B and D Meson Decays with Unquenched Improved Staggered Fermions

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Time Requested: 3,375,000 processor-hours on the Pentium clusters at Fermilab, or equivalent.

Abstract

A broad program to study leptonic and semi-leptonic decays of mesons containing a heavy quark is proposed. These calculations will allow lattice gauge theory to have much greater impact on accurate determination of CKM matrix elements from experimental results at BABAR, CLEO-c, Belle, CDF, and D0. The study will use gauge configurations that include effects of dynamical up, down and strange quarks. The heavy quark uses either the standard or an improved version of the Fermilab method. An improved staggered quark action (Asqtad) is used for the light quark, which allows a much closer approach to the chiral limit than previous work.

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 simple quantities as f_π, f_K, and heavy meson masses. The achievement of similar accuracies in comparably simple but phenomenologically important quantities in B and D physics is an exciting prospect. This proposal is part of a larger program with the goal of providing accurate lattice results for the most important quantities in Standard Model and non-Standard Model phenomenology. It is one of several lattice QCD proposals to the DOE that are part of this general effort. A huge experimental effort is currently devoted to B and D meson physics. However, the experimental measurements must be complemented by precise lattice QCD calculations of the corresponding weak matrix elements, if we are to extract accurate information for the parameters of the standard model from this effort. Hence this project is essential to High Energy Physics.

As explained below, we will address all sources of systematic error in our calculations. We expect that our results will have an unprecedented impact on CKM physics. The ultimate goal of this effort is to produce reliable results with few percent errors.

Many of us have been involved in studies of B and D meson quantities for many years. The main objects of our study are B, B_s, D, and D_s mesons. In the first year we studied two types of processes, purely leptonic decays, e. g., $D \to \ell\nu_\ell$, and semileptonic decays to light mesons, e. g., $D \to \pi\ell\nu_\ell$. We have just started to study other important processes. Codes for semileptonic decays to heavy mesons, e. g., $B \to D\ell\nu_\ell$ have been completed and are being tested. Codes for B-$\bar{B}$ mixing and $B \to D^*\ell\nu_\ell$ are under development.

Strong interaction effects in leptonic decays are characterized by the decay constants f_B, f_{B_s}, f_D and f_{D_s}. Semileptonic decays are characterized by form factors $F(q^2)$, where q is the momentum carried by the leptons. Accurate lattice QCD predictions of the decay constants and form factors are needed to extract the associated CKM matrix elements from experimental measurements of B and D meson decays. CLEO-c will provide precise measurements of the D and D_s leptonic and semileptonic decays to few percent accuracy. They will take appropriate ratios of leptonic and semileptonic decay rates to cancel the dependence on CKM matrix elements. Hence, the comparison of these experimental results with lattice QCD predictions offers an unprecedented opportunity to test the lattice approach. After confirmation, this will also yield new determinations of V_{cd} and V_{cs}. Furthermore, lattice results for f_B and f_{B_s} (and B_{B_d} and B_{B_s}) will have a major impact on the determination of the poorly known CKM matrix elements V_{td} and V_{ts} from experimental measurements of B-$\bar{B}$ and B_s-$\bar{B}_s$ mixing. Similarly, accurate lattice determinations of semileptonic form factors for B and B_s mesons to light mesons would provide a new window on the CKM matrix element V_{ub}. These determinations combined with others will provide new insights in investigating CKM *vs.* new physics CP breaking scenarios.

Together with these weak matrix element calculations, we will also calculate meson masses in the B, B_s, D, and D_s meson systems. The comparison of these calculations with experimental results will give us another test of our methods, in addition to providing us with determinations of the heavy quark mass parameters.

We will be using unquenched staggered fermion configurations with lattice spacings $a = 0.18$, 0.15, 0.125, 0.09, and 0.06 fm. These configurations have three nondegenerate flavors of improved staggered quarks at a range of light masses, $m_s/10 \leq m_l < m_s$. The $a = 0.125$ and 0.09 fm configurations are the MILC "coarse" and "fine" lattices generated at supercomputer centers [1]. The extra-coarse $a = 0.18$ fm lattices were begun at supercomputer centers and completed on the Fermilab clusters. The $a = 0.15$ fm configurations, if required, will be generated at Fermilab. The final $a = 0.09$ fm lattices, and the $a = 0.06$ fm lattices will be generated on the QCDOC [2].

It has been suggested that the size of the systematic errors associated with the chiral extrapolation in heavy-light systems may be considerably larger than previously believed. To study this effect one needs lighter quark masses, so that the chiral logarithm terms can actually be observed and included in a controlled way in the fits. Since we use improved staggered dynamical quarks, the masses of the sea quarks available to us are probably already light enough, and are certainly lighter than those of other groups. We are combining our heavy quarks with light staggered quarks, which makes it possible to construct mesons with very light valence u and d quarks. In order to obtain accurate information about the chiral logarithms from these simulations, it also will be necessary to have analytic results on heavy-light decay constants from chiral perturbation theory with staggered "taste" violations. Such calculations already exist for light-light meson masses and decay constants, and for heavy-light decay constants. Calculations for heavy-light semileptonic decays have recently been completed.

We have started our calculations using the clover action with the Fermilab interpretation for the heavy valence quarks. Two-loop operator renormalizations are ultimately required for high precision CKM phenomenology on the lattice. A program for accomplishing this is in progress in coordination with Howard Trottier and Matthew Nobes of Simon Fraser University. One-loop calculations of the heavy-light current renormalizations have currently been completed. In summary, we expect that our results will have control over all systematic errors, including sea quark effects, lattice spacing errors and perturbative errors.

These calculations will require heavy quark propagators with clover or highly improved quarks and light quark propagators using the Asqtad action. These two propagators are combined to create a meson propagator. Most of the computational effort is in the calculation of the quark propagators.

A Physical Review Letter on the first analysis of D semileptonic decay will shortly be published [3]. Conference reports on initial calculations of B semileptonic decays into π and D mesons [4], and D meson leptonic decays [5], appeared in the proceedings of Lattice 2004.

Codes

The inverters are available from a number of sources including MILC and FermiQCD. QDP improvements have been incorporated into the inverters used for the valence staggered quarks, as well as into the staggered unquenched code. The MILC code has been upgraded to include SciDAC QDP/C code with SSE single and double precision enhancements for the Asqtad single mass and multimass inverters. It also includes some improvements to the fermion force term algorithm that were developed for the QCDOC. SciDAC gauge configuration file formats are now supported by the MILC code through SciDAC QIO. Also added is the ability to read and write light staggered propagators in a format suitable for FNAL codes. The meson two-point function calculations are available in a CANOPY code. In last year's running, the heavy quark code achieved 410 MF/processor in single precision and 250 MF/processor in double precision on the 128 dual node P4 system. The staggered multimass inverter achieves 275 MF/processor in double precision on the same system. Single-precision unquenched Asqtad code gives 900 MF/processor on $16^3 \times 48$ lattices on the most recently installed P4 cluster, and 1070 MF/processor on large lattices. It takes about 680 dual node hours to perform a complete leptonic and semileptonic decay analysis on one $28^3 \times 64$, $a = 0.09$ configuration with 12 heavy quark color-spin sources, two heavy quark masses, three color sources of strange staggered quark, eight light quark masses, four time sources, and heavy-light analysis codes.

Resource Allocation

The heavy quark propagators are shared between this project and the companion quarkonium proposal from DiPierro et al.

In order to improve our understanding of discretization uncertainty, we have done a small amount of unquenched running to extend the the MILC "extra-coarse" ($a \sim 0.18$ fm) unquenched configuration data set to complement approximately the the "coarse" ($a \sim 0.125$ fm) data set. This required around 5% of our total running time. If the analysis of the extra-coarse configurations looks promising, we plan to generate an additional set of configurations with lattice spacing $a \sim 0.15$ fm.

We are currently almost finished with four time-sources on the first of three existing ensembles of fine lattice configurations. The next two existing MILC fine lattice ensembles will take around 750,000 node hours to finish. We expect to finish most of the second set during the remaining four months of the current allocation. The new cluster to be installed this winter is expected to more than double the capacity of the installed hardware. We therefore expect to complete the third fine lattice ensemble in the first two months of running in the time being requested under this proposal. The final (coming) fine lattice ensemble, with volume increased from 28^3 to 40^3, or by a factor of three, is expected to take around five or six months to analyze. The remainder of the time allocated in the comming year will be devoted to beginning the analysis of the new $a = 0.06$ lattices, which will have lattice volumes, and therefore time requirements, five times those of the smaller $a = 0.09$ lattices.

The MILC collaboration has an allocation of 927,000 processor-hours on the NCSA Tungsten Xeon cluster (3.2 GHz nodes, with Myrinet interconnect) for heavy-light decays which will also be allocated to this project.

Summary

At the end of the project we expect to have the world's best determination of heavy-light meson decay constants and semileptonic decay amplitudes. They will be of key importance to the experimental programs of Fermilab, CLEO-c, BaBAR, and Belle.

The propagators generated in this proposed work will be available initially at Fermilab for projects with other physics goals. As the results for the decay constants are generated, we will endeavor to make the propagators more widely available through either the Gauge Connection or its successor. Other SciDAC researchers who need these propagators more promptly should contact one of us to arrange access.

References

[1] C. W. Bernard *et al.*, Phys. Rev. D **64**, 054506 (2001) [arXiv:hep-lat/0104002]; C. Aubin *et al.*, arXiv:hep-lat/0402030.

[2] See the companion proposal to this one, C. Bernard et al., QCD with Three Flavors of Improved Staggered Quarks.

[3] C. Aubin *et al.*, arXiv:hep-ph/0408306, to appear in Phys. Rev. Lett.

[4] M. Okamoto *et al.*, arXiv:hep-lat/0409116.

[5] J. N. Simone *et al.*, arXiv:hep-lat/0410030.