



Received: 12-09-2025
Accepted: 22-10-2025

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Possible ω $\Upsilon(1S)$ Tetraquark Explanations for the $\chi_{b0}(2P)$

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Abstract

The $\chi_{b0}(2P)$ is investigated using a first-order tetraquark model. An ω $\Upsilon(1S)$ configuration is evaluated assuming weakly interacting ω and $\Upsilon(1S)$ meson clusters. The $\chi_{b0}(2P)$ model yields a $J^\pi = 0^+$ value in agreement with data as well

as 1^+ and 2^+ possible assignments. A mass of 10.3705 GeV/ c^2 is predicted by the model. This value is about 1.3% larger than the value suggested by the Belle Collaboration.

Keywords: R (3780) Tetraquark, First-Order Mass Formula, Quark Model, Cluster Model

1. Introduction

The Belle Collaboration ^[1] recently reported a study of the hadronic transition $\chi_{b0}(2P) \rightarrow \omega$ $\Upsilon(1S)$ using 28.2×10^6 $\Upsilon(3S)$ mesons recorded by the Belle detector. Ref. 1 presented the first evidence for the near-threshold transition $\chi_{b0}(2P) \rightarrow \omega$ $\Upsilon(1S)$. Since this resonance is near the ω $\Upsilon(1S)$ threshold, it is possible that the $\chi_{b0}(2P)$ is a ω $\Upsilon(1S)$ tetraquark. This possibility is investigated in this paper.

The $\chi_{b0}(2P)$ is investigated in terms of a first-order tetraquark model. This model is based on the semiempirical mass formula of Zel'dovich and Sakharov ^[2, 3]. The first-order tetraquark model provides the $\chi_{b0}(2P)$ mass as well J^π value. Since the first-order model is limited in scope, it only permits a primitive angular momentum coupling structure. Other tetraquark systems ^[4-23] were reasonably described by the first-order model.

2. Model and Formulation

The proposed first-order model is based on the semiempirical mass formula of Zel'dovich and Sakharov ^[2, 3]. This model assumes that two weakly bound meson clusters form the tetraquark, with zero angular momentum between the clusters.

The mesons (m) mass (M) is defined to have the form ^[2, 3]:

$$M_m = \delta_m + m_1 + m_2 + b_m [m_o^2 / (m_1 m_2)] \sigma_1 \cdot \sigma_2 \quad (1)$$

In Eq. 1, δ_m is defined to have the value 40 MeV/ c^2 ^[3], and m_i is the mass of the quark comprising the meson cluster ($i = 1$ and 2). The average mass of a first generation quark (u and d) is m_o ^[24, 25]. The scalar product of the quark spin vectors ($\sigma_1 \cdot \sigma_2$) is -3/4 and +1/4 for pseudoscalar and vector mesons, respectively ^[3].

Effective quark masses provided by Griffiths ^[24] are used to determine the meson cluster mass. The d, u, s, c, b, and t quarks have effective mass values of 340, 336, 486, 1550, 4730, and 177000 MeV/ c^2 , respectively ^[24]. Following the convention of the Standard Model, these quarks are grouped into three generations: [d(-1/3), u(+2/3)], [s(-1/3), c(+2/3)], and [b(-1/3), t(+2/3)] ^[24, 25]. The specific quark charges, in units of the unit charge e, are given within parentheses.

3. First-Order Mass Formula for the ω + $\Upsilon(1S)$ Tetraquark Description of the $\chi_{b0}(2P)$ Resonance

The first-order mass formula only provides a limited angular momentum coupling structure, and the spin of a tetraquark is derived from the angular momentum coupling of the two meson clusters.

$$J^\pi = J^\pi(1) \times L \times J^\pi(2) \quad (2)$$

The first-order model summarized in Eq. 2 only provides a primitive angular momentum coupling structure for the J^π

assignment, and $L = 0$ is a limiting condition of the model. Detailed meson cluster structural information, and strong coupling between the clusters are not included in the model formulation.

These aforementioned simplifications minimize model complexity, and permit the tetraquark mass formula to have the form ^[5-23]:

$$M = M_m(1) + M_m(2) + \Phi \quad (3)$$

In Eq. 3, the two meson clusters are denoted by the numbers 1 and 2, and the individual meson cluster mass is given by Eq. 1. The final term in Eq. 3 (Φ) is the interaction between the meson clusters that is assumed to be negligible relative to the magnitude of the meson masses. Accordingly, Eq. 3 suggests a quasimolecular four quark system that is characteristic of a weakly bound meson-meson system.

The $\chi_{b0}(2P)$ configuration is evaluated assuming weakly interacting $\omega + \Upsilon(1S)$ meson clusters. The $\chi_{b0}(2P)$ is modeled as a $1^- (\bar{u}\bar{u} + \bar{d}\bar{d})/\sqrt{2}$ ω cluster coupled to a $1^- b$ b -bar $\Upsilon(1S)$ meson cluster. This tetraquark has a model assignment of $J^\pi = 0^+, 1^+, 2^+$ assignment ($1^- \times 0 \times 1^-$ using Eq. 2). A 0^+ spin assignment was noted in Ref. 1.

The predicted first-order mass is based on Eq. 3:

$$M(\omega + \Upsilon(1S)) = M(\omega) + M(\Upsilon(1S)) + \Phi \quad (4)$$

Using Eq. 4 and the first-order mass formula of Eq. 1, a mass of 10.3705 GeV/c² is predicted. This value is about 1.3% larger than the value of Refs. 1 and 25.

4. First-Order Tetraquark Model Uncertainties and Limitations

There are a number of uncertainties and limitations that affect the model results. The limited angular momentum coupling structure restricts the available J^π values that can be evaluated. In addition, assuming zero angular momentum between the clusters also limits the evaluation of possible states.

The values for the effective quark masses ^[24] are not definitive. Although the weak coupling assumption appears to be reasonable, the exact magnitude for the interaction strength between the clusters is unknown ^[4-23]. The coupling strength will likely depend on the physical properties of the interacting systems. In spite of these uncertainties, the model continues to provide reasonably credible results ^[4-23] for candidate tetraquark systems.

5. Conclusions

The $\chi_{b0}(2P)$ mass and J^π value are investigated using a first-order tetraquark model. An $\omega + \Upsilon(1S)$ configuration is evaluated assuming weakly interacting ω and $\Upsilon(1S)$ meson clusters. The $\chi_{b0}(2P)$ model yields a $J^\pi = 0^+$ value that is agreement with experiment, and also 1^+ and 2^+ values. A mass of 10.3705 GeV/c² is predicted by the model. This value is about 1.3% larger than the value suggested by Belle Collaboration.

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