$\Lambda_b \to p\,\ell^-\,\bar{\nu}_\ell$ and $\Lambda_b \to \Lambda_c\,\ell^-\,\bar{\nu}_\ell$ form factors from lattice QCD with relativistic heavy quarks[†]

S. Meinel,[*1,*2] W. Detmold,[*3] and C. Lehner[*4]

The smallest and most uncertain element of the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix is V_{ub}. Improved measurements of $|V_{ub}|$ are important because they constrain the length of the left side of the $(\bar{\rho}, \bar{\eta})$ unitarity triangle, which lies opposite the precisely known angle β[1]. The matrix element $|V_{cb}|$ also plays a central role in flavor physics, as it normalizes the unitarity triangle and is the dominant source of uncertainty in Standard-Model predictions of the kaon CP-violation parameter ε_K[2].

Until recently, all direct determinations of $|V_{ub}|$ and $|V_{cb}|$ were performed using measurements of B meson semileptonic or leptonic decays at e^+e^- colliders. For both $|V_{ub}|$ and $|V_{cb}|$, there are tensions between the most precise extractions from exclusive and inclusive semileptonic B decays; the 2014 Review of Particle Physics lists[1]

$$\begin{aligned} |V_{ub}|_{\mathrm{excl.}} &= (3.28 \pm 0.29) \times 10^{-3}, \\ |V_{ub}|_{\mathrm{incl.}} &= (4.41 \pm 0.15^{+0.15}_{-0.17}) \times 10^{-3}, \\ |V_{cb}|_{\mathrm{excl.}} &= (39.5 \pm 0.8) \times 10^{-3}, \\ |V_{cb}|_{\mathrm{incl.}} &= (42.2 \pm 0.7) \times 10^{-3}. \end{aligned}$$

The Large Hadron Collider allows new determinations of $|V_{ub}|$ and $|V_{cb}|$ using the baryonic decays $\Lambda_b \to p\,\mu^-\bar{\nu}_\mu$ and $\Lambda_b \to \Lambda_c\,\mu^-\bar{\nu}_\mu$, provided that the relevant $\Lambda_b \to p$ and $\Lambda_b \to \Lambda_c$ hadronic form factors can be calculated. In this work, we performed a precise lattice QCD calculation of these form factors, utilizing lattice gauge-field ensembles generated by the RBC and UKQCD Collaborations. Using our form factor results, we can predict the $\Lambda_b \to p\,\mu^-\bar{\nu}_\mu$ and $\Lambda_b \to \Lambda_c\,\mu^-\bar{\nu}_\mu$ differential decay rates as functions of $|V_{ub}|^2$ and $|V_{cb}|^2$, as shown in Fig. 1. The LHCb Collaboration has recently measured the following ratio of the partially integrated decay rates[3],

$$\frac{\int_{15\,\mathrm{GeV}^2}^{q^2_{\mathrm{max}}} \frac{\mathrm{d}\Gamma(\Lambda_b \to p\,\mu^-\bar{\nu}_\mu)}{\mathrm{d}q^2}\mathrm{d}q^2}{\int_{7\,\mathrm{GeV}^2}^{q^2_{\mathrm{max}}} \frac{\mathrm{d}\Gamma(\Lambda_b \to \Lambda_c\,\mu^-\bar{\nu}_\mu)}{\mathrm{d}q^2}\mathrm{d}q^2} = (1.00 \pm 0.09) \times 10^{-2},$$

where the q^2-ranges were chosen to cover the region of the smallest uncertainties in our lattice QCD predictions. The combination of the LHCb measurement with our calculation gives

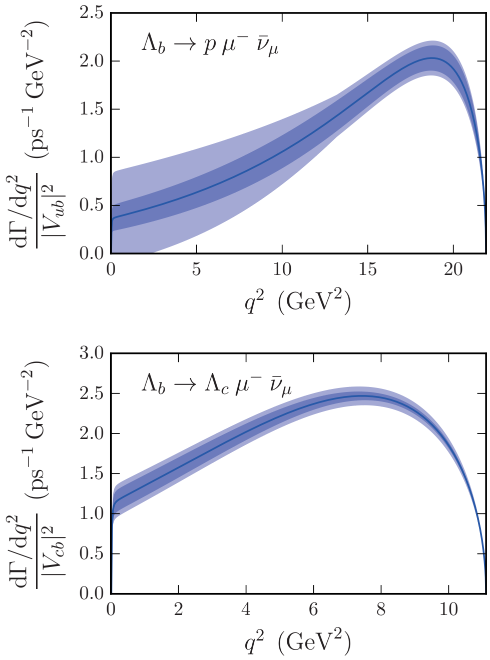

Fig. 1. Lattice QCD predictions for the $\Lambda_b \to p\,\mu^-\bar{\nu}_\mu$ and $\Lambda_b \to \Lambda_c\,\mu^-\bar{\nu}_\mu$ differential decay rates. The bands indicate the statistical-only and the total uncertainties.

$$\frac{|V_{ub}|}{|V_{cb}|} = 0.083 \pm 0.004(\mathrm{expt}) \pm 0.004(\mathrm{lattice}),$$

and, taking the 2014 PDG value for $|V_{cb}|$ from exclusive B decays,

$$|V_{ub}| = (3.27 \pm 0.23) \times 10^{-3}.$$

Because of the nonzero spin of the baryons, this analysis also provides important new constraints on possible right-handed currents beyond the Standard Model, whose existence had been suggested as an explanation of the exclusive-inclusive tension in $|V_{ub}|$[4]. The new measurement strongly disfavors this explanation [3], demonstrating that powerful complementary constraints on physics beyond the Standard Model can be derived from baryonic b decays.

References

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*1 RIKEN Nishina Center
*2 Department of Physics, University of Arizona
*3 Center for Theoretical Physics, Massachusetts Institute of Technology
*4 Physics Department, Brookhaven National Laboratory