SEMILEPTONIC FORM FACTORS FOR $B \to \pi\ell\nu$ DECAYS

Jonathan Flynn[1], Ryan Hill[1], Andreas Jüttner[1], Amarjit Soni[2], J Tobias Tsang[3], Oliver Witzel[4]
(RBC-UKQCD collaborations)
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[1]Physics and Astronomy, University of Southampton, Southampton, UK, [2]Physics Department, Brookhaven National Laboratory, Upton, USA, [3]CP3-Origins and IMADA, University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark, [4]Department of Physics, University of Colorado Boulder, Boulder, USA

INTRODUCTION

- The Standard Model (SM) is a description of the strong and electroweak forces and the particles they act upon
- Six quarks in the SM — u, d, c, s, t, b — distinguished by 'flavour'
- Composite particles in the SM (mesons, baryons) decay through weak processes that change the flavour of a constituent quark
- The CKM matrix is a 3×3 unitary matrix that parameterises the strength of flavour-changing weak interactions between the six SM quarks
- Violations of CKM unitary would indicate new physics like yet unknown new particles and/or interactions
- Two key variables needed to calculate CKM matrix elements:
  - Decay rates Γ — from experiment
  - QCD form factors f_+, f_0 — from theory simulations
- If the experiment and theory disagree then this is an exciting indication of new physics
- This work: improved determination of $B \to \pi\ell\nu$ form factors and matrix element $|V_{ub}|$

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- $2-3\sigma$ tension between $|V_{ub}|$ determinations from exclusive $B \to \pi\ell\nu$ and inclusive $B \to X_u\ell\nu$ decays $\Rightarrow$ new physics or not?
- Comparatively few studies of $B \to \pi\ell\nu$: more results desired!

LATTICE QCD SIMULATION

- Perturbation theory fails at the relevant energy scales: require a non-perturbative approach
- Lattice Quantum Chromodynamics (Lattice QCD) is a first-principles, systematically improvable non-perturbative formulation of QCD
- QCD fields are simulated at discrete points in a finite box
- Simulate 2-point functions for B and π mesons, and 3-point functions for the $B \to \pi$ process via Monte-Carlo integration of path integrals
- Fits to ratios of the 3-point and 2-point functions can be taken to extract the form factors $f_\perp$ and $f_\parallel$ that parameterise the spatial and temporal behaviour respectively for these simulations

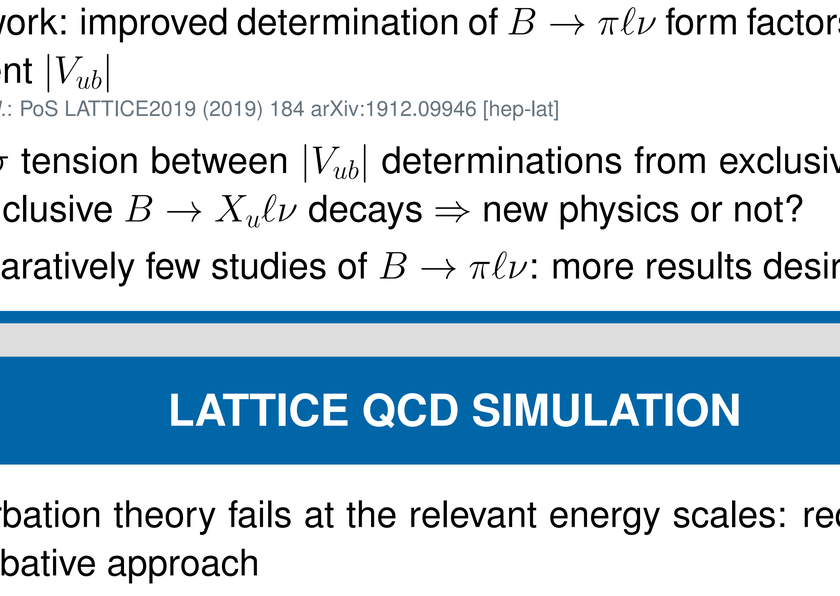

Figure 1: Ground-state (green) and first-excited-state (blue) fits to $f_\perp$ form factor data with final-state square lattice momentum equal to 1. The value of the form factor for the ground states is indicated at the y-axis.

- Obtain f_+, f_0 via a linear combination with meson masses
- These form factors are not the final result since they contain lattice artifacts: finite volume and discretisation effects that must be removed by extrapolating the results to the continuum.

CONTINUUM PHENOMENOLOGY

- Even state-of-the-art HPC resources cannot simulate QCD at physical quark masses, large volumes, and sufficiently small lattice spacings
- Requires extrapolation of lattice results to the physical continuum: here we are guided by SU(2) chiral perturbation theory
- Three key parameters: M_π, E_π, lattice spacing a
- Results from the lattice sample this parameter space:
  - At two values of M_π on a coarse (C) lattice spacing;
  - At three values on a medium (M) spacing;
  - At one value on a fine (F) spacing (for a total of six "ensembles")
- Sample E_π by varying π momenta on each ensemble
- Recover continuum behaviour: set $M_\pi = M_\pi^{\rm phys}$, $a = 0$ in fit result

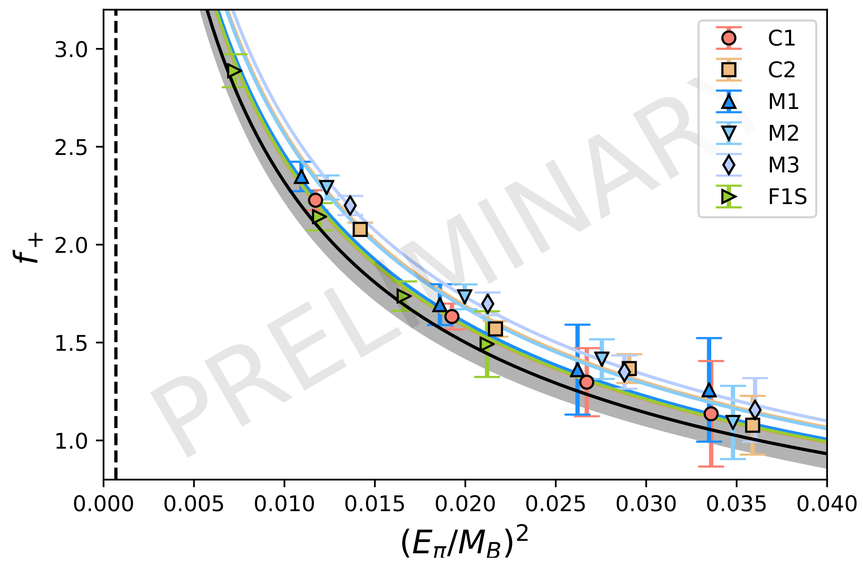

Figure 2: The SU(2) χPT-guided continuum result for the 24 data points for f_+. The lattice data points and fits are indicated with colours, whereas the continuum fit and statistical error are in black and grey.

- Inclusion of a new, finer lattice spacing with F1S ensemble has led to a substantial reduction in error over the previous 2015 analysis

  Flynn *et al.*,: Phys. Rev. D91 (2015) 074510, arXiv:1501.05373 [hep-lat]
- Consider possible variations of the continuum fit as a systematic error

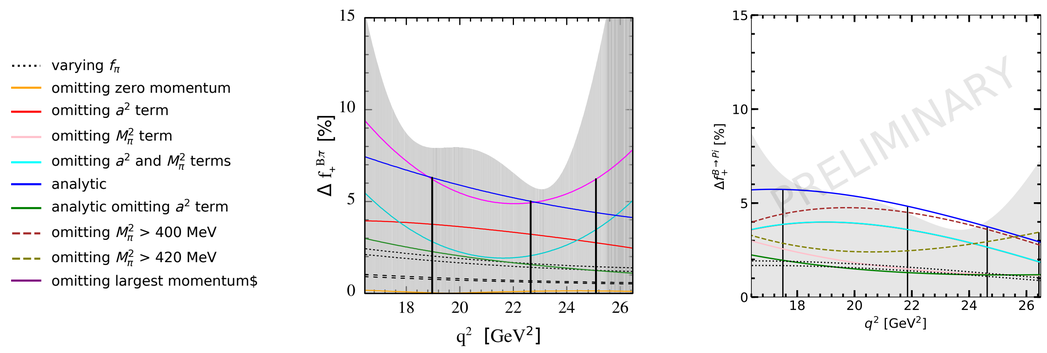

Figure 3: Previous (left) and new (right) continuum fit error budgets for the $B \to \pi\ell\nu$ f_+ form factor. The grey band is the statistical error on the preferred continuum fit, and the coloured lines indicate the percentage difference between the preferred fit and some variation.

- Combine this result with other sources of systematic error in order to build a complete error budget
- Extrapolate form factors over entire allowed momentum range using model independent parameterisations and compare to experiment
- Combine these results with the experimental data to obtain estimates of $|V_{ub}|$: currently finalising full momentum range extrapolation before this step.

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