Phenomenology of $\Lambda_b \to \Lambda_c \tau \bar{\nu}$ using lattice QCD calculations†

A. Datta,[*1,*2] S. Kamali,[*3] S. Meinel,[*3,*4] and A. Rashed[*1,*5]

In the Standard Model, the electroweak interactions are lepton-flavor-universal. Consequently, the ratios of branching fractions

$$R(D) = \frac{\mathcal{B}(B \to D\tau\bar{\nu})}{\mathcal{B}(B \to D\ell\bar{\nu})}, \quad (1)$$

$$R(D^*) = \frac{\mathcal{B}(B \to D^*\tau\bar{\nu})}{\mathcal{B}(B \to D^*\ell\bar{\nu})}, \quad (2)$$

where $\ell = e, \mu$, depend only on the lepton and hadron masses and the hadronic form factors. The experimental measurements of $R(D)$ and $R(D^*)$ by the Babar, Belle, and LHCb collaborations exceed the Standard-Model predictions with a combined significance of 4.1σ,[1)] hinting at the existence of new fundamental interactions that violate lepton-flavor universality.

The underlying $b \to c\tau\bar{\nu}$ transition can also be probed with the baryonic decay $\Lambda_b \to \Lambda_c\tau\bar{\nu}$, in particular by measuring the ratio

$$R(\Lambda_c) = \frac{\mathcal{B}(\Lambda_b \to \Lambda_c\tau\bar{\nu})}{\mathcal{B}(\Lambda_b \to \Lambda_c\ell\bar{\nu})}. \quad (3)$$

A precise Standard-Model prediction of $R(\Lambda_c)$ using the $\Lambda_b \to \Lambda_c$ vector and axial vector form factors from lattice QCD was given in Ref. 2).

In this work, we studied the effects of several new-physics scenarios that have been proposed to explain the excesses in $R(D^{(*)})$ on the decay $\Lambda_b \to \Lambda_c\tau\bar{\nu}$. Because some of these scenarios generate tensor couplings, we also determined the $\Lambda_b \to \Lambda_c$ tensor form factors from lattice QCD.

We demonstrated that a future measurement of $R(\Lambda_c)$ can tightly constrain all of the couplings g_L, g_R, g_S, g_P, and g_T in the $b \to c\tau\bar{\nu}$ effective Hamiltonian. We also analyzed six different leptoquark models, where we constrained the model parameters using the experimental measurements of $R(D)$, $R(D^*)$, the B_c lifetime τ_{B_c}, and the upper limits on $\mathcal{B}(B \to K^{(*)}\nu\bar{\nu})$. As an example, Fig. 1 shows the correlations between the predicted values of $R^{\rm Ratio}_{\Lambda_c} = R(\Lambda_c)/R(\Lambda_c)_{\rm SM}$ and $R^{\rm Ratio}_{D^*} = R(D^*)/R(D^*)_{\rm SM}$ for the $SU(2)$-singlet and $SU(2)$-doublet scalar leptoquarks S_1 and R_2, and for the $SU(2)$-singlet vector leptoquark U_1 (the latter is a particularly attractive model, which can simultaneously explain hints of lepton-flavor-university violation seen in $b \to s\ell^+\ell^-$ decays[3)]). Our analyses show that a future measurement of $R(\Lambda_c)$ can be helpful in discriminating between the different models.

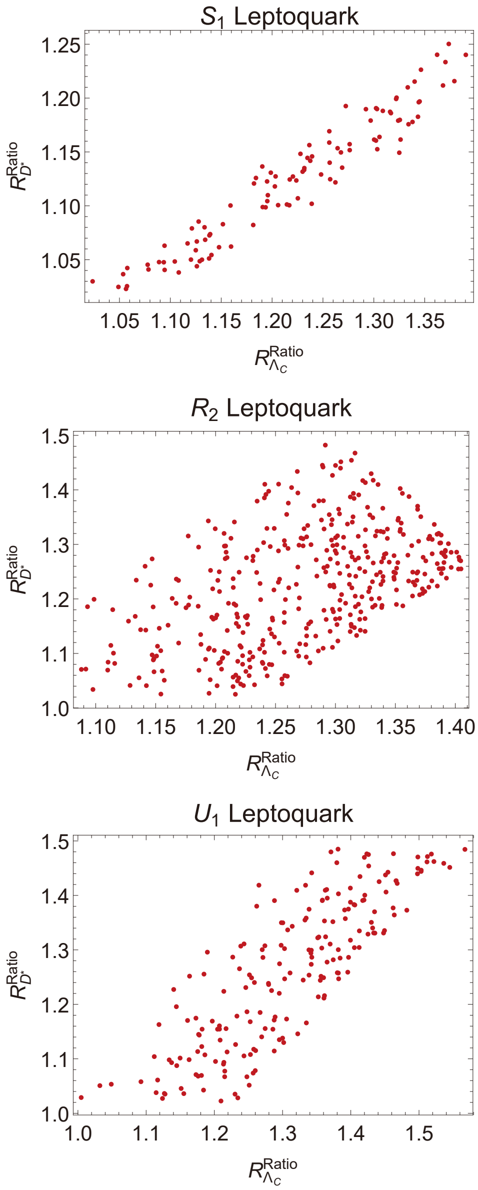

Fig. 1. Correlations between $R^{\rm Ratio}_{\Lambda_c} = R(\Lambda_c)/R(\Lambda_c)_{\rm SM}$ and $R^{\rm Ratio}_{D^*} = R(D^*)/R(D^*)_{\rm SM}$ in three different leptoquark scenarios. The points sample the region of couplings allowed by experimental measurements of $R(D)$, $R(D^*)$, τ_{B_c}, and $\mathcal{B}(B \to K^{(*)}\nu\bar{\nu})$.

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*1 Department of Physics and Astronomy, University of Mississippi
*2 Department of Physics and Astronomy, University of Hawaii
*3 RIKEN Nishina Center
*4 Department of Physics, University of Arizona
*5 Department of Physics, Ain Shams University

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