Form Factors For Heavy → Strange Semileptonic Decays

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B. Chakraborty: Today, 16:20, this session
D. Hatton: Tomorrow, 17:00, Had. Spec.
Overview

- Overview of heavy HISQ
- Results for $B_s \to \eta_s$ and what we can learn from it
- Moving towards $B \to K\ell^+\ell^-$
- Preliminary $B \to K\ell^+\ell^-$ and $D \to K\ell^-\bar{\nu}$ results
Overview of heavy HISQ

- Calculate meson form factors over the full range of $q^2 = (p_{\text{parent}} - p_{\text{daughter}})^2$ values
- Interested in $f_+(q^2)$ and $f_0(q^2)$ form factors for pseudo scalar to pseudo scalar decays
- Require three-point correlators with scalar and vector current insertions
Overview of heavy HISQ

- MILC HISQ 2+1+1 ensembles. All valence quarks HISQ
- 0.09fm 0.06fm and 0.045fm lattices for $B_s \rightarrow \eta_s$
- Physical $b$ is $am_b \approx 0.9$ on finest lattice
- Choose several heavy masses and daughter momenta for each ensemble
- Combine heavy mass fit with continuum extrapolation
- $D_s \rightarrow \eta_s$ comes ‘for free’
- Cover whole physical $q^2$ range
Overview of heavy HISQ

\( \Lambda_{\text{QCD}} = 0.5 \text{GeV} \)

\[
f_0(q^2) = \frac{1}{1 - \frac{q^2}{M_{H_s^0}^2}} \sum_{n=0}^{N-1} a_n^0 z^n,
\]

\[
f_+(q^2) = \frac{1}{1 - \frac{q^2}{M_{H_s^*}^2}} \sum_{n=0}^{N-1} a_n^+ \left( z^n - \frac{n}{N} (-1)^{n-N} z^N \right),
\]

\[
a_n^{0,+} = \left( 1 + \rho_n^{0,+} \log \left( \frac{M_{H_s}}{M_{D_s}} \right) \right) \times \sum_{i,j,k=0}^{N_{ijk}-1} d_{ijk}^{0,+} \left( \frac{\Lambda_{\text{QCD}}}{M_{H_s}} \right)^i \left( \frac{a m_{h}^{\text{val}}}{\pi} \right)^{2j} \left( \frac{a \Lambda_{\text{QCD}}}{\pi} \right)^{2k} \times \left( 1 + N_n^{0,+} \right).
\]
Continuum result at the $b$ mass in red. h-HISQ allows us to evaluate at any mass from $c$ to $b$. 

$B_s \to \eta_s$ results
$B_s \to \eta_s$ results

Form factors largely independent of spectator quark mass
Moving to $B \to K$

- Change spectator to light
- Calculate tensor form factor, using accurate tensor normalisation
- Include lattices with physical light quarks
- Include an overall chiral log term:

$$\text{logs} = 1 - \frac{9g^2}{8} \frac{m_l}{10m_s^\text{tuned}} \left( \log \left( \frac{m_l}{10m_s^\text{tuned}} \right) + \delta_{FV} \right)$$  \hspace{1cm} (3)
$B \rightarrow K$ preliminary results

Tensor important for SM $B \rightarrow K$ due to $b \rightarrow s$ transition
Normalisation with $\mu = 2\text{GeV}$, matched to $\overline{\text{MS}}$ at 3 loop at $b$ mass
$D \rightarrow K$ preliminary results \textit{(B. Chakraborty, C. T. H. Davies)}

\textit{Sets 1-3 physical v. coarse to fine Sets 4-7 $m_s/m_l = 5$, v.coarse to superfine}

\begin{itemize}
  \item Charm mass easy to reach on ensembles
  \item Full $q^2$ range $\implies$ can compare bin by bin with exp. partial decay rate data
  \item Lots of good exp. data available, can compare shape
\end{itemize}
$D \rightarrow K$ preliminary results (B. Chakraborty, C. T. H. Davies)

One σ error ellipses. Ratios of $f_+ z$ expansion coefficients $a_n$, directly comparable with experiment.
$D \to K$ preliminary results (B. Chakraborty, C. T. H. Davies)

Preliminary $V_{cs} = 0.9662(71)$, improvement on current PDG sl value of $0.967(25)$
Conclusions

- Heavy HISQ an effective method for studying heavy to strange decays and form factors
- Form factors largely independent of spectator quark mass
- Can improve upon $B \rightarrow K \ell^+ \ell^-$ and $D \rightarrow K \ell \bar{\nu}$ results
- Improvement on $V_{cs}$ determination from $D \rightarrow K \ell^- \bar{\nu}$ using bin by bin comparisons with experiment

Thanks for listening. Any questions?
\[ Z_V^0 Z_{\text{disc}} \langle \eta_s | V^0 | \hat{H}_s \rangle = \]
\[ f_{+ H_s \rightarrow \eta_s} (q^2) \left( p_{H_s}^0 + p_{\eta_s}^0 - \frac{M_{H_s}^2 - M_{\eta_s}^2}{q^2} q^0 \right) \]
\[ + f_{0 H_s \rightarrow \eta_s} (q^2) \frac{M_{H_s}^2 - M_{\eta_s}^2}{q^2} q^0, \quad (4) \]

\[ Z_{\text{disc}} \langle \eta_s | S | H_s \rangle = \frac{M_{H_s}^2 - M_{\eta_s}^2}{m_h - m_s} f_{0 H_s \rightarrow \eta_s} (q^2), \quad (5) \]
\[ z(q^2) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}}. \]  

(6)

\[ \frac{m_l}{m_s} \approx \frac{M_\pi^2}{M_{\eta_s}^2} \]  

(7)