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Semileptonic Λ_c decay to νl^+ and $\Lambda(1405)$

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We study the semileptonic decay of Λ_c to νl^+ and $\Lambda(1405)$, where the $\Lambda(1405)$ is seen in the invariant mass distribution of $\pi\Sigma$. We perform the hadronization of the quarks produced in the reaction in order to have a meson baryon pair in the final state and then let these hadron pairs undergo final state interaction from where the $\Lambda(1405)$ is dynamically generated. The reaction is particularly suited to study this resonance, because we show that it filters $I = 0$. It is also free of tree-level $\pi\Sigma$ production, which leads to a clean signal of the resonance with no background. This same feature has as a consequence that one populates the state of the $\Lambda(1405)$ with higher mass around 1420 MeV, predicted by the chiral unitary approach. We make absolute predictions for the invariant mass distributions and find them within the measurable range in present facilities. The implementation of this reaction would allow us to gain insight into the existence of the predicted two $\Lambda(1405)$ states and their nature as molecular states.

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I. INTRODUCTION

Semileptonic decays of the Λ_c account for a fair fraction of the total width. The branching ratios for decay into $\nu_e e^+ \Lambda$ and $\nu_\mu \mu^+ \Lambda$ are both about 2% [1–3], and they have been the object of theoretical study. Different semileptonic decays of the Λ_c have been studied theoretically within the formalism of heavy quark theory [4–6]. On the other hand, semileptonic decays of B mesons have got comparatively more attention, both experimentally and theoretically. Quark models are used for B and D decays in Ref. [7], the heavy quark effective theory is also considered in Ref. [8], the light-front formalism is used in a relativistic calculation of form factors for semileptonic decays in the constituent quark model in Ref. [9], and lattice QCD calculations have also brought their share to this problem [10]. More recently, the issue has been retaken. Quark models for semileptonic decays are used in Refs. [11–13], the heavy meson chiral perturbation theory is found particularly suited in the case with a small recoil (when the lepton pair carries much energy) and is used in Ref. [14], while for a large recoil an approach that combines both hard-scattering and low-energy interactions has been developed in Ref. [15].

Particular interest is offered by semileptonic decays into a pair of mesons when this pair interacts strongly, giving rise to resonances. The interest then is focused on the region of invariant masses where the resonance appears, looking for different channels. The fact that one needs only to study a narrow window of invariant masses allows one to use the practically constant hard form factors of these processes in that range and concentrate on the effects of the meson meson interaction, thus learning about details of hadron interactions and eventually of the nature of the resonances that are formed in the process. This is the spirit of the work in Refs. [16,17]. In [16], the molecular nature of the $D^*_{s0}(2317)$ and $D^*_0(2400)$ resonances is tested using the semileptonic B_s and B decays. In [17], the nature of the light scalar mesons $f_0(500)$, $f_0(980)$, $a_0(980)$, and $\kappa(800)$ is tested with the semileptonic decays of D mesons.

The $\Lambda(1405)$ is an emblematic baryon resonance which has captured the attention of hadron physicists for a long time, because it does not follow the standard pattern of the three quark baryons. Indeed, in Refs. [18,19], it was already suggested that this resonance should be a molecular state of $\bar{K}N$ and $\pi\Sigma$. The advent of the chiral unitary theory has allowed one to make this idea more precise and consistent with the basic dynamics of QCD encoded in the chiral Lagrangians [20–34]. Early in the developments of this theory, it was found in Ref. [23] that there are two poles in the same Riemann sheet and, hence, two states, associated to this resonance. A detailed study was done in Ref. [27] by looking at the breaking of SU(3), which confirmed the existence of these two poles and its dynamical origin. One of the consequences of the existence of these two states is that the shape of the resonance varies from one reaction to another, depending on the weight given to each one of the poles by the reaction mechanisms [35–42]. Originally, most reactions showed peaks around 1400 MeV, from where the nominal mass of the resonance was taken, but the $K^- p \to \pi^0\pi^0\Sigma^0$ [38] showed a neat peak around 1420 MeV, narrower than the one observed in Refs. [35,36]. This feature was interpreted within the chiral unitary approach in Ref. [43], showing the mechanisms that gave bigger weight to the resonance with a higher mass. Another relevant

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experiment was the one of Ref. [44], which showed a peak around 1420 MeV in the $K^- d \to n\pi\Sigma$ reaction, also interpreted theoretically in Ref. [45] along the same lines (see also the related Refs. [46,47]). Similarly, the thorough data on $\pi\Sigma$ photoproduction at Jefferson Lab [39,40], and the subsequent analysis in Refs. [48,49], have further clarified the situation concerning the two $\Lambda(1405)$ states.

The need to further clarify the existence and nature of these two $\Lambda(1405)$ states has prompted the suggestion of new reactions, using weak decay processes which, due to particular selection rules, act as filters of isospin $I = 0$ and allow the formation of the $\Lambda(1405)$ without contamination of the $I = 1$. This is the case of the $\Lambda_b \to J/\psi\Lambda(1405)$ decay proposed in Ref. [50], which has partially been measured in Ref. [51] and the $\Lambda_c \to \pi\Lambda(1405)$ proposed in Ref. [52] and currently under study at Belle [53]. The neutrino-induced production of the $\Lambda(1405)$ has also been suggested as a good tool to investigate the properties and nature of this resonance [54].

In the present work, we study theoretically the semileptonic Λ_c decay to νl^+ and $\Lambda(1405)$, which, as we shall see, is a perfect filter of $I = 0$ and, hence, a very good instrument to isolate the $\Lambda(1405)$ and study its properties. The work combines the findings of $\Lambda_b \to J/\psi\Lambda(1405)$ decay in Ref. [50] with those of the semileptonic D decay studied in Ref. [17] and makes absolute predictions for invariant mass distributions of $\pi\Sigma$, from where the signal of the $\Lambda(1405)$ should be seen, and $\bar{K}N$, in the reaction $\Lambda_c \to \nu l^+ MB$, with MB either $\pi^+\Sigma^-$, $\pi^-\Sigma^+$, $\pi^0\Sigma^0$, $K^- p$, or $\bar{K}^0 n$.

II. FORMALISM

The $\Lambda_c \to \nu e^+ \Lambda(1405)$ process proceeds at the quark level through a first step shown in Fig. 1.

The process involves the cs weak transition, which is Cabibbo favored, and this is the same one as in the D decays studied in Ref. [17]. There is, however, a novelty in the present process. Indeed, if we want to see the $\Lambda(1405)$, this must be done in the mass distribution of $\pi\Sigma$, and hence the sud quark of Fig. 1 must hadronize into a meson baryon component. This is done easily for mesons, since one introduces an extra $\bar{q}q$ meson with a vacuum quantum number, $\bar{u}u + \bar{d}d + \bar{s}s$, and then the two quarks after the weak process participate in the formation of the two mesons. With three quarks after the weak vertex, as in Fig. 1, the new $\bar{q}q$ pair can be placed in between different pairs of the sud quarks. However, there is some reason to do that involving the s quark, such that the s quark goes into the emerging meson. The reasons are the following:

(i) The Λ_c has $I = 0$, and this forces the ud initial state to be in an $I = 0$ state, $\frac{1}{\sqrt{2}}(ud - du)$. The dominant mechanism that requires just a one-body operator involving the c and s quarks will leave the ud original quarks as spectators and will still have $I = 0$ in the final state. They are also in $L = 0$ in a quark picture of the wave function. Since the $\Lambda(1405)$ has negative parity, it is the s quark that will convey this parity, hence being in $L = 1$ in a quark picture. Since in the $\bar{K}N$, or meson baryon states in general, all quarks are in the ground state, the s quark must be deexcited, and hence it has to participate in the hadronization.

(ii) Even then, we have the option to have the s quark belonging to the meson or to the baryon. If the s quark goes into the meson, the original u, d quarks are spectators and go into the final baryon, the other needed quark coming from the additional $\bar{q}q$ of the hadronization. If the s quark goes into the baryon, the original u or d quark must go into the meson. In these processes, the baryon is the heaviest particle, and the phase space favors the lighter mesons and leptons to carry the momenta and, thus, the energy. If we have $\nu_e l^+ \pi\Sigma$, the pair $\nu_e l^+$ and the pion would basically carry all the energy, and then the π (and the νe^+) has about 550 MeV/c. Also, the s quark will carry the same momentum as the $\nu_e e^+$ pair and go into the Σ, essentially at rest. One has then form factors from the quark nuclear wave functions, involving twice a fair amount of momentum transfer, and the mechanism is suppressed versus the one where the original u, d quarks are spectators. After the former discussion, the dominant mechanism for the hadronization is depicted in Fig. 2. This is what was done in the $\Lambda_c \to J/\psi MB$ [50] and the $\Lambda_c \to \pi MB$ [52] reactions.

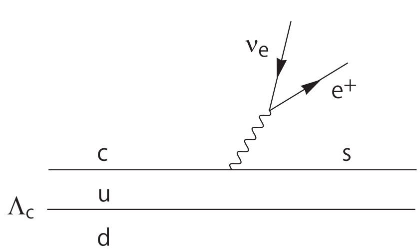

FIG. 1. Diagrammatic representation of the quark level for $\Lambda_c \to \nu_e e^+(sud)$.

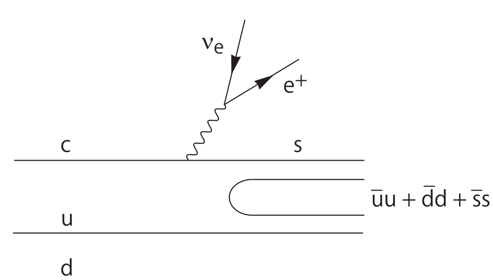

FIG. 2. Dominant mechanism for the hadronization into a meson baryon of the sud state after the weak process.

A. Hadronization

The procedure followed here is inspired in the approach of Ref. [55], where the basic mechanisms at the quark level are investigated, then pairs of hadrons are produced after implementing hadronization, and finally these hadrons are allowed to undergo final state interaction. With the u, d quarks as spectators in $I=0$, the final sud state also has $I=0$, and we, thus, have a filter of $I=0$. Then, upon hadronization, the final meson baryon is constructed as follows [50]:

$$|H\rangle = \frac{1}{\sqrt{2}}|s(\bar{u}u + \bar{d}d + \bar{s}s)(ud-du))\rangle = \frac{1}{\sqrt{2}}\sum_{i=1}^{3} P_{3i}q_i(ud-du),$$

where

$$q \equiv \begin{Bmatrix} u \\ d \\ s \end{Bmatrix}$$

and

$$P \equiv q\bar{q}^\tau = \begin{pmatrix} u\bar{u} & u\bar{d} & u\bar{s} \\ d\bar{u} & d\bar{d} & d\bar{s} \\ s\bar{u} & s\bar{d} & s\bar{s} \end{pmatrix}.$$

It is convenient to write the $q\bar{q}$ matrix P in terms of mesons, and we have

$$P \equiv \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} & K^0 \\ K^- & \bar{K}^0 & -\frac{\eta}{\sqrt{3}} + \frac{2\eta'}{\sqrt{6}} \end{pmatrix},$$

where the standard η, η' mixing has been assumed [50,56]. Neglecting the η' terms because of its large mass, as done in Ref. [50], we have

$$|H\rangle = \frac{1}{\sqrt{2}}\left(K^- u(ud-du) + \bar{K}^0 d(ud-du) - \frac{1}{\sqrt{3}}\eta s(ud-du)\right).$$

We can see that we have now the mixed antisymmetric representation of the octet of baryons. By taking this wave function for the p, n, and Λ states (see [57]), we find [50]

$$|H\rangle = |K^- p\rangle + |\bar{K}^0 n\rangle - \frac{\sqrt{2}}{3}|\eta\Lambda\rangle. \tag{1}$$

One must recall that the $\Lambda(1405)$ is obtained in a coupled channel from the interaction of the $\bar{K}N$, $\pi\Sigma$, $\eta\Lambda$, $K\Xi$ states; however, as a first step only the $\bar{K}N$ and $\eta\Lambda$ states are formed but not the $\pi\Sigma$ and $K\Xi$. Since the $\Lambda(1405)$ is seen in the $\pi\Sigma$ invariant mass spectrum, the only way to see $\pi\Sigma$ is through a rescattering of the $\bar{K}N$ and $\eta\Lambda$ states, and this involves directly the transition $\bar{K}N \to \pi\Sigma$ and $\eta\Lambda \to \pi\Sigma$ matrix elements that contain the $\Lambda(1405)$ pole. In other words, we do not have $\pi\Sigma$ at the tree level, and, thus, one avoids the background, hence, stressing more the $\Lambda(1405)$ signal. We have these two benefits in the reaction: there is an $I=0$ filter, and the $\Lambda(1405)$ is produced with no background.

B. Final state interaction

The final state interaction is depicted in Fig. 3.

The matrix element for the $\Lambda_c \to (\nu_e e^+)M_j B_j$ is then given by

$$t_{\mathrm{had},j}(M_{\mathrm{inv}}) = C\left(h_j + \sum_i h_i G_i(M_{\mathrm{inv}}) t_{ij}(M_{\mathrm{inv}})\right), \tag{2}$$

where from Eq. (1) we have

$$h_{\pi^0\Sigma^0} = h_{\pi^+\Sigma^-} = h_{\pi^-\Sigma^+} = 0, \qquad h_{\eta\Lambda} = -\frac{\sqrt{2}}{3},$$
$$h_{K^-p} = h_{\bar{K}^0 n} = 1, \qquad h_{K^+\Xi^-} = h_{K^0\Xi^0} = 0,$$
$$h_{\pi^0\Lambda} = h_{\eta\Sigma^0} = 0.$$

In Eq. (2), G_i is the loop function of the meson baryon and t_{ij} the scattering matrix in the basis of states K^-p, $\bar{K}^0 n$, $\pi^0\Lambda$, $\pi^0\Sigma^0$, $\eta\Lambda$, $\eta\Sigma^0$, $\pi^+\Sigma^-$, $\pi^-\Sigma^+$, $K^+\Xi^-$, $K^0\Xi^0$ with t given by the Bethe-Salpeter equation

$$t = [1 - VG]^{-1}V \tag{3}$$

and V the transition potential taken from Ref. [22]. The G function is regularized with a cutoff in three momenta, and we take $q_{\max} = 630$ MeV as in Ref. [22]. The factor C, which we take constant in the limited range of M_{inv} that we will study, encodes the matrix element of the hadronization.

On closing this section, we would like to make a connection to previous works on the creation of meson pairs which indicate a suppression on strangeness

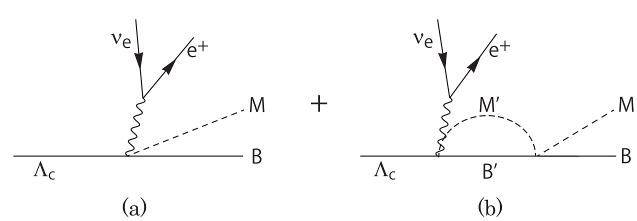

FIG. 3. Diagrams involved in the final state interaction of the primary MB mesons: (a) tree level and (b) rescattering.

production. Our mechanism for pair production is based on the hadronization introducing the $\bar{q}q$ pair with the vacuum quantum numbers $\bar{u}u + \bar{d}d + \bar{s}s$ [57,58]. We are assuming that this process is SU(3) symmetric; in particular, the $\bar{s}s$ pair is produced with the same weight as the $\bar{u}u$ and $\bar{d}d$. However, processes of strangeness production in e^+e^- and $p\bar{p}$ reactions indicate that there is a suppression in the strangeness production, implying a reduction factor in the production of the $\bar{s}s$ component [59–63]. It is interesting to look at this from the present perspective. In our formalism, a suppression of the $\bar{s}s$ component would revert into a suppression of the $\eta\Lambda$ component in the hadron state $|H\rangle$ of Eq. (1). We do not study the production of this channel in this work, since in the final reaction we look only at the $\bar{K}N$ and $\pi\Sigma$ states. However, through rescattering in Eq. (2), it can give a contribution to these processes. In our formalism, there is also a suppression of the contribution of this mode but from dynamical reasons. Indeed, the dynamics of the chiral unitary approach makes the transition t_{ij} matrix elements from $\eta\Lambda$ to $\bar{K}N$ small, as well as the diagonal $\eta\Lambda$ matrix element. The suppression in strangeness production would also appear here but for dynamical reasons of final state interaction, not from a direct suppression at the $\bar{q}q$ production level. The breaking of SU(3) due to a final state interaction, rather than to elementary vertices, is quite common in hadron physics. One of the remarkable cases is the generation of one $\Lambda(1405)$ and the $\Lambda(1670)$, which would be degenerate using the chiral Lagrangians and equal masses for the pseudoscalar mesons of the pion SU(3) multiplet and for the baryons of the proton octet. Indeed, as shown in Ref. [27], it is the meson baryon interaction and the consideration of different hadron masses that break the degeneracy, producing two states quite apart in energy.

C. The weak vertex

We must take into account the weak vertex, and altogether the matrix element T_{Λ_c} for the semileptonic decay is given by [17]

$$T_{\Lambda_c} = \frac{G_{\rm F}}{\sqrt{2}} L^\alpha Q_\alpha t_{\rm had}, \tag{4}$$

where

$$L^\alpha = \bar{u}_\nu \gamma^\alpha (1-\gamma_5) v_l, \qquad Q_\alpha = \bar{u}_q \gamma_\alpha (1-\gamma_5) u_c. \tag{5}$$

By following the steps of Refs. [16,17], we find for the sum and average over the polarization of the fermions

$$\frac{1}{2}\sum_{\rm pol} |T_{\Lambda_c}|^2 = \frac{4|G_{\rm F} t_{\rm had} V_{cs}|^2}{m_e m_\nu m_{\Lambda_c} m_R} (p_{\Lambda_c}\cdot p_\nu)(p_R \cdot p_e), \tag{6}$$

where R stands for the final MB system formed and, thus, $M_R = M_{\rm inv}$. Further steps are done in Ref. [16] to perform the angular integration of the leptons in the νe rest frame, and finally one obtains a formula for $\frac{d\Gamma}{dM_{\rm inv}}$ given by

$$\frac{d\Gamma_i}{dM_{\rm inv}} = \frac{|G_{\rm F} V_{cs} t_{{\rm had},i}|^2}{32\pi^5 m_{\Lambda_c}^3 M_{\rm inv}^{(i)}} \times \int dM_{\rm inv}^{(\nu e)} P^{\rm cm} \tilde{p}_\nu \tilde{p}_i (M_{\rm inv}^{(\nu e)})^2 \left(\tilde{E}_{\Lambda_c}\tilde{E}_i - \frac{\tilde{p}_{\Lambda_c}^2}{3}\right), \tag{7}$$

where $P^{\rm cm}$ is the momentum of the νe system in the Λ_c rest frame, $\tilde{p}_\nu$ is the momentum of the neutrino in the νe rest frame, $\tilde{p}_i$ is the relative momentum of the final meson in the $(MB)_i$ rest frame, $\tilde{E}_{\Lambda_c}$ and $\tilde{E}_i$ are the Λ_c and $(MB)_i$ energy, respectively, in the νe rest frame, and $\tilde{p}_{\Lambda_c}$ is the momentum of the Λ_c in the ν_e rest frame:

$$P^{\rm cm} = \frac{\lambda^{1/2}(m_{\Lambda_c}^2, M_{\rm inv}^{(\nu e)2}, M_{\rm inv}^{(i)2})}{2m_{\Lambda_c}}, \tag{8}$$

$$\tilde{p}_\nu = \frac{\lambda^{1/2}(M_{\rm inv}^{(\nu e)2}, m_\nu^2, m_e^2)}{2M_{\rm inv}^{(\nu e)}}, \tag{9}$$

$$\tilde{p}_i = \frac{\lambda^{1/2}(M_{\rm inv}^{(i)2}, m_i^2, M_i^2)}{2M_{\rm inv}^{(i)}}, \tag{10}$$

with m_i and M_i the meson and baryon masses, respectively, of the $(MB)_i$ final state,

$$\tilde{E}_{\Lambda_c} = \frac{m_{\Lambda_c}^2 + M_{\rm inv}^{(\nu e)2} - M_{\rm inv}^{(i)2}}{2M_{\rm inv}^{(\nu e)}}, \tag{11}$$

$$\tilde{E}_i = \frac{m_{\Lambda_c}^2 - M_{\rm inv}^{(\nu e)2} - M_{\rm inv}^{(i)2}}{2M_{\rm inv}^{(\nu e)}}, \tag{12}$$

$$\tilde{p}_{\Lambda_c}^2 = \tilde{E}_{\Lambda_c}^2 - m_{\Lambda_c}^2. \tag{13}$$

We take $G_{\rm F} = 1.166\times 10^{-5}\ {\rm GeV}^{-2}$ and $(V_{cs}) = \cos\theta_c = 0.986$, and for the constant C we take the same value that was obtained in the semileptonic decay of D to two mesons [17], which involves the cs transitions as here; $C = 4.597$ was adjusted to the experimental data of the $D^+ \to (\pi^+ K^-)_{s\text{-wave}} e^+ \nu_e$ reaction. This is not necessarily the case, since in Ref. [17] one studied decay of mesons, and here we have decay of baryons. The matrix elements are not necessarily the same, but as an order of magnitude this can serve. The real predictions of the work are the shape of the $\Lambda(1405)$, which is due to the state around 1420 MeV and the relative strength of $\bar{K}N$ mass distribution above the $\bar{K}N$ threshold and the $\pi\Sigma$ distribution at the resonance peak. As to the absolute ratio, we can get a feeling for the uncertainties by taking also the value of $C = 7.22$ obtained from the semileptonic B decays in Ref. [16].

III. RESULTS

In Fig. 4, we plot the integrand of the integral that appears Eq. (7) for different values of $M_{\rm inv}$. The calculations are done for $\nu_e e^+$. The results for $\nu_\mu \mu^+$ are very similar. As we can see, the strength of this distribution peaks at large values of $M_{\rm inv}^{(\nu e)}$, close to its maximum value, something that we already anticipated and used in discussions in the former section. This justifies taking elements of the work of Ref. [14], where the s-wave form factors prior to final state interaction of the hadrons are found to be very smooth, which justifies our choice of a constant C in our limited range of invariant masses.

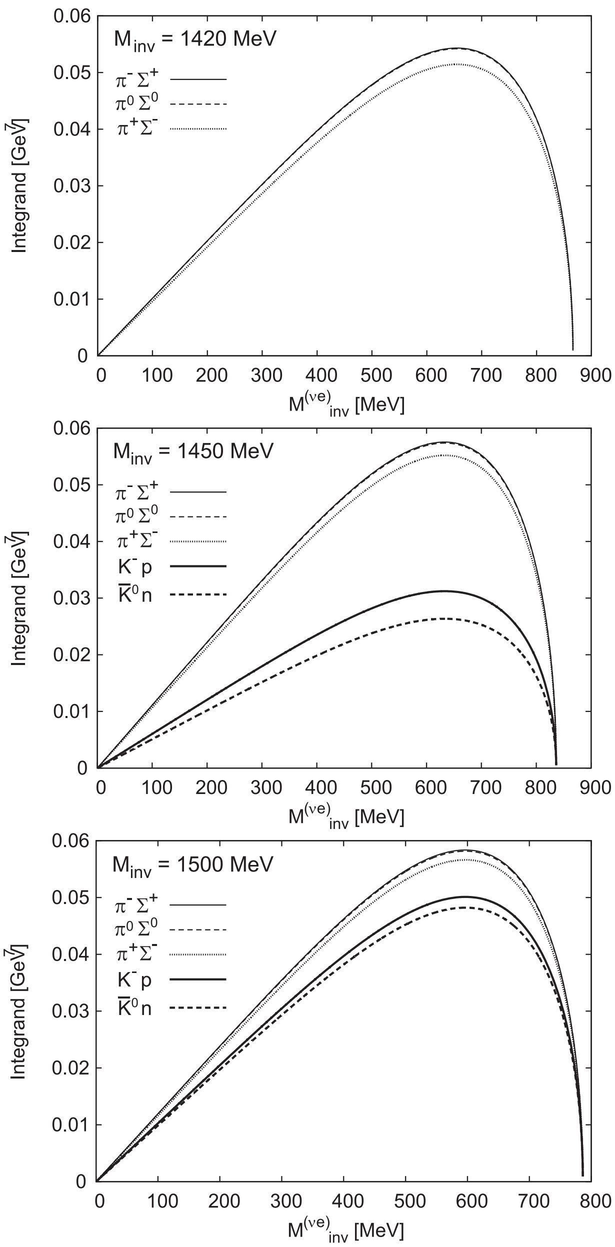

FIG. 4. The integrand of the integral that appears in Eq. (7) as a function $M_{\rm inv}^{(\nu e)}$ for different values of the invariant mass of the final MB pair. The value $C = 4.597$ is used.

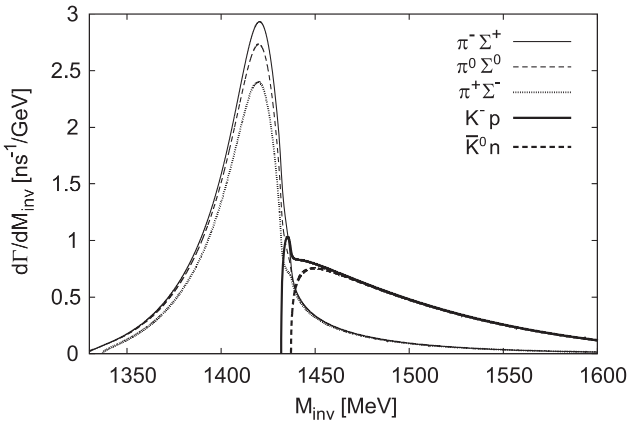

FIG. 5. The invariant mass distributions of Eq. (7) for different channels. The value $C = 4.597$ is used.

In Fig. 5, we show the final result for the invariant mass distribution of Eq. (7) for $\pi^+\Sigma^-$, $\pi^-\Sigma^+$, $\pi^0\Sigma^0$, K^-p, and $\bar{K}^0 n$ in the final state. We observe neat peaks for $\pi\Sigma$ around 1420 MeV. This means that one is mostly exciting the $\Lambda(1405)$ state at 1420 MeV. The other state is around 1385 MeV but does not play much of a role in this reaction. This has a dynamical reason. As is well known from the chiral unitary approach, the high mass $\Lambda(1405)$ state couples mostly to $\bar{K}N$, while the one at 1385 MeV couples more strongly to $\pi\Sigma$. Since in the primary production of MB we produce $\bar{K}N$, but not $\pi\Sigma$, it becomes clear that the resonance excited is the one around 1420 MeV. This is a neat prediction of the chiral unitary approach for these resonances that the experiment could prove or disprove.

We observe some differences in the strength for $\pi^-\Sigma^+$, $\pi^+\Sigma^-$, and $\pi^0\Sigma^0$. This is because, even if we have filtered $I = 0$ in this reaction, the scattering matrices induce a bit of isospin breaking and became the different masses of mesons and baryons in the same isospin multiplet. This can also be observed in the Bonn model in Fig. 3 of Ref. [50]. The result and the ordering of the strength of the channels are remarkably similar to what is obtained in Fig. 5 of Ref. [52].

The strength for the K^-p and $\bar{K}^0 n$ production is also similar to what is obtained in Refs. [50,52]. The strength of the $\bar{K}N$ distribution at its peak is about one-fourth of the strength of the $\pi\Sigma$ distribution at its peak, a feature also shared by these different works, and this is also a prediction of the chiral unitary approach. The fall down with $M_{\rm inv}$ of this distribution depends somewhat on the reaction and the particular model used. Here we use the lowest-order Weinberg Tomozawa term for the kernel V in Eq. (3), while in Ref. [50], in the Bonn model, higher-order terms were considered in the kernel [34].

The values obtained for $d\Gamma/dM_{\rm inv}$ are of the same order of magnitude as those found in Ref. [17] for the D semileptonic decays with two mesons in the final state.

If we integrate the strength below the $\Lambda(1405)$ peak, we find $\Gamma \simeq 0.108\ \mathrm{ns}^{-1}$, and the mean life of the Λ_c is $5\times 10^3\ \mathrm{ns}^{-1}$. Thus, we are talking about a branching ratio of about 2×10^{-5}, which is within measuring range, since boundaries of 10^{-6} for certain branching ratios have been established [3]. If we use instead the value $C = 7.22$ from Ref. [16], then the branching ratio becomes 5×10^{-5}. Accepting uncertainties in the value of C, the message is that the ratios obtained are within present measurable capacities.

IV. CONCLUSIONS

We have studied the semileptonic decay of the $\Lambda_c \to \nu_l l^+ MB$ with MB a pair of meson baryons, $\pi\Sigma$ or $\bar{K}N$. The idea is to look for the $\pi\Sigma$ mass distribution where the $\Lambda(1405)$ state of higher energy (around 1420 MeV) should show up. The reaction was shown to have some welcome features: it filters $I = 0$, and thus one avoids having to separate contributions from $I = 1$, which complicate the analysis of data in other reactions. Next, since the primary production of a meson baryon in this process does not produce $\pi\Sigma$, this channel will appear through a rescattering of the $\bar{K}N$ and $\eta\Lambda$, which are the states primarily produced. This avoids background originated from tree-level terms, and the resonance shows up more clearly. Finally, the chiral unitary approach predicts two states around the $\Lambda(1405)$: the one with lower mass coupling mostly to $\pi\Sigma$, and the one of higher mass coupling mostly to $\bar{K}N$. Since the reaction is such that the resonance is produced though a rescattering of a primary $\bar{K}N$, this guarantees that one will see mostly this latter state, and we predict a clean peak around 1420 MeV, that the experiment could support or disprove. In addition, we also make predictions for the production of $\bar{K}N$ pairs, which are tied to the dynamics of the chiral unitary approach and could be investigated at the same time.

The fact that we need only the mass distribution in a narrow region of the invariant mass allows us to factorize in a constant all elements of the weak transition and the hadronization which are not explicitly considered, and the dependence of the final distributions on the invariant mass is then tied to the final state interaction of the meson baryon pairs, which, in particular, generate the two $\Lambda(1405)$ states.

While most of the theoretical hadron community would agree on the existence of two states of the $\Lambda(1405)$ and the molecular nature of these states, there are still some differences as to the position of the lower mass state and details on the mass distributions. Also, these ideas are not so broadly accepted in the experimental hadron community. It is most convenient to carry out these experiments where neat predictions are made which are tied to the concrete chiral dynamics in coupled channels that generate these states. Experimental confirmation of these predictions would be a step forward to consolidate these ideas and make progress in the understanding of the nature of baryons.

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