Lattice QCD and the search for new physics

If you could see deep into the subatomic world with slow-motion glasses, you would see empty space teeming with particles, appearing and disappearing in a tiny fraction of a second. If you were very lucky you might glimpse a particle so heavy and rare as to have escaped detection so far at CERN's Large Hadron Collider. Such particles would be harbingers of new physics going beyond our existing Standard Model, but are proving very hard to find. One way to demonstrate their existence indirectly is through the impact they have, as part of the teeming vacuum, on the properties of particles we can study directly. A new experiment will start shortly at Fermilab near Chicago to measure the magnetic moment of the muon (a heavier cousin of the electron) to an astonishing accuracy of 1 part in 10^{10}. If we can calculate the effect of all the particles in the Standard Model on this magnetic moment, then a discrepancy with experiment would indicate the existence of new particles. An improved theoretical uncertainty from the Standard Model needs numerical calculations for the theory of the strong interaction, QCD. This is because the largest source of uncertainty comes from quarks, which are strongly interacting (see Figure 1); this contribution is known as the hadronic vacuum polarization (HVP). HPQCD has developed a new lattice QCD method using DiRAC to determine the HVP with improved accuracy.

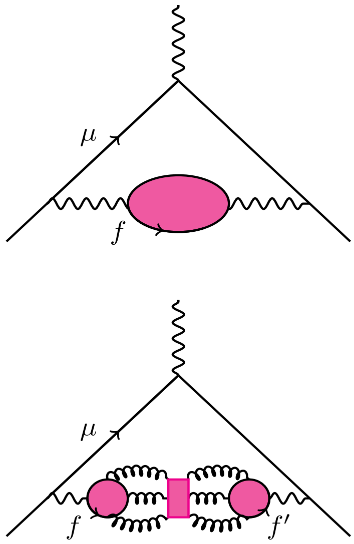

Figure 1. The interaction between a muon and a photon (wavy line) is complicated by the production of virtual particles such as quarks (f) and gluons (curly lines). Pink discs indicate strong interactions.

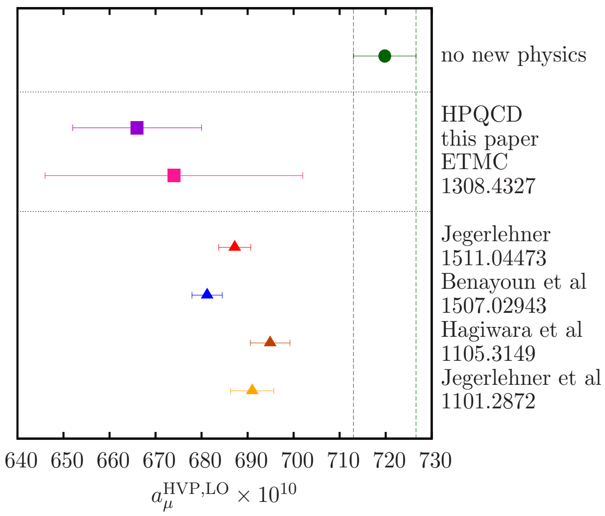

Figure 2. A summary of results for the hadronic vacuum polarization contribution to the magnetic moment of the muon. Our new result (filled purple square), shows significant improvement on earlier lattice QCD results (pink filled square). Results in the lower half are derived from experimental data from e+e- collisions. The green filled circle shows the value inferred from the current experimental result for the magnetic moment. The discrepancy seen may be a first sign of new physics.

We used our method to determine the strange and charm quark contributions to the HVP (arXiv:1403:1778) for the first time from lattice QCD, and then the very small bottom quark contribution (1408.5768). In the past year have determined the up and down quark contribution (1601.03071) and estimated the effect of `disconnected diagrams' (lower picture in Figure 1) (1512.03270). Our final result, summing all of these contributions, has a total uncertainty of 2% (see Figure 2). The error is dominated by possible systematic effects from ignoring the electric charge of the quarks and taking the masses of the up and down quarks to be the same. Work is now underway to include both of these effects in the calculation to reduce the uncertainty further, ahead of the new experimental results in 2018.