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Upper Limit on the Branching Ratio for the Decay $\tau^- \to \pi^- \eta \nu_\tau$ *

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ABSTRACT

We have searched for the decay $\tau^- \rightarrow \pi^- \eta \nu_\tau$ using the MARK II detector at the PEP e^+e^- storage ring. No evidence for the decay is found; the upper limit for the branching ratio is $B(\tau^- \rightarrow \pi^- \eta \nu_\tau) < 1.0\%$ at the 95% confidence level.

The effects of second class currents[1] have been extensively searched for in nuclear β decay and muon capture but to no avail.[2] The searches are at small momentum transfer and are complicated by nuclear form factors. Since the effects are proportional to the square of the momentum transfer, the τ lepton[3] allows a sensitive search[4] at large momentum transfer. Recently the HRS Collaboration reported evidence[5] for the second class current decay[6] $\tau^- \rightarrow \pi^- \eta \nu_\tau$. In this Letter, we present the result of a similar search using the Mark II detector.

The measurement is based on a data sample collected with the Mark II detector at the PEP e^+e^- storage ring operated at a center-of-mass energy of 29 GeV. The integrated luminosity for the sample is 220 pb^{-1} and corresponds to 30,000 produced τ-pair events. The Mark II detector has been described in detail elsewhere.[7] Features of the detector relevant for this analysis are the drift-chamber system and the central electromagnetic calorimeter. The drift chamber system consists of an inner high resolution drift chamber with seven concentric layers of sense wires and an outer drift chamber with sixteen layers of sense wires. The system measures charged-particle momenta with a resolution of $\sigma_p/p = [(0.02)^2 + (0.01p)^2]^{1/2}$($p$ in GeV/c) in a 2.3 kG solenoidal magnetic field. The calorimeter consists of eight lead liquid-argon (LA) modules with 14 radiation lengths, covering 65% of the solid angle, and detects electromagnetic showers with an energy resolution of $\sigma_E/E = 0.14/\sqrt{E}$ (E in GeV).

Production of τ-pairs at PEP energy yields a final state with a clear back-to-back topology, allowing events to be selected with little background. This analysis used only events that had zero net charge and contained two or four charged particles. The events were divided into two hemispheres by a plane perpendicular to the thrust axis and were required to have one charged particle in one hemisphere and one or three charged particles in the other. The total observed energy of each event was required to be between 7.25 and 23 GeV and the invariant mass of all particles in a hemisphere, including the photons, was required to be less than 2.0 GeV/c^2. In order to ensure a uniform trigger efficiency, the events were required to be in the central region of the detector, $|\cos\theta| < 0.7$, where θ is the polar angle of the thrust axis relative to the beam. Those hemispheres containing one charged particle and exactly two photons were considered to be potential candidates for the decay $\tau^- \rightarrow \pi^-\eta\nu_\tau$ with $\eta \rightarrow \gamma\gamma$. To reduce the probability that the photons were due to the interactions of the charged particles in the magnetic coil or in the LA, each of the photons was required to have energy greater than 300 MeV and to be more than 20 cm away from the locations where the charged particles struck the LA. These selection criteria yield 2276 two-photon candidates.

We searched for evidence for the η decay by studying the invariant mass spectrum of the two photons in the candidates. A Monte Carlo technique was used to determine the detection efficiency for the decay. The Monte Carlo simulation produced τ-pair events according to the standard electroweak theory, including α^3 QED corrections.[8] Each τ was allowed to decay according to the known branching ratios.[9] The simulation of electromagnetic interactions in the LA calorimeter was based on the EGS shower code.[10] The simulation[11] of hadronic interactions in the LA system was based on a library of real pion interaction data extracted from a sample of candidates for the decay $\tau^- \rightarrow \pi^-\pi^+\pi^-\pi^0\nu_\tau$.

The observed invariant mass spectrum of the two-photon system is shown in Fig. 1. A prominent π^0 signal is observed but there is no η signal. The Monte Carlo histogram, also shown in Fig. 1, is normalized to the observed π^0 peak

($m_{\gamma\gamma} < 300\,\mathrm{MeV/c^2}$) and contains the following branching ratios for the multiple neutral meson decay modes: $B(\tau^- \rightarrow \pi^- 2\pi^0 \nu_\tau) = 7.1\%$, $B(\tau^- \rightarrow \pi^- 3\pi^0 \nu_\tau) = 1.0\%$, and $B(\tau^- \rightarrow \pi^- \eta \pi^0 \nu_\tau) = 3.0\%$. It fits the data[12] without the decay $\tau^- \rightarrow \pi^- \eta \nu_\tau$. The predicted detection efficiency[13] is 4.2% for the $\pi^- \eta \nu_\tau$ decay.

We fit the observed mass spectrum in the region $180 < m_{\gamma\gamma} < 1000\ \mathrm{MeV/c^2}$ by a maximum likelihood technique to extract an upper limit for $\tau^- \rightarrow \pi^- \eta \nu_\tau$. The mass spectrum is represented by a Gaussian η signal plus a smooth background. The width of the Gaussian is determined in a Monte Carlo study. The background is parametrized by the sum of two exponentials,

$$e^{-\alpha_1 m} + \beta e^{-\alpha_2 m} \quad ,$$

where m is the mass of the two-photon system and α_1, α_2, β are the parameters. These parameters are obtained from a fit to the mass spectrum outside the η region, $440 < m_{\gamma\gamma} < 660\ \mathrm{MeV/c^2}$. The parameterization describes these data well, with a χ^2 of 21.0 for 27 degrees of freedom. With these parameters, the η region corresponds to a signal of 2.8 events on top of a background of 108 events. The 95% confidence level upper limit to the η signal is 19 events, corresponding to a limit on the branching ratio of $B(\tau^- \rightarrow \pi^- \eta \nu_\tau) < 0.75\%$. A slightly more stringent limit is obtained if the background parameters are allowed to be free in the fit. Using the background spectrum shape predicted by the Monte Carlo yields a similar limit.

The main systematic error is the uncertainty in the detection efficiency and pion interaction simulation. We have reported[14] a precise measurement of the branching ratio for $\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$ with an accuracy of 7%. The measurement is in excellent agreement with both the theoretical prediction and the results from other experiments. This η analysis is very similar to the π^0 measurement. Due to the larger opening angle[15] between the two photons in the η decay, there is less photon overlap confusion in the LA. Taking this into consideration, we estimate a systematic error of 7% for the uncertainty in the detection efficiency. Combining this error with the 3% statistical uncertainty in the efficiency due to limited Monte Carlo statistics and the 5% error in the luminosity measurement yields an upper limit of $B(\tau^- \to \pi^-\eta\nu_\tau)$ <0.88% at the 95% confidence level.

The limit also depends on the width of the η meson assumed in the fit. From the good agreement between the data and the Monte Carlo for the width of the π^0 signal observed in the τ events and the η signal observed in the hadronic events, we estimate a systematic uncertainty of 15% for the width. Including this uncertainty increases the limit to 1.0%.

The upper limit for the branching ratio of $B(\tau^- \to \pi^-\eta\nu_\tau) < 1.0\%$ corresponds to a signal of 25 events in the mass spectrum as shown in Fig. 2. The limit can be compared with the HRS measurement[5] of $B(\tau^- \to \pi^-\eta\nu_\tau) = (5.1 \pm 1.0 \pm 1.2)\%$, which corresponds to a signal of 128 events. Our result is in contradiction with the HRS measurement. Our result is in agreement with the upper limits of 2.5 and 1.3% from the Mark III[16] and Argus[17] Collaborations, respectively. Our result can be also compared with the indirect measurement[18] from the TPC Collaboration, $B(\tau^- \to K^-K^0\nu_\tau) < 0.26\%$. With the assumption[19] of an approximate flavor SU(3) symmetry, the TPC limit corresponds to $B(\tau^- \to \pi^-\eta\nu_\tau) < 5.1 \times B(\tau^- \to K^-K^0\nu_\tau) < 1.3\%$. Therefore our result is consistent with the TPC measurement.

We observe no evidence for second class current decay $\tau^- \to \pi^-\eta\nu_\tau$ and set an upper limit of $B(\tau^- \to \pi^-\eta\nu_\tau) < 1.0\%$ for the branching ratio at the 95%

confidence level.

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Figure Captions

Fig. 1. Two-photon invariant mass spectrum. The histogram shows the Monte Carlo expectation.

Fig. 2. An enlarged view of the mass spectrum. The full curve shows the best fit to the spectrum and the dotted curve shows the 95% confidence level limit of $B(\tau^- \rightarrow \pi^- \eta \nu_\tau) < 1.0\%$.

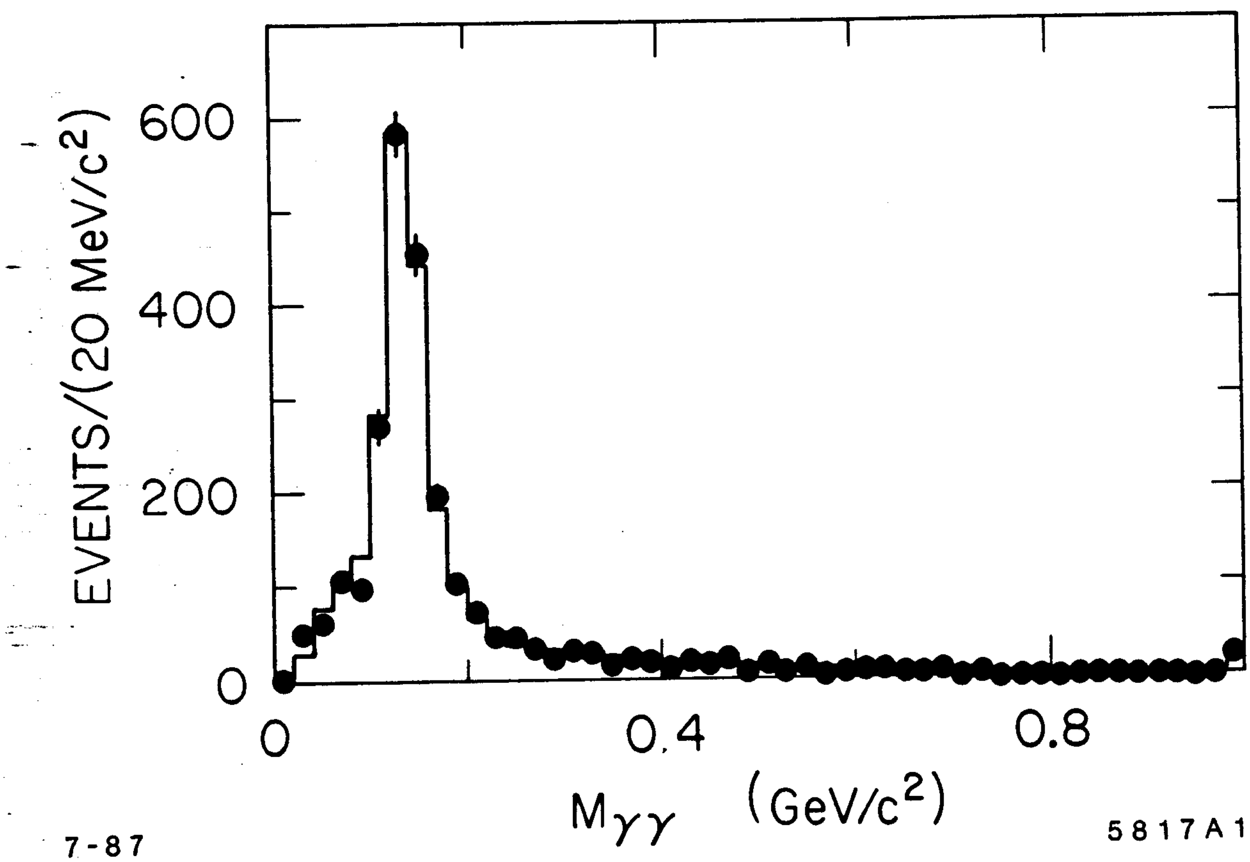
600
400
200
0
EVENTS/(20 MeV/c^2)
0
0.4
0.8
$M_{\gamma\gamma}$ (GeV/c^2)
7-87
5817A1

Fig. 1

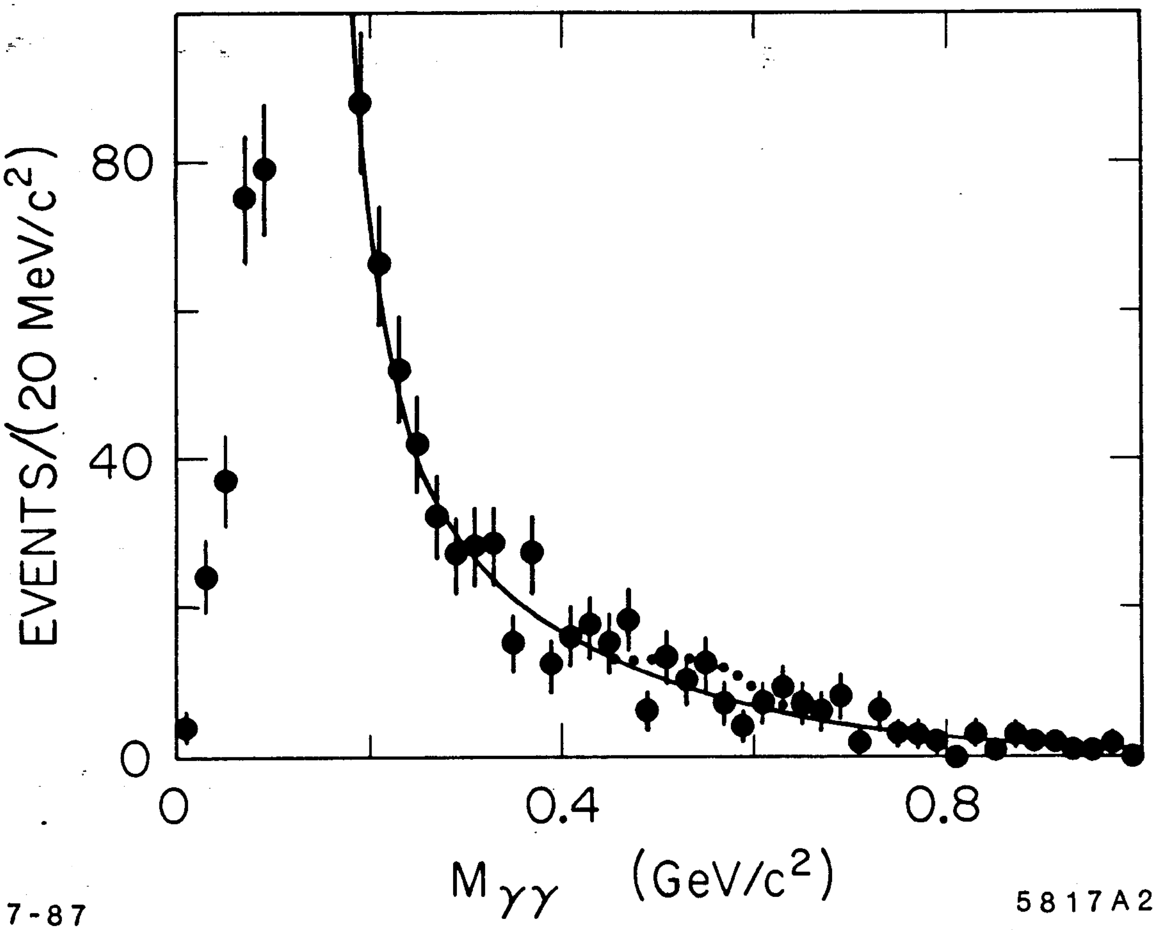

Fig. 2