Overview of HERMES results on longitudinal spin asymmetries

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Outline

- Introduction
- HERMES experiment overview
- Longitudinal double-spin asymmetries in semi-inclusive DIS
- Longitudinal beam-helicity asymmetries in semi-inclusive DIS
- Spin transfer coefficient $D_{LL}$ to $\Lambda$ hyperon in semi-inclusive DIS
- Summary
Deep-inelastic scattering (DIS) with charged lepton beams is the key tool for probing the structure of the nucleon. With polarized beams and targets the spin structure of the nucleon becomes accessible.

What we need:
- polarized lepton beams
- polarized targets
- large-acceptance spectrometer
- good particle identification (PID)
HERMES experiment

- Located at DESY, Hamburg
- 27.6 GeV longitudinally polarized (up to 60%) e+/e- beam
- Longitudinally polarized (up to 85%) H, D, $^3$He gas target, flip ~ 90 sec
- Transversely polarized H gas target
- Unpolarized H, D, Ne, ... Xe gas target
- Data taking end at 2007
• Top/bottom symmetry
• 40 mrad < θ < 220 mrad

• Particle ID detectors allow for:
  o - lepton/hadron separation
  o - Ring Cerenkov detector (RICH):
    pion/kaon/proton discrimination 2 GeV < p < 15 GeV
Longitudinal double-spin asymmetries

- Cross-section excluding transverse polarization
  - $\lambda$ - beam helicity
  - $\Lambda$ - target helicity
  - U/L – unpolarized/longitudinally polarized

$$\frac{d\sigma^h}{dx \, dy \, dz \, dP_{h\perp} \, d\phi} = \frac{2\pi\alpha^2}{xyQ^2} \frac{y^2}{2(1-\epsilon)} \left(1 + \frac{\gamma^2}{2x}\right)$$

$$F_{UU,T}^h + \epsilon F_{UU,L}^h + \lambda \lambda \sqrt{1 - \epsilon^2} F_{LL}^h$$

$$+ \sqrt{2\epsilon} \left[ \lambda \sqrt{1 - \epsilon} F_{LU}^{h,\sin\phi} + \Lambda \sqrt{1 + \epsilon} F_{UL}^{h,\sin\phi} \right] \sin\phi$$

$$+ \sqrt{2\epsilon} \left[ \lambda \Lambda \sqrt{1 - \epsilon} F_{LL}^{h,\cos\phi} + \sqrt{1 + \epsilon} F_{UU}^{h,\cos\phi} \right] \cos\phi$$

$$+ \Lambda \epsilon F_{UL}^{h,\sin 2\phi} \sin 2\phi + \epsilon F_{UU}^{h,\cos 2\phi} \cos 2\phi \right\}$$

Double-spin asymmetry

$$A_{LL}^h \equiv \frac{\sigma_{++}^h - \sigma_{+-}^h + \sigma_{-+}^h - \sigma_{--}^h}{\sigma_{++}^h + \sigma_{+-}^h + \sigma_{-+}^h + \sigma_{--}^h}$$
In experiment extract instead $A_{\parallel}$ which differs from $A_{LL}$ in the way the polarization is measured:

- $A_{LL}$: along virtual-photon direction
- $A_{\parallel}$: along beam direction (results in small admixture of transverse target polarization and thus contributions from $A_{LT}$)

$A_{\parallel}$ related to virtual-photon–nucleon asymmetry $A_1$

$$
A_1^h = \frac{1}{D(1 + \eta \gamma)} A_{\parallel}^h
$$

$$
D = \frac{1 - (1 - y) \epsilon}{1 + \epsilon R}
$$

$$
\eta = \frac{\epsilon \gamma y}{1 - (1 - y) \epsilon}
$$
x dependence of $A_{\parallel}$
z dependence of $A_{||}$

in general, no strong $z$-dependence visible

[arXiv:1810.07054]
$P_{h\perp}$ dependence of $A_{||}$

[arXiv:1810.07054]

again, no strong dependence
Charge-difference asymmetries

\[ A_{1}^{h^{+} - h^{-}}(x) \equiv \frac{\left( \sigma_{3/2}^{h^{+}} - \sigma_{3/2}^{h^{-}} \right) - \left( \sigma_{1/2}^{h^{+}} - \sigma_{1/2}^{h^{-}} \right)}{\left( \sigma_{1/2}^{h^{+}} - \sigma_{1/2}^{h^{-}} \right) + \left( \sigma_{3/2}^{h^{+}} - \sigma_{3/2}^{h^{-}} \right)} \]

1/2(3/2) – denotes beam and target spins antiparallel (parallel)

- no significant hadron-type dependence for deuterons
- deuteron results (unidentified hadrons) consistent with COMPASS
Summary

- several longitudinal double-spin asymmetries in SIDIS have been presented that:
  - extend the analysis of previous HERMES publications to include also transverse-momentum dependence
  - provide $A_{||}$ in addition to $A_1$
- within precision of the measurements, the virtual-photon-nucleon asymmetries display no significant dependence on $z$ and $P_{h\perp}$
- hadron-charge difference asymmetries in agreement with COMPASS
Beam-helicity asymmetries

- Cross-section excluding transverse polarization
  \( \lambda \) - beam helicity
  \( \Lambda \) - target helicity
  U/L – unpolarized/longitudinally polarized

\[
\frac{d\sigma^h}{dx\,dy\,dz\,dP_{h\perp}d\phi} = \frac{2\pi\alpha^2}{xyQ^2} \frac{y^2}{2(1-\epsilon)} \left( 1 + \frac{\gamma^2}{2x} \right)
\]

\[
\begin{aligned}
F^h_{UU,U} + \epsilon F^h_{UU,L} + \lambda \Lambda \sqrt{1-\epsilon^2} F^h_{LL} \\
+ \sqrt{2\epsilon} \left[ \lambda \Lambda \sqrt{1-\epsilon} F^h_{LU} \sin \phi + \Lambda \sqrt{1+\epsilon} F^h_{UL} \sin \phi \right] \sin \phi \\
+ \sqrt{2\epsilon} \left[ \lambda \Lambda \sqrt{1-\epsilon} F^h_{LL} \cos \phi + \sqrt{1+\epsilon} F^h_{UL} \cos \phi \right] \cos \phi \\
+ \Lambda \epsilon F^h_{UL} \sin 2\phi \sin 2\phi + \epsilon F^h_{UU} \cos 2\phi \cos 2\phi
\end{aligned}
\]

Single-spin asymmetry

\[
A^h_{LU} \equiv \frac{\sigma^h_{+-} + \sigma^h_{++} - \sigma^h_{-+} - \sigma^h_{--}}{\sigma^h_{+-} + \sigma^h_{++} + \sigma^h_{-+} + \sigma^h_{--}}
\]

\[
A^h_{LU} \approx \sqrt{2\epsilon(1-\epsilon)} \frac{F^h_{LU} \sin \phi}{F^h_{UU}} \sin \phi
\]
Beam-helicity asymmetries

\[ F_{LU}^{\sin \phi_h} = \frac{2M}{Q} C \left[ -\hat{h} \cdot k_T \left( xe H_1^1 + \frac{M_h}{M} f_1 \tilde{G}_1^1 \right) + \frac{\hat{h} \cdot p_T}{M} \left( xg_1^1 D_1 + \frac{M_h}{M} h_1^1 \tilde{E}_1 \right) \right] \]

Describe intrinsic motion of quarks and gluons inside target nucleon due to correlations of \( p_T \) and its spin \( s \) with the spin of the target nucleon \( S \)

asymmetry amplitudes extracted by minimizing

\[-\ln \mathbb{L} = -\sum_i w_i \ln \left[ 1 + P_{B,i} \sqrt{2\epsilon_i (1 - \epsilon_i)} A_{LU}^{h,\sin(\phi)} \sin(\phi_i) \right]\]

where \( w_i \) is event weight from hadron-ID, charge-symmetric background, etc.
Beam-helicity asymmetry
3D beam-helicity asymmetry for $\pi^-$
HERMES - CLAS comparison

opposite behavior at HERMES/CLAS of negative pions in z projection due to different x-range
consistent behavior for charged pions / hadrons at HERMES / COMPASS
Summary

- clearly non-zero beam-helicity asymmetries observed for charged pions and K+
- high-x behavior in HERMES - CLAS comparison might be driven by TMD e & Collins FF
- COMPASS and HERMES in agreement despite different Q2 ranges probed
Longitudinal spin transfer $D_{LL'}$ in SiDIS

Due to weak decay polarization of the $\Lambda$ can be extracted by measuring angular distribution of decay proton

$$P_L^\Lambda = P_\gamma D_{LL'} = P_b D(y) D_{LL'}$$

$L$ – primary axis, along virtual photon
$L'$ – secondary axis, along lambda momentum
$P_\gamma = P_v D(y)$, virtual gamma polarization
$D(y)$, depolarization factor

Longitudinal spin transfer coefficient give us access to spin structure of $\Lambda$ hyperon
Invariant mass distribution for $\Lambda$ and $\bar{\Lambda}$

Statistic for $\bar{\Lambda}$ is about 6 times less
Kinematical dependences of $D_{LL}$

HERMES preliminary (1996-2005)

$X$ vs. $D_{LL}$

$Z$ vs. $D_{LL}$

$X_F$ vs. $D_{LL}$
Comparison of HERMES data with other experiments
Summary

- Kinematical dependencies of spin transfer coefficient have been presented.
- All dependencies are practically flat (limited statistic?)
- Comparison with other experiments shows a good agreement.