The leading particle effect from light quark fragmentation in charm hadroproduction

Puze Gao\textsuperscript{1,2} and Bo-Qiang Ma\textsuperscript{3,1,a}

\textsuperscript{1} Department of Physics, Peking University, Beijing 100871, China
\textsuperscript{2} Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100080, China
\textsuperscript{3} CCAST (World Laboratory), P.O. Box 8730, Beijing 100080, China

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Abstract. The asymmetry of $D^-$ and $D^+$ meson production in $\pi^- N$ scattering observed by the E791 experiment is a typical phenomenon known as the leading particle effect in charm hadroproduction. We show that the phenomenon can be explained by the effect of light quark fragmentation into charmed hadrons (LQF). Meanwhile, the size of the LQF effect is estimated from data of the E791 experiment. A comparison is made with the estimate of the LQF effect from prompt like-sign dimuon rate in neutrino experiments. The influence of the LQF effect on the measurement of nucleon strange distribution asymmetry from charged current charm production processes is briefly discussed.

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1 Introduction

The leading particle effect in charm hadroproduction has been observed by many experiments \cite{1,2,3,4,5}. The main feature of this effect is the enhancement in the production of the charmed hadrons that carry the same valence flavor of the incident hadron in the forward region, i.e., at positive $x_F$, where $x_F$ is the Feynman variable for the produced hadron, $x_F \equiv P_F^\ast/P_{max}^\ast$, with $P_F^\ast$ being the momentum along the beam direction in the c.m. frame of the colliding hadrons. The result of the E791 experiment \cite{3} is a typical example of such phenomenon with high statistics. In the E791 experiment, a 500 GeV $\pi^- (\bar{u}d)$ beam is incident on a fixed target, and an obvious excess of $D^- (\bar{c}d)$ (having the same valence flavor $d$ with $\pi^-)$ over $D^+(\bar{c}d)$ has been observed. The asymmetry variable

\[ A \equiv \frac{d\sigma(D^-) - d\sigma(D^+)}{d\sigma(D^-) + d\sigma(D^+)} \]  \hspace{1cm} (1)

vs. $x_F$ and $P_T^2$ is used to describe the effect, and a clear rise of the asymmetry $A$ with $x_F$ has been observed.

On the theoretical side, because perturbative QCD (PQCD) predicts no asymmetry at leading order (LO) and very small asymmetry at next to leading order (NLO) for charm and anti-charm quark productions \cite{9,11}, the observed asymmetry is generally attributed to the hadronization processes. The “beam drag effect” \cite{8} implemented in the PYTHIA Monte Carlo explains the asymmetry through the color strings between the produced charmed quarks and the beam remnants that moving in the same general direction. The charged hadron produced through the decay/collapse of the low mass string may have more energy than the original charmed quark through the pull of the fast beam remnants. By adjusting some parameters of the model, they can reproduce the observed asymmetry. Another explanation is the intrinsic charm coalescence model \cite{9}, in which an intrinsic charm quark of the projectile combines a valence quark of similar rapidity to form the charmed leading particle. However, this model predicts much smaller asymmetry than what is observed experimentally. A further work is the heavy quark recombination model \cite{10}, in which a produced heavy (anti)quark recombines a light parton of similar velocity that participates in the hard scattering process. The work employs a simple PQCD $O(\alpha_s^3)$ picture and describes the high $x_F$ and $P_T^2$ distributions of the asymmetry very well. There are still other works of quark recombination and quark-gluon string model \cite{11,12}.

Although so much work has been done, we should still explore other possibilities. As first promoted by Dias de Deus and Duães \cite{13} in this field, we investigate the possible contribution of light quark fragmentation (LQF) into charmed hadrons. The LQF effect is an old idea originally suggested by Godbole and Roy \cite{14} to explain the unexpected high rate of prompt like-sign dimuon production from many neutrino experiments \cite{15,16}. Although there are deviations in experiments and later high statistic experiments tend to show a smaller effect than early experiments, the LQF effect could not be ruled out experimen-
tally. When the leading particle effect in charm hadroproduction is observed, Dias de Deus and Durães [13] point out that the generally neglected fragmentation, e.g. $d \rightarrow D^−(\bar{c}d)$ could be a possible mechanism to explain the observed asymmetry. When the NuTeV anomaly [17] is shown to be hopefully settled by the nucleon strange asymmetry [18,19,20,21,22,23,24], while on the other hand, CCFR and NuTeV measurements do not show evidence for the strangeness asymmetry [25,26], we point out that the LQF effect is possible to influence such measurements [27].

In this paper, we will investigate the LQF effect in charm hadroproduction, and estimate the size of the LQF effect from the E791 experiment. In section II, we will describe the physical mechanism of the LQF effect, and present its parametrization. A detailed description of our calculation will be given in section III. The results will be shown and be discussed in section IV. In section V we will give the summery and conclusions.

2 The LQF effect

In our model of the LQF effect, we differentiate the favored fragmentation $q \rightarrow D(\bar{c}q)$ or $\bar{q} \rightarrow D(c\bar{q})$, which is negligible, from the unfavored fragmentation, e.g., $q \rightarrow D(c\bar{q})$, which could be an indirect effect from LQF due tocharm flavor conservation and can be neglected, since it is mainly confined near target area, i.e., in large negative $x_f$, where experiments were intangible. In $\pi^-N$ scattering, for example, since there are more $d$ quarks than $\bar{d}$ quarks in $\pi^−$, more $d$ than $\bar{d}$ will participate in the hard scattering, and with the favored fragmentation of $d \rightarrow D^−(\bar{c}d)$ and $\bar{d} \rightarrow D^+(c\bar{d})$, more $D^−$ than $D^+$ will be produced in the forward region, and this is in accord with what is observed in experiments.

In this work, the picture of the LQF effect has some differences with works of other authors. We propose a pick-up mechanism of the light quark fragmentation. After hard scattering of subprocesses, the outgoing light quark will experience a period of hadronization. This period $\Delta T \sim 1/M$ is relatively longer compared to some processes with large energy transfer $\Delta t \sim 1/\Delta E$. Then, through large momentum transfer of the strong interaction, the outgoing light quark can pick up a charmed (anti-)quark from the nucleon sea, forming a cluster, which can then decay into a charmed hadron.

Although in the pick-up process, the light quark gives most of its energy and momentum to the nucleon system, the $Q^2$ of the interaction can be very small along the initial quark direction, and thus the process is actually a non-perturbative one and is not largely suppressed by $\alpha_s(Q^2)$. For a rough estimate, one can consider a massless outgoing light quark with energy $E_q$ in the nucleon rest frame. Through the pick-up process, the light quark turns to a constituent (with constituent mass to be about 0.3GeV) of the produced $D$ meson along its initial direction. It is easy to get the squared momentum transfer $Q^2 \sim 0.5$ GeV$^2$. The lowest momentum fraction of charmed sea from the nucleon in this process should be $\xi \sim m_c/\Delta E_q$, and the size of the LQF effect is roughly proportional to the number of charmed sea above $\xi$, $n_c \sim \int_0^\xi f(x)dx$. This will yield a $E_q$ dependence of the LQF effect, which is nearly a linear rise with $E_q$. This trend is consistent with the observed prompt like-sign dimuon rates in experiments [15,16].

From the pick-up process, the outgoing light quark can hadronize into a charmed hadron with a fraction $z$ of its initial energy along its initial direction in the nucleon rest frame. The flavor of the light quark is most probable to be a valence flavor of the produced hadron.

For a quantitative estimate of the LQF effect, we construct the parametrization of the light quark fragmentation function $D^D_q(z, E_q)$, which describes the fragmentation of light quark $q$ into $D^−$ meson (including $D^−$ from $D^{∗−}$ decay), with $E_q$ and $z$ being the energy of the light quark and the energy fraction of the produced $D^−$ meson, $z \equiv E_D/E_q$, in the nucleon rest frame. We assume charge symmetry $D^D_q(z, E_q) = D^D_{\bar{q}}(z, E_q) \equiv D_f(z, E_q)$ and take $D_f(z, E_q) = C(E_q) \cdot P(z)$, where $P(z)$ is a normalized parametrization and we use the form $P(z) \sim z^α(1−z)$ [28] with $α$ being a free parameter. The form of $C(E_q)$ should be an approximate linear rise as we have mentioned. We take the form $C(E_q) = a \cdot (E_q−E_0)$ when $E_q > E_0$, where $E_0$ corresponds to an energy threshold for the LQF effect. We also suppose a suppression for the fragmentation of low transverse momentum light quarks, which correspond to remote interactions. Thus we include the suppression factor $(1−m_H^2/p_{qT}^2)$ with the restriction $p_{qT}^2 > m_H^2$, where $m_H$ is the mass of the produced hadron, and $p_{qT}$ is the transverse momentum of the light quark. From above, we get the form of light quark fragmentation function:

$$D_f(z, E_q) = a(E_q−E_0)(1−m_H^2/p_{qT}^2)P(z, α), \quad (2)$$

where $E_0$, $a$ and $α$ are parameters to describe the size and the shape of the LQF effect.

3 Calculations for charm hadroproduction

For high energy hard scattering of hadrons A and B, the inclusive cross section for the production of hadron C can be factorized as

$$\frac{E_C d^3\sigma_{AB \rightarrow CX}}{d^3P_C} = \sum_{abcd} \int dx_1 dx_2 f_A^a(x_1, Q^2)f_B^b(x_2, Q^2) \times \frac{d\sigma_{ab \rightarrow ac}}{dt} D^C_c(z, Q^2) \frac{1}{\pi z}, \quad (3)$$

where $f_A^a(x_1, Q^2)$ and $f_B^b(x_2, Q^2)$ are the parton distribution functions, with $x_i$ being the momentum fraction carried by the parton in the infinite momentum frame (IMF). $\frac{d\sigma_{ab \rightarrow ac}}{dt}$ is the subprocess cross section, with $t$ being the parton level Mandelstam variable. $D^C_c(z, Q^2)$ is the fragmentation function of parton $c$ into hadron $C$, with $z$ being the energy fraction of parton $c$ carried by the hadron $C$. 

$$\frac{d\sigma_{ab \rightarrow ac}}{dt}$$
\[ z = E_C/E_c, \] in the parton c.m. frame. \( Q^2 \) is the factorization scale, which can be taken as the squared transverse momentum of the subprocess.

Now we consider the process \( \pi^-N \to D^\pm X \). Since charm hadrons is always regarded as the fragmentation product of charmed quarks, with the LO subprocesses \( gg \to c\bar{c} \) and \( q\bar{q} \to c\bar{c} \), and charge symmetry assumption \( D_1^{\pm}(z, Q^2) = D_2^{\mp}(z, Q^2) \), the produced \( D^+ \) and \( D^- \) should be symmetric. However, if the light quark fragmentation into charmed hadrons is non-negligible, additional contribution from the LQF effect should be considered according to Eq. (3). The largest contributions from the LQF effect are \( d + g \to d + g \), with \( d \to D^- \), and \( \bar{d} + g \to \bar{d} + g \), with \( \bar{d} \to D^+ \). Since more \( d \) than \( \bar{d} \) quarks exist in \( \pi^- \) and the nucleon, more \( d \) than \( \bar{d} \) quark will contribute to the process, and more \( D^- \) than \( D^+ \) will be produced, just as experimentally observed.

LO PQCD calculation of hadron production for fixed target experiments with factorization formula is a debated area, since \( Q^2 \) is generally only a few GeV\(^2\) in this energy region, and higher order corrections could be large. The NLO calculation (7) produces an increasing factor of about 2 relative to LO calculation, with a similar shape for differential cross sections. However, since we only aim at a sketchy estimate of the LQF effect in this work, and since the asymmetry of Eq. (1) that we calculate is a ratio of the cross sections, whose uncertainties may be cancelled to some extent, we expect reasonable results within uncertainties from LO calculation.

The differential cross section for the inclusive production of hadron \( C \) as a function of \( x_F \) can be expressed as

\[
\frac{d\sigma_{AB\to CX}}{dx_F} = \sum_{abcd} \int d\alpha d\beta d\gamma \frac{d\sigma_{ab\to cd}}{dt} D_c(z, Q^2) \left| \frac{dx_F}{dt} \right|^{-1},
\]

where \( x_F \) is the Feynman variable for hadron \( C \), \( x_F = 2P_z^*/\sqrt{s} \), with \( P_z^* \) being the momentum along the incident direction in the c.m. frame of the interacting hadrons \( A \) and \( B \), and \( S \) is the squared center of mass energy \( S = (P_A + P_B)^2 \).

When the masses of quarks and hadrons are neglected, \( P_C = zp_c \) will be hold in any reference frame, and \( x_F \) can be expressed as

\[
x_F = \frac{z(x_1 + x_2)\hat{t} + x_1\hat{s}}{\hat{s}},
\]

where \( \hat{s} = x_1x_2S \) is the squared center of mass energy of the subprocess. Thus the term \( \left| \frac{dx_F}{dt} \right|^{-1} \) in Eq. (4) is

\[
\left| \frac{dx_F}{dt} \right|^{-1} = \frac{x_1x_2S}{\hat{s}(x_1 + x_2)}.
\]

However, the masses of c quark and \( D^\pm \) meson should be considered in our case, and their effect can be taken as corrections to Eq. (5) and Eq. (6). The corrections are different for charmed quark fragmentation and light quark fragmentation into charmed hadrons.

In the case of charmed quark fragmentation, with consideration of charmed quark mass \( m_c \) and the produced charmed hadron mass \( m_H \), Eq. (5) and Eq. (6) can be corrected as

\[
x_F = \frac{z\frac{x_1}{2} - \frac{x_2}{2} + z'\frac{x_1}{2} + \frac{x_2}{2}(\hat{t} - \frac{m_c^2 + \hat{s}}{2})}{\hat{s}},
\]

and

\[
\left| \frac{dx_F}{dt} \right|^{-1} = \frac{x_1x_2S}{\hat{s}(x_1 + x_2)},
\]

where \( z' = z(1 - \epsilon_H + \epsilon_c) \), with \( \epsilon_H = \frac{m_H^2}{2E_s} \) and \( \epsilon_c = \frac{2m_c^2}{\hat{s}} \).

In the case of light quark fragmentation, when the produced charmed hadron mass \( m_H \) is considered, and notice that the fragmentation function is defined in the nucleon rest frame with \( z \) being the energy fraction of the produced hadron, Eq. (5) and Eq. (6) can be corrected as

\[
x_F = \frac{(x_1 + x_2)\hat{t} + x_1\hat{s}}{\hat{s}} - 2z\epsilon_H(E_A + M)p_{qz},
\]

and

\[
\left| \frac{dx_F}{dt} \right|^{-1} = \left[ \frac{z\frac{x_1}{2} + \frac{x_2}{2}(\hat{t} - \frac{2p_{qz}}{M\hat{s}})}{\hat{s}E_q - 1} \right]^{-1},
\]

where \( E_A \) is the incident energy, which is 500 GeV for the \( \pi^- \) beam in the E791 experiment, and \( M \) is the mass of the nucleon as target; \( \epsilon_H = \frac{m_H^2}{2E_s^2} \), and \( E_q \) and \( p_{qz} \) are the energy and longitudinal momentum of the outgoing light quark in the nucleon rest frame,

\[
E_q = x_1E_A\left(1 + \frac{\hat{t}}{\hat{s}}\right) + \frac{x_2M}{2},
\]

\[
p_{qz} = (x_1E_A + x_2M)\frac{\hat{t}}{\hat{s}} + x_1E_A + \frac{x_2M}{2}.
\]

Similarly, the differential cross section as a function of \( P_T^2 \) can be expressed as

\[
\frac{d\sigma_{AB\to CX}}{dP_T^2} = \sum_{abcd} \int d\alpha d\beta d\gamma \frac{d\sigma_{ab\to cd}}{dt} D_c(z, Q^2) \left| \frac{dP_T^2}{dt} \right|^{-1},
\]

When the mass effect is neglected, \( P_T^2 \) and \( \left| \frac{dP_T^2}{dt} \right|^{-1} \) can be expressed as

\[
P_T^2 = -z^2\left(\frac{\hat{s}}{\hat{s}} + \hat{t}\right),
\]

and

\[
\left| \frac{dP_T^2}{dt} \right|^{-1} = \frac{\hat{s}}{z^2|\hat{s} + 2\hat{t}|}.
\]
In case of charm quark fragmentation, with the inclusion of the mass effect, Eq. (14) and Eq. (15) can be corrected as

\[ P_T^2 = -z^2 \left( \frac{(\hat{t} - m_c^2)^2}{\hat{s}} + \hat{t} \right), \tag{16} \]

and

\[ \left| \frac{dP_T^2}{dt} \right|^{-1} = \frac{\hat{s}}{z^2 |\hat{s} + 2(\hat{t} - m_c^2)|}, \tag{17} \]

where \( z' = z(1 - \epsilon_H + \epsilon_c) \), with \( \epsilon_H = 2m_{\chi}^2/(z^2\hat{s}) \) and \( \epsilon_c = 2m_c^2/\hat{s} \). In case of light quark fragmentation from the nucleon rest frame, with the mass of the produced hadron \( m_H \) being considered, Eq. (14) and Eq. (15) can be corrected as

\[ P_T^2 = -z^2(1 - 2\epsilon_H^N)(\frac{\hat{t}}{\hat{s}} + \hat{t}), \tag{18} \]

and

\[ \left| \frac{dP_T^2}{dt} \right|^{-1} = \frac{\hat{s}}{z^2 |(1 - 2\epsilon_H^N) + 2\hat{t}|}, \tag{19} \]

where \( \epsilon_H^N \equiv m_{\chi}^2/(2z^2E_q^2) \), and \( E_q \) is expressed in Eq. (11).

In our calculations, \( \hat{s} \geq (2m_H)^2 \) and \( z \geq 2m_H/\sqrt{\hat{s}} \) are required in the \( \bar{c}c \) production and fragmentation processes, and \( m_H/E_q \leq z \leq 1 - (m_A - M)/E_q \) is required in light quark fragmentation. To compare our calculation with the E791 data, restriction \(-0.2 < x_F < 0.8\), just as in the experiment, is obliged in the calculation of \( P_T^2 \) distribution. As to the calculation of \( x_F \) distribution, \( P_T^2 \) is indirectly restricted by \( Q^2 \geq Q_0^2 \).

We use CTEQ6L1 parton distributions [29] for the nucleon, and we employ the LO parametrization forms of Ref. [30] for the parton distributions of the \( \pi^- \). Since the E791 experiment uses a target mainly of carbon, we take it as an isoscalar target for the nucleon parton distributions. We consider LO subprocesses \( gg \to \bar{c}c \) and \( q\bar{q} \to \bar{c}c \) for charm quark production, and various LO subprocesses including \( gg \to gg, gg' \to gg', q\bar{q} \to q\bar{q}, qg \to qg' \), \( qg \to gg, \bar{q}\bar{q} \to q\bar{q}, \bar{q}g \to qg, \bar{q}g' \to qg' \), for light quark d and \( \bar{d} \) production. The cross sections \( \frac{d^2 \sigma}{d^2 \hat{t}} \) for these subprocesses can be found in Refs. [31][32][33]. We use the LO running \( \alpha_s \) with \( A_{QCD} = 215 \text{ MeV} \) for \( n_f = 4 \) and \( A_{QCD} = 165 \text{ MeV} \) for \( n_f = 5 \), as specified in CTEQ6L1. We set factorization scale \( Q^2 = p^2_{T} + m_c^2 \) for charm quark production processes, and \( Q^2 = p^2_{T} \) for light quark production processes, with \( m_c = 1.5 \text{ GeV} \) and \( Q_0^2 = m_H^2 \approx 3.5 \text{ GeV}^2 \), where \( p_{T} \) is the transverse momentum of quark q. We use Peterson parametrization [34] for charm fragmentation function \( D_c^P(z, \epsilon_F) \), with \( \epsilon_F = 0.08 \) and the fragmentation fraction 0.23 for \( c \to D^+ \) (including \( D^+ \) from \( D^{*-} \) decay) [35][36]. For the light quark fragmentation \( d \to D^- \) and \( \bar{d} \to D^+ \), we use the parametrization of Eq. (2) and tuning the parameters to describe the observed asymmetry.

4 Results and discussions

From numerical calculations, we can find good descriptions of the observed asymmetry from the E791 experiment. Fig. 1 shows a set of the best fits for both \( x_F \) and \( P_T^2 \) distributions with the following parameters, \( E_q = 40 \text{ GeV} \), \( a = 2.0 \times 10^{-5} \text{ GeV}^{-1} \), and \( \alpha = 0.6 \). Notice that our \( A(x_F) \) result is consistent with the data of all \( x_F \) region, while \( A(P_T^2) \) result could not give a good description of the data below \( P_T^2 \sim 2 \text{ GeV}^2 \). This discrepancy, however, can be attributed to the unaccounted small random transverse momentum of the produced hadron relative to the direction of the light quark when it fragments. When this effect is considered, the sharp peak of \( D^+ \) produced from LQF at low transverse momentum could become broader, and the asymmetry curve should get greatly balanced at low \( P_T^2 \). Meanwhile, the general features of \( A(x_F) \) and \( A(P_T^2) \) \( (P_T^2 > 2) \) do not change.

\( E_q \) is a parameter that describes an energy threshold for light quark fragmentation into charmed hadrons. There are still uncertainties in its value, as our result is insensitive to this. Nevertheless, the overall size of the LQF effect (about \( a(E_q - E_0) \)) is quite stable in our fits, when changing \( E_0 \) from 10 to 80 GeV, to be about \( 2.4 \times 10^{-3} \) near \( E_q = 160 \text{ GeV} \), which is a typical energy under study. \( \alpha \) describes the shape of the fragmentation function for the LQF effect, and \( \alpha = 0.6 \) corresponds to a broad peak around \( z = 0.4 \).

In this work, we attribute the leading particle effect for charm hadroproduction to the LQF effect from the pick-up process of the produced light quarks. Nevertheless, we do not exclude other possible contributions that lead to the fragmentation of light quark into charmed hadrons, which should still be explored by some dedicated work.

From our LO calculation, the LQF effect could give a good description of the observed \( D^\pm \) asymmetry. On the other hand, we can get an estimate of the shape and the size of the LQF effect from the fitting results. When \( z \) is integrated out, the size of LQF effect can be drawn from Eq. (2) to be about \( a(E_q - E_0) \) when \( p_{GT}^2 \gg m_H^2 \), with \( E_0 = 40 \text{ GeV} \) and \( a = 2.0 \times 10^{-5} \text{ GeV}^{-1} \), one gets \( D_f(E_q) = 2(E_q - 40) \times 10^{-5} \). For a typical value \( E_q = 160 \text{ GeV} \), one gets \( D_f \sim 2.4 \times 10^{-3} \), which is very stable in our fit as we have mentioned above. However, there are still uncertainties for this fitting result both from LO calculations and from the parametrization of the light quark fragmentation function. Since the energy of fixed target experiments is limited, higher order effects will contribute and the calculated LO cross sections show a scale dependence. Meanwhile the low transverse momentum suppression factor \((1 - m_H^2/p_{GT}^2)\) in our parametrization gives an extra uncertainty by a factor of 1/3. As a sketchy estimate, we set an increasing factor of 2 and a decreasing factor of 3 as its uncertainties around the central value of our fit. Thus, for \( E_q = 160 \text{ GeV} \), we have an estimate of \( 0.8 \times 10^{-3} \leq D_f \leq 4.8 \times 10^{-3} \) i.e. \( D_f = (2.4^{+2.4}_{-1.0}) \times 10^{-3} \) for the size of the LQF effect.

Now we compare our result with the previous estimate of the LQF effect from neutrino induced dimuon produc-
In the previous work, the light quark fragmentation rate, defined as $D_q \equiv D_q^D + D_q^{D^*}$, is different from the definition in this work, which is the rate of $d \rightarrow D^-$ including $D^-$ from $D^*$ decay, i.e., $D_f = D_q^D + B^* D_q^{D^*}$, where $D_q^D$ and $D_q^{D^*}$ indicate direct fragmentation into $D$ or $D^*$ meson from light quarks, and $B^* \approx 1/3$ is the fraction for $D^{*-}$ decay to $D^-$ \[37\]. With an estimate for the ratio $D_q^{D^*}/D_q^D = 3/1$ from spin counting, we find that the $D_q$ in previous work should be one half smaller when it is compared to $D_f$ in this work. $D_q$ can be drawn from Eq. (13) of Ref. \[27\], $D_q/\langle f_c \rangle \approx 0.20 \sigma_{\mu^- \mu^-}/\sigma_{\mu^- \mu^+}$, with an estimate for $\langle f_c \rangle = 0.86$ and taking $\sigma_{\mu^- \mu^-}/\sigma_{\mu^- \mu^+} = (3.5 \pm 1.6)\%$ \[15\], which is the prompt dimuon rate for $100 < E_{\text{vis}} < 200$ GeV with cut $p_\mu > 6$ GeV. From above, one can get $D_q = (6.0 \pm 2.7) \times 10^{-3}$. Now we can compare $\langle D_q \rangle = (3.0 \pm 1.4) \times 10^{-3}$ with $D_f(E_q = 160$ GeV) = $(2.4 \pm 2.4) \times 10^{-3}$, for they have similar energy range. From above, we find that the size of the LQF effect from the estimate of this work of charm hadroproduction is a little smaller but consistent with that of the estimate from neutrino induced prompt $\mu^- \mu^-$ production process. Estimation of the LQF effect from $\mu^- \mu^+$ data in the previous work yields a much larger size, which is not supported by this work.

In our previous work \[27\], we have shown that the LQF effect could influence the measurement of nucleon strange asymmetry from charged current charm production processes. When the LQF effect is large enough, it can balance the effect from nucleon strange asymmetry, which could explain why CCFR and NuTeV experiments do not show evidence for the nucleon strange asymmetry. From the estimate of the LQF effect in this work, the size of the LQF effect at $E_q = 160$ GeV is about $(2.4 \pm 2.4) \times 10^{-3}$, which is still twice or more smaller to compensate the predicted nucleon strange asymmetry that can explain the Doctoral Program of Higher Education (China).

### 5 Summary

In this work, we have attempted to explain the leading particle effect in charm hadroproduction by the picture of light quark fragmentation into charged hadrons (LQF). We can obtain good descriptions of the observed $D^\pm$ asymmetry from the E791 experiment for both $x_F$ and $P_T^2$ distributions. Although the uncertainty from our LO PQCD calculation is large, we find a total size of the order of $10^{-3}$ for the LQF effect at a typical energy $E_q = 160$ GeV of the light quark. This result is consistent with the estimate of the LQF effect from neutrino induced prompt $\mu^- \mu^-$ data in our previous work. The influence of the LQF effect to the measurement of nucleon strange asymmetry in neutrino induced charged current charm production processes could be non-negligible.

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