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$\Sigma^*_{1/2^-}(1380)$ in the $\Lambda_c^+ \to \eta\pi^+\Lambda$ decay

Ju-Jun Xie[1] and Li-Sheng Geng[2,*]

[1]*Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China*
[2]*School of Physics and Nuclear Energy Engineering and International Research Center for Nuclei and Particles in the Cosmos and Beijing Key Laboratory of Advanced Nuclear Materials and Physics, Beihang University, Beijing 100191, China*

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A Σ^* state with spin parity $J^P = 1/2^-$ with mass and width around 1380 and 120 MeV, referred to as the $\Sigma^*_{1/2^-}(1380)$, has been predicted in several pentaquark models and inferred from the analysis of CLAS γp data. In the present work, we discuss how one can employ the $\Lambda_c^+ \to \eta\pi^+\Lambda$ decay to test its existence, as well as to study the $\Sigma^*(1385)$ state with $J^P = 3/2^+$. Because the final $\pi^+\Lambda$ system is in a pure isospin $I = 1$ combination, the $\Lambda_c^+ \to \eta\pi^+\Lambda$ decay can be an ideal process to study these Σ^* resonances. In particular, we show that the decay angle and energy distributions of the π^+ are very different for $\Sigma^*(1385)$ and $\Sigma^*_{1/2^-}(1380)$. The proposed decay mechanism as well as the existence of the $\Sigma^*_{1/2^-}(1380)$ state can be checked by future BESIII and Belle experiments.

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I. INTRODUCTION

Study of the spectrum of Σ^* states is one of the most important issues in hadronic physics [1,2]. Σ^* states were mostly produced and studied in $\bar{K}$-induced reactions, and our knowledge of them is still rather limited [1–3]. In the low-lying energy region, only a few Σ^* excited states are well established, such as the $\Sigma^*(1385)$ of spin parity $J^P = 3/2^+$, $\Sigma^*(1660)$ of $J^P = 1/2^+$, $\Sigma^*(1670)$ of $J^P = 3/2^-$, $\Sigma^*(1750)$ of $J^P = 1/2^-$, and $\Sigma^*(1775)$ of $J^P = 5/2^-$. The others are not well established and for some even their existence has not been confirmed [3]. Thus, more studies of Σ^* resonances both on theoretical and experimental sides are necessary.

Based on the pentaquark picture, a new Σ^* state with $J^P = 1/2^-$, referred to as the $\Sigma^*(1380)$, was predicted with mass around 1380 MeV [4]. Another more general pentaquark model [5] without introducing explicitly diquark clusters also predicts this new Σ^* state but with mass around 1405 MeV. The possibility for the existence of such a new $\Sigma^*(1380)$ state in J/ψ decays was pointed out in Refs. [6,7]. Later on, the studies of the $K^- p \to \Lambda\pi^+\pi^-$ reaction have shown some further evidence for the existence of the $\Sigma^*(1380)$ state, yielding a mass around 1380 MeV and a width about 120 MeV [8,9]. Furthermore, in Refs. [10–12], the role played by the new $\Sigma^*(1380)$ state in the $K\Sigma^*(1385)$ photoproduction and $\Lambda p \to p\Lambda\pi^0$ reaction was studied, and it was shown that, apart from the existing $\Sigma^*(1385)$ resonance, there are signs of the $\Sigma^*(1380)$ state. Recently, the existence of an isospin $I = 1$ resonance in the vicinity of the $\bar{K}N$ threshold was studied in Ref. [13] based on the analysis of the CLAS data on the $\gamma p \to K^+\pi^\pm\Sigma^\mp$ reactions [14]. Such a state is also discussed in Refs. [15–18] within the unitary chiral perturbation theory. However, the existence of such an $I = 1$ state around the $\bar{K}N$ threshold is less clear since it depends on the details of the fits performed [17]. Clearly, it is helpful to check the validity of pentaquark models by studying the contributions of the $\Sigma^*(1380)$ state in different reactions. Because the mass of this new Σ^* state is close to the well established $\Sigma^*(1385)$ resonance, it will manifest itself in the production of the $\Sigma^*(1385)$ resonance and as a result an experimental study of the $\Sigma^*(1385)$ resonance might interfere with that of the $\Sigma^*(1380)$, because their mass overlaps and they share the same $\pi\Lambda$ decay mode.

Recently, it has been shown that the nonleptonic weak decays of charmed baryons are useful processes to study hadronic resonances, some of which are subjects of intense debate about their nature [19–21]. For instance, the $\Lambda_c^+ \to \pi^+ MB$ weak decays were studied in Ref. [22], where M and B stand for mesons and baryons. It is shown there that these weak decays might be ideal processes to study the $\Lambda(1405)$ and $\Lambda(1670)$ resonances, because they are dominated by the isospin $I = 0$ contribution. In Ref. [23], the $\pi\Sigma$ mass distribution was studied in the $\Lambda_c^+ \to \pi^+\pi\Sigma$ decay with the aim of extracting the $\pi\Sigma$ scattering lengths. In a recent work [24] the role of the exclusive Λ_c^+ decays into a neutron in testing the flavor symmetry and final state interactions was investigated. It was shown that the three body nonleptonic decays are of great interest to explore final state interactions in Λ_c^+ decays. Along the same line, in Ref. [25], the $\Lambda_c^+ \to \pi^+\eta\Lambda$ decay was revisited taking into account both the $\eta\Lambda$ and $\pi^+\eta$ final state interactions. It was found that the $\pi^+\eta$ and $\eta\Lambda$ invariant mass distributions show clear cusp and peak structures, which can be associated with the $a_0(980)$ and $\Lambda(1670)$ resonances. These results clearly show that

*lisheng.geng@buaa.edu.cn

the Λ_c^+ decays provide an alternative useful source to obtain information on the structure of low lying hadronic states.

One should note that the above-mentioned works [22,25] considered only the color-favored external W-emission diagrams, but neglected the color-suppressed W-exchange diagrams [26,27]. On the other hand, the experimental measurements of the decay modes of $\Lambda_c^+ \to (\pi\Sigma)^+$, $\eta\Sigma^+$, and $\eta\Sigma^{*+}$ [3,28] indicate that the W-exchange diagrams, which are subject to color and helicity suppression, can become relevant in certain Λ_c^+ decay modes [29], where the external W-emission diagrams do not contribute. We note that recently the possibility of searching for Ξ_{bc}^0 and Ξ_{cc}^+ is explored in the W-exchange processes, $\Xi_{bc}^0 \to pK^-$ and $\Xi_{cc}^+ \to \Sigma_c^{++}(2520)K^-$ [30].

In this work, we study the role of the $\Sigma^*_{1/2^-}(1380)$ in the $\Lambda_c^+ \to \eta\Sigma^*_{1/2^-}(1380) \to \eta\pi^+\Lambda$ decay, which can proceed via the external W-emission diagram, similar to the P_c states produced in the $\Lambda_b^0 \to K^- P_c^+$ decay [31]. Meanwhile, for comparison, we study the $\Lambda_c^+ \to \eta\Sigma^{*+}(1385) \to \eta\pi^+\Lambda$ decay, which is dominated by the W-exchange diagram [32].

This article is organized as follows. In Sec. II, we present the theoretical formalism of the $\Lambda_c^+ \to \eta\pi^+\Lambda$ decay. Numerical results and discussions are presented in Sec. III, followed by a short summary in Sec. IV.

II. FORMALISM

In this section, we introduce the theoretical formalism and ingredients to study the $\Lambda_c^+ \to \eta\pi^+\Lambda$ decay. In the following, we use Σ_1^* and Σ_2^* to denote the $\Sigma^*_{1/2^-}(1380)$ state and the $\Sigma^*(1385)$ resonance.

A. Feynman diagrams and decay amplitudes

Because $\Sigma^*_{1/2^-}(1380)$ has a large five-quark component [4], it can be produced via the color-favored external W-emission diagram as shown in Fig. 1(a). The hadron level diagram for the decay of $\Lambda_c^+ \to \eta\Sigma^{*+}_{1/2^-}(1380) \to \eta\pi^+\Lambda$ is shown in Fig. 1(b) with $\Sigma^{*+}(1380)$ decaying into $\pi^+\Lambda$.

The general quark level internal W-exchange diagram for the $\Lambda_c^+ \to \eta\Sigma^{*+}(1385)$ is shown in Fig. 2(a). In principle, there are also penguin-type quark diagrams, which, however, can be neglected in charm decays due to Glashow-Iliopoulos-Maiani cancellation [32]. The decay of $\Lambda_c^+ \to \eta\Sigma^{*+}(1385) \to \eta\pi^+\Lambda$ at the hadron level is shown in Fig. 2(b).

The general decay amplitudes for $\Lambda_c^+ \to \eta\Sigma^{*+}_{1/2^-}(1380)$ and $\Lambda_c^+ \to \eta\Sigma^{*+}(1385)$ can be decomposed into two different structures as

$$\mathcal{M}(\Lambda_c^+ \to \eta\Sigma_1^{*+}) = i\bar{u}(q)(A_1 + B_1\gamma_5)u(p), \quad (1)$$

$$\mathcal{M}(\Lambda_c^+ \to \eta\Sigma_2^{*+}) = \frac{i}{m_\eta}\bar{u}_\mu(q)p_1^\mu(A_2 + B_2\gamma_5)u(p), \quad (2)$$

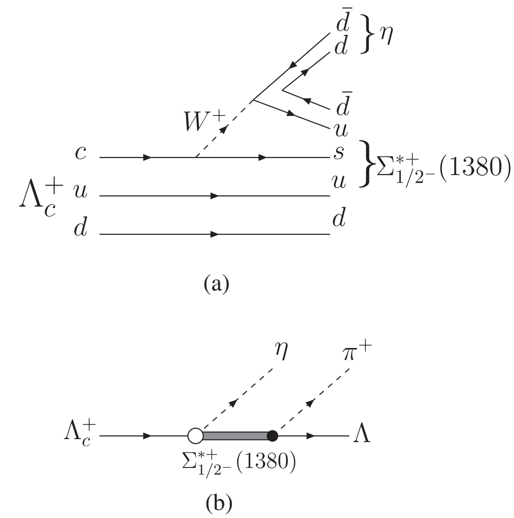

FIG. 1. Quark level diagram for $\Lambda_c^+ \to \eta\Sigma^{*+}_{1/2^-}(1380)$ (a) and hadron level diagram for $\Lambda_c^+ \to \eta\Sigma^{*+}_{1/2^-}(1380) \to \eta\pi^+\Lambda$ decay (b).

where q, p, and p_1 are the momentum of Σ_1^{*+} or Σ_2^{*+}, Λ_c^+, and η meson, the A_1 and B_1 are s-wave and p-wave amplitudes, while A_2 and B_2 are p-wave and D-wave amplitudes, respectively.

To get the whole decay amplitudes of the diagrams shown in Figs. 1(b) and 2(b), we use the interaction Lagrangian densities of Refs. [33–36] for $\Sigma_1^*\pi\Lambda$ and $\Sigma_2^*\pi\Lambda$ vertexes,

$$\mathcal{L}_{\pi\Lambda\Sigma_1^*} = g_{\pi\Lambda\Sigma_1^*}\bar{\Sigma}_1^*\vec{\tau}\cdot\vec{\pi}\Lambda + \text{H.c.}, \quad (3)$$

$$\mathcal{L}_{\pi\Lambda\Sigma_2^*} = \frac{g_{\pi\Lambda\Sigma_2^*}}{m_\pi}\bar{\Sigma}_2^{*\mu}(\vec{\tau}\cdot\partial_\mu\vec{\pi})\Lambda + \text{H.c.}, \quad (4)$$

where Σ_1^* and $\Sigma_2^{*\mu}$ are the fields for $\Sigma^*(1380)$ and $\Sigma^*(1385)$, respectively.

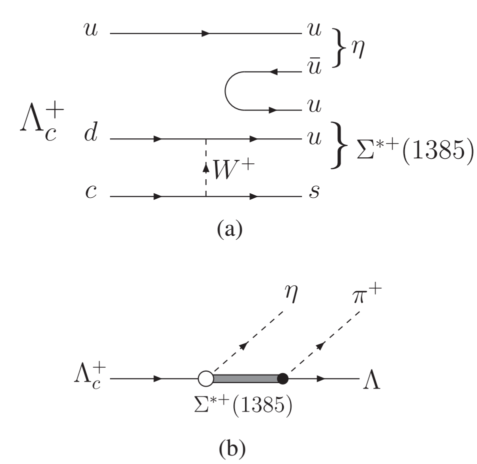

FIG. 2. Quark level diagram for $\Lambda_c^+ \to \eta\Sigma^{*+}(1385)$ (a) and hadron level diagram for $\Lambda_c^+ \to \eta\Sigma^{*+}(1385) \to \eta\pi^+\Lambda$ decay (b).

The coupling constant $g_{\pi\Lambda\Sigma_2^*} = 1.26$ is determined from the experimental partial decay width of $\Sigma^*(1385) \to \pi\Lambda$ [3]. For $g_{\pi\Lambda\Sigma_1^*}$, we fix it to be 2.12 [11,12], assuming that the $\Sigma^*(1380)$ total decay width, 120 MeV, is solely from the $\pi\Lambda$ decay.

The invariant decay amplitude of the $\Lambda_c^+ \to \eta\pi^+\Lambda$ is

$$\mathcal{M}_1 = i g_{\pi\Lambda\Sigma_1^*} \bar{u}(p_3) G^{\Sigma_1^*}(q)(A_1 + B_1\gamma_5)u(p), \quad (5)$$

$$\mathcal{M}_2 = \frac{i g_{\pi\Lambda\Sigma_2^*}}{m_\eta m_\pi} \bar{u}(p_3) p_2^\mu G^{\Sigma_2^*}_{\mu\nu}(q) p_1^\nu (A_2 + B_2\gamma_5)u(p), \quad (6)$$

where $\mathcal{M}_1$ and $\mathcal{M}_2$ stand for the contributions from $\Sigma^*_{1/2^-}(1380)$ and $\Sigma^*(1385)$, respectively. In the above equations, p_2 and p_3 represent the four-momenta of the final π^+ and Λ, respectively. The propagators for $\Sigma^*_{1/2^-}(1380)$ and $\Sigma^*(1385)$ are as follows:

$$G^{\Sigma_1^*}(q) = i\frac{\not{q} + M_{\Sigma_1^*}}{q^2 - M^2_{\Sigma_1^*} + iM_{\Sigma_1^*}\Gamma_{\Sigma_1^*}}, \quad (7)$$

$$G^{\Sigma_2^*}_{\mu\nu}(q) = i\frac{\not{q} + M_{\Sigma_2^*}}{q^2 - M^2_{\Sigma_2^*} + iM_{\Sigma_2^*}\Gamma_{\Sigma_2^*}} P_{\mu\nu}, \quad (8)$$

with

$$P^{\mu\nu} = -g^{\mu\nu} + \frac{1}{3}\gamma^\mu\gamma^\nu + \frac{2q^\mu q^\nu}{3M^2_{\Sigma_2^*}} + \frac{\gamma^\mu q^\nu - \gamma^\nu q^\mu}{3M_{\Sigma_2^*}}, \quad (9)$$

where $M_{\Sigma_1^*}$ ($M_{\Sigma_2^*}$) and $\Gamma_{\Sigma_1^*}$ ($\Gamma_{\Sigma_2^*}$) are the mass and total decay width of $\Sigma^*_{1/2^-}(1380)$ [$\Sigma^*(1385)$] resonance. We take $M_{\Sigma_1^*} = 1380$ MeV and $\Gamma_{\Sigma_1^*} = 120$ MeV as in Refs. [8,9]. For $M_{\Sigma_2^*}$ and $\Gamma_{\Sigma_2^*}$, we take $M_{\Sigma_2^*} = 1382.8$ MeV and $\Gamma_{\Sigma_2^*} = 36$ MeV as in the PDG [3].

B. Invariant mass, decay angle and energy distributions

The $\pi^+\Lambda$ invariant mass distribution for the $\Lambda_c^+ \to \eta\pi^+\Lambda$ decay reads [3]

$$\frac{d\Gamma}{dM_{\pi^+\Lambda}} = \frac{m_\Lambda}{32\pi^3 M_{\Lambda_c^+}} \int \sum |\mathcal{M}|^2 |\vec{p}_1||\vec{p}^*| d\cos\theta^*, \quad (10)$$

where $|\vec{p}^*|$ and θ^* are the three-momentum and decay angle of the outing π^+ (or Λ) in the center-of-mass (c.m.) frame of the final $\pi^+\Lambda$ system, $|\vec{p}_1|$ is the three-momentum of the final η meson in the rest frame of Λ_c^+, and $M_{\pi^+\Lambda}$ is the invariant mass of the final $\pi^+\Lambda$ system.

The decay angle and energy distributions of the outgoing particle can be used to distinguish the intermediate Σ^* resonances with different spin and parity. In the present case, we are interested in $d\Gamma/d\cos\theta^*$, which reads

$$\frac{d\Gamma}{d\cos\theta^*} = \frac{m_\Lambda}{32\pi^3 M_{\Lambda_c^+}} \int \sum |\mathcal{M}|^2 |\vec{p}_1||\vec{p}^*| dM_{\pi^+\Lambda}. \quad (11)$$

The energy distribution of the π^+ meson reads

$$\frac{d\Gamma}{dE_{\pi^+}} = \frac{m_\Lambda}{32\pi^3} \int \sum |\mathcal{M}|^2 dE_\Lambda, \quad (12)$$

where E_{π^+} and E_Λ are the energies of π^+ and Λ in the rest frame of Λ_c^+.

III. NUMERICAL RESULTS AND DISCUSSION

In Fig. 3 we show the Dalitz plot for $M^2_{\eta\pi^+}$ and $M^2_{\pi^+\Lambda}$ in the $\Lambda_c^+ \to \eta\pi^+\Lambda$ decay. If we take $M^2_{\pi^+\eta} \sim 1.0$ GeV^2, where the $a_0(980)$ meson gives significant contributions [25], we see that $M^2_{\pi^+\Lambda}$ goes from 1.6 to 3.0 GeV^2, but the range is similar for other values of $M^2_{\pi^+\eta}$ in a wide range. This means that the strength of $\pi^+\Lambda$ invariant mass distribution will spread in a wide range of $M^2_{\pi^+\eta}$ and we expect that the contribution from the $a_0(980)$ state will behave roughly like a background following the phase space. Hence, in this work we do not consider the contribution from $a_0(980)$ in the calculation of the $\pi^+\Lambda$ invariant mass distribution.

In Fig. 4 we show the Dalitz plot for $M^2_{\eta\Lambda}$ and $M^2_{\pi^+\Lambda}$ in the $\Lambda_c^+ \to \eta\pi^+\Lambda$ decay. If we take $M^2_{\eta\Lambda} \sim 2.8$ GeV^2, where the $\Lambda(1670)$ resonance gives significant contributions [25], we see that $M^2_{\pi^+\Lambda}$ stays in a very narrow and high energy range from 2.9 to 3.0 GeV^2, but we are interested in $d\Gamma/dM_{\pi^+\Lambda}$ in the range of $M^2_{\pi^+\Lambda}$ around 1.9 GeV^2. Hence we expect that the contribution of the $\Lambda(1670)$ resonance will not affect in any significant way the $\pi^+\Lambda$ mass distribution and we neglected its contribution in this work.

In order to evaluate the invariant mass, decay angle, and decay energy distributions of $d\Gamma/dM_{\pi^+\Lambda}$, $d\Gamma/d\cos\theta^*$ and $d\Gamma/dE_{\pi^+}$ we have to know the values of A_1, B_1, A_2 and B_2.

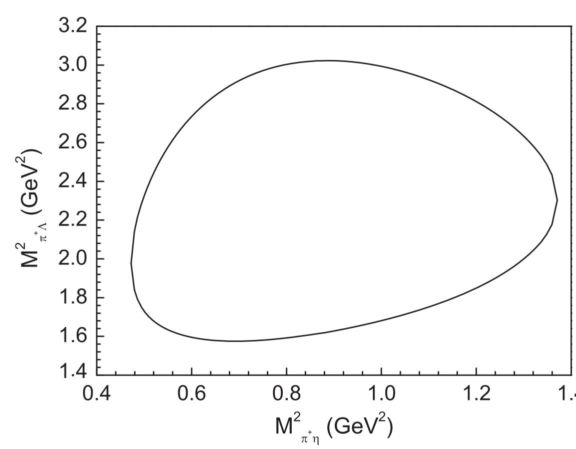

FIG. 3. Dalitz plot for $\Lambda_c^+ \to \eta\pi^+\Lambda$ decay, in the $\pi^+\eta$ and $\pi^+\Lambda$ invariant masses square.

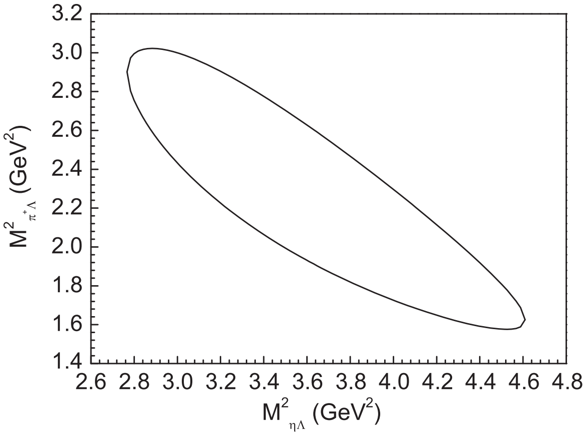

FIG. 4. Dalitz plot for $\Lambda_c^+ \to \eta\pi^+\Lambda$ decay, in the $\eta\Lambda$ and $\pi^+\Lambda$ invariant masses square.

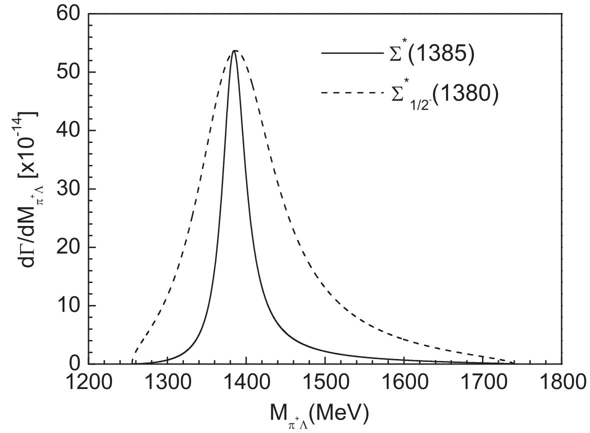

FIG. 5. Invariant mass distributions $d\Gamma/dM_{\pi^+\Lambda}$ as a function of $M_{\pi^+\Lambda}$.

Fortunately, we find that the shapes of the invariant mass, decay angle, and decay energy distributions of the A_1 (A_2) and B_1 (B_2) terms are similar and we take $A_1 = B_1$ and $A_2 = B_2$ in this work. They are also assumed to be constant.[1] From the Λ_c^+ total decay width $\Gamma_{\Lambda_c^+} = 3.29 \times 10^{-9}$ MeV and the branch ratio $\mathrm{Br}[\Lambda_c^+ \to \eta\Sigma^{*+}(1385)] = 1.08\%$ [3], we obtain $A_2 = B_2 = 5.51 \times 10^{-7}$, using the following decay width formula:

$$\Gamma[\Lambda_c^+ \to \eta\Sigma^{*+}(1385)] = \frac{A_2^2|\vec{p}|}{3\pi} \times \frac{M^2_{\Lambda_c^+}E^3 - 2M_{\Lambda_c^+}M^2_{\Sigma_2^*}E^2 + M^4_{\Sigma_2^*}E - m_\eta^2 M^2_{\Sigma_2^*}E}{M_{\Lambda_c^+}m_\eta^2 M^2_{\Sigma_2^*}}, \tag{13}$$

with

$$E = \frac{M^2_{\Lambda_c^+} + M^2_{\Sigma_2^*} - m_\eta^2}{2M_{\Lambda_c^+}}, \tag{14}$$

$$|\vec{p}| = \sqrt{E^2 - M^2_{\Sigma_2^*}}. \tag{15}$$

First, we investigate the role of the $\Sigma^*(1385)$ and $\Sigma^*_{1/2^-}(1380)$ resonances in the invariant mass distribution of $d\Gamma/dM_{\pi^+\Lambda}$, which is shown in Fig. 5. The solid line stands for the result considering only the contribution from $\Sigma^*(1385)$ with $A_2 = B_2 = 5.51 \times 10^{-7}$, while the dashed curve stands for contributions from only $\Sigma^*_{1/2^-}(1380)$. For comparison we normalize the two curves to the peak, which results in $A_1 = B_1 = 13.05 \times 10^{-7}$. From the figure we see that the contribution of $\Sigma^*_{1/2^-}(1380)$ makes the $\pi^+\Lambda$ mass distribution broader because of its relatively large decay width.

Because the $\Sigma^*(1385)$ resonance has spin parity $3/2^+$, it decays into $\pi\Lambda$ in the relative p-wave, while the $\Sigma^*_{1/2^-}(1380)$ state with $J^P = 1/2^-$ decays into $\pi\Lambda$ in the relative s-wave. Hence, we show in Figs. 6 and 7, the decay angle and energy distributions of the final π^+, respectively. The solid and dashed curves stand for the contribution of $\Sigma^*(1385)$ and $\Sigma^*_{1/2^-}(1380)$, respectively. The two curves are normalized to the same area in the range examined. One can see that the shapes of the contributions of $\Sigma^*(1385)$ and $\Sigma^*_{1/2^-}(1380)$ are very different. From this perspective, the existence of the $\Sigma^*_{1/2^-}(1380)$ state can be easily checked by future experimental measurements.

As discussed in the Introduction, there is a cusp structure or a narrow pole near the $\bar{K}N$ threshold in the $I = 1$ channel

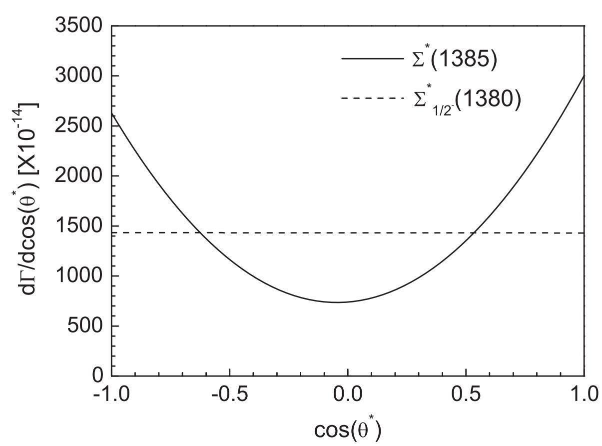

FIG. 6. Angle distributions $d\Gamma/d\cos\theta^*$ in the c.m. frame of the $\pi^+\Lambda$ system as a function of $\cos\theta^*$.

[1]In obtaining the decay amplitude, we have assumed the factorization of the hard process (the weak decay and hadronization) and the following decays of Σ^* resonances. Such a factorization scheme seems to work very well (see Ref. [37] for an extensive review). We note that a combination of the soft-collinear effective theory and χPT has been successfully developed to compute the generalized heavy-to-light form factors [38], where a similar factorization scheme is taken but with the hard process calculated in the QCD perturbation theory.

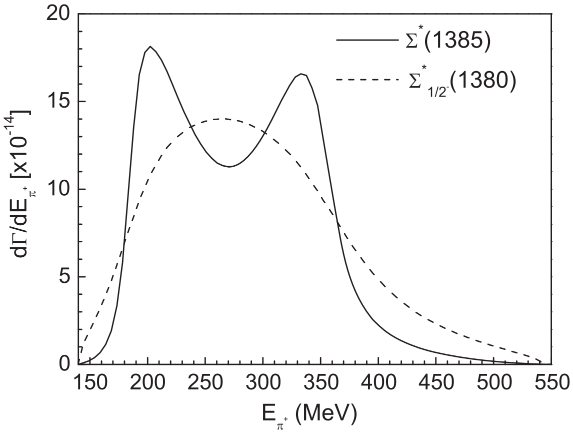

FIG. 7. Energy distributions $d\Gamma/dE_{\pi^+}$ in the rest frame of Λ_c^+ as a function of E_{π^+}.

[13,15–17]. This structure may also contribute to the $\Lambda_c^+ \to \eta\pi^+\Lambda$ decay. However, we expect that its contribution to the $\pi^+\Lambda$ invariant mass distribution should be different from the results shown in Fig. 5, since the structure is cusplike around the $\bar{K}N$ threshold, which could be easily distinguished from a real resonance.

IV. SUMMARY

By considering the contributions from the $\Sigma^*(1385)$ and $\Sigma^*_{1/2^-}(1380)$ resonances, we studied the $\pi^+\Lambda$ invariant mass, π^+ decay angle and decay energy distributions in the $\Lambda_c^+ \to \pi^+\eta\Lambda$ decay to understand better the $\Sigma^*_{1/2^-}(1380)$ state and also the decay mechanism. For the production of $\Sigma^*(1385)$, the weak interaction part is dominated by the internal W-exchange diagram, while for the $\Sigma^*_{1/2^-}(1380)$ production, the weak interaction part can proceed via the color-favored external W-emission diagram. This is because $\Sigma^*_{1/2^-}(1380)$ has a dominant five-quark component. The $\Sigma^*(1385)$ and $\Sigma^*_{1/2^-}(1380)$ resonances then decay into a $\pi^+\Lambda$ pair.

As evidenced from the line shape of the $\pi^+\Lambda$ invariant mass distribution, the $\Sigma^*_{1/2^-}(1380)$ state broadens the invariant mass distribution because of its large total decay width. Because the $\Sigma^*(1385)$ and $\Sigma^*_{1/2^-}(1380)$ resonances have different spin and parity, the final π^+ decay angle and energy distributions are much different.

On the experimental side, the decay mode $\Lambda_c^+ \to \pi^+\eta\Lambda$ has been observed [3] and the branching ratio $\mathrm{Br}(\Lambda_c^+ \to \pi^+\eta\Lambda)$ is determined to be $(2.3 \pm 0.5)\%$, which is one of the dominant decay modes of the Λ_c^+ state. Hence, the $\Lambda_c^+ \to \pi^+\eta\Lambda$ decay can be an ideal process to study the $\Sigma^*(1385)$ and $\Sigma^*_{1/2^-}(1380)$ resonances. Future experimental measurements of the invariant mass, decay angle and decay energy distributions studied in the present work will be very helpful in illuminating the existence of the $\Sigma^*_{1/2^-}(1380)$ state and improving our knowledge of its properties. For example, a corresponding experimental measurement could in principle be done by BESIII [39] and Belle [40] collaborations. Our present study proposed an alternative decay mechanisms for the $\Lambda_c^+ \to \pi^+\eta\Lambda$ decay and constituted a first effort to study the role of the $\Sigma^*_{1/2^-}(1380)$ state in relevant processes.

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