1 - 7 Possible $B^{(*)}\bar{K}$ Hadronic Molecule State

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In 2016, the D0 Collaboration observed a new narrow structure with the statistical significance of 5.1 σ in the $B_s^0\pi^\pm$ invariant mass spectrum, named X(5568)[1]. The observed resonance parameters of the structure are,

$$m = 5567.8 \pm 2.9(\text{stat})^{+0.9}_{-1.9}(\text{syst})\ \text{MeV},$$
$$\Gamma = 21.9 \pm 6.4(\text{stat})^{+5.0}_{-2.5}(\text{syst})\ \text{MeV},$$

respectively[1]. The observed channel indicates the isospin of the X(5568) is 1. If the structure decays into $B_s^0\pi^\pm$ via a S−wave, the quantum numbers of the X(5568) are $J^P = 0^+$.

The new structure X(5568) was observed in the $B_s\pi$ invariant mass spectrum, however, as indicated in the D0 paper[1], the observed structure may decay through the chain $B_s^{0*}\pi^0$, $B_s^{0*} \to B_s^0\gamma$, in which the soft photon may not be detected since the mass gap of B_s^{0*} and B_s^0 is less than 50 MeV. In other words, if there exist a state X in the $B_s^*\pi$ invariant mass spectra, one could find an enhanced structure in the $B_s\pi$ invariant mass spectra of the decay $X \to B_s^*\pi \to B_s\gamma\pi$. In this case, the observed state should decay into $B_s^{*0}\pi^\pm$, and the mass should be shifted by addition of the mass difference of B_s^{*0} and B_s^0, which is about 5616 MeV, while the width remains unchanged. This structure would be named X(5616) with the quantum number $J^P = 1^+$ if it couples to $B_s^{0*}\pi^\pm$ via the S−wave.

After the observation of the X(5568) by the D0 Collaboration, the LHCb Collaboration presented their measurement for the spectrum for the same final state[2], but did not find any structure corresponding to the X(5568). However, the statistical significance of X(5568) was reported to be 5.1 σ by the D0 collaboration, which indicates the high reliability of their results. In a word, more further experimental efforts are needed to clarify the controversial situation of X(5568).

On the theoretical side, one can find the X(5568)/X(5616) is a kind of state with four different flavors of quarks since the quark components of the $B_s^{(*)0}$ and $\pi^\pm$ are $\bar{b}s$ and $u\bar{d}/\bar{u}d$, respectively. Such a fully-open flavor state can not be included in the conventional quark model and was observed for the first time. Thus, both the tetraquark and hadronic interpretations were proposed for the X(5568)/X(5616)[3,4]. In the hadronic molecule assumption, the X(5568) and X(5616) are considered as the $B\bar{K}$ and $B^*\bar{K}$ bound states, respectively.

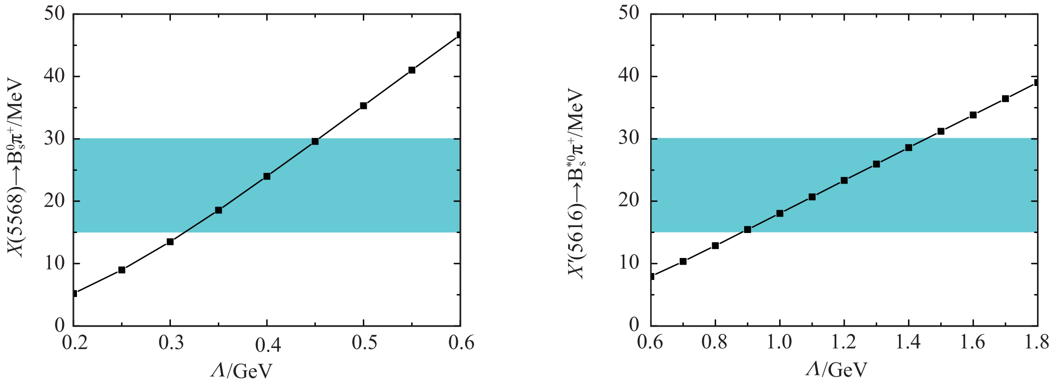

Fig. 1 (color online) Decay width of the $X(5568)^+ \to B_s^0\pi^+$ depending on Λ (left column). Decay width of the $X(5616)^+ \to B_s^{*0}\pi^+$ depending on Λ (right column). The blue band is the experimental measured width of corresponding process[1].

In the present work, we check the existence of the X(5568)/X(5616) by estimating their decays in the hadronic molecule frame[5]. In Fig. 1, the partial decay widths of transitions from X(5568)/X(5616) to $B_s\pi/B_s^*\pi$ are given, where the blue band is the experimental measured width for the corresponding process, and the range of the parameter values is chosen to be 0.2∼0.6 GeV for X(5568), and 0.6∼1.8 GeV for X(5616). Our estimation of the partial width for the $X(5568)^+ \to B_s^0\pi^+$ can overlap with the experimental measured one, and the overlapped Λ range is 0.31 ∼ 0.46 GeV. Also, the the overlapped Λ range for the X(5616) is 0.89∼1.43 GeV. Both the Λ range are of orderof 1 GeV, which is the empirical value of Λ. On the other word, we can not exclude the hadronic molecule intepretation for X(5568)/X(5616).

Furthermore, the radiative decays of the neutral states X(5568)^0 and X(5616)^0 are investigated. The partial width of the X(5568)$^0 \to \mathrm{B_s^{*0}}\gamma$ is estimated to be

$$\Gamma(\mathrm{X(5568)^0} \to \mathrm{B_s^{*0}}\gamma) = 2.7 \sim 4.7\,\mathrm{keV}, \tag{1}$$

The widths of the radiative decay processes for X(5616) are estimated to be

$$\begin{aligned} \Gamma(\mathrm{X(5616)^0} \to \mathrm{B_s^0}\gamma) &= 100 \sim 173 \text{ keV}, & (2)\\ \Gamma(\mathrm{X(5616)^0} \to \mathrm{B_s^{*0}}\gamma) &= 3 \sim 10 \text{ keV}. & (3) \end{aligned}$$

We propose to study these states by radiative decay experimentally, which would help us to further understand the observed structure in the $\mathrm{B_s}\pi$ invariant mass spectrum by the D0 Collaboration.

References

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1 - 8 Analysis of the Hidden Bottom Decays of Z_b(10610) and Z_b(10650) via Final State Interaction

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In 2011, the Belle Collaboration reported two new bottomonium-like states, $Z_b^\pm(10610)$ and $Z_b^\pm(10650)$ in the invariant mass spectrum of $\Upsilon(mS)\pi(m=1,2,3)$ and $h_b(nP)\pi(n=1,2)$ of the dipion decays of $\Upsilon(5S)$(Z_b and Z_b' refer to $Z_b(10610)$ and $Z_b(10650)$, respectively.)[1]. The quantum numbers of these bottomonium-like states were determined to be $J^P=1^+$ due to the analysis of charged pion angular distribution. From the observed channels of the Z_b and Z_b', one can find these two bottomonium-like states could not be conventional bottomonia and contain at least four constitute quarks.

Being the candidates of exotic states, the Z_b and Z_b have attracted the interest of theorists. Since the masses of Z_b and Z_b' are close to the $B\bar{B}^*$ and $B^*\bar{B}^*$ thresholds, respectively. It is naturally to consider these two states as the molecules of the $B\bar{B}^*$ and $B^*\bar{B}^*$, respectively. On the other hand, the tetraquark interpretation can not be excluded. The calculation of the spectrum under both the assumptions of hadronic molecules and tetraquark states were carried out in different works[2,3]. Also, the decay information can provide more information of the inner structure of the Z_b and Z_b'. For the transitions between the lower heavy quarkonium, the glue emission and hadronization is one of the most important mechanisms, which could be dealt by using the QCD Multipole-Expansion[4]. However, the investigations on the decays of the higher heavy quarkonium indicate that the final-states interactions play dominant roles in understanding the decay behaviors of the higher heavy quarkonium [5]. Furthermore, the Z_b' states contain at least four constitute quarks, the transitions between the Z_b' states and the bottomonium could occur va quark rearrangement. Such kind of quark rearrangements could phenomenologically be described in hadronic level, which is the same as the final state interactions in methodology.

Along this way, we apply the final state interaction mechanism to study the hidden bottom decays of the Z_b/Z_b'[6]. Our results point out that the final-state interaction plays important roles in interpretation of the branching ratios of the hidden bottom decays of the Z' states. Besides the observed channels of the Z_b/Z_b', the $\eta_b(nS)\rho$, $(n=1,2)$ modes can provide us more information on these two bottomonium-like states. We predict their branching ratios

$$\begin{aligned} \mathcal{B}(Z_b \to \eta_b(1S)\rho) &= (0.88 \sim 5.23)\%, \\ \mathcal{B}(Z_b \to \eta_b(2S)\rho) &= (0.11 \sim 0.43)\%, \\ \mathcal{B}(Z_b' \to \eta_b(1S)\rho) &= (0.49 \sim 8.34) \times 10^{-4}, \\ \mathcal{B}(Z_b' \to \eta_b(2S)\rho) &= (0.10 \sim 1.16) \times 10^{-4}, \end{aligned} \tag{1}$$

where the branching ratio of $Z_b \to \eta_b(1S)\rho$ could reach up to 5.23%, which is of the same order of $\mathcal{B}(Z_b \to \Upsilon(2S)\pi)$.