Lepton Flavour Violation and Lepton Number Violation in B decays at LHCb

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Lisa Fantini

on behalf of the LHCb Collaboration

University and INFN Perugia

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UNIVERSITÀ DEGLI STUDI
DI PERUGIA

INFN
Istituto Nazionale di Fisica Nucleare

LHCb

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Motivations

- Lepton flavour and lepton number conservation are accidental symmetries in the Standard Model (SM) → general motivation for these searches
- Lepton flavour violated for neutrinos via oscillations
- No LFV process for charged leptons observed yet
- LNV is useful to explain the origin of neutrino masses, the mechanisms for the matter-antimatter asymmetry in the Universe

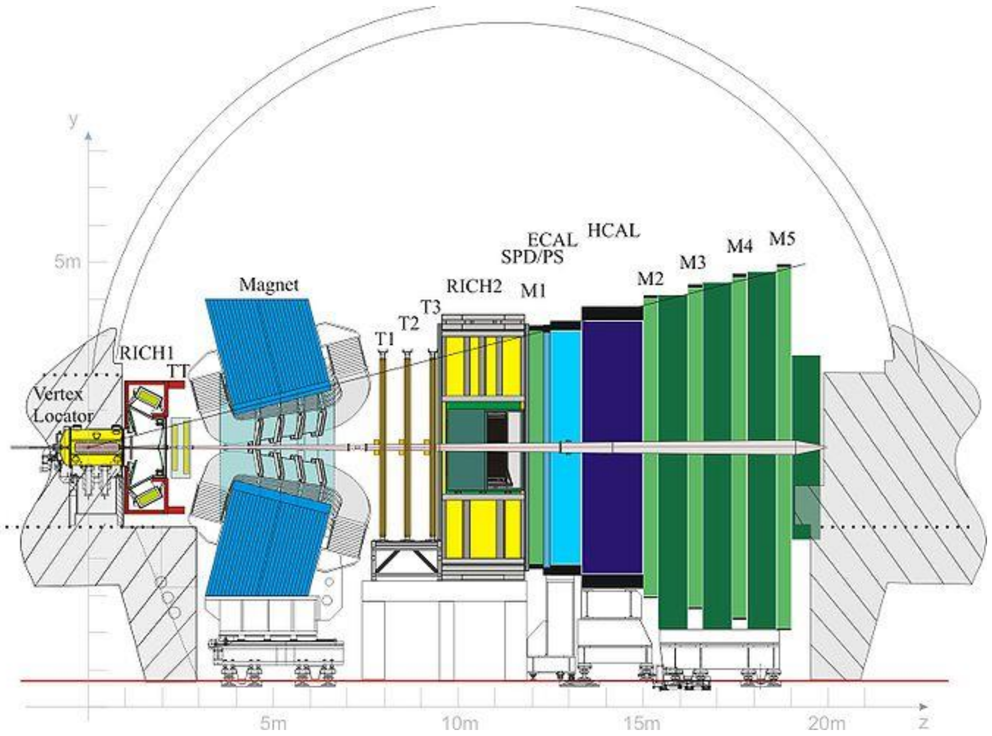
→ **observation of charged LFV and LNV processes would be a clear sign for New Physics (NP)**
→ **several extensions of the SM predict LFV and LNV**

Recent results from LHCb

LHCb experiment provides ideal environment for searching for LFV and LNV in B meson decays
[Int. J. Mod. Phys. A 30, 1530022 (2015)]

Lepton Flavour Violation:

- Search for $B^0 \to K^{*0}\mu^{\pm}e^{\mp}$ and $B_s^0 \to \phi\,\mu^{\pm}e^{\mp}$ [arXiv:2207.04005]
- Search for $B^0 \to K^{*0}\tau^{\pm}\mu^{\mp}$ [arXiv:2209.09846]

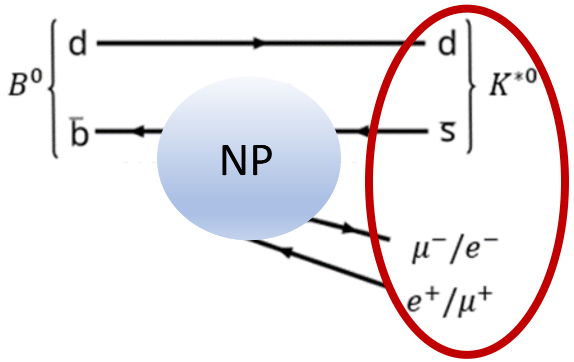


Baryon and Lepton Number Violation:

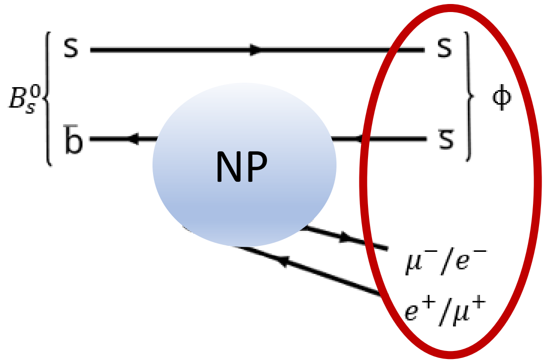
- Search for $B_{(s)}^0 \to p\mu^-$ [arXiv:2210.10412]

arXiv:2207.04005

$B^0 \rightarrow K^{*0}\mu^{\pm}e^{\mp}$ and $B_s^0 \rightarrow \phi\,\mu^{\pm}e^{\mp}$



LFV



Final states: $\overbrace{\boldsymbol{K^+\pi^-}}^{\text{from } K^{*0}}\boldsymbol{\mu^{\pm}e^{\mp}}$, $\overbrace{\boldsymbol{K^+K^-}}^{\text{from } \phi}\boldsymbol{\mu^{\pm}e^{\mp}}$

→ four charged particles

⬇

$K^+\pi^-(K^+K^-)$ invariant mass required close to nominal $K^{*0}(\phi)$ mass

- Signature: **event excess in the invariant mass spectrum of B decay products**
- Full LHCb dataset 9 fb^{-1}
- $B^0 \rightarrow K^{*0}\mu^{\pm}e^{\mp}$ treated separately depending on charge configuration of $K^+\mu$
  → NP and backgrounds differ between charge configurations

Background reduction:

- vetoes on misidentified B decays and semileptonic cascades involving D mesons
- BDT to suppress combinatorial background
- requirements on particle identification to suppress double misidentification ($B^0_{(s)} \rightarrow (K^{*0}/\phi)\pi^+\pi^-$)

$B^0 \rightarrow K^{*0}\mu^{\pm}e^{\mp}$ and $B_s^0 \rightarrow \phi\,\mu^{\pm}e^{\mp}$

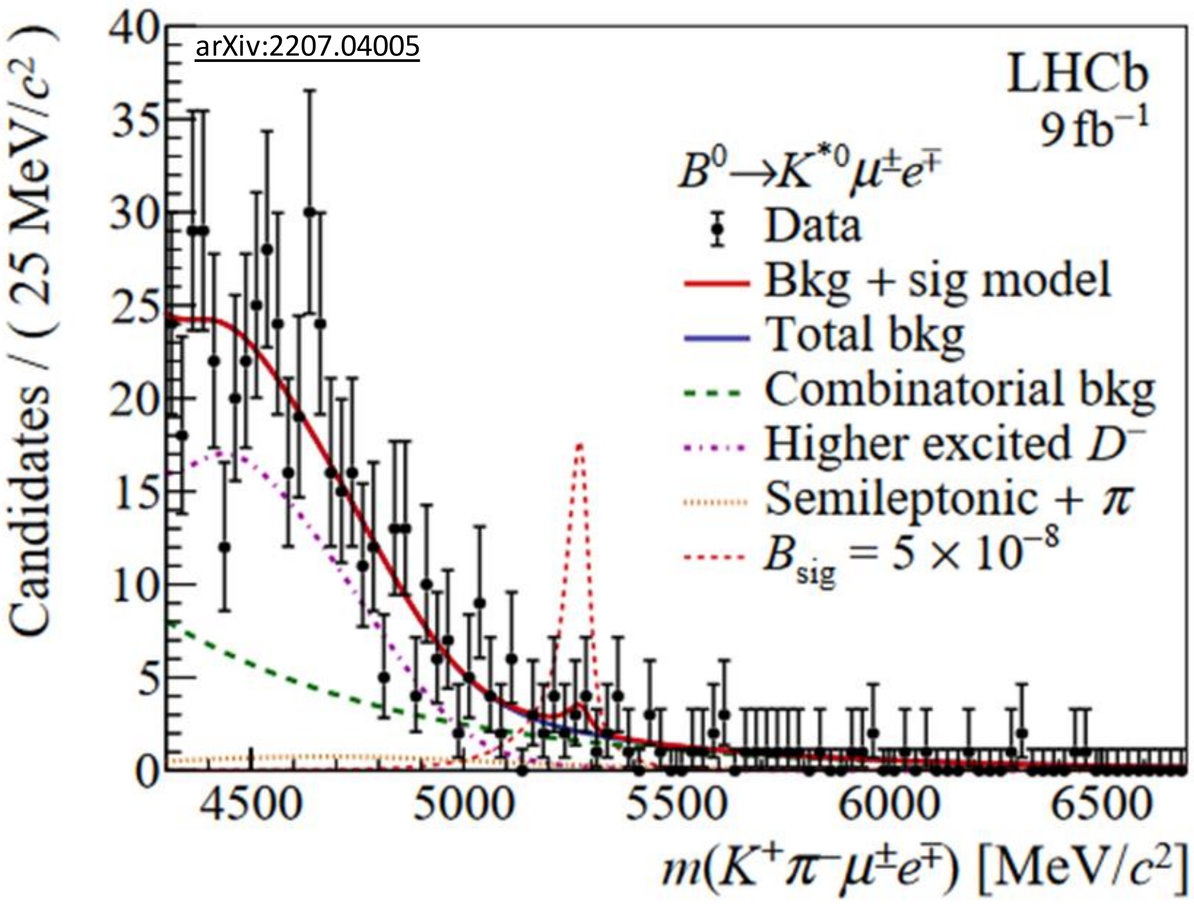
arXiv:2207.04005

Invariant mass fit:

Background models:

- some backgrounds can pass the vetoes
  → modelled from simulations
- combinatorial background measured from same-sign leptons data samples

→ **no significant excess found**

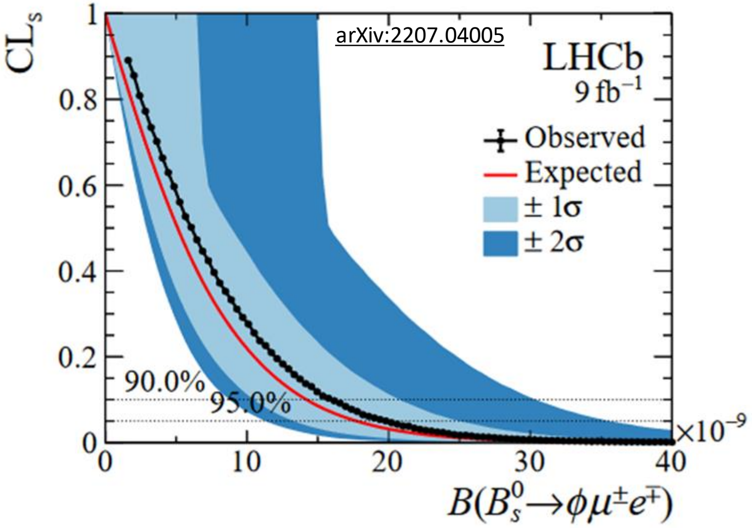


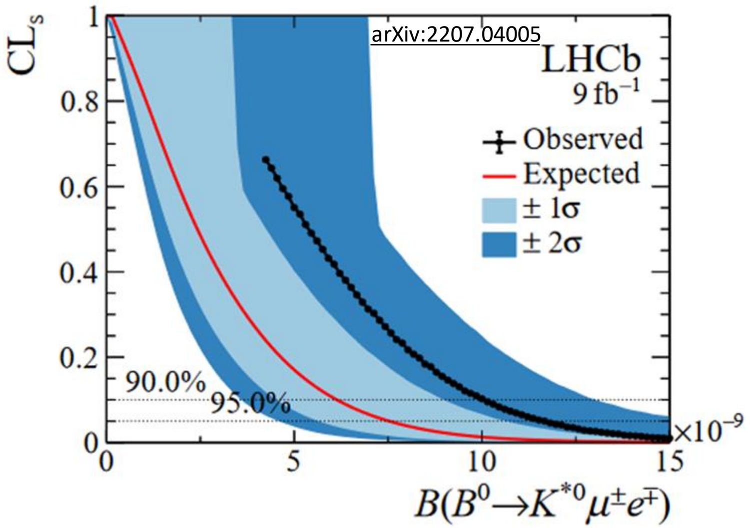
$B^0 \to K^{*0}\mu^{\pm}e^{\mp}$ and $B_s^0 \to \phi\,\mu^{\pm}e^{\mp}$: results

Set limits on branching ratios:

$$\mathcal{B}(B^0 \to K^{*0}\mu^+e^-) < 5.7(6.9)\cdot 10^{-9}$$
$$\mathcal{B}(B^0 \to K^{*0}\mu^-e^+) < 6.8(7.9)\cdot 10^{-9}$$
$$\mathcal{B}\left(B^0 \to K^{*0}\mu^{\pm}e^{\mp}\right) < 10.1(11.7)\cdot 10^{-9}$$
$$\mathcal{B}\left(B_s^0 \to \phi\mu^{\pm}e^{\mp}\right) < 16.0(19.8)\cdot 10^{-9}$$

at 90(95)% confidence level



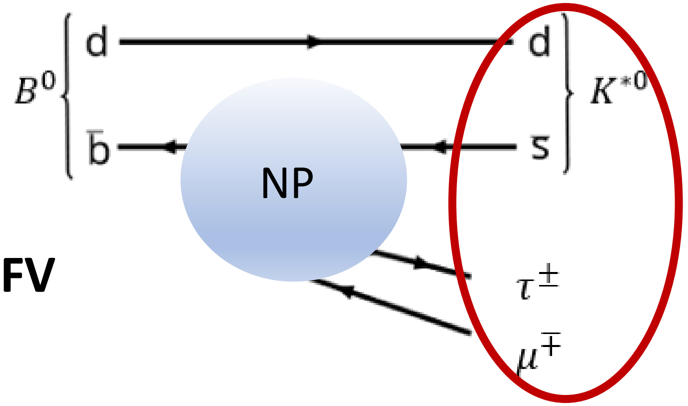


- K^{*0} channel: limit improved of one order of magnitude compared to previous searches
- ϕ channel: first limit on semileptonic LFV B_s^0 decay

Also set limits on parameters of two NP models: scalar model, left-handed model [EPJC 76 (2016) 134]

arXiv:2209.09846

$B^0 \to K^{*0}\tau^\pm\mu^\mp$



$$\text{Final states: } \underbrace{K^\pm\pi^\mp}_{\text{from } K^{*0}} \; \underbrace{\pi^+\pi^-\pi^\pm\nu_\tau(\pi^0)}_{\text{from } \tau^\pm} \; \mu^\mp$$

→ six charged particles

- Signature: **event excess in the invariant mass spectrum of B decay products**
- Full LHCb dataset 9 fb^{-1}

τ reconstruction:

- τ leptons decay undetected → reconstructed from decay products
- ν_τ and π^0 are not explicitly reconstructed → missing momentum

→ $m_{K^*\tau\mu}$ does not peak at B^0 mass

$$m_{corr} = \sqrt{p_\perp^2 + m_{K^*\tau\mu}^2} + p_\perp$$

missing momentum perpendicular to B^0 direction

Background reduction:

- Two BDT to suppress: combinatorial background, charmed mesons decays identified as τ
- Requirements on particle identification and intermediate masses, vetoes on physical backgrounds via D mesons

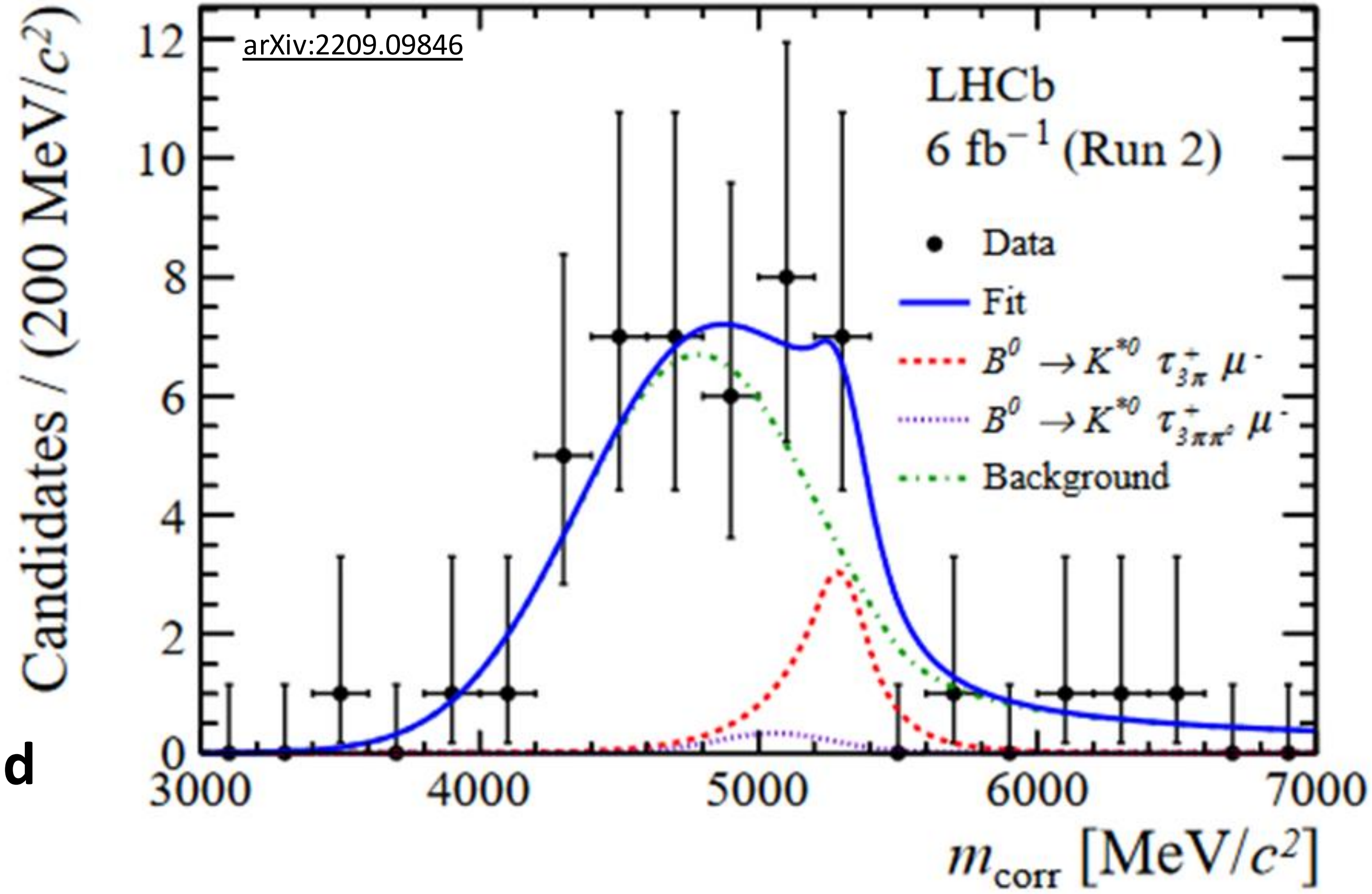
$B^0 \to K^{*0}\tau^{\pm}\mu^{\mp}$

Invariant mass fit:

Background model:

- control sample with loosened combinatorial BDT

→ **no significant excess found**



$B^0 \to K^{*0}\tau^{\pm}\mu^{\mp}$: results

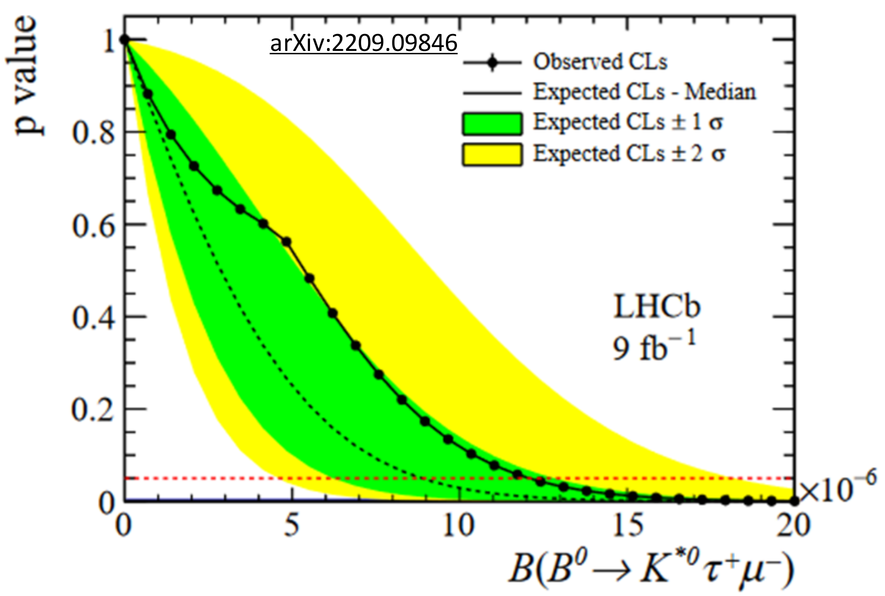
arXiv:2209.09846

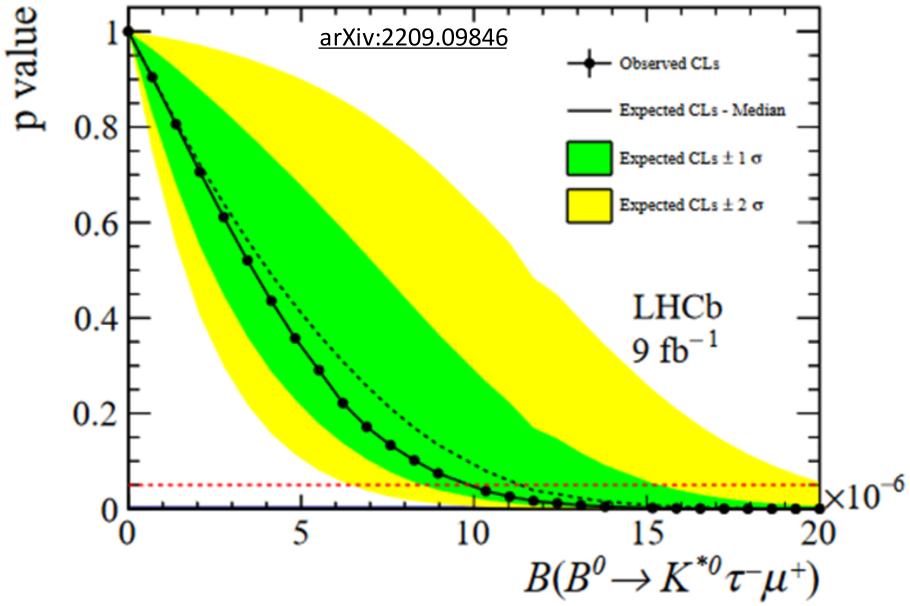
Set limits on branching ratios:

$$\mathcal{B}(B^0 \to K^{*0}\tau^+\mu^-) < 1.0(1.2)\cdot 10^{-5}$$
$$\mathcal{B}(B^0 \to K^{*0}\tau^-\mu^+) < 8.2(9.8)\cdot 10^{-6}$$

at 90(95)% confidence level

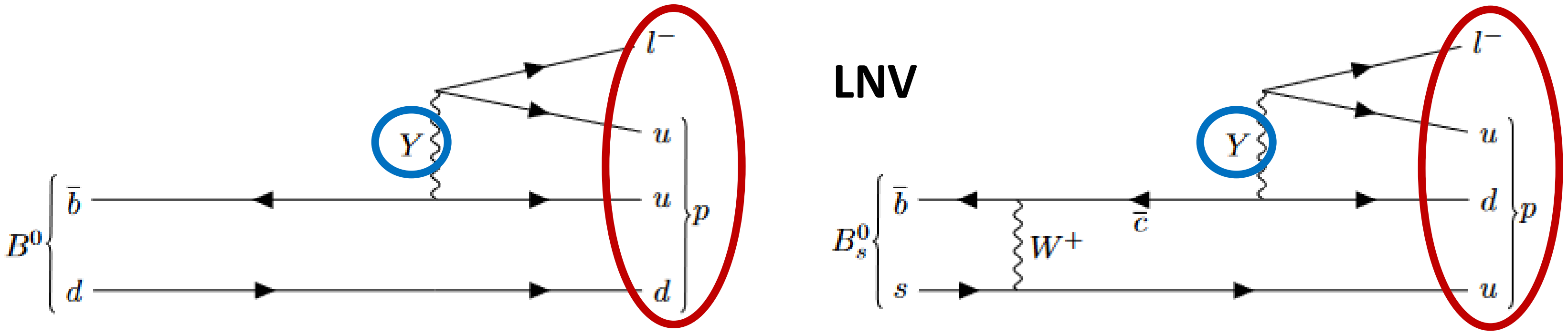
Most stringent limit on $b \to s\tau\mu$ transitions to date





arXiv:2210.10412

$B^0_{(s)} \to p\mu^-$



Hypothetical Feynman diagrams mediated by a hypothetical *Y* boson that couple quarks to leptons

Final state: $p\mu^-$

→ two charged particles

- Signature: **event excess in the invariant mass spectrum of B decay products**
- Full LHCb dataset 9 fb^{-1}

Background reduction:

- Requirements on particle identification to suppress physical backgrounds
- MVA with uniform output in [0, 1] to suppress combinatorial background

arXiv:2210.10412

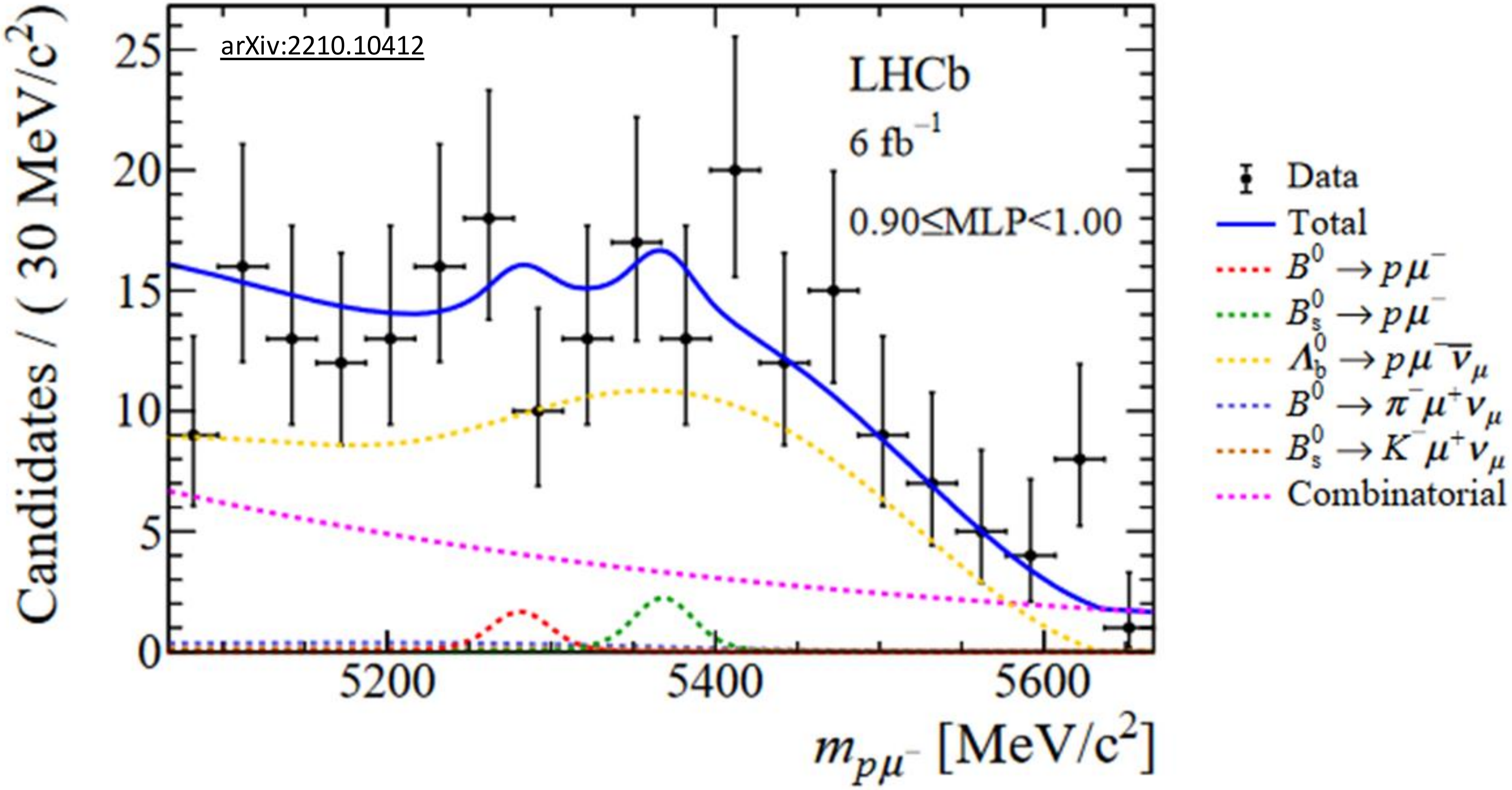
$B^0_{(s)} \to p\mu^-$

Invariant mass fit:

Fit performed in 7 regions of MVA output (lowest discarded due to high background)

Background models:

- some backgrounds are not sensitive to selection requirements → estimated from simulations
- residual combinatorial background modelled from same-sign final state data samples



no significant excess found

$B^0_{(s)} \rightarrow p\mu^-$: results

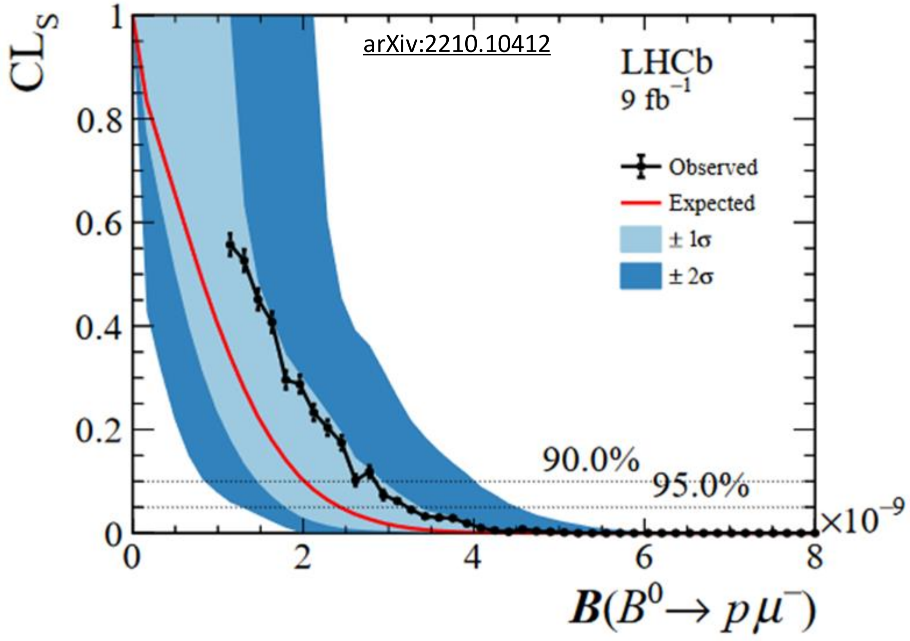
arXiv:2210.10412

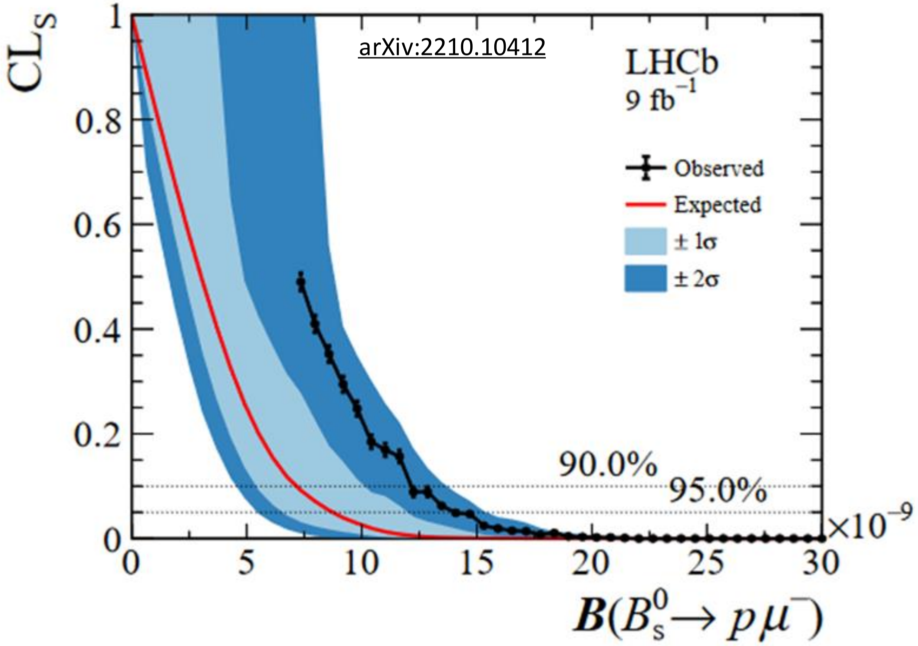
Set limits on branching ratios:

$$\mathcal{B}(B^0 \rightarrow p\mu^-) < 2.6(3.1) \cdot 10^{-9}$$
$$\mathcal{B}(B^0_s \rightarrow p\mu^-) < 12.1(14.0) \cdot 10^{-9}$$

at 90(95)% confidence level

→ **First limits on these decays to date**





Overview of previous LHCb results

Lepton Flavour Violation:

Process	**Upper limit**	**Data**	**Reference**
$B^+ \to K^+\mu^-\tau^+$	3.9×10^{-5} at 90% CL	$9\ fb^{-1}$	JHEP 06 (2020) 129
$B^+ \to K^+\mu^-e^+$ $B^+ \to K^+\mu^+e^-$	$7.0(9.5) \times 10^{-9}$ at $90(95)\%$ CL $6.4(8.8) \times 10^{-9}$ at $90(95)\%$ CL	$3\ fb^{-1}$	Phys. Rev. Lett.123 (2019) 241802
$B^0 \to \mu^\pm\tau^\mp$ $B^0_{(s)} \to \mu^\pm\tau^\mp$	1.4×10^{-5} at 95% CL 4.2×10^{-5} at 95% CL	$3\ fb^{-1}$	Phys. Rev. Lett. 123 (2019) 211801
$B^+ \to e^\pm\mu^\mp$	$1.0(1.3) \times 10^{-9}$ at $90(95)\%$ CL	$3\ fb^{-1}$	JHEP 03 (2018) 078

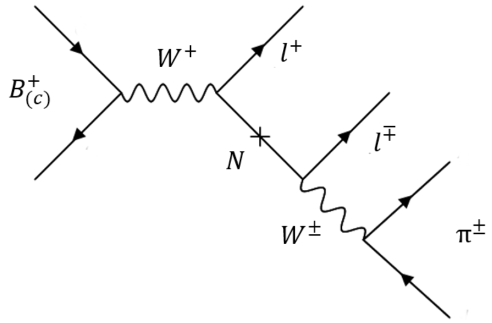
Lepton Number Violation:

Process	Upper limit	Data	Reference
$B^+ \to K^-\mu^+\mu^+$ $B^+ \to \pi^-\mu^+\mu^+$	5.4×10^{-8} at 95% CL 5.8×10^{-8} at 95% CL	$36\ pb^{-1}$	Phys. Rev. Lett. 108 (2012) 101601

Future perspectives

Further searches for LFV and LNV processes are possible at LHCb and new analyses are in progress, such as:

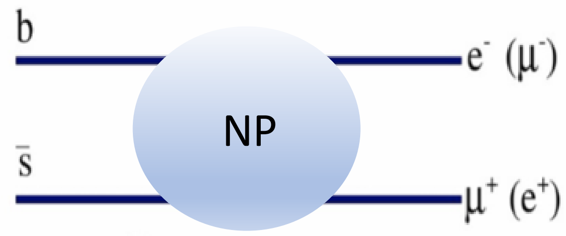
- Searches for Heavy Neutral Leptons (N), massive right-handed neutrinos, predicted by several NP theoretical models



$B^+ \rightarrow X\ \mu^+ N(\rightarrow \mu^\pm \pi^\mp)$ (LNV), $B^+ \rightarrow \mu^+ N(\rightarrow e^\pm \pi^\mp)$ (LFV and LNV)

(previous results on N's: Phys. Rev. Lett. 112 (2014) 131802, Phys. Rev. Lett. 108 (2012) 101601, Phys. Rev. D85 (2012) 112004)

- Search for $B^0_{(s)} \rightarrow e^\pm \mu^\mp$ (LFV) with Run 2 data



Summary

- LFV and LNV provide an interesting probe for NP

- No evidence for LFV or LNF yet, but stringent limits set

  → based on 9 fb^{-1} of data LHCb has put:
  - most stringent limit on
    - $\mathcal{B}(B^0 \to K^{*0}\mu^+e^-) < 5.7(6.9) \cdot 10^{-9}$
    - $\mathcal{B}(B^0 \to K^{*0}\mu^-e^+) < 6.8(7.9) \cdot 10^{-9}$
    - $\mathcal{B}\left(B^0 \to K^{*0}\mu^\pm e^\mp\right) < 10.1(11.7) \cdot 10^{-9}$
  - first limit on
    - $\mathcal{B}\left(B_s^0 \to \phi\mu^\pm e^\mp\right) < 16.0(19.8) \cdot 10^{-9}$
    - $\mathcal{B}(B^0 \to K^{*0}\tau^+\mu^-) < 1.0(1.2) \cdot 10^{-5}$
    - $\mathcal{B}(B^0 \to K^{*0}\tau^-\mu^+) < 8.2(9.8) \cdot 10^{-6}$
    - $\mathcal{B}(B^0 \to p\mu^-) < 2.6(3.1) \cdot 10^{-9}$
    - $\mathcal{B}(B_s^0 \to p\mu^-) < 12.1(14.0) \cdot 10^{-9}$

  at $90(95)\%\ CL$

- Several analyses with current data ongoing