Longitudinal spin transfer to the Λ and $\bar{\Lambda}$ hyperons in DIS

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Physical Motivation

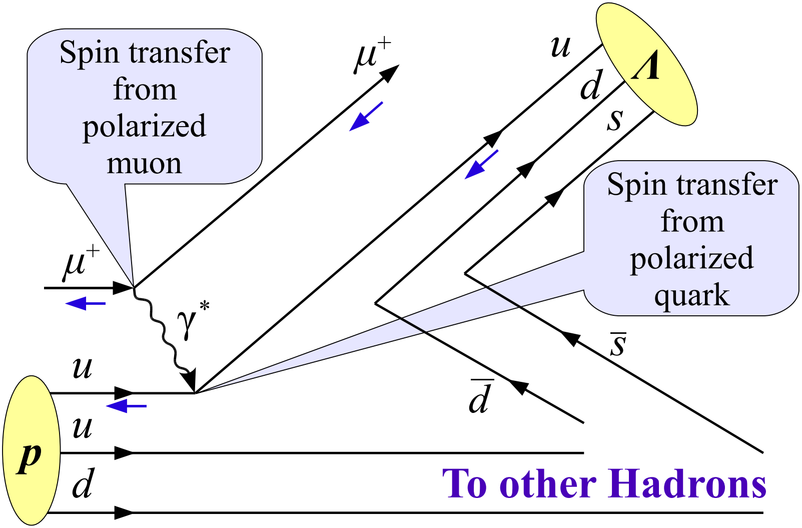
Longitudinal polarization of Λ and $\bar{\Lambda}$ in DIS is sensitive to:

- $s(x)$, $\bar{s}(x)$
- polarization of strange quarks Δs

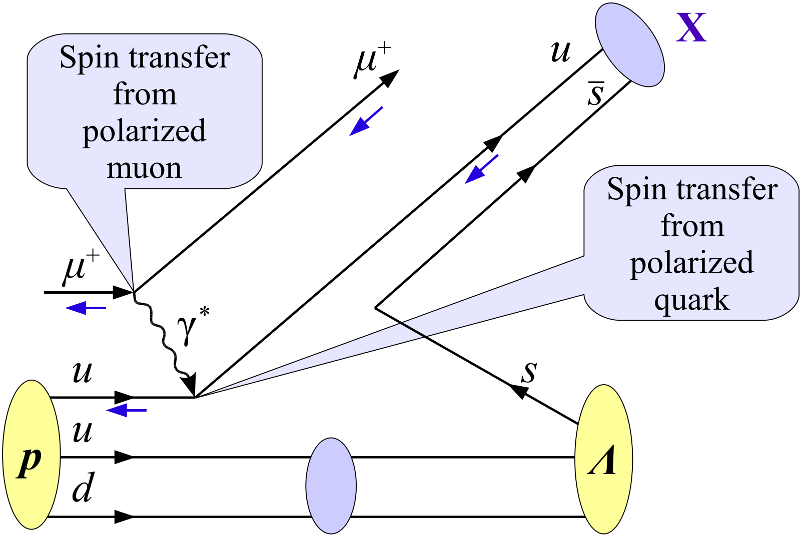
$$\Delta s = \int dx \left[s_{\uparrow}(x) - s_{\downarrow}(x) + \bar{s}_{\uparrow}(x) - \bar{s}_{\downarrow}(x) \right]$$

- Λ spin structure

Example of quark spin transfer to Λ in DIS



Example of diquark spin transfer to Λ in DIS



Polarization of Λ from quark fragmentation

Λ polarization from struck quark fragmentation in parton model:

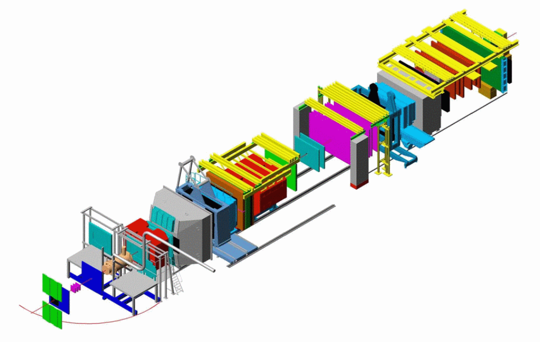
$$P_\Lambda = \frac{\sum_q e_q^2 \left[P_b D(y) q(x) + P_T \Delta q(x)\right] \Delta D_q^\Lambda(z)}{\sum_q e_q^2 \left[q(x) + P_b P_T D(y) \Delta q(x)\right] D_q^\Lambda(z)}$$

- $P_b D(y) q(x)$ – spin transfer from polarized muon
- $P_T \Delta q(x)$ – spin transfer from polarized quark
- A. Kotzinian, A. Bravar, D. von Harrach, *Eur.Phys.J.* **C2**, 329-337 (1998), hep-ph/9701384

Λ spin structure models

- SU(6) quark model: $\Delta\mathbf{s} = 1$, $\Delta\mathbf{u} = \Delta\mathbf{d} = 0$
  Even 100% polarization to **u** or **d** quarks
  has no influence on Λ polarization
  $P(\Lambda) = 0$ (due to **u** quark dominance)
- Burkard-Jaffe: $\Delta\mathbf{u} = \Delta\mathbf{d} = -0.23$
  $P(\Lambda) < 0$
- B.Q.Ma et al.: $\Delta\mathbf{u} = \Delta\mathbf{d} = \Delta\mathbf{s}$
  $P(\Lambda) > 0$
- Lattice QCD calculations: $\Delta\mathbf{u} = \Delta\mathbf{d} \simeq 0, \Delta\mathbf{s} = 0.68$
  $P(\Lambda) \simeq 0$

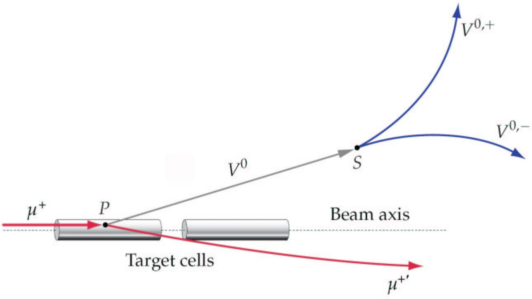
COMPASS Spectrometer setup



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

- 160 GeV μ^+ beam
- $2.8 \cdot 10^8$ μ/spill (4.8 s)
- $Q^2 > 1$ (GeV/c)^2: $(8.7 + 22.5) \cdot 10^7$ events

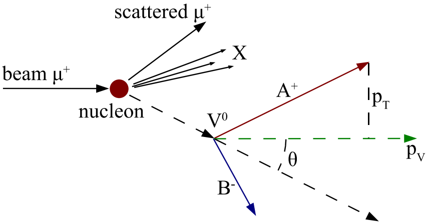
Particles production scheme

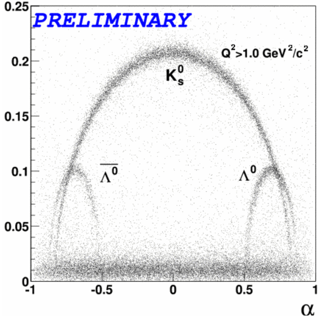


- Polarized target: two cells with opposite spin
- Results are averaged over target polarization
- No pion identification, thus K^0, Λ and $\bar{\Lambda}$ decays have identical signature: $V^0 \rightarrow V^{0,+} + V^{0,-}$

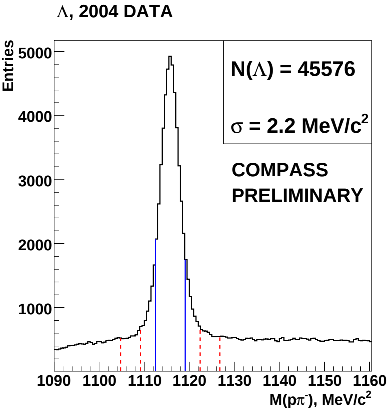
Events selection

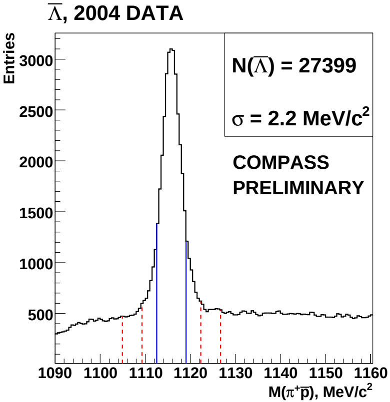
- Primary vertex inside the target
- Secondary vertex: 5 cm downstream of the last target cell
- $p_T > 23$ MeV$/c$
- $\theta < 0.01$ rad
- $Q^2 > 1$ (GeV$/c)^2$
- $0.2 < y < 0.9$





Invariant mass example: year 2004, Λ and $\bar{\Lambda}$





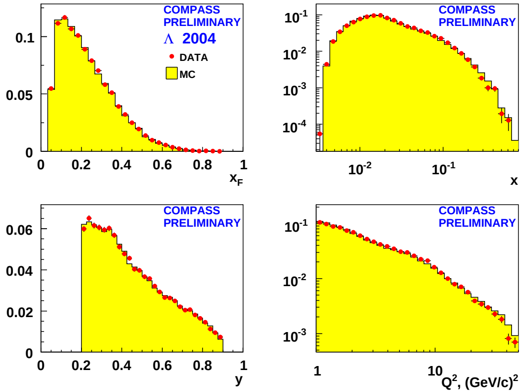
Sideband substraction method were used to obtain $\cos\theta_x$ angular dependencies.

Bands regions: $(-5; -3)$, $(-1.5; 1.5)$, $(3; 5)$ σ from mass peak.

Statistics: comparison with other experiments

	$N(\Lambda)$	$N(\bar{\Lambda})$
E665	750	650
NOMAD	8087	649
HERMES, 1996-2000	7300	1687
RHIC	30000	24000
COMPASS 2003-2004	70000	42000

Kinematic distributions for the selected Λ sample



Mean values:

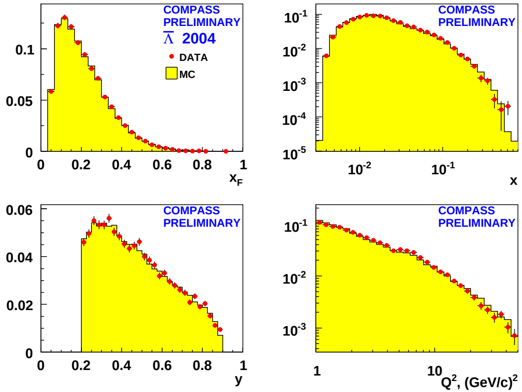
$\langle x \rangle = 0.05$

$\langle x_F \rangle = 0.23$

$\langle y \rangle = 0.46$

$\langle Q^2 \rangle = 3.31\ (\mathrm{GeV}/c)^2$

Kinematic distributions for the selected $\bar{\Lambda}$ sample



Mean values:

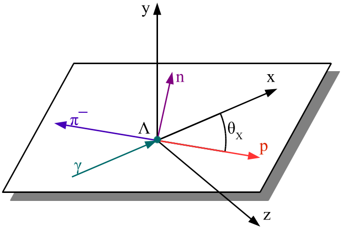
$\langle x \rangle = 0.05$

$\langle x_F \rangle = 0.22$

$\langle y \rangle = 0.48$

$\langle Q^2 \rangle = 3.27\ (\mathrm{GeV}/c)^2$

Λ-rest polarization reference frame



In Λ rest frame:

$$\frac{dN}{d\Omega} = \frac{N_{tot}}{4\pi}\left(1+\alpha\vec{P}\vec{k}\right)$$

$\alpha = +(-)0.642 \pm 0.013$ – Λ ($\bar{\Lambda}$) decay parameter, $\vec{P}$ – polarization vector, $\vec{k}$ – unit vector along the proton momentum, x-axis align with the virtual photon direction.

$$\frac{dN^{exp}}{N^{exp}_{tot}} = A(\theta_x)\frac{dN}{N_{tot}} = A(\theta_x)\frac{1}{4\pi}\left(1+\alpha\vec{P}\vec{k}\right)d(\cos\theta_x)d\phi$$

$$\vec{P}\vec{k} = P_x\cos\theta_x + \sin\theta_x\left(P_y\cos\phi + P_z\sin\phi\right)$$

Longitudinal polarization equations

After $d\phi$ integration we obtain:

$$\frac{dN^{exp}}{N^{exp}_{tot}}(\cos\theta_x) = \frac{A(\theta_x)}{2}\left(1 + \alpha P_x \cos\theta_x\right) d(\cos\theta_x)$$

For MC simulation with $\vec{P} = 0$:

$$\frac{dN^{mc}}{N^{mc}_{tot}}(\cos\theta_x) = \frac{A^{mc}(\theta_x)}{2} d(\cos\theta_x)$$

We assumed that $A(\theta_x) \simeq A^{mc}(\theta_x)$. And the final equation for P_x is:

$$\frac{dN^{exp}}{N^{exp}_{tot}} \frac{N^{mc}_{tot}}{dN^{mc}} = 1 + \alpha P_x \cos\theta_x$$

Longitudinal spin transfer equations

When P_x is estimated from angular dependence linear fit, spin transfer S_x may be evaluated. By definition longitudinal spin transfer is:

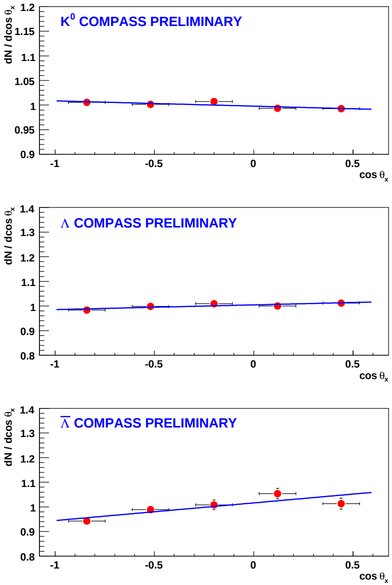
$$P_x = S_x P_b D(y),$$

where P_b – beam polarization and $D(y)$ – depolarization factor.

$$D(y) = \frac{1-(1-y)^2}{1+(1-y)^2}$$

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

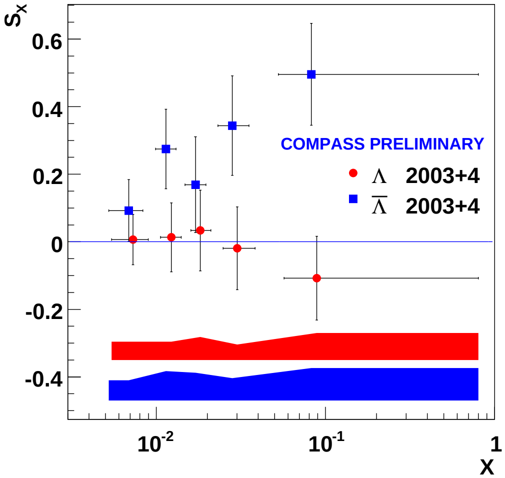
Example of angular dependence fits



$$\frac{dN^{exp}}{N^{exp}_{tot}} \frac{N^{mc}_{tot}}{dN^{mc}}(\cos\theta_x)$$

- Angular dependencies for K^0, Λ, $\bar{\Lambda}$
- 2004 year events
- $P(K) = 0.011 \pm 0.005$

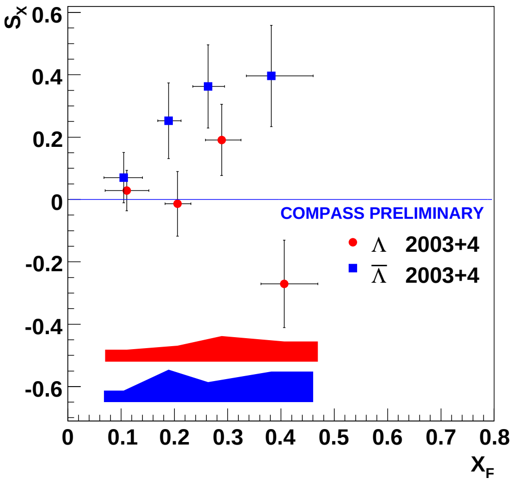
Comparison of Λ and $\bar{\Lambda}$: x



- $S_x(\Lambda) \neq S_x(\bar{\Lambda})$
- $S_x(\Lambda) \simeq 0$
- $S_x(\bar{\Lambda})$ rises with x

$$S_x(\Lambda) = -0.012 \pm 0.047 \pm 0.024$$
$$S_x(\bar{\Lambda}) = \quad 0.249 \pm 0.056 \pm 0.049$$

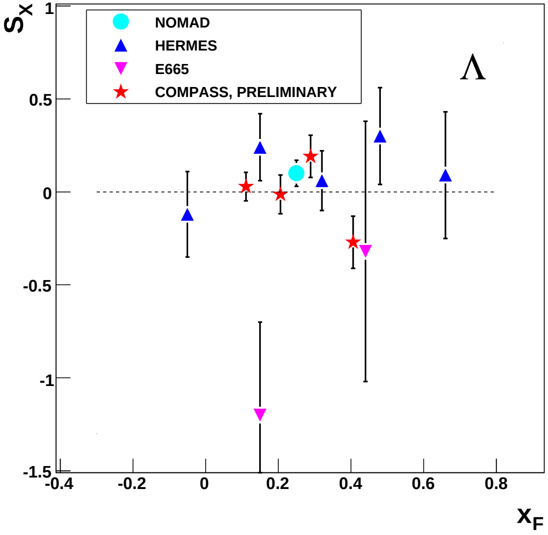
Comparison of Λ and $\bar{\Lambda}$: x_F



- $S_x(\bar{\Lambda})$ rises with x_F

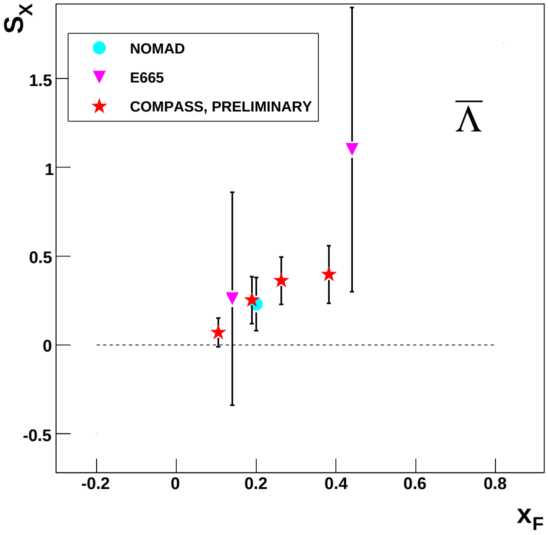
$$S_x(\Lambda) = -0.012 \pm 0.047 \pm 0.024$$
$$S_x(\bar{\Lambda}) = \quad 0.249 \pm 0.056 \pm 0.049$$

Comparison with other experiments: Λ



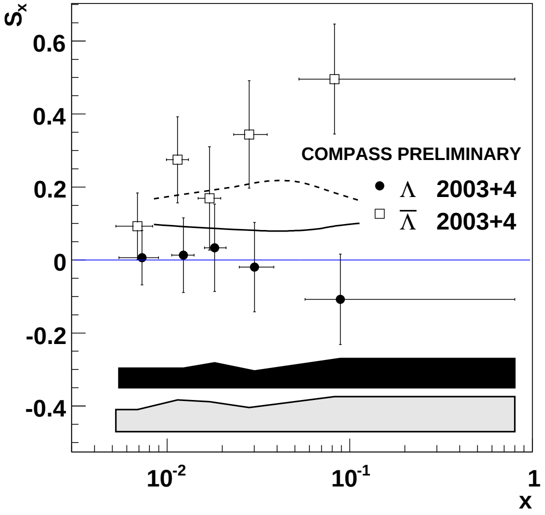
- COMPASS results agrees with HERMES ones.

Comparison with other experiments: $\bar{\Lambda}$



- COMPASS points are in agreement NOMAD point
- COMPASS is the only experiment now, which present $\bar{\Lambda}$ $S_x(x_F)$ dependence with good precision.

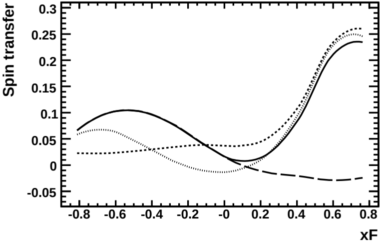
Theory predictions for Λ and $\bar{\Lambda}$: SU(6), CTEQ5



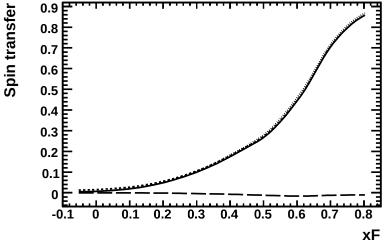
- Λ – solid line
- $\bar{\Lambda}$ – dashed line
- Result agrees with model within errors range.
- Spin transfer from diquark and string fragmentation not used.

Theory predictions for Λ and $\bar{\Lambda}$: SU(6), GRV98

Longitudinal spin transfer to Λ

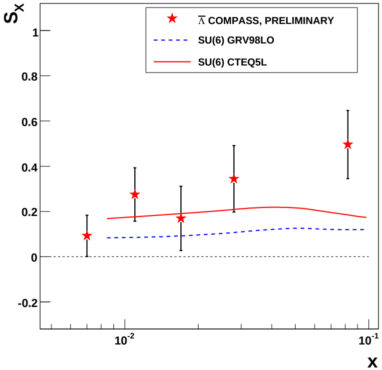


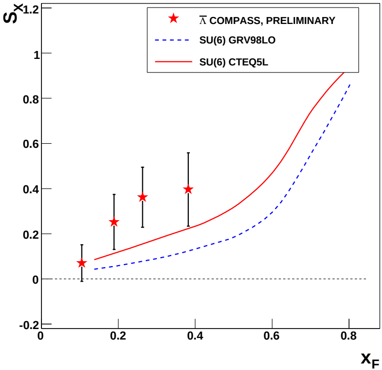
Longitudinal spin transfer to $\bar{\Lambda}$



- J. Ellis et al., *Eur.Phys.J.* **C52**, 283-294 (2007), hep-ph/0702222
- Solid line – total spin transfer to Λ and $\bar{\Lambda}$.
- Dashed line – spin transfer without s-quark contribution.

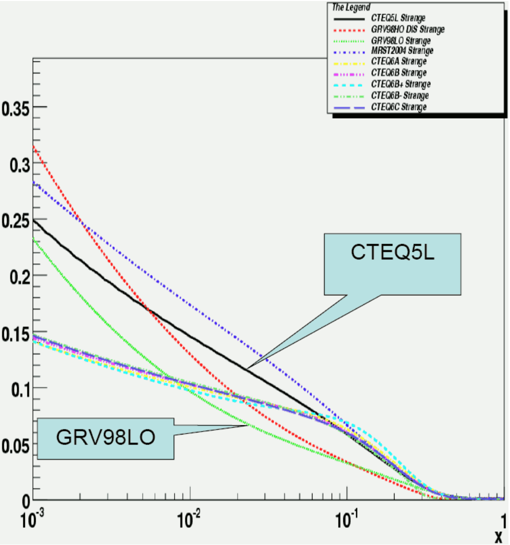
Comparison with theory: CTEQ5 and GRV98





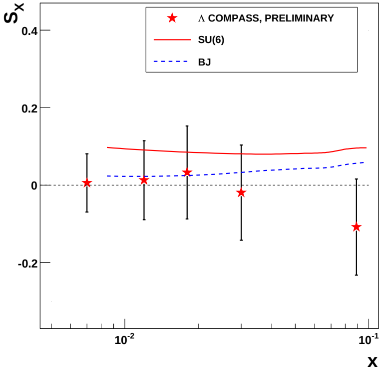
- Spin transfer from diquark fragmentation was not included
- COMPASS result agrees better with CTEQ5. It is a potential proof in favour of intrinsic nucleon strangeness.

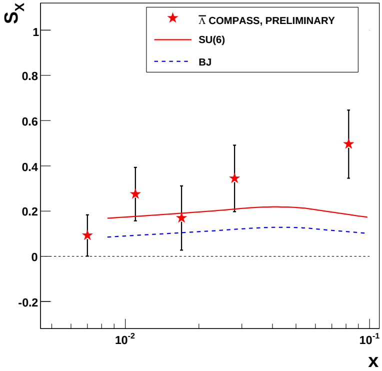
Spin transfer to $\bar{\Lambda}$ from s-quark



- Influence of different PDF on $\bar{\Lambda}$ spin transfer.
- $Q^2 = 4\ (\mathrm{GeV}/c)^2$.

Comparison with theory: Λ and $\bar{\Lambda}$ spin structure





- At present, the precision of the measurements is not enough to distinguish spin structure models.

Main results: part 1

- This report is one of the first public presentation of $\bar{\Lambda}$ and $\bar{\Lambda}$ spin transfer numbers and x, x_F dependencies on behalf of COMPASS collaboration.
  $S_x(\Lambda) = -0.012 \pm 0.047 \pm 0.024$
  $S_x(\bar{\Lambda}) = \quad 0.249 \pm 0.056 \pm 0.049$
- It is first analysis where $\bar{\Lambda}$ events statistic is enough to begin the study of spin transfer kinematic dependencies
  An overall statistics of years 2003 and 2004: 70000 Λ and 42000 $\bar{\Lambda}$.
- Spin transfer to $\bar{\Lambda}$ rises with x and x_F.

Main results: part 2

- $S_x(\Lambda) \neq S_x(\bar{\Lambda})$. Not trivial. Two explanations: in nucleon $s(x) \neq \bar{s}(x)$ or Λ ($\bar{\Lambda}$) spin carried not only by **s**- (**$\bar{\text{s}}$**-) quark.
- Better agreement with CTEQ5 PDF is a possible indication in favour of nucleon intrinsic strangeness.
- Result agrees with different Λ spin structure models within errors range. Better precision needed to discriminate them.
- $\bar{\Lambda}$ is a sensitive tool to study nucleon intrinsic strangeness.
- Current calculations underestimate spin transfer to $\bar{\Lambda}$. Need to add effects of diquark and string fragmentation.

What next?

- Longitudinal polarization and spin transfer for different target polarizations
- Correlation analysis of ΛK^0 and $\Lambda\bar{\Lambda}$ pairs
- Determination of polarization vector: P_x, P_y, P_z
- Analysis of the data collected in 2006 and 2007. Overall increase in statistics that is expected two times greater than presented today.