B-meson hadroproduction cross sections and up-to-date models

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"...το της Πυθίας γραμμα φραζει τανυν."
Πλατων, Νομοι 923 α 5.

Abstract

The comparison of B-meson production cross sections as the results of PYTHIA code and Quark Gluon String Model (QGSM) is carried out for energies of proton colliders: $S_p(p)S$, Tevatron and LHC. Model predictions are based on the idea of supercritical Pomeron exchanges with the phenomenological intercept $\Delta_P(0)=0.3$ for heavy quark production. Transverse momentum spectra of B-mesons are also compared. It is shown that the cross sections calculated with PYTHIA using CTEQ structure functions are in a contradiction with the asymptotical estimation of $B\bar{B}$ production cross sections in QGSM. Asymmetries between the spectra of $B^0$ and $\bar{B}0$ mesons are also contradicting. The reasons of the difference are discussed.

\footnote{Plato, Laws, 923 a 5.}
1 Introduction

We can’t say that the complete knowledge on beauty quark pair production is obtained now, since the data we have on $b\bar{b}$ production cross sections are not yet sufficient. In order to monitor the model ideas on the phenomenon it seems useful to revise once in a while the collected data. Recently the results of several experiments \cite{1, 2, 3} carried out at two energies of colliding protons, 630 GeV and 1.8 TeV, are represented in the literature.

In this article the two of the models are compared: on the one hand - the phenomenological Quark-Gluon String Model \cite{4}, based on idea of hadronic amplitude duality and on the theory of supercritical Pomeron, on the other hand - the wide-spread Monte Carlo code PYTHIA \cite{5}, which includes the results of QCD perturbative diagram calculations.

The production cross sections arising with energy is a fact which was widely discussed in recent studies \cite{6, 10}. The theory of supercritical Pomeron postulates the rising as $s^{\Delta P(0)}$, where $\Delta P(0) = \alpha P(0) - 1$, $\alpha P(0)$ is the intercept of Regge trajectory of Pomeron.

The energy behavior of the production cross section in QCD perturbative approach are provided by the choice of gluon structure functions of interacting hadrons. Most of those functions, which are accepted now for MC simulations of high energy collisions, are built to approximate the recent data from HERA measured up to $x = 10^{-4}$. It should be noticed, that all known gluon structure functions which satisfied this recent data, can be taken for the modelling of $b\bar{b}$ production at LHC, because the value $10^{-4}$ is the very region of $x$ attributed for B meson production at 14 TeV due to the following estimation: $2m_{B}/(14 TeV) \sim 10^{-4}$. One of those appropriate gluon distributions is CTEQ structure function, which is involved into PYTHIA code as default distribution.

2 Parameters defining the B-meson production cross sections in QGSM.

The major parameter of QGSM which defines the cross section dependence on energy is $\Delta P(0)_{eff}$, which have to be less than the same value for one Pomeron exchange, because multipomeron diagrams or branches should be taken into account in the calculations. This parameter depends on the mean value of transverse momenta transmitted in the process. Therefore the energy dependences of different mass particle production cross section
must be led by different $\Delta_P(0)_{eff}$. 

![Figure 1](image)

Figure 1: The $\Delta(Q^2)$ dependence obtained in H1 and one Pomeron exchange approximation (the solid line).

The $\Delta_P(0)(Q^2)$-dependence can be illustrated well with the data obtained in H1 experiment at HERA. The Pomeron exchange plays an important role in electron-proton collisions too. The multihadron production takes place in this process due to the Pomeron exchange between photon and beam proton. The $\Delta(Q^2)$ data are shown in Fig. , where each point was extracted from measured $F_2(x, Q^2)$ function by the approximation with the simple dependence: $F_2 \sim x^{-\Delta(Q^2)}$.

It should be noticed that the theoretical curve was calculated under the assumption of one Pomeron exchange which doesn’t include the branches as against the proton-proton interaction. The QGSM scheme for heavy meson production have to be similar to the one Pomeron exchange pattern due to the energy conservation reasons. So we can take for the $\Delta_{eff}$ the value 0.3 corresponding to the H1 data approximation at $Q^2 = (2m_B)^2$. It’s worth being stressed here, that this value differs from $\Delta_{ eff}=0.12$ which
was chosen for light quark meson production in early papers [10].

Another Regge trajectory parameter is important for model description of inclusive cross sections of B meson pair production, it’s \( \alpha_{\Upsilon}(0) \), the intercept of \( b\bar{b} \)-trajectory. It provides the increasing cross section at the energy region close after the B pair production threshold. There are various opinions about the value of this parameter. From the point of view of QGSM it may vary in the range of \(-16 \div 0 \) [10]. The other authors prefer to take \( \alpha_{\Upsilon}(0) = -9 \) [8].

The value \( \alpha_{\Upsilon}(0) = -16 \) will be taken here for to estimate the upper limit of growing cross section when it increases rapidly after the threshold. The parameter discussed above exists in the functions of fragmentation of quark-gluon strings into each sort of B-mesons. Those functions are written in QGSM according to the rules fulfilled by the Regge asymptotics [9].

For example, the function for d quark string fragmentation into \( B^+ \) contains the following factors:

\[
D_d^{B^+}(z) = \frac{a_0^B}{z}(1 - z)^{-\alpha_{\Upsilon}(0)\alpha_{\Upsilon}(0) + \lambda(1 + a_1^B z^2)},
\]

where \( a_0^B \) is the density parameter for fragmentation of quark-gluon string into B-mesons. The \( a_1^D \) is the parameter of string fragmentation asymmetry introduced in [10] to provide a transition between probabilities of the B production at \( z \to 0 \) and \( z \to 1 \). The value \( a_1^B \) can be of the order 10 and actually doesn’t impact on the value of B production cross section at energies higher than 1.8 TeV.

The calculations of \( p_\perp \) spectra of produced hadrons are also available in the framework of QGSM, as it had been done already in [12] for \( \pi \)-mesons. The spectra can be described up to the momenta of order few GeV/c in this substantially nonperturbative model. The distributions were of exponential character at low \( p_\perp \) in this approach. Therefore the transverse momenta distributions for heavy flavor particles was not elaborated in this model.

3 PYTHIA machinery

The version PYTHIA 5.7 was taken to calculate the spectra of B-mesons at three energies of colliding protons: 630 GeV, 1.8 TeV and 14 TeV. The CTEQ gluon structure function [11] are used in this version to describe the increasing cross sections. On the one hand the process of production of
such heavy quarks as \( b \) is good enough for being described by perturbative QCD diagram with gluon-gluon fusion. On the other hand, more and more low \( x \) gluons are involved into this process at energy rising and cross section becomes dependent on the accuracy of gluon structure function measured at low \( x \).

As it was mentioned in Introduction, we have precise data on \( F_2 \) due to HERA experiments up to \( x \sim 10^{-4} \), what is enough for the calculation of \( b\bar{b} \) production at LHC energies. Such a way CTEQ structure functions have to provide the right description of increasing cross sections of \( b\bar{b} \) pair production.

However, \( b \) quarks can be obtained not only in gluon fusion process. Two additional ways exist to produce \( b\bar{b} \) pair, they are: gluon splitting \( gg \rightarrow gg \), where gluons gives \( b\bar{b} \) pair in the next- to-leading order of corrections, and heavy flavor exitation \( Q_i g \rightarrow Q_i g \). In PYTHIA this subprocesses are taken into account with massless matrix elements. It is a problem how to sum the resulting distributions from such different deposits.

![Figure 2: Transverse momenta distributions of B-mesons fitted with PYTHIA.](image)
It makes the $p_\perp$-spectra at 1.8 Tev comparable with the data obtained in CDF experiment (see Fig.). At the same time there is not good description of UA1 data. It looks like the $p_\perp$ spectra were increased with additional fractions only by a factor and there is not any difference between the patterns of spectra for different subprocesses. It leads to rather flat form of transverse momentum distributions in PYTHIA and to small total cross section of B production at various energies.

4 Comparison of cross section energy dependences

The resulting energy dependences of production cross section are shown on Fig. for PYTHIA program and for QGS model as well.

![Graph showing energy dependences of B-meson cross section.](image)

Figure 3: Energy dependences of B-meson cross section.

As it was mentioned above the QGSM curve is highest as it is possible in this model after the normalisation to the CDF cross section. But latter was obtained due to PYTHIA (see Fig.). Thus the point where both curves
are crossing is rather conventional and depends on the form of $p_\perp$-spectra at low transverse momenta accepted in PYTHIA.

5 PYTHIA and QGSM predictions for the asymmetry between $B^0/\bar{B}^0$ spectra

It would be interesting to consider the leading effect in the spectra of B-mesons at various energies. The valuable asymmetry between $B^0$- and $\bar{B}^0$-meson spectra at LHC energy will be important for CP violation measurements. The recent prediction of the $y$ dependence of such leading/nonleading asymmetry [13] provided with PYTHIA simulations gives zero value of $A(y)$ in wide range of $y$ at the central region (see Fig.).

![Figure 4: $B^0/\bar{B}^0$ asymmetries at LHC energy given by PYTHIA and by QGS model; the value $\Delta_{eff}=0.3$ corresponds to the production of the mass of B-meson.](image)

The $A(y)$ dependence in fragmentation region $x_F \rightarrow 1$ contradicts with all similar asymmetry measurements for D-meson spectra [15, 16, 17, 14]. The intersection of inclusive spectra of different type of B-mesons gives
the asymmetry passing through zero at some $y_0$, while the measured spectra of leading particles are always higher than nonleading particle spectra, so the asymmetry is positive value. In opposite to PYTHIA predictions, the asymmetry calculated in the framework of QGSM is rising function up to $x_F \to 1$. This behavior is usually peculiar for the string approach because of so called ”beam drag” effect. The valuable asymmetry in central region given in QGSM prediction [18] is not enough small for not to be taken into account at CP violation measurements. It looks important to consider both these predictions in details and to discuss the probability of nonzero asymmetry in the production spectra at LHC energy.

6 Conclusions

We have compared two approaches for the understanding of the heavy flavored particle production: one of them is mostly perturbative and another one is nonperturbative at all. This comparison shows that some different suggestion has to be done for low transverse momenta distributions of $B$-mesons to put into agreement the both model predictions at LHC energy. The contradicting dependences for $B^0/\bar{B}^0$ asymmetry in the $B$ meson production spectra might be important for the CP violation measurements.

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