B.3: Hadronic molecules with heavy meson loops

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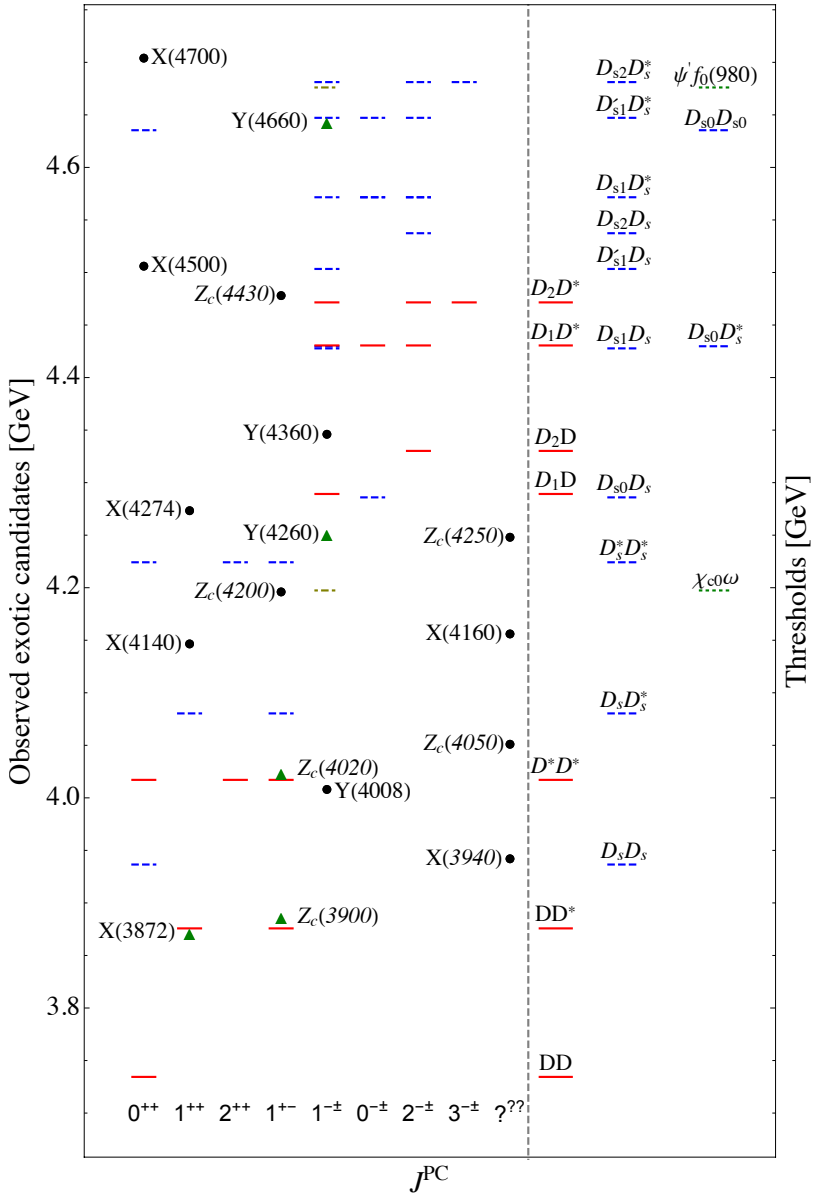
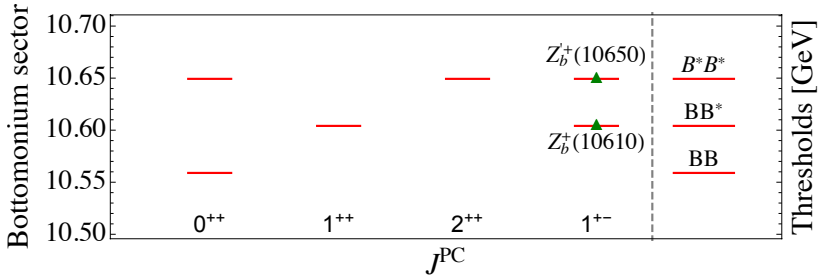
Result I: Exotic candidates in heavy quarkonium sector

F.K. Guo, C. Hanhart, Ulf-G. Meißner, QW, Q.Zhao, B.S.Zou, arXiv:1705.00141[hep-ph], review for RMP





★ Near-threshold states, e.g.

$$E_{Z_b}^{\text{Exp}} \sim 3 \text{ MeV}$$

⇒ Extended object

Size $\frac{\hbar c}{\gamma} \sim 1.56 \text{ fm} \gg R_0$

★ Exp: Belle, PRL116(2016)212001

$$\mathcal{BR}(Z_b \to B\bar{B}^* + c.c.) \sim 85.6\%$$

⇒ Large coupling $g_{Z_b BB^*}$

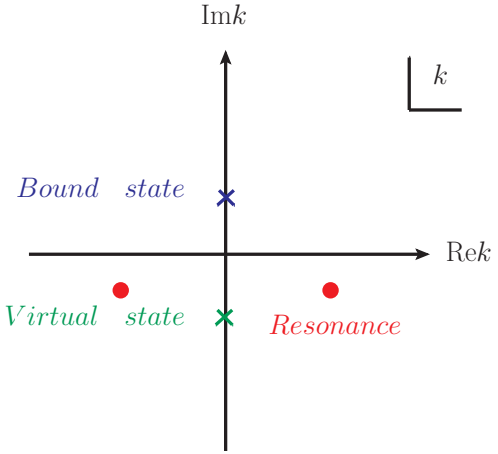
$$\frac{g_{\text{eff}}^2}{4\pi} = 4M^2 \left(\frac{\gamma}{\mu}\right)(1-\lambda^2)$$

Probability of molecule: $1-\lambda^2$

Result I: Identify hadronic molecules

F.K. Guo, C. Hanhart, Ulf-G. Meißner, QW, Q.Zhao, B.S.Zou, arXiv:1705.00141[hep-ph], review for RMP

$\Rightarrow$ poles of the S-matrix



$\Rightarrow$ the pole counting approach

$$k_1 = i\gamma \ , \quad k_2 = -i\gamma \left(\frac{2-\lambda^2}{\lambda^2} \right)$$

$\rightarrow$ molecule: $\lambda = 0 \rightarrow 1$ pole, $g_{\text{eff}} \uparrow$

$\rightarrow$ compact: $\lambda = 1 \rightarrow 2$ poles, $g_{\text{eff}} \downarrow$

$$\hookleftarrow \frac{{g_{\text{eff}}}^2}{4\pi} = 4M^2 \left(\frac{\gamma}{\mu} \right) \left(1 - \lambda^2 \right)$$

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F.K. Guo, C. Hanhart, Ulf-G. Meißner, QW, Q.Zhao, B.S.Zou, arXiv:1705.00141[hep-ph], review for RMP

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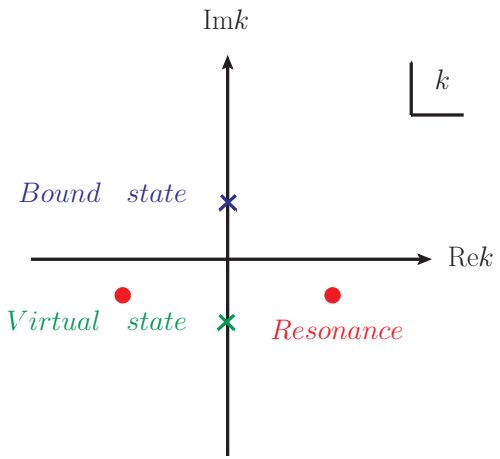

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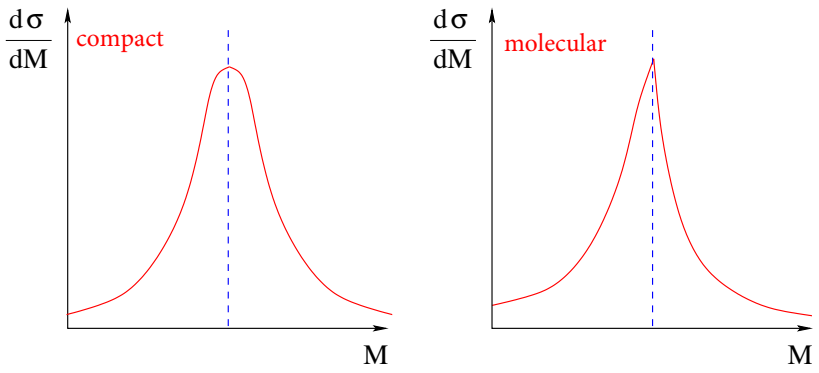
⇒ characterize the line shapes in inelastic channels

Symmetric→

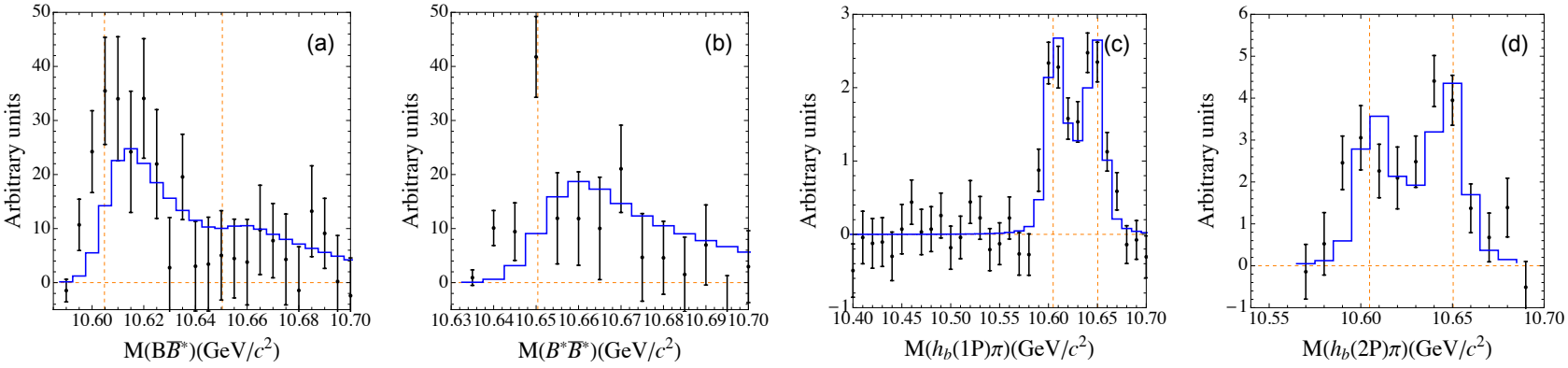


← Asymmetric

$$T_{\text{in.}}(E) = \frac{{g_{\text{eff}}}^2/2}{E - E_r + ({g_{\text{eff}}}^2/2)(ik+\gamma) + i\Gamma_0/2} \quad \text{with} \quad E = k^2/(2\mu)$$

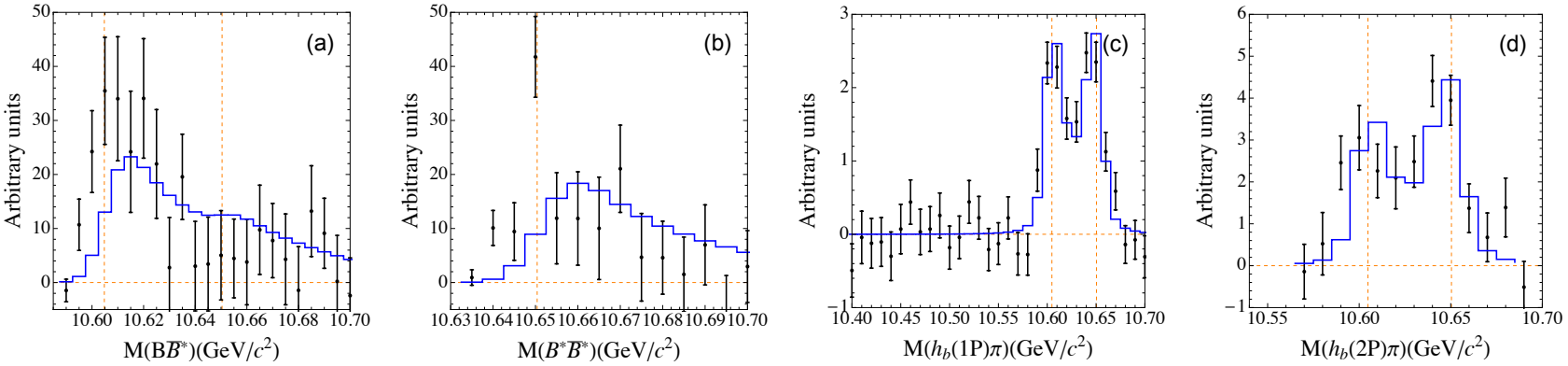
Result II: The line shapes of Z_b

A: Contact potential



Result II: The line shapes of Z_b

B: Contact potential+S-wave 1-π-potential

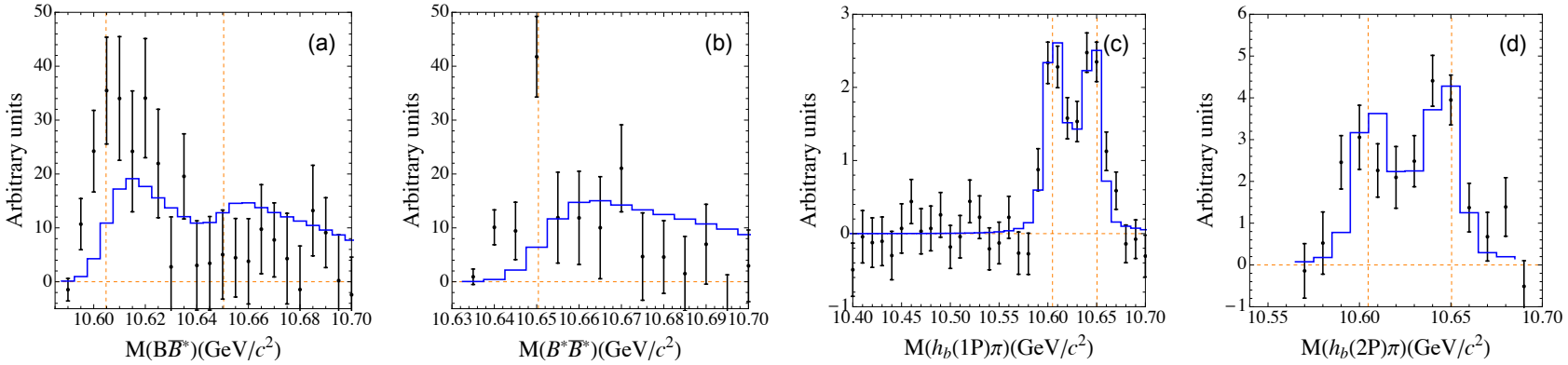


- ⋆ Include full dynamic 1-π-potential (1-η-potential)
- ⋆ Contrast with the 30% expectation of OPE near threshold

M.B. Voloshin, PRD92(2015)114003

Result II: The line shapes of Z_b

C: Contact potential+S- and D-wave 1-π-potential



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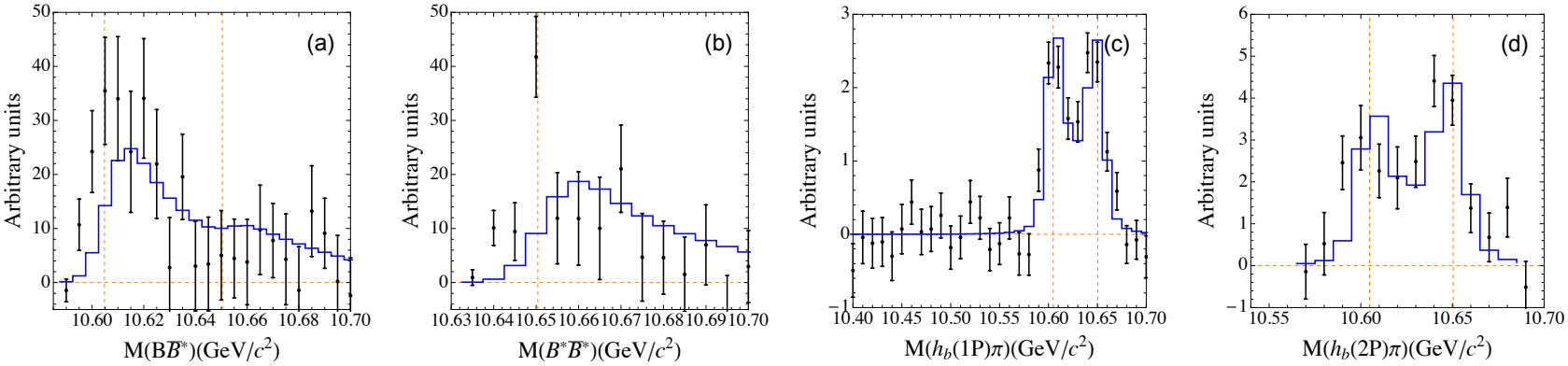
M.B. Voloshin, PRD92(2015)114003

Result II: The line shapes of Z_b

D: Contact potential+S- and D-wave 1-π- and 1-η-potential



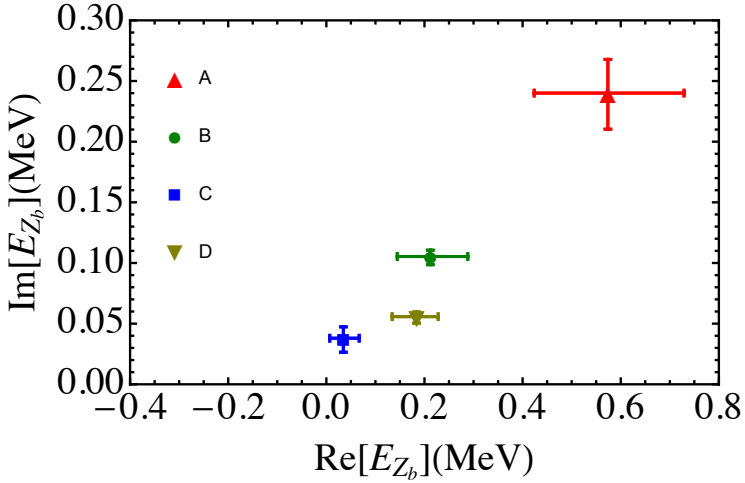
- ⋆ Include full dynamic 1-π-potential (1-η-potential)
- ⋆ Contrast with the 30% expectation of OPE near threshold

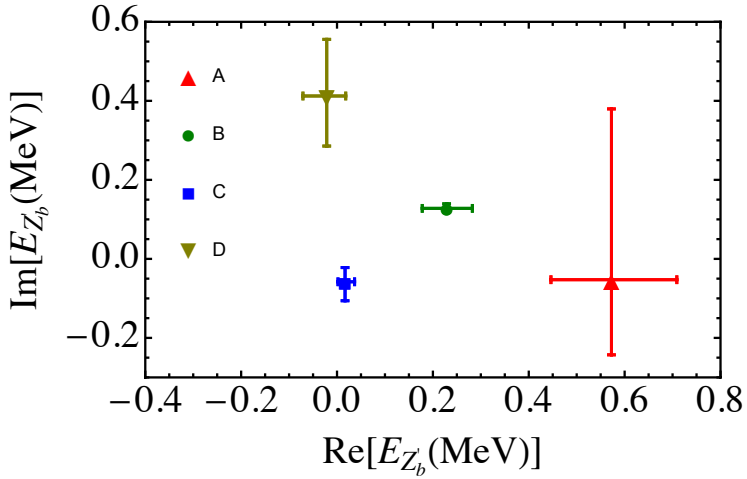
M.B. Voloshin, PRD92(2015)114003

- ⋆ Equally good fit for these four fit schemes, as V_{LO} is driven by the pole positions

Result II: The line shapes of Z_b

$Z_b^{(\prime)}$ poles





- ⋆ Include full dynamic 1-π-potential (1-η-potential)
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M.B. Voloshin, PRD92(2015)114003

- ⋆ Equally good fit for these four fit schemes, as V_{LO} is driven by the pole positions
- ⋆ The Z_b state behaves as a virtual state
- ⋆ $E_{Z_b} \simeq E_{Z_b'}$ except for Fit D, as $m_\eta^2/(2\mu) \sim m_{B^*} - m_B$

F.K. Guo, C. Hanhart, Y.S. Kalashnikova, R.V. Mizuk, A.V. Nefediev, QW, J.-L. Wynen, PRD93(2016)074031,

C.Hanhart, Y.S. Kalashnikova, P. Matuschek, R.V. Mizuk. A.V. Nefediev. QW, PRL115(2015) 202001

QW, C.Hanhart, A.V.Nefediev and J.-L Wynen, in preparation

Result III: HQSS for (B, B^*) and $(\bar{B}, \bar{B}^*)$ scattering

⇒ Potential S-wave $B^{(*)}\bar{B}^{(*)}$ hadronic molecules

S-wave	$B\bar{B}$	$B\bar{B}^* + c.c.$	$B^*\bar{B}^*$
J^{PC}	0^{++}	$1^{+\pm}$	$0^{++}, 1^{+-}, 2^{++}$
states	W_{b0}	W_{b1}, Z_b	W'_{b0}, Z'_b, W_{b2}

⇒ Two low-energy parameters in the heavy quark limit

⇒ No new parameter from meson exchange

PDG(from $D^* \to D\pi$), ALPHA coll. PLB740(2015)278

⇒ No significant impacts @ line shapes of the two Z_b states

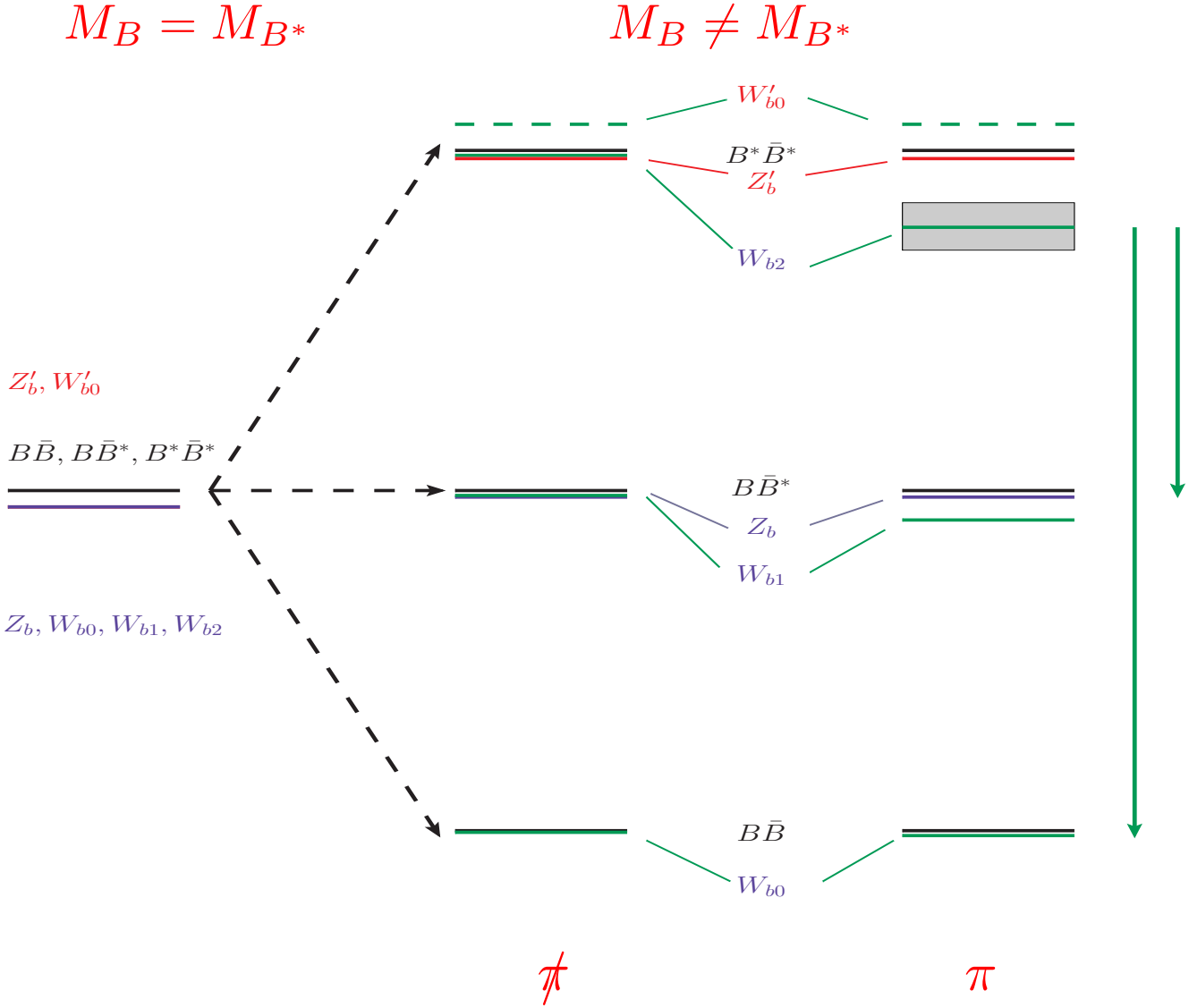
⇒ Impacts @ poles of their spin partners

all partial waves @ Baru et al. PLB763(2016)20

V.Baru, E. Epelbaum, A.A.Filin, C.Hanhart, A.V. Nefediev, JHEP1706(2017)158

Result III: HQSS violation

Location of spin partners is sensitive to $Z_b^{(\prime)}$ binding energies



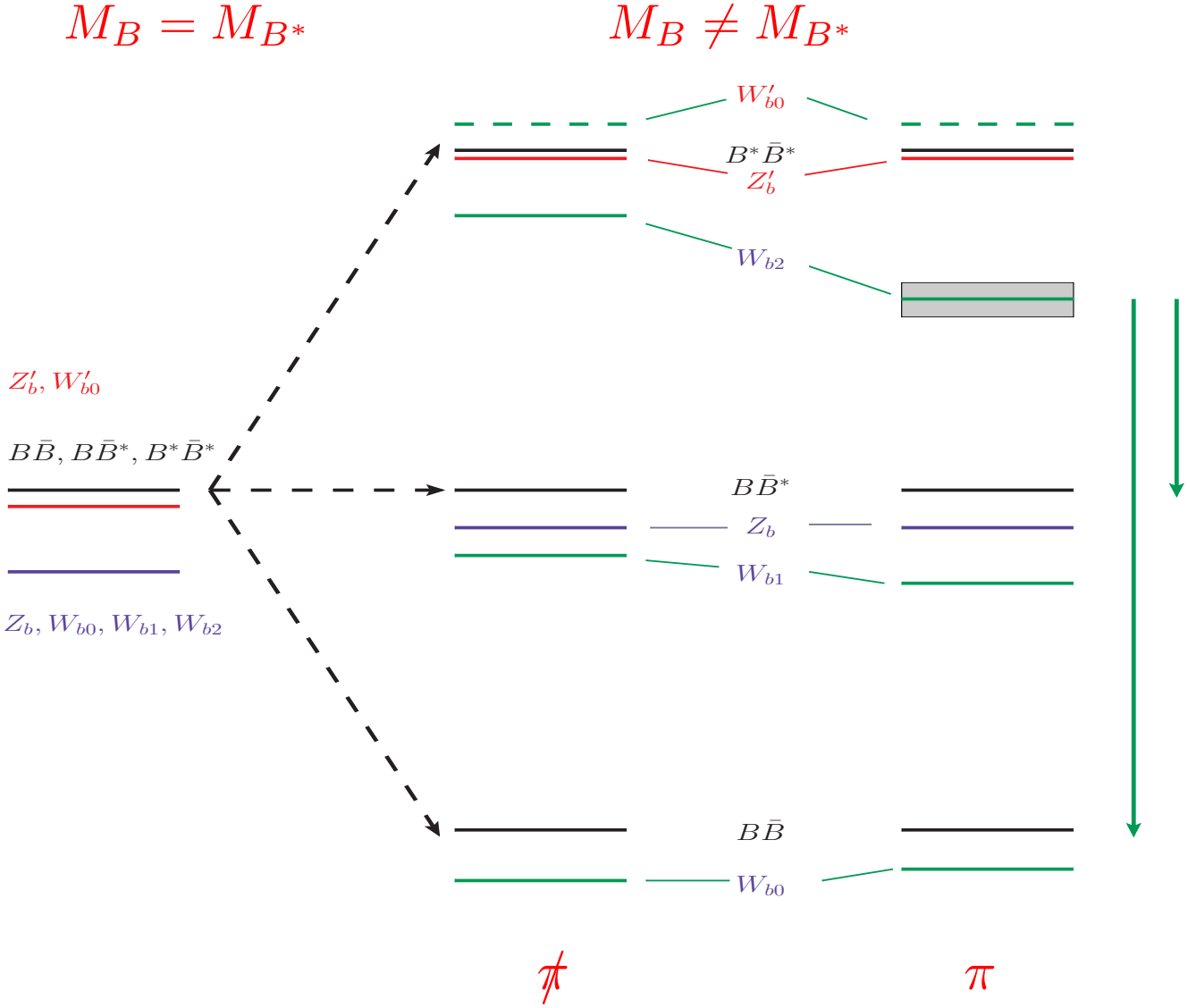
$E_V(Z_b) = 1$ MeV, $E_V(Z'_b) = 1$ MeV

F.-K. Guo et al. PRD93(2016)074031

V.Baru, E. Epelbaum, A.A.Filin, C.Hanhart, A.V. Nefediev, JHEP1706(2017)158

Result III: HQSS violation

When lifting spin symmetry, specific pattern emerges:



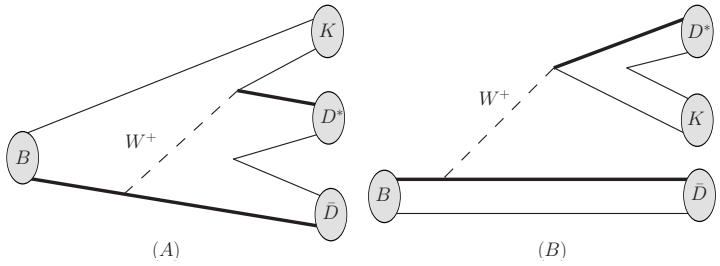
$E_B(Z_b) = 5$ MeV, $E_B(Z'_b) = 1$ MeV

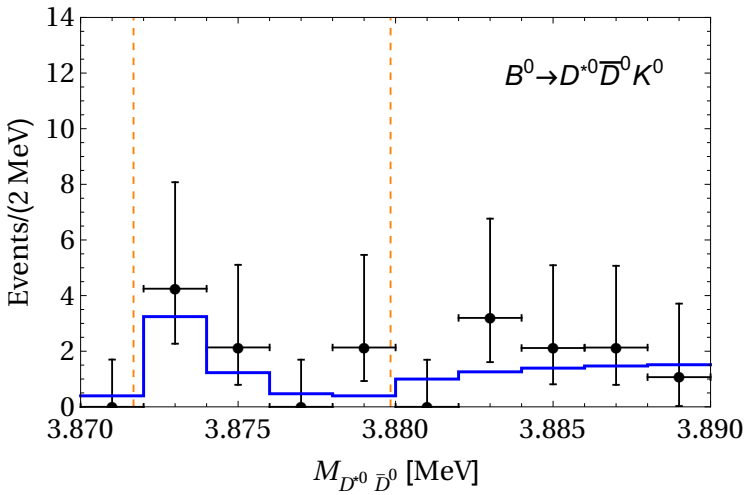
M. Cleven et al. EPJA47(2011)120

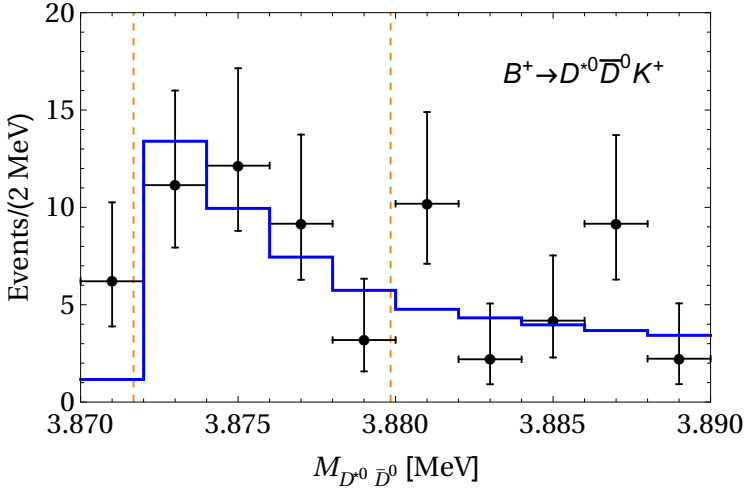
V.Baru, E. Epelbaum, A.A.Filin, C.Hanhart, A.V. Nefediev, JHEP1706(2017)158

Result IV: Absence of the $Z_c(3900)$ in B decays

Belle@2008







⇒ analyse the isospin amplitudes of the $B \to D^* \bar{D} K$ process

⇒ $q\bar{q}$ from vacuum is $I = 0$

⇒ include $D^* \bar{D}$ interaction

⇒ the production of isospin triplet $D^* \bar{D}$ is very tiny

⇒ absence of the $Z_c(3900)$

Z.Yang, QW, Ulf-G. Meißner, arXiv:1706.00960(2017)

Milestones

2016/2

- ⋆ Full analysis of the interaction between the (B, B^*) spin doublet and its anti-doublet with fully dynamic 1-π- and 1-η- exchange potentials

  → Fully achieved ✓

2017

- ⋆ Extend the fully dynamic 1-π- and 1-η- exchange potentials to the charm system (D, D^*) which needs to deal with the three-body unitarity self-consistently as well as the pion mass dependence of the physical quantities.

  → started (with Bonn/Jülich/Bochum/ITP/ITEP Moscow people)

- ⋆ Extend the above formulas to the scattering between the (D_1, D_2) doublet and the $(\bar{D}, \bar{D}^*)$ doublet.

  → will start (with Bonn/Jülich/Bochum/ITP/ITEP Moscow people)

- ⋆ Include the $\pi\pi$ and $K\bar{K}$ final state interaction in addition to the parametrisation we have for the two pion transition between heavy quarkonia.

  → in collaboration with A.1

Y.H. Chen, M. Cleven, J.T. Daub. F.K. Guo, C. Hanhart. B. Kubis, U.-G. Meißner, B.S. Zou, PRD95(2017)034022

Summary and Outlook

- ⋆ Project B.3 is on a good track
- ⋆ Fruitful collaborations (discussions) with other projects:

  A.1$\rightarrow$ $\pi\pi/K\bar{K}$ FSI

  A.5 $\rightarrow$ three-body unitarity and the pion mass dependence

  B.7 $\rightarrow$ employ the knowledge of nuclear physics

  B.2 $\rightarrow$ compare with the results in the tetraquark scenario

  ...

Publications

- ⋆ I. K. Hammer, C. Hanhart and A. V. Nefediev, "Remarks on meson loop effects on quark models," Eur. Phys. J. A **52**, no. 11, 330 (2016), [arXiv:1607.06971 [hep-ph]].
- ⋆ M. L. Du, U.-G. Meißner and Q. Wang, "P-wave coupled channel effects in electron-positron annihilation," Phys. Rev. D **94**, no. 9, 096006 (2016), [arXiv:1608.02537 [hep-ph]].
- ⋆ Z. Cao, M. Cleven, Q. Wang and Q. Zhao, "Open charm contributions to the E1 transitions of $\psi(3686)$ and $\psi(3770) \to \gamma\chi_{cJ}$," Eur. Phys. J. C **76**, no. 11, 601 (2016), [arXiv:1608.07947 [hep-ph]].
- ⋆ Z. Yang, Q. Wang and U.-G. Meißner, "Where does the X(5568) structure come from?," Phys. Lett. B **767**, 470 (2017), [arXiv:1609.08807 [hep-ph]].
- ⋆ V. Baru, C. Hanhart and A. V. Nefediev, "Can X(3915) be the tensor partner of the X(3872)?," JHEP **1706**, 010 (2017), [arXiv:1703.01230 [hep-ph]].
- ⋆ X. H. Liu and U.-G. Meißner, "Generating a resonance-like structure in the reaction $B_c \to B_s\pi\pi$," arXiv:1703.09043 [hep-ph] (submitted for publication).
- ⋆ V. Baru, E. Epelbaum, A. A. Filin, C. Hanhart and A. V. Nefediev, "Spin partners of the Z_b (10610) and Z_b (10650) revisited," JHEP **1706**, 158 (2017), [arXiv:1704.07332 [hep-ph]].
- ⋆ F. K. Guo, C. Hanhart, U.-G. Meißner, Q. Wang, Q. Zhao and B. S. Zou, "Hadronic molecules," arXiv:1705.00141 [hep-ph], review for Review Modern Physics.
- ⋆ Z. Yang, Q. Wang and U.-G. Meißner, "Isospin analysis of $B \to D^*\bar{D}K$ and the absence of the $Z_c(3900)$ in B decays," arXiv:1706.00960 [hep-ph] (submitted for publication).

Thank you very much for your attention!