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MEASUREMENT OF THE K_2^0 MEAN LIFE*

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In conjunction with our recent experiment on K_2^0-proton total cross sections,[1] we have measured the mean life of the K_2^0 meson. This was accomplished by determining the variation, due to decay in flight, of the momentum spectrum of a K_2^0 beam as a function of distance along the beam. Our results for the lifetime and the corresponding total decay rate, respectively, are

$$\tau=(5.15\pm0.14)\times10^{-8}\ \text{sec},$$

$$\Gamma=(19.4\pm0.5)\times10^{6}\ \text{sec}^{-1}.$$

The geometry of the experiment is shown in Fig. 1. The 3-GeV internal proton beam of the Princeton-Pennsylvania Accelerator (PPA) produced K_2^0 mesons in a Pt target.

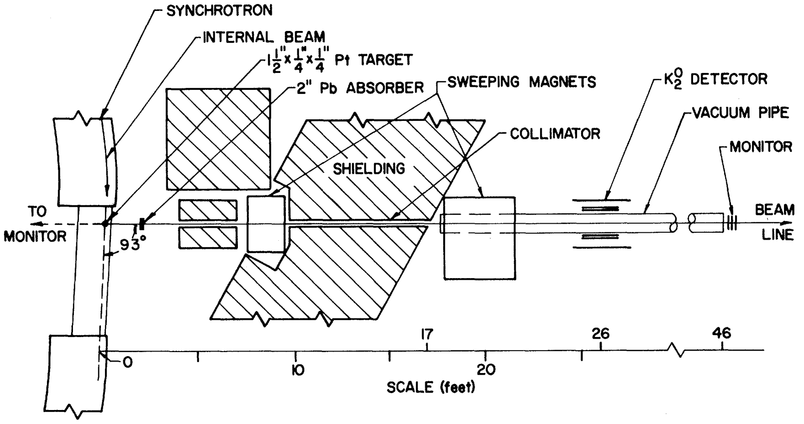

FIG. 1. Layout diagram showing the beam components. Six of the 12 counters comprising the detector are indicated.

The $K_2{}^0$ beam traversed a system consisting of a Pb gamma-ray filter, a charged-particle sweeping magnet, a defining collimator, a second sweeping magnet, and a detector. Following the collimator exit, the beam was in vacuum.

The $K_2{}^0$ detector (Fig. 2) was designed to respond to two or more charged particles emerging at wide angles from an evacuated beam channel containing only long-lived neutral particles. Such events correspond to $K_2{}^0$ decays, since the number of neutron decays is negligible. The instrument consisted of four scintillation-counter telescopes surrounding the beam vacuum pipe. Each telescope consisted of two "yes" counters separated by $\frac{1}{4}$ in. of steel and followed by 4 in. of Pb and a veto counter. The steel absorbed protons produced by stray neutron interactions in the scintillation plastic; the veto counters rejected particles originating outside the detector, and the Pb prevented particles originating inside the detector from reaching the veto counters. A coincidence of any two telescopes provided the $K_2{}^0$ signature.

The $K_2{}^0$ momenta were determined by a time-of-flight method. The synchrotron was operated in a mode such that the protons strike the Pt production target in very short (~1 nsec) bunches separated by 67.3 nsec in time.[2,3] For each detected $K_2{}^0$, a production time signal, derived from the synchrotron rf system,[4] was electronically compared with the detector signal to yield a pulse with amplitude corresponding to the $K_2{}^0$ time of flight. A pulse-height analyzer was used to collect a time-of-flight histogram of such $K_2{}^0$ events for a given detector position. The time-of-flight spectrum was converted to a momentum spectrum by calculation.

Data at various distances from the production target were taken with the same detector by translating it along the beam. For a given momentum p, the counting rates N_a and N_b at distances L_a and L_b are related (assuming temporarily that the detection efficiency is independent of distance) by

$$N_a = N_b \exp\{-(L_a - L_b)M/p\tau\}, \qquad (1)$$

where M and τ are the $K_2{}^0$ mass (497.8 MeV/c^2) and mean life. Hence a measurement of the rates at two distances is, in principle, sufficient to determine the mean life.

The beam intensity was monitored by two scintillation-counter telescopes, one inside the synchrotron ring and the other at the end of our neutral beam. The drift in the ratio of the two monitors was <0.2% per day, a stability which was more than adequate for a set of measurements at all detector positions.

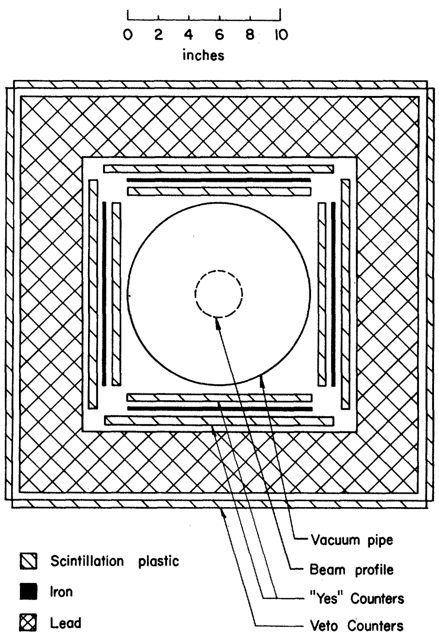

FIG. 2. End view of the $K_2{}^0$ detector. The dashed circle shows the beam-profile contour at half-maximum intensity at 26 ft from the target.

Timing calibrations were performed by removing the Pb gamma-ray filter and detecting e^+e^- pairs from a radiator placed in the beam. These pairs gave rise to peaks in the time spectrum which were used to calibrate the time scale: The positions of the peaks corresponded to particles with $\beta = 1$; the spacing between the peaks was related to the accurately known rf frequency of the synchrotron and hence yielded the scale factor. Other methods were used to check the timing with excellent agreement.[5] The absolute time calibration was then known to ±0.25 nsec, and the relative calibration for a $K_2{}^0$ with given momentum at two detector positions to, typically, ±0.1 nsec. The time resolution, determined by the width of the peaks, was ±1.6 nsec. After correction for differences between e pairs and K decay products, this results in typical time and momentum resolutions for K's of ±1.8 nsec and ±2.6%, respectively.

A number of sources of background were considered during the measurements and analysis: (1) Background not associated with the beam (cosmic rays, stray particles, phototube noise). This was measured by plugging the neutral beam channel. It was ~5% of the K_2^0 rate.

(2) "67-nsec ghosts." A K_2^0 event with nominal flight time t could have been produced by any proton bunch so that the actual flight time could have been $(t+67.3n)$ nsec, $n=0,1,2,\cdots$. In practice, $n=1$ (first "ghost") gave intensities ~1% of $n=0$, while the $n\geq 2$ intensities were negligible.[6] The $n=0$ contribution was considered to be "good" data. The $n=1$ contribution was treated as a background and was measured by means of operating the synchrotron with 134.6 nsec between bunches.

(3) Beam-associated background. Relatively high-energy neutrons, scattered from the collimator walls, and interacting in the inner walls of the detector, occasionally produced charged particles which triggered the detector. This contributed to the background at the high-momentum end of the K_2^0 spectrum. We avoided its effects by analyzing only those data considerably below the effective threshold (320 MeV/c) for the process.

(4) Accidentals. Measured by delayed coincidences, these were found to be zero at a significance level of 0.2% of the real rate.

The detection system successfully selected K_2^0 mesons, with tolerable background and well-known momenta, out of a beam containing gamma rays and neutrons at intensities of order 1000 times greater than that of the K's. The detector had a calculated efficiency of ~15% for those K's which decayed via charged modes over a 48-in. flight path in its vicinity. The counting rate, summed over all momenta, was ~10^4 K_2^0 mesons per hour (under the conditions: neutral beam solid angle $=0.76\times10^{-4}$ sr, 93° production angle, 26-ft detector position, 2×10^{11} protons/sec on $1\frac{1}{2}$-in. Pt target).

The detector was used in such a way as to provide multiple redundancy for various consistency checks. Data were taken at four distances from the production target to provide checks on possible distance-dependent systematic errors. In addition, we chose to store data for three different subsets of the six possible telescope pairs in separate banks of the pulse-height analyzer. This served as a check on background effects since the various subsets were affected in different ways by background. Finally, the collection of data over a fairly wide range of momenta allowed us to check momentum-dependent effects.

We elected to analyze the data in a way which does not give undue weight to the spectrum at one particular detector position. The dependence of the measured counting rate in the kth momentum bin on position can be described by the function

$$N_{0k}\exp[-L_i M/p_k\tau], \tag{2}$$

where p_k is the average K_2^0 momentum of the kth bin, N_{0k} is proportional to the corresponding rate at the target, and L_i is the target-to-detector distance for the ith data run. We represent the measured rates (after direct subtraction of backgrounds associated with the "67-nsec ghost" and not with the beam, and a correction for a small variation of detector efficiency with distance[7]) and the corresponding statistical uncertainties by N_{ik} and σ_{ik}. The target-spectrum parameters N_{0k} and the lifetime τ are varied to minimize the following chi-squared expression:

$$\chi^2=\sum_{i,k}[N_{ik}-N_{0k}\exp(-L_iM/p_k\tau)]^2/\sigma_{ik}^2. \tag{3}$$

This procedure yields the best-fit lifetime τ for the particular set of data used in the summation.

For "all" data, the χ^2 fit gives the following result for the lifetime (before final correction):

$$\tau=(5.17\pm0.13)\times10^{-8}\ \text{sec}, \tag{4}$$

where the (purely statistical) error is the appropriate diagonal element of the variance matrix. The χ^2 for this fit is 110.8 for 109 degrees of freedom, corresponding to the "chi-squared probability" $P(\chi^2)=44\%$. The data used are as follows: momentum bins of 10-MeV/c width between the limits 180 and 280 MeV/c, all counter-telescope combinations, and 14 data runs[8] including all of the distances 26, 31, 36, and 41 ft (15 ft corresponds to between 0.52 and 0.85 mean decay lengths for the momentum range used).

In order to check internal consistency, we have made fits to subsets of the data and have investigated their agreement, according to the following ways of subdividing the data: (1) separate lifetimes calculated from different telescope combinations, (2) different momenta, (3) different two- and three-distance combinations, and (4) data taken at different times during the experiment. The results are that, for each category, the fitted lifetimes are the same within statistics [by which we mean that $P(\chi^2)$

ranged between 14 and 38% for variations of independent data about the mean]. In addition, we have checked the stability of the lifetime and goodness of fit with respect to changing the 280-MeV/c upper momentum cutoff. We also made a completely independent analysis of the same data by calculating the lifetime from pairs of runs taken at different distances [cf. Eq. (1)] and averaging the results. The lifetime obtained was essentially the same as that obtained from the more sophisticated analysis.

Additional nonstatistical corrections to, and uncertainties in, the lifetime result (4) have been considered: The uncertainty in the distance variation of the efficiency[7] produced an uncertainty in the lifetime τ of ±1.0% of τ; the "empty-bunch" contamination,[3] a correction of $(-0.5\pm0.1)\%$; momentum resolution and binning effects, $(0.0\pm0.2)\%$; absolute time calibration, ±0.2%; and relative time calibration, ±0.3%. With the inclusion of these effects, our final result for the K_2^0 mean life is

$$\tau=(5.15\pm0.14)\times10^{-8}\text{ sec},$$

to be compared with the previous result, $(5.3\pm0.5)\times10^{-8}$ sec, of Fujii *et al.*[9]

Our measurement of the lifetime and other recent results[10] have been subjected to a "consensus analysis"[11] to yield the following results for the major partial rates:

$$\Gamma(K_2^0\to\pi^0+\pi^0+\pi^0)=(4.52\pm0.45)\times10^6\text{ sec}^{-1},$$

$$\Gamma(K_2^0\to\pi^++\pi^-+\pi^0)=(2.22\pm0.10)\times10^6\text{ sec}^{-1},$$

$$\Gamma(K_2^0\to\pi+e+\nu)=(7.15\pm0.42)\times10^6\text{ sec}^{-1},$$

$$\Gamma(K_2^0\to\pi+\mu+\nu)=(5.36\pm0.44)\times10^6\text{ sec}^{-1}.$$

The results of this analysis have been used by Russ[12] to revise the computation of the branching ratio for the two-pion decay of the K_2^0:

$$\frac{\Gamma(K_2^0\to\pi^++\pi^-)}{\Gamma(K_2^0\to\text{all modes})}=(1.50\pm0.11)\times10^{-3},$$

and the amplitude ratio:

$$|\eta_\pm|=\left[\frac{\Gamma(K_2^0\to\pi^++\pi^-)}{\Gamma(K_1^0\to\pi^++\pi^-)}\right]^{\frac{1}{2}}=(1.90\pm0.07)\times10^{-3}.$$

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[3] For our experiment, a set of modulated electrostatic deflection plates removed alternate proton bunches at injection. The amount of beam remaining in the "empty" bunches was 0.18% of that in the "full" bunches during our periods of data collection.

[4] The production time signal was essentially the rf master oscillator, gated by the signal which modulated the injector (Ref. 3).

[5] Other methods were calibrated low-loss cables and gamma-ray flight time between measured positions. In addition, the linearity of the timing system was found to be better than 0.5% by means of observing the flat time spectrum produced by counts arriving at random times.

[6] The reason for the low "ghost" rate was twofold: lower production spectrum and greater attenuation due to decays in flight between target and detector for lower momentum K's.

[7] Due to the beam angular divergence, the detector efficiency decreased by $(1.2\pm0.6)\%$ of its value for a 15-ft movement of the detector away from the target. This number was determined by extensive Monte Carlo calculations. The smallness of the effect has been understood independently.

[8] The 14 runs included all lifetime data taken after the experiment was "debugged," except for two additional runs. Each of these two was rejected on the grounds that its counting rate fluctuated by more than 3 standard deviations from the average rate for *its* detector position.

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