Searches for Leptonic B Decays at *BABAR*

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Measurements of the branching fractions of purely leptonic decays of B-mesons translate into constraints in the plane of the charged Higgs mass versus $\tan\beta$ which are relatively insensitive to the particular theoretical model. Using the full *BABAR* dataset of 450 million B-decays we search for these decays. No significant signal is found in the decays into electrons or muons and we set upper limits on the branching fractions of the order of a 10^{-6} at 90% confidence level. We measure the branching fraction of $B \to \tau\mu$ to be $(1.7 \pm 0.6) \times 10^{-4}$.

1 Theoretical Motivation

In the Standard Model, the purely leptonic decay of a charged B-meson proceeds through the annihilation of the two constituent quarks through a virtual W-Boson. The branching fraction (BF) of this decay can be expressed as follows:

$$\mathcal{B}(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 V_{ub}^2 \tau_B.$$

The dependence of $\mathcal{B}(B \to l\nu)$ on the lepton mass arises from helicity suppression. The ratio between the rates for the lepton species $\tau : \mu : e$ is $\sim 1 : 5 \times 10^{-3} : 10^{-7}$ which makes the τ channel the most abundant. The hadronic uncertainties contained in the decay constant f_B are calculable only in lattice theory and their direct measurement is solely possible through leptonic B-decays.

The $B \to \tau\nu$ decay has also an important impact in model beyond the Standard Model because it allows to constraint parameter of the New Physics. When adding an extended Higgs sector [1] the decay may also proceed via the exchange of a charged Higgs at tree level, so the branching fraction expression becomes

$$\mathcal{B}_{(B \to \tau\nu)} = \mathcal{B}_{SM} \times \left(1 - \frac{m_{B^\pm}^2}{m_{H^\pm}^2} \frac{\tan^2\beta}{(1 + \epsilon_0 \tan\beta)}\right)^2.$$

In the 2HDM type-II scenario without contributions from other SUSY particles, ϵ_0 is one.

2 *BABAR* Datasample and Results

The data used in this analysis were collected with the *BABAR* detector at the PEP-II storage ring at the SLAC National Accelerator Laboratory. We use the full *BABAR* dataset, corresponding to an integrated luminosity of $417.6\,\text{fb}^{-1}$ with center-of-mass (CM) energy equal to the $\Upsilon(4S)$

rest mass. These data contain $(458.9 \pm 5.1) \times 10^6 \, \Upsilon(4S) \to B\overline{B}$ pairs. In the BABAR detector is described in detail elsewhere [2].

$B^{\pm} \to \tau\nu$

While this decay has the highest branching fraction of the purely leptonic B decays, the presence of multiple neutrinos in the final state results in the lack of kinematic constraints for reconstruction of the signal-decay. We overcome this obstacle by fully reconstructing one the two B-decays, called tag B in the following, and subsequently search in the remainder of the event for the signal decay. We reconstruct the tag B two different classes of decays: semileptonic (SL) decays $B \to D^{(*)0}l\nu$ and fully hadronic decays $B \to D^{(*)0}X$, where X is a combination of pions and kaons. The presence of a well reconstructed tag B reduces the background from non-B decays greatly at the price of the tag reconstruction efficiency which is of order of a percent for the SL tag or about 0.2% for the hadronic tag. To further reject continuum events we employ event shape variables using the fact that the B-mesons are produced nearly at rest in the $\Upsilon(4S)$ decay and thus decay isotropically, while the products of other $\Upsilon(4S)$ decays are boosted and lead to di-jet like events. The most important variable for the rejection of both continuum and B-background is the extra energy (E_{extra}), which is the total energy of charged and neutral particles that cannot be directly associated with the reconstructed daughters of the tag B or the signal B. The left plot of Figure 2 shows the final E_{extra} for the hadronic tag samples in data and MC [3].

$B^{\pm} \to l\nu(l = e, \mu)$

The full hadronic reconstruction of one of the B decays determines the signal-B rest frame, allowing to extract the BF of the signal decay via a fit to the lepton momentum which exhibits a peak at 2.65 GeV due to the two-body nature of the signal-B decay. The fit to data is shown in the right plot of Figure 2[5]. The determination of the signal-B rest frame in SL-tagged events has an azimuthal ambiguity which leads to a less distinct peak.In the CM frame, the shapes of the lepton momentum of signal and background events are still different enough to allow for an inclusive analysis in addition to the tagged analyses. Here the less distinct signature is being balanced by the higher statistics avaliable without the tag-requirement and related inefficiency. We combine all particles besides signal candidate lepton into a B candidate and fit its mass and the lepton-momentum in the CM-system simultaneously[4].

The results of the BABAR searches for purely leptonic decays of charged B-mesons are summarized in Table 1.

Analysis method	$B \to e\nu$ 90% CL limit	$B \to \mu\nu$ 90% CL limit	$B \to \tau\nu$ 90% CL limit	$B \to \tau\nu$ central BF in 10^{-4}
Inclusive [4]	1.0×10^{-6}	1.9×10^{-6}	n/a	n/a
Hadronic Reco. [5, 3]	5.6×10^{-6}	5.2×10^{-6}	3.4×10^{-4}	$(1.8^{+0.9}_{-0.8} \pm 0.4 \pm 0.2)$
SL Reco. [6]	11×10^{-6}	8×10^{-6}	2.7×10^{-4}	$(1.7 \pm 0.8 \pm 0.2)$

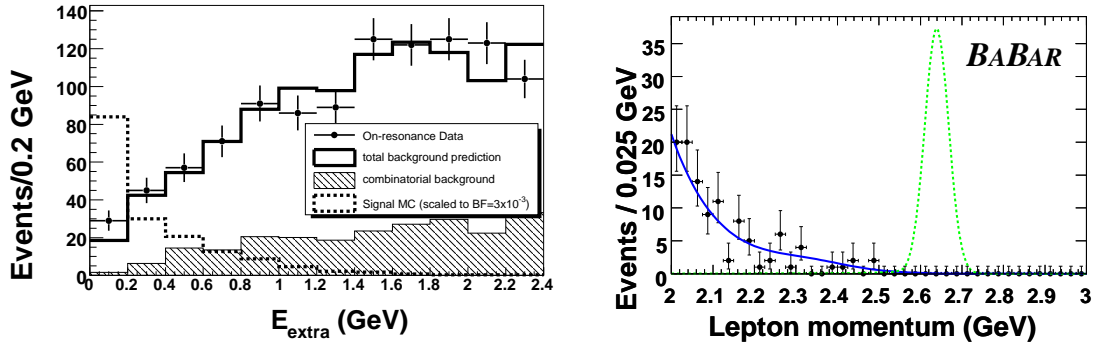Table 1: Results of the BABAR searches for purely leptonic decays of charged B-mesons.

Figure 1: E_{extra} for the hadronic tag $B \to \tau\nu$-samples (left) and the muon momentum (right) in data (dots), signal (dashed line) and background prediction (histograms) (left).

3 Conclusions

The *BABAR* measurements of $\mathcal{B}(B \to \tau\nu)$ have reached a significance of 2.3 or 2.2 σ in for the SL-tag and hadronic tag analyses respectively. The current world average of (1.73 ± 0.35)[7] has a $\approx$ 2σ disagreement with the SM prediction. It can be used to exclude parameter space in the $m_{H^\pm} - \tan\beta$ plane as shown in Figure 2. With currently available luminosity we can only set limits for $\mathcal{B}(B \to [e,\mu]\nu)$, but the muon channel with its striking signature will reach measurement levels at future B-factories [8].

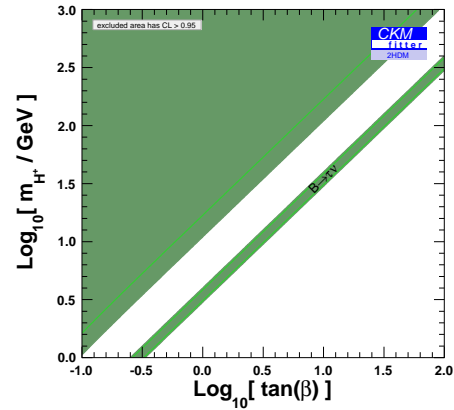Figure 2: Constraints on the 2HDM parameter space $(m_{H^\pm}, \tan\beta)$ from $B \to \tau\nu$ decays [7].

References

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