Hadron properties from Lattice QCD

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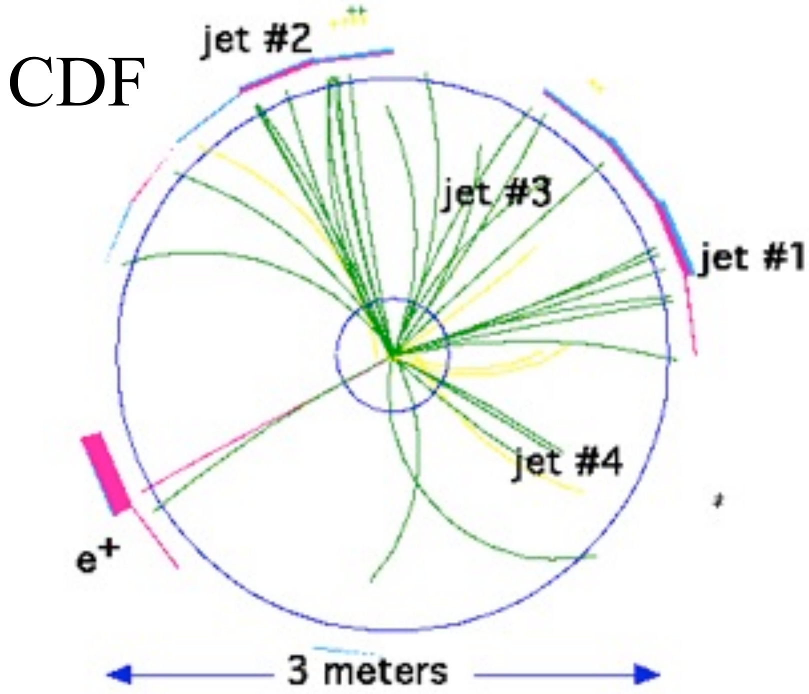
HPQCD collaboration

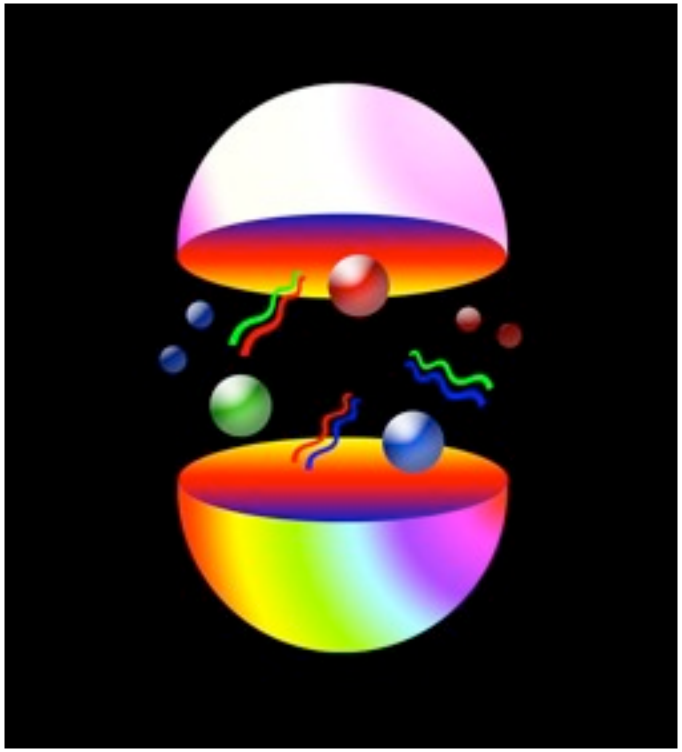
Hirschegg
January 2012

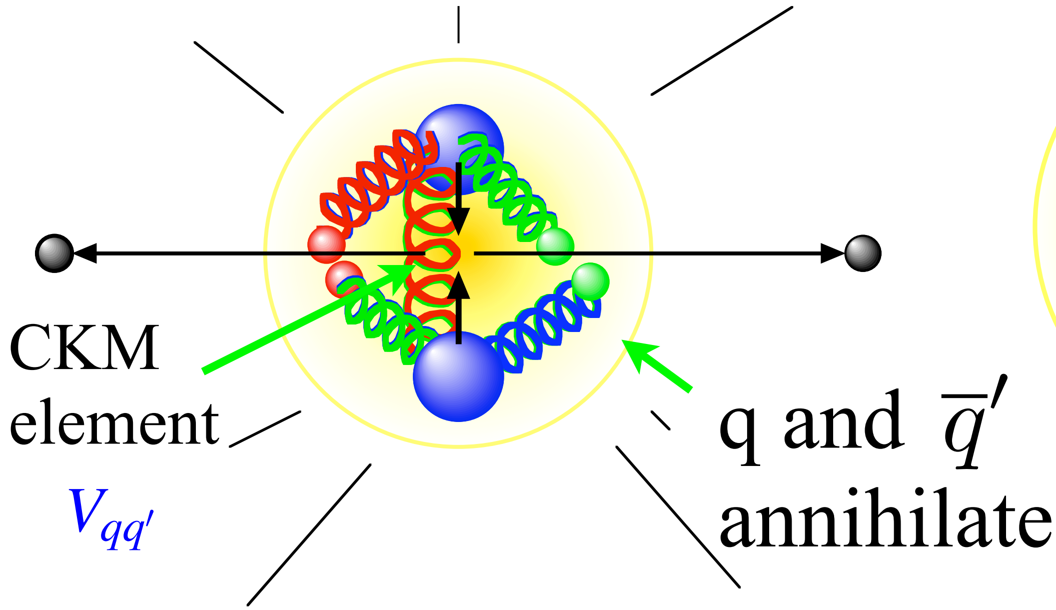
QCD is a key part of the Standard Model but quark confinement is a complication/interesting feature.

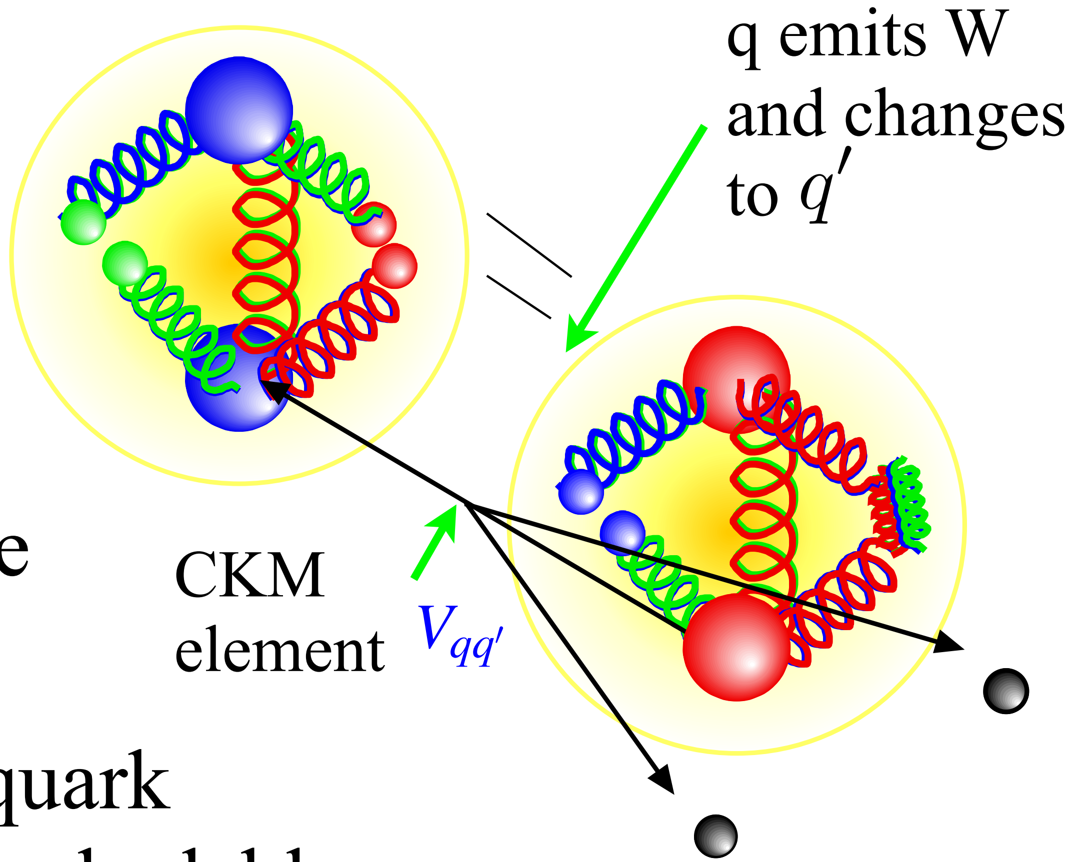


Cross-sections calculated at high energy using QCD pert. th. NLO gives ~5% errors. Also have pdf and hadronisation uncertainties

But properties of hadrons calculable from QCD if fully nonperturbative calc. is done - can test QCD and determine parameters very accurately (1%).

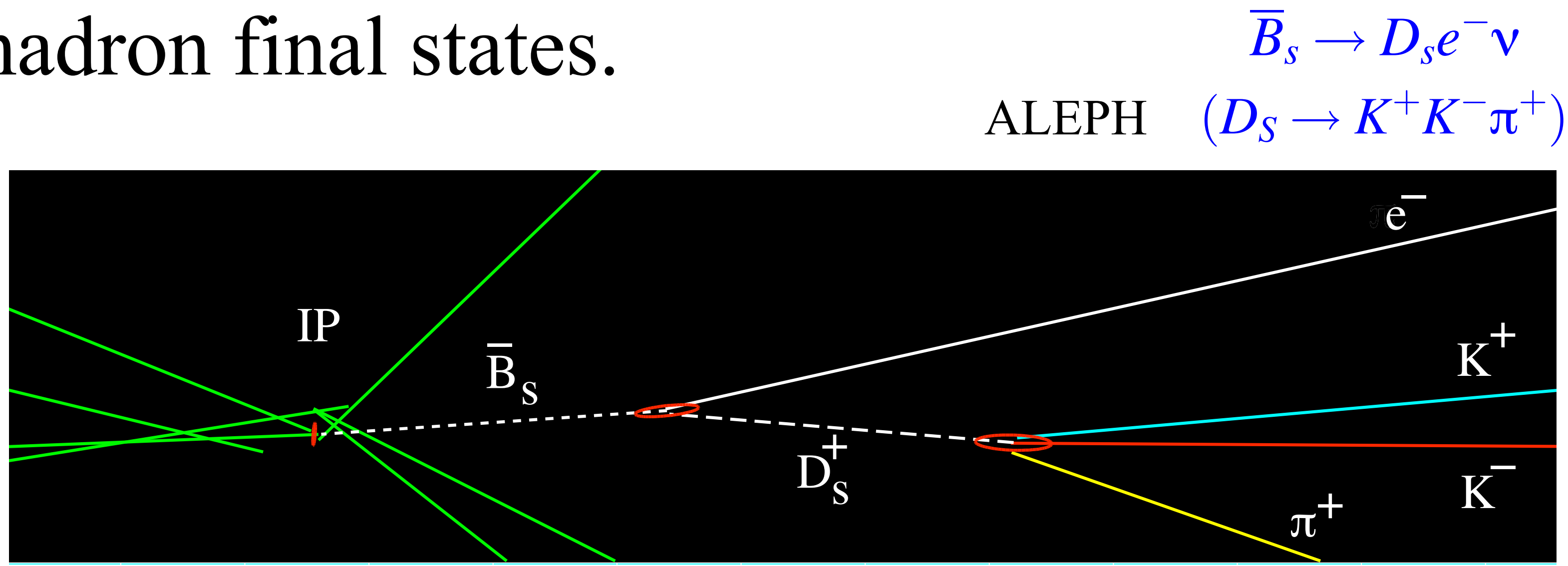




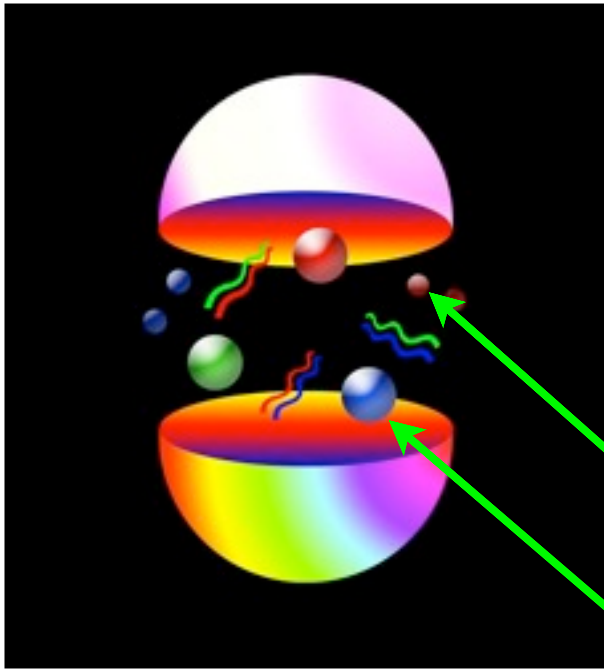


Rates for simple weak or em quark processes inside hadrons also calculable, but *not* multi-hadron final states.

Compare to exptl rate gives $V_{qq'}$ accurately



Lattice QCD = fully nonperturbative QCD calculation



RECIPE

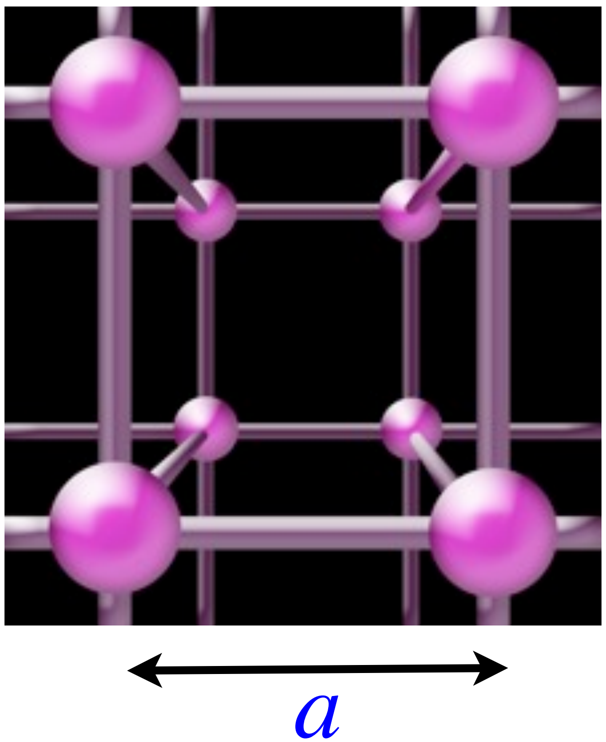
• Generate sets of gluon fields for Monte Carlo integrn of Path Integral (inc effect of u, d, s (+ c) sea quarks)

• Calculate averaged “hadron correlators” from valence q props.

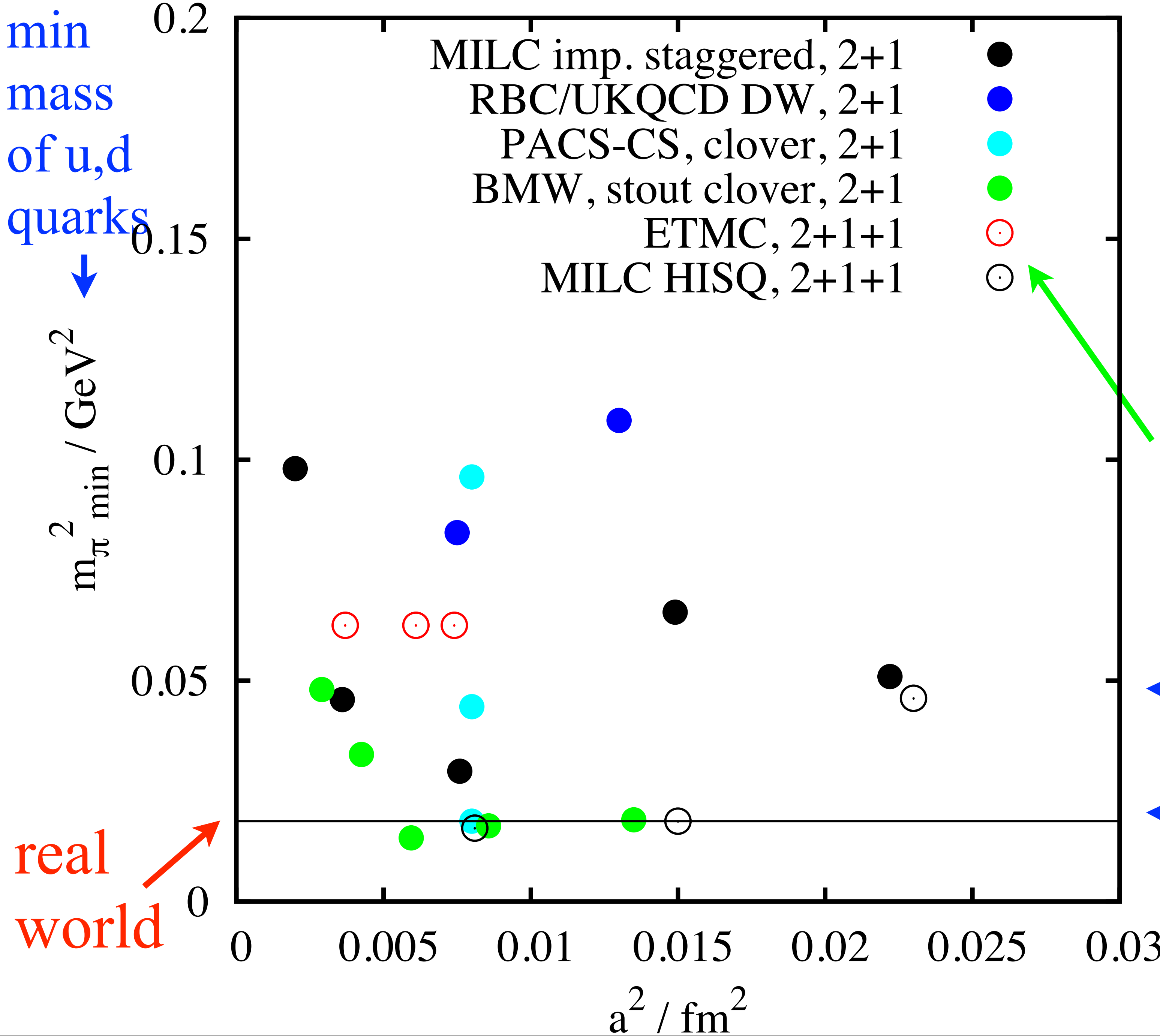
• Fit as a function of time to obtain masses and simple matrix elements

• Determine a and fix m_q to get results in physical units.

• extrapolate to $a=0, m_{u,d}=phys$ for real world



Example parameters for calculations now being done.
Lots of different formalisms for handling quarks.



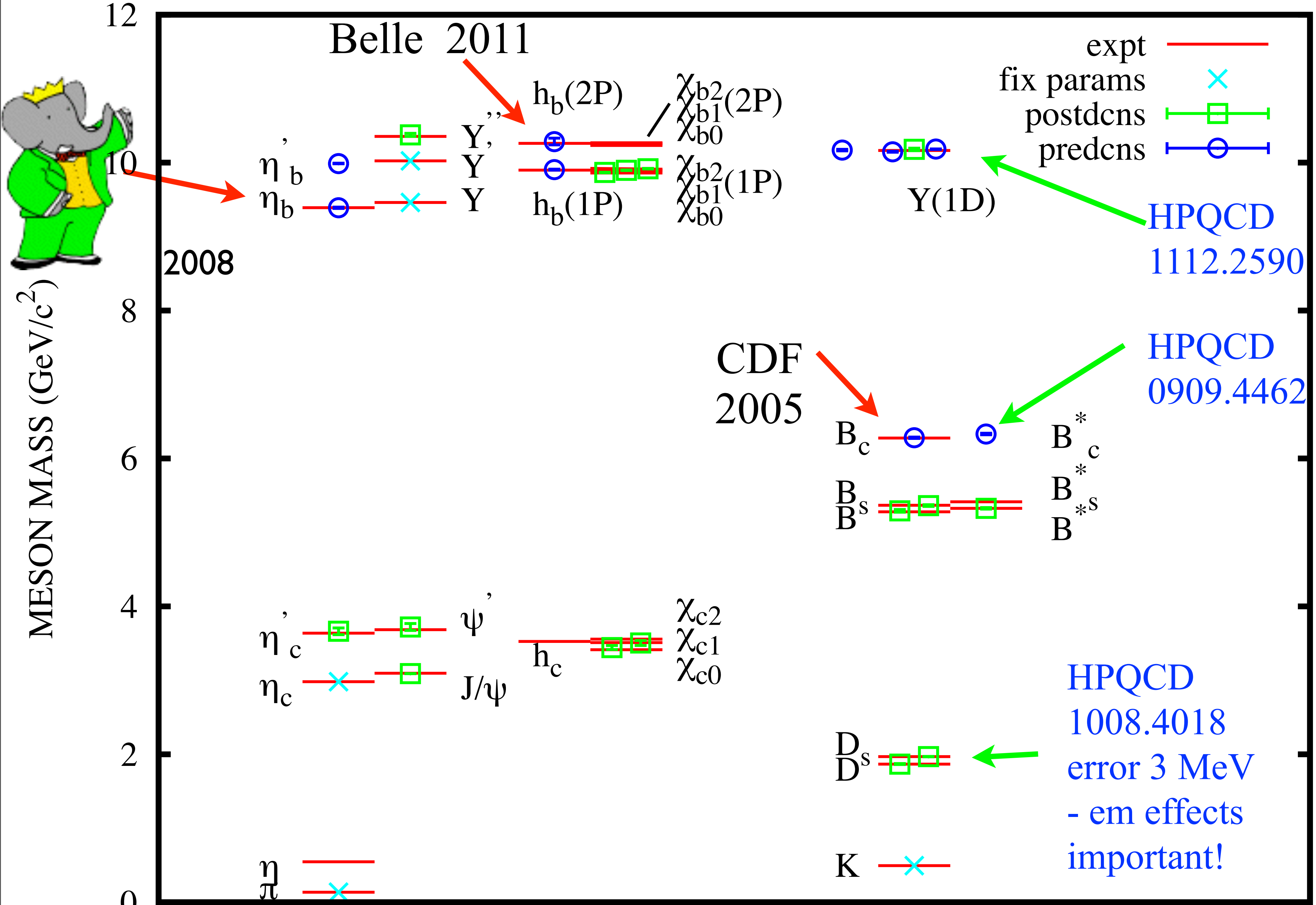
Volume of lattice also an issue - need $m_\pi L > 3$

"2nd generation" lattices inc. c quarks in sea

$m_{u,d} \approx m_s/10$

$m_{u,d} \approx m_s/27$

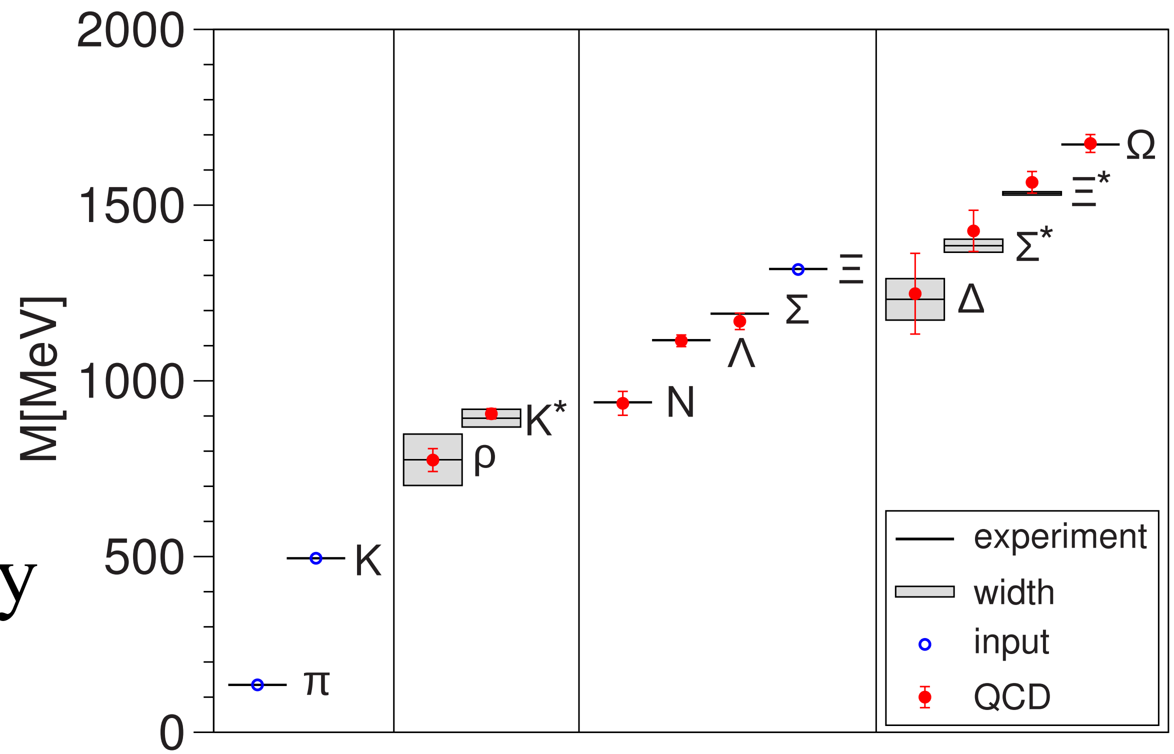
The gold-plated meson spectrum - HPQCD



older predcns: I. Allison et al, hep-lat/0411027, A. Gray et al, hep-lat/0507013

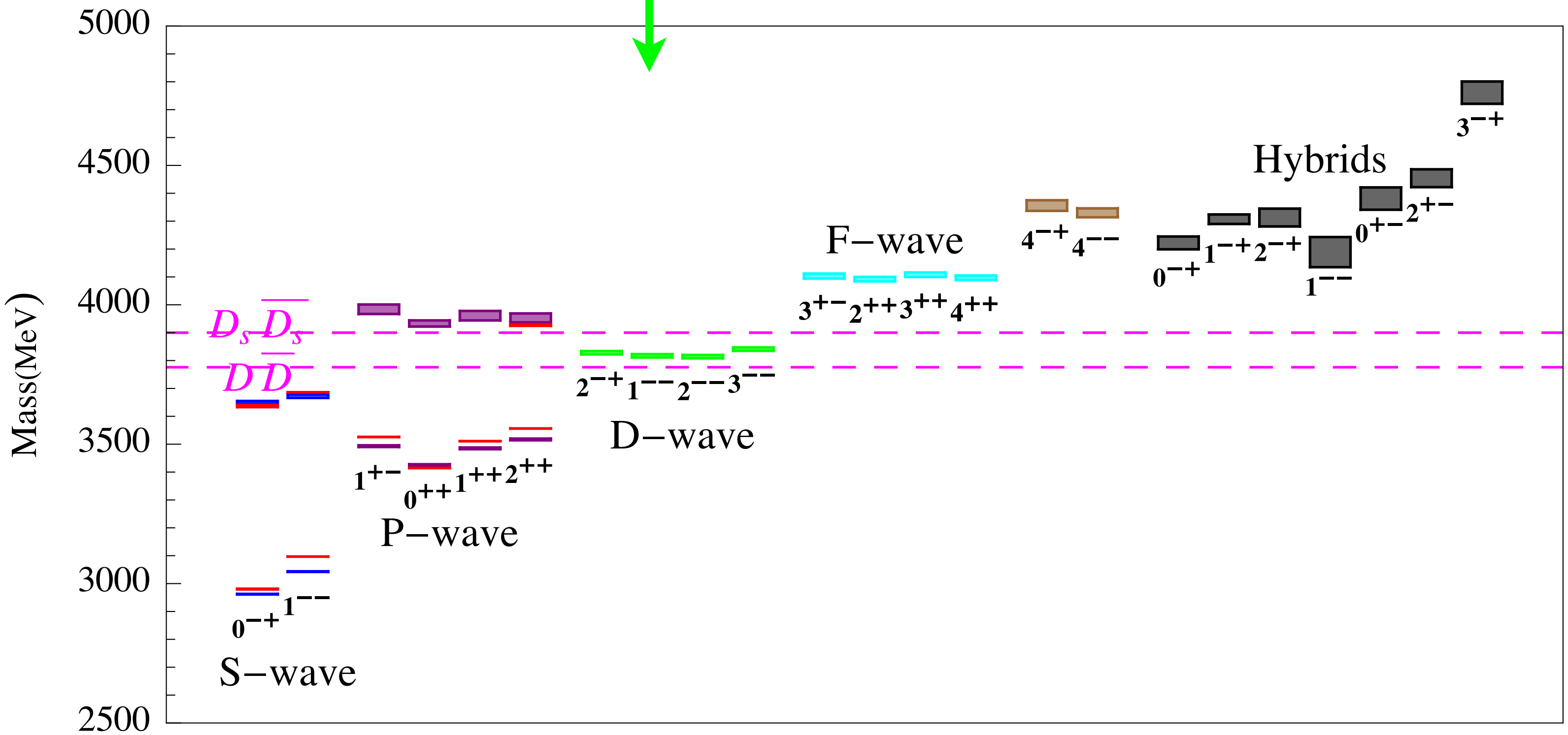
Light hadrons including baryons

(S. Durr et al, BMW collaboration,0906.3599)



Excited charmonium spectrum - preliminary

(Liu et al, HadSpec, 1112.1358, LAT11)



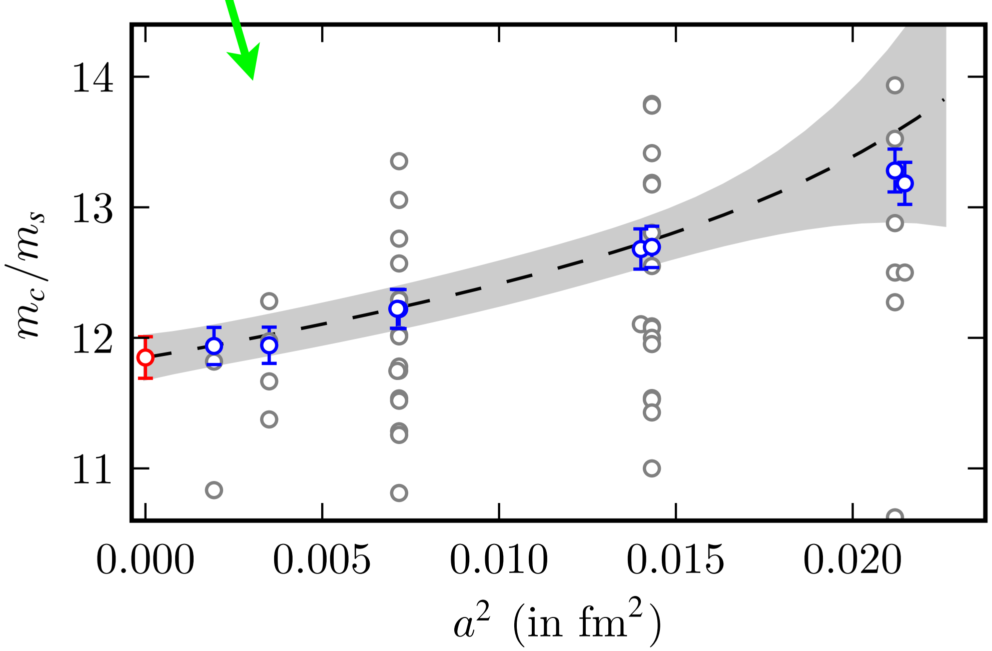
$$X_c(3872) = 1^{++}/2^{-+}$$

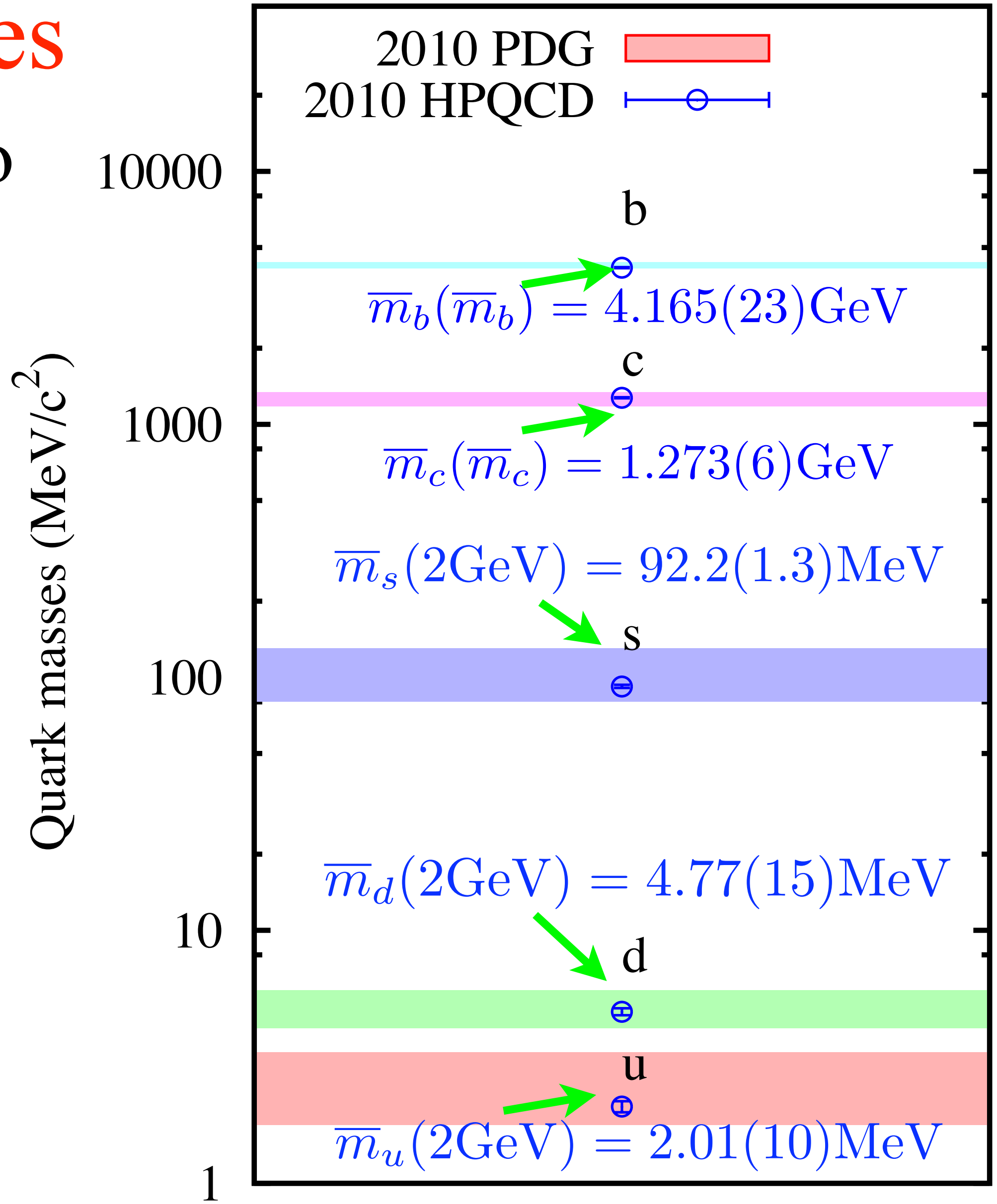
Lots of work in progress ...

Determining quark masses

Lattice QCD has direct access to parameters in Lagrangian for accurate tuning
- issue is converting to contnm schemes such as $\overline{MS}$

quark mass ratios very accurate:
e.g. m_c/m_s, m_b/m_c, $m_s/m_{u,d}$





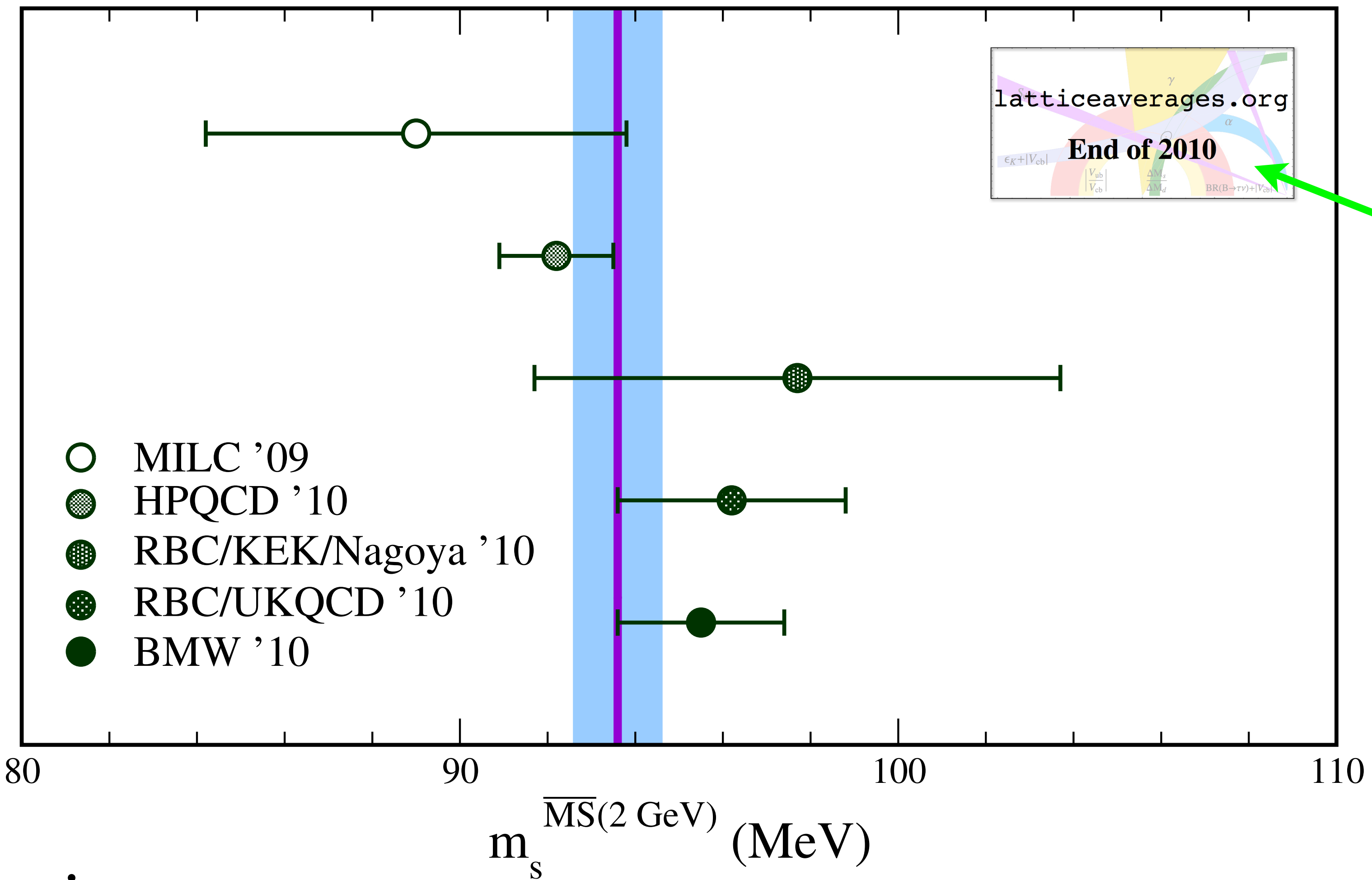
C. McNeile, CTHD et al, HPQCD, 0910.3102, 1004.4285

Can now rule out some quark mass matrix models ...

C. McNeile, 1004.4985

2010: Strong convergence of lattice results for strange quark mass

PDG to 130 MeV



J. Laiho, E. Lunghi, R. Van der Water see also Wittig LAT11

1% accuracy achieved

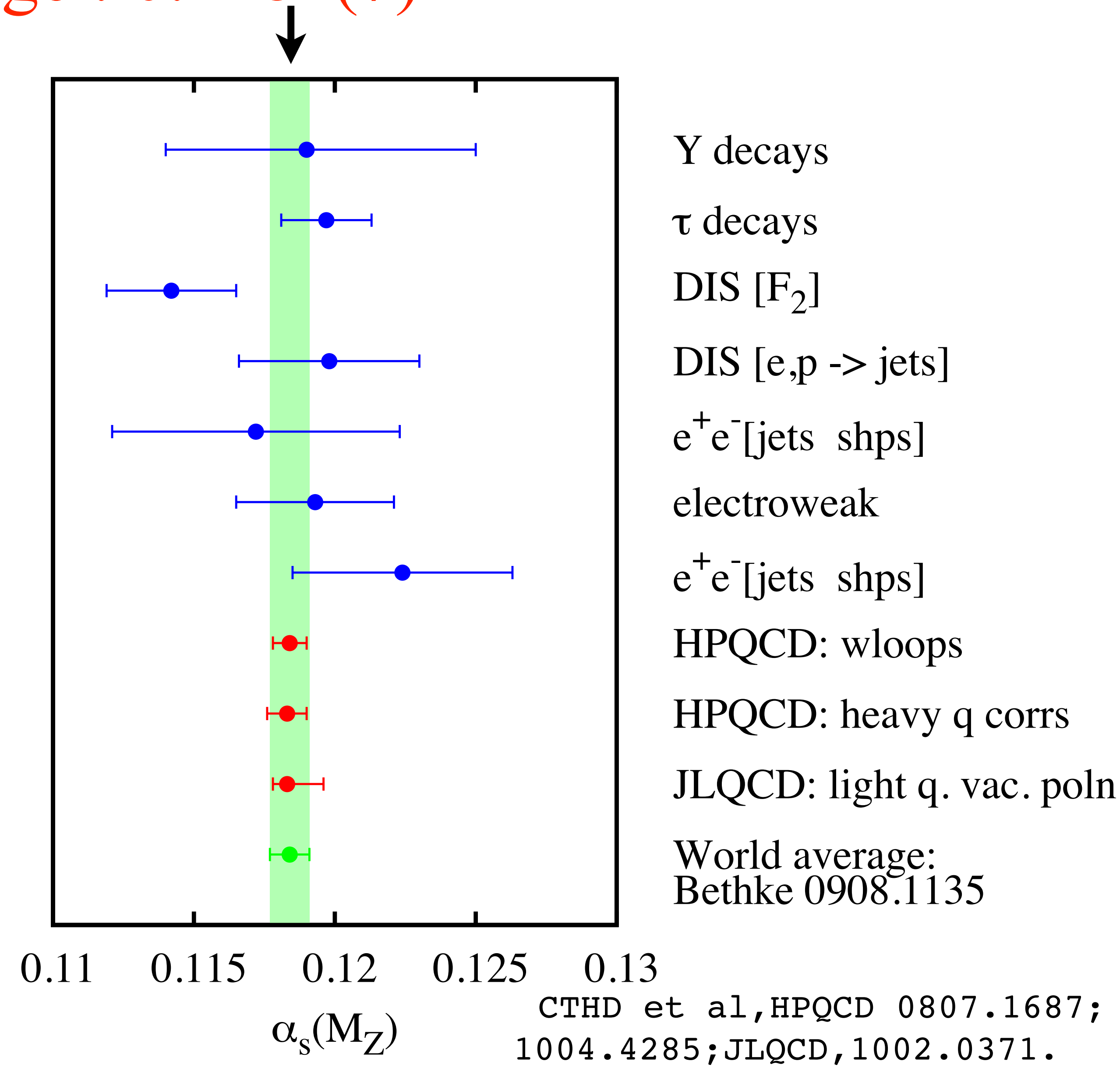
Lattice averages: $m_s = 93.6(1.1)\text{MeV};\ \frac{m_s}{m_u + m_d} = 27.55(14)$

Determining α_s

Lattice QCD now has several determns of α_s to 1%.
Dominate world average : 0.1184(7)

Key points:

- high statistical precision
- high order (NNLO) pert. th. exists and can estimate higher orders
- nonpert. systs. not a significant issue
- approaches very different - good test

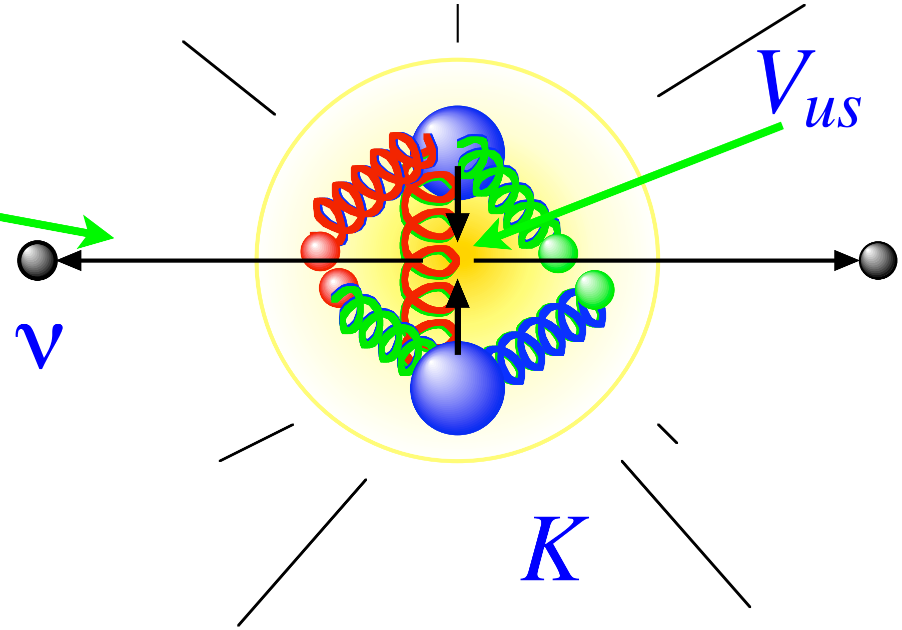


see 2011 Munich alphas workshop Shintani LAT11

CTHD et al,HPQCD 0807.1687; 1004.4285;JLQCD,1002.0371.

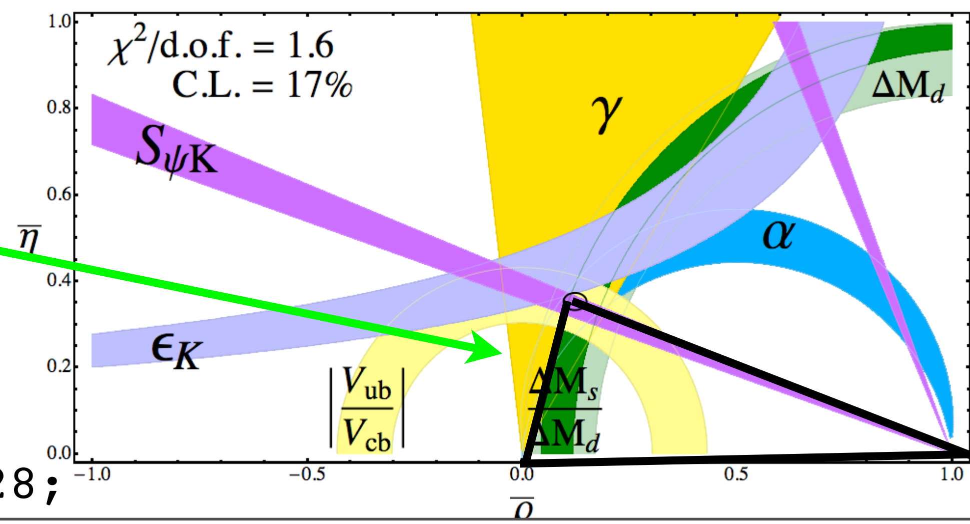
Weak decays probe structure, determine CKM elements

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

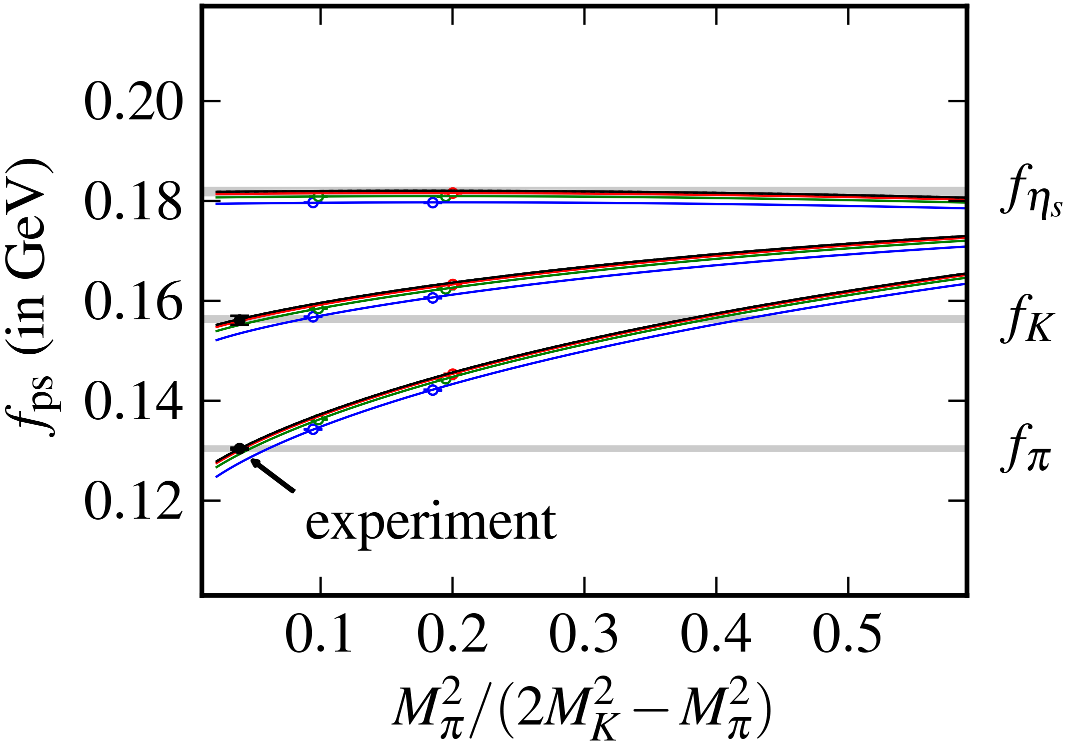


Expt = CKM x theory(QCD)

Need precision lattice QCD to get accurate CKM elements to constrain sides of UT.
If Vab known, compare lattice to expt to test QCD.

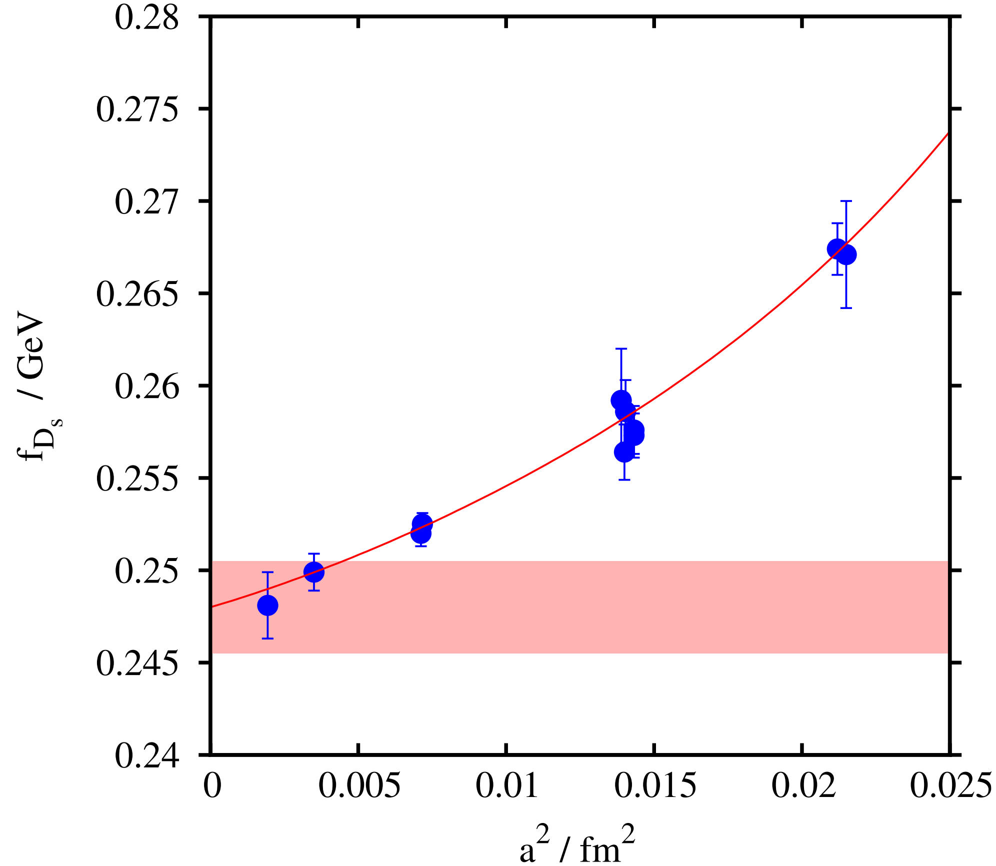


J.Laiho et al, 0910.2928;



Pseudoscalar decay constants can be accurately determined from meson correlator amplitudes using a formalism where PCAC holds.

Results with the Highly Improved Staggered Quark formalism



HPQCD: RJ Dowdall et al, 1110.6887;CTH Davies et al,1008.4018.

V_{us}

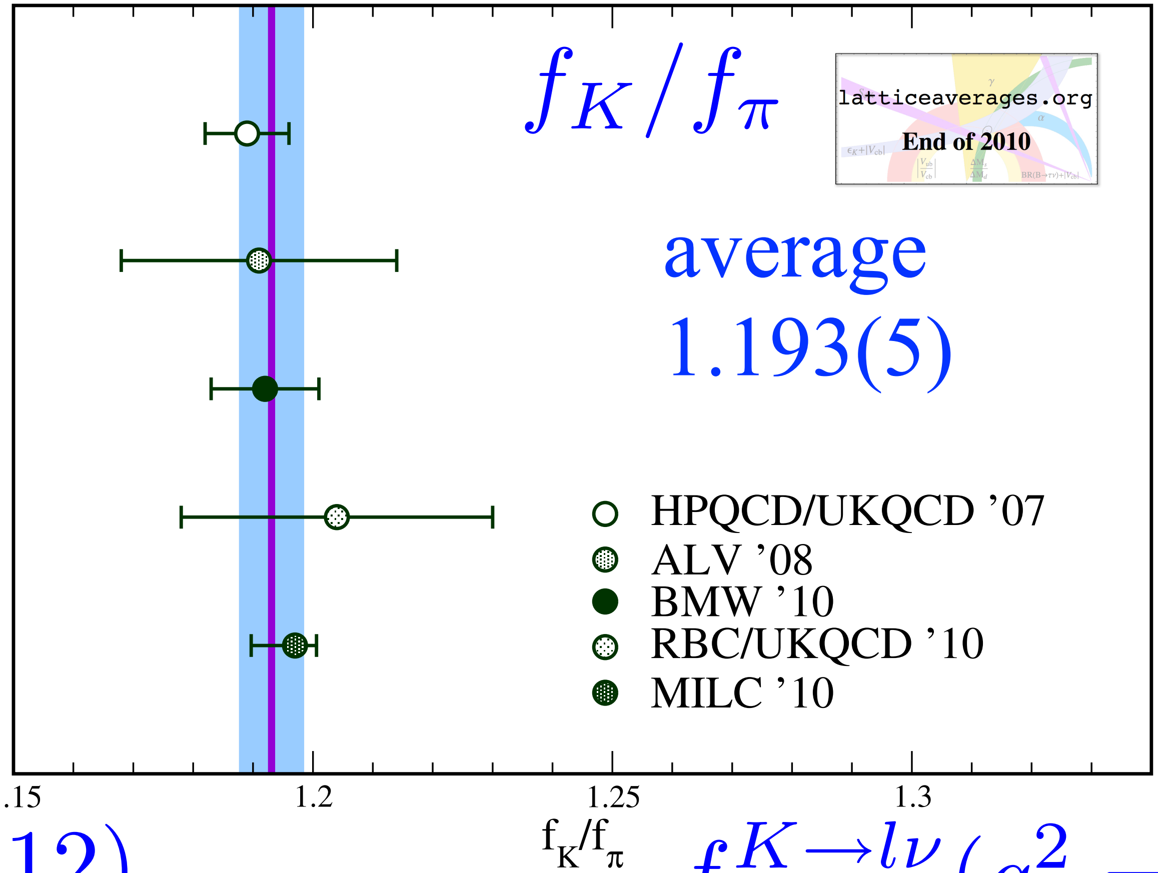
Error now < 0.5% using lattice QCD

Leptonic rate

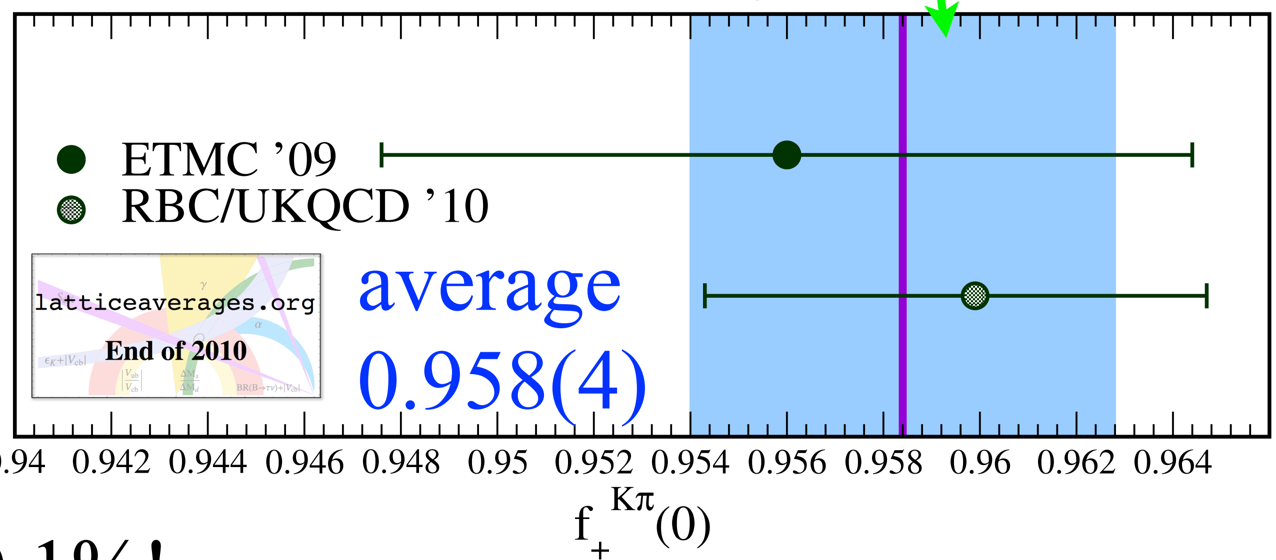
experiment e.g.KLOE:

$$\frac{\Gamma(K \to \mu\nu)}{\Gamma(\pi \to \mu\nu)} = 1.334(5)$$

gives: $V_{us} = 0.2252(12)$



$f_+^{K\to l\nu}(q^2 = 0)$



Semi-leptonic expt:

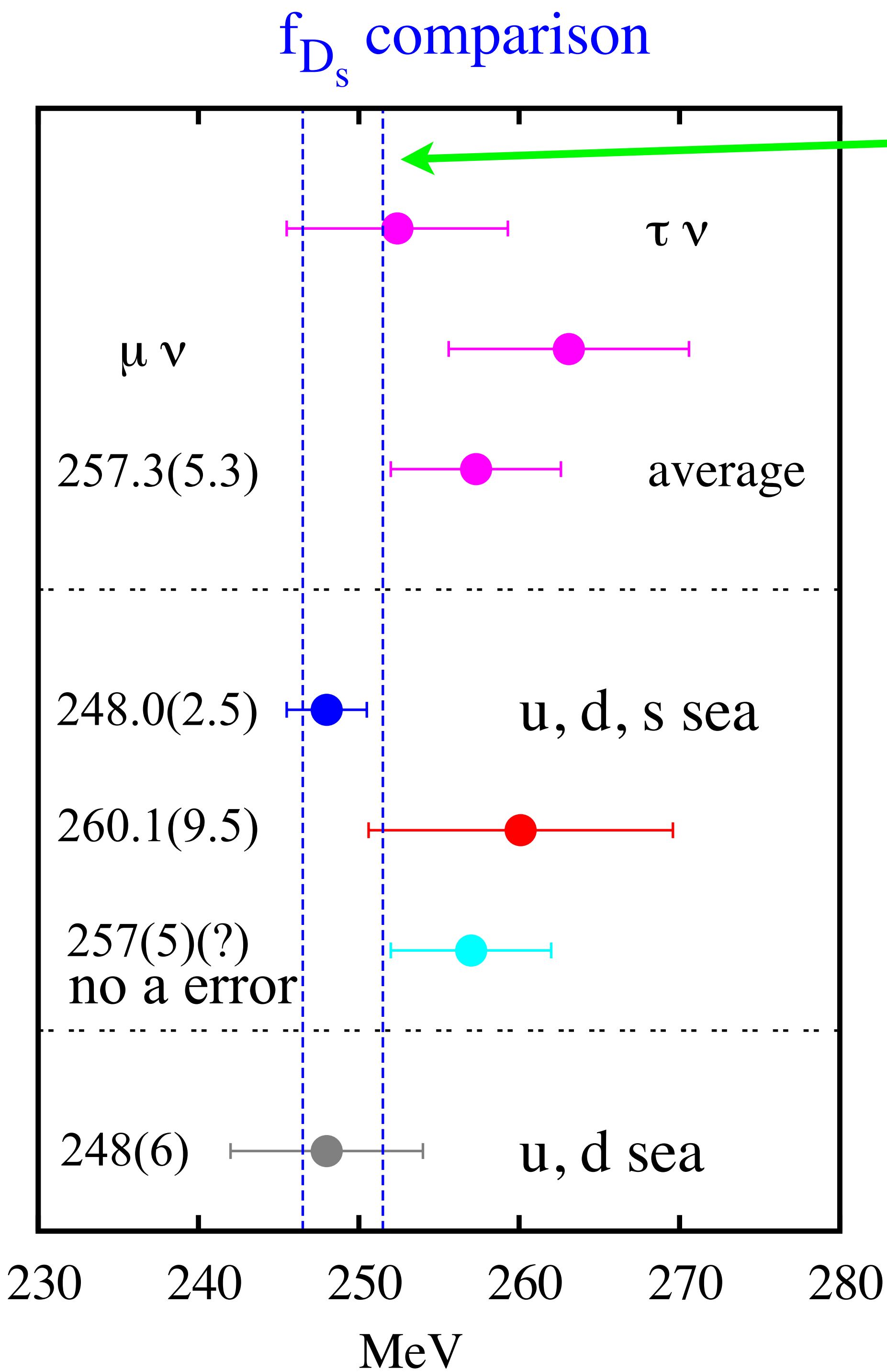
$f_+(0)V_{us} = 0.2166(5)$

gives:

$V_{us} = 0.2261(10)$

first row unitarity to < 0.1%!

D_s decay constant - update 2011



av. of HPQCD
Fermilab/MILC
=248.8(2.4) MeV

HFAG, Oct.10 using unitarity V_{cs}

CLEO, BaBar - BES will improve ....

1.6σ

HPQCD HISQ
1008.4018

HISQ, 5 a to 0.04fm
$m_{u,d}$ extrapoln

*

FNAL/MILC LAT11
Neil (poster)

Fermilab, a=0.12,0.09fm
$m_{u,d}$ extrapoln

PACS-CS RHQ
1104.4600 Namekawa (Wed)

RHQ, a=0.09fm
$m_{u,d}$ physical

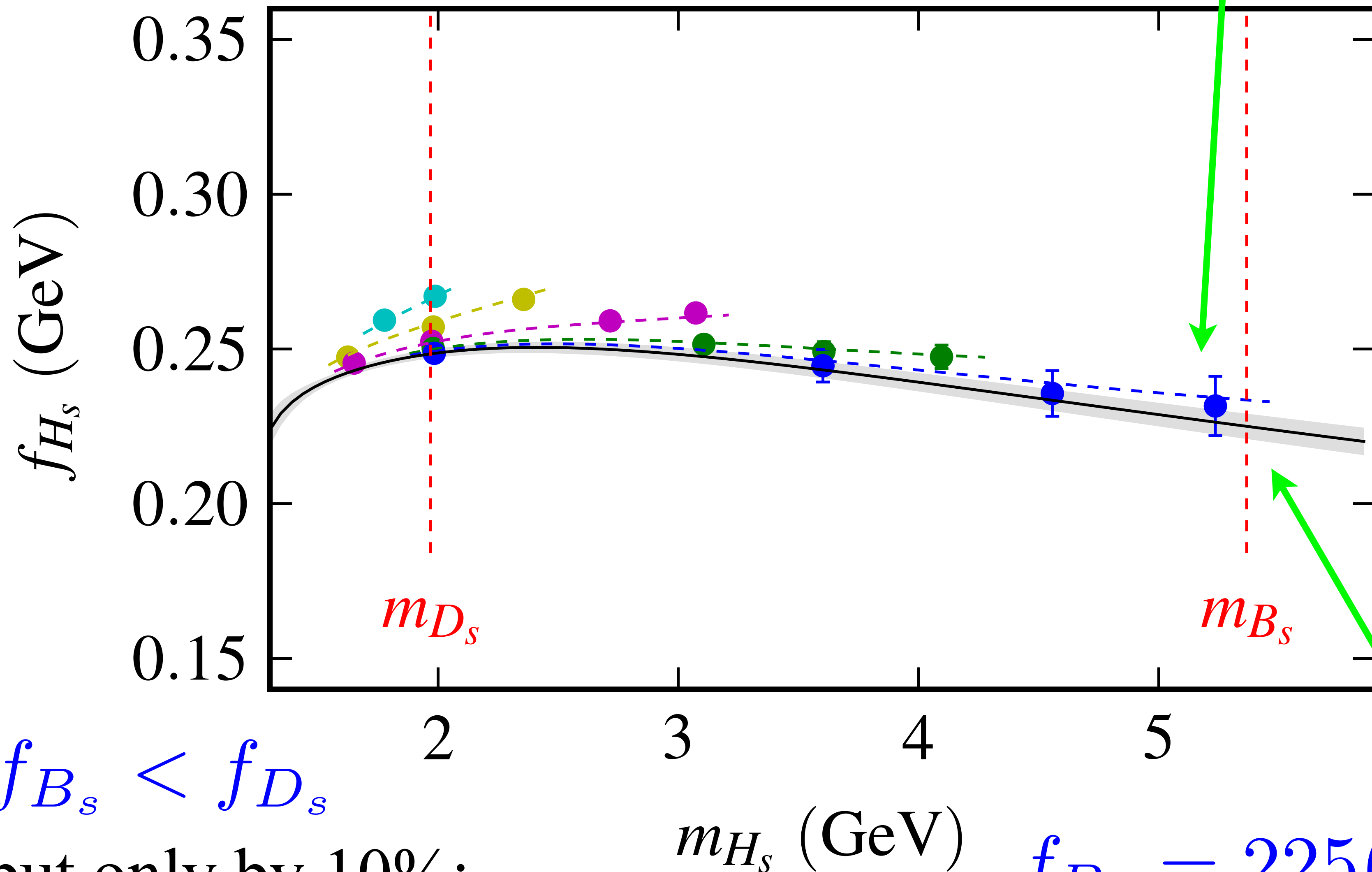
ETMC 1107.1441

TM, 4 a to 0.05fm
$m_{u,d}$ extrapoln

Mapping out dependence on heavy quark mass ...

uses HISQ and multiple m and a. Finest: a=0.045fm

HPQCD:
C McNeile
et al,
1110.4510.



$f_{B_s} < f_{D_s}$

but only by 10%:

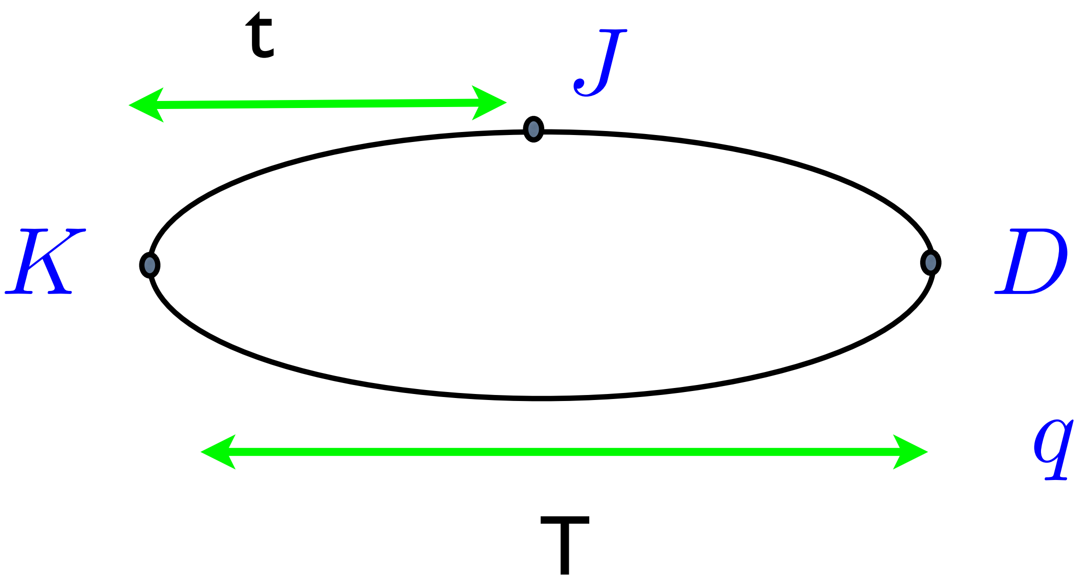
$f_{B_s}/f_{D_s} = 0.906(14)$

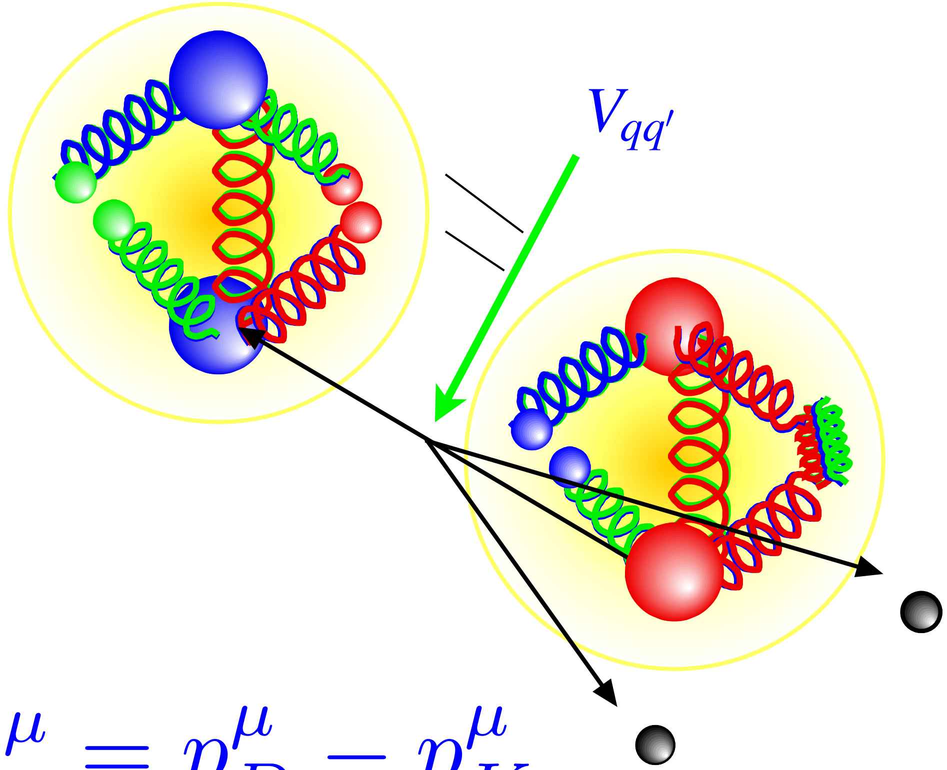
$f_{B_s} = 225(4)\text{MeV}$

expt: $f_B = 247(40)\text{MeV}$

Semileptonic form factors

3pt amp.





$$q^\mu = p_D^\mu - p_K^\mu$$

$$< K|V^\mu|D >= f_+(q^2)\left[p_D^\mu + p_K^\mu - \frac{M_D^2 - M_K^2}{q^2}q^\mu\right]$$

$$+f_0(q^2)\frac{M_D^2 - M_K^2}{q^2}q^\mu$$

meas. by expt

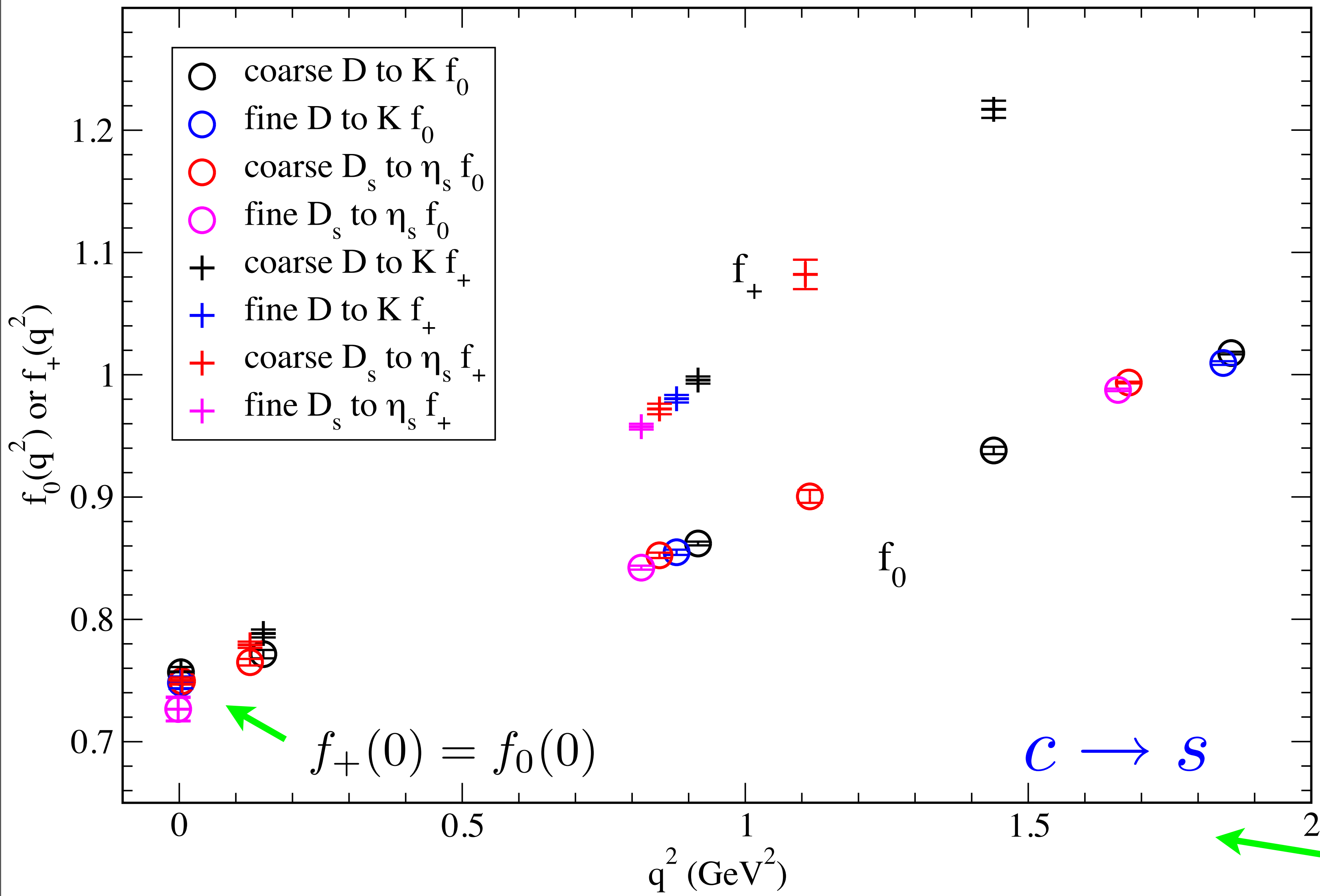
$D \to Kl\nu$

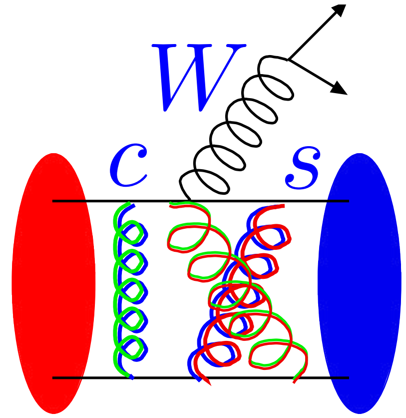
$$f_0(0) = f_+(0)$$

$$< K|S|D >= \frac{M_D^2 - M_K^2}{m_{0c} - m_{0s}} f_0(q^2)$$

abs. norm. for same c/s action HPQCD: 1008.4562

Semileptonic form factors for charmed mesons:





J. Koponen et al, HPQCD, LAT11

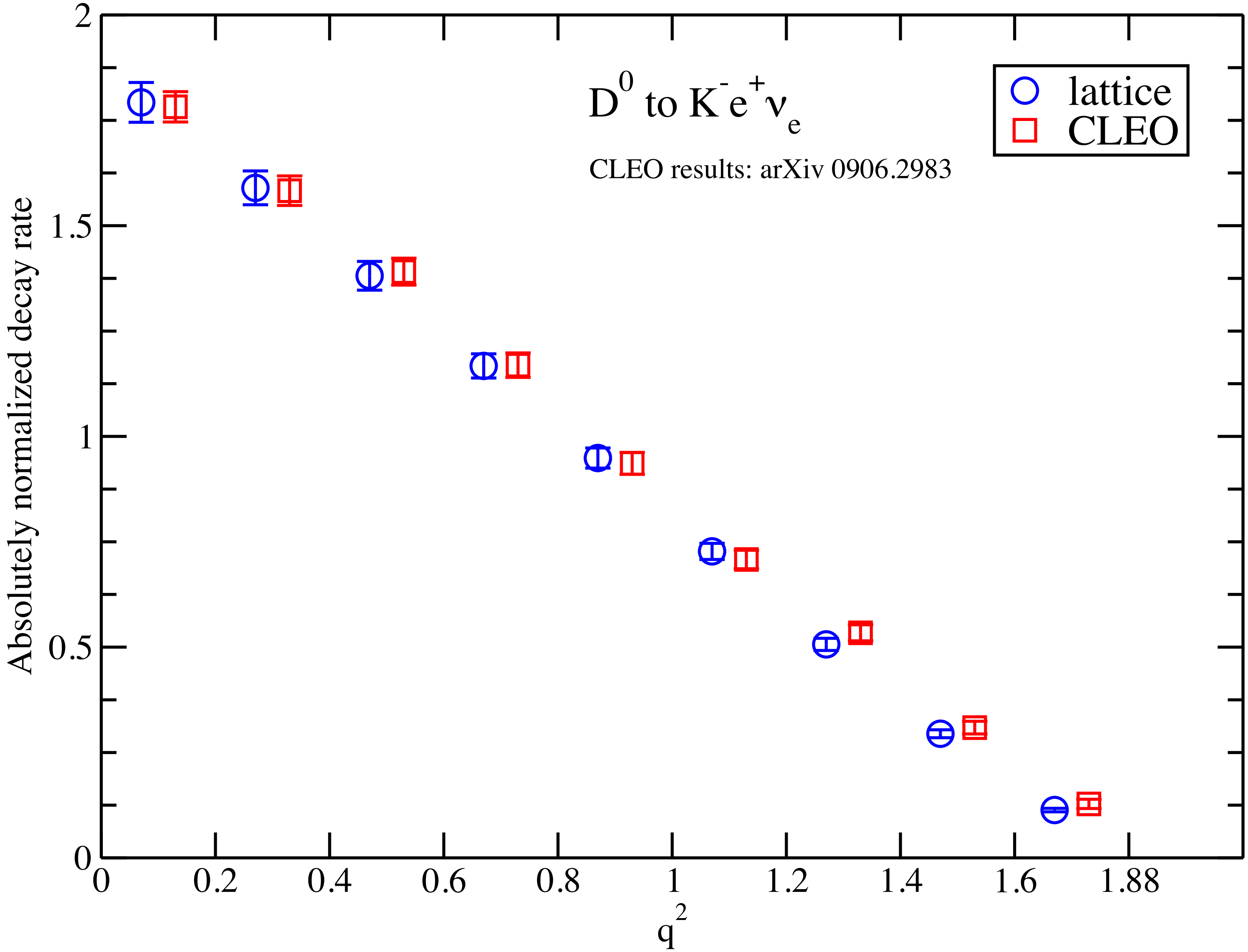
q^2 is 4-mom transfer between D and outgoing meson

Comparison to expt gives more detailed test of QCD.
Note: form factor seems to be independent of spectator quark in decay. (not predicted by QCD sum rules ....)

Convert to decay rate in q2 bins to compare to experiment:

$D \to K$

HPQCD PRELIMINARY



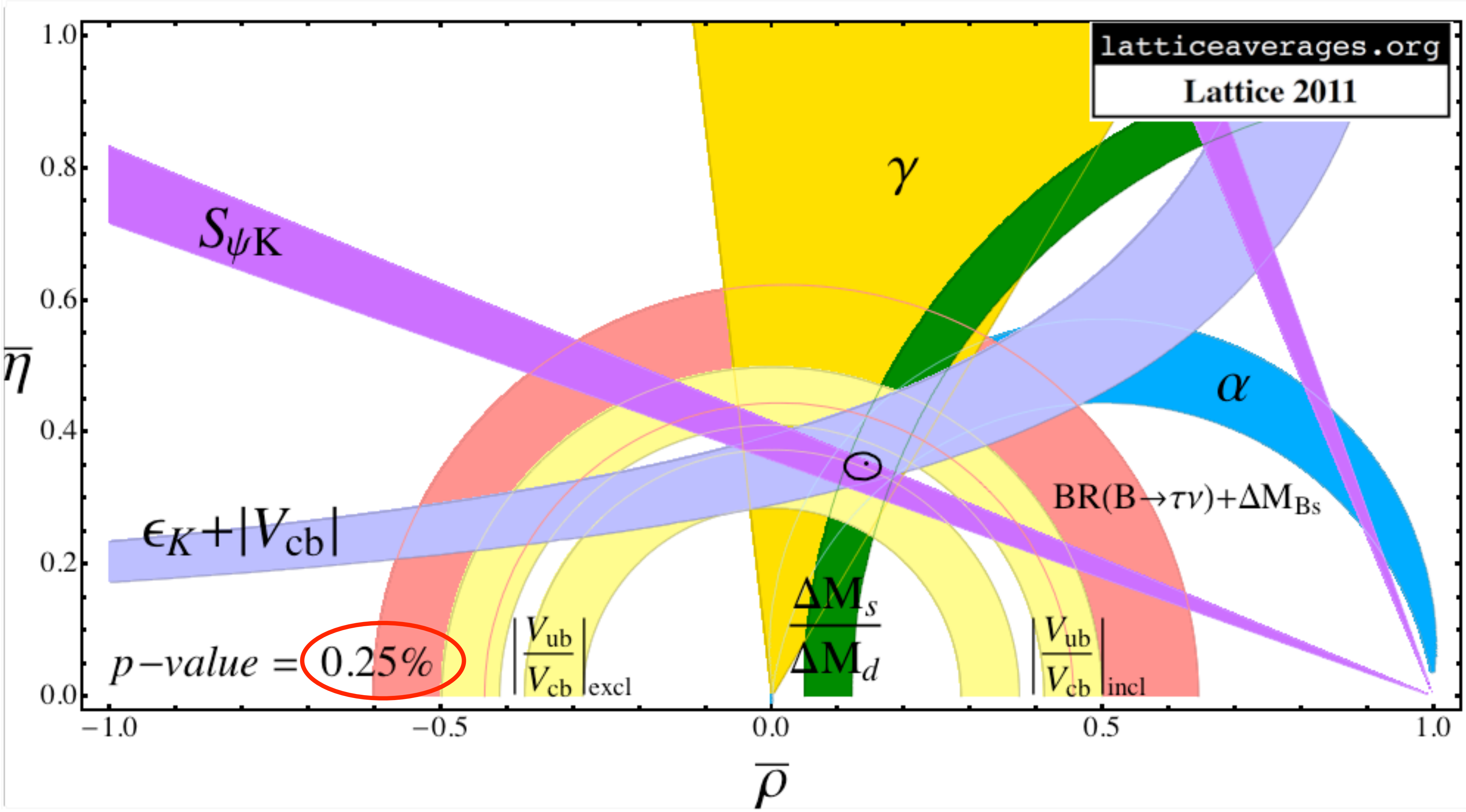
lattice and expt errors at 1-2%

using Vcs from unitarity

J. Koponen et al

UT fits using lattice QCD results

E. Lunghi, LAT11



Tensions in UT at 2-3σ level - improve precision further

Problems : $V_{ub,excl.} vs. V_{ub,incl.}$ excl. uses lattice, incl. does not
$\sin(2\beta) vs. \mathcal{B}r(B \to \tau\nu)$

Conclusion

• Lattice QCD results for gold-plated hadron masses and decay constants now very accurate. Gives QCD parameters and some CKM elements to 1%.. Info. appearing on how decay constants/form factors depend on quark masses.

Future

• sets of '2nd generation' gluon configs now have

$m_{u,d}$ at physical value (so no extrapoln) *or*

a down to 0.03fm (so b quarks are 'light') *or*

much higher statistics (for harder hadrons)

also can include charm in the sea now.

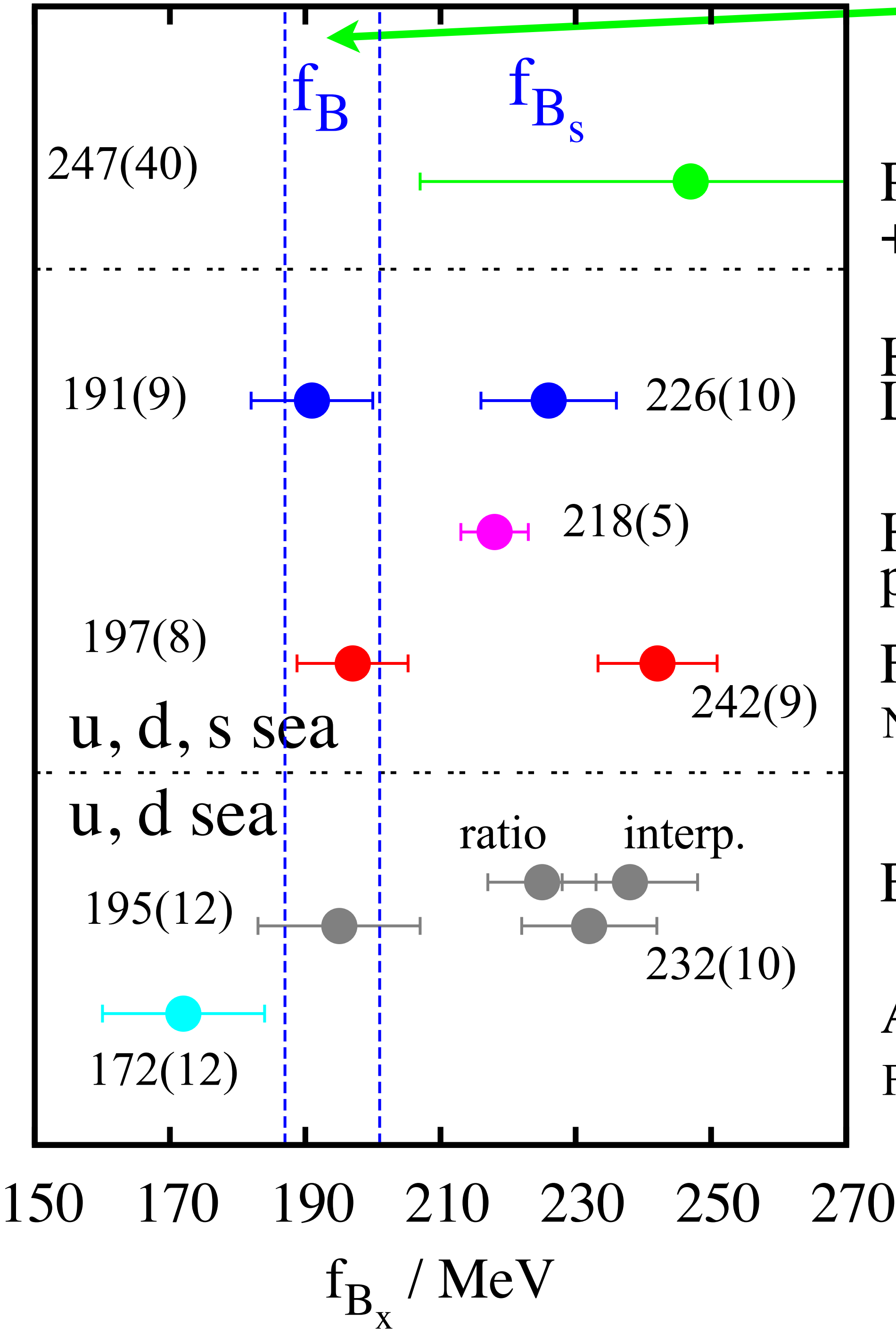
• Pushing errors down to 1% level for B physics still a lot of work but for ratios Bs/B will certainly be possible.

• Harder calculations (flavor singlet, excited states, nuclear physics) will improve

Spares

B, B_s decay constant update 2011

f_B average : 194(7) MeV
down from 2010



PDG av BR(B->τν)
+ PDG av Vub

f_B expt
(B_s has no leptonic decay)

HPQCD NRQCD LAT11 Shigemitsu (Mon)

HPQCD HISQ prelim.

2.4σ
apart for f_{Bs}

FNAL/MILC LAT11
Neil (poster)

ETMC 1107.1441

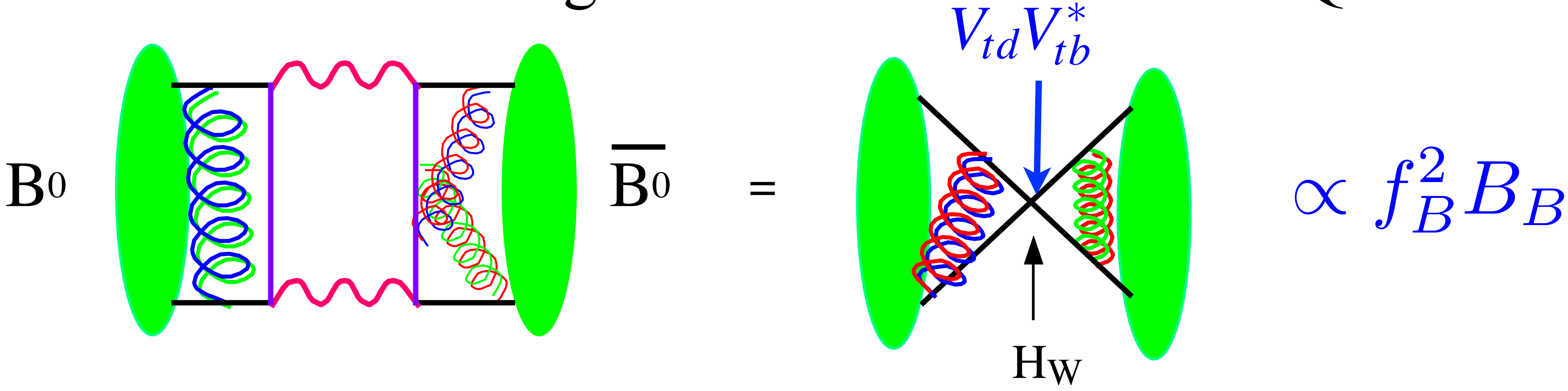
ALPHA LAT11
Fritzsch (Fri)

static +1/M
cont. + chiral extrap
a:0.075,0.065,0.048 fm

NOTE:
$f_{Bs} < f_{Ds}$ now quite clear

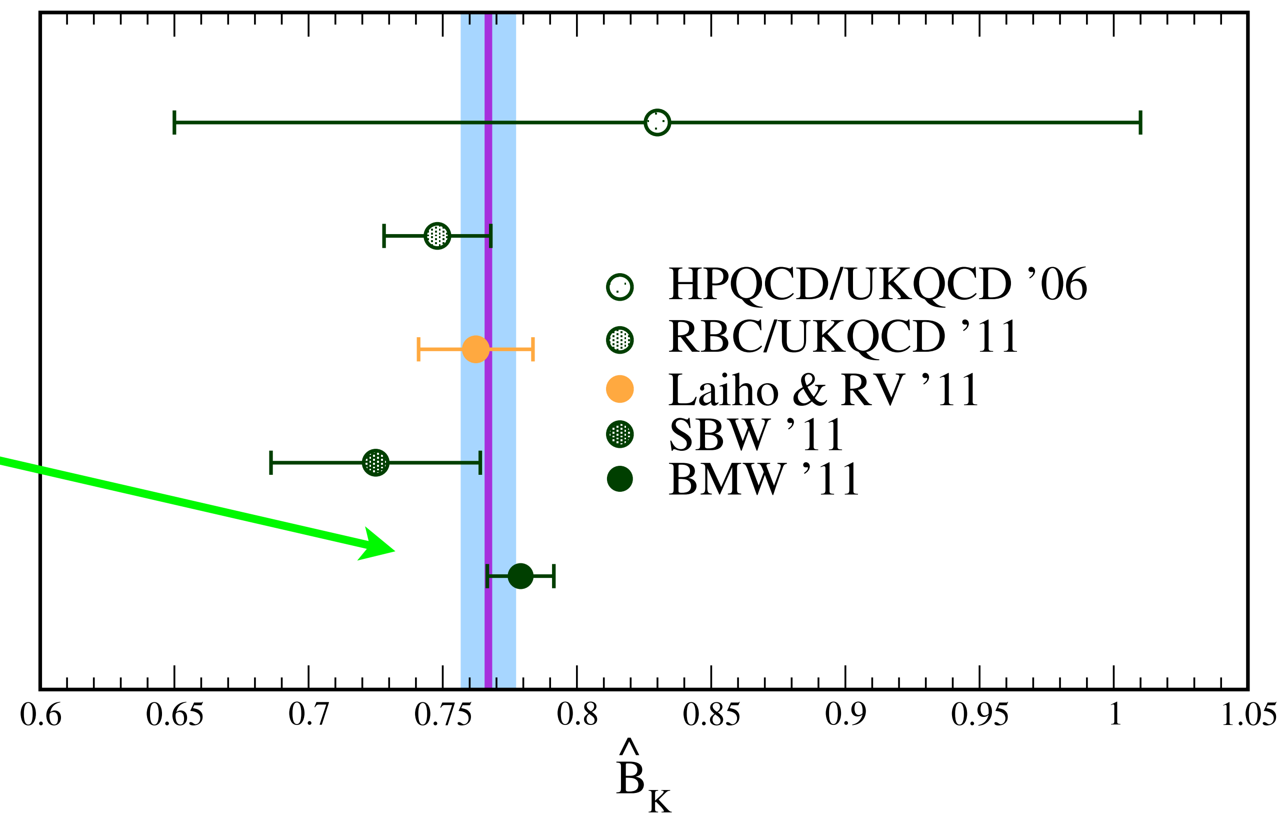
Neutral K and B mixing and oscillations

Result from "box diagram". Calculate in lattice QCD



2011 lattice QCD :
New B_K results
leads to 1.5% error.

Average: 0.767(10)



R. van de Water et al, + E. Lunghi, LAT11

Sunday, 15 January 2012

B_{B_s}, B_{B_d} less accurate since using nonrelativistic b

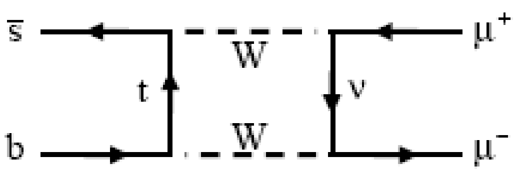
$$\xi = \frac{f_{B_s}\sqrt{B_{B_s}}}{f_B\sqrt{B_B}} = 1.26(3) \rightarrow \frac{|V_{td}|}{|V_{ts}|} = 0.214(5)$$

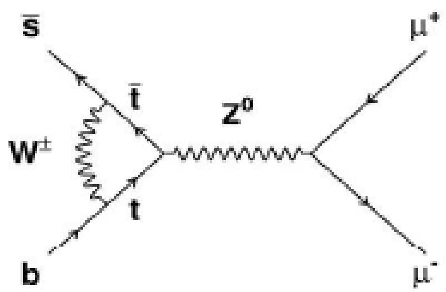
normln error cancels in ratio.

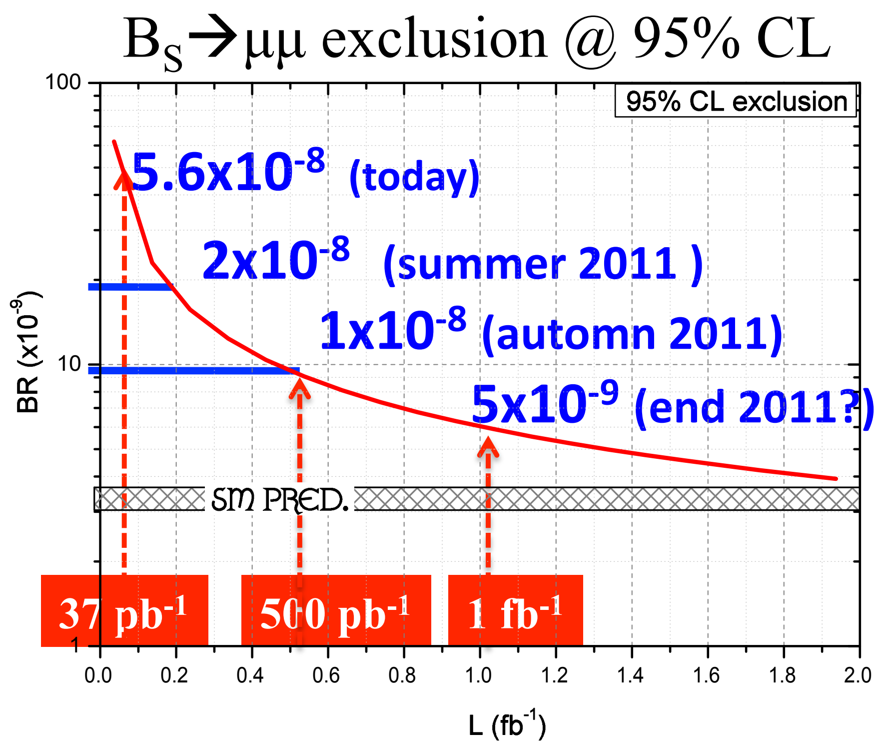
E. Gamiz et al, HPQCD, 0902.1815

Use to provide SM rate for LHCb of:

$$Br(B_s \to \mu^+\mu^-) = 3.19(19) \times 10^{-9}$$







LHCb/CMS limit : 1.1×10^{-8}

Need to improve lattice QCD error ..

G. Wilkinson, EPS11

Look at error budgets to see how things will improve in future ...

stats
tuning
chiral
continuum

$$\Delta_q = 2m_{Dq} - m_{\eta c}$$

	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

for different quantities different systematics are important