$b \to s\ell^+\ell^-$ TRANSITIONS AT LHCb*

Józef Borsuk

on behalf of the LHCb Collaboration

H. Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences
Radzikowskiego 152, 31-342 Kraków, Poland

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These proceedings show the most recent results of lepton universality test in $B^+ \to K^+\ell^+\ell^-$ decays and searches for the flavour-violating $B^+ \to K^+\mu^\pm e^\mp$ decays using data samples from the LHCb experiment. No signal was observed and lepton universality measured shows 2.5 σ deviation from the Standard Model prediction.

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1. Introduction

The Standard Model (SM) of particle physics is a result of work of many scientists through many years. It classifies all known elementary particles and describes their interactions except for gravitational force. Despite a great successes of the SM, it cannot be considered the final theory. There are still few unexplained phenomena such as matter–antimatter asymmetry or hierarchy problem. It does not incorporate massive neutrinos, dark matter particles or dark energy, and it contains 18 free parameters which had to be provided by experiment. With that amount of issues, searches for the so-called physics beyond the Standard Model (BSM) are crucial for making progress in our understanding of Nature. Recently, the first evidence for lepton-flavour violation (LFV) has been confirmed by observation of neutrino oscillation. Due to the fact that in charge sector LFV is negligible in the SM [1], any observation of such decays would be undeniable evidence for beyond SM processes.

The $b \to s\ell^+\ell^-$ transitions, where ℓ is a lepton, are flavour-changing neutral current processes, where the quark changes its flavour without altering its electric charge. Those transitions are suppressed in the SM and can

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proceed only through electroweak penguin or box diagrams. There are some new physics scenarios, where new heavy particles can contribute in those processes.

Both presented $B^+ \to K^+\ell^+\ell^-$ and $B^+ \to K^+\mu^\pm e^\mp$ decays are ideal not only to test LFV but also to investigate lepton universality (LU) which postulates that electroweak couplings of leptons to gauge bosons are independent of lepton flavour.

2. The LHCb detector

The LHCb detector [2] is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$. It contains ring-imaging Cherenkov detectors, hadronic and electromagnetic calorimeters, muon identification system and tracking detectors of high precision (shown in figure 1). This tracking system is composed of the vertex locator (VELO) surrounding the beam interaction region, a tracking station located upstream of the dipole magnets and three tracking stations located downstream of the dipole magnets. Particles inside the LHCb detector experience a bending field of around 4 Tm. The on-line event selection is formed by a trigger which consists of two stages: hardware stage, based on informations from the calorimeters and muon system; and software stage, which applies a full event reconstruction.

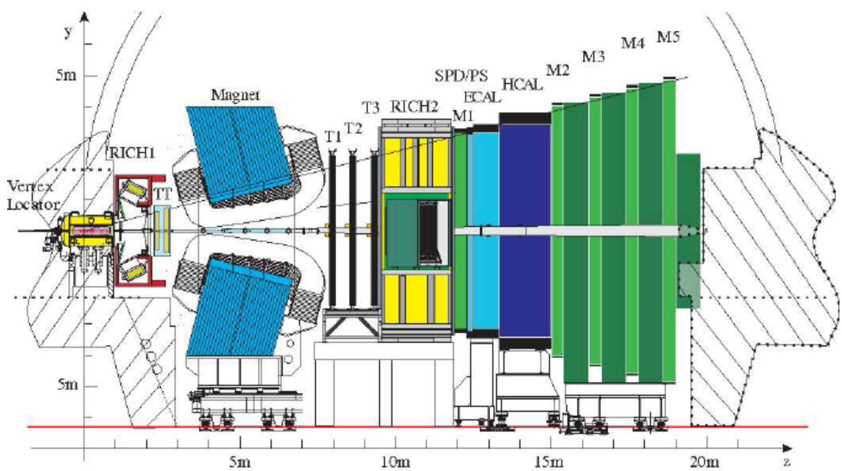

Fig. 1. The LHCb detector [2].

3. Flavour changing neutral currents

Flavour changing neutral currents (FCNC) are highly suppressed in the SM by the so-called GIM mechanism and can occur only through electroweak penguin or box loop diagrams. The Holy Grail of the FCNC is the $B^0 \to K^{*0}\ell^+\ell^-$ (shown in figure 2), because its sensitivity to BSM medatiors, such as leptoquarks or new gauge bosons.

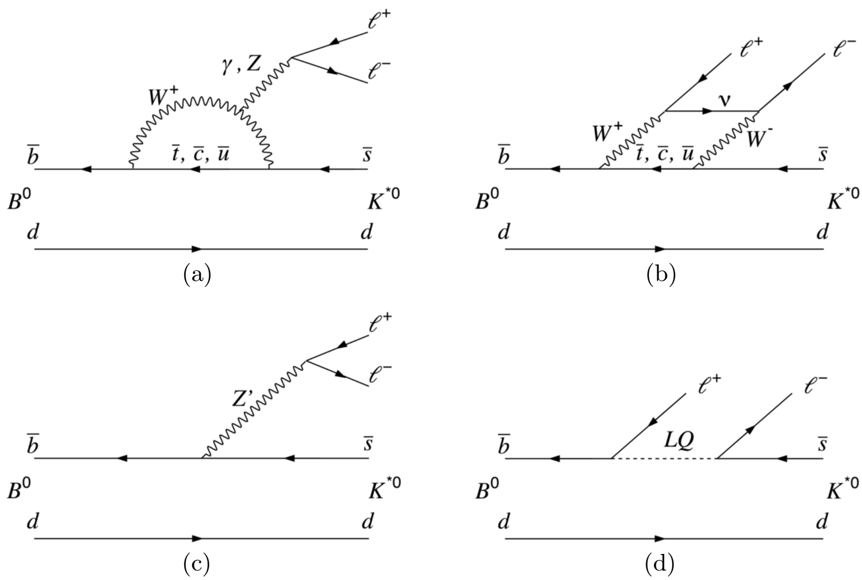

Fig. 2. Feynman diagrams of $B^0 \to K^{*0}\ell^+\ell^-$ decays in the SM (electroweak penguin diagram (a) and box diagram (b)) and NP processes involving gauge boson Z' (c) or leptoquark (d) [3].

3.1. *Lepton flavour violation in* $B^+ \to K^+\mu^\pm e^\mp$

Results of searching for lepton flavour violating $B^+ \to K^+\mu^\pm e^\mp$ decays are based on data recorded by the LHCb detector at the center-of-mass energies of 7 TeV (2011) and 8 TeV (2012). It corresponds to integrated luminosity of 3 fb^{-1} [4]. The branching fraction of $B^+ \to K^+\mu^\pm e^\mp$ decays is measured relative to the normalization channel using the formula

$$\mathcal{B}\left(B^+ \to K^+\mu^\pm e^\mp\right) = N\left(B^+ \to K^+\mu^\pm e^\mp\right) \times \alpha\,, \tag{1}$$

$$\alpha = \frac{\mathcal{B}\left(B^+ \to J/\psi(\to \mu^+\mu^-)K^+\right)}{\epsilon\left(B^+ \to K^+\mu^\pm e^\mp\right)} \frac{\epsilon\left(B^+ \to J/\psi(\to \mu^+\mu^-)K^+\right)}{N\left(B^+ \to J/\psi(\to \mu^+\mu^-)K^+\right)}\,,$$

where ϵ is the efficiency and N is the observed yield of a given decay channel.

Figure 3, where invariant mass distributions of the $B^+ \to K^+\mu^\pm e^\mp$ decays are presented, shows that only 1 candidate for the $B^+ \to K^+\mu^- e^+$ channel and 2 candidates for the $B^+ \to K^+\mu^+ e^-$ channel were found in the signal mass window $m(K^+\mu^\pm e^\mp) \in [5100, 5370]$ MeV$/c^2$. Upper limits were obtained with $\mathrm{CL_s}$ method [5] with combined data sets which were recorded in 2011 and 2012. Results, which are shown in figure 4 and Table I improve previous measurements [6] of those branching fractions noticeably.

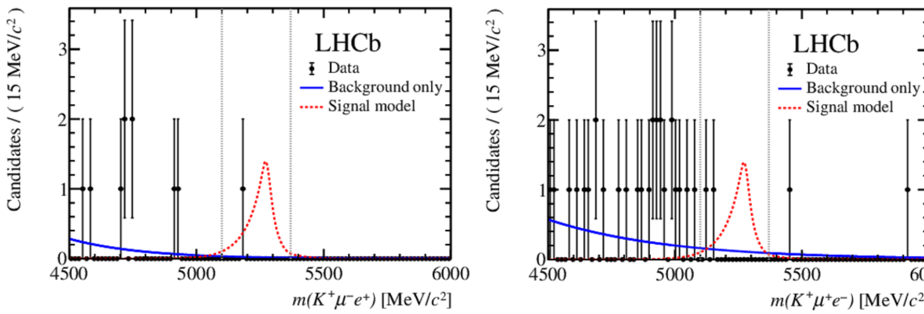

Fig. 3. Invariant mass distributions of the $B^+ \to K^+\mu^-e^+$ and $B^+ \to K^+\mu^+e^-$ with signal model fit function (dotted line) and background only fit function (continuous line) [4]. Two vertical dotted lines indicate signal window.

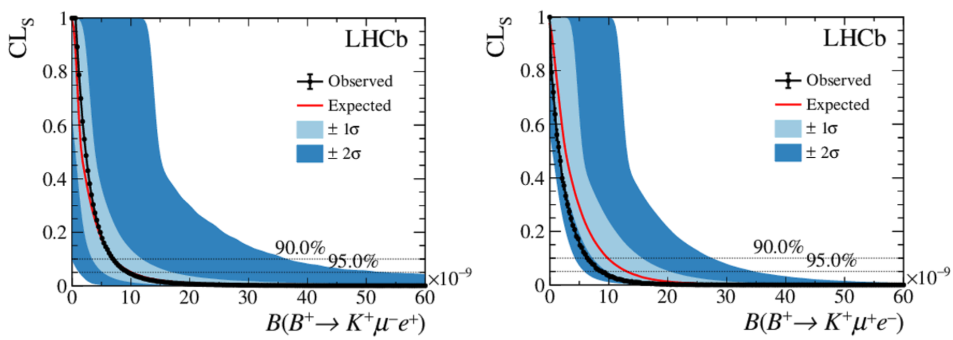

Fig. 4. Upper limits on the branching fractions of $B^+ \to K^+\mu^-e^+$ and $B^+ \to K^+\mu^+e^-$ decays with expected upper limits (continuous line) and observed upper limits (continuous line with data points) [4].

TABLE I

Upper limits on the branching fractions of $B^+ \to K^+\mu^\pm e^\mp$ decays for 90% and 95% confidence level [4].

	90% C.L.	95% C.L.
$\mathcal{B}(B^+ \to K^+\mu^-e^+)/10^{-9}$	7.0	9.5
$\mathcal{B}(B^+ \to K^+\mu^+e^-)/10^{-9}$	6.4	8.8

3.2. Lepton universality violation in $B^+ \to K^+\ell^+\ell^-$

The $B^+ \to K^+\ell^+\ell^-$ decay analysis used data collected during three data-taking periods 2011, 2012 and 2015–2016 at the center-of-mass energies 7 TeV, 8 TeV and 13 TeV, respectively, which correspond to integrated luminosity of 5 fb^{-1} [7]. Double ratio of branching fractions for $B^+ \to K^+\mu^+\mu^-$ and $B^+ \to K^+e^+e^-$ decays were measured in the dilepton mass squared range $1.1 < q^2 < 6\ \mathrm{GeV}^2/c^4$ using the following formula:

$$R_K = \frac{\mathcal{B}\left(B^+ \to K^+\mu^+\mu^-\right)}{\mathcal{B}\left(B^+ \to J/\psi(\to \mu^+\mu^-)K^+\right)} \Bigg/ \frac{\mathcal{B}\left(B^+ \to K^+e^+e^-\right)}{\mathcal{B}\left(B^+ \to J/\psi(\to e^+e^-)K^+\right)} \,. \quad (2)$$

To measure this quantity, knowledge of decay yields and selection efficiencies is needed. Due to the fact that $J/\psi \to \ell^+\ell^-$ decays have lepton-universal branching fractions up to 0.4% [8], efficiency of $B^+ \to K^+e^+e^-$ has to be known only relatively to $B^+ \to J/\psi(\to e^+e^-)K^+$ decay.

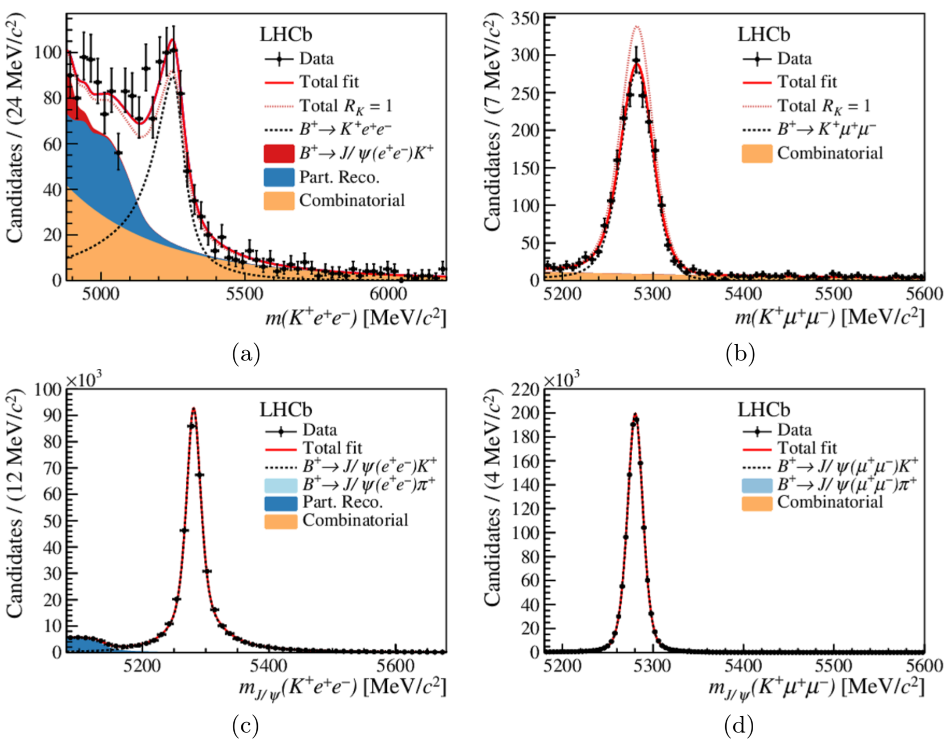

Fig. 5. Fits to the $m(K^+\ell^+\ell^-)$ invariant mass distribution for electron and muon candidates for nonresonant (a), (b) and resonant decays (c), (d) [7].

The R_K is determined using unbinned extended maximum likelihood fits to the invariant mass distribution of nonresonant candidates for each lepton type (figure 5). Yields of the resonant decays are included as constraints in this fit so the $B^+ \to K^+\mu^+\mu^-$ yield and R_K are fit parameters.

All four signal modes are modelled by Crystal Ball function which consists of Gaussian cores and power-law tails on both sides of the peak [9].

There is a visible difference in electron-mode signal mass shapes when we compare it to the mass shapes of the muon mode. That difference comes from the fact that in the electron mode, the sum of three distributions models whether a bremsstrahlung photon cluster was added to one, two or none of $e^\pm$ candidates. Efficiencies which are required for obtaining R_K are taken from simulation. The measured value of R_K is

$$R_K = 0.846^{+0.060+0.016}_{-0.054-0.014}\,, \tag{3}$$

where the first uncertainty is statistical and second is systematic. This is so far the most precise measurement of R_K and it agrees with SM expectations at level of 2.5 standard deviations.

4. Summary

Recent results of $b \to s\ell^+\ell^-$ transitions have been presented. The first example covered searches for lepton flavour violating $B^+ \to K^+\mu^\pm e^\mp$ decays. No excess over background-only hypothesis have been found and upper limits on the branching fractions of the $B^+ \to K^+\mu^\pm e^\mp$ decays were obtained, which improve previous limits [6]. The second example comprised lepton universality test in $B^+ \to K^+\ell^+\ell^-$ decays. Resulting R_K ratio is the most precise measurement and it agrees with the SM at 2.5 σ. The two presented decay modes are of the great importance for searching of physics beyond the Standard Model.

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