Mass spectra of $c\bar{b}$ meson in framework of pNRQCD

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Introduction

The study of $c\bar{b}$ meson is an important testing ground for understanding strong interaction physics because it is the only heavy meson family with different quarks. The spectra and properties of $c\bar{c}$ and $b\bar{b}$ are extensively studied in experiments and theory, data on $c\bar{b}$ or $b\bar{c}$ is scare. B_c^+ was first observed at OPAL[1] and CDF[2] collaborations simultaneously in 1980 via the decay mode $B_c^+ \rightarrow J/\psi(1S)\pi^+$ and $B_c^+ \rightarrow J/\psi(1s)\ell\nu_\ell$ and later observed at D0 and LHCB. $B_c(2S)^{\pm}$ was first observed at ATLAS[3] in 2014 in the decay mode $B_c(2S)^+ \rightarrow B_c^+\pi^+\pi^-$ with 5.2 standard deviation significance. Ongoing and forthcoming experiments at LHC and RHIC, are expected to generate large data of these particles and there is renewed interests in their theoretical investigations.

Phenomenologically, the relativistic quark model, screened potential model, constituent quark model are certain approaches for mass spectra calculations but Cornell Potential is most common among all. Quarks are bounded to each other due to flavor-independent gluonic degrees of freedom. At short distances perturbative dynamics dominate, at long distances nonpertubative effects become palpable. The Cornell potential takes care of both these assumptions, hence widely used and also confirmed by lattice QCD calculations[4]. A relativistic correction in the framework of effective field theory has been coupled with the Cornell potential. This relativistic correction to the has been derived in the framework of pNRQCD, and are usually classified in powers of the inverse of heavy quark mass or velocity[5, 6]. There are three well defined scales in heavy quarkonia; hard scale(m_Q), soft scale(p) and ultrasoft scale(K.E). $m >> mv >> mv^2$, with $m >> \Lambda_{QCD}$, Λ_{QCD} is a QCD scale parameter. To have better control of such hierarchy is to employ effective field theory for high precision calculation. Two such EFT's have been used by many authors in past namely non-relativistic QCD(NRQCD)[7, 8] and potential NRQCD (pNRQCD)[9]. In NRQCD soft and ultrasoft scales are probed which in some cases could make computations in terms of partonic degrees of freedom unreliable. It does not distinguish soft and ultrasoft scales hence complicates the power-counting. pNRQCD has been derived by integrating further the energy scale above mv in NRQCD.

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Mass spectra

Considering $c\bar{b}$ as non-relativistic system, to calculate the masses we consider it as a molecule. We use the following Hamiltonia [10]

$$H = M + \frac{P^2}{2m} + V_{pNRQCD}(r) + V_{SD}(r) \quad (1)$$

Here, M is the total mass of the system and m is the reduced mass of the system. The interaction potential $V_{pNRQCD}(r)$ encompasses three terms a coulombic term V_v(r)(vector), a confinement term V_s(scalar) and relativistic correction in the framework of pNRQCD; $V_p(r)$ [11, 15]. In order to calculate the S wave mass spectra we only consider spin-spin inter-

TABLE I: S wave spectra of $c\bar{b}$ meson (in GeV)

state	present	[17]	[18]	[19]
1^1S_0	6.274	6.272	6.278	6.275
1^3S_1	6.332	6.321	6.331	–
2^1S_0	6.851	6.864	6.863	6.842
2^3S_1	6.888	6.900	6.873	–

action in spin dependent term $V_{SD}(r)$ [12–14]

$$V_{pNRQCD}(r) = V_v(r) + V_s(r) + V_p(r) = -\frac{4\alpha_s}{3r} + Ar + \frac{1}{m}V^{(1)}(r) \quad (2)$$

$$V^{(1)}(r) = -\frac{9\alpha_c^2}{8r^2} + a\log r + C(const.) \quad (3)$$

In order to obtain the spin singlet-triplet hyperfine splitting of S wave states of $c\bar{b}$, we consider spin dependent part of the usual one gluon exchange potential given by,

$$V_{SD}(r) = V_{SS}(r)\left[S(S+1) - \frac{3}{2}\right] \quad (4)$$

We compute the ground state mass of bottomonia[16] and charmonia system to fix mass of bottom and charm quark, and there confinement strength. Then we take average of bottom and charm quark mass and also average of there confinement strength to get mass of $c\bar{b}$ meson(ground state) and its confinement strength. The mass spectra has been listed in Table 2. The Schrödinger equation considering the eigne value problem and solve by RK4 method numerically.

Results and Discussion

The calculated mass spectra has been compared with the experimental and other theoretical results. It can be observed that the relativistic correction to the potential plays an important role in mass spectra calculations.

References

[1] OPAL collaboration Phys. Lett. B 420, (1989).

[2] CDF Collaboration (F. Abe et al.), Phys. Rev. Lett. 81, 2432 (1998).

[3] ATLAS Collaboration Phys. Rev. Lett. 113, 21 (2014).

[4] G. S. Bali, K. Schilling, and C. Schlichter, Phys. Rev. D51, 5165 (1995).

[5] A. Pineda, A. Vairo, Phys. Rev. D63, 054007 (2001).

[6] A. Pineda, A. Vairo, Phys. Rev. D64, 039902 (2001).

[7] W. Casewell, G. Lepage, Phys. Lett. B167, 437 (1986).

[8] G.T Bodwin,E. Brateen, G.P Lepage, Phys. Rev. D 51 (1995) 1125.

[9] N. Brambilla, A. Pineda, J. Sotto, A. Vairo, Rev. Mod. Phys. 77, 1423 (2005).

[10] S.N Gupta and J.N Johnson, Phys. Rev. D51, 168 (1995).

[11] Y. Koma and M. Koma, Few Body Sys. 54, 1027 (2013).

[12] A.K Rai, R.H Parmar and P.C Vinodkumar, J. Phys. G28, 2275 (2002).

[13] A.K Rai, J.K Pandya and P.C Vinodkumar, J. Phys. G31, 1453 (2005).

[14] A.K Rai et al., Phys. Rev. C 78, 055202 (2008).

[15] A.K Rai and Raghav Chaturvedi, J.Phys.Conf.Ser. 934 no.1, 012033 (2017).

[16] Raghav Chaturvedi et.all arXiv:1810.13383.

[17] N.R.Soni, B.R.Joshi, R.P.Shah, H.R.chauhan, J.N. Pandya, Eur. Phys. J. C78, 592 (2018).

[18] N.Devlani, V.Kher, A.K.Rai, Eur. Phys. J. A50, 154 (2014).

[19] C.Patriginani et. al. Chin. Phys. C40, 100001 (2016).