Bottomed analog of $Z^+(4433)$

Kingman Cheung,[1,2] Wai-Yee Keung,[3] and Tzu-Chiang Yuan[2]

[1]*Department of Physics, National Tsing Hua University, Hsinchu 300, Taiwan*
[2]*National Center for Theoretical Sciences, Hsinchu 300, Taiwan*
[3]*Department of Physics, University of Illinois, Chicago Illinois 60607-7059, USA*

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The newly observed $Z^+(4433)$ resonance by BELLE is believed to be a tetraquark bound state made up of $(cu)(\bar{c}\,\bar{d})$. We propose the bottomed analog of this bound state, namely, by replacing one of the charm quarks by a bottom quark, thus forming $Z_{bc}^{0,\pm,\pm\pm}$. One of the Z_{bc} is doubly charged. The predicted mass of Z_{bc} is around 7.6 GeV. This doubly charged bound state can be detected by its decay into $B_c^\pm \pi^\pm$. Similarly, we can also replace both charm quark and antiquark of the $Z^+(4433)$ by bottom quark and antiquark, respectively, thus forming Z_{bb} the bottomonium analog of $Z^+(4433)$. The predicted mass of Z_{bb} is about 10.7 GeV.

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I. INTRODUCTION

A recent observation of a new resonance state, denoted by $Z^+(4433)$, by the BELLE Collaboration [1] via the decay channel

$$Z^+(4433) \to \psi' \pi^+ \tag{1}$$

may be interpreted as a tetraquark bound state made up of diquark-antidiquark $(cu)(\bar{c}\,\bar{d})$ [2]. However, there are alternative views that the observed peak is instead a rescattering effect of the $D^*(2010)\overline{D}_1(2420)$ molecule [3,4], because of the closeness to the $D^*(2010)\overline{D}_1(2420)$ production threshold. It remains unclear at the moment whether it is a genuine tetraquark or merely a rescattering effect.

If the observed peak is a genuine tetraquark, it is the first time that a charged tetraquark bound state is being observed. Unlike the interpretations of other possible tetraquark bound-state candidates [5], this charged tetraquark bound state is unambiguously interpreted as a 4-quark bound state, because it cannot arise from higher Fock states of charmonium. Maiani *et al.* [2] interpreted the new resonance as an orbitally excited state of $X(3872)$ and $X(3876)$. One of the reasons is that the mass difference between $Z^+(4433)$ and $X(3872)$ is close to the mass difference between ψ and ψ'. Another important property of this new state is its narrow width [1]

$$\Gamma = 44^{+17}_{-13}(\text{stat})^{+30}_{-11}(\text{syst})\ \text{MeV},$$

which suggests that it is not likely a loosely bound molecule of $D^*(2010)\overline{D}_1(2420)$, but perhaps a genuine tetraquark state [2].

In this note, we suggest looking for the bottomed analog of $Z^+(4433)$ by replacing one of the charm quarks by a bottom quark. We denote these bottomed tetraquarks by Z_{bc}. It can have a few charged states: $Z_{bc}^{0,\pm,\pm\pm}$. This suggestion is valid in the constituent quark model. The most interesting result is the existence of the doubly charged $Z_{bc}^{\pm\pm}$. We can even replace both the charm quark and antiquark of $Z^+(4433)$ by the bottom quark and antiquark, thus forming Z_{bb} the bottomonium analog of $Z^+(4433)$. We show in Table I the quark contents of these tetraquark bound states along with their charges and isospins.

II. MASS ESTIMATION

To get a crude estimate of the mass of the Z_{bc} states, we naively replace the charm quark mass by a bottom quark mass. We thus expect that the mass difference between B_c and ψ mesons of the same radial-orbital quantum numbers are nearly the same. The masses of B_c mesons cited below are taken from Ref. [6]. The experimental value [7] of the mass of the lowest B_c meson is very close to the prediction in Ref. [6] based on Buchmüller-Tye potential [8]. Experimentally, the following two mass differences

$$\begin{aligned} M[B_c(2^3S_1)] - M[\psi(2^3S_1)] &= 6899 - 3686\ \text{MeV} \\ &= 3213\ \text{MeV} \end{aligned} \tag{2}$$

and

$$\begin{aligned} M[B_c(1^3S_1)] - M[\psi(1^3S_1)] &= 6337 - 3097\ \text{MeV} \\ &= 3240\ \text{MeV} \end{aligned} \tag{3}$$

are indeed quite proximate. We thus expect

$$M[Z_{bc}] - M[Z_{cc}] \simeq 3200\ \text{MeV} \tag{4}$$

with an uncertainty of the order of 50–100 MeV. Therefore for $I = 1$, we predict the mass of the bottomed analog Z_{bc} to be

$$M[Z_{bc}] = 7630 \pm 100\ \text{MeV}. \tag{5}$$

Using the same approach the mass of the bottomonium analog Z_{bb} meson is predicted to be

$$\begin{aligned} M[Z_{bb}] &= M[Z_{cc}] + (M[\Upsilon(2^3S_1)] - M[\psi(2^3S_1)]) \\ &= M[Z_{cc}] + 6300\ \text{MeV} = 10730 \pm 100\ \text{MeV}. \end{aligned} \tag{6}$$

TABLE I. Quark contents of $Z(4433)$ and the bottomed analog Z_{bc} and the bottomonium analog Z_{bb}, ($Q = I_3 + Y$). The charge conjugated states of $Z_{bc}^{0,-,--}$ are not shown, but can be easily obtained. Normalization factor $1/\sqrt{2}$ is omitted for states of $I_3 = 0$.

I	I_3	$Z(4433)$, $Y = 0$	Z_{bc}, $Y = -1$	Z_{bb}, $Y = 0$
0	0	Z_{cc}^0: $(cu)(\bar{c}\,\bar{u}) + (cd)(\bar{c}\,\bar{d})$	Z_{bc}^-: $(bu)(\bar{c}\,\bar{u}) + (bd)(\bar{c}\,\bar{d})$	Z_{bb}^0: $(bu)(\bar{b}\,\bar{u}) + (bd)(\bar{b}\,\bar{d})$
	0	Z_{cc}^0: $(cu)(\bar{c}\,\bar{u}) - (cd)(\bar{c}\,\bar{d})$	Z_{bc}^-: $(bu)(\bar{c}\,\bar{u}) - (bd)(\bar{c}\,\bar{d})$	Z_{bb}^0: $(bu)(\bar{b}\,\bar{u}) - (bd)(\bar{b}\,\bar{d})$
1	+1	Z_{cc}^+: $(cu)(\bar{c}\,\bar{d})$	Z_{bc}^0: $(bu)(\bar{c}\,\bar{d})$	Z_{bb}^+: $(bu)(\bar{b}\,\bar{d})$
	−1	Z_{cc}^-: $(cd)(\bar{c}\,\bar{u})$	Z_{bc}^{--}: $(bd)(\bar{c}\,\bar{u})$	Z_{bb}^-: $(bd)(\bar{b}\,\bar{u})$

III. DISCUSSIONS

In Ref. [3], it was suggested that the observed peak of $Z^+(4433)$ is a rescattering effect of $D^*(2010)\overline{D}_1(2420)$ because of the closeness of the $D^*(2010)\overline{D}_1(2420)$ threshold. Analogously, the estimated mass of Z_{bc} in Eq. (5) is also close to the threshold of $B(5279)D_1(2420)$ or $B^*(5325)D_0^*(2400) \sim 7700$ MeV, within the uncertainty of our estimation.

Current experiments that can search for the proposed Z_{bc} or Z_{bb} bound states are the CDF and D0 because of their higher masses. The discovery channel would be

$$Z_{bc}^{++} \to B_c^+(2^3S_1)\pi^+, \tag{7}$$

where the $B_c^+(2^3S_1)$ is in turn detected by its decay into $B_c^+(1^3S_1) + \pi\pi$ [6]. We have no prediction for the production rate, because of the complicated fragmentation and recombination effects in forming the tetraquark state.

Similarly, the bottomonium analog can be searched for via the channel

$$Z_{bb}^+ \to \Upsilon(2S)\pi^+. \tag{8}$$

In summary, we have proposed the bottom and bottomonium analogs of the newly observed $Z^+(4433)$ meson at BELLE. The most interesting finding is the existence of doubly charged Z_{bc}^{++} state, which can be searched in the channel $B_c^+\pi^+$. Just like the $Z^+(4433)$, these analogs with isospin $I = 1$ are expected to be in the $2S$ states having $J^{PC} = 1^{+-}$. The $1S$ states and states with other J^{PC} assignments are also expected. Extension of the present analysis to the full $SU(3)$ symmetry including strangeness is straightforward and will not be presented here.

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