Exploring strong decay behavior of Σ_c baryon

Hardik Rathod,* Pooja Jakhad, and Ajay Kumar Rai
Department of Physics, Sardar Vallabhbhai National
Institute of Technology, Surat, Gujarat-395007, INDIA

Introduction

Examining the concepts of heavy quark symmetry and the chiral symmetry of light quarks starts with singularly charmed baryons, which have one heavy and two light quarks. In the past several years, Belle, BaBar, CLEO, and LHCb have all made experimental detections of many states of singly charmed baryons [1]. However, for Σ_c baryons, only states related to the 1S-wave with $J^P = \frac{1}{2}^+$ and $\frac{3}{2}^+$ have been determined. The Belle and BaBar collaborations have so far only detected one excited state of the Σ_c beryon, designated as $\Sigma_c(2800)$, in the $\Lambda_c^+\pi$ channel; nevertheless, its spin and parity remain unknown [2, 3]. The mass spectrum of excited Σ_c baryons has been studied using a variety of theoretical techniques in recent years, including Regge phenomenology [4], the hyper-central constituent quark model [5, 6], the QCD-motivated relativistic quark model [7], lattice QCD [8], QCD sum rules [9], and relativistic flux tube model [10–12].

The mass specra of $\Sigma_c(2800)$ baryon has been studied in our previous work using Regge phenomenology [4]. In this study, we provide further evidence for the spin-parity of the $\Sigma_c(2800)$ baryon by analyzing its strong decay pattern using Heavy Hadron Chiral Perturbation Theory (HHChPT)[13].

Theoretical Framework

The strong decay of singly charmed baryons involving the soft pseudoscalar mesons is most effectively described using HHChPT. The $1S$ Σ_c baryons decay strongly via the $\Lambda_c\pi$ channel, with their decay width in HHChPT being [13]

$$\Gamma[\Sigma_c \rightarrow \Lambda_c\pi] = \frac{g_2^2}{2\pi f_\pi^2}\frac{M_{\Lambda_c}}{M_{\Sigma_c}}p_\pi^3, \tag{1}$$

where the coupling constant $g_2 = 0.591$, M is the mass of baryon, p_π is the momentum of pion, and $f_\pi = 132MeV$.

The partial decay widths for $1P$-wave states of Σ_c baryons in HHChPT are following [13]:

$$\Gamma[\Sigma_c(1^2P_{1/2}) \rightarrow \Lambda_c\pi] = \frac{h_3^2}{2\pi f_\pi^2}\frac{M_{\Lambda_c}}{M_{\Sigma_c(1^2P_{1/2})}}E_\pi^2 p_\pi, \tag{2}$$

$$\Gamma[\Sigma_c(1^4P_{1/2}) \rightarrow \Sigma_c\pi] = \frac{h_4^2}{4\pi f_\pi^2}\frac{M_{\Sigma_c}}{M_{\Sigma_c(1^4P_{1/2})}}E_\pi^2 p_\pi, \tag{3}$$

$$\Gamma[\Sigma_c(1^2P_{3/2}) \rightarrow \Sigma_c^*\pi] = \frac{h_9^2}{9\pi f_\pi^2}\frac{M_{\Sigma_c^*}}{M_{\Sigma_c(1^2P_{3/2})}}p_\pi^5, \tag{4}$$

$$\Gamma[\Sigma_c(1^4P_{3/2}) \rightarrow \Lambda_c\pi] = \frac{4h_{10}^2}{15\pi f_\pi^2}\frac{M_{\Lambda_c}}{M_{\Sigma_c(1^4P_{3/2})}}p_\pi^5, \tag{5}$$

$$\Gamma[\Sigma_c(1^4P_{3/2}) \rightarrow \Sigma_c\pi] = \frac{h_{11}^2}{10\pi f_\pi^2}\frac{M_{\Sigma_c}}{M_{\Sigma_c(1^4P_{3/2})}}p_\pi^5, \tag{6}$$

$$\Gamma[\Sigma_c(1^4P_{3/2}) \rightarrow \Sigma_c^*\pi] = \frac{h_{11}^2}{10\pi f_\pi^2}\frac{M_{\Sigma_c^*}}{M_{\Sigma_c(1^4P_{3/2})}}p_\pi^5. \tag{7}$$

Similarly, we calculate the strong decay width of $\Sigma_c(1^4P_{5/2})$ [13]. Coupling constants h_3, h_4, h_9, h_{10}, and h_{11} are associated with h_2 or h_8 by [14, 15]

$$\begin{aligned} |h_3| &= \sqrt{3}|h_2|, & |h_4| &= 2|h_2|, \\ |h_8| &= |h_9| = |h_{10}|, & |h_{11}| &= \sqrt{2}|h_{10}|. \end{aligned} \tag{8}$$

Utilizing Eq. (2)-(8) and the theoretical masses extracted from Regge Phenomenology [4], the decay widths are calculated for $1P$-wave states of Σ_c baryon.

---

*Electronic address: `hardik13pr@gmail.com`

TABLE I: Masses (M) and Strong decay width (Γ) of Σ_c baryon (in MeV)

States $N^{2S+1}L_J$	Decay channel	Theoretical M [4]	Theoretical Γ	Experimental Γ[1]
$\Sigma_c^{++}(1^2S_{1/2})$	$\Lambda_c\pi$	2453.97	1.94	$1.89^{+0.09}_{-0.18}$
$\Sigma_c^{+}(1^2S_{1/2})$	$\Lambda_c\pi$	2452.65	2.23	2.30 ± 0.40
$\Sigma_c^{0}(1^2S_{1/2})$	$\Lambda_c\pi$	2453.75	1.91	$1.83^{+0.11}_{-0.19}$
$\Sigma_c^{*++}(1^4S_{3/2})$	$\Lambda_c\pi$	2518.41	14.59	$14.78^{+0.30}_{-0.40}$
$\Sigma_c^{*+}(1^4S_{3/2})$	$\Lambda_c\pi$	2517.40	15.11	$17.20^{+4.00}_{-2.20}$
$\Sigma_c^{*0}(1^4S_{3/2})$	$\Lambda_c\pi$	2518.48	14.61	$15.30^{+0.40}_{-0.50}$
$\Sigma_c^{++}(1^2P_{1/2})$	$\Lambda_c\pi$	2799.00	875.55	
$\Sigma_c^{+}(1^2P_{1/2})$	$\Lambda_c\pi$	2799.00	877.00	
$\Sigma_c^{0}(1^2P_{1/2})$	$\Lambda_c\pi$	2799.00	875.55	
$\Sigma_c^{++}(1^4P_{1/2})$	$\Sigma_c\pi$	2713.00	172.96	
$\Sigma_c^{+}(1^4P_{1/2})$	$\Sigma_c\pi$	2713.00	258.51	
$\Sigma_c^{0}(1^4P_{1/2})$	$\Sigma_c\pi$	2713.00	173.19	
$\Sigma_c^{++}(1^2P_{3/2})$	$\Sigma_c^*\pi$	2777.72	1.09	
$\Sigma_c^{+}(1^2P_{3/2})$	$\Sigma_c^*\pi$	2776.56	1.56	
$\Sigma_c^{0}(1^2P_{3/2})$	$\Sigma_c^*\pi$	2777.53	1.08	
$\Sigma_c^{++}(1^4P_{3/2})$	$\Lambda_c\pi, \Sigma_c\pi, \Sigma_c^*\pi$	2773.00	48.94	75^{+22}_{-17}
$\Sigma_c^{+}(1^4P_{3/2})$	$\Lambda_c\pi, \Sigma_c\pi, \Sigma_c^*\pi$	2773.00	53.75	62^{+60}_{-40}
$\Sigma_c^{0}(1^4P_{3/2})$	$\Lambda_c\pi, \Sigma_c\pi, \Sigma_c^*\pi$	2773.00	48.94	72^{+22}_{-15}
$\Sigma_c^{++}(1^4P_{5/2})$	$\Lambda_c\pi, \Sigma_c\pi, \Sigma_c^*\pi$	2846.13	100.84	
$\Sigma_c^{+}(1^4P_{5/2})$	$\Lambda_c\pi, \Sigma_c\pi, \Sigma_c^*\pi$	2845.24	111.57	
$\Sigma_c^{0}(1^4P_{5/2})$	$\Lambda_c\pi, \Sigma_c\pi, \Sigma_c^*\pi$	2846.20	100.84	

Results and Discussion

Our calculated results are listed in Table I. We observe that the decay widths of 1S-wave states are well reproduced. The LHCb has observed an excited state of the Σ_c baryon named $\Sigma_c(2800)$. However, the precise quantum numbers for this state are yet undetermined. The estimated masses for $\Sigma_c(1^2P_{3/2})$ and $\Sigma_c(1^4P_{3/2})$ in ref.[4] are quite close to the observed mass of $\Sigma_c(2800)$ state. But our calculated decay width of the $\Sigma_c(1^4P_{3/2})$ state is in good agreement with the experimentally measured width of $\Sigma_c(2800)$, suggesting that it predominantly corresponds to the $\Sigma_c(1^4P_{3/2})$ with spin-parity $\frac{3}{2}^-$.

References

[1] S. Navas *et al.* [Particle Data Group], Phys. Rev. D **110**, 030001 (2024).

[2] R. Mizuk *et al.* (Belle Collaboration), Phys. Rev. Lett. **94**, 122002 (2005).

[3] B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. D **78**, 112003 (2008).

[4] J. Oudichhya and A. K. Rai, Eur. Phys. J. A **59**, 123 (2023).

[5] Z. Shah *et al.*, Eur. Phys. J. A **52**, 313 (2016).

[6] K. Gandhi *et al.*, Int. J. Theor. Phys. **59**, 1129 (2020).

[7] D. Ebert, R. N. Faustov and V. O. Galkin, Phys. Rev. D **84**, 014025 (2011).

[8] P. Pérez-Rubio, S. Collins and G. S. Bali, Phys. Rev. D **92**, 034504 (2015).

[9] Z. G. Wang, Eur. Phys. J. A **47**, 81 (2011).

[10] P. Jakhad *et al.* Phys. Rev. D **108**, 014011 (2023).

[11] P. Jakhad *et al.*, DAE Symp. on Nucl. Phys. **67**, 935 (2023).

[12] P. Jakhad, J. Oudichhya and A. K. Rai, PoS **HQL2023**, 091 (2023).

[13] H. Y. Cheng and C. K. Chua, Phys. Rev. D **92**, 074014 (2015).

[14] D. Pirjol and T. M. Yan, Phys. Rev. D **56**, 5483 (1997).

[15] P. Jakhad *et al.*, [arXiv:2407.01655 [hep-ph]].