Heavy-light decay constants and mixing parameters from lattice QCD

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HPQCD collaboration

CKM08
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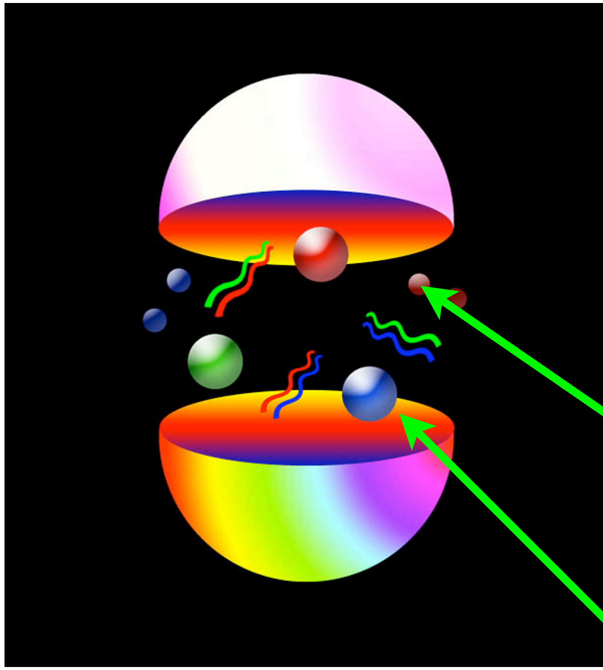
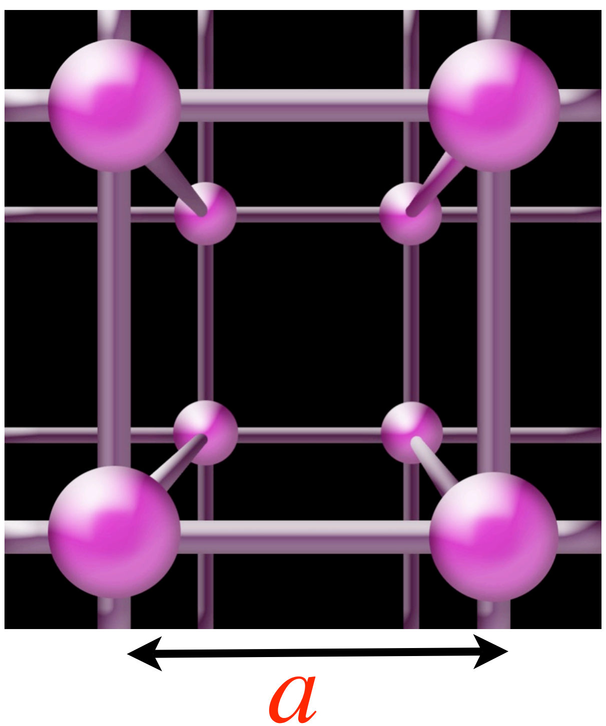
QCD is key part of SM but quark confinement tricky





Lattice QCD = full QCD effects

RECIPE

- Generate sets of gluon fields for Monte Carlo integrn of Path Integral (inc effect of sea quarks)
- Calculate averaged "hadron correlators" from valence q props.

$$< 0|M^{\dagger}(0)M(t)|0 >$$

- Fit for masses and simple matrix elements
- Fix m_q and determine a to get physical results

Simplest calculations are "2-point functions"

Fit $< 0|H^\dagger(0)H(t)|0 >$ = $\sum_i A_i e^{-E_i t}$

meson masses for this J^{PC}, i =0 is ground state

A = square of matrix element of H between vacuum and meson

Set H to local axial vector current that couples to W

A = square of decay constant, f, where

$$f_H m_H = < 0|\overline{\psi}\gamma_0\gamma_5\psi|H >$$

PRECISION lattice QCD i.e ~ 1% is possible for masses and decay constants of 'gold-plated hadrons'

- Allows non-trivial tests of QCD i.e. better than models.
- Allows accurate determn of SM parameters (inc CKM)
- Provides the underpinning for other calcs.

Statistical errors must be very good to test systematics.

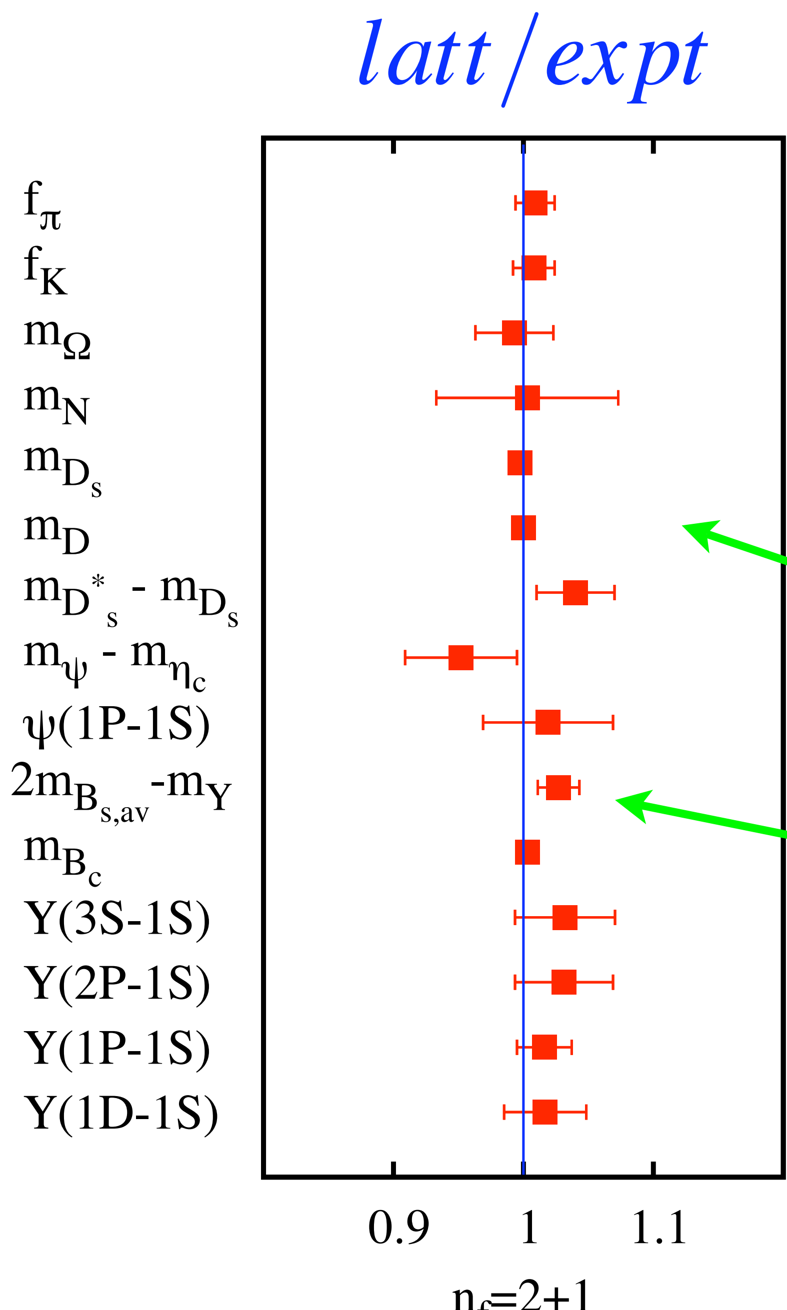
Expect an error budget ....

Systematics from:

- disc. errors (need several a values)
- extrapoln to physical u/d masses $m_s/10 < m_{u/d} < m_s/2$
- finite volume
- errors in fixing QCD parameters. Use, e.g.:

$$\Upsilon(2S-1S), m_\pi, m_K, m_{\eta_c}, m_\Upsilon$$

2007 HPQCD/MILC/FNAL summary of results



Analysis on MILC configs that include u,d, s improved staggered sea quarks - numerically fast

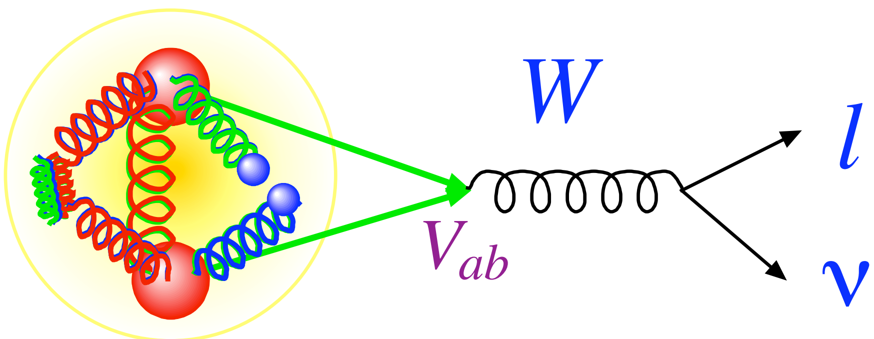
Recent highlight - very accurate charm physics - NEW results to follow

NEW B/Bs mixing results to follow

Results from other quark formalisms also now appearing ...

Impact of lattice QCD in CKM physics

$Br(H \rightarrow \mu\nu) \propto V_{ab}^2 f_H^2$



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

expt=(CKM)x(lattice calc.)

Decay const. + expt gives CKM K/π

or expt + CKM gives decay const. test vs lattice QCD

(return to B mixing later) D/D_s

Charm quarks in lattice QCD - heavy or light?

"Traditional" FNAL method is mixed - nonrel. dispersion reln reduces disc. errors in imp. Wilson light quark action.

New results use relativistic light quarks. Then:

- $E_{sim} = m$
- PCAC relation (if enough chiral symmetry) gives $Z = 1$

"latt-to-contnm" renormln

Key issue then is discretisation errors:

$$m = m_{a=0}(1 + A(m_c a)^2 + B(m_c a)^4 + \ldots$$

$$m_c a \approx 0.4,\ (m_c a)^2 \approx 0.2,\ \alpha_s (m_c a)^2 \approx 0.06,\ (m_c a)^4 \approx 0.04$$

for $a \approx 0.1 fm$

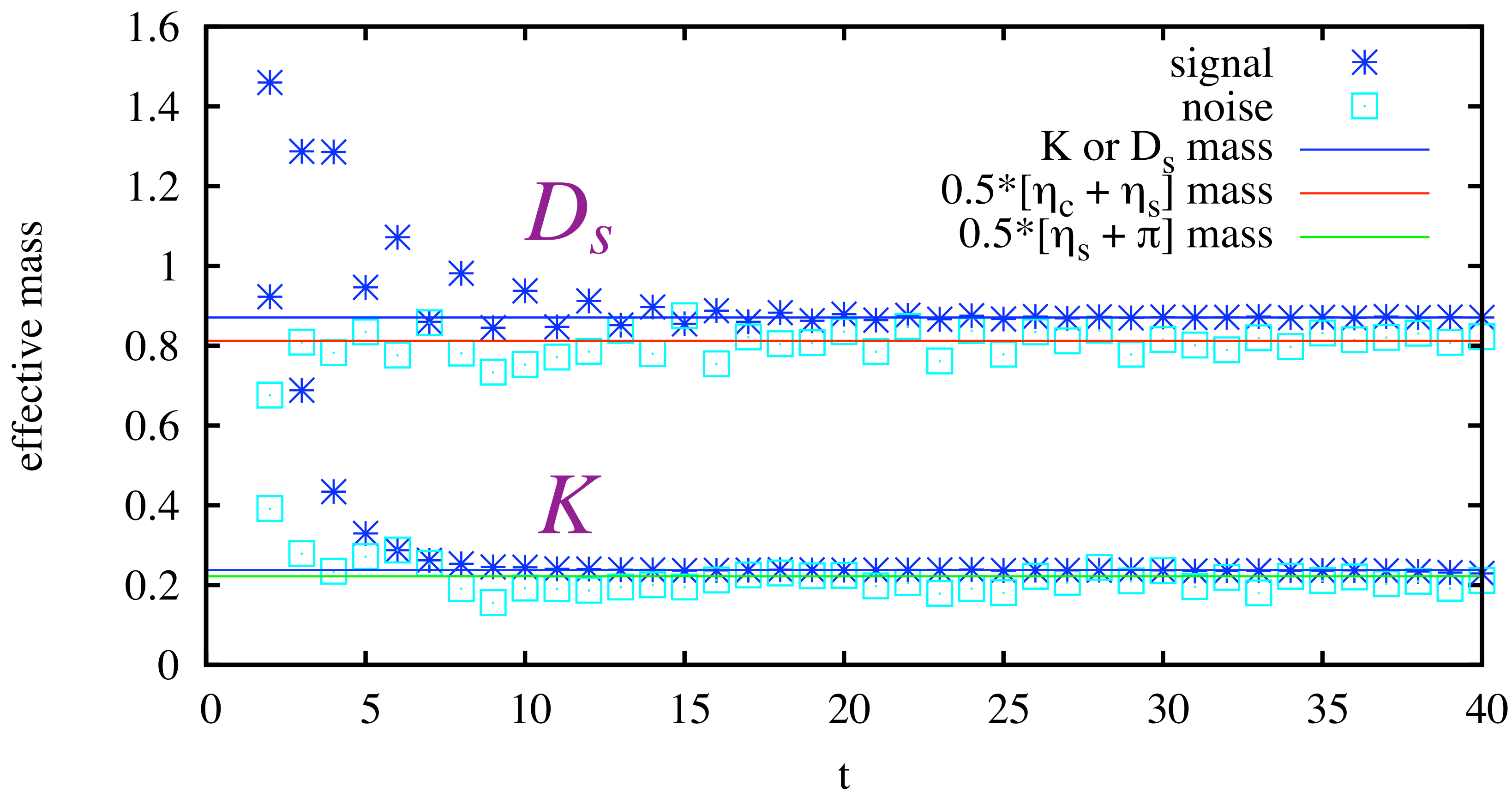
All are removed in Highly Improved Staggered Quark formalism, further improving Improved Staggered Quarks

Twisted mass approach removes O(a) errors. Also improved Wilson (needs Z), overlap ... being tried by different groups.

How well do we expect to be able to do?

Light decay constants calculable to 1-2% using variance reduction methods + continuum, chiral extrapoln.

MILC, HPQCD, ETMC ...

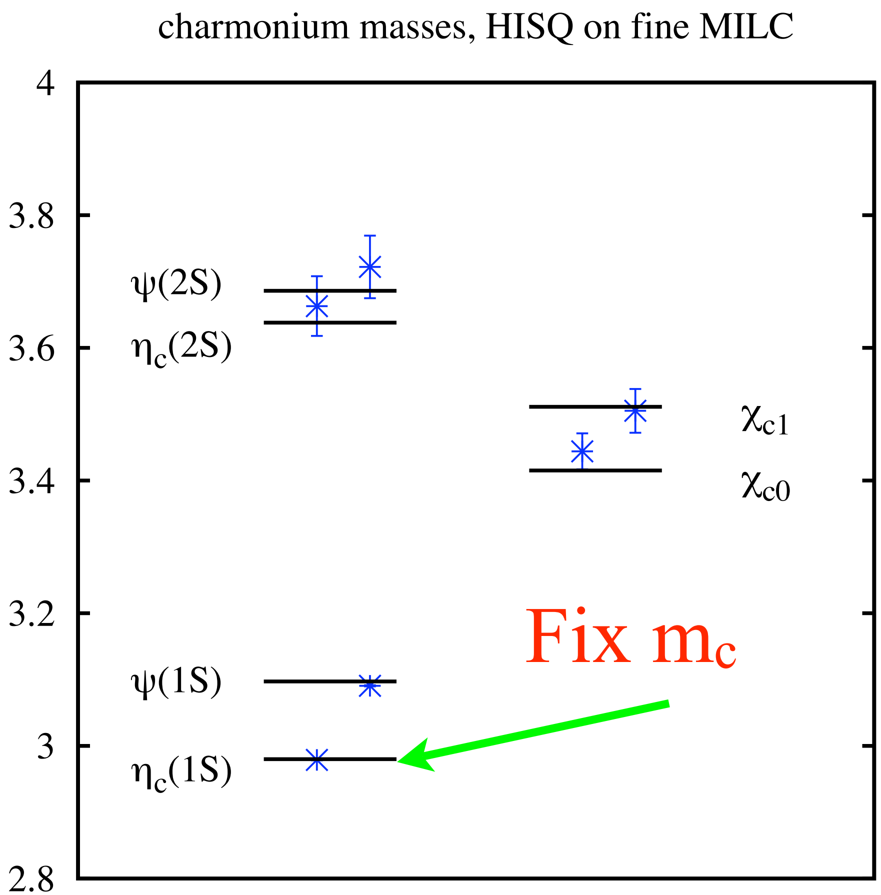


signal/noise not much worse in D system (it is worse in B system)

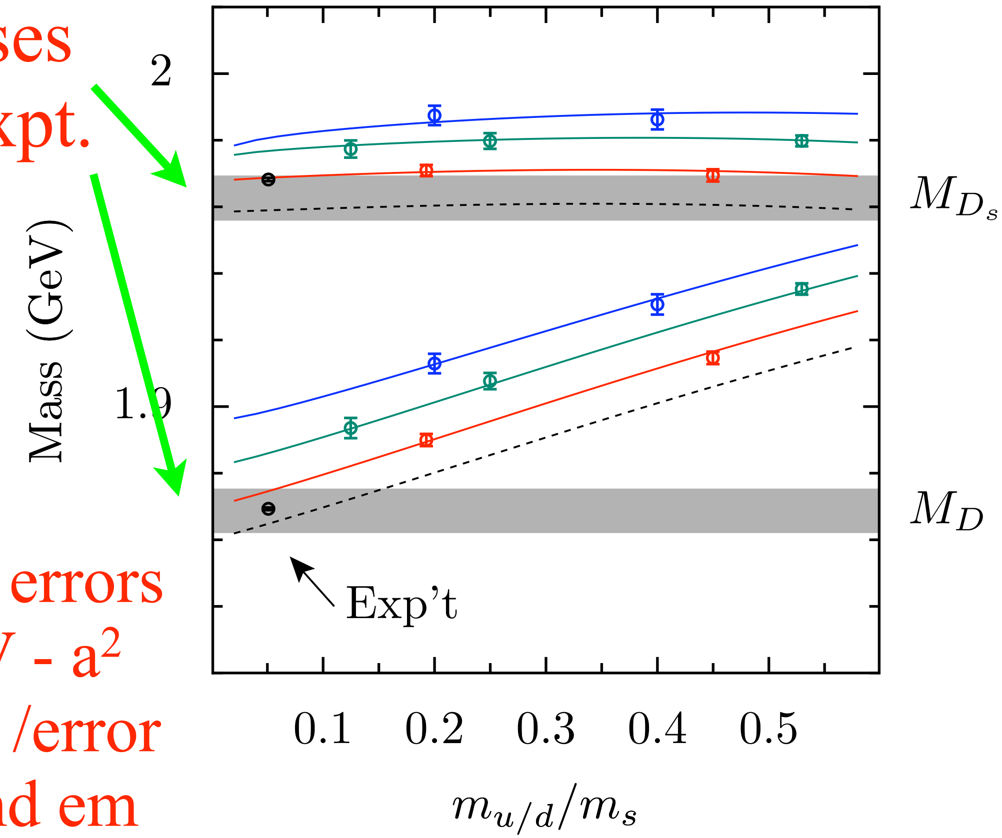
→ expect to be able to do calculations at 1-2% level for D/Ds. Poorer errors in past were not necessary.

Very precise D/Ds masses obtained with HISQ

NO free parameters



D/Ds masses vs expt.



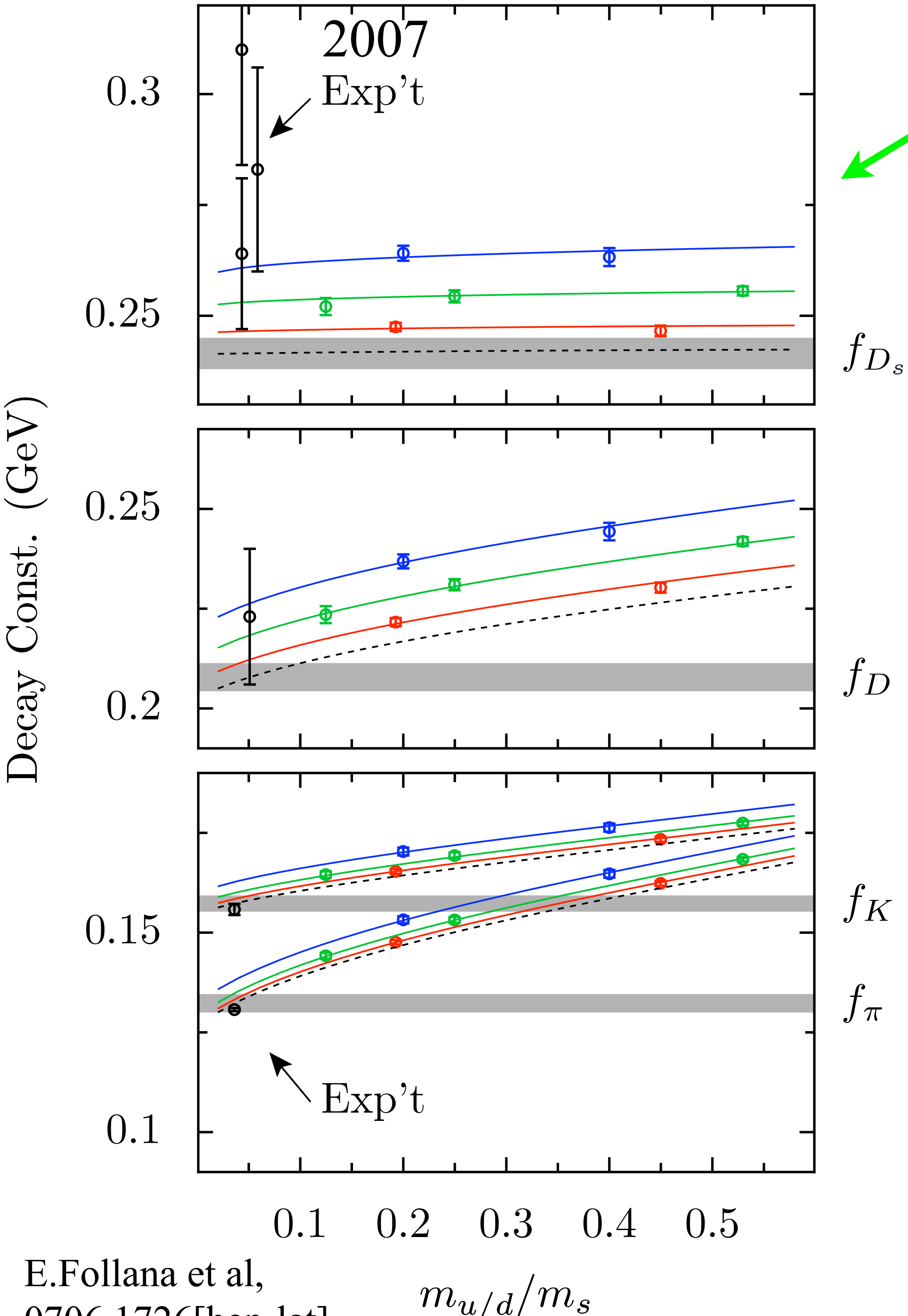
lattice errors 6 MeV - a^2 extrap /error in a and em corrns

A key test of disc. errors since charmonium and D have different dynamics → stringent test of QCD.

Can use to extract 1% accurate m_c

E.Follana et al, 0706.1726[hep-lat]; 0805.2999[hep-lat]

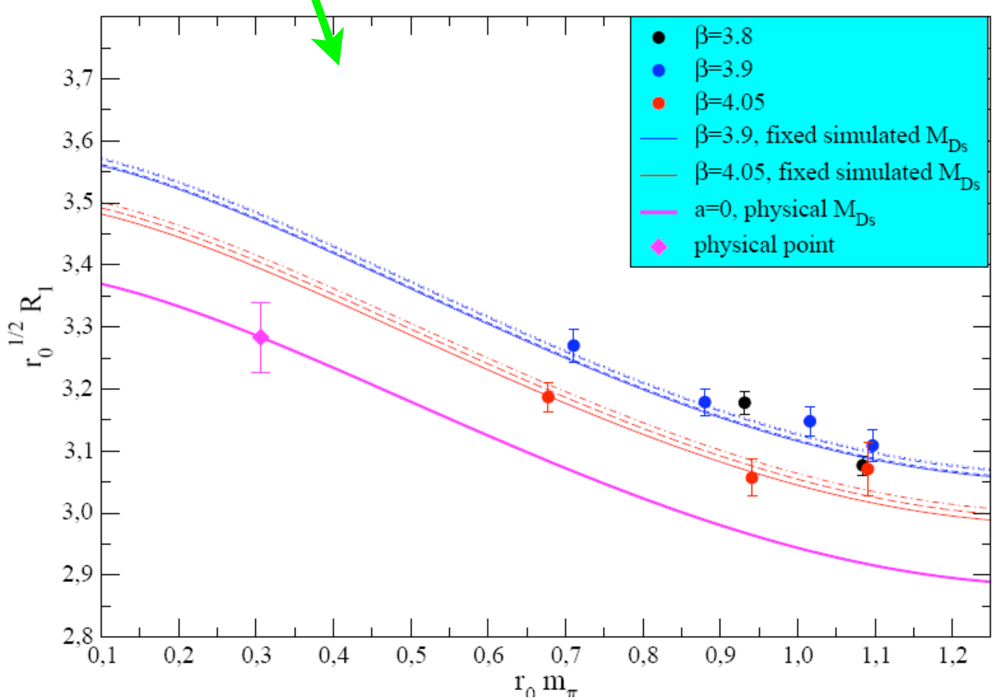
HPQCD - decay constants of $D/D_s/K/\pi$ to 2%.



E.Follana et al, 0706.1726[hep-lat]

ETMC also extrapolate ratios e.g.

$$R_1 = \frac{f_{D_s}\sqrt{M_{D_s}}}{f_K}$$

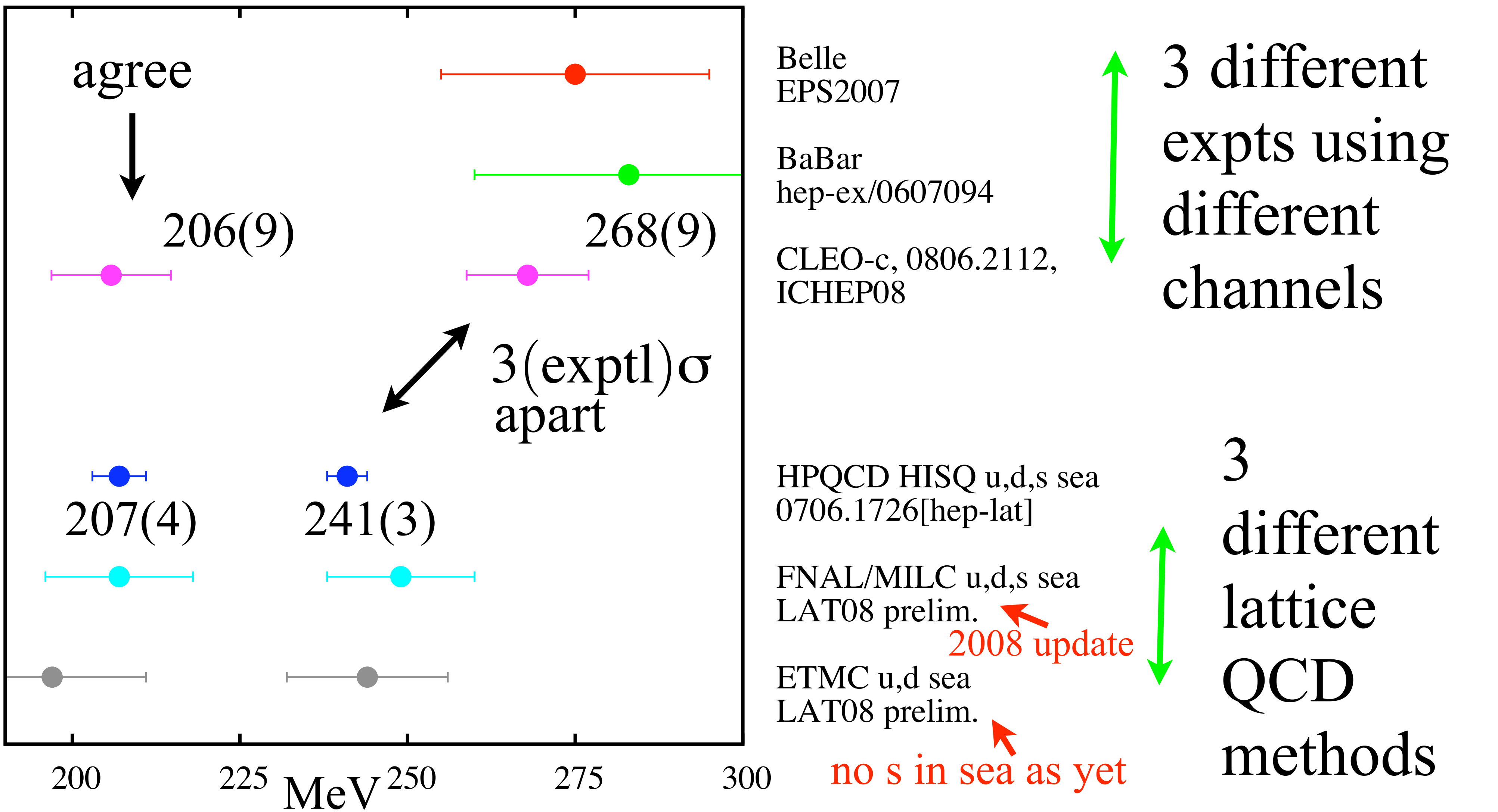


Tarantino et al, ETMC, LAT2008

2008 Improved accuracy from CLEO-c

Leptonic rate ⟶ decay constant using Vcs=Vud, Vcd=Vus

f_D f_{D_s}



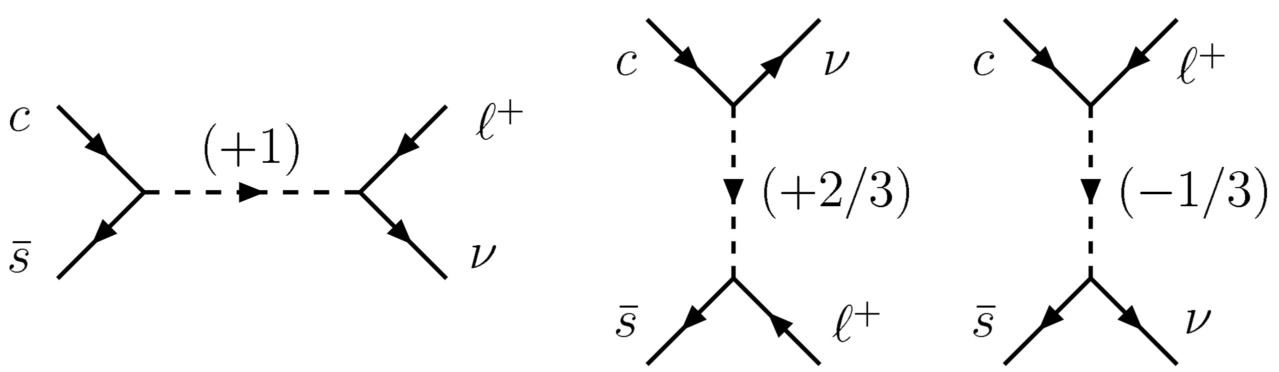
First disagreement between lattice and expt. New physics?

How can we interpret disagreement?

• Misunderstood syst. in expt? unlikely
QED corrns in expt case? (1% level, so no)
Expt needs to improve stats.

• Misunderstood syst. in theory? unlikely given other results
Further tests underway e.g. charmonium leptonic width.

• BSM physics ?
Was considered unlikely .... but is possible.



e.g new particles couple to c but not to d -leptoquarks, extra Higgs. See at LHC ?

Dobrescu,Kronfeld 0803.0512; Kundu, Nandi 0803.1898

Bottom quarks in lattice QCD - definitely heavy

$m_b a \approx 2$ on current lattices

Use the fact that $m_b a$ is not a dynamical scale to write down an effective theory in which it is removed.

Possibilities: HQET, NRQCD, FNAL heavy quarks

start with $m_b a = \infty$ → HQET

handles Υ *and* B → NRQCD

same method as for c → FNAL heavy quarks

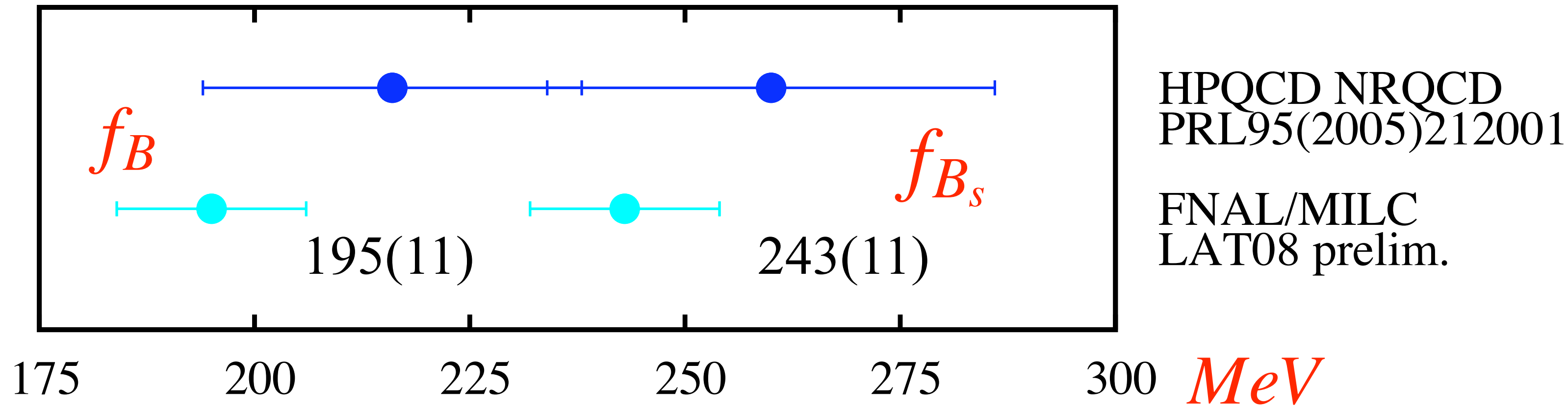
Now disc. errors set by e.g (mom. in bound state)a

$Z \neq 1$ is a major source of error. Also need to add relativistic corrns to current to match continuum

2008 - Results from HPQCD using NRQCD and FNAL/MILC using FNAL on the MILC configs

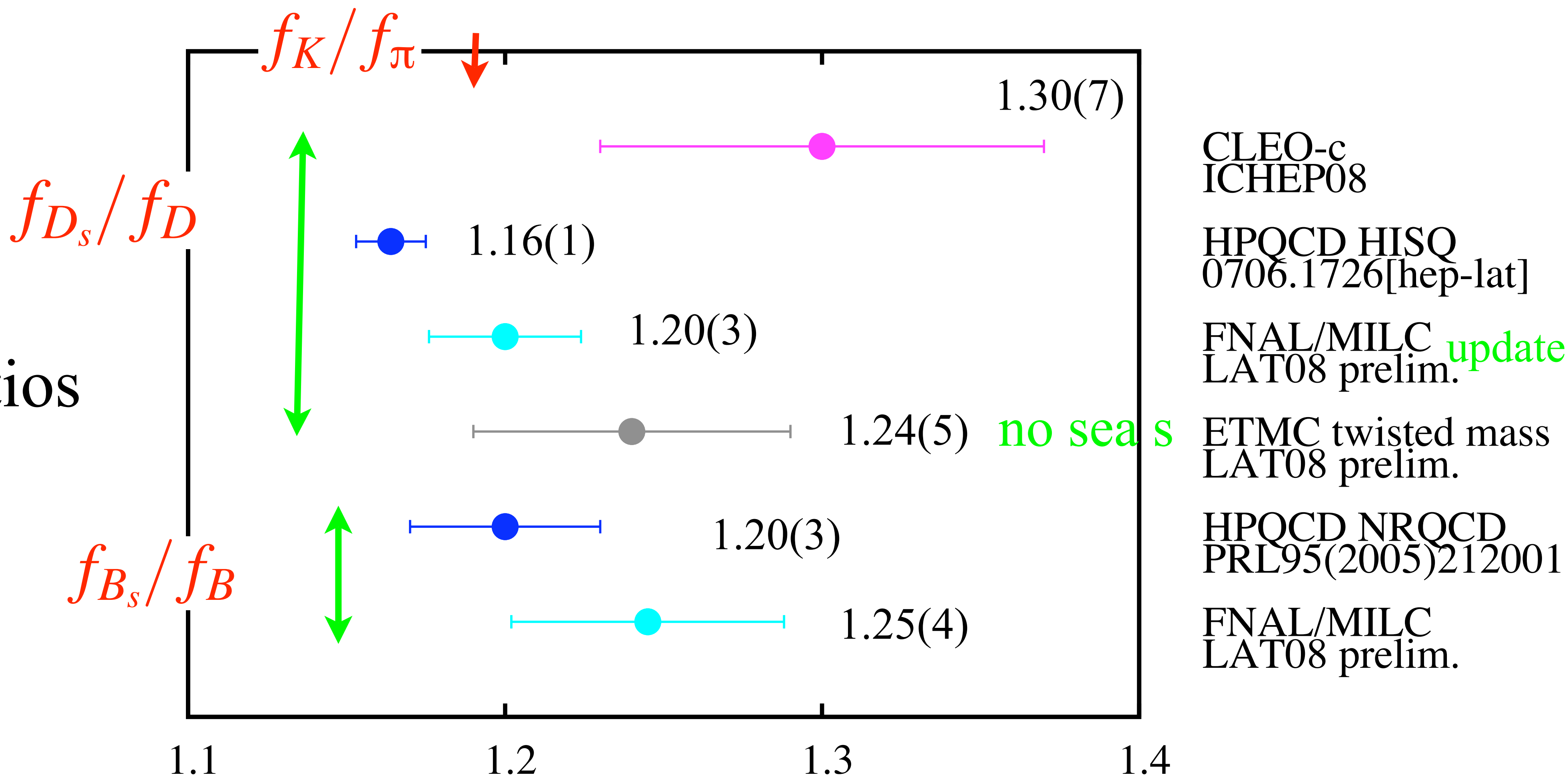
Several other groups making progress in HQET ....

B, B_s decay constants and their ratio (Z factors cancel)

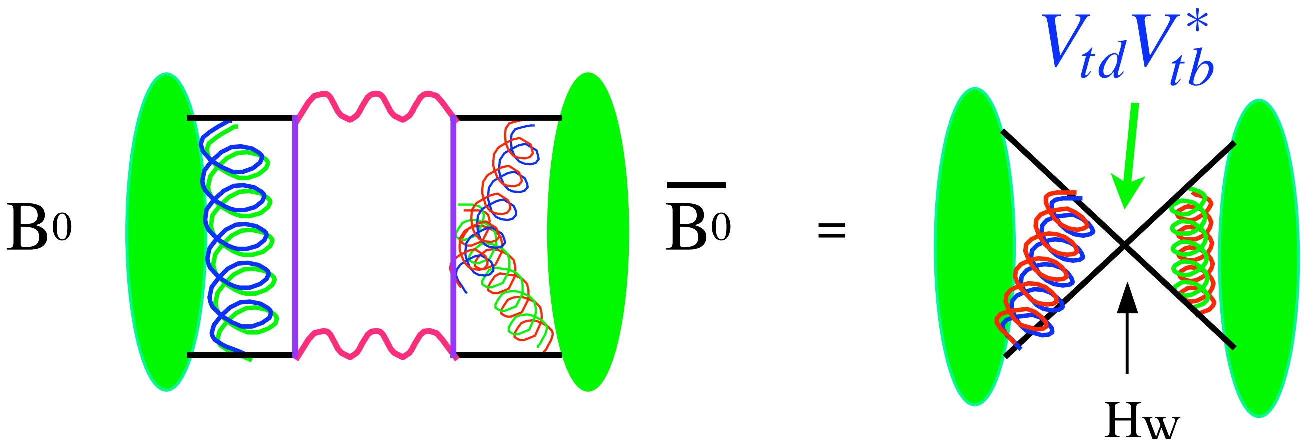


only B has leptonic decay - hard to measure

Ratios



b physics - B^0 mixing and key CKM constraint



Parameterise with $f_B^2 B_B$ where f_B is decay constant.

$$\Delta M_x = \frac{G_F^2 M_W^2}{6\pi^2} |V_{tx}^* V_{tb}|^2 \eta_2^B S_0(x_t) M_{B_x} f_{B_x}^2 \hat{B}_{B_x}$$

Take exptl ratio from oscillation rates for B_s and B_d

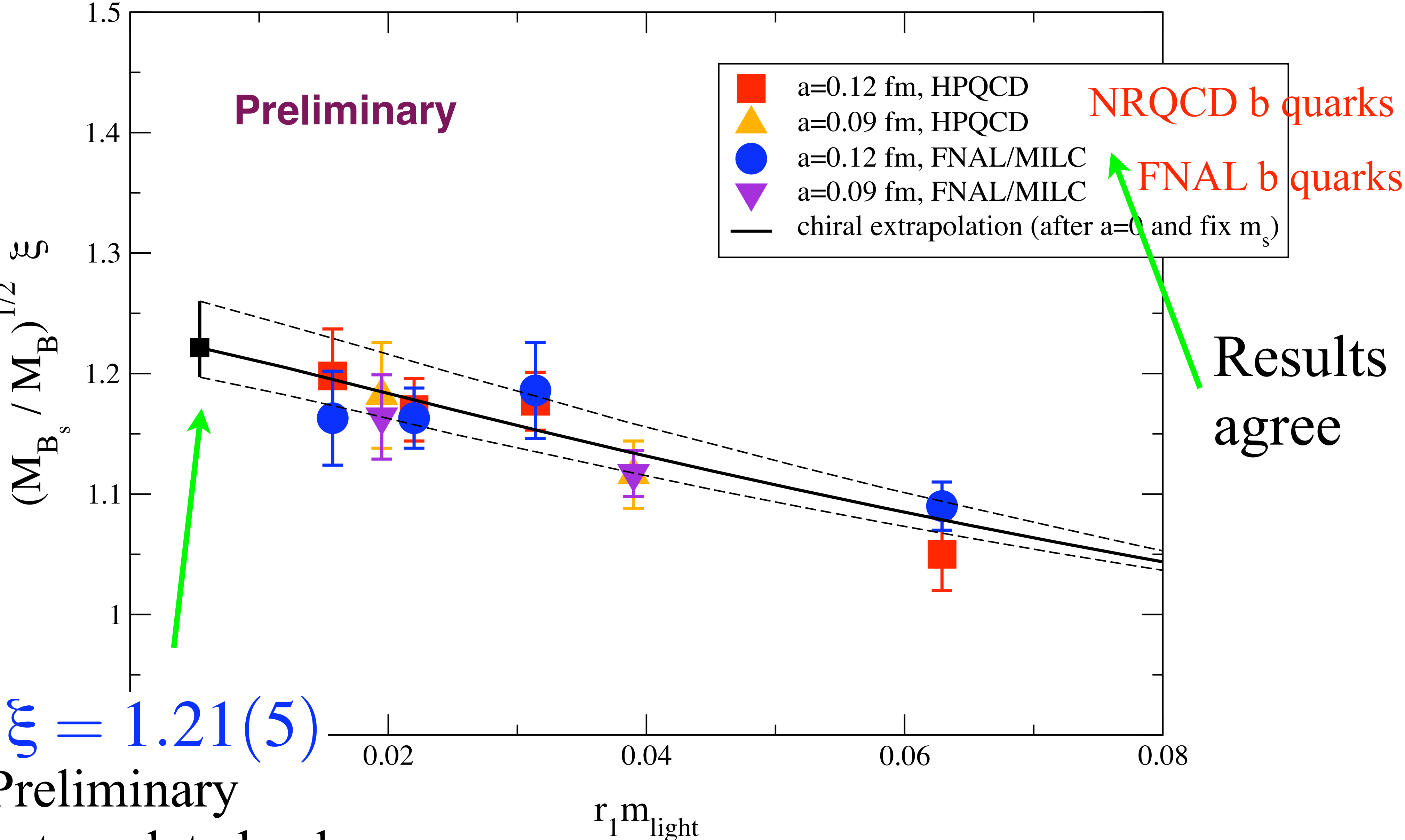
$$\left|\frac{V_{td}}{V_{ts}}\right| = \xi \sqrt{\frac{\Delta M_d M_{B_s}}{\Delta M_s M_{B_d}}}, \quad \xi = \frac{f_{B_s}\sqrt{B_{B_s}}}{f_B \sqrt{B_B}}$$

calculate in lattice QCD, renormln cancels

Often taken to be the same as f_{B_s}/f_B and close to f_{D_s}/f_D

Not exactly true

2008 New results for $\xi = \frac{f_{B_s}\sqrt{B_{B_s}}}{f_B\sqrt{B_B}}$ inc. u, d, s sea quarks using MILC configs

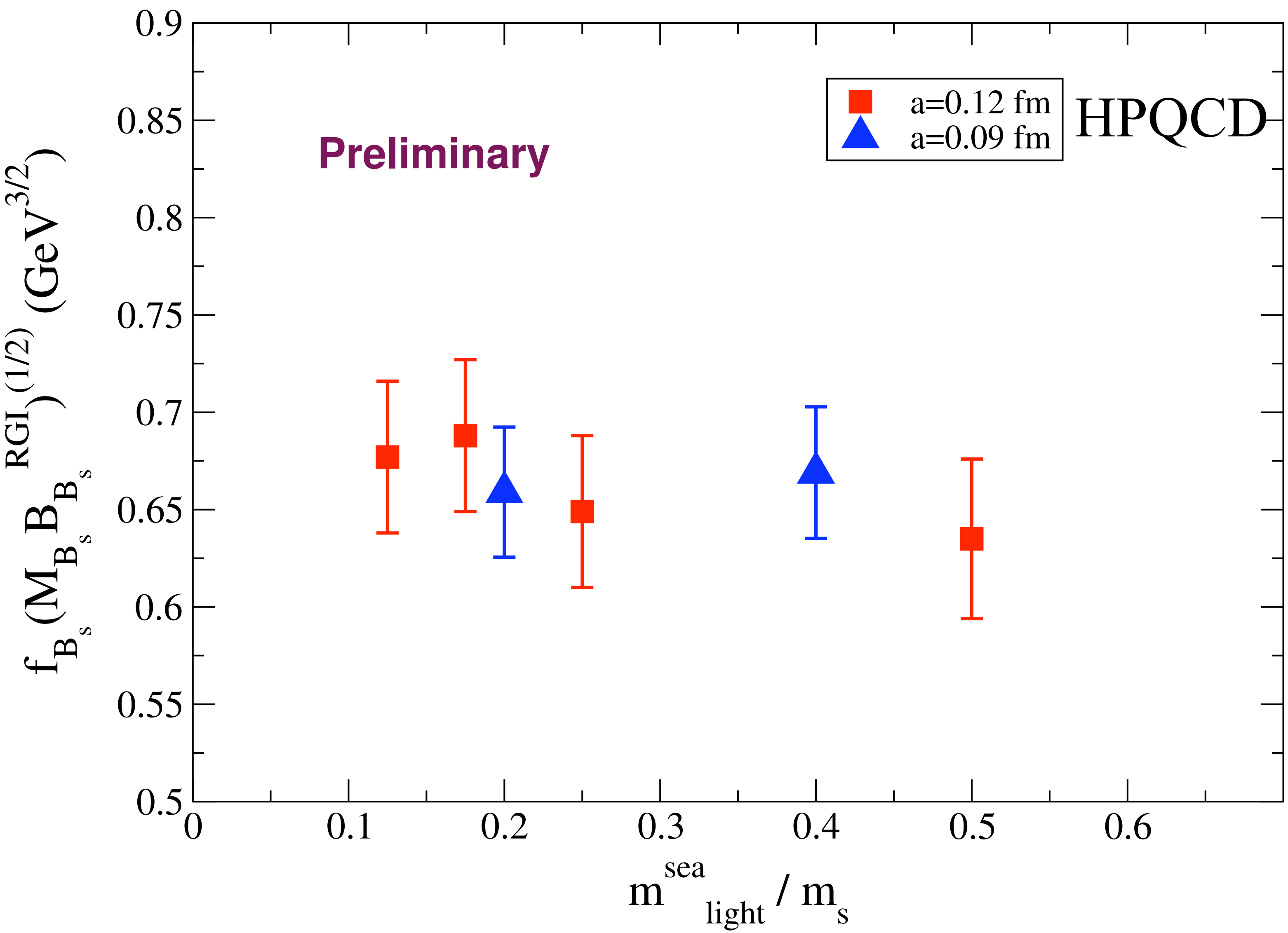


$\xi = 1.21(5)$

Preliminary extrapolated value

2008 Improved results for $f_{B_s}\sqrt{B_{B_s}}$

Inc. one-loop matching + corrns at Λ/M_b



previously:

$f_{B_s}\sqrt{B_{B_s}}$

=0.281(21) GeV

$\Delta M_s = 20(3) ps^{-1}$

Dalgic et al, HPQCD hep-lat/0610104

Also inc. first estimates of m.e. needed for $\Delta\Gamma_s$

$\Delta\Gamma_s = 0.10(3) ps^{-1}$

Main error is from perturbative matching to continuum - work underway to improve this

Conclusions

- We now have lattice results in charm physics with accuracy (2%) similar to that for light hadrons
- D_s decay constant is the *only* result (from ~ 15 quantities) that disagrees with experiment.
- Further tests this year confirm confidence in the lattice calculation $\longrightarrow$ must take this seriously. Lattice tests will continue
- First full QCD results this year for $\xi = \frac{f_{B_s}\sqrt{B_{B_s}}}{f_B\sqrt{B_B}}$
- Errors in $f_{B_s}\sqrt{B_{B_s}}$ dominated by perturbative matching error at 10%.

Future:

D/Ds

- Need significantly improved experimental error on f_{Ds} - currently 3x lattice error.
- Further lattice calculations in other formalisms needed.
- Similarly accurate semileptonic form factors for D/Ds/K need to be calculated.

B/Bs

- Need improved statistical accuracy on ξ
- Need improved matching for B/Bs decay constants and 4-quark operators
- Further lattice calculations in other formalisms needed.
- Also more accurate semileptonic form factors ...

Error budget - HPQCD calculation

	f_K/f_π	f_K	f_π	f_{D_s}/f_D	f_{D_s}	f_D	Δ_s/Δ_d
r_1 uncerty.	0.3	1.1	1.4	0.4	1.0	1.4	0.7
a^2 extrap.	0.2	0.2	0.2	0.4	0.5	0.6	0.5
finite vol.	0.4	0.4	0.8	0.3	0.1	0.3	0.1
$m_{u/d}$ extrap.	0.2	0.3	0.4	0.2	0.3	0.4	0.2
stat. errors	0.2	0.4	0.5	0.5	0.6	0.7	0.6
m_s evoln.	0.1	0.1	0.1	0.3	0.3	0.3	0.5
m_d, QED etc	0.0	0.0	0.0	0.1	0.0	0.1	0.5
Total %	0.6	1.3	1.7	0.9	1.3	1.8	1.2

E.Follana et al,
HPQCD
0706.1726[hep-lat]