INCLUSIVE η PRODUCTION IN τ DECAYS

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We have searched for inclusive η production in τ decays using a data sample of 2553 events of $e^+e^- \to \tau^+\tau^-$ in the one–three topology. The data were obtained using the High Resolution Spectrometer at $\sqrt{s}=29$ GeV. A 90% confidence level upper limit on the process $\tau^\pm \to \pi^\pm \eta X$ of 2.1% is found. Using τ decays to five charged particles limits of 0.5% on $\tau^\pm \to \pi^\pm \eta\eta X$ and 0.3% on $\tau^\pm \to \pi^\pm \pi^+ \pi^- \eta X$ are also obtained.

The observed properties of the τ lepton are generally in excellent agreement with it being a sequential lepton and its decays are well described by the standard model [1]. One outstanding problem however, is the discrepancy between the inclusive one-prong branching ratio and the sum of measured exclusive modes [2–4]. η production has been proposed as a possible explanation of this discrepancy, although the required level of η production would not be consistent with low energy e^+e^- annihilation data and the predictions of the standard model [5].

We have recently published evidence [6] for η production in the exclusive channel $\tau^\pm \to \pi^\pm \eta \nu$ using the decay $\eta \to \gamma\gamma$. The πη system has odd-*G* parity but is in the J^P series 0^+, 1^- and is, therefore, not expected in the standard model, since it would be produced by a second-class current [7].

In the present study, we have searched for inclusive η production in τ decays by analyzing the invariant mass distribution of the $\pi^+\pi^-$ system in three-prong τ decays. The specific decay chain looked for is $\tau^\pm \to \pi^\pm \eta X$ ($\eta \to \pi^+\pi^-\pi^0$) where X is one or more

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neutral particles. The data, corresponding to a total integrated luminosity of 300 pb^{-1}, were obtained at the PEP storage ring at a center of mass energy of 29 GeV using the high resolution spectrometer (HRS). A detailed description of the HRS can be found elsewhere [8]. For this analysis, the important features are a resolution at high momentum of $\sigma_p/p=2\times10^{-3}p$ (GeV/c) for charged particles and a barrel shower counter system with an energy resolution of $\sigma_E^2/E^2 \sim 0.16^2/E+0.06^2$ (E in GeV).

The cuts used to select events of the reaction $e^+e^- \to \tau^+\tau^-$ have been described previously [9] and resulted in a sample of 2553 events of the 1–3 topology in the solid angle region covered by the barrel shower counter system. The hadronic background is estimated to be $5.2\pm1.0\%$ based on an analysis of the three-prong effective mass. In order to search for $\eta\to\pi^+\pi^-\pi^0$, we have utilized the fact that this decay gives a peak in the $\pi^+\pi^-$ mass distribution between 0.28 and 0.41 GeV. The shape of this peak which has a width $\sim$80 MeV depends on the square of the η decay matrix element which can be parameterized as $1-a(3T_0/Q-1)$ where T_0 is the kinetic energy of the π^0 in the η rest frame and Q is the Q value for the decay. We have used $a=1.07$ as measured by Layter et al [10].

Since the decay $\eta\to\pi^+\pi^-\pi^0$ involves photons, the sample of 2553 three-prong τ decays was divided into 1446 events with neutral energy in the shower counter and 1107 events with no neutral energy. We have then assumed that the charged particles are pions and computed the two $\pi^+\pi^-$ mass combinations and the one doubly charged $\pi^\pm\pi^\pm$ mass combination for each sample. For most processes contributing to τ decay, for example ρ, ω and η production the $\pi^\pm\pi^\pm$ distribution will be identical to the distribution for one of the $\pi^+\pi^-$ combinations. A subtraction of this distribution from the total $\pi^+\pi^-$ mass spectrum will, therefore, yield the $\pi^+\pi^-$ distribution resulting from the decays of the resonances. Using this technique we have analysed the $\pi^+\pi^-$ mass distribution for the sample with no neutral energy and it is seen to be dominated by $\tau\to A_1\nu\to\rho^0\pi\nu$ as observed by other authors [11]. There are only a few events in the η region with $M_{\pi\pi}<0.41$ GeV.

The $\pi^+\pi^-$ mass distribution for the sample with neutral energy is shown in fig. 1. In order to determine the magnitude of η production, we have fitted

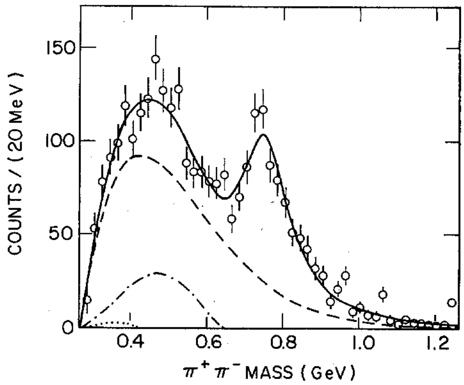

Fig. 1. The $\pi^+\pi^-$ mass distribution. The full line is the best fit fixing the $\tau\to\omega$ to be 1.75%. The inset curves show the fitted contributions from the η (dotted line), ω (dash, dot line) and the background (dashed line).

this spectrum with contributions from the η, ω, and ρ decays, plus a smooth background. For the background, we used a parameterization which gives an excellent fit to the $\pi^\pm\pi^\pm$ mass spectrum, as shown in fig. 2. In the fits to the $\pi^+\pi^-$ mass distribution however, the values of the background parameters are left free. The shape of the η and ω contributions have been determined using Monte Carlo events of τ decays passed through a full detector simulation [#1].

The fit to the data, shown in fig. 1 by the solid line, is the best fit obtained with all parameters free, except

[#1] The detector resolution and acceptance result in very small changes in the η and ω shapes. In addition the acceptance for the $\pi^+\pi^-$ system is the same as for a generic three-prong τ decay.

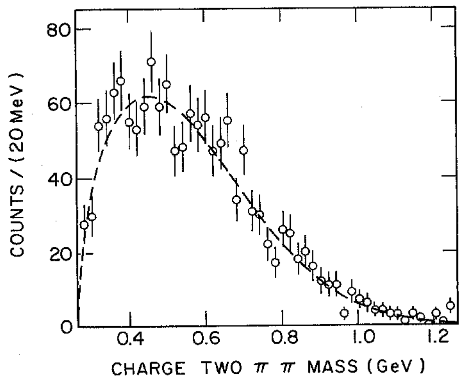

Fig 2. The charge-two $\pi^\pm\pi^\pm$ mass distribution for three-prong τ decays with additional neutral energy. The dashed line shows the best fit.

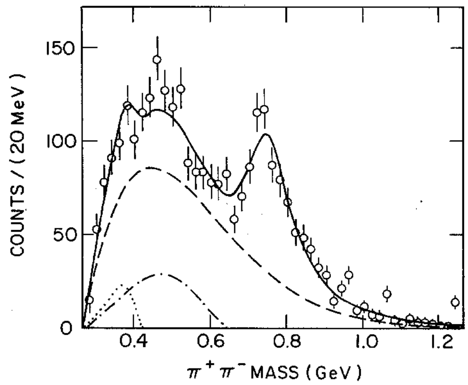

Fig. 3. The $\pi^+\pi^-$ mass distribution. The full line is the 90% upper limit fit with a $\tau\to\eta$ branching ratio equal to 2.1%. The inset curves show the fitted contributions from the η (dotted line), ω (dash, dot line) and the background (dashed line).

for a fixed $\tau\to\omega$ inclusive branching ratio of 1.75% #2. Only a small η contribution is found in this fit. To determine an upper limit on η production we now refit the data fixing η production at various values while leaving the parameters of the background free. Using the increase in χ^2 the 90% upper limit on η production is found and this fit is shown in fig. 3. After correcting for the η decay branching ratios, all acceptances and normalizing to $B_3 = 13.1 \pm 0.3\%$ [3] we find an upper limit on the branching ratio of $\tau^\pm\to\pi^\pm\eta X$, that is on inclusive η production, of 2.1% at the 90% confidence level.

Since the exact form of the background is unknown, we have tried a variety of fits to determine the sensitivity of the result to different assumptions. These tests included subtracting the doubly-charged events and fitting the resulting spectrum to $\rho+\omega+\eta+$smooth background. For various ω production rates and background shapes, we find fits corresponding to η branching ratios of 1.0–1.5%. Although there is no significant η signal, an inclusive η branching ratio of $1.0 \pm 0.7\%$ encompasses all of the fits. This result is consistent with the 2.1% upper limit previously quoted. Under the assumption that ω production is 1.5%, an absolute upper limit for the η production of 3.6% is obtained if, after the subtraction of the $\pi^\pm\pi^\pm$ distribution, all of the remaining events in the region $0.28 < M_{\pi\pi} < 0.41$ GeV are ascribed to η decay. This hypothesis, which requires the remaining $\pi^+\pi^-$ background to begin abruptly at 0.41 GeV, is not a reasonable interpretation of the data. However, we note that the excess of events in figs. 1 and 3 near 500 MeV #3 does suggest that our background parameterization is incomplete.

We have also used samples of Monte Carlo events including varying percentages of η to measure the sensitivity of the technique. The low mass peak in the $\pi^+\pi^-$ spectrum is clearly seen in the simulated events for a $\tau^\pm\to\pi^\pm\eta X$ branching ratio of 2% and a fit similar to that performed on the data gives the input branching ratio. This low mass peak is also seen in the hadronic annihilation data.

We note that the largest contribution for inclusive η production allowed within the current constraints of experimental data and the standard model involve τ decays to two η's [5]. Our best limit on $\tau^\pm\to\pi^\pm\eta\eta X$ is obtained from five-prong τ decays [13] by assuming all events which have two $\pi^+\pi^-$ mass combinations with $M < 0.41$ GeV could come from this process. This gives a 90% confidence level upper limit of 0.5% on the channel $\tau^\pm\to\pi^\pm\eta\eta X$. Similarly using events with one $\pi^+\pi^-$ mass less than 0.41 GeV gives an upper limit of 0.3% for $\tau^\pm\to\pi^\pm\pi^+\pi^-\eta X$. This last limit also sets the limit on $\tau^\pm\to\pi^\pm\pi^0\pi^0\eta\nu$ to be 0.3%.

The limit of 2.1% is not in agreement with our previously published result of $(5.1\pm1.5)\%$ for the branching ratio of the $\tau^\pm\to\pi^\pm\eta\nu$ using the $\eta\to\gamma\gamma$ decay mode. As stated in our previous paper however, a fit assuming no η and a smooth background had a χ^2 of 26.7 of which the η region contributed 10.9 corresponding to a 3.3 standard deviation effect. It appears, therefore, that our previous result is most probably due to a statistical fluctuation.

In summary, we have set a 90% confidence level upper limit on inclusive η production in τ decays of 2.1% and for decays involving two η's of 0.5% #4. These limits are truly inclusive in that they do not depend on assuming that the additional charged particles are pions or on the character of additional neu-

#2 ω production has been measured in the channel $\tau^-\to\omega\pi^-$ to be $1.5\pm0.3\pm0.3\%$ by ref. [12]. We have chosen 1.75% as the inclusive branching ratio, however, the results presented in this paper are not sensitive to changes in the ω production rate since its contribution is similar to the background.

#3 These events are not associated with the hadronic contamination in the τ sample.

#4 The 95% confidence level limits are 2.3% and 0.6%, respectively.

trals. The results are consistent with the standard model predictions and with cross sections from low energy e^+e^- annihilation. Our result means that η production cannot by itself explain the discrepancy between the sum of exclusive one-prong τ decays and the one-prong topological branching ratio. The current world average for B_1 is $86.8 \pm 0.3\%$ and the measured exclusive channels leave $\sim 7\%$ unaccounted for [3,14,15]. Our current limit would correspond to a one-prong contribution of $< 1.7\%$ for channels involving η production.

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