[5]R. W. Bland, M. G. Bowler, J. L. Brown, G. Goldhaber, S. Goldhaber, V. H. Seeger, and G. H. Trilling, Phys. Rev. Letters 18, 1077 (1967); R. W. Bland, G. Goldhaber, B. H. Hall, J. A. Kadyk, V. H. Seeger, G. H. Trilling, and C. G. Wohl, University of California Radiation Laboratory Report No. UCRL 18323, 1968 (unpublished).

[6]S. Andersson, C. Daum, F. C. Erné, J. P. Lagnaux, J. C. Sens, and F. Udo, Phys. Letters 28B, 611 (1969).

[7]The Basle convention for polarization was used. The polarization is defined with respect to the normal $\hat{n}=\hat{p}_i\times\hat{p}_f/|\hat{p}_i\times p_f|$, where $\hat{p}_i$ and $\hat{p}_f$ are unit vectors along the incoming K and outgoing K, respectively.

[8]R. E. Cutkosky and B. B. Deo, private communication.

[9]R. E. Cutkosky and B. B. Deo, Phys. Rev. 174, 1859 (1968).

[10]ZGS Users Handbook, 1969 (unpublished), p. 3.8.

[11]B. A. Leontić and J. Teiger, Brookhaven National Laboratory Report No. BNL 50031, 1966 (unpublished). We are grateful to B. Leontić for supplying us the design of this counter.

[12]P. Roubou, Cryogen. 6, 207 (1966); R. C. Niemann, F. Onesto, and O. J. Stover, Argonne National Laboratory Report No. ANL/HEP 6908 (unpublished).

[13]R. J. Abrams, R. L. Cool, G. Giacomelli, T. F. Kycia, B. A. Leontić, K. K. Li, and D. N. Michael, Phys. Rev. Letters 19, 259 (1967).

[14]G. Goldhaber, University of California Radiation Laboratory Report No. UCRL 17388, 1967 (unpublished); A. Bettini, M. Cresti, S. Limentani, L. Peruzzo, R. Santangelo, D. Locke, D. J. Crennell, W. T. Davies, and P. B. Jones, Phys. Letters 16, 83 (1965); V. Cook, D. Keefe, L. T. Kerth, P. G. Murphy, W. A. Wenzel, and T. F. Zipf, Phys. Rev. 129, 2743 (1963); W. Chinowsky, G. Goldhaber, S. Goldhaber, T. O'Halloran, and B. Schwarzschild, Phys. Rev. 139, B1411 (1965); A. S. Carroll, J. Fischer, A. Lundby, R. H. Phillips, C. L. Wang, F. Lobkowicz, A. C. Melissinos, Y. Nagashima, C. A. Smith, and S. Tewksbury, Phys. Rev. Letters 21, 1282 (1968), and University of Rochester Report No. UR-875-254 (unpublished).

[15]The inelastic parameters $\eta_{l\pm}$ were held at 1.0 for the F waves at 1.45 GeV/c and below. Note that the polarization data at 1.89 GeV/c have been combined with differential cross-section data at 1.96 and 1.97 GeV/c for the 1.95-GeV/c analysis. A large contribution to the χ^2 at 1.45 GeV/c and below comes from the differential cross-section data at backward angles where a discrepancy exists between the backward data of Carroll et al. (Ref. 14) and the bubble-chamber data of Bland et al. (Ref. 5) and Bettini et al. (Ref. 14). No adjustments have been made to any of the data used in this analysis.

[16]The F-wave phase shifts (not shown in Fig. 3) vary monotonically with momentum reaching their largest absolute magnitudes at 1.95 GeV/c, where $\delta_{F7/2}=0.11$, $\eta_{F7/2}=0.88$ and $\delta_{F5/2}=-0.09$, $\eta_{F5/2}=0.83$ for solution I. Corresponding values for solution II are 0.20, 0.91; -0.12, 0.86.

[17]E.g., R. C. Arnold and R. K. Logan, Phys. Rev. 177, 2318 (1969); M. L. Blackmon and G. R. Goldstein, Argonne National Laboratory Report No. ANL/HEP 6819 (unpublished).

[18]G. B. Dass, C. Michael, and R. J. N. Phillips, Nucl. Phys. B9, 549 (1969), and private communication.

MEASUREMENT OF THE RATIO OF AXIAL-VECTOR TO VECTOR CURRENT IN THE DECAY $\Sigma^-\to ne^-\bar{\nu}$*

A. P. Colleraine, T. B. Day, R. G. Glasser, R. Knop,† B. Sechi-Zorn, and G. A. Snow
Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742
(Received 16 June 1969)

From approximately 550 Σ^- electronic decays produced by stopping K^- in liquid hydrogen we have selected a sample of 49 events in which the neutron from the Σ^- leptonic decay is detected by a subsequent n-p scatter. A maximum-likelihood analysis, including the effect of about 20% background, indicates that the magnitude of the ratio of the coupling constants is $|G_a/G_v|=0.23\pm0.16$, in excellent agreement with the prediction of the Cabibbo theory.

In an effort to measure the ratio of the axial-vector to vector current in the weak $\Sigma^-\to n$ transition we have searched for proton recoils associated with scatters of the neutron from $\Sigma^-\to ne^-\bar{\nu}$ decays.[1,2] Approximately 550 such decays have been found in 4×10^5 pictures of stopping K^- in the Brookhaven National Laboratory 30-in. hydrogen bubble chamber.[3] In any doubtful case the Σ^- decay track was gap counted to insure that only electronic decays were included in the sample of events to be examined for recoils.

Each of the $\Sigma^-\to ne^-\bar{\nu}$ events found has been remeasured together with all visible recoil protons within 25 cm of the Σ^- decay vertex; an average of 5 such recoils was associated with each decay. The measurements were processed by the Maryland TVGP-SQUAW fitting program with four constraints overall for the reaction sequence

$$K^-p\to\Sigma^-\pi^+\ (K^-\text{ at rest}),$$
$$\Sigma^-\to ne^-\bar{\nu},$$
$$np\to np.$$

The K^-p reaction was fitted using three constraints; the Σ^- decay and np reaction, using one. There were many fits with very short recoils (lengths $\lesssim 0.5$ cm) which, because of their large measurement errors, are relatively easy for the kinematics program to incorporate in a fit. These short-recoil fits are heavily contaminated with background. To reduce this background we have applied the following stringent requirements to each event: (1) The laboratory dip angle of the Σ^- and e^- must be $\leq 70°$. (2) The end of the neutron (beginning of proton) must be more than 4.0 cm from all chamber boundaries. (3) The proton must stop in the chamber. (4) The length of the proton, neutron, and sigma tracks must lie within the following intervals: $0.70 \text{ cm} < l_p \leq 4.00$ cm, $0.25 \text{ cm} < l_n \leq 20.00$ cm, $0.10 \text{ cm} < l_\Sigma \leq 0.95$ cm. (5) The value of χ^2 for the three-constraint (3C) fit at the $K^-p \rightarrow \Sigma^-\pi^+$ vertex must be less than 11.3 (1% level) for an at-rest production process. (6) The difference between the χ^2 for the 4C overall fit and for the 3C production fit was required to be less than 4.0. This is a 1C test for the recoil fit at the 5% level of significance. (7) The electron laboratory momentum must satisfy $10.0 \text{ MeV}/c < P_e \leq 170.0 \text{ MeV}/c$ to insure positive identification. 49 events have survived the above cuts and these events have been plotted as solid circles on a scatter plot of protons versus neutron length [Fig. 1(a)].

To investigate the background due to random proton-recoil tracks happening to fit with Σ^- electronic decays, we simulated background events in the following ways: In the first method we used a sample of some 50 $\Sigma^- \rightarrow \Lambda^0 e^- \bar{\nu}$ decays[4] in which we ignored the visible Λ^0 and instead measured all proton recoils in the picture with the Σ^- as though it were a $\Sigma^- \rightarrow ne^-\bar{\nu}$ decay. The recoils from those 15 events which passed all criteria except the proton length test have been plotted as crosses in Fig. 1(a); only one of the fits occurred with a recoil of length ≥ 0.7 cm (this cut was put in to increase the discrimination between genuine and background events). This method of estimating the background has two drawbacks: The electron momentum spectra of the two Σ^- decay modes are significantly different and the statistics are very limited. A second study of the background was made by generating fake events from the real measurements by randomly associating recoils from one frame with a Σ^- decay in another. 300 Σ^- electronic decays have been used in four such background runs and have resulted in 24 fake events satisfying all our

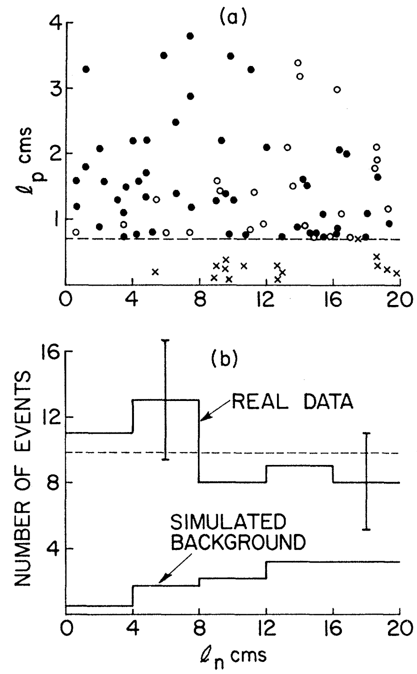

FIG. 1. (a) Plot of proton versus neutron lengths. The points (closed circles) represent the 49 real events, the open circles are the 24 Monte Carlo fake events, and the crosses are the recoils giving fits with $\Sigma^- \rightarrow \Lambda^0 e^- \bar{\nu}$ events. (b) Number of fits as a function of "neutron" length for the real data and the Monte Carlo background (normalized to 22% of the real data).

cuts. We, therefore, estimate that there should be $24 \times 550/(4 \times 300) = 11$ background events in the 49 found. The 24 fake events have been plotted as open circles in Fig. 1(a).

Another estimate of the amount of background can be obtained by studying the number of apparent events as a function of the distance of the recoil (neutron length) from the Σ^- decay vertex for both the true and the fake events. The fakes are principally from recoil protons caused by the approximately uniform neutron flux from the alternating-gradient synchrotron passing through the bubble chamber. This uniform density should produce a quadratic rise in the differential number of recoils, and consequently, in the number of fakes produced as the length of the "neutron" increases. The true recoil events, on the other hand, should be essentially independent of l_n. The graphs of Fig. 1(b) verify this; the number of simulated fake events is, indeed, seen to rise rapidly with the distance from the Σ^- decay vertex, whereas the number of real events actually decreases. This fall in the number of real events with increasing l_n is attributed to the fact that (a) the chamber is of finite size and (b) the recoil

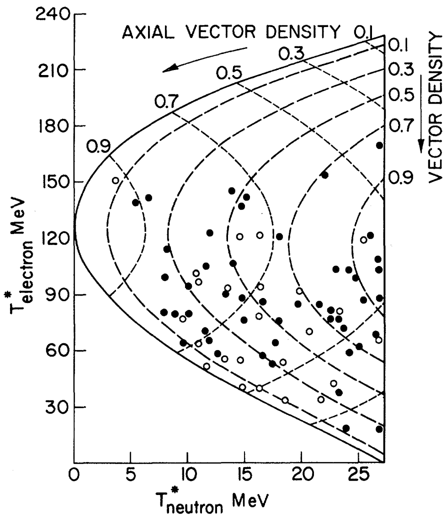

FIG. 2. Dalitz plot of T_e* vs T_n* in Σ^- rest frame. The points represented by closed and open circles are the 49 real and 24 background events, respectively. The curves, longer dashed line (shorter dashed line) represent contours of constant vector (axial-vector) current density.

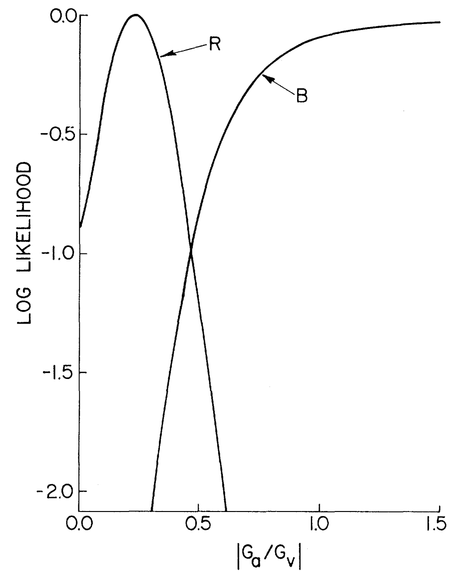

FIG. 3. The form of the likelihood function. Curve R is the result for the 49 real events including 22% background. Curve B is the result for the 24 pure fake events (the normalization is arbitrary).

scanning efficiency drops with increasing l_n. There were two cases in which two recoils fit with the same Σ^-, in rough agreement with the estimated background rate. Figure 2 is a Dalitz plot of the neutron and electron kinetic energies (in the Σ^- rest frame) for both the 49 actual and 24 simulated events.

The ratio of the axial-vector to vector current in the $\Sigma^- \rightarrow ne^-\bar{\nu}$ decay was estimated by a maximum-likelihood analysis.[5] Since the detection efficiency varies with electron momentum, the likelihood function used is the conditional probability density for the neutron energy given the electron energy and the observed directions of the Σ^- and e^-. The finite chamber volume and the neutron- and proton-length cuts required that we include in this density the effects of the energy-dependent n-p differential and total cross sections.[6] To allow for the approximately 20% background present in our real data the likelihood function also included the probability density due to background events. It is assumed that the fake events will uniformly populate the allowed physical region of the Dalitz plot and that the relative proportion of background events rises quadratically with the distance from the Σ^- decay. The form of the likelihood curve (including the background correction) is shown as curve R in Fig. 3. From this we estimate that the magnitude of the ratio of axial-vector to vector currents in our present sample of 49 $\Sigma^- \rightarrow ne^-\bar{\nu}$ events is

$$|G_a/G_v| = 0.23 \pm 0.16,$$

in excellent agreement with the Cabibbo-theory prediction of -0.24.[7] (If the background correction had been ignored, the result would be $|G_a/G_v| = 0.26 \pm 0.17$.)

For comparison purposes the 24 fake events have also been run through the likelihood program (without the background term). A number of these events lie right at the curved boundary of the Dalitz plot where the vector-current term is zero; this results in a likelihood curve (curve B, Fig. 3) that is predominantly axial vector.

Two other results for G_a/G_v for $\Sigma^- \rightarrow ne^-\bar{\nu}$ decays have been reported recently. Gershwin et al.[8] measured the e^- decay asymmetry from polarized Σ^-'s and found $G_a/G_v = -0.05_{-0.23}^{+0.32}$ or $+1.3_{-0.9}^{+10.0}$ (in the sign convention of Ref. 7), while Eisele et al.,[9] using a method similar to ours, have obtained $G_a/G_v = -0.47_{-0.37}^{+0.23}$ or $+0.42_{-0.21}^{+0.32}$. By combining the magnitudes of the likelihood curves of these experiments with our own, we obtain

$$G_a/G_v = 0.26_{-0.08}^{+0.12}.$$

In conclusion it should be mentioned that we have not included the weak-magnetism correction predicted by the Cabibbo theory since its effect is small compared with our present errors.

We wish to thank Dr. U. Nauenberg for making the Princeton $\Sigma^- \rightarrow ne^-\bar{\nu}$ events available to us. We are indebted to our scanners for carrying out efficiently and well this unusually difficult task, and to the 30-in. bubble-chamber crews and alternating-gradient synchrotron operating crews at Brookhaven National Laboratory together with Dr. A. Prodell and Dr. D. Berley for their expert help in obtaining the pictures.

*Work supported by U. S. Atomic Energy Commission.

†Present address: Rutgers—The State University, New Brunswick, N. J.

[1]R. E. Knop, T. B. Day, B. Sechi-Zorn, and R. G. Glasser, Bull. Am. Phys. Soc. 13, 587 (1968). B. Sechi-Zorn, Bull. Am. Phys. Soc. 13, 555 (1968).

[2]G. A. Snow, A. P. Colleraine, T. B. Day, R. G. Glasser, R. E. Knop, B. Sechi-Zorn, E. Bierman, and U. Nauenberg, in Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna, Austria, 1968 (unpublished); A. P. Colleraine, T. B. Day, R. G. Glasser, R. E. Knop, B. Sechi-Zorn, and G. A. Snow, Bull. Am. Phys. Soc. 14, 519 (1969).

[3]Four fifths of the data was scanned by the Maryland group, the remaining one fifth came from the Princeton rate-measurement experiment: E. Bierman, A. P. Colleraine, S. Konousu, U. Nauenberg, and L. Seidlitz, Phys. Rev. Letters 20, 1459 (1968).

[4]N. Barash, T. B. Day, R. G. Glasser, B. Kehoe, R. Knop, B. Sechi-Zorn, and G. A. Snow, Phys. Rev. Letters 19, 181 (1967).

[5]R. Knop, thesis, University of Maryland, Technical Report No. 975, 1969 (unpublished).

[6]Methods of Experimental Physics, edited by L. C. L. Yuan and C.-S. Wu (Academic Press, Inc., New York, 1961), Vol. 5, Pt. A.

[7]H. Filthuth, in Proceedings of the Topical Conference on Weak Interactions, CERN, 1969 (CERN Scientific Information Service, Geneva, Switzerland, 1969), p. 131. This prediction comes from a best fit to all the baryon demileptonic decay data using the simple one-angle Cabibbo theory with the parameters $\theta = 0.235$, $g_A^F = 0.49$, and $g_A^D = 0.74$.

[8]L. K. Gershwin et al., Phys. Rev. Letters 20, 1270 (1968).

[9]F. Eisele et al., to be published, and in Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna, Austria, 1968 (unpublished).

GENERAL FORM OF REGGE TRAJECTORY AND RESIDUE FUNCTIONS IN THE SCATTERING OF PARTICLES WITH SPIN*

Loyal Durand, III, and Paul M. Fishbane
Department of Physics, University of Wisconsin, Madison, Wisconsin 53706

and

Stanley A. Klein
Joint Science Department, Claremont Colleges, Claremont, California 91711

and

L. M. Simmons, Jr.
Department of Physics, University of Wisconsin, Madison, Wisconsin 53706
(Received 26 May 1969)

We present the most general forms for the trajectory and residue functions for daughter Regge poles which are consistent with analyticity and unitarity. Our results hold for arbitrary masses and spins of the external particles, all types of conspiracy, and general, nonparallel trajectories.

Two major problems are encountered in the construction of Regge-type expansions for two-body scattering amplitudes for general masses and spins of the external particles: (i) The individual terms in the expansion for an s-channel process $1+2\to 3+4$ contain spurious singularities at $s=0$ unless $m_1 = m_2$ and $m_3 = m_4$. (ii) The helicity amplitudes used to describe the scattering of particles with spin are not all independent at $s=0$ and at the pseudothresholds and thresholds, $s=(m_1\pm m_2)^2$ and $s=(m_3\pm m_4)^2$. The singularities at $s=0$ can be eliminated in the Regge expansion by the introduction of an infinite sequence of daughter Regge poles.[1] However, the conditions which ensure that the full scattering amplitude is analytic at $s=0$ impose nontrivial constraints on the behavior of the trajectory and residue functions near that point. Because of the kinematic restrictions on the helicity amplitudes at $s=0$ (conspiracy conditions) these constraints can connect the trajectory and residue functions for poles of opposite intrinsic parity (conspiracy).[2] The residue functions must also be adjusted to satisfy the kinematic constraints at pseudothresholds and thresholds.

The problem of determining the most general forms for Regge trajectory and residue functions which satisfy the constraints imposed by (i) and (ii) has been considered by many authors.[3-9] With the excep-