LHCb results on rare leptonic decays of B-mesons
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The Large Hadron Collider (LHC) is the world’s largest and most powerful particle collider. It lies in a tunnel 27 kilometres in circumference and as deep as 175 metres beneath the France–Switzerland border near Geneva.
LHCb detector

LHC runs

Two datasets of different size with different kinematics
Motivation

- Their time-integrated branching fractions are predicted in the SM with small uncertainty due to absence of hadrons in final state
- The decays are sensitive probes for physics beyond the SM
- Within the Standard Model (SM) of particle physics, fully leptonic decays of B mesons are very rare
Decays overview:

- Measurements of the $B^0_s \rightarrow \mu^+\mu^-$ branching fraction and effective lifetime and search for $B^0 \rightarrow \mu^+\mu^-$ decays
- Search for the decays $B^0_s \rightarrow \tau^+\tau^-$ and $B^0 \rightarrow \tau^+\tau^-$
- Search for the lepton-flavour violating decays $B^0_{(s)} \rightarrow e^\pm\mu^\mp$
- Search for the lepton-flavour-violating decays $B^0_s \rightarrow \tau^\pm\mu^\mp$ and $B^0 \rightarrow \tau^\pm\mu^\mp$
- Search for the rare decay $B^+ \rightarrow \mu^+\mu^-\mu^+\nu_\mu$
Measurements of the $B^0_s \rightarrow \mu^+ \mu^-$ branching fraction and effective lifetime and search for $B^0 \rightarrow \mu^+ \mu^-$ decays

Results are based on data collected with the LHCb detector, corresponding to an integrated luminosity of 1 fb$^{-1}$ of pp collisions at a centre-of-mass energy $\sqrt{s} = 7$ TeV, 2 fb$^{-1}$ at $\sqrt{s} = 8$ TeV and 1.4 fb$^{-1}$ recorded at $\sqrt{s} = 13$ TeV.
Normalization

Normalization channels are: \( B^+ \to J/\psi K^+ \) and \( B^0 \to K^+ \pi^- \)

\[
\mathcal{B}(B^0_{(s)} \to \mu^+ \mu^-) = \frac{\mathcal{B}_{\text{norm}} \epsilon_{\text{norm}} f_{\text{norm}}}{N_{\text{norm}} \epsilon_{\text{sig}} f_d(s)} \times N_{B^0_{(s)} \to \mu^+ \mu^-} \equiv \\
\equiv \alpha_{B^0_{(s)} \to \mu^+ \mu^-}^{\text{norm}} \times N_{B^0_{(s)} \to \mu^+ \mu^-}
\]
$B^0_s \rightarrow \mu^+ \mu^-$

LHCb

BDT $> 0.5$

Phys. Rev. Lett. 118, 191801
\( B^0_s \rightarrow \mu^+ \mu^- \)

![Graph showing decay time distribution for \( B^0_s \rightarrow \mu^+ \mu^- \)]

*Effective lifetime fit*

*LHCb*

*Phys. Rev. Lett. 118, 191801*
$B_s^0 \rightarrow \mu^+ \mu^-$

- $B_s^0 \rightarrow \mu^+ \mu^-$ signal is seen with a significance of 7.8 standard deviations
- The $B_s^0 \rightarrow \mu^+ \mu^-$ branching fraction is measured to be $(3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$, where the first uncertainty is statistical and the second systematic (Phys. Rev. Lett. 118, 191801)
- SM prediction: $B(B_s^0 \rightarrow \mu^+ \mu^-) = (3.65 \pm 0.23) \times 10^{-9}$ (PRL 112(2014)101801)
- Previous results from LHCb + CMS data analysis:
  $B(B_s^0 \rightarrow \mu^+ \mu^-) = 2.8^{+0.7}_{-0.6} \times 10^{-9}$ (Nature 522, 68–72 (04 June 2015))
• $\mathcal{B}^0_s \to \mu^+\mu^−$ effective lifetime
$\tau(\mathcal{B}^0_s \to \mu^+\mu^−) = 2.04 \pm 0.44 \pm 0.05\text{ps}$, where the first uncertainty is statistical and the second systematic

• No evidence for a $\mathcal{B}^0 \to \mu^+\mu^−$ signal is found, $\mathcal{B}(\mathcal{B}^0 \to \mu^+\mu^−) < 3.4 \times 10^{-10}$ at 95% confidence

• Previous results from LHCb + CMS data analysis:
$\mathcal{B}(\mathcal{B}^0 \to \mu^+\mu^−) = 3.9^{+1.6}_{-1.4} \times 10^{-10}$ (Nature 522, 68–72 (04 June 2015))

• All results are in agreement with the Standard Model expectations

(Phys. Rev. Lett. 118, 191801 )
Search for the decays $B_s^0 \rightarrow \tau^+ \tau^-$ and $B^0 \rightarrow \tau^+ \tau^-$

The analysis is performed with proton–proton collision data corresponding to integrated luminosities of 1.0 $fb^{-1}$ and 2.0 $fb^{-1}$ recorded with the LHCb detector at centre-of-mass energies of 7 and 8 TeV, respectively. The $\tau$ leptons are reconstructed through the decay $\tau \rightarrow \pi^- \pi^+ \pi^- \nu_\tau$. 
$B^0_{(s)} \rightarrow \tau^+ \tau^-$

- Assuming no contribution from $B^0 \rightarrow \tau^+ \tau^-$, 
  $B(B^0_s \rightarrow \tau^+ \tau^-) < 6.8 \times 10^{-3}$ at 95% CL
- If no contribution from $B^0_s \rightarrow \tau^+ \tau^-$ is assumed, 
  $B(B^0 \rightarrow \tau^+ \tau^-) < 2.1 \times 10^{-3}$ at 95% CL
- Previous limit (BaBar collaboration): $B(B^0 \rightarrow \tau^+ \tau^-) < 4.10 \times 10^{-3}$ at 90% CL
  

- These results correspond to the first direct limit on 
  $B(B^0_s \rightarrow \tau^+ \tau^-)$ and the world’s best limit on 
  $B(B^0 \rightarrow \tau^+ \tau^-)$

A search for the lepton-flavour violating (LFV) decays $B_{(s)}^{0} \rightarrow e^{\pm} \mu^{\mp}$ was performed using pp collision data collected at centre-of-mass energies of 7 and 8TeV, corresponding to a total integrated luminosity of 3$fb^{-1}$. Two normalisation channels were used: the $B_{(s)}^{0} \rightarrow K^{+} \pi^{-}$ decay which has a similar topology to that of the signal, and the $B^{+} \rightarrow J/\psi \ K^{+}$ decay, with $J/\psi \rightarrow \mu^{+} \mu^{-}$, which has an abundant yield and a similar purity and trigger selection.
LHCb

<table>
<thead>
<tr>
<th>Data</th>
<th>Total</th>
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<tbody>
<tr>
<td>Combinatorial</td>
<td></td>
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<tr>
<td>$\nu^- \mu^+ p \rightarrow b^0 \Lambda$</td>
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<tr>
<td>$\nu^+ \mu^- \pi \rightarrow 0 B^\pm \mu^\pm e$</td>
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<tr>
<td>$B^0 \rightarrow e^+ \mu^-$</td>
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<td>$B^0 \rightarrow e^- \mu^+$</td>
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(JHEP 1803 (2018) 078)
\[ B_{(s)}^0 \rightarrow e^\pm \mu^\mp \]

- No excesses are observed and upper limits on the branching fractions are set to \( B(B_s^0 \rightarrow e^\pm \mu^\mp) < 6.3 \times 10^{-9} \) and \( B(B^0 \rightarrow e^\pm \mu^\mp) < 1.3 \times 10^{-9} \) at 95% CL.

- These results represent the best upper limits to date and are a factor 2 to 3 better than the previous results from LHCb \( B(B_s^0 \rightarrow e^\pm \mu^\mp) < 1.4 \times 10^{-8} \) and \( B(B^0 \rightarrow e^\pm \mu^\mp) < 3.7 \times 10^{-9} \) at 95% CL (Phys. Rev. Lett. 111 (2013) 141801) (JHEP 1803 (2018) 078).
Search for the lepton-flavour-violating decays $B_s^0 \rightarrow \tau^\pm \mu^\mp$ and $B^0 \rightarrow \tau^\pm \mu^\mp$

A search for $B_s^0 \rightarrow \tau^\pm \mu^\mp$ and $B^0 \rightarrow \tau^\pm \mu^\mp$ decays is performed using data corresponding to an integrated luminosity of 3 fb$^{-1}$ of proton-proton collisions, recorded with the LHCb detector in 2011 and 2012.

The $\tau$ lepton is reconstructed in the $\tau \rightarrow \pi^- \pi^+ \pi^- \nu_\tau$ channel.
LHCb results on rare leptonic decays of B-mesons

(arXiv:1905.06614)
\[ \mathcal{B}(B^0_{(s)} \rightarrow \tau^\pm \mu^\mp) < 4.2 \times 10^{-5} \text{ at 95\% CL (Assuming no contribution from } B^0 \rightarrow \tau^\pm \mu^\pm) \]

\[ \mathcal{B}(B^0 \rightarrow \tau^\pm \mu^\pm) < 1.4 \times 10^{-5} \text{ at 95\% CL (Assuming no contribution from } B^0_s \rightarrow \tau^\pm \mu^\pm) \]

These are the first limit on \( \mathcal{B}(B^0_s \rightarrow \tau^\pm \mu^\pm) \) and the world’s best limit on \( \mathcal{B}(B^0 \rightarrow \tau^\pm \mu^\pm) \)

arXiv:1905.06614
Search for the rare decay

\[ B^+ \rightarrow \mu^+ \mu^- \mu^+ \nu_\mu \]

A search for the rare leptonic decay \( B^+ \rightarrow \mu^+ \mu^- \mu^+ \nu_\mu \) is performed using proton-proton collision data corresponding to an integrated luminosity of 4.7 fb\(^{-1}\) collected by the LHCb experiment. The search is carried out in the region where the lowest of the two \( \mu^+ \mu^- \) mass combinations is below 980 MeV/c\(^2\). The branching fraction of a \( B^+ \rightarrow \mu^+ \mu^- \mu^+ \nu_\mu \) signal is obtained by normalising to the \( B^+ \rightarrow J/\psi(\rightarrow \mu^+ \mu^-)K^+ \) decays.
LHCb 2011-16

Candidates / (50 MeV/c²)

Total Fit
Data
Combinatorial
Misidentified
Partially reconstructed
Prediction from PAN (2018) 81:347

$M_{\text{corr}}$ [MeV/c²]

\[ B^+ \rightarrow \mu^+\mu^-\mu^+\nu_\mu \]

- No signal is observed for the \( B^+ \rightarrow \mu^+\mu^-\mu^+\nu_\mu \) decay
- An upper limit of \( 1.6 \times 10^{-8} \) at 95% confidence level is set on the branching fraction, where the lowest of the two \( \mu^+\mu^- \) mass combinations is below \( 980\text{MeV}/c^2 \).
- The limit for the full kinematic region stays the same under the assumption that the decay is dominated by intermediate vector mesons.

Conclusions

- Lot of rare B mesons decays were studied by the LHCb team
- All results are consistent with the Standard Model
- Nearly all results presented are either unique or the most accurate for the time