angle θ, $(\partial I/\partial\theta)\Delta\theta$. We believe that the systematic checks (in the intrarun data sets and between the different runs) establish the stability of our data because there was an effective constancy of the size and the relative shape in the detector's angular sensitivity. It is important to note that the problem of uncertainty in $R(d)_\theta$ as a result of this problem is less serious than the uncertainty in the intensity determination; this is due to the data, at different fixed angles, being normalized to a common value at $d_{\min}(\theta)$. A slight change in the mean zenith angle setting has a much more significant influence on $I_\mu(d,\theta)$ than on $R(d)$. For simplicity the $R(d)_\theta$ ratio is displayed for $d=d_{\text{median}}$, with all of the error in θ being reflected in an additional uncertainty in $R(d)_\theta$; this is done rather than portraying the R results as sets of $(R,\Delta R; d,\Delta d)$.

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Measurement of the Σ^- Beta Decay Rate and an Improved Test of the $\Delta S = -\Delta Q$ Selection Rule*

B. Sechi-Zorn and G. A. Snow†
University of Maryland, College Park, Maryland 20742
(Received 12 February, 1973)

Analyzing Σ^- hyperons produced by K^- stopping in the 30-in. BNL hydrogen bubble chamber, we have obtained (a) an upper limit for the ratio $\Gamma(\Sigma^+\to e^+ n\nu)/\Gamma(\Sigma^-\to e^- n\nu)$ of 0.018 with 90% confidence and (b) a value for the branching ratio, $\Gamma(\Sigma^-\to e^- n\nu)/[\text{total }\Gamma(\Sigma^-)]$, equal to $(1.05\pm0.07)\times10^{-13}$, in good agreement with existing data.

I. INTRODUCTION

The universal $V-A$ Fermi interaction modified by the Cabibbo theory[1] is still in good agreement with the existing experimental data on hyperon leptonic decays.[2] In the last few years a number of articles summarizing the theory have been published, as for example the recent report by Chounet *et al.*,[3] so we shall refrain from a repetition here.

The useful data that can be obtained from hyperon leptonic decays to test this theory are (1) data on the search for the decay $\Sigma^+\to(e^+\text{ or }\mu^+)+n+\nu$ [this is a $\Delta S=-\Delta Q$ decay mode, and its existence will invalidate Cabibbo's hypothesis that the hadronic current should transform as an octet of vector and axial-vector currents under the SU_3 transformations[1]], and (2) determination of branching ratios, energy spectra, and angular or polarization correlation of the decay products for Λ, Σ, and Ξ leptonic decays. From these data the sign and magnitude of the vector and axial-vector coupling constants could in principle be determined and compared with the values predicted by the theory.[2,3]

We would like to report here on a measurement of the ratio

$$\Gamma(\Sigma^-\to e^-\nu n)/[\text{total }\Gamma(\Sigma^-)]$$

and of an upper limit to the ratio

$$\Gamma(\Sigma^+\to e^+\nu n)/\Gamma(\Sigma^-\to e^-\nu n)\ .$$

Preliminary reports of this work have been reported at international conferences in 1968 and 1969.[4]

II. METHOD OF THE EXPERIMENT

The Σ^+ and Σ^- hyperons were produced, in an exposure of the 30-in. BNL hydrogen bubble chamber to a beam of K^- mesons stopping inside the chamber, by the reactions

$$K^-+p\to\Sigma^-+\pi^+\ ,$$
$$K^-+p\to\Sigma^++\pi^-\ .$$

In about 10% of the cases, the $\Sigma^\pm$ hyperons were produced in a K^-+p interaction in which the K^- was not at rest.[5] 490 222 pictures, containing an average of ~10 stopping-K^- per picture, have been analyzed and 858 $\Sigma^-\to e^-n\nu^-$ decays have been found. No $\Sigma^+\to e^+n\nu$ with e^+ momentum larger than 70 MeV/c was found. In the 90% of the cases in which the $\Sigma^\pm$ are produced by K^- particles coming to rest in the hydrogen, the momentum of the Σ at production will be 181.3 MeV/c for the Σ^+ and 173.2 MeV/c for the Σ^- particle, corresponding to a Σ range maximum of 1.27 cm and 1.06 cm, respectively.[6] With such short ranges, almost all $\Sigma^\pm$ particles decay or interact inside the bubble chamber.

Ignoring radiative decay modes, the possible $\Sigma^\pm$

decay modes can be subdivided into the following three categories.

(1) $\Delta S = \Delta Q$ modes:

$$\Sigma^+ \to \pi^+ + n\ ,$$
$$\Sigma^- \to \pi^- + p\ ,$$
$$\Sigma^+ \to p + \pi^0\ ,$$
$$\Sigma^- \to \mu^- + p + \nu\ ,$$
$$\Sigma^- \to e^- + p + \nu\ .$$

(2) $\Delta S = 0$ modes:

$$\Sigma^- \to e^- + \Lambda + \nu\ ,$$
$$\Sigma^+ \to e^+ + \Lambda + \nu\ .$$

(3) $\Delta S = -\Delta Q$ modes:

$$\Sigma^+ \to \mu^+ + n + \nu\ ,$$
$$\Sigma^+ \to e^+ + n + \nu\ .$$

The Σ^- leptonic modes of decay are about 1000 times less frequent than the nonleptonic ones. The search for these relatively rare decays consisted in identifying at the measuring table the charged electrons by bubble-density and curvature observations, and by subsequently measuring on a precision measuring machine each possible candidate. The scanner was assured that both positive and negative electronic modes of decay existed and that any criteria of scanning had to be applied to both. A trained scanner can distinguish at the scanning table a track having a projected bubble density 1.5 times the minimum value from one having the minimum bubble density. Since the slope of the tracks relative to the front glass of the bubble chamber will affect the apparent bubble density, the "dip" angle δ (made by the track with its projection on the front glass) plays an important role in the selection criteria.

A track parallel to the front glass ($\delta = 0°$) will have a bubble density of 1.6 times the minimum bubble density if it is produced either by a π of 180-MeV/c momentum or by a μ of 135-MeV/c momentum.

The total number of $\Sigma^- \to \pi^- n$ events in our sample is of the order of 2×10^6. Out of 2×10^6 π^- mesons, ~5000 will decay in flight into a $\mu^- + \nu$ within the first 3 cm of π^- track and at a μ^- angle $\leq 14°$ relative to the π^-. A similar calculation applied to the ~0.5×10^6 $\Sigma^+ \to \pi + n$ events in our sample will give about 1200 $\pi^+ \to \mu^+ + \nu$ decays within the same limits. Both numbers are larger than the expected number of leptonic Σ decays. Because of this large background of muons, a search for $\Sigma^+ \to \mu^+ + n + \nu$ decays to obtain a limit on $\Delta S = -\Delta Q$ transition is not as decisive as the search for positron decays reported here. It is a mistake to lump the muon and electron decays together as has sometimes been done in the past.

To ensure that no μ was included in our sample of electrons and positrons, every decay particle which had a momentum larger than 135 MeV/c was gap-counted, using a mechanized gap-counting microscope,[7] to get a precise velocity measurement.

A measurement of the gap-length distribution of the track to be studied relative to the distribution of a minimum-ionizing one allows a determination of the relative bubble density, δ/δ_0, of the candidate. Figure 1 shows a plot of δ/δ_0 versus momentum for all the events that were gap-counted. The separation between electrons and muons is unambiguous below ~160 MeV/c. For momenta less than 150 MeV/c no candidate turned out to be anything but an electron, which justifies acceptance of the scanner's identification for events with momentum less than 135 MeV/c. No Σ^+ decay into positron at momentum higher than 70 MeV/c was found. All the μ^+ decay products found were consistent with decay in flight of the pion from the dominant decay mode: $\Sigma^+ \to \pi^+ + n$. In some cases the Σ^- decay track could be identified as an electron even at momenta higher than 165 MeV/c because it gave an obvious bremsstrahlung or a very energetic knock-on electron.

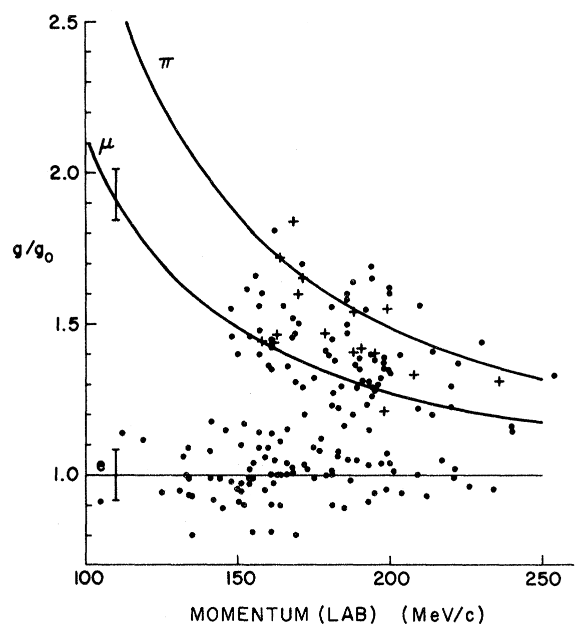

FIG. 1. Relative bubble density g/g_0 as a function of momentum in the laboratory for all gap-counted candidates. The dots refer to Σ^- decays, the crosses to Σ^+ decays. The bars indicate the magnitude of the error of g/g_0. The curves represent the expected g/g_0 dependence on momentum for electrons, muons, and pions.

TABLE I. Number of electronic events from Σ^- and Σ^+ hyperons subject to various limiting criteria.

Limiting criteria	Total number of events Σ^-	Σ^+
(1) $\Sigma^\pm$ length ≥ 1 mm	858	5
(2) Σ^- momentum ≥ 80 MeV/c at decay and $\Sigma^\pm$ length as in (1)	703	5
(3) $e^\pm$ momentum ≥ 70 MeV/c and Σ as in (1) and (2)	549	0
(4) $e^\pm$ momentum ≤ 120 MeV/c, $e^\pm$ dip $\leq 53°$, and Σ as in (1) and (2)	455	5

Since our electron identification criteria were definitive, no restriction was necessary for the K^- momentum at the point of interaction. Of the 858 Σ^- beta decay events found, there were 70 events produced by K^- interactions in flight. Table I gives the total number of events found and the different limiting criteria used. The justification for the inclusion of these limiting criteria is discussed throughout the paper.

The most important type of event that can be mistaken for a $\Sigma^- \to e^- n\nu$ decay is an $\Sigma^- + p$ interaction producing a Σ^0 that, in turn, decays into a $\Lambda^0 + e^+ + e^-$. If the Λ^0 decays into $\pi^0 + n$, the π^0 decays into $e^+ e^- \gamma$, and the e^+ annihilates quickly or is too slow to have a visible track in the chamber, the event (given the short Σ^0 lifetime) will be indistinguishable from an $\Sigma^- \to e^- n\nu$ event.

To minimize this background, no Σ^- having momentum $\leqslant 80$ MeV/c at the point of decay was accepted. Also no Σ^- that traveled less than 1 mm was included in the sample, to ensure the event could be measured with adequate kinematic discrimination. Out of the 858 events, 703 satisfied these criteria. Figure 2 gives the momentum distribution of the electrons obtained from these 703 events. Figure 3 gives the Σ^- dip distribution expressed in $\sin\delta$. The distribution is in very good agreement with an isotropic distribution, convincing us that no correction related to the Σ^- dip need be applied.

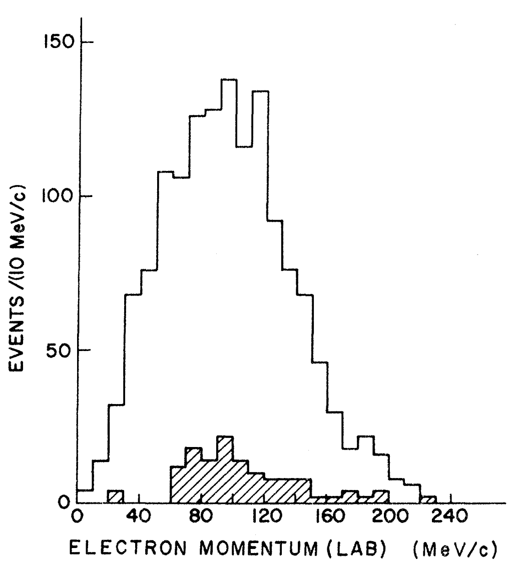

FIG. 2. Electron momentum distribution in the laboratory frame of reference in 10-MeV/c intervals obtained using the sample of 703 $\Sigma^- \to e^- n\nu$ events in which the Σ^- has a length ≤ 1 mm and a momentum ≤ 80 MeV/c. The cross-hatched region of the distribution represents events in which the Σ were produced by in-flight K^- particles.

III. SEARCH FOR $\Sigma^+ \to e^+ n\nu$ DECAYS

Since the electron momentum distributions from the decays $\Sigma^- \to e^- n\nu$ and $\Sigma^+ \to e^+ n\nu$ are very similar, we expect no difference in the scanning efficiency relative to either decay. Then the ratio of the decay rates, $\Gamma(\Sigma^+ \to e^+ n\nu)/\Gamma(\Sigma^- \to e^- n\nu)$, can be deduced from the ratio of the number of Σ^+ hyperons to Σ^- hyperons satisfying the criteria for acceptance ($\Sigma^\pm$ length at least 1 mm and Σ^- residual momentum at decay $\geqslant 80$ MeV/c). The difference between the Σ^+ and Σ^- lifetimes, and the fact that the ratio of Σ^- to Σ^+ produced is 2.34 in our sample, give for those Σ hyperons within the limits of our Σ acceptance criteria a ratio of

$$\frac{N(\Sigma^-)}{N(\Sigma^+)} = 4.25 \; .$$

To avoid inclusion of $\Sigma^\pm \to e^\pm \Lambda\nu$ events we eliminated all Σ decays having electron momentum

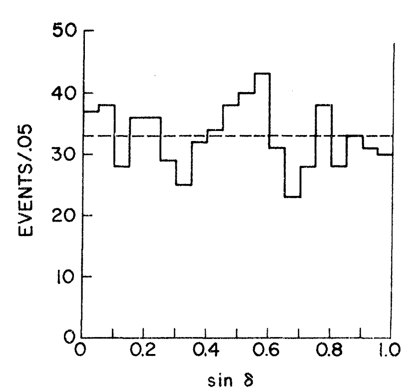

FIG. 3. Experimental dip distribution of Σ^- hyperons from $\Sigma^- \to e^- n\nu$ events in which the Σ was produced in a $K^- p$ reaction at rest.

≤ 70 MeV/c and consequently reduced our sample of 703 events to 549 $\Sigma^- \to e\nu n$ events. We found no $\Sigma^+ \to e^+ n\nu$ events with positron momentum ≥ 70 MeV/c, and five events with positron momentum ≤ 70 MeV/c, in good agreement with the number expected from $\Sigma^+ \to e^+\Lambda\nu$ decays in which the Λ decays neutrally.[8] The upper limit (90% confidence level) for the ratio of transition probabilities is then

$$\frac{\Gamma(\Sigma^+ \to e^+ n\nu)}{\Gamma(\Sigma^- \to e^- n\nu)} = \frac{4.25}{549} \times 2.3$$

$$= 0.018 \ .$$

IV. BRANCHING RATIO FOR Σ^- BETA DECAY

The procedure described above is sufficient to eliminate any differential biases between Σ^+ and Σ^- beta decays. To obtain the electron momentum distribution in Σ^- beta decays absolutely, however, we need to determine the detection efficiency as a function of momentum. Unlike the Σ^- track, the electron detection probability is a function of the electron dip angle. A study of the electron scanning efficiency as a function of its dip angle showed that the scanning efficiency drops drastically at a dip angle $>50°$, and forced us to include in our sample only events in which the electron dip angle δ was $\leq 53°$ or $\sin\delta \leq 0.80$.

A study of scanning efficiency as a function of the electron momentum (see Table II) showed also the necessity of limiting the events to those in which the electron momentum was ≤ 120 MeV/c. Applying these conditions, we found that the $\Sigma^- \to e^- n\nu$ sample was further reduced to 455 events. The momentum distribution of these 455 events corrected for scanning efficiency and dip angle (dip correction factor = 1.25) is shown in Fig. 4. The number of events after correction is 641 ± 45.

Since the Σ^- can decay into $\Sigma^- \to e^-\Lambda\nu$, this decay mode will be included in our sample if the Λ decays neutrally. From the observed number of $\Sigma^- \to e^-\Lambda\nu$ events in which the Λ decays visibly into a proton and a π^- meson,[8] we deduce that 32 events should be subtracted from our corrected sample.

TABLE II. Electron momentum distribution and scanning efficiencies for $\Sigma^- \to e^- n\nu$ events.

p_e (MeV/c)	Number of $\Sigma^- \to e^- n\nu$	Scanning efficiency
0– 60	125	0.87 ± 0.02
60– 90	163	0.83 ± 0.06
90–120	167	0.69 ± 0.06
120–135	51	0.46 ± 0.20

Subtracting from the 641 these 32 events we obtain a corrected number of $\Sigma^- \to e^- n\nu$ events in the electron momentum region 0–120 MeV/c of 609 ± 42.

To compare the distribution of these 609 events shown in Fig. 4 with the one expected in a $V-A$ interaction theory, we have used the calculation developed by Nieto[9] including only vector, axial-vector, and weak-magnetism hadronic coupling constants. The electron spectrum is slightly sensitive to the values of these constants.[3] The values used for the calculation were

vector constant $F_1 = -0.211$,

axial-vector constant $G_1 = 0.103$,

weak-magnetism constant $F_2 = 0.274$.

Using these coupling constants the fraction of the electron spectrum in the momentum region 0–120 MeV/c is 46.5% of the total.

The inclusion or exclusion of the weak-magnetism term would correspond to a change of about 5% in the calculation of the total electron spectrum

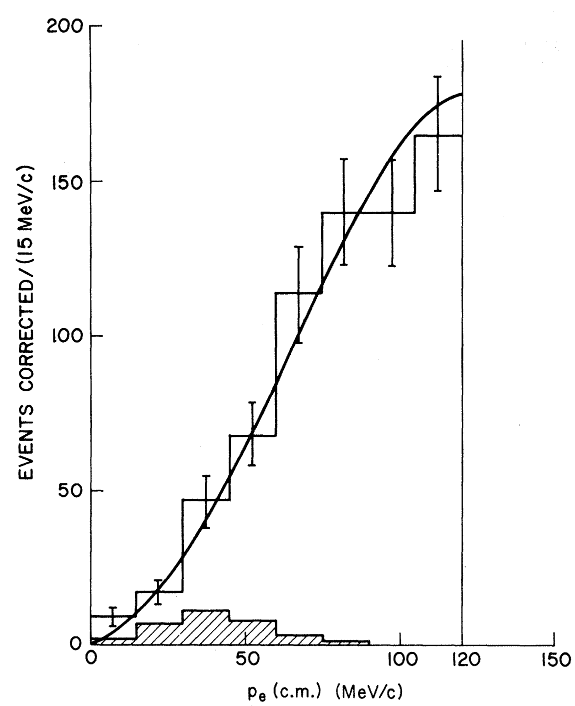

FIG. 4. Electron momentum distribution in the center-of-mass system for the corrected sample of 609 $\Sigma^- \to e^- n\nu$ events. The curve normalized to this sample of events represents the expected distribution for a $V-A$ interaction with coupling constant $F_1 = -0.211$, $G_1 = 0.103$, and $F_2 = 0.274$. The cross-hatched region represents the event subtracted to take into account $\Sigma^- \to e^-\Lambda\nu$ events with the Λ decaying neutrally.

TABLE III. Classification of visible charged secondaries produced in $K^- + p$ interactions in 9927 randomly selected frames.

Selection criteria	Number of events
1. (a) 2 charged π's (b) $\pi^+ + \Sigma^-$, $\pi^- + \Sigma^+ \searrow \pi^+ + n$ (c) $K_0 \to$ charged secondaries with K_0 projected length ≤ 2 mm	51 238
2. (a) $\pi^- + \Sigma^+ \searrow p + \pi^0$ (b) $\Lambda^0 \to p + \pi^-$ with Λ^0 projected length ≤ 2 mm	12 205
3. $\Lambda \to p\pi^-$ with 2 mm $\leq \Lambda^0$ projected length ≤ 5 mm	2596
4. $K_0 \to 2$ charged particles with 2 mm $\leq K_0$ projected length ≤ 5 mm	135

expected from the distribution up to 120 MeV/c. The electron spectrum is also slightly sensitive to the sign of G_1/F_1, but we do not believe that our data are accurate enough to shed any light on this important parameter. We have adopted the sign predicted by Cabibbo to deduce the Σ^- electronic branching ratio.

To calculate the branching ratio $\Gamma(\Sigma^- \to e n \nu)/$[total $\Gamma(\Sigma^-)$] the precise number of Σ^- present in the film scanned had to be found. To obtain this number we selected at random a sample of 9927 frames and counted and classified all K^- interactions present in each frame. To avoid errors in the classification, the events were subdivided into four large groups according to criteria that are easily distinguishable on the scanning table.

In Group I we include all "two-prong" events in which we could distinguish two π's as final charged products, or a π^+ and a Σ^-. It includes events as follows:

$K^- + p \to \pi^+ + \pi^- + \Lambda$ with no visible Λ decay,

$$K^- + p \to \pi^+ + \Sigma^-,\quad \Sigma^- \searrow \pi^- + n,$$

$$K^- + p \to \pi^- + \Sigma^+,\quad \Sigma^+ \searrow \pi^+ + n,$$

$K^- + p \to n + K^0$, $K^0 \searrow \pi^+ + \pi^-$ if the projected length that the K^0 traveled before decaying was ≤ 2 mm,

and

$K^- + p \to \pi^+ + \Sigma^-$ with Σ^- interacting in flight or at rest.

In Group II we include all two-prong events in which we could distinguish one π and one proton as final products. It includes

$$K^- + p \to \pi^- + \Sigma^+,\quad \Sigma^+ \searrow p + \pi^0,$$

$$K^- + p \to \pi^0 + \Sigma^0 \to \Lambda^0 + \gamma,\quad \Lambda^0 \searrow p + \pi^-,$$

and

$K^- + p \to \Lambda^0 + \pi^0$, $\Lambda^0 \searrow p + \pi^-$ if the projected length of the $\Lambda^0 \leq 2$ mm.

In Group III we count all events in which

$K^- + p \to \Lambda^0 + \pi^0$, $\Lambda^0 \searrow p + \pi^-$ if the projected length l of the Λ was in the interval 2 mm $\leq l \leq 5$ mm,

and in Group IV all

$K^- + p \to K^0 + n$ if the K^0's projected length d was in the interval 2 mm $\leq d \leq 5$ mm.

Table III gives the number of events found in each group.

The count was done twice; the bias in the counting appeared to be minimal, and the double scanning efficiency was estimated to be greater than 99%.

Using these numbers and applying the cuts previously described to the Σ^- events (i.e., the Σ^- should travel more than 1 mm and should have a momentum larger than 80 MeV/c before decay), we deduce that $(1.44 \pm 0.06) \times 10^6$ Σ^- hyperons decayed in the total sample of 490 222 frames scanned. The corrected number of $\Sigma^- \to e^- n\nu$ decays in the same frames was 609 ± 42, giving a branching ratio

TABLE IV. Comparison of this experiment with other hyperon-decay experiments.

	$10^3 \dfrac{\Gamma(\Sigma^- \to e^- n\nu)}{\text{Total }(\Sigma^-)}$	$\dfrac{\text{rate of } \Delta S = -\Delta Q \text{ transition}}{\text{rate of } \Delta S = \Delta Q \text{ transition}}$	Confidence level
This experiment	1.05 0.07 [a]	<0.018	90%
Murphy *et al.*[11]	$1.0^{+0.4}_{-0.3}$	<0.40	90%
Nauenberg *et al.*[10]	1.37 0.34	<0.15	80%
Miller *et al.*[12]	1.15 0.4		
Courant *et al.*[13]	1.43 0.3	<0.12	90%
Bierman *et al.*[14]	1.11 0.09	<0.06	90%
Ebenhoh *et al.*[2]	1.09 0.06	<0.019	90%
Cole *et al.*[15]	0.97 0.15	<0.12	95%

[a] The error quoted is statistical and does not include an additional uncertainty of ~5% due to possible variations in the theoretical formula used to extrapolate the momentum region $0 \le p_e \le 120$ MeV/c to the entire electron spectrum.

$$\frac{\Gamma(\Sigma^- \to e^- \nu n)}{\text{total }\Gamma(\Sigma^-)} = \frac{609 \pm 42}{0.46 \times (1.44 \pm 0.06) \times 10^6} = (1.05 \pm 0.07) \times 10^{-3}$$

This error does not include the bias due to the particular set of theoretical coupling constants used. This gives for the transition rate for Σ^- beta decay

$$\Gamma(\Sigma^- \to n e^- \nu) = (7.1 \pm 0.4) \times 10^6 \text{ sec}^{-1},$$

using the value $\tau_{\Sigma^-} = 1.48 \times 10^{-10}$ sec for the Σ^- mean life.

V. CONCLUSIONS

The measured Σ^- beta-decay branching ratio of $(1.05 \pm 0.07) \times 10^{-3}$ is in good agreement with the previously reported ones, as can be seen in Table IV.

No clear evidence for the violation of the $\Delta S = \Delta Q$ selection rule has so far been found. The one possible positron event from Σ^+ decay, reported by Nauenberg *et al.*[10] several years ago, has a high enough momentum so as not to be definitively distinguishable from a background muon. This experiment gives a limit for the ratio

$$\frac{\Gamma(\Sigma^+ \to e^+ n\nu)}{\Gamma(\Sigma^- \to e^- n\nu)} < 0.018$$

with 90% confidence. Table IV gives a list of the present limiting values obtained from Σ-hyperon decays. If one restricts one's attention to the momentum region below ~130 MeV/c, but above 70 MeV/c, *no* $\Sigma^+ \to e^+$ candidates have been found. The world's data then yield an upper limit

$$\frac{(\Delta S = -\Delta Q) \text{ rate}}{(\Delta S = +\Delta Q) \text{ rate}} \sim 1\%,$$

or an amplitude upper limit of ~10%.

As discussed in detail by Chounet *et al.*,[3] comparable or somewhat more stringent upper limits for $\Delta S = -\Delta Q$ amplitudes have been obtained from K_{l3} and K_{l4} decays.

ACKNOWLEDGMENTS

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Study of the η' Produced in K^-p Interactions at 2.885 GeV/c *

S. M. Jacobs, L. Kirsch, and P. Schmidt
Department of Physics, Brandeis University, Waltham, Massachusetts 02154

C. Y. Chang, B. V. Khouri, A. R. Stottlemyer, and G. B. Yodh
Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742

P. Gauthier, S. Glickman,† M. Goldberg, B. Meadows,‡ and G. C. Moneti
Department of Physics, Syracuse University, Syracuse, New York 13210

J. Brenner, J. Schneps, and G. Wolsky
Department of Physics, Tufts University, Medford, Massachusetts 02155
(Received 7 March 1973)

We have accumulated a sample of ~ 400 $\eta'(958)$ decays in the modes (1) $\eta' \to \pi^+\pi^-\gamma$ and (2) $\eta' \to \pi^+\pi^-\eta_N^0$ (N = neutral decay) from a 15.4-eV/μb study of K^-p interactions at 2.89 GeV/c. We find a branching ratio $R = (1)/(2) = 1.11 \pm 0.18$, where (1) is entirely $\eta' \to \rho^0\gamma$. A matrix-element analysis yields $J^P(\eta') = 0^-, 2^-$ as acceptable values for both samples. Production-decay angular correlations suggest that a $J^P = 2^-$ assignment is unlikely.

Although the η' was discovered in 1964,[1] its spin-parity and branching ratios remain uncertain. While it has been shown that the only acceptable G parity and isospin assignments are $I^G = 0^+$, previous spin and parity determinations have led to an ambiguity of $J^P = 0^-$ and 2^-. The branching ratio of $\eta' \to \pi^+\pi^-\gamma/\pi^+\pi^-\eta$ is not well established, with results varying by a factor of two.[2,3,4]

The results presented below are derived from a one million picture exposure of the BNL 31-in. hydrogen bubble chamber to a K^- beam of momentum 2.885 GeV/c. We have scanned and measured events with topology two prongs plus a V^0 in a fraction of film corresponding to 15.4 eV/μb. The channels of interest for this study are

$$K^-p \to \Lambda\pi^+\pi^-\eta_N \text{ (neutral decay)} \quad (1)$$
$$\to \Lambda\pi^+\pi^-\gamma \quad (2)$$
$$\to \Lambda\pi^+\pi^-\pi^0 \quad (3)$$
$$\to \Sigma^0\pi^+\pi^- \quad (4)$$
$$\to \Lambda\pi^+\pi^- . \quad (5)$$

Branching ratios. The relevant channels for our η' branching ratio determination are (1) and (2) where we study the decays $\eta' \to \pi^+\pi^-\eta_N$ and $\eta' \to \pi^+\pi^-\gamma$. The major difficulty in determining the η' branching ratio is the unbiased selection of η' events in reaction (2). These events are highly ambiguous with channels (3) and (4), so that attempts to separate these channels by kinematic fitting can lead to biases. For selection purposes, we have therefore chosen to treat the events of channels (1) to (4) as "unfitted events" at production, viz.,

$$K^-p \to \Lambda\pi^+\pi^- \text{MM}$$

where MM is the "missing mass."[5] While the highly constrained reaction (5) is also ambiguous with reaction (2), our Monte Carlo analyses indicate that a negligible amount of η' events could achieve a fit to (5), so these events have been removed from our sample.[6,7]

Our selection of events of reaction (1) is based on Figs. 1(a) and 1(b). Figure 1(a) shows the production angular distribution for the $\pi^+\pi^-$ MM system, with MM in the η region; the expected peripherality of η' production is apparent. Restricting $\cos\theta \geq 0.8$ (θ is the production angle between the proton and the Λ), we see in Fig. 1(b) an obvious enhancement where the $M^2(\pi^+\pi^-\text{MM})$ is in the η' region and the MM^2 is in the η region. The outlined selection region includes 215 events with an estimated 22 background events resulting in 193 ± 14 reaction (1) events.

As with reaction (1), we have selected reaction (2) events by restricting $\cos\theta \geq 0.8$. Resolution