Measurement of the Electron Asymmetry in the Beta Decay of Polarized Σ^- Hyperons

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The electron asymmetry was measured in the beta decay of polarized sigma hyperons $\Sigma^- \to ne^-\bar{\nu}$ produced in the reaction $K^-p \to \Sigma^-\pi^+$ at the $Y_0^*(1520)$ resonance. Particles were tracked in a magnetic spectrometer and a large-acceptance, segmented, gas-Cherenkov-scintillation counter array identified electrons. A maximum-likelihood analysis based on 193 events yields the electron asymmetry of $\alpha_e = 0.35 \pm 0.29$. The result favors a positive value for g_1/f_1 which is opposite to the Cabibbo-favored sign.

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There has been continuing interest in the semileptonic decays of hyperons. For the decay $A \to Be\bar{\nu}$, the matrix elements for the baryon current are given by

$$\begin{aligned} \langle n|V_\alpha|\Sigma\rangle &= \bar{U}_n(f_1\gamma_\alpha + f_2\sigma_{\alpha\beta}q_\beta/M_\Sigma)U_\Sigma, \\ \langle n|A_\alpha|\Sigma\rangle &= \bar{U}_n(g_1\gamma_\alpha\gamma_5 + g_2\sigma_{\alpha\beta}q_\beta\gamma_5/M_\Sigma)U_\Sigma, \end{aligned} \tag{1}$$

where $q_\alpha = (P_{\Sigma^-} - P_n)_\alpha = (P_{e^-} + P_\nu)_\alpha$. The terms proportional to electron mass have been omitted. The pseudotensor term q_2 is conventionally assumed to be negligible. The weak-magnetism term f_2 is related to the hadron anomalous magnetic moments through the conserved vector current hypothesis; the axial vector and vector form factors, g_1 and f_1, are calculated from the Cabibbo SU(3) model.[1] In particular, for $\Sigma^- \to ne^-\bar{\nu}$, the calculated ratio is[2] $g_1/f_1 = -0.343 \pm 0.014$ (where the sign convention is positive for neutron decay). The electron asymmetry is a sensitive indicator of the sign of g_1/f_1.

We have measured the asymmetry parameter α_e of the electron with respect to the Σ^- spin in the decay process $\Sigma^- \to ne^-\bar{\nu}$. In this experiment an enriched K^- beam[3] with momentum 414 MeV/c at the Argonne National Laboratory Zero-Gradient Synchrotron was used to produce polarized Σ^- in a liquid-hydrogen target ($K^-p \to \Sigma^-\pi^+$). The sigmas originate from the $Y_0^*(1520)$ resonance region and have average polarization 0.61 as calculated in the partial wave analysis of Gopal *et al.*[4] Kaons were electronically selected by time of flight, dE/dx, and a gas and two plastic Cherenkov counters which vetoed electrons and pions. These selection criteria produced a 95% pure tagged K^- beam of 414 MeV/c with $\Delta p/p \approx 2.3\%$ which was focused onto a cylindrical liquid-hydrogen target (38 cm long by 8 cm diam) contained in a foam Dewar. The target was surrounded with a segmented U-shaped multiwire proportional chamber and five magnetostrictive wire spark chambers. The experimental apparatus is shown in Fig. 1. The trajectories of pions from the production reaction $K^-p \to \Sigma^-\pi^+$ and electrons from the Σ^- decays were detected by multiwire proportional chambers and magnetostrictive spark chambers placed in a wide-gap C magnet (0.35-T central field). The electrons were identified by segmented Cherenkov (C) counter and scintillation counter arrays described elsewhere.[5] Pulse heights and times of flight of detected particles were recorded for each photomultiplier associated with the C and scintillation counters.

The geometry of this magnetic spectrometer was arranged into beam downstream, right, and left sections and the event trigger logic followed this division. Two types of triggers were recorded, slow and fast. Both required an incoming K^- beam particle and two charged particles leaving the hydrogen target. One of these was the π^+ and the other was the charged particle from the Σ^- decay. The slow trigger, which detected the π^- from the decay $\Sigma^- \to n\pi^-$, required signals from the U-shaped proportional chamber, one flat chamber in any of the geometrically defined sections, and a scintillator from the corresponding array behind the C counters. The fast trigger,

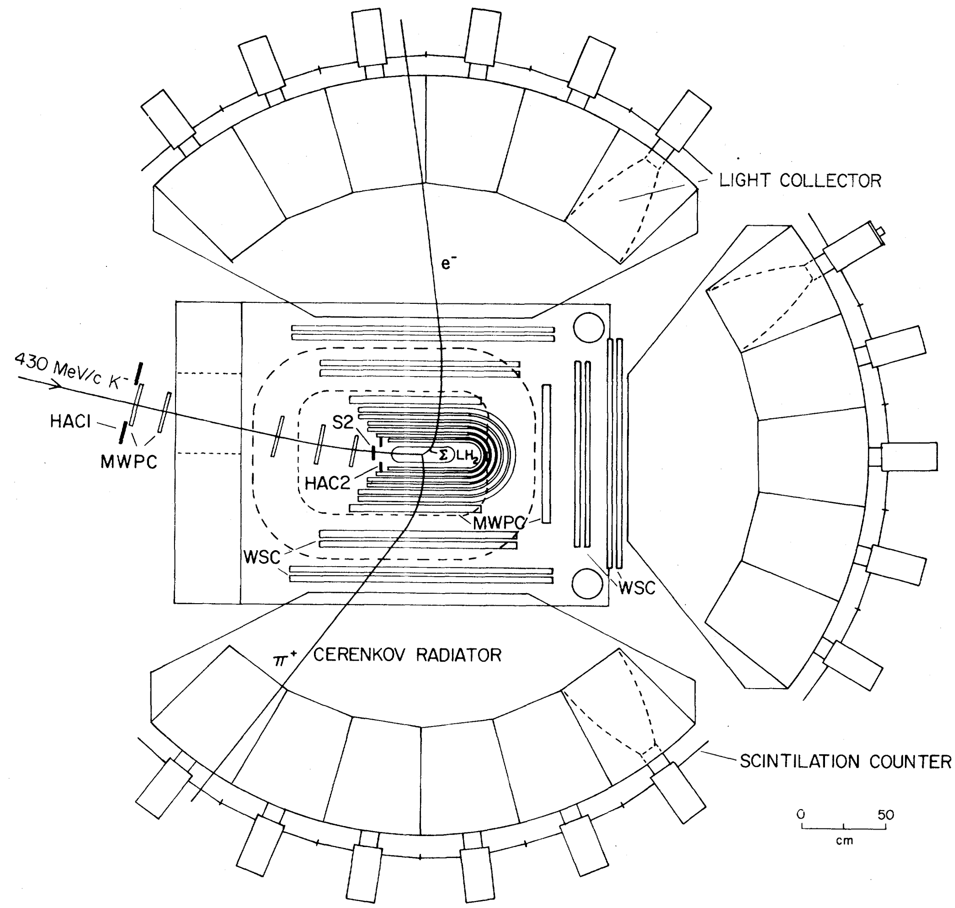

FIG. 1. Schematic of apparatus. MWPC denotes multiwire proportional chambers; WSC, wire spark chambers. S2 is a beam-defining scintillation counter and HAC1, HAC2 are anticoincidence counters.

which detected the e^- from a Σ^- beta decay, required a signal from the segmented C counter in coincidence with the slow trigger. The proportional chambers besides tracking particles also provided a prompt multiplicity trigger accepting events where the outgoing particles traversed the same geometric sector of the detector. The solid angles for the slow- and fast-trigger events were 4.5% and 3.0%, respectively.

Typically 8×10^5 beam particles per pulse reached the hydrogen target and of these 2×10^3 were K^-. Our trigger rate was three fast events per pulse and, by scaling the slow trigger 10 to 1, three slow events per pulse. In the total of 1600 h of data taking, 1.7×10^9 K^- produced 2.4 $\times 10^6$ triggers.

The accumulated data were analyzed off line with the criteria described below. A two-track event was required with a positive and a negative particle, which yielded 8.7×10^5 triggers. The production and decay vertices were chosen at the midpoint between the corresponding tracks at their closest approach. Each track had to miss its vertex by less than 25 mm and the production vertex was required to be within the target fiducial volume. Both of these tracks had to pass through or near the scintillation and C counters which signaled the event, yielding 3.8×10^4 triggers.

The momenta of the detected particles were determined[6] and the kinematic quantities, including energy losses, calculated to fit the hypothesis $K^-p\to\Sigma^-\pi^+$ followed by $\Sigma^-\to n\pi^-$ or $\Sigma^-\to ne\bar{\nu}$ for slow and fast triggers, respectively. Additional criteria removed events for which the pair of charged particles has invariant mass <125 MeV/c^2, both tracks triggered cells, or the reconstructed Σ^- path length l was outside the allowable limits set by the laboratory momentum spectrum and spatial reconstruction errors (-13 mm $\leq l \leq 305$ mm). Also the time-of-flight limits for slow and fast particles consistent with the production and decay kinematics of Σ^- were imposed. Finally identifiable background reactions were removed: $K^- \to \pi^-\pi^-\pi^+$, Σ^+ production followed by decay, and $K^-p \to \Lambda\pi^+\pi^-$. In our apparatus, K_{e3} decays ($K^-p \to K^0 n$; $K_L{}^0 \to \pi^+ e^- \nu$) were not uniquely identified and were partially removed by applying production/decay vertex criteria. The cumulative effect of these background-suppression steps, calibrated by a parallel analysis of Monte Carlo–generated data, was to remove 23% of the Σ^- beta decays. A larger sample of 1600 candidates was scanned on a video display to corroborate the track identification and reconstruction program. The data sample accepted for further analysis contains 193 events.

We checked for instrumental and analysis bias which could produce fake up-down asymmetry using Monte Carlo–generated and detected events of both slow- and fast-trigger types.

The measured asymmetry parameters from the nonleptonic decays are, for $\Sigma^- \to n\pi^-$,

$$\alpha_- = -0.073 \pm 0.055 \text{ (3389 events)};$$

for $\Sigma^+ \to n\pi^+$,

$$\alpha_+ = 0.063 \pm 0.104 \text{ (1937 events)};$$

for $\Sigma^+ \to p\pi^0$,

$$\alpha_+ = -0.92 \pm 0.41 \text{ (478 events)}.$$

All of the above asymmetry parameters are consistent with accepted values.[7] The symmetry for electron detection was measured for 8500 pairs identified by the C array. The up-down asymmetry with respect to the midplane was found to be 0.03 ± 0.02 implying no significant bias in the fast trigger.

The beta-decay sample contains two types of background events: $K^0 \to \pi^+ e \bar{\nu}$, and $\Sigma^- \to n\pi^-$ events for which the π^- was misidentified by the C counters. The electron asymmetry parameter is found by maximizing the logarithm of the likelihood function given by

$$\sum \log(1 + \alpha_e P \cos\theta). \qquad (2)$$

Here θ is the angle between the production plane normal and the electron in the Σ^- rest frame and P the polarization calculated for each Σ^-. The missing-mass distribution for these events is shown in Fig. 2. We analyzed events lying in a wide mass interval (1000–1360 MeV/c^2) and in a subsample corresponding to the narrower interval (1110–1290 MeV/c^2). The 193-event sample has a calculated 29% K_{e3} background which can be reduced to 20% by narrowing the missing-mass

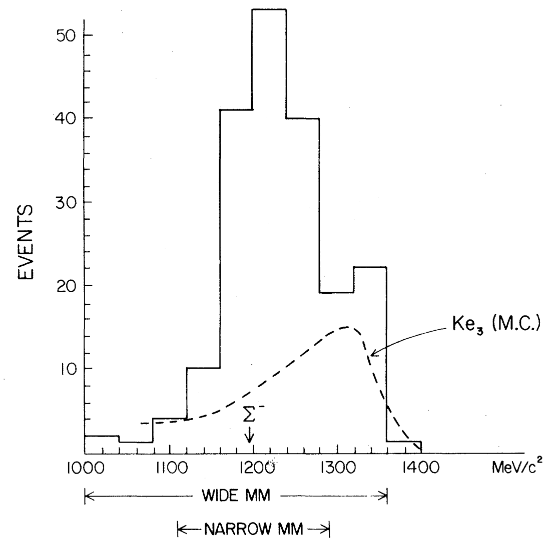

FIG. 2. Missing-mass distribution. The dashed curve is a Monte Carlo calculation of the K_{e3} background.

interval. The $\Sigma^- \to n\pi^-$ background is 7% for both samples. To account for the background effect on α_e we corrected the data with the weighted $P\cos\theta$ distributions from Monte Carlo–generated K_{e3} events and analyzed slow-trigger $\Sigma^- \to n\pi^-$ events. The asymmetries before correction are

$$\alpha_e = 0.35 \pm 0.25$$

(wide mass interval, 193 events) and

$$\alpha_e = 0.27 \pm 0.29$$

(narrow mass interval, 145 events). The corresponding asymmetries after correction are

$$\alpha_e = 0.35 \pm 0.29$$

(wide mass interval, 193 events) and

$$\alpha_e = 0.41 \pm 0.33$$

(narrow mass interval, 145 events). We adopt the more precise asymmetry derived from the corrected larger sample.

Our result shows that a positive sign is favored for g_1/f_1. Using conventional assumptions for the induced form factors, we find that $g_1/f_1 > -0.15$ with 95% confidence. Moreover, the absolute value of g_1/f_1 can be calculated from recent precise measurements of the neutron energy spectrum by Tanenbaum *et al.*[8] and Jeffreys[9] and since these are in excellent agreement, it is appropriate to average them:

$$|g_1/f_1| = 0.44 \pm 0.03.$$

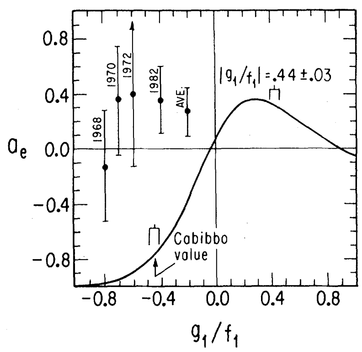

FIG. 3. Plot of electron asymmetry vs g_1/f_1 with $f_2 = -1.14 f_1$ and $g_2 = 0$. The $|g_1/f_1|$ values are derived from Refs. 8 and 9. The experimental values of α_e, shown by year of publication, are derived from Ref. 10 and the present work.

A positive value of g_1/f_1 corresponds to an asymmetry of $\alpha_e = 0.36$, which agrees with our measurement. However, the Cabibbo-favored negative value of g_1/f_1 corresponds to $\alpha_e = -0.69$ which is 3.5 standard deviations away from our measured value.

The effect of this experiment and previous measurements of α_e in determining the sign of g_1/f_1 is shown in Fig. 3. The previous world average for α_e was 0.19 ± 0.25. This experiment brings the world average to 0.26 ± 0.19, 5 standard deviations away from the Cabibbo-favored negative value.

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