

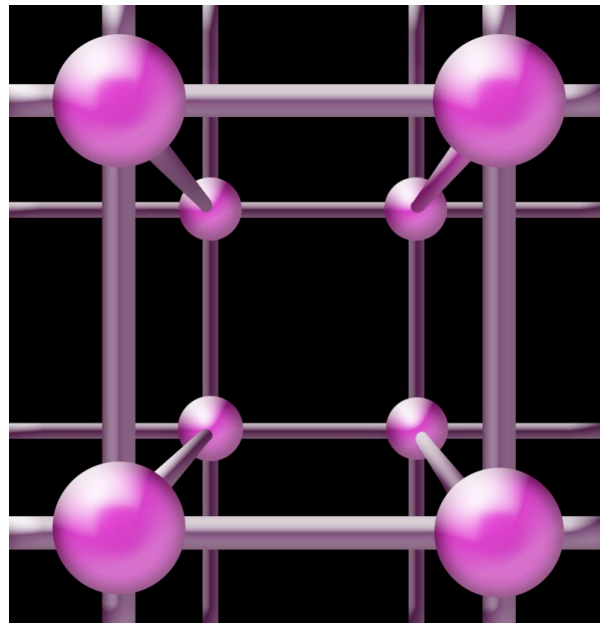
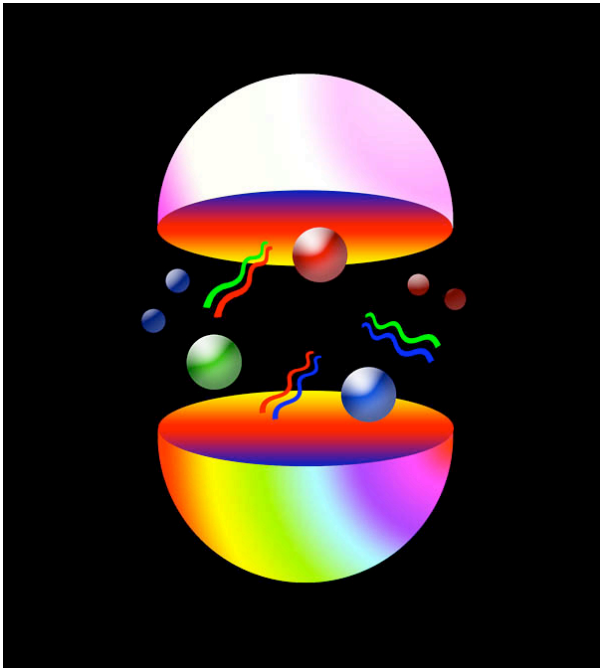


Lattice QCD status and prospects

Christine Davies
University of Glasgow,
HPQCD collaboration

Hadrons 2007
Frascati, Italy

QCD is key part of SM but quark confinement tricky



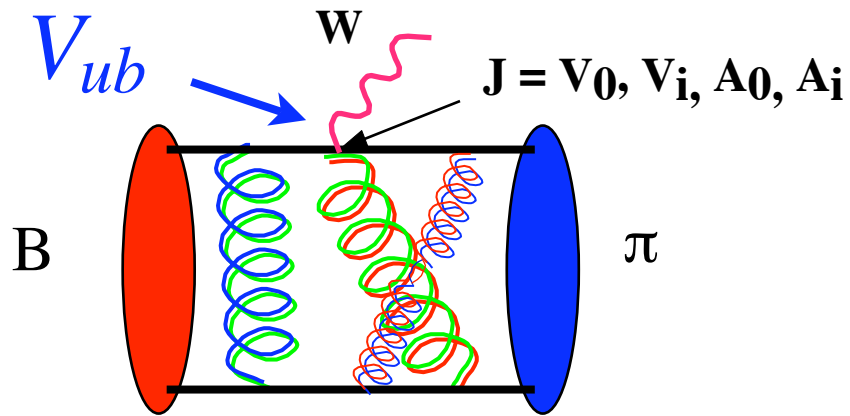
Lattice QCD enables calcn of QCD effects “from first principles”. Done by numerical evaln of Path Integral in a 4-d vol. of space-time defined as a lattice

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

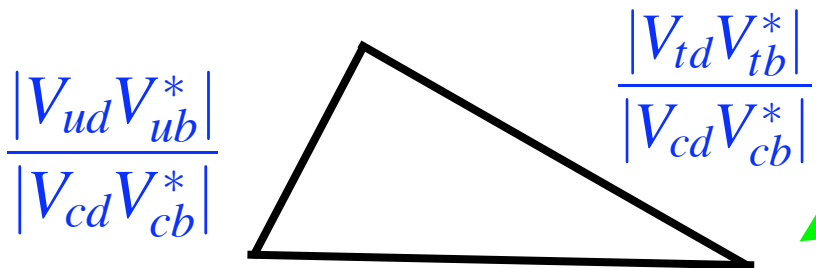
RECIPE

- 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 \longrightarrow flavor physics and CKM elements



expt=(CKM)x(lattice calc.)



1

$$\left(\begin{array}{ccc} V_{ud} & V_{us} & V_{ub} \\ \pi \rightarrow l\nu & K \rightarrow l\nu & B \rightarrow \pi l\nu \\ & K \rightarrow \pi l\nu & \\ V_{cd} & V_{cs} & V_{cb} \\ D \rightarrow l\nu & D_s \rightarrow l\nu & B \rightarrow D l\nu \\ D \rightarrow \pi l\nu & D \rightarrow K l\nu & \\ V_{td} & V_{ts} & V_{tb} \\ \langle B_d | \bar{B}_d \rangle & \langle B_s | \bar{B}_s \rangle & \end{array} \right)$$

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

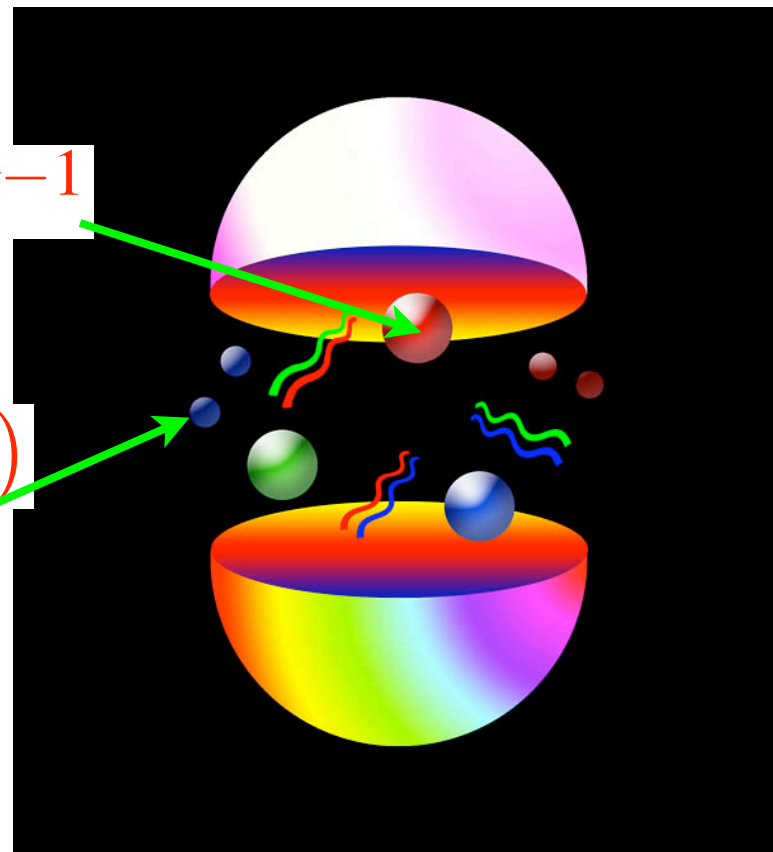
$$L_{q,QCD} = \bar{\Psi}(\gamma \cdot D + m)\Psi \equiv \bar{\Psi}M\Psi$$

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 $m_q \rightarrow 0$
and also as $a \rightarrow 0 \quad L \rightarrow \infty$



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

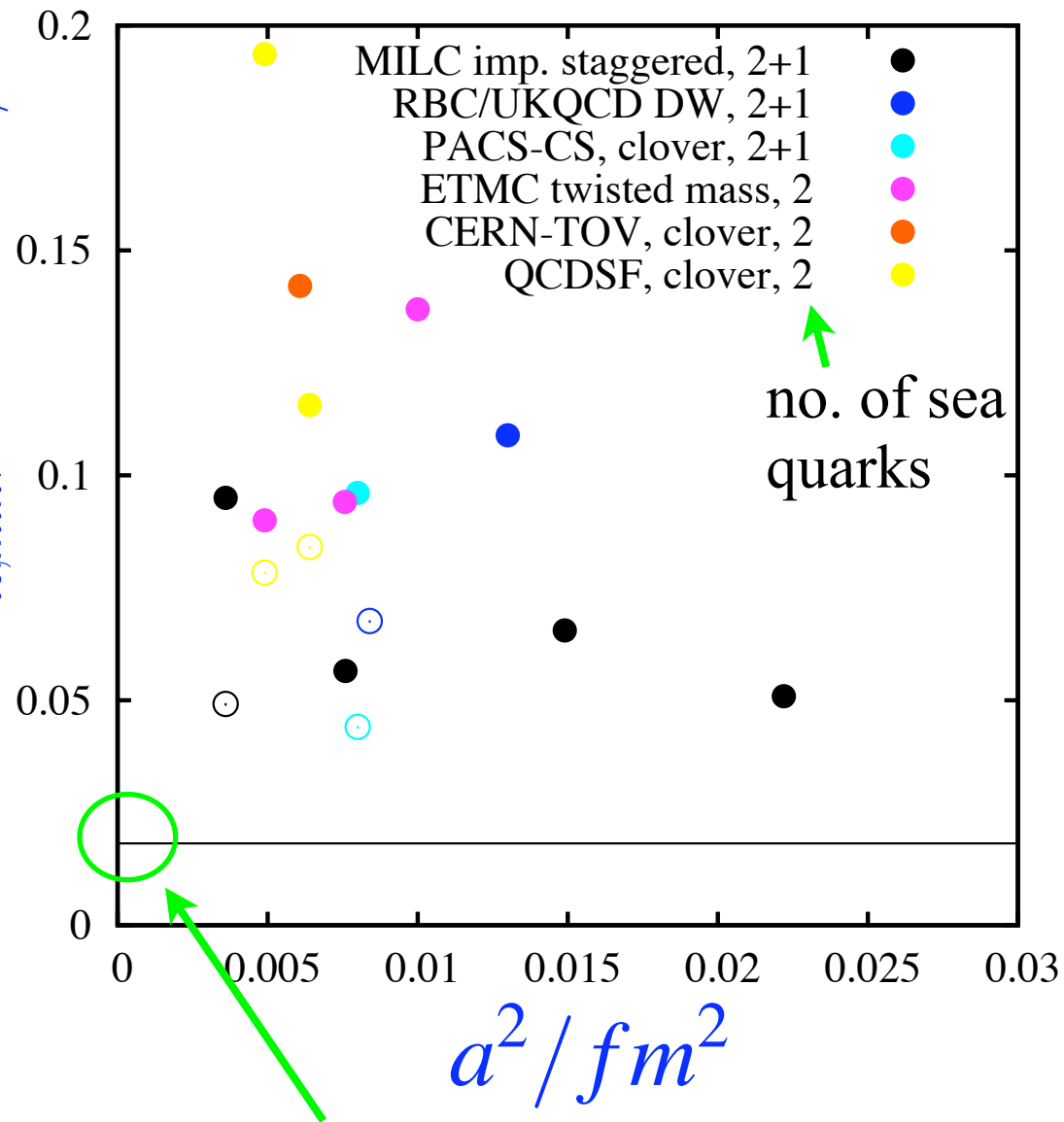
see <http://www.physik.uni-regensburg.de/lat07/>

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

$$m_{\pi,min}^2 / \text{GeV}^2 \equiv m_u/d$$

	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

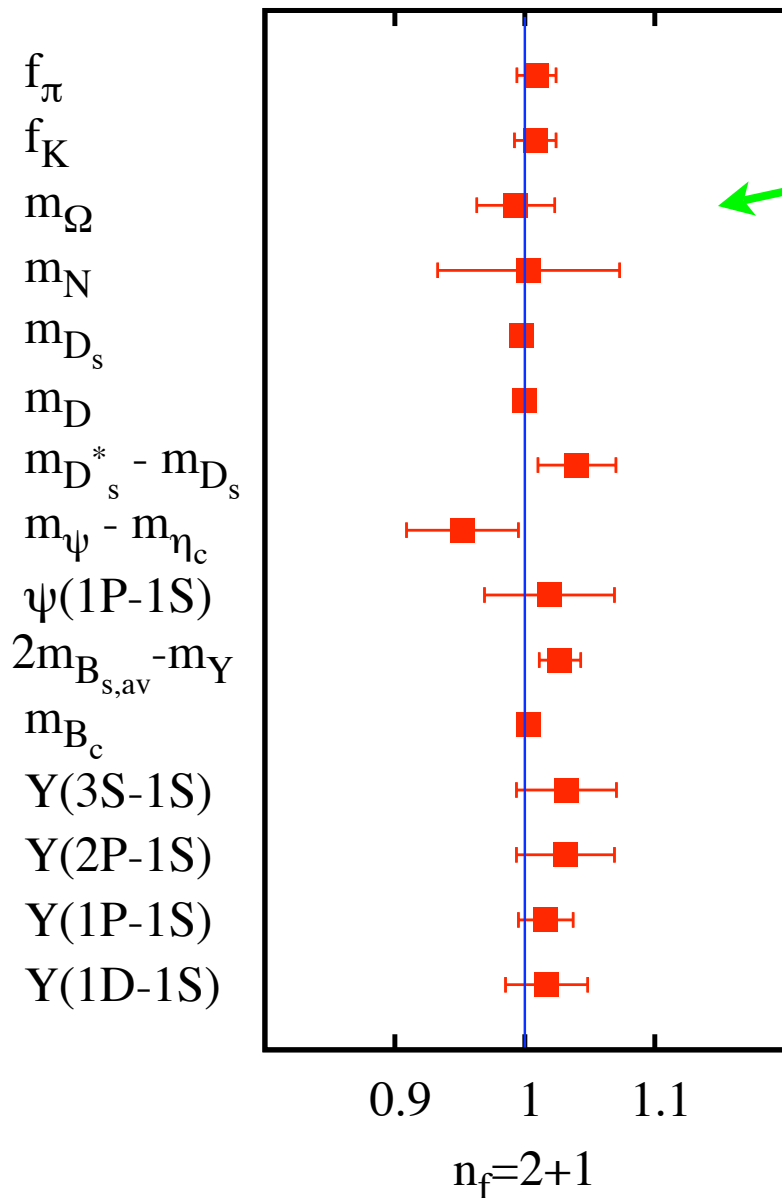


Extrapolate to physical point.
Also need large L and good statistics.

See Boyle, Urbach, Kuramashi, LAT07

2007 results

$\frac{latt}{expt}$



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

Update of 2003 results using imp. stag sea quarks.

Fix QCD params from

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

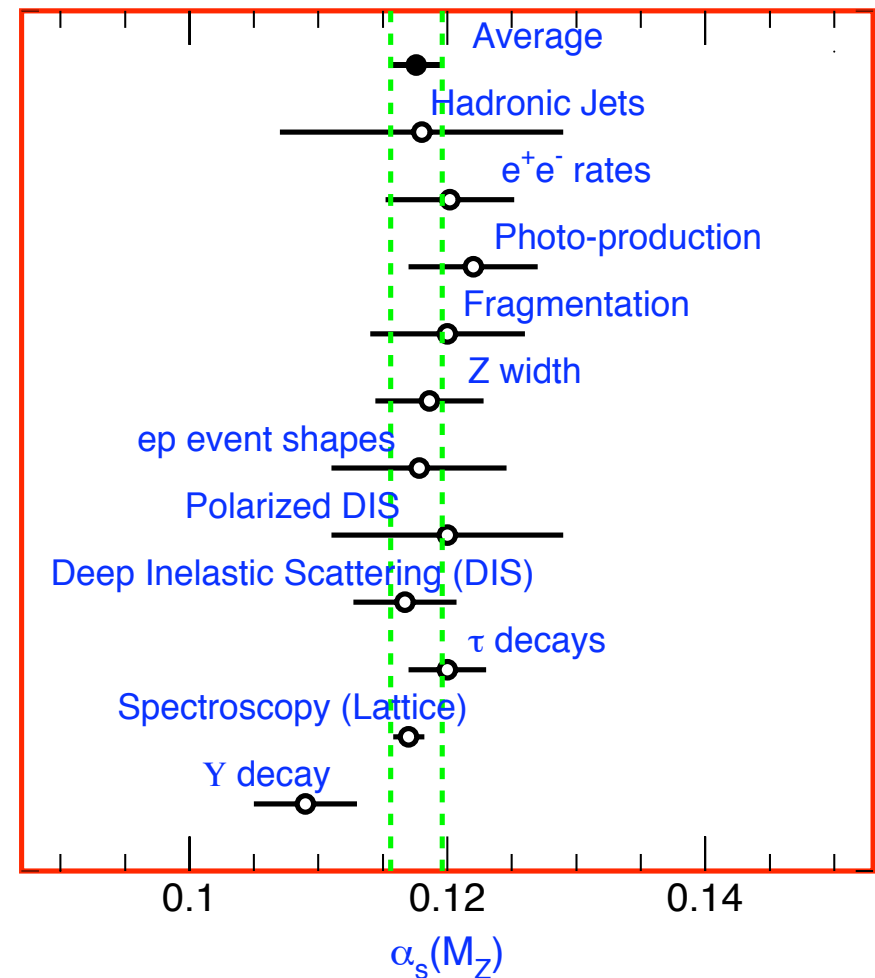
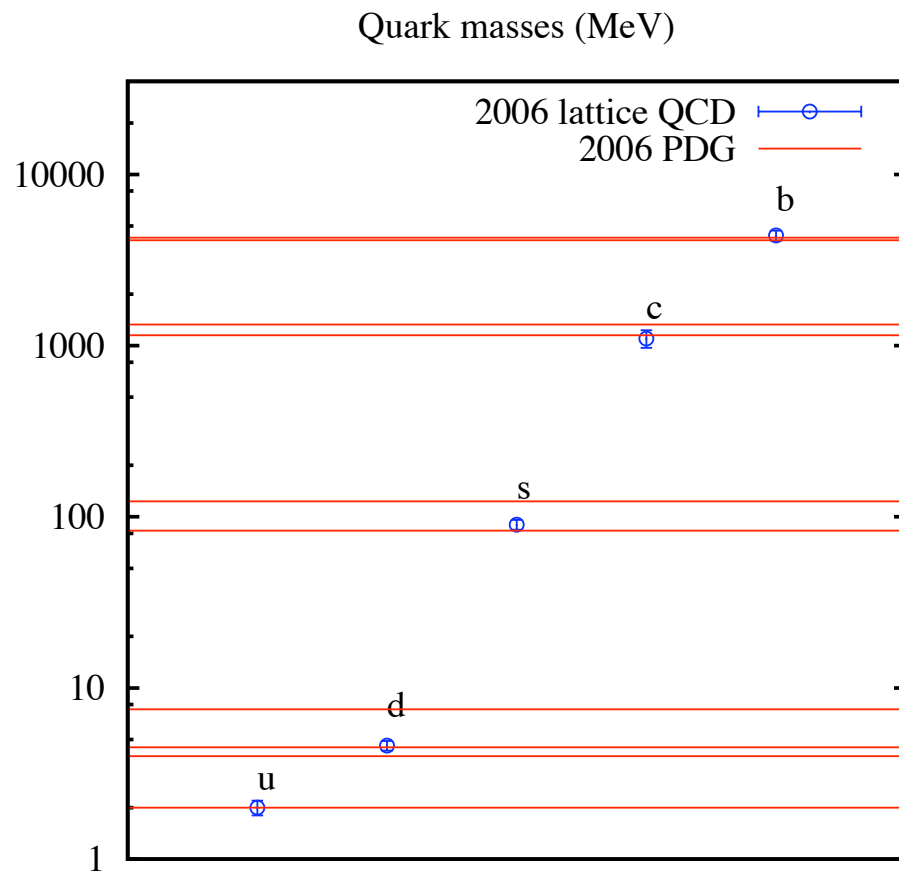
QA is dead!

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

- Parameters of QCD are well-determined from lattice, again with imp. stag sea quarks.

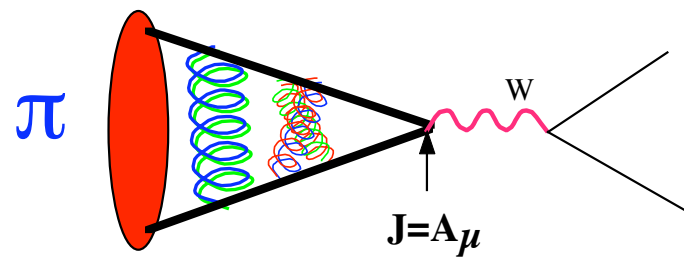
$$\alpha_s \sim 1\%$$

$m_q \sim \text{few } \% , \text{ u,d,s, } 10\% \text{ for c,b - improvement shortly}$



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

π leptonic decay

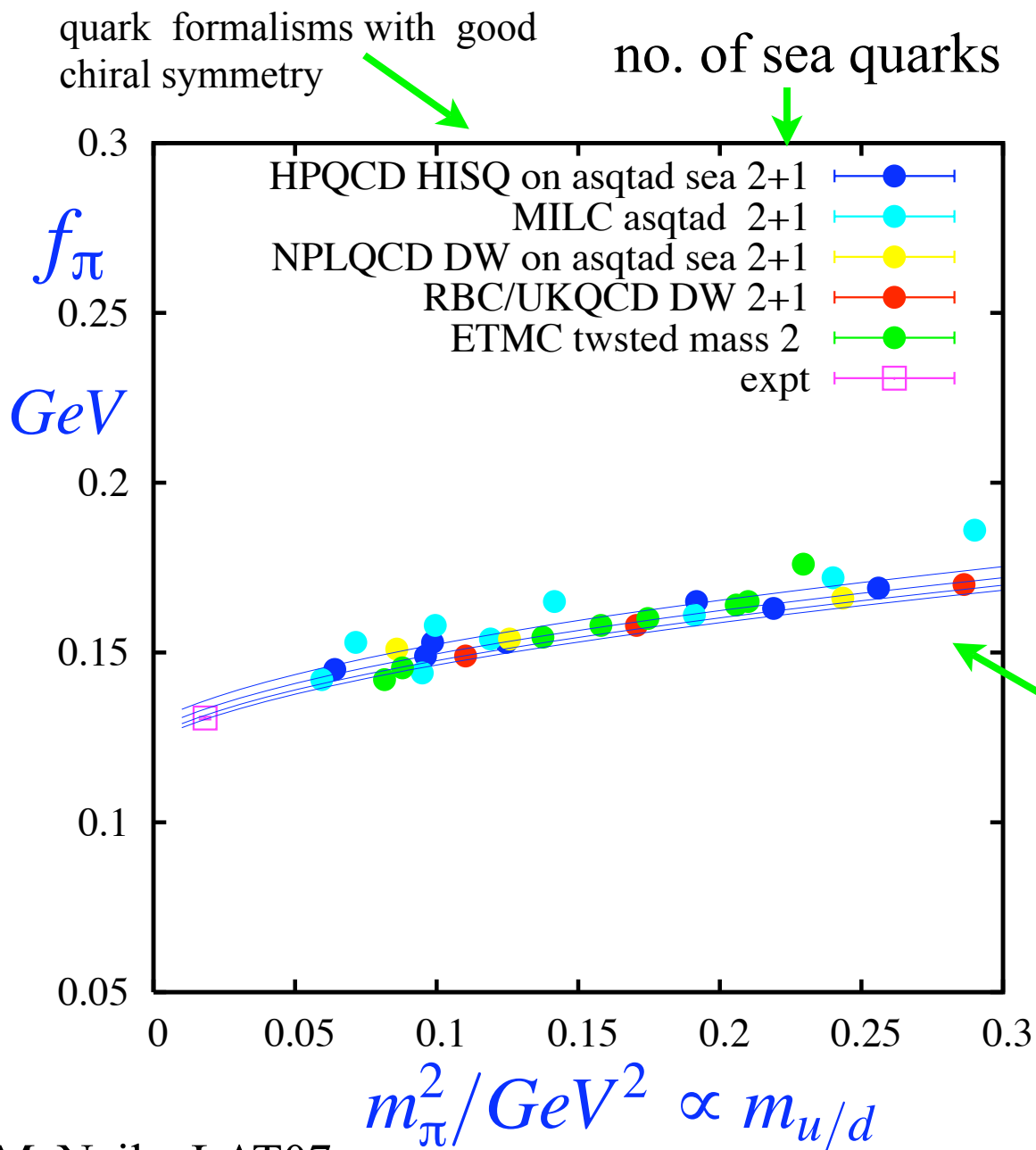


$$Br(\pi \rightarrow \mu \nu) \propto V_{ud}^2 f_\pi^2$$

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

Fitted lines from HISQ
HPQCD 0706.1726[hep-lat]

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

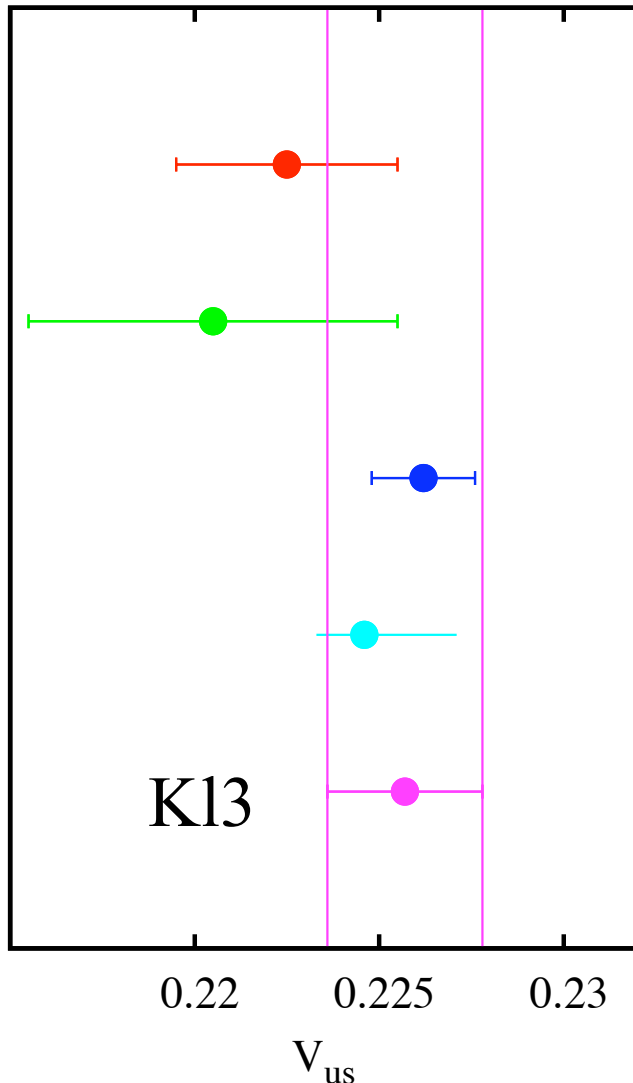


Kaon physics (K12) and V_{us}

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

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

V_{us} competitive w. PDG



RBC/UKQCD dw

PACS-CS clover

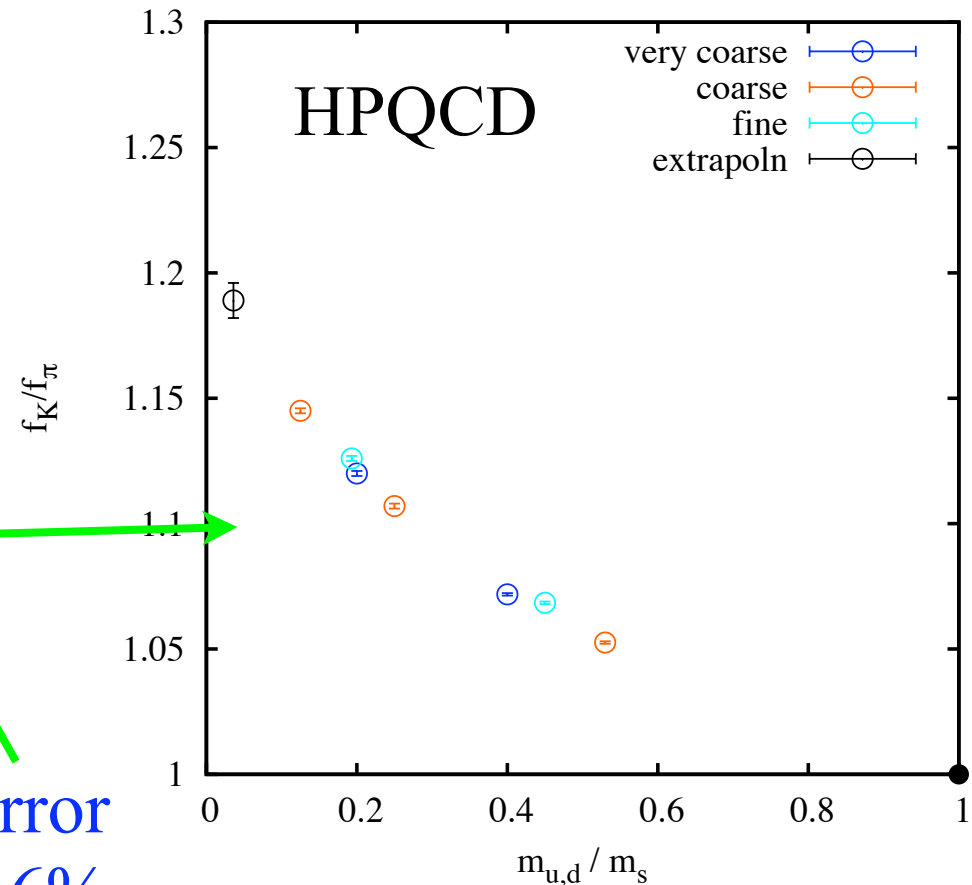
HPQCD HISQ

on asqtad sea

MILC asqtad

PDG 2006

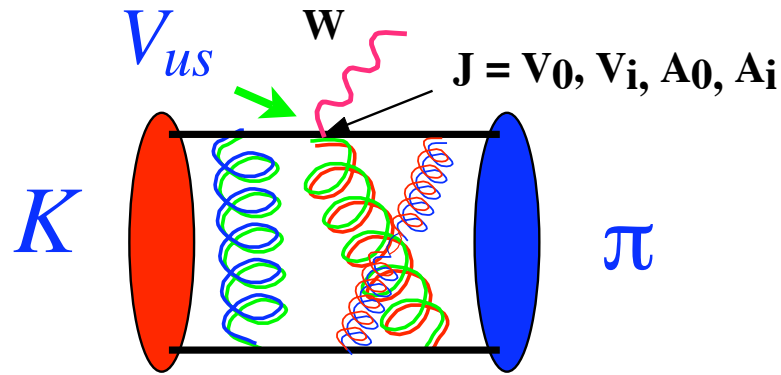
Error
0.6%



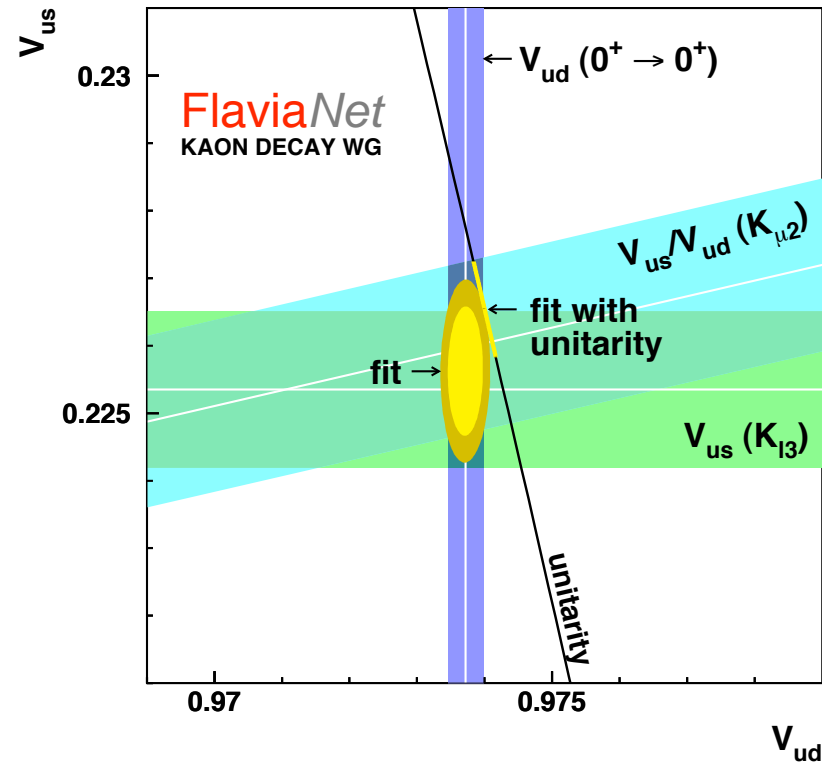
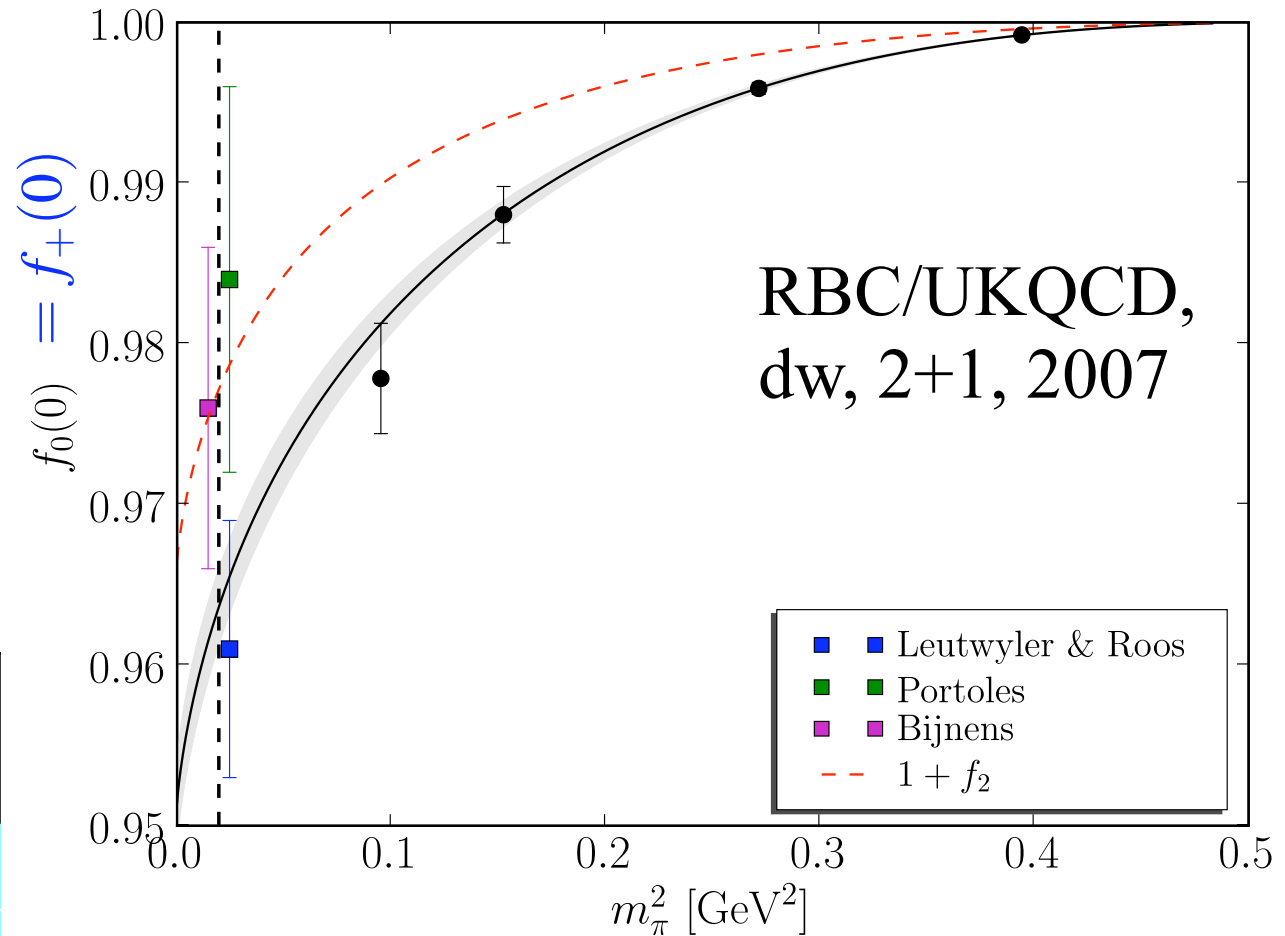
see Jüttner, LAT07

HPQCD: 0706.1726[hep-lat], error budget

K semileptonic decay (K13) and V_{us}



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



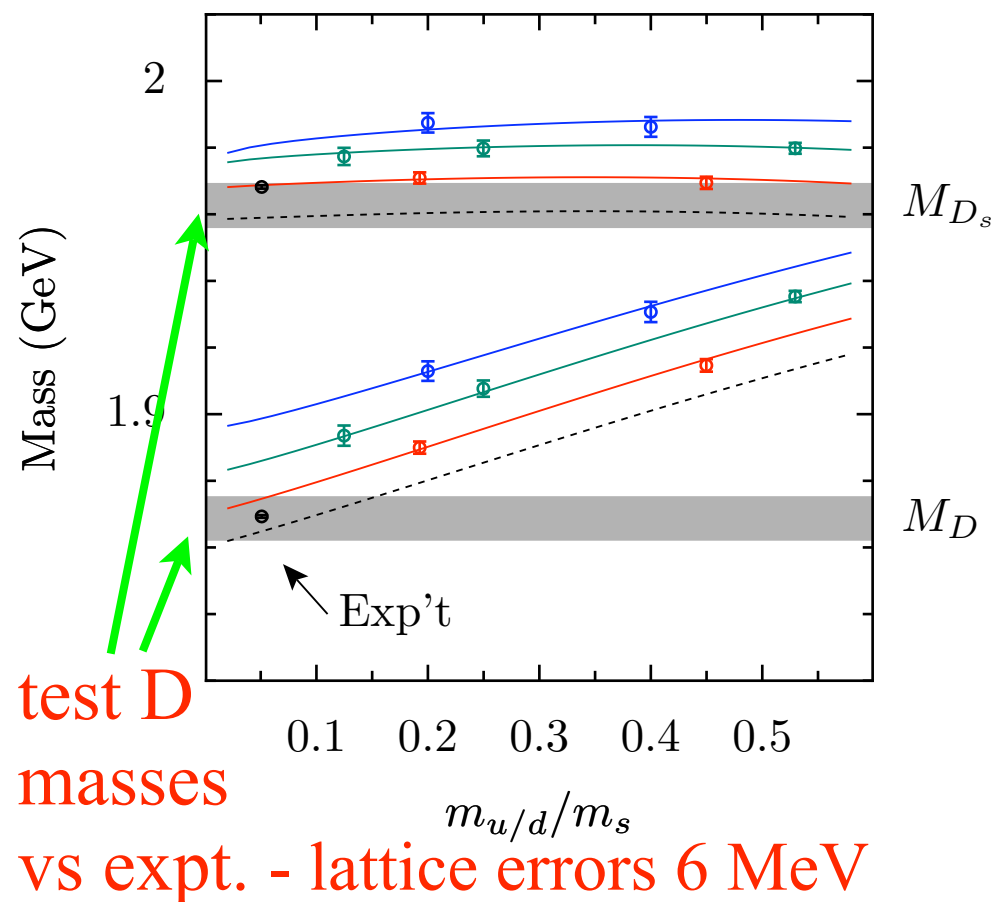
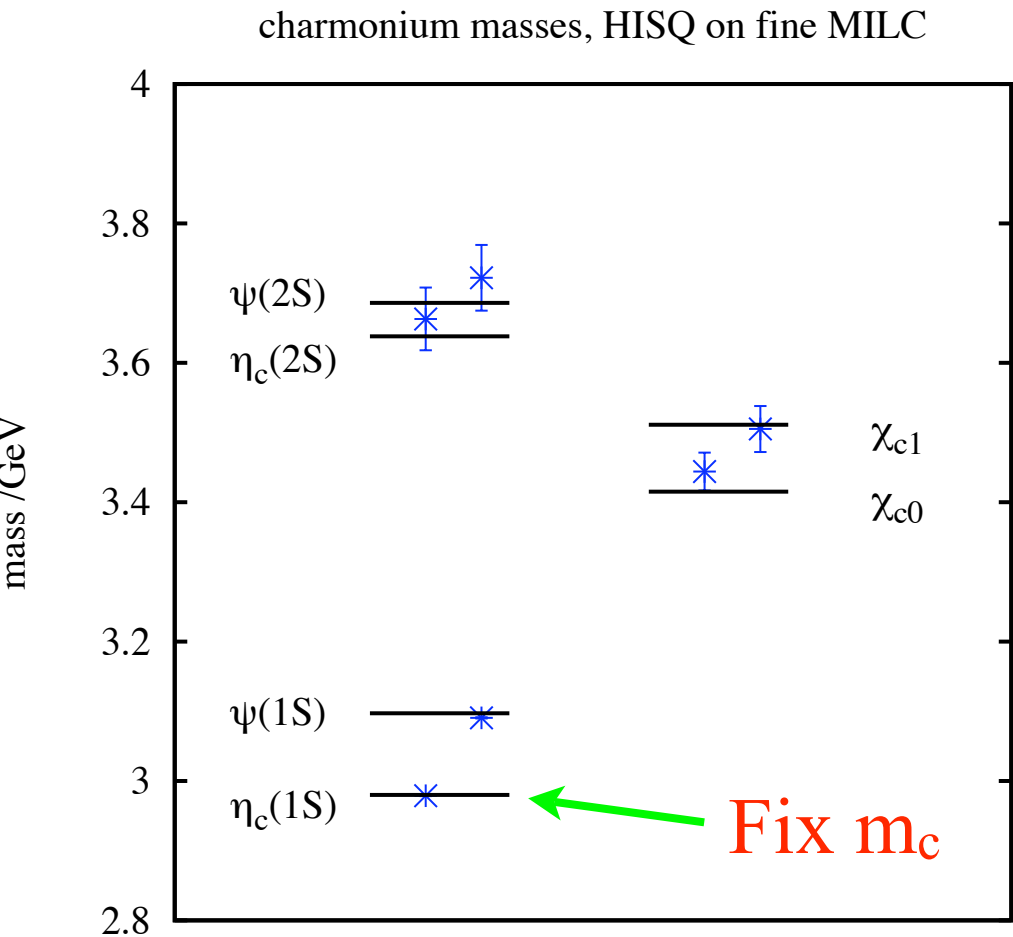
Extrapoln gives $f_+(0) = 0.9609(51)$

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

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

Charm physics, new method, 2007

HPQCD



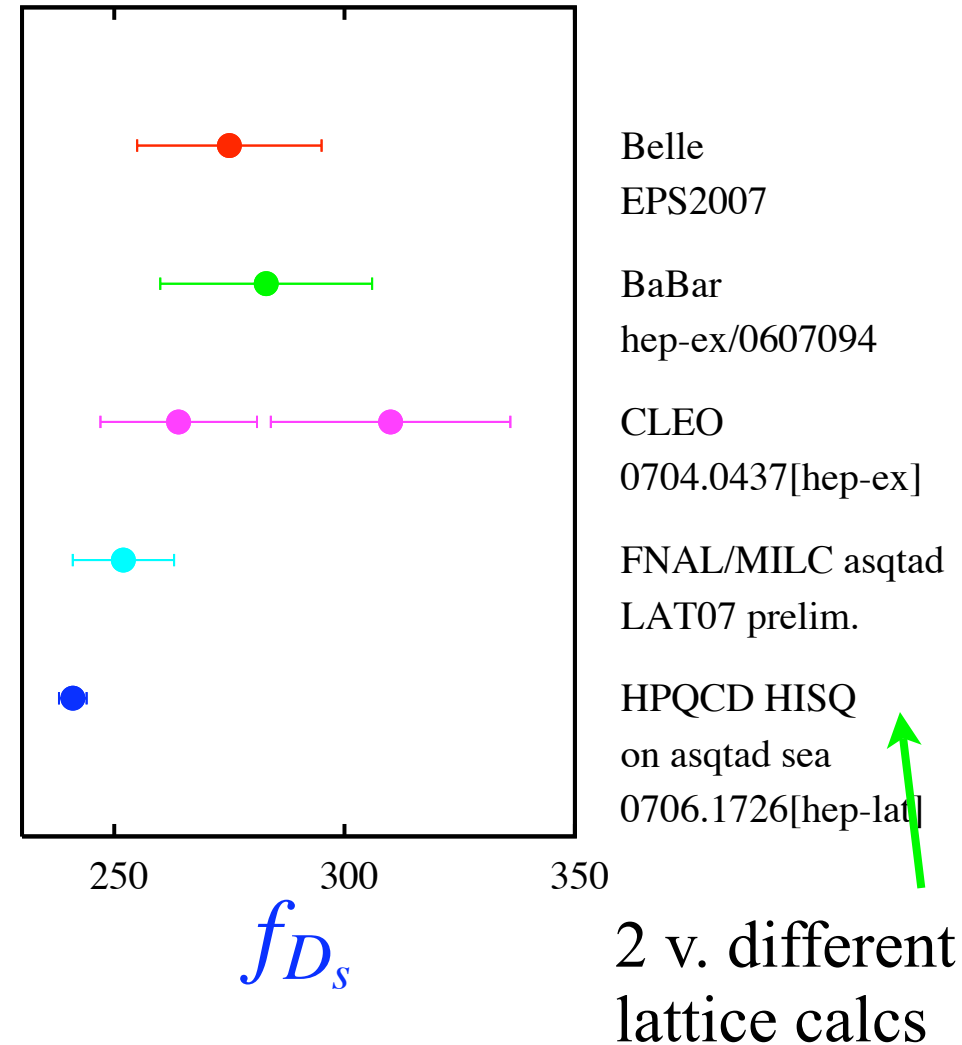
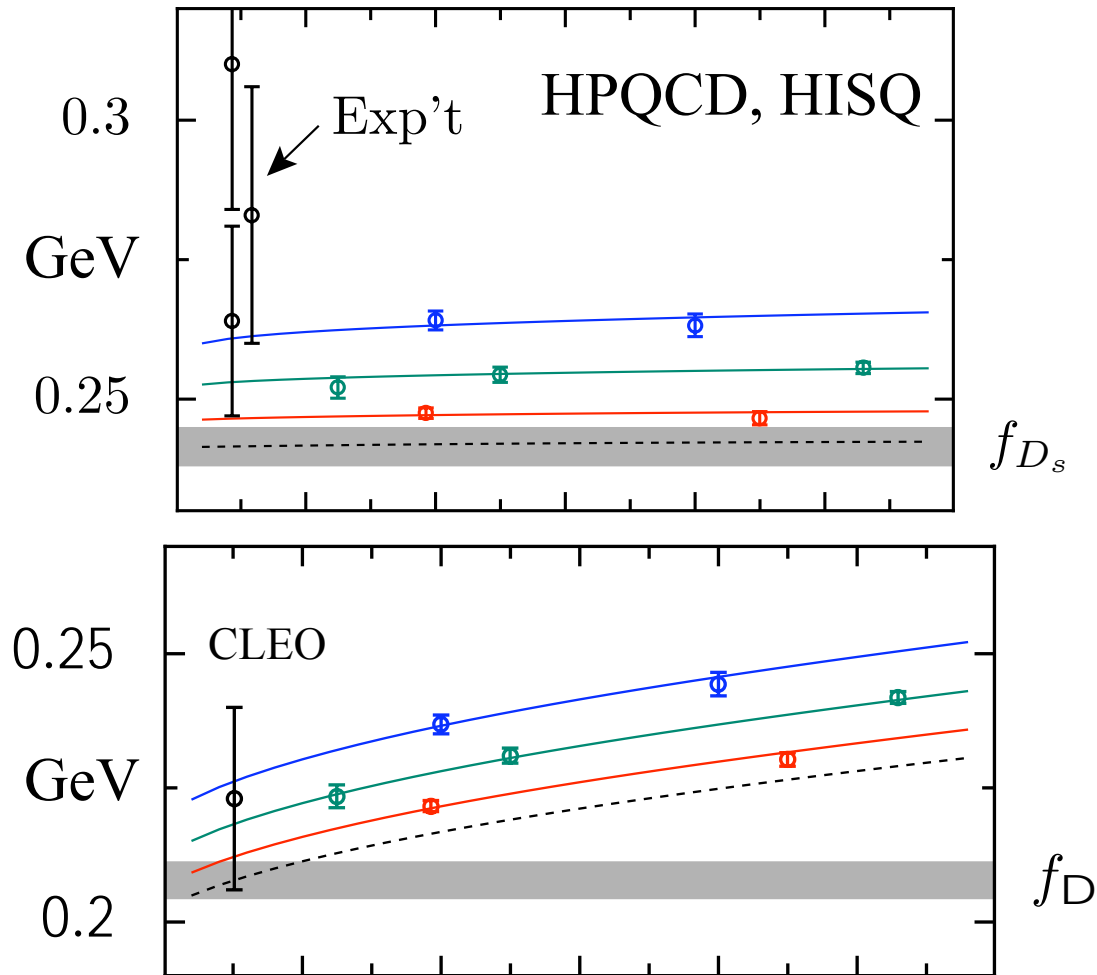
Key issue is discretisation errors, because $m_c a \sim 0.5$

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.

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

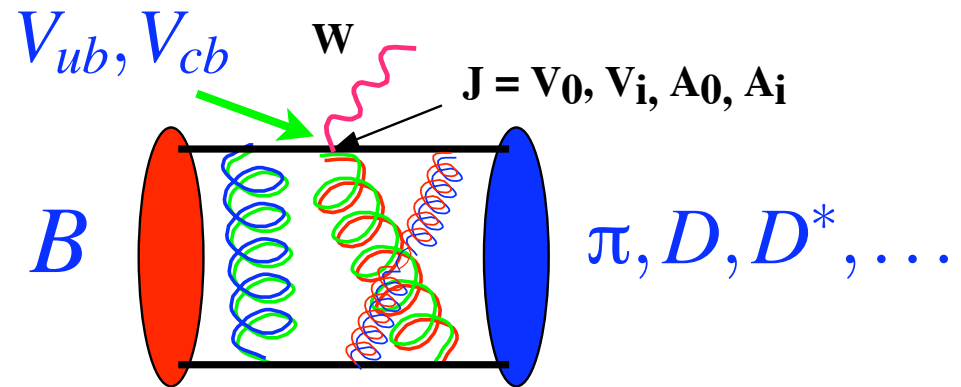
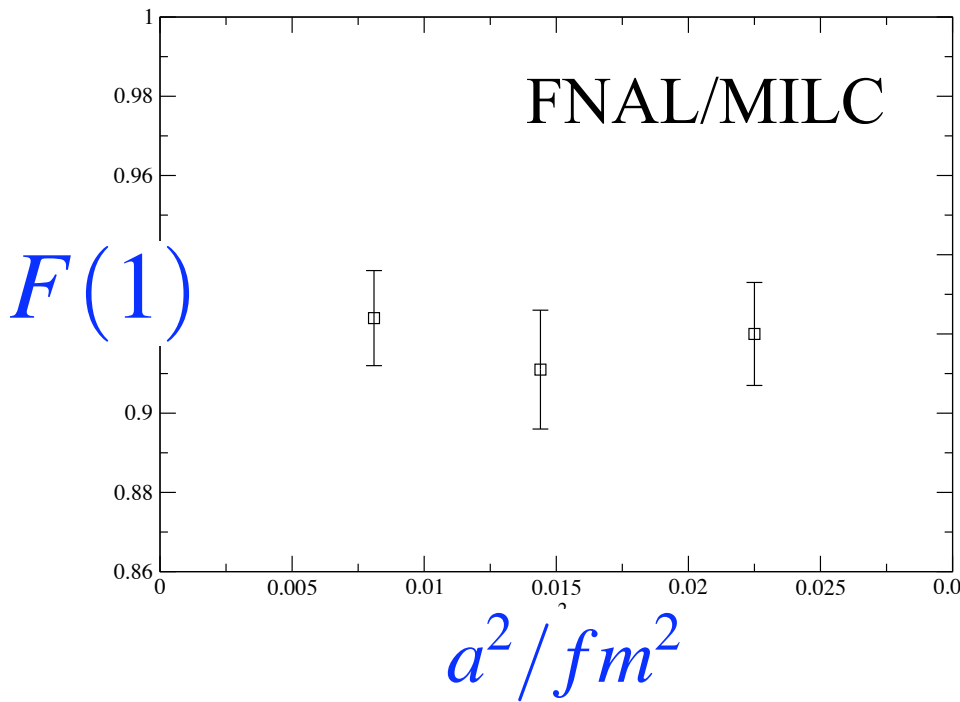
Lattice inc u,d,s sea vs expt



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

- expt uses $V_{cs} = V_{ud}$
- error will improve to few % in 2 yrs
- em corrs could be important ..

B excl. semileptonic decay and CKM constraint



$$B \rightarrow D^* l \nu \quad \text{Laiho, LAT07}$$

rate at zero recoil

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

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

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

\uparrow stat \uparrow syst \uparrow expt \uparrow latt

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

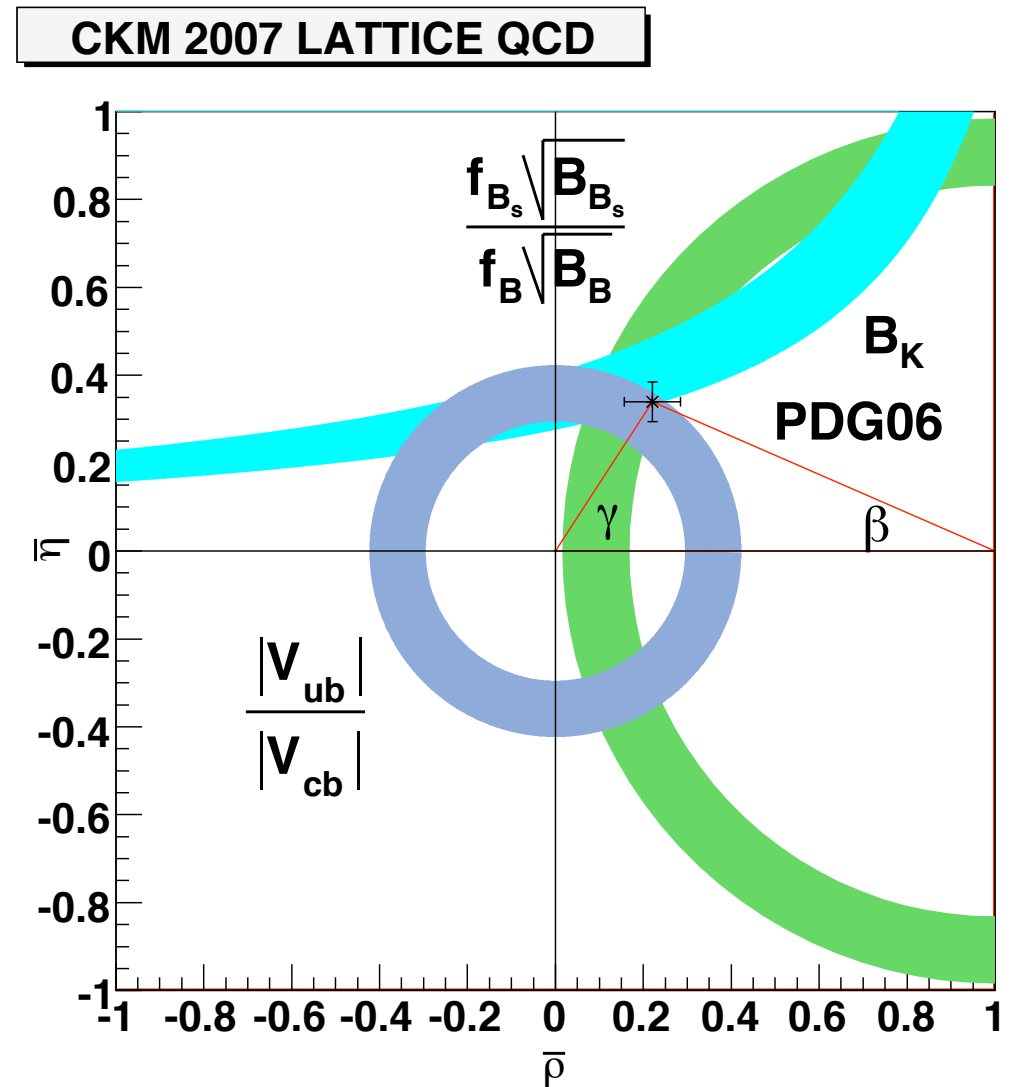
work underway to extend lattice results

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

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

Lattice inputs
(2+1 sea quarks):

$$\begin{aligned}
 &B_K \\
 &f_K/f_\pi, f_+(K \rightarrow \pi l \nu) \\
 &F(B \rightarrow D^* l \nu) \\
 &f_+(B \rightarrow \pi l \nu) \\
 &\frac{f_{B_s} \sqrt{B_{B_s}}}{f_B \sqrt{B_B}}
 \end{aligned}$$



Errors on lattice results should
halve over next two years

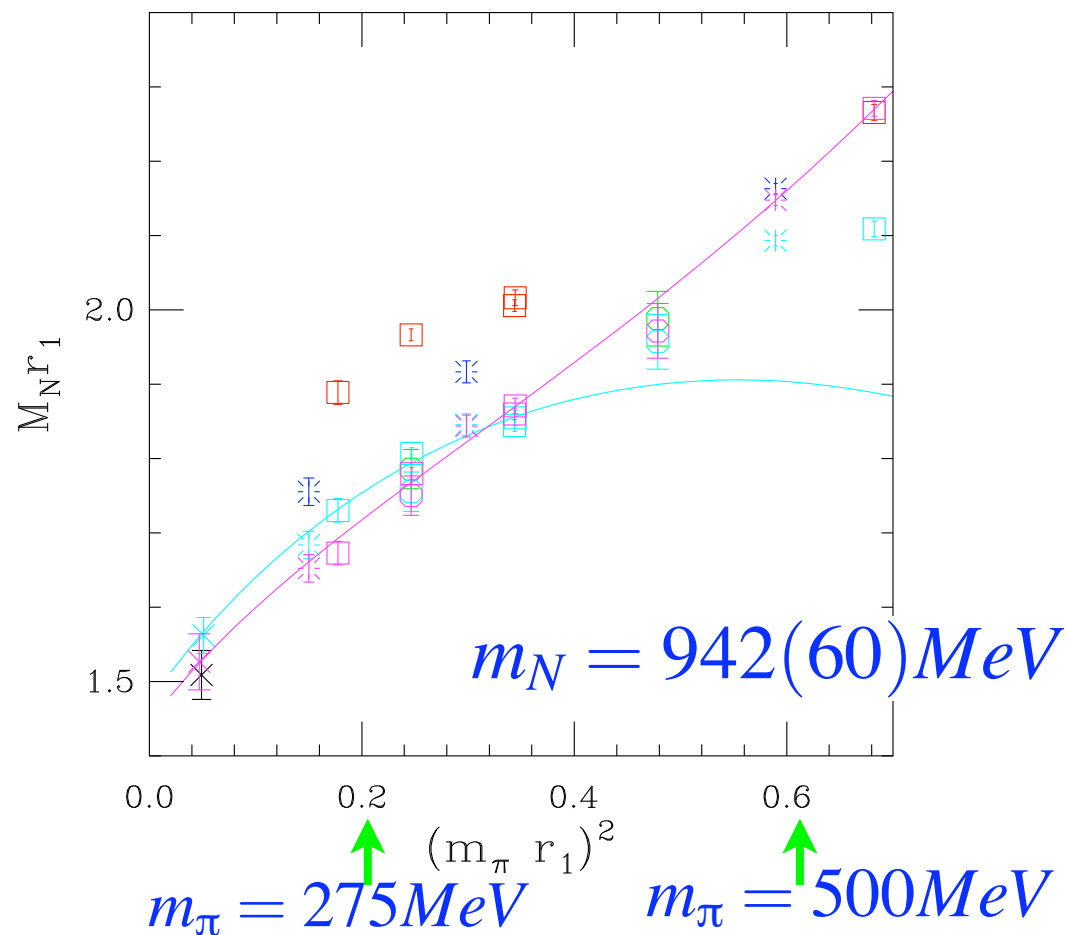
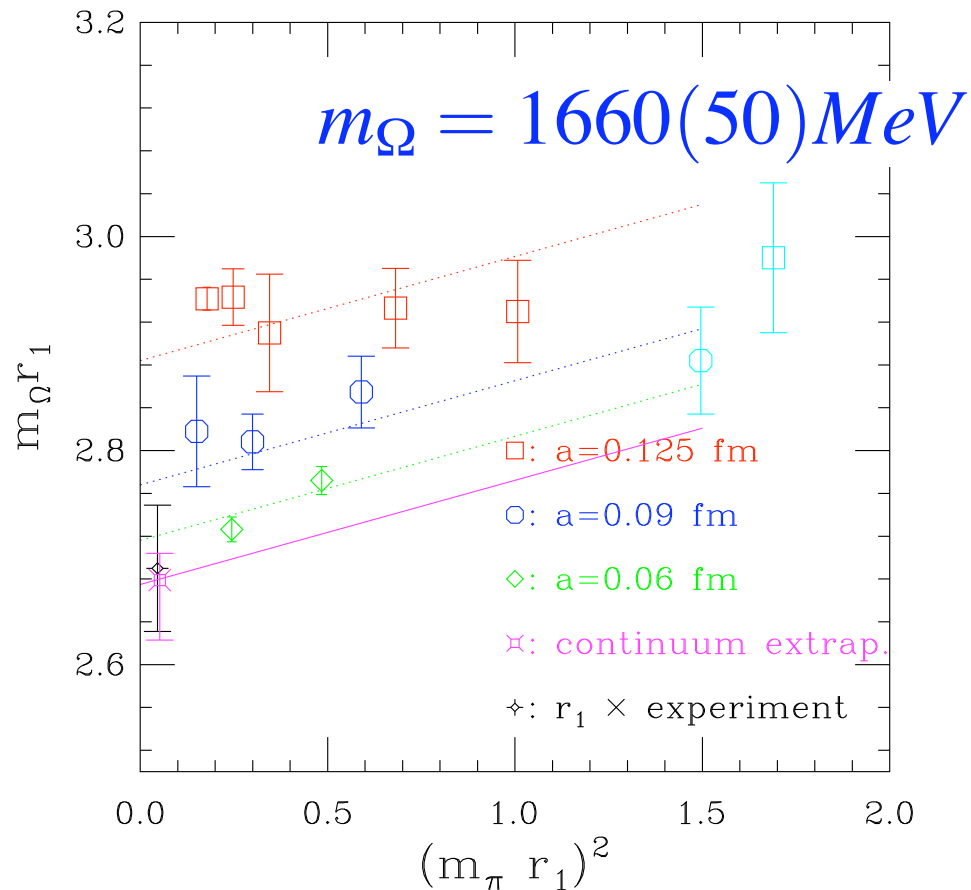
To others using lattice results: QA is dead!

Harder hadron physics

Baryons have exponentially growing signal/noise and harder to do chiral/continuum extrapoln

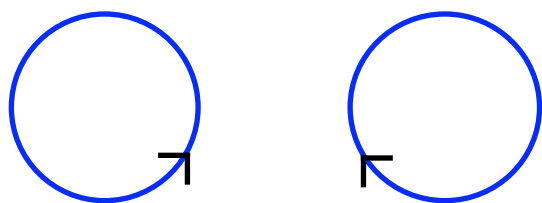
$$\begin{array}{c} \longrightarrow \\ \longrightarrow \\ \longrightarrow \end{array} 2 \quad = \quad \begin{array}{c} \longrightarrow \\ \longrightarrow \end{array} 3$$

$$\frac{\text{signal}}{\text{noise}} = \exp - \left(\frac{m_p}{1.5 \times m_\pi} \right)$$



Even harder hadron physics

Flavor singlet hadrons
require calculation of
disconnected diagrams

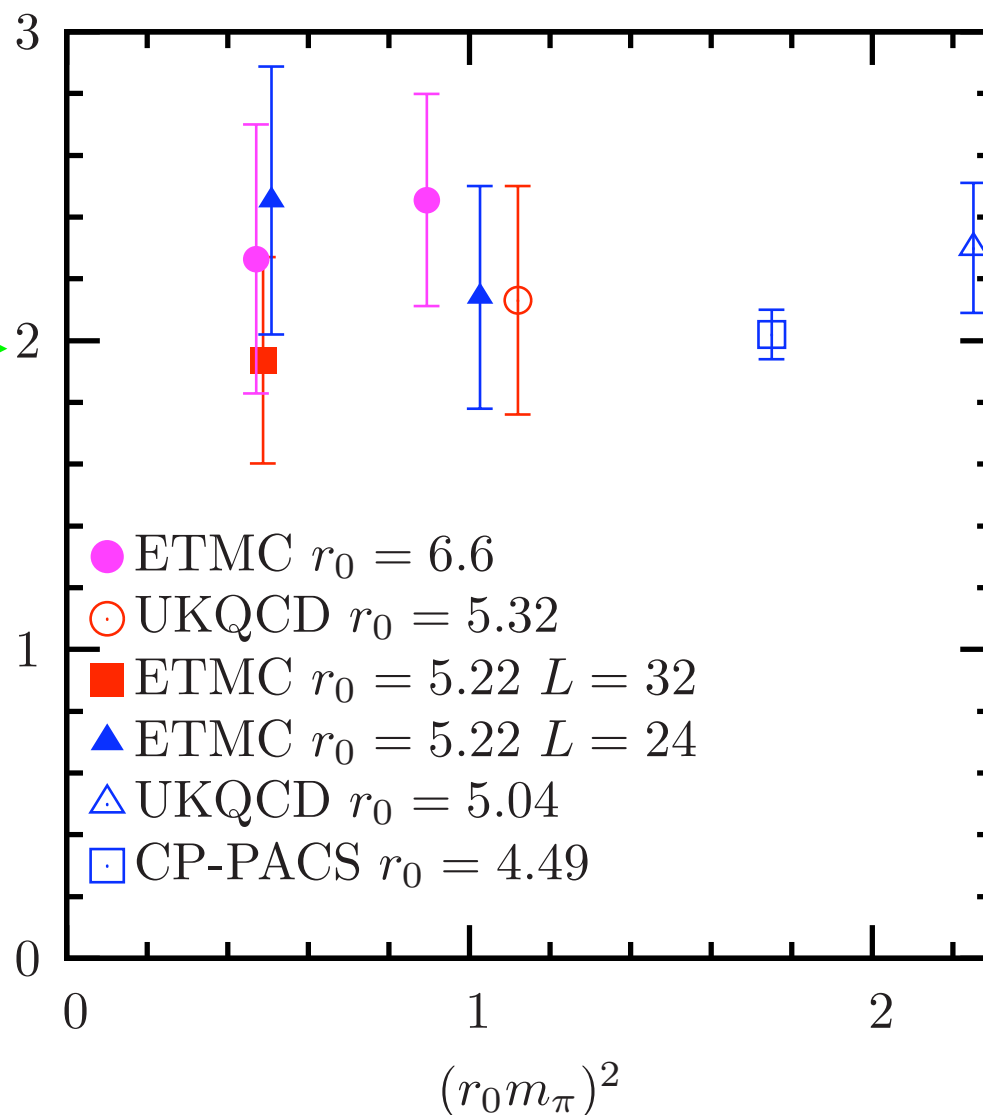


$850 MeV$
 $r_0 m_\eta$

Extremely noisy

New results this year
from ETMC for 2-flavor
case - 2+1 is harder

Flavor singlet PS η_2



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, phase structure at finite temp. etc etc. - see LAT07 website

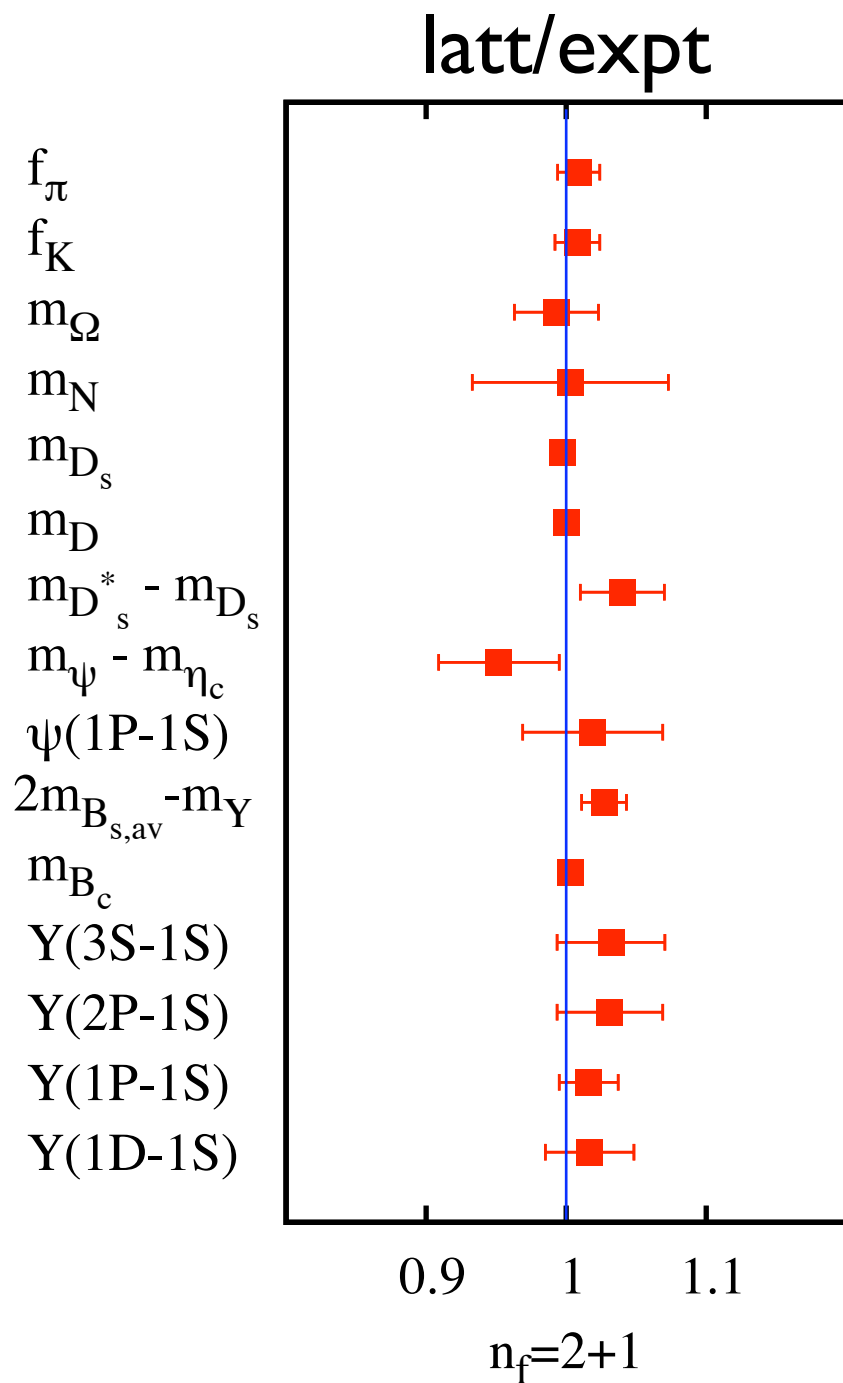
Future:

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

The background is black and features several 3D-rendered spheres in various colors including pink, orange, red, blue, and green. Some of these spheres are semi-transparent, revealing others behind them. Interspersed among the spheres are several wavy, ribbon-like lines in green, blue, and red. The overall composition is abstract and visually dynamic.

Round Table discussion

Christine Davies
University of Glasgow
HPQCD collaboration



Lattice QCD has made huge progress towards precision calculations for ‘gold-plated’ hadrons, particularly mesons, since 2003.

Gold-plated = stable, well away from decay thresholds, accurately measured exptlly. These can be used for precision test of QCD.

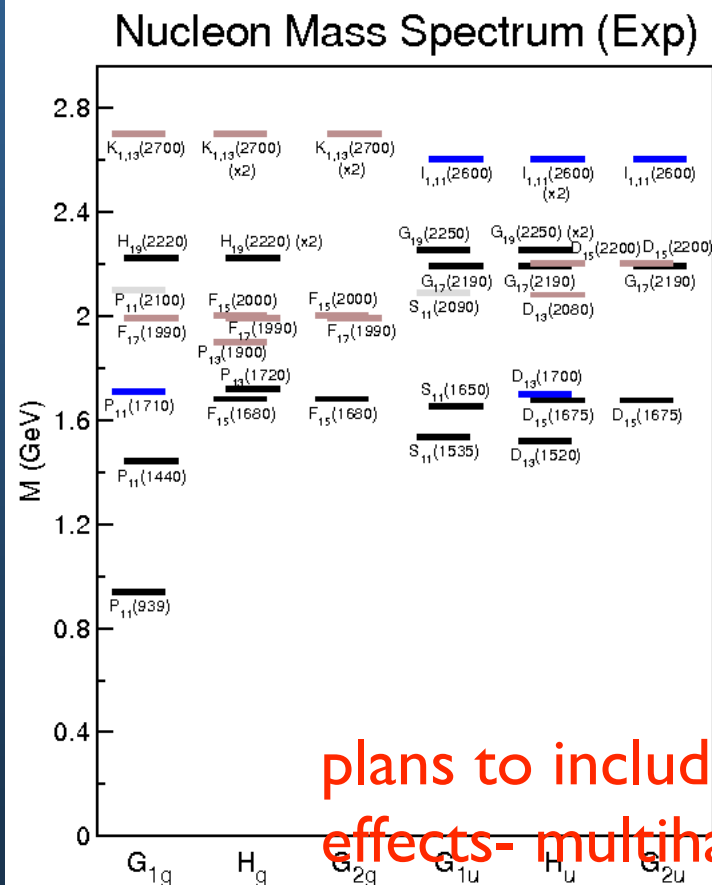
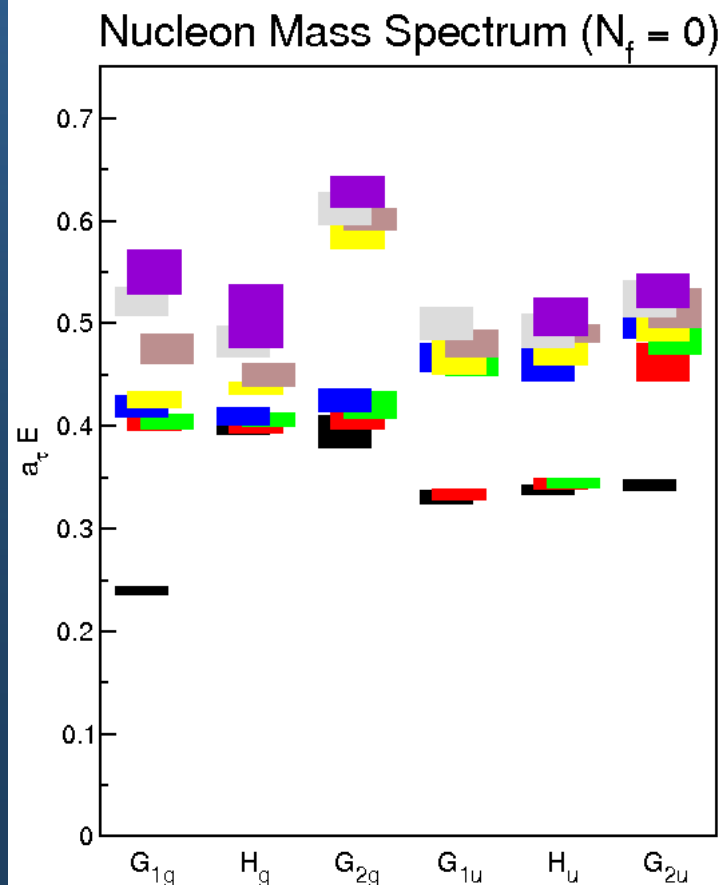
Excited states are noisy
Unstable hadrons associated with multihadron states etc
Precision will not be as good

Need to decide what question you are answering

Nucleon spectrum

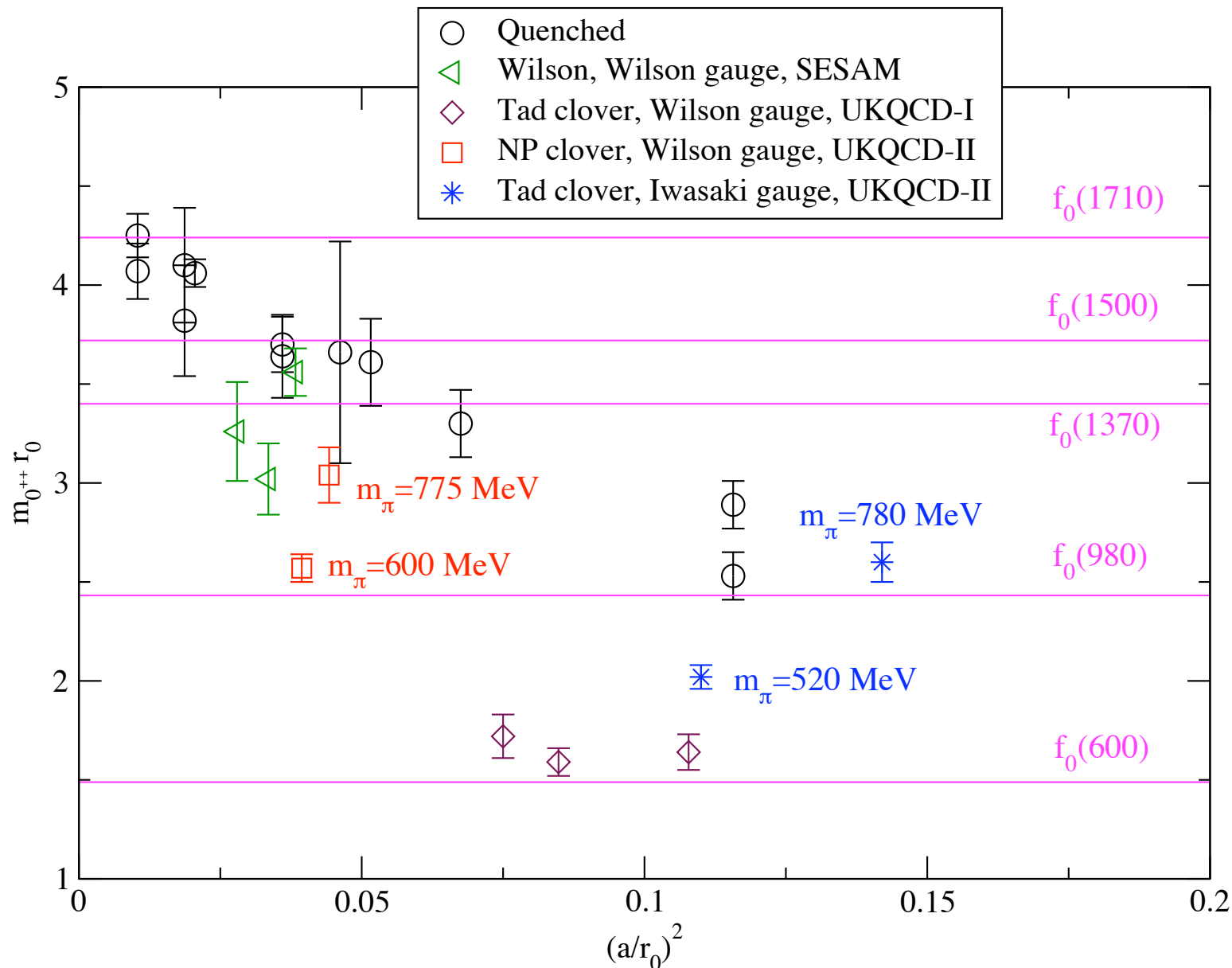
LHPC collaborn

- 200 quenched configs, $12^3 \times 48$ anisotropic Wilson lattice, $a_s \sim 0.1$ fm, $a_s/a_t \sim 3$, $m_\pi \sim 700$ MeV



plans to include sea quark effects- multihadron states a problem?

Flavor singlets/glueballs are also much harder



Key will be very high statistics, i.e. fast sea quark formalisms, and a good operator basis

Meanwhile, high precision results for gold-plated hadrons will continue to improve.

- Simultaneous calcns of heavy-heavy, light-light and heavy-light spectrum to a few MeV is a stringent test of QCD, not possible for models.
 - extend this to low-lying baryons, ‘silver-plated’ mesons

- Ditto for electroweak decays. Now have f_D, f_{D_s} to 2%. Calcn in progress for $\Gamma_{e^+e^-}(J/\psi)$ $\Gamma_{e^+e^-}(\phi)$

Requires understanding QED corrections.

Strong impact on flavor physics programme.

- expect accurate form factors, structure function moments for baryons.

- Many more calculations with different quark formulations will appear in next few years ...