Precise Determinations for the Decay Constants of B and D mesons

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HPQCD collaboration

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Outline

- Heavy quark treatments in HPQCD
  - NRQCD, HISQ, and Heavy HISQ
- B and B_s meson decay constants with 2% total errors
  - f_{Bs} with the Heavy HISQ method
  - Decay constants with the NRQCD + Heavy HISQ method
  - Br($B \rightarrow \tau\nu$) and sin(2β) tension
- $|V_{cd}|$ from D meson leptonic decays
  - Decay constants with HISQ charm quarks
  - f_{Ds} saga revisited, and lattice scale determination
- Summary

• Heavy quark treatments in HPQCD

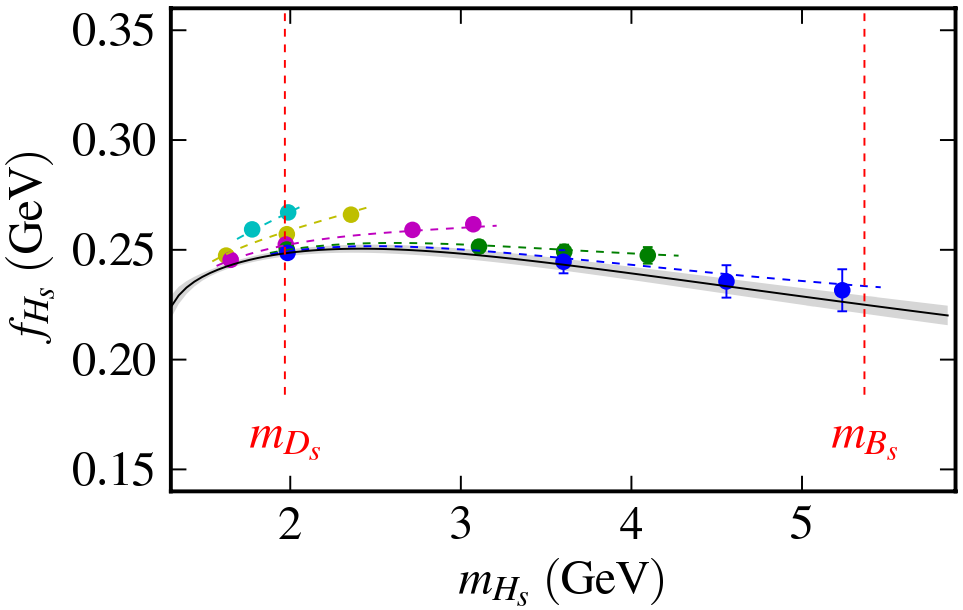
- Heavy quarks need a special treatment to put on the lattice.
  - Typical cut off (typical lattice size) = 2 GeV
  - Charm quark ~1 GeV, bottom quark ~ 4 GeV

- NRQCD for charm and bottom
  - Theoretically well known, easy to tune the quark mass
  - Large operator matching errors
- HISQ (Highly Improved Staggered Quark) for charm
  - It is so highly improved!
    - Leading error starts at $O(\alpha_s (am_h)^2 v^2/c^2)$ and $O((am_h)^4 v^2/c^2)$ (If am_c=0.6, it is about 2%)
  - So, we can treat charm quarks as other u,d, and s quarks
  - No operator matching needed, very easy to tune the quark mass
- Heavy HISQ for bottom
  - For very coarse lattice (a~0.15fm), am_c ~ 0.85: it worked great!
  - Simulate heavy HISQ quark: lighter than bottom, up to am_h = 0.85
  - Extrapolate to the bottom quark mass using HQET

• f_{Bs} from the Heavy HISQ method

C. McNeile et al. (HPQCD)
PRD 85 (2012) 031503

- Using MILC asqtad staggered N_f=2+1dynamic gauge configurations
- Simulate heavy HISQ quark: lighter than bottom, up to am_h = 0.85
- Five lattice spacings (0.15fm, 0.12fm, 0.09fm, 0.06fm, and 0.045fm)



- f_{Bs}=225(4) MeV
  previously 231(15)MeV
  (First 2% level calculations in b physics!)
- f_{Hs} ~ 1/sqrt(m_{Hs}) ?
  : Yes! fitted b = -0.51(13)
  (First empirical evidence!)
- f_{Bs}/f_{Ds} = 0.906(14)

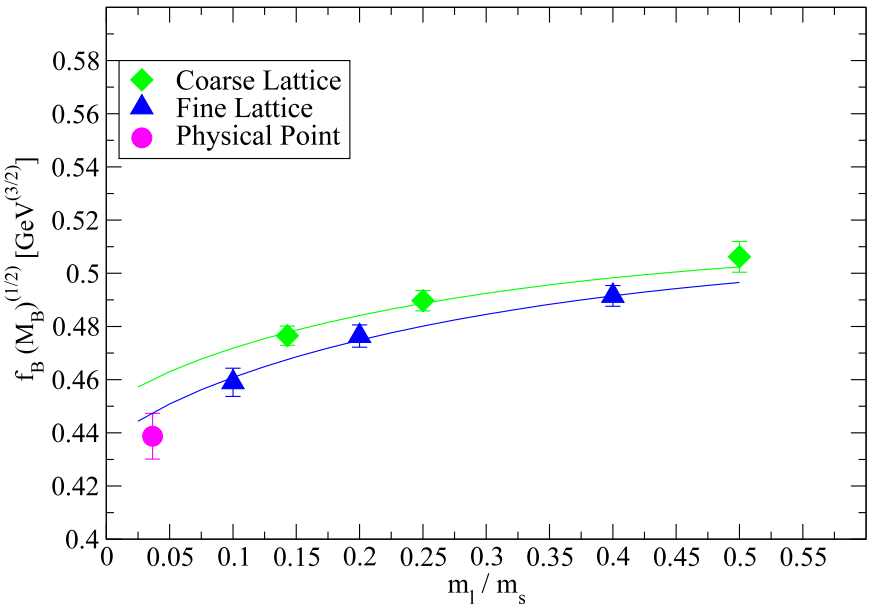
$$f_{H_s}(a, m_{H_s}, m_{\eta_s}) = (m_{H_s})^b \left(\frac{\alpha_V(m_{H_s})}{\alpha_V(m_{D_s})}\right)^{-2/\beta_0} \sum_{i=0}^{N_m-1} C_i(a) \left(\frac{1}{m_{H_s}}\right)^i + c_s(m_{\eta_s}^2 - m_{\eta_{s,phys}}^2)$$

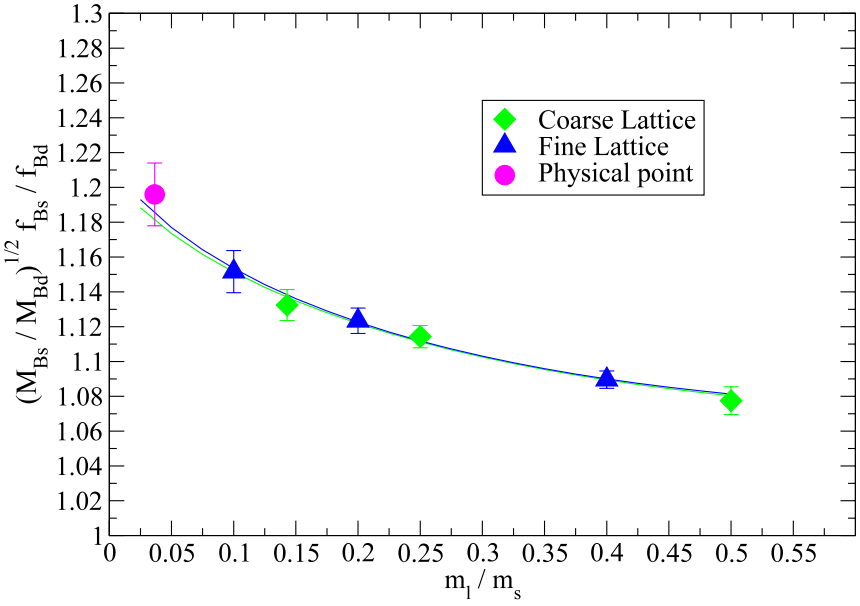
$$C_i(a) = \sum_{j,k,l=0}^{N_a-1} c_{ijkl} \left(\frac{am_h}{\pi}\right)^{2j} \left(\frac{am_s}{\pi}\right)^{2k} \left(\frac{a\Lambda_{QCD}}{\pi}\right)^{2l}$$

• f_{Bs}/f_B from NRQCD

HN et al. (HPQCD)
arXiv:1202.4914

- Using MILC asqtad staggered N_f=2+1dynamic gauge configurations
- NRQCD for the b quark, and HISQ for the light and strange quarks
- Two lattice spacings (0.12fm, and 0.09fm)
- Matching heavy-light currents with NRQCD and HISQ quarks
  - Chris Monahan's talk on Thursday from 3:30pm



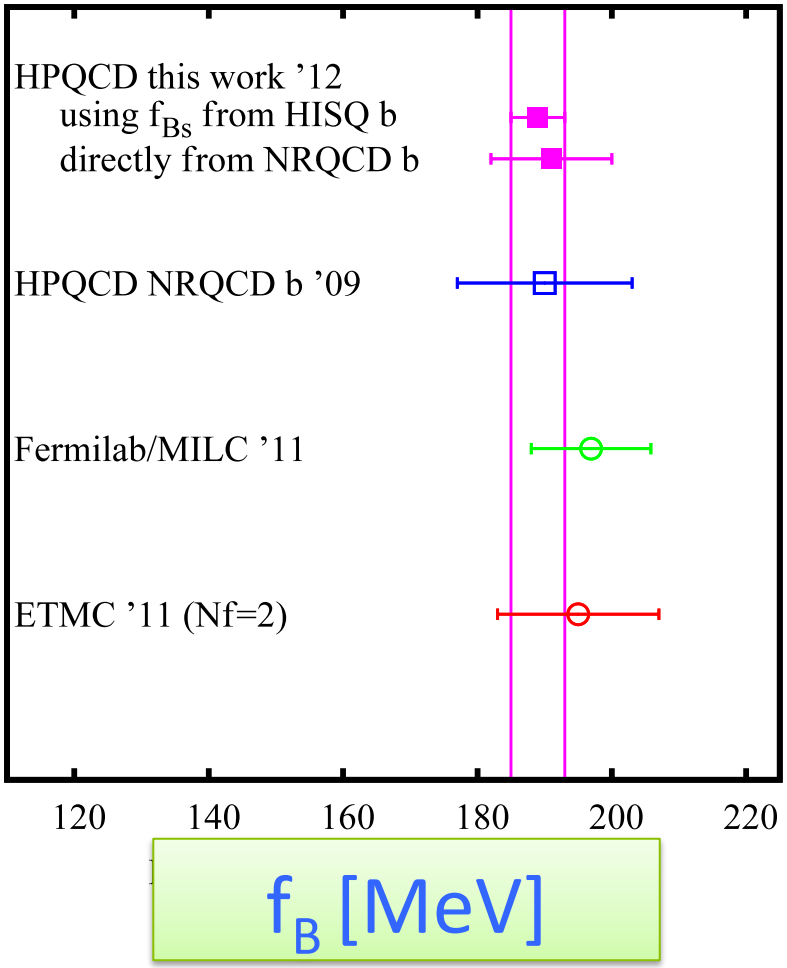


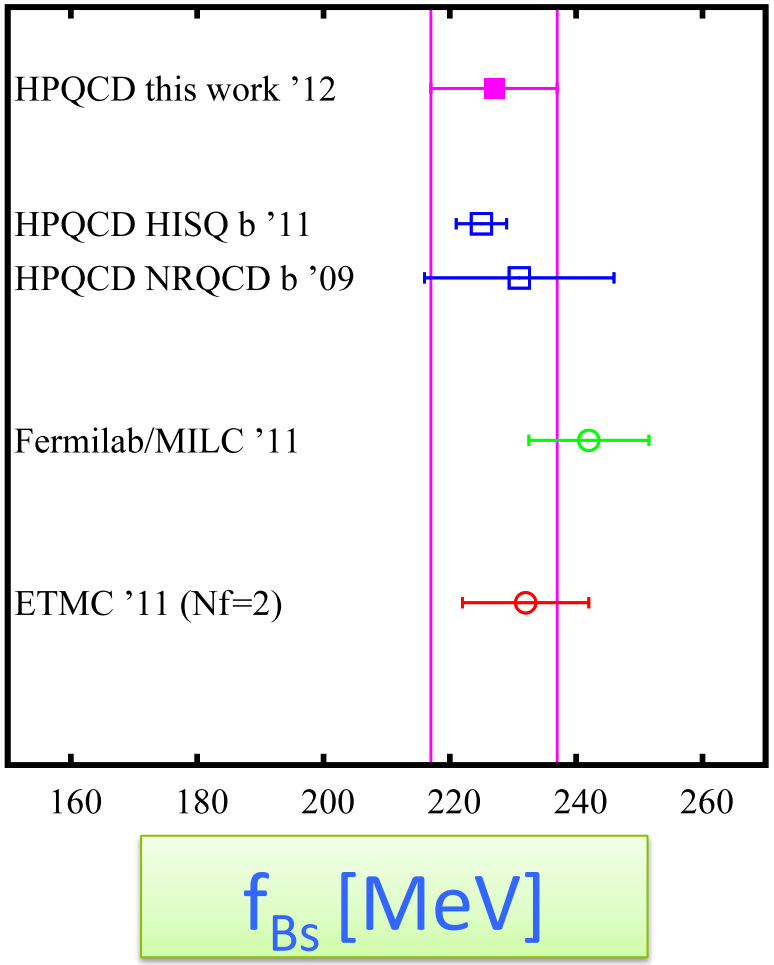
- f_B = 191(9) MeV, f_{Bs} = 228(10) MeV, and f_{Bs}/f_B = 1.188(18)

• f_B from the NRQCD + Heavy HISQ method

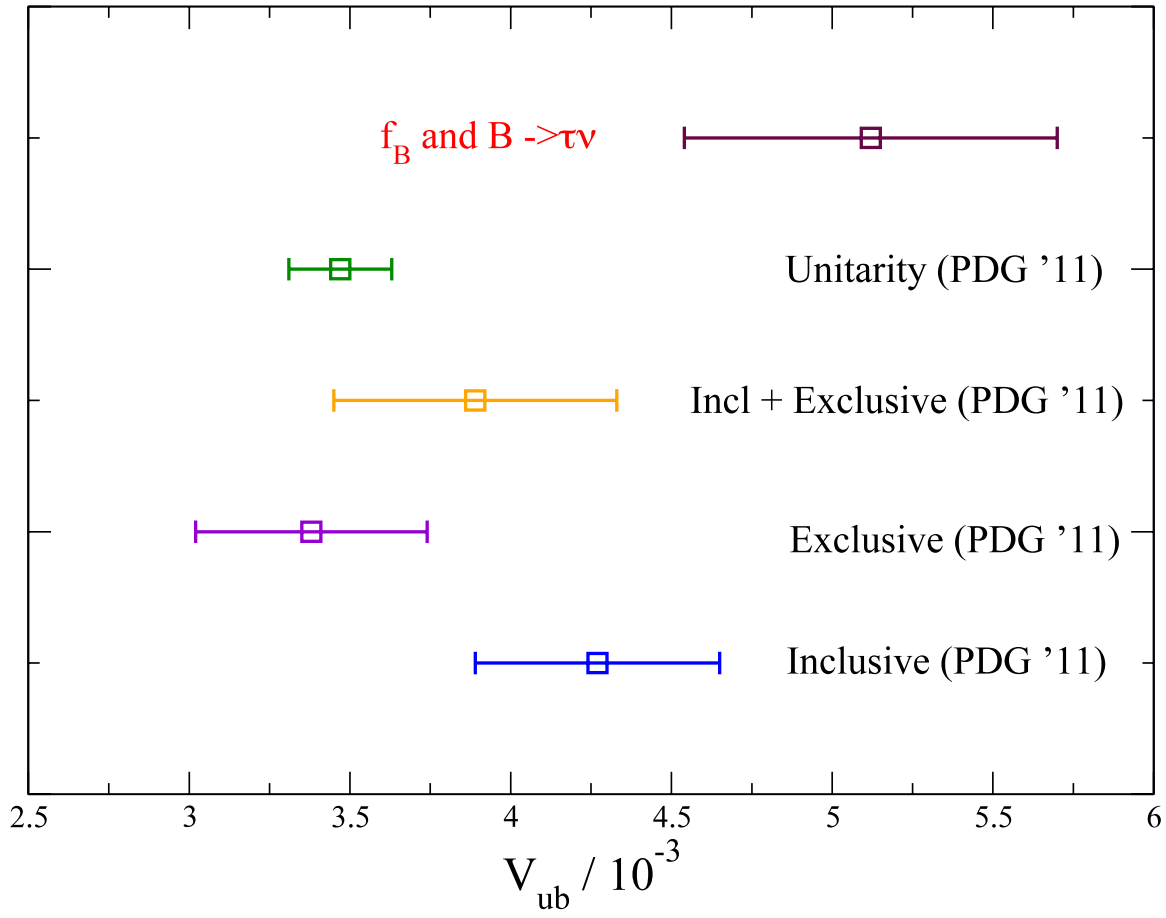
HN et al. (HPQCD)
arXiv:1202.4914

- We have very accurate f_{Bs}/f_B from the NRQCD method
- And, f_{Bs} from the Heavy HISQ method.
- f_B = 189(4) MeV and f_{Bs} = 225(4) MeV: the most precise results, so far.





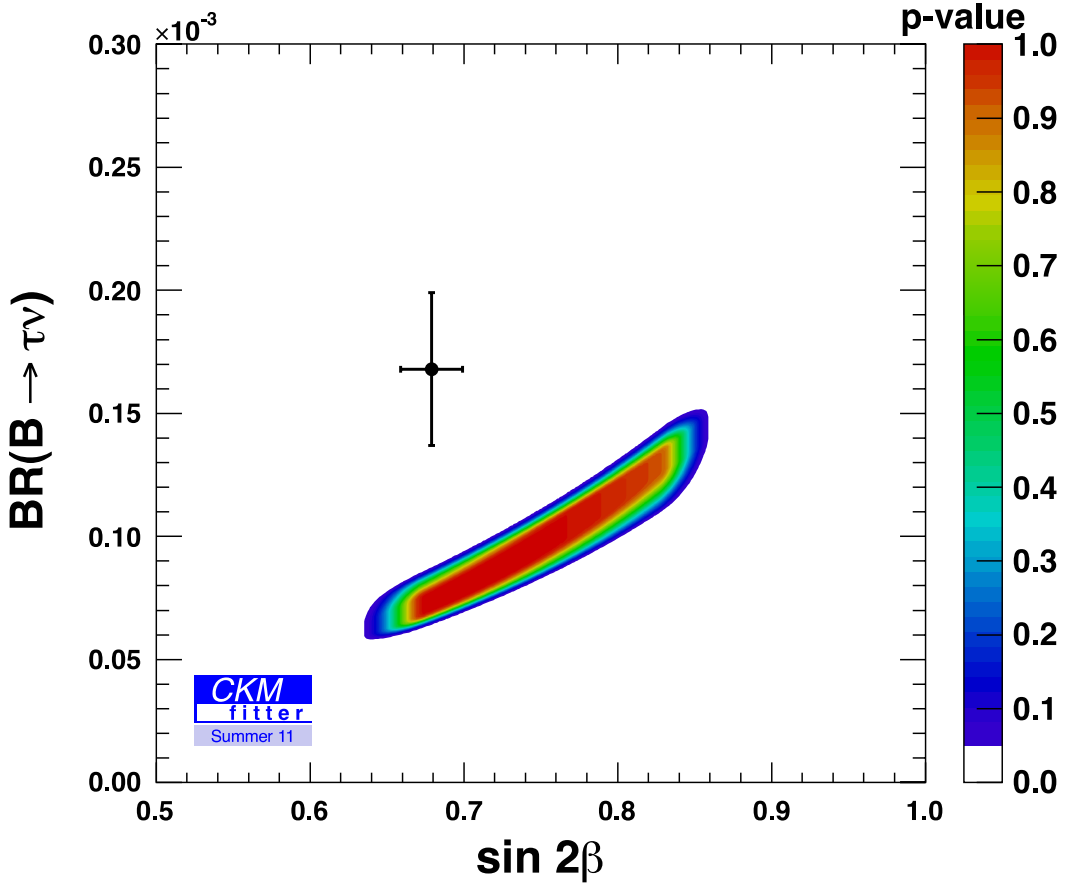
- $|V_{ub}|$ from f_B and Br(B→τν)



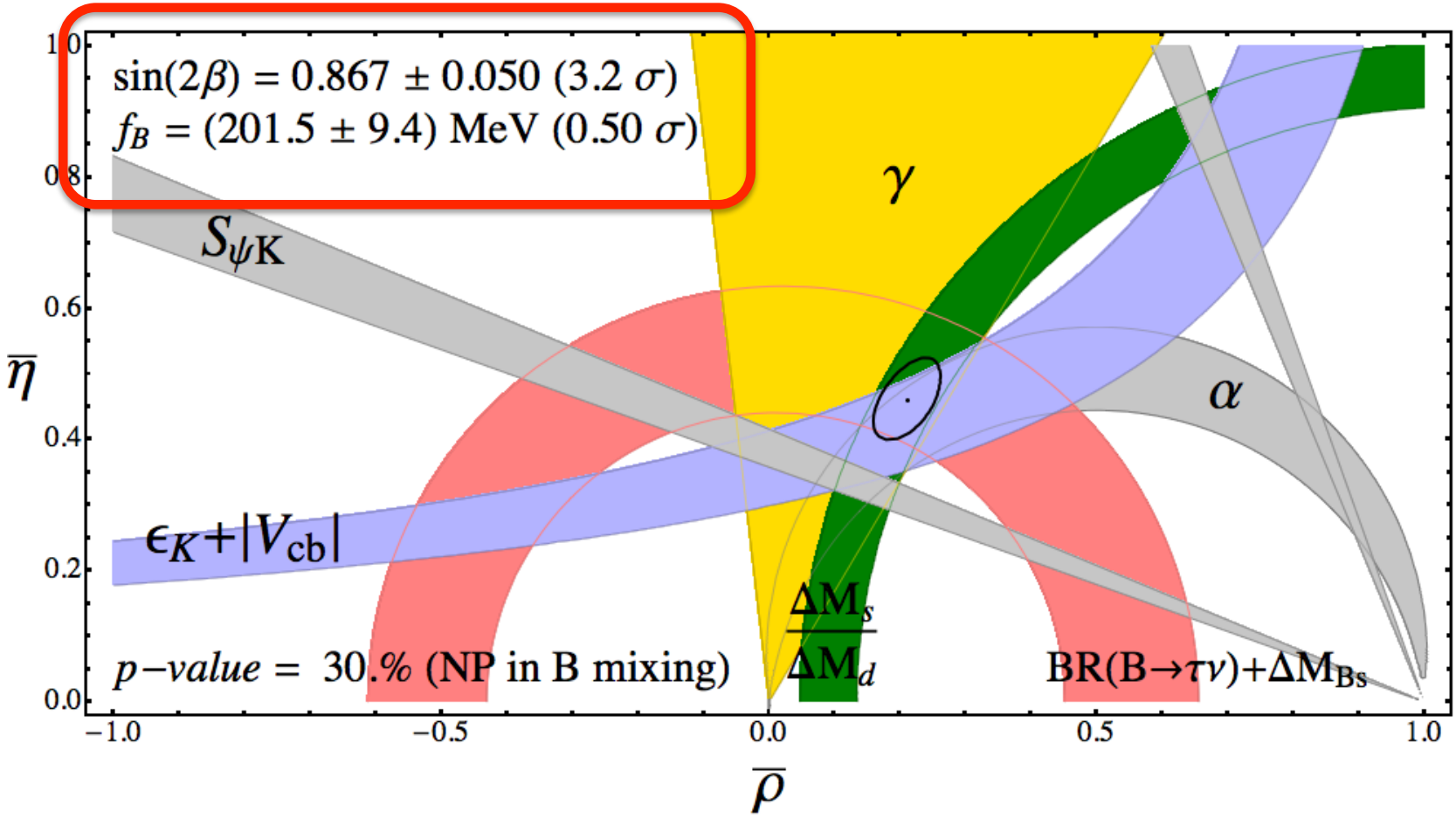
Direct 2.8 σ tension between the Standard Model!

- Br(B→τν) and sin(2β) tension

  - Tree level B leptonic decay is helicity suppressed.
  - From BaBar and Belle: Br(B→τν) = (1.64±0.34)×10^{-4} (HFAG)
  - Currently, 2.8 σ tension between sin(2β)

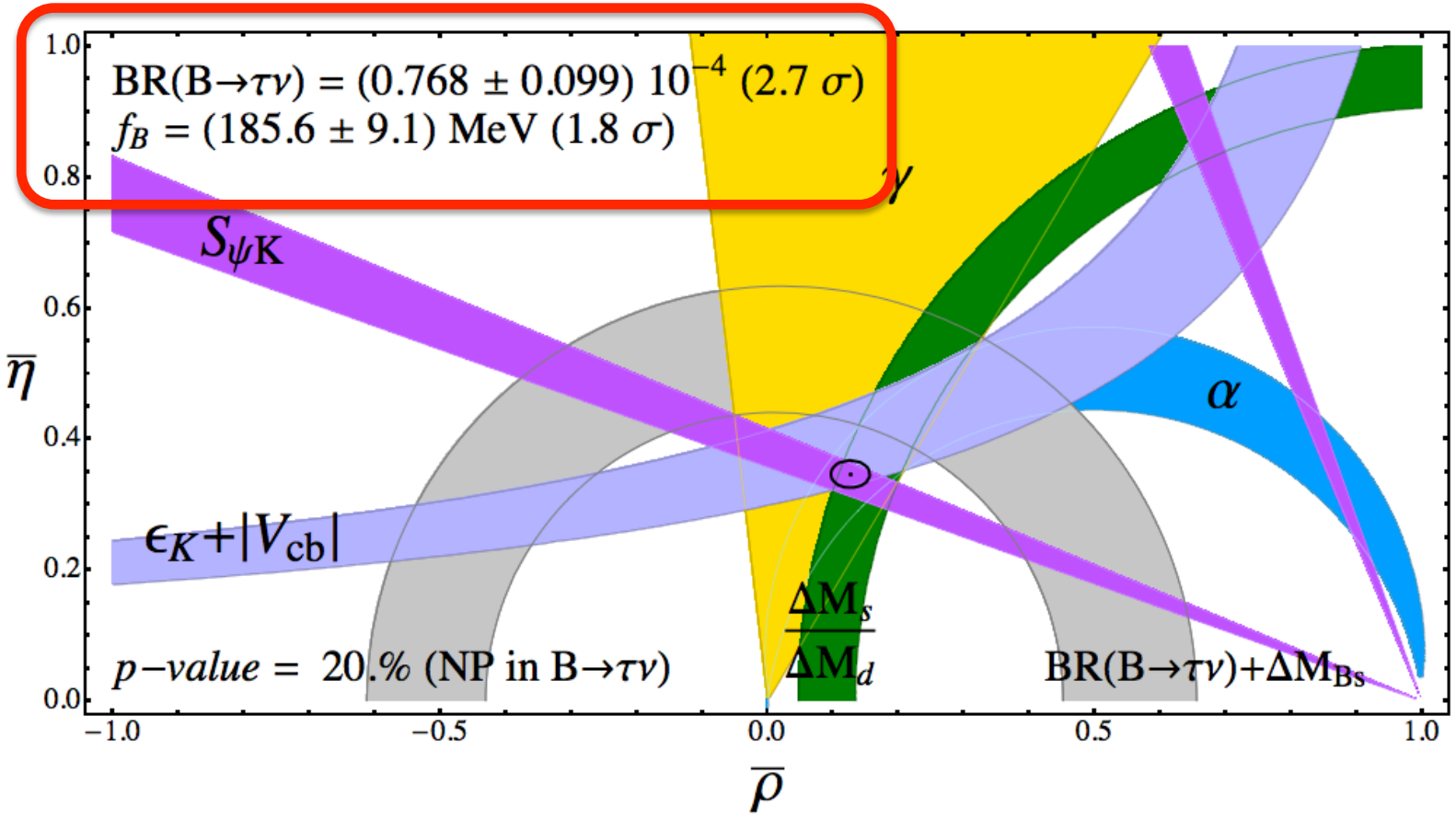


- Br(B→τν) and sin(2β) tension
  - Lunghi and Soni (arXiv:1104.2117)



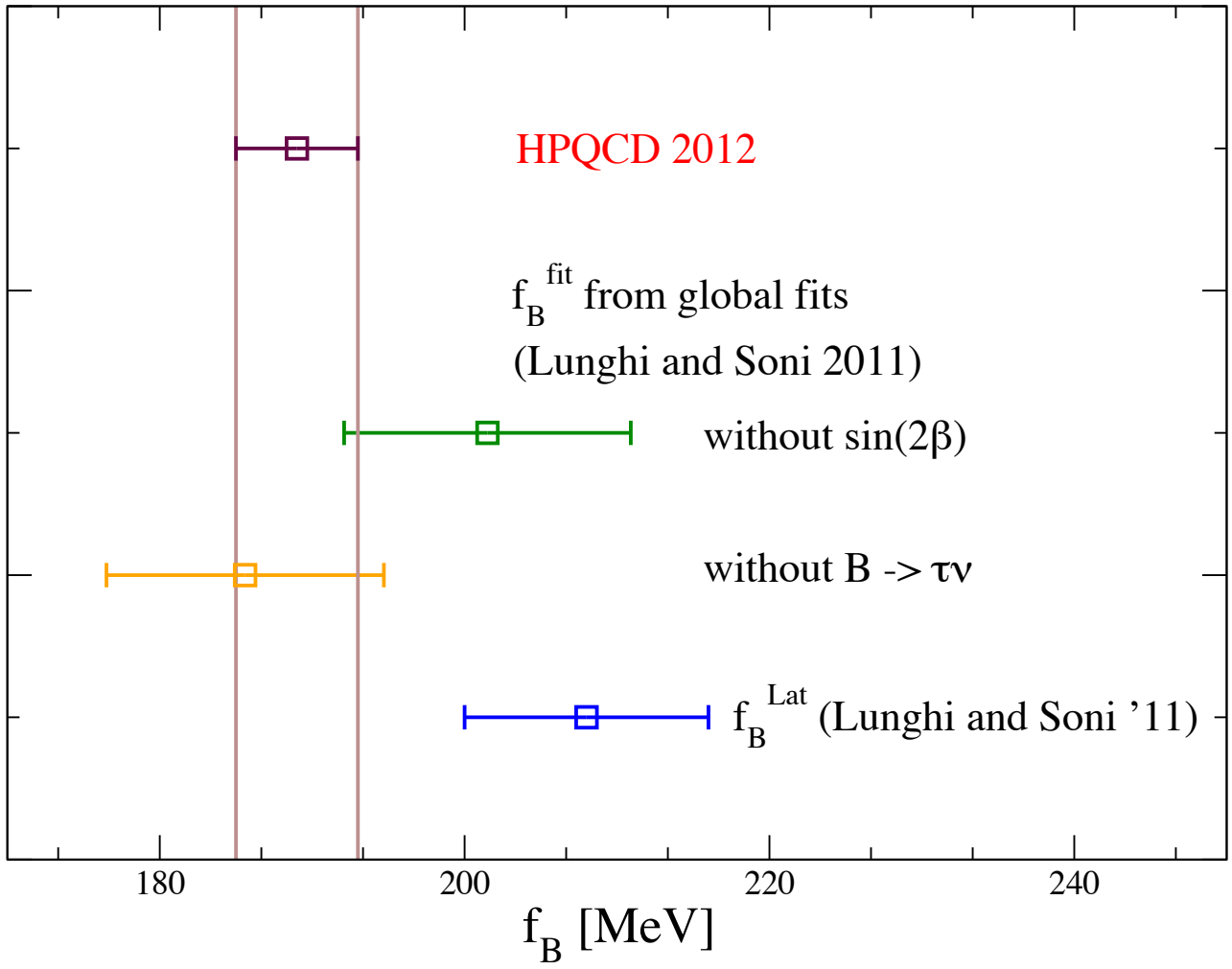
without sin(2β), with Br(B->τν)

- Br(B→τν) and sin(2β) tension
  - Lunghi and Soni (arXiv:1104.2117)

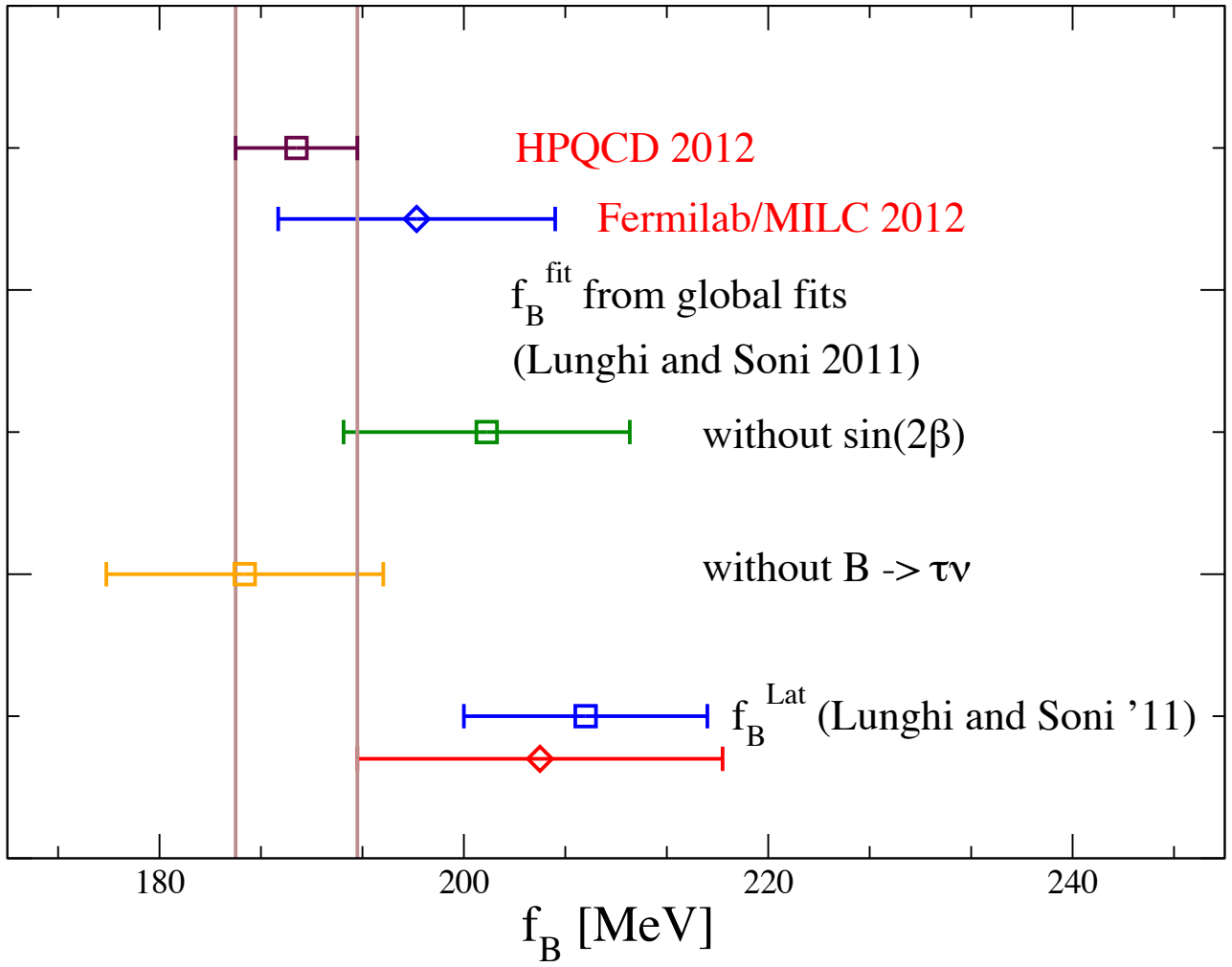


without Br(B->τν), with sin(2β)

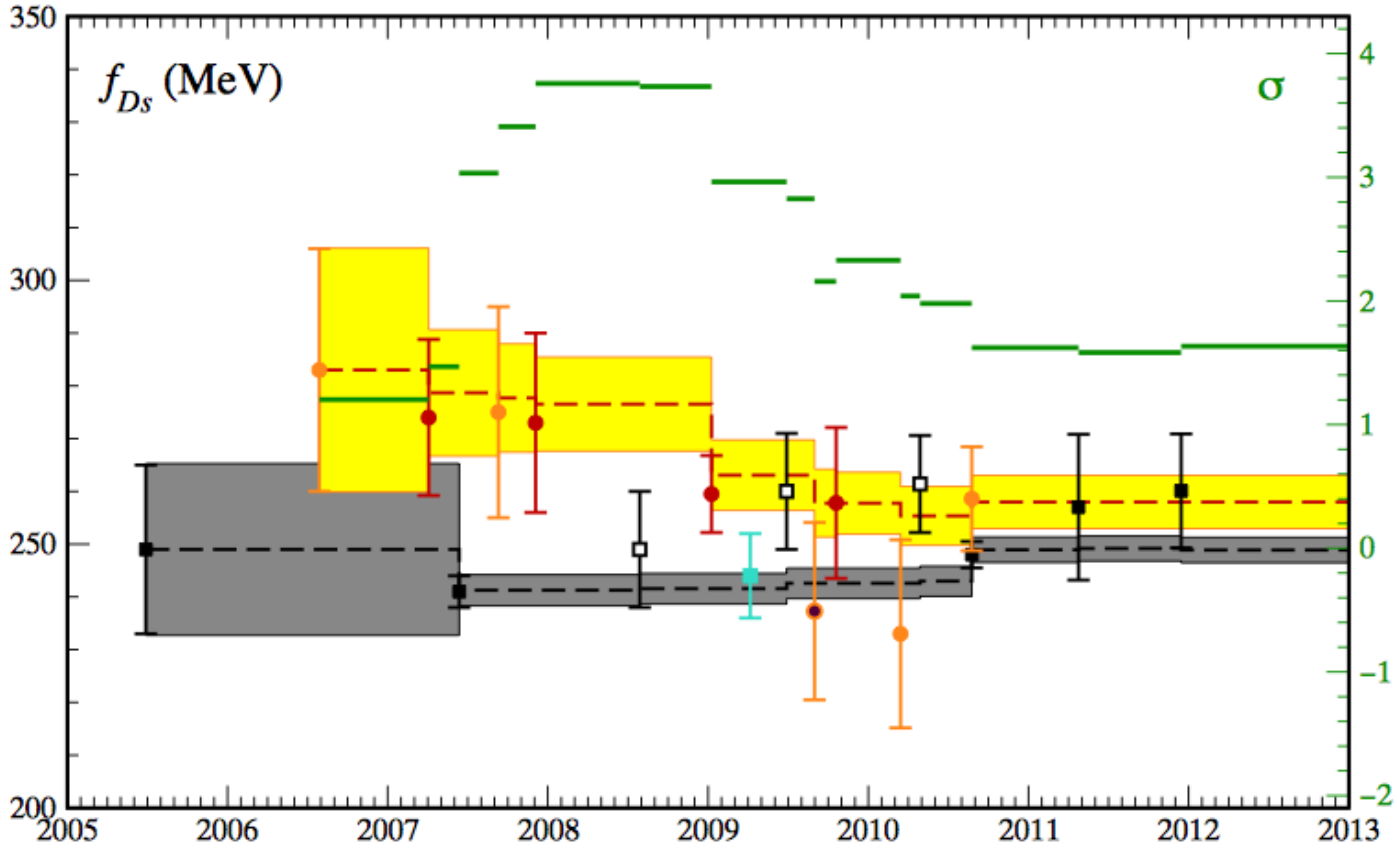
- Br(B→τν) and sin(2β) tension



- Br(B→τν) and sin(2β) tension



- D and D_s meson decay constants: f_{Ds} saga revisited!
  - HPQCD has some history on f_{Ds}
  - Previously, 3.8 σ tension between the experiments
  - Now, it has fallen to 1.6 σ
  - r_1 = 0.321(5) fm before 2010, r_1 = 0.3133(23) fm after 2010

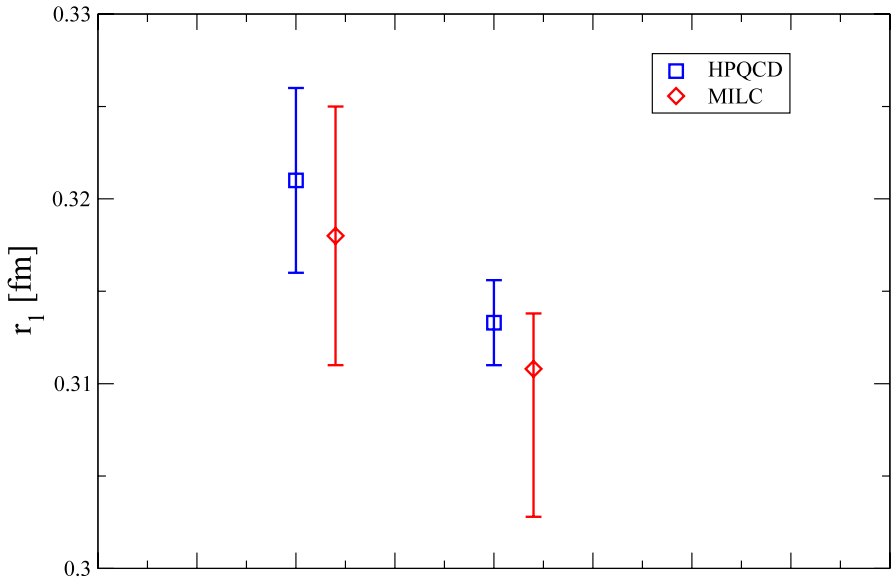


Plot from A. Kronfeld, 1203.1204

• Lattice spacing determinations

- Pion decay constant in lattice units: a f_π^{lat}
- a = (a f_π^{lat})/f_π^{phys}

- Better quantity? r_1 or r_0 is broadly used.
- r_1^2 F(r_1) = 1, F(r) = dV/dr, V(r) = static potential
- r_1 can be determined with sub-percent errors
  - It is in the lattice, so it is really r_1/a
- a M^{lat} -> r_1/a * a M^{lat} = r_1 M^{lat} (in r_1 unit)
  -> r_1 = (r_1 M^{lat})/M^{phys}
- Physical r_1 [fm] can be determined with around 1 percent errors

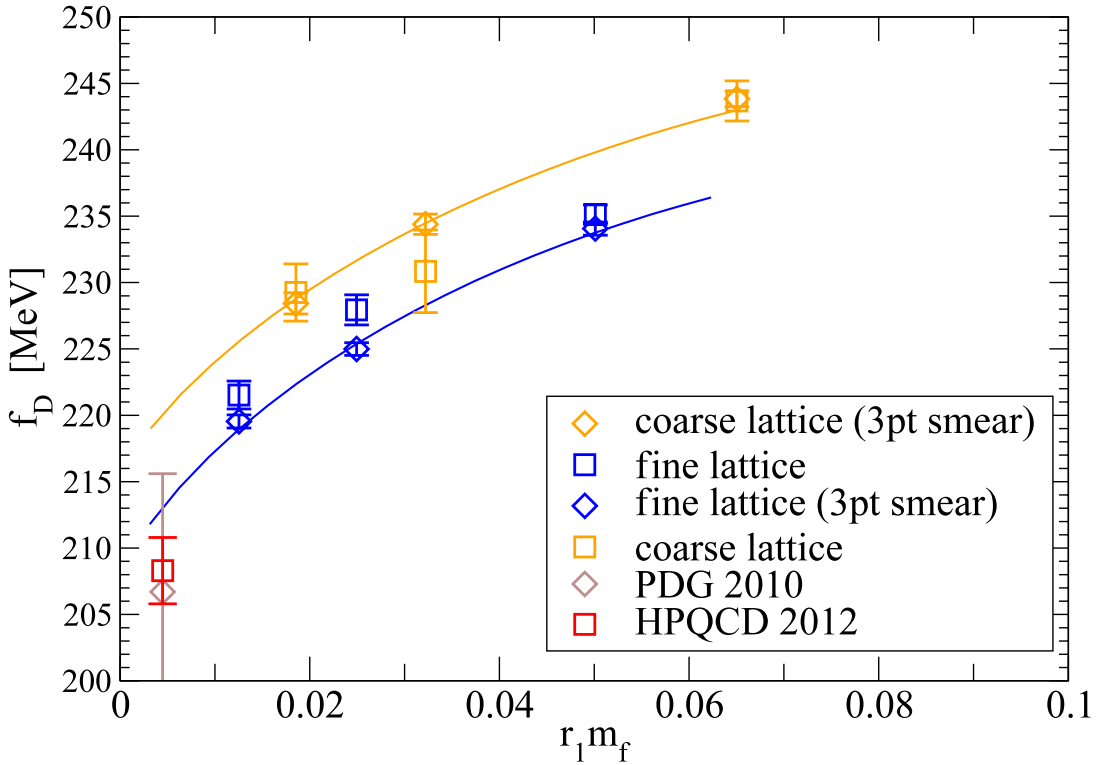


- HPQCD
  0.321(5) -> 0.3133(23)
- MILC
  0.318(7) -> 0.3108(15)($^{+30}_{-80}$)

• D meson decay constants

HN et al. (HPQCD)
arXiv:1206.4936

- Update f_D with updated r1
- Also, calculate f_{Ds} and f_{Ds}/f_D
- Using MILC asqtad staggered Nf=2+1dynamic gauge configurations
- HISQ fermion action for the strange and charm quarks
- Two lattice spacings (0.12fm, 0.09fm)
- Using 3pt smearing: Simultaneous fit with 3 point functions for D to K l ν semileptonic decays



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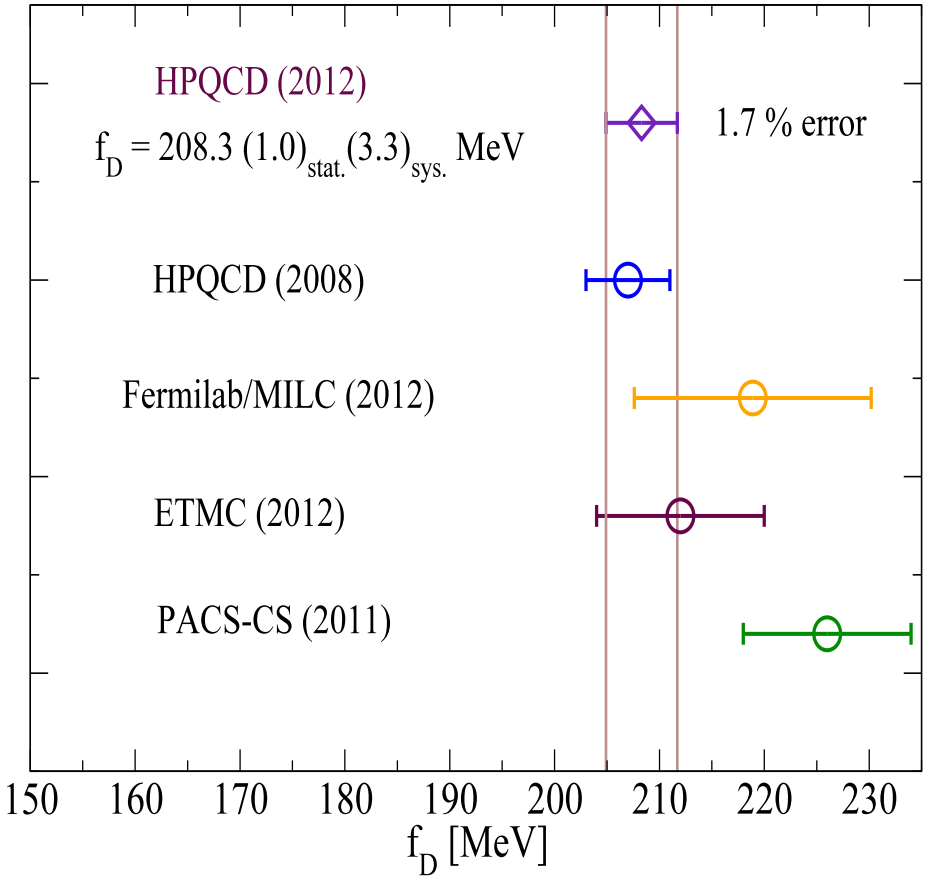
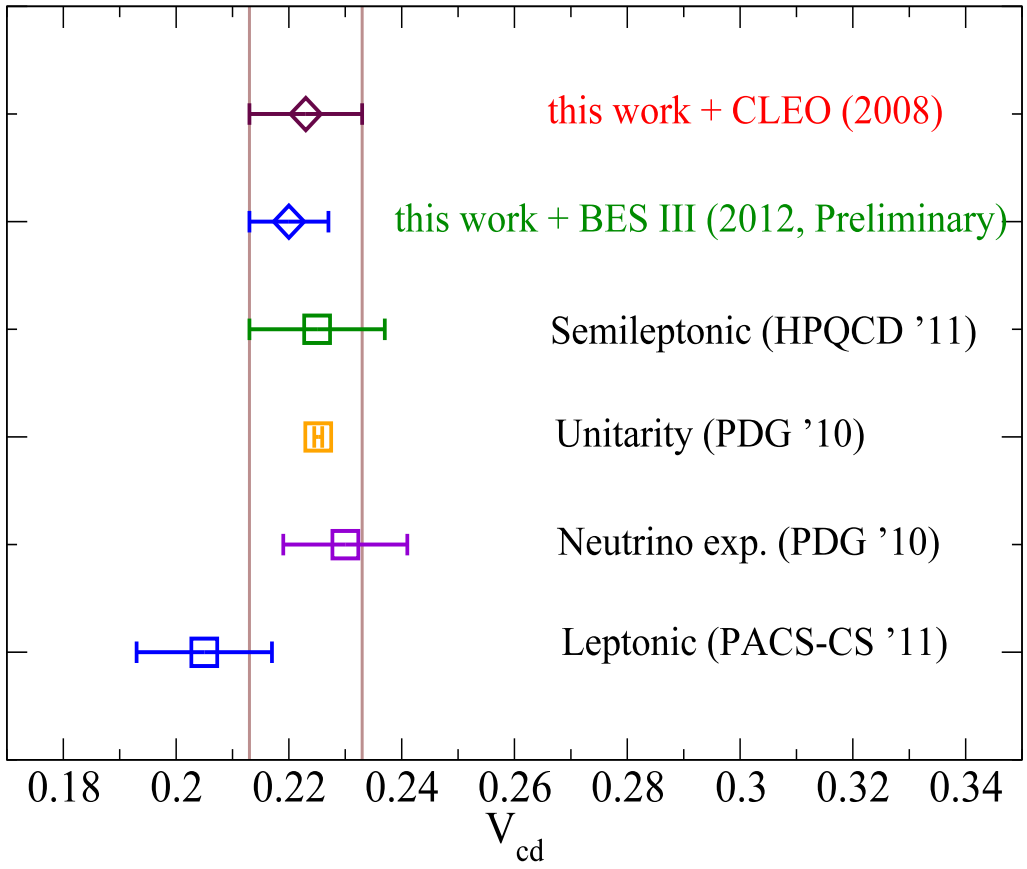


- f_D = 208.3 (1.0)$_{stat.}$ (3.3)$_{sys.}$
- f_{Ds} = 246.0 (0.7)$_{stat.}$ (3.5)$_{sys.}$
- f_{Ds}/f_D = 1.187 (4)$_{stat.}$ (12)$_{sys.}$

	f_D	f_{Ds}	f_{Ds}/f_D
statistics/fitting	0.5	0.3	0.3
scale r_1	0.7	0.7	-
r_1/a	0.04	0.05	-
continuum extrap.	1.2	1.2	0.9
chiral extrap. & $g_{D^*D\pi}$	0.7	0.2	0.5
mass tunings	0.1	0.2	0.2
finite volume	0.3	0.1	0.3
Total	**1.7 %**	**1.5 %**	**1.1 %**

• $|V_{cd}|$ from D meson leptonic decays

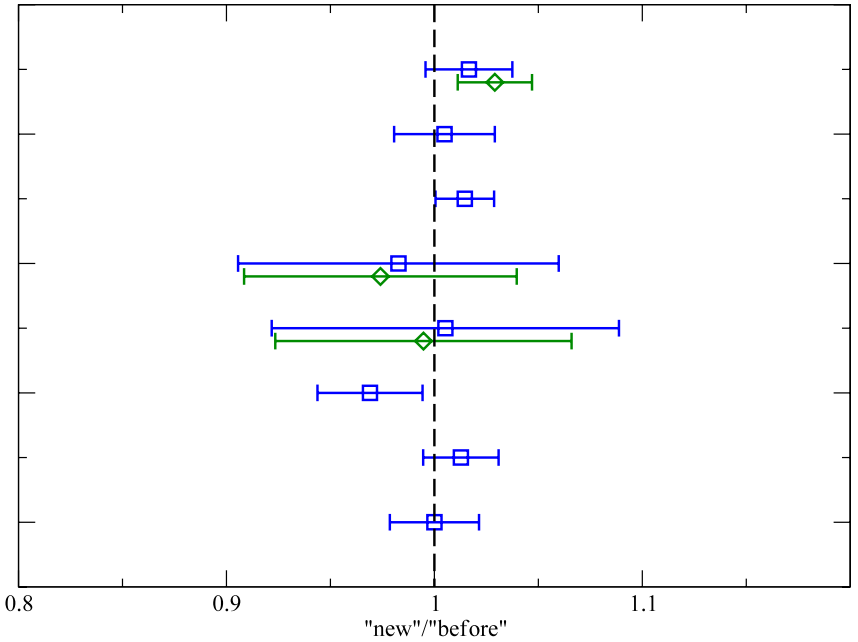
HN et al. (HPQCD)
arXiv:1206.4936



- $|V_{cd}| = 0.223\ (10)_{exp.}\ (4)_{lat.}$
- $[\ f_+^{D\to\pi}(0) / f_D\ ]_{lat.} = 3.20(15)\ GeV^{-1}$
- $[\ f_+^{D\to\pi}(0) / f_D\ ]_{exp.} = 3.19(18)\ GeV^{-1}$

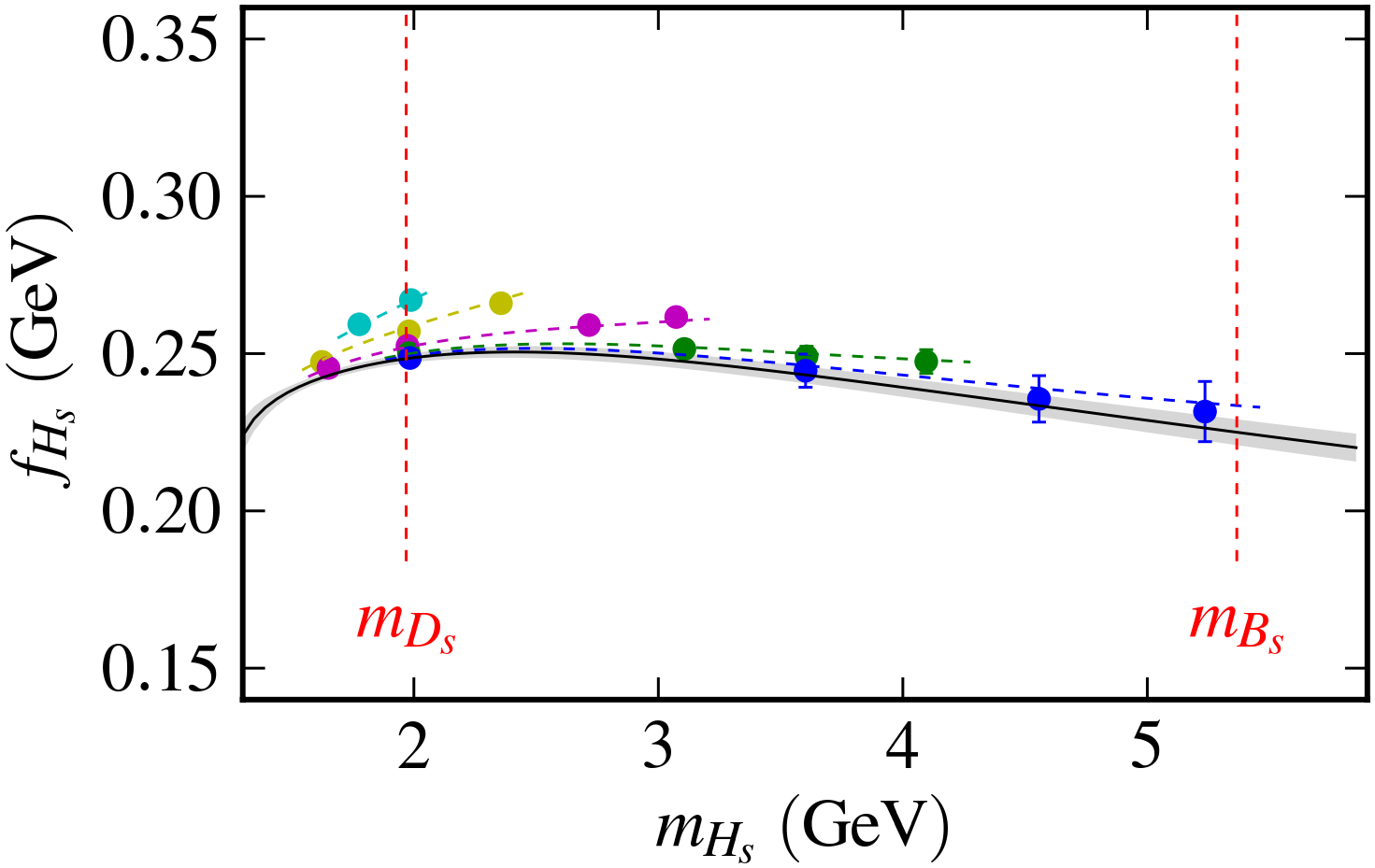
- Old r_1 vs. new r_1
  - Old r_1 = 0.321 (5) fm
  - New r_1 = 0.3133 (23) fm

	before	now
fDs	241(3)	246(4) [248(3)]
fD	207(4)	208(3)
fDs/fD	1.164(11)	1.187(12)
fBs	231(15)	228(10) [225(4)]
fB	190(13)	191(9) [189(4)]
fBs/fB	1.226(26)	1.188(18)
fK	157(2)	159(2)
fπ	132(2)	132(2)

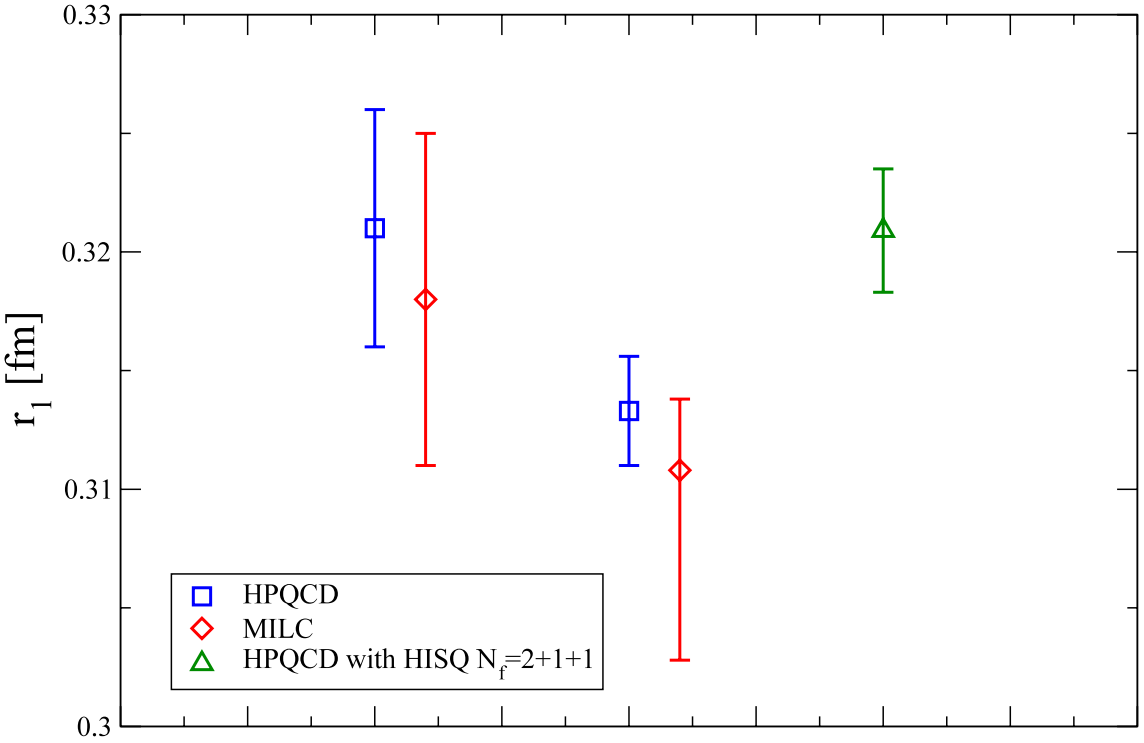


- The effect due to the scale changing is small.
- f_{Ds} is a special case!

- Old r_1 vs. new r_1
  - Old r_1 = 0.321 (5) fm
  - New r_1 = 0.3133 (23) fm



• Lattice spacing determinations: f_{Ds} saga revisited!



- HPQCD
  0.321(5) -> 0.3133(23)
- MILC
  0.318(7) -> 0.3108(15)($^{+30}_{-80}$)
- HPQCD with HISQ confs
  0.3209(29) (1110.6887)

- f_{Ds} at HISQ N_f=2+1+1 would be very interesting!
  - Talks by Doug Toussaint and Jongjeong Kim on Friday

• Summary

• HPQCD have been used NRQCD, HISQ, and Heavy HISQ for handling the heavy quarks.

• Using the Heavy HISQ and NRQCD methods, we obtained B and B_s decay constants with about 2% error.

  • Keep increasing precision would help to understand, for example, the B -> τν tension.

• We calculate $|V_{cd}|$ from the D decay constants with updated r_1

  • Good agreement with $|V_{cd}|$ from the semileptonic decay study.

  • Updated r_1 effects are small, except for f_{Ds}

  • f_{Ds} at HISQ N_f=2+1+1 configuration would be very interesting.

Back up

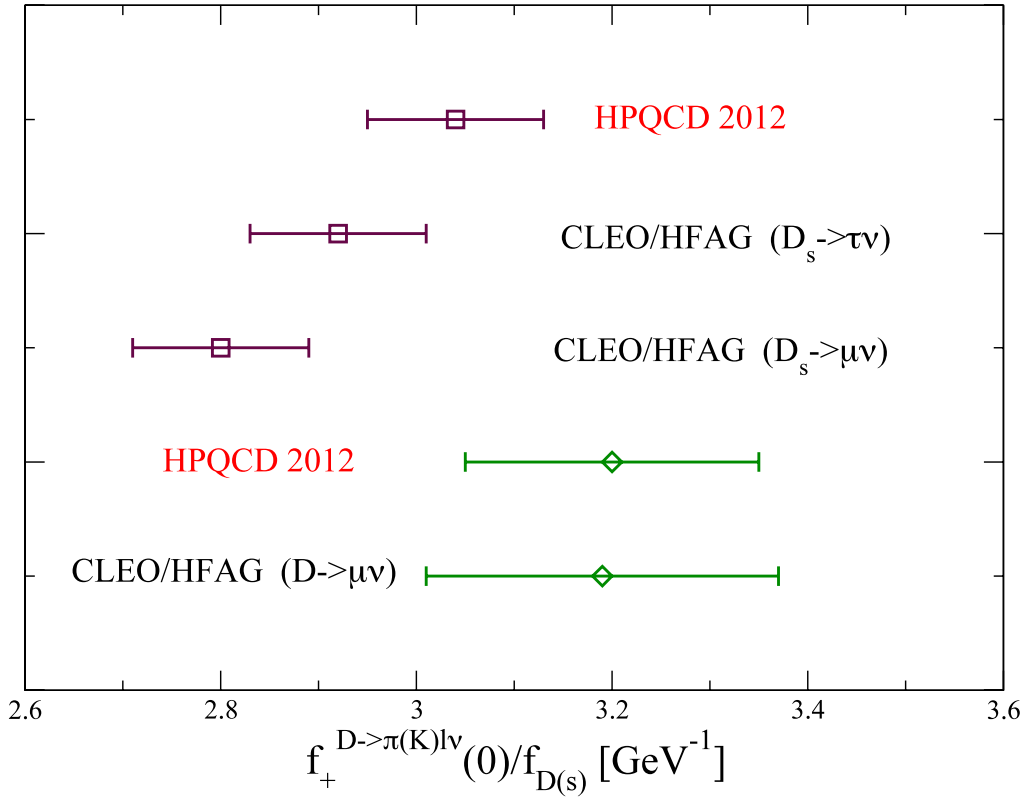
• V_{cs} and V_{cd} from the leptonic decays

Preliminary!

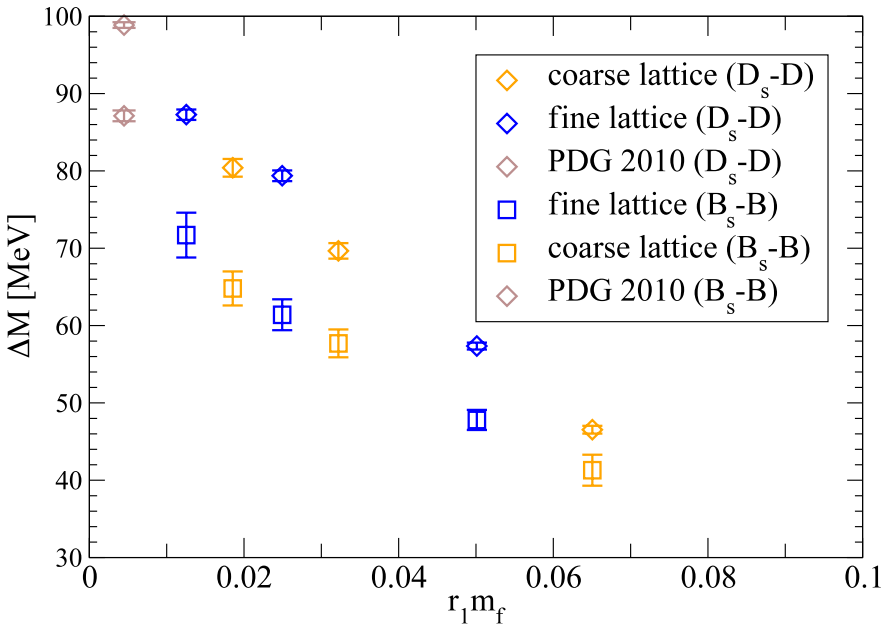
$$f_+^{D\to\pi l\nu}(0)|V_{cd}| = 0.145(4)(1) + 0.150(5)(2) \Rightarrow 0.148(5)(2)$$
$$f_+^{D\to Kl\nu}(0)|V_{cs}| = 0.717(6)(4) + 0.716(7)(9) \Rightarrow 0.717(7)(9)$$

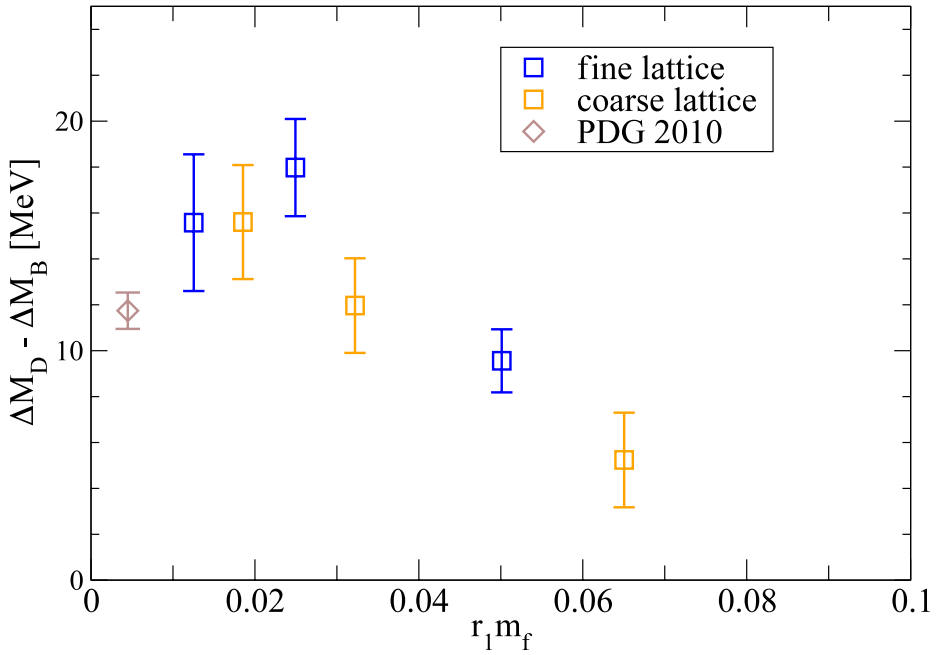
CLEO, PRD 80 (2009) 032005

$$f_D|V_{cd}| = 46.4 \pm 2.0\ MeV$$
$$f_{Ds}(D_s \to \tau\nu)|V_{cs}| = 245.6 \pm 6.7\ MeV$$
$$f_{Ds}(D_s \to \mu\nu)|V_{cs}| = 256.3 \pm 7.4\ MeV$$



- M_{hs}-M_{hl} mass splittings

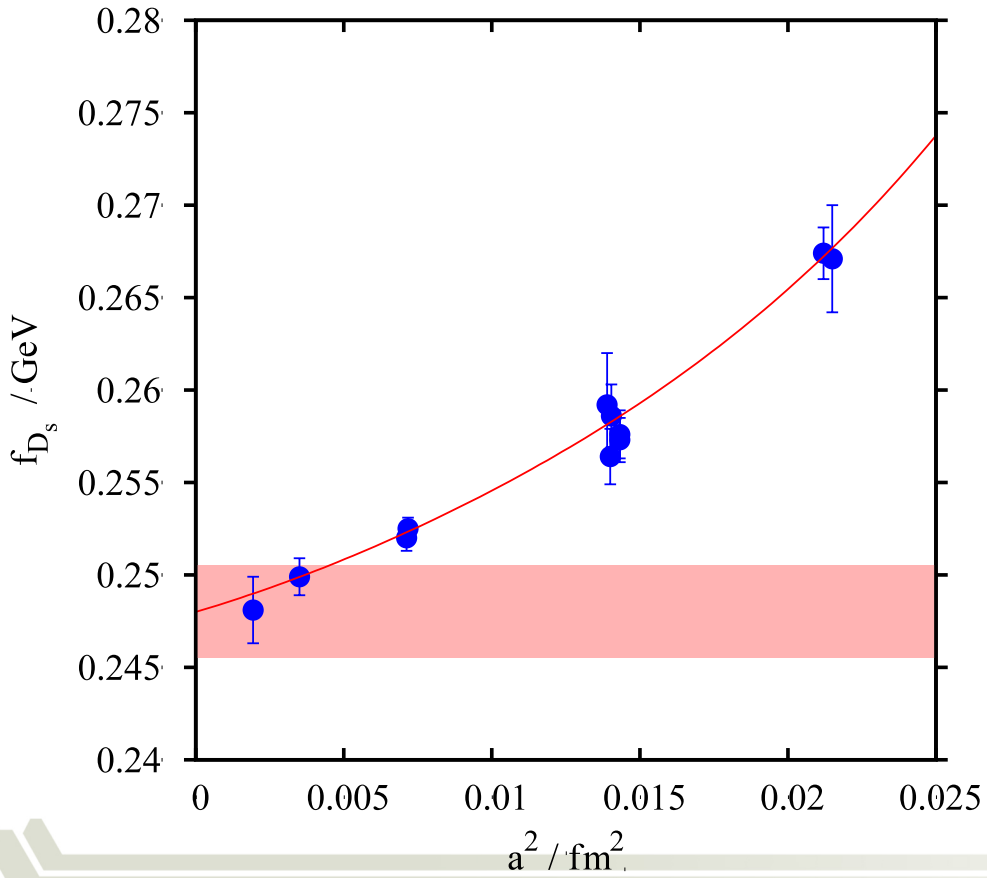




• D and D_s meson decay constants

C. Davies et al. (HPQCD)
PRD 82 (2010) 114504

- Update f_{Ds} with updated r1 and more data sets
- Using MILC asqtad staggered Nf=2+1dynamic gauge configurations
- HISQ fermion action for the strange and charm quarks
- Five lattice spacings (0.15fm, 0.12fm, 0.09fm, 0.06fm, and 0.045fm)
- f_{Ds} = 241(3) MeV → 248.0(2.5) MeV



• Tension?: Br(B->τν) & sin(2β)

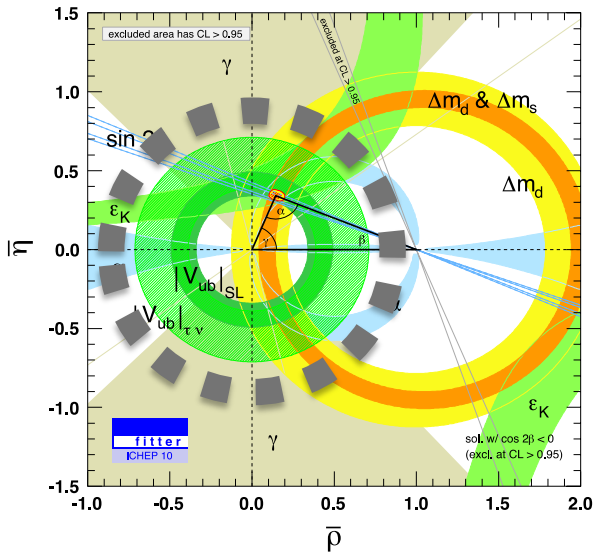
• Leptonic decays: Br(B->τν)

• BaBar

Hadronic tag : $(1.80^{+0.57}_{-0.54} \pm 0.26) \times 10^{-4}$ Preliminary. NEW

Semileptonic tag : $(1.7 \pm 0.87 \pm 0.2) \times 10^{-4}$

Combined result : $(1.76 \pm 0.49) \times 10^{-4}$



• Belle

Hadronic tag : $(1.79^{+0.56\ +0.46}_{-0.49\ -0.51}) \times 10^{-4}$

Semileptonic tag : $(1.54^{+0.38\ +0.29}_{-0.37\ -0.31}) \times 10^{-4}$ NEW!

Final result : $(1.64 \pm 0.34) \times 10^{-4}$ (HFAG)

R. Barlow, CKM 2010

- Unitarity triangle and Lattice QCD

$$V = \begin{pmatrix} |V_{ud}| \ (1-\lambda^2/2) & |V_{us}| \ (\lambda) & |V_{ub}| \ (A\lambda^3(\rho - i\eta)) \\ 0.97425\ (22) & 0.2252\ (9) & (3.89 \pm 0.44) \times 10^{-3} \\ |V_{cd}| \ (-\lambda) & |V_{cs}| \ (1-\lambda^2/2) & |V_{cb}| \ (A\lambda^2) \\ 0.230\ (11) & 1.023\ (36) & (40.6 \pm 1.3) \times 10^{-3} \\ |V_{td}| \ (A\lambda^3(1-\rho-i\eta)) & |V_{ts}| \ (-A\lambda^2) & |V_{tb}| \ (1) \\ (8.4 \pm 0.6) \times 10^{-3} & (38.7 \pm 2.1) \times 10^{-3} & 0.88 \pm 0.07 \end{pmatrix}$$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

$$= A\lambda^3(\rho + i\eta) - A\lambda^3 + A\lambda^3(1-\rho-i\eta) + \mathcal{O}(\lambda^4)$$