Status of $\Upsilon(10355)$, $\Upsilon(10860)$, $Y_b(10888)$ and $\Upsilon(11020)$ bottonia like states

P C Vinodkumar[1],* Manan Shah[1],† and Bhavin Patel[2]‡
[1]*Department of Physics, Sardar Patel University, Vallabh Vidyanagar-388120, INDIA and*
[2]*P. D. Patel Institute of Applied Sciences, CHARUSAT, Changa-388421, INDIA*

Introduction

Since the discovery of Υ, large number of bottonium excited states with their masses and decay widths have been recorded experimentally [1]. Though their spectra and decay properties are well studied, there exist disparities related to the decay properties of their excited states. For example, the unusual decay pattern of $\Upsilon(3S)$ into two pions known as the Vogel ($\Upsilon(\Delta n = 2)$) puzzle [2, 3] are resolved by invoking these higher bottonia states as admixtures of the respective $b\bar{b}$ states with $b\bar{b}g$ hybrids [2]. Further, if we consider the experimental energy level differences and leptonic decay rates of the excited states beyond $2S$ of the $b\bar{b}$ (1^{--}) states, their deviations from the expected behaviour provide a clue to consider them as admixtures of the nearby S and D states [4]. In this context we examine the status of $\Upsilon(10355)$, $\Upsilon(10860)$, $Y_b(10888)$ and $\Upsilon(11020)$ bottonia like states by looking into the behaviour of the energy level differences of bottonia states and their experimental leptonic decay widths.

Methodology

From the experimentally known $J^{PC} = 1^{--}$ bottonium states, their energy level differences are shown in Fig (1). One of our recent theoretical predictions of these states [5] are also shown for comparison. It is evident from the plot that $\Upsilon(10860)$ of bottonia like states are off from the expected trend as seen from the graph. Looking into their leptonic decay widths similar disparities are observed for the state $\Upsilon(10860)$ (See Fig. (2)).

When we consider admixture of $b\bar{b}g$ hybrid state bearing its mass equal to 10.1 GeV given by [6] yield the leptonic decay widths of $\Upsilon(10355)$ as 0.421 keV as against 0.33 keV predicted for pure $3S$ state [5] which are now in good agreement with the reported experimental values of 0.443 ± 0.008 keV. We also consider here the admixture of S−D waves in the case of other excited state.

Accordingly, the mixed state $R_{nS'}$ is represented in terms of the mixing angle θ as [4]

$$R_{nS'} = \cos\theta \; R_{nS} - \sin\theta \; R_{n'D} \qquad (1)$$

where the wave function at zero of the D-wave, $R_{n'D}(0)$ is defined in terms of the second derivative of the D−wave as $R''_{n'D}(0)/M^2_{n'D}$ [4]. These disturbed wave function at the origin are then employed to compute the leptonic decay widths of the mixed states. We employed here predicted masses and wave functions based on a phenomenological confinement model with Martin-like potential [5]. The mixing configuration, their mixing angle and predicted leptonic decay widths are listed in Table I.

Results and discussion

Our analysis based on the masses and leptonic decay widths together has provided a strong support to treat $\Upsilon(10355)$ as hybrid admixture state [2]. We find the admixture of hybrid state excludes the radiative correction to the leptonic decay widths. The analy-

*Electronic address: p.c.vinodkumar@gmail.com
†Electronic address: mnshah09@gmail.com
‡Electronic address: azadpatel2003@yahoo.co.in

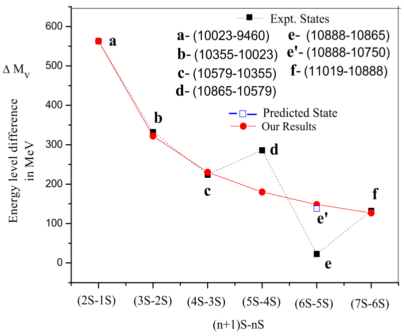

FIG. 1: Behavior of energy level shift of the (n+1)S−nS bottonium states

TABLE I: Mixing of mass spectra (in GeV) and leptonic widths (in keV) of $b\bar{b}$ states

Exp. State	Mixed config.	θ	$\Gamma^{e^+e^-}$	$\Gamma^{e^+e^-}_{[Expt.]}$ [1]
$\Upsilon(10355)$	Pure 3^3S_1		0.33	$0.443^{0.008}_{0.008}$
	$(\Upsilon(3S), b\bar{b}g)$	45°	0.421	
$\Upsilon(10860)$	$(5^3S_1,5^3D_1)$	49.44°	0.072	$0.31^{+0.07}_{-0.07}$
	$(5^3S_1,4^3D_1)$	NP	-	
$Y_b(10888)$	Pure 6^3S_1		0.158	-
	$(6^3S_1,6^3D_1)$	NP	-	-
	$(6^3S_1,5^3D_1)$	NP	-	-
$\Upsilon(11020)$	Pure 7^3S_1		0.134	$0.13^{+0.03}_{-0.03}$
	$(6^3S_1,6^3D_1)$	57.13°	0.040	
	$(6^3S_1,5^3D_1)$	NP	-	

NP= Not Possible

sis in the case of $\Upsilon(10860)$ shows that it cannot be qualified to be bottonia like state with and without mixing with D−states. Hence its status remains to be an exotic state. While $Y_b(10888)$ and $\Upsilon(11020)$ are identified to be the bottonia $6S$ and $7S$ states respectively. Thus the leptonic decay width of $Y_b(10888)$ is predicted as 0.16 keV. We also predict the mass of $\Upsilon(5S)$ to be around 10755 MeV and its leptonic decay width to be around 0.19 keV.

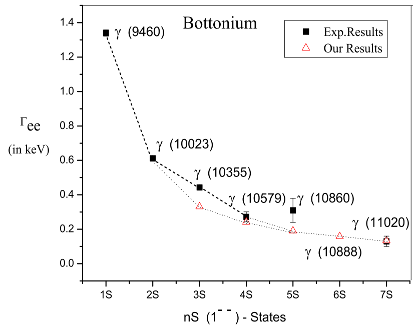

FIG. 2: Behaviour of leptonic decay width of Exp. bottonia states

Acknowledgments

The work is done under UGC Major research project NO. F.40-457/2011(SR).

References

[1] K Nakamura et al. (Particle Data Group), J.Phys. G **37**, 075021 (2010).

[2] Leonard S. Kisslinger, Phys. Rev. D 79 (2009) 114026.

[3] Helmut Vogel, in Proceedings of the 4th Flavour Physics and CP Violation Conference (FPCP'06)(2006). [arXiv:hep-ex/0606011]

[4] A.M. Badalian, B.L.G. Bakker and I.V. Danilkin. Physics of Atomic Nuclei,73 (2010) 138.

[5] Manan Shah, Arpit Parmar, P C Vinodkumar, Proc. DAE Symp. on Nucl. Phys. **56**, E62, 866 (2011); arXiv:1203.6184 [hep-ex].

[6] F. Iddir and L. Semlala, IJMP A 23 (2008) 5229.