MEASUREMENT OF THE LIFETIME OF THE SHORT-LIVED NEUTRAL K MESON

P. Lugaresi-Serra and M. Piccinini

Istituto di Fisica dell'Università di Bologna
Istituto Nazionale di Fisica Nucleare, Sezione di Bologna

R. Jennings

Department of Natural Philosophy, University of Glasgow

G. Bressi, G. Ciapetti, D. Zanello

Istituto di Fisica dell'Università di Roma
Istituto Nazionale di Fisica Nucleare, Sezione di Roma

E. Castelli, M. Furlan, C. Omero, P. Poropat, M. Sessa

Istituto di Fisica dell'Università di Trieste
Istituto Nazionale di Fisica Nucleare, Sezione di Trieste

ABSTRACT

The mean lifetime of the short-lived neutral kaon (K°_{S}) has been measured using a sample of 22500 K°_{S} produced in the 81 cm Saclay deuterium bubble chamber. Our best estimate of the K°_{S} mean lifetime is $\tau_{K^{\circ}_{S}} = (0.873 \pm 0.007) \cdot 10^{-10}$ sec.

1. - INTRODUCTION

In the course of a series of K^+d experiments at laboratory momenta below 1.5 GeV/c (1) we have observed about 28000 $K^o_s \to \pi^+\pi^-$ decays in the Saclay 81 cm deuterium bubble chamber.

The lifetime of the short-lived neutral K-meson has been determined from 20369 events, which represent a clean sample obtained after appropriate selections (Section 2).

A careful study of possible systematic errors due to these selection criteria has been made and we report our result which is insensitive to variations of these criteria. Moreover other sources of systematic errors have been taken into account: (a) the uncertainty in the K^o_s mass, (b) the error in the measurements of lengths and (c) the error in the K^o_s momenta arising from the uncertainties in the magnetic field. We show that the systematic errors associated with these effects are smaller than the quoted statistical error.

Three other high statistics bubble chamber experiments have been carried out on this subject: D.G. Hill et al. (2) and R.A. Donald et al.(3) have statistics that are comparable to ours, while O. Skjeggestad et al.(4) have more than double our statistics. The K^o_s lifetime has also been measured in an electronic experiment using a neutral kaon beam with statistics of 6 million events (5). The value of our experiment is reported in Table 1, together with the values that were found in the previously mentioned experiments.

2. - EXPERIMENTAL METHOD

The 81 cm Saclay bubble chamber filled with deuterium was exposed at the CERN 28 GeV protonsynchrotron to electrostatically separated K^+ beams at several momenta below 1.5 GeV/c. About 500,000 pictures were analysed and the details of these exposures can be found in reference (1). In particular the following reactions have been studied:

$$K^+ d \rightarrow K^o_s \, p \, n \, \pi^+ \qquad (1)$$

$$K^o_s \, p \, p \qquad (2)$$

$$K^o_s \, p \, p \, \pi^o \qquad (3)$$

with $K^o_s \rightarrow \pi^+\pi^-$ decays visible in the chamber and with both visible and non-visible spectator protons.

Most of the film was scanned twice for V^o associated to one or two prong production vertices. The overall scanning efficiency was found to be 96% for a single and 99% for a double scanning. Measurements were done on Mangiaspago and SMP machines. Measured events were processed through either the CERN THRESH-GRIND-SLICE or Rutherford Laboratory chain of programs of geometrical reconstruction and kinematics fitting. All the events failing at any stage were remeasured at least once.

All the V^o candidates were fitted to the $K^o_s \rightarrow \pi^+\pi^-$ hypothesis. Systematic event association was tried between the successfully fitted decays and all the possibile production vertices found in each picture, by means of 4C, for reactions (1) and (3), or 7C, for reaction (2), multivertex fits. Only successful multivertex fits were used. For these events the decay and production vertices were always uniquely associated. We imposed a probability cut of 0.1% for the unambiguous fits and all the ambiguous or unfitted events were checked by physicists at the scanning table. At our energies it is practically always possible to resolve the ambiguity by checking the track ionization and the very small number of the unresolvable events (about 0.3%) were removed from the sample. The unmeasurable events which were obviously not $K^o_s \rightarrow \pi^+\pi^-$ or were not associated with a primary vertex were not considered.

A fiducial volume for the production vertex and another larger fiducial volume for the decay vertex were chosen and a cut on the K_s^o momentum imposed at 100 MeV/c. 22,500 events, surviving the above cuts, were collected on Data Summary Tapes. The numbers of events according to primary K^+ momentum are listed in Table 2.

In Fig. 1 the K_s^o decay length distribution and in Fig. 2 the momentum spectrum for these events are shown.

In order to ensure a good visibility both in the scanning and measurement phases, the projected decay length of the K_s^o was required to be larger than 0.3 cm, while the decay length of the K_s^o was restricted to be less than 15 cm (see Section 4).

The sample of 20369 events which satisfied the above conditions was used in computing the mean lifetime of the short-lived neutral K-meson. The effects of these cuts on the K_s^o decay length and momentum is shown in Figs. 1 and 2.

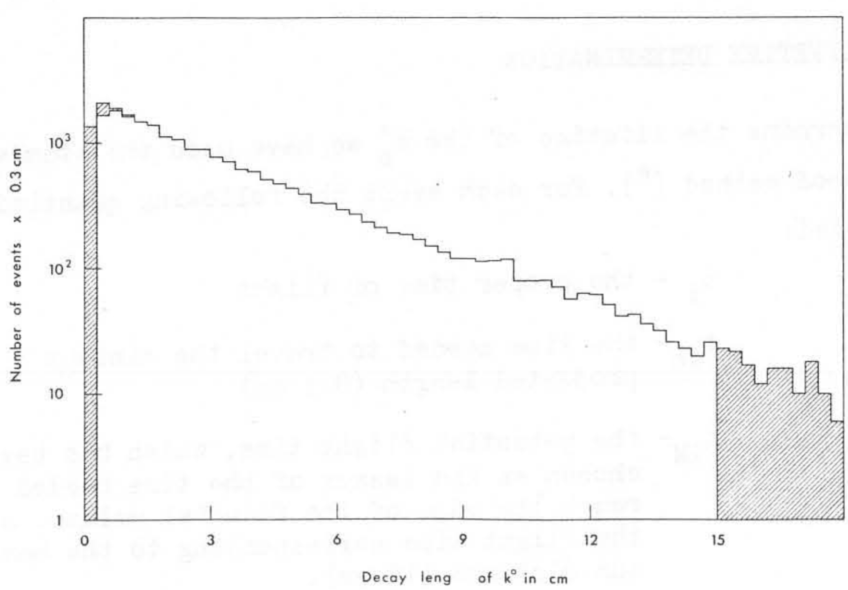

Fig. 1 - Decay length distribution of K_s^o. The dashed areas represent the effect of the cuts in length (see text).

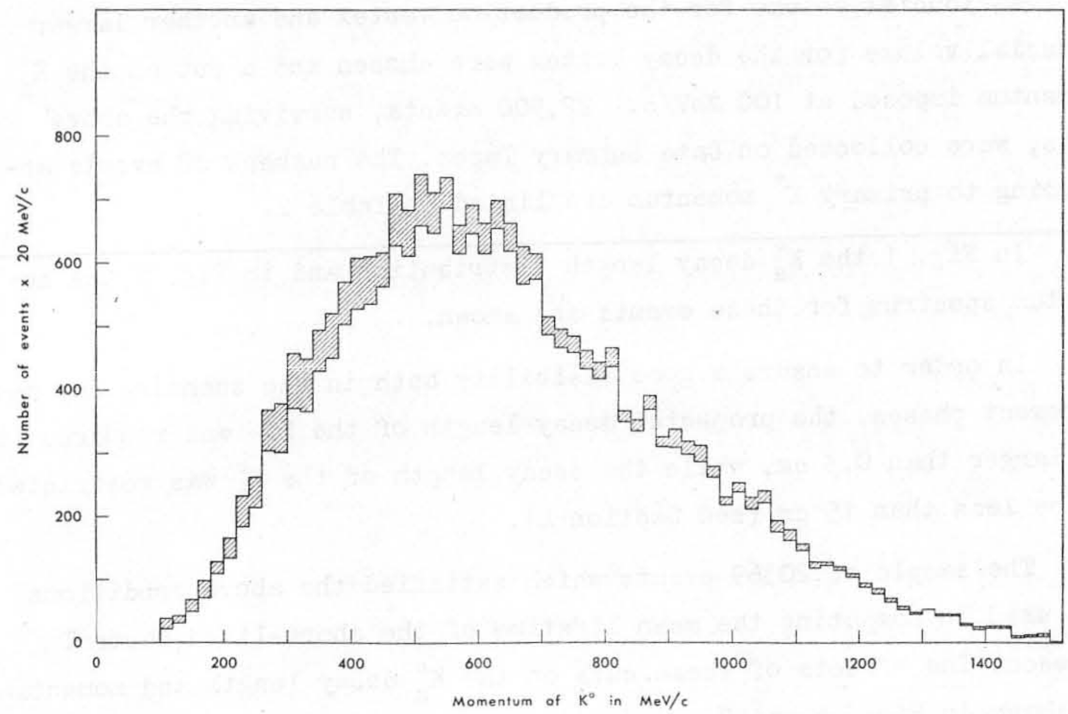

Fig. 2 - Momentum spectrum of the K_s^o's. The dashed area represents the effect of the cuts in length (see text).

3. - MEAN LIFETIME DETERMINATION

To determine the lifetime of the K_s^o we have used the standard maximum likelihood method [6]. For each event the following quantities have been evaluated:

- t_i - the proper time of flight
- t_{im} - the time needed to travel the minimum projected length (0.3 cm)
- t_{iM} - the potential flight time, which has been chosen as the lesser of the time needed to reach the edge of the fiducial volume, and the flight time corresponding to the maximum distance (15 cm).

The likelihood function is then given by:

$$L(\tau) = \prod_{i=1}^{N} \frac{1}{\tau} \frac{\exp(-t_i/\tau)}{\exp(-t_{im}/\tau)-\exp(-t_{iM}/\tau)} \qquad (4)$$

where N is the number of events and τ the K_S^o mean lifetime. The maximum of this likelihood function has been determined by successive approximations ([7]); we have found that the first approximation is sufficient and that the final value does not depend on the starting values (the K_S^o mean lifetimes of the Particle Data Tables ([8]) of the last 6 years were chosen as the starting values).

The following value has been obtained:

$$\tau = (0.8728 \pm 0.0071)\cdot 10^{-10} \text{ sec.}$$

The error quoted is purely statistical; the corrections for $K_\ell^o \to \pi^+\pi^-$ or K_S^o interactions were not taken into account.

In Fig. 3 we show the observed K_S^o decay time distribution. The straight dashed line is the time distribution obtained from our likelihood estimate of $\tau_{K_S^o}$. The full curve is the prediction from our maximum likelihood estimate after correcting for geometrical detection efficiency. A χ^2-test between this curve and observed distribution yields $\chi^2 = 19$ for 20 degrees of freedom in the $(0.5\text{-}2.5)\cdot 10^{-10}$ sec interval of the proper time of flight.

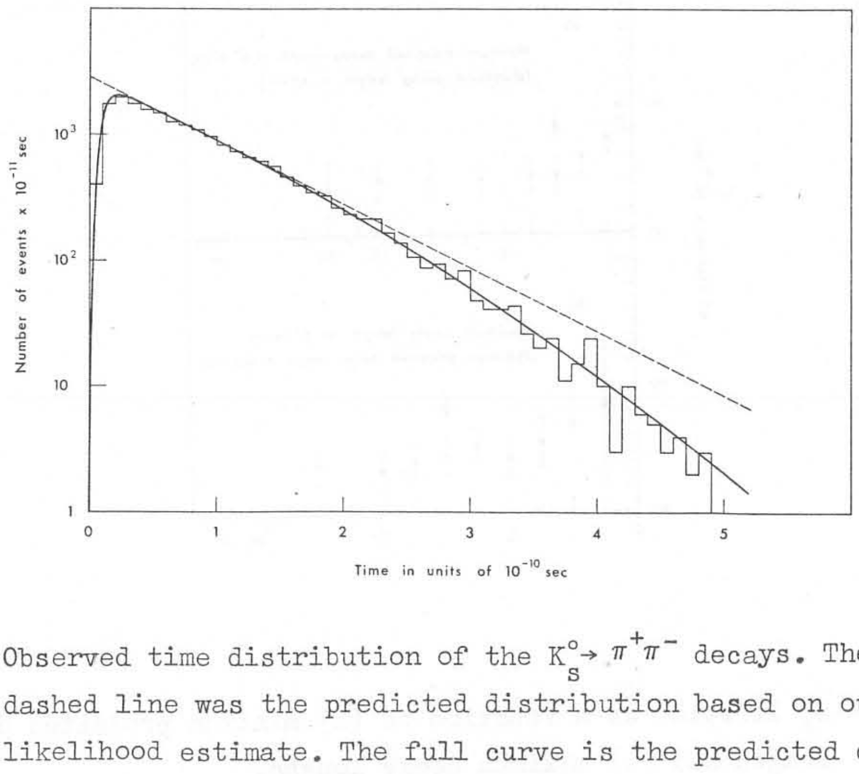

Fig. 3 - Observed time distribution of the $K_S^o \to \pi^+\pi^-$ decays. The straight dashed line was the predicted distribution based on our maximum-likelihood estimate. The full curve is the predicted distribution after correcting for geometrical detection efficiencies.

4. - CHECKS, CORRECTIONS AND ESTIMATE OF SYSTEMATIC ERRORS

We have checked that the final value of the K_s° mean lifetime does not depend, within statistical errors, on the particular reactions (1), (2) and (3), nor on the energy of the incoming beam, nor on the K_s° momentum.

The selection criteria on the K_s° decay length were checked separately. In Fig. 4a the K_s° mean lifetime is plotted as a function of the minimum projected decay length of the K_s° (when the maximum decay length is 15 cm) and in Fig. 4b as a function of the maximum decay length of the K_s° (when the minimum projected decay length is 0.3 cm). The arrows indicate the values used for our selection criteria. It can be seen that our cuts have been made in positions of relative stability.

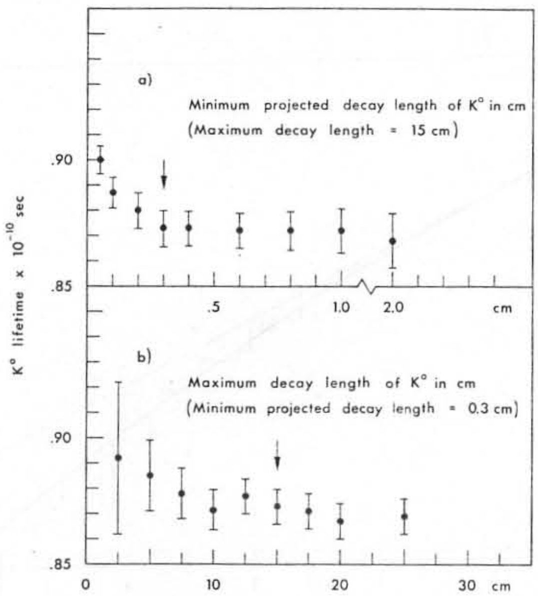

Fig. 4 - K_s° lifetime as a function of (a) minimum projected decay length and (b) maximum decay length.

Several corrections have to be taken into account:

a) Correction for K_s^o interactions

The value of the K_s^o mean lifetime, quoted in Section 3, must be corrected for events in which the K_s^o interacts in the chamber before the decay. We have:

$$\left(\frac{1}{\tau}\right)_{\text{corrected}} = \left(\frac{1}{\tau}\right)_{\text{meas.}} - \lambda_{\text{int.}}$$

where $\lambda_{\text{int.}}$ is the mean interaction rate of the K_s^o. In our case, considering the K_s^o momentum distribution, the correction appears to be of the order of 0.3% .

b) Correction for $K_\ell^o \to \pi^+\pi^-$ decays

The value of the K_s^o mean lifetime must be corrected for small contributions due to the decay $K_\ell^o \to \pi^+\pi^-$.

Since the range of lifetime covered in this experiment does not exceed 6 K_s^o lifetimes, the correction, following the discussion made in ref.(4), arising from $K_\ell^o \to \pi^+\pi^-$ decay is not larger than 0.3%.

As far as systematic errors are concerned we have made the following checks. For 5000 $K^+ \to \pi^+\pi^+\pi^-$ decays, the magnetic field values memorized in the GRIND Kinematics program were varied by small amounts around the nominal values, in such a way as to obtain the value of the K^+ mass quoted in the Particle Data Tables (i.e. M = 493.707 MeV). This test proved to us that the magnetic field is known within the order of 0.1%. We have used the value $m_{K_s^o}$ = 497.70 MeV for the K_s^o mass, which is also quoted in the Particle Data Tables.

In order to check the internal consistency of the procedure the quantity $(P_{K^o fit} - P_{K^o meas.})$ has been plotted. The fact that this quantity is symmetrically distributed around zero ensures that there is no systematic bias in the momentum measurements. Therefore, the errors in the masses and in the magnetic field cannot appreciably modify the value we have found.

Systematic errors may also arise from the measurements of the distance between the production and the decay vertices of the K_s^o. However, looking at the good geometry of the Saclay 81 cm bubble chamber, and moreover, considering the fact that all three views have always been measured, a possible systematic error of this kind seems to be negligible.

5. - CONCLUSIONS

The K_S^o mean lifetime has been measured using the maximum likelihood method. The following value has been found:

$$\tau_{K_S^o} = (0.873 \pm 0.007) \cdot 10^{-10} \text{ sec.}$$

where the error is statistical. The systematic errors are negligible in comparison with the statistical one.

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TABLE 1 - K_S^o mean lifetime latest values

Reference	K_S^o mean lifetime in 10^{-10} sec.
(2) 1968	0.865 ± 0.009
(3) 1968	0.856 ± 0.008
(4) 1972	0.8958 ± 0.0045
(5) 1974	0.8937 ± 0.0048
Present experiment	0.873 ± 0.007

TABLE 2 - Summary of the events available for the analysis of the K°_{s} mean lifetime.

Laboratory momentum GeV/c	Number of events			
	$K^{+}d \rightarrow K^{\circ}pn\pi^{+}$	$K^{+}d \rightarrow K^{\circ}pp$	$K^{+}d \rightarrow K^{\circ}pp\pi^{\circ}$	Total
0.64	8	1036	7	1051
0.72	83	2570	30	2683
0.78	38	914	27	979
0.85	266	1732	98	2096
0.90	438	1228	143	1809
0.98	563	742	218	1523
1.06	435	666	141	1242
1.13	782	1499	235	2516
1.21	630	555	218	1403
1.29	1064	748	388	2200
1.35	718	413	253	1384
1.42	651	379	230	1260
1.51	1261	639	454	2354
Totals	6937	13121	2442	22500

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