β DECAY OF THE Σ^+ AND Σ^- HYPERONS AND THE VALIDITY OF THE $\Delta S = \Delta Q$ LAW

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It has been proposed on the basis of certain models for the weak interaction[1,2] that the rule $\Delta S = \Delta Q$ should hold to all orders of the strong and electromagnetic interactions in leptonic decays of strange particles. Experimental results both in accord with the rule[3,4] and in disagreement[5,6] have been published. We report here a measurement of the rate of the process $\Sigma^- \rightarrow n + e^- + \nu_e$ which is allowed, as well as a search for the process $\Sigma^+ \rightarrow n + e^+ + \bar{\nu}_e$, which is forbidden by the rule.

To describe the technique we consider the three steps in the analysis:

(1) Scanning and measuring. —The Σ^+ and Σ^- hyperons are produced in the capture of stopping K^- mesons in the Columbia-Brookhaven National Laboratory 30-in. H_2 chamber. Events are accepted if the hyperon is clearly visible and colinear with the production pion. However, Σ^+ decays are rejected, to eliminate the $\Sigma^+ \rightarrow p$ decay, if the secondary of the decay stops in the chamber without visible decay. The capture pion, sigma, and decay track are then measured. Events are retained for subsequent analysis only if the dip angle of the decay track is less than 60° and if its length exceeds 10 cm.

(2) Analysis of the data. —In Figs. 1 and 2 we show the momentum distributions of the hyperon decay tracks, after each momentum has been transformed to the center of mass of the decaying hyperon on the assumption that it is a pion. The vast majority of the decays appear in the peaks corresponding to the decays $\Sigma^\pm \rightarrow n + \pi^\pm$. By restricting our attention to $p < 173$ MeV/c for Σ^- decays and $p < 166$ MeV/c for Σ^+ decays, the pionic decays are almost entirely eliminated, while 85% of the continuous spectrum of the leptonic decays is retained. All events in the low-momentum interval are reexamined and remeasured. There are several possible reasons for a low momentum measurement: (a) The pion has a medium angle scattering without visible proton recoil; (b) the pion decays into a muon while still in motion; (c) the event is poorly measured; (d) the momentum measurement is low because of multiple scattering; (e) the event is truly a leptonic decay or a radiative decay of the sigma. The events in categories (a), (b), and (c), when remeasured, are checked for a fit either to pion scattering, to decay of a pion into a muon, or to the normal sigma pionic decays. All events which fit any of these categories are deleted from

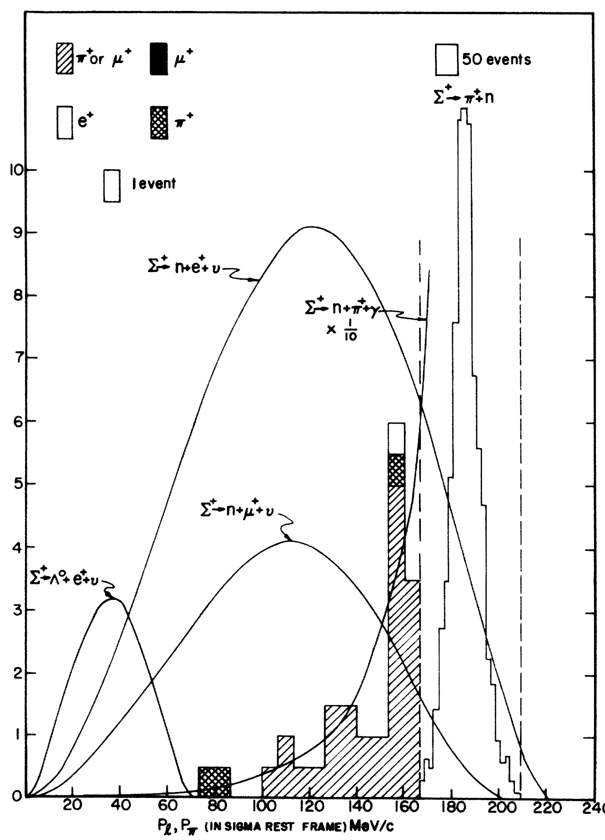

FIG. 1. Various Σ^+ differential decay rates.

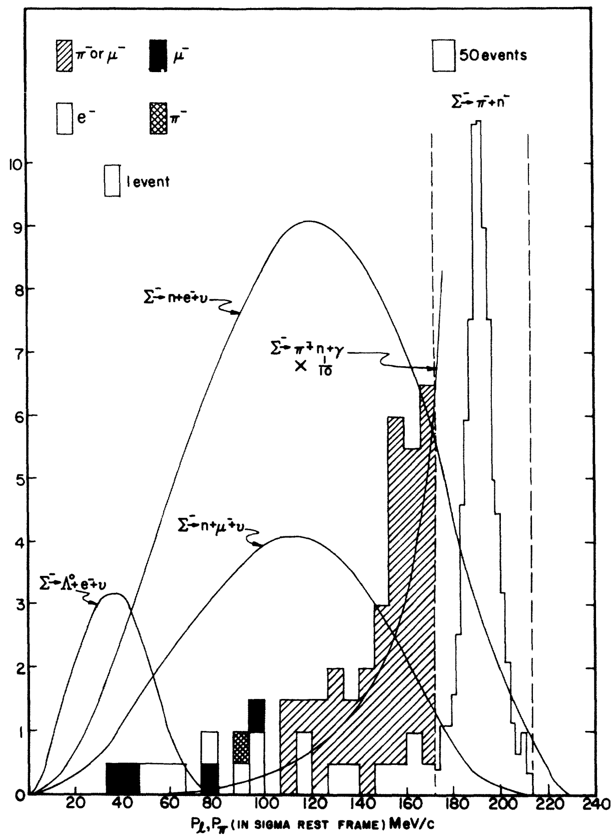

FIG. 2. Various Σ^- differential decay rates.

the list.

(3) Bubble counting. —After remeasurement we are left with the events which are either sigma leptonic decays, sigma radiative decays, or events which are normal sigma pionic decays but whose momentum measurement is low because of multiple scattering. It is not possible here in general to distinguish muons and pions, although a few low-momentum examples come to rest in the chamber and can so be distinguished. We have, therefore, no means of separating the muonic leptonic decay from the pionic decays. However, electrons can be distinguished from pions with substantial confidence by bubble count. The method we use is as follows: We measure the gap-length (distance between two bubbles in the track) distribution of the track in question by means of a microscope with a micrometer eyepiece. This distribution is then corrected for the dip and depth of the track relative to the plane of the cameras. In addition to K^- tracks in the chamber, there were also (unfortunately) quite a few ~450-MeV/c pion or muon beam tracks. We also measure the distribution of gap lengths for one of these beam tracks which appear in the neighborhood of the decay track from the sigma.

For each track we calculate[7]

$$m = 1/(\overline{X} - X_0)$$

where $\overline{X}$ = mean gap length measured, and X_0 = minimum gap length visible in the photograph. In hydrogen the following relation holds[7]:

$$\frac{m(450\text{-MeV}/c \text{ beam track})}{m(\text{sigma decay track})} = \frac{v^2(\text{sigma decay track})}{v^2(450\text{-MeV}/c \text{ beam track})}$$

where v is the velocity of the track.

To check the method we "bubble counted" 64 tracks, 10 of which are electrons from gamma rays that convert in the chamber; the rest are pions from sigma decays. The results are presented in Fig. 3. The error assigned to each bubble count is the statistical error $1/\sqrt{N}$ where N is

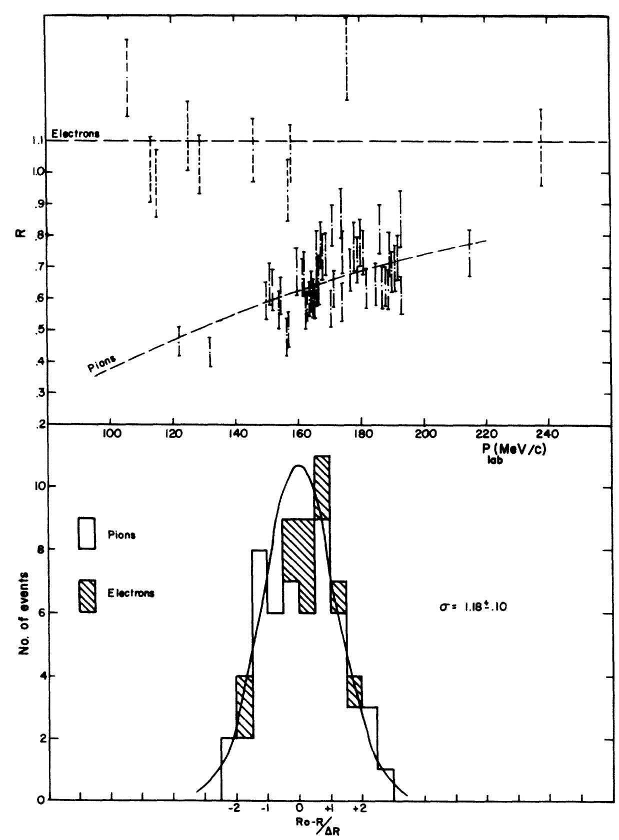

FIG. 3. Distribution of $R = \beta_{e,\pi}{}^2/\beta_\pi{}^2$ (450 MeV/c) for pions and electrons.

the number of gaps of length greater than X_0 measured in the track. The points with the dashed error bars are the results for electrons. The width of this experimental error distribution shows that we are underestimating the error by $(18 \pm 10)\%$. Even with this correction, however, the errors are small enough to make a substantially clear separation between electrons and pions or muons possible, but not between pions and muons. This can be seen from Fig. 3.

Using this technique we have analyzed 11 400 Σ^+ nonproton decays and 13 700 Σ^- decays. We have found one possible event of the type $\Sigma^+ \to e^+ + n + \nu$. The bubble counting gives a value for m which is 3.6 standard deviations from that expected for a pion and is 2.7 standard deviations from that expected for a muon. This implies that in our sample there is a 1% probability that the event is not an electron. We have found 16 events of the type $\Sigma^- \to n + e^- + \nu$ and 4 events of the type $\Sigma^- \to n + \mu^- + \nu$ where the μ^- stops in the chamber. Three of the 16 electron events are compatible with the decay $\Sigma^- \to \Lambda^0 + e^- + \nu$ where, however, the Λ^0 decay is not visible. Since in the same sample of data we have found one event in which the Λ^0 is visible, it is likely that all 3 events are of the type $\Sigma^- \to n + e^- + \nu$. The momentum distribution of these events is shown in Figs. 1 and 2.

Using these values, we find the branching ratio for Σ^- leptonic decay to be

$$\frac{R(\Sigma^- \to n + e^- + \nu)}{R(\Sigma^- \to \pi^- + n)} = \frac{16}{(13\,700)(0.85)} = (1.37 \pm 0.34) \times 10^{-3}.$$

Similarly, assuming there is one Σ^+ positron decay, we find the branching ratio for this decay to be

$$\frac{R(\Sigma^+ \to n + e^+ + \nu)}{R(\Sigma^+ \to \pi^+ + n)} \leq \frac{1}{(11\,400)(0.85)} = 1.03 \times 10^{-4}.$$

If in addition we consider the four $\Sigma^- \to n + \mu^- + \nu$ events found, we find that the $\Delta S = -\Delta Q$ decay rate is less than or equal to 6% of the $\Delta Q = \Delta S$ decay rate. Certainly the rate is less than 15% with an 80% confidence level. In addition, we note that the rate for the Σ^- leptonic decay is in reasonable agreement with the value predicted by Cabibbo.[8]

Preliminary results of this experiment, as well as a similar experiment performed by the CERN-Brookhaven-Maryland collaboration, have been reported at the Siena Conference,[9] and similar results have been reported by Murphy.[10] It is clear that in Σ decay as well as in K_{e4} decay,[3,4] the $\Delta S \neq \Delta Q$ amplitude is smaller than the $\Delta S = \Delta Q$ by a factor of at least 3. In the case of K^0 leptonic decay, previous evidence[5] for large $\Delta S \neq \Delta Q$ contributions has not been confirmed in recent experiments.[11] There remain only two pieces of evidence, to our knowledge. One is the example of the decay $\Sigma^+ \to \mu^+ + \nu + n$ reported by Barkas[6] some time ago in a sample of only ~100 Σ^+ decay. It is not clear to us that the statistical validity, impressive at the time, is still convincing now, after at least 10^5 Σ^+'s have been analyzed both here and at CERN for leptonic decay. There remains the event exhibited here. The identification is based on the bubble count. We have checked the count of the decay track against several tracks of known mass in the same picture, and we know of no systematic errors which might invalidate the result. Nevertheless, because on the one hand the technique is somewhat delicate, and on the other hand the theoretical implications are incisive, we feel that it is better to wait until possibly further events of this type are found before accepting the existence of $\Delta S \neq \Delta Q$ currents as experimentally established.

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