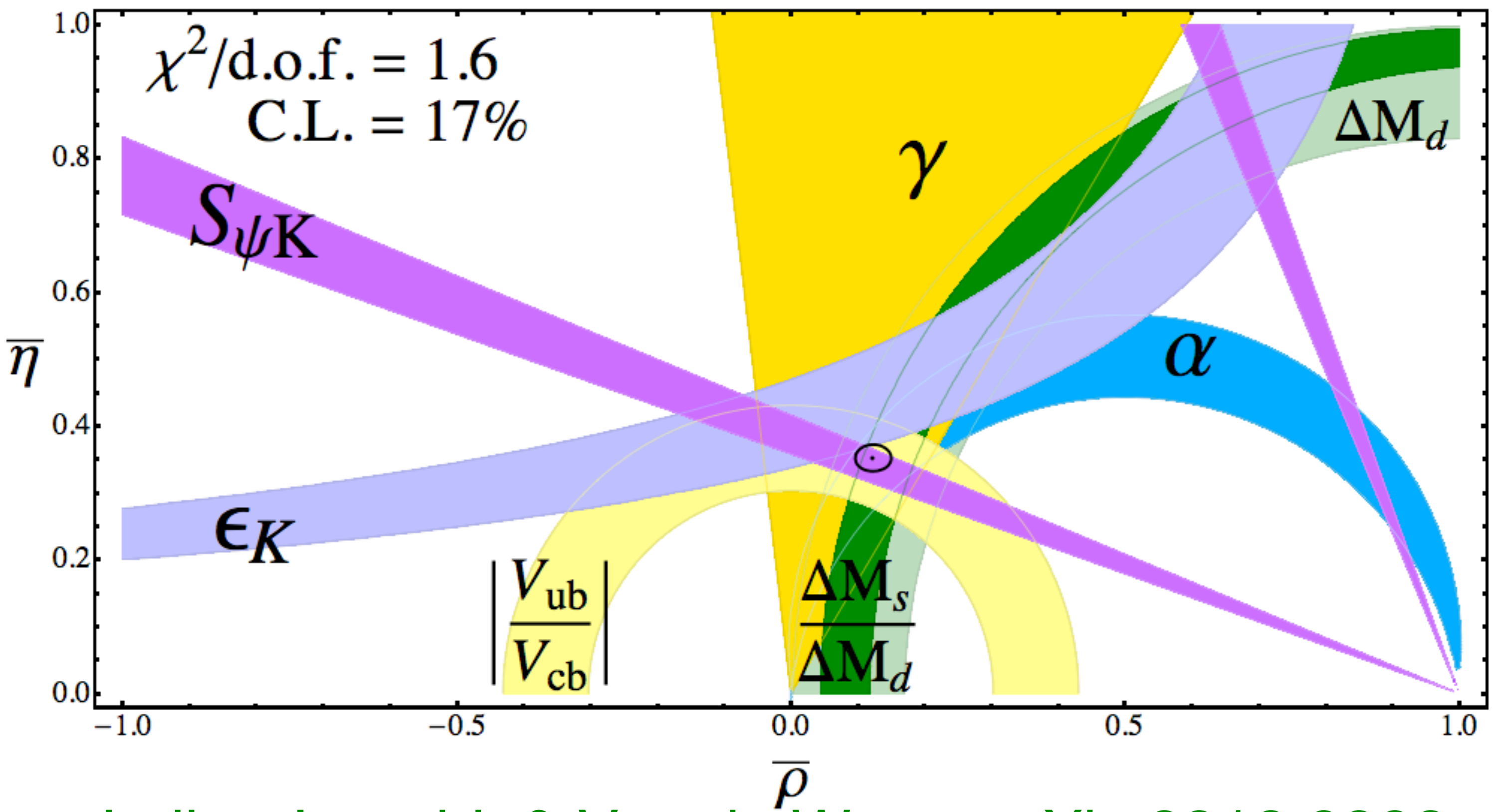
Leptonic B and D Decays on the Lattice

Claude Bernard
Washington University
St. Louis
(Fermilab Lattice/MILC Collaboration)

Lattice QCD Meets Experiment Workshop 2010
Fermilab, April 26-27

CKM FIT

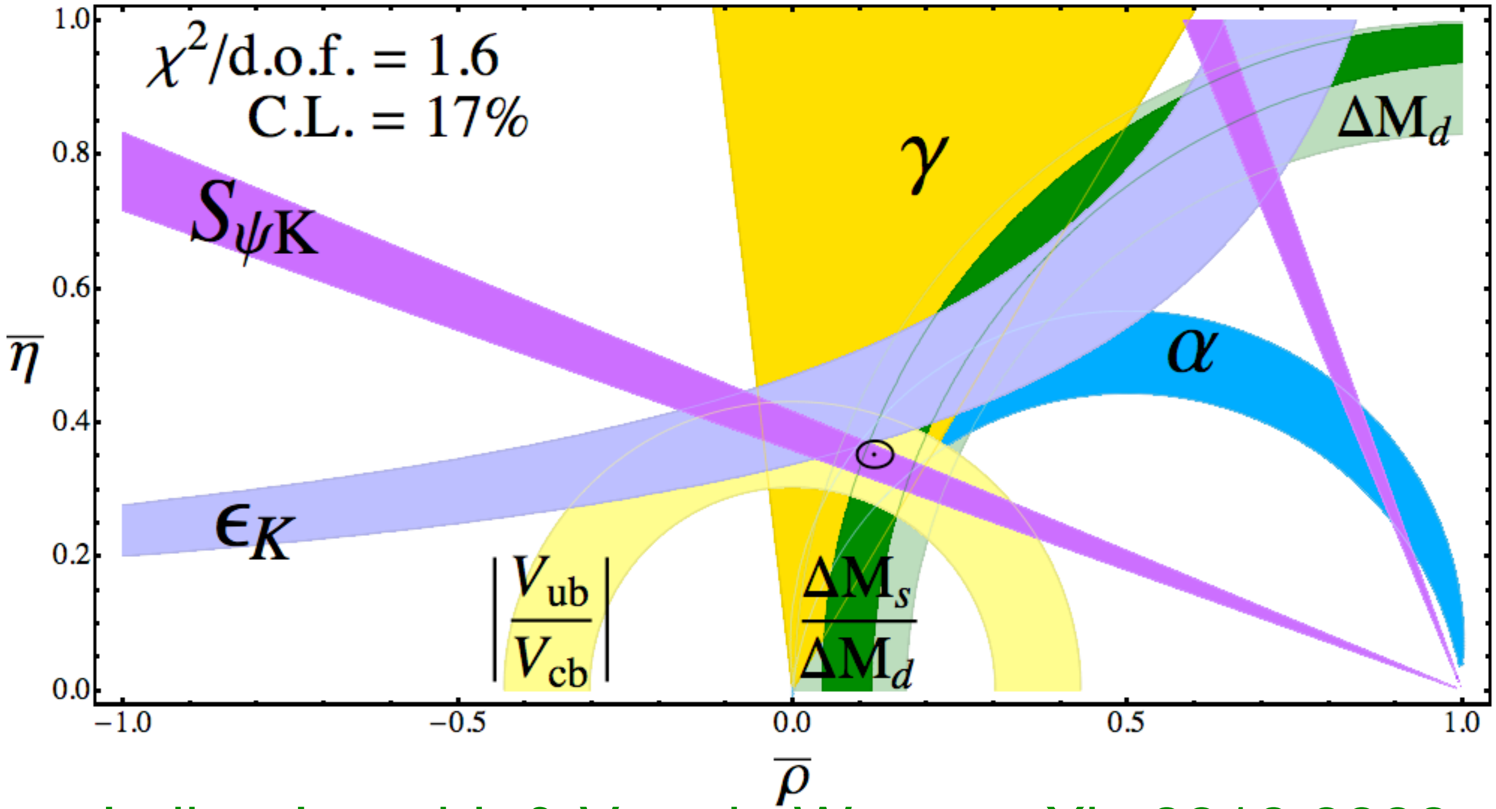
- Experimental errors < 1%
- Remaining significant errors are from lattice QCD.



From Laiho, Lunghi, & Van de Water, arXiv:0910.2928

CKM FIT

- Decay constants are important because f_{B_s}/f_B enters $\xi \equiv f_{B_s}\sqrt{B_{B_s}}/f_B\sqrt{B_B}$
  - relevant to $\Delta M_s/\Delta M_d$
  - See E. Gamiz talk this afternoon



From Laiho, Lunghi, & Van de Water, arXiv:0910.2928

More Motivation

- D system decay constants generally viewed as a good place to test lattice QCD.
  - but also possible (though unexpected) place for new physics.
  - f_{D_s} saga.
- BSM decay $B_s \to \mu^+\mu^-$ depends on hadronic matrix element f_{B_s} :
  - decay comes from effective Higgs coupling to $\bar{b}s$, usually through $\langle 0|\,\bar{b}\,\gamma_5\,s\,|B_s\rangle$
  - but this is proportional to f_{B_s} using equations of motion to relate pseudoscalar density to axial current.
  - Experimental status: Tevatron talk to follow by W. Hopkins.

Computations

- Simulations in full QCD with all systematics controlled have been done by 2 collaborations:
  - Fermilab Lattice/MILC
  - HPQCD
- Both use lattice configurations generated by MILC, with 3 flavors of dynamical light sea quarks, using the “rooted staggered” action for the quarks.
- There is also an evaluation with only 2 light flavors, but all other systematics controlled:
  - European Twisted Mass (ETM) Collaboration
- Finally, some results for the B system with 3 light flavors and static B quarks, but only at one lattice spacing so far:
  - RBC/UKQCD

Staggered Quarks

- Increasingly precise results from staggered simulations in past decade:
  - revived old concerns that a technical step in the simulations, "rooting," could be invalid and lead to incorrect results, even in continuum limit.
    - (rooting is the way staggered simulations deal with the lattice doubling problem for fermions)
  - issue has now been looked at in detail theoretically:
    - Shamir, CB, Golterman, Sharpe, Adams
  - and numerically:
    - Durr, Hoelbling, & Wegner; Follana, Hart, & Davies; MILC
- Conclusion: rooting step is valid.
  - but no proofs, of course, in nonperturbative QFT.
  - See reviews: Sharpe (06), Kronfeld (07), Golterman (08), MILC (09).

Analysis (Valence Quarks)

- Fermilab/MILC:
  - "Fermilab" action for bottom and charm valence quarks.
  - staggered ("asqtad") action for light valence quarks.
- HPQCD:
  - NRQCD action for valence bottom.
  - HISQ action (a highly improved version of staggered) for both charm and light valence quarks.
    - HISQ charm helps a lot to reduce heavy quark discretization errors: $O(a^2)$ instead of $O(a)$; light errors also reduced.
    - using same action for light & heavy valence has further technical advantages that also reduce errors.
    - Note: at the moment HISQ bottom not possible except possibly by extrapolation from lower masses.

Lattice Scale

- Lattice computations need one dimensionful experimental input to set scale of lattice spacing.
- Splittings of Υ (determined by HPQCD with NRQCD) were the most precise and have often been used.
- Scale traditionally converted to a value for r_1 (conveniently determined on lattice, but not directly experimentally accessible)
- HPQCD Υ + MILC r_1/a ➔

$r_1 = 0.318(7)$ fm MILC

$r_1 = 0.321(5)$ fm HPQCD

Lattice Scale

r_1 = 0.318(7) fm MILC
r_1 = 0.321(5) fm HPQCD
(from Υ)

- But MILC f_π has consistently given a higher energy scale (lower r_1) ~ 0.311 fm.
- Precision of f_π has improved over time, & it doesn't suffer from NRQCD truncation systematics of Υ scale.
- Summer '09, we switched to f_π scale.
- Fall '09, HPQCD redid Υ analysis with improved methods & combined with their f_π
- New scales: r_1 = 0.3117(6)(22) fm MILC (from f_π)
  r_1 = 0.3133(23)(3) fm HPQCD (from Υ, f_π)

MILC Ensembles

- MILC has generated ensembles of 2+1 flavors of rooted staggered quarks, with improved “asqtad” action:

MILC Ensembles

- MILC has generated ensembles of 2+1 flavors of rooted staggered quarks, with improved “asqtad” action:

Ensemble Lattice Spacing
0.15 fm
0.12 fm
0.09 fm
0.06 fm
0.045 fm

MILC Ensembles

- MILC has generated ensembles of 2+1 flavors of rooted staggered quarks, with improved "asqtad" action:

Ensemble Lattice Spacing	Fermilab/MILC analysis
0.15 fm	√
0.12 fm	√
0.09 fm	√
0.06 fm	partly done
0.045 fm	in progress

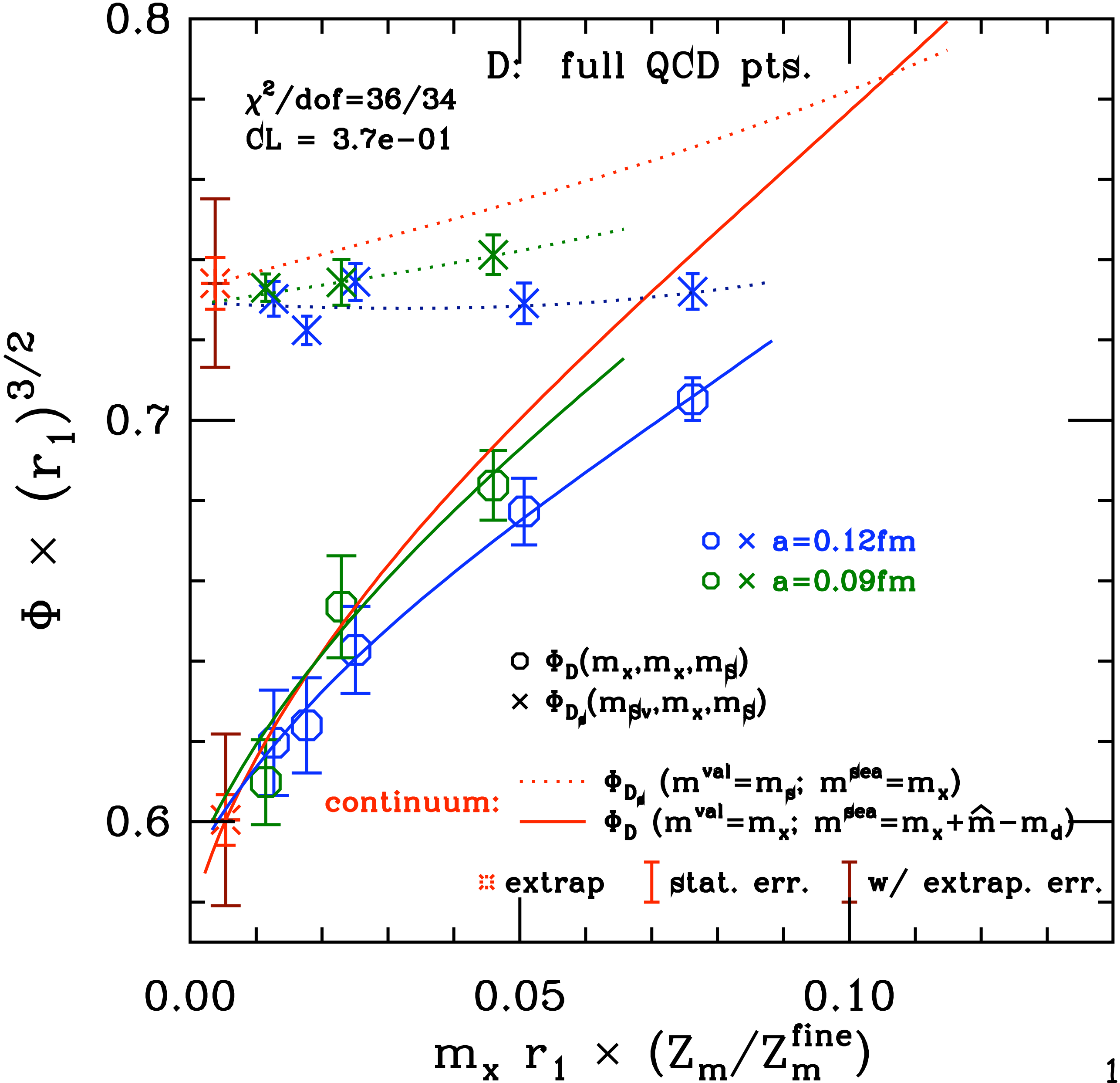
MILC Ensembles

- MILC has generated ensembles of 2+1 flavors of rooted staggered quarks, with improved "asqtad" action:

Ensemble Lattice Spacing	Fermilab/MILC analysis	HPQCD analysis
0.15 fm	√	√
0.12 fm	√	√
0.09 fm	√	√
0.06 fm	partly done	prelim. result
0.045 fm	in progress	prelim. result

D system

- Fermilab/MILC
- Quark mass & continuum extrapolations
- Heavy quark discretization errors are largest systematic

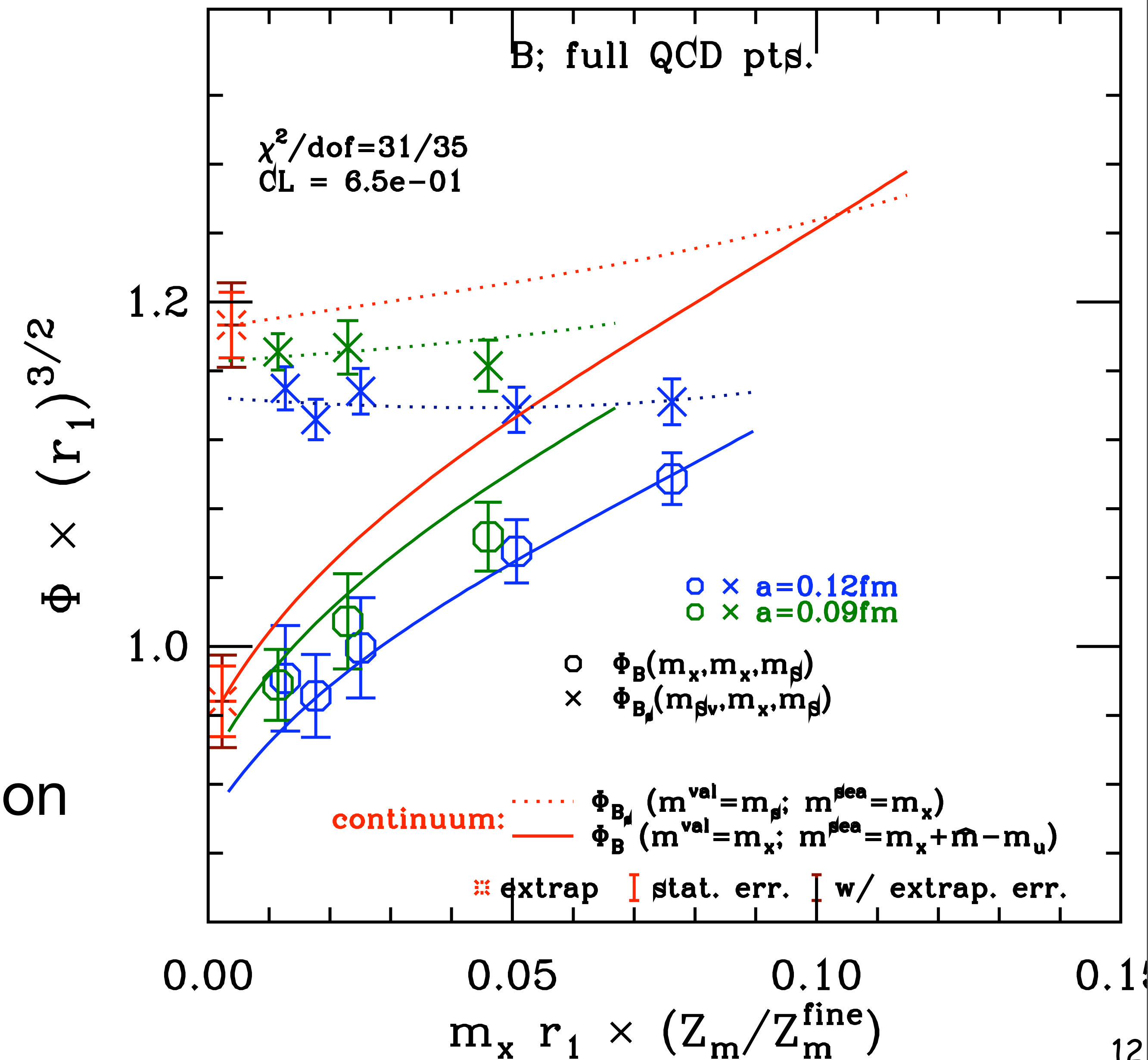


$(\Phi \equiv f\sqrt{M})$

B system

- Fermilab/MILC
- Quark mass & continuum extrapolations
- Statistics give biggest error
- Heavy quark discretization & mass extrapolation are comparable errors.

$(\Phi \equiv f\sqrt{M})$



Fermilab/MILC Results

$$
\begin{aligned}
f_{D_s} &= 261.4 \pm 7.7 \pm 5.0\ \text{MeV} \\
f_{D^+} &= 220.3 \pm 8.0 \pm 4.8\ \text{MeV} \\
f_{D_s}/f_{D^+} &= 1.187 \pm 0.013 \pm 0.015 \\
f_{B_s} &= 256.3 \pm 5.9 \pm 5.5\ \text{MeV} \\
f_{B_d} &= 211.8 \pm 6.3 \pm 5.5\ \text{MeV} \\
f_{B_s}/f_{B_d} &= 1.210 \pm 0.014 \pm 0.015
\end{aligned}
$$

- first error: statistics+discretization errors; second error: other systematics.
- slightly more than 1 (old) sigma increase in dimensionful numbers: half from scale change; rest from improved heavy quark tuning, chiral fits, statistics, & treatment of discretization errors.
- still preliminary; paper expected in summer.

Fermilab/MILC Results

$$f_{D_s} = 261.4 \pm 7.7 \pm 5.0 \text{ MeV}$$

$$f_{D^+} = 220.3 \pm 8.0 \pm 4.8 \text{ MeV}$$

$$f_{D_s}/f_{D^+} = 1.187 \pm 0.013 \pm 0.015$$

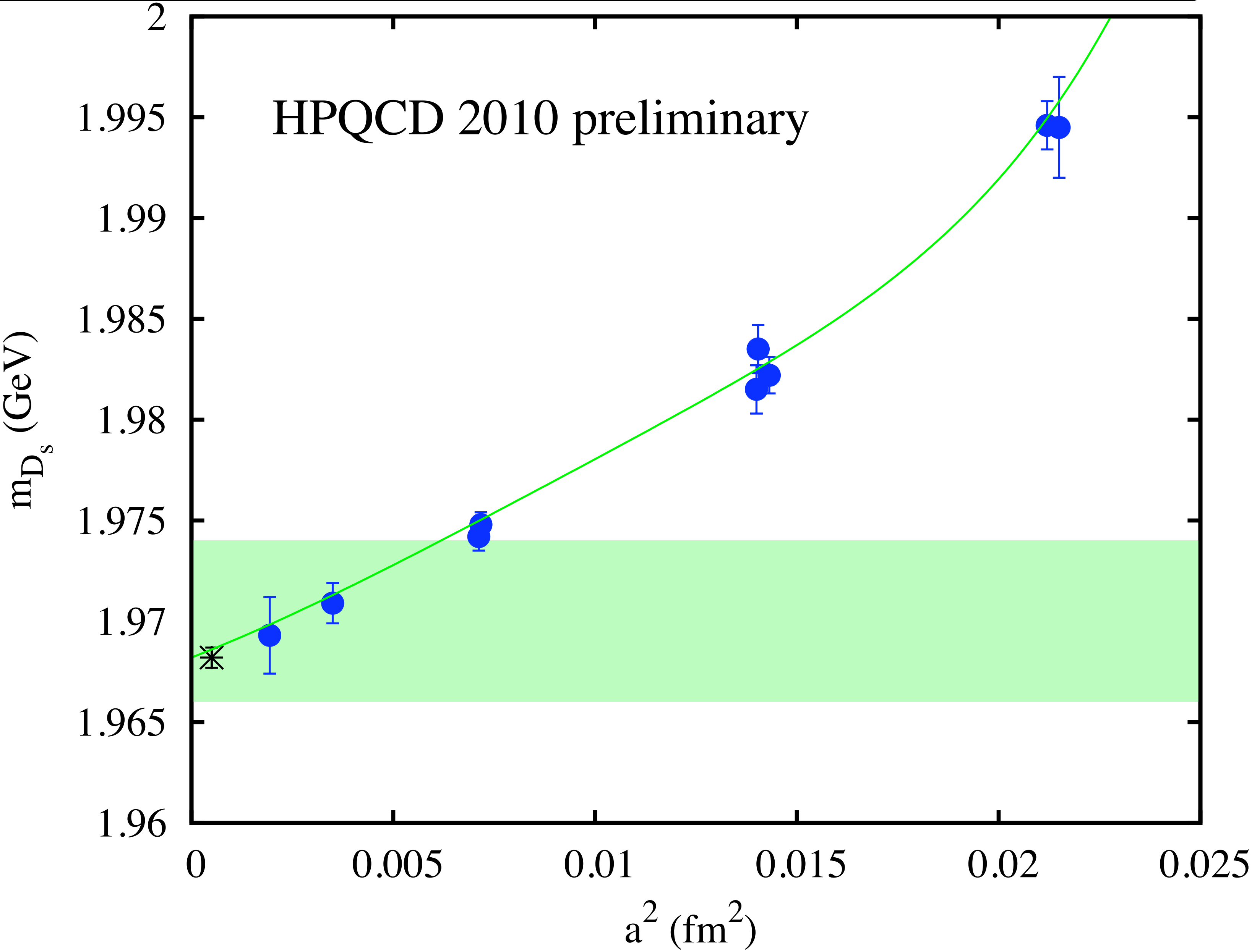
$$f_{B_s} = 256.3 \pm 5.9 \pm 5.5 \text{ MeV}$$

$$f_{B_d} = 211.8 \pm 6.3 \pm 5.5 \text{ MeV}$$

$$f_{B_s}/f_{B_d} = 1.210 \pm 0.014 \pm 0.015$$

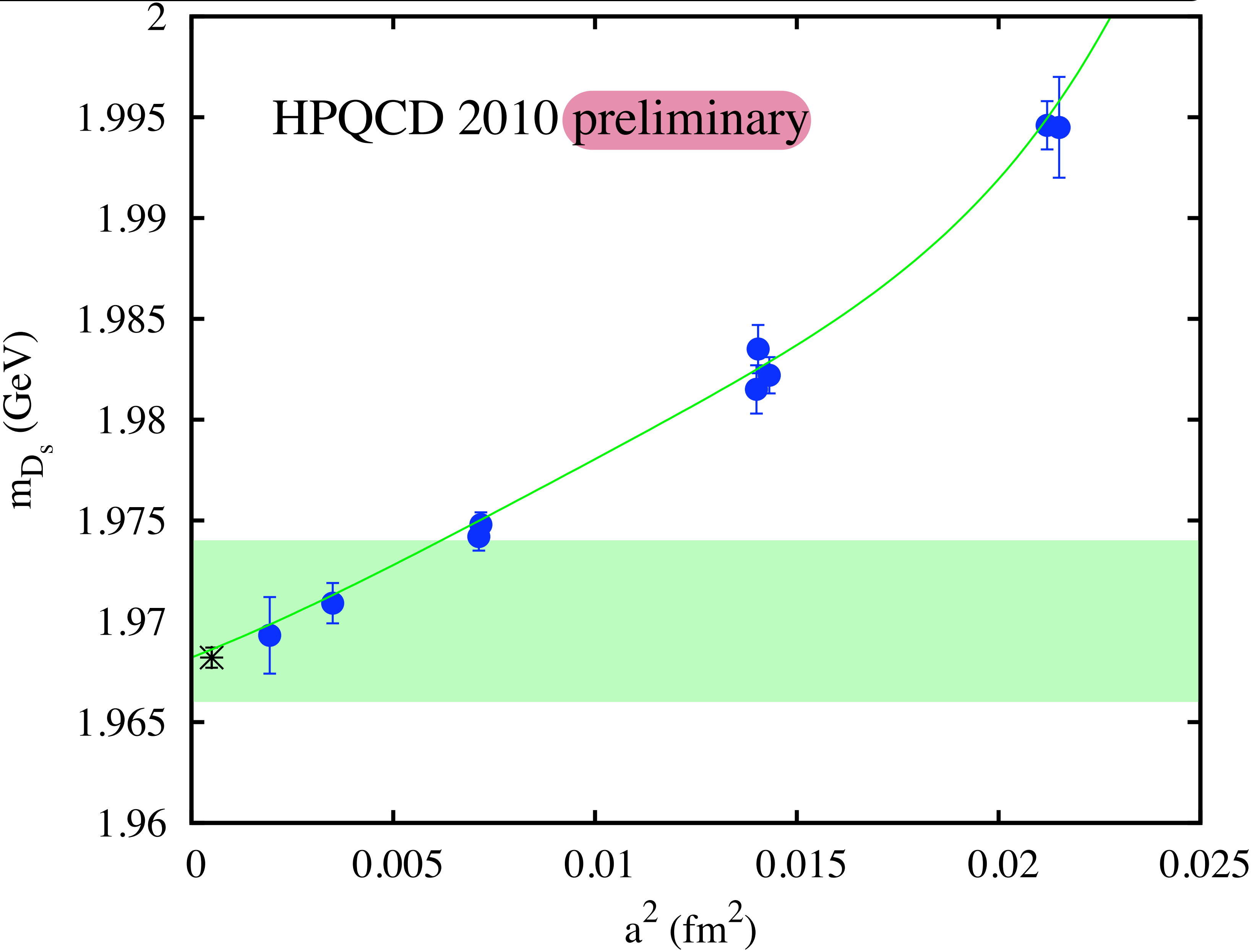
- first error: statistics+discretization errors; second error: other systematics.
- slightly more than 1 (old) sigma increase in dimensionful numbers: half from scale change; rest from improved heavy quark tuning, chiral fits, statistics, & treatment of discretization errors.
- still preliminary; paper expected in summer.

HPQCD: m_{Ds}



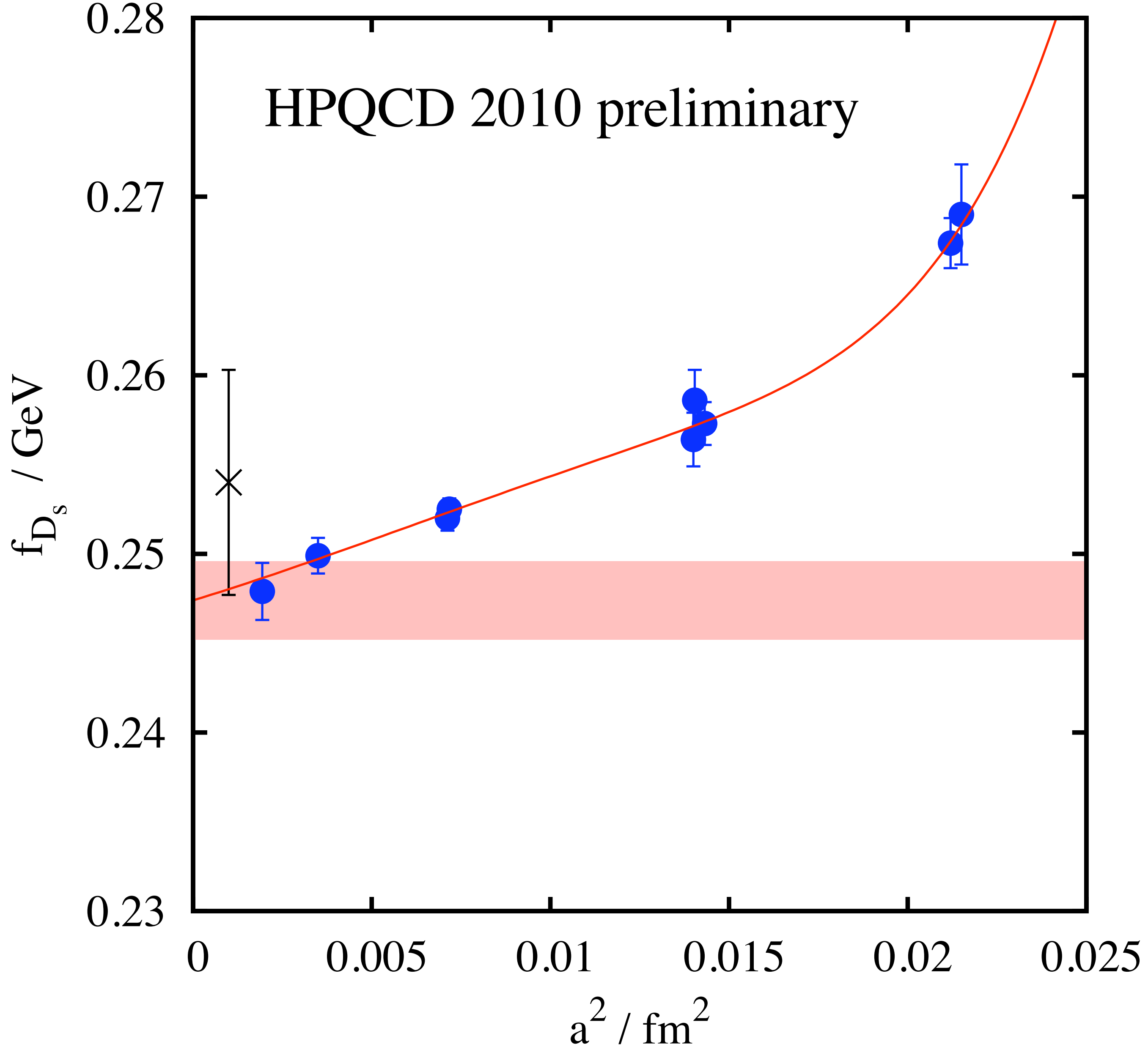
HPQCD 2010 preliminary
2
1.995
1.99
1.985
1.98
1.975
1.97
1.965
1.96
0
0.005
0.01
0.015
0.02
0.025
m_{D_s} (GeV)
a^2 (fm^2)

HPQCD: m_{Ds}

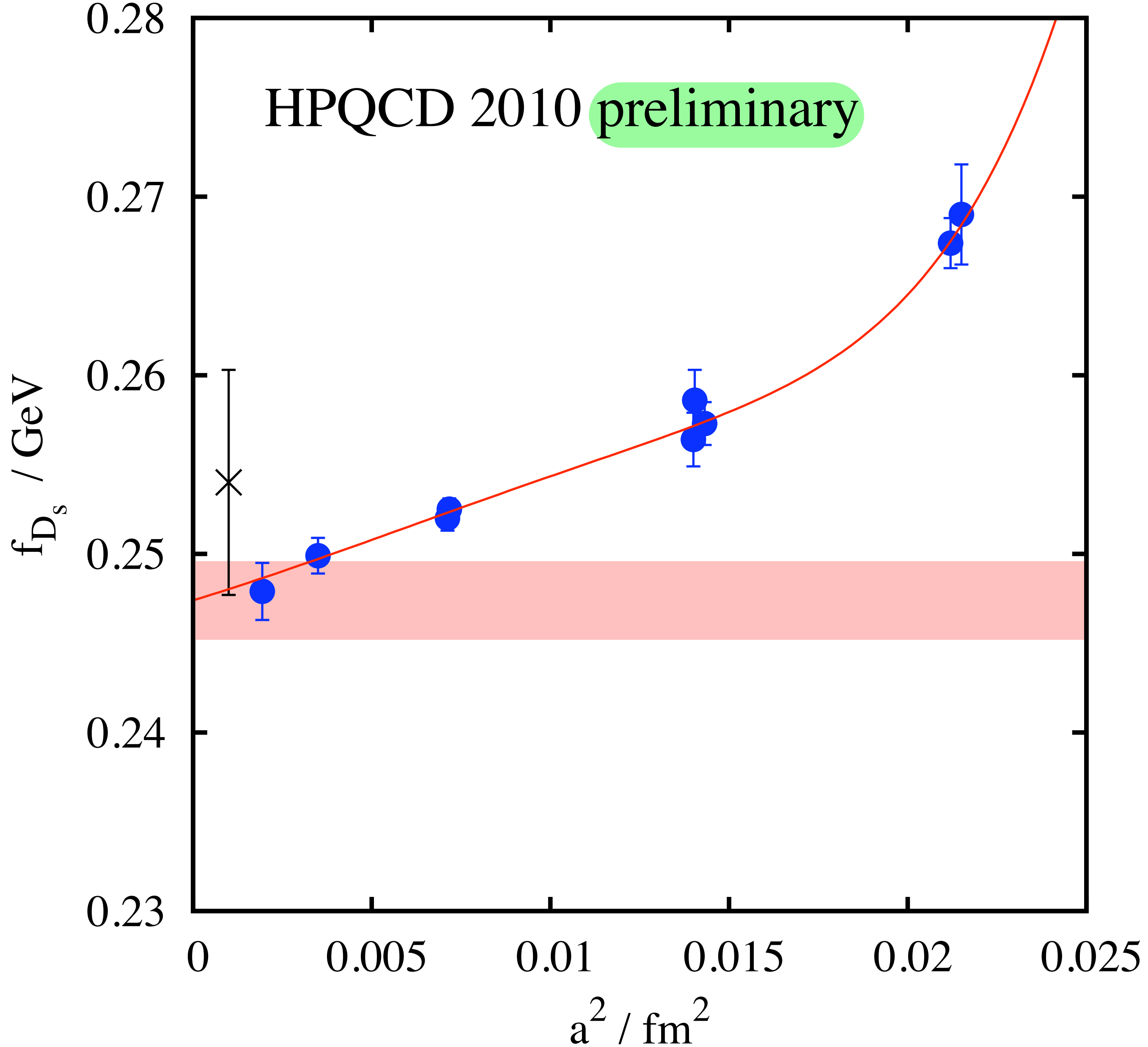


HPQCD 2010 preliminary
2
1.995
1.99
1.985
1.98
1.975
1.97
1.965
1.96
0
0.005
0.01
0.015
0.02
0.025
m_{D_s} (GeV)
a^2 (fm^2)

HPQCD: f_{D_s}


HPQCD 2010 preliminary
0.28
0.27
0.26
0.25
0.24
0.23
0
0.005
0.01
0.015
0.02
0.025
f_{D_s} / GeV
a^2 / fm^2

HPQCD: f_{D_s}



HPQCD 2010 preliminary
0.28
0.27
0.26
0.25
0.24
0.23
f_{D_s} / GeV
0
0.005
0.01
0.015
0.02
0.025
a^2 / fm^2

HPQCD Results

2007:

$$f_{D_s} = 241 \pm 3 \text{ MeV}$$

$$f_D = 207 \pm 4 \text{ MeV}$$

$$f_{D_s}/f_D = 1.164 \pm 0.011$$

HPQCD Results

2007:

$$f_{D_s} = 241 \pm 3 \text{ MeV}$$

$$f_D = 207 \pm 4 \text{ MeV}$$

$$f_{D_s}/f_D = 1.164 \pm 0.011$$

prelim. 2010:

$$f_{D_s} = 247 \pm 2 \text{ MeV}$$

HPQCD Results

2007:

$$f_{D_s} = 241 \pm 3 \text{ MeV}$$

$$f_D = 207 \pm 4 \text{ MeV}$$

$$f_{D_s}/f_D = 1.164 \pm 0.011$$

prelim. 2010:

$$f_{D_s} = 247 \pm 2 \text{ MeV}$$

- Main change is from change of scale

HPQCD Results

2007:

$$f_{D_s} = 241 \pm 3 \text{ MeV}$$

$$f_D = 207 \pm 4 \text{ MeV}$$

$$f_{D_s}/f_D = 1.164 \pm 0.011$$

2009:

$$f_{B_s} = 240 \pm 16 \text{ MeV}$$

$$f_{B_d} = 197 \pm 14 \text{ MeV}$$

$$f_{B_s}/f_{B_d} = 1.226 \pm 0.026$$

prelim. 2010:

$$f_{D_s} = 247 \pm 2 \text{ MeV}$$

- Main change is from change of scale

HPQCD Results

2007:

$$f_{D_s} = 241 \pm 3 \text{ MeV}$$

$$f_D = 207 \pm 4 \text{ MeV}$$

$$f_{D_s}/f_D = 1.164 \pm 0.011$$

prelim. 2010:

$$f_{D_s} = 247 \pm 2 \text{ MeV}$$

- Main change is from change of scale

2009:

$$f_{B_s} = 240 \pm 16 \text{ MeV}$$

$$f_{B_d} = 197 \pm 14 \text{ MeV}$$

$$f_{B_s}/f_{B_d} = 1.226 \pm 0.026$$

- They showed scale dependence explicitly --- I have put in their new scale.

ETMC Results

from 2009:

$$f_{D_s} = 244 \pm 8 \text{ MeV}$$

$$f_D = 197 \pm 9 \text{ MeV}$$

$$f_{D_s}/f_D = 1.24 \pm 0.011$$

prelim. 2009:

$$f_{B_s} = 243 \pm 14 \text{ MeV}$$

$$f_{B_d} = 191 \pm 14 \text{ MeV}$$

$$f_{B_s}/f_{B_d} = 1.27 \pm 0.05$$

ETMC Results

from 2009:

$$f_{D_s} = 244 \pm 8 \text{ MeV}$$

$$f_D = 197 \pm 9 \text{ MeV}$$

$$f_{D_s}/f_D = 1.24 \pm 0.011$$

prelim. 2009:

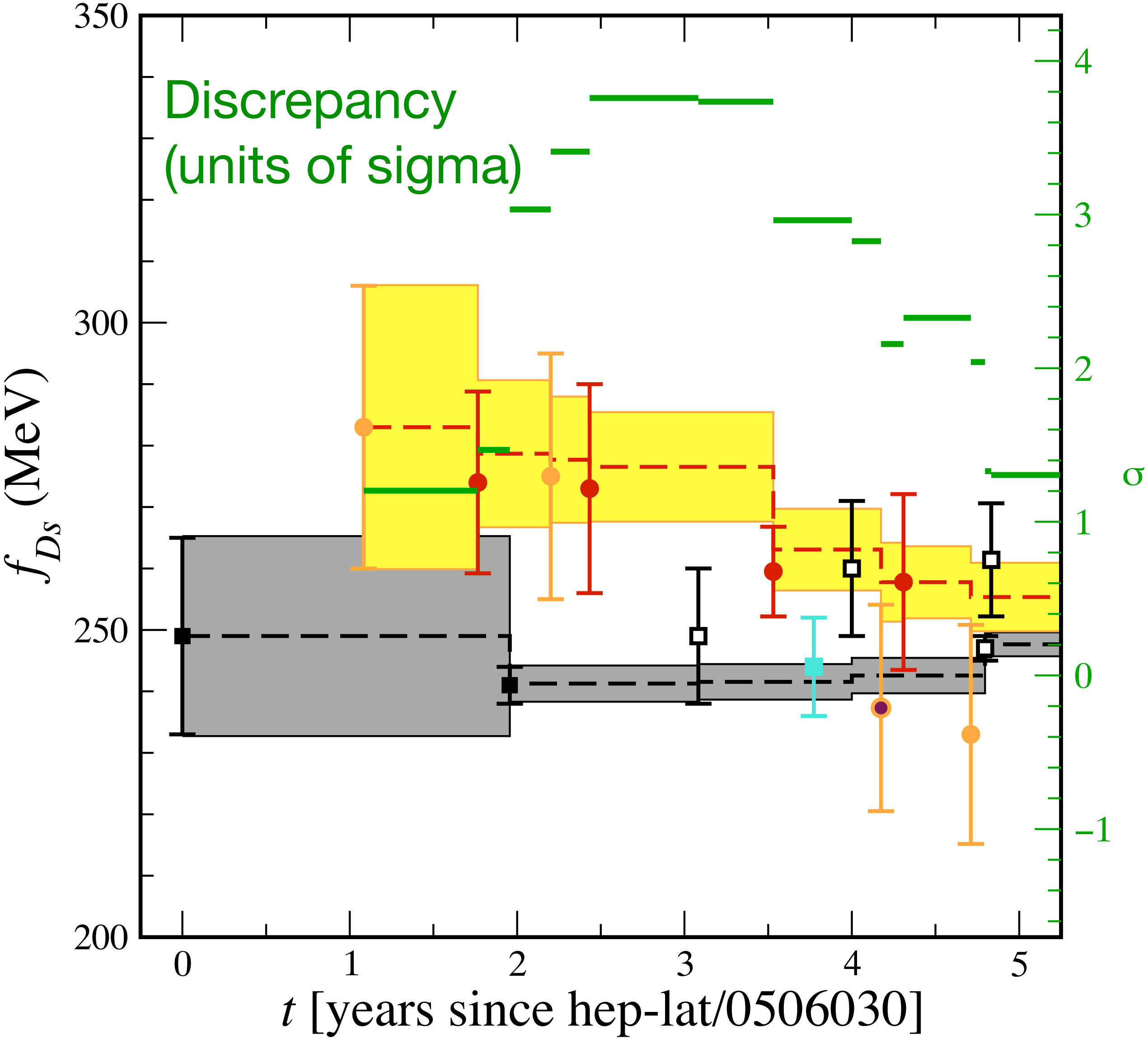
$$f_{B_s} = 243 \pm 14 \text{ MeV}$$

$$f_{B_d} = 191 \pm 14 \text{ MeV}$$

$$f_{B_s}/f_{B_d} = 1.27 \pm 0.05$$

- Two flavors of sea quarks!

f_{D_s} Saga

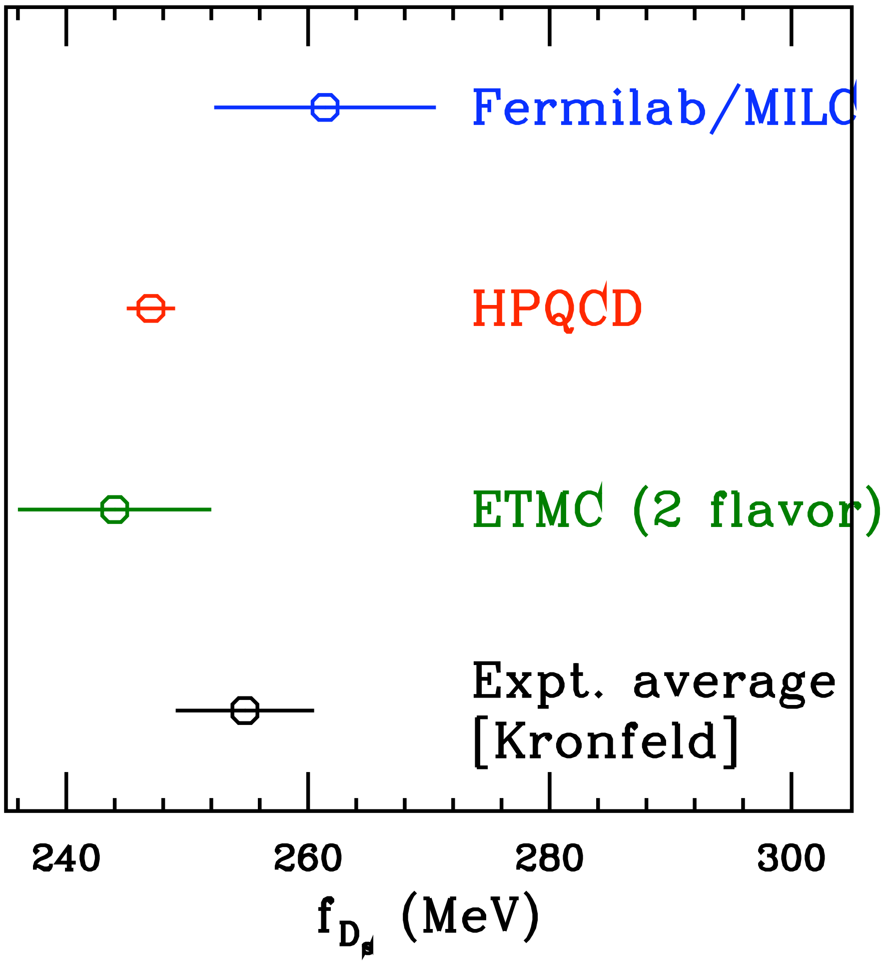


- **Yellow:** expt. average
- **Gray:** lattice average
- Circles: expts.:
  - orange: $\Upsilon(4S)$
  - red: $D_s^{(*)} D_s^{(*)}$ threshold
- Squares: lattice
  - filled: published
  - open: prelim or conference proc.
  - cyan: 2 flavors

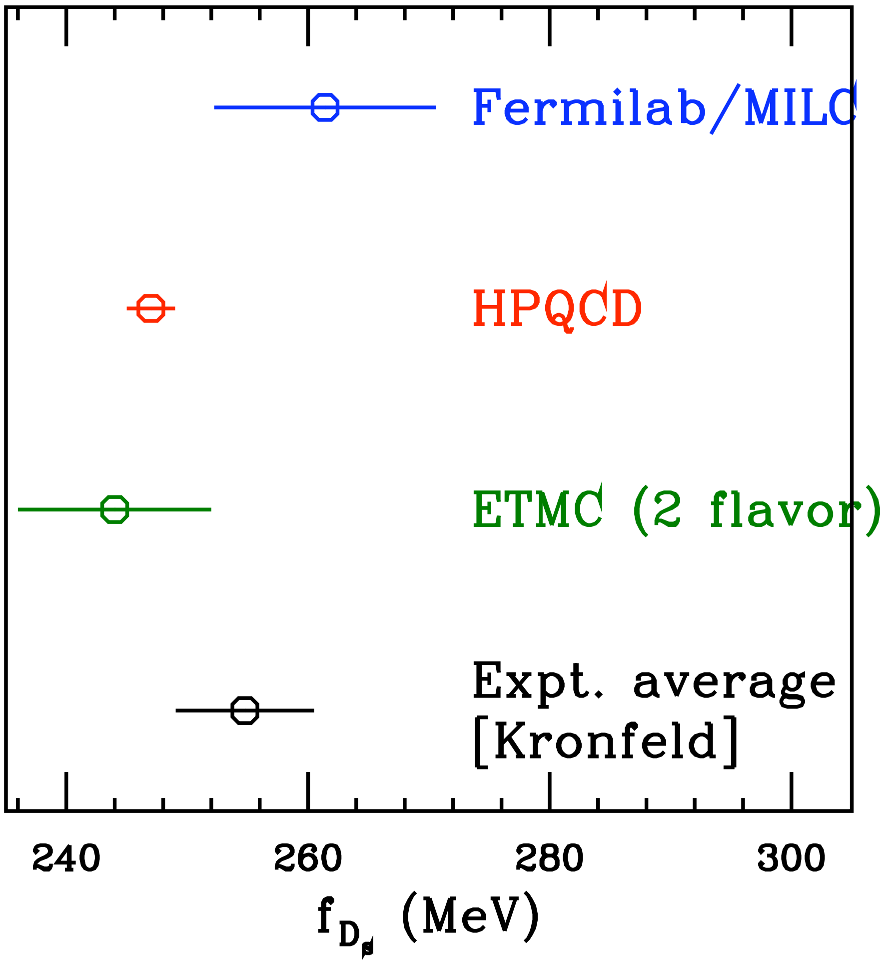
from Kronfeld, arXiv:0912.0543, & his updates.

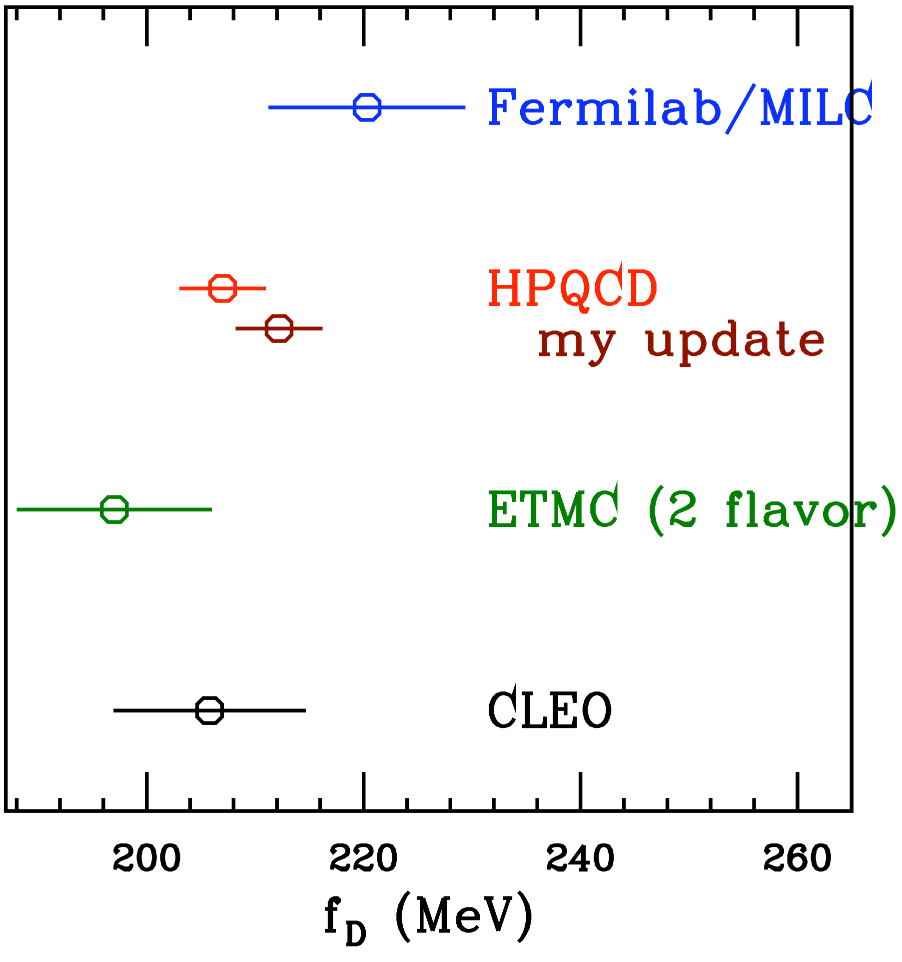
Comparison: D system

Comparison: D system



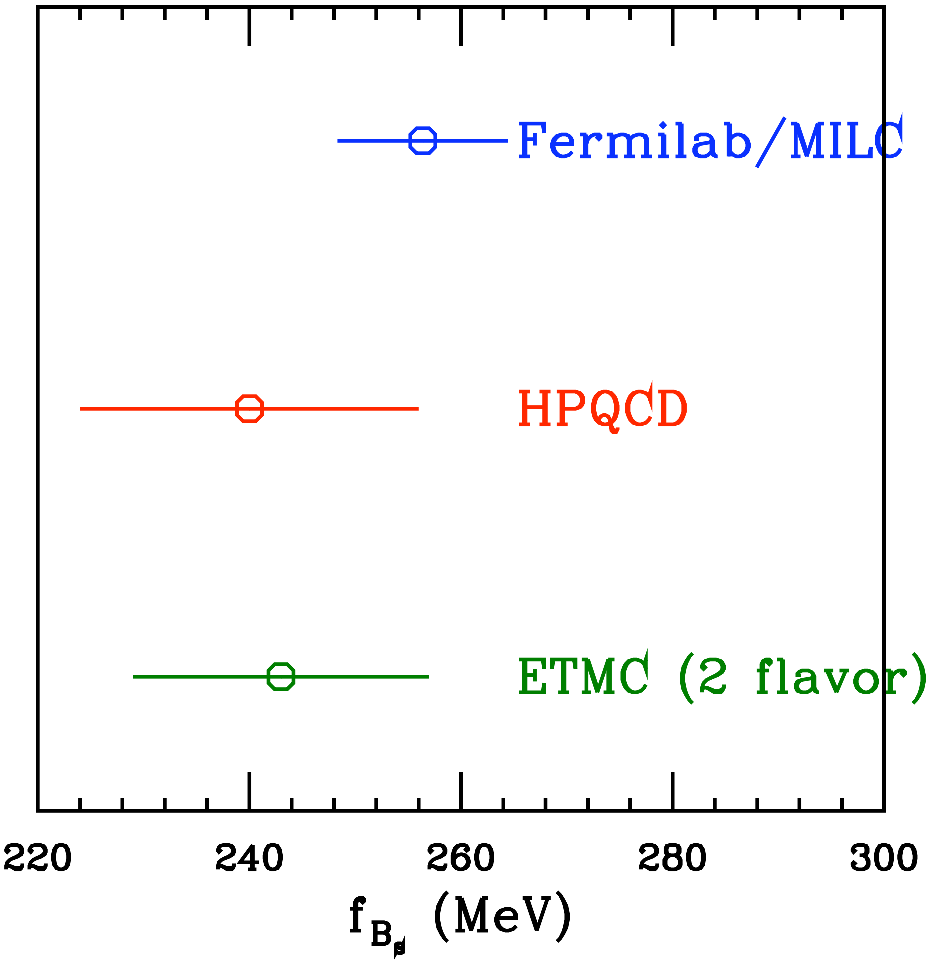
Comparison: D system



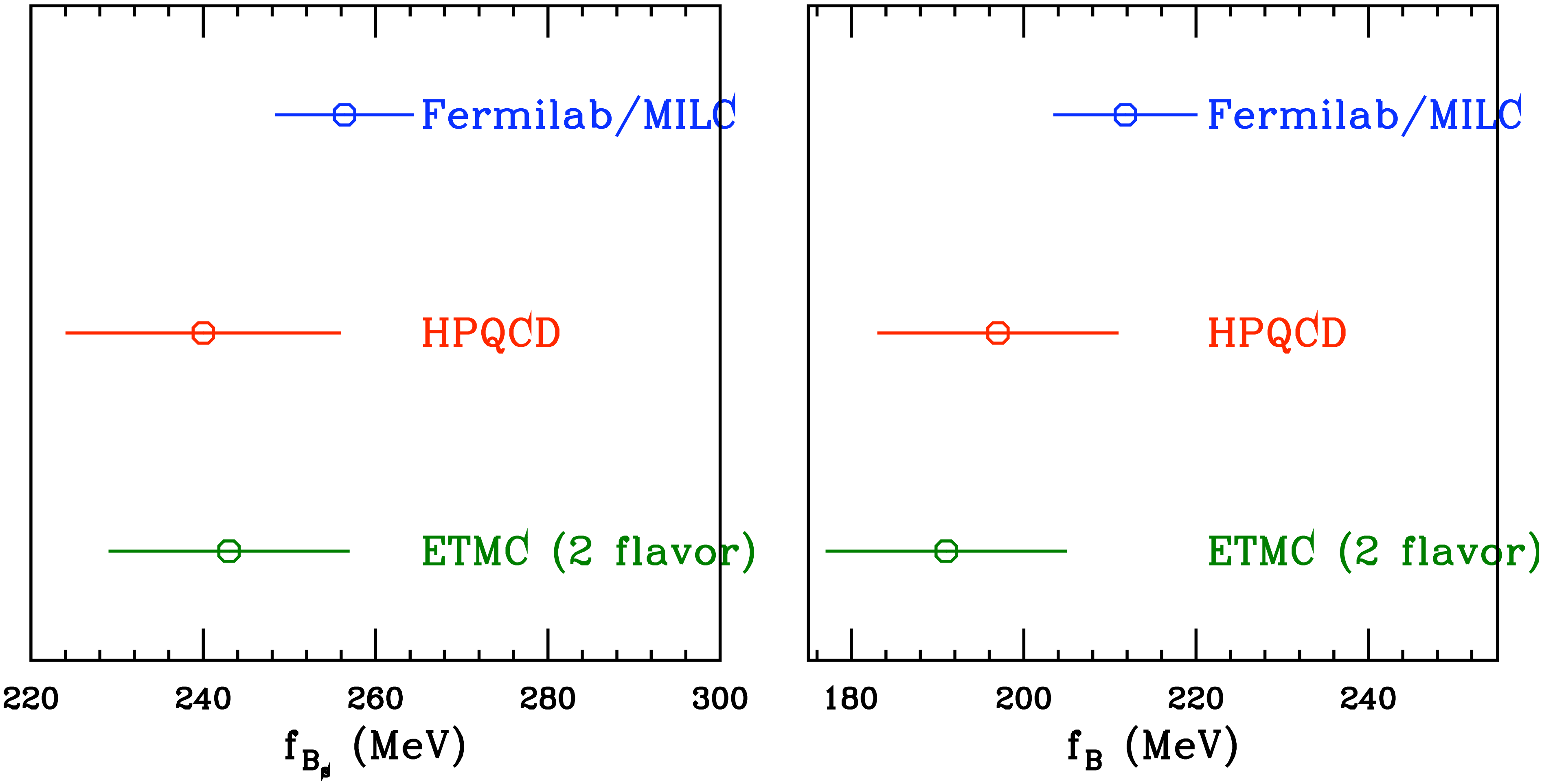


Comparison: B system

Comparison: B system



Comparison: B system



Outlook: Fermilab/MILC

Outlook: Fermilab/MILC

	% Errors		
Quantity	Now	~1 year	~3-5 yrs.
f_{D_s}	3.5	1.8	0.6
f_D	4.3	2.2	0.7
f_{D_s}/f_D	1.7	0.9	0.2

Outlook: Fermilab/MILC

	% Errors		
Quantity	Now	~1 year	~3-5 yrs.
f_{D_s}	3.5	1.8	0.6
f_D	4.3	2.2	0.7
f_{D_s}/f_D	1.7	0.9	0.2

HISQ valence & sea

Outlook: Fermilab/MILC

	% Errors		
Quantity	Now	~1 year	~3-5 yrs.
f_{D_s}	3.5	1.8	0.6
f_D	4.3	2.2	0.7
f_{D_s}/f_D	1.7	0.9	0.2
f_{B_s}	3.1	1.7	0.9
f_B	4.0	2.0	1.0
f_{B_s}/f_B	1.8	0.9	0.3

HISQ valence & sea

Outlook: Fermilab/MILC

	% Errors		
Quantity	Now	~1 year	~3-5 yrs.
f_{D_s}	3.5	1.8	0.6
f_D	4.3	2.2	0.7
f_{D_s}/f_D	1.7	0.9	0.2
f_{B_s}	3.1	1.7	0.9
f_B	4.0	2.0	1.0
f_{B_s}/f_B	1.8	0.9	0.3

HISQ valence & sea

Fermilab valence b; HISQ sea & light valence

Outlook: Fermilab/MILC

	% Errors		
Quantity	Now	~1 year	~3-5 yrs.
f_{D_s}	3.5	1.8	0.6
f_D	4.3	2.2	0.7
f_{D_s}/f_D	1.7	0.9	0.2
f_{B_s}	3.1	1.7	0.9
f_B	4.0	2.0	1.0
f_{B_s}/f_B	1.8	0.9	0.3

HISQ valence & sea

Fermilab valence b; HISQ sea & light valence

- May do better for B with HISQ valence & extrapolation (HPQCD)

Outlook: Fermilab/MILC

	% Errors		
Quantity	Now	~1 year	~3-5 yrs.
f_{D_s}	3.5	1.8	0.6
f_D	4.3	2.2	0.7
f_{D_s}/f_D	1.7	0.9	0.2
f_{B_s}	3.1	1.7	0.9
f_B	4.0	2.0	1.0
f_{B_s}/f_B	1.8	0.9	0.3

HISQ valence & sea (f_{D_s}, f_D, f_{D_s}/f_D at ~3-5 yrs.)

Fermilab valence b; HISQ sea & light valence (f_{B_s}, f_B, f_{B_s}/f_B at ~3-5 yrs.)

- May do better for B with HISQ valence & extrapolation (HPQCD)
- Or doing f_{B_s}/f_{D_s} with Fermilab heavy quark + HISQ f_{D_s}

Fermilab Lattice/MILC Collaboration

J. Bailey	Fermilab
A. Bazavov	U. of Arizona
C. Bernard	Washington U.
C. DeTar	U. of Utah
M. Di Pierro	De Paul
A.X. El-Khadra	U. of Illinois
E.D. Freeland	Washington U.
E. Gamiz	Fermilab
S. Gottlieb	U. of Indiana
U.M. Heller	APS
J.E. Hetrick	U. of the Pacific
A.S. Kronfeld	Fermilab
J. Laiho	U. of Glasgow
L. Levkova	U. of Utah
P.B. Mackenzie	Fermilab
M.B. Oktay	U. of Utah
J. Simone	Fermilab
R. Sugar	U.C. Santa Barbara
D. Toussaint	U. of Arizona
R.S. Van de Water	BNL