Search for New Physics with Rare Heavy Flavour Decays at LHCb

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on behalf of the LHCb collaboration
Menu

1. $B^0 \rightarrow K^*\gamma$ and $B^0_s \rightarrow \phi\gamma$
2. $B^0 \rightarrow K^*\mu\mu$
3. $B^0_s \rightarrow \mu\mu$

1. Detector performance
2. Lessons from early data
3. Expectations
Rare decays: Motivation (1)

- Flavour changing neutral currents
- Occur in SM only through loop diagrams
- New Physics can appear at same order as SM

\[ B^0_{(s)} \rightarrow K^*(\phi)\gamma \]
\[ B^0 \rightarrow K^*\mu\mu \]
\[ B^0_s \rightarrow \mu\mu \]
Rare decays: Motivation (2)

- Flavour changing neutral currents
- Probe V-A structure of SM
- In HQET expressed in terms of Wilson coefficients

\[ H_{\text{eff}} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i(\mu, M_{\text{heavy}}) \mathcal{O}_i(\mu) \]

\[ B^0_{(s)} \to K^*(\varphi)\gamma \]
\[ B^0 \to K^*\mu\mu \]
\[ B^0_s \to \mu\mu \]

In principle both left- and righthanded, \( \mathcal{O}_{7\gamma} \) and \( \mathcal{O}_{7\gamma}' \),

\( \mathcal{O}_{7\gamma}, \mathcal{O}_{9V}, \mathcal{O}_{10A}, \mathcal{O}_S, \mathcal{O}_P \)

\( \mathcal{O}_{10A}, \mathcal{O}_S, \mathcal{O}_P \)

Effectively:

\( b \to \gamma/Z^0, s \)

\( \ell \to \gamma/Z^0, \ell \)

In principle both left- and righthanded, \( \mathcal{O}_{7\gamma} \) and \( \mathcal{O}_{7\gamma}' \).

\( \mathcal{O}_{7\gamma}: \) Scalar current (Higgs)

\( \mathcal{O}_{7\gamma}': \) Pseudo-scalar

Highly suppressed in SM

\( e.g. W.\, \text{Altmannshofer et al., JHEP 0901:019, 2009} \)
The LHCb Detector

- Muon System
- RICH Detectors
- Vertex Locator
- Calorimeters
- Tracking System
- Interaction Point
The LHCb Detector
The LHCb Detector

Interaction Point

\[ B^0 \rightarrow K^* \mu \mu \]
\[ B^0_s \rightarrow \mu \mu \]

Lifetime,
\[ B^0 \rightarrow X \gamma \]
\[ B^0 \rightarrow K^* \mu \mu \]
\[ B^0_s \rightarrow \mu \mu \]

Suppress background, \( \sigma(M_B) \)
\[ B^0 \rightarrow X \gamma \]
\[ B^0 \rightarrow K^* \mu \mu \]
\[ B^0_s \rightarrow \mu \mu \]
See also:

- Conor Fitzpatrick’s talk Monday, “Charmonium and Heavy Flavour Production at LHCb”
- Rob Lambert’s talk Tuesday, “Studies of semileptonic decays with the LHCb detector”
- Johan Blouw’s talk Wednesday, “Search for New Physics in CP-violating Phenomena at LHCb”
- Pascal Perret’s talk today at 15:55, “Future and prospects in flavour physics from LHCb, ATLAS and CMS”
LHC and LHCb performance

- LHC and LHCb show excellent performance

- Results shown today use \(\sim 0.5 \text{ pb}^{-1}\)

\[ \text{eff}_{\text{LHCb}} = 91.3\% \]
**LHC and LHCb performance**

**LHC fill 14 Oct 2010:**
- 248 bunches per beam
- $L_{\text{inst}} = 9.2 \times 10^{31} \text{cm}^{-2}\text{s}^{-1}$

6 pb$^{-1}$ in 6 days

$\text{eff}_{\text{LHCb}} = 91.3\%$
Radiative Decays: Motivation

- Branching Ratio constrains NP models
  - \( \text{BR}_{\text{theory}}(B^0 \rightarrow X_s \gamma) = 3.15 \pm 0.23 \times 10^{-4} \) \( \text{Belle, PRL, 103: 241801, 2009} \)
  - \( \text{BR}_{\text{exp}}(B^0 \rightarrow X_s \gamma) = 3.56 \pm 0.26 \times 10^{-4} \) \( \text{M. Misiak, PRL, 98: 022002, 2007} \)

- Polarization of photon can still reveal large NP effects

1) Determine admixture of \( \gamma_L \) and \( \gamma_R \) from \( B^0_s \rightarrow \phi \gamma \) decay rate
   - \( B^0_s \rightarrow \phi \gamma \) is not a CP eigenstate, so no exponential decay distribution
   - predominantly \( \bar{B}^0_s \rightarrow \phi \gamma_L \) and \( B^0_s \rightarrow \phi \gamma_R \)
   - Change of relative fraction affects the decay distribution

2) Measure angular distribution through \( B^0 \rightarrow K^* \gamma(e^+e^-) \)
Radiative Decays: Detector performance and Expectation

- Special photon/electron trigger lines
- ECAL calibration OK

→ See also Pascal Perret’s talk today at 15:55, “Future and prospects in flavour physics from LHCb, ATLAS and CMS”

- In 100 pb\(^{-1}\) expect competitive measurement of direct CP asymmetry in \(B^0 \rightarrow K^* \gamma\)
- In 2 fb\(^{-1}\) expect 250 \(B^0 \rightarrow K^* e^+ e^-\) events
**B^0 \rightarrow K^*\mu\mu: Motivation**

- Hadronic uncertainties largely cancel in angular asymmetries
- Forward-backward asymmetry $A_{FB}$ easiest

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**Example:**

\[(4/3) \times A_{FB}\]

- Zero-crossing point particularly interesting:
  - Small hadronic uncertainties
  - Directly sensitive to $C_7$ and $C_9$
$B^0 \rightarrow K^* \mu \mu$: Detector performance

- Muon ID efficiency
  - Good agreement data, MC
- K ID efficiency
  - Avg K id eff = 96%
  - Avg π misid rate = 7%
- Trigger efficiency
  - No bias in $\theta_l$ introduced

![Muon ID efficiency graph](chart1.png)

![K ID efficiency graph](chart2.png)

$J/\psi \rightarrow \mu \mu$

$\phi \rightarrow K^+ K^-$

$K_s \rightarrow \pi^+ \pi^-$

$K^+ \rightarrow K^+ : (95.95 \pm 0.27)\%$

$\pi^+ \rightarrow K^+ : (7.16 \pm 0.02)\%$
\( B^0 \rightarrow K^* \mu \mu: \) Lessons from early data

\( D^0 \rightarrow K\pi\pi\pi \)

- Similar topology
- Check bias introduced by trigger and selection

- Good data mc agreement
- Muon id not included
$B^0 \rightarrow K^*\mu\mu$: Lessons from early data

$B^0 \rightarrow J/\psi K^*$
- Applied $B^0 \rightarrow K^*\mu\mu$ event selection
- Data and MC normalized to $\sigma_{bb}$
- Efficiency estimates from MC reliable
$B^0 \rightarrow K^* \mu \mu$: Expectation

- Expectation LHCb, 100 pb$^{-1}$
  - ~150 events
  - Statistical errors only
  - Compared to Belle and BaBar

- Assuming Belle central value: 1.5σ SM exclusion
$B^0 \rightarrow K^*\mu\mu$: Expectation

- **Expectation LHCb, 2 fb$^{-1}$**
  - $\sim 3000$ events
  - Statistical errors only
  - Compared to Belle and BaBar

- **Assuming Belle central value: 5.4$\sigma$ SM exclusion**

![Graph showing SM exclusion at 5.4$\sigma$ with data points for LHCb, Belle, and BaBar.](image)
$B^0 \rightarrow K^* \mu \mu$: ?

Minimal Flavour Violation

Flavour Blind MSSM

General MSSM (large Im$(C_7')$)

General MSSM (modified $C_7$, $C_7'$, $C_{10}$)


Extra dimensions (Kaluza Klein modes in ACD model)


T. Hurth, hep-ph/0212304
**$B^0_s \rightarrow \mu\mu$: Motivation**

- Branching Ratio very sensitive to NP models
  \[
  \text{BR}(B^0_s \rightarrow \mu^+ \mu^-)|_{\text{SM}} = (3.6 \pm 0.4) \times 10^{-9}
  \]
- BR strongly enhanced in MSSM at large $\tan\beta$: $\propto \tan^6\beta/m_A^4$
- Example: 10x higher BR for $\tan\beta=50(20)$, $m_{H^+}=800(200)$ GeV

Allowed parameter space from fit in constrained MSSM:

\[1-\text{CL}\]


Niels Tuning (Nikhef) - HQL 2010
\[ B^0_s \rightarrow \mu^+\mu^-: \text{Motivation} \]

- Branching Ratio very sensitive to NP models
  \[ \text{BR}(B^0_s \rightarrow \mu^+\mu^-)|_{\text{SM}} = (3.6 \pm 0.4) \times 10^{-9} \quad \text{A.Buras, EPS09, arXiv:0910.1032} \]
- BR strongly enhanced in MSSM at large tan\( \beta \): \( \propto \tan^6 \beta / m_A^4 \)
- Example: 10x higher BR for \( \tan \beta = 50(20) \), \( m_{H^+} = 800(200) \) GeV

Allowed parameter space from fit in non-univ Higgs mass (NUHM):

\[ A.\text{Buras et al., Nucl.Phys.B659:3,2003} \]
**$B^0_s \rightarrow \mu\mu$: Motivation**

- Branching Ratio very sensitive to NP models
  \[ \mathrm{BR}(B^0_s \rightarrow \mu^+\mu^-)|_{SM} = (3.6 \pm 0.4) \times 10^{-9}. \quad \text{A.Buras, EPS09, arXiv:0910.1032} \]
- BR strongly enhanced in MSSM at large $\tan \beta$: \[ \propto \tan^6 \beta / m_A^4 \]
- Example: 10x higher BR for $\tan \beta = 50(20)$, $m_{H^+} = 800(200)$ GeV

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**Curves obtained through SuperIso, (eg. F.Mahmoudi, arXiv:0906.0369)**

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$B^0_s \rightarrow \mu\mu$: Isolate the signal

Binned Max Likelihood in 3-dim:
1) Mass
2) $\mu$-ID
3) Geometrical Likelihood
   (lifetime, $IP_B$, $IPS_\mu$, DOCA, isolation)

- $J/\psi \rightarrow \mu\mu$: $\mu$-performance
- $B^0 \rightarrow h^+h^-$: GL and mass

15 Oct 2010

LHCb Preliminary
$\sqrt{s} = 7$ TeV Data
$L = 3$ pb$^{-1}$

$B^0 \rightarrow K\pi$

$\mu_d = 5.2747 \pm 0.0024$ GeV/c$^2$
$\sigma = 0.0244 \pm 0.0023$ GeV/c$^2$
$\nu_{K^0} = 144 \pm 14$
$B^0_s \to \mu\mu$: Lessons from early data: μ-ID

- **$J/\psi \to \mu\mu$ “tag-and-probe”**
  - High μ-ID and trigger efficiency
  - Good data/mc agreement
- **$K_S \to \pi^+\pi^-$**
  - Low mis-ID rate
  - Good data/mc agreement

\[15 \text{ Oct } 2010\]
$B^0_s \rightarrow \mu\mu$: Lessons from early data: mass

- Good data/MC agreement
  - Alignment ongoing
  - Background well described
- Mass resolution at $m_{B_s}$ expected around 22 MeV

\[ \sigma(M) = 16 \text{ MeV} \rightarrow \sigma(M) = 50 \text{ MeV} \]
$B^0_s \rightarrow \mu\mu$: Lessons from early data: mass

- Good data/MC agreement
  - Alignment ongoing
  - Background well described
- Mass resolution at $m_{B_s}$ expected around 22 MeV

$B^0 \rightarrow K \pi : \quad \sigma(M) = 25 \text{ MeV}$

(close to 22 MeV from MC)
$B^0_s \rightarrow \mu\mu$: Lessons from early data: GL

- **Sensitive region:**
  - $GL > 0.5$, $\Delta m = 60\text{MeV}$
- **In 2011 expect (assuming SM...):**
  - $\sim 6$ signal events
  - $\sim 30$ bkd events
- **Background well described for high GL**

**Signal (MC):**

- $B^0_s \rightarrow \mu\mu$
- $B^0 \rightarrow \pi\pi$ (not triggered on $\pi$'s)

**Background (data):**

- $L = 0.2\text{ pb}^{-1}$

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15 Oct 2010

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**$B^0_s \rightarrow \mu\mu$: Normalization**

\[
\text{BR}(B^0_s \rightarrow \mu^+\mu^-) = \text{BR}(B_q \rightarrow \mu\mu) \times \frac{f_q}{f_s} \frac{\epsilon_X \epsilon_{\mu\mu}}{\epsilon_{\mu\mu} N_X} \]

- Main normalization channels:
  - $B^+ \rightarrow J/\psi K^+$
  - $B^0 \rightarrow J/\psi K^*$
  - $B^0_s \rightarrow J/\psi \phi$

CDF: $f_d/f_s = 0.16 \pm 13\%$ (ignoring SU(3) breaking effects and environment dependent)  
*CDF, Phys.Rev.D77:072003,2008*

Belle: $\text{BR}(B_s \rightarrow J/\psi \phi) = 1.15 \times 10^{-3} \pm 25\%$  
(23.6 fb$^{-1}$, 20% of available dataset)  
*R. Louvot, arXiv:0905.4345v2*

$f_d/f_s$: Largest uncertainty in BR determination
\( B^0_s \rightarrow \mu \mu: \) Normalization

\[
\text{BR}(B^0_s \rightarrow \mu^+ \mu^-) = \text{BR}(B_q \rightarrow X \frac{f_q}{f_s} \frac{\epsilon_X}{\epsilon_{\mu\mu}} \frac{N_{\mu\mu}}{N_X})
\]

- Main normalization channels:
  - \( B^+ \rightarrow J/\psi K^+ \)
  - \( B^0 \rightarrow J/\psi K^* \)
  - \( B^0_s \rightarrow J/\psi \phi \)

CDF: \( f_s/f_d = 0.16 \ 13\% \) (ignoring SU(3) breaking effects and environment dependent)  


Belle: \( \text{BR}(B_s \rightarrow J/\psi \phi) = 1.15 \times 10^{-3} \ 25\% \)  
(23.6 fb\(^{-1}\), 20% of available dataset)  
R. Louvot, arXiv:0905.4345v2

Novel method:
- Use \( B_s \rightarrow D_s^{-} \pi^+ \) and \( B^0 \rightarrow D^{-} K^+ \)

\[
\frac{f_d}{f_s} = 12.88 \times \frac{\tau_{B_s}}{\tau_{B_d}} \times \left[ N_a N_F \frac{\epsilon_{D_s \pi}}{\epsilon_{D_d K}} \frac{N_{D_d K}}{N_{D_s \pi}} \right]
\]

\[
N_a = \left| \frac{a_1(D_s \pi)}{a_1(D_d K)} \right|^2, \quad N_F = \left[ \frac{F^{(s)}_0(m_{2\pi})}{F^{(d)}_0(m_{2K})} \right]^2
\]

- Expect total uncertainty on \( f_d/f_s \) of 6%
- Increase NP discovery potential
- Need lattice calculations for form factors

**$B^0_s \rightarrow \mu\mu$: Normalization**

- $B^0_s \rightarrow D_s^- \pi^+$ already observed
- **Clean sample, large S/B**

**Novel method:**
- Use $B_s \rightarrow D_s^- \pi^+$ and $B^0 \rightarrow D^- K^+$

\[
\frac{f_d}{f_s} = 12.88 \times \frac{\tau_{B_s}}{\tau_{B_d}} \times \left[ N_a N_F \frac{\epsilon_{D_s \pi}}{\epsilon_{D_d K}} \frac{N_{D_d K}}{N_{D_s \pi}} \right]
\]

\[
N_a = \left| \frac{a_1(D_s \pi)}{a_1(D_d K)} \right|^2, \quad N_F = \left[ \frac{F_0^{(s)}(m^2_{\pi})}{F_0^{(d)}(m^2_K)} \right]^2
\]

- Expect total uncertainty on $f_d/f_s$ of 6%
- Increase NP discovery potential
- Need lattice calculations for form factors

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15 Oct 2010

Niels Tuning (Nikhef) - HQL 2010
$B^0_s \rightarrow \mu\mu$: Expectation

- With 50 pb$^{-1}$ possibly already approach new limit
  $\text{BR}(B^0_s \rightarrow \mu\mu) > 3.4 \times 10^{-8}$ @ 90% CL

- With 1 fb$^{-1}$ possible to claim NP at 5$\sigma$ if $\text{BR} \sim 5 \times \text{BR}_{SM}$:
  $\text{BR}(B^0_s \rightarrow \mu\mu) > 1.7 \times 10^{-8}$

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90% CL exclusion

**2010?**

- **LHCb** expectation
- **SM prediction**
- **CDF exclusion at 95% C.L.**

- **D0 (6.1 fb$^{-1}$)**
- **CDF (6.1 fb$^{-1}$)**
- **D0 (11 fb$^{-1}$)**
- **CDF (11 fb$^{-1}$)**

@ 3.5 + 3.5 TeV

NP discovery potential

**2011?**

- 5$\sigma$ NP discovery (bound)
- 5$\sigma$ NP discovery ($N_F \in [1.2, 1.4]$)

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From:

R. Fleischer et al.,

**From:**

R. Fleischer et al.,

(\(\sigma_{bb} = 500 \mu b\))
Conclusions

Q LHCb detector in excellent position for exciting Rare Decay results soon:

1) In 100 pb$^{-1}$ expect competitive measurement of direct CP asymmetry in $B^0 \rightarrow K^{*\gamma}$

2) In 100 pb$^{-1}$ could observe $1.5\sigma$ deviation from SM in $A_{FB}$ with $B^0 \rightarrow K^{*\mu\mu}$ (assuming central value from Belle)

3) With 50 pb$^{-1}$ hope to approach or surpass world best sensitivity in $B^{0}_s \rightarrow \mu\mu$