Lattice QCD results for precision $b$ and $c$ physics

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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*<sub>s</sub> decay constants

Semileptonic decay form factors

- *D* → *K*, *Λ*<sub>b</sub> → *p*, *B* → *K*, *Λ*<sub>b</sub> → *Λ*

Out of time? If not, *B* → *D* and *B* → *π* quickly

Lattice 2013
$B$ & $B_s$ decay constants

\[ \langle 0| A^{\mu} | B(p) \rangle = p^{\mu} f_B \]
\(B \& B_s\) decay constants

- NRQCD/HISQ incl rad impr. on \(n_f = 2+1+1\) MILC HISQ

- Incl. lattices with physical \(m_\pi\)

- Operator matching \(\Rightarrow 4\%\) uncertainty in \(f\)'s

- Statistics, fits in \(a^2, r_1\) give 2-3\% uncertainties

\[f_B = 186(4) \text{ MeV}; \quad f_{Bs} = 224(4) \text{ MeV}; \quad f_{Bs}/f_B = 1.205(7)\]

\[ B \rightarrow \tau \nu \text{ and } B_s \rightarrow \mu \mu \]

\[ \frac{1}{|V_{ub}|^2} \mathcal{B}(B \rightarrow \tau \nu) = 6.05(20) \]

\[ \mathcal{B}(B \rightarrow \tau \nu) = 1.14(22) \times 10^{-4} \Rightarrow |V_{ub}| = 0.0043(4) \]

(HFAG May 2013)

New SM prediction, ignoring \( B_s \) oscillations

\[ \mathcal{B}(B_s \rightarrow \mu^+ \mu^-) = 3.17(15)(9) \times 10^{-9} \]

Including \( B_s \) oscillations

\[ \mathcal{B}(B_s \rightarrow \mu^+ \mu^-) = 3.47(19) \times 10^{-9} \]


Measured! \( 3.2^{+1.5}_{-1.2} \times 10^{-9} \) LHCb, PRL 110 (2013)
**$D \to Kl\nu$**

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 $q^2$:  

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

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

Series (z) expansion

\[ t = q^2 \quad t_{\pm} = (m_B \pm m_F)^2 \]

Choose, e.g. \( t_0 = 12 \text{ GeV}^2 \)

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

Simplified series expansion

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

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; ...
\[ \Lambda_b \rightarrow p \ell^- \nu \]

In the static limit, 10 form factors reduce to 2

\[ \langle p(p', s') | \bar{s} \Gamma Q | \Lambda_Q(v, 0, s) \rangle = \bar{u}(p', s') [F_1(p' \cdot v) + \psi F_2(p' \cdot v)] \Gamma U(v, s) \]

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

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

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

W Detmold et al, arXiv:1306.0446
B → K \ell^+\ell^-

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

Gray: SM result (short distance only)

\[ \Lambda_b \rightarrow \Lambda \, l^+ l^- \]

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

In the static limit, 10 form factors reduce to 2

\[
\langle \Lambda(p', s') | \bar{s} \Gamma Q | \Lambda_Q(v, 0, s) \rangle = \bar{u}(p', s')[F_1(p' \cdot v) + \varphi F_2(p' \cdot v)]\Gamma U(v, s)
\]

Δ_b \rightarrow \Lambda \ l^+ l^-

CDF: red; LQCD: blue

LHCb: blue; binned LQCD: red/yellow

LHCb, R Aaij, arXiv:1306.2577
\[ B \rightarrow D l \nu \]

- BaBar 3.4\(\sigma\) excess in
  \[ R(D^{(*)}) = \frac{BR(B \rightarrow D^{(*)} \tau \nu)}{BR(B \rightarrow D^{(*)} l \nu)} \]
- Massive \(\tau\) 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 1.7\(\sigma\)
\[ B \rightarrow \pi l \nu \]

- 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.
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

- $B \rightarrow \pi$ 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
- $D_s \rightarrow \phi$ form factors from HPQCD; $D \rightarrow \pi/K$ and $D_s \rightarrow K$ from ETMC
- $K$ and $D$ oscillations from ETMC
- $B \rightarrow D$ from FNAL/MILC
- Paper on $B_{(s)} \rightarrow K^*/\phi$
- Some results will improve LQCD precision, others will provide important checks of formulations and systematic errors