A STUDY OF BOTTOM BARYONS WITH EXTENDED LOCAL HIDDEN GAUGE APPROACH

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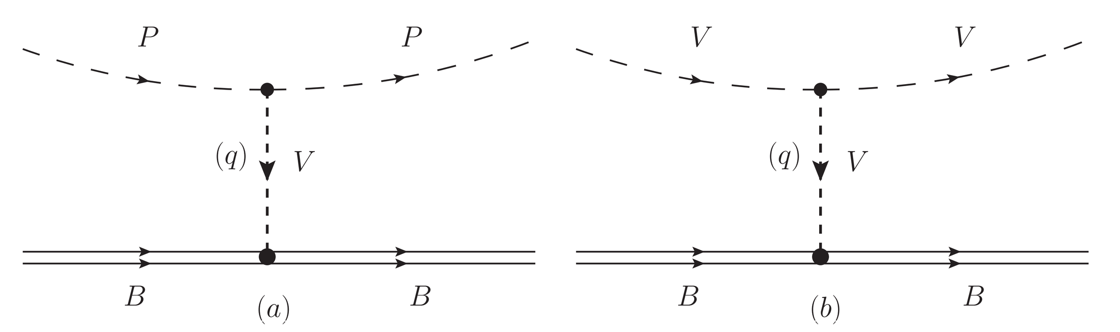
INTRODUCTION

Recently, the discovery of the two Λ_b excited states by the LHC$_b$ collaboration (RAaij *et al.*, 2012), $\Lambda_b(5912)$ and $\Lambda_b(5920)$ with $J^P = 1/2^-, 3/2^-$ respectively, drives more attention to the beauty sector, since the widths of these two states are very small, less than 1 MeV. The higher one is also confirmed by the CDF collaboration (T. A. Aaltonen *et al.*, 2013).

In this work, using the extended local hidden gauge formalism and the coupled channel approach, we investigate the open beauty system of meson-baryon interaction. The the assumption that the heavy quarks act as spectators at the quark level automatically leads us to the results of the heavy quark spin symmetry for pion exchange.

FORMALISM1

We investigate the coupled channels $\pi\Sigma_b$, $\pi\Lambda_b$, $\eta\Lambda_b$, $\eta\Sigma_b$, $\bar{B}N$ with $I = 0,\ 1$. Similarly, we also study the $\bar{B}^*N$ and $\pi\Sigma_b^*$, $\eta\Sigma_b^*$, $\bar{B}\Delta$, $\bar{B}^*\Delta$ channels, belonging to a decuplet of $3/2^+$ states. Using the local hidden gauge approach, the meson baryon interaction proceeds via the exchange of vector mesons as depicted in Figure:



The transition potential is given by

$$V = -C_{ij}\frac{1}{4f^2}(2\sqrt{s} - M_{B_i} - M_{B_j})\sqrt{\frac{M_{B_i}+E_i}{2M_{B_i}}}\sqrt{\frac{M_{B_j}+E_j}{2M_{B_j}}}. \quad (1)$$

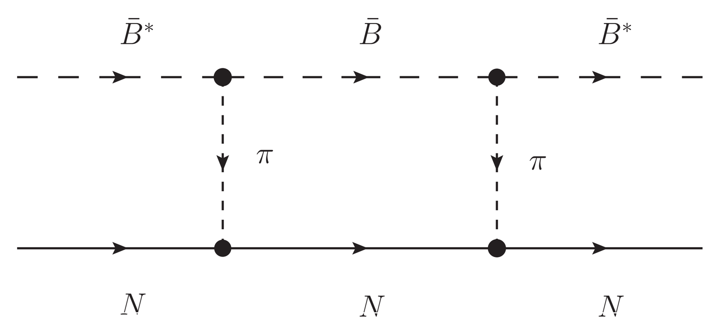
In coupled channels we use the Bethe-Salpeter equation

$$T = [1 - V\,G]^{-1}\,V. \quad (2)$$

More details can be seen in our recent paper: *Phys.Rev. D* **89** *(2014) 054023* .

FORMALISM2

Next, we break the degeneracy of the $1/2^-$, $3/2^-$ states of the $\bar{B}^*N$ sector, with mixing states of $\bar{B}^*N$ and $\bar{B}N$ in both sectors. This means that it is sufficient to evaluate the contribution of the box diagrams as below:



Finally we obtain the following results for the $\bar{B}^*N \to \bar{B}N \to \bar{B}^*N$ box diagram

$$\begin{aligned} J &= 1/2: \quad \delta V = FAC\left(\frac{\partial}{\partial m_\pi^2}I_1' + 2\,I_2' + I_3'\right),\\ J &= 3/2: \quad \delta V = FAC\left(\frac{\partial}{\partial m_\pi^2}I_1'\right), \end{aligned} \quad (3)$$

where

$$\begin{aligned} I_1' &= \int \frac{d^3q}{(2\pi)^3}\frac{4}{3}\vec{q}^{\,4}\frac{1}{2\omega_B(\vec{q})}\frac{M_N}{E_N(\vec{q})}\frac{Num}{Den},\\ I_2' &= \int \frac{d^3q}{(2\pi)^3}2\vec{q}^{\,2}\frac{1}{2\omega_B(\vec{q})}\frac{M_N}{E_N(\vec{q})}\frac{Num}{Den}, \\ I_3' &= \int \frac{d^3q}{(2\pi)^3}\frac{3}{2\omega_B(\vec{q})}\frac{M_N}{E_N(\vec{q})}\\ &\quad\times\frac{1}{P^0_{in} + K^0_{in} - E_N(\vec{q}) - \omega_B(\vec{q}) + i\epsilon}, \end{aligned} \quad (4)$$

with

$$\begin{aligned} FAC &= \frac{9}{2}g^2\left(\frac{m_{B^*}}{m_{K^*}}\right)^2\left(\frac{F+D}{2f_\pi}\right)^2,\\ Num &= K^0_{in} - E_N(\vec{q}) - 2\omega_\pi(\vec{q}) - \omega_B(\vec{q}) + P^0_{in},\\ Den &= 2\omega_\pi(\vec{q})[P^0_{in} - \omega_\pi(\vec{q}) - \omega_B(\vec{q}) + i\epsilon]\\ &\quad\times[K^0_{in} - E_N(\vec{q}) - \omega_\pi(\vec{q}) + i\epsilon]\\ &\quad\times[P^0_{in} + K^0_{in} - E_N(\vec{q}) - \omega_B(\vec{q}) + i\epsilon], \end{aligned}$$

with P^0_{in}, K^0_{in} the incoming $\bar{B}^*$, N energies.

For the other boxes, such as $\bar{B}N \to \bar{B}^*N \to \bar{B}N$ for $I = 0$, and for $I = 1$ $\bar{B}\Delta \to \bar{B}^*\Delta \to \bar{B}\Delta$, $\bar{B}^*\Delta \to \bar{B}\Delta \to \bar{B}^*\Delta$, $\bar{B}\Delta \to \bar{B}^*N \to \bar{B}\Delta$, $\bar{B}^*\Delta \to \bar{B}N \to \bar{B}^*\Delta$, we obtain similar results and more details can be referred to our paper.

RESULTS

Finally, since we have many intermediate results, we summarize all the results that we obtain with $q_{max} = 776$ MeV, which was used to fix one of the Λ_b energies. The results are shown in Table, where we also write for a quick intuition the main channel of the state.

main channel	J	I	$(E,\ \Gamma)$ [MeV]	Exp.
$\bar{B}N$	$1/2$	0	5820.9, 0	-
$\pi\Sigma_b$	$1/2$	0	5969.5, 49.2	-
$\bar{B}^*N$	$1/2$	0	5910.7, 0	$\Lambda_b(5912)$
$\bar{B}^*N$	$3/2$	0	5920.7, 0	$\Lambda_b(5920)$
$\rho\Sigma_b$	$1/2$	0	6316.6, 2.8	-
$\rho\Sigma_b$	$3/2$	0	6315.7, 3.8	-
$\bar{B}N$, $\pi\Sigma_b$	$1/2$	1	6179.4, 122.8	-
$\pi\Sigma_b$	$1/2$	1	6002.8, 132.4	-
$\bar{B}\Delta$, $\pi\Sigma_b^*$	$3/2$	1	5932.9, 0	-
$\pi\Sigma_b^*$	$3/2$	1	6063.8, 167.0	-
$\bar{B}^*N$	$1/2, 3/2$	1	6202.2, 0	-
$\rho\Sigma_b$	$1/2, 3/2$	1	6477.2, 10.0	-
$\bar{B}^*\Delta$	$1/2, 3/2, 5/2$	1	6022.9, 0	-
$\rho\Sigma_b^*$	$1/2, 3/2, 5/2$	1	6491.7, 1.6	-

In summary, we predict 6 states with $I = 0$, two of them corresponding to the $\Lambda_b(5912)$ and $\Lambda_b(5920)$, and 8 states with $I = 1$. The energies of the states range from about 5800 MeV to 6500 MeV.

DISCUSSION

Comparing the results with the work of C. Garcia-Recio *et al.*, PRD87, 034032, 2013, we obtained some consistent results in $I = 0$. The two states associated to the $\Lambda_b(5912)$ and $\Lambda_b(5920)$ exhibit, as here, a substantial coupling to $\bar{B}^*N$. There is also a $1/2^-$ state in that work at 5797 MeV which we find at 5820 MeV, only 33 MeV higher, and another state at 6009 MeV that we find at 5969 MeV, 40 MeV below. The mostly $\rho\Sigma_b$ state found here at 6316 MeV, basically degenerate in $J = 1/2,\ 3/2$, was either not found or not searched for in that work because of its higher mass.

The states of $I = 1$ are not investigated in that work. Thus, these states are our predictions with the same parameters in $I = 0$, and we find quite a few, some of them narrow enough for a clear experimental observation.

CONCLUSION

In this work we studied the interaction of $\bar{B}N$, $\bar{B}\Delta$, $\bar{B}^*N$ and $\bar{B}^*\Delta$ states with its coupled channels: $\pi\Sigma_b$, $\pi\Lambda_b$, $\eta\Sigma_b$ (for the $\bar{B}N$); $\pi\Sigma_b^*$, $\eta\Sigma_b^*$ (for the $\bar{B}\Delta$); $\rho\Sigma_b$, $\omega\Lambda_b$, $\phi\Lambda_b$, $\rho\Sigma_b^*$, $\omega\Sigma_b^*$, $\phi\Sigma_b^*$ (for the $\bar{B}^*N$); and $\rho\Sigma_b^*$, $\omega\Sigma_b^*$, $\phi\Sigma_b^*$ (for the $\bar{B}^*\Delta$).

- The $I = 0$ sector: 6 **bound states**, two of them are associated to the experimental findings $\Lambda_b(5912)$ and $\Lambda_b(5920)$, and one of them degenerate in spin $J = 1/2,\ 3/2$;
- The $I = 1$ sector: 8 **states, less bound**, two of them degenerate in spin $J = 1/2,\ 3/2$, and two more degenerate in spin $J = 1/2,\ 3/2,\ 5/2$.

Hope that these states can be found in the experiment in the future.