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Title: **Simulating the Decays of Bottom and Charm Mesons**

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Simulating the Decays of Bottom and Charm Mesons

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Abstract

This is the final report of a one-year, Laboratory Directed Research and Development (LDRD) project at Los Alamos National Laboratory (LANL). The objectives of this project were (1) to develop the computer code necessary for the simulation of heavy quarks using the nonrelativistic quantum chromodynamics (NRQCD) approach using the massively parallel Connection Machine CM-5; and (2) to combine these heavy quarks with $O(a)$ improved light quarks to obtain experimentally interesting predictions of QCD. We succeeded in our development effort and we already have preliminary results for the mass spectrum and decay constants of the heavy-light hadrons.

Background and Research Objectives

Our current knowledge of the interactions of all elementary particles is classified under four basic kinds of interactions called strong, weak, electromagnetic and gravitational. The first three constitute a unified theory called the Standard Model of particle physics. This model has only 19 free parameters, and yet it is able to explain and predict (at least qualitatively) the results of most of the experiments in particle physics. What is lacking is precise comparisons of the predictions of the model and experiments. As a result, 11 of these 19 parameters are poorly determined. One of the primary goals of particle physicists today is to determine these parameters. Once this is done we will be able to either establish the Standard Model as the correct theory or, in the process, get hints of a more complete theory.

There exist reliable analytical techniques to calculate the effects of the weak and electromagnetic interactions. The strong interactions (also called quantum chromodynamics, or QCD), however, are characterized by a coupling constant that is too

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large to allow us to extract reliable predictions of QCD using analytical methods. One needs nonperturbative methods that do not rely on expansions in terms of a small coupling constant. To date, the most successful method of treating this sector of the theory is called lattice gauge theory, which can be solved through large scale numerical simulations.

Simulations of lattice QCD require the ability to harness the resources of leading-edge computer technology since it is a problem that requires large memory machines with teraflop capability. Over the last several years, we have harnessed the power of the 1024-node CM5 at Los Alamos and have developed highly optimized programs on it. As a result of this effort, our Lattice QCD collaboration is in the very forefront of such calculations. So far this collaboration has concentrated on the physics of the three light quarks, the up, down, and strange quarks. We have produced state-of-the-art results for the spectrum and quantum mechanical matrix elements of weak interactions within hadronic states. The results of our simulations can be related to the weak decays of hadrons that are being measured in high energy laboratories around the world.

One of the best ways of fixing two of the parameters characterizing the most subtle features of the Standard Model (CP violation) is by the study of the weak decays of the heavy charm and bottom quarks. Experimental data on these decays has started to become available and now is the right time to sharpen the theoretical predictions. For this purpose we need to incorporate these heavy quarks into lattice QCD simulations, for, once again, the QCD corrections to these weak processes make other theoretical methods unreliable. Unfortunately, the systematic errors due to lattice discretization effects preclude the approach that has been successful for the study of light quarks. It is necessary to extend the standard framework of lattice QCD if we are to include the physics of heavy quarks reliably.

In the last few years an alternate approach called nonrelativistic QCD (NRQCD) has shown great promise for including charm and bottom quarks in lattice simulations. We feel that the NRQCD approach will be successful in providing reliable results for decays of mesons containing charm or bottom quarks. Our goal, therefore, was to refine the computational techniques needed for this method and to produce state-of-the-art results for heavy-light mesons that will help provide stringent tests of the Standard Model.

In addition, in the process of developing and optimizing the necessary Lattice QCD codes on the latest emerging computer technology, we will continue to play an important role in the development of high performance computing and communications.

Importance to LANL's Science and Technology Base and National R&D Needs

One of the chief goals of high-energy experiments over the next two decades is to test the Standard Model of particle interactions. To do this requires that we include the QCD effects non-perturbatively. Only then can one confront theory with experiment and look for signatures of new physics. The calculations we have started will allow us to estimate, from first principles, some of the least well-known parameters of the standard model, and to make quantitative predictions. This theoretical input will complement the Laboratory's experimental effort and the two together will help us better understand the basic laws of nature.

A second equally important aspect of this project is computational. QCD simulations are ideal for evaluating the robustness of the hardware and software of emerging parallel architectures. We have continued to work very closely with the Advanced Computing Laboratory (ACL) to develop high performance computing capability at LANL.

Scientific Approach and Accomplishments

We developed computer code to simulate NRQCD quarks on the CM-5 and combine them with the $O(a)$ improved light quarks. We have generated 95 16^3x48 lattices so far and have finished a preliminary analysis of 75 of them. Our calculations are the only ones in the world that include all the $O(1/M^2)$ corrections along with corrections for lattice discretization errors, which contribute to the same order. So far, we have measured the masses and decay constants of heavy-heavy, heavy-light and light-light hadrons with the heavy quark in the region of the b quark. In addition, we have analyzed how these quantities scale with the heavy quark mass.

Our preliminary analysis of the light-light spectrum agrees with existing data and allows us to determine the scale of the lattice self-consistently. We find that the lattice discretization scale is 1.9 GeV as calculated from the meson spectrum. We calculated the heavy-light spectrum as a function of the heavy quark mass. A direct measurement of the hyperfine splitting confirmed the expectation that this quantity is insensitive to the $O(1/M^2)$ corrections. We also calculated the P-state spectrum and showed that the statistical errors are already small enough to estimate the splittings.

We analyzed the various pieces contributing to the decay constants of heavy-light mesons separately. In the b-quark mass region, the individual higher order terms (those proportional to $1/M^2$) are quite significant. We are currently in the process of computing the renormalization constants needed to predict the physical values of these decay constants from our lattice data.

With this technology in hand, we are now in the process of adding more physical observables to the set of quantities that we measure. In the near future, we hope to use these measurements to provide solid data on the experimentally relevant predictions of decay rates of B and B^1 mesons.

Publication

1. Khan, A. A. and Bhattacharya, T. "B and B_c mesons with NRQCD and Clover actions," Los Alamos Report LA-UR-96-3338 (1996).