Weak decays of b and c quarks

RBC- and UKQCD collaborations

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Snowmass Rare Processes and Precision Measurements Frontier
Town Hall Meeting · October 2, 2020

Weak decays of b and c quarks

RBC- and UKQCD collaborations

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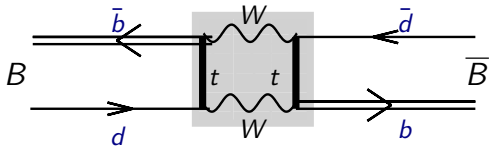
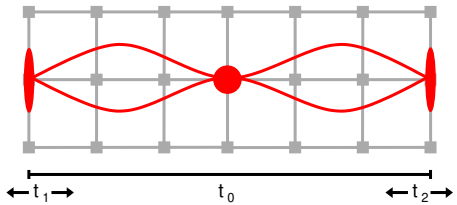
Motivation

- Tree- and loop-level decays of b and c quarks allow to test and constrain the Standard Model
- To fully leverage experimental research program, achieve theoretical uncertainties of similar size
- Effects of the strong force need nonperturbative method like lattice QCD
- RBC-UKQCD is planning to generate a new set of dynamical gauge field configurations to significantly improve results for b and c quarks
  - $\rightarrow$ Chiral domain-wall fermions at physical up/down, strange, and charm quark masses
  - $\rightarrow$ Inverse lattice spacings in the range $a^{-1} = 3 - 5$ GeV
  - $\rightarrow$ Benign extrapolation to reach physical b quark mass (all quarks same relativistic action)
  - $\rightsquigarrow$ Algorithmic challenges (e.g. tunneling of topological charge) are subject of active research

Neutral meson mixing, meson lifetimes, and leptonic decays





- Loop-level processes allow determination of CKM matrix elements $|V_{td}|$ and $|V_{ts}|$
- Important constraint in global CKM triangle fits
- Experimentally measured oscillation frequencies are known at sub-percent precision
- Recently we achieved percent-level precision for SU(3) breaking ratios in mixing
- In the next few years we aim to
  - → Determine bag parameters, decay constants, and their ratios with sub-percent level precision
    - ⇝ Need to account for electromagnetic effects
  - → Determine life times at percent-level precision

Example: SU(3) breaking ratios (ξ)

- Oscillation frequencies parametrized by

$$\Delta m_q = \frac{G_F^2 m_W^2}{6\pi^2} \eta_B S_0 M_{B_q} f_{B_q}^2 B_{B_q} |V_{tq}^* V_{tb}|^2, \qquad q = d, s$$

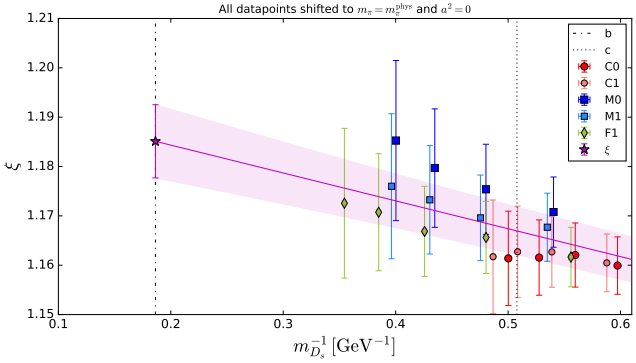
[Boyle et al. arXiv:1812.08791]

- Advantageous to consider

[Bernard, Blum, Soni PRD58(1998)014501]

$$\frac{\Delta m_s}{\Delta m_d} = \frac{M_{B_s}}{M_{B_d}} \xi^2 \frac{|V_{ts}|^2}{|V_{td}|^2}$$

$$\xi^2 = \frac{f_{B_s}^2 B_{B_s}}{f_{B_d}^2 B_{B_d}}$$



Exclusive semileptonic decays at tree- and loop-level

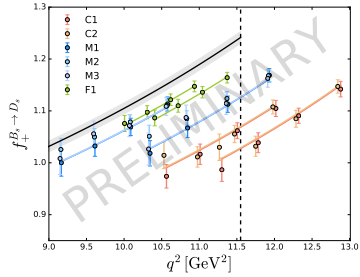
- At tree level, SM allows only charged weak current flavor-changing decays
  - → In combination with experimental measurements, extract CKM matrix elements
  - → Absence of tree-level neutral current decays provides stringent tests of the SM
- R-ratios: decays with same hadronic but different generations of leptonic final states

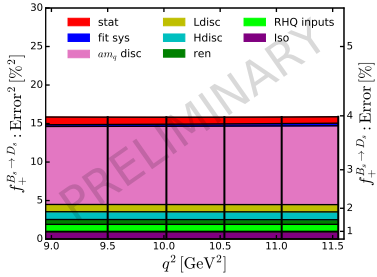
- Calculate form factors for tree- and loop-level $B_{(s)}$ and $D_{(s)}$ decays with pseudoscalar or vector hadronic final state
  - → Directly cover most of the allowed range of momentum transfer q^2
  - → Achieve sub-percent level precision for pseudoscalar final states
  - → Overcome narrow-width approximation for vector final states
  - → Better understand impact of long-distance contributions (charm resonances) in loop-level decays

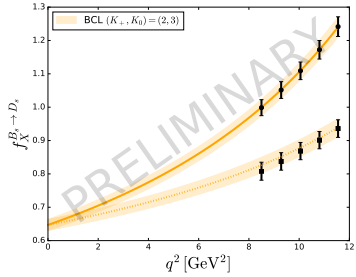
- Explore heavy meson decays to multi-hadron states e.g. $D \to \pi\pi$
- Semi-leptonic decays of baryons

Example: $B_s \to D_s \ell \nu$

[Flynn, Hill, Jüttner, Lizarazo, Soni, Tsang, OW in preparation]







- Colored data points are outcome of numerical simulations on different ensembles
- Perform combined correlated fit to obtain f_+ and f_0 at physical quark masses and in the continuum
- Estimate and account for systematic effects
- Cover full q^2 range by performing a z expansion (BGL, BCL)
- Combine with experimental data or compare to other calculations

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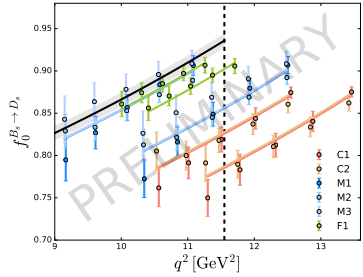
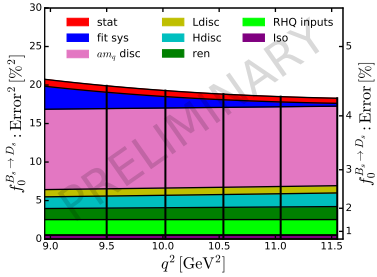
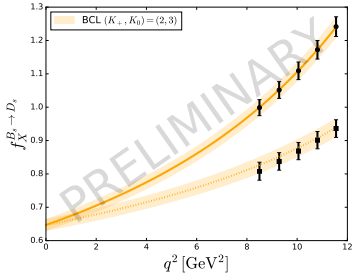
[Flynn, Hill, Jüttner, Lizarazo, Soni, Tsang, OW in preparation]







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Inclusive decays and distribution amplitudes

- New ideas to calculate inclusive decays using lattice QCD
  [Gambino, Hashimoto PRL125(2020)032001] [Hashimoto PTEP(2017)053B03] [Hansen, Meyer, Robaina PRD96(2017)094513]

→ Gain new insight into long-standing deviation between inclusive and exclusive $|V_{ub}|$ and $|V_{cb}|$

→ Explore nonperturbative determination of $B_{(s)}$ and $D_{(s)}$ meson distribution amplitudes

Radiative decays

- Additional hard photon lifts helicity suppression in leptonic decay of a pseudoscalar meson
  → Larger set of operators in the weak effective Hamiltonian
- For large photon energy, $B \to \ell\nu_\ell\gamma$ is clean probe of first inverse moment $1/\lambda_B$ of B meson LCDA
  → Similarly $D_{(s)} \to \ell\nu_\ell\gamma$ provides insight for the charm sector taking advantage of BESIII data
- General procedure is established [Kane et al. arXiv:1907.00279][Desiderio et al. arXiv:2006.05358]