Hadronic Loop Effects in D_s Meson Mass Spectrum

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Introduction

Basic model of Hadronic Loop Effects lie in the formulation of $^3P_0$ quark pair-creation model (QPC). QPC model assumes that quark pairs are generated with vacuum quantum numbers $J^{PC} = 0^{++}$. Meson continuum loops in bare state of the system induce mass shifts in the spectrum of the corresponding bare state. The possiblility of existence of allowed hadronic loops in the coupled channel continuum is derived considering the OZI (Okubo-Zweig-Iizuka) rule, which is inherited in the formulation of QPC[1][2][3][4].

Theoretical Background

In the quenched quark model for D_s meson, mass spectrum is obtained by solving mass equation for Hulthen Potential. Inclusion of virtual hadron loops will induce meson continuum states in bare mesonic state $|A\rangle$,

The wave function for the system obeys eigenvalue equation;

$$H|\psi\rangle = M|\psi\rangle \quad (1)$$

where $|\psi\rangle$ is represents full hadronic state.

The full hadronic state is combination of bare state A, and mesons in contiuuum; B and C.

$$|\psi\rangle = |A\rangle + \sum_{BC} |BC\rangle \quad (2)$$

where sum runs over intermediate two-meson continuum states, they are given in results and discussion.

The eigen value equation for combined system is decsribed by Hamiltonian consistituted with valence Hamiltonian H_0 for D_s meson system and an interaction Hamiltonian H_I for coupling between the bare states $|A\rangle$ and hadron loop states $|BC\rangle$;

$$H = H_0 + H_I \quad (3)$$

Here interaction part of the Hamiltonian H_I is responsible for quark pair production with vacuum numbers;

$$H_I = g \int d^3x \bar{\psi}\psi \quad (4)$$

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

$$\langle BC|H_I|A\rangle = h_{fi}\delta(\vec{P}_A - \vec{P}_B - \vec{P}_C) \quad (5)$$

where h_{fi} is the decay amplitude.

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

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

The decay amplitude is given by;

$$\frac{d\Gamma_{A\to BC}}{d\Omega} = 2\pi P \frac{E_B E_C}{M_A} |h_{fi}|^2 \quad (6)$$

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 total decay rate is given by:

$$\Gamma_{A\to BC} = 2\pi P \frac{E_B E_C}{M_A} |\mathscr{M}_{LS}|^2 \quad (7)$$

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Results and Discussion

The mass spectrum of D_s meson is obtained by considering three-dimensional harmonic oscillator basis. Eigen value equation is evauated by minimization method of Rayleigh-Ritz method. 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.

In present work the bare mass of the D_s system is calculated in NRQM using Hulthen potential. The Hulthen potential is a short-range potential which behaves like Coulomb potential for small values of r and decreases exponentially for large values of r[5]. The Hulthen potential V_H is defined as,

$$V_H(\vec{r}) = -\mu_0 \frac{\exp(\frac{-r}{\mu})}{1-\exp(\frac{-r}{\mu})} \tag{8}$$

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

Bare States	Mass (M)	DK	D^*K	DK^*	D^*K^*	$D_s\eta'$	$D_s^*\eta'$	$D_s\phi$	$D_s^*\phi$	δM
$1\,^1S_0$	1968.41	-	31.4526	27.3289	49.1984	-	22.1321	-	21.4119	151.5239
$1\,^3S_1$	2112.17	14.6778	24.5487	20.7551	36.9793	9.0987	16.343	8.72966	15.7517	146.88396
$1\,^1P_1$	2461.54	-	34.6323	20.8042	33.6868	-	13.9377	-	13.1724	116.2334
$1\,^3P_0$	2318.4	34.791	-	-	66.4948	13.3034	-	12.6777	-	127.2669
$1\,^3P_1$	2536.09	-	43.7359	45.5697	80.3648	-	33.742	-	32.3814	235.7938
$1\,^3P_2$	5876	33.9038	49.3289	30.1383	105.451	16.8041	23.8488	15.9138	22.6588	298.0475
$1\,^3D_1$	6110	26.6684	5.44633	7.20614	138.392	9.78075	4.51212	9.02867	4.17217	205.20658
$1\,^3D_2$	6092	-	27.3081	29.7608	99.3526	-	19.3703	-	17.8243	193.6161
$1\,^3D_3$	6095	36.1432	50.9196	32.0209	25.2212	19.3355	24.1511	18.1843	22.8181	228.7939
$2\,^1S_0$	5978	-	21.9993	17.9829	35.955	-	17.7141	-	17.5135	111.1648
$2\,^3S_1$	6003	7.2303	14.4543	11.8539	23.8108	5.84121	11.6789	5.77582	11.5482	92.19343
$2\,^3P_0$	6204	3.64378	-	-	8.56971	3.22052	-	3.19861	-	18.63254
$2\,^3P_1$	6717	-	44.3869	34.8082	48.3282	-	34.2111	-	33.7684	195.5028
$2\,^3P_2$	6228	6.68893	10.0286	8.08087	30.1068	5.3027	7.95145	5.23833	7.85498	81.25266

In the evaluation of mass and mass shifts, because of mesonic loops[6] DK, D^*K, DK^*, D^*K^*, $D_s\eta'$, $D_s^*\eta'$, $D_s\phi$ and $D_s^*\phi$, 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.

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