PROCEEDINGS OF SCIENCE

Charged Lepton Flavour Violation searches in B decays at LHCb

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Charged lepton flavour violation (cLFV) is a flavour-changing short-range interaction among charged leptons. The cLFV processes, although allowed by neutrino oscillations, are highly suppressed in the Standard Model (SM). Since their occurrence is below any current experiment sensitivity, observing a cLFV process would constitute a clear probe of physics Beyond the Standard Model (BSM). The LHCb collaboration has conducted searches of cLFV decays involving different lepton flavour couplings and set the most constraining upper limits on the branching fractions of $b \to sll'$ transitions, where leptons with different flavours are direct products of the decay of b-quark mesons. They allow boundaries to be set in the parameter space of various BSM models.

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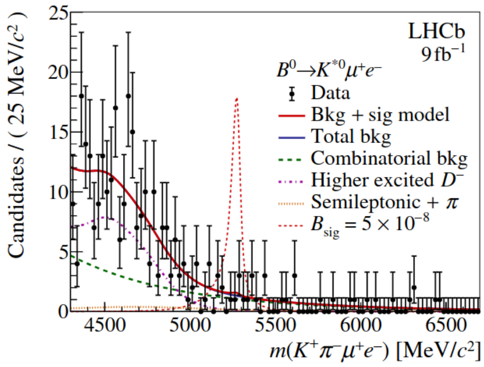
1. Introduction

According to the SM, the lepton flavour is conserved in electroweak transitions, meaning that the different flavours of leptons do not mix or transform into each other. Extending the SM to include neutrino oscillation, cLFV decays can happen only through loop diagrams with neutrino mixing. Hence, they're highly suppressed. The predicted branching ratio [1]is much below any experimental sensitivity. Therefore, any observation of cLFV processes would be a sign of physics BSM [2].

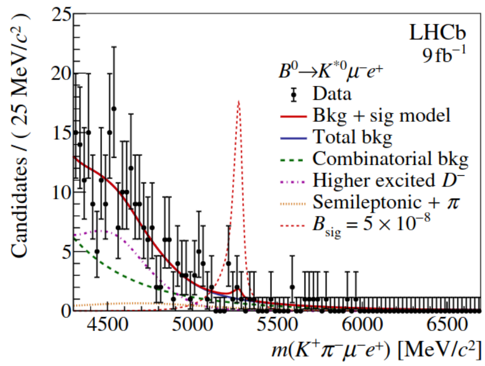
The LHCb experiment [3] at LHC is dedicated to performing heavy-flavor physics measurements. It is an excellent place to search for indirect evidence of physics BSM. These proceedings report on the most recent cLFV searches conducted at LHCb, including the searches for $B^0 \to K^{*0}\mu^\pm e^\mp$ and $B_s^0 \to \phi\mu^\pm e^\mp$ [4] in Section 2, the search for $B^0 \to K^{*0}\tau^\pm\mu^\mp$ [5] in Section 3 and the search for $B_s^0 \to \phi\tau^\pm\mu^\mp$ [6] in Section 4. The searches exploit proton-proton collision data collected between 2011 and 2012, at the centre-of-mass energy $\sqrt{s}$ of 7 and 8 TeV, and between 2015 and 2018, at $\sqrt{s}$ = 13 TeV. The first data sample corresponds to 3 fb^{-1} and the second to 6 fb^{-1}, for a total integrated luminosity of 9 fb^{-1}.

2. Search for the lepton flavour violating decays $B^0 \to K^{*0}\mu^\pm e^\mp$ and $B_s^0 \to \phi\mu^\pm e^\mp$

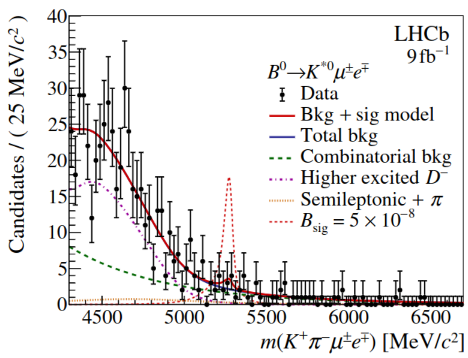
Since BSM physics could affect the charge combinations of leptons in the final states, $B^0 \to K^{*0}\mu^+ e^-$ and $B^0 \to K^{*0}\mu^- e^+$ are considered separately. Results merging both charge combinations are also presented. Charge separation is not performed for $B_s^0 \to \phi\mu^\pm e^\mp$ decays because the scalar ϕ meson, decaying into two opposite charge kaons, makes $B_s^0 \to \phi\mu^+ e^-$ and $\bar{B}_s^0 \to \phi\mu^- e^+$ indistinguishable. Samples of $B^0 \to J/\psi(\to \mu^+\mu^-)K^{*0}$ and $B_s^0 \to J/\psi(\to \mu^+\mu^-)\phi$ decays are used as normalization modes. The signal candidate selection is based on strong particle identification and K^* and ϕ mesons mass window requirements. Furthermore, vetoes are applied to reject background from J/ψ and $\psi(2s)$ resonances and semileptonic cascades involving charm mesons. Finally, separate BDTs are applied to remove the combinatorial background for the two signal decays. The signal shapes are determined from the simulation, with additional corrections determined from $J/\psi K^*$ and $J/\psi\phi$ control samples. Signal decays are searched for by performing unbinned maximum likelihood fits to the invariant mass distributions of reconstructed $B^0_{(s)}$ candidates. The fit model includes signal, combinatorial background and background from semileptonic cascade decays involving higher excited $D^-_{(s)}$ resonances and other semileptonic decays with an additional charged pion. No significant signal excess is observed for either channel. Limits to the branching ratio of the decays are set assuming uniform phase-space distribution in the kinematics of the simulation. Figure 1 shows the fit results for every channel and the upper limits. Additionally, limits are set in different BSM scenarios [7], such as for the scalar model $C^9 \neq 0$ and for the left-handed model $C^9 = -C^{10} \neq 0$ [8].



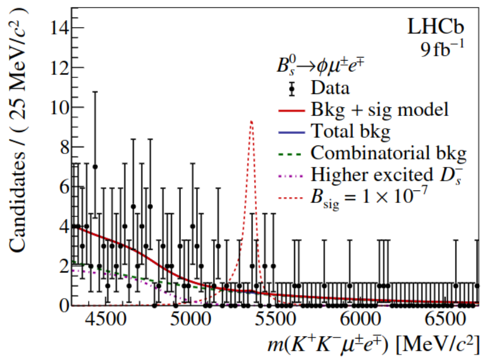
(a) $\mathcal{B}(B^0 \to K^{*0}\mu^+e^-) < 5.7(6.9)\times10^{-9}$



(b) $\mathcal{B}(B^0 \to K^{*0}\mu^-e^+) < 6.8(7.9)\times10^{-9}$



(c) $\mathcal{B}(B^0 \to K^{*0}\mu^\pm e^\mp) < 10.1(11.7)\times10^{-9}$



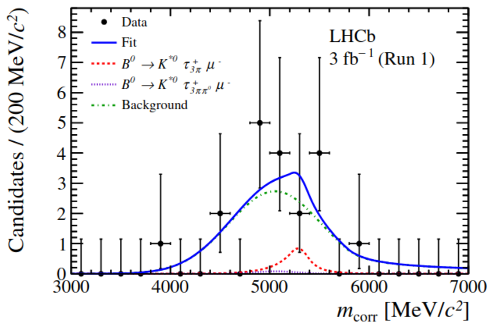
(d) $\mathcal{B}(B_s^0 \to \phi\mu^\pm e^\mp) < 16.0(19.8)\times10^{-9}$

Figure 1: Unbinned maximum likelihood fits to the invariant mass distributions for $B^0 \to K^{*0}\mu^+e^-$ (1a), $B^0 \to K^{*0}\mu^-e^+$ (1b), $B^0 \to K^{*0}\mu^\pm e^\mp$ (1c) and $B_s^0 \to \phi\mu^\pm e^\mp$ (1d). For illustration purposes, the signal shape, scaled to a branching fraction of 5×10^{-8} for $B^0 \to K^{*0}\mu^\pm e^\mp$ and 1×10^{-7} for $B_s^0 \to \phi\mu^\pm e^\mp$, is drawn as red dashed line. Below each fit, the observed limit at 90(95)% CL is provided, assuming the phase space distribution of simulated kinematics.

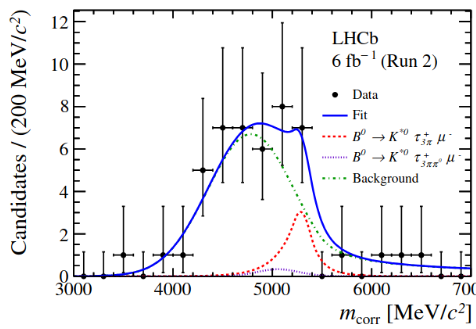
3. Search for the lepton flavour violating decays $B^0 \to K^{*0}\tau^\pm\mu^\mp$

The K^{*0} meson is reconstructed through a K^+ and π^-, while the τ lepton through its hadronic decay into pions and a neutrino. The experiment does not detect the neutrino. For this reason, the B candidate's mass is corrected to take into account the missing energy [9]. The normalization decay used for the analysis is $B \to D_s^+(\to K^+K^-\pi^+)D^-(\to K^+\pi^-\pi^-)$, given the similarity of the decay topology and the precise measurement of its branching fraction. Events are selected by applying in sequence fiducial requirements and a couple of BDTs trained to suppress combinatorial background and reject intermediate charm mesons. In addition, particle identification requirements, a multivariate isolation classifier, and mass vetoes are applied to remove misidentified backgrounds, partially reconstructed decays and semileptonic cascades involving charm mesons. Unbinned maximum likelihood fits to the distribution of the corrected mass of the B candidates surviving the selection are performed simultaneously for data collected in 2011-2012 and data collected from

2015 to 2018 (see Figure 2). The fit model includes the signal, whose parameters are directly fixed from the simulated events and the background. The background model parameters are determined from a control sample extracted from data loosening the combinatorial selection. No significant signal is observed, and an upper limit is set on the branching fractions of the decays, separately treated for charge combination. Simulated events are produced assuming a uniform phase-space distribution in the kinematics of K^{*0}, μ and τ. However, efficiency maps are provided as a function of the invariant mass squared of $K^{*0}\mu$ and $\tau\mu$ to allow for a recast of the results according to a specific theoretical model.

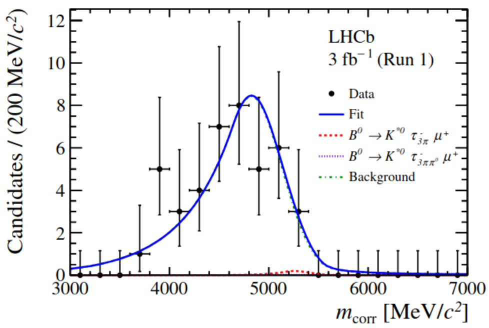


(a) $B^0 \to K^{*0}\tau^-\mu^+$ 2011-2012 data

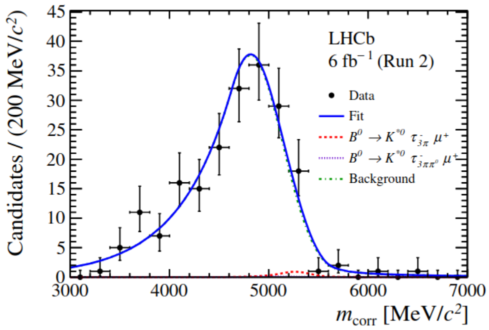


(b) $B^0 \to K^{*0}\tau^-\mu^+$ from 2015 to 2018 data

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



(c) $B^0 \to K^{*0}\tau^+\mu^-$ 2011-2012 data



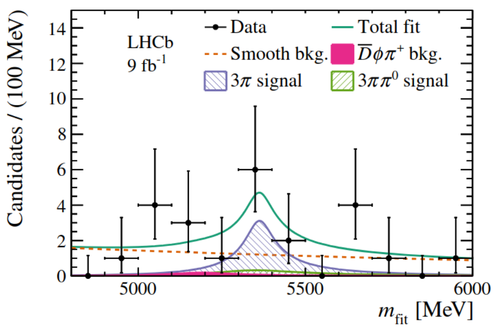
(d) $B^0 \to K^{*0}\tau^+\mu^-$ from 2015 to 2018 data

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

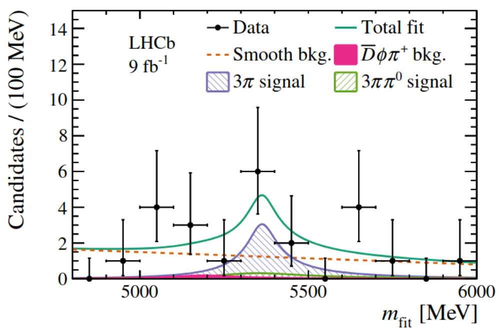
Figure 2: Unbinned maximum likelihood fits to the corrected mass distributions for $B^0 \to K^{*0}\tau^-\mu^+$ (2a, 2b) and $K^{*0}\tau^+\mu^-$ (2c, 2d). Fits are performed simultaneously for data collected in 2011-2012 (2a, 2c) and data from 2015 to 2018 (2b, 2d). Below the distributions for each charge combination, the limit is set at 90(95)% CL, simulating uniform phase space signal.

4. Search for the lepton flavour violating decays $B^0_s \to \phi\tau^\pm\mu^\mp$

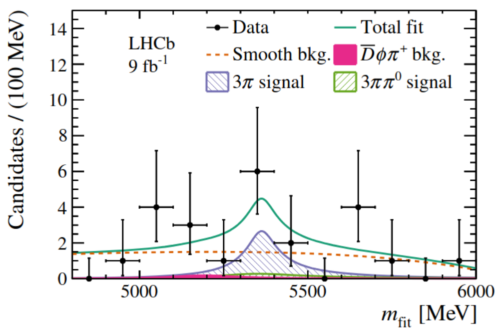
The final state comprises six charged tracks, with the ϕ meson decaying into two opposite charge kaons via strong interaction and τ leptons decaying hadronically into pions and a neutrino. The non-reconstructed neutrino leads to the presence of missing energy, as in the previous analysis. In this case, a kinematic fit is applied to determine the mass of the signal candidates, setting constraints to the mass of the τ and the B and τ directions of flight. The normalization channel used is $B_s^0 \to \psi(2s)\phi$. Signal candidates are selected by applying strong particle identification and ϕ mesons mass window requirements. Vetoes are applied on mass window requirements for the J/ψ and $\psi(2s)$ masses. In addition, further background reduction is obtained by applying two classifiers trained to suppress combinatorial and partially reconstructed backgrounds. An unbinned maximum likelihood fit is applied to the mass distribution of B_s^0 candidates to search for signal decays. The fit model includes the signal, determined from the simulation, one irreducible component of the misidentified background, $B^0 \to \bar{D}\phi\pi$, and the remaining background. The latter is modeled using four different parameterizations: exponential, linear, quadratic, and the product of the exponential and linear functions. For each value of the branching ratio, the lowest of the test statistics obtained by scanning over the background models is the one retained. The overall best fit uses the linear background model, resulting in a signal branching fraction of 4.1×10^{-6}. Figure 3 shows fit results for every background parameterization and the upper limit set at 90(95)% CL.



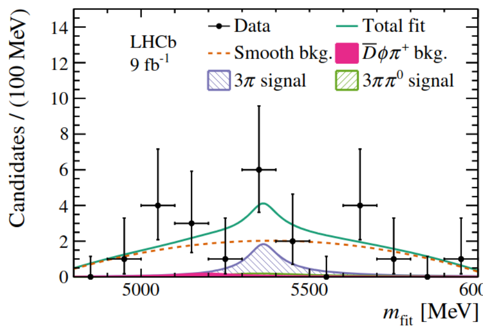
(a) Exponential



(b) Linear



(c) Quadratic



(d) Product of linear and exponential

$$\mathcal{B}(B_s^0 \to \phi\tau^\pm\mu^\mp) < 1.0(1.1) \times 10^{-5}$$

Figure 3: Distributions of refitted mass overlaid with the fit results corresponding to four background models: exponential (3a), linear (3b), quadratic (3c) and product of linear and exponential functions (3d). Signal and peaking $D\phi\pi^+$ background components are also shown. Below the plots, the upper limit is set at 90(95)% CL.

5. Conclusion and Outlook

Theorists have proposed models to extend the SM that could include cLFV processes. This has been reflected in the experimental scientific community, where research has ensued in this field. LHCb, as previously Babar and Belle and now Belle II, is a front-runner experiment for these searches. These proceedings report on the latest searches performed at LHCb. Table 1 shows the current upper limits on the branching fractions of cLFV B decays. Further measurements will improve the sensitivity of the LHCb experiment, thanks to the new data that is being collected. They will help to clarify and discriminate between different BSM scenarios.

Table 1: Limits set at 90% CL by the LHCb experiment on LFV B decays.

Decay	Limit (90% C.L.)	Integrated luminosity
$B^0_{(s)} \to e^{\mp}\mu^{\pm}$	1.0×10^{-9} (5.4×10^{-9}) [10]	$3 fb^{-1}$
$B^0 \to K^{*0} e^{\mp}\mu^{\pm}$	10.1×10^{-9} [4]	$9 fb^{-1}$
$B^0 \to K^{*0} e^{-(+)}\mu^{+(-)}$	5.7×10^{-9} (6.8×10^{-9}) [4]	$9 fb^{-1}$
$B^+ \to K^+ e^{+(-)}\mu^{-(+)}$	7.0×10^{-9} (6.4×10^{-9}) [11]	$3 fb^{-1}$
$B^0_s \to \phi e^{\pm}\mu^{\mp}$	1.6×10^{-8} [4]	$9 fb^{-1}$
$B^0_{(s)} \to \tau^{\mp}\mu^{\pm}$	1.4×10^{-5} (4.2×10^{-5}) [12]	$3 fb^{-1}$
$B^+ \to K^+\tau^+\mu^-$	3.9×10^{-5} [13]	$9 fb^{-1}$
$B^0 \to K^{*0}\tau^{+(-)}\mu^{-(+)}$	1.0×10^{-5} (9.8×10^{-6}) [5]	$9 fb^{-1}$
$B^0_s \to \phi\tau^{\pm}\mu^{\mp}$	1.0×10^{-5} [6]	$9 fb^{-1}$

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