$\Lambda_b \to \Lambda\,\ell^+\ell^-$ form factors, differential branching fraction, and angular observables from lattice QCD with relativistic b quarks[†]

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

Decays of bottom hadrons involving the flavor-changing neutral-current transition $b \to s\,\ell^+\ell^-$ are highly suppressed in the Standard Model, so that small effects from new physics could cause significant changes in the observed decay rates and angular distributions. The recent precise experimental results from LHCb for the mesonic decays $B \to K\mu^+\mu^-$, $B \to K^*\mu^+\mu^-$, and $B_s \to \phi\mu^+\mu^-$ indeed show some deviations from the available Standard-Model predictions, but it remains unclear whether these deviations are caused by new fundamental physics or by problems with the calculations of the hadronic contributions[1)].

The baryonic decay mode $\Lambda_b \to \Lambda(\to p\,\pi)\ell^+\ell^-$ can shed new light on these puzzles. Similarly to $B \to K^*(\to K\,\pi)\ell^+\ell^-$, this decay provides a wealth of angular observables that can be used to disentangle the contributions from individual operators in the $b \to s\,\ell^+\ell^-$ effective Hamiltonian[2)]. At the same time, the theoretical description of $\Lambda_b \to \Lambda(\to p\,\pi)\ell^+\ell^-$ is cleaner than that of $B \to K^*(\to K\,\pi)\ell^+\ell^-$ because the Λ is stable under the strong interactions.

The $\Lambda_b \to \Lambda(\to p\,\pi)\ell^+\ell^-$ differential decay rate depends on the hadronic matrix elements

$$\langle \Lambda(p',s')|\,\overline{s}\,\gamma^\mu\,b\,|\Lambda_b(p,s)\rangle, \quad (1)$$
$$\langle \Lambda(p',s')|\,\overline{s}\,\gamma^\mu\gamma_5\,b\,|\Lambda_b(p,s)\rangle, \quad (2)$$
$$\langle \Lambda(p',s')|\,\overline{s}\,i\sigma^{\mu\nu}q_\nu\,b\,|\Lambda_b(p,s)\rangle, \quad (3)$$
$$\langle \Lambda(p',s')|\,\overline{s}\,i\sigma^{\mu\nu}q_\nu\gamma_5\,b\,|\Lambda_b(p,s)\rangle, \quad (4)$$

which can be decomposed into ten form factors. In this work, we performed a precise lattice QCD determination of these form factors, utilizing lattice gauge-field ensembles generated by the RBC and UKQCD Collaborations. Based on these form factors, we then calculated the $\Lambda_b \to \Lambda(\to p\,\pi)\ell^+\ell^-$ differential decay rate and the complete set of angular observables (for unpolarized Λ_b) in the Standard Model. Our results for the differential branching fraction $\mathrm{d}\mathcal{B}/\mathrm{d}q^2 = \tau_{\Lambda_b}\mathrm{d}\Gamma/\mathrm{d}q^2$ and for the lepton-side forward-backward asymmetry $A^\ell_{\rm FB}$ are shown in Fig. 1. Also included in the plots are the measurements of these observables from the LHCb Collaboration[3)].

In the high-q^2 region from 15 to 20 GeV^2, the magnitude of the lepton-side forward-backward asymmetry measured by LHCb is smaller than the theoretical value by 3.3σ. The measured differential branching fraction exceeds the theoretical value by 1.6σ. While the latter deviation is not yet statistically significant, it is in the opposite direction to what has been observed mesonic B decays[1)]. More precise experimental results, including for the branching ratio of the normalization mode $\Lambda_b \to J/\psi\,\Lambda$, would be very useful in clarifying this aspect of the results.

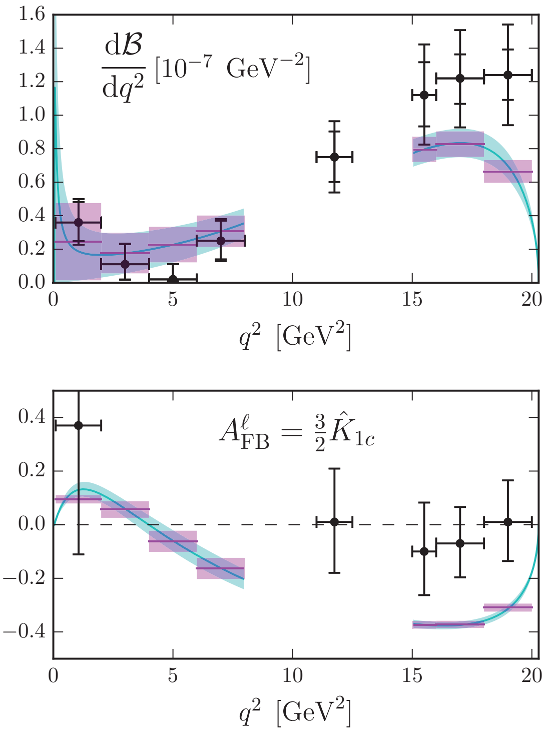

Fig. 1. The $\Lambda_b \to \Lambda(\to p\,\pi)\ell^+\ell^-$ differential branching fraction (top) and lepton-side forward-backward asymmetry (bottom). The cyan and magenta curves (without and with q^2-binning) show the Standard-Model predictions obtained from the form factors computed in lattice QCD; the black data points are the experimental results from LHCb[3)]. The regions near $q^2 \sim m^2_{J/\psi}, m^2_{\psi'}$, where resonant long-distance effects are dominant, are excluded from the analysis.

References
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*1 Center for Theoretical Physics, Massachusetts Institute of Technology
*2 RIKEN Nishina Center
*3 Department of Physics, University of Arizona