Exotic mesons with hidden bottom near the thresholds

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Crossover of Hadron and Nuclear Physics at Kyusyu, 9/6/2013

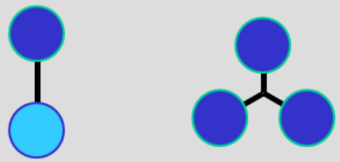
Outline

- Introduction
  - Exotic hadrons
  - $Z_b(10610)$ and $Z_b(10650)$
- $B\bar{B}$ molecules with One Boson Exchange Potential model (OBEP)
- The relation of spin structures and decay properties of Z_b
- Summary

Exotic hadron

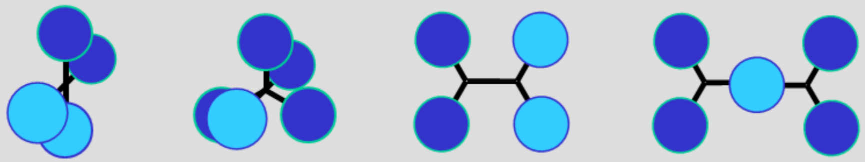
We know

mesons and baryons

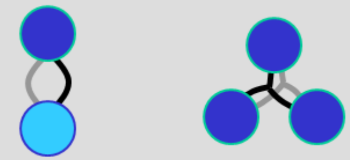


QCD also allows

molecules/multi-quarks



hybrids



glueballs

and more

W. Gradl at Charm2012

✓ Candidates of exotic hadrons :X(3872), Z(3900), Y_b, Z_b ...

$Z_b(10610)$ and $Z_b(10650)$

Decay process

✓ $\Upsilon(5S) \rightarrow Z_b\pi \rightarrow \Upsilon(nS)\ \pi\pi$

✓ $\Upsilon(5S) \rightarrow Z_b\pi \rightarrow h_b(mP)\pi\pi$

✓ $\Upsilon(5S) \rightarrow Z_b\pi \rightarrow B^*\bar{B}^{(*)}\ \pi\pi$

✳ n=1,2,3 m=1,2

Mass and width

✓ $Z_b(10610)$: Z_b

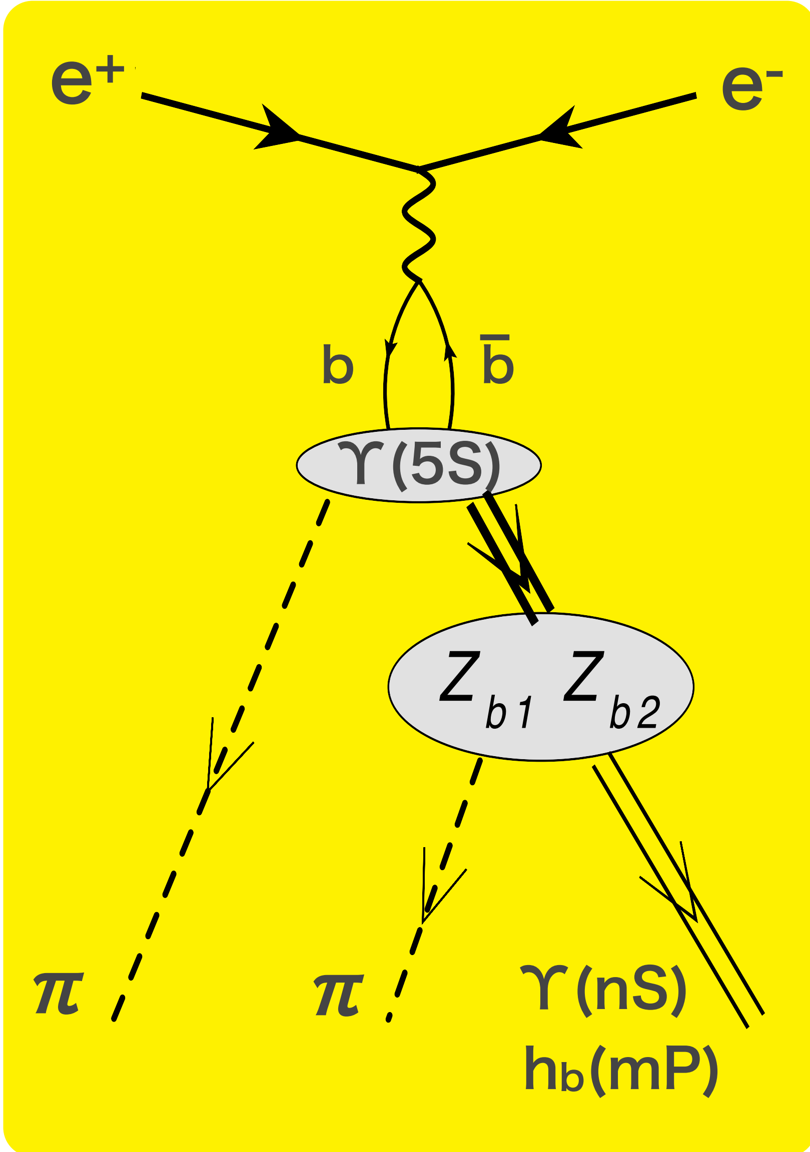
$M = 10607.4 \pm 2.0$ MeV ~$B\bar{B}^*$

$\Gamma = 18.3 \pm 2.4$ MeV

✓ $Z_b(10650)$: Z_b'

$M = 10652.2 \pm 1.5$ MeV ~$B^*\bar{B}^*$

$\Gamma = 11.5 \pm 2.2$ MeV



Belle group, PRL108, 112001 (2012).

Properties of Z_b

Exotic quantum numbers

✓ $I^G(J^P)=1^+(1^+)$

✓ Z_b is the “genuine” exotic state

Exotic twin resonances

✓ The masses of Z_b’s are very close to the respective thresholds of $B\bar{B}^*$ and $B^*\bar{B}^*$

Exotic decays

✓ The decay of $\Upsilon(5S) \to Z_b\pi \to h_b(mP)\pi\pi$ is not suppressed although it needs spin flip

Z_b is a candidate of $B^*\bar{B}^{(*)}$ molecule !

$B\bar{B}$ molecules with OBEP

S. Ohkoda, Y. Yamaguchi, S. Yasui, K. Sudoh, and A. Hosaka,
Phys. Rev. D86, 014004 (2012)

Features of the heavy meson molecule

1. The kinetic term of Hamiltonian is suppressed

✓ Because the reduced mass is larger in heavy mesons

✓ two body systems :

$$\mu_{NN} \simeq 470 \text{ MeV}$$

$$\mu_{DD*} \simeq 970 \text{ MeV}$$

$$\mu_{BB*} \simeq 2650 \text{ MeV}$$

$$H = \frac{P^2}{2\mu} + V(r)$$

2. B and B* are degenerate thanks to HQS

✓ The interaction of the heavy quark spin is suppressed in heavy quark sector

✓ The effects of channel-couplings becomes lager

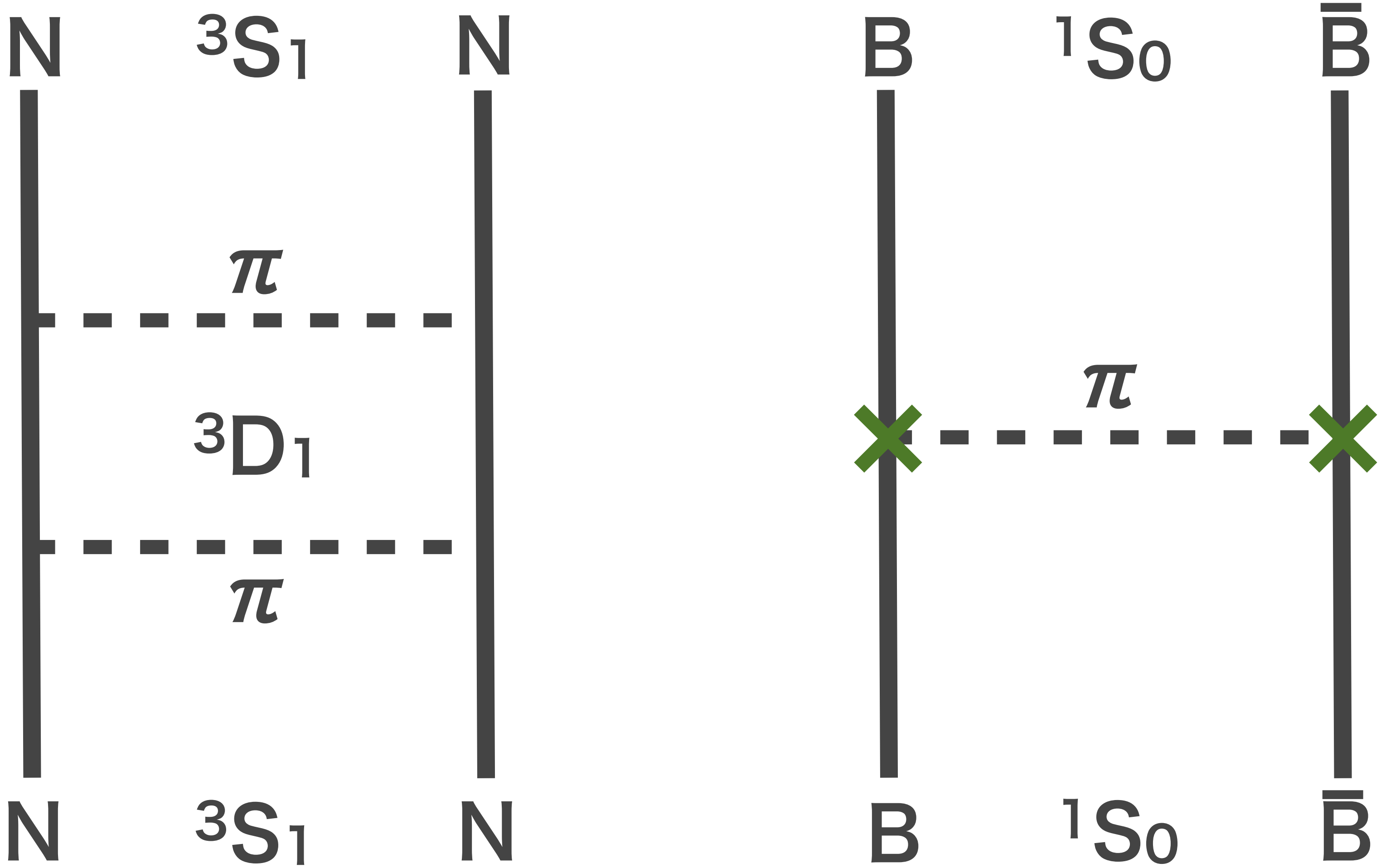
✓ Mass splittings:

$$m_{K^*} - m_K \simeq 400 \text{ MeV}$$

$$m_{D^*} - m_D \simeq 140 \text{ MeV}$$

$$m_{B^*} - m_B \simeq 45 \text{ MeV}$$

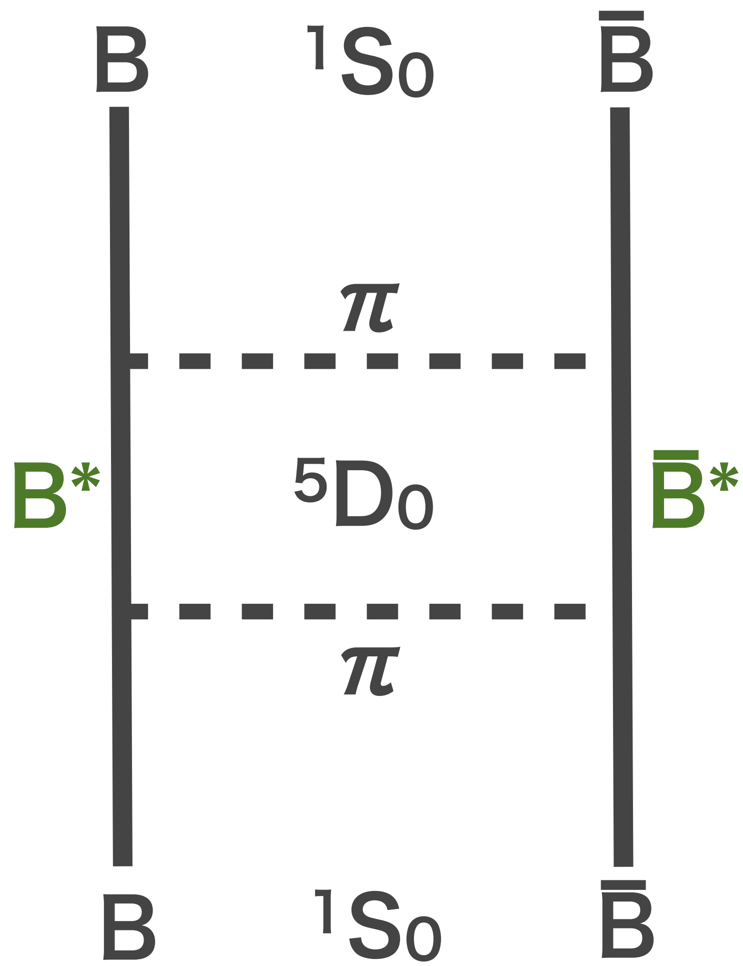
Tensor force in NN and B$\bar{B}$ systems



✓ S-D wave mixing causes the tensor interaction

✓ B and $\bar{B}$ are irrelevant without heavy quark symmetry

Tensor force in NN and $B\bar{B}$ systems



✓ S-D wave mixing causes the tensor interaction

✓ the mass degeneracy causes the tensor interaction

Potential model

✓ Effective Lagrangians

$$\mathcal{L}_{\pi HH} = g\,\mathrm{tr}\bar{H}_a H_b \gamma_\nu \gamma_5 A^\nu_{ba}$$

$$\mathcal{L}_{vHH} = -i\beta\,\mathrm{tr}\bar{H}_a H_b v^\mu (\rho_\mu)_{ba} + i\lambda\,\mathrm{tr}\bar{H}_a H_b \sigma_{\mu\nu} F_{\mu\nu}(\rho)_{ba}$$

✓ Potential for Zb

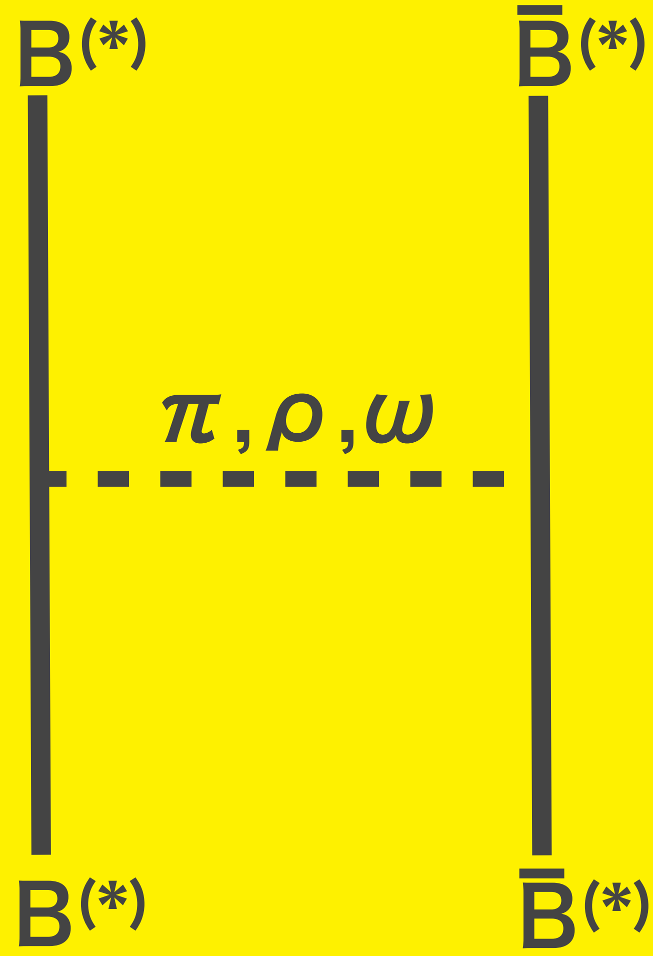
Components :

$\frac{1}{\sqrt{2}}(\mathrm{B\bar{B}^*} - \mathrm{B^*\bar{B}})(^3S_1)$, $\frac{1}{\sqrt{2}}(\mathrm{B\bar{B}^*} - \mathrm{B^*\bar{B}})(^3D_1)$,

$\mathrm{B^*\bar{B}^*}(^3S_1)$, $\mathrm{B^*\bar{B}^*}(^3D_1)$

Potential :

$$V^{\pi}_{1^{+-}} = \begin{pmatrix} V_C & -\sqrt{2}V_T & -2V_C & -\sqrt{2}V_T \\ -\sqrt{2}V_T & V_C + V_T & -\sqrt{2}V_T & -2V_C + V_T \\ -2V_C & -\sqrt{2}V_T & V_C & -\sqrt{2}V_T \\ -\sqrt{2}V_T & -2V_C + V_T & -\sqrt{2}V_T & V_C + V_T \end{pmatrix},$$



Results

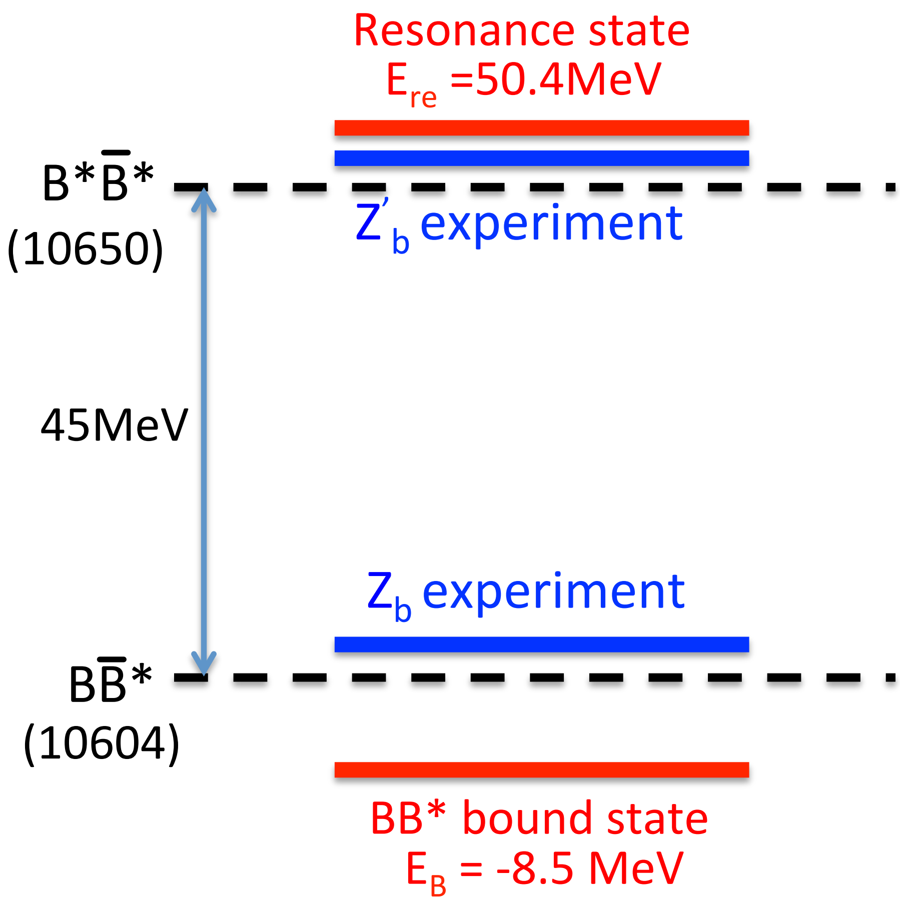
✓ $I^G(J^P)=1^+(1^+)$

✓ Our model well explains the masses of Z_b's

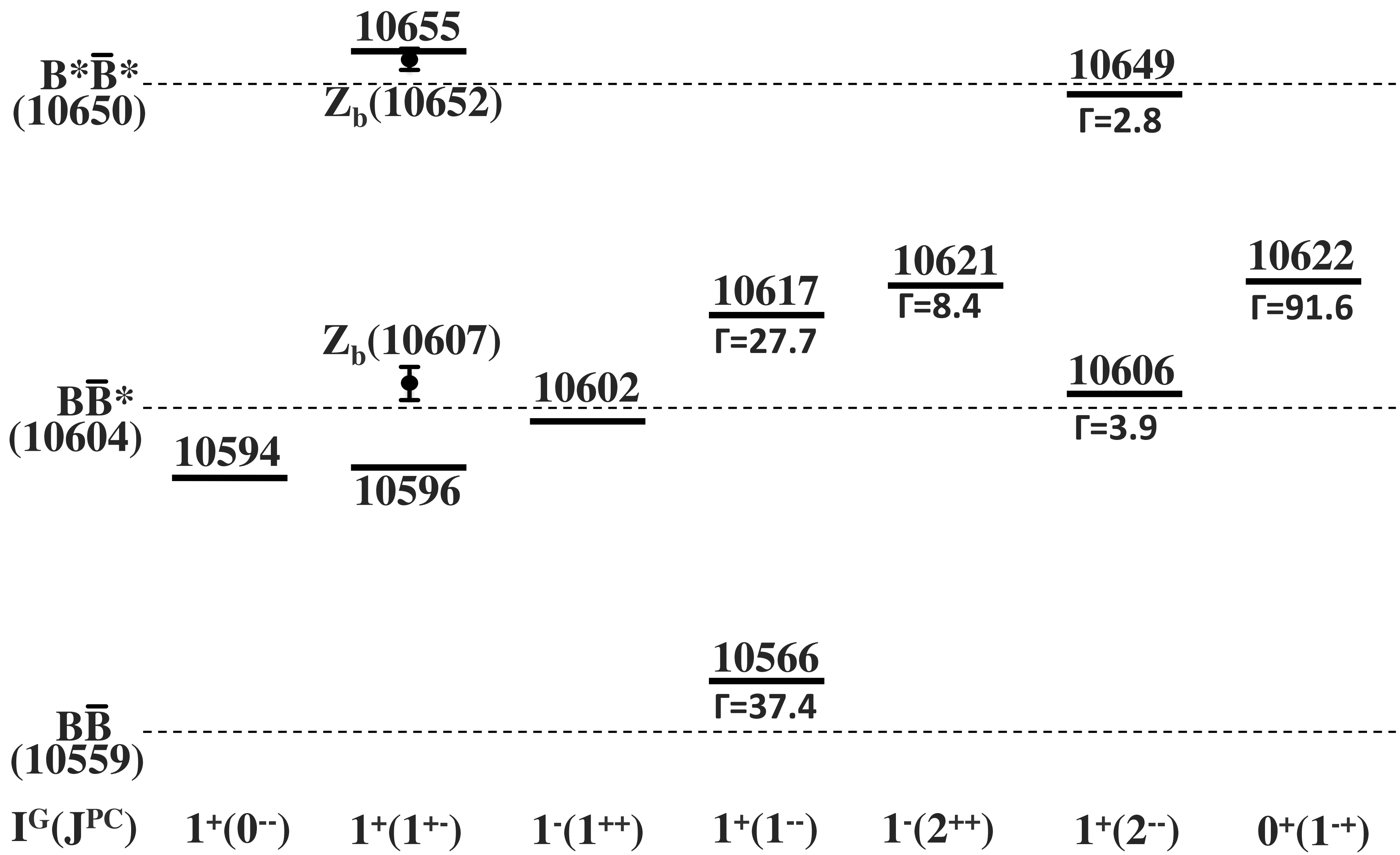
✓ OPEP is dominant in the heavy meson molecules.

Contributions for each mesons

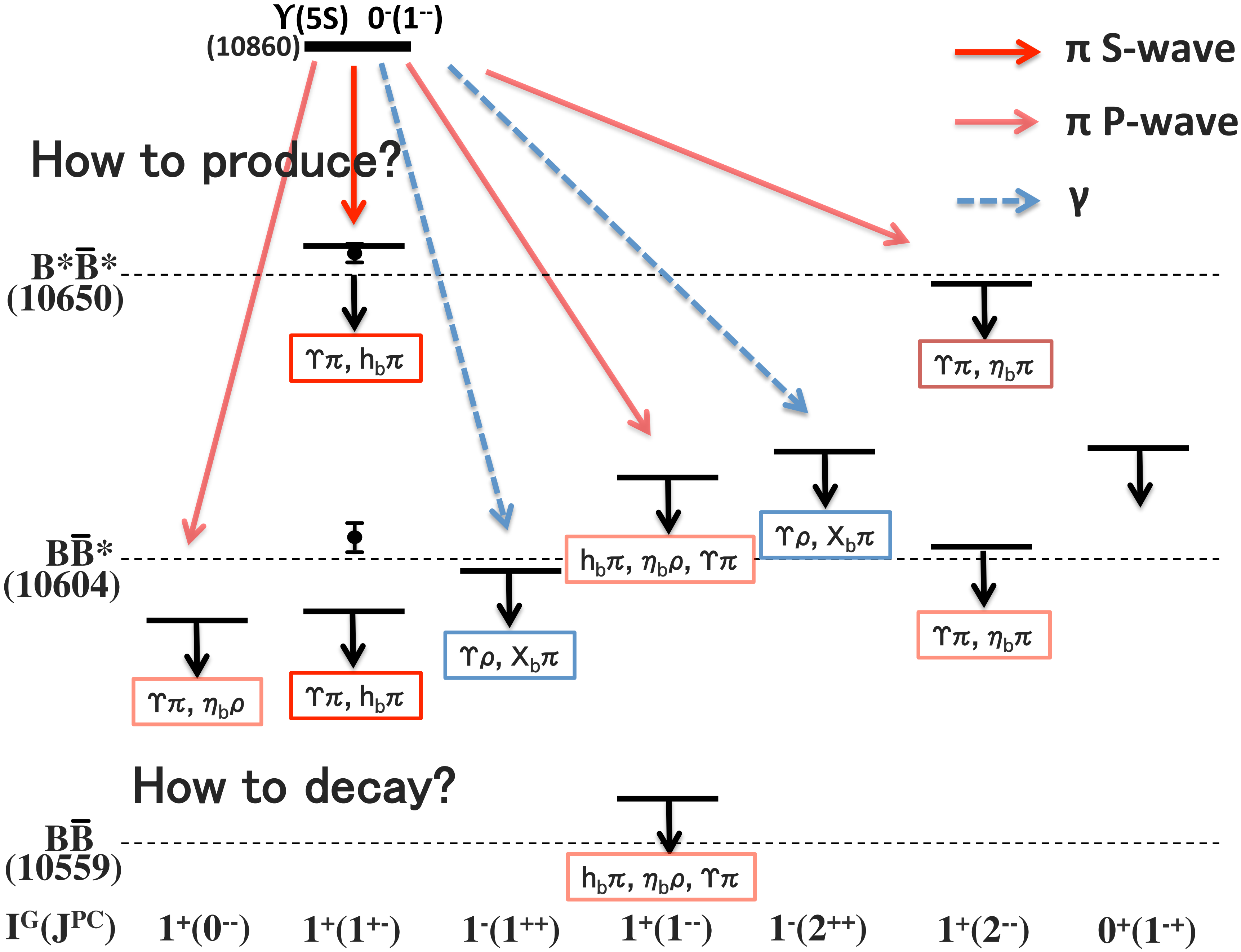
(Unit is MeV)	V_π	V_ρ	V_ω
$< V >$	-84.6	3.7	-8.4



BB̄ bound and resonance states



Decays of BB̄ states



Relations of spin structures and decay properties of Z_b

S. Ohkoda, Y. Yamaguchi, S. Yasui, K. Sudoh, and A. Hosaka,
Phys.Rev. D86, 117502 (2012).

Light spin complex

✓ In the heavy quark limit, new conserved quantity appear —— light spin complex

$$S_l = J - S_H$$

S_l : Light spin complex
J : Total angular momentum
S_H : Heavy quark spin

✓ We can write the wave function of heavy hadrons as the direct product of $S_H \otimes S_l$

		J^{PC}		$S_H \otimes S_l$		$b\bar{b}(^{2S+1}L_J)$
Υ	:	1^{--}	:	$1_H \otimes 0_l$	:	$b\bar{b}(^3S_1)$
h_b	:	1^{+-}	:	$0_H \otimes 1_l$	:	$b\bar{b}(^1P_1)$
χ_{bJ}	:	1^{++}	:	$(1_H \otimes 1_l)_J$	:	$b\bar{b}(^3P_J)$

The spin structure of Z_b

✓ The spin structures of Z_b's are given as

	$S_H \otimes S_l$	Component
Z_b	: $\frac{1}{\sqrt{2}}(0^-_H \otimes 1^-_l) + \frac{1}{\sqrt{2}}(1^-_H \otimes 0^-_l)$:	$\frac{1}{\sqrt{2}}(B\bar{B}^* - B^*\bar{B})(^3S_1)$
Z_b'	: $\frac{1}{\sqrt{2}}(0^-_H \otimes 1^-_l) - \frac{1}{\sqrt{2}}(1^-_H \otimes 0^-_l)$:	$B^*\bar{B}^*(^3S_1)$

✓ Z_b is a mixture state of 0_H and 1_H

✓ $(0_H \otimes 1_l)$ decays to $h_b\pi$, $\eta_b\gamma$, ...

✓ $(1_H \otimes 0_l)$ decays to $\Upsilon\pi$, $\chi_{bJ}\gamma$, ...

$Z_b \rightarrow \chi_{bJ}\,\gamma$

✓ $\chi_{b0} + \gamma$ (P-wave)

$$|\chi_{b0}\gamma(M1)>|_{J=1} = (1_H^- \otimes 1_l^-)|_{J=0} \otimes (0_H^+ \otimes 1_l^+)$$

$$= \frac{1}{3}(1_H^- \otimes 0_l^-) - \frac{1}{\sqrt{3}}(1_H^- \otimes 1_l^-)|_{J=1} + \frac{\sqrt{5}}{3}(1_H^- \otimes 2_l^-)|_{J=1}$$

✓ $\chi_{b1} + \gamma$ (P-wave)

$$|\chi_{b1}\gamma(M1)>|_{J=1} = -\frac{1}{\sqrt{3}}(1_H^- \otimes 0_l^-) + \frac{1}{2}(1_H^- \otimes 1_l^-)|_{J=1} + \frac{15}{6}(1_H^- \otimes 2_l^-)|_{J=1}$$

✓ $\chi_{b2} + \gamma$ (P-wave)

$$|\chi_{b2}\gamma(M1)>|_{J=1} = -\frac{\sqrt{5}}{3}(1_H^- \otimes 0_l^-) + \frac{\sqrt{15}}{6}(1_H^- \otimes 1_l^-)|_{J=1} + \frac{1}{6}(1_H^- \otimes 2_l^-)|_{J=1}$$

$$\begin{array}{ccccc} \Gamma(Z_b^0 \rightarrow \chi_{b0}\gamma) & : & \Gamma(Z_b^0 \rightarrow \chi_{b1}\gamma) & : & \Gamma(Z_b^0 \rightarrow \chi_{b2}\gamma) \\ 1 & : & 3 & : & 5 \end{array}$$

✓ This ratio is testable with experiment

Summary

- We studied the $B^{(*)}\bar{B}^{(*)}$ bound and resonant states
- The potential model suggests Z_b's have molecular type of structure and predicts a number of exotic mesons
- The pion interaction is dominant in the system of the heavy meson molecule
- Analyzing the spin structure gives useful information of the decay properties