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Search for second-class currents with the τ decay into $\pi\eta\nu$

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The hadronic weak currents without strangeness can be classified into first- and second-class currents according to their G-transformation properties. In the Standard Model, second-class currents are strongly suppressed by isospin symmetry violation and no such currents have been observed so far. Given its quantum numbers, the decay $\tau^- \to \pi^-\eta\nu_\tau$ can be induced only through second-class currents, with theoretical predictions estimating a branching ratio of $\mathrm{O}(10^{-5})$. Such a fraction is reachable within the available integrated luminosity at the Belle experiment. In this work, we report the status of the analysis of the decay channel $\tau^- \to \pi^-\eta\nu_\tau$ based on Monte Carlo simulated samples. Expected sensitivities assuming the full data size of the Belle experiment are also presented.

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1. Introduction

The weak hadronic currents without strangeness can be classified into two types depending on their G-parity transformation properties [1]: first-class currents transform as $PG(-1)^J = +1$, while the second-class currents (SCC) must follow $PG(-1)^J = -1$, where P is the parity and J is the spin of the current. In the Standard Model, SCC are strongly suppressed due to isospin symmetry and no such currents have been observed so far, providing a good environment for the search of new physics effects coming from the contribution of scalar and tensor currents [2].

Among the SCC τ decays, we focus on the decay $\tau^- \to \pi^-\eta\nu_\tau$ ($J^{PG} = 0^{+-}$). Theoretical calculation predict a branching fraction of O(10^{-5})[3], which is in a range accessible using the data set obtained with the Belle detector at the KEKB e^+e^- collider [4]. In this note, we report the status in the analysis of the decay channel $\tau^- \to \pi^-\eta\nu_\tau$, based on Monte Carlo (MC) simulated samples and expected significance assuming full data collected in the Belle experiment.

In previous studies, Belle (BaBar) reached 90% confidence level upper limits on the branching fractions $BR(\tau^- \to \pi^-\eta\nu_\tau) < 7.3\times10^{-5}(9.9\times10^{-5})$ [5, 6].

2. Signal reconstruction for $\tau^- \to \pi^-\eta\nu_\tau$ with $\eta \to \pi^-\pi^+\pi^0$

To select $\tau^- \to \pi^-\eta\nu_\tau$ candidates, the event is divided by the thrust vector into two hemispheres in the center-of-mass frame regarded as the signal and tag sides with three and one tracks, respectively; for the signal side the τ lepton decays into $\pi\eta\nu_\tau$ with $\eta \to \pi^-\pi^+\pi^0$ and for the tag side the τ decays to $l\nu_\tau\nu_l$ ($l = e$ or μ).

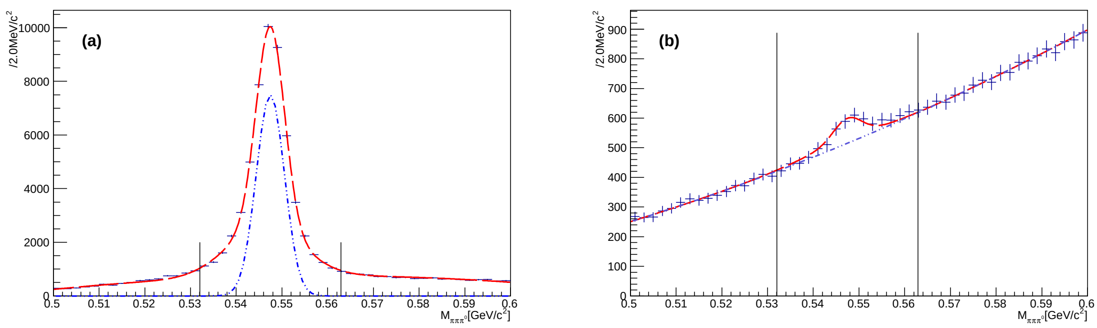

Figure 1: (a) $M_{\pi\pi\pi^0}$ distribution for signal MC. Fit result curve is shown by the red dashed curve. The blue dash-dotted line is the main peak of the signal contribution. (b) $M_{\pi\pi\pi^0}$ distribution for $\tau^+\tau^-$ MC samples of 702.9 fb^{-1}. The red full and blue chain curve show the fit result and yield for non-η background, respectively. The yield for η candidates is 419.1 ± 82.6.

Since the τ lepton is not fully reconstructed due to the neutrino, we evaluate the signal yield using the number of η candidates from a fit on the invariant mass $M_{\pi\pi\pi^0}$ of $\pi^-\pi^+\pi^0$ candidates, where the four-momentum of the π^0 is evaluated after a mass-constraint fit. There exist two $\pi^-\pi^+\pi^0$ combinations in the signal side, and we treat both combinations as η candidates. The probability density functions used for signal and background are a double-Gaussian and a second order polynomial, respectively. From the signal MC a signal window is set as 547 ± 15 MeV/c^2, which corresponds to $\pm\,5\sigma$ region of the main peak as shown in Fig. 1(a). From a data set of

1.3×10^7 MC events, the fit yields $(4.64 \pm 0.03) \times 10^4$ events as signal. The signal detection efficiency is then $0.350 \pm 0.002\%$.

3. Expected background

The background is categorized whether or not the η candidate is included in signal side. The first category has τ decays and $q\bar{q}$ ($q = u, d, s, c$) continuum events with an η that is expected to contaminate the $M_{\pi\pi\pi^0}$ signal peak. The second one forms combinatorial backgrounds. Two-photon processes are confirmed to be negligible after applying the selections. The number of expected background events with an η is estimated from the generic MC samples of $e^+e^- \to \tau^+\tau^-(q\bar{q})$, which are five times larger than the experimental data available, as summarized in Table 1.

Mode	Branching fraction [7]	Expected number for 702.9 fb^{-1}
$\tau^- \to \pi^-\eta\pi^0\nu_\tau$	$(1.39 \pm 0.07) \times 10^{-3}$	35.1 ± 2.2
$\tau^- \to K^-\eta\nu_\tau$	$(1.55 \pm 0.08) \times 10^{-4}$	114.0 ± 4.1
$\tau^- \to K^{*-}\eta\nu_\tau$	$(1.38 \pm 0.15) \times 10^{-4}$	259.1 ± 6.1
$q\bar{q}$ continuum	—	72.8 ± 14.1

Table 1: Contamination of the $M_{\pi\pi\pi^0}$ signal region by τ decays, their branching fractions and expected number of events.

The number of expected signal events will be calculated from the experimental data, subtracting the numbers of estimated background events to the fit result to the $M_{\pi\pi\pi^0}$ distribution, after scaling with the integrated luminosity. For demonstration, we analyze a generic $e^+e^- \to \tau^+\tau^-$ MC sample excluding the signal mode, which corresponds to an integrated luminosity of 702.9 fb^{-1}, as shown in Fig. 1(b). We obtain 16$\pm$86 signal events, which is consistent with zero.

4. Expectation of significance

The significance is evaluated considering data recorded by the Belle experiment at the $\Upsilon(4S)$ resonance (702.9 fb^{-1}), and data recorded at the $\Upsilon(4S)$, $\Upsilon(5S)$ resonances and continuum scan (915.1 fb^{-1}). The estimated number of signal N_{signal} and the significance S are defined as

$$N_{\text{signal}} = 2\varepsilon N_{\tau\tau} BR(\tau^- \to \pi^-\eta\nu_\tau) \tag{4.1}$$

$$S = N_{\text{signal}}/E_{\text{signal}}, \tag{4.2}$$

where ε is the selection efficiency, $N_{\tau\tau}$ is the number of τ-pair events and E_{signal} is the error of the signal yield. The significance for each assumption of luminosity L and $BR(\tau^- \to \pi^-\eta\nu_\tau)$ is shown in Table 2.

5. Summary

In order to search for SCC through τ lepton decays, we study the sensitivity for the decay $\tau^- \to \pi^-\eta\nu_\tau$ with $\eta \to \pi^-\pi^+\pi^0$, based on MC samples corresponding to the full data set collected by the Belle experiment. A significance of 2.6σ is estimated to be achieved with the full data set and $BR(\tau^- \to \pi^-\eta\nu_\tau) = 4.4 \times 10^{-5}$.

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$BR(\tau^- \to \pi^- \eta \nu_\tau)$	L, fb^{-1}	N_{signal}	Significance S, σ
4.4×10^{-5}	702.9	245	2.3
	915.1	259	2.6
1.0×10^{-5}	702.9	45	0.5
	915.1	59	0.6

Table 2: Significance for each assumption of luminosity L and $BR(\tau^- \to \pi^- \eta \nu_\tau)$. The assumptions for $BR(\tau^- \to \pi^- \eta \nu_\tau)$ follow from the theoretical predictions and the previous study at Belle [5].

6. Discussion

In order to improve the significance, we would like to include hadronic tag τ decay as well. If we include $\tau^- \to \pi^- \nu_\tau$ in the tag side τ decay, the significance increases to 3.4 σ for 915.1 fb^{-1} and $BR(\tau^- \to \pi^- \eta \nu) = 4.4 \times 10^{-5}$ from a naive estimation considering the branching fraction of such a hadronic decay. Another possibility is to reconstruct the subdecay modes of the η meson besides $\pi^- \pi^+ \pi^0$. The branching fraction of the decay $\eta \to \gamma\gamma$ is larger ($(39.41 \pm 0.20)\%$), but a larger background contribution is expected too. According to rough estimations, considering the ratio between the number of signal events to the sum of signal and background events, the reachable significance is around 3.0σ from the decay $\eta \to \gamma\gamma$ only. Consequently, it turns out that using the decay $\eta \to \gamma\gamma$ provides a similar significance as using the decay $\eta \to \pi^- \pi^+ \pi^0$. Including the decay $\eta \to \gamma\gamma$ in this analysis should be seriously considered later.

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