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First-order Estimates of the $t\bar{t}$ Meson and ttt Baryon Masses

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Abstract
The first-order model of Zel'dovich and Sakharov is used to determine the theoretical $t\bar{t}$ meson and ttt baryon masses. These mesons and baryons are heavier than any known standard model particle, and have not been detected at the Large Hadron Collider. However, these states could be discovered in future machines. The primitive spin structure of the model predicts a 0^+ or 1^+ for the $t\bar{t}$ meson and $1/2^+$ or $3/2^+$ for the ttt baryon. First-order $t\bar{t}$ meson and ttt baryon masses are calculated to be 354 and 531 GeV/c^2, respectively.

Keywords: First-order meson and baryon mass formula, $t\bar{t}$ meson and ttt baryon masses, Cluster model, and Quark model

1. Introduction

The top quark (t) occupies a unique role in the standard model of particle physics. It has a large mass and its couplings to the Higgs boson and to longitudinal gauge bosons are larger than those of the light quarks [1, 2]. These characteristics suggest that the top quark could be fundamentally different than its lighter counterparts. Detailed measurements of top quark properties could determine if there is new high scale physics affecting its interactions.

The Large Hadron Collider and its predecessor accelerators have been remarkably successful in discovering new particles [1]. Ref. 1 provides a detailed listing of existing mesons, baryons, tetraquarks, pentaquarks, and other exotic structures. These structures include the d, u, s, c, and b quarks and their associated antiquarks. To date, no mesons or baryons containing the t quark or its antiparticle have been observed and these structures remain hypothetical. However, the possible construction of the Future Circular Collider and subsequent accelerators opens the possibility that these states could be observed [2].

The most massive mesons and baryons involving the t quark would be $t\bar{t}$ and ttt, respectively. These would be direct analogues of the $s\bar{s}$ and sss states that have been observed as unique states or a constituent component of a state [1]. This paper estimates the masses of these hypothetical top quark structures using a first-order model [3, 4].

2. Formalism

Meson (m) and baryon (b) masses are determined utilizing the methodology of Zel'dovich and Sakharov [3, 4].

$$M_m = \delta_m + m_1 + m_2 + b\,(m_0^2 / m_1 m_2)\, \sigma_1 \cdot \sigma_2 \tag{1}$$

$$M_b = \delta_b + m_1 + m_2 + m_3 + (b/3)\,[(m_0^2 / m_1 m_2)\, \sigma_1 \cdot \sigma_2 + (m_0^2 / m_1 m_3)\, \sigma_1 \cdot \sigma_3 + (m_0^2 / m_2 m_3)\, \sigma_2 \cdot \sigma_3] \tag{2}$$

Where $\delta_m = 40$ MeV/c^2, $\delta_b = 230$ MeV/c^2, m_i is the mass of the quark comprising the meson (i = 1, 2) or baryon (i = 1, 2, 3), m_0 is the average mass of a first generation quark, and b = 615 MeV/c^2. In Eq. 1, $\sigma_1 \cdot \sigma_2$ = -3/4 or 1/4 for a pseudoscalar or vector meson, respectively.

In Eq. 2, the values of $\sigma_i \cdot \sigma_j$ depend on the baryon spin. For a J = 3/2 baryon, $\sigma_i \cdot \sigma_j$ has the value 1/4. If the total baryon spin is 1/2 and it has two *identical* quarks q_2 and q_3, the values of $\sigma_i \cdot \sigma_j$ are:

$$\sigma_2 \cdot \sigma_3 = 1/4 \text{ and } \sigma_1 \cdot \sigma_2 = \sigma_1 \cdot \sigma_3 = -1/2 \tag{3}$$

If the baryon contains three different quarks, then the values of $\sigma_i \cdot \sigma_j$ are defined by the methodology of Refs. 3 and 4.

Eqs. 1 and 2 utilize effective quark masses. These masses were determined by Griffiths [5] for d, u, s, c, b, and t quarks that have the values 340, 336, 486, 1550, 4730, and 177000 MeV/c^2, respectively. Using the convention of the Standard Model [1, 5], the 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)]. Quark charges are given within the parentheses in terms of the unit charge e.

3. Results and Discussion

The theoretical $t\bar{t}$ meson and ttt baryon masses and their associated J^π values are determined within the scope of the first-order approach. These results are theoretical and should serve as a guide to future experimental efforts that investigate top quark mesons and baryons.

3.1 Predicted Spin and Parity Assignments

The $t\bar{t}$ meson and ttt structures are modeled using the approach of Refs. 3 and 4. Given these cluster configurations, the total spin and parity of the assumed configurations within the scope of the first-order model are:

$$J^\pi(t\bar{t}) = \frac{1}{2}^+ \otimes \frac{1}{2}^+ = 0^+,\ 1^+ \tag{4}$$

$$J^\pi(ttt) = \frac{1}{2}^+ \otimes \frac{1}{2}^+ \otimes \frac{1}{2}^+ = \frac{1}{2}^+,\ \frac{3}{2}^+ \tag{5}$$

3.2 Predicted Mass Values

The $t\bar{t}$ meson and ttt mass values as predicted by the first-order model are given by Eqs. 1 and 2, respectively. Using these relationships, the $t\bar{t}$ meson and ttt mass values are predicted to be 354 and 531 GeV/c^2, respectively. These masses exceed the values for any known meson and baryon.

4. Conclusions

The first-order meson and baryon model of Zel'dovich and Sakharov is used to determine theoretical the $t\bar{t}$ meson and ttt baryon masses. These mesons and baryons are heavier than any known standard model particle, and have not been detected at the Large Hadron Collider. However, they could be discovered in future machines. The primitive spin structure of the model predicts a 0^+ or 1^+ for the $t\bar{t}$ meson and $1/2^+$ or $3/2^+$ for the ttt baryon. First-order $t\bar{t}$ meson and ttt baryon masses are calculated to be 354 and 531 GeV/c^2, respectively.

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