D and D_s decay constants from Lattice QCD

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HPQCD collaboration

charm2009,
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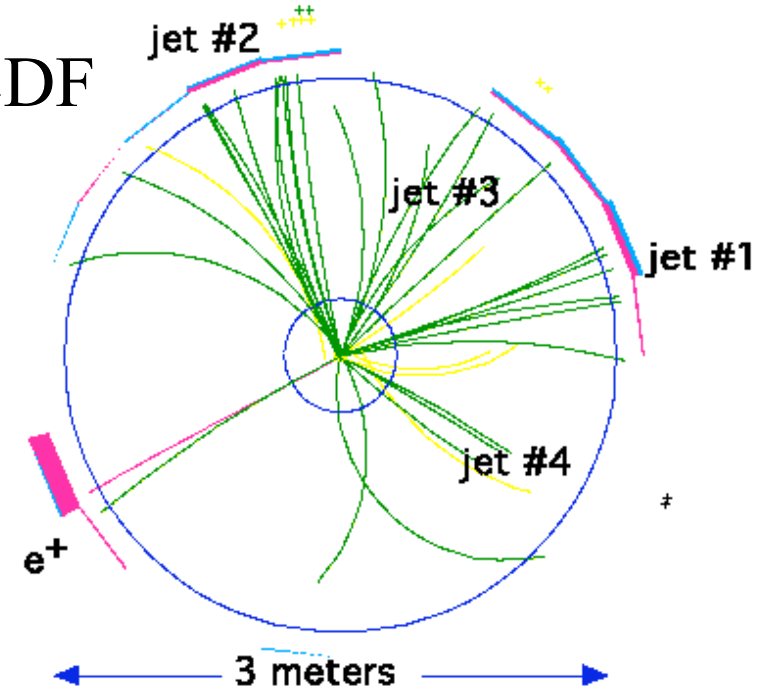
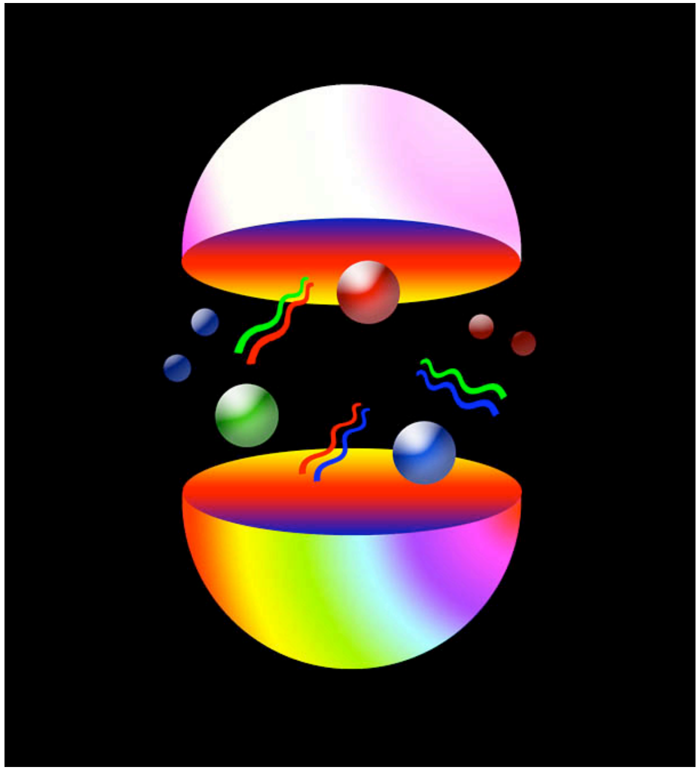
QCD is a key part of the Standard Model but quark confinement complicates things.

CDF



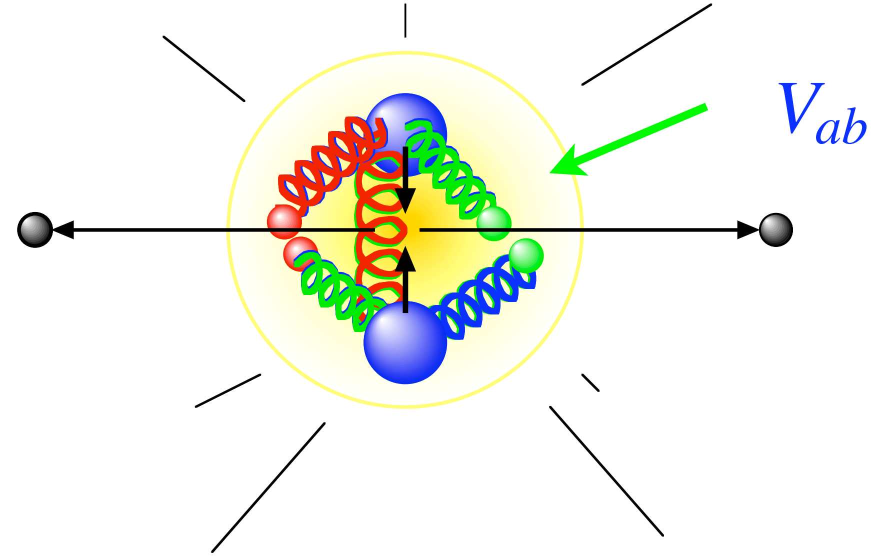
QCD only tested to 5-10% level at high energies from comparison of e.g. jet phenomena to pert.th.



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

Simplest calcs are for meson masses and decay constants

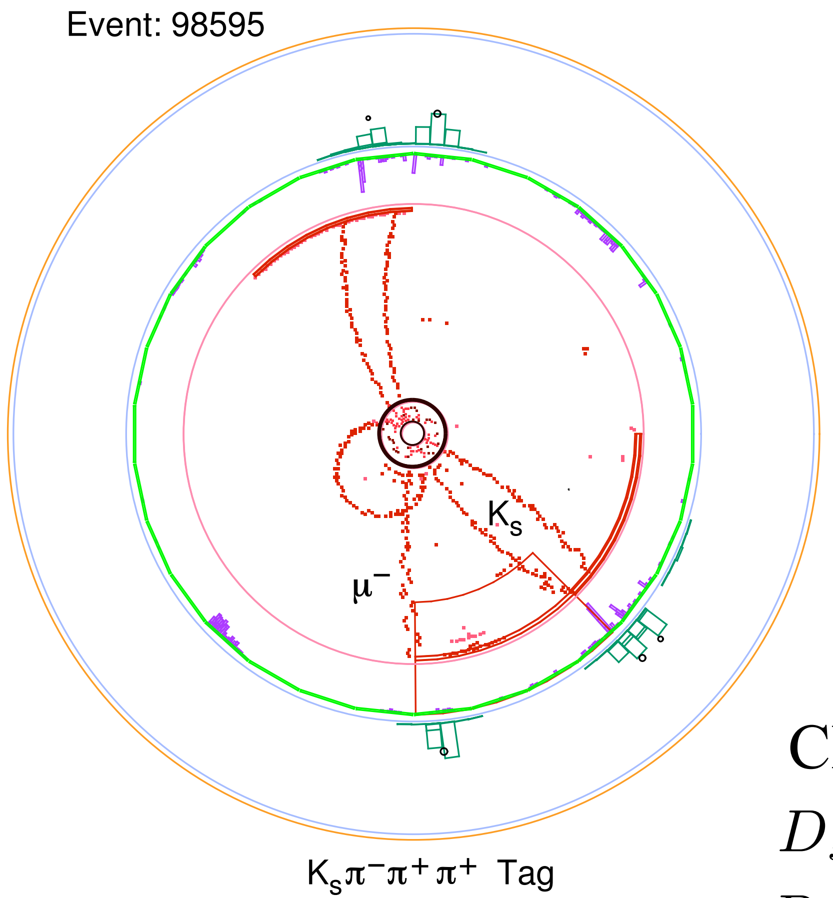
Decay constants related to annihilation rate via W or γ



$$Br(H \to \mu\nu) \propto V_{ab}^2 f_H^2$$

$$< 0|\overline{\psi}\gamma_0\gamma_5\psi|H >= f_H m_H$$

f_H is a property of the meson calculable in lattice QCD



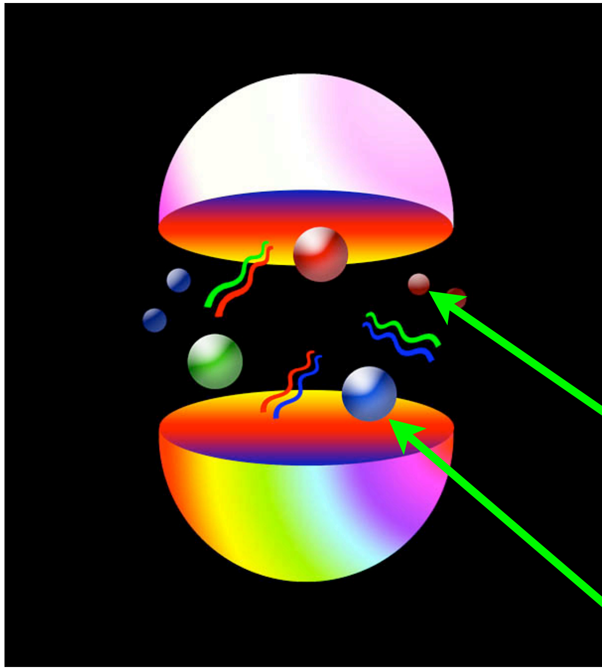
CLEO-c

$D_s \to \mu\nu$

$D_s \to K\pi\pi\pi$

Similarly for vector mesons ....

Lattice QCD = fully nonperturbative QCD calculation



RECIPE

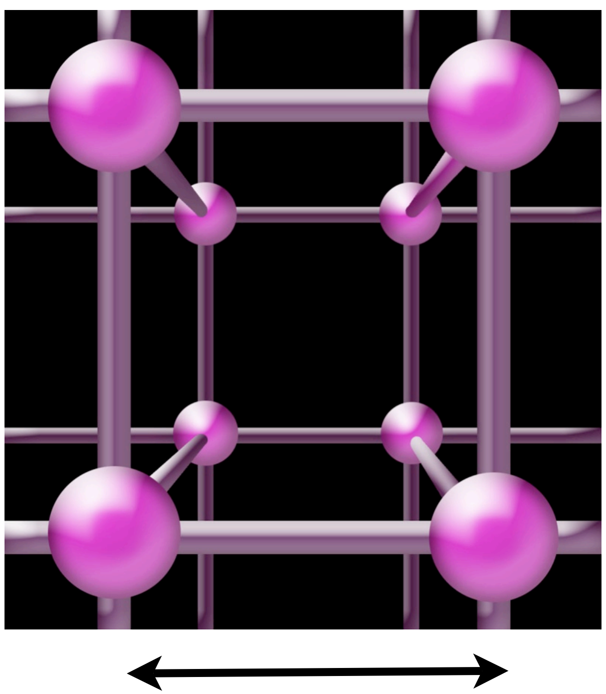
• Generate sets of gluon fields for Monte Carlo integrn of Path Integral (inc effect of sea quarks)

• Calculate averaged "hadron correlators" from valence q props.

$$< 0|M^{\dagger}(0)M(t)|0 >$$

• Fit for hadron masses and decay constants.

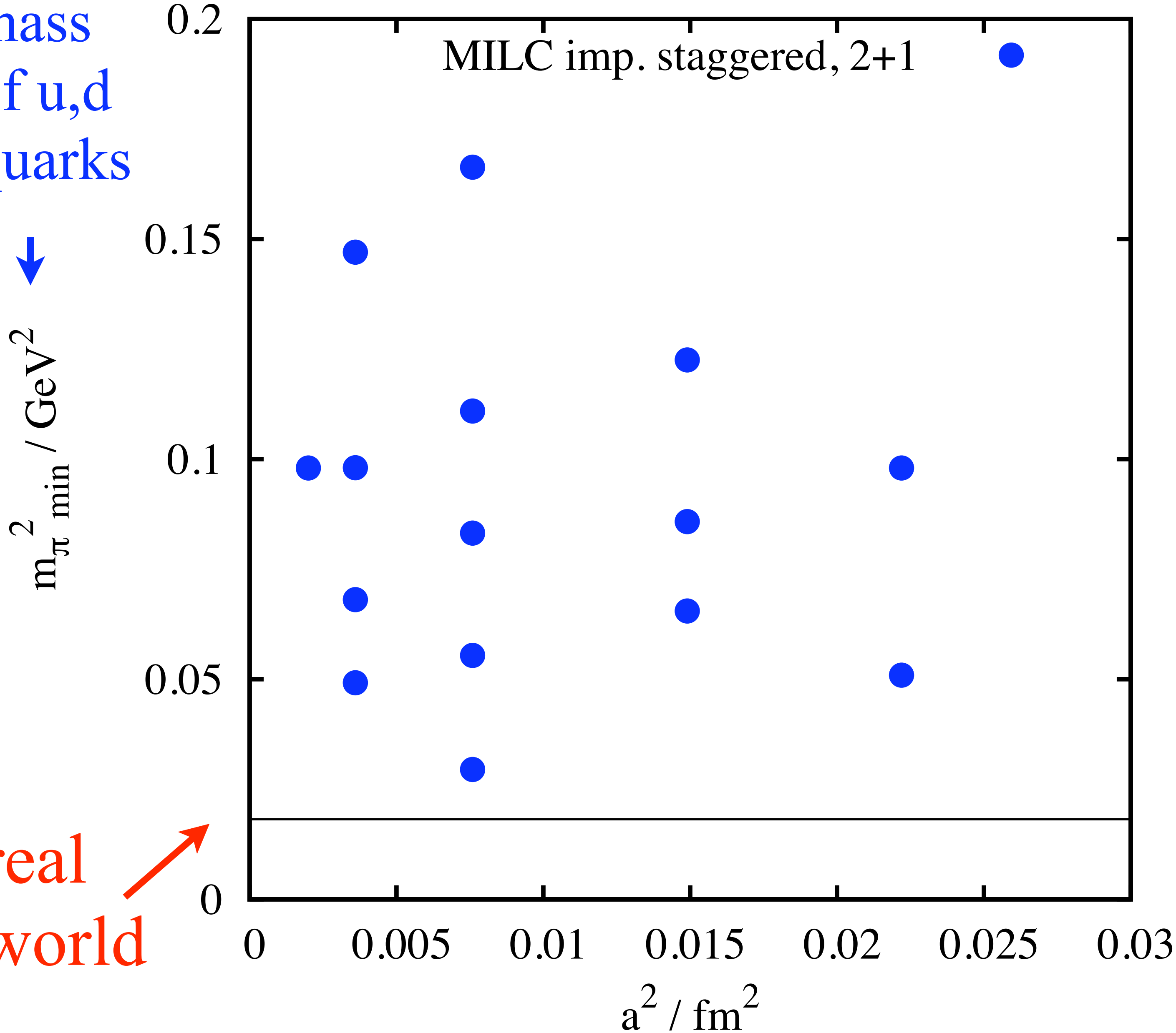
• Fix m_q and a to get physical results - extrapolate to real world



a

Parameters for calculations done using improved staggered sea quarks. Results from other formalisms also.

mass of u,d quarks



real world

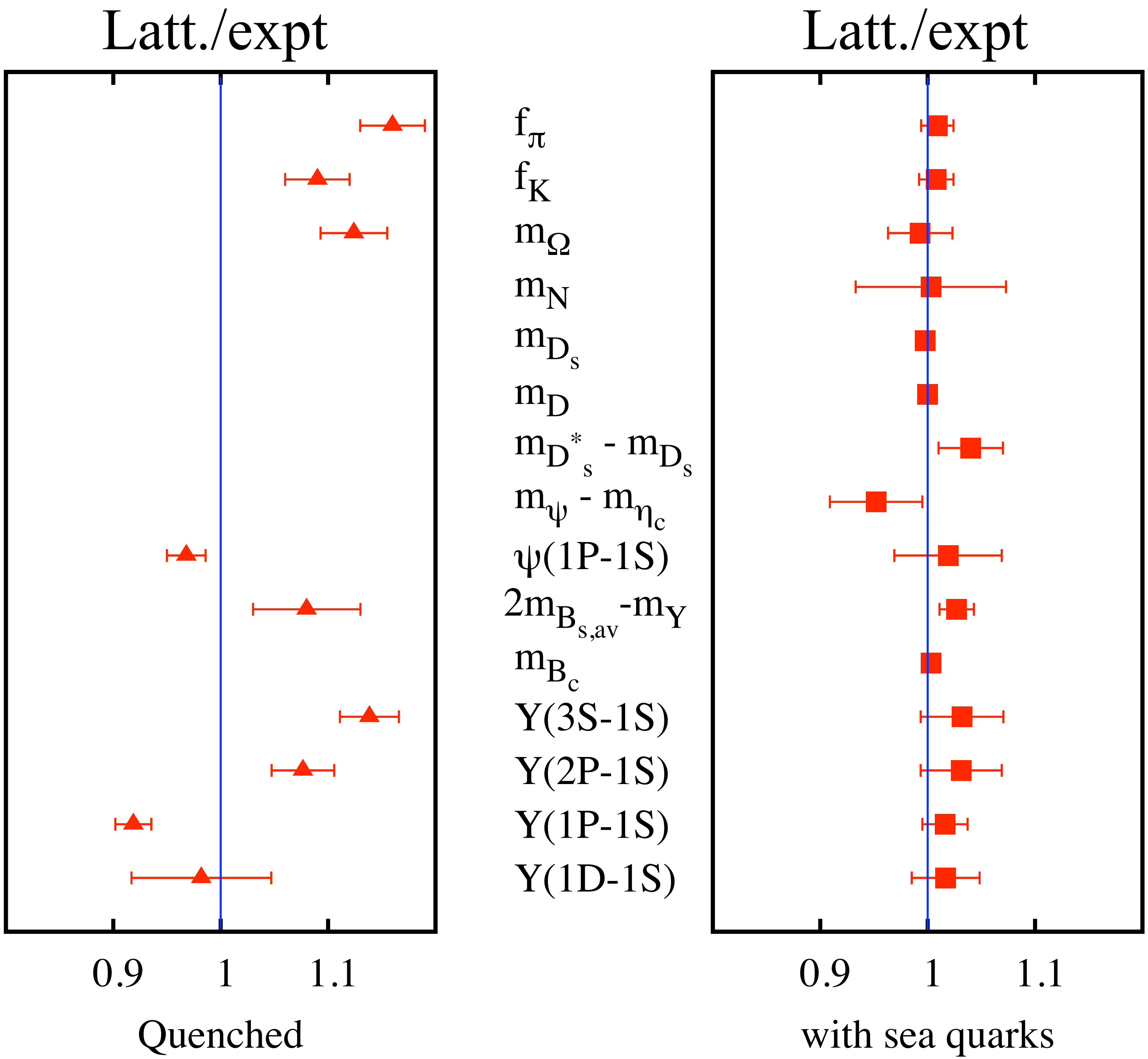
Volume of lattice also an issue - need $\sim (>2.5\text{fm})^4$

$\leftarrow$ $m_{u,d} \approx m_s/5$

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

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

Including u, d and s sea quarks is critical for accurate results, but numerically expensive - particularly light $m_{u,d}$.



HPQCD/ MILC 2008 "ratio plot".

NEW: big improvement in charm sector

update of:
C. Davies et al, hep-lat/0304004

Charm quarks in lattice QCD - heavy or light?

Advantages of relativistic light quarks:

- $E_{sim} = m$
- PCAC relation (if enough chiral symmetry) gives $Z = 1$
- same action as for u, d, s, so cancellation in ratios

Key issue is discretisation errors:

$$m = m_{a=0}(1 + A(m_c a)^2 + B(m_c a)^4 + \dots$$

$$m_c a \approx 0.4,\ (m_c a)^2 \approx 0.2,\ \alpha_s (m_c a)^2 \approx 0.06,\ (m_c a)^4 \approx 0.04$$

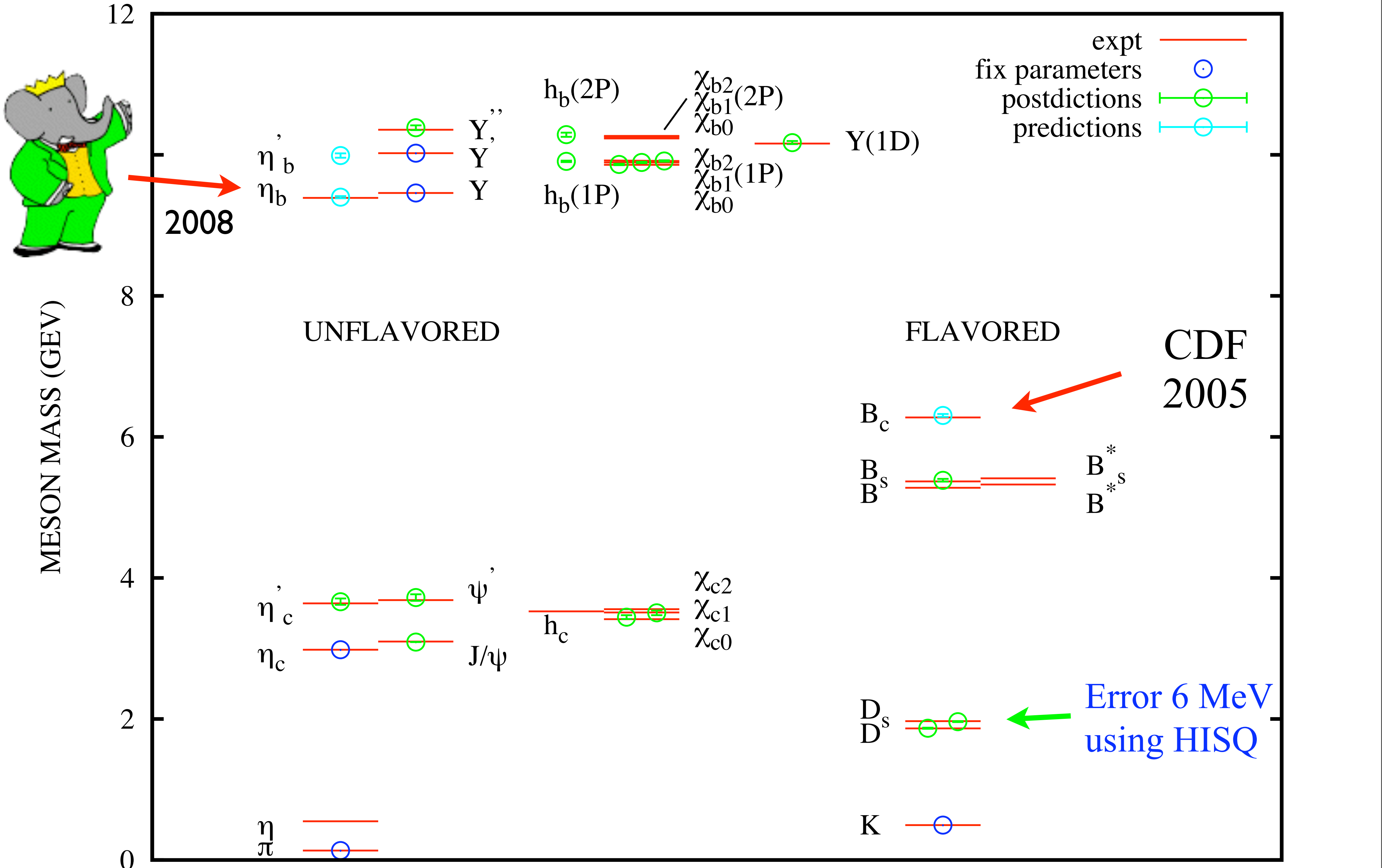
for $a \approx 0.1 fm$

Need to remove *all* of these errors for precision results

This is done in Highly Improved Staggered Quarks (HISQ) formalism, further improving Improved Staggered Quarks

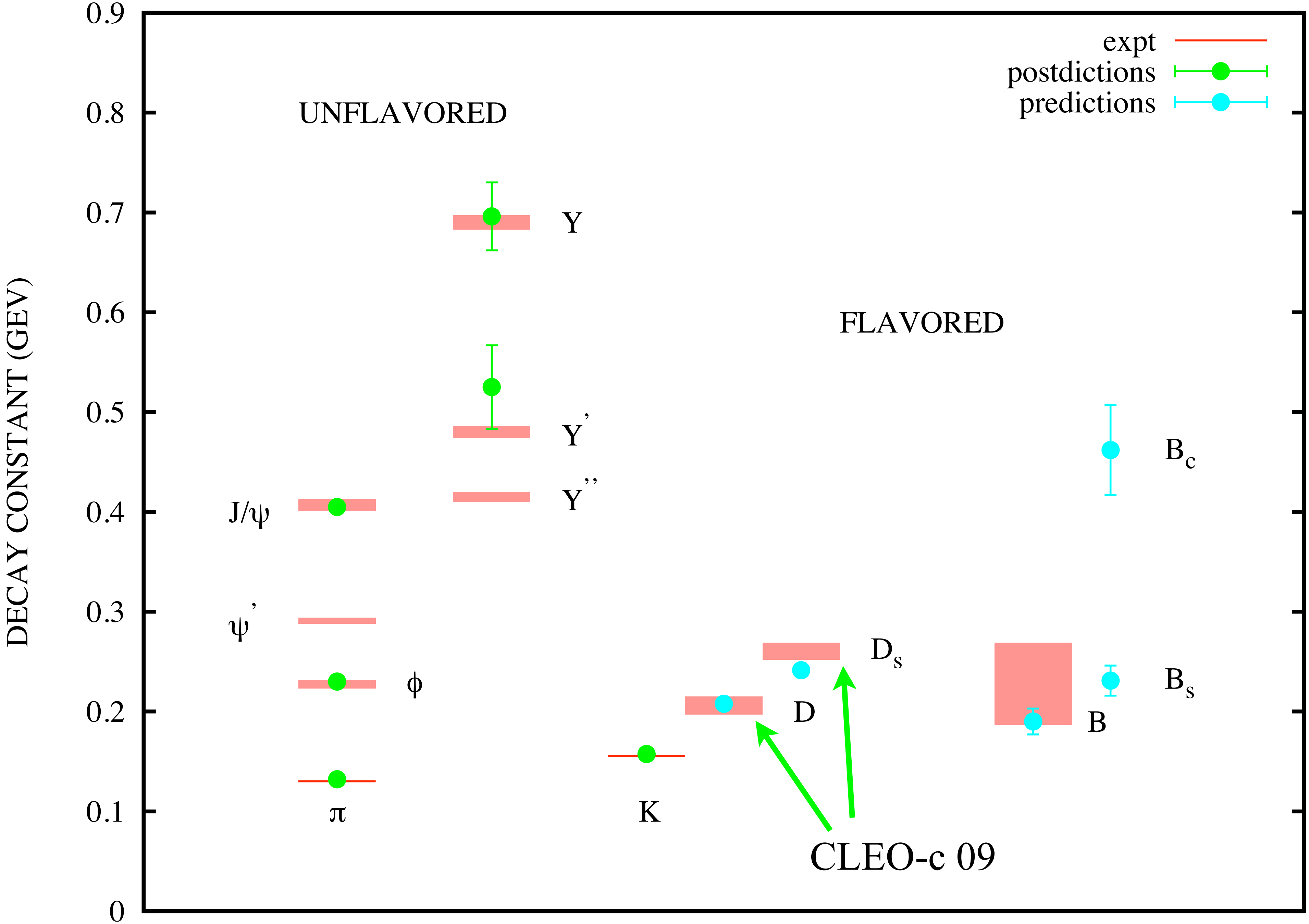
E. Follana et al, hep-lat/0610092

Overview: The gold-plated meson spectrum - HPQCD

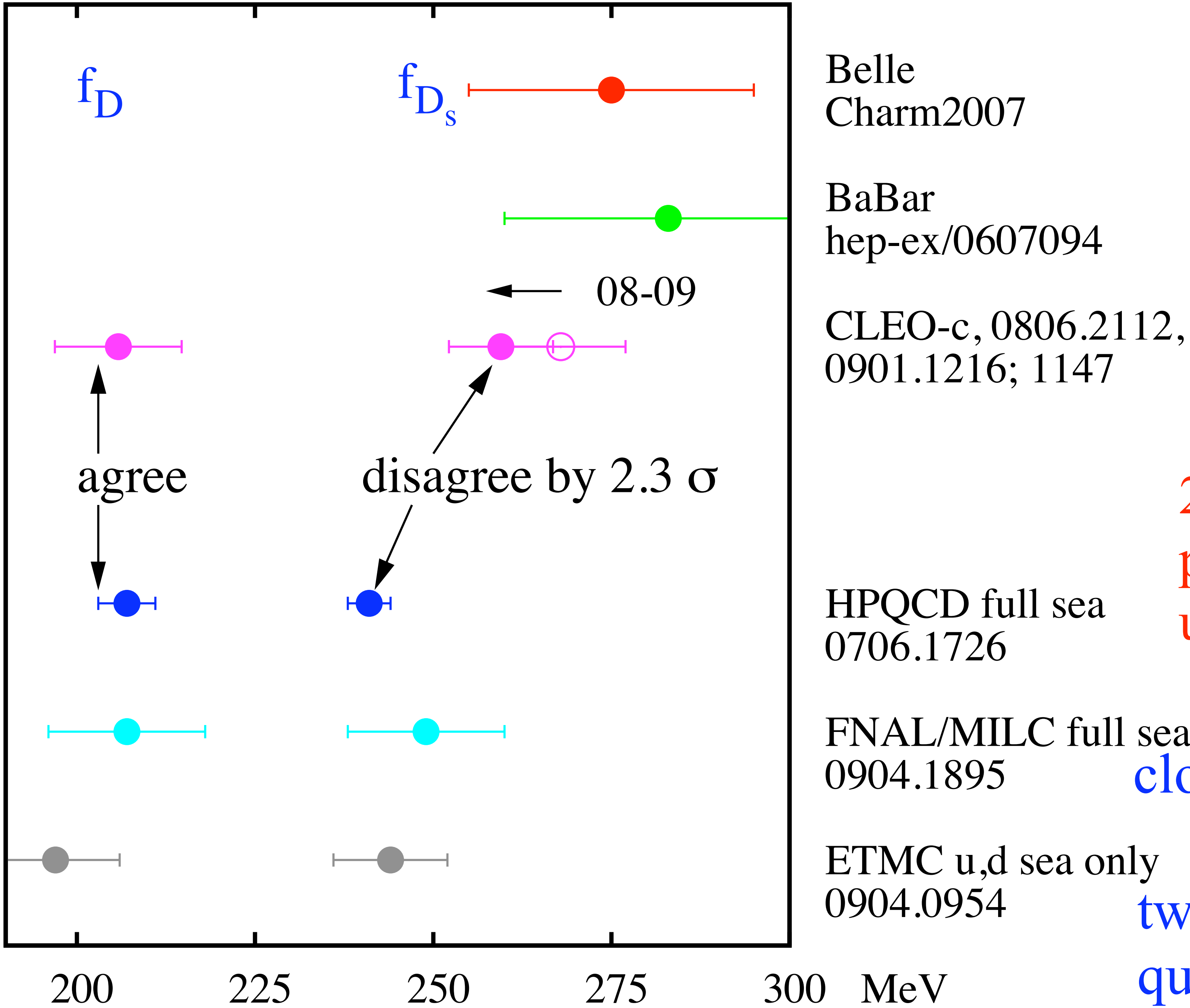


Overview: Gold-plated meson decay constants - HPQCD

vectors preliminary



Precision decay constants now available for D, D_s :

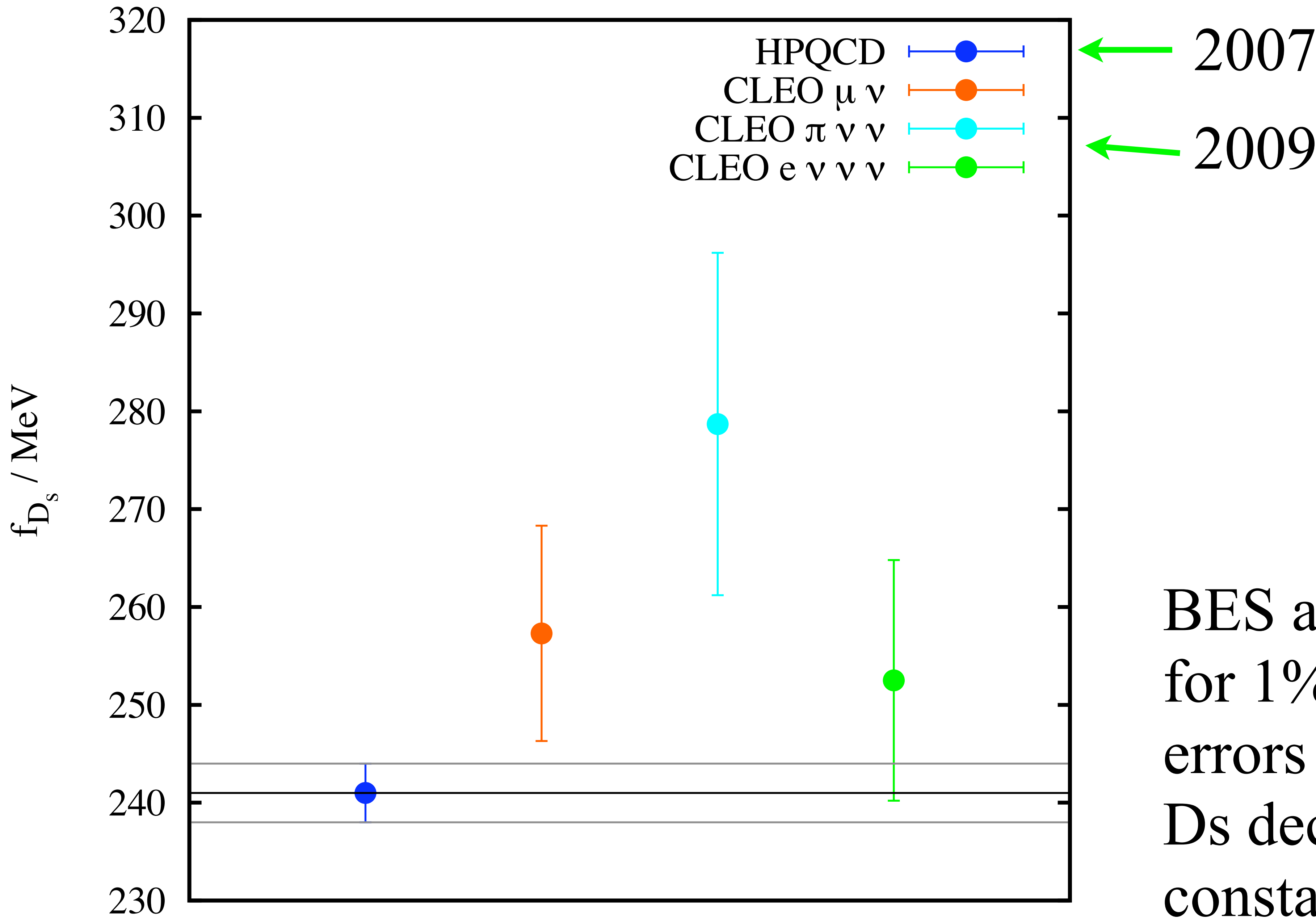


2% errors possible using HISQ

clover c quarks

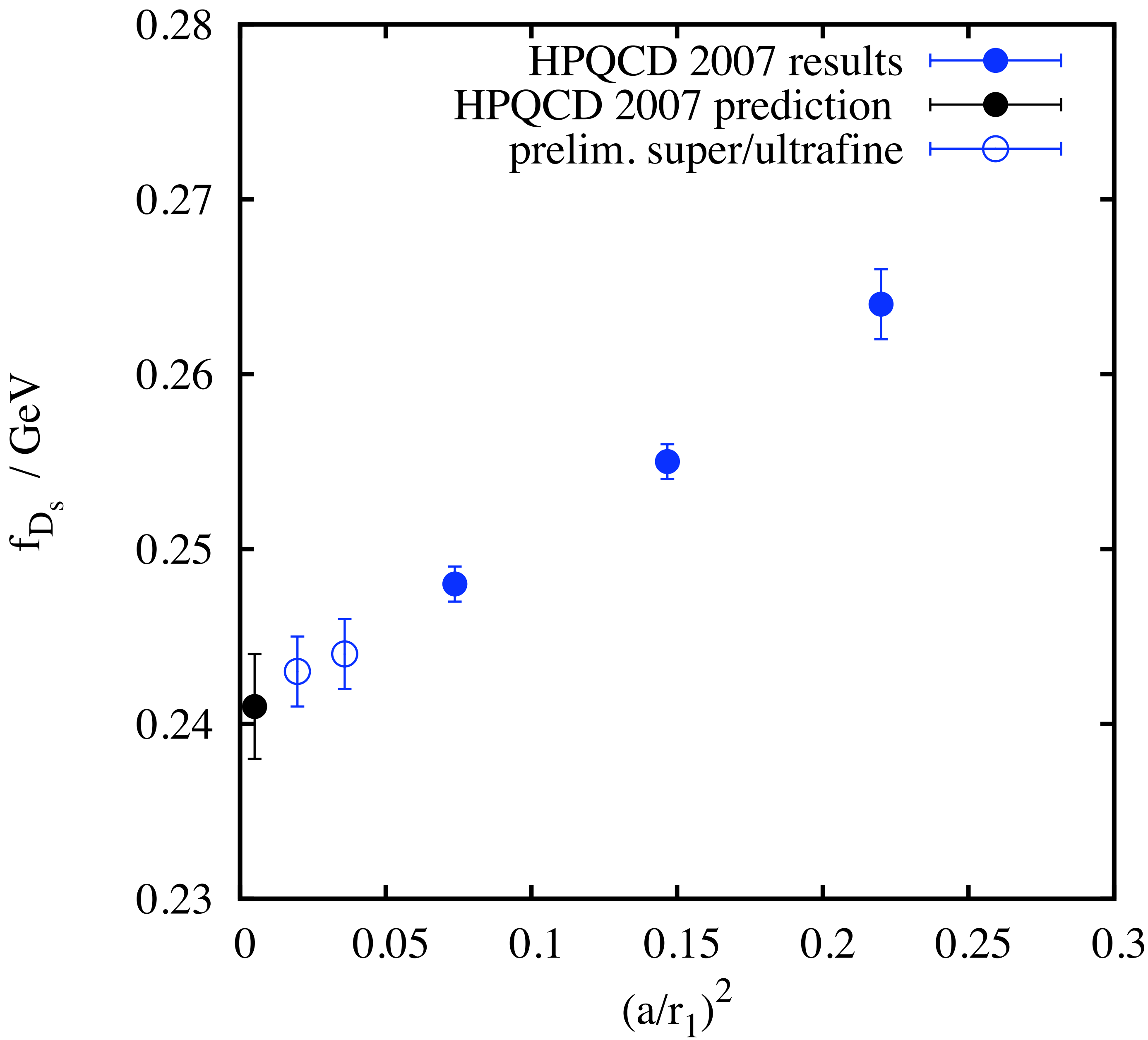
twisted mass quarks

More detailed comparison - lattice vs CLEO-c for D_s



BES aims for 1% errors on Ds decay constant ...

Main issue in lattice QCD calcn of f_{D_s} is control of discretisation errors

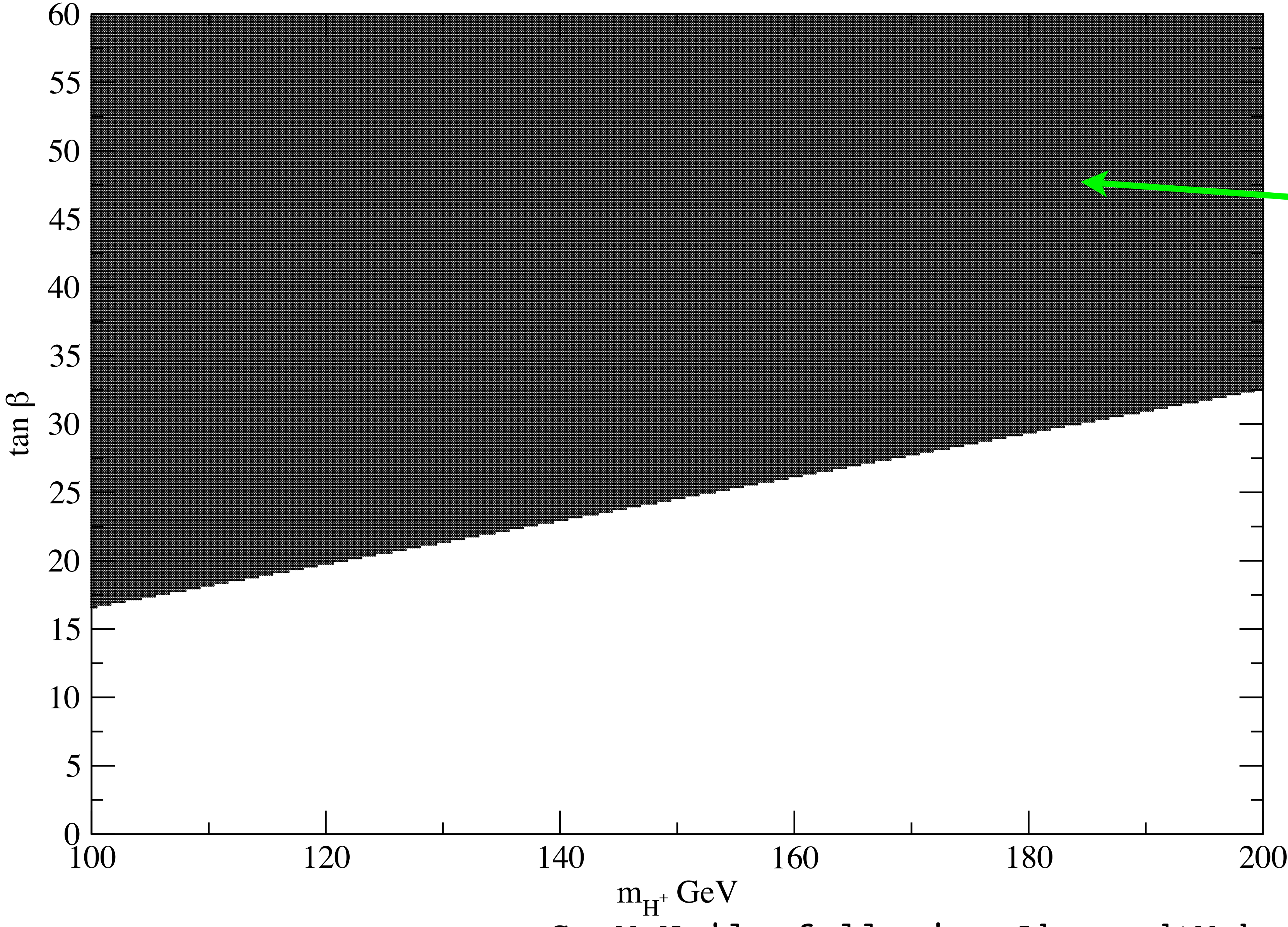


NEW HPQCD results using HISQ 2009
- added two finer MILC lattices
- result unchanged

Key remaining error is determn of lattice spacing

Can use lattice vs expt for f_{D_s} to limit BSM physics

e.g. presence of charged Higgs REDUCES annihilation rate

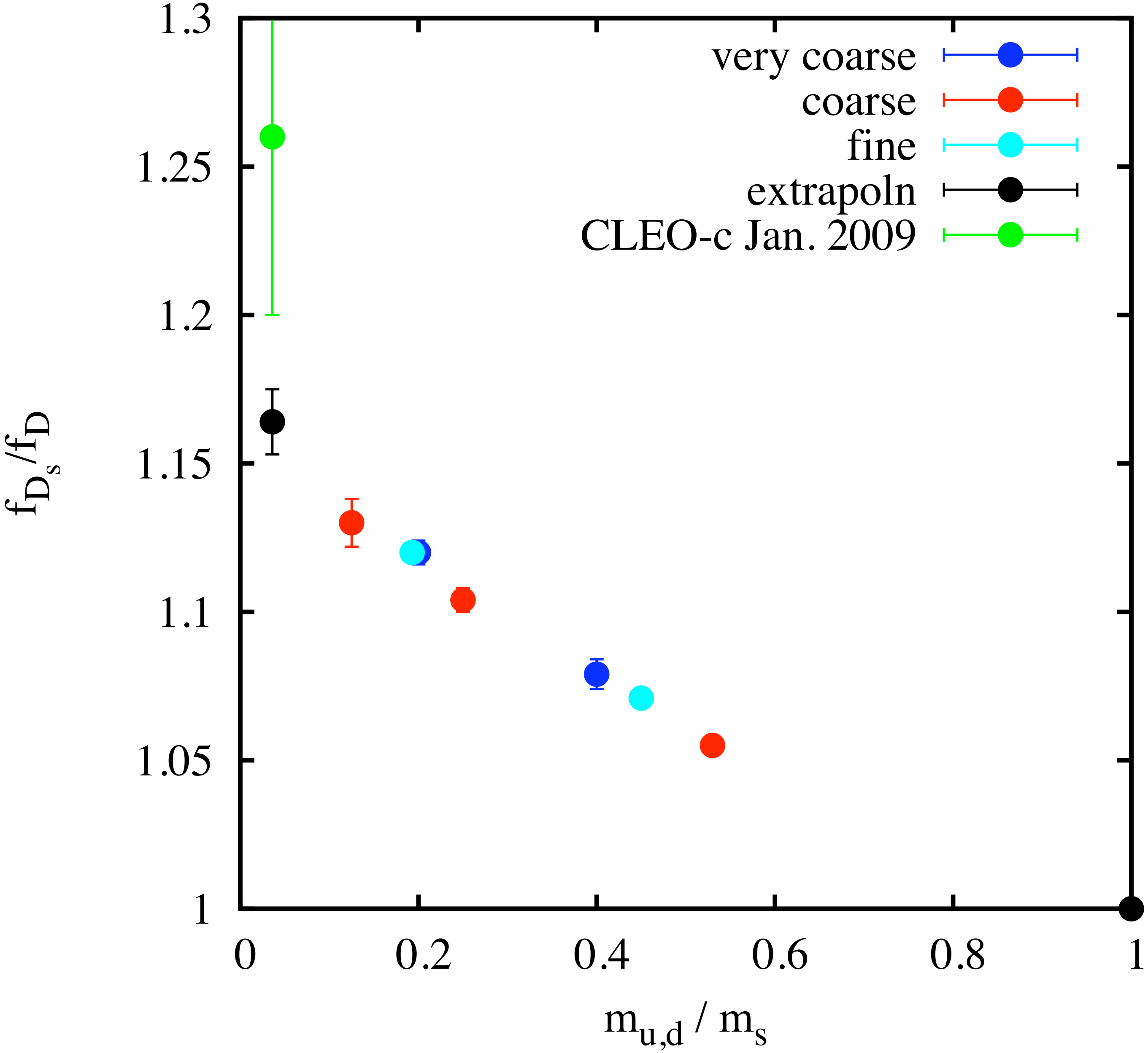


ruled out currently

Needs accurate m_c/m_s

C. McNeile following Akeroyd+Mahmoudi 0902.2393

Main issue in lattice QCD calcn of f_D is approach to the physical u/d mass limit



Discretisation effects cancel in ratio with f_{Ds}

Configs now available with $m_{u,d}/m_s = 0.05$, so improved calcs will be possible

Decay constants for B and B_s mesons

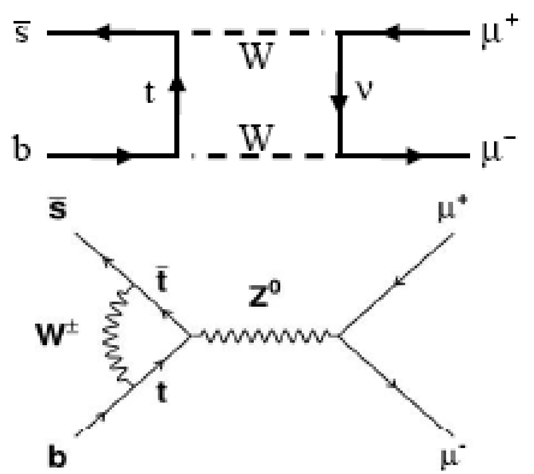
Expt is very hard: for f_B, exptl error (Belle from $B \to \tau\nu$) 20%.

Lattice results, HPQCD 2009 using NRQCD, error 6%:

$$f_B = 190(13) MeV$$

$$f_{B_s} = 231(15) MeV$$ N.B no actual leptonic decay

Usefulness is in providing SM rate for:



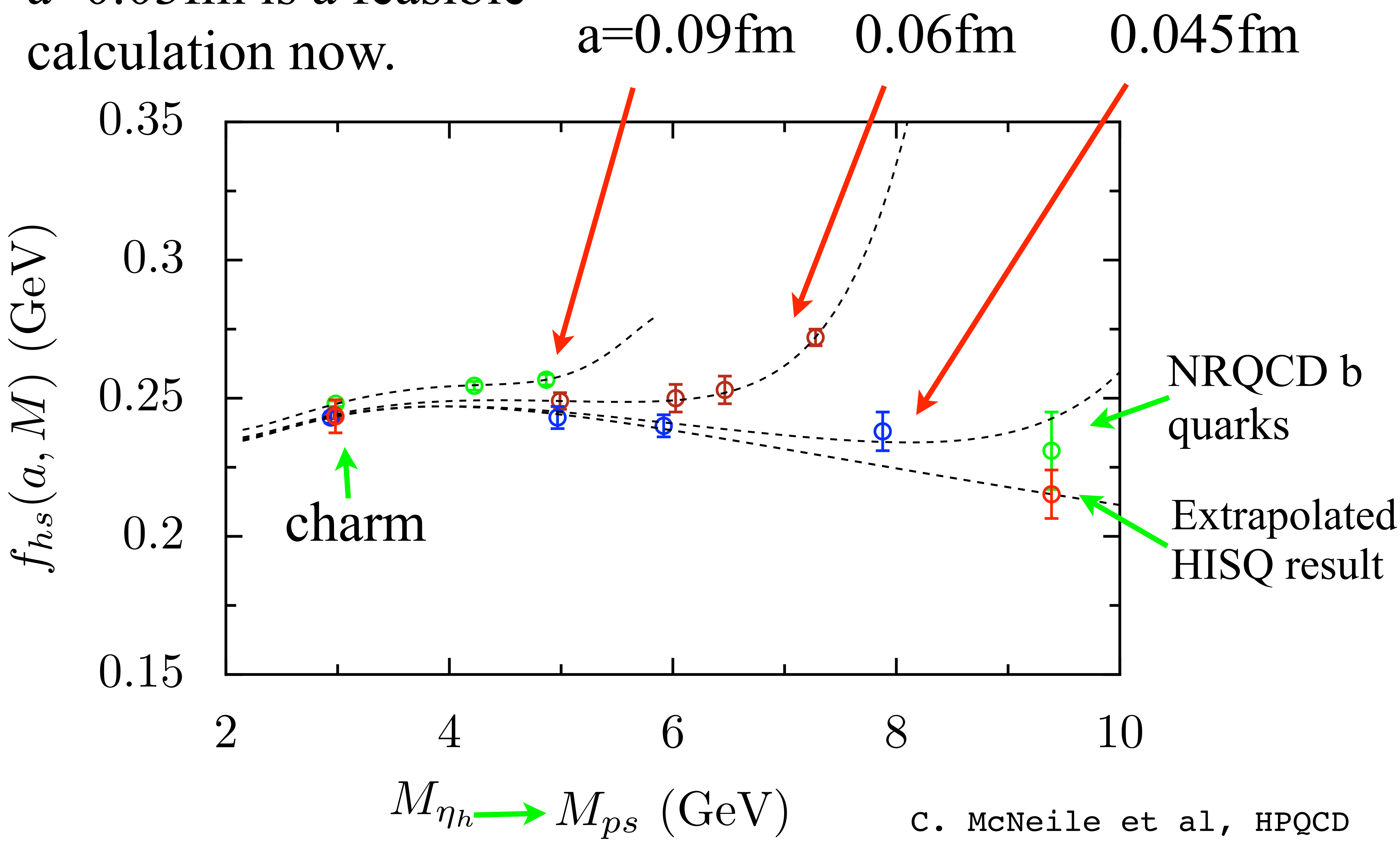
$$Br(B_s \to \mu^+\mu^-) = 3.5(5) \times 10^{-9}$$

Sensitive to new physics and will be seen by LHCb ...

E. Gamiz et al, HPQCD, 0902.1815

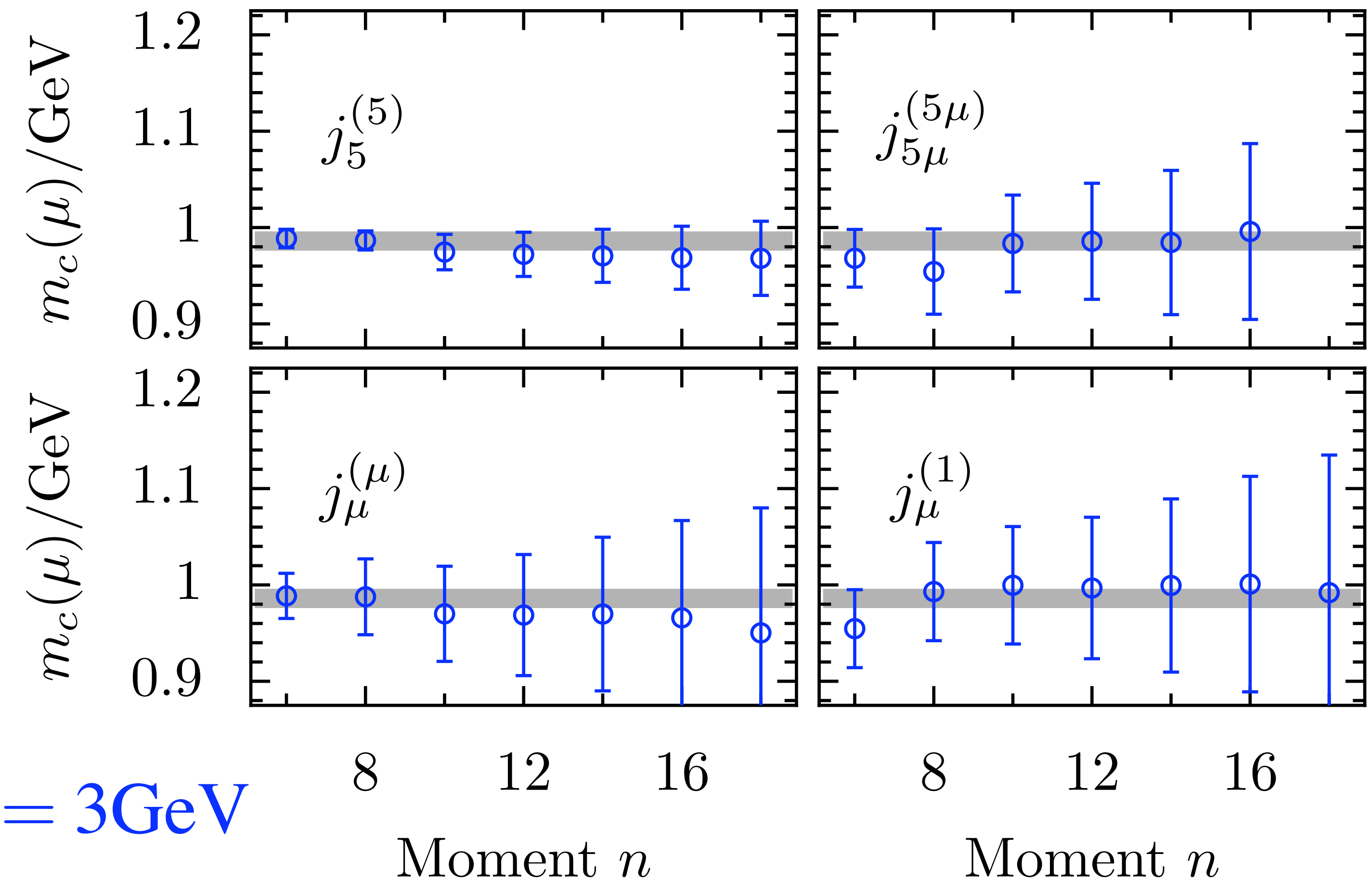
In future: use HISQ for b quarks also! Lots of a values allows us to fit disc. errors over c to b range and remove.

a=0.03fm is a feasible calculation now.



C. McNeile et al, HPQCD

1% accurate value for m_c possible



$\mu = 3\text{GeV}$

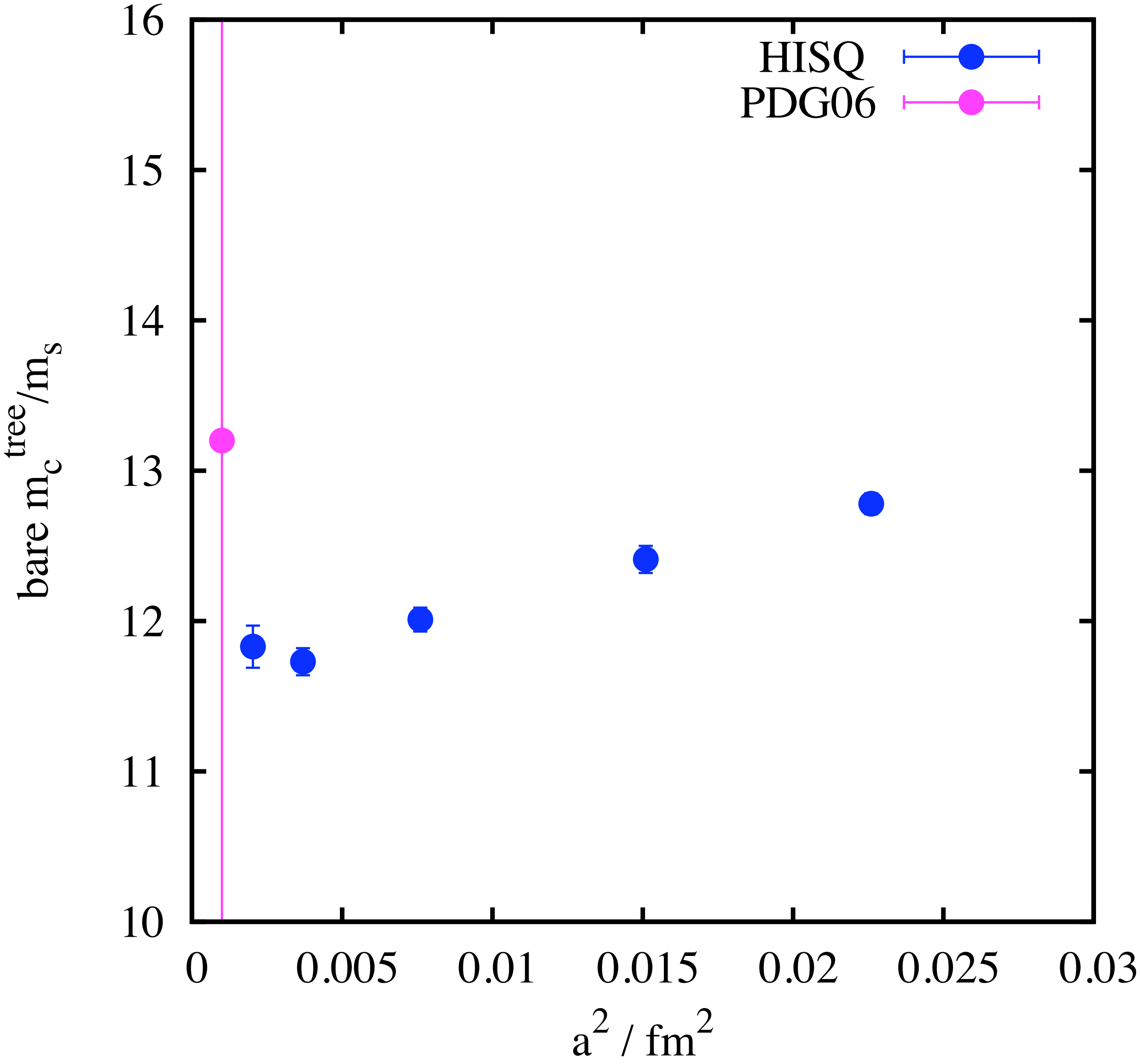
I. Allison et al, HPQCD, 0805.2999

Best lattice result from pseudoscalar

$m_c(3\text{GeV}) = 0.986(10)\text{GeV}$ $\quad m_c(m_c) = 1.267(9)\text{GeV}$

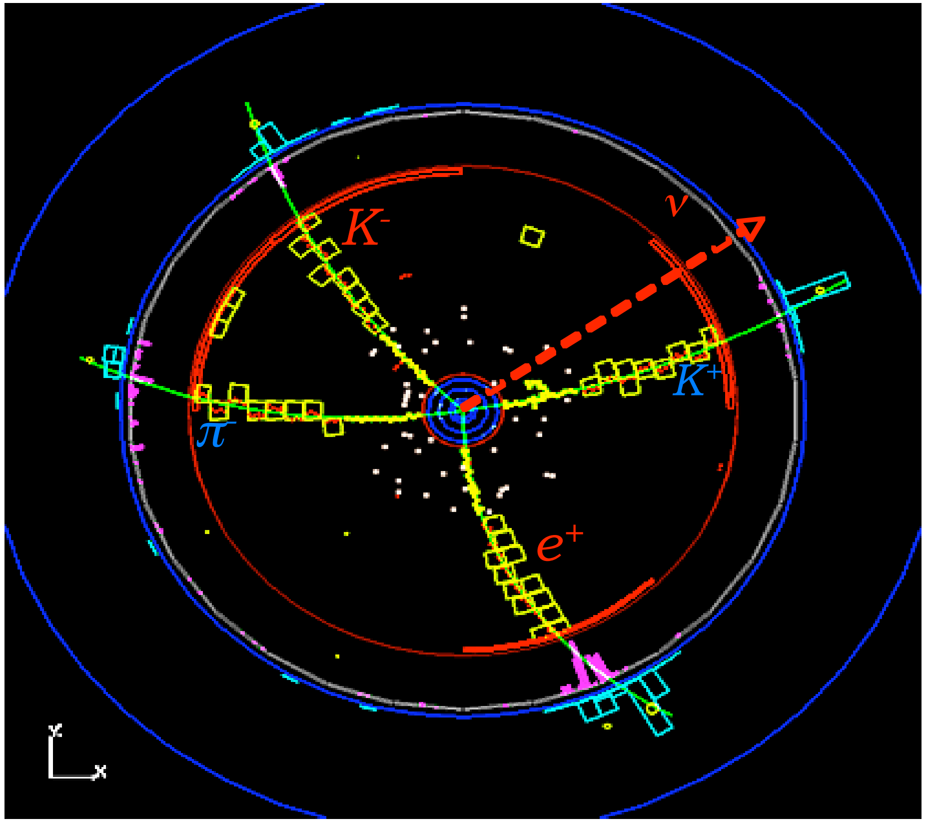
Contnm uses vector, $R(e^+e^-) = 0.986(13)$ GeV Kühn et al hep-ph/0702103

Can also obtain accurate m_c/m_s and hence m_s



HPQCD preliminary result: 11.7(2)

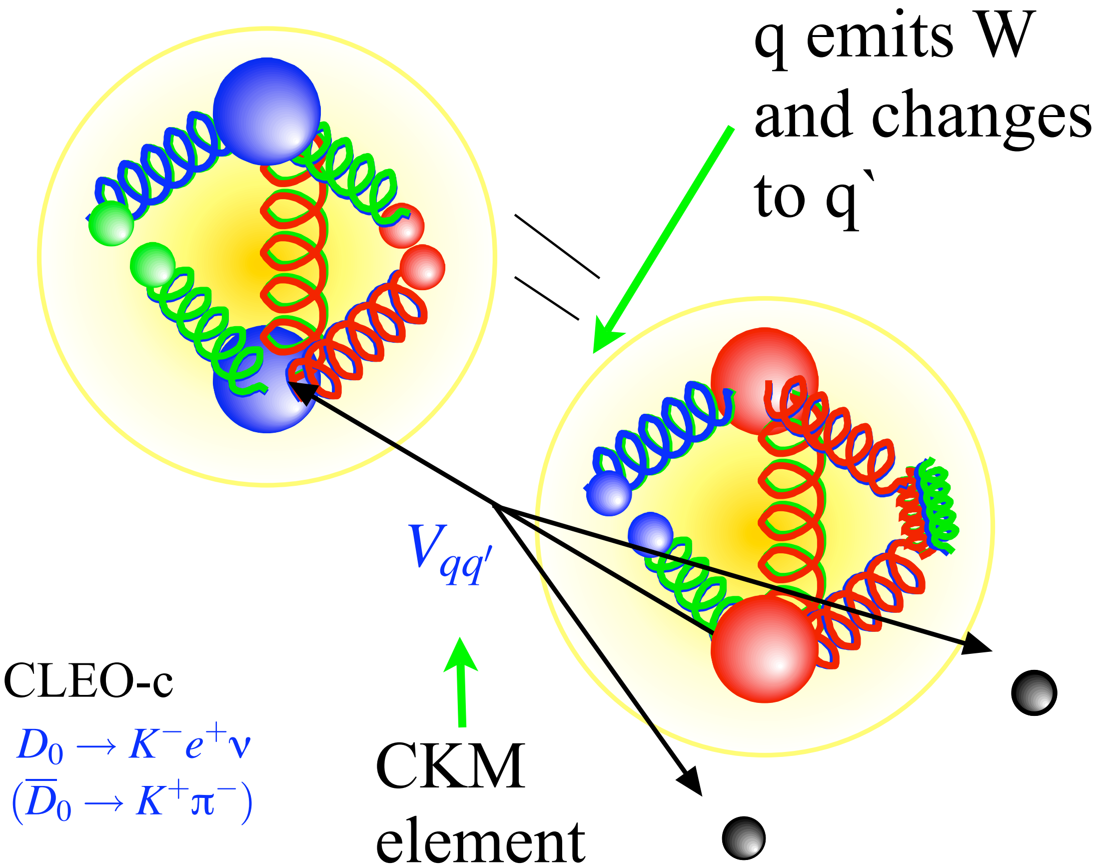
This is all part of the same lattice calcn that gives D and Ds decay constants ..



CLEO-c

$D_0 \to K^- e^+ \nu$

$(\overline{D}_0 \to K^+ \pi^-)$



Semileptonic weak decay processes e.g $D \to Kl\nu$ also calculable in lattice QCD.

Harder because of final state meson and current calculations not as good. Aim for 2% errors here also.

FUTURE

Sub-percent errors need (e.g. for decay constants):

- Better than 0.5% determn of the lattice spacing.
- Lighter $m_{u,d}$ for less chiral extrapoln uncertainty
- Bigger volumes, e.g. $(4\text{fm})^4$ for π .
- Higher statistics for B
- Lattice spacings ~ 0.03fm for relativistic B/Bs

"2nd generation" gluon configurations now being planned. Include improvements such as:

- $m_u \neq m_d$. Allows electromagnetic effects to be inc. (affect hadron masses at few MeV level). Better m_u, m_d.
- c quarks in the sea. Can check the effect of this.
- Further improved gluon action for lower disc. errors.

Conclusions

- Highly improved relativistic approach (HISQ) to charm physics in lattice QCD achieves 2% errors for simple quantities - meson masses, decay constants and quark masses for u, d, s, and c.
- Comparison to expt. allows limitations on (discovery of?) BSM physics.
- In future can reduce lattice errors further. Exptl errors need to improve.
- Improved calculations of semileptonic form factors for D weak decays underway.
- Now applying relativistic technique to b physics ...

Complete error budget for HPQCD calculation of decay constants 0706.1726

	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