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Tests of lepton flavour universality in $b \to c\ell\nu$ decays with $\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu$ at the LHCb experiment

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Summary. — The combination of lepton flavour universality measurements carried out in $b \to c\ell\nu$ decays has shown possible hints of deviation with respect to the Standard Model. The LHCb experiment contributed to the combination with analyses of semi-tauonic decays with both leptonic and hadronic decays of the τ lepton. This document reports tests of lepton flavour universality in semileptonic b-meson decays performed by the LHCb experiment using the muonic τ decay channel.

1. – Introduction

In the Standard Model (SM) of particle physics the coupling of the electroweak gauge bosons to the leptons is independent of the lepton flavour. This property is also known as lepton flavour universality (LFU). Any observation of LFU violation can be a clear sign of physics beyond the SM. Semileptonic b-meson decays represent an ideal test bench for the LFU hypothesis since $\mathcal{O}(10\%)$ of b-mesons decay semileptonically and thanks to a relatively simple description in the SM of these tree level processes. In the SM, any discrepancy between decays to different leptons originates only from phase space differences. Natural variables to test the LFU hypothesis are, therefore, ratios of branching fractions, such as $\mathcal{R}(H_c) = \frac{\mathcal{B}(B \to H_c \tau \nu_\tau)}{\mathcal{B}(B \to H_c \mu \nu_\mu)}$.

A tension at the level of 3σ [1] with respect to the SM predictions is observed in the combination of the measurements of $\mathcal{R}(D)$ and $\mathcal{R}(D^*)$ performed by the Belle, BaBar and LHCb Collaborations. The LHCb experiment contributed to this combination with two measurements of the $\mathcal{R}(D^*)$ parameter using the dataset collected during the RunI (2011–2012), corresponding to an integrated luminosity of $3\,\text{fb}^{-1}$. The measurements were carried out, respectively, in the $\tau \to \mu\nu\nu$ and $\tau \to 3\pi(\pi^0)$ channels. The LHCb Collaboration also reported a measurement of $\mathcal{R}(J/\psi)$ in the muonic decay channel of the τ lepton.

(*) On behalf of the LHCb Collaboration.

2. – Measurement of $\mathcal{R}(D^*)$ with $\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu$

The measurement is performed by means of a maximum likelihood binned fit in variables that separate the signal ($B \to D^* \tau\nu$), normalization ($B \to D^* \mu\nu$) and background contributions: the squared missing mass, the invariant squared mass of the leptonic system and the energy of the lepton in the B meson rest frame.

In this measurement [2], in order to reconstruct an approximated B rest frame, it is assumed that the boost of the B meson and the one of the visible ($D^*\mu$) system are equal along the beam axis direction. The resolution obtained on the fit variables under this assumption, of ∼20% in both the signal and the normalization channels, is enough to separate the tauonic from the muonic contribution. The physical backgrounds are suppressed using selections on the response of a Boosted Decision Tree (BDT) that assigns a probability to each track in the event which has not been associated to the B decay vertex, of coming from the B decay. The value measured is $\mathcal{R}(D^*) = 0.336 \pm 0.027(\text{stat.}) \pm 0.030(\text{syst.})$ [2], with a tension with respect to the SM prediction at the level of 2.1σ.

3. – Measurement of $\mathcal{R}(J/\psi)$ with $\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu$

The $B_c \to J/\psi \ell \nu$ decay is not accessible to the B-factories which take data at the centre-of-mass energy of the Υ_{4S}. This channel has been used by the LHCb Collaboration to perform the measurement of $\mathcal{R}(J/\psi)$ [3], using $J/\psi \to \mu^+\mu^-$ decays. Signal and normalization modes, which have the same ($\mu\mu\mu$) final state, are separated using a fit to the same variables as the $\mathcal{R}(D^*)$ measurement and the B_c lifetime, reconstructed in the aforementioned approximated rest frame.

The main systematic uncertainty comes from the poor knowledge of the $B_c \to J/\psi\mu\nu$ form factors, for which no precise lattice QCD calculation has been performed yet. The analysis reported a value of $\mathcal{R}(J/\psi) = 0.71 \pm 0.017(\text{stat.}) \pm 0.018(\text{syst.})$ [3], with a discrepancy at the level of 2σ with respect to the SM predictions and resulted in the first observation of the $B_c \to J/\psi\tau\nu$ decay with a significance of 3σ.

4. – Future analyses

New analyses are under way to test the LFU hypothesis using $b \to c\ell\nu$ decays in both the muonic and hadronic τ decay channels. A promising measurement is the one of the $\mathcal{R}(\Lambda_c)$ parameter with $\Lambda_b \to \Lambda_c \ell\nu$ decays, which is accessible only at hadron colliders and could probe NP models with a different tensorial structure. The dataset collected in the RunII (2015–2018) altogether with the data that will be collected with the LHCb upgrade detector [4], will help to reduce the statistical and many systematics uncertainties, reaching a sensitivity of the order of few percents in many $\mathcal{R}$ ratio measurements [5].

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