Branching ratio & Decay width of the decay channels $\mathrm{T}_{\mathrm{cc\bar{c}\bar{c}}} \rightarrow \eta_c$ + light hadrons , $\mathrm{T}_{\mathrm{cc\bar{c}\bar{c}}} \rightarrow \mathrm{J}/\psi$ + light hadrons.

Rahulbhai Mistry[1]*, Ajay Majethiya[1], P.C. Vinodkumar[2]
[1]Department of physics, V.S. Patel College of Arts & Science, Bilimora Affiliated to Veer Narmad South Gujarat University, Surat 395007, Gujarat, India.
[2]Department of physics, Sardar Patel University, Vallabh Vidyanagar, Anand 388 120, Gujarat, India.
* Email: mistrirahul24@gmail.com

1. Introduction

In the field of exotic hadrons, recently X (6900) state which contains all charm quarks ($\mathrm{cc\bar{c}\bar{c}}$) is discovered at LHCb [1]. The discovery of this experimental state created a new window in the research field of hadron physics. The tetraquark $T_{cc\bar{c}\bar{c}}$ is assumed to be a colour singlet state consists of diquark and antidiquark, which are composed of 2 quarks in the colour triplet state and other 2 antiquarks in the colour antitriplet state [2,3]. Theoretically, first ever research work on Tetraquark containing all charm quarks has published by Iwsaki in 1975 [4]. In the following years, Chao has studied $T_{cc\bar{c}\bar{c}}$ in the diquark (cc)-antidiquark ($\bar{c}\bar{c}$) model. So, this discovery of the exotic state created an increase in interest theoretically as well as experimentally, it motivates to study the static and dynamic properties of all charm tetraquarks.

In this paper, we present our study of the mass spectra and branching ratio of the decay channel T → η_c + light hadrons and $\mathrm{T}_{\mathrm{cc\bar{c}\bar{c}}} \rightarrow \mathrm{J}/\psi +$ light hadrons in a diquark-diantiquark non-relativistic model by solving the Schrödinger equation using variational method.

2.Theoretical Approach

For the present study, it is convenient to work in the Centre of mass frame, where the two body problems are solved with the central potential. For the study of S-wave masses of di-quark system (cc) we have considered a non-relativistic Hamiltonian given by

$$H_d = \frac{{p_d}^2}{2m_d} + V_d(r_d) \tag{1}$$

Where r is the distance between two quarks.

for antidiquark system we have considered a non-relativistic Hamiltonian given by

$$H_{\bar{d}} = \frac{{p_{\bar{d}}}^2}{2m_{\bar{d}}} + V_{\bar{d}}(r_{\bar{d}}) \tag{2}$$

To obtain masses of di-quark and Tetraquark we solve the basic Schrödinger equation with diquark-antidiquark interaction potential.

$$\mathrm{V(r)} = \mathrm{V_v} + \mathrm{V_s} = -\frac{\alpha_c}{\mathrm{r}} + \mathrm{Ar}^{\nu} \tag{3}$$

Where $\alpha_c = \frac{2}{3}\alpha_s$ for diquark(antidiquark) system & $\alpha_c = \frac{4}{3}\alpha_s$ for Tetraquark system, A is confining strength and υ is varying from 0.1 to 2.0.

Masses of the di-quark and di-antiquark system are given by:

$$m_d = m_Q + m_Q + E_d + \langle V_{SD}\rangle_{QQ} \tag{4}$$

$$m_{\bar{d}} = m_{\bar{Q}} + m_{\bar{Q}} + E_{\bar{d}} + \langle V_{SD}\rangle_{\bar{Q}\bar{Q}} \tag{5}$$

Masses of The Tetraquark diquark-antidiquark bound system are given by:

$$m_{d-\bar{d}} = m_d + m_{\bar{d}} + E_{d\bar{d}} + \langle V_{SD}\rangle_{d\bar{d}} \tag{6}$$

Here is the brief description of method to calculate the decay width and branching ratio of above mention channels:

First from the Fierz transformation [5]

$$\mathrm{T(J = 0^{++})} = |\, (c\bar{c})^1_3\, (c\bar{c})^1_3 \,\rangle^0_1 =$$
$$-\frac{1}{2}\left(\sqrt{\frac{1}{3}}\, |\, (c\bar{c})^1_1\, (c\bar{c})^1_1 \,\rangle^0_1 - \sqrt{\frac{2}{3}}\, |\, (c\bar{c})^1_8\, (c\bar{c})^1_8 \,\rangle^0_1\right) +$$
$$\frac{\sqrt{3}}{2}\left(\sqrt{\frac{1}{3}}\, |\, (c\bar{c})^0_1\, (c\bar{c})^0_1 \,\rangle^0_1 - \sqrt{\frac{2}{3}}\, |\, (c\bar{c})^0_8\, (c\bar{c})^0_8 \,\rangle^0_1\right) \tag{7}$$

Decay widths are proportional to the parameter [6]

$$\xi = \frac{|\Psi_T(0)|^2}{|\Psi_{J/\psi}(0)|^2} \tag{8}$$

For the colour singlet and spin 0 pair decay into 2 gluons, which lead to decay $\mathrm{T}\rightarrow\eta_c+$ light hadrons for which decay width is given by [6]:

$$\Gamma_1=\Gamma\,(\mathrm{T}\rightarrow\eta_c+\text{light hadrons})=2\cdot\frac{1}{4}\cdot|\psi(0)_{\mathrm{T}}|^2\,\upsilon\,\sigma((c\bar{c})_1^0\rightarrow 2\text{ gluons})\qquad(9)$$

For colour singlet and spin 1 pair decays into 3 gluons, leads to decay $\mathrm{T}\rightarrow\mathrm{J}/\psi+\text{light hadrons}$ for which decay width is given by [6]:

$$\Gamma_2=\Gamma\,(\mathrm{T}\rightarrow\mathrm{J}/\psi+\text{light hadrons})=2\cdot\frac{1}{12}|\psi(0)_{\mathrm{T}}|^2\,\upsilon\,\sigma((c\bar{c})_1^1\rightarrow 3\text{ gluons})\qquad(10)$$

For $(c\bar{c})_8^1$ annihilated into light quark pairs which leads to decay $\mathrm{T}\rightarrow c+\bar{c}+q+\bar{q}$ for which decay width is given by [6]:

$$\Gamma_3=\Gamma\,(\mathrm{T}\rightarrow c+\bar{c}+q+\bar{q})=2\cdot\frac{1}{6}\cdot\frac{1}{4}\cdot\left(\frac{4\pi\alpha_s{}^2}{3}\,\frac{4}{m_{J/\psi}{}^2}\right)|\psi(0)_{\mathrm{T}}|^2\cdot\xi\qquad(11)$$

by considering the contribution of (u, d, s) quark flavours the total decay width with spectroscopic factor in (7) given by:

$$\Gamma(\mathrm{T}(\mathrm{J}=0^{++}))=\Gamma_1+\Gamma_2+3\Gamma_3\qquad(12)$$

3. Results and conclusion

Our calculated results for the branching ratio and decay width of decay channel T→ η_c +light hadrons and $\mathrm{T}\rightarrow\mathrm{J}/\psi+\text{light hadrons}$ with potential index ν varying from 0.1 to 2.0 are presented in Table 1 and 2.

Branching ratio and decay width for the given channels with ν =1.0 are in good agreement with other available theoretical result.

T→ η_c +light hadrons			
υ	ξ	Branching ratio	Decay width (MeV)
0.1	10.8	0.93	173
0.5	5.88	0.84	94.0
1.0	4.09	0.75	65.4
1.5	3.44	0.71	55.0
2.0	2.86	0.67	45.7
		0.75[6]	

Table 1. branching ratio and decay width of channel T→ η_c +light hadrons for $\mathrm{J}=0^{++}$

T→*J*/ψ + light hadrons			
υ	ξ	Branching ratio	Decay width (MeV)
0.1	10.8	$9.3\cdot10^{-4}$	0.173
0.5	5.88	$8.4\cdot10^{-4}$	0.094
1.0	4.09	$7.5\cdot10^{-4}$	0.065
1.5	3.44	$7.1\cdot10^{-4}$	0.055
2.0	2.86	$6.7\cdot10^{-4}$	0.045
		$7.3\cdot10^{-4}$[6]	

Table 2. branching ratio and decay width of channel T→*J*/ψ + light hadrons for $\mathrm{J}=0^{++}$

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