UPPER LIMIT FOR THE DECAY $\tau\rightarrow\eta\pi\nu$

CELLO Collaboration

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The semi-hadronic decay of the $\tau\to\eta\pi\nu$ has been studied in the reaction $e^+e^-\to\tau^+\tau^-$ at center-of-mass energies between 14.0 and 46.8 GeV with the CELLO detector at PETRA. No evidence for the decay has been found with an upper limit of 1.4% at 90% CL for the branching ratio $\tau\to\eta\pi\nu$. This is in contradiction to a recent measurement of this final state at the 5% level. In the standard model this decay is strongly suppressed.

1. Introduction

Recently the HRS Collaboration [1] claimed to have observed the decay $\tau\to\eta\pi\nu$ in a high-statistics e^+e^- experiment with a branching ratio of $(5.1\pm1.5)\%$. Considering the quantum numbers of the $\eta\pi$ system, which has natural spin–parity ($J^P=0^+$ or 1^-) but odd G parity, this decay must be either a manifest violation of G parity in strong interactions or mediated by a second-class current [2]. Such currents are strongly suppressed in the standard theory of electroweak interactions. In the isospin limit (equal masses for the light quarks) second-class currents vanish altogether. Isospin violations are naturally expected of order α, the fine structure constant, so that branching ratios around 10^{-4} for the quoted decay are possible. It has been shown by various authors [3,4] that it is rather difficult, even in non-standard models, to obtain a large branching ratio at the few-percent level as reported. If the claimed decay were indeed confirmed the standard view of electroweak interactions would be subject to a major revision.

In order to study the decay $\tau\to\eta\pi\nu$ it is most important to isolate a clear signal for the η meson. The η decays mainly into the channels $\gamma\gamma$, $3\pi^0$, and $\pi^+\pi^-\pi^0$. In their analysis, HRS have concentrated on the decay mode into 2γ. Our analysis uses both the channels $\eta\to\gamma\gamma$ and $\eta\to\pi^+\pi^-\pi^0$. High-resolution liquid-argon calorimeters give CELLO an ability to investigate in great detail $\tau^+\tau^-$ final states containing several photons in addition to charged particles [5,6].

We are unable to confirm the signal quoted by HRS. In contrast, we present an upper limit for the decay $\tau\to\eta\pi\nu$, based on about one third of our total statistics.

2. Detector description

The data were taken, using the CELLO detector at PETRA, at CM energies between 14.0 and 46.8 GeV. The total integrated luminosity used for this analysis is about 65 pb^{-1}. CELLO [7] is a general-purpose magnetic detector equipped with a thin superconducting solenoid. Charged particles are measured in a cylindrical detector made of interleaved drift and proportional chambers in a 1.3 T magnetic field yielding a momentum resolution of $\sigma(p)/p=0.02p$ (p in GeV/c) without beam constraint over 91% of the full solid angle. For neutral-particle detection and charged-lepton identification we use the barrel part of a 20 radiation-lengths, fine-grain liquid-argon calorimeter which covers a solid angle of 86% of 4π. The energy deposited by particles in the liquid argon is collected on lead strips with three different orientations. The calorimeter is layered to yield 7 samplings in depth. This allows a very detailed measurement of the lateral and longitudinal shower development. The energy resolution is $\sigma(E)/E=0.05+0.10/\sqrt{E}$ (E in GeV), and the angular resolution varies from 6 to 10 mrad. Muons are detected behind an 80 cm thick iron absorber by large planar drift chambers covering 92% of 4π. The spatial resolution of these chambers is 0.6 cm in both coordinates.

3. Data sample

Due to its fine-grain calorimeter and central wire-chamber assembly the CELLO detector in principle is able to detect all τ decay channels. In our selections, however, we did not attempt to include $\tau^+\tau^-$ events where both τ's decay into either electrons or muons. Details of our selection procedures are described elsewhere [5,6].

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An important feature of the data analysis is a final visual scan which removes residual background in the selected event sample. A major source of this background is multihadronic events with unreconstructed charged particles leaving the central wire chamber assembly in the forward and backward directions, and radiative Bhabha events with incomplete reconstruction of charged particles and/or neutral showers.

The final event sample consists of 1970 events with an estimated background from non-tau final states of about 1.5%.

Efficiencies due to the selection procedure were determined by Monte Carlo methods using a detailed simulation of the reaction $e^+e^-\to\tau^+\tau^-$, including radiative effects to order α^3, in the CELLO detector. The four-vector generator [8] incorporated spin effects of the final state τ's. All known τ decay channels were simulated with the branching ratios recently determined [5]. The events were then passed through the same reconstruction and analysis programs as the data. An overall selection efficiency, including the scanning, of about 46% is obtained within our polar angle acceptance of $|\cos\theta|<0.85$. The main losses come from cuts to suppress QED background.

For the present analysis we generated, in addition to the conventional decay channels, a $\tau^+\tau^-$ event sample where one τ was allowed to decay into $\eta\pi\nu$ while the other τ decayed according to the known branching ratios. The mass spectrum for the hadronic system $\eta\pi$ was chosen according to a standard $V-A$ interaction with an effective mass cut-off at 1 GeV. The $\eta\pi$ system was assumed to be in an s wave. All possible decays for the η meson with branching ratios larger than 10^{-3} were simulated, the most important being $\eta\to\gamma\gamma$ (39%), $\eta\to\pi^0\pi^0\pi^0$ (32%), and $\eta\to\pi^+\pi^-\pi^0$ (24%). We found that the τ events containing η's have a slightly better selection efficiency (about 50%) than the average τ event.

4. Photon selection

The most important aspect of the present analysis lies in the proper identification and reconstruction of photons in the τ final state. Showers in the calorimeter are reconstructed in space using the analog signals from the lead strips in all three orientations. Those showers not linked to tracks in the central chambers are called neutral showers and are subsequently subjected to a selection procedure in order to identify the genuine photons.

Photons are required to have a minimum energy of 1% of the beam energy, corresponding to an effective energy cut of about 170 MeV. We furthermore required at least two adjacent layers in depth to contain energy in order to eliminate showers faked by electronic noise. Since electromagnetic showers were searched for, any neutral shower with substantial energy deposition behind 6 radiation lengths was rejected. This cut excludes photon showers with a late conversion but, most importantly, eliminates fragments from hadronic showers in the vicinity of charged particles. To further suppress hadronic showers or bremsstrahlung photons near unidentified electrons the neutral showers were required to be isolated in space by at least 3° from any charged-particle track. Monte Carlo simulation shows that the above criteria lead to photon efficiencies around 80% for energies above 1 GeV, falling to 50% at 500 MeV, and 10% at 100 MeV.

5. Search for the reaction $\tau\to\eta\pi\nu$

In order to investigate the decay $\tau\to\eta\pi\nu$ we restrict ourselves to the two decay modes of the η meson with a photon multiplicity of two, namely $\eta\to\gamma\gamma$ and $\eta\to\pi^+\pi^-\pi^0$. In the following we will discuss these two decay modes separately.

5.1. The decay $\eta\to\gamma\gamma$. For this decay mode we selected final states with one charged particle and exactly two photons in either of the two hemispheres defined by the plane normal to the event thrust axis. The η meson should show up as a bump at 550 MeV in the two-photon invariant mass distribution. This mass distribution is shown in fig. 1. No indication can be found for an η signal. A clear π^0 signal is visible as expected from the dominant decay $\tau\to\rho\nu$, $\rho\to\pi\pi^0$. We find the mass value, the line shape and the yield in excellent agreement with our Monte Carlo calculations incorporating standard τ decays. Events beyond the π^0 mass come from multiphoton final states (multi π^0 τ decays, radiative processes) where only two photons have been detected. If the two detected photons are associated with different π^0's the invariant mass is generally expected to be larger than the π^0 mass.

In order to test the sensitivity of the experiment to

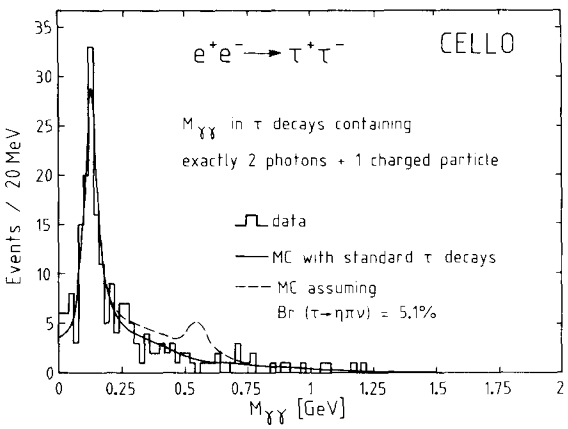

Fig. 1. Invariant γγ mass from τ final states containing exactly two photons plus one charged particle. The solid line drawn corresponds to the expectation from the known τ decays. The dashed line corresponds to the expectation including additionally the decay channel $\tau\rightarrow\eta\pi\nu$ with a branching ratio of 5.1%.

this particular η decay we subjected our simulated events containing $\tau\rightarrow\eta\pi\nu$ to the same selection criteria as the data and obtain a distribution for the invariant γγ mass as shown in fig. 2. A clear η peak at 550 MeV with a width of 40 MeV is predicted.

From our Monte Carlo calculations we estimate a detection efficiency for the decay $\tau\rightarrow\eta\pi\nu$, $\eta\rightarrow\gamma\gamma$ of 9.5%, not including the branching ratio of $\eta\rightarrow\gamma\gamma$. Within the η band between 460 and 660 MeV we observe 11 events whereas the expected background is 13.5 events. From these numbers we derive an upper limit for the η of 5.8 (7.2) events at the 90% (95%) CL. Fluctuations of the background, assuming Poisson statistics, are taken into account. These numbers translate into a 90% (95%) CL upper limit of 1.4% (1.7%) for the branching ratio of $\tau\rightarrow\eta\pi\nu$. The limits include uncertainties in the relative detection efficiency for the decay $\tau\rightarrow\eta\pi\nu$, $\eta\rightarrow\gamma\gamma$ with respect to the standard τ decay channels (4%) as well as the errors due to the limited statistics in the generated Monte Carlo events (3%). We prefer to derive the quoted upper limits by conservatively taking into account background fluctuations in the whole η-containing interval between 460 and 660 MeV rather than fitting a hypothetical η mass distribution to the γγ mass spectrum. The results therefore do not depend on assumptions concerning the experimental line shape of the η signal nor on the specific form of the background in the vicity of the η.

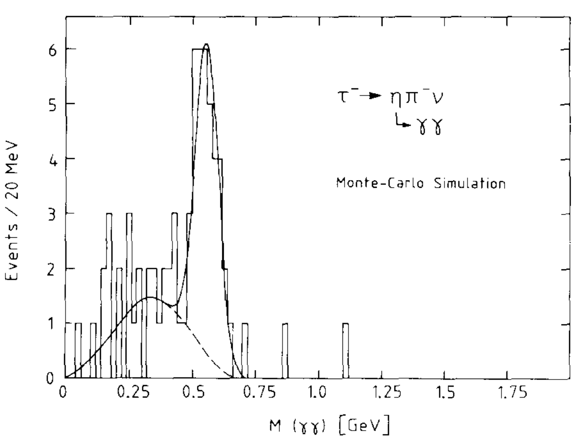

Fig. 2. Invariant γγ mass from τ final states decaying into ηπν from a detailed Monte Carlo simulation of the CELLO detector. Only final states containing exactly two photons plus one charged particle are included in the figure. The line drawn is the result of a fit assuming a gaussian peak over a general polynomial background.

A Monte Carlo calculation assuming a branching ratio of 5.1% as measured by the HRS Collaboration yields 21 events above background in the η band, in clear contradiction to our data, as shown in fig. 1.

5.2. The decay $\eta\rightarrow\pi^+\pi^-\pi^0$. For the decay mode of the η into $\pi^+\pi^-\pi^0$ we selected final states with three charged particles and one or two photons in either of the two event hemispheres. The low *Q* value in the decay $\eta\rightarrow 3\pi$, in combination with the high Lorentz boost of the τ leptons, leads to very collimated particle jets in the detector. As a consequence, showers from the various pions tend to overlap thus reducing the detection efficiency for photons. We therefore allow one missing photon and reconstruct the invariant mass of the three-pion system from two oppositely charged pions and one or two additional photons. In the case of two detected photons we attempt a fit to the neutral pion mass and reject events with a χ^2 probability for the fit of less than 1%. This method tends to systematically shift the mass of the three-pion system towards lower values. In order to study this mass shift we analysed the simulated $\tau\rightarrow\eta\pi\nu$, $\eta\rightarrow\pi^+\pi^-\pi^0$ decays according to the above prescription and obtain the invariant mass distribution for the three-pion system shown in fig. 3. Also drawn in the figure is the result of a fit superimposing a gaussian distribution to describe the line shape of the η peak on a general polynomial background.

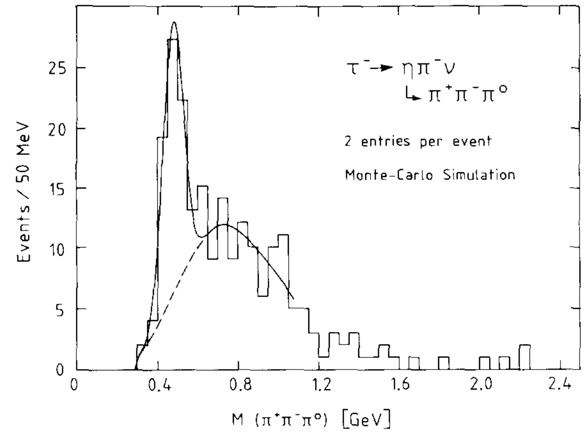

Fig. 3. Monte Carlo simulation of the invariant $\pi^+\pi^-\pi^0$ mass from τ final states containing three charged particles plus one or two photons. The line drawn is the result of a fit assuming a gaussian peak over a general polynomial background.

As expected, the central value of the mass is shifted down to 480 MeV from the true value of 548 MeV. The mass resolution is 50 MeV. From the number of Monte Carlo events in the η band (400–550 MeV) we obtain an efficiency of 9.4% to observe the decay $\tau\to\eta\pi\nu$, $\eta\to\pi^+\pi^-\pi^0$, very similar to the decay of the η into two photons.

In fig. 4 we show the mass distribution of the three-pion system obtained from the τ data sample. No η signal is observed at the expected position of about 480 MeV. We see, however, indications of a narrow structure consistent with our mass resolution (about 45 MeV) near the position of the ω meson. This state has first been observed by the ARGUS Collaboration [9]. Here we do not attempt to measure the branching ratio for this decay but rather concentrate on the mass region around the η. Performing a fit to the mass distribution superimposing a gaussian with central value and width fixed to the η values obtained from our Monte Carlo simulation (see fig. 3) we obtain results preferring negative (unphysical) amplitudes for the gaussian, centered at 460 MeV. We interpret this as indication of a statistical fluctuation in the data and assume for the further analysis that no signal is seen above the background (zero amplitude). In the η band we observe 26 events giving a 90% (95%) CL upper limit of 9.8 (12.3) events. Due to the much larger background in the three-pion decay channel as compared to the $\gamma\gamma$ channel the upper limit obtained for the branching ratio of $\tau\to\eta\pi\nu$ is considerably weaker and is found to be 3.8% (4.6%) at 90% (95%) CL.

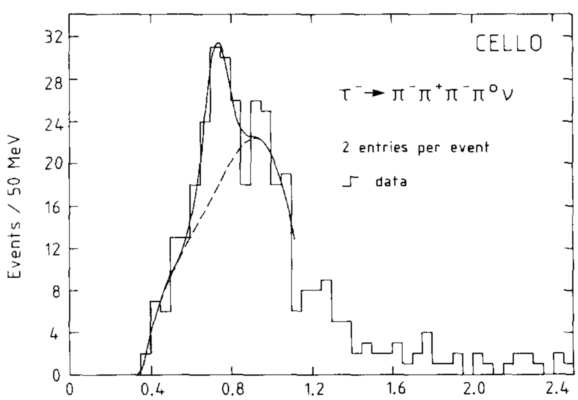

Fig. 4. Invariant $\pi^+\pi^-\pi^0$ mass from τ final states containing three charged particles plus one or two photons. The line drawn is the result of a fit assuming a gaussian for the ω peak over a general polynomial background.

6. Conclusion

We have searched for the decay $\tau\to\eta\pi\nu$ in about one third of the full statistics of the CELLO experiment. No signal is found in either of the decay channels $\eta\to\gamma\gamma$ and $\eta\to\pi^+\pi^-\pi^0$. We place an upper limit of 1.4% (90% CL) for this branching ratio from an analysis of final states where the η decays into two photons. Similar limits in either of the two decay channels have also been reported by other experiments [10]. The HRS result of (5.1 ± 1.5)% for the decay branching ratio $\tau\to\eta\pi\nu$ is thus not confirmed.

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