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On the anomalies recently discovered in semileptonic B decays to the third family

P. Biancofiore
Università di Bari e INFN, Sezione di Bari - Bari, Italy

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Summary. — The ratios $\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(B\to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(B\to D^{(*)}\mu\bar{\nu}_\mu)}$ measured by BABAR Collaboration deviate from the standard model expectations; at the same time the purely leptonic channel $B \to \tau\bar{\nu}_\tau$, has been found in better consistency with the standard model. We provide an attempt to reconcile these two experimental facts, within a New Physics Scenario, by adding a tensor operator in the effective weak Hamiltonian. We calculate the effects of such an operator in a set of observables, in semileptonic $B \to D^{(*)}$ modes as well as in semileptonic B and B_s decays to excited positive parity charmed mesons.

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The BABAR measurements of the rates of B^- and $\bar{B}^0$ semileptonic decays into $D^{(*)}$ and a τ lepton significantly deviate from the standard model (SM) expectation. The experimental results for the $B \to D^{(*)}\tau\bar{\nu}_\tau$ decay widths normalized to the widths of the corresponding modes having a light $\ell = e$, μ lepton in the final state are [1]: $\mathcal{R}^-(D) = \frac{\mathcal{B}(B^-\to D^0\tau^-\bar{\nu}_\tau)}{\mathcal{B}(B^-\to D^0\ell^-\bar{\nu}_\ell)} = 0.429 \pm 0.082 \pm 0.052$, $\mathcal{R}^-(D^*) = \frac{\mathcal{B}(B^-\to D^{*0}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(B^-\to D^{*0}\ell^-\bar{\nu}_\ell)} = 0.322 \pm 0.032 \pm 0.022$, $\mathcal{R}^-(D) = \frac{\mathcal{B}(B^-\to D^0\tau^-\bar{\nu}_\tau)}{\mathcal{B}(B^-\to D^0\ell^-\bar{\nu}_\ell)} = 0.429 \pm 0.082 \pm 0.052$ and $\mathcal{R}^0(D^*) = \frac{\mathcal{B}(\bar{B}^0\to D^{*+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0\to D^{*+}\ell^-\bar{\nu}_\ell)} = 0.355 \pm 0.039 \pm 0.021$ (where the first and second error are the statistic and systematic uncertainty, respectively). The measurements have been estimated to deviate at the global level of 3.4σ with respect to SM predictions [1, 2]. The hadronic matrix elements in $B \to D^{(*)}\ell\bar{\nu}_\ell$ depend on several hadronic form factors, which in the infinite heavy quark mass limit, formalized by the heavy quark effective theory (HQET), can all be related to the Isgur-Wise function ξ [3]. Howevever it is also important to stress that, taking into account the radiative and mass corrections respectively at order α_s and $1/m_b$ in the form factors (worked out by Caprini *et al.* in [4]), the tension with the experimental data still survives.

Several analyses tried to explain the anomaly within a New Physics scenario in which new scalars couple to leptons proportionately to the lepton mass, to guarantee the enhancement of the τ modes. This is what happens in models with two Higgs doublets

(2HDM), however the simplest of such scenarios has been ruled out by the BABAR Fit [1]. Other variants of the 2HDM together with other models providing explicit flavor violation, might explain the measurements; nevertheless, an enhancement of the purely leptonic B decay rate is generally implied, an occurrence that recent new Belle [5] and BABAR [6] data seem to exclude.

In order to provide an explanation of the observed enhancement in the semileptonic channels $B \to D^{(*)}$ with a τ lepton in the final state, avoiding at the same time an effect in the purely leptonic channel, we consider the following effective Hamiltonian [7]:

$$(1) \qquad H_{eff} = \frac{G_F}{\sqrt{2}} V_{cb} \left[\bar{c}\gamma_\mu(1-\gamma_5)b\, \bar{\ell}\gamma^\mu(1-\gamma_5)\bar{\nu}_\ell + \epsilon_T^\ell\, \bar{c}\sigma_{\mu\nu}(1-\gamma_5)b\, \bar{\ell}\sigma^{\mu\nu}(1-\gamma_5)\bar{\nu}_\ell \right],$$

where a new tensorial effective operator has been added; such an operator could naturally emerge in models with leptoquarks (moreover we assume that the main coupling is to the heaviest lepton). It is also worth investigating those observables which can provide signatures for a deviation with respect to the SM, since they are affected by the new operator. By parameterizing the effective coupling as $\epsilon_T = |a_T|e^{i\theta} + \epsilon_{T_0}$, we are able to constrain from the experimental data the allowed region of variability of ϵ_T on the complex plain, which reads: $\mathrm{Re}[\epsilon_{T_0}] = 0.17$, $\mathrm{Im}[\epsilon_{T_0}] = 0$, $|a_T| \in [0.24,\, 0.27]$ and $\theta \in [2.6,\, 3.7]\,\mathrm{rad}$. Allowing the ϵ_T to vary in this range, we calculate the differential decay widths for both the channels $B \to D^{(*)}\tau\bar{\nu}_\tau$. We observe no deviations in the normalized distributions with respect to SM as the BABAR Collaboration found [8]. Another important observable is the forward-backward $\mathcal{A}_{FB}(q^2)$ asymmetry, defined as: $\mathcal{A}_{FB}(q^2) = [\int_0^1 \mathrm{d}\cos\theta_\ell \frac{\mathrm{d}\Gamma}{dq^2 \mathrm{d}\cos\theta_\ell} - \int_{-1}^0 \mathrm{d}\cos\theta_\ell \frac{\mathrm{d}\Gamma}{dq^2 \mathrm{d}\cos\theta_\ell}] / \frac{\mathrm{d}\Gamma}{\mathrm{d}q^2}$. While in the $B \to D$ channel we observe no significantly deviation in the shape of the distribution with respect to SM, in the $B \to D^*$ channel we obtain a sizable shift of the zero of the distribution (at $q^2 \approx 8.7\,\mathrm{GeV}^2$) with respect to that of the SM (at $q^2 \approx 6.2\,\mathrm{GeV}^2$). In order to get more predictive our model, we investigate also the phenomenology of those exclusive semileptonic B and B_s transitions into excited charmed mesons, which can be affected by the new structure in the effective Hamiltonian. The lightest multiplet of such hadrons considered in our analysis corresponds to the the quark-model p-wave ($\ell = 1$) mesons, and it is generically denoted $D^{**}_{(s)}$ comprising four positive parity states which, in the heavy-quark limit, belong to two spin doublets $[D^*_{(s)0},\, D'_{(s)1}]$ and $[D_{(s)1},\, D^*_{(s)2}]$. We find that the tensor operator produces a sizable increase in the ratios $\mathcal{R}(D^{**}_{(s)})$, which is correlated for the two members in each doublet. Moreover, the hadronic uncertainty is mild.

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