# $\Lambda_c \to N$ form factors from lattice QCD and phenomenology of $\Lambda_c \to n\,\ell^+\nu_\ell$ and $\Lambda_c \to p\,\mu^+\mu^-$ decays[†]

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The $\Lambda_c \to N$ transition form factors are relevant both for the charged-current decays $\Lambda_c \to n\,\ell^+\nu_\ell$ and for the GIM-suppressed neutral-current decays $\Lambda_c \to p\,\ell^+\ell^-$. In this work, the first lattice QCD calculation of the $\Lambda_c \to N$ form factors was performed, and predictions were made for the rates and angular distributions of the aforementioned decays. The calculation was based on lattice gauge field ensembles generated by the RBC and UKQCD Collaborations,[1] with $2+1$ flavors of domain wall fermions. Two lattice spacings, $a \approx 0.11$ fm and $a \approx 0.085$ fm, and pion masses in the range 230 MeV $\lesssim m_\pi \lesssim$ 350 MeV were used. The form factors were extrapolated to the continuum limit and the physical pion mass via modified $z$ expansions.

The $\Lambda_c \to n\,e^+\nu_e$ differential decay rate predicted using the form factor results is shown in Fig. 1. This decay not yet been observed in experiments. The integrated decay rate obtained here is higher than most previous theoretical estimates.

In the effective-field-theory analysis, $c \to u\,\ell^+\ell^-$ decays such as $\Lambda_c \to p\,\mu^+\mu^-$ receive contributions both from quark-bilinear operators, whose matrix elements are given by the form factors calculated here, and from four-quark and gluonic operators[2] that contribute through nonlocal matrix elements containing an additional insertion of the quark electromagnetic current. For the $\Lambda_c \to p\,\mu^+\mu^-$ differential branching fraction, a perturbative treatment of these nonlocal matrix elements[3] yields the blue dashed curve shown in Fig. 2. It is, however, well known that intermediate light-meson resonances enhance the matrix elements of the four-quark operators by several orders of magnitude. A simple Breit-Wigner model for the contributions from the $\rho^0$, $\omega$, and $\phi$ resonances gives the orange curve in Fig. 2.

The LHCb Collaboration recently performed a search for $\Lambda_c \to p\,\mu^+\mu^-$ decays,[4] and reported an upper limit of $\mathcal{B}(\Lambda_c \to p\,\mu^+\mu^-) < 7.7 \times 10^{-8}$ in the dimuon mass region excluding $\pm 40$ MeV intervals around $m_\omega$ and $m_\phi$. This measurement constrains new-physics contributions to the Wilson coefficients $C_9$ and $C_{10}$ to be of order $\mathcal{O}(1)$. While the theoretical predictions for the $\Lambda_c \to p\,\mu^+\mu^-$ decay rate are very unreliable, the forward-backward asymmetry in the angular distribution is nonzero only in the presence of new physics, and a measurement would provide a clean test of the Standard Model.

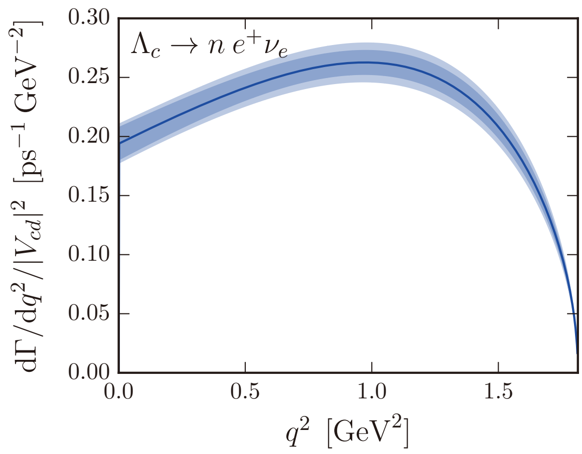


Fig. 1. The $\Lambda_c \to n\,e^+\nu_e$ differential decay rate, without the factor of $|V_{cd}|^2$.

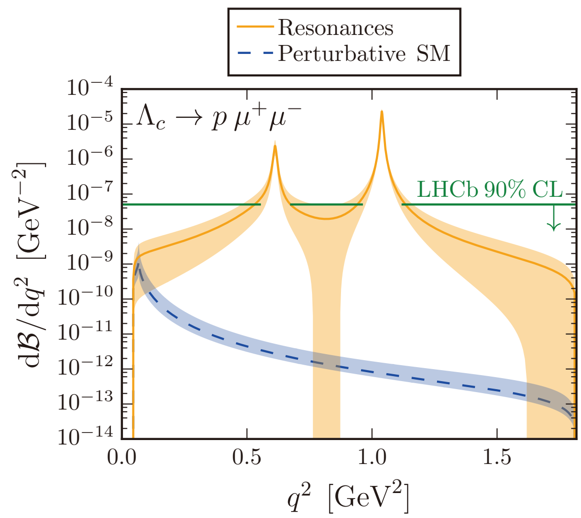


Fig. 2. The $\Lambda_c \to p\,\mu^+\mu^-$ differential branching fraction, calculated using effective Wilson coefficients from perturbation theory (blue dashed curve) or using a Breit-Wigner model for the contributions from the $\rho^0$, $\omega$, and $\phi$ resonances. Also indicated is the upper limit obtained by LHCb.[4]

References
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† Condensed from the article in arXiv:1712.05783
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