Addendum to “Overview of Λ_c decays”

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An earlier analysis of observed and anticipated Λ_c decays [1] is provided with a table of inputs and a figure denoting branching fractions. This addendum is based on the 2018 compilation in Ref. [2] and employs a statistical isospin model to estimate branching fractions for as-yet-unseen decay modes.

The decays of the charmed baryon Λ_c [2] appear to be within about 10% of fully mapped out [1] when a statistical isospin model [3, 4] is used to estimate branching fractions for as-yet-unseen decay modes. In this addendum to Ref. [1] we display graphically the modes which have been seen and those anticipated. Part of the ~ 10% shortfall may be composed of decay modes such as Λ_c → Λ^*ℓ+ν_ℓ, where Λ^* is an excited resonance, or may be due to a shortcoming in the statistical isospin model. Cabibbo-suppressed modes appear to be less well-represented by known or anticipated decays, and are worthy of more experimental study. In order for this analysis to serve as a model-independent counterpart to a Particle Data Group analysis of D_s decays [5], measurements of inclusive branching fractions of Λ_c decays need to be undertaken. [An example is the result from BESIII [6], B(Λ_c → Λ + X) = (38.2^{+2.8}_{−2.2} ± 0.8)%.] Λ_c branching fractions and their sources are listed in Tables I and II. These serve as inputs to Fig. 1 in which the branching fractions are indicated by the areas of the boxes. Shaded areas correspond to processes not represented by observed decays, but whose rates are anticipated using a statistical isospin model [1]. The figures show only central values; errors are quoted in the tables.

Some qualifying remarks are in order. The pK−π+ decay mode, frequently used to normalize others, is not firmly pinned down yet, with an S-value of 1.4 [2]. The statistical isospin model is poorly obeyed for the N̄Kπ and Σ3π modes but well obeyed for the Σ2π modes [1], possibly indicating the need to take account of resonant substructure. Nevertheless, one can draw some general conclusions.

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We see a shortfall of about 10% in accounting for all $\Lambda_c$ decays. This could be filled in part by semileptonic decays to excited final states, but a measurement $\mathcal{B}(\Lambda_c \to \Lambda e^+\nu_e + X) = (3.95 \pm 0.34 \pm 0.09)\%$ by the BESIII Collaboration \cite{besIII} limits this possibility.

(2) The Cabibbo-suppressed (CS) modes are not as well represented as the Cabibbo-favored (CF) ones, though the anticipated totals are not far from the expected ratio $|V_{cd}/V_{cs}|^2$, where $V_{ij}$ are elements of the Cabibbo-Kobayashi-Maskawa matrix.

(3) Modes involving neutrons, $\eta$, and $\eta'$ are under-represented.

(4) There is sufficient phase space to accommodate higher-multiplicity modes, such as $\Sigma 4\pi$ and $N 5\pi$, but no evidence for them has been presented so far.

(5) The statistical isospin model itself may be at fault. Inclusive branching fractions in $\Lambda_c$ decays would be very helpful in anticipating as-yet-unseen modes without the help of models, as has been done for $D_s$ decays \cite{ds}.

We urge more studies of $\Lambda_c$ decay modes containing neutrons, $\eta$, and $\eta'$; greater investigation of the singly-Cabibbo-suppressed and higher-multiplicity modes; and inclusive studies. Determination of resonant substructure is a crucial ingredient in filling gaps only partially addressed by an imperfect statistical isospin model.

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References

[1] M. Gronau and J. Rosner, Phys. Rev. D 97, 116015 (2018).
[2] M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018).
[3] E. Fermi, Phys. Rev. 92, 452 (1953); 93, 1434(E) (1954); K. M. Watson, Phys. Rev. 85, 852 (1952); I. Smushkevich, Dokl. Akad. Nauk SSSR 103, 235 (1955); C. G. Wohl, Am. J. Phys. 50, 748 (1982); A. J. MacFarlane, G. Pinski and G. Sudarshan, Phys. Rev. 140, B1045 (1965); A. Pais, Annals Phys. 9, 548 (1960); 22, 274 (1963); M. Peshkin, Phys. Rev. 121, 636 (1961).
[4] M. Peshkin and J. L. Rosner, Nucl. Phys. B 122, 144 (1977).
[5] Particle Data Group \cite{pdg}, mini-review no. 83, “$D_s$ branching fractions,” J. L. Rosner and C. G. Wohl.
[6] M. Ablikim et al. (BESIII Collaboration), Phys. Rev. Lett. 121, 062003 (2018).
[7] M. Ablikim et al. (BESIII Collaboration), Phys. Lett. B 783, 200 (2018).
[8] M. Ablikim et al. (BESIII Collaboration), Phys. Rev. Lett. 115, 221805 (2015).
[9] M. Ablikim et al. (BESIII Collaboration), Phys. Lett. B 767, 42 (2017).
[10] H. Y. Cheng, X. W. Kang and F. Xu, Phys. Rev. D 97, 074028 (2018).
[11] S. Meinel, Phys. Rev. D 97, 034511 (2018).
[12] M. Ablikim et al. (BESIII Collaboration), arXiv:1805.09060 [hep-ex].
Table I: Branching fractions of CF $\Lambda_c$ decays.

| Mode                  | Value (%) | Source |
|-----------------------|-----------|--------|
| $pK^+$                | 3.16 ± 0.16 | [2]    |
| $pK^0\pi^+$           | 6.23 ± 0.33 | [2]    |
| $pK^0\pi^0$           | 3.64 ± 0.50 | [2]    |
| $pK^0\eta$            | 3.92 ± 0.26 | [2]    |
| $pK^+\pi^0\eta$       | 1.6 ± 0.4  | [2]    |
| $pK^0\pi^+\pi^0\eta$  | 4.42 ± 0.31 | [2]    |
| $pK^0\pi^+\pi^0\eta$  | 3.18 ± 0.24 | [2]    |
| $pK^-2\pi^+\pi^-$     | 0.14 ± 0.09 | [2]    |
| Other $N\bar{K}2\pi$  | 5.28 ± 0.39 | [1]    |
| $\Lambda\pi^+$        | 1.29 ± 0.07 | [2]    |
| $\Lambda\pi^+\pi^0$   | 7.0 ± 0.4   | [2]    |
| $\Lambda2\pi^+\pi^-$  | 3.61 ± 0.29 | [2]    |
| $\Lambda\pi^+2\pi^0$  | 2.41 ± 0.13 | [1]    |
| $\Lambda2\pi^+\pi^0\pi^-$ | 2.2 ± 0.8 | [2] |
| $\Lambda\pi^+3\pi^0$  | 0.55 ± 0.2  | [1]    |
| $\Sigma^0\pi^+$       | 1.28 ± 0.07 | [2]    |
| $\Sigma^+\pi^0$       | 1.24 ± 0.10 | [2]    |
| $\Sigma^{-}\pi^+\pi^+$| 1.86 ± 0.18 | [2]    |
| $\Sigma^0\pi^+\pi^0$  | 3.03 ± 0.23 | [2]    |
| $\Sigma^+\pi^+\pi^-$  | 4.41 ± 0.20 | [2]    |
| $\Sigma^+\pi^0\pi^0$  | 1.23 ± 0.12 | [2]    |
| $\Sigma^02\pi^+\pi^-$ | 1.10 ± 0.30 | [2]    |
| $\Sigma^-2\pi^+\pi^0$ | 2.1 ± 0.4   | [2]    |
| Other $\Sigma3\pi$    | 4.1 ± 0.5   | [1]    |
| $\Sigma^+\eta$        | 0.69 ± 0.23 | [2]    |
| $\Sigma^+\omega$      | 1.69 ± 0.21 | [2]    |
| $\Lambda K^+K^-$      | 0.56 ± 0.11 | [2]    |
| $\Sigma^+K^+K^-$      | 0.34 ± 0.04 | [2]    |
| Other $\Sigma K\bar{K}$| 0.68 ± 0.34 | [1]    |
| $\Xi^+K^+$            | 0.55 ± 0.07 | [2]    |
| $\Xi^-K^+\pi^+$       | 0.62 ± 0.06 | [2]    |
| Other $\Xi K\pi$      | 1.24 ± 0.12 | [1]    |
| $\Lambda\mu^+\nu_\mu$| 3.49 ± 0.53 | [9]    |
| $\Lambda\epsilon^+\nu_\epsilon$ | 3.63 ± 0.43 | [8]    |
| Total                 | 83.17 ± 4.92 |        |

*aBranching fractions for modes with $\overline{K}^0$ are obtained by doubling those quoted for $K_S$.
*bIsospin statistical model [1]. cSubtraction of known modes from estimated total.
*dTotal estimated assuming equal branching fractions for each charge state.
*e$\Sigma^+\omega$ quoted separately. fPDG value averaged with new value from [7].
Table II: Branching fractions of CS $\Lambda_c$ decays, in percent.

| Mode                  | Value (%) | Source       |
|-----------------------|-----------|--------------|
| $p\pi^0$              | 0.008     | Theory [10]  |
| $n\pi^+$              | 0.027     | Theory [10]  |
| $p\eta$               | $0.124 \pm 0.030$ | Theory [2]  |
| $p\pi^+\pi^-$         | $0.42 \pm 0.04$     | Theory [2]  |
| Other $N\pi\pi$      | $0.84 \pm 0.08$     | Theory [1]a  |
| $N3\pi$               | $1.22 \pm 0.30$     | Theory [1]b  |
| $p2\pi^+2\pi^-$       | $0.22 \pm 0.14$     | Theory [2]  |
| Other $N4\pi$         | $0.88 \pm 0.56$     | Theory [1]a  |
| $pK^+K^-$             | $0.10 \pm 0.04$     | Theory [2]  |
| Other $NK^+K^-$       | $0.20 \pm 0.08$     | Theory [1]a  |
| $\Lambda K^+$         | $0.06 \pm 0.012$    | Theory [2]  |
| $\Sigma^0 K^+$        | $0.051 \pm 0.008$   | Theory [2]  |
| $\Sigma^+ K^0$        | $0.051 \pm 0.008$   | Theory [1]a  |
| $\Sigma^+ K^+\pi^-$  | $0.21 \pm 0.06$     | Theory [2]  |
| Other $\Sigma K\pi$  | $0.84 \pm 0.24$     | Theory [1]a  |
| $ne^+\nu_e$           | $0.41 \pm 0.03$     | Lattice QCD [11] |
| $n\mu^+\nu_\mu$      | $0.40 \pm 0.03$     | Lattice QCD [11] |
| Total                 | $6.06 \pm 0.84$     |              |

a Total estimated assuming equal branching fractions for each charge state.

b Branching ratio to $p\pi^+\pi^0\pi^-$ taken as $(0.304 \pm 0.076)$% (geometric mean of $p\pi^+\pi^-$ and $p2\pi^+2\pi^-$ modes) multiplied by 4 for total number of charge states.
Figure 1: Branching fractions of \( \Lambda_c \) decays. Left: Cabibbo-favored (CF, governed by weak transition \( c \to sW^* \)); right: Cabibbo-suppressed (CS, governed by weak transition \( c \to dW^* \)).