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A SEARCH FOR THE DECAY $B^+ \to \tau^+\nu_\tau$ AT BABAR

MOUSUMI DATTA*

The Department of Physics, University of Wisconsin at Madison,
Madison, Wisconsin 53706-1390, USA.†

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We present a search for the decay $B^+ \to \tau^+\nu_\tau$ in 124.1×10^6 $B\overline{B}$ decays recorded with the BABAR detector at the SLAC PEP-II B-Factory. A sample of events with one reconstructed exclusive semi-leptonic B decay ($B^- \to D^{*0}\ell^-\overline{\nu}_\ell$) is selected, and in the recoil a search for $B^+ \to \tau^+\nu_\tau$ signal is performed. The τ is identified in the following channels: $\tau^+ \to e^+\nu_e\overline{\nu}_\tau$, $\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$, $\tau^+ \to \pi^+\overline{\nu}_\tau$, $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$, $\tau^+ \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$. We find no evidence of signal, and we set a preliminary upper limit on the branching fraction of $\mathcal{B}(B^+ \to \tau^+\nu_\tau) < 4.3 \times 10^{-4}$ at the 90% confidence level (CL). This result is then combined with a statistically independent BABAR search for $B^+ \to \tau^+\nu_\tau$ to give a combined preliminary limit of $\mathcal{B}(B^+ \to \tau^+\nu_\tau) < 3.3 \times 10^{-4}$ at 90% CL.

Keywords: leptonic; tau; taunu.

1. Introduction

In the Standard Model (SM), the purely leptonic decay $B^+ \to \tau^+\nu_\tau$ [a] proceeds via quark annihilation into a W^+ boson. The branching fraction is given by:

$$\mathcal{B}(B^+ \to \tau^+\nu) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left[1 - \frac{m_\tau^2}{m_B^2}\right]^2 \tau_B f_B^2 \mid V_{ub} \mid^2, \tag{1}$$

where we have set $\hbar = c = 1$, G_F is the Fermi constant, V_{ub} is a quark mixing matrix element, f_B is the B^+ meson decay constant, τ_B is the B^+ lifetime, and m_B and m_τ are the B^+ meson and τ masses. The decay amplitude for $B^+ \to \ell^+\nu_\ell$ process is proportional to the lepton mass and decay to the lighter leptons is severely suppressed. The $B^+ \to \tau^+\nu_\tau$ mode is therefore the most promising for discovery at existing experiments. The SM estimate of the $B^+ \to \tau^+\nu_\tau$ branching fraction is $(9.3 \pm 3.9) \times 10^{-5}$, using $V_{ub} = (3.67 \pm 0.47) \times 10^{-4}$ and $f_B = 0.196 \pm 0.032$ [2] in Eq. 1. Physics beyond the SM, such as supersymmetry or two-Higgs doublet models, could enhance $\mathcal{B}(B^+ \to \tau^+\nu_\tau)$ by up to a factor of five through the introduction of a charged Higgs boson [1]. Current theoretical values for f_B (obtained from lattice QCD calculations) [2] have large uncertainty, and the $B^+ \to \ell^+\nu_\ell$ decays may be the only clean experimental method of measuring f_B precisely.

*On behalf of BABAR Collaboration.
†Graduate student, University of Wisconsin, Physics Department, 1150 University Avenue, Madison, WI 53706.
[a] Charge-conjugate modes are implied throughout this paper.

Purely leptonic B decays have not yet been observed. CLEO [3] and experiments at LEP [4,5,6] have searched for this process and published limits on the branching fraction. The Belle collaboration has a preliminary result on the search for this decay [7] and the upper limit on branching fraction is 2.9×10^{-4} at the 90% CL. The *BABAR* collaboration has results on the search for $B^+ \rightarrow \tau^+\nu_\tau$ decays [8] using a sample of 88.9×10^6 $B\overline{B}$ decays and the obtained upper limit is 4.2×10^{-4} at the 90% CL. Here we report on a preliminary result from a different analysis at *BABAR* on a larger dataset [9].

2. Analysis Method

Due to the presence of multiple neutrinos in the final states, the $B^+ \rightarrow \tau^+\nu_\tau$ decay mode lacks the kinematic constraints which are usually exploited in B decay searches in order to reject backgrounds. The strategy adopted for this analysis is to reconstruct exclusively the decay of one of the B mesons in the event, referred to as "tag" B, and to compare the remaining particle(s) in the event, referred as the "signal side", with the signature expected for the decay $B^+ \rightarrow \tau^+\nu_\tau$.

The tag B is reconstructed in the set of decay modes $B^- \rightarrow D^{*0}\ell^-\overline{\nu}_\ell$, where ℓ is e or μ. The D^{*0} is reconstructed in $D^0\pi^0$ and $D^0\gamma$ modes. The D^0 is reconstructed in four decay modes: $K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$, $K^-\pi^+\pi^0$, and $K^0_s\pi^+\pi^-$ ($K^0_s \rightarrow \pi^+\pi^-$). The tag reconstruction efficiency ($\varepsilon_{\rm tag}$) in the signal Monte Carlo (MC) simulation is (1.818 $\pm$ 0.074 (stat.) $\pm$ 0.055 (syst.)) $\times 10^{-3}$.

The $B^+ \rightarrow \tau^+\nu_\tau$ signal events are searched for in the following τ decay modes: $e^+\nu_e\overline{\nu}_\tau$, $\mu^+\nu_\mu\overline{\nu}_\tau$, $\pi^+\overline{\nu}_\tau$, $\pi^+\pi^0\overline{\nu}_\tau$, $\pi^+\pi^-\pi^+\overline{\nu}_\tau$. We select events with one or three signal-side track(s). The $e^+\nu_e\overline{\nu}_\tau$, $\mu^+\nu_\mu\overline{\nu}_\tau$, $\pi^+\overline{\nu}_\tau$, and $\pi^+\pi^0\overline{\nu}_\tau$ signal modes contain one signal-side track and are separated by appropriate particle identification. The $\pi^+\overline{\nu}_\tau$ and the $\pi^+\pi^0\overline{\nu}_\tau$ modes contain a pion signal track and are further characterized by requiring that the event contain zero and non-zero signal-side π^0 mesons, respectively. The most powerful variable for separating signal and background is the remaining neutral energy ($E_{\rm extra}$), calculated by adding the center-of-mass energy of the photons with minimum cluster energies of 20 MeV, that are not associated with either the tag B or the π^0 candidate from $\tau^+ \rightarrow \pi^+\pi^0\overline{\nu}_\tau$ signal decay. For signal events the neutral clusters contributing to $E_{\rm extra}$ can only come from processes like beam-background, hadronic split-offs, and bremsstrahlung. Thus the signal events peak at low $E_{\rm extra}$ values and the background events, which contain additional sources of neutral clusters, are distributed towards higher $E_{\rm extra}$ values. The $E_{\rm extra} < 0.3$ GeV region is defined as the signal region.

Background consists primarily of B^+B^- events in which the tag B meson has been correctly reconstructed. The recoil side contains particles which are not reconstructed by the tracking detectors or calorimeters. Often these events contain one or more K^0_L and/or neutrinos. The continuum background contributes to hadronic τ decay modes. Background is suppressed by requirements on missing mass, momentum of the τ daughter particles etc. The $\pi^+\pi^0\overline{\nu}_\tau$ and $\pi^+\pi^-\pi^+\overline{\nu}_\tau$ decays proceed via intermediate ρ and a_1 resonances, which can be used for further background rejection. Background estimation is performed by extrapolation of the data side band ($0.35 < E_{\rm extra} < 1.0$ GeV) to the signal region, using the $E_{\rm extra}$ shape in the MC distribution.

3. Results

Number of observed events in on-resonance data in the signal region, together with the expected number of background events, and signal-side selection efficiencies (ε_i) calculated with respect to the total number of reconstructed tag B mesons are listed in table 1. We determine the $B^+ \to \tau^+\nu_\tau$ branching fraction from the number of signal candidates s_i in data for each τ decay mode, according to $s_i = N_{B\overline{B}}\mathcal{B}(B^+ \to \tau^+\nu_\tau)\varepsilon_{\rm tag}\varepsilon_i$. Here $N_{B\overline{B}}$ is 124.1×10^6 , the total number of $B\overline{B}$ pairs in data. The results from each decay mode are combined using modified frequentist method [10,11]. Since we have no evidence of signal we set an upper limit on the branching fraction at $\mathcal{B}(B^+ \to \tau^+\nu_\tau) < 4.3 \times 10^{-4}$ at the 90% C.L.

Table 1. Shown are the signal-side selection efficiencies, number of expected background events, and observed number of on-resonance data events in the signal region.

Selection	Signal-side Efficiency (%)	Expected Background Events	Observed Events in On-resonance Data
$e^+\nu_e\overline{\nu}_\tau$	$8.36 \pm 0.42 \pm 0.28$	15.15 ± 3.14	13
$\mu^+\nu_\mu\overline{\nu}_\tau$	$4.30 \pm 0.28 \pm 0.17$	8.05 ± 2.07	10
$\pi^+\overline{\nu}_\tau$	$22.34 \pm 0.72 \pm 1.36$	55.30 ± 7.37	72
$\pi^+\pi^0\overline{\nu}_\tau$	$3.01 \pm 0.24 \pm 0.25$	29.80 ± 5.10	30
$\pi^+\pi^-\pi^+\overline{\nu}_\tau$	$2.07 \pm 0.20 \pm 0.13$	25.10 ± 3.87	26

The *BABAR* Collaboration reported a search for the $B^+ \to \tau^+\nu_\tau$ decay [8], where the tag B mesons are reconstructed in hadronic modes $B^- \to D^{(*)0}X^-$. Here X^- represents a combination of pions or kaons. The hadronic tag analysis is statistically independent from the current analysis and therefore can be combined. The combined upper limit on the branching fraction is $\mathcal{B}(B^+ \to \tau^+\nu_\tau) < 3.3 \times 10^{-4}$ at the 90% C.L.

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