Summary. — Lepton universality violation would represent a signal of physics beyond the Standard Model. Semileptonic decays of beauty mesons in third-generation leptons are particularly interesting, since anomalies have been observed in the measurement of their Branching Ratios. This contribution reports on the measurements of the observable $R(D^*) = \frac{B(B^0 \rightarrow D^{*-}\tau^+\nu_{\tau})}{B(B^0 \rightarrow D^{*-}\mu^+\nu_{\mu})}$ performed at LHCb using both leptonic and hadronic decay channels of the \(\tau\) lepton.

1. – Introduction

In the Standard Model (SM) of particle physics the electroweak couplings of the gauge bosons to the leptons are independent of their flavour, a property known as lepton universality (LU), so the observation of LU violation would be a clear signal of physics processes beyond the SM.

The branching fractions ratio

\[
R(D^{(*)}) = \frac{B(B^0 \rightarrow D^{(*)}\tau^+\nu_{\tau})}{B(B^0 \rightarrow D^{(*)}\mu^+\nu_{\mu})}
\]

represents a sensitive probe for LU violation.

The combination of the measurements of $R(D^{(*)})$ already performed by BaBar [1], Belle [2-4] and LHCb [5] Collaborations shows a discrepancy of about 4\(\sigma\) with respect to the values of $R(D^{(*)})$ calculated within the SM [6]. All of these measurement have been performed reconstructing the \(\tau\) lepton through the leptonic decay $\tau^+ \rightarrow \mu^+\nu_{\mu}\bar{\nu}_{\tau}$ \(^{(1)}\).

\(^{(1)}\) Charge conjugated decay modes are implied throughout the document.
2. - Measurement with the $\tau^+ \to \pi^+ \pi^- \pi^+(\pi^0)\nu_\tau$ channel

In LHCb a measurement of $R(D^*)$ using the hadronic $\tau$ decay has been performed. The signal chosen for this analysis is $B^0 \to D^{*-} \tau^+ \nu_\tau$, where the $D^{*-}$ is reconstructed through the $D^{*-} \to D^0(\to K^+\pi^-)\pi^-$ decay chain, while the $\tau$ lepton is reconstructed through the $\tau^+ \to \pi^+ \pi^- \pi^+(\pi^0)\nu_\tau$ decay. The chosen normalization channel is $B^0 \to D^{*-} \pi^- \pi^- \pi^+$, because most of the systematic uncertainties cancel out in the efficiency ratio, since signal and normalization have the same final state.

The most dominant background consists of inclusive decays of $b$-hadrons to $D^{*3}\pi X$, where the three pions come promptly from the $b$-hadron decay vertex. Since the $\tau$ decay vertex is reconstructed with good resolution, it is possible to suppress this kind of background requiring the $\tau$ vertex to be downstream, along the beam direction, with respect to the $B$ vertex with a $4\sigma$ significance.

The background surviving the first selection is mainly due to double-charmed $B$ decays, since their topology is very similar to the signal one. In order to discriminate this background from signal, a set of variables is used: variables computed with two partial reconstruction techniques, one in signal hypothesis and the other in background hypothesis; isolation variables; variables related to the $3\pi$ system dynamics. These variables are used as input to train a boosted decision tree (BDT).

The partial reconstruction in signal hypothesis allows to compute the squared $B \to D^*$ transferred momentum $q^2$ and the $\tau$ decay time with a sufficiently good resolution to maintain separation between signal and background.

Three-dimensional shapes of $q^2$, $\tau$ decay time and BDT output are extracted from simulated and data-driven control samples which represent the various contributions in data. In order to extract the signal yield, the three-dimensional shapes are used to perform an extended maximum-likelihood template fit on data in the high-BDT region.

To select normalization events, the $\tau$ vertex requirement is reversed, i.e., the $\tau$ vertex is required to be upstream with respect to the $D^0$ vertex with a $4\sigma$ significance. The normalization yield is obtained by fitting the $D^{*3}\pi$ invariant mass distribution.

3. - Results

The result of the measurement is

\begin{equation}
R(D^*) = 0.285 \pm 0.019 \text{(stat)} \pm 0.025 \text{(syst)} \pm 0.014 \text{(ext)},
\end{equation}

and has the best statistical precision among all the measurements of $R(D^*)$ performed so far. It is higher than the SM calculation and consistent with it within one standard deviation.

REFERENCES