On B_c meson hadroproduction at high energy

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Plan

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1 Introduction

Recently, B_c-mesons were observed experimentally at the Fermilab Tevatron $p\bar{p}$ collider [CDF 1998 and 2001]. At this energy ($\sqrt{S} = 1.8$ TeV) the total B_c-meson production cross section is not small (~ 1 nb), but it is small-x region ($x \sim M/\sqrt{S} \ll 1$) where the k_T-factorization approach [Gribov, Levin and Ryskin, 1983; Collins and Ellis, 1991; Catani, Ciafoloni and Hautmann, 1991; Fadin and Lipatov, 1996] is more adequate for describing the perturbative evolution of the gluon distribution function.

Resent calculations of the B_c- and $B_c^\star$-mesons hadroproduction were obtained in the collinear parton model using different approaches:

1. Fragmentation [Berezhnoy, Likhoded, 1995; Chen, 1996; Rückl, 1998; Saleev, D.V., 2004; ...]
2. Fusion [Kiselev, Likhoded, Onishchenko, 2000; Kolodziej, Rückl, 1995; Saleev, D.V., 2005; ...]
3. Charm excitation [Baranov, 1997; Saleev, D.V., 2004]

2 The k_T-factorization approach

Consideration of the small-x region ($x \ll 1$) or very high energies leads to the big logarithmic contribution $\sim (\alpha_s \log(1/x))^n$ in the resummation procedure, which is described by the BFKL evolution equation [Kuraev, Lipatov and Fadin, 1976; Balitsky and Lipatov, 1978] for an unintegrated gluon distribution function $\Phi(x, |\vec{k}_T|^2, \mu^2)$.

Accordingly the high energy factorization scheme or the k_T-factorization approach, the initial t-channel gluons have a transverse momentum and they are off-mass-shell. For the processes with the t-channel off-shell gluons were suggested the effective Feynman rules and the special trick for a choice of the initial gluon polarization 4-vector [Collins and Ellis, 1991]:

$$\varepsilon^\mu(k_T) = \frac{k_T^\mu}{|\vec{k}_T|}, \tag{1}$$

In the k_T-factorization approach, which generalizes the collinear parton model to the region of small x, the hadronic and partonic cross sections are related as follows:

$$\sigma^{\mathrm{KT}}(p+\bar{p}\to b+\bar{b}+X,s)=\int\frac{dx_1}{x_1}\int d|\vec{k}_{1T}|^2\int\frac{d\varphi_1}{2\pi}\Phi(x_1,|\vec{k}_{1T}|^2,\mu^2)\times$$
$$\times\int\frac{dx_2}{x_2}\int d|\vec{k}_{2T}|^2\int\frac{d\varphi_2}{2\pi}\Phi(x_2,|\vec{k}_{2T}|^2,\mu^2)\hat{\sigma}(R+R\to b+\bar{b},\vec{k}_{1T},\vec{k}_{2T},\hat{s}), \qquad (2)$$

where $\Phi(x,|\vec{k}_T|^2,\mu^2)$ is the unintegrated gluon distribution function in a proton (unintegrated refers to the transverse momentum), $k_i=x_ip_i+k_{i,T}$ is the 4-momentum of the initial **off-shell gluon**, $k_{i,T}=(0,\vec{k}_{i,T},0)$ is the transverse momentum of the initial gluon, $k_i^2\simeq-|\vec{k}_{i,T}|^2$, φ_i is the angle between the gluon transverse momentum and the fixed axis OX in the plane XOY, $\hat{s}=x_1x_2s-|\vec{k}_{1T}|^2-|\vec{k}_{2T}|^2$. In the numerical calculations we have used the following parameterizations for the unintegrated gluon distribution function in a proton: JB [Blumlein, 1995], JS [Jung and Salam, 2001] and KMR [Kimber, Martin and Ryskin, 2001].

- Resently, in the framework of Quasi-Multi-Regge kinematics (QMRK) [Fadin and Lipatov, 1989] the initial t-channel gluons are considered as Reggeons (or **reggeized gluons**) [Fadin and Lipatov, 1996] which are interacted with quarks and Yang-Mills on-shell gluons by the specific way. After that the Feynman rules for the effective theory with the nonabelian gauge invariant action, were derived for the following vertices [Antonov, Lipatov, Kuraev and Cherednikov, 2004]: Rgg, RRg, $RRgg$, $Rggg$ and $RRggg$.
- The squared amplitudes an the leading order (LO) of α_s which were obtained with **reggeizied gluons** or **off-shell gluons** in initial state have the same form [Saleev and D.V., 2003].
- Nowadays the NLO calculations in the framework of the k_T-factorization approach is open question.

3 Fragmentation and fusion formalisms

- In the region where $p_T \gg m_{B_c}$ ($p_T > 30$ GeV) fragmentation formalism could be used [Berezhnoy, Likhoded and Shevlyagin, 1995; Kolodziej, Leike and Rückl, 1995; Chang, 1995].

$$d\sigma(pp \to B_c X) = \sum_i \int dz D_{i\to B_c}(z) \cdot d\hat{\sigma}(pp \to i), \tag{3}$$

- The QCD evolution of the fragmentation function $D_{\bar{b}\to B_c}$ is described by the DGLAP [Gribov and Lipatov, 1972; Dokshitzer, 1977; Altarelli and Parisi, 1977] evolution equation

$$\mu^2 \frac{\partial D}{\partial \mu^2}(z, \mu^2) = \frac{\alpha_s(\mu^2)}{2\pi} \int_z^1 \frac{dx}{x} P_{q\to q}(\frac{x}{z}) D(x, \mu^2), \tag{4}$$

- Numerical calculations shows that QCD evolution of the fragmentation function adduce to small changes ($\sim 5\%$) at high p_T region in the p_T-spectra of the B_c-meson hadroproduction [Likhoded, Saleev and D.V., 2005].

- At the small p_T region the fusion formalism [Bodwin, Braaten and Lepage, 1995] could be used:

$$d\hat{\sigma}(\mathcal{H}) = \sum_n d\hat{\sigma}(Q\bar{Q}[n])\langle\mathcal{O}^{\mathcal{H}}[n]\rangle. \tag{5}$$

$$d\hat{\sigma}(a+b \to c\bar{b}[^{2S+1}L_J^{(1,8)}] \to B_c) = d\hat{\sigma}(a+b \to c\bar{b}[^1S_0^{(1)}, {}^3S_1^{(1)}])\frac{\langle\mathcal{O}^{B_c}[^1S_0^{(1)}, {}^3S_1^{(1)}]\rangle}{2N_c(2J+1)}. \tag{6}$$

The projectors on the spin-0 and spin-1 states reads [Kühn, Kaplan and Safiani, 1979]:

$$\Pi_0 = \frac{1}{\sqrt{8m^3}}\left(\frac{\hat{p}}{2} - \hat{q} - m\right)\gamma_5\left(\frac{\hat{p}}{2} + \hat{q} + m\right), \tag{7}$$

$$\Pi_1^\alpha = \frac{1}{\sqrt{8m^3}}\left(\frac{\hat{p}}{2} - \hat{q} - m\right)\gamma^\alpha\left(\frac{\hat{p}}{2} + \hat{q} + m\right). \tag{8}$$

- It is needed to calculate the process (36 diagrams):

$$g + g \to B_c + b + \bar{c}. \tag{9}$$

4 Model of charm excitation in a proton

There are two different approaches:

- Model of intrinsic charm [Brodsky, 1980; Brodsky and Peterson, 1981].
  - c-quark contribution to the wave function of a proton ($\sim 0.2\%$).
  - $\lim_{x\to 0} C^{\mathrm{int}}(x) = 0$.
- Model of new degrees of freedom excitation [Barger, Halzen and Keung, 1982].
  - $Q^2 \gg 2m_c^2$.
  - The QCD evolution of the c-quark distribution function is described by the DGLAP [Gribov and Lipatov, 1972; Dokshitzer, 1977; Altarelli and Parisi, 1977] evolution equation.
  - The GRV [Gluck, Reya and Vogt, 1995] and CTEQ [CTEQ Collaboration, 2000] parameterizations of the c-quark distribution function gave the same results in the B_c-meson hadroproduction processes.

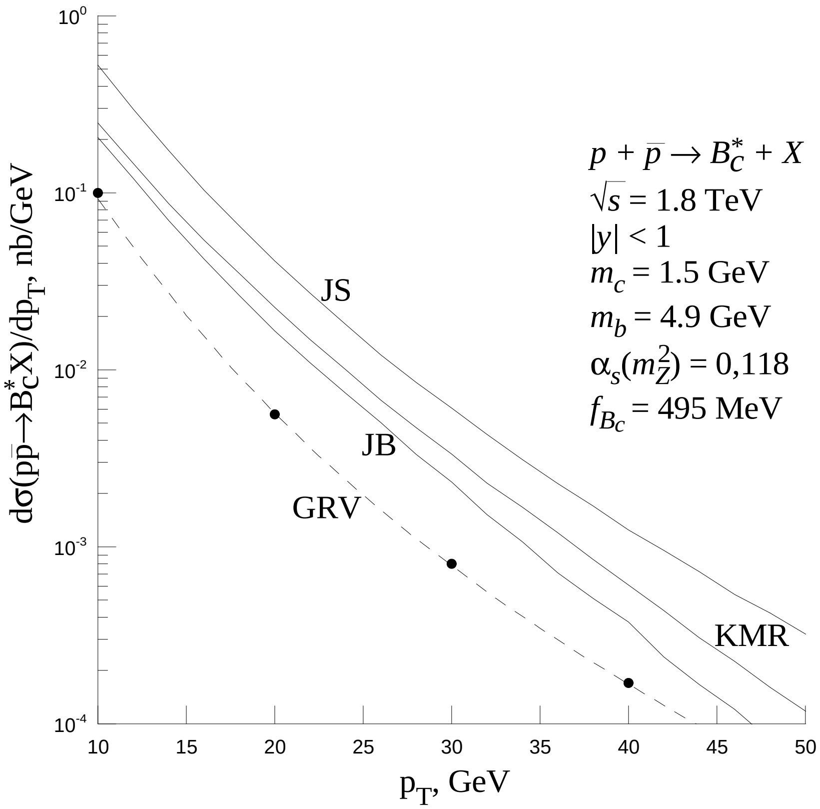

Figure 1: The $B_c^\star$ meson p_T-spectrum at $\sqrt{s} = 1.8$ TeV and $|y| < 1$ in the fragmentation model. The points show the results obtained by Cheung and Yuan in 1996.

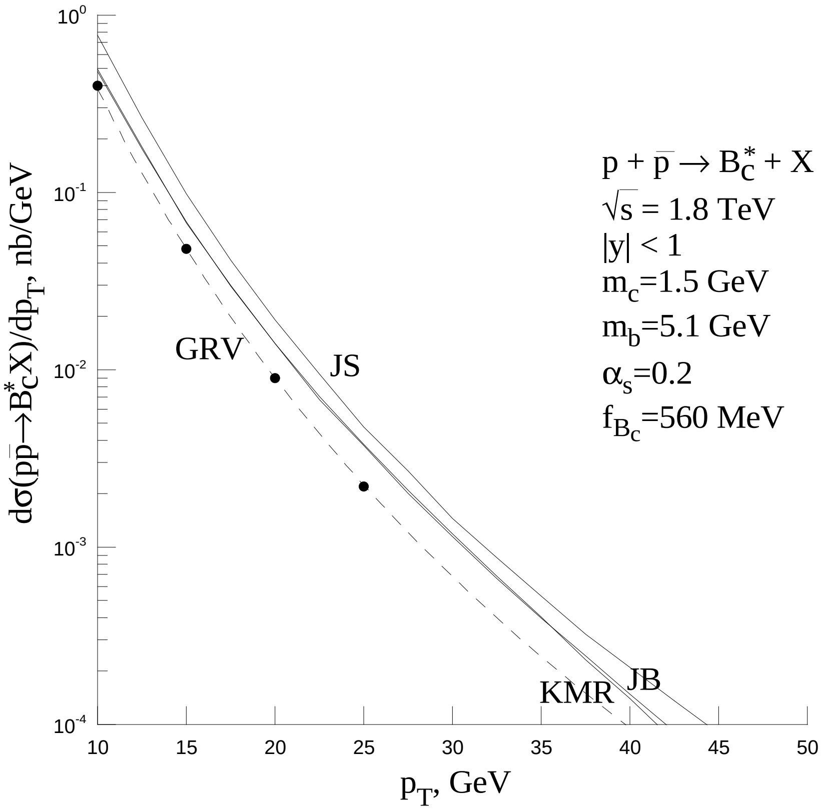

Figure 2: The $B_c^\star$ meson p_T-spectrum at $\sqrt{s} = 1.8$ TeV and $|y| < 1$ in the fusion model. The points show the results obtained by Berezhnoy, Kiselev and Likhoded in 1996.

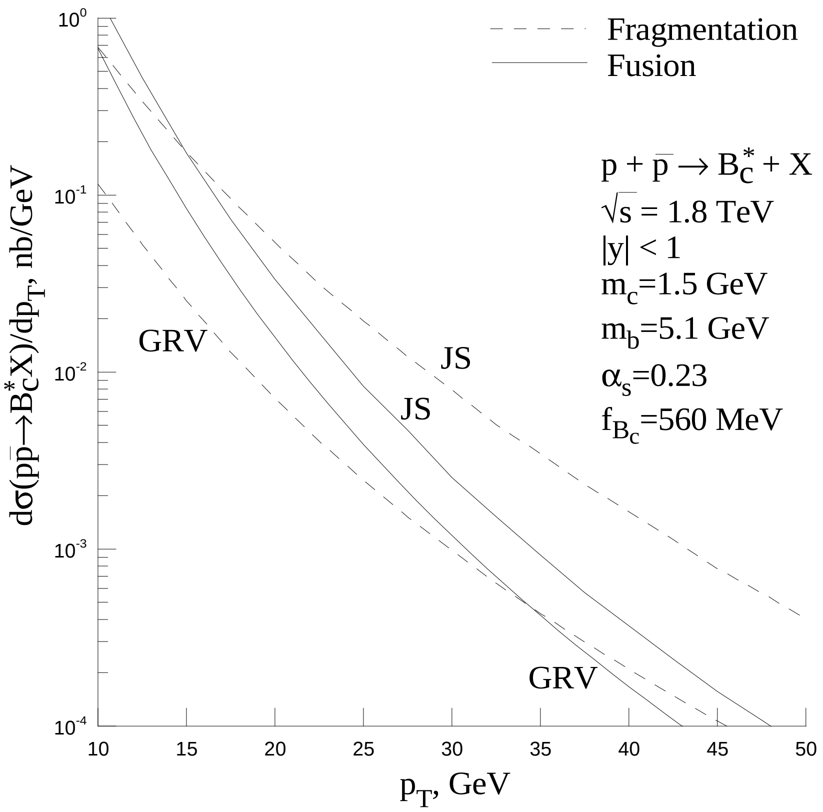

Figure 3: The $B_c^\star$ meson p_T-spectrum at $\sqrt{s} = 1.8$ TeV and $|y| < 1$ in different models.

Table 1: Total cross section of the B_c- and $B_c^\star$-meson production at Tevatron [CDF, 2001]. $\sqrt{S} = 1.8$ TeV, $|y| < 1$ and $p_{T,min} = 6$ GeV. All values of cross sections in nb.

Collinear model, fragmentation	Collinear model, fusion	The k_T-factorization, fragmentation	The k_T-factorization, fusion	Experimental data
1.7 ± 0.8	10.4 ± 6.3	7.4 ± 5.4	15.2 ± 9.7	10 ± 6

Table 2: Total cross section of the B_c- and $B_c^\star$-meson production at LHC. $\sqrt{S} = 14$ TeV, $|y| < 2.5$ and $p_{T,min} = 10$ GeV. All values of cross sections in nb.

Collinear model, fragmentation	Collinear model, fusion	The k_T-factorization, fragmentation	The k_T-factorization, fusion
28 ± 14	172 ± 105	122 ± 90	252 ± 160

5 Conclusion

- The collinear parton model and the k_T-factorization approach predict the same p_T dependence for B_c-meson hadroproduction processes.
- Results which were obtained in the framework of the model of charm excitation in a proton are coincides with well known results for real gluon-gluon fusion.
- The relative role of the fragmentation and fusion models is different in the k_T-factorization approach (fragmentation dominate at $p_T \geq 20$ GeV) and in the collinear parton model (fragmentation dominate at $p_T \geq 40$ GeV).
- The main uncertainties in the k_T-factorization approach comes from a different choice of the unintegrated gluon distribution functions.