B Decays on the Lattice

and

Results for Flavor Phenomenology

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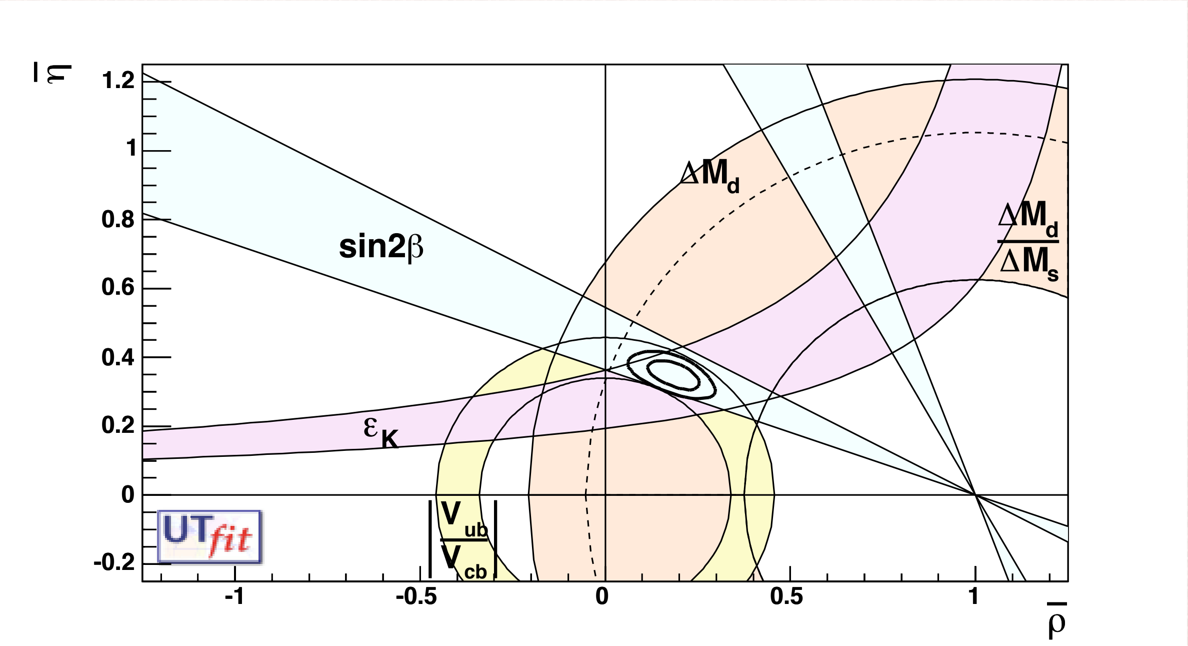
Outline

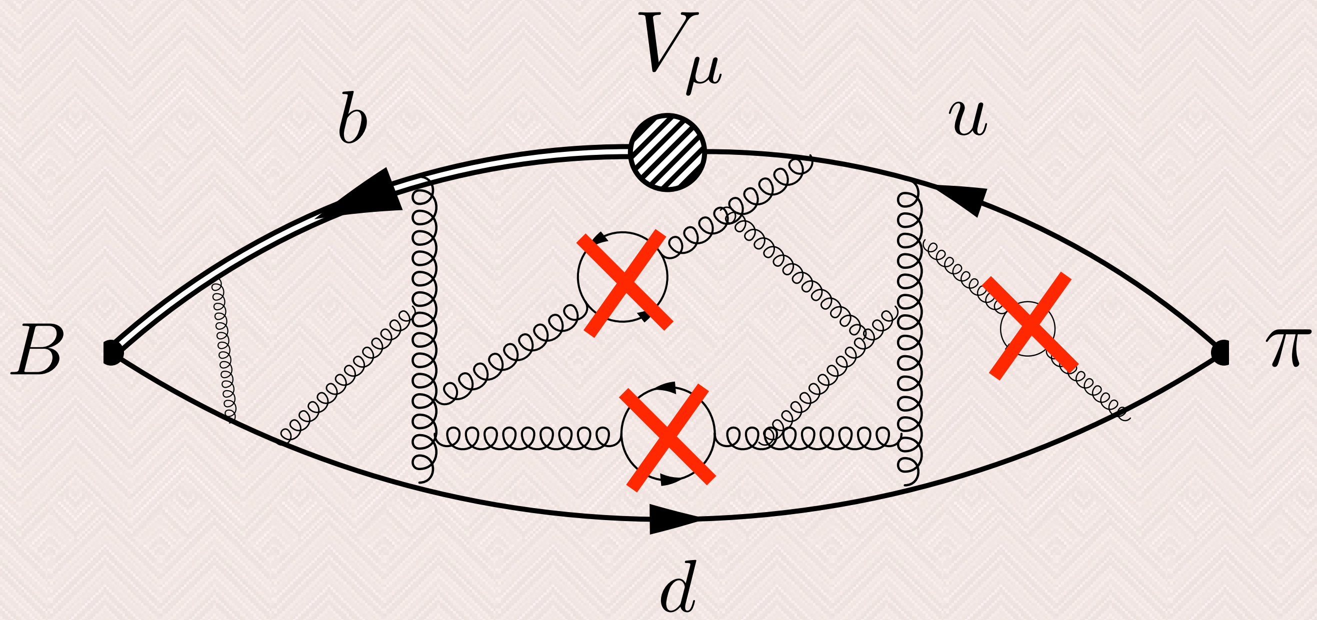
- Motivation



- What's new? Lattice QCD with light sea quarks
- Leptonic decay constants
- Semileptonic form factors
- Outlook

Correlation function for B to pi

in the Quenched or Valence Approximation



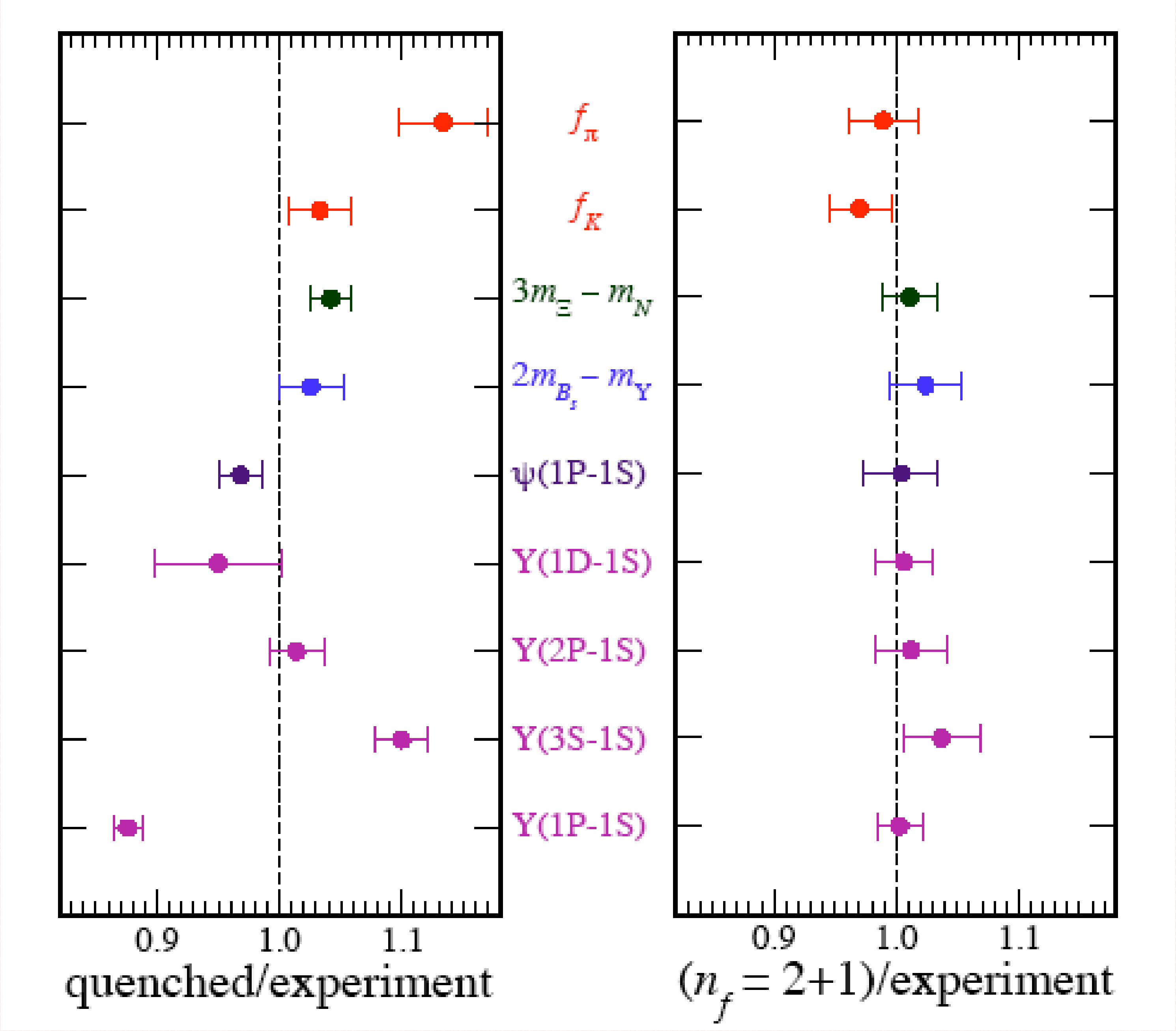
$$\langle J_\pi(y) V_\mu(0) J_B(x) \rangle \;=\; \int [dU] J_\pi(y) V_\mu(0) J_B(x) \;\det Q[U]\; e^{-S_{\rm glue}}$$

Probabilistic weight for generating "important" gluon field configurations

A Smattering of Staggering

- Naive fermion discretization has 15 extra states (“doublers”)
- $$G(p)a \;=\; \frac{1}{i\sum_\mu \gamma_\mu \sin(p_\mu a)}$$
- Staggered quarks are cheap to simulate because they turn the doubling problem into an asset -- spin diagonalization
- Remaining doubler degrees-of-freedom (4) interpreted as “tastes” (artificial flavors)
- “Fourth-root trick” used to get right number of sea quarks
  No proof showing this is theoretically sound or unsound

Quenched vs. Light Improved Staggered



C. Davies, *et al.* PRL **92**, 022001 (2004)

MILC Collaboration Lattices

Sea quarks and states of Sin

- Quenched

  Theoretically wrong. 10-20% disagreement with experiment.

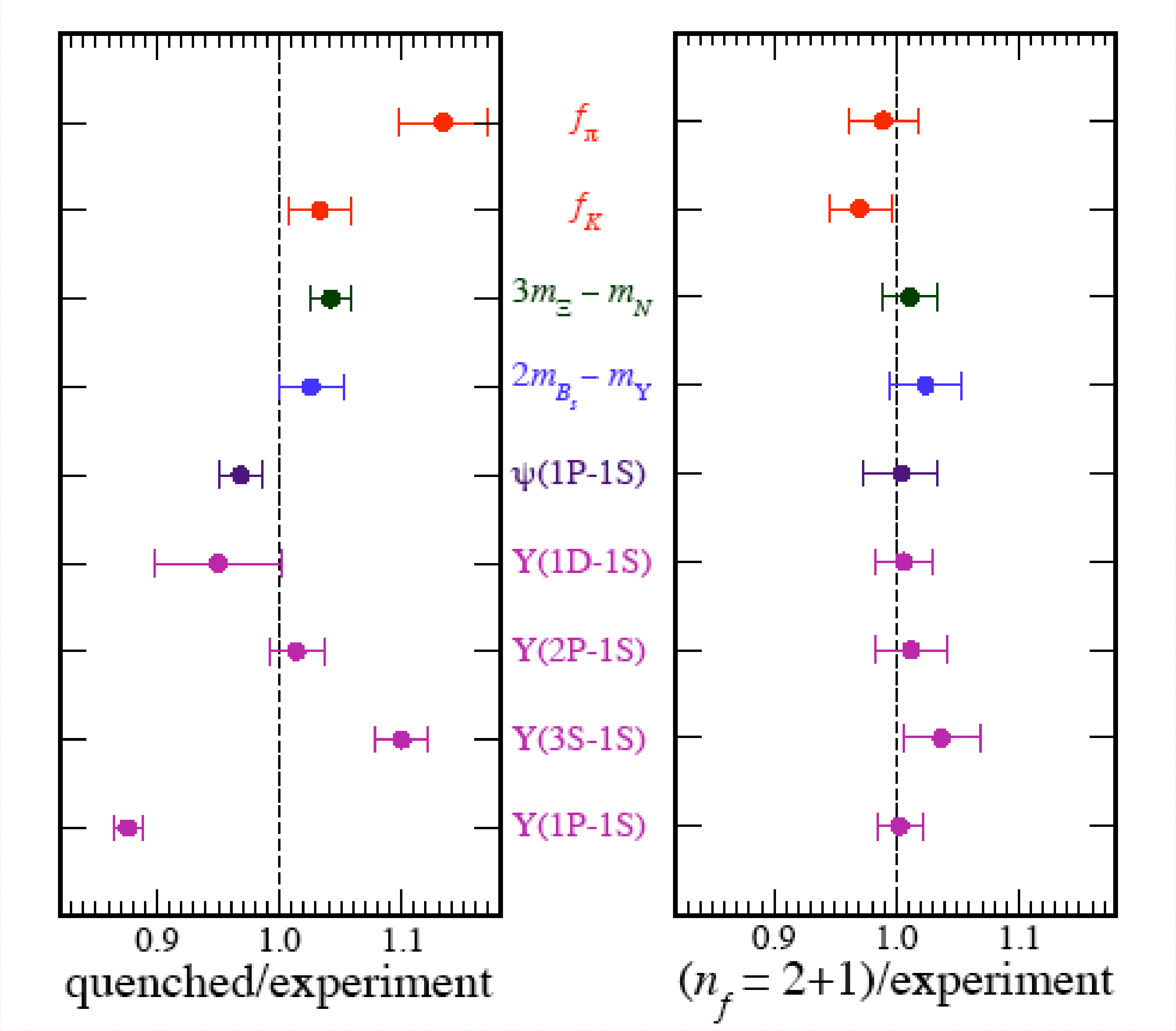
- Lighter staggered

  Theoretically uncertain. Agreement with experiment within quoted uncertainties. Permits simulation inside chiral regime

- Heavier Wilson, twisted-mass, domain wall, overlap, fixed point

  Theoretically sound. More costly, so heavier mass required. Extrapolation to physical sea quark masses: inside chiral regime???

Quenched vs. Light Improved Staggered



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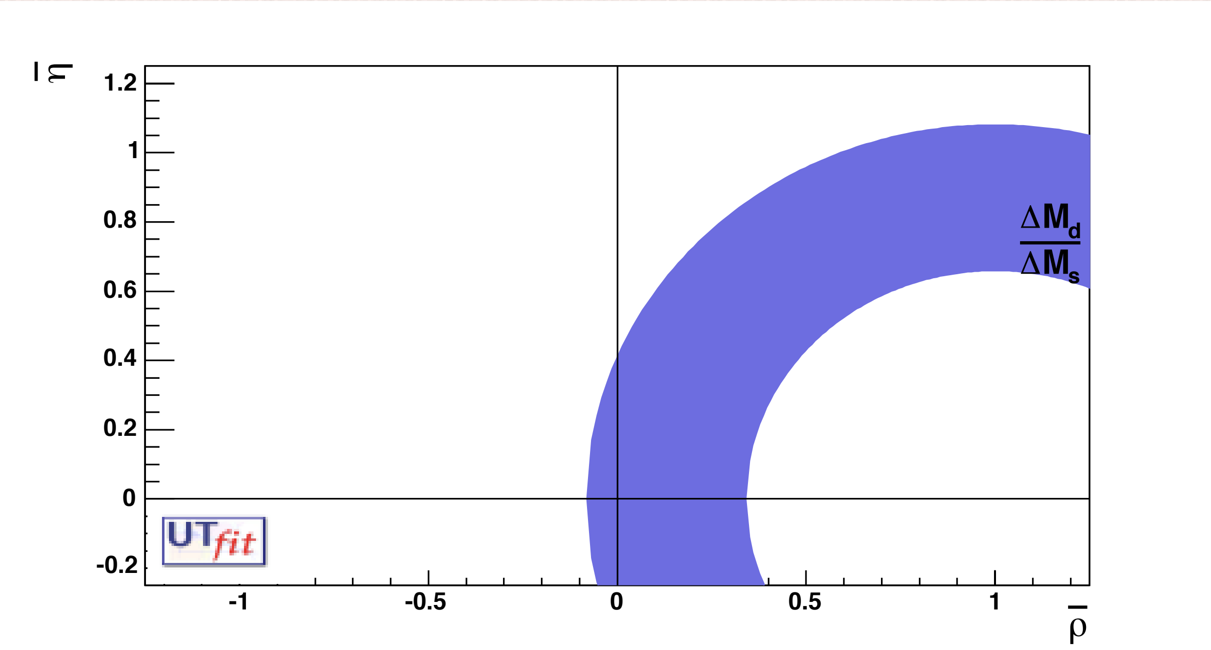
MILC Collaboration Lattices

B Decay Constants

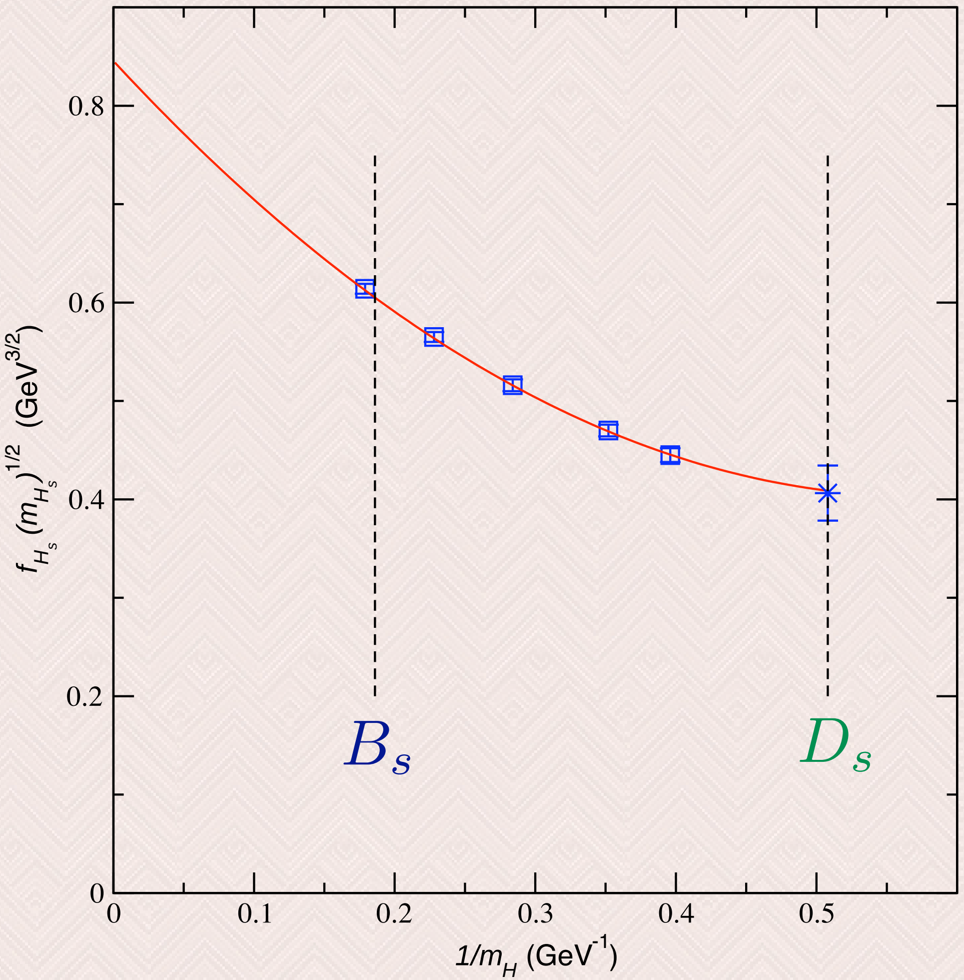


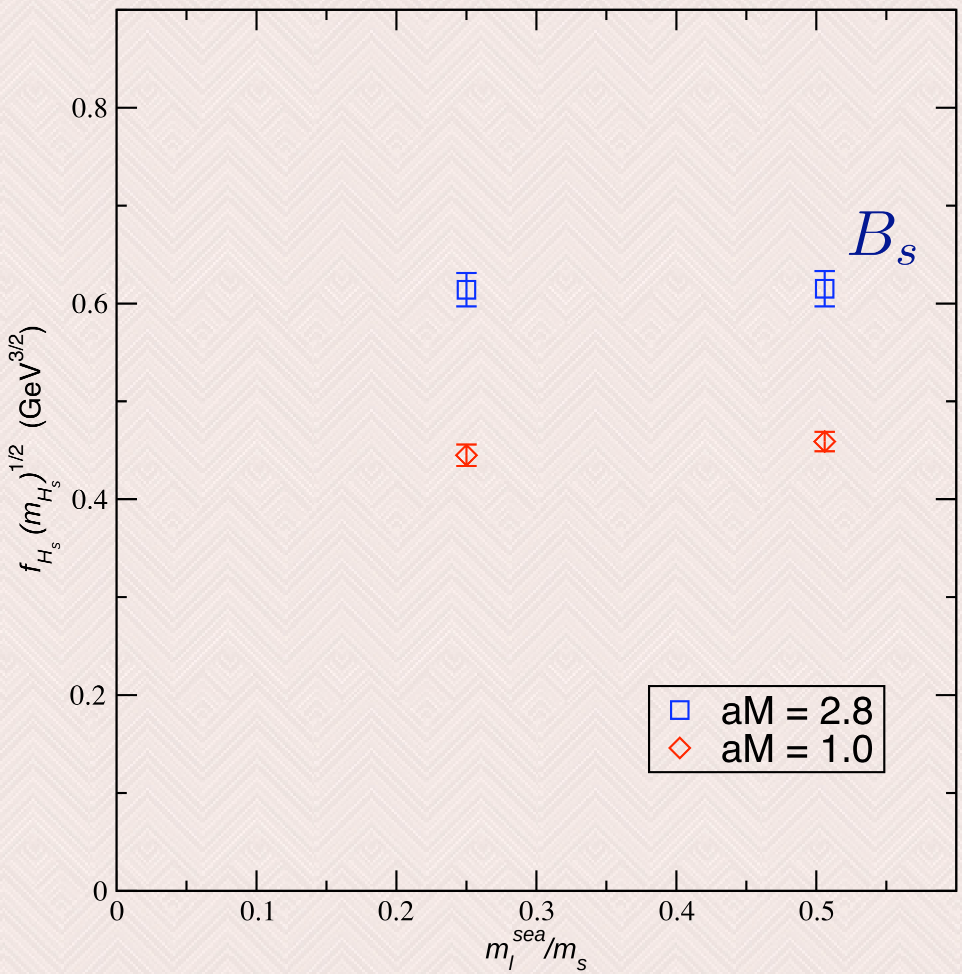
$$\Delta M_d = \frac{G_F^2}{6\pi^2} m_W^2 \eta_B S(x_t) m_{B_d} f_{B_d}^2 B_{B_d} |V_{td} V_{tb}^*|^2$$

$$\frac{\Delta M_s}{\Delta M_d} = \frac{m_{B_s}}{m_{B_d}} \frac{f_{B_s}^2 B_{B_s}}{f_{B_d}^2 B_{B_d}} \left| \frac{V_{ts}}{V_{td}} \right|^2$$

$$\equiv \xi^2$$

B_s Decay Constant





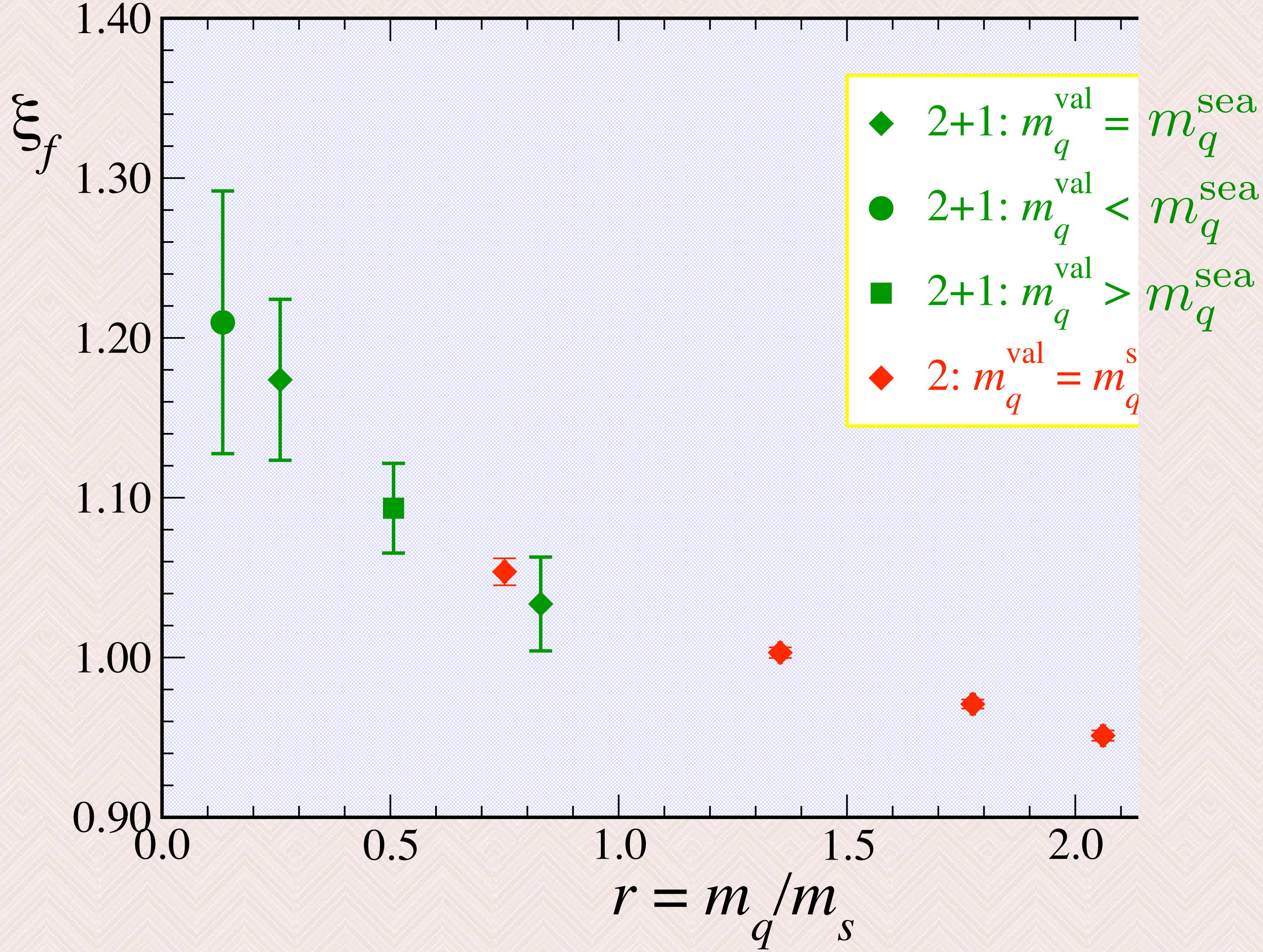
$$f_{B_s} = 260 \pm 7 \pm 26 \pm 8 \pm 5 \text{ MeV}$$

stat perturb hq discr

M.W., *et al*. PRL 92 (2004)

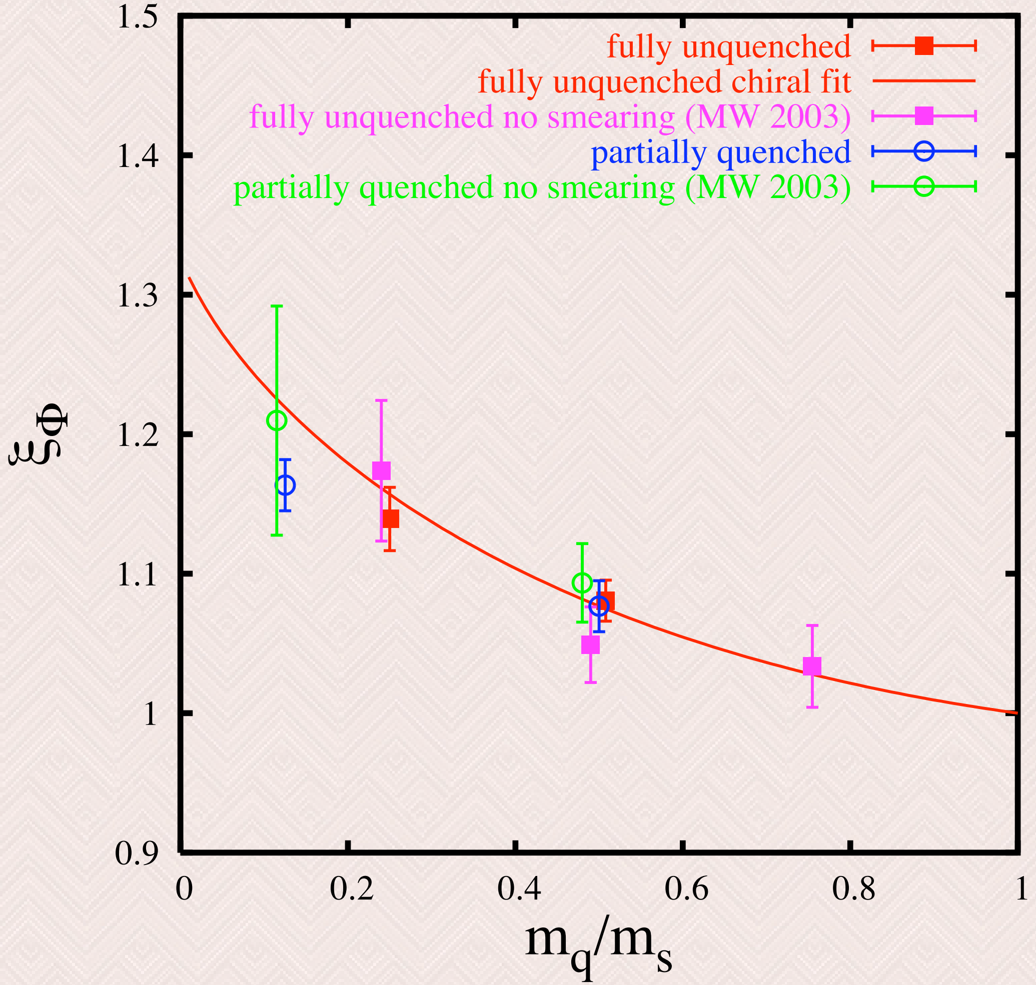
B_s/B Decay Constants

HPQCD[MILC] & JLQCD
$n_f = 2+1$ $n_f = 2$



From A. Kronfeld, Lattice 2003

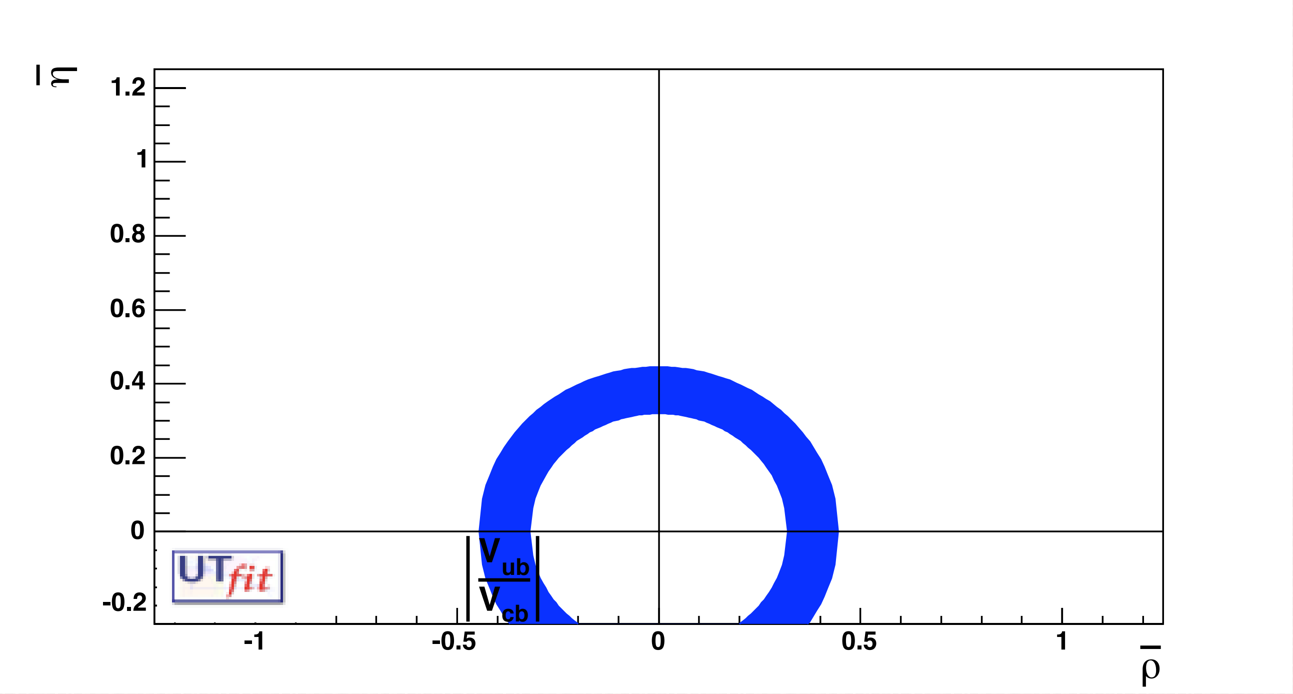
$$\xi_\Phi \equiv \frac{f_{B_s}\sqrt{m_{B_s}}}{f_B\sqrt{m_B}}$$



- MILC configurations
- NRQCD + KS
- Smeared sources/sinks improve statistics

A. Gray, *et al.*, Lattice 2004

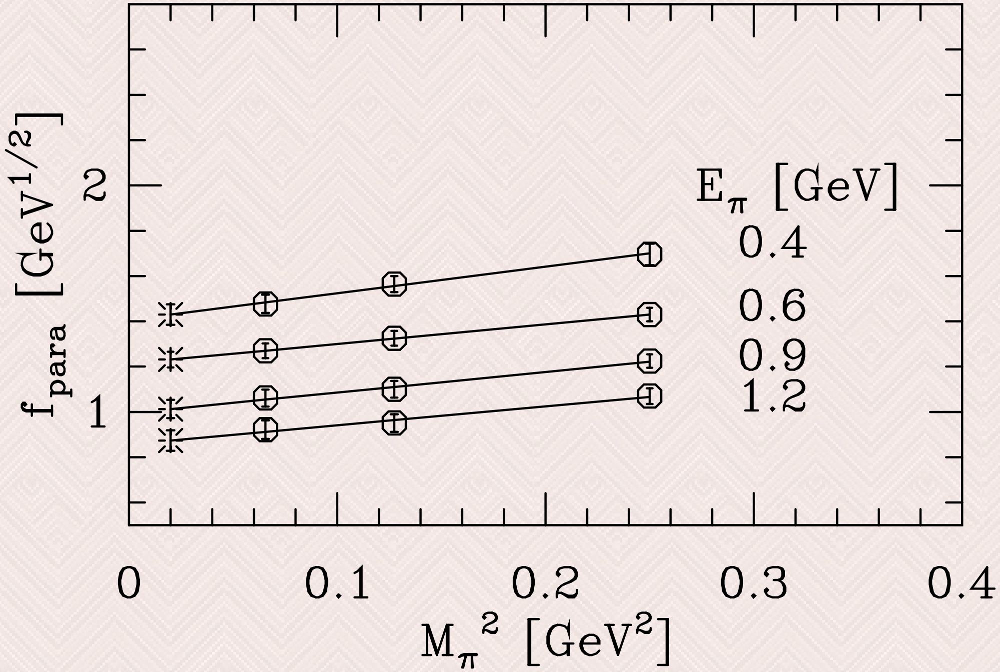
$B \to \pi \ell \nu$ form factors

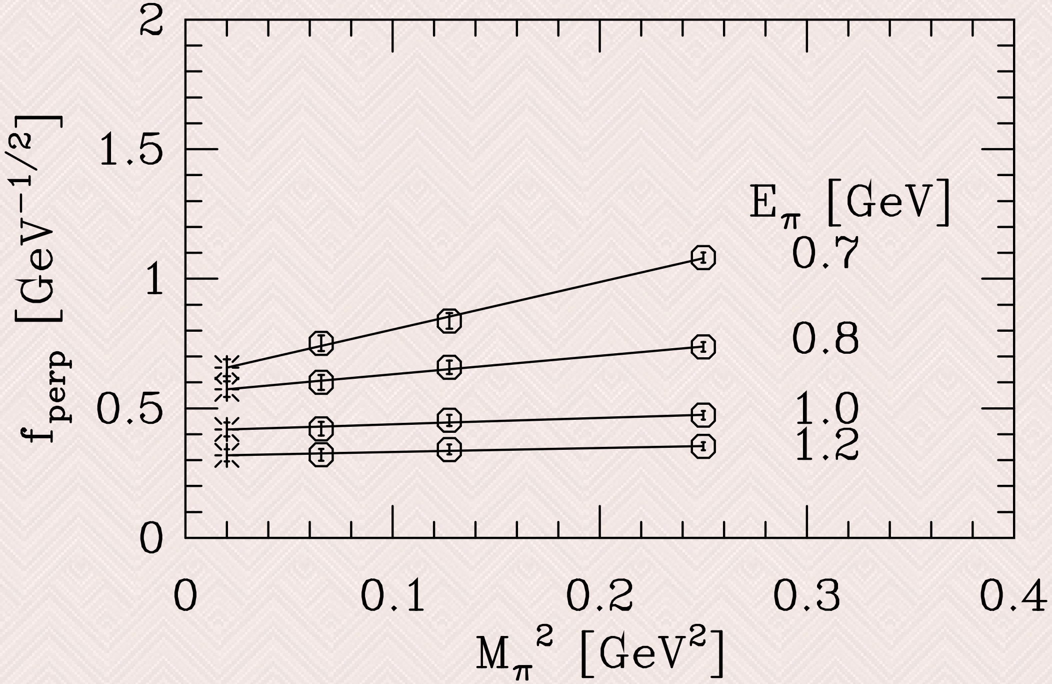


$$\langle \pi(p') | V^\mu | B(p) \rangle \;=\; f_+(q^2)(p^\mu + p'^\mu) \;+\; f_-(q^2)(p^\mu - p'^\mu)$$

$$\frac{1}{|V_{ub}|^2} \frac{d\Gamma}{dq^2} \;=\; \frac{G_F^2}{24\pi^3} |\vec{p'}|^3 \, |f_+(q^2)|^2$$

Physical quark mass extrapolations



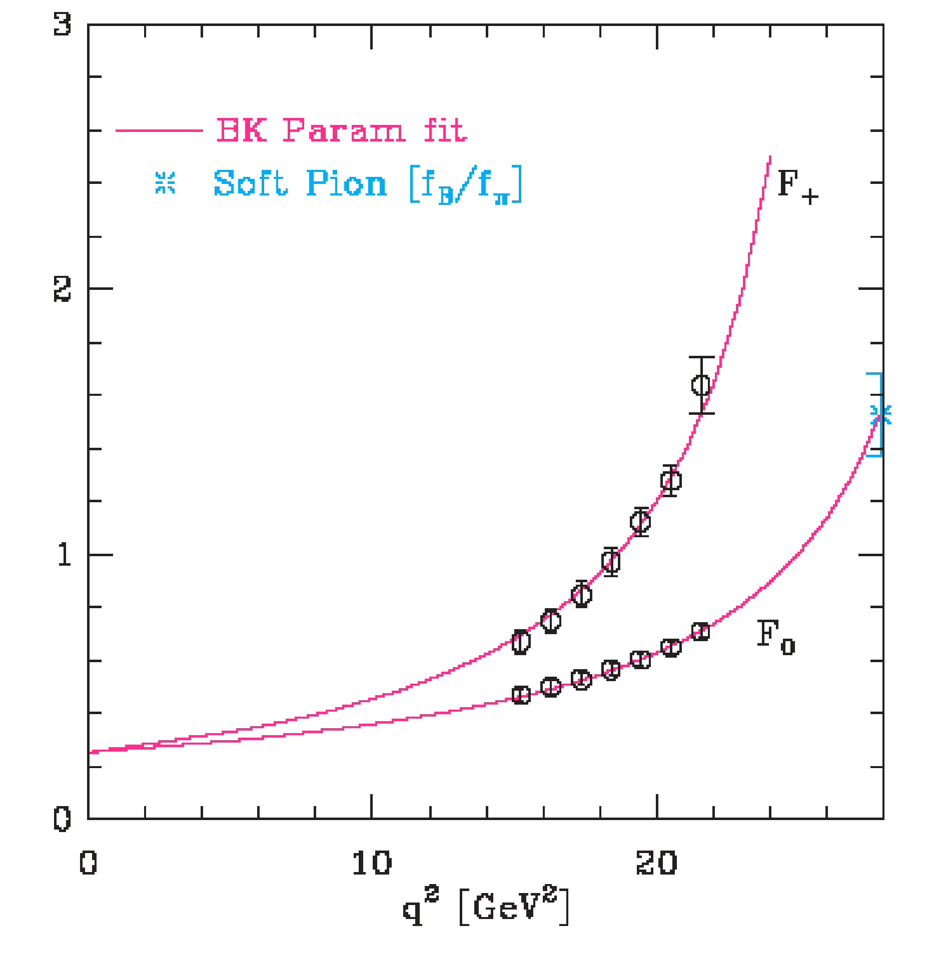


- NRQCD heavy + KS light
- coarser MILC configs
- partially quenched
- $m_{ud}^{sea} = m_s/4$
- linear chiral extrapolation

J. Shigemitsu, Lattice 2004

Preliminary form factors

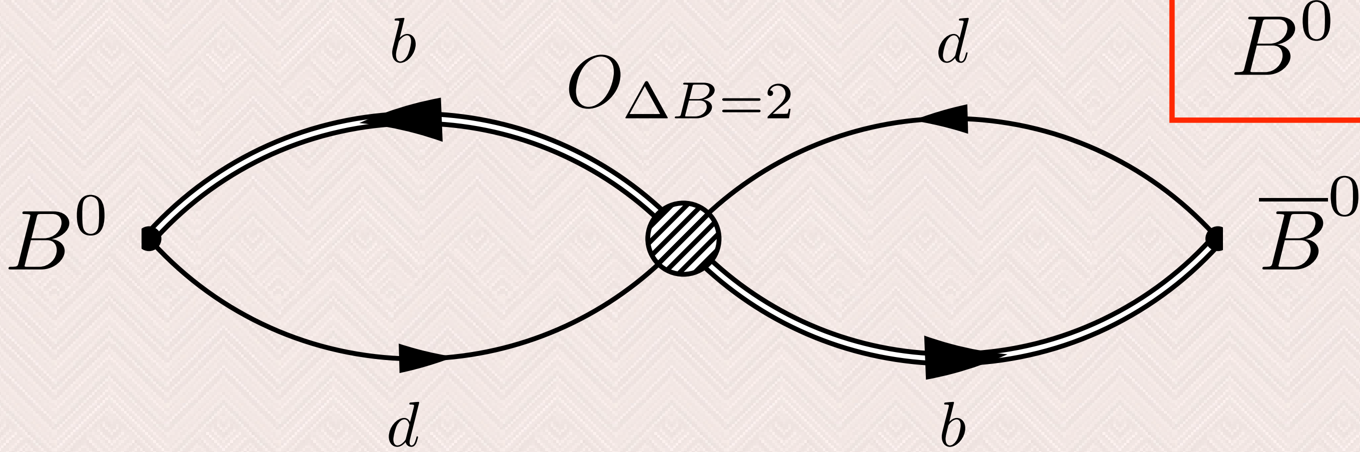
J. Shigemitsu, *et al.* (Lattice 2004) hep-lat/0408019



- Sea quark fixed to $m_s/4$
- Fits to Becirevic-Kaidalov ansatz
- $f_0(0) = f_+(0) = 0.25(2)$
- Used CLEO branching fractions hep-ex/0304019

$$|V_{ub}| = \begin{cases} 3.86(32)(58) \times 10^{-3} & 0 \leq q^2 \leq q^2_{max} \\ 3.52(73)(44) \times 10^{-3} & 16\, GeV^2 \leq q^2 \end{cases}$$

(expt)(lattice)



$B^0 - \overline{B}^0$ mixing

$$\langle \overline{B}_s^0 | (\bar{b}s)_{V-A}(\bar{b}s)_{V-A} | B_s^0 \rangle = \frac{8}{3} f_{B_s}^2 m_{B_s}^2 B_{B_s}$$

$$\langle \overline{B}_s^0 | (\bar{b}s)_{S-P}(\bar{b}s)_{S-P} | B_s^0 \rangle = -\frac{5}{3} \left(\frac{f_{B_s} m_{B_s}^2}{m_b + m_s} \right)^2 B_{S_s}$$

- JLQCD, PRL 91 (2003); N. Yamada, Lattice 2001:
- $B_{S_s}(m_b) = 0.86(3)(7)$
- A. Gray (HPQCD), Lattice 2004 - Calculation underway
- Chiral symmetry reduces mixings NRQCD+KS or Tsukuba+DWF (N. Yamada, Lattice 2004)

$$\begin{aligned} B_{B_d}(m_b) &= 0.836(27)(^{+\ 0}_{-27})(56), \\ B_{B_s}(m_b) &= 0.850(22)(^{+18}_{-\ 0})(57)(^{+5}_{-0}), \\ \frac{B_{B_s}}{B_{B_d}} &= 1.017(16)(^{+53}_{-\ 0})(17)(^{+6}_{-0}). \end{aligned}$$

Summary & Outlook

- (Improved) staggered quarks are cheap, thus permit simulations with "light enough" sea quarks
  - Chiral perturbation theory converges
  - Unique set of bare coupling, quark masses gives correct physics
- Final result for B_s decay constant
- Working hard on chiral extrapolation to get B decay constant
- $B \to \pi \ell \nu$ form factors, one sea quark mass done
- $B^0 - \overline{B^0}$ mixing matrix element computation underway

Related Work

- Our sibling collaboration, FNAL/MILC, for *D* decays
  - Decay constants - J. Simone, *et al.*, at Lattice 2004
  - Semileptonic form factors - M. Okamoto, *et al.,* Lattice 2004, DPF 2004 and hep-ph/0408306 (submitted to PRL)
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- My Lattice 2004 review talk, to appear on the arXiv in Sept.