Very rare decay searches at LHCb

Implications of LHCb measurements and future prospects

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Introduction

LHCb very rare decays current searches
- \( B_{d,s} \rightarrow \mu^+\mu^- \)
- \( B_{d,s} \rightarrow \mu^+\mu^-\mu^+\mu^- \)
- Searches for Majorana neutrinos in \( B^- \) decays
- \( \tau^\pm \rightarrow \mu^+\mu^-\mu^\pm \)
- \( K_s \rightarrow \mu^+\mu^- \)

Prospects for other channels

Conclusions
Introduction
Introduction

- General concept of **very rare decays** in LHCb:
  - Access NP through new virtual particles entering in the loop: **indirect search of NP**, accessing higher energy scales!
  - Very relevant test of SM predictions, for extremely small BR.

- Searches are experimentally similar:
  - **Control channels** used to avoid dependence on simulation.
  - **Geometrical properties** combined in MVA to classify the events.
  - **Use of normalization channels** (with similar geometry/trigger) to convert observed number of events in BR, without use of absolute luminosity.
  - **Blind** analyses (signal region not looked at until the analyses are frozen)
  - Produce results which **constraint the phase space of NP**!
LHCb very rare decays current searches

\[ \rightarrow B_{d,s} \rightarrow \mu^+\mu^- \]
**B_{d,s} \rightarrow \mu^+\mu^-- Introduction**

- B_{d,s} \rightarrow \mu^+\mu^- decays are very suppressed in the SM:
  - BR(B_s \rightarrow \mu\mu) = (3.2 \pm 0.2) \times 10^{-9}
  - BR(B_d \rightarrow \mu\mu) = (0.10 \pm 0.01) \times 10^{-9}

- They turn out to be, however, very sensitive to scalar and pseudo-scalar operators, so sensitive to NP.

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Selection: apply some cuts on all $\mu\mu$ candidates to remove most of the background.

Classify each event using two variables (bins in a 2D parameter space):
- **Geometrical properties** (combined in Boosted Decision Tree)
- **Invariant Mass**

Treat each bin as an independent experiment. Results combined using $\text{CL}_s$ method (Modified Frequentist Approach)

Use of control channels to calibrate and normalize (normalization to $B^+\rightarrow J/\psi K^+$, $B_d\rightarrow K\pi$ and $B_s\rightarrow J/\psi \Phi$, give compatible results)
**Results in 1 fb^{-1} consistent with SM**

- Data
- Error in sum of all expected background contributions (hatched area)

Results in most sensitive region of BDT

**SM signal**
Combinatorial bkg.

**B_{d,s} \rightarrow h^+h^- misID**
Crossfeed between channels

- **B_{d,s} \rightarrow \mu^+\mu^- - Mass projections**
- **B_{0} \rightarrow \mu\mu**
- **B_{0_s} \rightarrow \mu\mu**
**B_{d,s} \to \mu^+\mu^- - Results**

- **Limits 1 fb^{-1} @ 95% CL (WB)**
  - $\text{BR}(B_s \to \mu^+\mu^-) < 4.5 \times 10^{-9}$
  - $\text{BR}(B_d \to \mu^+\mu^-) < 8.1 \times 10^{-10}$

- **BR(B_s \to \mu^+\mu^-) estimate:**
  - $\text{BR}(B_s \to \mu^+\mu^-) = (0.8^{+1.8}_{-1.3}) \times 10^{-9}$

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NP could still be there, suppressing $B_s \to \mu^+\mu^-$. With the 2012 data, we could be able to find a 3σ evidence if $\text{BR}(B_s \to \mu^+\mu^-)$ is SM.

For the theory implications of the result, see talks by G. Isidori and N. Mahmoudi.
LHCb very rare decays current searches

$B_{d,s} \rightarrow \mu^+\mu^-\mu^+\mu^-$
SM process: $B_{d,s} \rightarrow \mu^+\mu^-\gamma^*$ with $\gamma^* \rightarrow \mu^+\mu^-$
- Non-resonant BR predicted to be $10^{-10} - 10^{-11}$
  

Decay sensitive to NP:
- eg sGoldstinos ($B_s \rightarrow S(\mu^+\mu^-)P(\mu^+\mu^-)$)

Resonant decay mode
$B_s \rightarrow J/\psi(\mu^+\mu^-)\Phi(\mu^+\mu^-)$ with expected BR at the level of $(2.3\pm0.9) \times 10^{-8}$.
Observed yield consistent with expectation.

Cut based analysis, normalization to $B_d \rightarrow J/\psi K^*$. Non-resonant peaking backgrounds kept under control
$B_{d,s} \rightarrow \mu^+\mu^-\mu^+\mu^-$ - Results

- Number of observed events in 1 fb$^{-1}$ consistent with background expectation

- Set a limit on signal events using the CL$_s$ method (as in $B_s \rightarrow \mu^+\mu^-$)

- Limits @ 95% CL (first world limits on these decays)

\[
\begin{align*}
\text{BR}(B_s \rightarrow \mu^+\mu^-\mu^+\mu^-) & < 1.3 \times 10^{-8} \\
\text{BR}(B_d \rightarrow \mu^+\mu^-\mu^+\mu^-) & < 5.4 \times 10^{-9}
\end{align*}
\]

LHCb preliminary, 1 fb$^{-1}$

LHCb-CONF-2012-010
LHCb very rare decays current searches

Searches for Majorana neutrinos in $B^-$ decays
B\(^-\) \rightarrow D^+\mu^-\mu^- and B\(^-\) \rightarrow D^{*+}\mu^-\mu^- can arise from the presence of virtual Majorana neutrinos of any mass. Other states containing π\(^+\), D\(^+_s\), or D\(^0\)π\(^+\) can be mediated by an on-shell Majorana neutrino.

No signal found in the searched channels in 0.41 fb\(^{-1}\).

B\(^-\) \rightarrow π^+\mu^-\mu^- has been used to establish neutrino mass dependent upper limits on the coupling |\(V_{\mu4}\)| of a heavy Majorana neutrino to a muon and a virtual W.
LHCb very rare decays current searches

$\tau^{\pm} \rightarrow \mu^{+}\mu^{-}\mu^{\pm}$
$\tau^\pm \to \mu^+\mu^-\mu^\pm$

**Theory interest**

- Decay extremely suppressed in SM $\text{BR} \sim 10^{-40}$

- But very enhanced by several NP models

<table>
<thead>
<tr>
<th>Model, processes</th>
<th>$B(\tau^- \to \mu^+\mu^-\mu^-)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unparticles</td>
<td>$10^{-3} - 10^{-11}$</td>
</tr>
<tr>
<td>Neutral SUSY Higgs</td>
<td>$&lt; 10^{-7}$</td>
</tr>
<tr>
<td>Littlest Higgs with T-Parity</td>
<td>$&lt; 10^{-8}$</td>
</tr>
<tr>
<td>Non universal gauge interaction</td>
<td>$&lt; 10^{-8}$</td>
</tr>
<tr>
<td>mSUGRA + seesaw</td>
<td>$&lt; 10^{-9}$</td>
</tr>
<tr>
<td>SUSY + seesaw (Higgs mediated)</td>
<td>$&lt; 10^{-10}$</td>
</tr>
<tr>
<td>SUSY SO(10) + seesaw</td>
<td>$&lt; 10^{-10}$</td>
</tr>
<tr>
<td>SM + heavy Majorana neutrino</td>
<td>$&lt; 10^{-10}$</td>
</tr>
<tr>
<td>SM + neutrino oscillations</td>
<td>$&lt; 10^{-40}$</td>
</tr>
</tbody>
</table>

see talk by S. Davidson
Current limits (@ 90% CL)

- BaBar \( \text{BR}(\tau^\pm \rightarrow \mu^+\mu^-\mu^\pm) < 3.3 \times 10^{-8} \)
- Belle \( \text{BR}(\tau^\pm \rightarrow \mu^+\mu^-\mu^\pm) < 2.1 \times 10^{-8} \)

* Extrapolating from these results, a future super B factory (SuperB or SuperKEKB) is expected to reach a sensitivity of

\[
\text{BR}(\tau^\pm \rightarrow \mu^+\mu^-\mu^\pm) \sim 10^{-9} - 10^{-10} \text{ with 75 ab}^{-1}
\]

B. Meadows et al., arXiv:1109.5028
**Analysis strategy**

- Initial loose selection
- Discriminate signal from background in bins of 3 distributions:
  - Likelihoods from geometrical variables
  - Likelihoods from muon PID variables
  - $3\mu$ invariant mass
- Calibrate the 3 likelihoods on data
- Background estimation from mass sidebands
  - Specific backgrounds also considered
- Relative normalization with $D_s \rightarrow \phi(\mu\mu)\pi$
- Blind analysis

→ Competitive sensitivity can be reached very soon
LHCb very rare decays current searches

\[ \text{K}_s \rightarrow \mu^+\mu^- \]
FCNC, with SM BR predicted,
- \( \text{BR}(K_s \rightarrow \mu^+\mu^-) \sim 5 \times 10^{-12} (\pm 30\%) \)
  

- Probe CP violating phase in
  \( s \rightarrow d l^+ l^- \) amplitude
- Interesting region for NP:
  \( \text{BR} \) below \( 10^{-10,-11} \)

Experimental status: current limit from 1973!
- \( \text{BR}(K_s \rightarrow \mu^+\mu^-) < 3.2 \times 10^{-7} \) @ 90% CL
  
$K_S \to \mu^+\mu^-$ - Analysis strategy

- Use $K_S^0 \to \pi^+\pi^-$ to calibrate and normalize.
  - Use same geometrical selection for both channels
- Build geometrical BDT and classify events in 2D space.

- Assess possible backgrounds:
  - Combinatorial, extrapolate from sidebands
  - $K_S^0 \to \pi^-(\mu^-\bar{\nu})\pi^+(\mu^+\nu)$
  - Physical: $K_S \to \pi^+\mu^-\nu$, $K_L \to \mu^-\mu^+$

- Combine results using CL$_S$ method

  With 1 fb$^{-1}$, expected upper limit in the range $10^{-8} - 10^{-9}$
Prospects for other channels
Prospects for other channels

- $B_{d,s} \rightarrow \mu^+\mu^-\gamma$
  - Sensitivity to NP not clear to us, regardless of its SM BR.
  - The mode is accessible experimentally, but more challenging than $B_s \rightarrow \mu^+\mu^-$. See next talk by A. Petrov

- $B_{d,s} \rightarrow J/\psi\gamma$
  - Similar situation to $B_{d,s} \rightarrow \mu^+\mu^-\gamma$. LHCb could measure the BR, depending on its actual value

- $B_{d,s} \rightarrow e\mu$
  - Studies of this decay ongoing, world best limit should be in reach with 1 fb$^{-1}$

- $B_{d,s} \rightarrow \tau\tau$
  - Also preliminary work done. Experimentally not easy, because of difficult reconstruction of $\tau$
Conclusions
Conclusions

- **Very rare decays** are a very relevant indirect search for NP.
  - These decays are a strong point of LHCb! Several searches performed, with the advantage of being similar from an experimental point of view.

- New results presented in $B_{d,s} \rightarrow \mu^+\mu^-$, $B_{d,s} \rightarrow \mu^+\mu^-\mu^+\mu^-$ and Majorana neutrinos search. Very important constraint to NP phase space, in particular from $B_{d,s} \rightarrow \mu^+\mu^-$, where a world best upper limit on the BR has been set!

- New results soon:
  - $\tau^\pm \rightarrow \mu^+\mu^-\mu^\pm$
  - $K_s \rightarrow \mu^+\mu^-$

And more to come...