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Possible hidden-bottom pentaquarks from P-wave $\Lambda_b B^{(*)}$/ $\Sigma_b^{(*)} B^{(*)}$ interactions

arXiv: 2607.14913

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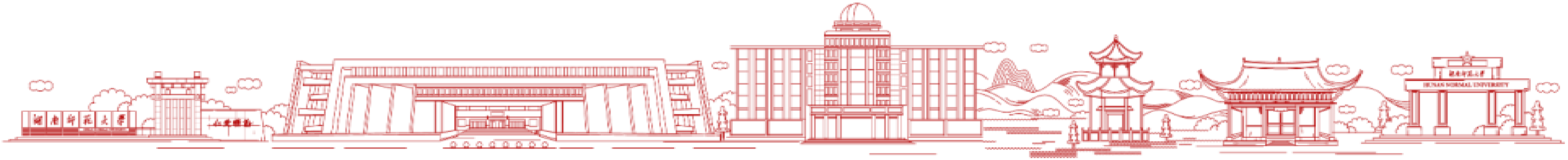

第十一届XYZ研讨会@贵阳

2026.7.24

Outline

I. Background and motivation: Similar hadronic molecular states exist in the bottom quark sector;

II. Theoretical framework;

III. Numerical results: single-channel and coupled-channel analysis;

IV. Summary

1

Background and motivation

1.1 Hadronic molecular state

- The **hadronic molecular state** consists of two or more hadrons, which form weak binding via strong interactions.

1. Chin. Sci. Bull.59, 3815-3830 (2014).
2. PTEP 2016 no.6, 062C01 (2016).
3. Phys. Rept. 639, 1-121 (2016).
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5. Prog. Part. Nucl. Phys. 93, 143-194 (2017).
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8. Prog. Part. Nucl. Phys. 107,237-320 (2019).
9. Phys. Rept. 873, 1-154 (2020).
10. Phys. Rept. 1019, 1-149 (2023).
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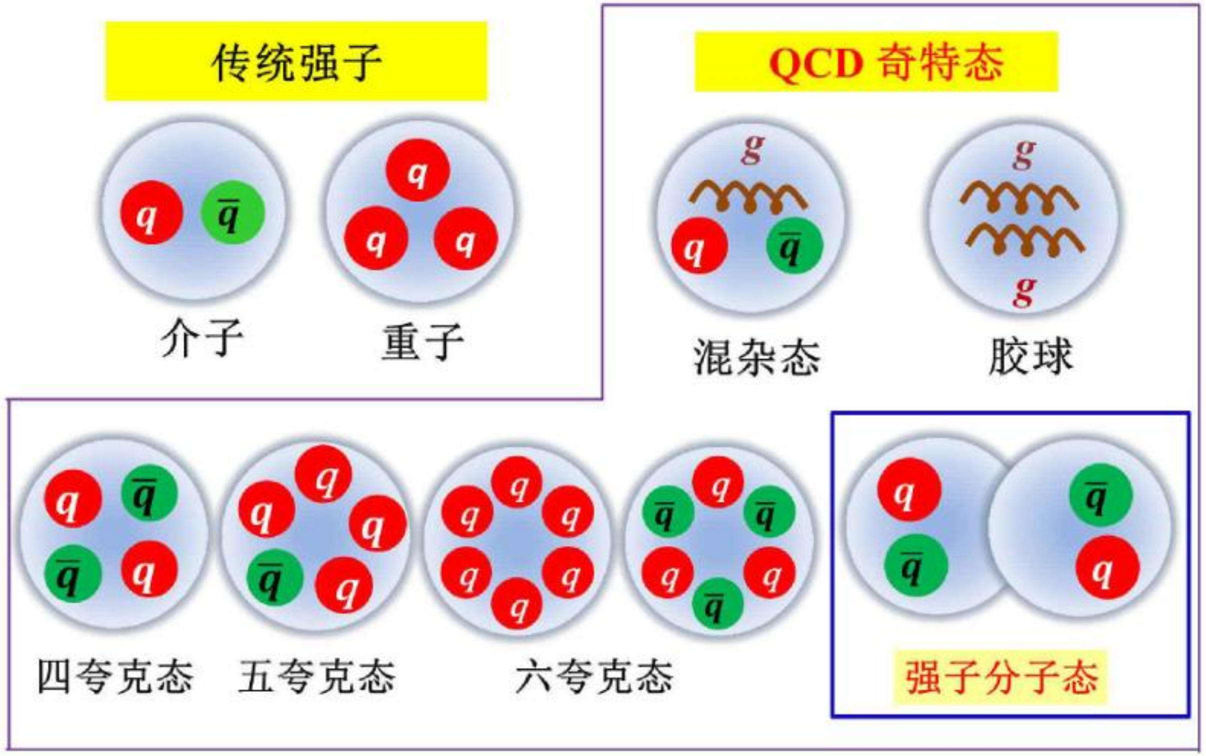

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1 Background and motivation

1.2 Experimental status

- Current studies have largely focused on meson-meson and meson-baryon systems in the charm sector:

2003	2007	2011	2015-2019	2021-2022
$X(3872)$ $D\bar{D}^*$	$Y(4260)$ $Z(4430)$ $D\bar{D}_1$, $\bar{D}_1D^*$	$Z_b(10610)$ $Z_b(10650)$ $B\bar{B}^*$, $B^*\bar{B}^*$	$P_c(4312)$ $P_c(4440)$ $P_c(4457)$	$T_{cc}^+(3875)$ DD^*

- Compared to charmed hadronic molecules, research on their bottom counterparts has lagged, partly due to their higher production thresholds and limited experimental data in earlier years.

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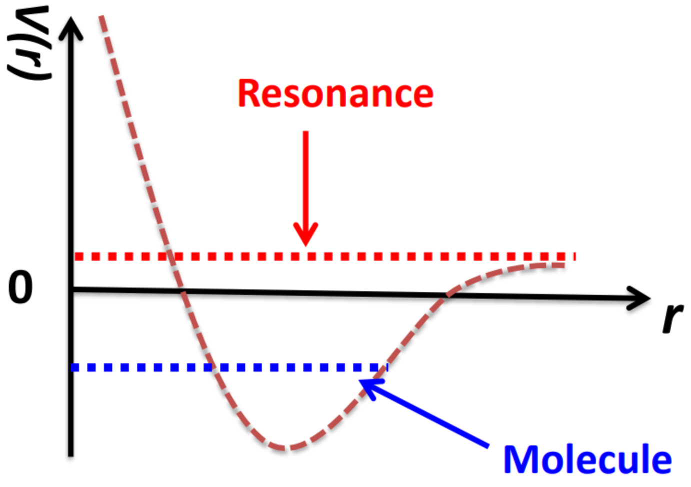
Background and motivation

1.3 P-wave interactions

- The centrifugal barrier can suppress shallow bound states, while it can also sustain resonances.

- For a P-wave molecule, the orbital excitation flips the overall parity, leading to quantum numbers distinct from those of the S -wave systems.



$$V_{\text{eff}}(r) = V(r) + \boxed{\frac{\hbar^2 l(l+1)}{2\mu r^2}} \longrightarrow$$ P-wave centrifugal barrier : $\frac{\hbar^2}{\mu r^2}$

- Our results offer key theoretical insights into the interaction mechanisms of the heavy-flavor baryon-meson systems.

- May also help to clarify the internal structures of the observed Pc states.

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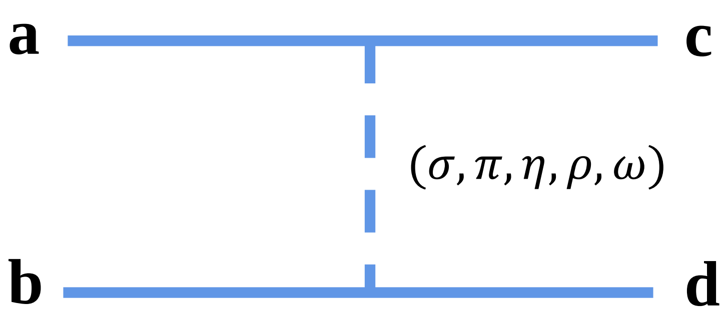
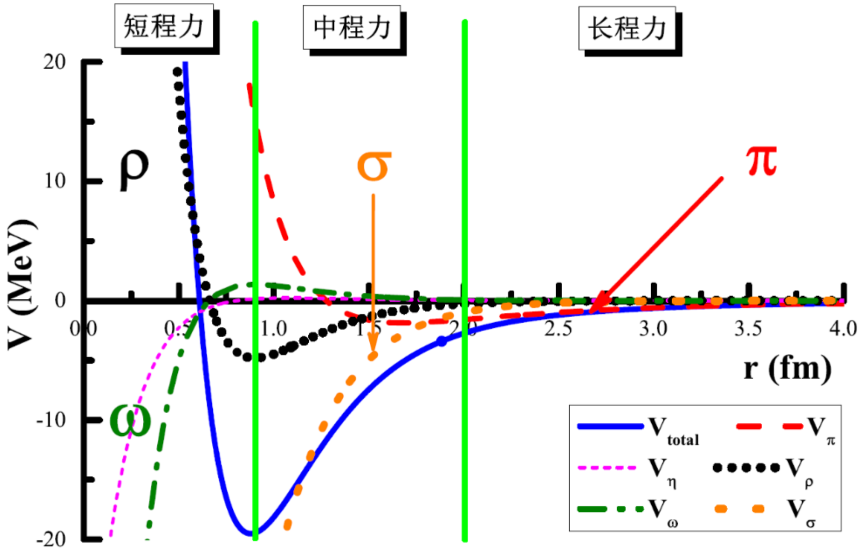
2 Theoretical framework

2.1 OBE model

Yukawa, Proc. Phys. Math. Soc. Japan 17, 48 (1935)

- 1935, Yukawa: pion-exchange and nucleon-nucleon interaction.
- In the OBE model, the interaction between two hadrons is mediated by the exchange of light mesons.
- Nijimegen potential and Bonn potential:
- ρ/σ exchange~**two π** exchange;
- ω exchange~**multi-π** exchange





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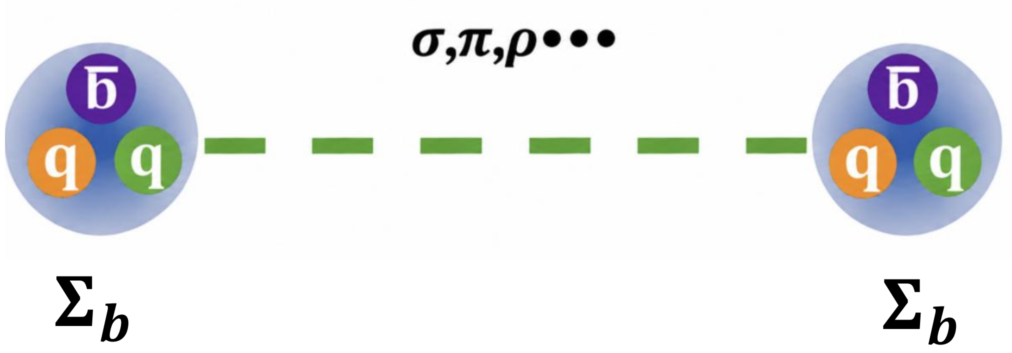
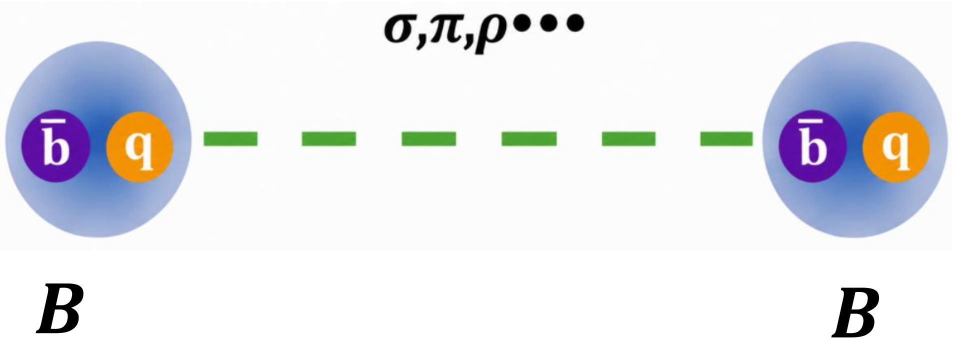
2 Theoretical framework

2.1 Effective Lagrangians





$g_S = 0.76$	$g = 0.59$	$\beta = 0.9$
$l_S = 6.2$	$g_1 = 0.94$	$\beta_S = -1.74$
$\lambda = 0.56\ \mathrm{GeV}^{-1}$	$\lambda_S = -3.31\ \mathrm{GeV}^{-1}$	$g_V = 5.8$

heavy quark symmetry and chiral symmetry;

$$
\begin{aligned}
\mathcal{L}_H &= g_S\langle \bar{H}_a^{(\bar{Q})}\sigma H_b^{(\bar{Q})}\rangle + ig\langle \bar{H}_a^{(\bar{Q})}\gamma_\mu \mathcal{A}^\mu_{ab}\gamma_5 H_b^{(\bar{Q})}\rangle \\
&\quad - i\beta\langle \bar{H}_a^{(\bar{Q})} v_\mu\left(\mathcal{V}^\mu-\rho^\mu\right)_{ab} H_b^{(\bar{Q})}\rangle \\
&\quad + i\lambda\langle \bar{H}_a^{(\bar{Q})}\sigma_{\mu\nu}F^{\mu\nu}(\rho)H_b^{(\bar{Q})}\rangle, \\
\mathcal{L}_{\mathcal{B}_{\bar{3}}} &= l_B\langle \bar{\mathcal{B}}_{\bar{3}}\sigma\mathcal{B}_{\bar{3}}\rangle + i\beta_B\langle \bar{\mathcal{B}}_{\bar{3}}v^\mu(\mathcal{V}_\mu-\rho_\mu)\mathcal{B}_{\bar{3}}\rangle, \\
\mathcal{L}_{\mathcal{B}_6^{(*)}} &= l_S\langle \bar{\mathcal{S}}_\mu\sigma\mathcal{S}^\mu\rangle - \frac{3}{2}g_1\varepsilon^{\mu\nu\lambda\kappa}v_\kappa\langle \bar{\mathcal{S}}_\mu\mathcal{A}_\nu\mathcal{S}_\lambda\rangle \\
&\quad + i\beta_S\langle \bar{\mathcal{S}}_\mu v_\alpha\left(\mathcal{V}^\alpha-\rho^\alpha\right)\mathcal{S}^\mu\rangle \\
&\quad + \lambda_S\langle \bar{\mathcal{S}}_\mu F^{\mu\nu}(\rho)\mathcal{S}_\nu\rangle, \\
\mathcal{L}_{\mathcal{B}_{\bar{3}}\mathcal{B}_6^{(*)}} &= ig_4\langle \bar{\mathcal{S}}^\mu\mathcal{A}_\mu\mathcal{B}_{\bar{3}}\rangle + i\lambda_I\varepsilon^{\mu\nu\lambda\kappa}v_\mu\langle \bar{\mathcal{S}}_\nu F_{\lambda\kappa}\mathcal{B}_{\bar{3}}\rangle + \mathrm{h.c.}
\end{aligned}
$$

1. Chin. Phys. C 36, 6-13 (2012).
2. Phys. Rep. 281, 145 (1997).
3. Phys. Lett. B 292, 119(1992).
4. Phys. Rev.D 85, 014015 (2012).

Theoretical framework

2.1 OBE model

- Amplitude $\quad \mathcal{M}(\mathrm{a}+\mathrm{b}\to\mathrm{c}+\mathrm{d})$
- Breit approximation $\quad V(\vec{q}) = -\mathcal{M}(a+b\to c+d)/\sqrt{2m_a 2m_b 2m_c 2m_d}$
- Fourier transform $\quad V(r)= \int \frac{\mathrm{d}^3 q}{(2\pi)^3} e^{i\vec{q}\cdot\vec{r}} V(\vec{q}) F^2(q^2, m_E^2)$
- Form factor $\quad F(q^2, m_E^2) = \frac{\Lambda^2 - m^2}{\Lambda^2 - q^2}$

Form factor $F(q^2, m_E^2)$ (One free parameter$< 2G$eV), m and q are the cutoff, mass and four-momentum of the exchanged meson, respectively.

Numerical results

3.1 Molecule

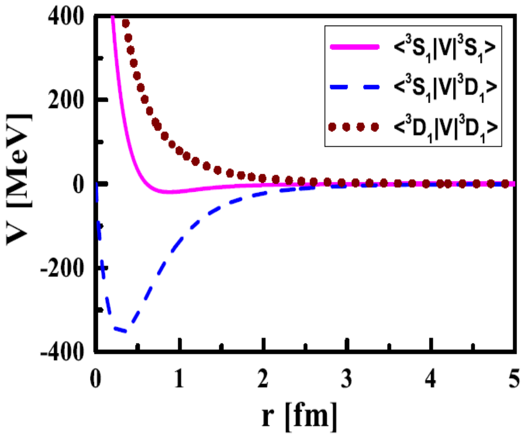
- In judging the reasonableness of the loosely bound state, we adhere to thecriterion based on:
- $\Lambda \sim 1$ GeV
- E to be of the order of a few to several tens of MeV
- rRMS ~ 1 fm.

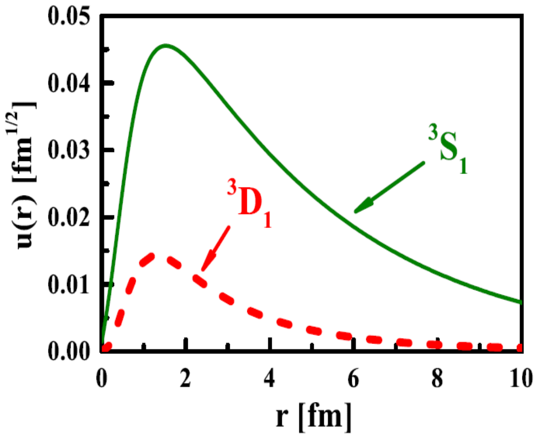
The cutoff parameter Λ, binding energy E, massM, and radius rRMS are given in units of GeV, MeV, MeV, and fm

Deuteron

loosely bound molecular state,

composed by a proton and a neutron





Effective potentials

Wave functions

$I(J^P) = 0(1^+),\ E = -2.225$ MeV, $R = 4.318$ fm

3 Numerical results

3.2 Resonances

Resonances: Shape-type; Feshbach-type

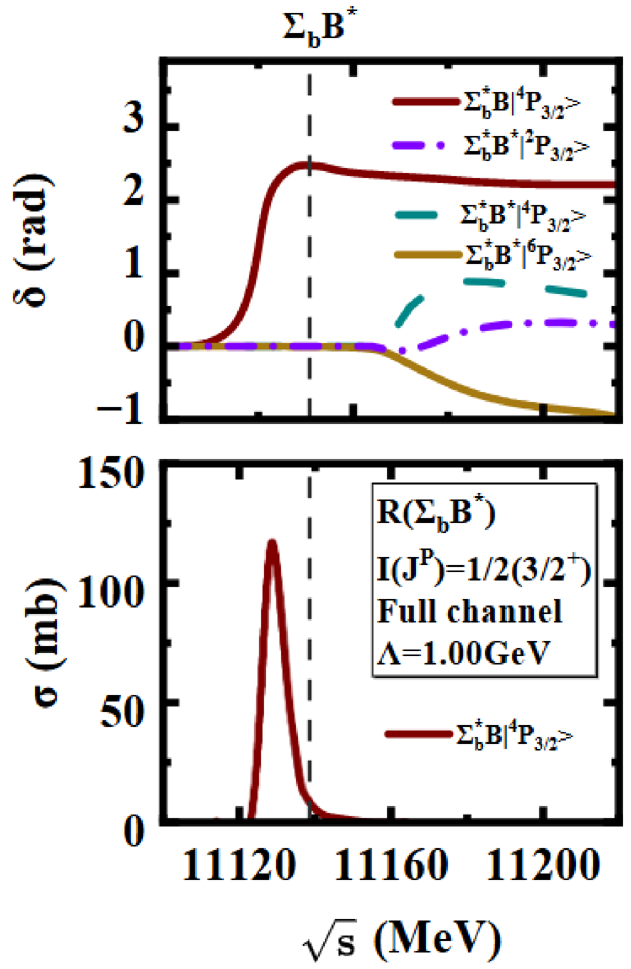
- Scattering cross section

$$\sigma_t = \frac{4\pi}{2\mu E}\sum_{l=0}^{\infty}(2l+1)\sin^2\delta_l(E)$$

$$\delta_l(E_r) = (n+1/2)\pi, \quad n = 0, 1, 2\cdots$$

$$\Gamma_r = 2\Big/\left(\frac{d\delta}{dE}\right)_{E_r}$$

- Mass: $M = M_{\Sigma_b^*} + M_B + E$



3 Numerical results

3.3 $\frac{1}{2}(\frac{1}{2}^+)$ system

$\Lambda_b B/\ \Lambda_b B^*/\ \Sigma_b B/\ \Sigma_b^* B/\ \Sigma_b B^*/\ \Sigma_b^* B^*$

Bound states

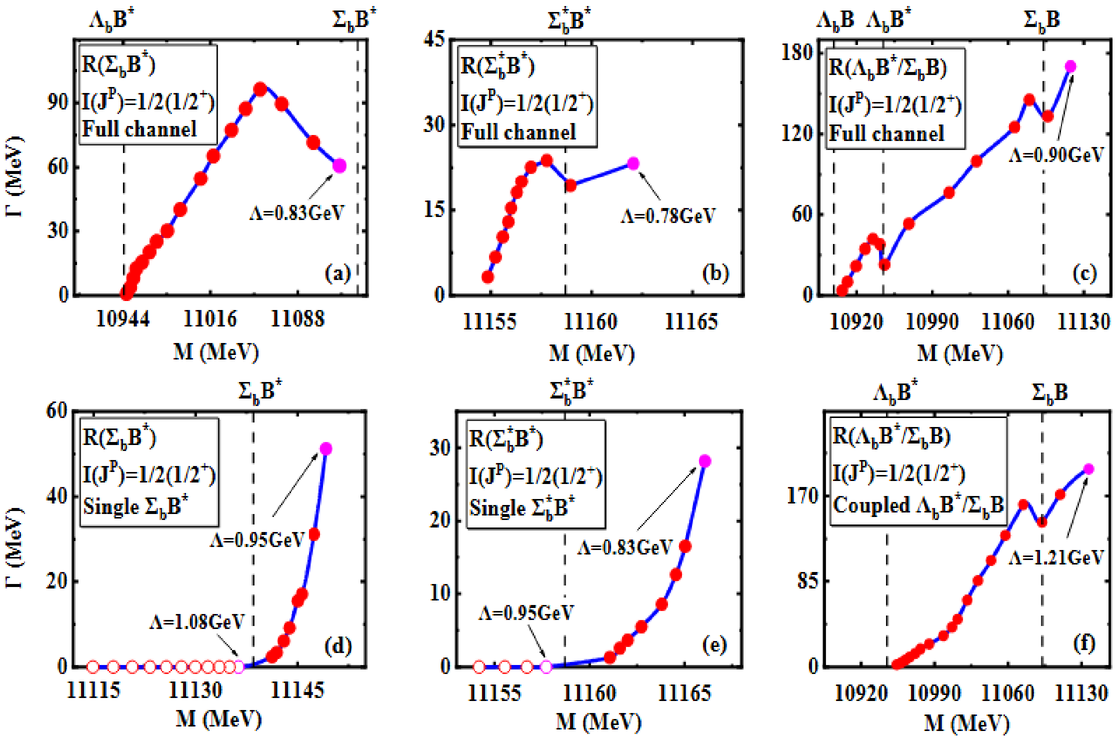
Couple channel

Λ	E	r_{RMS}	$\Lambda_b B(^2P_{\frac{1}{2}})$	$\Lambda_b B^*(^2P_{\frac{1}{2}}/^4P_{\frac{1}{2}})$	$\Sigma_b B(^2P_{\frac{1}{2}})$	$\Sigma_b^* B(^2P_{\frac{1}{2}})$	$\Sigma_b B^*(^2P_{\frac{1}{2}}/^4P_{\frac{1}{2}})$	$\Sigma_b^* B^*(^2P_{\frac{1}{2}}/^4P_{\frac{1}{2}})$
1.04	-0.97	0.90	$\boxed{42.26}$	19.25/ 0.17	5.42	1.01	3.36/ 4.96	22.33/ 1.24
1.05	-10.05	0.52	$\boxed{29.42}$	23.09/0.24	5.81	1.62	5.50 /4.97	27.44/ 1.91
1.06	-20.99	0.45	$\boxed{23.49}$	24.28 /0.46	5.72	2.03	7.13/ 4.62	29.92 / 2.35

Single channel

Λ	E	r_{RMS}	$\Sigma_b B^*(^2P_{\frac{1}{2}}/^4P_{\frac{1}{2}})$
1.08	-2.18	1.22	**88.13**/ 11.87
1.10	-5.00	0.98	**89.70**/ 10.30
1.12	-8.53	0.84	**90.89**/ 9.11
Λ	E	r_{RMS}	$\Sigma_b^* B^*(^2P_{\frac{1}{2}}/^4P_{\frac{1}{2}})$
0.95	-0.98	1.58	**79.53**/ 20.47
0.99	-6.02	0.99	**82.40**/ 17.60
1.03	-13.86	0.78	**84.49**/ 15.51

Resonances



$\mathrm{I}(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

$\Sigma_b B^*$, $\Sigma_b^* B^*$ → good molecular candidates

$\Lambda_b B^*/\Sigma_b B$ → Feshbach-type Resonance

3 Numerical results

3.4 $\frac{1}{2}(\frac{3}{2}^+)$ system

$\Lambda_b B/\ \Lambda_b B^*/\ \Sigma_b B/\ \Sigma_b^* B/\ \Sigma_b B^*/\ \Sigma_b^* B^*$

Bound states

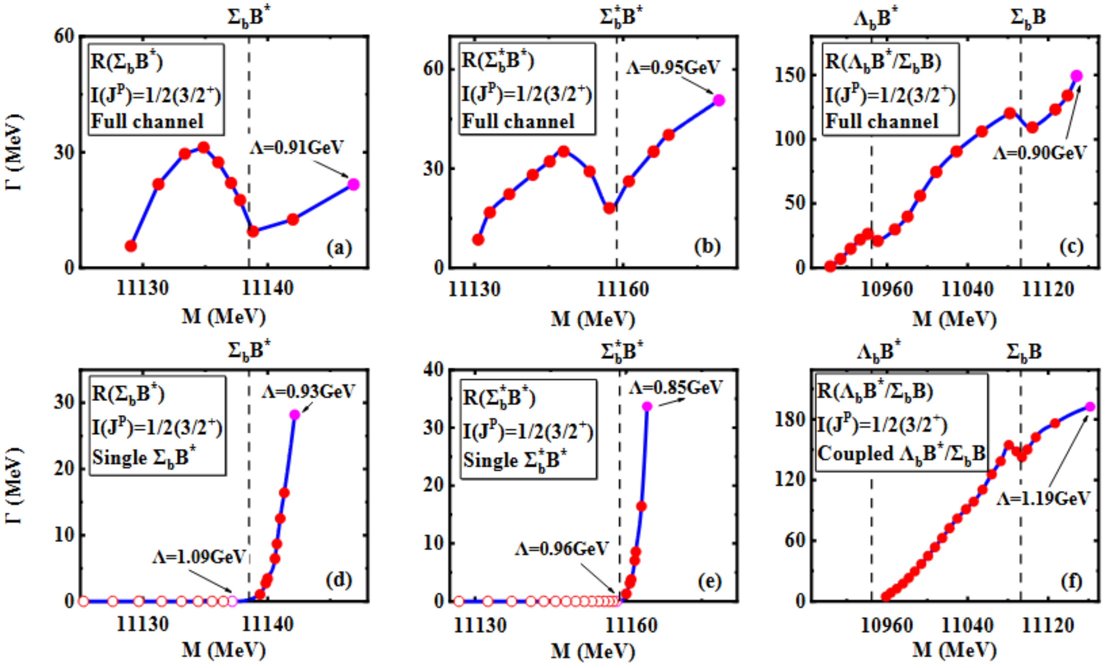
Couple channel

Λ	E	$r_{\rm RMS}$	$\Lambda_b B(^2P_{\frac{3}{2}})$	$\Lambda_b B^*(^2P_{\frac{3}{2}}/^4P_{\frac{3}{2}})$	$\Sigma_b B(^2P_{\frac{3}{2}})$	$\Sigma_b^* B(^4P_{\frac{3}{2}})$	$\Sigma_b B^*(^2P_{\frac{3}{2}}/^4P_{\frac{3}{2}})$	$\Sigma_b^* B^*(^2P_{\frac{3}{2}}/^4P_{\frac{3}{2}}/^6P_{\frac{3}{2}})$
1.07	-5.5	0.49	23.33	26.14/0.97	4.80	0.14	6.44/1.02	**35.90/1.19/0.07**
1.08	-18.14	0.40	17.70	27.50/0.87	4.93	0.16	7.98/0.93	**38.69/1.21/0.03**
1.09	-32.23	0.37	14.94	27.72/0.77	4.91	0.17	9.15/0.84	**40.30/1.18/0.02**

Single channel

Λ	E	$r_{\rm RMS}$	$\Sigma_b B^*(^2P_{\frac{3}{2}}/^4P_{\frac{3}{2}})$
1.11	-2.96	1.35	**54.30**/ 45.70
1.13	-5.41	1.07	**67.98**/ 32.02
1.15	-8.83	0.88	**74.41**/ 21.59
Λ	E	$r_{\rm RMS}$	$\Sigma_b^* B^*(^2P_{\frac{3}{2}}/^4P_{\frac{3}{2}}/^6P_{\frac{3}{2}})$
0.96	-0.63	1.98	**36.13/63.47** / 0.40
0.99	-3.10	1.27	**49.36 /49.83** / 0.81
1.02	-7.03	0.98	**61.49**/ 37.33/ 1.18

Resonances



$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$ $\Sigma_b B^*$, $\Sigma_b^* B^*$ → good molecular candidates

$\Lambda_b B^*/\Sigma_b B$ → Feshbach-type Resonance

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3 Numerical results

3.5 $\frac{1}{2}(\frac{5}{2}^+)$ system

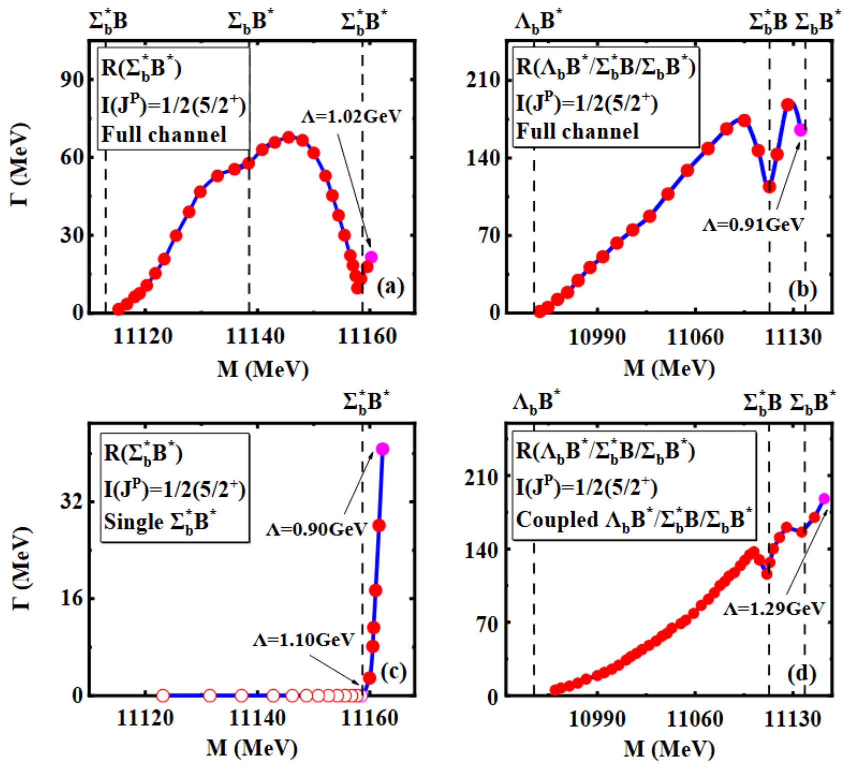
$\Lambda_b B^* / \Sigma_b^* B / \Sigma_b B^* / \Sigma_b^* B^*$

Bound states

Couple channel	Λ	E	$r_{\rm RMS}$	$\Lambda_b B^*(^4P_{\frac{5}{2}})$	$\Sigma_b^* B(^4P_{\frac{5}{2}})$	$\Sigma_b B^*(^4P_{\frac{5}{2}})$	$\Sigma_b^* B^*(^4P_{\frac{5}{2}}/^6P_{\frac{5}{2}})$
	1.10	-2.38	0.69	**56.88**	15.39	0.41	27.27/ 0.05
	1.11	-10.20	0.50	**50.81**	17.47	0.41	31.28/ 0.03
	1.12	-19.12	0.44	**47.09**	18.66	0.40	33.83/ 0.02

Single channel	Λ	E	$r_{\rm RMS}$	$\Sigma_b^* B^*(^4P_{\frac{5}{2}}/^6P_{\frac{5}{2}})$
	1.10	-0.25	3.05	1.81/ **98.19**
	1.30	-4.50	1.49	4.49/ **95.50**
	1.50	-12.51	1.07	12.85/ **87.15**

Resonances



$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$ $\Sigma_b^* B^*$ → good molecular candidates

$\Lambda_b B^* / \Sigma_b^* B / \Sigma_b B^*$ → Feshbach-type Resonance

3 Numerical results

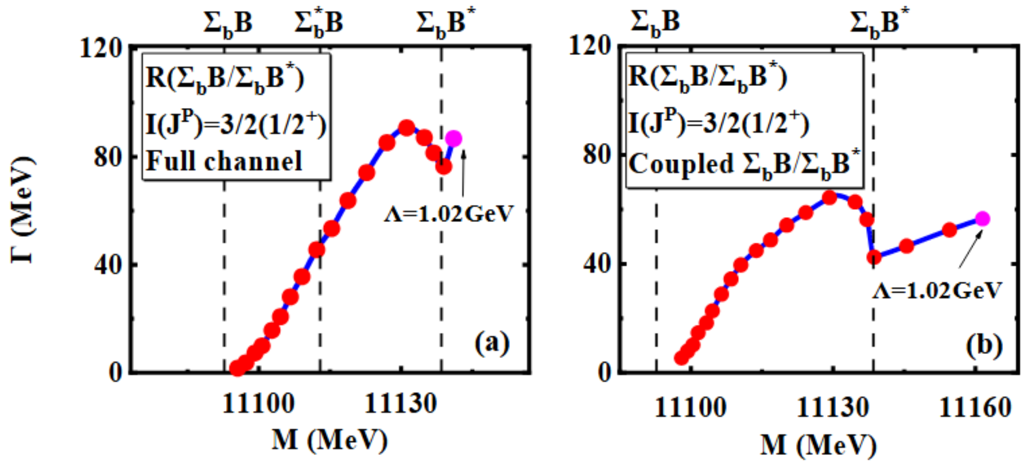
3.6 $\frac{3}{2}(\frac{1}{2}^{+})$ system

$\Sigma_b B/\ \Sigma_b^* B/\ \Sigma_b B^*/\ \Sigma_b^* B^*$

Bound states

Couple channel	Λ	E	r_{RMS}	$\Sigma_b B(^2P_{\frac{1}{2}})$	$\Sigma_b^* B(^2P_{\frac{1}{2}})$	$\Sigma_b B^*(^2P_{\frac{1}{2}}/^4P_{\frac{1}{2}})$	$\Sigma_b^* B^*(^2P_{\frac{1}{2}}/^4P_{\frac{1}{2}})$
	1.21	-0.11	1.79	**61.45**	2.72	1.10 / 32.98	~0 / 1.75
	1.23	-4.61	0.86	**47.14**	5.15	1.21 /43.18	~0 / 3.32
	1.25	-11.12	0.69	**38.83**	7.73	1.04 /47.34	~0 / 5.06

Resonances



- The I = 3/2 systems are expected to behave differently from the I = 1/2.
- The attractive interaction mediated by exchanged mesons is generally weakened, and larger cut-off values are usually required to obtain the bound states or resonances.

$\Sigma_b B\ /\ \Sigma_b B^*$ → Feshbach-type Resonance

3 Numerical results

3.7 $\frac{3}{2}(\frac{3}{2}^+)$ system

$\Sigma_b B/\ \Sigma_b^* B/\ \Sigma_b B^*/\ \Sigma_b^* B^*$

Bound states

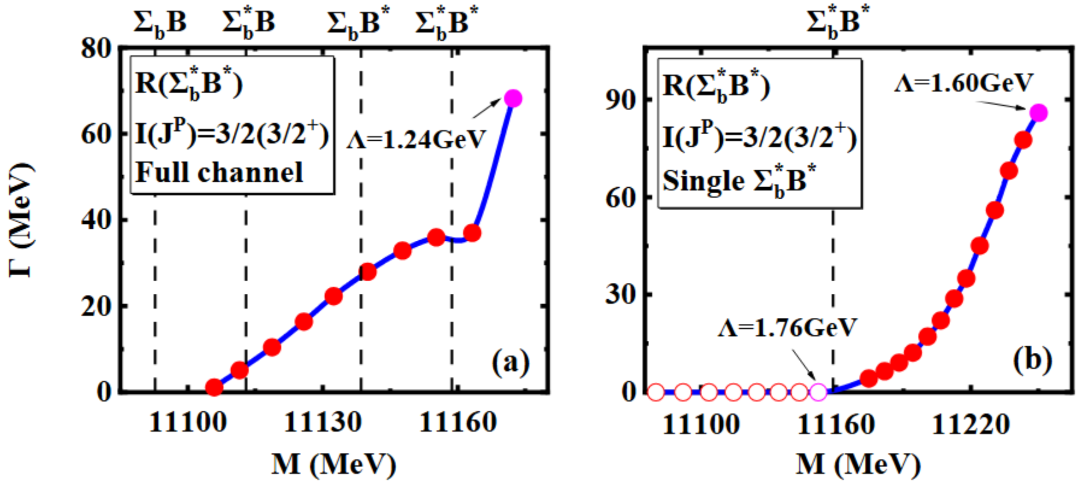
Couple channel

Λ	E	$r_{\rm RMS}$	$\Sigma_b B(^2P_{\frac{3}{2}})$	$\Sigma_b^* B(^4P_{\frac{3}{2}})$	$\Sigma_b B^*(^2P_{\frac{3}{2}}/^4P_{\frac{3}{2}})$	$\Sigma_b^* B^*(^2P_{\frac{3}{2}}/^4P_{\frac{3}{2}}/^6P_{\frac{3}{2}})$
1.35	-5.69	0.46	7.41	34.14	0.06 / **37.96**	0.01 / 17.86/ 2.56
1.36	-17.16	0.38	4.79	34.62	0.03 / **39.45**	0.01/ 19.30/ 1.80
1.37	-29.79	0.34	3.54	34.67	0.02 /**40.18**	0.01 / 20.25/ 1.33

Single channel

Λ	E	$r_{\rm RMS}$	$\Sigma_b^* B^*(^2P_{\frac{3}{2}}/^4P_{\frac{3}{2}}/^6P_{\frac{3}{2}})$
1.752	-0.56	1.20	2.34/ 0.68/ **96.98**
1.760	-6.79	0.91	1.52/ 0.28/ **98.02**
1.768	-13.17	0.78	0.68/ 0.03/ **99.29**

Resonances



$\Sigma_b^* B^*$ $I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$ → molecular candidate

3 Numerical results

3.8 $\frac{3}{2}(\frac{5}{2}^+)$ system

$\Sigma_b^* B / \Sigma_b B^* / \Sigma_b^* B^*$

Bound states

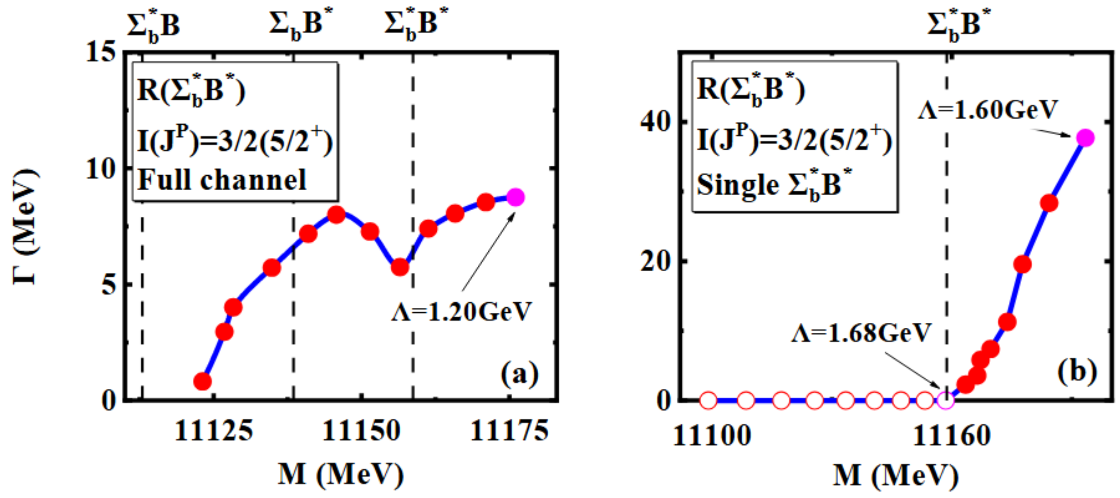
Couple channel

Λ	E	r_{RMS}	$\Sigma_b^* B(^4P_{\frac{5}{2}})$	$\Sigma_b B^*(^4P_{\frac{5}{2}})$	$\Sigma_b^* B^*(^4P_{\frac{5}{2}}/^6P_{\frac{5}{2}})$
1.32	-7.12	0.45	**38.59**	**38.67**	22.73/ 0.01
1.33	-16.24	0.40	**37.37**	**39.37**	23.25/0.01
1.34	-26.22	0.38	**36.65**	**39.76**	23.58/ 0.01

Single channel

Λ	E	r_{RMS}	$\Sigma_b^* B^*(^4P_{\frac{5}{2}}/^6P_{\frac{5}{2}})$
1.68	-0.25	1.13	2.45/ **97.55**
1.69	-6.47	0.87	1.48/ **98.52**
1.70	-12.45	0.70	0.17/ **99.83**

Resonances



$\Sigma_b^* B^*$ $\mathrm{I}(J^P) = \frac{3}{2}(\frac{5}{2}^+)$ → good molecular candidate

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4 Summary

- In this work, we have systematically studied the possible hidden-bottom molecular pentaquark states arising from the P-wave $\Lambda_b B^{(*)}$/ $\Sigma_b^{(*)} B^{(*)}$ interactions within the OBE model.

$I(J^P)$	$\frac{1}{2}(\frac{1}{2}^+)$	$\frac{1}{2}(\frac{3}{2}^+)$	$\frac{1}{2}(\frac{5}{2}^+)$	$\frac{3}{2}(\frac{1}{2}^+)$	$\frac{3}{2}(\frac{3}{2}^+)$	$\frac{3}{2}(\frac{5}{2}^+)$
Molecules	$\Sigma_b B^*$ $\Sigma_b^* B^*$	$\Sigma_b B^*$ $\Sigma_b^* B^*$	$\Sigma_b^* B^*$	\	$\Sigma_b^* B^*$	$\Sigma_b^* B^*$
Feshbach-type	$\Lambda_b B^*$/ $\Sigma_b B$	$\Lambda_b B^*$/ $\Sigma_b B$	$\Lambda_b B^*$/ $\Sigma_b^* \mathrm{B}$/ $\Sigma_b B^*$	$\Sigma_b \mathrm{B}$ / $\Sigma_b B^*$	\	\

- The identification of such states would offer crucial insights into the nature of exotic hadrons and deepen our understanding of the interaction mechanisms between heavy baryons and heavy mesons.

Thanks for your attention