Tetraquark Interpretation of charged Bottomonium-like $Z_b(10610)$ and $Z_b(10650)$and implications

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TR7 – CP violation, etc

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Work with Ahmed Ali, Christian Hambrock

arXiv: 1110.1333, Phys.Rev.D 85, 054011

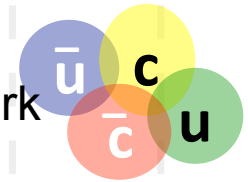
Mesonic spectroscopies beyond QM?

Glueball

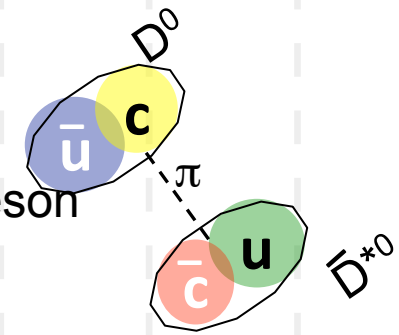
Color-singlet multi-gluon bound state

Four-quark states

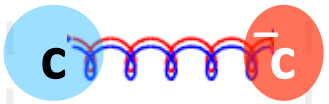
tightly bound diquark-diantiquark



loosely bound meson-antimeson "molecule"



qq̄-gluon hybrid meson

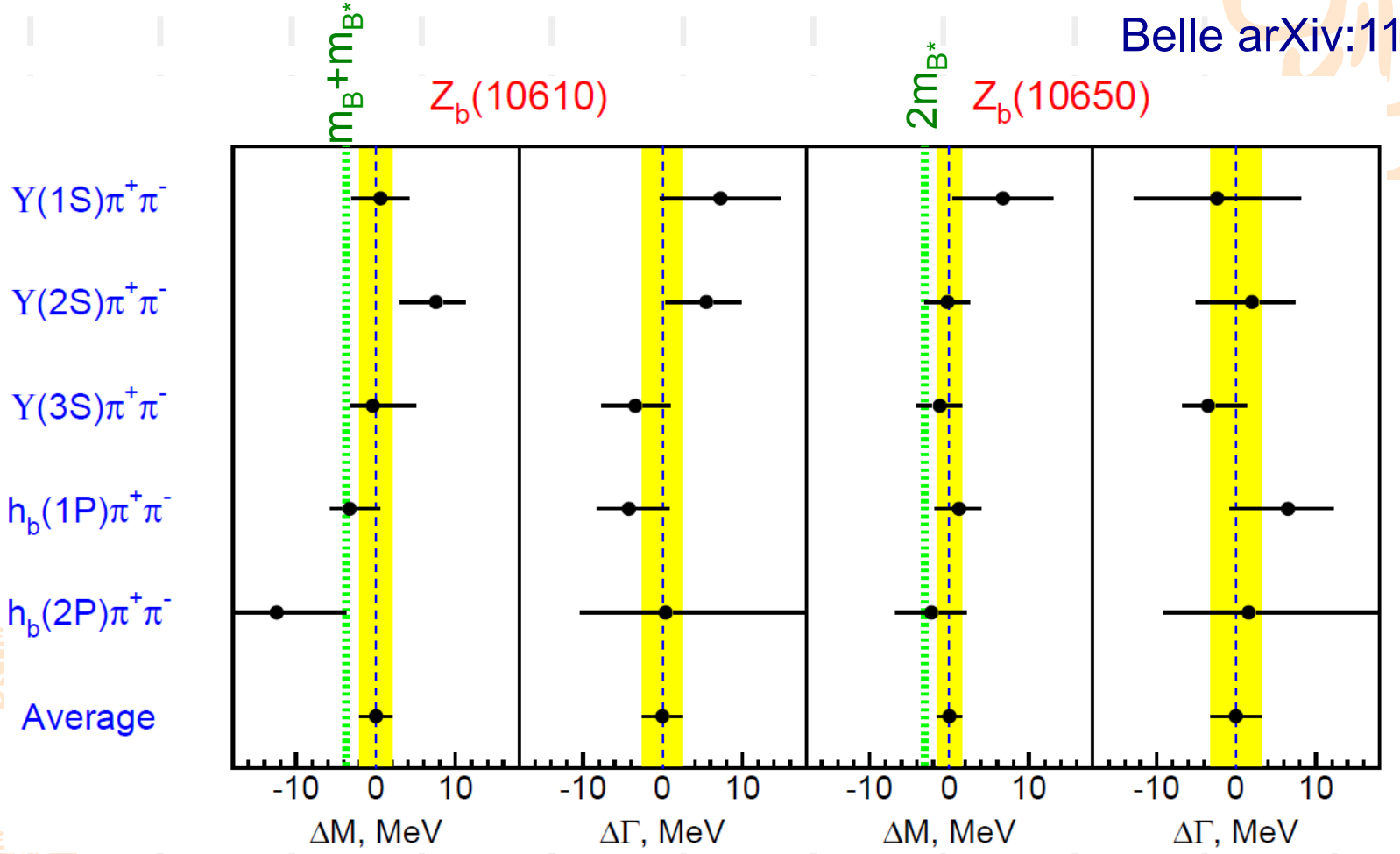


Candidates: "XYZ"

State	M (MeV)	Γ (MeV)	J^{PC}	Decay Modes	Production Modes
$Y_s(2175)$	2175 ± 8	58 ± 26	1^{--}	$\phi f_0(980)$	e^+e^- (ISR) $J/\psi \to \eta Y_s(2175)$
$X(3872)$	3871.4 ± 0.6	< 2.3	1^{++}	$\pi^+\pi^- J/\psi$, $\gamma J/\psi, D\bar{D}^*$	$B \to KX(3872)$, $p\bar{p}$
$X(3915)$	3914 ± 4	23 ± 9	$0/2^{++}$	$\omega J/\psi$	$\gamma\gamma \to X(3915)$
$Z(3930)$	3929 ± 5	29 ± 10	2^{++}	$D\bar{D}$	$\gamma\gamma \to Z(3940)$
$X(3940)$	3942 ± 9	37 ± 17	$0^{?+}$	$D\bar{D}^*$ (not $D\bar{D}$ or $\omega J/\psi$)	$e^+e^- \to J/\psi X(3940)$
$Y(3940)$	3943 ± 17	87 ± 34	$?^{?+}$	$\omega J/\psi$ (not $D\bar{D}^*$)	$B \to KY(3940)$
$Y(4008)$	4008^{+82}_{-49}	226^{+97}_{-80}	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^- (ISR)
$X(4160)$	4156 ± 29	139^{+113}_{-65}	$0^{?+}$	$D^*\bar{D}^*$ (not $D\bar{D}$)	$e^+e^- \to J/\psi X(4160)$
$Y(4260)$	4264 ± 12	83 ± 22	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^- (ISR)
$Y(4350)$	4361 ± 13	74 ± 18	1^{--}	$\pi^+\pi^- \psi'$	e^+e^- (ISR)
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$\Lambda_c^+\Lambda_c^-$	e^+e^- (ISR)
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$\pi^+\pi^- \psi'$	e^+e^- (ISR)
$Z(4050)$	4051^{+24}_{-23}	82^{+51}_{-29}	?	$\pi^\pm \chi_{c1}$	$B \to KZ^\pm(4050)$
$Z(4250)$	4248^{+185}_{-45}	177^{+320}_{-72}	?	$\pi^\pm \chi_{c1}$	$B \to KZ^\pm(4250)$
$Z(4430)$	4433 ± 5	45^{+35}_{-18}	?	$\pi^\pm \psi'$	$B \to KZ^\pm(4430)$
$Y_b(10890)$	$10,890 \pm 3$	55 ± 9	1^{--}	$\pi^+\pi^-\Upsilon(1,2,3S)$	$e^+e^- \to Y_b$
$Z_b(10610)$	10607 ± 2	18.4 ± 2.4	1^+	$\pi^\pm h_b(1,2P), \pi^\pm \Upsilon(1,2,3S)$	$Y_b/\Upsilon(5S) \to \pi Z_b(10610)^\pm$
$Z_b(10650)$	10652 ± 2	11.5 ± 2.2	1^+	$\pi^\pm h_b(1,2P), \pi^\pm \Upsilon(1,2,3S)$	$Y_b/\Upsilon(5S) \to \pi Z_b(10650)^\pm$

Discovery in $Y_b/\Upsilon(5S) \rightarrow \Upsilon(nS)/h_b(mP)\pi^+\pi^-$

Belle arXiv:1110.2251

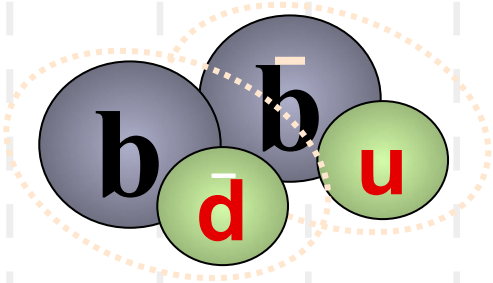


$Z_b(10610)$ **M=10607.2±2.0 MeV** **$Z_b(10650)$** **M=10652.2±1.5 MeV**

For discussion on $Y_b(10890)$ see Prof. Ahmed Ali's talk

$Z_b \rightarrow \Upsilon(1S)\pi \rightarrow$ Two Z_b states contain a $\bar{b}b$ quark pair

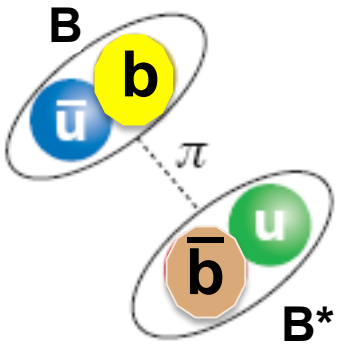
charge = ± 1 → Z_bs must contain additional light quarks

$Z_b^+ =$ 

"minimal" quark configuration : Four-quark states!

$B\text{-}\bar{B}^*$ & $B^*\text{-}\bar{B}^*$ molecules?

$Z_b(106010)^{\pm}$



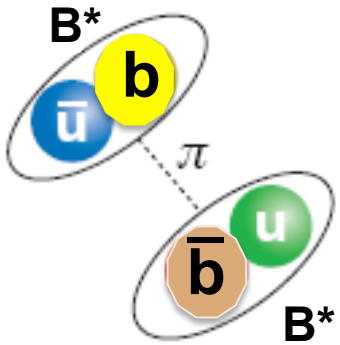
$B\text{-}\bar{B}^*$ "molecule"

Belle
1110.2251

M=10607.2±2.0 MeV

PDG: $M_B + M_{B^*} = 10604.5 \pm 0.6$ MeV

$Z_b(106050)^{\pm}$



$B^*\text{-}\bar{B}^*$ "molecule"

M=10652.2±1.5 MeV

$M_{B^*} + M_{B^*} = 10650.2 \pm 1.0$ MeV

Theoretical explanation - exotic strucutes

- **S-wave $B\bar{B}^*$ and $B^*\bar{B}^*$ molecular states**

Bondar, Garmash, Milstein, Mizuk, Voloshin, arXiv:1105.4473
Zhang, Zhong, Huang, arXiv:1105.5472
Voloshin, arXiv:1105.5829
Yang,Ping, Deng, Zong, arXiv:1105.5935
Sun, He, Liu, Luo, Zhu, arXiv:1106.2968
……

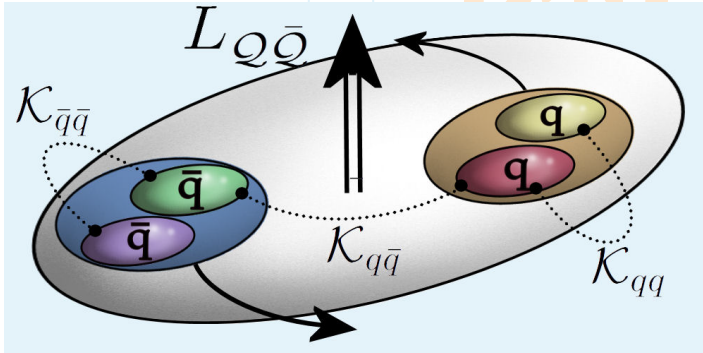
- **Tetraquark state**

Yang, Ping, Deng, Zong, arXiv:1105.5935
Guo, Cao, Zhou, Chen, arXiv:1106.2284
Ali, Hambrock, Wang, arXiv:1110.1333
……

Tetraquark interpretation

$Z_b \rightarrow \Upsilon(1S)\pi \rightarrow$ Two Z_b states must contain a bb quark pair

charge = ± 1 ➔ Z_bs must contain additional light quarks



$$|\tilde{Z}_b\rangle = \left(0_{[bq]} \otimes 1_{[\bar{b}\bar{q}]} - 1_{[bq]} \otimes 0_{[\bar{b}\bar{q}]}\right)/\sqrt{2},$$
$$|\tilde{Z}_b'\rangle = 1_{[bq]} \otimes 1_{[\bar{b}\bar{q}]}.$$

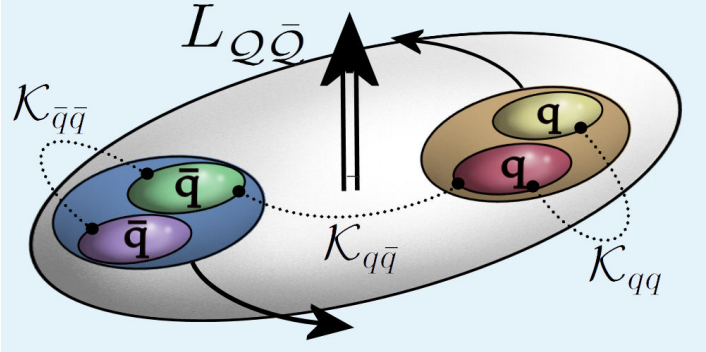
i. Two states with $J^{PC} = 0^{++}$:

$$|0^{++}\rangle = |0_Q, 0_{\bar{Q}};\ 0_J\rangle\,;$$
$$|0^{++\prime}\rangle = |1_Q, 1_{\bar{Q}};\ 0_J\rangle\,.$$

ii. Three states with $J = 1$:

$$|1^{++}\rangle = \frac{1}{\sqrt{2}}\left(|0_Q, 1_{\bar{Q}};\ 1_J\rangle + |1_Q, 0_{\bar{Q}};\ 1_J\rangle\right);$$
$$|1^{+-}\rangle = \frac{1}{\sqrt{2}}\left(|0_Q, 1_{\bar{Q}};\ 1_J\rangle - |1_Q, 0_{\bar{Q}};\ 1_J\rangle\right);$$
$$|1^{+-\prime}\rangle = |1_Q, 1_{\bar{Q}};\ 1_J\rangle\,.$$

Tetraquark interpretation



$$H = 2m_Q + H_{SS}^{(QQ)} + H_{SS}^{(Q\bar{Q})} + H_{SL} + H_{LL}.$$

$$\begin{aligned}
H_{SS}^{(QQ)} &= 2(\mathcal{K}_{bq})_{\bar{3}}[(\mathbf{S}_b.\mathbf{S}_q) + (\mathbf{S}_{\bar{b}}.\mathbf{S}_{\bar{q}})], \\
H_{SS}^{(Q\bar{Q})} &= 2(\mathcal{K}_{b\bar{q}})(\mathbf{S}_b.\mathbf{S}_{\bar{q}} + \mathbf{S}_{\bar{b}}.\mathbf{S}_q) + 2\mathcal{K}_{b\bar{b}}(\mathbf{S}_b.\mathbf{S}_{\bar{b}}) + 2\mathcal{K}_{q\bar{q}}(\mathbf{S}_q.\mathbf{S}_{\bar{q}}), \\
H_{SL} &= 2A_Q(\mathbf{S}_Q.\mathbf{L} + \mathbf{S}_{\bar{Q}}.\mathbf{L}), \\
H_{LL} &= B_Q \frac{L_{Q\bar{Q}}(L_{Q\bar{Q}}+1)}{2}.
\end{aligned}$$

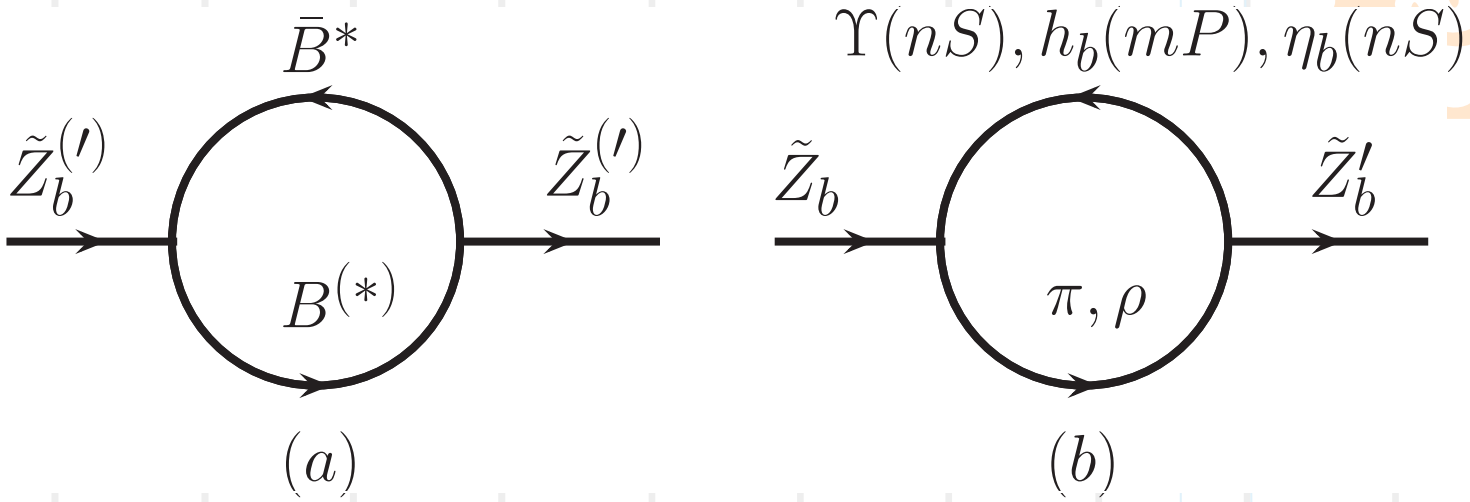
Maiani, et.al 2005
Ali, et.al, 2010

$$m_{Z_b} = (10443^{+35}_{-36})\text{MeV}, \; m_{Z_b'} = (10628^{+53}_{-54})\text{MeV},$$
$$\Delta m_{Z_b} = 2\sqrt{a^2+b^2} = (185^{+21}_{-18})\text{MeV}.$$

Data: **$m(Z_b(10610))=10607.2\pm2.0$ MeV** **$m(Z_b(10650)=10652.2\pm1.5$ MeV**

The naïve tetraquark model fails to explain the Z_bs' masses.

meson loop corrections



Including the loop corrections, we now have the following structure for the 2×2 mass matrix

$$M = \hat{M} + \sum_i c_i \begin{pmatrix} \Gamma_i^{\tilde{Z}_b} & -\sqrt{\Gamma_i^{\tilde{Z}_b}\Gamma_i^{\tilde{Z}_b'}} \\ -\sqrt{\Gamma_i^{\tilde{Z}_b}\Gamma_i^{\tilde{Z}_b'}} & \Gamma_i^{\tilde{Z}_b'} \end{pmatrix}, \quad (11)$$

meson loop corrections

Including the loop corrections, we now have the following structure for the 2×2 mass matrix

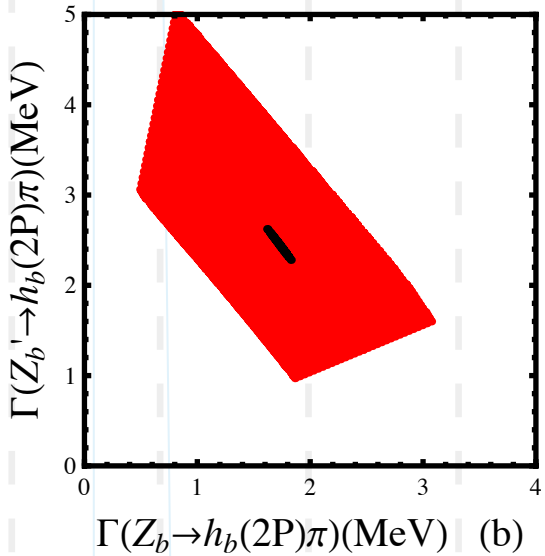
$$M = \hat{M} + \sum_i c_i \begin{pmatrix} \Gamma_i^{\tilde{Z}_b} & -\sqrt{\Gamma_i^{\tilde{Z}_b}\Gamma_i^{\tilde{Z}'_b}} \\ -\sqrt{\Gamma_i^{\tilde{Z}_b}\Gamma_i^{\tilde{Z}'_b}} & \Gamma_i^{\tilde{Z}'_b} \end{pmatrix}, \quad (11)$$

$c_{h_b(2P)\pi}$	$c_{\eta_b\rho}$	$c_{h_b(1P)\pi}$	c_{BB^*}
45^{+11}_{-10}	-1.1	3 ± 1	-1.1

The coefficient for h_b(2P)pi final state is largest!

$$\Gamma(Z_b \to h_b(2P)\pi) = (1.7^{+1.3}_{-1.2})\text{MeV},$$
$$\Gamma(Z'_b \to h_b(2P)\pi) = (2.5^{+2.5}_{-1.5})\text{MeV}.$$

$$r_{h_b(2P)\pi} \equiv |g_{Z'_b h_b(2P)\pi}/g_{Z_b h_b(2P)\pi}| = 1.2^{+1.1}_{-0.5}.$$



(b)

meson loop corrections

$$\Gamma(Z_b \to h_b(2P)\pi) = (1.7^{+1.3}_{-1.2})\text{MeV},$$
$$\Gamma(Z_b' \to h_b(2P)\pi) = (2.5^{+2.5}_{-1.5})\text{MeV}.$$

$$r_{h_b(2P)\pi} \equiv |g_{Z_b' h_b(2P)\pi}/g_{Z_b h_b(2P)\pi}| = 1.2^{+1.1}_{-0.5}.$$

Belle data (1110.2251): $$a_{h_b(2P)\pi} = 1.6^{+0.6+0.4}_{-0.4-0.6}$$

$$a_i e^{i\phi_i} \equiv \frac{g_{Y_b Z_b'\pi} \times g_{Z_b' i}}{g_{Y_b Z_b \pi} \times g_{Z_b i}},$$ the ratio products of the production andcorresponding decay amplitudes of the $Z_b(10610)$ and $Z_b(10650)$ in given final states.

Summary

- The two charged Z_b states are exotic and may play an important role to understand QCD dynamics in bottomonium sector

- Naïve tetraquark model fails to explain the mass of Z_b states

- We consider the meson loop corrections to the Z_b spectrum

- With the measured Z_b masses, we have derived the partial decay widths of Z_b into $h_b(2P)\pi$ final state.

Thank you for your attention!