

Beyond Standard Model searches through heavy flavors at *BABAR*

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The *BABAR* experiment recorded 471×10^6 $B\bar{B}$ pairs at the $\Upsilon(4S)$ resonance (corresponding to an integrated luminosity of 429 fb^{-1}). We present here a selection of recent results from the *BABAR* collaboration: search for lepton-number violation in the decay $B^+ \rightarrow h^- \ell^+ \ell^+$, search for lepton-flavor violation in $B^\pm \rightarrow h^\pm \tau \ell$ and CP -violation in $\tau^- \rightarrow K_s^0 (\geq 0\pi^0) \nu_\tau$.

1 Search for lepton-number violation in the decay $B^+ \rightarrow h^- \ell^+ \ell^+$

In the Standard Model (SM), the lepton number L is conserved in low-energy collisions and decays. Through neutrino oscillation L -conservation can be violated, for example in the process $B^+ \rightarrow h^- \ell^+ \ell^+$; highly suppressed in the SM, this lepton-number violating process can be enhanced in several Beyond SM scenarios, such as left-right symmetric gauge theories, $SO(10)$ supersymmetry, R -parity violating models, or extra-dimensions.

In this analysis [1], four final states are considered: the decay channel is $B^+ \rightarrow h^- \ell^+ \ell^+$ with $h = K, \pi$ and $\ell = e, \mu$. The continuum and $B\bar{B}$ backgrounds are rejected using bagged decision trees (BDT), based on ΔE (the difference between the expected B energy and the reconstructed B energy), event shape and vertexing variables. A likelihood ratio R is constructed from the $B\bar{B}$ BDT. Unbinned maximum likelihood fits of m_{ES} and R , the likelihood ratio, are performed for each of the four modes. We use the $B^+ \rightarrow J/\psi h^+$ data control sample to obtain the m_{ES} fit parameters. The fits are shown in Fig. 1, where we observe that no signal is seen. From these negative results, we obtain upper limits at 90% confidence level (CL) on the four states: $\mathcal{B}(B^+ \rightarrow K^- e^+ e^+) < 3.0 \times 10^{-8}$, $\mathcal{B}(B^+ \rightarrow K^- \mu^+ \mu^+) < 6.7 \times 10^{-8}$, $\mathcal{B}(B^+ \rightarrow \pi^- e^+ e^+) < 2.3 \times 10^{-8}$, and $\mathcal{B}(B^+ \rightarrow \pi^- \mu^+ \mu^+) < 10.7 \times 10^{-8}$. These upper limits are 40-70 times more stringent than previous limits set by other experiments.

2 A search for the decay modes $B^\pm \rightarrow h^\pm \tau \ell$

FCNC and charged lepton flavor violation are forbidden in the SM at tree level. However, in many extensions of the SM, these effects could be enhanced, especially for the second and third generation [2]. We study [3] the eight final states $B^\pm \rightarrow h^\pm \tau \ell$, with $h = K, \pi$ and $\ell = e, \mu$. The final states $B^\pm \rightarrow K^\pm \tau e$, $B^\pm \rightarrow \pi^\pm \tau \mu$, and $B^\pm \rightarrow \pi^\pm \tau e$ have never been done before. We fully reconstruct the hadronic B on one side (the “tag” B) using final states of the type

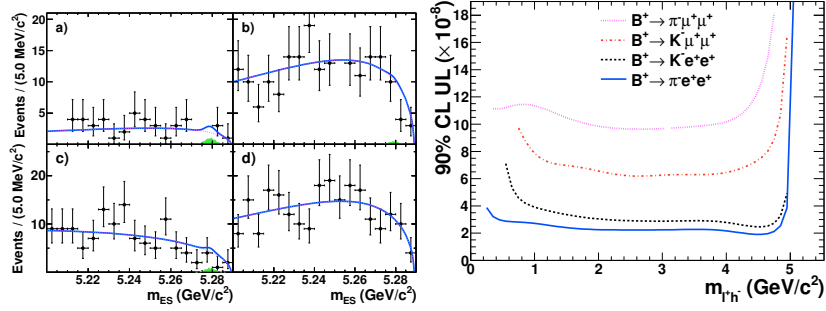


Figure 1: Left: m_{ES} distributions for a) $B^+ \rightarrow K^- e^+ e^+$, b) $B^+ \rightarrow K^- \mu^+ \mu^+$, c) $B^+ \rightarrow \pi^- e^+ e^+$, and d) $B^+ \rightarrow \pi^- \mu^+ \mu^+$. The solid blue line is the total fit, the dotted magenta line is the background, the solid green histogram is the signal. Right: 90% CL upper limits on the branching fractions as a function of the mass m_{l+h} .

$B^- \rightarrow D^{(*)0} X^-$, where X^- is composed of $\pi^\pm$, $K^\pm$, K_s^0 , and π^0 . This determines the three-momentum of the other B (the “signal” B) on the other side and thus allows us to indirectly reconstruct the τ lepton through:

$$\vec{p}_\tau = -\vec{p}_{\text{tag}} - \vec{p}_h - \vec{p}_\ell; \quad E_\tau = E_{\text{beam}} - E_h - E_\ell; \quad m_\tau = \sqrt{E_\tau^2 - |\vec{p}_\tau|^2},$$

where $(E_\tau, \vec{p}_\tau)$, $(E_h, \vec{p}_h)$, and $(E_\ell, \vec{p}_\ell)$ are the corresponding four-momenta of the reconstructed signal objects, and where $\vec{p}_{\text{tag}}$ is the three-momentum of the tag B , and E_{beam} the beam energy. The τ is required to decay to a “one-prong” final state: $\tau \rightarrow e \nu \bar{\nu}$, $\tau \rightarrow \mu \nu \bar{\nu}$, and $\tau \rightarrow (n \pi^0) \pi \nu$ with $n \geq 0$. The signal branching fraction is determined by using the ratio of the number of $B^\pm \rightarrow h^\pm \tau \ell$ signal candidates to the yield of control samples of $B^+ \rightarrow \bar{D}^{(*)0} \ell^+ \nu$; $\bar{D}^0 \rightarrow K^+ \pi^-$ events from a fully reconstructed hadronic $B^\pm$ decay sample.

The background is mainly coming from semileptonic B decays and from semileptonic D decays. We remove these backgrounds by rejecting the signal B candidates where two of their daughters are kinematically compatible with originating from a charm decay. After this requirement, we reject the continuum background using a cut on the likelihood ratio R , based on particle identification and event shape variables.

The signal region is defined as $\pm 60 \text{ MeV}/c^2$ around the indirectly reconstructed τ mass m_τ . Figure 2 show an example of m_τ distributions for the data, for the background, and for the signal MC. No signal is observed, which allows us to put 90% CL limit on the branching fractions. Assuming $\mathcal{B}(B^+ \rightarrow h^+ \tau^- \ell^+) = \mathcal{B}(B^+ \rightarrow h^+ \tau^+ \ell^-)$, we obtain the combined limits shown in Table 1. These limits can be translated into model-independent bounds on the energy scale of new physics in flavor-changing operators [4]: $\Lambda_{bd} > 11 \text{ TeV}$ and $\Lambda_{bs} > 15 \text{ TeV}$ (at 90% CL), which improved the previous limits of 2.2 and 2.6 TeV, respectively.

3 Search for CP violation in the decays $\tau^- \rightarrow \pi^- K_s^0 (\geq 0 \pi^0) \nu_\tau$

CP violation, until now, has only been observed in hadronic decays (K , B , and D systems). However, Bigi and Sanda predict [5] a non-zero decay rate asymmetry for τ decays to final

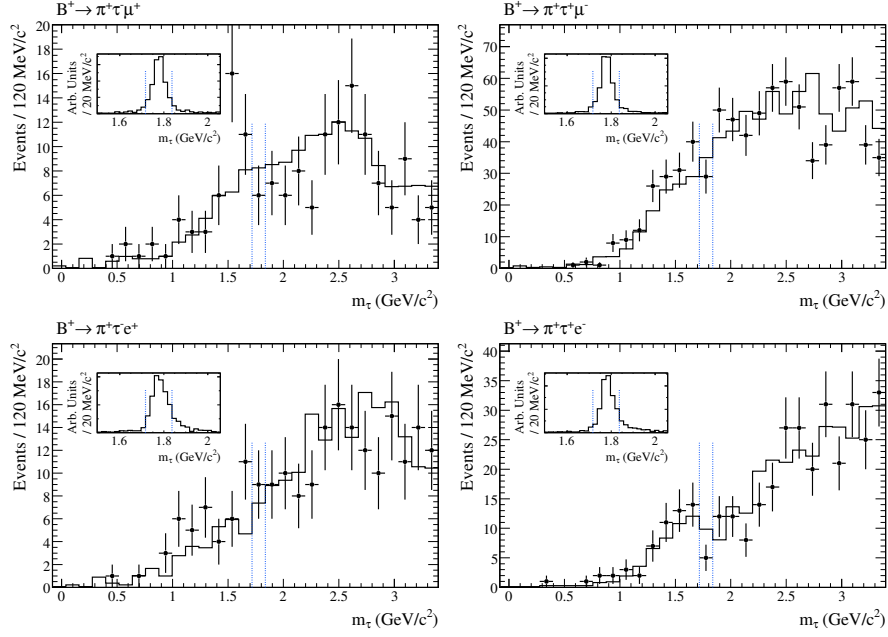


Figure 2: Observed distributions of the τ invariant mass for the $B \rightarrow \pi\tau\ell$ modes. The distributions show the sum of the three τ channels (e, μ, π). The points with error bars are the data. The solid line is the background MC which has been normalized to the area of the data distribution. The dashed vertical lines indicate the m_τ signal window range. The inset shows the m_τ distribution for signal MC.

Table 1: Branching fraction central values and 90% CL upper limits (UL) for the combination $\mathcal{B}(B^+ \rightarrow h^+\tau\ell) \equiv \mathcal{B}(B^+ \rightarrow h^+\tau^-\ell^+) + \mathcal{B}(B^+ \rightarrow h^+\tau^+\ell^-)$.

Mode	$\mathcal{B}(B \rightarrow h\tau\ell) (\times 10^{-5})$	
	central value	90% CL UL
$B^+ \rightarrow K^+\tau\mu$	$0.0^{+2.7}_{-1.4}$	< 4.8
$B^+ \rightarrow K^+\tau e$	$-0.6^{+1.7}_{-1.4}$	< 3.0
$B^+ \rightarrow \pi^+\tau\mu$	$0.5^{+3.8}_{-3.2}$	< 7.2
$B^+ \rightarrow \pi^+\tau e$	$2.3^{+2.8}_{-1.7}$	< 7.5

states containing a K_s^0 meson, due to the CP violation in the kaon sector. The decay rate asymmetry is:

$$A_Q = \frac{\Gamma(\tau^+ \rightarrow \pi^+ K_s^0 \bar{\nu}_\tau) - \Gamma(\tau^- \rightarrow \pi^- K_s^0 \nu_\tau)}{\Gamma(\tau^+ \rightarrow \pi^+ K_s^0 \bar{\nu}_\tau) + \Gamma(\tau^- \rightarrow \pi^- K_s^0 \nu_\tau)},$$

and is predicted to be equal to $(0.33 \pm 0.01)\%$. Any deviation from the SM prediction could be a sign of new physics. It has to be noted that A_Q is independent of the number of neutral pions in the final state. Recently, Grossman and Nir [6] noticed that the calculation needs to take

into account interferences between the amplitudes of intermediate K_S^0 and K_L^0 mesons, which are as important as the pure K_S^0 amplitude. This means that A_Q depends on the reconstruction efficiency as a function of the $K_S^0 \rightarrow \pi^+\pi^-$ decay time.

We study here [7] the decay channel $\tau^- \rightarrow \pi^- K_S^0 (\geq 0\pi^0) \nu_\tau$. The event is divided into two hemispheres, one corresponding to the signal side, and one to the tag side with $\tau^- \rightarrow \ell^- \bar{\nu}_\ell \nu_\tau$, $\ell = e, \mu$. The selection of the signal events requires that the invariant mass of the reconstructed τ lepton is smaller than $1.8 \text{ GeV}/c^2$. After a two-stage likelihood selection (reducing mainly continuum background and K_S^0 one, respectively), we obtain 199064 candidates for the electron tag channel (e -tag), and 140602 for the muon tag channel (μ -tag). The composition of the sample in term of signal and background events is presented in Table 2.

Table 2: Composition of the sample after all selection criteria have been applied.

Source	Fractions (%)	
	e -tag	μ -tag
$\tau^- \rightarrow \pi^- K_S^0 (\geq 0\pi^0) \nu_\tau$	78.7 ± 4.0	78.4 ± 4.0
$\tau^- \rightarrow K^- K_S^0 (\geq 0\pi^0) \nu_\tau$	4.2 ± 0.3	4.1 ± 0.3
$\tau^- \rightarrow \pi^- K^0 \bar{K}^0 \nu_\tau$	15.7 ± 3.7	15.9 ± 3.7
Other background	1.40 ± 0.06	1.55 ± 0.07

We need to correct the raw asymmetry from the pollution of the other modes shown in Table 2. For the mode $\tau^- \rightarrow K^- K_S^0 (\geq 0\pi^0) \nu_\tau$, the expected asymmetry is opposite to the one from the signal, and for the mode $\tau^- \rightarrow \pi^- K^0 \bar{K}^0 \nu_\tau$, the expected asymmetry is zero. Furthermore, an additional correction was pointed out recently [8]: we need to take into account a correction on the asymmetry A_Q due to the different nuclear-interaction cross-section of the K^0 and $\bar{K}^0$ mesons with the material in the detector. We calculate this correction to be $(0.07 \pm 0.01)\%$ and we subtract it from the measured asymmetry. After all corrections are applied, and after combining the results from the e -tag and μ -tag, we obtain $A_Q = (-0.36 \pm 0.23 \pm 0.11)\%$.

As we mentioned, this result should be compared with the prediction of the SM, corrected by the $K_S^0 \rightarrow \pi^+\pi^-$ decay time dependence. Using the MC sample, we find a multiplicative factor of 1.08 ± 0.01 . The SM decay-rate asymmetry, after correction, is then predicted to be $A_Q^{\text{SM}} = (0.36 \pm 0.01)\%$. We observe that our measurement is 2.8 standard deviations away from the SM prediction.

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