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Charged Bottomonium-Like Structures $Z_b(10610)$ and $Z_b(10650)$

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Abstract The observation of two charged bottomonium-like structures $Z_b(10610)$ and $Z_b(10650)$ has stimulated extensive studies of the properties of $Z_b(10610)$ and $Z_b(10650)$. In this talk, we briefly introduce the research status of $Z_b(10610)$ and $Z_b(10650)$ combined with our theoretical progress.

1 Introduction

In the past 8 years, experiments have made big progress on the observations of charmonium-like or bottomonium-like states $X$, $Y$, $Z$, which have stimulated theorists’ interest in revealing their underlying structures. Thus, studying charmonium-like and bottomonium-like states is an active and important research field in hadron physics at present, which can further deepen our understanding of the properties of $X$, $Y$, $Z$ and improve our knowledge about non-perturbative QCD.

Very recently, the Belle Collaboration [1] reported the first observation of two charged bottomonium-like structures, which makes the family of bottomonium-like abundant. By analyzing the $\Upsilon(nS)\pi^\pm (n = 1, 2, 3)$ and $h_b(mP)\pi^\pm (m = 1, 2)$ invariant mass spectra of $\Upsilon(5S) \rightarrow \Upsilon(nS)\pi^+\pi^-$, $h_b(mP)\pi^+\pi^-$ hidden-bottom dipion decays, Belle observed that there exist two enhancement structures around 10,610 and 10,650 MeV, which are named as $Z_b(10610)$ and $Z_b(10650)$, where $Z_b(10610)$ and $Z_b(10650)$ are close to the thresholds of $B^0\bar{B}^0$ and $B^{*}\bar{B}^{*}$, respectively.

Due to the peculiarities of $Z_b(10610)$ and $Z_b(10650)$, theorists have paid more attentions to the observed novel phenomena by different approaches [2–14]. In the following, we will introduce the theoretical progress on the study of $Z_b(10610)$ and $Z_b(10650)$.

2 The Puzzles in the Hidden-bottom Dipion Decays of $\Upsilon(5S)$ and $Z_b$ Structures

Before the observation of two $Z_b$ structures [1], the Belle Collaboration measured the $e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(2S)\pi^+\pi^-$ processes near the peak of the $\Upsilon(5S)$ resonance at $\sqrt{s} = 10.87$ GeV [15], which indicates that there exist the anomalous $\Upsilon(1S)\pi^+\pi^-$ and $\Upsilon(2S)\pi^+\pi^-$ productions, i.e., the branching ratios of $\Upsilon(5S) \rightarrow \Upsilon(1S)\pi^+\pi^-$ and $\Upsilon(5S) \rightarrow \Upsilon(2S)\pi^+\pi^-$ are larger than the dipion-transition rates between the lower members of the $\Upsilon$ family by two orders of magnitude [15].
For solving this puzzling phenomena, rescattering mechanism was proposed in Ref. [16]. Since $\Upsilon(5S)$ is above the threshold of $B$ meson pair, the coupled channel effect becomes important, which makes the intermediate hadronic loops constructed by $B^{(*)}/\bar{B}^{(*)}$ mesons play crucial role to understanding the anomalous $\Upsilon(1S)\pi^+\pi^-$ and $\Upsilon(2S)\pi^+\pi^-$ production [16]. As an alternative explanation, tetraquark state $Y_b(10890) = [bg][\bar{b}g]$ was introduced in Ref. [17]. Later, authors of Ref. [18] studied the Belle data by analyzing the dipion invariant mass spectrum and the $\cos \theta$ distribution of $Y_b$ decays into $\Upsilon(1S)\pi^+\pi^-$ and $\Upsilon(2S)\pi^+\pi^-$, and claimed that the tetraquark interpretation can well describe the anomalous rates observed by Belle [15].

Later, in Ref. [19] we indicated that the $\cos \theta$ distribution of $Y_b \to \Upsilon(2S)\pi^+\pi^-$ given by Ref. [18] is not consistent with the Belle data, and proposed an alternative approach to try to explain Belle observation of $\Upsilon(5S)$ decays into $\Upsilon(1S)\pi^+\pi^-$ and $\Upsilon(2S)\pi^+\pi^-$, where the interference between the direct dipion transition and the final state interaction corresponding to the first and the second diagrams of Fig. 1, respectively. Under this scenario, we can explain the anomalous rates of $\Upsilon(1S)\pi^+\pi^-$ and $\Upsilon(2S)\pi^+\pi^-$ production in $\Upsilon(5S)$ decays, especially the inverse rates $\Gamma(\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-) > \Gamma(\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-)$. Besides, the dipion invariant spectrum and the $\cos \theta$ distribution of $\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-$ can be reproduced. However, the $\cos \theta$ distribution of $\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$ cannot be described by the scenario in Ref. [19].

This fact mentioned above shows that a new puzzle appears in the $\Upsilon(5S)$ decays, especially the inverse rates $\Gamma(\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-)$. Since two $Z_b$ structures play crucial role to understanding the anomalous $\Upsilon(5S)$ decay, we need to consider new mechanism involved in the $\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$ decay. Since two $Z_b$ structures are from the hidden-bottom dipion decays of $\Upsilon(5S)$ [15], we realized that there exists the extra intermediate $Z_b(10610)$ and $Z_b(10650)$ contributions to the $\Upsilon(5S)$ decays just depicted by the last two diagrams in Fig. 1. Thus, in Ref. [3] we included all mechanisms listed in Fig. 1 to redo the analysis of the $\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$ decay.

The results presented in Fig. 2 indicate that including the intermediate $Z_b(10610)$ and $Z_b(10650)$ contribution can produce the $\cos \theta$ distribution of $\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$ consistent with the experimental data [15]. This observation provides an indirect evidence to the existence of two charged $Z_b$ structures, and gives a possible approach to solve the puzzles existing in the $\Upsilon(5S)$ hidden-bottom dipion decays. However, we must find the source to generate the $Z_b(10610)$ and $Z_b(10650)$ structures. In the following, we introduce the exotic state explanations to $Z_b(10610)$ and $Z_b(10650)$.

3 Exotic State Assignments to Two Charged $Z_b$ Structures

Since the charged $Z_b(10610)$ and $Z_b(10650)$ are close to the $B\bar{B}^*$ and $B^*\bar{B}^*$ thresholds, respectively, $Z_b(10610)$ and $Z_b(10650)$ can be as good candidate of exotic state. Before the observation of these two charged bottomonium-like states, the analysis in Refs. [20,21] indicates that there probably exists a loosely

![Fig. 1](Color online.) The schematic diagrams of $\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$. The first diagram describes the direct production of $\Upsilon(2S)\pi^+\pi^-$ without the intermediate meson contribution. The second diagram is due to the rescattering mechanism [16], where the dipion is from intermediate $\sigma(600)$. The third and the fourth diagrams reflect two newly observed $Z_b$ structures contributing to the $\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$ decay.

![Fig. 2](Color online.) The dipion invariant mass spectrum and the $\cos \theta$ distribution of the $\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$ decay. Here, the dots with error bars are from Belle measurement, while the histograms are the theoretical results [3]. The first two diagrams or the last two diagrams are the results without or with the intermediate $Z_b$ contribution to the $\Upsilon(2S)\pi^+\pi^-$ decay.