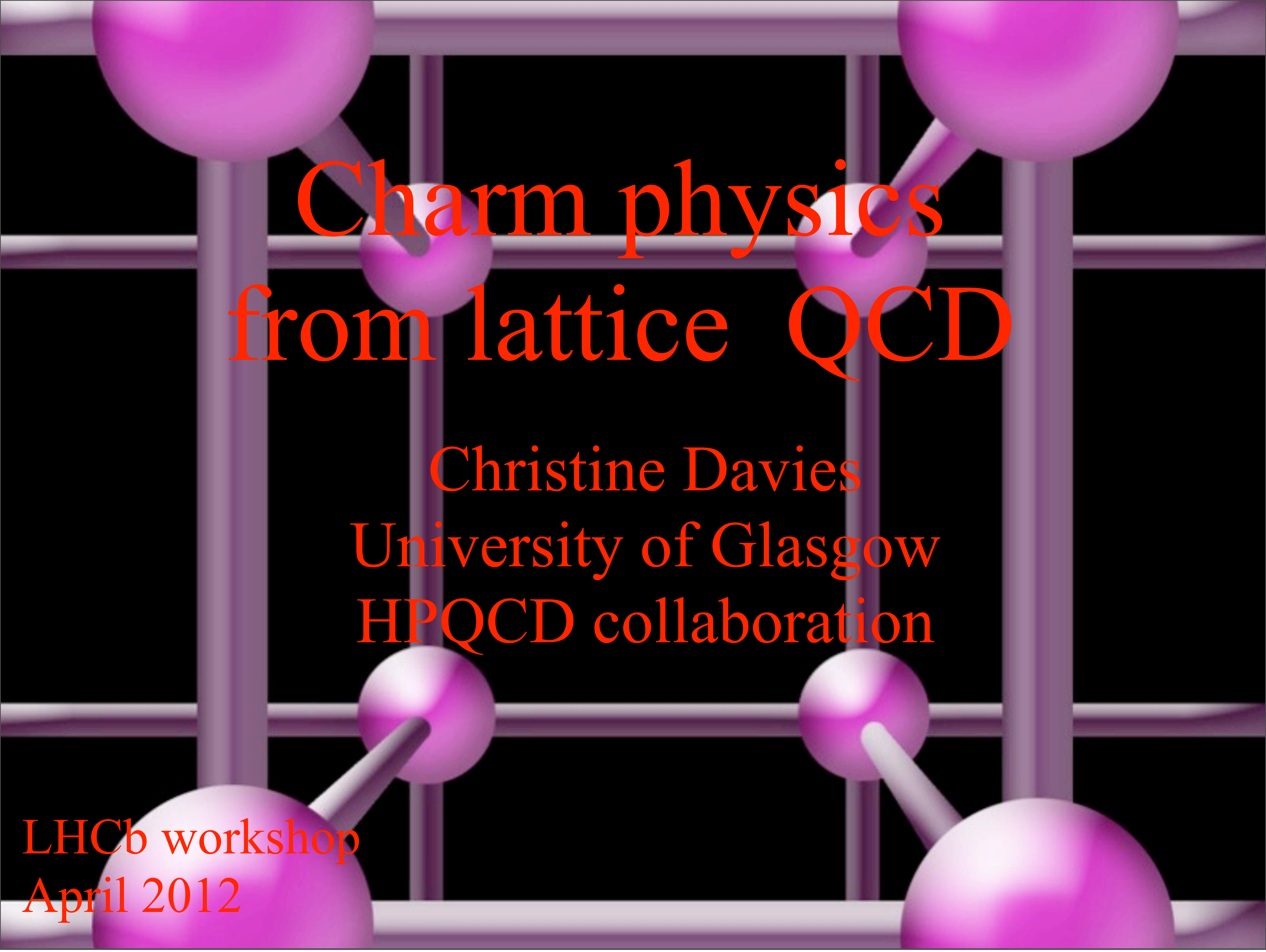


Charm physics from lattice QCD

Christine Davies
University of Glasgow
HPQCD collaboration

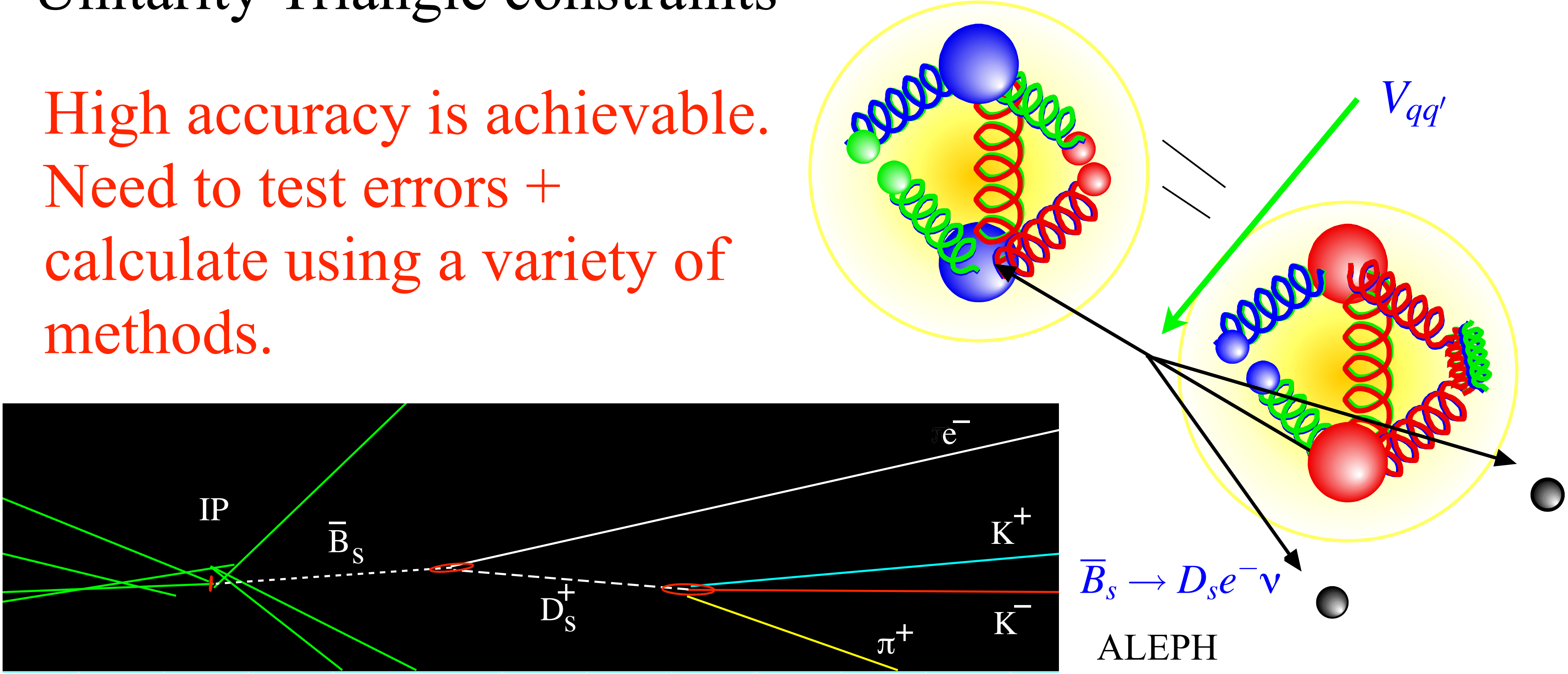
LHCb workshop
April 2012

Charm (and bottom) physics

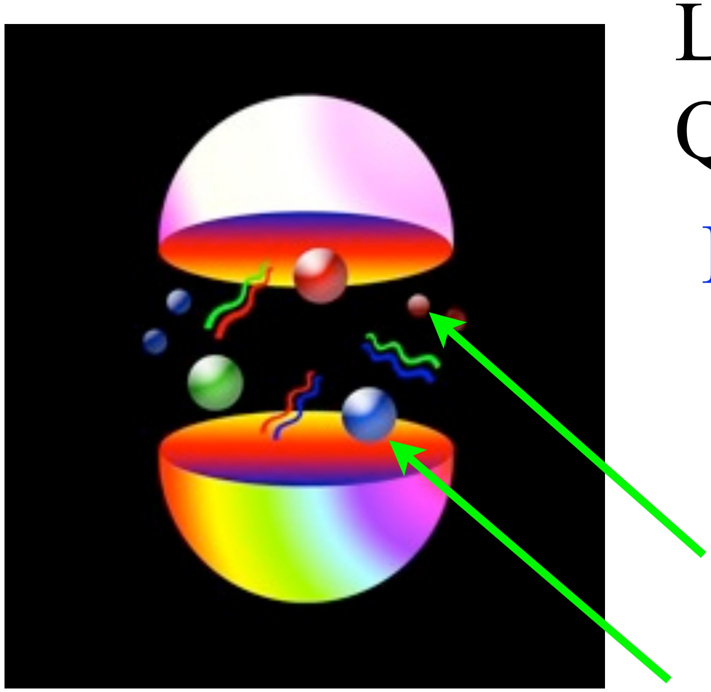
Lattice QCD allows ‘first principles’ determination of :

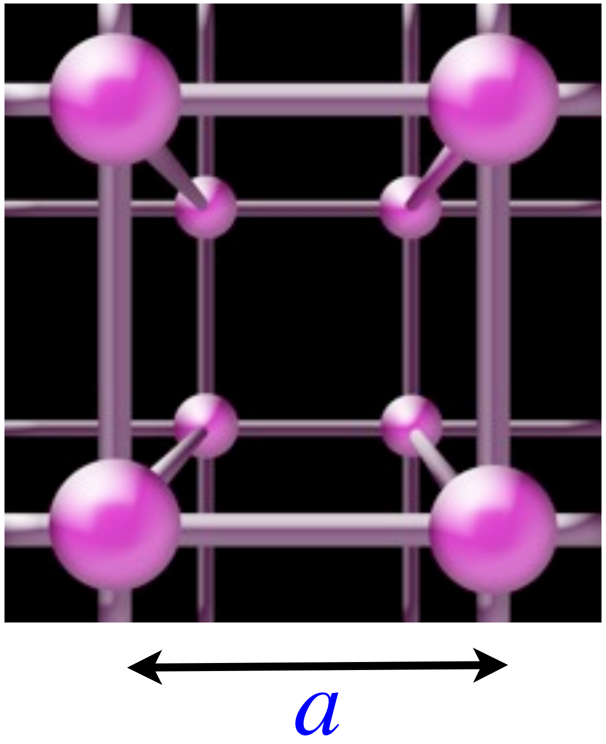
- ‘gold-plated’ hadron masses for accurate tests/predictions and determination of m_Q.
- simple hadronic weak decay matrix elements, key to Unitarity Triangle constraints

High accuracy is achievable. Need to test errors + calculate using a variety of methods.



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

Issues with handling ‘heavy’ quarks on the lattice in the same way as light quarks:

quark mass

$$L_q = \overline{\psi}(\not{D} + m)\psi \rightarrow \overline{\psi}(\gamma \cdot \Delta + ma)\psi$$

lattice spacing

Δ is a finite difference on the lattice - leads to discretisation errors. What sets the scale for these?

For light hadrons the scale is Λ_{QCD}

For heavy hadrons the scale can be m_Q

$$M = M_{a=0}(1 + A(m_Q a)^2 + B(m_Q a)^3 + \ldots)$$

hadron mass

assuming O(m_Qa) improved

$m_c a \approx 0.4, m_b a \approx 2$ for $a \approx 0.1\mathrm{f}m$

➡ nonrelativistic methods escape this problem but at the price of other systematic errors.

➡ best approach depends on how small is a

Recent progress for charm quarks in lattice QCD

Treat relativistically using:

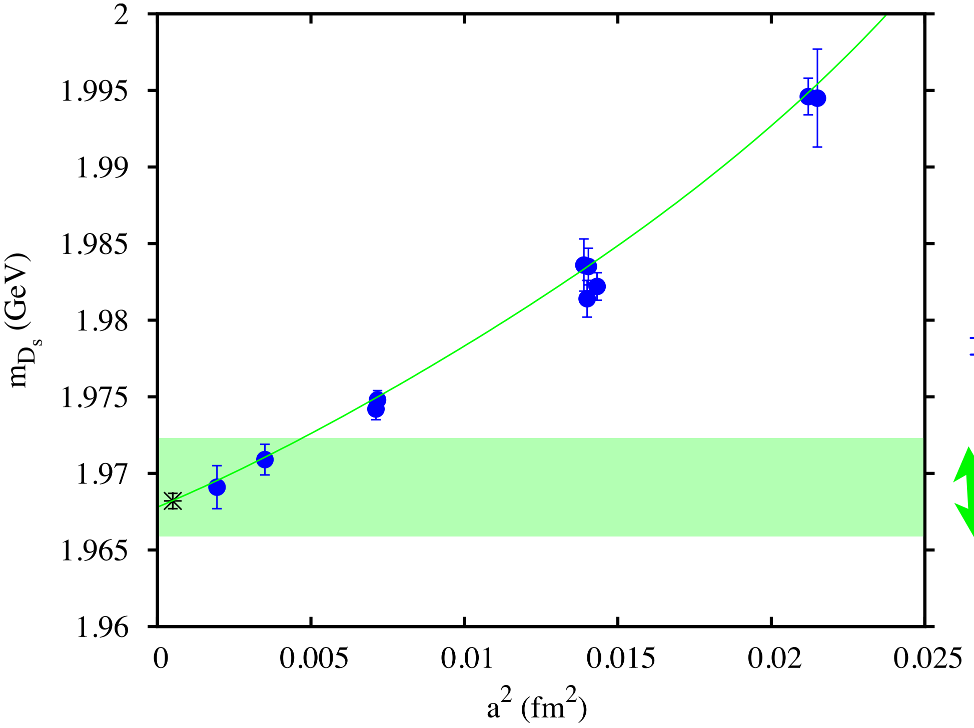
Highly improved staggered quarks (HISQ) HPQCD

Twisted mass quarks ETMC

Spectrum Tests D_s, η_c masses easy + accurate.

Use one to fix m_c and test the other - errors a few MeV!

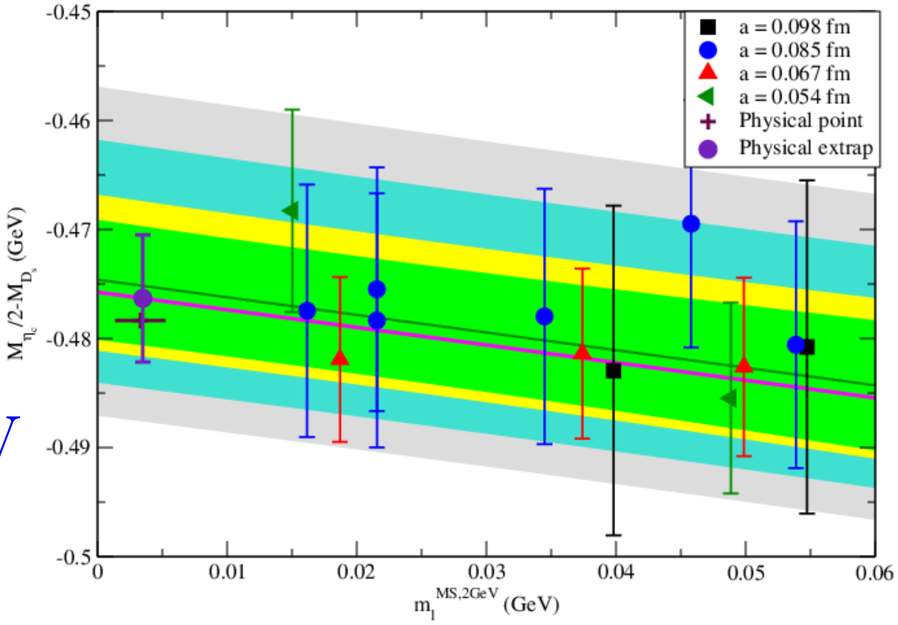
HISQ `HPQCD,1008.4018`



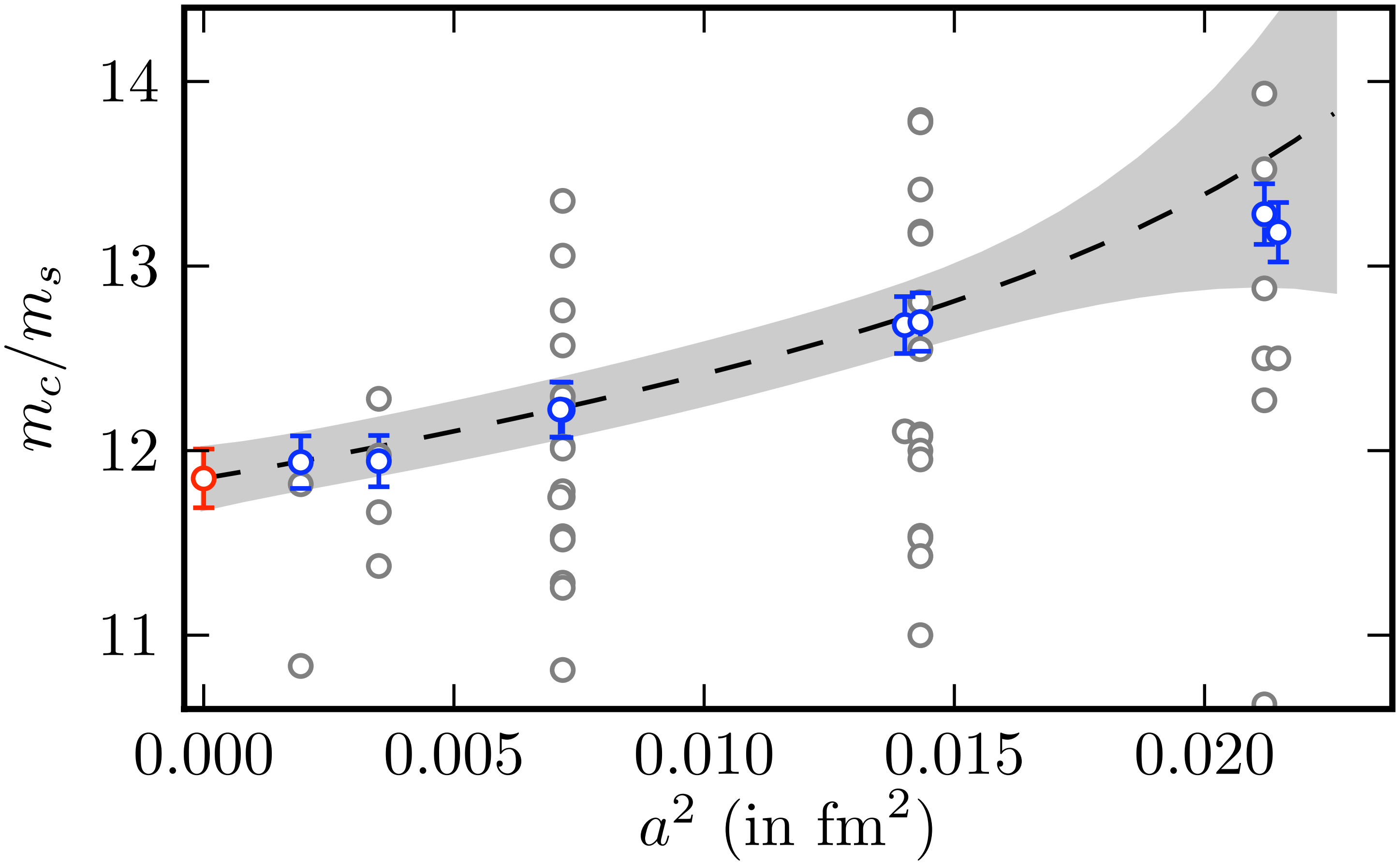
±7MeV

±3MeV

TM



Quark mass ratios from lattice QCD



$$\frac{\overline{m}_{q1}(\mu)}{\overline{m}_{q2}(\mu)} = \left(\frac{m_{q1,latt}}{m_{q2,latt}}\right)_{a=0}$$

`HPQCD, 0910.3102`

Determine m$_c$/m$_s$ using HISQ for both - allows connection from heavy to light for first time

$$\frac{m_c}{m_s} = 11.85(16)$$

use for accurate m_s from accurate m_c →

$$m_c^{\overline{MS}}(m_c) =$$

1.273(6) GeV

`HPQCD, 1004.4285`

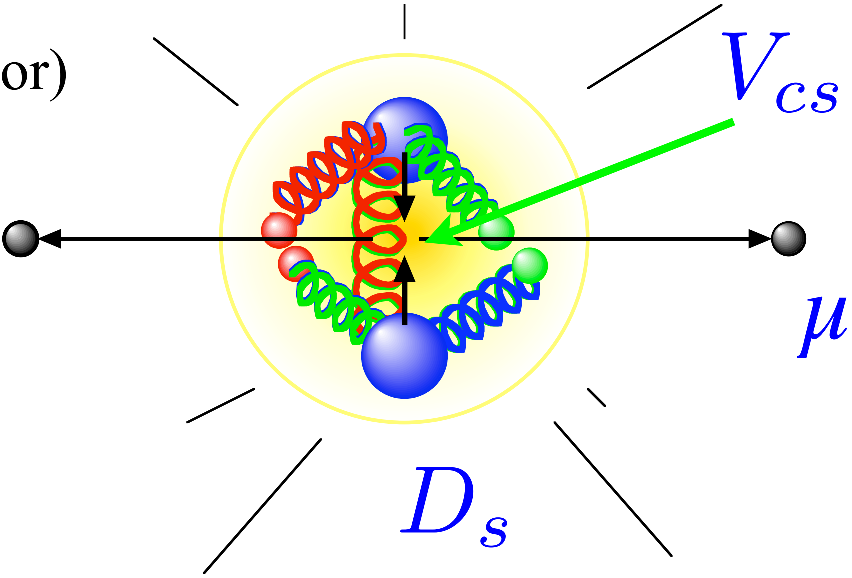
Decay constants

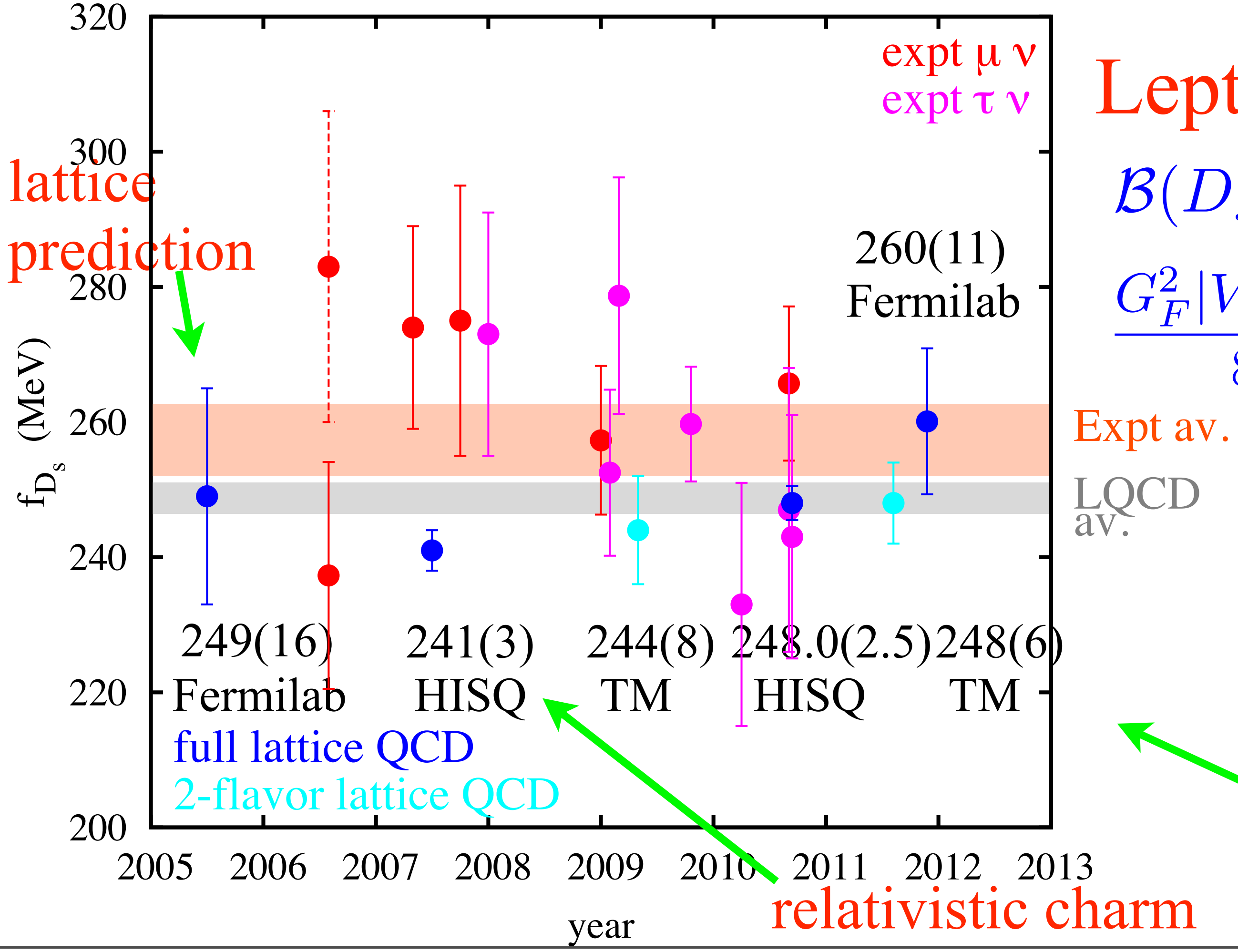
(amplitude of hadron correlator)

$$< 0|\bar{c}\gamma_0\gamma_5 s|D_s >= f_{D_s} M_{D_s}$$

or, in formalism with PCAC reln:

$$(m_s + m_c) < 0|\bar{c}\gamma_5 s|D_s >= f_{D_s} M^2_{D_s}$$





Leptonic decay rate:

$$\mathcal{B}(D_s \to l\nu_l) = \frac{G_F^2|V_{cs}|^2\tau_{D_s}}{8\pi} f^2_{D_s} m_{D_s} m_l^2 \left(1 - \frac{m_l^2}{m^2_{D_s}}\right)^2$$

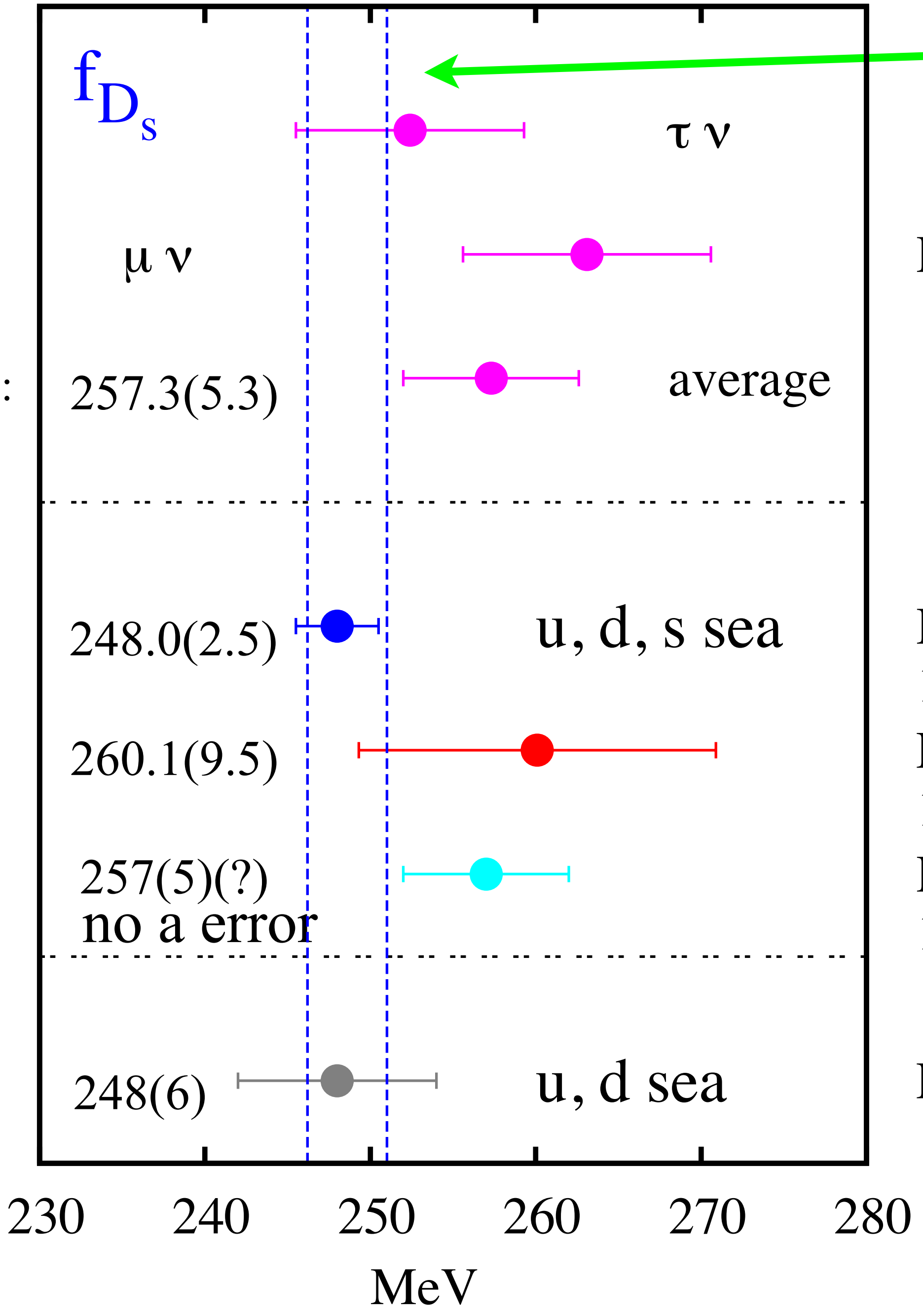
can extract f_{D_s} from expt. if V_{cs} assumed

exciting history!

Decay constants - updates 2011

`CD, LAT11, 1203.3862`

PDG12:
260(5)



av. of HPQCD
Fermilab/MILC
=248.6(2.4) MeV

HFAG, Jan.11

CLEO, BaBar - BES will improve ....

1.6σ

HPQCD HISQ
1008.4018

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

FNAL/MILC
1112.3051

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

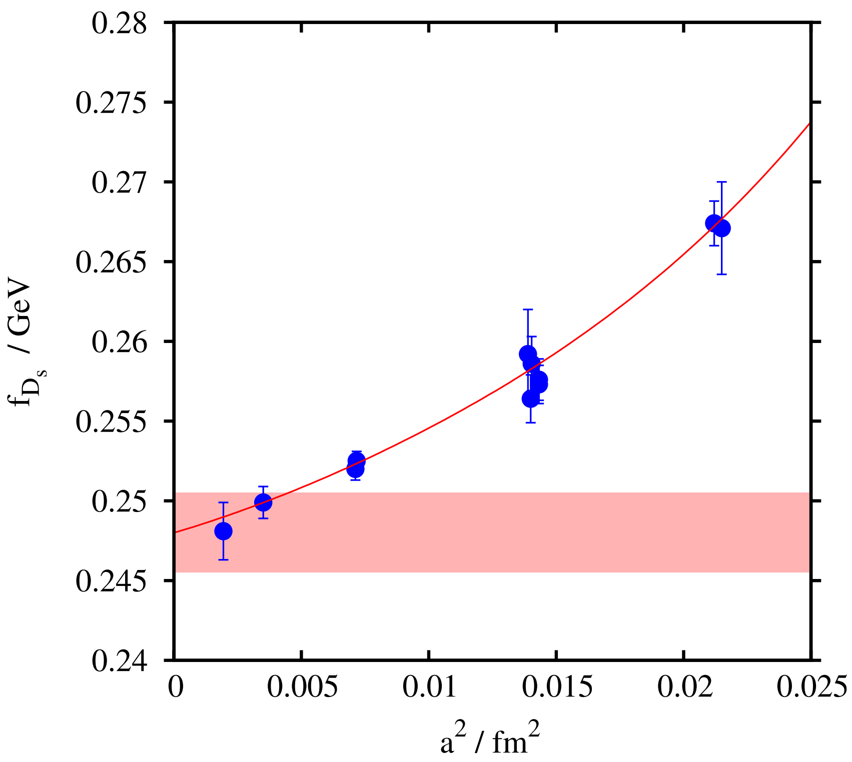
PACS-CS RHQ
1104.4600

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

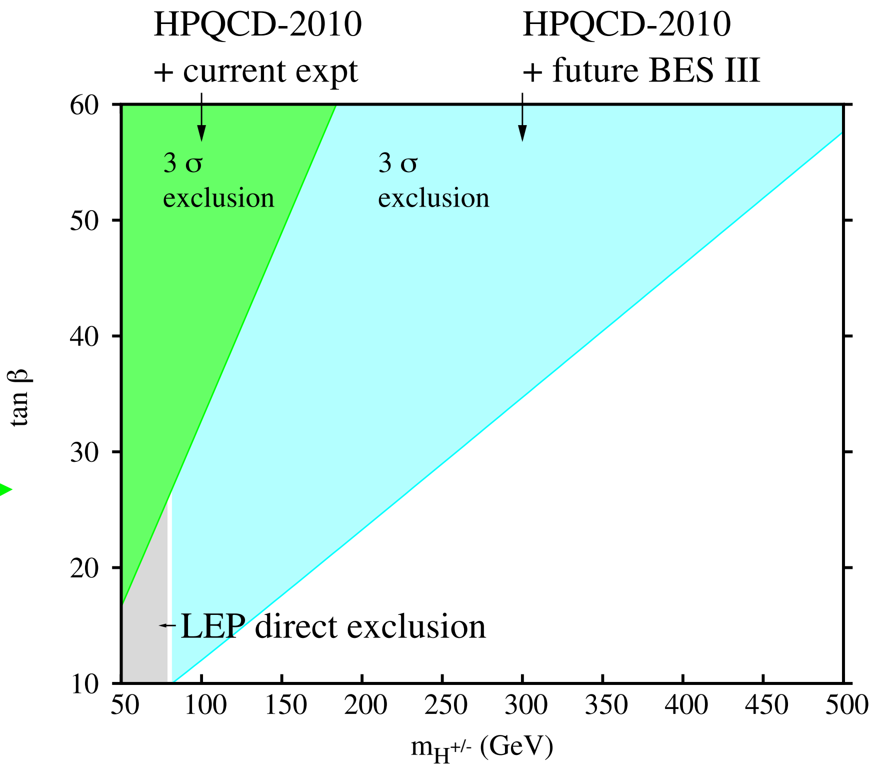
ETMC 1107.1441

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

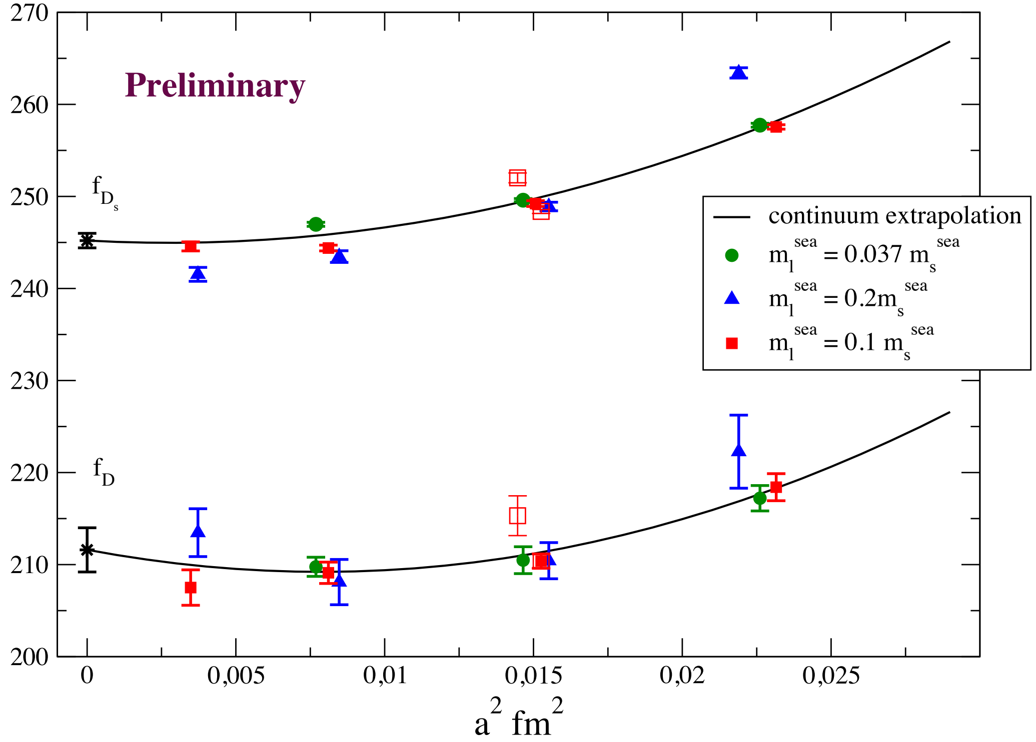
HPQCD/HISQ 1004.4018



bound on charged Higgs



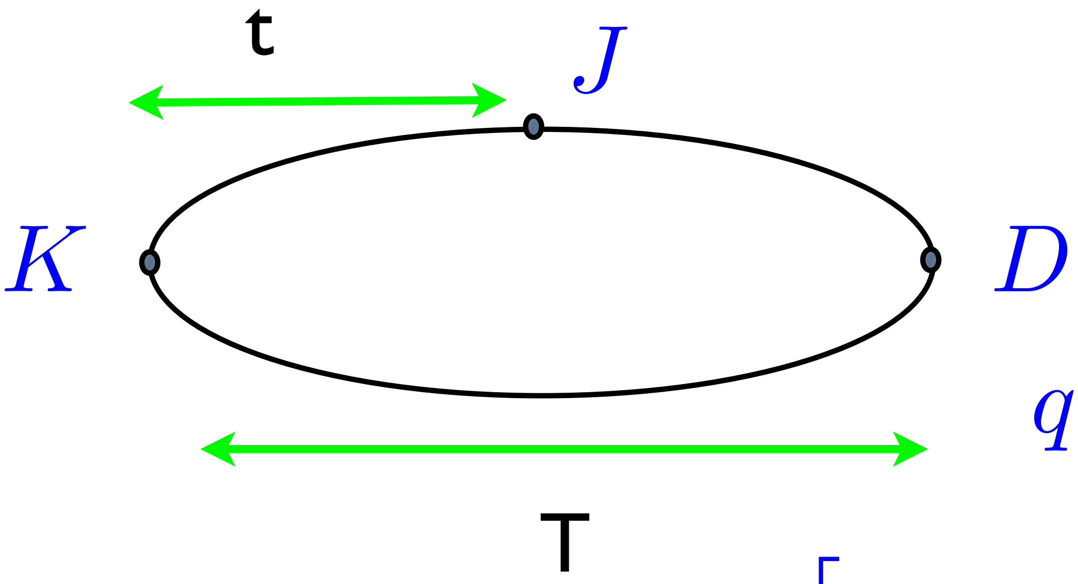
New results 2012 agree from Fermilab/MILC using HISQ with u, d, s and c quarks in sea and u/d mass at physical value

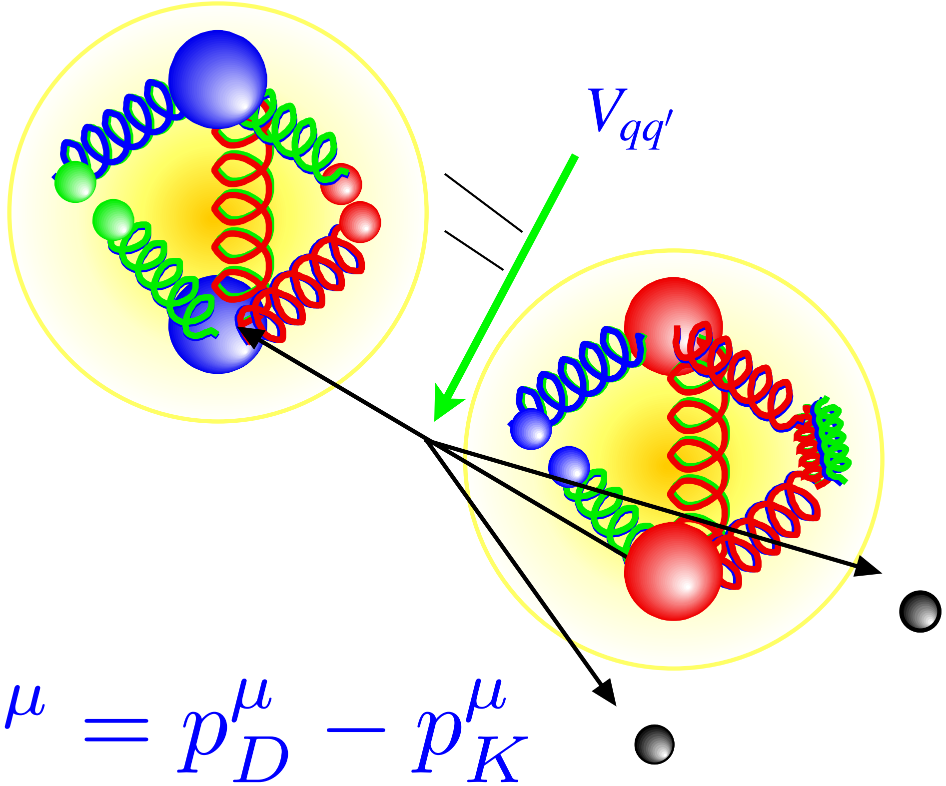


E. Gamiz, ECT workshop, April 2(

Semileptonic form factors

3pt amp. $D \to K l \nu$





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

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

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

expt:

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2 p_K^3}{24\pi^3}|V_{cs}|^2|f_+(q^2)|^2$$

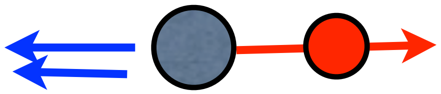
$$< K|S|D >= \frac{M_D^2 - M_K^2}{m_{0c} - m_{0s}} f_0(q^2)$$

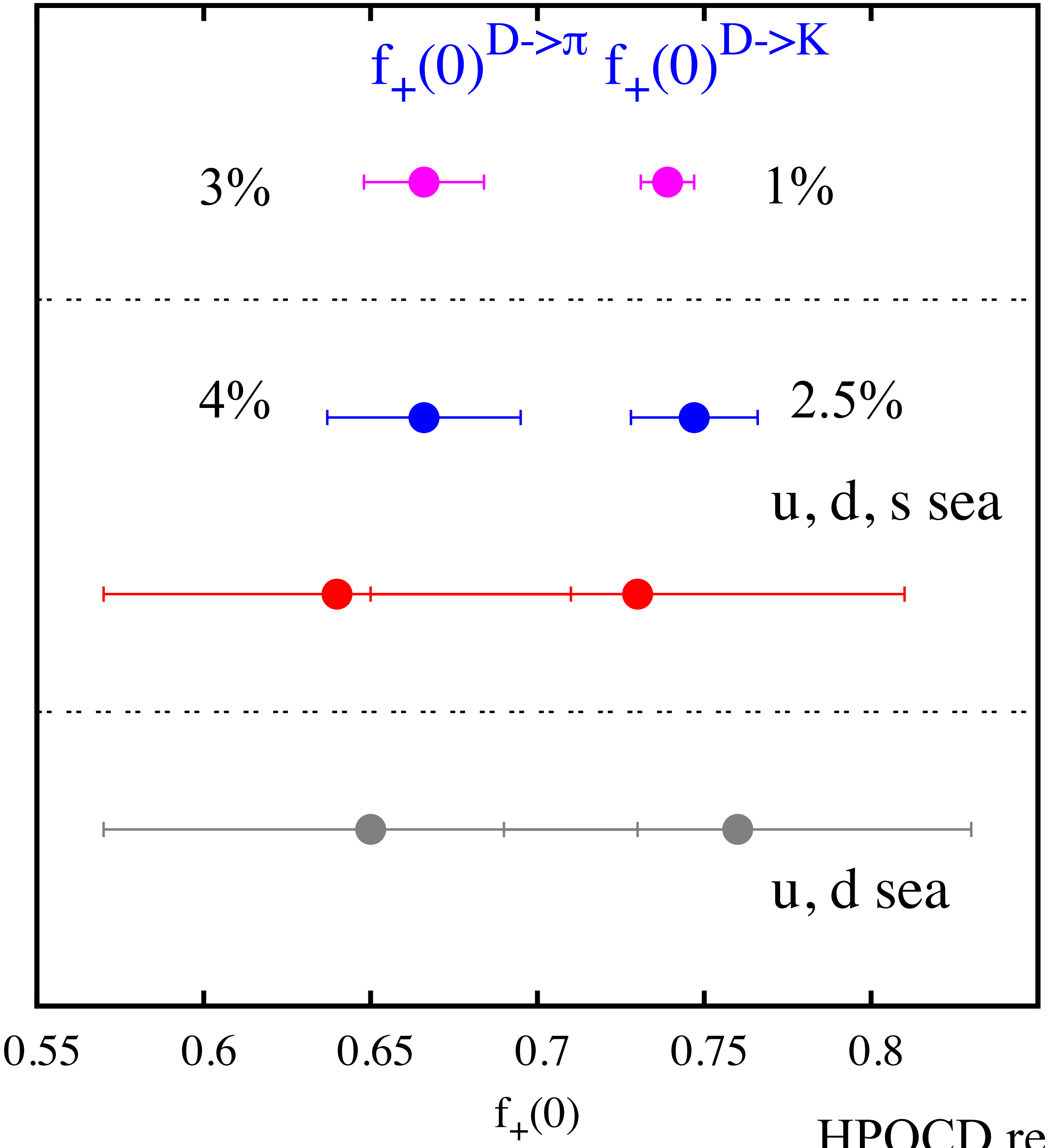
abs. norm. for c/s HISQ
HPQCD: 1008.4562

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

Updates on $f_+(0)$ 2011

Quoting results at $q^2=0$, max. recoil, is just convention.





using unitarity:

CLEO 0906.2983

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

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

HPQCD HISQ 1008.4562;1109.1501 — 2 a values; scalar

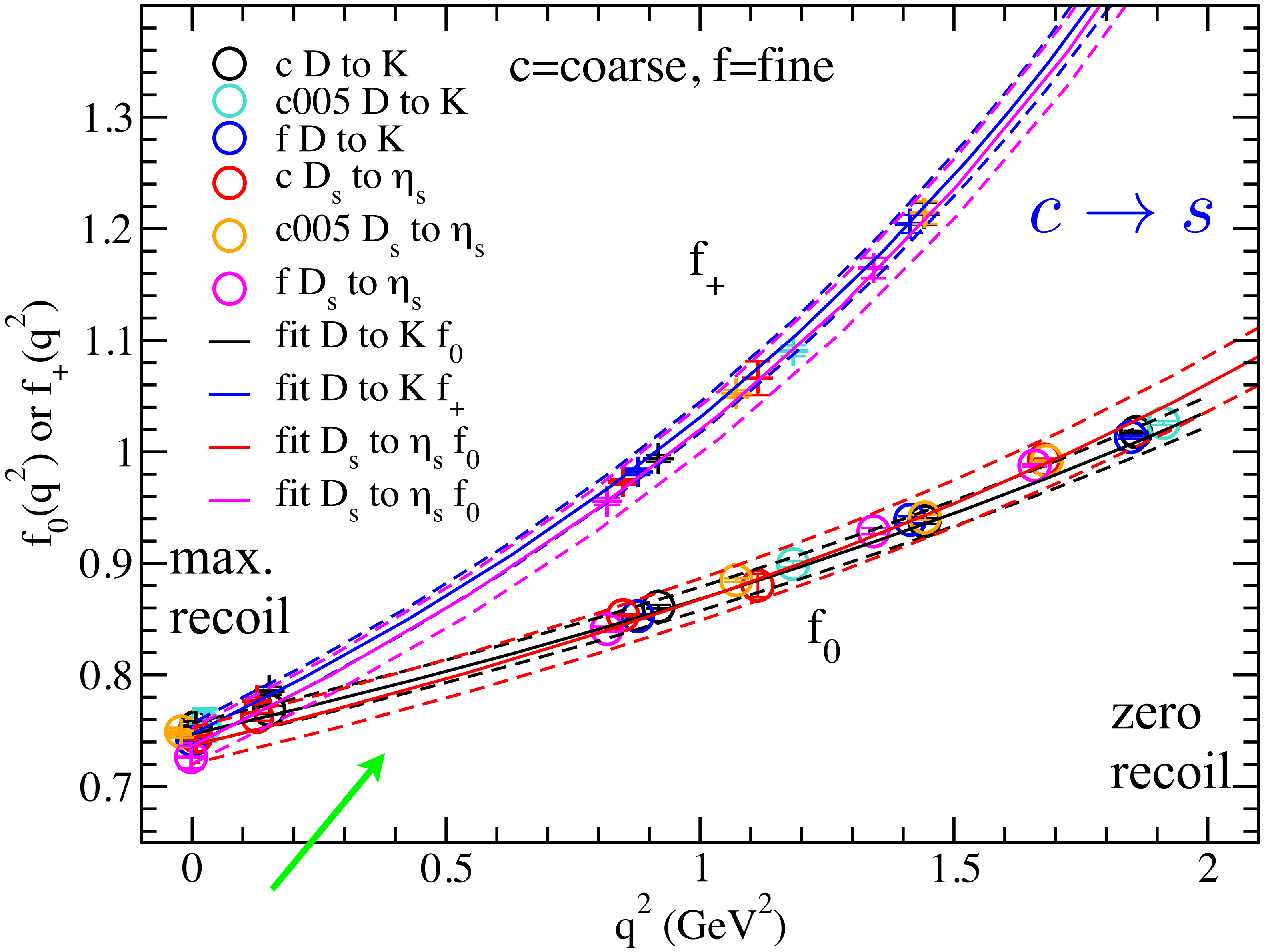
FNAL/MILC hep-ph/0408306+ — 1 a value; vector FNAL renorm.

ETMC 1104.0869 — 3 a values; vector + double ratios to cancel Z

HPQCD results will improve further....

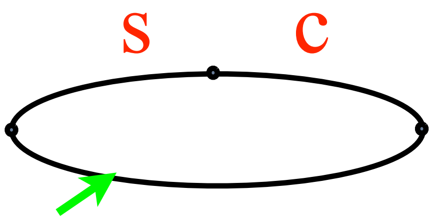
Lattice QCD can also calculate full q^2 dependence:

J. Koponen et al, HPQCD, 1111.0225



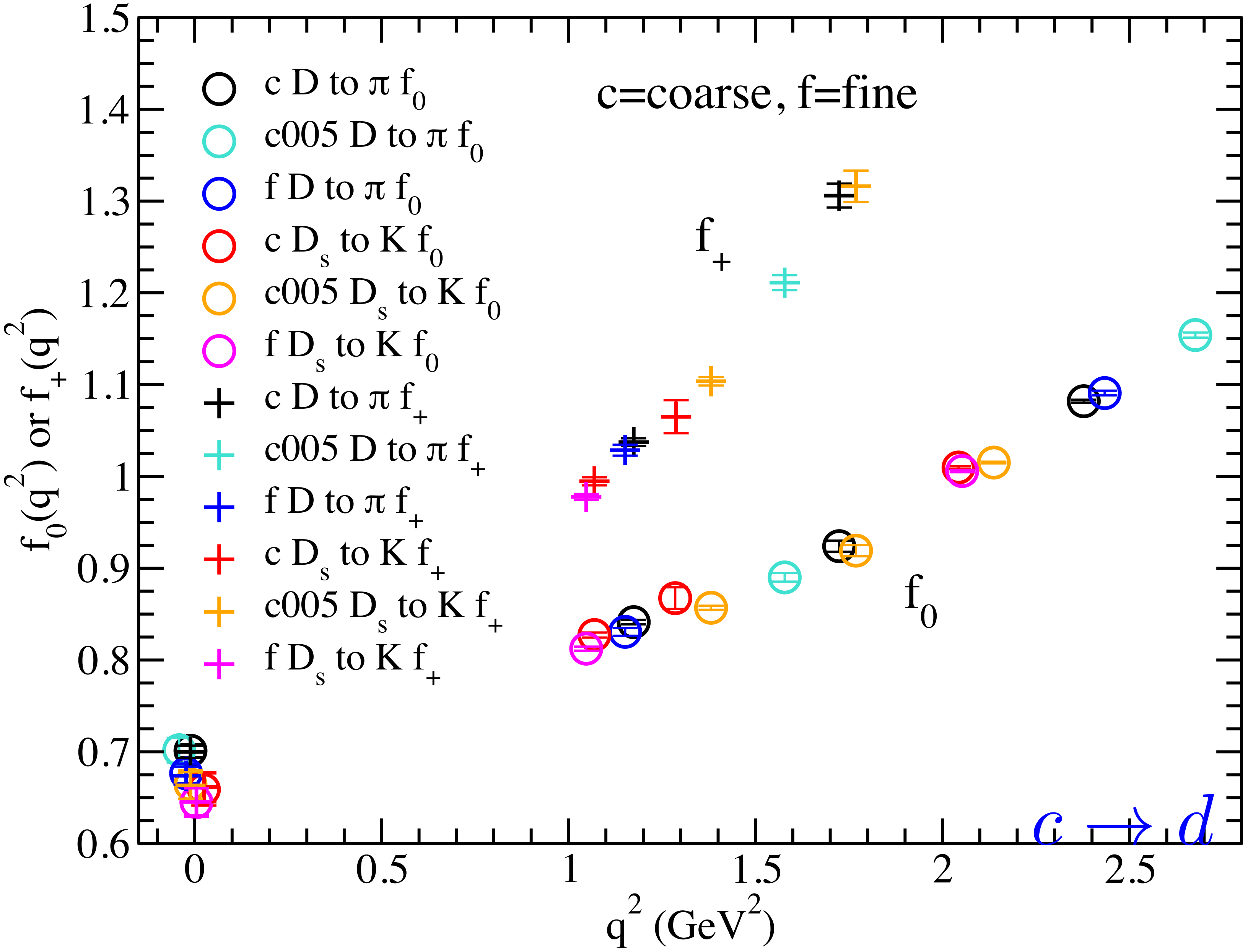
Abs. norm. vector and scalar ops

disc. effects very small



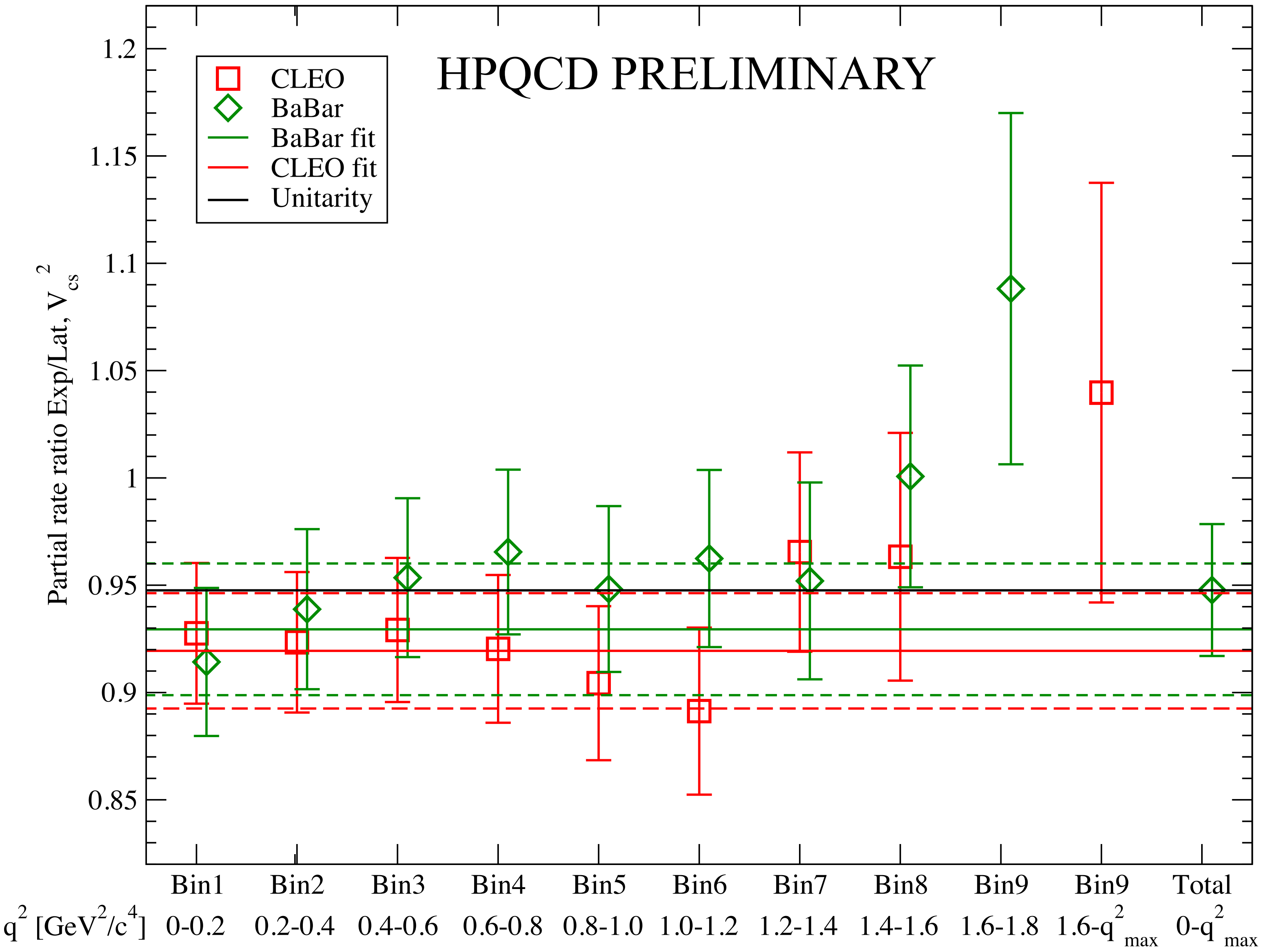
**NOTE ** very little dependence on spectator quark

Spectator quark mass independence also true for $D \to \pi$ and $D_s \to K$ - both exptlly accessible



J. Koponen et al, HPQCD, 1111.0225

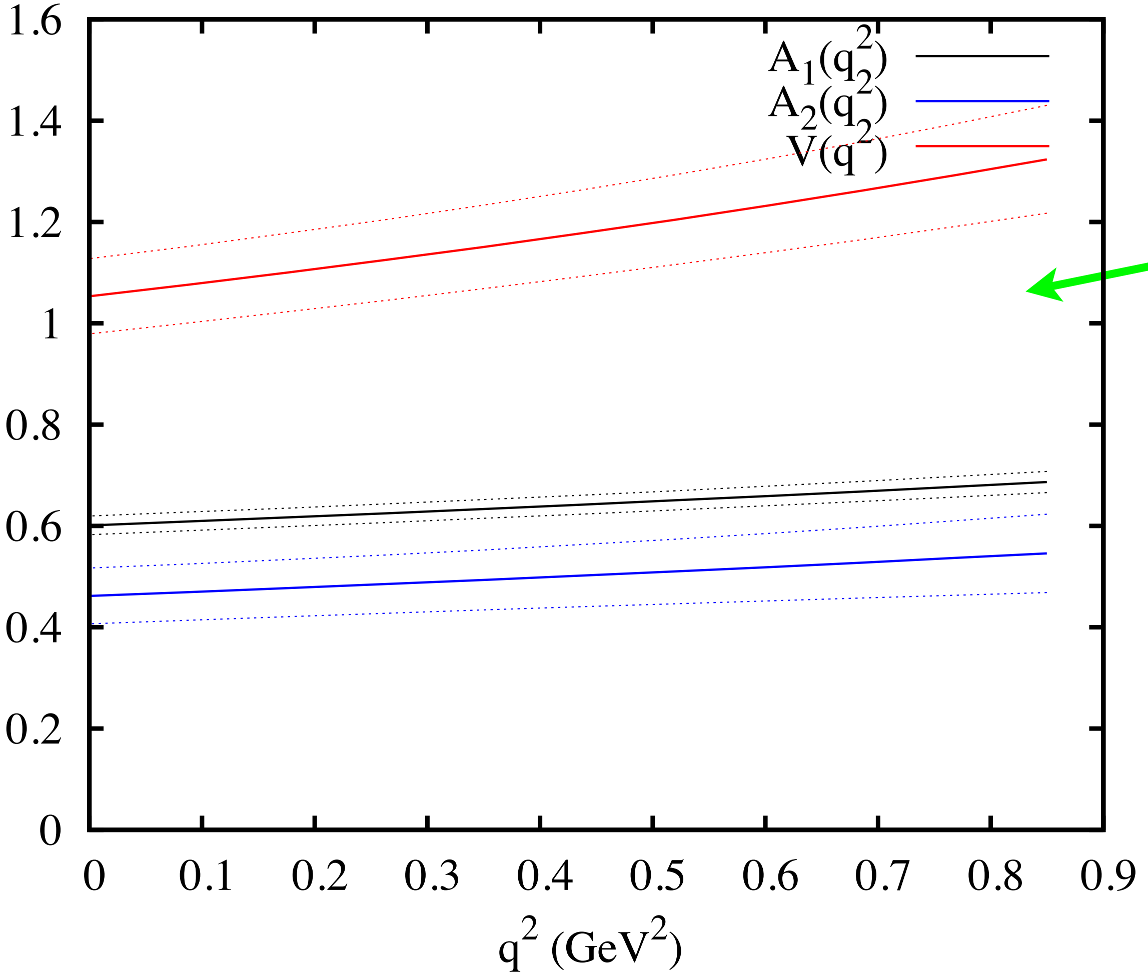
Can extract V_{cs} from comparison to experiment at any q^2



Will allow 1.5% determn of V_{cs}

lattice errors best at high q^2, expt at low q^2.

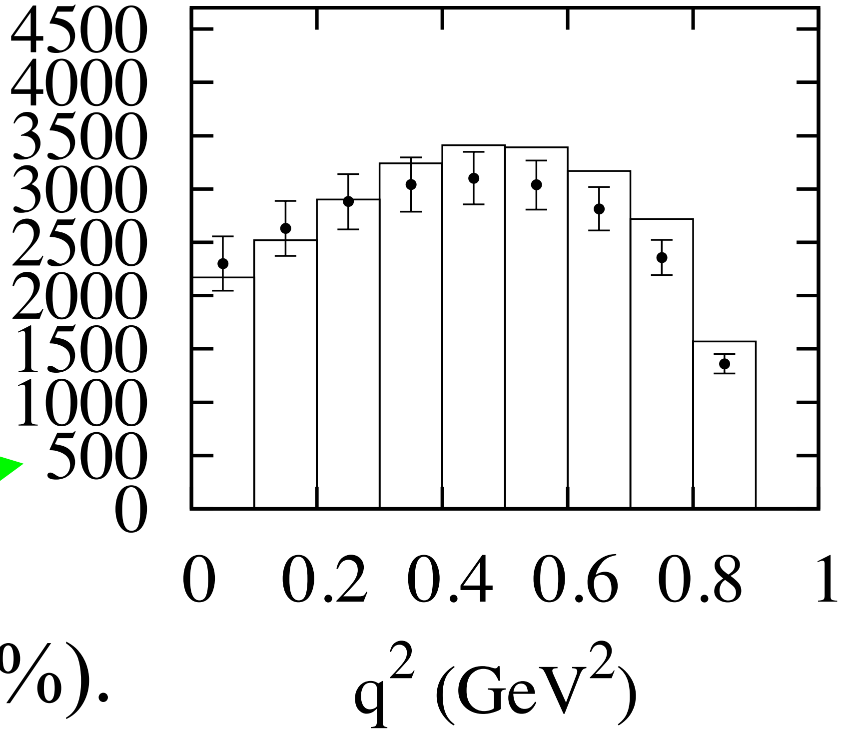
Axial and vector form factors for $D_s \to \phi l \nu$



$c \to s$

`G. Donald et al,`
`HPQCD, 1111.0254`

Now more formfactors/ helicity amplitudes since vector final state.

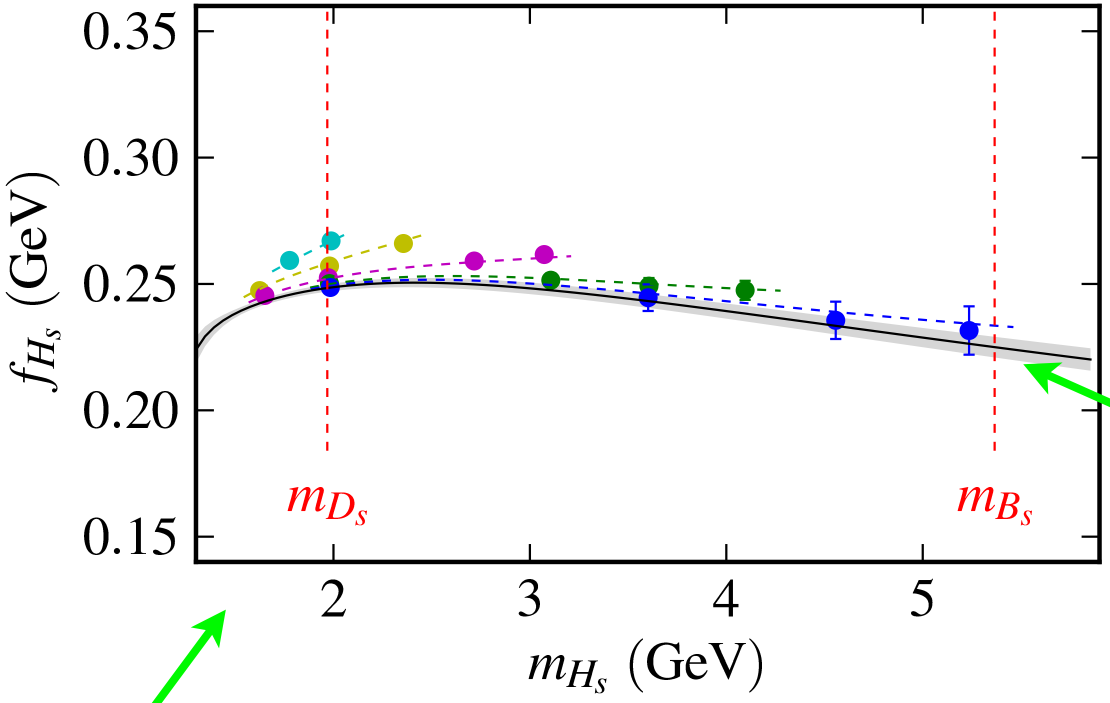


Comparison to BaBar rate in q^2 bins using $V_{cs} = 0.97345$. Can also use to extract V_{cs} (to 5%).

`BaBar, PRD78:051101 (2008)`

Heavy-strange decay constants

– use HISQ for quarks heavier than c and extrapolate up to b using multiple lattice spacings



$$f_{H_s} = A(m_{H_s})^b \left(\frac{\alpha_V(m_{H_s})}{\alpha_V(m_{D_s})}\right)^{-2/\beta_0} \times$$

$$\sum C_i(a)\left(\frac{1\mathrm{GeV}}{m_{H_s}}\right)^i$$

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

using HISQ so no renormln needed. Error smaller than nonrel. methods and best so far.

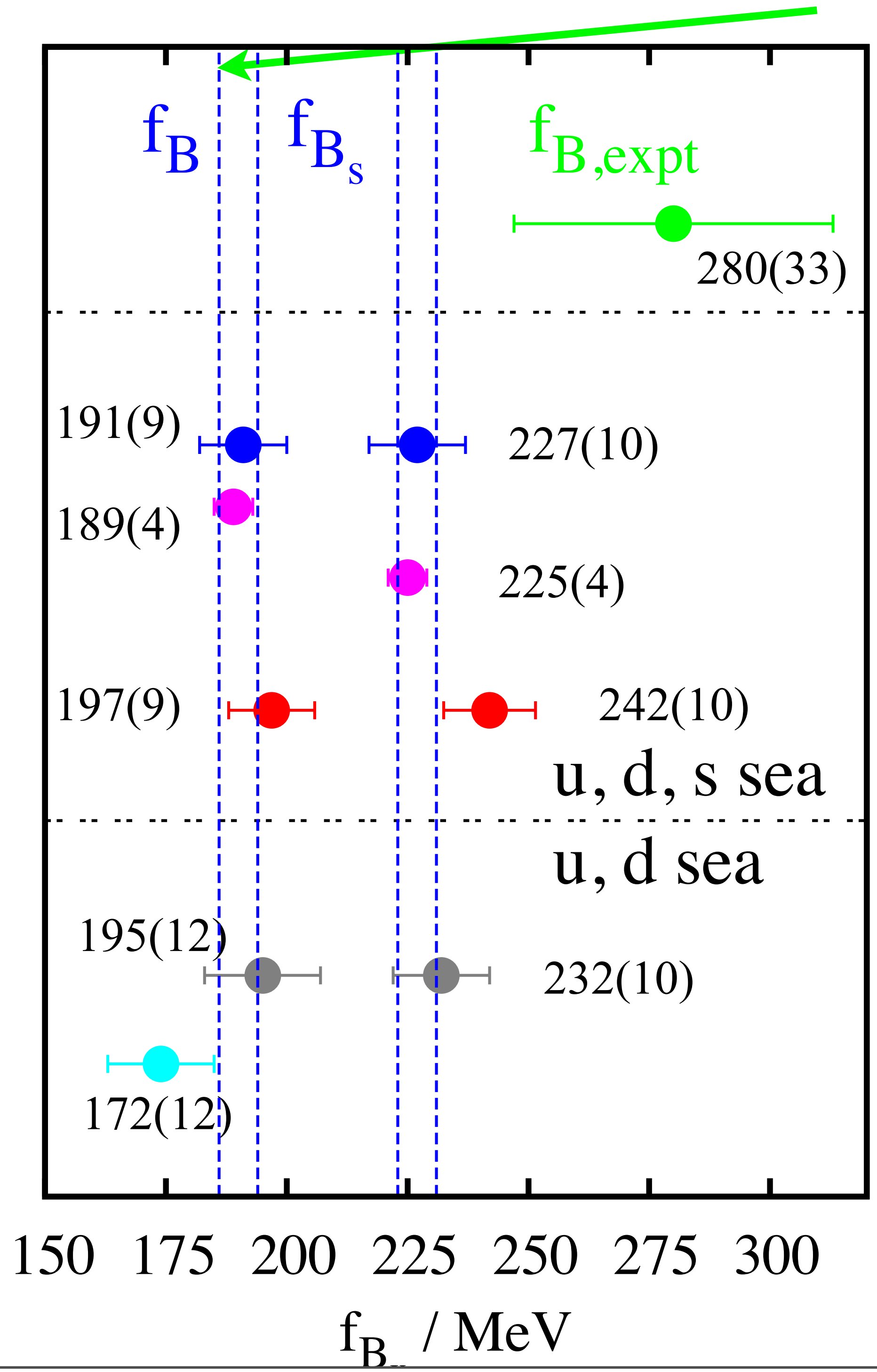
Note $f_{B_s} < f_{D_s}$ - in fact f_{D_s} a max.

Future plan - repeat for semileptonic form factors

f_{B_s}, f_B comparison

CD, LAT11, 1203.3862

f_B lattice average : 190(4) MeV



PDG av BR(B->τν)
+ PDG av Vub

f_B expt

HPQCD NRQCD
1202.4914

HPQCD HISQ
1110.4510

FNAL/MILC 1112.3051

ETMC 1107.1441

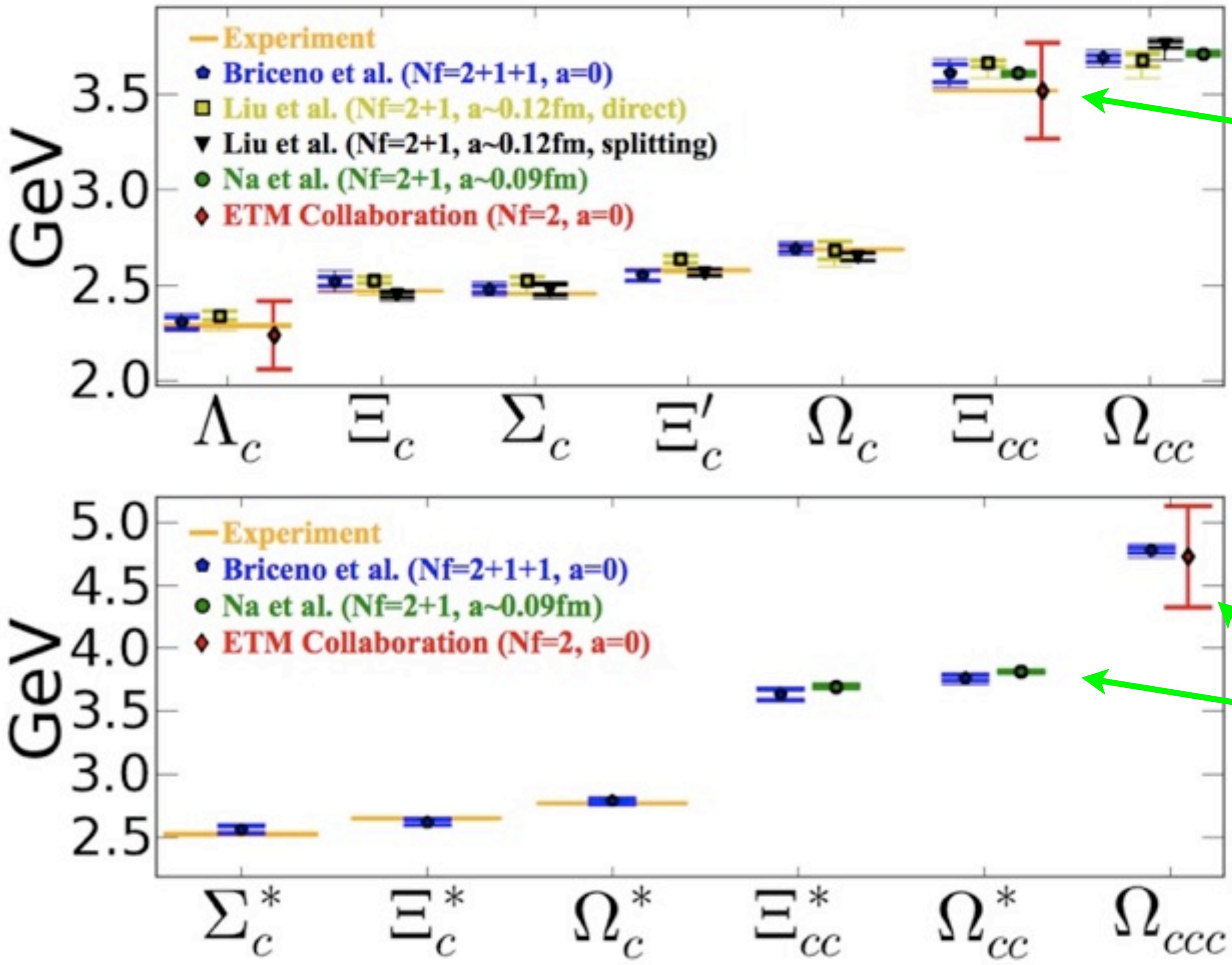
ALPHA 1112.6175

most accurate f_{Bs} available - most accurate f_B from combining with NRQCD ratio

tension with expt ...

Further spectroscopy : Charmed baryon masses

R. Briceno, D. Bolton, H-W. Lin,1111.1028

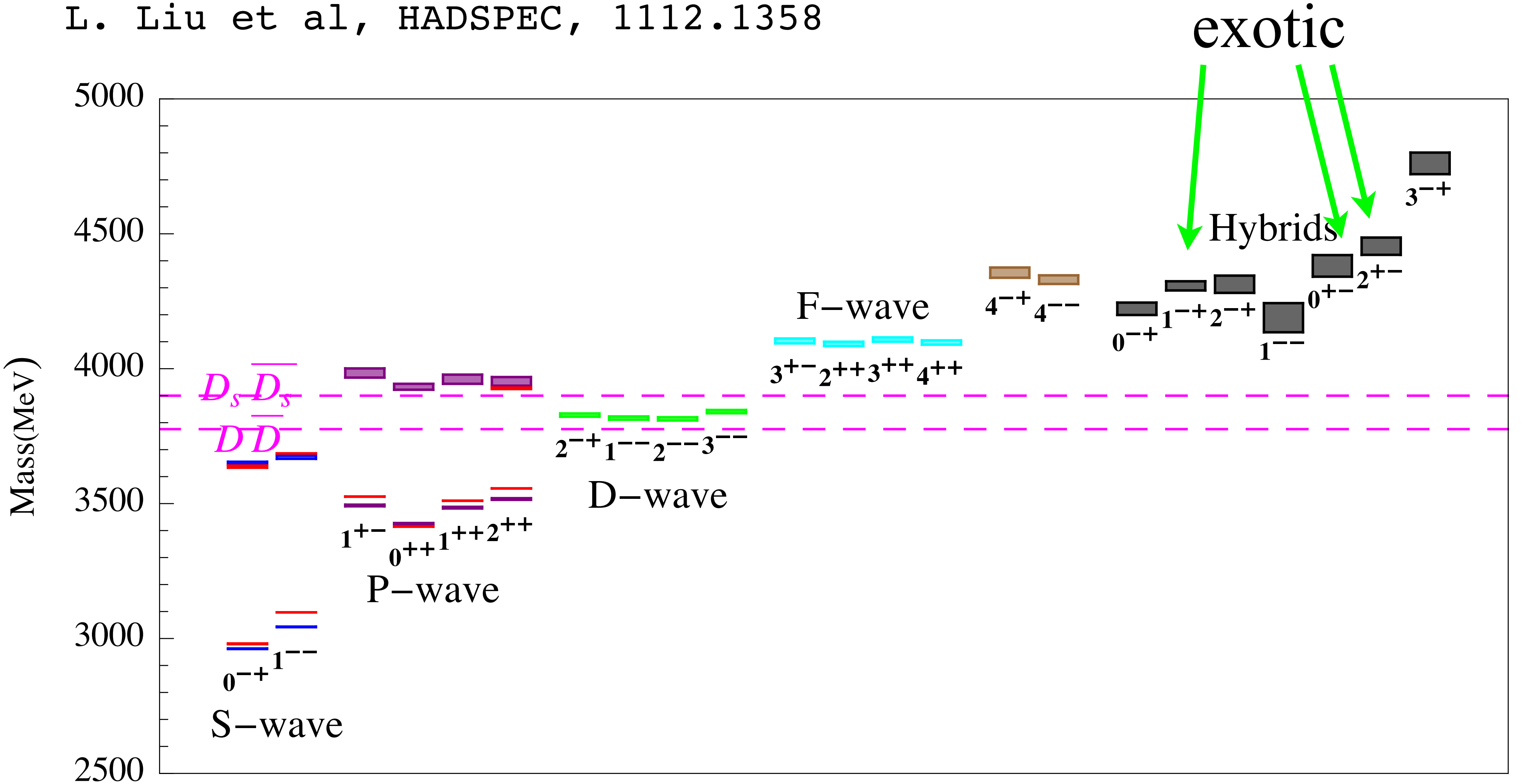


SELEX - wrong?

predictions

Charmonium spectroscopy

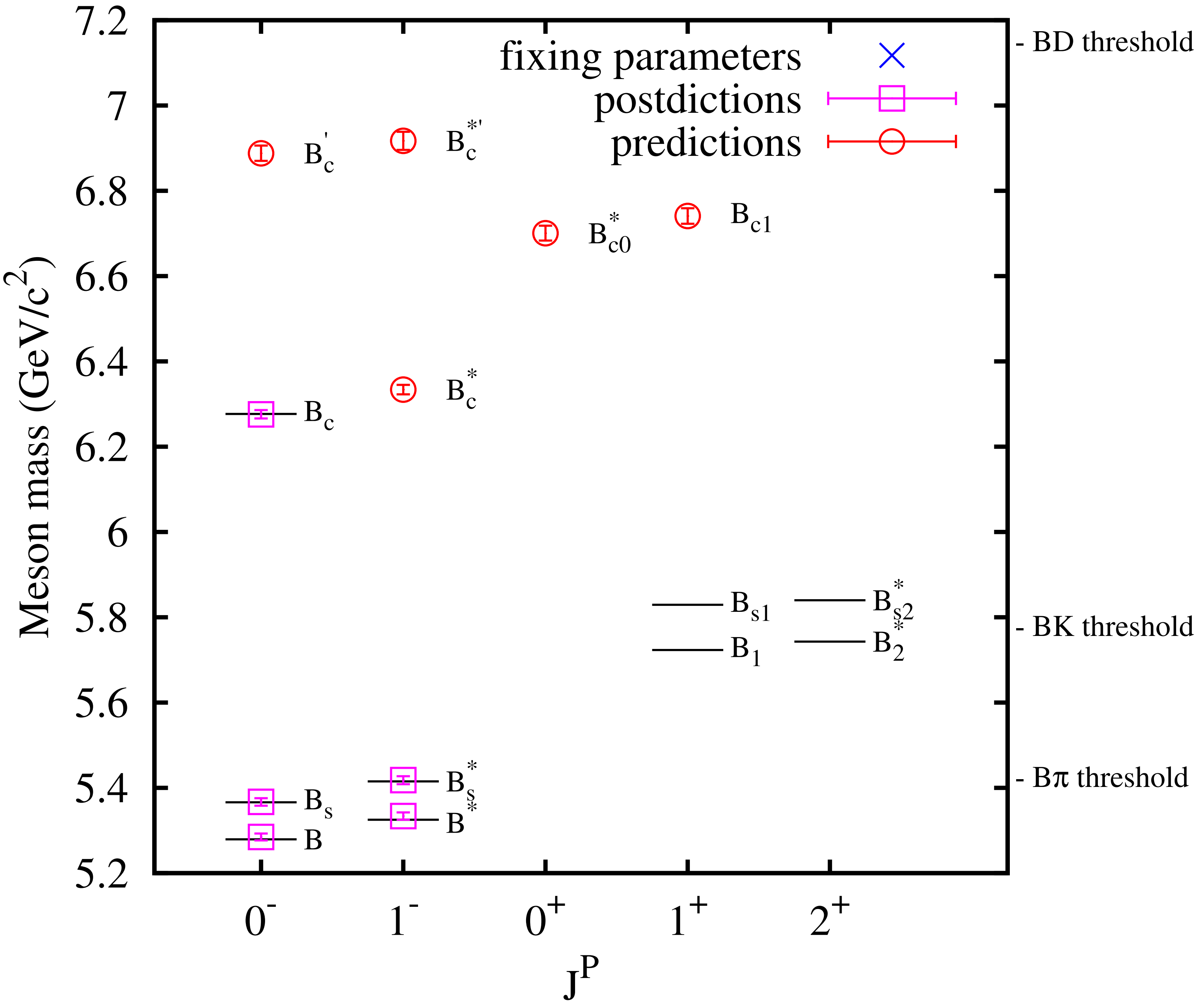
L. Liu et al, HADSPEC, 1112.1358



Use anisotropic lattices and many operators to obtain full spectrum of single meson states. 1 ensemble so far.

B_c meson spectrum

R. J. Dowdall et al, HPQCD, 1112.0449



Conclusions

- Accuracy from lattice QCD charm physics in now very good. 1-2% precision possible on masses, decay constants and form factors with improved relativistic actions such as HISQ.
  Need more results with such formalisms .. e.g. TM

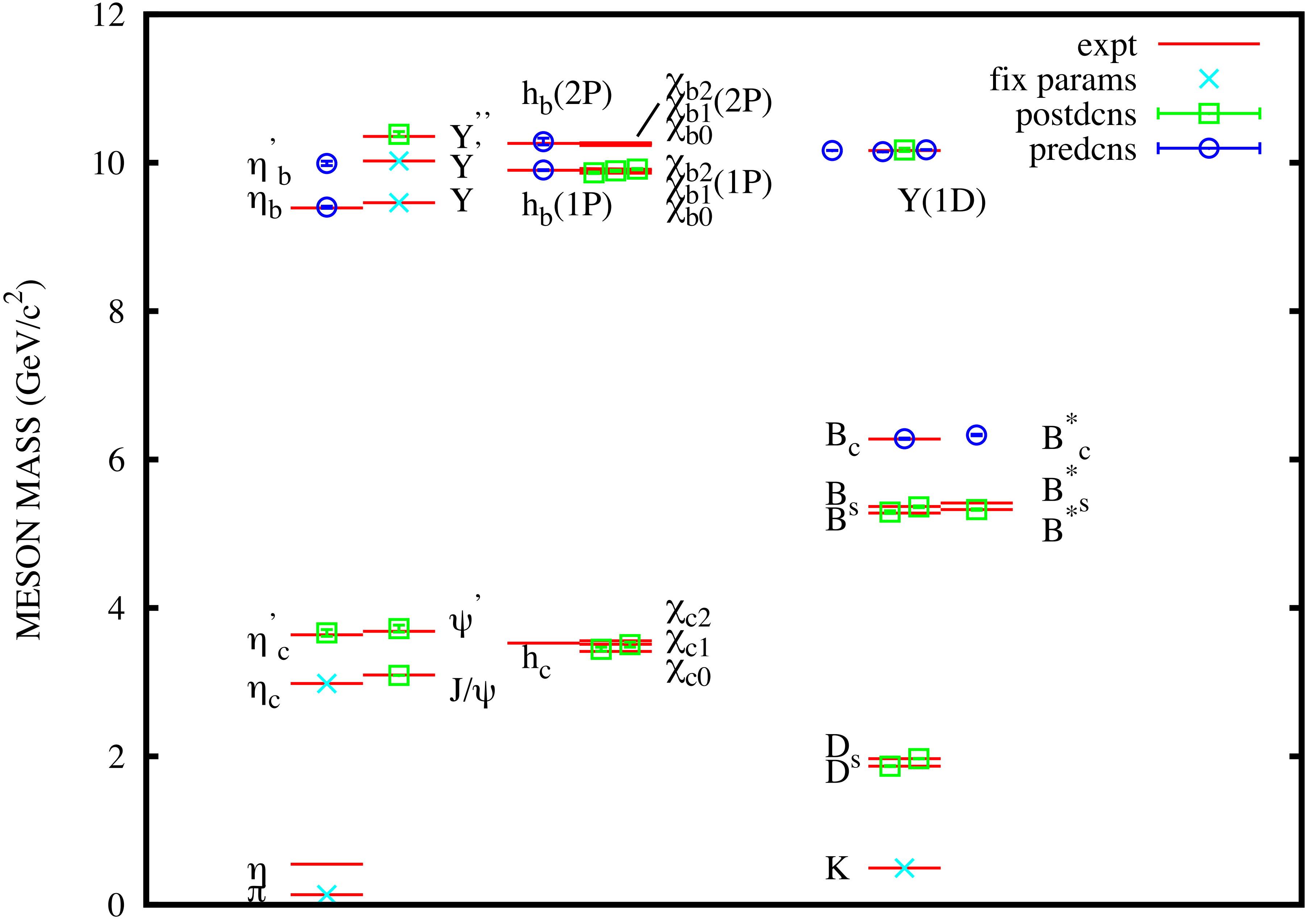
- Semileptonic form factors are important tests of SM. For D/D_s decays all q^2 accessible to lattice QCD. Form factors have little spectator quark dependence.
  Lattice QCD is expanding the number of different ffs calculated.

- Extrapolation to b from c with HISQ/TM. Promising for masses + decay constants.
  Now move to semileptonic ffs. Tests at c form baseline.

Spares

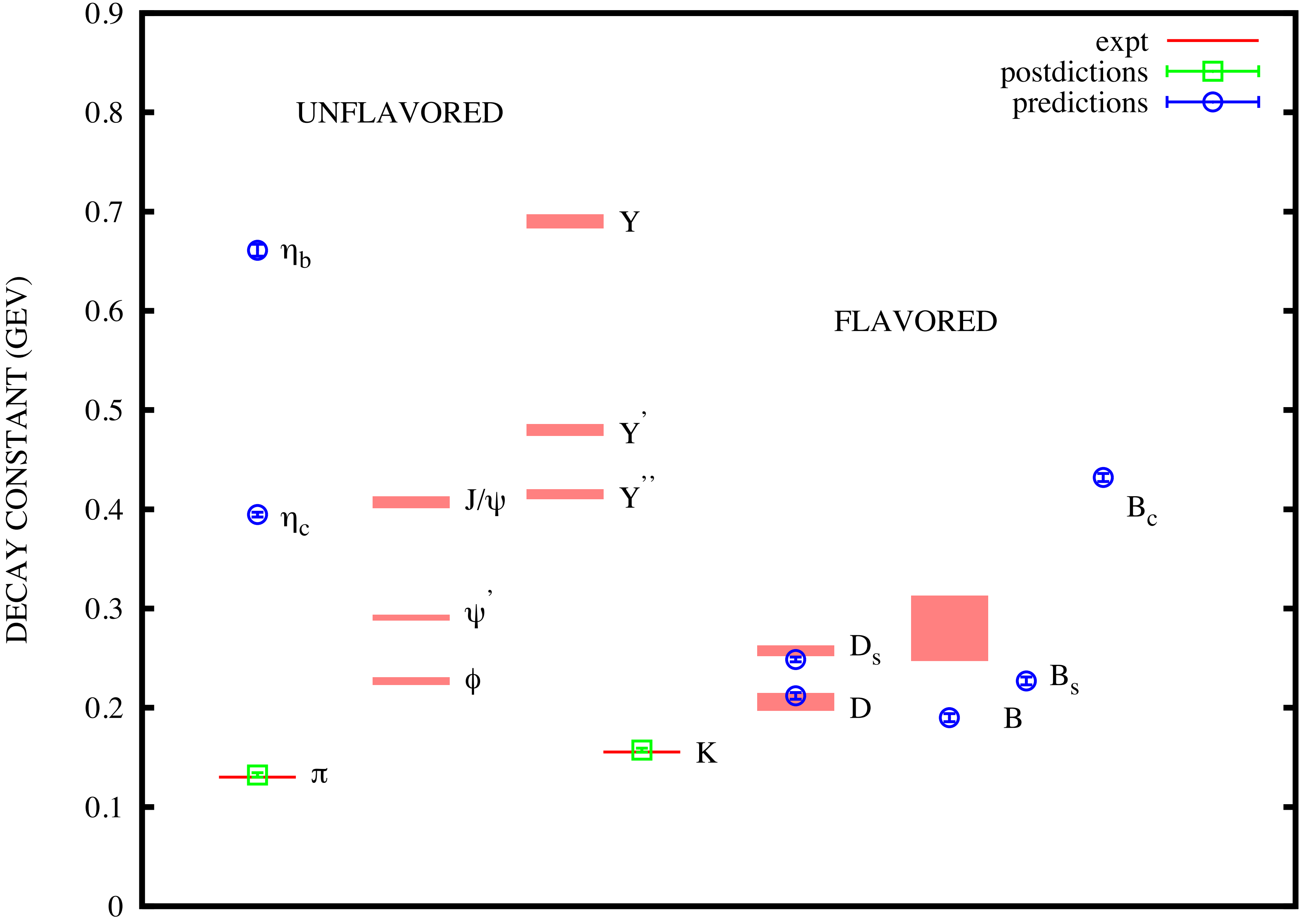
Spectrum of gold-plated mesons

HPQCD 2011



C. Davies, 1203.3862

Summary plot for decay constants



More work on vectors (em decays) underway ....