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

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

$$R(D) = \frac{\mathcal{B}(B \rightarrow D\tau\bar{\nu})}{\mathcal{B}(B \rightarrow D\bar{\nu})},$$

$$R(D^*) = \frac{\mathcal{B}(B \rightarrow D^*\tau\bar{\nu})}{\mathcal{B}(B \rightarrow D^*\bar{\nu})},$$

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 $4.1\sigma$, hinting at the existence of new fundamental interactions that violate lepton-flavor universality.

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

$$R(\Lambda_c) = \frac{\mathcal{B}(\Lambda_b \rightarrow \Lambda_c\tau\bar{\nu})}{\mathcal{B}(\Lambda_b \rightarrow \Lambda_c\bar{\nu})}.$$  

A precise Standard-Model prediction of $R(\Lambda_c)$ using the $\Lambda_b \rightarrow \Lambda_c$ 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 $\Lambda_b \rightarrow \Lambda_c\tau\bar{\nu}$. Because some of these scenarios generate tensor couplings, we also determined the $\Lambda_b \rightarrow \Lambda_c$ tensor form factors from lattice QCD.

We demonstrated that a future measurement of $R(\Lambda_c)$ can tightly constrain all of the couplings $g_L, g_T, g_S, g_P$, and $g_T$ in the $b \rightarrow c\tau\bar{\nu}$ 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 $\tau_{B_c}$, and the upper limits on $\mathcal{B}(B \rightarrow K^{(*)}\nu\bar{\nu})$.

As an example, Fig. 1 shows the correlations between the predicted values of $R(\Lambda_c) = R(\Lambda_c)/R(\Lambda_c)_{\text{SM}}$ and $R(D^*) = R(D^*)/R(D^*)_{\text{SM}}$ 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 $b \rightarrow s\ell^+\ell^-$ decays). Our analyses show that a future measurement of $R(\Lambda_c)$ can be helpful in discriminating between the different models.

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

References