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Test of lepton flavour universality in decays with electrons and muons in the final state at the LHCb experiment

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Summary. — This contribution presents the R_K measurement and angular analysis of the $B^0 \to K^{*0} e^+ e^-$ decay performed by the LHCb collaboration and gives an overview of the ongoing and future measurements of rare decays proceeding through a $b \to s\ell^+\ell^-$ transition.

1. – Motivation

The decays involving a $b \to s\ell^+\ell^-$ transition are suppressed in the Standard Model due to the absence of flavour changing neutral currents at tree level and are hence highly sensitive to virtual particles and interactions predicted by several extensions of the Standard Model. In particular, the comparison between decays with muons and electrons in the final state allows to probe New Physics involving lepton flavour universality violation.

Decays with muons in the final state have a clear signature and are reconstructed with high resolution thanks to the muon detectors. On the contrary, electrons are reconstructed using the calorimeters and their kinematic variables must be corrected to account for bremsstrahlung emission. Two measurements involving electrons in the final state are described in the following. Both are based on proton-proton collision data, corresponding to an integrated luminosity of $3.0\,\mathrm{fb}^{-1}$, recorded by the LHCb experiment at center-of-mass energies of 7 and 8 TeV. Involving most of the challenges related to the reconstruction of electrons in the LHCb detector, these measurements are crucial to gain some profitable experience for all the electron modes.

2. – The R_K measurement

In the Standard Model, the ratio of the branching fractions of the $B^0 \to K^+\mu^+\mu^-$ and $B^0 \to K^+e^+e^-$ decays, referred to as R_K, is predicted to be unity within an uncertainty of $\mathcal{O}(10^{-3})$ [1]. However, discrepancies are expected in several New Physics scenarios, involving new scalar or pseudoscalar interactions [1] or Z' bosons coupling differently to electrons and muons [2-4].

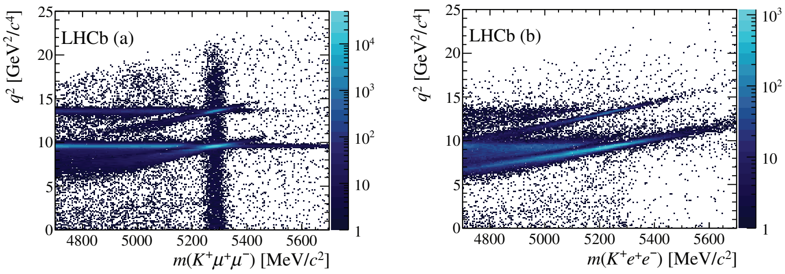

Fig. 1. – Distribution of signal candidates in the $(m_{K^+l^+l^-}, q^2)$ plane for the muon (left) and electron (right) modes. The two horizontal bands corrrespond to the J/ψ and $\psi(2S)$ resonances, while the diagonal band corresponds to the radiative tail generated by bremsstrahlung emission and is, as expected, more pronounced in the electron mode.

The value of R_K has been measured by LHCb in the q^2 region between 1 and $6\,\mathrm{GeV}^2/c^4$ [5]. The measurement has been performed with respect to the resonant mode, $B^0 \to K^+ J/\psi(\to \ell^+\ell^-)$, which allows to reduce systematic uncertainties and simplify part of the efficiencies. The distribution of the signal candidates in the $(m_{K^+\ell^+\ell^-}, q^2)$ plane is shown in fig. 1 for the muon (left) and electron (right) modes. The number of signal events has been obtained from an unbinned extended maximum-likelihood fit of the B^+ invariant-mass distribution. Since the distribution of the signal candidates in the electron mode depends on the nature of the particle that has triggered the event (lepton or hadron) and on the number of bremsstrahlung photons emitted by each electron, the data sample is split into distinct trigger categories and a simultaneous fit is performed in each of them, using an independent shape for each bremsstrahlung category. The B^+ invariant-mass distribution and the corresponding fit for the three trigger categories are shown in fig. 2. The measured value of R_K is $0.745^{+0.090}_{-0.074} \pm 0.036$, where the first uncertainty is statistical and the second systematic. This result corresponds to the most precise measurement to date and it is compatible with the Standard Model prediction at 2.6 standard deviations.

3. – The angular analysis of the $B^0 \to K^{*0}e^+e^-$ decay

Due to the presence of a vector meson in the final state, this decay provides a richer phenomenology than the previous one. In this case, in fact, the differential decay width

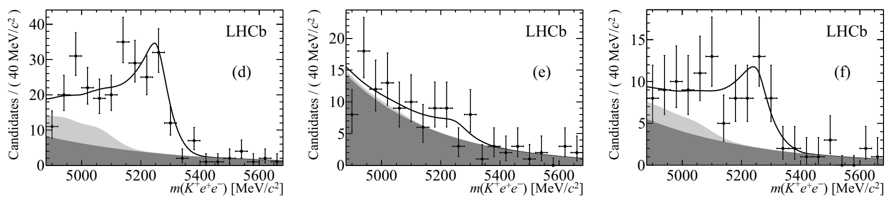

Fig. 2. – B^+ invariant-mass distribution (dots with error bars) and corresponding fit (solid line) of the $B^+ \to K^+e^+e^-$ candidates belonging to events triggered by leptons (left), hadrons (middle), or other particles (right). The fit model consists of tree contributions: the signal, the combinatorial background (dark shaded area), and the background due to the partially reconstructed decays (light shaded area).

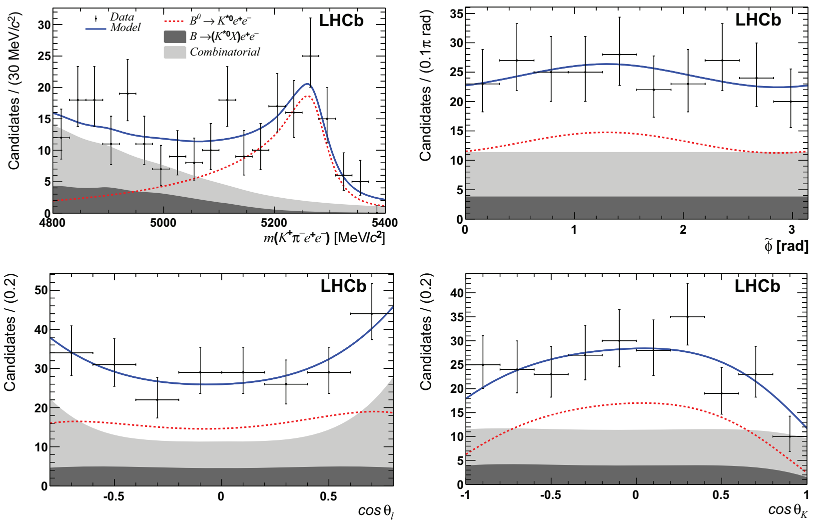

Fig. 3. – B^0 invariant-mass distribution (dots with error bars) and corresponding fit (solid line). The fit model consists of three contributions: signal (dotted line), combinatorial background (light shaded area), and background due to the partially reconstructed decays (dark shaded area).

can be expressed in terms of q^2 and three decay angles (θ_l,θ_k, and ϕ) [6]. In addition, the recent measurement of the $B^0 \to K^{*0}\mu^+\mu^-$ decay has shown a discrepancy in the P_5' observable, corresponding to 3.4 standard deviations with respect to the Standard Model prediction [6], which might be related to New Physics scenarios involving lepton flavour universality violation [7]. Repeating the measurement on the analogous decay with electrons in the final state might hence shade some light on this intriguing anomaly. Compared to the angular analysis of the $B^0 \to K^{*0}\mu^+\mu^-$ decay, this measurement has the advantage of a simplified formalism, since the lepton masses are negligible. The differential decay width can be written in terms of four angular observables: F_L, the longitudinal polarisation fraction of the K^{*0}, $A_T^{(2)}$ and A_T^{Im}, related to the polarisation of the photon, and A_T^{Re}, related to the lepton forward-backward asymmetry [8]. As for the R_K measurement, the electrons in the final state require to consider different trigger and bremsstrahlung categories.

The measurement has been performed by the LHCb experiment in the low q^2 region, from 0.0020 ± 0.0008 to $1.120 \pm 0.060\,\mathrm{GeV}^2/c^4$ [9]. This region is dominated by the $b \to s\gamma$ transition and is hence particularly suitable to measure the photon polarisation and the C_7 and C_7' Wilson coefficients. The angular observables have been obtained by fitting the B^0 invariant mass distribution and the three decay angles, as shown in fig. 3. The measured values are

$$\begin{aligned}
F_L &= +0.16 \pm 0.06 \pm 0.03,\\
A_T^{(2)} &= -0.23 \pm 0.23 \pm 0.05,\\
A_T^{Im} &= +0.14 \pm 0.22 \pm 0.05,\\
A_T^{Re} &= +0.10 \pm 0.18 \pm 0.05,
\end{aligned}$$

where the first uncertainty is statistical and the second systematic. All the results are dominated by the statistics uncertainty and are found to be compatible with the Standard Model predictions [10, 11].

4. – Conclusions and future prospects

The two measurements discussed above are dominated by the statistics uncertainty, so it will be worth to update both results with the LHC Run II statistics. In the meantime, several analyses are ongoing to exploit the potential of the rare decays proceeding through a $b \to s\ell^+\ell^-$ transition. They include the R_{K^*} measurement, that is, the analogous of the R_K measurement in the $B^0 \to K^{*0}\ell^+\ell^-$ mode, the angular analysis of the non-resonant $B^0 \to K\pi\ell^+\ell^-$ decay, the angular analysis of the $B^0 \to K^{*0}e^+e^-$ decay in two different q^2 regions, between 1 and $6\,\mathrm{GeV}^2/c^4$ and above the $\psi(2S)$ resonance, and the P_5' electron-muon asymmetry. The results of this wide physics program will allow to extend our knowledge on potential New Physics that violates lepton flavour universality.

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