Λ Polarization Measurements at COMPASS

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on behalf of the COMPASS collaboration

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DIS06
XIV International Workshop on Deep Inelastic Scattering
Tsukuba, 21st April 2006
Outline

1. Longitudinal $\Lambda$ and $\bar{\Lambda}$ polarization
   - Introduction
   - Extraction Method
   - Results

2. $\Lambda$ production from transversely polarized target
   - $\Lambda$ polarization and transversity
   - Extraction method
   - Results

3. Spontaneous transverse hyperon polarization
Why $\Lambda$ polarization?

**Ideal probe to study spin effects in high energy reactions**

<table>
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<th>Self-analyzing weak decay $\Lambda \rightarrow p \pi^-$, BR $\approx 64%$</th>
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- Suppression of background contaminations
- Correction of apparatus effects (acceptance)
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The Experimental Setup

Fixed target experiment @ CERN SPS

- 2-stage spectrometer
- longitudinally polarized $160\ \text{GeV/c} \ \mu^+$-beam
- Longitudinally/transversely polarized $^6\text{LiD}$ target

Setup 2003 (topview)

COMPASS is able to study all aspects of $\Lambda$ polarization.
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$\Lambda$ Polarization Measurements at COMPASS
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\( \Lambda \) Polarization Measurements at COMPASS
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The Experimental Setup

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Setup 2003 (topview)

COMPASS Layout 2003 (Topview)

- Target
- SM1
- SM2
- HCAL1
- HCAL2
- ECAL2
- RICH
- $\mu$F1
- $\mu$F2
- $\mu$F3

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Longitudinal $\Lambda$ and $\bar{\Lambda}$ polarization

$\Lambda$ production from transversely polarized target

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Introduction

Extraction Method

Results

Long. $\Lambda$ Polarization in Current Fragmentation Region

Accessible physics

- Study of spin transfer process $q \rightarrow \Lambda$
- $\Lambda$ spin structure
- Test of $q\bar{q}$ symmetry of strange sea in nucleon:
  - $s(x)$ vs. $\bar{s}(x)$
  - $\Delta s(x)$ vs. $\Delta \bar{s}(x)$
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Longitudinal $\Lambda$ Polarization – Parton Model

Assuming $x_F > 0$ and quark fragmentation

\[
P_L^\Lambda = \frac{\sum_q e_q^2 \left[ P_B \cdot D_L(y) \cdot q(x_{Bj}) + f \cdot P_N \cdot \Delta q(x_{Bj}) \right]}{\sum_q e_q^2 \left[ q(x_{Bj}) + f \cdot P_N \cdot P_B \cdot D_L(y) \cdot \Delta q(x_{Bj}) \right]} \frac{\Delta D_{\Lambda/q}(z_h)}{\hat{D}_{\Lambda/q}(z_h)}
\]

with \( D_L(y) = \frac{1-(1-y)^2}{1+(1-y)^2} \) longitudinal depolarization factor

- \( P_B \) beam polarization $\approx -76\%$
- \( f \) target dilution factor $\approx 0.45$
- \( P_N \) target polarization $\approx 50\%$

Measurement of polarized fragmentation function $\Delta D_{\Lambda/q}(z_h)$

averaging over target polarization $\implies P_N = 0$
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Model calculations

- Significant contribution from diquark fragmentation for $x_F > 1$
  J. Ellis et al., EPJ C25, 603 (2002)

- About 40\% indirect $\Lambda$s from $\Sigma^0$, $\Sigma(1385)$, and $\Xi$
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## Extraction Method for Angular Distributions

### Longitudinal polarization
- **Analyzer** along virtual photon direction
- Angular distribution of proton w.r.t. $\gamma^*$ in $\Lambda$ rest frame

### Bin-by-bin Method
- Event-by-event identification of hyperons not required
- Subdivision of sample into bins in $\cos \theta$
- For each bin invariant mass histogram
- Fit of histogram $\Rightarrow$ number of $\Lambda$s from fit parameter
  $\Rightarrow$ background corrected angular distribution

### Acceptance correction
from MC simulations (LEPTO) of unpolarized $\Lambda(\bar{\Lambda})$ decays
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MC improved Background Description

Background contributions

- No particle ID used in $\Lambda$ selection
- Kinematically indistinguishable $K_s^0$
- Combinatorial background
- $e^+e^-$ pairs from $\gamma$ conversion

Kaon Background from MC

- Kaon distribution $K(m_{p\pi^-})$
- Data are fitted with $\text{Gauss}(x) + aK(x) + c_0 + c_1x$
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**COMPASS 2003, Preliminary**

Fit result
Total background
Kaons background

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$\Lambda$ Polarization Measurements at COMPASS
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Kinematics of $\Lambda$ Prod. (2003, $Q^2 > 1$ GeV$^2$)

**Total statistics 2003**

- 31,000 $\Lambda$s
- 18,000 $\bar{\Lambda}$s

**Mean values**

- $\langle x_{Bj} \rangle = 0.0283$
- $\langle x_F \rangle = 0.23$
- $\langle y \rangle = 0.48$
- $\langle z \rangle = 0.29$
- $\langle Q^2 \rangle = 3.55$ GeV$^2$
- $\langle W \rangle = 11.7$ GeV
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$\Lambda$ production from transversely polarized target
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$y$- and $x_{Bj}$-Dependence of long. Pol., $Q^2 > 1 \text{ GeV}^2$

Systematic errors $< 5\%$
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Transversely polarized target

Measured process: \( \mu N^\uparrow \rightarrow \mu' \Lambda^\uparrow X \)

Underlying elementary QED process: \( \gamma^* q^\uparrow \) scattering

Transverse \( \Lambda \) polarization gives information about initial transverse quark polarization \( \Delta_T q(x_{ Bj}) \) in nucleon.
$\Lambda$ production from transversely polarized target

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**Extraction method**

**Results**

**COMPASS**
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Assuming $x_F > 0$ and quark fragmentation

\[
P_T^\Lambda = f \cdot P_N \cdot D_T(y) \frac{\sum_q e_q^2 \Delta_T q(x_{Bj}) \Delta_T D_{\Lambda/q}(z_h)}{\sum_q e_q^2 q(x_{Bj}) \hat{D}_{\Lambda/q}(z_h)}
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with \( D_T(y) = \frac{2(1-y)}{1+(1-y)^2} \) transverse depolarization factor

\( f \) target dilution factor \( \approx 0.45 \)

\( P_N \) target polarization \( \approx 50 \% \)

Chiral-odd partner of $\Delta_T q(x_{Bj})$: transversity fragmentation function

\[
\Delta_T D_{\Lambda/q}(z_h) \equiv D_{\Lambda/\uparrow \, q}(z_h) - D_{\Lambda/\downarrow \, q}(z_h)
\]

- both $\Delta_T q(x_{Bj})$ and $\Delta_T D_{\Lambda/q}(z_h)$ unknown
Λ polarization and Transversity

Assuming $x_F > 0$ and quark fragmentation

$$P_T^\Lambda = f \cdot P_N \cdot D_T(y) \frac{\sum q e_q^2 \Delta Tq(x_{Bj}) \Delta_T D_{\Lambda/q}(z_h)}{\sum q e_q^2 q(x_{Bj}) \hat{D}_{\Lambda/q}(z_h)}$$

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### Assumption: $x_F > 0$ and quark fragmentation

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transverse depolarization factor

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COMPASS Polarized Target

- **3He-Precooler**
- **Superconducting solenoid (2.5 T)**
- **Dilution refrigerator (T ~ 50 mK)**
- **6LiD target cells**
- **COMPASS Acceptance (180 mrad)**
- **SMC Acceptance (70 mrad)**

- **2 target cells**, each 60 cm long
- **0.5 T magnetic dipole field sustains transverse polarization**

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COMPASS Polarized Target

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Acceptance Correction – Bias Canceling

- Background subtraction using **bin-by-bin method**

**Assumptions**

- Constant target polarization: $P_N^{(1)} = P_N^{(2)}$
- Constant acceptance: $A_1^+(\theta) = A_2^- (\theta)$ and $A_1^- (\theta) = A_2^+ (\theta)$
Acceptance Correction – Bias Canceling

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**Exploit symmetry**
- Extract correction function from data
- Recombination of data samples from two target cells and two polarization configurations
- Acceptance corrected angular distribution $e_T(\theta) = \alpha_\Lambda P_T^\Lambda \cos \theta$

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Acceptance Correction – Bias Canceling

- Background subtraction using **bin-by-bin method**

**Exploit symmetry**

- Extract correction function from data
- Recombination of data samples from two target cells and two polarization configurations
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Upstream cell

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Downstream cell

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Overall available Statistics (2002-03, $Q^2 > 1$ GeV$^2$)

All 2002+2003 transversity data

Number of $\Lambda$: ~20000

$Q^2 > 1$ (GeV/c)$^2$

$0.1 < y < 0.9$

$M_{p\pi^-} - M_\Lambda$ [GeV/c$^2$]

Preliminary
$x_{Bj}$-Dependence of Transv. $\Lambda$ Polarization, $Q^2 > 1 \text{ GeV}^2$

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Preliminary
Outline

1. Longitudinal $\Lambda$ and $\bar{\Lambda}$ polarization
   - Introduction
   - Extraction Method
   - Results

2. $\Lambda$ production from transversely polarized target
   - $\Lambda$ polarization and transversity
   - Extraction method
   - Results

3. Spontaneous transverse hyperon polarization
Spontaneous Transverse Hyperon Polarization

Production of polarized hyperons in **unpolarized** inclusive reactions

- **Parity conservation**
- **Polarization** transverse to production plane

**Naïve expectation**

- High energy $\implies$ large number of production channels: comparable magnitudes + various relative phases
- Random interference $\implies$ small polarization

**Big surprise 1976 at Fermilab**

- Discovery of sizeable transverse polarization $P_T^Λ = -28 \pm 8 \%$
  - in $p$ Be $\rightarrow Λ↑X @ p_{Beam} = 300$ GeV/c
- No model is able to explains all experimental data
- Only few data from photo-production

**COMPASS**

Boris Grube, TU München
Longitudinal $\Lambda$ and $\bar{\Lambda}$ polarization
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- Analyzer along production plane normal

![Diagram showing scattering and decay planes with various particles and momenta](image)
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Scattering Plane
Production Plane
Decay Plane

Boris Grube, TU München
\Lambda Polarization Measurements at COMPASS
Background Subtraction and Acceptance Correction

Bin-by-bin method – separation of $K^0$ background

- Expansion of $\Lambda$ invariant mass histogram with $K^0$ mass
- Full two-dimensional fit in $(m_{p\pi^-}, m_{\pi^+\pi^-})$ plane
- Extraction of false $K^0$ background polarization in same kinematical region as $\Lambda$

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- Exploits mid-plane symmetry of apparatus
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![Graph showing invariant mass distribution](image)

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

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

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- 2002-04, all $Q^2$: $1.6 \cdot 10^6$ $\Lambda$s and $0.9 \cdot 10^6$ $\bar{\Lambda}$s
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### Longitudinal polarization transfer
- **2003 data sample**
- **Similar longitudinal polarization** of $\Lambda$ and $\bar{\Lambda}$
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### Transverse polarization transfer
- **2002 + 2003 transversity data sample**
- **Slight tendency to negative polarizations**
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### Both analyses
- **Significant increase of statistics** with 2004 data
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Mean values

\[ \langle x_{Bj} \rangle = 0.0258 \]
\[ \langle x_F \rangle = 0.21 \]
\[ \langle y \rangle = 0.51 \]
\[ \langle z \rangle = 0.27 \]
\[ \langle Q^2 \rangle = 3.50 \text{ GeV}^2 \]
\[ \langle W \rangle = 12.1 \text{ GeV} \]
Angular Distributions (2002, $Q^2 > 1 \text{ GeV}^2$)

![Graphs showing angular distributions for $K^0$, $\Lambda$, and $\bar{\Lambda}$](image)

**Preliminary**

Boris Grube, TU München

Λ Polarization Measurements at COMPASS
Spin Transfer to $\Lambda$ and $\bar{\Lambda}$ (2002, $Q^2 > 1$ GeV$^2$)

```
\begin{center}
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
$X_F$ & 0 & 0.2 & 0.4 & 0.6 & 0.8 \\
\hline
Spin transfer & \star $\Lambda$, COMPASS & \triangle $\Lambda$, HERMES & \circ $\Lambda$, NOMAD & \square $\Lambda$, E665 & \star $\bar{\Lambda}$, COMPASS & \circ $\bar{\Lambda}$, NOMAD & \square $\bar{\Lambda}$, E665 \\
\hline
\end{tabular}
\end{center}
```
Selection cuts

- Primary vertex in target
- Secondary $V^0$ vertex outside of target
- Collinearity angle
  $\theta_{\text{col}} < 10$ mrad
- $V^0$ decay daughters:
  $p > 1$ GeV/c and
  $p_T > 23$ MeV/c
- $V^0$ momentum
  $p_{V^0} > 10$ GeV/c
- DIS cut: $Q^2 > 1$ GeV$^2$ and
  $0.2 < y < 0.9$
Kinematics of $\Lambda$ Production

- Mean virtual photon transverse depolarization factor
  $\langle D_T(y) \rangle \approx 0.8$
- Majority of $\Lambda$s produced in current fragmentation region $x_F > 0$
- Accessible $x_{Bj}$ ranges
  - All $Q^2$: $10^{-5} < x_{Bj} < 1$
  - $Q^2 > 1$ GeV$^2$: $3 \cdot 10^{-3} < x_{Bj} < 1$
$x_{Bj}$-Dependence of Transv. $\Lambda$ Polarization, All $Q^2$

All 2002+2003 transversity data

All $Q^2$

$0.1 < y < 0.9$

Preliminary
Study of systematic Effects

- False $K^0$ polarization
- Subdivision of target cells into two halves
- Artificial change of orientation of target polarization: horizontal, random orientation

Systematic effects are smaller than statistical errors
Selection cuts

- Primary vertex in target
- Secondary $V^0$ vertex outside of target
- Collinearity angle $\theta_{\text{col}} < 10$ mrad
- $V^0$ decay daughters:
  - $p > 1$ GeV$/c$ and $p_T > 23$ MeV$/c$
  - $0.1 < y < 0.9$
Dependence of $\Lambda$ Pol. on $x_F$ and $p_T$ (2002 Data, all $Q^2$)

Boris Grube, TU München

$\Lambda$ Polarization Measurements at COMPASS
Dependence of $\bar{\Lambda}$ Pol. on $x_F$ and $p_T$ (2002 Data, all $Q^2$)

Boris Grube, TU München

$\Lambda$ Polarization Measurements at COMPASS
Overall available Statistics (2002-04, all $Q^2$)

1.6 \cdot 10^6 \Lambda s

0.9 \cdot 10^6 \bar{\Lambda}s

COMPASS 2002-04, all $Q^2$

preliminary

PDG