Heavy hyperons production in DIS

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on behalf of the COMPASS collaboration

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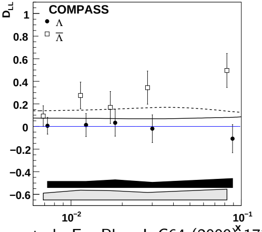
Physics motivation

- Understanding of the mechanism of heavy hyperons and antihyperons production in DIS. No measurements of the heavy antihyperon yields were existing before.
- Role of heavy hyperons decays in the production and polarization of Λ and $\bar{\Lambda}$.



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

Indirect Λ (from heavy hyperons decays) is about 40 %.
What about $\bar{\Lambda}$?

- Dependence of heavy hyperons production on Q^2.
- Testing and tuning the existing MC generator ($\Sigma^{\pm}(1385)/\Lambda$, $\bar{\Sigma}^{\pm}(1385)/\bar{\Lambda}$).

Yields of heavy hyperons and antihyperons

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

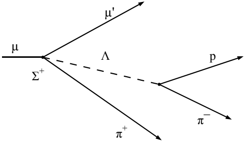
$$\mu^+ + d \rightarrow \mu^+ + \Lambda\,(\bar{\Lambda}) + X \qquad (1)$$

direct

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

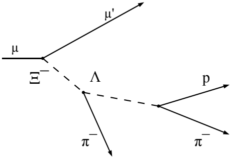
indirect

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

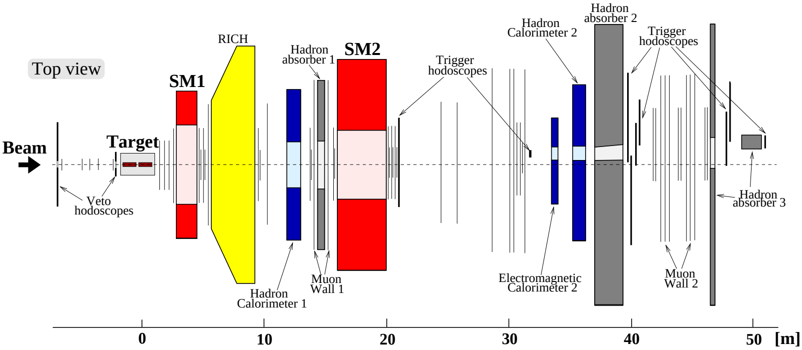


$$\mu^+ + d \rightarrow \mu^+ + \Sigma^0(1385) + X \quad (4)$$
$$\searrow \Lambda + \gamma$$

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



COMPASS spectrometer



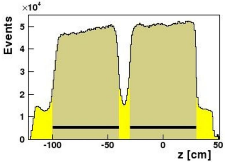
Muon beam
160 GeV/c μ^+
$2 \cdot 10^8 \mu/16.8s$
Target material ^6LiD

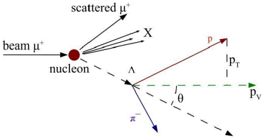
Spectrometer
Two magnets (1 Tm, 4.4 Tm)
PID: π, K, p RICH
ECAL, HCAL, muon filter

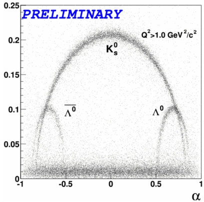
Vertex selection criteria

2003 - 2004 data were used for this analysis.

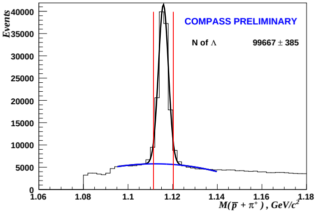
- Primary vertex inside the target.
- Secondary vertex: 5 cm downstream of the last tardet cell.
- The χ^2 value of the secondary vertex is $\chi^2 < 2$.
- $p_t > 23$ MeV/c – to reject e^+e^- pairs from the γ conversion.
- $p_\pm > 1$ GeV/c.
- Cut on x_F: $0.05 < x_F < 1.0$
- The DIS cuts were $Q^2 > 1$ $(\text{GeV}/c)^2$ and $0.2 < y < 0.9$.
- $\theta_{coll.} < 0.01$ rad. for Σ.



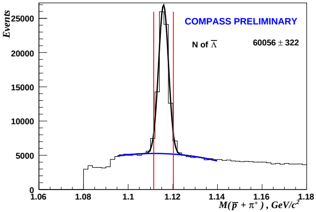




Distributions of $p\pi^-$ and $\bar{p}\pi^+$ invariant mass from the experimental data



$N(\Lambda) = 99667 \pm 385$



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

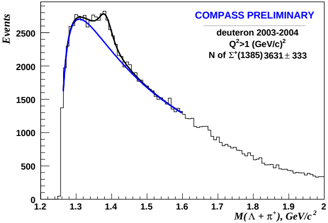
	$N(\Lambda)$	$N(\bar{\Lambda})$
E665	750	650
NOMAD	8087	649
HERMES	26714	3610
RHIC	13000	10000
COMPASS	100000	60000

To determine the $\Lambda\ \pi$ invariant mass, the events with an invariant mass of $p\pi^-$ $(\bar{p}\pi^+)$ within a $\pm 2\ \sigma$ interval from the mean value of the Λ $(\bar{\Lambda})$ peak are taken.

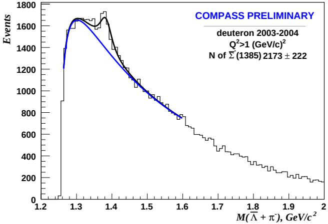
Criteria for the $\pi^-(\pi^+)$ selection

- no μ
- from primary vertex
- $p < 140$ GeV
- No short track, $z > 350$ cm.

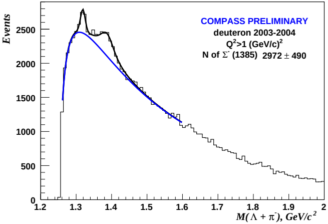
Distributions of $\Lambda\pi^\pm$ and $\bar{\Lambda}\pi^\pm$ invariant mass from the experimental data



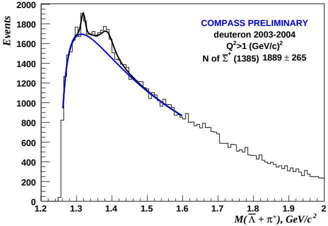
$$N(\Sigma^+) = 3631 \pm 333$$



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



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



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

Fitting procedure

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

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

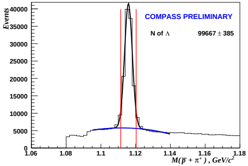
and the background function

$$B(x) = A \cdot (x - M_l)^B \cdot e^{-C \cdot (x - M_l)^D}$$

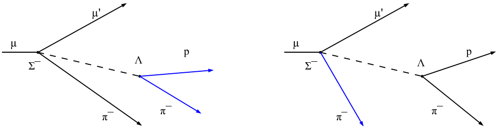
Fit parameters:
N - total numbers
M - mass of resonance (fixed)
Γ - width of resonance (fixed)
σ - width of Gaussian
A - amplitude of background
B, C, D - free parametres
M_{th} - reaction threshold mass (1.254 GeV mass of $\Lambda + \pi$)

Estimation of the systematic effects

- **Selection cut:**
  To estimate the systematic error related to 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 $\pm 1.5\,\sigma$.



- **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

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

$$R^+ = \Sigma^+(1385)/\Lambda = 0.055 \pm 0.005 \pm 0.005$$
$$\bar{R}^- = \overline{\Sigma}^-(1385)/\bar{\Lambda} = 0.047 \pm 0.006 \pm 0.005$$
$$R^- = \Sigma^-(1385)/\Lambda = 0.056 \pm 0.009 \pm 0.007$$
$$\bar{R}^+ = \overline{\Sigma}^+(1385)/\bar{\Lambda} = 0.039 \pm 0.006 \pm 0.006$$

Ratios $R = Y(H)/Y(\Lambda)$ and $\bar{R} = Y(\bar{H})/Y(\bar{\Lambda})$ corrected to the acceptance values.

These ratios were used to tune the LEPTO generator parameters.

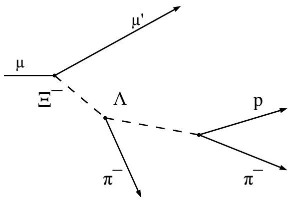
Criteria for the $\Xi^-(\bar{\Xi}^+)$ selection

Ξ^-

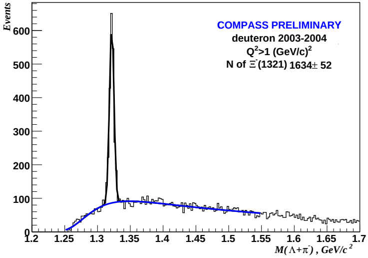
- Close distance approach $CDA < 0.7$ cm
- $z(\Xi^-) > z(PV)$
- $z(\Xi^-) < z(\Lambda^0)$
- $\theta_{coll_\Xi} < 0.02$ rad. This cut selects Ξ events with the momentum looking at the primary vertex.

π^-

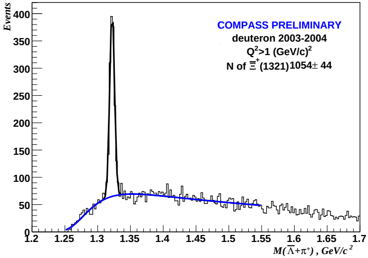
- negative particle
- no μ
- not coming from primary vertex
- $p < 140$ GeV
- No short track, $z > 350$ cm.



Distributions of $\Lambda\pi^-$ and $\bar{\Lambda}\pi^+$ invariant mass from the experimental data



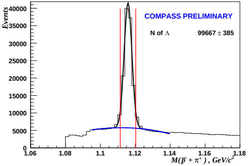
$N(\Xi^-) = 1634 \pm 52$



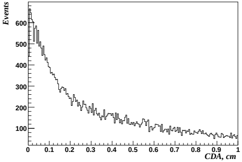
$N(\overline{\Xi}^+) = 1054 \pm 44$

Estimation of the systematic effects

- **Selection cut:**
  To estimate the systematic error related to 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 $\pm 1.5\,\sigma$.



- **Influence of the CDA cut:**
  To evaluate the influence of the CDA cut on we change the given criterion on 0.2 cm instead of 0.7 cm.



Systematic error due to influence of the CDA is comparable with statistic error.

Yields of heavy (anti-)hyperons

Clear signal from $\Xi^-(\bar{\Xi}^+)$ is observed in DIS.

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

$$R^- = \Xi^-(1321)/\Lambda = 0.037 \pm 0.003 \pm 0.002$$
$$\bar{R}^+ = \bar{\Xi}^+(1321)/\bar{\Lambda} = 0.046 \pm 0.004 \pm 0.002$$

Ratios $R = Y(H)/Y(\Lambda)$ and $\bar{R} = Y(\bar{H})/Y(\bar{\Lambda})$ corrected to the acceptance values.

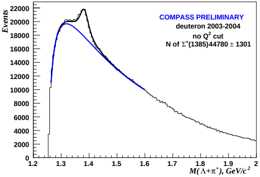
These ratios are used to tune the LEPTO generator parameters.

Without DIS cuts: $Q^2 > 0$ and $0 < y < 1$.

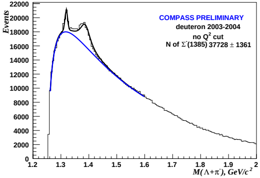
- Primary vertex inside the target.
- Secondary vertex: 5 cm downstream of the last tardet cell.
- The χ^2 value of the secondary vertex is $\chi^2 < 2$.
- $\theta_{coll.} < 0.01$ rad.
- $p_t > 23$ MeV/c – to reject e^+e^- pairs from the γ conversion.
- $p_\pm > 1$ GeV/c.
- Cut on x_F: $0.05 < x_F < 1.0$
- There is no cuts $Q^2 > 1\ (\mathrm{GeV}/c)^2$ and $0.2 < y < 0.9$ anymore.

DIS cuts:	Without DIS cuts:
$N(\Lambda) = 100000 \pm 380$	$N(\Lambda) = 1060000 \pm 1200$
$N(\overline{\Lambda}) = 60000 \pm 320$	$N(\overline{\Lambda}) = 580000 \pm 1000$

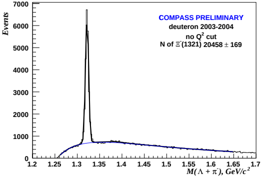
Distributions of $\Lambda\pi^\pm$ and $\bar{\Lambda}\pi^\pm$ invariant mass from the experimental data without DIS cuts



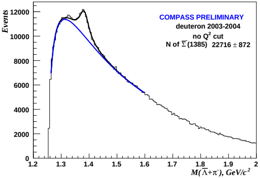
$N(\Sigma^+) = 40000 \pm 1250$
DIS:$N(\Sigma^+) = 3600 \pm 330$



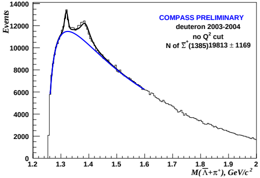
$N(\Sigma^-) = 35200 \pm 1500$
$N(\Sigma^-) = 3000 \pm 500$



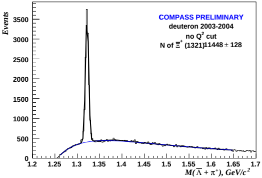
$N(\Xi^-) = 20500 \pm 170$
$N(\Xi^-) = 1600 \pm 50$



$N(\overline{\Sigma}^-) = 20000 \pm 850$
DIS:$N(\overline{\Sigma}^-) = 2200 \pm 220$



$N(\overline{\Sigma}^+) = 19500 \pm 1200$
$N(\overline{\Sigma}^+) = 1900 \pm 260$



$N(\overline{\Xi}^+) = 11500 \pm 130$
$N(\overline{\Xi}^+) = 1050 \pm 40$

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
Ξ/Λ (no cut)/Ξ/Λ (DIS cut)	
Ξ^-/Λ	1.06 ± 0.09
$\bar{\Xi}^+/\bar{\Lambda}$	1.06 ± 0.09

The ratios Σ/Λ, Ξ/Λ do not dependent on DIS cuts.

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 ± 0.005	0.058 ± 0.011
$\overline{\Sigma}^-(1385)/\bar{\Lambda}$	0.047 ± 0.006	–
$\Sigma^-(1385)/\Lambda$	0.056 ± 0.009	0.026 ± 0.009
$\overline{\Sigma}^+(1385)/\bar{\Lambda}$	0.039 ± 0.006	–
$\Xi^-(1321)/\Lambda$	0.034 ± 0.003	0.019 ± 0.017
$\overline{\Xi}^+(1321)/\bar{\Lambda}$	0.039 ± 0.004	–

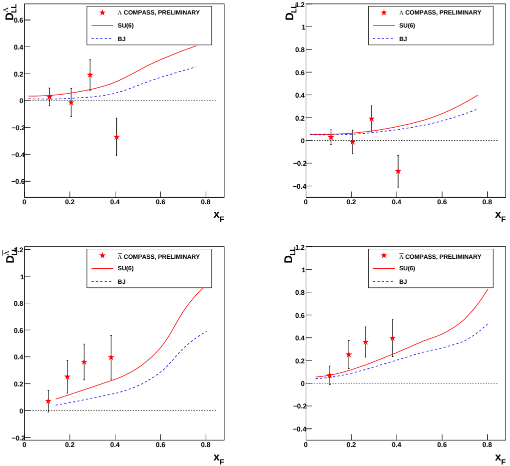
Tuning the Monte Carlo

The column R is experimental data.
The column LEPTO COMPASS corresponds to the LEPTO-generated data with the tuned parameters.

Ratios	LEPTO Default	R	LEPTO COMPAS
$\Lambda/\bar{\Lambda}$	1.22 ± 0.01	1.71 ± 0.02	1.72 ± 0.01
K/Λ	6.06 ± 0.01	6.21 ± 0.05	6.22 ± 0.01
Σ^+/Λ	0.082 ± 0.001	0.055 ± 0.005	0.052 ± 0.001
$\bar{\Sigma}^-/\bar{\Lambda}$	0.074 ± 0.001	0.047 ± 0.006	0.038 ± 0.001
Σ^-/Λ	0.084 ± 0.001	0.056 ± 0.009	0.067 ± 0.001
$\bar{\Sigma}^+/\bar{\Lambda}$	0.060 ± 0.001	0.039 ± 0.006	0.037 ± 0.001
Ξ^-/Λ	0.051 ± 0.0008	0.034 ± 0.003	0.029 ± 0.001
$\bar{\Xi}^+/\bar{\Lambda}$	0.056 ± 0.0008	0.039 ± 0.014	0.040 ± 0.001

Influence on the $\Lambda(\bar{\Lambda})$ polarization

LEPTO Default*: LEPTO COMPASS:



Λ

★ - COMPASS results

BJ - blue line

SU(6) - red line

$\bar{\Lambda}$

* J.Ellis, A.M.Kotzinian, D.Naumov, M.G.Sapozhnikov, Eur.Phys.J.C52,283(2007)

Conclusion

- The yields of heavy (anti-)hyperons in DIS were measured:

$$
\begin{aligned}
R^+ &= \Sigma^+(1385)/\Lambda = 0.055 \pm 0.005 \pm 0.005 \\
\bar{R}^- &= \bar{\Sigma}^-(1385)/\bar{\Lambda} = 0.047 \pm 0.006 \pm 0.005 \\
R^- &= \Sigma^-(1385)/\Lambda = 0.056 \pm 0.009 \pm 0.007 \\
\bar{R}^+ &= \bar{\Sigma}^+(1385)/\bar{\Lambda} = 0.039 \pm 0.006 \pm 0.006 \\
R^- &= \Xi^-(1321)/\Lambda = 0.037 \pm 0.003 \pm 0.002 \\
\bar{R}^+ &= \bar{\Xi}^+(1321)/\bar{\Lambda} = 0.046 \pm 0.004 \pm 0.002
\end{aligned}
$$

- The relative yields of indirect Λ and $\bar{\Lambda}$ production are similar
- The ratios Σ/Λ, Ξ/Λ do not dependent on Q^2 (DIS cuts)
- The LEPTO generator parameters have been tuned to reproduce the yields
- The values of Σ/Λ are important for correct description of $\Lambda(\bar{\Lambda})$ spin transfer

Tuning the Monte Carlo

In Table a comparison between the default LEPTO parameters and the NOMAD tuned ones is given. The results of the COMPASS tuning are given in the last column.

Parameters	Default	NOMAD	COMPASS tuning
PARJ(1)	0.1	0.05	0.03
PARJ(2)	0.3	0.21	0.45
PARJ(3)	0.4	0.07	0.175
PARJ(4)	0.05	0.001	0.078
PARJ(5)	0.5	0.97	3.0
PARJ(6)	0.5	0.5	0.5
PARJ(7)	0.5	0.39	0.13

PARJ(1) is $P(qq)/P(q)$, the suppression of diquark-antidiquark pair production in the colour field, compared with quark(antiquark) production;
PARJ(2) is P(s)/P(u), the suppression of s quark pair production in the field compared with u- or d- pair production;
PARJ(3) is (P(us)/P(ud))/(P(s)/P(d)), the extra suppression of strange diquark production compared with the normal suppression of strange quarks;
PARJ(4) is $(1/3)P(ud_1)/P(ud_0)$, the suppression of spin 1 diquarks compared with spin 0 ones (excluding the factor 3 coming from spin counting);
PARJ(5) is parameter determining relative occurence of baryon production by $BM\bar{B}$ and by $B\bar{B}$ configurations in the popcorn baryon production model, roughly $P(BM\bar{B})/(P(B\bar{B}) + P(BM\bar{B}))$ = PARJ(5)/(0.5+PARJ(5));
PARJ(6) is extra suppression for having a ss pair shared by the B and $\bar{B}$ of a $BM\bar{B}$ situation;
PARJ(7) is extra suppression for having a strange meson M in a $BM\bar{B}$ configuration.