1 - 20 Bottomonium-like States in Coupled-channel Model with on-shell Approximation*

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At present the Bottomonium spectra have not been so well explored as the Charmonium spectra. Espescially, the Bottomonium states found in experiment are less than the Charmonium states. However, prior to the discovery of $Z_c(3900)$ in the $\pi^+ J/\psi$ invariant mass spectra, the charged states possibly composed of at least four-quark is well established in Bottomonium sector, namely the $Z_b(10610)$ and $Z_b(10650)$ states[1]. They are narrow structures in the mass spectra of the $\pi^\pm\Upsilon(nS)$ $(n=1,2,3)$ and $\pi^\pm h_b(mP)$ $(m=1,2)$. It is possible to predict other Bottomonium-like states in the coupled-channel model based on the measured masses and widths of these states. The coupled-channel model considers the important rescattering process of final hadrons and is usually proceeded from the Bethe-Salpeter equation, whose expression in the on-shell approximation is written as follows[2]:

$$T=V+VGT=\frac{V}{1-VG},$$

where T is the matrix of two-body scaterring amplitudes. Here V is the interaction kernel composed of t-channel and contact terms in the tree level. It could be constructed from chiral Lagrangians within the framework of the hidden gauge formalism and decomposed in terms of partial waves. The diagonally propagator matrix G can be calculated as two-meson loop function using dimensional regularization. The states could be dynamically generated as poles in the second Riemann sheet as long as the analiticity and unitarity are kept in the above equation. The vector meson - vector meson (VV) channel, vector meson - pseudoscalar meson (VP) channel and pseudoscalar meson - pseudoscalar meson (PP) channel are included in the model. Both the non-strangeness $(S=0)$ and strangeness $(S=1)$ channels are considered.

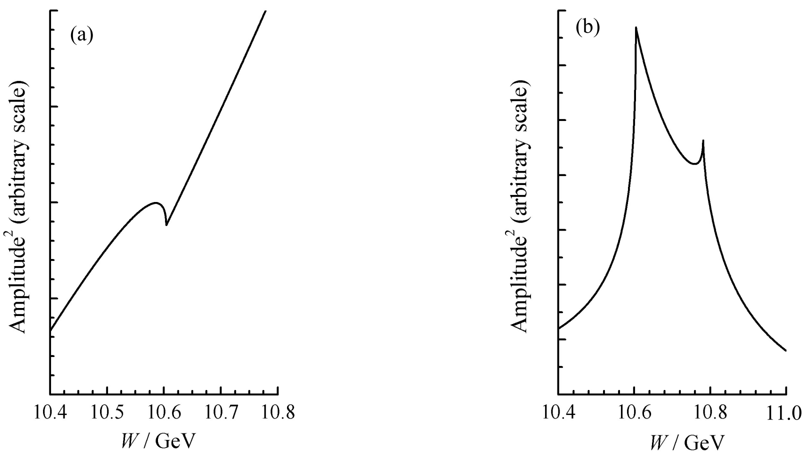

Fig. 1 The calculated amplitudes squared versus the center-of-mass energy W in the $B_s^*\bar{B}_s$ channel with $I^GJ^{PC}=1^-1^{++}$ (a) and $I^GJ^{PC}=0^+1^{++}$ (b).

As shown in Fig. 1, two typical squared amplitudes $|T|^2$ versus the center-of-mass energy W in the $B_s^*\bar{B}_s+c.c$ channel are given. In the $I^GJ^{PC}=1^-1^{++}$ sector we do not find any pole so we may conclude that there is no state with this quantum number. This is the only one quantum number which has no dynamically generated states. In Fig. 1(b), we show the $I^GJ^{PC}=0^+1^{++}$ sector, where two clear peaks appear in the calculated squared amplitudes. Other states coming up in the model are summarized in Table 1. Especially, the $Z_b(10610)$ and $Z_b(10650)$ both with $1^+(1^{+-})$ are found in the VV and VP channel, respectively. Their properties are used to pin down the parameters from the regularization procedure of propagator G in the model[3].

It is noted that some of the states are close to the $B\bar{B}$ and $B^*\bar{B}$ thresholds, which is a direct consequence of the location of $Z_b(10610)$ and $Z_b(10650)$ states. As can be seen, most of these states are narrow except four of them. Among these wide states, one of them located at 9 886.0 MeV with $0^+(0^{++})$ in the PP channel is too broad to be experimentally observed.

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We also pay attention to the uncertainties of these predicted masses and widths. If the experimental errors of $Z_b(10610)$ and $Z_b(10650)$ are used as guideline, the uncertainties of the predicted states tend to be small. The photoproduction cross section of these states is estimated to be in the level of nb. Though this is small and beyond the scope of current high energy machine, it is encouraged to search them in the near future because the planned accelerators will soon cover this region.

Table 1 Pole positions of states in coupled-channel model with chiral Lagrangians with the input of $Z_b(10650)^a$ with M=10 652.2±1.5 MeV and Γ=11.5± 2.2 MeV and $Z_b(10610)^b$ with M=10 607.2±2.0 MeV and Γ=18.4± 2.4 MeV

	S	$I^G(J^{PC})$	RE($\sqrt{s}$) / MeV	IM($\sqrt{s}$)/ MeV
VV	0	$0^+(0^{++})$	10 650.2	4
	0	$0^-(1^{+-})$	10 428.8	0
			10 650.2	111
	0	$0^+(2^{++})$	10 650.2	5
	0	$1^-(0^{++})$	10 650.2	2
	0	$1^+(1^{+-})$	10 650.2[a]	1
	0	$1^-(2^{++})$	10 650.2	5
VP	0	$1^+(1^{+-})$	10 604.2[b]	-6
	0	$1^-(1^{++})$	—	—
	0	$0^+(1^{++})$	10 604.2	-95
			10 781.0	-118
	0	$0^-(1^{+-})$	10 781.7	-1
PP	0	$0^+(0^{++})$	10 645.4	-8
			9 886.0	Broad
	0	$1^-(0^{++})$	10 558.0	-6
	1	$\frac{1}{2}(0^+)$	10 558.0	-3
			10 732.8	-6

References

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1 - 21 Study the in-medium Effect of K^- by the Λ Hyperon Production in Ni+Ni at 1.91 *A*GeV *

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Since the quark strongly couples to the $\bar{q}q$ pairs in vacuum, the chiral symmetry is spontaneously broken in the QCD ground state. This mechanism generates more than 90% of hadron mass[1]. In hot and dense environment, the quark condensate, *i.e.* the ground state expectation value of the scalar quark density, is expected to decrease. At nuclear saturation density ρ_0, the magnitude of the quark condensate is predicted to be reduced by about 1/3 from its value in vacuum[2]. In such an environment, the properties of a hadron, like its decay width Γ and mass, are expected to change, and this is the so-called in-medium effect (IME). Theoretical it is predicted that the mass of K^- would decrease with increasing the medium density[2], due to a strong K^-N attractive interaction.

In heavy ion collisions (HIC) at CSR/SIS18 energies (1 ∼ 2 *A*GeV), the density of the created fireball can reach up to 2 ∼ 3 ρ_0. The K^- meson can be produced by multi-step reactions (*e.g.* $N^*N \rightarrow ppK^+K^-$), although its threshold energy is about 2.5 GeV for fixed target reaction $pp \rightarrow ppK^-K^+$. For non-central HICs at intermediate energies, the created fireball strongly interacts with the cold spectator matter. This phenomenon was demonstrated by the measured excitation function of the elliptic flow v_2. In non-central HICs, in the target/projectile rapidity region the yields of the Λ hyperon could be produced in the process of K^- and spectator matter interaction, *i.e.* $K^-N \rightarrow \pi\Lambda$. While for the central HICs, the Λ hyperons are produced in the fireball and its yields has no IME contribution of K^- associated with the spectator. By comparing the yield of the Λ hyperon at target/projectile rapidity region under different centrality conditions, the IME effect of K^- could be extracted.