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

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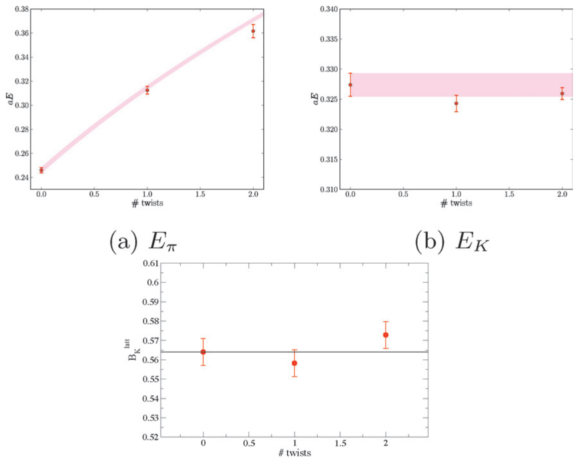
Direct CP-violation in $K \to \pi\pi$ decays manifests as a difference in phase between the decay amplitudes in the $I = 2$ and $I = 0$ channels and is parameterized experimentally as ϵ'. This quantity is extremely sensitive to Beyond the Standard Model sources of CP-violation; therefore, an accurate Standard Model calculation is greatly desired. As low-energy strong interactions play an important role, use of lattice QCD is required to study these processes. Although ϵ' has been known experimentally since the late 1990's, it is only recently that the techniques and raw computing power for performing a realistic first-principles calculation have become available. The main technical difficulty is finding a strategy for obtaining an energy conserving decay because only the ground state is easily accessible in lattice calculations. The lowest-energy two-pion state comprises stationary pions, and its energy (assuming physical quark masses) is only 270 MeV, far below the 500 MeV mass of the kaon.

The RBC and UKQCD collaborations have successfully performed calculations of the $I = 2$ channel amplitude[1,2)], solving the issue of obtaining physical kinematics by modifying the lattice boundary conditions (BC) of the down quarks from periodic to antiperiodic such that the charged-pion ground state is moving. Unfortunately this manifestly breaks the isospin symmetry. For the $I = 2$ decay, it is possible to relate the amplitude to an unphysical one in which the final state cannot mix with other isospin states, but this cannot be performed for the $I = 0$ decay. Instead, we intend to use G-parity boundary conditions (GPBC).

G-parity is a combination of charge conjugation and an isospin rotation by π radians about the y-axis. Both charged and neutral pions are eigenstates of this operation with eigenvalue -1; hence, its application at a spatial boundary causes the pion states to become antiperiodic in that direction, removing the stationary ground state. However, in this setup, operators involving both strange and light quarks cannot be combined to form G-parity eigenstates e.g., the K^0 state $\bar{s}d$ transforms to the unphysical $\bar{s}\bar{u}$ state at the boundary. We solve this issue by placing the s-quark in an isospin doublet with a fictional degenerate partner, referred to as s', and impose GPBC on this pair. We can then form a state, $\tilde{K} = \frac{1}{\sqrt{2}}(\bar{s}d + \bar{u}s')$, which is an eigenstate of G-parity with eigenvalue $+1$, and thus has a stationary ground state. For the $K \to \pi\pi$ measurement the effects of the fictional state $\bar{u}s'$ are expected to be small as it must propagate across the boundary to interact with the decay operator.



(a) E_π (b) E_K (c) B_K

Fig. 1.: Top: the pion and kaon energies, respectively as a function of the number of G-parity directions (twists), overlaid by the expected continuum dispersion relations. Bottom: B_K as a function of the number of G-parity directions.

To demonstrate that the GPBC have the desired effect, we generated several fully dynamical ensembles with a relatively small volume and a large (420 MeV) pion mass, with GPBC in zero, one, and two directions, each with periodic BC in the remaining directions. In Fig. 1, we plot the measured pion and kaon energies as the number of directions with GPBC is increased. We observe that the pion energies agree well with the continuum dispersion relation and that stationary kaon states can be produced in this framework. Because the quantity B_K, which represents the amplitude of mixing between neutral kaon states via the weak interaction, involves only kaons, we expect it will remain constant as we change the number of directions with GPBC; we observe that this is indeed the case.

We have since began generating a fully dynamical ensemble with a large volume and physical quark masses using the USQCD collaboration's IBM Bluegene/Q machine at BNL, and we expect to soon begin measurements. Once completed, the results can be combined with those for the $I = 2$ channel to finally obtain a first-principles value for ϵ'.

References
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