$B_c^+ \to D^0\ell^+\nu$ with lattice QCD: a heavy to light quark transition

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Introduction

The *bottom* quark is roughly 2000 times as massive as the *up* quark. To study the tree-level quark transition $b \to u$ (parametrised by the CKM matrix element V_{ub}) with lattice QCD requires very fine lattices to handle discretisation effects that grow with powers of am_b, as well as a very large lattices to reduce artefacts from having very light particles in a finite box. This amounts to a computationally demanding calculation.

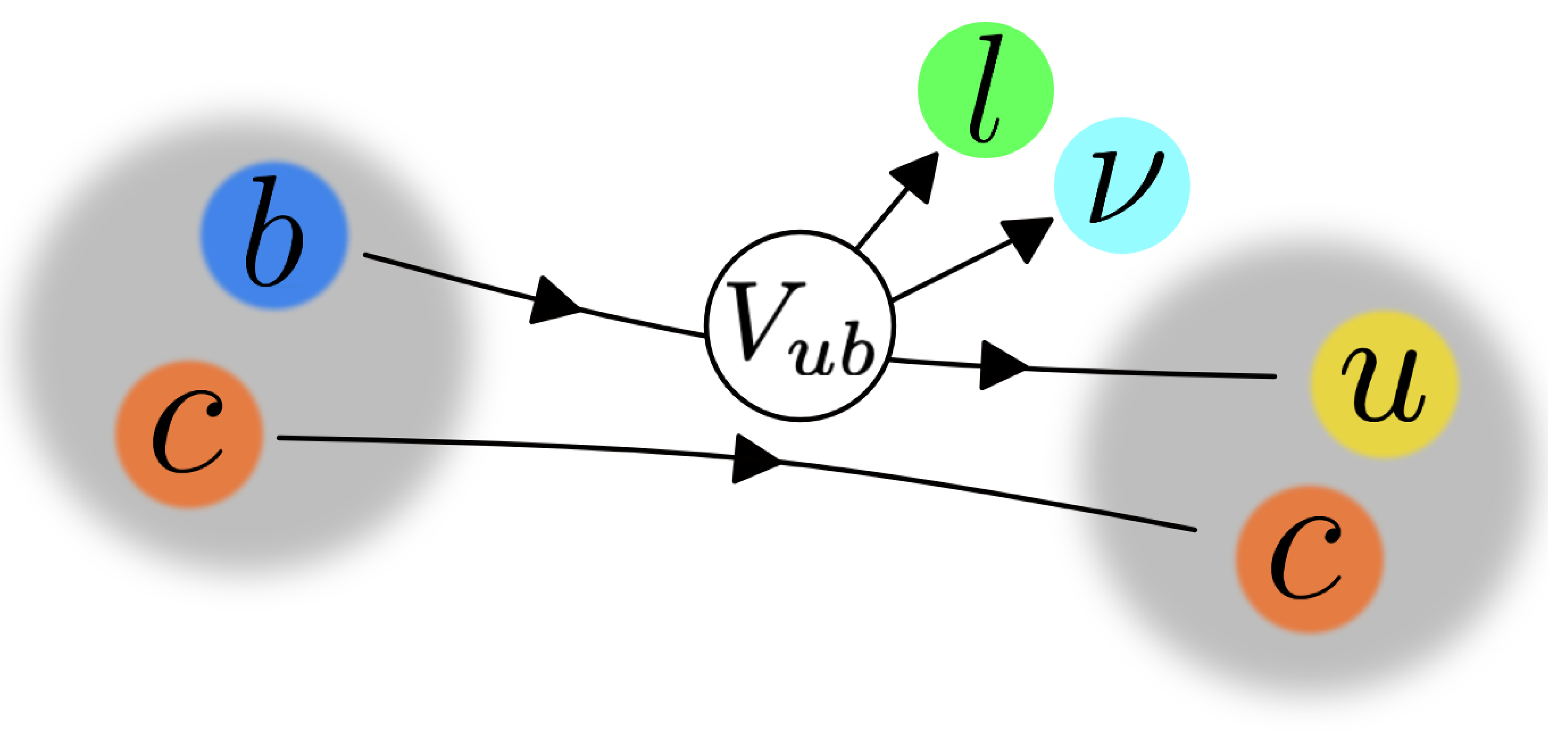

Figure 1: Cartoon of the $B_c^+ \to D^0\ell^+\nu$ tree-level semileptonic weak decay.

We study the process $B_c^+ \to D^0\ell^+\nu$ in which a $b \to u$ transition occurs. We use a selection of fine lattices and generate quark propagators at small masses with non-zero momentum for the first time. This enables us to describe the physics of the transition throughout the entire physical range of squared 4-momentum transfer q^2.

Lattice Methodology

The form factors $f_0(q^2)$ and $f_+(q^2)$, derived from the matrix element of the vector current V^μ between the initial and final hadronic states, B_c^+ and D^0 respectively, are extracted at various q^2 and extrapolated to the physical-continuum limit before combining with the CKM matrix element V_{ub} to predict the semileptonic decay rate $\Gamma(B_c^+ \to D^0\ell^+\nu)$. We use HPQCD's *heavy-HISQ* method (see [1] for example) in which the HISQ formalism [2] is used for all flavours of quark and data with lighter-than-physical b quarks informs results with b quarks at their physical mass. This strategy is fully-relativistic. We non-perturbatively renormalise the local lattice vector current that facilitates the flavour-changing process by using the Partially Conserved Vector Current Ward identity.

We extract the matrix elements from Euclidean-space correlators on the lattice. Lattice correlators are realised by taking a Monte-Carlo average of a trace of space-colour propagator matrices over a set of gauge field configurations (generated by the MILC Collaboration). The matrices are found by a costly inversion computation.

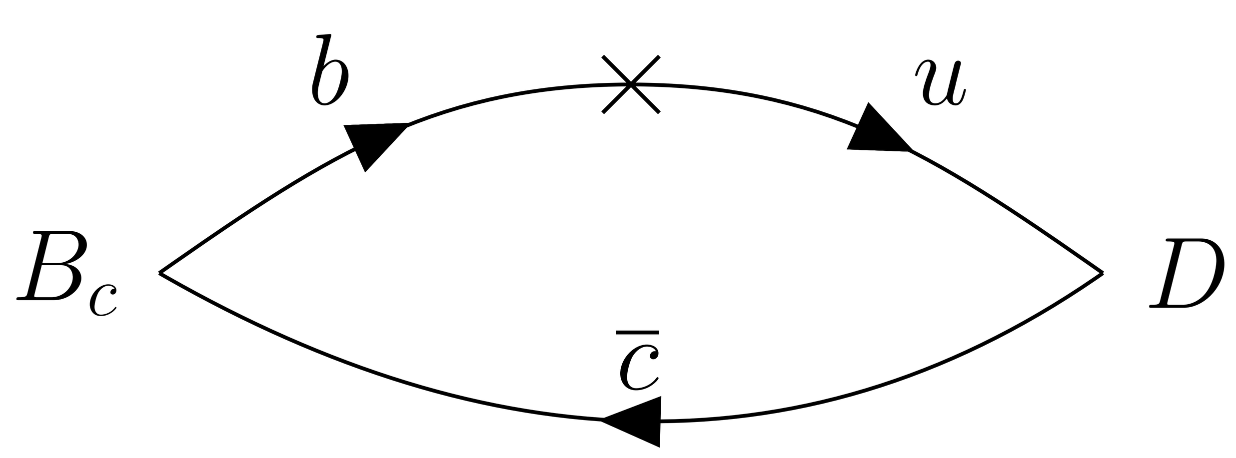

Figure 2: Diagrammatic representation of the 3-point correlators. Lines denote propagators and the flavour-changing insertion is given by a cross.

Using the DiRAC HPC Facility

We use the DiRAC HPC Facility to compute a variety of propagators on each set configuration. The following propagators are calculated on the *Peta4-Skylake* CPU cluster:

- HISQ propagators at the mass of the charm quark and heavier at zero-momentum
- Light HISQ propagators on our finest lattice at 3 different non-zero momenta ($\sim$ 2 million core hours)

The latter forms the bulk of our computational expense. These propagators will be reused in the future for other calculations of heavy-to-light quark transitions. Other propagators are being reused from previous calculations having been originally calculated on the superseded *Darwin* cluster.

As well as generating propagators for constructing correlation functions, we also carry out a selection of correlator fits on CSD3 to probe stability and accuracy of the extraction of matrix elements.

Results (preliminary)

In the below figure, we show preliminary results for the vector current form factors $f_{0,+}$ corresponding to physical quark masses in the continuum limit (vanishing lattice spacing).

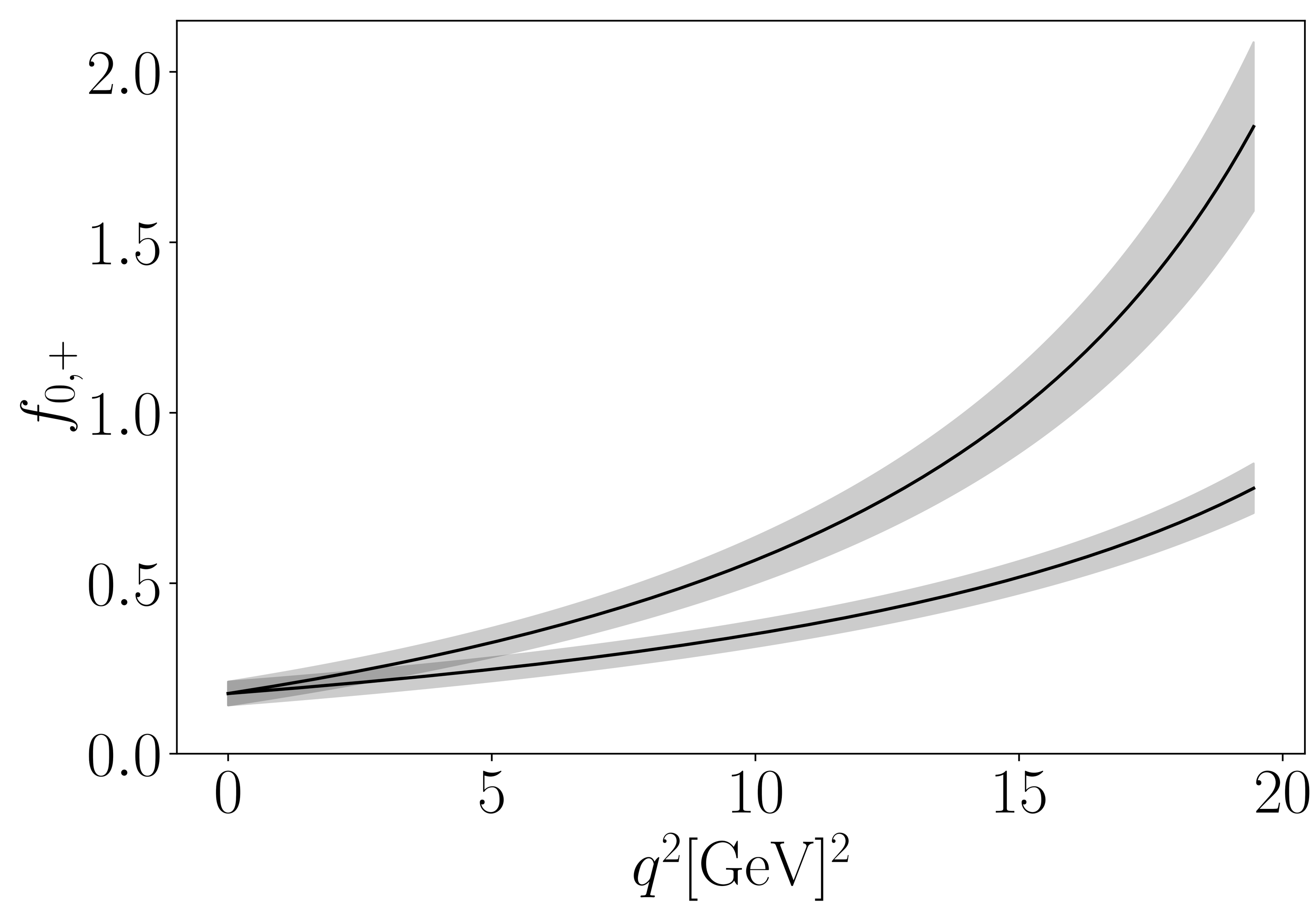

Figure 3: Form factors f_0 (bottom) and f_+ (top) for $B_c^+ \to D^0\ell^+\nu$ from our heavy-HISQ analysis.

Collection of lattice data is ongoing. Comparing our form factors from lattice QCD with observation of the decay $B_c^+ \to D^0\ell^+\nu$ from experiment will lead to a new exclusive determination of the CKM matrix element V_{ub}. Historically, there has been long-standing tension between exclusive determinations (from specific decays, e.g. $B \to \pi$) of V_{ub} and the inclusive determination (summing over all possible final hadron states). Our calculation here will provide another perspective on the mysteries of the CKM matrix.

[1] E. McLean et al., Phys. Rev. D 101, 074513 (2020)

[2] E. Follana et al., Phys. Rev. D 75, 054502 (2007)