Lattice QCD 2007

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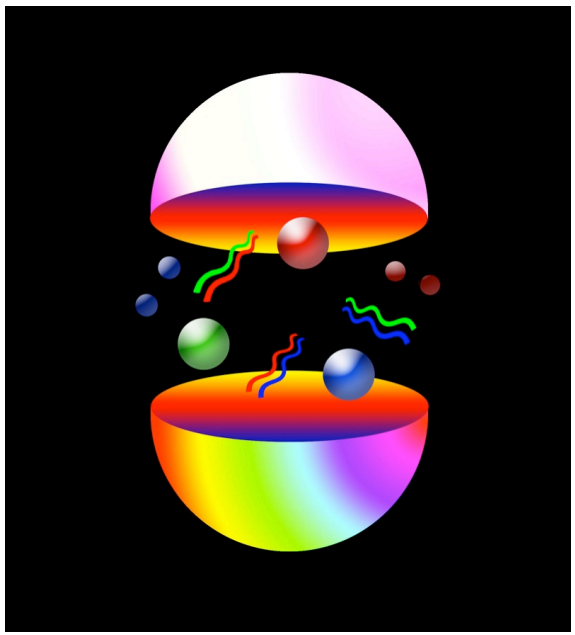
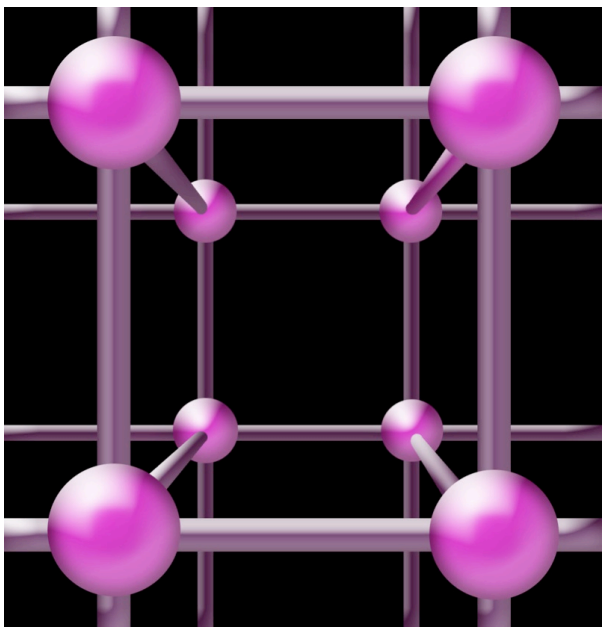
HPQCD collaboration

Lepton-photon 2007
Daegu, Korea

QCD is key part of SM but quark confinement tricky





Lattice QCD enables calcn of QCD effects "from first principles". Done by numerical evaln of Path Integral in a 4-d vol. of space-time defined as a lattice

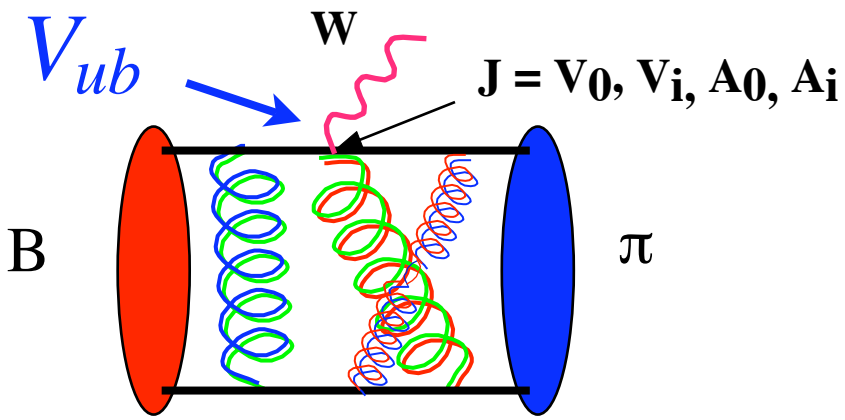
$$\int dA_\mu e^{-L_{QCD}} O(A_\mu)$$

RECIPE

- Generate sets of gluon fields that contribute most to the PI
- Calculate averaged "hadron correlators" on these and fit to obtain masses and simple matrix elements
- Fix m_q and determine a to get physical results

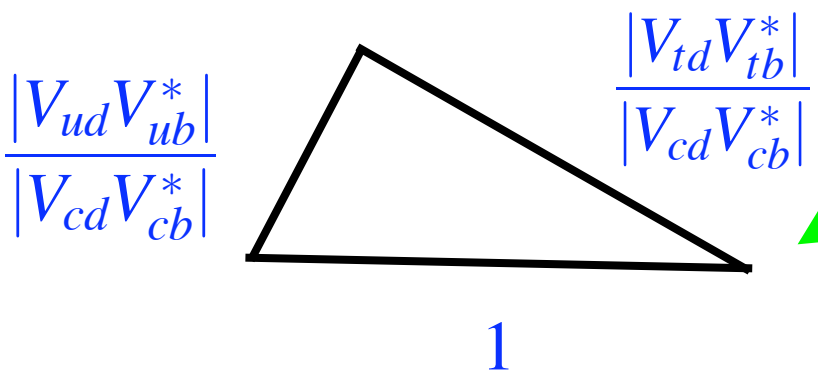
Where can lattice QCD have most immediate impact?

Precision calculations of electroweak decay rates for gold-plated hadrons → CKM physics



expt=(CKM)x(lattice calc.)

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



Unitarity triangle - test this!

I will concentrate on results relevant to this programme...

Why is lattice QCD so hard?

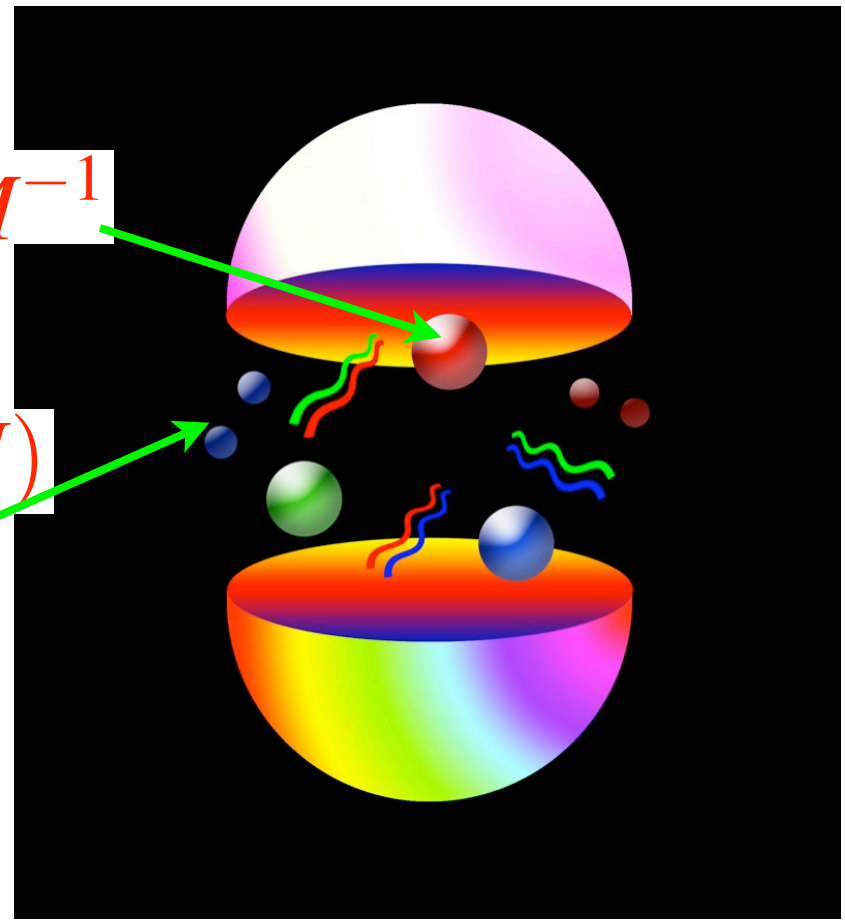
Handling light u,d, s quarks is a big headache

$$L_{q,QCD} = \overline{\psi}(\gamma \cdot D + m)\psi \equiv \overline{\psi} M \psi$$

Quarks must be 'integrated out'
by inverting Dirac matrix M

valence quarks, calculate M^{-1}

sea quarks, include $det(M)$
in importance sampling
gluons



Cost inc. as $m_q \to 0$
and also as $a \to 0 \quad L \to \infty$

The story so far ....

Early days (before 2000) - u, d, s sea quarks omitted or inc. with u/d masses 10-20x too big. (Quenched approx.)
Systematic errors 10-20 % and theory not self-consistent

Now (since 2000) - possible to inc. u/d sea quarks with masses only 3-5x too large and extrapolate to real world.
Improved staggered quark formalism first to do this since numerically very fast.

2007 - improved staggered calculations have matured.
Results using other formalisms now appearing

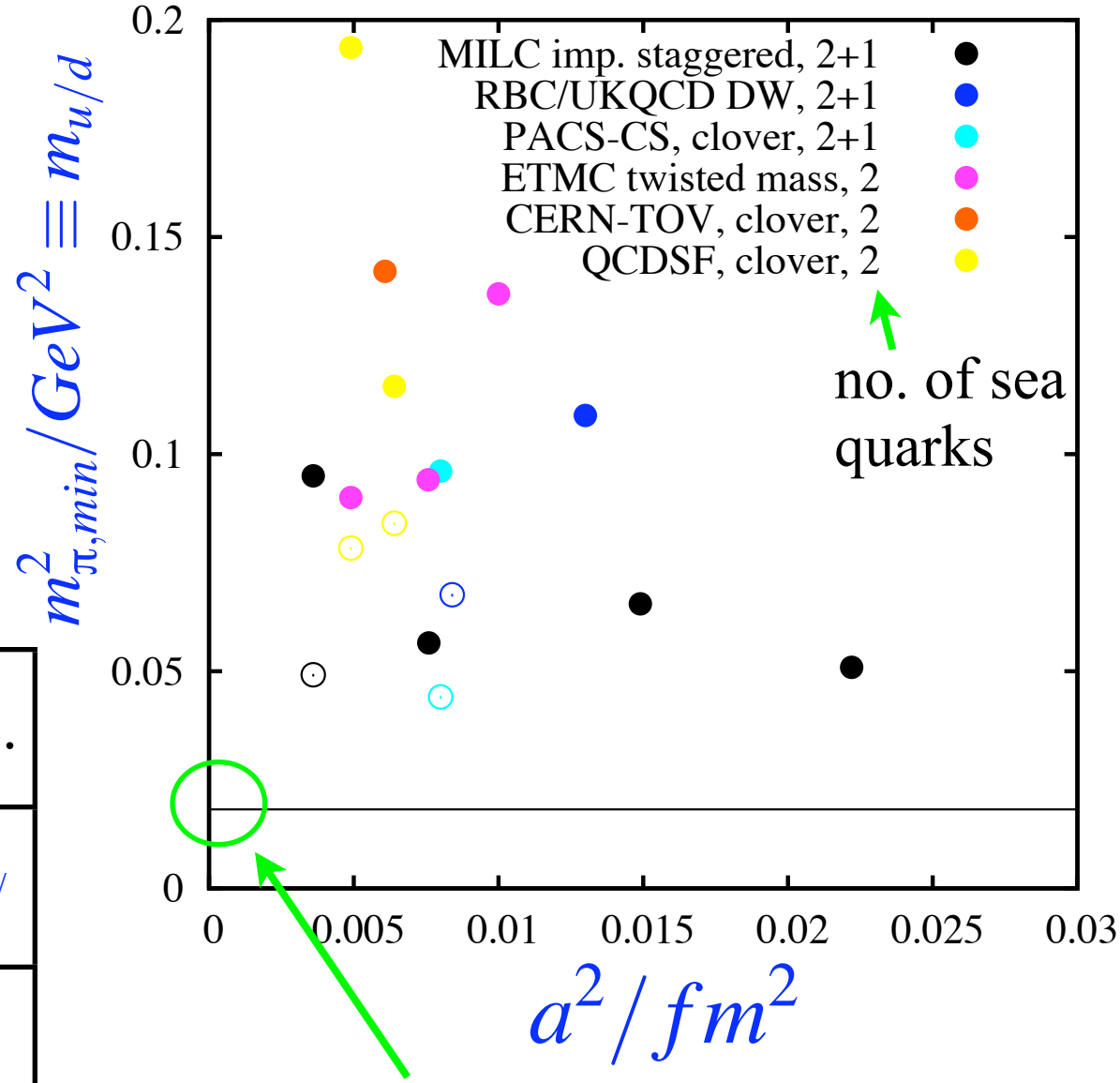
Future - looks good. Lots of analysis to be done ....

see http://www.physik.uni-regensburg.de/lat07/

Status of configs 2007

Choice of light quark formalism - issues are speed, disc. errors, chiral symmetry + technical issues. Can also mix e.g. dw valence on stagg. sea

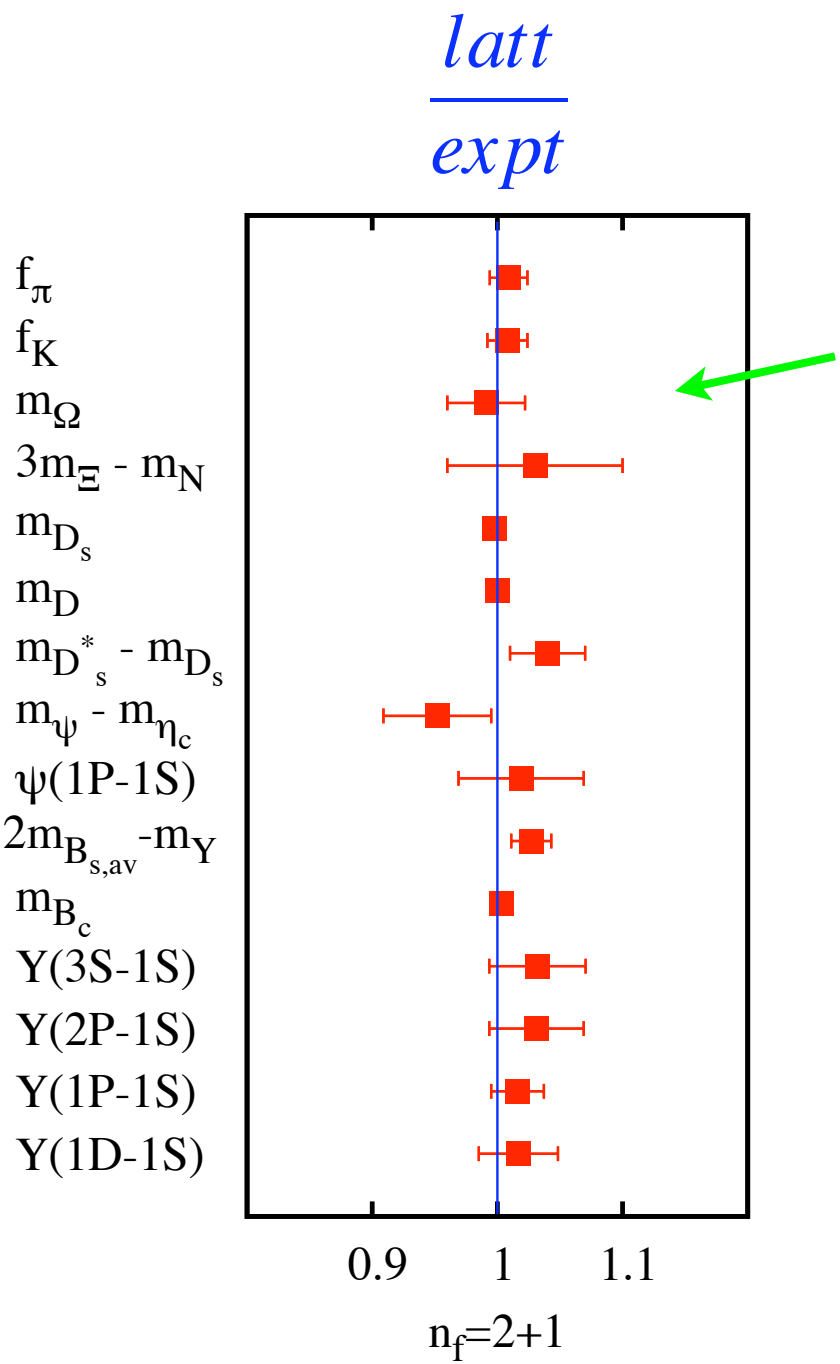
	speed	chiral symm.	collab.
imp.stagg. (asqtad)	fast	OK	MILC/ HPQCD/ FNAL
domain wall	slow	good	RBC/ UKQCD
clover	fast	bad	PACS-CS QCDSF CERN-TOV
twisted mass	fast	OK	ETMC



Extrapolate to physical point. Also need large L and good statistics.

See Boyle, Urbach, Kuramashi, LAT07

2007 results



Essential to check how lattice QCD is doing vs well-known gold-plated experimental quantities

Update of 2003 results using imp. stagg sea quarks.
Fix QCD params from
$\Upsilon(2S-1S), m_\pi, m_K, m_{\eta_c}, m_\Upsilon$

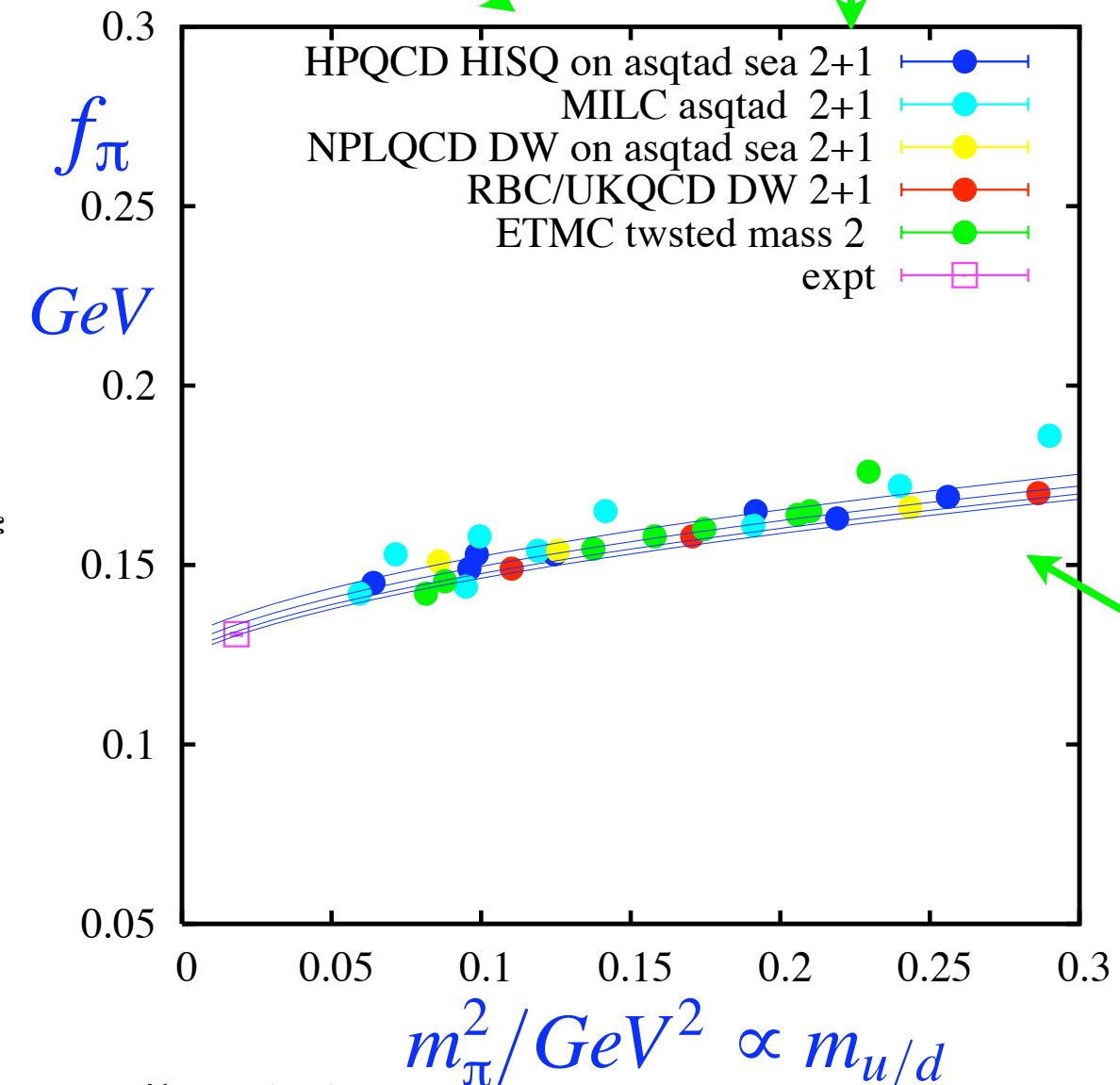
QA is dead!

New (HPQCD): Highly improved staggered quarks (HISQ) - improves disc. errors further over asqtad. Allows use for c quarks.

Can compare results from different formalisms away from physical point if accurate enough.

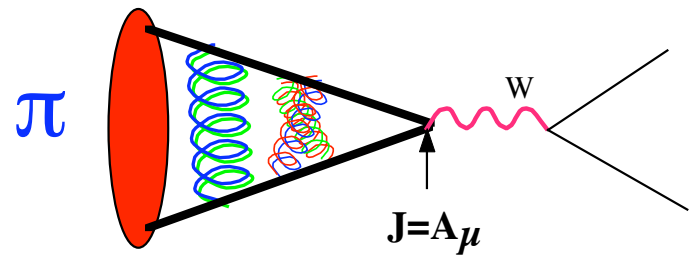
quark formalisms with good chiral symmetry

no. of sea quarks



Fitted lines from HISQ HPQCD 0706.1726[hep-lat]

π leptonic decay



$$Br(\pi \rightarrow \mu\nu) \propto V_{ud}^2 f_\pi^2$$

Need multiple a and $m_{u/d}$ for chiral and contnm extrapoln for final result.

Need large volumes for accuracy - test vol. effects vs. chiral pert. th. (MILC, ETMC, QCDSF, RBC)

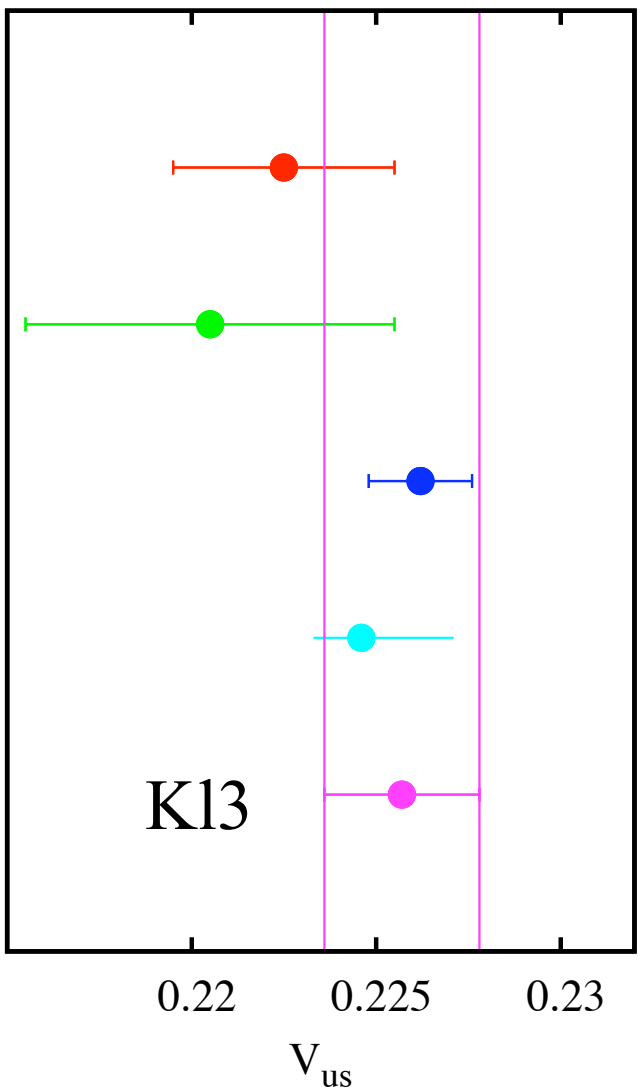
McNeile, LAT07

Kaon physics (Kl2) and V_{us}

$$\frac{\Gamma(K \to \mu\nu)}{\Gamma(\pi \to \mu\nu)} \to \frac{V_{us}^2 f_K^2}{V_{ud}^2 f_\pi^2}$$

2007 results for calcs with u, d, s sea quarks

V_{us} competitive w. PDG



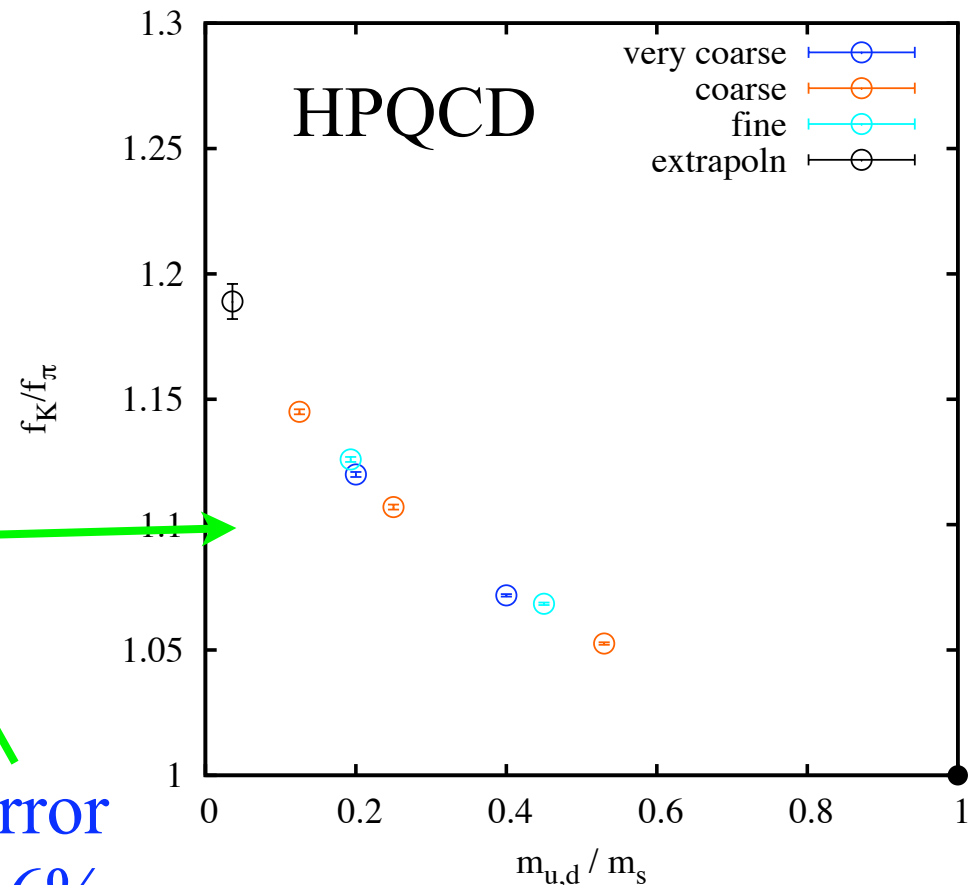
RBC/UKQCD dw

PACS-CS clover

HPQCD HISQ on asqtad sea

MILC asqtad

PDG 2006

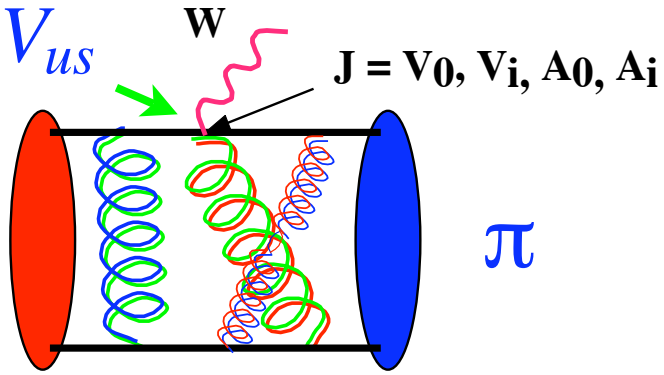


Error 0.6%

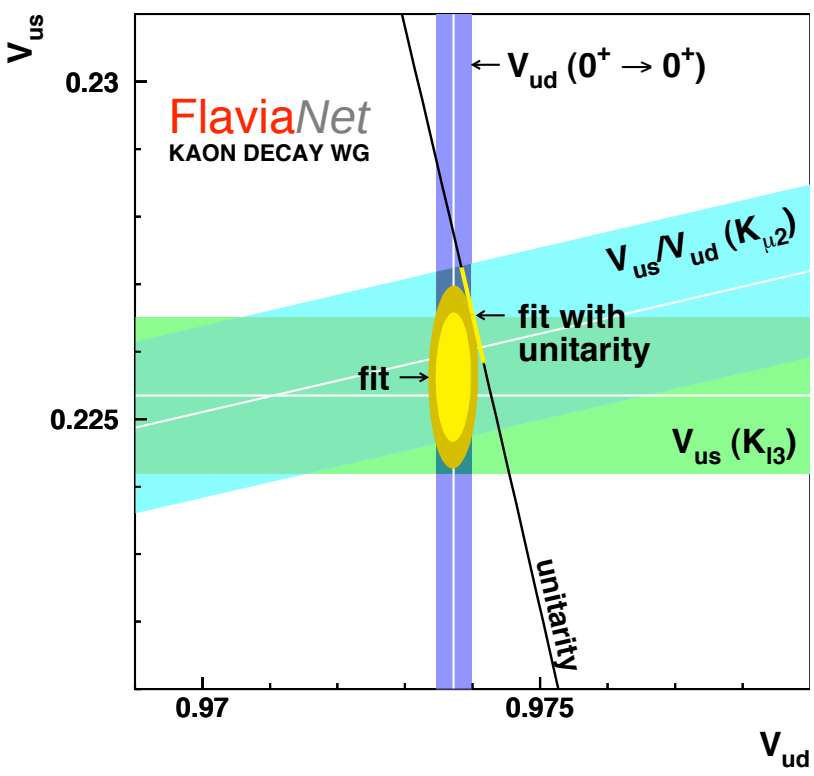
see Jüttner, LAT07

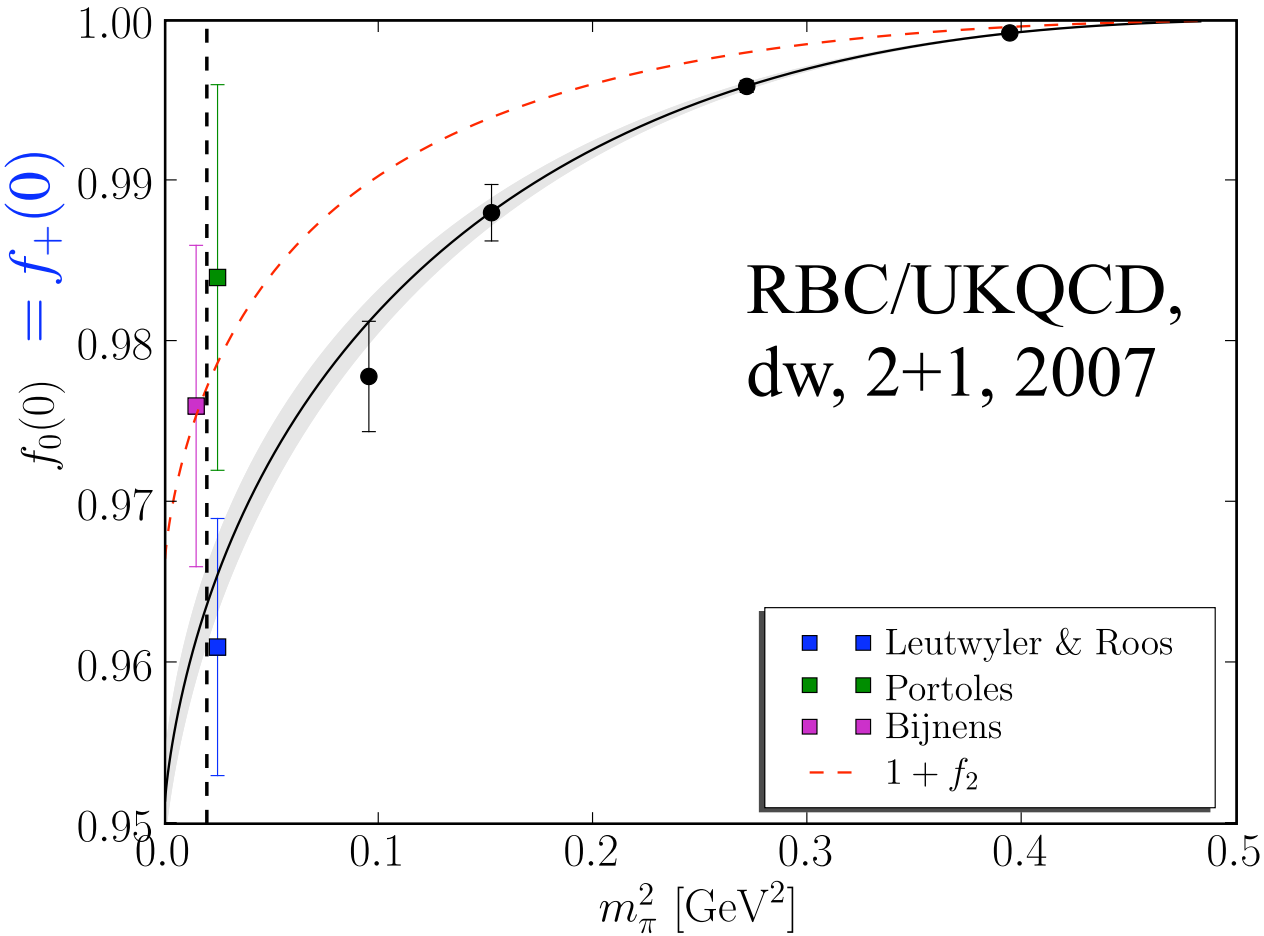
HPQCD: 0706.1726[hep-lat] , error budget

K semileptonic decay (Kl3) and V_{us}



$$|V_{us} f_+^{K\pi}(0)| = 0.21673(46)$$



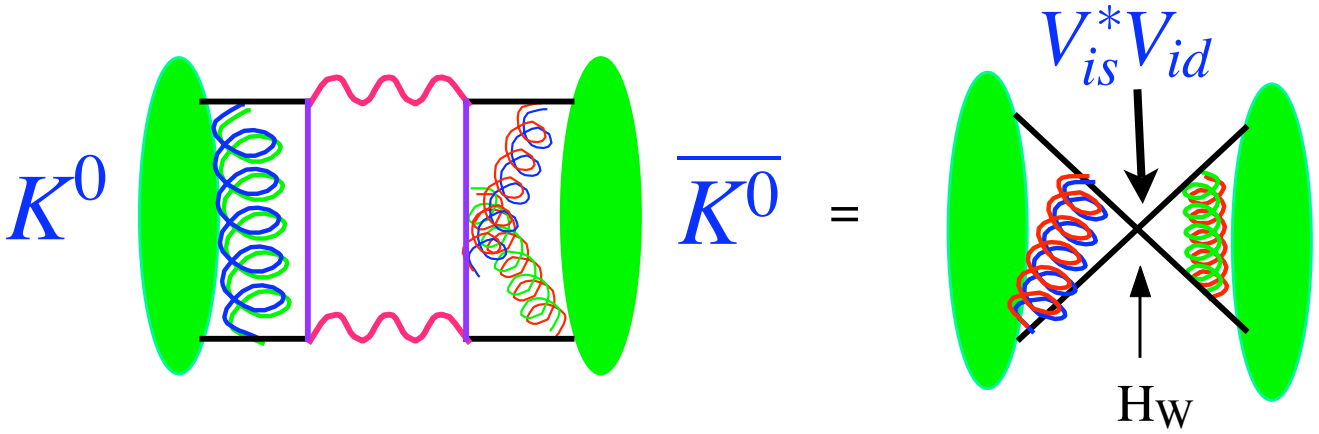


Extrapoln gives $f_+(0) = 0.9609(51)$

$$V_{us} = 0.2257(15)$$

Lattice error 0.5%, need to check disc. errors + other calcs. See Jüttner, LAT07

K^0 mixing and CKM constraint



Mixing through box gives indirect CP violn - measure

$$\varepsilon = \frac{K_L \to \pi\pi}{K_s \to \pi\pi}$$

Calculate box in lattice QCD - needs good chiral symmetry

$\propto f_K^2 B_K \longrightarrow$ from ε and B_K get constraint on UT

2007 result - RBC/UKQCD dw 2+1

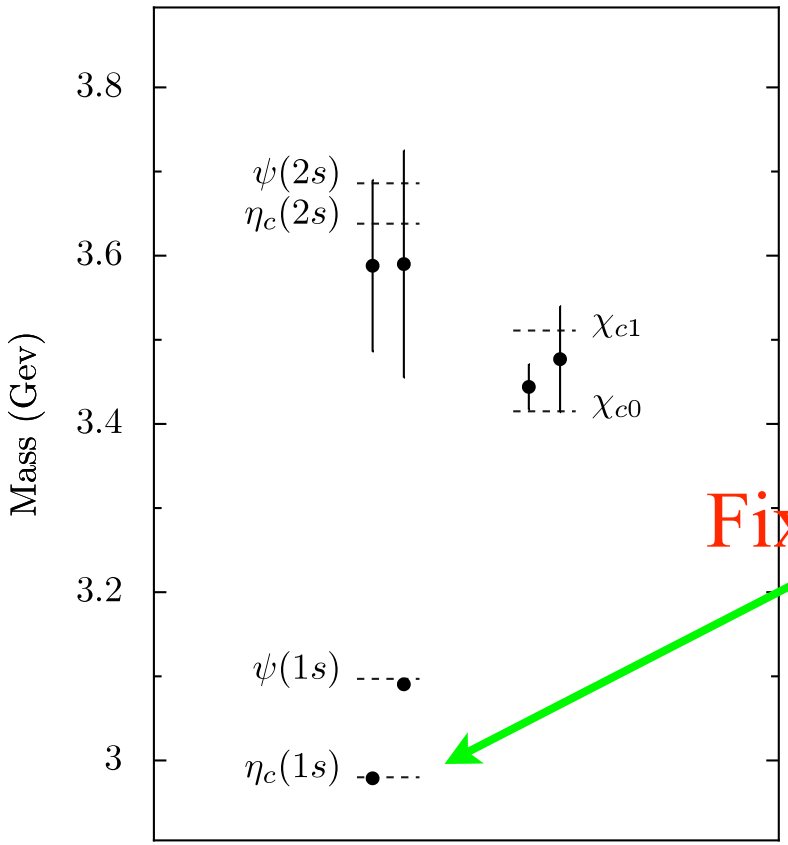
$$B_K^{\overline{MS}}(2GeV) = 0.557(12)(29)(+0-28)$$

hep-ph/0702042 on 16^3, one a

Boyle LAT07, bigger volume, 24^3, result is lower

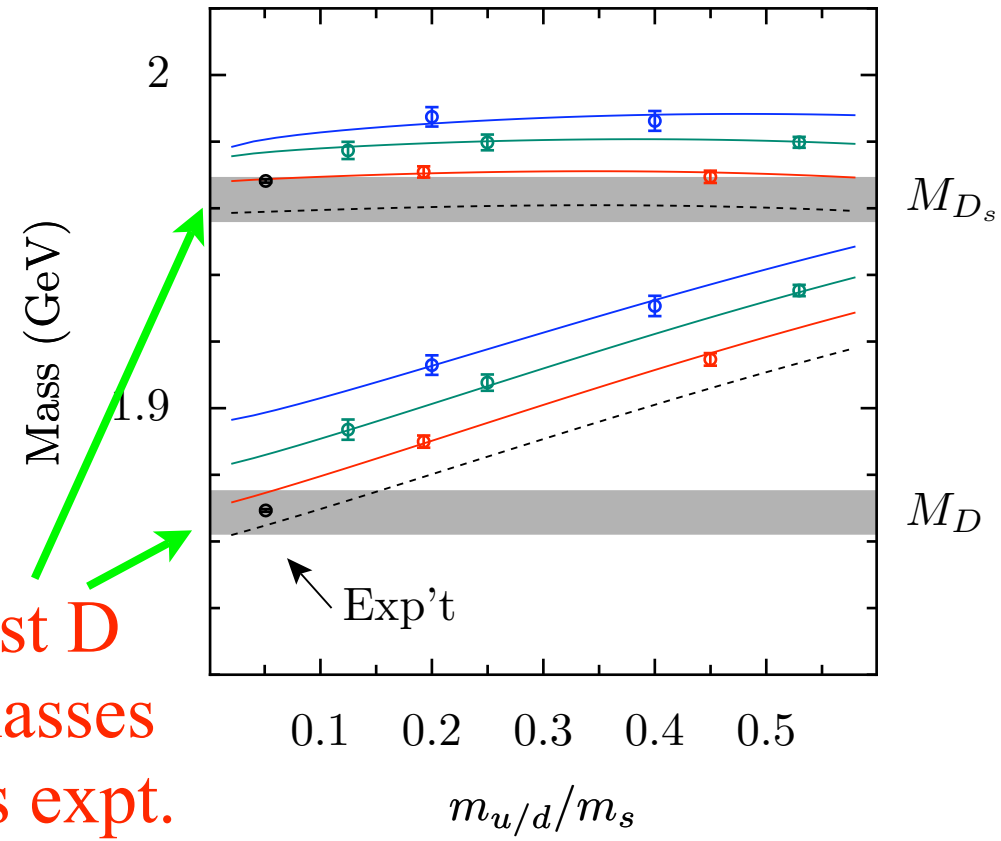
See also Van der Water, LAT07, dw on asqtad sea, 2 a values, big volumes, result shortly ...

Charm physics, new method, 2007 HPQCD



Fix m_c

test D masses vs expt.

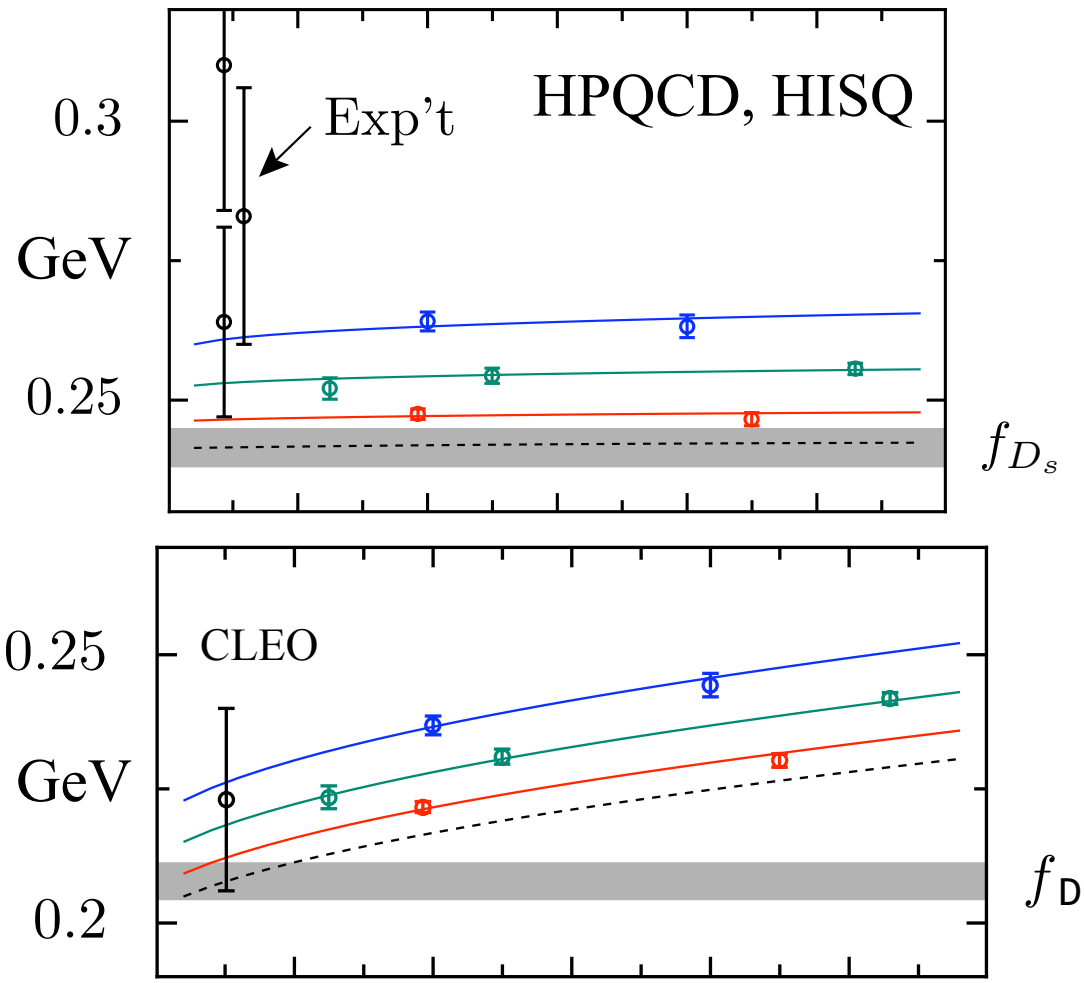


Key issue is discretisation errors, because $m_c a \sim 0.5$

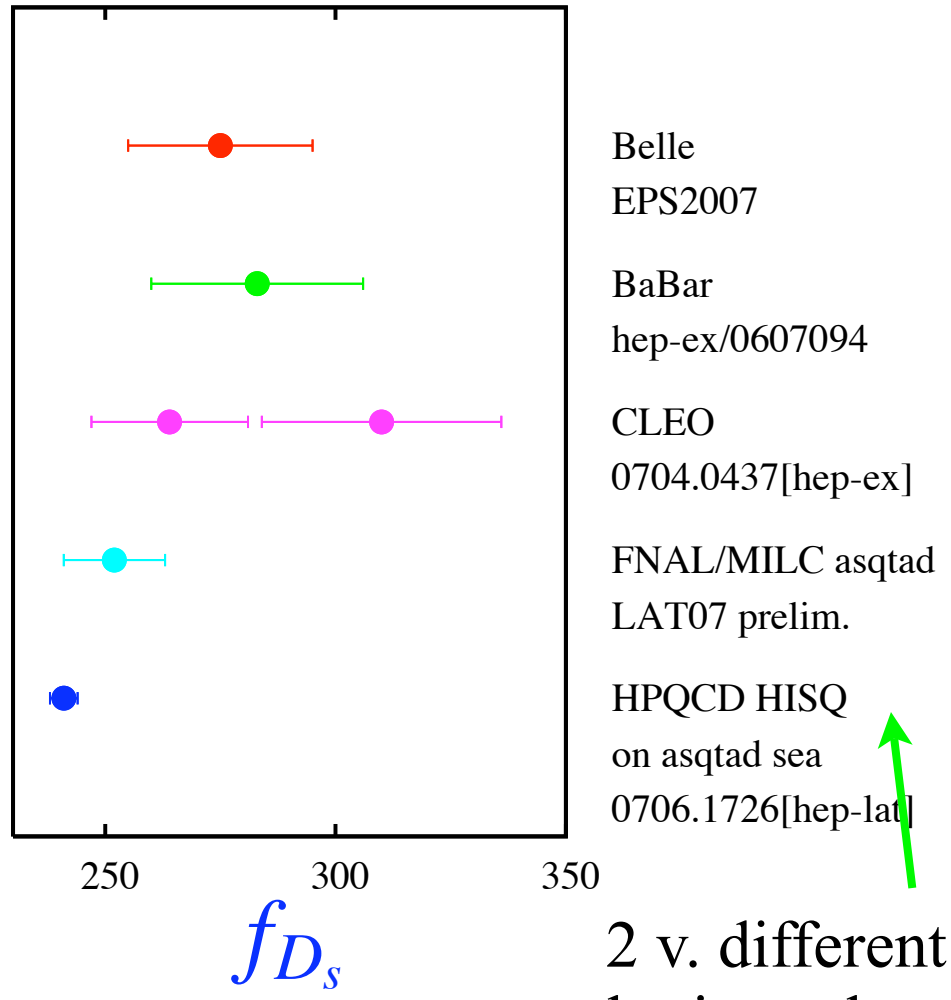
HISQ - much improved control of disc. errors
can use for charmonium and D - more tests of lattice QCD possible. Same action as for u,d,s.

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

2007 New Results for D, D_s decay constants, $D_x \longrightarrow l\nu$ for comparison to experiment



Lattice inc u,d,s sea vs expt

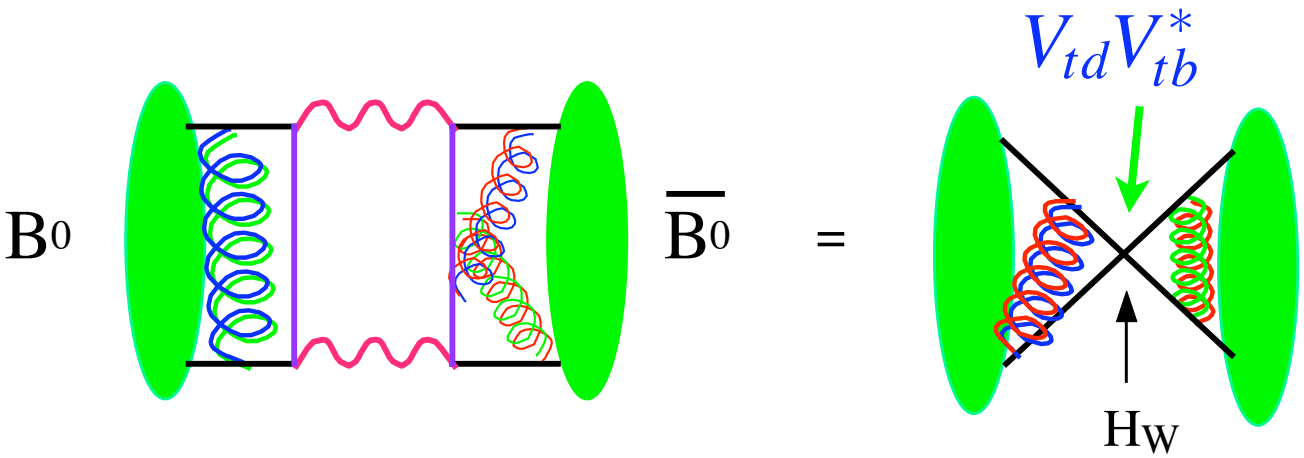


2 v. different lattice calcs

Next two years: more lattice results and improved semileptonic form factors also ...

- expt uses Vcs = Vud
- error will improve to few % in 2 yrs
- not all em corrns calculated ..

b physics - B^0 mixing and CKM constraint



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

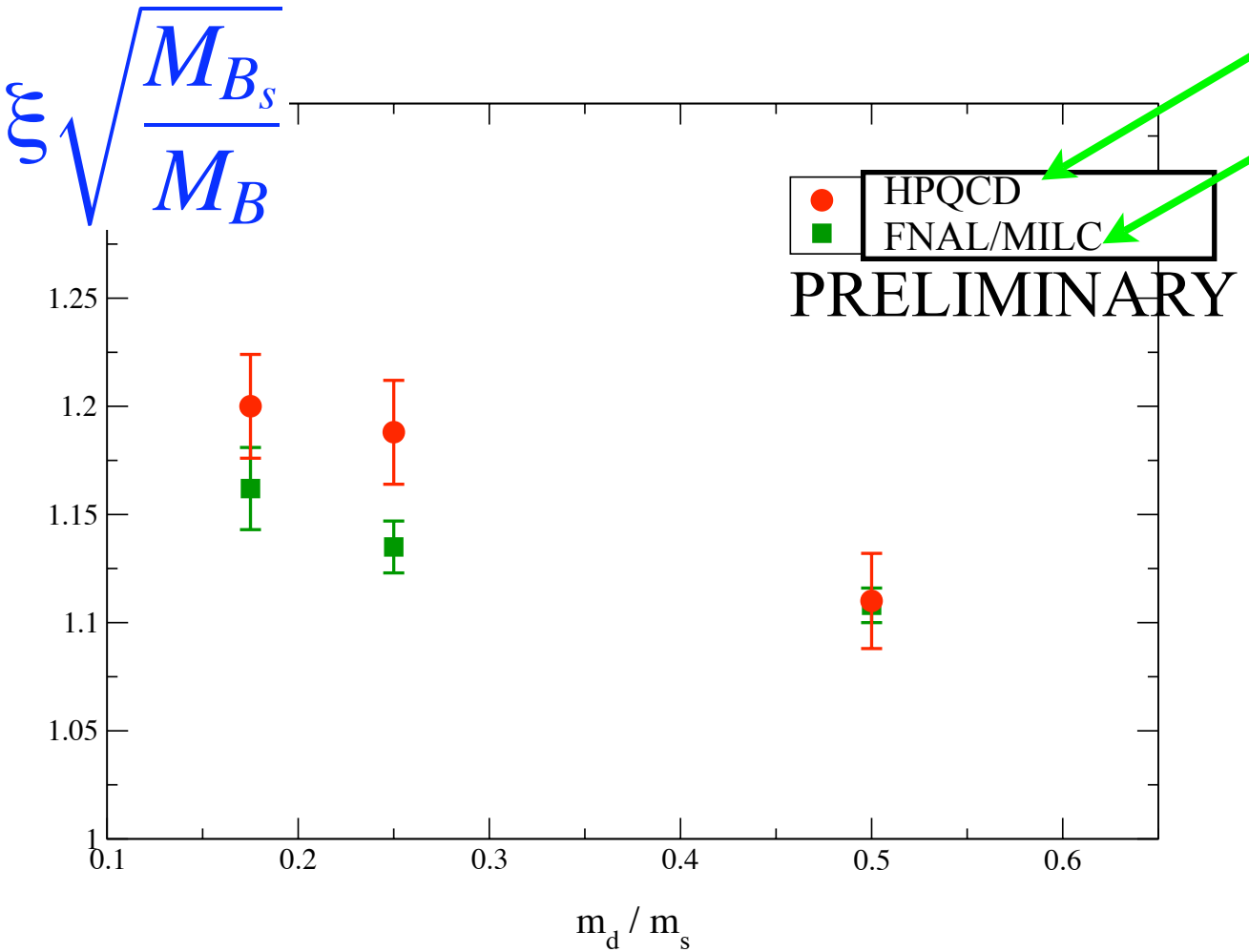
$$\Delta M_x = \frac{G_F^2 M_W^2}{6\pi^2} |V_{tx}^* V_{tb}|^2 \eta_2^B S_0(x_t) M_{B_x} f_{B_x}^2 \hat{B}_{B_x}$$

Take exptl ratio from oscillation rates for B_s and B_d

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

calculate in lattice QCD, renormln cancels

2007 New results for $\xi = \dfrac{f_{B_s}\sqrt{B_{B_s}}}{f_B\sqrt{B_B}}$ inc. u, d, s sea quarks



NRQCD for b

FNAL for b

HPQCD
hep-lat/0610104

$f_{B_s}\sqrt{\hat{B}_{B_s}} = 0.281(21)GeV$

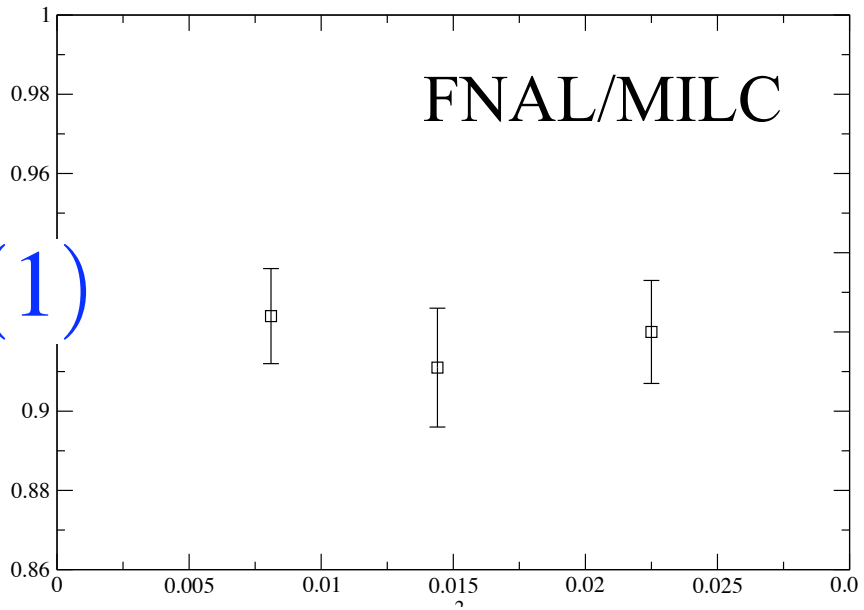
one value of a so far, main error is renormln of lattice 4-q operator

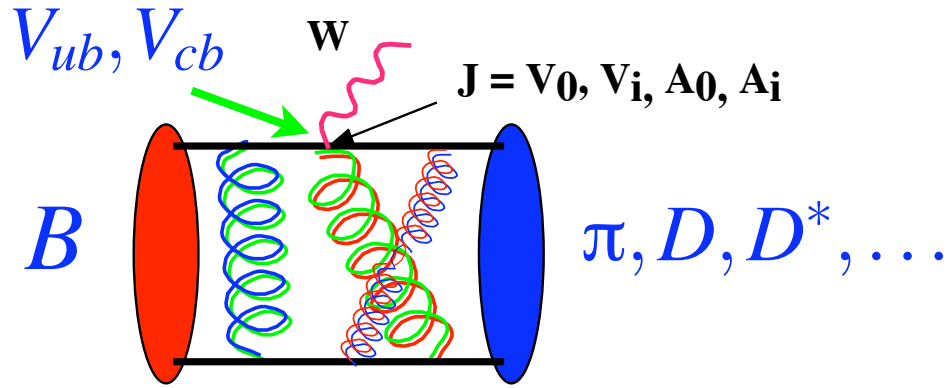
Can compare to easier lattice calc. of f_{B_s}/f_B

HPQCD, hep-lat/0507015 1.20(3)
FNAL/MILC, Simone, LAT07 1.26(4)

Gamiz, LAT07

B excl. semileptonic decay and CKM constraint





$B \to D^* l \nu$ Laiho, LAT07

rate at zero recoil

$\propto |V_{cb} F(1)|^2$

FNAL/MILC with u, d, s sea quarks, 3 values of a

$F(1) = 0.930(12)(19)$ —HFAG→ $V_{cb} = 38.7(0.7)(0.9) \times 10^{-3}$

stat syst expt latt

$B \to \pi l \nu$ Flynn+Nieves 0705.3553[hep-ph] combine lattice (HPQCD, FNAL/MILC) with LCSR, get

$V_{ub} = 3.47(29) \times 10^{-3}$

work underway to extend lattice results

Use lattice results with u, d, s sea quarks + experiment for constraints on unitarity triangle.

Lattice inputs (2+1 sea quarks):

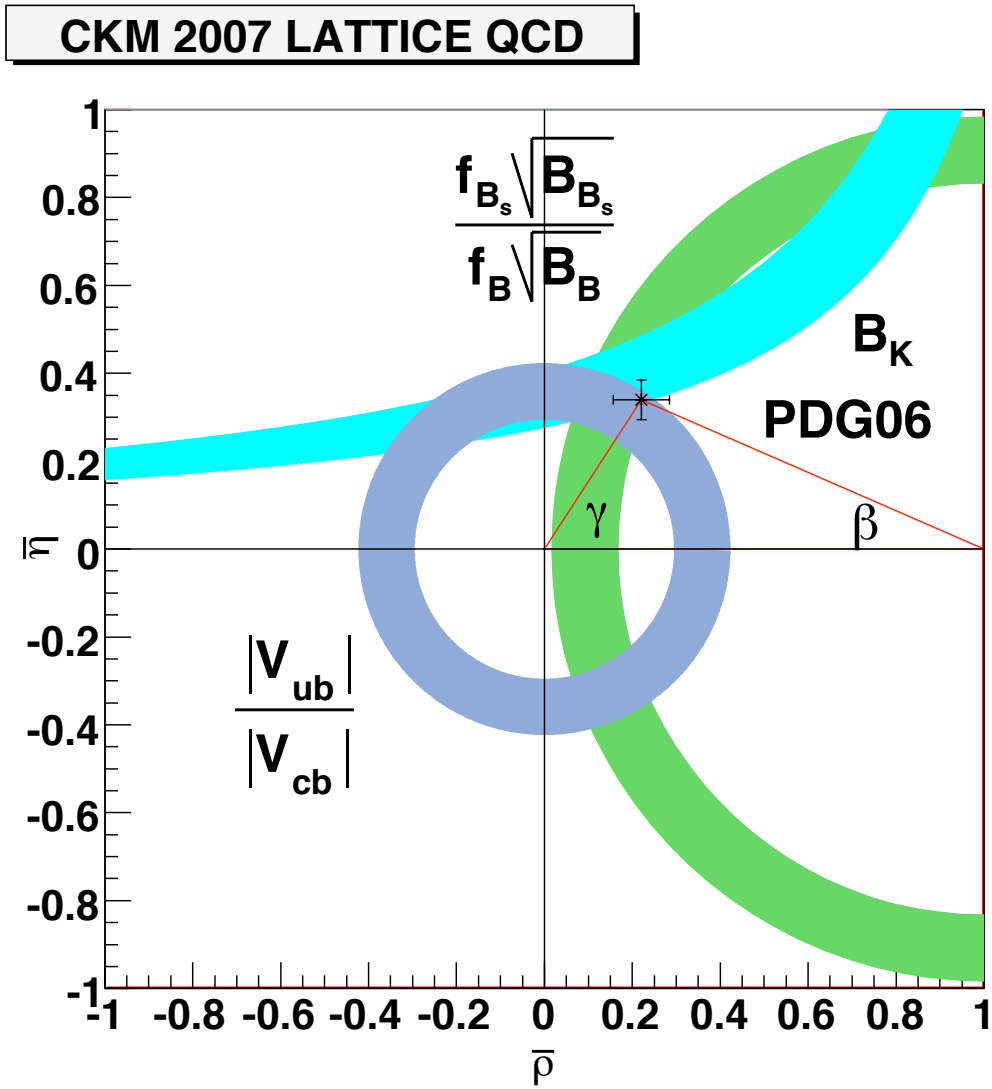
B_K

f_K/f_π , $f_+(K \to \pi l \nu)$

$F(B \to D^* l \nu)$

$f_+(B \to \pi l \nu)$

$\dfrac{f_{B_s}\sqrt{B_{B_s}}}{f_B\sqrt{B_B}}$



Errors on lattice results should halve over next two years

To others using lattice results: QA is dead!

Conclusions

• Lattice calculations inc. sea quarks are in excellent shape. Calcs. with staggered quarks continue to improve and good results appearing now from other quark formalisms.

• Significant new results this year in s and c physics

• I have not mentioned hadron structure, harder meson and baryon spectrum calcs, phase structure at finite temp. etc etc. - see LAT07 website

Future:

In next two years, errors on CKM constraints should halve. More checks will be done against other gold-plated decays.

Thanks to:

Claude Bernard, Peter Boyle, Elvira Gamiz, Andreas Jüttner, Jack Laiho, Peter Lepage, Craig McNeile, Matthew Moulson, Gerrit Schierholz, Junko Shigemitsu, Jim Simone, Doug Toussaint, Carsten Urbach, Ruth van der Water, Kit Wong

and

Conference organisers here in Korea