Digamma, digluon and leptonic decay widths of bottomonia

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Introduction

Decay properties of $b\bar{b}$ meson are of special experimental and theoretical interest because they provide us with further insight on their dynamics along with the knowledge we have gained from the spectra of these families. Many phenomenological studies on numerous observables of the $b\bar{b}$ bound states have established that the non-relativistic nature appears to be an essential ingredient to understand the dynamics of heavy quarkonia [1]. We compute the digamma and digluon decay width of the S-wave $\eta_b(0^{++})$, P-wave $\chi_{b0}(0^{++})$ and $\chi_{b2}(2^{++})$ as well as leptonic decay widths of S-wave $\Upsilon(1^{--})$ from the parameters employed in computation of the masses of the system in extended harmonic confinement model and compare them with other theoretical models and experimental results.

Methodology

We have successfully employed phenomenological harmonic potential scheme to compute masses of bound states of heavy quarkonia and the resulting parameters and wave functions have been used to study various decay properties [2]. Using the model parameters and the radial wavefunctions, we compute the digamma ($\Gamma_{\gamma\gamma}(\eta_b)$) and digluon ($\Gamma_{gg}(\chi_b)$) decay widths. Digamma decay widths of P-wave $b\bar{b}$ state $\chi_{b,1}$ is forbidden according to the Landau-Yang theorem. Most of the quark model predictions [3, 4] for the S-wave $\eta_b \to \gamma\gamma$ width are comparable with the experimental result, while the theoretical predictions for the P-wave ($\chi_{b0,2} \to \gamma\gamma$) widths differ largely from the experimental observations [3]. The contribution from QCD corrections takes care of this discrepancy. The one-loop QCD radiative corrections in the digamma decay widths of $^1S_0$ (η_b), $^3P_0$ (χ_{b0}) and $^3P_2$ (χ_{b2}) are computed using the non relativistic expressions given by [5, 6]

$$\Gamma_{\gamma\gamma}(\eta_b) = \frac{3e_b^4\alpha_{em}^2 M_{\eta_b}|R_0(0)|^2}{2m_b^3} \times \left[1 - \frac{\alpha_s}{\pi}\frac{(20-\pi^2)}{3}\right] \quad (1)$$

$$\Gamma_{\gamma\gamma}(\chi_{b0}) = \frac{27e_b^4\alpha_{em}^2 M_{\chi_{b0}}|R_1'(0)|^2}{2m_b^5}\left[1 + B_0\frac{\alpha_s}{\pi}\right] \quad (2)$$

$$\Gamma_{\gamma\gamma}(\chi_{b2}) = \frac{4}{15}\frac{27e_b^4\alpha_{em}^2 M_{\chi_{b2}}|R_1'(0)|^2}{2m_b^5} \times \left[1 + B_2\frac{\alpha_s}{\pi}\right] \quad (3)$$

where, $B_0 = \pi^2/3 - 28/9$ and $B_2 = -16/3$ are the next to leading order (NLO) QCD radiative corrections [7].
Similarly, the digluon decay width of η_b, χ_{Q0} and χ_{Q2} states are given by [8],

$$\Gamma_{gg}(\eta_b) = \frac{\alpha_s^2 M_{\eta_b}|R_0(0)|^2}{3m_b^3}[1 + C_Q(\alpha_s/\pi)] \quad (4)$$

$$\Gamma_{gg}(\chi_{b0}) = \frac{3\alpha_s^2 M_{\chi_{b0}}|R_1'(0)|^2}{m_b^5}[1 + C_{0Q}(\alpha_s/\pi)] \quad (5)$$

$$\Gamma_{gg}(\chi_{b2}) = \left(\frac{4}{15}\right)\frac{3\alpha_s^2 M_{\chi_{b2}}|R_1'(0)|^2}{m_b^5} [1 + C_{2Q}(\alpha_s/\pi)] \quad (6)$$

Here, the quantities in the brackets are the NLO QCD radiative corrections [7] and the

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coefficients have $C_Q = 4.4$, $C_{0Q} = 10.0$ and $C_{2Q} = -0.1$ values for bottom quark.

The leptonic decay widths including first order QCD radiative corrections are computed using [13]

$$\Gamma_{\ell^+\ell^-}(\Upsilon n^3S_1) = 16\pi\alpha^2 e_q^2 \frac{|R_0(0)|^2}{m_V^2}\left(1 - \frac{16\alpha_s}{3\pi}\right) \tag{7}$$

where the symbols have their usual meaning.

TABLE I: Digamma and digluon decay width of bottomonia

Decay	Present	CPP$_\nu$	[10]	[11]	[11]
Digamma decay widths (keV)					
$\Gamma_{\gamma\gamma}(\eta_b)$	0.519	0.618	0.520[12]	0.30	0.32
$\Gamma_{\gamma\gamma}(\chi_{b0})$	0.346	0.185	0.080	0.032	0.094
$\Gamma_{\gamma\gamma}(\chi_{b2})$	0.086	0.030	0.008	0.005	0.005
Digluon decay widths (MeV)					
$\Gamma_{gg}(\eta_b)$	3.26	17.9	12.46	11.5	12.9
$\Gamma_{gg}(\chi_{b0})$	2.22	5.25	2.15	0.96	2.74
$\Gamma_{gg}(\chi_{b2})$	0.434	0.82	0.22	0.33	0.25

TABLE II: Leptonic decay widths of bottomonia (keV)

State	Present	[14]	[15]	[3]
1^3S_1	1.347	1.207	1.33	1.34 ± 0.018
2^3S_1	0.631	0.513	0.62	0.612 ± 0.011
3^3S_1	0.261	0.330	0.48	0.443 ± 0.008
4^3S_1	0.102	0.242	0.40	0.272 ± 0.029

Results and Conclusion

The digamma decay widths from the current calculations are found to match with the other theoretical model quite well as seen from Table I. The digluon decay widths are found to be an order less for S-wave η_b with compared to other values, however the P-wave values for the same are quite in good agreement with the other models. The overall leptonic decay widths are matching well with the experimental results as seen from Table II. Our results fall a bit rapidly as one moves to excited S-wave states. But none of the potential models provides consistent leptonic decay widths for all S-wave vector mesons. This very discrepancy in decay properties of mesons keeps the interest lively for further investigations in rescaling of wave function and inclusion of various correction terms.

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