$\gamma\gamma\gamma$ and Light Hadron decay widths of S wave charmonia

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Introduction

Charmonia happen to be an ideal system to test assumptions of QCD. Unlike the case of light quark hadrons, for charmonia the value of strong running coupling constant (α_s) is sufficiently small ≈ 0.30 also the relative binding energy is small so as to make the perturbative calculations possible. We calculated the mass spectra of charmonia by solving the the Schrödinger equation for Coulomb plus power potential by using hydrogen like trial wave function. The potential index has been varied from 0.5 to 2.0. By using the model parameters and value of the obtained wavefunctions $\gamma\gamma\gamma$ and Light hadron decay width of the 1^1S_0 and 2^1S_0 have been calculated. The light hadron decay width has been calculated by NRQCD mechanism [1–4]. The new upcoming experimental facilities will provide accurate information regarding this system [5, 6].

Theoretical framework for Masses and Decay properties

We consider the non-relativistic Hamiltonian [7, 8].

$$H = M + \frac{P^2}{2m} + V(r) \tag{1}$$

Where, M is the sum of the constituent quarks, m is the reduced mass of the system and V(r) is the interaction potential. The interaction potential is considered to be of the form of Coulomb plus power potential,

$$V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + Ar^{\nu} \tag{2}$$

Where, α_s is the running coupling constant, 4/3 is colour factor for mesons, A is the potential parameter and ν is power index. The value of ν has been varied from 0.5 to 2.0. We have calculated the decay width at origin and at finite radial separation also known as color Compton radius and compared the results with the other theoretical models. We have employed exponential trial wave function of hydrogen like to generate the mass spectra. Ritz Variational scheme has been used to obtain the expectation value of the Hamiltonian,

$$H\psi = E\psi \tag{3}$$

From this method the ground state mass of the system can be determined. Appropriate orthogonal polynomial is multiplied to the trial wave function to get the excited states. We have assumed the trial wave function for (n, l) state to be hydrogen like radial wave function,

$$R_{nl}(r) = \left(\frac{\mu^3(n-l-1)!}{2n(n+l)!}\right)^{1/2} (\mu r)^l \; e^{-\mu r/2} \; L^{2l+1}_{n-l-1}(\mu r) \tag{4}$$

Here, μ is the variational parameter and $L^{2l+1}_{n-l-1}(\mu r)$ is associated Laguerre polynomial. For a chosen value of ν, the variational parameter μ is determined for each state using the Virial theorem

$$<KE> = \frac{1}{2}\left\langle \frac{rdV}{dr} \right\rangle \tag{5}$$

We have taken $m_c = 1.31 GeV$ and $\alpha_c(c\bar{c}) = 0.40$. For each choice of ν potential parameter A and μ is fixed so as to get the ground state mass of charmonia.

The study of $J/\psi \rightarrow \gamma\gamma\gamma$ is very important as this decay is almost exclusive and has been used for the precision tests for QED [1–4] and also probe the strong interaction. The decays $1^{--} \rightarrow \gamma\gamma\gamma$ have very small decay rates proportional to α^3 and is given by [1–4].

$$1^{--} \rightarrow 3\gamma = \frac{2^{10}}{3^7\pi}(\pi^2 - 9)\frac{\alpha^3}{M^2}|R_s|^2 \tag{6}$$

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TABLE I: $\gamma\gamma\gamma$ decay width of S wave $c\bar{c}$ meson (in eV).

$\Gamma_{\gamma\gamma\gamma}$	state	0.5	0.7	0.9	1	1.1	1.3	1.5	2.0	[5]
$\Gamma_{\gamma\gamma\gamma}(r=0)$	1^1S_0	3.265	4.3668	5.403	4.613	6.358	7.250	8.080	9.885	1.077±0.006
	2^1S_0	0.655	1.011	1.393	1.582	1.776	2.150	2.515	3.343	
$\Gamma_{\gamma\gamma\gamma}(r=ccr)$	1^1S_0	1.626	2.026	2.370	2.112	2.664	2.922	3.150	3.649	
	2^1S_0	0.348	0.492	0.629	0.692	0.754	0.868	0.971	1.182	

TABLE II: Light hadron decay widths of $c\bar{c}$ meson by NRQCD mechanism(in MeV)

Decay width(Γ)	0.5	0.7	0.9	1.0	1.1	1.3	1.5	2.0
1^1S_0								
$\Gamma(r=0)$	3.885	5.431	6.417	6.977	7.541	8.604	9.619	11.780
$\Gamma(ccr)$	1.921	2.517	2.814	2.994	3.158	3.463	3.750	4.297
[4]				14.38±1.07±1.43				
2^1S_0								
$\Gamma(r=0)$	0.779	1.201	1.652	1.875	2.106	2.539	2.994	3.979
$\Gamma(ccr)$	0.418	0.586	0.747	0.822	0.892	1.027	1.156	1.412

Here, M is the mass of the corresponding state and $|R_s|^2$ is the square of the value of wave function.

The Light Hadron decay width is determined by the non-perturbative approach like NRQCD in order to test the non-perturbative aspects of QCD for heavy flavor studies. It is believed that NRQCD has all corrective contribution for the calculation of decay width. [1, 3]

$$\Gamma(\eta_c \to LH) = \frac{N_c Im f_1(^1S_0)}{\pi M^2}|\bar{R_{\eta c}}|^2 + \frac{N_c Im g_1(^1S_0)}{\pi M^4} Re(\bar{R_s}^* \nabla^2 \bar{R_s}) \quad (7)$$

Results and Conclusion

It can be observe that the value of the $\gamma\gamma\gamma$ decay width at zero quark anti-quark separation is bit higher than the experimental value but when calculated at color compton radius the value is nearby the experimental value at $\nu = 0.7$. For the decay width calculation of Light Hadron by NRQCD approach it can be observed that the calculated result is bit higher when compared with the experimental results and the difference further increases when results are calculated at color compton radius. Thus, it can be observed that the color compton radius suppresses the value of the decay width. The details of this study will be presented in the conference.

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