The $B^{(*)}\bar{K}^{(*)}$ coupled-channel system in the hidden-gauge approach

J. Sánchez-Illana, R. Molina, P.-P. Shi, Physics Letters B 881 (2026) 140888.

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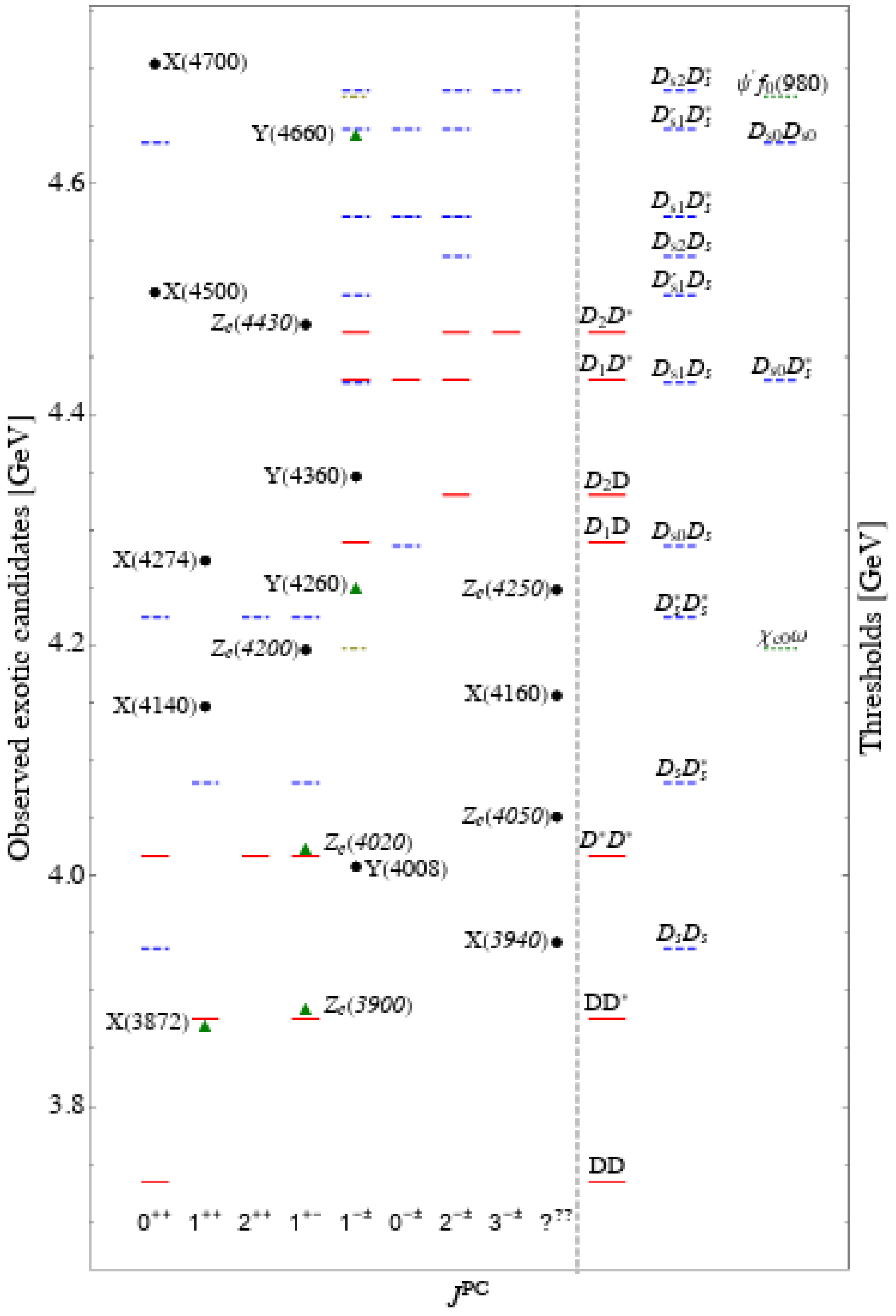
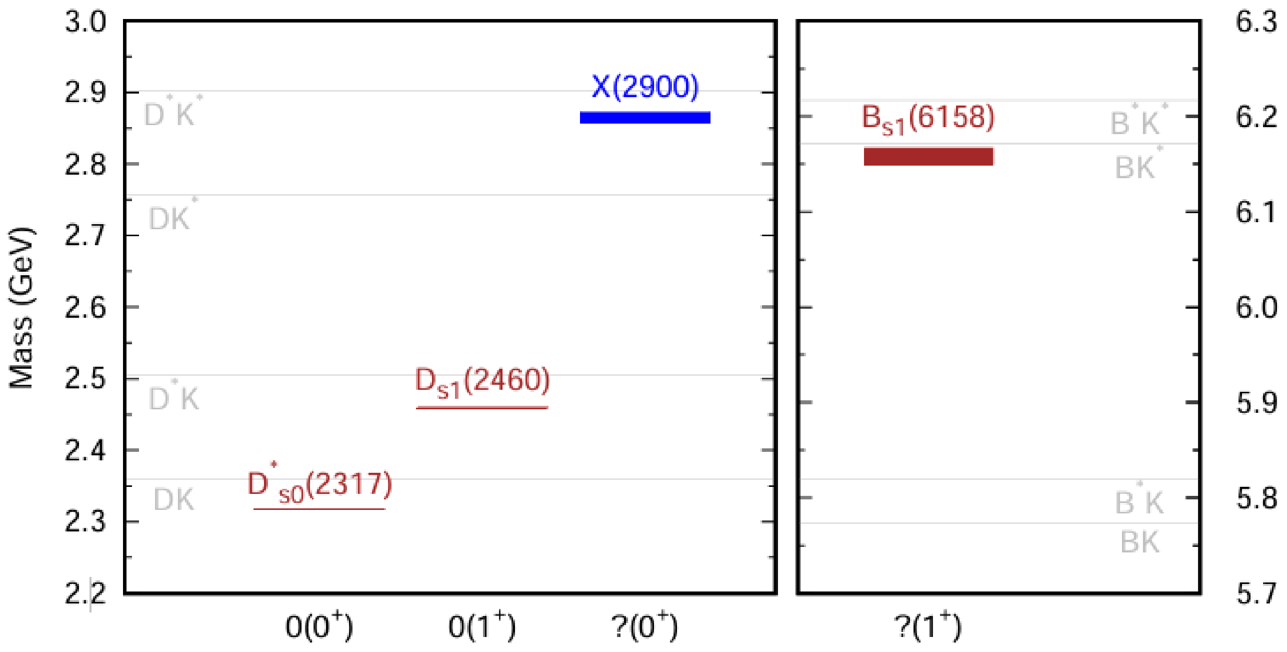
Clues in the charm sector





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Lots of data

Little data

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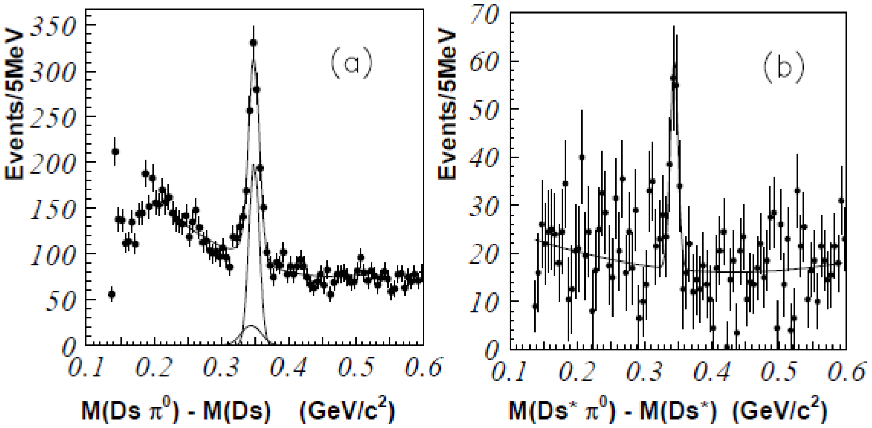
Clues in the charm sector



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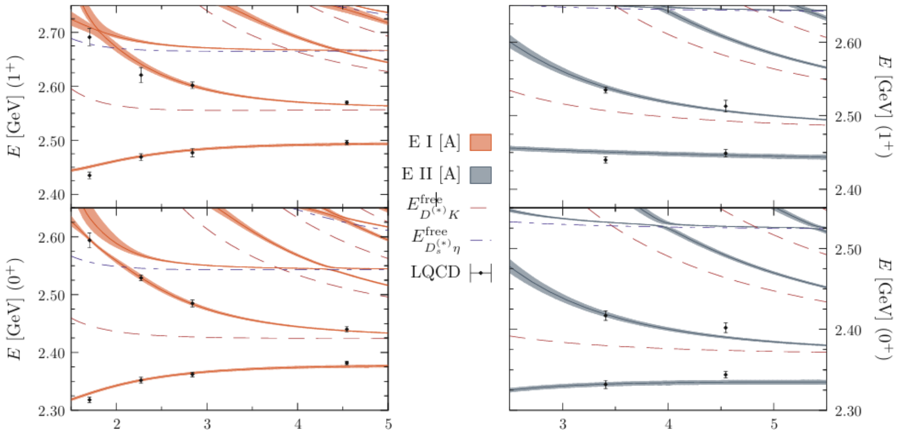


M. Albaladejo, P. Fernandez-Soler, J. Nieves, and P. G. Ortega, Eur. Phys. J. C 78, 722 (2018).

A. Martínez Torres, E. Oset, S. Prelovsek, and A. Ramos, Reanalysis of lattice QCD spectra leading to the D∗ s0(2317) and D∗ s1(2460), JHEP 05, 153, arXiv:1412.1706 [hep-lat].

$D_{s0}(2317), D_{s1}(2460)$

- $c\bar{s}$ state
- **Molecular DK, D*K state**
- Compact tetraquark
- Mixed state

- $D_{s0}(2317) \sim 72\% \pm 18\%$ molecular component.
- $D_{s1}(2460) \sim 57\% \pm 27\%$ molecular component.

Clues in the charm sector

Charm-Strange Sector

Molecular
$D_{s0}(2317), D_{s1}(2460)$

$c \leftrightarrow b$

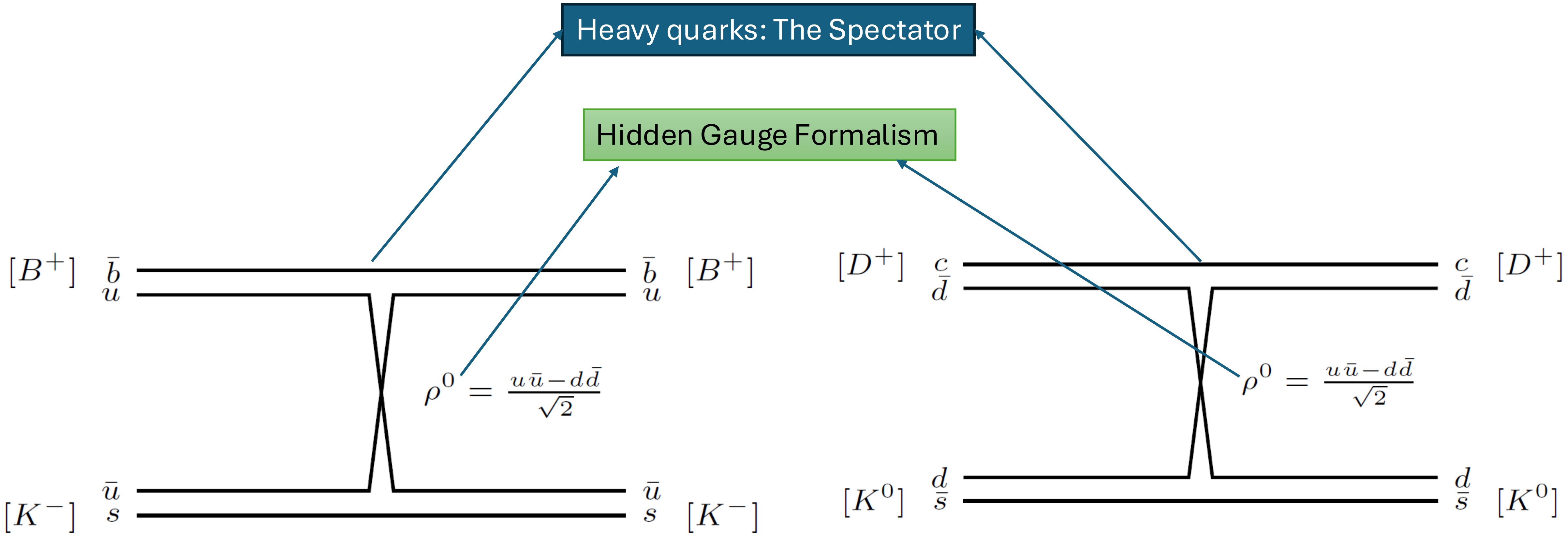
Heavy Flavour Symmetry

Bottom-Strange Sector

Molecular
B_{s0}, B_{s1} states

WHAT EFT's HAVE TO SAY ABOUT THIS?

Formalism



Heavy quarks: The Spectator
Hidden Gauge Formalism
$[B^+]$ $\bar{b}$ u
$\bar{b}$ u $[B^+]$
$\rho^0 = \frac{u\bar{u} - d\bar{d}}{\sqrt{2}}$
$[K^-]$ $\bar{u}$ s
$\bar{u}$ s $[K^-]$
$[D^+]$ c $\bar{d}$
c $\bar{d}$ $[D^+]$
$\rho^0 = \frac{u\bar{u} - d\bar{d}}{\sqrt{2}}$
$[K^0]$ d $\bar{s}$
d $\bar{s}$ $[K^0]$

Formalism

- We have

$$\mathcal{L}_{VVV} = ig\langle (V^\nu \partial_\mu V_\nu - \partial_\mu V^\nu V_\nu) V^\mu \rangle,$$

$$\mathcal{L}_{VPP} = -ig\langle [P, \partial_\mu P] V^\mu \rangle.$$

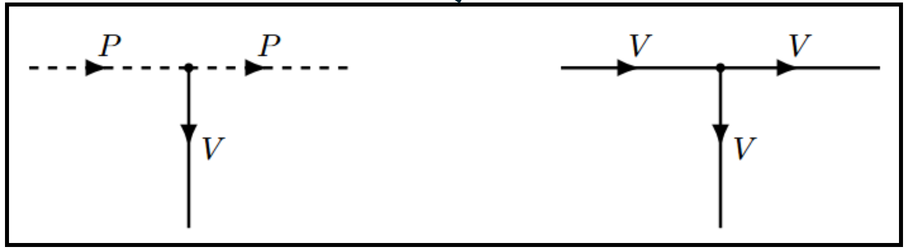
where

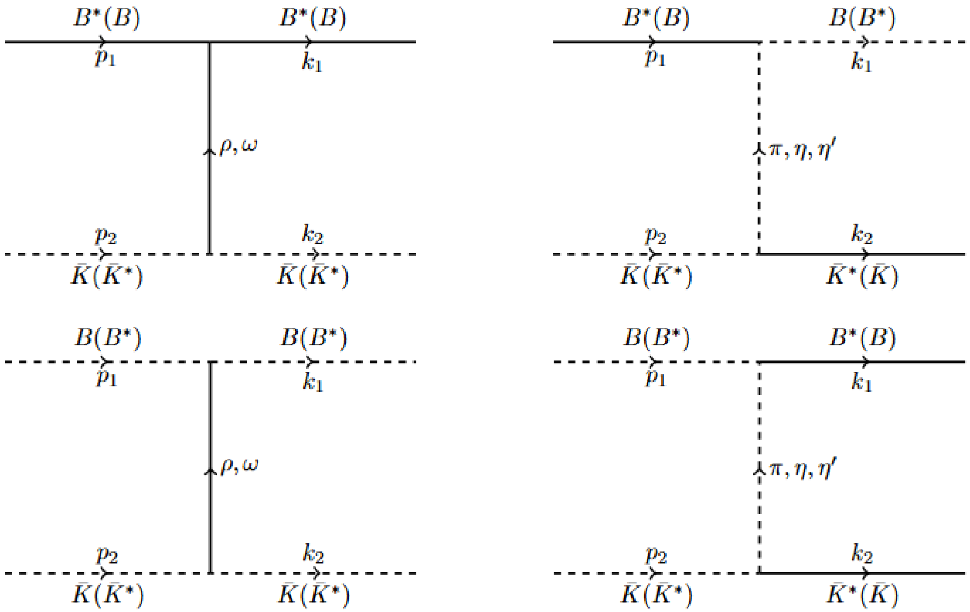
$$g = \frac{M_V}{2f}, \qquad g_{B^*BP} = 8.33.$$

F. Gil-Domínguez, A. Giachino y R. Molina, Physical Review D 111, 016029, 2025.

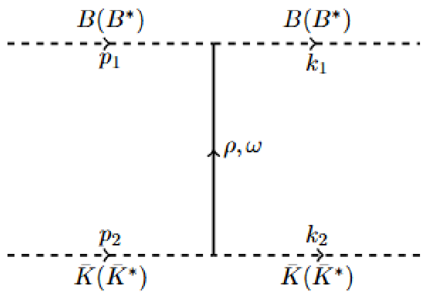
$$P = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} & \pi^+ & K^+ & B^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} & K^0 & B^0 \\ K^- & \bar{K}^0 & -\frac{\eta}{\sqrt{3}} + \sqrt{\frac{2}{3}}\eta' & B_s^0 \\ B^- & \bar{B}^0 & \bar{B}_s^0 & \eta_b \end{pmatrix}$$

$$V_\mu = \begin{pmatrix} \frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & \rho^+ & K^{*+} & B^{*+} \\ \rho^- & -\frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & K^{*0} & B^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi & B_s^{*0} \\ B^{*-} & \bar{B}^{*0} & \bar{B}_s^{*0} & \Upsilon \end{pmatrix}_\mu$$



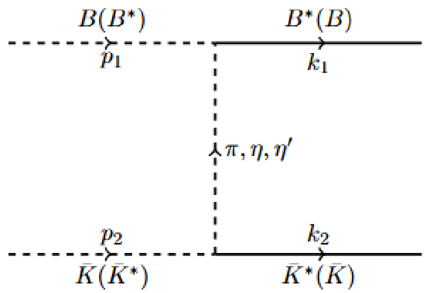


Formalism



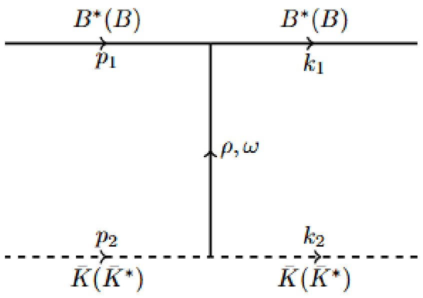
$$\frac{g^2}{2}\left(3D_{su}(m_\rho) + D_{su}(m_\omega)\right)$$

$$\frac{g^2}{2}\left(3D_{su}(m_\rho) + D_{su}(m_\omega)\right) \varepsilon(p_1)\cdot\varepsilon^*(k_1)\, \varepsilon(p_2)\cdot\varepsilon^*(k_2)$$



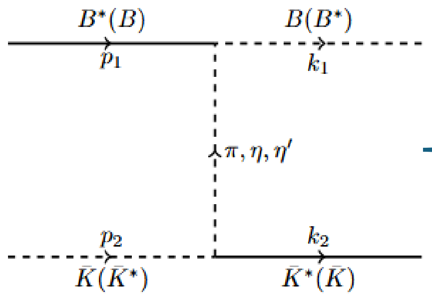
$$\frac{2g^2}{3}\left(-4D_t(m_\eta) + D_t(m_{\eta'}) - 9D_\pi\right) p_1\cdot\varepsilon^*(k_1)\, p_2\cdot\varepsilon^*(k_2)$$

$$\frac{2g^2}{3}\left(-4D_t(m_\eta) + D_t(m_{\eta'}) - 9D_\pi\right) k_1\cdot\varepsilon(p_1)\, k_2\cdot\varepsilon(p_2)$$



$$-\frac{g^2}{2}\left(3D_{su}(m_\rho) + D_{su}(m_\omega)\right) \varepsilon(p_1)\cdot\varepsilon^*(k_1)$$

$$-\frac{g^2}{2}\left(3D_{su}(m_\rho) + D_{su}(m_\omega)\right) \varepsilon(p_2)\cdot\varepsilon^*(k_2)$$



$$\frac{2g^2}{3}\left(-4D_t(m_\eta) + D_t(m_{\eta'}) - 9D_\pi\right) k_1\cdot\varepsilon(p_1)\, p_2\cdot\varepsilon^*(k_2)$$

$$\frac{2g^2}{3}\left(-4D_t(m_\eta) + D_t(m_{\eta'}) - 9D_\pi\right) k_2\cdot\varepsilon(p_2)\, p_1\cdot\varepsilon^*(k_1)$$

$$D_{su}(m) = \frac{s-u}{t-m^2}, \qquad D_t(m) = \frac{1}{t-m^2},$$

$$D_\pi = \frac{1}{2E_\pi}\left[\frac{1}{\sqrt{s} - E_{p_2} - E_{k_1} - E_\pi + i\varepsilon} + \frac{1}{\sqrt{s} - E_{p_1} - E_{k_2} - E_\pi + i\varepsilon}\right].$$

Formalism

TABLE I. Interaction for the different coupled-channel systems considered contributing to the quantum numbers J^P.

Channel (J^P)	Potential
$B\bar{K} - B^*\bar{K}^*$ $(0^+, 2^+)$	$V_{11} = \frac{g^2}{2}\left(3D_{su}(m_\rho) + D_{su}(m_\omega)\right)$ $V_{12} = \frac{2g^2}{3}\left(-4D_t(m_\eta) + D_t(m_{\eta'}) - 9D_\pi\right) p_1\cdot\varepsilon^*(k_1)\, p_2\cdot\varepsilon^*(k_2)$ $V_{21} = \frac{2g^2}{3}\left(-4D_t(m_\eta) + D_t(m_{\eta'}) - 9D_\pi\right) k_1\cdot\varepsilon(p_1)\, k_2\cdot\varepsilon(p_2)$ $V_{22} = \frac{g^2}{2}\left(3D_{su}(m_\rho) + D_{su}(m_\omega)\right) \varepsilon(p_1)\cdot\varepsilon^*(k_1)\, \varepsilon(p_2)\cdot\varepsilon^*(k_2)$
$B^*\bar{K} - B\bar{K}^*$ (1^+)	$V_{11} = -\frac{g^2}{2}\left(3D_{su}(m_\rho) + D_{su}(m_\omega)\right) \varepsilon(p_1)\cdot\varepsilon^*(k_1)$ $V_{12} = \frac{2g^2}{3}\left(-4D_t(m_\eta) + D_t(m_{\eta'}) - 9D_\pi\right) k_1\cdot\varepsilon(p_1)\, p_2\cdot\varepsilon^*(k_2)$ $V_{21} = \frac{2g^2}{3}\left(-4D_t(m_\eta) + D_t(m_{\eta'}) - 9D_\pi\right) k_2\cdot\varepsilon(p_2)\, p_1\cdot\varepsilon^*(k_1)$ $V_{22} = -\frac{g^2}{2}\left(3D_{su}(m_\rho) + D_{su}(m_\omega)\right) \varepsilon(p_2)\cdot\varepsilon^*(k_2)$
$B^*\bar{K}^*$ (1^+)	$\frac{g^2}{2}\left(3D_{su}(m_\rho) + D_{su}(m_\omega)\right) \varepsilon(p_1)\cdot\varepsilon^*(k_1)\, \varepsilon(p_2)\cdot\varepsilon^*(k_2)$

Formalism

Lippmann-Schwinger equation:

$$T_{ij}(E,p,k) = V_{ij}(E,p,k) + \sum_k \int_\Lambda \frac{d^3\,\vec{q}}{(2\pi)^3} V_{ik}(E,p,q) I_k(E,q) T_{kj}(E,q,k)\,,$$

where

$$I_k(E,q) = \frac{\omega_1(q)+\omega_2(q)}{2\omega_1\omega_2}\cdot\frac{1}{E^2-\left(\omega_1(q)+\omega_2(q)\right)^2+i\epsilon},\ I(E,q) = \frac{1}{4\omega_{\bar{K}^*}\omega_{B^{(*)}}}\cdot\frac{1}{P^0-\omega_{\bar{K}^*}-\omega_{B^{(*)}}+i\frac{\Gamma}{2}}\,.$$

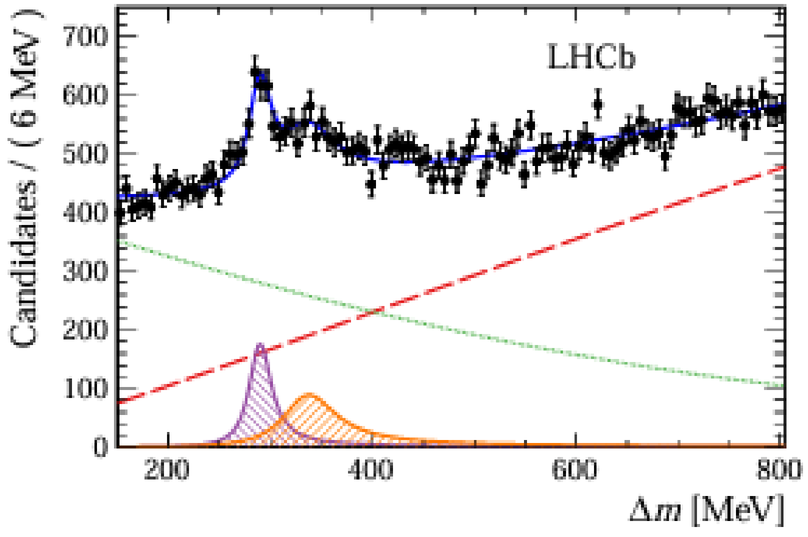
Three-body cut

$$\boldsymbol{T} = \frac{\boldsymbol{V}}{I-\boldsymbol{VG}}$$

$$\det(I-\boldsymbol{VG}) = 0$$

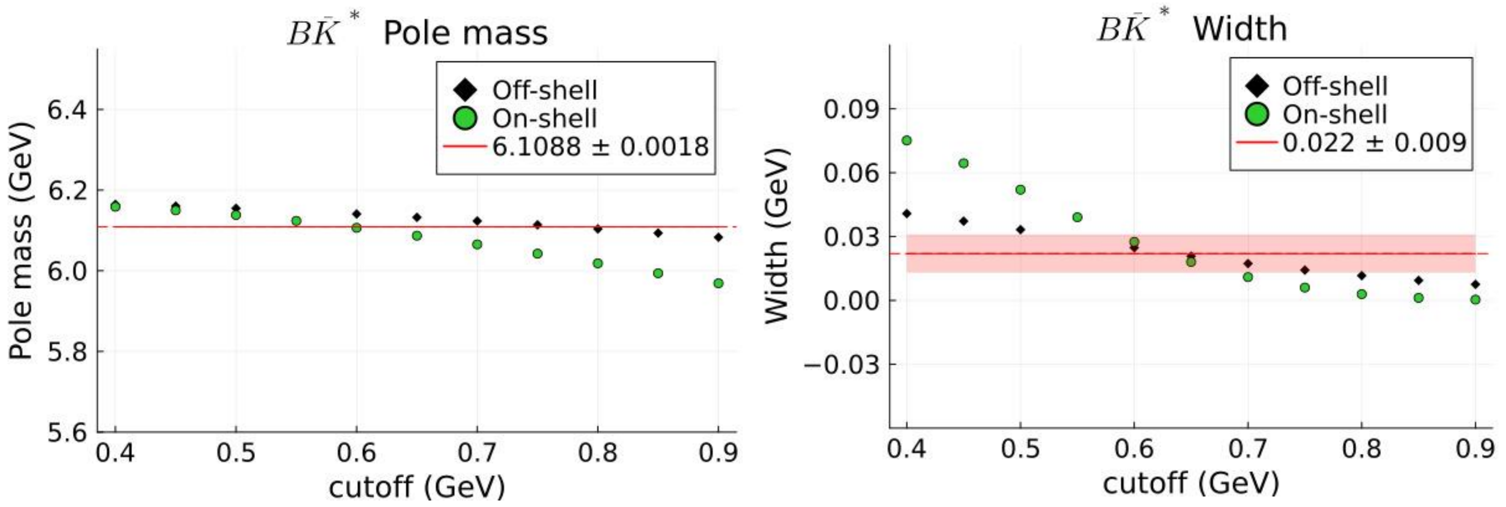
- Bound state.
- Virtual state.
- Resonance.

Results



R. Aaij et al. (LHCb),Eur. Phys. J. C 81, 601 (2021), arXiv:2010.15931 [hep-ex]

If decays in $B^{*+}K^{-}$,
$m_1 = (6108.8 \pm 1.8)$ MeV,
$\Gamma_1 = (22 \pm 9)$ MeV,
$m_2 = (6158 \pm 9)$ MeV,
$\Gamma_2 = (72 \pm 43)$ MeV.



OFF-SHELL $\xrightarrow{\chi^2/_{d.o.f} = 1.15}$ $\Lambda = 775$ MeV

ON-SHELL $\xrightarrow{\chi^2/_{d.o.f} = 0.72}$ $\Lambda = 593$ MeV

Results

$m_1 = (6108.8 \pm 1.8)$ MeV,
$\Gamma_1 = (22 \pm 9)$ MeV.

TABLE II. Predicted pole positions of the $B^{(*)}\bar{K}^{(*)}$ systems with the on-shell potentials. In the fourth column, "+" and "−" indicate that the poles lie on the physical and unphysical RS relative to the corresponding two-body cut, respectively. For the $B^{(*)}\bar{K}^{*}$ systems, all poles lie on the second RS associated with the $B^{(*)}\bar{K}\pi$ three-body cut, which is not explicitly shown in the fourth column. The quantity g_i in the fifth column denotes the S-wave effective coupling. The sixth column, labeled "Thr.", represents the relevant threshold. The mass splitting E_b is defined as the difference between the real part of the pole position and the relevant threshold. We implement errors from $\Lambda = 593 \pm 8$ MeV.

J^P	Channel	Pole [MeV]	RS	g_i [GeV]	Thr. [MeV]	E_b [MeV]
0^+	$B\bar{K}$	5758.9 ± 1.5	$(+)$	23.0 ± 0.5	5775.0	-16.1 ± 1.5
1^+	$B^*\bar{K}$	5804.0 ± 1.5	$(+)$	23.0 ± 0.5	5820.0	-16.0 ± 1.5
1^+	$B\bar{K}^*$	$6109.0 \pm 1.4 - (7.2 \pm 0.5)i$	$(+)$	$39.5 \pm 0.5 - (2.5 \pm 0.4)i$	6173.0	-64.0 ± 1.4
$0^+/1^+/2^+$	$B^*\bar{K}^*$	$6154.1 \pm 1.5 - (7.2 \pm 0.6)i$	$(+)$	$38.8 \pm 0.4 - (2.8 \pm 0.4)i$	6218.0	-63.9 ± 1.5

TABLE III. Same as Table II, but using the off-shell interaction. The g_i in the fifth column is the S-wave effective coupling, except for the $J^P = 2^+$ case, where we also include the D-wave coupling. Since the D-wave coupling is generally too small, we do not show the numerical result in the table for other cases. The errors shown in the table are evaluated from the systematic error in the cutoff parameter, $\Lambda = 775 \pm 8$ MeV.

J^P	Channel	Pole [MeV]	RS	g_i [GeV] (wave)	Thr. [MeV]	E_b [MeV]
0^+	$B\bar{K}$–$B^*\bar{K}^*$	5752.4 ± 1.3	$(+,+)$	24.9 ± 0.4 -5.9 ± 0.3	5775.0	-22.6 ± 1.3
		$6153.8 \pm 1.5 - (6.2 \pm 0.3)i$	$(-,+)$	$0.8 \pm 0.2 + (1.1 \pm 0.3)i$ $-45.1 \pm 0.6 + (2.4 \pm 0.4)i$	6218.0	-64.2 ± 1.5
1^+	$B^*\bar{K}$–$B\bar{K}^*$	5800.0 ± 0.8	$(+,+)$	25.1 ± 0.4 -4.8 ± 0.3	5820.0	-20.0 ± 0.8
		$6108.0 \pm 1.6 - (10.3 \pm 0.4)i$	$(-,+)$	$0.53 \pm 0.12 + (1.2 \pm 0.3)i$ $-52.5 \pm 0.6 + (1.5 \pm 0.3)i$	6173.0	-65.0 ± 1.6
1^+	$B^*\bar{K}^*$	$6155.7 \pm 1.7 - (6.4 \pm 0.4)i$	$(+)$	$45.1 \pm 0.5 - (2.2 \pm 0.2)i$	6218.0	-62.3 ± 1.7
2^+	$B\bar{K}$–$B^*\bar{K}^*$	$6154.0 \pm 1.4 - (6.2 \pm 0.3)i$	$(-,+)$	$[69 \pm 4 + (2.3 \pm 0.3)i] \times 10^{-3}$ $-45.1 \pm 0.6 + (2.4 \pm 0.4)i$	6218.0	-64.0 ± 1.4

$m_2 = (6158 \pm 9)$ MeV,
$\Gamma_2 = (72 \pm 43)$ MeV.

Outlook

To be included in a future global fit.

New experimental constraint → $\boxed{B_{s0}^*(5700)}$ $M_{B_{s0}^*} = 5698.9 \pm 2.2$ MeV

On-shell single channel results using the $B_{s0}^*(5700)$ as input. We implement errors from $\Lambda = 874 \pm 8$ MeV.

J^P	Channel	Pole [MeV]	RS	Thr. [MeV]	E_b [MeV]
0^+	$B\bar{K}$	5698.9 ± 1.5	$(+)$	5775.0	-76.1 ± 1.5
1^+	$B^*\bar{K}$	5744.0 ± 1.5	$(+)$	5820.0	-76.0 ± 1.5
1^+	$B\bar{K}^*$	$5981.9 \pm 1.4 - (0.17 \pm 0.05)i$	$(+)$	6173.0	-191.1 ± 1.4
$0^+/1^+/2^+$	$B^*\bar{K}^*$	$6026.9 \pm 1.5 - (0.17 \pm 0.06)i$	$(+)$	6218.0	-191.1 ± 1.5

Decay width: $B_{s0}^* \to B_s \pi^0$ → $\boxed{\Gamma(B_{s0}^*) = 50 \pm 12 \text{ KeV}}$

Preliminary estimate

F.Gil-Domínguez and R. Molina, Phys. Rev. D 109, 096002 (2024)

Conclusions

Using HGF, taking into account the three-body effect when $\bar{K}^*$ is envolved, we have solved the LS equation in the on-shell and off-shell approach.

The cutoff is determined by reproducing the pole position of $B_{sJ}(6063)^0$, interpreting it as a $B\bar{K}^*$ molecule.

Our results support the existence of six $B^{(*)}\bar{K}^{(*)}$ molecules:

1. Two poles near $B\bar{K}$ and $B^*\bar{K}$ thresholds.
2. A pole close to the $B\bar{K}^*$. Possibly corresponds to $B_{sJ}(6063)^0$.
3. Three poles in the $B^*\bar{K}^*$ system with $J^P = 0^+, 1^+, 2^+$. The $J^P = 1^+$ molecule may be related to the $B_{sJ}(6114)^0$ state.

THANK YOU FOR YOUR ATTENTION

SS wave expansión for $B^*\overline{K}^*$

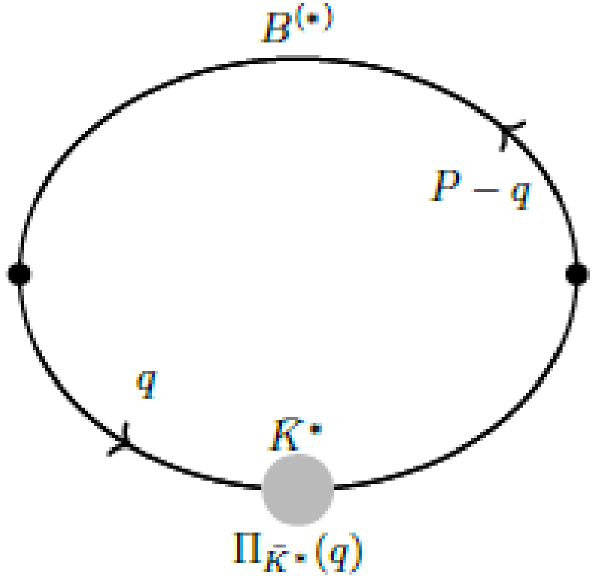
$$V_0(p,k) = \int_{-1}^{1} dz\ D(s,t,u)\left[\frac{1}{2} - \frac{pkz}{6m_{p_1}m_{k_1}} - \frac{pkz}{6m_{p_2}m_{k_2}} + \frac{p^2k^2}{6m_{p_1}m_{k_1}m_{p_2}m_{k_2}}\right],$$

$$V_1(p,k) = \int_{-1}^{1} dz\ D(s,t,u)\left[\frac{1}{2} - \frac{pkz}{6m_{p_1}m_{k_1}} - \frac{pkz}{6m_{p_2}m_{k_2}}\right],$$

$$V_2(p,k) = \int_{-1}^{1} dz\ D(s,t,u)\left[\frac{1}{2} - \frac{pkz}{6m_{p_1}m_{k_1}} - \frac{pkz}{6m_{p_2}m_{k_2}} + \frac{p^2k^2}{30m_{p_1}m_{k_1}m_{p_2}m_{k_2}}(3z^2-1)\right],$$

Loop

$$G(P^0) \approx \int \frac{d^4p}{(2\pi)^4} \frac{1}{4\omega_{\bar{K}^*}\omega_{B^{(*)}}} \cdot \frac{1}{q^0 - \omega_{\bar{K}^*} + i\frac{\Gamma}{2}} \cdot \frac{1}{P^0 - q^0 - \omega_{B^{(*)}} + i\varepsilon}.$$



We integrate the q^0 component,

$$G(P^0) = \int \frac{dq}{8\pi^2 \omega_{\bar{K}^*}\omega_{B^{(*)}}} \cdot \frac{\vec{q}^2}{P^0 - \omega_{\bar{K}^*} - \omega_{B^{(*)}} + i\frac{\Gamma}{2}}.$$

Riemann Sheets

The on-shell momentum p_k^{on} is determined by the zeros of the denominator of the Green's function.

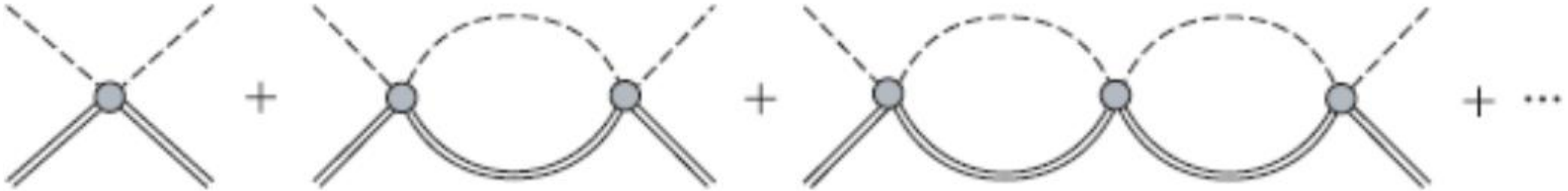
$$G_k^{on,-}(E) = G_k^{on,+}(E) + \frac{ip_k^{on}}{4\pi E},$$
$$G_k^{on,+}(E) = \int \frac{d^3q}{(2\pi)^3} I_k(E,q).$$

Considering the second RS of the $B^{(*)}K\pi$ three-body cut, the momentum-dependent partial width can be replaced by

$$\Gamma_i(M) \to -\Gamma_i(M) \text{ for } \Im(M) < 0.$$

Lippmann-Schwinger unitarization

$$T = V + V\,G\,V + V\,G^2\,V + \ldots = V + V\,G$$



Nagahiro H. et al., "Hidden gauge formalism for the radiative decays of axial-vector mesons", Phys. Rev. D 79, 014015(2009); arXiv:0809.0943[hep-ph].