Longitudinal polarisation of the Λ and $\bar{\Lambda}$ hyperons in DIS at COMPASS

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In this paper we present results on the measurements of longitudinal polarisation of Λ and $\bar{\Lambda}$ hyperons produced in deep-inelastic scattering (DIS) averaged on the target polarisation and its dependence on the target polarisation. The longitudinal polarisation of Λ and $\bar{\Lambda}$ hyperons is sensitive to the unpolarised strange $s(x)$ and antisrange $\bar{s}(x)$ quark distribution functions in the nucleon respectively. 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 hyperon 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.

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. COMPASS spectrometer [3] consists of two parts based on large magnets SM1 and SM2. The first part of the setup is build around the SM1 magnet; thanks to its large angle aperture, it is used for measuring momentum of soft particles. The second part, build around the SM2 magnet, detects particles at small angles and large momenta. 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, Q^2 is the negative squared four-momentum of the virtual photon). 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 coaxialy 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 $\mu^+ + d \to \mu^+ + \Lambda(\bar{\Lambda}) + X$, 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 in the region where 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 $0.05 < x_F < 0.5$, where x_F (the Feynman variable is $x_F = 2p_L/W$, where p_L is the particle longitudinal momentum in the hadronic centre-of-mass system, whose invariant mass is W) is positive with the average value $\overline{x}_F = 0.22(0.20)$. 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 peaks of Λ and $\bar{\Lambda}$ are shown in Fig.1 for the data of the 2004 run.

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 $\overline{Q^2} = 3.7$(GeV/c)^2 respectively. Our statistics (2003+2004 years) is about 70000 Λ and 42000 $\bar{\Lambda}$. This is much more

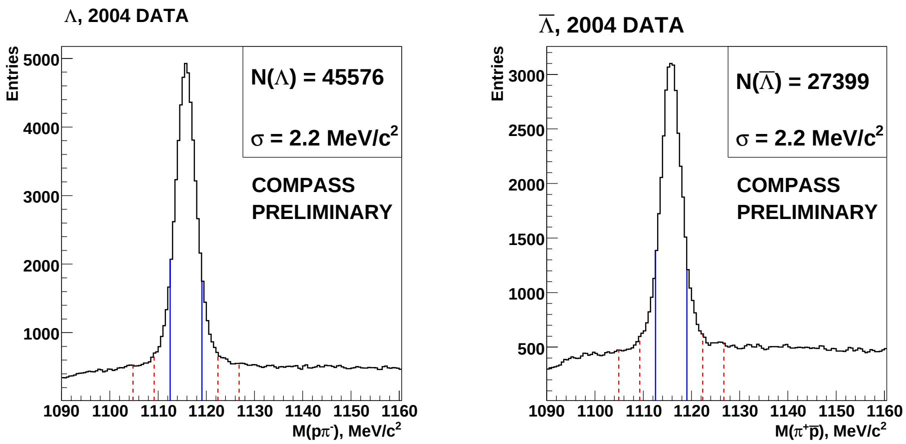

Figure 1. The invariant mass distribution for the $p\pi^-$ (left) and $\bar{p}\pi^+$ (right) hypothesis for the data of 2004 run. The solid lines marks the band of the $\Lambda(\bar{\Lambda})$ signal, the dashed lines show the sidebands used for determination of the background regions.

then in all previous experiments [4–7]. Detailed description of this analysis is given in [8].

The angular distribution of the decay protons (antiprotons) in the $\Lambda(\bar{\Lambda})$ rest frame for determination of longitudinal polarisation of hyperons was used

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

here N_{tot} is the total number of acceptance corrected $\Lambda(\bar{\Lambda})$, the longitudinal polarisation P_L is the projection of the polarisation vector on the momentum vector of the virtual photon, $\alpha = +(-)0.642 \pm 0.013$ is the $\Lambda(\bar{\Lambda})$ decay parameter, θ is the angle between the direction of the decay proton for Λ(antiproton - for $\bar{\Lambda}$) and the corresponding axis. The acceptance correction was determined using the Monte Carlo simulation for unpolarised Λ and $\bar{\Lambda}$ decays. To obtain angular distributions of $\Lambda(\bar{\Lambda})$, the sideband substraction method was used. The events with an invariant mass within a $\pm 1.5\sigma$ interval from the mean value of the $\Lambda(\bar{\Lambda})$ peak are taken as signal. The background regions are selected from the left and right sides of the invariant mass peak. Each band is 2 σ wide and starts at a distance of 3 σ from the central value of the peak. The bands of the signal, as well as the background regions, are shown in Fig.1. The $\Lambda(\bar{\Lambda})$ angular distribution is determined by substracting the averaged angular distribution of the events in the sidebands from the angular distribution of those in the signal region.

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 depolarization 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. Also there are systematic errors from variation of selection cuts and from uncertainty of the sidebands substraction method.

In Fig.2 the x_F - dependence of the spin transfers to hyperons in comparison with other experiments is shown. In all x_F interval the spin transfer to Λ is about zero, but the spin transfer to $\bar{\Lambda}$ increases with x_F reaching 40%. The COMPASS data are in a good agreement with results of other experiments. There are not enough data about spin transfer to $\bar{\Lambda}$ hyperon. The x_F - dependence of the spin transfer to $\bar{\Lambda}$ in the COMPASS experiment is unique at this moment.

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 $\bar{\Lambda}$. The x-dependence of hyperon polarisations for different target polarisations is shown in Fig.3. 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.

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. The present COMPASS data are the most precise measurements to date of the longitudinal spin transfer to Λ and $\bar{\Lambda}$ in DIS. The results show that the spin transfer to Λ is small with $D^{\Lambda}_{LL} = -0.012 \pm 0.047 \pm 0.024$ at $\bar{x}_F = 0.22$. The spin transfer to $\bar{\Lambda}$ is larger with $D^{\bar{\Lambda}}_{LL} = 0.249 \pm 0.056 \pm 0.049$ at $\bar{x}_F = 0.20$. These values are in agreement with results of previous measurements [4–7].

We have measured the x_F dependences of the longitudinal spin transfer whith are different for Λ and $\bar{\Lambda}$ hyperons. The spin transfer to Λ is small, compatible with zero, in the entire domain of the measured kinematic variable. In contrast, the longitudinal spin transfer to $\bar{\Lambda}$ increases with x_F reaching values of $D_{LL} = 0.4 - 0.5$.

We have also measured the dependence of the longitudinal polarisations of Λ and $\bar{\Lambda}$ hyperons on the target polarisation for the first time. Within the present statistical accuracy no dependence was observed.

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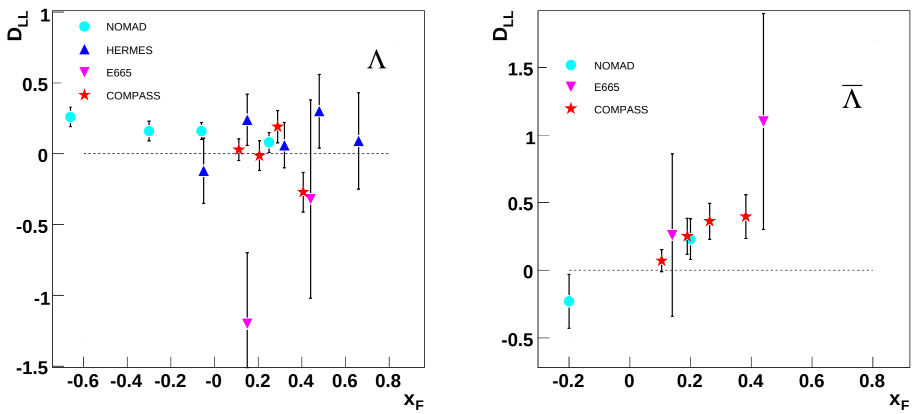

Figure 2. The x_F - depenence of the longitudinal spin transfer to Λ (left) and to $\bar{\Lambda}$ (right) hyperons for the COMPASS (stars) in comparisone with other experiments [4–7](NOMAD data - circles, E665 - reverse triangles, HERMES - triangles).

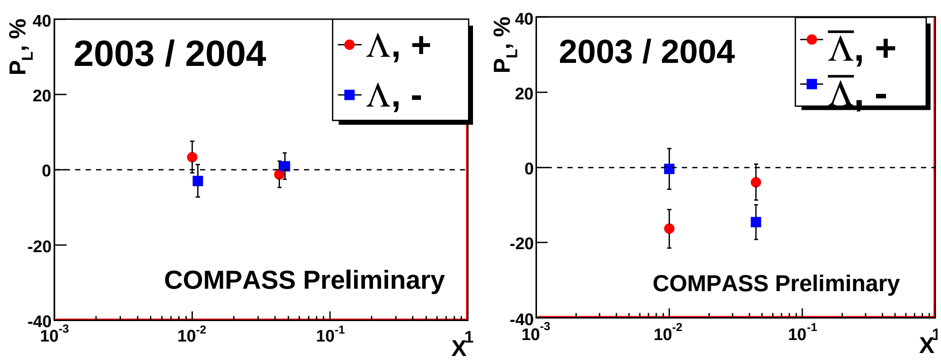

Figure 3. The x - dependence of Λ (left) and $\bar{\Lambda}$ (right) polarisation for different target polarisation. Red circles - hyperon polarisation at “positive” target polarisation, blue squeres - hyperon polarisation at “negative” target polarisation.