

INCLUSIVE HADRONIC PRODUCTION OF THE  $B_c$  MESON  
VIA HEAVY QUARK FRAGMENTATION \*

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ABSTRACT

We summarize the studies on the hadronic production of S- and P-wave ( $\bar{b}c$ ) mesons via direct fragmentation of the bottom antiquark as well as the Altarelli-Parisi induced gluon fragmentation.

The direct production of heavy mesons like  $J/\psi$ ,  $\Upsilon$ , and ( $\bar{b}c$ ) mesons can provide very interesting tests for perturbative QCD. According to the potential model calculation<sup>1</sup>, for ( $\bar{b}c$ ) mesons the first two sets ( $n = 1$  and  $n = 2$ ) of S-wave states, the first ( $n = 1$ ) and probably the entire second set ( $n = 2$ ) of P-wave states, and the first set ( $n = 1$ ) of D-wave states lie below the  $BD$  flavor threshold. Since the annihilation channel of excited ( $\bar{b}c$ ) mesons is suppressed relative to the electromagnetic and hadronic transitions, the excited states below the  $BD$  threshold will cascade down into the ground state  $B_c$  via emission of photons and/or pions. Inclusive production of the  $B_c$  meson therefore includes the production of the  $n = 1$  and  $n = 2$  S-wave and P-wave states, and the  $n = 1$  D-wave states. Here we do not include the D-wave contributions since they are expected to be very small.

Intuitively, the dominant production of ( $\bar{b}c$ ) mesons at the large transverse momentum region should come from the direct fragmentation of the heavy  $\bar{b}$  antiquark<sup>2,3</sup>. We calculate the hadronic production of S- and P-wave ( $\bar{b}c$ ) mesons using the fragmentation approach<sup>4,5,6</sup>. The fragmentation approach essentially involves the factorization of the whole production process into the production of a high energy parton (a  $\bar{b}$  antiquark or a gluon) and the fragmentation of this parton into various ( $\bar{b}c$ ) states. The novel feature in our approach<sup>2,3</sup> is that the relevant fragmentation functions at the heavy quark mass scale can be calculated in perturbative QCD. Let  $H$  denotes any ( $\bar{b}c$ ) meson states. The differential cross section  $d\sigma/dp_T$  versus the transverse momentum  $p_T$  of  $H$  is given by

$$\frac{d\sigma}{dp_T}(p\bar{p} \rightarrow H(p_T)X) = \sum_{ij} \int dx_1 dx_2 dz f_{i/p}(x_1, \mu) f_{j/\bar{p}}(x_2, \mu) \left[ \frac{d\hat{\sigma}}{dp_T}(ij \rightarrow \bar{b}(p_T/z)X, \mu) \right. \\ \left. \times D_{\bar{b} \rightarrow H}(z, \mu) + \frac{d\hat{\sigma}}{dp_T}(ij \rightarrow g(p_T/z)X, \mu) D_{g \rightarrow H}(z, \mu) \right]. \quad (1)$$

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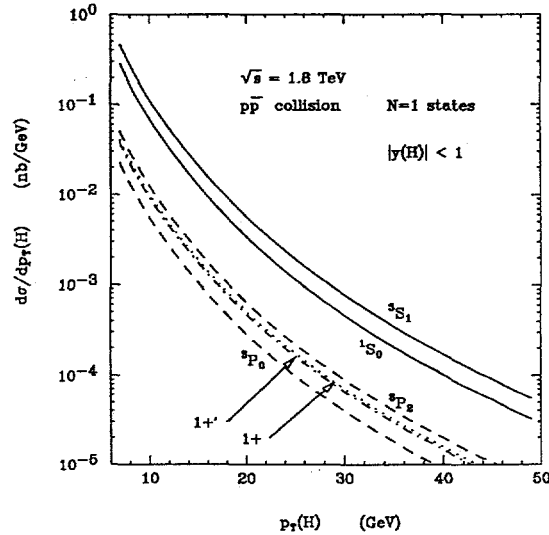


Figure 1: The differential cross section  $d\sigma/p_T$  versus  $p_T$  of the  $(\bar{b}c)$  meson ( $H$ ) in various spin-orbital states with  $n = 1$  at the Tevatron. The acceptance cuts are  $p_T(H) > 6$  GeV and  $|y(H)| < 1$ .

For the production of  $\bar{b}$  we include the subprocesses  $gg \rightarrow b\bar{b}$ ,  $g\bar{b} \rightarrow g\bar{b}$ , and  $q\bar{q} \rightarrow b\bar{b}$ ; while for the gluon  $g$  we include the subprocesses  $gg \rightarrow gg$ ,  $q\bar{q} \rightarrow gg$ , and  $gq(\bar{q}) \rightarrow gq(\bar{q})$ . In Eq. (1), a common scale  $\mu$  is chosen for parton distribution functions, parton-parton scattering, and fragmentation functions. We estimate the dependence on  $\mu$  by varying the scale  $\mu = (0.5 - 2)\mu_R$ , where  $\mu_R = \sqrt{p_T^2(\text{parton}) + m_b^2}$ . This choice of scale avoids the large logarithms in the short-distance part  $\hat{\sigma}$ 's. However, logarithms of order  $\mu_R/m_b$  have to be summed in the fragmentation functions, which is implemented by evolving the Altarelli-Parisi (AP) equations for the fragmentation functions<sup>4,5</sup>. The initial conditions for the AP equations are the fragmentation functions that we can calculate by perturbative QCD at the initial scale  $\mu_0$ , which is of the order of the  $b$ -quark mass. At present, all the S-wave<sup>2</sup> and P-wave<sup>3</sup> fragmentation functions for  $\bar{b} \rightarrow (\bar{b}c)$  have been calculated to leading order in  $\alpha_s$ . To obtain the fragmentation functions at an arbitrary scale greater than  $\mu_0$ , we numerically integrate the AP evolution equations.

Other details in inputs can be found in Ref. 6. We impose  $p_T(H) > 6$  GeV and  $|y(H)| < 1$  cuts on the  $(\bar{b}c)$  state  $H$ . The  $p_T$  spectra for the  $(\bar{b}c)$  state  $H$  with various spin-orbital quantum numbers are shown in Fig. 1 and Fig. 2 for  $n = 1$  and  $n = 2$ , respectively. Thus, we can also obtain the inclusive production rate of  $B_c$  as a function of  $p_T^{\min}(B_c)$  by integrating the  $p_T$  spectra. Table 1 gives the inclusive cross sections for the  $B_c$  meson at the Tevatron as a function of  $p_T^{\min}(B_c)$ , including  $n = 1$  and  $n = 2$  S- and P-wave state contributions. The variations versus the scale  $\mu$  between  $\mu_R/2$  and  $2\mu_R$  are always within a factor of two, and are rather insensitive to changes in scale when  $p_T^{\min}(B_c) \gtrsim 10$  GeV.

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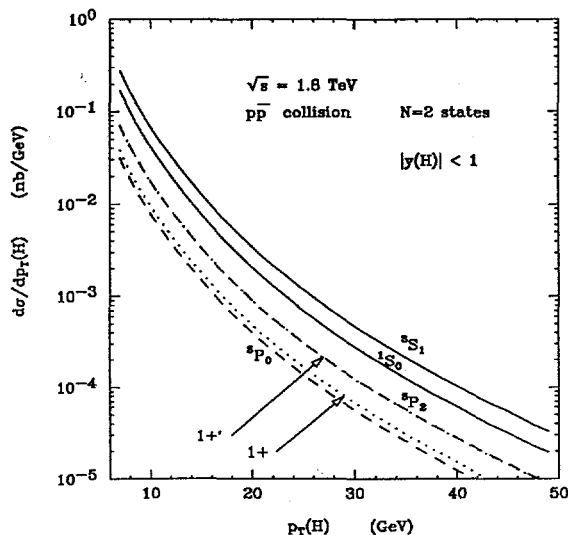


Figure 2: Same as Fig.1 for  $n = 2$ .

At the end of Run Ib at the Tevatron, the total accumulated luminosities can be up to  $100\text{--}150 \text{ pb}^{-1}$  or more. With  $p_T > 6 \text{ GeV}$ , there are about  $5 \times 10^5 B_c^+$  mesons. In the future, when the Main Injector is installed in the Run II, which can accumulate  $1\text{--}2 \text{ fb}^{-1}$  luminosity, there will be of order  $10^7 B_c$  mesons. At the LHC there will be about  $3 \times 10^9 B_c$  mesons with  $p_T > 10 \text{ GeV}$  at the assumed  $100 \text{ fb}^{-1}$  luminosity.

In conclusion, there should be enough signature events to confirm the existence of  $B_c$  at the Tevatron, and the LHC will be a copious source of  $B_c$ . This work was supported by US DOE-FG03-93ER40757.

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Table 1: Inclusive production cross sections for the  $B_c$  meson at the Tevatron including the contributions from all the S-wave and P-wave states below the  $BD$  threshold as a function of  $p_T^{\min}(B_c)$ . The acceptance cuts are  $p_T(B_c) > 6 \text{ GeV}$  and  $|y(B_c)| < 1$ .

$p_T^{\min} \text{ (GeV)}$	$\sigma \text{ (nb)}$		
	$\mu = \frac{1}{2}\mu_R$	$\mu = \mu_R$	$\mu = 2\mu_R$
6	2.81	5.43	6.93
10	0.87	1.16	1.22
15	0.26	0.29	0.26
20	0.098	0.097	0.083
30	0.021	0.018	0.014

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