Semi-leptonic B and B_s-decays with charming hadronic final state

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http://rbc.phys.columbia.edu/USQCD/B-physics/

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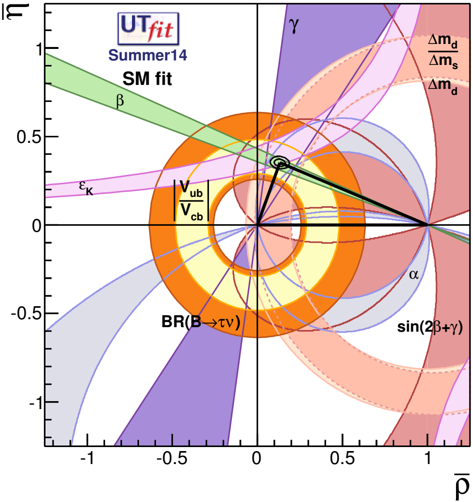
Motivation: CKM unitarity triangle fit



$|V_{cb}|$ enters crucially as normalization of the unitarity triangle

$\varepsilon_K \propto |V_{cb}|^4$

http://utfit.roma1.infn.it, http://ckmfitter.in2p3.fr, http://www.latticeaverages.org

Motivation

- Form factors for $B \to D^{(*)}\ell\nu$
  - $\to$ Allow to determine the CKM matrix-element $|V_{cb}|$
  - $\to$ $|V_{cb}|$ enters as normalization in the unitary triangle fit
  - $\to$ $2-3\ \sigma$ discrepancey between $|V_{cb}|^{\text{incl}}$ and $|V_{cb}|^{\text{excl}}$
  - $\to$ Atlas, CMS, LHCb and Belle II will improve experimental results

- $2-3\ \sigma$ tension in $R_{D^{(*)}}$ ratio — independent of $|V_{cb}|$

[Fajfer et al. PRD 85 (2012) 094025],[J. Bailey et al. PRL 109 (2012) 071802],[BaBar PRL 109 (2012) 101802]

$$R_{D^{(*)}} = \mathcal{B}(B \to D^{(*)}\tau\nu_\tau)/\mathcal{B}(B \to D^{(*)}\ell\nu_\ell),\ \text{with}\ \ell = e, \mu$$

- $\to$ Due to its mass τ is sensitive to both form factors $f_+(q^2)$ and $f_0(q^2)$, $\ell = e, \mu$ are dominated by $f_+(q^2)$
- $\to$ Anomaly in R_{D^*} is seen by BaBar, LHCb, and Belle
- $\to$ New physics?

Motivation: $R_{D^{(*)}}$

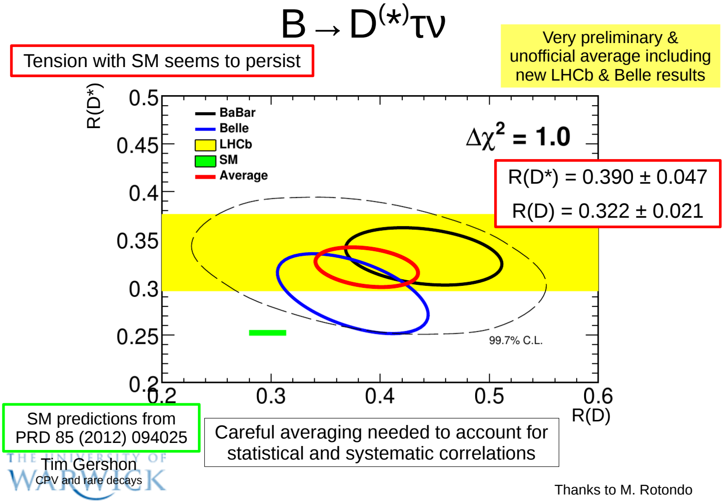


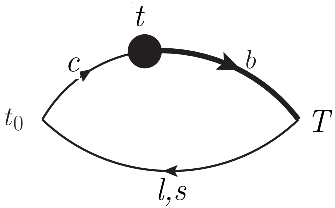
Figure: [Talk by T. Gershon at MIAPP June 2015]

Our RHQ Project

- Use domain-wall light quarks and nonperturbatively tuned relativistic b-quarks to compute at few-percent precision
  - Nonperturbative tuning of RHQ parameters [PRD 86 (2012) 116003]
  - Decay constants f_B and f_{B_s} [PRD 91 (2015) 054502]
  - $B \to \pi \ell \nu$ and $B_s \to K \ell \nu$ form factors [PRD 91 (2015) 074510]
  - $g_{B^* B \pi}$ coupling constant [PRD 93 (2016) 014510]
  - B^0–$\overline{B^0}$ mixing
  - Rare B decays [arXiv:1511.06622]

- f_B, f_{B_s}, and semi-leptonic form factors
  - $O(a)$ improvement at 1-loop and mostly nonperturbative renormalization
  - Correction factors and coefficients computed at 1-loop
- B mixing
  - Tree-level $O(a)$ improvement
  - Perturbative or mostly nonperturbative renormalization

$B_{(s)} \to D_{(s)}^{(*)}$ form factors



- Re-use DWF point-source light and strange quark propagators
- Generate Gaussian smeared MDWF charm quark propagators (on the fly)
- Create Gaussian smeared-source sequential heavy quark propagators

- Compute all possible contractions for pseudoscalar or vector final states
- General building blocks code incl. terms for 1-loop $O(\alpha_S a)$ improvement
- Coefficients to be computed in lattice perturbation theory

2+1 Flavor Domain-Wall Iwasaki ensembles

L	a^{-1}(GeV)	am_l	am_s	M_π(MeV)	# configs.	#sources	
24	1.785	0.005	0.040	338	1636	1	[PRD 78 (2008) 114509]
24	1.785	0.010	0.040	434	1419	1	[PRD 78 (2008) 114509]
32	2.383	0.004	0.030	301	628	2	[PRD 83 (2011) 074508]
32	2.383	0.006	0.030	362	889	2	[PRD 83 (2011) 074508]
32	2.383	0.008	0.030	411	544	2	[PRD 83 (2011) 074508]
48	1.730	0.00078	0.0362	139	40	81/1*	[PRD 93 (2016) 074505]
64	2.359	0.000678	0.02661	139	—	—	[PRD 93 (2016) 074505]
48	$\sim$2.7	0.002144	0.02144	$\sim$250	$>$ 50	24	[in progress]

* All mode averaging: 81 "sloppy" and 1 "exact" solve [Blum et al. PRD 88 (2012) 094503]

- Lattice spacing determined from combined analysis [Blum et al. PRD 93 (2016) 074505]
- a: $\sim$ 0.11 fm, $\sim$ 0.08 fm, $\sim$ 0.07 fm

Up, down, and strange quarks

- Domain-wall fermions with same parameters as in the sea-sector (domain-wall hight M_5, extension of 5^{th} dimension L_s)
- Unitary and partially quenched quark masses
- Strange quarks at/near physical the physical value

Charm quarks

- Möbius DWF optimized for heavy quarks [Boyle et al. JHEP 1604 (2016) 037]
- $M_5 = 1.6$, $L_s = 12$
- Discretization errors well under control for $am_c < 0.45$
  - → On coarse ($a^{-1} = 1.785$ GeV) ensembles we simulate just below m_c^{phys}
  - → Simulate 3–4 charm-like masses and then extrapolate/interpolate
  - → Linear extrapolation is small and benign; interpolation is safe

Charm extrapolation

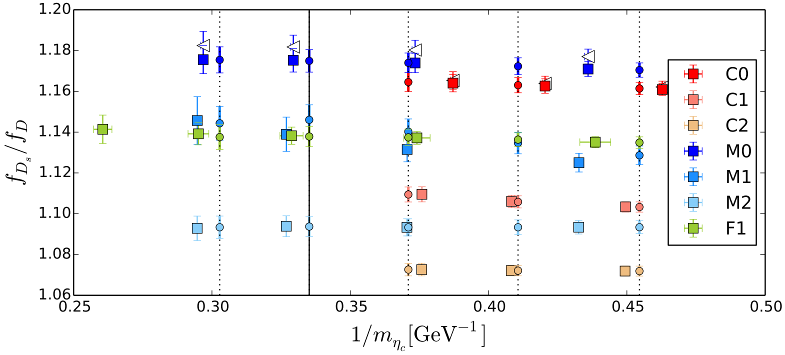


Figure: [Boyle et al. arXiv:1511.09328]

- Open triangles: simulated data with mistuned valence strange quark mass
- Squares: data after correcting valence strange quark
- Circles: interpolation to reference masses

MDWF charm quarks

Advantages

- Very similar setup for computing $B_s \to D_s$ as for $B_s \to K$
  - $\to$ Only minor modifications for the perturbative calculations
- No nonperturbative tuning of the RHQ action for charm quarks
- Allows to explore new concept of heavy DWF for semileptonic decays
  - $\to$ Fully nonperturbative renormalization of f_D in progress

Disadvantages

- Larger numerical costs than RHQ charm
- On coarse ensembles small extrapolation needed

Bottom quarks

- Relativistic Heavy Quark action developed by Christ, Li, and Lin
  [Christ et al. PRD 76 (2007) 074505], [Lin and Christ PRD 76 (2007) 074506]
- Allows to tune the three parameters ($m_0 a$, c_P, ζ) nonperturbatively
  [PRD 86 (2012) 116003]
- Builds upon Fermilab approach [El-Khadra et al. PRD 55 (1997) 3933]
  by tuning all parameters of the clover action non-perturbatively;
  close relation to the Tsukuba formulation [S. Aoki et al. PTP 109 (2003) 383]
- Heavy quark mass is treated to all orders in $(m_b a)^n$
- Expand in powers of the spatial momentum through $O(\vec{p}a)$
  - Resulting errors will be of $O(\vec{p}^2 a^2)$
  - Allows computation of heavy-light quantities with discretization errors of the same size as in light-light quantities
- Applies for all values of the quark mass
- Has a smooth continuum limit
- Recently re-tuned to account for updated values of a^{-1}

Proposal 2016/17

- Request: 16.0 M Jpsi core hours for computing
  + 3.8 M Jpsi core hours for storage
- Aim: compute $B_{(s)} \to D_{(s)}$ form factors and determine $|V_{cb}|$ as well as $R_{D^{(*)}}$ ratios
- Provide results based on different gauge fields and actions and thus with uncorrelated statistical and different systematic errors to existing results in the literature
- Explore semileptonic decays with heavy MDWF

Questions from the SPC (shortend)

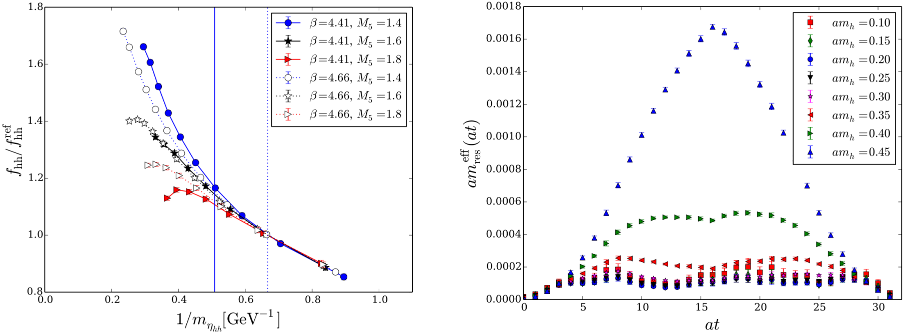
1) Expectations for the precision of your calculation (stat. and sys.)
   - We target statistical and systematic errors to be both less than 2%
2) Controlling the error of the charm extrapolation and expected size
   - The charm extrapolation is small and we expect a sub-percent error
3) Plan to use double-ratios like Fermilab/MILC
   - Double ratios roughly double the costs so we did not propose to use them; we are however investigating the advantages and may refine our computational strategy
4) Have you considered a multi-mass inverter for DW charm propagators?
   - Multi-mass solvers do not exist for DWF
5) Have you considered performing a blind analysis?
   - Yes, we look into adding a blinding factor to our PT computed factors
6) Can you run on the new Jlab machine, if a) cpu, b) GPU, c) KNL?
   - Sorry, transferring 200 TB will neither make the site managers nor us happy

Resources and Acknowledgements

- Simulations on 24^3, 32^3, and the 48^3 ensemble with physical pions
  USQCD: kaon, J/psi, Ds, Bc, and pi0 cluster at Fermilab
  BNL and Columbia U: small local clusters
- Simulations on the $a^{-1} \sim 2.7$ GeV 48^3 ensemble
  ARCHER UoE: Cray XC30
  DiRAC UoE: BG/Q

MARIE CURIE ACTIONS
SEVENTH FRAMEWORK PROGRAMME

Extra: Heavy MDWF



Figures: [Boyle et al. JHEP 1604 (2016) 037]

- $M_5 = 1.6$ has smallest discretization errors
- For $am \gtrsim 0.4$ $m_{\rm res}$ does not plateau