Di-photon($\gamma\gamma$) decay for charmonium ($c\bar{c}$)

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Introduction

Quarkonia ($Q\bar{Q}$) are bounded with heavy(Q) quark and antiquark($\bar{Q}$) [1]. Recently, many X Y Z resonance states have been discovered, and they are still being examined using different relativistic and non-relativistic potential models [2]. Charmonium system allows the prediction of some of the parameters of the states, using non-relativistic and relativistic potential models, lattice QCD, NRQCD and sum rules [3]. The success of various of theoretical (phenomenological) model like relativistic quark model [4], Non- relativistic quark model [2, 5–7] are help us for more calculation of Quarkonia. Non-relativistic models have been significantly successful in interpreting the heavy quarkonia spectroscopy [8–13]. The screening potential ($V(\vec{r}) = \frac{A}{\mu}(1 - e^{-\mu r})$) helps to study effective quenching between quark and anti-quark. In this paper we employ screening potential to study the mass spectroscopy and various decay properties of heavy-heavy and light-heavy flavoured mesons [8–13].

$$H = \sqrt{p^2 + m_q^2} + \sqrt{p^2 + m_{\bar{Q}}^2} + V(\mathbf{r}) \quad (1)$$

Quarkonia annihilation decays are very helpful for creating resonances, identifying conventional mesons, and determining multi-quark structures [14]. One of the first applications of perturbative QCD was the decay of heavy quarkonia [15]. Using the Van Royen-Weisskopf [16] relation, we predict annihilation decay widths and we conclude that the inclusion of QCD correction factors are of importance for obtaining accurate results.

$$f^2_{p_{cor}/v_{cor}} = \frac{12|\Psi_{p_A/v_B}(0)|^2}{M_{p_A/v_B}}\bar{C}^2(\alpha_s) \quad (2)$$

Short-distance factor is related to annihilation width of heavy quark anti-quark and this part is calculated in terms of running coupling constant $\alpha_s(mQ)$, evaluated at scale of heavy-quark mass (mQ), while long-distance factor that contains all non- perturbative effects of QCD is expressed in terms of mesons non-relativistic wave function or its derivative [7]. The values of the wave-functions are extracted and employed to calculate $\gamma\gamma$ within the non-relativistic QCD formalism [17]. The non-relativistic QCD (NRQCD) and potential non-relativistic QCD (pNRQCD) formalizations can be used to resolve the vast range of differences in annihilation decay widths using the various models exhibit.

Decay into photons

The annihilation decay of the charmonia states into di-photons, with and without radiative QCD corrections are given by [18]

$$\Gamma\left(n^1S_0 \to \gamma\gamma\right) = \frac{3e_Q^4\alpha^2|R_{nS}(0)|^2}{m_Q^2}\left(1 - \frac{3.4\alpha_s}{\pi}\right) \quad (3)$$

$$\Gamma\left(n^3P_0 \to \gamma\gamma\right) = \frac{27\alpha_e^2 e_Q^4|R'_{nP}(0)|^2}{m_Q^4}\left(1 + \frac{0.2\alpha_s}{\pi}\right) \quad (4)$$

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TABLE I: Masses and di-photon ($\gamma\gamma$) decay widths without and with correction factor for $c\bar{c}$ (in keV)

State	Present masses(GeV)	Present work $\Gamma_{\gamma\gamma}$	$\Gamma^{ef}_{\gamma\gamma}$	Experimental [1]	Ref.[19, 20] $\Gamma_{\gamma\gamma}$	$\Gamma^{ef}_{\gamma\gamma\gamma}$
η_c(1S)	3.096	6.891	4.374	5.1±0.4	10.351	6.621
η_c(2S)	3.639	1.117	0.746	2.15±0.6	4.501	2.879
1^3P_0	3.492	1.115	1.179	2.36±0.35	1.973	2.015
2^3P_0	3.884	1.140	1.165		2.299	2.349

Results and Discussion

The mass spectra of radial as well as orbitally excited states have been studied by several theoretical approaches [2, 5–13]. First we calculate masses for charmonia using Eqn. (1) and employ it in Eqns. (3,4) for calculate decay width of di-photon. Calculate the partial decay widths Γ and Γ^{ef} (with QCD correction factor) of annihilation processes for di and tri-photon. The results are compared with experimental data from the PDG [1] as well as with other theoretical estimates [19, 20]. When the first order QCD radiative correction is not included, the estimated di-photon decay widths for the 1S and 2S states closely match the experimentally obtained decay widths, but the decay width decreases when first order included. The decay widths of all the P wave states are low compare to experimental results. We observe that our calculated di-photon decay width results for 1^3P_0 and 2^3P_0 are lower when compared to the decay widths predicted by other theoretical models [19, 20]. We also notice an extensive variation in estimated annihilation decay width values, which may be caused by various approaches to relativistic corrections and the significant uncertainty brought on by the model's wave function dependence. The more detail about masses and decay annihilation for two $\gamma\gamma$ of $c\bar{c}$ will be presented in poster.

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