The Ξ_c and Ξ_b excited states generated from meson–baryons interaction in coupled channels

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CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
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INTRODUCTION

- Recently detected Resonanes:

$$\Xi_c(2930)(J=?^?)$$

Y.B.Li et al.[Belle],Eur.Phys.J.C78,252(2018)

$$\Xi_b(6227)(J=?^?)$$

R. Aaij et al.[LHCb], Phys. Rev. Lett.121, 072002 (2018)

INTRODUCTION

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$\Xi_c(2930)(J=?^?)$ $\Xi_b(6227)(J=?^?)$

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- Many other resonances:

$\Xi_c(2790)(J=1/2^-)$ $\Xi_c(2815)(J=3/2^-)$ $\Xi_c(2970)(J=?^?)$ $\Xi_c(3055)(J=?^?)$

$\Xi_c(3080)(J=?^?)$ $\Xi_c(3123)(J=?^?)$

FORMALISM

$$J^P = 1/2^-$$

$\Xi_c\pi$	$\Xi'_c\pi$	$\Lambda_c\bar{K}$	$\Sigma_c\bar{K}$	ΛD	$\Xi_c\eta$	ΣD	$\Xi'_c\eta$	$\Omega_c K$	ΞD_s
2607	2716	2782	2949	2983	3017	3060	3126	3191	3287

$$J^P = 1/2^-,\ 3/2^-$$

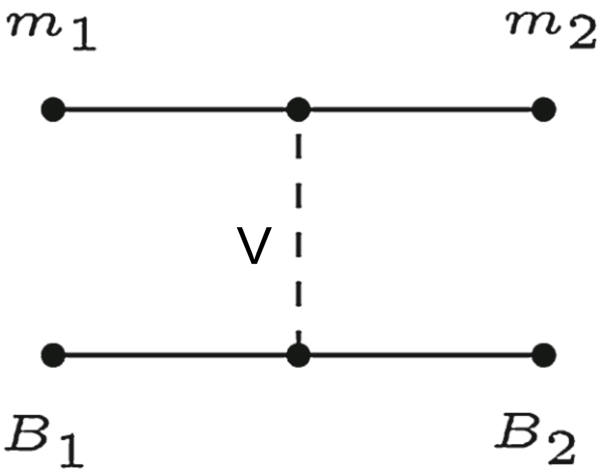
ΛD^*	$\Lambda_c\bar{K}^*$	ΣD^*	$\Xi_c\rho$	$\Xi_c\omega$	$\Sigma_c\bar{K}^*$
3124	3182	3202	3245	3252	3349

$$J^P = 3/2^-$$

$\Xi^*_c\pi$	$\Sigma^*_c\bar{K}$	$\Xi^*_c\eta$	$\Sigma^* D$	$\Omega^*_c K$
2784	3014	3194	3252	3262

FORMALISM

$J^P = 1/2^-$



FORMALISM

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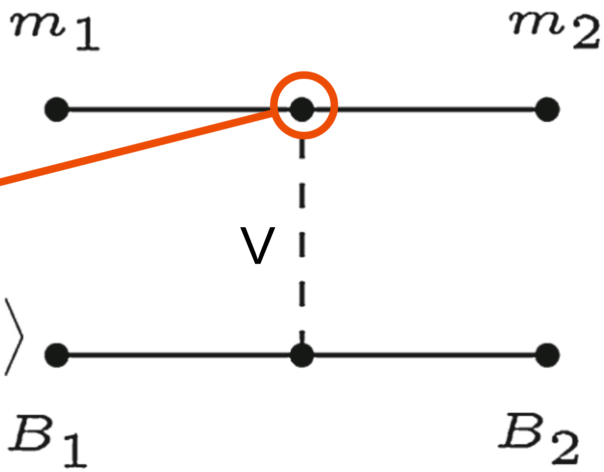
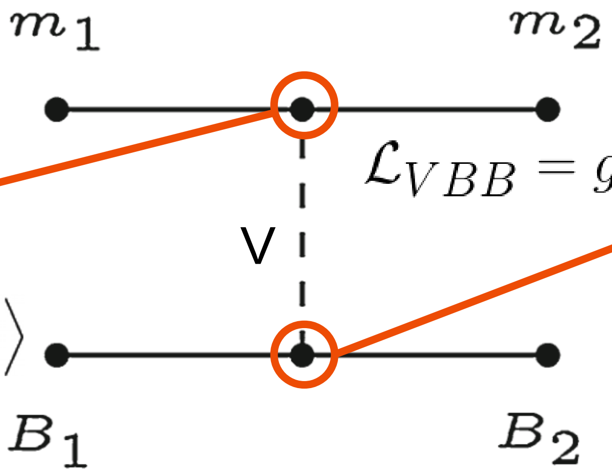


$$\mathcal{L}_{VPP} = -ig\left\langle [\phi, \partial_\mu \phi]\, V^\mu \right\rangle$$

FORMALISM

$$J^P = 1/2^-$$

$$\mathcal{L}_{VBB} = g\left(\bar{B}\gamma_\mu\left[V^\mu, B\right] + \left\langle \bar{B}\gamma_\mu B\right\rangle \left\langle V^\mu \right\rangle\right)$$



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Phys.Rev.D97, 094035 (2018)
Phys.Rev.D98, 094017 (2018)

$$\mathcal{L}_{VB_fB_i} = g\langle B_f|V_{ql}|B_i\rangle$$

$$|B\rangle = |\phi_{\text{flavor}}\rangle \otimes |\chi_{\text{spin}}\rangle$$

$$|\Xi_c^+\rangle = \frac{1}{\sqrt{2}}|c(us - su)\rangle \otimes |\chi_{\text{MA}}\rangle$$

$$\rho^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$$

$$\omega = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})$$

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.

$$\mathcal{L}_{VBB} = g\left(\bar{B}\gamma_\mu\left[V^\mu, B\right] + \left\langle \bar{B}\gamma_\mu B\right\rangle \left\langle V^\mu \right\rangle\right)$$

Phys.Rev.D97, 094035 (2018)
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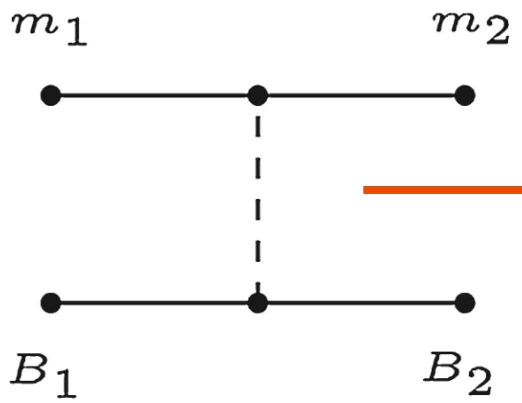
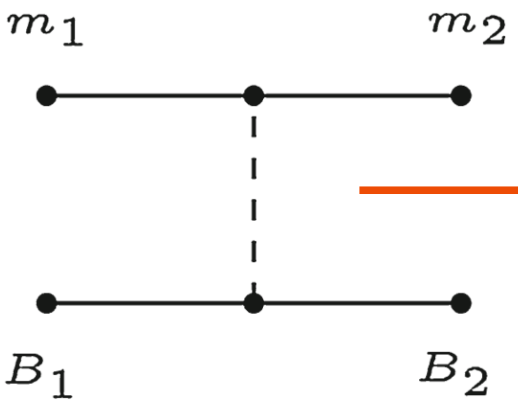


$$V_{ij} = D_{ij}\frac{2\sqrt{s} - M_i - M_j}{4f_\pi^2}\sqrt{\frac{E_i + M_i}{2M_i}}\sqrt{\frac{E_j + M_j}{2M_j}}$$

$$T_{ij} = [1 - VG]^{-1}_{ik} V_{kj}$$

Sharp Cutoff



$$V_{ij} = \boxed{D_{ij}} \frac{2\sqrt{s} - M_i - M_j}{4 f_\pi^2} \sqrt{\frac{E_i + M_i}{2M_i}} \sqrt{\frac{E_j + M_j}{2M_j}}$$

$$T_{ij} = [1 - VG]^{-1}_{ik} V_{kj}$$

Sharp Cutoff

$J_{baryon}=1/2$	$\Xi_c\pi$	$\Xi'_c\pi$	$\Lambda_c\bar{K}$	$\Sigma_c\bar{K}$	ΛD	$\Xi_c\eta$	ΣD	$\Xi'_c\eta$	$\Omega_c K$	ΞD_s
$\Xi_c\pi$	-2	0	$-\sqrt{\frac{3}{2}}$	0	$\frac{1}{2\sqrt{2}}\lambda$	0	$-\frac{1}{2\sqrt{2}}\lambda$	0	0	0
$\Xi'_c\pi$		-2	0	$-\frac{1}{\sqrt{2}}$	$-\frac{3}{2\sqrt{6}}\lambda$	0	$-\frac{1}{2\sqrt{6}}\lambda$	0	$-\sqrt{3}$	0
$\Lambda_c\bar{K}$			-1	0	$-\frac{1}{\sqrt{3}}\lambda$	$\frac{2}{\sqrt{3}}$	0	0	0	0
$\Sigma_c\bar{K}$				-3	0	0	$-\frac{1}{\sqrt{3}}\lambda$	-2	0	0
ΛD					-1	$-\frac{1}{6}\lambda$	0	$\frac{1}{2\sqrt{3}}\lambda$	0	$-\frac{\sqrt{6}}{2}$
$\Xi_c\eta$						0	$-\frac{1}{2}\lambda$	0	0	$\frac{1}{\sqrt{6}}\lambda$
ΣD							-3	$-\frac{1}{2\sqrt{3}}\lambda$	0	$-\sqrt{\frac{3}{2}}$
$\Xi'_c\eta$								0	$-\frac{2\sqrt{6}}{3}$	$-\frac{1}{3\sqrt{2}}\lambda$
$\Omega_c K$									-2	$-\frac{1}{\sqrt{3}}\lambda$
ΞD_s										-2

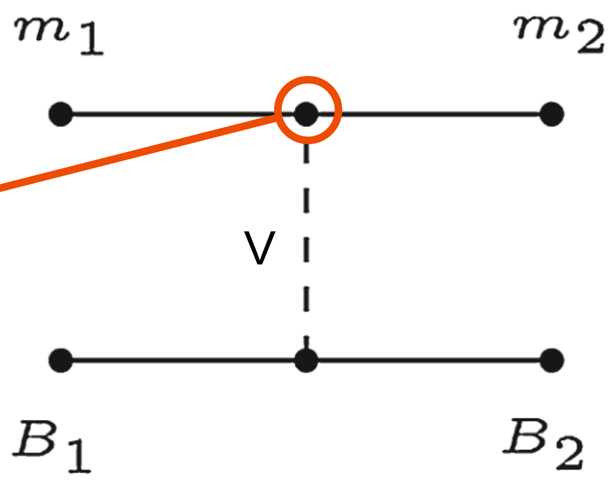
$J_{baryon}=1/2$	$\Xi_c\pi$	$\Xi'_c\pi$	$\Lambda_c\bar{K}$	$\Sigma_c\bar{K}$	ΛD	$\Xi_c\eta$	ΣD	$\Xi'_c\eta$	$\Omega_c K$	ΞD_s
$\Xi_c\pi$	-2	0	$-\sqrt{\frac{3}{2}}$	0	$\boxed{\frac{1}{2\sqrt{2}}\lambda}$	0	$\boxed{-\frac{1}{2\sqrt{2}}\lambda}$	0	0	0
$\Xi'_c\pi$		-2	0	$-\frac{1}{\sqrt{2}}$	$\boxed{-\frac{3}{2\sqrt{6}}\lambda}$	0	$\boxed{-\frac{1}{2\sqrt{6}}\lambda}$	0	$-\sqrt{3}$	0
$\Lambda_c\bar{K}$			-1	0	$\boxed{-\frac{1}{\sqrt{3}}\lambda}$	$\frac{2}{\sqrt{3}}$	0	0	0	0
$\Sigma_c\bar{K}$				-3	0	0	$\boxed{-\frac{1}{\sqrt{3}}\lambda}$	-2	0	0
ΛD					-1	$\boxed{-\frac{1}{6}\lambda}$	0	$\boxed{\frac{1}{2\sqrt{3}}\lambda}$	0	$-\frac{\sqrt{6}}{2}$
$\Xi_c\eta$						0	$\boxed{-\frac{1}{2}\lambda}$	0	0	$\boxed{\frac{1}{\sqrt{6}}\lambda}$
ΣD							-3	$\boxed{-\frac{1}{2\sqrt{3}}\lambda}$	0	$-\sqrt{\frac{3}{2}}$
$\Xi'_c\eta$								0	$-\frac{2\sqrt{6}}{3}$	$\boxed{-\frac{1}{3\sqrt{2}}\lambda}$
$\Omega_c K$									-2	$\boxed{-\frac{1}{\sqrt{3}}\lambda}$
ΞD_s										-2

$$\boxed{\lambda \simeq 1/4}$$

FORMALISM

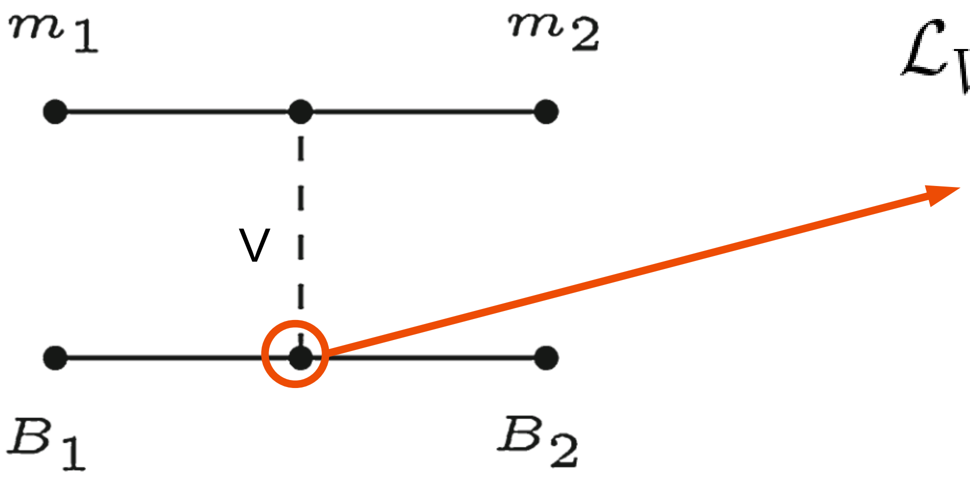
$J^P = 1/2^-,\ 3/2^-$

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



FORMALISM

$J^P = 3/2^-$



$$\mathcal{L}_{VB_f^*B_i^*} = g\langle B_f^*|V_{ql}|B_i^*\rangle$$

FORMALISM

Bottom case is the same but $\lambda \simeq 0.1$

RESULTS CHARM SECTOR

RESULTS

Poles in the $J^P = 1/2^-$ sector from pseudoscalar-baryon interaction (all units are in MeV)

q_{max}	600	650	700	750	800
	$2684.23 + i89.72$	$2679.71 + i76.48$	$2673.49 + i64.54$	$2666.24 + i54.01$	$2658.68 + i44.52$
	$2800.72 + i100.03$	$2801.80 + i86.16$	$2803.28 + i72.06$	$2803.31 + i57.77$	$2794.76 + i31.06$
	$2880.76 + i10.31$	$2842.47 + i10.13$	$\boxed{\mathbf{2791.30 + i3.63}}$	$2738.46 + i1.36$	$2685.56 + i0.89$
	$2896.57 + i1.34$	$2870.10 + i10.64$	$2850.70 + i16.38$	$2830.84 + i23.17$	$2817.77 + i40.45$
	$2969.50 + i3.30$	$2955.62 + i5.10$	$\boxed{\mathbf{2937.15 + i7.31}}$	$2913.82 + i10.03$	$2886.31 + i13.46$
	$3171.55 + i32.48$	$3160.12 + i37.77$	$3148.11 + i41.88$	$3135.67 + i44.96$	$3125.96 + i47.18$

$\boxed{\Xi_c(2790)(J = 1/2^-)}$

$\boxed{\Xi_c(2930)(J = ?^?)}$

$\Xi_c(2790)(J = 1/2^-)$ $\Gamma = 9.51 \pm 0.76\text{MeV}$

The coupling constants to various channels and $g_i G_i^{II}$ for the pole at $2191.30 + i3.63$ MeV in the $J^P = 1/2^-$ sector with $q_{max} = 700$ MeV (all units are in MeV)

$2791.30 + i3.63$	$\Xi_c \pi$	$\Xi'_c \pi$	$\Lambda_c \bar{K}$	$\Sigma_c \bar{K}$	ΛD
g_i	$-0.01 - i0.03$	$0.39 - i0.44$	$-0.09 - i0.05$	$1.05 - i0.47$	$1.91 - i0.09$
$g_i G_i^{II}$	$0.78 + i0.53$	$-3.98 + i14.85$	$2.70 + i0.73$	$-11.27 + i4.95$	$-7.45 + i0.27$
	$\Xi_c \eta$	ΣD	$\Xi'_c \eta$	$\Omega_c K$	ΞD_s
g_i	$0.23 + i0.03$	$\mathbf{8.82 + i0.38}$	$0.49 - i0.17$	$0.21 - i0.26$	$5.44 + i0.20$
$g_i G_i^{II}$	$-2.00 - i0.26$	$\mathbf{-29.16 - i1.48}$	$-3.53 + i1.19$	$-1.42 + i1.74$	$-11.96 - i0.49$

Only channel “seen”

Channel	$\Xi_c \pi$	$\Xi'_c \pi$	$\Lambda_c \bar{K}$
Γ_i	0.04	8.00	0.12

$$\Xi_c(2930)(J=?^?) \qquad \Gamma = 20.5 \pm 6\text{MeV}$$

The coupling constants to various pseudoscalar-baryon channels and $g_i G_i^{II}$ for the pole at 2937.15 MeV in the $J^P = 1/2^-$ sector with $q_{max} = 700$ MeV (all units are in MeV)

2937.15 + *i*7.31	$\Xi_c\pi$	$\Xi_c'\pi$	$\Lambda_c\bar{K}$	$\Sigma_c\bar{K}$	ΛD
g_i	$-0.29+i0.10$	$0.03-i0.32$	$0.28-i0.22$	$0.27+i0.08$	$\mathbf{3.96-i0.29}$
$g_iG_i^{II}$	$0.83-i9.44$	$6.42+i6.63$	$0.31+i10.35$	$-5.40-i1.98$	$\mathbf{-27.75+i0.73}$

	$\Xi_c\eta$	ΣD	$\Xi_c'\eta$	$\Omega_c K$	ΞD_s
g_i	$-0.07+i0.39$	$-2.44+i0.10$	$0.09+i0.04$	$-0.12-i0.26$	$3.55-i0.13$
$g_iG_i^{II}$	$1.11-i5.19$	$12.15-i0.15$	$-0.85-i0.40$	$0.98+i2.23$	$-9.83+i0.23$

Only channel “seen”

Channel	$\Xi_c \pi$	$\Xi'_c \pi$	$\Lambda_c \bar{K}$
Γ_i	5.22	4.45	5.88

The poles in the $J^P = 1/2^-, 3/2^-$ sector from the vector-baron interaction (all units are in MeV)

q_{max}	600	650	700	750	800
	3055.63	3016.46	**2973.76**	2928.28	2880.75
	3117.37	3094.39	**3068.21**	3040.89	3013.14
	3121.75	3115.67	**3109.04**	3100.55	3090.16
	3234.03+i0.22	3204.98	3174.50	3143.09	3111.43

$\boxed{\Xi_c(3080)(J=?^?)}$ $\boxed{\Xi_c(2970)(J=?^?)}$ $\boxed{\Xi_c(3055)(J=?^?)}$ $\boxed{\Xi_c(3123)(J=?^?)}$

2973.76	ΛD^*	$\Lambda_c \bar{K}^*$	ΣD^*	$\Xi_c \rho$	$\Xi_c \omega$	$\Sigma_c \bar{K}^*$
g_i	0	0.07	**9.30**	0.33	0.30	0.55
$g_i G_i^{II}$	0	−0.48	**−31.85**	−2.29	−2.02	−2.87
3068.21	ΛD^*	$\Lambda_c \bar{K}^*$	ΣD^*	$\Xi_c \rho$	$\Xi_c \omega$	$\Sigma_c \bar{K}^*$
g_i	0.37	**3.08**	−0.26	**3.57**	−0.85	−0.04
$g_i G_i^{II}$	−2.33	**−30.22**	1.20	**−30.89**	7.19	0.22
3109.04	ΛD^*	$\Lambda_c \bar{K}^*$	ΣD^*	$\Xi_c \rho$	$\Xi_c \omega$	$\Sigma_c \bar{K}^*$
g_i	**3.05**	0.05	0.03	−0.51	0.09	0.01
$g_i G_i^{II}$	**−26.23**	−0.60	−0.17	5.04	−0.81	−0.05

$\boxed{\Xi_c(2930)(J=?^?)}$ $\boxed{\Xi_c(3055)(J=?^?)}$

The poles in the $J^P = 3/2^-$ sector from the pseudoscalar-baron interaction (all units are in MeV)

q_{max}	600	650	700	750	800
	$2868.84 + i101.02$	$2869.69 + i87.71$	$2870.00 + i71.15$	$2871.12 + i55.04$	$2888.93 + i43.98$
	$2950.39 + i11.19$	$2932.11 + i15.01$	$\boxed{\mathbf{2912.78 + i19.94}}$	$2891.71 + i27.88$	$2855.31 + i26.46$
	$3099.36 + i0.55$	$3059.03 + i0.89$	$\boxed{\mathbf{3015.18 + i1.37}}$	$2968.69 + i2.98$	$2918.23 + i7.32$
	$3243.94 + i32.64$	$3233.36 + i38.32$	$3222.35 + i42.93$	$3211.05 + i46.56$	$3199.61 + i49.32$

The coupling constants to various pseudoscalar-baryon channels and $g_i G_i^{II}$ for the poles in the $J^P = 3/2^-$ sector with $q_{max} = 700$ MeV (all units are in MeV)

2912.78 + i19.94	$\Xi_c^*\pi$	$\Sigma_c^*\bar{K}$	$\Xi_c^*\eta$	Σ^*D	Ω_c^*K
g_i	$0.41 - i1.28$	$\mathbf{3.78 - i0.47}$	$1.87 - i0.12$	$-1.09 - i0.83$	$0.16 - i0.85$
$g_i G_i^{II}$	$11.65 + i36.25$	$\mathbf{-48.53 + i2.60}$	$-14.80 + i0.42$	$3.17 + i2.60$	$-1.34 + i6.20$
3015.18 + i1.37	$\Xi_c^*\pi$	$\Sigma_c^*\bar{K}$	$\Xi_c^*\eta$	Σ^*D	Ω_c^*K
g_i	$0.03 - i0.24$	$0.11 + i0.07$	$0.42 + i0.03$	$\mathbf{8.94 - i0.04}$	$-0.04 - i0.20$
$g_i G_i^{II}$	$4.82 + i5.04$	$-3.19 - i1.64$	$-4.18 - i0.34$	$\mathbf{-33.36 + i0.03}$	$0.31 + i1.72$

$\boxed{\Xi_c(2930)(J=?^?) \quad \Gamma = 20.5 \pm 6\text{MeV}}$

$\boxed{\Xi_c(3055)(J=?^?) \quad \Gamma = 7.8 \pm 1.9 \text{ MeV}}$

RESULTS BOTTOM SECTOR

The poles in the $J^P = 1/2^-$ sector from the pseudoscalar-baron interaction (all units are in MeV)

q_{max}	600	650	700	750	800
	$6002.21 + i81.90$	$5997.45 + i69.73$	$5991.25 + i58.74$	$5984.13 + i49.02$	$5976.61 + i40.29$
	$6152.19 + i91.66$	$6152.17 + i78.48$	$6152.24 + i64.42$	$6150.40 + i48.36$	$6137.15 + i27.48$
	$6237.52 + i11.30$	$\boxed{\mathbf{6220.30 + i12.60}}$	$6201.74 + i19.00$	$6183.11 + i27.85$	$6175.03 + i40.45$
	$6263.48 + i0.07$	$6205.08 + i2.94$	$6141.06 + i1.73$	$6073.96 + i0.17$	$6004.35 + i0.44$
	$6359.89 + i0.82$	$6338.97 + i1.44$	$6312.50 + i2.42$	$6280.97 + i3.77$	$6244.54 + i5.65$
	$6513.45 + i29.56$	$6501.26 + i33.87$	$6488.63 + i37.17$	$6482.88 + i39.75$	$6482.86 + i41.90$

$$\boxed{\Xi_b(6227)(J = ?^?) \qquad \Gamma = 18 \pm 6 \text{ MeV}}$$

The coupling constants to various pseudoscalar-baryon channels and $g_i G_i^{II}$ for the poles in the $J^P = 1/2^-$ sector with $q_{max} = 650$ MeV (all units are in MeV)

$6220.30 + i12.60$	$\Xi_b \pi$	$\Xi_b' \pi$	$\Lambda_b \bar{K}$	$\Sigma_b \bar{K}$	$\Lambda \bar{B}$
g_i	$0.01 + i0.02$	$0.34 - i0.91$	$0.01 - i0.01$	$\mathbf{3.53 - i0.14}$	$-1.03 + i0.61$
$g_i G_i^{II}$	$-0.60 + i0.05$	$10.08 + i25.84$	$0.42 + i0.15$	$\mathbf{-44.85 - i0.67}$	$1.47 - i0.78$
	$\Xi_b \eta$	$\Sigma \bar{B}$	$\Xi_b' \eta$	$\Omega_b K$	ΞB_s
g_i	$-0.00 + i0.04$	$-2.09 + i4.72$	$1.80 + i0.02$	$0.09 - i0.65$	$-1.93 + i2.81$
$g_i G_i^{II}$	$0.02 - i0.38$	$2.54 - i5.25$	$-13.14 - i0.55$	$-0.74 + i4.33$	$1.45 - i2.02$

$$\frac{\mathcal{B}(6220.30 \to \Lambda_b \bar{K})}{\mathcal{B}(6220.30 \to \Xi_b \pi)} = 0.5$$

$$\boxed{1 \pm 0.5}$$

R. Aaij et al.[LHCb], Phys. Rev. Lett.121, 072002 (2018)

The poles in the $J^P = 1/2^-, 3/2^-$ sector from the vector-baron interaction (all units are in MeV)

q_{max}	600	650	700	750	800
	6342.09	6295.86	6244.94	6190.01	6131.80
	6425.22	6407.58	6379.79	6351.13	6322.26
	6434.39	6417.24	6406.58	6393.82	6378.88
	$6579.47 + i0.05$	$6548.79 + i0.03$	6516.72	6484.01	6451.25

The poles in the $J^P = 3/2^-$ sector from the pseudoscalar-baron interaction (all units are in MeV)

q_{max}	600	650	700	750	800
	$6169.97 + i92.88$	$6169.85 + i80.29$	$6168.88 + i66.55$	$6166.89 + i49.80$	$6155.48 + i29.00$
	$6258.53 + i10.88$	$\boxed{\mathbf{6240.21 + i14.65}}$	$6221.49 + i19.71$	$6203.04 + i27.94$	$6193.81 + i39.67$
	$6474.16 + i0.14$	$6424.37 + i0.20$	$6369.22 + i0.34$	$6309.51 + i0.68$	$6245.85 + i2.08$
	$6538.85 + i30.15$	$6527.01 + i34.64$	$6514.86 + i38.05$	$6502.41 + i40.62$	$6500.43 + i42.56$

The coupling constants to various pseudoscalar-baryon channels and $g_i G_i^{II}$ for the poles in the $J^P = 3/2^-$ sector with $q_{max} = 650$ MeV (all units are in MeV)

6240.21 + i14.65	$\Xi_b^* \pi$	$\Sigma_b^* \bar{K}$	$\Xi_b^* \eta$	$\Sigma^* \bar{B}$	$\Omega_b^* K$
g_i	$0.23 - i0.93$	$\mathbf{3.39 - i0.36}$	$1.74 - i0.10$	$-0.78 - i0.36$	$0.03 - i0.65$
$g_i G_i^{II}$	$13.03 + i24.31$	$\mathbf{-43.16 + i1.85}$	$-12.78 + i0.27$	$0.63 + i0.30$	$-0.29 + i4.27$

$$\boxed{\Xi_b(6227)(J =?^?) \qquad \Gamma = 18 \pm 6 \text{ MeV}}$$

CONCLUSIONS

- Used the Bethe–Salpeter coupled channel formalism to study the $\Xi_{c(b)}$ states, considering three types of interactions (PB, V B and PB*)
- Calculate the couplings of the poles, the wave function and evaluate decay widths to the open channels
- Only one free parameter and cutoffs in the charm and beauty sectors
- Good agreement with some of the already observed states
- Predictions of spin and parity of these states
- Future experiments should tell us more