Short Communication

Possible Tetraquark Explanations for the G(3900)

Joseph Bevelacqua[1]

1. Bevelacqua Resources, United States

The G(3900) is investigated using a first-order tetraquark model. A DD-bar*/D* D configuration is evaluated assuming weakly interacting D^0 and D^{*0} meson clusters. The G(3900) model yields a $J^\pi = 1^+$ value. This agrees with the S-wave value, but differs from the 0^- P-wave value. A mass of 3792 MeV/c^2 is predicted by the model. This value is about 3% smaller the value suggested by Lin et al.[1]

Corresponding author: Joseph J. Bevelacqua, bevelresou@aol.com

1. Introduction

In Ref. 1, the BESIII Collaboration recently performed a precise measurement of the $e^- e^+ \rightarrow$ D D-bar Born cross sections, and confirmed the G(3900) structure with high significance. The newly observed G(3900) is interpreted as the P-Wave DD-bar */D*D resonance. Lin et al.[1] performed calculations with various angular momentum values for systems up to P-wave. Incorporating various quantum numbers, Ref. 1 predicted a set of DD-bar*/D*D and DD^* states. The S-wave DD-bar*/D*D state was assigned a $J^\pi = 1^+$, P-wave DD-bar*/D*D state 0^-, and P-wave DD^* states 0^-.

This paper evaluates the G(3900) in terms of a first-order tetraquark model using the formulation based on the semiempirical mass formula proposed by Zel'dovich and Sakharov[2][3]. The G(3900) mass as well as predicted J^π value are provided by the first-order model. Unfortunately, the first-order model only permits a primitive coupling structure, and cannot reproduce the wealth of angular momentum values provided in Ref. 1. The first-order mass formula has been previously used to describe other tetraquark systems[4][5][6][7][8][9][10][11][12][13][14][15][16][17][18][19][20][21][22].

2. Model and Formulation

The Zel'dovich and Sakharov semiempirical mass formula[2][3] is the basis for the first-order model. This model assumes the tetraquark is comprised of two meson clusters that are weakly bound. Within the limitations of the model, the angular momentum between the clusters is assumed to be zero.

Mesons (m) are defined within the Zel'dovich and Sakharov mass (M) formula[2][3] to have the form:

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

In Eq. 1, m_i is the mass of the quark comprising the meson cluster (i = 1 and 2). m_o is the average mass of a first generation quark (u and d)[23][24]. The quark spin vectors (σ_i) complete the specification of the parameters defining Eq. 1. δ_m and b_m are defined to have the values 40 MeV/c^2 and 615 MeV/c^2, respectively[3]. The scalar product of the quark spin vectors ($\boldsymbol{\sigma_1 \cdot \sigma_2}$) is -3/4 and +1/4 for pseudoscalar and vector mesons, respectively[3].

Quark masses must be specified to utilize Eq. 1. Eq. 1 utilizes the effective quark masses provided by Griffiths[23]. Effective masses for the d, u, s, c, b, and t quarks have the values 340, 336, 486, 1550, 4730, and 177000 MeV/c^2, respectively[2][3]. 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)][23][24]. Individual quark charges, in units of the unit charge e, are given within parentheses.

3. First-Order Mass Formula for the B D-bar and B* D-bar States

Within the scope of the first-order mass formula, 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 a J^π assignment. 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][6][7][8][9][10][11][12][13][14][15][16][17][18][19][20][21][22]

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

where the 1 and 2 notations denote the two meson clusters, and the meson cluster mass is given by Eq. 1. In Eq. 3, **Φ** is the interaction between the meson clusters. Given the negligible cluster coupling assumption, Eq. 3 represents a quasimolecular four quark system characterized by a weakly bound meson-meson system.

3.1. $D^0 D^{*0}$ Tetraquark

The DD-bar*/D*D configuration is evaluated assuming weakly interacting D^0 and D^{*0} meson clusters. The D^0D^{*0} tetraquark is modeled as a 0^- c u-bar cluster coupled to a 1^- c-bar u excited meson cluster. This tetraquark has a 0^- x 0 x 1^- = 1^+ assignment. The predicted first-order mass is based on Eq. 3

$$M(D^0 + D^{*0}) = M(D^0) + M(D^0) + \Delta(D^{*0} - D^0) + \Phi \quad (4)$$

with Φ assumed to be much smaller than the meson masses. Using Eq. 4 and the first-order mass formula of Eq. 1, a mass of 3792 MeV/c^2 is predicted. This value is about 3% smaller than the value of Ref. 1. The 1^+ spin assignment agrees with the S-wave value[1].

3.2. First-Order Tetraquark Model Uncertainties

There are a number of uncertainties that affect the model results. These include the values for the effective quark masses[23]. The weak coupling assumption appears to be reasonable, but the exact magnitude for the interaction strength between the clusters is unknown[4][5][6][7][8][9][10][11][12][13][14][15][16][17][18][19][20][21][22]. In spite of these uncertainties, the model continues to provide reasonably credible results[4][5][6][7][8][9][10][11][12][13][14][15][16][17][18][19][20][21][22].

4. Conclusions

The G(3900) mass and J^π value are investigated using a first-order tetraquark model. A DD-bar*/D*D configuration is evaluated assuming weakly interacting D^0 and D^{*0} meson clusters. The G(3900) model yields a $J^\pi = 1^+$ value. This agrees with the S-wave value, but differs from the 0^- P-wave value. A mass of 3792 MeV/c^2 is predicted by the model. This value is about 3% smaller the the value suggested by Lin et al.[1]

References

1. a, b, c, dLin ZY, et al. Identification of the G (3900) Structure as the P-Wave DD-bar*/D*D-bar Resonance. Phys Rev Lett. 133: 241903 (2024).
2. a, b, c, dZel'dovich YB, Sakharov AD. Kvarkovaia struktura i massy sil'novzaimodeistvuyushchikh chastits. Yad Fiz. 4: 395 (1966).
3. a, b, c, d, e, fSakharov AD. Mass formula for mesons and baryons. Sov Phys JETP. 51: 1059 (1980).
4. a, b, cBevelacqua JJ. First-Order Tetraquark Mass Formula. Physics Essays. 29: 198 (2016).
5. a, b, c, dBevelacqua JJ. Description of the X (5568) and Proposed 750 GeV/c2 State in Terms of a First-Order Tetraquark Mass Formula. Physics Essays. 29: 367 (2016).
6. a, b, c, dBevelacqua JJ. Fusion of Doubly Heavy Mesons into a Tetraquark. Physics Essays. 31: 167 (2018).
7. a, b, c, dBevelacqua JJ. Possible Tetraquark Explanation for the Proposed X (3872). Physics Essays. 32: 469 (2019).
8. a, b, c, dBevelacqua JJ. Description of the X (6900) as a Four Charmed Quark State in Terms of a First-Order Tetraquark Mass Formula. Qeios. KLXLKJ, 1 (2020). doi:10.32388/KLXLKJ.
9. a, b, c, dBevelacqua JJ. Description of the X (2900) as an Open Flavor Tetraquark in Terms of a First-Order Mass Formula. Qeios. OVLMEB, 1 (2020). doi:10.32388/OVLMEB.
10. a, b, c, dBevelacqua JJ. Possible Tetraquark Explanation for the Proposed Zcs (3985)-. Qeios. GLTEU2, 1 (2021). doi:10.32388/GLTEU2.
11. a, b, c, dBevelacqua JJ. Possible Tetraquark Explanation for the X (6200). Qeios. J6AFYW, 1 (2021). doi:10.32388/J6AFYW.
12. a, b, c, dBevelacqua JJ. Possible Tetraquark Explanation for the Tcc+. Qeios. OMDGAQ, 1 (2021). doi:10.32388/OMDGAQ.
13. a, b, c, dBevelacqua JJ. Possible Tetraquark Explanation for the Proposed Zcs (4000)+ and Zcs (4220)+. Qeios. PPLMWV, 1 (2021). doi:10.32388/PPLMWV.
14. a, b, c, dBevelacqua JJ. Possible Tetraquark Explanation for the Proposed X (3960). Qeios. O1LoYM, 1 (2022). doi:10.32388/O1LoYM.
15. a, b, c, dBevelacqua JJ. Possible Tetraquark Explanation for the Proposed T (2900)++ and T (2900)o Structures. Qeios. V6WLTS, 1 (2022). doi:10.32388/V6WLTS.
16. a, b, c, dBevelacqua JJ. Possible K K bar Tetraquark Explanation for the fo(1370). Qeios. HBDQXV, 1 (2023). doi:10.32388/HBDQXV.

17. a, b, c, dBevelacqua JJ. Possible f Quark Model of Tetraquarks and Pentaquarks. Qeios. 8T3IVE, 1 (2023). doi:10.32388/8T3IVE.
18. a, b, c, dBevelacqua JJ. Possible Tetraquark Explanation for the Υ(10753). Qeios. NZRGH3, 1 (2023). doi:10.32388/NZRGH3.
19. a, b, c, dBevelacqua JJ. Possible Tetraquark Explanation for the ψ(4230), ψ(4360), and ψ(4415). Qeios. D5HK0o, 1 (2024). doi:10.32388/D5HK0o.
20. a, b, c, dBevelacqua JJ. Possible Tetraquark Explanation for the J/ψK0S Structure Observed in Proton-Proton Collision Data at Center-of-Mass Energies of 7, 8, and 13 TeV. Qeios. YFT8L5, 1 (2024). doi:10.32388/YFT8L5.
21. a, b, c, dBevelacqua JJ. Possible Explanations for the Proposed J/Ψ + J/Ψ and J/Ψ + Ψ(2S) Tetraquark States. Qeios. W2A4LD, 1 (2024). doi:10.32388/W2A4LD.
22. a, b, c, dBevelacqua JJ. Possible Tetraquark Explanations for the B D-bar and B-star D-bar States Proposed by Lattice QCD Calculations. Qeios. 8MWBEY, 1 (2024). doi:10.32388/8MWBEY.
23. a, b, c, dGriffiths D. Introduction to Elementary Particles. 2nd ed. (Wiley-VCH, Weinheim, 2008).
24. a, bParticle Data Group. Review of Particle Physics. Phys Rev D. 110: 030001 (2024).

Declarations

Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.