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Measurement of the decays $\tau^- \to K^{\star -} \nu_\tau$ and $\tau^- \to \rho^- \nu_\tau$

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Abstract. Using the ARGUS detector at DORIS II, we have determined the branching ratios for the decays $\tau^- \to K^{*-} \nu_\tau$ and $\tau^- \to \rho^- \nu_\tau$ to be $(1.23 \pm 0.21^{+0.11}_{-0.21})\%$ and $(21.5 \pm 0.4 \pm 1.9)\%$, respectively. These results are in agreement with theoretical expectations based on the standard model.

The decays of the τ lepton provide a very clean environment to test the standard model. Since the τ lepton is the only lepton massive enough to decay into hadrons, the hadronic charged weak currents can be studied in a detailed fashion. In this paper we present new and precise measurements of the branching ratios

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for $\tau^- \to K^{*-} \nu_\tau$ and $\tau^- \to \rho^- \nu_\tau$*. Definite predictions exist within the standard model [1–3]. The CVC hypothesis relates the decay $\tau^- \to \rho^- \nu_\tau$ to the measured $e^+e^- \to \pi^+\pi^-$ cross section. For the decay $\tau^- \to K^{*-} \nu_\tau$, however, the coupling strength of the strange hadronic current to the W boson is unknown within the standard model and has to be calculated using asymptotic flavour symmetry [4–6], which predicts the ratio of coupling constants g_ρ and g_{K^*} to be $g_\rho/g_{K^*} = m_\rho/m_{K^*}$. The ratio of the two partial widths is given by

$$\frac{\Gamma(\tau^- \to K^{*-} \nu_\tau)}{\Gamma(\tau^- \to \rho^- \nu_\tau)} = \tan^2 \theta_c \frac{g_{K^*}^2}{g_\rho^2} f(m_{K^*}, m_\rho, m_\tau) \quad (1)$$

where θ_c is the Cabibbo angle and $f(m_{K^*}, m_\rho, m_\tau)$ is a function depending on the masses of the K^{*-}, ρ^-, and τ^-. Our measurement thus directly tests the standard model predictions and the sum rules derived from asymptotic flavour symmetry.

The data for this measurement were obtained using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY. The data comprise an integrated luminosity of 198 pb^{-1} at centre-of-mass energies ranging from 9.4 to 10.6 GeV. This corresponds to 202,200 produced τ pairs. The ARGUS detector has been described in detail elsewhere [7]. This analysis relies mainly on the central drift chamber and the shower counters, which provide measurements of particle momenta and energies respectively, with very good resolution.

The τ pair event selection was based primarily on topological criteria, since their low multiplicities and jet-like structure result in characteristic topologies. Events were accepted as $\tau\bar{\tau}$ candidates, if they had a 1–1 topology or 1–3 topology. The opening angle between the two tracks in the former case, and that between the lone track and each one of the tracks on the 3-prong side in the latter case, was required to be greater than 90°. Beam-gas and beam-wall events were suppressed by requiring a main vertex inside a cylindrical volume of $r < 1.5$ cm and length along the beam direction $|z| < 5.0$ cm, centered around the nominal interaction point. Two-photon background was reduced by requiring the transverse momentum sum to be $|\Sigma \mathbf{p}_t|^2 \geqq 0.7$ GeV^2/c^2. Monte Carlo studies showed that the contamination from this background became negligible then. Further selection criteria differ for the decays $\tau^- \to \rho^- \nu_\tau$ and $\tau^- \to K^{*-} \nu_\tau$ and are described separately below.

The $\tau^- \to K^{*-} \nu_\tau$ decay was studied by selecting events of the type

$$\begin{array}{l} e^+e^- \to \tau^-\tau^+ \\ \quad \tau^+ \hookrightarrow 1 \text{ prong} + \text{neutrals} \\ \quad \tau^- \hookrightarrow K^{*-}\nu_\tau \\ \qquad K^{*-} \hookrightarrow K_s^0 \pi^- \\ \qquad\quad K_s^0 \hookrightarrow \pi^+\pi^-. \end{array} \quad (2)$$

The events were required to have exactly four tracks with charge sum equal to zero and fulfill the 1–3 topological criterion. In addition, all neutral clusters with an energy larger than 50 MeV deposited in the shower counters, had to be confined to the one-prong hemisphere. On the three prong side, two oppositely charged tracks were required to form a secondary vertex well separated from the primary vertex. Specifically, the tracks forming the secondary vertex were required to have a distance of closest approach to the primary vertex, $r_{\min}$, such that $|r_{\min}/\sigma_{r_{\min}}| \geqq 6$. Radiative QED events with subsequent conversion of the photon into an e^+e^- pair were removed by requiring the opening angle, ϕ, between the two tracks forming the secondary vertex to satisfy $\cos\phi \leqq 0.975$. For events satisfying these criteria, the invariant mass distribution of the two associated tracks from the secondary vertex, considered as pions, is shown in Fig. 1. A clear K_s^0 peak is seen with very little background. Accepted candidates were required to have a mass within $\pm 3\sigma$ of the accepted value for the K_s^0 mass. These selection criteria resulted in a data sample of 76 events.

The invariant mass of the K_s^0 combined with the third track on the 3-prong side, assuming the pion

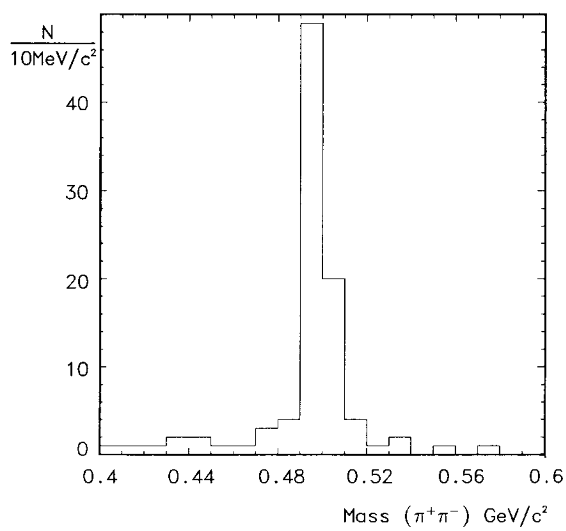

Fig. 1. $\pi^+\pi^-$ invariant mass distribution for events which are candidates for reaction (2)

* References in this paper to a specific charged state are to be interpreted as also implying the charge conjugate state. In addition, unless otherwise qualified, the terms K^{*-} and ρ^- refer to the K^{*-} (892) and ρ^- (770) respectively

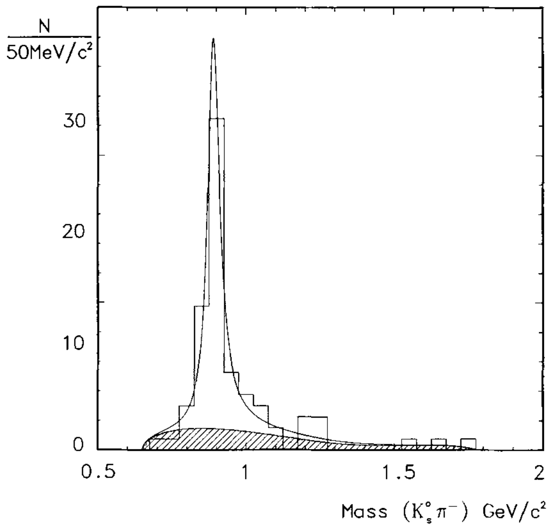

Fig. 2. Invariant mass distribution of the $K_s^0 \pi^-$ system. The solid line is a fit to the data using a relativistic Breit-Wigner function times the τ phase space plus a polynomial background, the latter shown hatched

mass for the latter, is shown in Fig. 2. A clear K^{*-} peak is seen with little background. The invariant mass distribution was fitted with a relativistic Breit-Wigner function, with fixed K^{*-} parameters, times τ phase space [8], plus a second order polynomial describing the hadronic background. The shape of this background was taken from a Monte Carlo simulation of $q\bar{q}$ events and was fixed in the fit. The fit yields a signal of $N=54 \pm 9$ K^{*-} events on a background of 27 ± 9 events.

In order to obtain the acceptance, events representing reaction (2) were simulated by Monte Carlo methods with initial state radiation effects included and with the branching ratios of all the known decay modes contributing to the one prong topology taken from previous measurements [9]. The events were then passed through a full detector simulation [10] and the same selection procedure was applied as for the data. The acceptance was found to be 1.27% with the branching fractions of K^{*-} and K_s^0 included [11]. There is a small additional loss of events due to fake photons which appear in the 3-prong hemisphere. The acceptance is corrected for this effect by a factor of 0.99 which was determined from events triggered by cosmic-ray muons during beam crossings. This gives a total acceptance of $\eta = 1.26\%$. The branching ratio BR $(\tau^- \to K^{*-} \nu_\tau)$ is obtained from the relation

$$\mathrm{BR}(\tau^- \to K^{*-} \nu_\tau) * \mathrm{BR}(\tau^- \to 1 \text{ prong} + \text{neutrals}) = N/(2 * N_{\tau\bar{\tau}} * \eta).$$

Taking the one-prong branching ratio of the τ as being $(86.5 \pm 0.3)\%$ [11], we get

$$\mathrm{BR}(\tau^- \to K^{*-} \nu_\tau) = (1.23 \pm 0.21^{+0.11}_{-0.21})\%.$$

The systematic errors have been calculated from the relative uncertainties of the acceptance (8%), the luminosity (4%), and possible feed down from the decay

$$\tau^- \to \rho(1600)) \, \nu_\tau \quad \hookrightarrow K_L^0 K^{*-}$$

which we estimate from Monte Carlo studies to be $\approx 14\%$.

The decay $\tau^- \to \rho^- \nu_\tau$ was studied using events of the type

$$e^+ e^- \to \tau^- \tau^+, \quad \tau^+ \hookrightarrow e^+, \mu^+, \pi^+, K^+ + \nu(s), \quad \tau^- \hookrightarrow \rho^- \nu_\tau, \quad \rho^- \hookrightarrow \pi^0 \pi^-, \quad \pi^0 \hookrightarrow \gamma\gamma. \tag{3}$$

The events were required to have exactly two charged tracks with a 1–1 topology and charge sum equal to zero and to have either one or two neutral clusters. Both charged tracks were required to have a polar angle such that $|\cos\theta| \leqq 0.75$. The two photons from the π^0 decay may either form two separated neutral clusters in the shower counter array or merge into one cluster. Accordingly the events fall into two categories, those with a single neutral cluster and those with two neutral clusters. These two cases are treated separately.

In the two cluster case, each cluster was required to have an energy between 50 and 700 MeV, deposited in at least two neighboring shower counters. Bhabhas and other QED events, as well as exclusive resonance decays, were rejected by requiring the total visible energy in the event to be less than 8.0 GeV and the total scalar momentum sum to be less than 9.0 GeV/c. The invariant mass of the two neutral clusters is shown in Fig. 3. A clear π^0 peak is seen with little background. Accepted π^0 candidates were required to have $\chi^2 < 5$ from a 1-C fit to the π^0 mass. The resulting data sample contains 1447 events with π^0 candidates. The background in this sample from τ decays other than $\tau^- \to \rho^- \nu_\tau$ was determined from a Monte Carlo simulation to be 12%. Specific channels considered were τ decays with $2\pi^0$'s and $K\pi^0$. The contribution from decays involving 3 or more π^0's was ignored. The process (3) does not include the decay $\tau \to \rho \nu_\tau$ for the second τ; background in the event sample from cases in which both τ's decay into ρ's is estimated to be 2%. The invariant mass of the π^0 and the charged track in the same hemisphere, assumed to be a pion, is plotted in Fig. 4a.

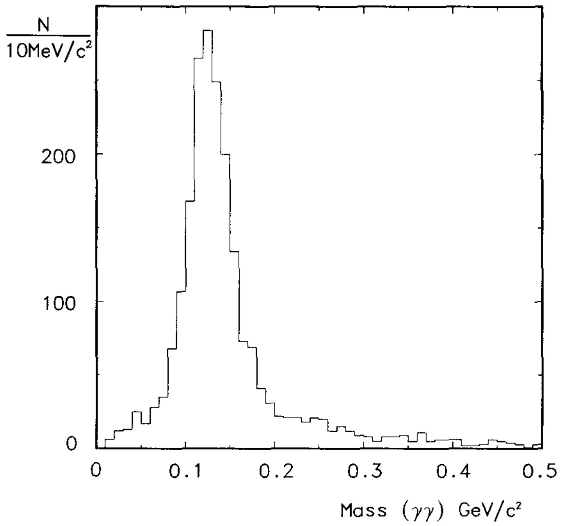

Fig. 3. $\gamma\gamma$ invariant mass distribution for events which are candidates for reaction (3)

A clean ρ peak is seen with very little background. The invariant mass distribution was fitted with a relativistic Breit-Wigner function with fixed ρ^- parameters times the τ phase space [8] and a background whose shape and normalization were taken from the Monte Carlo study. By this procedure we obtain a signal of 1236 ± 37 events of type (3).

For the events with a single cluster, the neutral cluster was required to have an energy larger than 1.0 GeV, and a polar angle θ such that $|\cos\theta| \leqq 0.75$, in order to ensure good energy resolution. Radiative QED events were rejected by requiring that the neutral track have an angle of separation, α, from the charged track in the same hemisphere satisfying $\cos\alpha < 0.98$. Bhabhas and other QED events, as well as exclusive resonance decays, were rejected by requiring the total energy contained in the event to be less than 6.0 GeV and the total scalar momentum sum to be less than 8.0 GeV/c. The invariant mass of the neutral track, assumed to be a π^0, combined with the charged track in the same hemisphere, assumed to be a pion, is plotted in Fig. 4b. The distribution is dominated by the $\rho^-(770)$ with 3815 entries below the τ mass. The feed down due to τ decays other than $\tau^- \to \rho^- \nu_\tau$ was obtained as in the two cluster case to be 8%. The case where both τ's decay into ρ^-'s contribute another 4%. Remaining QED background was estimated by extrapolation from the region above the total energy cut to be 3%.

The total acceptance was determined to be 10.9% in the same manner as for the K^{*-} decay, the double and single cluster cases contributing 3.1% and 7.8% respectively. Using ($46.7 \pm 0.8\%$ [9]) for the branching ratio of the τ^+ into e^+, μ^+, π^+, K^+ + neutrino(s), we

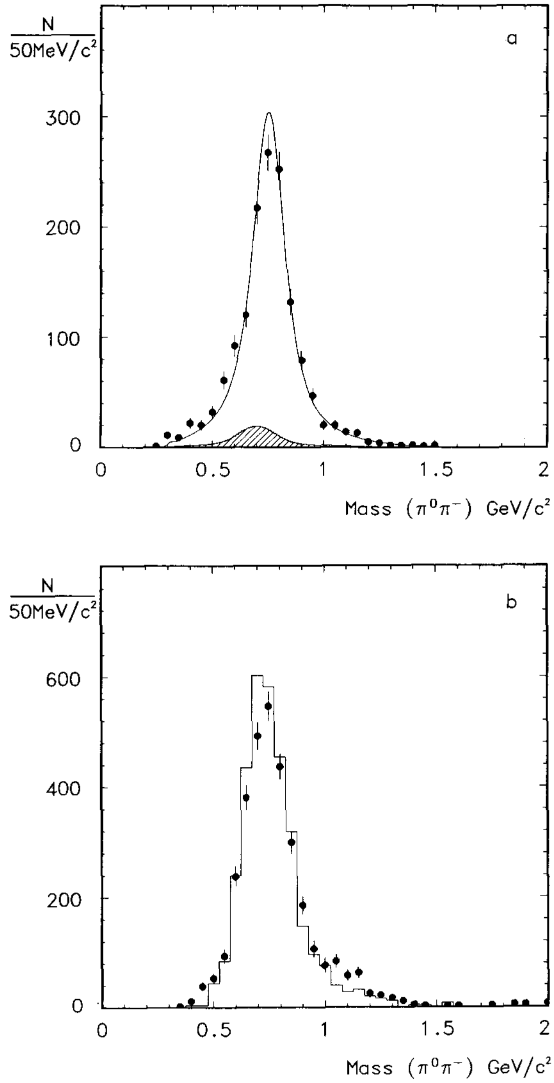

Fig. 4. The invariant mass distribution of the $\pi^+\pi^0$ system for: **a** two-neutral-cluster π^0's. The solid line is a fit to the data of a relativistic Breit-Wigner function with fixed ρ^- parameters times τ phase space plus background from feed down of other τ decays, the latter shown hatched; **b** single-cluster π^0's, background subtracted. The histogram shows the result of a Monte Carlo simulation

obtain for the decay $\tau^- \to \rho^- \nu_\tau$ a branching ratio

$$BR(\tau^- \to \rho^- \nu_\tau) = (21.5 \pm 0.4 \pm 1.9)\%.$$

The separate branching ratios for the single-cluster and two-cluster events agree within their statistical errors. Systematic errors have been calculated from the relative uncertainties of the acceptance (7.8%), the luminosity (4.0%) and the background estimation (2.0%).

The decay $\tau^- \to \rho^- \nu_\tau$ is the largest exclusive τ decay channel and contributes to the 1-prong topology. In view of the current discrepancy between topological and exclusive branching ratios for the τ, it is desirable to have several independent measurements of this branching ratio. Theoretical estimates of the $\tau^- \to \rho^- \nu_\tau$ branching fraction are based on the CVC hypothesis which relates the isovector part of the e^+e^- annihilation into hadrons to the vector part of the charged weak current or to the experimental width of the $\rho^0 \to e^+e^-$ [1–3]. Our measurement is in good agreement with these predictions and with other measurements [9].

In contrast, the decay $\tau^- \to K^{*-} \nu_\tau$ is relatively rare and measurements of $BR(\tau^- \to K^{*-} \nu_\tau)$ have so far involved only a small number of events, resulting in a large dispersion for the reported values [9]. Our measurement is based on the largest sample of events to date and, in addition, the measurement of $BR(\tau^- \to \rho^- \nu_\tau)$ in the *same* experiment permits a reliable determination of the ratio of branching ratios

$$BR(\tau^- \to K^{*-} \nu_\tau)/BR(\tau^- \to \rho^- \nu_\tau) = 0.057 \pm 0.010^{+0.006}_{-0.010}$$

free of common systematic uncertainties. The value obtained for this ratio is compatible with a model prediction of 0.052 that takes into account $SU(3)$ breaking via the Das-Mathur-Okubo sum rules [4].

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