Polarized Parton Distribution in Neutrino Induced Heavy Flavor Production

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Abstract. In order to examine polarized strange quark distribution, semi–inclusive $D/\bar{D}$ production in neutrino deep inelastic scattering is studied including $\mathcal{O}(\alpha_s)$ corrections. Cross section and spin asymmetry are calculated by using various parametrizations of polarized parton distribution functions. It is found that $\bar{D}$ production is promising to directly extract the polarized strange sea.

1. Introduction

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. As is well known, the polarized parton distribution function (PDF) plays an important role in deep understandings of spin structure of the nucleon. However, knowledge about the polarized sea–quark and gluon distributions remain still poor, and theoretical and experimental ambiguities are rather large. In particular, flavor structure of the sea–quark distribution has been actively studied in these years. There are so far several parametrization models of sea–quark distributions. Though the simplest case is to assume the flavor $\mathrm{SU}(3)_f$ symmetry, a new parametrization including the violation of the $\mathrm{SU}(3)_f$ symmetrty has been also proposed [1]. In order to understand the spin structure of the nucleon, we need more information about the polarized sea–quark and gluon distribution functions.

Charged current (CC) DIS is effective to extract the flavor decomposed polarized PDFs, since $W^{\pm}$ boson changes the flavor of parton. Since there is no intrinsic heavy flavor component in the nucleon, we can extract information of 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.

2. Charm Production in CC DIS

We have numerically calculated the spin-dependent cross section and the spin asymmetry A^D which is defined by

$$A^D \equiv \frac{d\sigma(+)/dx - d\sigma(-)/dx}{d\sigma(+)/dx + d\sigma(-)/dx} = \frac{d\Delta\sigma/dx}{d\sigma/dx}, \tag{1}$$

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

$$\frac{d^3\Delta\sigma^{\nu p}}{dxdydz} = \frac{G_F^2 s}{2\pi(1+Q^2/M_W^2)^2}\left[(1-y)g_4^{W^\mp} + y^2 x g_3^{W^\mp} \pm y(1-\frac{y}{2})x g_1^{W^\mp}\right]. \tag{2}$$

The $+$ and $-$ in front of the 3rd term correspond to when initial beam is neutrino and anti-neutrino, respectively. Kinematical variables x and y are Bjorken scaling variable and inelasticity, respectively, 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 photon, respectively. The polarized structure functions g_i in $\nu\vec{p}$ scattering are obtained by the following convolutions:

$$\begin{aligned}\mathcal{G}_i^c(x,z,Q^2) &= \Delta s'(\xi,\mu_F^2)D_c(z) \\ &+ \frac{\alpha_s(\mu_R^2)}{2\pi}\int_\xi^1 \frac{d\xi'}{\xi'}\int_{\max(z,\zeta_{\min})}^1 \frac{d\zeta}{\zeta}\left\{\Delta H_i^q(\xi',\zeta,\mu_F^2,\lambda)\Delta s'(\frac{\xi}{\xi'},\mu_F^2)\right. \\ &\left. + \Delta H_i^g(\xi',\zeta,\mu_F^2,\lambda)\Delta g(\frac{\xi}{\xi'},\mu_F^2)\right\} D_c(\frac{z}{\zeta}),\end{aligned} \tag{3}$$

where $\Delta s'$ means $\Delta s' \equiv |V_{cs}|^2\Delta s + |V_{cd}|^2\Delta d$ with CKM parameters. $\Delta H_i^{q,g}$ are coefficient functions of quarks and gluons, which can be calculated by using perturbative QCD. $D_c(z)$ represents the fragmentation function of an outgoing charm quark decaying to D meson, and we adopted the parametrization proposed by Peterson *et al.* [3]. $\mathcal{G}_i$ is related to the polarized structure functions through $\mathcal{G}_1 \equiv g_1/2$, $\mathcal{G}_3 \equiv -g_3$, and $\mathcal{G}_4 \equiv -g_4/2\xi$. Similar analyses have been done by Kretzer *et al.*, in which charged current charm production at NLO in ep and νp scattering is discussed [4].

3. Numerical Results

In numerical calculations, we used the GRV98[5] and MRST99[6] parametrizations as the unpolarized PDFs. As for the polarized PDFs, we adopted the AAC00[7], BB02[8], GRSV01[9], and LSS02[10] parametrizations which are now widely used.

We show the spin asymmetry A^D in Fig. 1 as a function of x at initial neutrino beam energy $E_\nu = 200$ GeV. Left panel and right panel in Fig. 1 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^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

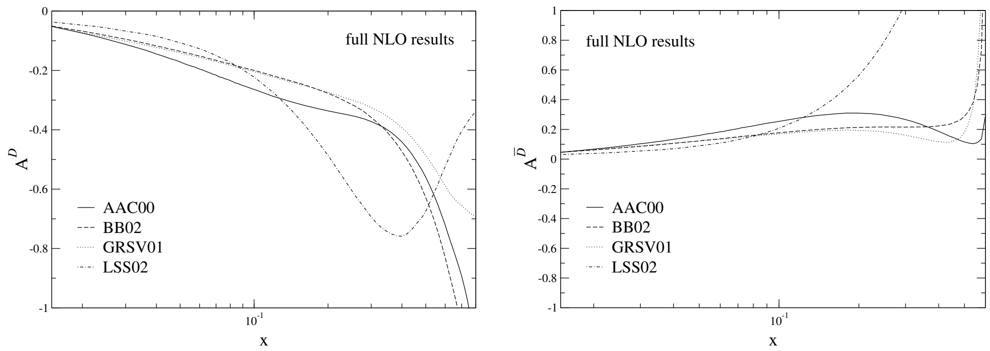

Figure 1. x distribution of spin asymmetries in NLO at $E_\nu = 200$ GeV for D production (left panel) and $\bar{D}$ production (right panel). Solid, dashed, dotted, and dot-dashed lines show the case of AAC00 set-2, BB02 scenario-2, GRSV01 standard set, and LSS02 $\overline{\mathrm{MS}}$ parametrizations, respectively.

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 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.

4. Summary

In summary, semi-inclusive $D/\bar{D}$ meson production in CC DIS in neutrino–polarized proton scattering is discussed. The cross sections and the spin asymmetries are calculated including $\mathcal{O}(\alpha_s)$ corrections with various parametrization models of polarized PDFs. The $\bar{D}$ production is promising to examine 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 $\Delta s(x, Q^2)$.

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