B meson decay constants from FNAL, NRQCD, and HISQ action

Heechang Na
University of Utah

CKM 2014 at Vienna University of Technology, Vienna, Austria

Sep-8-2014

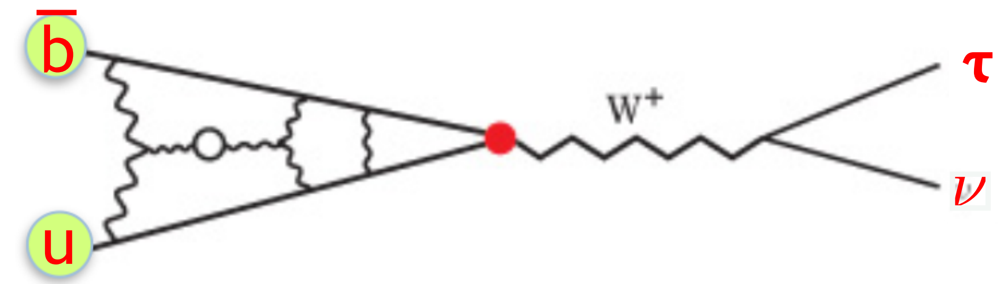
Outline

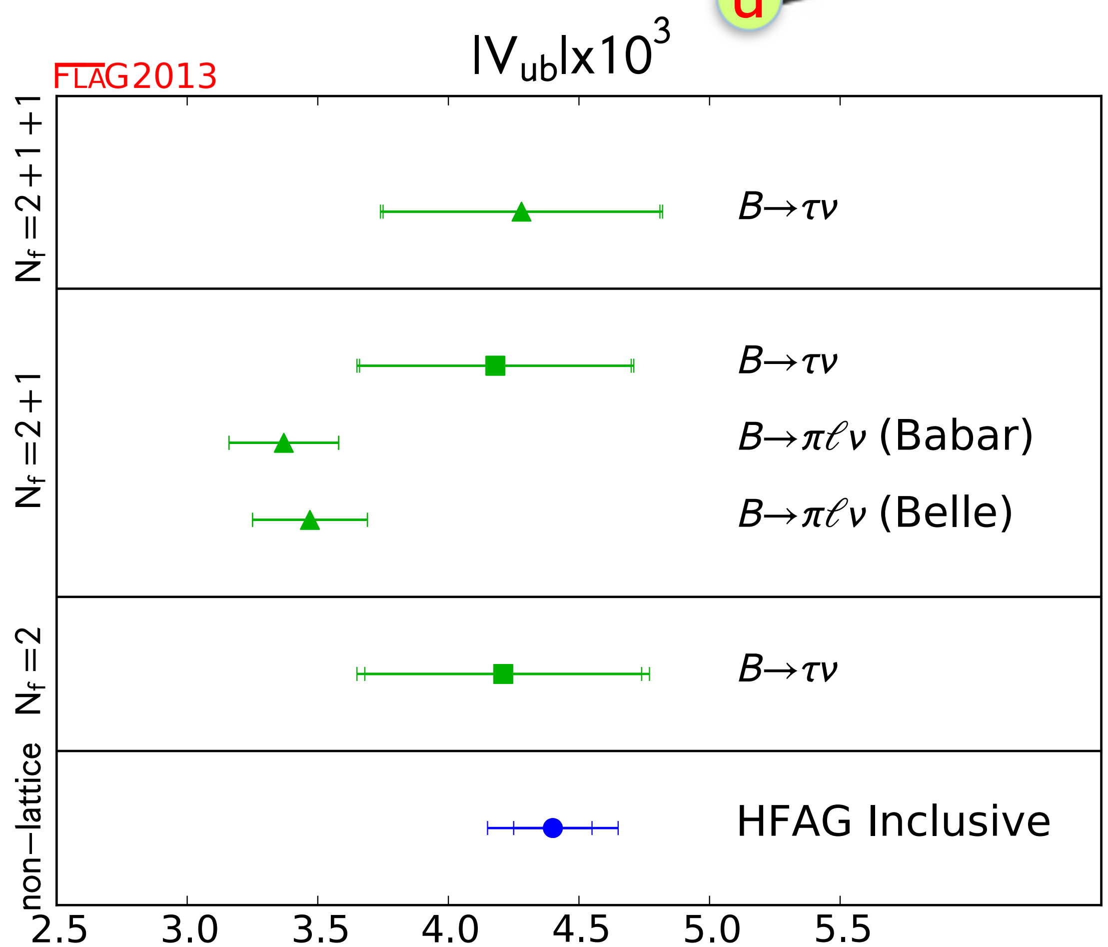
- **Introduction**
  - f_B and f_{Bs} in the Standard Model and searching New Physics
  - B meson decay constants in lattice QCD
- **Lattice methods for heavy quarks**
  - FNAL, HISQ, and NRQCD action
  - Important ingredients
- **Calculations from HPQCD**
  - Heavy HISQ method
  - NRQCD: ratio method
  - NRQCD: 2+1+1 MILC lattice + physical pion mass
- **Calculations from Fermilab/MILC**
  - FNAL method
  - Future plan
- **Summary**

Introduction

- Leptonic decay of B meson
  - V_{ub}: B → l ν

$$\Gamma \propto |V_{ub}|^2 f_B^2$$

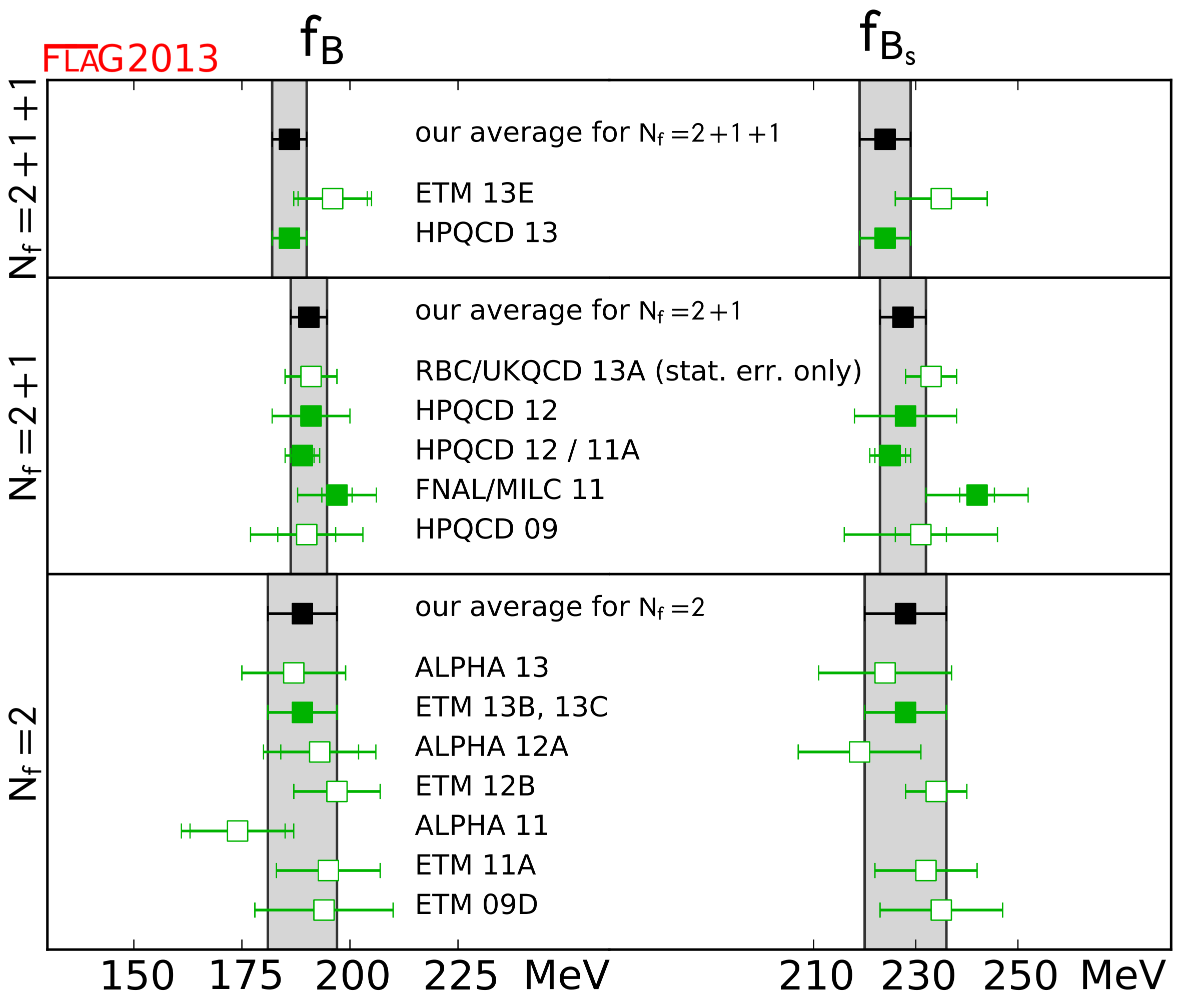


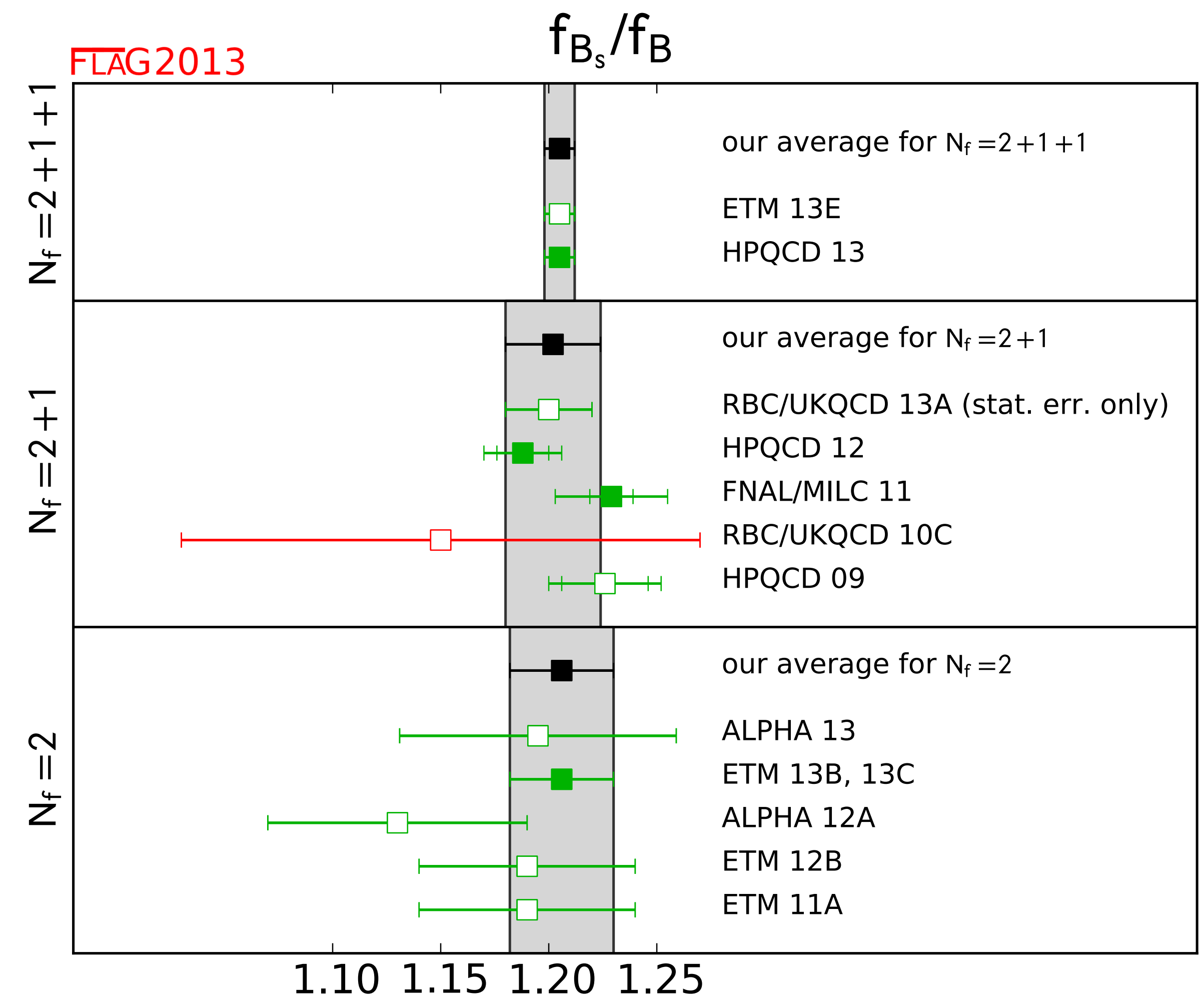


- f_{Bs}: no B_s → l ν leptonic decays in tree level
  - However, one can define the matrix elements, and it is useful.
  - Br($B_s \to \mu^+\mu^-$) in the Standard Model
    - Around 30% of the total errors came from f_{Bs}

Introduction

- B meson decay constants have been calculated from lattice QCD extensively.

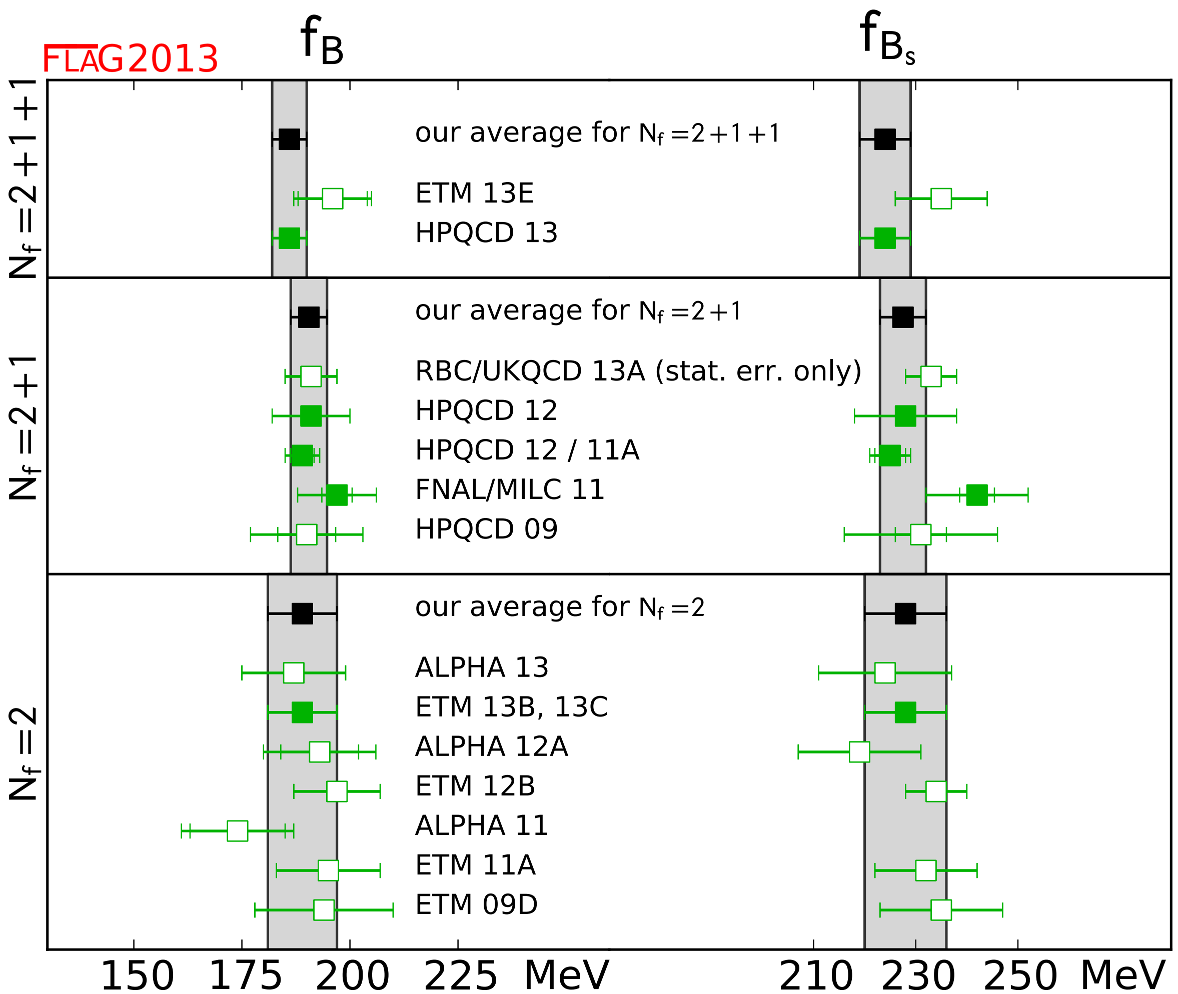


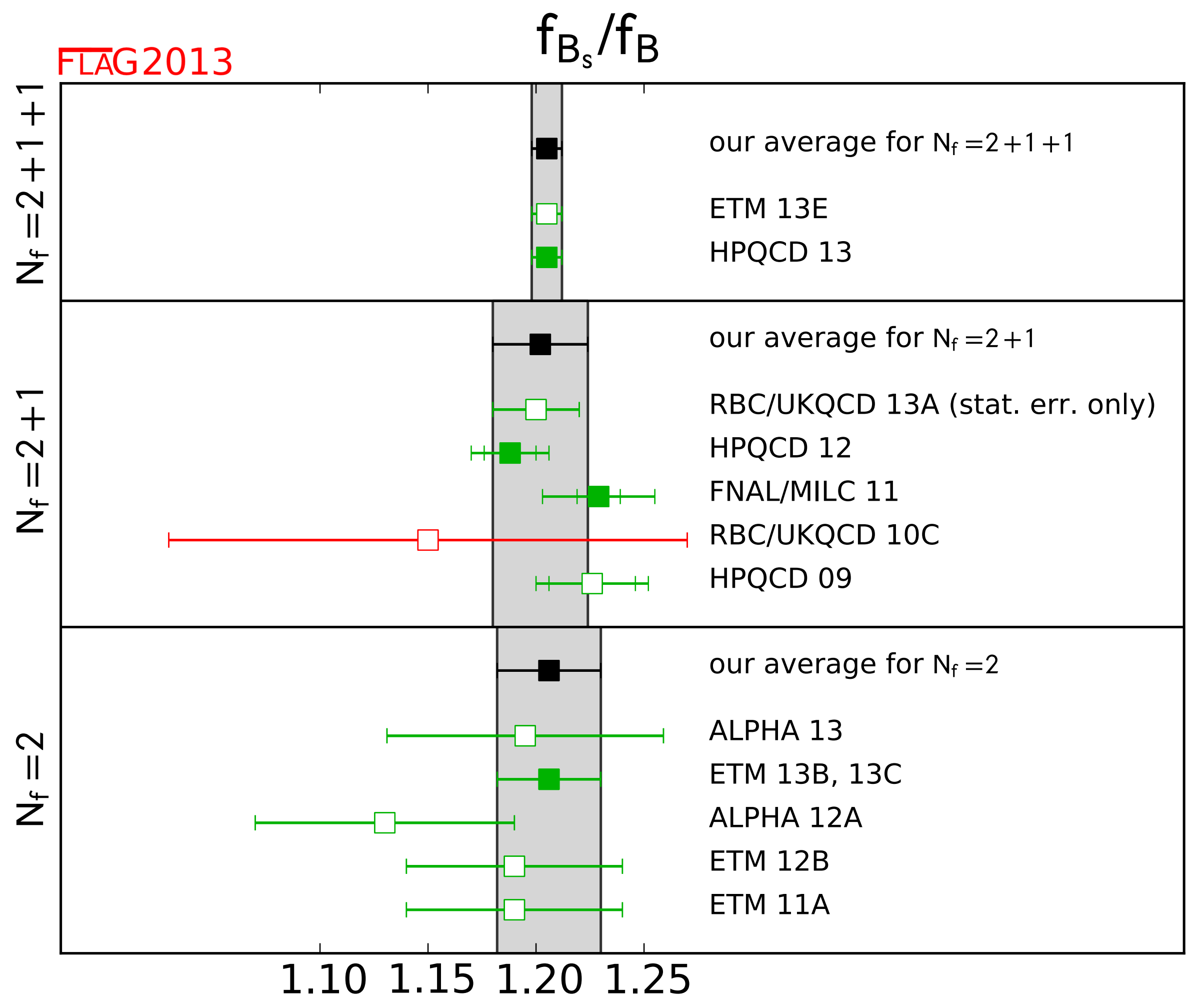


- FLAG: Flavor Lattice Averaging Group
  - Aoki et al., 1310.8555

Introduction

- B meson decay constants have been calculated from lattice QCD extensively.





- I will focus on the solid green squares on N_f=2+1 and 2+1+1
  - MILC gauge configurations using staggered fermion actions:
    - HPQCD and Fermilab/MILC
- Note that there are many new calculations reported at Lattice 2014.
  - RBC/UKQCD, Ishikawa et al., ALPHA, and ETM

Lattice methods for heavy quarks

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

- **NRQCD**
  - Theoretically well known, easy to tune the quark mass
  - Large operator matching errors
- **Heavy HISQ** for bottom (**HTC**: Heavier Than Charm)
  - **HISQ** (Highly Improved Staggered Quark)
    - 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, one can treat charm quarks as other u,d, and s quarks
    - No operator matching needed, easy to tune the quark mass
  - For coarse lattice (a~0.15fm), am_c ~ 0.85: it worked great! (a~0.09fm, am_c~0.6)
  - Simulate heavy HISQ quark: lighter than bottom, up to am_h = 0.85
  - Extrapolate to the bottom quark mass using HQET
- **Fermilab interpretation**
  - Clover Wilson action with Fermilab interpretation
  - Correct continuum and heavy quark limit
  - Systematically improvable in arbitrarily high orders of $1/m_Q$

Lattice methods for heavy quarks

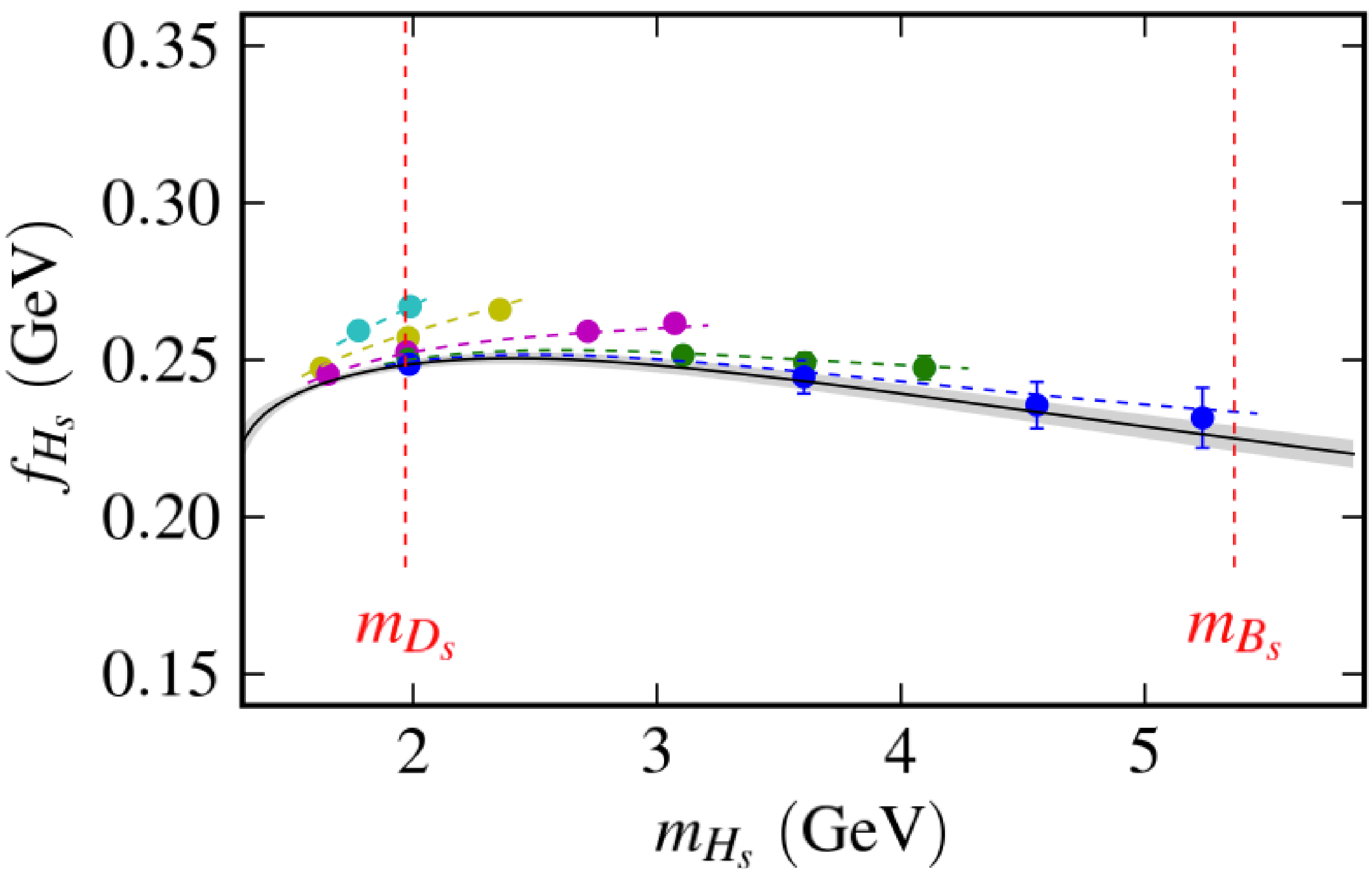
- **Important ingredients**
  - Light quark mass
    - Chiral extrapolation → Chiral interpolation
  - Smaller lattice spacings
    - 0.03 fm lattice
  - Statistics
  - Heavy quark discritization errors
  - Matching
    - The current renormalization
  - Electromagnetic effects and isospin breaking
- **Resources**
  - MILC N_f=2+1 asqtad gauge configurations
  - MILC N_f=2+1+1 HISQ gauge configurations with physical pion mass

Calculations from HPQCD

- **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
- HISQ fermion action for the strange and heavy valence quarks
- 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)

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

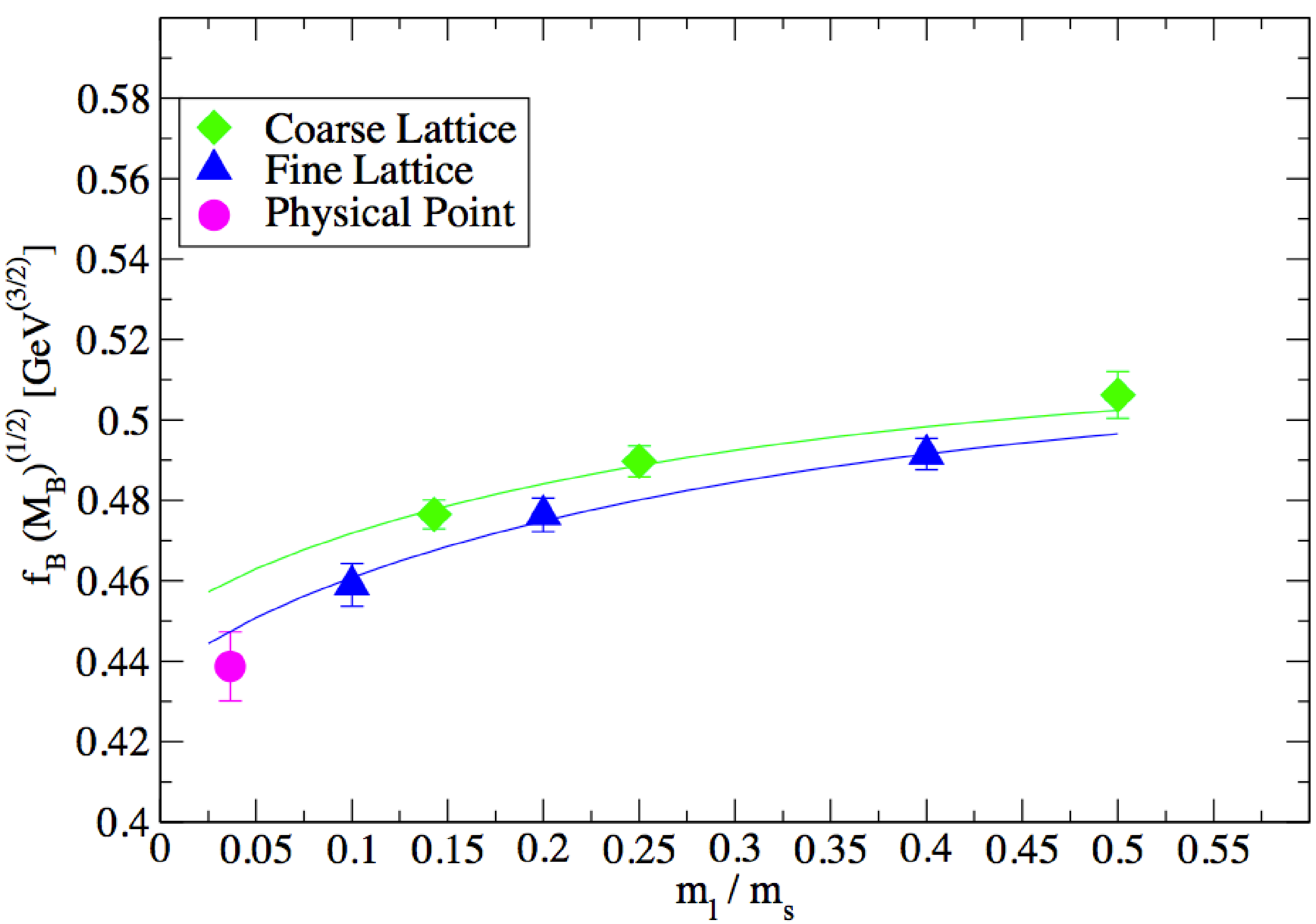
$$C_i(a) = \sum_{j,k,l=0}^{N_a-1} c_{ijkl}\left(\frac{am_h}{\pi}\right)^{2j}\left(\frac{am_s}{\pi}\right)^{2k}\left(\frac{a\Lambda_{QCD}}{\pi}\right)^{2l}$$

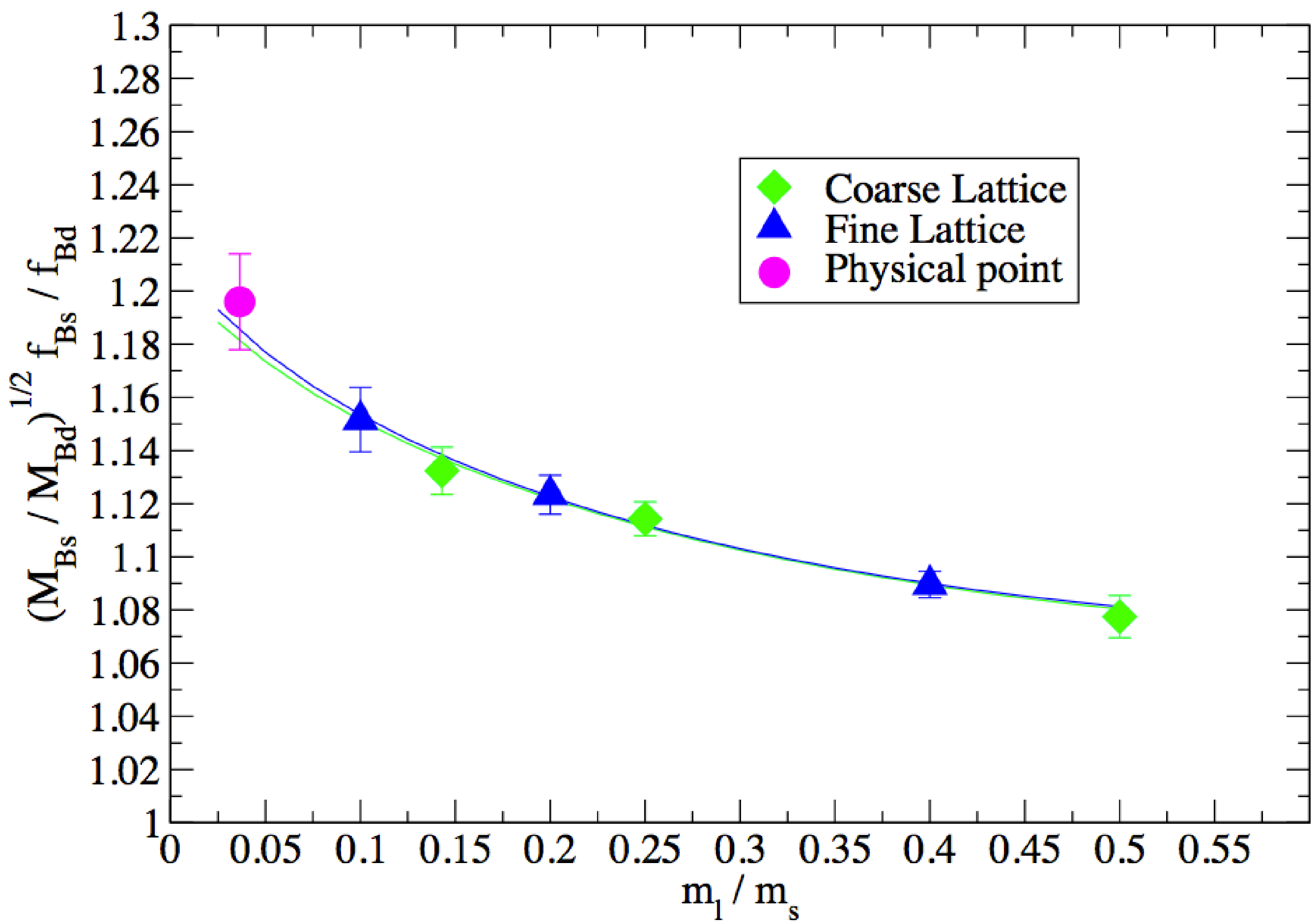
Calculations from HPQCD

- **f_{Bs}/f_B from NRQCD**

HN et al. (HPQCD)
PRD 86 (2012) 034506

- 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



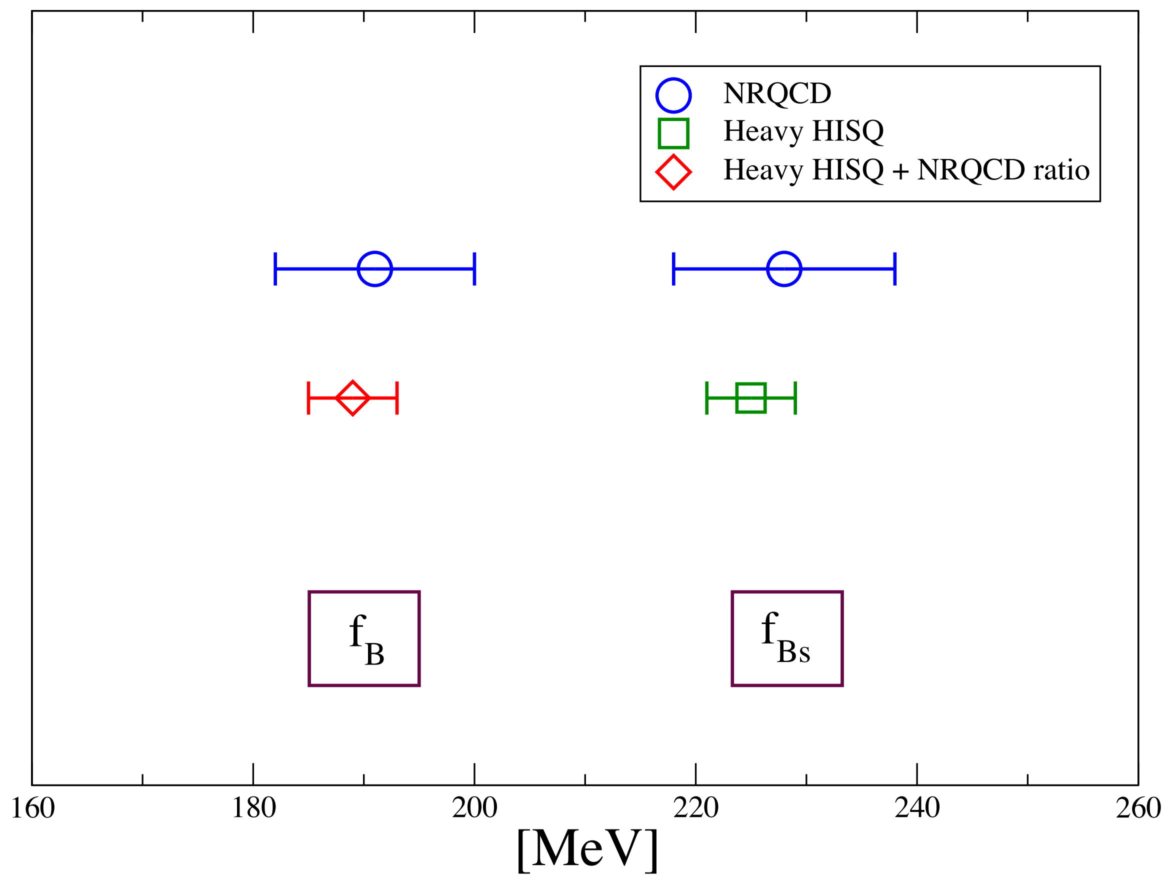


- f_B = 191(9) MeV, f_{Bs} = 228(10) MeV, and f_{Bs}/f_B = 1.188(18)

Calculations from HPQCD

HN et al. (HPQCD)
PRD 86 (2012) 034506

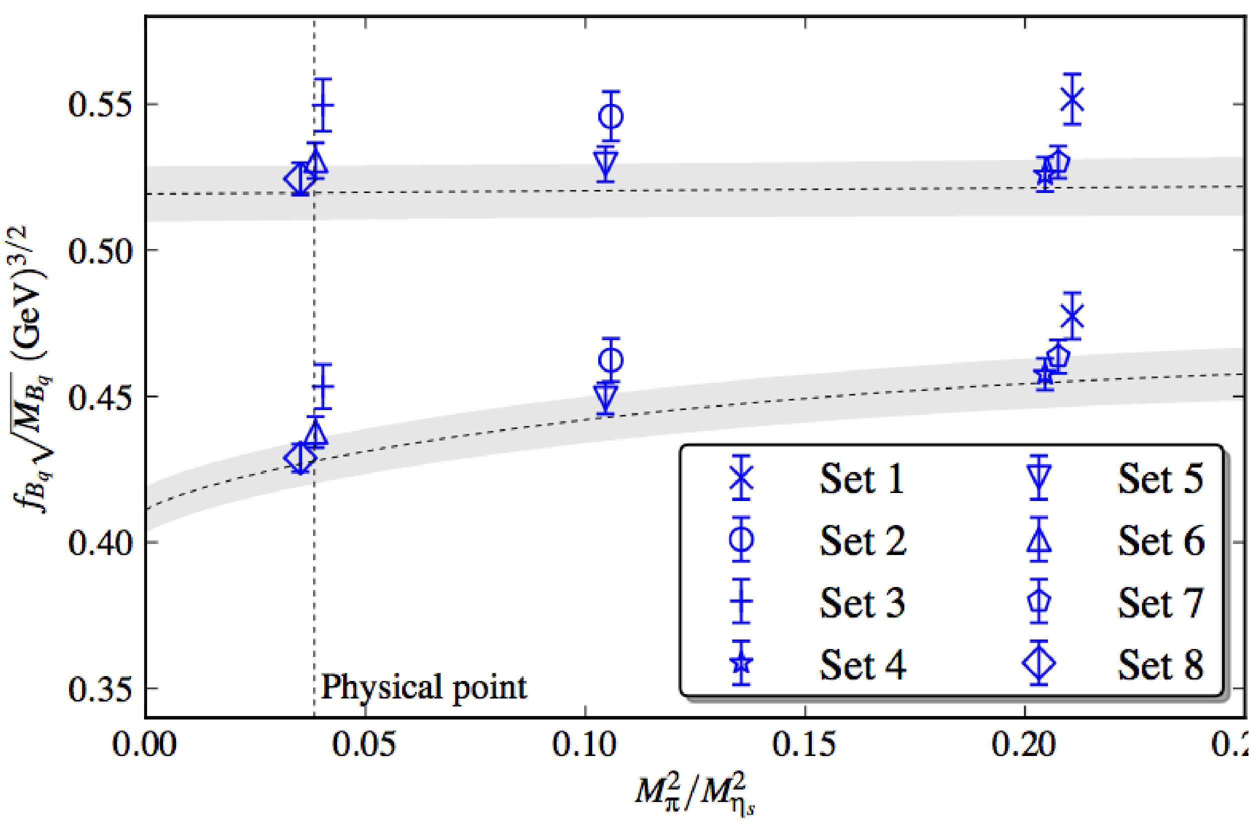
- **f_B from the NRQCD + Heavy HISQ method**
  - Very accurate f_{Bs}/f_B from the NRQCD method
    - $f_{Bs}/f_B = 1.188(18)$
  - And, f_{Bs} from the Heavy HISQ method.
    - f_{Bs}=225(4) MeV
  - f_B = 191(9) MeV : without the ratio, 5% error
  - → f_B = 189(4) MeV : 2.1% error

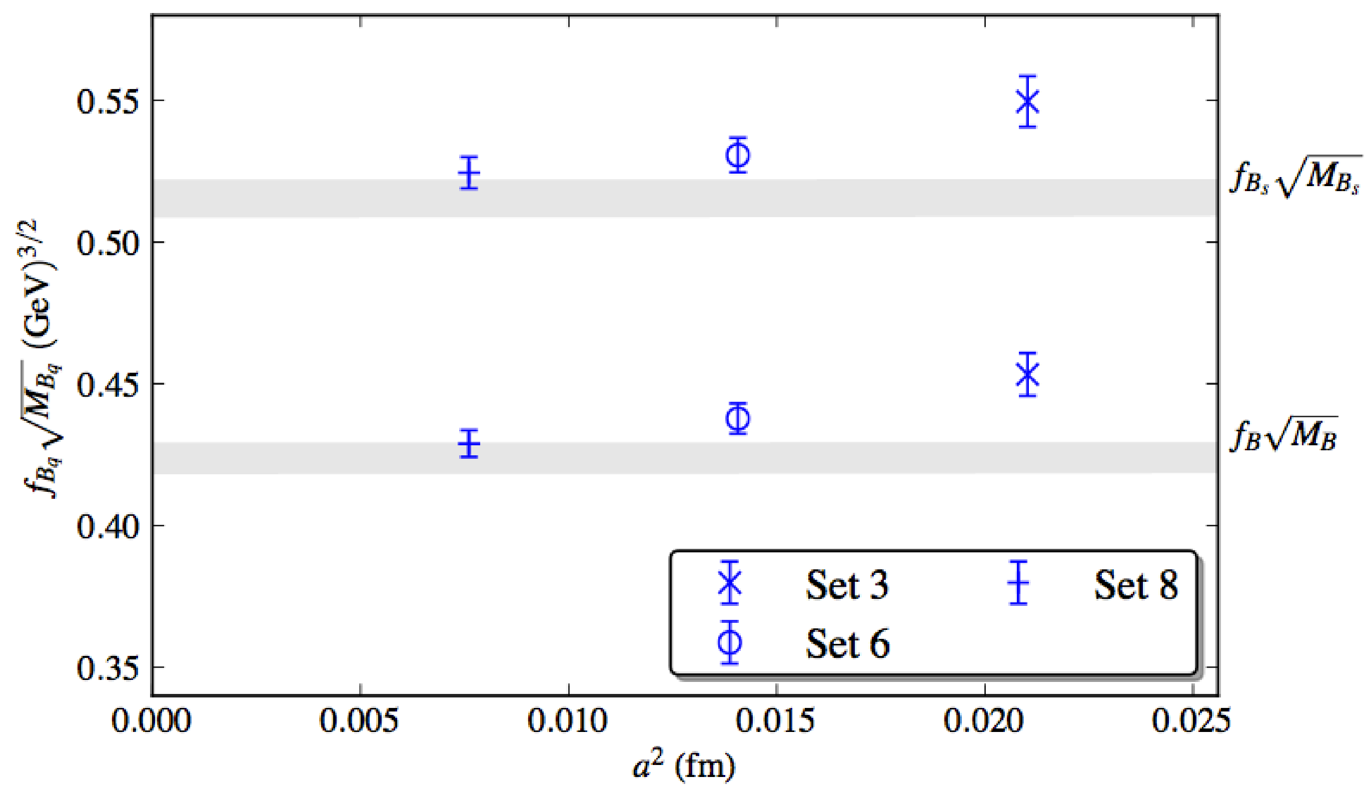


Calculations from HPQCD

R. Dowdall et al. (HPQCD)
PRL 110 (2013) 222003

- **NRQCD + N_f=2+1+1 + physical pion mass**
  - MILC N_f=2+1+1 gauge configurations
    - with physical pion mass → very small chiral “interpolation” errors
  - O(v^4) Improved NRQCD
  - Matching errors: 4% → 1.2%



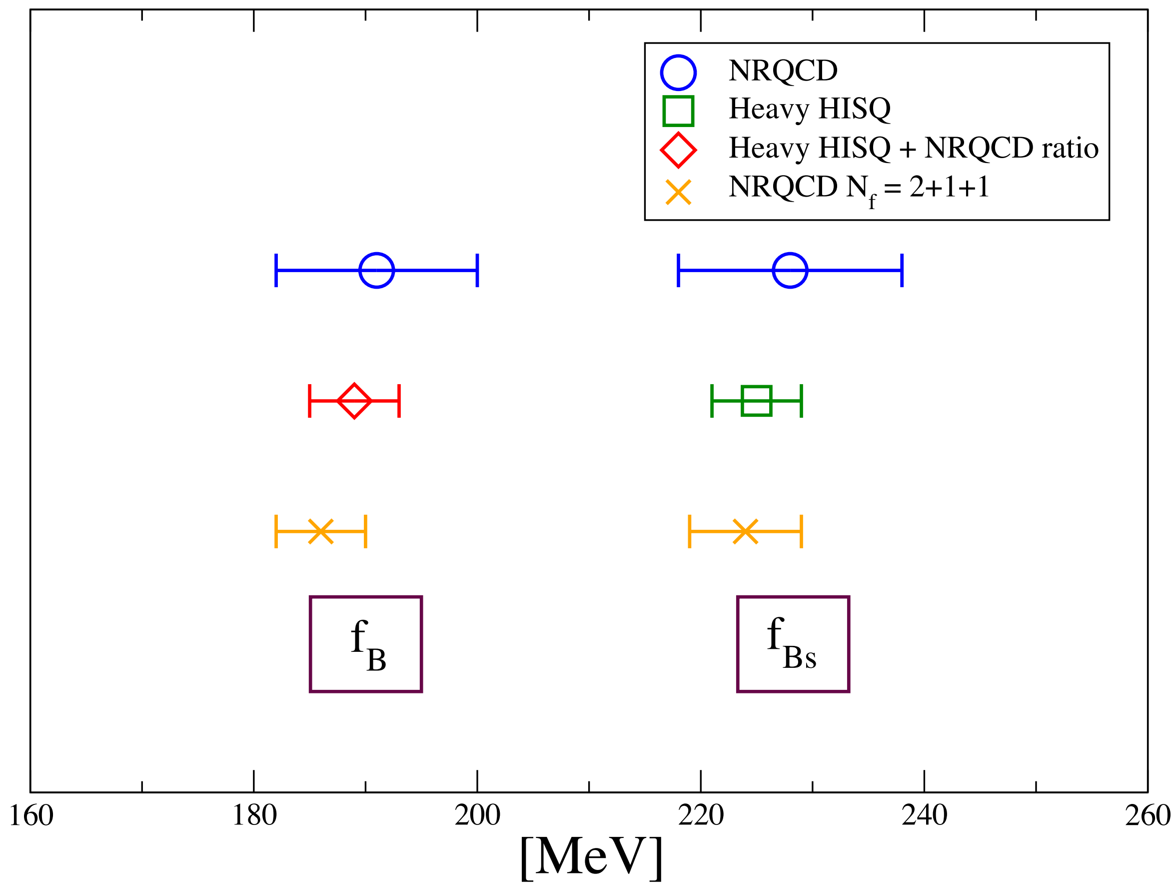


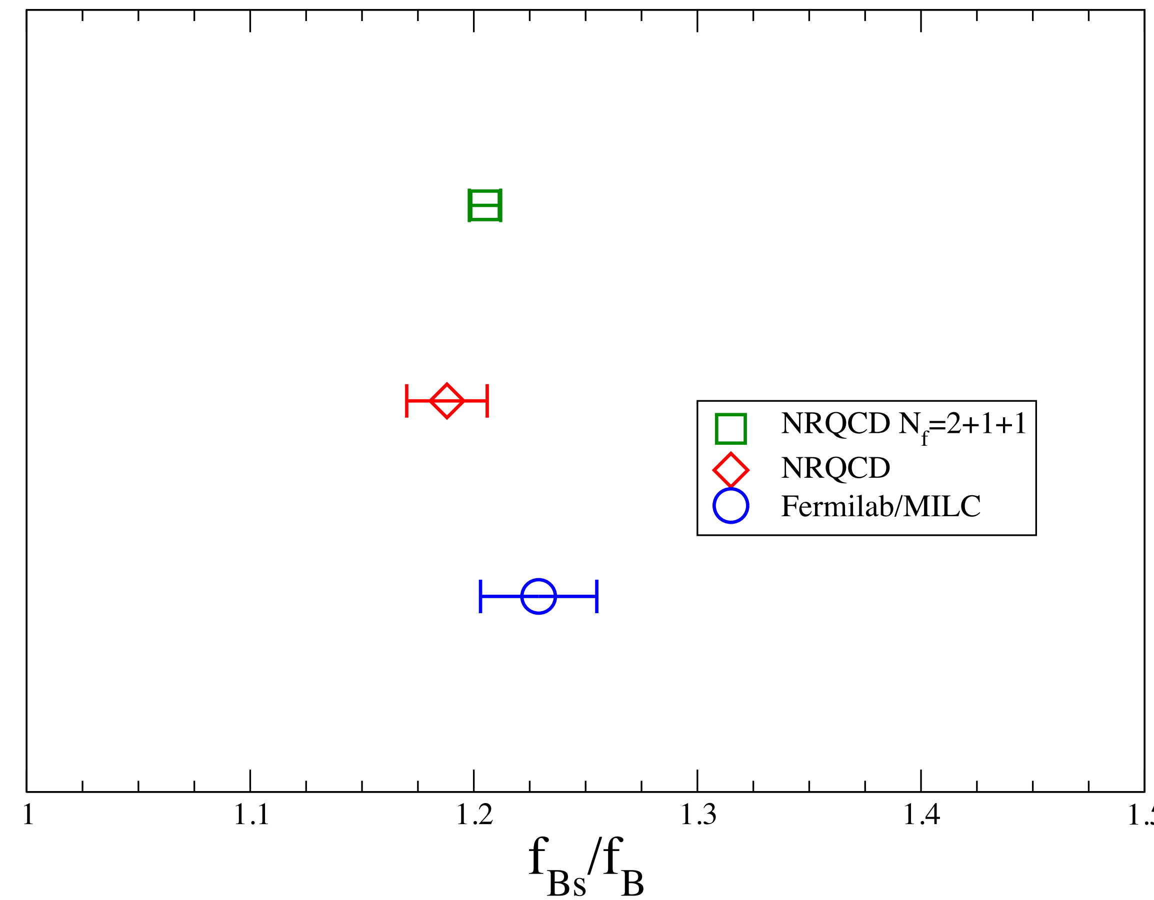
Calculations from HPQCD

- **NRQCD + N_f=2+1+1 + physical pion mass**

R. Dowdall et al. (HPQCD)
PRL 110 (2013) 222003

- MILC N_f=2+1+1 gauge configurations
  - with physical pion mass → very small chiral “interpolation” errors
- O(v^4) Improved NRQCD
- Matching errors: 4% → 1.2%
- Even more precise ratio: f_{Bs}/f_B = 1.205(7)

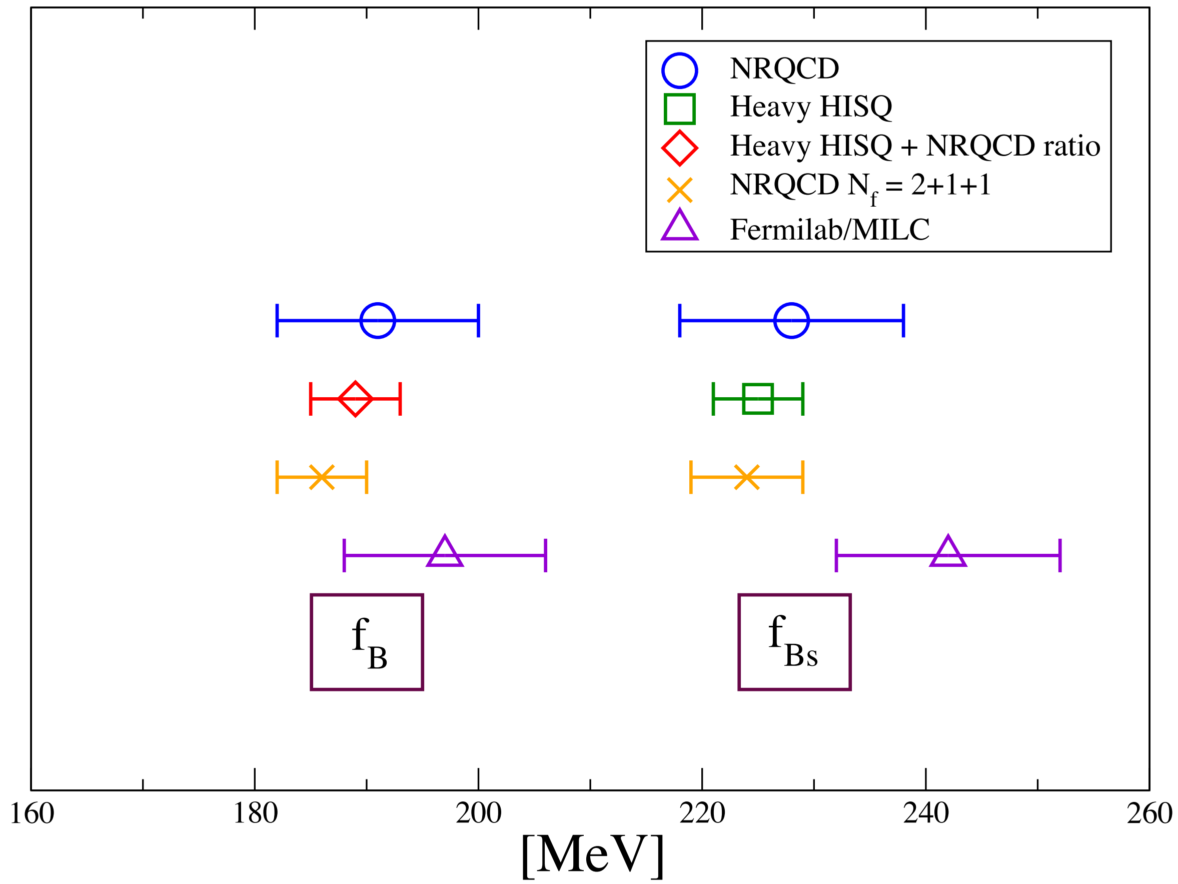


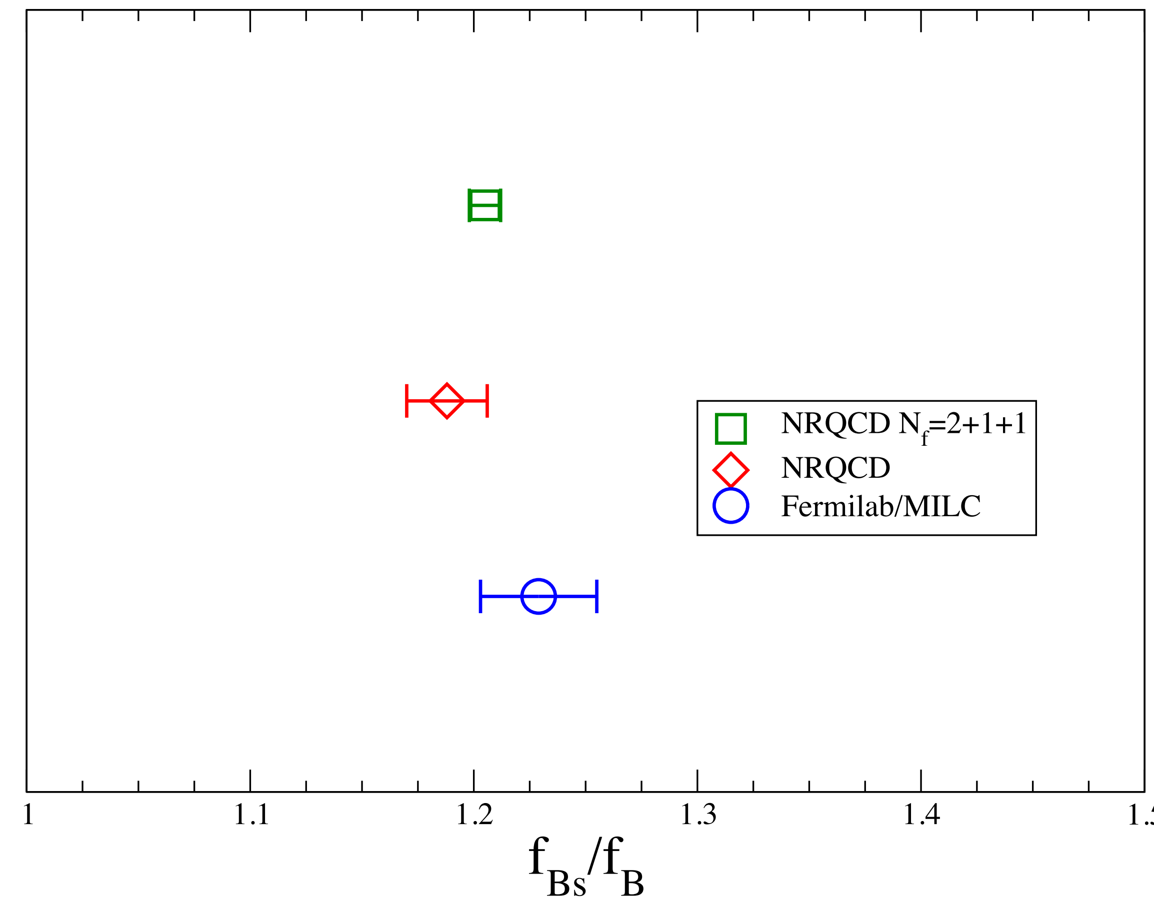


Calculations from Fermilab/MILC

A. Bazavov et al. (FNAL/MILC)
PRD 85 (2012) 114506

- **Wilson clover action with Fermilab interpretation**
  - MILC N_f=2+1 asqtad ensembles
  - asqtad light quarks and Fermilab heavy quarks
  - Mostly nonperturbative renormalization (mNPR)
  - HMrSχPT (Heavy Meson Rooted Staggered Chiral PT)
  - After five preliminary reports
    - LAT2006 094, LAT2007 310, LAT2008 278, LAT2009 249, LAT2010 317

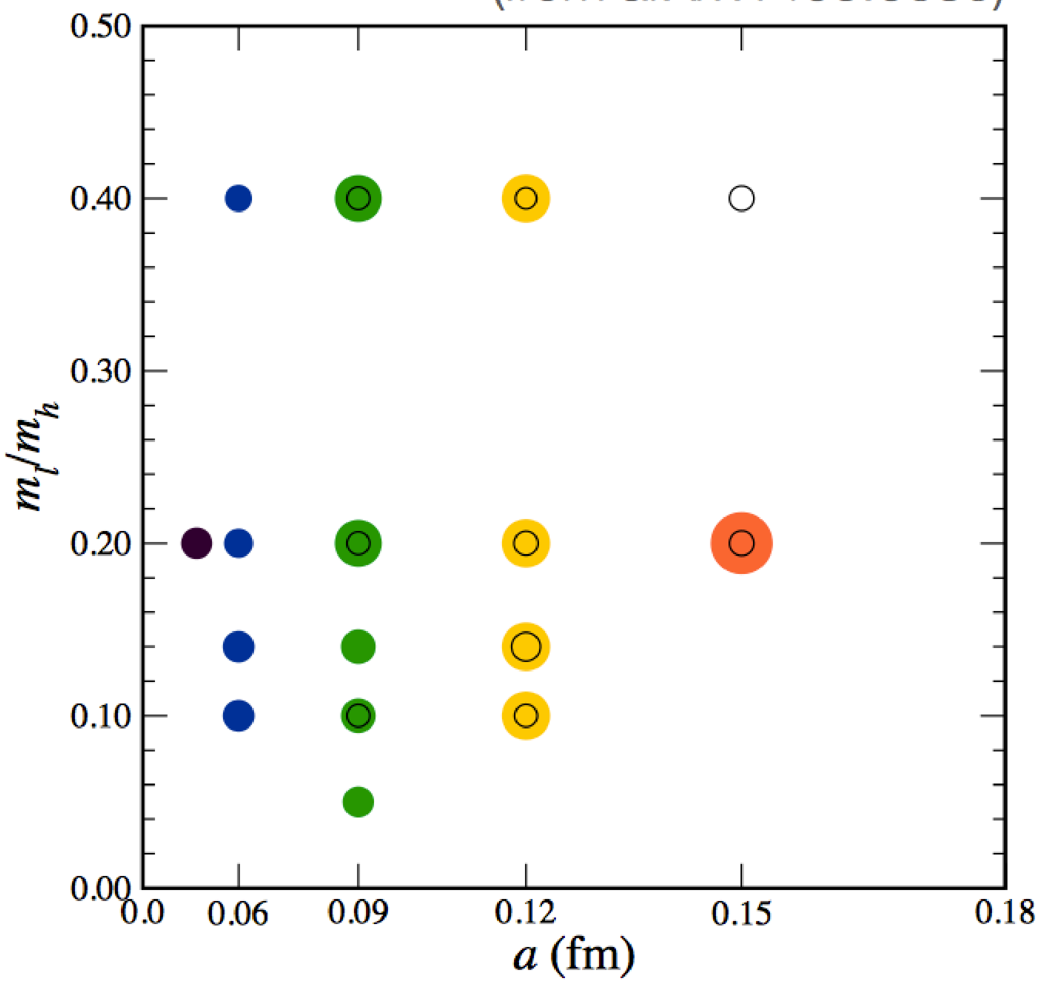


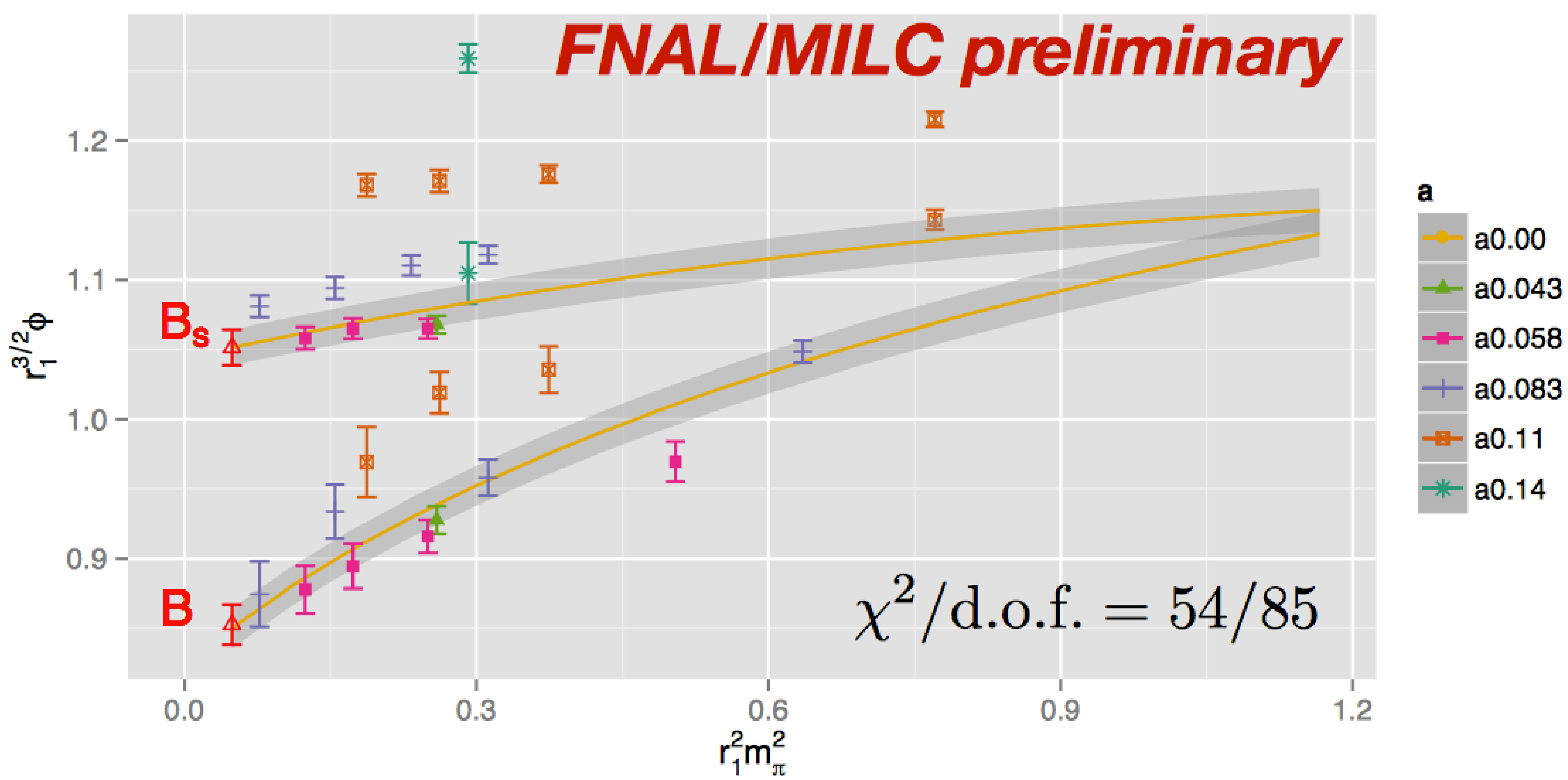


Calculations from Fermilab/MILC

- **Next steps!**
  - MILC N_f=2+1 asqtad ensembles
    - With the full set of the whole ensembles

(from arXiv:1403.0635)





E. Neil, Lattice 2014

Calculations from Fermilab/MILC

- **Next steps!**
  - MILC **N_f=2+1** asqtad ensembles
    - With the full set of the whole ensembles
  - MILC **N_f=2+1+1** HISQ ensembles
    - Clover wilson with Fermilab interpretation
    - Heavier Than Charm (HTC) HISQ
      - for f_{Bs} as well as f_B
      - 0.03fm lattices ($96^3 \times 288$) are under way
        - 0.03fm → 6.6GeV : one can calculate fully relativistic bottom quarks!
      - New techniques
        - Random-wall sources
        - Covariant Approximation Averaging

Summary

- B meson decay constants calculations with Staggered sea quarks have been very successful!
  - Two independent collaborations and three different heavy quark discritization methods deliver the consistent results
  - 2% errors for f_B and f_{Bs} and 1% errors for f_{Bs}/f_B
    - The errors are well understood: full error budget
  - The second generation MILC ensembles including the sea charm quark effects and physical pion mass.
- Fully utilizing the MILC N_f=2+1+1 HISQ ensembles is forthcoming.
  - Including physical pion mass
  - Better discritization errors
  - Better statistics with new techniques
  - Stay tuned!