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Possible Tetraquark Explanation for the Y(10753)

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Abstract

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The Y(10753) has been interpreted as a conventional bottomonium, hybrid, or tetraquark state. Given the uncertainty in the structure of the Y(10753)) system, this paper investigates its structure in terms of a $\omega\chi_{bJ}(1P)$ tetraquark. The tetraquark structure of the Y(10753) structure is investigated using a first-order tetraquark mass formula. This mass relationship is based on weakly bound ω plus $\chi_{bJ}(1P)$ meson clusters. The first-order tetraquark mass formula provides a predicted mass within about 4% of the experimental value and the J^{π} predictions are in agreement with the range of values suggested by the data.

1.0 Introduction

In Ref. 1, the Belle II Collaboration investigated the reaction e + e – → $\omega\chi_{bJ}(1P)$ (J = 0, 1, or 2) using data at center-of-mass energies of 10.701, 10.745, and 10.805 GeV[2]. The Belle II Collaboration reports the first observation of a $\omega\chi_{bJ}(1P)$ resonance at 10.745 GeV. As part of this effort, Ref. 1 reviewed the character of the Y(10753). The Belle II Collaboration notes that the Y(10753) has been interpreted as a conventional bottomonium, hybrid, or tetraquark state. Its existence has been predicted in molecular and tetraquark models, with calculated masses close to the BB-bar* threshold or in the 10 to 11 GeV/c^2 range, respectively.

Given the uncertainty in the structure of the Y(10753) system, this paper investigates its structure in terms of a $\omega\chi_{bJ}(1P)$ tetraquark. A first-order tetraquark model has been successful in the description of a number of systems[3-16], and its description using these first-order models is a reasonable approach to investigate its structure.

2.0 Model and Formulation

Zel'dovich and Sakharov[17,18] proposed a semiempirical mass formula that provides a prediction of mesons and baryons in terms of effective quark masses. Within this formulation, quark wave functions are assumed to reside in their lowest 1S state. These meson mass formulas are used as the basis for deriving a first-order tetraquark mass formula. In particular, the model proposed in this paper assumes the tetraquark is partitioned into two meson clusters with the interaction between the clusters providing a minimal contribution to the tetraquark mass.

The meson mass (M_m) formula of Refs. 3 - 16 is:

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

where m_1 (m_2) is the mass of the first (second) quark comprising the meson, m_0 is the average mass of a first generation quark[16,17], and the σ_i (i = 1 and 2) are the spin vectors for the quarks incorporated into the meson. The parameters δ_m and b_m are 40 MeV/c^2 and 615 MeV/c^2, respectively[18].

The last term in Eq. 1 represents the spin-spin interaction of the quarks and $\sigma_1 \cdot \sigma_2$ is the scalar product of the quark spin vectors. $\sigma_1 \cdot \sigma_2$ has the value -3/4 and +1/4 for pseudoscalar and vector mesons, respectively[18].

In formulating the tetraquark mass formula, effective quark masses provided by Griffiths[19] are utilized. These effective masses for d, u, s, c, b, and t quarks are 340, 336, 486, 1550, 4730, and 177000 MeV/c^2, respectively. The effective masses are utilized in Eq. 1.

These six quarks are arranged in three generations: [d(-1/3), u(+2/3)], [s(-1/3), c(+2/3)], and [b(-1/3), t(+2/3)][20]. The three generations are specified by the square brackets and the quark charges [in elementary charge units (e)] are given within parentheses.

3.0 First-Order Mass Formula for the $\omega\chi_{bJ}$(1P) tetraquark

The spin of a tetraquark within the first-order mass formula is determined by coupling the two meson clusters

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

where the first-order mass formula assumes a minimally interacting L=0 configuration[3-16] between the ω and χ_{bJ}(1P) meson clusters. Eq. 2 provides a primitive J^π assignment using the possible meson clusters. The ω and χbJ(1P) have 1^- and 1^+ assignment, respectively. Applying Eq. 2 yields a $1^- \times 0 \times 1^+ = 0^-, 1^-$, and 2^- assignments in agreement with range of values predicted from the data[1]. The Y(10753) system has a 1^- assignment[20].

The first-order mass formula used in this paper partitions the tetraquark into ω and χ_{bJ}(1P) vector meson clusters. Using this structure, the tetraquark mass formula involving ground state meson clusters is assumed to have the form[3-16]

$$M (\omega + \chi_{bJ}(1P)) = M_{vm}(\omega) + M_{vm}(\chi_{bJ}(1P)) + \Phi \quad (3)$$

where **Φ** defines the interaction between the meson clusters. Within the scope of this mass formula, the meson-meson cluster interaction is assumed to be weak and sufficiently small to be ignored. Accordingly, Eq. 3 represents the ω + χbJ(1P) structure as a quasimolecular four quark systems whose basic character is a weakly bound meson-meson system where the mesons reside in their ground states.

4.0 Results and Discussion

The angular momentum coupling from Eq. 2 and the first-order mass formula of Eqs. 1 and 3 are used to construct the ω + χbJ(1P) states. As noted previously, the spin and parity assignment for the ω + χbJ(1P) state is derived from Eq. 2. The resulting $J^{\pi} = 0^{-}$, 1^{-}, and 2^{-} assignments are in agreement with range of values predicted from the data[1]. As noted in Refs 3 – 16, the first-order mass formula only provides a primitive spin and parity assignment for the meson-meson cluster configuration.

Eqs. 1 and 3 lead to a predicted the ω + χbJ(1P) mass of 10371 MeV/c^2. This result is about 4% smaller than the experimental Y(10753) value[1,20]. Although these results are encouraging, they are based on a first-order mass formula with a number of uncertainties including the assumed quark masses[19], and the magnitude of the meson-meson cluster interaction. However, the model does provide an initial description of the ω + χbJ(1P) tetraquark that is in reasonable agreement with the experimental data[1].

5.0 Conclusions

The recently proposed ω + χbJ(1P) structure[1] is investigated using a first-order tetraquark mass formula. This mass relationship is based on weakly bound ω + χbJ(1P) meson clusters.

The assumed ω + χbJ(1P) meson cluster configuration leads to a mass result that is within about 4% of the measured Y(10753) value[1,20]. The predicted first-order J^{π} values are also in agreement with the range of values (0^{-}, 1^{-}, and 2^{-}) suggested by the data.

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