Rare $\Lambda_b$ decays in a quark model

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Outline

• Introduction
• Form Factors
• Results
  Decay Rates
  Forward-Backward Asymmetry
• Conclusions
• Current and Future Work
Introduction

No experimental data for rare $\Lambda_b \rightarrow \Lambda^{(*)}$ decays.
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Searches to begin at LHCb.
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Searches to begin at LHCb.

800 events expected for dileptonic decays to ground state $\Lambda$. 
Introduction

For the transition $b \to s \ell^+ \ell^-$ the effective Hamiltonian is

$$\mathcal{H}_{\text{eff}} = \frac{G_F \alpha_{em}}{\sqrt{2} 4\pi} V_{tb} V_{ts}^*[2i \frac{m_b}{q^2} C_7(m_b) \bar{s} \sigma^{\mu \nu} q_\nu (1 + \gamma_5) b \bar{\ell} \gamma_\mu \ell 
+C_9(m_b) \bar{s} \gamma^\mu (1 - \gamma_5) b \bar{\ell} \gamma_\mu \ell + C_{10}(m_b) \bar{s} \gamma^\mu (1 - \gamma_5) b \bar{\ell} \gamma_\mu \gamma_5 \ell]$$
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To include long distance contributions from charmonium resonances, replace $C_9$ with

$$C_9^{\text{eff}} = C_9 + Y_{LD}(q^2)$$
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$$H_{\text{eff}} = \frac{G_F \alpha_{\text{em}}}{\sqrt{2} \frac{\alpha}{4\pi}} V_{tb} V_{ts}^{*} \left[ 2i \frac{m_b}{q^2} C_7(m_b) \bar{s} \sigma^{\mu \nu} q_\nu (1 + \gamma_5) b \bar{\ell} \gamma_{\mu} \ell ight] + C_9(m_b) \bar{s} \gamma^{\mu} (1 - \gamma_5) b \bar{\ell} \gamma_{\mu} \ell + C_{10}(m_b) \bar{s} \gamma^{\mu} (1 - \gamma_5) b \bar{\ell} \gamma_{\mu} \gamma_5 \ell$$

To include long distance contributions from charmonium resonances, replace $C_9$ with

$$C_9^{\text{eff}} = C_9 + Y_{LD}(q^2)$$

$Y_{LD}$ contains a Breit-Wigner term.
Form Factors

Vector current:

\[
\langle \Lambda | \bar{s} \gamma^\mu b | \Lambda_b \rangle = \bar{u}(p_\Lambda, s_\Lambda) \left[ F_1(q^2) \gamma^\mu + F_2(q^2) \frac{p_{\Lambda b}^\mu}{m_{\Lambda b}} ight. \\
\left. + F_3(q^2) \frac{p_{\Lambda}^\mu}{m_{\Lambda}} \right] u(p_{\Lambda b}, s_{\Lambda b})
\]
Form Factors

Vector current:

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\langle \Lambda | \bar{s} \gamma^\mu b | \Lambda_b \rangle = \bar{u}(p_\Lambda, s_\Lambda) \left[ F_1(q^2) \gamma^\mu + F_2(q^2) \frac{p^\mu_{\Lambda b}}{m_{\Lambda b}} \right. \\
\left. + F_3(q^2) \frac{p^\mu_\Lambda}{m_\Lambda} \right] u(p_{\Lambda b}, s_{\Lambda b})
\]

Axial vector current:

\[
\langle \Lambda | \bar{s} \gamma^\mu \gamma_5 b | \Lambda_b \rangle = \bar{u}(p_\Lambda, s_\Lambda) \left[ G_1(q^2) \gamma^\mu + G_2(q^2) \frac{p^\mu_{\Lambda b}}{m_{\Lambda b}} \right. \\
\left. + G_3(q^2) \frac{p^\mu_\Lambda}{m_\Lambda} \right] \gamma_5 u(p_{\Lambda b}, s_{\Lambda b})
\]
Form Factors

Tensor current:

$$\langle \Lambda | \bar{s}\sigma^{\mu\nu}b | \Lambda_b \rangle = \bar{u}(p_{\Lambda}, s_{\Lambda}) \left[ H_1(q^2)\sigma^{\mu\nu} 
+ H_2(q^2)(p_{\Lambda_b}^\mu \gamma^\nu - p_{\Lambda_b}^\nu \gamma^\mu)/m_{\Lambda_b} 
+ H_3(q^2)(p_{\Lambda}^\mu \gamma^\nu - p_{\Lambda}^\nu \gamma^\mu)/m_{\Lambda} 
+ H_4(q^2)(p_{\Lambda_b}^\mu p_{\Lambda}^\nu - p_{\Lambda_b}^\nu p_{\Lambda}^\mu)/(m_{\Lambda_b}m_{\Lambda}) \right] u(p_{\Lambda_b}, s_{\Lambda_b})$$
Form Factors \( J^\pi_\Lambda = 1/2^+ \)
Results

\[ p_{\Lambda_b} \rightarrow l^- + p_\Lambda \]

\[ \theta \]
Results

\[ q = p_{\Lambda_b} - p_{\Lambda}, \]

\[ \hat{s} = \frac{q^2}{m_{\Lambda_b}^2}, \]
Decay rates $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$
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Decay rates $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$
## Decay rates

Branching ratios for $\Lambda_b \to \Lambda \mu^+ \mu^-$ in units of $10^{-6}$

<table>
<thead>
<tr>
<th>$J^\pi_\Lambda$</th>
<th>This work</th>
<th>Aslam et al</th>
<th>Wang et al</th>
<th>Chen et al</th>
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</thead>
<tbody>
<tr>
<td>1/2$^+$</td>
<td>4.4</td>
<td>5.9</td>
<td>6.1</td>
<td>2.1 (QCDSR)</td>
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<td></td>
<td></td>
<td></td>
<td>1.2 (PM)</td>
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<tr>
<td>1/2$^+_1$</td>
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<td></td>
<td></td>
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<tr>
<td>1/2$^-$</td>
<td>0.73</td>
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<tr>
<td>3/2$^-$</td>
<td>0.94</td>
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<tr>
<td>3/2$^+$</td>
<td>0.095</td>
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<tr>
<td>5/2$^+$</td>
<td>0.12</td>
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</tbody>
</table>
### Decay rates

#### Branching ratios for $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$ in units of $10^{-6}$

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<tr>
<td>$1/2^+$</td>
<td>64</td>
<td>39</td>
<td>46</td>
<td>53 (QCDSR)</td>
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<td></td>
<td></td>
<td></td>
<td>36 (PM)</td>
</tr>
<tr>
<td>$1/2_1^+$</td>
<td>4.2</td>
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<td></td>
</tr>
<tr>
<td>$1/2^-$</td>
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<tr>
<td>$3/2^-$</td>
<td>57</td>
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<tr>
<td>$3/2^+$</td>
<td>16</td>
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<tr>
<td>$5/2^+$</td>
<td>15</td>
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</tr>
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</table>
Forward-Backward asymmetry

\[ \mathbf{p}_{\Lambda_b^+} \rightarrow \mathbf{l}^- + \mathbf{p}_\Lambda \]

\[ \cos \theta \]
Forward-Backward asymmetry

$$A_{FB}(\hat{s}) = \frac{\int_{0}^{1} d\hat{z} \frac{d^2\Gamma}{d\hat{s}d\hat{z}}}{d\Gamma/d\hat{s}} - \frac{\int_{-1}^{0} d\hat{z} \frac{d^2\Gamma}{d\hat{s}d\hat{z}}}{d\Gamma/d\hat{s}}; \hat{z} = \cos \theta$$
Forward-Backward asymmetry $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$
Forward-Backward asymmetry $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$

![Graph showing differential asymmetry vs. s parameter]

Differential asymmetry

- $1/2^+$
- $1/2_1^+$
- $1/2^-$
- $3/2^+$
- $3/2_1^+$
- $5/2^+$

Rare $\Lambda_b$ decays in a quark model – p. 16
Conclusions

Charmonium resonances greatly influence the integrated rates in the dimuon decays.
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Decays to the $3/2^-$ state become almost as strong as decays to the ground state.
Current and Future Work

Numerical computation of form factors.
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Lepton polarization asymmetries.
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- Numerical computation of form factors.
- Lepton polarization asymmetries.
- Baryon polarization asymmetries.
Current and Future Work

Numerical computation of form factors.

Lepton polarization asymmetries.

Baryon polarization asymmetries.

Radiative decays.