Perspective of Spin-Observable Measurements in Semi-Inclusive DIS Strangeness Production with an 11 GeV Beam at Jefferson Lab

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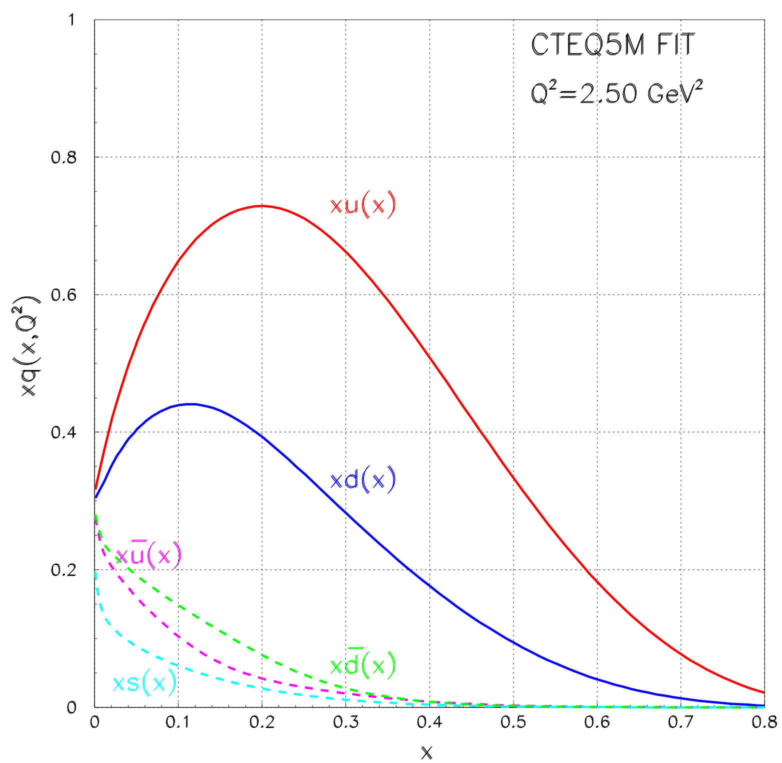
With the planned energy upgrade to 11 GeV and a large acceptance CLAS12 detector operated at the high luminosity of 10^{35} cm^{-2}s^{-1}, Jefferson Lab will provide unique opportunities to study strangeness productions (ϕ meson and Λ^0 hyperon in particular) in semi-inclusive DIS reactions in the current fragmentation regime ($x_F > 0$, $z > 0.5$).

- Accessing strangeness through SIDIS. Sensitivity of charged Kaon production to $s(x)$.
- An alternative method of accessing $(\Delta s + \Delta \bar{s})/(s + \bar{s})$. SIDIS ϕ production.
- Event rates in current fragmentation region with CLAS12 detector and 11 GeV beam.
- Spin-observables in SIDIS Λ production. Rate estimation.
- Summary and conclusions.

Can We Access Δs through SIDIS ?



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

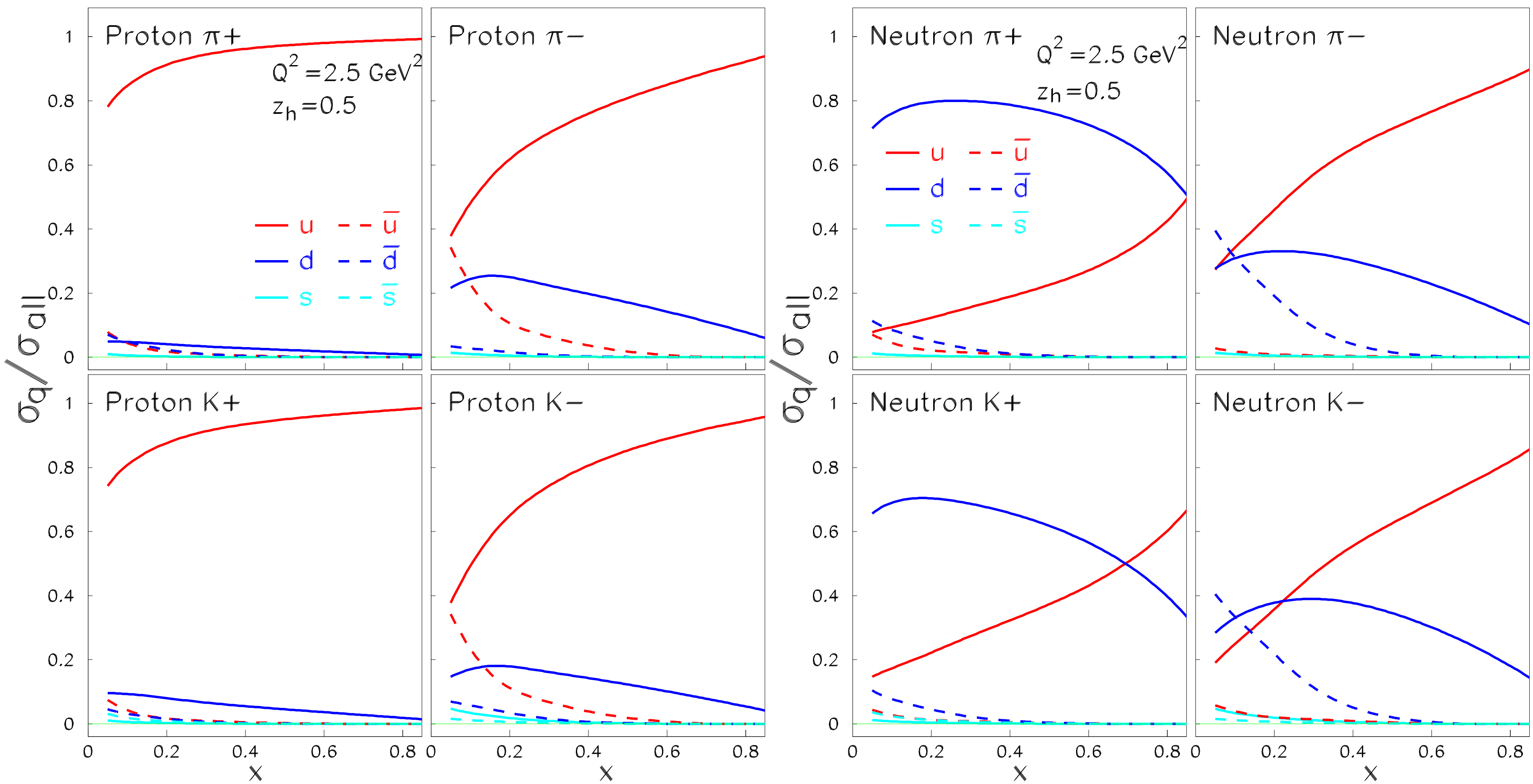
In SIDIS, detect different h off different targets to enhance sensitivity to PDFs through the fragmentation functions D_q^h.

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

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

Sensitivity to PDFs in Unpolarized Cross-Sections σ_{1N}^{h}

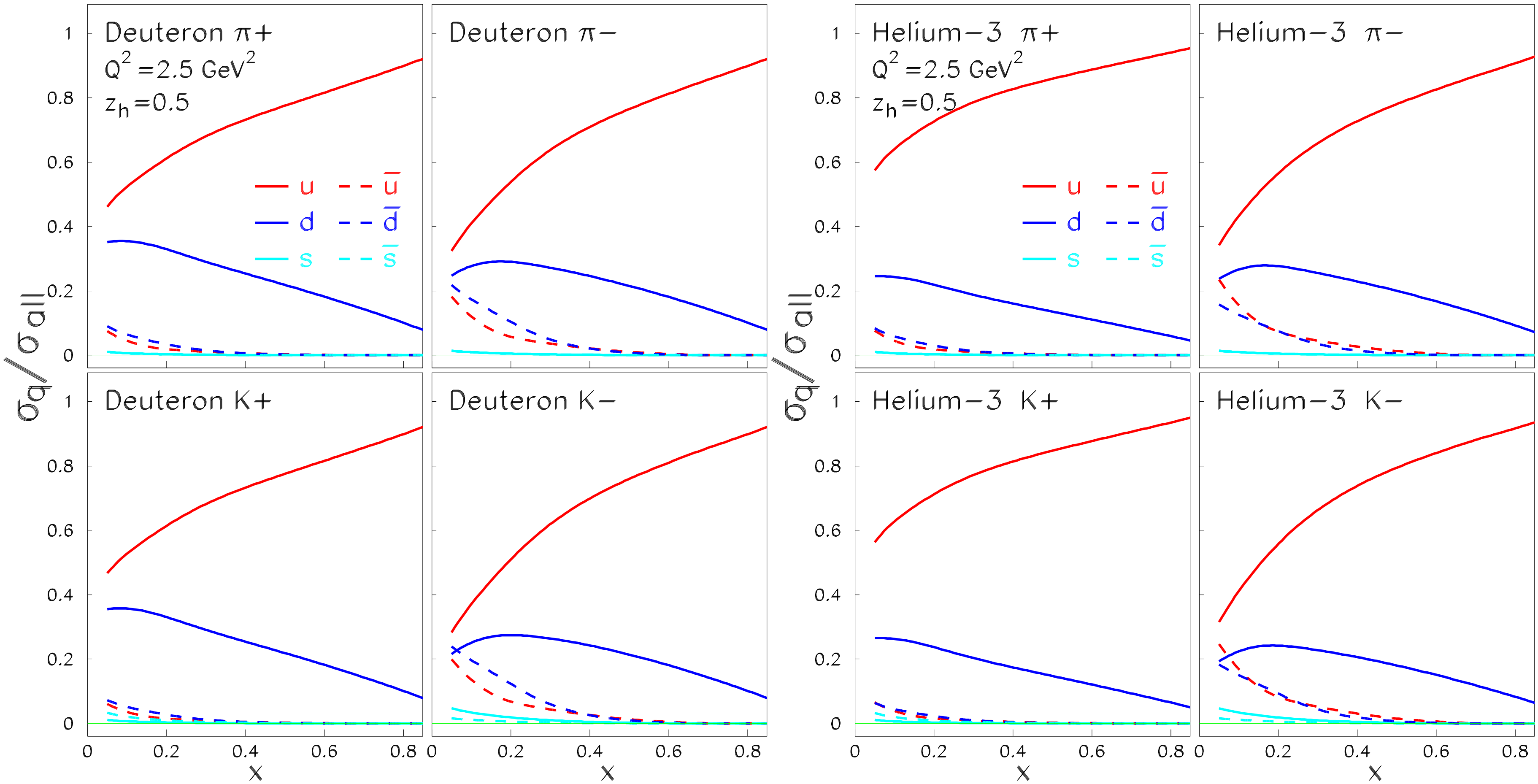
CTEQ5 PDFs, KKP fragmentation functions.



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

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

Strange quarks contribute less than 3% to total SIDIS Kaon cross section at $x > 0.03$.



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

SIDIS ϕ production: strong contributions of s and $\bar{s}$ to the cross section.

$\phi = (s\bar{s})$. $\phi \to K^+K^-$, $M = 1.020$ GeV. Full width $\Gamma = 4.43$ MeV.

Two types of fragmentation function under SU(2) and charge conjugation:

Favored: $D_s^\phi = D_{\bar{s}}^\phi$, unfavored: $D_u^\phi = D_{\bar{u}}^\phi = D_d^\phi = D_{\bar{d}}^\phi$, and one expects $D_u^\phi \ll D_s^\phi$.

Leading order cross sections:

$$\sigma_p^\phi(x,z) = [4u(x) + d(x)] \cdot D_u^\phi(z) + [s(x) + \bar{s}(x)] \cdot D_s^\phi(z),$$

$$\sigma_n^\phi(x,z) = [4d(x) + u(x)] \cdot D_u^\phi(z) + [s(x) + \bar{s}(x)] \cdot D_s^\phi(z).$$

$s + \bar{s}$ contribute to $10 \sim \ 20\%$ of the cross section.

Measurements on unpolarized Proton and Deuteron targets:

$$\sigma_p^\phi = (4u + d) \cdot D_u^\phi + (s + \bar{s}) \cdot D_s^\phi,$$

$$\sigma_{p+n}^\phi = 5\,(u + d) \cdot D_u^\phi + 2\,(s + \bar{s}) \cdot D_s^\phi.$$

$$(s + \bar{s}) \cdot D_s^\phi = \frac{4u + d}{3(u - d)} \cdot \sigma_{p+n}^\phi - \frac{5(u + d)}{3(u - d)} \cdot \sigma_p^\phi.$$

Measurements of double-spin asymmetries on polarized Proton and Deuteron targets:

$$\frac{\Delta s + \Delta \bar{s}}{s + \bar{s}} = \frac{A_{1p+n}^\phi - \frac{5(u + d)}{4u + d} \cdot \frac{\sigma_p^\phi}{\sigma_{p+n}^\phi} \cdot A_{1p}^\phi}{1 - \frac{5(u + d)}{4u + d} \cdot \frac{\sigma_p^\phi}{\sigma_{p+n}^\phi}}.$$

If we determine measure cross section ratio to 1% level, asymmetries to 0.3$\%$.

$\Rightarrow$ $\pm 10\%$ uncertainty on $\dfrac{\Delta s + \Delta \bar{s}}{s + \bar{s}}$. Don't even care F.F.-ratio in this method.

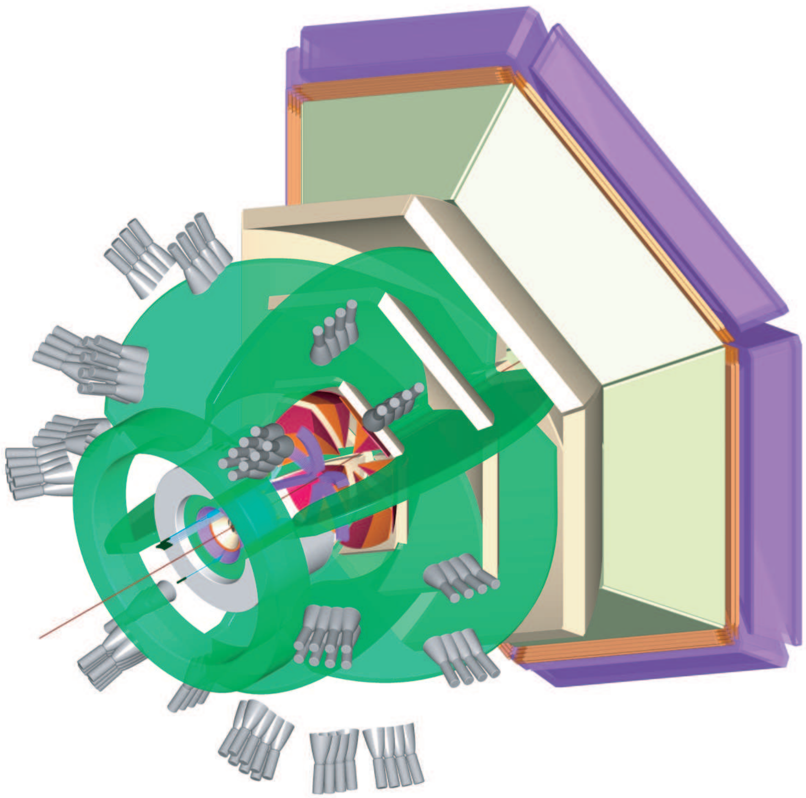
Or, use the well-known inclusive asymmetries A_{1p} and A_{1d} as extra inputs to solve for $\Delta s + \Delta \bar{s}$ in the over-constrained relations:

$$\frac{\sigma_p^\phi}{\sigma_{p+n}^\phi} = \frac{\frac{4u+d}{5(u+d)} \cdot \frac{D_u^\phi}{D_s^\phi} + \frac{s+\bar{s}}{5(u+d)}}{\frac{D_u^\phi}{D_s^\phi} + \frac{2(s+\bar{s})}{5(u+d)}}$$

$$A_{1p}^\phi = \frac{A_{1p} \cdot \frac{D_u^\phi}{D_s^\phi} + \frac{\Delta s + \Delta \bar{s}}{4u+d}}{\frac{D_u^\phi}{D_s^\phi} + \frac{s+\bar{s}}{4u+d}}$$

$$A_{1p+n}^\phi = \frac{A_{1d} \cdot \frac{D_u^\phi}{D_s^\phi} + \frac{2(\Delta s + \Delta \bar{s})}{5(u+d)}}{\frac{D_u^\phi}{D_s^\phi} + \frac{2(s+\bar{s})}{5(u+d)}}$$

JLab 12 GeV upgrade: the Large Acceptance Hall (CLAS12)



A large acceptance detector for multi-particle detection, cover up to 30°.

- Luminosity (unpolarized target): 10^{35} cm^{-2}s^{-1}.
- Luminosity (polarized proton NH_3): 2^{34} $\vec{p}$ cm^{-2}s^{-1}. 80% polarization.

Momentum resolution $\sim 1\%$, angular resolution 2.0 mrad.

We performed LUND Monte Carlo simulations and compared CLAS12 with HERMES 1996-2000 event sample.

Monet Carlo event selection:

- DIS: $Q^2 > 1.0$ GeV^2, $W > 2.0$, access $0.12 < x < 0.5$.
- SIDIS: $W' > 2.0$ GeV, $z_\phi > 0.5$. Current fragmentation: $x_F > 0$.
- Reconstructed ϕ mass.

About $\sim 20\%$ of ϕ come from the struck strange-quark.

4 hours of CLAS12 run $\approx$ HERMES 1996-2000 data sample ($\sim$3k SIDIS ϕ).

100 days of CLAS12 (unpol. p) $\Rightarrow$ 2 million SIDIS ϕ events.

Assuming CLAS12 will run:

100 days on unpolarized proton. 100 days on unpolarized deuteron.

> 150 days on polarized proton. > 150 days on polarized deuteron.

$\Rightarrow$ better than 1$\%$ statistical accuracies on A_{1p}^{ϕ} and A_{1p+n}^{ϕ} over 4-x bins in $0.12 < x < 0.5$.

Issues to be Addressed Further

Interpretation:

- Physics background: gluon fusion.
- Physics background: target fragmentation v.s current fragmentation.

Quark to ϕ fragmentation functions D_u^ϕ and D_s^ϕ:

- Data from existing e^+e^- measurements (BELLE) ?
- Models to predict fragmentation function ratios D_u^ϕ/D_s^ϕ ?
- SU(2) and charge conjugation for fragmentation functions ?

A detailed experiment proposal to be submitted in 2007 to JLab's 12 GeV PAC.

SIDIS Λ^0 production with CLAS12

Λ hyperons have the peculiar feature of revealing their polarization through the angular distribution of their weak decay $\Lambda \to p\pi$ with an analyzing power of 0.642 ± 0.013; such a self-analyzing feature allowed the spin components of the final state Λ to be extracted (see HERMES, COMPASS and RHIC talks of this conference). Many measurements were made in the history, and the results often turned out to be very surprising.

Quark configuration $\Lambda^0 = (uds)$. $m_\Lambda = 1115.68$ MeV, very narrow, $c\tau = 7.89$ cm.
$\Rightarrow$ Very relaxed requirements on PID precision and background rates.

We performed LUND Monte Carlo studies of SIDIS Λ production with an 11 GeV beam and the large acceptance CLAS12 detector, and compared rates with HERMES 1996-2000 events sample.

Monet Carlo event selection:

- DIS: $Q^2 > 1.0$ GeV^2, $W > 2.0$, access $0.12 < x < 0.5$.
- SIDIS: $W' > 2.0$ GeV, $z_\Lambda > 0.5$. Current fragmentation: $x_F > 0$.
- Reconstructed Λ mass 10 MeV cut. 5 cm decay length cut.

2~ 3 hours of CLAS12 run $\approx$ HERMES 1996-2000 data sample ($\sim$10k SIDIS Λ).

100 days of CLAS12 (unpol. p) $\Rightarrow$ 10 million SIDIS Λ events.

To get 1% precision on Λ polarization one only needs $\sim$ 20k events.

Can afford to cut on $x_F > 0.2$.

Spin observables in Λ production: long. double-spin asymmetries

Following M. Anselmino *et. al* (hep-ph/0302008), we define:

$$d\sigma_{\lambda\mu}^{\Lambda h} \equiv \frac{d\sigma^{l(\lambda)p(\mu)\to\Lambda(h)X}}{dxdydz}$$

Neglecting weak interaction contribution, there are 4 independent helicity observables involve longitudinal double-spin.

The spin-averaged (unpolarized) cross section is:

$$d\sigma^{\Lambda} = \frac{2\pi\alpha^2}{sx}\frac{1+(1-y)^2}{y^2}\sum_q e_q^2\, q(x)\cdot D_{\Lambda/q}(z),$$

Beam-target longitudinal double-spin asymmetry:

$$A_{\|} \equiv \frac{d\sigma_{++}^{\lambda} - d\sigma_{+-}^{\lambda}}{2d\sigma^{\Lambda}} = \frac{y(2-y)}{1+(1-y)^2}\frac{\sum_q e_q^2\,\Delta q(x)\cdot D_{\Lambda/q}(z)}{\sum_q e_q^2\, q(x)\cdot D_{\Lambda/q}(z)},$$

Beam to Λ longitudinal spin transfer with an unpolarized nucleon:

$$P_{+0} \equiv \frac{d\sigma_{+0}^{\lambda+} - d\sigma_{+0}^{\lambda-}}{2d\sigma^{\Lambda}} = \frac{y(2-y)}{1+(1-y)^2} \frac{\sum_q e_q^2\, q(x) \cdot \Delta D_{\Lambda/q}(z)}{\sum_q e_q^2\, q(x) \cdot D_{\Lambda/q}(z)}.$$

- Check-1: at high enough-x, when s-quark contribution to the cross section can be neglected, one expects

$$P_{+0}(p) = P_{+0}(n) = P_{+0}(p+n) = D(y) \cdot \frac{\Delta D_{\Lambda/u}(z)}{D_{\Lambda/u}(z)}.$$

- Check-2: $\dfrac{\Delta D_{\Lambda/q}(z)}{D_{\Lambda/q}(z)}$ agrees with neutrino scattering data on longitudinal $\vec{\Lambda}$.

Target to Λ longitudinal spin transfer with an unpolarized lepton beam:

$$P_{0+} \equiv \frac{d\sigma_{0+}^{\lambda+} - d\sigma_{0+}^{\lambda-}}{2d\sigma^{\Lambda}} = \frac{\sum_q e_q^2\, \Delta q(x) \cdot \Delta D_{\Lambda/q}(z)}{\sum_q e_q^2\, q(x) \cdot D_{\Lambda/q}(z)}.$$

- Check-3: a well-defined relation between three observables.

$$P_{o+} = A_{||} \cdot P_{+0}/D^2(y).$$

Spin observables in Λ production: transverse target spin transfer to $\Lambda^{\uparrow}$

$lp^{\uparrow} \to \Lambda^{\uparrow} X$ with an unpolarized lepton, a transversely polarized nucleon (S_N) and measure the Λ transverse polarization P_N which is orthogonal to the $\gamma^{\star} - \Lambda$ plane:

$$P_N^{[0S_N]} = \frac{2(1-y)}{1+(1-y)^2} \frac{\sum_q e_q^2 \, h_{1q}(x) \cdot \Delta_T D_{\Lambda/q}(z)}{\sum_q e_q^2 \, q(x) \cdot D_{\Lambda/q}(z)}.$$

Access transversity without involving quark transverse momentum k_T. No complications of Sivers function.

When neglecting sea quarks, on a proton:

$$P_N^{[0S_N]}(p) = \frac{2(1-y)}{1+(1-y)^2} \frac{4h_{1u} + h_{1d}}{4u + d} \cdot \frac{\Delta_T D_{\Lambda/u}(z)}{D_{\Lambda/u}(z)}.$$

On a deuteron:

$$P_N^{[0S_N]}(p+n) = \frac{2(1-y)}{1+(1-y)^2} \frac{h_{1u} + h_{1d}}{u + d} \cdot \frac{\Delta_T D_{\Lambda/u}(z)}{D_{\Lambda/u}(z)}.$$

Single-spin asymmetry: induced polarization $\Lambda^{\uparrow}$

Unpolarized beam, measure the Λ transverse polarization P_N which is orthogonal to the $\gamma^{\star} - \Lambda$ plane:

$$P_N(\Lambda, p_T) = \frac{\sum_q e_q^2 q(x) \cdot \Delta^N D_{\Lambda^{\uparrow}/q}(z, p_T)}{\sum_q e_q^2 q(x) \cdot D_{\Lambda/q}(z, p_T)}.$$

At large enough x, neglecting s-quark:

$$P_N(\Lambda) = \frac{\Delta^N D_{\Lambda^{\uparrow}/u}}{D_{\Lambda/u}}.$$

- Check-4: $P_N(\Lambda, p) = P_N(\Lambda, p+n)$.

The same quantity shows up in neutrino charge current reaction $\nu p \to l\Lambda^{\uparrow} X$.

- Check-5: $P_N^{[\nu l]} = P_N(\Lambda)$.

Summary

- SIDIS charged Kaon production measurements have limited sensitivity to Δs.
- ϕ production in SIDIS offers an alternative probe to access Δs. I presented two methods to obtaining Δs:
  - Use A^{ϕ}_{1p}, A^{ϕ}_{1p+n} and cross section ratio $\sigma^{\phi}_{p}/\sigma^{\phi}_{p+n}$.
  - Use A^{ϕ}_{1p}, A^{ϕ}_{1p+n}, cross section ratio $\sigma^{\phi}_{p}/\sigma^{\phi}_{p+n}$, as well as inclusive DIS asymmetries A_{1p} and A_{1d}.
- With 11 GeV beam and the large acceptance CLAS12 spectrometer operated at $\mathcal{L} = 10^{35}$ cm^{-2} s^{-1}, $\sim$ 1.0 million SIDIS ϕ events are expected for each targets, providing an opportunity to determine Δs.
- $\sim$ 10.0 million SIDIS Λ (1 million $\bar{\Lambda}$) events are expected for each targets, providing access to many new spin observables, fragmentation functions and quark transversity distributions.
- Many build-in cross checks.