Excited charmonium mesons production in e^+e^- annihilation at $\sqrt{s} = 10.6$ GeV

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In this paper the production of excited vector and pseudoscalar charmonium mesons in e^+e^- annihilation is analyzed in the framework of the light cone. In particular the cross sections $e^+e^- \to \psi(2S)\eta_c(1S)$, $\psi(1S)\eta_c(2S)$, $\psi(2S)\eta_c(2S)$ have been calculated. It is shown that contrary to NRQCD, the cross sections calculated in the framework of the light cone agree with experimental data.

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I. INTRODUCTION

J/ψ, η_c mesons production in e^+e^- annihilation at energy $\sqrt{s} = 10.6$ GeV remains a very interesting task for theoretical investigations. The cross section of the process $e^+e^- \to \psi\eta_c$ measured at the Belle experiment was first presented in Ref. [1]. The lower bound of the cross section measured at Belle

$$\sigma(e^+e^- \to \psi\eta_c) > 33 \text{ fb}$$

is about an order of magnitude higher, than the theoretical predictions [2] obtained in the framework of NRQCD [3]. Some efforts were made to explain this discrepancy. For example, in [4] it was assumed that some of Belle's $J/\psi\eta_c$ signal could actually be $J/\psi J/\psi$ events but later in [5,6] it was shown that QCD corrections decrease the value of the $e^+e^- \to J/\psi J/\psi$ cross section and subsequent Belle analysis [7] excluded this possibility completely. Among the other possible explanations the contributions from glueball [8] or color-octet states. See also a complete review of the Quarkonium Working Group [9] and references therein.

There was hope for the improvement of theoretical prediction by higher order QCD corrections. As was shown in Ref. [10], QCD corrections really increase the cross section by a factor of 1.8, but this is still insufficient to reach the experimental results obtained at Belle.

Recently a surprisingly simple solution of this problem was found. It turns out that by taking into account the intrinsic motion of quarks inside charmonium mesons, one can significantly increase the value of the cross section. This effect was first observed in the framework of the light cone expansion method in Refs. [11,12]. In Ref. [13] this effect was considered as the expansion of the amplitude in relative velocity of quark inside mesons.

In the last paper it was proved that NRQCD series for the amplitude of the process $e^+e^- \to \psi\eta_c$ in relative velocity of quark-antiquark pairs in the ψ, η_c mesons converges slowly (in potential models relative velocity for these mesons is $v \sim 0.5$ [14]). The reason for such behavior is due to the strong dependence of quark and gluon propagators in the diagrams of the process from the relative momentum of quark-antiquark pairs in mesons. In order to show that this effect really takes place for the process $e^+e^- \to \psi\eta_c$, the amplitude was expanded in a relative velocity series (except the propagators of intermediate particles for which the exact expression was used). The resulting NRQCD prediction is multiplied by the factor that represents internal motion of quark-antiquark pairs inside mesons and the cross section becomes in 2–5 times greater than that in the framework of NRQCD, depending on the width of the wave function used. Thus one can conclude that the usage of the leading approximation of NRQCD proved to be unreliable for $e^+e^- \to \psi\eta_c$ at energy $\sqrt{s} = 10.6$ GeV.

As it was mentioned already, the other method that can be used for theoretical prediction of cross section of the process $e^+e^- \to \psi\eta_c$ is the light cone expansion method. The cross section calculated in the framework of the light cone does not contradict to the experiment data. Unfortunately in Refs. [11,12] this method was used only for the calculation of the $e^+e^- \to \psi\eta_c$ cross section. It would be interesting to see how this method works in other reactions measured at the experiments. For instance, in addition to the process $e^+e^- \to \psi\eta_c$, Belle collaboration has measured the cross sections of the processes $e^+e^- \to \psi(2S)\eta_c$, $\psi\eta_c(2S)$, $\psi(2S)\eta_c(2S)$, $\psi\chi_{c0}$, $\psi(2S)\chi_{c0}$ [15]. Lately the *BABAR* experiment has measured the cross sections of the processes $e^+e^- \to \psi\eta_c$, $\psi\eta_c(2S)$, $\psi\chi_{c0}$ [16]. In the frame work of NRQCD these processes were considered in Ref. [2]. As in the case of $e^+e^- \to \psi\eta_c$, Belle and *BABAR* results are in contradiction with NRQCD predictions. In our paper we will consider leading order contribution to the processes $e^+e^- \to \psi(2S)\eta_c$, $\psi\eta_c(2S)$, $\psi(2S)\eta_c(2S)$ in the framework of the light cone. As to the processes $e^+e^- \to \psi\chi_{c0}$, $\psi(2S)\chi_{c0}$ we will argue that the leading order contribution to the cross section in $1/s$ series is much less than next-to-leading order (NLO). We are going to calculate the NLO contribution in our forthcoming publication.

This paper is organized as follows. The next section is devoted to the consideration of the processes $e^+e^- \to \psi(2S)\eta_c$, $\psi\eta_c(2S)$, $\psi(2S)\eta_c(2S)$ in the framework of the

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light cone. In Sec. III we argue that light cone LO contribution to the cross sections $e^+e^- \to \psi\chi_{c0}, \psi(2S)\chi_{c0}$ is much less than the NLO one. In the last section we summarize our results.

II. THE PROCESSES $e^+e^- \to \psi\eta_c, \psi(2S)\eta_c, \psi\eta_c(2S), \psi(2S)\eta_c(2S)$.

In this section the processes $e^+e^- \to VP$, where $V = \psi(1S), \psi(2S)$, $P = \eta_c(1S), \eta_c(2S)$ will be considered. The cross section of the process can be written as follows:

$$\sigma(e^+e^- \to VP) = \frac{\pi\alpha^2 q_c^2}{6}\left(\frac{2|\mathbf{p}|}{\sqrt{s}}\right)^3 |F_{vp}|^2, \tag{1}$$

where $\sqrt{s}$ is the invariant mass of the e^+e^- system, p is the momentum of the final mesons in the center mass frame. The form factor F_{vp} is defined in the following way:

$$\langle V(p_1, \lambda), P(p_2)|J_\mu|0\rangle = \epsilon_{\mu\nu\rho\sigma} e^\nu p_1^\rho p_2^\sigma F_{vp}. \tag{2}$$

The asymptotic behavior of form factor F_{vp} with mesons in the final state can be obtained from the following formula [17]:

$$\langle M(p_1, \lambda_1) M(p_2, \lambda_2)|J_\mu|0\rangle \sim \left(\frac{1}{\sqrt{s}}\right)^{|\lambda_1 - \lambda_2|+1}. \tag{3}$$

Obviously in the case $M(p_1, \lambda_1) = V(p_1, \lambda), M(p_2, \lambda_2) = P(p_2)$, the helicity $\lambda_2 = 0$. As to the helicity λ_1 it is seen from formula (2) that vector meson V is transversely polarized $\lambda_1 = \pm 1$. So the asymptotic behavior of the amplitude is

$$\langle V(p_1, \lambda), P(p_2)|J_\mu|0\rangle \sim 1/s, \tag{4}$$

or $F_{vp} \sim 1/s^2$ is the asymptotic behavior of the form factor.

Two diagrams that give contributions to the amplitude of the processes under consideration are presented in Fig. 1. The other two diagrams can be obtained from the depicted ones by charge conjugation. The leading order contribution to the form factor was first obtained in Refs. [11,12] where the process $e^+e^- \to \psi\eta_c$ was considered. In our paper we follow Ref. [12]. In deriving the expression for the form factor F_{vp} in Ref. [12], the mass difference of the final mesons ψ and η_c was disregarded. The mass difference of ψ and η_c mesons is about ~100 MeV and this value cannot give a large correction to the cross section. But if, for instance, $\psi(2S)$ and η_c mesons are considered, the mass difference is about ~700 MeV. As it will be seen from the subsequent analysis, this value is large enough to give a large correction to the cross section under consideration. So we have derived the formula for the form factor by taking into the account different masses of final mesons. The expression for the form factor F_{vp} can be written as follows:

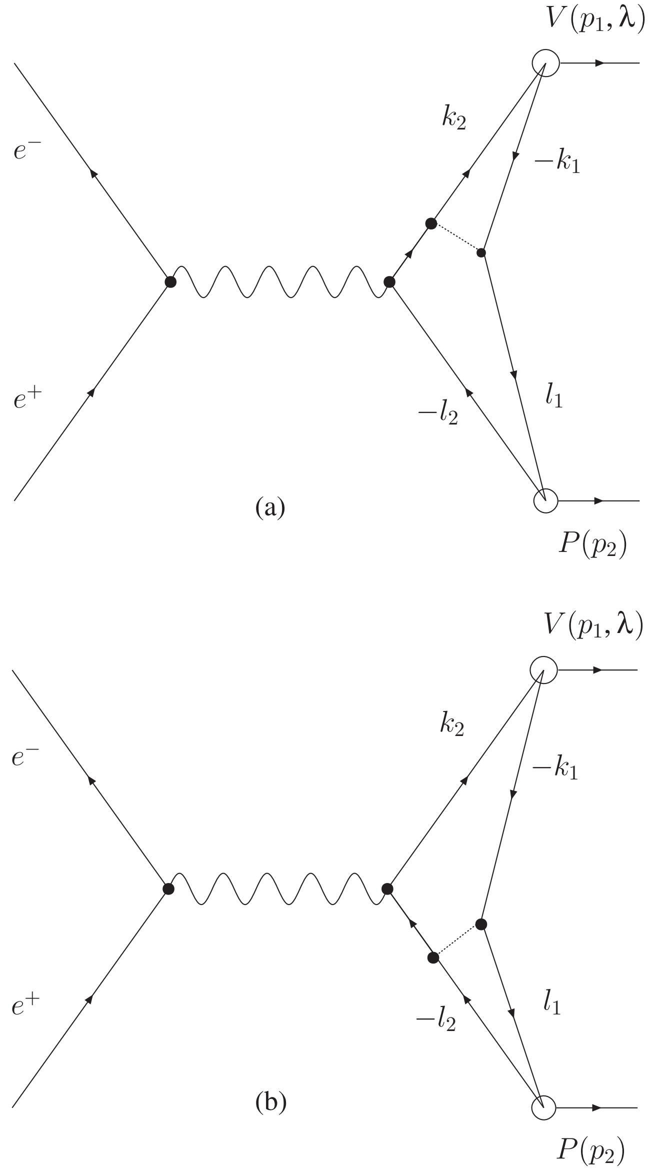

FIG. 1. The diagrams for the pair charmonium mesons production in e^+e^- annihilation.

$$|F_{vp}(s)| = \frac{32\pi}{9}\left|\frac{f_V f_P M_P M_V}{q_0^4}\right| I_0, \tag{5}$$

$$\begin{aligned} I_0 = \int_0^1 dx_1 \int_0^1 dy_1 \alpha_s(k^2)\bigg\{ & \frac{M_P}{M_V^2}\frac{Z_t Z_p V_T(x) P_P(y)}{d(x,y)s(x)} \\ & - \frac{1}{M_P}\frac{\overline{M}_Q^2}{M_V^2}\frac{Z_m^\sigma Z_t V_T(x) P_A(y)}{d(x,y)s(x)} + \frac{1}{2M_P}\frac{V_L(x)P_A(y)}{d(x,y)} \\ & + \frac{1}{2M_P}\frac{(1-2y_1)}{s(y)}\frac{V_\perp(x)P_A(y)}{d(x,y)} \\ & + \frac{1}{8}\left(1 - Z_t Z_m^k \frac{4\overline{M}_Q^2}{M_V^2}\right)\frac{1}{M_P}\frac{(1+y_1)V_A(x)P_A(y)}{d^2(x,y)}\bigg\}. \end{aligned}$$

Where $q_0^2 \simeq (s - M_V^2 - M_P^2)$, $P_A, P_P, V_T, V_L, V_\perp, V_A$ are the light cone wave functions defined in [12], M_V, M_P are the mass of the vector and pseudoscalar mesons correspondingly, $\overline{M}_Q = M_Q^{\overline{MS}}(\mu = M_Q^{\overline{MS}})$, Z_t and Z_p are the renormalization factors of the local tensor and pseudoscalar currents, $d(x, y)$, $s(x)$, $s(y)$ are defined as follows:

$$d(x, y) = \frac{k^2}{q_0^2} = \left(x_1 + \frac{\delta}{y_1}\right)\left(y_1 + \frac{\delta}{x_1}\right), \qquad \delta = \left(Z_m^k \frac{\overline{M}_Q}{q_0}\right)^2,$$

$$s(x) = \left(x_1 + \frac{(Z_m^\sigma \overline{M}_Q)^2}{y_1 y_2 q_o^2}\right), \qquad s(y) = \left(y_1 + \frac{(Z_m^\sigma \overline{M}_Q)^2}{x_1 x_2 q_o^2}\right),$$

$$Z_p = \left[\frac{\alpha_s(k^2)}{\alpha_s(\overline{M}_Q^2)}\right]^{-3C_F/b_o}, \qquad Z_t = \left[\frac{\alpha_s(k^2)}{\alpha_s(\overline{M}_Q^2)}\right]^{C_F/b_o},$$

$$Z_m(\mu^2) = \left[\frac{\alpha_s(\mu^2)}{\alpha_s(\overline{M}_Q^2)}\right]^{3C_F/b_o}, \qquad M_Q(\mu^2) = Z_m(\mu^2) M_Q,$$

$$Z_m^k = Z_m(k^2), \quad Z_m^\sigma = Z_m(\sigma^2),$$

where $M_Q(\mu^2)$ is the running MS-mass, $C_F = 4/3$, $b_o = 25/3$, $k = (k_1 + l_1)$ is virtual gluon momentum, $\sigma = -k_1 - l_1 - l_2$ is virtual quark momentum in Fig. 1(b). For the light cone wave functions $P_A, P_P, V_T, V_L, V_\perp, V_A$ of $1S$ state mesons, we will use the expressions proposed in Ref. [12]:

$$\phi_i(x, v^2) = c_i(v^2)\phi_i^a(x)\left\{\frac{x_1 x_2}{[1 - 4x_1 x_2(1 - v^2)]}\right\}^{1-v^2} \tag{6}$$

where v is a characteristic speed of quark-antiquark pairs in mesons, c_i is the coefficient which is fixed by the wave function normalization $\int dx \phi_i(x, v^2) = 1$, ϕ^a is the asymptotic expression for the wave function.

In order get the wave functions of $2S$ states, the following procedure will be used. We recall that the $2S$ state Coulomb wave function has the form:

$$\Psi_{2S}(r) \sim (1 - q_0 r)\exp(-q_0 r) = \left(1 + q_0 \frac{d}{dq_0}\right)\Psi_{1S}(r), \tag{7}$$

where $q_0 = q_B/2$ is the mean momentum of a quark inside a meson, $\Psi_{1S}(r)$ is the $1S$ Coulomb wave function with Born momentum equals q_0. In momentum space the $2S$ wave function has the form

$$\phi(p) \sim \left(1 + q_0 \frac{d}{dq_0}\right)\frac{1}{(p^2 + q_0^2)^2} = \frac{p^2 - 3q_0^2}{(p^2 + q_0^2)^2}. \tag{8}$$

The $2S$ wave function (8) has zero at $p^2 = 3q_0^2$. Obviously this zero has nothing to do with real zero of the $c\bar{c}(2S)$ meson wave function. In order to connect the wave function (8) with a more realistic model, we replace $1 + q_0 \frac{d}{dq_0}$ by $1 + \beta q_0 \frac{d}{dq_0}$. The constant β is fixed by the condition that zero of the modified wave function must coincide with zero obtained from the solution of Schrodinger equation with potential [14]. Thus we obtain $\beta = 0.38$. Now it is easy to find the wave function of $2S$ state:

$$\phi(p) \sim \left(1 + \beta q_0 \frac{d}{dq_0}\right)\left\{\frac{x_1 x_2}{[1 - 4x_1 x_2(1 - v^2)]}\right\}^\alpha = \left(1 - 8v^2\beta \frac{\alpha x_1 x_2}{[1 - 4x_1 x_2(1 - v^2)]}\right) \times \left\{\frac{x_1 x_2}{[1 - 4x_1 x_2(1 - v^2)]}\right\}^\alpha \tag{9}$$

The constant α equals unity in the case of the usual Coulomb wave function. In Ref. [12], the constant α was taken to be $1 - v^2$ (6), since this value allows one to link different behaviors of the wave function: $v \to 0$ and $v \to 1$. In our analysis we will take the same value of this constant. Finally, one gets the light cone wave functions $P_A, P_P, V_T, V_L, V_\perp, V_A$ of $2S$ state mesons

$$\phi_i(x, v^2) = c_i(v^2)\phi_i^a(x)\left(1 - 8v^2\beta \frac{(1 - v^2)x_1 x_2}{[1 - 4x_1 x_2(1 - v^2)]}\right) \times \left\{\frac{x_1 x_2}{[1 - 4x_1 x_2(1 - v^2)]}\right\}^{1-v^2} \tag{10}$$

The asymptotic expressions for the wave function ϕ^a are given as follows for the leading twist 2 wave functions:

$$P_A(x) = V_L(x) = V_T(x) = \phi^a(x) = 6x_1 x_2, \tag{11}$$

for the nonleading twist 3 wave functions:

$$P_P(x) = 1, \qquad V_\perp(x) = \frac{3}{4}[1 + (x_1 - x_2)^2], \qquad V_A(x) = P_T(x) = 6x_1 x_2. \tag{12}$$

The expression for the light cone wave function (6) and (10) is one of the possible ways to link different limits: quark-antiquark pairs in mesons being in the rest $v \to 0$ and very light quark $v \to 1$. In the former limit one obviously gets $\sim\delta(x - 1/2)$, the later one leads to the function $\sim\phi^a$.

In the numerical analysis the following parameters will be used:

$$\overline{M}_c = 1.2 \text{ GeV}, \quad \psi(1S), \eta_c(1S)|f_P| \simeq |f_V| \simeq 0.41 \text{ GeV}, \quad \psi(2S), \eta_c(2S)|f_P| \simeq |f_V| \simeq 0.28 \text{ GeV}, \tag{13}$$

The values of f_V were obtained from decay width $\Gamma(V \to e^+e^-)$

$$\Gamma(V \to e^+e^-) = \frac{16\pi\alpha^2}{27}\frac{|f_V|^2}{M_V}. \tag{14}$$

The constants f_V, f_P are considered to be equal: $f_P \simeq f_V$. For $\alpha_s(\mu)$ the one-loop result will be used

$$\alpha_s(\mu) = \frac{4\pi}{b_0 \log(\mu^2/\Lambda^2)}, \tag{15}$$

with $\Lambda = 200$ MeV. The last parameter needed for nu-

TABLE I.

H_1H_2	$\sigma_{BABAR} \times Br_{H_2 \to \text{charged}>2}$ (fb) [15]	$\sigma_{\text{Belle}} \times Br_{H_2 \to \text{charged}>2}$ (fb) [16]	σ_{LO} (fb)	σ_{NRQCD} (fb) [2]
$\psi(1S)\eta_c(1S)$	$17.6 \pm 2.8^{+1.5}_{--.+}$	$25.6 \pm 2.8 \pm 3.4$	26.7	2.31
$\psi(2S)\eta_c(1S)$	$\cdots$	$16.3 \pm 4.6 \pm 3.9$	16.3	0.96
$\psi(1S)\eta_c(2S)$	$16.4 \pm 3.7^{+2.4}_{-\times.''}$	$16.5 \pm 3.0 \pm 2.4$	26.6	0.96
$\psi(2S)\eta_c(2S)$	$\cdots$	$16.0 \pm 5.1 \pm 3.8$	14.5	0.40

merical analysis is the width of the wave function v^2. It will be taken from potential models [14]:

$$\psi,\ \eta_c v^2 = 0.23, \qquad \psi(2S),\ \eta_c(2S) v^2 = 0.29. \qquad (16)$$

The result of the calculation is presented in Table I. The second and the third columns contain experimental result measured at *BABAR* and Belle experiments. In the fourth column the results of this section are presented. In order to compare the result with NRQCD predictions for the processes under consideration, the fifth column contains the predictions in the framework of this model.

From Table I one sees that the predictions of the cross section of the processes $e^+e^- \to \psi\eta_c$, $\psi(2S)\eta_c$, $\psi\eta_c(2S)$, $\psi(2S)\eta_c(2S)$ in the framework of the light cone is much greater than NRQCD predictions. As was noted above, the reason of this discrepancy may be attributed to the fact that at leading approximation NRQCD does not regard the motion inside final mesons. In Ref. [2] it was noted that NRQCD corrections to the amplitude with final $\psi(2S)$, $\eta_c(2S)$ mesons are large (the expansion parameter in this case is about $v^2 \sim 0.7$), so the application of NRQCD to this processes is unreliable. Moreover, the strong dependence of the amplitude from the propagators of the intermediate particles mentioned above does not improve NRQCD either. Therefore, the NRQCD prediction is in poor agreement with the experiment data. In contrast to NRQCD, the leading order light cone predictions are in better agreement with data, from what one may suppose that light cone expansion is more reliable for $e^+e^- \to VP$ at energy $\sqrt{s} = 10.6$ GeV. The problem with light cone expansion is connected with poor knowledge of the light cone wave function (6) and (10), especially in the case of the $2S$ meson. In order to get a better understanding of the processes under consideration in addition to the next to leading term in $1/s$ expansion, one should obtain better knowledge of wave functions (6) and (10).

Another source of the uncertainty is QCD radiative corrections to the amplitudes of the processes under consideration. In Ref. [10], one-loop corrections to the process $e^+e^- \to \psi\eta_c$ were calculated in the framework of NRQCD. The resulting cross section was enhanced by a factor of 1.8. Therefore, QCD corrections give considerable contribution and should be taken into the account.

There are two contributions to the form factor F_{vp} factored in formula (5). The first contribution originates from the wave function of mesons at the origin and it is proportional to $\sim f_V f_P$. The second contribution regards internal motion of quark-antiquark pairs inside mesons and it is proportional to I_0. As was noted above, leading NRQCD approximation does not take into account the contribution of the second type. Moving from the lower $c\bar{c}$ states to the upper ones, we diminish the value of the constant f_V, f_P. So in the framework of NRQCD the cross sections for the production of upper $c\bar{c}$ mesons are less than that for the lower $c\bar{c}$ states. This effect is well seen in Table I. The second contribution $\sim I_0$, where the internal motion is taken into account, compensates the first effect since upper lying resonances are broader. At first sight one may conclude that the cross section of the processes $e^+e^- \to \psi(2S)\eta_c$ and $e^+e^- \to \psi\eta_c(2S)$ cannot differ significantly. But our calculations show that the cross section $e^+e^- \to \psi\eta_c(2S)$ is almost 2 times larger than that for $e^+e^- \to \psi(2S)\eta_c$. The reason for such a large discrepancy consists in the fact that some terms in formula (5) are multiplied by the factor M_P/M_V. This factor enhances or diminishes different terms in (5), which results in the enhancement of the $\sigma(e^+e^- \to \psi\eta_c(2S))$ in comparison with $\sigma(e^+e^- \to \psi(2S)\eta_c)$.

It should be noted that the prediction for the cross section of the process $e^+e^- \to \psi\eta_c(2S)$ in the framework of the light cone is almost twice as large as the results obtained by Belle and *BABAR*. But one can suppose that, similar to the amplitude enhancement, the $1/s$ correction is enhanced by the factor M_P/M_V. So $1/s$ corrections for this process are of particular importance and if one takes into account these corrections, it is likely that a better agreement with the experiments will be achieved. Additionally, in the framework of the light cone, the cross section of $e^+e^- \to \psi\eta_c(2S)$ is almost 2 times larger than that for $e^+e^- \to \psi(2S)\eta_c$, which can be checked at the experiments where $\sqrt{s} \gg 10$ GeV since at large energies $1/s$ corrections are much less than leading order contribution.

III. THE PROCESSES $e^+e^- \to \psi(1S)\chi_{c0}$, $\psi(2S)\chi_{c0}$.

Leading asymptotic behavior of matrix element $\langle V(p_1, \lambda), S(p_2)|J_\mu|0\rangle$ may be derived from formula (3).

Here we have $M(p_1, \lambda_1) = V(p_1, \lambda)$, $M(p_2, \lambda_2) = S(p_2)$. Obviously the helicity λ_2 equals zero. As to the vector meson V, the leading contribution is given by the helicity $\lambda_1 = 0$. So the asymptotic behavior of the amplitude is

$$\langle V(p_1, \lambda), S(p_2)|J_\mu|0\rangle \sim \frac{1}{\sqrt{s}}. \quad (17)$$

Then the asymptotic behavior of the cross section $\sigma(e^+e^- \to VS)$ is $\sim 1/s^3$. Unfortunately, leading in $1/s$ expansion contribution is much less than NLO. To prove this, the NRQCD result for the cross section of the processes under consideration obtained in Ref. [2] will be used. Let us consider the process $e^+e^- \to \psi(1S)\chi_{c0}$. The cross section of this process can be represented in the form

$$\sigma = \frac{\pi^3}{3^5 s}\alpha^2\alpha_s^2 q_c^2 F_0 r^2\sqrt{1-r^2}\frac{f_V^2 f_S^2}{m_c^4}, \quad (18)$$

where $r^2 = 16m_c^2/s$ and $F_0 = 2(18r^2 - 7r^4)^2 + r^2(4 + 10r^2 - 3r^4)^2$. Let us substitute $s \to 10.6^2\xi$ and expand the above formula in $1/\xi$ series ($m_c = 1.4$ GeV). We get

$$\sigma = \frac{0.15}{\xi^3} + \frac{1.84}{\xi^4} + O(1/\xi^5). \quad (19)$$

Thus one sees that in the framework of NRQCD NLO correction at energy $\sqrt{s} = 10.6$ GeV is an order of magnitude larger than the leading one. In the light cone, the NRQCD result is multiplied by the factor that accounts for internal motion. Thus if one supposes that these factors are of the same order of magnitude for LO and NLO contributions, one may conclude that the NLO contribution in the framework of the light cone is much larger than LO. The same is true for the process $e^+e^- \to \psi(2S)\chi_{c0}$. The leading order result can be found in Ref. [18]. The NLO contribution will be considered in our forthcoming publication.

IV. DISCUSSION

In this paper we have reanalyzed the production of excited charmonium mesons pair in e^+e^- annihilation (i.e. the reactions $e^+e^- \to \psi(1S)\eta_c(1S)$, $\psi(2S)\eta_c(1S)$, $\psi(1S)\eta_c(2S)$, $\psi(2S)\eta_c(2S)$ and $\psi\chi_{c0}$) in the framework of the light cone. It is shown that the internal motion of quarks inside charmonium mesons leads to a substantial increase of the cross sections of these processes and reasonable agreement between theoretical predictions and available experimental data can be reached.

It is also shown that if one supposes that LO and NLO factors regarding internal motion inside mesons are of the same order at energy $\sqrt{s} = 10.6$ GeV, the NLO contribution to the cross sections $e^+e^- \to \psi(1S)\chi_{c0}$, $\psi(2S)\chi_{c0}$ is about an order of magnitude higher than the LO contribution. So in order to achieve agreement between the theoretical predictions for the cross sections of the processes $e^+e^- \to \psi(1S)\chi_{c0}$, $\psi(2S)\chi_{c0}$ and experimental data, one should calculate the NLO contribution to these cross sections.

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