

**Abstract.** We review some recent measurements of $B$ meson decays that involve leptons in the final states and that are sensitive to physics beyond the Standard Model, such as the electroweak penguin decays $B \rightarrow X_s \ell^+ \ell^-$, the Lepton Number Violating process $B \rightarrow X \ell^\pm \ell'^\pm$ and the tree-level dominated decay with $\tau$ leptons: $B \rightarrow \tau \nu\tau$ and $B \rightarrow D^{(*)}\tau\nu\tau$.

1 Introduction

The BaBar experiment has collected about $470\times10^6$ couple of $B\bar{B}$ events from the $\Upsilon(4S)$ decays. This huge sample allowed to perform stringent studies on $B$ meson properties and successfully confirmed the Standard Model (SM) predictions in the flavour sector. Although no relevant deviations from the SM have yet been found with the current statistics by BaBar and Belle, it is of paramount importance to continue to search for New Physics (NP) sign through indirect virtual contributions in the $B$ decays.

Here we present some recent result from BaBar on $B$ meson decays in channels with leptons in the final state. All the results presented are based on the full available dataset.

2 Inclusive $B \rightarrow X_s \ell^+ \ell^-$ decays

The process $b \rightarrow s \ell^+ \ell^-$, where $b$ is a bottom quark, $s$ is a strange quark, and $\ell^+ \ell^-$ is an $e^+e^-$ or $\mu^+\mu^-$ pair, is a FCNC process forbidden at lowest order in the Standard Model but is allowed via EW penguin and W-box diagrams. The amplitude for this decays is expressed in terms of perturbatively calculable effective Wilson coefficients. The non-SM contributions can modify the Wilson coefficients from the SM expectations. The exclusive channels $B \rightarrow K\ell^+\ell^-$ and $B \rightarrow K^*\ell^+\ell^-$ are currently extensively studied at B-Factories and LHCb. The study of the inclusive channel, where one does not look in a specific final state, is complementary to the exclusive studies.

Here we report a recent BaBar measurement [2] of the $B \rightarrow X_s \ell^+ \ell^-$ decay, using a sum over exclusive final states, which provides a basis for an extrapolation to the fully inclusive rate. We measure the total Branching Fraction (BF) as well as partial BF in five bins of $q^2 \equiv m_{\ell^+\ell^-}^2$. The $X_s$ states are reconstructed in 10 separate $X_s$ hadronic final states ($K^+, K^+\pi^0$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+$, $K^0_s$, $K^0_s\pi^0$, $K^0_s\pi^+$, $K^0_s\pi^-\pi^0$ and $K^0_s\pi^-\pi^+$), combining these with $e^+e^-$ and $\mu^+\mu^-$ pairs. We limit the number of pions in the final state to two and require $m_{X_s} < 1.8$ GeV/$c^2$ since the expected $S/N$ ratio decrease very rapidly with the mass and the $X_s$ pion multiplicity. The reconstructed states, taking into account

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the presence of the $K_L$ and the $K_s \to \pi^0\pi^0$, represent about 70% of the total inclusive rate. We suppress the $e^+e^- \to q\bar{q}$ events (where $q = u, d, s, c$ quark) and $B\bar{B}$ combinatoric background using Boosted Decision Trees (BDTs) exploiting many kinematical and topological quantities. In each $q^2$ bin, we extract the signal yield with a 2-D maximum likelihood fit using the mass of the $B$ meson candidate and a likelihood ratio based on the BDTs used to suppress the $B\bar{B}$ backgrounds. From the extracted signal yields and the efficiencies, we compute the partial $BF$s in each $q^2$ bin. The measured partial $BF$s in the various $q^2$ bins analysed is reported in Fig. 1. The lepton-flavour averaged result for the

$$BF(B \to X, \mu^+\mu^-) = (1.59 \pm 0.11) \cdot 10^{-6}$$

is within $2\sigma$ with the prediction in the region $I$ ($BF(B \to X, \mu^+\mu^-) = (1.60^{+0.44 +0.17}_{-0.39 -0.13} \pm 0.18) \cdot 10^{-6}$) and for $q^2 > 14.4 \text{ GeV}^2/c^4$ (II) is $BF = (0.57_{-0.15}^{+0.16} +0.03 -0.02 \pm 0.00) \cdot 10^{-6}$, where the uncertainties are statistical, systematics and due to the model-dependent extrapolation to the full rates. The measured rate is in very good agreement with the SM predictions. It is interesting to note that the $e^+e^-$ results are systematically higher than the $\mu^+\mu^-$ case, but they are compatible within the experimental uncertainties. It should be noted here that the explanation of the LHCb observation of the anomaly in one of the observables [4], as suggested in [5] would result in a decrease of the inclusive $BF$ of up to about 25% in both the region $I$ and $II$ and this is not compatible with our result.

3 Search for $B \to X\ell^+\ell^-$

The neutrino oscillation suggests that lepton number may not be conserved, moreover the lepton-number violation (LNV) is a necessary condition for leptogenesis as an explanation of the baryon asymmetry of the Universe [7]. Many models beyond the SM predict the LNV in $B$ meson decays with a rate that could be accessible with the present data available [6]. CLEO performed [8] for the first time searches of LNV processes in the $B$ meson decays like $B^+ \to X\ell^+\ell^+$, where $X$ is a charged particle or resonance and $\ell/\bar{\ell} = e$ or $\mu$. Recently LHCb [11], BaBar [10] and Belle [9] reported search for these processes using much higher statistics.

Here we report the recent BaBar search [12] for $B^+ \to X\ell^+\ell^+$ with $X = K^-, \pi^-\rho^-, K^{*-}$ or $D^-$. The huge background is suppressed with a BDT that uses many event-shape and signal kinematic discriminant variables. The signal is extracted from a 3-D unbinned maximum likelihood fit to the BDT output, the $B$ candidate mass, and $dE = E_B^* - E_{c.m.}$, where $E_B^*$ is the energy of the $B$ candidate in the $c.m.$ frame. We find no significant signal yields and place upper limits on the $BF$ in the range $(1.5-26) \cdot 10^{-7}$. These limits are in many cases more stringent than previous best measurements. In Fig. 2 we report a summary of the existing upper limits on a large set of studies $B$-meson LNV processes.
4 \( B \to \tau \nu_\tau \) and \( B \to D^* \tau \nu_\tau \)

The FCNC processes are powerful tools to search for physics beyond the SM, but tree level dominated processes are good as well to constraint important kind of NP. Many extended versions of the SM require changes in the Higgs sector, with the prediction of many Higgs bosons, both neutral and charged. A prototype of these models is the widely studies 2 Higgs-Doublet-Model of type-II, that require changes in the Higgs sector, with the prediction of many Higgs bosons, both neutral and charged.

Figure 2. The upper limits on various \( B \) meson LNV processes obtained by CLEO, Belle, BaBar and LHCb. The most recent upper limits (90% C.L.) on the \( BF \) of various \( B^- \to X^+ \ell^- \) processes obtained by BaBar [12] are in the range \( 1.2 \cdot 10^{-7} \sim 26 \cdot 20^{-7} \) and they are indicated with the filled triangles. For modes with \( \rho, \pi \) and \( K \) the limits are an order of magnitudes more stringent than previous best results [8]. The upper limit for the \( B \to D^* \ell^- \) are compatible with those reported by Belle in Ref. [9].

\( \text{Figure 2.} \)
on $D^0$, $D^+$, $D^{*0}$ and $D^{*+}$ and the results are $R(D) = BF(B \to D \tau \nu)/BF(B \to D \ell (e\ or\ \mu)\nu) = 0.440 \pm 0.058\ (stat) \pm 0.042\ (syst)$ and $R(D^*) = BF(B \to D^* \tau \nu)/BF(B \to D^* \ell (e\ or\ \mu)\nu) = 0.332 \pm 0.024\ (stat) \pm 0.018\ (syst)$ ($B^0$ and $B^+$ isospin constrained results). The measurement of the ratios $R(D)$ and $R(D^*)$ has the advantage that they are experimentally very clean because many systematics cancel in the ratio. Moreover the theoretical predictions in the SM are reliable and affected by a small uncertainties: $R(D) = 0.297 \pm 0.017$ and $R(D) = 0.252 \pm 0.003$ [17]. The BaBar result is compatible with the Belle results obtained with a similar technique [18] and exceed the SM prediction by 3.4σ, if we consider the excess in both the $R^D$ and $R^{D^*}$ ratios. In the 2HDM of type II, there is a substantial impact on the ratios $R(D)$ and $R(D^*)$ due to the $H^+$ contribution. Because the preferred $\tan\beta/m_{H^+}$ regions for $R(D)$ and $R(D^*)$ are not compatible, we are able to put a severe constraint in the $\tan\beta/m_{H^+}$ plane for the 2HDM of type II (Fig. 3), that is so disfavoured at more than 3σ.

The hadronic $B$ tagging technique allows to measure the $B \to \tau \nu$ and $B \to D(\star) \tau \nu$ decays with good precision despite the weak experimental signature. These channels put constraints on $\tan\beta/m_{H^+}$ ratio for the 2HDM that are complementary or stronger than the constraints set by CMS and ATLAS.

![Figure 3](image.png)

**Figure 3.** Constraints in the $\tan\beta - m_{H^+}$ plane in the 2HDM of type II obtained from the BaBar measurement of $R(D^{(*)})$ (left) and from the BaBar and Belle results on $B \to \tau \nu_\tau$ branching fraction (right). The vertical red band is the excluded region of $m_{H^+}$ that comes from $B \to X_s \gamma$ [19]. The BaBar $R(D^{(*)})$ allows to exclude the entire plane at more than 3σ level.

## 5 Conclusions

The decays of $B$ mesons with leptons in the final states are a very powerful probe to search for NP effects due to virtual heavy particles in the tree and loop diagrams. Here we presented some recent BaBar results. NP has not been observed yet, but some interesting tensions are present and these require more studies from both the experimental and theoretical side.

## References