z-dependence observed for $z > 0.5$.

Leading order naive x-z factorization is not violated much.

Thomas Jefferson National Accelerator Facility

Newport News, Virginia.



6 GeV polarized electron beam ($P_e = 85\%$, $I = 120\ \mu$A).

Continuous beam to three experiment halls for fixed target experiment.

Electron beam helicity is randomly flipped at a rate of 30 Hz.

Hall A: two high resolution magnetic spectrometers.

Hall B: a large acceptance spectrometer.

Hall C: two magnetic spectrometers.

High Luminosity for SIDIS at Jefferson Lab

Polarized proton in Hall C (NH_3): $\mathcal{L}_{\vec{p}} = 0.85 \times 10^{35}$ cm^{-2}s^{-1}.

(HERMES:$\mathcal{L}_{\vec{p}} = 1.3 \times 10^{31}$ cm^{-2}s^{-1}).

Polarized ^{3}He in Hall A : $\mathcal{L}_{\vec{H}e} = 1.0 \times 10^{36}$ cm^{-2}s^{-1}.

(HERMES:$\mathcal{L}_{\vec{H}e} = 6.2 \times 10^{31}$ cm^{-2}s^{-1}).

Typical scattering angle is 30° for SIDIS at JLab (compare with $0^\circ - 10^\circ$ at HERMES).

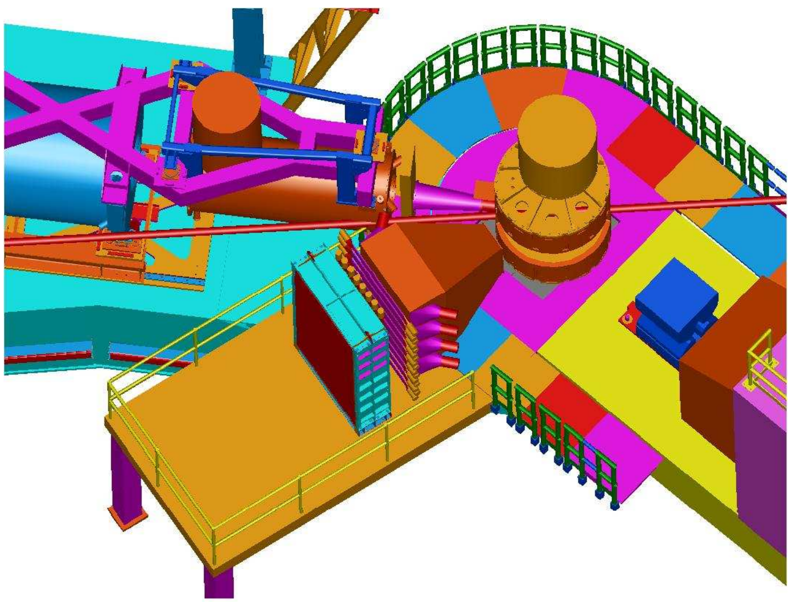
Access $0.12 < x < 0.42$ with $\langle Q^2 \rangle$=2.2 GeV^2 with $W > 2.3$ GeV.

Semi-SANE: A Jefferson Lab Hall C Experiment

E04-113: P. Bosted, D. Day, X. Jiang and M. Jones co-spokespersons

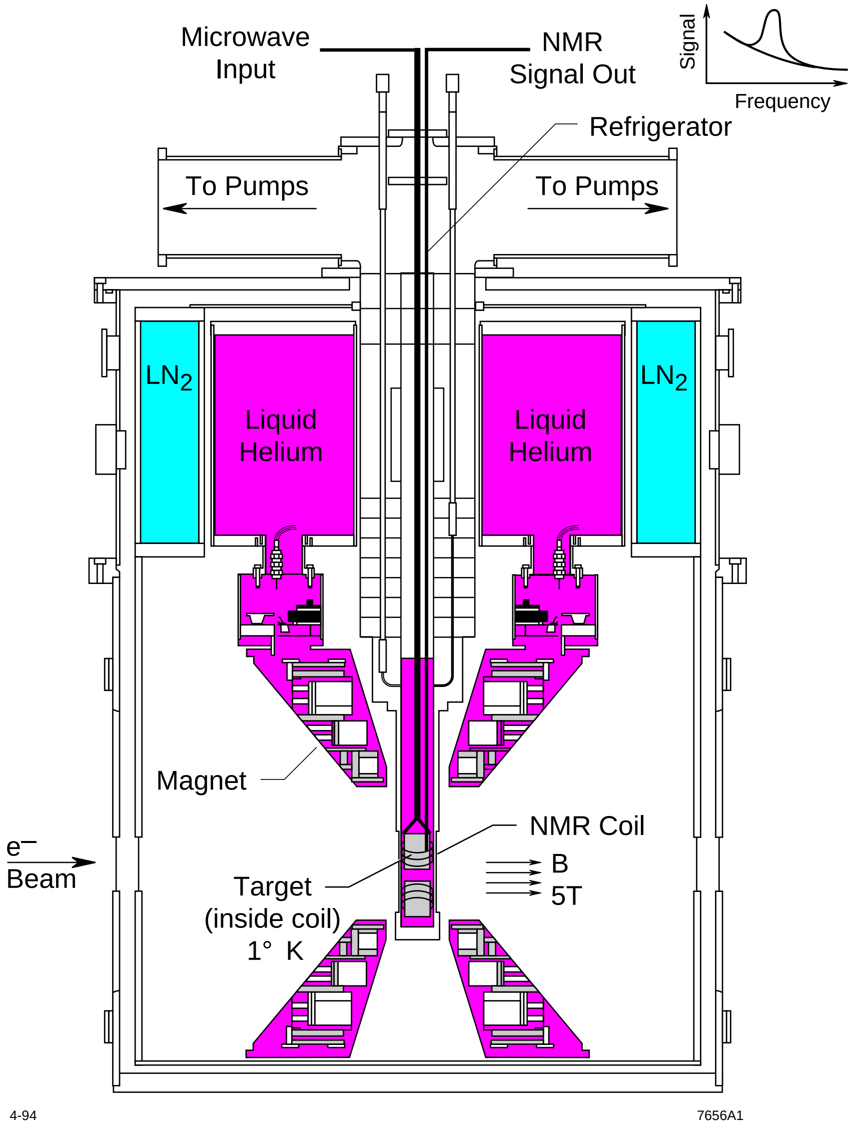
ANL, Duke, FIU, Hampton, JLab, Kentucky, UMass, Norfolk, ODU, RPI, Rutgers, Temple, UVa, W&M, Yerevan, Regina, IHEP-Protvino.

High precision asymmetry data in deep-inelastic $\vec{N}(\vec{e}, e'h)$ ($N = p, d$, $h = \pi^{\pm}, K^{\pm}$).



- $E_0 = 6$ GeV, $P_B = 0.80$.
- e-Arm: a calorimeter array $@30^{\circ}$.
- h-Arm: HMS spectrometer @10.8°, 2.71 GeV/c, $z \approx 0.5$. Particle ID detectors for π/K separation.
- Target: polarized NH_3 ($\vec{p}$) and LiD ($\vec{d} = \vec{p} + \vec{n}$).

The Standard Hall C Solid Polarized Target ($\vec{p}$, $\vec{d}$)

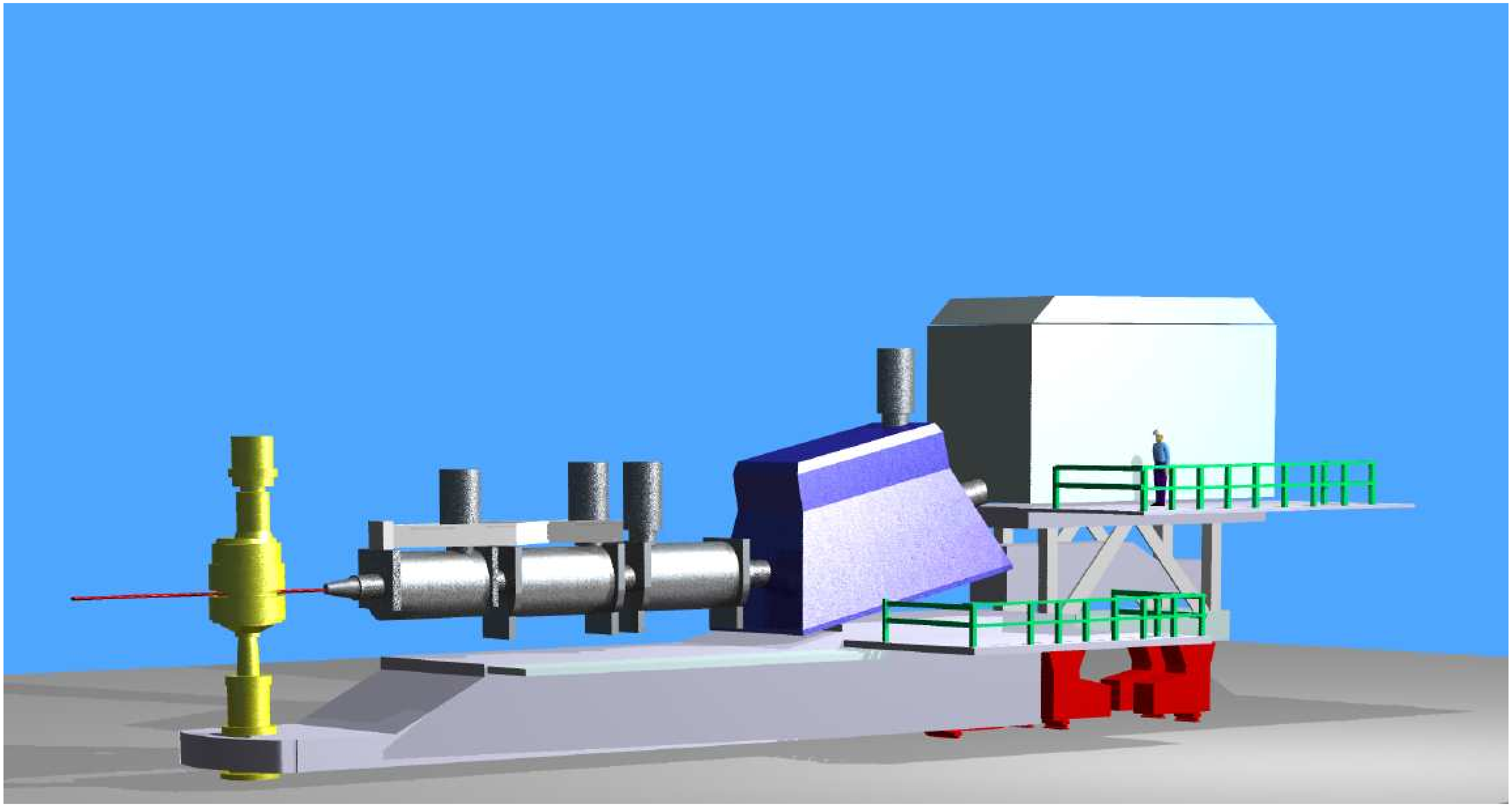


- Dynamic nuclear polarization.
- Used in many experiments at SLAC and JLab.
- Strong magnetic field (5 T), low temperature (1K).
- P_T(NH$_3$)=80%, P_T(LiD) $\approx 20\%$.
- Dilution factor: $f^h = 0.17 \sim 0.22$(NH$_3$), $0.40 \sim 0.45$ (LiD).

e-Arm: an Array of Lead-Glass Calorimeter

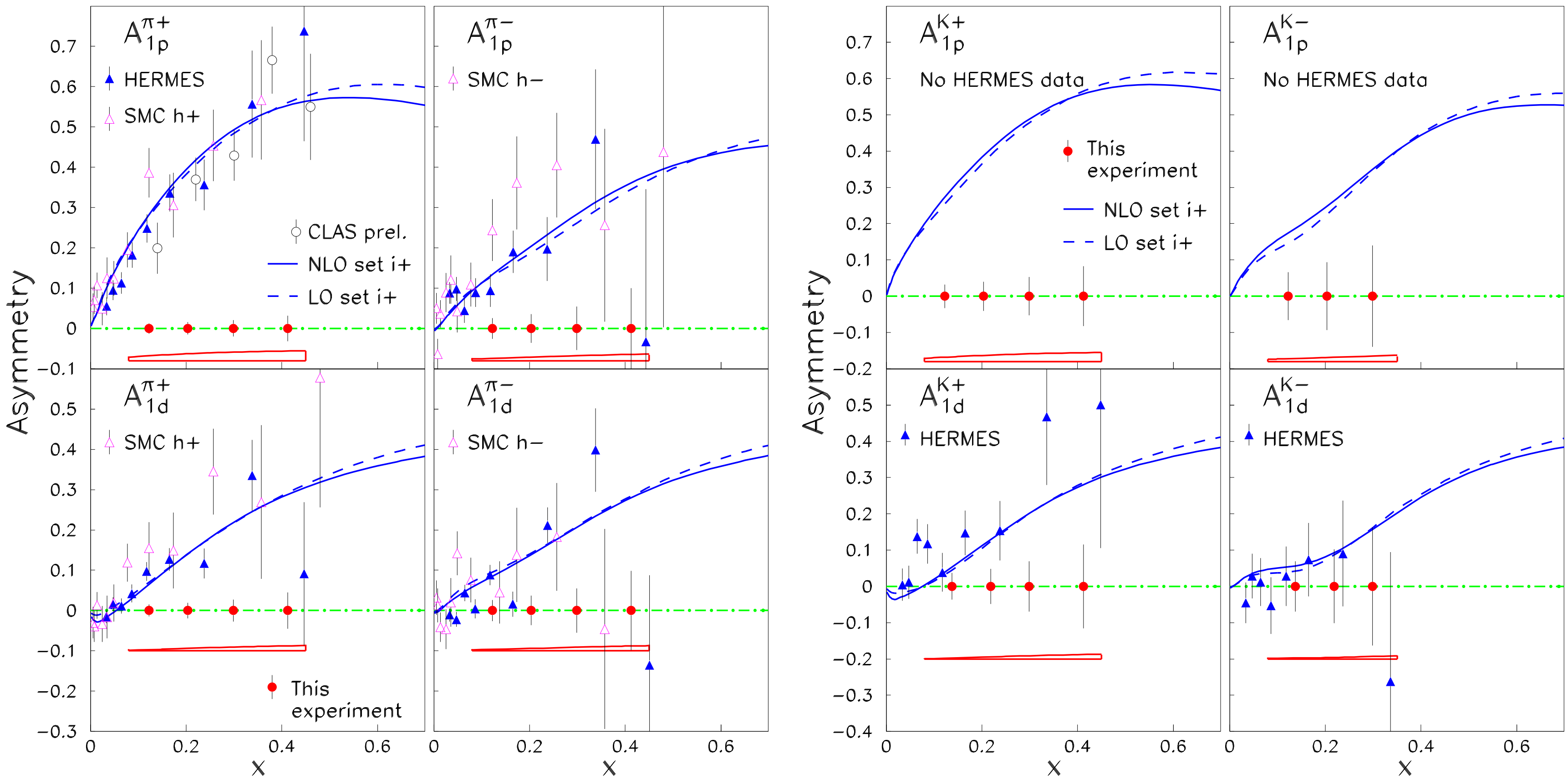
Total absorption detector.
4cm$\times$4cm$\times$40cm lead-glass blocks, covers 1.2 m$\times$ 2.2 m.

h-Arm: the Hall C High Momentum Spectrometer



Use the existing spectrometer HMS to detect 2.7 GeV/c hadrons (π^+, K^+, or π^-, K^-) in coincidence with the scattered electron.

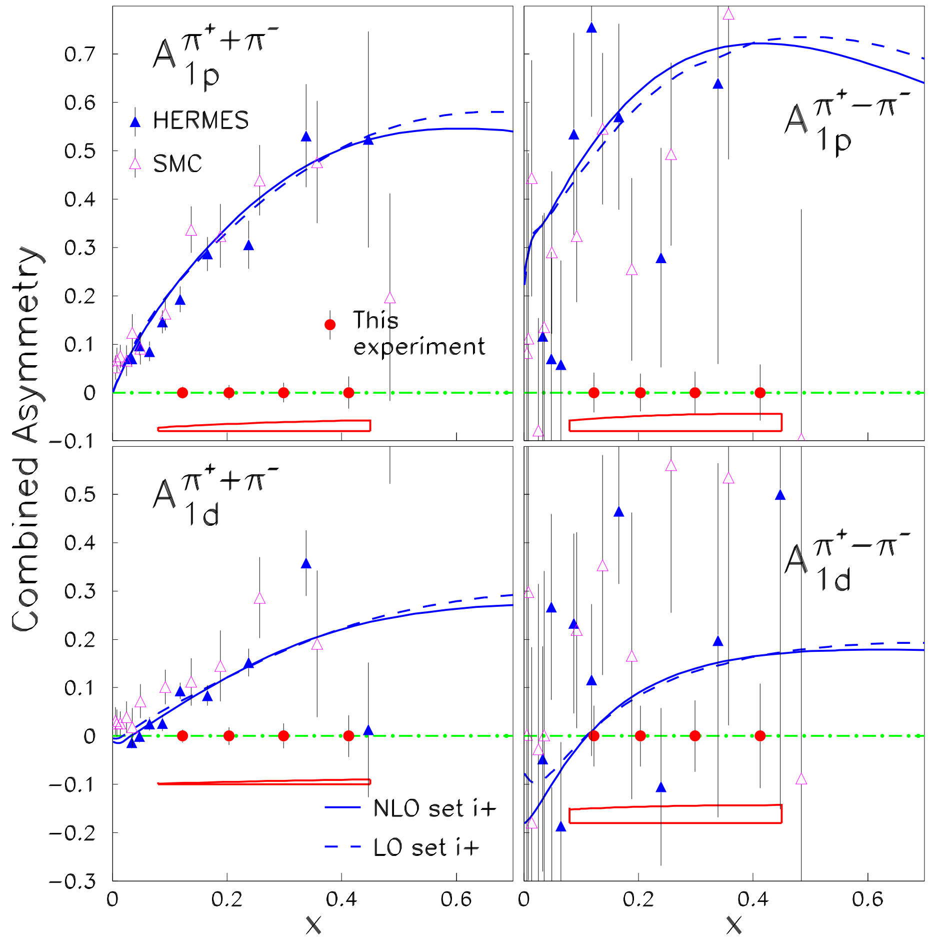
The Expected Results: Double-Spin Asymmetries A_{1N}^{h}



Approved for 25 days beam time. Significant improvements on the statistical accuracy of $A_{1N}^{\pi^{\pm}}$.

First data on $A_{1p}^{K^{\pm}}$.

The Combined Asymmetries: $A_{1N}^{\pi^+ + \pi^-}$ and $A_{1N}^{\pi^+ - \pi^-}$



Get rid of some higher order complications by using the observables related to $\pi^+ - \pi^-$.

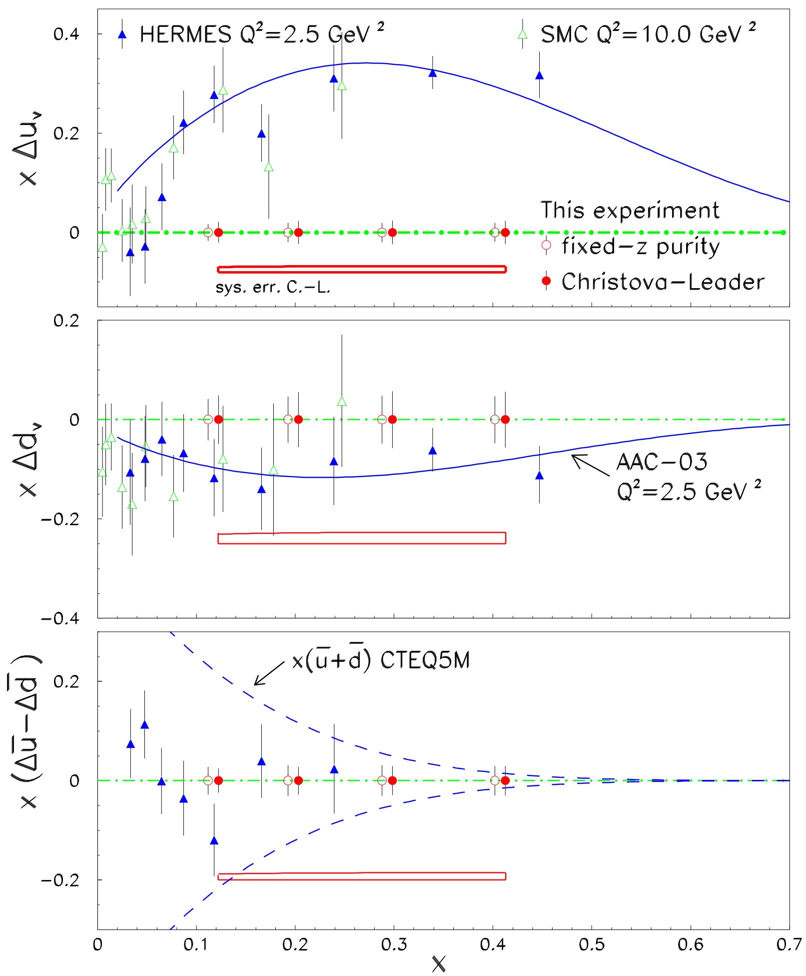
To obtain $A_{1N}^{\pi^+-\pi^-}$ we need:

Well-controlled phase space and hadron PID

$$A_{1N}^{\pi^+-\pi^-} = \frac{\Delta\sigma_N^{\pi^+} - \Delta\sigma_N^{\pi^-}}{\sigma_N^{\pi^+} - \sigma_N^{\pi^-}} = \frac{A_{1N}^{\pi^+} - A_{1N}^{\pi^-} \cdot r}{1-r}, \quad r = \frac{\sigma^{\pi^-}}{\sigma^{\pi^+}} = 0.27 \sim 0.64.$$

(Method not applies for low-z kinematics where $\sigma^{\pi^-}/\sigma^{\pi^+} \sim 1.0$)

The Expected Results on Δq



Jefferson Lab E04-113
$E_0 = 6$ GeV

$$\Delta u_v = \Delta u - \Delta \bar{u}$$
$$\Delta d_v = \Delta d - \Delta \bar{d}$$

Tow independent methods of flavor decomposition:

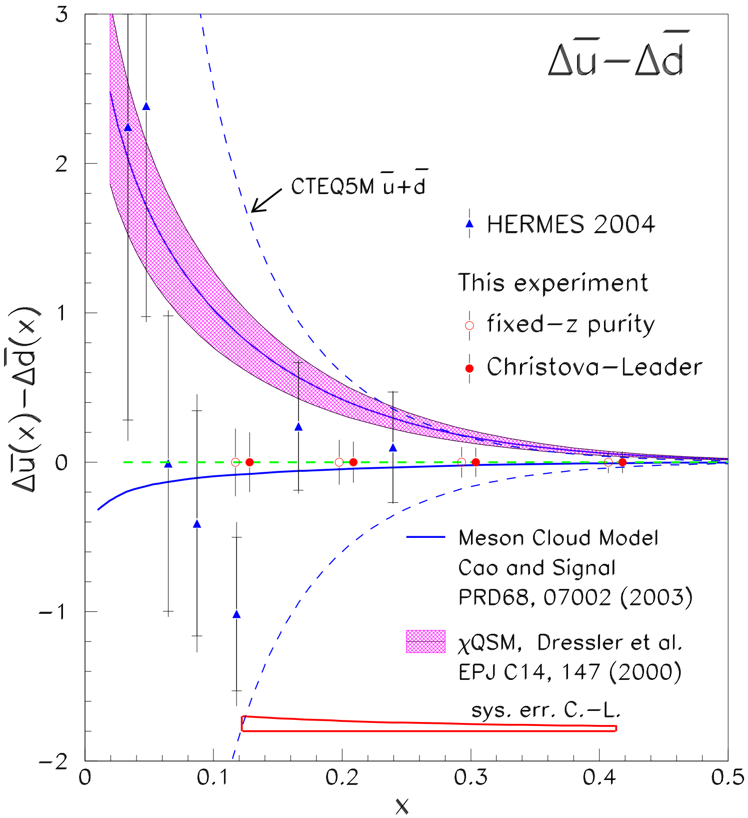
i, Christova-Leader method.

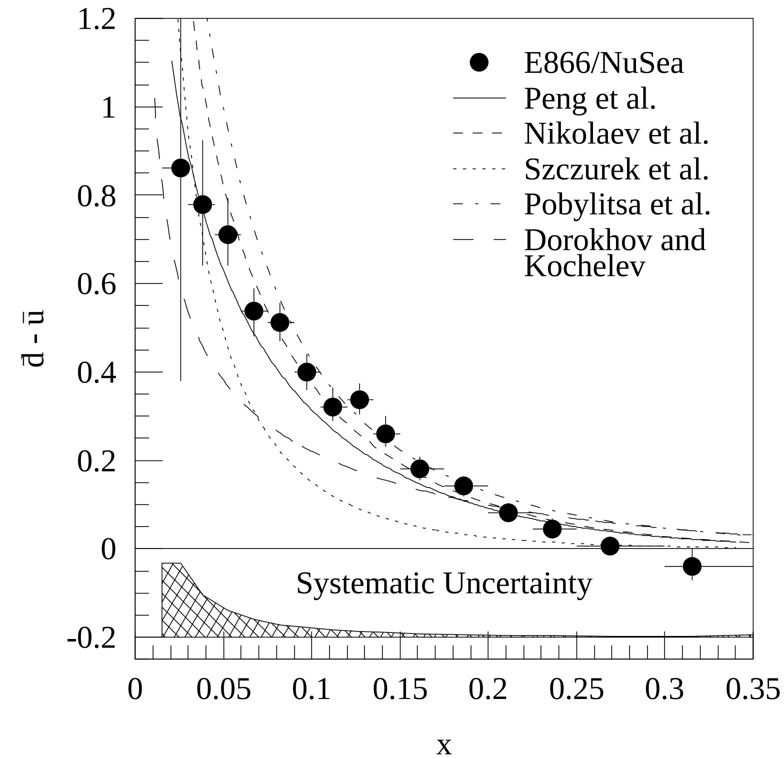
ii, "Purity" at a fixed-z.

Statistical uncertainties dominate.

One expects at least $\Delta\bar{u} - \Delta\bar{d} > (\bar{d} - \bar{u})$!!!

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 $pp, pd \to \mu^+\mu^-$ 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: $\int_0^1 [\Delta\bar{u}(x) - \Delta\bar{d}(x)]dx = \frac{5}{3} \cdot \int_0^1 [\bar{d}(x) - \bar{u}(x)]dx \approx 0.2.$

Test a wide range of model predictions of $\int_0^1 (\Delta\bar{u} - \Delta\bar{d})dx$:

- Meson cloud (π) model: 0.
- Chiral-quark soliton model: 0.31.
- Pauli-blocking model: $0.2 \sim 0.3$.
- Instanton model: 0.2
- Statistical model: 0.12

Methods of Spin-Flavor Decomposition

Four leading-order methods:

- The LO Christova-Leader method: $A_{1p}^{\pi^+ - \pi^-}$, $A_{1d}^{\pi^+ - \pi^-} \Rightarrow \Delta u_v, \Delta d_v$. Use $g_1^p(x) - g_1^n(x)$ as inputs to obtain $\Delta\bar{u} - \Delta\bar{d}$.
- "Fixed-z purity" method: calculate purity (inputs: PDFs and ratio of $D^-(z)/D^+(z)$) for well-localized z-bins. Solve linear equations $\vec{A}(x,z) = \mathcal{P}(x,z)\vec{Q}(x)$.
- Monte Carlo purity method (HERMES). Purity from a LUND based Monte Carlo.
- LO global fit.

Two next-to-leading order methods:

- The NLO Christova-Leader method (inputs: PDFs and $D^+(z) - D^-(z)$).
- NLO global fit method (D. de Florian, G. Navarro and R. Sassot hep-ex/0504155).

Consistency checks between different methods provide clear measures of systematic uncertainty associated with the flavor decomposition methods.

NLO Global Fits to DIS and SIDIS Data

(hep-ph/0504155, 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.
- Translate into error bands on double-spin asymmetry observables.

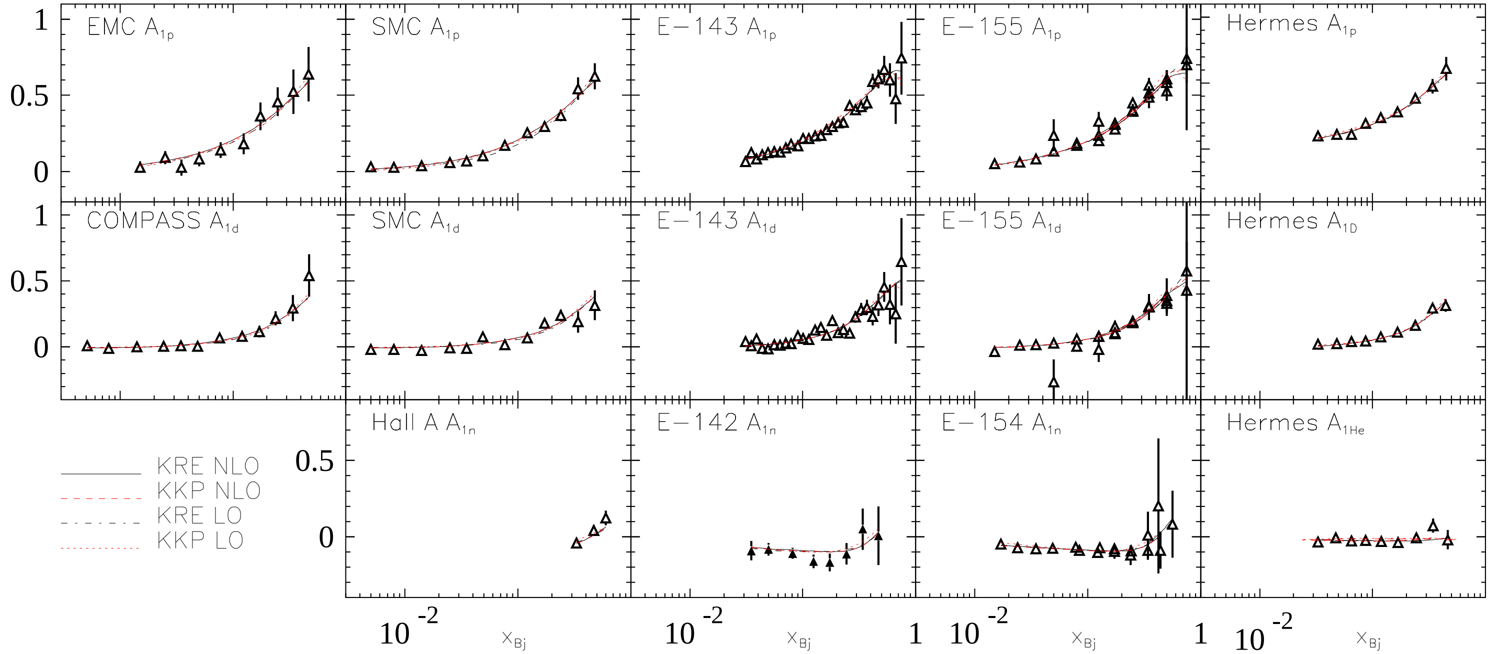
Inclusive:

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

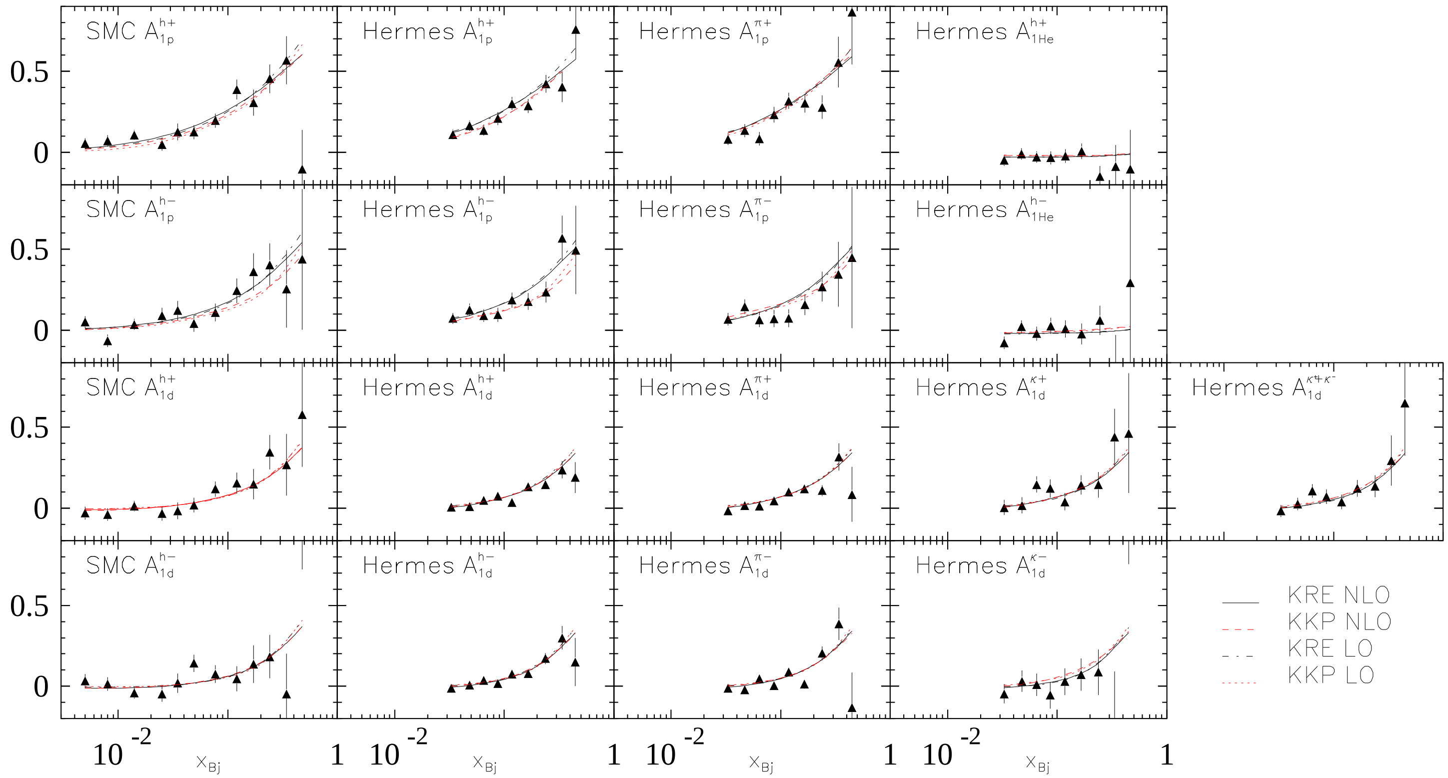
Semi-inclusive:

$$\begin{aligned}
g_1^{N\,h}(x,z,Q) \quad = \quad & \frac{1}{2}\sum_{q,\bar{q}} e_q^2 \Bigg[\Delta q\left(x,Q^2\right) D_q^H\left(z,Q^2\right) \\
+ \quad & \frac{\alpha_s(Q^2)}{2\pi} \int_x^1 \frac{d\hat{x}}{\hat{x}} \int_z^1 \frac{d\hat{z}}{\hat{z}} \Bigg\{ \Delta q\left(\frac{x}{\hat{x}},Q^2\right) \Delta C_{qq}^{(1)}(\hat{x},\hat{z},Q^2) D_q^H\left(\frac{z}{\hat{z}},Q^2\right) \\
& + \Delta q\left(\frac{x}{\hat{x}},Q^2\right) \Delta C_{gq}^{(1)}(\hat{x},\hat{z},Q^2) D_g^H\left(\frac{z}{\hat{z}},Q^2\right) \\
& + \Delta g\left(\frac{x}{\hat{x}},Q^2\right) \Delta C_{qg}^{(1)}(\hat{x},\hat{z},Q^2) D_q^H\left(\frac{z}{\hat{z}},Q^2\right) \Bigg\} \Bigg]
\end{aligned}$$

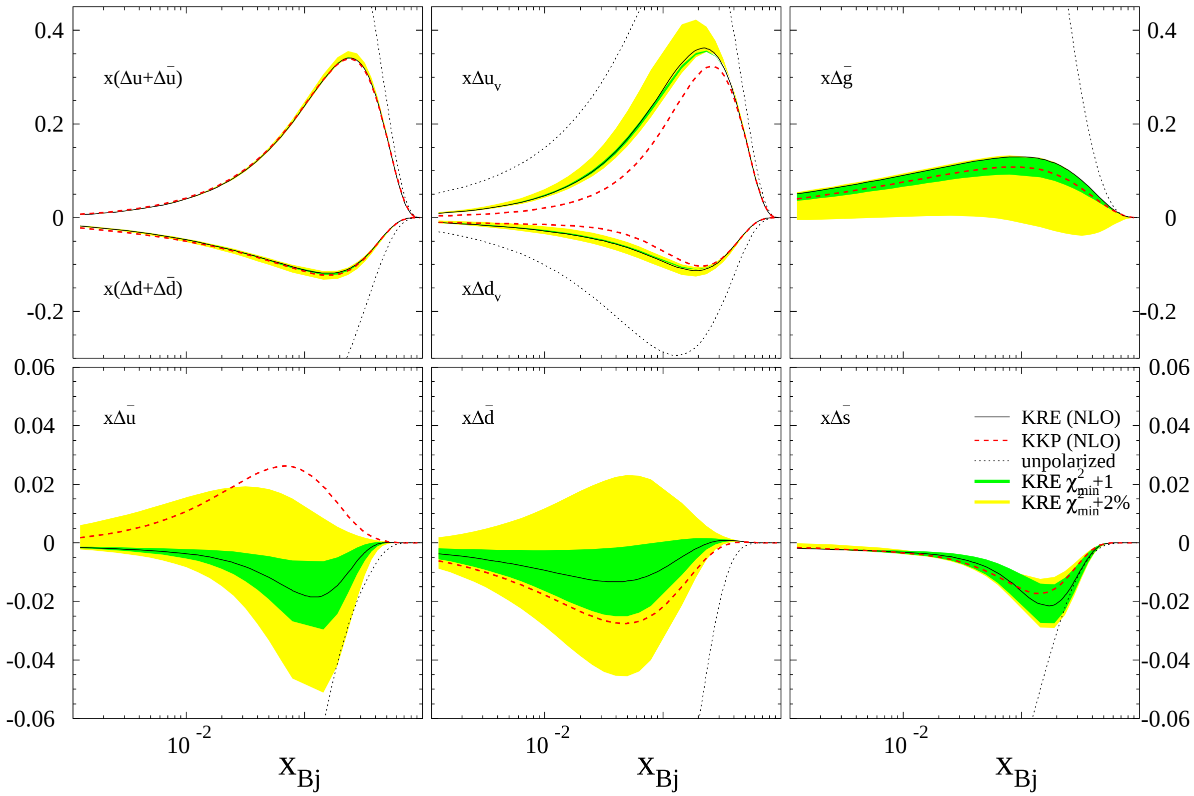
The Best Fit Compare with Inclusive Data:



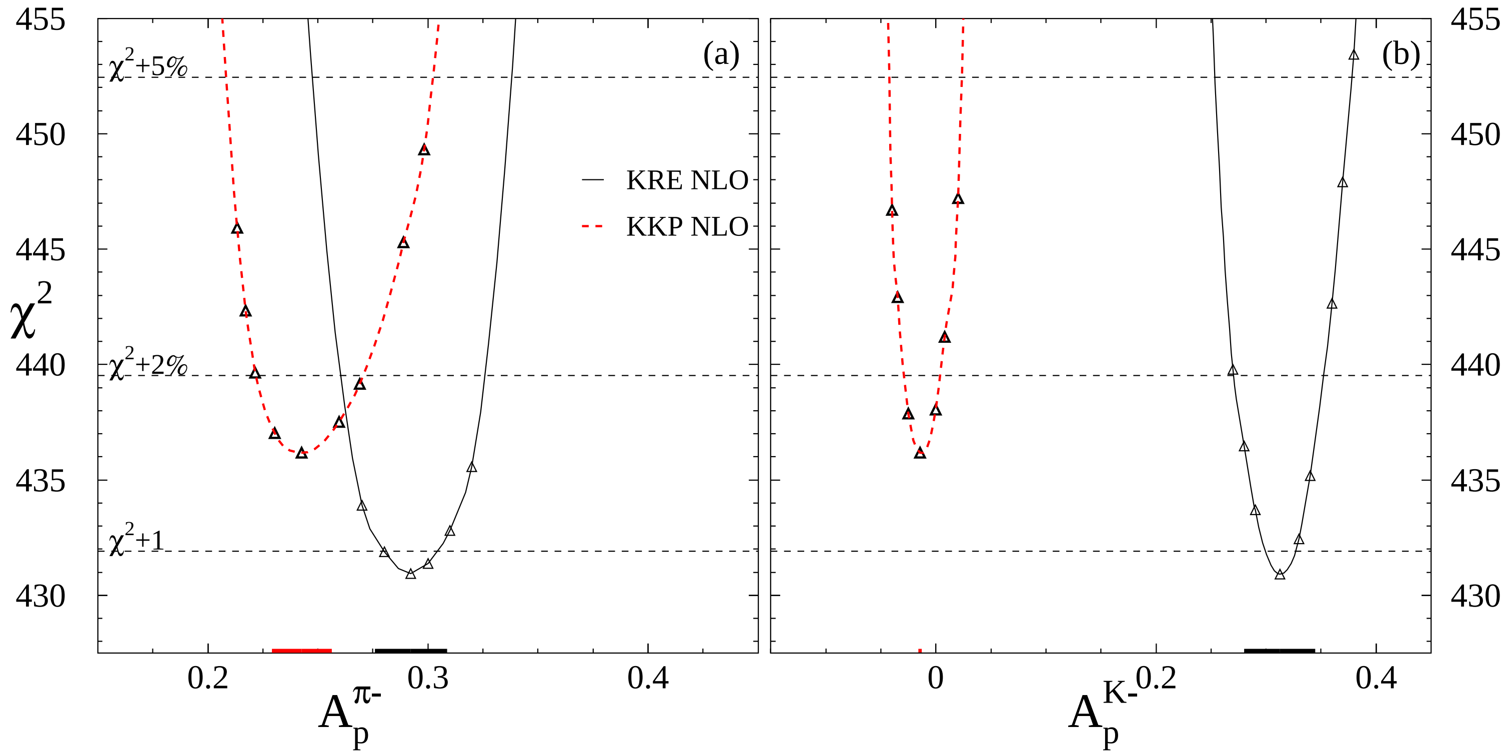
The Best Fit Compare with Semi-Inclusive DIS Data:



Error bands of NLO polarized PDF

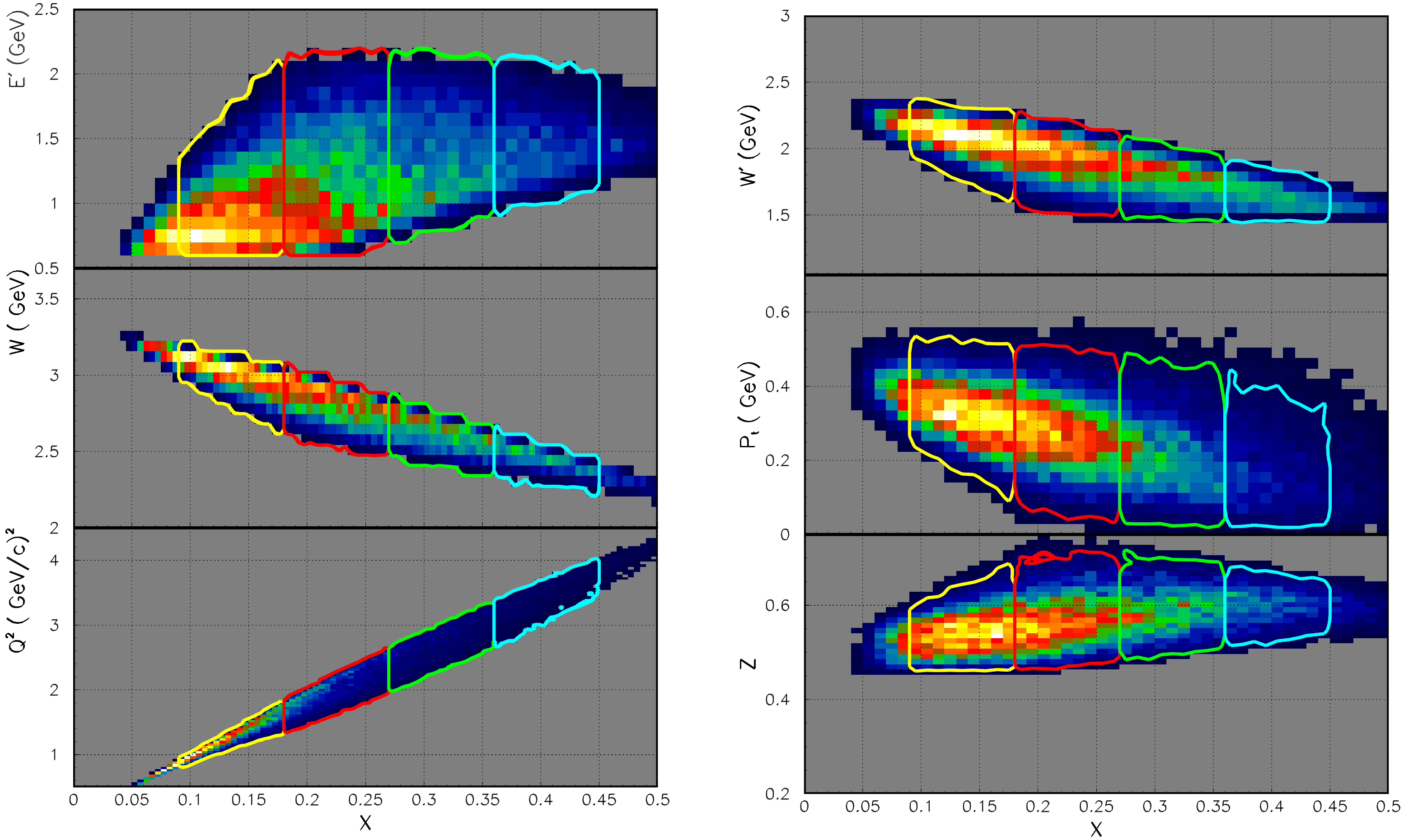


Translated into Uncertainties in semi-SANE Observables



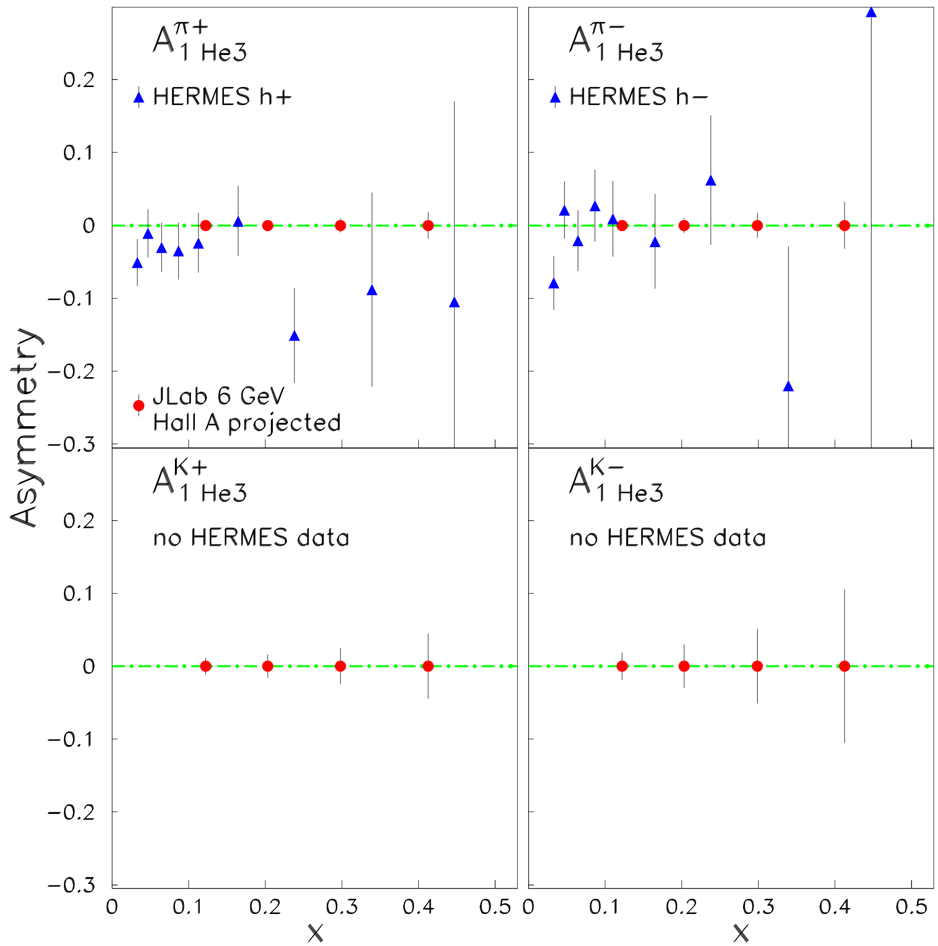
Experiment error bar on $A_{1p}^{\pi^-}$ and $A_{1p}^{K^-}$ for $x = 0.2$ bin. Kaon production data will put strong constrains on the fragmentation functions (Kretzer vs. KKP)

Kinematics and Phase Space Coverage



$0.122 < x < 0.413$, $\langle Q^2 \rangle = 2.2$ GeV^2. $z > 0.5$. Only shown $W' > 1.5$ GeV.

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



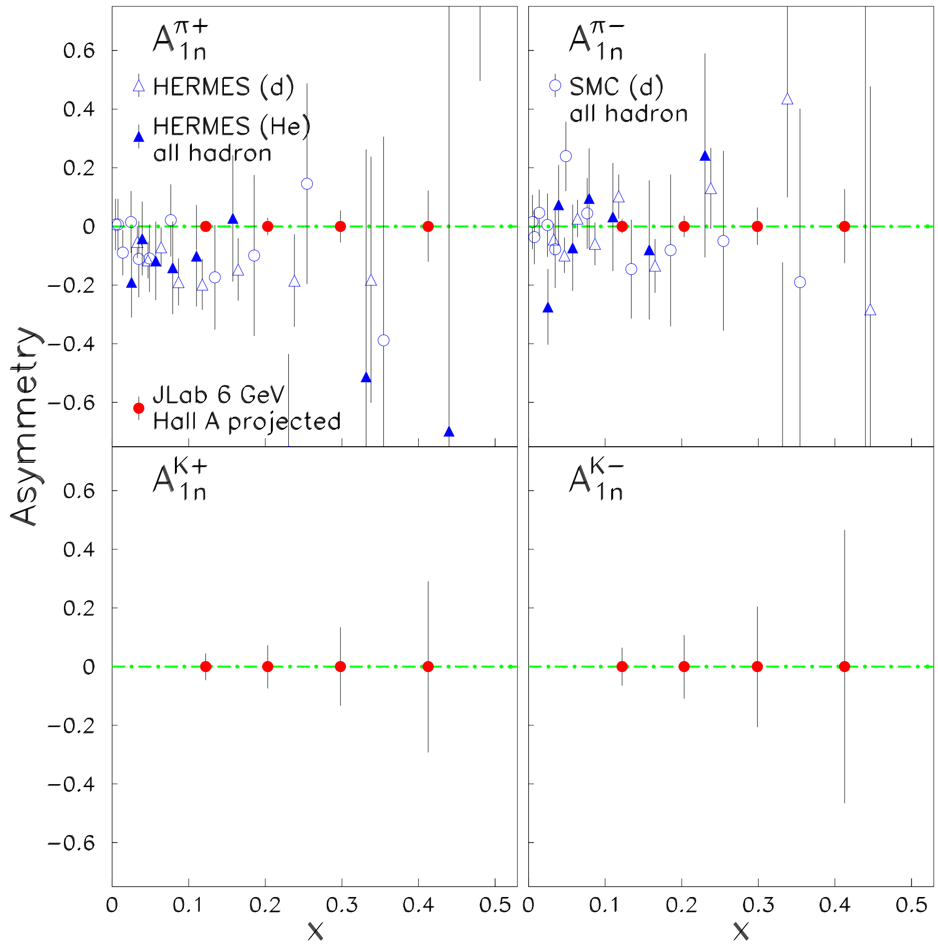
A new proposal to be submitted to JLab PAC28 in June, 2005.

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

- A^h_{1n} are more sensitive to Δd.
- Constrain Δu_v and Δd_v through $A^{\pi^+ - \pi^-}_{1n}$.
- First data on $A^{K^+}_{1n}$ and $A^{K^-}_{1n}$
- High precision inputs to the global NLO fit.
- Provide consistency checks with $\vec{p}$, $\vec{d}$ data.

- All equipments exist in Hall A.
- Need 28 days of beam time.

Translate into A^h_{1n}



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.
- 28 days of beam time.

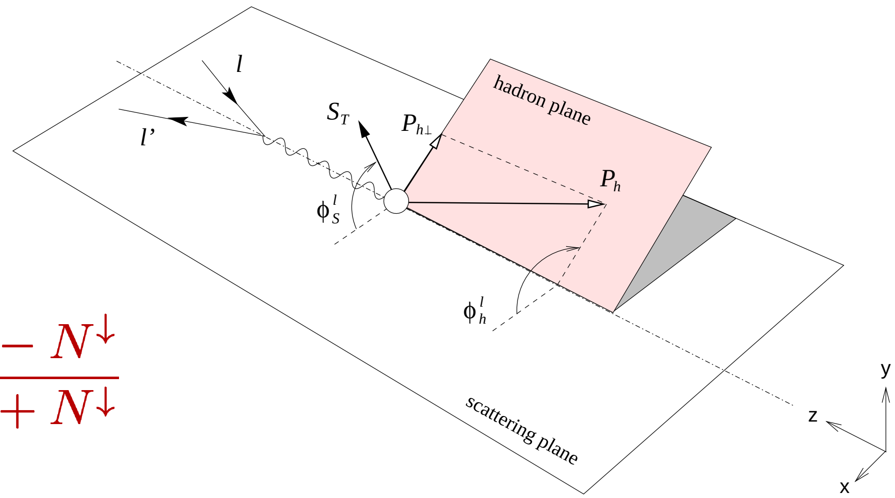
Neutron Transversity: Jefferson Lab Experiment E03-004

Spokespersons: J.-P. Chen (JLab), X. Jiang (Rutgers), J.-C. Peng (UIUC)

Argonne, CalState-LA, Duke, E. Kentucky, FIU, UIUC, JLab, Kentucky, Maryland, UMass,

MIT, ODU, Rutgers, Temple, UVa, W&M, USTC-China, CIAE-China, Glasgow-UK, INFN-Italy,

U. Ljubljana-Slovenia, St. Mary's-Canada, Tel Aviv-Israel, St. Petersburg-Russia.



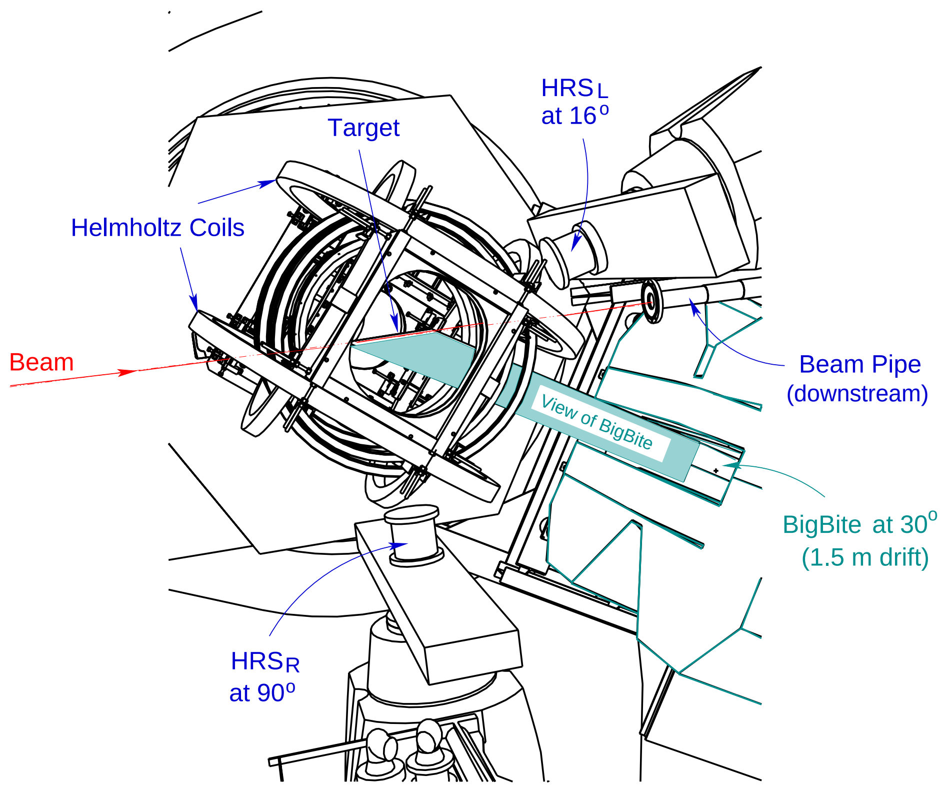
$$A_{UT}(\phi_h^l, \phi_S^l) = \frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow}$$

$$A_{UT} \propto |S_T|(1-y) \cdot \frac{P_{h\perp}}{zM_h} \sin(\phi_h^\ell + \phi_S^\ell) \cdot \sum e_q^2\, h_1^q(x) H_1^{\perp f}(z, P_{h\perp}^2)$$

$$+ \quad |S_T|(1-y+\frac{y^2}{2}) \frac{P_{h\perp}}{zM_N} \sin(\phi_h^\ell - \phi_S^\ell) \cdot \sum e_q^2\, f_{1T}^{\perp(1)q}(x) D_1^q(z_h, P_{h\perp}^2)$$

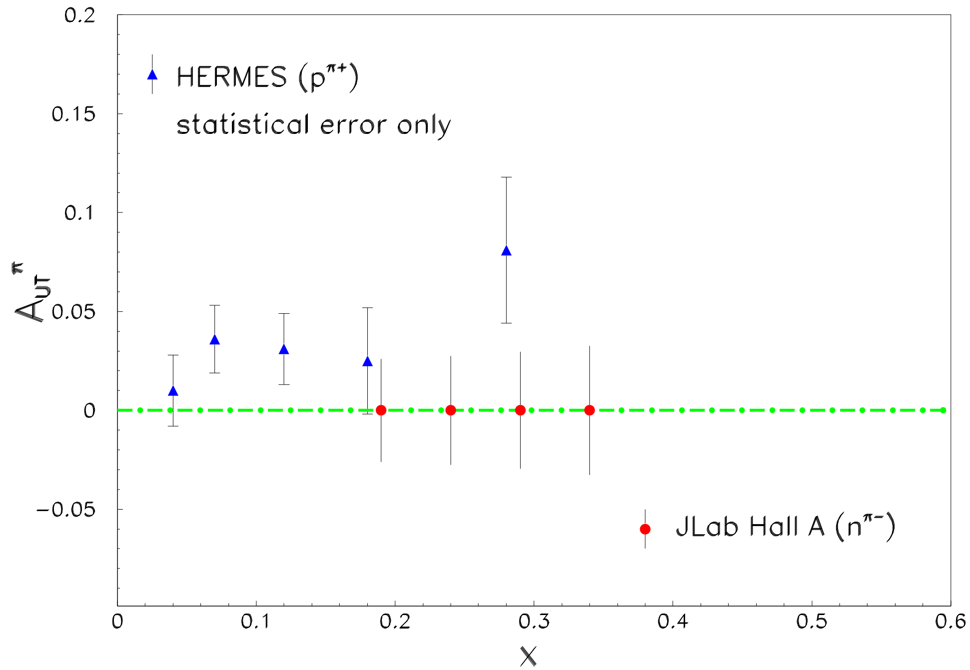
$\Rightarrow$ A 6 GeV beam on a transversely polarized ^{3}He target: $n^\uparrow(e, e'\pi^-)X$.

E03-004 Layout : $n^{\uparrow}(e, e'\pi^{-})X$



- A magnetic spectrometer BigBite as e-arm: at 30°.
- One existing high resolution spectrometer as h-arm: at 16°.
- Hall A ^{3}He$^{\uparrow}$ target. Rotate ϕ_S to cover $\phi_{Collins}$ and ϕ_{Sivers}.

Compared with Hermes Data



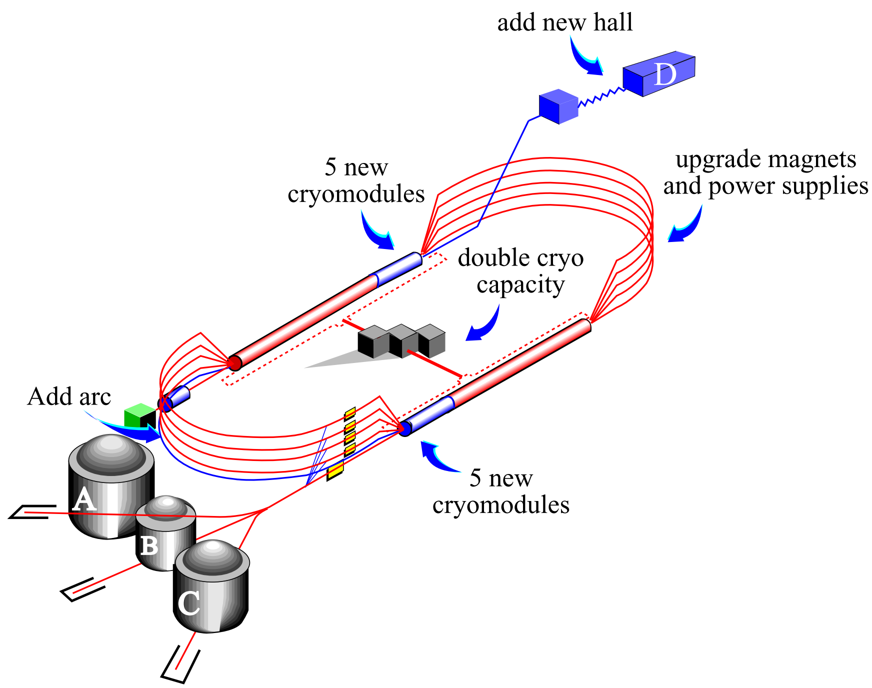
$$A_{UT}^{\pi^+}(p) \propto 4\delta u \cdot H_1^{\perp +} + \delta d \cdot H_1^{\perp -}$$

$$A_{UT}^{\pi^-}(n) \propto 4\delta d \cdot H_1^{\perp -} + \delta u \cdot H_1^{\perp +}$$

$A_{UT}^{\pi^+}(p)$: δu dominates.

$A_{UT}^{\pi^-}(n)$: access both δu and δd.

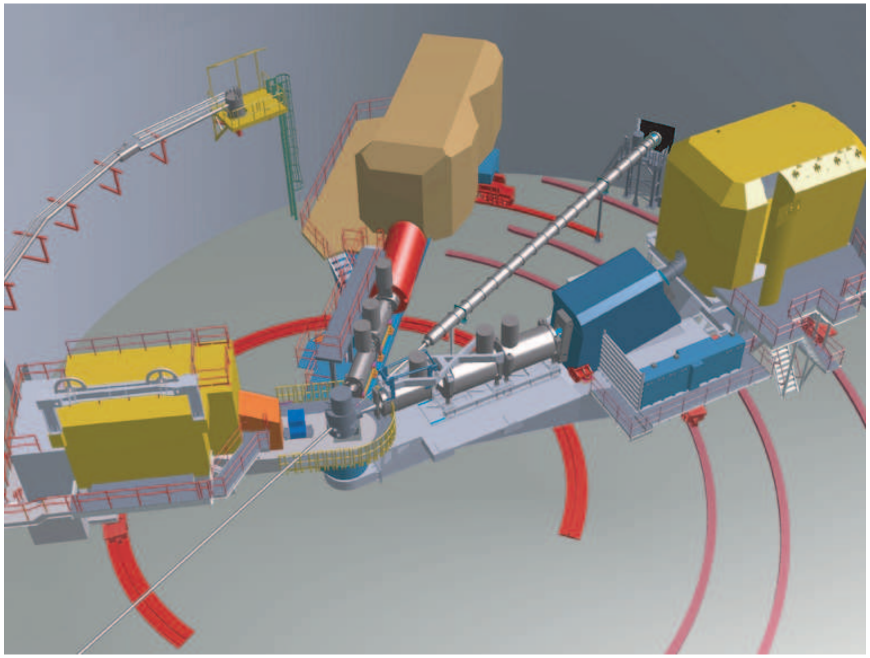
Spin Physics with Jefferson Lab 12 GeV Upgrade



The planned 12 GeV energy upgrade:

- Hall D: a new Hall for real photon physics.
- Hall B: a large acceptance detector for low luminosity operation.
- Hall C: a pair of magnetic spectrometers for high luminosity operation.

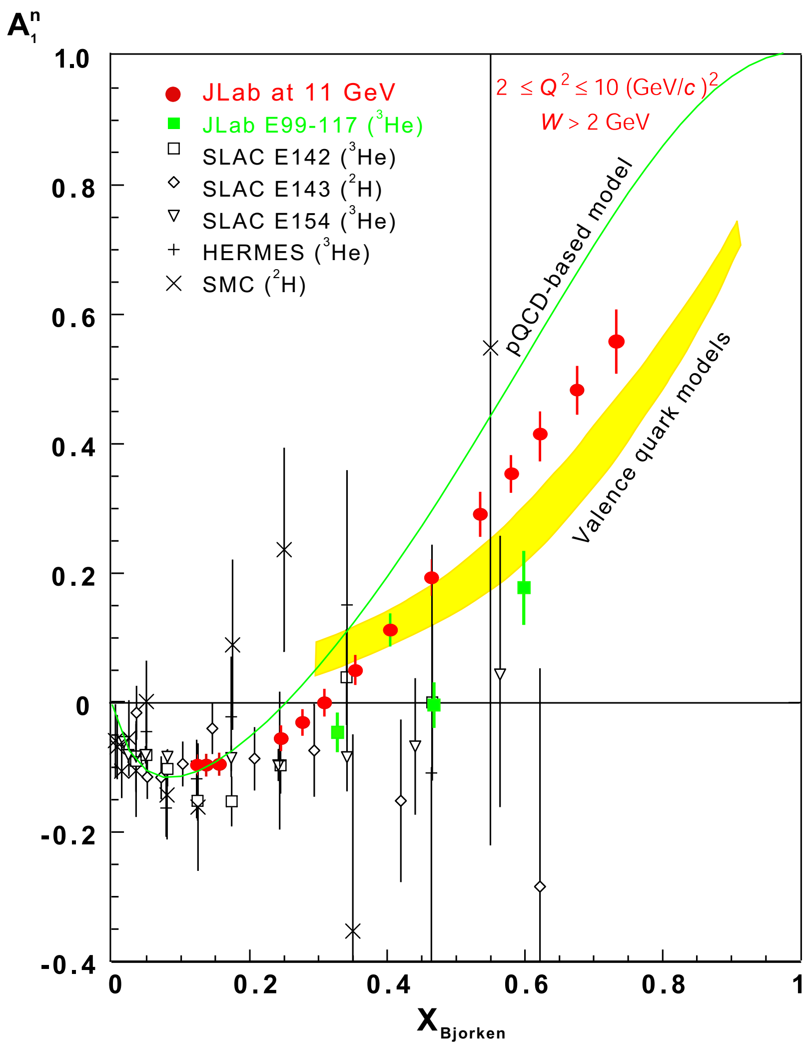
Spin Physics in the High Luminosity Hall



A new magnetic spectrometer to pair with the existing HMS spectrometer.

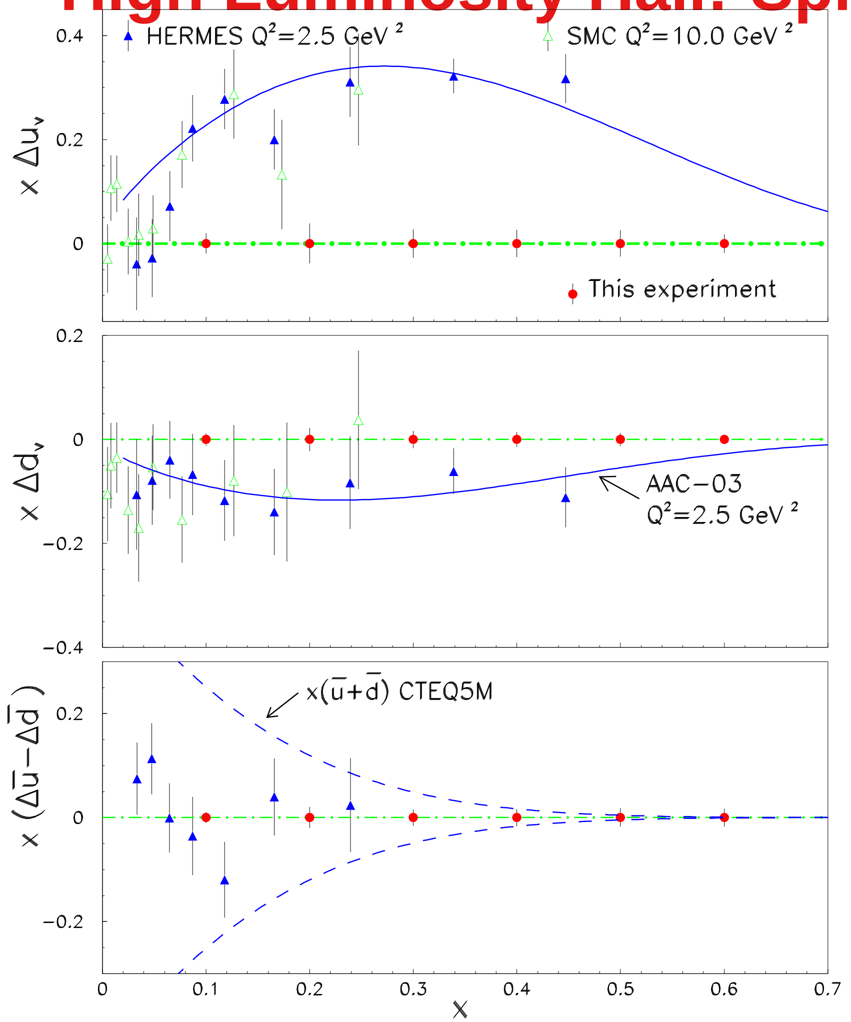
- Inclusive spin asymmetry at high-x.
- Spin-flavor decomposition on polarized NH_3, LiD and ^{3}He targets.
- Flavor asymmetry in the polarized sea.
- Transversely polarized target to measure transversity.

High Luminosity Hall: A_1^n at High-x

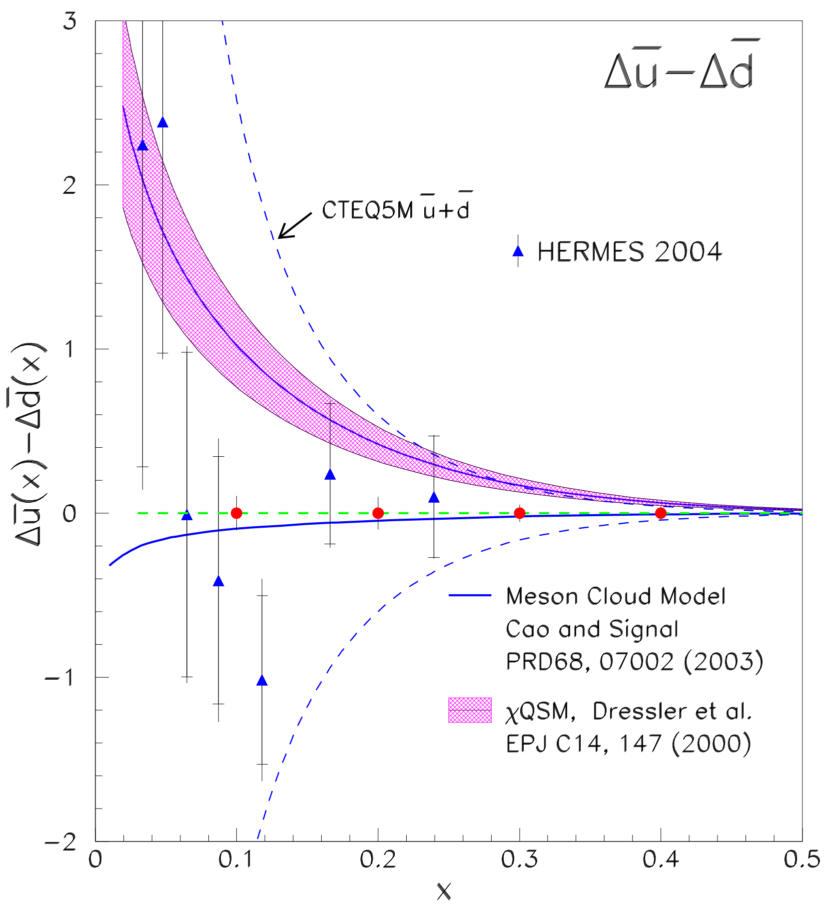


- Inclusive spin asymmetry at high-x.

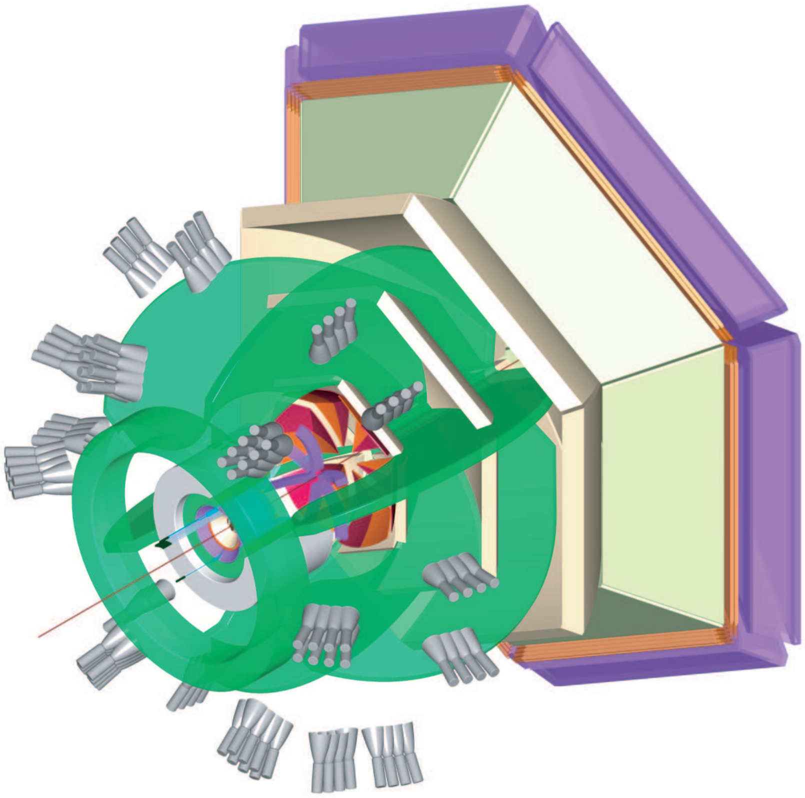
High Luminosity Hall: Spin-Flavor Decomposition



11 GeV beam on NH_3 and ^{3}He targets.



Spin Physics in the Large Acceptance Hall

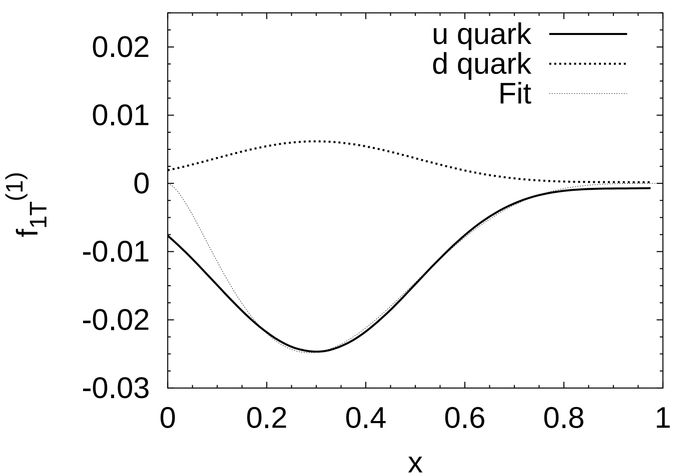


A large acceptance detector designed for multi-particle detection and a large azimuthal coverage.

- Spin asymmetries in exclusive channels, study of generalized parton distributions, link with quark angular momentum.
- Semi-Inclusive asymmetries with longitudinal and transverse targets. Transversity and Sivers asymmetries. Transverse momentum dependent quark distributions.

The Combined A_{UT}^{h} to Extract Sivers Function $f_{1T}^{\perp q}$

Leading twist quark transverse momentum dependent distribution, originated from the imaginary part of the interference between $L = 0$ and $L = 1$ wave function.



Bag model calculation, F. Yuan, hep-ph/0308157

At the leading order:

$$\left(A_{UT}^{\pi^{+}+\pi^{-}}\right)_{Sivers}(p) = \frac{4f_{1T}^{\perp u} + f_{1T}^{\perp d}}{4u + d}$$

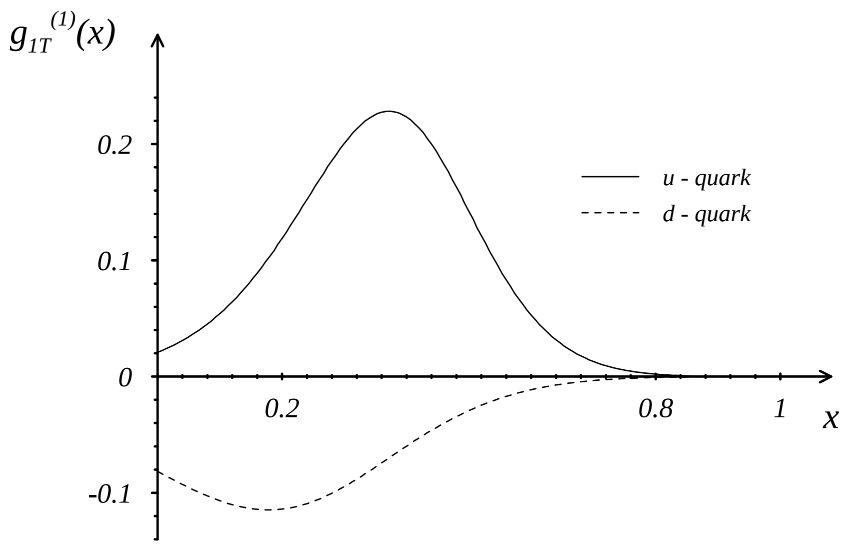
$$\left(A_{UT}^{\pi^{+}+\pi^{-}}\right)_{Sivers}(n) = \frac{f_{1T}^{\perp u} + 4f_{1T}^{\perp d}}{u + 4d}$$

$$\left(A_{UT}^{\pi^{+}-\pi^{-}}\right)_{Sivers}(p) = \frac{4f_{1T}^{\perp u_v} - f_{1T}^{\perp d_v}}{4u - d}$$

$$\left(A_{UT}^{\pi^{+}-\pi^{-}}\right)_{Sivers}(n) = \frac{f_{1T}^{\perp u_v} - 4f_{1T}^{\perp d_v}}{u - 4d}$$

The Combined A_{LT}^{h} Asymmetries to Extract g_{1T}^{q}

Leading twist quark transverse momentum dependent distribution, originated from the real part of the interference between $L = 0$ and $L = 1$ wave function. Double-spin asymmetries A_{LT}^{h} with $\cos(\phi_h - \phi_S)$ dependence.



Bag model calculation, Jacob, Mulders and Rodrigues, NPA 1997.

At the leading order:

$$A_{LT}^{\pi^+ + \pi^-}(p) = \frac{4g_{1T}^{u} + g_{1T}^{d}}{4u + d}$$

$$A_{LT}^{\pi^+ + \pi^-}(n) = \frac{g_{1T}^{u} + 4g_{1T}^{d}}{u + 4d}$$

$$A_{LT}^{\pi^+ - \pi^-}(p) = \frac{4g_{1T}^{u_v} - g_{1T}^{d_v}}{4u_v - d_v}$$

$$A_{LT}^{\pi^+ - \pi^-}(n) = \frac{g_{1T}^{u_v} - 4g_{1T}^{d_v}}{u_v - 4d_v}$$

Double-spin asymmetries A_{LT}^{h} from JLab experiments.

A Few Comments on g_{1T}

A leading-twist k_T dependent distribution:

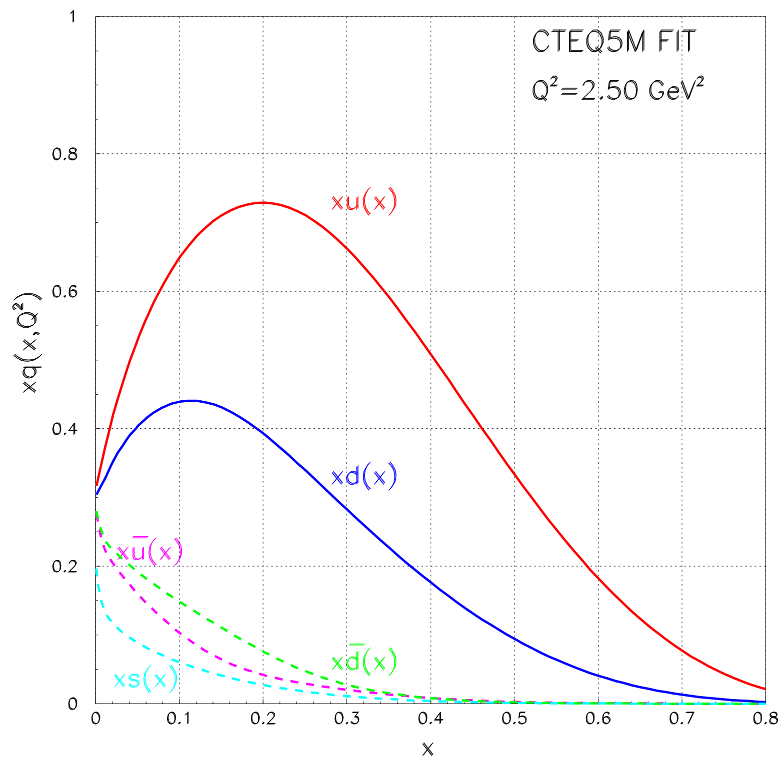
- Never been measured before. No clue on its size. $g_{1T} \equiv 0$ if quark angular momentum $L_q = 0$.
- Linked through Lorentz invarience: $g_2(x) = -\frac{d}{dx} g_{1T}(x)$.
- Some calculation expect a large asymmetry (Yuan, Gamberg).
- Positivity limit link g_{1T} with $f_{1T}^{\perp}$.
- One expects g_{1T}^u / g_{1T}^d behave like g_1^u / g_1^d ?

On the experiment side:

- One of the easiest SIDIS observable to measure at Jefferson Lab.
- HERMES should already have data on $A_{LT}^h(p)$.

Will we have suprises on g_{1T} ? What're our expectations on g_{1T} to start with ?

Can We Access Δs through SIDIS ?



$\Leftarrow$ PDFs from CTEQ5 ($s = \bar{s}$).

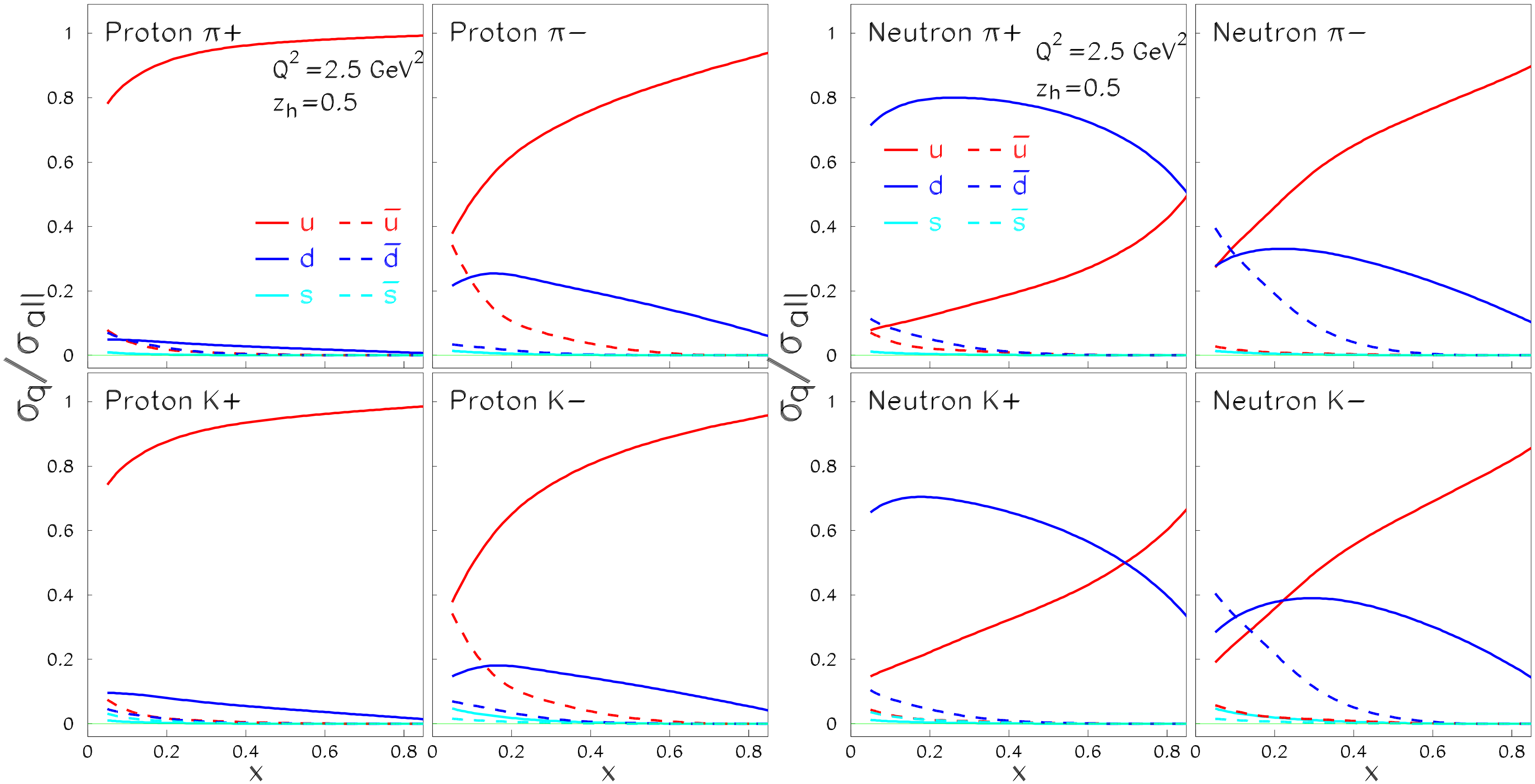
In SIDIS, detect different h off different targets to enhance sensitivity to PDFs through the fragmentation functions D_q^h.

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}

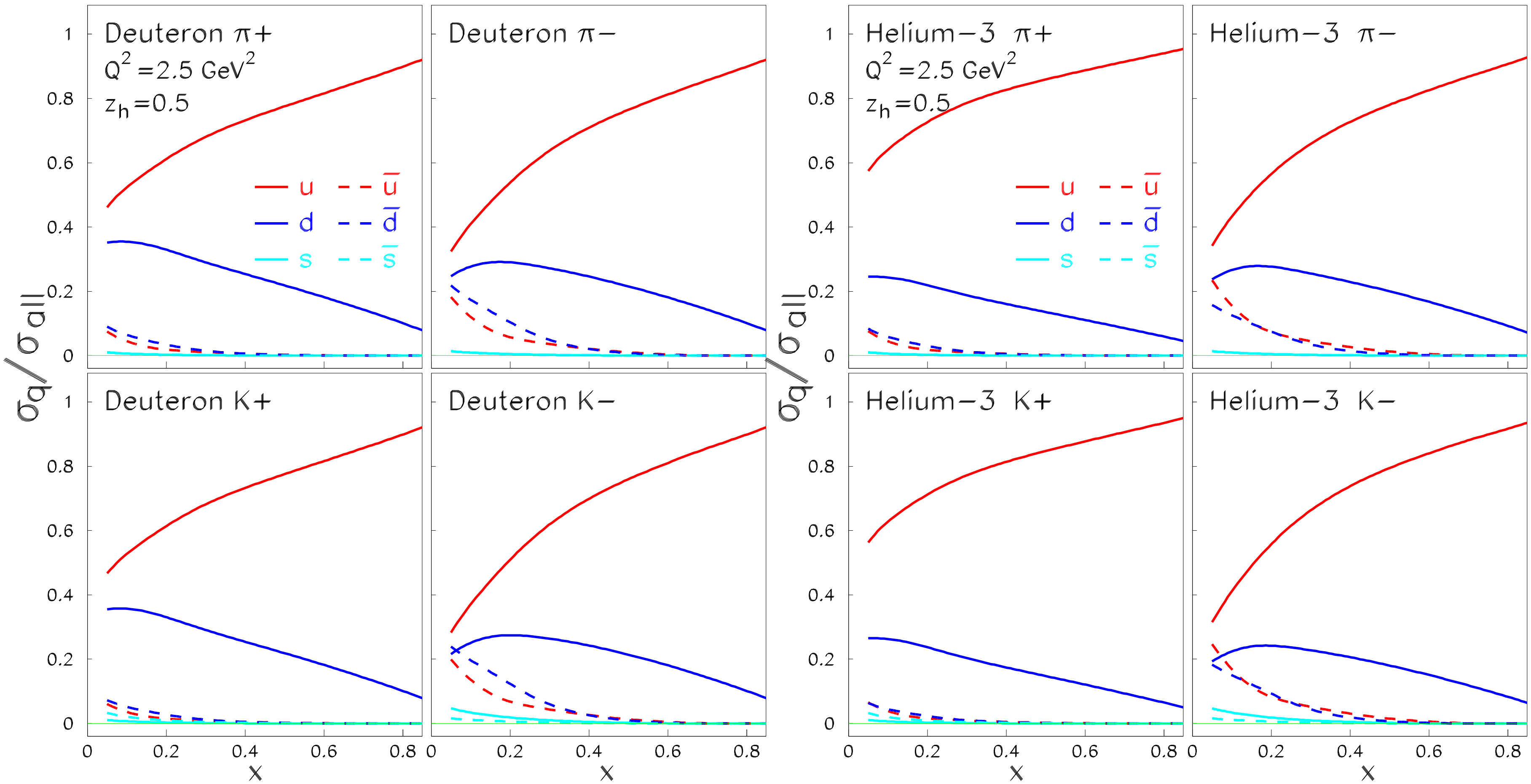
CTEQ5 PDFs, KKP fragmentation functions.



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

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

No sensitivity to $s(x)$ at $x > 0.03$.



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

Summary

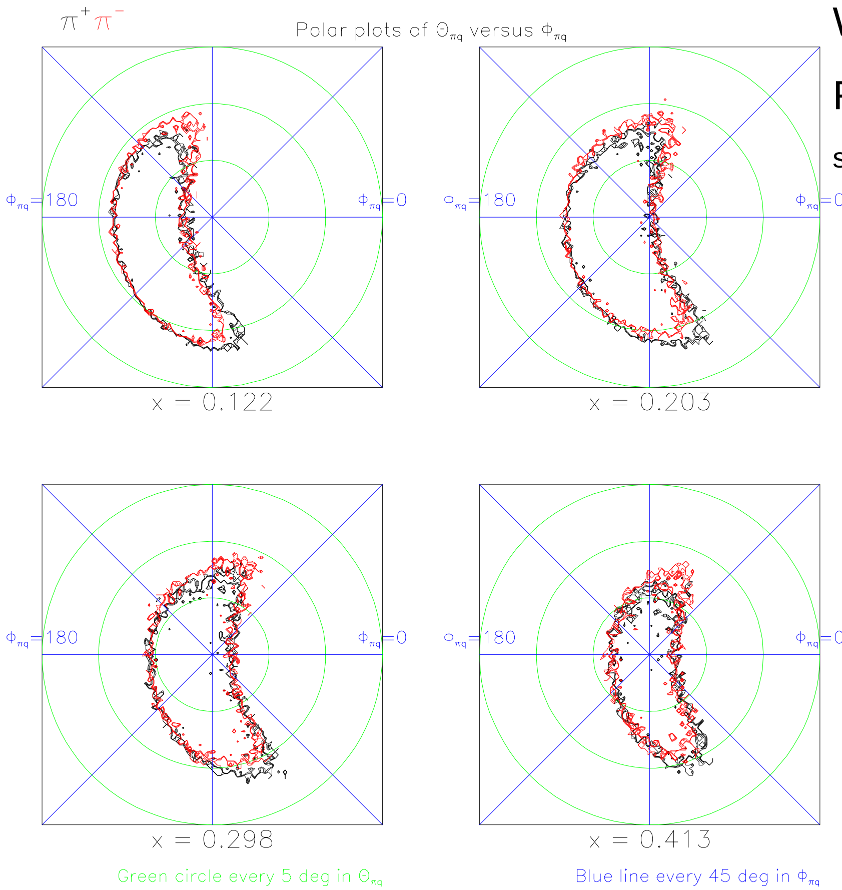
After HERMES, spin physics through SIDIS will be one of the major physics topics at Jefferson Lab at 6 and 12 GeV.

- Spin-flavor decomposition with $\vec{p}$ and $\vec{d}$ (E04-113 in Hall C).
- Spin-flavor decomposition with polarized ^{3}He (new proposal in Hall A).
- Neutron SSA and transversity in Hall A (E03-004).
- Proton SSA and transversity in Hall C (under development).
- Quark transverse momentum dependent distribution g_{1T} on proton (easy for Hall C).

Two comments:

- Δs can not be accessed through SIDIS in the existing machines.
- g_{1T} measurements will come in the next few years.

Angular Coverage in (θ_{qh}, ϕ_l^h)



We cover at least 180° in ϕ_l^h.

Related terms in ϕ_l^h:

see Boer and Mulders, PRD57, 5780 (1998)

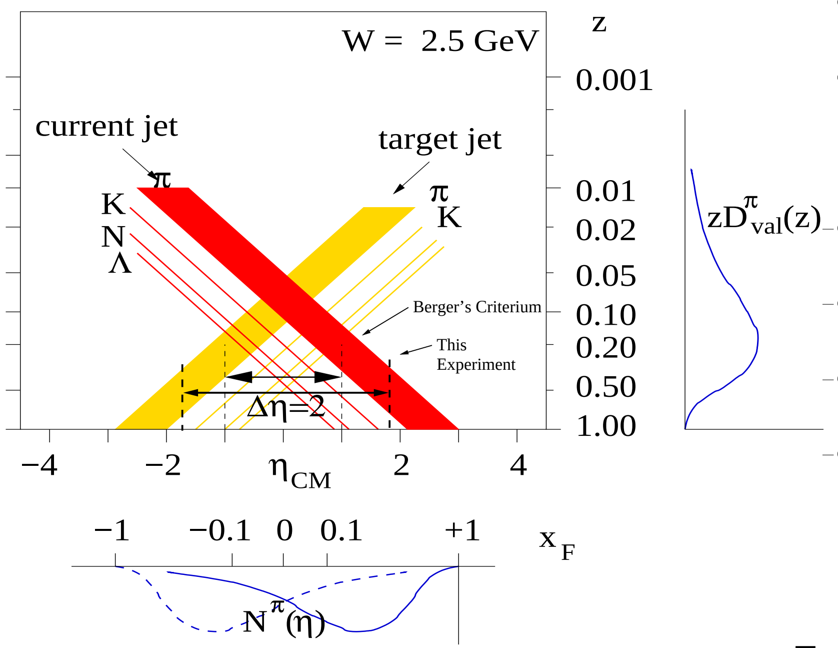
- $\cos(2\phi_l^h)$ term in $d\sigma^h$ averaged out.
- $\cos(\phi_l^h)$ term in A_{LL} is small ($\propto S_T$), reverse sign when target spin is reversed.
- Unexpected $\sin(\phi_l^h)$ term in A_{LL} can be checked with data.
- Extra free physics: large enough coverage in ϕ_l^h even allow extraction of single-spin asymmetry A_{UL} for $\sin\phi_l^h$ and $\sin(2\phi_l^h)$ moments.

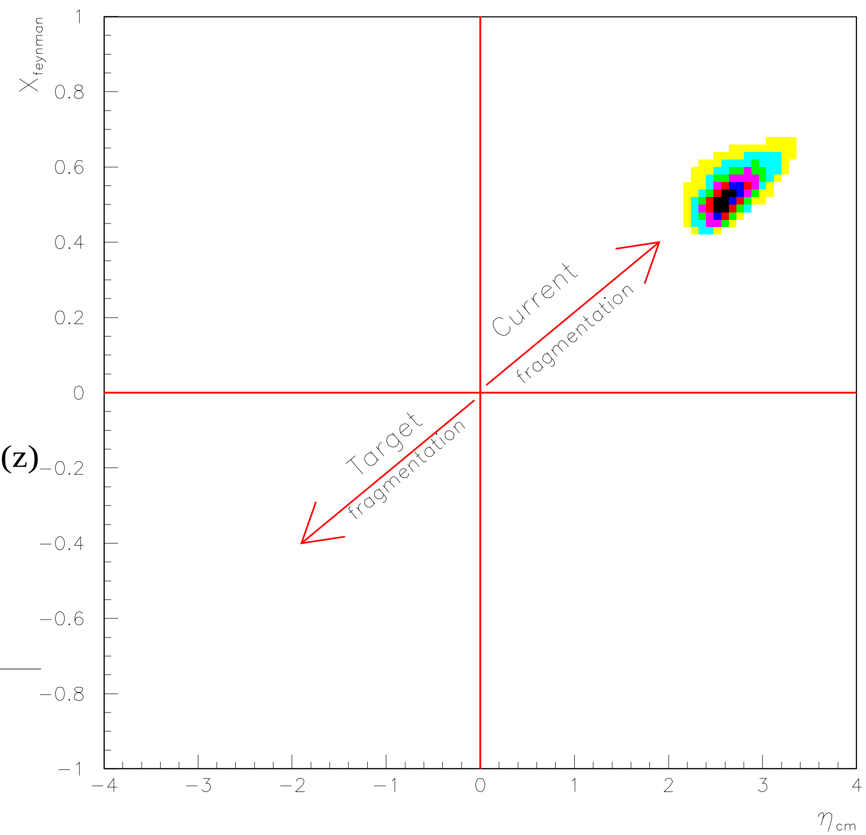
Kinematics Strongly Favor Current Fragmentation

Center of Mass rapidity

$\eta_{CM} = \frac{1}{2} ln \frac{E^\star + P_L^\star}{E^\star - P_L^\star}$

and $x_F = \frac{P_L^\star}{P_{L max}^\star}$ (P. Mulders, hep-ph/0010199.)





For $\pi^\pm$, $\eta_{CM} \sim 2.8$ ($\Delta\eta_{CM} \approx 5.6$), $x_F \sim 0.5$.