Search for lepton flavour violation at LHCb

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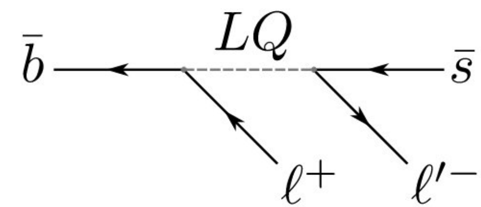
on behalf of the LHCb collaboration

Why lepton flavour violation (LFV)?

Example of beyond-SM process with leptoquark



- LFV decays are forbidden in the SM
- Access to much larger masses of New Physics particles than in direct searches
- Neutrino oscillations lead to LFV for neutral leptons
- No LFV process for charged leptons observed yet
- Clear null-tests of the SM

arXiv:2207.04005

$$\mathcal{B}(B^0 \to K^{*0}\mu^\pm e^\mp) < 10.1 \times 10^{-9}$$

$$\mathcal{B}(B_s^0 \to \phi\mu^\pm e^\mp) < 16.0 \times 10^{-9}$$

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$$\mathcal{B}(\tau^- \to \mu^-\mu^+\mu^-) < 4.6 \times 10^{-8}$$

Phys. Lett. B754 (2016) 167

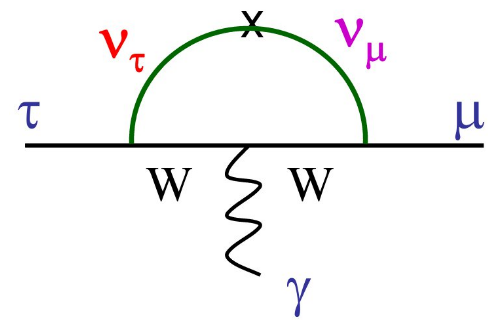
$$\mathcal{B}(D^0 \to e^\pm\mu^\mp) < 1.3 \times 10^{-8}$$

LFV in theoretical framework

There are several proposition for a LFV models, some within the experimental range of near future detectors.

Models	References	$\tau \to \mu\gamma$
SM + ν mixing	Lee, Shrock, PRD 16 (1977) 1444 Cheng, Li, PRD 45 (1980) 1908	10^{-54}-10^{-40}
SUSY + Higgs	Dedes, Ellis, Raidal, PLB 549 (2002) 159 Brignole, Rossi, PLB 566 (2003) 517	10^{-10}
SM + Maj ν_R	Cvetic, Dib, Kim, Kim, PRD 66 (2002) 034008	10^{-9}
Non-universal Z'	Yue, Zhang, Liu, PLB 547 (2002) 252	10^{-9}
mSUGRA + Seesaw	Ellis et al. EPJ C14 (2002) 319 Antusch et al. JHEP 11 (2006) 090	10^{-8}- 10^{-12}
SUSY SO(10)	Masiero, Vempati, Vives, NPB 649 (2003) 189 Fukuyama et al. EPJ C56 (2008) 125	10^{-8}- 10^{-10}
MLFV	Cirigliano, Grinstein, NPB 752 (2006) 18	10^{-8}
Little Higgs	Goto et al, PRD 83 (2011) 053011 Rai Choudhury et al. PRD 75 (2007) 055011	10^{-8}- 10^{-11}

Lepton Flavour Violation in Tau Lepton decays - Jorge Portolés, CPAN 2010



$$\mathcal{B}(\tau^- \to \mu^-\gamma) < 4.5 \times 10^{-8},$$
$$\mathcal{B}(\tau^- \to e^-\gamma) < 12.0 \times 10^{-8}$$

Phys.Lett.B666:16-22,2008

JHEP 11 (2018) 081

Effective Hamiltonian

It is also possible to define a model independent description, by adding additional Wilson coefficients and related operators.

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} \frac{\alpha}{4\pi} V_{tb} V_{ts}^* \sum_i \left(C_i^\ell \mathcal{O}_i^\ell + C_i'^\ell \mathcal{O}_i'^\ell \right)$$

$$\mathcal{O}_9^\ell = (\bar{s}\gamma_\mu P_L b)\left(\bar{\ell}\gamma^\mu \ell\right)$$

$$\mathcal{O}_{10}^\ell = (\bar{s}\gamma_\mu P_L b)\left(\bar{\ell}\gamma^\mu \gamma_5 \ell\right)$$

arXiv:2207.04005

Search for the lepton-flavour violating decays

Signal:

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

$$B_s^0 \to \phi \mu^{\pm} e^{\mp}$$

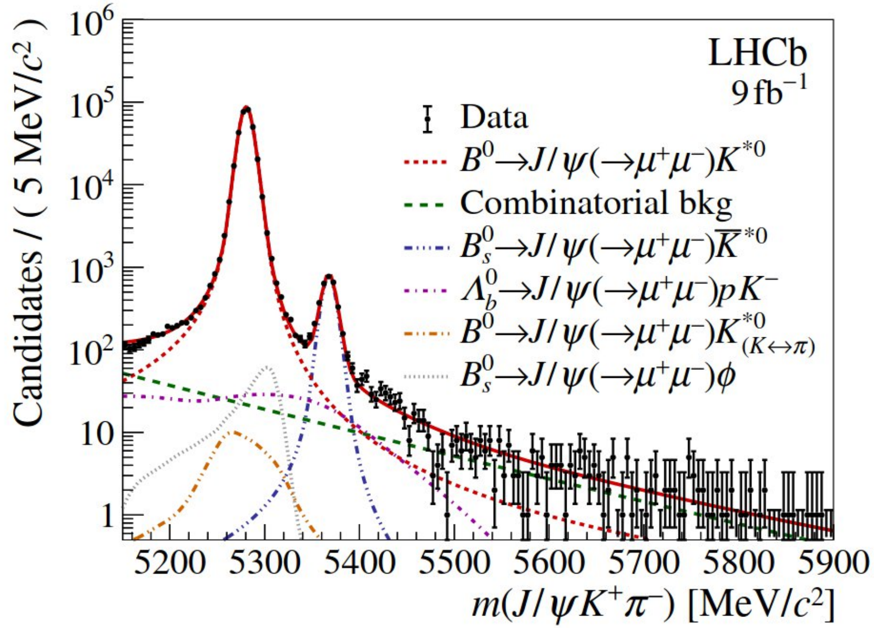
Normalisation:

$$B_s^0 \to J/\psi(\to \mu^+ \mu^-)\phi$$

$$B^0 \to J/\psi(\to \mu^+ \mu^-) K^{*0}$$

Signal branching fraction:

$$\mathcal{B}_{\text{sig}} = \frac{\mathcal{B}_{\text{norm}}}{N_{\text{norm}}} \times \frac{\varepsilon_{\text{norm}}}{\varepsilon_{\text{sig}}} \times N_{\text{sig}}$$



arXiv:2207.04005

Search for the lepton-flavour violating decays

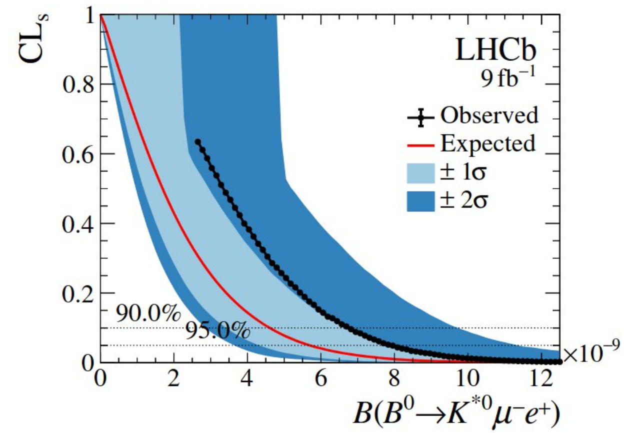
Analysis Strategy

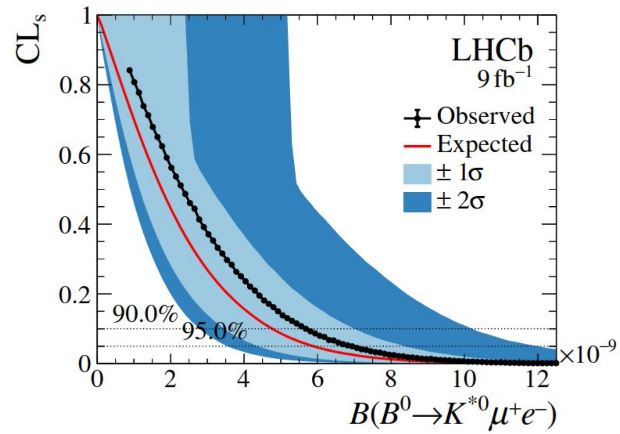
- blind analysis
  (signal window [4900, 5600] MeV)
- full LHCb luminosity (9 fb^{-1})
- two charge categories:

$$B^0 \to K^{*0}\mu^+ e^-$$

$$B^0 \to K^{*0}\mu^- e^+$$

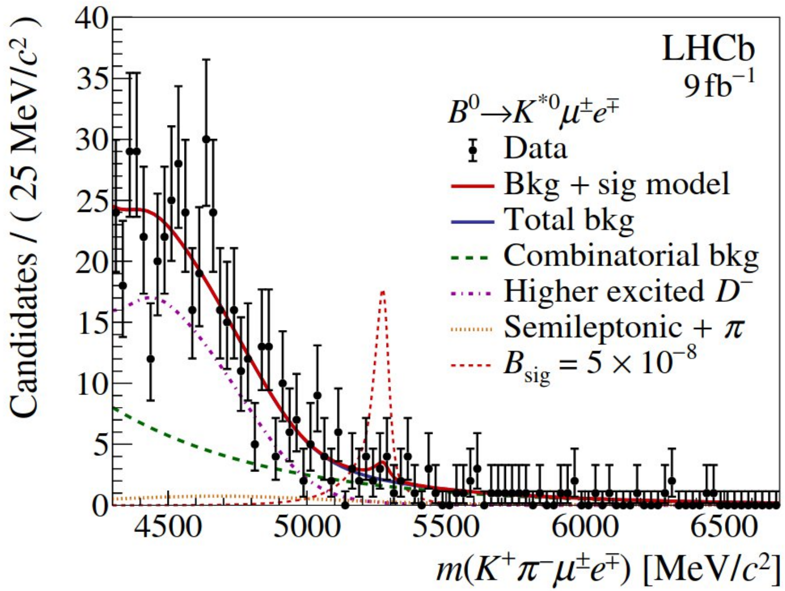
- muon hardware trigger
- selection with BDT classifier

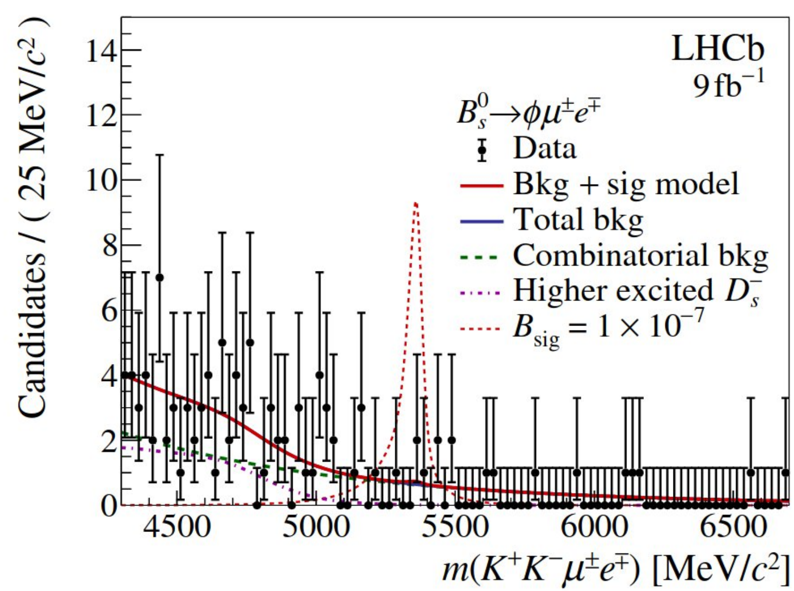




arXiv:2207.04005

Results





$$\mathcal{B}(B^0 \to K^{*0}\mu^+e^-) < 5.7 \times 10^{-9}$$
$$\mathcal{B}(B^0 \to K^{*0}\mu^-e^+) < 6.8 \times 10^{-9}$$
$$\mathcal{B}(B^0 \to K^{*0}\mu^\pm e^\mp) < 10.1 \times 10^{-9}$$
$$\mathcal{B}(B_s^0 \to \phi\mu^\pm e^\mp) < 16.0 \times 10^{-9}$$

Limits with background only hypothesis at 90% CL.

$\Lambda_c \to pe\mu$ decay

- Main goal of the analysis is to measure or set the limit on the $\Lambda_c \to pe\mu$ decay rate relative to the $\Lambda_c \to p\phi(\mu\mu)$ channel
- Data sample: Run2 - 2016, 2017, 2018
- Samples split between two **bremsstrahlung categories**
- Samples split between two **charge combinations:**
  - $\Lambda_c^+ \to p^+e^+\mu^-$ (SS) $\quad$ $\mathrm{BF} < 9.9 \times 10^{-6}$ CL $= 90\%$
  - $\Lambda_c^+ \to p^+e^-\mu^+$ (OS) $\quad$ $\mathrm{BF} < 1.9 \times 10^{-5}$ CL $= 90\%$

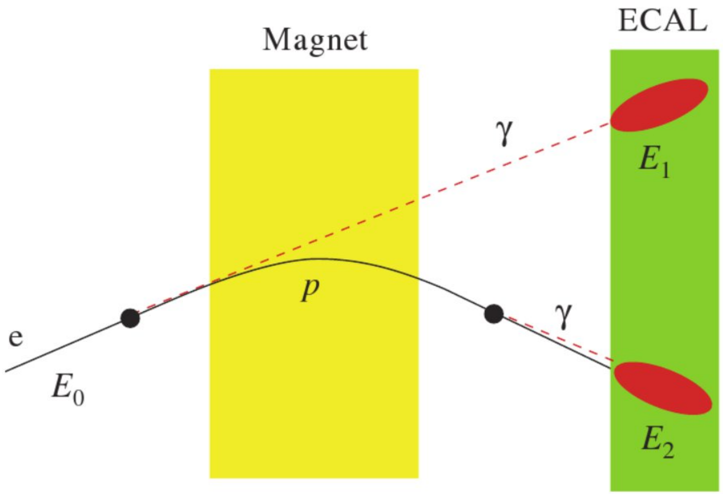
BaBar
Phys. Rev. D 84, 072006

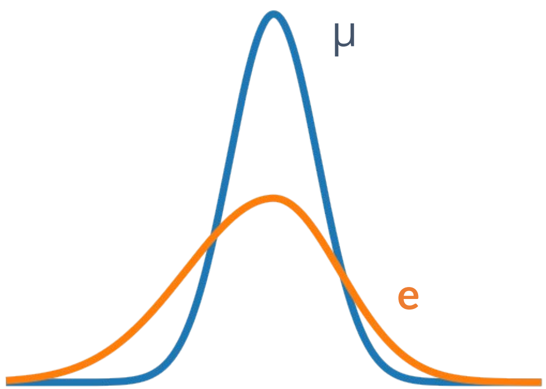
- **Blind analysis** - Λ_c mass signal region removed from the data
- Signal branching fraction:

$$\mathcal{B}_{\rm sig} = \frac{\mathcal{B}_{\rm norm}}{N_{\rm norm}} \times \frac{\varepsilon_{\rm norm}}{\varepsilon_{\rm sig}} \times N_{\rm sig}$$

Experimental challenges - bremsstrahlung

- Electrons in LHCb can lose some energy via bremsstrahlung radiation before reaching calorimeter.
- Very difficult in charm decays where electrons are slow and mass resolution is very limited.
- Same process is negligible for muons at this energy scale.

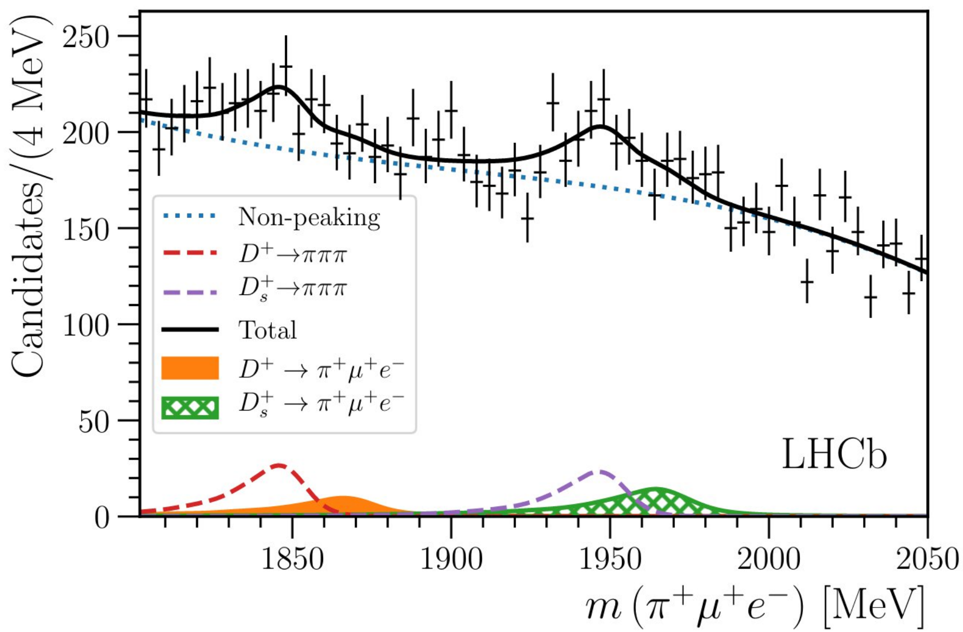




This process changes a mass distribution for decays with electrons in a final state.

Experimental challenges – misidentification

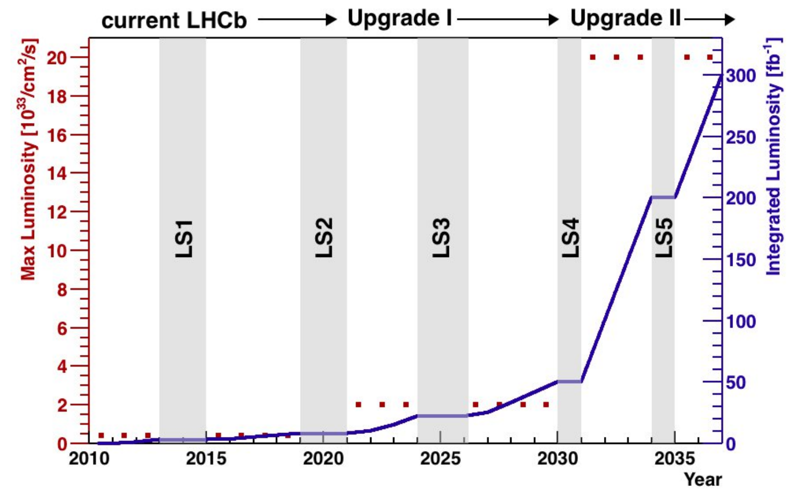
Misidentified background from hadronic decays is especially problematic, because it is usually located near the expected signal peak, which combined with a low statistic character of the measurement can reduce the sensitivity.

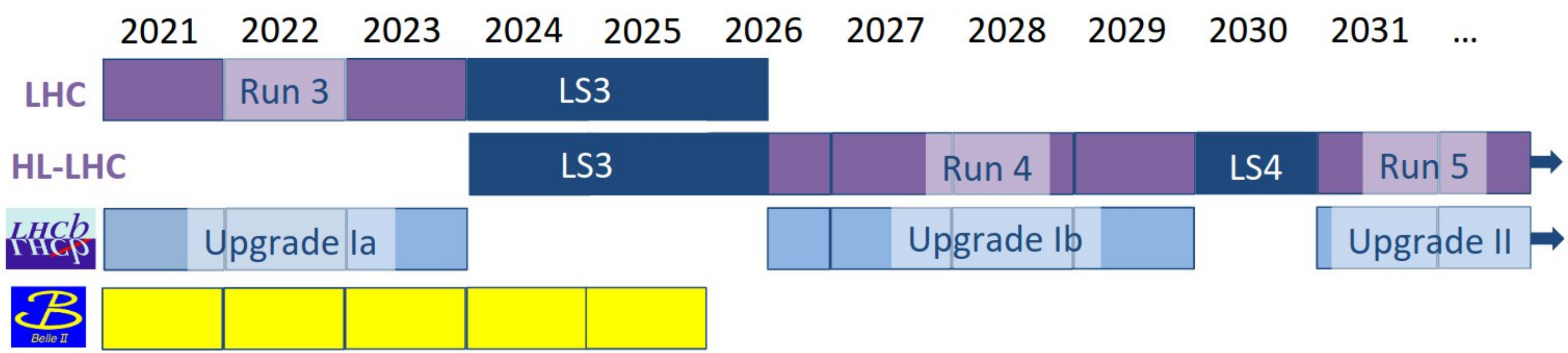


LHCB-PUB-2018-009
LHCB-TDR-023

Looking into the future

Presented today results were calculated based on 9 fb^{-1} sample. Ultimately, the LHCb project is going to collect 300 fb^{-1}, which will significantly increase sensitivity to the NP in LFV and FCNC sectors.





Summary

- LFV processes are good probes for a New Physics particles
- Experiments are starting to get closer to the branching fractions predicted by theories
- One have to take into account experimental limitations like for example: bremsstrahlung and misidentification
- Higher statistics from HL-LHC will significantly improve current upper limits

$J/\psi \to \tau\mu$
$B^0 \to \mu e$
$B^0 \to \tau e$
$B^0 \to \tau\mu$
$B \to K\mu e$
$B \to K^* \mu e$
$B^+ \to K^+ \tau e$
$B^+ \to K^+ \tau\mu$
$B_s^0 \to \mu e$
$B_s^0 \to \tau\mu$

Backup

Mod. Phys. Lett. A 36 (2021) 2130002

Clear null-tests of the SM

SM does not include any LFV processes and similar non-LFV decays are strongly suppressed at the tree-level.