Lattice QCD 2011

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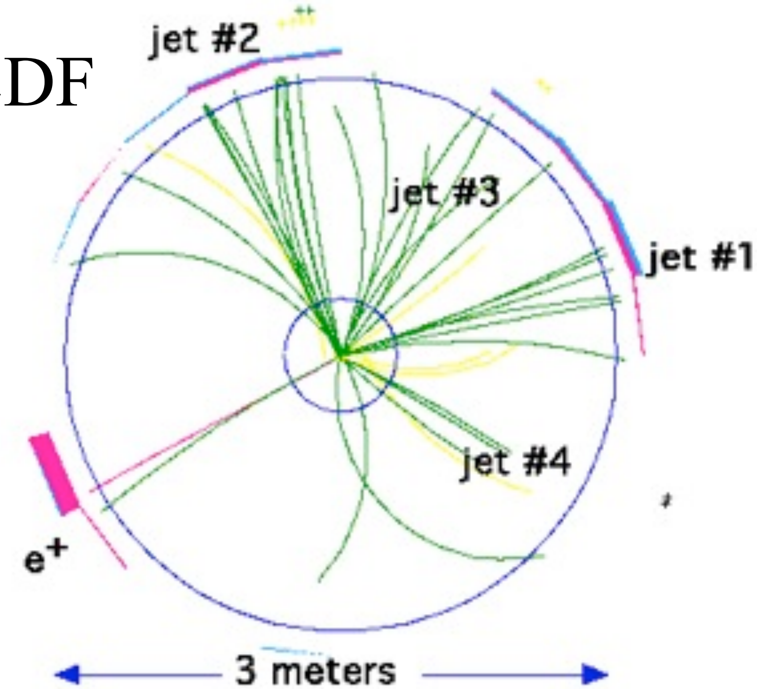
HPQCD collaboration

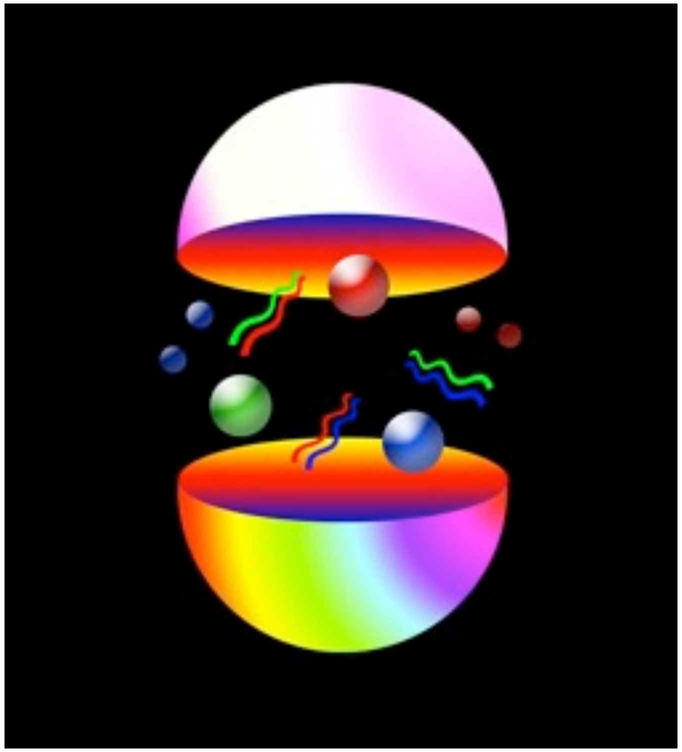
IOP NPPD meeting
April 2011

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

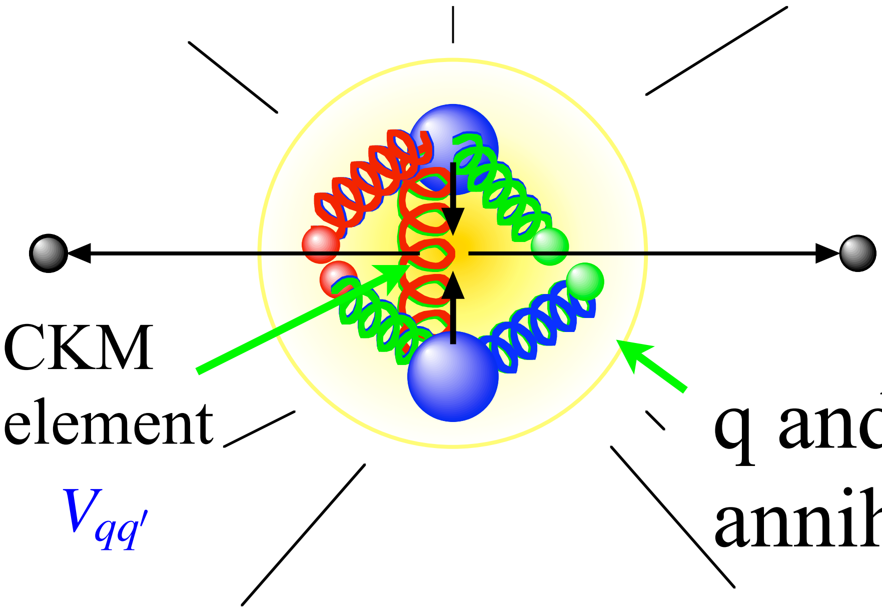
CDF

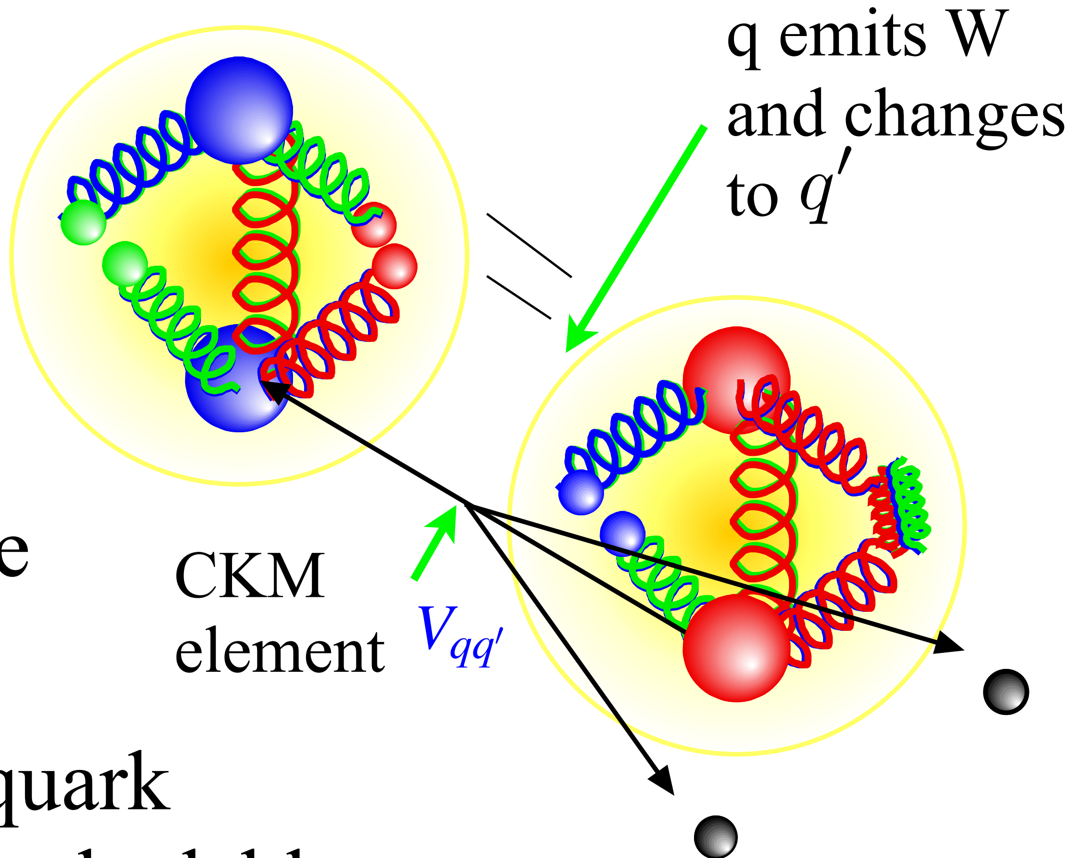


Cross-sections calculated at high energy using QCD pert. th. NLO gives ~5% errors. Also have pdf and hadronisation uncertainties



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



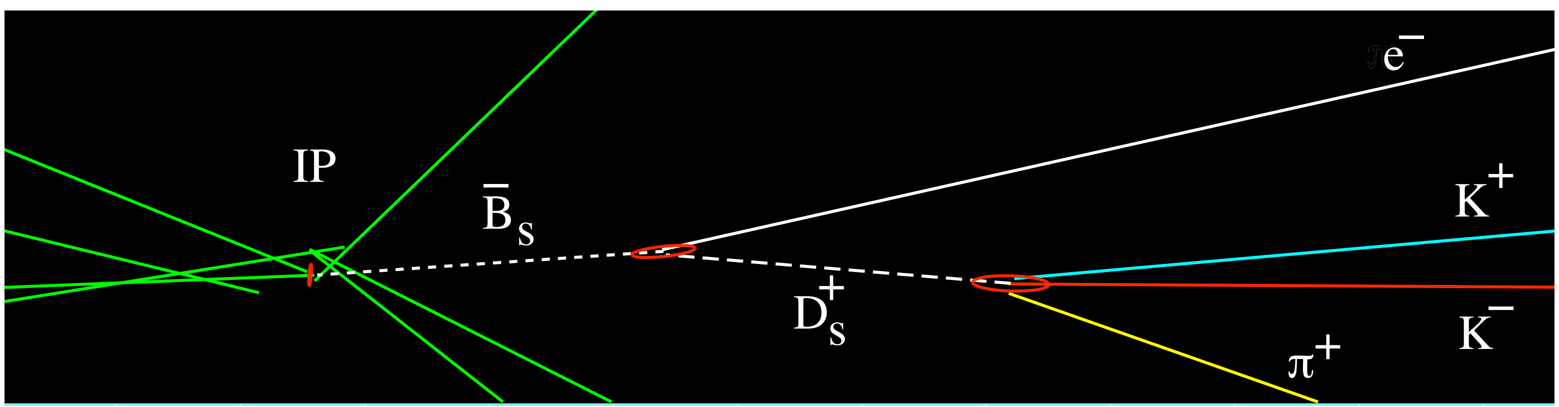


Rates for simple weak or em quark processes inside hadrons also calculable, but *not* multi-hadron final states.

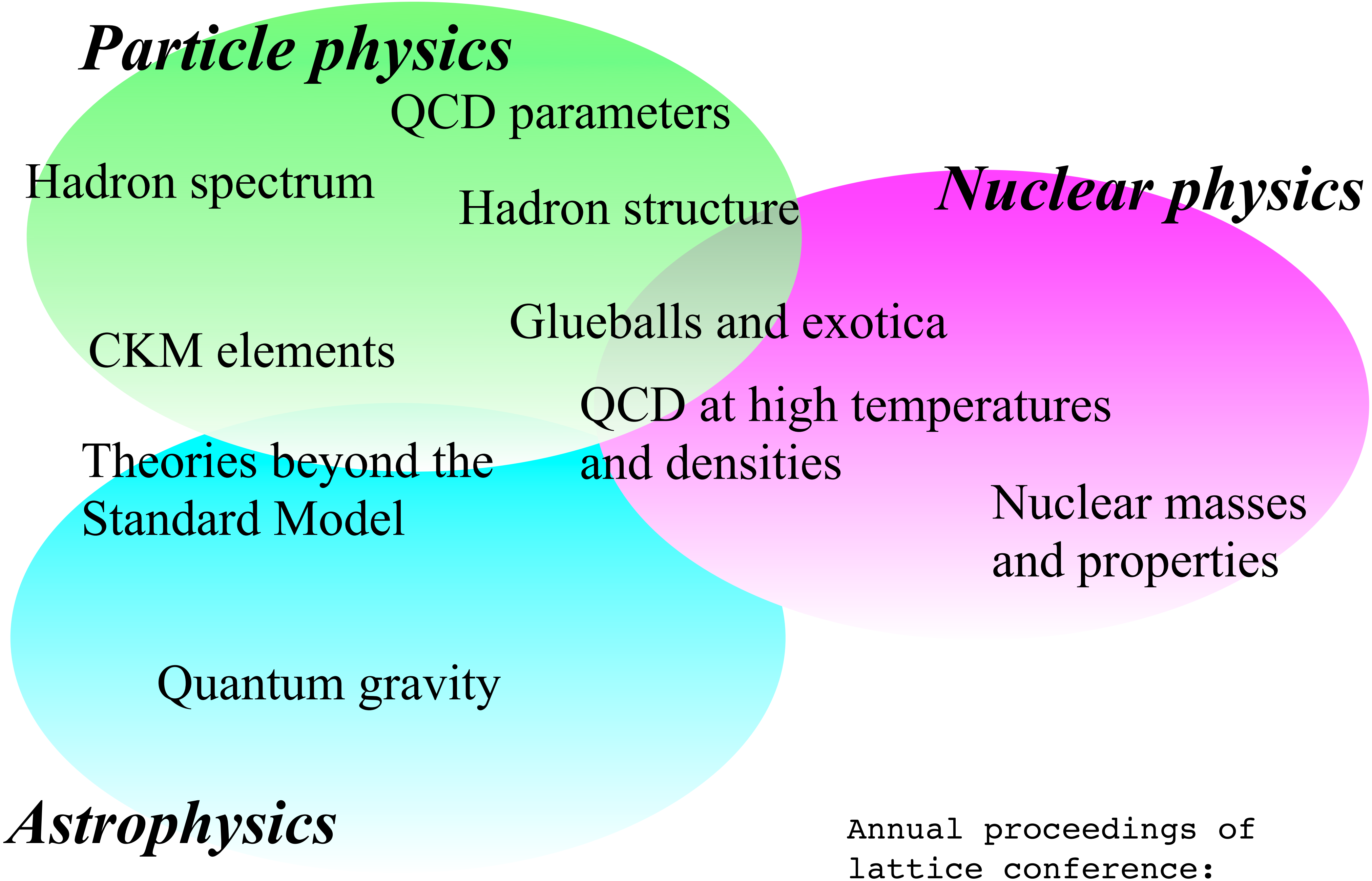
$\overline{B}_s \to D_s e^- \nu$

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

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

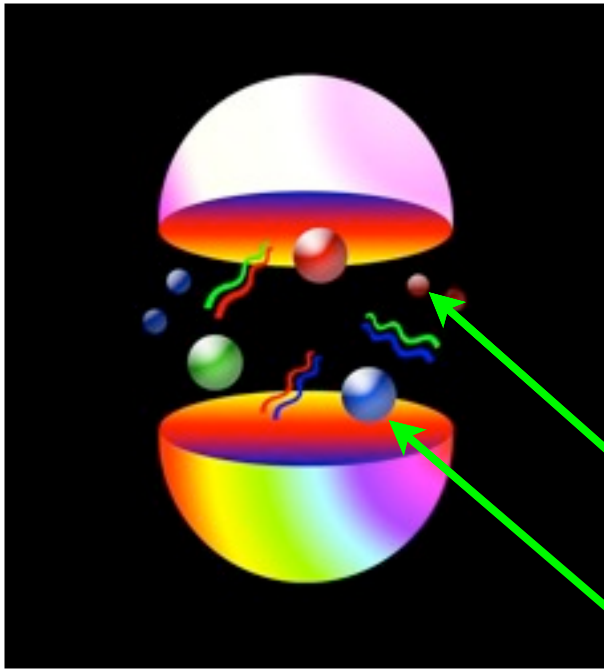


Applications of Lattice QCD/Lattice field theory



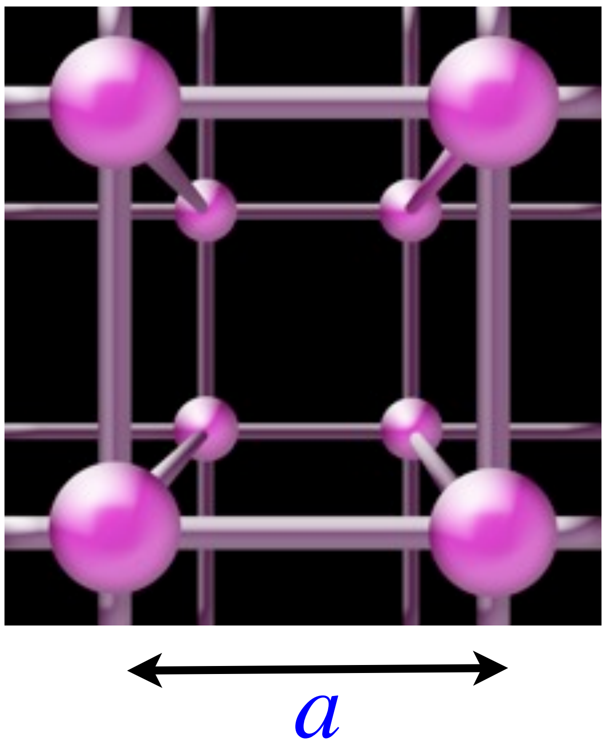
Annual proceedings of lattice conference: http://pos.sissa.it/

Lattice QCD = fully nonperturbative QCD calculation



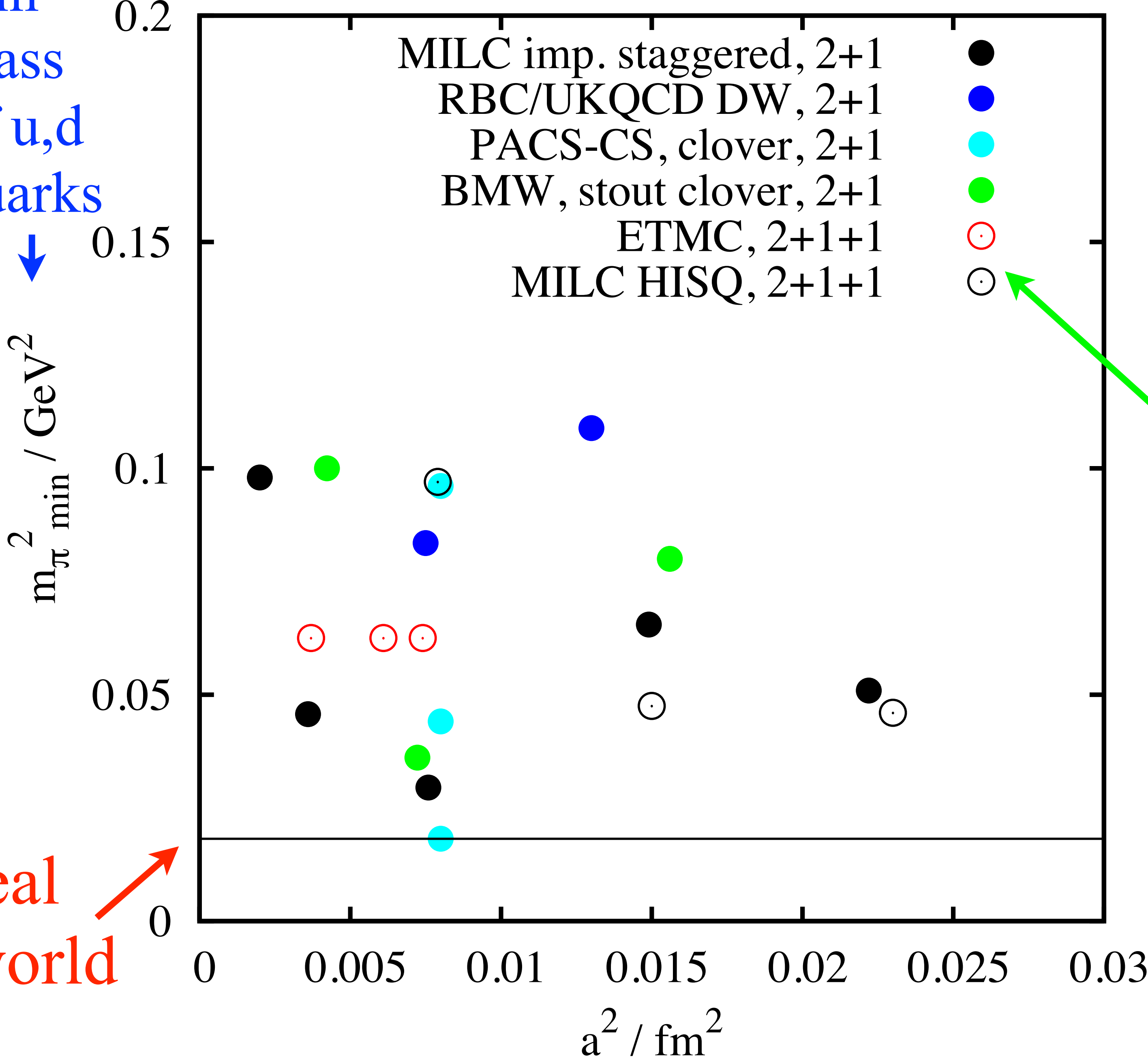
RECIPE

- 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 $m_\pi L > 3$

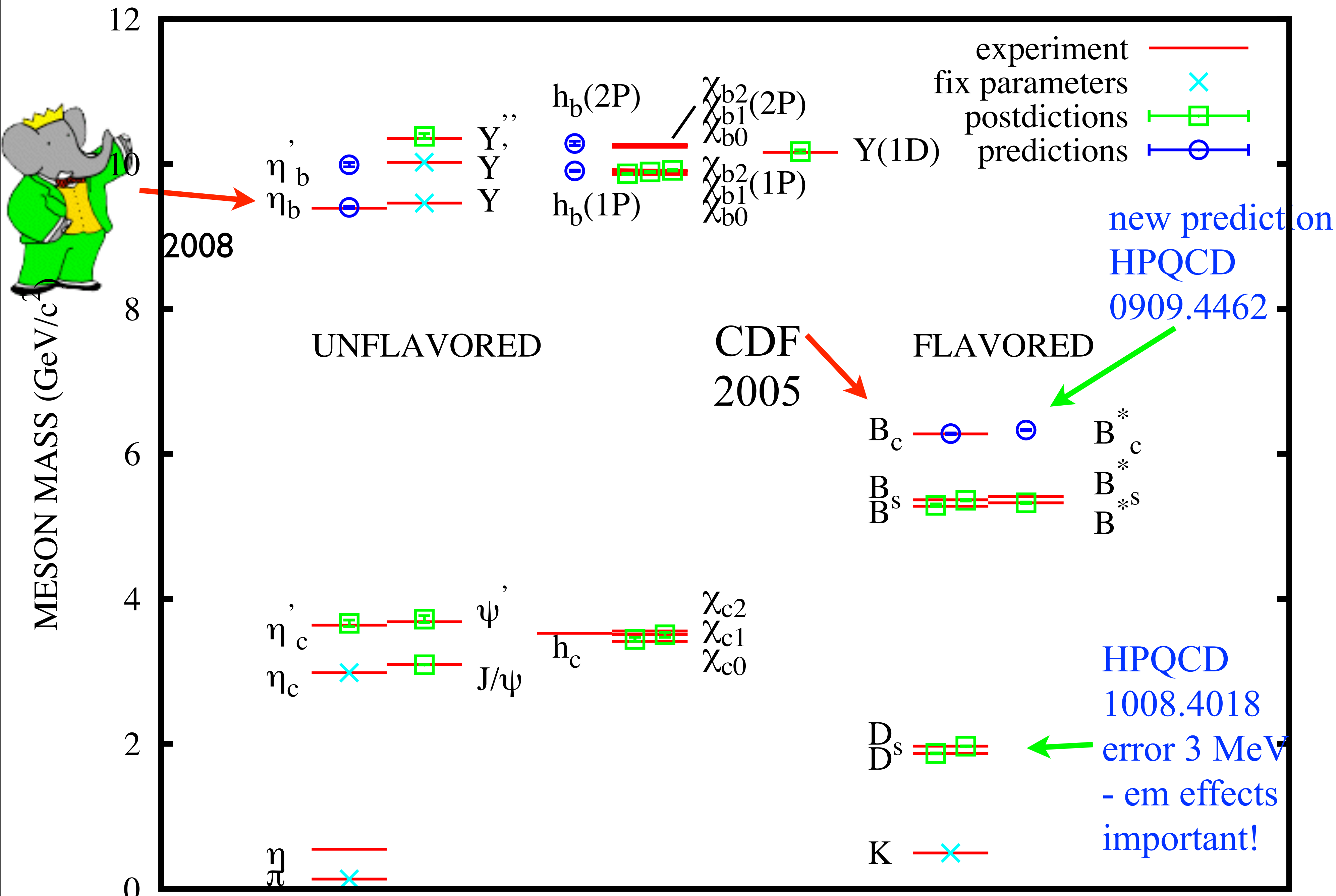
"2nd generation" lattices inc. c quarks in sea

(R. Dowdall talk Tues.)

← $m_{u,d} \approx m_s/10$

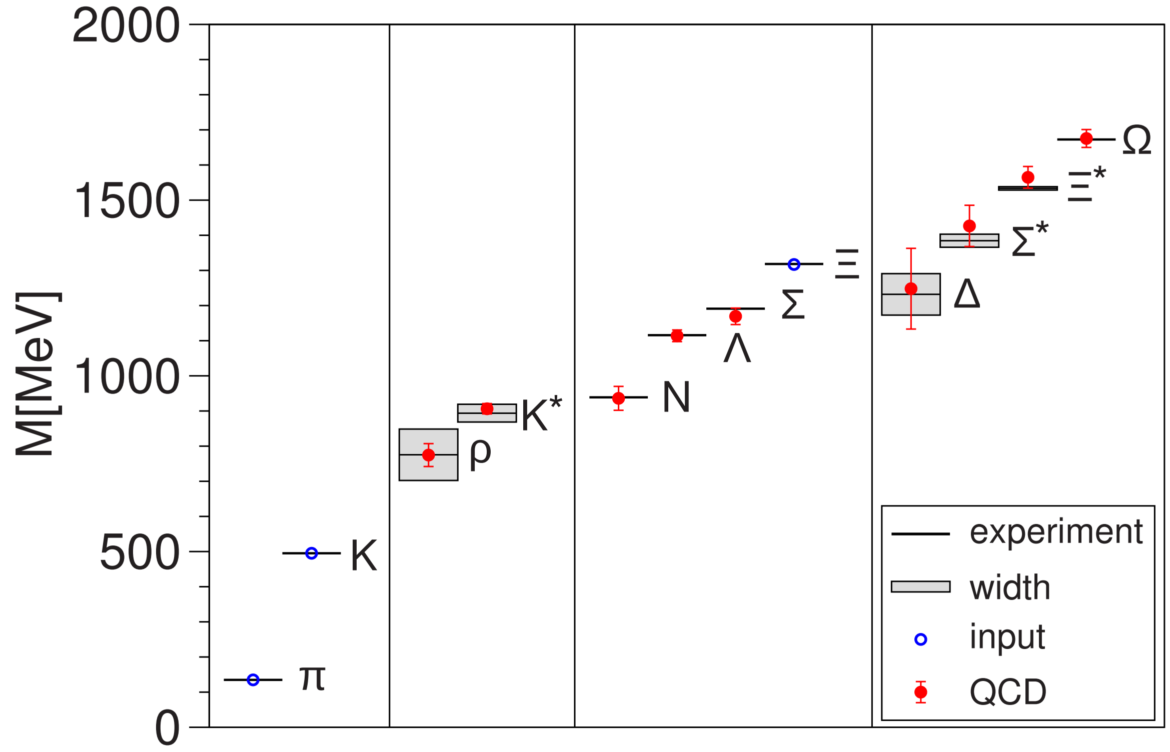
← $m_{u,d} \approx m_s/27$

The gold-plated meson spectrum - HPQCD

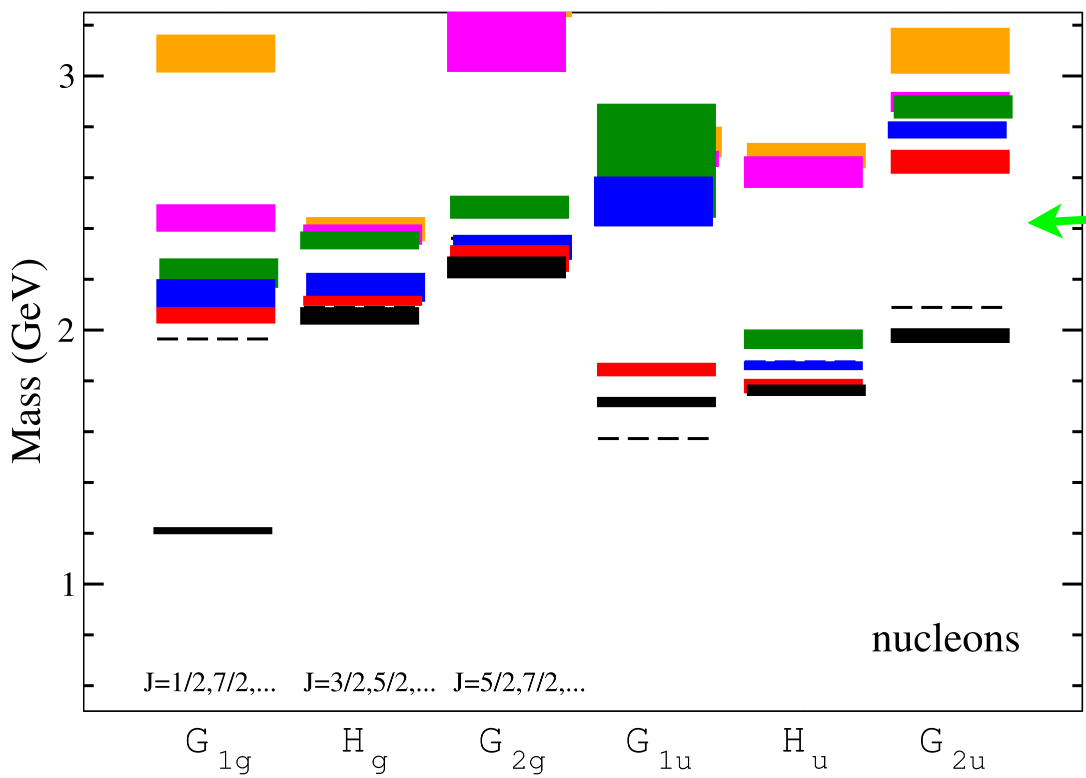


I. Allison et al, hep-lat/0411027, A. Gray et al, hep-lat/0507013

Light hadron spectrum including baryons



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



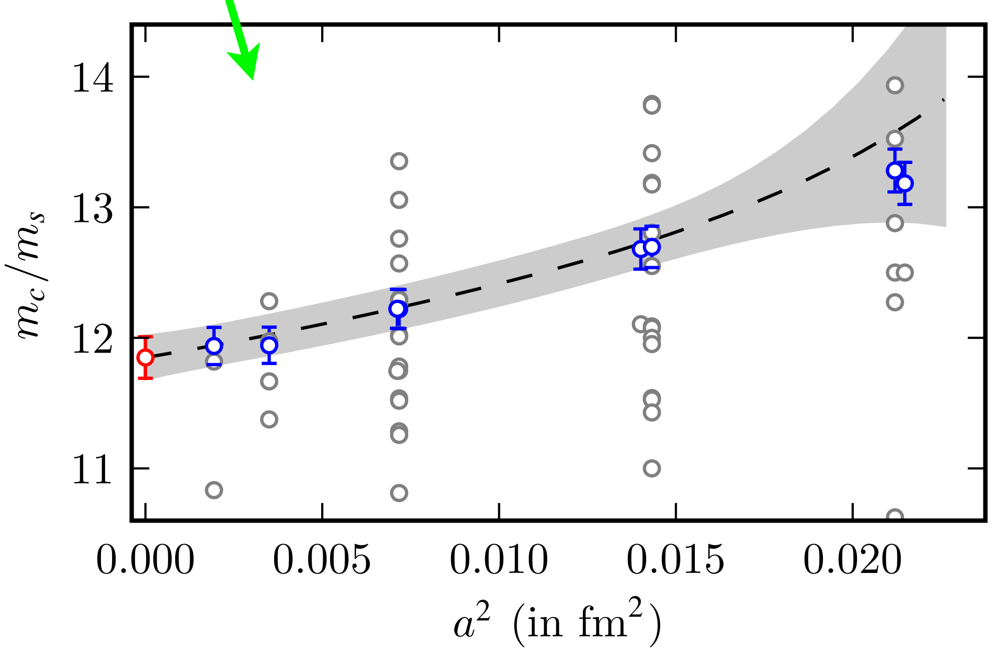
Excited nucleon spectrum - preliminary calculations inc. the effect of sea quarks, not yet at physical masses.

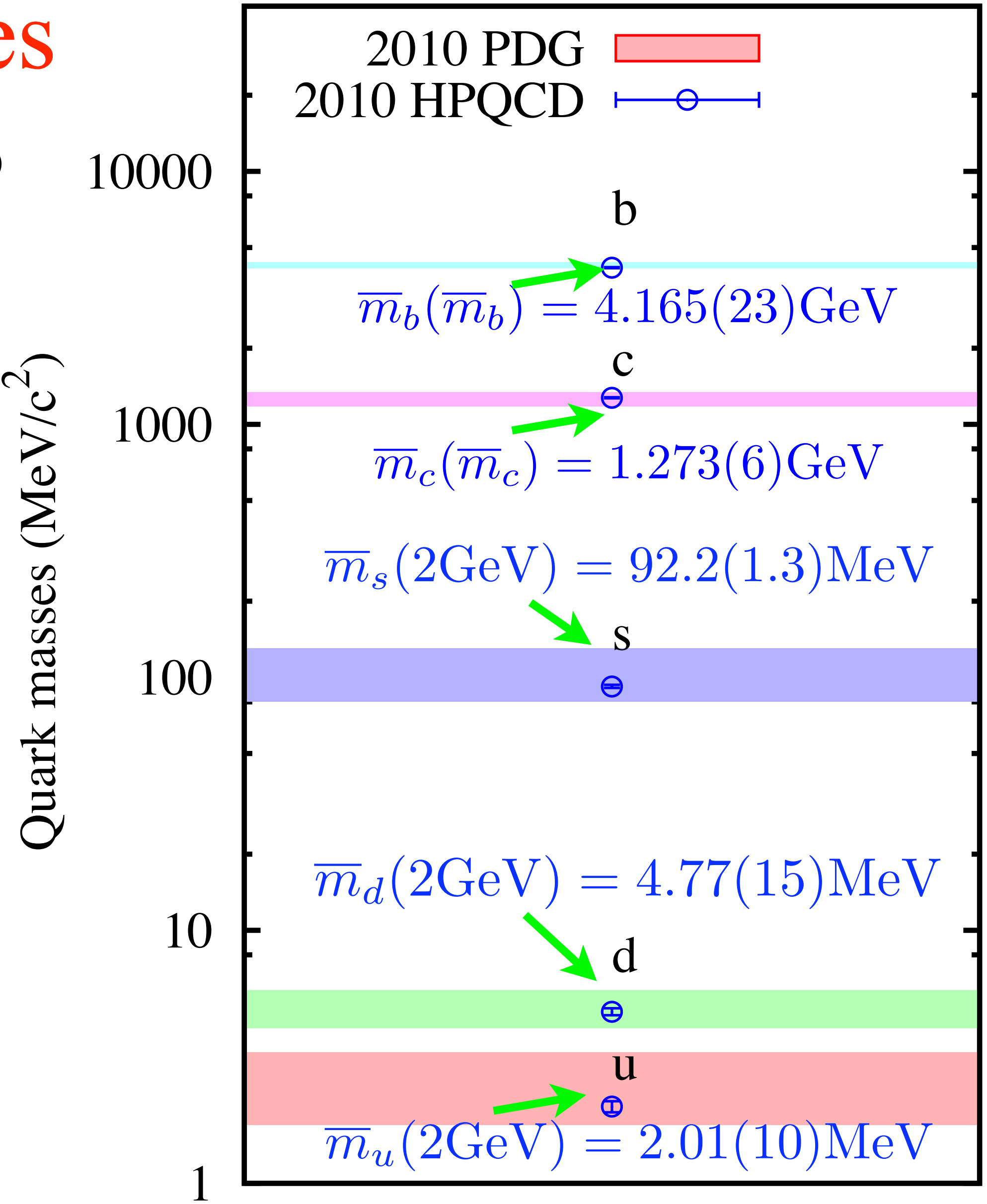
(J. Foley, talk Mon., Bulava et al, HadSpec, 1004.5072)

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, $m_s/m_{u,d}$





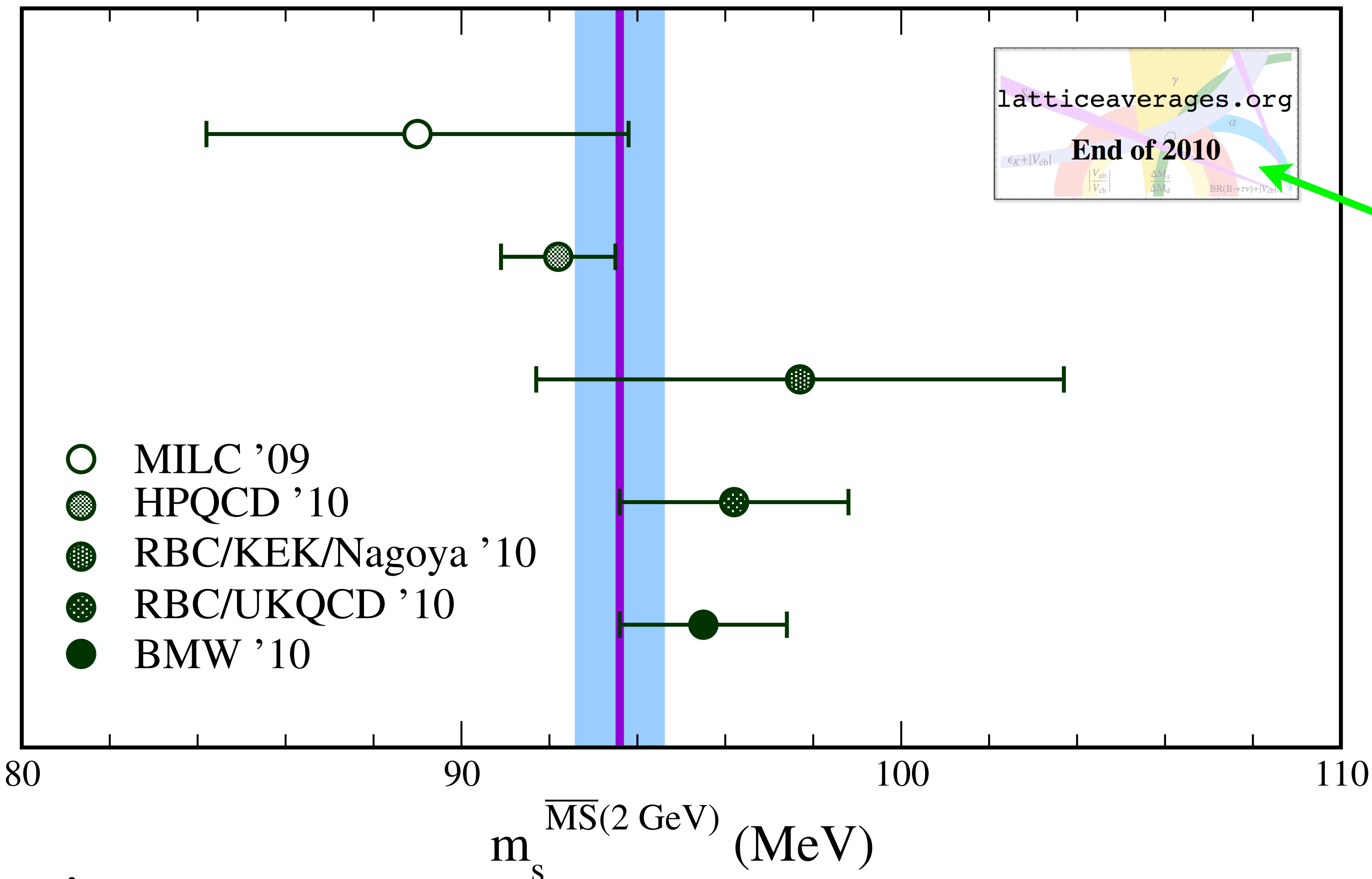
C. McNeile, CTHD et al, HPQCD, 0910.3102, 1004.4285

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

1% accuracy achieved

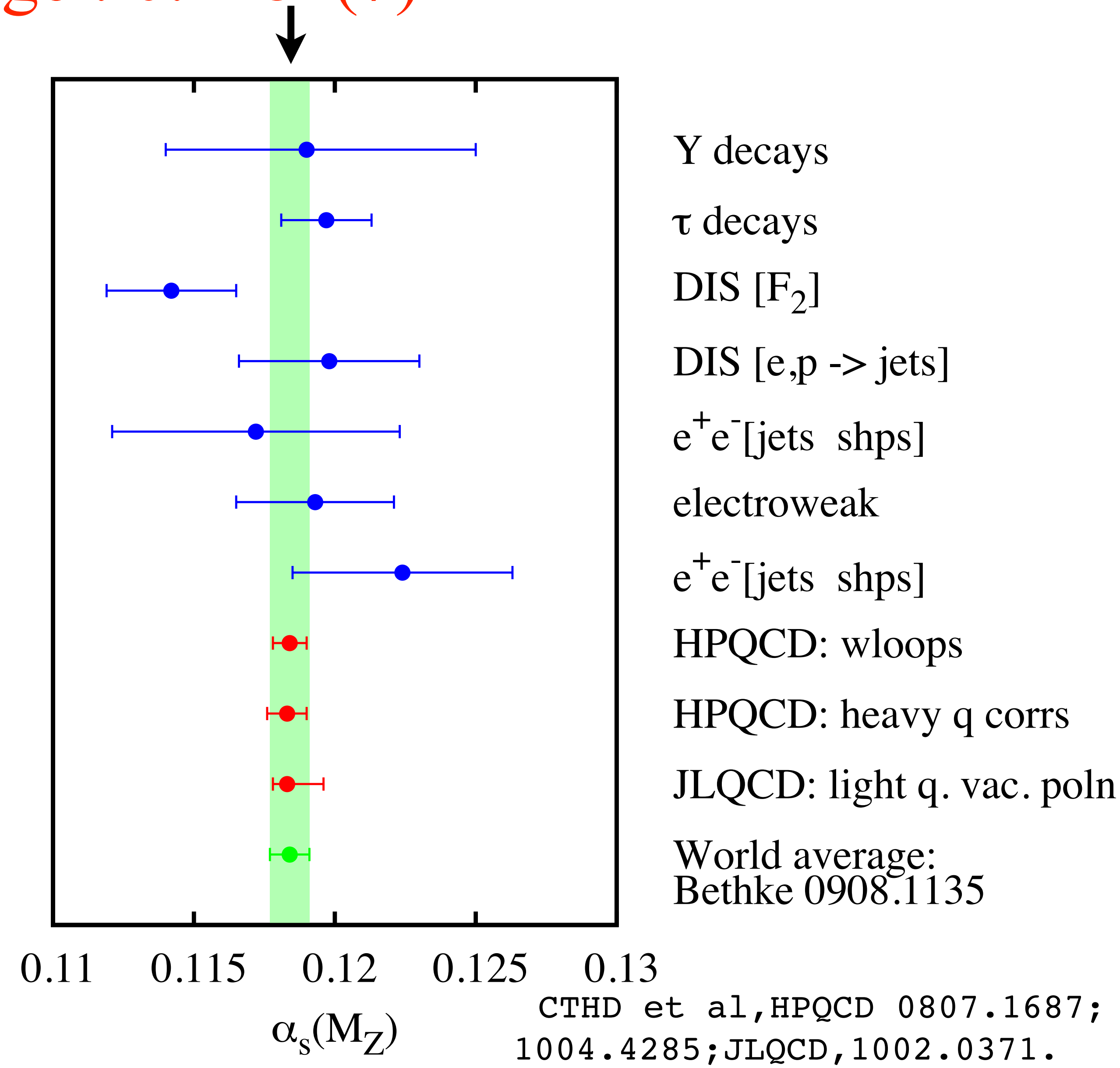
Lattice averages: $m_s = 93.6(1.1)\text{MeV}; \quad \frac{m_s}{m_u + m_d} = 27.55(14)$

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

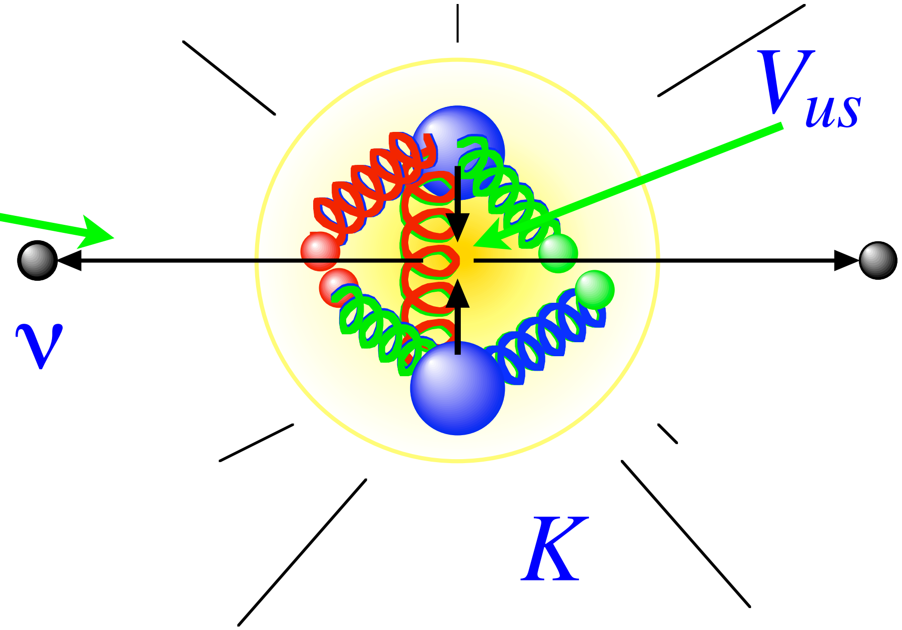


see 2011 Munich alphas workshop

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

Determining the Cabibbo-Kobayashi-Maskawa matrix

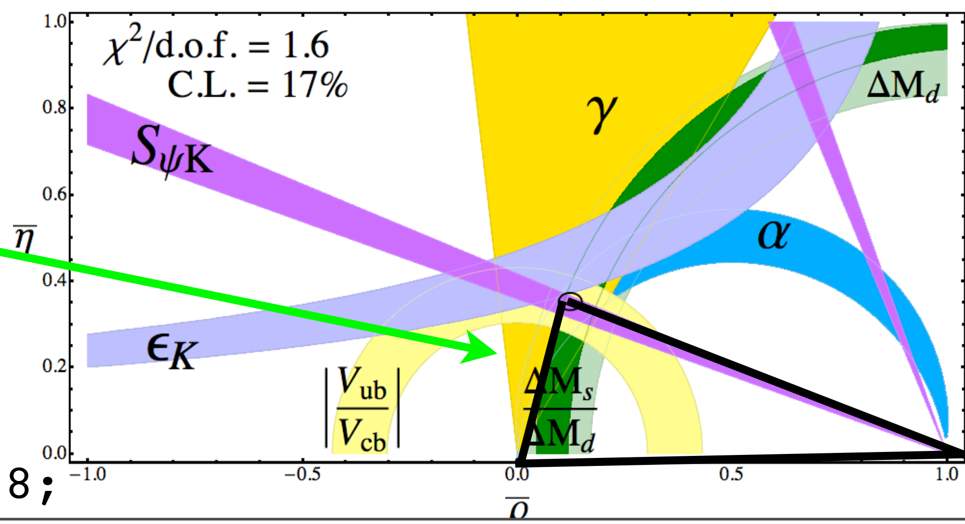
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ \pi \to l\nu & K \to l\nu & B \to \pi l\nu \\ & K \to \pi l\nu & \\ V_{cd} & V_{cs} & V_{cb} \\ D \to l\nu & D_s \to l\nu & B \to Dl\nu \\ D \to \pi l\nu & D \to Kl\nu & \\ V_{td} & V_{ts} & V_{tb} \\ \langle B_d|\overline{B}_d\rangle & \langle B_s|\overline{B}_s\rangle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



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}

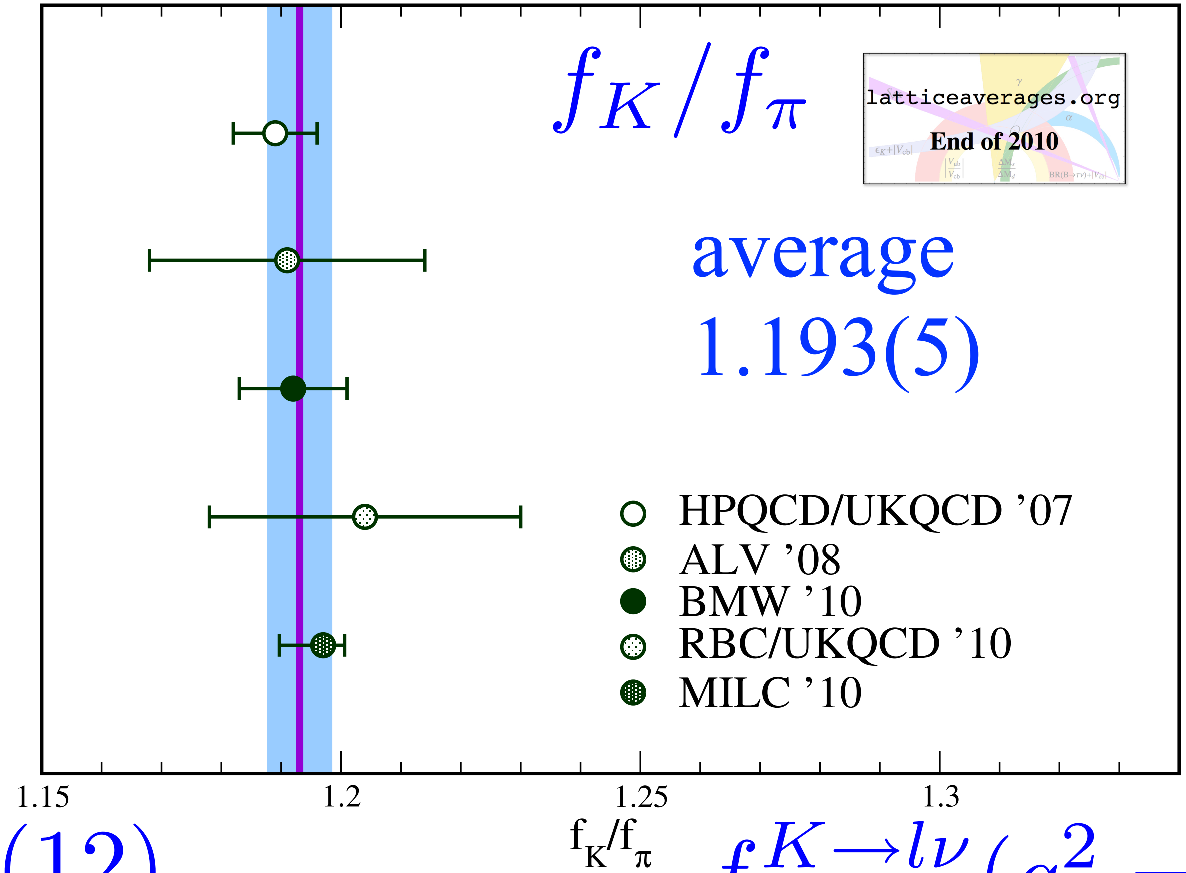
Error now < 0.5% using lattice QCD

Leptonic rate

experiment e.g.KLOE:

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

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

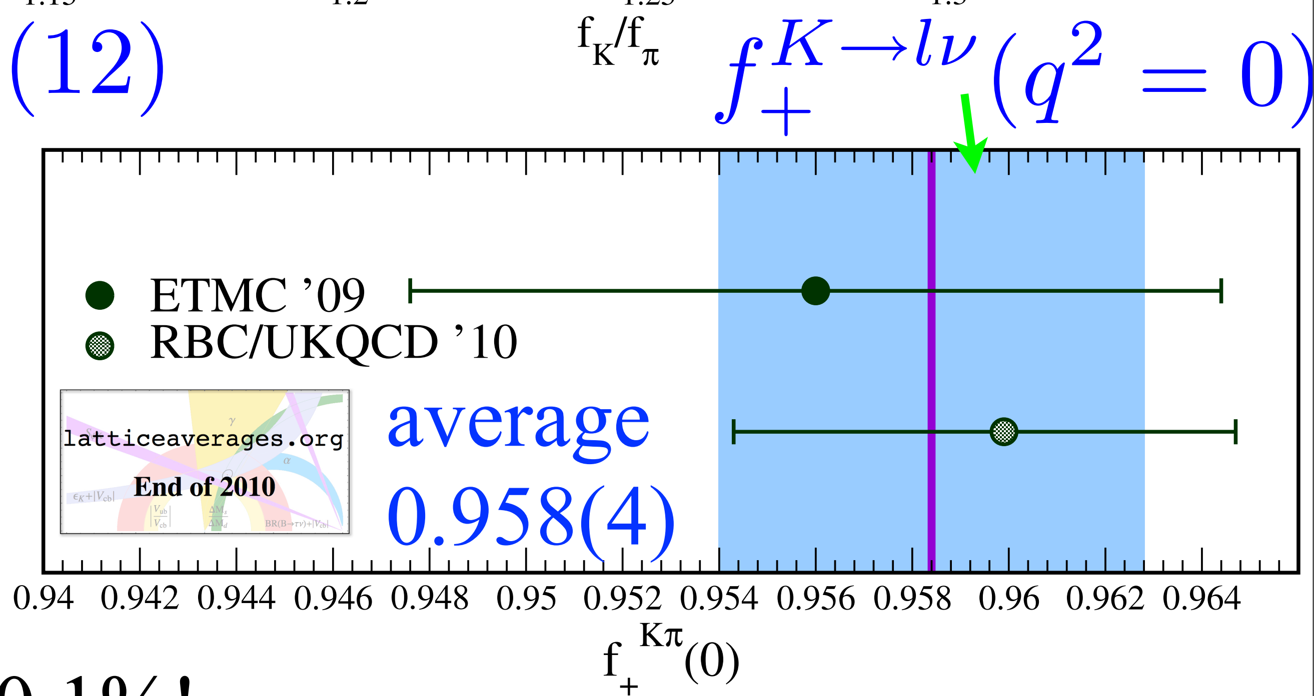


Semi-leptonic expt:

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

gives:

$V_{us} = 0.2261(10)$



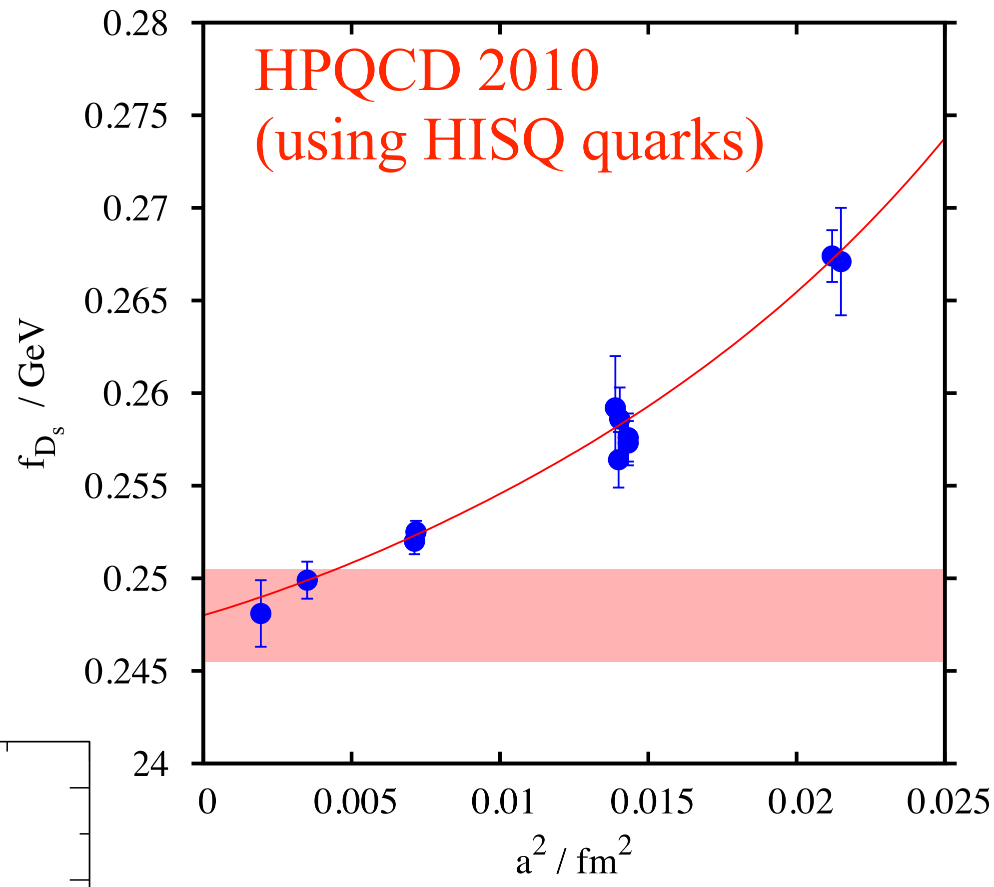
first row unitarity to < 0.1%!

V_{cs}

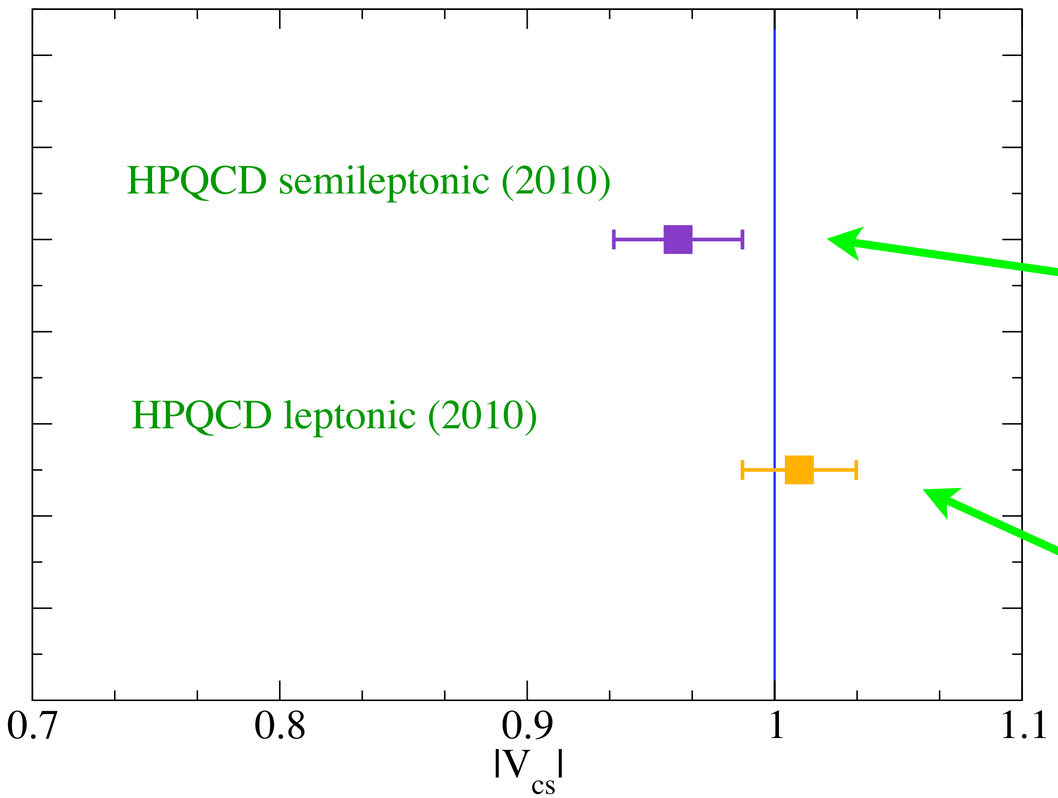
2010: Lattice error :

f_{D_s} : 1%

$f_+^{D \to K l \nu}(q^2 = 0)$: 2.5%



CTHD, Na et al, HPQCD, 1008.4018; 1008.4562

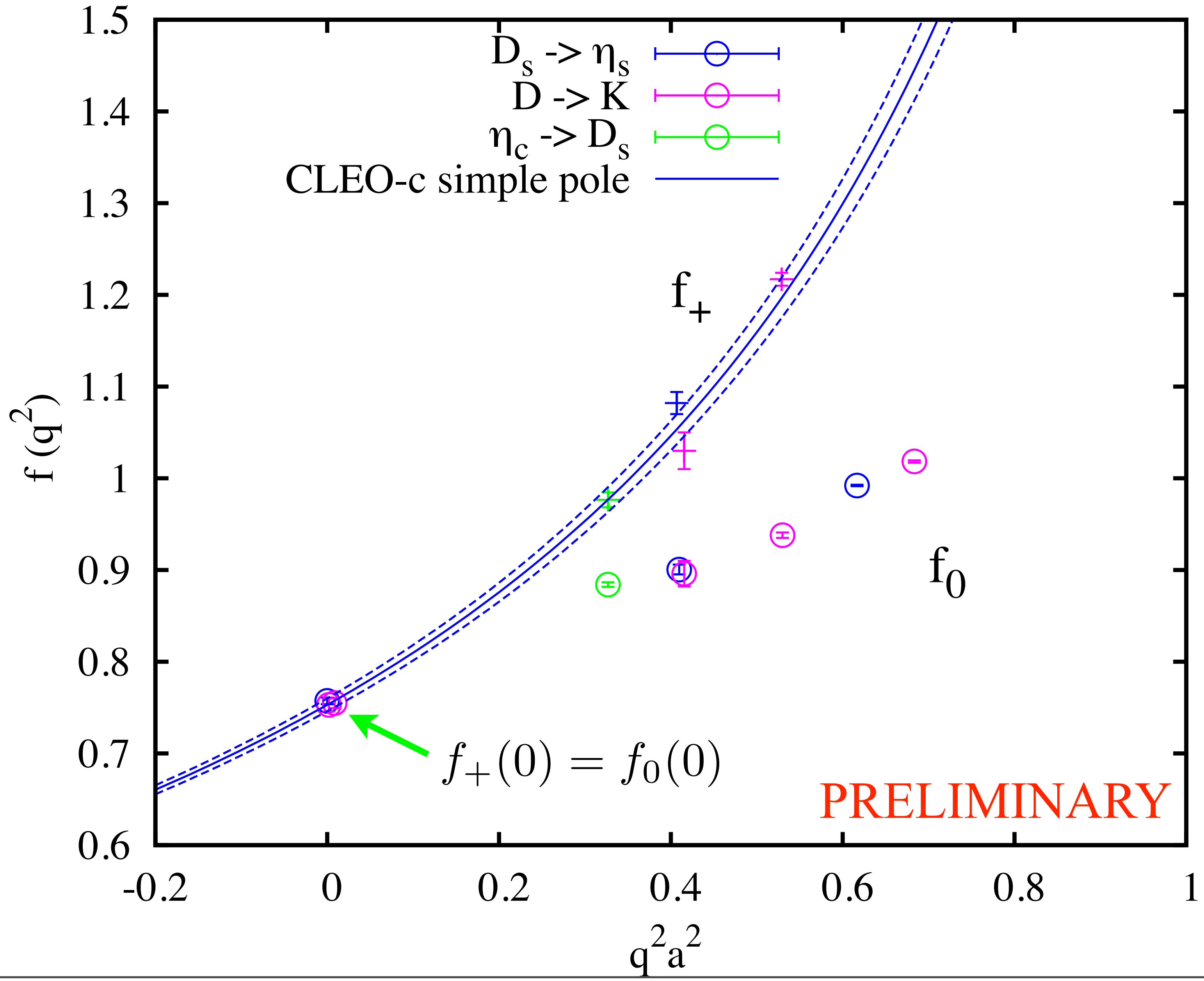


0.961(26)
error dominated by theory (now 2.5%)

1.010(22)
error dom. by expt (now 2%, BES will improve)

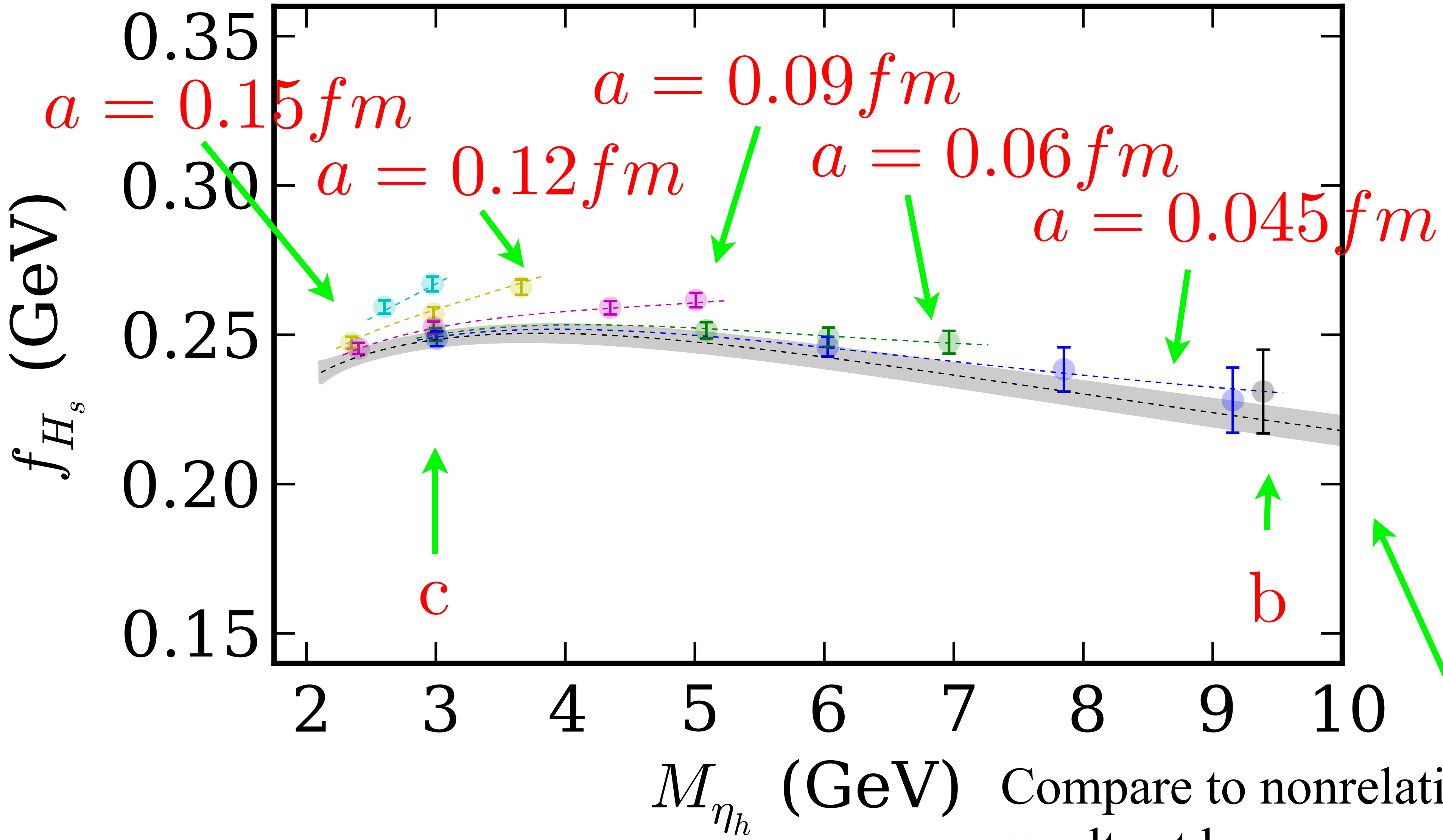
In progress: improving lattice QCD calculation of $f_+(q^2)$

J. Koponen, HPQCD, Monday afternoon talk



Comparison to expt will provide more detailed test of QCD. Note how form factor same for different processes all involving $c \rightarrow s$ decay.

B results less accurate : use of nonrelativistic effective theories gives ~5% normln uncty. Future: use relativistic formalism even for b quarks - needs very fine lattices ...

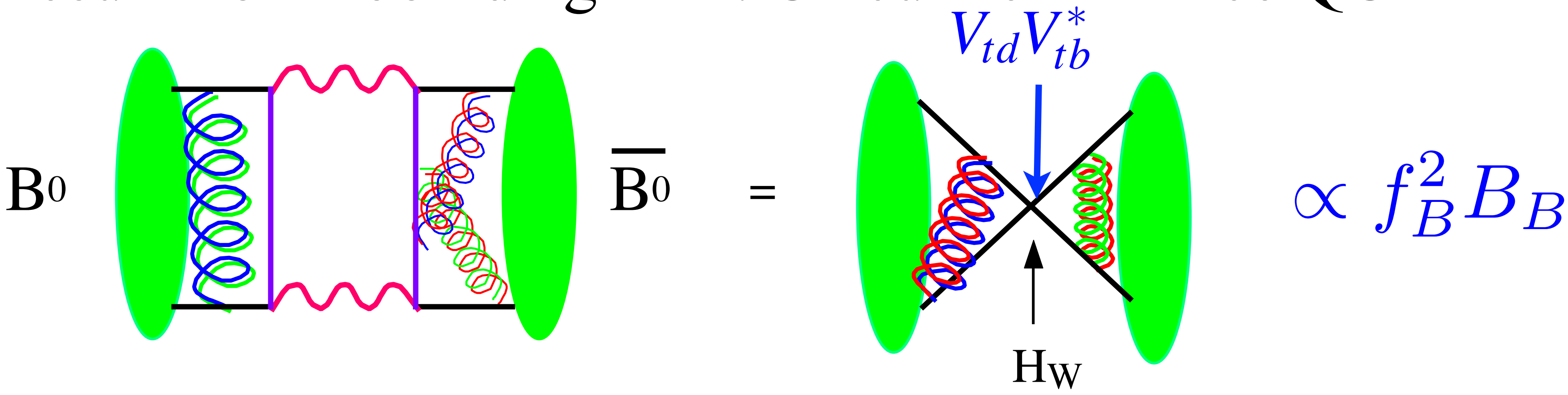


Compare to nonrelativistic results at b

C. McNeile, CTHD, HPQCD, in progress

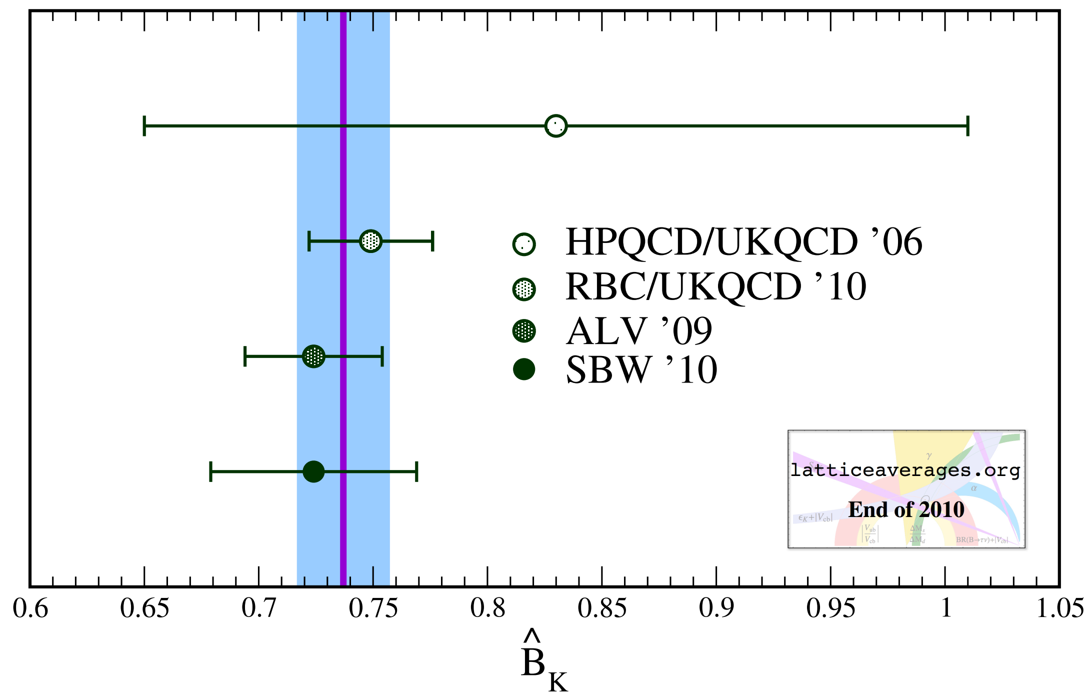
Neutral K and B mixing and oscillations

Result from "box diagram". Calculate in lattice QCD



2010 lattice QCD :
New B_K results
leads to 3% error.

Average: 0.737(20)



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

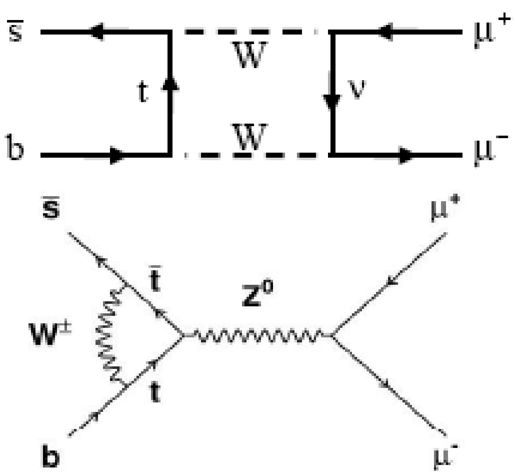
$$\xi = \frac{f_{B_s}\sqrt{B_{B_s}}}{f_B\sqrt{B_B}} = 1.26(3) \rightarrow \frac{|V_{td}|}{|V_{ts}|} = 0.214(5)$$

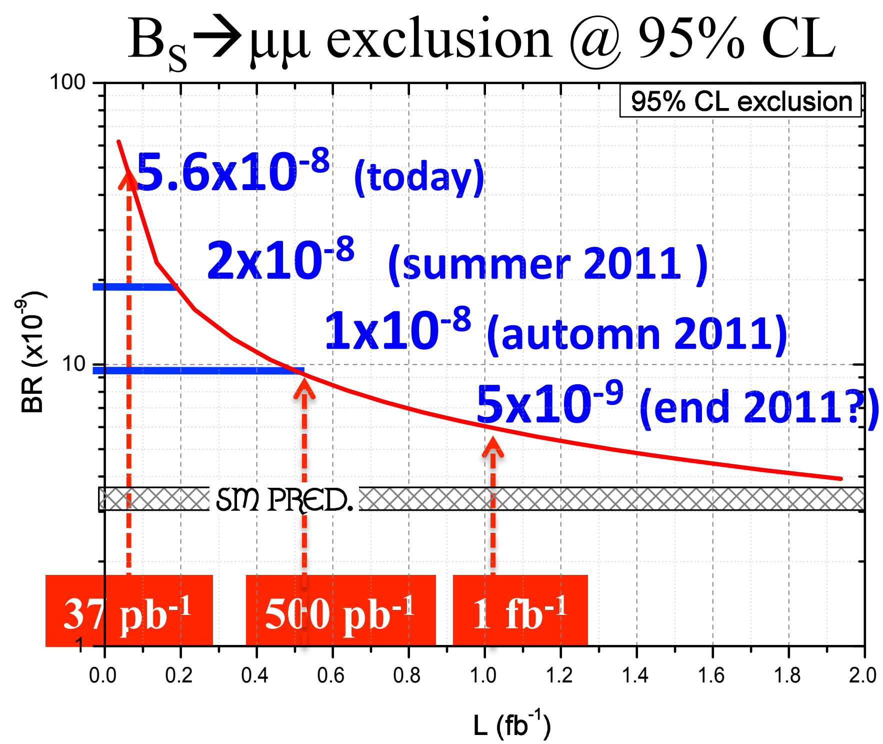
normln error cancels in ratio.

E. Gamiz et al, HPQCD, 0902.1815

Use to provide SM rate for LHCb of:

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

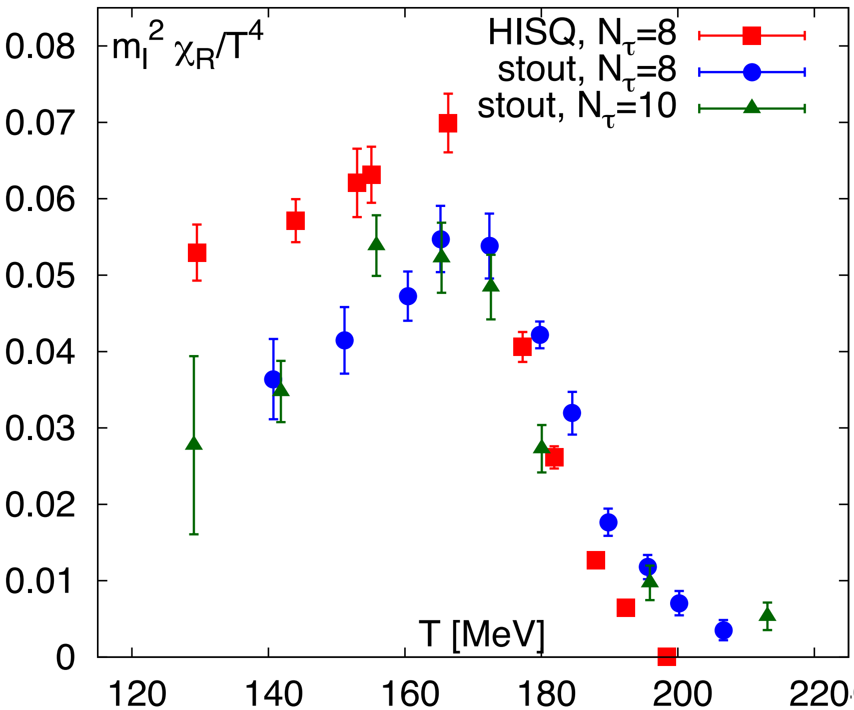




Need to improve lattice QCD error ..

New LHCb limit 1103.2465

Other results

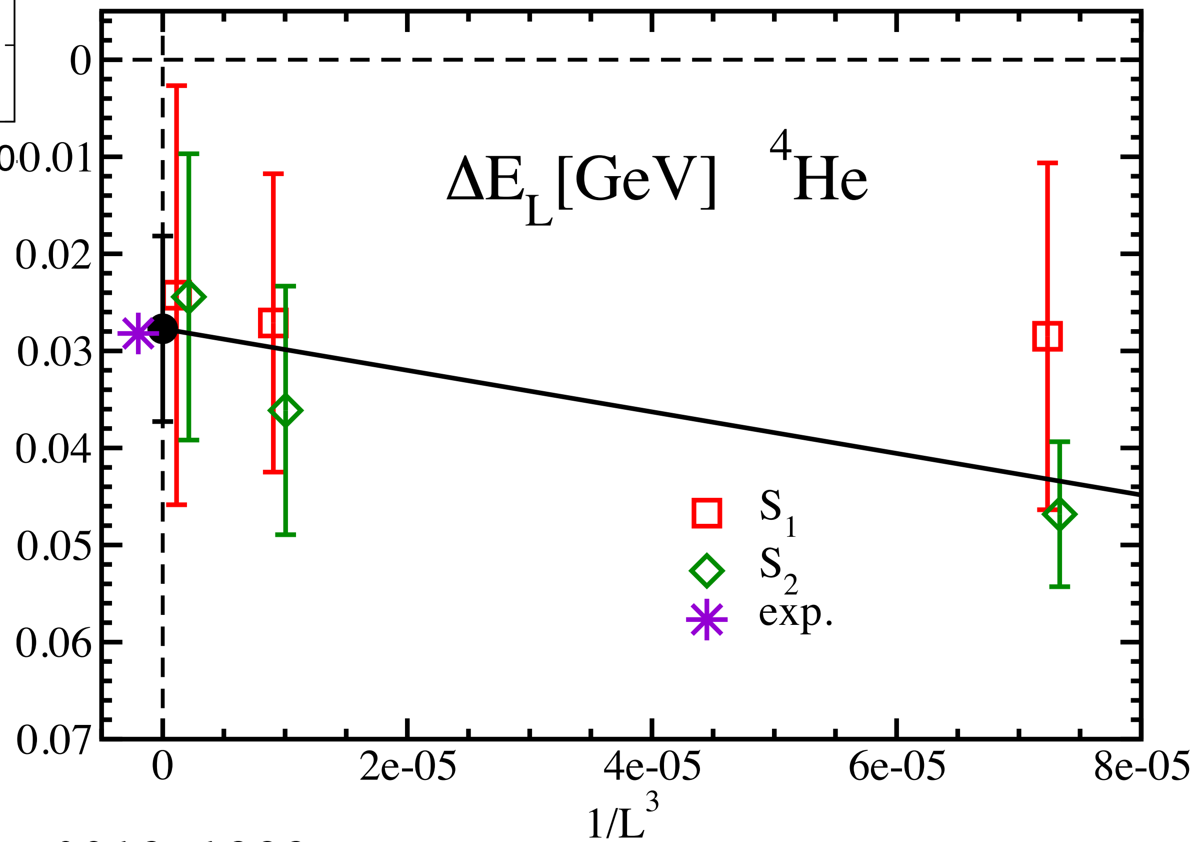


QCD at finite temperature - discrepancies in values obtained for T_c being resolved. Conclude:

T_c: 145-165 MeV

K. Kanaya, 1012.4247

Binding energy of a helium nucleus - first calculations giving plausible results but this is quenched QCD.



T. Yamazaki et al, PACS-CS, 0912.1383

New £13M HPC facility for UKQCD consortium + Virgo, Cosmos, Miracle .. funded by STFC + LFCF

DiRAC = Distributed Research using Advanced Computing

clusters in Cambridge, Liverpool, Plymouth, Southampton

← Darwin cluster, Cambridge

2-rack BG/P system at Swansea - BG/Q at Edinburgh later this year. →

International collaborn growing feature of lattice QCD ...

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 will be possible.

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

Look at error budgets to se 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

Lattice QCD is definitely useful!