Exascale Computing

in the Heavy Quark Sector

Scientific Challenges for Understanding the Quantum Universe and the Role of Computing at Extreme Scale

Stanford, 9 - 11 December, 2008

presented by :

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Large number of heavy quark quantities currently studied on the lattice and much sought after by experimentalists and phenomenologists.

As we contemplate the possibility of Exascale Computing, we need to ask ourselves, and in particular our experimental colleagues, which of the above quantities would make a truly significant difference and hence should be given highest priority.

Here is an incomplete list of current (unquenched) topics.

	current lattice errors	experim. errors where applicable		current lattice errors	experim. errors where applicable
f_{D_s}	1.5% - 4%	3.7%	f_{B_s}	5.6% - 10%	>20%
f_D	2% - 5%	4.3%	f_B	4.5% - 10%	
f_{D_s}/f_D	1% - 2.3%	5.7%	f_{B_s}/f_B	3% - 10%	
$f_+^{D\to K}$	10%	1.5%	$B \to D^*$	2.6%	1.5%
$f_+^{D\to\pi}$	11%	3%	$B \to \pi$	10% - 15%	6%
m_c	1% - 2.5%		$f_B\sqrt{B_B}$	12%	0.5%
m_b	1%- 1.5%		$f_{B_s}\sqrt{B_{B_s}}$	8%	0.35%
α_s	1%		$\frac{f_{B_s}\sqrt{B_{B_s}}}{f_B\sqrt{B_B}}$	4%	0.3%
			$(= \xi)$		$(\sqrt{\Delta M_q})$

Does not include spectroscopy (e.g. heavy baryons)

Since other speakers are discussing “Charm”, “Bottom” and “HQET” physics in general at this workshop, I will just pick three topics that I believe “easily” justify the need for factors of $10^3 \sim 10^4$ in computing resources.

1. Quantities that are still statistics limited (e.g. $B \to \pi$ semileptonic)

2. Handling the “bottom” quark on 0.02fm lattices, i.e. “what I would do with 0.02fm lattices”.

3. Precision calculations and scale setting

Statistical + Chiral/Continuum Extrapolation Errors in B Semileptonic Decays

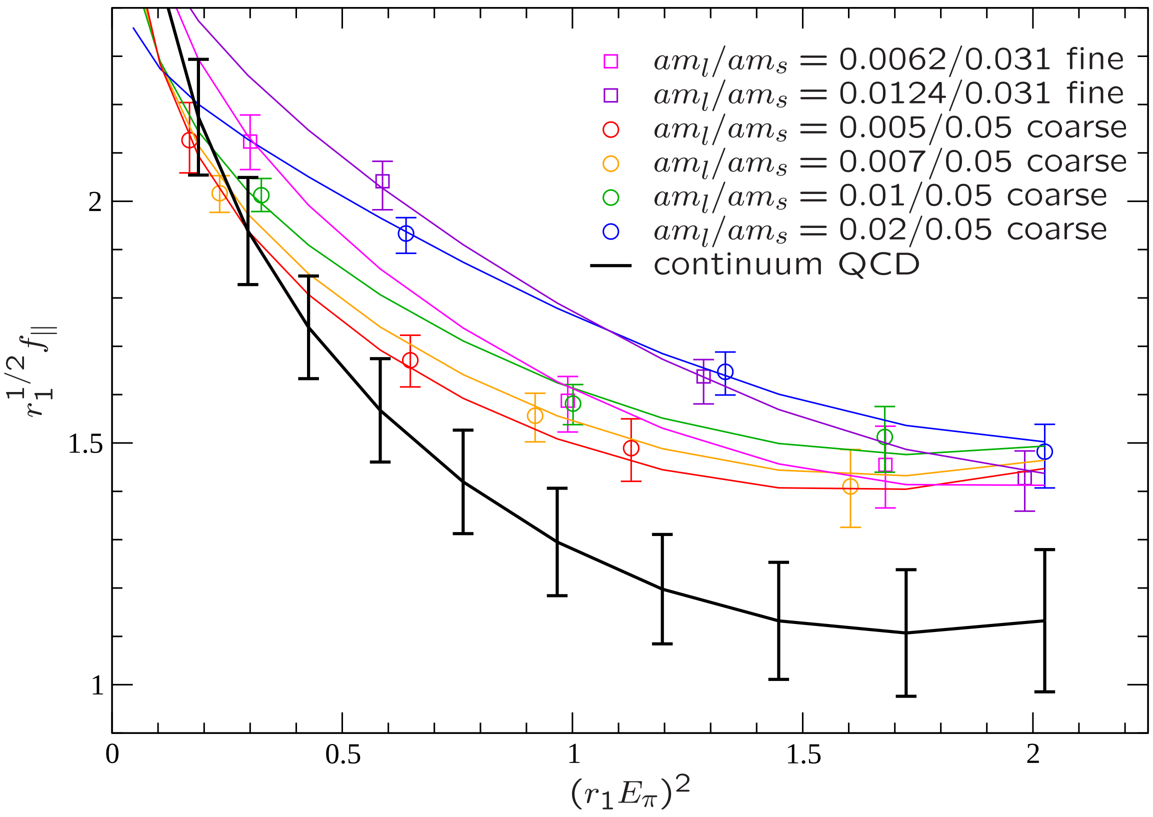
Recent state-of-the-art calculation by the Fermilab/MILC collaboration, arXiv:0811.3640 [hep-lat] gives $|V_{ub}|$ with about $\sim$ 10% accuracy. In their Table with error budget for $f_+(q^2)$ one finds "statistics + χPT" errors of 6 $\sim$ 8% for the range 19 $\leq q^2 \leq$ 24GeV^2.

In an older paper by HPQCD, the "statistics and chiral extrapolation" error is given at 10%.

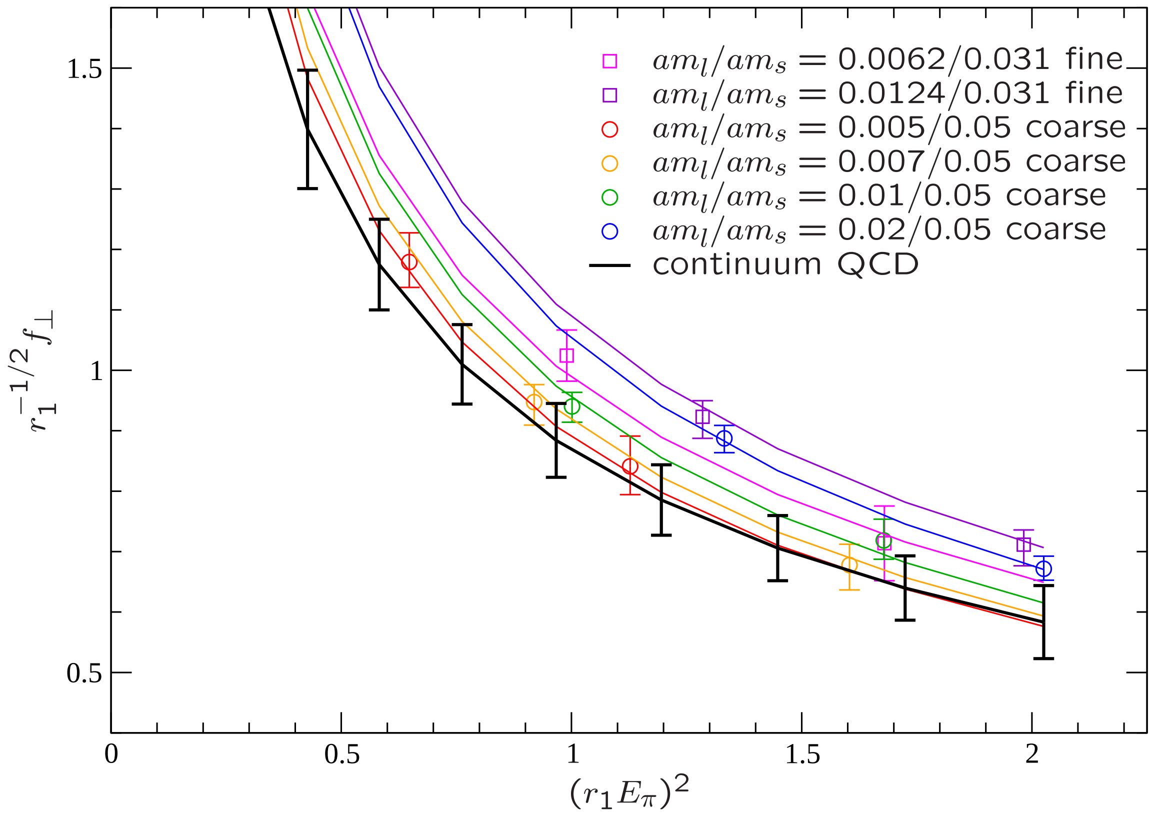
A factor of $10^2 \sim 10^3$ is required to reduce statistical errors to where we would like them to be, and much more if one wants to go to larger pion momenta.

Small statistical errors are a prerequisite for being able to do the Chiral & Continuum Extrapolations in a controlled way.

Currently, however, statistical errors are still much too large.



Courtesy Ruth Van de Water



Courtesy Ruth Van de Water

Statistical errors should be small enough so that we can identify genuine light quark mass and/or lattice spacing dependence. Data should be telling us whether we have included enough terms in ChPT and/or have modeled discretization effects correctly.

What can be done beyond just increasing statistics by huge factors ?

- Better sources, e.g. random wall sources (K.Wong LAT07) Random wall sources improved statistical errors by factors of 2 to 4 for pion correlators with momentum as high as $\frac{2\pi}{L}(3,0,0)$. Encouraging initial test for 3-point correlators. However computationally costly. Each momentum needs separate source.

- "twisted B.C." (used by ETMC and Becirevic-Haas-Mescia in D semileptonic decays)
  More flexibility in choosing E_π (or q^2).

- Jury is still out on Moving NRQCD

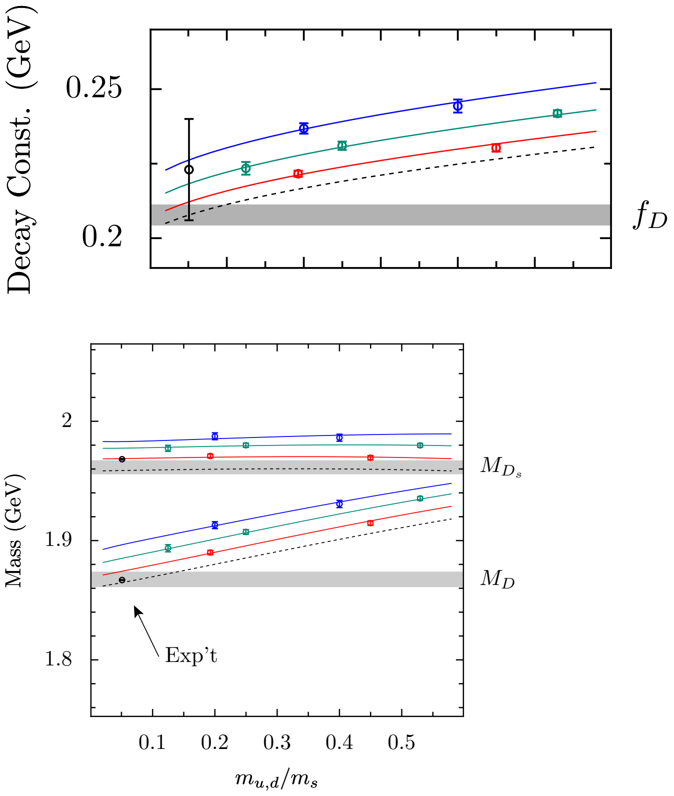
So, B meson semileptonic decay calculations give one example of where factors of $10^2 \sim 10^3$ increase in size of ensembles and in CPU time for analysis runs could have significant phenomenological impact. Many other examples are being discussed at this workshop.

Hopefully, experiments will continue somewhere in the world and experimental errors will come down as well.

It will be interesting to see whether the current tension between exclusive and inclusive determinations of $|V_{ub}|$ will be resolved or become more pronounced in the future. We also need to keep an eye on global CKM unitarity triangle analyses including direct measurements of $\sin(2\beta)$.

What I would Do with 0.02fm Lattices

Recall recent work by HPQCD with HISQ CHARM quarks



These calculations used

0.15fm (blue) : $am_c = 0.85$
0.12fm (green) : $am_c = 0.66$
0.09fm (red) : $am_c = 0.43$

With HISQ charm, calculations of f_{D_s} and f_D become similar to that of f_K and f_π.
Errors only slightly larger

What I would Do with 0.02fm Lattices (cont'd)

Use $\frac{m_b}{m_c} \approx 3.3$

$am_b = 0.85$: 0.15fm $\rightarrow$ 0.046fm

$am_b = 0.66$: 0.12fm $\rightarrow$ 0.037fm

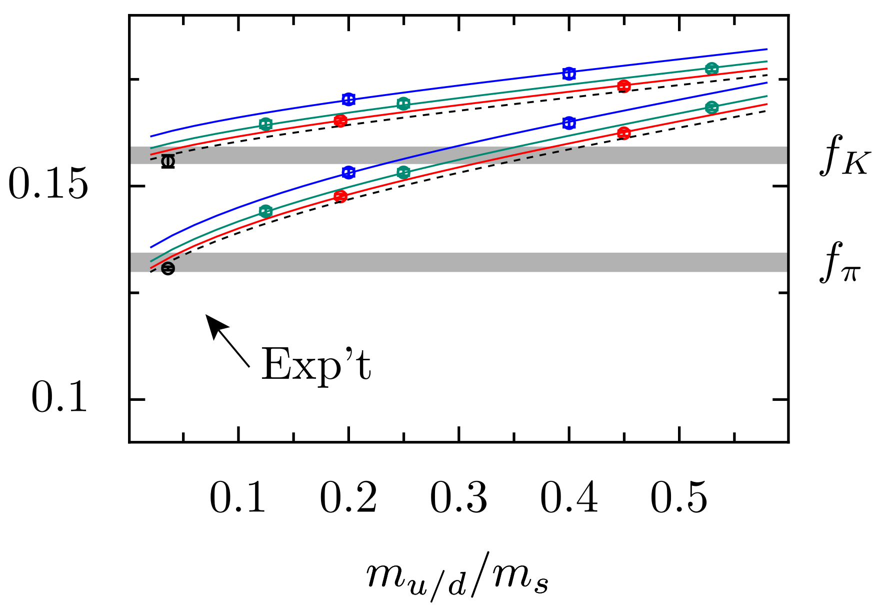
$am_b = 0.43$: 0.09fm $\rightarrow$ 0.028fm

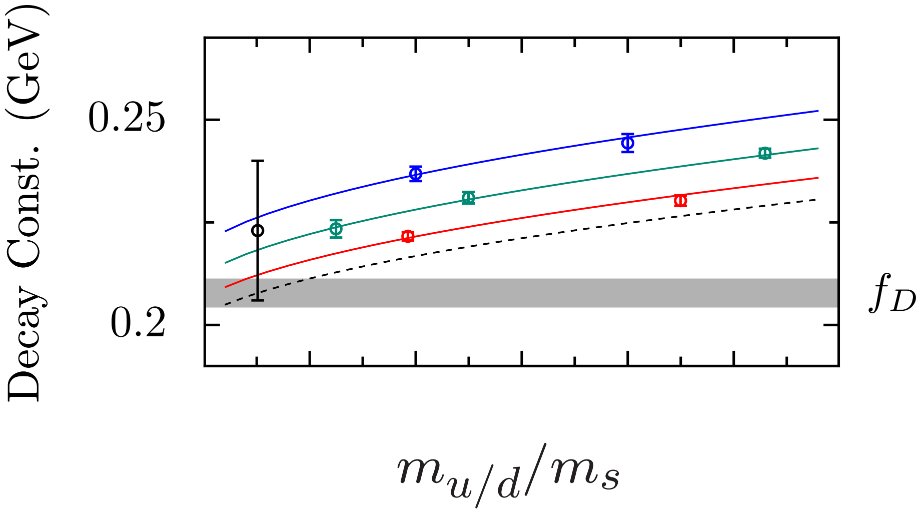
$am_b = 0.28$: 0.06fm $\rightarrow$ 0.019fm

Should be obvious what I would do with 0.02fm lattices.

! HISQ Bottom Quarks !

What I would Do with 0.02fm Lattices (cont'd)





Will future f_B calculations look like this?

What I would Do with 0.02fm Lattices (cont'd)

Fully relativistic b-quarks mean no Z-factors in decay constants (or vector form factors if using conserved current) and of course no 1/M current corrections etc.

One will still have problems with statistics in semileptonic decays and in covering a wide range of q^2. Also need to think about four-fermion operators.

Fully relativistic b-quarks do not necessarily have to be HISQ. Any sufficiently improved quark action with good chiral behavior should work. E.g. no $\mathcal{O}(a^2)$ errors, $c(p) = 1$ imposed nonperturbatively etc.
Then it appears $am_b \sim 0.5$ o.k..

On the other hand, work with fully relativistic charm by Twisted Mass Collaboration and also some Overlap work exist at current lattice spacings without full improvement through $\mathcal{O}(a^2)$.

Precision Calculations and Scale Setting

For several quantities total errors of $\leq 2\%$ have now been achieved. In most of those cases a dominant, if not the dominant, error comes from uncertainty in $\frac{r_1}{a}$ or the actual physical value of r_1.

$f_\pi,\ f_K$: r_1 errors overwhelm all other errors

$f_D,\ f_{D_s}$: r_1 error $= 1.4\%$, total error $= 1.8\%$

$m_c^{\overline{MS}}(m_c^{\overline{MS}})$:
tuning error for bare m_c from r_1 and $\frac{r_1}{a} = 0.8\%$
total error $= 1\%$

$f_{B_q}\sqrt{M_{B_q}}$: error in $r_1^{3/2} = 2.2\%$

We need to get errors in r_1 (or equivalent) from current $\sim$1.5% $\rightarrow < 0.5\%$.
This is so even if we are happy to stop at $\sim$ 1% accuracy for most other quantities.

At the same time need errors in $\frac{r_1}{a}$ (or equivalent) to come down $\sim$ 0.5% $\rightarrow$ $\sim$ 0.2%. This is important when handling simultaneous chiral and continuum extrapolations of data from many ensembles (many lattice spacings and quark masses).

Only then can other quantities be obtained with 1 $\sim$ 2% accuracy.

Most likely at this level possible electromagnetic effects will need to be looked at as well.

Setting the Scale (e.g. fixing r_1)

f_π : MILC (2007) 1.7%

Υ(2S-1S) : HPQCD (2005) ~1.5%
will be updated shortly. However difficult to get below 1% in accuracy with current ensembles.

$M_{D_s} - \frac{1}{2}M_{J/\Psi}$: HPQCD work in progress

M_{Ω^-} : PACS-CS (2008) ~1.5%
MILC (2007) $r_1 M_{\Omega^-} = 2.679^{+.025}_{-.056} \rightarrow r_1 = 0.316^{+3}_{-7}$GeV.
+1% or -2%.

All comparable to each other, but all well above the $< 0.5\%$ goal.

Summary

Three topics from among a great many possible ones were discussed

- Example where just vastly increasing the size of ensembles and spending hugely more time on analysis runs would lead to big improvements. Could easily absorb factors of
  $\sim 10^3$ - 10^4 more computing resources.

- Possibility of fully relativistic Bottom Quarks.
  $am_b \sim 0.5$ should be fine for highly improved actions.

- When doing $\sim 1\%$ accurate calculations.
  will need to know scale to even higher precision.

Heavy Quark quantities will continue to be important in the LHC era. Particularly relevant examples would include,

- Complete set of $\Delta B = 2$ four-fermion operators.
  Several more hadronic matrix elements are needed in BSM (e.g. SUSY) than in the SM. B_s-mixing sensitive to new physics.

- Heavy Baryons of great interest to LHCb (and Tevatron) experimentalists.

- Heavy Quark Masses, m_c and m_b, and also α_s important inputs for BSM model builders.

- Rare B Decays, $B \to K^* \gamma$, $B \to K^* l^+ l^-$ etc. , all sensitive to New Physics.
  These face challenges similar to or even greater than in B semileptonic decays.