NEW MEASUREMENT OF THE K_S BRANCHING RATIO*

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We have measured the K_S^0 charged-to-neutral branching ratio by examining ~25 000 K^+ charge-exchange reactions in a Freon bubble chamber. Our result, 2.10 ± 0.06, is in poor agreement with a recent measurement by Gobbi et al. who obtained a value of 2.285 ±0.055, while it is in fairly good agreement with the average of earlier experiments.

I. General description of the method. —We use ~150 000 pictures taken in a K^+ beam with the Michigan-Argonne heavy-liquid chamber filled with Freon, CF_3Br, a liquid whose radiation length is ~11 cm. The K^+ mesons were transported through a two-stage separated beam at a momentum of 825 MeV/c and, after traversing the wall of the chamber and ~23 cm of Freon, entered our fiducial volume at a momentum of ~700 MeV/c. Typical pictures contained two or three K^+ entering the fiducial volume.

The basis of our method was to use the charge exchange of a K^+ as a signature for the creation of a K^0. The vicinity of a charge exchange (type-I event) could then be examined for evidence of a charged decay of the K^0 (a V whose arms were consistent with $\pi^+\pi^-$) or a neutral decay (one or more electron pairs). The topological definition of a charge exchange was a beam-track interaction whose visible products, if any, were protons, i.e., heavily ionizing positive tracks which stopped in the chamber without evidence of a subsequent decay.

There are two difficulties with the method as described so far. The first is that a π^+ contamination in the beam produces π^0's by charge exchange and such events are not easily distinguished from K^+ charge exchanges followed by a neutral decay of the K^0. A second difficulty is that many of the K^0's decay so close to the charge-exchange point that the separation between that point and the vertex of the V cannot be resolved by the scanner.

In order to overcome these difficulties we asked the scanners to look for any beam interactions which produced a negative track (a type-II event). By subsequent examination of the type-II events we were able to classify them as follows:

(1) The negative track was a π^- and was accompanied by a π^+. Other tracks (if any) from the interaction vertex were protons. Since none of the events of this type was accompanied by V's we deduced that either they arose from a π^+ contamination in the beam or they were charged decays of K^0's very close to the charge-exchange vertex.

(2) The negative track was a π^- and all other tracks (if any) from the vertex were protons. Since none of the events of this type was accompanied by V's we deduced that they were due to the interaction of a π^+ contamination in the beam.

(3) The negative track was a π^- and was accompanied by two π^+ tracks and no other tracks. Such events were easily recognized as τ^+ decays in flight.

(4) The negative track was an electron either from a Dalitz pair or from the conversion of a γ ray close to the interaction vertex.

We used the "π^- only" events described in (2) above as a measure of the π^+ contamination in the K^+ beam. The scanners scanned 9400 π^+ pictures taken at precisely the same momentum as the K^+ pictures. The scanning rules for the π^+ film were the same as those for the K^+ film.

II. Scanning and editing of the film.—All the film was double scanned for type-I and type-II events. The scanners were instructed to scan along the tracks from the point where they entered the fiducial volume to the point where they left it, typically a distance of ~55 cm. Only those tracks which entered the fiducial volume within ±6° of the average beam direction were scanned. Since in the huge fringing field of the chamber magnet the beam bends through ~80° before entering the fiducial volume, this rule ensured that only "on-momentum" tracks were scanned. All disagreements from the double scan were checked and resolved by a third scanner. The efficiency of the double scan was ~99.5% and was independent of the final classification of the events.

All the events were now subjected to an editing by experienced scanners. In the case of type-I events they checked to see that the charge-exchange vertex obeyed the scanning rules and that there were no other type-I events within a distance of 10 cm on any of the four projected views. 10 cm on the scanning machine corresponds to ~20 cm in real space. If the event passed both these tests a template consisting of two concentric circles of radii 5 and 10 cm, respectively, was centered on the charge-exchange vertex and the area within the outer circle scanned on all four views for one or more electron pairs. Note was taken of any electron pair with an apex within the 10-cm circle on all four views. At this point no judgement was made concerning the origin of the γ ray. The only other test applied to the electron pair was that its entire track length could not fit within a square 1 cm on a side. This imposed a low-energy cutoff of about 10 MeV on the accepted electron pairs. Events which passed these tests were denoted as "γ events" and were passed on to a second editing as such.

In addition to searching for electron pairs, the first editor also searched for V's whose apex lay within the 5-cm circle on all four views. Such events were noted as V events. In order not to miss V's with wide opening angles, the first editor was instructed to count as V's stray tracks intersecting the 5-cm circle provided they were not obviously beam tracks or connected to beam tracks.

Events which passed both the γ test and the V test were denoted as γ-V events.

In the case of type-II events, the first editor examined them and classified them as described in Sec. I, then the first editor searched for V's and electron pairs in the same way as for type-I events.

Physicists carried out a second editing of the film. We examined all γ events, V events, and γ-V events. We checked to see that the arms of each V were consistent with being $\pi^+\pi^-$ tracks and that the orientation of the V relative to the charge-exchange vertex was consistent with conservation of momentum. All events whose arms were consistent with $\pi^+\pi^-$ tracks were accepted. Those events whose orientation was inconsistent with the conservation of momentum were denoted as scattered V events.

In the case of γ events and γ-V events we examined each electron pair whose apex lay within the 10-cm radius on all four views to see if it had an origin other than the charge-exchange vertex. The event remained a γ event if there was at least one electron pair within the 10-cm radius for which no origin, other than the charge-exchange vertex, could be found, and provided the electron pair(s) could have come from within the 5-cm circle on all four views.[1]

The results of the editing of both the K^+ and π^+ film are summarized in Table I.

In order to check the accuracy of the editing procedure we re-edited a 20% sample of the film and compared the results with the original editing. In each event category we found errors (~3%) of both omission and commission approximately equal in numbers so that the corrections applied to each category for such errors are small. These corrections are listed in Table II.

A further check on the V events was obtained by measuring a randomly chosen sample of ~2000 events and processing them through the heavy-liquid geometry program SHAPE.[2] For these events we have plotted distributions of effective mass, momentum, and proper time in Fig. 1.

III. Corrections to the data.—Table II contains a summary of the corrected results. The largest corrections to the data are for π^+ contamination of the beam and for background γ events, i.e., γ events which are not the result of K_S^0 decay into neutral pions. We discuss the corrections below.

(A) π^+ contamination of the beam. We estimated the number of events in each category which were produced by the interaction of a π^+ contaminant in the K^+ beam, by comparing the results from the π^+ film with those from K^+ film. Since events which have a π^- track but no π^+ track at the interaction vertex cannot be produced by a K^+ interaction but only by a π^+ interaction, the number of such events is a measure of the π^+ contamination.

(B) Background γ events. Background γ events have the following sources: (1) stray electron pairs, i.e., electron pairs whose origin is unrelated to the charge-exchange vertex being examined; (2) π^0 produced along with the charge ex-

Table I. Disposition of events in the K^+ and π^+ film after second editing.

	K^+ Film		π^+ Film	
V events including Type II events with $\pi^+\pi^-$ at interaction vertex	7381	(535)[a]	195	(195)
Scattered V events	267	(0)	0	
γ-V events	119	(22)	0	
Total V events	7767		195	
γ events including Type II events whose negative track is an electron at the interaction vertex	4180	(26)	1025	(28)
Type II events with π^- but no π^+ at the interaction vertex	76	(76)	275	(275)
Events with neither a V nor a γ	11480	(0)	1244	(0)
Total of all events	23503		2739	

[a]The numbers in parentheses denote the number of type-II events in each category.

Table II. Corrected number of K^0 decays.

a) $\underline{K_S^\circ \to \pi^+\pi^-}$		
Total V events from 2nd edit	7767 ± 88	
Estimated editing errors	+60 ± 40	
Estimate of $\pi^+\pi^-$ events due to π^+ contamination in the beam	-57 ± 8	
Corrected number of $K_s \to \pi^+\pi^-$		7770 ± 97
b) $\underline{K_S^\circ \to \pi^\circ\pi^\circ}$		
Total γ events from 2nd edit	4180 ± 65	
Estimated editing errors	-20 ± 40	
Estimate of γ events due to π^+ contamination in the beam	-284 ± 36	
Estimate of γ events due to background γ's	-258 ± 36	
Estimate of unobserved γ's	+80 ± 35	
Corrected number of $K_s \to \pi^\circ\pi^\circ$		3698 ± 98
Total K_s decays		11468 ± 138
c) $\underline{\text{Total of } K_S^\circ + K_L^\circ}$		
Total of all events from 2nd edit	23503	
Estimated number due to π^+ contamination in the beam	-757	
Corrected number of K^+ charge exchanges	22746	

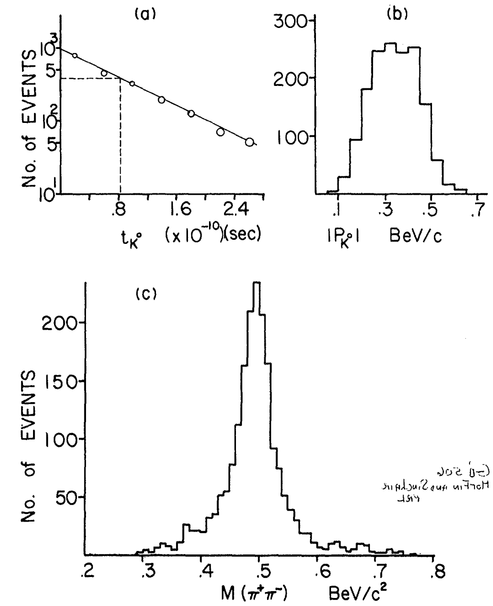

FIG. 1. (a) Proper-time distribution of measured sample $K^0 \to \pi^+\pi^-$. The diameter of the circle at each data point represents the statistical error, while the intersecting dashed lines give the e^{-1} point and the corresponding lifetime. (b) Lab-momentum distribution of K^0's produced via K^+ charge-exchange reaction. (c) Effective mass of $\pi^+\pi^-$ system. Each bin is 10 MeV/c in width. Full width at half-maximum is ≈0.050 BeV/c^2 with center of peak at ≈0.495 BeV/c^2.

change; (3) a $\bar{K}$ interaction producing a Λ which decays by the neutral mode $n\pi^0$; and (4) K_L^0 decay into neutral pions. We estimated the sum of sources (1) and (2) from the number of γ-V events, i.e., events with both a $\pi^+\pi^-$ decay and one or more electron pairs. Source (3) we estimated by counting, in a sample of the film, the number of Λ decays into the charged mode $p\pi^-$. Source (4) is negligible.

(C) Unobserved γ events. The probability of none of the four γ rays from the neutral decay of the K_S^0 converting within the 10-cm scanning circle is only about 1%. However, not all of the converted γ rays will be observed by the scanner. Some will be missed because they are dipping steeply in the chamber, others because their energy is too low. It is an important advantage of this experiment that the correction for unobserved γ events remains small even when low scanning efficiencies are assumed. For example, if one adopts a model in which the scanning efficiency for electron pairs varies from 0 to 0.95 as the energy varies from 0 to 70 MeV, but never gets above 0.95, and in which the finding of dipped electron pairs is further inhibited by a factor which varies from 1 to 0 as the dip increases from 60° to 90°, then one can demonstrate by Monte Carlo techniques that the number of unobserved γ events is increased by only 1.5% over a model in which all converted γ rays are observed. We adopted a scanning model which predicted correctly the relative numbers of 2γ, 3γ, and 4γ conversions observed within the 10-cm scanning circle. Using this scanning model we estimate the number of unobserved γ events to be 80 ± 35.

IV. Results. – From the corrected number of K_S^0 decays shown in Table II we find the ratio of charged to neutral decays to be 2.10 ± 0.06. This result is in poor agreement with a recent measurement by Gobbi et al.[3] who obtained a value of 2.285 ± 0.055, but it is in fairly good agreement with the average of earlier experiments.[4]

The difference of the branching ratio from 2 depends on the interference of the isospin-0 and isospin-2 amplitudes in the decay and also on the factor $\cos(\delta_2 - \delta_0)$, where δ_2 and δ_0 are S-wave $\pi\pi$ phase shifts for isospins 2 and 0, respectively, at a mass of the $\pi\pi$ system equal to the mass of the kaon.[5] There are also terms of the order of 2% or less due to phase space and soft-photon emission which have been calculated by Abbud, Lee, and Yang[5] and more recently by Belavin and Narodetsky.[6] In the approximation that we neglect the $\Delta I=\frac{5}{2}$ contribution to the decay, the entire isospin-2 contribution comes from $\Delta I=\frac{3}{2}$ and can be determined from the relative decay rates of K^+ and K^0 to two pions. We may then use the value of the K_S^0 branching ratio to determine the absolute value of $\delta_2-\delta_0$. Using our result for the branching ratio and the estimate of Ref. 6 for soft-photon emission, we find $|\delta_2-\delta_0|=74°\pm10°$.

From Table II we see that the ratio of K_S^0 decays to all K^0 produced by the charge exchanges studied is 0.504 ± 0.006. The value to be expected for this number depends on the regenerative properties of the medium through which the K^0's move. We estimate that for the conditions of this experiment it could have a value anywhere between 0.50 and 0.53 depending on the phase of the amplitude for coherent regeneration in the Freon.

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[1]The neutral decay vertex, which is the copunctal point of the electron pairs, is poorly defined, and the physicists doing the second editing noted 60 γ events for which they were uncertain as to whether the decay vertex was within or without the 5-cm circle. We assigned 40 of these events to within the circle and estimate the error in this procedure to be ±10 events.

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$\bar{p}$-p ELASTIC SCATTERING AT 8 AND 16 GeV/c*

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Angular distributions are presented for $\bar{p}$-p elastic scattering at 8 and 16 GeV/c for $|t|<1.3$ (GeV/c)^2. At both energies there is structure in the differential cross sections in the region $0.5\le|t|\le1.0$ (GeV/c)^2, similar to that observed at lower energies. The diffraction peak continues to expand with increasing incident momentum.

Previous experimental studies of $\bar{p}$-p scattering[1] have shown a minimum in the differential cross section in the neighborhood of $-t=0.5$ (GeV/c)^2 and a secondary maximum at about $-t=0.8$ (GeV/c)^2. Some of these experiments have also shown that the logarithmic slope of the forward diffraction peak decreases with increasing energy, in contrast to the behavior exhibited in p-p elastic scattering. It is of great interest to extend these measurements to the highest possible energies. The present experiment, performed at the Brookhaven National Laboratory (BNL) alternating-gradient synchrotron, used a missing-mass spectrometer to study $\bar{p}$-p elastic scattering at 8- and 16-GeV/c incident momentum. The range of four-momentum transfer covered was $0.046\le-t\le0.925$ (GeV/c)^2 at 8 GeV/c and $0.111\le-t\le1.40$ (GeV/c)^2 at 16 GeV/c.

The apparatus has been discribed by Anderson et al.[2] and will only be discussed briefly here. Negative secondary particles were momentum analyzed by a counter hodoscope at the first focus of the beam. The overall momentum acceptance of the beam-transport system was 3% and the momentum resolution was ±0.25%. The angle of the incident particle was measured by a second