Results from Lattice QCD 2011

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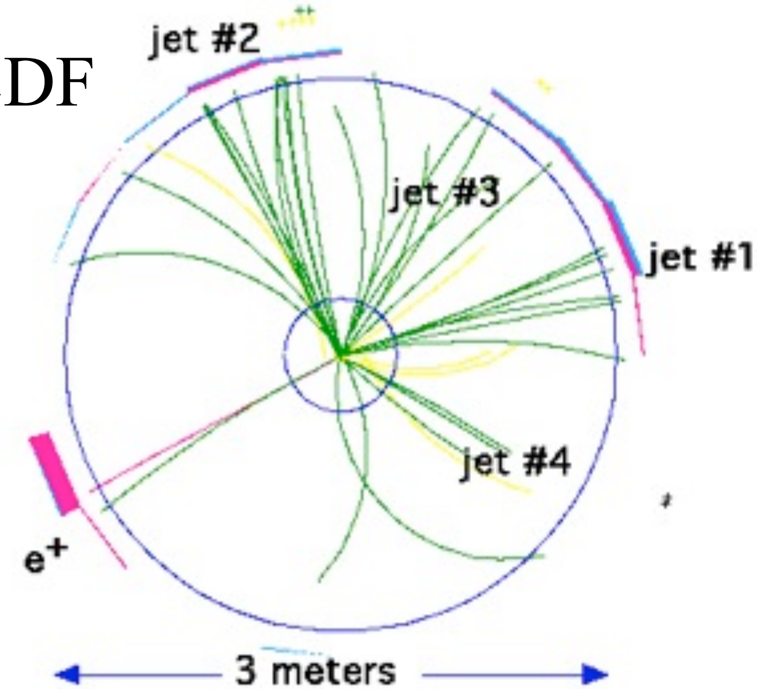
HPQCD collaboration

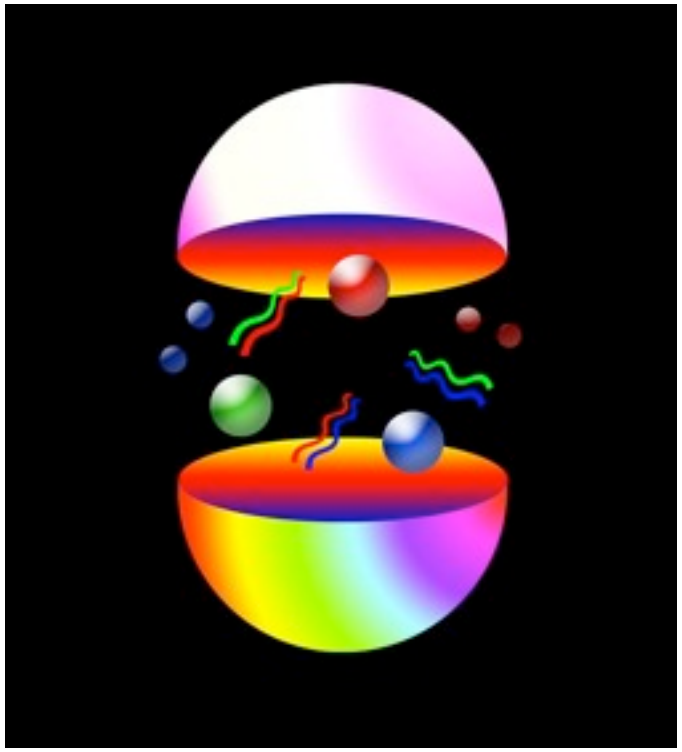
Physics in Collision
August 2011

QCD is a key part of the Standard Model but quark confinement complicates things.

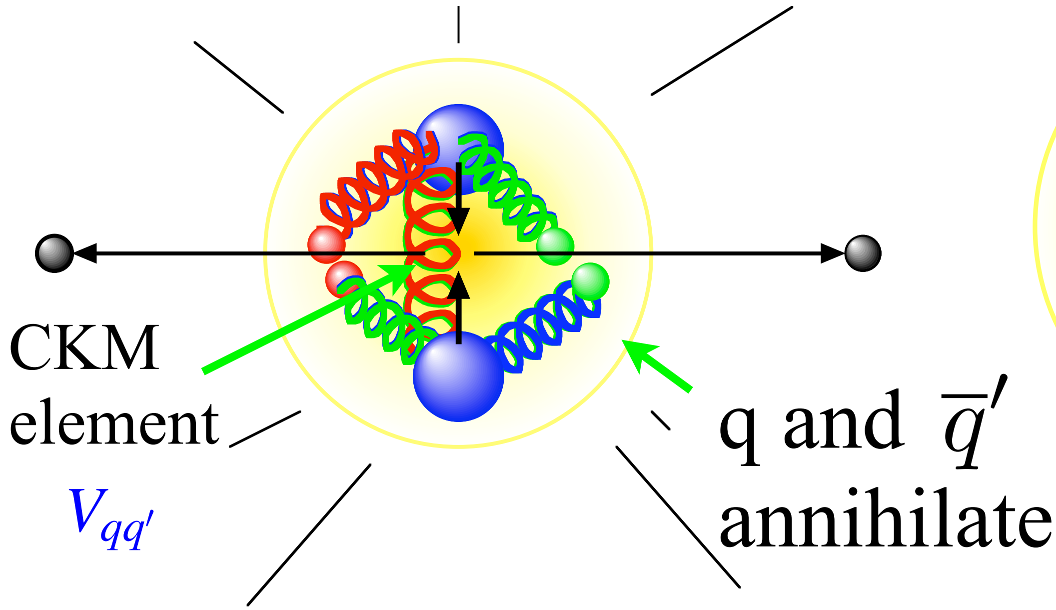
CDF

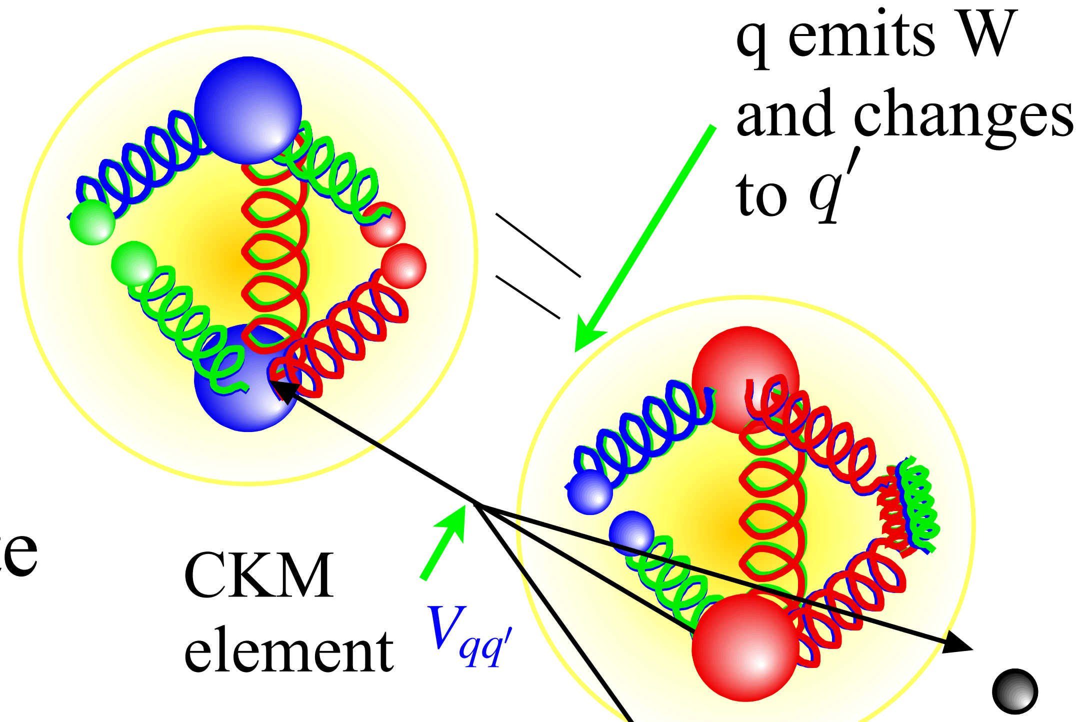


Cross-sections calculated at high energy using QCD pert. th. NLO gives ~5% errors. Also have pdf and hadronisation uncertainties



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



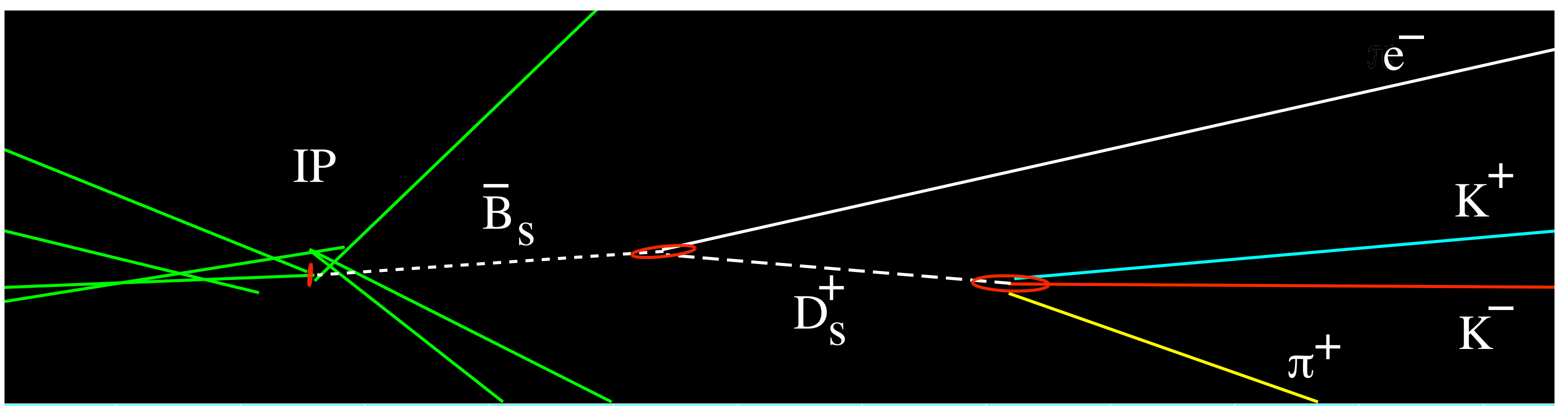


Rates for simple weak or em quark processes inside hadrons also calculable, but *not* multi-hadron final states.

$\overline{B}_s \longrightarrow D_s e^- \nu$

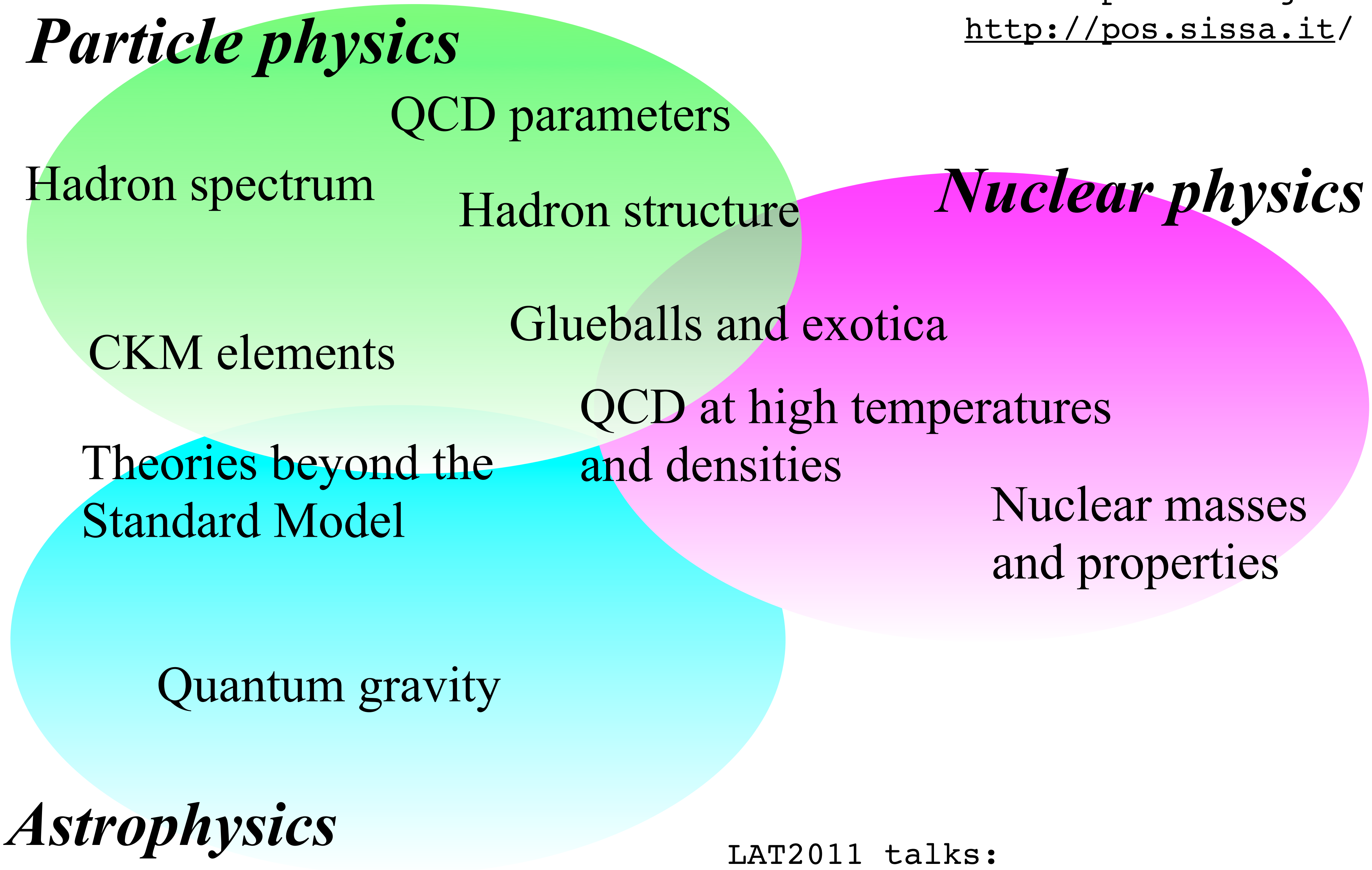
ALEPH $(D_S \longrightarrow K^+ K^- \pi^+)$

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

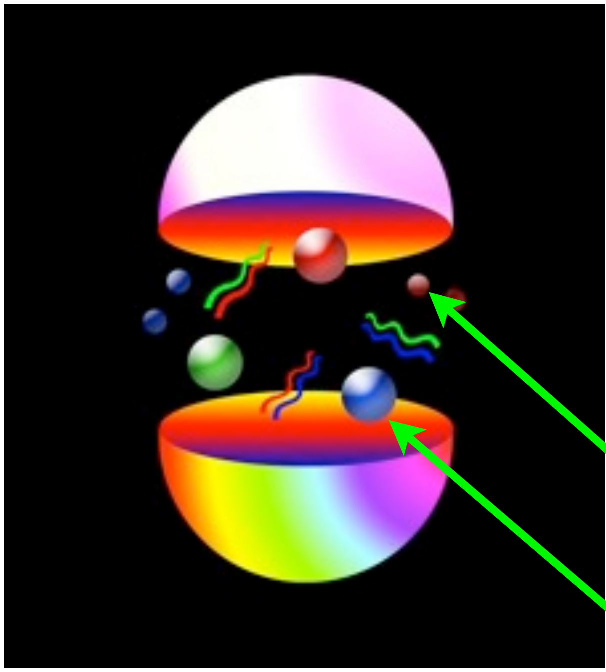


Applications of Lattice QCD/Lattice field theory

Annual proceedings:
http://pos.sissa.it/



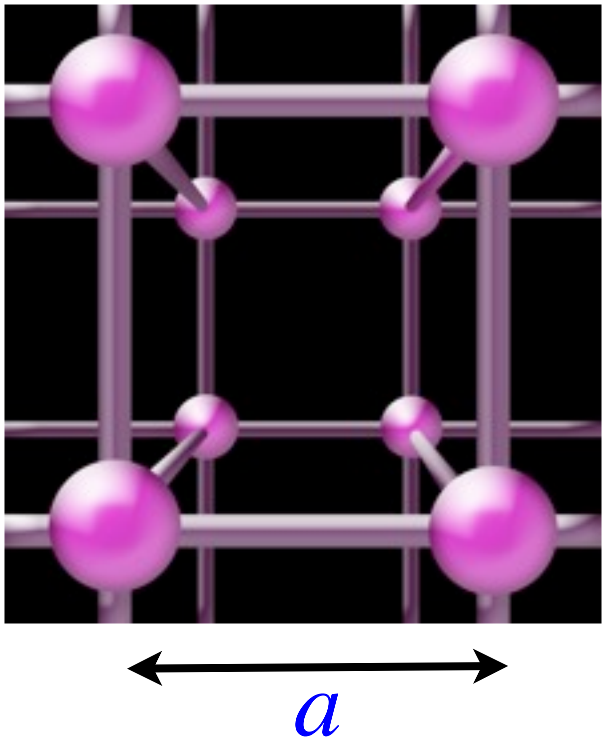
LAT2011 talks:
https://lat11.llnl.gov/index.php



Lattice QCD = fully nonperturbative QCD calculation

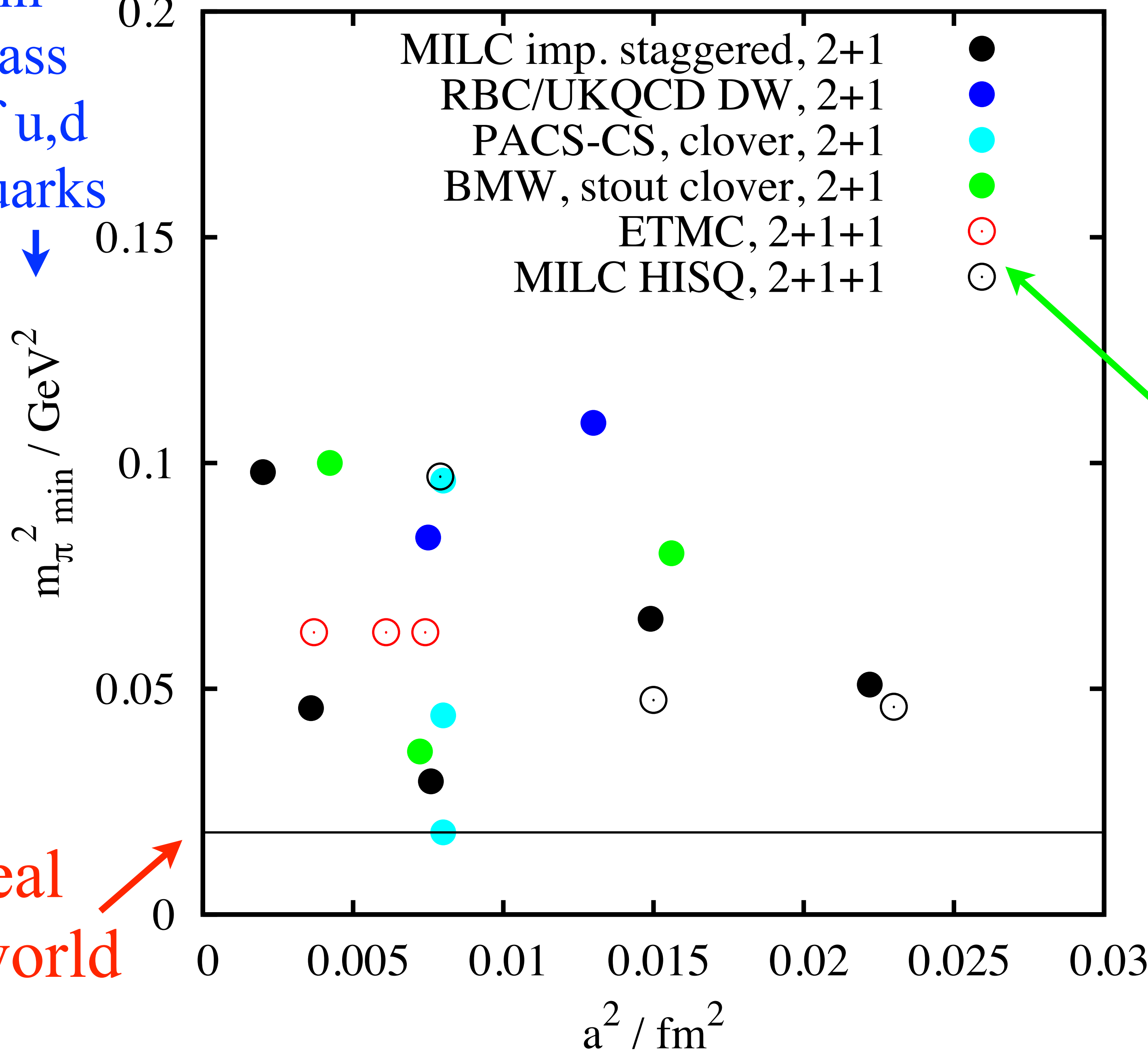
RECIPE

- Generate sets of gluon fields for Monte Carlo integrn of Path Integral (inc effect of u, d and s 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.

min mass of u,d quarks



real world

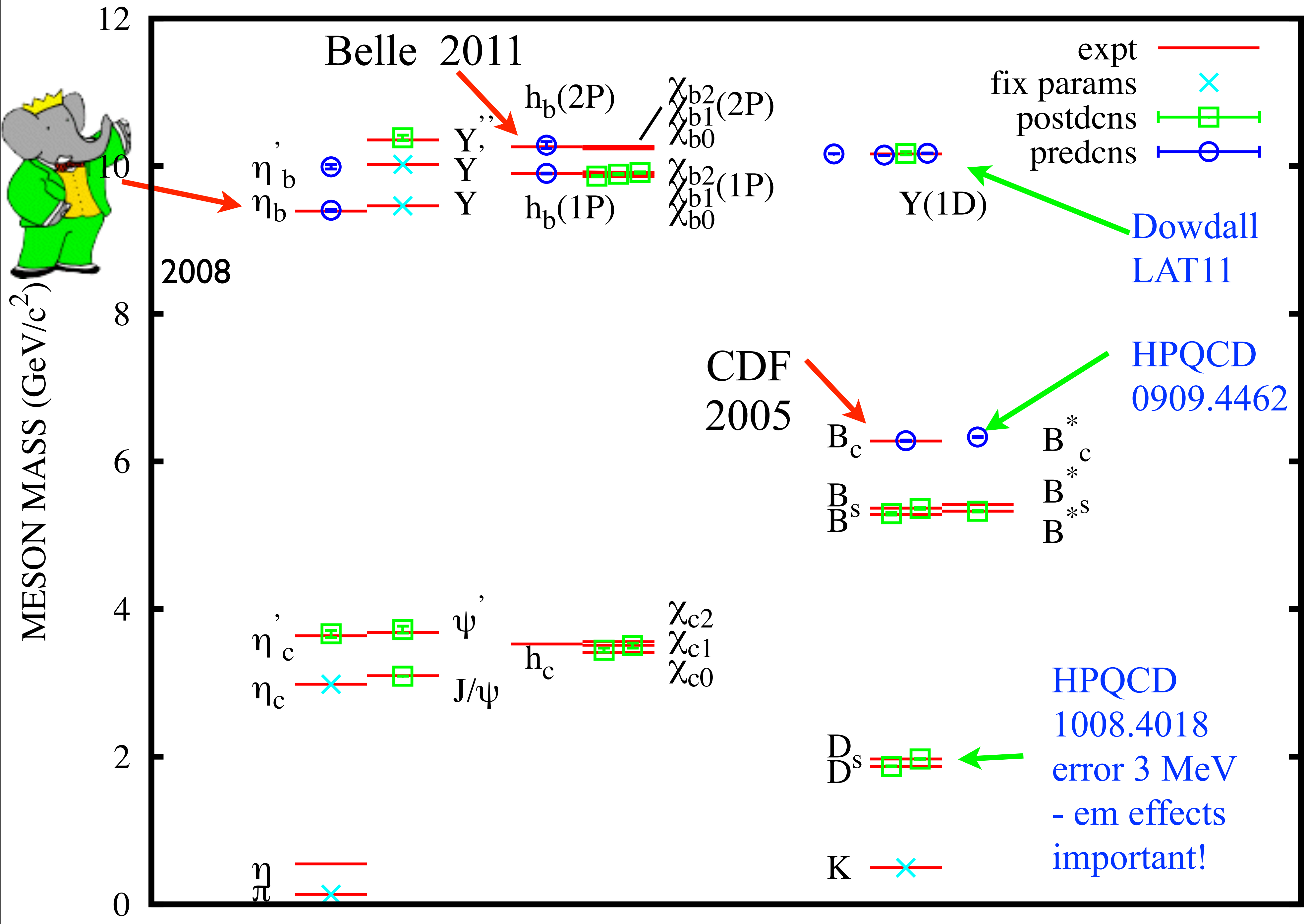
Volume of lattice also an issue - need $m_\pi L > 3$

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

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

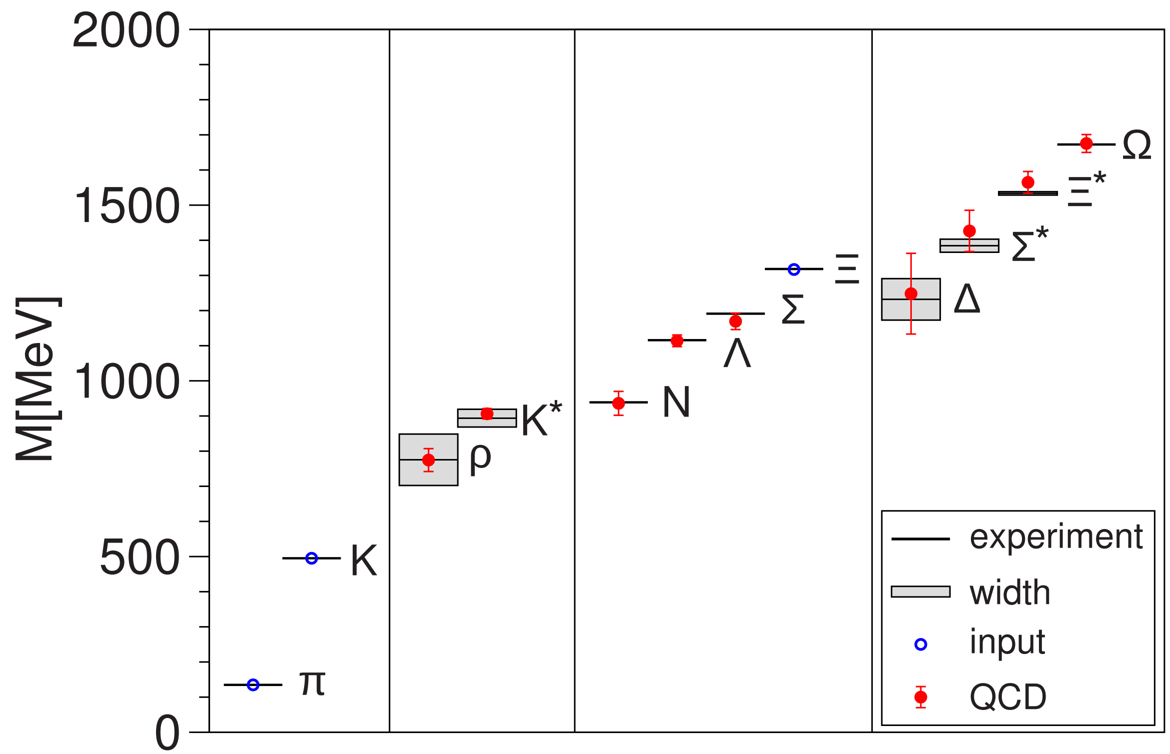
$m_{u,d} \approx m_s/27$

The gold-plated meson spectrum - HPQCD

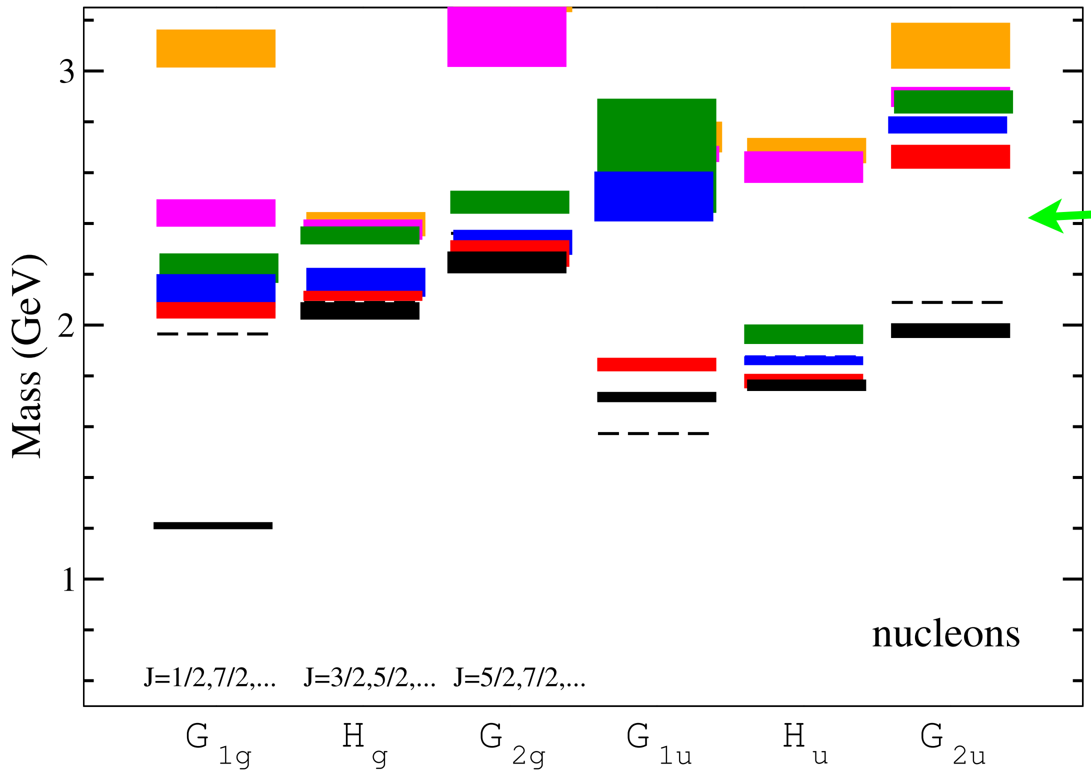


older predcns: I. Allison et al, hep-lat/0411027, A. Gray et al, hep-lat/0507013

Light hadron spectrum including baryons



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



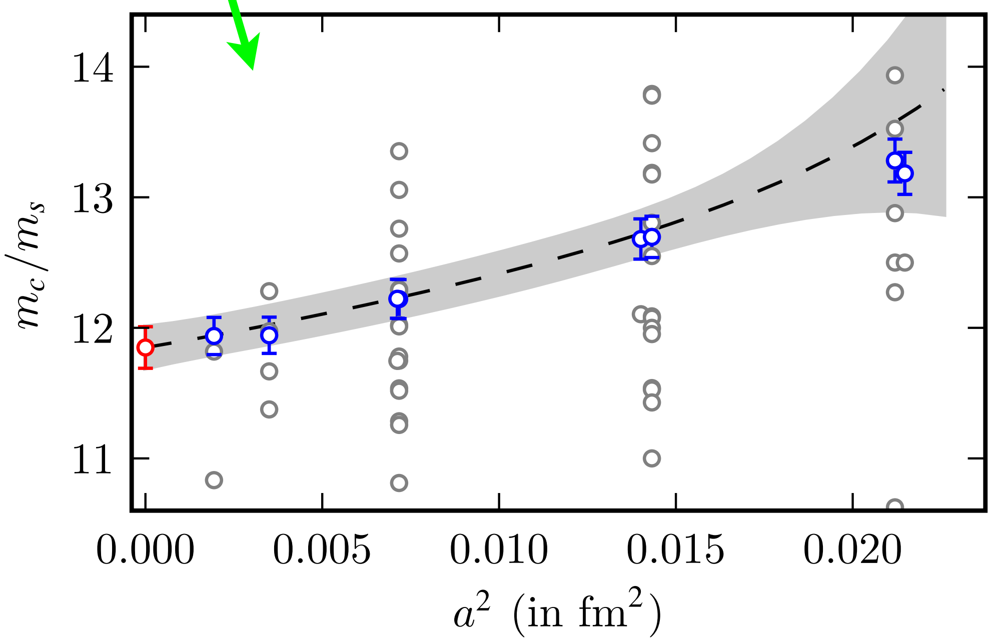
Excited nucleon spectrum - preliminary calculations inc. the effect of sea quarks, not yet at physical masses.

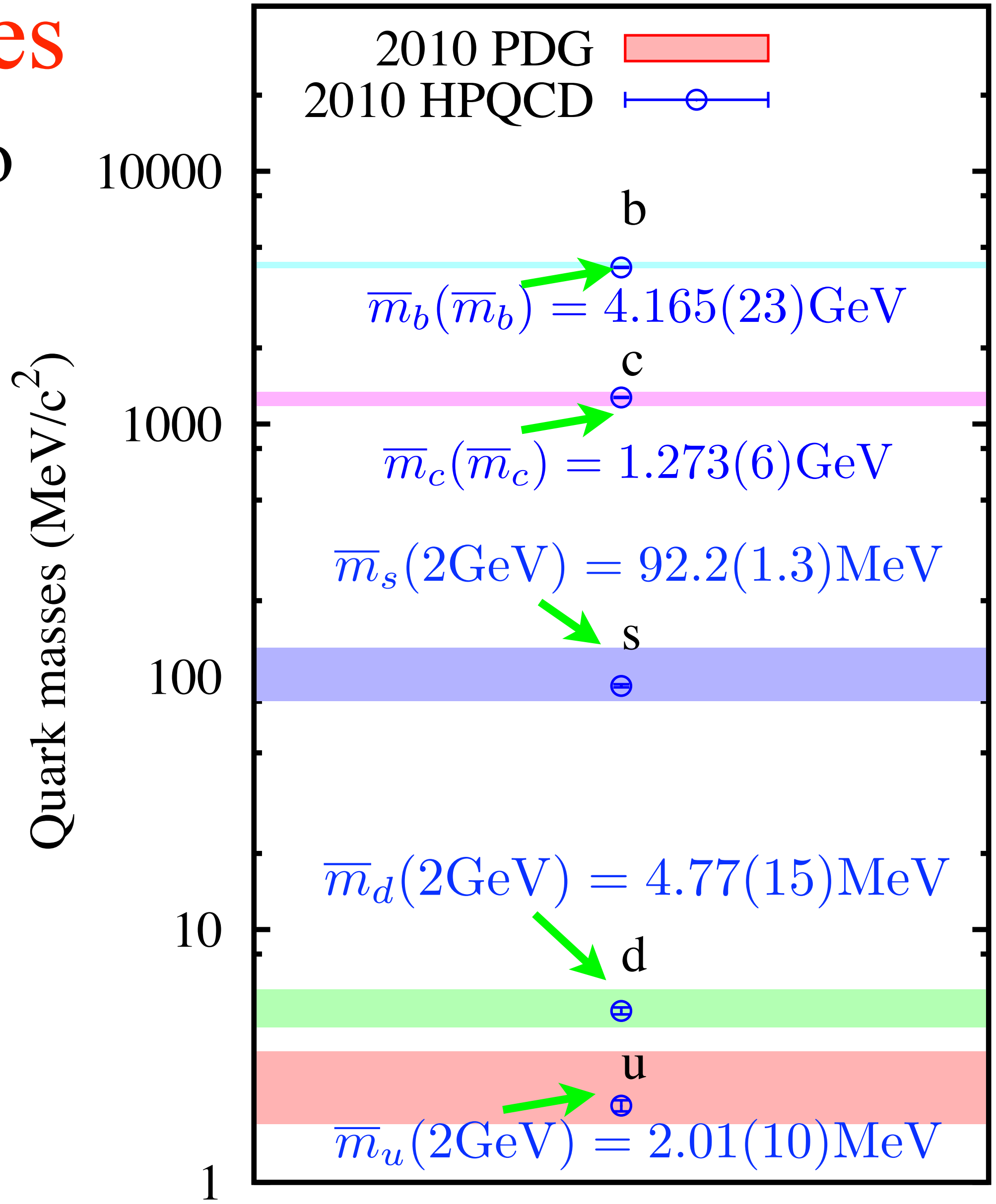
(Bulava et al, HadSpec, 1004.5072, LAT11)

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, $m_s/m_{u,d}$





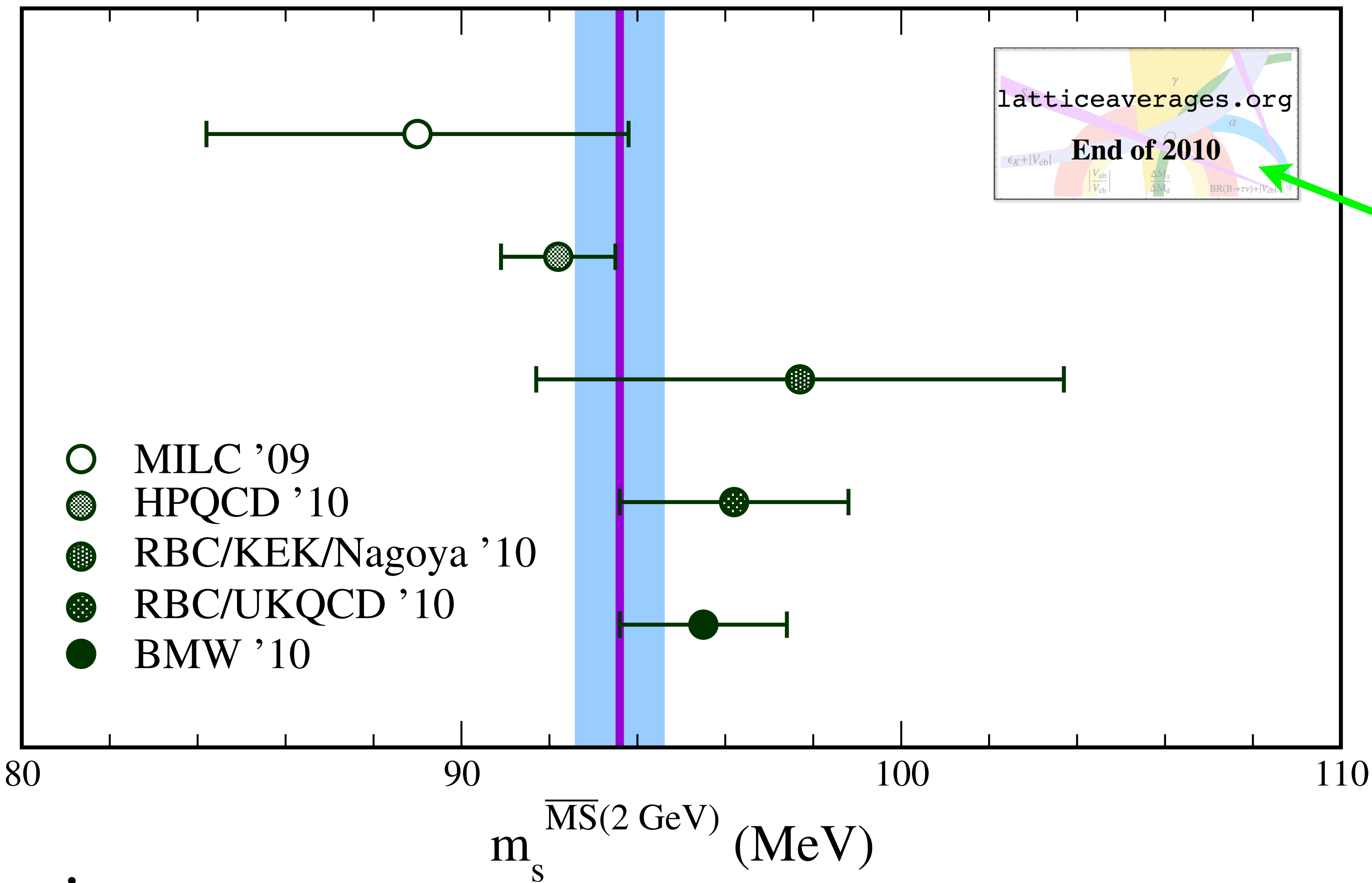
C. McNeile, CTHD et al, HPQCD, 0910.3102, 1004.4285

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

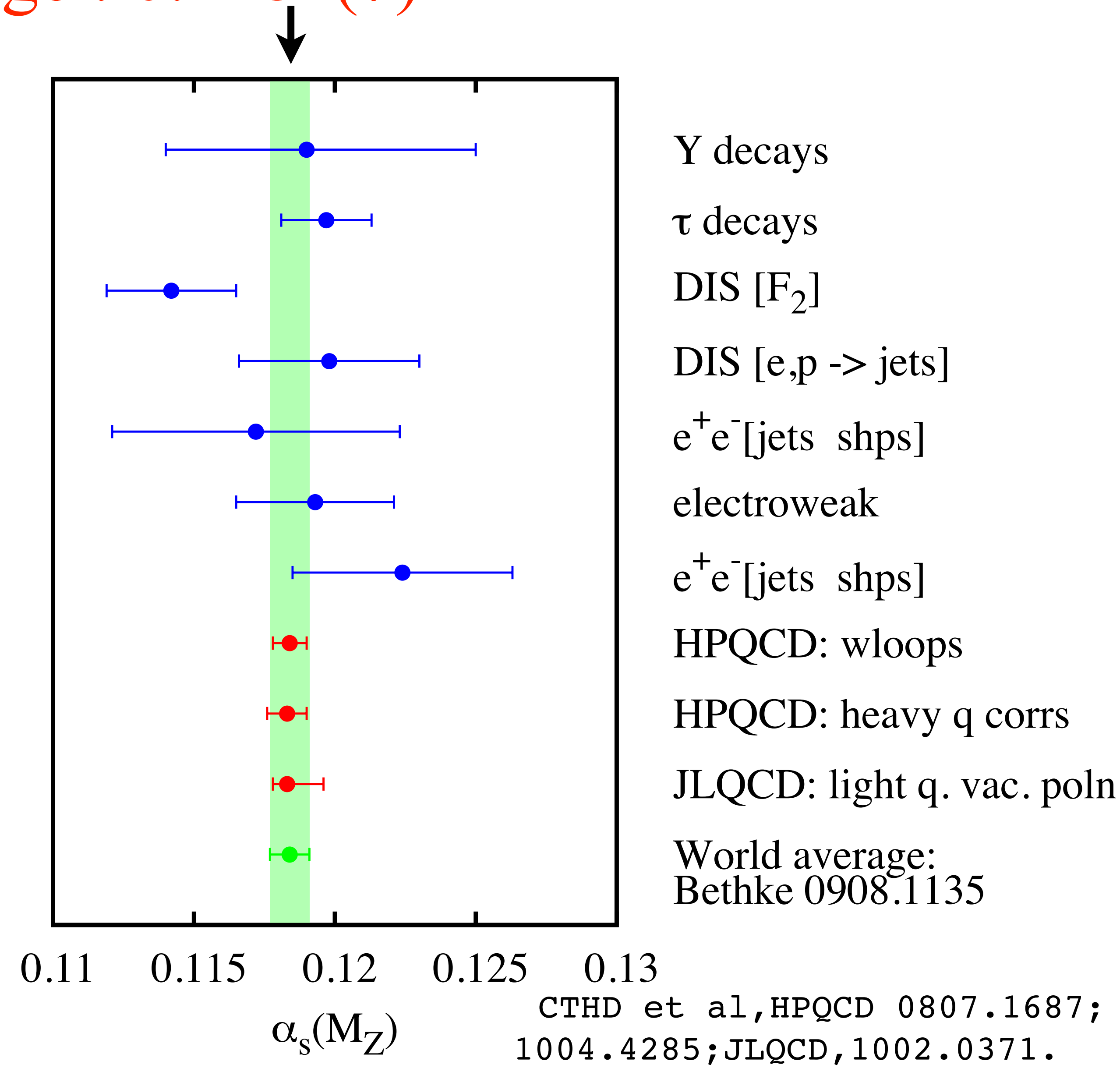
Lattice averages: $m_s = 93.6(1.1)\mathrm{MeV};\ \dfrac{m_s}{m_u + m_d} = 27.55(14)$

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

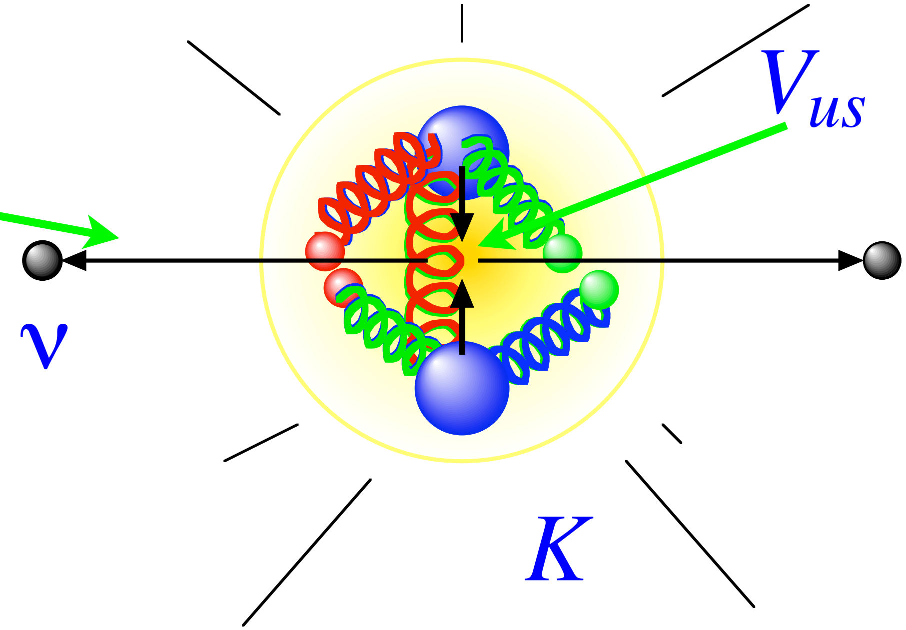


see 2011 Munich alphas workshop Shintani LAT11

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

Determining the Cabibbo-Kobayashi-Maskawa matrix

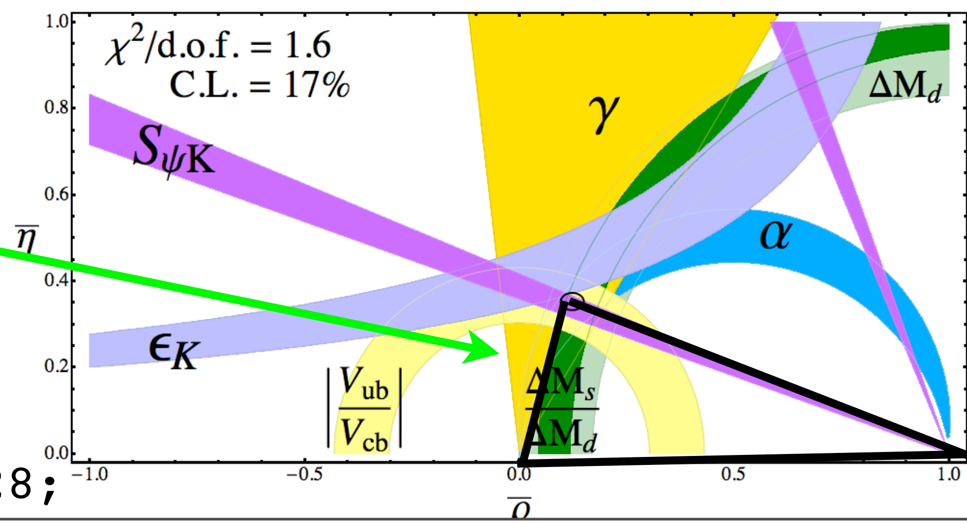
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ \pi \to l\nu & K \to l\nu & B \to \pi l\nu \\ & K \to \pi l\nu & \\ V_{cd} & V_{cs} & V_{cb} \\ D \to l\nu & D_s \to l\nu & B \to Dl\nu \\ D \to \pi l\nu & D \to Kl\nu & \\ V_{td} & V_{ts} & V_{tb} \\ \langle B_d|\overline{B}_d\rangle & \langle B_s|\overline{B}_s\rangle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



Expt = CKM x 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;

V_{us}

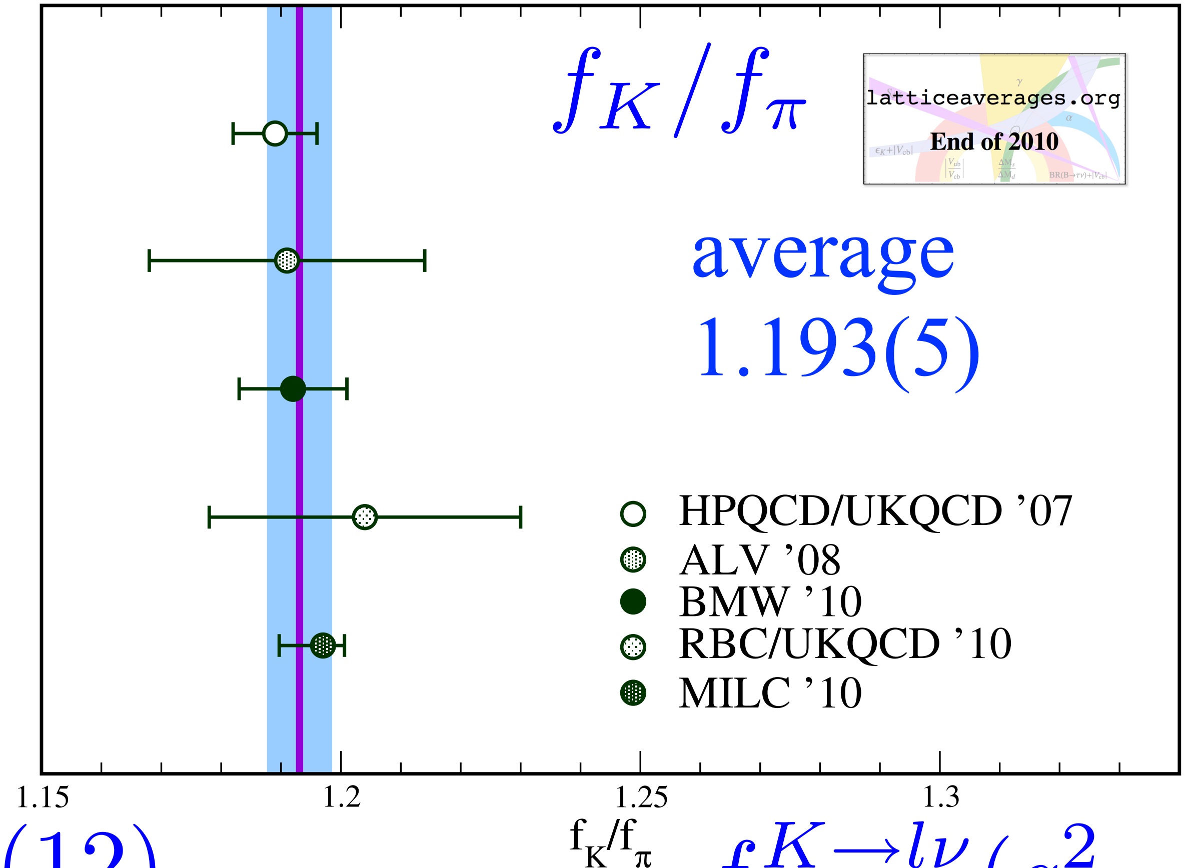
Error now < 0.5% using lattice QCD

Leptonic rate

experiment e.g.KLOE:

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

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



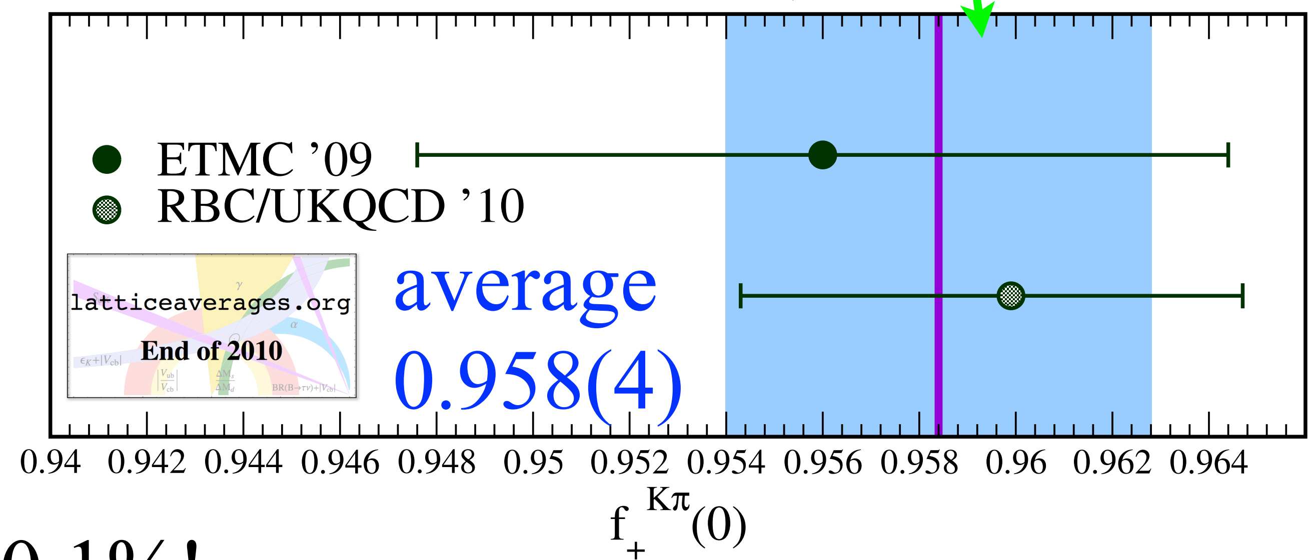
Semi-leptonic expt:

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

gives:

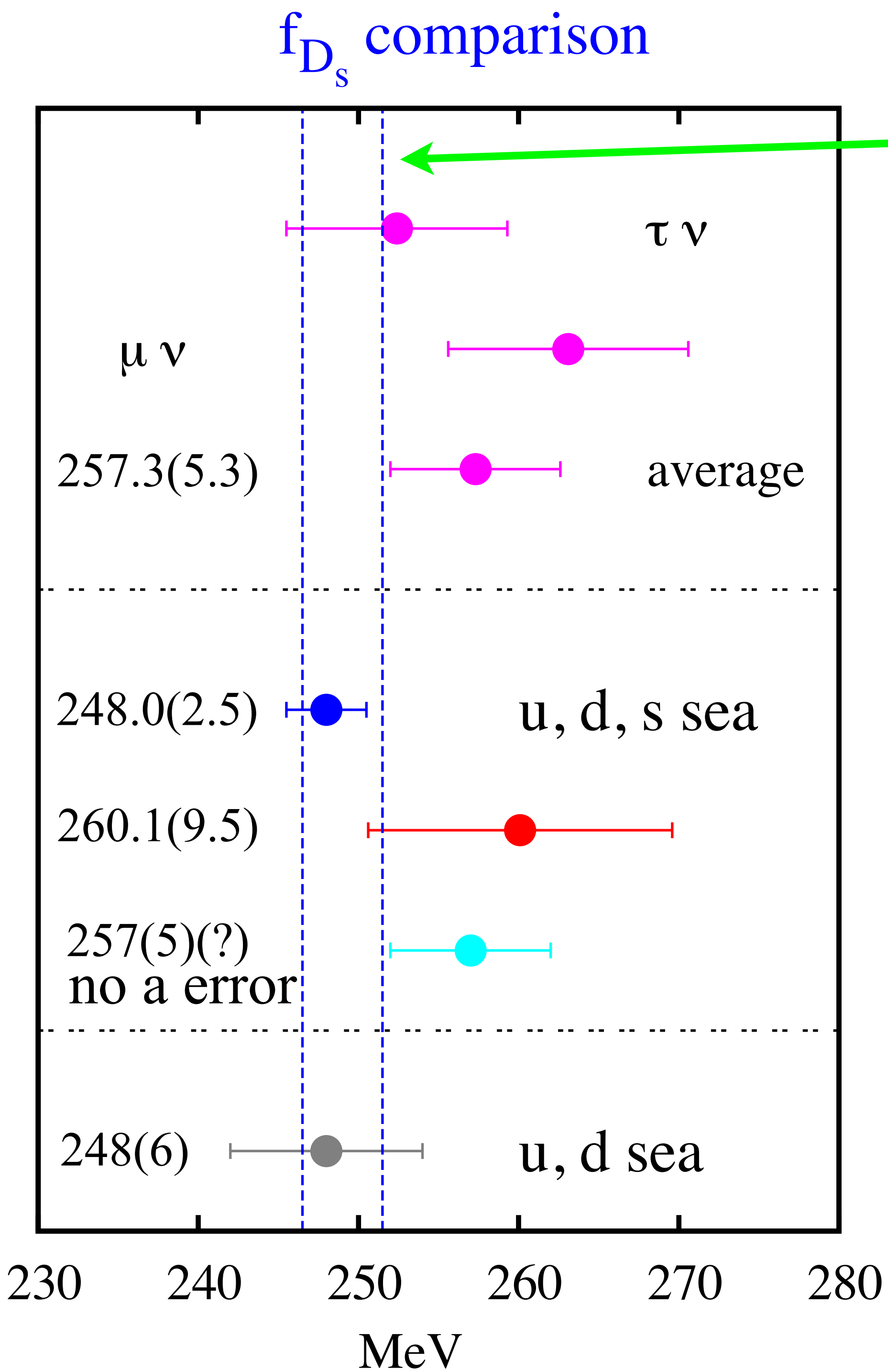
$$V_{us} = 0.2261(10)$$

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



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

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

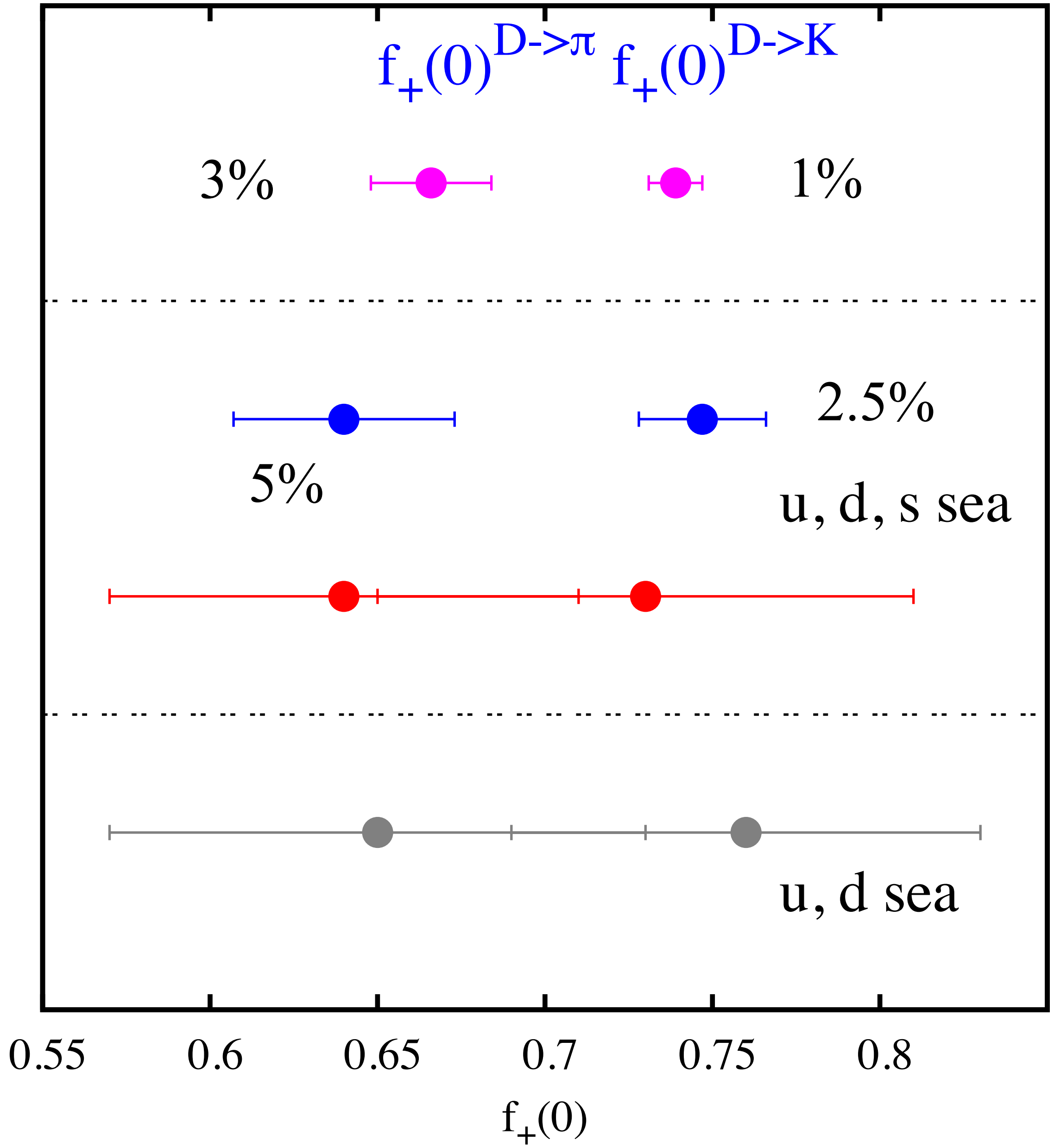
PACS-CS RHQ
1104.4600 Namekawa (Wed)

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

ETMC 1107.1441

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

Update on D meson semileptonic form factor, $f_+(0)$ 2011



using unitarity:

CLEO 0906.2983

$$V_{cs} = 0.97345(16)$$

$$V_{cd} = 0.2252(7)$$

HPQCD HISQ 1008.4562;LAT11 — 2 a values; scalar

FNAL/MILC hep-ph/0408306 — 1 a value; vector + FNAL renorm. Bailey (Wed)

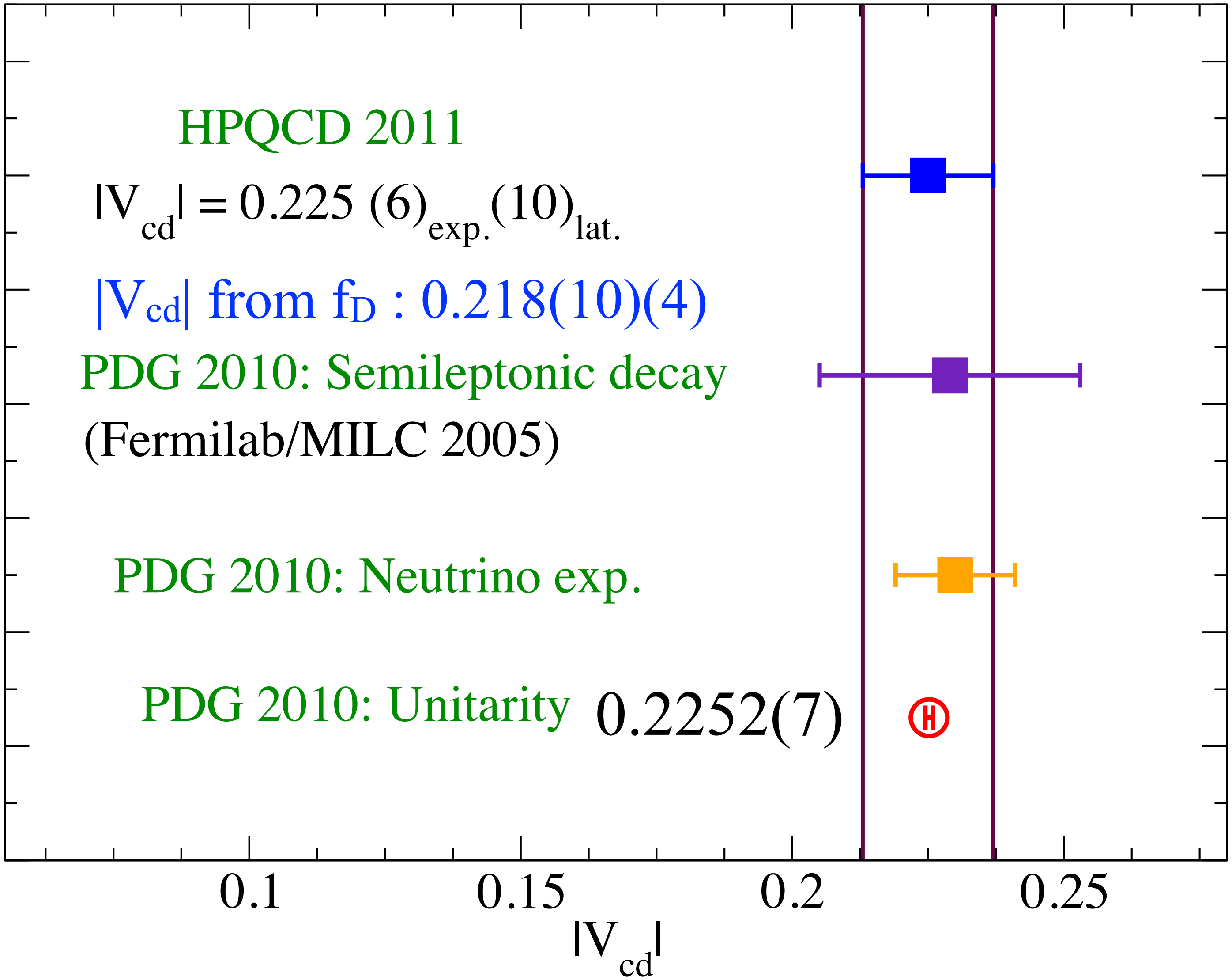
ETMC LAT10 — 3 a values; vector + double ratios to cancel Z

HPQCD results - improved error since no operator normalisation uncertainty

Direct determn of V_{cd}

H. Na et al, HPQCD, LAT11 (updated)

1008.4018



Determn of Vcd from D semileptonic decay now as good as from neutrino scattering

second row unitarity from lattice QCD:

$$|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2 = 0.98(5)$$

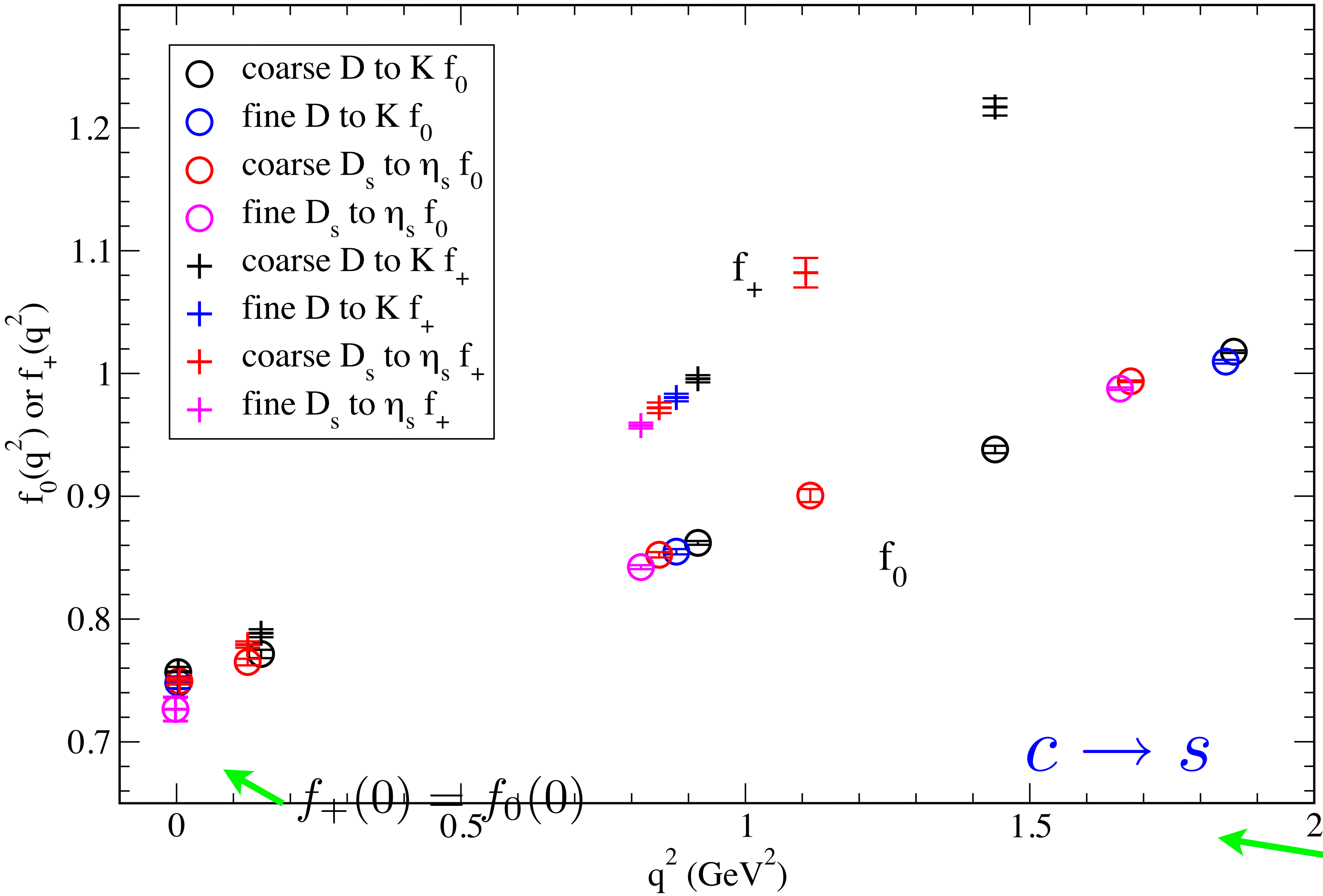
$0.225(12)$ $0.961(26)$ $39.7(1.0) \times 10^{-3}$

HPQCD:1008.4562, LAT11

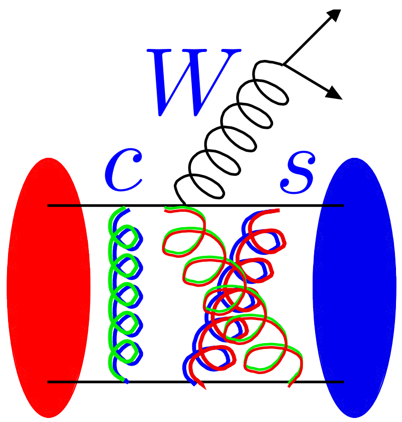
Fermilab/MILC, CKM10

$B \to D^* l\nu$

In progress: improving lattice QCD calculation of $f_+(q^2)$



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



J. Koponen et al, HPQCD, LAT11

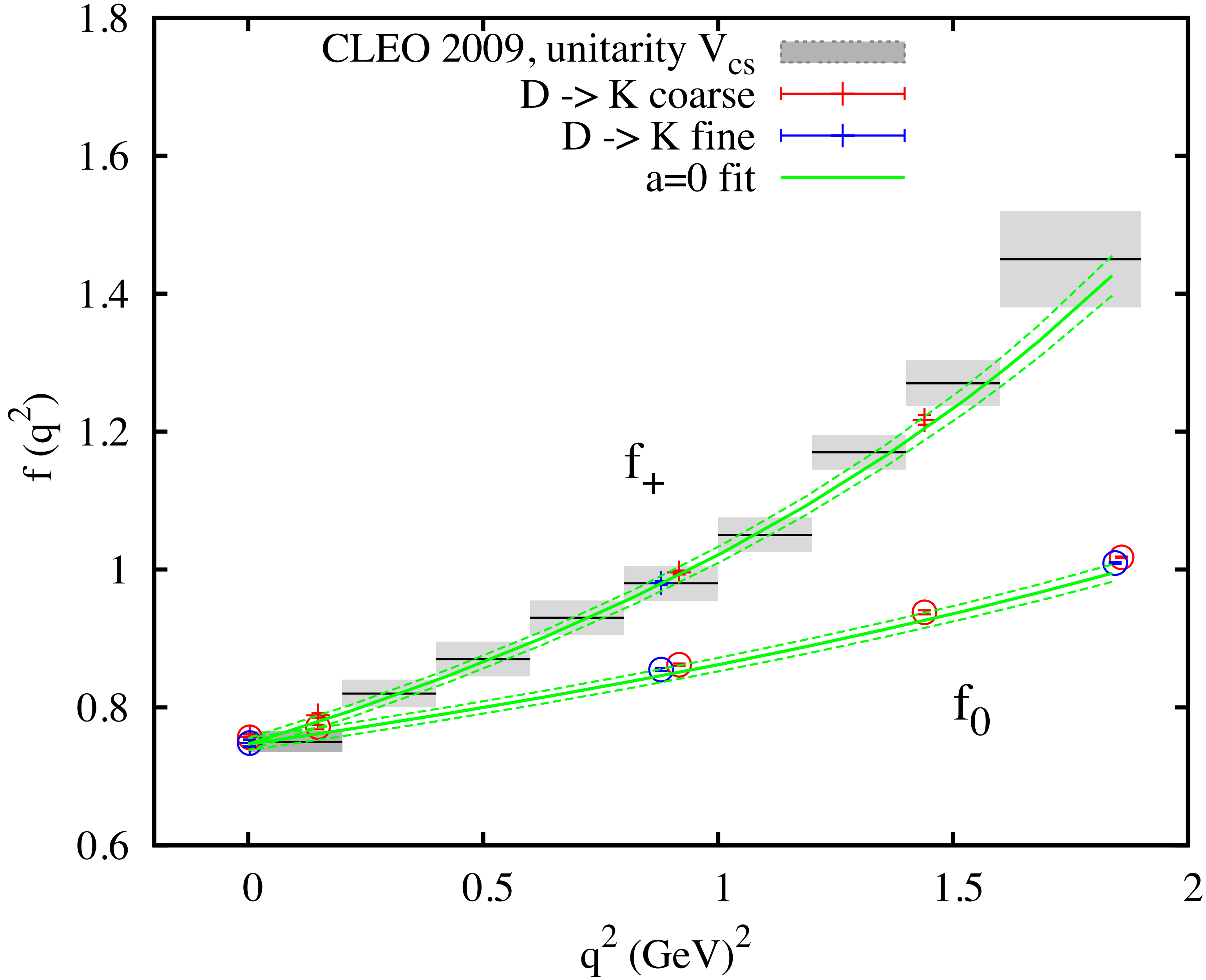
q^2 is 4-mom transfer between D and outgoing meson

Comparison to expt gives more detailed test of QCD.
Note: form factor seems to be independent of spectator quark in decay.

Updates on $f_+(q^2)$ 2011

$D \to K$

HPQCD PRELIMINARY



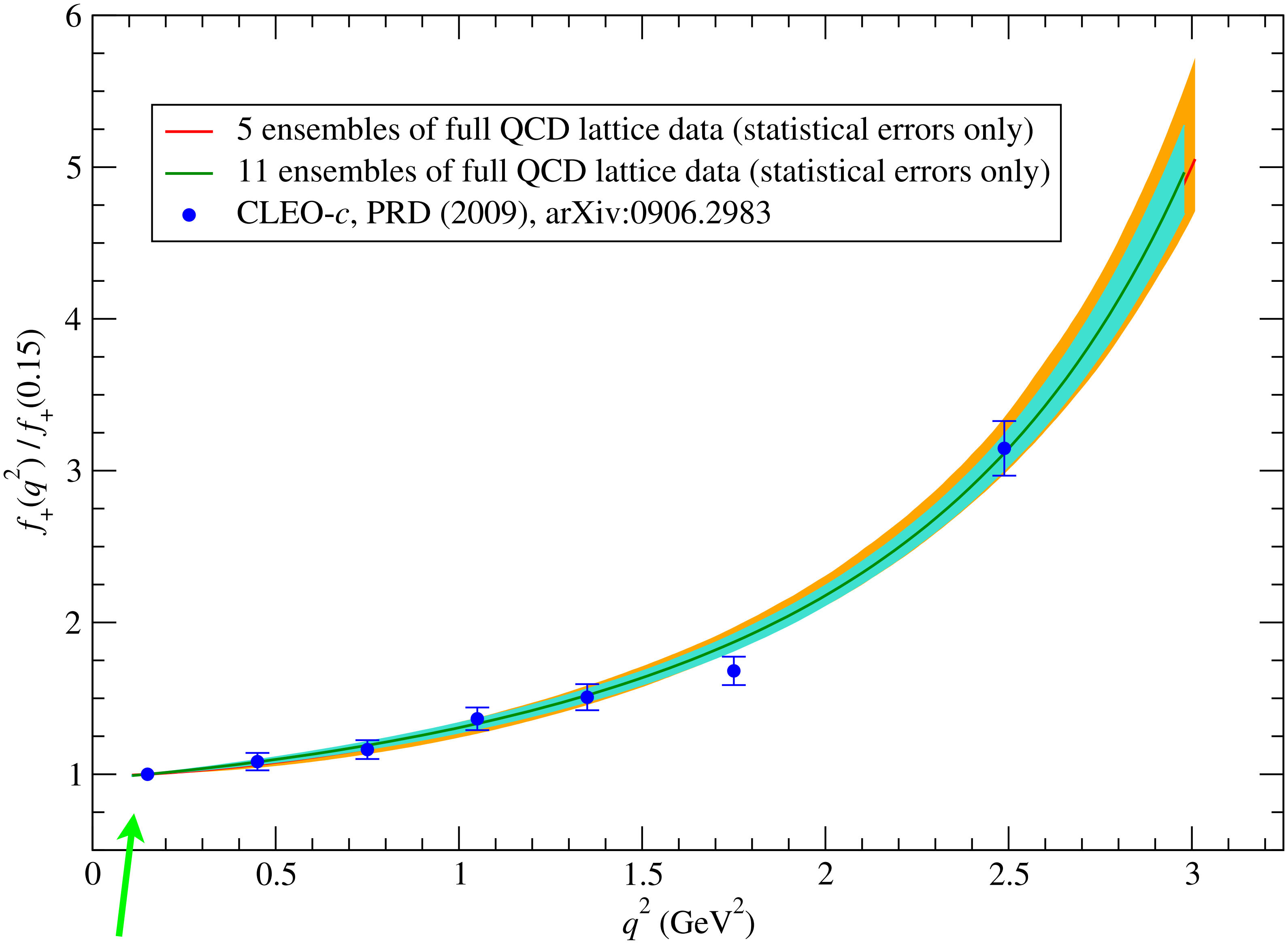
v. high stats - 16000 corrs x 4T

1-2% errors will allow accurate comparison of shape to expt

J. Koponen et al, HPQCD, LAT11

$D \to \pi$

Fermilab/MILC PRELIMINARY



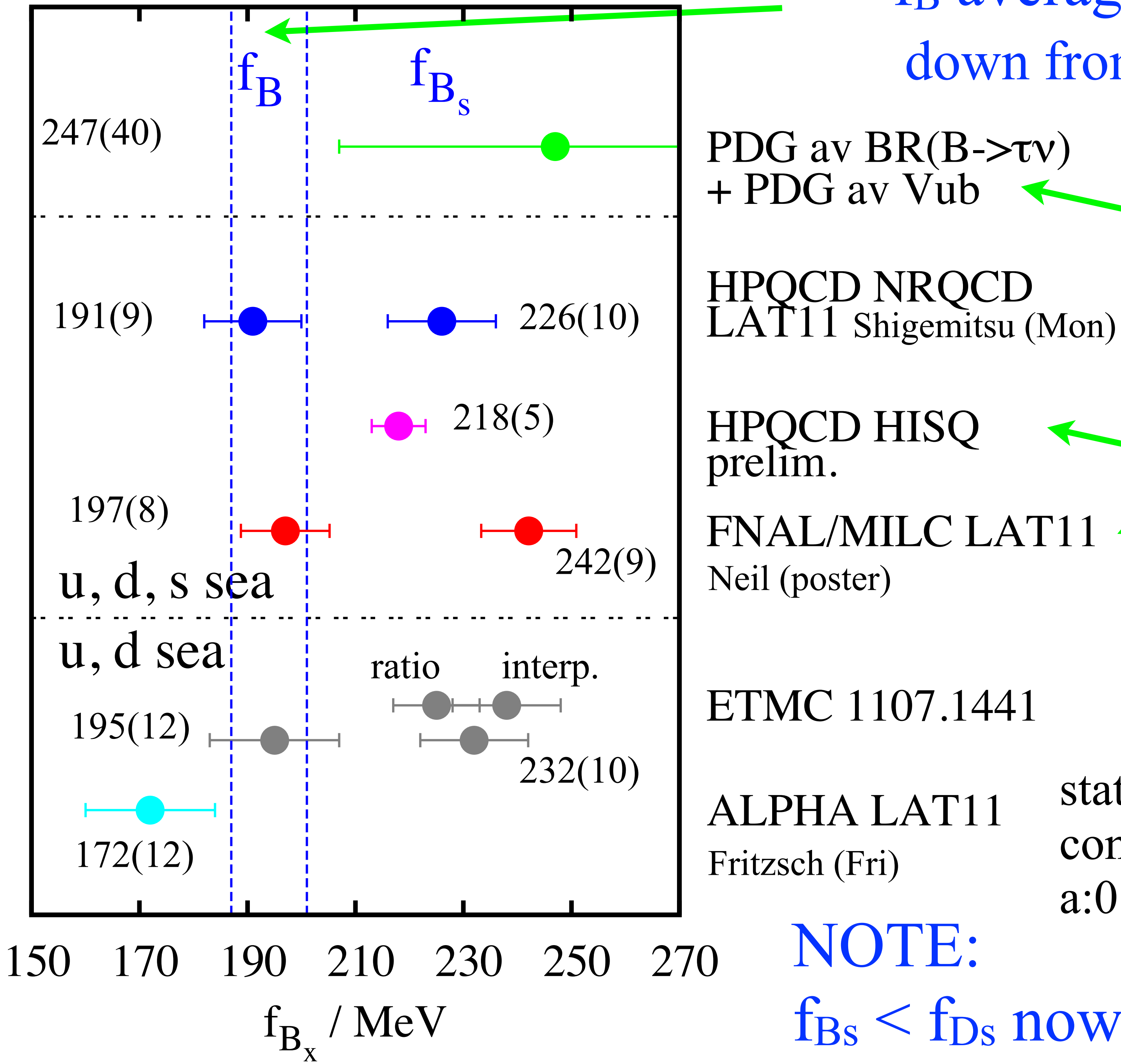
3 a values; 11 ensembles; blind analysis

shape defined wrt reference q^2 at 0.15 GeV^2

normalization error 3% inc. heavy q disc. errors

J. Bailey et al, Fermilab/ MILC, LAT11

B, B_s decay constant update 2011



f_B average : 194(7) MeV
down from 2010

f_B expt
(B_s has no leptonic decay)

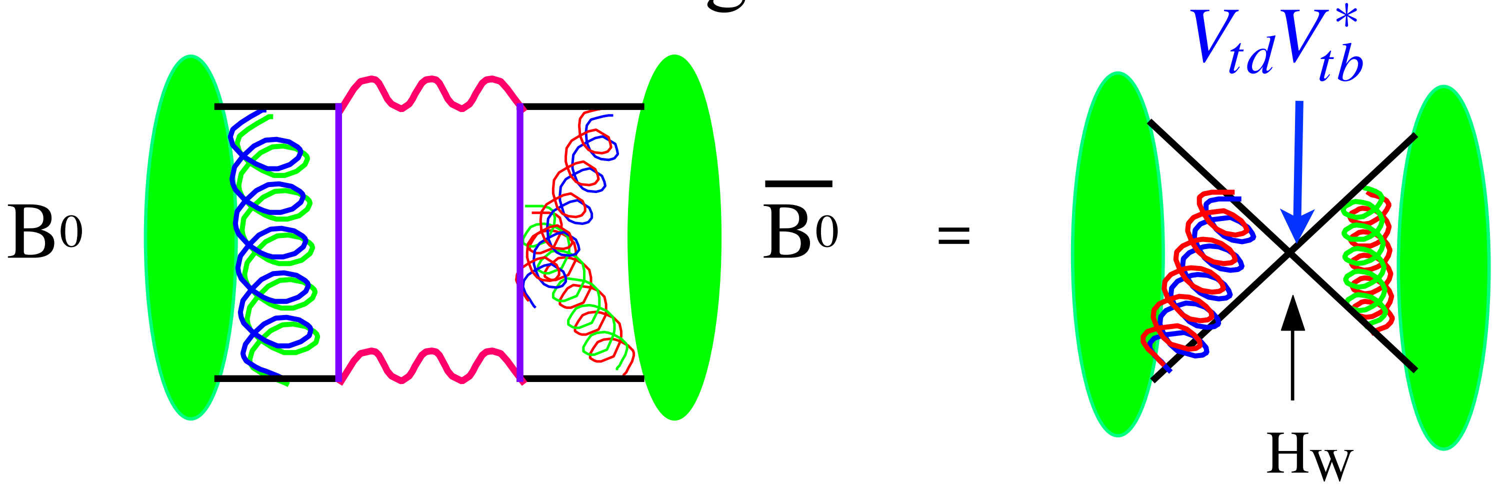
2.4σ
apart for f_{Bs}

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

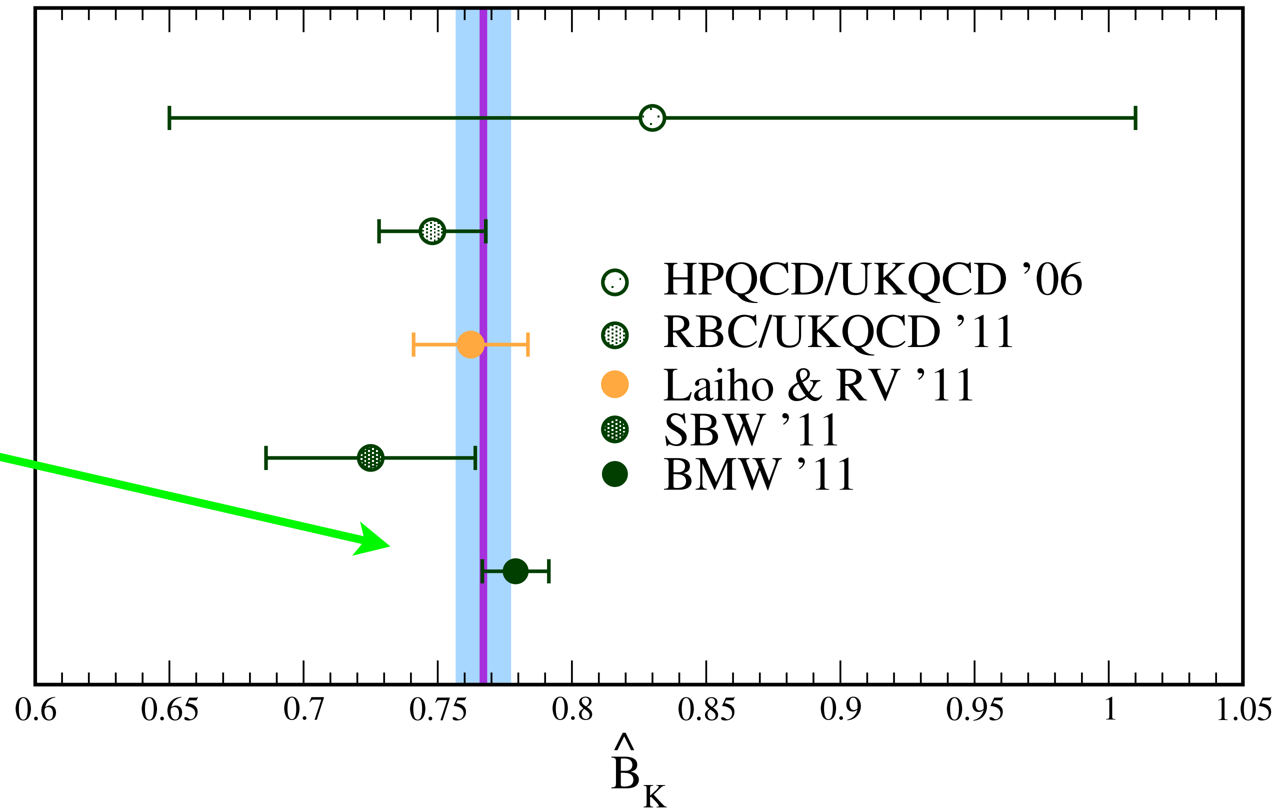
Result from "box diagram". Calculate in lattice QCD



$\propto f_B^2 B_B$

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

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

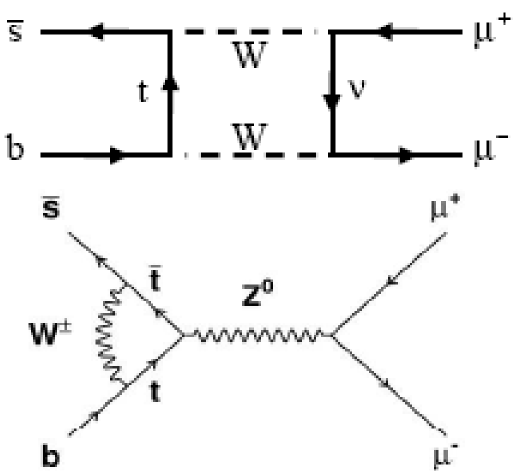
$$\xi = \frac{f_{B_s}\sqrt{B_{B_s}}}{f_B\sqrt{B_B}} = 1.26(3) \longrightarrow \frac{|V_{td}|}{|V_{ts}|} = 0.214(5)$$

normln error cancels in ratio.

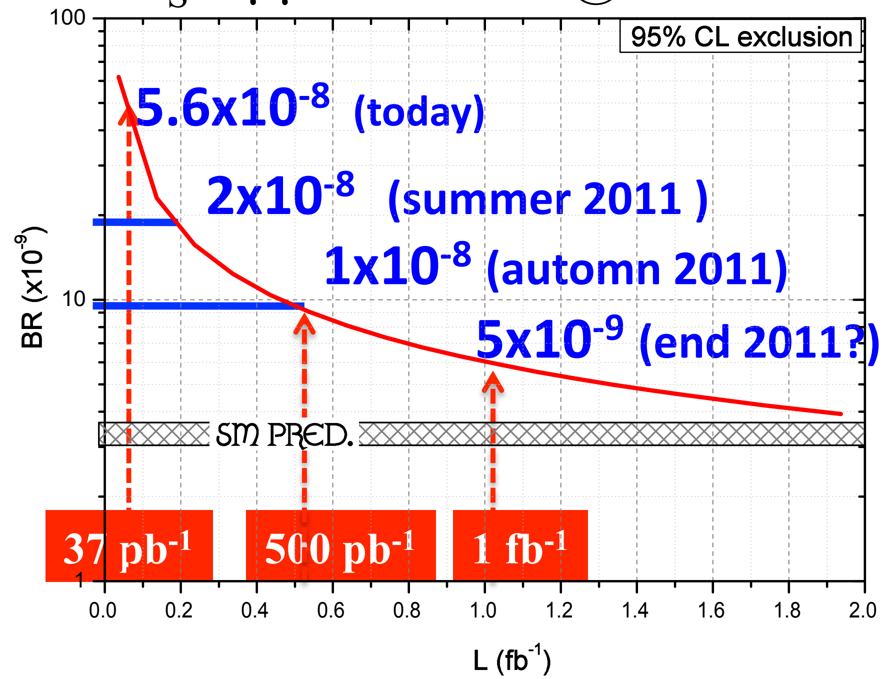
E. Gamiz et al, HPQCD, 0902.1815

Use to provide SM rate for LHCb of:

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



B$_S$→μμ exclusion @ 95% CL

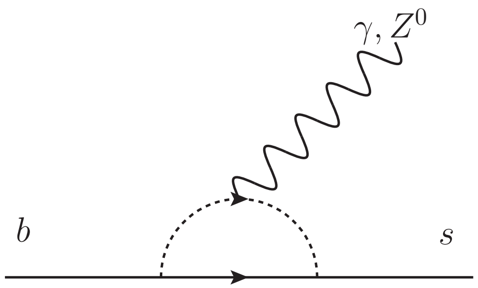


LHCb/CMS limit : 1.1×10^{-8}

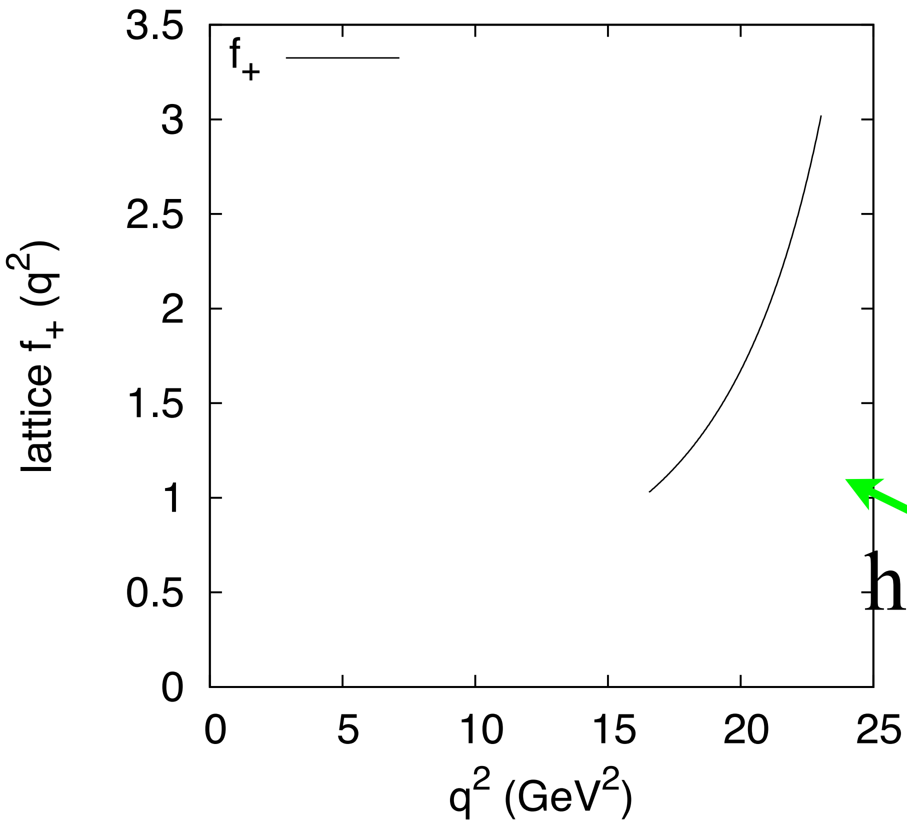
Need to improve lattice QCD error ..

G. Wilkinson, EPS11

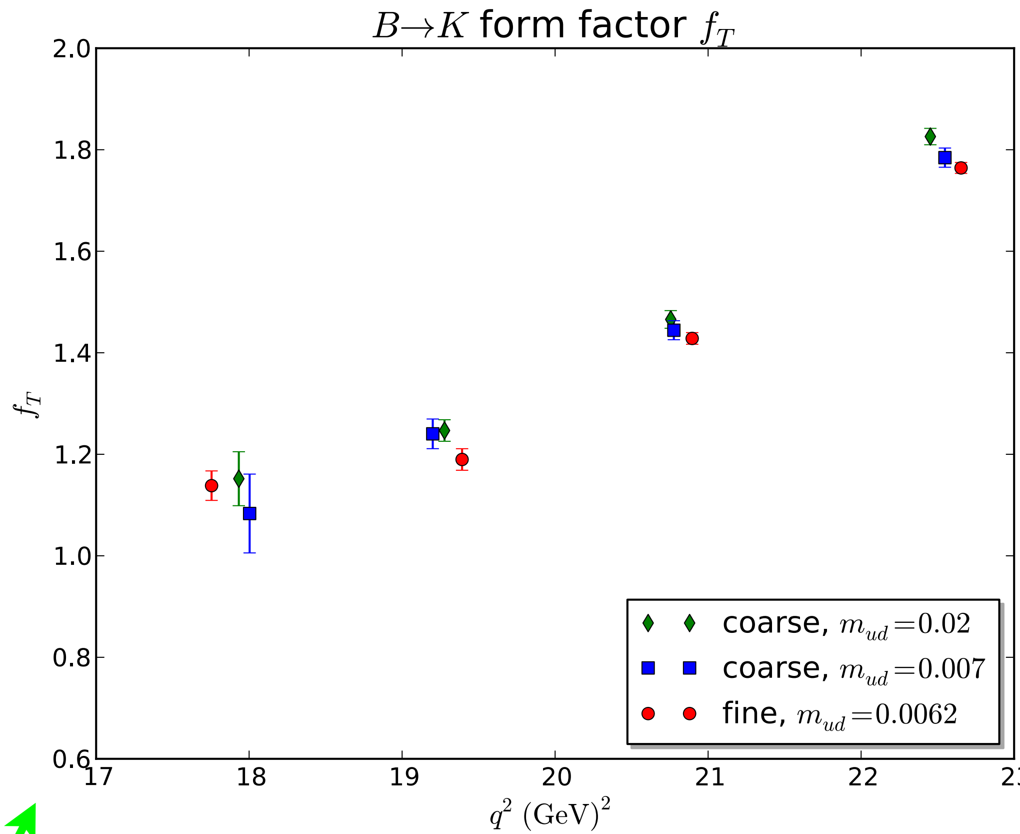
Semileptonic form factors $B \to K l^+ l^-$ preliminary



LHCb hope to see new physics



high q^2



$B \to K$ tensor form factor

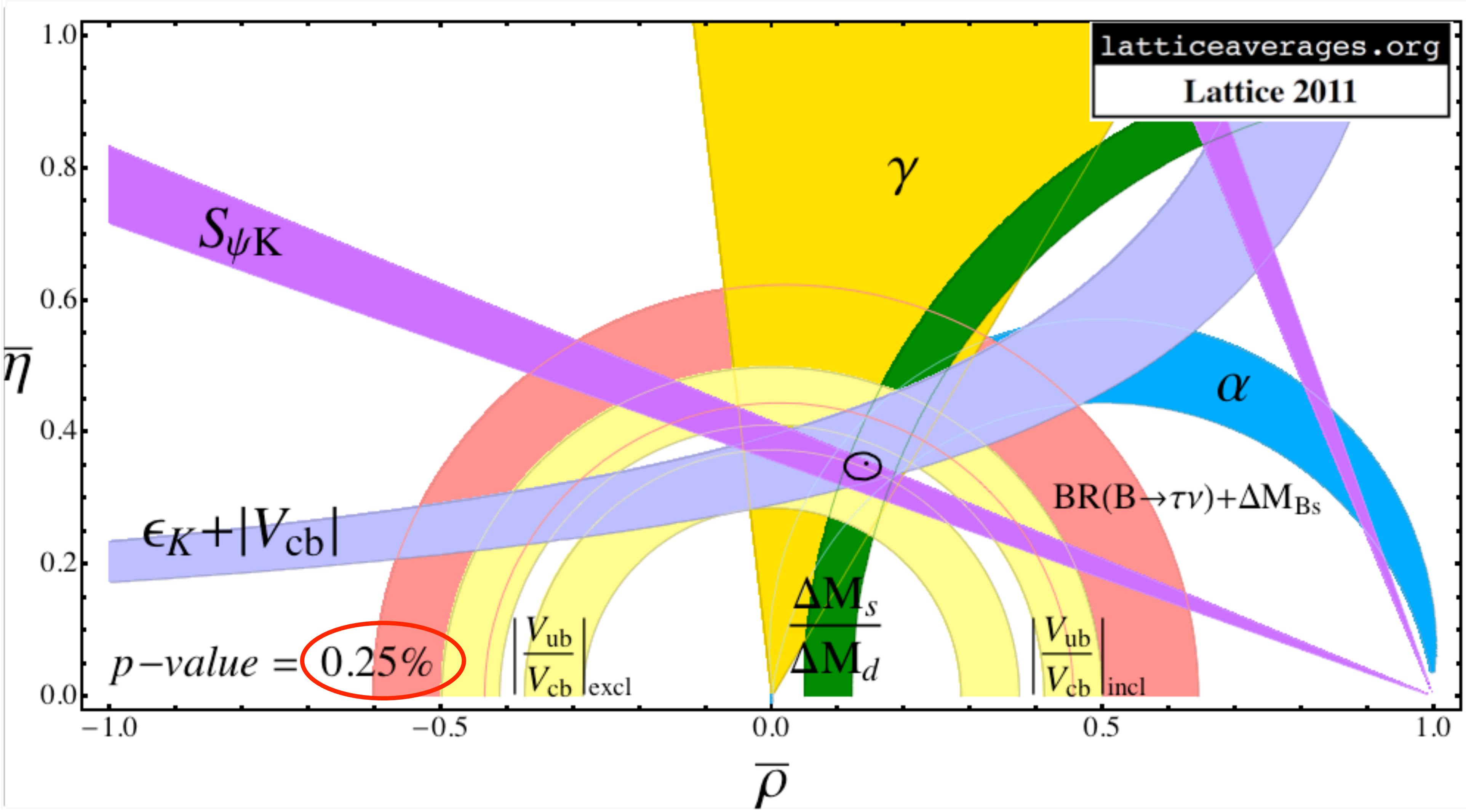
NRQCD b, asqtad l, MILC 2+1, 2a, Horgan, Liu, Meinel, Wingate

$B \to K$ vector form factor

Fermilab b, asqtad l, MILC 2+1, 3a, Fermilab/MILC, Zhou LAT11

UT fits using lattice QCD results

E. Lunghi, LAT11



Tensions developing in UT at 2-3 σ level

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

• very accurate results are available now from lattice QCD for QCD parameters and for simple hadron masses and decay matrix elements important for flavour physics.

Future

• sets of '2nd generation' gluon configs will 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

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