SEARCH FOR THE DECAY $\tau^- \to \nu_\tau \eta \pi^-$

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We have searched for the decay $\tau^- \to \nu_\tau \eta \pi^-$ using data accumulated by the ARGUS detector at the e^+e^- storage ring DORIS II at DESY. No η signal was found in the $\pi^+\pi^-\pi^0$ subsystems of the decay $\tau^- \to \nu_\tau \pi^- \pi^- \pi^+ \pi^0$. We obtain an upper limit for the branching ratio of the decay $\tau^- \to \nu_\tau \eta \pi^-$ of 1.3% at the 95% confidence level.

In the SU(2)×U(1) standard model of the electroweak interaction, semihadronic τ^- [#1] decays are described by the exchange of a W^- boson between the $\tau^-\nu_\tau$ and the $\bar{u}d$ system, followed by the hadronisation of the quark–antiquark pair. The only possible combinations of spin, parity, and G-parity quantum numbers predicted by the standard V–A theory for isovector hadronic final states in τ decays [1] are

$$J^{PG}=1^{-+} \quad \text{(first-class vector current)}\,,$$

$$J^{PG}=0^{--},\,1^{+-} \quad \text{(first-class axial-vector current)}\,.$$

Second-class currents are defined to have the opposite G-parity compared to first-class currents [2]. The observation of τ decays into hadronic final states with J^{PG} other than 1^{-+}, 0^{--} or 1^{+-} would indicate the existence of second-class currents, G-parity violation in the hadronisation process, or other non-standard decay mechanism.

In a previous publication [3] we reported on the observation of the decay $\pi^-\to\nu_\tau\omega\pi^-$ and obtained a branching ratio of $(1.5\pm0.3\pm0.3)\%$. This decay mode was used to search for second-class axial–vector currents, but no evidence was found. The $\omega\pi^-$ system is dominantly in a $J^P=1^-$ state, and the differential partial width for the decay is in good agreement with the prediction based on CVC. In this report we describe the search for the decay $\tau^-\to\nu_\tau\eta\pi^-$. This decay mode has been proposed by several authors [4] as a genuine testing ground for the existence of second-class vector currents. The possible J^{PG} states of the $\eta\pi^-$ system are 0^{+-} or 1^{--}. Compared to searches for second-class currents in nuclear physics [5], where many form factors can contribute and the small four-momentum transfer may suppress the signal, the decay $\tau^-\to\nu_\tau\eta\pi^-$ is a unique indication for second-class vector currents. The HRS collaboration has recently reported evidence for the decay $\tau^-\to\nu_\tau\eta\pi^-$ and obtained a branching ratio of $(5.1\pm1.5)\%$ [6].

The measurement reported here was performed using the ARGUS detector at the e^+e^- storage ring DORIS II. The detector is a 4 π spectrometer, described in detail elsewhere [7]. An important feature of the detector is the eleectromagnetic calorimeter, located inside the solenoid, which covers 96% of the full solid angle. It was used for the detection of photons with energies down to 50 MeV. The event sample used for this analysis corresponds to an integrated luminosity of 234 pb^{-1}, accumulated at centre-of-masss energies ranging from 9.4 to 10.6 GeV. The selection method has been described elsewhere [3,8]. τ pair events were selected corresponding to the following combination of decays:

$$e^+e^-\longrightarrow\tau^+\ \ \tau^-\longrightarrow\nu_\tau\pi^-\pi^-\pi^+\pi^0$$
$$\tau^+\longrightarrow\bar{\nu}_\tau e^+\nu_e,\ \bar{\nu}_\tau\mu^+\nu_\mu,\ \bar{\nu}_\tau\pi^+,\ \bar{\nu}_\tau K^+,\ \text{or}\ \bar{\nu}_\tau\rho^+\,.$$

In order to enhance the acceptance for the decay $\eta\to\pi^+\pi^-\pi^0$, we released the cut in the $\pi^+\pi^-$ invariant mass which was used in ref. [3] to suppress converted photons. The 1043 selected events represent a reasonably clean sample of τ decay candidates in the channel $\tau^-\to\nu_\tau\pi^-\pi^-\pi^+\pi^0$. The distribution of the four-pion invariant mass is shown in fig. 1. The histogram gives the same distribution for events in which at least one of the $\pi^+\pi^-\pi^0$ subsystems has an invariant mass of less than 650 MeV/c^2.

The efficiency for observing the decay $\tau^-\to\nu_\tau\eta\pi^-$ with the subsequent decay $\eta\to\pi^+\pi^-\pi^0$ was determined by means of a Monte Carlo calculation. τ pair

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[15] Supported by the US Department of Energy, under contract DE-AS09-80ER10690.
[#1] References in this paper to a specific charged state are to be interpreted as also implying the charge conjugate state.

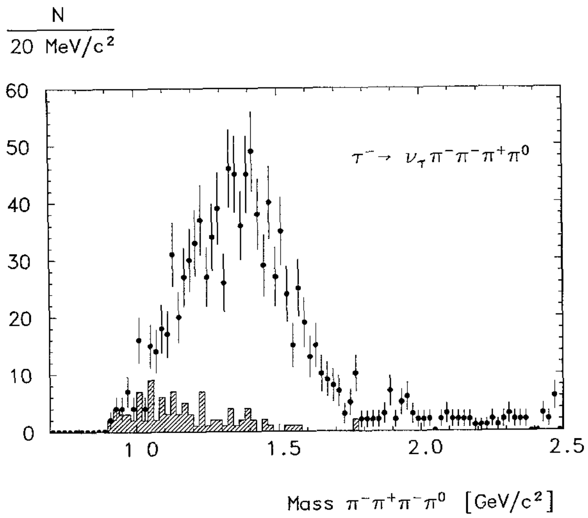

Fig 1. Distribution of the four-pion invariant mass from the decay $\tau^-\to\nu_\tau\pi^-\pi^-\pi^+\pi^0$ The histogram shows the same distribution for events in which at least one of the $\pi^+\pi^-\pi^0$ subsystems has an invariant mass of less than 650 MV/c^2

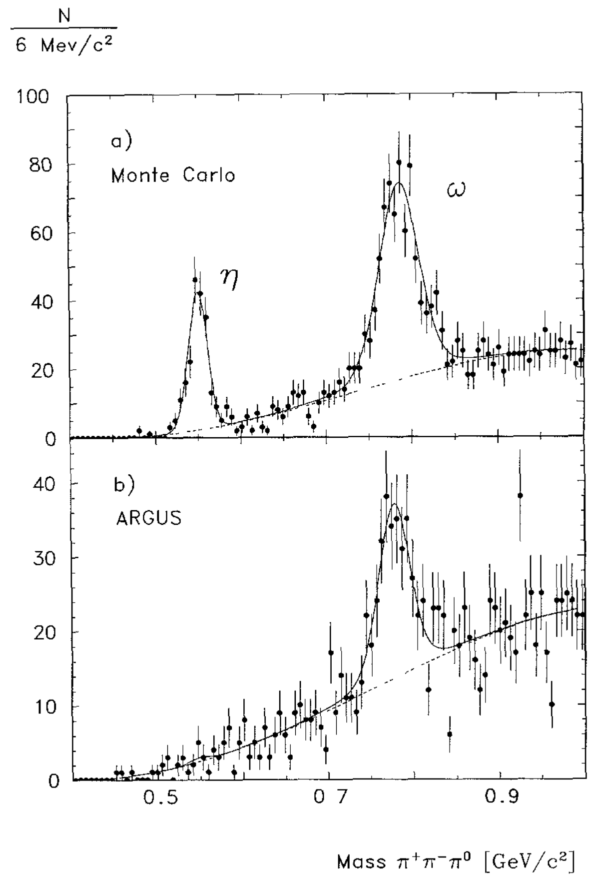

Fig. 2. Distribution of the invariant mass of the $\pi^+\pi^-\pi^0$ subsystem. Note that there are two entries per event. The full curves show the result of the maximum likelihood fits described in the text The background distributions are indicated by the dashed curves. (a) Monte Carlo generated events with an assumed ratio of branching ratios of $\mathrm{Br}(\tau^-\to\nu_\tau\eta\pi^-)/\mathrm{Br}(\tau^-\to\nu_\tau\omega\pi^-)=5/1\ 5$. (b) Data

events with one τ decaying into one charged particle and the other τ decaying into $\nu_\tau\pi^-\pi^-\pi^+\pi^0$ were generated. The latter decays were composed of 26% $\tau^-\to\nu_\tau a_0^-(980)$ with $a_0^-(980)\to\eta\pi^-$ and $\eta\to\pi^+\pi^-\pi^0$, 30% $\tau^-\to\nu_\tau\rho^-(1250)$ with $\rho^-(1250)\to\omega\pi^-$ and $\omega\to\pi^+\pi^-\pi^0$, and 44% $\tau^-\to\nu_\tau\rho^-(1600)$ with $\rho^-(1600)\to\pi^-\pi^-\pi^+\pi^0$. This corresponds to a ratio of branching ratios $\mathrm{Br}(\tau^-\to\nu_\tau\eta\pi^-)/\mathrm{Br}(\tau^-\to\nu_\tau\omega\pi^-)$ of 5/1.5. For the η and ω decays into $\pi^+\pi^-\pi^0$ the appropriate matrix elements were used [9,10]. The generated events were passed through a detector simulation [11] and analysed in the same way as the data. The invariant mass distribution of the $\pi^+\pi^-\pi^0$ subsystems is shown in fig. 2a. Note that there are two entries per event. The numbers of accepted η and ω events were obtained by fitting a gaussian to the η peak, a gaussian folded with a simple Breit–Wigner to the ω peak and a polynomial for the background. The ratio of η and ω efficiencies was found to be 0.35 ± 0.05. In this ratio, the systematic errors on the efficiency determination largely cancel. Using a phase space distribution instead of the $a_0^-(980)$ resonance does not, within the errors, change the efficiency for the $\eta\pi^-$ final state.

The invariant $\pi^+\pi^-\pi^0$ mass distribution from the data is shown in fig. 2b. The number of τ decays into $\eta\pi^-$ and $\omega\pi^-$ was determined in the same way as for the Monte Carlo events, but with position and width of the η peak fixed at the expected values of 549 MeV/c^2 and 11.0 MeV/c^2, respectively. The maximum likelihood fit gave $N_\eta=2.25^{+5.47}_{-4.10}$ and $N_\omega=199\pm27$. With the η and ω branching ratios for the decay into $\pi^+\pi^-\pi^0$ given in ref. [12] and the ratio of η and ω efficiencies obtained by the Monte Carlo calculation described above, we find for the ratio of branching ratios $\mathrm{BR}(\tau^-\to\nu_\tau\eta\pi^-)/\mathrm{Br}(\tau^-\to\nu_\tau\omega\pi^-)=0.122\pm0.299$. With a branching ratio for the decay $\tau^-\to\nu_\tau\omega\pi^-$ of $(1.5\pm0.3\pm0.3)\%$ [3] and taking into account a possible uncertainty in the $\pi^+\pi^-\pi^0$ mass scale, we convert that ratio into an upper limit and obtain as the final result

$$Br(\tau^- \to \nu_\tau \eta \pi^-) < 1.3\%$$

at the 95% confidence level.

In summary, we find no indication for the decay $\tau^- \to \nu_\tau \eta \pi^-$. We obtain an upper limit for the branching ratio appreciably smaller than the recently published value of $(5.1 \pm 1.5)\%$ [6]. We find no evidence for second-class vector currents.

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