Lepton-flavour violating meson decays at LHCb

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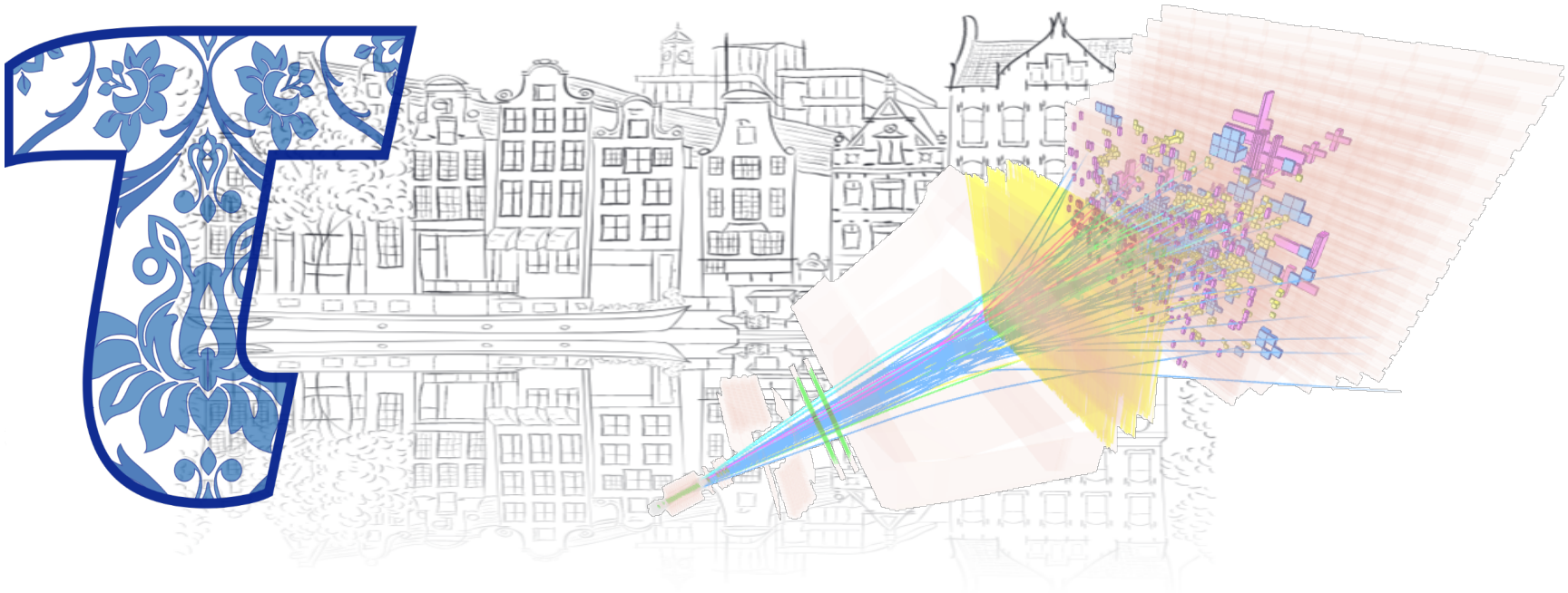


Maarten van Veghel,
on behalf of the LHCb Collaboration

Lepton-flavour violation in meson decays

Why interesting?

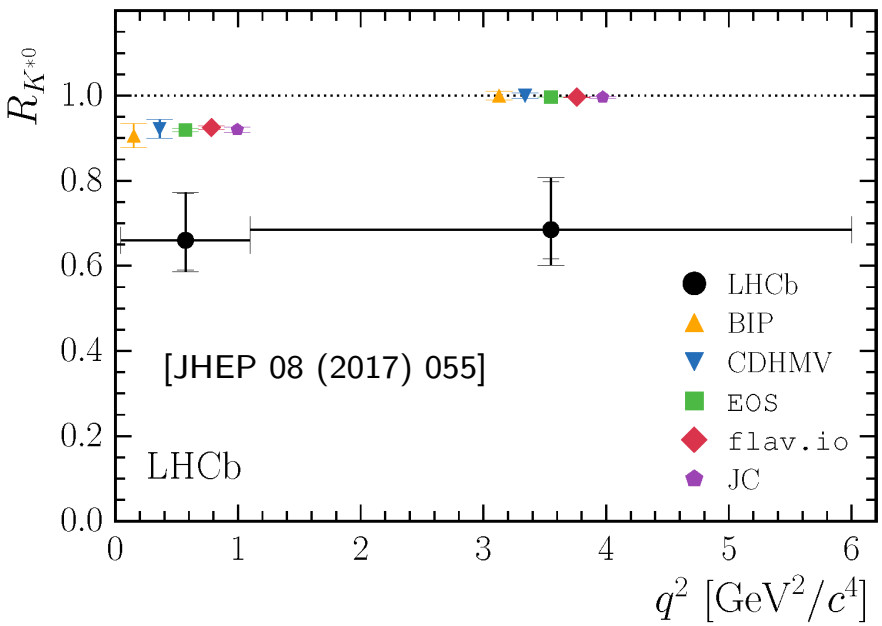
While interest in lepton-flavour violation has been there for a long time, there is renewed interest, especially in the heavy flavour sector

B anomalies

- As you already saw in *e.g.* Sean's talk *(link)*, there are **tensions** seen with lepton universality
- Also tension in (related) $b \to s\ell^+\ell^-$ processes like R_K [Phys. Rev. Lett. 113, 151601 (2014)] and R_{K^*} [JHEP 08 (2017) 055]

$R_{K^{*0}}$

$$R_{K^{*0}} = \frac{\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{*0}e^+e^-)}$$

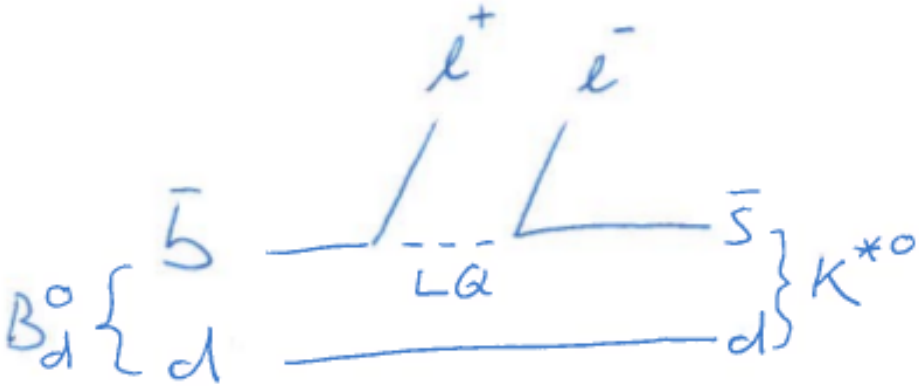


Lepton-flavour violation in meson decays

Lepton flavour violation linked to lepton universality[1]

- For example **leptoquark** model could **explain** seen **tensions**
- Opens up possibilities for lepton flavour violation (like $X \to e^{\pm}\mu^{\mp}$)

$\boldsymbol{B^0 \to K^{*0}\ell^+\ell^-}$ (tensions)

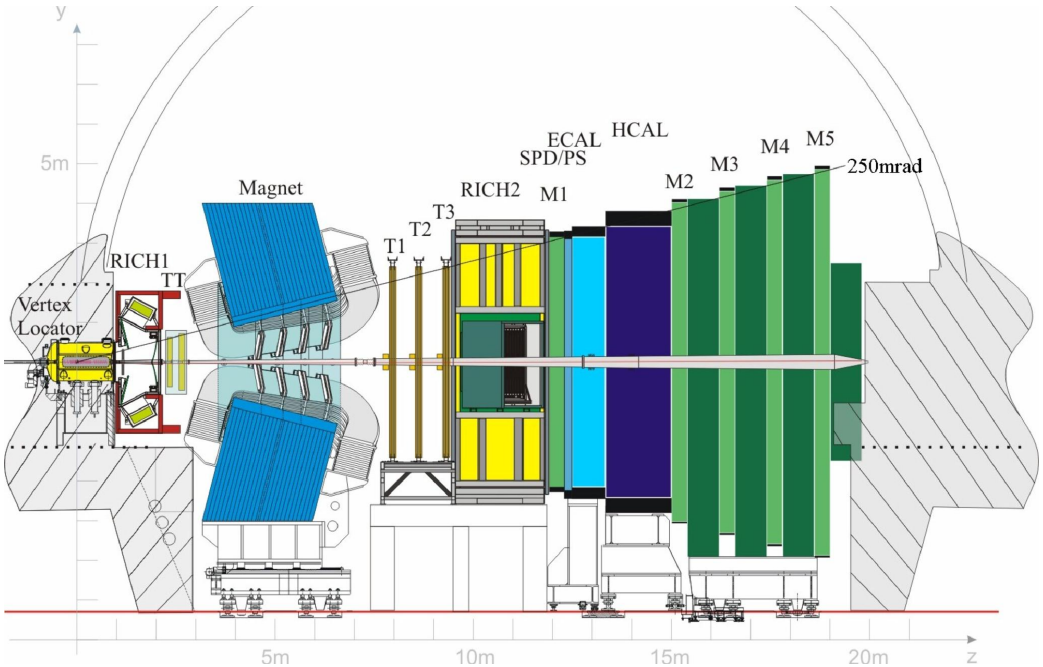


$\boldsymbol{B^0_s \to \ell'^+\ell^-}$ (like $B^0_{(s)} \to e^{\pm}\mu^{\mp}$)

[1] Glashow, Guadagnoli and Lane [Phys.Rev.Lett. 114 (2015) 091801]

The LHCb detector at the LHC

- Aim is to measure properties of ***b* and *c* hadrons** which are produced at **very high rates** with *pp* collisions at the LHC
  (27% of b and $\overline{b}$ quarks within LHCb geometry)
- Good at triggering on **displaced tracks** (heavy flavour decays) and displaced muons in particular
- ECAL, Muon Stations and RICH give good PID performance



Performance

momentum resolution: Δ p / p = 0.5 % at low momentum to 1.0% at 200 GeV/c (see the detector performance paper for a plot)
ECAL resolution (nominal): 1 % + 10 %/ √(E[GeV])
impact parameter resolution: (15 +29/pT[GeV]) μm
invariant mass resolution: ~8 MeV/c^2 for B → J/ψ X decays with constraint on J/ψ mass ~22 MeV/c^2 for two-body B decays ~100 MeV/c^2 for B_s → φ γ, dominated by photon contribution
decay time resolution: ~45 fs for B_s → J/ψ φ and for B_s → D_s π
percentage of working detector channels: ~99 % for all sub-detectors
data taking efficiency:90 % (good for analyses: 99%)
trigger efficiencies: ~ 90 % for dimuon channels ~ 30 % for multi-body hadronic final states
track reconstruction efficiency: ~ 96 % for long tracks
Particle ID efficiency: Electron ID ~ 90 % for ~ 5 % e→h mis-id probability Kaon ID ~ 95 % for ~ 5 % π→K mis-id probability Muon ID ~ 97 % for 1-3 % π→μ mis-id probability

[Int. J. Mod. Phys. A30, 1530022 (2015)]

Lepton-flavour violation analyses at LHCb

- Discussed in **this talk**
  - $\boldsymbol{D^0 \to e^{\pm}\mu^{\mp}}$ [Phys.Lett. B754 (2016) 167-175]
  - $\boldsymbol{B^0 \to e^{\pm}\mu^{\mp}}$ and $\boldsymbol{B_s^0 \to e^{\pm}\mu^{\mp}}$ [JHEP 1803 (2018) 078]
- Other published LFV decay analyses at LHCb
  - $\tau^+ \to \mu^+\mu^-\mu^+$ [JHEP 02 (2015) 121]:
    - ★ $\mathcal{B}(\tau^+ \to \mu^+\mu^-\mu^+) < 4.6 \times 10^{-8}$ at 90% C.L. with 2011 and 2012 data, about a factor 2 higher than best limit set by Belle [Phys.Lett. B687 (2010) 139-143].
- Will briefly discuss what to expect in **the future**!

$D^0 \to e^\pm \mu^\mp$

Interest

- Strongly suppressed in Standard Model, accessible by neutrino oscillations
- Strong enhancements in certain SUSY models, **leptoquarks** and multiple-Higgs-doublet models. For branching fraction at level of $\mathcal{O}(10^{-6})$, $\mathcal{O}(10^{-8})$, $\mathcal{O}(10^{-9})$ respectively.

Previous limit set by Belle [Phys. Rev. D 81, 091102(R) (2010)]

$$\mathcal{B}(D^0 \to e^\pm \mu^\mp) < 2.6 \times 10^{-7} \text{ at } 90\% \text{ C.L.}$$

Goal

- Search and determine / set limit of branching fraction: $\mathcal{B}(D^0 \to e^\pm \mu^\mp)$
- Performed on Run 1 dataset (2011/2012) corresponding to $3\,\text{fb}^{-1}$ of pp collisions at $(7/8)\,\text{TeV}$

$D^0 \to e^{\pm}\mu^{\mp}$: strategy

Phys.Lett. B754 (2016) 167-175

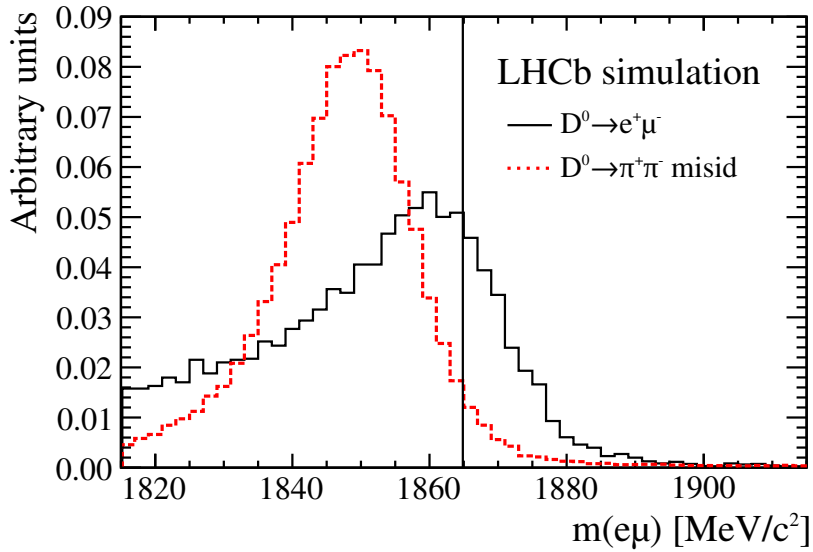
Selection

- Use $D^{*+} \to D^0\pi^+$ to selection D^0's, giving *extra background reduction*, by fitting both invariant mass of D^0 and $D^{*+} - D^0$
- Normalize to $D^0 \to K^-\pi^+$
- On top of cut-based selection, a Boosted Decision Tree (**BDT**) is used to divide the sample further, to increase sensitivity
- Trained on simulation for signal, data side-bands for background

Backgrounds

- Main background: $D^0 \to \pi^+\pi^-$
- Peaks underneath signal!
- MisID probability, in this case **very low** at $\epsilon(\pi^+\pi^- \to e^{\pm}\mu^{\mp}) = (1.8 \pm 0.4) \times 10^{-8}$!

Signal and $D^0 \to \pi^+\pi^-$

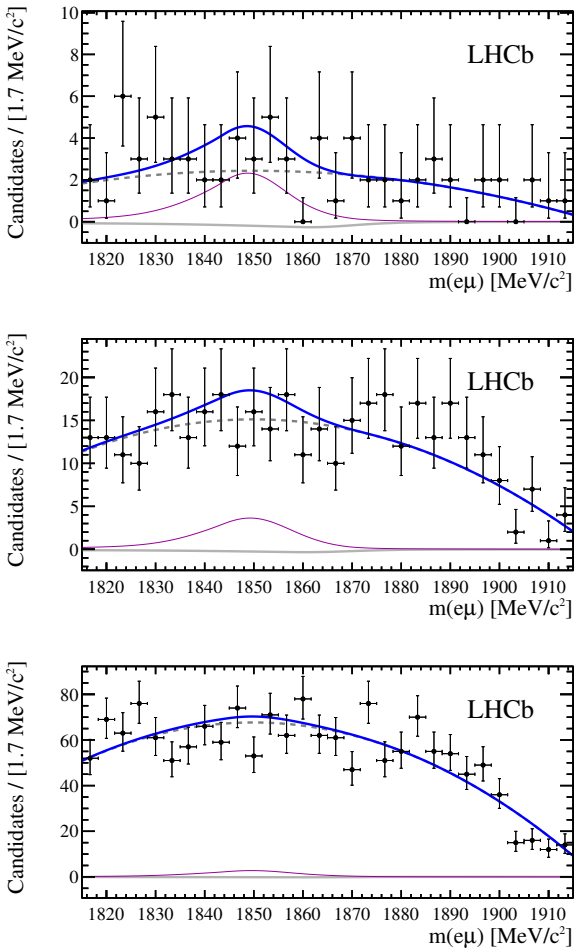


$D^0 \to e^{\pm}\mu^{\mp}$: mass fits

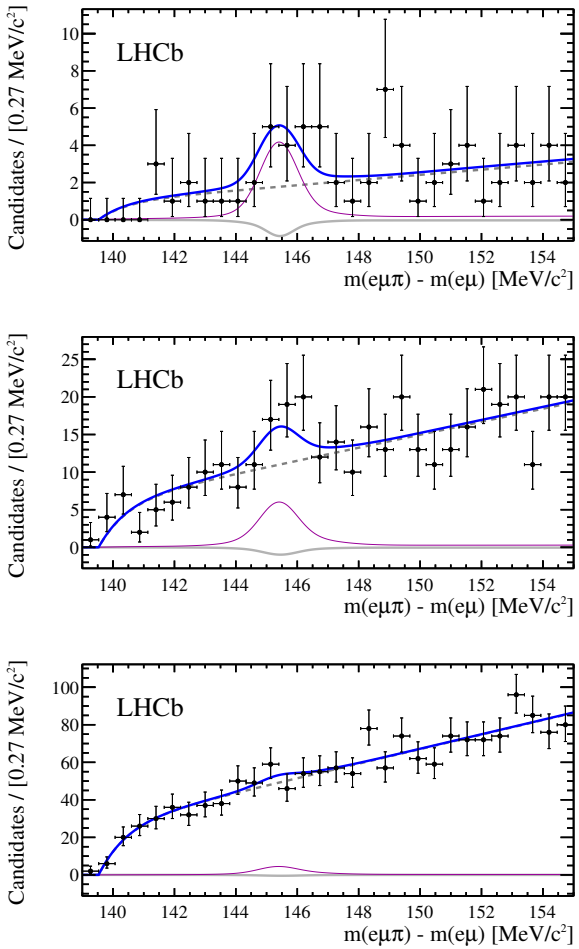
Phys.Lett. B754 (2016) 167-175

- Mass fit (2D; both D^0 and $D^{*+} - D^0$) in 3 bins of BDT output
- Top is signal like, middle is intermediate and bottom is background like

D^0 mass



$D^{*+} - D^0$ mass



$D^0 \to e^{\pm}\mu^{\mp}$: results

Phys.Lett. B754 (2016) 167-175

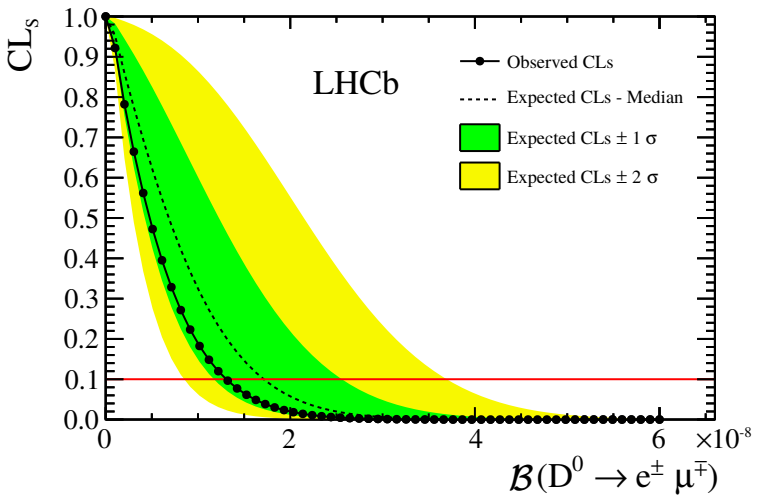
Search

- Fit results in yield for $D^0 \to e^{\pm}\mu^{\mp}$ of -7 ± 15
- No significant signal seen, consequently, with normalization, a limit is set

Limit

New limit set with factor 20 improvement on previous best limit

$$\mathcal{B}(D^0 \to e^{\pm}\mu^{\mp}) < 1.3 \times 10^{-8} \text{ at } 90\% \text{ C.L.}$$



$B^0 \to e^\pm \mu^\mp$ and $B_s^0 \to e^\pm \mu^\mp$

Interest

- Strongly suppressed in Standard Model, same as $D^0 \to e^\pm \mu^\mp$, accessible by neutrino oscillations
- As for $D^0 \to e^\pm \mu^\mp$ also enhancements in certain SUSY models, **leptoquarks** and multiple-Higgs-doublet models, but with couplings to b, like in lepton-universality tensions

Previous limits set by LHCb

$$\mathcal{B}(B^0 \to e^\pm \mu^\mp) < 2.8 \times 10^{-9} \text{ at } 90\% \text{ C.L.}$$
$$\mathcal{B}(B_s^0 \to e^\pm \mu^\mp) < 1.1 \times 10^{-8} \text{ at } 90\% \text{ C.L.}$$

Presenting improved analysis with full LHC Run 1 data

$B^0_{(s)} \to e^{\pm}\mu^{\mp}$: strategy

JHEP 1803 (2018) 078

Selection

- Normalize to both $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$ and $B^0 \to K^+\pi^-$
- **BDT** is used, trained against combinatorial background
- Trained on simulation for signal, same-sign (wrong sign) data for background

Improvements

with respect to previous LHCb analysis

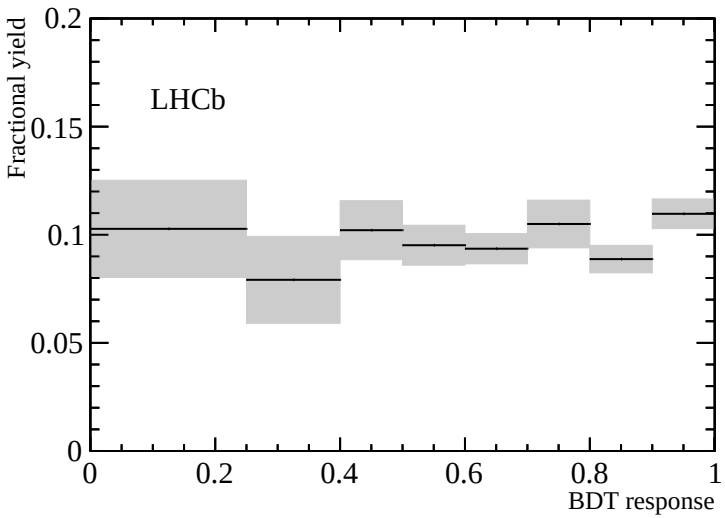
- Three times more data in total
- More triggers used, so higher efficiency
- Much improved and dedicated BDT is trained / used.

$B^0_{(s)} \to e^{\pm}\mu^{\mp}$: backgrounds and BDT

JHEP 1803 (2018) 078

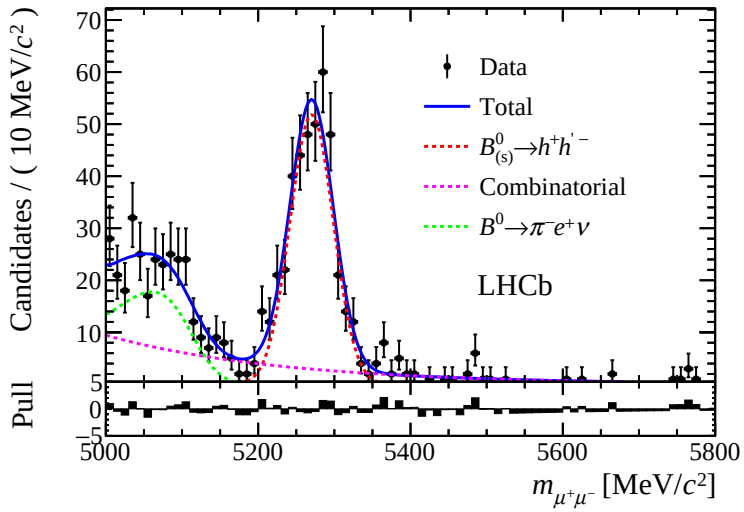
BDT

- Output flat for signal on simulation
- Does not contain PID information,
  therefore response determined on data with $B^0 \to K^+\pi^-$



Backgrounds

- Main (peaking) background is $B^0 \to K^+\pi^-$
- Particle identification selection reduces it to **negligible amounts**
- Efficiencies cross-checked, for example with $B^0 \to K^+\pi^-$ fit with only electron PID



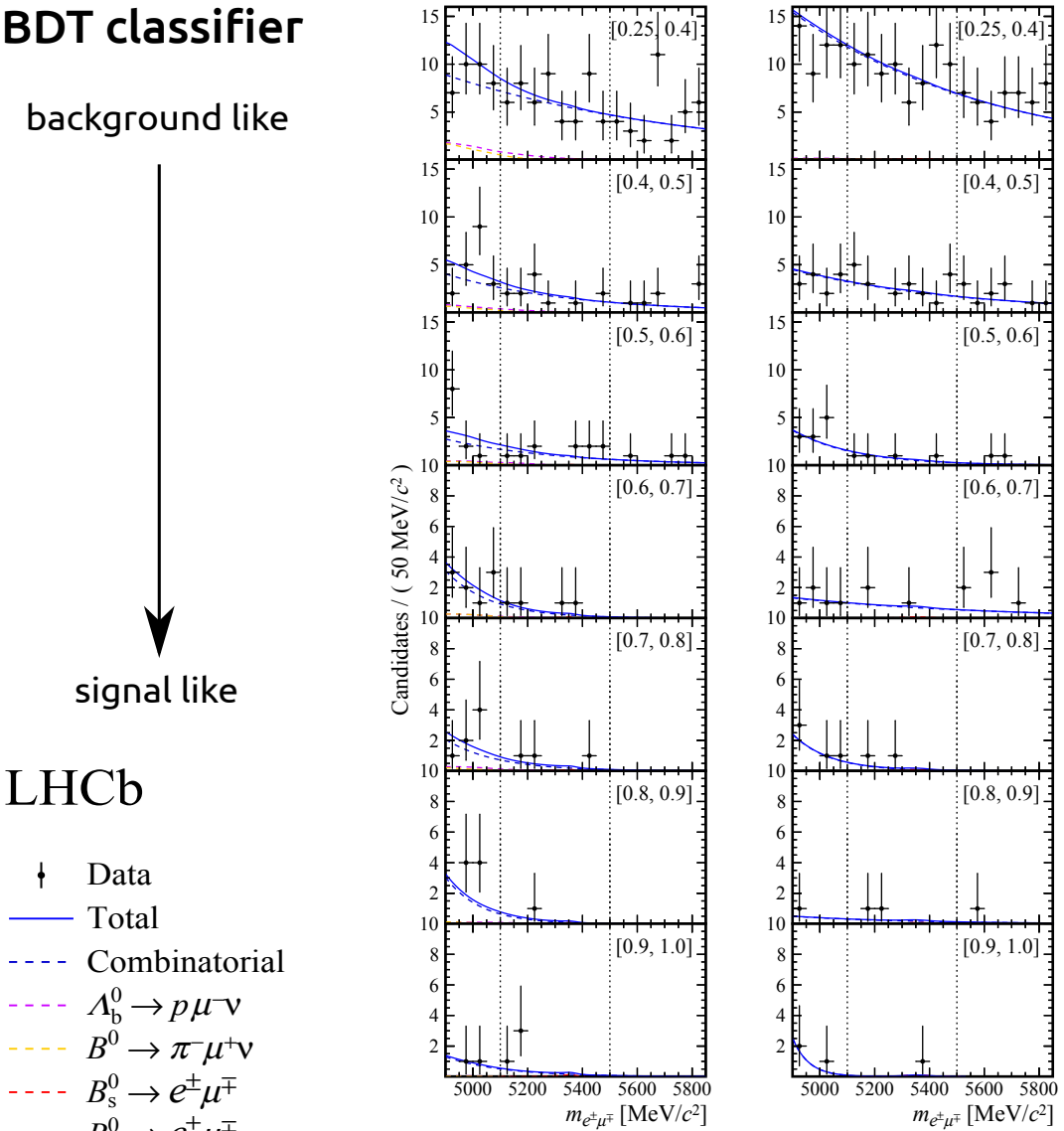
$B^0_{(s)} \to e^\pm \mu^\mp$: mass fits

JHEP 1803 (2018) 078

BDT classifier

background like

signal like



recovered bremsstrahlung without with

$B^0_{(s)} \to e^{\pm}\mu^{\mp}$: results

JHEP 1803 (2018) 078

Search

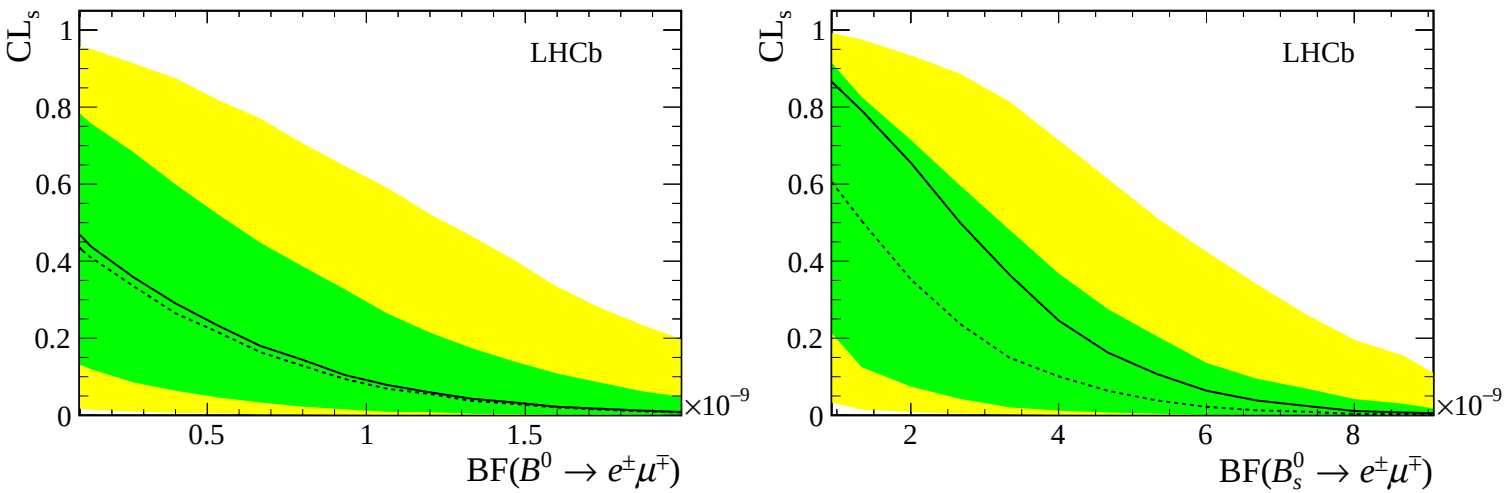
- No significant signal seen, consequently, with normalization, a limit is set

Limit

New limit set with factor 2 to 3 improvement on previous best limit

$$\mathcal{B}(B^0 \to e^{\pm}\mu^{\mp}) < 1.3 \times 10^{-9} \text{ at } 90\% \text{ C.L.}$$

$$\mathcal{B}(B^0_s \to e^{\pm}\mu^{\mp}) < 6.3 \times 10^{-9} \text{ at } 90\% \text{ C.L.}$$



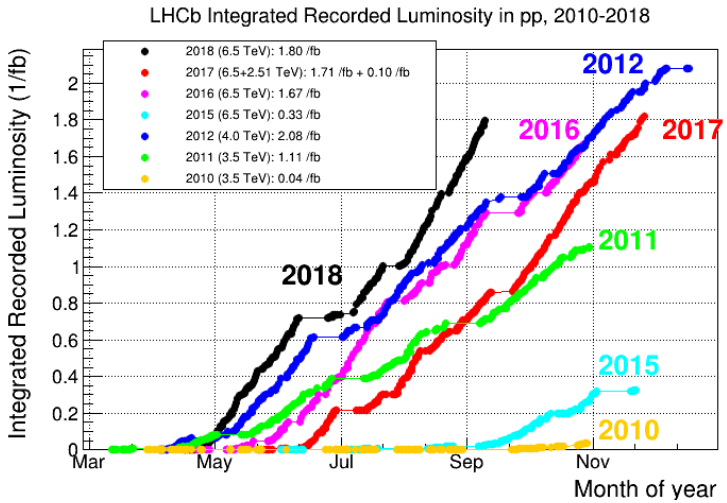
Prospects

More decay modes

- More analyses: *e.g.* $B^0_{(s)} \to \tau^\pm\mu^\mp$, $B^+ \to K^+ e^\pm \mu^\mp$, $B^0 \to K^{(0*)}\tau^\pm\mu^\mp$

More data

- So far, LFV analyses published with Run 1 dataset (2011/2012) corresponding to $3\,\text{fb}^{-1}$ of pp collisions at $(7/8)\,\text{TeV}$
- Current LHC Run 2 is approaching $\mathbf{6fb^{-1}}$ of pp collisions at $13\,\text{TeV}$!
- So much more data to analyse



Summary

- Searches for lepton-flavour violating meson decays at **LHCb**
- Renewed interest due to **tensions** in lepton universality
- Presented $D^0 \to e^\pm \mu^\mp$, $B^0 \to e^\pm \mu^\mp$ and $B_s^0 \to e^\pm \mu^\mp$ with (improved) best limits
- Helps constraining new physics, *e.g.* models with **leptoquarks**
- *More results* to come at LHCb in terms of lepton-flavour violating meson decays with new data (still coming in as we speak) and more channels!