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Lepton flavour violation and universality tests at LHCb

Miriam Lucio Martínez[a,*]

[a]*Nikhef Institute for Subatomic Physics, Amsterdam, The Netherlands*

E-mail: miriam.lucio.martinez@cern.ch

The coupling of the electroweak gauge bosons of the Standard Model (SM) of particle physics to leptons is flavour universal. Experimental tests of this principle are highly sensitive to New Physics particles which couple differently among the leptonic families. A violation of lepton flavour universality, together with the flavour anomalies that have been observed, could imply the existence of lepton-flavour violating b-hadron decays. Recent results from the LHCb experiment on lepton flavour universality and lepton flavour violation are discussed in this talk.

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[1]on behalf of the LHCb Collaboration
[*]Speaker

1. Introduction

In the SM, the electroweak couplings are the same across the three generations of leptons, which translates into the amplitude of the processes involving these particles being identical, setting aside phase space and helicity suppression effects. This concept is referred to as *Lepton Flavour Universality (LFU)*. Moreover, evidence has been observed of *Lepton Flavour Violation (LFV)* processes involving neutrinos [1]. LFV can take place with charged particles within the SM only through loop diagrams with neutrino mixing, having a branching fraction beyond current experimental reach.

Beyond the SM (BSM) alternatives proposed to explain the *flavour anomalies* (see for example [2, 3]) usually feature LFU violation and strongly enhanced values for the branching fraction of LFV decays, thus making these strong probes for such models.

2. LFU tests

LFU tests can be subdivided into two groups, depending on whether they involve *semileptonic* ($b \to cl\nu$) or *rare* ($b \to sl^+l^-$) decays. The former are mediated by charged currents, such that they can proceed at tree level and have large branching fractions. As for the latter, they are mediated by neutral currents, occurring only at loop level and hence being very suppressed in the SM.

2.1 Semileptonic decays

In this subset of LFU tests the aim is to compute the ratio of branching fractions for decays involving taus with respect to those involving muons. Since most of the hadronic uncertainties cancel out in this ratio, the SM predictions have very small theoretical uncertainties. Nevertheless, they present some experimental challenges, mainly caused by the presence of at least one neutrino in the final state that is used to reconstruct the taus, which cannot be detected at LHCb. The results presented in this section have been obtained using data collected at the LHCb detector during Run 1.

2.1.1 Measurement of $\mathbf{R(D^*)}$

The ratio of branching fractions $R(D^*) = \mathcal{B}(B \to D^*\tau\nu_\tau)/\mathcal{B}(B \to D^*\mu\nu_\mu)$ is measured using hadronic tau decays ($\tau \to \pi^+\pi^-\pi^-(\pi^0)\nu_\tau$) and the $B^0 \to D^*\pi^+\pi^-\pi^+$ decay as normalization channel. The obtained result, $R(D^*) = 0.291 \pm 0.019(\text{stat}) \pm 0.026(\text{syst}) \pm 0.013(\text{ext})$ [4], where the third uncertainty is due to the limited knowledge of the $B^0 \to D^*\pi^+\pi^-\pi^+$ branching fraction. The systematic uncertainty is currently dominated by simulation statistics and is compatible with the previous LHCb result using the muonic channel [5] and with the SM within 1σ [6].

Figure 1 shows the combination from the Heavy Flavour Averaging Group (HFLAV) for $R(D)$ and $R(D^*)$ along with the SM prediction and the individual measurements from LHCb, Belle and BaBar [7]. The overall combination shows a tension with the SM of about 3.1σ.

2.2 Rare decays

The ratio of branching fractions of rare decays with muons and electrons in the final state is predicted to be very close to 1, with a very small theoretical uncertainty (of the order of 1%

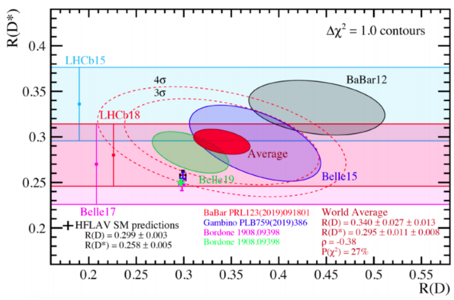

Figure 1: Summary of the measurements of $R(D)$ and $R(D^*)$ (from [7]).

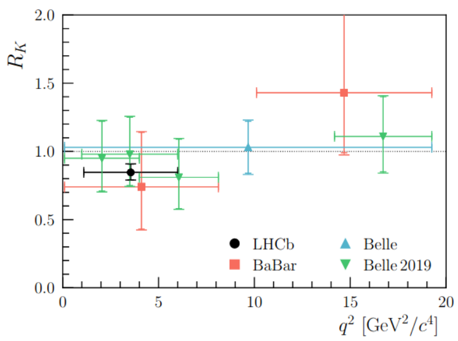

Figure 2: Comparison of the LHCb $R(K)$ measurements [10, 11] with previous experimental results from the B-factories [12–14].

for B mesons [8]). The experimental challenges are in this case low statistics, the presence of several background sources and the bremsstrahlung radiation emitted by electrons. In order to better manage the uncertainties, double ratios are computed using the resonant modes, where LFU has been extensively tested [9].

2.2.1 Measurement of R(K)

For this analysis, the ratio of $B^+ \to K^+e^+e^-$ and $B^+ \to K^+\mu^+\mu^-$ branching fractions are measured in the dilepton mass-squared range $1.1 < q^2 < 6.0 GeV^2/c^4$, using the full LHCb Run 1 dataset and part of the Run 2 (2015-2016) dataset, thus having twice as many B^+ as the previous LHCb measurement [10]. As cross-checks of the analysis procedure, both $r_{J/\psi} = \mathcal{B}(B^+ \to J/\psi(\to \mu^+\mu^-)K^+)/\mathcal{B}(B^+ \to J/\psi(\to e^+e^-)K^+)$ and $R_K^{\psi(2S)} = \frac{\mathcal{B}(B^+\to\psi(2S)(\to\mu^+\mu^-)K^+)}{\mathcal{B}(B^+\to J/\psi(\to\mu^+\mu^-)K^+)} / \frac{\mathcal{B}(B^+\to\psi(2S)(\to e^+e^-)K^+)}{\mathcal{B}(B^+\to J/\psi(\to e^+e^-)K^+)}$ are computed and found to be compatible with unity, and the flatness for $r_{J/\psi}$ against several kinematic variables is tested. The final result, $R(K) = 0.846^{+0.060+0.016}_{-0.054-0.014}$ [11], where the first uncertainty is statistical and the second systematic, is compatible with the SM expectation at 2.5σ level [8]. Results from LHCb, Belle [12, 13] and BaBar [14] are shown in Fig. 2 in bins of q^2.

2.2.2 Measurement of $\mathbf{R(pK)^{-1}}$

This measurement is the first test of LFU using b baryons, which are abundantly produced at LHC. It is performed using the full LHCb Run 1 dataset and part of the Run 2 (2016) dataset in the

q^2 range $0.1 < q^2 < 6.0 GeV^2/c^4$ and the pK^- mass range $m(pK^-) < 2600 MeV/c^2$. The result, $R^{-1}_{pK} = 1.17^{+0.18}_{-0.16} \pm 0.17$ [15], where the first uncertainty is statistical and the second systematic, is compatible with unity within 1σ and constitutes an independent test of the SM [16].

3. LFV searches

3.1 $\mathbf{B^+ \to K^+ \mu^\pm e^\mp}$

The strategy followed in this analysis that uses the full LHCb Run 1 dataset includes $B^+ \to K^+ J/\psi(\to \mu^+\mu^-)$ and $B^+ \to K^+ J/\psi(\to e^+e^-)$ as normalization and control channels, respectively. No significant excess is found in the signal region, and upper limits are set using CL_s method: $\mathcal{B}(B^+ \to K^+\mu^- e^+) < 7.0(9.5) \times 10^{-9}$ and $\mathcal{B}(B^+ \to K^+\mu^- e^+) < 6.4(8.8) \times 10^{-9}$ at 90(95)% CL [17], which improves the previous limit [18] by more than one order of magnitude.

3.2 $\mathbf{B^+ \to K^+ \mu^- \tau^-}$

The full LHCb dataset is used for this search, where the B^+ originates from the $B^{*0}_{s2} \to B^+ K^-$ decays and the taus are reconstructed inclusively, primarily via decays with a single charged particle. No excess is observed in the signal region. The world-best upper limit is found to be $\mathcal{B}(B^+ \to K^+\mu^-\tau^-) < 3.9(4.5) \times 10^{-9}$ at 90(95)% CL [19].

3.3 $\mathbf{B^0_{(s)} \to e^\pm \mu^\mp}$

For this analysis, a simultaneous invariant-mass fit is performed in 2 bremsstrahlung categories and 7 Boosted Decision Tree bins, using data collected by the LHCb collaboration during Run 1. The observed yields are found to be consistent with the background-only hypothesis. The strongest limits for these two channels are determined to be $\mathcal{B}(B^0_s \to e^\pm\mu^\mp) < 5.4(6.3) \times 10^{-9}$ and $\mathcal{B}(B^0 \to e^\pm\mu^\mp) < 1.0(1.3) \times 10^{-9}$ at 90(95)% CL [20], where the former assumes an amplitude completely dominated by the heavy eigenstate.

3.4 $\mathbf{B^0_{(s)} \to \tau^\pm \mu^\mp}$

The taus from the final state in this search with Run 1 LHCb data are reconstructed hadronically, using two intermediate resonances to help isolate signal from background. In the absence of signal, the most stringent limit is set of $\mathcal{B}(B^0 \to \tau^\pm\mu^\mp) < 1.2(1.4) \times 10^{-5}$ at 90(95)% CL, and a first limit of $B^0_s \to \tau^\pm\mu^\mp$ is set to $\mathcal{B}(B^0_s \to \tau^\pm\mu^\mp) < 3.4(3.5) \times 10^{-5}$ at 90(95)% CL [21].

4. Conclusions and outlook

LFU tests and LFV searches represent theoretically clean probes for physics beyond the Standard Model and they can help explaining the anomalies measured by LHCb, BaBar and Belle. Recent results from LHCb have been presented. More statistics is needed in order to disentangle possible BSM contributions. The forthcoming measurements from LHCb (including Run 2 updates and new channels) and Belle II, as well as data that will be collected during the LHCb Upgrade, will help to further clarify the current situation.

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References

[1] B. J. Rebel [MINOS], Nucl. Phys. B Proc. Suppl. **168** (2007), 195-198 doi:10.1016/j.nuclphysbps.2007.02.014 [arXiv:hep-ex/0701049 [hep-ex]].

[2] M. Bordone, C. Cornella, J. Fuentes-Martin and G. Isidori, Phys. Lett. B **779** (2018), 317-323 doi:10.1016/j.physletb.2018.02.011 [arXiv:1712.01368 [hep-ph]].

[3] A. Celis, J. Fuentes-Martin, M. Jung and H. Serodio, Phys. Rev. D **92** (2015) no.1, 015007 doi:10.1103/PhysRevD.92.015007 [arXiv:1505.03079 [hep-ph]].

[4] R. Aaij *et al.* [LHCb], Phys. Rev. D **97** (2018) no.7, 072013 doi:10.1103/PhysRevD.97.072013 [arXiv:1711.02505 [hep-ex]].

[5] R. Aaij *et al.* [LHCb], Phys. Rev. Lett. **115** (2015) no.11, 111803 doi:10.1103/PhysRevLett.115.111803 [arXiv:1506.08614 [hep-ex]].

[6] S. Fajfer, J. F. Kamenik and I. Nisandzic, Phys. Rev. D **85** (2012), 094025 doi:10.1103/PhysRevD.85.094025 [arXiv:1203.2654 [hep-ph]].

[7] Y. S. Amhis *et al.* [HFLAV], [arXiv:1909.12524 [hep-ex]], updated results and plots available at `https://hflav.web.cern.ch`.

[8] M. Bordone, G. Isidori and A. Pattori, Eur. Phys. J. C **76** (2016) no.8, 440 doi:10.1140/epjc/s10052-016-4274-7 [arXiv:1605.07633 [hep-ph]].

[9] P.A. Zyla et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01 (2020).

[10] R. Aaij *et al.* [LHCb], Phys. Rev. Lett. **113** (2014), 151601 doi:10.1103/PhysRevLett.113.151601 [arXiv:1406.6482 [hep-ex]].

[11] R. Aaij *et al.* [LHCb], Phys. Rev. Lett. **122** (2019) no.19, 191801 doi:10.1103/PhysRevLett.122.191801 [arXiv:1903.09252 [hep-ex]].

[12] J. T. Wei *et al.* [Belle], Phys. Rev. Lett. **103** (2009), 171801 doi:10.1103/PhysRevLett.103.171801 [arXiv:0904.0770 [hep-ex]].

[13] A. Abdesselam *et al.* [Belle], [arXiv:1908.01848 [hep-ex]].

[14] J. P. Lees *et al.* [BaBar], Phys. Rev. D **86** (2012), 032012 doi:10.1103/PhysRevD.86.032012 [arXiv:1204.3933 [hep-ex]].

[15] R. Aaij *et al.* [LHCb], JHEP **05** (2020), 040 doi:10.1007/JHEP05(2020)040 [arXiv:1912.08139 [hep-ex]].

[16] J. Fuentes-Martín, G. Isidori, J. Pagès and K. Yamamoto, Phys. Lett. B **800** (2020), 135080 doi:10.1016/j.physletb.2019.135080 [arXiv:1909.02519 [hep-ph]].

[17] R. Aaij *et al.* [LHCb], Phys. Rev. Lett. **123** (2019) no.24, 241802 doi:10.1103/PhysRevLett.123.241802 [arXiv:1909.01010 [hep-ex]].

[18] B. Aubert *et al.* [BaBar], Phys. Rev. D **73** (2006), 092001 doi:10.1103/PhysRevD.73.092001 [arXiv:hep-ex/0604007 [hep-ex]].

[19] R. Aaij *et al.* [LHCb], JHEP **06** (2020), 129 doi:10.1007/JHEP06(2020)129 [arXiv:2003.04352 [hep-ex]].

[20] R. Aaij *et al.* [LHCb], JHEP **03** (2018), 078 doi:10.1007/JHEP03(2018)078 [arXiv:1710.04111 [hep-ex]].

[21] R. Aaij *et al.* [LHCb], Phys. Rev. Lett. **123** (2019) no.21, 211801 doi:10.1103/PhysRevLett.123.211801 [arXiv:1905.06614 [hep-ex]].