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Hadronic Tau Decays at *BABAR*

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Abstract. Precision measurements of the exclusive branching fraction $\tau^- \to K^-\pi^0\nu_\tau$ and $\tau^- \to h^-h^-h^+\nu_\tau$, where the h represent either a pion or a kaon, from the *BABAR* Experiment are presented. The branching fraction for $\tau^- \to K^-K^-K^+\nu_\tau$ is the first resonant plus non-resonant measurement of this mode and the branching fraction $\tau^- \to \phi\pi^-\nu_\tau$ is also a first measurement. In addition, we present the new measurement of the branching fraction of $\tau^- \to \phi K^-\nu_\tau$.

1. Introduction

The coupling of the weak current to the first and second generations of quarks may be measured to an precedent precision in hadronic τ decays[1]. By utilizing QCD Sum Rules to compare τ decays with unit strangeness to non-strange τ decays, one can extract the CKM matrix element $|V_{us}|$ and the strange quark mass[2, 3, 4, 5, 6]. The extraction of these Standard Model (SM) parameters are presently limited by the experimental measurements of the strange spectral density function. Two of the strange decay modes that contribute significantly to the total uncertainty of the strange spectral density function are $\tau^- \to K^-\pi^0\nu_\tau$ and $\tau^- \to K^-\pi^-\pi^+\nu_\tau$. The $\mathcal{B}(\tau^- \to \phi\pi^-\nu_\tau)$ which is an OZI decay, provides information about $\phi - \omega$ mixing[7].

2. The *BABAR* Detector, Data set, and Monte Carlo Samples

This analysis employs data collected with the *BABAR* detector at the PEP-II storage ring which has a centre-of-mass (CM) energy near $\sqrt{s} = 10.58$GeV. At these energies, the cross section is $\sigma(\tau^+\tau^-) = (0.919 \pm 0.003)$nb[8]. A detailed description of the *BABAR* detector can be found in [9]. The $\tau^- \to K^-\pi^0\nu_\tau$ analysis used a data set with 211 million $\tau^+\tau^-$ pairs while the $\tau^- \to h^-h^-h^+\nu_\tau$ analysis used a slightly larger data set with 314 million $\tau^+\tau^-$ pairs. Details about the Monte Carlo (MC) samples can be found in [10, 11].

3. Measurements of Hadronic τ Branching Ratios

A pure sample of $\tau^+\tau^-$ pair events are selected by requiring the events to contain a hadronic component and an isolated leptonic decay which is separated from the hadrons by the plane perpendicular to the thrust axis in the CM. Events are required to have a missing momentum for the undetected neutrinos and a high thrust to be consistent with coming from $\tau^+\tau^-$ pair decays.

Once the $\tau^+\tau^-$ pair events are selected, identification of the hadronic decay begins. In the $\tau^- \to K\pi^0\nu_\tau$ analysis the signal side is required to contain a single charged kaon and a π^0 particle. The branching fraction is then determined from $\mathcal{B}(\tau^- \to K^-\pi^0\nu_\tau) =$

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$\frac{1}{2\mathcal{L}\sigma_{\tau^+\tau^-}} \frac{N^{Sel}-N^{Bkg}}{\epsilon_{\tau\to K^-\pi^0\nu_\tau}}$ where $\mathcal{L}$ is the luminosity, $\sigma_{\tau^+\tau^-}$ is the $e^+e^- \to \tau^+\tau^-$ cross section, N^{Sel} is the number of selected event, N^{Bkg} is the number of background events determined from the MC and $\epsilon_{\tau^-\to K^-\pi^0\nu_\tau}$ is the $\tau^- \to K^-\pi^0\nu_\tau$ efficiency determined from the MC. Details for this analysis can be found in [10].

In the $\tau^- \to h^-h^-h^+\nu_\tau$ signal side the 3 hadrons must not be identified as electrons. Events with large unassociated net neutral energies are rejected to remove π^0 backgrounds. The hadron particles are then identified as either pion or kaon separating the event into the four decay modes: $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$, $\tau^- \to K^-\pi^-\pi^+\nu_\tau$, $\tau^- \to K^-\pi^-K^+\nu_\tau$, and $\tau^- \to K^-K^-K^+\nu_\tau$. The number of signal events, in true mode j, is extracted by means of a migration matrix, $\mathbf{N}_j^{Sig} = \sum_i (\epsilon^{-1})_{ji} \left(\mathbf{N}_i^{Data} - \mathbf{N}_i^{Bkg}\right)$ where $\mathbf{N}_i^{Data}$ is the number of selected data in channel i, $\mathbf{N}_i^{Bkg}$ is the number of background events in channel i and ϵ_{ij} is the migration matrix. The branching fraction is then obtained from $\mathbf{Br}_j = \frac{\mathbf{N}_j^{Sig}}{2\mathcal{L}\sigma_{\tau^+\tau^-}}$. The $\phi(1020)$ peaks observed in both the $\tau^- \to K^-\pi^-K^+\nu_\tau$, and $\tau^- \to K^-K^-K^+\nu_\tau$ decay modes are measured by means of a binned maximum likelihood fit of the K^+K^- invariant mass plots where the kaon selection has been loosened to increase the selection efficiency. The K^+K^- invariant mass distribution with the fitted function overlayed may be found in Figs. 1 and 2 in [11]. A more indepth description of the $\tau^- \to h^-h^-h^+\nu_\tau$ analysis may be found in [11]. The measured branching fractions compared to the world average values can be found in Table 1.

Table 1. Summary of the branching ratios presented in this paper and the world averages for comparison.

Decay Mode	World Average	*BABAR* Measurement
$\tau^- \to K^-\pi^0\nu_\tau$	$(4.54 \pm 0.30) \times 10^{-3}$ (PDG Avg. [12])	$(4.16 \pm 0.03 \pm 0.18) \times 10^{-3}$
$\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$	$(9.02 \pm 0.08) \times 10^{-2}$ (PDG Fit. [12])	$(8.83 \pm 0.01 \pm 0.13) \times 10^{-2}$
$\tau^- \to K^-\pi^-\pi^+\nu_\tau$	$(3.33 \pm 0.35) \times 10^{-2}$ (PDG Fit. [12])	$(2.73 \pm 0.02 \pm 0.09) \times 10^{-3}$
$\tau^- \to K^-\pi^-K^+\nu_\tau$	$(1.53 \pm 0.10) \times 10^{-2}$ (PDG Fit. [12])	$(1.346 \pm 0.010 \pm 0.036) \times 10^{-3}$
$\tau^- \to K^-K^-K^+\nu_\tau$	$< 3.7 \times 10^{-5} CL = 90\%$ [12]	$(1.58 \pm 0.13 \pm 0.12) \times 10^{-5}$
$\tau^- \to \phi\pi^-\nu_\tau$	$< 2.0 \times 10^{-4} CL = 90\%$ [12]	$(3.42 \pm 0.55 \pm 0.25) \times 10^{-5}$
$\tau^- \to \phi K^-\nu_\tau$	$(4.06 \pm 0.25 \pm 26) \times 10^{-2}$ [13]	$(3.39 \pm 0.20 \pm 0.28) \times 10^{-5}$

4. Conclusion

With these new branching fractions, and the recent $\mathcal{B}(\tau^- \to K_S\pi^-\nu_\tau)$ from Belle[14], the strange spectral density function can be updated yielding a measurement of $|V_{us}|$. Fig. 1 includes the measured values of $|V_{us}|$ present at EPS 2007 and recent values from [15]. Although the $R^{0,0}$ spectral moment are known to have theoretical issues with convergence, the other weights do not exhibit this problem. The deviation of $|V_{us}|$ extracted from τ from the unitarity value and the possibility of new physics make measurements of the strange spectral density function from hadronic τ decays and $\tau^- \to K^-\nu_\tau$ very interesting.

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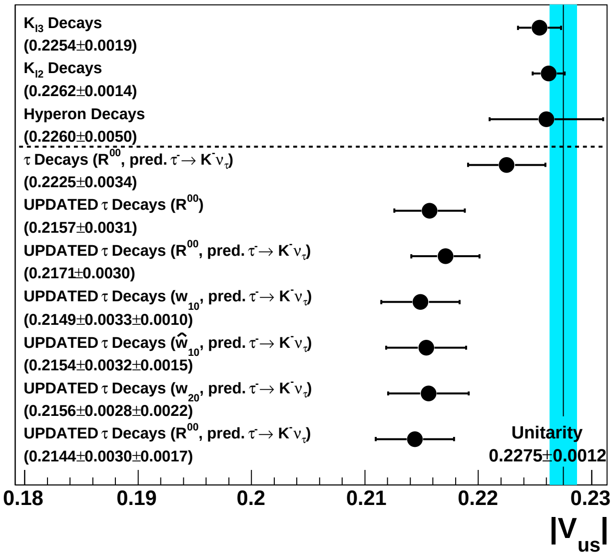

Figure 1. An update of the $|V_{us}|$ extraction from hadronic τ decays with the new branching fractions from this paper and the $\mathcal{B}(\tau^- \to K_S \pi^- \nu_\tau)$ by Belle[14]. The upper three values of $|V_{us}|$ are the current non-τ measurements[16, 17, 18], while the fourth value was the $|V_{us}|$ measurement from tau decays before the updated branching fractions[18]. The updated values of $|V_{us}|$ from τ decays [15, 18, 19] have a significant deviation from the light grey band which represent the unitarity value of $|V_{us}|$.

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