Double heavy quarkonium production in electron-positron annihilation at energy $\sqrt{s}$= 10.6 GeV

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In this work we study the exclusive production process $e^- + e^+ \rightarrow J/\psi + \eta_c$ at energy $\sqrt{s} = 10.6GeV$ observed at B-factories whose measurements have recently been done by Babar and Belle groups [1]. It is well known that there was a significant discrepancy between the experimental measurements [1] and the non-relativistic QCD (NRQCD) predictions for this process at centre of mass energies $\sqrt{s} \approx 10.6GeV$. This process has been studied in a Bethe-Salpeter formalism under Covariant Instantaneous Approximation (CIA) [2,3]which is a Lorentz- invariant generalization of Instantaneous Approximation (IA).

We now calculate the cross section for the process $e^- + e^+ \rightarrow J/\psi + \eta_c$ for which our results are comparable with the data[1]. There are four Feynman diagrams in the leading order (LO) of QCD for the process $e^+ + e^- \longrightarrow J/\Psi + \eta_c$. One of these is depicted in Fig.1. The other three diagrams can be obtained by permutations. The adjoint 4D BS wave functions for η_c meson is $\overline{\Psi}(P_b, q_b) = S_F(-q_2)\Gamma^P(\widehat{q_b})S_F(q_4)$ and for J/ψ meson is $\overline{\Psi}(P_a, q_a) = S_F(-q_3)\Gamma^V(\widehat{q_a})S_F(q_1')$ where q_a, q_b are the internal momenta of the hadrons J/Ψ and η_c respectively with the corresponding hadron-quark vertex functions Γ^V and Γ^P [2,3,4,5].

The details of momentum labeling of one of the Feynman diagrams contributing to this process is shown in Fig. 1 below. Using Feynman rules, one can obtain the amplitude for each of the diagrams. The amplitude corresponding to process in Fig.1 is given by

$$M_1 = \frac{c\delta_{\mu\nu} e e_Q g_s^2}{s}\overline{v}(p_2)\gamma_\mu u(p_1)\int d^4q_a d^4q_b \times Tr[S_F(-q_3)\Gamma_v(\hat{q_a})S_F(q_1')\gamma_\beta S_F(q_1) \gamma_\nu S_F(-q_2)\Gamma_p(\hat{q_b})S_F(q_4)\gamma_\alpha]\frac{\delta_{\alpha\beta}}{k^2} \quad (1)$$

where c $=\frac{4}{3}$ is the color factor, the Mendelstam variable s is defined as, $s = -(p_1 + p_2)^2$ and $e_Q = 2e/3$ is the electric charge of the charmed quark. In the heavy quark limit, total hadron momentum, $P \sim M$ and internal momentum $q << M$. In this limit, we can express the amplitude M_1 as

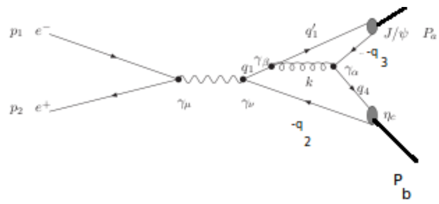

FIG. 1: Momentum labeling of one of the Feynman diagrams contributing to this process

$$M_1 = \frac{-2^{14}\pi^2\alpha_{em}\alpha_s m_c^3}{3^2 s^3}\epsilon_{\alpha\mu\lambda\sigma}\varepsilon_\alpha P_{b\lambda}P_{a\sigma}[\overline{v}(p_2)\gamma_\mu u(p_1)]\xi_a\xi_b. \quad (2)$$

Here N_p and N_v in $\xi_{a,b}$ (see Ref.[2] for details)are the BS normalizers for η_c and J/ψ respectively which are evaluated by using the current conservation condition. The values of BS normalizers thus obtained for J/ψ and η mesons are $N_v = .0504GeV^{-3}$ and $N_P = .0410GeV^{-3}$ respectively. The total amplitude for the process $e^+e^- \longrightarrow J/\Psi\eta_c$ can be obtained by summing over the amplitudes of all the four diagrams contributing to this process. The unpolarized total cross section is obtained by summing over various J/Ψ spin-states and averaging over those of the initial state e^+e^-. Thus, in the CM frame the total cross section, σ, is given by [2]

$$\sigma = \frac{2^{30}\pi^3\alpha_{em}^2\alpha_s^2 m_c^6}{83^5 s^4}(1-\frac{16m_c^2}{s})^{\frac{3}{2}}\xi_a^2\xi_b^2. \quad (3)$$

In this paper we have calculated the cross section of the exclusive process of $e^+e^- \longrightarrow J/\Psi\eta_c$ at energy $\sqrt{s} = 10.6GeV$ in the framework of BSE under CIA [2] using only the leading order (LO) diagrams in QCD. We find the theoretical value of $\sigma[e^+e^- \longrightarrow J/\Psi\eta_c] = 21.75fb$ (for details see [2]), which is broadly in agreement with the Babar's data $\sigma[e^+e^- \longrightarrow J/\Psi\eta_c] = (17.6 \pm 2.8 \pm 2.1)fb$ and the Belle's data, $\sigma[e^+e^- \longrightarrow J/\Psi\eta_c] = (25.6 \pm 2.8 \pm 3.4)fb$[1].

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