Progress toward an *ab initio*, Standard Model calculation of direct CP-violation in K-decays

C. Kelly*1 for the RBC and UKQCD collaborations

Recent theoretical and computational advances in the field of lattice QCD have opened the door to an *ab initio* determination of ϵ', the measure of direct CP-violation in Standard Model $K \to \pi\pi$ decays. New sources of direct CP-violation are required to explain the observed matter-antimatter asymmetry in the Universe, and ϵ' is particularly sensitive to the contributions introduced by many Beyond the Standard Model theories. A comparison of the Standard Model value to the precisely measured experimental number may therefore provide evidence of new physics.

In $K \to \pi\pi$ decays, the final $\pi\pi$ state can have either isospin $I = 2$ or 0 and ϵ' manifests as a difference in the complex phases of the corresponding amplitudes, A_2 and A_0 respectively: $\epsilon' \propto \left(\frac{\mathrm{Im}A_2}{\mathrm{Re}A_2} - \frac{\mathrm{Im}A_0}{\mathrm{Re}A_0}\right)$.

The RBC and UKQCD collaborations have successfully performed calculations of A_2 with 10% total errors1), and only A_0 remains to be determined. This is significantly more difficult than A_2, firstly because the $\pi\pi$ state can mix with the vacuum, leading to disconnected diagrams in which the two pions annihilate and are recreated at a later time. Such diagrams are typically extremely noisy and require advanced techniques such as all-to-all (A2A) propagators. The second difficulty is in creating a $\pi\pi$ state that is degenerate with the kaon such that the decay occurs with physical kinematics. This requires the pions to be moving, necessitating the use of G-parity spatial boundary conditions2) (GPBC) to control the statistical noise.

Efficient use of GPBC and A2A introduces a large number of computational challenges that must be overcome. To this end, we developed parallel code highly optimized for the IBM Blue Gene/Q machines at BNL, ANL and Edinburgh University and have, to date, generated $\mathcal{O}(100)$ independent measurements of the $K \to \pi\pi$ amplitude. The measurements were performed on a custom generated ensemble with a $(4.6\text{ fm})^3$ lattice volume and a relatively coarse 0.143 fm lattice spacing. We use a three-flavor chiral action with degenerate up and down quarks and a physical strange quark.

With our chosen lattice parameters we obtain a measured pion mass of $m_\pi = 142.4(1.3)$ MeV and a kaon mass of $m_K = 489.9(2.4)$ MeV, very close to their physical values of 135 MeV and 495 MeV respectively. We use GPBC in all three spatial directions and obtain a $\pi\pi$ energy of $E_{\pi\pi} = 524(45)$ MeV, which agrees with the kaon mass within errors, suggesting a near-physical decay.

In Fig. 1 we plot the contributions to A_0 from the Q_2 and Q_6 operators, which respectively dominate ReA_0 and ImA_0. Here we use a $K \to \pi\pi$ time separation of 12, and fit to the plateau between $t = 4$–8; outside of this region the signal is contaminated by excited states. Our analysis also includes measurements with $K \to \pi\pi$ time separations of 10 and 14. Preliminary results from our current, somewhat limited, data set suggest a ∼50% statistical error on our result for ReA_0 and ∼40% for ImA_0. The error is almost completely dominated by the disconnected diagrams, despite our use of A2A methods, and can only be resolved with more statistics. We anticipate doubling the statistics within the next 6 months.

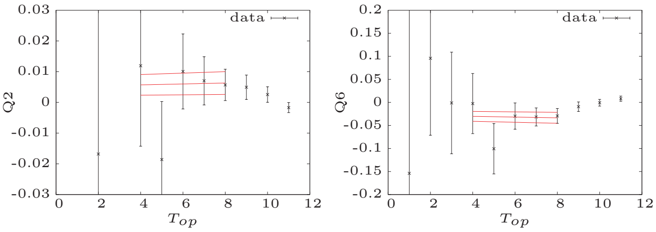

Fig. 1.: Lattice time dependence of Q_2 and Q_6, the dominant contributions to ReA_0 and ImA_0 respectively. The fit is shown in red.

The systematic errors on our results are dominated by the discretization error and the error on the Wilson coefficients. The former arises because the measurement is performed on a single, coarse lattice, and is expected to be $\mathcal{O}(20\%)$; in future calculations this can be removed by performing a continuum extrapolation over results computed at different lattice spacings. The Wilson coefficients are involved because we match the low-energy lattice calculation to the three-flavor Weak effective theory where the charm has been integrated out perturbatively; as the charm is comparatively light, it is not clear how reliable this is. We intend to study this by comparing A_0 computed using cheaper lattice calculations with stationary pions and both three and four dynamical flavors. Ultimately we intend to repeat the calculation with a dynamical charm quark.

References

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2) C. Kelly, PoS LATTICE **2012**, 130 (2012).

[*1] RIKEN Nishina Center, Brookhaven National Laboratory