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$B \to K \nu \overline{\nu}$, $B \to \tau \nu$, $B \to \mu \nu$ Searches at BABAR

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Abstract. We present a search for the $B^- \to K^- \nu \overline{\nu}$, $B^- \to \tau^- \overline{\nu}$ and $B^- \to \mu^- \overline{\nu}$ decays in a data sample of 82 fb^{-1} collected at the $\Upsilon(4S)$ resonance with the *BABAR* detector at the SLAC PEP-II asymmetric B Factory. We find no evidence of signal for such decays and for all of them we set a 90% C.L. upper limit. For the $B^- \to K^- \nu \overline{\nu}$ decay we set a 90% C.L. upper limit of $\mathcal{B}(B^- \to K^- \nu \overline{\nu}) < 7.0 \times 10^{-5}$. For the $B^- \to \tau^- \overline{\nu}$ decay we set a 90% C.L. upper limit of $\mathcal{B}(B^- \to \tau^- \overline{\nu}) < 4.1 \times 10^{-4}$. For the $B^- \to \mu^- \overline{\nu}$ decay we set a 90% C.L. upper limit of $\mathcal{B}(B^- \to \mu^- \overline{\nu}) < 6.6 \times 10^{-6}$. All results are preliminary.

PACS. PACS-key e^+e^- collisions – PACS-key Rare B meson decays

1 Introduction

We present a search for the $B^- \to K^- \nu \overline{\nu}$ [1], $B^- \to \tau^- \overline{\nu}$ [2,3] and $B^- \to \mu^- \overline{\nu}$ [4] decays (charged conjugate modes are implied) in a data sample of 82 fb^{-1} collected at the $\Upsilon(4S)$ resonance with the *BABAR* detector at the SLAC PEP-II asymmetric B Factory [5].

The $B^- \to K^- \nu \overline{\nu}$ decay proceeds via the flavour-changing neutral-current (FCNC) $b \to s \nu \overline{\nu}$ described at one-loop level in the Standard Model (SM) by "penguin" and "box" diagrams shown in Figure 1. The SM expectation for $B^- \to K^- \nu \overline{\nu}$ branching fraction is $\mathcal{B}(B^- \to K^- \nu \overline{\nu}) \approx 4 \times 10^{-6}$.

The purely leptonic decay $B^- \to \ell^- \overline{\nu}$ is sensitive to the Cabibbo-Kobayashi-Maskawa matrix element V_{ub} and the B meson decay constant f_B, known only from theory [6]. In the SM the amplitude of the process is due to the annihilation of the B meson quark content into a virtual W boson (Figure 2). The resulting expression of the branching fraction is:

$$\mathcal{B}(B^- \to \ell^- \overline{\nu}) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B, \tag{1}$$

where G_F is the Fermi coupling constant, m_l and m_B are the lepton and the B meson masses, τ_B is the B^- lifetime.

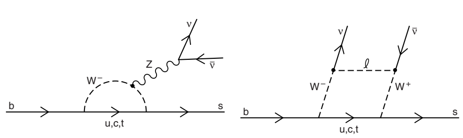

Fig. 1. Electroweak penguin (left) and box (right) Feynman diagrams for the process $b \to s \nu \overline{\nu}$ predicted by the SM.

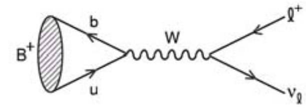

Fig. 2. The purely leptonic B decay proceeds via quark annihilation into a W boson.

The muon channel is experimentally simpler (a monochromatic muon in the B rest frame) but the helicity suppression makes the process quite rare ($\mathcal{B}(B^- \to \mu^- \overline{\nu}) \sim 4 \times 10^{-7}$). The τ channel is more abundant (SM expectation from PDG 2002 [7] is $\mathcal{B}(B^- \to \tau^- \overline{\nu}) \sim 9 \times 10^{-5}$) but the presence of two or three undetectable neutrinos in the final state makes the background rejection an experimental challenge. We find no evidence of signal and for each of them we set an upper limit at the 90% confidence level (C.L.).

2 Samples definition

The searches for $B^- \to K^- \nu \overline{\nu}$ and $B^- \to \tau^- \overline{\nu}$ are both performed on two different and statistically independent samples. This allows to combine the upper limits set on each sample. The first is the e^-hadronic sample in which one of the B mesons (tag B) from the $\Upsilon(4S)$ decay is reconstructed in a set of hadronic modes. They can be summarized as $B^\pm \to D^{(*)0} X^\pm$, where $D^{(*)0}$ is a charmed meson and $X^\pm$ is a system of charged and neutral hadrons composed by $n_1\pi^\pm + n_2 K^\pm + n_3 \pi^0 + n_4 K_S^0$ ($n_1 = 1, ...5$, $n_2 = 0, ...2$, $n_3 = 0, ...2$ and $n_4 = 0, 1$) and having total charge equal to ± 1. The D^{*0} is reconstructed in the decay mode $D^0 \pi$ and the D^0 candidate is reconstructed in four decay modes: $D^0 \to K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+\pi^-$,

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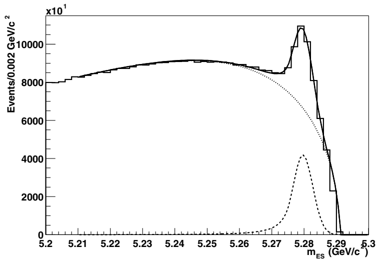

Fig. 3. Fit to the $m_{\rm ES}$ distribution.

$K^0_S\pi^-\pi^+$. The tag B is identified using two beam constrained kinematic variables, ΔE and the energy substituted mass $m_{\rm ES}$. They are defined as $\Delta E = E^*_B - E_{beam}$ and $m_{\rm ES} = \sqrt{[(s/2 + \mathbf{p_i}\cdot\mathbf{p_B})^2/E^2_i] - |\mathbf{p_B}|^2}$, where E^*_B is the energy of the B meson and E_{beam} is the beam energy, both in the $\Upsilon(4S)$ frame, $\sqrt{s}$ is the total energy of the e^+e^- system in the $\Upsilon(4S)$ rest frame, and $(E_i, \mathbf{p_i})$ and $(E_B, \mathbf{p_B})$ are the four-momenta of the e^+e^- system and the reconstructed B candidate respectively, both in the laboratory frame. Figure 3 shows a fit to the $m_{\rm ES}$ distribution. All remaining tracks and neutral objects are associated with the recoiling B (signal side). The second sample is the e^-semi-leptonic sample defined by one B^+ meson decaying in $\bar{D}^0\ell^+\nu_\ell X$ final state where X is either a photon, π^0 or nothing. The two samples are mutually exclusive and therefore statistically independent. In both cases there is a strong suppression of the continuum and combinatorial background but the reconstruction efficiency is of the order of $0.25 - 0.30\%$.

3 Search for the $B^- \to K^-\nu\overline{\nu}$ decay

The search for $B^- \to K^-\nu\overline{\nu}$ is based on the hadronic sample (Sec. 2). The tag B yield is obtained from the peaking component of the $m_{\rm ES}$ distribution. The signal region is defined by $5.272\,{\rm GeV}/c^2 < m_{\rm ES} < 5.288\,{\rm GeV}/c^2$. Events in the region $5.225\,{\rm GeV}/c^2 < m_{\rm ES} < 5.265\,{\rm GeV}/c^2$ are retained for background studies. Combinatorial and continuum background are reduced by cutting on the thrust angle Θ^T and the $|cos\Theta^T|$. Candidate events are required to have one signal-side charged track identified as a kaon having momentum in the center-of-mass (CM) frame greater than $1.5\,{\rm GeV}/c$. A veto on π^0 candidates is imposed. In addition, cuts on the signal-side residual neutral energy, E_{extra}, and the direction of the missing momentum vector in the CM-frame are applied. The overall efficiency is $\varepsilon_{tot} = (0.046 \pm 0.005)\%$. The uncertainty on the efficiency is due to both statistics and systematics. Backgrounds consist primarily of B^+B^- events in which additional particles are not reconstructed. Three events have been observed in the signal region, with an expected background 2.7 ± 0.8. The limit $\mathcal{B}(B^- \to K^-\nu\overline{\nu}) < 1.05 \times 10^{-4}$ is set. This analysis can be combined with the result of a preliminary *BABAR* search for $B^- \to K^-\nu\overline{\nu}$ reported in [8], based on a sample of $50.7\,{\rm fb}^{-1}$ of data using the

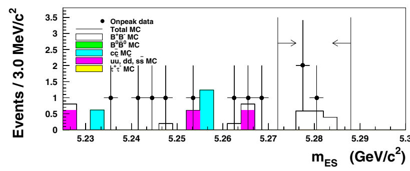

Fig. 4. The $m_{\rm ES}$ distribution of events passing all other $B^- \to K^-\nu\overline{\nu}$ selection cuts, showing the three selected events in the signal region.

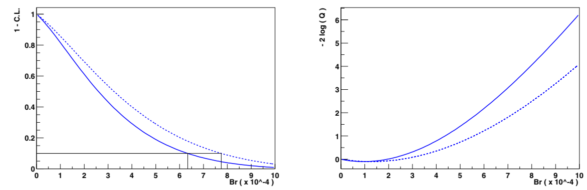

Fig. 5. Distributions of the confidence level (left) and likelihood ratio (right) as a function of $\mathcal{B}(B^- \to \tau^-\overline{\nu})$. The dashed (solid) curve corresponds to the case in which the uncertainty on the expected background is included (not included).

semi-leptonic sample (see Sec. 2). This analysis yielded a limit of $\mathcal{B}(B^- \to K^-\nu\overline{\nu}) < 9.4 \times 10{-}5$ at the 90% C.L. A combined limit of $\mathcal{B}(B^- \to K^-\nu\overline{\nu}) < 7.0 \times 10^{-5}$ at the 90% C.L. is obtained.

4 Search for the $B^- \to \tau^-\overline{\nu}$ decay

Two analysis have been performed. One using the hadronic sample and the other one using the semi-leptonic sample, as described in Sec. 2. Since the two samples are statistically independent, the results have been combined.

4.1 Search for $B^- \to \tau^-\overline{\nu}$ using the hadronic sample

We define the signal region on the tag B side to be $-0.09 < \Delta E < 0.06\,{\rm GeV}$ and $m_{\rm ES} > 5.27\,{\rm GeV}/c^2$ and we use the events contained in the sideband $5.21 < m_{\rm ES} < 5.26\,{\rm GeV}/c^2$ as a control sample for continuum and combinatorial background. In the events where a tag B is reconstructed we search for decays of the recoil B in a τ plus a neutrino; the τ lepton is identified in the following decay channels: $\tau^- \to e^-\nu\overline{\nu}$, $\tau^- \to \mu^-\nu\overline{\nu}$, $\tau^- \to \pi^-\overline{\nu}$, $\tau^- \to \pi^-\pi^0\nu$, $\tau^- \to \pi^-\pi^+\pi^-\nu$. Three preselctions are established according to the τ decay channels under study. We require one track and no π^0 or one track and one π^0 or three traks and no π^0. The selected track is not identified as kaon and must be identified as lepton or a pion. Additional cuts are applied on missing momentum, residual neutral energy, track momentum and invariant masses. Backgrounds are mainly from V_{cb} events. The signal selection efficiency is 11.3%. A likelihood ratio estimator is used to combine more channels. The total expected background is $37.6 \pm 4.7 \pm 1.5$ and the selected events are 35. The limit we set is $\mathcal{B}(B^- \to \tau^-\overline{\nu}) < 7.7 \times 10^{-4}$. Figure 5 shows the C.L. and likelihood ratio distributions.

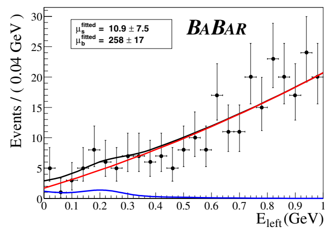

Fig. 6. Residual neutral energy spectrum and the fit of the likelihood function to the spectrum. Dots are the data, the black line is the global fit, the red line is the background shape fit and the blue line is the signal shape fit.

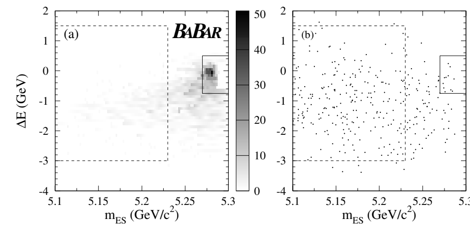

Fig. 7. Distributions of ΔE *vs* $m_{\rm ES}$ in the $B^- \to \mu^-\overline{\nu}$ Monte Carlo signal (left) and the data (right). The signal box (sideband) is represented by the solid (dashed) line.

4.2 Search for $B^- \to \tau^-\overline{\nu}$ using the semi-leptonic sample

In the events where a tag B is reconstructed we search for decays of the recoil B in a τ plus a neutrino; the τ lepton is identified in the $\tau^- \to e^-\nu\overline{\nu}$ and $\tau^- \to \mu^-\nu\overline{\nu}$ channels. Fisrt, we apply a veto on $\tau^+\tau^-$ events. Then we select the signal events by requiring only one charged track having low impact parameter. The track is not identified as a kaon and is identified as lepton. The residual neutral energy (E_{left}) is used to model a probability density function to extract signal and background contributions. The signal selection efficiency is 22.5%. An extended likelihood fit is performed. In the signal region, defined by $E_{left} < 0.35$ GeV, the background yield is 258 ± 17 is in agreement with the expectation from extrapolating sideband data into the E_{left} signal region, 274 ± 19. The limit we set is $\mathcal{B}(B^- \to \tau^-\overline{\nu}) < 4.9 \times 10^{-4}$.

4.3 Combined limit on $B^- \to \tau^-\overline{\nu}$

The two independent limits on $B^- \to \tau^-\overline{\nu}$ have been combined using the same stastistical tecnique used in Sec. 4.1 to combine more channels. The combined limit is $\mathcal{B}(B^- \to \tau^-\overline{\nu}) < 4.1 \times 10^{-4}$. A theoretical application of this result can be found in [9].

5 Search for the $B^- \to \mu^-\overline{\nu}$ decay

$B^- \to \mu^-\overline{\nu}$ is a two-body decay so the muon must be mono-energetic in the signal B rest frame (B mesons from $\Upsilon(4S) \to B\overline{B}$ decay have a total momentum of 320 MeV/$c$in the CM-frame). The momentum of the muon is given by $p^* \approx m_B/2$. We select events with one identified muon candidate. Any other charged tracks or neutral cluster is assigned to the companion B selected using the kinematic variables ΔE and energy-substituted mass, $m_{\rm ES}$. Events with additional identified leptons are discarded to discriminate against events containing additional neutrinos. The request on muon candidate momentum to have $2.58 < p^* < 2.78$ GeV/c is useful to reject backgrounds that come from B semi-leptonic decays involving $b \to u\mu\nu$ transitions and from non-resonant qq (continuum) events where a charged pion is mistakenly identified as a muon. The cut is asymmetric about the signal peak due to the decreasing momentum distribution of the backgrounds. Continuum backgrounds are further suppressed using the event shape variables Θ^T and $|cos\Theta^T|$ (used also in Sec. 3). After applying all selection criteria and after applying the necessary corrections to the MC, the $B^- \to \mu^-\overline{\nu}$ efficiency is determined to be $2.09 \pm 0.06(stat) \pm 0.13(syst)$%. In the on-resonance data we find 11 events in the signal box where $5.0^{+1.8}_{-1.4}$ background events are expected. The probability of a background fluctuation yielding the observed number of events or more is about 4%.

We set an upper limit on the $B^- \to \mu^-\overline{\nu}$ branching fraction using $\mathcal{B}(B^- \to \mu^-\overline{\nu}) < n_{UL}/S$ where n_{UL} is the 90% C.L. upper limit on the number of signal events observed and S is the sensitivity of the experiment which is the product of the signal efficiency and the number of charged B mesons in the sample. To determine the number of charged B mesons we assume equal production of B^0 and B^+ in $\Upsilon(4S)$ decays. Systematic uncertainties are included in the limit. The preliminary result is $\mathcal{B}(B^- \to \mu^-\overline{\nu}) < 6.6 \times 10^{-6}$ at the 90% confidence level.

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