Rescattering effects of baryon and antibaryon in heavy quarkonium decays

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Abstract

Rescattering effects of baryon and antibaryon in heavy quarkonium decays are investigated by studying their angular distributions. The rescattering amplitudes are phenomenologically evaluated by modeling the intermediate range interaction as a σ or pion meson exchange between quark-antiquark pairs. The results show that the rescattering effects play an important role in determination of the angular distribution in heavy quarkonium decays. Especially, for $J/\psi$ and $\psi(2S)$ decays into $\Lambda \bar{\Lambda}$, $\Sigma^0 \bar{\Sigma}^0$, and $\Xi^- \bar{\Xi}^+$ the angular distribution parameters could turn to be negative values in the limit of helicity conservation. These results provide us a possible explanation for understanding the negative sign of the angular distribution parameter measured for $J/\psi \rightarrow \Sigma^0 \bar{\Sigma}^0$, namely, it might come from the baryonic $SU(3)_F$ symmetry breaking by incorporating rescattering effects.

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1 Introduction

Exclusive decays of heavy quarkonium into baryon antibaryon pairs ($BB$) are widely investigated as a laboratory to test perturbative QCD (pQCD) properties or to study the baryonic properties \textsuperscript{13}.\textsuperscript{14}.\textsuperscript{15}.\textsuperscript{16}.\textsuperscript{17}. The branching fractions of $J/\psi$ and $\psi'$ decays into $BB$ have been systematically studied in the framework of pQCD \textsuperscript{13}.\textsuperscript{14}. The angular distributions of $e^+e^- \rightarrow J/\psi, \psi' \rightarrow B\bar{B}$ ($B\bar{B}$: octet baryon), were also investigated theoretically and experimentally by many groups \textsuperscript{8}.\textsuperscript{9}.\textsuperscript{10}.\textsuperscript{11}. For $J/\psi$ produced from $e^+e^-$ annihilation, they must have spin ±1 along the beam direction. For exclusive decays of $J/\psi$ into octet baryonic pair, the outgoing $BB$ can be taken either S-wave or D-wave state in laboratory system, thus the experimental observation of the outgoing baryon direction takes the form $dN/d\cos\theta \propto (1 + \alpha \cos^2\theta)$, where $\theta$ is the angle between outgoing baryon direction and $e^+e^-$ beam direction. The angular distribution parameters of $\alpha$ have been measured by many groups \textsuperscript{10}.\textsuperscript{11}.\textsuperscript{12}. Recently, the BES collaboration have released a more accurate measurement on the parameter $\alpha$ for $J/\psi \rightarrow p\bar{p}$, $\Lambda \bar{\Lambda}$ and $\Sigma^0 \bar{\Sigma}^0$ decays with 58 million $J/\psi$ events accumulated at BEPC as shown in Table \textsuperscript{1}. It is interesting to note that the parameter $\alpha$ for $J/\psi \rightarrow \Sigma^0 \bar{\Sigma}^0$ is negative within 1σ accuracy, and the sign of the central value of $\alpha$ for $J/\psi \rightarrow \Xi^- \bar{\Xi}^+$ measured at Mark II is also negative though its uncertainty is still very large.

Theoretically, the study on the angular distribution parameter provides us a copious information on polarization of decaying particles, decay mechanisms, and strong interaction and so on. Brodsky and Lepage once demonstrated that the exclusive process at large momentum transfer $Q^2$ can be used to test the gluon spin and other basic elements of perturbative quantum chromodynamics.
They verified that the vector-gluon coupling conserves quark helicity when quark and gluon masses are negligible at the large scale $Q^2$. Since the hadronic helicity is the sum of the helicities of its valence quarks, thus leads to the conclusion that the total hadronic helicity is conserved up to corrections of order $m_q/Q$ or higher. For $e^+e^- \rightarrow J/\psi \rightarrow B\bar{B}$ decays, angular distributions take the form of $dN/d\cos \theta \propto 1 + \alpha \cos^2 \theta$ by the selection of the helicity conservation rule, which gives the asymptotic value of $\alpha = 1$. They conclude that verifying the $1 + \cos^2 \theta$ angular distribution would provide one with a clear proof of the spin one assumption for the gluon, since with a scalar or a tensor gluon one would be led to a $\sin^2 \theta$ distribution.

In the past, this asymptotic value has been corrected by many groups. In charmonium decays, we are far from an asymptotic regime due to the factor that $m_B/m_{J/\psi} \sim 1/3$ is far from negligible. The baryonic mass effects have already been investigated by Claudson, Glashow and Wise [2], and they found a value of $\alpha = 0.46$ for $J/\psi \rightarrow p\bar{p}$, which confirms the idea of large mass corrections to the asymptotic value. The quark mass effect has been investigated by Carimalo [4]. It is assumed that the quark created with effective mass $m$ inside a baryon carries one-third of the total momentum of the out-going baryon, and the three symmetric gluons carry the same momentum ($M_{J/\psi}/3$) with no other extra interaction. In this simple static-quark model, the angular distribution can be explicitly expressed by

$$\alpha = \frac{(1 + u)^2 - u(1 + 6u)}{(1 + u)^2 + u(1 + 6u)} \text{ with } u = \frac{m_B^2}{m_{J/\psi}^2}$$

(1)

This formula gives the parameter $\alpha = 0.69$ for $J/\psi \rightarrow p\bar{p}$, very close to the experimental value. However, the calculated branching fraction of $J/\psi \rightarrow B\bar{B}$ decays are inconsistent with measured values with $1\sigma$ in this model. Some authors argued that the non-perturbative effects of the baryon should be parameterized in the calculation. Further investigations including quark mass effects, electromagnetic effects and higher-twist corrections to $\alpha$ have been made with a general conclusion of $0 < \alpha < 1$ [3, 8].

Phenomenologically, some authors argued that, in charmonium decays, rescattering effects between the final particle states sometimes are essential to explain experimental observations. For example, a $p\bar{p}$ rescattering near their threshold could make some contributions to the observation on the near threshold-enhancement of $J/\psi \rightarrow \gamma p\bar{p}$ [4]. In meson sector, one example is that the rescattering of $a_2 p$ and $a_1 p$ into $p\tau$ can change the $p\tau$ production rate substantially, which could be one of explanation for the $p\tau$ puzzle [2]. Whether the $B\bar{B}$ rescattering could change their distribution significantly? Stimulated by recent BES observations, we make a further investigation on the angular distribution for heavy quarkonium decays into $B\bar{B}$ by taking rescattering effects into account.

\section{2 Model and Formulation}

The $B\bar{B}$ produced from heavy quarkonium decays moves oppositely with higher momentum (see Figure 1(a)), they might experience an intermediate-range interaction by exchange of mesons (Figure 1(b)). We assume that the outgoing baryonic pair survives from the interaction without annihilation. We only consider one-pion and tow-pion exchange processes. In principle, other
mesons with higher masses might be exchanged, their contributions are supposed to be less than pion-exchange processes. As traditional treatments to the NN interaction, the process of two-pion exchange is described by the picture of $\sigma$ meson exchange. For consideration of isospin conservation, one-pion exchange could be allowed in $\pi\pi$ and $\Xi^-\Xi^+$ decays suppressed by an isospin factor of 1/3, and not allowed in $\Lambda\Lambda$ and $\Sigma^0\Sigma^0$ decays. As in chiral quark model, we model the intermediate range attraction in the $BB$ interaction as a rescattering of $q\bar{q}$ quarks by exchanging a $\sigma$ or pion meson (Figure 1(c)).

\[\text{Fig. 1: The schematic illustration for heavy quarkonium decays into } BB \text{ (a) and via a rescattering process of } BB \text{ (b), which is equivalent to a exchange of a meson between } q\bar{q} \text{ quarks (c).}\]

The helicity amplitude corresponding to Figure 1(a) and (b) can be expressed as:

\[M_1 = D_{M,\lambda_1 - \lambda_2}^J(\theta_2, \phi_2) F_{\lambda_1', \lambda_2'} \text{, for Figure 1(a)} \quad (2)\]

\[M_2 = \sum_{\lambda_1, \lambda_2, J} (2J + 1) D_{M,\lambda_1 - \lambda_2}^J(\theta_1, \phi_1) F_{\lambda_1, \lambda_2} T_{\lambda_1', \lambda_2', \lambda_1, \lambda_2} D_{\lambda_1 - \lambda_2, \lambda_1' - \lambda_2'}^J(\theta_2, \phi_2) \text{, for Figure 1(b)} \quad (3)\]

where $M, \lambda_1(\lambda_1')$ and $\lambda_2(\lambda_2')$ denote the helicity of heavy quarkonium, baryon and antibaryon, respectively. For heavy quarkonium production from positron annihilation, $M = \pm 1$. $F$ and $T$ are helicity amplitudes corresponding to heavy quarkonium decays into $BB$ and $BB$ rescattering processes, respectively. For considering parity invariance and time reversal invariance, one has $F_{-+} = F_{++}, F_{-+} = F_{++}, T_{-+} = -T_{+-}, T_{++} = -T_{++} = T_{+-} = T_{-+} = -T_{+-} = T_{++} = T_{+-} = T_{-+} = T_{++} = T_{+-} = T_{-+} = T_{++} = T_{+-} = T_{-+} = T_{++}$ and $T_{++} = T_{+-} = T_{-+} = T_{++}$.

Note that interference terms vanish between $M_1$ and $M_2$ due to the orthogonal $D-$function, then the angular distribution of the decayed baryon is expressed by:

\[\frac{d\Gamma}{d\cos\theta_2} = \sum_{M, \lambda_1', \lambda_2'} |M_1|^2 d\phi_2 + |M_2|^2 d\theta_1 d\phi_1 d\phi_2 \propto 1 + \alpha' \cos^2 \theta_2, \quad (4)\]

with

\[\alpha' = \{4\alpha - 9\pi^2[(\alpha - 1)(4T_2T_4 + 2T_2^2) + 6T_1^2(\alpha + 1) + \alpha(2T_4^2 - 3T_3^2) - 2T_4^2 - 2T_3^2]\} / [4 + 27\pi^2(2T_1^2 + T_2^2)(1 + \alpha)], \quad (5)\]

where $\alpha = |F_{-+}|^2 - 2|F_{++}|^2 + |F_{++}|^2$ is the net angular distribution parameter for $BB$ without rescattering effects. If the rescattering effects vanish, i.e. $T_1 \rightarrow 0$, then $\alpha' = \alpha$. It is worthwhile to note that the sign of $\alpha'$ could be positive or negative determined by $BB$ scattering amplitudes.

Unfortunately, evaluation of rescattering amplitudes in the framework of pQCD cannot be made without models, this is mainly due to the fact that the non-perturbative information on bound states can not be fully determined from a reliable method in theory. For low lying states of octet baryons, we will employ the so-called constituent quark model to evaluate rescattering amplitudes. For $\sigma$ exchange, we define an operator

\[A_{\lambda_1', \lambda_2, \lambda_1, \lambda_2}(p_1 q_1' q_1, s_1 s_1' s_1') = \int \frac{d^3x}{2\pi^3} \frac{1}{x^2 - m_\sigma^2 + i\Gamma_\sigma m_\sigma} [\bar{u}(p_1, s_1')g_\sigma u(p_2, s_3)\bar{v}(q_3, s_3)g_\sigma v(q_3 + x, s_3)] \times \delta^4(p_1 - p_1')\delta^4(p_2 - p_2')\delta^4(p_3 - p_3' - x) + \text{permutation terms}, \quad (6)\]
where \( g_\sigma \) is the effective coupling strength of a \( \sigma \) meson to \( q\bar{q} \) quarks, which will be fixed by using the angular distribution parameter of \( J/\psi \to p\bar{p} \) as input value. \( \Gamma_\sigma \) and \( m_\sigma \) are the \( \sigma \)'s decay width and mass, respectively. \( x \) denotes the transferred momentum. \( u(p_i, s_i) \) and \( v(q_i, \bar{s}_i) \) are Dirac spinors for quarks and antiquarks with helicity \( s_i \) and \( \bar{s}_i \), respectively. Their normalization is taken as \( \bar{u}u = -\bar{v}v = m/E \). For one-pion exchange, the \( g_\sigma \) should be replaced by \( \gamma_5 g_\sigma \) and propagator by \( 1/(x^2 - m_\sigma^2 + i\epsilon) \). Then the rescattering helicity amplitude is evaluated by:

\[
T_{\chi_i\chi'_i,\lambda_2\lambda_2} = \int \prod_{i=1,3} d^3p_i d^3q_i d^3\vec{q}_i \delta^3(\vec{p}_i - \vec{q}_i - \vec{p}_3) \delta^3(\vec{q}_2 - \vec{p}_1 - \vec{p}_3) \delta^3(\vec{q}_3 - \vec{q}_1 - \vec{q}_2 - \vec{q}_3),
\]

where \( \psi_B(p_i, s_i)\psi_B(q_i, \bar{s}_i) \) is the product of \( B \) and \( \bar{B} \) wave function in momentum space, which includes the spin, flavor and spatial wave function. They are constructed in the naive quark model.

3 Numerical Results

3.1 SU(6) basis

For illuminating the role of the effect of SU(3)\(_F\) symmetry breaking in rescattering processes, we firstly evaluate rescattering amplitudes by using SU(6) basis and then compare it with the so-called \( uds \) basis. We naively assume that the masses of quarks satisfy \( m_u = m_d = m_s = m_B/3 \), where \( m_B \) is the baryonic mass. This means that we neglect binding energies in the baryonic bound state and use the non-relativistic static quark model. The spin-flavor wave functions of octet baryon are described by:

\[
\psi_{SF}^B = \psi_{SF}^\bar{B} = \frac{1}{\sqrt{2}} (\chi^\rho \phi^\rho + \chi^\lambda \phi^\lambda),
\]

where \( \chi^\rho \) and \( \chi^\lambda \) are the mixed-symmetry pair spin-\( \frac{1}{2} \) wave function. For example, we have

\[
\chi^\rho_{1/2,1/2} = -\frac{1}{\sqrt{6}} \{ | \uparrow \downarrow \uparrow \rangle + | \downarrow \uparrow \downarrow \rangle - 2 | \uparrow \uparrow \downarrow \rangle \},
\]

\[
\chi^\lambda_{1/2,3/2} = \frac{1}{\sqrt{2}} \{ | \uparrow \downarrow \downarrow \rangle - | \downarrow \uparrow \uparrow \rangle \},
\]

for the case of the total spin \( \frac{3}{2} \) and its projection \( \frac{1}{2} \). The flavor wave function \( \phi^\rho \) and \( \phi^\lambda \) are exactly analogous to the spin wave function but in the flavor space. As in the most naive quark model, we assume that the bound state wave function for constituent quarks can be described by a simple harmonic-oscillator eigenfunction in their center-of-mass (c.m.) system, i.e.

\[
\phi(\vec{k}_\rho, \vec{k}_\lambda) = \frac{1}{(\pi\beta)^{3/2}} e^{-(\vec{k}_\rho^2 + \vec{k}_\lambda^2)/2\beta}
\]

where \( \beta \) is the harmonic-oscillator parameter and \( \vec{k}_\rho, \vec{k}_\lambda \) are defined as \( \vec{k}_\rho = (\vec{k}_1 + \vec{k}_2 - 2\vec{k}_3)/\sqrt{6} \), and \( \vec{k}_\lambda = (\vec{k}_1 - \vec{k}_2)/\sqrt{2} \) with \( \vec{k}_1, \vec{k}_2 \) and \( \vec{k}_3 \) the momenta for the three quarks in c.m. system of the corresponding baryon.

3.2 uds basis

To count for the SU(3)\(_F\) symmetry breaking in strange baryons, we use the so-called \( uds \) basis, which makes explicit SU(3)\(_F\) symmetry breaking under exchange of unequal mass quarks [17]. Flavor functions for strange baryons are taken as

\[
\phi_\Lambda = \frac{1}{\sqrt{2}} (ud - du) s,
\]

\[
\phi_\Sigma = \frac{1}{\sqrt{2}} (ud + du) s,
\]

\[
\phi_\Xi = ssd,
\]
and the construction of the spin wave function $\chi$ proceeds exactly analogously to that of the flavor wave functions. For instance, the spin wave functions for the total angular momentum quantum $1/2$ with their $z$ projection $1/2$ are:

\[ \chi = \frac{1}{\sqrt{2}} (|\uparrow\uparrow\uparrow\rangle - |\downarrow\uparrow\uparrow\rangle) \]

\[ \chi = \frac{1}{\sqrt{6}} (|\uparrow\downarrow\uparrow\rangle + |\downarrow\uparrow\uparrow\rangle - 2|\uparrow\uparrow\downarrow\rangle) \]

\[ \chi = \frac{1}{\sqrt{6}} (|\uparrow\downarrow\uparrow\rangle + |\downarrow\uparrow\uparrow\rangle - 2|\uparrow\uparrow\downarrow\rangle) \]

The spatial wave function for the ground state of the strange baryons are chosen similarly to those of protons, but have an asymmetry between the $\rho$ and $\lambda$ oscillators. In the baryonic c.m. system, it reads:

\[ \psi(E_p, E_\lambda) = \frac{1}{(\pi^2 \beta_\rho \beta_\lambda)^{3/4}} e^{-(E^2_p/2\beta_\rho + E^2_\lambda/2\beta_\lambda)} \]

where $\beta_\rho = (3km)^{1/2}$ and $m$ is the quark mass. For example, we take $m = m_u$ for $\Lambda, \Sigma$, and take $m = m_u$ for $\Xi$. $\beta_\lambda = (3km)^{1/2}$ with $m_\lambda = 3m_m/(2m + m_\lambda) > m (m_\lambda = m_u$ for $\Lambda, \Sigma$, and $m_\lambda = m_u$ for $\Xi$). Using these equations, we relate $\beta_\rho(\Lambda, \Sigma, \Xi)$ and $\beta_\lambda(\Lambda, \Sigma, \Xi)$ to the harmonic-oscillator parameter $\beta$ of nucleons, i.e., $\beta_\rho(\Lambda, \Sigma) = \beta_\rho(\Xi) = \sqrt{m_\sigma/m_\text{had}}$, and $\beta_\lambda(\Lambda, \Sigma, \Xi) = \sqrt{m_\lambda/m_\text{had}}(\Lambda, \Sigma, \Xi)$.

Tab. 2: The angular distribution parameters for $J/\psi, \psi'$ and $\Upsilon(1S)$ decays into $pp, \bar{\Lambda}, \Sigma^0\Sigma^0$ and $\Xi^0\Xi^0$ incorporated $B\bar{B}$ rescattering effects by exchange of a $\sigma$ meson. The parameters are set as $m_u = m_d = m_s = m_{\text{quark}}$ and $\beta = 0.16\text{GeV}^2$ for SU(6) basis, while $m_u = m_d = 310\text{MeV}, m_s = 490\text{MeV}$ and $\beta = 0.16\text{GeV}^2$ for $uds$ basis.

| Channel | SU(6) basis | $uds$ basis |
|---------|-------------|-------------|
| $J/\psi \to pp$ | $\alpha' = (14.8 - 8.5\alpha_0) g^2$ | $\alpha' = (14.8 - 8.5\alpha_0) g^2$ |
| $\Lambda\bar{\Lambda}$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ |
| $\Sigma^0\Sigma^0$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ |
| $\Xi^0\Xi^0$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ |
| $\Upsilon(1S) \to pp$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ |
| $\Lambda\bar{\Lambda}$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ |
| $\Sigma^0\Sigma^0$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ |
| $\Xi^0\Xi^0$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ |
| $\Xi^0\Xi^0$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ | $\alpha' = 4g^2(1+\alpha_0) g^2$ |

For numerical evaluation of rescattering amplitude of $B\bar{B}$, there are three parameters to be determined, i.e. the quark mass $m_u, m_s$ and the harmonic oscillator parameter $\beta$ in nucleon spatial wave functions. As usually used in naive quark model, we set $m_u = m_s = 310\text{MeV}, m_s = 490\text{MeV}$ and $\beta = 0.16\text{GeV}^2$. The rescattering amplitudes $T\_i (i = 1, 2, 3, 4)$ are obtained by evaluating the integration of Equation (16) directly. The numerical program can be obtained from authors. Then we list the angular distribution by incorporation of $B\bar{B}$ rescattering effects in Table 2.
The observed angular distribution of $B\bar{B}$ depends on the effective coupling strength $g_\sigma$ and the net parameter $\alpha$. In the chiral quark model, the coupling strength $g$ is determined from $g_{N\pi NN}$ [19], which is $g = 2.62$. Here we fix this parameter by using the experimentally angular distribution of $J/\psi \to p\bar{p}$ as an input value. For consistency the net parameter $\alpha$ should be calculated from the same quark model. Carimalo formula is a good approximation in the description of the net parameter $\alpha$ by incorporating baryonic structure information. If the quark mass is negligible or $4m_B^2 \ll M^2$ ($M$: heavy quarkonium mass), the net parameter tends to the asymptotic value $\alpha = 1$. We will see how the observed angular distribution parameter changes when the quark mass vanishes, so as to check its asymptotic behavior under the condition of the helicity conservation.

As shown in Table 3, if the difference between the light quark masses and strange quark masses is ignored and octet baryons are described by SU(6) wave function, the observed angular distribution parameters remain positive when the net parameter $\alpha$ tends to the asymptotic value. Though the experimental value for $J/\psi \to \Lambda\bar{\Lambda}$ seems to be consistent with results from SU(6) basis, it is not enough to distinguish the SU(6) basis from the $uds$ basis due to the uncertainty of the net parameter $\alpha$. It is worthwhile to note that calculated values using the $uds$ basis for $J/\psi$ decays into strange baryons change their signs when the $\alpha$ tends to the asymptotic value. Though the experimental error for $J/\psi \to \Sigma^0\Sigma^0$ is still larger, the measured central value for this decay is negative within 1$\sigma$ accuracy. So this result provides us a possible explanation for understanding the negative sign of angular distribution parameter for $J/\psi \to \Sigma^0\Sigma^0$ decay, namely, it might come from the baryonic SU(3)$_F$ symmetry breaking by incorporating rescattering effects. For further test of rescattering effects in charmonium decays, higher accurate measurements of the angular distribution for $J/\psi, \psi' \to \Sigma^0\Sigma, \Xi^-\Xi^+$ are desirable.

Tab. 3: Comparison of the angular distribution parameter between experimental and theoretical values by SU(6) basis and $uds$ basis. Where the values of $\alpha'(\alpha = 1)$ and $\alpha'$ (Carimalo) indicate that the net parameter $\alpha$ are set to one and evaluated by Carimalo formula, respectively.

| Channel | SU(6) basis | $uds$ basis | Experimental value |
|---------|-------------|-------------|--------------------|
| $J/\psi \to p\bar{p}$ | $\alpha'(\alpha = 1)$ | $\alpha'(\text{Carimalo})$ | $\alpha'(\alpha = 1)$ | $\alpha'(\text{Carimalo})$ | $\alpha'$ |
| $\Lambda\bar{\Lambda}$ | 0.66 | 0.69 | -0.13 | 0.37 | 0.65 ± 0.11 [10] |
| $\Sigma^0\Sigma^0$ | 0.65 | 0.63 | -0.34 | 0.23 | -0.24 ± 0.20 [10] |
| $\Xi^-\Xi^+$ | 0.64 | 0.45 | -0.33 | 0.18 | -0.13 ± 0.59 [11] |
| $\psi' \to p\bar{p}$ | 0.70 | 0.84 | 0.70 | 0.84 | 0.67 ± 0.16 [12] |
| $\Lambda\bar{\Lambda}$ | 0.69 | 0.80 | -0.11 | 0.20 | ... |
| $\Sigma^0\Sigma^0$ | 0.68 | 0.78 | -0.30 | 0.19 | ... |
| $\Xi^-\Xi^+$ | 0.68 | 0.75 | -0.31 | -0.03 | ... |
| $\Upsilon(1S) \to p\bar{p}$ | 0.84 | 0.98 | 0.84 | 0.98 | ... |
| $\Lambda\bar{\Lambda}$ | 0.80 | 0.97 | -0.06 | 0.59 | ... |
| $\Sigma^0\Sigma^0$ | 0.80 | 0.96 | -0.24 | 0.74 | ... |
| $\Xi^-\Xi^+$ | 0.78 | 0.95 | -0.31 | -0.28 | ... |

The case of one-pion exchange is also investigated in $p\bar{p}$ and $\Xi^-\Xi^+$ decays under the SU(6) basis and $uds$ basis. Parameters are chosen as same as the $\sigma$-exchange case. Numerical results show that the contribution of one-pion exchange from the two mixed-symmetry spin wave functions plays a different role in the evaluation of rescattering amplitudes. Since the coupling of $q\bar{q}\pi$ is selected as $g_{\pi\gamma\gamma}$, the contribution from the $\lambda-$type spin wave function is dominant over $\rho-$type functions. Thus the values of rescattering amplitudes for $\Xi^-\Xi^+$ decays under the $uds$ basis are quite smaller than those under the SU(6) basis. With the same treatment as to the $\sigma$ exchange case, the effective coupling strength of $g_\sigma$ is determined by using the experimental value of $J/\psi \to p\bar{p}$ decay as an input value, we find out an approximate relation $\alpha' \cong \alpha$ for $J/\psi$, $\psi(2S)$ and $\Upsilon(1S)$ decays into $p\bar{p}$ and $\Xi^-\Xi^+$ channels under the two bases used.
4 Discussion and Summary

Based on our evaluation, we suggest that charmonium decays into $\Sigma^0\Sigma^0$ and $\Xi^-\Xi^+$ could be used to look for $B\bar{B}$ rescattering effects. For $\Upsilon(1S) \rightarrow B\bar{B}$ decays, the branching fraction is relatively smaller than that for charmonium decays, furthermore, its $B\bar{B}$ rescattering amplitudes are largely suppressed by a factor of $1/M^2_{\Upsilon}$. It should be pointed out that the $B\bar{B}$ angular distribution does not become isotropic at the limit of the baryonic zero-velocity, instead it is dominantly determined by rescattering processes. From the point of this view, the rescattering effects should be looked for in the decay with a slowly moving $B\bar{B}$ pair.

It is instructive to compare our results with ones from the quark-scalar-diquark model in [18]. In the asymptotic limit, i.e., the helicity conservation, the sign of parameter $\alpha'$ from $uds$ basis turns to be negative. In [18] the negative sign of this parameter appears when the masses of quarks, gluons and baryons tend to zero for point-like baryons. This implies that if some interactions between out-going quarks are considered, the sign of the angular distribution parameter could flip in the asymptotic limit of the helicity conservation.

To summarize: the rescattering effects of $B\bar{B}$ in heavy quarkonium decays are investigated by studying the angular distributions. The rescattering amplitudes are phenomenologically evaluated by modeling the intermediate range interaction as a $\sigma$ or pion meson exchange between $q\bar{q}$ quarks. The results show that the rescattering effects play an important role in determination of the angular distribution in heavy quarkonium decays. To compare the calculated values by using the SU(6) basis and the $uds$ basis, one finds that the parameter $\alpha'$ turns to be negative values by suing the $uds$ basis in the limit of asymptotic value $\alpha = 1$. Even though the accurate values of $\alpha'$ are not fully determined in our calculation due to uncertainties of the net parameter $\alpha$, we conclude that these results still provide us a possible explanation for understanding the negative sign of angular distribution parameter measured in the decay $J/\psi \rightarrow \Sigma^0\Sigma^0$, namely, it might come from the baryonic SU(3)$_F$ symmetry breaking by incorporating rescattering effects. For further test of rescattering effects in charmonium decays, higher accurate measurements of the angular distribution for $J/\psi \rightarrow \Sigma^0\Sigma^0, \Xi^-\Xi^+$ are desirable.

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