Polarized $s$–quark Distribution
in Charmed Hadron Leptoproduction

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ABSTRACT

In order to extract the polarized strange quark density in proton, we studied the semi–inclusive $\Lambda_{c}^{+}/\bar{\Lambda}_{c}^{+}$ leptoproduction in charged current DIS at THERA energies. We indicate that measurements of the spin correlation between the incident proton and the produced $\Lambda_{c}^{+}/\bar{\Lambda}_{c}^{+}$ baryon gives us information about the polarized strange quark distribution.

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1 Introduction

Proton spin puzzle is currently one of the most challenging topics in high energy spin physics. As is well known, proton spin is composed of the spin and orbital angular momentum of quarks and gluons. The polarized parton distribution function (PDF) plays an important role on deep understandings of the spin structure of proton. However, knowledge about the polarized sea quark distribution remains still poor. In order to understand the spin structure of proton, we need more information about the polarized sea quark distribution functions. Recently, HERMES group has reported [1] that direct measurement of the strange sea is required to explain the violation of the Ellis–Jaffe sum rule [2]. So far, there are several parametrization models of the strange quark distribution. Though the most simplest case is to assume the flavor SU(3)$_f$, a new parametrization taken account of the violation of SU(3)$_f$ is also recently proposed [3].

The study of heavy quark production in deep inelastic scattering (DIS) is one of the promising way to access the parton density in proton, since heavy quark is not main constituents of proton and is only produced in hard processes. Heavy quark leptoproduction in neutral current DIS has already measured by some collaborations at HERA. However, no measurement of heavy quark production in charged current DIS has been so far done at HERA due to the small cross section. We can expect that the cross section for charged current heavy quark production will be several times larger at THERA than at HERA [4]. THERA is a future high energy $ep$ collider which uses electron or positron from the linear collider TESLA at energies of 250 GeV to 800 GeV and proton from HERA at energy 920 GeV. Thus, charged current heavy quark production is also interesting and challenging topics.

In this work, to examine the polarized $s/\bar{s}$ quark distribution, we have studied semi–inclusive $\Lambda^+_c/\bar{\Lambda}^+_c$ leptoproduction in charged current DIS; $l^+ + \vec{p} \rightarrow \nu + \bar{\Lambda}^+_c + X$, $l^- + \vec{p} \rightarrow \bar{\nu} + \Lambda^+_c + X$, where arrows attached to particles mean that these particles are polarized. These processes might be observed in the forthcoming THERA experiments. Since in the naive quark model, the $\Lambda^+_c$ baryon is composed of a heavy $c$–quark and anti–symmetrically combined light $u$ and $d$–quarks, we can assume the polarization of $\Lambda^+_c$ baryon to be the one of charm quark. In addition, $\Lambda^+_c$ is dominantly produced by the fragmentation of charm quark which is originated from strange quark through the $t$–channel $W^\pm$ boson exchange at the leading order. Therefore, there can be a correlation between the strange quark polarization and the produced charm quark polarization. Hence we can expect that the measurement of the spin correlation between the incident proton and the produced $\Lambda^+_c/\bar{\Lambda}^+_c$ gives us information about the polarized $s/\bar{s}$ quark distribution in proton.
2 Double Spin Asymmetry

For above processes, we calculated the double spin asymmetry $A_{LL}^{H}$ for final state hadron specified by $H$ ($\Lambda_c^+$ or $\bar{\Lambda}_c^+$), which is given by

$$A_{LL}^{H} = \frac{d\sigma_{++} - d\sigma_{+-} + d\sigma_{-+} - d\sigma_{--}}{d\sigma_{++} + d\sigma_{+-} + d\sigma_{-+} + d\sigma_{--}} = \frac{d\Delta\sigma/dp_T}{d\sigma/dp_T},$$

where $d\sigma_{+-}$, for instance, denotes that the helicity of proton is positive and the one of $H$ is negative. $p_T$ is a transverse momentum of final hadron $H$.

For $\Lambda_c^+$ production, the spin–dependent differential cross section at leading order level can be generally written by

$$d\Delta\sigma(l^+ p \to \bar{\nu}\Lambda_c^+ X) = \left\{U_{cs}^2 \Delta s(x) + U_{cd}^2 \Delta d(x)\right\} dx \left(\frac{d\Delta\sigma}{dt}\right) dt d\Delta C_{LL}^\Lambda_c^+ (z) dz,$$

where $\Delta s(x)$ and $\Delta d(x)$ are the polarized $s$–quark and $d$–quark distribution functions, respectively. $U_{cs}$ and $U_{cd}$ are CKM parameters. $\Delta D_c^\Lambda_c^+ (z)$ is the polarized fragmentation function of outgoing charm quark decaying into $\Lambda_c^+$. We used the model of Peterson et al. as the unpolarized fragmentation function. Unfortunately, we have at present no data about the polarized fragmentation function because of lack of experimental data. By analogy with the study on $\Lambda$ polarization, we took the following ansatz:

$$\Delta D_c^\Lambda_c^+ (z) = C_c^\Lambda_c^+ (z) D_c^\Lambda_c^+ (z),$$

where $C_c^\Lambda_c^+ (z)$ is the scale–independent spin transfer coefficient. Here we apply the analysis on $\Lambda$ production to $\Lambda_c^+$ production and choose the following two models: $C_c^\Lambda_c^+ (z) = 1$ (the naive nonrelativistic quark model) and $C_c^\Lambda_c^+ (z) = z$ (the jet fragmentation models) to evaluate cross sections.

The double spin asymmetry $A_{LL}^{\Lambda_c^+}$ is described in terms of the spin transfer coefficient $C_c^\Lambda_c^+ (z)$ and the ratio of the PDF’s as

$$A_{LL}^{\Lambda_c^+} \propto C_c^\Lambda_c^+ (z) \frac{U_{cs}^2 \Delta s(x) + U_{cd}^2 \Delta d(x)}{U_{cs}^2 s(x) + U_{cd}^2 d(x)}.$$

Thus $A_{LL}^{\Lambda_c^+}$ is proportional to linear combination of the polarized $s$–quark and $d$–quark distribution function. Since the contribution from the valence $d$–quark is large, the $s$–quark distribution is not so clearly extracted in $\Lambda_c^+$ production case.

On the contrary, $A_{LL}^{\bar{\Lambda}_c^+}$ in $\bar{\Lambda}_c^+$ production can be represented as

$$A_{LL}^{\bar{\Lambda}_c^+} \propto C_c^{\bar{\Lambda}_c^+} (z) \frac{U_{cs}^2 \bar{s}(x) + U_{cd}^2 \bar{d}(x)}{U_{cs}^2 \bar{s}(x) + U_{cd}^2 \bar{d}(x)} = C_c^{\bar{\Lambda}_c^+} (z) \frac{\Delta \bar{s}(x)}{\bar{s}(x)} \simeq C_c^{\Lambda_c^+} (z) \frac{\Delta s(x)}{s(x)},$$

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in which the $\bar{d}$–quark contribution and CKM parameters can be eliminated, and
then $A_{LL}^{\Lambda^+}$ is directly proportional to the strange quark distribution function alone. Therefore, we can clearly extract the polarized strange quark distribution $\Delta s(x)$. Note that above equation is derived in both cases; the flavor SU(3)$_f$ case ($\Delta \bar{u}(x) = \Delta \bar{d}(x) = \Delta \bar{s}(x)$) and the non–SU(3)$_f$ case ($\Delta \bar{u}(x) = \Delta \bar{d}(x) = \lambda \Delta \bar{s}(x)$).

3 Numerical Results

Setting a charm quark mass $m_c = 1.5$ GeV and the relevant collider energy $\sqrt{s} = 300$ GeV, we numerically calculated the spin–independent and dependent differential cross sections and the double spin asymmetry. As for the PDF’s, we used the GRV98 [9] parametrization as the unpolarized PDF, and the AAC [10] and “standard scenario” of GRSV01 [11] parametrizations for the polarized one.

We show the double spin asymmetry in Fig. 1 as a function of $p_T$ at $\sqrt{s} = 300$ GeV for $\Lambda^+_c$ production (left panel) and for $\bar{\Lambda}^+_c$ production (right panel). In order to suppress the contributions from the diffractive process and higher twist corrections, we have imposed the kinematical cut on $p_T$ as $p_T > 2$ GeV in numerical calculations. In figures, the bold and normal lines show the case of AAC parametrization and “standard scenario” of GRSV01 parametrization, respectively. The solid lines represent the spin transfer coefficient $C_{\Lambda^+_c}(z) = 1$ case, while the dashed lines represent $C_{\lambda \bar{c}}^{\Lambda^+_c}(z) = z$ case.

As shown in figures, $A_{LL}^{\Lambda^+_c}$ in smaller $p_T$ regions does not depend on the model of polarized PDF’s, and is strongly affected by the shape of the spin transfer coefficient $C_{\lambda \bar{c}}^{\Lambda^+_c}(z)$. Therefore, The $\Lambda^+_c$ production is effective for extracting information about the polarized fragmentation function $\Delta D_{\Lambda^+_c}(z)$. In addition, we can directly measure the polarized strange quark distribution function, though the parametrization model dependence is not so large. On the other hand, for $\bar{\Lambda}^+_c$ production $A_{LL}^{\bar{\Lambda}^-}$ for GRSV01 parametrization rapidly decreases in larger $p_T$ regions, and we see big difference between two parametrization models. Therefore, measuring $A_{LL}^{\bar{\Lambda}^-}$ in larger $p_T$ regions is quite effective for testing the model of polarized PDF’s, since the ambiguity of the polarized fragmentation function becomes small.

4 Summary

In summary, to extract information about the polarized strange quark distribution in proton, the semi–inclusive $\Lambda^+_c/\bar{\Lambda}^+_c$ production in charged current DIS in unpolarized

\[ \lambda \] represent a degree of SU(3)$_f$ violation and is a parameter which should be determined from experiments [3].
lepton–polarized proton collisions was studied. $\bar{\Lambda}^+_c$ production is most promising not only for testing the parametrization models of PDF’s but also for directly extracting the polarized strange quark distribution $\Delta s(x)$ by measuring the double spin asymmetry $A_{LL}^{\Lambda_c^+}$.

![Graphs showing $p_T$ distribution of double spin asymmetries at $\sqrt{s} = 300$ GeV for $\Lambda_c^+$ production (left panel) and for $\bar{\Lambda}_c^+$ production (right panel).]

Figure 1: $p_T$ distribution of double spin asymmetries at $\sqrt{s} = 300$ GeV for $\Lambda_c^+$ production (left panel) and for $\bar{\Lambda}_c^+$ production (right panel).

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