MEASUREMENT OF THE INCLUSIVE $K^0_s$ BRANCHING FRACTION IN $\tau$ DECAY


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The inclusive production of $K^0_s$ mesons in $\tau$ 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 $B(\tau^-\rightarrow K^0X\nu_\tau) = (0.64 \pm 0.15)\%$. The measurement is consistent with all $K^0_s$ coming from the Cabibbo-suppressed decay $\tau^-\rightarrow K^*\nu_\tau$ with a branching ratio of $(1.9 \pm 0.3 \pm 0.4)\%$.

This letter reports a new measurement of the inclusive production of $K^0_s$ mesons in $\tau$ decays. The clean sample of $\tau$ 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 $K^0_s \rightarrow \pi^+\pi^-$ component can be measured with high efficiency and little background. The dominant source of the $K^0_s$ particles in $\tau$ decays is the $J^P=1^-$ Cabibbo-suppressed decay $\#1 \tau^-\rightarrow K^\ast^-\nu_\tau$, whose ratio to the electron branching fraction $B(\tau^-\rightarrow e^-\nu_\tau)$ is given by the standard model [2–4] as

$$B(\tau^-\rightarrow K^\ast^-\nu_\tau) = \frac{6\pi}{B(\tau^-\rightarrow e^-\nu_\tau)} G_{K^\ast} \phi(m_\tau, m_{K^\ast}) \sin^2\theta_C, \quad (1)$$

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

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

The measurement result is based on data collected at $\sqrt{s}=29$ GeV by the high resolution spectrometer.
(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 \( \sigma_p/p \approx 2.0 \times 10^{-3}p \) (\( p \) 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° 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/c², 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/c² 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° 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 \( \rho_{\perp} / R_{\perp} < 0.05 \), where \( \rho_{\perp} \) 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 \( \chi^2 \) per degree of freedom less than 2.0.
6. The angular distribution of the individual tracks in the K° rest frame was required to satisfy \( |\cos \theta^*| < 0.9 \), where \( \theta^* \) is the angle between the momentum vector of the pion and the K° direction of flight in the K° rest frame.

Assuming both particles of the candidate pair to be pions, the invariant mass distribution of the K° can-
candidates 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 \((K^0,\pi^-)\) 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 \(K^0\) candidates combined with the bachelor pion. The shape of this background estimate agrees with the \((K^0_s,\pi^-)\) 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.

Hadronic background to this \(K^0\) signal has been estimated at \(\sim 1\) event by searching for \(K^0\) candidates in three-prong hadronic jets. The remaining source of background comes from non-

\(K^0\) candidates in the inclusive \(\tau\) 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

\[
B(\tau^- \rightarrow K^0 X^- \nu_\tau) = (0.64 \pm 0.15)\%.
\]

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

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

\[
B(\tau^- \rightarrow K^0_s (3X^\pm) \nu_\tau) < 0.087\%.
\]

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

Associating all the 44 events with the decay channel \( \tau^+ \rightarrow K^*^- (892) \nu_\tau \), 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 \((8 \pm 2\) background events\)), detection efficiency \((14.6 \pm 0.73)\%\), total luminosity \((82000 \pm 4100\) 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 \( \tau \) decay to the tensor meson \( K^*- (1430) \nu_\tau \) 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 \((0.85 \pm 0.02)\% \times G_{K^*}^2\). Assuming the standard model correctly describes \( \tau \) 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 \( G_\rho \) through the relation \[5-7\]

\[
G_{K^*}/G_\rho = m_{K^*}/m_\rho = 1.16 .
\]

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

\[
R = \frac{B(\tau^- \rightarrow K^*^- (892) \nu_\tau)}{B(\tau^- \rightarrow \rho^- (770) \nu_\tau)} = \tan^2 \theta_C (G_{K^*}/G_\rho)^2 \phi (m_\tau, m_{K^*}, m_\rho). \tag{5}
\]

This in turn yields \( G_{K^*}/G_\rho = 1.5 \pm 0.3 \). With unbroken \( SU(3) \), \( G_{K^*}/G_\rho = 1.0 \). 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 \( \tau \) decay and have found the dominant source to be through \( \tau^- \rightarrow K^*^- \nu_\tau \), 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 \( \tau^- \rightarrow K^*- (1430) \nu_\tau \) of less than 0.3\% at the 95\% confidence level.

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