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Determination of the Branching Ratio $\tau \to \rho\nu$*

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Abstract

The decay $\tau \to \rho\nu$ was studied in τ- pair production by e^+e^- annihilation at $\sqrt{s} = 3.77$ GeV. The branching ratio was measured to be $B(\rho\nu) = 22.3 \pm 1.4 \pm 1.6\%$.

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We report an analysis of the decay of the τ lepton into $\rho\nu$ from a measurement of τ-pairs in $e^{\mp}\pi^{\pm}\pi^0$ and $\mu^{\mp}\pi^{\pm}\pi^0$ final states produced by e^+e^- annihilation. The data were taken with the MARK III detector at the SLAC e^+e^- storage ring SPEAR. A total integrated luminosity of $9.4pb^{-1}$ was collected at a c.m. energy of 3.77 GeV, which is at the peak of the ψ'' resonance and 0.20 GeV above $\tau\bar{\tau}$ threshold.

The analysis was similar to our study of the leptonic decays of the τ [1]. Details of the detector performance can be found in Ref. 1. and 2. . Charged particles were tracked in the drift chamber with a momentum resolution of $\delta p/p = 0.015\sqrt{1+p^2}$, with p in GeV/c. Photons were detected in the shower counters, which cover 94% of 4π sr, with an efficiency which increased from 40% at 0.030 GeV to $\sim$ 100% at 0.100 GeV and beyond. The energy resolution was $\delta E/E \sim 17\% / \sqrt{E(\mathrm{GeV})}$.

Charged particles were identified on the basis of information provided by the time-of-flight (TOF) counters, the shower counters and the muon detector. For optimum particle identification, electrons and pions were accepted only in the region where the TOF counters overlap with the shower counters, requiring $|\cos\theta| < 0.76$, where θ is the polar angle with respect to the beam axis. Furthermore, areas of the shower counters with reduced efficiency due to support structures (9% of 4π sr) were excluded.

The probability for misidentifying pions as electrons was typically less than 4%. The threshold for muon detection is 0.55 GeV/c. The probability for misidentifying pions as muons via decay and punch-through rises from zero at 0.55 GeV/c to $13 \pm 3\%$ at 0.85 GeV/c, and drops to 6% for $p > 0.9$ GeV/c when a more restrictive muon criterium is applied.

The criteria for selecting τ-pair events leading to $e^{\mp}\pi^{\pm}\gamma\gamma$ and $\mu^{\mp}\pi^{\pm}\gamma\gamma$ final states were chosen to suppress backgrounds whose main sources are leptons from one and two photon QED processes and charm production.

Candidate events were required to have:

- two well measured tracks of opposite charge and each with momentum $p < 0.75$ p_{beam} (= 1.41 GeV/c) ;
- the sum of the charged particle momenta $(p_1 + p_2) > 0.4$ p_{beam} (= 0.75 GeV/c);
- one track identified as an electron or a muon , the other as a pion;
- an acolinearity angle, θ_{acol}, between the two charged tracks of $2.5° < \theta_{acol} < 177.5°$ and an acoplanarity angle, θ_{acop}, $> 6°$ where θ_{acop} is the angle between the planes spanned by the beam direction and the momentum vectors of the lepton and charged pion;
- two isolated photons . An isolated photon, γ_{isol}, was defined as a shower with energy $\geq$ 0.030 GeV separated from any charged track by more than 45 cm on the face of the shower counter (corresponding to an angle *w.r.t.* the charged track direction of about 18°). Two isolated photons closer than 20 cm were combined into one;
- no extra isolated photons.

The two photons were constrained to the π^0 mass by a kinematic fit (1C). Events with $\chi^2 < 6$ and both fitted photon energies above 0.040 GeV were retained yielding 332 $e^{\mp}\pi^{\pm}\pi^{0}$ and 173 $\mu^{\mp}\pi^{\pm}\pi^{0}$ events. Figures 1 a,b show the $\gamma\gamma$ mass spectra in the two channels for the events that passed the fit. Clear π^{0} signals with little background are observed.

Possible sources of background are charm production, nonresonant events produced under the ψ'' peak and τ pair production with decays into other final states.

A part of the background was determined by selecting events with three (instead of two) isolated photons and requiring that two of these each have an energy above 0.040 GeV. All possible combinations of $\gamma\gamma$ pairs were fit to a π^{0} and the fit with the best χ^{2} showed that the majority of these events contain a π^{0}. Events of this type must be due to background processes. Under the assumption that the origin of the (3 γ_{isol})-events are processes in which two π^{0} are produced, but one photon is lost, the background feeding down to the signal channels was determined. One of the three photons was randomly removed and the resulting events then normalised to the signal channels. The integrated detection inefficiency for the loss of one isolated photon needed for this determination was derived using a Monte Carlo simulation [3][4] of $\tau\bar{\tau} \rightarrow (\mu^{\mp}\nu\nu)(A_{1}(1270)^{\pm}\nu)$. These small backgrounds feeding down into the $e^{\mp}\pi^{\pm}\pi^{0}$ and $\mu^{\mp}\pi^{\pm}\pi^{0}$ classes are shown as the dashed curves in figure 1. The number of background events with four charged particles where two escaped detection is negligible. The background from charm production was estimated by considering $D\bar{D}$ production and specific hadronic and semileptonic decay channels. The total background from charm production, including also channels which by misidentification of particles can produce signal events was found to be 0.03 and 0.1 events for the $e^{\mp}\pi^{\pm}\pi^{0}$ and $\mu^{\mp}\pi^{\pm}\pi^{0}$ final states, respectively.

The criteria discussed above were used to subject 10^5 events of the type $J/\psi \to 2$ charged particles $+ \geq 0\gamma$ to the selection used for the signal channels. No events were found to be selected and we concluded from this that the contamination by nonresonant $\tau\bar{\tau}$ events was negligible.

Production of τ pairs is itself an important background mainly because of misidentification of particles: muons below 0.55 GeV/c are called pions; above 0.6 GeV/c pions have a nonzero probability to be classified as muons. As noted above, pions can also be misidentified as electrons. The main sources of background were the τ-pair decay channels $\tau\bar{\tau} \to (\pi^{\mp}\nu)(\rho^{\pm}\nu)$ and $(\rho^{\mp}\nu)(\rho^{\pm}\nu)$ and channels containing an $A_1(1270)$. The contamination from these processes was computed by generating Monte Carlo events including the misidentification probabilities for $\pi \to e, \mu$. The $\pi\rho$ channel resulted in 8.8 ± 1.5 and 15.1 ± 2.1 background events for the $e^{\mp}\pi^{\pm}\pi^{0}$ and $\mu^{\mp}\pi^{\pm}\pi^{0}$ channels, respectively. Both, the $\rho\rho$ channel and channels with an $A_1(1270)$ are included in the background (8.4 ± 1 and 4.5 ± 0.8 respectively) obtained from the analysis of the events with three isolated photons, as they contain two π^0 in the initial state. Finally, the signal channel $\tau\bar{\tau} \to (\mu^{\mp}\nu\nu)$ $(\rho^{\pm}\nu)$ produced 4.1 ± 1.0 background events for the $e^{\mp}\pi^{\pm}\pi^{0}$ channel by both $\pi \to e$ and $\mu \to \pi$ misidentifications, as found by a Monte Carlo simulation. The dotted histograms in Figure 1 show the described backgrounds summed up for each of the two signal channels. Above a $\gamma\gamma$ mass of 0.3 GeV/c the background observed in the data is well described. A cross check of the measured background from the ($3\ \gamma_{isol}$)- analysis was done using the Monte Carlo simulation of $\mu A_1(1270)$ and $\rho\rho$ events yielding good agreement with the measured distribution.

For subsequent analysis events with $\gamma\gamma$ masses between 0.0 and 0.3 GeV/c^2 were considered as signal. Figures 2 a,b show the $\pi^{\pm}\pi^0$ mass distributions for these events together with the dotted curve describing the above discussed backgrounds. Pure ρ signals on small backgrounds are observed. For the branching ratio determination an additional cut of ± 0.5 GeV/c^2 around the peak in the $\pi^{\pm}\pi^0$ mass was applied. This cut removes 10 and 5 events respectively in the $e^{\mp}\pi^{\pm}\pi^0$ and $\mu^{\mp}\pi^{\pm}\pi^0$ channels. It was checked that the extracted cross sections and branching ratios are not sensitive to tighter cuts in the $\pi^{\pm}\pi^0$ mass. The total numbers of background events in the two channels within all the cuts were 21.3 ± 2.1 (stat) ± 5.0 (syst) and $19.6 \pm 2.2 \pm 3.0$ leading to $280.7 \pm 17.6 \pm 5.0$ $e^{\mp}\pi^{\pm}\pi^0$ and $139.4 \pm 12.8 \pm 3.0$ $\mu^{\mp}\pi^{\pm}\pi^0$ background substracted events.

The detection efficiencies were calculated by generating Monte Carlo events according to $\tau\bar{\tau} \to (\ell\nu\nu)\ (\rho\nu) \to \ell^{\mp}\pi^{+}\pi^0$, $\ell = e, \mu$ including radiative effects.[3] The generated events were passed through the detector simulation, reconstruction, and selection program.

The detection efficiencies were found to be 0.1438 ± 0.0035 and 0.0698 ± 0.0025 for the $e^{\mp}\pi^{\pm}\pi^0$ and $\mu^{\mp}\pi^{\pm}\pi^0$ final states. A systematic error of 0.002 in the efficiencies was determined by varying the decay distributions of the ρ in the Monte Carlo. After correcting for radiative effects which increase the cross sections by 8%, we obtained:

$$\sigma(e^+e^- \to \tau^+\tau^- \to e\rho) = 0.225 \pm 0.014 \pm 0.010\,\mathrm{nb}$$

and

$$\sigma(e^+e^- \to \tau^+\tau^- \to \mu\,\rho) = 0.230 \pm 0.021 \pm 0.011\,\mathrm{nb}$$

where a systematic uncertainty of 4% was included for the luminosity. From a comparison with our cross sections $\sigma(e^+e^- \to \tau^+\tau^- \to ee) = 0.092 \pm 0.008 \pm 0.006\,\mathrm{nb}$ and $\sigma(e^+e^- \to \tau^+\tau^- \to \mu\mu) = 0.085 \pm 0.014 \pm 0.008\,\mathrm{nb}$ reported previously[1] and using the QED cross sections for $\tau^+\tau^-$ production we obtain for the ρ branching ratio: $B(\tau \to \rho\nu) = 22.0 \pm 1.7 \pm 1.2\%$ from the $e^\mp\pi^\pm\pi^0$ channel, and $23.4 \pm 2.9 \pm 1.6\%$ from the $\mu^\mp\pi^\pm\pi^0$ channel. The weighted average of the two values is

$$B(\tau \to \rho\nu) = 22.3 \pm 1.4 \pm 1.6\% \ .$$

In summary, the decay $\tau \to \rho\nu$ was studied in the final states $e^\mp\pi^\pm\pi^0$ and $\mu^\mp\pi^\pm\pi^0$. The presently published world average [5] for the branching ratio of this decay is $22.1 \pm 2.4\%$. Our measurement of $B(\tau \to \rho\nu) = 22.3 \pm 1.4 \pm 1.6\%$ compares well with this value.

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Figure Captions

1. **(a) $\gamma\gamma$ mass spectrum from $e^{\mp}\pi^{\pm}\pi^{0}$ events (dashed and dotted curves are backgrounds described in the text).**

   (b) $\gamma\gamma$ mass spectrum from $\mu^{\mp}\pi^{\pm}\pi^{0}$ events (dashed and dotted curves are backgrounds described in the text).

2. **(a) $\pi^{\pm}\pi^{0}$ mass spectrum from $e^{\mp}\pi^{\pm}\pi^{0}$ events (dotted curve is background).**

   (b) $\pi^{\pm}\pi^{0}$ mass spectrum from $\mu^{\mp}\pi^{\pm}\pi^{0}$ events (dotted curve is background).

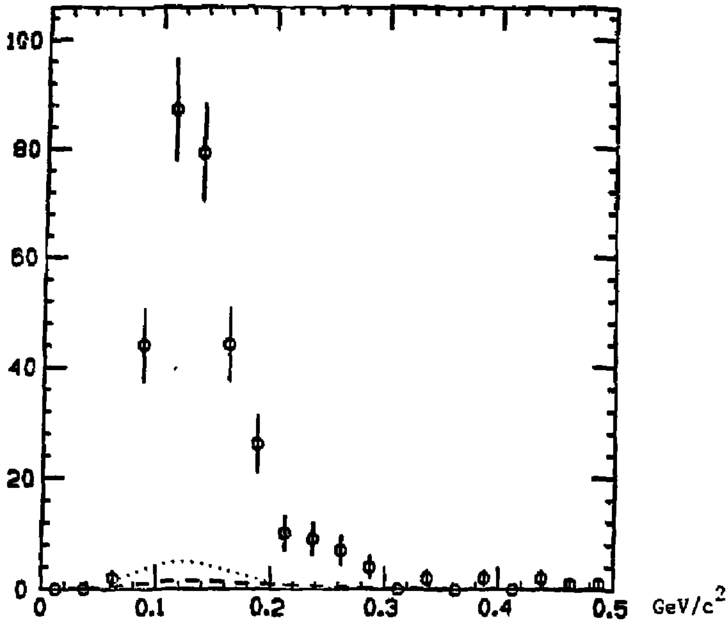

Fig. 1a. $\gamma\gamma$ mass for $e^{\mp}\pi^{\pm}\pi^{0}$ events. (dashed and dotted curves are backgrounds described in the text).

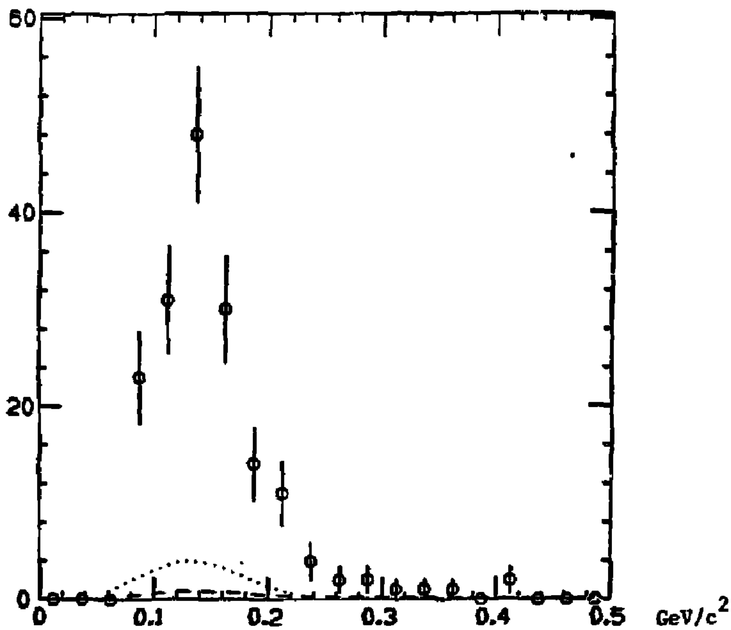

Fig. 1b. $\gamma\gamma$ mass for $\mu^{\mp}\pi^{\pm}\pi^{0}$ events. (dashed and dotted curves are backgrounds described in the text).

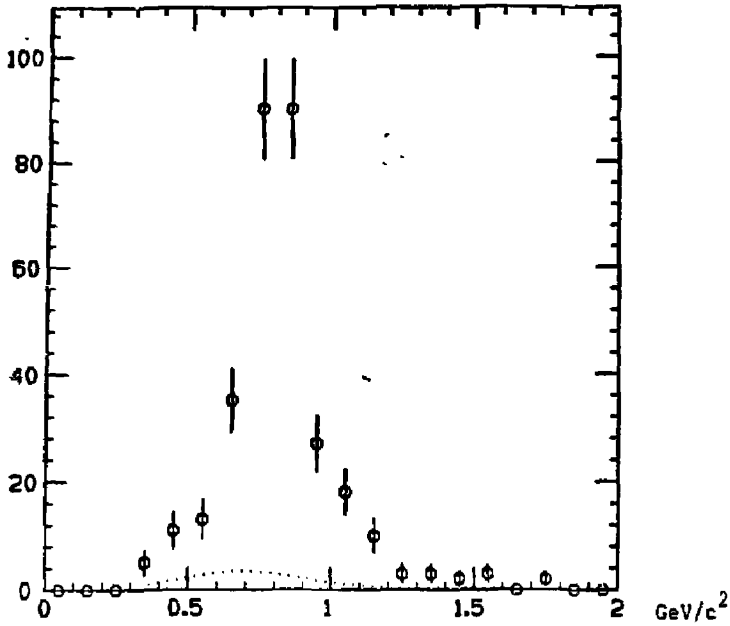

Fig. 2a. $\pi^{\pm}\pi^{0}$ mass for $\mu^{\mp}\pi^{\pm}\pi^{0}$ events. (dotted curve is background).

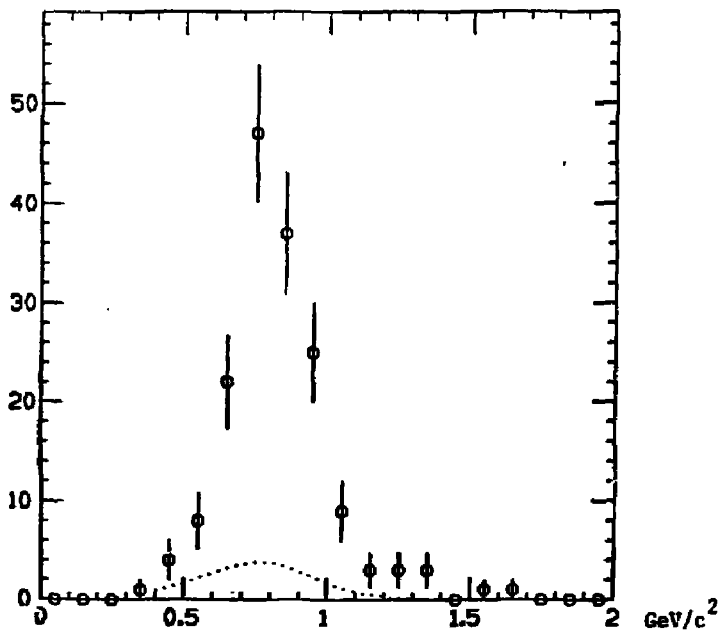

Fig. 2b. $\pi^{\pm}\pi^{0}$ mass for $\mu^{\mp}\pi^{\pm}\pi^{0}$ events. (dotted curve is background).

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