Spin transfer to \( \Lambda_c^+ \) hyperons in polarized proton collisions at RHIC

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The analysis\(^1\) of helicity transfer to \( \Lambda_c^+ \) in polarized proton collisions is extended to the proton helicity correlations with the \( \Lambda_c^+ \) transverse polarization in the production plane (parameter \( D_{LS} \)). The available spin transfer observables for the collisions of two longitudinally polarized protons are evaluated. It is shown that, in the central region at \( \Lambda_c^+ \) transverse momenta of a few GeV/c, \( D_{LS} \) parameters are of about the same size as the helicity-to-helicity correlations. The methodical issue of using spin transfers for cross-checks of systematic errors in cross-section \( A_{LL} \) measurements at polarized proton colliders is also briefly discussed.

1 Introduction

Spin transfers to inclusive strange and charmed hyperons in polarized proton collisions have been recently proposed\(^1, 2\) as a probe for the polarized gluon distribution \( \Delta G/G \) of proton. Compared to the usually considered for this purpose cross-section asymmetry \( A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \), where \( \sigma^{++} \) and \( \sigma^{+-} \) are the cross sections for same and opposite helicities of colliding protons, spin transfers are linear with \( \Delta G/G \) while \( A_{LL} \propto (\Delta G/G)^2 \). This means that spin transfers might become more sensitive probes for polarized gluon distribution if \( \Delta G/G \) appeared to be small. The other difference is that, unlike \( A_{LL} \), spin transfer measurements generally do not require monitoring the relative luminosity of collisions with different polarizations of initial protons. Such monitoring is not a simple task at a proton collider with longitudinally polarized beams and is always considered as a potential source of systematic errors. And, in general, measuring a number of sensitive characteristics rather than one and comparing them to the predictions of theoretical models could serve as a good consistency check of the model’s assumption.

In the papers\(^1\), the measurements of helicity-to-helicity transfer parameter \( D_{LL} \) in gluon fusion dominant \( \Lambda_c^+ \) production at RHIC with polarized protons have been proposed and studied\(^3\). In this report, we extended this analysis

\(^1\)The notation \( A_{LL} \) has been used for \( D_{LL} \) in Refs\(^1\).
to the proton helicity correlations with the $\Lambda^+_c$ transverse polarization in the production plane (parameter $D_{LS}$)\(^2\). The $D_{LS}$ is also expected to be nonzero at $\Lambda^+_c$ transverse momenta ($P_T$) of a few GeV/c due to the large $c$-quark mass. Moreover, for each spin transfer, $LL$ and $LS$, we evaluated two more observables: $D^{++}_{LL}$ and $D^{+-}_{LL}$, $\Pi = L, S$, which will be measured at RHIC in collisions of two polarized protons of the same and opposite helicities:

\[
D^{++}_{LL} = \frac{\sigma^{++}_{LL} - \sigma^{-+}_{LL} - \sigma^{+-}_{LL} + \sigma^{-+}_{LL}}{\sigma^{++}_{LL} + \sigma^{-+}_{LL} + \sigma^{+-}_{LL} + \sigma^{-+}_{LL}}, \quad \Pi = L, S
\]

In Eqs. (1), $\sigma^{-+}_{LS}$, for example, is for the production cross-section of $\Lambda^+_c$ with the polarization “+1” along the $S$-axis in the collisions of two proton beams, both of the negative helicity equal to “-1”.

Parameters $D_{LL}$ for collisions of polarized protons at unpolarized are the weighted with $A_{LL}$ averages of $D^{++}_{LL}$ and $D^{+-}_{LL}$:

\[
D_{LL} = \frac{1}{2}[D^{++}_{LL}(1 + A_{LL}) + D^{+-}_{LL}(1 - A_{LL})]
\]

In turn, if all three $D$’s for the same final spin component were measured, then $A_{LL}$ can be derived, using Eq. (2). As it mentioned above, the $A_{LL}$ determined this way would potentially be free from systematics due to monitoring the relative luminosity of collisions with different beam polarizations. With this approach, the statistical error $\delta A_{LL} \approx 2\sqrt{\frac{\alpha_p}{P\sqrt{N}}}\sqrt{\frac{\sigma^{++}_{LL}}{D_{LL}^{++}}}$, where $\alpha$ is the hyperon decay asymmetry parameters; $P$ is the beam polarization; $N$ is the combined statistics in 3 measurements. This error would usually be noticeably larger than of “direct” $A_{LL}$ measurements. However, if the systematic rather than statistic is an issue, then using spin transfers in high event rate processes, along with Eq. (2), could be an option.

2 Numerical results and discussion

The leading order calculations for pseudo-rapidity dependences of 6 spin transfer parameters, averaged over $P_T$ interval from 2 to 5 GeV/c, are shown in Fig. 1. These results have been obtained, using the same assumptions as in the analyses\[^{[1]}\]. Only the dominant partonic subprocess of gluon fusion, $gg \rightarrow \eta c\bar{c}$, was taken into account. The same spin dependent fragmentation function $\Delta D(z) = C(z) \cdot D(z)$ were used for both the longitudinal and transverse spin transfers from $c$-quark to $\Lambda^+_c$, where $D(z)$ is the “unpolarized” quark fragmentation function. For the $C(z)$, two options are compared: $C(z) = 1$ and $C(z) = z$. The shown statistical errors are for the integrated luminosity of 320 pb\(^{-1}\) and beam polarization of 70%, assuming that the decay chain $\Lambda^+_c \rightarrow \Lambda^0 \pi^+ \rightarrow p\pi^- \pi^+$

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\[^{2}\]L and S axes here correspond to $Z$ and $X$ in the notations of book\[^{[3]}\].
Figure 1: $\eta$-dependences of spin transfer parameters for inclusive $\Lambda_\p^+$ production in polarized proton collisions at $\sqrt{S} = 200$ GeV. The leading order predictions for $AAC$ [4] and $GRSV$ [5] polarized gluon distributions are compared. Each error bar is for the integrated statistics within a pseudo-rapidity interval of $\Delta \eta = 1$. See text for other details.

is to be used for measuring the $\Lambda_\p^+$ polarization, with the detection efficiency at $\sim 10\%$.

In the central region of $|\eta| < 1$, $D_{LL}$’s and $D_{LS}$’s are of about the same size in the range of $\sim 5$–15%. As $\eta$ increases, all $D_{LL}$’s grow up to $\sim 20$–30% at $\eta \sim 2$ for the $AAC$ parameterization [4], while $D_{LS}^{+}$ stays almost flat. The achievable statistical errors of about 1% are small enough to clearly separate predictions for the shown models even in the central rapidity region. Since only a half of the total luminosity will be utilized for measuring $D_{L\Pi}^{++}$, and the other half will go to the measurements of $D_{L\Pi}^{+-}$, the statistical errors for these parameters would be larger than for $D_{LL}$ by a factor of $\sqrt{2}$. However, it is worth underlining that $D_{LL}^{++} \approx 2D_{LL}$ and $D_{LS}^{+} \approx 2D_{LS}$ for $\eta$ in the vicinity of zero. These relations follow from Eq. (2) with $|A_{LL}| \ll 1$, and taking into account the “forward–backward” symmetry of the initial system of two colliding protons. As
a result, in the central region, the statistical significance of measurements with two polarized beams would be higher compared to the case of only one beam being polarized.

3 Summary

It is shown that both components, $D_{LL}$ and $D_{LS}$, of the proton helicity transfer to the polarization of inclusive $\Lambda_c^+$ hyperons are expected to be equally sensitive to $\Delta G/G$. In the central region, the expected effects at $\sim 5$–$15\%$ are well above the achievable at RHIC statistical errors, which are also small enough for distinguishing the AAC$^1$ and GRSV$^5$ parameterizations for $\Delta G/G$. The really large spin transfers at the level of up to 20–30\% are expected at $\eta \sim 2$ and beyond, which could be potentially accessible at STAR$^6$, but definitely with the recently proposed new RHIC-II detector$^7$.

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