

Lepton Number Violation in b-hadrons decays at the LHC

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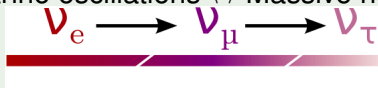
October 4, 2017

Outline

- 1 Introduction
- 2 LHC
- 3 Limits
- 4 Conclusions, perspectives

Introduction

Neutrino oscillations \leftrightarrow Massive neutrinos



Questions pending:

- 1 Sterile neutrinos?
- 2 Dirac or Majorana?
- 3 How many?

Dirac or Majorana?

Lepton number is not conserved if Majorana neutrinos

→ Typically tested via $0\nu\beta\beta$ decay

The presentation is based on works

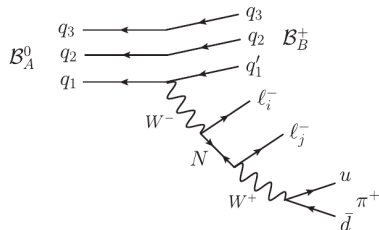
<https://arxiv.org/abs/1708.01516>

<https://arxiv.org/abs/1705.10606>

Theoretical approach

Simplified approach with:

- 1 One Majorana heavy neutrino N
- 2 Mixing only to muons
- 3 Mixing $V_{\mu N}$
- 4 Neutrino mass m_N
- 5 Few GeV mass as a benchmark



(b) $B_A^0 \rightarrow B_B^+ \pi^+ \ell_i^- \ell_j^-$

We consider two production processes where the CMS and LHCb experiments could have sensitivity

- 1 $pp \rightarrow \Lambda_b + X$
- 2 $pp \rightarrow B_s + X$

We consider the following $\Delta L = 2$ decay channels

- 1 $\Lambda_b \rightarrow p \pi^+ \mu^- \mu^-$
- 2 $\Lambda_b \rightarrow \Lambda_c^+ \pi^+ \mu^- \mu^-$
- 3 $B_s \rightarrow K^- \pi^- \mu^+ \mu^+$
- 4 $B_s \rightarrow D_s^- \pi^- \mu^+ \mu^+$

Sensitivity with the LHCb experiment

Expected number of events at LHCb:

$$N_{\text{exp}}^{\text{LHCb}} = \sigma(pp \rightarrow H_b X)_{\text{acc}} f(b \rightarrow \Lambda_b(B_s)) \text{BR}(\Lambda_b(B_s) \rightarrow \Delta L = 2) \\ \times \epsilon_D^{\text{LHCb}}(\Lambda_b(B_s) \rightarrow \Delta L = 2) P_N^{\text{LHCb}} \mathcal{L}_{\text{int}}^{\text{LHCb}}$$

$\sigma(pp \rightarrow H_b X)_{\text{acc}}$: production cross-section

$f(b \rightarrow \Lambda_b(B_s))$: hadronization factor of a b -quark to $\Lambda_b(B_s)$ baryon(meson)

$\mathcal{L}_{\text{int}}^{\text{LHCb}}$: integrated luminosity

$\text{BR}(\Lambda_b(B_s) \rightarrow \Delta L = 2)$: branching fraction of the LNV process

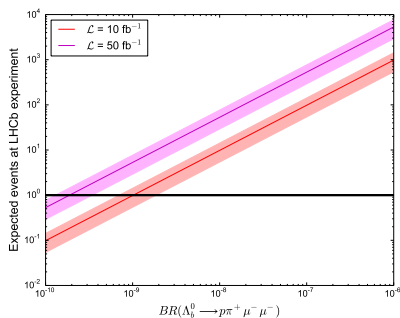
P_N^{LHCb} : Majorana neutrino acceptance factor

$\epsilon_D^{\text{LHCb}}(\Lambda_b(B_s) \rightarrow \Delta L = 2)$: detection/reconstruction efficiency

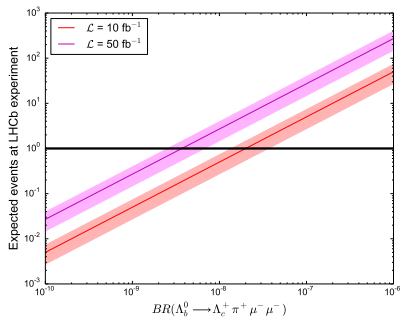
Derived from measurement: $\sigma(pp \rightarrow H_b X)_{\text{acc}} = (75.3 \pm 5.4 \pm 13.0) \mu\text{b}$,
 $f(b \rightarrow \Lambda_b(B_s)) = 0.053 \pm 0.017 (0.103 \pm 0.005)$, $\epsilon_D^{\text{LHCb}}(\Lambda_b(B_s) \rightarrow \Delta L = 2)$

Free parameters: $\text{BR}(\Lambda_b(B_s) \rightarrow \Delta L = 2)$, heavy neutrino lifetime

Expected number of events in the LHCb experiment as a function of $BR(\Lambda_b \rightarrow \Delta L = 2)$ for different values of $\mathcal{L}_{\text{int}}^{\text{LHCb}}$



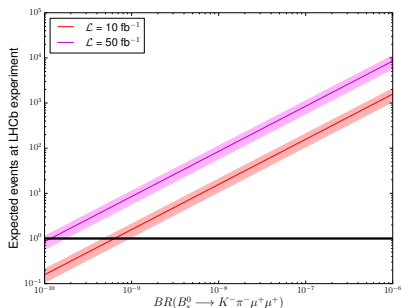
$$\epsilon_D^{\text{LHCb}}(\Lambda_b \rightarrow p\pi^+\mu^-\mu^-)P_N^{\text{LHCb}} \simeq 0.0121 \pm 0.0030$$



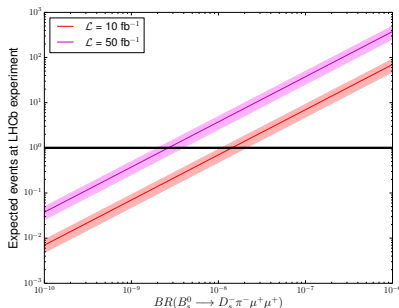
$$\epsilon_D^{\text{LHCb}}(\Lambda_b \rightarrow \Lambda_c^+\pi^+\mu^-\mu^-)P_N^{\text{LHCb}} \simeq 0.0098 \pm 0.0025 \text{ with}$$

$$BR(\Lambda_c^+ \rightarrow pK^-\pi^+) = (6.35 \pm 0.33)\%$$

Expected number of events in the LHCb experiment as a function of $BR(B_s \rightarrow \Delta L = 2)$ for different values of $\mathcal{L}_{\text{int}}^{\text{LHCb}}$



$$\epsilon_D^{\text{LHCb}}(B_s \rightarrow K^- \pi^- \mu^+ \mu^+) P_N^{\text{LHCb}} \simeq (1.10 \pm 0.27) \%$$



$$\epsilon_D^{\text{LHCb}}(B_s \rightarrow D_s^- \pi^- \mu^+ \mu^+) P_N^{\text{LHCb}} \simeq (0.89 \pm 0.22) \% \text{ and } BR(D_s^+ \rightarrow K^+ K^- \pi^+) = (5.45 \pm 0.17) \times 10^{-2}$$

Sensitivity with the CMS experiment

Expected number of events at CMS:

$$N_{\text{exp}}^{\text{CMS}} = \sigma(pp \rightarrow \Lambda_b(B_s)X)_{\text{acc}} \text{BR}(\Lambda_b(B_s) \rightarrow \Delta L = 2) \\ \times \epsilon_D^{\text{CMS}}(\Lambda_b(B_s) \rightarrow \Delta L = 2) P_N^{\text{CMS}} \mathcal{L}_{\text{int}}^{\text{CMS}}$$

$\sigma(pp \rightarrow \Lambda_b(B_s)X)$: production cross-section

$\mathcal{L}_{\text{int}}^{\text{CMS}}$: integrated luminosity

$\text{BR}(\Lambda_b(B_s) \rightarrow \Delta L = 2)$: branching fraction of the LNV process

P_N^{CMS} : Majorana neutrino acceptance factor

$\epsilon_D^{\text{CMS}}(\Lambda_b(B_s) \rightarrow \Delta L = 2)$: detection/reconstruction efficiency

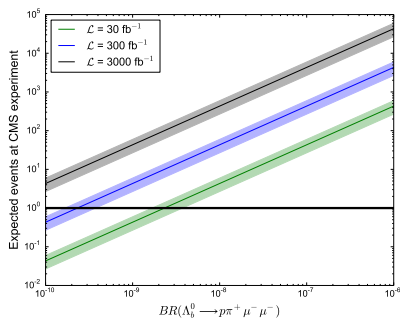
Derived from measurement:

$$\sigma(pp \rightarrow \Lambda_b(B_s)X)_{\text{acc}} = (1.97 \pm 0.72)(11.98 \pm 0.17) \mu\text{b},$$

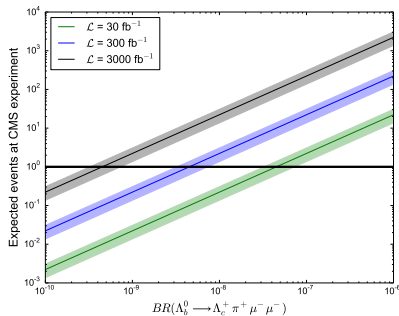
$$\epsilon_D^{\text{CMS}}(\Lambda_b(B_s) \rightarrow \Delta L = 2)$$

Free parameters: $\text{BR}(\Lambda_b(B_s) \rightarrow \Delta L = 2)$, heavy neutrino lifetime

Expected number of events in the CMS experiment as a function of $BR(\Lambda_b \rightarrow \Delta L = 2)$ for different values of $\mathcal{L}_{\text{int}}^{\text{CMS}}$



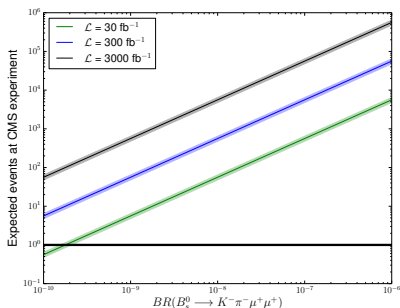
$$\epsilon_D^{\text{CMS}}(\Lambda_b \rightarrow p\pi^+\mu^-\mu^-)P_N^{\text{CMS}} \simeq 0.073 \pm 0.015$$



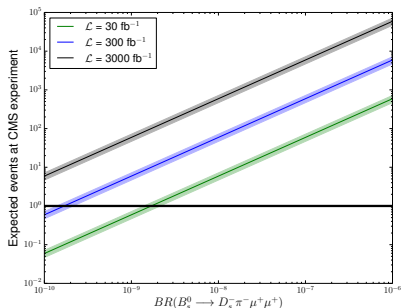
$$\epsilon_D^{\text{CMS}}(\Lambda_b \rightarrow \Lambda_c^+\pi^+\mu^-\mu^-)P_N^{\text{CMS}} \simeq 0.059 \pm 0.013 \text{ with}$$

$$BR(\Lambda_c^+ \rightarrow pK^-\pi^+) = (6.35 \pm 0.33)\%$$

Expected number of events in the CMS experiment as a function of $\text{BR}(B_s \rightarrow \Delta L = 2)$ for different values of $\mathcal{L}_{\text{int}}^{\text{CMS}}$

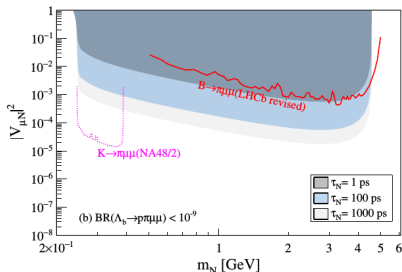
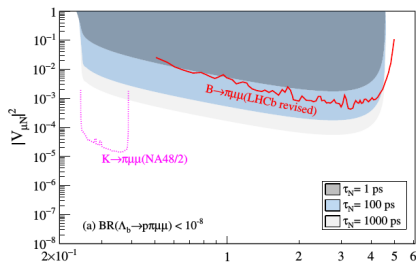


$$\epsilon_D^{\text{LHCb}}(B_s \rightarrow K^- \pi^- \mu^+ \mu^+) P_N^{\text{LHCb}} \simeq (1.56 \pm 0.05) \%$$



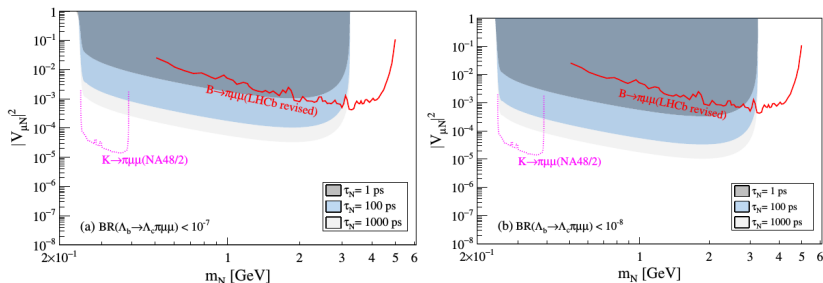
$$\epsilon_D^{\text{CMS}}(B_s^0 \rightarrow D_s^- \pi^- \mu^+ \mu^+) = (1.26 \pm 0.04) \% \\ \text{with } \text{BR}(D_s^- \rightarrow 3 \text{ charged tracks}) = (13.00 \pm 1.96) \%$$

Projected limits - Λ_b



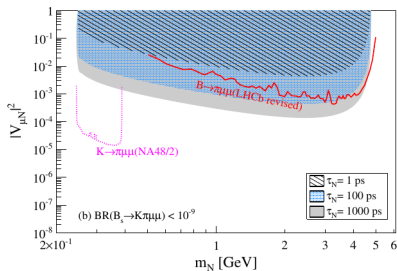
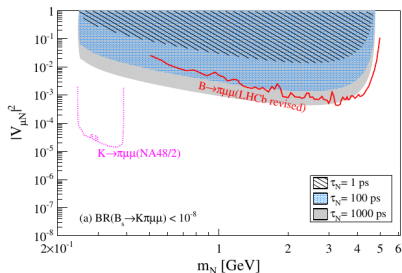
Exclusion regions on $(m_N, |V_{\mu N}|^2)$ plane for: (left) $\text{BR}(\Lambda_b^0 \rightarrow p\pi^+\mu^-\mu^-) < 10^{-8}$ and (right) $\text{BR}(\Lambda_b^0 \rightarrow p\pi^+\mu^-\mu^-) < 10^{-9}$. The [black, blue, green] region represents the constraints obtained for heavy neutrino lifetimes of $\tau_N = [1, 100, 1000]$ ps.

Projected limits - Λ_b



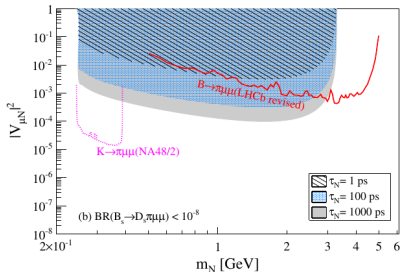
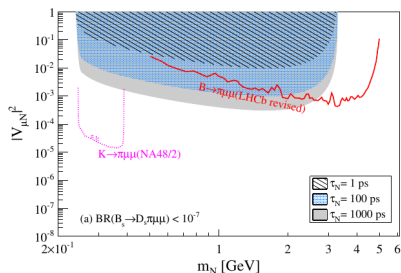
Exclusion regions on $(m_N, |V_{\mu N}|^2)$ plane for: (left) $\text{BR}(\Lambda_b^0 \rightarrow \Lambda_c \pi^+ \mu^- \mu^-) < 10^{-7}$ and (right) $\text{BR}(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^+ \mu^- \mu^-) < 10^{-8}$. The [black, blue, green] region represents the constraints obtained for heavy neutrino lifetimes of $\tau_N = [1, 100, 1000]$ ps.

Projected limits - B_s



Exclusion regions on $(m_N, |V_{\mu N}|^2)$ plane for (left) $\text{BR}(B_s^0 \rightarrow K^- \pi^- \mu^+ \mu^+) < 10^{-8}$ and (right) $\text{BR}(B_s^0 \rightarrow K^- \pi^- \mu^+ \mu^+) < 10^{-9}$. The black, blue, gray regions represent the bounds obtained for heavy neutrino lifetimes of $\tau_N = 1, 100, 1000$ ps, respectively

Projected limits - B_s



Exclusion regions on $(m_N, |V_{\mu N}|^2)$ plane for (left) $\text{BR}(B_s^0 \rightarrow D_s^- \pi^- \mu^+ \mu^+) < 10^{-7}$ and (right) $\text{BR}(B_s^0 \rightarrow D_s^- \pi^- \mu^+ \mu^+) < 10^{-8}$. The black, blue, gray regions represent the bounds obtained for heavy neutrino lifetimes of $\tau_N = 1, 100, 1000$ ps, respectively



Conclusions

- We have utilized a toy model to study LNV processes in the LHC
- Two processes where the LHC experiments have sensitivity are identified
- A simple extrapolation of CMS and LHCb results and performance show that these two experiments are sensitive to these final states
- It has been clearly stated that CMS and LHCb measurements of these channels could cover parts of the parameter phase space that are not currently covered by any other measurements

