HPQCD: hints of new physics in rare B decays

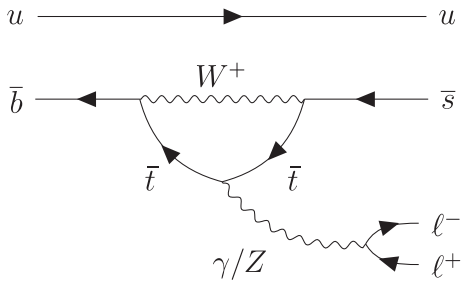

Figure 1. A possible decay pathway for $B^+ \to K^+ l^+ l^-$ in the Standard Model. The b quark in the B meson on the left undergoes a transition to an s quark, forming a K meson on the right. This can only happen via a loop containing W bosons and top quarks in the SM and has very low probability. Theories beyond the SM can have additional particles that appear instead of the W-t loop.

A key aim of the worldwide particle physics programme is to find evidence of new physics beyond our current Standard Model (SM) that would allow us to develop a more complete theory of fundamental physics. B meson decays are a good place to look because some of these are very rare in the SM but the presence of new particles could boost their rates. The process in which a B meson (containing a b quark) decays to a K meson (containing an s quark) and a lepton/anti-lepton (electron, muon or tau) pair is a good example. It must proceed in the SM via a loop made of W bosons and top quarks, as in Fig. 1, and is highly suppressed. New particles could shortcut this loop and give a very different rate (smaller or larger depending on the combination with the SM process). Theorists in the HPQCD collaboration have been spearheading the international effort to calculate B meson SM decay rates from lattice QCD. Our efficient method for handling quarks on a spacetime lattice makes the DiRAC CSD3 supercomputer at Cambridge ideal for our calculations and enables us to achieve world-leading accuracy.

Fig. 2 below shows our results (arXiv:2207.13371, 2207.12468) for the fraction of B^+ that decay to $K^+ l^+ l^-$ compared to the experimental data. The LHCb experiment at CERN has the most accurate data, and we see that there is a significant difference between their values and the lattice QCD calculation, especially at low values of q^2, where q^2 is the invariant mass-squared of the $l^+ l^-$ pair. Between $q^2 = 1$ and 6 GeV^2 the difference exceeds 4 times its uncertainty, which could be a hint of new physics in this decay process. The low q^2 region is challenging for lattice QCD because the K meson has large momentum there. HPQCD's calculation represents the first time that this has been successfully tackled. As we can see in Fig. 2, the low q^2 region is important because experimental results are often better there.

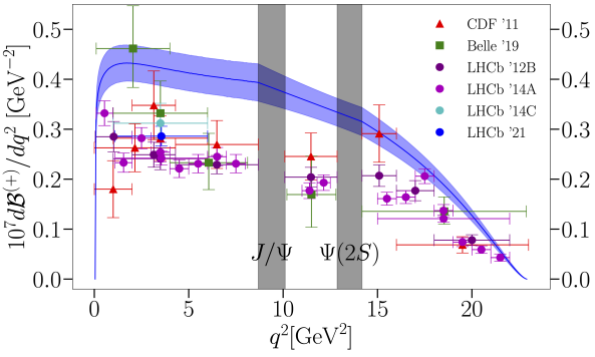

Figure 2. The blue band shows HPQCD's results (with their uncertainty) for the fraction of B+ mesons that decay to $K^+ l^+ l^-$ as a function of the invariant mass-squared (q^2) of the $l^+ l^-$ pair. The points show experimental results, including those from the LHCb experiment at CERN.

HPQCD was also able to predict the SM rate for $B \to K \nu \bar{\nu}$ (ν is a neutrino). This process has not been seen by experiment yet but should be visible at the BelleII experiment at superKEKB in Japan in future. It provides further exciting opportunities for new physics searches.