Production and polarization of the Λ and ¯Λ hyperons in DIS at COMPASS

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on behalf of the COMPASS collaboration

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Outline

- Longitudinal polarization of $\Lambda$ and $\bar{\Lambda}$ hyperons in DIS (averaged on target polarization). \(^1\)

- Dependence of $\Lambda$ and $\bar{\Lambda}$ longitudinal polarization on the target polarization.

- Yield of heavy hyperons and antihyperons in DIS

\(^1\) COMPASS Collab. EPJC 64 (2009) 171-179
Longitudinal polarization of $\Lambda$ and $\bar{\Lambda}$ in the current fragmentation region (CFR, $x_F > 0$) semi-inclusive DIS is sensitive to:

- $s(x), \bar{s}(x)$
- polarization of strange quarks $\Delta s$ (via target polarisation dependence)

\[
\Delta s = \int dx \left[ s_{\uparrow}(x) - s_{\downarrow}(x) + \bar{s}_{\uparrow}(x) - \bar{s}_{\downarrow}(x) \right]
\]
Year 2003:
\[ P_b = -0.76 \pm 0.04 \]

Year 2004:
\[ P_b = -0.80 \pm 0.04 \]

160 GeV \( \mu^+ \) beam

2.8 \( \cdot \) \( 10^8 \) \( \mu \)/spill (4.8 s/16.8 s)

\( Q^2 > 1 \) (GeV/c\(^2\)): 31.2 \( \cdot \) \( 10^6 \) events
Polarized target

- target material: $^6$LiD
- polarisation: $> 50\%$
- dilution factor: $\sim 0.4$
- Dynamic Nuclear Polarization
- solenoid field: 2.5 T
  acceptance: 70 mrad
- $^3$He/$^4$He: $T_{min} \approx 50$ mK
- two 60 cm long target cells with opposite polarisation
- regular polarisation reversal by field rotation
Event selection

- Primary vertex inside the target cells
- Secondary vertex: 5 cm downstream of the last target cell
- The $\chi^2$ value of the secondary vertex is $\chi^2 < 2$
- $p_T > 23 \text{ MeV}/c$ - to reject $e^+ e^-$ pairs from the $\gamma$ conversion
- $p_\pm > 1 \text{GeV}/c$
- The DIS cuts $Q^2 > 1 \text{(GeV}/c)^2$ and $0.2 < y < 0.9$
- Collinearity cut $\theta_{\text{coll}} < 0.01 \text{ rad}$
- $0.05 < x_F < 0.5$
<table>
<thead>
<tr>
<th>Experiment</th>
<th>$\Lambda$</th>
<th>$\bar{\Lambda}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>E665</td>
<td>750</td>
<td>650</td>
</tr>
<tr>
<td>NOMAD</td>
<td>8087</td>
<td>649</td>
</tr>
<tr>
<td>HERMES</td>
<td>7300</td>
<td>1687</td>
</tr>
<tr>
<td>RHIC</td>
<td>13000</td>
<td>10000</td>
</tr>
<tr>
<td>COMPASS (polarisation analysis)</td>
<td>70000</td>
<td>42000</td>
</tr>
<tr>
<td>COMPASS (heavy hyperon analysis)</td>
<td>100000</td>
<td>60000</td>
</tr>
</tbody>
</table>

COMPASS has the largest number of $\Lambda$ and $\bar{\Lambda}$. 
Invariant mass example: year 2004, $\Lambda$ and $\bar{\Lambda}$

$\Lambda$, 2004 DATA

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

COMPASS PRELIMINARY

$\bar{\Lambda}$, 2004 DATA

\[ N(\bar{\Lambda}) = 27399 \]
\[ \sigma = 2.2 \text{ MeV/c}^2 \]

COMPASS PRELIMINARY

Sideband subtraction method was used to obtain $\cos \theta$ angular distribution.

Bands regions: $(-5; -3)$, $(-1.5; 1.5)$, $(3; 5) \sigma$ from mass peak.
Longitudinal $\Lambda$ ($\bar{\Lambda}$) polarisation

$-1 < \cos \theta < 0.6$

\[
\frac{1}{N_{tot}} \frac{dN}{d\cos \theta} = \frac{1}{2} \left( 1 + \alpha P_L \cos \theta \right)
\]

$P_L$ - longitudinal polarisation of hyperon.

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

By definition longitudinal spin transfer is:

\[
D_{LL} = \frac{P_L}{(P_b D(y))},
\]

Depolarisation factor

\[
D(y) = \frac{1-(1-y)^2}{1+(1-y)^2}
\]
Example of angular distribution fits

Angular dependencies for \( \Lambda, \bar{\Lambda} \)

- 2004 year events
- \(-1 < \cos \theta < 0.6\)
Spin transfer to $\Lambda$ and $\bar{\Lambda}$: $x_{Bj}$

$D_{LL}^\Lambda > D_{LL}^{\bar{\Lambda}}$

Theory predictions:
SU(6), CTEQ5

$\Lambda$ – solid line
$\bar{\Lambda}$ – dashed line

$D_{LL}^\Lambda = -0.012 \pm 0.047 \pm 0.024$

$D_{LL}^{\bar{\Lambda}} = 0.249 \pm 0.056 \pm 0.049$

Spin transfer to Λ and $\bar{\Lambda}$: $x_F$

$D_{LL}^\Lambda = -0.012 \pm 0.047 \pm 0.024$

$D_{LL}^{\bar{\Lambda}} = 0.249 \pm 0.056 \pm 0.049$

- $D_{LL}^{\bar{\Lambda}} > D_{LL}^\Lambda$
- theory predictions: SU(6), CTEQ5
- $\Lambda$ – solid line
- $\bar{\Lambda}$ – dashed line
Comparison with theory ($\bar{\Lambda}$): CTEQ5 and GRV98

Spin transfer to $\bar{\Lambda}$ for different choices of PDFs
- CTEQ5 – solid line
- GRV98 – dashed line
- $D_{LL}(\bar{s}) = 0$
- BJ and SU(6) models – 2 lower lines
- Data for $\bar{\Lambda}$ are sensitive to the $\bar{s}(x)$ distribution
Dependence on the target polarisation $\Delta P/P$

### Dependence on pol. PDFs

\[ \Delta P/P = \frac{P_- - P_+}{(P_- + P_+)/2}, \quad \text{on y axis} \]

\[ \Delta P/P \text{ changes a sign in } x_{Bj} \text{ region} \]

A. Kotzinian, talk at DIS09, arXiv:0907.3270
Dependence on the target polarisation

No significant dependence is found.

Averaged over full kinematics:

\[ \Delta P^\Lambda = P^\Lambda_+ - P^\Lambda_- = -0.01 \pm 0.04 \]

\[ \Delta P^{\bar\Lambda} = P^{\bar\Lambda}_+ - P^{\bar\Lambda}_- = +0.01 \pm 0.05 \]
To determine to what extent the yields of heavy hyperons and antihyperons are different.

To check the hypothesis that polarization of $\Lambda$ and $\bar{\Lambda}$ are different due to different contribution of indirect $\Lambda$ and indirect $\bar{\Lambda}$.

Yields of heavy hyperons and antihyperons

Decay of heavy strange hyperons is one of possible sources of $\Lambda$ ($\bar{\Lambda}$) production.

\[
\begin{align*}
\mu^+ + d &\rightarrow \mu^+ + \Lambda (\bar{\Lambda}) + X \quad (1) \\
\mu^+ + d &\rightarrow \mu^+ + \Sigma^+(1385) + X \quad (2) \\
\mu^+ + d &\rightarrow \mu^+ + \Sigma^-(1385) + X \quad (3) \\
\mu^+ + d &\rightarrow \mu^+ + \Sigma^0(1385) + X \quad (4) \\
\mu^+ + d &\rightarrow \mu^+ + \Xi^-(1321) + X \quad (5)
\end{align*}
\]

V. Alexakhin  \hspace{1cm}  $\Lambda$ and $\bar{\Lambda}$ in DIS
Distributions of $p\pi^-$ and $\bar{p}\pi^+$ invariant mass for experimental data

To determine the $\Lambda\pi$ invariant mass, the events with an invariant mass of $p\pi^-$ within a $\pm 2\sigma$ interval from the mean value of the $\Lambda$ ($\bar{\Lambda}$) peak are taken.

- $0.05 < x_F < 1.0$ (no cut on $x_F$ max)
- $-1 < \cos \theta < 1$ (all range)
Distributions of $\Lambda\pi^\pm$ and $\bar{\Lambda}\pi^\pm$ invariant mass for experimental data

$N(\Sigma^+) = 3631 \pm 333$

$N(\Sigma^-) = 2173 \pm 222$

$N(\Sigma^-) = 2970 \pm 490$

$N(\bar{\Sigma}^+) = 1889 \pm 265$
Yields of heavy (anti-)hyperons

The relative yields of heavy (anti-)hyperons production in DIS were measured at COMPASS spectrometer:

\[ R^+ = \Sigma^+(1385)/\Lambda = 0.055 \pm 0.005 \pm 0.0045 \]
\[ \bar{R}^- = \Sigma^-(1385)/\bar{\Lambda} = 0.047 \pm 0.006 \pm 0.0053 \]
\[ R^- = \Sigma^-(1385)/\Lambda = 0.056 \pm 0.009 \pm 0.0074 \]
\[ \bar{R}^+ = \Sigma^+(1385)/\bar{\Lambda} = 0.039 \pm 0.006 \pm 0.0064 \]

- Systematic errors include background shape and selection cuts variation.
- Results are used for event generator tuning.
The yield of the heavy hyperons in DIS was measured by the NOMAD collaboration in neutrino DIS.

<table>
<thead>
<tr>
<th>Ratios</th>
<th>Present data</th>
<th>NOMAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Sigma^+(1385)/\Lambda$</td>
<td>$0.055 \pm 0.005 \pm 0.0045$</td>
<td>$0.058 \pm 0.011$</td>
</tr>
<tr>
<td>$\Sigma^-(1385)/\bar{\Lambda}$</td>
<td>$0.047 \pm 0.006 \pm 0.0053$</td>
<td>$-$</td>
</tr>
<tr>
<td>$\Sigma^-(1385)/\Lambda$</td>
<td>$0.056 \pm 0.009 \pm 0.0074$</td>
<td>$0.026 \pm 0.009$</td>
</tr>
<tr>
<td>$\Sigma^+(1385)/\bar{\Lambda}$</td>
<td>$0.039 \pm 0.006 \pm 0.0064$</td>
<td>$-$</td>
</tr>
</tbody>
</table>
The presented data are the most precise measurements to date of the longitudinal spin transfer to $\Lambda$ and $\bar{\Lambda}$ in DIS.

\[
D_{LL}^{\Lambda} = 0 : -0.012 \pm 0.047 \pm 0.024 \\
D_{LL}^{\bar{\Lambda}} \neq 0 : 0.249 \pm 0.056 \pm 0.049
\]

$D_{LL}^{\Lambda} \neq D_{LL}^{\bar{\Lambda}}$

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 $\bar{s}(x)$

The yields of heavy (anti-)hyperons in DIS were measured.

The relative yields of indirect $\Lambda$ and $\bar{\Lambda}$ production are similar
Backup slides
Polarization of $\Lambda$ from quark fragmentation

$\Lambda$ polarization from struck quark fragmentation in parton model:

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

- $P_b D(y)q(x)$ – spin transfer from polarized muon
- $P_T \Delta q(x)$ – spin transfer from polarized quark

Fitting procedure

These distributions have been fitted by a sum of Breit-Wigner convoluted with gaussian

\[ R(x) = \frac{\Gamma}{2 \cdot \pi} \cdot \int \frac{Ndt}{(t-M)^2+(\frac{\Gamma}{2})^2} \cdot \frac{1}{\sqrt{2 \cdot \pi}} \cdot e^{-0.5\left(\frac{t-x}{\sigma}\right)^2} \]

and the background function

\[ B(x) = A \cdot (x - M_l)^B \cdot e^{-C \cdot (x - M_l)^D} \]

**Fit parameters:**
- N - total numbers
- M - mass of resonance (fixed)
- \( \Gamma \) - width of resonance (fixed)
- \( \sigma \) - width of Gaussian
- A - amplitude of background
- B, C, D - free parameters
- Ml - reaction threshold mass (1.254 GeV mass of \( \Lambda \pm \pi \))
Estimation of the systematic effects

- **Selection cut:**
  To estimate the systematic error connected with the particular choice of the selection cut of the $\Lambda$ ($\bar{\Lambda}$) sample we change the width of the central band from $\pm 2\sigma$ to $\pm 2.5\sigma$ and $\pm 1.5\sigma$.

Contribution of cut variation to the systematic error was found to be negligible.

- **Background shape:**
  To estimate this effect we evaluate the background using mixed event method, in which the shape of the background distribution in the $\Lambda\pi$ invariant mass was determined combining $\Lambda$ and $\pi$ from different events of the same topology.

Systematic error due to background shape is comparable with statistic error.
Yields of heavy (anti-)hyperons

Table: The ratios of the hyperon yields for the events with and without the DIS cuts

<table>
<thead>
<tr>
<th>Hyperon</th>
<th>Ratio without cut</th>
<th>Ratio with DIS cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Sigma^+/\Lambda$</td>
<td>$1.03 \pm 0.08$</td>
<td></td>
</tr>
<tr>
<td>$\bar{\Sigma}^-/\bar{\Lambda}$</td>
<td>$0.97 \pm 0.11$</td>
<td></td>
</tr>
<tr>
<td>$\Sigma^-/\Lambda$</td>
<td>$1.03 \pm 0.16$</td>
<td></td>
</tr>
<tr>
<td>$\bar{\Sigma}^+/\bar{\Lambda}$</td>
<td>$0.97 \pm 0.13$</td>
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