B Production In p-p and A-A Collisions

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Abstract

This is an extension of our recent work on $D^+(c\bar{d}), D^0(c\bar{u})$ production from p-p and d-Au collisions to $B^+(b\bar{d}), B^0(b\bar{u})$ production from p-p and A-A collisions. The rapidity cross sections for $B^+(c\bar{d}), B^0(b\bar{u})$ production from both p-p and A-A collisions are estimated. Our present work makes use of previous work on $J/\Psi, \Psi'(2S), \Upsilon(nS)$ production in p-p and A-A collisions, with the main new aspect being the fragmentation probability, $D_{b\rightarrow b\bar{q}}$, which turns out to be similar to the fragmentation probability $D_{c\rightarrow c\bar{q}}$ used in our recent work.

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1 Introduction

We consider $B^+(b\bar{d}), B^0(b\bar{u})$ production via unpolarized p-p collisions at 200 GeV, an extension of our recent work on $D^+(c\bar{d}), D^0(c\bar{u})$ production[1]. We make use of previous work on $J/\Psi, \Psi'(2S)$ and $\Upsilon(nS)$ production via p-p collisions[2] and A-A collisions[3]. In addition to being an important study of QCD, the estimate of $B$ production via A-A collisions could provide a test of the production of Quark Gluon Plasma (QGP) in relativistic heavy ion collisions (RHIC).

As in our previous work we use the color octet model[4, 5, 6], which is consistent with experimental studies at $E=200$ GeV [7, 8]. In Refs.[2],[3] 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 $b\bar{d}$. A fragmentation process converts a $b\bar{b}$ into a $b\bar{d} − db$, for example. We use the fragmentation probability, $D_{b\rightarrow b\bar{q}}$ of Braaten et. al.[9, 10].

2 Differential $pp \rightarrow BX$ cross section

Using what in Ref[11] is called scenario 2, the production cross section with gluon dominance for BX is

$$\sigma_{pp \rightarrow BX} = \int_a^1 \frac{dx}{x} f_g(x, 2m)f_g(a/x, 2m)\sigma_{gg \rightarrow BX} ,$$ (1)
with \[10\]
\[
\sigma_{gg \rightarrow BX} = 2\sigma_{gg \rightarrow b\bar{b}} D_{b \rightarrow b\bar{q}} ,
\]
where \(\sigma_{gg \rightarrow b\bar{b}}\) is similar to the charmonium production cross section in Ref\[2\] and \(D_{b \rightarrow b\bar{q}}\) is the total fragmentation probability. For \(E = \sqrt{s} = 200\) GeV the gluon distribution function for bottomonium quarks is
\[
f_g(y) = 275.14 - 6167.6x(y) + 36871.3x(y)^2
\]
(3)

We use the quark fragmentation probability, \(D_{b \rightarrow b\bar{q}}\) of Braaten et. al.\[9, 10\].

From Ref\[10\], using for the light quark mass = (up-mass + down-mass) / 2 = 3.5 MeV.
\[
D_{b \rightarrow b\bar{q}} = 9.21 \times 10^5 \alpha_s |R(0)|^2 / \pi ,
\]
(4)
in units of \(1/\text{GeV}^3\), with \(\alpha_s = .26\). For a 1S state \(|R(0)|^2 = 4/(a_o)^3\). For a \(b\bar{q}\) state, \((1/a_o) = m_q \simeq 3.5\) MeV. Therefore,
\[
|R(0)|^2 \simeq 1.71 \times 10^{-7} \quad \text{(GeV)}^3
\]
\[
D_{b \rightarrow b\bar{q}} \simeq 3.39 \times 10^{-3} ,
\]
(5)
so \(D_{b \rightarrow b\bar{q}} \simeq D_{c \rightarrow c\bar{q}}[1]\).

The calculation of the cross section is similar to that in Ref\[2\].
\[
\frac{d\sigma_{pp \rightarrow BX}}{dy} = Abb * f_g(x(y), 2m)f_g(a/x(y), 2m) \frac{dx(y)}{dy} \frac{1}{x(y)} D_{b \rightarrow b\bar{q}} ,
\]
(6)
with rapidity \(y\)
\[
y = \frac{1}{2} \ln(\frac{E + p_z}{E - p_z})
\]
\[
x(y) = 0.5 \left[ \frac{m}{E} (\exp y - \exp (-y)) + \sqrt{\frac{m}{E} (\exp y - \exp (-y))^2 + 4a} \right] ,
\]
(7)
where \(Abb\) is the matrix element for bottomonium production\[2\] modified by an effective mass \(m_s\): \(Abb = 7.9 \times 10^{-4}(1.5/m_s)^3\) nb. For \(m_s = 5.0\) GeV \(Abb = 2.13 \times 10^{-5}\) nb.

From Eq\(6\) we find \(\frac{d\sigma_{pp \rightarrow BX}}{dy}\) shown in the figure below, with \(m_s=5.0\) GeV.
3 Total $pp \to BX$ cross section

The total cross section for $pp \to BX$ is\cite{2}

$$\sigma_{pp\to BX} = \int_a^1 \frac{dx}{x} Abf(x(y), 2m) f_g(\frac{a}{x(y)}, 2m) D_{b\to b\bar{q}}.$$  \hspace{1cm} (8)

From Eqs\,(3,5) and $Abf$ one obtains

$$\sigma_{pp\to BX} \simeq 0.4823\text{nb}.$$  \hspace{1cm} (9)

Since $\sigma_{pp\to DX} \simeq 2680.0\text{nb}$\cite{1}, the ratio of $\sigma_{pp\to BX}$ to $\sigma_{pp\to DX}$ is

$$RR \equiv \frac{\sigma_{pp\to BX}}{\sigma_{pp\to DX}} \simeq 1.8 \times 10^{-4},$$  \hspace{1cm} (10)

due to the difference in the quark mass and values of $f_g$ for bottom vs charm quarks.
A number of experiments have measured $\sigma \bar{b}b$ cross sections at $\sqrt{s_{pp}}=200$ GeV[12, 20, 21, 15]. Experimental measurements of $B^+, B^-, B^0$ production via p-p collisions are expected in the future.

4 Differential $Cu-Cu, Au-Au \rightarrow BX$ cross sections

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 $B$ production via Cu-Cu and Au-Au collisions.

In this Section we estimate the production of $B^+, B^0$ from Cu-Cu and Au-Au collisions, using the methods given in Ref.[3] for the estimate of production of $\Psi$ and $\Upsilon$ states via Cu-Cu and Au-Au collisions based on p-p collisions.

The differential rapidity cross section for B+X production via A-A collisions is given by $\frac{d\sigma_{pp\rightarrow BX}}{dy}$ with modification described in Ref.[3] for Cu-Cu and Au-Au collisions:

\[ \frac{d\sigma_{AA\rightarrow BX}}{dy} = R_{AA}N_{bin}^{AA} \left( \frac{d\sigma_{pp\rightarrow BX}}{dy} \right) , \]  

(11)

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

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

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

(12)

which was evaluated in Ref.[3], where it was shown that $\bar{x}(y) \simeq x(y)$

Experimental studies show that for $\sqrt{s_{pp}} = 200$ GeV $R_{AA}^E \simeq 0.5$ both for Cu-Cu[18, 19] and Au-Au[20, 21, 22]. The number of binary collisions are $N_{bin}^{AA}$=51.5 for Cu-Cu[23] and 258 for Au-Au.

From Eqs(6) and (11) one obtains the differential rapidity cross section for B+X production via Cu-Cu and Au-Au collisions

\[ \frac{d\sigma_{Cu-Cu\rightarrow BX}}{dy} = (51.5/2) \times Abb \ast f_g(x(y), 2m)f_g(a/x(y), 2m)\frac{dx(y)}{dy} \frac{1}{x(y)}D_{b\rightarrow b\bar{q}} , \]  

\[ \frac{d\sigma_{Au-Au\rightarrow BX}}{dy} = (258/2) \times Abb \ast f_g(x(y), 2m)f_g(a/x(y), 2m)\frac{dx(y)}{dy} \frac{1}{x(y)}D_{b\rightarrow b\bar{q}} . \]  

(13)
\( \frac{d\sigma_{Cu-Cu \rightarrow BX}}{dy} \) and \( \frac{d\sigma_{Au-Au \rightarrow BX}}{dy} \) are shown in the figures below.

Figure 2 \( \frac{d\sigma}{dy} \) for \( E=200 \text{ GeV} \) Cu-Cu collisions producing B+X

Figure 3 \( \frac{d\sigma}{dy} \) for \( E=200 \text{ GeV} \) Au-Au collisions producing B+X
4.1 Total $CuCu \rightarrow BX$ and $AuAu \rightarrow BX$ cross sections

Total $\sigma_{CuCu \rightarrow BX}$ and $\sigma_{AuAu \rightarrow BX}$ cross sections are obtained from $\sigma_{pp \rightarrow BX}$ Eq(9) by multiplying $\sigma_{pp \rightarrow BX}$ by $R_{AA}N_{bin}^{AA}$. Therefore

$$\sigma_{CuCu \rightarrow BX} \cong (51.5/2) \times 0.4823\text{nb} = 12.42\text{nb}$$
$$\sigma_{AuAu \rightarrow BX} \cong (258/2) \times 0.4823\text{nb} = 62.22\text{nb} .$$

(14)

5 Conclusions

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

Acknowledgements

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