IL NUOVO CIMENTO **43 C** (2020) 75
DOI 10.1393/ncc/i2020-20075-6

Colloquia: IFAE 2019

Lepton Flavour Universality tests in the decay channel $B^0 \rightarrow D^{*-} \tau^+\nu_\tau$ with $\tau^+ \rightarrow \pi^+\pi^-\pi^+\bar{\nu_\tau}$ at LHCb

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received 8 June 2020

Summary. — This document reports the first measurement of $B^0 \rightarrow D^{*-} \tau^+\nu_\tau$ branching fraction performed by the LHCb Collaboration considering semileptonic b-hadron decays with the τ lepton reconstructed with three charged pions in the final state. The impact of such measurement on the current tests of lepton flavour universality is discussed.

1. – Introduction

The Standard Model (SM) of particle physics assumes that the couplings between leptons and the electroweak gauge bosons are independent of the lepton flavour up to a correction due to the mass. This property is known as Lepton Flavour Universality (LFU). Any deviation from the LFU can be considered as a hint of new physics (NP). Ideal laboratories to test the LFU are the b-hadron semileptonic decays that are charged current processes mediated by a $W^\pm$ boson. These tree-level processes have branching fractions of the order of a few percent and are theoretically well described by the SM. In particular, the so-called semi-tauonic $b \rightarrow c\tau\nu$ transition could receive enhanced NP contributions due to its large τ mass. To test the LFU the ratio of branching fractions $\mathcal{R}(D^*) = \mathcal{B}(B^0 \rightarrow D^{*-}\tau^+\nu_\tau)/\mathcal{B}(B^0 \rightarrow D^{*-}\mu^+\nu_\mu)$ is considered, for both the muonic $\tau^+ \rightarrow \mu^+\nu_\mu\bar{\nu_\tau}$ and $\tau^+ \rightarrow \pi^+\pi^+\pi^-\bar{\nu_\tau}$ decay modes. The ratio allows to cancel the theoretical uncertainties related to the form factors, to remove the dependence on the CKM matrix element $|V_{cb}|$, and to reduce the experimental uncertainties. The SM foresees the value of this ratio to be $\mathcal{R}(D^*) = 0.258 \pm 0.005$ [1] and deviates from the unity due to the different lepton masses. Exploiting the abundance of the b-hadron produced in the LHCb [2] environment and the features of the detector, that allow to reconstruct the b-hadron decay vertex with high precision and to perform particle identification [3], the first measurement of $\mathcal{R}(D^*)$ considering the $\tau^+ \rightarrow \pi^+\pi^-\pi^+\bar{\nu_\tau}$ final state has been performed [4].

2. – Measurement of $R(D^*)$

The first measurement of $R(D^*)$ with three charged pions in the final state of the τ decay has been published by LHCb in 2017 [4], using the Run 1 dataset, corresponding to an integrated luminosity of $3\,\mathrm{fb}^{-1}$. In this decay, the reconstruction of the τ decay vertex is possible and allows to highly suppress the main background contamination. The presence of the neutrinos in the final state prevents the full reconstruction of the B^0 kinematics, and approximations to determine the τ and the B^0 momenta are needed. In order to reduce systematic effects the ratio $\mathcal{K}(D^*) = \mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\tau)/\mathcal{B}(B^0 \to D^{*-}\pi^+\pi^-\pi^+)$ has been measured, where a normalization channel with the same visible final state as the signal channel has been used. The main background source due to the inclusive b-hadron decays into c-hadron and three charged pions, $B^0 \to D^{*-}\pi^+\pi^-\pi^+(X)$, is reduced requiring a displacement between the B^0 and τ decay vertices ($\Delta z > 4\sigma_{\Delta z}$). The second largest background, the so-called doubly charmed decays, $B^0 \to D^{*-}H_c$, where $H_c = D^+, D^0, D_s^+$, is rejected using a multivariate analysis (Boosted Decision Tree, BDT), which exploits the differences in the dynamics of the final state generated by the decay of the H_c meson with respect to that of the τ lepton. The signal yield is obtained performing a 3-dimensional fit to the distributions of the squared four-momentum transfer to the lepton system, the reconstructed τ decay time, and the output of the BDT. The yield of the normalization channel is obtained from an unbinned fit to the invariant mass of the $D^{*-}\pi^+\pi^-\pi^+$ system reconstructed as similarly as possible to the signal. The ratio $\mathcal{R}(D^*)$ is then obtained multiplying $\mathcal{K}(D^*)$ by the ratio of the known measurements of $\mathcal{B}(B^0 \to D^{*-}\pi^+\pi^-\pi^+)$ and $\mathcal{B}(B^0 \to D^{*-}\mu^+\nu_\mu)$ [1]. The measured value of $\mathcal{R}(D^*)$ is $0.280 \pm 0.018(\mathrm{stat.}) \pm 0.029(\mathrm{syst.})$, in agreement with the SM prediction within 1σ, and is consistent with the previous measurements [1].

3. – Conclusions and future developments

The combination of the measurements of $\mathcal{R}(D^*)$, performed exploiting both the hadronic and the muonic τ decay channels, with the measurements of $\mathcal{R}(D)$ by the BaBar, Belle and LHCb Collaborations is above the SM prediction of 3.07σ [1]. New measurements of $\mathcal{R}(D^*)$ are expected from the analysis of the data collected by the LHCb during the Run 2, with 4-fold increased statistics. Complementary tests of LFU using additional b-hadron decays that can be studied at LHC, including for example B_c and Λ_b, are also foreseen to be measured by the LHCb experiment.

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