Searches for Lepton Flavour Violation at LHCb

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Lepton Flavour Violation at LHCb - Introduction

Why search for lepton flavour violation (LFV)?

- Lepton flavour conservation is an accidental symmetry in the SM ($m_\nu = 0$)
- Normalized rates of LFV processes involving charged leptons are tiny $\mathcal{O}(10^{-55}) - \mathcal{O}(10^{-40})$ in the SM

  $\Rightarrow$ LFV hadron decays would be a striking signature of new physics

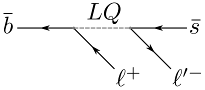
- Connection between violation of lepton flavour universality (LFU) and LFV

  $\Rightarrow$ Current interest in LFV in light of observed LFU anomalies R_K, R_{K^*}, R_D, R_{D^*}

LFU and LFV

Connection between LFU and LFV: They appear alongside each other in many models of new physics, $b \to s\ell^+\ell'^-$ transitions particularly interesting

Example: Leptoquarks



$$\mathcal{B}(B \to K\mu^\pm e^\mp) \sim 3 \cdot 10^{-8} \left(\frac{1-R_K}{0.23}\right)^2, \quad \mathcal{B}(B \to K(e^\pm, \mu^\pm)\tau^\mp) \sim 2 \cdot 10^{-8} \left(\frac{1-R_K}{0.23}\right)^2$$

$$\frac{\mathcal{B}(B_s \to \mu^+ e^-)}{\mathcal{B}(B_s \to \mu^+\mu^-)_{\rm SM}} \sim 0.01 \left(\frac{1-R_K}{0.23}\right)^2, \quad \frac{\mathcal{B}(B_s \to \tau^+(e^-, \mu^-))}{\mathcal{B}(B_s \to \mu^+\mu^-)_{\rm SM}} \sim 4 \left(\frac{1-R_K}{0.23}\right)^2.$$

JHEP12(2016)027

$\Rightarrow$ Observable rates for LFV processes in models for LFU anomalies

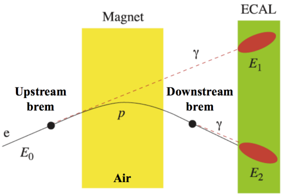
- $e\mu$ pair in the final state:
  - $\mathcal{B}(B_s^0 \to e^\pm \mu^\mp)$ up to 10^{-11} Hiller, Loose, Schönwald JHEP 12 (2016) 027
  - $\mathcal{B}(B \to K^{(*)} e^\pm \mu^\mp)$ up to 10^{-8}
- $\tau\mu$ pair in the final state:
  - $\mathcal{B}(B_s^0 \to \tau^\pm \mu^\mp)$ up to 10^{-4} Bordone et al., JHEP 1810 (2018) 148
  - $\mathcal{B}(B \to K^{(*)} \tau^\pm \mu^\mp)$ up to 10^{-5}

Common challenges in searches for LFV

- LFV decays forbidden in SM $\rightarrow$ Large samples of b hadrons (D mesons) needed ✓
- Understanding of backgrounds crucial
  SM source of $\ell^{\pm}\ell'^{\mp}$ pairs: Semileptonic cascades involving D decays
- Two different lepton flavours $\rightarrow$ Additional challenge e/τ reconstruction:

Final state with $e\mu$ pair

- Electron's bremsstrahlung losses degrade $\sigma(m_{\mathrm{B}})$, effects mitigated by brem photon recovery in electron reconstruction



- Hardware trigger E_T^e thresholds higher than for p_T^{μ}

Final state with $\tau\mu$ pair

- τ reconstructed through its decays

  Leptonic:
  - $BR(\tau^- \rightarrow \mu^- \nu\nu) = 17.41 \pm 0.04$ %
  - $BR(\tau^- \rightarrow e^- \nu\nu) = 17.83 \pm 0.04$ %

  Hadronic:
  - $BR(\tau^- \rightarrow \pi^- \nu) = 10.83 \pm 0.06$ %
  - $BR(\tau^- \rightarrow \pi^- \pi^0 \nu) = 25.52 \pm 0.09$ %
  - $BR(\tau^- \rightarrow \pi^- \pi^0 \pi^0 \nu) = 9.30 \pm 0.11$ %
  - $BR(\tau^- \rightarrow \pi^- \pi^+ \pi^- \nu) = 9.31 \pm 0.06$ %
  - $BR(\tau^- \rightarrow \pi^- \pi^+ \pi^- \pi^0 \nu) = 4.62 \pm 0.06$ %

- ν : Missing momentum degrades $\sigma(m_{\mathrm{B}})$
- τ decay vertex cannot always be reconstructed

$B^+ \to K^+\mu^\pm e^\mp$: Introduction / Selection

Analysis essentials

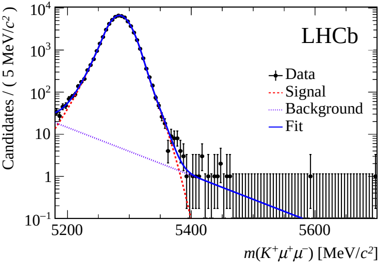
- LHCb Run I data, $\mathcal{L}_{int} = 3\ \text{fb}^{-1}$
- Signature:
  Muon provides highly efficient trigger
  3 tracks forming secondary vertex

Selection

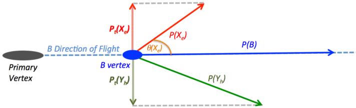
- Significant background from semileptonic cascades $B^+ \to \overline{D}^0(\to K^+\ell'^-\bar{\nu}_{\ell'}h')\ell^+\nu_\ell h$
  $\Rightarrow D^0$ veto $m(K^+\ell^-) > 1885$ MeV
- Topological BDT against combinatorial
- 2nd BDT including m_B^{HOP} variable against semileptonic cascades
- Tight PID cuts on kaon and leptons

PRL 123, 241802 (2019)

Normalization channel:
$B^+ \to J/\psi(\to \mu^+\mu^-)K^+$

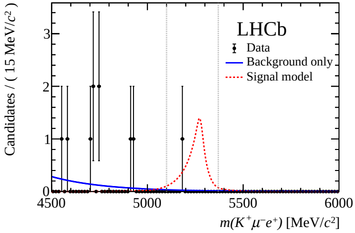


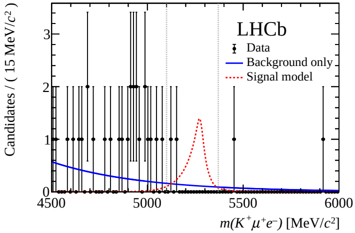
m_B^{HOP}: Correct $\vec{p}^{\,e}$ for $p_\perp^e / p_\perp^{K\mu}$ imbalance



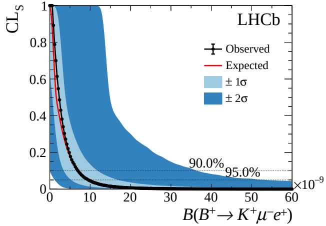
$B^+ \to K^+\mu^\pm e^\mp$: Results

Analysis split by charge of the $\mu^\pm e^\mp$ pair

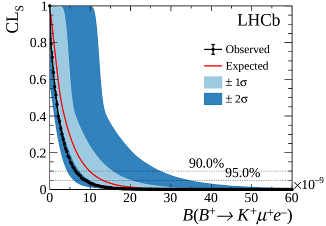




$\mathcal{B}(B^+ \to K^+\mu^- e^+) < 9.5 \cdot 10^{-9}$ at 95% CL



$\mathcal{B}(B^+ \to K^+\mu^+ e^-) < 8.8 \cdot 10^{-9}$ at 95% CL



Systematic uncertainties in the limit <7%

Improving former most stringent limit from BaBar by one order of magnitude

Starting to probe interesting range of parameter space for LFU+LFV models

$B^0_{(s)} \to V^0 e^{\pm}\mu^{\mp}$ Work in progress

Cover in 1 analysis: $B^0_d \to K^*(892)^0(\to K^+\pi^-)\mu^{\pm}e^{\mp}$
$B^0_s \to \phi(1020)(\to K^+K^-)\mu^{\pm}e^{\mp}$

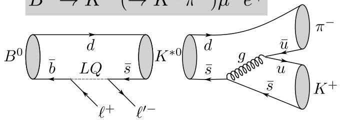
Analysis essentials

- Full Run1 + Run2 data, $\mathcal{L}_{int} = 9\ \text{fb}^{-1}$
- Signature:
  Muon provides highly efficient trigger
  4 tracks forming secondary vertex

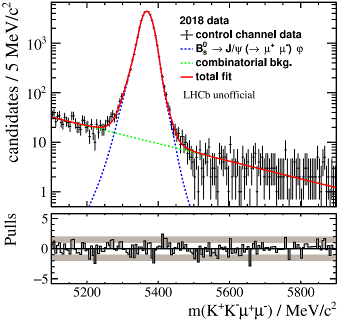
Selection

- Selection as similar as possible for both channels
  Main differences:
  - Meson mass window
    $\Delta m_\phi = \pm 12$ MeV, $\Delta m_{K^*} = \pm 100$ MeV
  - K/π PID
- Vetoes against charmonium resonances, large background from semileptonic cascades
- Topological BDT against combinatorial
- Tight PID cuts on $K, (\pi)$, and leptons

$B^0 \to K^{*0}(\to K^+\pi^-)\mu^{\pm}e^{\mp}$



Normalization channel:
$B^0_{(s)} \to V^0 J/\psi(\to \mu^+\mu^-)$



$B^0_{(s)} \to V^0 e^\pm \mu^\mp$: Background from Semileptonic Cascades

Large background from semileptonic cascades (SC) with $D^{(*)-}$, $D_s^{(*)-}$ mesons

$$B^0_{(s)} \to D^-_{(s)}(\to V^0 \ell'^- \bar{\nu}_{\ell'})\ \ell^+ \nu_\ell \quad , \quad B^0_{(s)} \to D^{*-}_{(s)}[\to D^-_{(s)}(\to V^0 \ell'^- \bar{\nu}_{\ell'})\ \pi^0/\gamma\ ]\ \ell^+ \nu_\ell$$

Example $\phi e \mu$ channel:

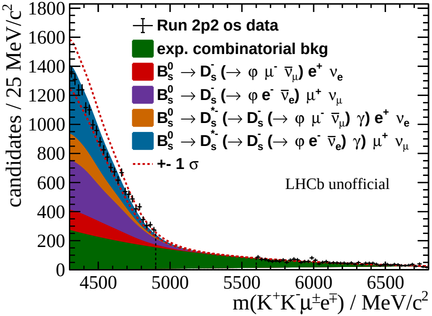
$\mathcal{B}(B^0_s \to D_s^- \ell^+ \nu_\ell) = (8.24 \pm 0.75) \times 10^{-2}$

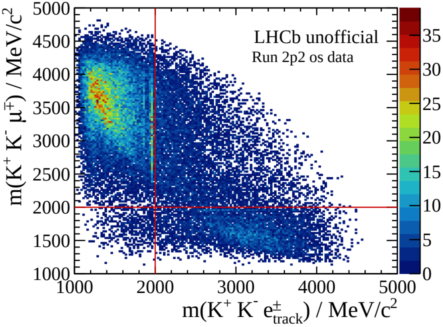
$\mathcal{B}(D_s^- \to \phi e^- \bar{\nu}_e) = (2.39 \pm 0.16) \times 10^{-2}$

$M(K^+K^-\ell)$ from $D^-_{(s)}$ decay limited by $M(D^-_{(s)})$

$\Rightarrow$ Veto cut: $M(K^+K^-\ell^\pm) > 2$ GeV

Run2p2 (2017/2018) data after $\phi e \mu$ pre-selection:



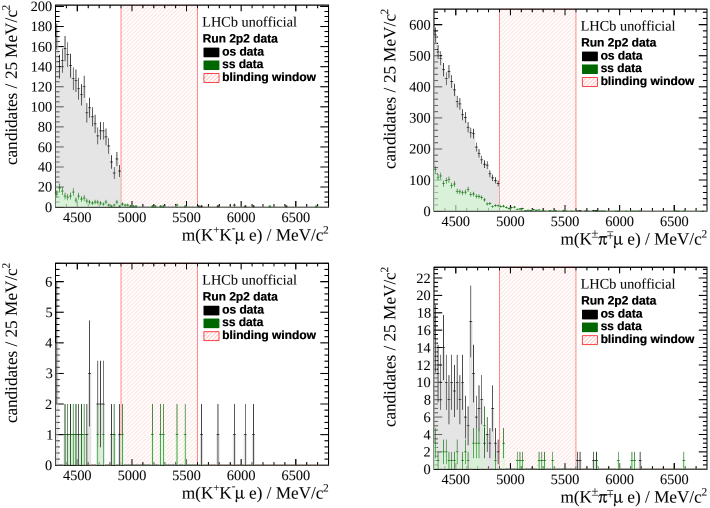


$B^0_{(s)} \to V^0 e^\pm \mu^\mp$: Blinded B Mass Work in progress

$\phi e\mu$ | $K^*(892)^0 e\mu$

Presel. + BDT

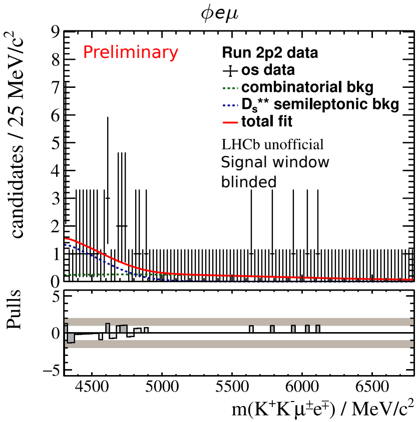
Full Selection

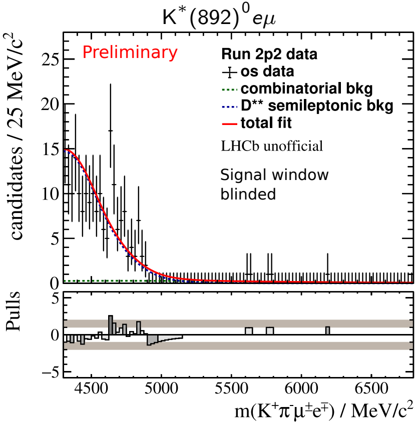


Both signal channels almost background-free within blinding window

$K^*(892)^0 e\mu$ channel: Sizeable background remaining in lower mass sideband from SCs involving D^{**} decays, modelled in fit to $m(B)$

$B^0_{(s)} \to V^0 e^\pm \mu^\mp$: Expectation   Work in progress





Expected limits (90% CL) full Run1 + Run2 (very preliminary, analysis ongoing):

$\mathcal{B}(B^0_s \to \phi e^\pm \mu^\mp) \lesssim \mathcal{O}(10^{-8})$

Currently no limit in the literature

$\mathcal{B}(B^0_d \to K^*(892)^0 e^\pm \mu^\mp) \lesssim \mathcal{O}(5 \times 10^{-9})$

Belle: $\mathcal{B}(B^0_d \to K^*(892)^0 e^\pm \mu^\mp) < 1.8 \times 10^{-7}$

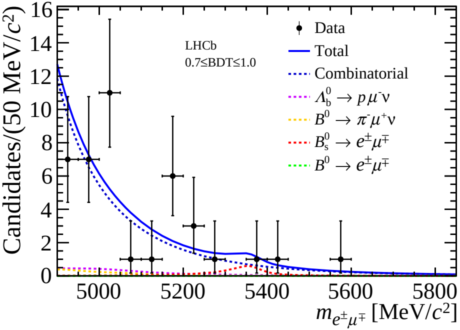
[Belle, Phys. Rev. D 98, 071101 (2018)]

$B^0_{s,d} \to e^{\pm}\mu^{\mp}$: Results (Run 1)

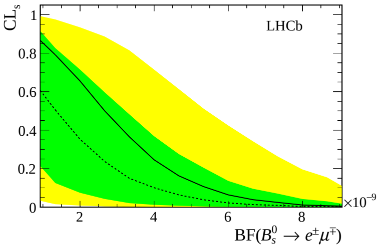
Full LHCb Run I data, $\mathcal{L}_{int} = 3\ \text{fb}^{-1}$

JHEP 1803 (2018) 078

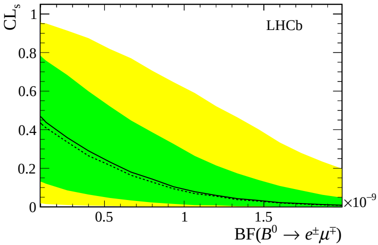
Simult. fit of $m(B^0_{s,d})$ in 14 brem×BDT bins



$\mathcal{B}(B^0_{sH} \to e^{\pm}\mu^{\mp}) < 6.3 \cdot 10^{-9}$ at 95% CL



$\mathcal{B}(B^0_{d} \to e^{\pm}\mu^{\mp}) < 1.3 \cdot 10^{-9}$ at 95% CL

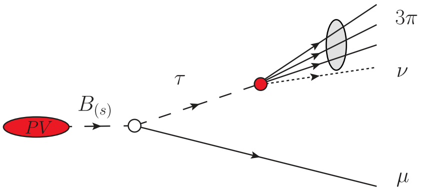


3 scenarios considered in the interpretation:
$B^0_d \to e^{\pm}\mu^{\mp}$; $B^0_{sH} \to e^{\pm}\mu^{\mp}$, $B^0_{sL} \to e^{\pm}\mu^{\mp}$

Impact of systematic uncertainties on expected limit $< 5\%$

$B^0_{s,d} \to \tau^\pm\mu^\mp$: Introduction

First LHCb search for LFV with τ lepton in the final state PRL 123, 211801 (2019)



Analysis essentials

- LHCb Run I data, $\mathcal{L}_{int} = 3\ \text{fb}^{-1}$
- τ reconstructed in 3-prong channel $\tau^\pm \to \pi^\pm\pi^\mp\pi^\pm\nu$ $\mathcal{B}(\tau^\pm \to \pi^\pm\pi^\mp\pi^\pm\nu) = 9.31 \pm 0.06\%$
- Normalization channel: $B^0_d \to D^-(\to K^+\pi^-\pi^-)\pi^+$
- Same-sign data $\tau^\pm\mu^\pm$ used to model background

Signal toplogy & selection basics

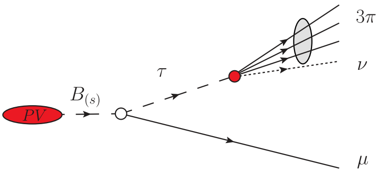
- Muon provides efficient L0/HLT1 triggers
- τ decay vertex reconstruction $\Rightarrow$ Reconstruction of p_ν, $m(B^0_{s,d})$
- τ decays via intermediate resonances $\tau^\pm \to a_1^\pm(1260)\nu \to \rho(770)\pi^\pm\nu \to \pi^\pm\pi^\mp\pi^\pm\nu$ $\Rightarrow$ Rejection of low $m(\pi^+\pi^-)$ bkgs

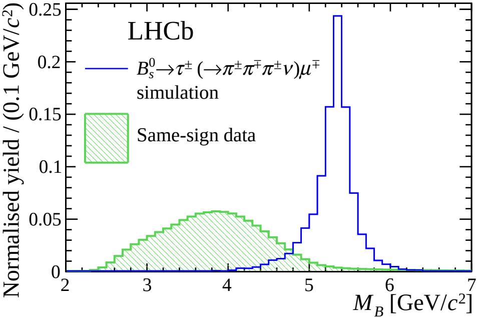
$\epsilon^{tot}_{sel}(B^0_s \to \tau^\pm\mu^\mp) \approx 1.6 \cdot 10^{-4}$

$B^0_{s,d} \to \tau^\pm \mu^\mp$: $m(B^0_{s,d})$ calculation

$m(B^0_{s,d})$ calculation

Available information for kinematic constraints:
Muon & pion tracks, primary vertex, τ decay vertex, m_τ
$\Rightarrow$ $m(B^0_{s,d})$ determined analytically up to a 2-fold ambiguity
$m(B^0_{s,d})$ solution with best discrimination power and corresponding p_ν chosen

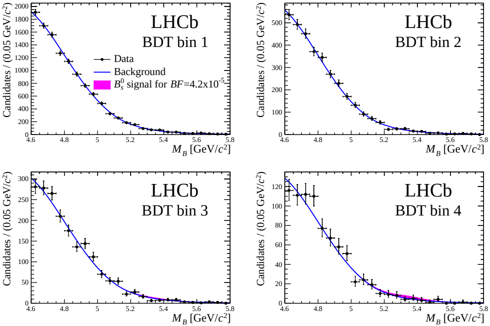




Refit of the decay tree with the inferred neutrino momentum performed
Fit parameters and their uncertainties used in the selection

$B^0_{s,d} \to \tau^\pm \mu^\mp$: Results

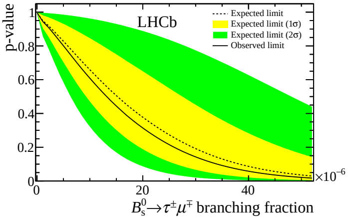
Simultaneous fit of $m(B^0_{s,d})$ in 4 BDT bins



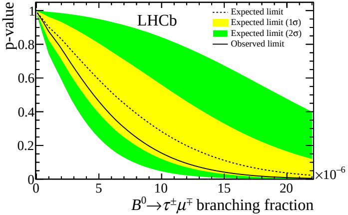
Two scenarios considered: $B^0_{s,d} \to \tau^\pm \mu^\mp$

Impact of systematic uncertainties on expected limit: 35%

$\mathcal{B}(B^0_s \to \tau^\pm \mu^\mp) < 4.2 \cdot 10^{-5}$ at 95% CL



$\mathcal{B}(B^0_d \to \tau^\pm \mu^\mp) < 1.4 \cdot 10^{-5}$ at 95% CL

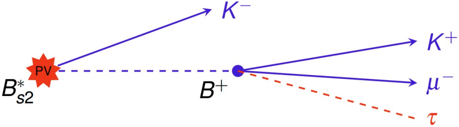


Improving the former most stringent limit on $\mathcal{B}(B^0_d \to \tau^\pm \mu^\mp)$ (BaBar) by a factor 2
First limit on $\mathcal{B}(B^0_s \to \tau^\pm \mu^\mp)$, in the range of interest of models for LFU anomalies

NEW $B^+ \to K^+\tau^+\mu^-$ using $B_{s2}^{*0} \to B^+K^-$ decays

First search for $B \to X\tau\mu$ signature in LHCb, $L_{int} = 9\ \text{fb}^{-1}$ JHEP 06 (2020) 129

Inclusive τ reconstruction using $B_{s2}^{*0} \to B^+K^-$ decays:

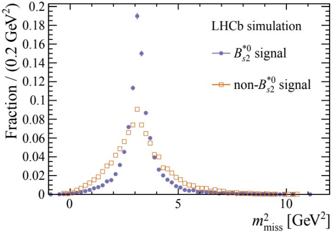


1. Reconstruct B^+ decay vertex from $K^+\mu^-$ pair
2. Select corresponding PV and K^- track
3. Use $m(B^+)$ and $m(B_{s2}^{*0})$ constraints

$\Rightarrow p(B^+)$, m^2_{miss} can be inferred

Downside:
$B_{s2}^{*0} \to B^+K^-$ accounts for $\sim 1\%$ of B^+ production

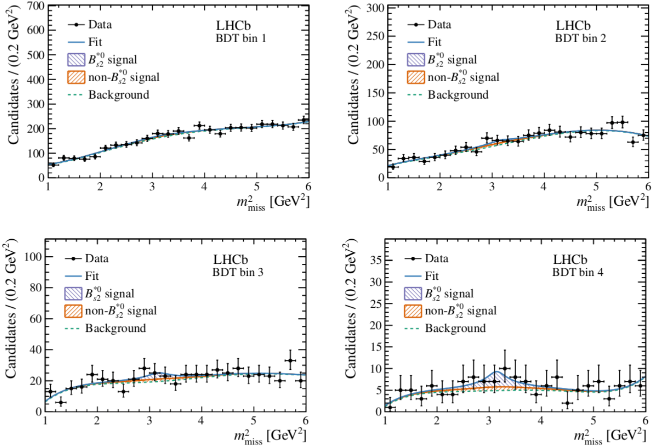
m^2_{miss} peaks at m^2_τ for signal



Analysis targeting 1-prong τ decays (3-prong signal vetoed, dedicated analysis ongoing)

$B^+ \to K^+\tau^+\mu^-$ using $B_{s2}^{*0} \to B^+K^-$: Results

Simultaneous fit to m_{miss}^2 in 4 BDT bins



- No significant excess
- 3 different signal models considered

  Baseline model: PHSP decay

Observed limit: $\mathcal{B}(B^+ \to K^+\tau^+\mu^-) < 3.9 \times 10^{-5}$ (90% CL)
Expected limit: $\mathcal{B}(B^+ \to K^+\tau^+\mu^-) < 2.3 \times 10^{-5}$ (90% CL)

World-leading limit: $\mathcal{B}(B^+ \to K^+\tau^+\mu^-) < 2.8 \times 10^{-5}$ (90% CL)
BaBar Coll., PRD 86 (2012) 012004

$B \to X\,\tau\mu$: Upcoming LHCb Results Work in progress

$B^+ \to K^+\tau^\pm\mu^\mp$ 3-prong τ decay

- Reconstructed τ decays: $\mathcal{B}(\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau) = (9.31 \pm 0.06)\%$
  $\mathcal{B}(\tau^+ \to \pi^+\pi^-\pi^+\pi^0\overline{\nu}_\tau) = (4.62 \pm 0.06)\%$
- B mass reconstruction: Decay chain including neutrino fitted using DecayTreeFitter
  Nucl.Instrum.Meth. A552 (2005) 566-575
- Analysis using full Run 1 + Run 2 dataset ongoing
  Aim is to push the limit on $\mathcal{B}(B^+ \to K^+\tau^\pm\mu^\mp)$ below 5×10^{-6} at 90% CL

$B^0_d \to K^*(892)^0\tau^\pm\mu^\mp$

- Reconstructed τ decays: $\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$ and $\tau^+ \to \pi^+\pi^-\pi^+\pi^0\overline{\nu}_\tau$
- B mass reconstruction: $m_B^{corr} = \sqrt{(m_B^{reco})^2 + (p_\perp^{miss})^2} + p_\perp^{miss}$
- Analysis using full Run 1 + Run 2 dataset under review
  Aim is a world-best limit: $\mathcal{B}(B^0_d \to K^*(892)^0\tau^\pm\mu^\mp) \lesssim$ few $\times 10^{-5}$ at 90% CL

Other paths to explore: LFV in charm decays

NEW: LHCb-PAPER-2020-007 (in preparation, shown by Chris Burr at ICHEP '20)

One search for 25 decays $D^+_{(s)} \to h^\pm \ell^+ \ell'^\mp$ ($h \in \{K, \pi\}$; $\ell \in \{e, \mu\}$)
including LFV and lepton number violating (LNV) decays

2016 data
$L_{int} = 1.7$ fb^{-1}

eμ modes (the six $e\mu$ rows, from $\pi^+e^+\mu^-$ to $K^-\mu^+e^+$, are boxed; the D_s^+ improvement factors 150.0 and 500.0 are boxed in red)

PRELIMINARY!

Decay	Branching fraction upper limit $[10^{-9}]$				Improvement factor	
	D^+		D_s^+			
	90 % CL	95 % CL	90 % CL	95 % CL	D^+	D_s^+
$D^+_{(s)} \to \pi^+\mu^+\mu^-$	67	74	180	210	1.1	2.3
$D^+_{(s)} \to \pi^-\mu^+\mu^+$	14	16	86	96	1.6	1.4
$D^+_{(s)} \to K^+\mu^+\mu^-$	54	61	140	160	79.0	150.0
$D^+_{(s)} \to K^-\mu^+\mu^+$	-	-	26	30	-	500.0
$D^+_{(s)} \to \pi^+e^+\mu^-$	210	230	1100	1200	14.0	11.0
$D^+_{(s)} \to \pi^+\mu^+e^-$	220	220	940	1100	16.0	21.0
$D^+_{(s)} \to \pi^-\mu^+e^+$	130	150	630	710	16.0	13.0
$D^+_{(s)} \to K^+e^+\mu^-$	75	83	790	880	16.0	18.0
$D^+_{(s)} \to K^+\mu^+e^-$	100	110	560	640	28.0	17.0
$D^+_{(s)} \to K^-\mu^+e^+$	-	-	260	320	-	23.0
$D^+_{(s)} \to \pi^+e^+e^-$	1600	1800	5500	6400	0.7	2.3
$D^+_{(s)} \to \pi^-e^+e^+$	530	600	1400	1600	2.1	3.0
$D^+_{(s)} \to K^+e^+e^-$	850	1000	4900	5500	1.2	0.8
$D^+_{(s)} \to K^-e^+e^+$	-	-	770	840	-	6.7

No significant excess observed
Result(s) significantly expanding the LHCb rare charm + LFV programs

Searches for LFV (+LNV/BNV) in LHCb

Published searches for LFV using (parts of) LHCb data

Decay	Publication	Year	Type	Limit $\mathcal{B}$ (95% CL) Strongest limit in lit.
$B^+ \to K^+\tau^+\mu^-$	JHEP 06 (2020) 129	2020	LFV	4.5×10^{-5}
$B^+ \to K^+e^\pm\mu^\mp$	PRL 123 (2019) 241802	2019	LFV	8.8×10^{-9}
$B^0 \to \tau^\pm\mu^\mp$	PRL 123 (2019) 211801	2019	LFV	1.4×10^{-5}
$B^0 \to e^\pm\mu^\mp$	JHEP 1803 (2018) 078	2018	LFV	1.3×10^{-9}
$D^0 \to e^\pm\mu^\mp$	PLB 754 (2016) 167	2016	LFV	1.6×10^{-8}
$\tau^- \to \mu^+\mu^-\mu^-$	JHEP 02 (2015) 121	2015	LFV	5.6×10^{-8}
$\tau^- \to p^+\mu^-\mu^-$	PLB 724 (2013) 36	2013	BNV+LNV	5.7×10^{-7}
$B^- \to \pi^+\mu^-\mu^-$	PRL 112 (2014) 131802	2014	LNV	4.0×10^{-9}
$D^- \to \pi^+\mu^-\mu^-$	PLB 724 (2013) 203	2013	LNV	2.5×10^{-8}

Work on Run I+II updates (adding almost 4× Run I statistics) ongoing

More searches for LFV working towards publication, Run I+II

$\boldsymbol{\tau\mu}$: $B^+ \to K^+\mu^-\tau^+$ (τ 3-prong), $B^0_d \to K^*\mu^-\tau^+$, $B^0_s \to \phi\mu^-\tau^+$

$\boldsymbol{e\mu}$: $B^0_d \to K^*e^-\mu^+ + B^0_s \to \phi e^-\mu^+$, $\Lambda_b \to \Lambda e^-\mu^+$

Search program motivated by LFU anomalies largely covered

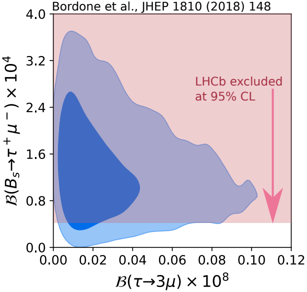
Summary

- LHCb has a strong program of searches for LFV hadron (and τ) decays
  In the light of the LFU anomalies, the LFV effort has been intensified

- LHCb has demonstrated its capability to push the sensitivity of searches for LFV in 2- and 3-body decays with $e\mu$ and $\mu\tau$ pairs

Current sensitivities: $\mathcal{O}(10^{-9})$ for $\mathcal{B}(\mathrm{B} \to X\, e\mu)$
$\mathcal{O}(10^{-5})$ for $\mathcal{B}(\mathrm{B} \to X\, \tau\mu)$

Probing interesting regions in parameter space of several BSM models for LFU anomalies



Stay tuned for the next round of results from LHCb LFV searches

- LHCb upgrades and Belle II will allow for further significant improvement of current sensitivities in the coming years

BACKUP

Searches for LFV - A Glimpse into the future

Decay	Max. NP LFU models	Best Limit 90% CL	Exp.	LHCb Run 3	Belle II 50 ab^{-1}
$B_d^0 \to e\mu$		1.0×10^{-9}	LHCb	2×10^{-10}	-
$B_s^0 \to e\mu$	10^{-11}	5.4×10^{-9}		8×10^{-10}	-
$B^+ \to K^+ e\mu$	10^{-8}	6.4×10^{-9}	LHCb	$\sim 10^{-9}$	-
$B^+ \to K^+ \tau\mu$	10^{-5}	4.8×10^{-5}	BaBar	$\sim 10^{-6}$	3.3×10^{-6}
$B_d^0 \to K^* \tau\mu$	10^{-5}	-	-	$\sim 10^{-6}$	few $\times 10^{-6}$
$B^+ \to K^+ \tau e$		3.0×10^{-5}	BaBar	-	2.1×10^{-6}

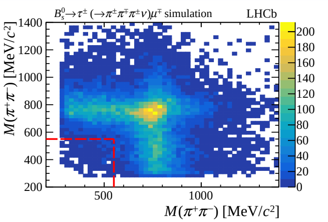
Official LHCb expectations from arXiv:1808.08865 in blue
Official Belle II expectations from arXiv:1808.10567 in orange
Guess from similar channels or extrapolation for luminosity in grey

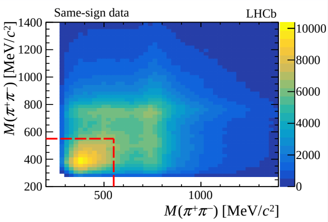
Tests of charged lepton flavour conservation will benefit from LHCb / Belle II competition and complementarity in the coming years

$B^0_{s,d} \to \tau^\pm \mu^\mp$: Selection

Preselection

- Cut-based preselection using resonance structure of the τ decay

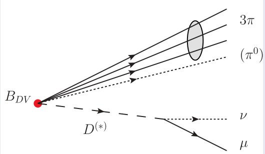




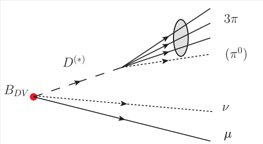
- BDT combining 7 isolation variables

Selection targeting specific bkgs

- BDT against combinatorial bkg
- $\tau_\tau/\sigma(\tau_\tau) > 1.8$
  Rejection of 'reverse topology'



- Remaining background dominated by 'signal topology'. modelled in the fit



- Final BDT, $m(B^0_{s,d})$ fit in 4 BDT bins

$$\epsilon^{tot}_{sel}(\mathrm{B^0_s} \to \tau^\pm\mu^\mp) \approx 1.6 \cdot 10^{-4}$$

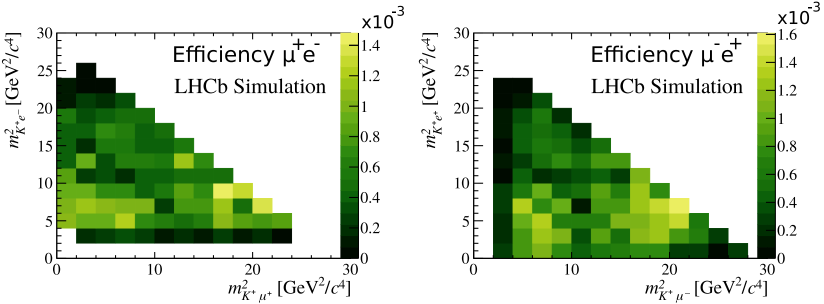
$B^+ \to K^+\mu^\pm e^\mp$: Signal model / (Re-)Interpretation

Analysis split according to charge combination of the $\mu^\pm e^\mp$ pair:

$B^+ \to K^+\mu^+e^-$ $\qquad$ $B^+ \to K^+\mu^-e^+$

(BSM) Model independent approach:

- Phase space decay model used for signal decay
- Efficiency maps provided over the Dalitz plane
  $\to$ Re-weighting allows for re-interpretation of exclusion limits in terms of a specific signal



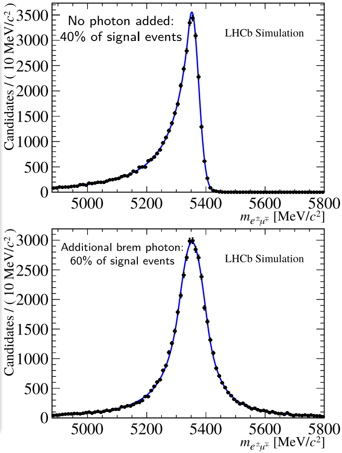
$B^0_{s,d} \to e^{\pm}\mu^{\mp}$: Introduction

Search for LFV with purely leptonic final state, electron reconstruction challenging

JHEP 1803 (2018) 078

Analysis essentials

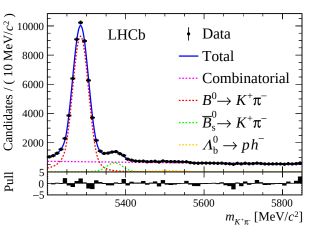
- LHCb Run I data, $\mathcal{L}_{int} = 3\ \text{fb}^{-1}$
- Signature:
  - Efficient trigger: both muon/electron triggers
  - Secondary vertex formed by $e^{\pm}\mu^{\mp}$ candidates fulfilling tight PID requirements
- Recovery of bremsstrahlungs photons in e reco
  $\Rightarrow$ Analysis split into brem/no brem categories
  Separate evaluation of ϵ_{sig}, mass shape
- 2 normalization channels:
  - $B^0_d \to K^+\pi^-$ (topology)
  - $B^+ \to J/\psi K^+$ (high yield, similar triggers)

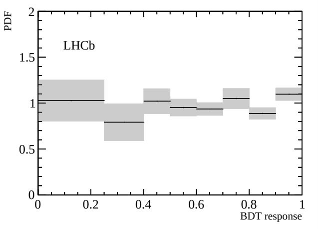


$B^0_{s,d} \to e^\pm \mu^\mp$: Selection

Selection and background

- Topological BDT targeting combinatorial
  Uniform response for signal $\to$ Flatness checked using $B^0_d \to K^+\pi^-$ selected data





- Peaking bkg $B^0 \to h^+h'^-$ reduced to ~ 0.1 events by tight PID requirements
- Remaining exclusive background contribution dominated by partially reconstructed processes $B^0 \to \pi^-\mu^+\nu_\mu$ and $\Lambda_b \to p\ell^-\bar{\nu}_\ell$ is modelled in the fit

Signal efficiencies obtained from simulation except for trigger and PID efficiencies

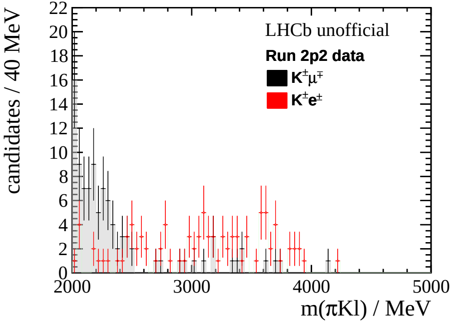
$$\epsilon^{tot}_{sel}(B^0_d \to e^\pm\mu^\mp) = (2.22 \pm 0.05)\% \quad , \quad \epsilon^{tot}_{sel}(B^0_s \to e^\pm\mu^\mp) = (2.29 \pm 0.05)\%$$

Evidence for D^{**} cascades in data

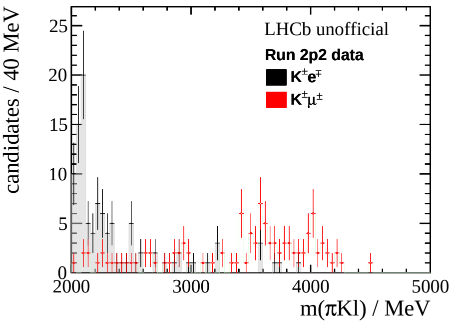
Example: $B_d^0 \to D_2^*(2460)^-(\to \bar{D}^0(\to K^+ e^- \bar{\nu}_e)\pi^-)\ \mu^+\nu_\mu$

$(K\ell)_{os}\pi < M(D^{**}) \to$ Check $M(K\ell\pi)$ separately for $(K\ell)_{os}\pi$ and $(K\ell)_{ss}\pi$

$(K\mu)_{os}/(Ke)_{ss}$ events after full selection



$(K\mu)_{ss}/(Ke)_{os}$ events after full selection



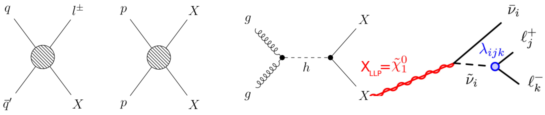
- Kinematic endpoint at $M(D^{**}) \sim 2.5$ GeV visible in $M((K\ell)_{os}\pi)$, not in $M((K\ell)_{ss}\pi)$, as expected for D^{**} cascades
- Cost of tightning the D-veto cut to $M(K\pi\ell) > 2.5$ GeV would be a $\sim 15\%$ loss in signal efficiency
  D^{**} background contribution modelled in fit to $M(B)$ instead

Other paths to explore: Long-lived particles Preliminary

LHCb-PAPER-2020-027
(in preparation)

Search for long-lived particle decay $X_{LLP} \to e^{\pm}\mu^{\mp}\nu$

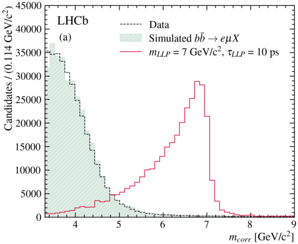
- Based on Run 2 data (2016-2018), $L_{int} = 5.1\ \text{fb}^{-1}$
- Parameter space: $7\ \text{GeV} \leq m(X_{LLP}) \leq 50\ \text{GeV}$
  $2\ \text{ps} \leq \tau(X_{LLP}) \leq 50\ \text{ps}$
- 3 production modes + different X_{LLP} candidates

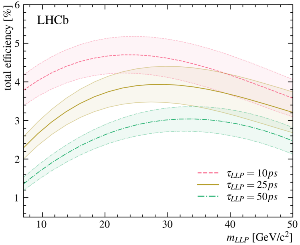


- Selection: Detached, isolated $e^{\pm}\mu^{\mp}$ vertex in VELO
- Background: Data-driven, $b\bar{b} \to e\mu + X$ dominant
- Fit: Simultaneous fit to m_{corr}, $FD(X_{LLP})$

Focus on lower signal mass range where LHCb results are unique/competitive

$$m_{corr} = \sqrt{m^2(e\mu) + p_{\perp}^2(e\mu)} + p_{\perp}(e\mu)$$

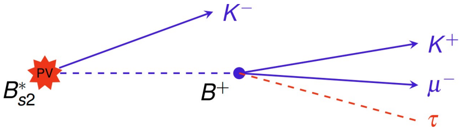




NEW $B^+ \to K^+\tau^+\mu^-$ using $B_{s2}^{*0} \to B^+K^-$ decays

First search for $B \to X\tau\mu$ signature in LHCb, $L_{int} = 9$ fb^{-1} JHEP 06 (2020) 129

Inclusive τ reconstruction using $B_{s2}^{*0} \to B^+K^-$ decays:



1. Reconstruct B^+ secondary decay vertex from $K^+\mu^-$ pair
2. Select corresponding PV and K^- track

$\xRightarrow[m(B_{s2}^{*0})]{m(B^+)}$ $p(B^+)$ determined up to a quadratic ambiguity $\Rightarrow$ m_{miss}^2 peak at m_τ^2 for signal

Downside: $B_{s2}^{*0} \to B^+K^-$ decays account for only $\sim 1\%$ of B^+ production

- Analysis targeting 1-prong τ decays (3-prong signal vetoed, dedicated analysis)
  Require additional track t^+ from secondary B^+ vertex for background rejection
- Only $B^+ \to K^+\tau^+\mu^-$ channel considered
  $B^+ \to K^+\tau^-\mu^+$ with significantly higher background from $B \to \bar{D}X\mu^+\nu_\mu$

$B^+ \to K^+ \tau^+ \mu^-$ using $B_{s2}^{*0} \to B^+ K^-$

Analysis overview

- Signal: B^+ component not from B_{s2}^{*0} included, peaks at $m_{miss}^2 = m_\tau^2$

  2 signal shapes used in the final fit to m_{miss}^2
- Norm. channel: $B^+ \to K^+ J/\psi(\to \mu\mu)$ used to determine $f_{B_{s2}^{*0}}^{sig} = (25.4 \pm 1.8)\%$
- Background: Mainly partially reconstructed B decays, suppressed using BDT

  Control sample: Same-sign B^+K^+

  Remaining background has smooth distribution in m_{miss}^2