Lattice QCD results for precision b and c physics

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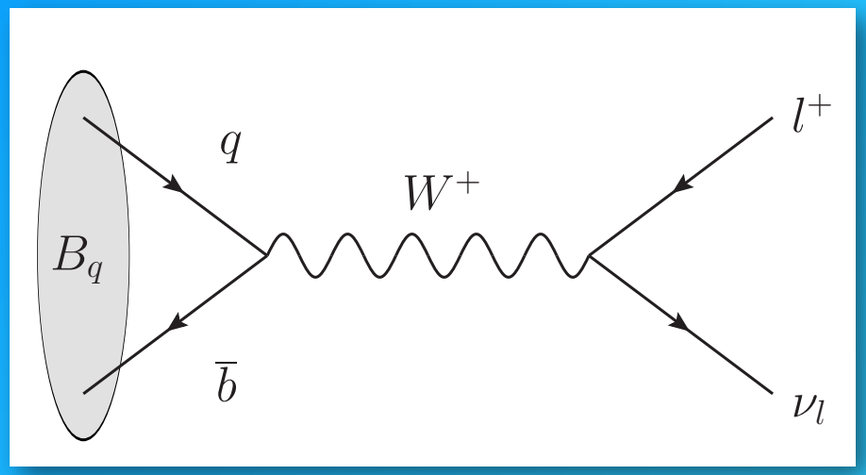
Precision

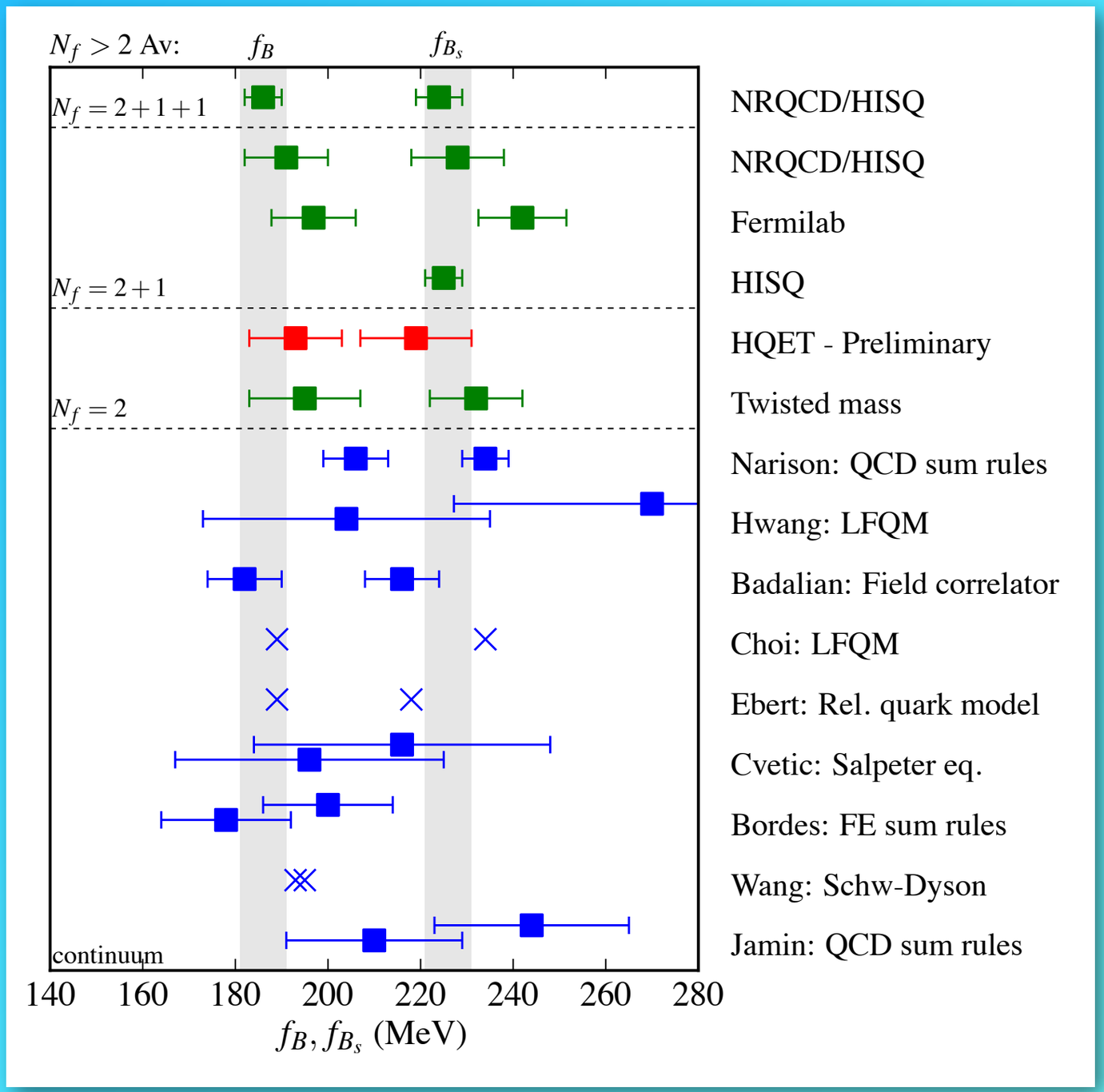
- Short review talk ⇒ discretion to make personal choices
- See also C Sachrajda's plenary LQCD talk on Tuesday, 12:30
- Straight to results

- B and B_s decay constants
- Semileptonic decay form factors
  - $D \to K,\ \Lambda_b \to p,\ B \to K,\ \Lambda_b \to \Lambda$
- Out of time? If not, $B \to D$ and $B \to \pi$ quickly
- Lattice 2013

B & B_s decay constants

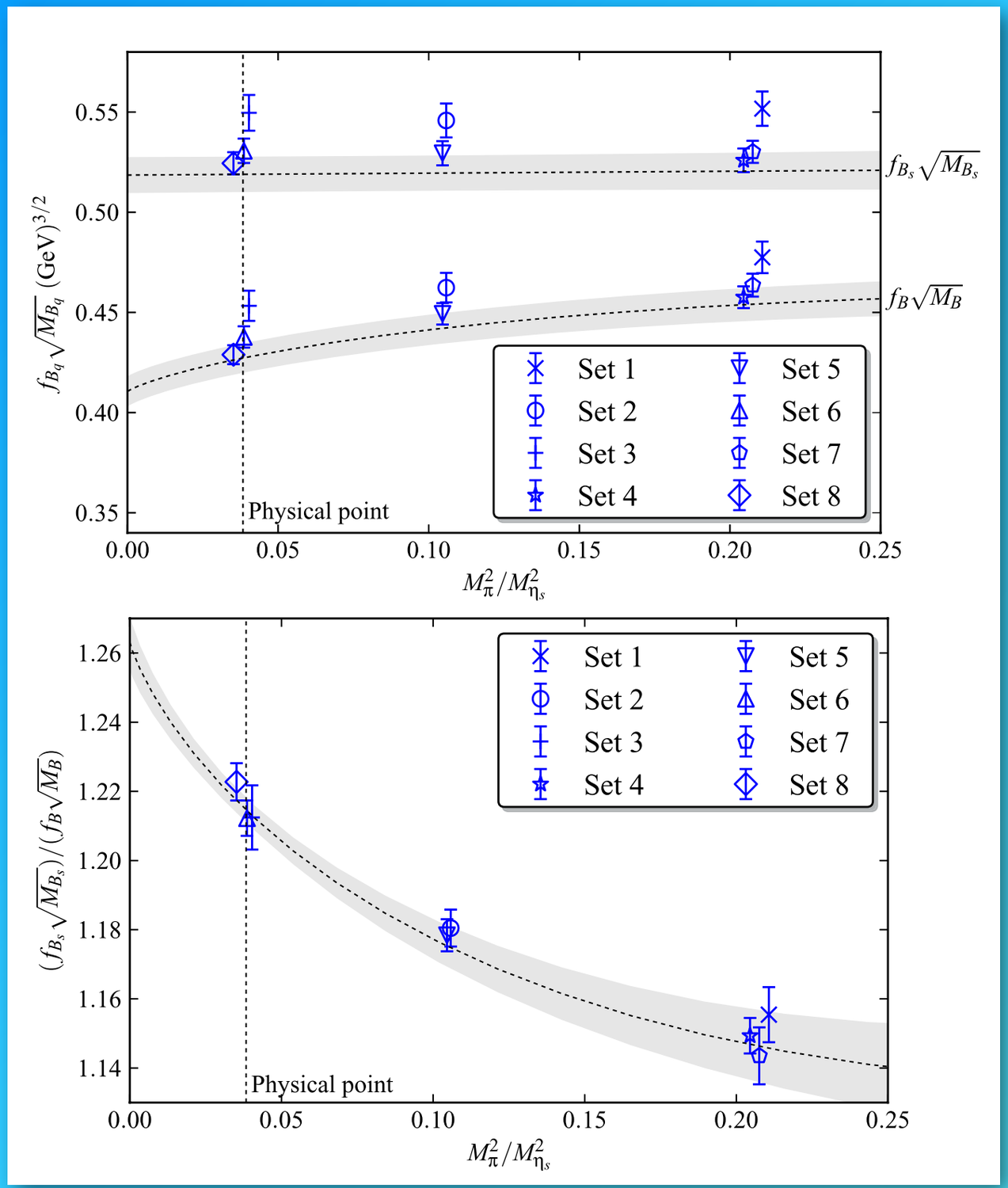


$$\langle 0|A^\mu|B(p)\rangle = p^\mu f_B$$



Plot from R. Dowdall, FPCP 2013

B & B_s decay constants



- NRQCD/HISQ incl rad impr. on n_f=2+1+1 MILC HISQ
- Incl. lattices with physical m_π
- Operator matching ⇒ 4% uncertainty in f's
- Statistics, fits in a^2, r_1 give 2-3% uncertainties
- f_B = 186(4) MeV; f_{Bs} = 224(4) MeV; f_{Bs}/f_B = 1.205(7)

R. Dowdall *et al*, PRL 110 (2013)

$B \to \tau\nu$ and $B_s \to \mu\mu$

$$\frac{1}{|V_{ub}|^2}\mathcal{B}(B \to \tau\nu) = 6.05(20)$$

$$\mathcal{B}(B \to \tau\nu) = 1.14(22) \times 10^{-4} \qquad \Rightarrow |V_{ub}| = 0.0043(4)$$

(HFAG May 2013)

New SM prediction, ignoring B_s oscillations

$$\mathcal{B}(B_s \to \mu^+\mu^-) = 3.17(15)(9) \times 10^{-9}$$

Including B_s oscillations

$$\mathcal{B}(B_s \to \mu^+\mu^-) = 3.47(19) \times 10^{-9}$$

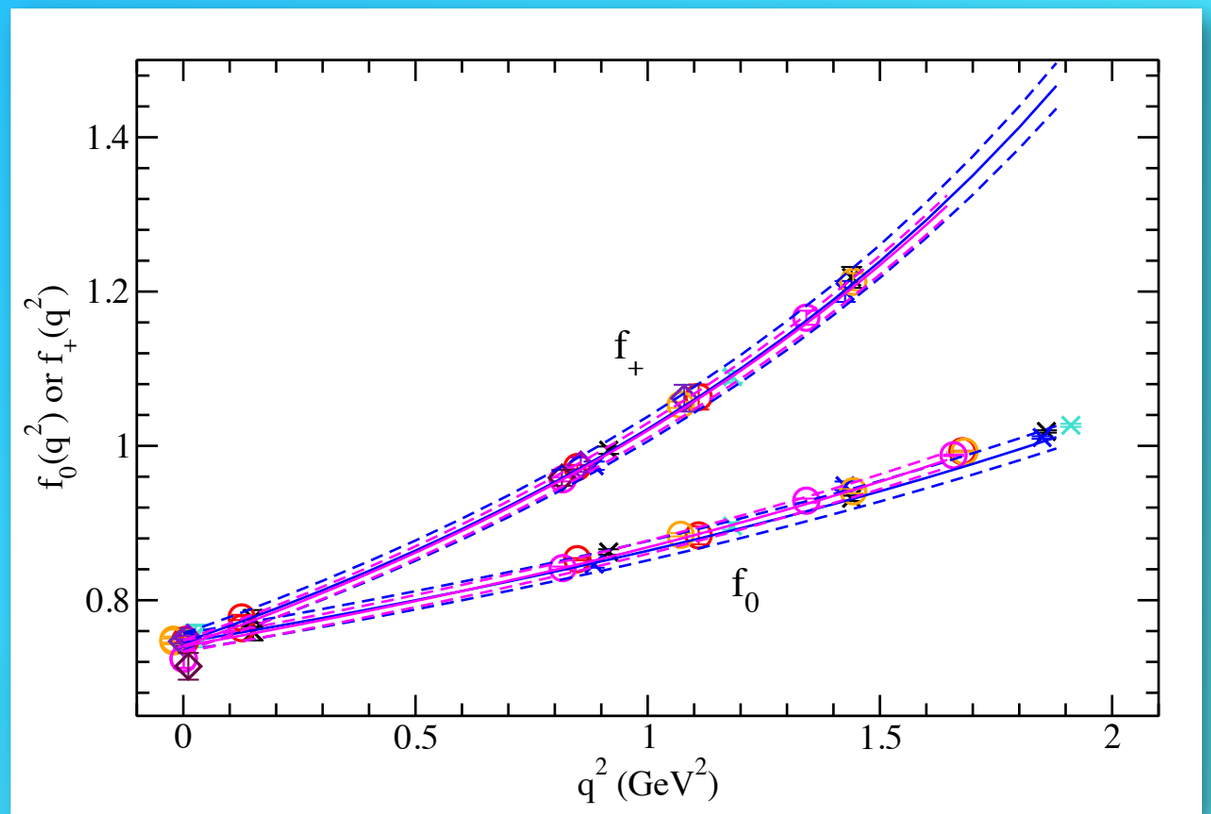
updating A Buras et al, EPJ C72 (2012) and K De Bruyn et al, PRL 109 (2012)

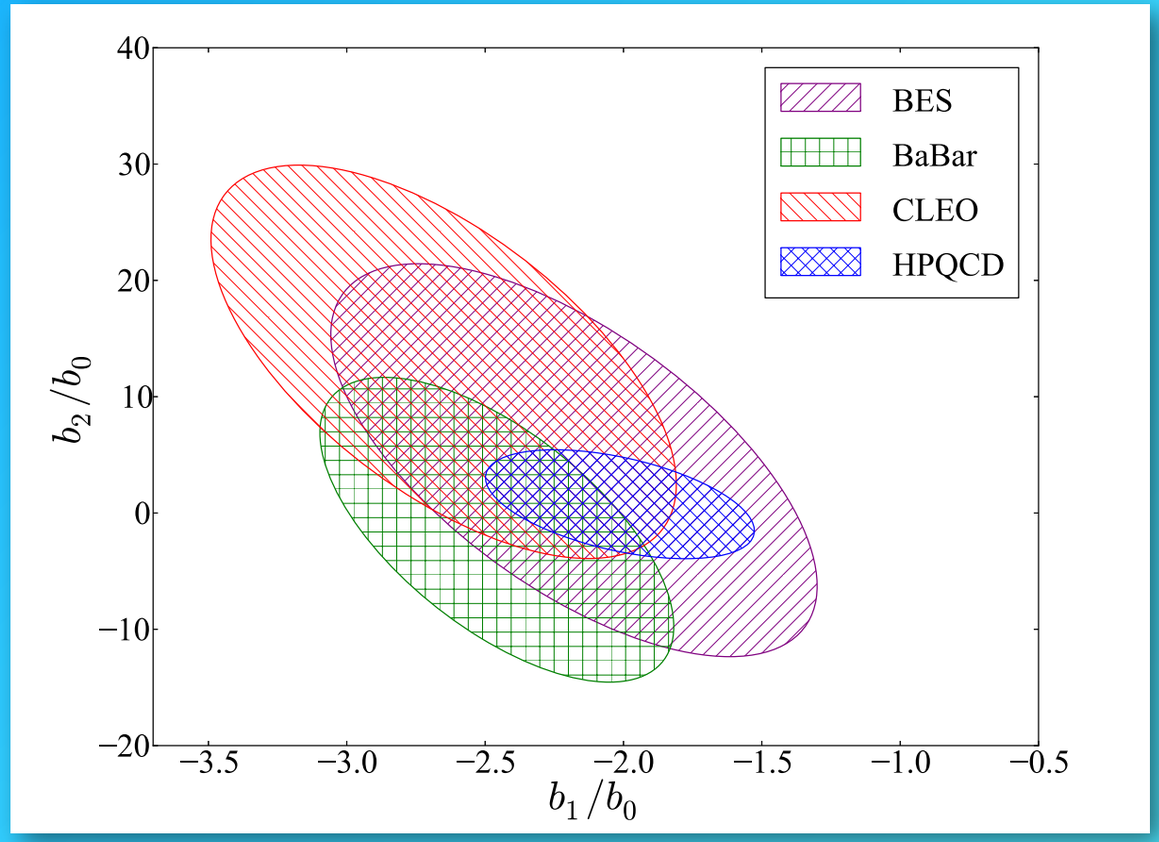
Measured! $3.2^{+1.5}_{-1.2} \times 10^{-9}$ LHC*b*, PRL 110 (2013)

$D \to K l \nu$

HPQCD Collaboration
(using HISQ valence on MILC n_f=2+1 asqtad)

Fit value: $f_+(0) = 0.745(11)$





Using data & form factors over whole range of q^2:

$V_{cs} = 0.963(5)(14)$ (expt)(lqcd)

J Koponen *et al*, arXiv:1305.1462. See also FNAL/MILC and ETM Collaborations

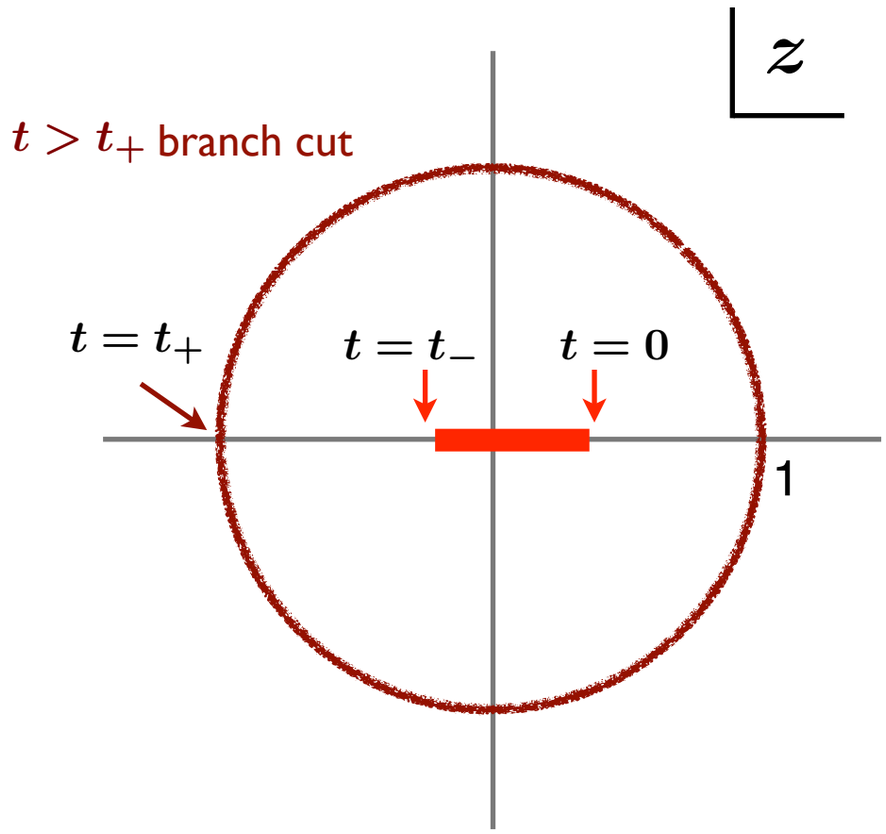
Form factor shape

Series (z) expansion

$$t = q^2 \qquad t_\pm = (m_B \pm m_F)^2$$

Choose, *e.g.* $t_0 = 12\ \mathrm{GeV}^2$

$$z = \frac{\sqrt{t_+ - t} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - t} + \sqrt{t_+ - t_0}}$$



Simplified series expansion

$$F(t) = \frac{1}{1 - t/m_{\mathrm{res}}^2} \sum_n a_n z^n$$

Series expansion

$$F(t) = \frac{1}{P(t)\Phi(t)} \sum_n b_n z^n$$

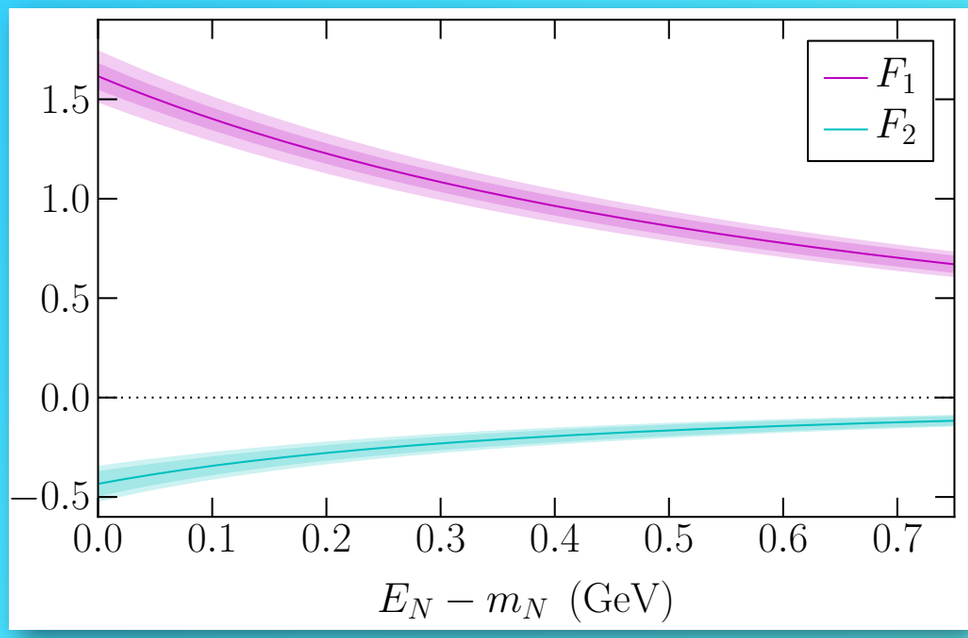
Bourrely, Caprini, Lellouch PRD **79** (2009) following Okubo; Bourrely, Machet, de Rafael; Boyd, Grinstein, Lebed; Boyd & Savage; Arneson *et al.;* FNAL/MILC lattice collab; ...

$\Lambda_b \to p\, l^- \nu$

In the static limit, 10 form factors reduce to 2

$$\langle p(p',s')|\,\bar{s}\Gamma Q\,|\Lambda_Q(v,0,s)\rangle \;=\; \bar{u}(p',s')[F_1(p'\cdot v) + \not{v} F_2(p'\cdot v)]\Gamma\,\mathcal{U}(v,s)$$

(using Static+DWF on n_f=2+1 RBC-UKQCD)

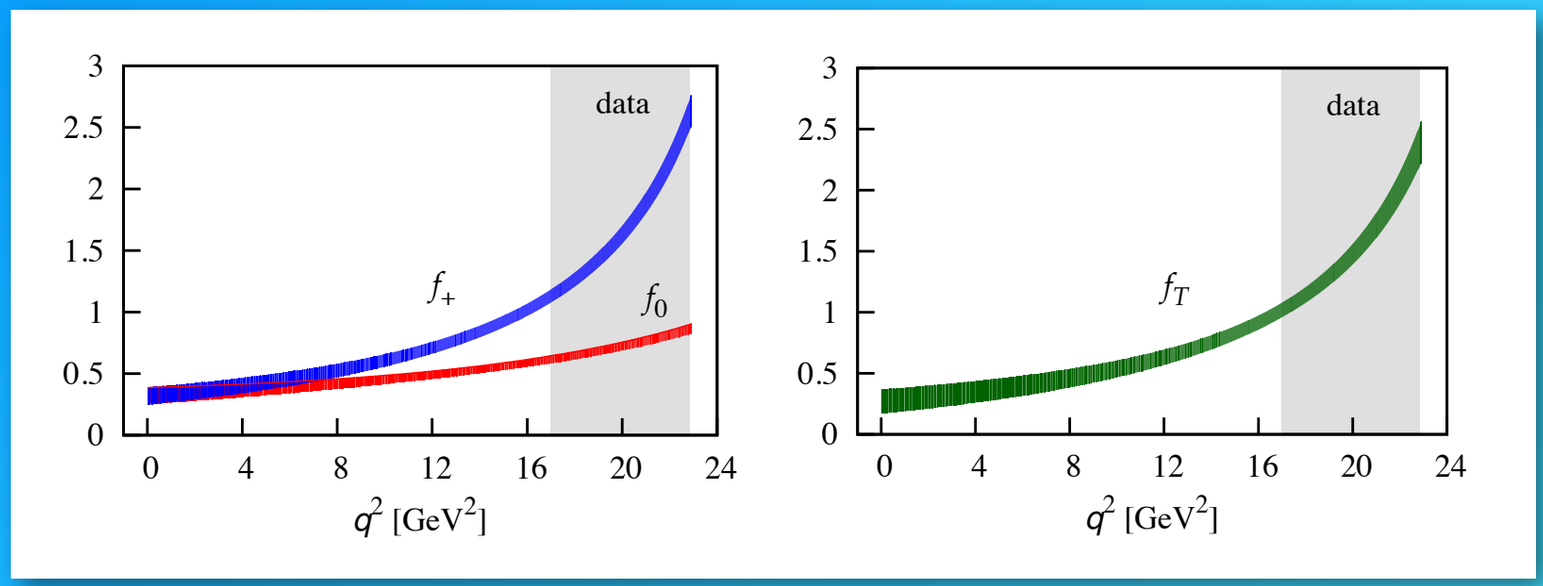


With expt data, could lead to $|V_{ub}|$with 15% theory error

$$\frac{1}{|V_{ub}|^2}\int_{14\ \mathrm{GeV}^2}^{q^2_{\mathrm{max}}} \frac{\mathrm{d}\Gamma(\Lambda_b \to p\,\ell^-\bar{\nu}_\ell)}{\mathrm{d}q^2}\mathrm{d}q^2 = \begin{cases} 15.3 \pm 2.4 \pm 3.4\ \ \mathrm{ps}^{-1} & \text{for} \quad \ell = e, \\ 15.3 \pm 2.4 \pm 3.4\ \ \mathrm{ps}^{-1} & \text{for} \quad \ell = \mu, \\ 12.5 \pm 1.9 \pm 2.7\ \ \mathrm{ps}^{-1} & \text{for} \quad \ell = \tau. \end{cases}$$

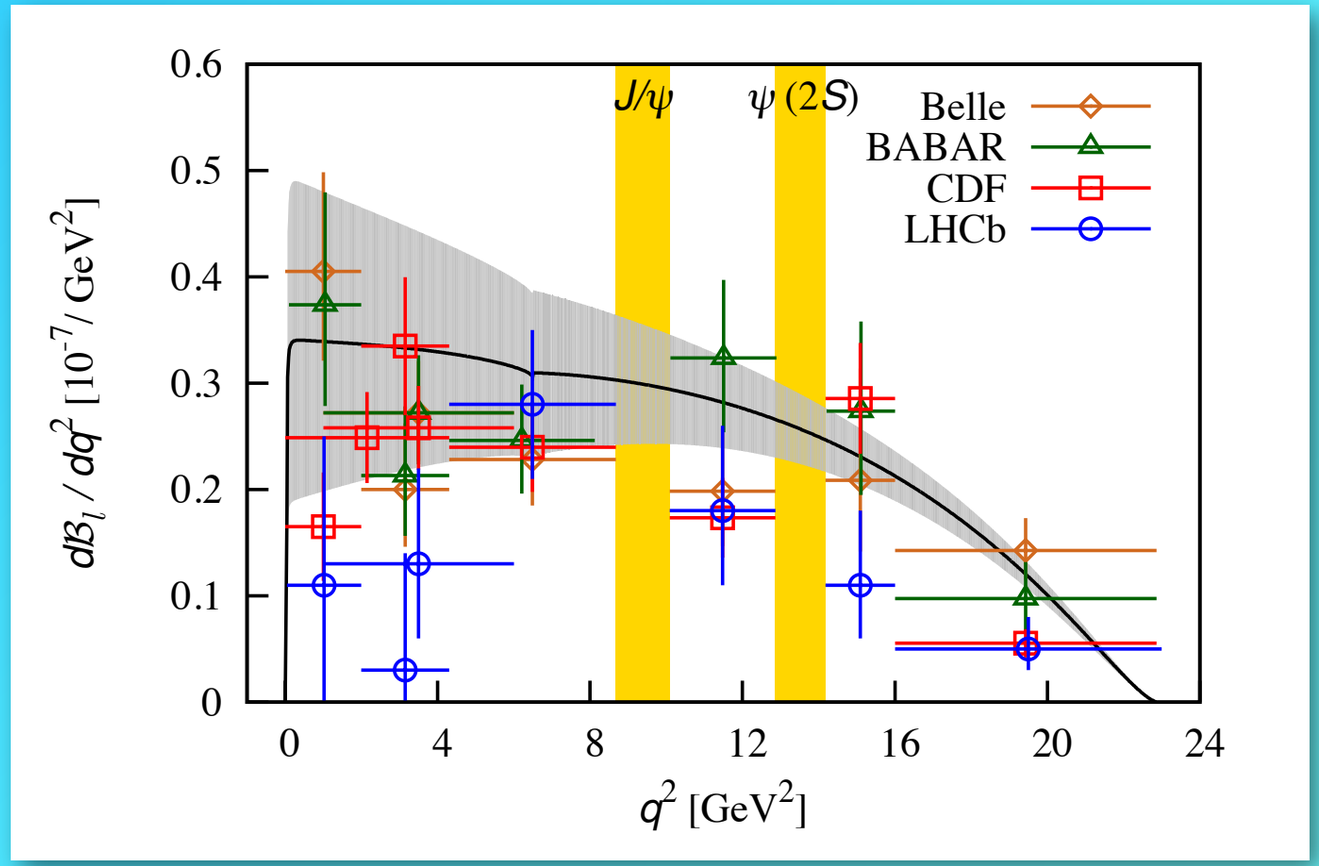
W Detmold *et al*, arXiv:1306.0446

$B \to K l^+ l^-$



HPQCD Collaboration (using NRQCD+HISQ valence on MILC n_f=2+1 asqtad)

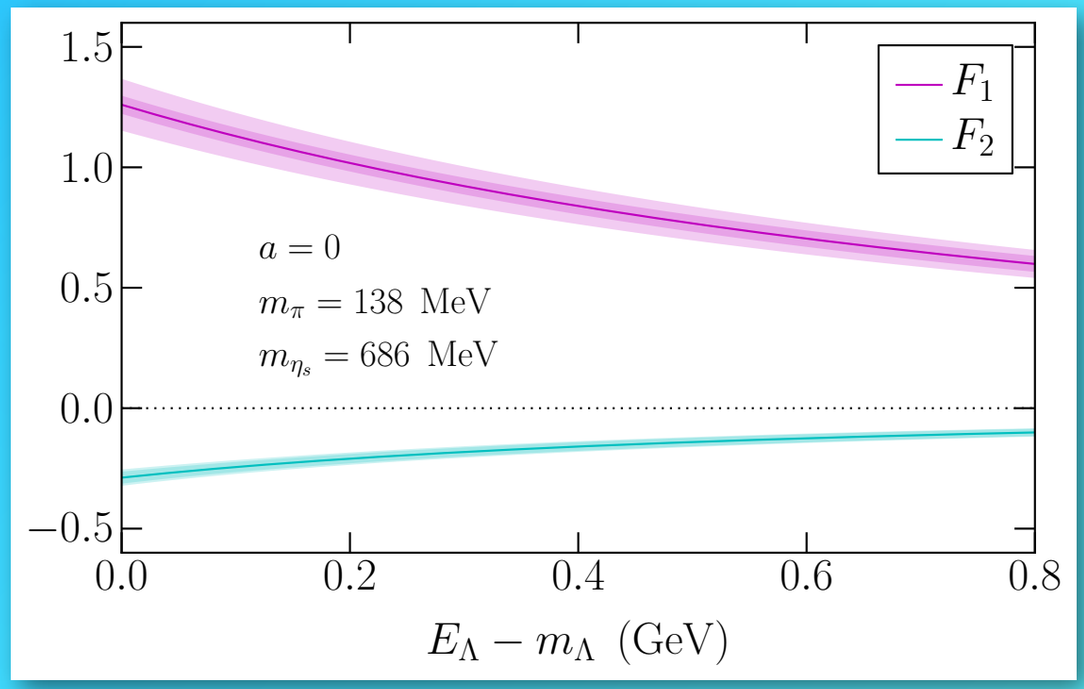
Gray: SM result (short distance only)



C. Bouchard *et al*, arXiv:1306.0434, arXiv:1306:2384

$\Lambda_b \to \Lambda\, l^+ l^-$

(using Static+DWF on n_f=2+1 RBC-UKQCD)

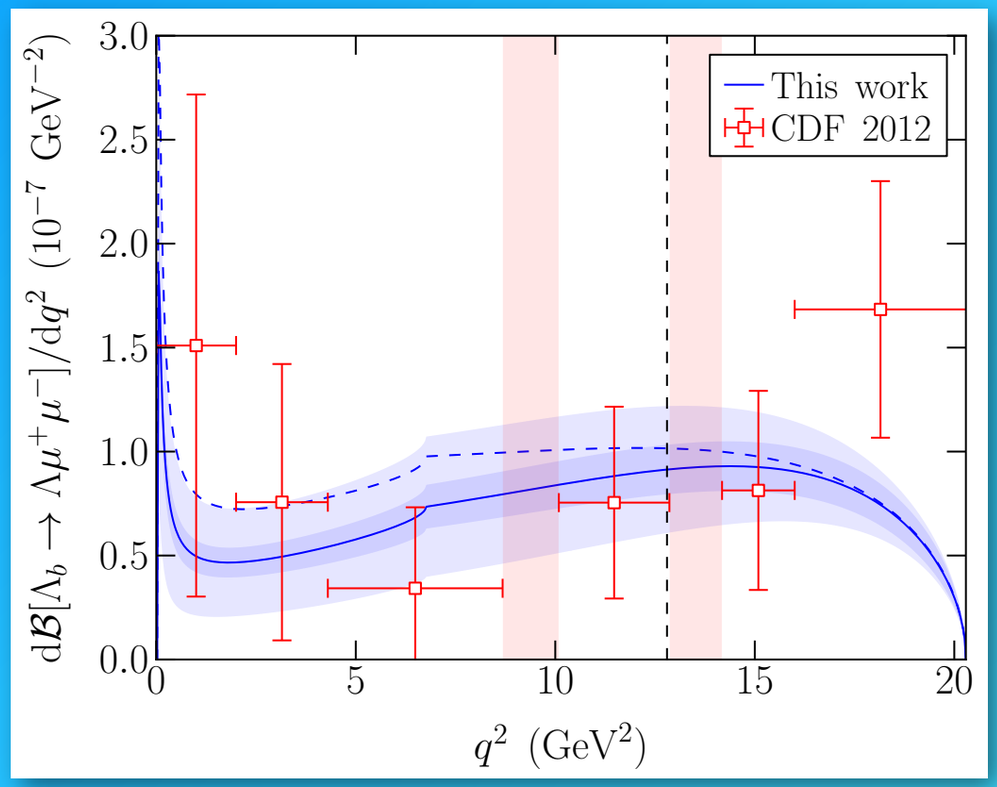


In the static limit, 10 form factors reduce to 2

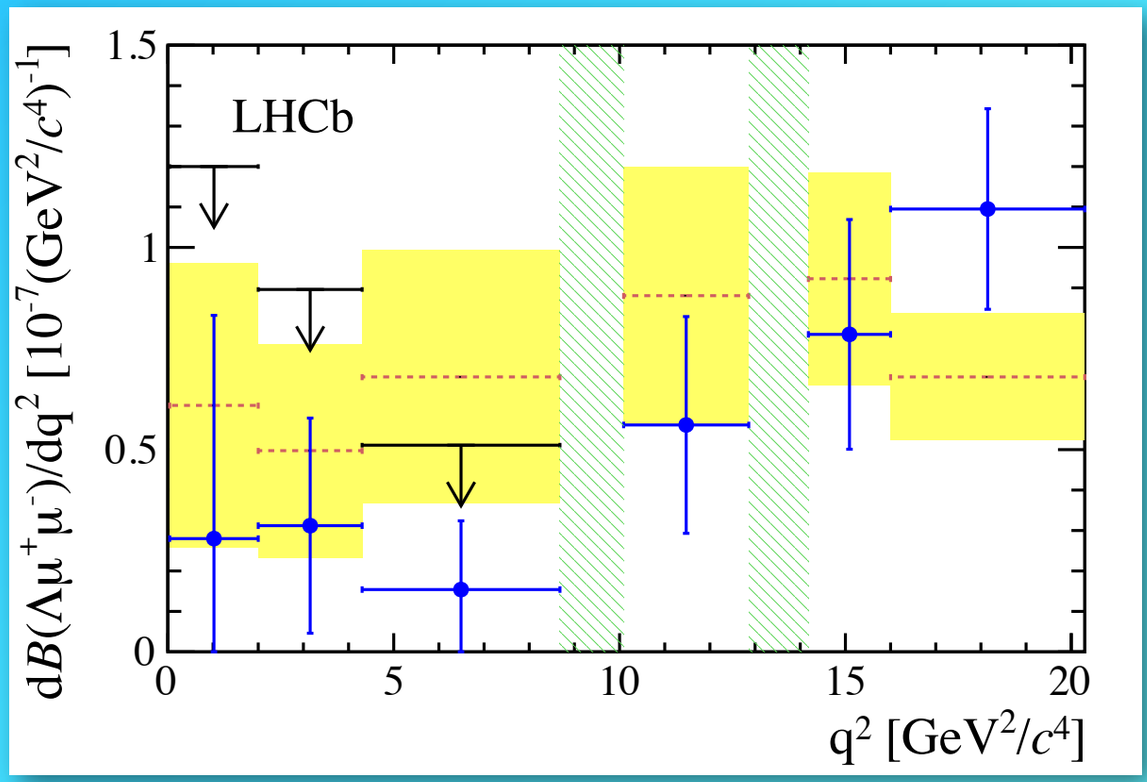
$$\langle \Lambda(p',s')|\, \bar{s}\Gamma Q\, |\Lambda_Q(v,0,s)\rangle \;=\; \bar{u}(p',s')\left[F_1(p'\cdot v) + \not{v} F_2(p'\cdot v)\right]\Gamma\, \mathcal{U}(v,s)$$

W Detmold *et al.*, Phys Rev D87 (2013)

$\Lambda_b \to \Lambda\, l^+ l^-$



CDF: red; LQCD: blue



LHCb: blue; binned LQCD: red/yellow

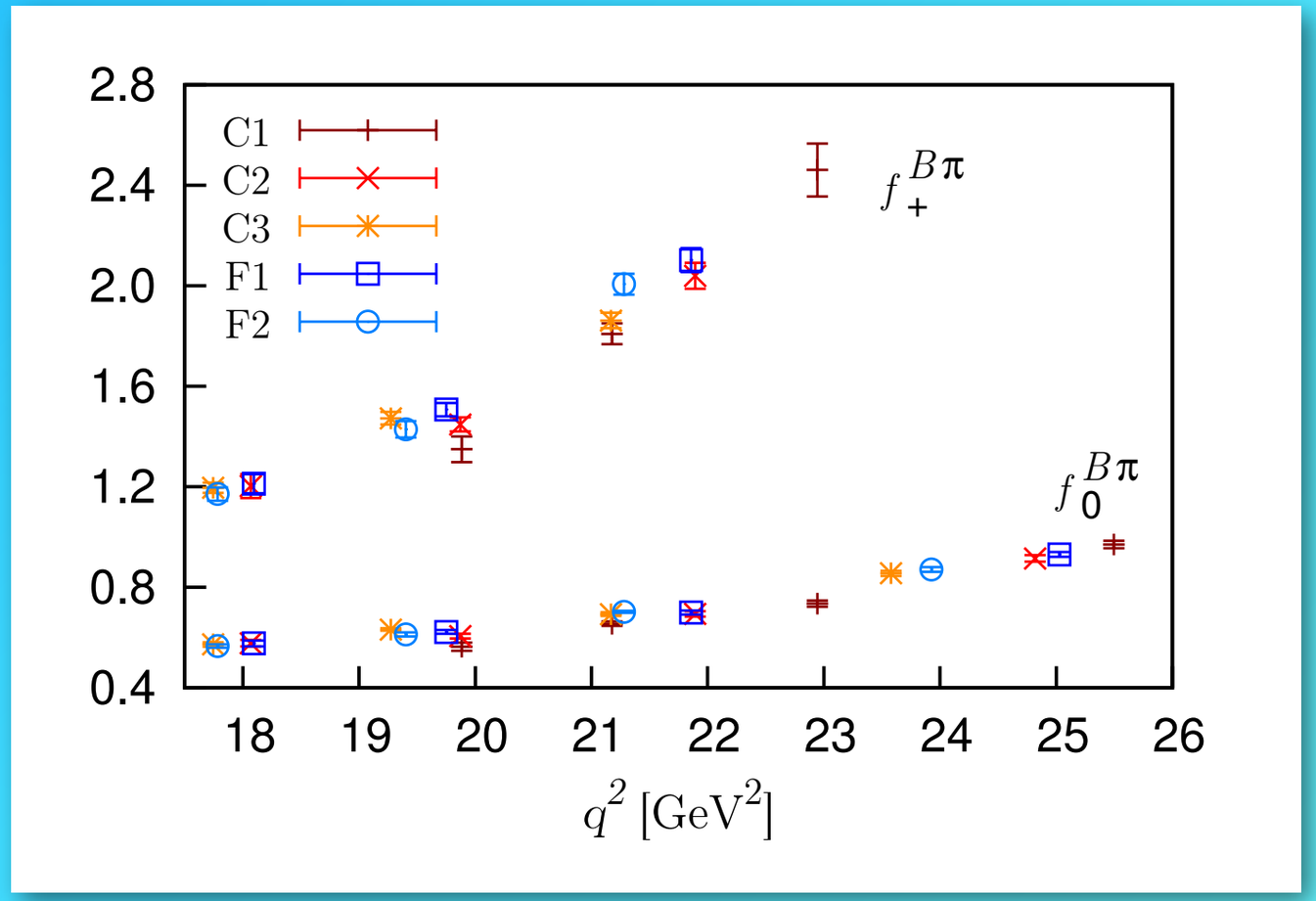
W Detmold *et al.*, Phys Rev D87 (2013)
CDF, public note 108xx, v0.1, http://www-cdf.fnal.gov/physics/new/bottom/bottom.html
LHCb, R Aaij, arXiv:1306.2577

$B \to D\, l\, \nu$

- BaBar 3.4σ excess in
  - $R(D^{(*)}) = \mathrm{BR}(B \to D^{(*)}\, \tau\, \nu)/\mathrm{BR}(B \to D^{(*)}\, l\, \nu)$
- Massive τ implies contribution from scalar f.f.
- Bailey et al (FNAL/MILC), PRL 109 (2012) update SM computation of *R(D)* with unquenched LQCD
- Excess vs. SM now 1.7σ

$B \to \pi l \nu$

- HPQCD (2006) and FNAL/MILC (2009) due to be updated
- ALPHA collaboration using HQET, forecast 15% determination of $|V_{ub}|$, arXiv:1211.6327
- HPQCD updating with NRQCD/HISQ on MILC lattices.
  Previous operator matching error was probably too conservative.



C Bouchard *et al.*,
arXiv:1210.6992

Lattice 2013

29 July - 3 Aug, http://www.lattice2013.uni-mainz.de

- Many new results to be presented soon
- My EPS HEP proceedings will include some of these
- Review talk by A. El-Khadra (45 min talk, 15 page proceedings)
- Expect new results

Expect new results @ Lattice 2013

- $B \to \pi$ form factors with relativistic heavy quarks, update with NRQCD
- B physics results from CLS (wilson) and twisted-mass fermions
- D and D_s decay constants from FNAL/MILC
- $D_s \to \varphi$ form factors from HPQCD; $D \to \pi/K$ and $D_s \to K$ from ETMC
- K and D oscillations from ETMC
- $B \to D$ from FNAL/MILC
- Paper on $B_{(s)} \to K^*/\varphi$
- Some results will improve LQCD precision, others will provide important checks of formulations and systematic errors