Light is right – working with up and down quarks at physical masses

The world of quarks and gluons, currently the most fundamental building blocks of matter known, is hidden from us. Quarks are never seen as free particles; instead we see their bound states, known as hadrons, in experiments such as those at CERN's Large Hadron Collider. Accurate calculations with the theory that describes quark and gluon interactions, Quantum Chromodynamics (QCD), are critical to connect the world of quarks to that of hadrons in a quantitative way.

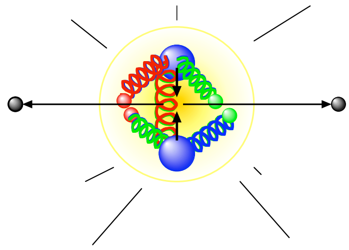

Figure 1. A meson annihilates to a lepton and antineutrino (from a virtual W boson)

Calculations are made tractable through a numerical technique known as lattice QCD, but they are computationally very challenging. The numerical cost increases as the quark mass falls and so one issue has been that of handling up and down quarks. These have very small masses (a few percent of that of the proton) in the real world. In the past calculations have been done with several values of heavier masses and then an extrapolation to the physical point is performed.

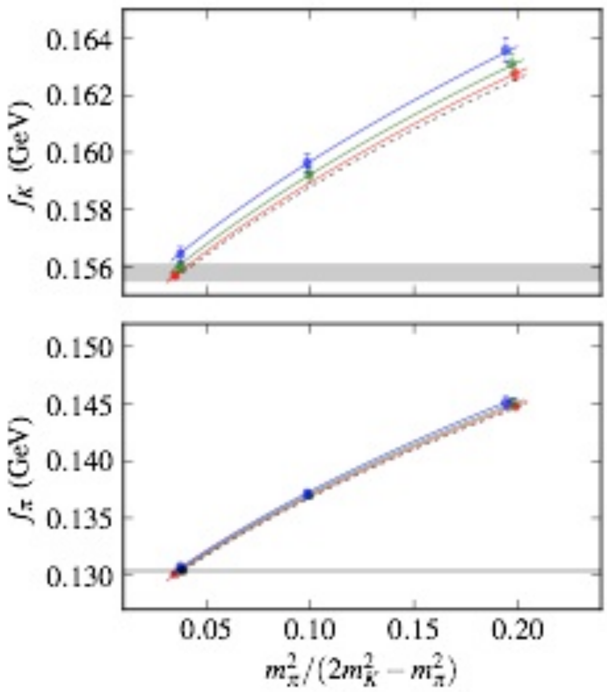

Figure 2. Our results for decay constants of K and π mesons as a function of the up/down quark mass. The results shown at 0.036 on the x-axis correspond to the real-world masses.

With the computing resources of DiRAC phase II, we are now able to perform calculations with up and down quarks having their physically light masses and this means that more accurate results can be obtained.

Key calculations that we have performed in this way during 2013 are those of the decay constants of the π, K, B and B_s mesons. The decay constant parameterizes the probability of the quark and antiquark in the meson being at the same point and annihilating, for example to a W boson of the weak force, as seen in Figure 1.

Our results for the decay constants are the world's most accurate. They have enabled us to test the CKM matrix of couplings between quarks and the W boson with unprecedented accuracy. We have also improved the prediction of the rate from known physics of the very rare process $B_s \rightarrow \mu^+\mu^-$, recently seen by the LHCb experiment. The sensitivity of this process to new physics makes a future comparison of the experimental and theoretical rates potentially very exciting.