$B \to \ell\ell K^{(*)}$ prospects at LHCb

- Theoretical motivation
- Zero of FBA in $B^0 \to \mu\mu K^*$
- $R_K$ in $B^\pm \to \mu\mu K^\pm$ and $B^\pm \to e e K^\pm$
**b → sℓℓ decays**

- Second-order diagram
- Sensitive to
  - SuSy,
  - graviton exchanges,
  - extra dimensions
$b \rightarrow s \ell \ell$ decays

- Second-order diagram
- Sensitive to
  - SuSy,
  - graviton exchanges,
  - extra dimensions
- Well known SM branching ratio
  $(1.36 \pm 0.08) \cdot 10^{-6}$ (NNLL) for $s = q^2/m_b^2 < 0.25$
- Inclusive decays difficult to access at hadron colliders
- Exclusive decays affected by hadronic uncertainties

P. Koppenburg  
B $\rightarrow \ell \ell K^{(*)}$ prospects at LHCb— Flavour in Era of the LHC — 09/11/2005 WG2 – p.2/16
Observables

Solution: Use ratios where hadronic uncertainties cancel out

- CP asymmetry

[Goto et. al, hep-ph/9609512]
Solution: Use ratios where hadronic uncertainties cancel out

- CP asymmetry
- ✔ Ratio of $ee$ and $\mu\mu$ modes

[Goto et. al, hep-ph/9609512]
Observables

**Solution:** Use ratios where hadronic uncertainties cancel out

- CP asymmetry
- ✔ Ratio of ee and $\mu\mu$ modes
- ✔ Forward-backward asymmetry

![Graph showing asymmetry and ratios](image)

[Goto et. al, hep-ph/9609512]
**Observables**

**Solution:** Use ratios where hadronic uncertainties cancel out

- CP asymmetry
- ✔ Ratio of $ee$ and $\mu\mu$ modes
- Forward-backward asymmetry
- CP asymmetry in FBA

[Graph showing $A_F(b \to s\ell^+\ell^-)$ with various cases marked by different styles and labels.]

[Goto et. al, hep-ph/9609512]
Observables

Solution: Use ratios where hadronic uncertainties cancel out

- CP asymmetry
- ✔ Ratio of $ee$ and $\mu\mu$ modes
- Forward-backward asymmetry
- CP asymmetry in FBA
- ✔ Zero of FBA

$\delta_0 = \frac{-2C_7^{\text{Eff}}}{C_9^{\text{Eff}}(s_0)}$

[Goto et. al, hep-ph/9609512]
Zero of FBA in $B^0 \rightarrow \mu\mu K^*$

Jose Helder Lopes
Public LHCb notes 2003-104 & 2005-010
**B^0 \rightarrow \mu \mu K^* selection**

Main selection criteria:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu p_T )</td>
<td>&gt; 900 MeV</td>
</tr>
<tr>
<td>( \pi p_T )</td>
<td>&gt; 200 MeV</td>
</tr>
<tr>
<td>( \pi ) and K IP</td>
<td>&gt; 2( \sigma )</td>
</tr>
<tr>
<td>K* ( p_T )</td>
<td>&gt; 900 MeV</td>
</tr>
<tr>
<td>( \mu \mu ) and K* ( \chi^2 )</td>
<td>&lt; 8</td>
</tr>
<tr>
<td>B ( \chi^2 )</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>B IP</td>
<td>&lt; 3.5( \sigma )</td>
</tr>
<tr>
<td>( \mu \mu ) and K* PV separation</td>
<td>&gt; 1.5( \sigma )</td>
</tr>
<tr>
<td>( J/\psi ) veto</td>
<td>2900–3200 MeV</td>
</tr>
<tr>
<td>( \psi(2S) ) veto</td>
<td>3650–3725 MeV</td>
</tr>
<tr>
<td>K* mass</td>
<td>( m_{K^*} \pm 100 \text{ MeV} )</td>
</tr>
</tbody>
</table>

Optimised for BR.
Maybe not optimal for zero of FBA
**B^0 \rightarrow \mu \mu K^* selection**

Expected signal and background yields in 2 fb^{-1} of data, i.e. \( 10^7 \) s at \( \mathcal{L} = 2 \cdot 10^{32} \).

Assuming the SM BR of \( 12 \cdot 10^{-7} \)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Stats.</th>
<th>Yield</th>
<th>B/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B^0 \rightarrow \mu \mu K^* )</td>
<td>50k</td>
<td>4400 ± 100</td>
<td></td>
</tr>
<tr>
<td>( B \bar{B} )</td>
<td>11M</td>
<td>1000–11700</td>
<td>0.2–2.6</td>
</tr>
<tr>
<td>( b \rightarrow \mu c(\mu q) )</td>
<td>200k</td>
<td>500–1900</td>
<td>0.1–0.4</td>
</tr>
<tr>
<td>2 (( b \rightarrow \mu ))</td>
<td>1.8M</td>
<td>750 ± 130</td>
<td>0.17 ± 0.03</td>
</tr>
<tr>
<td>( J/\psi )</td>
<td>200k</td>
<td>20–80</td>
<td>0.02–0.1</td>
</tr>
</tbody>
</table>

B/S ratios limited by low background MC statistics

2003 MC, Geant 3 — to be updated
To assess errors on FBA: run many pseudo-experiments with reasonable signal and data assumptions.

- Use reconstructed dimuon mass spectrum and FBA angle
To assess errors on FBA: run many pseudo-experiments with reasonable signal and data assumptions.

- Use reconstructed dimuon mass spectrum and FBA angle
- Get errors on dimuon mass spectrum

Relative errors on branching fraction after 1 year:

- $1-6 \text{ GeV}^2$: $\pm 5.7\%$
- $> 14 \text{ GeV}^2$: $\pm 3.2\%$

Much less than hadronic uncertainties
Zero of FBA

- **2 fb\(^{-1}\):** \((4.0 \pm 1.2)\) GeV\(^2\) with 4% inefficiency
Zero of FBA

- 2 fb$^{-1}$: $(4.0 \pm 1.2)$ GeV$^2$ with 4% inefficiency
- 10 fb$^{-1}$: $(4.0 \pm 0.5)$ GeV$^2$

$\Rightarrow$ 13% error on $C_7^{\text{Eff}}/C_9^{\text{Eff}}$

![Graph showing typical FBA(s) measurement and spread of $s_0$]
$R_K$ in $B^\pm \rightarrow \mu \mu K^\pm$ and $B^\pm \rightarrow eeK^\pm$

Patrick Koppenburg
$B^\pm \rightarrow \ell\ell K^\pm$

Measure the ratio: \cite{Hiller & Krüger, hep-ph/0310219}

$$R_X = \frac{\int ds \frac{d\Gamma(B \rightarrow X \mu^+ \mu^-)}{ds}}{\int ds \frac{d\Gamma(B \rightarrow X e^+ e^-)}{ds}} = \begin{cases} 
1.000 \pm 0.001 & X = K \\
0.991 \pm 0.002 & X = K^* 
\end{cases}$$

Corrections to unity can be large ($\mathcal{O}(10\%)$) in models that distinguish between lepton flavours, like interactions involving neutral Higgs bosons (typically MSSM at large $\tan \beta$).

In this study we integrate in the range $4m^2_\mu \leq s \leq 6 \text{ GeV}^2$
Relation to $B_s \to \mu\mu$

\[ R_K \propto BR(B_s \to \mu\mu) \]

Assuming:

- right-handed currents negligible
- (Pseudo-)scalar couplings $\propto m_\ell$, (à la neutral higgs, not the case for broken $R$-parity)
- No CP-phases beyond the SM
- \ldots

I.e. SM, MSSM with MFV at large $\tan \beta \ldots$
Relation to $B_s \to \mu\mu$

![Graph showing $R_K$ and $R_K^*$ with $A_t < 0$ and $C_P > 0$.]

Experimental status:

<table>
<thead>
<tr>
<th>$R_X$</th>
<th>BaBar (208 fb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_K$</td>
<td>$1.06 \pm 0.48 \pm 0.05$</td>
</tr>
<tr>
<td>$R_K^*$</td>
<td>$0.93 \pm 0.46 \pm 0.12$</td>
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</tbody>
</table>

<table>
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<tr>
<th>$R_K$</th>
<th>Belle (250 fb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.38^{+0.39}_{-0.41}$</td>
<td>$0.98^{+0.30}_{-0.31} \pm 0.08$</td>
</tr>
</tbody>
</table>

$10^6 \times BR(B_s \to \mu\mu)$

[Hiller & Krüger, hep-ph/0310219]
Relation to $B_s \rightarrow \mu \mu$

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$B_s \rightarrow \mu \mu$: The present CDF limit is $1.5 \cdot 10^{-7}$ at 90% CL

[Hiller & Krüger, hep-ph/0310219]

$10^6 \times BR(B_s \rightarrow \mu \mu)$

[Hep-ex/0508036]
Relation to $B_S \rightarrow \mu \mu$

- We also plan to measure the $B_S \rightarrow \mu \mu$ branching fraction.
- A disagreement would imply New Physics beyond a minimal model:
  - $R$-parity violating SuSy
  - right-handed couplings
  - ...
$B^{\pm} \rightarrow llK^{\pm}$ **Selection**

<table>
<thead>
<tr>
<th>Selection</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\ell p_T$, $K p_T$</td>
<td>$\geq 1500$ MeV</td>
</tr>
<tr>
<td>$K$ IP significance</td>
<td>$\geq 2$</td>
</tr>
<tr>
<td>$ll \chi^2$</td>
<td>$\leq 9$</td>
</tr>
<tr>
<td>$B \chi^2$</td>
<td>$\leq 30$</td>
</tr>
<tr>
<td>$B$ IP significance</td>
<td>$\leq 4$</td>
</tr>
<tr>
<td>$B$ flight significance</td>
<td>$\geq 5$</td>
</tr>
<tr>
<td>$B$ mass window</td>
<td>$\pm500$ MeV</td>
</tr>
</tbody>
</table>

- Selection optimised to minimize $R_K$ error in one year
- 2004 MC, Geant 4
- **Statistics**: 18M $B\overline{B}$, 4M $J/\psi \rightarrow ll$, 2M signal and specific backgrounds. More to come.
Trigger

- High trigger efficiency in L0 and L1 because of the leptons
- In the HLT we require the signal to be fully reconstructed
  → Which is difficult for electrons

One solution is to develop an inclusive dilepton trigger.
Selection cuts:

- $\ell p_T \geq 500 \text{ MeV}$
- $\ell\ell \chi^2 \leq 9$
- $\ell\ell p_T \geq 1250 \text{ MeV}$
- $\ell\ell$ flight signif. $\geq 2$

- 68% for $ee$ at $70 \pm 8 \text{ Hz}$
- 75% for $\mu\mu$ at $130 \pm 12 \text{ Hz}$
B versus dilepton mass after selection

$B \rightarrow eeK$

$B \rightarrow \mu\mu K$

Signal

$J/\psi K$

$J/\psi$

$B\bar{B}$

$(\mu\mu K^* \text{ missing})$
$R_K$ with $2\text{ fb}^{-1}$

- The signal is fitted by a Crystal-Ball function
- The background is fitted by a 2nd-order polynomial
- The parameters of the Crystal-Ball function are fixed from the signal MC

<table>
<thead>
<tr>
<th></th>
<th>Height</th>
<th>Mean</th>
<th>Sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>eeK</td>
<td>$47.2 \pm 4.6$</td>
<td>$5245\text{ MeV}$</td>
<td>$74\text{ MeV}$</td>
</tr>
<tr>
<td>$\mu\mu K$</td>
<td>$1013 \pm 31$</td>
<td>$5279\text{ MeV}$</td>
<td>$15\text{ MeV}$</td>
</tr>
</tbody>
</table>

$\Rightarrow R_K = 1 \text{ (fixed)} \pm 0.10$

...or as good as with $2.5\text{ ab}^{-1}$ at a B factory

(Zoom)
In 2012, measure $B_s \rightarrow \mu\mu$ and get 4.5% error on $R_K$:

- $\text{BR}(B_s \rightarrow \mu\mu)$ compatible with SM ($\sim 3 \cdot 10^{-9}$)
- $R_K \sim 1$: Compatible with SM or MSSM with small $\tan \beta^3 / m_A^2$

Possible status with $10 \text{ fb}^{-1}$

[10^6 \times \text{BR}(B_s \rightarrow \mu\mu)]

[Hiller & Krüger, hep-ph/0310219]
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$10^6 \times \text{BR}(B_s \to \mu\mu)$

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  - $R_K \neq 1$: New Physics — Right-handed currents or broken lepton-universality

- $\text{BR}(B_s \rightarrow \mu \mu)$ larger than SM: New Physics

- $R_K$ sets constraints on NP parameters
Conclusions

- $B^0 \to \mu\mu K^*$ one of the top priorities at LHCb:
  - Can get 13% error on $C^\text{Eff}_7/C^\text{Eff}_9$ with 10 fb$^{-1}$
  - More optimisation work needed

- $B^{\pm} \to llK^{\pm}$ promising at LHCb
  - Get 10% error on $R_K$ in one year
  - Control channel for $B^0 \to \mu\mu K^*$ FBA
  - $R_K^*$ with $B^0 \to \mu\mu K^*$: to be studied

Ready for Penguins at CERN!