

Λ_b AND Ξ_b WEAK DECAYS INTO Λ_c^* AND Ξ_c^* AND DYNAMICS OF Λ_c^* AND Ξ_c^{**}

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We report on work done for the decay rates of $\Lambda_b \rightarrow \pi^- \Lambda_c(2595)$ ($\Lambda_c(2625)$) from the perspective that the $\Lambda_c(2595)$ and $\Lambda_c(2625)$ are dynamically generated resonances from the DN , D^*N interaction and coupled channels. We also evaluate the semileptonic decays going to these resonances, $\Lambda_b \rightarrow \bar{\nu}_l l \Lambda_c(2595)(\Lambda_c(2625))$, and a good agreement is found with experiment. The exercise is also done for the $\Xi_b^- \rightarrow \pi^- (D_s^-) \Xi_c^0(2790)$ ($\Xi_c^0(2815)$) and $\Xi_b^- \rightarrow \bar{\nu}_l l \Xi_c^0(2790)(\Xi_c^0(2815))$, making predictions for the rates of these decays.

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1. Introduction

The $\Lambda_c(2595)$ has been considered as the analog of the $\Lambda(1405)$ in [1, 2]. While the $\Lambda(1405)$ is mostly made of $\bar{K}N$, the $\Lambda_c(2595)$ is obtained in coupled channels in [1, 2] and couples mostly to DN . This view was challenged in [3], where by using a spin–isospin symmetry with the SU(8) group it was found that it also had a considerable coupling to D^*N . A detailed study using the local hidden gauge approach [4] and connecting D^*N with DN with pion exchange was done in [5], and it was also found that the $\Lambda_c(2595)$ has a sizable coupling to both components. The present work studies two reactions that are sensitive to these couplings, and the

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agreement with experiment gives support to this picture. The reactions are $\Lambda_b \rightarrow \pi^- \Lambda_c(2595)$ and $\Lambda_b \rightarrow \pi^- \Lambda_c(2625)$. The $\Lambda_c(2625)$ appears in the same picture but since it is a $3/2^-$ it only couples to D^*N in s -wave.

2. Formalism

In Fig. 1, we show at the microscopic level how the reaction proceeds. The weak transition occurs on the b quark, which turns into a c quark, and a π^- is produced through the mechanism of external emission [6]. Since we have a $1/2^-$ or $3/2^-$ state at the end, and the u, d quarks are spectators, the final c quark must carry negative parity and hence must be in an $L = 1$ level. Since in our picture the $\Lambda_c(2595)$ and $\Lambda_c(2625)$ come from meson–baryon interaction, we must hadronize the final state including a $\bar{q}q$ pair with the quantum numbers of the vacuum. This is done following the work of Ref. [8]. We include the $\bar{u}u + \bar{d}d + \bar{s}s$ as in Fig. 1. In [7], the details are given on which meson–baryon pairs are produced from this hadronization and with which weight.

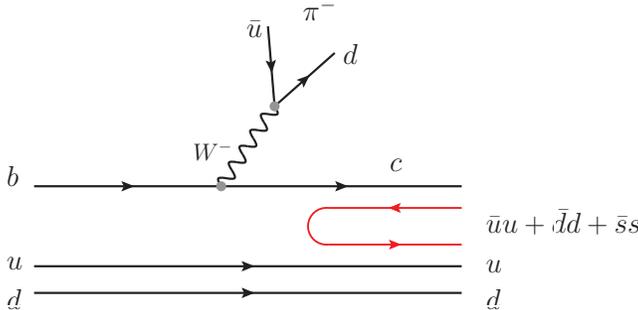


Fig. 1. Diagrammatic representation of the decay with hadronization creating the $\bar{q}q$ pairs.

One obtains

$$|H'\rangle = \left| D^0 p + D^+ n + \sqrt{\frac{2}{3}} D_s^+ \Lambda \right\rangle \simeq \sqrt{2} |DN, I = 0\rangle, \tag{1}$$

where we neglect the $D_s^+ \Lambda$ that has a much higher mass than the DN and does not play a role in the generation of the $\Lambda_c(2595)$. The isospin $I = 0$ in Eq. (1) comes from the implicit phase convention in our approach, with the doublets $(D^+, -D^0)$ and (\bar{D}^0, D^-) .

The production of the resonance is done after the produced DN in the first step merges into the resonance, as shown in Fig. 2. The transition matrix for the mechanism of Fig. 2 gives us

$$t_R = V_P \sqrt{2} G_{DN} g_{R,DN}, \tag{2}$$

where V_P is a factor that includes the dynamics of $\Lambda_b \rightarrow \pi^- DN$, G_{DN} is the loop function for the DN propagation [5], and $g_{R,DN}$ is the coupling of the resonance to the DN channel in $I = 0$ [5].

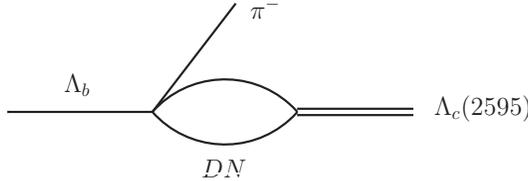


Fig. 2. Diagram to produce the $\Lambda_c(2595)$ through an intermediate propagation of the DN state.

The width for the decay process is given by

$$\Gamma_R = \frac{1}{2\pi} \frac{M_{\Lambda_c^*}}{M_{\Lambda_b}} \overline{\sum \sum} |t_R|^2 p_{\pi^-}, \tag{3}$$

where $\overline{\sum \sum}$ stands for the sum and average over polarizations.

The arguments used above can be equally used for the production of D^*N . Finally, after some subtle Racah algebra, we obtain

$$\left[\overline{\sum \sum} |t_R|^2 \right]_1 = \left(q^2 + \omega_\pi^2 \right) \left| \frac{1}{2} G_{DN} g_{R,DN} + \frac{1}{2\sqrt{3}} G_{D^*N} g_{R,D^*N} \right|^2, \quad \text{for } J = \frac{1}{2}, \tag{4}$$

and

$$\left[\overline{\sum \sum} |t_R|^2 \right]_2 = 2\omega_\pi^2 \left| \frac{1}{\sqrt{3}} G_{D^*N} g_{R,D^*N} \right|^2, \quad \text{for } J = \frac{3}{2}, \tag{5}$$

where q, ω_π are the momentum and the energy of the pion.

3. Results

By looking at Eq. (3), we can immediately write the ratio of Γ for $\Lambda_c(2595)$ and $\Lambda_c(2625)$ production

$$\frac{\Gamma[\Lambda_b \rightarrow \pi^- \Lambda_c(2595)]}{\Gamma[\Lambda_b \rightarrow \pi^- \Lambda_c(2625)]} = \frac{M_{\Lambda_c(2595)} p_{\pi 1}}{M_{\Lambda_c(2625)} p_{\pi 2}} \frac{\left[\overline{\sum \sum} |t_R|^2 \right]_1}{\left[\overline{\sum \sum} |t_R|^2 \right]_2}, \tag{6}$$

where $p_{\pi 1}$ and $p_{\pi 2}$ are the pion momenta for the $\Lambda_c(2595)$ and $\Lambda_c(2625)$ production, respectively, and $\left[\overline{\sum \sum} |t_R|^2 \right]_{1,2}$ are given by Eqs. (4) and (5)

respectively. Using the numerical values of [5], we find

$$\frac{\Gamma[\Lambda_b \rightarrow \pi^- \Lambda_c(2595)]}{\Gamma[\Lambda_b \rightarrow \pi^- \Lambda_c(2625)]} = 0.76. \quad (7)$$

Experimentally, we have [9]

$$\text{BR}[\Lambda_b \rightarrow \pi^- \Lambda_c(2595), \Lambda_c(2595) \rightarrow \Lambda_c \pi^+ \pi^-] = (3.2 \pm 1.4) \times 10^{-4}, \quad (8)$$

$$\text{BR}[\Lambda_b \rightarrow \pi^- \Lambda_c(2625), \Lambda_c(2625) \rightarrow \Lambda_c \pi^+ \pi^-] = (3.1 \pm 1.2) \times 10^{-4}. \quad (9)$$

Since the BR for $\Lambda_c^* \rightarrow \Lambda_c \pi^+ \pi^-$ is 67% for both resonances, the ratio of partial decay widths for the $\Lambda_c(2595)$ to $\Lambda_c(2625)$ summing in quadrature the relative errors is given by

$$\left. \frac{\Gamma[\Lambda_b \rightarrow \pi^- \Lambda_c(2595)]}{\Gamma[\Lambda_b \rightarrow \pi^- \Lambda_c(2625)]} \right|_{\text{Exp}} = 1.03 \pm 0.60. \quad (10)$$

The value that we get in Eq. (7) is compatible within errors.

4. Semileptonic $\Lambda_b \rightarrow \bar{\nu}_l \Lambda_c(2595)$ and $\Lambda_b \rightarrow \bar{\nu}_l \Lambda_c(2625)$ decays

In [10], the related $\Lambda_b \rightarrow \bar{\nu}_l \Lambda_c(2595)$ and $\Lambda_b \rightarrow \bar{\nu}_l \Lambda_c(2625)$ decays are studied. The mechanism for this process is depicted in Fig. 3, where a π^- is replaced by a $\bar{\nu}_l$ pair. The hadronization proceeds in the same way as before: Details can be seen in [10] and we quote here the final result

$$\frac{\Gamma[\Lambda_b \rightarrow \bar{\nu}_l \Lambda_c(2595)]}{\Gamma[\Lambda_b \rightarrow \bar{\nu}_l \Lambda_c(2625)]} = 0.39. \quad (11)$$

The experimental data from the PDG are [9]

$$\begin{aligned} \text{BR}[\Lambda_b \rightarrow \bar{\nu}_l \Lambda_c(2595)] &= (7.9_{-3.5}^{+4.0}) \times 10^{-3}, \\ \text{BR}[\Lambda_b \rightarrow \bar{\nu}_l \Lambda_c(2625)] &= (13.0_{-5.0}^{+6.0}) \times 10^{-3}. \end{aligned} \quad (12)$$

The ratio, summing in quadrature the experimental errors, is

$$\left. \frac{\Gamma[\Lambda_b \rightarrow \bar{\nu}_l \Lambda_c(2595)]}{\Gamma[\Lambda_b \rightarrow \bar{\nu}_l \Lambda_c(2625)]} \right|_{\text{Exp}} = 0.6_{-0.3}^{+0.4}. \quad (13)$$

We can see that there is the agreement between theory and experiment within errors.

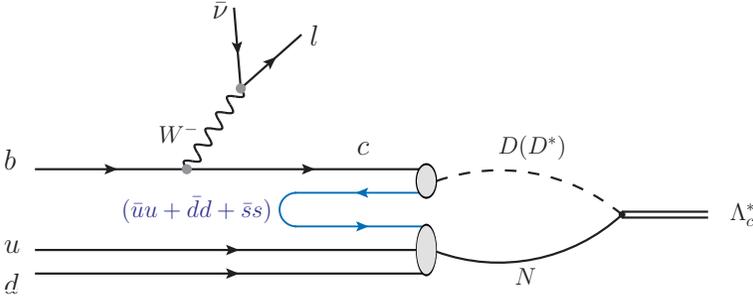


Fig. 3. Mechanism to produce a Λ_c^* resonance that is mostly made from DN, D^*N .

5. $\Xi_b^- \rightarrow \pi^- (D_s^-) \Xi_c^0(2790) (\Xi_c^0(2815))$ and $\Xi_b^- \rightarrow \bar{\nu}_l l \Xi_c^0(2790) (\Xi_c^0(2815))$

In [11], we have studied the nonleptonic and semileptonic decays $\Xi_b^- \rightarrow \bar{\nu}_l l \Xi_c^0(2790) (\Xi_c^0(2815))$. The formalism proceeds identically as before, but the building blocks of the $\Xi_c^0(2790) (\Xi_c^0(2815))$ are now $D\Sigma$ and DA and $D^*\Sigma$ and D^*A . The couplings and G functions are taken from [3].

In this case, after the hadronization, we have now the component

$$|H'\rangle = \frac{1}{\sqrt{2}} |D^0 \Sigma^0\rangle + |D^+ \Sigma^-\rangle + \frac{1}{\sqrt{6}} |D^0 \Lambda\rangle. \tag{14}$$

We obtain the ratio

$$R_1 = \frac{\Gamma_{\Xi_b^- \rightarrow \pi^- \Xi_c^0(2790)}}{\Gamma_{\Xi_b^- \rightarrow \pi^- \Xi_c^0(2815)}} = 0.384, \tag{15}$$

and for the semileptonic decay, we obtain

$$R = \frac{\Gamma_{\Xi_b^- \rightarrow \bar{\nu}_l l \Xi_c^0(2790)}}{\Gamma_{\Xi_b^- \rightarrow \bar{\nu}_l l \Xi_c^0(2815)}} = 0.198. \tag{16}$$

There are not yet results for this decay but it is good to have predictions for the likely case that these decays can also be measured in the near future.

6. Conclusions

We have shown some examples where the couplings of some dynamically generated resonances to pseudoscalar baryon and vector baryon are at work. The results are very sensitive to these couplings to the point that the ratio of rates shows changes by two orders of magnitude if we reverse the relative signs of the couplings. We showed one example where the agreement with

experiment is found good and have made predictions for one yet unobserved case. This should also serve as incentive to carry out these new experiments in the future.

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REFERENCES

- [1] J. Hofmann, M.F.M. Lutz, *Nucl. Phys. A* **763**, 90 (2005).
- [2] T. Mizutani, A. Ramos, *Phys. Rev. C* **74**, 065201 (2006).
- [3] O. Romanets *et al.*, *Phys. Rev. D* **85**, 114032 (2012).
- [4] M. Bando, T. Kugo, K. Yamawaki, *Phys. Rep.* **164**, 217 (1988).
- [5] W.H. Liang, T. Uchino, C.W. Xiao, E. Oset, *Eur. Phys. J. A* **51**, 16 (2015).
- [6] L.L. Chau, *Phys. Rep.* **95**, 1 (1983).
- [7] W.H. Liang, M. Bayar, E. Oset, *Eur. Phys. J. C* **77**, 39 (2017).
- [8] L. Roca, M. Mai, E. Oset, U.-G. Meißner, *Eur. Phys. J. C* **75**, 218 (2015).
- [9] K.A. Olive *et al.* [Particle Data Group], *Chin. Phys. C* **38**, 090001 (2014) and 2015 update.
- [10] W.H. Liang, E. Oset, Z.S. Xie, *Phys. Rev. D* **95**, 014015 (2017).
- [11] R.P. Pavao, W.H. Liang, J. Nieves, E. Oset, *Eur. Phys. J. C* **77**, 265 (2017).