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

S. Y. Hsueh, D. Muller, J. Tang, R. Winston, and G. Zapalac
Enrico Fermi Institute, The University of Chicago, Chicago, Illinois 60637

and

E. C. Swallow
Department of Physics, Elmhurst College, Elmhurst, Illinois 60126, and Enrico Fermi Institute, The University of Chicago, Chicago, Illinois 60637

and

J. P. Berge, A. E. Brenner, P. Grafstrom, E. Jastrzembski, J. Lach, J. Marriner, R. Raja, and V. J. Smith[(a)]
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

and

E. McCliment and C. Newsom
Department of Physics, University of Iowa, Iowa City, Iowa 52242

and

E. W. Anderson
Department of Physics, Iowa State University, Ames, Iowa 50011

and

A. S. Denisov, V. T. Grachev, A. V. Kulikov, V. A. Schegelsky, D. M. Seliverstov, N. N. Smirnov, N. K. Terentyev, I. I. Tkatch, and A. A. Vorobyov
Leningrad Nuclear Physics Institute, Leningrad, U.S.S.R.

and

P. S. Cooper, P. Razis, and L. J. Teig[(b)]
J. W. Gibbs Laboratory, Yale University, New Haven, Connecticut 06511
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We report the results of a Fermilab Tevatron experiment using a Σ^- beam with a measured polarization of 0.22 ± 0.04. We find the electron asymmetry in Σ^- beta decay to be $\alpha_e = -0.53 \pm 0.14$ on the basis of a sample of 25 000 events, in agreement with the Cabibbo model and in contradiction with previous experiments. The corresponding value for the ratio of axial-vector to vector form factors is $g_1/f_1 = -0.29 \pm 0.07$.

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The electron asymmetry α_e in Σ^- beta decay is highly sensitive to the ratio of axial-vector to vector form factors g_1/f_1 (see Fig. 1). The magnitude $|g_1/f_1|$ is obtained from unpolarized decays; two recent high-statistics experiments[1,2] combined give $|g_1/f_1| = 0.36 \pm 0.04$.

A recent fit of beta-decay data in the baryon octet by the Cabibbo model[3] predicts[4] for $\Sigma^- \rightarrow ne\bar{\nu}$, $g_1/f_1 = -0.28 \pm 0.02$, which corresponds to a large negative electron asymmetry $\alpha_e = -0.51 \pm 0.04$ (Fig. 1). In fact, of all the hyperons, $\Sigma^- \rightarrow ne\bar{\nu}$ is the only accessible decay for which the Cabibbo model predicts a relative sign which is *opposite* to that familiar from neutron or lambda beta decay. Previous experiments with polarized Σ^- have failed to confirm this distinctive test of the theory; the electron asymmetry averaged over four earlier experiments[5-8] totaling 352 events is $\alpha_e = 0.26 \pm 0.19$. An attempt was made[1] to infer the sign of g_1/f_1 from the shape of the electron energy spectrum. This analysis favored the negative sign. However, the dependence of the electron spectrum on g_1/f_1 is both small and sensitive to the choice of f_2 and to radiative corrections.

The high flux of polarized Σ^- available[9] with the Fermilab Tevatron made it possible to study Σ^- beta decay on a statistical level far beyond that of previous experiments. In our experiment we detected 90 000 Σ^- beta decays. This Letter reports a g_1/f_1 sign determination based on an initial sample of 25 000 events.

In the experimental configuration shown in Fig. 2, 400-GeV/c protons from the Fermilab Tevatron were incident on a copper target placed at the upstream end of the hyperon channel.[10] The 250-GeV/c secondary beam emerging from the magnet was limited to an emittance of ± 16 GeV/c and 1 μsr; its composition was about 10% Σ^-, 0.5% Ξ^-, and the rest mostly π^-. By an appropriate setting of the incident proton angle in the horizontal plane, hyperons were produced polar-

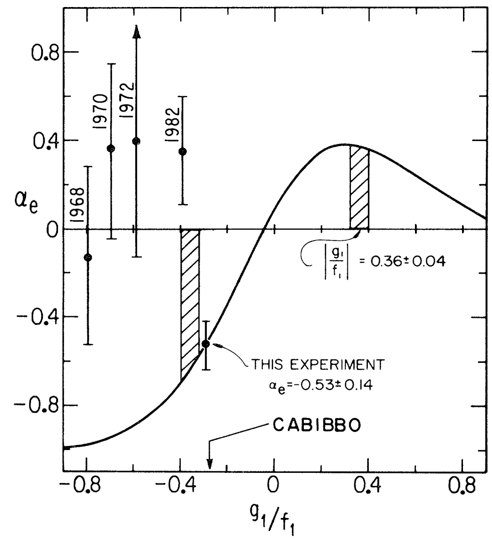

FIG. 1. Plot of electron asymmetry vs g_1/f_1 with conventional assumptions on induced form factors ($f_2/f_1=-1.14$, $g_2=0$) and on q^2 dependence (see Refs. 1 and 15). The shaded regions indicate results for $|g_1/f_1|$ from the latest high-statistics unpolarized Σ^- experiments (Refs. 1 and 2). Also shown (by year) are the results from previous polarized Σ^- experiments (Refs. 5–8) and the result of this experiment. Indicated is the Cabibbo fit of Bourquin *et al.* (Ref. 4).

ized in the vertical direction. During data taking we alternated between -3, $+3$, and 0 mrad; the data at 0 mrad provided a nominally unpolarized sample. The beam intensity was typically 2×10^5 in a 15-sec spill with 3×10^{11} protons on target.

Our principal experimental problem was to select beta decays in the presence of the 1000 times more frequent two-body decay, $\Sigma^-\to n\pi^-$. This problem was solved by double identification of the electrons by means of a transition radiation detector (TRD) followed by a lead-glass calorimeter (LGC). By this method the two-body decays were suppressed by a factor of 50 000 while maintaining 94% efficiency for electrons. The TRD consisted of twelve identical modules,[11] each containing a polypropylene foil radiator and a multiwire proportional chamber filled with 70% Xe and 30% CH_4. The sensitive area of the TRD was 1.0×0.6 m^2. Its efficiency was $>99\%$ for electrons with energies above 5 GeV. The LGC was a longitudinal stack of four layers, each layer consisting of eighteen type-SF5 glass blocks,[12] $15\times15\times45$ cm^3 each. The sensitive area of the LGC was 1.35×0.90 m^2 and its thickness 26 radiation lengths. Its energy resolution was 4.3% (full width at half maximum) at 25 GeV. Four scintillation multiplicity counters between the TRD and LGC signaled interactions in the TRD material.

The Σ^- were measured in the proportional-wire-chamber (PWC) system to a resolution (σ) of 25 μrad in azimuth and dip which determined their momenta to an accuracy of $\Delta p/p=0.7\%$. Charged decay tracks were measured by the drift-chamber spectrometer to a resolution (σ) of $\Delta(1/p)=0.0004$ $(\mathrm{GeV}/c)^{-1}$, 150 μrad in azimuth, and 50 μrad in dip. A neutron calorimeter[13] (NC) capable of measuring energy to $70\%/\sqrt{E}$ was used only as a loose trigger requirement.

Our experiment simultaneously recorded both $\Sigma^-\to ne\bar{\nu}$ and a sample of $\Sigma^-\to n\pi^-$ triggers. The $\Sigma^-\to ne\bar{\nu}$ trigger consisted of an incident track defined by beam scintillation counters in the PWC region, the detection of an electron in the TRD (≥ 12 transition radiation photons detected by ≥ 7 cham-

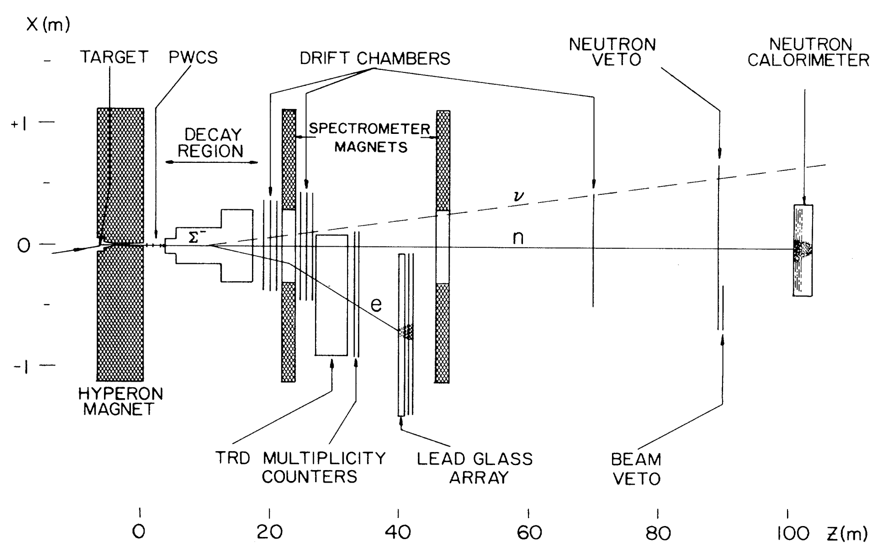

FIG. 2. Plan view of the apparatus; note that the x and z scales are different. Typical particle trajectories are also shown. The incident proton beam corresponds to a positive targeting angle.

bers), and the detection of a neutron in the neutron calorimeter (no signal in the neutron veto counter and $\geqslant 20$ GeV energy deposited in the NC). The $\Sigma^- \rightarrow n\pi^-$ trigger was identical except that the electron requirement was absent. The trigger rate was about 1800 per spill, about five of which were genuine $\Sigma^- \rightarrow ne\bar{\nu}$.

The analysis was performed with events where a single beam track was found in the PWC's and a single decay track was found in the drift chambers. The position of the decay vertex was required to be within a 12-m-long fiducial volume just downstream of the beam-defining PWC's. The electron momentum was required to be between 12.5 and 50 GeV/c to ensure inclusion within the fiducial volume of the LGC. We have checked by a Monte Carlo simulation that this selection had negligible effect on the electron asymmetry.

The principal background in the "electron" trigger is from the dominant $\Sigma^- \rightarrow n\pi^-$ decay. This hadronic background was reduced to a very low level while maintaining high electron efficiency (94%) by a series of off-line cuts. These relied on information from the TRD and multiplicity counters, the shower development in the LGC, and the requirement that the energy E measured by the LGC agree with the momentum P determined by the magnet spectrometer. The events selected by this procedure are displayed in Fig. 3 as a function of E/P. A similar plot for triggers without the electron requirement is also shown for comparison. As seen from the figure, the selected events contain only 3% hadronic background. Moreover, by analyzing the event sample on either side of the peak and calculating the appropriate effective mass, we are able to identify the sources of hadronic background as $\Sigma^- \rightarrow n\pi^-$ decays (1.8%) and $\Xi^- \rightarrow \Lambda\pi^-$ (1.2%). There is also background associated with sources of electrons, estimated to be the following: $K^- \rightarrow \pi^0 e\bar{\nu}$ (3%), $\Sigma^- \rightarrow \Lambda e\bar{\nu}$ (1%), and $\Xi^- \rightarrow \Lambda e\bar{\nu}$ (1%). Supporting evidence that background from processes other than Σ^- decay is very small comes from our fitted lifetime of 152 ± 3 psec for beta decays. This agrees well with the world average Σ^- lifetime[4] of 148 ± 1 psec.

To extract the electron asymmetry from $\Sigma^- \rightarrow ne\bar{\nu}$ we calculate for each decay $\cos(\theta_y)$, where θ_y is the angle between the electron and the y axis in the Σ^- rest frame (in our right-handed coordinate system, the y axis is vertical and the z axis is along the beam). The Σ^- polarization was parallel (-3 mrad) or antiparallel ($+3$ mrad) to the y axis. We then form for each $\cos(\theta_y)$ bin, the quantity $(F^+ - F^-)/(F^+ + F^-)$, where F is the fraction of events in the bin and the superscript $+$ $(-)$ refers to polarization parallel (antiparallel) to the y axis. This procedure cancels possible effects of instrumental acceptance, so that one expects $(F^+ - F^-)/(F^+ + F^-) = A_e^y \cos(\theta_y)$, where $A_e^y = \alpha_e P_\Sigma$ and P_Σ is the magnitude of the Σ^- polarization. Figure 4(a) shows the relevant plot for beta decays which clearly demonstrates large asymmetry in $\cos(\theta_y)$: $A_e^y = -0.108 \pm 0.011$ before background corrections, and $A_e^y = -0.117 \pm 0.013$ after correction. As a check, the analogous quantity calculated with respect to θ_x is expected to show no asymmetry since there should be no Σ^- polarization in the x direction. Our data [Fig. 4(c)] support this: $A_e^x = 0.012 \pm 0.011$. As another approach, we divided both the $+3$- and -3-mrad data by the 0-mrad data, obtaining y slopes of 0.109 ± 0.031 and -0.107 ± 0.031, respectively, consistent with the above result.

The sign of the electron asymmetry was determined by comparison with the decay $\Sigma^- \rightarrow n\pi^-$, for which the pion asymmetry is known[14] to be $\alpha_\pi = +0.068 \pm 0.008$. For this purpose a sample of 800 000 $\Sigma^- \rightarrow n\pi^-$ events was analyzed in the same way as the beta decays. The results are shown in Figs. 4(b) and 4(d). As is evident from the figure, the asymmetry A_π^y is *opposite* in sign from A_e^y. *From this obser-*

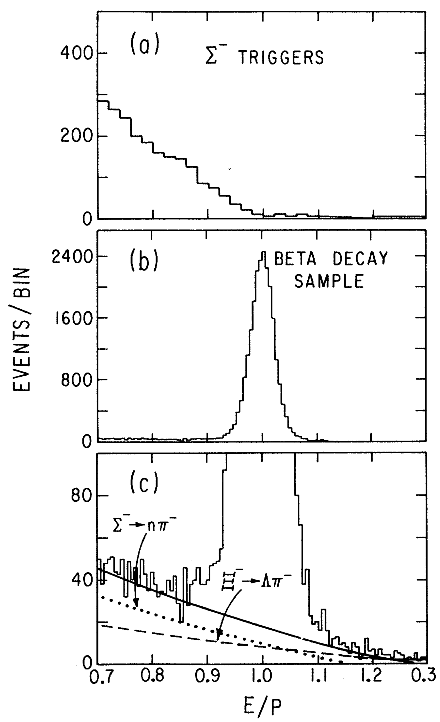

FIG. 3. Plot of E/P (a) for a representative sample of events without the electron requirement and (b) for our final beta-decay candidates. Plot (c) shows the same events as (b) with an expanded vertical scale to indicate hadronic background (solid line) which is the sum of contributions from $\Xi^- \rightarrow \Lambda\pi^-$ (dashed line) and $\Sigma^- \rightarrow n\pi^-$ (dotted line). In our final sample, we accept events in the region $0.85 \leqslant E/P \leqslant 1.15$, for which the hadron background is only 3%.

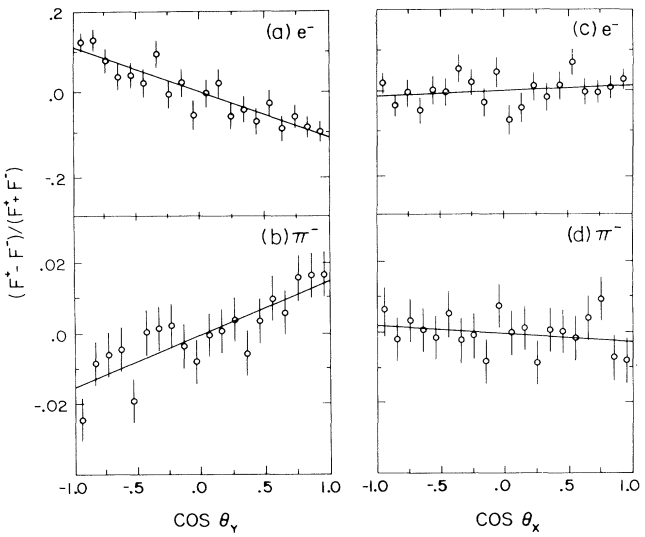

FIG. 4. (a) Plot of $(F^+ - F^-)/(F^+ + F^-)$ vs $\cos(\theta_y)$ for beta decays showing a fitted slope of $A_e^y = -0.108 \pm 0.011$ with χ^2/d.o.f. = 0.83. (b) The same plot for two-body decays, giving a slope with opposite sign, $A_\pi^y = 0.015 \pm 0.002$. For this plot, χ^2/d.o.f. = 1.01. (c) Plot of $(F^+ - F^-)/(F^+ + F^-)$ vs $\cos(\theta_x)$ for beta decays showing a fitted slope of $A_e^x = 0.012 \pm 0.011$ with χ^2/d.o.f. = 1.08, in agreement with no polarization in the x direction. (d) The same plot for two-body decays, showing a fitted slope of $A_\pi^x = -0.002 \pm 0.002$ with χ^2/d.o.f. = 0.74, in agreement with no polarization in the x direction.

vation it follows directly that α_e has negative sign.

The measured value of α_π can also be used to determine the Σ^- polarization:

$$P_\Sigma = A_\pi^y / \alpha_\pi = 0.22 \pm 0.04, \tag{1}$$

where the error does not include the uncertainty in α_π. This value is in agreement with previous measurements of Σ^- polarization.[9] Using our measured Σ^- polarization, we obtain

$$\begin{aligned}\alpha_e &= A_e^y / P_\Sigma \\ &= -0.53 \pm 0.05(\text{stat.}) \\ &\qquad \pm 0.04(\text{syst.}) \\ &\qquad \pm 0.12(\text{polarization}) \\ &= -0.53 \pm 0.14(\text{combined}),\end{aligned} \tag{2}$$

where the errors have been combined in quadrature. The uncertainty in α_π[14] is included in the error estimate.

This result is in excellent agreement (see Fig. 1) with the Cabibbo-model value[4] of $\alpha_e = -0.51 \pm 0.04$ and thus confirms a key prediction of the theory. Furthermore, we can use the dependence of α_e on the form factors[15] to derive

$$g_1/f_1 = -0.29 \pm 0.07, \tag{3}$$

which agrees in magnitude with previous results from unpolarized decays.

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[(a)]Permanent address: H. H. Wills Physics Laboratory, University of Bristol, Bristol BS8 1TL, England.

[(b)]Present address: Mitre Corporation, Bedford, Mass. 01730.

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