MEASUREMENT OF THE INCLUSIVE K^0_S BRANCHING FRACTION IN τ DECAY

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The inclusive production of K^0_S mesons in τ lepton decay has been studied using the high resolution spectrometer at the PEP e^+e^- storage ring operated at $\sqrt{s}=29$ GeV. The data sample corresponds to an integrated luminosity of 300 pb^{-1}. The measured branching fraction is $B(\tau^-\to K^0_S X^- \nu_\tau)=(0.64\pm0.15)\%$. The measurement is consistent with all K^0_S coming from the Cabibbo-suppressed decay $\tau^-\to K^{*-}(890)\nu_\tau$ with a branching ratio of $(1.9\pm0.3\pm0.4)\%$.

This letter reports a new measurement of the inclusive production of K^0_S mesons in τ decays. The clean sample of τ decays that can be identified at PEP/PETRA energies provides an ideal laboratory for studies of the charged weak current [1]. The high energy of the produced lepton pairs and the low charged multiplicity of their decays means that the $K^0_S\to\pi^+\pi^-$ component can be measured with high efficiency and little background. The dominant source of the K^0_S particles in τ decays is the $J^P=1^-$ Cabibbo-suppressed decay [#1] $\tau^-\to K^{*-}\nu_\tau$, whose ratio to the electron branching fraction $B(\tau^-\to e^-\bar{\nu}_e\nu_\tau)$ is given by the standard model [2–4] as

$$\frac{B(\tau^-\to K^{*-}\nu_\tau)}{B(\tau^-\to e^-\bar{\nu}_e\nu_\tau)}=\frac{6\pi}{m_\tau^8}\, G^2_{K^*}\phi(m_\tau, m_{K^*})\sin^2\theta_C\,, \qquad (1)$$

where θ_C is the Cabibbo mixing angle and $\phi(m_\tau, m_{K^*})$ is a phase space factor.

This ratio depends on the coupling at the W–K* vertex (G_{K^*}) which is not predicted by the standard model, but can be estimated from asymptotic flavor symmetry [5–7]. In contrast, the W–ρ coupling (G_ρ) for the $J^P=1^-$ Cabibbo-favored decay, $\tau^-\to\rho^-\nu_\tau$, can be inferred [2] from the measured $e^+e^-\to\rho^0$ cross section via the conserved vector current (CVC) hypothesis. Hence, through eq. (1), the measurement of the $\tau^-\to K^{*-}\nu_\tau$ branching fraction can be interpreted within the standard model as a measurement of G_{K^*}, thereby testing asymptotic flavor symmetry. The $\tau^-\to K^0_S X^-\nu_\tau$ inclusive sample can also be used to set limits on the branching fractions to high mass vector states such as $\tau^-\to\rho^-(1600)\nu_\tau$, as well as the forbidden decay $\tau^-\to K^{*-}(1430)\nu_\tau$.

The measurement result is based on data collected at $\sqrt{s}=29$ GeV by the high resolution spectrometer

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[#1] Throughout the text, τ^- is used symbolically for both charged states.

(HRS) at the PEP e^+e^- storage ring facility. The integrated luminosity is 300 pb^{-1}, corresponding to the production of 40 000 τ pair events. The HRS has been described in detail elsewhere [8]; the features pertinent for this analysis include a drift chamber system that provided charged tracking over 90% of the solid angle with a momentum resolution of $\sigma_p/p \cong 2.0 \times 10^{-3} p$ (p in GeV/c) for high momentum tracks. A lead-scintillator electromagnetic calorimetry system covered 85% of the solid angle with an energy resolution of $\sigma_E/E = 0.16/\sqrt{E}$ (E in GeV) in the central region, and $0.20/\sqrt{E}$ (E in GeV) in the forward and backward regions. A vertex chamber [9] provided charged tracking down to a radial distance from the beam axis of 9 cm, which is comparable to the mean flight path of K_S^0 mesons (10 cm) produced in τ decays at PEP.

A detailed description of the selection criteria used to identify τ decays has been reported elsewhere [10,11]. The three- and five-prong τ decays used in this analysis were required to recoil against a τ decaying into a single charged track in the opposite hemisphere. The scalar sum of the charged track momenta was required to be greater than 7.25 GeV/c to suppress beam–gas interactions and two-photon events. Hadronic events were suppressed by requiring that the invariant mass of the charged tracks in the three- and five-prong hemispheres be less than 1.8 GeV/c^2, assuming that all charged particles were pions. In addition, the invariant mass of all charged particles and photons in the one-, three-, and five-prong hemispheres were required to be less than 1.5, 2.0, and 3.0 GeV/c^2 respectively. To further suppress the hadronic background in the five-prong hemisphere, the momentum of the five-prong system was required to be less than 600 MeV/c in the parent τ rest frame. Radiative events of Bhabha scattering and τ pair production populating the three- or five-prong hemispheres were suppressed by requiring that no tracks in the hemispheres deposit an energy consistent with being an electron. To further reduce beam–gas interactions, one track in each hemisphere was required to pass with 0.5 cm of the interaction point in the plane perpendicular to the beam axis, and within 5 cm along the beam axis. These selection criteria gave a data sample of 3510 three-prong τ decays, and a data sample of 21 five-prong τ decays. The level of hadronic background was estimated at 0.7% and 5% in the three- and five-prong decays respectively. These values were obtained by imposing the selection criteria on a sample of one-, three-, and five-prong jets that recoiled against a jet of at least four well measured tracks.

A K_S^0 candidate was defined as a pair of oppositely charged tracks in the same hemisphere that satisfied the following criteria:

(1) The sum of the individual track impact parameters exceeded 2 mm in the plane perpendicular to the beam.

(2) The two tracks formed a vertex located between 1 cm and 50 cm in radial distance from the beam axis.

(3) There were no hit drift chamber wires between the candidate vertex and the e^+e^- interaction point on the individual tracks.

(4) The pair momentum vector pointed back to the interaction point with $\rho_\perp^0/R_\perp < 0.05$, where $\rho_\perp^0$ is the impact parameter of the pair momentum vector in the radial direction, and $R_\perp$ is the radial distance to the candidate vertex.

(5) The two individual tracks fit well to a common vertex with a χ^2 per degree of freedom less than 2.0.

(6) The angular distribution of the individual tracks in the K_S^0 rest frame was required to satisfy $|\cos\theta^*| < 0.9$, where θ^* is the angle between the momentum vector of the pion and the K_S^0 direction of flight in the K_S^0 rest frame.

Assuming both particles of the candidate pair to be pions, the invariant mass distribution of the K_S^0 can-

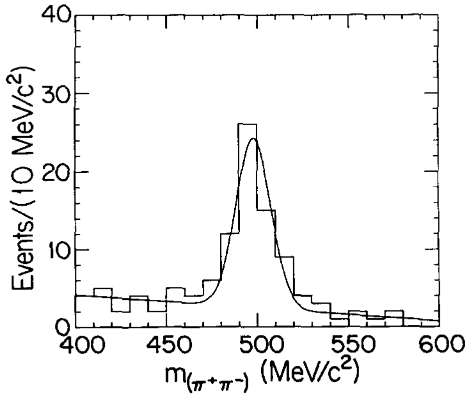

Fig. 1. The invariant mass distribution for $K_S^0 \to \pi^+\pi^-$ candidates. The fitted curve is a gaussian constrained to the K^0 mass plus a linear background. The width of the gaussian is fixed at $\sigma = 7$ MeV/c^2.

didates found in the three-prong sample is shown in fig. 1. A clear peak at the K^0 mass (498 MeV/c^2) can be seen with little background. The curve shown is a gaussian constrained to the K^0 mass plus a linear background which is fitted to the data. The width of the gaussian was fixed at the value ($\sigma = 7$ MeV/c^2) determined from a Monte Carlo simulation. The decay length distribution for the 52 candidates having an invariant mass within 15 MeV/c^2 of the K^0 mass is shown in fig. 2. The curve in fig. 2 was obtained from a Monte Carlo simulation and normalized to the candidates that decayed beyond the vertex chamber (> 10 cm). An inclusive Monte Carlo estimate of the background of misidentified candidate vertices inside the vertex chamber (< 10 cm) is also shown in fig. 2. The shape of this background estimate agrees with the decay length distribution obtained from the side-bands of fig. 1.

To search for $K^{*-}(890)$ decays, the momenta of the candidates were combined with the bachelor particle, considered as a pion. The resulting (K^0_S, π^-) invariant mass distribution is shown in fig. 3, and is dominated by the $K^{*-}(892)$. Also shown in fig. 3 is a normalized inclusive Monte Carlo estimate of misidentified K^0_S candidates combined with the bachelor pion. The shape of this background estimate agrees with the (K^0_S, π^-) mass distribution where the candidate K^0_S was taken from the side-bands of fig. 1. The Monte Carlo used in the background estimates and detection efficiency calculations generated events that were passed through a full detector simulation and the same chain of analysis as the data.

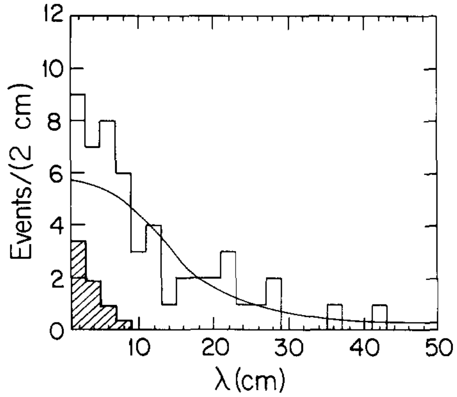

Fig. 2. The decay length distribution of the 52 K^0_S candidates within 15 MeV/c^2 of the K^0 mass. The curve was determined with a Monte Carlo simulation and normalized to the candidates that decayed outside the vertex chamber (> 10 cm). The shaded histogram was obtained from a normalized inclusive Monte Carlo estimate of the background of misidentified candidate vertices inside the vertex chamber (< 10 cm).

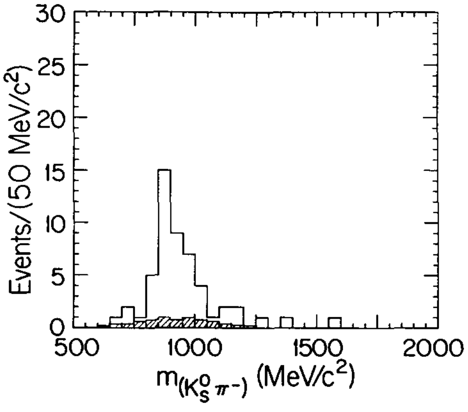

Fig. 3. The (K^0_S,π^-) invariant mass distribution. The shaded histogram was obtained from a normalized inclusive Monte Carlo estimate of misidentified candidates combined with the bachelor pion.

Hadronic background to this K^0_S signal has been estimated at ~1 event by searching for K^0_S candidates in three-prong hadronic jets. The remaining source of background comes from non-K^0_S candidates in the inclusive τ sample. Monte Carlo studies show that this background is small and flat in the region of the K^0 mass. This background is consistent with the excess events at small decay length in fig. 2. After subtracting this background, a signal of 44 events remain yielding an inclusive branching fraction of

$$B(\tau^- \to K^0_S X^- \nu_\tau) = (0.64 \pm 0.15)\% . \qquad (2)$$

The error includes uncertainties in the background subtraction, detection efficiency and the integrated luminosity.

We have also searched for $K^0_S \to \pi^+\pi^-$ decays in the five-prong τ sample. Upon finding no K^0_S candidates, a 95% confidence limit can be set on the inclusive branching fraction:

$$B(\tau^- \to K^0_S (3X^\pm)^- \nu_\tau) < 0.087\% . \qquad (3)$$

From fig. 3 it is evident that production of K^0_S particles in three-prong τ decay proceeds dominantly through the $K^{*-}(892)$ resonance. Background contributions[#2] to the $\tau^- \to K^{*-}\nu_\tau$ decay from $\tau^- \to \rho^-(1600)\nu_\tau \to K^0_L K^{*-}\nu_\tau$ can be estimated from the $\rho^-(1600) \to K^0_S K^{*-}$ decay that would populate the five-prong topology. Inequality (3) limits the $\rho(1600)$ background contribution to the $\tau^- \to K^{*-}\nu_\tau$ branching fraction at 0.25% (95% confidence level). This limit is consistent with the measurement [12] of $B(\tau^- \to K^+\pi^-K^-\nu_\tau) = 0.22^{+0.17}_{-0.11}$, assuming this branching fraction is dominated by the $\tau^- \to \rho^-(1600)\nu_\tau$ channel.

Associating all the 44 events with the decay channel $\tau^- \to K^{*-}(892)\nu_\tau$, yield a branching fraction of $(1.9 \pm 0.3 \pm 0.4)\%$ where the first error is statistical and the second systematic. The latter error includes uncertainties in the background subtraction (8 ± 2 background events), detection efficiency (14.6 ± 0.73)%, total luminosity ($82\,000 \pm 4100$ decays), and the possible $\rho(1600)$ source of K* production. This result is somewhat larger but consistent with other measurements [13–15].

The single event with a $K^0_S\pi^-$ mass of 1578 MeV/c^2 is consistent with the expected hadronic background. This event also gives a 95% confidence level limit on the forbidden τ decay to the tensor meson $K^{*-}(1430)$ of 0.3%. The previously published limit for this channel was 0.9% [13].

The standard model expectation for the branching fraction for $K^{*-}\nu_\tau$ is $(0.85 \pm 0.02)\% \times G^2_{K^*}$. Assuming the standard model correctly describes τ decay but with an unknown W–K* coupling, our measurement gives $G_{K^*} = 1.5 \pm 0.3$.

Asymptotic flavor symmetry relates G_{K^*} in terms of G_ρ through the relation [5–7]

$$G_{K^*}/G_\rho = m_{K^*}/m_\rho = 1.16 \,. \tag{4}$$

This prediction can be tested by using the world average branching fraction for the $J^P = 1^-$ Cabibbo-favored decay $\tau^- \to \rho^-(770)\nu_\tau$ of $(22.1 \pm 1.1)\%$ [1] which gives a ratio $R = 0.086 \pm 0.028$ where

$$R = \frac{B(\tau^- \to K^{*-}(892)\nu_\tau)}{B(\tau^- \to \rho^-(770)\nu_\tau)}$$

$$= \tan^2\theta_C \, (G_{K^*}/G_\rho)^2 \phi(m_\tau, m_{K^*}, m_\rho) \,. \tag{5}$$

This in turn yields $G_{K^*}/G_\rho = 1.5 \pm 0.3$. With unbroken SU(3), G_{K^*}/G_ρ is 1.0. The uncertainty in the measured value of R, however, precludes a precise test.

In conclusion, we have measured the inclusive production of K^0_S particles in three-prong τ decay and have found the dominant source to be through $\tau^- \to K^{*-}\nu_\tau$ as expected from the standard model. The absence of high mass events in the $K^0_S\pi^-$ mass distribution sets an upper limit on the branching fraction of the forbidden decay $\tau^- \to K^{*-}(1430)\nu_\tau$ of less than 0.3% at the 95% confidence level.

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[#2] $\tau^- \to Q^-_{(1,2)}\nu_\tau$ can subsequently decay into $K^{*-}(890)$ and neutral particles as well. This background is limited to less than 0.02% from a measurement of the $\tau^- \to K^-\pi^+\pi^-\nu_\tau$ decay (see ref. [12]).