Studies with semileptonic decays at LHCb

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on behalf of the LHCb Collaboration
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Introduction

Semileptonic $b$-hadron decays important tests of the Standard Model:
- Measure quark mixing CKM matrix elements $|V_{cb}|, |V_{ub}|$
- Validate understanding of QCD in decays

- More theoretically clean than fully hadronic decays
- Can study lepton flavor universality in charged current (talk by P. Owen)
- Semileptonic decays also useful for many more measurements!
Huge data samples

- Expect almost **100 million reconstructed** semileptonic decays in Runs 1 and 2
- Access to all $B$ flavor decays
- Clean signatures for muonic modes means low non-semileptonic backgrounds

Excellent for measurements such as total cross-section
Large samples also useful for other measurements

CP violation in mixing

Lifetime of $B^0_s$ and $D^+_s$ – see talk by M. Dorigo today
Reconstruction techniques

- Missing at least one neutrino, but still have good handles on kinematics
- Different techniques used, and still room for new ideas

Assuming one neutrino:

Using velocity from reconstructed part:

Preliminary

\[ \text{Candidates / (4 MeV/c}^2) \]

\[ M^*(\Lambda_0^b K^-) - M^*(\Lambda_0^b) [\text{MeV/c}^2] \]

\[ \text{Pulls} \]

\[ 9.35 < q^2 < 12.60 \text{ GeV}^2/c^4 \]

Data \( \nu_{\tau} \) \( D^* \rightarrow B X')X \nu_l \rightarrow (c D^*H \rightarrow B \nu D^{*+}l \rightarrow B \nu \mu \) D* \rightarrow B Combinatorial \mu Misidentified

New full reconstruction

- Use $B_{s2}^*$ decays to calculate $B^+$ momentum with no assumption on missing part of decay
- First application to $D$ fractions coming soon
- Promising technique for large future datasets
Studies with baryons

- Previously measured ratio $|V_{ub}|/|V_{cb}|$ using $\Lambda_b^0$ decays
- In the future, want to measure $|V_{cb}|$ in this channel
- First step is form factor measurement
$\Lambda_b^0 \rightarrow \Lambda_c^+ \mu \nu$

Form factor measurement

- Differential distributions key for comparisons with Heavy Quark Effective Theory and Lattice QCD
- Necessary to measure CKM parameters ($|V_{cb}|$ in overall factor $G$)
- Measure form-factors as one Isgur-Wise function $\xi_B$: 

$$q^2 = \text{momentum transfer}^2$$

$$w = \frac{m_{\Lambda_b^0}^2 + m_{\Lambda_c^+}^2 - q^2}{2m_{\Lambda_b^0} m_{\Lambda_c^+}}$$

$$\frac{d\Gamma}{dw} = GK(w)\xi_B^2(w)$$

Kinematic factor
"Backgrounds" are interesting!

- Excited states are backgrounds to ground state decay
- Measure excited $\Lambda_c^+$ with $\Lambda_c^+ \pi^+ \pi^-$

- $\Lambda_c(2765)^+$ not well measured previously
Future measurements

- Thousands of excited $\Lambda_c^+$ in Run 1 alone
- More data provides large samples of decays to e.g. $D_{(s)1}$ and $D_{(s)2}^*$
- More detailed studies will also help understand feed-down contributions

<table>
<thead>
<tr>
<th>Final state</th>
<th>Yield</th>
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<tbody>
<tr>
<td>$\Lambda_c(2595)^+\mu^-\bar{\nu}_\mu$</td>
<td>$8569 \pm 144$</td>
</tr>
<tr>
<td>$\Lambda_c(2625)^+\mu^-\bar{\nu}_\mu$</td>
<td>$22965 \pm 266$</td>
</tr>
<tr>
<td>$\Lambda_c(2765)^+\mu^-\bar{\nu}_\mu$</td>
<td>$2975 \pm 225$</td>
</tr>
<tr>
<td>$\Lambda_c(2880)^+\mu^-\bar{\nu}_\mu$</td>
<td>$1602 \pm 95$</td>
</tr>
<tr>
<td>$\Lambda_c^+\mu^-\bar{\nu}_\mu X$</td>
<td>$(2.74\pm0.02) \times 10^6$</td>
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</tbody>
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Unfolding to $w$

- Kinematics assume one neutrino in final state
- Unfold using Singular Value Decomposition
- Corrected for acceptance and efficiency
- Final $w$ distribution fit with multiple ansatz
Slope of $\xi_B$ at $w = 1$ is key observable

Measured:

$$\rho^2 = 1.63 \pm 0.07 \pm 0.08$$

Theory:

<table>
<thead>
<tr>
<th>Method</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lattice(^1)</td>
<td>$\rho^2 = 1.2^{+0.8}_{-1.1}$</td>
</tr>
<tr>
<td>QCD sum rules(^2)</td>
<td>$1.35 \pm 0.13$</td>
</tr>
<tr>
<td>HQET(^3)</td>
<td>1.51</td>
</tr>
</tbody>
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Comparison to lattice

- Unfold also to $q^2$
- Comparison with lattice calculation\(^1\) (gray band)
- Also described by single form factor fit (blue line)
- Future studies with normalization channel can extract $|V_{cb}|$

\(^1\) Phys. Rev. D92 (2015) 034503
Future directions

$B_c^+$ decays

- Results from the $R(J/\psi)$ measurement demonstrate possibility to measure form factor parameters for $B_c^+$ decays
- 20,000 normalization decays in Run 1 with selection designed for $\tau$
Conclusions

- LHCb continues to accumulate large data samples of semileptonic decays of all flavors
  - Many potential measurements of semileptonic dynamics still to be made
  - Also useful for many other types of measurements
- Developing new analysis ideas that will take advantage of future datasets
- Continue to probe the decay of $\Lambda_b^0$ with form factor measurement
- Understanding excited final states necessary for strong future results