HPQCD

The weighty issue of quarks

Electrons make circular tracks when they move perpendicular to a magnetic field in a particle detector. From the radius of the circle, knowing the electric charge, we can determine the electron mass. Quarks, on the other hand, are never seen as free particles. Instead all we see in our particle detectors are the bound states of quarks, called hadrons. We can measure hadron masses, but how do we then determine, or even define, the mass of a quark?

The answer is that we must define the mass as the parameter that enters the equations of QCD, the theory of the strong interaction that binds quarks into hadrons. We can solve the equations of QCD using the numerical approach of lattice QCD and hence determine the quark mass parameter that we need to put into the theory to give the correct mass for a calibration hadron containing that quark. Since experimentalists can measure some hadron masses very well, we can do this accurately. For example, to fix the charm quark mass, m_c, we use the mass of the η_c (pictured in Figure 1).

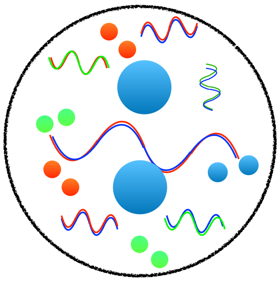

Figure 1. An artist's impression of an $\eta_c$meson containing a charm quark and antiquark (large blue circles) in a strongly interacting background soup of gluons (wavy lines) and quark-antiquark pairs (small circles).

To be of use to other theorists, however, we must convert the lattice quark mass into that appropriate to QCD defined in continuous space-time. We must do this accurately too, to avoid introducing a sizeable uncertainty into the result.

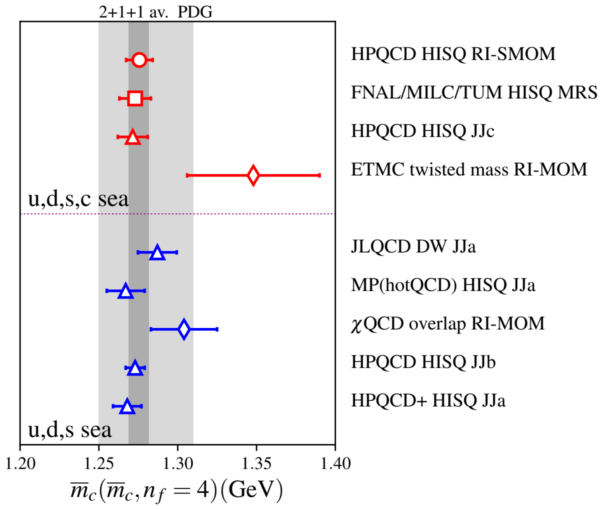

Figure 2. A comparison of lattice QCD results for mc, given in the conventional continuum QCD scheme. The top result is our new one, and the third our 2014 result, both obtained on DiRAC. The dark grey band is the lattice QCD world average, with much better uncertainty than the previous average light grey band (marked PDG).

HPQCD developed one of the main techniques used to determine quark masses (the JJ method) and most recently used this, on DiRAC, to determine m_c to 1% in 2014 (arXiv:1408.4169). This year we used a completely different technique (called RI-SMOM) to 'match' our lattice quark mass to that of continuum QCD, directly on the lattice (arXiv:1805.06225). We were careful to quantify and remove lattice artefacts, which had been ignored in previous calculations. Our new 1% accurate result agrees very well with our 2014 value and also with a third, MRS, method developed by FNAL/MILC/TUM in 2018. This gives a world-average for m_c of 1.2753(65) GeV (1.36 times the mass of the proton). The quark masses need to be accurately known so that we can test whether the newly-discovered Higgs boson is behaving as we expect when it decays to hadrons via quark-antiquark pairs of different flavours.