Longitudinal polarization of the Λ and $\bar{\Lambda}$ hyperons in DIS at COMPASS (2003-2004)

Perevalova Ekaterina

JINR, Dubna
On behalf of COMPASS collaboration

31.08.2009

- Longitudinal polarization of Λ and $\bar{\Lambda}$ hyperons in DIS (averaged on target polarization). [1]
- Dependence of Λ and $\bar{\Lambda}$ longitudinal polarization on the target polarization.

[1] *COMPASS Collab.* CERN-PH-EP/2009-011, hep-ex/0907.0388; sub. EPJ C

Physical Motivation

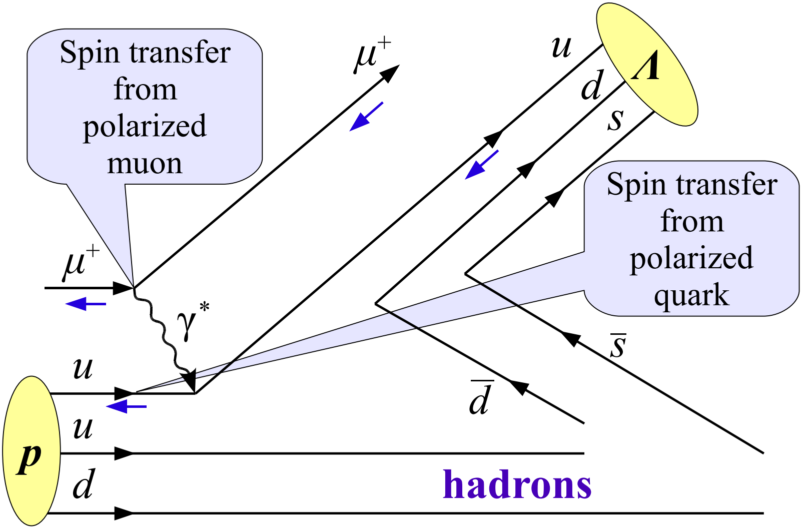
Longitudinal polarization of Λ and $\bar{\Lambda}$ in DIS is sensitive to:

- $s(x)$, $\bar{s}(x)$
- 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

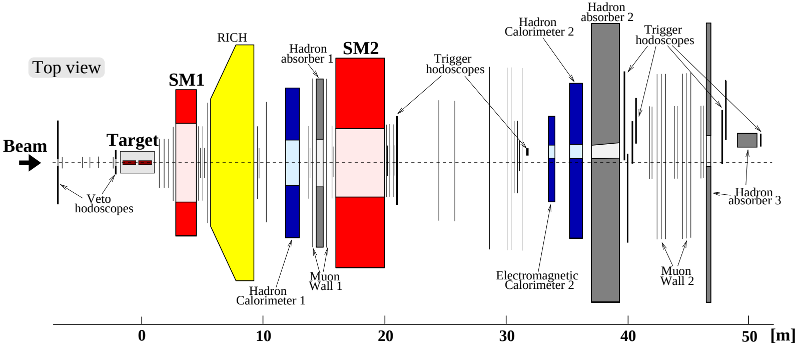
Example of quark spin transfer to Λ in DIS



Λ spin structure models

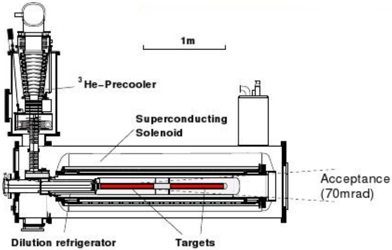
- SU(6) quark model: $\Delta \mathbf{s} = 1$, $\Delta \mathbf{u} = \Delta \mathbf{d} = 0$
  Even 100% polarization to **u** or **d** quarks
  has no influence on Λ polarization
  $P(\Lambda) = 0$ (due to **u** quark dominance)
- Burkard-Jaffe: $\Delta \mathbf{u} = \Delta \mathbf{d} = -0.23$
  $P(\Lambda)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

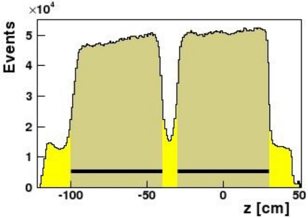
COMPASS Spectrometer setup



- Year 2003: $P_b = -0.76 \pm 0.04$
- Year 2004: $P_b = -0.80 \pm 0.04$
- 160 GeV μ^+ beam
- $2.8 \cdot 10^8$ $\mu/$spill (4.8 s)
- $Q^2 > 1$ $(\mathrm{GeV}/c)^2$: $(8.7 + 22.5) \cdot 10^7$ events

Polarized target





- target material: ^{6}**LiD**
- polarisation: $> \mathbf{50\%}$
- dilution factor: $\sim \mathbf{0.4}$
- 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

F. Kabuss, IWHSS08, Torino 31.3.2008

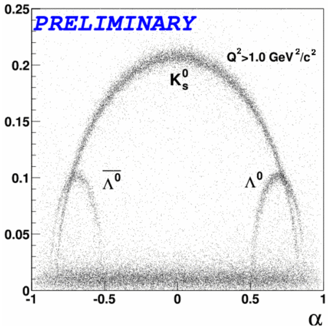
Production of Λ, $\bar{\Lambda}$ and K

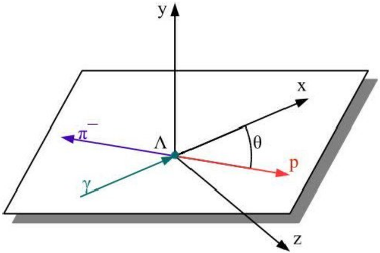
- $\mu^+ + d \longrightarrow \mu^+ + \Lambda + X$
  $\Lambda \longrightarrow p + \pi^-$
- $\mu^+ + d \longrightarrow \mu^+ + \bar{\Lambda} + X$
  $\bar{\Lambda} \longrightarrow \bar{p} + \pi^+$
- $\mu^+ + d \longrightarrow \mu^+ + K_S + X$
  $K_S \longrightarrow \pi^+ + \pi^-$

No PID identification

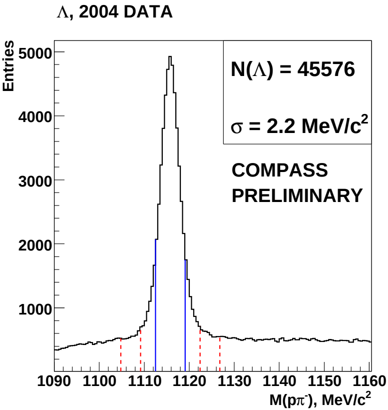
Events selection

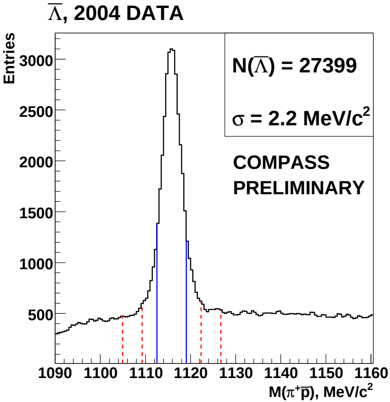
- Primary vertex inside the target
- Secondary vertex: 5 cm downstream of the last target cell
- $p_T > 23$ MeV$/c$
- $\theta < 0.01$ rad
- $Q^2 > 1\ (\text{GeV}/c)^2$
- $0.2 < y < 0.9$
- $p_{\pm} > 1 GeV/c$
- $0.05 < x_F < 0.5$
- $-1 < \cos\theta < 0.6$





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





Sideband substraction method were used to obtain $\cos\theta$ angular distribution.

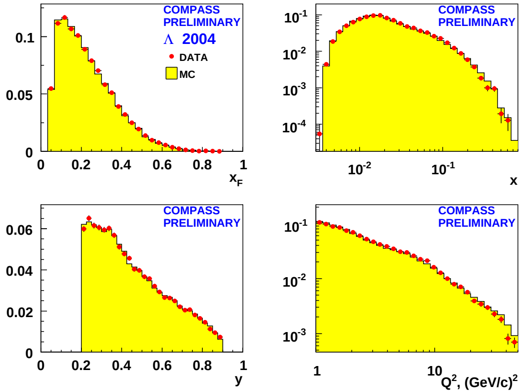
Bands regions: $(-5;-3)$, $(-1.5;1.5)$, $(3;5)$ σ from mass peak.

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

COMPASS has the greatest number of Λ and the considerable number of $\bar{\Lambda}$ is unique.

Kinematic distributions for the selected Λ sample



Mean values:

$\langle x \rangle = 0.05$

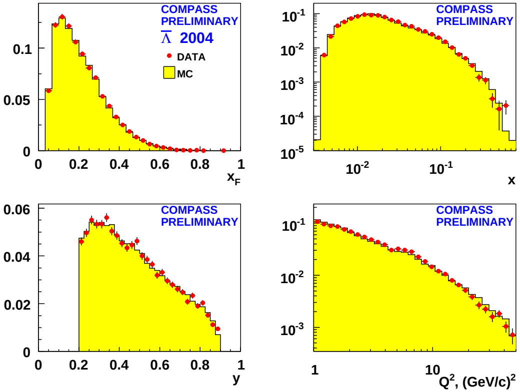
$\langle x_F \rangle = 0.23$

$\langle y \rangle = 0.46$

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

Good agreement between data and MC
Wide range of x_{Bj}

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 and $\bar{\Lambda}$ have similar kinematic regions

Longitudinal polarization and spin transfer equations

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

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

$$\frac{1}{N_{tot}}\frac{dN}{dcos\theta} = \frac{1}{2}(1 + \alpha P_L cos\ \theta)$$

By definition longitudinal spin transfer is:

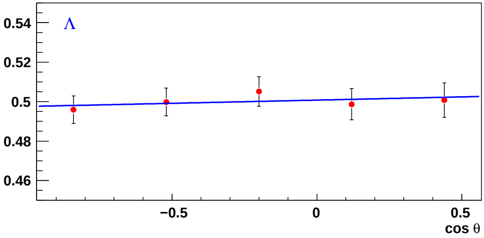
$$P_L = D_{LL} P_b D(y),$$

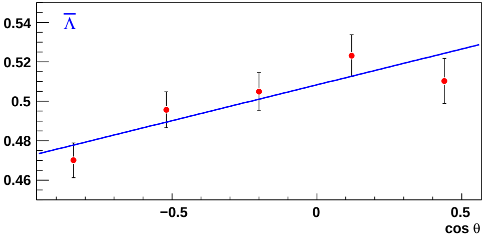
where P_b – beam polarization and $D(y)$ – depolarization factor.

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

Measurement of $cos\theta$ distribution gives access to P_L

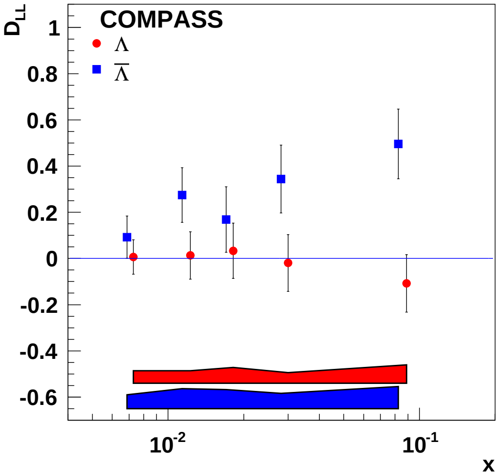
Example of angular distribution fits





- Angular dependencies for Λ, $\bar{\Lambda}$
- 2004 year events

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



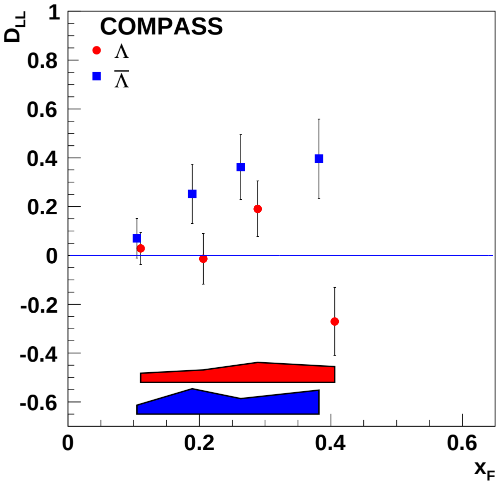
- $D_{LL}^{\Lambda} \neq D_{LL}^{\bar{\Lambda}}$
- $D_{LL}^{\Lambda} \simeq 0$

$$D_{LL}^{\Lambda} = -0.012 \pm 0.047 \pm 0.024$$
$$D_{LL}^{\bar{\Lambda}} = \quad 0.249 \pm 0.056 \pm 0.049$$

Estimation of systematic errors

	Λ	$\bar{\Lambda}$
Spin transfer to kaons, $\delta(MC_1)$	0.016	0.016
Variation of selection cuts, $\delta(MC_2)$	0.016	0.044
Uncertainty of the ss-method, $\delta(ss)$	0.010	0.016
Uncertainty of the beam polarization, $\delta(P_b)$	0.0006	0.013
σ_{syst}	0.024	0.049

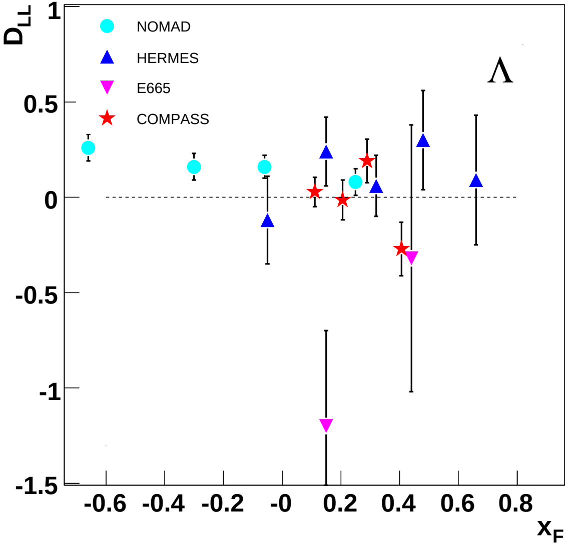
Results: Comparison of Λ and $\bar{\Lambda}$: x_F



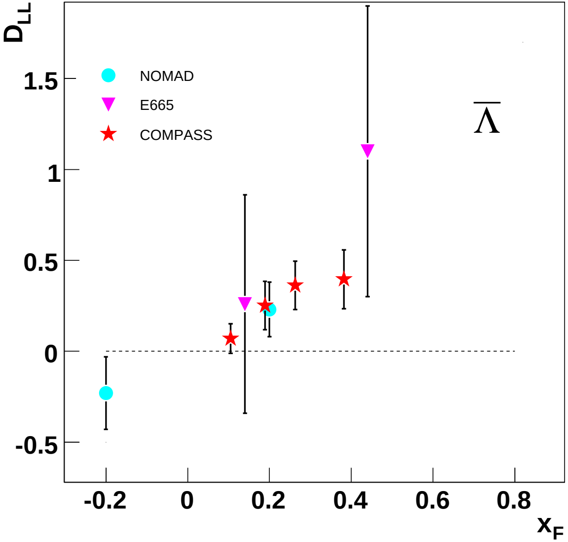
- $D_{LL}^{\bar{\Lambda}}$ rises with x_F

$$D_{LL}^{\Lambda} = -0.012 \pm 0.047 \pm 0.024$$
$$D_{LL}^{\bar{\Lambda}} = \quad 0.249 \pm 0.056 \pm 0.049$$

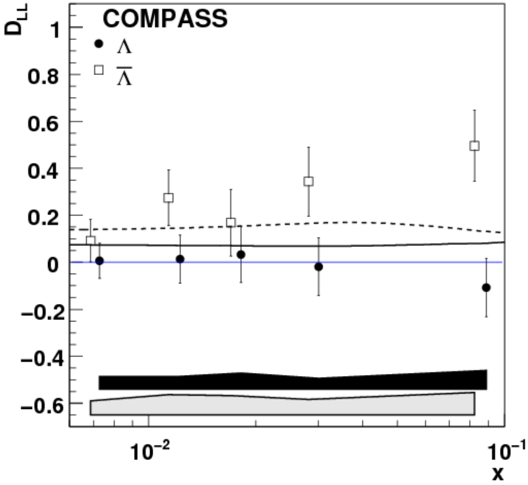
Results: Comparison with other experiments: Λ



- COMPASS results agree with other experiments.



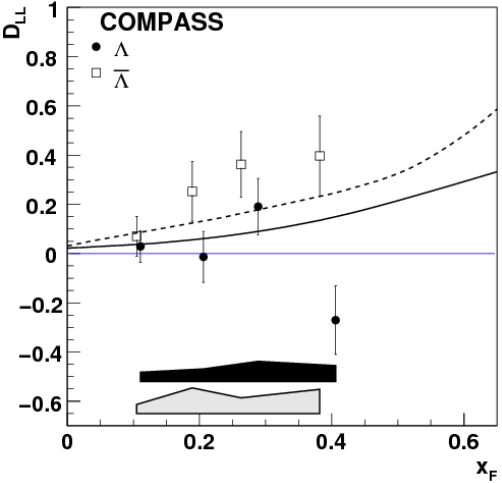
- COMPASS data are in agreement with NOMAD data
- it is the only data on x_F - dependence of $\bar{\Lambda}$



- Λ – solid line
- $\bar{\Lambda}$ – dashed line
- theory predictions: $D_{LL}^{\bar{\Lambda}} > D_{LL}^{\Lambda}$

J.Ellis et al., Eur.Phys.J. C52 (2007) 283

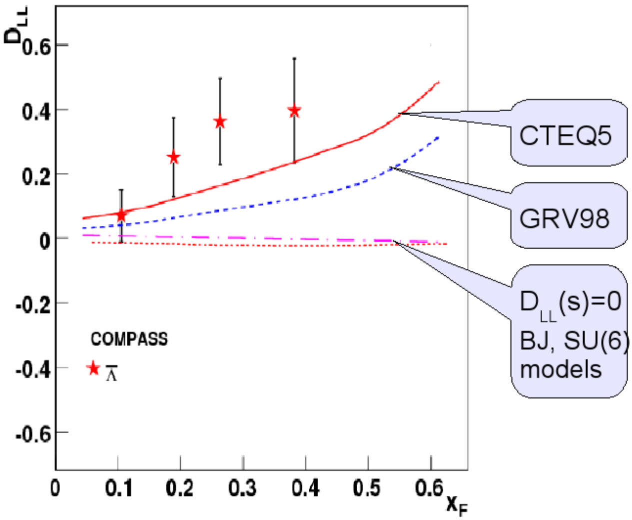
Theory predictions for Λ and $\bar{\Lambda}$: SU(6), CTEQ5



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

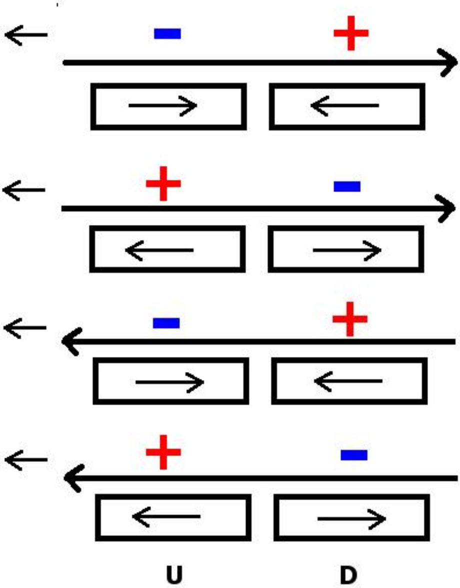
J.Ellis et al., Eur.Phys.J. C52 (2007) 603

Comparison with theory ($\bar{\Lambda}$): CTEQ5 and GRV98



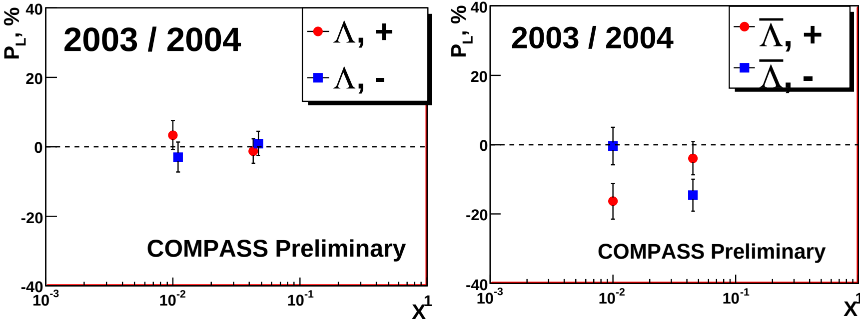
- Data for $\bar{\Lambda}$ are sensitive to the $s(x)$ distribution

Positive and negative target polarizations



- P_+ - when direction of target cell polarization, coincide with direction of muon beam polarization
- P_- - when they are opposite

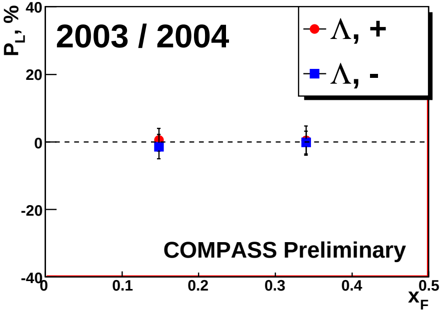
Dependence on the target polarization: x-distribution

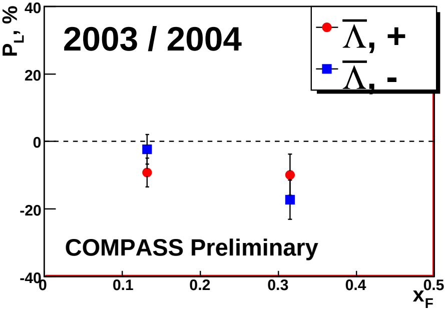


$$\Delta P = P_- - P_+ = -0.01 \pm 0.04 \text{ - } \Lambda$$
$$\Delta P = P_- - P_+ = 0.01 \pm 0.05 \text{ - } \bar{\Lambda}$$

No significant dependence is found.

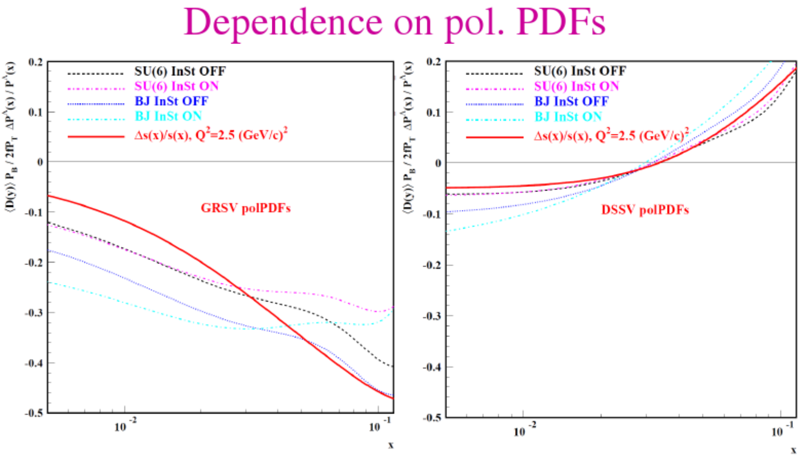
Dependence on the target polarization: x_F-distribution





$$\Delta P = P_- - P_+ = -0.01 \pm 0.04 \text{ - } \Lambda$$
$$\Delta P = P_- - P_+ = 0.01 \pm 0.05 \text{ - } \bar{\Lambda}$$

Fit for $\Delta P/P$



$\Delta P/P = \frac{P_- - P_+}{(P_- + P_+)/2}$, on y axis $\frac{<D(y)P_b>}{2fP_T}\frac{\Delta P^{\bar\Lambda}(x)}{P^{\bar\Lambda}(x)}$

$\Delta P/P$ changes a sign in x_{Bj} region

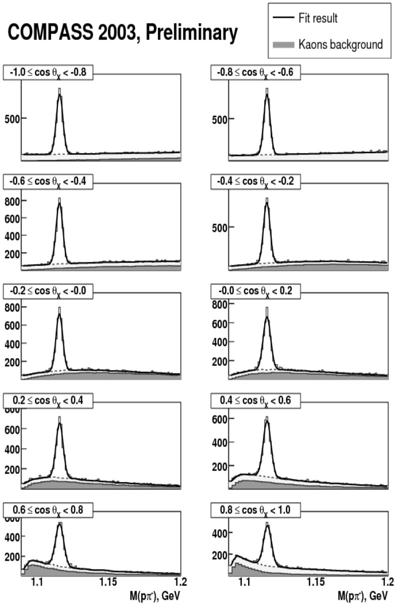
A.Kotzinian, DIS09

Results:

- The presented data are the most precise measurements to date of the longitudinal spin transfer to Λ 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 $\bar{s}(x)$

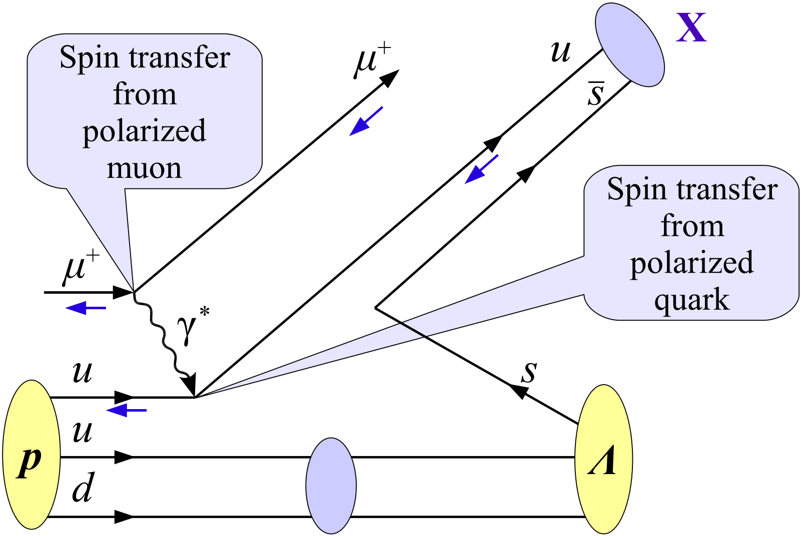
Backup slides

Invariant mass of Λ on $cos\theta$

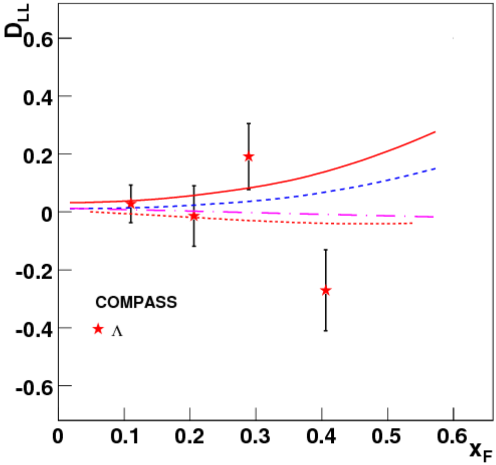


Kaon background is important at large $cos\theta$

Example of diquark spin transfer to Λ in DIS



Comparison with theory (Λ): CTEQ5 and GRV98



- CTEQ5 – solid line
- GRV98 – dashed line
- $D_{LL}(s) = 0$ BG and SU(6) models – 2 lower lines

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

Polarization of Λ from quark fragmentation

Longitudinal polarization of Λ and $\bar{\Lambda}$ in DIS is sensitive to $s(x)$, $\bar{s}(x)$

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

For $P_T = 0$:

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

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

Spin transfer of Λ and $\bar{\Lambda}$: $P_T = 0$

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

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

$$D_{LL}(\bar{\Lambda}) > D_{LL}(\Lambda)$$

- $s(x) \neq \bar{s}(x)$
- $D_q^{\Lambda}(z) > D_q^{\bar{\Lambda}}$