Charmed Hadron Production at RHIC

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ABSTRACT

To extract information about polarized gluon distribution in the proton, charmed hadron, actually $\Lambda_c^+$, productions at RHIC experiment are studied. We found that the spin correlation asymmetry between the initial proton and the produced $\Lambda_c^+$ is enable us to distinguish parameterization models of polarized gluons.

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1 Introduction

Since the surprising EMC measurement\(^1\) of the polarized structure function of proton 
\(g_1^p(x, Q^2)\) was reported more than ten-years ago, the spin structure of the proton is still
mysterious problem being called the proton spin puzzle\(^2\). As is well known, a proton is
not an elementary but compound particle and thus, its spin is carried by its constituents
as described by a sum rule,

\[
\frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + \langle L_z \rangle_{q+g} \quad (1)
\]

where \(\frac{1}{2}\) on the left side means a spin of the proton, while \(\Delta \Sigma, \Delta G\) and \(\langle L_z \rangle_{q+g}\) represent the amount of the proton spin carried by the constituent quarks, gluons and
their orbital angular momenta, respectively. An extensive study on polarized structure
functions of nucleons brought about a rather good information of valence quark distri-
butions in the proton, however, knowledge of \(\Delta G\) and \(\langle L_z \rangle_{q+g}\) is still poor because it is very difficult to directly extract its information from existing experimental data. In
this work, we are interesting in the polarized gluon distribution \(\Delta G\). So far, to extract
its information, many processes depending on the gluon interactions have been proposed
and studied.

Here, to study the polarized gluon distribution in a proton, we propose another
process,

\[
p p \rightarrow \Lambda_c^+ X,
\]

which could be observed in forthcoming BNL-RHIC experiment. In this process, \(\Lambda_c^+\) is
dominantly produced via fragmentation of a charm quark originated from gluon–gluon
fusion\(^3\). Thus, its cross section is directly proportional to the gluon distribution in
the proton. Moreover, the \(\Lambda_c^+\) is composed of a heavy quark \(c\) and antisymmetrically
combined light \(u\) and \(d\) quarks. Hence, the \(\Lambda_c^+\) spin is basically carried by a charm quark
through gluon–gluon fusion. Therefore, observation of the spin of the produced \(\Lambda_c^+\) gives
us information about the polarized gluons in the proton

\(^1\)Since charm quarks are tiny contents in the proton, the gluon–gluon fusion process is dominant for charm quark production.
2 Spin Correlation Asymmetry

To get information of $\Delta G$, we introduce the spin correlation asymmetry of the target proton and produced $\Lambda_c^+$ baryon,

$$A_{LL} = \frac{d\sigma_{++} - d\sigma_{+-} + d\sigma_{-+} - d\sigma_{--}}{d\sigma_{++} + d\sigma_{+-} + d\sigma_{-+} + d\sigma_{--}}$$

$$\equiv \frac{d\Delta\sigma/dX}{d\sigma/dX}, \quad (X = \eta \text{ or } p_T), \quad (2)$$

where $d\sigma_{+-}$, for example, denotes the spin-dependent differential cross section with the positive helicity of the target proton and the negative helicity of the produced $\Lambda_c^+$ baryon. $\eta$ and $p_T$ mean pseudo-rapidity and transverse momentum of produced $\Lambda_c^+$, respectively. Moreover, according to quark-parton model, $d\Delta\sigma/dX$ can be expressed as

$$\frac{d\Delta\sigma}{dX} = \int_{Y_{\text{min}}}^{Y_{\text{max}}} \int_{x_a}^{1} \left( \int_{z_{\text{min}}}^{1} \int_{x_b}^{1} \right) G_{p_A \rightarrow q_a}(x_a, Q^2) \Delta G_{\bar{q}_B \rightarrow \bar{g}_b}(x_b, Q^2) \Delta D_{c \rightarrow \bar{c}}(z)$$

$$\times \frac{d\Delta\hat{\sigma}}{d\hat{t}} J dx_a dx_b dY, \quad (X, Y = \eta \text{ or } p_T \ (X \neq Y)), \quad (3)$$

where $G_{p_A \rightarrow q_a}(x_a, Q^2)$, $\Delta G_{\bar{q}_B \rightarrow \bar{g}_b}(x_b, Q^2)$ and $\Delta D_{c \rightarrow \bar{c}}(z)$ represent the unpolarized gluon distribution function, the polarized gluon distribution function and the spin-dependent fragmentation function of the outgoing charm quark decaying into a polarized $\bar{c}$, respectively. $d\Delta\hat{\sigma}/d\hat{t}$ is the spin correlation differential cross section in the subprocess and $J$ is the Jacobian which transforms the variables $z$ and $\hat{t}$ into $\eta$ and $p_T$.

3 Numerical Calculation

To numerically estimate $A_{LL}$, we use, as input parameters, $m_c = 1.25$ GeV, $m_p = 0.938$ GeV and $m_{\Lambda_c^+} = 2.28$ GeV. We limit the integration region of $\eta$ and $p_T$ of produced $\Lambda_c^+$ as $-1.3 \leq \eta \leq 1.3$ and $3$ GeV $\leq p_T \leq 15(40)$ GeV for $\sqrt{s} = 200(500)$ GeV in order to get rid of the contribution of the diffractive $\Lambda_c^+$ production and also the $\Lambda_c^+$...
production through a single charm quark production via $W$ boson exchange and $W$ boson production. In addition, we take the GRSV01$^5$ and AAC$^6$ parameterization models for the polarized gluon distribution function and GRV98$^7$ for the unpolarized one. Though both of GSRSV01 and AAC models excellently reproduce the experimental data on the polarized structure function of nucleons $g_1(x)$, the polarized gluon distributions for those models are quite different. In other words, the data on polarized structure function of nucleons $g_1(x)$ alone are not enough to distinguish the model of gluon distributions.

Since the process is semi-inclusive, the fragmentation function of a charm quark to $\Lambda_c^+$ is necessary to do numerical calculation. For the unpolarized fragmentation function, we use Peterson fragmentation function$^8$, $D_{c \to \Lambda_c^+}(z)$. However, since we have no data, at present, about polarized fragmentation function for the polarized $\Lambda_c^+$ production, we take the following ansatz for the polarized fragmentation function $\Delta D_{\bar{c} \to \bar{\Lambda}_c^+}(x)$,

$$\Delta D_{\bar{c} \to \bar{\Lambda}_c^+}(z) = C_{c \to \Lambda_c^+} D_{c \to \Lambda_c^+},$$

where $C_{c \to \Lambda_c^+}$ is scale-independent spin transfer coefficient. In this analysis, we study two cases: (A) $C_{c \to \Lambda_c^+} = 1$ (non-relativistic quark model) and (B) $C_{c \to \Lambda_c^+} = z$ (Jet fragmentation model$^9$).

Numerical results of $A_{LL}$ are shown in Fig. 1 and Fig. 2. As shown in Fig. 1 and Fig. 2, $A_{LL}$ is rather sensitive to the model of the polarized gluon distribution functions. Therefore, the process discussed here could provide good information about the distribution of the polarized gluons in a nucleon. Especially, the $\eta$ dependence of $A_{LL}$ at $\sqrt{s} = 200$GeV is the most effective to distinguish the parameterization models of polarized gluon because the magnitude of a numerical value of $A_{LL}$ is larger than others.

4 Summary

To extract information of polarized gluon distribution in the proton, we have proposed an interesting process; $p\bar{p} \to \bar{\Lambda}_c^+ X$ and calculated the spin correlation asymmetry, $A_{LL}$, defined by Eq. (3). We found that in this process, $A_{LL}$ is rather sensitive to the parameterization models of polarized gluon, and thus, process is quite promising for testing
the models of polarized gluon distribution. Error estimation is important and now is undergoing. To get better knowledge of $\Delta G$, we need more detailed information about the spin-dependent fragmentation function of a charm quark to $\Lambda_c^+$. 

\[ -1.3 -1 -0.5 0 0.5 1 1.3 \]
\[ -0.15 -0.1 -0.05 0 0.05 0.1 0.15 0.2 \]

Figure 1: $A_{LL}$ as a function of $\eta$ (left panel) and $p_T$ (right panel) at $\sqrt{s}=200\,\text{GeV}$.

\[ -1.3 -1 -0.5 0 0.5 1 1.3 \]
\[ -0.06 -0.05 -0.04 -0.03 -0.02 -0.01 0 \]

Figure 2: $A_{LL}$ as a function of $\eta$ (left panel) and $p_T$ (right panel) at $\sqrt{s}=500\,\text{GeV}$.

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