D Production In p-p and d-Au Collisions

Leonard S. Kisslinger
Department of Physics, Carnegie Mellon University, Pittsburgh, PA 15213
Ming X. Liu and Patrick McGaughey
P-25, Physics Division, Los Alamos National Laboratory, Los Alamos, NM 87545

Abstract

This is an extension of our previous work on J/Ψ, $\Psi'(2S)$, $\Upsilon(nS)$ production in p-p and A-A collisions to the production of $D^+(c\bar{d}), D^o(c\bar{u})$, with the main new aspect being the fragmentation probability, $D_{c\to c\bar{q}}$, which has been calculated almost two decades ago. The rapidity cross sections for $D^+(c\bar{d}), D^o(c\bar{u})$ production from both p-p and d-AU collisions is estimated.

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1 Introduction

We consider $D^+(c\bar{d}), D^o(c\bar{u})$ production via unpolarized p-p collisions at 200 GeV, an extension of our previous work on $J/\Psi, \Psi'(2S)$, and $\Upsilon(nS)$ production[1]. In addition to being an important study of QCD, it also could provide a test of the production of Quark Gluon Plasma (QGP) in relativistic heavy ion collisions (RHIC), which would be an extension of our work on A-A production of heavy quark states[2]. Estimates of $D^+(c\bar{d}), D^o(c\bar{u})$ production via d-Au collisions are also made, using the methods of Ref.[2].

As in our previous work we use the color octet model[3, 4, 5], which is consistent with experimental studies at E=200 GeV [6, 7]. In Refs.[1],[2] the mixed hybrid theory was used for the production of $\Psi'(2S), \Upsilon(3S)$, but this not relevant for the present theory.

The main new aspect of the present work is that while a gluon can produce a $c\bar{c}$ or $b\bar{b}$ state, it cannot directly produce a $c\bar{d}$. A fragmentation process converts a $c\bar{c}$ into a $c\bar{d} - d\bar{c}$, for example. We use the fragmentation probability, $D_{c\to c\bar{q}}$ of Bratten et. al.[8].

2 Differential $pp \to DX$ cross section

Using what in Ref[9] is called scenerio 2, the production cross section with gluon dominance for DX is

$$\sigma_{pp\to DX} \quad = \quad \int_a^1 \frac{dx}{x} f_g(x, 2m) f_g(a/x, 2m) \sigma_{gg\to DX} \ , \qquad (1)$$

with[8]

$$\sigma_{gg\to DX} \;=\; 2\sigma_{gg\to c\bar{c}} D_{c\to c\bar{q}} \;, \tag{2}$$

where $\sigma_{gg\to c\bar{c}}$ is similar to the charmonium production cross section in Ref[1] and $D_{c\to c\bar{q}}$ is the total fragmentation probability. For $E=\sqrt{s}$=200 GeV the gluon distribution funtion is

$$f_g(y) \;=\; 1334.21 - 67056.5x(y) + 887962.0x(y)^2 \tag{3}$$

We use the quark fragmentation probability, $D_{c\to c\bar{q}}$ of Bratten et. al.[8], illustrated in the figure below.

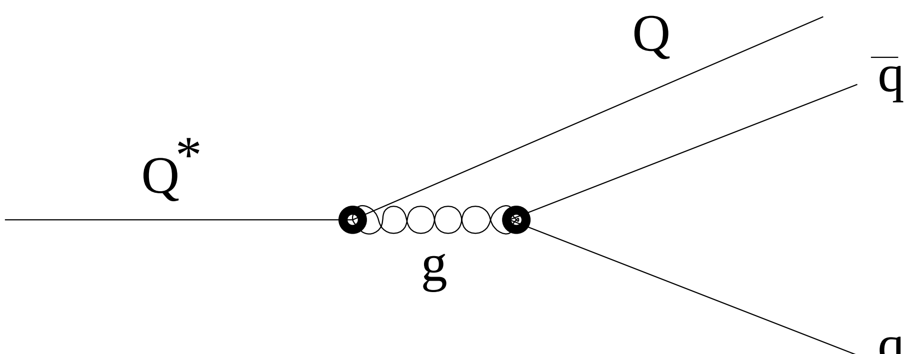

Figure 1: Quark fragmentation for $Q^* \to (Q\bar{q}) + q)$

From Ref[8], using for the light quark mass=(up-mass+down-mass)/2= 3.5 Mev.

$$D_{c\to c\bar{q}} \;=\; 9.21\times 10^5 \alpha_s^2 |R(0)|^2/\pi \;, \tag{4}$$

in units of $(1/GeV^3)$, with $\alpha_s = .26$. For a 1S state $|R(0)|^2 = 4/(a_o)^3$. For a $c\bar{q}$ state, $(1/a_o) = m_q \simeq 3.5$ MeV. Therefore,

$$\begin{aligned} |R(0)|^2 &\simeq 1.71\times 10^{-7}\ \ (\mathrm{GeV})^3 \\ D_{c\to c\bar{q}} &\simeq 3.39\times 10^{-3} \;. \end{aligned} \tag{5}$$

The calculation of the cross section is similar to that in Ref[1].

$$\frac{d\sigma_{pp\to DX}}{dy} \;=\; Acc * f_g(x(y),2m) f_g(a/x(y),2m) \frac{dx(y)}{dy}\frac{1}{x(y)} D_{c\to c\bar{q}} \;, \tag{6}$$

with rapidity y

$$\begin{aligned} y &= \frac{1}{2} ln(\frac{E+p_z}{E-p_z}) \\ x(y) &= 0.5\left[\frac{m}{s}(\exp y - \exp(-y)) + \sqrt{(\frac{m}{s}(\exp y - \exp(-y)))^2 + 4a}\right] \;, \end{aligned} \tag{7}$$

where Acc is the matrix element for charmonium production[1] modified by an effective mass ms: $Acc = 7.9 * 10^{-4}(1.5/ms)^3 nb$.

From Eq(6) we find $\frac{d\sigma_{pp\rightarrow DX}}{dy}$ shown in the figure below, with ms=1.5 GeV.

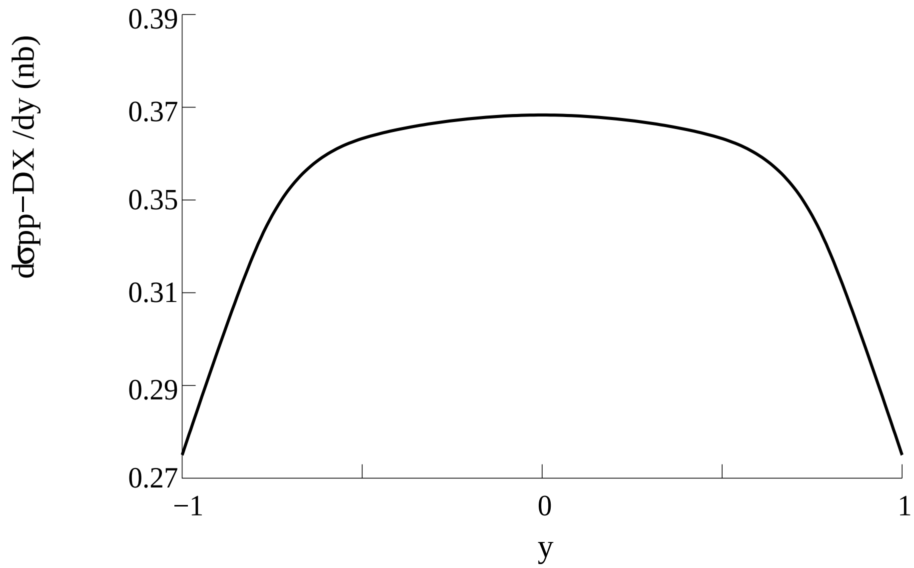

Figure 2: $d\sigma/dy$ for E=200 GeV unpolarized p-p collisions producing D+X

3 Total $pp \rightarrow DX$ cross section

The total cross section for $pp \rightarrow DX$ is[1]

$$\sigma_{pp\rightarrow DX} = \int_a^1 \frac{dx}{x} Acc * fg(x(y), 2m) fg(a/x(y), 2m) D_{c\rightarrow c\bar{q}} \,. \tag{8}$$

From Eqs(3,5) and Acc one obtains

$$\sigma_{pp\rightarrow DX} = 2.678\mu\text{b} \tag{9}$$

A number of experiments have measured $\sigma_{c\bar{c}}$ cross sections at $\sqrt{s_{pp}}$=200 GeV[10, 11, 12, 13]. Theoretical estimates of heavy quark state production via p-p collisions at RHIC and LHC energies were made almost two decades ago[14]. Experimental measurements of D^+, D^-, D^0 production via p-p collisions are expected in the future.

4 Differential $dAu \rightarrow DX$ cross section

Open Charm yields in d+AU Colllisions at $\sqrt{s_{NN}}$=200 GeV have been measured via STAR[15] and PHENIX[16] experiments. Cold nuclear matter effects on heavy-quark production were estimated for a number of rapidities via PHENIX experiments[16]. We use the results of this experiment for the study of D production via d-Au collisions.

In this Section we estimate the production of D^+, D^0 from d-Au collisions, using the methods given in Ref.[2] for the estimate of production of Ψ and Υ states via Cu-Cu and Au-Au collisions based on p-p collisions.

The differential rapidity cross section for D+X production via d-Au collisions is given by $\frac{d\sigma_{pp\rightarrow DX}}{dy}$ with modification described in Ref.[2] for Cu-Cu and Au-Au collisions:

$$\frac{d\sigma_{dAu\rightarrow DX}}{dy} = R_{dAu} N_{coll}^{dAu} \left(\frac{d\sigma_{pp\rightarrow DX}}{dy}\right) , \tag{10}$$

where R_{dAu} is the nuclear-modification factor, N_{coll}^{dAu} is the number of binary collisions, and $\left(\frac{d\sigma_{pp\rightarrow DX}}{dy}\right)$ is the differential rapidity cross section for DX production via nucleon-nucleon collisions in the nuclear medium.

$\left(\frac{d\sigma_{pp\rightarrow DX}}{dy}\right)$ is given by Eq(6) with $x(y)$ replaced by the function $\bar{x}$, the effective parton x in the nucleus Au[17]:

$$\bar{x}(y) = x(y)(1 + \frac{\xi_g^2(A^{1/3}-1)}{Q^2}) , \tag{11}$$

which was evaluated in Ref.[2], where it was shown that $\bar{x}(y) \simeq x(y)$

In Ref.[16] the quantities R_{dAu} and N_{coll}^{dAu} (called R_{dA} and $< N_{coll} >$ in that article) were estimated from experiments on p+p and d+Au collisions. From that reference (see FIG.3) we use

$$\begin{aligned} R_{dAu} &\simeq 1.0 \\ N_{coll}^{dAu} &\simeq 10.0 . \end{aligned} \tag{12}$$

Note that Ref.[16] shows $\simeq 50$ % larger R_{dA} for muons at negative rather than positive rapidity. However, the magnitude of these rapidities is much larger than those in our calculation.

From Eqs(6,10,12), one obtains the differential rapidity cross section for D+X production via dAu collisions, $\frac{d\sigma_{dAu\rightarrow DX}}{dy}$ shown in Figure 3

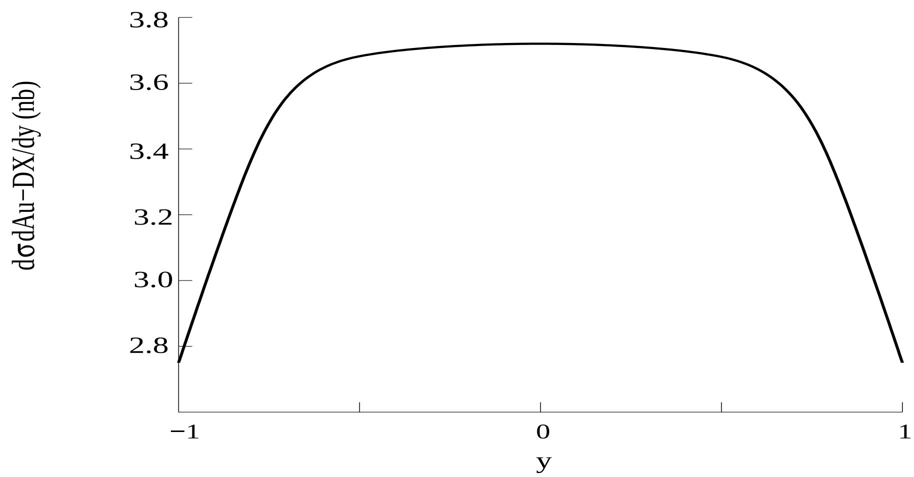

Figure 3: $d\sigma/dy$ for E=200 GeV d-Au collisions producing D+X

In Ref.[15] although $\frac{d\sigma_{dAu \to DX}}{dy}$ was not measured, the electron distributions for $p + p \to e + X$ and $d + AU \to e + X$ were measured (Ref.[15], FIG. 2) as a function of transverse momentum (p_T), and the ratio $d + AU \to e + X/p + p \to e + X$ in the range $1 < p_T < 2$ GeV/c was consistent with $R_{dAu} N_{coll}^{dAu} \simeq 10$, Eq(12).

5 Conclusions

We have estimated the production of heavy-quark mesons $D^+(c\bar{d}), D^o(c\bar{u})$ $+X$ via p-p colllisions using the color octet model with an extension of our previous work on production of $\bar{c}c$ and $\bar{b}b$ states to $\bar{d}c$ or $\bar{u}c$ D-meson states using fragmentation. Our results are expected to be tested by p-p collision experiments in the future. We have also estimated the production of D-meson states via d-Au collisions, using experimental results for the nuclear modification and number of binary collisions in recent d-Au collisions experiments, which also might be measured in future experiments.

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