Precision lattice calculation of D and D_s decay constants.

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Charm 2007, Cornell University

HPQCD collaboration

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Thanks: The MILC collaboration for making their configurations publicly available.

Outline

- Motivation.
- Heavy quarks.
- Results for masses and decay constants.

(Phys.Rev.D75:054502,2007, hep-lat/0610092, arXiv:0706.1726)

Motivation

- To test lattice field theory as a tool for studying strongly coupled field theories. Compare precision calculations of masses and decay constants with experimental results.
- To calculate theoretical quantities needed in the analysis of experimental data, for example, in the determination of elements of the CKM matrix.

Heavy Quarks

- The discretization errors grow with the quark mass as powers of am.
- For a direct simulation, we need:

  $am_h \ll 1$ (heavy quarks)
  $La \gg m_\pi^{-1}$ (light quarks)

- If m_h is large enough, $\Rightarrow$ effective field theory (NRQCD, HQET). Very successful for b physics.

Charm quarks

- The charm quark is in between the light and heavy mass regime.
- Quite light for an easy application of NRQCD.
- Quite large for relativistic quark actions, $am_c \lesssim 1$.
- However, by using a very accurate action (HISQ) and fine enough lattices (MILC), it is possible to get accurate results.
  - Errors for HISQ: $\mathcal{O}((am)^4, \alpha_s(am)^2)$.
  - Non-relativistic system: further suppression by factors of (v/c).
  - Can reduce the errors to the few percent level.
  - Simple: use the same action in the charmonium and the charm-light sector.
- We will use this action both for heavy-heavy and heavy-light systems $\Rightarrow$ consistency check.

Configurations

MILC ensembles: $2+1$ ASQTAD sea quarks: $(m_l,\ m_l,\ m_s)$

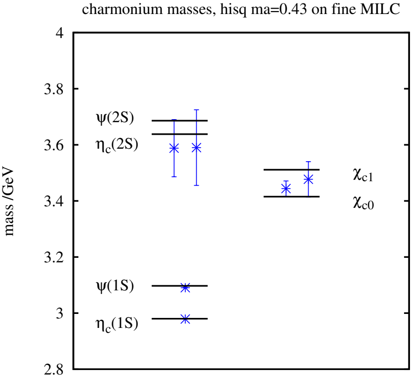
- Very coarse: a $\approx$ 0.16 fm, 16^3x 48
  - $m_l = m_s/2.5,\ m_s/5$
  - Valence HISQ: $am_c = .85$

- Coarse: a $\approx$ 0.12 fm
  - $m_l = m_s/2,\ m_s/4$ $\quad 20^3x$ 64
  - $m_l = m_s/8,$ $\quad 24^3x$ 64
  - Valence HISQ: $am_c = .66$

- Fine: a $\approx$ 0.09 fm, $\quad 28^3x$ 96.
  - $m_l = m_s/2.5,\ m_s/5$
  - Valence HISQ: $am_c = .43$.

Masses and decay constants

- We use the mass of the η_c to fix the mass of the charm quark.
- We adjust the coefficient of the Naik term to have $c^2 = 1$.
  This further reduces the discretization errors by factors of $\frac{v}{c}$.



Hyperfine splitting
111(5) (Exp: 117(1)) MeV

Masses and decay constants

- Meson decay constants:

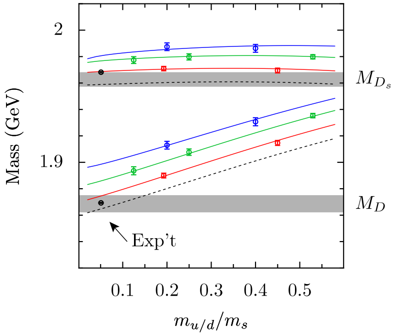
$$\Gamma(P \to l\nu_l(\gamma)) = \frac{G_F^2|V_{ab}|^2}{8\pi} {f_P}^2 m_l^2 m_P \left(1 - \frac{m_l^2}{m_P^2}\right)^2$$
$$\langle 0|A^\mu|P(p)\rangle = f_P p_\mu$$

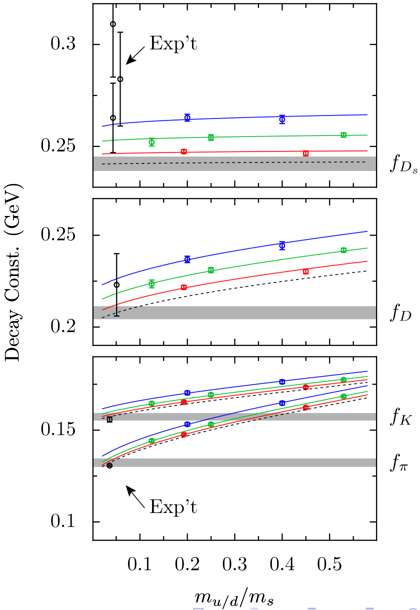
PCAC:

$$f_P {m_P}^2 = (m_a + m_b) < 0|\bar{a}\gamma_5 b|P >$$

- We do a simultaneous bayesian fit of the masses and decay constants to the chiral and continuum limits.

Masses and decay constants



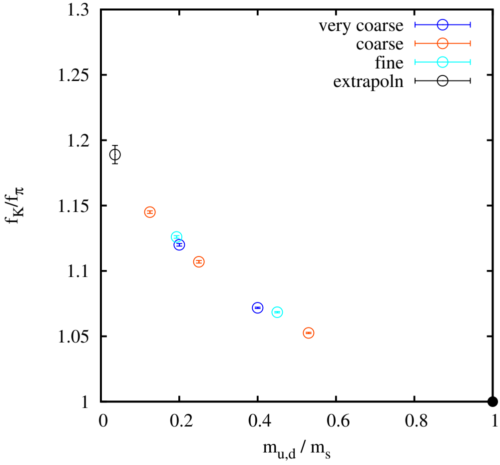


$m_{D_s} = 1.963(5)$ (exp. 1.968) GeV.
$m_D = 1.869(6)$ (exp. 1.869) GeV.

$$\frac{(2m_{D_s} - m_{\eta_c})}{(2m_D - m_{\eta_c})} = 1.249\ (14)$$

(exp. 1.260(2)) GeV

Decay constants



$$\frac{f_K}{f_\pi} = 1.189(7)$$

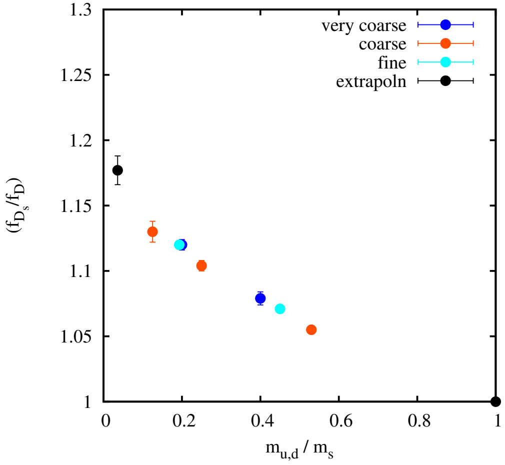
Using experimental leptonic branching fractions (KLOE)

$$V_{us} = 0.2262(13)(4)$$

This gives the unitarity relation

$$1 - V_{ud}^2 - V_{us}^2 - V_{ub}^2 = 0.0006(8)$$

Decay constants



$f_{D_s} = 241(3)$ MeV
$f_D = 208(4)$ MeV
$\frac{f_{D_s}}{f_D} = 1.177(11)$

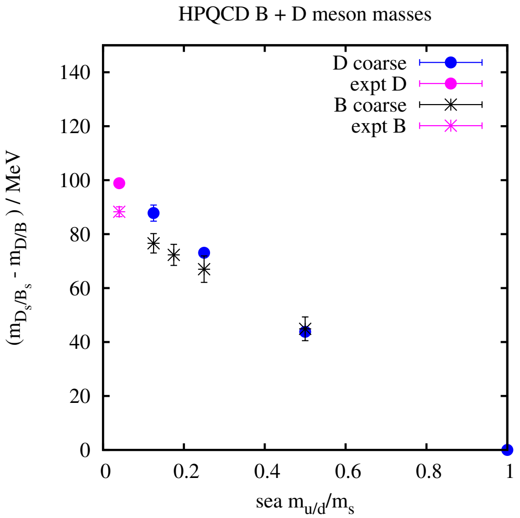
Using experimental values from CLEO-c for μ decay:

$$V_{cs} = 1.07(1)(7)\ (PDG : 0.96(9))$$

$$\frac{V_{cs}}{V_{cd}} = 4.42(4)(41)$$

Mass differences

- We plot $m_{D_s}(m_l) - m_D(m_l)$ and $m_{B_s}(m_l) - m_B(m_l)$ as a function of the sea light quark mass, m_l.



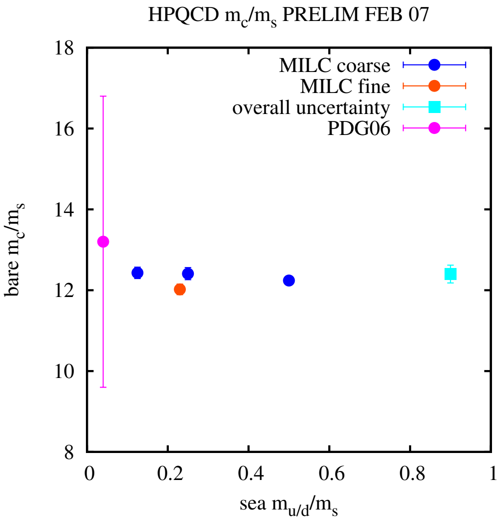
Conclusions

- The use of a highly improved quark action and fine enough lattices provides a very good way of studying systems with charm quarks from first principles.
- We can calculate accurately a number of interesting quantities, which can be checked against experimental results.

Outlook

- Direct determination of m_c from the lattice. Needs perturbative calculation (underway.) Accurate m_c/m_s.
- New method for the calculation of m_c (in collaboration with K. Chetyrkin et al, Karlsrue.) combining continuum perturbation results for the moments of the η_c correlator with lattice data. Preliminary, work in progress.
- Leptonic decay width $\psi \to e^+e^-$. Known accurately from experiment ($\sim 2\%$).
- Semileptonic form factors: $D \to \pi l\nu, D \to Kl\nu$

M_c / M_s



HPQCD m_c/m_s PRELIM FEB 07
MILC coarse
MILC fine
overall uncertainty
PDG06
bare m_c/m_s
sea m_u/d/m_s
18
16
14
12
10
8
0
0.2
0.4
0.6
0.8
1