Mass shift in Bs Meson Spectrum with Hadronic Loop Effects

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Introduction

In quenched quark models of mesons virtual hadronic loops were not considered, while unquenched quark model has incorporated hadronic loops through coupled channel effects. Virtual meson loops are created via $(q\bar{q}) \rightarrow (q\bar{n})(n\bar{q})$ states and recoupled back to the bare state q/barq. These loops will induce mass shifts in the mass spectrum of bare meson[1].

Coupled Channel Effect has been modelled in the framework of $^3P_0$ pair-creation model. $^3P_0$ model has been tuned with OZI (Okubo-Zweig-Iizuka) rule and it gives us wholesome idea of allowed and forbidden decays. According to OZI rule disconnected quark diagrams will be suppressed relative to connected ones. $^3P_0$ model has been predominantly used for open flavour strong decays of meson sector and generated quark pairs have vacuum quantum numbers $J^{PC} = 0^{++}$. In coupled channel effects, the decays $A \rightarrow BC \rightarrow A$, here A, B and C denotes mesons, induces mass shifts in the bare state A and corresponding decays takes place in the rest frame[2][3].

The mass spectrscopy and decay properties of B and B_s is studied using Hulthen potential in non-relativistic model. Since hadron loop effects are not considered generally in potential model studies, current work includes the effect for open-bottom (B_s) meson mass spectrum, with mesonic continuum states $|BC\rangle$ for corresponding open flavour strong decay[4]; BK, B^*K, BK^*, B^*K^*, $B_s\eta'$, $B_s^*\eta'$, $B_s\phi$ and $B_s^*\phi$.

Theoretical Background

Inclusion of Hadron loop effects will induce meson continuum states in bare mesonic state $|A\rangle$, correspondingly full hadronic state is characterised by:

$$|\psi\rangle = |A\rangle + \sum_{BC} |BC\rangle \tag{1}$$

where sum runs over intermediate two-meson continuum states, which listed above.

The wave function obeys eigenvalue equation;

$$H|\psi\rangle = M|\psi\rangle \tag{2}$$

The combined system is decsribed by Hamiltonian consists of a valence Hamiltonian H_0 for B_s meson system and an interaction Hamiltonian H_I for coupling between the states $|A\rangle$ and $|BC\rangle$;

$$H = H_0 + H_I \tag{3}$$

The matrix elements of the valence-continuum coupling Hamiltonian is given by

$$\langle BC|H_I|A\rangle = h_{fi}\delta(\vec{P}_A - \vec{P}_B - \vec{P}_C) \tag{4}$$

where h_{fi} is the decay amplitude.

The eigenstate of bare meson state is with eigen value $E_A = \sqrt{M_A^2 + P_A^2}$. Since, $^3P_0$ model presumes open flavour decay in rest frame, $\vec{P}_A = 0$, eigen value obtained to be the rest mass and $|\vec{P}_B| = |\vec{P}_C| = P$

The mass shift of meson A due to its continuum coupling to BC can be expressed in terms of partial wave amplitude $\mathscr{M}_{LS}$ as

$$\Delta M_A^{(BC)} = \int_0^\infty dp \frac{p^2}{E_B + E_C - M_A - i\varepsilon} \int d\Omega_p |h_{fi}(p)|^2$$
$$= \int_0^\infty dp \frac{p^2}{E_B + E_C - M_A - i\varepsilon} \sum_{LS} |\mathscr{M}_{LS}|^2$$

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$$\Delta M_A^{(BC)} = \mathscr{P}\int_0^\infty dp \frac{p^2}{E_B+E_C-M_A}\sum_{LS}|\mathscr{M}_{LS}|^2 + i\pi\left(\frac{p*E_B*E_C}{M_A}\sum_{LS}|\mathscr{M}_{LS}|^2\right)|_{E_B+E_C=M_A}$$

The decay amplitude is given by;

$$\frac{d\Gamma_{A\to BC}}{d\Omega} = 2\pi P\frac{E_BE_C}{M_A}|h_{fi}|^2 \quad (5)$$

and the total decay rate is given by:

$$\Gamma_{A\to BC} = 2\pi P\frac{E_BE_C}{M_A}|\mathscr{M}_{LS}|^2 \quad (6)$$

Results and Discussion

In present work the bare mass of the B_s system is calculated using the Hulthen potential as Coulomb-like potential with non-realtivistic approach in simple harmonic oscillator basis. The form of oscillator wave function is given below

$$\psi_{nlm}(r,\theta,\phi) = N\left(\frac{r}{b}\right)^l L_n^{l+1/2}(\frac{r}{b})exp\left(-\frac{r^2}{2b^2}\right)Y_{lm}(\theta,\phi)$$

where $|N|$ is the normalizing constant.

For the evaluation of bare state masses and mass shifts due to continuum couplings, BK, B^*K, BK^*, B^*K^*, $B_s\eta'$, $B_s^*\eta'$, $B_s\phi$ and $B_s^*\phi$ meson loops, following parameters are used: $M_D = 1869.62$ MeV, $M_{D_s} = 1968.47$ MeV, $M_{D^*} = 2010.26$ MeV, $M_{D_s^*} = 2112.1$ MeV, $M_K = 493.67$ MeV, $M_{K^*} = 892$ MeV and $M_{\eta'} = 957.78$ MeV, $M_\phi = 1019.44$ MeV.

TABLE I: The mass shifts of bare B_s state due to individual loop are shown here, δM depicts total mass shift

Bare States	Mass (M)	BK	B^*K	BK^*	B^*K^*	$B_s\eta'$	$B_s^*\eta'$	$B_s\phi$	$B_s^*\phi$	δM
$1\,^1S_0$	5365	-	37.1928	29.1583	56.0735	-	25.0072	-	24.0983	171.5301
$2\,^1S_0$	5978	-	21.9993	17.9829	35.955	-	17.7141	-	17.5135	111.1648
$1\,^3S_1$	5414	13.9616	26.3268	20.3283	39.2017	9.00021	17.3157	8.64638	16.6615	148.44219
$2\,^3S_1$	6003	7.2303	14.4543	11.8539	23.8108	5.84121	11.6789	5.77582	11.5482	92.19343
$1\,P_1$	5853	-	78.6815	22.4097	41.3744	-	16.6509	-	15.5787	174.6952
$1\,^3P_0$	5827	25.7946	-	-	92.3306	-	15.6274	-	-	133.7526
$2\,^3P_0$	6204	3.64378	-	-	8.56971	3.22052	-	3.19861	-	18.63254
$1\,^3P_1$	5858	-	15.9125	47.5205	92.0671	-	38.4382	-	36.7191	234.6574
$2\,^3P_1$	6717	-	44.3869	34.8082	48.3282	-	34.2111	-	33.7684	195.5028
$1\,^3P_2$	5876	33.9038	49.3289	30.1383	105.451	16.8041	23.8488	15.9138	22.6588	298.0475
$2\,^3P_2$	6228	6.68893	10.0286	8.08087	30.1068	5.3027	7.95145	5.23833	7.85498	81.25266
$1\,D_2$	6092	-	27.3081	29.7608	99.3526	-	19.3703	-	17.8243	193.6161
$1\,^3D_1$	6110	26.6684	5.44633	7.20614	138.392	9.78075	4.51212	9.02867	4.17217	205.20658
$1\,^3D_3$	6095	36.1432	50.9196	32.0209	25.2212	19.3355	24.1511	18.1843	22.8181	228.7939

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