SU(3) symmetry and its breaking effects in semileptonic heavy baryon decays

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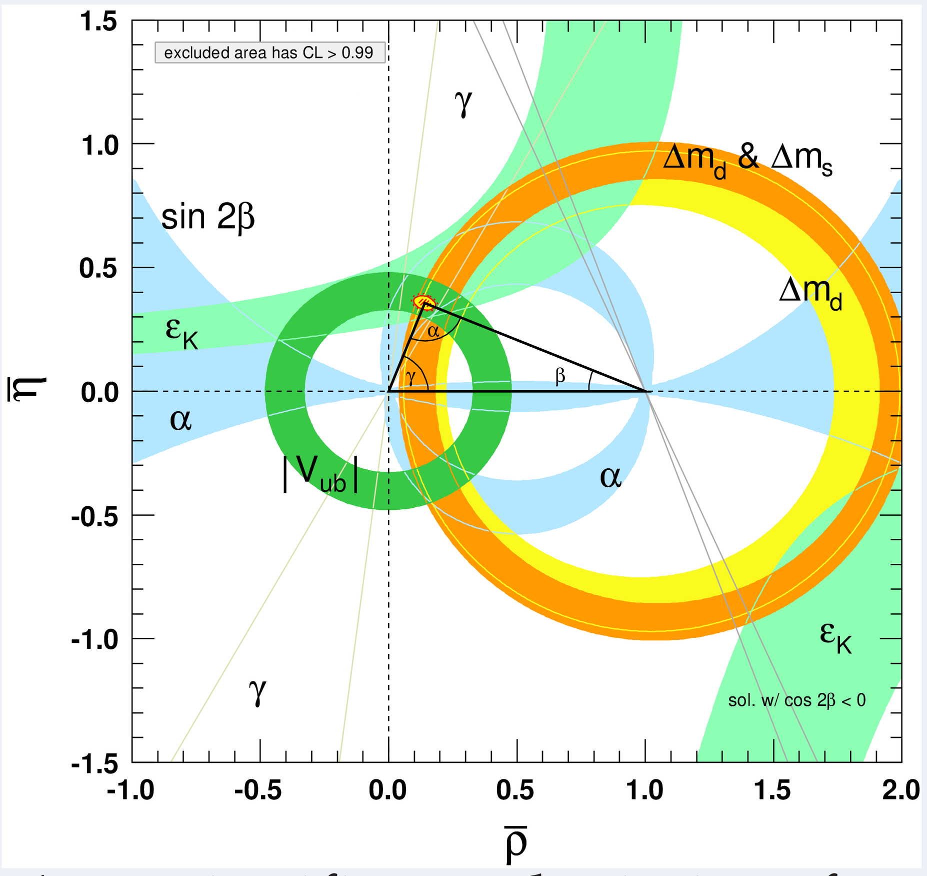
Physics. Letter. B **823 (2021) 136765**
HFCPV 2021, Nov. 10-14, 2021, Guangzhou, China

Introduction



Any significant deviation from SM predictions for the CKM matrix will provide clues for new physics beyond SM. The study of semi-leptonic decays of charmed baryons, which can provide an ideal way to determine the $|V_{cd}|$ and $|V_{cs}|$, is of great value.

A model-independent approach, the flavor SU(3) symmetry has been argued to work better in charmed baryon decays and bottomed baryon decays.

Experiment Vs. SU(3) analysis

Belle collaboration has provided a measurement of the Ξ_c^0 branching fractions

$$\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e) = (1.31 \pm 0.04 \pm 0.07 \pm 0.38)\% \,,$$
$$\mathcal{B}(\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu) = (1.27 \pm 0.06 \pm 0.10 \pm 0.37)\% \,, \quad (1)$$

which is about a factor of 2 more precise than the ALICE result:

$$\mathcal{B}_{\mathrm{ALICE}}(\Xi_c^0 \to \Xi^- e^+ \nu_e) = (2.5 \pm 0.8)\% \,. \quad (2)$$

channel	branching ratio(%)	
	experimental data	SU(3) symmetry
$\Lambda_c^+ \to \Lambda^0 e^+ \nu_e$	3.6 ± 0.4	3.6 ± 0.4 (input)
$\Lambda_c^+ \to \Lambda^0 \mu^+ \nu_\mu$	3.5 ± 0.5	3.5 ± 0.5 (input)
$\Xi_c^+ \to \Xi^0 e^+ \nu_e$	2.3 ± 1.5	12.17 ± 1.35
$\Xi_c^0 \to \Xi^- e^+ \nu_e$	1.54 ± 0.35	4.10 ± 0.46
$\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu$	1.27 ± 0.44	3.98 ± 0.57

For semileptonic charmed baryon decays, the helicity amplitude relation from SU(3)

$$\Gamma(\Xi_c^{0/+} \to \Xi^{-/0} \ell^+ \nu_\ell) = \frac{3}{2} \Gamma(\Lambda_c^+ \to \Lambda^0 \ell^+ \nu_\ell). \quad (3)$$

Then we obtain the branching ratios of $\Xi_c^{0,+}$ shown in Table, from which one can find an obvious deviation between experiments and theory.

References

References

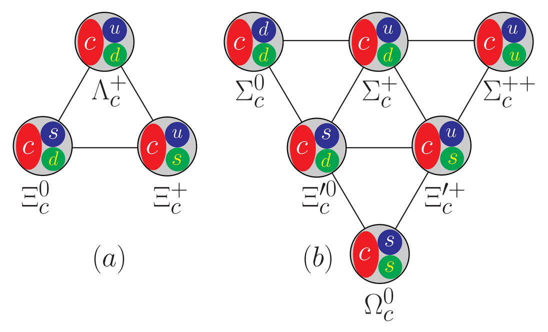
[1] Y. B. Li *et al.* [Belle], Phys. Rev. Lett. **127** (2021) no.12, 121803

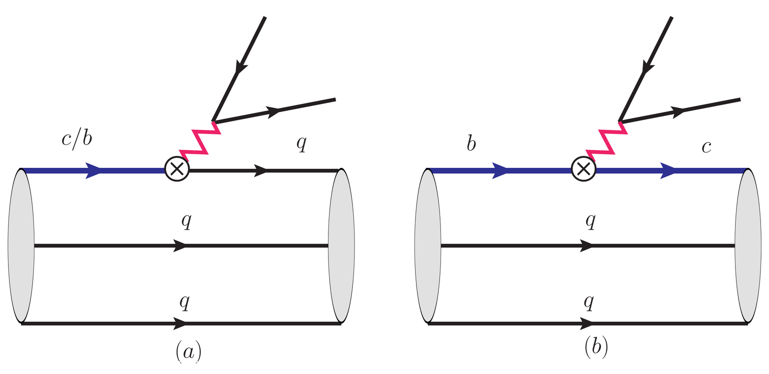
[2] C. Q. Geng, C. W. Liu and T. H. Tsai, Phys. Lett. B **790** (2019), 225-228

[3] P. A. Zyla *et al.* [Particle Data Group], PTEP **2020**, no.8, 083C01 (2020) doi:10.1093/ptep/ptaa104

SU(3) symmetry for charmed baryon semileptonic decays

Using the SU(3) analysis, we can fit the parameters form factors f_1 and f_1' with experimental data. Obviously, the χ^2 in fitting is too large to be considered as a good fit, which implies that the SU(3) symmetry is not a good symmetry for charmed baryon decays.





channel	branching ratio(%)	
	experimental data	fit data
$\Lambda_c^+ \to \Lambda^0 e^+ \nu_e$	3.60 ± 0.40	1.94 ± 0.18
$\Lambda_c^+ \to \Lambda^0 \mu^+ \nu_\mu$	3.5 ± 0.5	1.87 ± 0.176
$\Xi_c^+ \to \Xi^0 e^+ \nu_e$	2.3 ± 1.5	6.53 ± 0.60
$\Xi_c^0 \to \Xi^- e^+ \nu_e$	1.54 ± 0.35	2.17 ± 0.20
$\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu$	1.27 ± 0.44	2.09 ± 0.19
$\chi^2/d.o.f = 14.3$	$f_1 = 1.05 \pm 0.30$	$f_1' = 0.11 \pm 0.95$

SU(3) symmetry breaking

At the leading order, the helicity amplitudes for the decay channel of mass eigenvalue states $\Xi_c^{0mass} \to \Xi^- \ell^+ \nu_\ell$ and $\Xi_c^{+mass} \to \Xi^0 \ell^+ \nu_\ell$ become $H^{mass}_{\lambda,\lambda_w} \propto V_{cs}^*(a_1^{\lambda,\lambda_w} + a_2^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w} + \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)$, where we have neglected the $O(m_s^2)$ and higher order corrections.

channel	amplitude I	amplitude II
$\Lambda_c^+ \to \Lambda^0 l^+ \nu$	$-\sqrt{\frac{2}{3}}(a_1^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w})V_{cs}^*$	$-\sqrt{\frac{2}{3}}(a_1^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w})V_{cs}^*$
$\Lambda_c^+ \to n l^+ \nu$	$a_1 V_{cd}^*$	$a_1 V_{cd}^*$
$\Xi_c^+ \to \Sigma^0 \ell^+ \nu_\ell$	$\frac{(a_1^{\lambda,\lambda_w} + a_3^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} - \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cd}^*}{\sqrt{2}}$	$\frac{(a_1^{\lambda,\lambda_w} + a_3^{\lambda,\lambda_w} - a_4'^{\lambda,\lambda_w})V_{cd}^*}{\sqrt{2}}$
$\Xi_c^+ \to \Lambda^0 \ell^+ \nu_\ell$	$-\frac{(a_1^{\lambda,\lambda_w} + 2a_2^{\lambda,\lambda_w} - a_3^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} + \frac{3c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cd}^*}{\sqrt{6}}$	$-\frac{(a_1^{\lambda,\lambda_w} + 2a_2'^{\lambda,\lambda_w} - a_3^{\lambda,\lambda_w} - a_4'^{\lambda,\lambda_w})V_{cd}^*}{\sqrt{6}}$
$\Xi_c^+ \to \Xi^0 \ell^+ \nu_\ell$	$-(a_1^{\lambda,\lambda_w} + a_2^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w} + \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cs}^*$	$-(a_1^{\lambda,\lambda_w} + a_2'^{\lambda,\lambda_w} - a_4'^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w})V_{cs}^*$
$\Xi_c^0 \to \Sigma^- \ell^+ \nu_\ell$	$(a_1^{\lambda,\lambda_w} + a_3^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} - \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cd}^*$	$(a_1^{\lambda,\lambda_w} + a_3^{\lambda,\lambda_w} - a_4'^{\lambda,\lambda_w})V_{cd}^*$
$\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$	$(a_1^{\lambda,\lambda_w} + a_2^{\lambda,\lambda_w} - a_4^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w} + \frac{c_1^{\lambda,\lambda_w}}{\sqrt{2}}\theta)V_{cs}^*$	$(a_1^{\lambda,\lambda_w} + a_2'^{\lambda,\lambda_w} - a_4'^{\lambda,\lambda_w} + a_5^{\lambda,\lambda_w})V_{cs}^*$

where "amplitude I" and "amplitude II" represent helicity amplitude analysis and $\Xi_c^{0/+}$–$\Xi_c'^{\,0/+}$ mixing, respectively. And the contributions from "helicity amplitude" represented by a_i, c_1 is the first order contribution in "$\Xi_c^{0/+}$–$\Xi_c'^{\,0/+}$ mixing".

Data analysis and prediction

channel	branching ratio(%)		
	experimental data	fit data(pole model)	fit data(constant).
$\Lambda_c^+ \to \Lambda^0 e^+ \nu_e$	3.6 ± 0.4	3.61 ± 0.32	3.62 ± 0.32
$\Lambda_c^+ \to \Lambda^0 \mu^+ \nu_\mu$	3.5 ± 0.5	3.48 ± 0.30	3.45 ± 0.30
$\Xi_c^+ \to \Xi^0 e^+ \nu_e$	2.3 ± 1.5	3.89 ± 0.73	3.92 ± 0.73
$\Xi_c^0 \to \Xi^- e^+ \nu_e$	1.54 ± 0.35	1.29 ± 0.24	1.31 ± 0.24
$\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu$	1.27 ± 0.44	1.24 ± 0.23	1.24 ± 0.23
fit parameter (pole model)	$f_1 = 1.01 \pm 0.87$, $\delta f_1 = -0.51 \pm 0.92$ $f_1' = 0.60 \pm 0.49$, $\delta f_1' = -0.23 \pm 0.41$		$\chi^2/d.o.f = 1.6$
fit parameter (constant)	$f_1 = 0.86 \pm 0.92$, $\delta f_1 = -0.25 \pm 0.88$ $f_1' = 0.85 \pm 0.36$, $\delta f_1' = -0.43 \pm 0.50$		$\chi^2/d.o.f = 1.9$

Prediction:

$$\begin{aligned}
\mathcal{B}(\Lambda_c^+ \to n e^+ \nu_e) &= (0.520 \pm 0.046)\%, \quad \mathcal{B}(\Lambda_c^+ \to n \mu^+ \nu_\mu) = (0.506 \pm 0.045)\% \,, \\
\mathcal{B}(\Xi_c^+ \to \Sigma^0 e^+ \nu_e) &= (0.496 \pm 0.046)\%, \quad \mathcal{B}(\Xi_c^+ \to \Sigma^0 \mu^+ \nu_\mu) = (0.481 \pm 0.044)\%, \\
\mathcal{B}(\Xi_c^+ \to \Lambda^0 e^+ \nu_e) &= (0.067 \pm 0.013)\%, \quad \mathcal{B}(\Xi_c^+ \to \Lambda^0 \mu^+ \nu_\mu) = (0.069 \pm 0.0213)\%, \\
\mathcal{B}(\Xi_c^0 \to \Sigma^- e^+ \nu_e) &= (0.333 \pm 0.031)\%, \quad \mathcal{B}(\Xi_c^0 \to \Sigma^- \mu^+ \nu_\mu) = (0.323 \pm 0.029)\%. \quad (4)
\end{aligned}$$

Similar analyses are carried out for the semileptonic decays of anti-triplet beauty baryons to octet baryons and anti-triplet charmed baryons.

Conclusions

- **SU(3) symmetry not a good symmetry for charmed baryon decays**
- **Prediction the branching ratios:** $\Lambda_c^+ \to n \ell^+ \nu_\ell$ **,** $\Xi_c^+ \to \Sigma^0 \ell^+ \nu_\ell$ **,** $\Xi_c^+ \to \Lambda^0 \ell^+ \nu_\ell$ **and** $\Xi_c^0 \to \Sigma^- \ell^+ \nu_\ell$
- **Extended the analysis to the decays of anti-triplet beauty baryons.**