Semileptonic B_c decays from full lattice QCD

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Intro & Motivation

- Obtain $|V_{cb}|$ from $b \to c$ transitions in semileptonic decays.
- Treatment of c and especially b quarks challenging in lattice simulations due to lattice artifacts which grow as $(am_q)^n$.
- We use two complementary approaches:
  - Highly improved relativistic action at small a, extrapolate $m_h \to m_b$.
  - Improved non-relativistic formalism (NRQCD) at m_b.
- First study:
  - $B_c \to \eta_c$
  - $B_c \to J/\psi$ [measureable at LHCb and/or Belle II ?]
- More precise $b \to c$ currents used in $B \to D$, $B \to D^*$.

DiRAC II computing

Computations carried out on the Darwin cluster at Cambridge.

Includes:

- 9600 Intel Sandy Bridge cores
- 2.6 GHz, 4 GB RAM/core
- 2 PB storage

Part of STFC's HPC facility for theoretical particle physics and astronomy.

$B_c \to \eta_c$

$$Z\langle \eta_c(p)|V^\mu|B_c(P)\rangle = f_+(q^2)\left[P^\mu + p^\mu - \frac{M^2-m^2}{q^2}q^\mu\right] + f_0(q^2)\,\frac{M^2-m^2}{q^2}\,q^\mu\,,$$

From PCVC,

$$\langle \eta_c(p)|S|B_c(P)\rangle = \frac{M^2-m^2}{m_{b0}-m_{c0}} f_0(q^2)$$

Find Z by calculating both matrix elements at $q^2_{\max}$.

$B_c \to \eta_c$

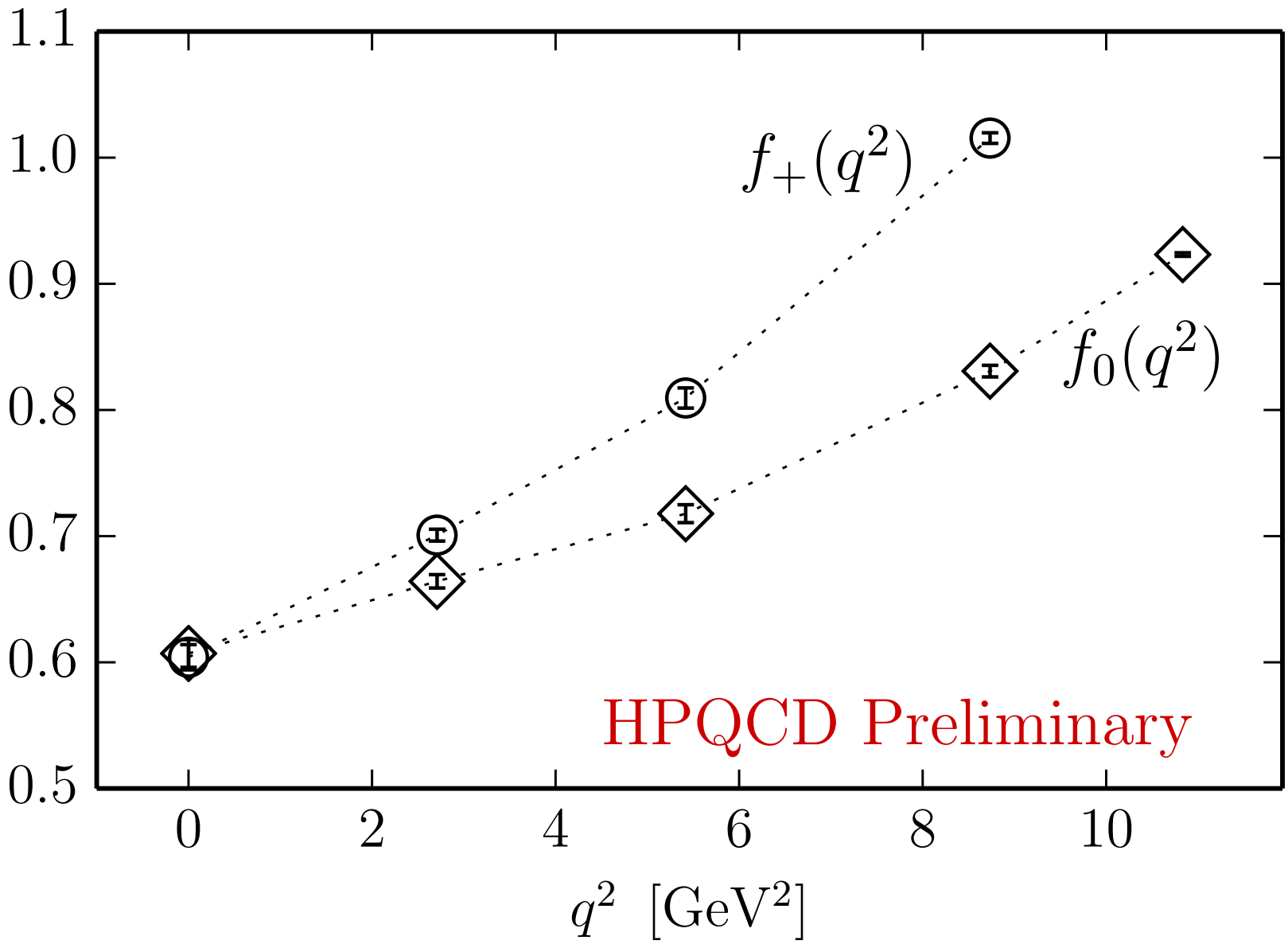
f_0 and f_+ are determined in the NRQCD formalism from matrix elements of the vector current $\langle V_\mu^{\rm nrqcd} \rangle$, where

$$V_0^{\rm nrqcd} = (1 + \alpha_s z_0^{(0)}) \left[V_0^{(0)} + (1 + \alpha_s z_0^{(1)}) V_0^{(1)} + \alpha_s z_0^{(2)} V_0^{(2)} \right]$$

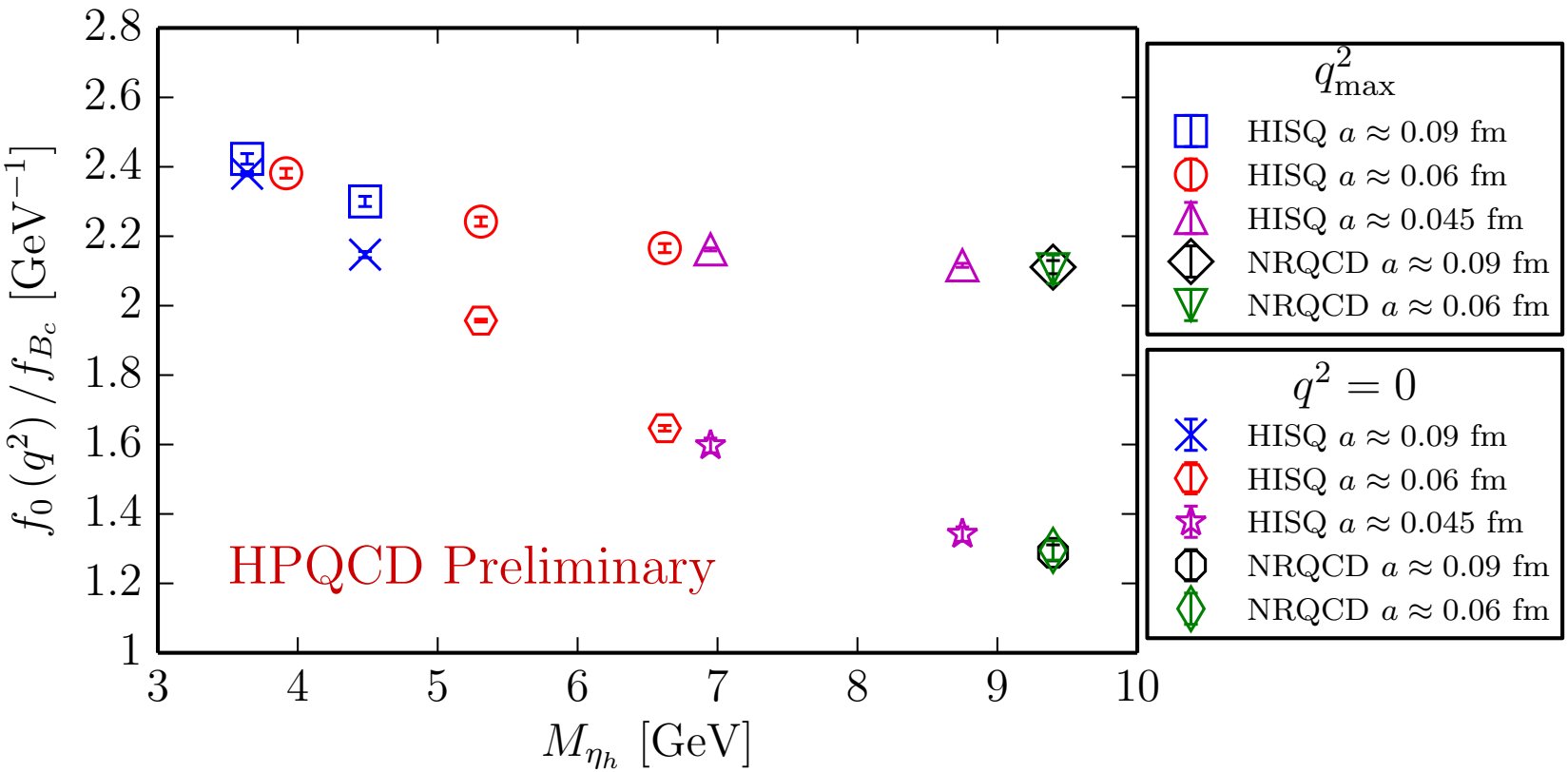
$$V_k^{\rm nrqcd} = (1 + \alpha_s z_k^{(0)}) \Big[V_k^{(0)} + (1 + \alpha_s z_k^{(1)}) V_k^{(1)} + \alpha_s z_k^{(2)} V_k^{(2)} + \alpha_s z_k^{(3)} V_k^{(3)} + \alpha_s z_k^{(4)} V_k^{(4)} \Big] .$$

One goal of the present work is to constrain the coefficients entering $V_\mu^{\rm nrqcd}$ using fully relativistic HISQ data.

$B_c \to \eta_c$ form factors from NRQCD



f_0 from relativistic HISQ quarks



Summary

- A promising approach to study of $b \to c$ transitions:
  - Lattice NRQCD with HISQ quarks, plus
  - Fully relativistic formulation, extrapolate m_h to m_b.
- Proof-of-principle demonstrated for f_0.
  - Controlled calculation over full q^2 range.
  - Good agreement seen with NRQCD results.
- Outputs:
  - B_c to $J/\Psi \to$ new possible determination of $|V_{cb}|$.
  - Improved understanding of NRQCD currents feeds into additional calculations (B to D, B to D^*, ...).