High-Precision Heavy-Quark Physics

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Abstract

The HPQCD Collaboration wishes to continue its program of high-precision lattice QCD studies of heavy-quark physics. This requires sign-ficant computing resources for generating heavy-quark propagators and analyzing them, and for completing the high-order perturbative matching calculations needed to connect lattice QCD results to the continuum. Resources are also needed for preliminary studies of a new staggered light-quark discretization that reduces taste-changing effects another factor of 3 relative to improved staggered quarks.

Researchers

The HPQCD Collaboration is a collaboration of collaborations focused on achieving few-percent precision in a wide range of lattice calculations, with an emphasis on systems containing heavy quarks (Bs, Ds, Υs and ψs). The collaboration currently involves groups from Cambridge, Cornell, Glasgow, Illinois, Indiana, Ohio State, Simon Fraser University, Southern Methodist University, and Triumph. The work described in this proposal will be carried out by the following subset of the collaboration:

- Cambridge: Ron Horgan (PI), Quentin Mason (postdoc), and one student;
- Cornell: Peter Lepage (PI) and Matthew Nobes (postdoc);
- Glasgow: Christine Davies (PI), E. Follana, A. Dougall (postdocs), and 1 student;
- Ohio State: Junko Shigemitsu (PI), A. Gray (postdoc), and one student;
- Simon Fraser University Howard Trottier (PI) and one students;
- Southern Methodist University: Kent Hornbostel (PI);
- TRIUMF: Richard Woloshyn (PI).

The number of students involved is approximate; it cannot be predicted exactly at this time.

Allocation Request

We request 150×128 node-days of processor time on the Fermilab cluster during the next year. The Fermilab cluster is the most appropriate for two reasons. First we will be sharing large numbers of light-quark propagators with other components of the HPQCD collaboration, including the Fermilab group. Second, a significant part of our processor time will be required for computing NRQCD-type propagators and evaluating two-loop perturbation theory diagrams, both of which are most efficiently done on clusters. This proposal is a continuation of our proposal last spring (and therefore has significant overlap with that proposal).

Scientific Program

Our goal is few-percent accurate calculations of the spectra, decay constants, mixing amplitudes, and semi-leptonic form factors of Bs and Ds using the following ingredients:

- the MILC collaboration's existing $n_f = 3$ unquenched configurations at $a = 1/8\,\text{fm}$ and $a = 1/11\,\text{fm}$;
- improved staggered quark propagators for light valence quarks;
- NRQCD and moving NRQCD propagators, through order $1/M^2$, for heavy valence quarks;
- perturbatively improved currents, through order α_s^2 and $1/M^2$;
- a new more highly improved staggered quark action (HISQ[1]) for light quarks;
- the HISQ action for c quarks (in addition to using NRQCD).

These results will have an immediate impact on heavy-quark physics since the target precision is almost an order of magnitude better than what is currently available. In particular, there are several D meson properties that can be predicted before they are measured (with comparable precision) by CLEO-c.

HPQCD, working with the MILC collaboration, has already demonstrated that high-precision results are feasible using the MILC configurations: we have demonstrated 2–3% accuracy in calculations of the upsilon spectrum, elements of the B, ψ, and light baryon spectra, and the pion and kaon decay constants—nine quantities in all so far, with no free parameters. A new determination of $\alpha_s(M_Z)$ is now complete, and the result agrees with the current world average to within perturbative errors of ±1–2%.

This feasibility study addressed three critical systematic errors. First it showed that finite lattice spacing errors, including "taste-changing" effects in improved staggered quarks, are no larger than a few percent on the finer MILC lattices (and probably a lot smaller, especially for heavy-quark mesons). Second, it showed that the MILC quark masses are sufficiently small for reliable chiral extrapolations to physical u and d masses, again with final errors of order a few percent or less. Finally, MILC results already demonstrated that finite-volume effects are negligible at the few-percent level for all quark masses down to $m_s/8$, the smallest mass studied. We are currently measuring correlation times for the finer MILC lattices; correlations are negligible for the coarse lattices.

HPQCD has successfully completed (and published) new results for the B spectrum, decay constants, and semileptonic form factors that demonstrate the utility of improved staggered valence quarks. The MILC code was used to compute light-quark propagators and NRQCD, through order v^4, was used for the b quark. Studies are currently underway of three-point amplitudes for computing semileptonic form factors, and of mixing. A new analysis of the B_c spectrum is in progress. Codes for NRQCD through order v^6 and $1/M^3$ have been written and debugged; a code for moving NRQCD has been written and debugged (a first paper is almost ready for publication). HPQCD has also made considerable progress on the perturbative calculations.

The computer allocation in this proposal is to cover three types of calculation:

- Unquenched feasibility tests using a new variation of improved staggered quarks (HISQ) with much smaller (3×) taste-changing errors. Errors due to taste-changing interactions are still rather large for light-quark hadrons (but not heavy-light mesons). HPQCD's new action has substantially smaller taste-changing errors, but requires a more complicated gluon updating algorithm that must be tested against existing work. We estimate spending 60×128 node-days of computer time on these tests. This should produce new sets of configurations at medium lattice spacings ($\approx 1/8\,\mathrm{fm}$).

- The computation of NRQCD and moving NRQCD propagators for a wide range of heavy-quark masses and reference frames (for moving NRQCD): Each light-quark propagator will be reused dozens of times in combination with different heavy-quark propagators in a wide range of calculations of B and D properties (decay constants, mixing, form factors at all momenta). Our recent experience indicates that the computer time required for the heavy-quark propagators is therefore comparable to that needed for the light-quark propagators (40×128 node-days). NRQCD-type propagators are computed time slice by time slice on a single processor, with no need for inter-processor communication. This makes clusters the obvious choice for such work, and code design and optimization is straightforward. We do not save NRQCD propagators.

- The computaion of HISQ propagators for c quarks. These could be significantly more accurate that NRQCD propagators, and have dramatically less (10×) taste-violation than conventional staggered quarks (which is important for analyzing fine structure, for example). HPQCD is beginning a systematic study of the utility of the HISQ formalism for c quarks, and will need to generate several hundred of propgators at medium and small lattice spacings. We estimate this will require 50×128 node-days.

- High-order perturbation theory calculations: Two-loop lattice perturbation theory integrals are very expensive to compute. We have created a parallel version of vegas for use on a cluster. (Clusters are again ideal because inter-processor communication is minimal.) We estimate that about 20% of our allocation will be used for perturbation theory. The major consumers of time will be matching calculations for B/D decay constants, semileptonic form factors, and mixing amplitudes.

References

[1] Highly Improved Staggered Quarks (HISQ) are improved staggered quarks (like asqtad) but with a more sophisticated smearing of the links that suppresses not just tree-level but also one-loop taste changing interactions. Like asqtad, the action has no $\mathrm{O}(a^2)$ tree-level errors.