Study on the rare decays of \( Y(4630) \) induced by final state interactions

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A resonance \( Y(4630) \) at the invariant mass spectrum of \( \Lambda_c \bar{\Lambda}_c \) observed by the Belle Collaboration triggers a hot discussion about its inner structure. Since it preferably decays into two charmed baryons \( \Lambda_c \bar{\Lambda}_c \), it is tempted to conjecture it as a tetraquark. Because the dominant decay portal \( Y(4630) \to \Lambda_c \bar{\Lambda}_c \) is close to the energy threshold, the final state interactions may be significant and result in other baryonic and/or mesonic final states whose branching fractions are sizable to be measured in the future experiments. In this work we calculate the branching ratios of the \( Y(4630) \) decays into \( p\bar{p}, D^{±+}D^{±−}, \pi^+\pi^- \), and \( K^+K^- \) which are induced by the \( \Lambda_c \bar{\Lambda}_c \)-re-scattering. The resultant decay patterns will be tested by the future experiments and the consistency degree with the data composes a valuable probe for the tetraquark conjecture.

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I. INTRODUCTION

The Belle Collaboration reported a charmonium-like state \( Y(4630) \) in the \( \Lambda_c \bar{\Lambda}_c \) invariant mass spectrum from the \( e^+e^- \to \Lambda_c \bar{\Lambda}_c \) process [1], where its resonance parameters include mass \( M = (4634.8_{−2.0}^{+5.5}) \text{ MeV} \) and width \( \Gamma = (92^{+10}_{−24})_{−21} \text{ MeV} \). \( Y(4630) \) was produced directly by the \( e^+e^- \) annihilation and its \( J^{PC} \) quantum number is identified as \( 1^{−} \).

After the observation of \( Y(4630) \), several theoretical explanations to it were proposed (see Refs. [2, 3] for more details). In the following, we briefly review them. In Ref. [4], authors studied the interaction of charmed baryon and anti-charmed baryon via one boson exchange model and explained \( Y(4630) \) to be a \( \Lambda_c \bar{\Lambda}_c \) baryonium state. Simonov proposed a model to study baryon-antibaryon production [5], which is due to the \((q\bar{q})(q\bar{q})\) pair creation inside a hadron. By this mechanism, he further investigated the electroweak production of \( \Lambda_c \bar{\Lambda}_c \), which can explain why the \( Y(4630) \) enhancement structure appears in the \( \Lambda_c \bar{\Lambda}_c \) invariant mass spectrum [5]. There are other assumptions about the structure that \( Y(4630) \) and \( Y(4660) \) may be the same state while the later one is seen at the invariant mass spectrum of \( \psi(2S)\pi^+\pi^- \) of the \( e^+e^- \) annihilation [7], so it is naturally to assume that the state is a molecular state of \( \psi(2S) \) + \( f_0(980) \) [6]. Considering \( Y(4630) \to \Lambda_c \bar{\Lambda}_c \) and \( Y(4660) \to \psi(2S)\pi^+\pi^- \) altogether, \( Y(4630) \) may possess a small fraction of molecular component \( \psi(2S) + f_0(980) \) and its decay mode can be realized via a secondary process where the virtual \( f_0(980) \) transits into a pion pair. \( Y(4630) \) was interpreted as tetraquark state in Refs. [8, 9]. Brodsky et al. [10] proposed the color flux model to be responsible for the diquark and anti-diquark interaction in the tetraquark sector. Maiani et al. suggested \( Y(4630) \) could be a tetraquark state with an orbital angular momentum \( L = 1 \) [8], while Cotugno et al. [9] indicated that \( Y(4630) \) can be the first radial excitation of another charmonium-like state \( Y(4360) \) under the tetraquark assignment.

Besides these exotic state assignments to \( Y(4630), Y(4630) \) were explained as a \( 5^3S_1 \) charmonium [11, 12]. Additionally, in Ref. [13], authors analyzed the experimental data of \( e^+e^- \to \Lambda_c \bar{\Lambda}_c \), and found that the \( \Lambda_c \bar{\Lambda}_c \) signal contains vector charmonia \( \psi(5S) \) and \( \psi(3D) \), while the threshold behavior of \( \Lambda_c \bar{\Lambda}_c \) cross section can be due to appearance of \( \psi(3D) \) [13].

Although different assignments to \( Y(4630) \) were given, it is obvious that the inner structure of \( Y(4630) \) is not finally determined. Facing such research status, we still need to pay more efforts to reveal its properties.

The key point is to explain why \( Y(4630) \) was observed in the \( \Lambda_c \bar{\Lambda}_c \) invariant mass spectrum. Very recently, Liu, Ke, Liu, Li [14] conjectured \( Y(4630) \) to be a tetraquark which is composed of a diquark and an anti-diquark, and studied its dominate decay channel. Under this scenario, \( Y(4630) \) should dominantly decay into \( \Lambda_c \bar{\Lambda}_c \), which has been observed in Ref. [1].

Along this line [14], in this work we want to further study the rare strong decay modes of \( Y(4630) \). As a radially excited state of the diquark-antidiquark bound state [14], i.e. following Cotugno et al., \( Y(4630) \) is supposed to be the radially-excited state of \( Y(4360) \) and \( Y(4630) \) overwhelmingly decays into \( \Lambda_c \bar{\Lambda}_c \), but since \( \Lambda_c \bar{\Lambda}_c \) production occurs near the threshold of the available energy (mass of \( Y(4630) \)), the final state interactions [15–20] at the hadron level may be significant. Such hadronic re-scattering processes would induce a series of final products which can be observed by future experiments even though such channels might be of relatively small fractions. Based on the assumption that \( Y(4630) \) is a pure tetraquark and the mode \( Y(4630) \to \Lambda_c \bar{\Lambda}_c \) dominates, we estimate the branching ratios of several typical decay modes: \( Y(4630) \to \Lambda_c \bar{\Lambda}_c \to \) various products, such as \( p\bar{p} \) and \( D^{∗+}D^{∗−}, \pi^+\pi^- \) and \( K^+K^- \), etc., which might be sizable for more precise measurements.

Until now, \( Y(4630) \) has only been observed in the \( \Lambda_c \bar{\Lambda}_c \) final state, searching for its other decay modes will be an intriguing research topic. It is obvious that this study will provide a basis for further experimental exploration of \( Y(4630) \). By the measurements, the inner structure of \( Y(4630) \) can be better understood.

This paper is organized as follows. After introduction, in section II, we formulate the decay widths of \( Y(4630) \) to \( p\bar{p}, \)
$D^{(*)}D^{(*)}$, $\pi^+\pi^-$ and $K^+K^-$ respectively. The numerical results are presented in the following section along with all necessary input parameters. The last section is devoted to our conclusion and discussions on the implications of those numerical results.

II. $Y(4630)$ DECAYS TO HADRON-ANTIHADRON PAIRS

Since only the decay mode of $Y(4630) \to \Lambda_c \bar{\Lambda}_c$ has been observed so far, we assume it to be a tetraquark with hidden charm which would preferably transit into an open-charmed baryon-pair like $\Lambda_c \bar{\Lambda}_c$ \cite{14}. However, there must be other channels with smaller branching ratios besides the dominant one, such as $e^+e^- \to Y(4630) \to N\bar{N}$, $D^{(*)}D^{(*)}$, $\pi^+\pi^-$ and $K^+K^-$ may occur through re-scattering between $\Lambda_c$ and $\bar{\Lambda}_c$. Below, let us focus on a few typical modes which are of sizable fractions and may be observed in more accurate measurements. The Feynman diagrams related to the discussed rare strong decays are listed in Fig. 1. (1) The decay $Y(4630) \to N\bar{N}$ can occur via a re-scattering process, where $\Lambda_c$ and $\bar{\Lambda}_c$ exchange a $D$ or $D^*$ meson at t-channel as shown in Fig. 1 (a). Here, $N = p, n$ denotes nucleons. (2) The decay $Y(4630) \to D^{(*)}D^{(*)}$ occurs through $\Lambda_c - \bar{\Lambda}_c$ re-scattering, where a baryon is exchanged at t-channel and the leading one should be a neutron (see Fig. 1 (b)). (3) The decay $Y(4630) \to \pi^+\pi^-$ (or $K^+K^-$) can occur through $\Lambda_c - \bar{\Lambda}_c$ re-scattering by exchanging $\Sigma_c$ or $\Sigma'_c$ baryon with spin $J = 1/2$ at t-channel. Those processes are shown in Fig. 1 (c). It seems reasonable that our calculation should also be applicable if the $Y(4630)$ is a molecule whose ingredients are $\Lambda_c$ and $\bar{\Lambda}_c$ (so called the baryonium), since there exists strong coupling between $Y(4630)$ and $\Lambda_c \bar{\Lambda}_c$.

For quantitatively calculating these decay processes, we adopt the effective Lagrangian approach. Here, the effective Lagrangian depicting the interaction of $Y(4630)$ with $\Lambda_c \bar{\Lambda}_c$ is [21]

$$\mathcal{L}_{Y(4630)\Lambda_c \bar{\Lambda}_c} = g_{Y\Lambda_c \bar{\Lambda}_c} Y^\mu \bar{\Lambda}_c \gamma^\mu \Lambda_c. \quad (1)$$

Following the strategy of Refs. [22, 23], we can get the effective interaction among $\Lambda_c$, $N$ and $D^{(*)}$ as

$$\langle \Lambda_c(p - q)|D(-q)N(p)\rangle = g_{\Lambda_c N D} u_{\Lambda_c}(p - q)\gamma_5 u_N(p), \quad (2)$$

$$\langle \Lambda_c(p - q)|D^*(q)N(p)\rangle = u_{\Lambda_c}(p - q)\left[ g_{\Lambda_c ND} f_Y^D + i \frac{g_{\Lambda_c ND}'}{m_{\Lambda_c} + m_N} \sigma_{\mu\nu} e^{i\theta(q)} \right] u_N(p) \quad (3)$$

In the expression of $\langle \Lambda_c(p - q)|D^*(-q)N(p)\rangle$, the second term $i \frac{g_{\Lambda_c ND}'}{m_{\Lambda_c} + m_N} \sigma_{\mu\nu} e^{i\theta(q)}$ depends on the exchange momentum $q^\prime$ which is small, so that in practical computation it can be neglected.

In addition, $\Lambda_c$ coupling with $\Sigma_c(1435)$ and $\pi(K)$ can be expressed as

$$\mathcal{L}_{\Lambda_c \Sigma_c} = \left\{ \mathcal{L}_{\Lambda_c \Sigma_c}^{(1)} - \mathcal{L}_{\Lambda_c \Sigma_c}^{(2)} \right\} + \mathcal{L}_{\Lambda_c \Sigma_c}^{(3)} \quad (4)$$

which were constructed in Refs. [24, 25]. It should be specially clarified that only the $SU(3)$ sextet states $\Sigma'_c$ (not the antitriplet state $\Sigma_c$) appear in the coupling, under the heavy quark limit [24].

With the above preparation, we write out the decay amplitudes corresponding to Fig. 1 (a). For the case where the exchanged meson is $D$-meson, the decay amplitude is

$$M_{Y(4630)\to NN}^D = \int \frac{d^4q}{(2\pi)^4} \bar{u}(p_1) g_{\Lambda_c N D} f_Y^D \left( \gamma^\mu + i \frac{q^\mu}{(p_1 - q)^2 - m_{\Lambda_c}^2} \right) \frac{i(q_1 - q + m_{\Lambda_c})}{(p_1 - q)^2 - m_{\Lambda_c}^2} \times g_{Y\Lambda_c \Lambda_c} f_Y \gamma^\nu (p_2) \times \frac{1}{q^2 - m_D^2} F^2(m_D^2, q^2). \quad (5)$$

In the above amplitudes, $F(m_D^2, q^2)$ is the form factor, which is introduced to compensate the off-shell effect of exchanged $D^{(*)}$ and we will discuss it in some details in next section.

After averaging over initial spin and summing over final spins, the decay width $\Gamma[Y(4630) \to N\bar{N}]$ can be written as

$$\Gamma\left[Y(4630) \to N\bar{N}\right] = \left| p \right| \left| M(Y(4630) \to N\bar{N}) \right|^2 \quad (6)$$

with

$$M(Y(4630) \to N\bar{N}) = M_{Y(4630)\to N\bar{N}}^D + M_{Y(4630)\to N\bar{N}}^{D^\ast}, \quad (7)$$

where $|p| = \sqrt{m_{Y(4630)}^2 - 4m_N^2}/2$. In next section we will present the numerical results of the widths which depend on the parameter $\alpha$ which is defined below Eq. (15).
In the following, we also obtain the decay amplitudes for those processes shown in Fig. 1 (b). For \( Y(4630) \rightarrow D^+ D^- \), its amplitude is

\[
\mathcal{M}(Y(4630) \rightarrow D^+ D^-) = \int \frac{d^4 q}{(2\pi)^4} (-1) \text{Tr} \left[ g_{\Lambda N D^+ Y^+} i \left( \frac{\not q - \not g + m_\Lambda}{(p_1 - q)^2 - m_\Lambda^2} \right) \times g_{Y A, \Lambda} \cdot \not q \times g_{N D^+ D^-} \times F^2 (m_\Lambda^2, q^2) \right],
\]

(9)

For the processes \( Y(4630) \) decaying into \( D^+ D^- \) and \( D^{*+} D^- \), their decay amplitudes denote

\[
\mathcal{M}(Y(4630) \rightarrow D^+ D^-) = \int \frac{d^4 q}{(2\pi)^4} (-1) \text{Tr} \left[ g_{\Lambda N D^+ Y^+} i \left( \frac{\not q - \not g + m_\Lambda}{(p_1 - q)^2 - m_\Lambda^2} \right) \times g_{Y A, \Lambda} \cdot \not q \times g_{N D^+ D^-} \times F^2 (m_\Lambda^2, q^2) \right],
\]

(10)

and

\[
\mathcal{M}(Y(4630) \rightarrow D^{*+} D^-) = \int \frac{d^4 q}{(2\pi)^4} (-1) \text{Tr} \left[ g_{\Lambda N D^+ Y^+} i \left( \frac{\not q - \not g + m_\Lambda}{(p_1 - q)^2 - m_\Lambda^2} \right) \times g_{Y A, \Lambda} \cdot \not q \times g_{N D^+ D^-} \times F^2 (m_\Lambda^2, q^2) \right],
\]

(11)

respectively. The general expression of decay width

\[
\Gamma \left[ Y(4630) \rightarrow D^{(*)+} D^{(*)-} \right] = \frac{|q|^2 |\mathcal{M}(Y(4630) \rightarrow D^{(*)+} D^{(*)-})|^2}{24\pi m_{Y(4630)}^2},
\]

where \(|q| = \lambda^{1/2}(m_{Y(4630)}^2, m_{D^{(*)+}}^2, m_{D^{(*)-}}^2)/(2m_{Y(4630)})\) is the three-momentum of the final states in the center of mass frame of \( Y(4630) \). \( \Lambda(a, b, c) = a^2 + b^2 + c^2 - 2ab - 2ac - 2bc \) is the Källen function.

Similarly, we obtain the decay amplitudes of \( Y(4630) \) decaying into \( \pi^+ \pi^- \) and \( K^+ K^- \) as

\[
\mathcal{M}(Y(4630) \rightarrow \pi^+ \pi^-) = \int \frac{d^4 q}{(2\pi)^4} (-1) \text{Tr} \left[ g_{\Lambda N D^+ Y^+} i \left( \frac{\not q - \not g + m_\Lambda}{(p_1 - q)^2 - m_\Lambda^2} \right) \times g_{Y A, \Lambda} \cdot \not q \times g_{N D^+ D^-} \times F^2 (m_\Lambda^2, q^2) \right],
\]

(12)

and

\[
\mathcal{M}(Y(4630) \rightarrow K^+ K^-) = \int \frac{d^4 q}{(2\pi)^4} (-1) \text{Tr} \left[ g_{\Lambda N D^+ Y^+} i \left( \frac{\not q - \not g + m_\Lambda}{(p_1 - q)^2 - m_\Lambda^2} \right) \times g_{Y A, \Lambda} \cdot \not q \times g_{N D^+ D^-} \times F^2 (m_\Lambda^2, q^2) \right],
\]

(13)

III. THE NUMERICAL RESULTS

Now in terms of the formulation derived in the past section, we numerically compute the decay widths of the aforementioned processes. The input parameters are taken from Refs. [1, 25, 27], totally, we have \( g_2 = 0.598, f = 92.3 \) MeV, \( m_{Y(4630)} = 4.630 \) GeV, \( m_D = 1.865 \) GeV, \( m_{D^*} = 2.007 \) GeV, \( m_{\Lambda} = 2.286 \) GeV, \( m_{\Sigma_c} = 2.455 \) GeV, \( m_{\Xi_c} = 2.578 \) GeV, \( m_K = 0.497 \) GeV, \( m_{\pi} = 0.135 \) GeV, \( m_{\rho} = 0.940 \) GeV and \( m_{\phi} = 0.938 \) GeV. The coupling constants \( g_{\Lambda N D^+}, g_{\Lambda N D^+} \) is 10.7^{+5.3}_{-4.3} \) and \( g_{\Lambda N D^+} = 5.8^{+2.5}_{-2.1} \) are borrowed from Refs. [22, 23], where we take those central values in our calculation. The coupling constant \( g_{\Lambda N D^+} \) is obtained by fitting the available experimental data. Since the branching ratio of \( B(Y(4630) \rightarrow \Lambda_c \Lambda_c) \) is not very accurately determined yet and the resonance peak is only observed at this channel, we have a reason to assume that \( Y(4630) \) predominantly decays into \( \Lambda_c \Lambda_c \), so its partial width is approximately equal to the total width of \( Y(4630) \).
With the effective Lagrangian in Eq. (1), the decay width is written as

$$\Gamma(Y(4630) \rightarrow \Lambda_c \bar{\Lambda}_c) = \frac{|k|(m_{Y(4630)}^2 + 2m_{\Lambda_c}^2)}{6\pi m_{Y(4630)}^2} g_{Y(4630)}^2$$ \(14\)

where \(|k| = \sqrt{m_{Y(4630)}^2 - 4m_{\Lambda_c}^2}/2\). By fitting the experimental width of \(Y(4630)\) \((\Gamma_{Y(4630)} = 92\text{ MeV} [1])\), we assume \(Y(4630) \rightarrow \Lambda_c \bar{\Lambda}_c\) to be dominate decay of \(Y(4630)\), we obtain \(g_{Y(4630)}^2 = 1.78\).

The form factor at the effective hadronic vertices is introduced to compensate the off-shell effects of the intermediate agents (baryon or meson), and a reasonable choice for it is suggested by Cheng et al. [26] as

$$F(m_E^2, q^2) = \frac{\Lambda^2 - m_E^2}{\Lambda^2 - q^2}$$ \(15\)

where the cut-off parameter \(\Lambda\) can be parametrized as \(\Lambda = \alpha \Lambda_{QCD} + m_E\) with \(\Lambda_{QCD} = 220\text{ MeV}\) and \(\alpha\) is a phenomenological parameter of order of unity [26]. In the above expression, \(m_E\) denotes the mass of the exchanged particle.

| Channel                  | Branching ratio |
|--------------------------|-----------------|
| \(D^+ D^-\)             | \(0.085\) (fixed) [28] \(0.14\) (fixed) [29] |
| \(D^+ D^- + h.c.\)      | \(0.122\)       |
| \(D^{*+} D^-\)          | \(0.094\)       |
| \(p \bar{p}\)           | \(0.037\)       |
| \(\pi^+ \pi^-\)         | \(1.65 \times 10^{-6}\) \(2.62 \times 10^{-6}\) |
| \(K^+ K^-\)             | \(3.63 \times 10^{-6}\) \(5.73 \times 10^{-6}\) |

TABLE I: The calculated upper limit for the branching ratios of \(Y(4630) \rightarrow D^{(*)} D^{(*)}\), \(p \bar{p}\), \(\pi^+ \pi^-\) and \(K^+ K^-\) with typical values \(\alpha = 1.5\) and \(1.7\), extracted by the similar way to that of \(Y(4630) \rightarrow D^+ D^-\). [30] and \(\sigma(e^+ e^- \rightarrow D^{(*)} D^{(*)}) = 0.44 \pm 0.12\) nb at \(\sqrt{s} = 4.63\) GeV [30] were applied to this estimate.

In the following, we discuss how to constrain the \(\alpha\) value by the experimental data. We note that the cross section of \(e^+ e^-\) annihilation into \(D^+ D^-\) has been measured by Belle [28] and BaBar [29], while the cross section for \(e^+ e^- \rightarrow \Lambda_c \bar{\Lambda}_c\) has been given by the Belle collaboration [1]. The general expression of cross sections for the \(e^+ e^- \rightarrow Y(4630) \rightarrow f\) is

$$\sigma(e^+ e^- \rightarrow Y(4630) \rightarrow f) = \frac{12\pi \Gamma_Y^{e^+ e^-} B(Y \rightarrow f) \Gamma_Y}{(s - m_f^2)^2 + m_f^2 \Gamma_f^2}$$ \(16\)

where \(f\) denotes the final states, \(\Gamma_Y^{e^+ e^-}\) and \(B(Y \rightarrow f)\) are the dilepton partial width of the \(Y(4630)\) and the branching ratio for the \(Y(4630) \rightarrow f\) decay, respectively. Thus, the ratio of the partial widths for \(D^+ D^-\) and \(\Lambda_c \bar{\Lambda}_c\) can be defined as

$$R_{D^+ D^-} \equiv \frac{\Gamma[Y(4630) \rightarrow D^+ D^-]}{\Gamma[Y(4630) \rightarrow \Lambda_c \bar{\Lambda}_c]} = \frac{\sigma(e^+ e^- \rightarrow Y(4630) \rightarrow D^+ D^-)}{\sigma(e^+ e^- \rightarrow Y(4630) \rightarrow \Lambda_c \bar{\Lambda}_c)}$$ \(17\)

The signal of the \(Y(4630)\) in the \(e^+ e^- \rightarrow \Lambda_c \bar{\Lambda}_c\) had been clearly observed and the cross section for \(e^+ e^- \rightarrow Y(4630) \rightarrow \Lambda_c \bar{\Lambda}_c\) was reported to be \(0.47^{+0.22}_{-0.22}\) nb at \(\sqrt{s} = 4.63\) GeV [1]. However, in the cross sections for \(e^+ e^- \rightarrow D^+ D^-\), the signal of the \(Y(4630)\) has not been observed [28, 29]. Here, we suppose that only some fraction of the \(e^+ e^- \rightarrow D^+ D^-\) cross section at \(4.63\) GeV turns out to be due to the \(Y(4630)\). Then, we take \(\sigma(e^+ e^- \rightarrow Y(4630) \rightarrow D^+ D^-) = g_0 \sigma(e^+ e^- \rightarrow D^+ D^-)\) with \(g \leq 1\). According to \(\sigma(e^+ e^- \rightarrow Y(4630) \rightarrow D^+ D^-) = 0.04 \pm 0.035\) nb and \(0.065 \pm 0.055\) nb from the Belle [28] and BaBar collaborations [29], respectively, we get \(R_{D^+ D^-} = g(0.085^{+0.024}_{-0.064})\) and \(g(0.14^{+0.034}_{-0.098})\), which indicates that the upper limit of the \(R_{D^+ D^-}\) is determined to be \(0.085_{-0.064}^{+0.024}\) or \(0.14_{-0.098}^{+0.034}\) depending on the data given by different collaborations. With the upper
limit of the $R_{D^+D^-}$, we can fix the parameter $\alpha$ introduced for our model dependent calculations, then with the determined $\alpha$ we can roughly estimate the upper limits of the branching ratios of other rare decays. In addition, one should notice that the experimental errors of the cross sections of $e^+e^- \rightarrow D^+D^-$ are relatively large at the central values of the cross sections around 4.6 GeV, thus further precise measurements in this region should provide us more information of the $Y(4630)$ resonance.

Under the diquark-antidiquark assignment to $Y(4630)$ suggested in Ref. [14], we take the width of $Y(4630)$ as the input of $\Gamma [Y(4630) \rightarrow \Lambda_c \Lambda_c]$. Then, we estimate $\Gamma [Y(4630) \rightarrow D^+D^-] = 7.8^{+6.7}_{-4.5} \text{MeV}$ and $12.8 \pm 10.3 \text{MeV}$, by which we fix $\alpha = 1.5$ and 1.7, respectively, by the formula of $Y(4630) \rightarrow D^+D^-$ presented in Sec. II. In the following, we adopt the obtained typical $\alpha = 1.5$ and 1.7 to further estimate other rare strong decays of $Y(4630)$ discussed in this work, which are shown in Table I.

We list the branching ratios of the rare strong decays of $Y(4630)$ with typical $\alpha$ values in Table I, and will discuss dependence of these branching ratios of the rare strong decays of $Y(4630)$ on $\alpha$ (see Fig. 2).

Fig. 1 (a) and (c) demonstrate that there exists an OZI suppression for $c\bar{c}$ annihilation while for the $K$ meson production (Fig. 1 (c)) $s\bar{s}$ annihilation is also OZI suppressed. Thus, one expects that the branching ratios determined by Fig. 1 (a) and (c) are somewhat smaller than that of Fig. 1 (b). As shown in Table I, the obtained results reflect this fact.

IV. DISCUSSION AND CONCLUSION

In this work, based on the postulation that $Y(4630)$ observed by the Belle collaboration at the invariant mass spectrum of $\Lambda_c \Lambda_c$ and not at other channels, is a tetraquark composed of a diquark and an anti-diquark [14], we suggest that it overwhelmingly decays into $\Lambda_c \Lambda_c$. Since the production of $\Lambda_c \Lambda_c$ is close to the available energy threshold, the hadronic final state interactions might be significant. The inelastic rescattering processes may produce other final state particles which can be either mesons or baryons.

By the standard strategy for dealing with inelastic rescattering processes, we provide several predictions on the branching ratios of $Y(4630)$ decays into $p\bar{p}, D^+\bar{D}^0, \pi^+\pi^-$, and $K^+K^-$. As the free parameter in our calculation, $\alpha$ is fixed by fitting the experimental data of [28, 29] whose procedures is just illustrated in Sec. III. As a matter of fact, some other channels, such as vector meson pairs $\rho\rho$ etc. may also exist in the final states with similar orders of magnitude. Definitely, we do not cover all of them, but select several typical processes to show the scenario.

Since we take the total width of $Y(4630)$ as the partial width of $Y(4630) \rightarrow \Lambda_c \Lambda_c$ for our numerical computations, certain errors might be caused. However, as we argued above, the $Y(4630) \rightarrow \Lambda_c \Lambda_c$ is the overwhelming mode, the errors brought up by the approximation are not serious and the subsequent results are trustworthy, in particular the quantitative conclusion should not be changed.

The suggested final states are of smaller branching ratios as expected, our numerical results show that they are at order $O(10^{-3})$ to $O(10^{-2})$, which are too small to be detected by the present experiments, but will definitely be "seen" by the future much more precise measurements.

Obviously, if $Y(4630)$ is not a tetraquark, but a molecular state as suggested by some authors, or their mixture, its decay pattern would be different from our prediction based on the tetraquark assumption. Namely, if $Y(4630)$ is a molecular state with more components beside $\Lambda_c \Lambda_c$, one would expect other final states to have larger branching fractions than we estimate in this work; while for the dynamical diquark model of Brodsky et al. [10] in which the diquarks are far separated, since the two components are far apart, except $\Lambda_c \Lambda_c$ no other direct final states could be produced. Therefore future measurements on various decay channels of $Y(4630)$ will help to pin down the identity of this resonance.

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