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One Explanation for the Exotic State Y(4260)

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Abstract

In this Letter we interpret the Y(4260), a state recently discovered by the BaBar Collaboration that has a mass within the range of conventional charmonium states, as having a molecular-state structure. In our scheme this molecular-like state is not constructed out of two-quark mesons, but rather out of baryons, i.e., the Y(4260) is a baryonium state. With this interpretation, the unusual measured properties of the Y(4260) are easily understood and some further peculiar decay characteristics are predicted.

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Physics research at heavy-flavor energy scales, e.g., at charm and bottom masses, has recently made several discoveries. Among these are the observations of several new resonances or resonant structures. Very recently, a resonant structure named the Y(4260) was observed by the BaBar Collaboration in the initial-state radiation process $e^+e^- \to \gamma\ \pi^+\pi^- J/\psi$ [1]. This state must have the same quantum numbers as the photon, $J^{PC} = 1^{--}$, and is a broad resonance with a fitted width of

$$\Gamma = 90 \text{ MeV} . \tag{1}$$

Since the mass of the Y(4260) is within the range of conventional charmonium states, a natural explanation is that it contains charm-anticharm constituents. However, although the observed enhancement is at 4.26 GeV, quite a ways about open-charm threshold, there is no experimental signal for $D\bar{D}$ in its observed decays. Presently, except for Ref.[2] where the Y(4260) is still interpreted as a normal member in the charmonium spectra, a common belief is that it is rather an exotic (or cryptoexotic) state. The authors of Refs. [3, 4, 5] propose that the new state is a charmonium hybrid that is configured out of a pair of charm-anticharm quarks and a gluon. Ref. [6] thinks the Y(4260) may be the first orbital excitation of a diquark-antidiquark state $[cs][\bar{c}\bar{s}]$. In Ref. [7], Liu *et al.* explain the resonance as a molecular state composed of a ρ and χ_c, while the authors of Ref. [8] take it as a ω and χ_c molecular state.

In our understanding, the Y(4260) might be a baryonium state containing hidden charm and made out of Λ_c-$\bar{\Lambda}_c$ (we use Λ_c-$\bar{\Lambda}_c$ to represent Λ_c^+-Λ_c^- hereafter in this paper). This model not only gives a natural explanation for the state's observed and unobserved decays, but can also make predictions of some further peculiar properties, which could be measured by future experiments, as explained in the following.

At an e^+ e^- collider, any directly produced state is naively thought to be flavor symmetric in its inner structure, a view held by most of the earlier speculations on the Y(4260), e.g., the $[cs][\bar{c}\bar{s}]$ interpretation. Our model follows this idea as well. In the Λ_c-$\bar{\Lambda}_c$ assignment, the $\pi^+\pi^- J/\psi$ decay process can proceed easily, as shown schematically in Figure 1(a). However, the $D\ \bar{D}$ exclusive decay is almost impossible. One way to produce a $D\ \bar{D}$ pair is to let one pair of light quarks annihilate into a photon(Figure 1(b)), which is an electromagnetic process and, hence, is highly suppressed relative to the observed decay mode. A rough calculation tells us that the $D\ \bar{D}\ \gamma$ decay process should be two orders of magnitude smaller than the observed $\pi^+\pi^- J/\psi$ decay. Another possibility is to let a pair of light quarks annihilate into a gluon, followed by a complicated color rearrangement to make the $D\ \bar{D}$ configuration. Normally, this kind of decay scheme is suppressed by the color factor N_c. In the baryonium model, the most important open-charm decay process of the Y(4260) should be into $D^*\bar{D}^*\pi$, but not into $D\bar{D}\pi$ because of the requirements of parity, angular momentum and isospin conservation. Since for Λ_c-$\bar{\Lambda}_c$ baryonium there are no constituent strange quarks, the decay to final states with strangeness, such as $D_s\ \bar{D}_s$

and $K^+\ K^-\ J/\psi$, should also be suppressed relative to the observed mode $\pi^+\pi^- J/\psi$[†].

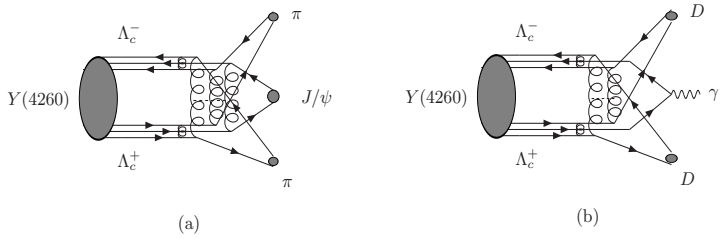

Figure 1: (a)The schematic Feynman diagram of $Y(4260)$ decaying into $J/\psi\ \pi\pi$; (b)The schematic Feynman diagram of $Y(4260)$ radiative decay to two D mesons and a photon process.

In fact, the baryonium conjecture is not really a big surprise. In the framework of QCD, this kind of states might exist, similar to Helium. After the advent of QCD, indeed, there have been lots of theoretical speculations and experimental efforts on it. Nevertheless, no definite observation is confirmed to be a baryonium up to now. With experiment in progress, to find the signature of baryonium state by the today's highly efficient machines is not impossible. For instance, the recent measurements by BES [10] and BELLE [11] stimulate a new round of interest in baryonium physics. The BES observation on the $p\bar{p}$ threshold enhancement in J/ψ decays has been interpreted as possibly a proton-antiproton baryonium [12]. Similarly, the BELLE measurement also has the baryonium interpretation [13].

In the baryonium configuration of Y(4260), the constituent baryons Λ_c and $\bar{\Lambda}_c$ in principle should not be restricted to being a color singlet. These two three-quark baryon-like clusters can carry color indices, which enables the binding energy to be easily as large as several hundred MeV, like in the case of charmonium or bottomonium. Note that, in principle, in the large-N_c limit the baryonium binding energy can be very large. In our case, roughly speaking, the binding energy is about [14]

$$M(Y(4260)) - 2M(\Lambda) \approx 310\ MeV\ . \tag{2}$$

Due to the large uncertainties in the experimental measurement, these number should only be considered as an order-of-magnitude estimation.

To distinguish our interpretation from other exotic state explanations is easy experimentally. One of the main results of our model is that the new observed resonance should

[†]This prediction is roughly confirmed by the recent measurement from the CLEO Collaboration [9]. They find evidence for a K^+K-J/ψ signal in Y(4260) decays with a rate much smaller than for $\pi^+\pi^- J/\psi$.

have a large branching ratio in the $e^+e^- \to \gamma_{ISR}\pi^+\pi^-\psi'$ process which is suppressed in most other schemes. Another unique feature of our model is that the two-body decay is generally suppressed, while the three-body decay is favored since the six-quark components of the baryonium makes the later much easier. Recently, the BaBar Collaboration has also measured the $e^+e^- \to \mathrm{ISR} + \ p + \bar{p}$ process [15]. They find no clear signal of a resonance-like structure at the energy of 4260 MeV. They set an upper limit on the ratio of branching fractions:

$$\frac{B(e^+e^- \to p + \bar{p})}{B(e^+e^- \to \pi^+\pi^- J/\psi)} < 13\% \ . \tag{3}$$

In our model, this result is easy to understand. Without considering the complicated color rearrangement, to annihilate the charm quark pair and meanwhile to produce a pair of light quarks there will be a hard propagator of $1/(2m_c)^4$ in the context of pQCD. This may suppress the $p\ \bar{p}$ production process by about two orders of magnitude relative to the $\pi^+\pi^- J/\psi$ production.

According to our point of view, the baryonium state includes no strange quark(s) or constituent gluon(s), so its decay to the $J/\psi\ K^+\ K^-$ is not favored. It would be suppressed by the annihilation-production transition rate, which in practice may not be too big, relative to the observed $J/\psi\ \pi^+\ \pi^-$ channel. However, in Refs.[4] and [6], by using some subtle schemes this point can also be achieved. On the other hand, according to Ref.[7], it is almost impossible for the $Y(4260)$ to decay to $\psi'\ \pi^+\ \pi^-$ since the χ_{c1} mass is lower than that of the ψ' state. In our model, it is possible and we can even give a rough estimation of the relative rates of these two decay channels, i.e.,

$$R_{\psi'/\psi} = \frac{\Gamma(Y(4260) \to \psi'\pi^+\pi^-)}{\Gamma(Y(4260) \to J/\psi\pi^+\pi^-)} \approx \frac{\Omega_1}{\Omega_2}\frac{|\psi'(0)|^2}{|\psi(0)|^2} \approx \ 0.19\frac{\Gamma(\psi' \to e^+e^-)}{\Gamma(J/\psi \to e^+e^-)} \approx 0.08 \ . \tag{4}$$

Here, we neglect the dynamical difference of the new state decaying into $J/\psi\pi^+\pi^-$ and $\psi'\pi^+\pi^-$, but only integrate over kinematic phase space $\Omega_{1,2}$; the $\psi'(0)$ and $\psi(0)$ represent the ψ' and J/ψ radial wavefunctions at the origin in the quark model, respectively. Since there are more than 100 observed $Y(4260) \to \pi^+\pi^- J/\psi$ events, from (4) we would expect only a small number of $\pi^+\pi^-\psi'$ events with the present experimental statistics. In addition, in our model the $e^+e^- \to \gamma_{ISR}\pi^0\pi^0\psi$ is allowed, and the isospin and statistical analysis tells us that it is about half the rate of the observed one[‡], that is

$$\Gamma[Y(4260) \to \pi^0\pi^0\psi] \approx \frac{1}{2}\Gamma[Y(4260) \to \pi^+\pi^-\psi] \ . \tag{5}$$

While the $\pi^0\pi^0\psi$ final state is hard to pin down experimentally, in our assignment, in principle we know this mode should be there, contrary to the prediction in Ref. [7].

In conclusion, in this work we propose a new model to explain the recent observation of the Y(4260) state at PEP-II. In our scenario this new resonance is a bound state of

[‡]It has also been confirmed by the recent CLEO measurement [9].

baryons, a Λ_c pair, i.e., an ortho-baryonium state. If our assignment for the resonance Y(4260) is correct, the pseudoscalar para-baryonium partner should also exist in nature.

In our model, the observed nature of Y(4260) can be easily understood. We have also made some predictions based on our explanation for this state. Some of these predictions are distinctively different from predictions based upon other speculations, which are left for future experiments to measure. In the baryonium interpretation the smallness of K^+K^-J/ψ and non-observation of $D\bar{D}$ decay modes in the present experiment, which are the dominant decay products in other measured normal s-wave charmonium excited states, can be well explained. According to our calculation, the $\psi'\pi^+\pi^-$ decay mode of the concerned state is marginally observable with the present experimental statistics. In our model, the decay mode of $D^*\bar{D}^*\pi$ is observable with the collected data or in the near future, but the mode of $D\bar{D}\pi$ is highly restricted. And, we can explain BaBar's new upper limit for Y(4260) to $p\ \bar{p}$. Finally, it should be noted that our assignment for the new measured resonance (enhancement) at 4260 MeV as a baryonium state might only be an approximate description. In reality, it could be a mixture of baryonium and convention charmonium states.

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