Charmed baryon weak decays with $SU(3)_F$ symmetry

An exploration of flavor symmetries and parity violation

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Reseach findings

The helicity for quantum states is defined as $\vec{J}\cdot\vec{P}/|P|$. Although the quantity is invariant under the rotation, it flip sign under the parity transformation as shown in Figure. 1. Clearly, the differences of helicity between initial and final state indicate the processes do not obey parity symmetry, which is a main feature in weak interaction. Consequently, the up-down asymmetry parameter is defined as

$$\alpha = \frac{d\Gamma(\vec{P}\cdot\hat{p}=+1) - d\Gamma(\vec{P}\cdot\hat{p}=-1)}{d\Gamma(\vec{P}\cdot\hat{p}=+1) + d\Gamma(\vec{P}\cdot\hat{p}=-1)},$$

where Γ is the decay width and $\hat{p}$ is the polarization. Nonzero value of up-down asymmetry parameter indicates parity violation in the decay process.

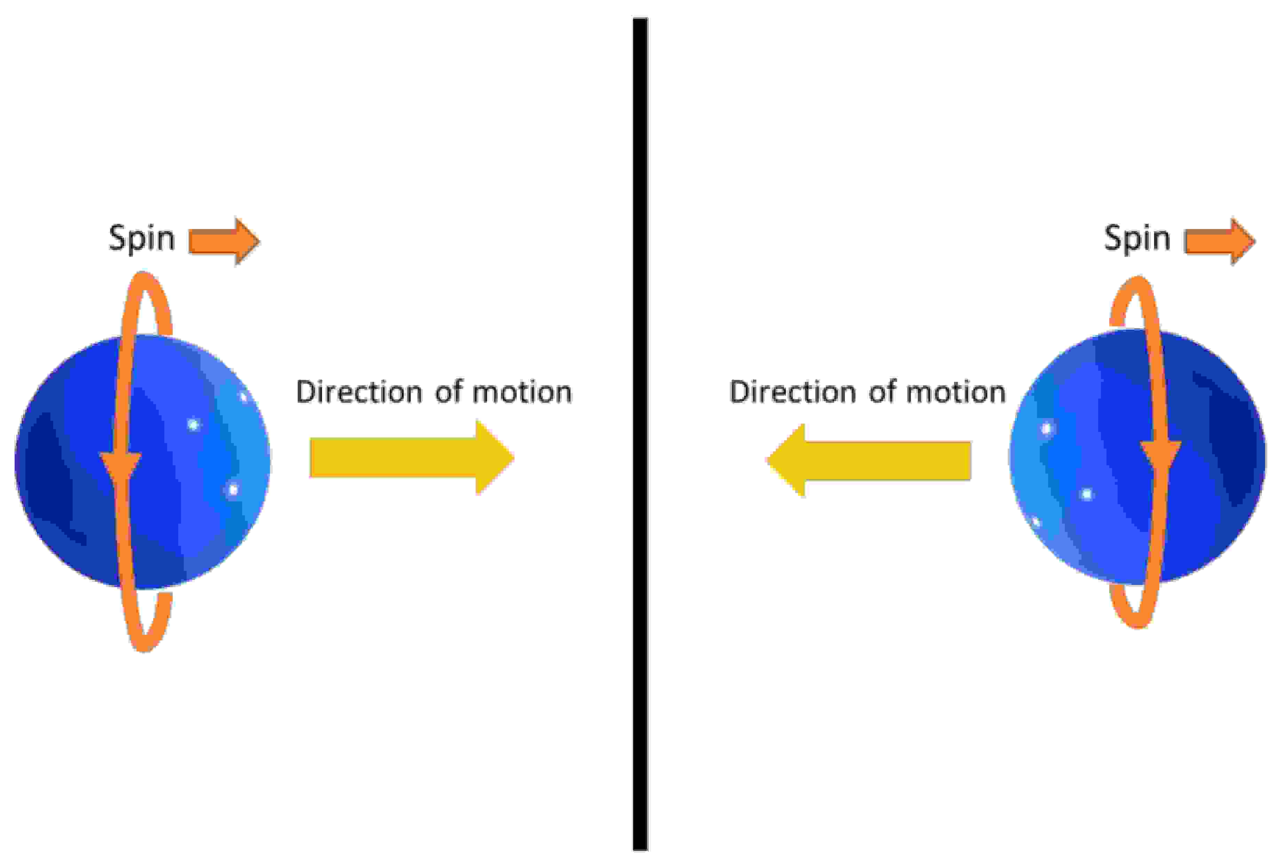

Figure 1: Under parity transformation the helicity $\vec{J}\cdot\vec{P}$ change sign as shown in the figure.

In the limit of $SU(3)_F$ flavor symmetry, up, down and strange quarks are the same under strong interaction. Since then, the amplitudes among different decays are linked.

We analyze the decay processes of $\mathbf{B}_c \to \mathbf{B}_n M$ with the $SU(3)_F$ flavor symmetry and spin-dependent amplitudes, where $\mathbf{B}_c(\mathbf{B}_n)$ and M are the anti-triplet charmed (octet) baryon and nonet meson states, respectively. In the $SU(3)_F$ approach, it is the first time that the decay rates and up-down asymmetries are fully and systematically studied without neglecting the $\mathcal{O}(\overline{15})$ contributions of the color anti-symmetric parts in the effective Hamiltonian. Our results of the up-down asymmetries based on $SU(3)_F$ are quite different from the previous theoretical values in the literature. In particular, we find that the up-down symmetry of $\alpha(\Lambda_c^+ \to \Xi^0 K^+)_{SU(3)} = 0.94^{+0.06}_{-0.11}$, which is consistent with the recent experimental data of 0.77 ± 0.78 by the BESIII Collaboration, but predicted to be zero in the literature. We also examine the $K_S^0 - K_L^0$ asymmetries between the decays of $\mathbf{B}_c \to \mathbf{B}_n K_S^0$ and $\mathbf{B}_c \to \mathbf{B}_n K_L^0$ with both Cabibbo-allowed and doubly Cabibbo-suppressed transitions.

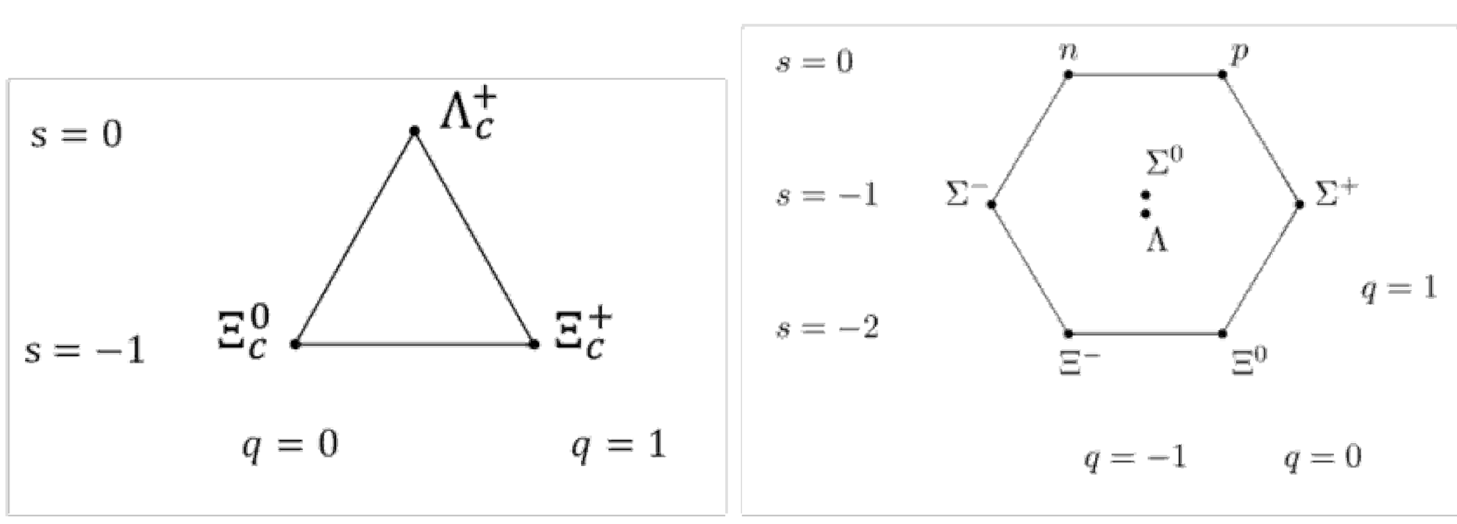

Figure 2: $SU(3)_F$ multiplets for $\frac{1}{2}^+$ baryons

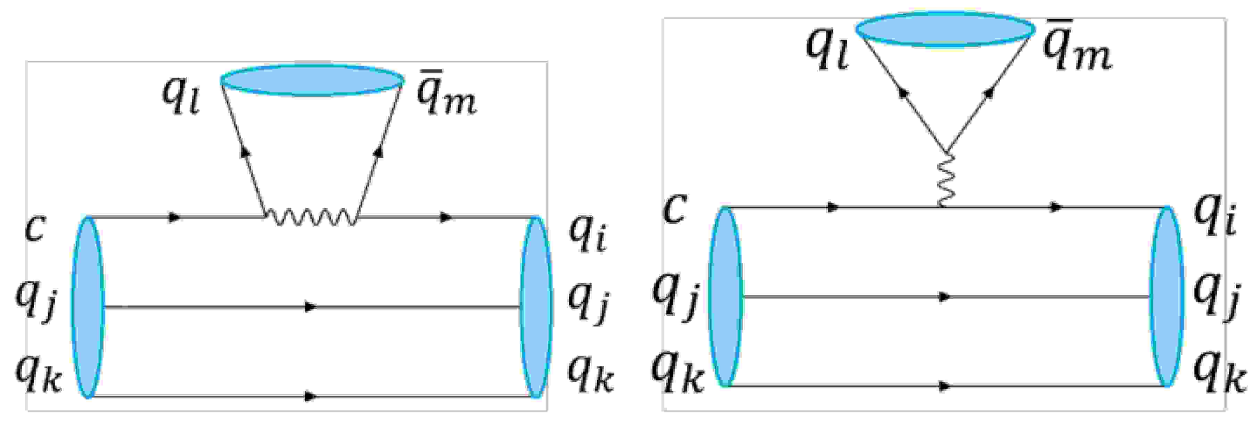

Figure 3: Typical factorizable Feymann digrams

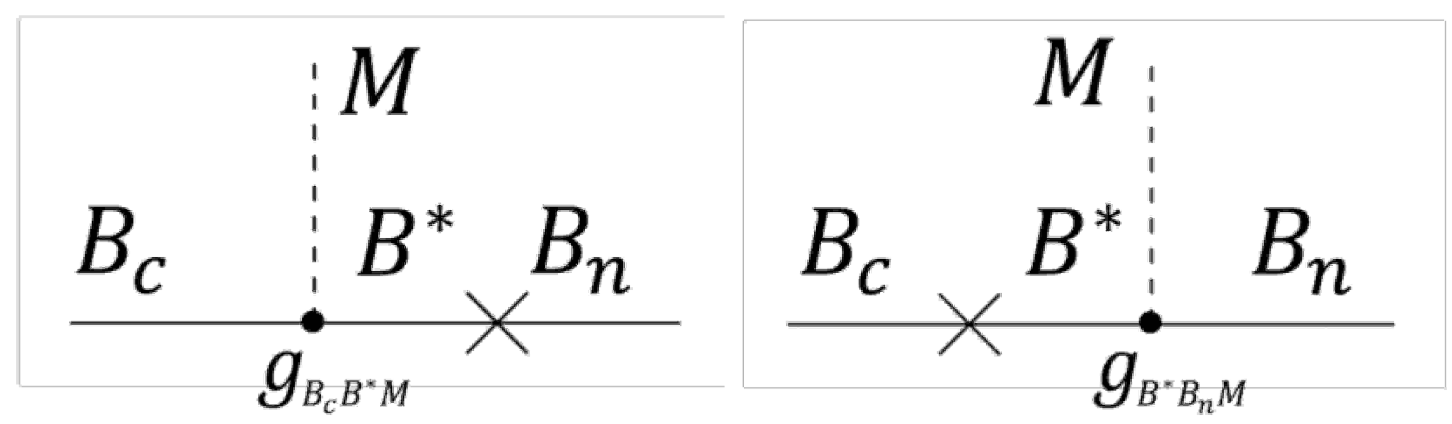

Figure 4: Typical nonfactorizable Feymann digrams

Channel	$\mathcal{B}_{exp}$	α_{exp}	$\mathcal{B}_{SU(3)_F}$	$\alpha_{SU(3)_F}$
$\Lambda_c^+ \to \Lambda^0\pi^+$	$(13.0 \pm 0.7)\times 10^{-3}$	-0.80 ± 0.11	$(12.8 \pm 0.7)\times 10^{-3}$	-0.78 ± 0.07
$\Lambda_c^+ \to pK_S^0$	$(15.8 \pm 0.8)\times 10^{-3}$	0.18 ± 0.45	$(15.6 \pm 0.8)\times 10^{-3}$	0.02 ± 0.30
$\Lambda_c^+ \to \Sigma^0\pi^+$	$(12.9 \pm 0.7)\times 10^{-3}$	-0.57 ± 0.12	$(12.6 \pm 0.6)\times 10^{-3}$	-0.57 ± 0.09
$\Lambda_c^+ \to \Sigma^+\pi^0$	$(12.4 \pm 1.0)\times 10^{-3}$	-0.73 ± 0.18	$(12.6 \pm 0.6)\times 10^{-3}$	-0.57 ± 0.09
$\Lambda_c^+ \to \Sigma^+\eta$	$(4.1 \pm 2.0)\times 10^{-3}$		$(4.0 \pm 1.6)\times 10^{-3}$	$-0.86^{+0.52}_{-0.14}$
$\Lambda_c^+ \to \Sigma^+\eta'$	$(13.4 \pm 5.7)\times 10^{-3}$		$(14.5 \pm 6.0)\times 10^{-3}$	$0.87^{+0.13}_{-0.19}$
$\Lambda_c^+ \to \Xi^0K^+$	$(5.9 \pm 1.0)\times 10^{-3}$	0.77 ± 0.78	$(5.7 \pm 0.9)\times 10^{-3}$	$1.00^{+0}_{-0.02}$
$\Lambda_c^+ \to p\pi^0$	$(0.8 \pm 1.3)\times 10^{-4}$		$(1.1 \pm 0.9)\times 10^{-4}$	$0.85^{+0.15}_{-0.23}$
$\Lambda_c^+ \to p\eta$	$(12.4 \pm 3.0)\times 10^{-4}$		$(11.5 \pm 2.7)\times 10^{-4}$	0.62 ± 0.38
$\Lambda_c^+ \to \Lambda^0K^+$	$(6.1 \pm 1.2)\times 10^{-4}$		$(6.6 \pm 0.9)\times 10^{-4}$	0.10 ± 0.25
$\Lambda_c^+ \to \Sigma^0K^+$	$(5.2 \pm 0.8)\times 10^{-4}$		$(5.2 \pm 0.7)\times 10^{-4}$	$-0.98^{+0.03}_{-0.02}$
$\Xi_c^0 \to \Xi^-\pi^+$	$(18.0 \pm 5.2)\times 10^{-3}$	-0.6 ± 0.4	$(29.5 \pm 1.4)\times 10^{-3}$	-1.00 ± 0.00
$\Xi_c^0 \to \Lambda^0K_S^0$			$(6.9 \pm 0.3)\times 10^{-3}$	-0.32 ± 0.17
$\Xi_c^+ \to \Xi_0\pi^+$	$(16 \pm 8)\times 10^{-3}$		$(4.2 \pm 1.7)\times 10^{-3}$	-0.42 ± 0.58
$^{**}\mathcal{R}_{\Xi_c^0}$	0.210 ± 0.028			

Table 1: Results compare to the experiments

channel	Irreducible amplitude for A	$10^3\mathcal{B}_{SU(3)_F}$	$\alpha_{SU(3)_F}$	$\mathbf{R}_{K^0_{S,L}}$
$\Lambda_c^+ \to pK_S^0$	$\sqrt{2}\left((a_1-\frac{a_6}{2})+(a_3-\frac{a_6}{2})s_c^2\right)$	15.7 ± 0.8	$-0.89^{+0.26}_{-0.11}$	0.009 ± 0.011
$\Lambda_c^+ \to pK_L^0$	$-\sqrt{2}\left((a_1-\frac{a_6}{2})-(a_3-\frac{a_6}{2})s_c^2\right)$	15.5 ± 0.8	$-0.92^{+0.21}_{-0.08}$	
$\Xi_c^+ \to \Sigma^+K_S^0$	$-\sqrt{2}\left((a_3-\frac{a_6}{2})+(a_1-\frac{a_6}{2})s_c^2\right)$	$4.9^{+5.9}_{-4.2}$	$0.89^{+0.11}_{-0.46}$	0.118 ± 0.078
$\Xi_c^+ \to \Sigma^+K_L^0$	$\sqrt{2}\left((a_3-\frac{a_6}{2})-(a_1-\frac{a_6}{2})s_c^2\right)$	$3.9^{+5.1}_{-3.5}$	$1.00^{+0.00}_{-0.18}$	
$\Xi_c^0 \to \Sigma^0K_S^0$	$(a_2+a_3-\frac{a_6}{2})+(a_1-\frac{a_6}{2})s_c^2$	0.5 ± 0.4	$-0.34^{+0.95}_{-0.66}$	0.170 ± 0.146
$\Xi_c^0 \to \Sigma^0K_L^0$	$-(a_2+a_3-\frac{a_6}{2})+(a_1-\frac{a_6}{2})s_c^2$	$0.3^{+0.5}_{-0.3}$	0.28 ± 0.71	
$\Xi_c^0 \to \Lambda^0K_S^0$	$\frac{1}{\sqrt{3}}((2a_1-a_2-a_3-\frac{a_6}{2})$ $-(a_1-2a_2-2a_3+\frac{a_6}{2})s_c^2)$	5.0 ± 0.3	-0.70 ± 0.28	-0.043 ± 0.003
$\Xi_c^0 \to \Lambda^0K_L^0$	$-\frac{1}{\sqrt{3}}((2a_1-a_2-a_3-\frac{a_6}{2})$ $+(a_1-2a_2-2a_3+\frac{a_6}{2})s_c^2)$	5.5 ± 0.3	-0.66 ± 0.28	

Table 2: Results of $K_L - K_S$ asymmetries

Reference

[1] C. Q. Geng, Y. K. Hsiao, C. W. Liu and T. H. Tsai, "Charmed Baryon Weak Decays with SU(3) Flavor Symmetry," JHEP **1711**, 147 (2017)

[2] C. Q. Geng, C. W. Liu and T. H. Tsai, "Asymmetries of anti-triplet charmed baryon decays," Phys. Lett. B **794**, 19 (2019)

研究心得: 對稱性在理論物理一直扮演著至關緊要的角色,他指引人們如何建構符合現象的理論。對稱性的應用一直以來都是我極感興趣 的問題。而對稱性的破缺也往往給人莫大的驚奇。對我來說,了解一個對稱性的應用、自然中存有的對稱性與對稱性的破缺除了非 常有趣以外,也是很有科學價值的。