$\Lambda_b \to \pi^- \Lambda_c^*$ and $\Lambda_b \to D_s^- \Lambda_c^*$ Decays in the molecular picture of $\Lambda_c(2595)$ and $\Lambda_c(2625)$

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Hadron 2017

25-29 September 2017, Salamanca, Spain

Based on: **WHL, M. Bayar, E. Oset, Eur. Phys. J. C 77 (2017) 39.**

Outline

- Introduction and motivation
- Formalism
- Results and discussions
- Summary

◆ Introduction and motivation

- $\Lambda_c(2595)$ and $\Lambda_c(2625)$ are excited states of Λ_b, with narrow width.

In PDG:

$\Lambda_c(2595)^+$ $I(J^P) = 0(\frac{1}{2}^-)$ Status: ∗∗∗

$$\Gamma_{\Lambda_c(2595)} = 2.59 \pm 0.30 \pm 0.47 \ \text{MeV}$$

$\Lambda_c(2625)^+$ $I(J^P) = 0(\frac{3}{2}^-)$ Status: ∗∗∗

$$\Gamma_{\Lambda_c(2625)} < 0.97 \ \text{MeV}$$

- **Open question:** Are $\Lambda_c(2595)$ and $\Lambda_c(2625)$ normal *qqq* states or exotic states?

◆ Introduction and motivation

- **Theroretical results from a study on baryon states with open charm in the extended local hidden gauge approach**

[WHL, T. Uchino, C.W. Xiao and E. Oset, EPJA 51 (2015) 16]

➢ Considering both pseudoscalar-baryon and vector-baryon interactions.

Pseudoscalar-baryon coupled channels (I= 0): $DN,\ \pi\Sigma_c,\ \eta\Lambda_c$

Vector-baryon coupled channels (I= 0): $D^*N,\ \rho\Sigma_c,\ \omega\Lambda_c,\ \phi\Lambda_c$

➢ Both $\Lambda_c(2595)$ and $\Lambda_c(2625)$ are generated dynamically from meson – baryon interaction.

$\Lambda_c(2595)$ couples mostly to DN and D^*N. $\Lambda_c(2625)$ couples mostly to D^*N.

- **This work, to test the molecular picture of $\Lambda_c(2595)$ and $\Lambda_c(2625)$ in $\Lambda_b \to \pi^-\Lambda_c^*$ and $\Lambda_b \to D_s^-\Lambda_c^*$ decays.**

◆ Formalism

$\Lambda_b \to \pi^- \Lambda_c^*$ decay :

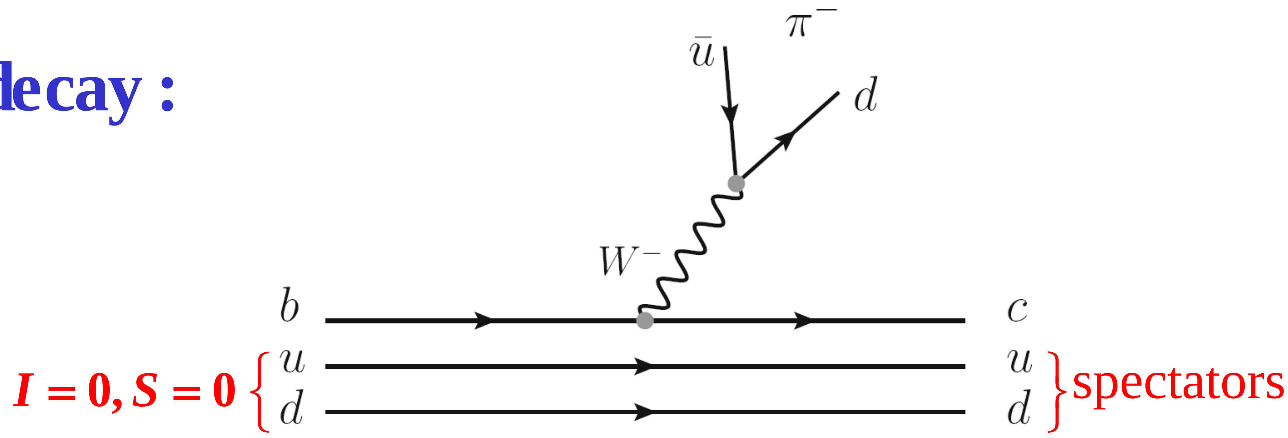
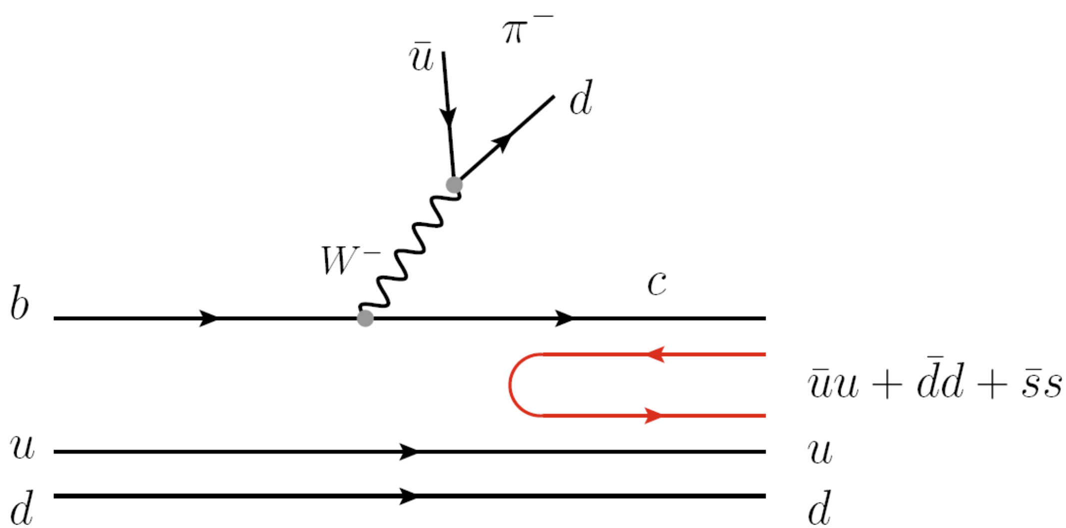


Fig. 1 Basic diagram for $\Lambda_b \to \pi^- \Lambda_c(2595)$.



(with the quantum numbers of the vacuum)

Fig. 2 Hadronization creating $\bar{q}q$ pairs

Formalism

- **Flavour aspect of the hadronization**

Original state $|\Lambda_b\rangle = \frac{1}{\sqrt{2}}|b(ud-du)\rangle$ —weak process→ $|H\rangle = \frac{1}{\sqrt{2}}|c(ud-du)\rangle$

hadronization

$$|H'\rangle = \frac{1}{\sqrt{2}}|c(\bar{u}u+\bar{d}d+\bar{s}s)(ud-du)\rangle$$

in term of hadrons

$$|H'\rangle = \left|D^0 p + D^+ n + \sqrt{\frac{2}{3}} D_s^+ \Lambda\right\rangle$$

Neglect $D_s^+\Lambda$, for its much higher mass than *DN*. (Its contribution will be considered later.)

$$|H'\rangle \simeq \sqrt{2}|DN, I=0\rangle$$

◆ Formalism

- **Production of Λ_c^* resonance**

The transition matrix for Fig. 3:

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

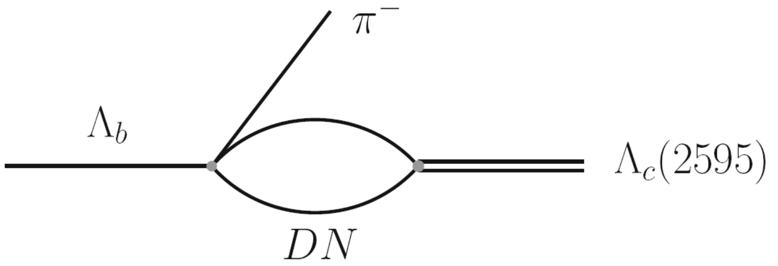


Fig. 3 Diagram to produce $\Lambda_c(2595)$ through an intermediate propagation of *DN* state.

V_P —— a factor that includes the dynamics of $\Lambda_b \to \pi^- DN$, involving the weak matrix elements;

G_{DN} —— loop function for the *DN* propagation;

$g_{R,DN}$ —— coupling of the resonance to DN channel in $I = 0$.

[WHL, T. Uchino, C.W. Xiao and E. Oset, EPJA 51 (2015) 16]

For the case of *D*N* production, the V_P factor would be different.

◆ Formalism

- **Evaluation of the weak matrix elements (V_P factor)**

(Detail can be seen in **[WHL, M. Bayar, E. Oset, Eur. Phys. J. C 77 (2017) 39]**)

$$\boldsymbol{V_P} \sim \left(iq + i\frac{w_\pi}{q}\vec{\sigma}\cdot\vec{q} \right)\delta_{J,\frac{1}{2}} + \left(-i\frac{w_\pi}{q}\sqrt{3}\vec{S}^{+}\cdot\vec{q} \right)\delta_{J,\frac{3}{2}},$$

with $q^0, \vec{q}$ the energy and momentum of the pion, $\vec{\sigma}$ the Pauli spin matrix.

$\vec{S}^{+}$ is the spin transition operator from spin 1/2 to 3/2 , defined as

$$\left\langle \frac{3}{2}M' \middle| \vec{S}^{+}\cdot\vec{q} \middle| \frac{1}{2}M \right\rangle = \mathcal{C}\left(\frac{1}{2}1\frac{3}{2};\ M_\mu M' \right)$$

Clebsch-Gordan coefficient

There is a common factor for $\Lambda_b \to \pi^- \Lambda_c(2595)$ and $\Lambda_b \to \pi^- \Lambda_c(2625)$,

$$\mathrm{ME}(q) \equiv \int r^2 \mathrm{d}r\ j_1(qr)\ \varphi_{\mathrm{in}}(r)\ \varphi^{*}_{\mathrm{fin}}(r).$$

φ_{in} and φ_{fin} are the radial wave functions of b and c quarks.

◆ Formalism

- **Decay width for $\Lambda_b \to \pi^- \Lambda_c^*$**

The full transition t matrix for $\Lambda_b \to \pi^- \Lambda_c^*$

$$t_R = \left(iq + i\frac{w_\pi}{q}\vec{\sigma}\cdot\vec{q} \right)\left(\frac{1}{2}G_{DN}\, g_{R,DN} + \frac{1}{2\sqrt{3}}G_{D^*N}\, g_{R,D^*N} \right)\delta_{J,\frac{1}{2}} - \left(+i\frac{w_\pi}{q}\sqrt{3}\vec{S}^+\cdot\vec{q} \right)\frac{1}{\sqrt{3}}G_{D^*N}\, g_{R,D^*N}\, \delta_{J,\frac{3}{2}}. \quad (40)$$

Factors $G_{D^{(*)}N}\ g_{R,D^{(*)}N}$ are taken from

[WHL, T. Uchino, C.W. Xiao and E. Oset, EPJA 51 (2015) 16]

The decay width for $\Lambda_b \to \pi^- \Lambda_c^*$

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

◆ Formalism

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

$$\left[\overline{\sum}\sum|t_R|^2\right]_1 = (q^2+w_\pi^2)\left|\frac{1}{2}G_{DN}\ g_{R,DN} + \frac{1}{2\sqrt{3}}G_{D^*N}\ g_{R,D^*N}\right|^2, \quad \text{for } J=\frac{1}{2}; \tag{41}$$

and

$$\left[\overline{\sum}\sum|t_R|^2\right]_2 = 2w_\pi^2\left|\frac{1}{\sqrt{3}}G_{D^*N}\ g_{R,D^*N}\right|^2, \quad \text{for } J=\frac{3}{2}. \tag{42}$$

Results and discussions

- **The ratio of Γ for $\Lambda_c(2595)$ and $\Lambda_c(2625)$ production**

Ours:

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

PDG:

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

Compatible within errors!

$$\frac{\Gamma[\Lambda_b \to D_s^- \Lambda_c(2595)]}{\Gamma[\Lambda_b \to D_s^- \Lambda_c(2625)]} = 0.54 \, .$$

Results and discussions

- **The relative sign of the coupling of $\Lambda_c(2595)$ to DN and D^*N**

$$\left[\overline{\sum}\sum |t_R|^2\right]_1 = (q^2 + w_\pi^2)\left|\frac{1}{2}G_{DN}\, g_{R,DN} + \frac{1}{2\sqrt{3}}G_{D^*N}\, g_{R,D^*N}\right|^2, \quad \text{for } J = \frac{1}{2}; \tag{41}$$

DN and D^*N contributions are about the same for the $\Lambda_c(2595)$ case.

[WHL, T. Uchino, C.W. Xiao and E. Oset, EPJA 51 (2015) 16]

	$G_{DN} \cdot g_{R,DN}$	$G_{D^*N} \cdot g_{R,D^*N}$
$\Lambda_c(2595)(J = \frac{1}{2})$	$13.88 - 1.06i$	$26.51 + 2.1i$
$\Lambda_c(2625)(J = \frac{3}{2})$	0	29.10

The D^*N component in $\Lambda_c(2595)$ is relevant;

The relative sign of the coupling of $\Lambda_c(2595)$ to DN and D^*N is of crucial importance.

Results and discussions

- **Contributions from $D_s\Lambda$ and $D_s^*\Lambda$ channels**

$$G_{DN}\cdot g_{R,DN}\rightarrow G_{DN}\cdot g_{R,DN}+\frac{1}{\sqrt{2}}\sqrt{\frac{2}{3}}G_{D_s\Lambda}\cdot g_{R,D_s\Lambda},$$

$$G_{D^*N}\cdot g_{R,D^*N}\rightarrow G_{D^*N}\cdot g_{R,D^*N}+\frac{1}{\sqrt{2}}\sqrt{\frac{2}{3}}G_{D_s^*\Lambda}\cdot g_{R,D_s^*\Lambda}.$$

Table 3 The values of $G_{D_s\Lambda}\cdot g_{R,D_s\Lambda}$ and $G_{D_s^*\Lambda}\cdot g_{R,D_s^*\Lambda}$ from Ref. [43]

	$G_{D_s\Lambda}\cdot g_{R,D_s\Lambda}$	$G_{D_s^*\Lambda}\cdot g_{R,D_s^*\Lambda}$
$\Lambda_c(2595)(J=\frac{1}{2})$	$2.76-0.068i$	$4.62-0.12i$
$\Lambda_c(2625)(J=\frac{3}{2})$	0	$-0.065+0.91i$

Results and discussions

The ratios with corrections from $D_s\Lambda$ and $D_s^*\Lambda$ channels

$$\frac{\Gamma[\Lambda_b \to \pi^- \Lambda_c(2595)]}{\Gamma[\Lambda_b \to \pi^- \Lambda_c(2625)]} = 0.76 \sim 0.91,$$

PDG:

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

$$\frac{\Gamma[\Lambda_b \to D_s^- \Lambda_c(2595)]}{\Gamma[\Lambda_b \to D_s^- \Lambda_c(2625)]} = 0.54 \sim 0.65.$$

The inclusion of $D_s\Lambda$, $D_s^*\Lambda$ channels improves the agreement with experiment.

Summary

- In the picture that the $\Lambda_c(2595)$ and $\Lambda_c(2625)$ are dynamically generated resonances from the interaction of DN, D^*N with coupled channels, we studied $\Lambda_b \to \pi^-(D_s^-)\Lambda_c(2595)$ and $\Lambda_b \to \pi^-(D_s^-)$ $\Lambda_c(2625)$ decays. Ratios of decay widths were predicted.

- The predicted ratio $\Gamma(\Lambda_b \to \pi^-\Lambda_c(2595))/\Gamma(\Lambda_b \to \pi^-\Lambda_c(2625))$ is in good agreement with the experimental data, showing that the molecular picture of $\Lambda_c(2595)$ and $\Lambda_c(2625)$ is reasonable.

- The relative sign of the coupling of $\Lambda_c(2595)$ to DN and D^*N is important to have good agreement with exp..

Thank you for your attention!