Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics B 911 (2016) 36–51

NUCLEAR PHYSICS B

www.elsevier.com/locate/nuclphysb

Relativistic corrections to the pair B_c-meson production in e^+e^- annihilation

A.A. Karyasov, A.P. Martynenko *, F.A. Martynenko

Samara University, Moskovskoye Shosse 34, 443086, Samara, Russia

Received 2 May 2016; received in revised form 1 July 2016; accepted 31 July 2016

Available online 4 August 2016

Editor: Hong-Jian He

Abstract

Relativistic corrections to the pair B_c-meson production in e^+e^--annihilation are calculated. We investigate a production of pair pseudoscalar, vector and pseudoscalar+vector B_c-mesons in the leading order perturbative quantum chromodynamics and relativistic quark model. Relativistic expressions of the pair production cross sections are obtained. Their numerical evaluation shows that relativistic effects in the production amplitudes and bound state wave functions three times reduce nonrelativistic results at the center-of-mass energy $s = 22$ GeV.

1. Introduction

In recent years, one of the important centers of research in the quark physics was the study of the mechanisms of heavy quarkonium production in electron–positron annihilation, and at the Large Hadron Collider. Such studies allow us to test the Standard Model, to clarify the values of fundamental parameters of the theory, to test theoretical models used for a description of heavy quark bound states in quantum chromodynamics. One of the important reactions that occur in the electron–positron annihilation is the pair production of heavy quarkoniums and diquarks [1,2]. In the study of such reactions it has been found what significantly increases the role of the theory

* Corresponding author.
E-mail address: a.p.martynenko@samsu.ru (A.P. Martynenko).

http://dx.doi.org/10.1016/j.nuclphysb.2016.07.034

of the formation of bound quark states, namely, how originally appeared two quarks and two anti-quarks at small distances then combine into mesons. It has been shown that it is impossible to achieve a good description of experimental data without accounting effects of relative quark motion [3–12]. A system ($\bar{b}c$) with open beauty and charm has a special place among the heavy quarkoniums since its decay mechanism differs significantly from the decay mechanism of charmonium or bottomonium. At that time, as the pair charmonium and bottomium production in electron–positron annihilation already studied both theoretically and experimentally [2,13,14], the production of a pair of B_c mesons is studied much less. It has its own specific features. The research of B_c meson production will extend quantitative understanding of quantum chromodynamics, the check of the bound state theory of quarks with different flavors.

This work continues the series of our works on exclusive double charmonium production in e^+e^- annihilation to the case of B_c-meson production. The mechanism of pair B_c meson production in electron–positron annihilation is more simple in comparison with other reactions of proton–proton interaction. Our approach to the calculation of the observed cross sections for pair production of mesons is based on methods of relativistic quark model (RQM) and perturbative quantum chromodynamics [8,15–21]. This approach allows a systematic account of relativistic effects as in the construction of relativistic amplitudes of pair production of mesons, relativistic production cross sections, and in the description of bound states of quarks themselves through the use of the corresponding quark interaction potential. In general, this approach creates a microscopic picture of the interaction of quarks at different stages of meson production. It also allows you to perform a self-consistent calculation of numerous parameters that define the cross section for meson production, from relativistic parameters determining the movement of heavy quarks, to the masses themselves of quark bound states. We can say that one of the main problems of the theory of strong interactions – a significant increase in the phenomenological parameters of various types, is solved in this case within the model. The aim of our work is to extend previously used methods for pair charmonium production to the case of quarks of different flavors. The question naturally arises of whether there can be the pair B_c meson production processes in electron–positron annihilation quite probable that they can be observed in the experiment. In our work we try to show that the process of pair production of B_c mesons has a clear experimental prospect.

2. General formalism

Two production amplitudes of the B_c meson pair in leading order of the QCD coupling constant α_s are presented in Fig. 1. Two other amplitudes can be obtained by corresponding permutations. There are two stages of B_c meson production process [22,23]. At the first process step, which is described by perturbative QCD, the virtual photon γ^* and then virtual gluon g^* produce two heavy quarks (bc) and two heavy antiquarks ($\bar{b}\bar{c}$) with the following four-momenta:

$$p_1 = \eta_1 P + p,\ p_2 = \eta_2 P - p,\ (p \cdot P) = 0,\ \eta_i = \frac{M^2_{B_{\bar{b}c}} \pm m_1^2 \mp m_2^2}{2M^2_{B_{\bar{b}c}}}, \tag{1}$$

$$q_1 = \rho_1 Q + q,\ q_2 = \rho_2 Q - q,\ (q \cdot Q) = 0,\ \rho_i = \frac{M^2_{B_{b\bar{c}}} \pm m_1^2 \mp m_2^2}{2M^2_{B_{b\bar{c}}}}$$

where $M_{B_{\bar{b}c}}$ is the mass of pseudoscalar B_c^+ or vector B_c^{*+} meson consisting of $\bar{b}$-antiquark and c-quark. $P(Q)$ are the total four-momenta of mesons B_c^+ and B_c^{*-}, relative quark four-momenta