PROCEEDINGS OF SCIENCE

Second-class current in $\tau \to \pi\eta\nu$ analysis and measurement of $\tau \to hh'h''\nu$ from Belle ∼Electroweak physics from Belle∼

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Based on a 670 fb^{-1} data sample accumulated at the Belle detector, we have looked for a second-class current decays $\tau \to \pi\eta\nu$ and $\tau \to \pi\eta'(958)\nu$. First possible indications for the $\tau \to \pi\eta\nu$ decay are attained with a 2.4 significance corresponding to the branching fraction $\mathscr{B}(\tau^- \to \pi^-\eta\nu_\tau) = (4.4 \pm 1.6 \pm 0.8) \times 10^{-5}$ or $\mathscr{B} < 7.3 \times 10^{-5}$ at 90% confidence level. Also, the upper limit on $\mathscr{B}(\tau^- \to \pi^-\eta'(958)\nu_\tau)$ is set as 4.6×10^{-6} at the 90% confidence level. We have also measured the branching fractions for τ decay into three charged pseudoscalars, and examined their invariant mass distributions.

The 2009 Europhysics Conference on High Energy Physics,
July 16 - 22 2009
Krakow, Poland

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1. Introduction

Second-class currents (SCC) introduced by S. Weinberg in 1958 [1] are expected to be rather small in the standard model and vanish in the limit of the isospin symmetry. The second-class (first-class) current is defined by $PG(-1)^J = -1$ $(+1)$, where P is the parity, G is the G-parity and J is the spin of the decay current. So far, only first-class currents have been observed in weak interactions; no process via SCC has been ever found. In τ decay, $\tau^- \to \pi^-\eta^{(\prime)}\nu_\tau$ is the typical decay mode purely induced by SCC, and the current upper limit on its branching fraction is set as 1.4×10^{-4} (7.2×10^{-6}) at the 95% (90%) confidence level (CL) by CLEO (BaBar) [2][3]. The predicted branching fraction [4] for $\tau^- \to \pi^-\eta\nu_\tau$ decay is $\mathcal{O}(10^{-5})$ which is within the sensitivity accessible at Belle with data samples.

In order to acquire essential information on the CKM matrix element, $|V_{us}|$, the strange-quark mass, m_s, and the hadronic form factors, we analyze $\tau^- \to h^-h'^+h''^-\nu_\tau$ $(h = \pi, K)$ decays in terms of their branching fractions and invariant mass distribution for $h^-h'^+h''^-$.

The description of the Belle detector at the KEKB asymmetric-energy e^+e^- collider can be found elsewhere [5].

2. $\tau^- \to \pi^-\eta\nu_\tau$

To select $\tau^- \to \pi^-\eta\nu_\tau$ candidates, the event topology is required to be a $3-1$ prong, where one τ (signal τ) decays to $\pi\pi\pi\pi^0\nu$ with $\pi^0 \to \gamma\gamma$ and the other (tagged τ) decays leptonically. The invariant masses, calculated from all of the 4-momenta of the signal and tag sides, are required to be less than the τ mass, and the direction of the missing momentum to be within the detector acceptance.

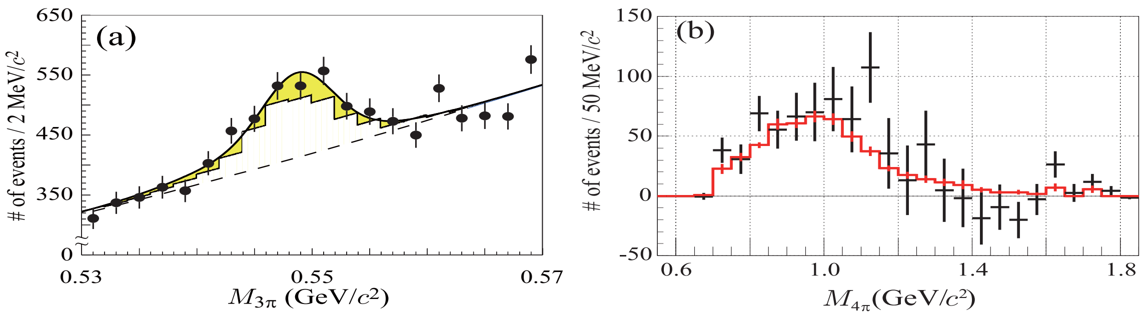

Figure 1: (a) $M_{3\pi}$ distribution. The full and dashed curves indicate the fit result and combinatorial BG's, respectively, and the histogram is the η-peaking contaminations. (b) $M_{\pi\eta}(= M_{4\pi})$ distribution of the η candidates (crosses). The η-peaking contaminations are shown by the histogram.

We obtain the $M_{3\pi}$ distribution, as shown in Fig. 1(a). A Monte Carlo (MC) investigation tells us that the combinatorial BG's comprise $\tau^- \to \pi^-\pi^+\pi^-\pi^0\nu_\tau$ ($\sim$ 60%), $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ + two extra γ's ($\sim$ 26%) and the others: such as other generic τ decays and the $q\bar{q}$ process ($\sim$ 14%). We evaluate the number of η candidates $(N_\eta^{\rm fit})$ by fitting the above-obtained $M_{3\pi}$ distribution with the signal plus BG functions, each represented by three combined Gaussian functions and the 2nd polynomial function. The fit provides $N_\eta^{\rm fit} = 749.2 \pm 67.3$ with $\chi^2/\mathrm{NDF} = 62.6/48$. These η events are contaminated with η-peaking BG's, coming from the $\tau^- \to \pi^-\pi^0\eta\nu_\tau$, $K^{*-}\eta\nu_\tau$, $K^-\eta\nu_\tau$

and $q\bar{q}$ processes. Based on our recent precise measurement of the branching fractions of these τ decay-modes [6], MC attributes 558.3 ± 13.3 events to such a BG contamination (indicated by the histogram in Fig. 1(a)). The obtained number of the signal events is 190.9 ± 68.6. The signal detection efficiency is evaluated to be 4.4%, and the total systematic uncertainty is 17.6%, where the largest contribution comes from the error of the branching fraction of $\tau^- \to \pi^-\pi^0\eta\nu_\tau$. The branching fraction is accordingly obtained as

$$\mathscr{B}(\tau^- \to \pi^-\eta\nu_\tau) = (4.4 \pm 1.6 \pm 0.8) \times 10^{-5}, \tag{2.1}$$

where the second (third) term is the statistical (systematic) uncertainty. The significance of this result is 2.4σ from the null value: we can set the upper limit of $\mathscr{B}(\tau^- \to \pi^-\eta\nu_\tau) < 7.3 \times 10^{-5}$ at the 90% CL. [1]

The $M_{\pi\eta} (= M_{4\pi})$ distribution for the η signals ($542 < M_{\eta(3\pi)} < 556$ (GeV/c^2)) is extracted by subtracting the combinatorial BG's using the η's side-band events, as can be seen in Fig. 1(b), where the histogram is the contamination of the η-peaking BG's, estimated by MC. There is a 2.4σ difference between the extracted data and contaminated BG's. Further, from theory the $\pi\eta$ system is expected to proceed predominantly via the $a_0(980)$ and partly $\rho(770)$ resonances, whereas the distribution of the data is rather flat from 0.8 to 1.0 GeV/c^2 showing an enhancement at 1.1 GeV/c^2. A study is in progress.

3. $\tau^- \to \pi^-\eta'(958)\nu_\tau$

Candidates for $\eta' \to \pi^+\pi^-\eta$ decay with $\eta \to \gamma\gamma$ are looked for by applying similar selection criteria as for $\tau^- \to \pi^-\eta\nu_\tau$. We obtain the number of candidates as $n_{\eta'} = -2.9^{+24.5}_{-23.7}$ events with a detection efficiency of 2.9%: No appreciable η' signal is found. The resulting upper limit on the branching fraction is found to be $\mathscr{B}(\tau^- \to \pi^-\eta'\nu_\tau) < 4.6 \times 10^{-6}$ at the 90% CL. This is the most strict upper limit so far attained.

4. $\tau^- \to h^-h'^+h''^-\nu_\tau$ ($h = \pi, K$)

The signal is selected by requiring 3 prongs on the signal τ and a lepton on the tagged τ. The most essential element of this study relies on particle identification, especially, K/π identification. Thus, the threshold of likelihood for K/π separation is determined so as to maximize its figure of merit. Since substantial BG's are attributed to cross-feeds among the different signal modes of

	Belle	BaBar [7]	PDG2006 [8]
$\mathscr{B}(\tau^- \to \pi^-\pi^+\pi^-\nu_\tau)$ $(\times 10^{-2})$	$8.42 \pm 0.01^{+0.24}_{-0.23}$	$8.83 \pm 0.01 \pm 0.13$	9.02 ± 0.08
$\mathscr{B}(\tau^- \to K^-\pi^+\pi^-\nu_\tau)$ $(\times 10^{-3})$	$3.28 \pm 0.02 \pm 0.12$	$2.73 \pm 0.02 \pm 0.09$	3.33 ± 0.35
$\mathscr{B}(\tau^- \to K^-K^+\pi^-\nu_\tau)$ $(\times 10^{-3})$	$1.53 \pm 0.01 \pm 0.05$	$1.35 \pm 0.01 \pm 0.04$	1.53 ± 0.10
$\mathscr{B}(\tau^- \to K^-K^+K^-\nu_\tau)$ $(\times 10^{-5})$	$2.62 \pm 0.23 \pm 0.22$	$1.58 \pm 0.13 \pm 0.12$	< 3.7

Table 1: List of the branching fractions for $\tau^- \to h^-h'^+h''^-\nu_\tau$ obtained by Belle, BaBar and PDG2006. Because PDG2008 results include BaBar's results, those in PDG2006 are listed.

[1] The corresponding confidence interval for branching fraction is $[1.7, 7.3] \times 10^{-5}$ at the 90% CL.

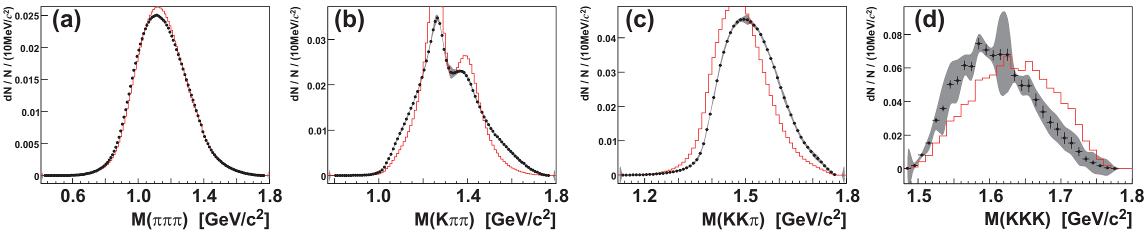

Figure 2: Unfolded mass spectra for (a) $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$, (b) $K^-\pi^+\pi^-\nu_\tau$, (c) $K^-K^+\pi^-\nu_\tau$ and (d) $K^-K^+K^-\nu_\tau$. The crosses are the unfolded mass spectrum with the statistical uncertainties, and the shaded bands indicate their systematic uncertain ranges, while the histograms are TAUOLA generator predictions, normalized to the total number of events.

the $\tau^- \to h^-h'^+h''^-\nu_\tau$ decay due to K/π mis-identification, a simultaneous evaluation of them is performed. Table 1 summarizes the resulting branching fractions.

The resulting $M_{h^-h'^+h''^-}$ distributions are unfolded from the detector response by means of the response matrix. The matrix is evaluated from a MC simulation, and inverted in the unfolding process based on the Singular Value Decomposition technique. The unfolded spectra are shown in Fig. 2. This is the first report of the unfolded mass distributions for the $h^-h'^+h''^-$ systems. With increasing the number of Kaons, the difference between data and TAUOLA becomes larger.

5. Summary

Since its introduction in 1958, we have first found a possible indication of the second-class current of the $\tau^- \to \pi^-\eta\nu_\tau$ decay, using 670 fb^{-1} of data accumulated by the KEKB-Belle experiment. The observed branching fraction is

$$\mathscr{B}(\tau^- \to \pi^-\eta\nu_\tau) = (4.4 \pm 1.6 \pm 0.8) \times 10^{-5}.$$

Its significance corresponds to a 2.4σ. Also, we attained the most strict upper limit on the other SCC decay, as $\mathscr{B}(\tau^- \to \pi^-\eta'\nu_\tau) < 4.6 \times 10^{-6}$ at the 90% CL. In addition, we measured the branching fractions of $\tau^- \to h^-h'^+h''^-\nu_\tau$ ($h = \pi, K$) decays, and for the first time evaluated the unfolded distributions of $M_{hh'h''}$.

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