

Probing nucleon strange asymmetry from charm production in neutrino deep inelastic scattering

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Abstract. We propose a means to detect the nucleon strange quark-antiquark asymmetry, which is predicted as a non-perturbative effect, but still unchecked directly by available experiments. The difference for the $D(\bar{c}c)$ and $\pi^0$ meson production cross sections in neutrino and antineutrino induced charged current deep inelastic scattering is illustrated to be sensitive to the nucleon strange asymmetry. Prospect is given and the effect due to the light quark fragmentation is also discussed for the extraction of the strange asymmetry in future experiments.

1 Introduction

Nucleon structure is a natural laboratory to understand QCD and is worth to study for its own sake. The nucleon strange quark-antiquark asymmetry is an interesting feature predicted as a natural consequence of the non-perturbative aspect of the nucleon. Recently, the nucleon strange asymmetry has been suggested as a promising mechanism to explain the NuTeV anomaly within the framework of Standard Model.

While the experimental evidence for such an asymmetry is still inconclusive, there are some approaches such as the global analysis of deep inelastic scattering (DIS) data, which show a favor for an asymmetric strange sea, in agreement qualitatively with the intrinsic sea theory. On the other hand, the CCFR next-to-leading-order (NLO) analysis of the neutrino induced dimuon production result favors a symmetric strange sea. It seems that more precise and dedicated research is needed to address the problem in a clear way.

The measurement of the strange quark distribution relies on charged current (CC) DIS processes. One method is through parity violating structure functions for isoscalar target in CC DIS: $F_2^\nu - F_2^\bar{\nu} = 2[s(x) + \bar{s}(x) - c(x) - \bar{c}(x)]$, which gives the total distribution of the strange sea. Another way is through the combination of CC parity conserving structure function $F_2^\nu$ with the charged lepton DIS structure function $F_{2\mu}^\nu$, for isoscalar target, $\frac{1}{2}F_2^\nu - 3F_{2\mu}^\nu = x[\frac{1}{2}s(x) - \frac{1}{2}\bar{s}(x) - c(x)]$. Such an idea has been applied using high statistic neutrino and charged lepton DIS data, and the result at low $x$ shows a sizable disagreement with the direct measurement from the CCFR dimuon result [15]. The extraction of a small quantity from the difference of two large quantities may suffer from systematic uncertainties, which also seems to be the case for the extraction of the strange asymmetry by CC parity conserving structure functions: $F_2^\nu - F_2^\bar{\nu} = 2x[s(x) - \bar{s}(x)]$.

A method free from the above drawback is to use the charged current charm production process, which is the main idea of the CCFR and NuTeV dimuon experiments [13,16,17], with its leading order (LO) subprocesses being $\nu_\mu s \to \mu^- c$ and $\nu_\mu d \to \mu^- c$. The latter subprocess is Cabibbo suppressed, thus the charm production in $\nu$-induced process is most sensitive to the strange quark distribution in the nucleon. Similarly, the anticharm production in $\bar{\tau}$-induced process is sensitive to the antistrange quark distribution, as the corresponding partner subprocesses are $\bar{\tau}_\mu\bar{\tau} \to \mu^+ \bar{\tau}$ and $\bar{\tau}_\mu\bar{d} \to \mu^+ \bar{\tau}$, with the latter subprocess being Cabibbo suppressed.

The oppositely charged dimuon signature is easy to identify and measure in massive detectors, which allow for the collection of high statistics data samples, e.g., the CCFR experiment has a sample of data with 5030 $\nu_\mu$ induced events and 1060 $\bar{\nu}_\mu$ induced events, and the NuTeV has 5102 $\nu_\mu$ induced events and 1458 $\bar{\nu}_\mu$ induced events [17]. However, these two experiments neither show strong support for an asymmetric strange sea, nor can they rule it out [15,12]. There are uncertainties in the estimation of the semi-monic decay of the charmed hadrons [13], e.g., the average semi-leptonic branching ratio for $\nu$ and $\bar{\nu}$ induced events was only constrained by $\frac{\bar{\tau}_\mu\bar{d}}{\tau_\mu\bar{d}} = 0.0114 \pm 0.011 \sim 0 - 20\%$ [13]. Besides, the interplay of strange...
asymmetry and the light quark fragmentation (LQF) effect, as will be discussed in section 4, can only be drawn more clearly in inclusive measurement of charged and neutral charm productions. Thus a direct measurement of charmed hadrons produced in \( \nu \) and \( \bar{\nu} \) induced CC DIS will provide more valuable information to probe the \( s \) and \( \bar{s} \) distributions of the nucleon. It is the purpose of this work to show that inclusive charm productions in neutrino and antineutrino induced CC DIS processes will be a promising way to detect the strange quark-antiquark asymmetry.

2 Charged current charm production

The differential cross section for charmed hadron \( H^+ \) production in neutrino induced CC DIS can be factorized as

\[
\frac{d^3\sigma_{\nu,N \rightarrow H^+X}}{d\xi dy dz} = \sum_q \frac{d^2\sigma_{\nu,N \rightarrow qX}}{d\xi dy} D_q^{H^+}(z),
\]

where the function \( D_{q}^{H^+}(z) \) describes the fragmentation of a quark \( q \) into the charmed hadron \( H^+ \), with \( z \) being the momentum fraction of the quark \( q \) carried by the produced hadron \( H^+ \). For the purpose of this article, the charged hadron \( H^+ \) is taken to be \( D^+ (c\bar{c}) \) or \( D^0 (c\bar{c}) \) meson, with \( H^− \) denoting its antiparticle \( D^- (\bar{c}d) \) or \( \bar{D}^0 (\bar{c}d) \).

It is generally believed that the possibility for light quark fragmentation into charmed hadrons is very small. For example, the Lund string model implemented in some popular Monte Carlo programs predicts a suppression proportional to \( \exp(-bm_\xi^2) \) for \( q\bar{q} \) production in the process of hadronization [19]. With a knowledge of the strange suppression \( \lambda \sim 0.3 \) [20,21], the suppression for charm will be lower than \( 10^{-4} \), which can be safely neglected.

In this case, at leading order, only the \( \nu_\mu s \rightarrow c\mu^- \) and \( \nu_\mu d \rightarrow c\mu^- \) subprocesses contribute to charmed hadron production for isoscalar target and neglecting target mass effects, the leading order differential cross section for charm production is given by [14,16]:

\[
\frac{d^3\sigma_{\nu_\mu,N \rightarrow \mu^- cX}}{d\xi dy} = \frac{2G^2M\nu_\mu}{\pi(1 + Q^2/M_W^2)^2} \left(1 - \frac{m_c^2}{2M\nu_\mu \xi} \right) \times \xi \left[ \frac{d(\xi) + u(\xi)}{2} |V_{cd}|^2 + s(\xi)|V_{cs}|^2 \right],
\]

where \( \xi \) is the momentum fraction of the struck quark in the infinite momentum frame. It is introduced with the consideration of a non-negligible charm quark mass, and is related to Bjorken scaling variable \( x \) through (neglecting light quark mass): \( \xi \approx x(1 + m_c^2/Q^2) \), referred to as slow-rescaling. The term \( (1 - m_c^2/2M\nu_\mu \xi) \) in Eq. 2 is introduced as an energy threshold for charm production and is supported by experiments [22].

3 Probing the nucleon strange asymmetry

The differential cross sections for charmed hadrons, namely, \( H^+ (D^+ or D^0) \) and \( H^- (D^- or \bar{D}^0) \), produced in \( \nu \) and \( \bar{\nu} \) induced CC DIS respectively, are closely related to the \( s \) and \( \bar{s} \) distributions of the nucleon, and their difference, as can be seen in the following, is quite sensitive to the nucleon strange asymmetry.

Neglecting the light quark fragmentation effect, and using Eq. 2 and its corresponding partner process for \( \bar{\nu} \) production \( \bar{\nu}_N \rightarrow \bar{c}\mu^X \), we can write the difference between \( H^+ \) and \( H^- \) production cross sections in CC DIS:

\[
f_{H^+} - f_{H^-} = \frac{d^3\sigma_{\nu_\mu,N \rightarrow H^+X}}{d\xi dy dz} - \frac{d^3\sigma_{\nu_\mu,N \rightarrow H^{-}X}}{d\xi dy dz} = \frac{2G^2M\nu_\mu}{\pi(1 + Q^2/M_W^2)^2} \left(1 - \frac{m_c^2}{2M\nu_\mu \xi} \right) \times \left\{ \frac{1}{2} \xi [d_c(\xi) + u_c(\xi)] |V_{cd}|^2 + \xi [s(\xi) - \bar{s}(\xi)] |V_{cs}|^2 \right\} D_c^{H^+}(z),
\]

where charge symmetry \( D_c^{H^+}(z) = D_c^{H^-}(z) \) for fragmentation process is assumed, and \( u_c(\xi) \equiv u(\xi) - \bar{s}(\xi) \) and \( d_c(\xi) \equiv d(\xi) - \bar{d}(\xi) \) are valence quark distributions of the proton.

From Eq. 3, one sees that two terms, \( \xi |d_c(\xi) + u_c(\xi)| \) and \( \xi |s(\xi) - \bar{s}(\xi)| \), contribute to the cross section difference \( f_{H^+} - f_{H^-} \), with \( |V_{cd}|^2 \approx 0.05 \) and \( |V_{cs}|^2 \approx 0.95 \) [23] being their respective weights. The strange asymmetric part of Eq. 3 can be estimated from an integral on variable \( \xi \), to contribute a fraction

\[
P_{3A} \approx \frac{2S^-|V_{cd}|^2}{Q_V |V_{cd}|^2 + 2S^- |V_{cs}|^2},
\]

to the integral of the cross section difference \( \int d\xi \{f_{H^+} - f_{H^-}\} \). Here, \( S^- \) and \( Q_V \) are defined as \( S^- \equiv \int \xi |s(\xi) - \bar{s}(\xi)| d\xi \) and \( Q_V \equiv \int \xi |d_c(\xi) + u_c(\xi)| d\xi \).

In Table 1, results of the strange asymmetry from some models accounting for the NuTeV anomaly are listed, together with our estimations of the contributions due to strange asymmetry to the the cross section difference \( f_{H^+} - f_{H^-} \), namely, the \( \xi \) integrated fraction \( P_{3A} \).

As shown in Table 1, from the model calculations [17,18,19] that can explain the NuTeV anomaly, the strange asymmetry contributes a sizable proportion (12% ~ 40%) to the cross section difference. Note that the distribution functions \( \xi |d_c(\xi) + u_c(\xi)| \) and \( \xi |s(\xi) - \bar{s}(\xi)| \) may evolve with \( Q^2 \), turning flatter and shifting towards smaller \( \xi \) region as \( Q^2 \) increases. However, their relative feature will remain and the proportion of \( S^- \) to \( Q_V \), will be of the same order in larger \( Q^2 \) and in \( Q^2_0 \). Thus, as to their relative feature, it does not matter much whether the parton distributions are taken at \( Q^2_0 \) or at larger \( Q^2 \). Since the peak of \( \xi |s(\xi) - \bar{s}(\xi)| \) is confined in narrower \( \xi \) region than \( \xi |d_c(\xi) + u_c(\xi)| \), its contribution is expected to be more prominent than the integrated one in Table 1. Thus it is promising to measure the strange quark-antiquark asymmetry from \( f_{H^+} - f_{H^-} \).

Compared to the sum of the cross sections \( f_{H^+} + f_{H^-} \), the cross section difference \( f_{H^+} - f_{H^-} \) is not a very small
quantity, as can be seen from the ratio of their integrals,
\[
R = \frac{\int d\xi (f_{H^+} - f_{H^-})}{\int d\xi (f_{H^+} + f_{H^-})} \approx \frac{Q_V |V_{cd}|^2 + 2S^- |V_{cs}|^2}{(Q_V + 2Q_S)|V_{cd}|^2 + 2S^+ |V_{cs}|^2},
\]
where \(Q_S \equiv \int \xi (\overline{\Psi}(\xi) + \Psi(\xi))d\xi\) and \(S^+ = \int \xi [s(\xi) + \overline{s}(\xi)]d\xi\). With a calculation of the \(Q_V\), \(Q_S\) and \(S^+\) from CTEQ5 parametrization at \(Q^2 = 16\text{GeV}^2\), together with \(|V_{cd}|^2 = 0.05\) and \(|V_{cs}|^2 = 0.95\), the ratio \(R\) is estimated to be about 20% (25%) for 2S^-/QV being 0.007 (0.022) from Table 1. Thus the cross section difference \(f_{H^+} - f_{H^-}\) is a significant quantity that can be extracted from the semi-inclusive differential cross sections.

Neutrino experiment with emulsion target, like the CHORUS detector, is ideal for the study of charmed hadron production. Compared to dimuon studies, it has a much lower level of background and is free from the uncertainties that exist in charm muonic weak decay processes [15]. And for statistics, CHORUS reported in total about 94000 neutrino CC events located and fully reconstructed, in which about 2000 charm events were observed [24]. This has been compatible with dimuon statistics. If such (or higher) statistics can be achieved with both neutrino and antineutrino beams of high energies in future experiments, the question about strange asymmetry is promising to be settled.

### 4 Light quark fragmentation

The possibility that a light quark fragments into charmed hadrons (associated charm production) can be an interesting effect of non-perturbative QCD, and it has been explored [26] to explain the unexpected high rate of like-sign dimuons production from many neutrino experiments [27, 28, 29]. Although the field has been inactive for years, and in practice people generally assume the light quark fragmentation (LQF) to be negligible, the physical possibility of a small contribution is not ruled out. In fact, as to our consideration, neutrino experiments can be slightly different from \(e^+e^-\) experiments in this respect. The scattered light quark with high momentum can pick up a charm quark or antiquark from nucleon sea to form a \(D\) meson, and the larger the energy of the light quark, the more the ability that it can pick up a charm from the sea. This energy dependence is apparent in prompt like-sign dimuons production rates in many experiments [27, 28, 29]. Since the scattered quark has most of the energy in the collision, it is much more promising to pick up the charm quark from nucleon sea than other produced quarks in fragmentation process. Thus as to our consideration such fragmentation as \(u \rightarrow \overline{D}^0(\tau_u), d \rightarrow D^- (\tau_d)\) can possibly be non-negligible in high energy neutrino experiments.

In case that light quark can fragment into charmed hadrons, the process can manifest itself in a number of observables, such as the prompt like-sign dilepton and triton production in high energy neutrino experiments [30]. Direct observations of two charmed hadrons in nuclear emulsion target [31], and charm production in hadron collisions [32, 33]. Among these, the prompt like-sign dimuon productions have been the most seriously studied and we will use some of the data for a quantitative estimate of light quark fragmentation function and its influence on the extraction of strange asymmetry from CC charm production processes.

Prompt like-sign dimuons \((\mu^+\mu^-)\) can be produced through the process: \(\nu + d \rightarrow u + \mu^+\), with the scattered \(u\) to fragment into \(D^0(\tau_u)\) or \(D^0(\tau_u)\) meson. Its differential cross section can be expressed as:
\[
d^3\sigma_{\nu N \rightarrow \mu^+\mu^- X}/dxdydz = \frac{2G^2 M_E\nu |V_{ud}|^2}{\pi(1 + Q^2/M_W^2)^2} \frac{u(x) + d(x)}{2} D_\nu(z) B_{D^0} \tag{6}
\]
where \(D_\nu(z)\) is the total fragmentation function for a light quark to fragment into charmed hadrons, defined as \(D_\nu(z) = D^P(z) + D^\tau(z)\), with \(D^P(z) = D^P(\tau_d) = D^P(\tau_u) = \frac{D^P(\tau_u) - D^P(\tau_d)}{2}\) simply assumed. Note here that \(D_\nu(z)\) is energy dependent in analogous to containing an energy suppression factor for charm production. \(B_{D^0}\) is the inclusive muonic decay ratio for \(D^0\) meson decay into \(\mu^- X\), which is the same for \(D^0\) meson, since all \(D^0\) will decay into \(\overline{D}^0\) at first.

Similarly, the differential cross section for prompt \(\mu^+\mu^+\) production in \(\tau\) induced DIS on isoscalar target is
\[
d^3\sigma_{\tau N \rightarrow \mu^+\mu^+ X}/dxdydz = \frac{2G^2 M_E\nu |V_{ud}|^2}{\pi(1 + Q^2/M_W^2)^2} \frac{\pi(x) + \overline{d}(x)}{2} D_\tau(z) B_{D^0} \tag{7}
\]

Many experimental groups have reported positive results on prompt like-sign dimuon production. Among them the CDHSW [27] and CCFR [28] data have a high precision and show much consistency with each other. Another high precision experiment CHARM [29], which has reported a much higher \(\mu^-\mu^-\) production rate, received doubts on their estimate of \(\pi/K\) decay background [27].

Besides, their kinematic cut \(p_\mu > 4\text{ GeV}\), which is lower than other experiments (\(p_\mu > 9\text{ GeV}\), can permit more

### Table 1. Contributions of \(s/\overline{t}\) asymmetry to NuTeV anomaly and to \(f_{H^+} - f_{H^-}\)

| Models        | \(Q^2\) | To NuTeV anomaly | \(2S^-/QV\) | To \(f_{H^+} - f_{H^-}\) |
|---------------|---------|------------------|-------------|-------------------|
| Ding-Ma [5]   | \(Q^2\) | 30% \(-80\%)     | 0.007 \(\sim\) 0.018 | 12% \(\sim\) 26%   |
| Alwall-Ingelman [7] | 20 GeV^2 | 30%             | 0.009       | 15%               |
| Ding-Xu-Ma [8] | \(Q^2\) | 60% \(-100\%)    | 0.014 \(\sim\) 0.022 | 21% \(\sim\) 29%   |
| Wakamatsu [9] | 16 GeV^2 | 70% \(-110\%)    | 0.022 \(\sim\) 0.035 | 30% \(\sim\) 40%   |
is needed. Remember that $\sigma_{\mu^-\mu^-}$ is the charm suppression factor. To illustrate this, we will compare the contribution of LQF effect with that of strange asymmetry on the difference between $\nu$ and $\bar{\nu}$ induced DIS. As mentioned previously, these data are less influenced by kinematic cut and thus are better suited for the extraction of the LQF effect. The prompt dimuon rates from CDHSW with visible energy $E_{\text{vis}}$ in range $100 \sim 200$ GeV are listed in Table 2.

As can be seen from Table 2, the prompt dimuon rates $\sigma_{\mu^-\mu^-}/\sigma_{\mu^+\mu^+}$ still show a slight dependence on kinematic cut, though much smaller than the $\sigma_{\mu^-\mu^-}/\sigma_{\mu^+\mu^+}$ data do. Thus we can only estimate the order of magnitude for the LQF effect with the reported data.

The rate $\sigma_{\mu^-\mu^-}/\sigma_{\mu^+\mu^+}$ (without any kinematic cut) can be deduced by Eq. (8) and Eq. (9) with an integral on kinematic variables to approximate

$$\frac{\sigma_{\mu^-\mu^-}}{\sigma_{\mu^+\mu^+}} \approx \frac{Q_{\text{ud}}|V_{\text{ud}}|^2}{Q_{\text{ud}}|V_{\text{ud}}|^2 + S|V_{\text{cs}}|^2} \frac{D_{q}B_{D^0}}{f_c B_{D^0}}.$$  

With the measured $B_{D^0} \approx 6.87\%$ and $B_{\bar{D}^0} \approx 8.8%$, together with $Q_{\text{ud}}$ and $S$ from CTEQ5 at $Q^2 = 16$ GeV$^2$,

$$\frac{D_{\bar{q}}}{f_c} \approx 0.199 \frac{\sigma_{\mu^-\mu^-}}{\sigma_{\mu^+\mu^+}}.$$  

With the experimental data on $\sigma_{\mu^-\mu^-}/\sigma_{\mu^+\mu^+}$ from Table 2, one can easily estimate $D_{q}/f_c$ by Eq. (13).

Since we are most interested in the strange quark-antiquark asymmetry here, we will directly address the influence of LQF effect on the extraction of strange asymmetry. Because LQF effect contributes differently for $\nu$ induced $\mu^-\mu^+$ production and for $\bar{\nu}$ induced $\mu^-\mu^-$ production, it will give different corrections to $s$ and $\bar{s}$ distributions, and thus influence the measurement of strange asymmetry from opposite-sign dimuon method. To illustrate this, we will compare the contribution of LQF effect with that of strange asymmetry on the difference between $\nu$ and $\bar{\nu}$ induced opposite-sign dimuon production cross sections. The latter (strange asymmetry contribution) can be drawn from model predictions in the last column of Table 1, when assuming the average muonic branching ratio of charmed hadrons to be the same for $\nu$ and $\bar{\nu}$ induced CC DIS $\overline{B}_c(\frac{z}{x})$. The former (LQF contribution) can be deduced from Eq. (8)-Eq. (11) with an assumption $\overline{B}_{D^{(*)+}} = \overline{B}_{D^{(*)-}}$, and be compared to the strange asymmetry part with an integral on kinematic variables. The fraction of the LQF contribution is

$$P_{\text{LQF}} = \frac{\delta(\sigma_{\mu^-\mu^-} - \sigma_{\mu^+\mu^+}) |\overline{B}_{D^{(*)+}}|}{(\sigma_{\mu^-\mu^-} - \sigma_{\mu^+\mu^+})_{\text{total}}} \approx -\frac{\frac{1}{2}Q_V|V_{\text{ud}}|^2}{Q_V|V_{\text{ud}}|^2 + 2S|V_{\text{cs}}|^2} \frac{D_{q}B_{D^{(*)+}}}{f_c B_{D^{(*)+}}}.$$  

To assess $P_{\text{LQF}}$, the value of $\overline{B}_{D^{(*)+}}$ is needed. Remember that $\overline{B}_{D^{(*)+}} = bBB_{D^0} + (1-b)BB_{D^+}$, with $b \equiv D^0/D$. The unknown $b$ is the fraction of vector $D^*$ meson in light quark fragmentation. When we set $b$ to be $1/3 \sim 2/3$, and
Table 2. Prompt dimuon rates for 100 < $E_{\text{vis}}$ < 200 GeV \[27\]

| $p_{\mu}$ > 6 GeV | $\sigma_{\mu^-}/\sigma_{\mu^+}$ | $\sigma_{\mu^-}/\sigma_{\mu^+}$ | $\sigma_{\mu^+}/\sigma_{\mu^-}$ | $\sigma_{\mu^+}/\sigma_{\mu^-}$ |
|-------------------|-----------------|-----------------|-----------------|-----------------|
| 6.3 ± 1.6%        | 1.6 ± 0.74%     | 4.5 ± 2.0%      | 2.2 ± 1.0%      |
| 9.1 ± 1.2%        | 1.05 ± 0.43%    | 4.4 ± 1.8%      | 1.7 ± 0.7%      |
| 15.0 ± 1.3%       | 0.52 ± 0.22%    | 4.1 ± 2.3%      | 0.8 ± 0.45%     |

Thus, we get an estimate of the LQF contribution to be a few percent compared to strange asymmetry contribution $P_{\text{SA}}$: 12% ~ 40%. However, the constraint of $P_{\text{LQF}}$ can be also done with $\sigma_{\mu^+}/\sigma_{\mu^-}$ data, and the result is $P'_{\text{LQF}} = (-33.19\pm 1.6\%)$, which is very large compared to result from the $\sigma_{\mu^-}/\sigma_{\mu^+}$ data. This large discrepancy is difficult to explain at present, and may imply an uncertainty in the estimate of the LQF contribution in the opposite-sign dimuon measurements of strange asymmetry.

From the sign and size of $P_{\text{LQF}}$, one sees that the LQF effect contributes oppositely to the predicted strange asymmetry contribution on the whole, with a rate that could be non-negligible in opposite-sign dimuon experiments.

The LQF effect also exists in the process of inclusive charm productions that we suggest. For D ± production, the cross section difference, $f_D^+ - f_D^-$, for $\nu$ and $\bar{\nu}$ induced CC DIS will include an additional term from light quark fragmentation:

$$
\delta(f_D^+ - f_D^-)_{\text{LQF}} = \frac{-2G^2M_E|V_{ud}|^2}{\pi(1 + Q^2/M_W^2)}D_q(z)(1 - \varepsilon) \times \left[ \frac{d_u(x) + u_u(x)}{2} \right] (1 - y)^2,
$$

where $\varepsilon = Bb$ is introduced with the consideration that part of $D^+(D^-)$ will decay into $D^0(T^0)$ and will not contribute to the cross sections.

For neutral charm production, LQF contributes to $T^0$ production in $\nu$ induced CC DIS ($\nu + d \rightarrow \mu^- + u, u \rightarrow T^0(\mp))$, and to $D^0$ production in $\bar{\nu}$ induced CC DIS. In case that $D^0$ and $T^0$ are not distinguished by emulsion target, the $T^0(D^0)$ production in $\nu$ ($\bar{\nu}$) induced CC DIS from LQF will be incorporated to $D^0(D^0)$ production in $\nu(\bar{\nu})$ induced CC DIS. Thus an additional term from LQF will contribute to $f_D^0 - f_D^0$ via:

$$
\delta(f_D^0 - f_D^0)_{\text{LQF}} = \frac{-2G^2M_E|V_{ud}|^2}{\pi(1 + Q^2/M_W^2)}D_q(z)(1 - \varepsilon') \times \left[ \frac{d_u(x) + u_u(x)}{2} \right],
$$

where $\varepsilon' = (1 - y)^2Bb$, which is introduced from $\bar{d}(d)$ fragmentation into $D^{*+}(D^{*-})$ mesons that then decay into $D^0(T^0)$ and contribute to cross section difference $f_D^0 - f_D^0$.

The proportion of LQF contribution to inclusive charm production cross section difference $f_{H^+} - f_{H^-}$, namely $P_{\text{LQF}}^{H^\pm}$, can be estimated similarly to that of dimuon productions. With an integral on kinematical variables of Eq. 13, Eq. 14, Eq. 15, and using charm production fractions $\int D^0(z)dz \approx 0.26$ and $\int D^0(z)dz \approx 0.66$ for $E_\nu > 80$ GeV \[25\], $P_{\text{LQF}}^{H^\pm}$ is estimated (in unites of $P_{\text{LQF}}$) to be:

$P_{\text{LQF}}^{D^\pm} \approx 1.6P_{\text{LQF}}$ for $D^\pm$ meson productions, and $P_{\text{LQF}}^{D^0} \approx -2.6P_{\text{LQF}}$ for $D^0, T^0$ meson productions.

If the LQF contribution $P_{\text{LQF}}$ in opposite-sign dimuons measurement is in the order of a few percent percent and opposite to strange asymmetry production $P_{\text{SA}}$: 12% ~ 40%, just as we have estimated, the LQF will contribute to inclusive charm production with a larger proportion (in the order of about ten percent or even larger). For inclusive $D^\pm$ production, LQF contributes oppositely compared to strange asymmetry when $x(s(x) > 0$. On the other hand, for inclusive CC neutral charm ($D^0(T^0)$) production, LQF contributes positively compared to strange asymmetry when $x(s(x) > 0$. A separation of the LQF effect and the strange asymmetry effect can be made from the distinct features of $f_D^+ - f_D^-$ and $f_D^0 - f_D^0$ measured by nuclear emulsion target. Thus, the inclusive measurement of charged and neutral charm production in $\nu$ and $\bar{\nu}$ induced CC DIS will shed light on both the strange asymmetry and the LQF effect.

Dedicated analysis of charm productions in neutrino experiments and in other processes will be helpful for a more precise estimate and constraint for the light quark fragmentation effect.

5 Conclusions

For probing the nucleon strange asymmetry, we analyzed the charged current charm production processes, in particular, the $\nu_\mu$ induced $H^+ (D^+ or D^0)$ production and the $\bar{\nu}_\mu$ induced $H^- (D^- or \bar{T}^0)$ production processes. The strange asymmetry from various model calculations that can explain the NuTeV anomaly is shown in general to contribute a sizable proportion (12% ~ 40%) to the $H^\pm$ differential cross section difference $f_{H^+} - f_{H^-}$. Thus, measurement of these cross sections with high energy neutrino and antineutrino beams on nuclear emulsion target is very
promising to detect the strange quark-antiquark asymmetry.

Meanwhile, we analyzed the possible light quark fragmentation (LQF) effect from prompt like-sign dimuon data and studied its influence on the measurement of strange asymmetry. Our result is that the LQF may be an important source that reduces the effect of strange asymmetry from opposite sign dimuon studies. And for inclusive charged current (CC) charm production with emulsion target, since the contributions of LQF are in opposite directions for \( D^\pm \) and for \( D^0 \) (\( \bar{D}^0 \)) productions, a separation of the LQF effect from strange asymmetry effect can be made by the separate measurement of \( D^\pm \) and neutral charm differential cross sections in CC DIS. Thus the inclusive measurement of charmed hadrons can shed light on both strange asymmetry and the LQF effect. Further analysis and constraint for LQF effect from various experiments will also be helpful for the purpose of measuring the strange asymmetry more reliably.

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