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

Vladimir Rapatskiy

JINR, Dubna
On behalf of COMPASS collaboration

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Motivation

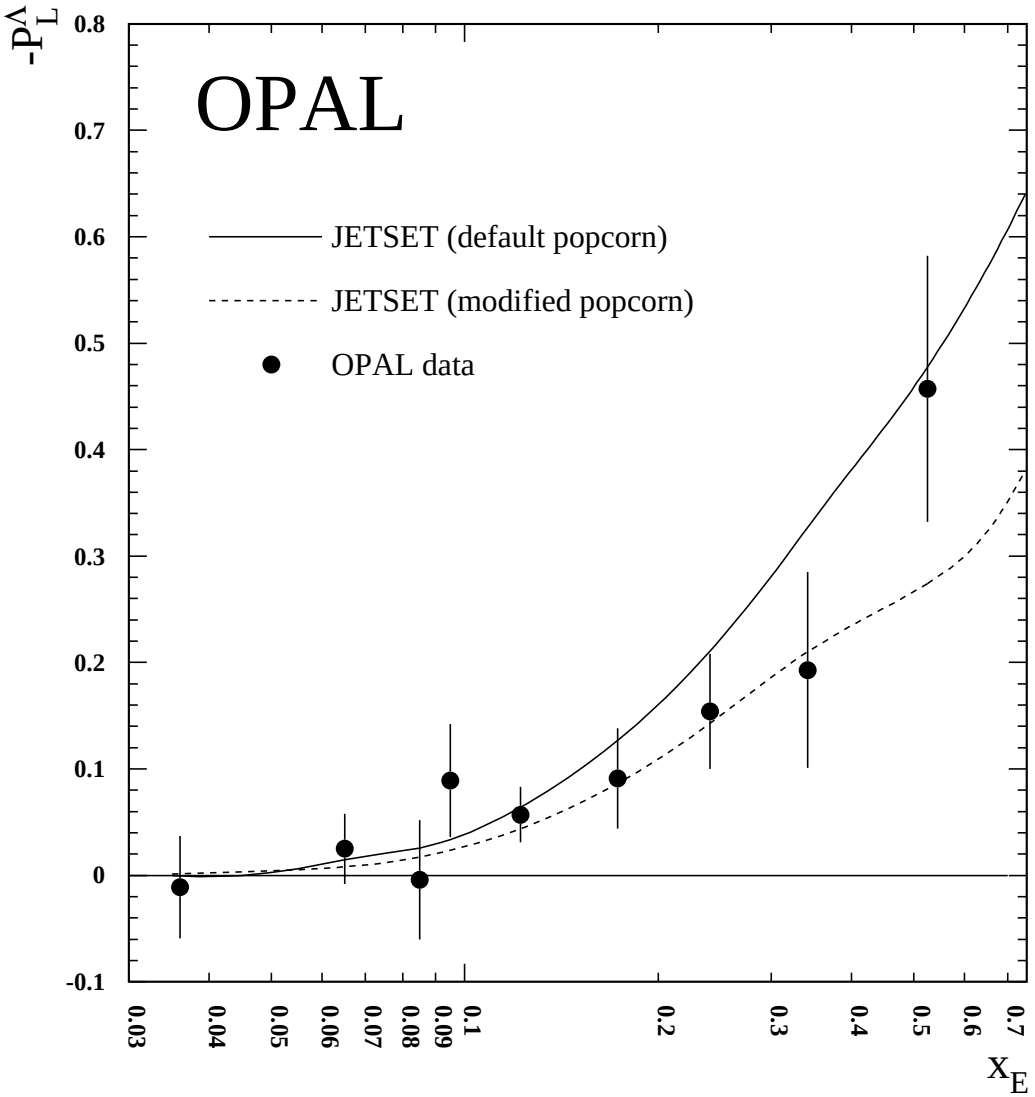
Longitudinal polarization of Λ and $\overline{\Lambda}$ in DIS is sensitive to:

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

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

- Λ spin structure

Motivation: spin transfer from s-quark to Λ



hep-ex/9708027:

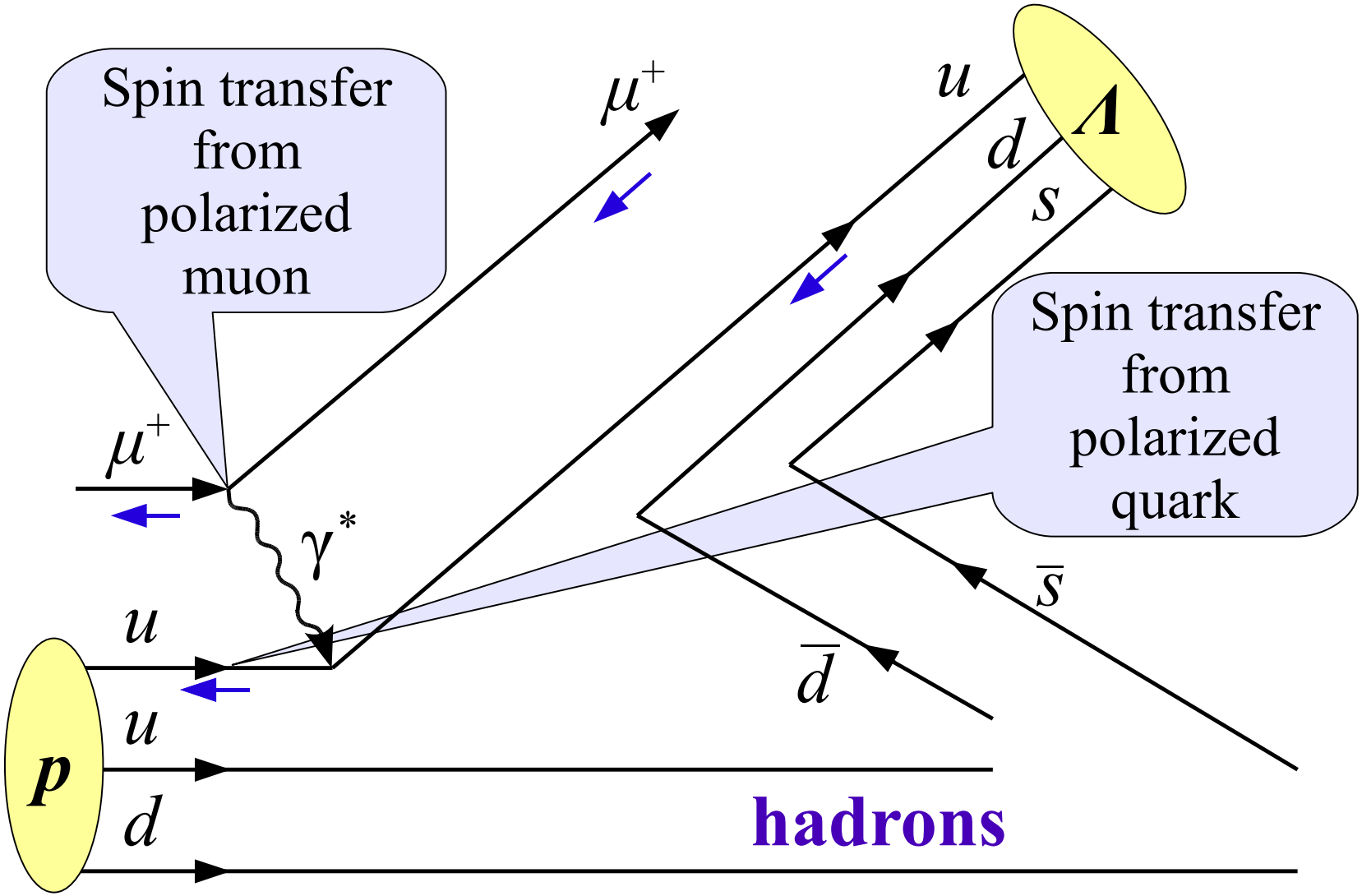
$e^+e^- \longrightarrow Z^0 \longrightarrow s\bar{s}$

$P_s = -0.91$

$\Lambda : u \uparrow d \downarrow s \uparrow$

Polarized s-quarks transfer the polarization to Λ.

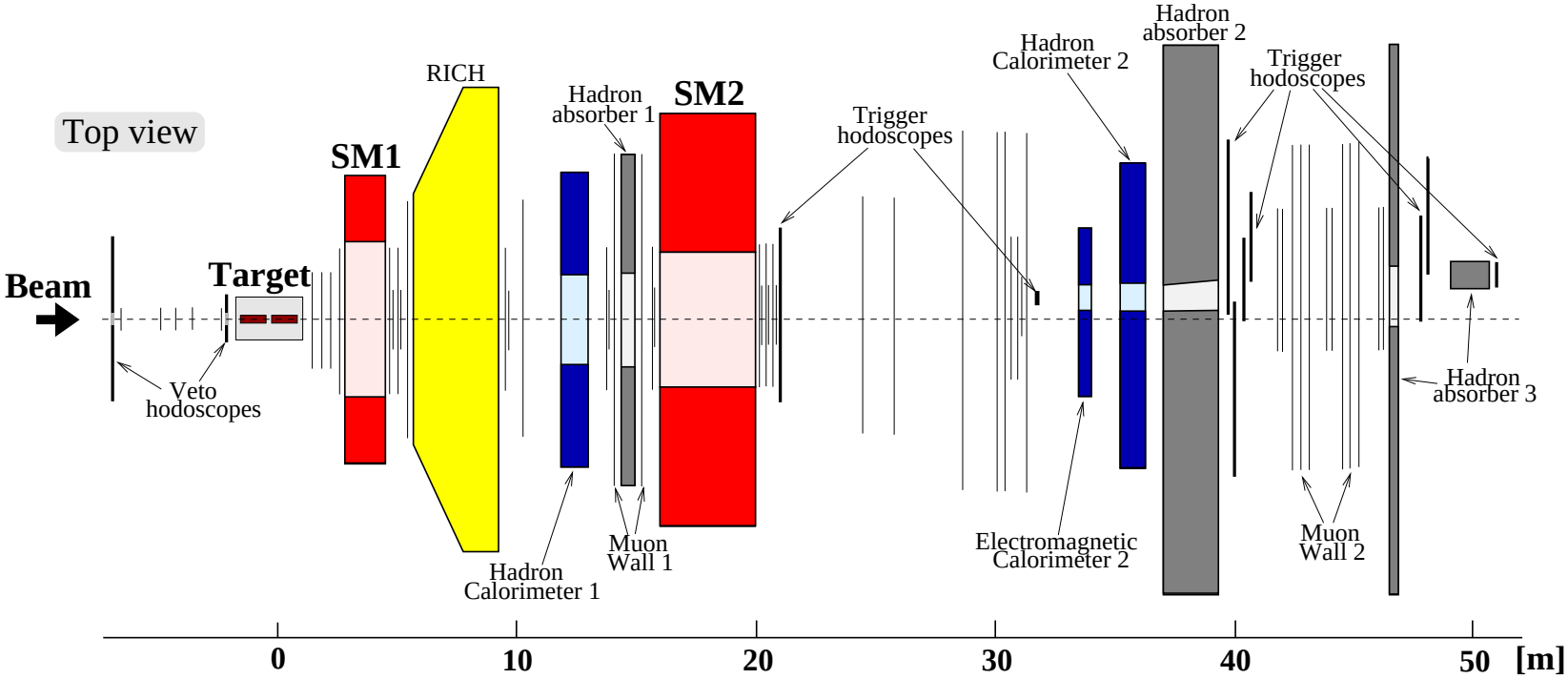
Example of quark spin transfer to Λ in DIS



Λ spin structure models

- SU(6) quark model: $\Delta\mathbf{s} = 1$, $\Delta\mathbf{u} = \Delta\mathbf{d} = 0$
  Even 100% polarization to $\mathbf{u}$ or $\mathbf{d}$ quarks
  has no influence on Λ polarization
  $P(\Lambda) = 0$ (due to $\mathbf{u}$ 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:

$P_b = -0.80 \pm 0.04$

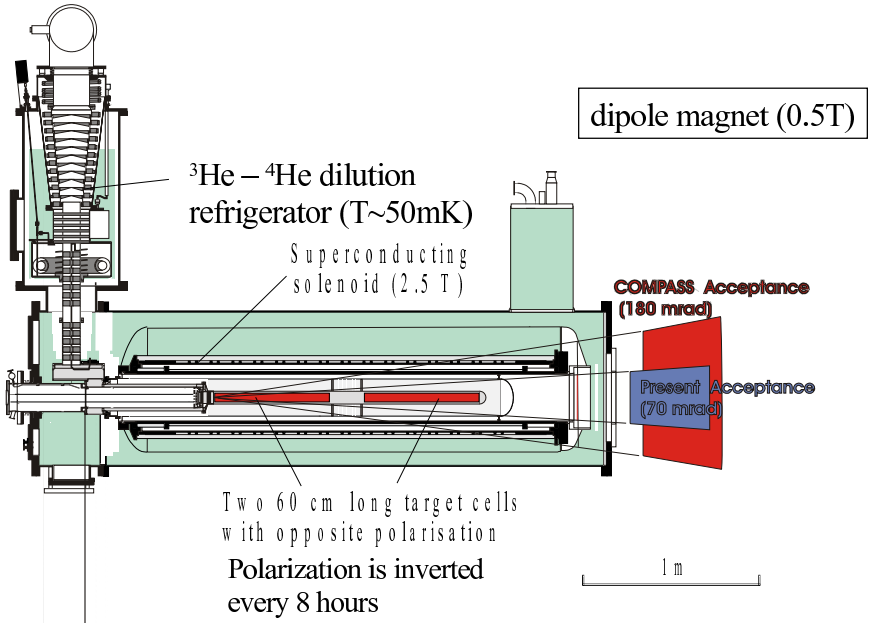
160 GeV μ^+ polarized beam

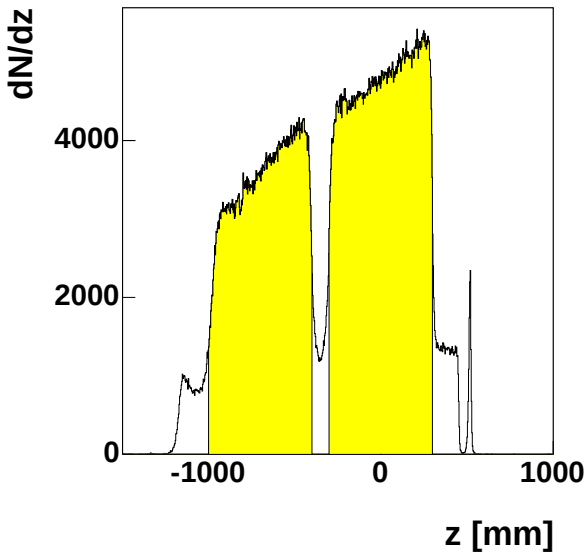
$2.8 \cdot 10^8$ μ/spill (4.8 s)

$Q^2 > 1$ $(\mathrm{GeV}/c)^2$:

$(8.7 + 22.5) \cdot 10^7$ events

COMPASS Polarized target





- Target material: ^{6}LiD
- Polarization: $> 50\%$
- Dilution factor: ~ 0.4
- Solenoid field: 2.5 T
- Acceptance: 70 mrad
- ^{3}He/^{4}He: $T_{\mathtt{min}} \approx 50$ mK
- Two 60 cm long target cells with opposite polarization
- Regular polarization reversal by field rotation

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

Production of V^0 – neutral decay vertex:

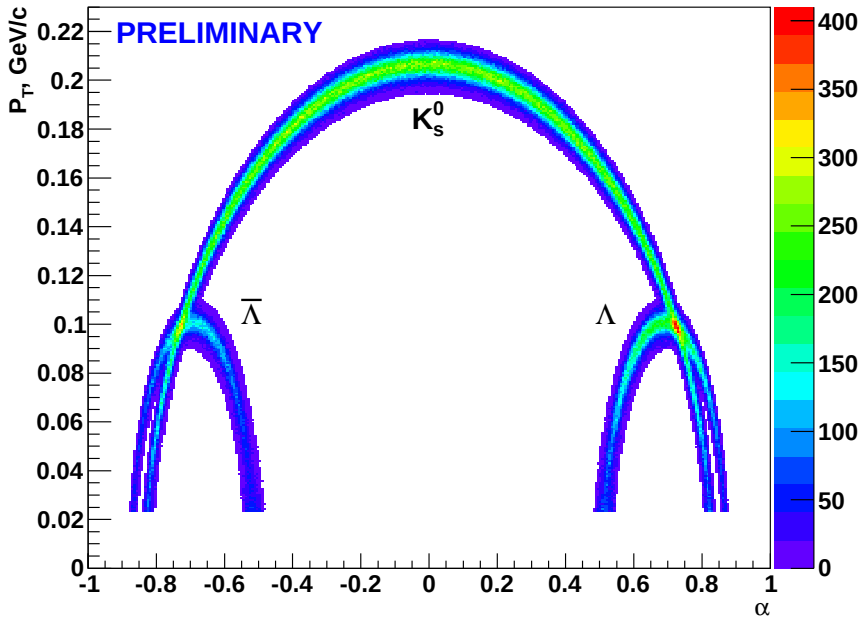
- $\mu^+ + d \rightarrow \mu^+ + V^0 + X$
- $V^0 \equiv (\Lambda, \overline{\Lambda}$ or $K_s)$

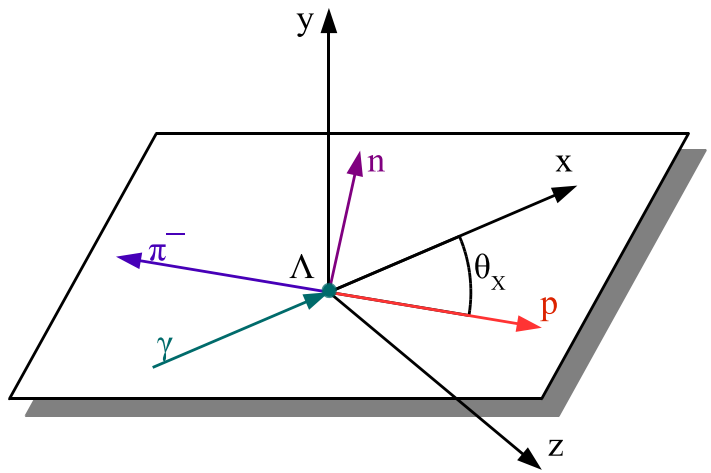
V^0 decay signature:

- $\Lambda \rightarrow p + \pi^-$
- $\overline{\Lambda} \rightarrow \overline{p} + \pi^+$
- $K_s \rightarrow \pi^+ + \pi^-$

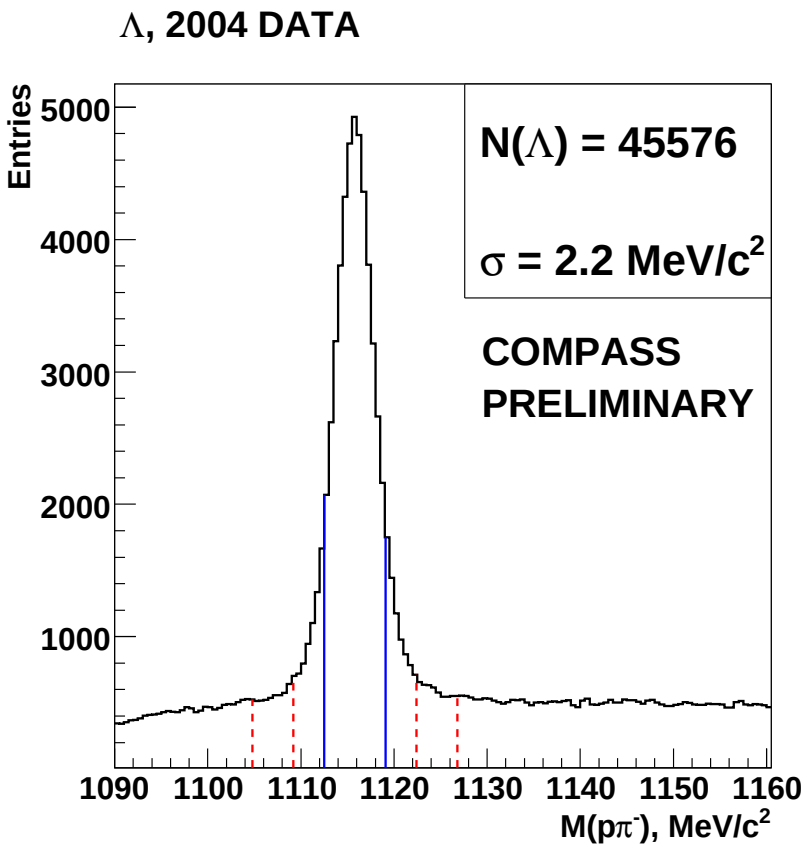
Events selection

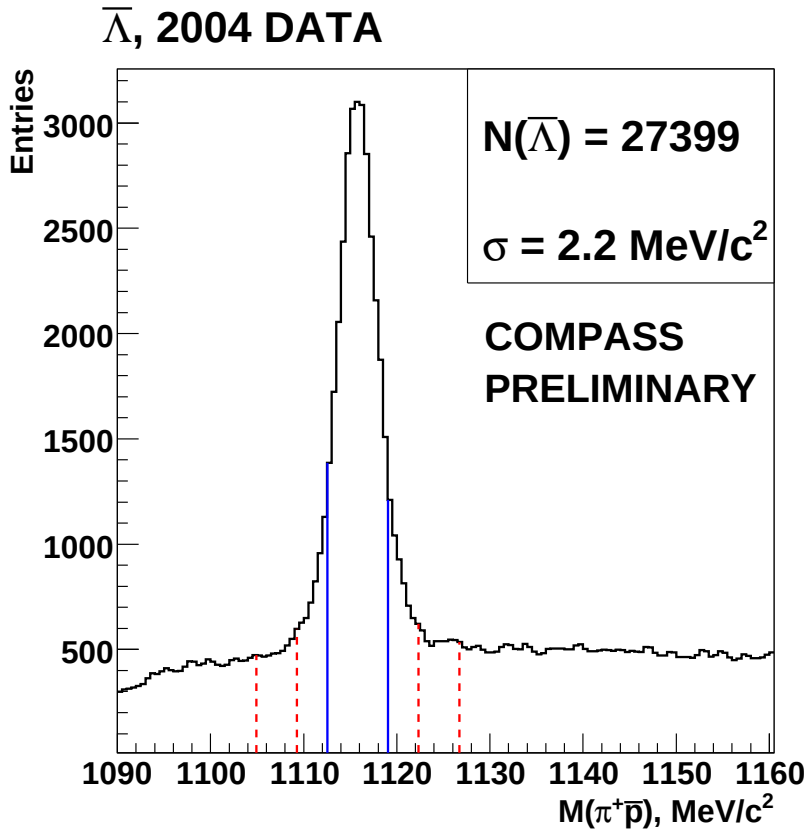
- Primary vertex inside the target
- Secondary vertex: 5 cm downstream of the last target cell
- $p_T > 23$ MeV/c
- $\theta < 0.01$ rad
- $Q^2 > 1$ (GeV/c)^2
- $0.2 < y < 0.9$
- $p^{\pm} > 1$ GeV/c
- $0.05 < x_F < 0.5$
- $-1 < \cos\theta < 0.6$





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





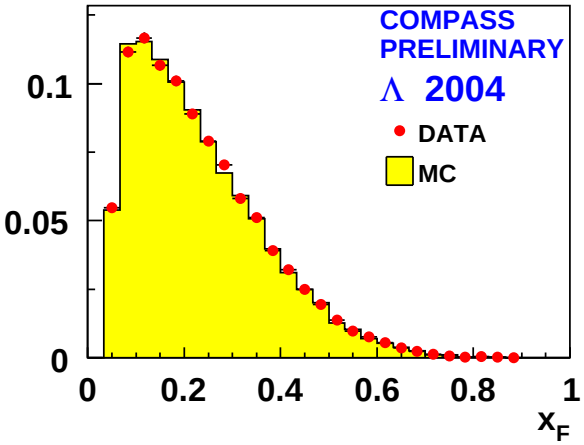
Sideband substraction method were used to obtain $\cos\theta$ angular distribution. Bands regions: $(-5;-3)$, $(-1.5;1.5)$, $(3;5)$ σ from mass peak.

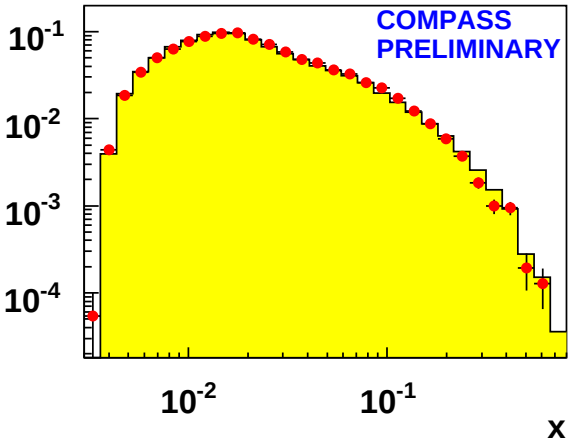
Statistics: comparison with other experiments

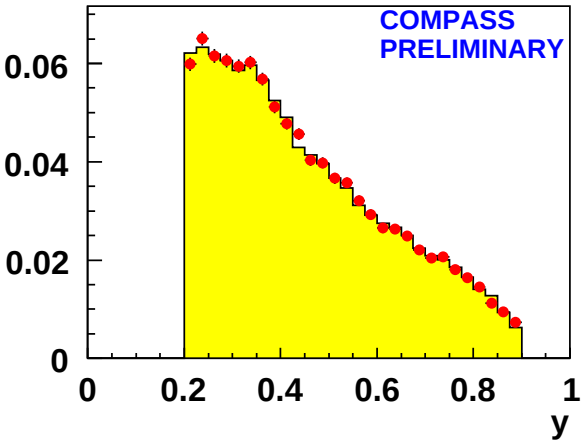
	Year publ.	E GeV	N(Λ)	N($\bar{\Lambda}$)
E665	2000	470	750	650
NOMAD	2000	43.8	8087	649
HERMES,	2006	27.5	7300	1687
RHIC	2006	$\sqrt{s} = 200$	30000	24000
COMPASS	2008	160	70000	42000

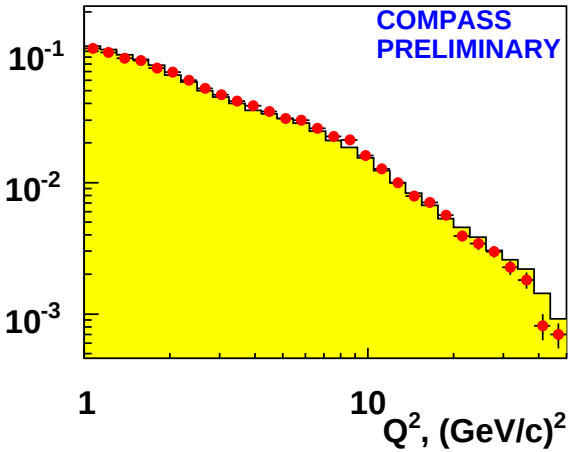
COMPASS has collected the largest number of events

Kinematic distributions for the selected Λ sample









Mean values:

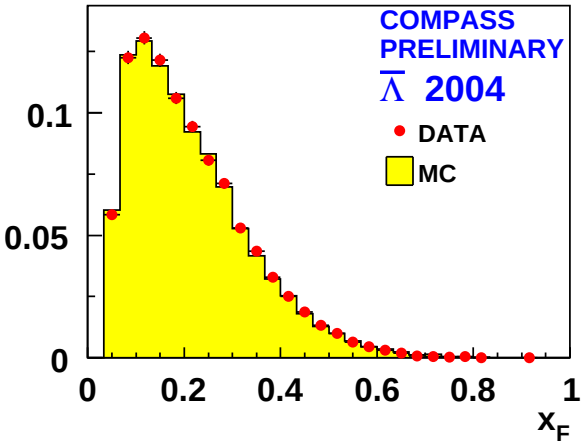
$\langle x \rangle = 0.05$

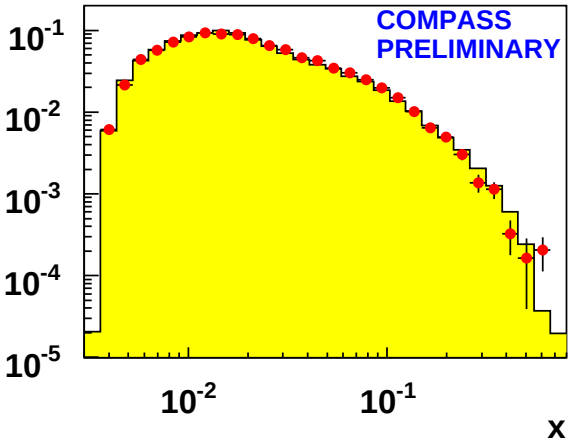
$\langle x_F \rangle = 0.23$

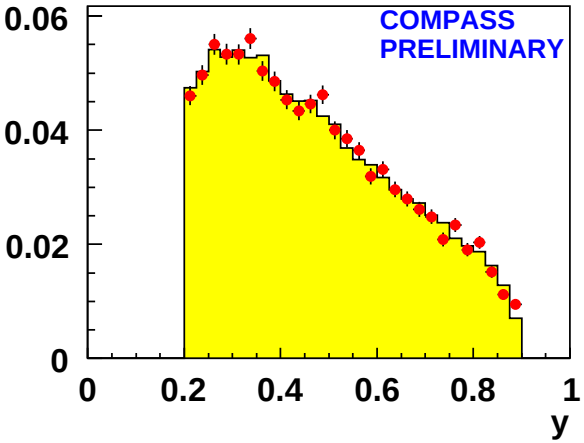
$\langle y \rangle = 0.46$

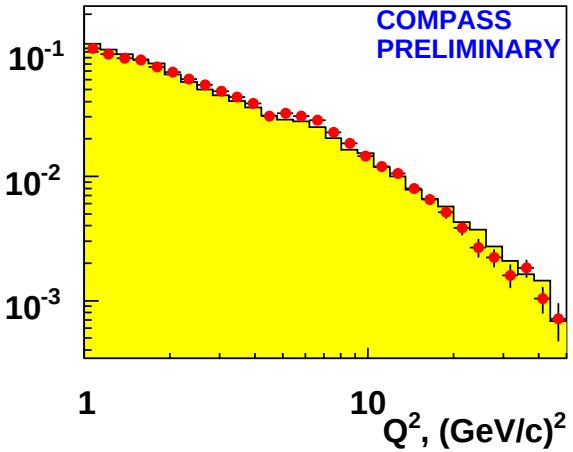
$\langle Q^2 \rangle = 3.31\ (\mathrm{GeV}/c)^2$

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









Mean values:

$\langle x \rangle = 0.05$

$\langle x_F \rangle = 0.22$

$\langle y \rangle = 0.48$

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

Polarization and spin transfer equations

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

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

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

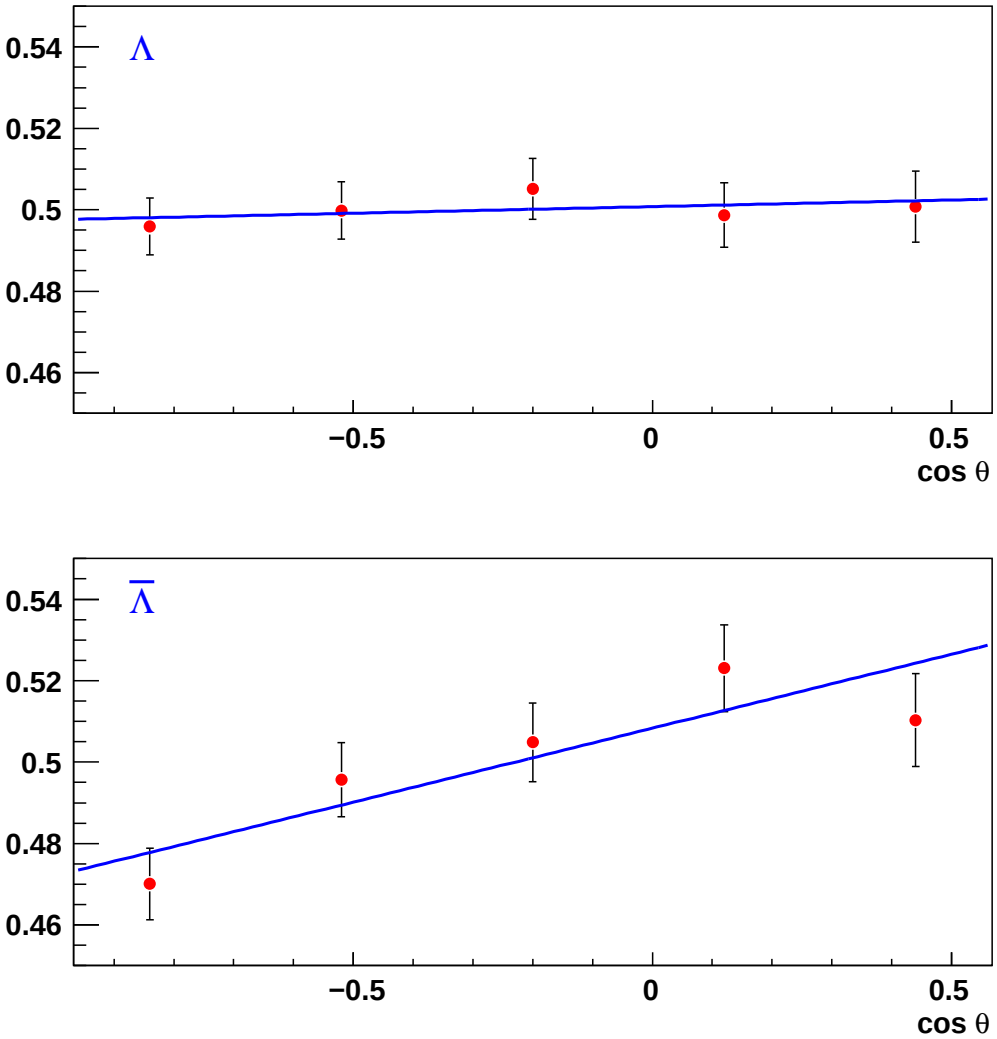
By definition longitudinal spin transfer D_{LL} evaluates from:

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

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

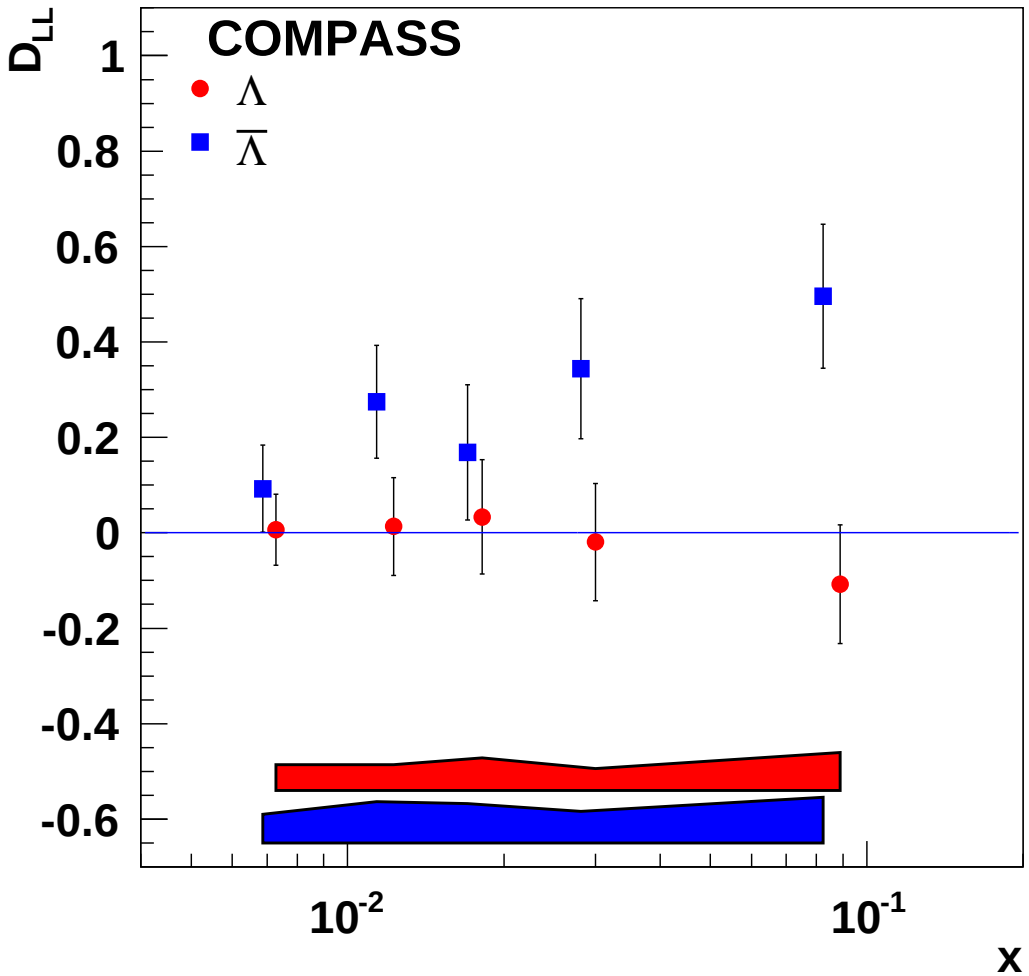
$$D(y) = \frac{1 - (1-y)^2}{1 + (1-y)^2}$$

Example of angular distribution fits



- Angular dependencies for Λ and $\overline{\Lambda}$
- 2004 year events

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



- $D_{LL}^{\Lambda} \neq D_{LL}^{\overline{\Lambda}}$
- $D_{LL}^{\Lambda} \sim 0$

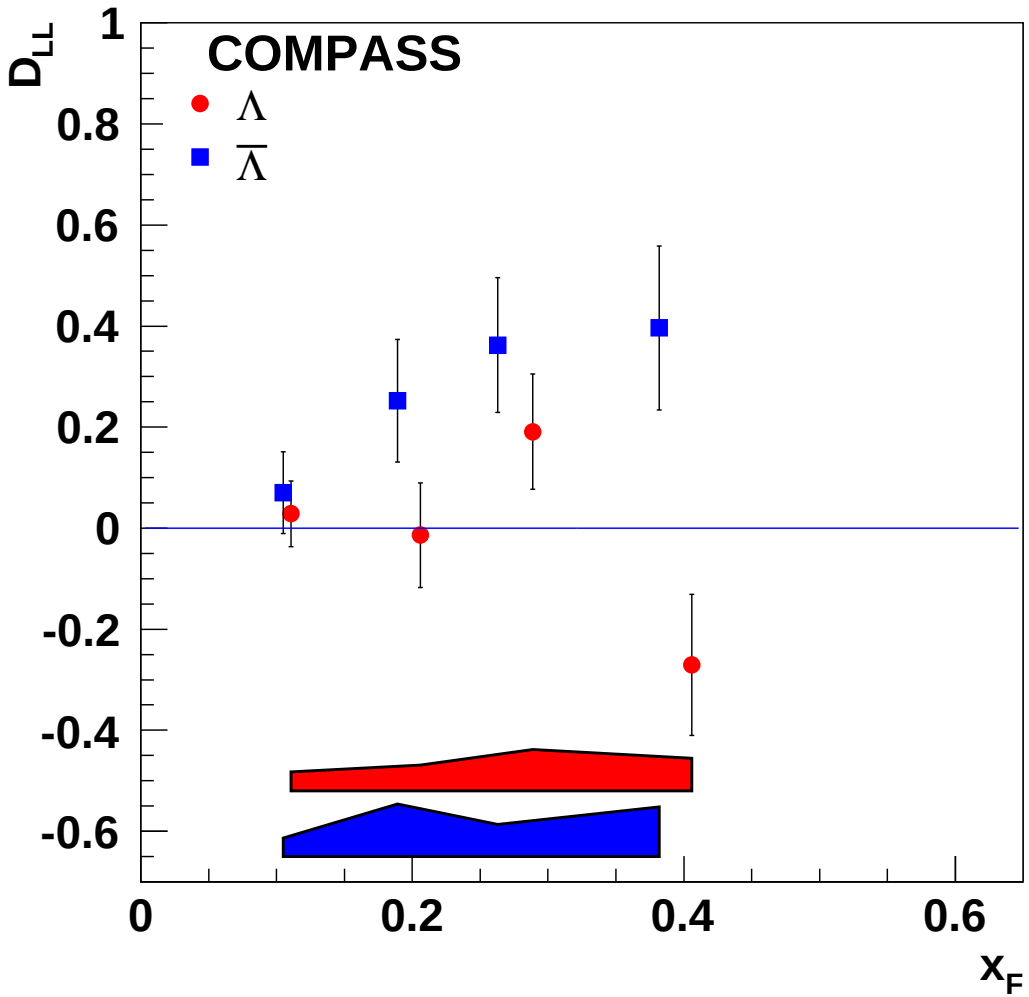
Λ: $D_{LL} = -0.012 \pm 0.047 \pm 0.024$

$\overline{\Lambda}$: $D_{LL} = \quad 0.249 \pm 0.056 \pm 0.049$

Estimation of systematic errors

	Λ	$\overline{\Lambda}$
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
Summary systematic error:	0.024	0.049

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

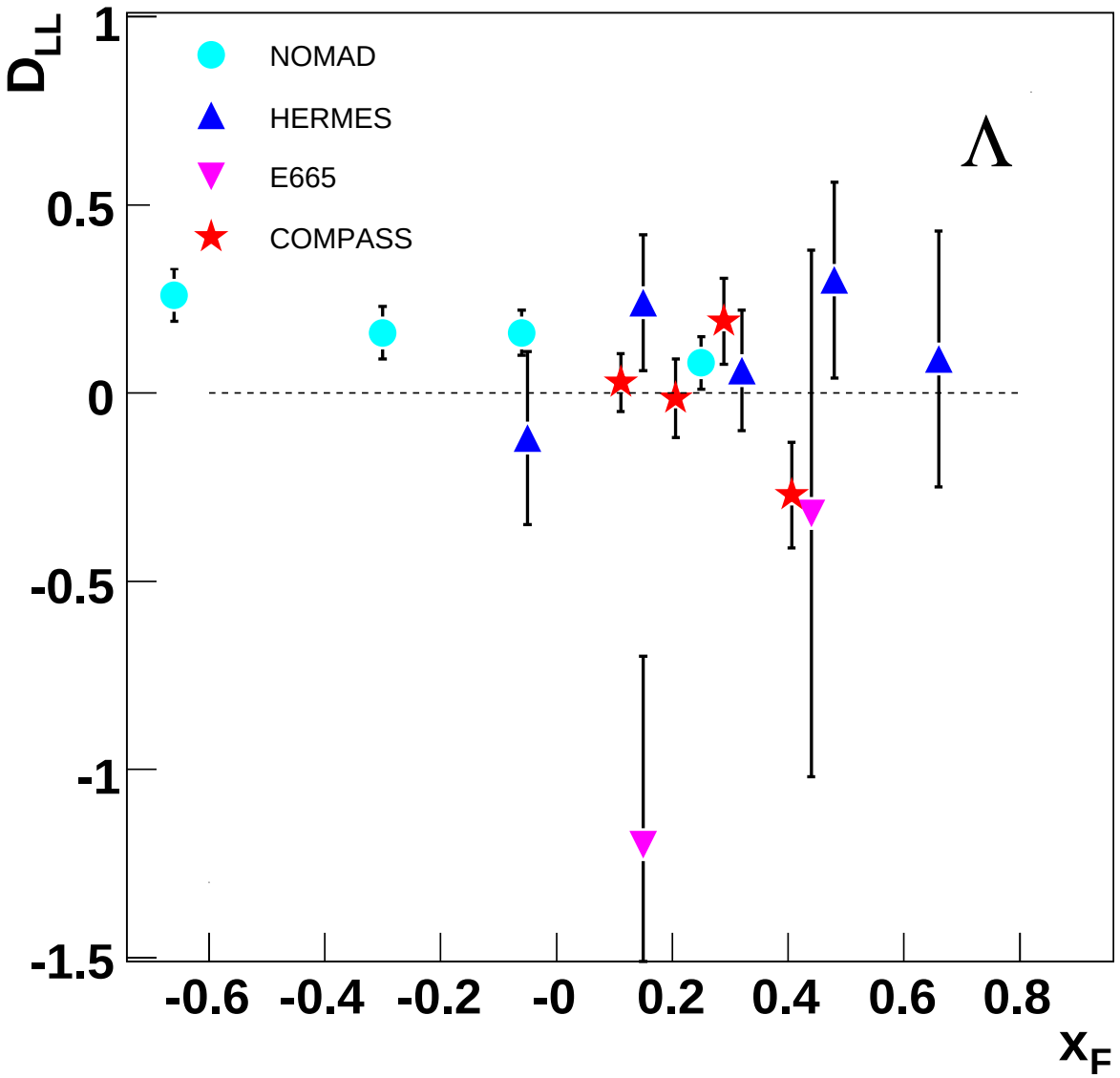


- $D_{LL}^{\overline{\Lambda}}$ rises with x_F

Λ: $D_{LL} = -0.012 \pm 0.047 \pm 0.024$

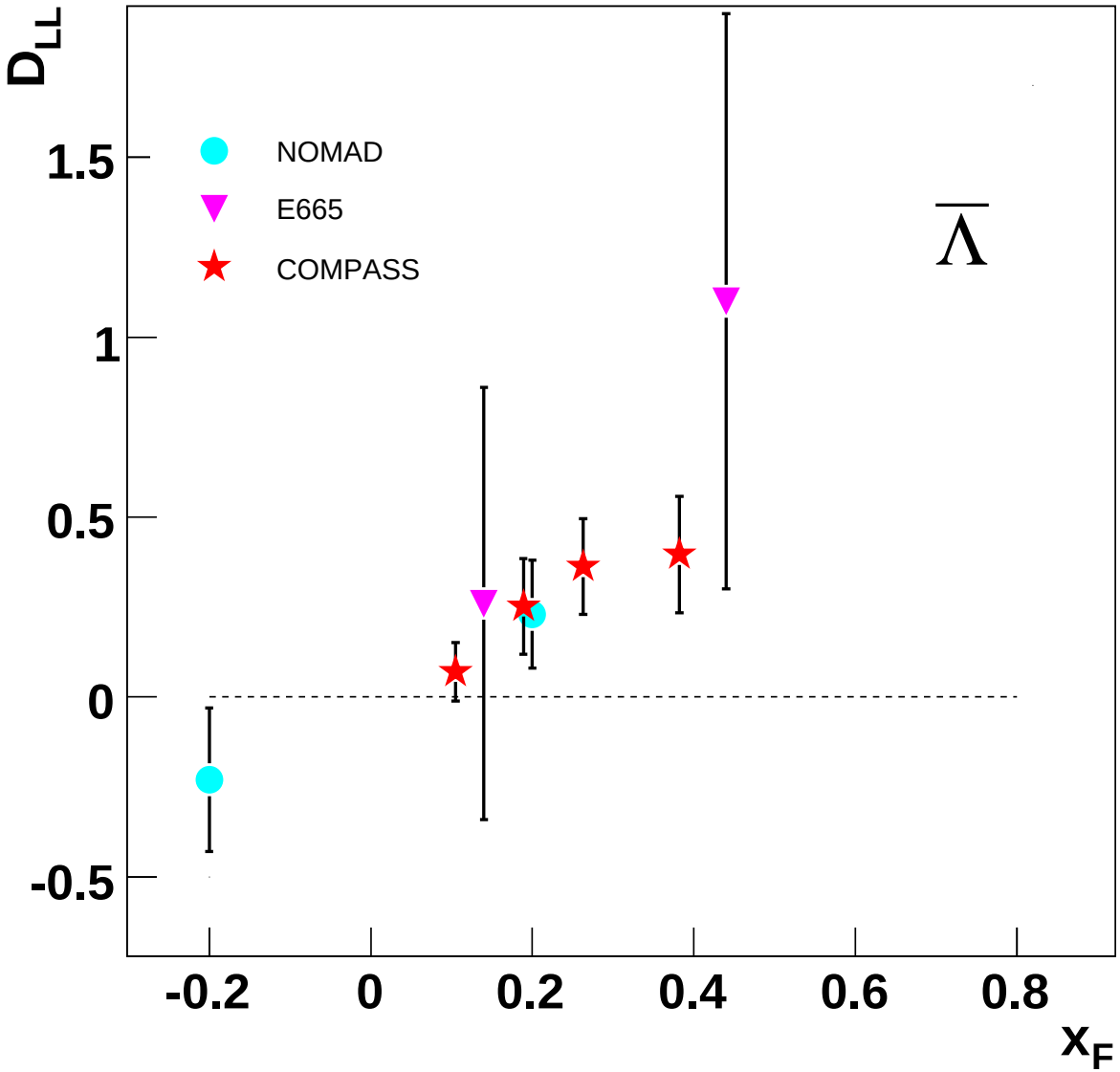
$\overline{\Lambda}$: $D_{LL} = \quad 0.249 \pm 0.056 \pm 0.049$

Comparison with other experiments: Λ



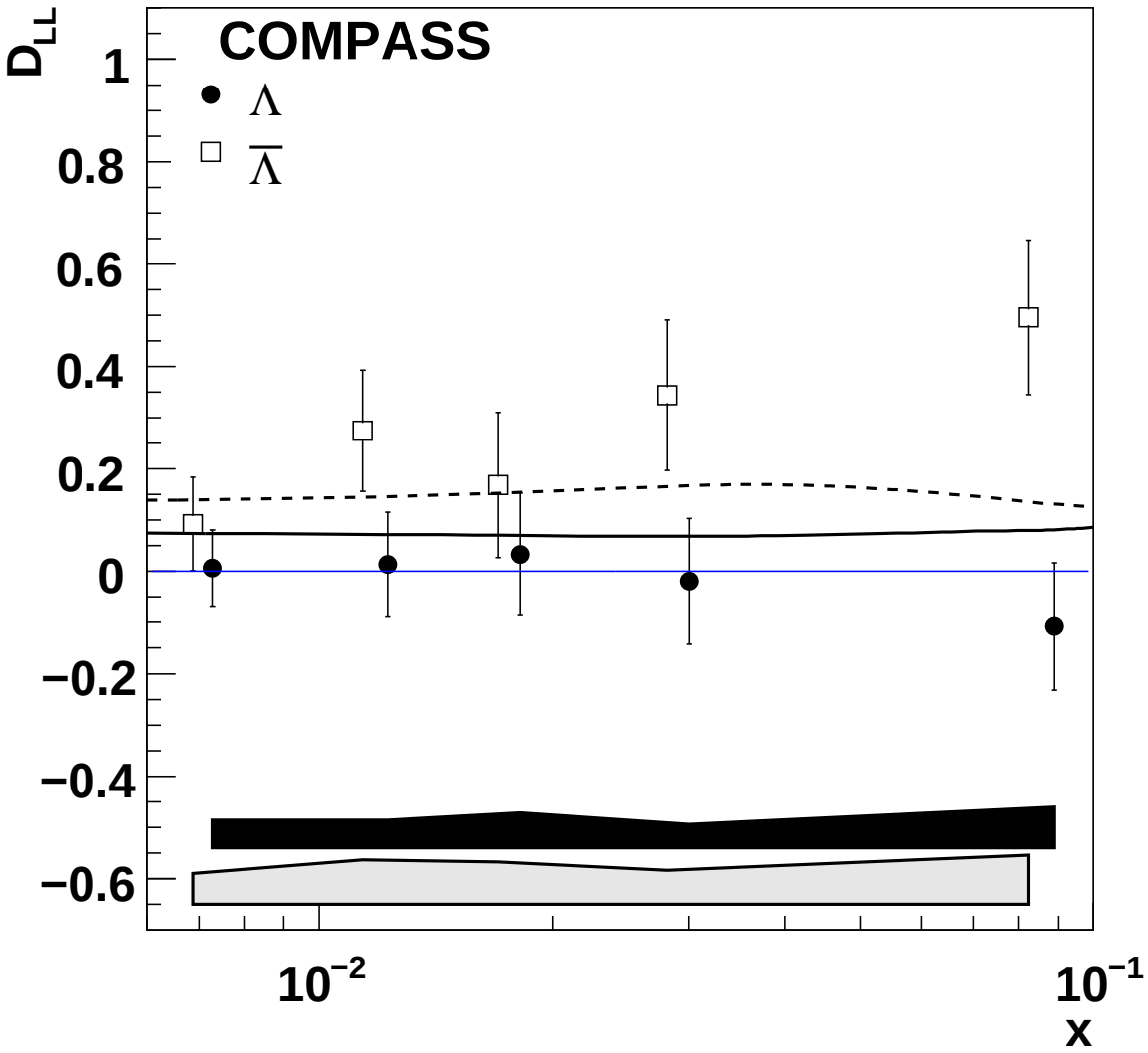
- COMPASS results agree with other experiments

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



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

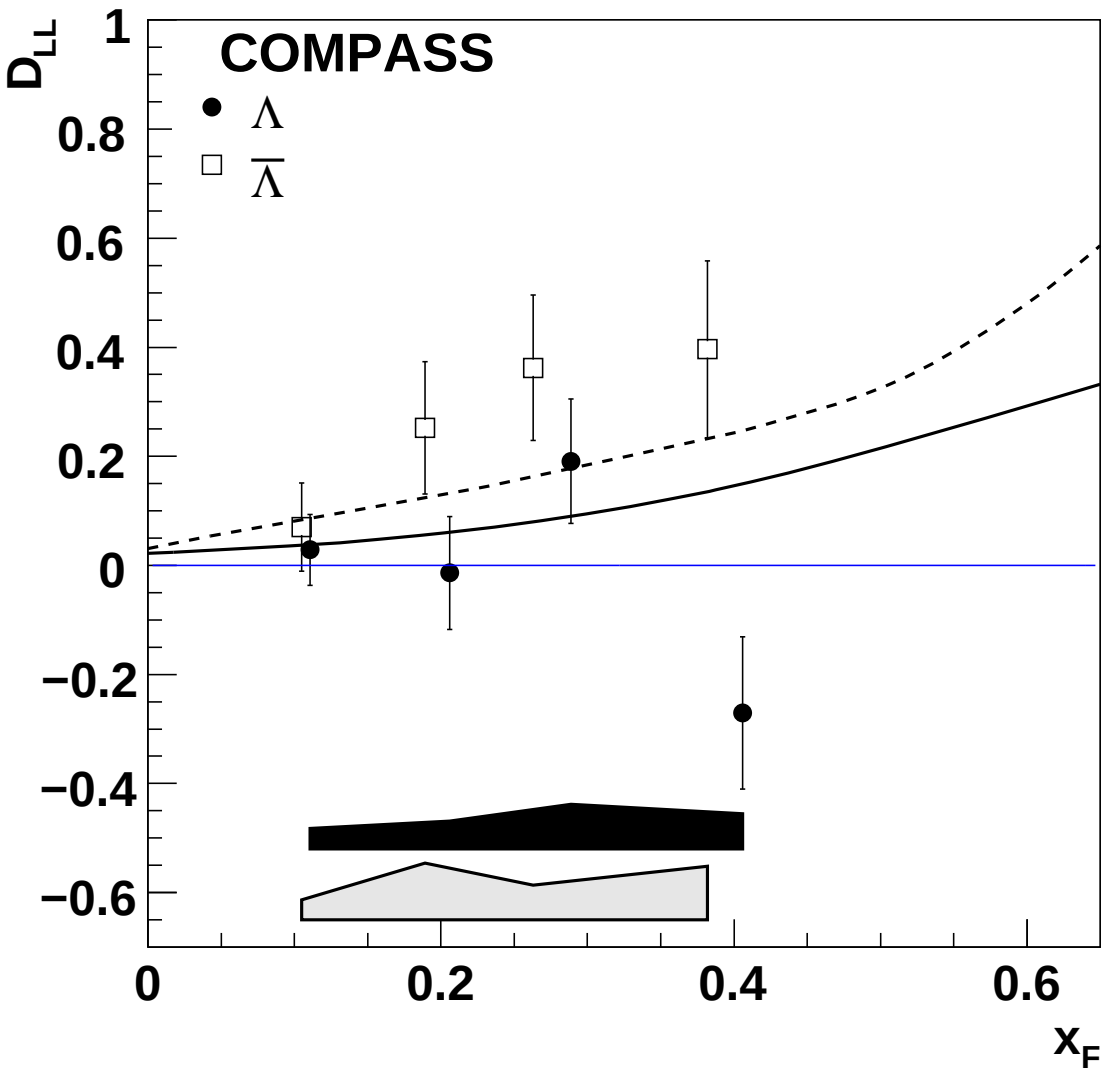
Theory predictions for Λ and $\overline{\Lambda}$: SU(6), CTEQ5



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

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

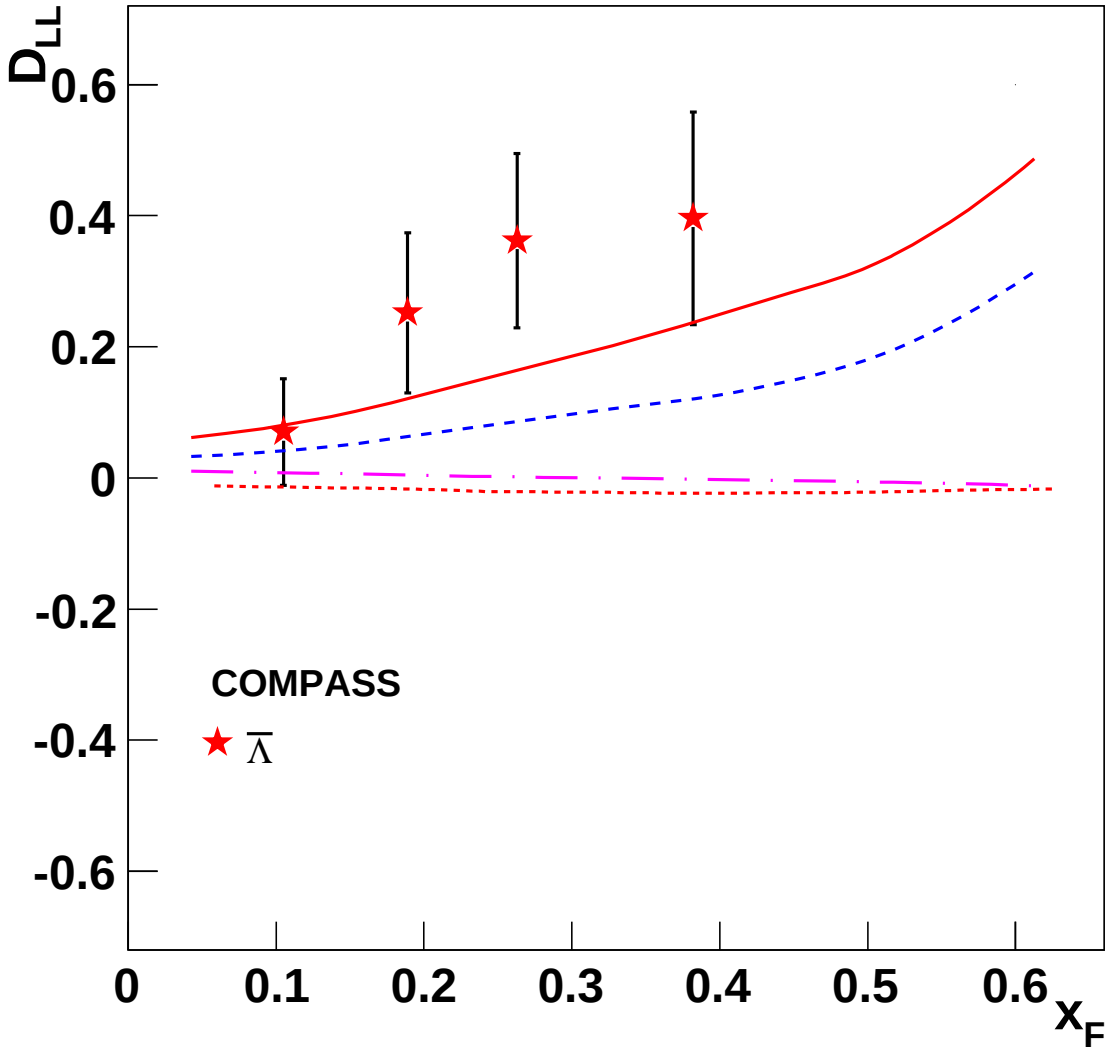
Theory predictions for Λ and $\overline{\Lambda}$: SU(6), CTEQ5



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

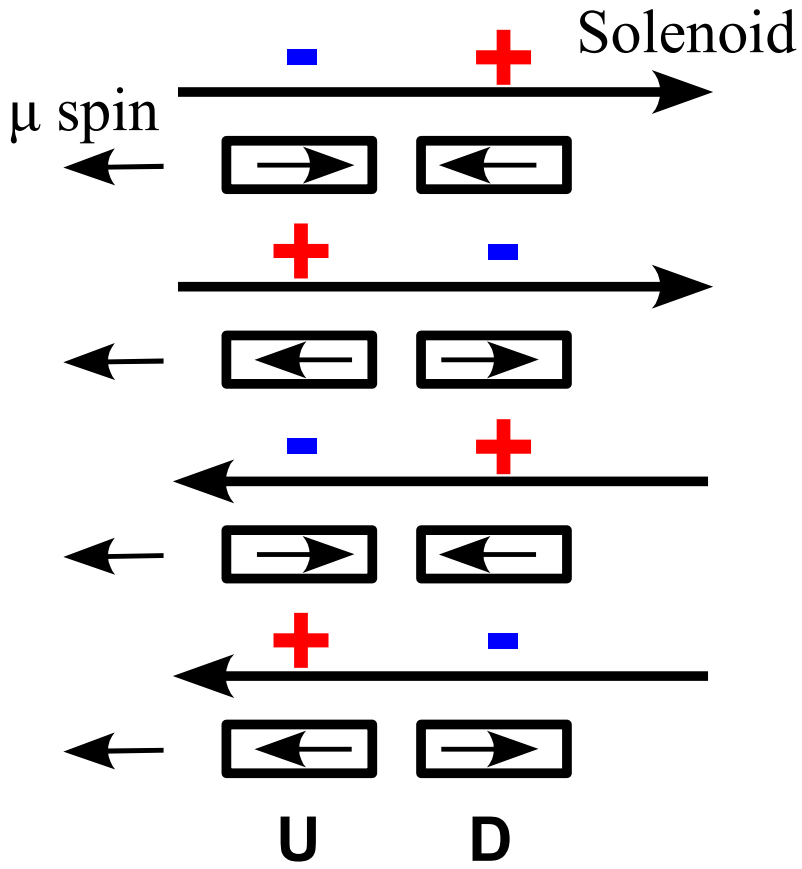
J.Ellis et al., Eur.Phys.J. C52 (2007) p. 283

Comparison with theory (Λ): CTEQ5 and GRV98



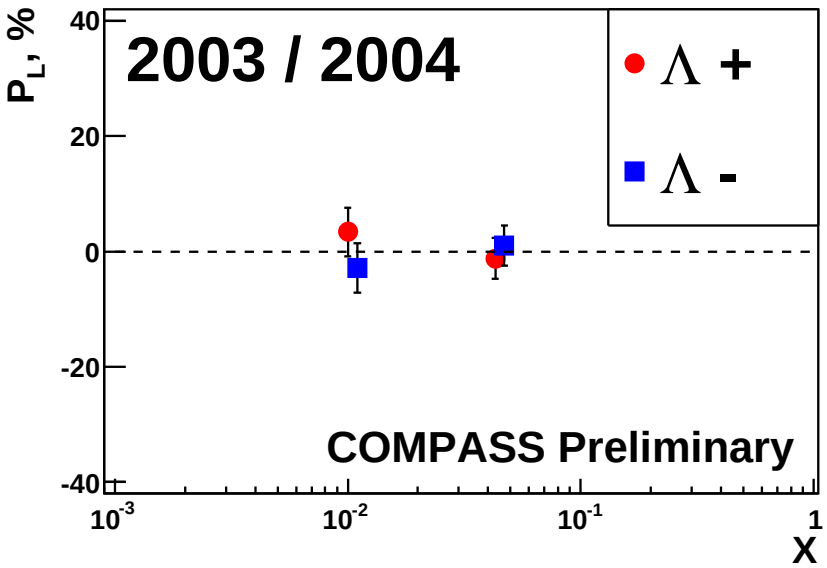
- CTEQ5 – solid line
- GRV98 – dashed line
- $D_{LL}(\bar{s}) = 0$ BJ and SU(6) models – 2 lower lines

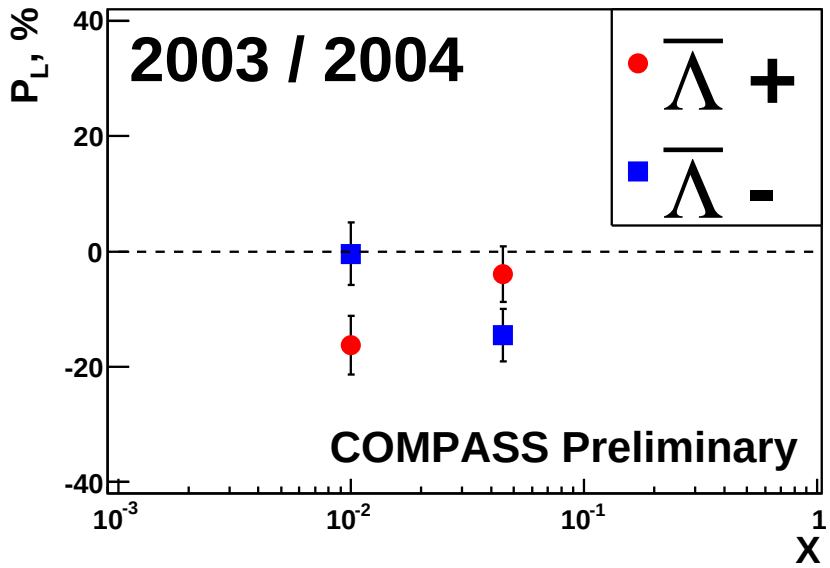
Positive and negative target polarizations



"+" – when direction of target cell polarization, coincide with direction of muon beam polarization.
"–" – when they are opposite

Dependence on the target polarization: x

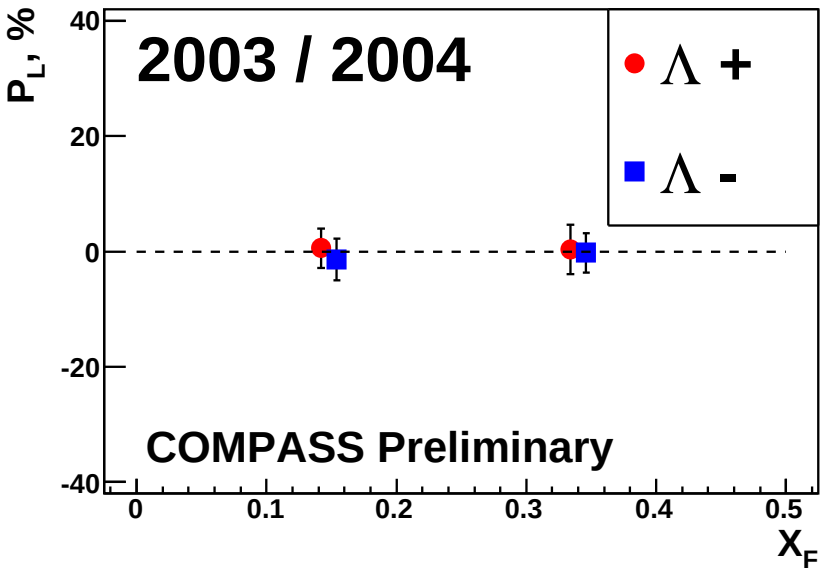


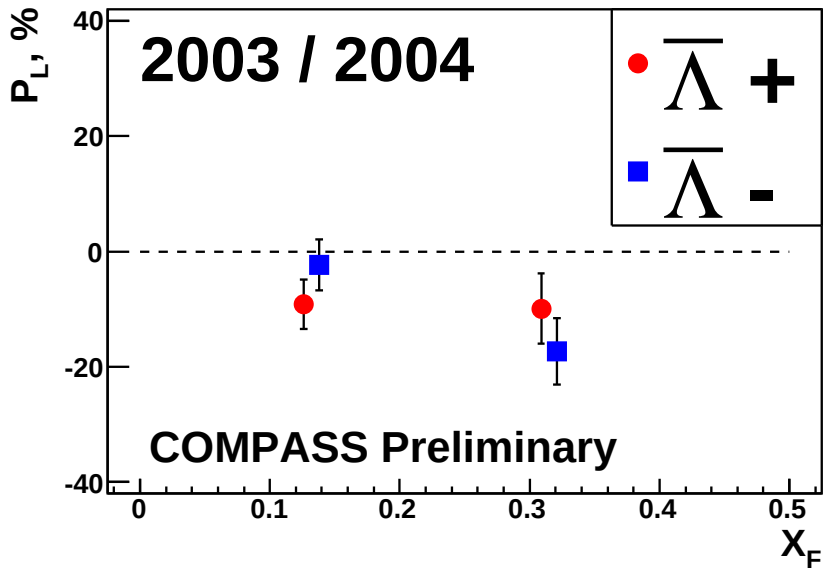


For full kinematic range:

- Λ: $\Delta P_L = P^+ - P^- = +0.01 \pm 0.04$
- $\overline{\Lambda}$: $\Delta P_L = P^+ - P^- = -0.01 \pm 0.05$

Dependence on the target polarization: x_F





For full kinematic range:

- Λ: $\Delta P_L = P^+ - P^- = +0.01 \pm 0.04$
- $\overline{\Lambda}$: $\Delta P_L = P^+ - P^- = -0.01 \pm 0.05$

Results

- The presented data are the most precise measurements of the longitudinal spin transfer to Λ and $\overline{\Lambda}$ in DIS.
  $D_{LL}^{\Lambda} = -0.012 \pm 0.047 \pm 0.024$
  $D_{LL}^{\overline{\Lambda}} = +0.249 \pm 0.056 \pm 0.049$
  $D_{LL}^{\Lambda} \neq D_{LL}^{\overline{\Lambda}}$
- It is first analysis where $\overline{\Lambda}$ 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 $\overline{\Lambda}$.
- First data on dependence of longitudinal Λ and $\overline{\Lambda}$ polarizations on the target polarization were shown.
  ΔP_L averaged over kinematic range:
  Λ: $\Delta P_L = P^+ - P^- = +0.01 \pm 0.04$
  $\overline{\Lambda}$: $\Delta P_L = P^+ - P^- = -0.01 \pm 0.05$