Baryons with bottom as meson-baryon molecular state

Author: Josep Arnau Marsé i Valera
Facultat de Física, Universitat de Barcelona, Martí i Franquès 1, 08028 Barcelona, Spain.

Advisor: Àngels Ramos Gómez

Abstract: We study the possibility that some of the four peaks recently observed in the $\Xi_b^0 K^-$ mass spectrum by the LHCb collaboration, or the other four non statistically significant peaks in the higher energy region, could correspond to states with five quarks, structured as meson-baryon molecules. These states emerge from a unitarized s-wave amplitude obtained from an appropriate effective meson-baryon Lagrangian. To confirm that some of these states are of molecular origin, more statistics would be needed in that energy region. It would also be necessary to assign the values of spin-parity, since our model predicts pseudoscalar-baryon molecules with $J^P = \frac{1}{2}^-$ or degenerate vector-baryon molecules with $J^P = \frac{1}{2}^-$ or $J^P = \frac{3}{2}^-$, while quark-models can give higher spin configurations.

I. INTRODUCTION

The recent observation of four excited Ω_b^- resonances decaying into $\Xi_b^0 K^-$ by the LHCb Collaboration [1] encouraged some groups to find a theoretical explanation of their inner structure. Some of them interpret these states as ordinary $1P$ excitations of tree quarks (Ref. [2]), while others [3] claim a possible molecular nature, which assumes that these states are composed by five quarks (4 quarks and 1 antiquark), structured in a quasi-bound state of an interacting meson-baryon pair.

The four new peaks have the following properties:

$$\begin{aligned}
\Omega_b(6316)^- : \quad & M = 6315.64 \pm 0.31 \pm 0.07 \pm 0.50 \text{ MeV}, \\
& \Gamma < 2.8 \text{ MeV}, \\
\Omega_b(6330)^- : \quad & M = 6330.30 \pm 0.28 \pm 0.07 \pm 0.50 \text{ MeV}, \\
& \Gamma < 3.1 \text{ MeV}. \\
\Omega_b(6340)^- : \quad & M = 6339.71 \pm 0.26 \pm 0.05 \pm 0.50 \text{ MeV}, \\
& \Gamma < 1.5 \text{ MeV}. \\
\Omega_b(6350)^- : \quad & M = 6349.88 \pm 0.35 \pm 0.05 \pm 0.50 \text{ MeV}, \\
& \Gamma = 1.4^{+1.0}_{-0.8} \pm 0.1 \text{ MeV}. \qquad (1)
\end{aligned}$$

However, in this work we also want to pay attention to the structures in the higher energy region, that have been seen but with low statistics at 6402, 6427, 6467 and 6495 MeV.

In the original work of Ref. [3] five theoretical peaks were obtained, none of which fitted the experimental results. The aim of this work is, firstly, to try to adjust the theoretical peaks into the higher energy structures, which is similar to what is done in Ref. [4]. Next, we will force our model to see if it is possible to reproduce the lower energy resonances listed in (1), as the two lower energy states in our model are not far in energy terms from the experimental resonances, so we think that this option shouldn't be discarded at the moment.

II. FORMALISM

The model of the meson-baryon interaction used in this work is based on the tree-level diagrams of figure 1. For the s-wave amplitude we only consider the t-channel term (Fig. 1(a)), which is the most important contribution. The s- and u- channel terms (Fig. 1(b) and (c)) contribute mostly to the p-wave amplitude. In Ref. [5] the contribution from these terms in the light sector $S = -1$, $B = 0$ were calculated, and they pointed out that the s- and u- channel contribution can reach around 20% of that of the dominant t-channel around 200 MeV above the threshold. We expect that in the heavy sector $S = -2$, $B = -1$ these terms will contribute less, as the intermediate baryon is more than five times more massive. Therefore the contribution from s- and u- channels should be around 4% in the range of 6300 − 6900 MeV, and in the present study it is neglected.

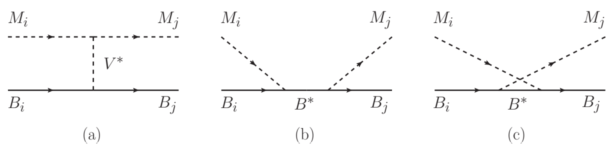

Fig. 1: Leading order tree level diagrams contributing to the meson-baryon interaction. Baryons and mesons are depicted by solid and dashed lines, respectively.

To obtain the s-wave interaction kernel V_{ij} we employ the effective Lagrangians that describe the vertex couplings of the vector meson to pseudoscalar mesons (VPP) and baryons (VBB) which are obtained using the hidden gauge formalism [6]:

$$\mathcal{L}_{VPP} = ig\langle [\partial_\mu \phi, \phi]\, V^\mu \rangle, \qquad (2)$$

$$\mathcal{L}_{VBB} = \frac{g}{2} \sum_{i,j,k,l=1}^{4} \bar{B}_{ijk} \gamma^\mu \left(V^k_{\mu,l} B^{ijl} + 2 V^j_{\mu,l} B^{ilk} \right), \quad (3)$$

where g is a coupling constant related to the pion decay constant, $f = 93$ MeV, and a representative mass of a vector meson without bottom quark, m_V:

$$g = \frac{m_V}{2f} \tag{4}$$

Using these effective Lagrangians we can obtain the s-wave interaction kernel V_{ij} as it is done in Ref. [3]:

$$V_{ij}(\sqrt{s}) = -C_{ij}\frac{1}{4f^2}\left(2\sqrt{s} - M_i - M_j\right) N_i N_j \tag{5}$$

where M_i, M_j are the masses of the baryons, N_i and N_j are the normalization factors $N_i = \sqrt{(E_i + M_i)/2M_i}$ and E_i, E_j are the energies of the baryons. To obtain the values of C_{ij} we have to take the limit $t \ll m_V$ after evaluating the diagrams using the effective Lagrangians (2) and (3).

The indices i and j refer to the different meson-baryon channel and, in the case we are studying ($I = 0$, $S = -2$, $B = -1$), we have seven possible channels for the pseudoscalar-baryon sector, which are $\bar{K}\Xi_b(6290)$, $\bar{K}\Xi_b'(6431)$, $\bar{B}\Xi(6597)$, $\eta\Omega_b(6593)$, $\eta'\Omega_b(7004)$, $\eta_b\Omega_b(15444)$ and $\bar{B}_s\Omega_{bb}(>15000)$, with their threshold masses in parenthesis. We will neglect the contribution from the two later channels with double bottom, as their mass is much larger than the other channels.

Once we know the channels of our study, we can obtain the coefficients C_{ij}, listed in Table I, where the factor κ_b corrects for the much higher mass of the exchanged vector bottom meson and it is derived from the expression:

$$\kappa_b = -\frac{m_V^2}{t - {m_V^b}^2} \simeq -\frac{m_V^2}{(m_K - m_B)^2 - m_{B_s*}^2} \sim 0.1 \tag{6}$$

	$\bar{K}\Xi_b$	$\bar{K}\Xi_b'$	$\bar{B}\Xi$	$\eta\Omega_b$	$\eta'\Omega_b$
$\bar{K}\Xi_b$	1	0	$\sqrt{\frac{3}{2}}\kappa_b$	0	0
$\bar{K}\Xi_b'$		1	$\frac{1}{\sqrt{2}}\kappa_b$	$-\sqrt{6}$	0
$\bar{B}\Xi$			2	$-\frac{1}{\sqrt{3}}\kappa_b$	$-\sqrt{\frac{2}{3}}\kappa_b$
$\eta\Omega_b$				0	0
$\eta'\Omega_b$					0

Table I: Coefficients C_{ij} of the interaction pseudoscalar meson with baryon in the $I = 0$, $S = -2$, $B = -1$ sector

The interaction of vector mesons with baryons is obtained with a similar formalism but now involving the tree-vector VVV vertices, which are obtained from:

$$\mathcal{L}_{VVV} = ig\langle [V^\mu, \partial_\nu V_\mu]\, V^\nu \rangle \tag{7}$$

The resulting interaction kernel for the VB interaction is the same as that of (5) but now adding the product of polarization vectors, $\epsilon_i \epsilon_j$.

In this case, the allowed vector meson-baryon channels are $\bar{K}^*\Xi_b(6688)$, $\bar{K}^*\Xi_b'(6829)$, $\bar{B}^*\Xi(6642)$, $\omega\Omega_b(6829)$, $\phi\Omega_b(7066)$, $\Upsilon\Omega_b(15501)$ and $B_S^*\Omega_{bb}(>15000)$, where we again will neglect the double bottomed channels, for the same reason we did in the PB sector. The coefficients C_{ij} can be obtained from those of the PB interaction in Table I doing the following changes:

$$\pi \to \rho,\ K \to K^*,\ \bar{K} \to \bar{K}^*,\ D \to D^*,\ \bar{D} \to \bar{D}^*,$$

$$\frac{1}{\sqrt{3}}\eta + \sqrt{\frac{2}{3}}\eta' \to \omega \qquad \text{and} \quad -\sqrt{\frac{2}{3}}\eta + \frac{1}{\sqrt{3}}\eta' \to \phi\ , \tag{8}$$

and they are listed in Table II.

	$\bar{K}^*\Xi_b$	$\bar{K}^*\Xi_b'$	$\bar{B}^*\Xi$	$\omega\Omega_b$	$\phi\Omega_b$
$\bar{K}^*\Xi_b$	1	0	$\sqrt{\frac{3}{2}}\kappa_b$	0	0
$\bar{K}^*\Xi_b'$		1	$\frac{1}{\sqrt{2}}\kappa_b$	$-\sqrt{2}$	2
$\bar{B}^*\Xi$			2	$-\kappa_b$	0
$\Omega\Omega_c$				0	0
$\phi\Omega_c$					0

Table II: Coefficients C_{ij} of the interaction of vector mesons with baryons in the $I = 0$, $S = -2$, $B = -1$ sector

To find the resonances, we will look for poles on the scattering amplitude T_{ij}, unitarized via the coupled channel Bethe-Salpeter equation, which implements the resummation of loop diagrams to infinite order:

$$T_{ij} = V_{ij} + V_{il}G_lV_{lj} + V_{il}G_lV_{lk}G_kV_{kj} + ... = V_{ij} + V_{il}G_lT_{lj} \tag{9}$$

where, if we factorize the V and T matrices on-shell out of the internal integral, we can obtain the following solution:

$$T = (1 - VG)^{-1}V \tag{10}$$

The loop function G_l is given by:

$$G_l = i\int \frac{d^4q}{(2\pi)^4}\frac{2M_l}{(P-q)^2 - M_l^2 + i\epsilon}\frac{1}{q^2 - m_l^2 + i\epsilon} \tag{11}$$

where M_l and m_l are the masses of the baryon and meson in the loop respectively, $P = p + k = (\sqrt{s}, 0)$ is the total four momenta in the c.m. frame, and q denotes the four momenta of the intermediate loop.

The loop function diverges logarithmically, so we must renormalize it. In order to do so we employ a *cut-off* method, which consists in changing the infinity of the integral upper limit by a proper large enough number, Λ. Doing that we can see that G_l becomes:

$$G_l^{\text{cut}} = \int_0^\Lambda \frac{d^3q}{(2\pi)^3}\frac{1}{2\omega_l(\vec{q}\,)}\frac{M_l}{E_l(\vec{q}\,)}\frac{1}{\sqrt{s} - \omega_l(\vec{q}\,) - E_l(\vec{q}\,) + i\epsilon}, \tag{12}$$

We can also use the *dimensional regularization* which leads to:

$$\begin{aligned} G_l =& \frac{2M_l}{16\pi^2}\Big\{a_l(\mu) + \ln\frac{M_l^2}{\mu^2} + \frac{m_l^2 - M_l^2 + s}{2s}\ln\frac{m_l^2}{M_l^2} + \\ &+ \frac{q_l}{\sqrt{s}}\left[\ln\left(s - (M_l^2 - m_l^2\right) + 2q_l\sqrt{s}\right) \\ &\qquad + \ln\left(s + (M_l^2 - m_l^2\right) + 2q_l\sqrt{s}) \\ &\qquad - \ln\left(-s + (M_l^2 - m_l^2\right) + 2q_l\sqrt{s}) \\ &\qquad - \ln\left(-s - (M_l^2 - m_l^2\right) + 2q_l\sqrt{s})\Big]\Big\}, \end{aligned} \tag{13}$$

and introduces a subtraction constant, $a(\mu)$, at the regularization scale μ. The value of the subtraction constant that produces the same loop function at the energy threshold than that obtained with a cut-off Λ can be obtained using the relation

$$a_l(\mu) = \frac{16\pi^2}{2M_l}\left(G_l^{\mathrm{cut}}(\Lambda) - G_l(\mu, a_l = 0)\right). \tag{14}$$

The resonances are generated as poles of the scattering amplitude T_{ij} in the so-called *second Riemann sheet*, obtained by using the loop function:

$$G_l^{\mathrm{II}}(\sqrt{s} + i\epsilon) = G_l(\sqrt{s} + i\epsilon) + i\frac{q_l}{4\pi\sqrt{2}}. \tag{15}$$

Around the pole, the scattering amplitude can be approximated as:

$$T_{ij} \simeq \frac{g_i g_j}{z - z_p}, \tag{16}$$

an expression which allows on to obtain the g_i values for all the channels. In addition, we calculate the compositeness defined as:

$$\chi_i = \left|g_i^2\frac{\partial G_i(z_p)}{\partial z}\right| \tag{17}$$

III. RESULTS

In this section we present the results from our approach and we will try to see if we can fit them into the experimental observations. We first present the results obtained in the pseudoscalar-baryon sector. In the model PB 1 we reproduce the results from Ref [3], so we suppose that the subtraction constants, which are obtained for a regularization scale of $\mu = 1$ GeV, are evaluated for all the PB channels with the same cut-off of $\Lambda = 800$ MeV using Eq. (14). We choose this value as it corresponds to the mass of the exchanged vector meson in the t-channel diagram which is integrated out when we take the $t \to 0$ limit.

Using this model we can see that the scattering amplitude shows two poles, visualized in Fig. 2 (purple line). We note that the first small peak that appears in all the models in Fig. 2 is not a pole, but a cusp that sometimes appears at a meson-baryon threshold. It is also important to see that all the states in the PB sector have well-defined spin-parity, which is $J^P = \frac{1}{2}^-$, as they are generated from the interaction of a pseudoscalar meson ($J^P = 0^-$) and a baryon of the ground state octet ($J^P = \frac{1}{2}^+$) in s-wave ($L = 0$).

$0^- \oplus \frac{1}{2}^+$ interaction in the $(I,S,B) = (0,-2,-1)$ sector						
Model PB 1						
M(Mev)			6418.22		6518.78	
Γ(MeV)			0.00		1.24	
	a_i	Λ(MeV)	$\lvert g_i\rvert$	χ_i	$\lvert g_i\rvert$	χ_i
$\bar{K}\Xi_b(6290)$	-3.57	800	0.01	0.000	0.17	0.001
$\bar{K}\Xi_b'(6430)$	-3.62	800	1.32	0.546	0.06	0.000
$\bar{B}\Xi(6597)$	-3.24	800	0.28	0.002	5.23	0.972
$\eta\Omega_b(6593)$	-3.63	800	2.02	0.327	0.08	0.001
$\eta'\Omega_b(7004)$	-3.53	800	0.00	0.000	0.12	0.001

Table III: Energy, width, compositeness and couplings of the various channels of the different Ω_b^- states generated from the PB interaction employing Model PB 1.

Looking at results from model PB 1 in Table III, it is natural to think that, modifying the values of the subtraction constants within a reasonable range, we will be able to reproduce the high-energy peaks. To this end we relax the condition that all loop functions match, at the corresponding threshold, the cut-off loop function with $\Lambda = 800$ MeV, similarly to what is done in Ref. [3] to accommodate their results of the Ω_c states.

So, if we modify the value of the cut-off of two channels we can obtain two different models where the two poles can represent the high energy resonances. None of the values of the cut-off that are modified in models PB 2 and PB 3 are larger than $1300 - 1400$ MeV, which we think is the maximum reasonable value for a cut off, as we can see in Table IV. Model PB 2 is equivalent to the model presented in [4] as it represents the same peaks ($\Omega_b(6402)$ and $\Omega_b(6467)$), which couple strongly to same main channels.

Once we have reproduced the high energy structures our objective is to try to force our model a little bit more and fit the poles of the scattering amplitude to the low energy peaks.

When we try to lower the poles of our model by changing the cut-off values we systematically obtain the width of the second pole to be $\Gamma > 3.5$ MeV, which is larger that the experimental values reported in Ref. [1]. With these results we have to assume that the second pole can not represent any of the low energy peaks, but the first pole still can as its width remains within the experimental boundaries.

Keeping thit in mind we can easily obtain two different models (PB 4 and PB 5) where the first pole fits into one

$0^- \oplus \frac{1}{2}^+$ interaction in the $(I,S,B)=(0,-2,-1)$ sector						
Model PB 2						
M(Mev)			6402.53		6465.52	
Γ(MeV)			0.00		2.30	
	a_i	Λ(MeV)	$\|g_i\|$	χ_i	$\|g_i\|$	χ_i
$\bar{K}\Xi_b(6290)$	-3.57	800	0.00	0.000	0.48	0.034
$\bar{K}\Xi_b'(6430)$	-3.62	800	1.58	0.519	0.49	0.028
$\bar{B}\Xi(6597)$	-3.34	980	0.58	0.007	7.00	0.873
$\eta\Omega_b(6593)$	-3.68	910	1.97	0.298	0.51	0.017
$\eta'\Omega_b(7004)$	-3.53	800	0.00	0.000	0.17	0.001
Model PB 3						
M(Mev)			6401.57		6426.56	
Γ(MeV)			0.12		2.95	
	a_i	Λ(MeV)	$\|g_i\|$	χ_i	$\|g_i\|$	χ_i
$\bar{K}\Xi_b(6290)$	-3.57	800	0.05	0.000	0.24	0.005
$\bar{K}\Xi_b'(6430)$	-3.62	800	1.55	0.493	0.28	0.041
$\bar{B}\Xi(6597)$	-3.40	1120	1.61	0.054	6.31	0.895
$\eta\Omega_b(6593)$	-3.68	910	1.93	0.286	0.39	0.018
$\eta'\Omega_b(7004)$	-3.53	800	0.03	0.000	0.15	0.001
Model PB 4						
M(Mev)			6339.83		6404.02	
Γ(MeV)			0.02		3.95	
	a_i	Λ(MeV)	$\|g_i\|$	χ_i	$\|g_i\|$	χ_i
$\bar{K}\Xi_b(6290)$	-3.57	800	0.02	0.001	0.29	0.009
$\bar{K}\Xi_b'(6430)$	-3.762	1140	1.85	0.387	0.17	0.006
$\bar{B}\Xi(6597)$	-3.43	1160	0.92	0.015	6.71	0.937
$\eta\Omega_b(6593)$	-3.77	1120	2.10	0.286	0.22	0.004
$\eta'\Omega_b(7004)$	-3.53	800	0.01	0.000	0.16	0.001
Model PB 5						
M(Mev)			6330.57		6403.93	
Γ			0.01		3.95	
	a_i	Λ(MeV)	$\|g_i\|$	χ_i	$\|g_i\|$	χ_i
$\bar{K}\Xi_b(6290)$	-3.57	800	0.02	0.000	0.29	0.009
$\bar{K}\Xi_b'(6430)$	-3.772	1170	1.89	0.383	0.15	0.005
$\bar{B}\Xi(6597)$	-3.43	1160	0.83	0.012	6.72	0.939
$\eta\Omega_b(6593)$	-3.79	1170	2.06	0.270	0.19	0.003
$\eta'\Omega_b(7004)$	-3.53	800	0.01	0.000	0.16	0.001

Table IV: Energy, width, compositeness and couplings to the various channels of the different Ω_b^- states generated from PB interaction employing different sets of subtraction constant (cut-off values)

of the low energy resonances and the second one fits to one of the high energy structures as seen in Fig. 2 (a) and Table IV. This time it is necessary to change three cut-offs to values near 1100 MeV which is still a reasonable value.

We next present the results from the vector meson-baryon interaction where we again firstly suppose that the cut-off value for all the channels is $\Lambda = 800$ MeV [3].

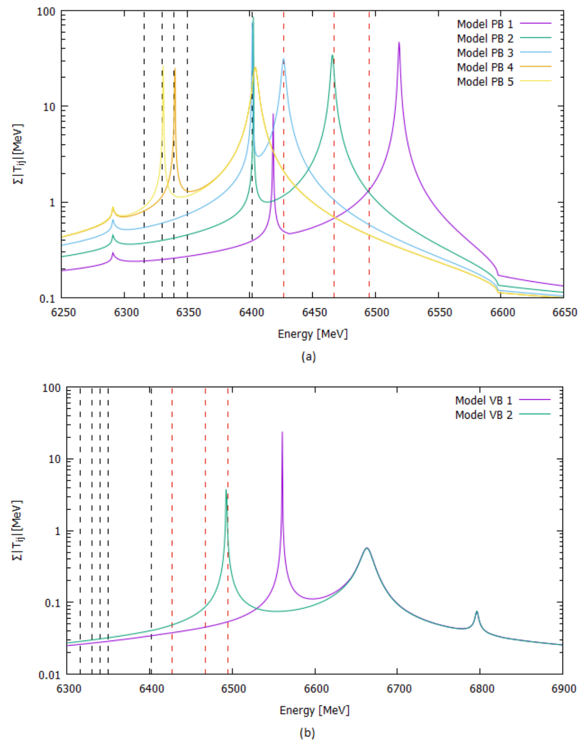

Fig. 2: Solid lines represent the sum over all j channels of the module of the PB scattering amplitude, $|T_{ij}|$ where in (a) the i channel correspond to $\bar{B}\Xi$ for the models PB 1, 2, 3, 4 and 5, and for (b) corresponds to $\bar{K}^*\Xi_b$, for the models VB 1 and 2. The vertical black dashed lines represent the location of the experimental states published in [1], while the red ones denote those of the non statistical significant peaks.

This will be denoted as model VB 1. We want to note that these states are degenerated in spin-parity as they are formed by a vector meson ($J^P = 1^-$) and a baryon ($J^P = 1/2^+$) so the spin-parity of those states can be $J^P = 1/2^-$ or $J^P = 3/2^-$.

As we can see in Fig. 2 (b) and Table VI none of the poles of model VB 1 coincide with the experimental peaks. In order to move the three of them to the experimental region we have to change the cut-off of all the channels into a value around $\Lambda \simeq 1500 - 1600$ MeV, as seen in Table V (a), which is not reasonable with the model we are using. Even if we try to only fit two states, one of the cut-off values has to be $\Lambda \sim 1600$ MeV, as seen in Tab. V (b), which again is not reasonable. So the last thing that we can do is to try to move the theoretical lower energy pole which is closer, in energetic terms, to the high energy peaks of the experimental spectrum.

To fit the lower energy VB resonance into the experimental peaks we only need to change the value of one the cut-offs to $\Lambda = 1030$ MeV, as seen in Fig. 2 (b) and Table VI for the VB Model 2, so is a reasonable model. We note that in this model we are interpreting the $\Omega_b^-(6495)$ as a VB molecular state, which is the same result that the authors of [4] obtained with their model.

	Three peaks set (a)				
	$\bar{B}^*\Xi$	$\bar{K}^*\Xi_b$	$\bar{K}^*\Xi_b'$	$\omega\Omega_b$	$\phi\Omega_b$
a_i	-3.45	-3.90	-3.85	-3.85	-3.93
Λ(MeV)	1170	1790	1570	1450	1750
	Two peaks set (b)				
a_i	-3.46	-3.84	-3.52	-3.55	-3.52
Λ(MeV)	1190	1640	830	770	800

Table V: Subtractions constants and equivalent cut-off values of a set that can reproduce either three (a) or two (b) of the high energy peaks

$1^- \oplus \frac{1}{2}^+$ interaction in the $(I,S,B)=(0,-2,-1)$ sector								
Model VB 1								
M(MeV)			6559.94		6663.88		6795.94	
Γ(MeV)			0.00		19.12		3.78	
	a_i	Λ(MeV)	$\|g_i\|$	χ_i	$\|g_i\|$	χ_i	$\|g_i\|$	χ_i
$\bar{B}^*\Xi$	-3.26	800	5.31	0.968	0.22	0.004	0.11	0.000
$\bar{K}^*\Xi_b$	-3.46	800	0.23	0.005	2.32	1.350	0.02	0.000
$\bar{K}^*\Xi_b'$	-3.51	800	0.14	0.001	0.03	0.000	1.15	0.295
$\omega\Omega_b$	-3.57	800	0.10	0.001	0.04	0.001	1.40	0.424
$\phi\Omega_b$	-3.52	800	0.07	0.000	0.00	0.000	2.00	0.280
Model VB 2								
M(Mev)			6492.20		6663.83		6795.95	
Γ(MeV)			0.00		19.01		3.74	
	a_i	Λ(MeV)	$\|g_i\|$	χ_i	$\|g_i\|$	χ_i	$\|g_i\|$	χ_i
$\bar{B}^*\Xi$	-3.38	1030	6.30	0.957	0.18	0.002	0.10	0.000
$\bar{K}^*\Xi_b$	-3.46	800	0.21	0.003	2.32	1.350	0.02	0.000
$\bar{K}^*\Xi_b'$	-3.51	800	0.28	0.005	0.03	0.000	1.15	0.295
$\omega\Omega_b$	-3.57	800	0.04	0.000	0.03	0.000	1.40	0.424
$\phi\Omega_b$	-3.52	800	0.19	0.002	0.00	0.000	2.00	0.280

Table VI: Energy, width, compositeness and couplings to the various channels of the different Ω_b^- states generates from VB interaction employing different sets of subtraction constants (cut-off values)

IV. CONCLUSIONS

In this work we have studied different possible models that can explain some of the experimental peaks that have been reported by the LHCb Collaboration in $\Xi_b^0 K^-$ the spectrum leading to Ω_b^- states in the $I=0$, $S=-2$ and $B=-1$ sector. The results from models PB 1 and VB 1 show that at least three of the resonances have energies similar to the states found by the LHCb Collaboration. Modifying some parameters within a reasonable range, we could build different models that can reproduce some experimental peaks.

In the pseudoscalar-baryon sector we were able to build four models that reproduce two experimental peaks, all of them include the state $\Omega_b^-(6402)$ together with $\Omega_b^-(6467)$, $\Omega_b^-(6427)$, $\Omega_b^-(6340)$ and $\Omega_b^-(6330)$ in models PB 2, PB 3, PB 4 and PB 5, respectively. These states the would have $J^P=\frac{1}{2}^-$, which is different from the quark model expectations since, in the case of $\Omega_b^-(6340)$ Ref. [2] obtains, $J^P=\frac{3}{2}^-$. Meanwhile, in the vector meson-baryon sector, we only could generate one model that could reproduce one of the high energy structures, that of a tentative the $\Omega_b^-(6495)$ state.

To determine which of the models represents better the Ω_b^- spectrum it would be necessary to have more statistics in the region where we see the high energy peaks, as well as a proper determination of the spin-parity of the observed states.

V. ACKNOWLEDGMENTS

First of all, I would like to express my gratitude to my advisor Àngels Ramos for guiding and helping me during all the work. I also want to thank Gloria Montaña for the support given during some parts of the process. And I want to give special thanks to my family and all my friends for the moral support.

[1] R. Aaij *et al.* [LHCb], Phys. Rev. Lett. **124**, no.8, 082002 (2020) doi:10.1103/PhysRevLett.124.082002 [arXiv:2001.00851 [hep-ex]].

[2] H. X. Chen, E. L. Cui, A. Hosaka, Q. Mao and H. M. Yang, Eur. Phys. J. C **80**, no.3, 256 (2020) doi:10.1140/epjc/s10052-020-7824-y [arXiv:2001.02147 [hep-ph]].

[3] G. Montaña, A. Feijoo and À. Ramos, Eur. Phys. J. A **54**, no.4, 64 (2018) doi:10.1140/epja/i2018-12498-1 [arXiv:1709.08737 [hep-ph]].

[4] W. H. Liang and E. Oset, Phys. Rev. D **101**, no.5, 054033 (2020) doi:10.1103/PhysRevD.101.054033 [arXiv:2001.02929 [hep-ph]].

[5] J. A. Oller and U. G. Meissner, Phys. Lett. B **500**, 263-272 (2001) doi:10.1016/S0370-2693(01)00078-8 [arXiv:hep-ph/0011146 [hep-ph]].

[6] J. Hofmann and M. F. M. Lutz, Nucl. Phys. A **763**, 90-139 (2005) doi:10.1016/j.nuclphysa.2005.08.022 [arXiv:hep-ph/0507071 [hep-ph]].

[7] W. H. Liang, J. M. Dias, V. R. Debastiani and E. Oset, Nucl. Phys. B **930**, 524-532 (2018) doi:10.1016/j.nuclphysb.2018.03.008 [arXiv:1711.10623 [hep-ph]].

[8] A. Ramos, A. Feijoo, Q. Llorens and G. Montaña, Few Body Syst. **61**, no.4, 34 (2020) doi:10.1007/s00601-020-01566-0 [arXiv:2009.04367 [hep-ph]].