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b-hadron semileptonic decays with τ leptons in final states in LHCb

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Summary. — Lepton universality, described in the Standard Model, predicts equal coupling between gauge bosons and the three lepton families. SM extensions give additional interactions, implying in some cases a stronger coupling with the third generation of leptons. Semileptonic decays of b-hadrons provide a sensitive probe to such New Physics effects. The presence of additional charged Higgs bosons, required by such SM extensions, can have significant effect on the semileptonic decay rate of $\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$. The combination of experimental measurements give a deviation from the standard model prediction of about $4\,\sigma$. It is therefore important to perform additional measurements in this sector in order to improve the precision and confirm or disprove this deviation. Results obtained by LHCb on $B^0 \to D^{*-}\tau^+\nu_\tau$ decays, where the τ decays leptonically, are reported. The LHCb perspectives with other final states are discussed.

1. – b-hadron semileptonic decays with τ leptons in final states

Semileptonic decays of b-hadrons have been successfully studied at the B factories [1,2] using high purity and high statistics $D^{(*)}\tau\nu$ samples. Despite the hadronic environment, thanks to the high boost of the b-hadrons produced and the excellent vertexing capabilities, LHCb is also able to study such kind of decays and extend to other b-hadrons. However, several challenges must be dealt with: the reconstruction of the decay kinematics, in order to distinguish between signal and background, the suppression of the background due to additional charged and/or neutral particles, and the identification of a suitable normalization channel. These challenges have different levels of importance and difficulty, and different solutions have to be identified, depending on the final state under consideration, *e.g.* whether the τ decays leptonically or hadronically.

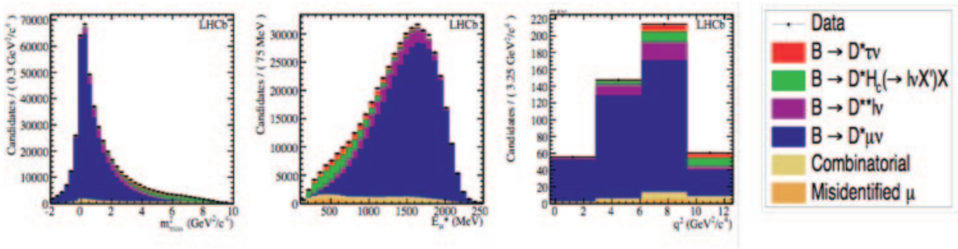

Fig. 1. – 3D binned likelihood fit results with the various components in the missing mass, $m^2_{\rm miss}$, the squared invariant mass of the lepton pairs, q^2 and the energy of the muon in the B rest frame, E_μ, for $B \to D^*\tau\nu(\tau \to \mu\nu\nu)$ analysis.

2. – $\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$ with $\tau^- \to \mu^-\nu_\tau\bar{\nu}_\mu$

In signal $B \to D^*\tau\nu(\tau \to \mu\nu\nu)$ decays there are three missing neutrinos. Due to the high boost of the B meson, its flight direction is well known and the magnitude of the B momentum can be determinated by approximating its boost along the beam direction with the one of the $D^*\mu$ system. In this way, it is possible to compute other kinematic variables of the decay such as the missing mass $m^2_{\rm miss} = (p_B - p_{D^{*-}} - p_\mu)$, the squared invariant mass of the lepton pair $q^2 = (p_B - p_{D^{*-}})$, and the energy of the muon E_μ in the B rest frame. The normalization channel is $B \to D^*\mu\nu_\mu$. Sources of background are due to charmed meson decaying in leptons, feed-down of $D^{**}l\nu$ decays, combinatorial background and mis-identified muons. The obtained distributions show a broadening, but the discrimination power between signal and normalization channel is preserved. A Binned Likelihood fit using 3D templates ($m^2_{\rm miss}$, q^2 and E_μ) has been performed. The fit projections are shown in fig. 1. The templates for signal and normalization are extracted from Monte Carlo simulation, templates for backgrounds are validated using control samples in data and the form factors (from HQET) for signal and normalization channel are included as external constraints.

The following result is obtained on the full Run1 dataset, corresponding to an integrated luminosity of 3 fb^{-1} [3]: $R(D^*) = \frac{\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu)} = 0.336 \pm 0.027(stat) \pm 0.030(syst)$ where the systematic uncertainties are dominated by the Monte Carlo statistics and the background due to mis-identified muons. The combination of the LHCb measurement with the previous ones performed by BaBar and Belle [1, 2] gives a deviation of 3.9σ with the Standard Model prediction.

3. – $\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$ with $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ and prospects for other final states

Another way to measure $R(D^*)$ is by using the hadronic $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ decay channel. Thanks to the three charged particles in the final state, it is possible to reconstruct the τ decay vertex with a good precision. This allows to separate signal from the most abundant background due to hadronic B decays in final states containing D^* and three pions. Requiring the vertex of the three pions is sufficiently downstream with respect to be 5 standard deviations downstream with respect to the D^0 vertex, it is possible to reduce the background due to $B \to D^*3\pi X$ decays by a factor 10^4. The remaining background is due to B decays where the 3π vertex is significantly displaced from the B vertex, such as $B \to D^*D^{(*)}_{(s)}(\to 3\pi X)$. Such background can be suppressed by

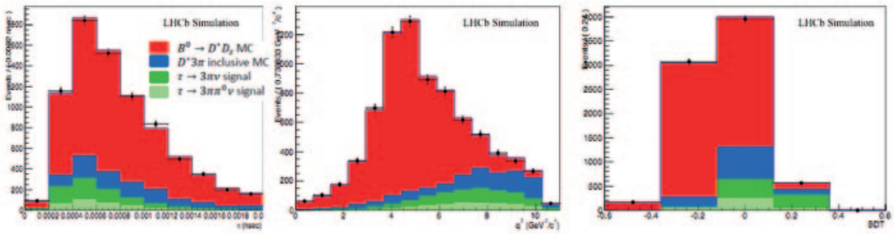

Fig. 2. – 3D binned likelihood fit in the τ decay time, the squared invariant mass of the lepton pairs q^2 and the result of the output of a boosted decision tree. The different fit components are shown in different colors.

using a multivariate approach based on partial reconstruction techniques and charged and neutral particles vetoes in a cone of a given size around the signal candidate.

A feasibility study has been performed on a simulated sample containing signal and background in the expected proportions, corresponding to 2 fb^{-1} of equivalent luminosity. A 3D Binned likelihood fit shown in fig. 2, has been performed in the τ decay time, the squared invariant mass of the lepton pairs q^2 and the result of the output of a boosted decision tree. The signal yield is determinated with a 5% statistical precision.

Furthermore LHCb can potentially measure semi-tauonic decays of all b-hadrons, *e.g.*, $B_c \to J/\psi \tau \nu$, $B_s \to D_s \tau \nu$, $\Lambda_b \to \Lambda_c^{(*)} \tau \nu$, $B^0 \to D^+ \tau \nu$, using both hadronic and muonic channel of the τ.

4. – Conclusions

Despite initial expectations, LHCb has an extremely good potential in measuring semileptonic b-hadrons decays with τ leptons in the final state. A measurement of $R(D^*)$ has been performed using muonic τ decays. The combination of $R(D^*)$ and $R(D)$ from Belle, BaBar and LHCb provide a 3.9σ deviation from the standard model values. A measurement of $R(D^*)$ by using adronic τ decays in three charged particles is ongoing. The expected result will give a precision on $R(D^*)$ comparable to the current world average.

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