



Lepton Flavor (Number) Violating at LHCb

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On behalf of LHCb

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Outline

- Motivation
- Overview of recent LFV (LNV) searches @ LHCb All preliminary
 - $B^0 \rightarrow K^{*0} \mu^\pm e^\mp$ and $B_s^0 \rightarrow \phi \mu^\pm e^\mp$
 - $B^0 \rightarrow K^{*0} \tau^\pm \mu^\mp$ New result
 - $B_{(s)}^0 \rightarrow p \mu^-$ New result
- Summary

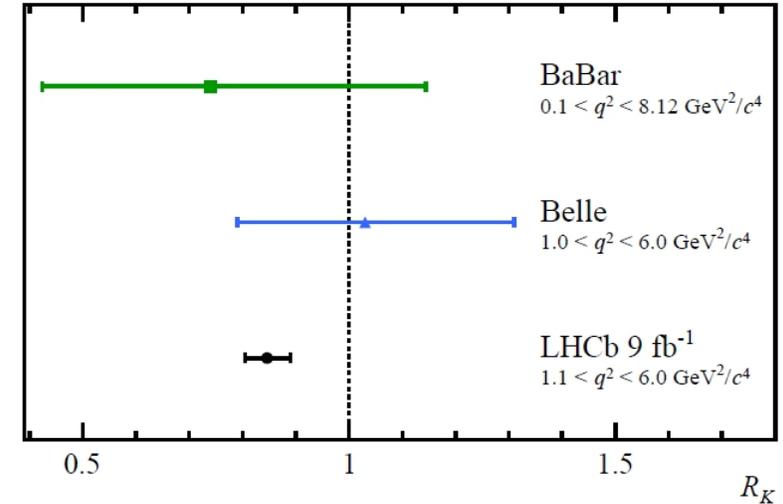
Motivation

- Lepton flavor violation (LFV) exists in neutrino oscillation
- Lepton flavor non-universality is closely related to cLFV
 - LHCb recently reported 3.1 sigma with SM

[Nature Phys. 18 (2022) 3, 277]

See Sebastian's talk "Lepton Flavour Universality tests in electroweak penguin decays at LHCb" on Saturday afternoon.

- Matter-antimatter asymmetry in the universe?
- Observation of charged LFV (LNV) decays will be a clear sign for NP (lepto-quark, Z' , etc.)



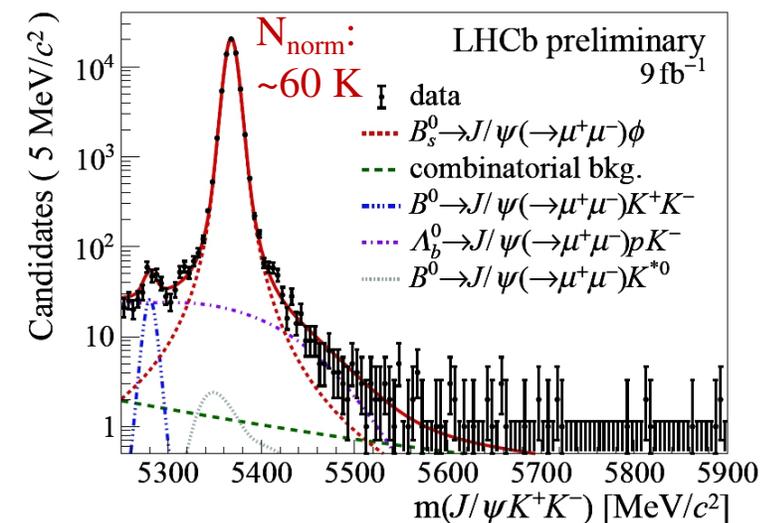
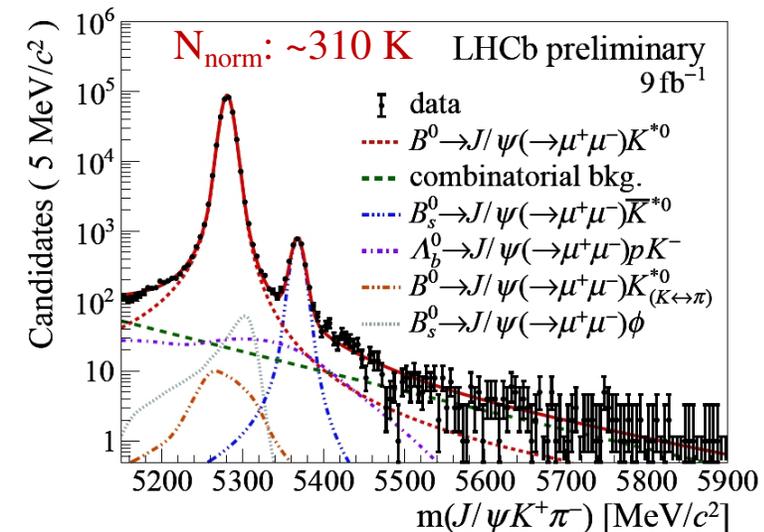
$$R_H \equiv \frac{\int_{q_{\min}^2}^{q_{\max}^2} \frac{d\mathcal{B}(B \rightarrow H\mu^+\mu^-)}{dq^2} dq^2}{\int_{q_{\min}^2}^{q_{\max}^2} \frac{d\mathcal{B}(B \rightarrow He^+e^-)}{dq^2} dq^2}.$$

Baryon (Lepton)
number violation
BNV(LNV)

$$B^0 \rightarrow K^{*0} \mu^\pm e^\mp \text{ \& } B_S^0 \rightarrow \phi \mu^\pm e^\mp$$

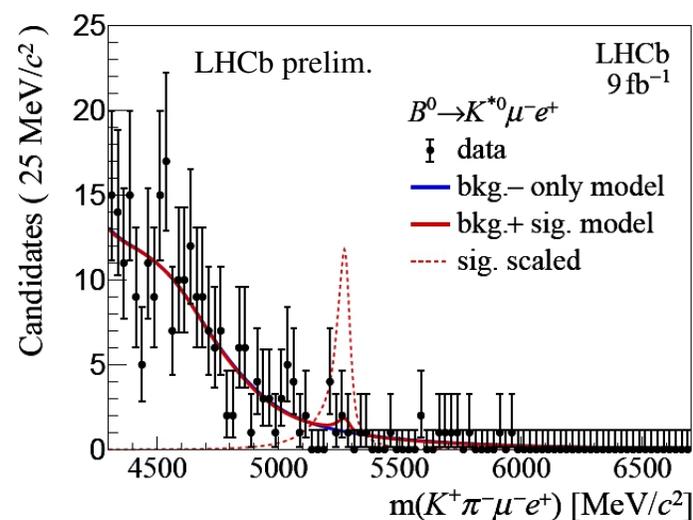
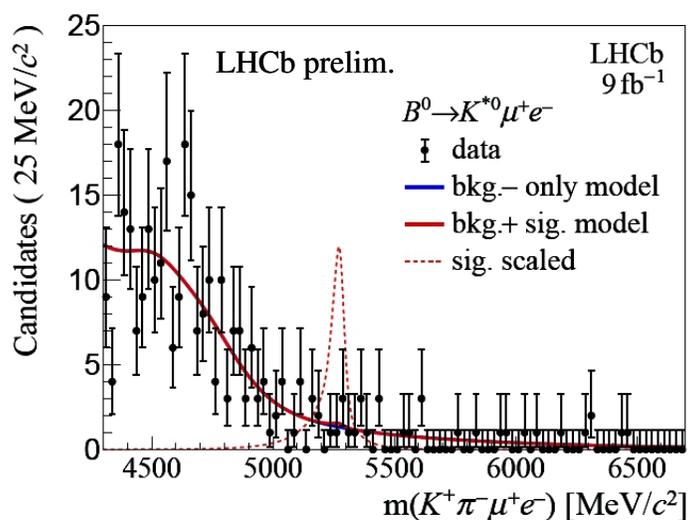
- Using full LHCb 9 fb⁻¹ data set
- Final states: $K^+ \pi^- \mu^\pm e^\mp$ & $K^+ K^- \mu^\pm e^\mp$
- Invariant mass of $K^+ \pi^- (K^+ K^-)$ required to be within 100 MeV (12 MeV) of known $K^{*0} (\phi)$ mass
- Normalization channels:
 - $B^0 \rightarrow J/\psi (\mu^+ \mu^-) K^{*0}$ and $B_S^0 \rightarrow J/\psi (\mu^+ \mu^-) \phi$
- Signal branching fractions:

$$\mathcal{B}_{\text{sig}} = \frac{\mathcal{B}_{\text{norm}}}{N_{\text{norm}}} \times \frac{\epsilon_{\text{norm}}}{\epsilon_{\text{sig}}} \times N_{\text{sig}}$$
 - $B^0 \rightarrow K^{*0} \mu^\pm e^\mp$ includes 3 combinations
 - $K^+ \mu^-$ or $K^+ \mu^+$ or $K^\pm \mu^\mp$

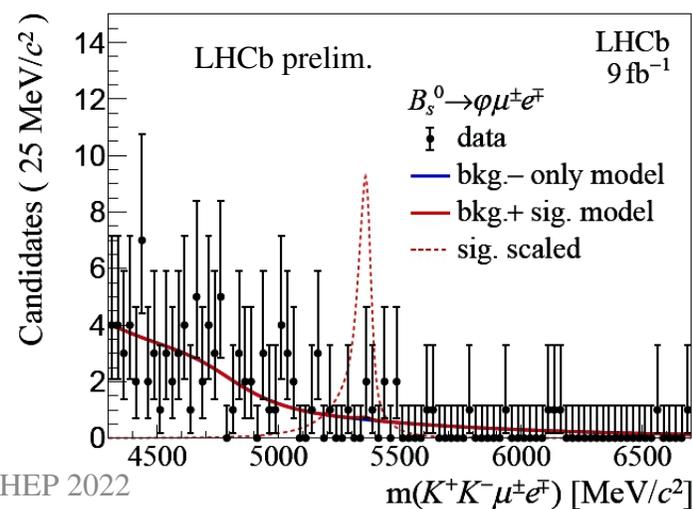
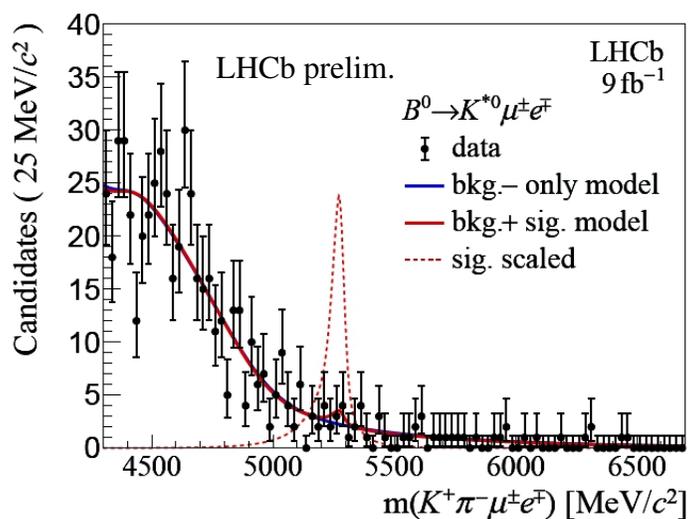


$B^0 \rightarrow K^{*0} \mu^\pm e^\mp$ & $B_s^0 \rightarrow \phi \mu^\pm e^\mp$: details

Charge split for K^{*0} mode:

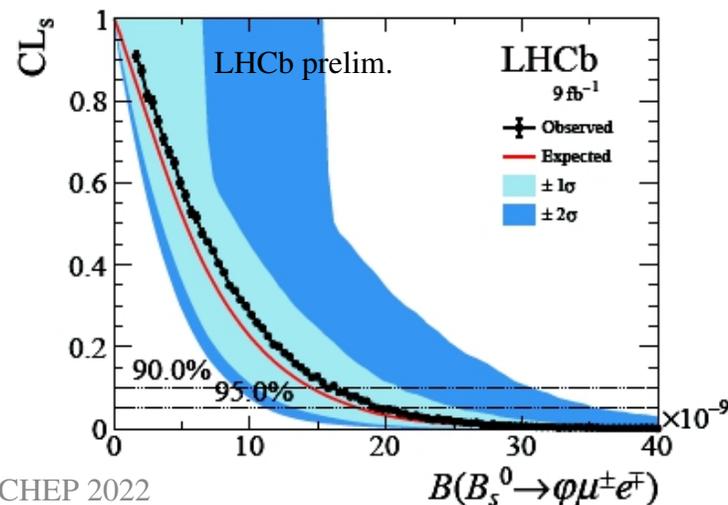
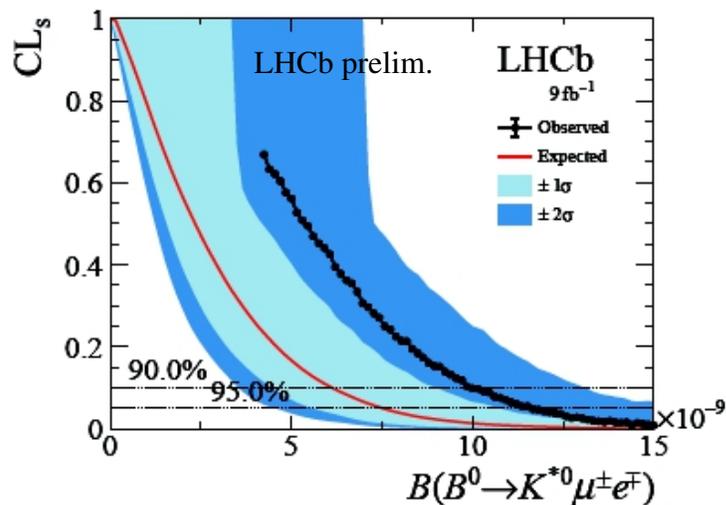
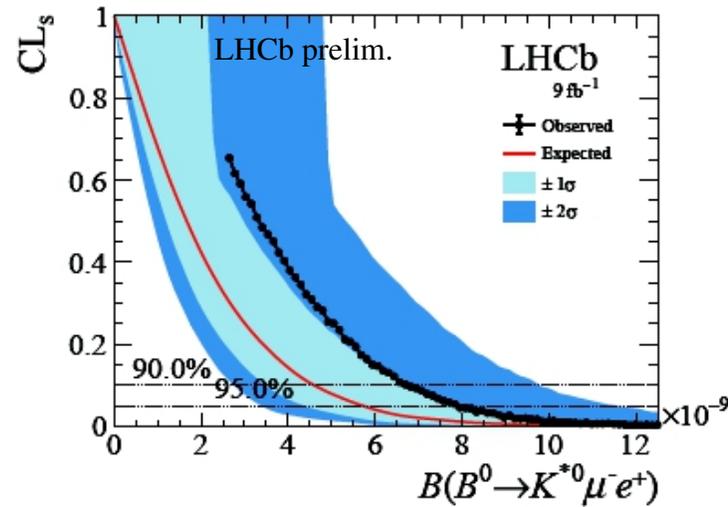
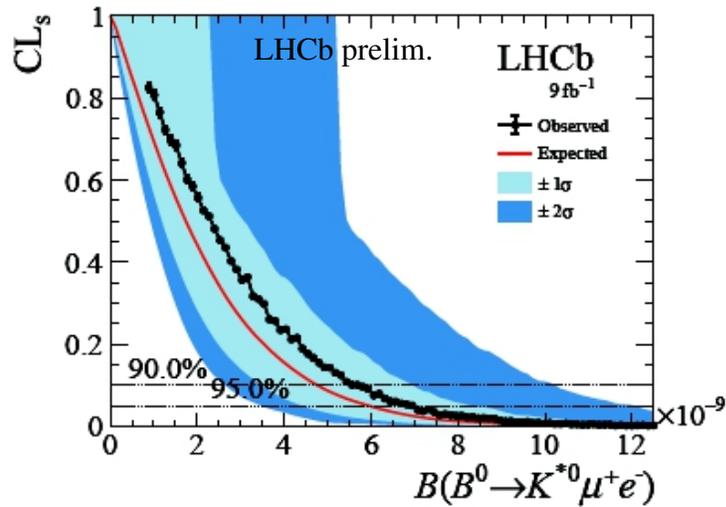


Signal arbitrarily scaled for illustrational purpose



$B^0 \rightarrow K^{*0} \mu^\pm e^\mp$ & $B_s^0 \rightarrow \phi \mu^\pm e^\mp$: CL_s method

Charge split for K^{*0} mode:



$B^0 \rightarrow K^{*0} \mu^\pm e^\mp$ & $B_s^0 \rightarrow \phi \mu^\pm e^\mp$: results

- Currently best upper limits @ 90% (95%) CL:

$$\begin{aligned} \mathcal{B}(B^0 \rightarrow K^{*0} \mu^+ e^-) &< 5.7 \times 10^{-9} \quad (7.0 \times 10^{-9}), \\ \mathcal{B}(B^0 \rightarrow K^{*0} \mu^- e^+) &< 6.7 \times 10^{-9} \quad (7.9 \times 10^{-9}), \\ \mathcal{B}(B^0 \rightarrow K^{*0} \mu^\pm e^\mp) &< 9.9 \times 10^{-9} \quad (11.6 \times 10^{-9}) \end{aligned} \quad \text{LHCb prelim.}$$

- About one order of magnitude improvement over Belle results

[PRD 98 (2018) 071101]

- Also the most stringent limits on a semileptonic LFV b-hadron decay

- First search on a semileptonic LFV decay:

$$\mathcal{B}(B_s^0 \rightarrow \phi \mu^\pm e^\mp) < 15.9 \times 10^{-9} \quad (19.4 \times 10^{-9}) \quad \text{LHCb prelim.}$$

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

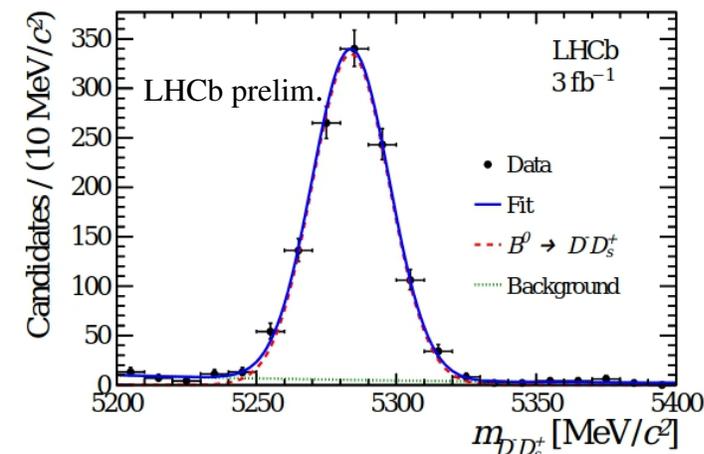
- Using full LHCb 9 fb⁻¹ data set
- Final states: $K^+ \pi^- \pi^\pm \pi^\mp \pi^\mp \mu^\pm$
 - 2 signal channels: $\tau^\mp \rightarrow \pi^\pm \pi^\mp \pi^\mp (\pi^0) \nu_\tau$ **same final states**
 - search for $K^+ \tau^+$ and $K^+ \tau^-$ separately
 - Invariant mass of K^{*0} required to be 0.7-1.1 GeV and τ to be 0.5-2 GeV
 - corrected mass: $m_{\text{corr}} = \sqrt{p_\perp^2 + m_{K^* \tau \mu}^2 + p_\perp^2}$

- Normalization channels:

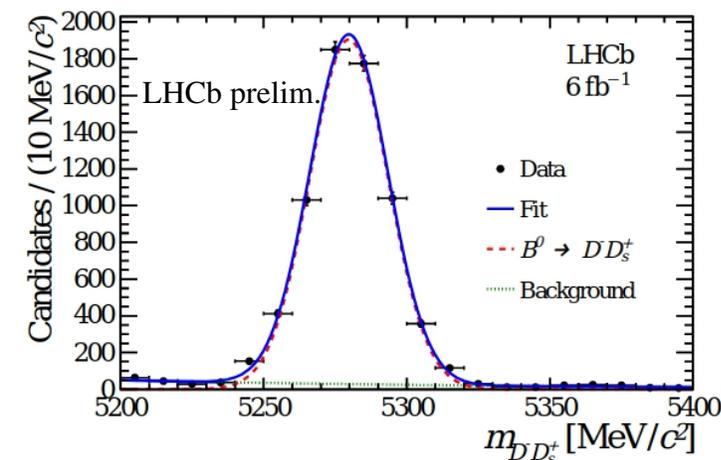
$$B^0 \rightarrow D^- (K^+ \pi^- \pi^-) D_s^+ (K^+ K^- \pi^+)$$
- Signal yield:

$$Y_{\tau 3\pi}^{\text{run}} = \frac{\mathcal{B}(B^0 \rightarrow K^{*0} \tau^- \mu^+) \cdot \mathcal{B}(K^{*0} \rightarrow K^+ \pi^-) \cdot \mathcal{B}(\tau^- \rightarrow \pi^- \pi^+ \pi^- \nu_\tau)}{\mathcal{B}(B^0 \rightarrow D^- D_s^+) \cdot \mathcal{B}(D^- \rightarrow K^+ \pi^- \pi^-) \cdot \mathcal{B}(D_s^+ \rightarrow K^+ K^- \pi^+)} \cdot \sum_{y \in \text{run}} \left(\frac{\varepsilon Y_N}{\varepsilon_N} \right)_y$$

$N_{\text{norm}}: \sim 1200$

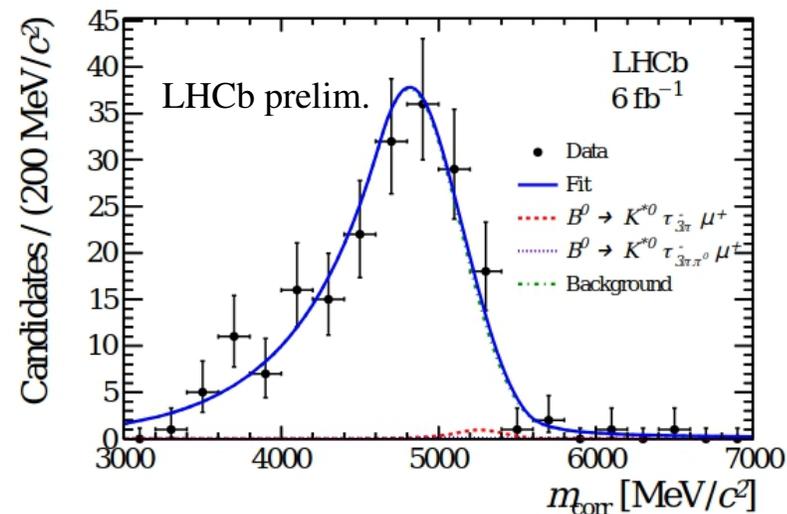
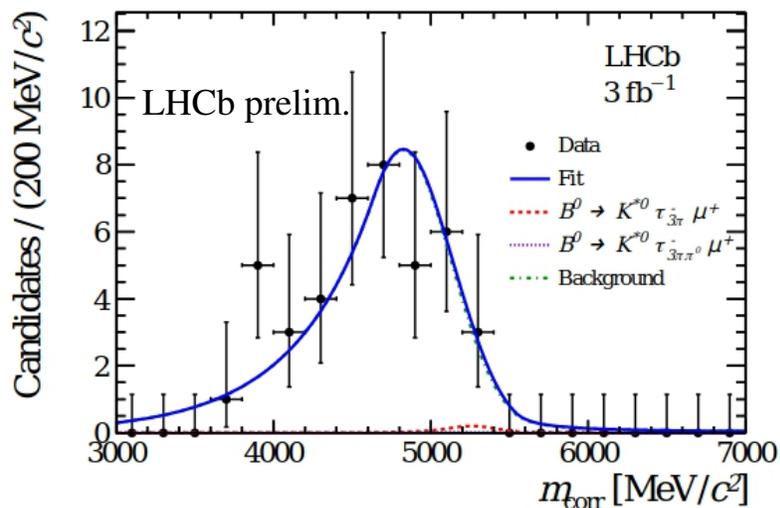


$N_{\text{norm}}: \sim 6500$

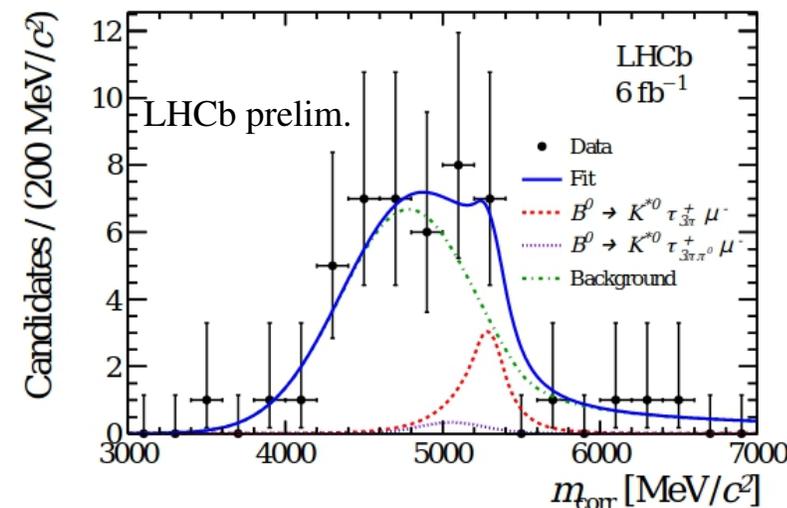
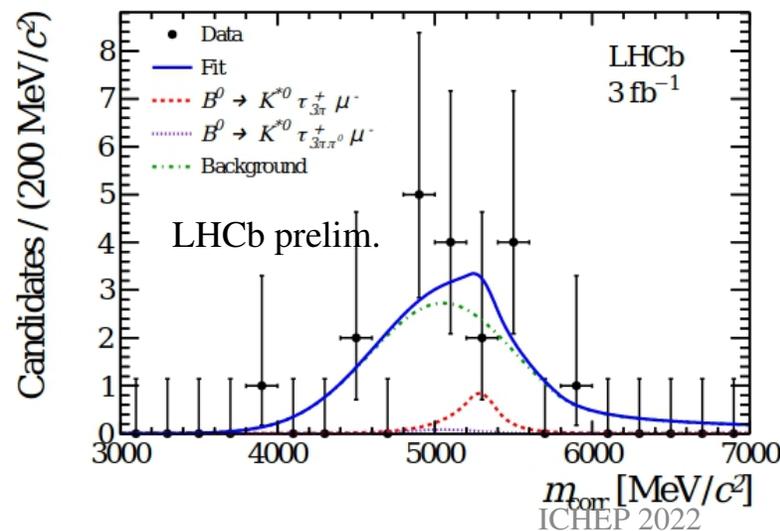


$B^0 \rightarrow K^{*0} \tau^\pm \mu^\mp$: details

$K^+ \tau^-$



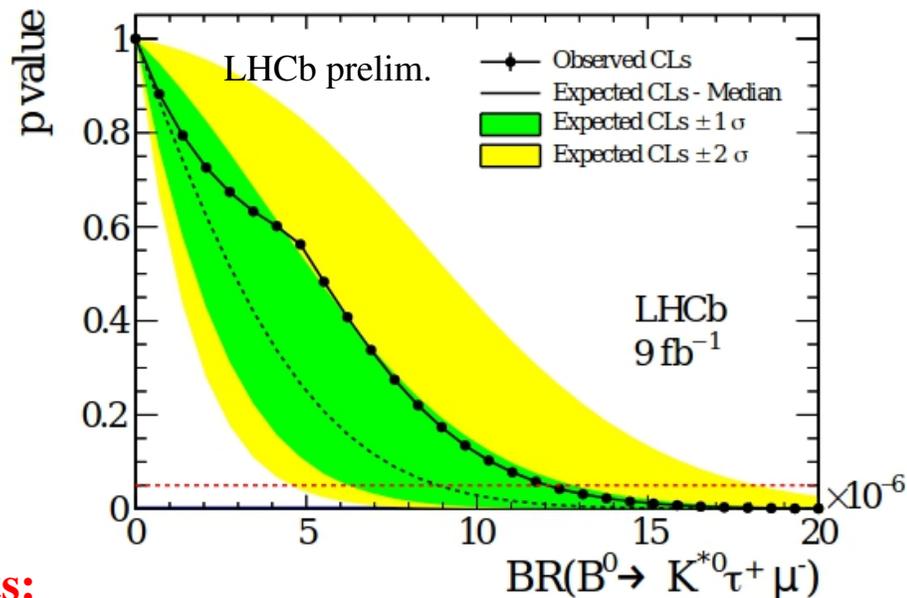
$K^+ \tau^+$



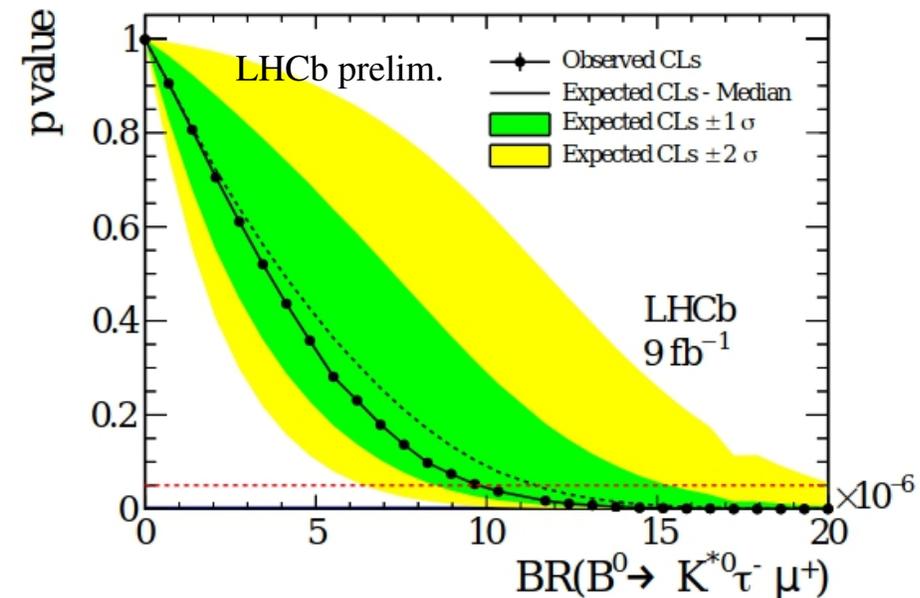
$B^0 \rightarrow K^{*0} \tau^\pm \mu^\mp$: CL_s method

First search for $B^0 \rightarrow K^{*0} \tau^\pm \mu^\mp$:

$K^+ \tau^+$



$K^+ \tau^-$



New results:

@ 90% (95%) CL

$$\mathcal{B}(B^0 \rightarrow K^{*0} \tau^+ \mu^-) < 1.0 \text{ (1.2)} \times 10^{-5}$$

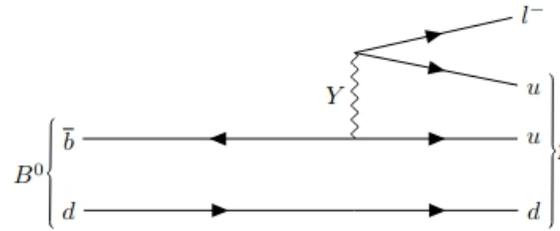
@ 90% (95%) CL

$$\mathcal{B}(B^0 \rightarrow K^{*0} \tau^- \mu^+) < 8.2 \text{ (9.8)} \times 10^{-6}$$

$B^0 \rightarrow p \mu^-$ & $B_S^0 \rightarrow p \mu^-$

BNV and LNV decays

- Using full LHCb 9 fb⁻¹ data set



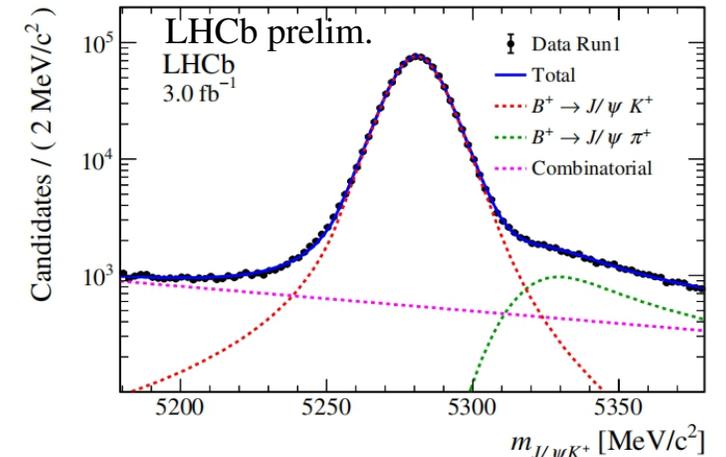
- Search window is [5067,5667] MeV with signal region [5217,5457] MeV blinded
- Normalization channels:

$$B^+ \rightarrow J/\Psi (\mu^+ \mu^-) K^+$$

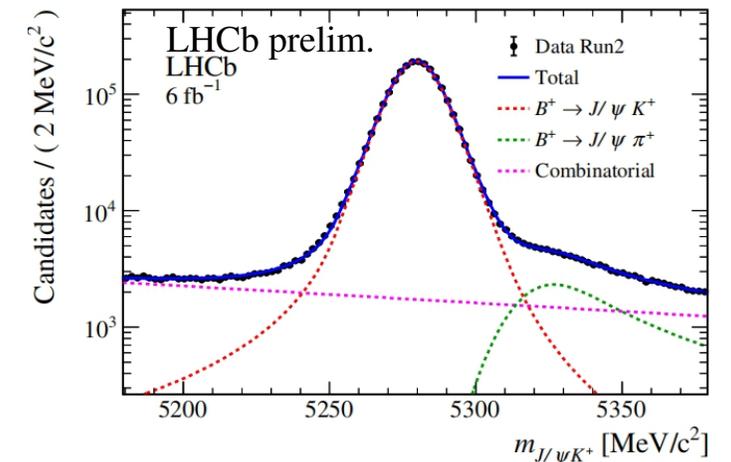
- Signal branching fractions:

$$B(B_{d,s}^0 \rightarrow p^\pm \mu^\mp) = \frac{f_{cal}}{f_{d,s}} \frac{\epsilon_{cal}}{\epsilon_{B_{d,s}^0 \rightarrow p^\pm \mu^\mp}} \frac{N_{B_{d,s}^0 \rightarrow p^\pm \mu^\mp}}{N_{cal}} B_{cal}$$

$N_{\text{norm}}: \sim 220 \text{ K}$



$N_{\text{norm}}: \sim 87 \text{ K}$

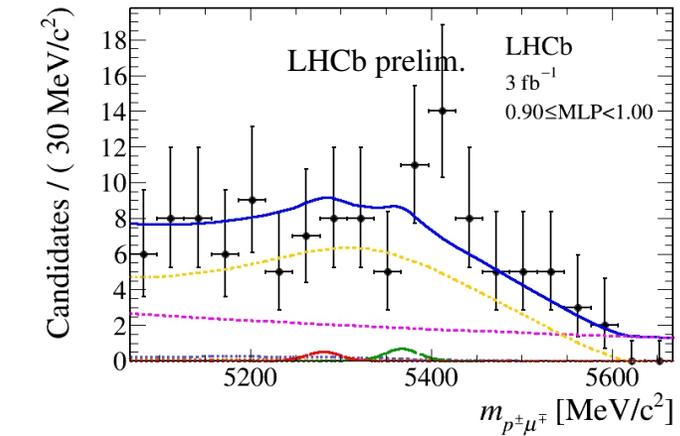
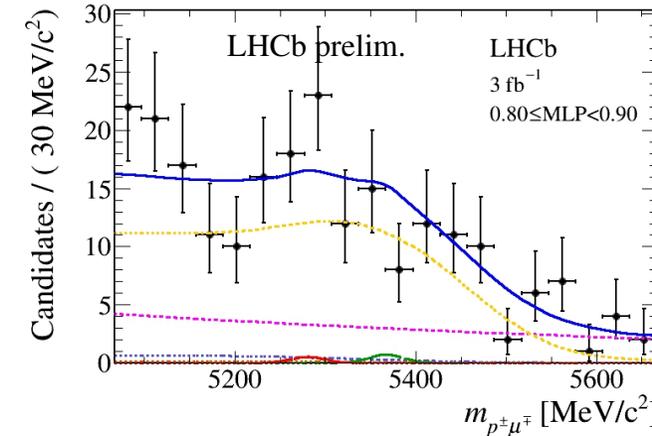
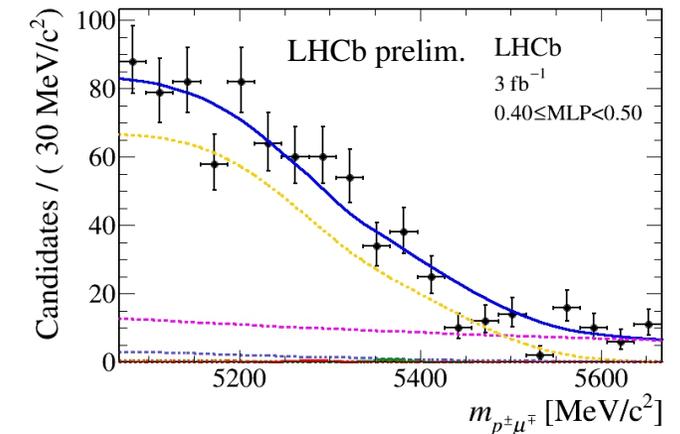
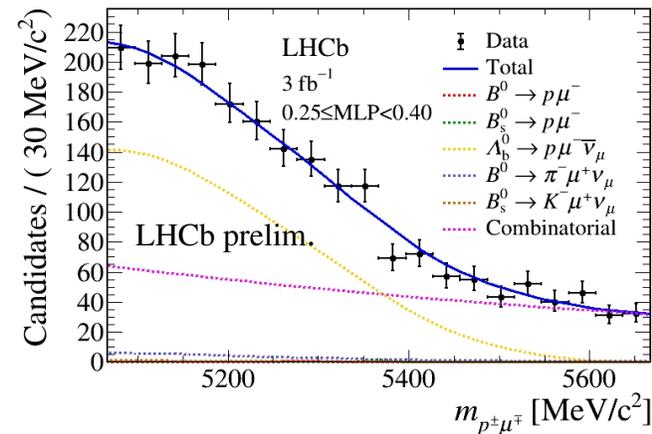


$B^0 \rightarrow p \mu^-$ & $B_s^0 \rightarrow p \mu^-$: details

the first 2 bins

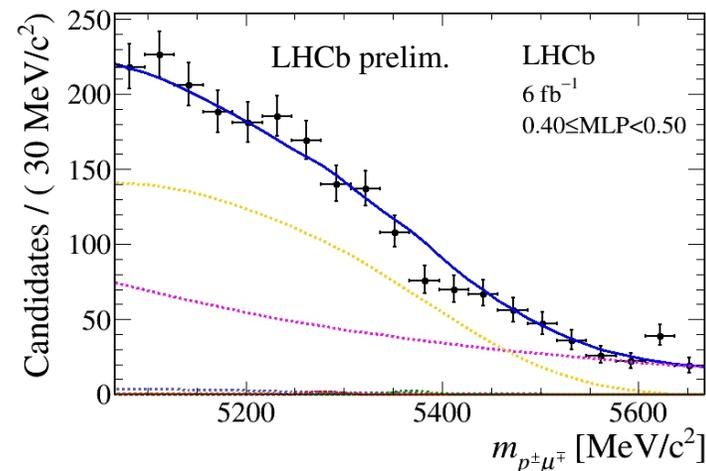
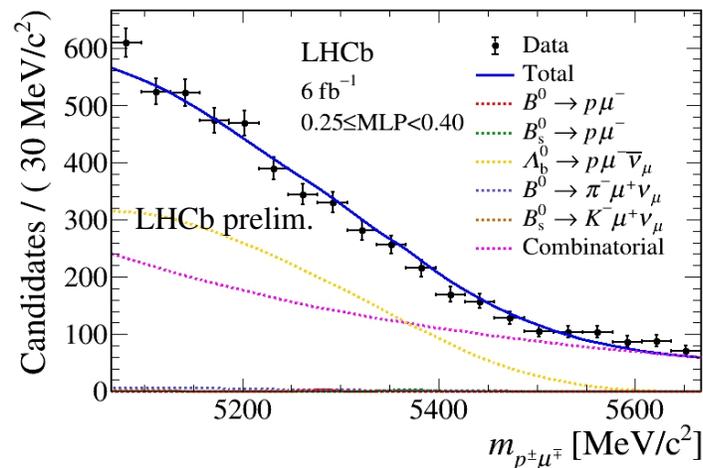
- MLP bin: **0, 0.25**, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0
- Simultaneous fit in the 14 MLP bins (7 bins for Run1 and Run2 respectively)

the last 2 bins

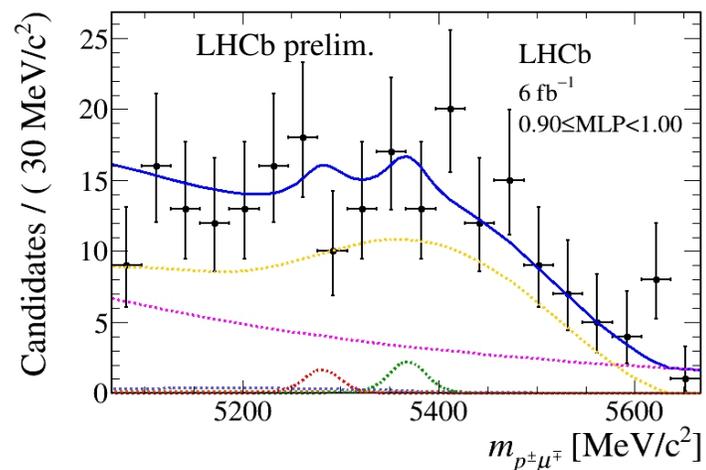
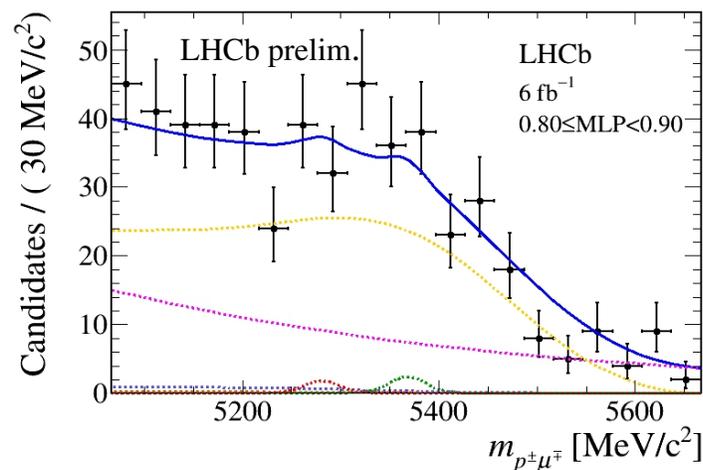


$B^0 \rightarrow p\mu^-$ & $B_s^0 \rightarrow p\mu^-$: details

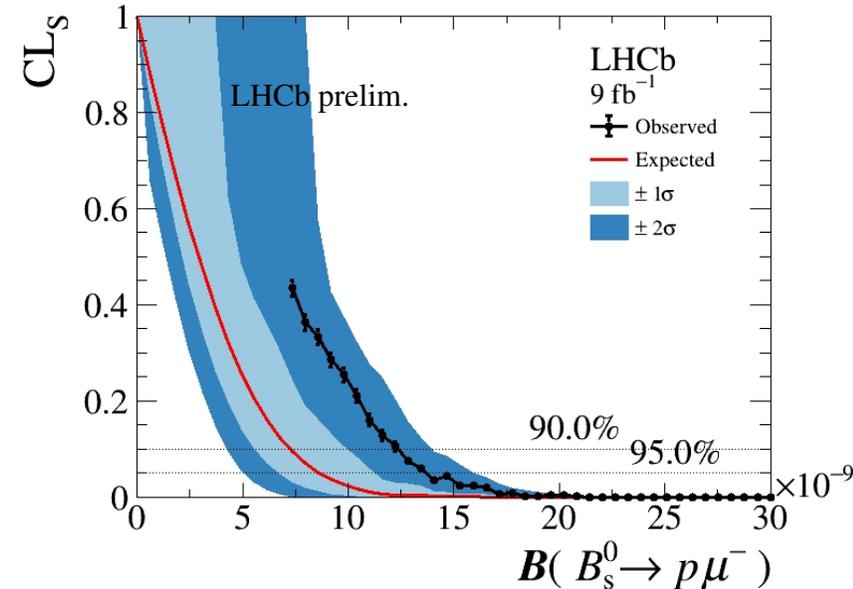
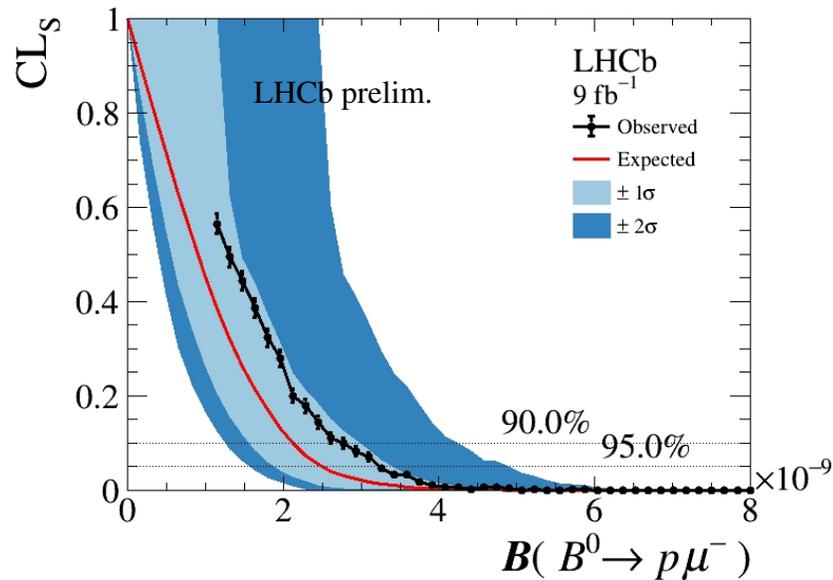
the first 2 bins



the last 2 bins



$B^0 \rightarrow p\mu^-$ & $B_s^0 \rightarrow p\mu^-$: CL_s method



New results:

@ 90% (95%) CL

First search for $B_{(s)}^0 \rightarrow p\mu^-$: $\mathcal{B}(B^0 \rightarrow p\mu^-) < 2.6(3.1) \times 10^{-9}$

$\mathcal{B}(B_s^0 \rightarrow p\mu^-) < 1.2(1.4) \times 10^{-8}$

Summary

- Together with LFU tests, LFV is very interesting to probe for NP
- LNV/BNV searches help to understand matter-antimatter asymmetry
- LHCb provides ideal environment for searching for LFV(LNV) in heavy flavor decays
- No evidence for LFV(LNV), although the world's best upper limits on the BFs are set
- More results with current data are on the way
- Looking forward to new data (Run3 and beyond) in the years to come