Heavy quark physics with light dynamical quarks (plus a lot of other stuff)

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HPQCD and UKQCD collaborations

Key aim of HPQCD collabn: accurate calcs in lattice QCD, emphasising heavy q physics. Requires a whole range of lattice systematic errors to be simultaneously minimised - critical one has been inclusion of light dynamical quarks.

- Current results on heavy quark physics, α_s etc
- Developments for calculations for next 1-2 years

Japan Sept 2004

People involved in various aspects of this work:

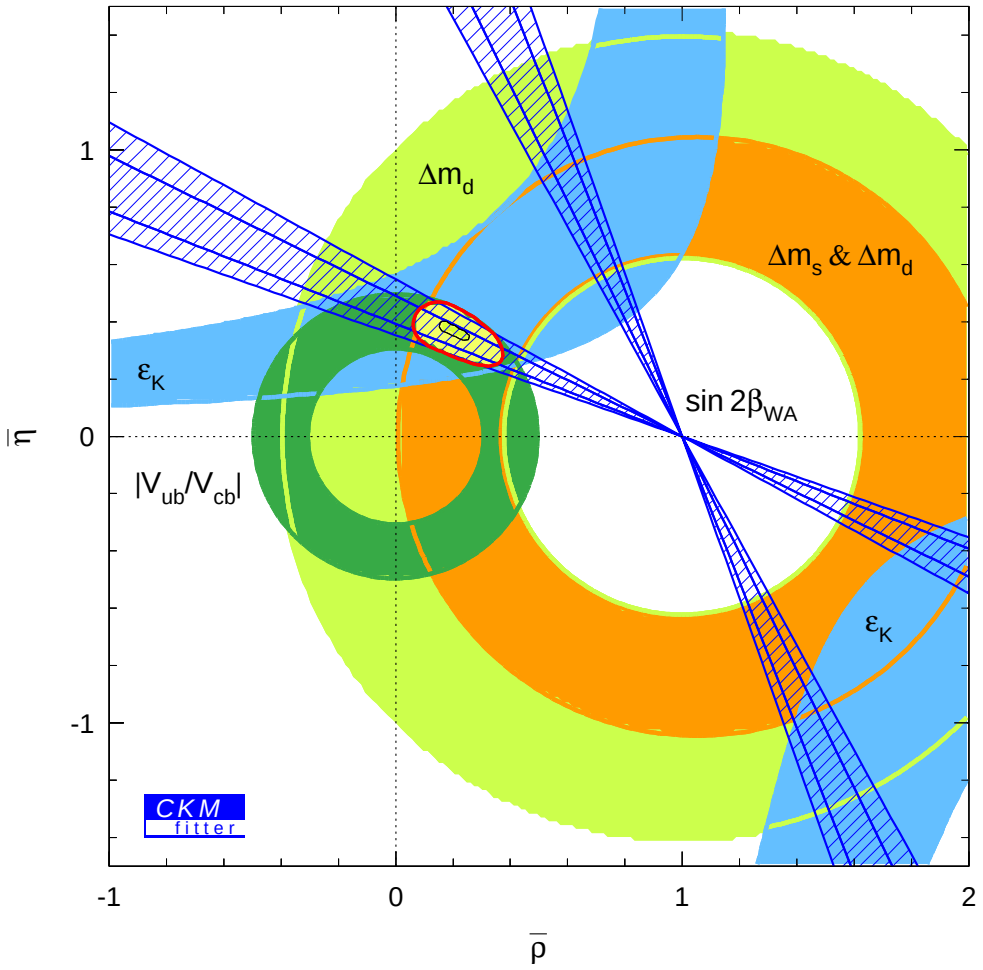
I. Allison, S. Collins, CD, K. Foley, E. Follana, E. Gamiz, A. Gray, E. Gulez, A. Hart, P. Lepage, Q. Mason, M. Nobes, J. Shigemitsu, H. Trottier, M. Wingate
HPQCD/UKQCD

C. Aubin, C. Bernard, T. Burch, C. DeTar, S. Gottlieb, E. Gregory, U. Heller, J. Hetrick, J. Osborn, R. Sugar, D. Toussaint,
MILC

M. Di Pierro, A. El-Khadra, A. Kronfeld, P. Mackenzie, D. Menscher, M. Okamoto, J. Simone
HPQCD/Fermilab

The Unitarity triangle

Important objective of current particle physics: accurate determination of elements of CKM matrix.



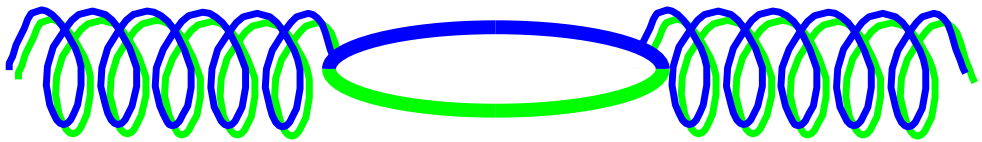
B factory prog. needs small 2-3% *reliable* lattice QCD errors for $B_{s/d}$ oscillations, $B \to D$ or π decay.

CLEO-c will test lattice predictions for D physics in next 2 years.

Requires *all* systematic errors to be small simultaneously. Precise quenched calcs are no good!

HPQCD/MILC results 2003

MILC collab. have used improved staggered quark formalism (+ highly improved gluon action) to generate ensembles of configurations which include 2+1 flavours of dynamical quarks.



2 = u, d degenerate with masses down to $m_s/8$.

1 = s (can ignore heavy c, b, t dynamical qs.)

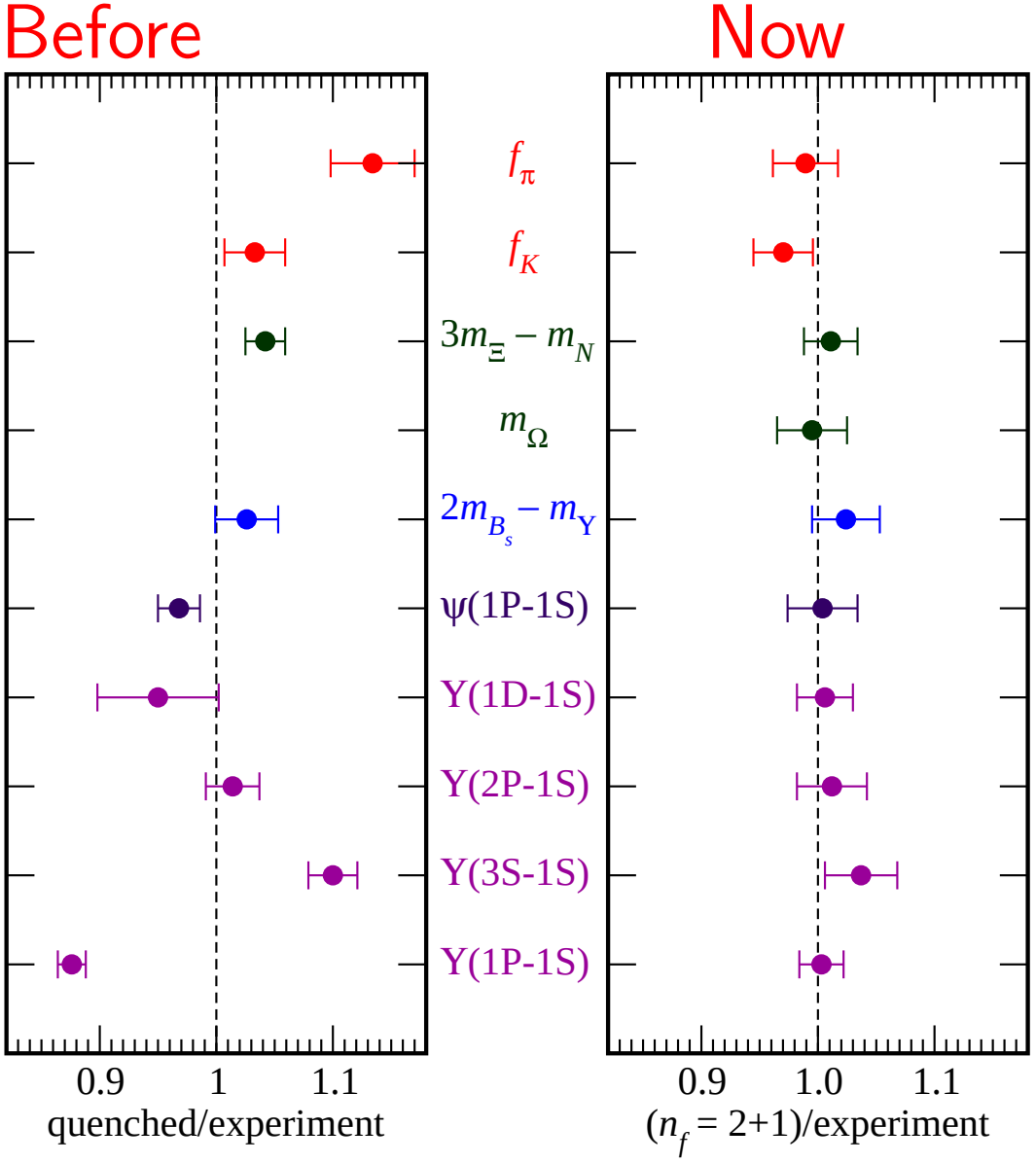
3 values of lattice spacing, $a \approx$ 0.087 fm and 0.12fm and 0.18fm.

Fix 5 free parameters of QCD (bare $m_u = m_d$, m_s, m_c, m_b, and $a \equiv \alpha_s$) using

$m_\pi, m_K, m_{D_s}, m_\Upsilon$ and $\Delta E_\Upsilon(2S - 1S)$. These are 'gold-plated' quantities (e.g. stable hadron masses).

Compute other 'gold-plated' quantities as a test of (lattice) QCD.

Lattice QCD/Experiment (no free parameters!):



Tests:

light mesons and baryons

heavy-light mesons

heavyonium

Find agreement with expt (at last!) when correct dyn. quark content is present.

Quenched approx. has syst. errors 10% and internal inconsistency.

Davies *et al*, hep-lat/0304004 + Toussaint,Davies, LAT04

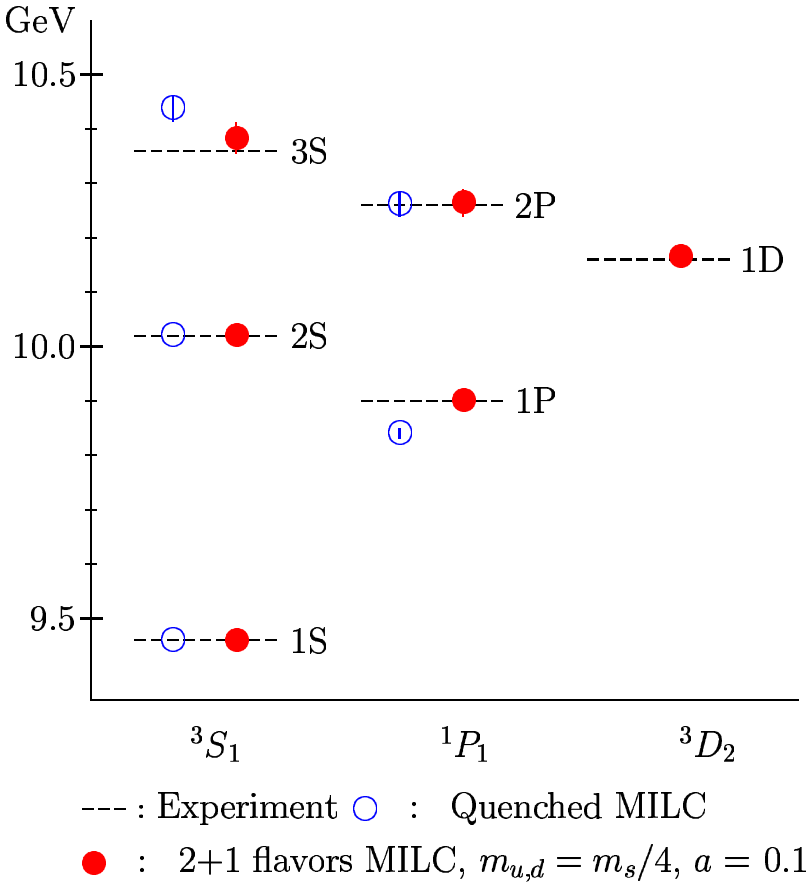
$\Upsilon(b\bar{b})$ spectrum

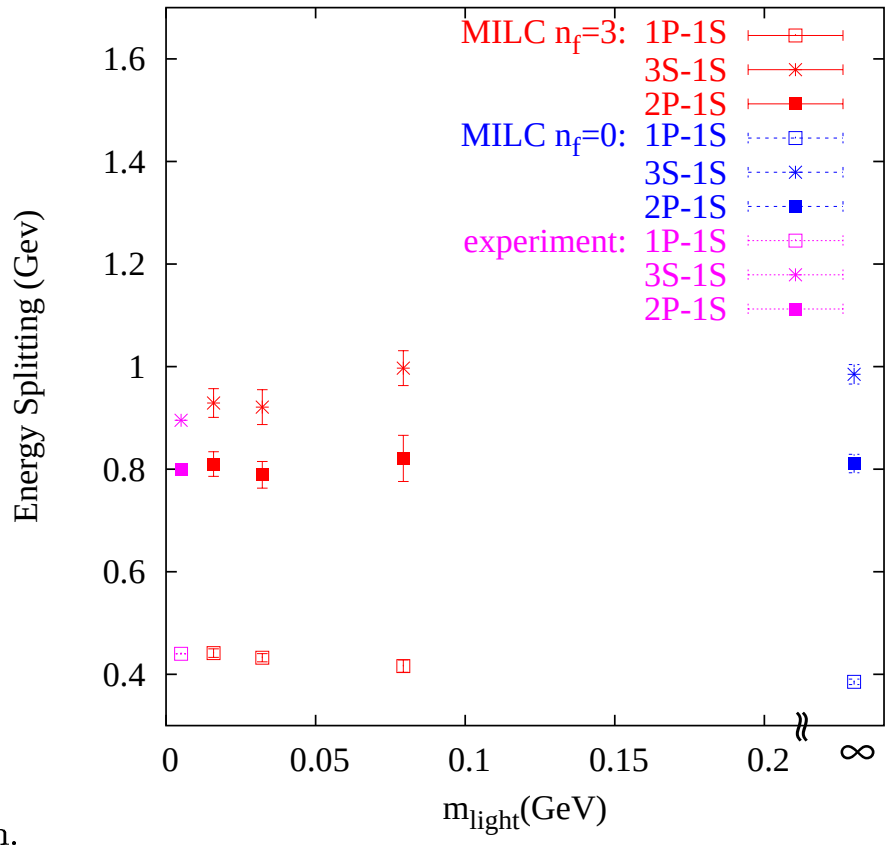
Lattice NRQCD for bs on MILC configs. Tests/tunes action for Bs.

2S-1S fixes a and 1S fixes am_b.

1-loop matching gives $m_{b,\overline{MS}}(m_{b,\overline{MS}})$=4.3(3) GeV.

Further tests - fine structure, leptonic width, in progress.

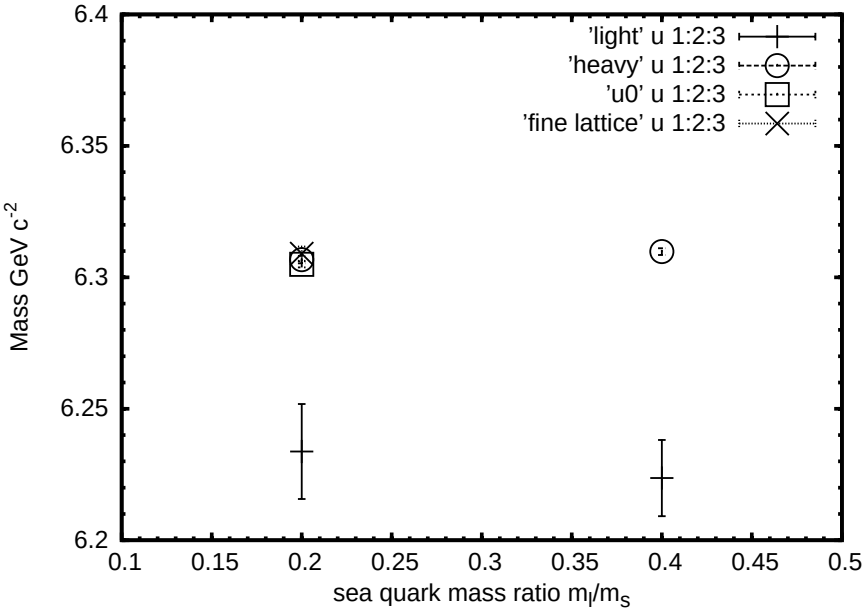


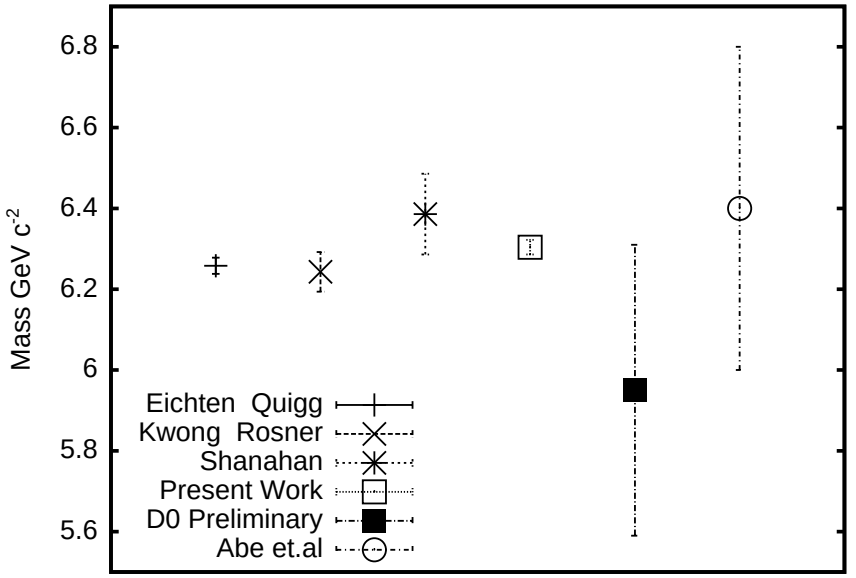


Gray, Davies et al, HPQCD, hep-lat/0310041, Gulez,Shigemitsu, hep-lat0312017.

Prediction of B_c mass.

From difference between mass of B_c (NRQCD b, Fermilab c) and average of Υ and J/ψ, get 6.305(20) GeV.





New exptl results expected from run II at FNAL.

Allison, Davies, Gray, Kronfeld, Mackenzie, Simone (HPQCD), LAT04

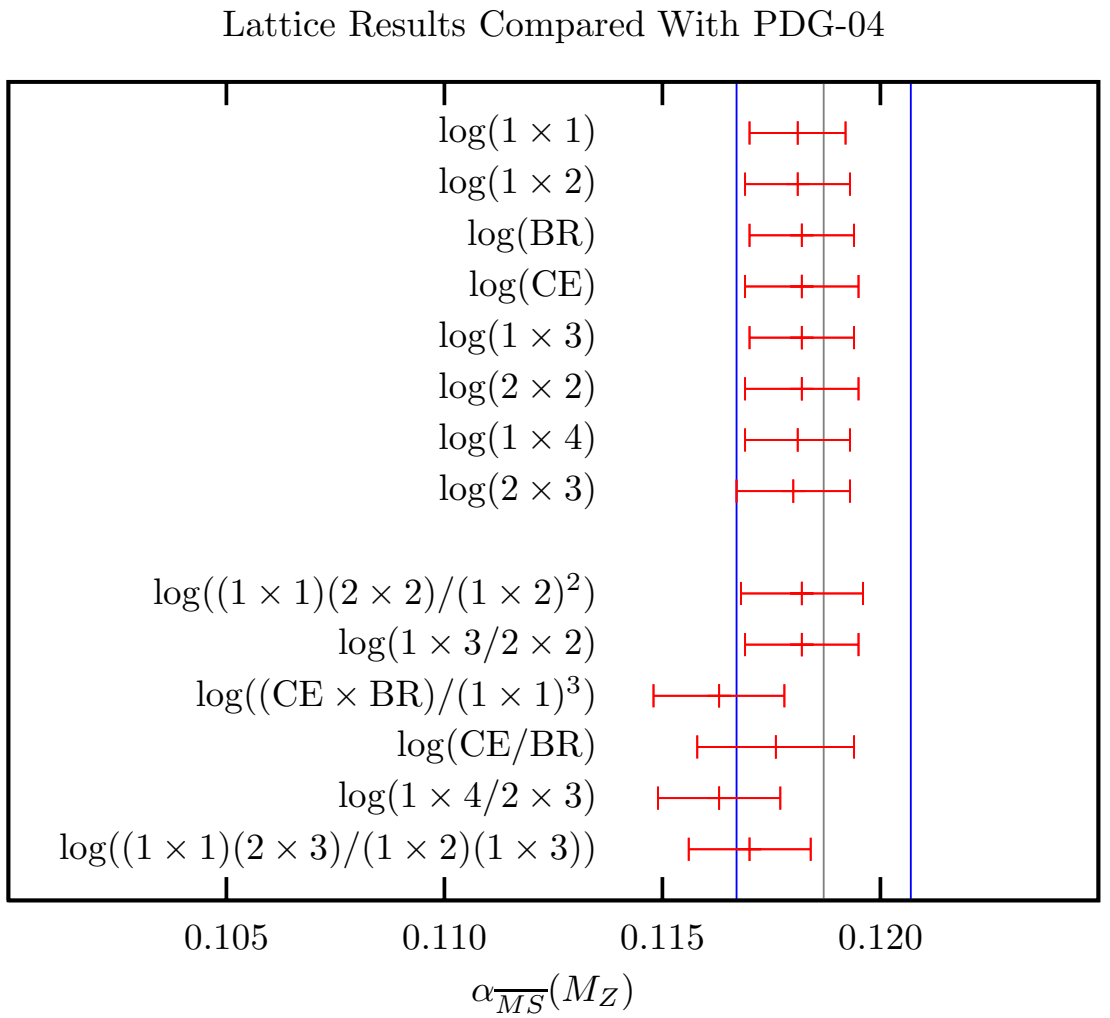
Precise determination of α_s.

Mean value of various Wilson loops and their ratios calculated to 3rd order in lattice pert. th. and on the lattice.

Results available at 3 values of a (inc. MILC super-coarse) allows higher order terms to be estimated.

Preliminary result: $\alpha_s(M_z) = 0.1181(15)$.

Improves on PDG.



Mason, Trottier, *et al* (HPQCD), LAT04

Gold-plated quantities for the CKM matrix

Gold-plated decays (i.e at most one hadron in final state) exist for almost every element ($+ K - \overline{K}$ mixing). Can now calculate these accurately in lattice QCD. Important for lattice calcs to have extensive cross-checks for error calibration: Υ, B, ψ, D, etc.

$$\begin{pmatrix} \mathbf{V_{ud}} & \mathbf{V_{us}} & \mathbf{V_{ub}} \\ \pi \to l\nu & K \to l\nu & B \to \pi l\nu \\ & K \to \pi l\nu & \\ \mathbf{V_{cd}} & \mathbf{V_{cs}} & \mathbf{V_{cb}} \\ D \to l\nu & D_s \to l\nu & B \to D l\nu \\ D \to \pi l\nu & D \to K l\nu & \\ \mathbf{V_{td}} & \mathbf{V_{ts}} & \mathbf{V_{tb}} \\ \langle B_d | \overline{B}_d \rangle & \langle B_s | \overline{B}_s \rangle & \end{pmatrix}$$

Unquenched results for f_{B_s} and B_{B_s}

Use MILC dynamical 2+1 configs. Make a B_s meson from an NRQCD b quark and an improved staggered s antiquark.

Gives:

$f_{B_s} = 260 \pm 7(\text{stat}) \pm 26\ (\text{p.th.}) \pm 8\ (\text{rel}) \pm 5\ (\text{disc})\text{MeV}$

Major error is from matching to contnm in pert. th. (done through $\mathcal{O}(\alpha_s/M)$), 2-loop calcn underway (Mason, Nobes, Trottier).

Preliminary result on $B - \overline{B}$ mixing:

$f_{B_s}\sqrt{B_{B_s}(m_b)} = 0.197(16)(28)$ GeV

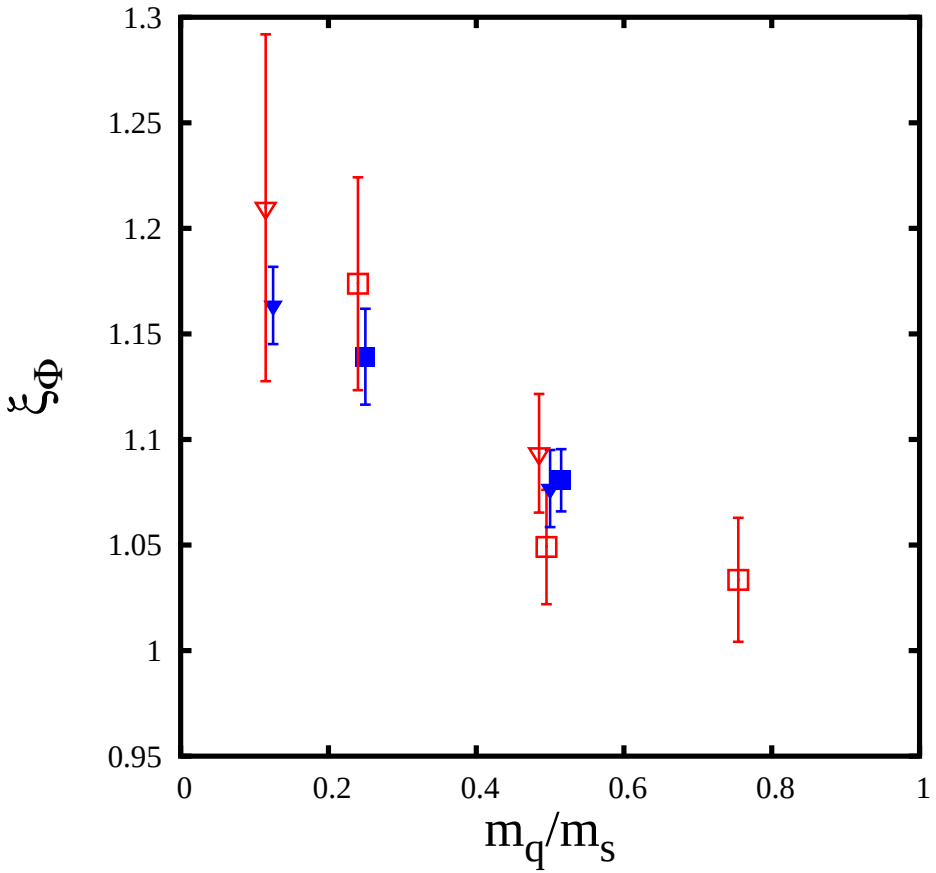
Matched to $\mathcal{O}(\alpha_s)$.

Wingate, Shigemitsu, HPQCD, hep-lat/0311130; Gray, Shigemitsu, LAT04

Unquenched results for f_B

Calculate $\xi = f_{B_s}\sqrt{M_{B_s}}/f_{B_d}\sqrt{M_{B_d}}$, pert. Zs cancel.

'Hot' issue is chiral extrapoln. Expect large log term, becomes visible with light dynamical quarks.

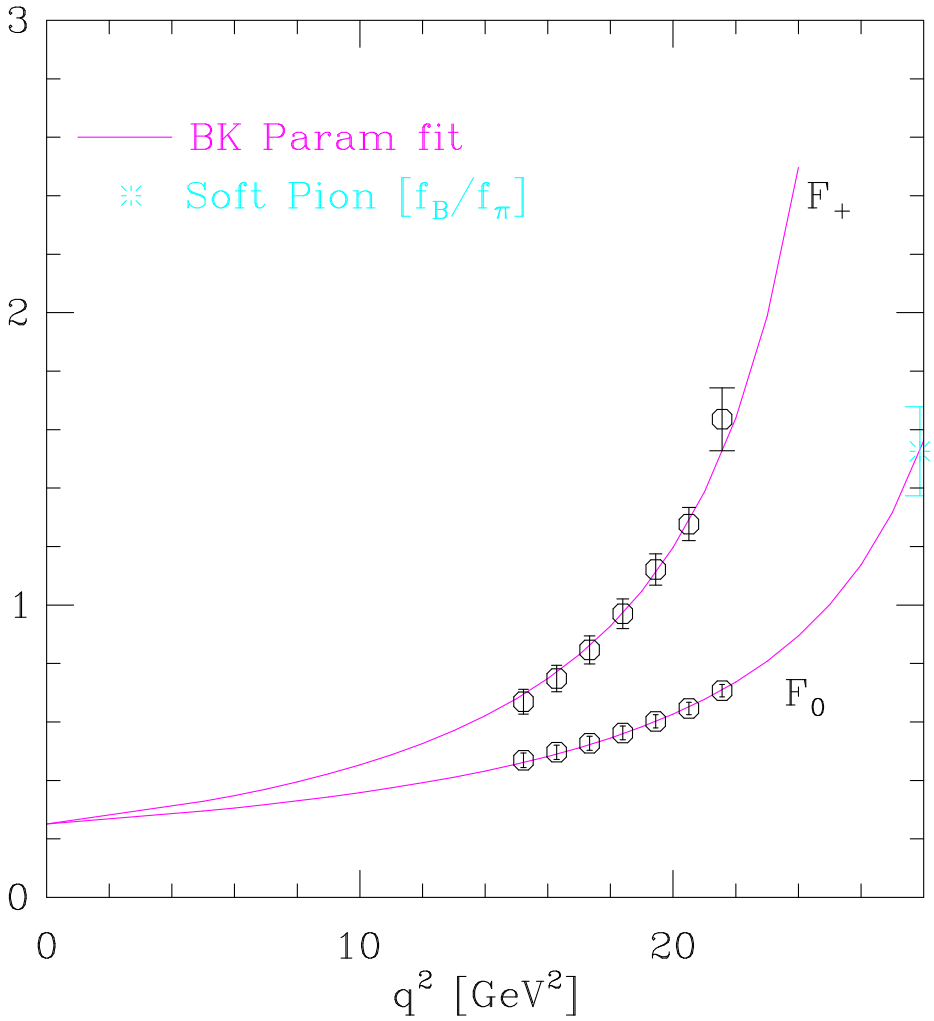


Results significantly improved on smearing - now do staggered chiral extrapolns (Aubin, Bernard).

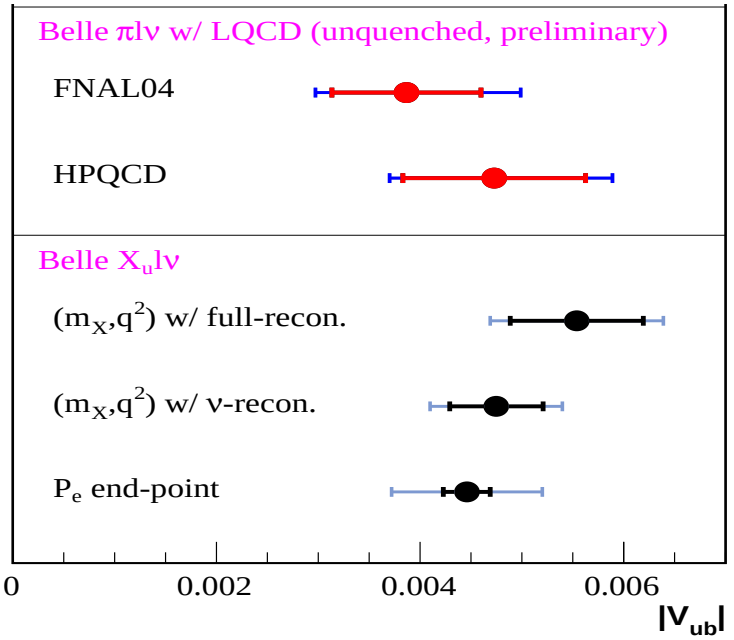
Gray, Gulez, Shigemitsu, LAT04

Unquenched results for $B \to \pi$ form factors

Extrapoln to physical m_π is done at fixed E_π and is not far (lightest $m_\pi = 260$ MeV).



Shigemitsu+Gulez, HPQCD, LAT04



Used by Belle in new V_{ub} determn. (hep-ex/0408145)

Future work on $B \to \pi$

Repeat on fine MILC lattices and renormalise current with 2-loop calcn.
May also manage D on coarse MILC (but see later).

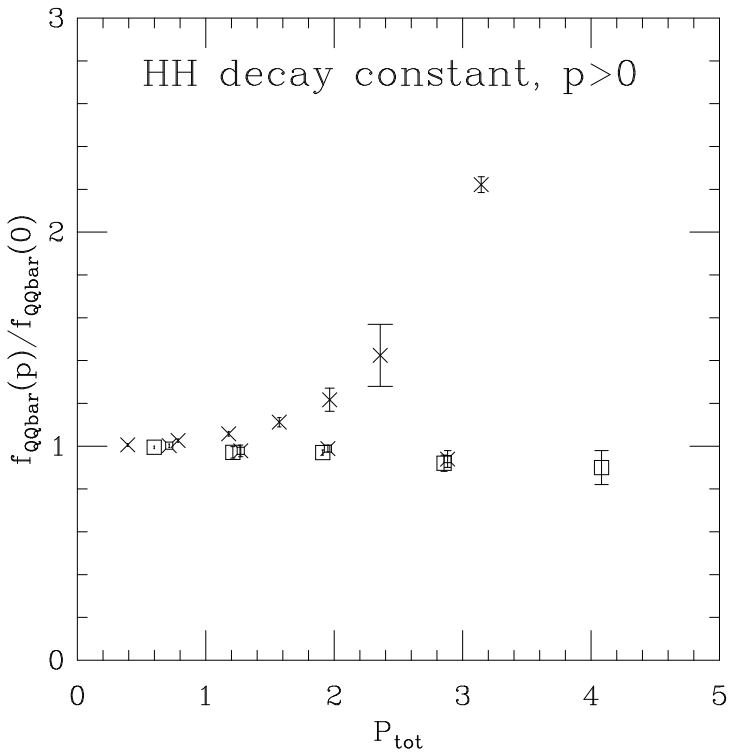
Will also focus on moving NRQCD.

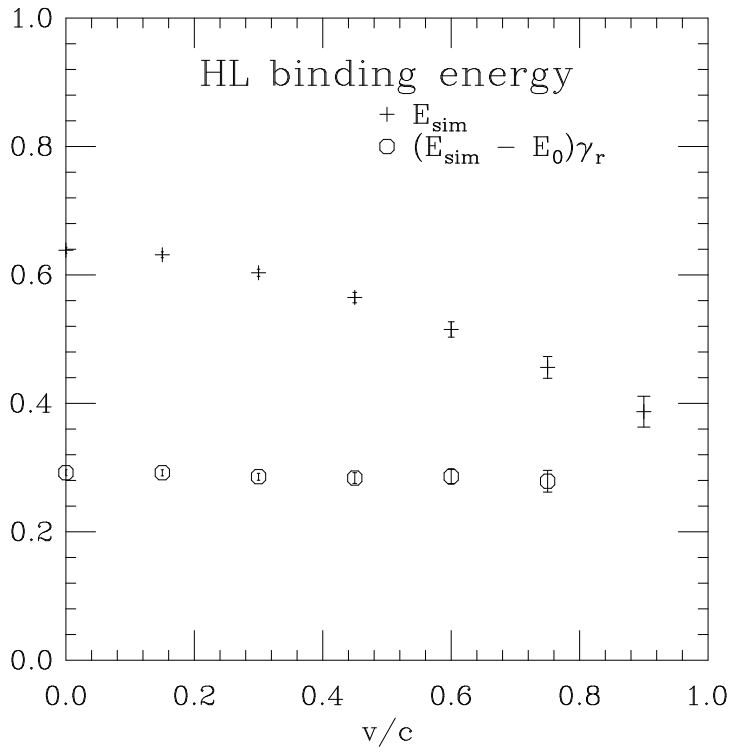
Problem with $B \to \pi$ is large stat. + syst. errors at large (pa) of π.
Instead, give B momentum in lattice frame. Most of this is carried by b and can be treated exactly (not discretised).
$P_b = m_b u + k$. $u = \gamma(1, \vec{v})$. Remnant reparam. inv. on lattice protects $m_b u$ from large renormln.
Can then cover whole q^2 range for $B \to \pi$.

Early work by Hashimoto and Sloan. We have extended action, tested heavy-heavy and heavy-light and done $\mathcal{O}(\alpha_s)$ pert. th.

Tests of moving NRQCD

Simplest H used in quenched tests: $(-D^2 + (v \cdot D)^2)/2m\gamma - iv \cdot D$.





All looks good. v dependence not large and can be understood.

Now try real calcs ...

Foley, Lepage, Davies, Dougall, HPQCD, LAT04

Current status - B_K

Best quenched B_K from JLQCD using unimproved staggered quarks.

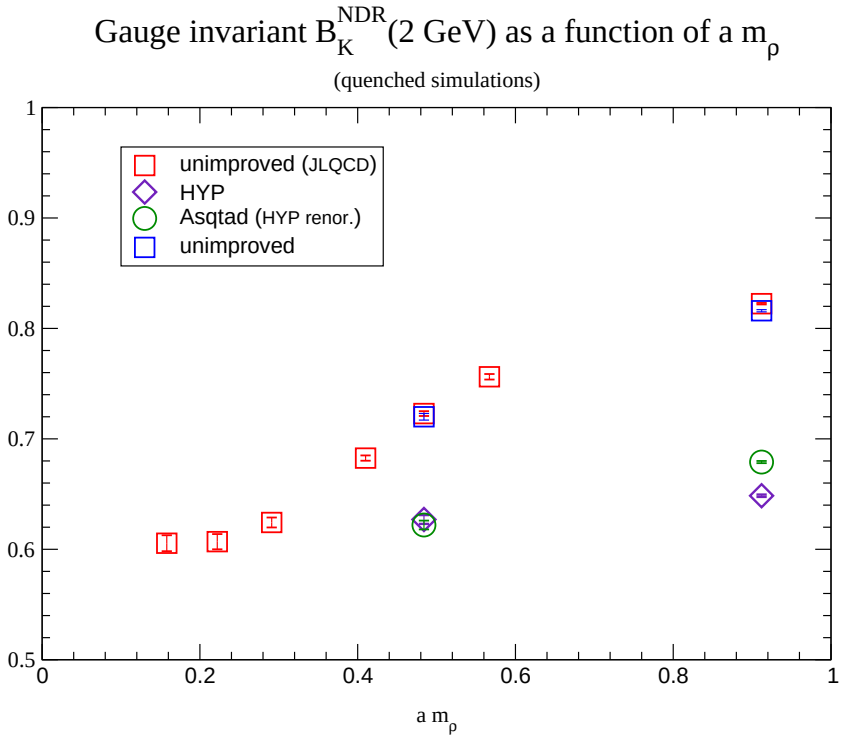
but these results apparently have large disc. errors.

New results with imp. staggered quarks show much better scaling.

This may be largely a renormln. effect, in fact.

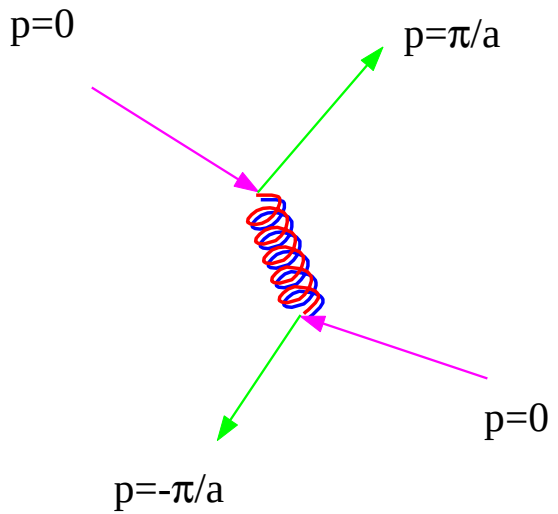
B_K in dynamical QCD in progress (HPQCD).

Gamiz, Collins, Davies, HPQCD, LAT04



Further improving the staggered formalism

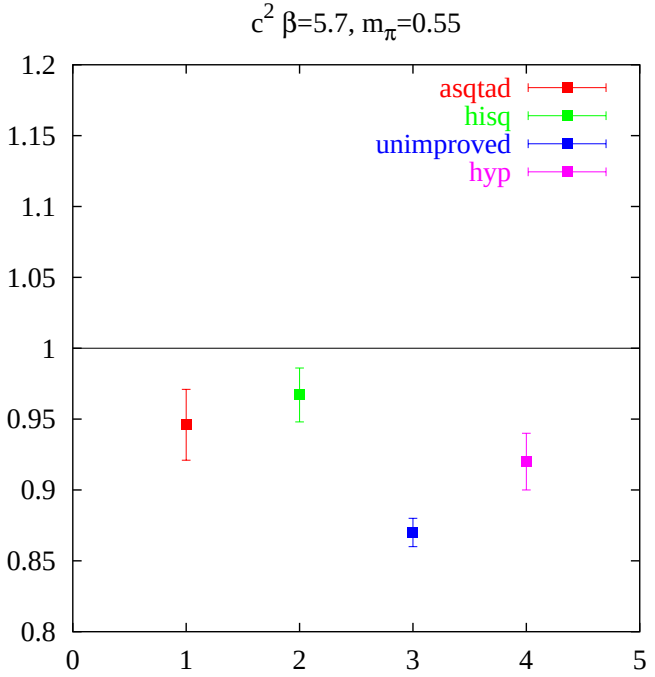
Limit to precision with asqtad improved staggered quarks is still taste-changing interactions associated with high-momentum gluon exchange.

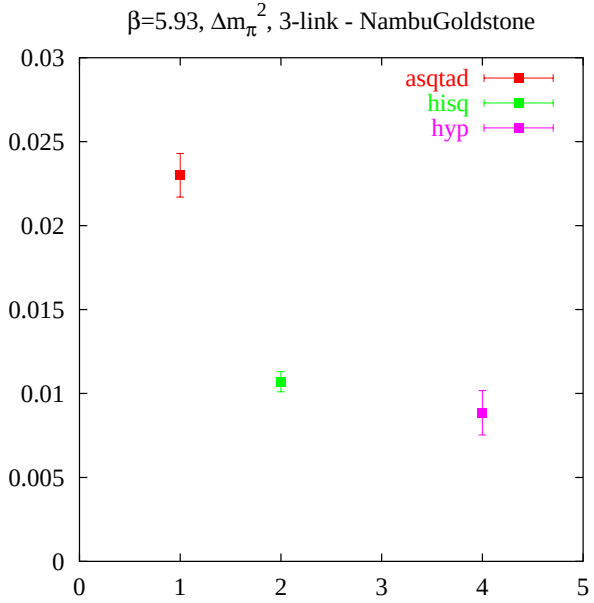


Improve action further by repeating the 'Fat7' smearing. Add Naik and Lepage terms (x2) as before to keep an action with $\alpha_s a^2$ errors $only$. This is the Highly Improved Staggered Quark action (HISQ).

Discretisation errors

HISQ shows v. good behaviour on taste-changing and dispersion reln.

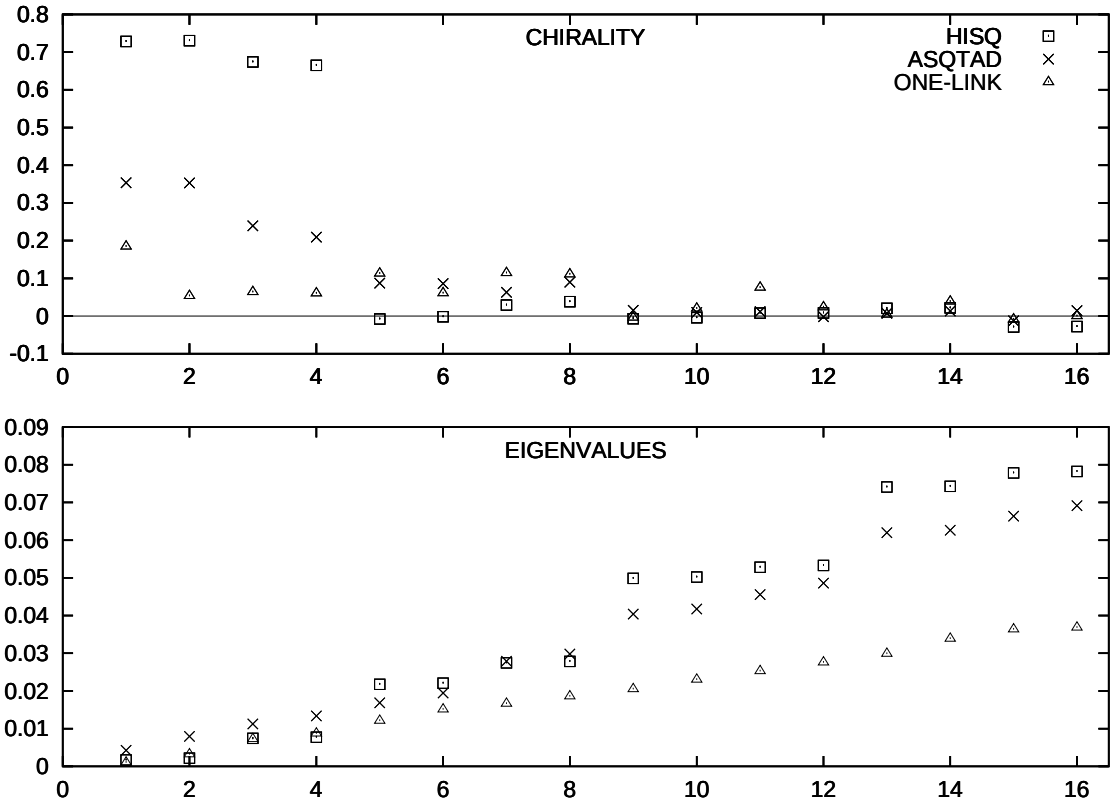




Follana, Mason, Davies, HPQCD, in preparation

Sensitivity to topology of the staggered formalism

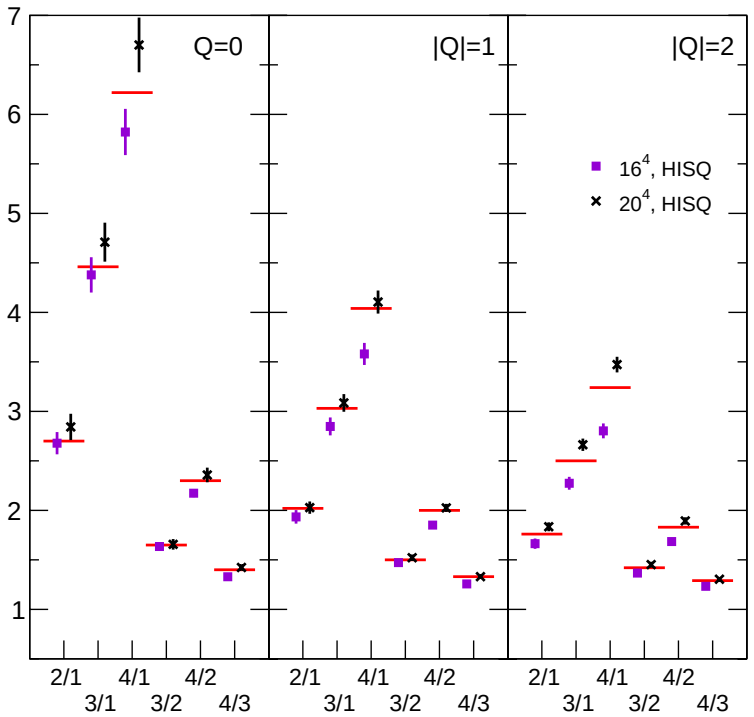
Number of 'almost-zero' eigenvalues agrees with the index theorem, (Q=2 here) and they have chirality close to 1.



Also improved staggered quarks show excellent 4-fold symmetry in eigenvalue spectrum as they must in contm limit. (These tests in quenched approx. on improved glue configs.)

Follana, Hart, Davies, HPQCD, LAT04

Sensitivity to topology of the staggered formalism



Follana, Hart, Davies, HPQCD, LAT04

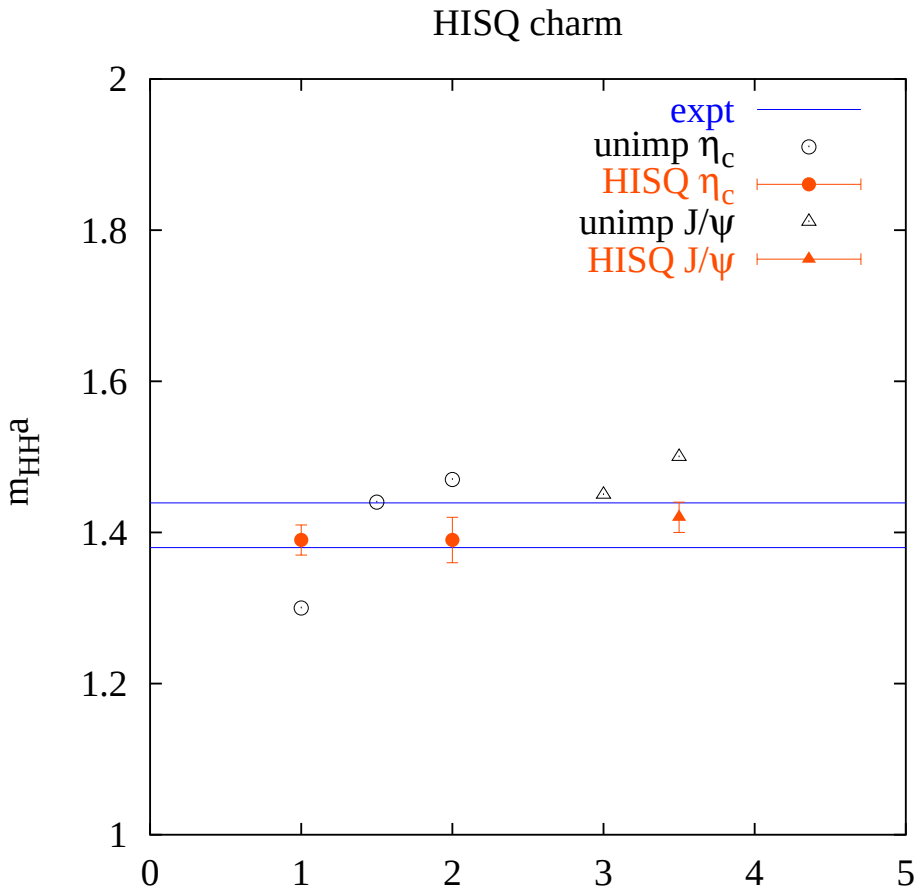
Eigs also agree with the predictions from universality/random matrix theory.

$x/y =< \lambda_x > / < \lambda_y >$

Drop 'would-be' zero modes and replace quartets by average values to obtain λ_i.

Undershoot visible at LAT04 is cured on bigger (20^4) volume.

Future: Use HISQ for charm



Allison, Davies, Follana, Lepage, Mason HPQCD

Unimproved calcs (JLQCD hep-lat/9411012) had problems with taste-changing in $\pi \equiv \eta_c$. This is much improved for HISQ.

Plan: try this on MILC fine (and planned superfine) lattices where $\alpha_s(m_c a)^2 =$ a few %.

Conclusions

- Huge progress in lattice QCD recently with new calculations with 2+1 flavors of light dynamical quarks and $m_{u/d} < m_s/2$.
- Gold-plated matrix elements for CKM determinations are in progress, with lots of results reported this year (hear more in Paul Mackenzie's talk).
- Future work based on some new techniques which have lots of promise.