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Observation of τ Lepton Decays to η mesons

THE CRYSTAL BALL COLLABORATION

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ABSTRACT With the Crystal Ball detector at DORIS II we have searched for unknown decay modes of the τ lepton into 1 charged particle plus neutrals. A significant η signal is found in the 2 photon invariant mass distribution. Under the assumption that the η mesons are produced in the decay $\tau^{\pm} \rightarrow \eta\pi^{0}\pi^{\pm}\nu_{\tau}$ we determine a branching ratio BR($\tau^{\pm} \rightarrow \eta\pi^{0}\pi^{\pm}\nu_{\tau}$)=$(XX \pm YY \pm ZZ)$%.

The search for η mesons in decays of the τ lepton is motivated by the apparent discrepancy between inclusive and exclusive measurements of τ branching ratios into 1 charged partcile plus neutrals. Whereas inclusive measurements yield a branching ratio [1] BR=(86.5 $\pm$0.3)%, the known exclusive decay modes add up [1] to BR=(76.2 $\pm$2.0)%. Therefore 5-10% are not yet discovered. A recent TPC measurement [2] of the branching ratio BR($\tau^{\pm} \rightarrow \pi^{\pm}\pi^{0}\nu_{\tau}+$ additional neutrals) = (14 $\pm$2 $\pm$2) % supports the existence of τ decay modes which might contain additional η or π^0 mesons. The $\pi^{\pm}\pi^{0}\pi^{0}\nu_{\tau}$ and $\pi^{\pm}\pi^{0}\pi^{0}\pi^{0}\nu_{\tau}$ [1] modes do not seem to account for all of the missing channels. Channels involving π^0s are fairly well known from measurements by magnetic detectors (due to the fine segmentation of their shower counters), since for π^0s the angular measurement dominates the mass resolution. Reconstruction of η mesons using the decay mode $\eta \rightarrow \gamma\gamma$ on the other hand requires very good energy measurement of the photons, a domain of a calorimetric detector like the Crystal Ball. The $\pi^{+}\pi^{-}\pi^{0}$ decay mode of the η cannot be used since it is obscured by the combinatorics of pions in the ω [3] and ρ' [1] decay mode of τ leptons. Therefore we have searched for $\eta \rightarrow \gamma\gamma$ in τ decays, complementary to the TPC [2] measurement using π^0s.

The data were collected with the Crystal Ball detector at the DORIS II storage ring in the $e^{+}e^{-}$ center-of-mass energy range from 9.4 GeV to 10.6 GeV. The data sample used corresponds to a luminosity of $160 pb^{-1}$ corresponding to about 360K τ leptons.

The Crystal Ball detector [5] consists of a spherical, segmented shell of NaI(Tl) shower counters which cover 93% of the full solid angle. The coverage is increased to 98% of 4π by NaI(Tl) endcaps. The thickness of the NaI(Tl) shell corresponds to 16 radiation lengths and to one nuclear absorption length. The direction of charged particles is measured by a system of proportional tube chambers with charge division readout. Depending on the run period, this system consisted of 3 or 4 double layers of tubes.

We search for η mesons in τ decays using a sample of $\tau\bar{\tau}$ events where each τ lepton is required to decay into 1 charged particle. To suppress beam-gas and beam-wall events the events are required to have less than 100 MeV desposited in the endcaps. Furthermore we cut in a variable $E_T^2 = \sum_i E_i^2 \sin^2\Theta_i$ where we sum the squared transverse energy in all crystals, Θ being the polar angle of the crystal centroid. Studies of separated beam data suggest a cut in this variable of $E_T^2 \geq 0.3\,\mathrm{GeV}^2$ to get rid of virtually all non e^+e^-annihilation events. Events from QED radiative Bhabhas are removed by allowing for no energy deposition greater than 85% of the beam energy.

We use a tagging method to further select the reaction under investigation: One charged particle has to have a lateral pattern of energy deposition compatible with an electromagnetically showering particle. This enriches the τ decay mode $\tau^{\pm} \rightarrow e^{\pm}\nu_e\nu_\tau$, but also accepts some amount of $\tau^{\pm} \rightarrow \pi^{\pm}\nu_\tau$ and $\tau^{\pm} \rightarrow \rho^{\pm}\nu_\tau \rightarrow \pi^{\pm}\pi^0\nu_\tau$ since an interacting pion will have an energy dependent chance to pass the cut on the lateral shower pattern. The other τ lepton is then searched for in new decay modes.

In order to demonstrate our ability to select clean $\tau\bar{\tau}$ events by the procedure descibed above we compare the energy spectrum of the tagged particle in data and luminosity weighted Monte Carlo simulation of radiatively corrected τ pair production which includs a 7.5 % branching ratio for $\tau^{\pm} \rightarrow \eta\pi^0\pi^{\pm}\nu_\tau$. The energy spectrum in figure 1 shows the data as histogram and Monte Carlo as points with error bars. The spectra not only coincide within errors in shape but also in magnitude.

Next we require at least 2 neutral clusters with a lateral energy deposition consistent with expectations for a single electromagnetic shower, in the following to be called photon. The 2 photon invariant mass distribution in figure 2 shows a prominent π^0 peak, mostly due to $\tau^{\pm} \rightarrow \rho^{\pm}\nu_\tau \rightarrow \pi^{\pm}\pi^0\nu_\tau$ and $\tau^{\pm} \rightarrow A_1^{\pm}\nu_\tau$. These π^0s photons make a large combinatorial background under a potential η singal. Therefore for each candidate photon we examine mass combinations between it and each of the other photons in the same event. If one of the masses comes within 3 σ of the π^0, the photon candidate is rejected. The resulting "π^0 subtracted" 2 γ mass distribution of remaining candidate photons is shown in figure 3, and exhibits a significant η signal. A fit to a third order polynomial background and a Gaussian with free width and position yields a 5.5 σ effect at a mass $M = (550.0 \pm 4.3)\,\text{MeV}$ with a width of $W = (20.3 \pm 4.1)\,\text{MeV}$.

In order to provide proof that the decay observed does not proceed via $\tau^{\pm} \rightarrow \eta\pi^{\pm}\nu_\tau$, we investigate the π^0 subtracted 2 photon invariant mass spectrum for events containing exactly 2 photons (insert in figure 3). No sign of an η signal can be seen. We therefore are confident that we observe η production with additional neutrals in τ decays. This result is supported by the fact that $\tau^{\pm} \rightarrow \eta\pi^{\pm}\nu_\tau$ would be a second class current, which is expected to be forbidden [4]. Moreover the inclusive measurement [2] of

$\pi^{\pm}\pi^0$ plus additional neutrals suggests decays involving η mesons and π^0s.

Since we do not determine the invariant mass distribution of the $\eta\pi^0\pi^{\pm}$ system from the data (the charged pion momentum is not measured) we determine the width of the Gaussian from Monte Carlo simulation to range from 21 MeV to 28 MeV over the full kinematical range of invariant masses. Within this range the statistical significance of the signal is always greater than 5.5 σ (for fixed width). This uncertainty in the width of the Gaussian introduces a systematical error of XX% into the determination of the branching ratio.

A number of background checks was performed by applying the above described selection to Monte Carlo events simulating 3 gluon decays of the Υ resonances, $q\bar{q}$ continuum production and $\gamma\gamma$ scattering into η and η' mesons. A negligible contribution from such sources to the signal observed was found. Moreover we used separated beam data to study non e^+e^- annihilation events and found their contribution to be negligible as well.

With a detection efficiency of XX%, determined with the Monte Carlo, XXX events in the signal and ...K τ leptons we arrive at a branching ratio $\mathrm{BR}(\tau^{\pm} \rightarrow \eta\pi^0\pi^{\pm}\nu_{\tau}) = (xx \pm YY \pm zz)\%$, where the first error is statistical and the second is systematic. The systematic error results from the following sources: The number of τ leptons is proportional to the luminosity and thus known to 5% (the contribution from Υ resonance decays has been taken into account). The uncertainty in the determination of the width of the η signal introduces another xx%. Finally a yy% additional error results from the combined uncertainties in the Monte Carlo simulation and the branching ratios used for the conventional τ decay modes.

In summary we observe in τ decays a significant signal of η mesons accompanied by additional neutrals. With the assumption that all η mesons originate from the decay $\tau^{\pm} \rightarrow \eta\pi^0\pi^{\pm}\nu_{\tau}$ we obtain a branching ratio $\mathrm{BR}(\tau^{\pm} \rightarrow \eta\pi^0\pi^{\pm}\nu_{\tau}) = (XX \pm YY \pm ZZ)\%$. This result is in good agreement with a recent result from the HRS collaboration at PEP [6], claiming a branching ratio BR=(8±4)% for this gta decay mode. It is also well consistent with the strength for such a decay allowed by the measurement of $\mathrm{BR}(\tau^{\pm} \rightarrow \pi^{\pm}\pi^0\nu_{\tau} +$ additional neutrals$) = (13.9 \pm 2.0 \pm 2.1)\%$ by the TPC collaboration at PEP [2]. Our observation helps to account for the missing decay modes of the τ lepton into 1 charged particle and neutrals.

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FIGURE CAPTIONS

Figure 1: Energy spectrum of the particle used for tagging for data (histogram) and Monte Carlo (points with error bars)

Figure 2: 2 photon invariant mass distribution, the π^0 peak is mostly due to $\tau^\pm \rightarrow \rho^\pm \nu_\tau \rightarrow \pi^\pm \pi^0 \nu_\tau$ and $\tau^\pm \rightarrow A_1^\pm \nu_\tau$

Figure 3: a π^0 decay within 3 σ. 2 photon invariant mass distribution, π^0 subtracted The fit is a Gaussian of fixed width and position (determined by Monte Carlo methods) and a third order polynomial background. Inserted is this distribution for final states with exactly 2 photons.

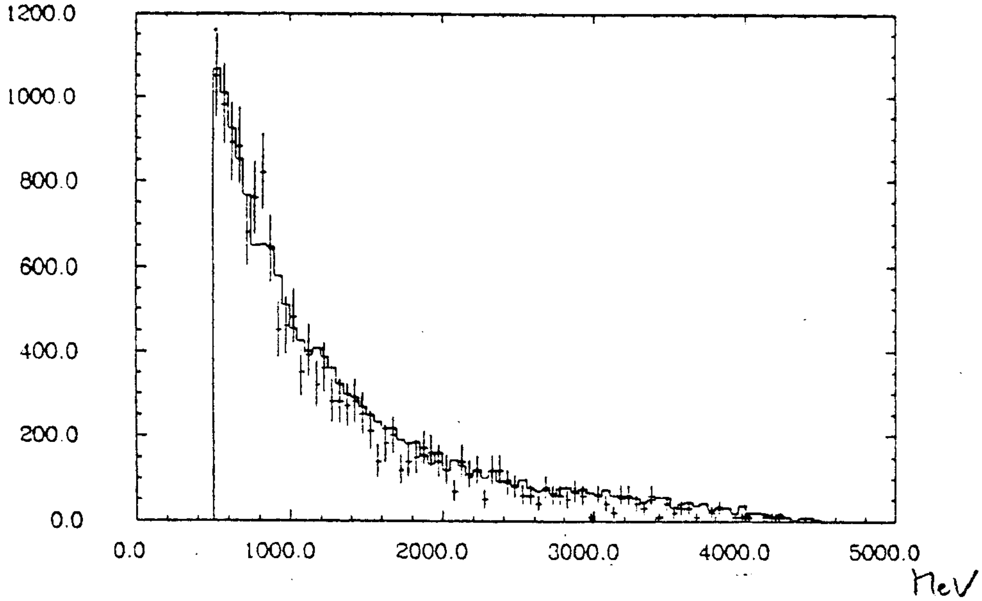


Figure 1:

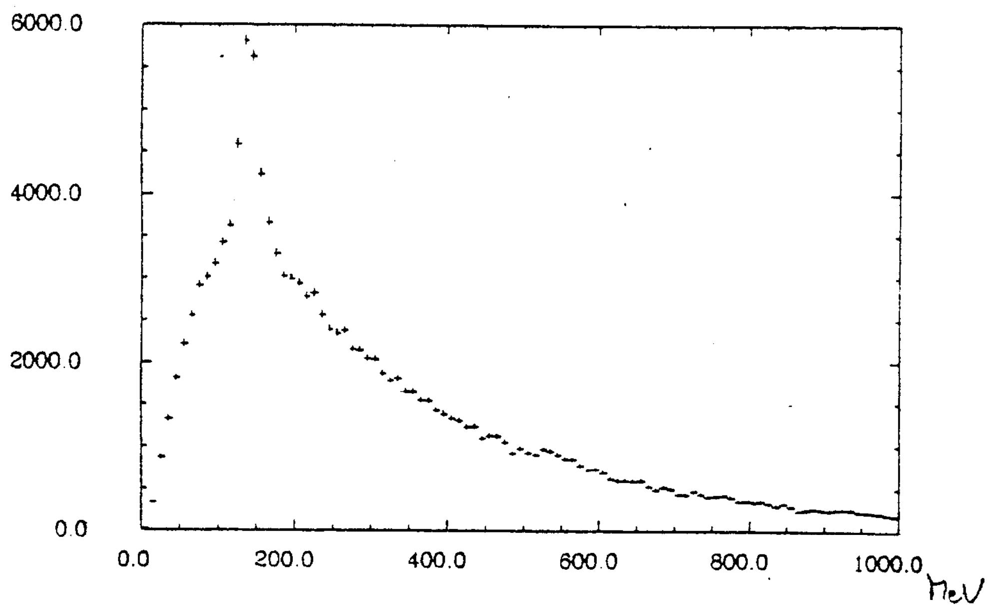
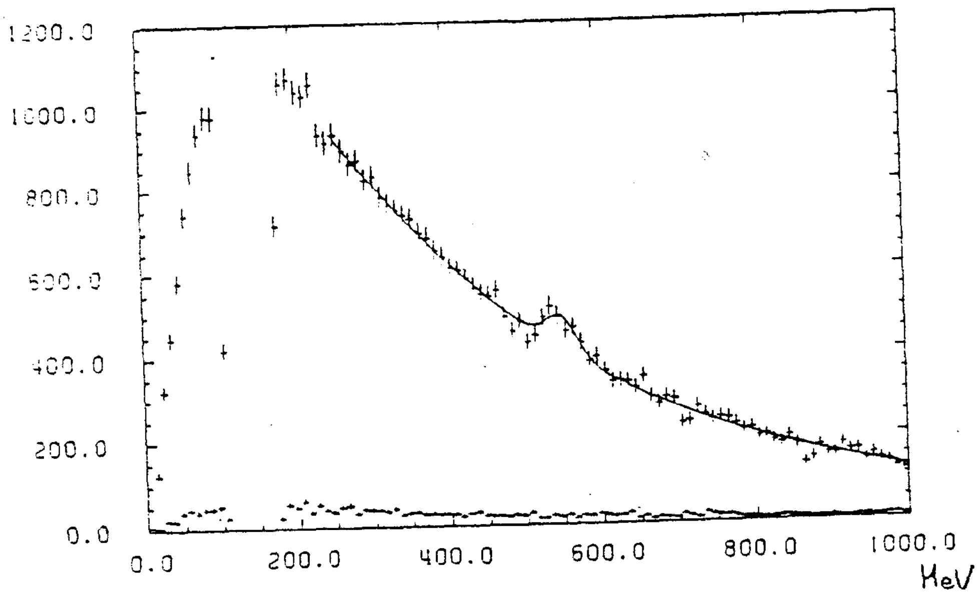


Figure 2: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MeV

Figure 3: