$D$ Meson Production in Neutrino DIS as a Probe of Polarized Strange Quark Distribution

Kazutaka Sudoh

Radiation Laboratory, RIKEN (The Institute of Physical and Chemical Research), Wako, Saitama 351-0198, JAPAN
E-mail: sudou@rarfaxp.riken.go.jp

Abstract. Semi-inclusive $D\bar{D}$ productions in neutrino deep inelastic scattering are studied including $\mathcal{O}(\alpha_s)$ corrections. Supposing a future neutrino factory, cross sections and spin asymmetries in polarized processes are calculated by using various parametrization models of polarized parton distribution functions. It is found that $D$ production is promising to directly extract the strange quark distribution.

INTRODUCTION

Flavor structure of sea quark distributions has been actively studied in recent years. Most of parametrization models are assumed the flavor SU(3)$_f$ symmetry for the sea quark distributions. However, there is an attempt to include the violation of the SU(3)$_f$ symmetry [1]. Knowledge about the polarized sea quark distributions remains still poor.

A study of heavy flavor production in deep inelastic scattering (DIS) is one of the most promising ways to access the parton density in the nucleon. Since the heavy quark mass scale is quite larger than $\Lambda_{QCD}$, it is considered that we can treat heavy quarks purely perturbatively. Heavy quarks are produced only at the short distance scale within the framework of a fixed flavor number scheme (FFNS), where only light quarks ($u, d$, and $s$) and gluons are considered as active partons, and any heavy quarks ($c, b, ...$) contribution is calculated in fixed order $\alpha_s$ perturbation theory.

Charged current (CC) DIS is effective to extract the flavor decomposed polarized parton distribution function (PDF), since $W^\pm$ boson changes the flavor of parton. Since there is no intrinsic heavy flavor component in the FFNS, we can extract information about the parton flavor in the nucleon from the study of heavy flavor production in CC DIS. Actually, the NuTeV collaboration reported a measurement of unpolarized $s$ and $\bar{s}$ quark distributions by measuring dimuon cross sections in neutrino-DIS [2].

In this work, to extract information about the polarized PDFs we investigated $D\bar{D}$ meson production in CC DIS including $\mathcal{O}(\alpha_s)$ corrections in neutrino and polarized proton scattering; $\nu + \vec{p} \to l^- + D + X, \bar{\nu} + \vec{p} \to l^+ + \bar{D} + X$. The leading order process is due to $W$ boson exchange $W^+ s(d) \to c$. In addition, several processes are taken account of $\mathcal{O}(\alpha_s)$ next-to-leading order (NLO) calculations, in which gluon radiation processes $W^+ s(d) \to cg$, virtual corrections to remove singularity coming from soft gluon radiation, and boson-gluon fusion processes $W^+ g \to c\bar{s}(\bar{d})$ are considered. These processes might be observed in the forthcoming neutrino experiments.
CHARM PRODUCTION IN CC DIS

We have numerically calculated the spin-independent and -dependent cross sections, and the spin asymmetry $A^D$ which is defined by

$$A^D \equiv \frac{d\sigma(+) / dx - d\sigma(-) / dx}{d\sigma(+) / dx + d\sigma(-) / dx} = \frac{d\Delta\sigma / dx}{d\sigma / dx},$$

(1)

where $+$ and $-$ denote the helicity of the target proton. The spin-dependent cross section can be written in terms of the polarized structure functions $g_i$ as follows:

$$\frac{d^3\Delta\sigma^{vp}}{dx dy dz} = \frac{G_F^2 s}{2\pi(1 + Q^2/M_W^2)} \left[(1 - y)g_4^{W^+} + y^2 x g_3^{W^+} \pm y(1 - \frac{y}{2}) x g_1^{W^+}\right],$$

(2)

where $Q^2 = -q^2$ and $G_F, s, a, M_W$ denote the Fermi coupling, center of mass energy squared, and $W^\pm$ boson mass, respectively. Note that the $+$ and $-$ in front of the 3rd term correspond to when initial beam is anti-neutrino and neutrino, respectively. Kinematical variables $x$ and $y$ are Bjorken scaling variable and inelasticity defined according to the standard DIS kinematics, and $z$ is defined by $z = P_p \cdot P_D / P_p \cdot q$ with $P_p, P_D$ and $q$ being the momentum of proton, $D$ meson, and $W^\pm$ boson, respectively. The polarized structure functions $g_i$ in $\nu \bar{p}$ scattering are obtained by the following convolutions:

$$G_i(x, z, Q^2) = \Delta s'(\xi, \mu_F^2) D_c(z)$$

$$+ \frac{\alpha_s(\mu_R^2)}{2\pi} \int_\xi^1 \frac{d\xi'}{\xi'} \int_{\max(\zeta, \xi_{\min})}^{1} \frac{d\zeta}{\zeta} \left\{ \Delta H^q_i(\xi', \xi, \mu_F^2, \lambda, \Delta g_i) D_c(z) \right\} D_{c}(z),$$

(3)

where $\Delta s'$ means $|V_{cb}|^2 \Delta s + |V_{cd}|^2 \Delta d$ with CKM parameters. $\Delta H^{q,g}_i$ are coefficient functions of quarks and gluons, which can be calculated by using perturbative QCD. The argument $\xi$ is the slow rescaling parameter, and $\xi'$ and $\xi$ are the partonic scaling variables which are defined for the parton momentum $p_i$ as

$$\xi = \frac{Q^2}{2P_p \cdot q} \left(1 + \frac{m_c^2}{Q^2}\right), \; \xi' = \frac{Q^2}{2p_{s,g} \cdot q} \left(1 + \frac{m_c^2}{Q^2}\right), \; \zeta = \frac{p_{s,g} \cdot P_c}{p_{s,g} \cdot q}.$$  

(4)

$D_c(z)$ represents the fragmentation function of an outgoing charm quark decaying to $D$ meson. For the fragmentation function, we adopted the parametrization proposed by Peterson et al. [3] and recently developed by Kretzer et al. [4]. $G_i$ is related to the polarized structure functions through $G_i \equiv g_i/2, G_3 \equiv g_3$, and $G_4 \equiv g_4/2\xi$. Similar analyses have been done by Kretzer et al., in which charged current charm production at NLO in $ep$ and $\nu p$ scattering is discussed [5].

NUMERICAL RESULTS

In numerical calculations, we set a charm quark mass $m_c = 1.4$ GeV, an initial neutrino energy $E_\nu = 200$ GeV, and the factorization scale $\mu_F$ which is equal to the renor-
FIGURE 1. The spin-independent differential cross sections for the process $\nu \bar{p} \rightarrow l^- DX$ at $E_\nu = 200$ GeV as a function of $x$. We show the contribution from each diagram (left panel) and parametrization dependence of the unpolarized PDFs (right panel). Solid, dashed, and dotted lines in the left panel show the cross section in full NLO, full NLO with $g(x) = 0$, and LO calculation, respectively. Solid and dashed lines in the right panel represent the case of MRST99 and GRV98 parametrizations, and bold and normal lines are full NLO and LO cross sections, respectively.

We show the spin-independent differential cross section for $D$ meson production $\nu \bar{p} \rightarrow l^- DX$ in Fig. 1. The left panel in Fig. 1 represents the contribution to the cross section from each diagram. Solid, dashed, and dotted lines indicate the contribution from full NLO, full NLO with $g(x) = 0$, and LO diagrams to the $x$ differential cross section, respectively. Hence, the difference between the dashed and dotted lines comes from the gluon radiation process $W^+ s(d) \rightarrow cg$ and virtual corrections, while the difference between the solid and dashed lines comes from the boson-gluon fusion process ($W^+ g \rightarrow c\bar{s}(d)$). As shown in Fig. 1, the contribution from the NLO boson-gluon fusion process is considerably large. This is because the gluon distribution is sufficiently larger than the strange quark distribution, though the short distance matrix element in NLO is suppressed by the strong coupling constant $\alpha_s$.

Comparison of the cross section using MRST99 and GRV98 parametrization for the unpolarized PDFs is represented in the right panel in Fig. 1. The gap between two dashed lines stems from the difference of behavior of the unpolarized strange quark distribution, since only the strange quark distribution contributes to the cross section at the LO level. We found that the parametrization dependence is quite large. It is indicated that even the unpolarized PDFs still has large ambiguity, in spite of the analyses of unpolarized processes are investigated for a long time. Therefore, this reaction is effective to determine the unpolarized strange quark distribution, because the charm quark production in CC DIS using neutrino beams is sensitive to the strange density in the nucleon.

The spin-dependent cross section for $D$ meson production is presented in Fig. 2. We
show the comparison between LO (left panel) and full NLO (right panel) results with various parametrization models of the polarized PDFs. We see large contribution from NLO corrections and the parametrization model dependence of the polarized PDFs. As well as the unpolarized case, the cross sections are dominated by the LO process and boson-gluon fusion process at NLO. Contribution from the gluon radiation and virtual corrections are not significant in the cross sections.

Both the LO and full NLO results by the LSS parametrization are quite large compared with other parametrization. In the LSS parametrization, the polarized strange quark distribution has the peak at $x \sim 0.2$, whereas the polarized gluon distribution is not significant in this $x$ region. Therefore, the LO cross section becomes large, and the difference between the LO and full NLO cross sections is consequently small for the LSS parametrization. On the other hand, the NLO cross sections by GRSV and BB parametrizations are quite similar in whole $x$ regions, though we see some difference in the LO cross section.

We show the spin asymmetry $A^D$ in Fig. 3 as a function of $x$. Left panel and right panel in Fig. 3 represent asymmetries for $D$ production and $\bar{D}$ production, respectively. For $D$ production, $s$, $d$ quarks and gluon distribution contribute to the asymmetry $A^D$. $A^D$ is dominated by valence $d_v$ quark at large $x$ ($x > 0.3$), though the $d$ quark component is quite highly suppressed by CKM. On the contrary, for $\bar{D}$ production, $\bar{s}$, $\bar{d}$ quarks and gluon component contribute to the asymmetry $A^{\bar{D}}$. The $\bar{d}$ quark contribution is almost negligible. Therefore, the asymmetry is directly affected by the shape of the $\bar{s}$ quark distribution.

As shown in both figures, spin asymmetries strongly depend on parametrization models. We see that the case of the LSS parametrization is quite different from the ones of other parametrizations. In particular, the asymmetry by the LSS parametrization in $\bar{D}$ production goes over 1 at $x \sim 0.3$, though the asymmetry should be less than 1. This is because the polarized $s$ quark distribution in their parametrization extremely violates the positivity condition at $x \sim 0.3$. Measurement of $\bar{D}$ production in this reaction is effective to test the parametrization models of the polarized PDFs. In semi-inclusive DIS, we
have an additional ambiguity coming from the fragmentation function. However, the ambiguity can be neglected in the $x$ distribution of $A^D$, since the kinematical variable related to fragmentation is integrated out in this distribution.

**SUMMARY**

In summary, semi-inclusive $D/\bar{D}$ meson productions in CC DIS in neutrino-polarized proton scattering are discussed. The cross sections and the spin asymmetries are calculated including $\mathcal{O}(\alpha_s)$ corrections with various parametrization models of the polarized PDFs. The $\bar{D}$ production is promising to extract the sea quark density. This is not the case for the $D$ production because of the large $d_v$ contribution over the sea quark contribution. If the gluon polarization $\Delta g(x, Q^2)$ is fixed by RHIC experiments with high accuracy, we can directly extract the strange sea $\Delta s(x, Q^2)$.

**REFERENCES**