Quarkonium Physics with Unquenched Improved Staggered Fermions

December 20, 2004

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Time Requested: 1,125,000 processor-hours on the Pentium clusters at Fermilab, or equivalent.

Abstract

This proposal is part of a coordinated effort to calculate some of the most important quantities relevant for standard model phenomenology. We propose a study of the masses and leptonic decays of heavy quarkonium states below open flavor threshold. In addition to providing new and precise determinations of α_s and heavy quark masses, comparison to existing and upcoming experimental results will add an important test of the lattice QCD. In particular, quarkonium is ideal for testing improved heavy quark actions, and verifying that its uncertainties are well understood.

Scientific Program

Recent progress with improved staggered fermions has made possible unquenched calculations of much higher precision than previously achieved. Recent results from the MILC, Fermilab, and Cornell groups achieved accuracies of $2-5\%$ in such very simple quantities as f_π, f_K, and heavy meson mass splittings. These quantities are part of a group that can be considered "golden quantities" of lattice QCD: stable meson masses, mixings and single-particle decays. A large subset of the most important quantities in lattice phenomenology is in this set of particularly easy quantities, and a coordinated effort is underway by several large American collaborations to perform these calculations.

The quarkonium program described here is complementary to the SciDAC proposals on heavy quark physics with lattice NRQCD by Lepage et al., and on heavy-light physics by Bernard et al. It is a companion proposal in particular to the proposal by Bernard et al. All methods, software, and benchmarks are joint between the two proposals, so the details will not be repeated here. This work and that of the Bernard et al. proposal use the four component heavy fermions of El-Khadra et al. (the Fermilab fermions), and are thus complementary to the program of the Lepage et al. proposal.

Lepage et al. use nonrelativistic fermions, which are much quicker to calculate than Fermilab fermions and thus have better statistical errors. They are awkward at small lattice spacing, however. Agreement of the two methods therefore will provide an important check of the calculations.

Although the properties of quarkonia are easy to estimate using potential models, they are interesting for lattice QCD for just that reason. Before the advent of good unquenched calculations, potential models enabled one to estimate the effects of the quenched approximation. Such quantities as α_s and the heavy quark masses could therefore be obtained with reasonable precision before analogous quantities could be obtained from light quark physics. Unquenched calculations will yield these quantities with accuracies limited only by perturbation theory. In current unquenched calculations, they serve several additional important purposes. First, because they are well-understood with potential models, one can expect particular quarkonium properties to be very sensitive to certain correction operators. For example, the splitting of the χ_c states is expected to be very sensitive to the $\mathcal{O}(v^4)$ correction $\overline{\psi}\sigma \cdot \nabla \times E\psi$. Therefore, quarkonium calculations are important test beds for improved actions. Second, quarkonium decays test methods analogous to those of phenomenological crucial heavy-light meson decays: leptonic decays of quarkonia are similar to leptonic decays of heavy-lights, and electromagnetic transitions of quarkonia are similar to semileptonic decays of heavy-lights. Thus, a successful quarkonia program bolsters confidence in the heavy-light program, and hence, lattice CKM determinations. CLEO-c will improve dramatically the accuracy of these charmonium decays over the next couple years, making our calculations of quarkonium properties timely in their own right.

Most of the data generated for heavy-light calculations are needed in charmonium calculations. Some additional quark propagators are necessary, because excited states are much more interesting in quarkonia. Quarkonium excited states are hadronically very narrow, whereas heavy-light excited state are hadronically broad, and therefore less likely to be calculable with high precision. Excited states require separate sources to optimize statistics beyond what may be strictly necessary for heavy-light physics.

Codes and Resources

Codes and benchmarks are identical to those of the companion Bernard et al. heavy-light proposal.

This proposal shares charm quark propagators with that project. Time for charm quarks is allocated between the projects so that they run in tandem on each configuration. Currently, this proposal is accounting for about 2/3 of the charm production. It is specifically for the additional heavy quark sources required for excited states of quarkonium on the same data sets. The number of processor hours required to generate the required charm propagators is 230/configuration for the required two additional smeared sources and the charmonium analysis code. Under this proposal, we plan to complete the running on the MILC fine, $a = 0.09$ lattices in the first eight months, and to begin the analysis of the $a = 0.06$ lattices, as discussed in detail in the companion heavy-light proposal by Bernard et al.

The propagators generated in this proposed work will be available for projects with other physics goals.

Summary

We propose a study of the masses, leptonic decays, and eventually electromagnetic transitions of quarkonium states below open flavor threshold. In addition to providing new and precise determinations of α_s and heavy quark masses, comparison to existing and upcoming experimental results will add an important test of the overall program. Finally, quarkonium is an ideal system for testing the improved heavy quark action, which is an essential component of this program.