FORMATION OF HEAVY HYPERONS AND ANTIHYPERONS IN DIS AT COMPASS

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Abstract

The yields of heavy hyperons and antihyperons have been studied in deep inelastic scattering at the COMPASS experiment at CERN. The data were collected during the years 2003-2004 with a 160 GeV polarised μ^+ scattered off a polarised ^{6}LiD target. Signals from $\Sigma^\pm(1385)$ and $\bar{\Sigma}^\pm(1385)$ decays were reconstructed. The ratios of $\Sigma^\pm/\Lambda$, $\bar{\Sigma}^\pm/\bar{\Lambda}$ and $\Lambda/\bar{\Lambda}$ were determined. These ratios were used to tune parameters of the LEPTO generator. Dependence of the yields of heavy hyperons production on Q^2 has been studied.

1 Introduction

It is important to measure the yields of heavy hyperons and antihyperons in deep inelastic scattering (DIS) for understanding the dynamics of the hyperon production and polarization. The decays of the heavy hyperons are also important for Λ and $\bar{\Lambda}$ production and polarization. It is known [1] that a significant part of the Λ hyperons in DIS is produced indirectly, via decays of heavy hyperons such as $\Sigma^0, \Sigma(1385), \Xi$ etc. The polarization of these indirect Λ hyperons may influence on the Λ polarization. On the other hand, the role of the indirect $\bar{\Lambda}$ hyperons, forming in the decays of heavy antihyperons, is not known. No measurements of the heavy antihyperon yields in the DIS exist before.

The yields of the heavy hyperons in the neutrino DIS were measured by the NOMAD collaboration [2]. They have found strong deviation of the measured yields from the Monte Carlo predictions. The experimental yields were used to tune the parameters of the LEPTO generator.

Main motivation of the present work is to determine the yields of heavy hyperons and antihyperons in DIS and use them to tune the LEPTO parameters. It turns out that the tuned LEPTO significantly changed the theoretical predictions of the Λ and $\bar{\Lambda}$ polarization. It demonstrates the importance of the knowledge of the heavy hyperon yields.

2 The experimental setup

COMPASS is a fixed-target experiment at the CERN Super Proton Synchrotron (SPS) using high-energy muon and hadron beams. A detailed description of the COMPASS setup is given elsewhere [3]. The data used in the present analysis were collected in 2003-2004 using a 160 GeV polarised muon beam scattered off a large polarised ^{6}LiD target. The beam intensity is 2×10^8 muons per spill. The polarized target of the COMPASS spectrometer consists of two cells with a length of 60 cm each and a diameter of 3 cm, separated by a 10 cm gap. Both cells are placed inside a conductive solenoid with magnetic field 2.5 T and temperature about

50 mK. The data from both longitudinal target spin orientations were recorded simultaneously and averaged in this analysis.

3 The data analysis

The event selection requires a reconstructed interaction vertex defined by the incoming and the scattered muon located inside the target. DIS events are selected by cuts on the photon virtuality ($Q^2 > 1\ \ (\mathrm{GeV}/c)^2$) and on the fractional energy of the virtual photon ($0.2 < y < 0.9$). The data sample consists of $8.67 \cdot 10^7$ DIS events from the 2003 run and $22.5 \cdot 10^7$ DIS events from the 2004 run.

We studied following decays of heavy hyperons and antihyperons:

$$\mu^+ + d \to \mu^+ + \Sigma^{\pm}(1385) + X \qquad (\Sigma^{\pm}(1385) \to \Lambda + \pi^{\pm})$$

$$\mu^+ + d \to \mu^+ + \bar{\Sigma}^{\pm}(1385) + X \qquad (\bar{\Sigma}^{\pm}(1385) \to \bar{\Lambda} + \pi^{\pm})$$

In these strong processes a heavy hyperon is decayed in the primary vertex, whereas the secondary vertex is a signature for the $\Lambda(\bar{\Lambda})$ weak decays in $p\pi^-(\bar{p}\pi^+)$.

The analysis is started from the reconstruction of the vector of the momentum of the $\Lambda(\bar{\Lambda})$ hyperon. The Λ and $\bar{\Lambda}$ events were selected by requiring the incoming and outgoing muon tracks together with at least two hadron tracks forming the secondary vertex. The criteria for the $\Lambda(\bar{\Lambda})$ selection were basically the same as in the analysis of the longitudinal spin transfer to $\Lambda(\bar{\Lambda})$ [4].

We select $\Lambda(\bar{\Lambda})$ events in the current fragmentation region $x_F > 0.05$, where x_F is the Feynman variable $x_F = 2p_L/W$, p_L is the particle longitudinal momentum in the hadronic centre-of-mass system, whose invariant mass is W. The angle θ_{coll} between the hyperon momentum and the line connecting the primary and the secondary vertex is required to be $\theta_{coll} < 0.01$ rad. This cut selects events with the correct direction of the hyperon momentum vector with respect to the primary vertex resulting in a reduction of the combinatorial background. A cut on the transverse momentum p_t of the decay products with respect to the hyperon direction of $p_t > 23$ MeV/c is applied in order to reject e^+e^- pairs due to γ conversion.

The $p\pi^-$ and $\bar{p}\pi^+$ invariant mass distributions with peak Λ and $\bar{\Lambda}$ are presented in Fig. 1. They were fitted within 1.095-1.140 GeV interval by the sum a Gaussian for the Λ signal and the third order polynomial for the background. The total number of events after all selection cuts are $N(\Lambda) = 99667 \pm 385$ and $N(\bar{\Lambda}) = 60056 \pm 322$. This is much more then in all previous experiments on Λ and $\bar{\Lambda}$ production in DIS [1, 2, 5].

The $\Sigma^{\pm}(1385)$ and $\bar{\Sigma}^{\pm}(1385)$ resonances decay in $\Lambda\pi^+$ and $\bar{\Lambda}\pi^-$ in the primary vertex. To determine the $\Lambda\pi$ invariant mass, the events with an invariant mass of $p\pi^-$ within a $\pm 2\ \sigma$ interval from the mean value of the $\Lambda(\bar{\Lambda})$ peak are taken. Then for each selected event the momenta of all pions from the primary vertex are combined with the momentum of Λ to calculate the corresponding invariant mass distribution.

In Fig. 2 the $\Lambda\pi^+$ and $\bar{\Lambda}\pi^-$ invariant mass distributions with peak the $\Sigma^+(\bar{\Sigma}^-)$ for experimental data are shown. The signal was parametrized as a Breit-Wigner function convoluted with a gaussian

$$R(x) = \frac{\Gamma}{(2 \cdot \pi)^{3/2}} \cdot \int \frac{N dt}{(t - M)^2 + (\frac{\Gamma}{2})^2} \cdot e^{-\frac{1}{2}(\frac{t-x}{\sigma})^2} \tag{1}$$

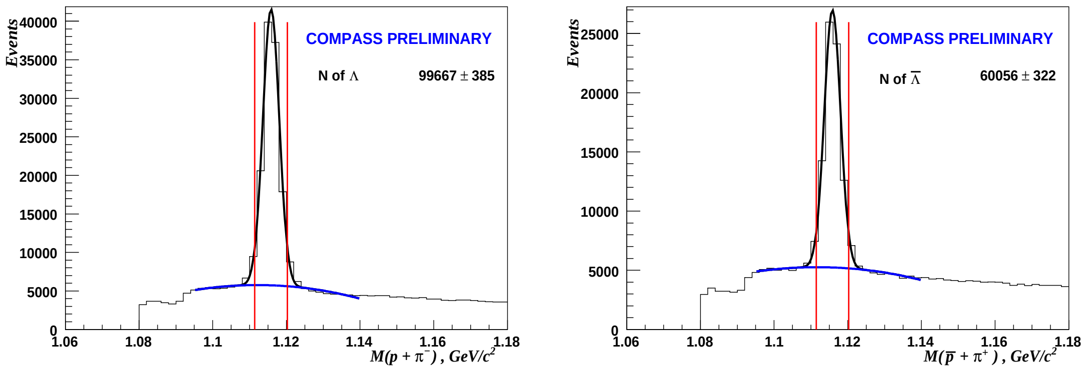

Figure 1: Invariant mass distributions of $p\pi^-$ and $\bar{p}\pi^+$. The vertical lines show the (2σ) region selected.

and the background as

$$B(x) = a \cdot (x - M_{th})^b \cdot e^{-c\cdot(x-M_{th})^d}. \tag{2}$$

Here the mass M and the width Γ of the hyperon were fixed according to the Particle Data Group Tables. $M_{th} = 1254$ MeV is the sum of the Λ and π mass.

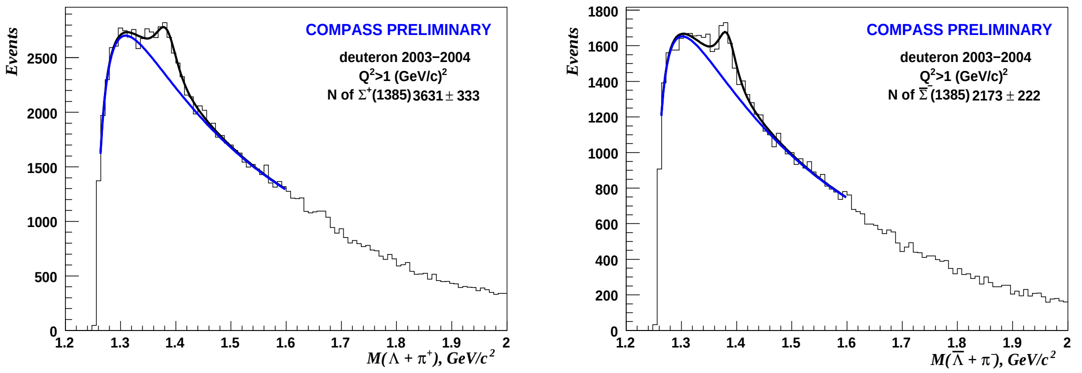

Figure 2: Invariant mass distributions of $\Lambda\pi^+$ and $\bar{\Lambda}\pi^-$.

In Fig. 3 the $\Lambda\pi^-$ and $\bar{\Lambda}\pi^+$ invariant mass distributions for experimental data are shown. One could see two peaks: the narrow one is due to part of the decays of $\Xi^-(\bar{\Xi}^+)$, which passed the collinearity cut. The wider peak at Fig. 3 is from $\Sigma^-(\bar{\Sigma}^+)$. The Ξ peak was fitted by a gaussian, the Σ peak was fitted by convolution of Breit-Wigner and gaussian (1).

The total number of events are $N(\Sigma^+) = 3631 \pm 333$, $N(\Sigma^-) = 2972 \pm 490$, $N(\bar{\Sigma}^-) = 2173 \pm 222$ and $N(\bar{\Sigma}^+) = 1889 \pm 265$.

For studying of the systematic effects 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. The systematic error connected with the particular choice of the selection cut of the Λ ($\bar{\Lambda}$) sample is estimated by changing the width of the central band from $\pm 2\,\sigma$ to $\pm 2.5\,\sigma$ and $\pm 1.5\,\sigma$. In the result, the systematic error turns out to be less or comparable with the statistical error.

The ratios for the yields of the heavy hyperons and antihyperons production to Λ and

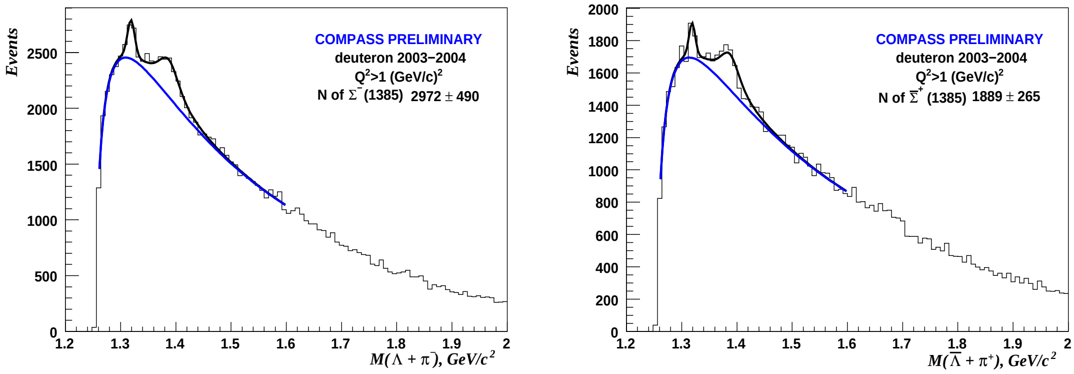

Figure 3: Invariant mass distributions of $\Lambda\pi^-$ and $\bar{\Lambda}\pi^+$.

$\bar{\Lambda}$ yields are the following:

$$R^+ = \Sigma^+(1385)/\Lambda = 0.055 \pm 0.005(stat) \pm 0.0045(syst) \quad (3)$$
$$\bar{R}^- = \bar{\Sigma}^-(1385)/\bar{\Lambda} = 0.047 \pm 0.006(stat) \pm 0.0053(syst) \quad (4)$$
$$R^- = \Sigma^-(1385)/\Lambda = 0.056 \pm 0.009(stat) \pm 0.0074(syst) \quad (5)$$
$$\bar{R}^+ = \bar{\Sigma}^+(1385)/\bar{\Lambda} = 0.039 \pm 0.006(stat) \pm 0.0064(syst) \quad (6)$$

These ratios are corrected on the experimental acceptance evaluated by the Monte Carlo. The acceptance correction includes the correction on all hyperon and Λ decays.

Main conclusion from the data (3)-(6) is that the percentage of the indirect Λ from the decays of $\Sigma(1385)$ in the total Λ sample is similar as percentage of indirect $\bar{\Lambda}$ from decays of $\bar{\Sigma}(1385)$. However, the percentage of indirect $\bar{\Lambda}$ from $\bar{\Sigma}(1385)$ decays is slightly less. It is important to note, that we compare the yields for Λ and $\bar{\Lambda}$ hyperons created in the current fragmentation region ($x_F > 0.05$).

The yields of the heavy hyperons in the neutrino DIS was measured by the NOMAD collaboration [2]. In Table 1 a comparison between COMPASS and NOMAD experemental data is given. The ratio $\Sigma^+(1385)/\Lambda$ was found to be $R^+ = 0.058 \pm 0.011$, in agreement with (3). The ratio $\Sigma^-(1385)/\Lambda$ was $R^- = 0.026 \pm 0.008$, two times smaller than our results (5). The difference between R^+ and R^- is natural for the neutrino-nucleon interaction. The neutrino preferentially interacts with d-quark, producing Σ^+, which is uus system, more easily than Σ^-, which is dds. No measurements of the heavy antihyperon yields in DIS were available prior to the COMPASS data.

Table 1: Comparison between COMPASS and NOMAD experemental data.

Ratios	COMPASS	NOMAD
$\Sigma^+(1385)/\Lambda$	0.055 ± 0.005	0.058 ± 0.011
$\bar{\Sigma}^-(1385)/\bar{\Lambda}$	0.056 ± 0.002	–
$\Sigma^-(1385)/\Lambda$	0.056 ± 0.009	0.026 ± 0.009
$\bar{\Sigma}^+(1385)/\bar{\Lambda}$	0.039 ± 0.006	–

The experimental relative yields (3)-(6) were used to tune the parameters of the LEPTO generator. The COMPASS Monte Carlo code is based on the LEPTO 6.5.1 generator [6] providing DIS events which are passed through a GEANT-based apparatus simulation programme and the same chain of reconstruction procedures as the experimental events. In Table 2 a comparison between the default LEPTO parameters, the NOMAD and the COMPASS ones is given. The results of the tuning on the COMPASS data are given in the last column.

Table 2: Comparison between the default LEPTO parameters[6], NOMAD [2] and present tuning.

Parameters	Default	NOMAD	COMPASS
PARJ(1)	0.1	0.05	0.055
PARJ(2)	0.3	0.21	0.2
PARJ(3)	0.4	0.07	0.97
PARJ(4)	0.05	0.001	0.007
PARJ(5)	0.5	0.97	3.0
PARJ(6)	0.5	0.5	0.5
PARJ(7)	0.5	0.39	0.97

The tuned LEPTO correctly reproduce the experimentally measured yields of $\Sigma(1385)$ and $\bar{\Sigma}(1385)$ as well as the ratios $\Lambda/\bar{\Lambda}$ and K/Λ.

The new LEPTO parameters strongly influence the theoretical predictions of the $\Lambda(\bar{\Lambda})$ polarization. To demonstrate the effect of the new LEPTO parameters, the spin transfer to Λ and $\bar{\Lambda}$ is calculated using the theoretical model of [7].

In Fig. 4 the x_F dependence of the spin transfer to the Λ and $\bar{\Lambda}$ calculated for the new (right) and old (left) LEPTO parameters is shown. One could see that the calculation with the tuned LEPTO predicts different x_F dependence of the spin transfer than the default LEPTO. The calculations with the tuned LEPTO shows no dependence of the Λ spin transfer with the x_F. Fig. 4 demonstrates that the knowledge of the heavy hyperons yields is important for the correct interpretation of the Λ and $\bar{\Lambda}$ hyperons polarization.

It is interesting how the yields of heavy hyperons changed if one refrain from the DIS cuts. We remove the demands that the $Q^2 > 1$ $(\mathrm{GeV}/c)^2$ and $0.2 < y < 0.9$. The data sample increases by a factor of 10. In total, there are $N(\Lambda) = 1208413 \pm 1312$ and $N(\bar{\Lambda}) = 654387 \pm 1067$. However no change in the ratios Σ/Λ and $\bar{\Sigma}/\bar{\Lambda}$ is found within the statistical errors. In Table 3 the ratios Σ/Λ and $\bar{\Sigma}/\bar{\Lambda}$ with and without the DIS cuts are compared.

Table 3: The ratios of the hyperon yields for 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

In conclusion, the yields of the $\Sigma(1385)$ and $\bar{\Sigma}(1385)$ in DIS are measured. The percentage of the indirect Λ from the decays of $\Sigma(1385)$ in the total Λ sample is similar to the percentage of indirect $\bar{\Lambda}$ from decays of $\bar{\Sigma}(1385)$. The yields are used to tune the LEPTO generator

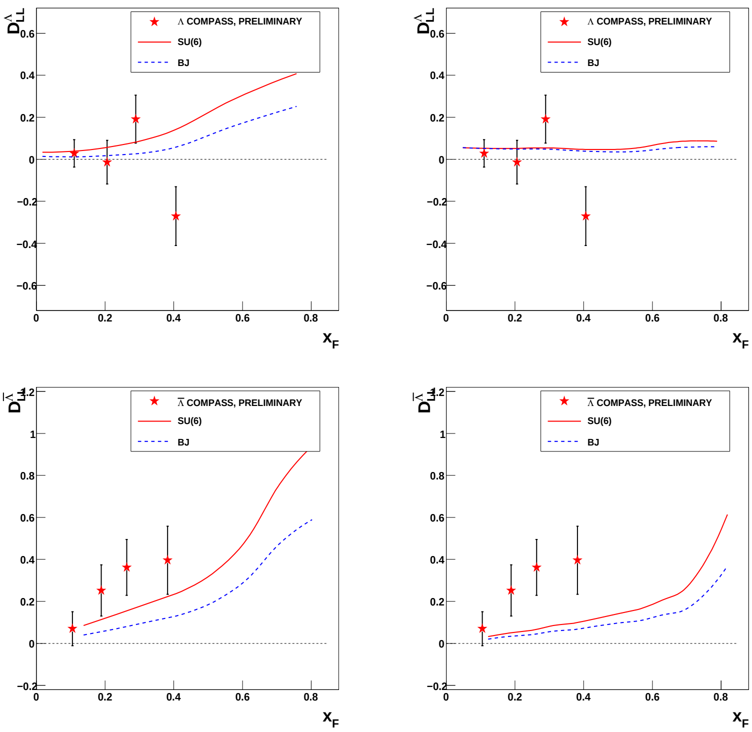

Figure 4: Comparison of the spin transfer to the Λ and $\bar{\Lambda}$ calculated for the new (right) and old (left) LEPTO parameters. The red lines corresponds to the SU(6) model for the Λ spin structure, whereas the blue lines corresponds to the calculations [7] in the BJ-model [8].The experimental data are from [4].

parameters. Theoretical calculations with the tuned LEPTO parameters demonstrate substantial impact on the Λ and $\bar{\Lambda}$ spin transfer. Removing the DIS cuts does not change the ratios Σ/Λ and $\bar{\Sigma}/\bar{\Lambda}$ within the statistical errors.

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