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# Tau Decays at *BABAR*

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**Abstract**

Recent results of tau lepton decay studies based on luminosities between 350 $\text{fb}^{-1}$ and 469 $\text{fb}^{-1}$ collected with the *BABAR* detector at the PEP-II $e^+e^-$ collider at the SLAC National Accelerator Laboratory are presented. The analyses reported here are Charged Current Lepton Universality and measurements of $|V_{us}|$ using $\tau^- \to e^-\overline{\nu}_e\nu_\tau$, $\mu^-\overline{\nu}_\mu\nu_\tau$, $\pi^-\nu_\tau$, and $K^-\nu_\tau$ decays, as well as searches for Second Class Currents in $\tau^- \to \omega\pi^-\nu_\tau$ decays, studies of Lepton Flavor Violations, and a tau mass measurement and CPT-Test. If not explicitly mentioned, charge conjugate decay modes are also implied.

*Key words:* tau, $\text{V}_{\text{us}}$, tau mass, lepton flavor violation, lepton universality, BaBar, second class currents, CPT
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## 1. Lepton Universality

Tau decays into a single charged particle and one or two neutrinos can be used to test the assumption that all three leptons have equal coupling strength ($g_\ell$) to the charged gauge bosons of the electro-weak interaction, known as charged current lepton universality. While a precise measurement of the ratio $\frac{\mathcal{B}(\tau^- \to \mu^-\overline{\nu}_\mu\nu_\tau)}{\mathcal{B}(\tau^- \to e^-\overline{\nu}_e\nu_\tau)}$ tests $\mu-$e charged current lepton universality, the ratio $\frac{\mathcal{B}(\tau^- \to (\pi,K)^-\nu_\tau)}{\mathcal{B}((\pi,K)^- \to \mu^-\overline{\nu}_\mu)}$ tests $\tau - \mu$ charged current lepton universality with the light mesons $\pi$ or K.

Tests of $\mu - e$ universality can be expressed as: $\left(\frac{g_\mu}{g_e}\right)^2 = \frac{\mathcal{B}(\tau^- \to \mu^-\overline{\nu}_\mu\nu_\tau)}{\mathcal{B}(\tau^- \to e^-\overline{\nu}_e\nu_\tau)} \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}$, where $f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \log x$, assuming that the neutrino masses are

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negligible. Similar equations can be derived for the tau-muon universality: $\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{\mathcal{B}(\tau^- \to (\pi,K)^- \nu_\tau)}{\mathcal{B}((\pi,K)^- \to \mu^- \overline{\nu}_\mu)} \frac{2m_{(\pi,K)} m_\mu^2 \tau_{(\pi,K)}}{\delta_{\tau^- \to (\pi,K)^- \nu / (\pi,K)^- \to \mu^- \nu} m_\tau^3 \tau_\tau} \left(\frac{1 - m_\mu^2 / m_{(\pi,K)}^2}{1 - m_{(\pi,K)}^2 / m_\tau^2}\right)^2$ relating ratios of coupling constants to ratios of branching fractions, using radiative corrections from [1] and world averaged mass and lifetime values from [2]. Our preliminary results for the branching ratio measurements are [3] $\mathcal{B}(\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau) = (17.46 \pm 0.06 \pm 0.06) \cdot 10^{-2}$, $\mathcal{B}(\tau^- \to \pi^- \nu_\tau) = (10.59 \pm 0.04 \pm 0.11) \cdot 10^{-2}$, and $\mathcal{B}(\tau^- \to K^- \nu_\tau) = (6.92 \pm 0.04 \pm 0.10) \cdot 10^{-3}$. The first errors are statistical and the second ones systematical in nature. Together with the world average of $\mathcal{B}(\tau^- \to e^- \overline{\nu}_e \nu_\tau) = (17.82 \pm 0.05) \cdot 10^{-2}$ [2] we calculate the following ratios of leptonic coupling constants: $|\frac{g_\mu}{g_e}| = 1.0036 \pm 0.0020$, and $|\frac{g_\tau}{g_\mu}| = 0.9859 \pm 0.0057$ $(0.9836 \pm 0.0087)$ using pions (kaons), which are all consistent with the expectation of equal coupling of the leptons.

## 2. Measurement of $|V_{us}|$ from $\tau^- \to K^- \nu_\tau$ and $\tau^- \to \pi^- \nu_\tau$ Decays

The largest off-diagonal element, $|V_{us}|$, of the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix can be measured from the ratio of strange to non-strange inclusive branching fractions of the $\tau$ lepton, interpreted in the framework of the Operator Product Expansion (OPE) and finite energy sum rules (FESR) [4].

Encapsulating all non-perturbative effects in the precisely known ratio $f_K/f_\pi = 1.189 \pm 0.007$ [5] and following the discussion in [6] about long-distance electroweak contributions of $\delta = 1.0003 \pm 0.0044$, we measure $\frac{\mathcal{B}(\tau^- \to K^- \nu_\tau)}{\mathcal{B}(\tau^- \to \pi^- \nu_\tau)} = \frac{f_K^2 |V_{us}|^2}{f_\pi^2 |V_{ud}|^2} \frac{\left(1 - m_K^2/m_\tau^2\right)^2}{(1 - m_\pi^2/m_\tau^2)^2} \cdot \delta$ to be $(0.06531 \pm 0.00056(\text{stat}) \pm 0.00093(\text{syst}))$. From that we obtain $|V_{us}| = 0.2254 \pm 0.0023$ [3], which is consistent with the value calculated from unitarity.

## 3. Search for Second Class Currents in the Decay $\tau^- \to \omega \pi^- \nu_\tau$

The conservation of isospin symmetry implies that the hadronic currents corresponding to $J^{PG} = 0^{++}, 0^{--}, 1^{+-}, 1^{-+}$ are favored and $J^{PG} = 0^{+-}, 0^{-+}, 1^{++}, 1^{--}$ are strongly suppressed. These are known as First and Second Class Currents (FCC, SCC) [7]. The decay $\tau^- \to \omega \pi^- \nu_\tau$ proceeds dominantly through FCC ($J^{PG} = 1^{-+}$) mediated by the $\rho$ resonance occurring through a P-wave. However, it may also proceed through SCC ($J^{PG} = 0^{-+}, 1^{++}$) mediated by the $b_1(1235)$ resonance occurring through S- and D-waves [8]. These contributions can be studied using the distribution of the angle $\theta_{\omega\pi}$ between the normal to the $\omega$ decay plane and the direction of the remaining $\pi^-$ in a $\tau^- \to \omega \pi^- \nu_\tau$ decay measured in the $\omega$ rest frame. While the FCC contribution is proportional to $(1 - \cos^2\theta_{\omega\pi})$, the SCC contributions are proportional to a constant, $\cos^2\theta_{\omega\pi}$ or $(1 + 3\cos^2\theta_{\omega\pi})$. We perform a combined fit of these angular distributions to the background subtracted and efficiency corrected data and find no evidence for SCC. A 90% confidence level Bayesian upper limit for the ratio of SCC to FCC in $\tau^- \to \omega \pi^- \nu_\tau$ decays is set at 0.69%, which is an order of magnitude improvement over the previous best upper limit [9].

## 4. Search for Lepton Flavor Violating Decays $\tau^- \rightarrow l^- K_s^0$ and $\tau^- \rightarrow l^-(\rho^0, K^{*0}, \phi)$

Lepton Flavor Violation (LFV) is forbidden in the Standard Model (SM) if neutrinos are mass-less. Any occurrences of LFV decays would be a clear sign of new physics. Since no neutrinos appear in theses decays the reconstructed particles' mass and energy correspond to that of the decaying $\tau$, which makes for a clean signature of the reconstructed events. These analyses are performed in a blinded fashion, disguising the signal area until the estimated background in the signal region and all systematic effects have been studied. For the different decay modes we expect between 0.68 and 5.34 background events in the signal area, while we observe between 0 and 6. The resulting upper limits are between $1.8 \cdot 10^{-7}$ and $8 \cdot 10^{-9}$, improving previous or providing first time measurements [10].

## 5. Measurement of the Tau Mass and CPT Invariance

Analyzing tau decays to three charged particles we employ a so called pseudo-mass endpoint method to measure the tau lepton mass [11]. Disregarding the energy taken away by the $\tau$ neutrino in the $\tau$ rest frame one can determine an upper limit for the tau mass purely from the kinematics of the reconstructed particles and the a-priori knowledge of the center-of-mass (CM) energies from this formula in the CM system: $m_{\tau-psudo} \geq \sqrt{M_h^2 + (E_{CM} - 2E_h)(E_h - P_h)}$. $M_h, E_h$, and $P_h$ are the mass, energy and momentum of the reconstructed three charged particle system from the $\tau$ decay. This analysis is basically free from backgrounds and the largest systematic uncertainties stem from the intrinsic mass scale errors when reconstructing particle momenta in the detector. We determine the $\tau$ mass to be $(1776.68 \pm 0.12 \pm 0.41)$ MeV where the first error is statistic and the second systematic. We also measure the mass difference between the positively and negatively charged $\tau$ lepton and calculate the CPT-invariant quantity $(M_{\tau^+} - M_{\tau^-})/M_{\text{average}}$ to be $(-3.5 \pm 1.3) \cdot 10^{-4}$. These preliminary results are compatible with current measurements while the CPT measurements being slightly more precise.

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