Fermilab Heavy-Light Meson Calculations

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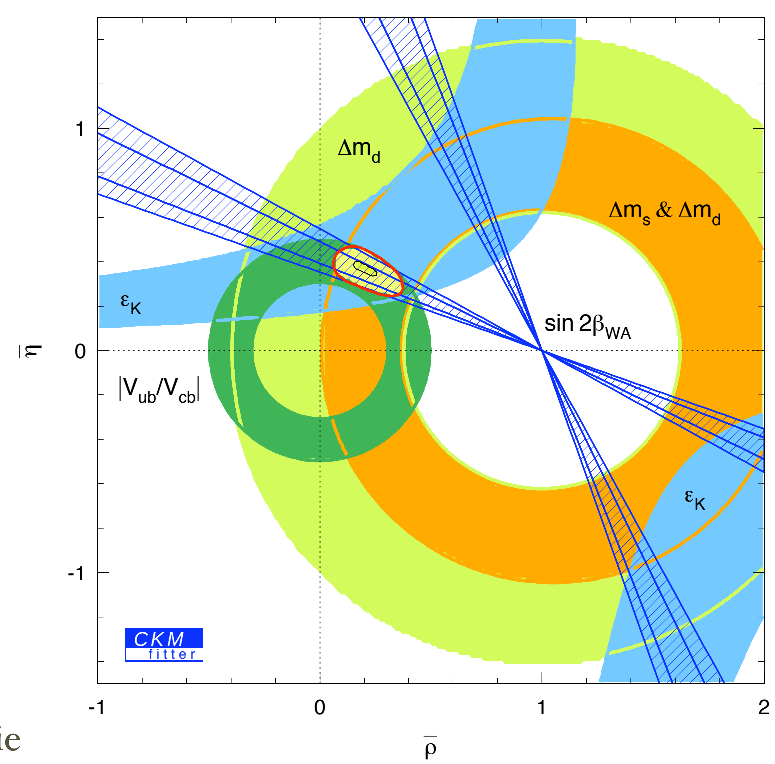
Parts of talk done in collaboration with MILC and/or with HPQCD.

Christine Davies talk, parts of Steve Gottlieb's, and this one parts of one overall program: gold-plated processes with unquenched improved staggered fermions.

"Gold-plated": stable particle processes with a single particle in the final state.

Why focus on gold-plated quantities? The experiments that most need lattice calculations are often known to few per cent accuracy.

Lattice calculations that are done most precisely will have the most practical impact.



Future experimental error in CKM matrix element determinations for which high accuracy lattice calculations are foreseeable.

$\mathbf{V_{ud}}$ $-$	$\mathbf{V_{us}}$ $K \to \pi l \nu$ $1\% \to few 0.1\%$	$\mathbf{V_{ub}}$ $B \to \pi l \nu$ $BaBar, Belle :< 5\%?$
$\mathbf{V_{cd}}$ f_D $CLEO : 2.4\%$ $D \to \pi l \nu$ $CLEO : 0.8\%$	$\mathbf{V_{cs}}$ f_{D_s} $CLEO : 2.1\%$ $D \to K l \nu$ $CLEO : 0.6\%$	$\mathbf{V_{cb}}$ $B \to D l \nu$ $BaBar, Belle :< 3\%$
$\mathbf{V_{td}}$ $< B_d \vert \overline{B_d} >$ $BaBar, Belle : 1\%$	$\mathbf{V_{ts}}$ $< B_s \vert \overline{B_s} >$ $CDF : 0.5\%$	$\mathbf{V_{tb}}$ $-$

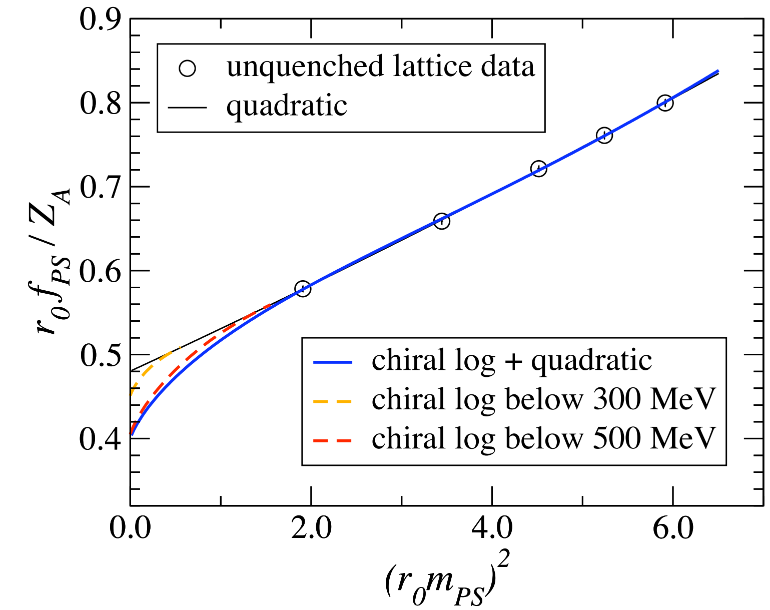
$B \to \psi K_s \Rightarrow \sin(2\beta)$, BaBar, Belle: 7% don't need lattice.

ϵ_K, PDG: 0.6%

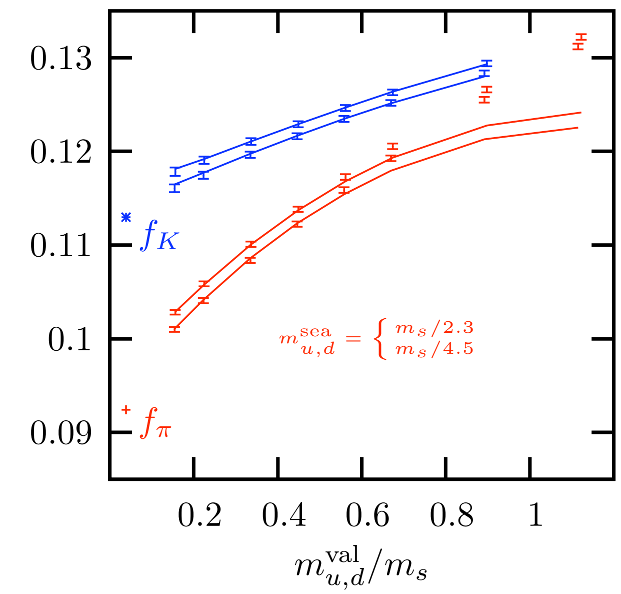
Why staggered fermions?

Wilson fermions have a hard time reaching below $m_u \sim m_s/2$.

Hard to reduce chiral extrapolation uncertainties below 10% from there.



Wilson fermions, JLQCD



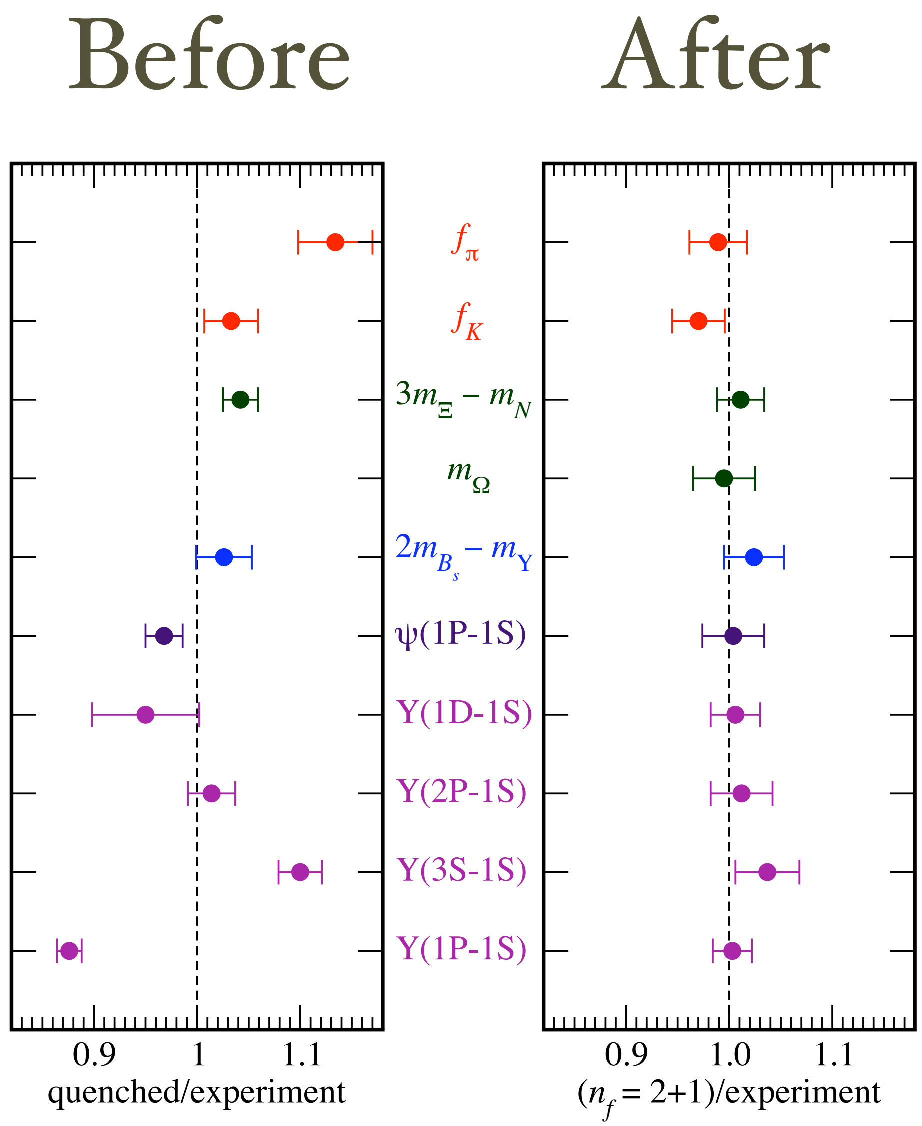
Improved staggered fermions, MILC/HPQCD/UKQCD, Fermilab.

Overlap/domain wall fermions have good chiral behavior, but are slower. Staggered fermions will get to higher precision faster.

Quark masses and coupling constant are fixed from gold-plated quantities.

Other known gold-plated quantities should agree.

Calculate needed inputs for phenomenology.



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

Data sets.

MILC unquenched 2+1 flavor "asqtad" improved staggered lattices.

Tyically 500 configurations generated at each lattice spacing and light quark mass.

	Lattice volume	a^{-1} (GeV)	Status	TF years
"Extra Coarse"	16^3*48	1.1	started	
"Coarse"	20^3*64	1.6	Main results	0.1
"Fine"	28^3*96	2.2	started	2.5
"Super Fine"	42^3*144	3.3		

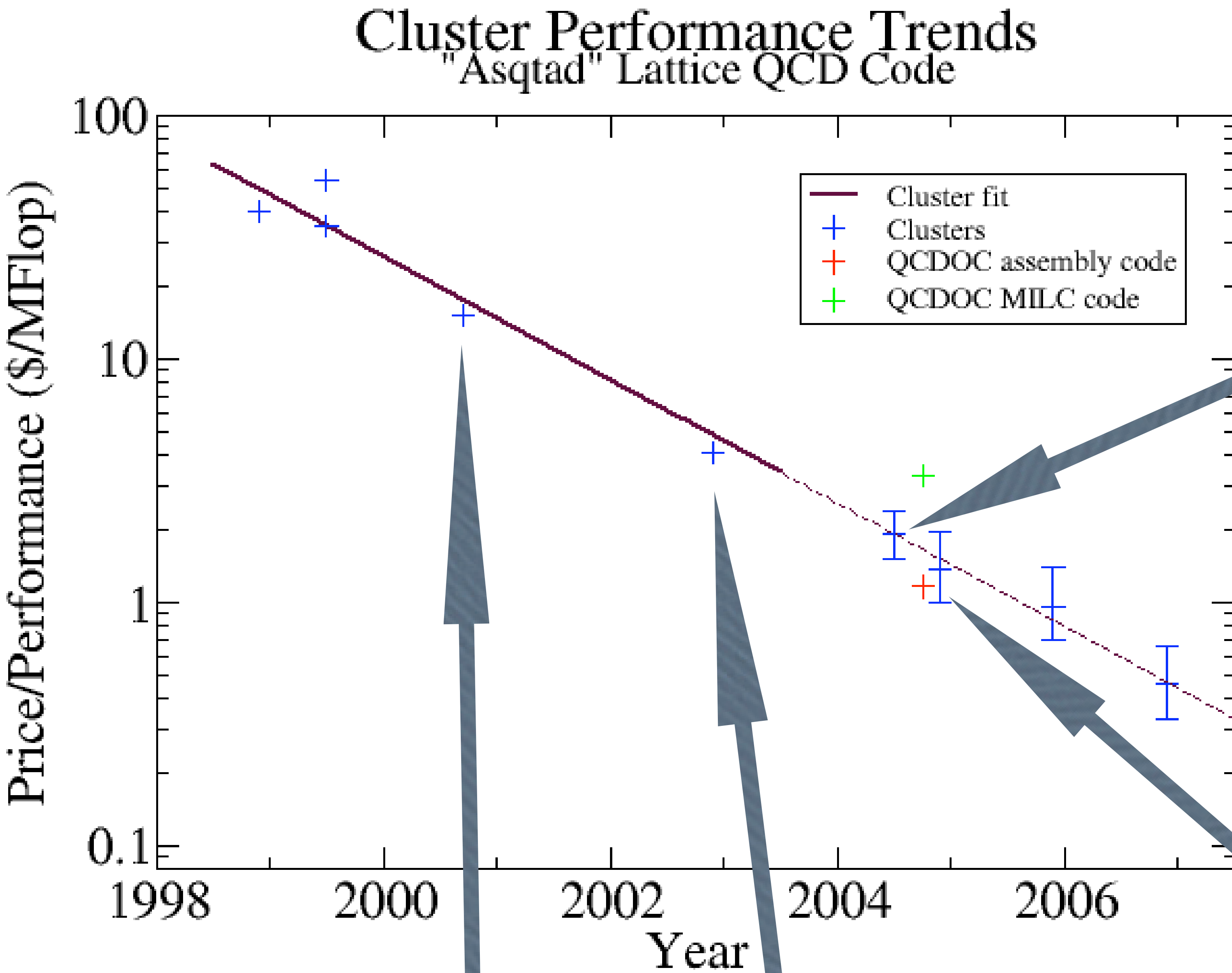
Most of our work so far done on "coarse" lattice set.

10s of % of time to generate configurations has be spent analyzing them.

Computers

Valence quark propagators and meson analysis were done on the Fermilab clusters: 256 nodes on two 128 port Myrinet switches, 120+140=360 GF total.

See http://lqcd.fnal.gov.



2004:
128 P4 singles,
reuse Myrinet switch.
Incremental cost:
$1/MF.

256 node, P4 singles?
Infiniband switch.

2005: 512 node,
$1M, 1 TF.

2006: 1024 node,
$1.5 M, 3 TF
(or double).

Vendor Roadmaps:

2004: Q1 P4E,
Q4 1 →2 GB/sec, PCI Express.

2005: H1 800→1066 MHz memory bus.

2006: H1 Fully buffered dimm memory bus, dual core processors. Infiniband integrated in motherboard?

This work: unquenched heavy quark phenomenology with Fermilab heavy quarks and improved staggered light quarks.

Charmonium

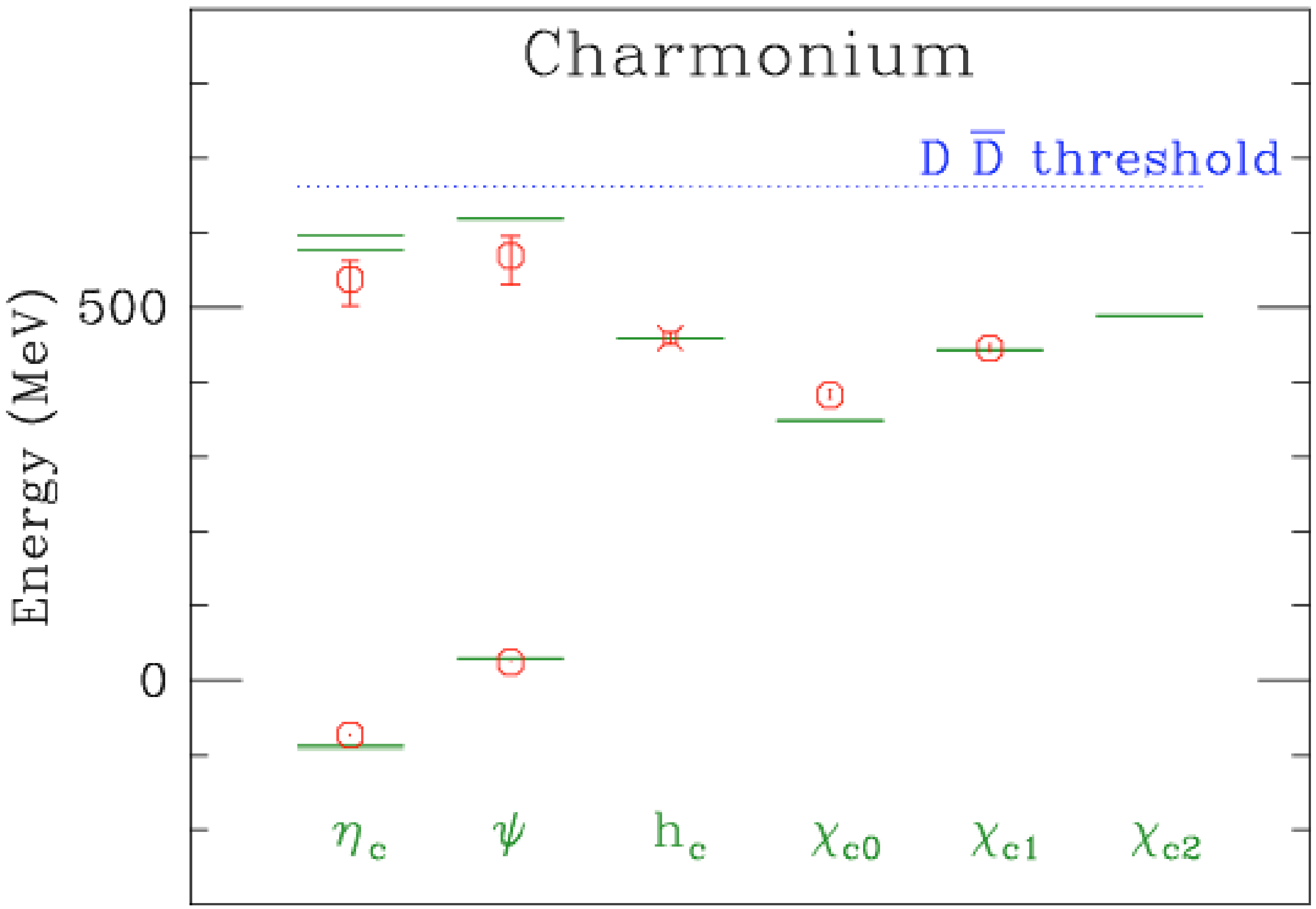


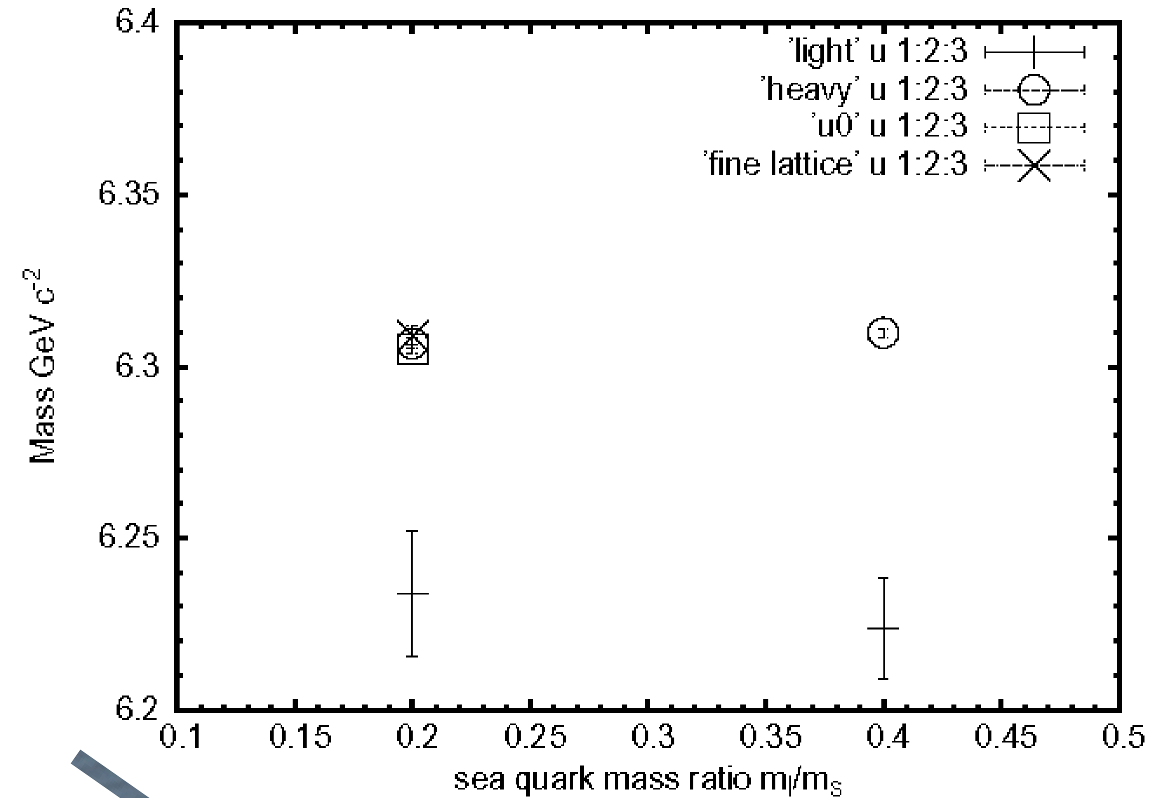
Table 1
The bare light sea quark mass and coupling β for the MILC three-flavor gluon ensembles. The strange quark has mass $am_s = 0.05$ Lattice spacings are given in GeV. The $2S$-$1S$ results are from Reference [3].

am_l	beta	cfgs	$a_\psi^{-1}(1P\text{-}1S)$	$a_\Upsilon^{-1}(2S\text{-}1S)$
.007	6.76	403	1.55(3)	—
0.01	6.76	593	1.56(2)	1.59(2)
0.02	6.79	460	1.59(3)	1.61(2)
0.03	6.81	549	1.57(3)	1.60(3)

Simone, Lattice 2003

Bc mass

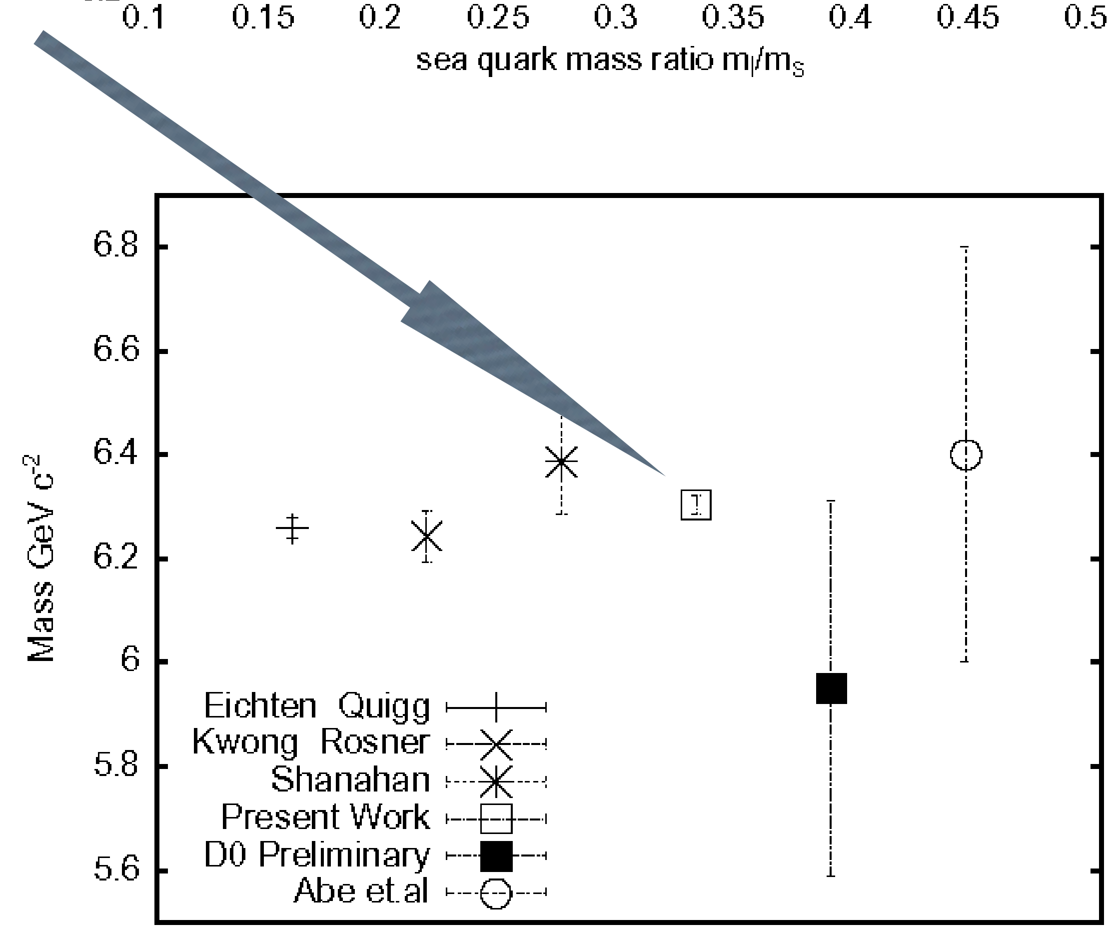
NRQCD b quarks,
Fermilab c quarks.



From

$$M_{B_c} - \frac{1}{2}\left[M_\psi + M_\Upsilon\right] = E_{B_c} - \frac{1}{2}\left[E_\psi + E_\Upsilon\right]$$

get M_{Bc} = 6.305 (20) GeV.



Experimental result expected this year.

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

f_D and f_{Ds}

We're concentrating on charm before bottom because of the pending revolution in charm data from CLEO.

CLEO expects:
Semileptonic decays to 1%.
Decay constants to 2%.

New tests of lattice methods from CKM independent amplitude ratios:

$$f_D/D \to \pi l\nu \text{ and } f_{D_s}/D \to K l\nu$$

New high precision experimental data for Vcd and Vcs.

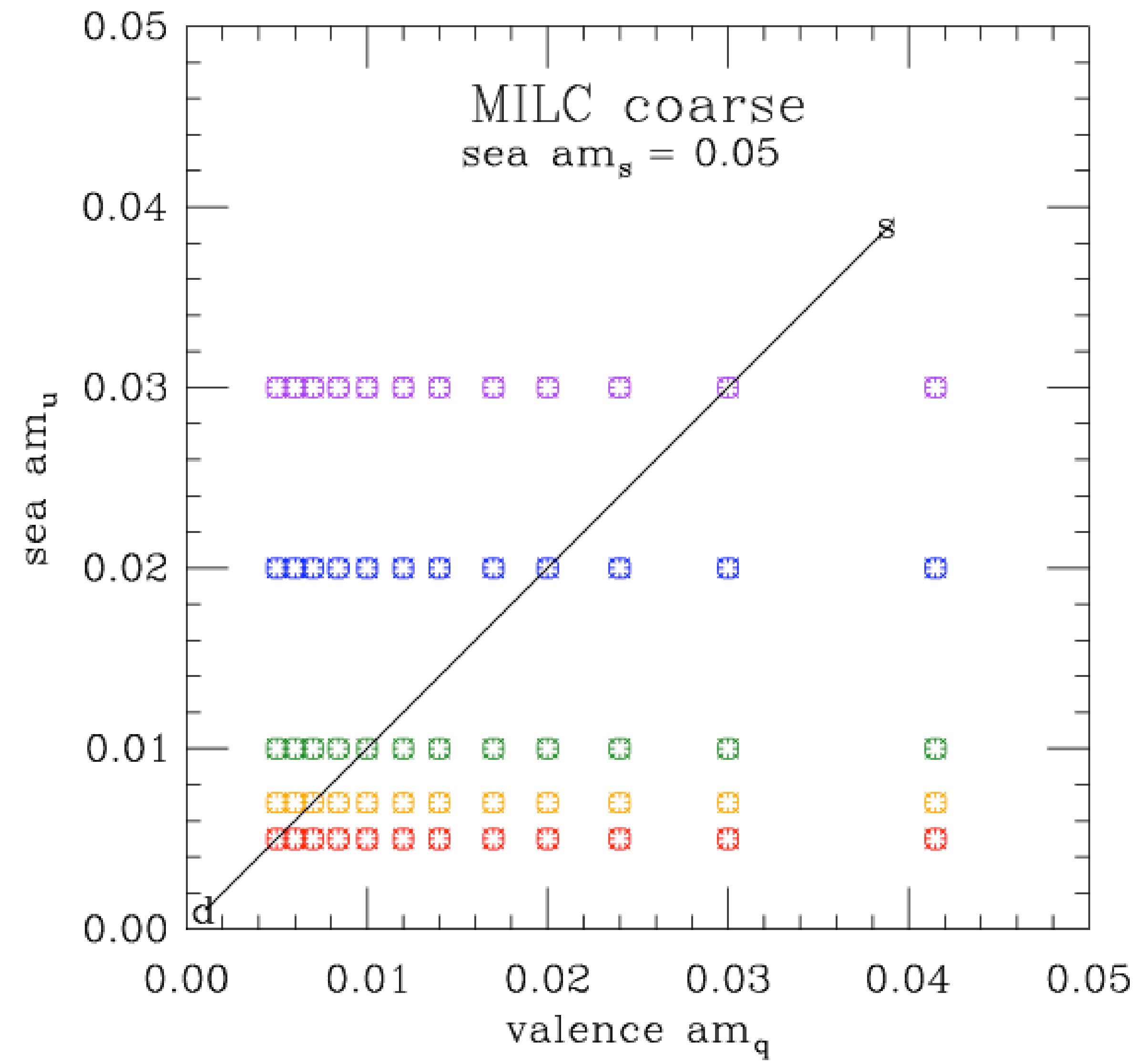
Taking data now, results in about a year.

Quark masses used.

Lots of partially quenched valence masses from a multimass inverter.

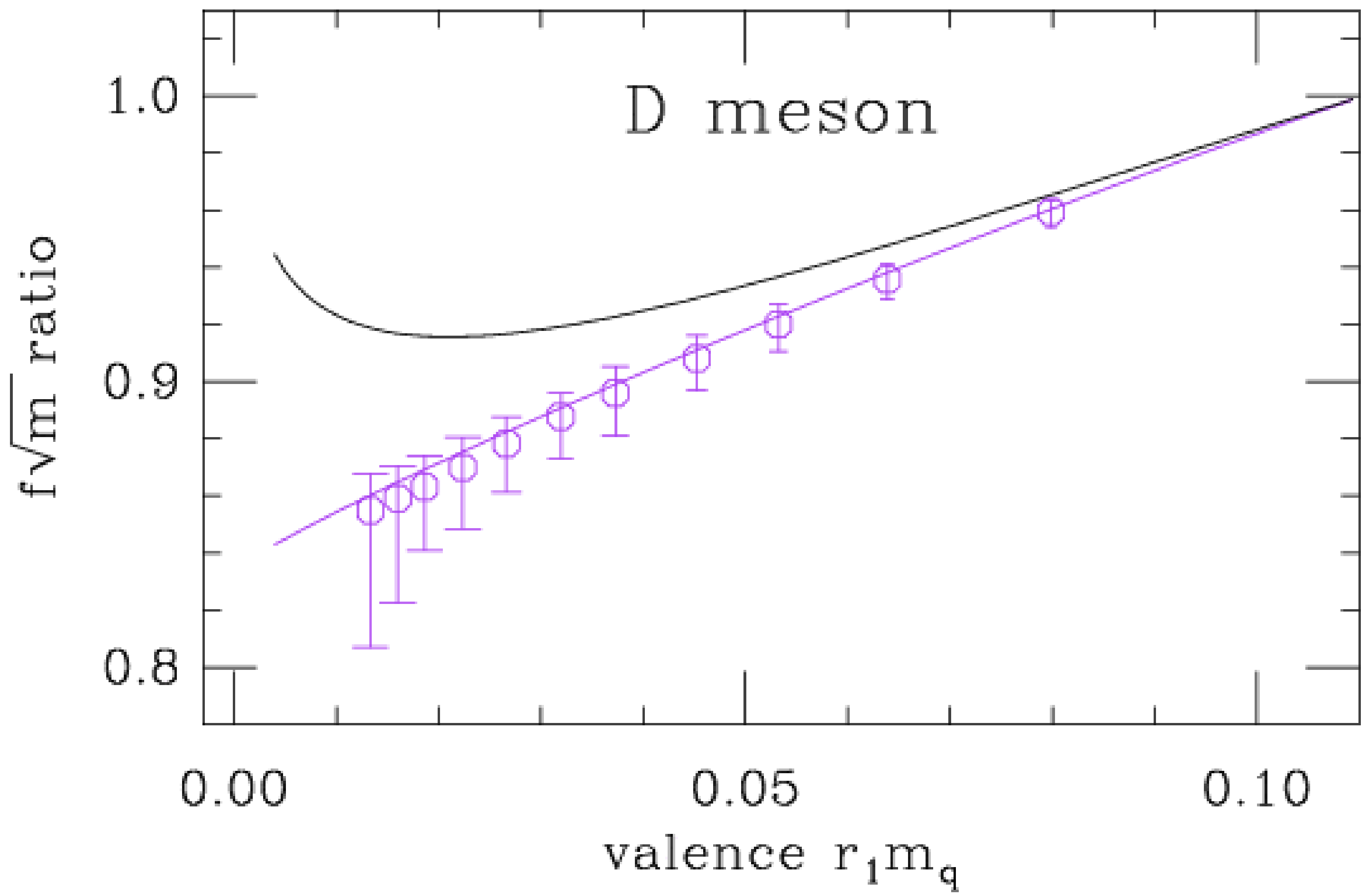
Partially quenched, finite *a* staggered chiral perturbation theory, Bernard and Aubin.

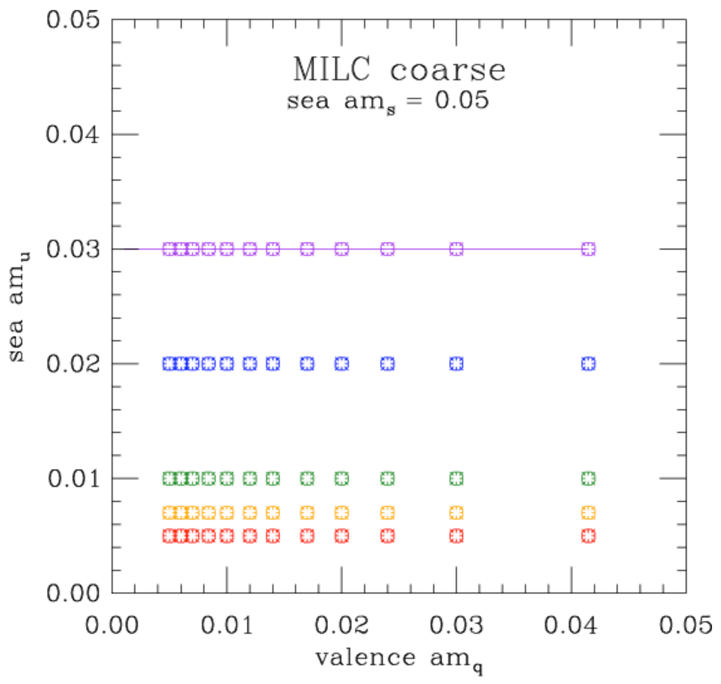
One-loop corrections, Nobes and Trottier.



Simone, Lattice 2004
Fermilab/MILC

0.030/0.05

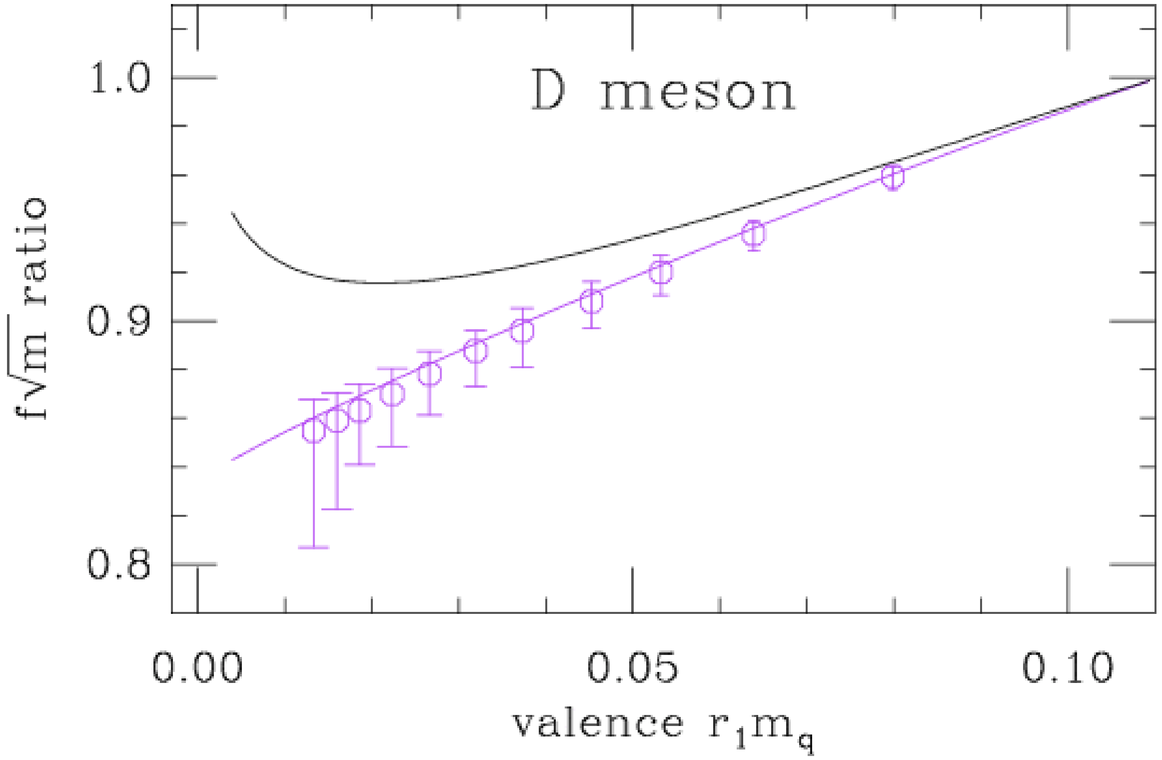




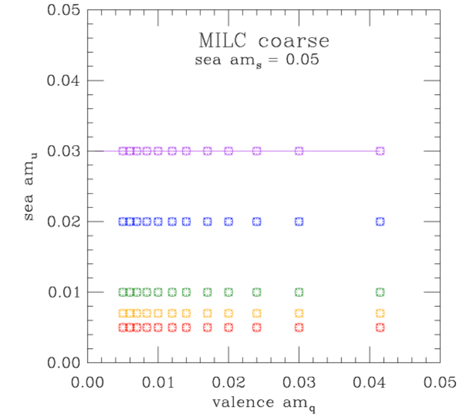
Fit including staggered discretization effects.

Fit without discretization effects.

Ensemble 0.030/0.05



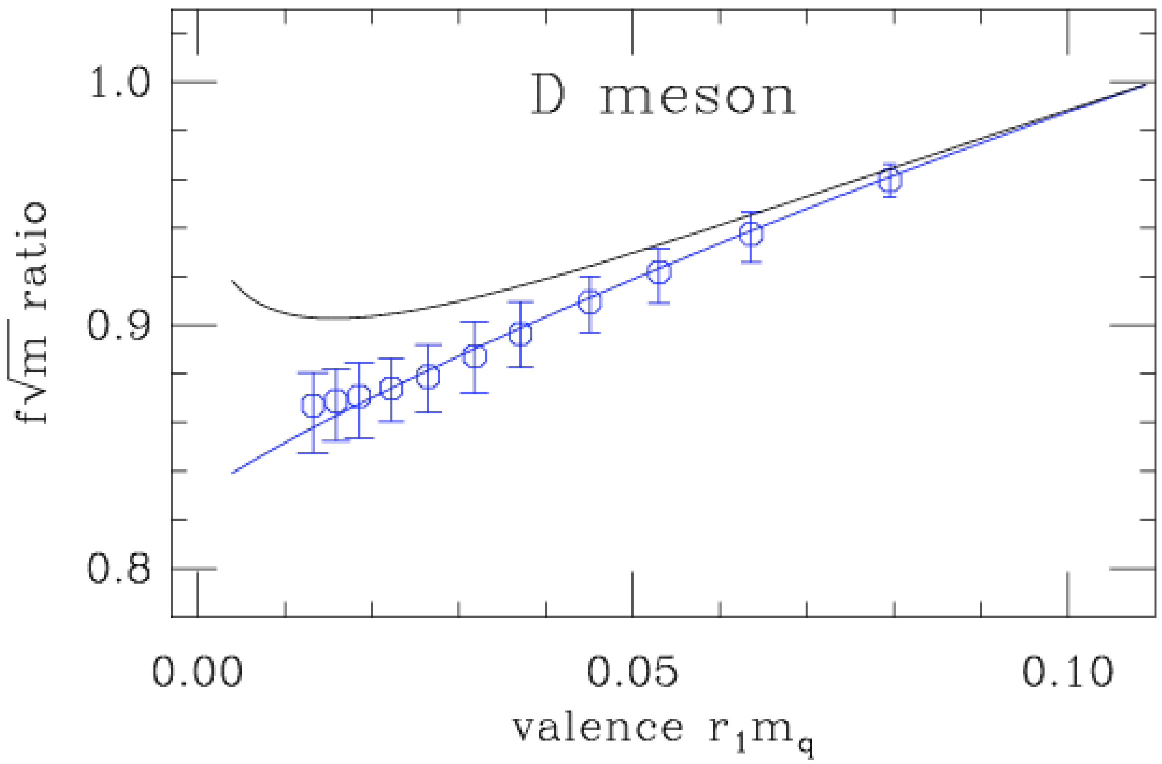
The mass plane



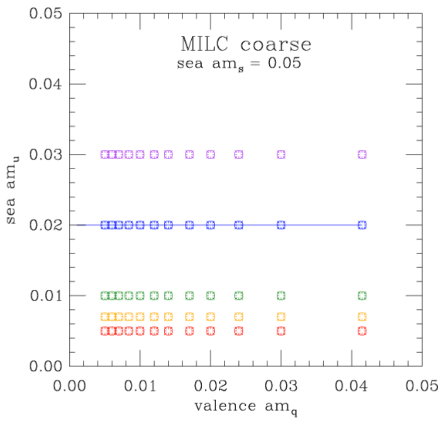
Fit including staggered discretization effects.

Fit without discretization effects.

Ensemble 0.020/0.05



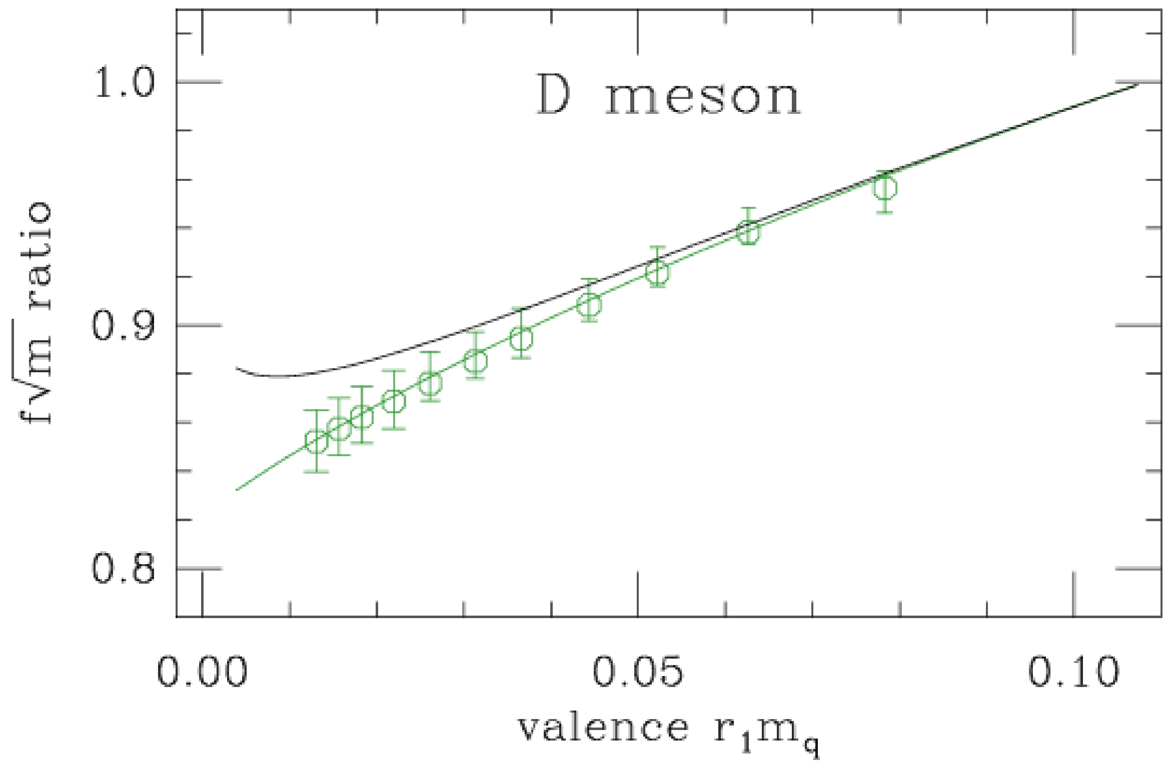
The mass plane



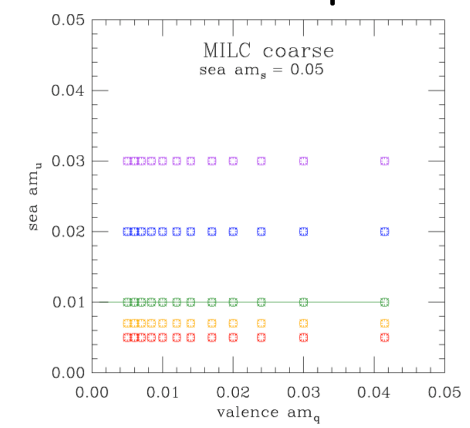
Fit including staggered discretization effects.

Fit without discretization effects.

Ensemble 0.010/0.05



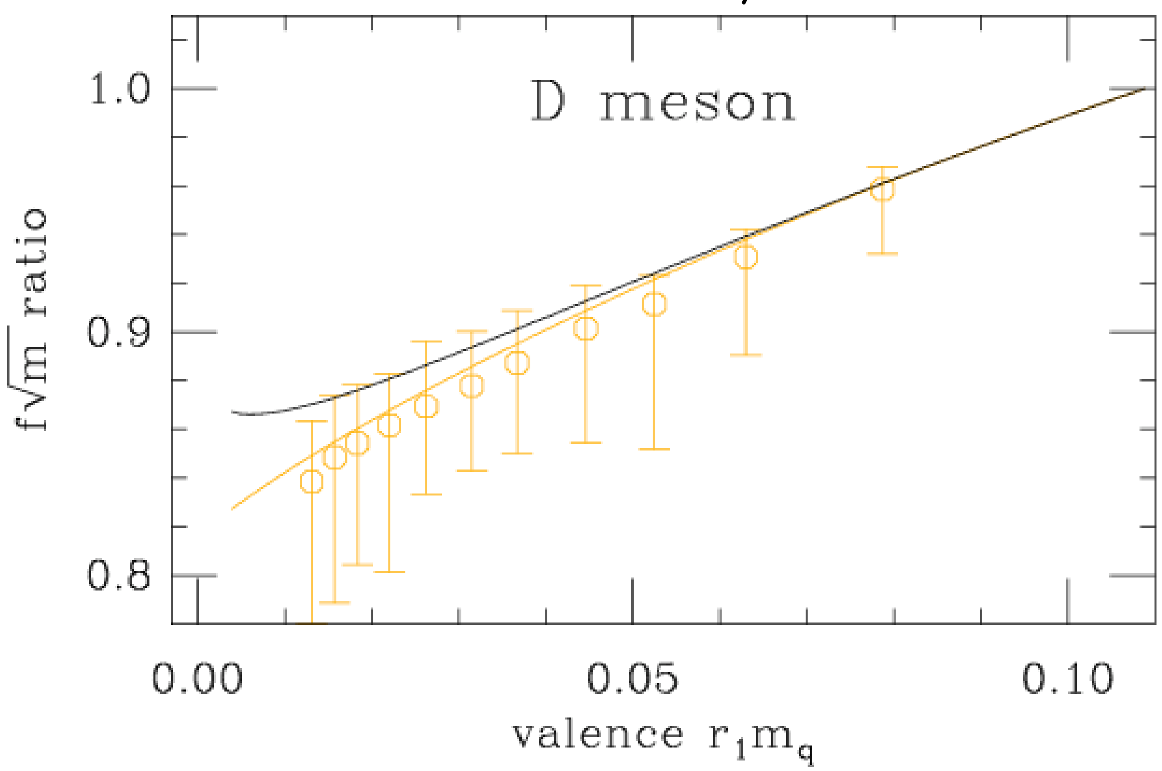
The mass plane



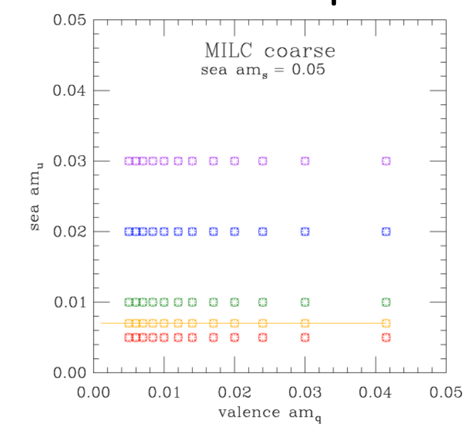
Fit including staggered discretization effects.

Fit without discretization effects.

Ensemble 0.007/0.05



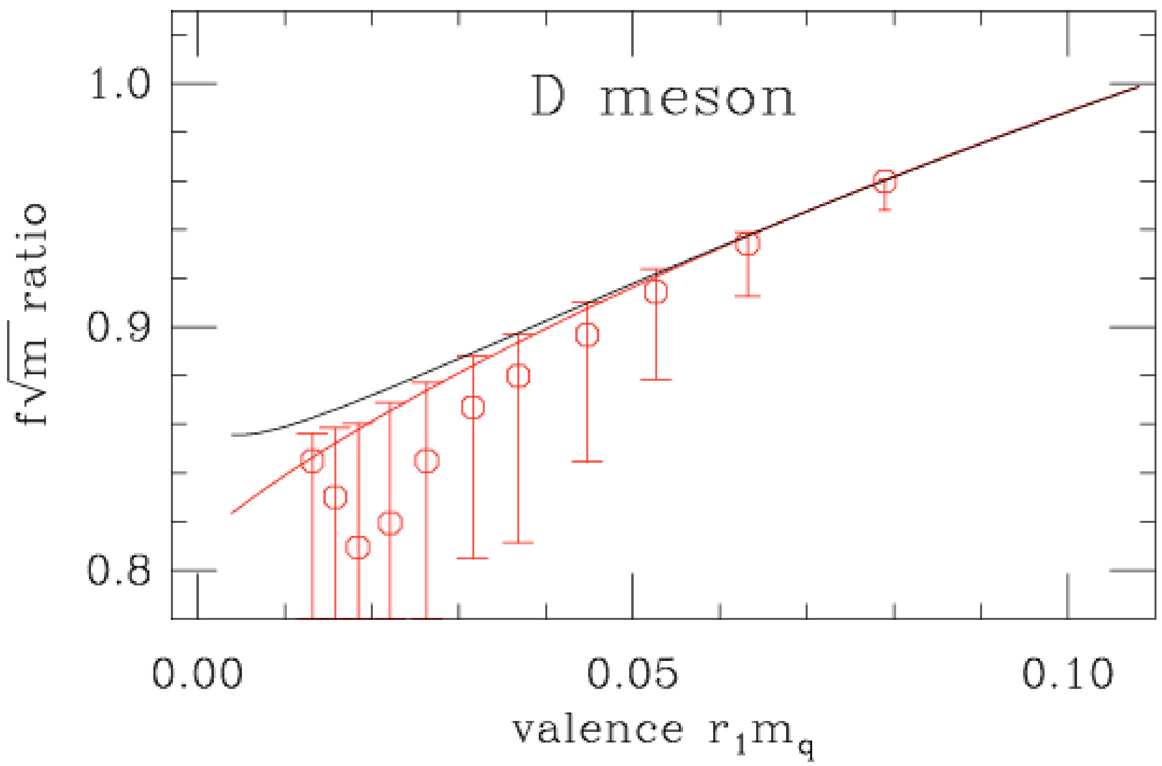
The mass plane



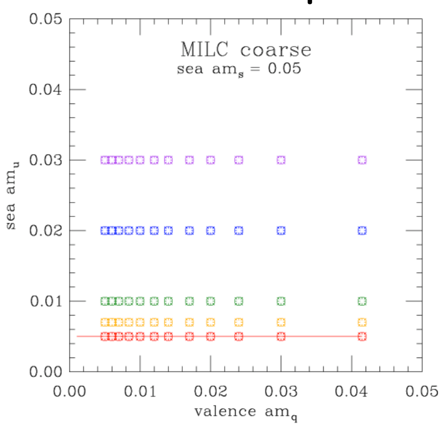
Fit including staggered discretization effects.

Fit without discretization effects.

Ensemble 0.005/0.05



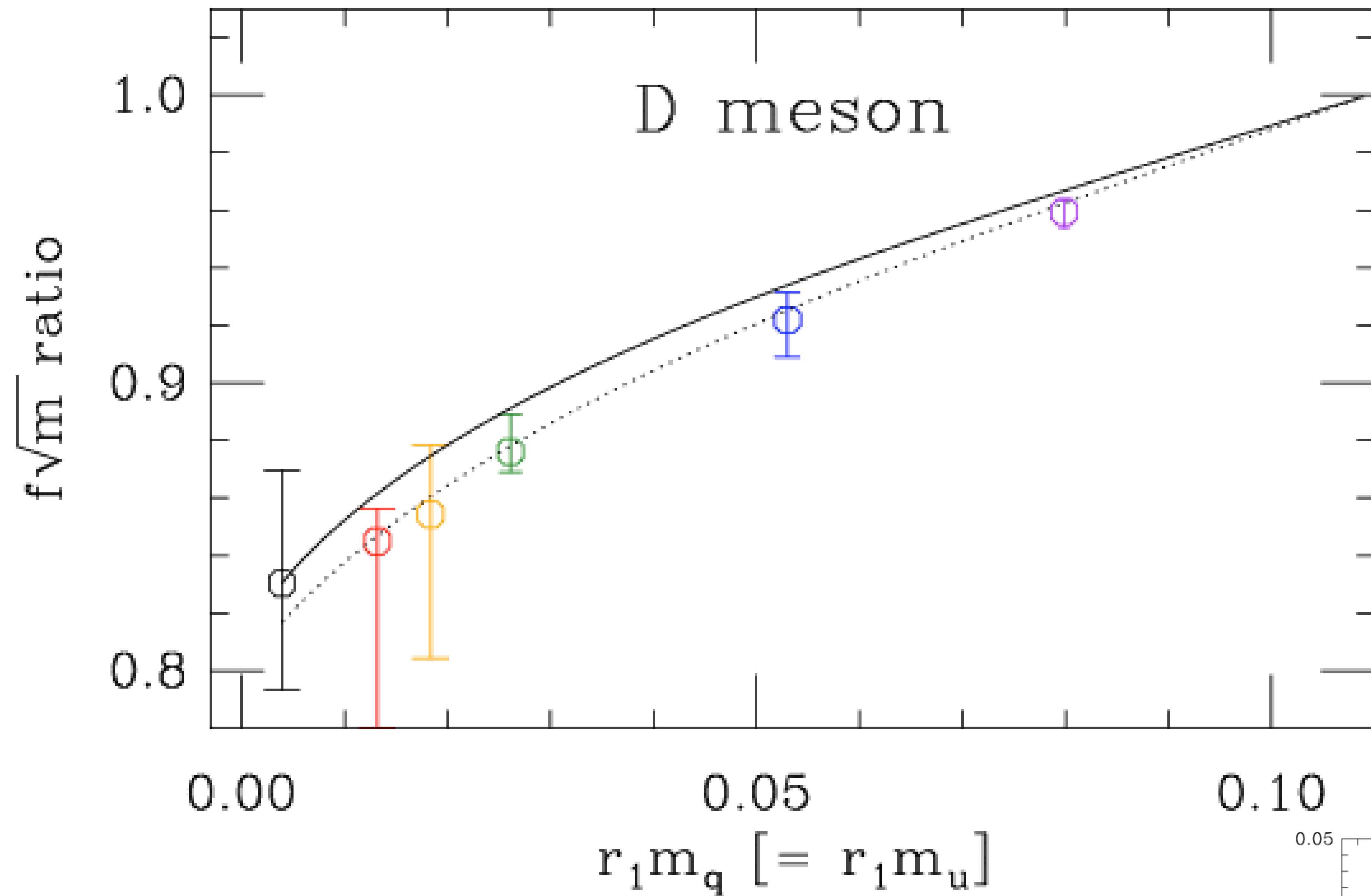
The mass plane

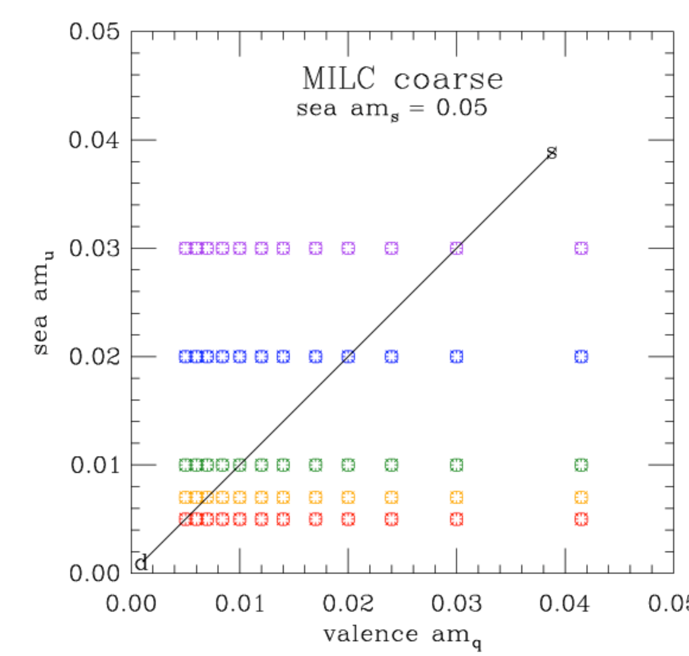


Fit including staggered discretization effects.

Fit without discretization effects.

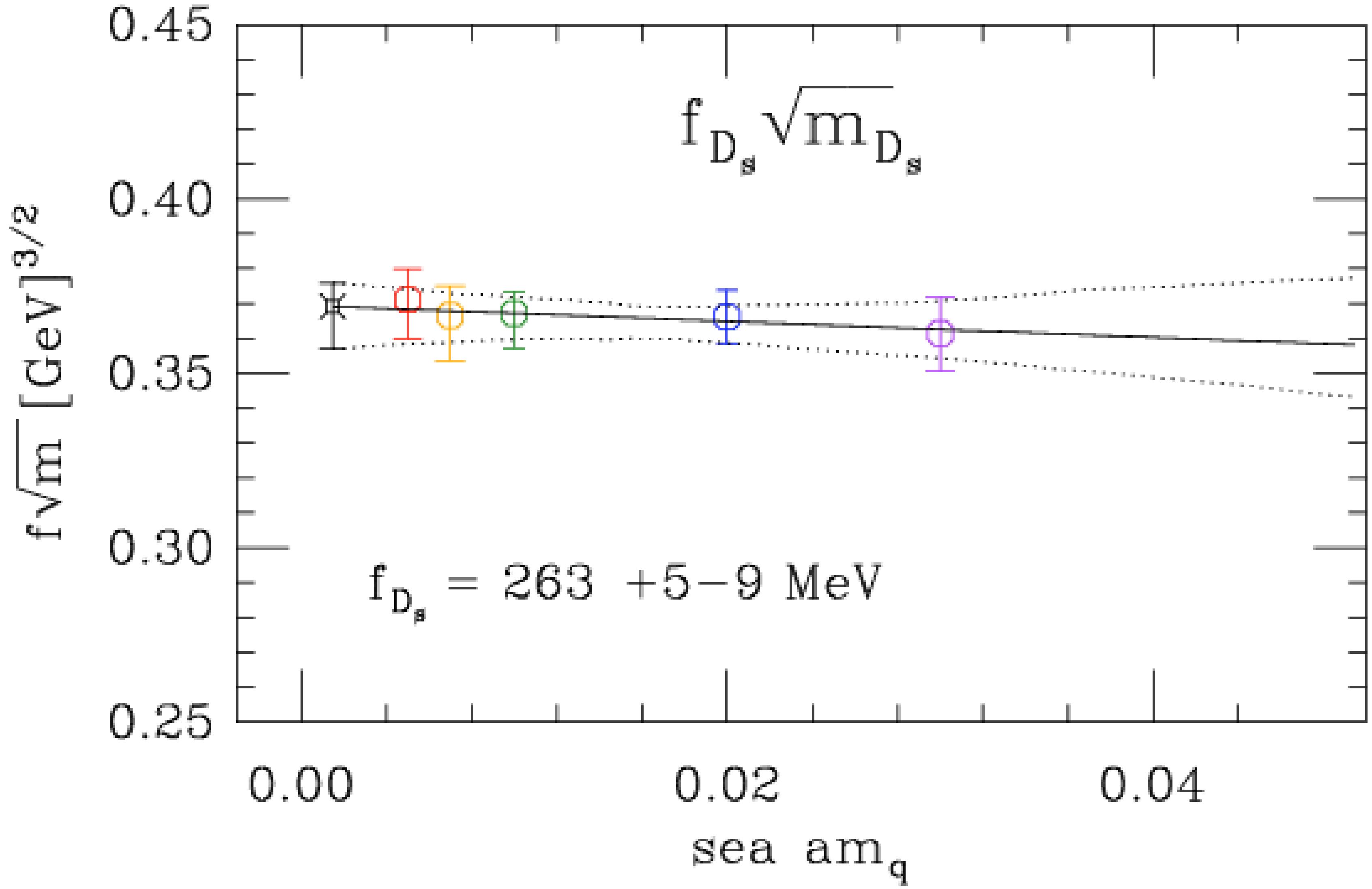
extrapolate along full QCD





Result from fit to all data:

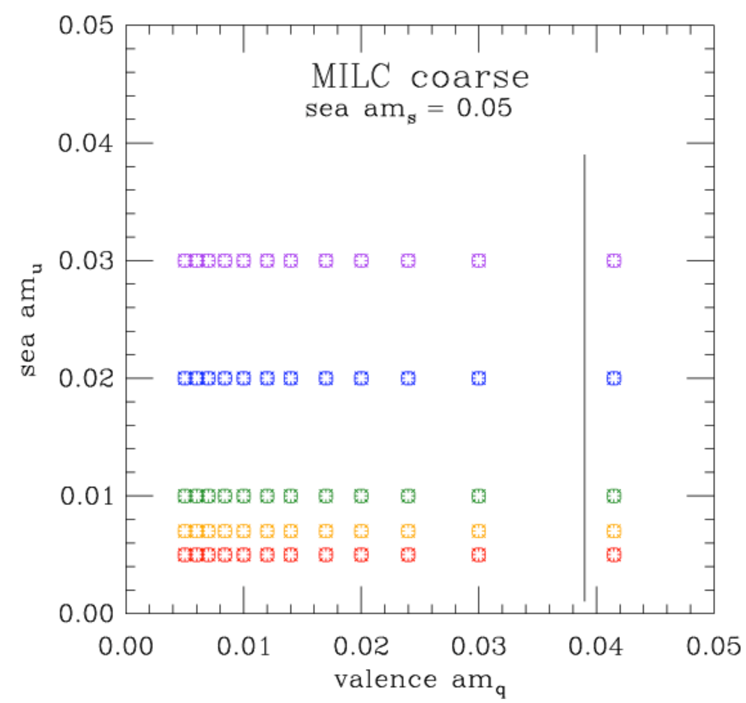
$$f_D \quad = \quad 224^{+10}_{-14} \pm 22 \quad \text{MeV}$$



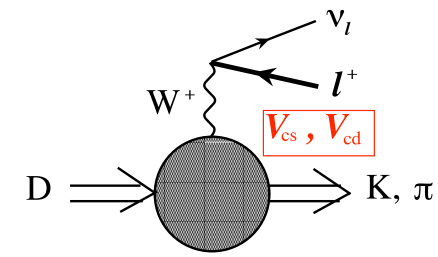
$$\frac{f_{D_s}\sqrt{m_{D_s}}}{f_D\sqrt{m_D}} = 1.20 \pm .06 \pm .06$$

$$f_{D_s} = 263^{+5}_{-9} \pm 24 \quad \text{MeV}$$

$$f_D = 224^{+10}_{-14} \pm 22 \quad \text{MeV}$$

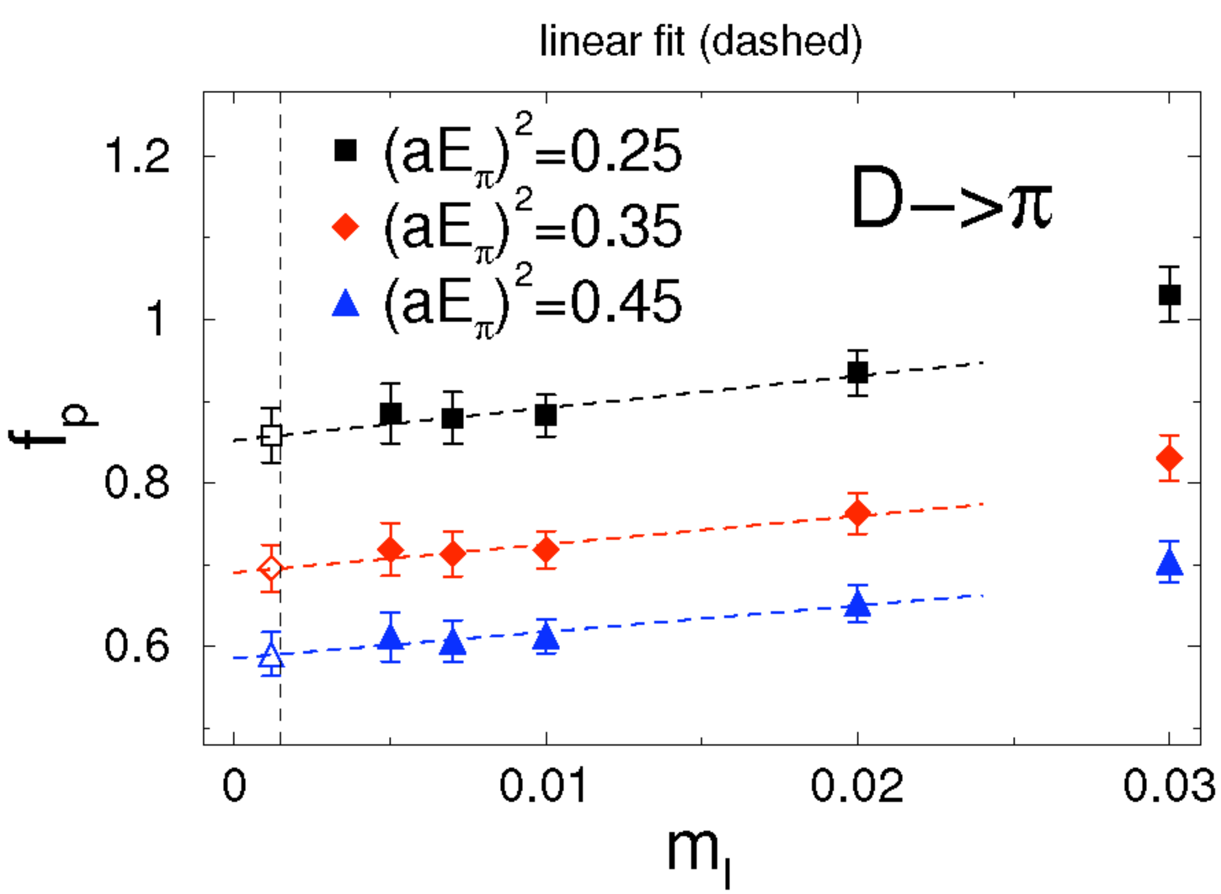


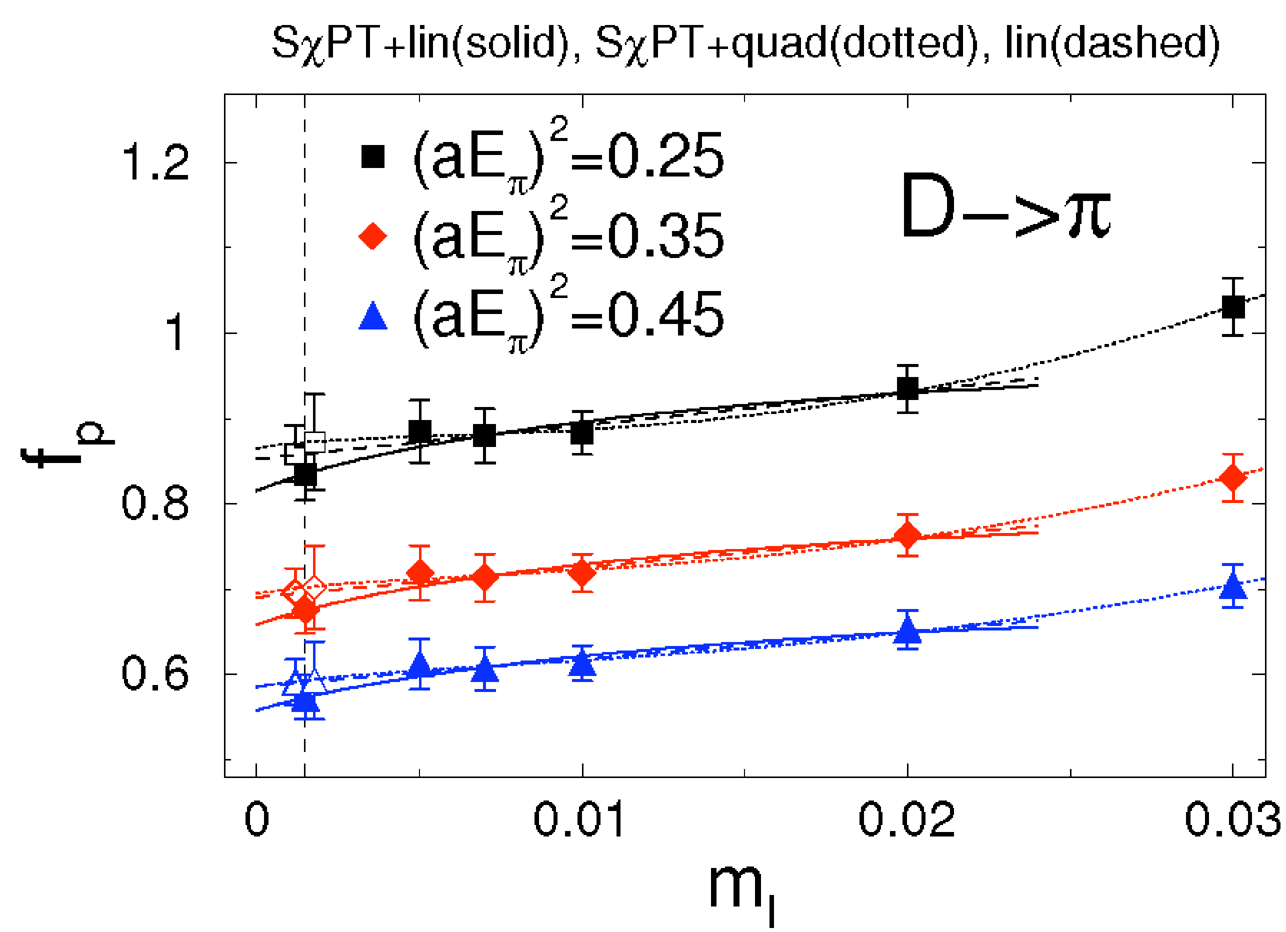
D and B semileptonic decays.



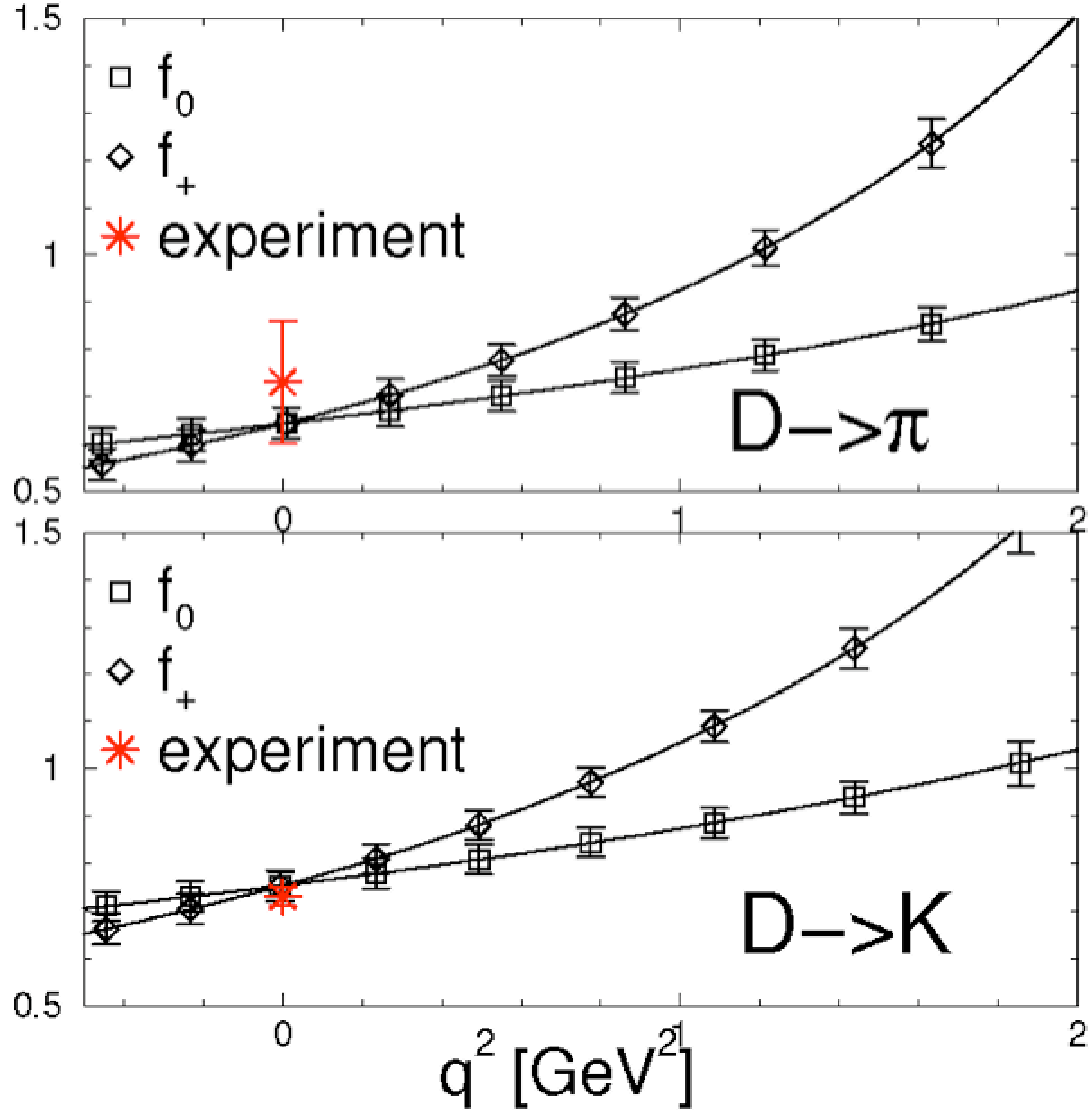
Okamoto, Lattice 2004
Fermilab/MILC

Unquenched only.
Same ingredients as decay constants:
Nobes, one-loop QCD, Aubin, staggered chiral PT.





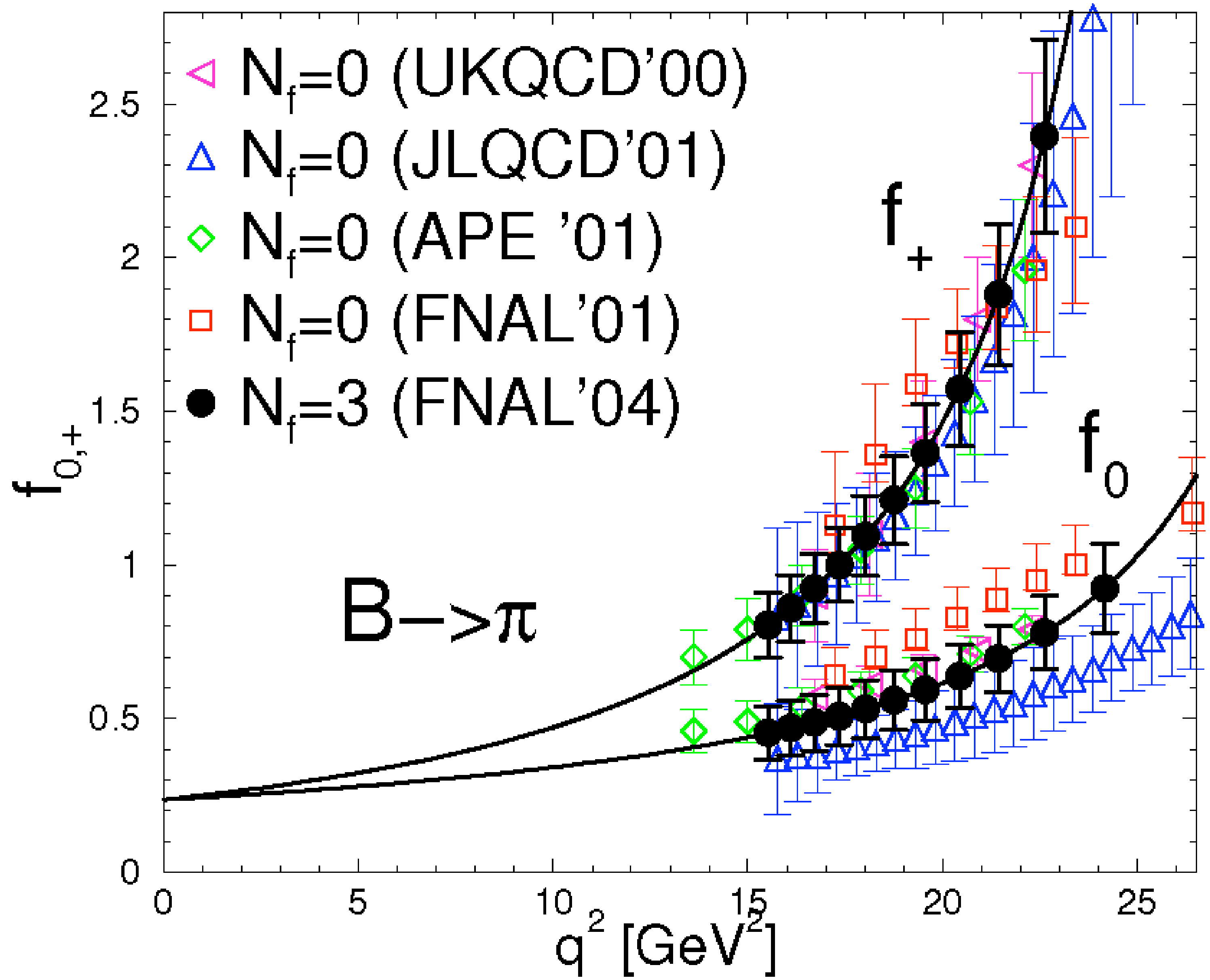
$$\langle \pi | V^\mu | D \rangle = f_+(q^2) \left[p_D + p_\pi - \frac{m_D^2 - m_\pi^2}{q^2} q \right]^\mu + f_0(q^2) \frac{m_D^2 - m_\pi^2}{q^2} q^\mu$$



$$f_+^{D\to\pi}(0) = 0.64(3)(5) \quad , \quad f_+^{D\to K}(0) = 0.73(3)(6)$$

B→πlν

(preliminary!).



$B \to Dl\nu$

$$\langle D|V^\mu|B\rangle = \sqrt{m_B m_D} \times [h_+(w)(v_B+v_D)^\mu + h_-(w)(v_B-v_D)^\mu],$$

where $w = v_B \cdot v_D$.

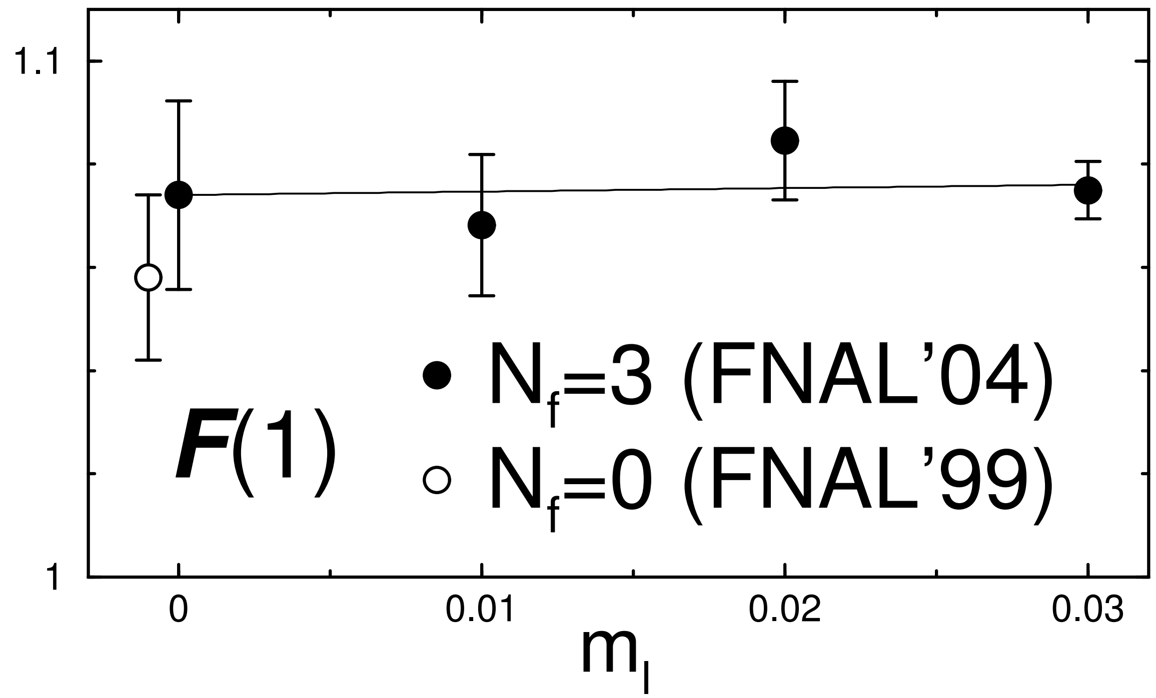
$$\frac{d\Gamma(B \to Dl\nu)}{dw} \propto |\mathcal{F}_{B\to D}(w)|^2 |\mathbf{V_{cb}}|^2$$

$$\mathcal{F}_{B\to D}(w) = h_+(w) - \frac{m_B - m_D}{m_B + m_D} h_-(w).$$

Ratio method (S. Hashimoto *et.al.* '99)

$$\frac{C^{DV_0B}(t)C^{BV_0D}(t)}{C^{DV_0D}(t)C^{BV_0B}(t)} \to \frac{\langle D|V_0|B\rangle\langle B|V_0|D\rangle}{\langle D|V_0|D\rangle\langle B|V_0|B\rangle} = |h_+^{B\to D}(1)|^2$$

$\mathcal{F}(1) = 1$ in $B = D$ limit.



$$\mathcal{F}^{n_f=3}_{B\to D}(1) = 1.074(18)(15)$$

$\mathbf{D} \to \mathbf{K l}\nu$, $\mathbf{D} \to \pi \mathbf{l}\nu$ (nearly final results)

- $f_+^{D\to\pi}(0) = 0.64(3)(5)$
- $f_+^{D\to K}(0) = 0.73(3)(6)$

$\mathbf{B} \to \pi\mathbf{l}\nu$, $\mathbf{B} \to \mathbf{D l}\nu$ (preliminary)

- $f_+^{B\to\pi}(0) = 0.24(3)(2)$
- $\mathcal{F}_{B\to D}(1) = 1.07(2)(2)$

CKM matrix with $n_f = 3$ LQCD (preliminary)

$$\begin{pmatrix} \mathbf{V_{ud}} & \mathbf{V_{us}} & \mathbf{V_{ub}} \\ \mathrm{N/A} & \mathrm{N/A} & 3.6(5)(4)(3)\times10^{-3} \\ \mathbf{V_{cd}} & \mathbf{V_{cs}} & \mathbf{V_{cb}} \\ 0.24(1)(2)(2) & 0.97(4)(8)(2) & 3.8(1)(1)(6)\times10^{-2} \\ \mathbf{V_{td}} & \mathbf{V_{ts}} & \mathbf{V_{tb}} \\ \mathrm{N/A} & \mathrm{N/A} & \mathrm{N/A} \end{pmatrix}$$

4/**9** being determined with $n_f = 3$ LQCD.

LQCD unitarity check!

$$(|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2)^{1/2} = 1.00(4)(8)(2)$$

Future program.

- Full set of CKM related amplitudes including B Bbar and $K \to \pi l \nu$.

- Now doing MILC fine (a^{-1}~2.2 GeV) and extra-coarse (a^{-1}~1.1 GeV) data sets.

- More highly improved charm quark actions.

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