Longitudinal polarization of $\Lambda$ and $\bar{\Lambda}$ in DIS at COMPASS

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On behalf of the COMPASS Collaboration

DIS-09, Madrid
Physical motivation

Longitudinal polarization of $\Lambda$ and $\bar{\Lambda}$ in DIS is sensitive to:

- $s(x)$, $\bar{s}(x)$
- polarization of strange quarks $\Delta s$
  
  $$\Delta s = \int dx [s_\uparrow(x) - s_\downarrow(x) + \bar{s}_\uparrow(x) - \bar{s}_\downarrow(x)]$$
- $\Lambda$ spin structure
Λ production in DIS, quark fragmentation

Quark fragmentation

Spin transfer from polarized muon

Spin transfer from polarized quark

Λ spin structure
Λ spin structure

- **SU(6) quark model:** \( \Delta s_\Lambda = 1, \Delta u_\Lambda = \Delta d_\Lambda = 0 \)
  100% polarization to \( u \) or \( d \) quarks is no influence on polarization of \( \Lambda \)
  \( P(\Lambda) = 0 \) (for \( u \)-quarks dominance)

- **Burkardt-Jaffe:** \( \Delta u_\Lambda = \Delta d_\Lambda = -0.23 \)
  \( P(\Lambda) \) – negative

- **B.Q.Ma et al.:** \( \Delta u_\Lambda = \Delta d_\Lambda = \Delta s_\Lambda \)
  \( P(\Lambda) \) – positive

- **Lattice calculations:** \( \Delta u_\Lambda = \Delta d_\Lambda \sim 0, \Delta s_\Lambda = 0.68 \)
  \( P(\Lambda) \sim 0 \)
• Production

• Spin transfer to $\Lambda$ and $\bar{\Lambda}$ is mainly due to fragmentation of target remnant and $u,d$-quarks.

Spin transfer to $\Lambda$ and $\bar{\Lambda}$ is mainly due to interaction with strange quark and antiquark.
COMPASS Detector

- Muon filter 1
- ECal1 & HCal1
- SM1 Drift. Ch. RICH
- GEM & MWPCs
- Polarized target
- Beam
- GEM & Micromegas
- Scintillating fibers
- GEM & Straw

160 GeV $\mu^+$ beam
$2.8 \cdot 10^8 \mu$/spill (4.8 s)

$P_b = -0.76 \pm 0.04 - 2003$
$P_b = -0.80 \pm 0.04 - 2004$

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Polarized $^6\text{LiD}$ target (2002-2004)

- polarisation: $> 50\%$
- dilution factor: $\sim 0.4$
- Dynamic Nuclear Polarization
- solenoid field: 2.5 T
- acceptance: 70 mrad
- $^3\text{He}/^4\text{He}$: $T_{min} \approx 50$ mK
- two 60 cm long target cells with opposite polarisation
- regular polarisation reversal by field rotation
Production of $\Lambda(\bar{\Lambda})$

$\bar{\mu}^+ + d \rightarrow \mu^+ + \Lambda + X$

$\Lambda \rightarrow p + \pi^-$

No PID used

$\bar{\mu}^+ + d \rightarrow \mu^+ + \bar{\Lambda} + X$

$\bar{\Lambda} \rightarrow \bar{p} + \pi^+$

$\tilde{\mu}^+ + d \rightarrow \mu^+ + K_S + X$

$K_S \rightarrow \pi^+ + \pi^-$

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Event selection

- **Primary vertex:** in the target
- **Secondary vertex:** 5 cm downstream the target
- $p_T > 23$ MeV/c
- $0 < \theta < 0.1 \text{ rad}$
- $Q^2 > 1$ (GeV/c$^2$
- $0.2 < y < 0.9$

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Comparison with other experiments

<table>
<thead>
<tr>
<th></th>
<th>$N(\Lambda)$</th>
<th>$N(\bar{\Lambda})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>E665</td>
<td>750</td>
<td>650</td>
</tr>
<tr>
<td>NOMAD</td>
<td>8 087</td>
<td>649</td>
</tr>
<tr>
<td>HERMES, 1996-2000</td>
<td>7 300</td>
<td>1 687</td>
</tr>
<tr>
<td>RHIC</td>
<td>30 000</td>
<td>24 000</td>
</tr>
<tr>
<td>COMPASS, 2003,2004</td>
<td>70 000</td>
<td>42 000</td>
</tr>
</tbody>
</table>

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Good agreement between data and MC

\[ \Lambda \]

\[ \langle x_{Bj} \rangle = 0.05 \]
\[ \langle x_F \rangle = 0.23 \]
\[ \langle y \rangle = 0.46 \]
\[ \langle Q^2 \rangle = 3.31 \text{ GeV}^2 \]
\[ \langle x_{Bj} \rangle = 0.050 \]
\[ \langle x_F \rangle = 0.22 \]
\[ \langle y \rangle = 0.48 \]
\[ \langle Q^2 \rangle = 3.27 \text{ GeV}^2 \]
Longitudinal polarization $P_L$

\[
\frac{dN}{d\Omega} = \frac{N_{tot}}{4\pi} (1 + \alpha \vec{P} \cdot \vec{k})
\]

$\alpha = (+)0.642 \pm 0.013$ - $\Lambda(\bar{\Lambda})$ decay parameter

$P$ - polarization vector

$k$ - unit vector along the decay proton momentum

$L$-axis - along the momentum of virtual photon

\[
\frac{N^{obs}}{N_{tot}} \frac{d \cos \theta}{d \cos \theta} = \frac{1 + \alpha \cdot P_L \cdot \cos \theta}{2}
\]
Determination of the angular distribution:

- sidebands subtraction

\[ N(\Lambda) = 45576 \]
\[ \sigma = 2.2 \text{ MeV/c}^2 \]

COMPASS PRELIMINARY
Angular distributions of $\Lambda$ and $\bar{\Lambda}$ (run 2004)

Acceptance correction – using unpolarized MC

$P(K^0)=0.011 \pm 0.005$
Longitudinal spin transfer $D_{LL}$

$D_{LL'}$ - polarization of the struck quark along the axis $L$ is transferred to the $\Lambda$ along the secondary axis $L'$

In our case: $L = L'$

$$P_L = D_{LL} P_b D(y)$$

$P_b$ – beam polarization, $D(y)$ – depolarization factor

$$D(y) = \frac{1 - (1 - y)^2}{1 + (1 - y)^2}$$
Comparison of $\Lambda$ and $\bar{\Lambda}$: $x$

\[ DLL(\Lambda) \neq DLL(\bar{\Lambda}) \]

\[ DLL(\Lambda) = -0.012 \pm 0.047 \pm 0.024 \]
\[ DLL(\bar{\Lambda}) = 0.249 \pm 0.056 \pm 0.049 \]

Table 2. Systematic errors for the spin transfer to $\Lambda$ and $\bar{\Lambda}$.

<table>
<thead>
<tr>
<th>Source of Error</th>
<th>$\Lambda$</th>
<th>$\bar{\Lambda}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spin transfer to kaons, $\delta(K_S^0)$</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td>Variation of the $\cos \theta$ cut, $\delta(\theta)$</td>
<td>0.016</td>
<td>0.044</td>
</tr>
<tr>
<td>Uncertainty of the ss-method, $\delta(ss)$</td>
<td>0.010</td>
<td>0.016</td>
</tr>
<tr>
<td>Uncertainty of the beam polarization, $\delta(P_b)$</td>
<td>0.0006</td>
<td>0.013</td>
</tr>
</tbody>
</table>

$s_{syst} = 0.024 \pm 0.049$

The results are averaged over target polarization
Comparison of $\Lambda$ and $\bar{\Lambda}$: $x_F$

The results are averaged over target polarization

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$P_L$: dependence on the target polarization

\[ \Delta P = P_- - P_+ = -0.01 \pm 0.04, \quad \Lambda \]
\[ = 0.01 \pm 0.05, \quad \bar{\Lambda} \]

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Comparison with other experiments: $\Lambda$

![Graph showing comparison of $D^-_\Lambda$ with different experiments.](chart.png)

Legend:
- NOMAD
- HERMES
- E665
- COMPASS

Preliminary results

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Comparison with other experiments: \( \bar{\Lambda} \)
Theory predictions for $\Lambda$ and $\bar{\Lambda}$

Preliminary predictions for $\Lambda$ and $\bar{\Lambda}$


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Sensitivity to the strange distribution $\bar{s}(x)$

- CTEQ5L
- GRV98
- $D_{LL}(\bar{s})=0$, BJ model
- $D_{LL}(\bar{s})=0$, SU(6) model

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Sensitivity to the strange distribution \( s(x) \)
Conclusions

- Preliminary results on $\Lambda$ and $\bar{\Lambda}$ in transfer in DIS are obtained on statistics 70,000 $\Lambda$ and 42,000 $\bar{\Lambda}$.

- $\text{DLL}(\Lambda) \neq \text{DLL}(\bar{\Lambda})$.

- $\text{DLL}(\Lambda) \sim 0$.

- $\text{DLL}(\bar{\Lambda})$ may be as large as 0.4-0.5.

- First measurement of the $\Lambda$ ($\bar{\Lambda}$) polarization for different target polarization. No significant dependence is found.

- Comparison with theory: spin transfer to $\bar{\Lambda}$ is sensitive to $\Lambda(x)$.

- Present statistics is only 25% of already accumulated.

More interesting things are coming.

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Backup slides
• Influence to different PDF’s

\[ Q^2 = 4 \text{ GeV}^2 \]
Polarization of $\Lambda$ from quark fragmentation

Spin transfer from polarized muon

$$P_\Lambda = \frac{\sum_q e_q^2 [P_b D(y)q(x) + P_T \Delta q(x)] \Delta D^\Lambda_q(z)}{\sum_q e_q^2 [q(x) + P_b P_T D(y)\Delta q(x)] D^\Lambda_q(z)}$$

Spin transfer from polarized quark

$$\Delta D^\Lambda_q = D^{+\Lambda}_q - D^{-\Lambda}_q$$

$$D^\Lambda_q = D^{+\Lambda}_q + D^{-\Lambda}_q$$

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Polarization of $\Lambda$: $P_T = 0$

$$P_\Lambda = \frac{\sum_q e_q^2 P_b D(y)q (x) \Delta D_q^\Lambda (z)}{\sum_q e_q^2 q (x) D_q^\Lambda (z)}$$

$$\Delta D_u^\Lambda = \Delta D_d^\Lambda = 0;$$

$$\Delta D_{\bar{u}}^\Lambda = \Delta D_{\bar{d}}^\Lambda = 0;$$

$$D_{LL}^\Lambda = \frac{1}{9} \frac{s(x) \Delta D_s^\Lambda (z)}{\sum_q e_q^2 q (x) D_q^\Lambda (z)}$$

$$D_{LL}^{\bar{\Lambda}} = \frac{1}{9} \frac{\bar{s}(x) \Delta D_{\bar{s}}^{\bar{\Lambda}} (z)}{\sum_q e_q^2 q (x) D_q^{\bar{\Lambda}} (z)}$$
\( D_{LL}(\bar{\Lambda}) > D_{LL}(\Lambda) \)

\[
D_{LL}^\Lambda = \frac{1}{9} \frac{s(x) \Delta D_s^\Lambda(z)}{\sum_q e_q^2 q(x) D_q^\Lambda(z)}
\]

\[
D_{LL}^{\bar{\Lambda}} = \frac{1}{9} \frac{\bar{s}(x) \Delta D_s^{\bar{\Lambda}}(z)}{\sum_q e_q^2 q(x) D_q^{\bar{\Lambda}}(z)}
\]

Even if \( s(x) = \bar{s}(x) \), \( D_{LL}(\bar{\Lambda}) > D_{LL}(\Lambda) \) due to difference of the denominator:

\( D_{u,d}(\Lambda) > D_{u,d}(\bar{\Lambda}) \)

Independent quark fragmentation:

• \( D_{LL}(\bar{\Lambda}) > D_{LL}(\Lambda) \)
• Sensitivity to \( s(x) \)

Are these conclusions still valid in a more advanced model?
Spin transfer from polarized quark to $\Lambda$

$$e^+ e^- \rightarrow Z^0 \rightarrow s \bar{s}$$

$$P_s = -0.91$$

Polarized quarks, indeed, transfer the polarization to $\Lambda$. 

Figure: The polarization $P_s$ is shown as a function of $x_E$. The data points are compared to predictions from JETSET using different parameterizations. The error bars represent the statistical plus systematic uncertainties.
Impact of LEP data


\[ \Delta u_\Lambda = \Delta d_\Lambda = \Delta s_\Lambda \]

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Theory predictions for $\Lambda / \bar{\Lambda}$

Transverse polarization $P_Y$

First analysis on 2002 data, all $Q^2$

- 160,000 $\Lambda$s and 85,000 $\bar{\Lambda}$s
- Small positive $\Lambda$ polarization:
  
  $$P_T^\Lambda = +2.7 \pm 0.9 \text{(stat.)} \pm 1.1 \text{(sys.)} \%$$

  - Sign opposite to $\Lambda$ polarization in $p$ and $\pi^-$ beams
  - Same sign as in $K^-$ beam
  - Much lower absolute value

- $\bar{\Lambda}$ unpolarized:
  
  $$\bar{P}_T^{\bar{\Lambda}} = -0.3 \pm 1.4 \text{(stat.)} \pm 1.8 \text{(sys.)} \%$$
• θ - between virtual photon and p in Λ c.m.s.

• Kaon background is important at large cosθ

• cut

  -1 < cosθ < 0.6