CONF-870797--9

ANL-HEP-CP--87-59

DE88 002915

MEASUREMENT OF THE INCLUSIVE K_S^0 BRANCHING FRACTION IN τ DECAY

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ABSTRACT

A data sample corresponding to an integrated luminosity of 300 pb^{-1} of e^+e^- annihilations at 29 GeV was used to measure the inclusive branching fraction $\tau^- \rightarrow K_S^0 X^- \nu_\tau$. The experiment was performed using the High Resolution Spectrometer at the PEP storage ring. The measured branching fraction is $(0.64 \pm 0.15)\%$. The data are consistent with all K_S^0 coming from the Cabibbo-suppressed decay $\tau \rightarrow K^{*-}(890)\nu_\tau$ leading to a branching ratio of $(1.9 \pm 0.28 \pm 0.25)\%$ for this channel. The inclusive sample was used to set 90% CL limits on the branching fractions of $\tau^- \rightarrow \rho^-(1600)\nu_\tau$ and $\tau^- \rightarrow K^{*-}(1430)\nu_\tau$ of 8.5%, and 0.3% respectively.

Submitted to the 1987 International Symposium on Lepton and Photon Interactions at High Energies.

July 26-31, 1987, Hamburg, W. Germany

DISCLAIMER

This letter reports a new measurement of the inclusive production of K_S^0 in τ decays to three and five charged prongs. The clean sample of τ pairs that can be identified at PEP/PETRA energies allows detailed measurements of the charged weak current. The high energy of the produced lepton pairs and the low charged multiplicity of their decays means that the $K_S^0 \to \pi^+\pi^-$ component can be measured with high efficiency and little background. The dominant source of the K_S^0 particles in τ decays is the $J^P = 1^-$ Cabibbo-suppressed decay mode $\tau^- \to K^{*-}\nu_\tau$ whose branching fraction can be estimated[1-3] from the τ lifetime[4,5] and the standard model. The actual value of this branching fraction depends on the W–K^* coupling (G_{K^*}) which is not predicted by the standard model, but can be estimated from asymptotic flavor symmetry.[6-8] The equivalent W–ρ coupling (G_ρ) for the $J^P = 1^-$ Cabibbo favored decay can be inferred from the measured $e^+e^- \to \rho^0$ cross section via the CVC hypothesis.[1] Therefore, from equation (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^*}, where θ_C is the Cabibbo mixing angle, τ_τ is the τ lifetime, and $\phi(m_\tau, m_{K^*})$ is a phase space factor that depends only on the mass of the τ and K^*.

$$BR(\tau^- \to K^{*-}\nu_\tau) = \tau_\tau \frac{1}{16\pi}(\frac{G_W^2}{m_W^2}\sin\theta_C)^2 G_{K^*}^2 \phi(m_\tau, m_{K^*}) \qquad (1)$$

The $\tau^- \to K_S^0 X^- \nu_\tau$ inclusive sample can also be used to set limits on the branching fractions to high mass vector states such as $\tau^- \to \rho^-(1600)\nu_\tau$, and the forbidden decay $\tau^- \to K^{*-}(1430)\nu_\tau$.

This measurement is based on 300 pb^{-1} of data taken at $\sqrt{s} = 29\ GeV$ by the High Resolution Spectrometer (HRS) at the PEP e^+e^- storage ring facility. This integrated luminosity corresponds to the production of about 41,000 τ pair events. The HRS has been described in detail elsewhere[9] ; the features pertinent for this analysis include charged tracking over 90% of the total solid angle with a momentum resolution of $\sigma_p/p \cong 2.0\times10^{-3}p$ (p in GeV/c) for $p > 200MeV/c$, and electromagnetic calorimetry over 85% of the total 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 region.A vertex chamber[10] provided charged tracking down to a radial distance from the beam axis of 9 cm. The mean flight path of K_S^0 particles produced in τ decays at PEP energies is $\sim$ 10 cm. The 16.2 kG solenoidal magnetic field of the detector aided the identification of τ pair events by separating well the high momentum charged tracks produced in these low multiplicity events.

A detailed description of the selection criteria used to identify three and five charged prong τ decays with the HRS has been reported elsewhere.[11,12] The selection criteria important for this analysis will now be discussed. The events used for this analysis were required to have three or five well measured charged tracks recoiling against one well measured 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 low energy beam-gas events. The remaining backgrounds were from low multiplicity hadronic and radiative Bhabha events. Hadronic events were suppressed by requiring that the mass reconstructed from charged tracks in the three and five-prong hemispheres was less than 1.8 GeV/c^2, assuming that all charged particles were pions. In addition, the reconstructed mass of all charged particles and photons in the one, three, and five-prong hemispheres was required to be less than 1.5 GeV/c^2, 2.0 GeV/c^2, and 3.0 GeV/c^2. To suppress the remaining hadronic background in the five prong hemisphere the reconstructed momentum of the charged five-prong system was required to be less than 600 MeV/c in the parent τ rest frame. Radiative Bhabha and radiative τ events in the three and five-prong hemispheres respectively were suppressed by requiring that no tracks in the three and five-prong hemispheres deposit an energy in the calorimeter consistent with being an electron. To further suppress beam-gas events, one track in each hemisphere was required to pass within 0.5 cm of the interaction point in the plane perpendicular to the beam axis, and within 5 cm of the interaction point along the beam axis. The hadronic background was estimated by imposing the selection criteria on a sample of one, three, and five-prong jets that recoiled against a jet of at least 4 well measured tracks.

This selection criteria gave a data sample of 3510 three-prong τ decays having an estimated hadronic background of 0.7%, and a data sample of 44 five-prong τ decays having an estimated background of $\sim$ 50%. The predominant background in the five-prong sample was due to Dalitz pairs associated with a three-prong τ decay where the electron tracks of the Dalitz pair did not intercept the calorimeter. Since the invariant mass of these pairs is very small they present no background for this inclusive K_S^0 measurement. The hadronic background in the five-prong sample is estimated to be $\sim 5\%$.

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

- The sum of the individual track impact parameters exceeded 2 mm in the plane perpendicular to the beam.
- The two tracks formed a vertex located between 1 cm and 50 cm in radial distance from the beam axis.
- No drift chamber wires at radii smaller than that of the candidate vertex had fired on the individual tracks.
- The pair momentum pointed back to the interaction point with $\rho_\perp^0/R_\perp < 0.05$, where $\rho_\perp^0$ is the pair momentum impact parameter in the plane perpendicular to the beam axis, and $R_\perp$ is the radius of the candidate vertex in the plane perpendicular to the beam axis.
- The two individual tracks fitted well to a common vertex with a $\chi^2/DOF < 2.0$.
- To suppress non-K_S^0 pairs from the inclusive 3-prong τ decay background, 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 candidate pion momentum 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 candidates found in the three-prong τ decay sample is shown in Fig. 1. A clear peak at the K^0 mass (498 MeV/c^2) can be seen with very little background. The curve shown is a Gaussian constrained to the K^0 mass plus a linear background fitted to the data. The width of the Gaussian was fixed at the value ($\sigma = 7MeV/c^2$) determined from a Monte Carlo simulation.

The decay length distribution of the 52 candidates having an invariant mass within 15 MeV/c^2 of the K^0 mass is shown in Fig. 2. The curve shown was obtained from a Monte Carlo simulation of the experiment, normalized to the data greater than 10 cm, and it shows that the mean lifetime is consistent with that expected. These 52 candidates were then combined with the bachelor charged particle, considered as a pion, to give the invariant mass distribution of Fig. 3. The mass distribution is clearly dominated by the $K^*(892)$. The curve shown is a Breit-Wigner shape convoluted with the K_S^0 resolution function as determined by a Monte Carlo simulation with the normalization set by the data. The Monte Carlo used in these comparisons generated the exclusive decay channel:

$$\tau^- \to K^{*-}(892)\nu_\tau \to K_S^0\pi^-\nu_\tau \to \pi^+\pi^-\pi^-\nu_\tau$$

The generated events were then processed through a full detector simulation and the results used to estimate the detection efficiency.

Low multiplicity hadronic backgrounds to this K_S^0 signal have been studied by searching for candidates in a three-prong sample of hadronic jets, and by measuring the rejection of the invariant mass cuts on a sample of one and three-prong hadronic jets. These studies indicate the hadronic background is ≤ 1 event. The remaining source of background comes from non-K_S^0 candidates in the inclusive τ sample. This non-K_S^0 background has been estimated from an inclusive τ decay Monte Carlo that did not include K_S^0 decays. It is small and flat in the region of the K^0 mass. After correcting for this background and subtracting a hadronic background of one event, 44 events remain. This level of background is consistent with the excess events at low radii in Fig. 2, and at high mass in Fig. 3. These 44 events determine the three-prong inclusive branching fraction:

$$BR(\tau^- \to K_S^0X^-\nu_\tau) = (0.64 \pm 0.15)\%$$

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

Upon finding no K_S^0 candidates in the sample of five-prong τ decays, and using a Monte Carlo to estimate the detection efficiency of five-prong τ decays that include $K_S^0 \rightarrow \pi^-\pi^+$ decays, 90% CL limits can be set on the following inclusive branching fractions:

$$BR(\tau^- \rightarrow K_S^0(3X^{\pm})^-\nu_\tau) < 0.00067$$

$$BR(\tau^- \rightarrow K_S^0K_S^0X^-\nu_\tau) < 0.0022$$

From Fig. 3 it is evident that production of K_S^0 particles in three-prong τ decay procedes dominantly through the $K^{*-}(892)$ resonance. Backgrounds to the $\tau^- \rightarrow K^{*-}\nu_\tau$ decay from heavier meson decays which subsequently decay into K^{*-} and un-identified neutral particles will now be discussed. The only other resonant τ decays permitted by isospin and angular momentum conservation that can produce K_S^0 particles through the $K^{*-}(892)$ resonance are the Cabibbo-suppressed decays $\tau^- \rightarrow Q^-(1280)\nu_\tau$, $\tau^- \rightarrow Q^-(1400)\nu_\tau$, and the Cabibbo-favored decay $\tau^- \rightarrow \rho^-(1600)\nu_\tau$. Background contributions to the $\tau^- \rightarrow K^{*-}\nu_\tau$ decay from $\tau^- \rightarrow Q^-\nu_\tau \rightarrow K^{*-}X^0\nu_\tau$ can be estimated from a measurement[13] of the $\tau^- \rightarrow K^-\pi^+\pi^-\nu_\tau$ decay which is expected to be dominated by the Q resonances. This measurement limits the background contribution to the $\tau^- \rightarrow K^{*-}\nu_\tau$ branching fraction through the Q resonances at 0.02%.

Background contributions to the $\tau^- \rightarrow K^{*-}\nu_\tau$ decay from $\tau^- \rightarrow \rho^-(1600)\nu_\tau \rightarrow K_L^0K^{*-}\nu_\tau$ can be estimated from the $\rho^-(1600) \rightarrow K_S^0K^{*-}$ decay that populates five-prong τ decays. The 90% CL limits on five-prong τ decays that include K_S^0 reported above holds the background contribution to the $\tau^- \rightarrow K^{*-}\nu_\tau$ branching fraction from $\rho^-(1600) \rightarrow K_L^0K^{*-}$ decays at 0.18% (90% CL). By using the $BR(\rho^-(1600) \rightarrow \bar{K}^*K + K^*\bar{K}) = (9 \pm 2)\%$[14] the $\tau^- \rightarrow \rho^-(1600)\nu_\tau$ branching fraction can be limited to less than 8.5% (90% CL).

Associating all of the 44 events with the decay channel $\tau^- \rightarrow K^{*-}(892)\nu_\tau$, yields a branching fraction of $(1.9 \pm 0.28 \pm 0.25)\%$ where the first error is statistical and the second systematic. The systematic error includes uncertainties in the background subtraction, detection efficiency, total luminosity, and the possible $\rho(1600)$ source of K^* production. This result is consistent with other measurements.[15,16] The single event with a $K_S^0\pi^-$ mass of

1578 MeV/c^2 is consistent with the expected hadronic background. This event also gives a limit on the forbidden τ decay to the tensor meson, and corresponds to a 90% CL limit on the branching fraction of $\tau^- \rightarrow K^{*-}(1430)\nu_\tau$ of 0.3%.This limit is a 3 times smaller than the previously published limit.[17]

The standard model expectation[1–3] for the branching fraction of the resonant decay channel $\tau^- \rightarrow K^{*-}\nu_\tau$ is $(0.85 \pm 0.03)\% \times G^2_{K^*}$, where the source of error is from the uncertainty in the τ lifetime.[5] Assuming the standard model correctly describes τ decay but with an unknown W–K^* coupling, this measurement gives $G_{K^*} = 1.50 \pm 0.15$.

Asymptotic flavor symmetry predicts G_{K^*} in terms of G_ρ through the relation[6–8]:

$$\frac{G_{K^*}}{G_\rho} = \frac{m_{K^*}}{m_\rho} \qquad (2)$$

This prediction can be tested by employing the recently well measured $J^P = 1^-$ Cabibbo-favored decay $\tau^- \rightarrow \rho^-(770)\nu_\tau$ branching fraction[15] to form the ratio:

$$R = \frac{BR(\tau^- \rightarrow K^{*-}(892)\nu_\tau)}{BR(\tau^- \rightarrow \rho^-(770)\nu_\tau)} = \tan^2\theta_C \left(\frac{G_{K^*}}{G_\rho}\right)^2 \phi(m_\tau, m_{K^*}, m\rho)$$

Assuming $G_\rho = G_{K^*}$, and $\tan^2\theta_C = 0.053$[18] , R is predicted to be 0.038 [1–3]. For $G_{K^*} = \frac{m_{K^*}}{m_\rho} G_\rho$, R increases to 0.052 [1–3]. The measured value of R is 0.086 ± 0.028, is consistent with both expectations. Although the measured value of R favors the SU(3) breaking predicted in equation (2), the uncertainty in the measured value precludes a precise test of asymptotic flavor symmetry.

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 $\tau^- \rightarrow K^{*-}\nu_\tau$ at a level expected from the standard model. The absence of high mass events in the K^0_S mass distribution was used to set a limit on the branching fraction of the forbidden decay $\tau^- \rightarrow K^{*-}(1430)\nu_\tau$ to be less than 0.3% at a 90% CL. We have also used the absence of observed K^0_S particles in five-prong τ decays to limit the branching fraction of $\tau^- \rightarrow \rho^-(1600)\nu_\tau$ to be less than 3.5% at a 90% CL.

We wish to convey our gratitude to the *SLAC* cryogenic group and the technical staffs of PEP and the collaborating institutions, whose important contributions made this experiment possible. This work has been supported in part by the U.S. Department of Energy under contracts No. W–31–109–ENG–38, No. DE–AC02–76ER01112, No. DE–AC03–76F000998, No. DE–AC02–76ER01428 and No. DE–AC02–84ER40125.

FIGURE CAPTIONS

*Fig.*1 The invariant mass distribution for $K_S^0 \to \pi^+\pi^-$ decay 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 $\sigma = 7\ MeV/c^2$.

*Fig.*2. The Decay length distribution of the 52 K_S^0 candidates within 15 MeV/c^2 of the K^0 mass. The curve, which is normalized to the data greater than 10 cm, is determined by a Monte Carlo simulation. The excess events at low radii are consistent with the non-K_S^0 background of 7 events.

*Fig*3. (K_S^0, π^-) invariant mass. The curve comes from a Monte Carlo simulation of the exclusive decay $\tau^- \to K^{*-}\nu_\tau$ normalized to the data. The excess events at high mass are consistent with a non-K_S^0 background of 7 events and a hadronic background of 1 event.

REFERENCES

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1. Yung-Su Tsai, *Phys. Rev.* **D4**, 2821 (1971).
2. H. Thacker and J.J. Sakurai, *Phys. Rev. Lett.* **36B**, 103 (1971).
3. F. J. Gilman, S.H. Rhie, *Phys. Rev.* **D38**, 1066 (1985).
4. S. Abachi et. al, (HRS Collaboration), Argonne Preprint # ANL-HEP-PR-87-1, Submitted to Phys. Rev. Lett.
5. For a recent review see, for example, B.C. Barish, R. Stroynowski, Cal. Tech. preprint CALT-68-1425. Submitted to Physics Reports.
6. T. Das, V. S. Mathur, S. Okubo *Phys. Rev. Lett.* **18**, 761 (1967).
7. S. Matsuda, S. Oneda, *Phs. Rev.* **171**, 1743 (1968).
8. S. Oneda, *Phys. Rev.* **D35**, 397 (1987).
9. D. Bender et al. (HRS Collaboration), *Phys. Rev.* **D30**, 515 (1984).
10. P. Baringer et al. (HRS Collaboration), *Nucl. Inst. Meth.* **A254**, 542, (1987).
11. K.K. Gan, et. al. (HRS Collaboration), *Phys. Rev. Lett.* **55**, 570, (1985).
12. I. Beltrami et al. (HRS Collaboration), *Phys. Rev. Lett.* **54**, 1775, (1985).
13. G. B. Mills et al. (DELCO Collaboration), *Phys. Rev. Lett.* **54**, 624 (1985).
14. Particle Data Group, *Phys. Lett.*, **107B**, (1986).
15. J. M. Yelton et al. (MARK II Collaboration), *Phys. Rev. Lett.* **56**, 812 (1986).
16. H. Aihara et al. (TPC Collaboration), *Phys. Rev.* **D35**, 1553, (1987).
17. J. M. Dorfan et al. (MARK II Collaboration), *Phys. Rev. Lett.* **46**, 215 (1981).

18. J.M. Gaillard, G. Sauvage, *Ann. Rev. Nucl. Par. Sci.* **34**, (1984).

Candidate pair invariant mass.

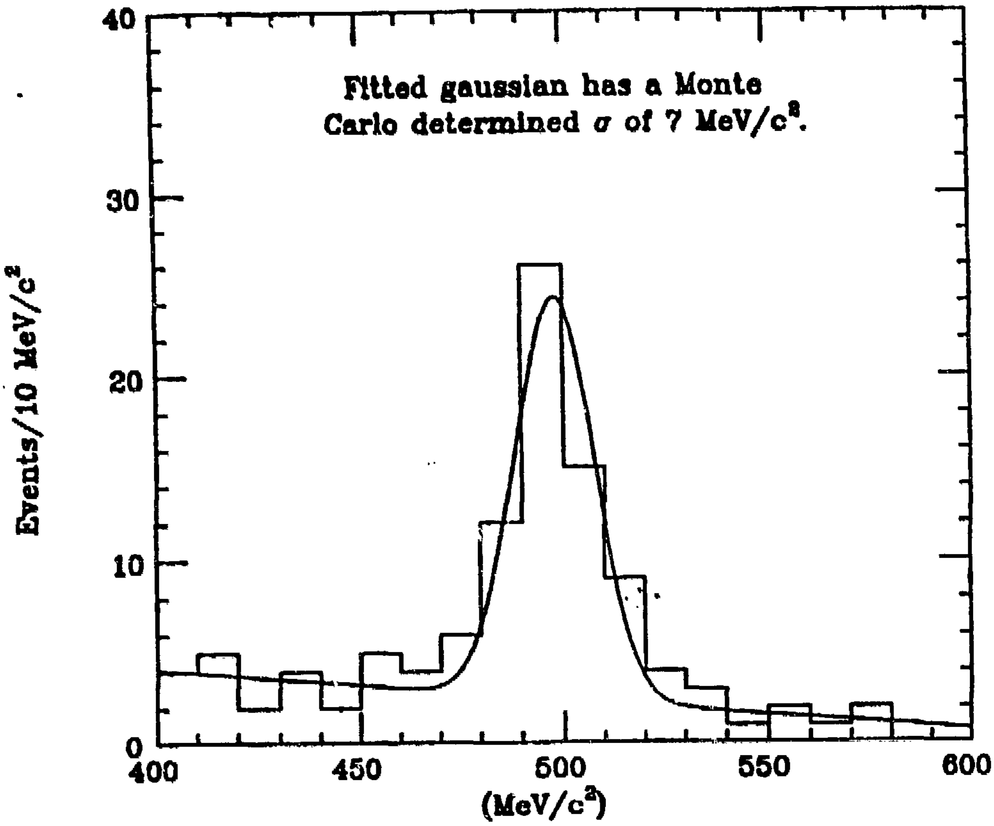
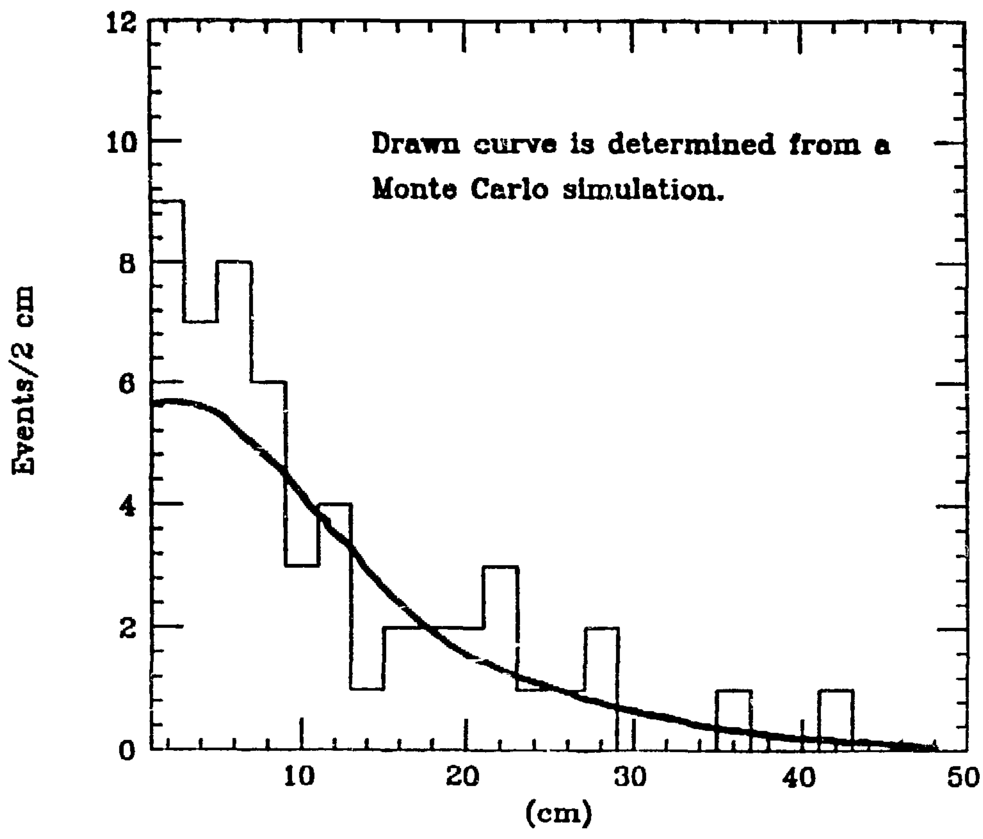
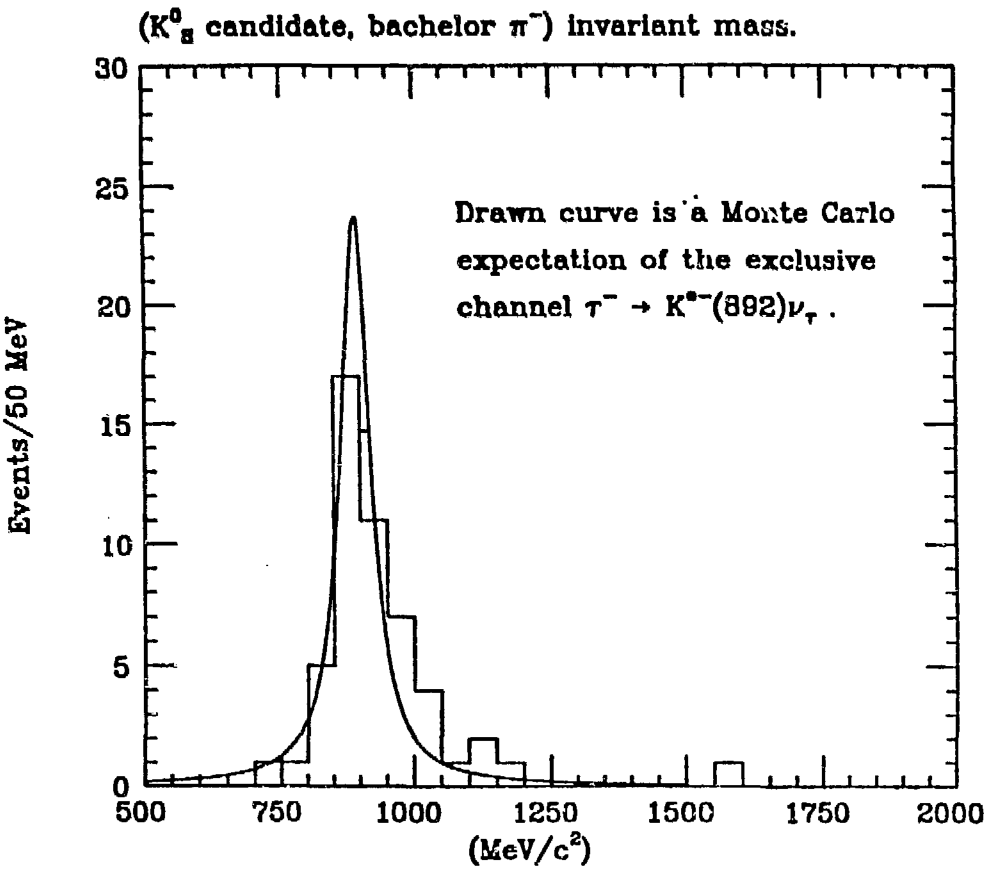


Fig. 1.

Decay length of candidate pair.





(K^0_s candidate, bachelor π^-) invariant mass.
Drawn curve is a Monte Carlo
expectation of the exclusive
channel $\tau^- \to K^{*-}(892)\nu_\tau$.
Events/50 MeV
(MeV/c²)
0
5
10
15
20
25
30
500
750
1000
1250
1500
1750
2000

Fig 3.