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

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Λ and $\bar{\Lambda}$ hyperons were produced at the COMPASS experiment at CERN, using Deep-Inelastic Scattering (DIS) of 160 GeV/c polarized muons on a longitudinally polarized target. The study of Λ and $\bar{\Lambda}$ hyperons in DIS is important for the understanding of the nucleon structure, the mechanisms of hyperon production and the hyperon spin structure. In particular, it may provide valuable information on the unpolarized strange quark distributions $s(x)$ and $\bar{s}(x)$ in the nucleon. The data sample contains about 70 000 Λ and 42 000 $\bar{\Lambda}$. Large and comparable statistics on both Λ and $\bar{\Lambda}$ hyperons is a distinct feature of the COMPASS experiment. Preliminary results on polarization of Λ and $\bar{\Lambda}$ hyperons and yields of heavy hyperons in DIS are presented.

The results on the production of heavy hyperons and the longitudinal polarisation of Λ and $\bar{\Lambda}$ hyperons produced in deep-inelastic scattering (DIS) are presented. The longitudinal polarisation of Λ and $\bar{\Lambda}$ hyperons is sensitive to the unpolarised strange $s(x)$ and anti-strange $\bar{s}(x)$ quark distribution functions in the nucleon. This sensitivity comes from the spin structure of Λ hyperon. In the naive quark model, the u and d quarks are always polarized in opposite directions, therefore spin of the Λ is carried only by the strange quark. LEP experiments [1,2] have shown that if strange quarks are polarised then the produced Λ-hyperons are also polarised.

It is important to measure the yields of heavy hyperons and antihyperons in deep inelastic scattering (DIS) for understanding the dynamics of hyperon production and polarization. The decays of heavy hyperons are also important for Λ and $\bar{\Lambda}$ production and polarization. It is known [3] 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 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.

We have studied Λ and $\bar{\Lambda}$ production by scattering 160 GeV polarised μ^+ off a polarised ^{6}LiD target in the COMPASS experiment at CERN[4]. The data used in the present analysis were collected during the years 2003-2004. An average value of muon beam polarisation was $P_b = -0.76 \pm 0.04$ in 2003 run and $P_b = -0.80 \pm 0.04$ in the 2004 run. We have about $31.2 \cdot 10^7$ events in the DIS region ($Q^2 > 1$ (GeV/c)^2). The polarized target of the COMPASS spectrometer consists of two cells with a length of 60 cm each and a diameter of 3 cm. They are placed coaxially along the beam direction with a distance of 10 cm between them. Both cells are placed inside a conductive solenoid with magnetic field 2.5 T and temperature about 50 mK. Using the dynamic nuclear polarization method, they are polarized along the beam in opposite directions.

We study reactions of $\Lambda(\bar{\Lambda})$ production $\mu^+ + N \to \mu^+ + \Lambda(\bar{\Lambda}) + X$, in which hyperons were identified by products of decays $\Lambda(\bar{\Lambda}) \to p(\bar{p}) + \pi^-(\pi^+)$. It was required that the primary vertex was inside the target and that the secondary vertex, in which Λ decays, was outside the target. Data were analysed in the region of DIS where $Q^2 > 1$ (GeV/c)^2 and the fractional energy of the virtual photon is in the interval $0.2 < y < 0.9$. For this analysis we select $\Lambda(\bar{\Lambda})$ events in the current fragmentation region $0.05 < x_F < 0.5$, here x_F is the Feynman variable $x_F = 2p_L/W$, where p_L is the particle longitudinal momentum in the hadronic center-of-mass system, whose invariant mass is W, its average value is $\overline{x}_F = 0.22(0.20)$.

A distinctive feature of the COMPASS experiment is its large region of Bjorken x extending to values as low as $x = 0.005$. The average values of x and Q^2 are $\overline{x} = 0.03$ and $\overline{Q^2} = 3.7(\mathrm{GeV/c})^2$ respectively. Our statistics for 2003 and 2004 runs is about 70000 Λ and 42000 $\bar{\Lambda}$. This is much more then in all previous experiments [3,5–7]. Detailed description of this analysis is given in [8].

The angular distribution of the decay protons (antiprotons) in the $\Lambda(\bar{\Lambda})$ rest frame was used for determination of longitudinal polarisation. Longitudinal spin transfer is defined as part of muon beam polarization (P_b) which is transfered to the hyperon $P_L = D^{\Lambda}_{LL} P_b D(y)$, where $D(y) = \frac{1-(1-y)^2}{1+(1-y)^2}$ is the virtual photon depolarisation factor. The spin transfer $D^{\Lambda}_{LL'}$ describes the probability that the polarisation of the struck quark along the primary quantisation axis L is transferred to the Λ hyperon along the secondary quantisation axis L'. In our case the primary and the secondary axes are the same, $L = L'$, and coincide with the virtual photon momentum.

Averaged on all kinematic variables, the longitudinal spin transfer to the Λ hyperon is $D^{\Lambda}_{LL} = -0.012 \pm 0.047_{stat} \pm 0.024_{syst}$ and to the $\bar{\Lambda}$ it is $D^{\bar{\Lambda}}_{LL} = \ 0.249 \pm 0.056_{stat} \pm 0.049_{syst}$. We can conclude that the spin transfer to Λ is compatible with zero whereas the spin transfer to the $\bar{\Lambda}$ is strictly positive. The resulting systematic error has several sources. Largest of them is uncertainty of the acceptance correction determined by the Monte Carlo simulation.

The x and x_F dependences of the spin transfers to Λ and $\bar{\Lambda}$ are shown in Figs. 1. These dependences are different for Λ and $\bar{\Lambda}$. The spin transfer to Λ is small and compatible with zero in the entire x range, while the spin transfer to $\bar{\Lambda}$ reaches values as large as $D^{\bar{\Lambda}}_{LL} = 0.4 - 0.5$.

A similar difference is observed in the x_F dependence (Fig. 1b). The spin transfer to $\bar{\Lambda}$ tends to increase with x_F, the same trend was found for the Λ polarization in the experiments at LEP [1,2], while the Λ one does not show any significant x_F dependence.

In Fig. 2 the degree of the sensitivity to the strange parton distributions is illustrated by the comparison of the results obtained with the CTEQ5L [9](solid line) and GRV98LO [10](dashed line) parton distributions. The GRV98 set is chosen because of its assumption that there is no intrinsic nucleon strangeness at a low scale and the strange sea is of pure perturbative origin. The CTEQ collaboration allows non-perturbative strangeness in the nucleon. The amount of this intrinsic strangeness is fixed from the dimuon data of the CCFR and NuTeV experiments [13]. As a result, the $s(x)$ distribution of CTEQ is larger than the GRV98 one by a factor of about two in the region $x = 0.001 - 0.01$. The results in Fig. 2 show that the data on Λ can not discriminate between the predictions since the spin transfer to Λ is small. For the $\bar{\Lambda}$ hyperon the use of CTEQ5L set leads to a prediction which is nearly twice larger than the one with the GRV98LO and much closer to the data. This behavior reflects the difference in the corresponding $\bar{s}$-quark distributions.

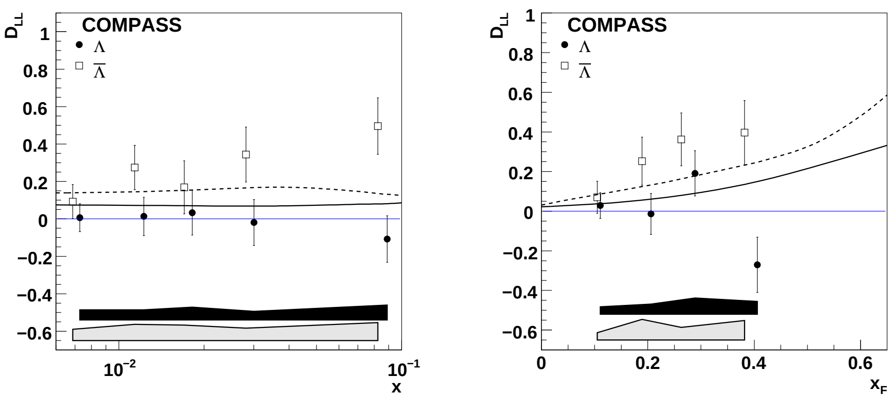
We have also studied the dependence of the hyperon polarisation on the target polarisation. The direction of the muon beam polarization was kept constant, but the direction of the target cells polarisation was reversed every 8 hours. The difference between hyperon polarisations for the different target polarisation is $\Delta P = P_- - P_+$. Here P_+ is the polarisation of hyperon in the case when the direction of the beam polarisation coincides with the direction of target polarisation, P_- is the polarisation of hyperon when they are opposite. Averaged on all kinematic variables this difference is $\Delta P = -0.01 \pm 0.04$ for Λ and $\Delta P = 0.01 \pm 0.05$ for $\bar{\Lambda}$. There is no significant dependence from the target polarisation neither for Λ , nor for $\bar{\Lambda}$. However, for the $\bar{\Lambda}$ sample, ΔP changes its sign in different x regions. In the future we have to increase statistics for further analysis of x - dependence of ΔP for $\bar{\Lambda}$ hyperon.

We studied following decays of heavy hyperons and antihyperons:

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

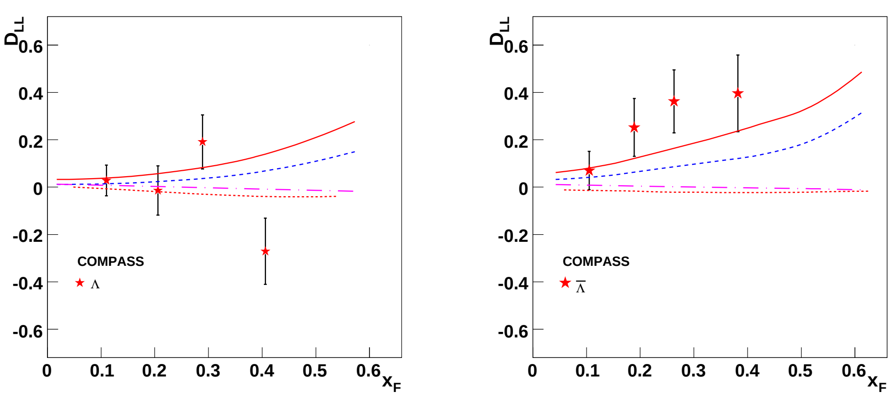
$$\mu^+ + N \to \mu^+ + \bar{\Sigma}^{\pm}(1385) + X \ (\bar{\Sigma}^{\pm}(1385) \to \bar{\Lambda} + \pi^{\pm})$$

In these strong processes the heavy hyperon decays at the primary vertex, whereas the secondary vertex is a signature for the $\Lambda(\bar{\Lambda})$ weak decays in



a) b)

Figure 1. The x (a) and x_F (b) dependencies of the longitudinal spin transfer to Λ (dots) and $\bar{\Lambda}$ (squares). The solid line corresponds to the theoretical calculations of [11](Model B, SU(6),CTEQ5L) for Λ and the dashed line is for the $\bar{\Lambda}$ spin transfer.The shaded bands show the size of the corresponding systematic errors.



a) b)

Figure 2. The x_F dependences of the longitudinal spin transfer to Λ (a) and $\bar{\Lambda}$ (b) calculated in [11](model B) for the GRV98LO parton distribution functions (dashed lines), the CTEQ5L pdf (solid lines) and for the CTEQ5L without spin transfer from the s-quark (dash-dotted lines). The SU(6) model for the Λ spin structure is assumed. The dotted lines corresponds to the calculations for the CTEQ5L without spin transfer from the s-quark in the BJ-model of Λ spin [12].

to $p\pi^-(\bar{p}\pi^+)$. The $\Sigma^{\pm}(1385)$ and $\bar{\Sigma}^{\pm}(1385)$ resonances decay in $\Lambda\pi^+$ and $\bar{\Lambda}\pi^-$ in the primary vertex. The distributions have been fitted by a sum of the Breit-Wigner convoluted with the gaussian for the signal and the background function. The total number of events are $N(\Sigma^+) = 3631 \pm 311$, $N(\Sigma^-) = 2970 \pm 490$, $N(\bar{\Sigma}^-) = 2173 \pm 222$ and $N(\bar{\Sigma}^+) = 1889 \pm 265$.

For a study of the systematic effects we evaluate the background using a mixed event method, in which the shape of the background distribution in the $\Lambda\pi$ invariant mass is 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 interval from the mean value of the $\Lambda(\bar{\Lambda})$ peak 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 heavy hyperons and antihyperons to Λ and $\bar{\Lambda}$ are the following:

$$R^{+} = \Sigma^{+}(1385)/\Lambda = 0.055 \pm 0.005 \pm 0.0045 \quad (1)$$

$$\bar{R}^{-} = \bar{\Sigma}^{-}(1385)/\bar{\Lambda} = 0.047 \pm 0.006 \pm 0.0053 \quad (2)$$

$$R^{-} = \Sigma^{-}(1385)/\Lambda = 0.056 \pm 0.009 \pm 0.0074 \quad (3)$$

$$\bar{R}^{+} = \bar{\Sigma}^{+}(1385)/\bar{\Lambda} = 0.039 \pm 0.006 \pm 0.0064 \quad (4)$$

The yields of the heavy hyperons in the DIS were measured by the NOMAD collaboration [15]. The ratio $\Sigma^{+}(1385)/\Lambda$ was found to be $R^{+} = 0.058 \pm 0.011$, in agreement with our value. The ratio $\Sigma^{-}(1385)/\Lambda$ was $R^{-} = 0.026 \pm 0.008$, two times smaller than our result. The difference between R^{+} and R^{-} is natural for the neutrino-nucleon interaction. No measurements of the heavy antihyperon yields in the DIS existed before. It is interesting how the yields of heavy hyperons change if one refrains from DIS cuts. We remove the demands that the $Q^2 > 1$ (GeV/c)^2 and $0.2 < y < 0.9$. The data sample increases by a factor 10. However, no change in the ratios Σ/Λ and $\bar{\Sigma}/\bar{\Lambda}$ is found within the statistical errors.

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 $\bar{\Sigma}(1385)$. The yields are used to tune the LEPTO generator parameters.

The longitudinal polarisation transfer from polarised muons to semi-inclusively produced Λ and $\bar{\Lambda}$ hyperons has been studied in deep-inelastic scattering at the COMPASS experiment. We have also measured the dependence of the longitudinal polarisations of Λ and $\bar{\Lambda}$ hyperons on the target polarisation. Within the present statistical accuracy no dependence was observed. The yields of the $\Sigma(1385)$ and $\bar{\Sigma}(1385)$ in DIS have been measured. 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 $\bar{\Sigma}(1385)$.

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