Transverse target spin asymmetries at COMPASS

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on behalf of the COMPASS collaboration

Hadron Structure '11, Tatranská Štrba, Slovak Republic
The COMPASS experiment at CERN
The COMPASS spectrometer in 2007

- Two stage spectrometer
- Longitudinal polarized $\mu$-beam
- 2002-2004 polarized 6LiD (deuterium) target
- 2007 & 2010 polarized NH$_3$ (proton) target
- Tracking
- Calorimetry
- Particle identification (RICH)

beam: 160 GeV/c
intensity: $2 \cdot 10^8 \mu^+/$spill
luminosity: $5 \cdot 10^{32}$ cm$^{-2}$ s$^{-1}$
The COMPASS target system

- Upgrade of target system in 2005
- Three cells with opposite polarisation (2002-04 two cells)
- 180 mrad geometrical acceptance
- $^6\text{LiD}$:
  - polarization: $\sim48\%$
  - dilution factor: $\sim0.38$
- $\text{NH}_3$:
  - polarization: $\sim90\%$
  - dilution factor: $\sim0.15$
- Transverse polarization reversed every week via microwave
Spin structure → Transversity

Three distribution functions are necessary to describe the spin structure of the nucleon in LO:

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Quark distribution
$q(x) = q^+(x) + q^-(x)$

Helicity distribution
$\Delta q(x) = q^+(x) - q^-(x)$

Transversity distribution
$\Delta_\perp q(x) = q^\perp(x) - q^{\perp}(x)$

- $l N^\uparrow \rightarrow l' hX$  Collins FF
- $l N^\uparrow \rightarrow l' hhX$  Interference FF
- $l N^\uparrow \rightarrow l' \Lambda X$  FF of $q^\perp \rightarrow \Lambda$
Spin structure → Transversity

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Quark distribution
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Transversity distribution
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- $l N^\uparrow \rightarrow l' h X$ **Collins FF**
- $l N^\uparrow \rightarrow l' h h X$ **Interference FF**
- $l N^\uparrow \rightarrow l' \Lambda X$ **FF of $q^\perp \rightarrow \Lambda$**
The Collins modulation

For measuring Transversity quark spin must flip:
→ $\Delta_T q(x)$ decouples from inclusive DIS

Product of $\Delta_T q(x)$ and another chiral-odd function needed: Collins FF $\Delta^0_T D^h_q$
→ $\Delta_T q(x)$ can be extracted via SIDIS on a transversely polarized target.

$$A_{Coll} = \frac{A_C^h}{f \cdot P_T \cdot D_{nn}} = \frac{\sum_q e_q^2 \Delta_T q \cdot \Delta^0_T D^h_q}{\sum_q e_q^2 q \cdot D^h_q}$$

with $P_T$ the target polarization, $f$ the dilution factor and $D_{NN}$ the spin transfer coefficient from the initial to the struck quark

Azimuthal distribution of the produced hadrons:

$$N^\pm_h(\Phi_C) = N^0_h(1 \pm A_C^h \sin(\Phi_C))$$

with Collins angle $\Phi_C = \phi_h - \phi_{s'} = \phi_h + \phi_S - \pi$
# Hadron statistics

## Deuteron data (2002-2004)

### Charged hadrons

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<tr>
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<tbody>
<tr>
<td>$h^+$</td>
<td>8.5M</td>
<td></td>
</tr>
<tr>
<td>$h^-$</td>
<td>7.0M</td>
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### Identified hadrons

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<table>
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<tr>
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<tbody>
<tr>
<td>$\pi^+$</td>
<td>5.2M</td>
<td></td>
</tr>
<tr>
<td>$\pi^-$</td>
<td>4.5M</td>
<td></td>
</tr>
<tr>
<td>$K^+$</td>
<td>0.9M</td>
<td></td>
</tr>
<tr>
<td>$K^-$</td>
<td>0.6M</td>
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## Proton data (2007)

### Charged hadrons

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<tr>
<td>$h^+$</td>
<td>15.1M</td>
<td>10.2M</td>
</tr>
<tr>
<td>$h^-$</td>
<td>12.0M</td>
<td>8.1M</td>
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### Identified hadrons

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<tr>
<td>$\pi^+$</td>
<td>9.6M</td>
<td>6.6M</td>
</tr>
<tr>
<td>$\pi^-$</td>
<td>8.4M</td>
<td>5.8M</td>
</tr>
<tr>
<td>$K^+$</td>
<td>1.7M</td>
<td>1.2M</td>
</tr>
<tr>
<td>$K^-$</td>
<td>1.1M</td>
<td>0.7M</td>
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The Collins modulation – 2007 data

- at small $x$ asymmetries are compatible with zero
- Large signal in the valence region of opposite sign for positive and negative hadrons

$\sigma_{syst} \sim 0.5 \sigma_{stat}$
The Collins modulation

deuteron $\leftrightarrow$ proton

\[ A_{Coll}^p \]

proton

Large signal in the valence region

\[ A_{Coll}^d \]

deuteron

Asymmetries compatible with zero for deuteron data $\rightarrow$ u-d cancellation

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The Collins modulation
Comparison to model predictions

Comparison with the predictions from the fit to the COMPASS deuteron data, HERMES proton data and BELLE e+e− data (Anselmino et al.):
Hadron identification

RICH

- $\text{C}_4\text{F}_{10}$ radiator gas
- likelihood-based algorithm
- purity of $\pi$ sample $> 99\%$

COMPASS 2007 proton data

- $p_{\pi} \sim 3\,\text{GeV}/c$
- $p_{K} \sim 9\,\text{GeV}/c$
- $p_{\pi}^{p} \sim 17\,\text{GeV}/c$
- $p_{\pi}^{2007} \sim 50\,\text{GeV}/c$
The Collins modulation
Identified hadrons 2007

strong signal for $\pi$ in the valence region

\[ K^+, \pi^+: \sigma_{syst} \sim 0.5 \sigma_{stat} \quad ; \quad K^-, \pi^-: \sigma_{syst} \sim 0.7 \sigma_{stat} \]

negative trend for $K^+$

positive trend for $K^-$
The Collins modulation
Identified hadrons compared to Hermes

COMPASS 2007 proton data

preliminary

positive K

negative K

preliminary

positive π

negative π
The Collins modulation
Comparison to model predictions of identified pions

COMPASS 2007 proton data

\[ A^p_{\text{Coll}} \]

π⁺

π⁻

COMPASS 2007 proton data

M.Anselmino et al.

Transverse spin physics

Taking into account the transverse momentum $k_T$ of the quarks:

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Transverse spin physics: TMDs

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<td>$h_{1T}^l(x, k_T)$ Boer-Mulders</td>
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<td>$g_1(x, k_T)$</td>
<td>$h_{1L}^l(x, k_T)$ Worm-gear 1</td>
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<tr>
<td>T</td>
<td>$f_{1T}^l(x, k_T)$ Sivers</td>
<td>$g_{1T}^l(x, k_T)$ Worm-gear 2</td>
<td>$h_{1T}^l(x, k_T)$ Transversity $h_{1T}^l(x, k_T)$ Pretzelosity</td>
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The Sivers modulation

Sivers function $f_{1T}^I(x,k_T)$: Correlation between the transverse spin of a nucleon and the intrinsic transverse momentum of unpolarized quarks

$$A_{Siv} = \frac{A_S^h}{f \cdot P_T} = \frac{\sum_q e_q^2 \cdot f_{1Tq}^I D_q^h}{\sum_q e_q^2 \cdot f_{1q} D_q^h}$$

Azimuthal distribution of the produced hadrons:

$$N_{h}^{\pm}(\Phi_C) = N_{h}^{0}(1 \pm A_S^h \sin(\Phi_S))$$

With Sivers angle $\Phi_S = \phi_h - \phi_s$
The Sivers modulation - 2007 data

- positive signal for positive hadrons
- $h^-$ asymmetry compatible with zero
The Sivers modulation
deuteron $\leftrightarrow$ proton

**proton**

![Graph showing $A_{Siv}^p$ vs $x$ and $p_T^h$](image1)

- Positive signal for positive hadrons

**deuteron**

![Graph showing $A_{Siv}^d$ vs $x$ and $p_T^h$](image2)

- Compatible with zero

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The Sivers modulation W dependency?

Hints for a possible W dependence of the h^+ Sivers asymmetry

PLB 692 (2010)

COMPASS 2007 proton data

\begin{align*}
A_S^{p}\text{ (positive hadrons)} & \quad A_S^{n}\text{ (negative hadrons)} \\
\begin{array}{c}
\begin{array}{c}
\text{positive hadrons} \\
\text{negative hadrons}
\end{array}
\end{array}
\end{align*}

\begin{align*}
A_S^{p} & \quad A_S^{n}
\end{align*}

\begin{align*}
\langle Q^2 \rangle & \text{ (GeV/c}^2) \quad W \text{ (GeV/c}^2)
\end{align*}

\begin{align*}
\langle Q^2 \rangle & \text{ (GeV/c}^2) \\
\begin{array}{c}
\begin{array}{c}
W>7.5 \text{ GeV/c}^2 \\
W<7.5 \text{ GeV/c}^2
\end{array}
\end{array}
\end{align*}

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The Sivers modulation
Comparison to model predictions

Comparison with the predictions from the fit to the COMPASS deuteron and HERMES proton data:

$A_{Sy}$ vs. $x$ 
$A_{Sy}$ vs. $z$ 
$A_{Sy}$ vs. $p_T^h$
The Sivers modulation
Identified hadrons

\[ A_{Siv}^P \]

\( K^+, K^-, \pi^- \sim 0.5\sigma_{\text{stat}}, \pi^+ \sim 0.6\sigma_{\text{stat}}, \pi^+ \text{ scale uncertainty} \pm 0.012 \text{ (abs.)} \)

\[ A_{Siv}^P \]

\( K^+, K^-, \pi^- \sim 0.5\sigma_{\text{stat}}, \pi^+ \sim 0.6\sigma_{\text{stat}}, \pi^+ \text{ scale uncertainty} \pm 0.012 \text{ (abs.)} \)
The Sivers modulation
Identified hadrons

COMPASS 2007 proton data

preliminary

COMPASS 2007 proton data

preliminary

COMPASS 2007 proton data

preliminary

COMPASS 2007 proton data

preliminary

COMPASS 2007 transverse proton data

Clear signal for Sivers asymmetry at small values of W
Conclusions

2007 proton data fully analysed:
- large Collins asymmetry
- positive signal for Sivers asymmetry for positive hadrons
- possible $W$ dependence of Sivers asymmetry
- Sivers asymmetry for $K^+$ larger than for all positive hadrons
- clear signal for Sivers asymmetry for $K^+$ at small values of $W$

2010: one year of data taking on a transversely polarized proton target
- higher statistics
- analysis ongoing
SPARES
Data selection
DIS cuts

\[ Q^2 > 1 \text{ (GeV}/c)^2 \]
\[ 0.1 < y < 0.9 \]
\[ W > 5 \text{ GeV}/c^2 \]
Data selection
Hadron cuts

\[ p_T > 0.1 \text{ GeV}/c \]
\[ z > 0.2 \]
Identified hadrons
kinematical values

COMPASS 2007 transverse proton data

dN/dln(x)

charged hadrons
charged π
charged K

COMPASS 2007 transverse proton data

dN/dp_T

COMPASS 2007 transverse proton data

dN/dz

COMPASS 2007 transverse proton data

dN/dy

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