Production and polarization of the Λ and $\bar{\Lambda}$ hyperons in DIS at COMPASS

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on behalf of the COMPASS collaboration

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Joint Institute for Nuclear Research
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Outline

- 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.
- Yield of heavy hyperons and antihyperons in DIS

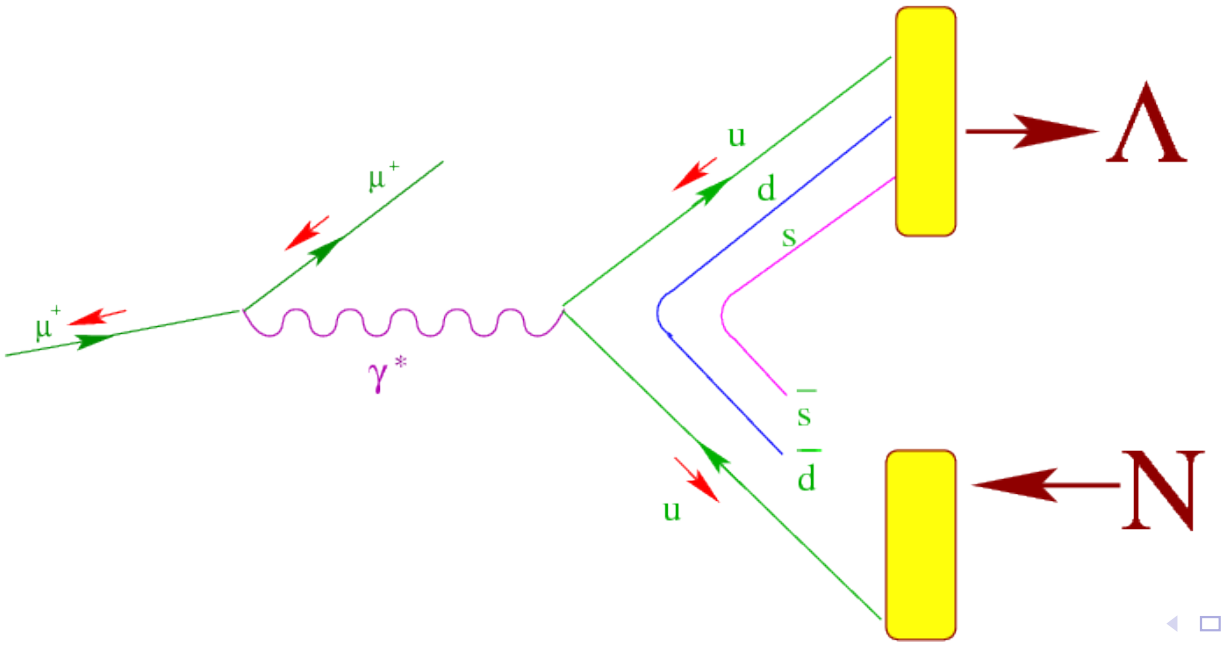
[1] *COMPASS Collab. EPJC 64 (2009) 171-179*

Physical Motivation

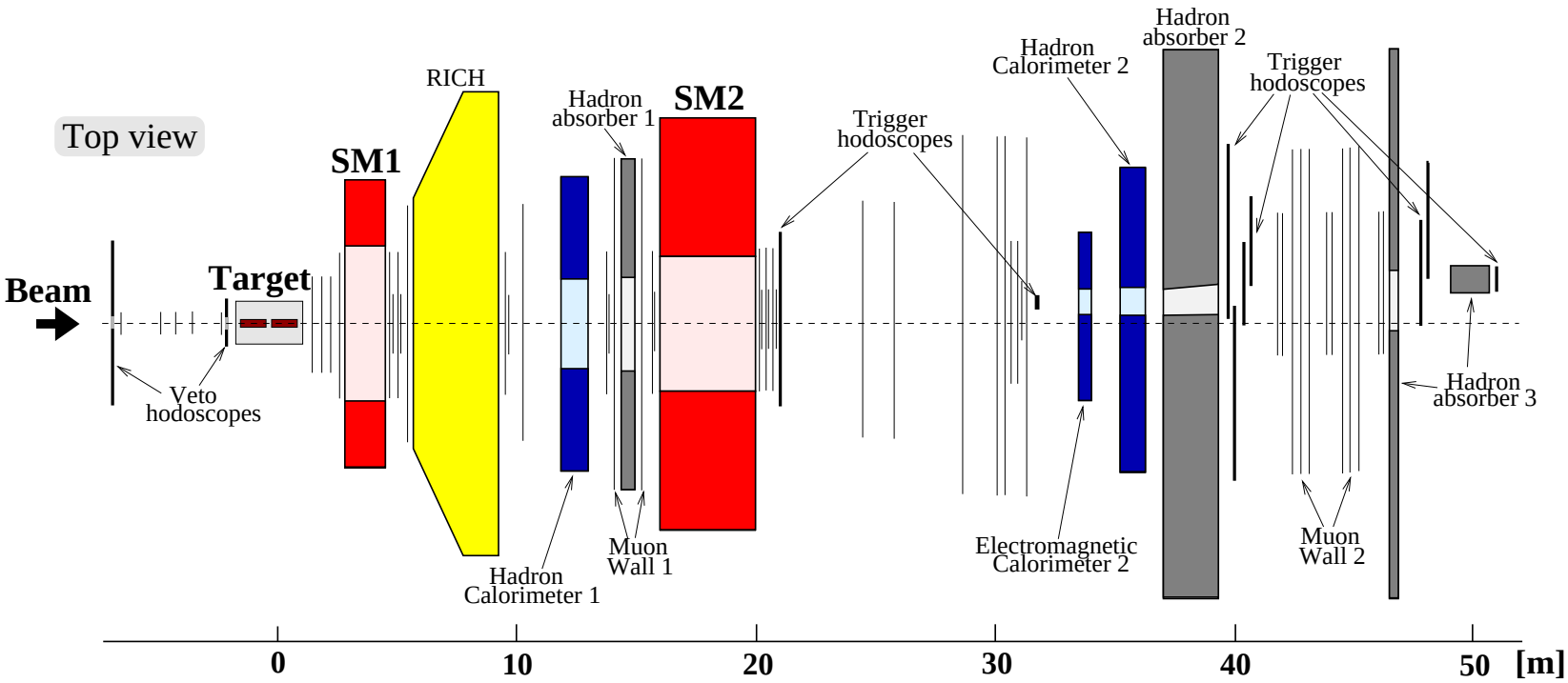
Longitudinal polarization of Λ and $\overline{\Lambda}$ in the current fragmentation region (CFR, $x_F > 0$) semi-inclusive DIS is sensitive to:

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

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



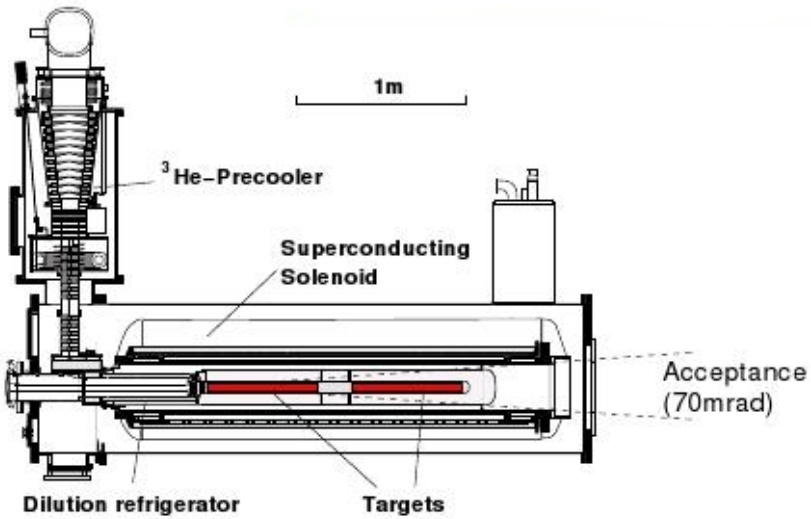
COMPASS Spectrometer setup

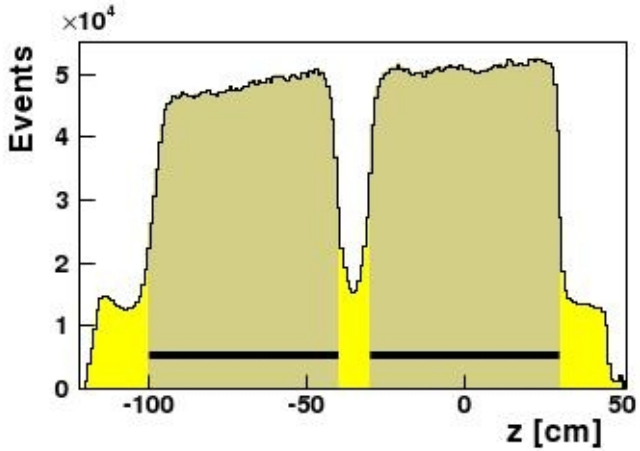


- Year 2003:
  $P_b = -0.76 \pm 0.04$
- Year 2004:
  $P_b = -0.80 \pm 0.04$

- 160 GeV μ^+ beam
- $2.8 \cdot 10^8$ μ/spill (4.8 s/16.8 s)
- $Q^2 > 1$ (GeV/c)^2: $31.2 \cdot 10^6$ events

Polarized target

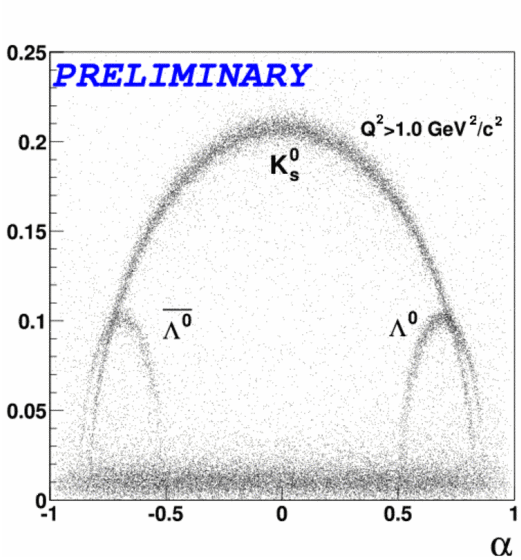


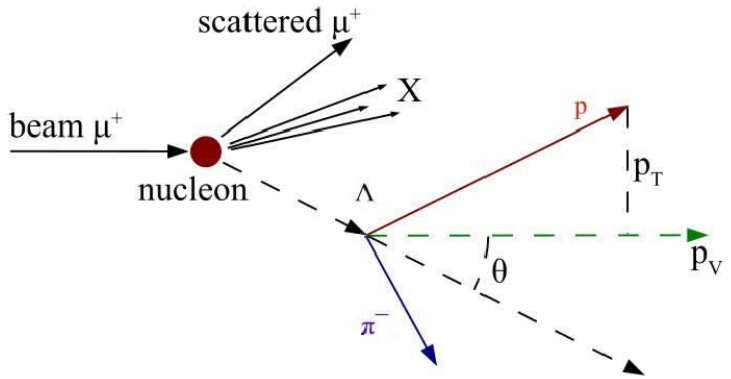


- target material: ^{6}LiD
- polarisation: $> 50\%$
- dilution factor: ~ 0.4
- Dynamic Nuclear Polarization
- solenoid field: 2.5 T
  acceptance: 70 mrad
- ^{3}He/^{4}He: $T_{min} \approx 50$ mK
- two 60 cm long target cells with opposite polarisation
- regular polarisation reversal by field rotation

Event selection

- Primary vertex inside the target cells
- Secondary vertex: 5 cm downstream of the last target cell
- The χ^2 value of the secondary vertex is $\chi^2 < 2$
- $p_T > 23$ MeV$/c$ - to reject e^+e^- pairs from the γ conversion
- $p_\pm > 1 GeV/c$
- The DIS cuts $Q^2 > 1$ (GeV$/c)^2$ and $0.2 < y < 0.9$
- collinearity cut $\theta_{coll} < 0.01$ rad
- $0.05 < x_F < 0.5$



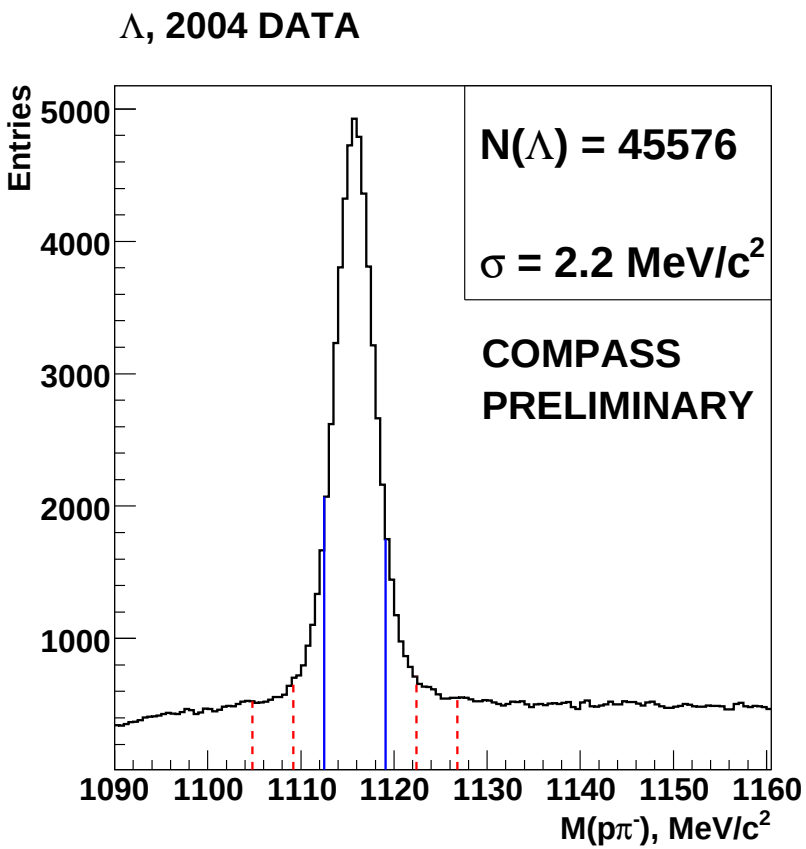


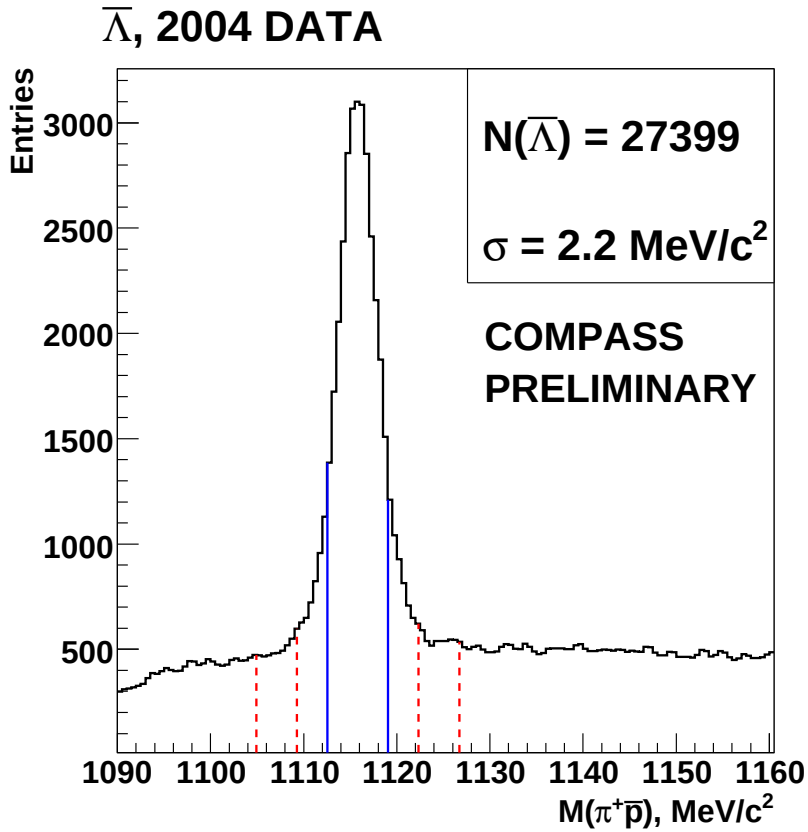
Statistics: comparison with other experiments

Experiment	Λ	$\bar{\Lambda}$
E665	750	650
NOMAD	8087	649
HERMES	7300	1687
RHIC	13000	10000
COMPASS (polarisation analysis)	70000	42000
COMPASS (heavy hyperon analysis)	100000	60000

COMPASS has the largest number of Λ and $\bar{\Lambda}$.

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

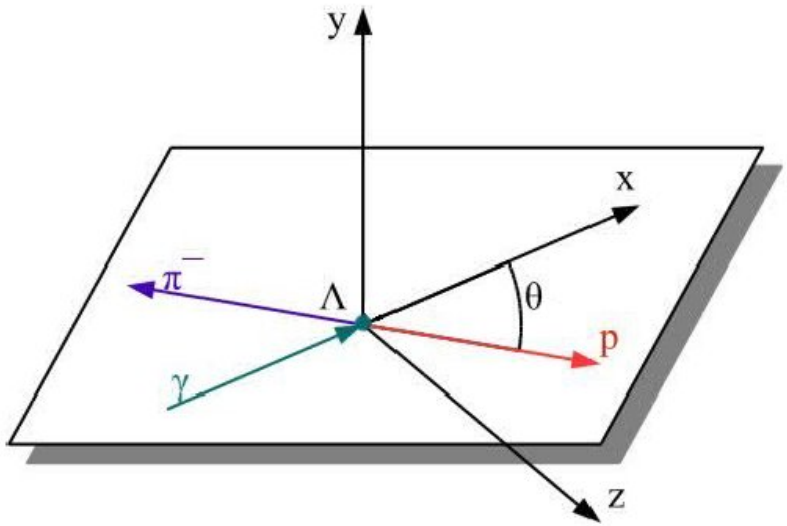




Sideband subtraction method was used to obtain cos θ angular distribution.

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

Longitudinal Λ ($\bar{\Lambda}$) polarisation



$-1 < \cos\theta < 0.6$

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

P_L - longitudinal polarisation of hyperon.

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

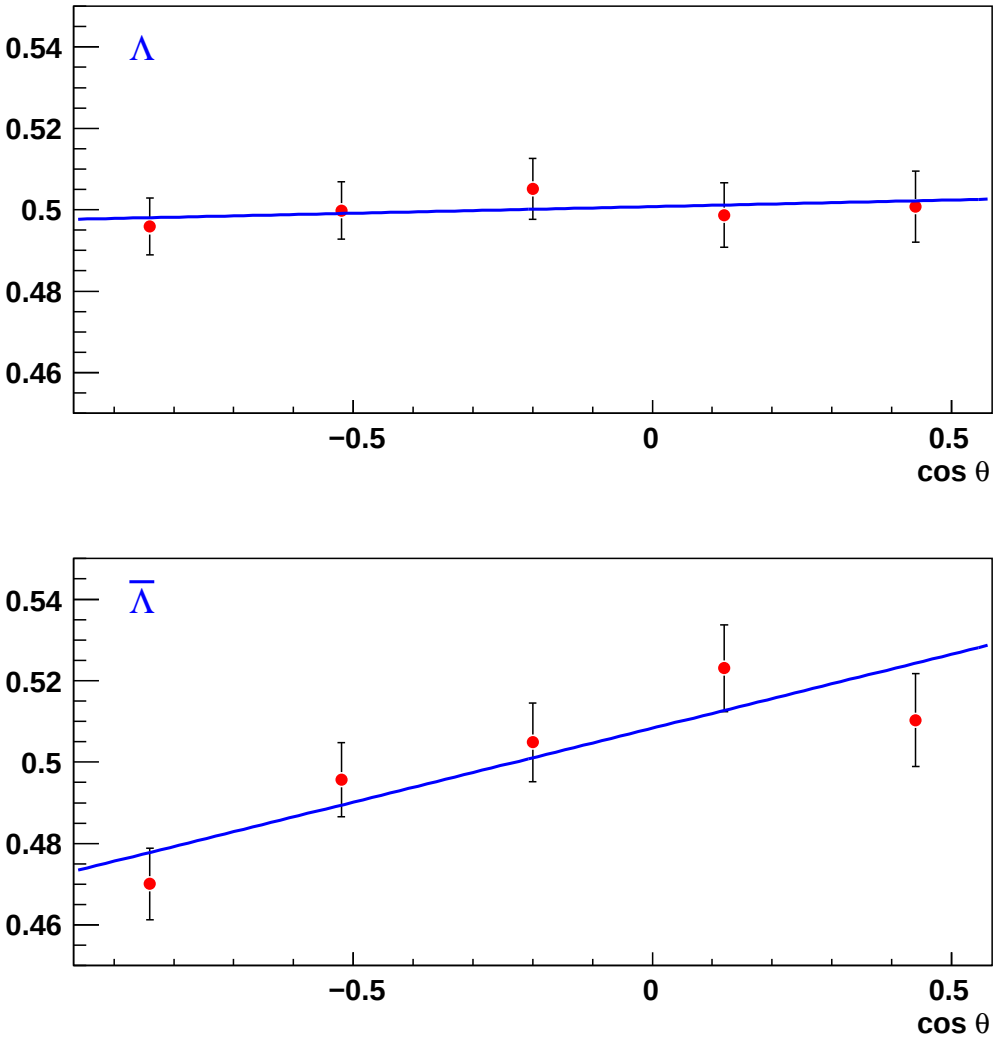
By definition longitudinal spin transfer is:

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

Depolarisation factor

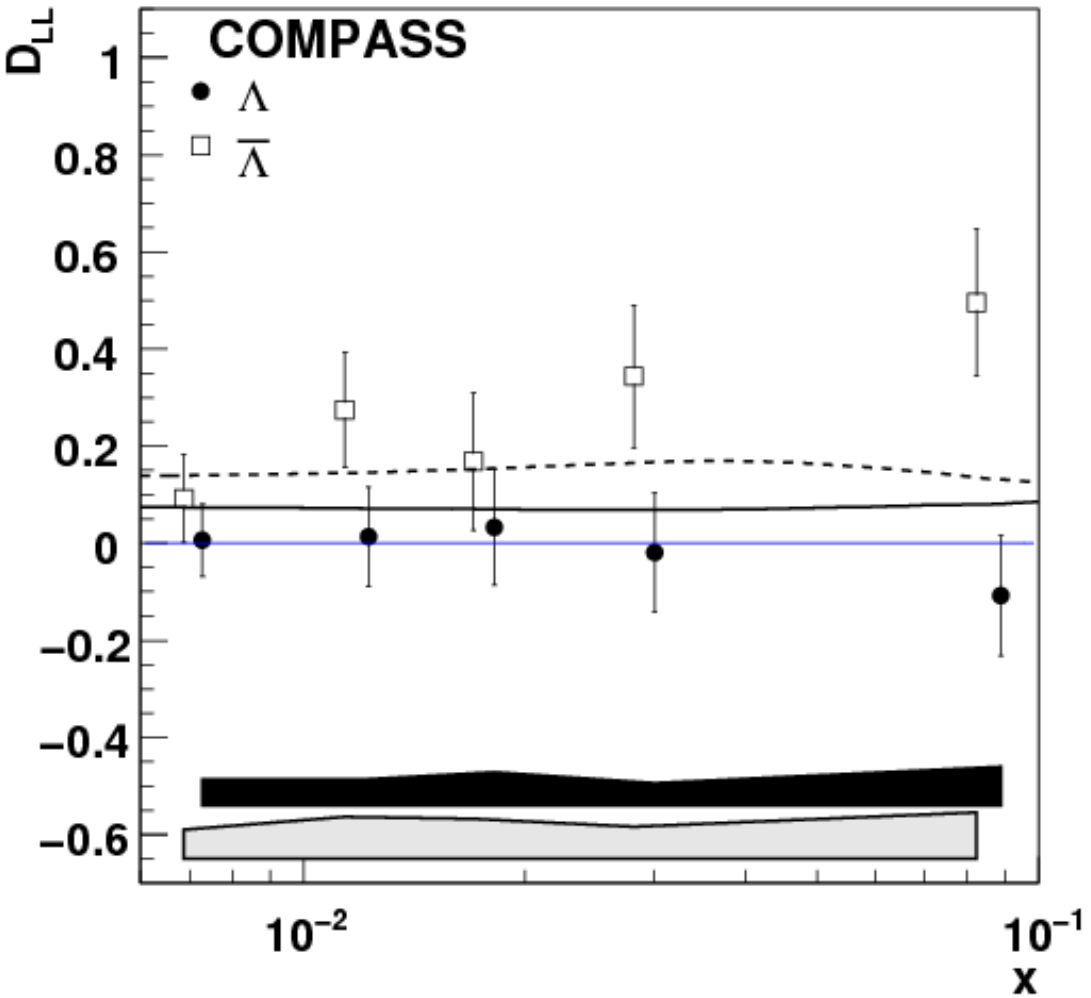
$D(y) = \frac{1-(1-y)^2}{1+(1-y)^2}$

Example of angular distribution fits



- Angular dependencies for Λ, $\bar{\Lambda}$
- 2004 year events
- $-1 < \cos\theta < 0.6$

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

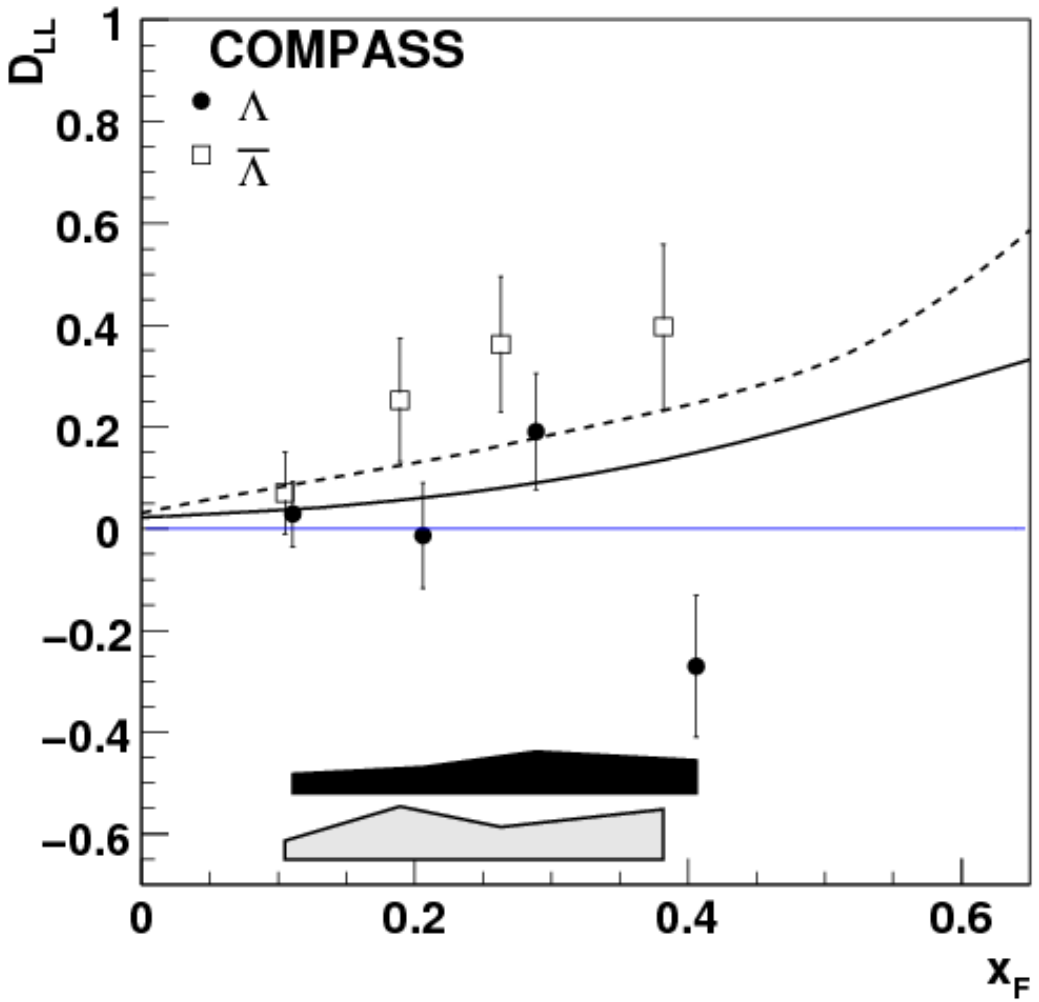


- $D_{LL}^{\bar{\Lambda}} > D_{LL}^{\Lambda}$
- theory predictions: SU(6), CTEQ5
- Λ – solid line
- $\bar{\Lambda}$ – dashed line

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

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

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



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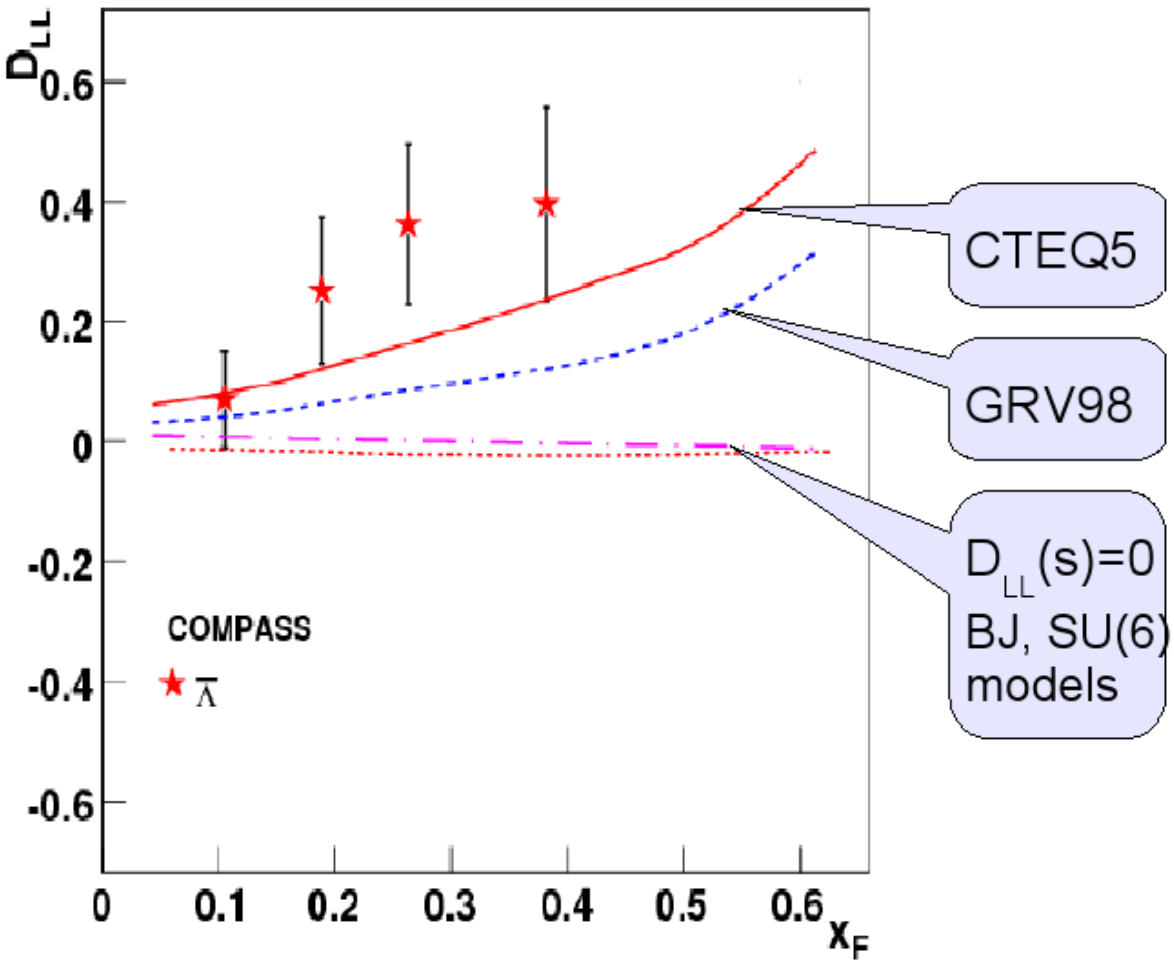
$$D_{LL}^{\Lambda} = -0.012 \pm 0.047 \pm 0.024 \qquad D_{LL}^{\bar{\Lambda}} = 0.249 \pm 0.056 \pm 0.049$$

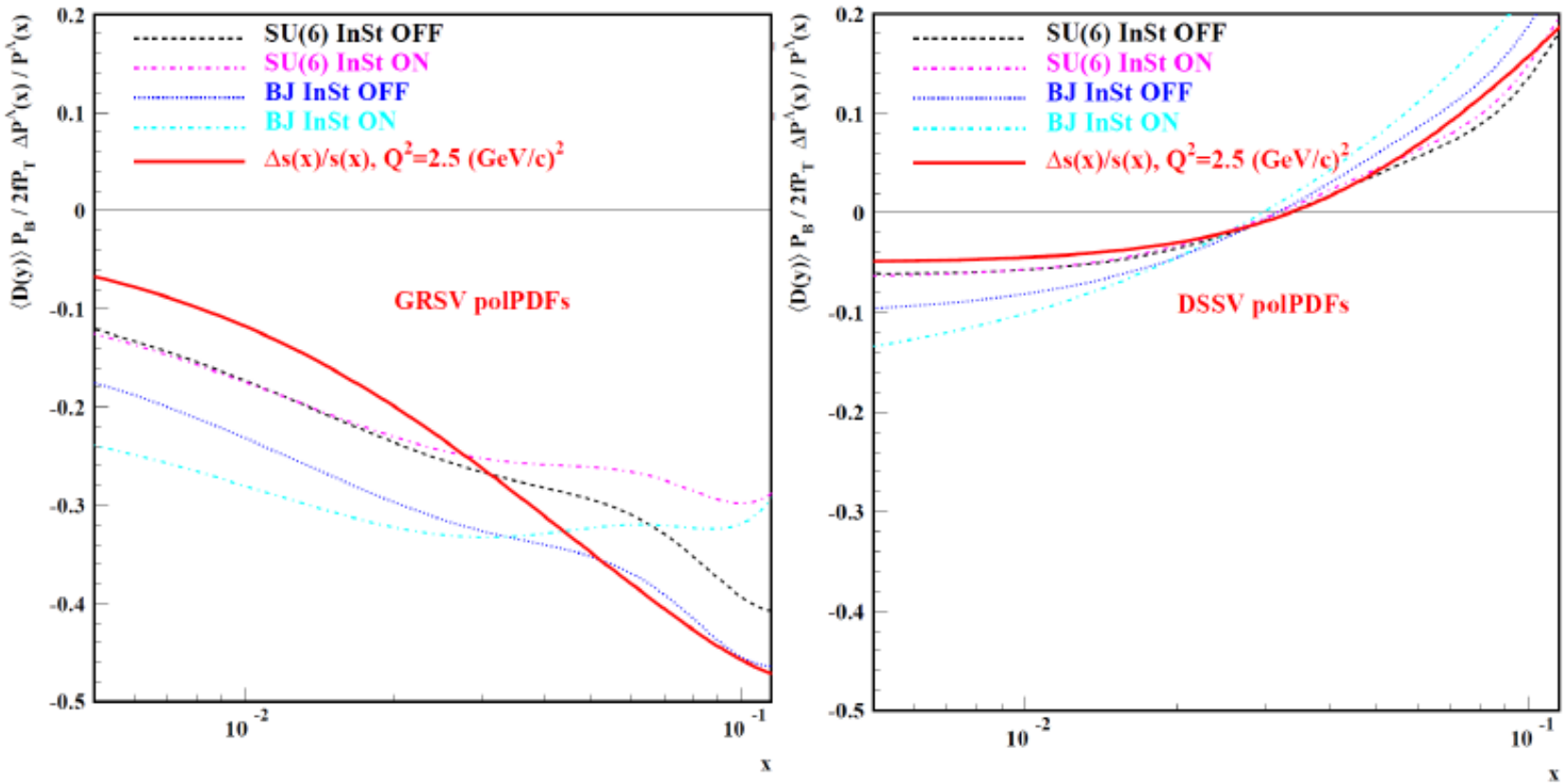
Comparison with theory ($\bar{\Lambda}$): CTEQ5 and GRV98



- 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

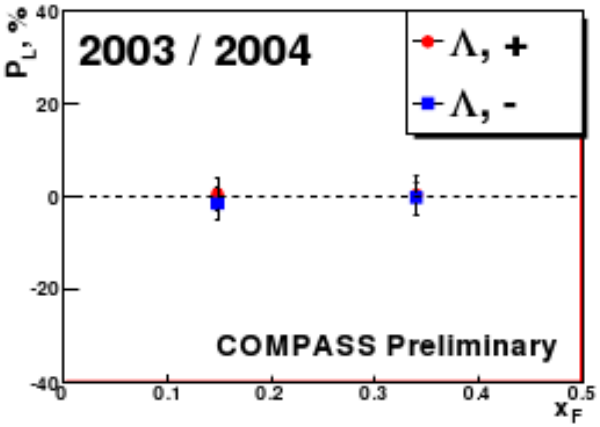


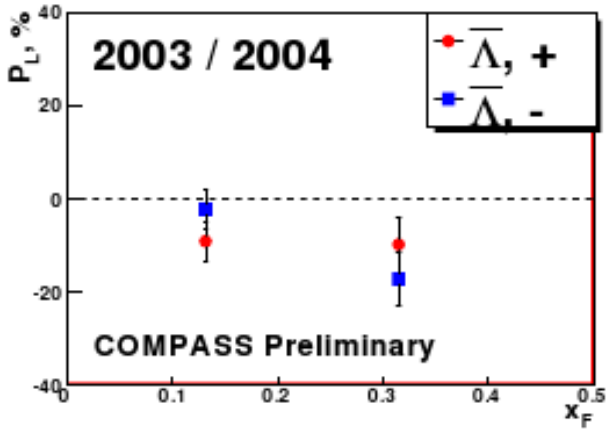
$\Delta P/P = \frac{P_- - P_+}{(P_- + P_+)/2}$, on y axis $\frac{<D(y)P_b>}{2fP_T}\frac{\Delta P^{\bar{\Lambda}}(x)}{P^{\bar{\Lambda}}(x)}$

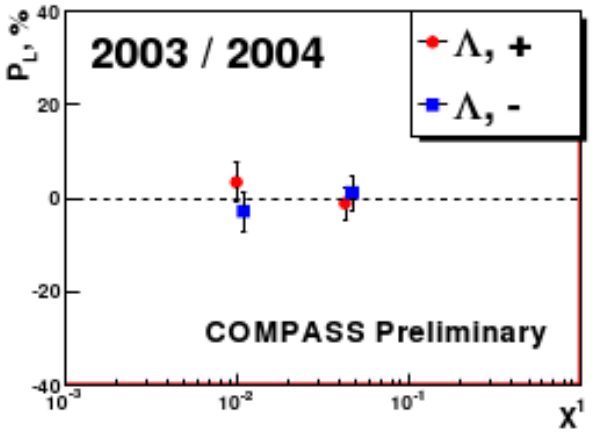
$\Delta P/P$ changes a sign in x_{Bj} region

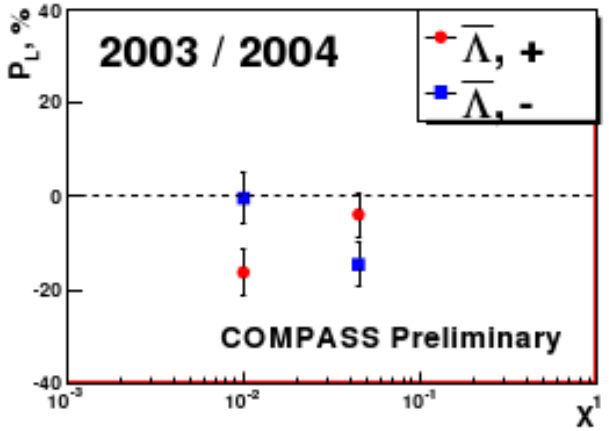
A.Kotzinian, talk at DIS09, arXiv:0907.3270

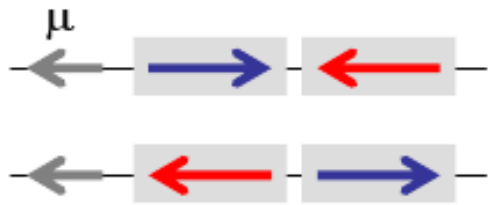
Dependence on the target polarisation











\+ : target pol. is same to μ pol.

– : target pol. is opposite to μ pol.

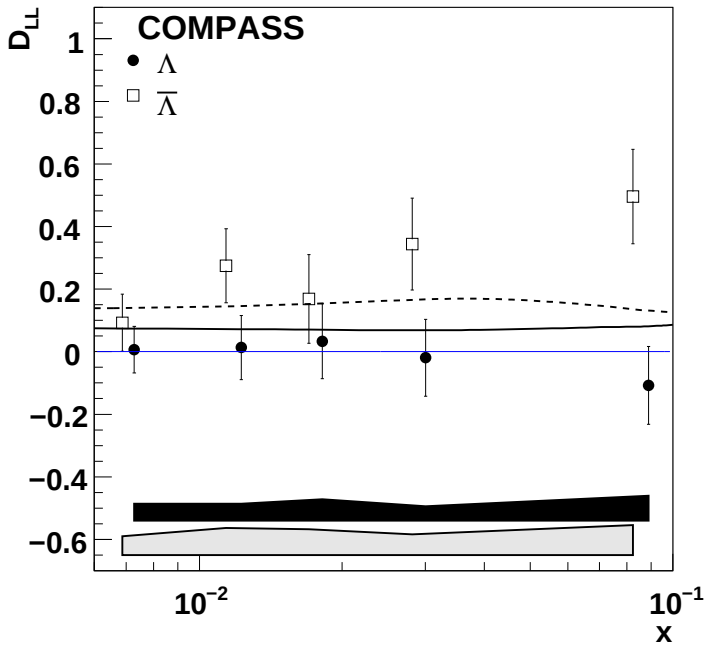
Averaged over full kinematics : $\Delta P^{\Lambda} = P_{+}^{\Lambda} - P_{-}^{\Lambda} = -0.01 \pm 0.04$

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

No significant dependence is found.

Yield of heavy hyperons and antihyperons

- To determine to what extent the yields of heavy hyperons and antihyperons are different.
- To check the hypothesis that polarization of Λ and $\bar{\Lambda}$ are different due to different contribution of indirect Λ and indirect $\bar{\Lambda}$.



COMPASS Collaboration, M.Alekseev et al., Eur.Phys.J. C64 (2009) 171.

Yields of heavy hyperons and antihyperons

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

$$\mu^+ + d \rightarrow \mu^+ + \Lambda\,(\bar{\Lambda}) + X \qquad (1)$$

direct

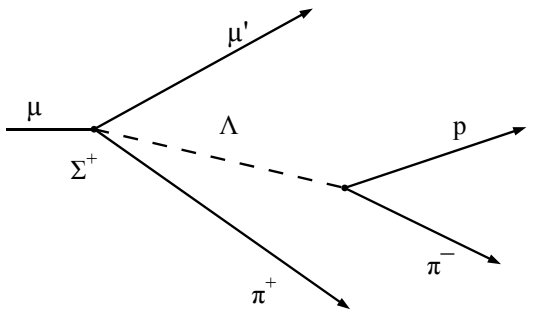
$$\mu^+ + d \rightarrow \mu^+ + \Sigma^+(1385) + X \qquad (2)$$
$$\searrow \Lambda + \pi^+$$

$$\mu^+ + d \rightarrow \mu^+ + \bar{\Sigma}^-(1385) + X \qquad (3)$$
$$\searrow \bar{\Lambda} + \pi^-$$

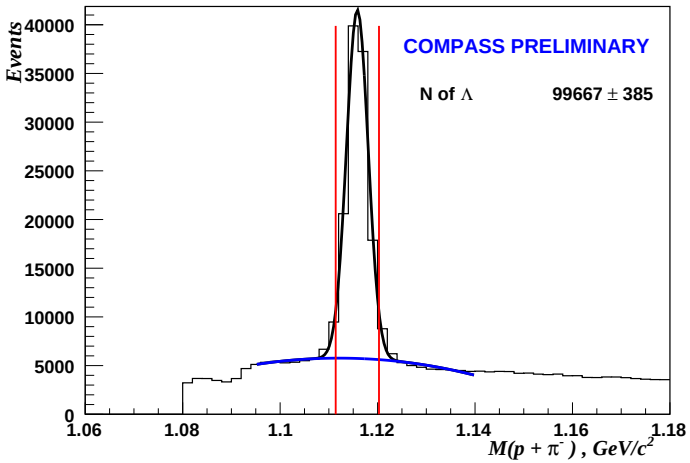
indirect

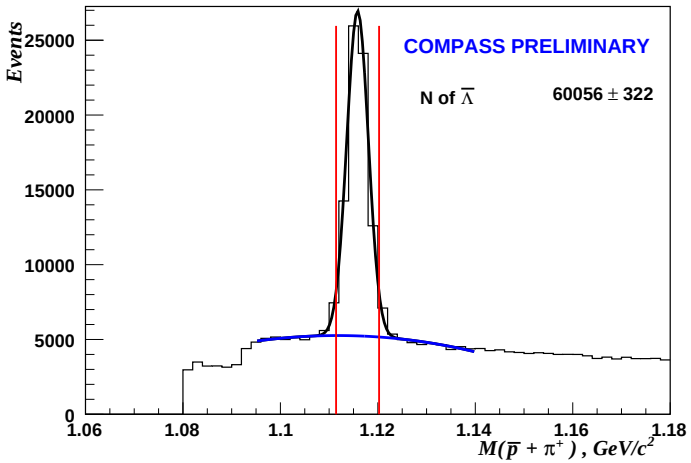
$$\mu^+ + d \rightarrow \mu^+ + \Sigma^0(1385) + X \qquad (4)$$
$$\searrow \Lambda + \gamma$$

$$\mu^+ + d \rightarrow \mu^+ + \Xi^-(1321) + X \qquad (5)$$
$$\searrow \Lambda + \pi^-$$



Distributions of $p\pi^-$ and $\bar{p}\pi^+$ invariant mass for experimental data

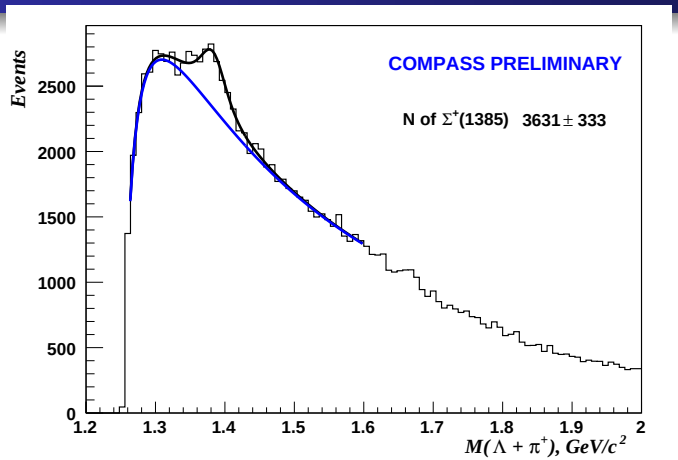




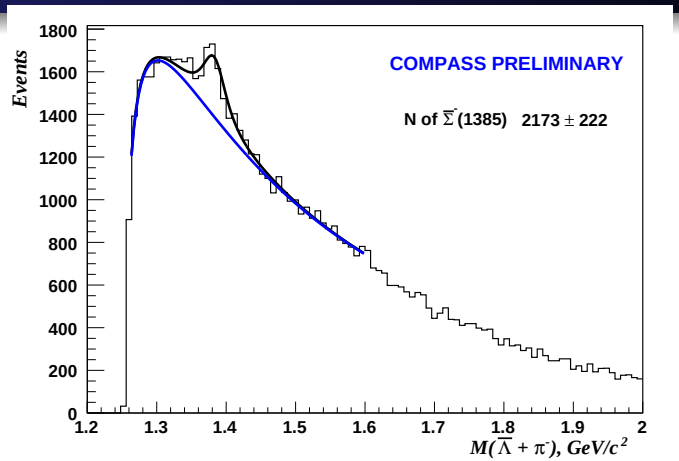
$N(\Lambda) = 99667 \pm 385$ $N(\bar{\Lambda}) = 60056 \pm 322$

- To determine the Λ π invariant mass, the events with an invariant mass of $p\pi^-$ within a ± 2 σ interval from the mean value of the Λ ($\bar{\Lambda}$) peak are taken.
- $0.05 < x_F < 1.0$ (no cut on x_F max)
- $-1 < \cos\theta < 1$ (all range)

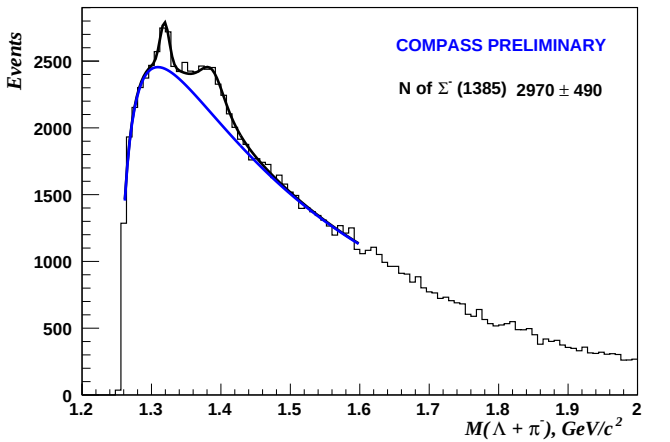
Distributions of $\Lambda\pi^{\pm}$ and $\bar{\Lambda}\pi^{\pm}$ invariant mass for experimental data



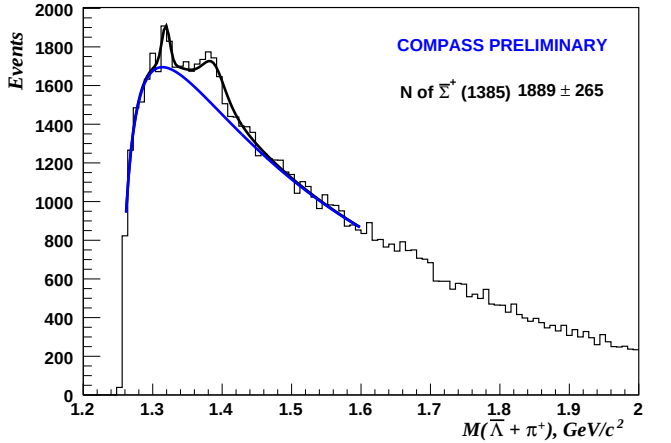
$$N(\Sigma^{+}) = 3631 \pm 333$$



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



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



$$N(\overline{\Sigma}^{+}) = 1889 \pm 265$$

Yields of heavy (anti-)hyperons

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

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

- Systematic errors include background shape and selection cuts variation.
- Results are used for event generator tuning.

Comparison with other experiments

The yield of the heavy hyperons in DIS was measured by the NOMAD collaboration in neutrino DIS.

Ratios	Present data	NOMAD
$\Sigma^+(1385)/\Lambda$	$0.055 \pm 0.005 \pm 0.0045$	0.058 ± 0.011
$\overline{\Sigma}^-(1385)/\bar{\Lambda}$	$0.047 \pm 0.006 \pm 0.0053$	–
$\Sigma^-(1385)/\Lambda$	$0.056 \pm 0.009 \pm 0.0074$	0.026 ± 0.009
$\overline{\Sigma}^+(1385)/\bar{\Lambda}$	$0.039 \pm 0.006 \pm 0.0064$	–

Summary:

- The presented data are the most precise measurements to date of the longitudinal spin transfer to Λ and $\bar{\Lambda}$ in DIS.
  $D_{LL}^{\Lambda} = 0 : -0.012 \pm 0.047 \pm 0.024$
  $D_{LL}^{\Lambda} \neq 0 : 0.249 \pm 0.056 \pm 0.049$

  $D_{LL}^{\Lambda} \neq D_{LL}^{\bar{\Lambda}}$
- 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 Λ and $\bar{\Lambda}$ production are similar

Backup slides

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

Fitting procedure

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

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

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)

Γ - width of resonance (fixed)

σ - width of Gaussian

A - amplitude of background

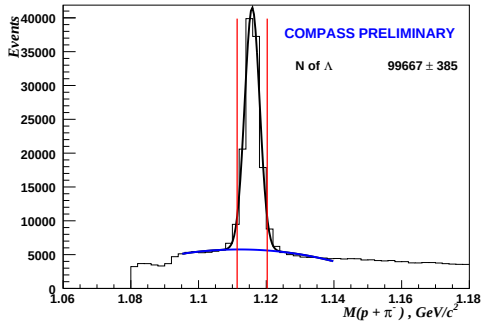
B, C, D - free parameters

Ml - reaction threshold mass (1.254 GeV mass of $\Lambda + \pi$)

Estimation of the systematic effects

- **Selection cut:**

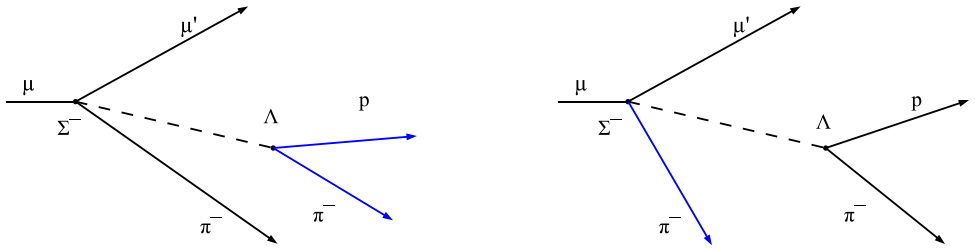
  To estimate the systematic error connected with the particular choice of the selection cut of the Λ ($\bar{\Lambda}$) sample we change the width of the central band from $\pm 2\,\sigma$ to ± 2.5 and $\pm 1.5\,\sigma$.



  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 Λ and π 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

Σ/Λ (no cut)/Σ/Λ (DIS cut)	
Σ^+/Λ	1.03 ± 0.08
$\bar{\Sigma}^-/\bar{\Lambda}$	0.97 ± 0.11
Σ^-/Λ	1.03 ± 0.16
$\bar{\Sigma}^+/\bar{\Lambda}$	0.97 ± 0.13