MEASUREMENTS OF HYPERON SEMILEPTONIC DECAYS
AT THE CERN SUPER PROTON SYNCHROTRON

III. THE $\Sigma^- \rightarrow ne^- \bar{\nu}$ DECAY MODE

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ABSTRACT

The charged hyperon beam at the CERN Super Proton Synchrotron (SPS) has been used to collect data on semileptonic decays of Σ^- , Ξ^- , and Λ . In this article we report results on the $\Sigma \rightarrow n e \bar{\nu}$ decay mode. A magnetic channel selected 100 GeV/c (130 GeV/c) negatively charged particles produced in the forward direction by interaction of the 210 GeV/c (240 GeV/c) SPS proton beam on a BeO target. The Σ^- hyperons were identified in a DISC Čerenkov counter, and the negatively charged decay particle was analysed by a magnetic spectrometer. The neutron direction was obtained from the Σ^- decay vertex and from the impact point measured in a neutron detector. Electron-hadron discrimination was achieved by the combined use of lead-glass and transition radiation detectors.

The $\Sigma \rightarrow n e \bar{\nu}$ branching ratio measurement gave a value of $(0.96 \pm 0.05) \times 10^{-3}$.

Measurements of the centre-of-mass distributions (baryon kinetic energy, electron-antineutrino correlation, and Dalitz plot distributions) yield the axial-vector to vector form factor ratio $|g_1/f_1| = 0.34 \pm 0.05$. From the study of the electron momentum spectrum, the negative sign of g_1/f_1 , which is expected within the Cabibbo theory framework, is favoured by at least 2.6 standard deviations. The effects of q^2 -dependence of f_1 and g_1 and of radiative corrections, the measurement of the weak magnetism form factor f_2 , and the effect of possible second-class current terms are discussed.

Results on the other Ξ^- , Σ^- , and Λ semileptonic decays are reported in separate articles.

1. INTRODUCTION

We report a measurement of the branching ratio

$$R = \Gamma(\Sigma^- \rightarrow ne^-\bar{\nu})/\Gamma(\Sigma^- \rightarrow n\pi^-)$$

and on the determination of the ratio of the axial-vector and vector form factors g_1/f_1 from the centre-of-mass distributions for the decay $\Sigma \rightarrow ne\bar{\nu}$.

This measurement is part of an experimental programme carried out at the CERN SPS hyperon beam to determine the above quantities for the following semileptonic hyperon decays: $\Sigma^- \rightarrow ne^-\bar{\nu}$, $\Sigma^- \rightarrow Ae^-\bar{\nu}$, $\Lambda \rightarrow pe^-\bar{\nu}$, and $\Xi^- \rightarrow \Lambda(\Sigma^0)e^-\bar{\nu}$. Thus the results from a single experiment will be used to perform a global fit for the determination of the relevant parameters of Cabibbo theory -- the Cabibbo angle θ_C and the two reduced matrix elements F and D.

The results on the other decays are being published in separate papers [1,2]. A detailed description of the hyperon beam and the experimental apparatus can be found elsewhere [3]. The hyperons were produced by 210 or 240 GeV/c protons, and the magnetic channel accepted particles within a momentum bite of $\pm 10\%$, up to 140 GeV/c. The hyperons were selected in the forward direction and were thus not polarized.

The data on $\Sigma \rightarrow ne\bar{\nu}$ decay were taken in two periods of one week each, under different running conditions. About 75% of the data were obtained at a Σ^- momentum of 130 GeV/c and the remaining 25% at 100 GeV/c. Both sets of data were used for the form factor analysis, whereas the branching ratio measurement was based on the 130 GeV/c data alone. The data were taken at a reduced beam intensity to keep the trigger rate at an acceptable level. With a beam flux of 3×10^5 (8×10^5) per second at 130 GeV/c (100 GeV/c), the Σ^- counting rate was 4.5×10^3 (1.6×10^3) per second.

Preliminary results on this decay mode have already been reported [4].

2. EXPERIMENTAL SET-UP

The apparatus is shown in Fig. 1. The most important difference between this arrangement and the one used for measuring the other decays was the addition of a neutron detector located in front of the lead-glass array.

The Σ^- hyperons were identified by the DISC Čerenkov counter. The direction of the incoming hyperon was measured in the beam chamber telescope (BC1 to BC4) with a precision of 0.07 mrad, making it possible to determine the momentum to an accuracy of $\pm 1\%$ (Ref. 3).

For the Σ^- which decayed in the region indicated in the figure, the charged track (e^- or π^-) was detected in the two drift chamber telescopes, one upstream of the spectrometer magnet (DC0 to DC4) and one downstream (DC5 to DC8). The track momentum was obtained with a precision of $\Delta p/p \leq 1\%$. The decay vertex was obtained from the intersection of the beam track and the spectrometer track.

The separation of $\Sigma \rightarrow n\bar{\nu}$ decays from the predominant $\Sigma \rightarrow n\pi$ decay channel was achieved by a lead-glass array and two transition radiation detectors. The use and the performance of these devices are described in detail elsewhere [5]. The threshold gas Čerenkov counter and the lead/scintillator detector (shown in Fig. 1) were not used for the $\Sigma \rightarrow n\bar{\nu}$ measurement. The over-all pion rejection was of the order of 45,000, with an electron detection efficiency of 75%.

The neutron direction was obtained from the Σ^- decay vertex and from the impact point measured in the neutron detector. This detector comprised 10 modules, each consisting of a 1 cm thick iron plate followed by two proportional chamber planes, measuring the horizontal (x) and the vertical (y) coordinates. The chamber planes had a wire spacing of 4 mm and a circular active area of diameter 256 mm, about twice as large as the neutron spot for both $\Sigma \rightarrow n\bar{\nu}$ and $\Sigma \rightarrow n\pi$ decays. The amount of matter in the detector corresponded to 0.55 absorption lengths; thus the probability for a neutron to produce a hadronic shower was 40%. A scintillator located in front of the last iron plate was used to trigger on events with a well-formed neutron shower.

A reconstruction algorithm was used to calculate the x and y coordinates of the impact point of the neutron. It was developed from a detailed study of neutron showers from $\Sigma \rightarrow n\pi$ decays, where the neutron impact position was predicted from the measured Σ^- and π^- tracks. The algorithm was 75% efficient, resulting in an over-all neutron detection efficiency of $40\% \times 75\% = 30\%$.

The neutron resolution function could be described by the superposition of two Gaussian distributions with respective weights of 55% and 42% and widths of 3.0 mm and 8.3 mm (r.m.s.), together with a flat tail of 3% extending to the edges of the detector.

3. THE TRIGGER

Two classes of events were recorded:

- i) a " Σ^- trigger", which provided a sample of $\Sigma \rightarrow n\pi$ decays for the branching ratio determination and for monitoring purposes;
- ii) a "leptonic trigger", which enriched the percentage of $\Sigma \rightarrow n\bar{\nu}$ decays.

The Σ^- trigger consisted of a coincidence between scintillators T (Fig. 1) and the DISC Čerenkov counter tuned to detect Σ^- particles. In addition, a requirement was made that there be no signal in the halo counter A. Different DISC diaphragms were used to optimize the hyperon identification at the two momenta. The E^- contamination was 6% (< 1%) at 130 (100) GeV/c.

The leptonic trigger was derived from the Σ^- trigger by two further constraints:

- i) an electron signature was required by asking that the signal from the first layer of the lead-glass array be above a predetermined threshold;
- ii) a signal from the scintillator in the neutron counter was also required.

4. DATA SELECTION

4.1 Track requirements

A Σ^- decay was defined by three track segments: in the beam chambers; upstream of the magnet (DC0 to DC4); and downstream of the magnet (DC5 to DC8). The decay

vertex formed by segments 1 and 2 had to be located within the range $Z = 12.4$ m and, within errors, $Z = 1.3$ m (see Fig. 1). The decay angle had to be ≥ 2 mrad. Segments 2 and 3 were required to match at the central plane of the magnet, and the momentum of the decay particle had to be less than 55 GeV/c. Events with more than one Σ^- decay candidate were rejected. A pulse-height cut on the counter T at the exit of the DISC was imposed to reject events with multiple beam tracks or interactions in the region of the DISC.

The decay particle trajectory was required to intercept the lead-glass array. Furthermore, a minimum horizontal distance of the impact point from the beam axis was imposed: $x \geq 275$ mm for the leptonic samples and $x \geq 160$ mm for the hadronic samples. At 130 (100) GeV/c, the cut on the leptonic sample suppressed 38% (35%) of the background from $\Sigma \rightarrow n\pi$ decays at a cost of 13% (4.4%) of the genuine $\Sigma \rightarrow ne\bar{\nu}$ decays.

During the data-taking at 130 GeV/c, one column of lead-glass blocks did not contribute to the electron trigger. Consequently, events with electron trajectories intercepting a region of 300 mm width (corresponding to about two columns) centred on that column were rejected in the leptonic samples, causing the dip in the electron momentum spectrum at 10 GeV/c apparent in Fig. 2.

4.2 Hadronic samples

The hadronic decays recorded at both momenta were used for studying the acceptance of the apparatus, for measuring the mean beam momenta, and for investigating the effects of residual hadronic background in the leptonic samples. Only the 130 GeV/c data were used in the branching ratio determination. The 6% contamination of E^- in the Σ^- trigger (section 3) was eliminated with negligible loss of genuine $\Sigma \rightarrow n\pi$ events by requiring the $(E - \pi)$ missing mass to be less than 1100 MeV/c². Figure 3 shows the $(\Sigma - \pi)$ missing-mass spectrum and Fig. 4 the pion momentum spectrum in the centre-of-mass system after this cut.

4.3 Leptonic samples

The $\Sigma \rightarrow ne\bar{\nu}$ candidates had to fulfil two electron requirements: the combined information from the two transition radiation counters and the ratios between the measured electron momentum and the energies deposited in the first two lead-glass layers had to satisfy the conditions discussed in Ref. 5. The total pion rejection, including the effects of the trigger requirement, was 45,000:1, as evaluated from the observed $\Sigma \rightarrow n\pi$ background discussed in subsection 4.4.

The efficiency of the electron detectors was determined directly from the data. Two classes of events were considered. In the first sample, the lead-glass requirements were relaxed compared with those used in the final selection, whilst the transition radiation requirement was made more stringent. For the other sample, there was no transition radiation requirement, and more stringent lead-glass requirements were used. In both samples, events with a $(\Sigma - \pi)$ missing mass close to the neutron mass were rejected. This reduced the background from $\Sigma \rightarrow n\pi$ decays to a negligible level. The efficiencies for the 130 GeV/c data were:

- lead-glass efficiency = $(88.5 \pm 2.0)\%$, including the inefficiency of $(2.7 \pm 1.7)\%$ caused by the trigger threshold;
- transition radiation efficiency = $(84.9 \pm 1.0)\%$;
- total electron efficiency $\varepsilon_e = (75.1 \pm 1.9)\%$.

4.3.1 Branching ratio sample

Only the data at 130 GeV/c were used for the branching ratio measurement. In this analysis, no requirement was made on the neutron reconstruction. However, there still existed a difference in the $\Sigma \rightarrow ne\bar{\nu}$ and $\Sigma \rightarrow n\pi$ efficiencies because a signal from the neutron scintillator was required in the trigger. In 42% of the $\Sigma \rightarrow ne\bar{\nu}$ events the electron track before the magnet pointed towards the neutron counter. The amount of matter upstream of the magnet was 0.085 radiation lengths, causing about 20% of these electrons to emit a bremsstrahlung γ -ray with an energy of more than 1 GeV. Such γ -rays could produce additional triggers in the neutron scintillator. To avoid this problem, we rejected all leptonic events for which the

initial electron trajectory intercepted the neutron counter, resulting in a branching ratio sample of 3262 events.

4.3.2 Form factor samples

For the form factor determination, the data at both momenta were used. We selected only those events which had a reconstructed impact point in the neutron counter. For about 10% of these events, the neutron-shower reconstruction algorithm selected the shower of a bremsstrahlung γ -ray emitted by the electron. Such events were characterized by a very small apparent neutron-electron angle and were removed by requiring $\theta_{ne} > 2$ mrad. Finally, a cut was applied on the calculated angle between the neutrino and the beam track. This removed about 10% of the data, but only 3% of the good events.

The final form factor samples contained a total of 4456 events, 3350 (1106) at 130 (100) GeV/c.

4.4 Residual backgrounds

Backgrounds from antiprotons and electrons in the beam were reduced to a negligible level by the cuts on the decay angle and electron momentum. There remained three types of background, namely: interactions, leptonic decays, and non-leptonic decays.

Interactions producing a π^0 could simulate a leptonic decay and contaminate the leptonic sample. They were reduced by the cuts on the vertex position and on the pulse height in counter T, and by the requirement of just one decay track (see subsection 4.1). This background was studied by searching for apparent scatters on the electron track, and by comparing the pulse-height distributions for hadronic and leptonic events in a scintillation counter upstream of the magnet (multiplicity counter in Fig. 1). The estimated contamination was $(2 \pm 1)\%$.

Backgrounds from other hyperon leptonic decays were calculated using the known branching ratios. The results are summarized in Table 1.

The non-leptonic background ($\Sigma \rightarrow n\pi$) was estimated directly from the peak in the $(\Sigma - \pi)$ mass distribution (see Fig. 5). It was evaluated to be 170 ± 35 events

in the branching ratio sample, corresponding to $(5 \pm 1)\%$. In the form factor samples, this background has the lower value $(3 \pm 1)\%$, the difference resulting from the cut on the electron direction in the branching ratio sample. For the form factor determination, the background was subtracted statistically using a sample of $\Sigma \rightarrow n\pi$ decays.

The different contributions to the electron momentum spectrum are shown in Fig. 2.

5. BRANCHING RATIO DETERMINATION

The branching ratio $R = \Gamma(\Sigma \rightarrow ne\bar{\nu})/\Gamma(\Sigma \rightarrow n\pi)$ was obtained from the following formula:

$$R = \frac{N_\ell}{N_h \times p} \times \frac{a_h}{a_\ell} \times \frac{1}{\epsilon_e}.$$

Here N_ℓ and N_h are the effective numbers of $\Sigma \rightarrow ne\bar{\nu}$ and $\Sigma \rightarrow n\pi$ events. Taking into account the backgrounds considered in subsection 4.4, $N_\ell = 2847$. The observed number of $\Sigma \rightarrow n\pi$ decays was corrected for the loss of pions by interactions in the apparatus, which was estimated to be $(3 \pm 1)\%$. After this correction $N_h = 5099$; $p = 2036$ is the trigger prescaling factor (2^{11} corrected by 0.6% for dead-time effects), and $\epsilon_e = 0.751 \pm 0.019$ is the electron efficiency (see subsection 4.3).

The acceptances a_ℓ and a_h were obtained by Monte Carlo calculations. The change in the shape of the density distribution over the Dalitz plot, which is due to radiative corrections, was taken into account in the calculation of the acceptance a_ℓ . This effect decreased the value of a_ℓ by 1.2%. Since $\Sigma \rightarrow ne\bar{\nu}$ and $\Sigma \rightarrow n\pi$ events have the same topologies, and since the branching ratio R depends only on the ratio of the acceptances, most sources of systematic errors cancel in the determination of R . Nevertheless, the Monte Carlo simulation (MC) was carefully checked (Ref. 1), comparing many distributions of hadronic and leptonic decays with the data. The result was $a_h/a_\ell = 2.62$, where a factor of 1.60 comes from the cut on the electron direction in the leptonic sample.

With these numbers, we obtain

$$R = (0.96 \pm 0.05) \times 10^{-3} ,$$

where the error contains contributions from statistics (2.3%), from the $\Sigma \rightarrow n\pi$ background subtraction in the leptonic data (1.0%), from the estimate of leptonic backgrounds and interaction losses (2.6%), from the electron efficiency (2.6%), and from the acceptance calculations (2.0%). These errors have been added quadratically to give a total error of 5.0%.

A comprehensive survey of possible systematic errors was performed, and the more important ones are described below.

The calculated acceptance of the apparatus depends only slightly on the choice of form factors. For the result given above, we used $g_2 = 0$, $g_1/f_1 = -0.33$, and the value expected from the conserved vector current (CVC) hypothesis $f_2/f_1 = -1.137$. If, for instance, the weak magnetism term is neglected, the calculated acceptance changes by -0.7%. Varying g_2/f_1 between -10 and +10, or g_1/f_1 between -1 and +1, produces changes of less than 1%.

The stability of the result throughout the time of data-taking, as a function of the decay vertex position and for variations of the electron track fiducial cuts, was checked. Restrictions were imposed on the number of track elements in the beam chambers and in DC0 to DC4 upstream of the magnet in order to reduce the background from other leptonic decays and from interactions. A reconstructed neutron shower was required. Within the statistical accuracy, the result was found to be stable against all these variations.

The most recent and precise published measurements of the $\Sigma \rightarrow ne\bar{\nu}$ branching ratio are those of Sechi-Zorn and Snow [6] and Ebenhöh et al. [7]. Both experiments studied Σ^- produced by K^- stopping in a liquid-hydrogen bubble chamber, and in neither case was it possible to accept $\Sigma \rightarrow ne\bar{\nu}$ events in which the electron was in the upper part of the centre-of-mass momentum spectrum because of the potential background from $\Sigma \rightarrow n\pi$ decays. As a consequence, it was necessary to make an acceptance correction which was sensitive to the exact choice of weak form factors.

Furthermore, the effects on the acceptances of internal radiative corrections were neglected. Since these corrections displace the electron spectrum downwards in momentum they have a significant effect on the acceptance calculated for the lower part of this spectrum. For these reasons it is very difficult to compare these and similar earlier experiments, and in particular to combine the results to obtain an average value.

For the purpose of comparing our result with those of Refs. 6 and 7, we have attempted to estimate the branching ratio which would have been obtained in each case if our form factor values and radiative corrections to the acceptance had been used in the original analyses. The results are shown in Table 2, where R is the published branching ratio, R' is our recalculated value, and $\Delta R = R' - R$. The branching ratios are reduced in both cases, improving the agreement with our experiment. The change is especially significant in the case of Ref. 6. However, there are clearly difficulties in using the results of published experiments in this way. This procedure should be considered only as an illustration of the problems encountered in comparing different experiments with theory and combining the results to obtain an average value.

6. FORM FACTOR ANALYSIS

6.1 Introduction

The matrix element of the hadronic current can be expressed as a function of form factors f_i , g_i ($i = 1, 3$). The differential decay rate $d^2\Gamma/dT_e dT_n$, the spectrum of the neutron kinetic energy T_n in the Σ^- rest frame, and the distribution of the electron-neutrino angle $\cos \theta_{e\nu}$ are all sensitive to the absolute value of g_1/f_1 , the axial-vector to vector form factor ratio. In addition, the spectrum of the electron energy T_e and hence the distribution over the Dalitz plot are weakly sensitive to the relative sign of g_1 and f_1 .

To extract the form factors, the experimental distributions were compared to the corresponding ones from Monte Carlo simulation. The events were generated

according to the phase-space distribution. For a given set of form factors, each event was weighted by the differential decay rate to produce the appropriate kinematic distributions. In the fitting process various sets of form factors were used, and the resulting MC distributions were compared with the data. The best values of the form factors were obtained by the least-squares method.

6.2 Axial-vector and vector form factors

6.2.1 Determination of $|g_1/f_1|$

The data were analysed under the following assumptions: terms involving f_3 , g_2 , and g_3 were neglected. For f_2 the value predicted by the CVC hypothesis was used. The dependence of the form factors g_1 and f_1 upon the square of the four-momentum transfer q^2 was parametrized in the following way (see Ref. 1):

$$\begin{aligned} f_1(q^2) &= f_1(0)(1 + 2 q^2/M_V^2) , \\ g_1(q^2) &= g_1(0)(1 + 2 q^2/M_A^2) , \end{aligned}$$

with $M_V = 0.97 \text{ GeV}/c^2$ and $M_A = 1.25 \text{ GeV}/c^2$.

The neutron energy was not measured; thus one obtained two solutions for the neutron momentum from the measured neutron direction,

$$p_{1,2} = p_0 \pm \sqrt{D} .$$

For about 30% of the events the discriminant D had a negative value because of the finite experimental resolution. For these events, only the quantity p_0 , the mean of the two solutions, was used. We call T_1 , T_2 , and T_0 the centre-of-mass "neutron kinetic energies" (T_n) corresponding to p_1 , p_2 , and p_0 , respectively. In Table 3 we give the values obtained for the form factor ratio from fits to the various distributions of the 130 GeV/c data. The pseudo-distributions are those for which T_0 has been used. The two solutions corresponding to T_1 and T_2 have been entered in the Dalitz plot, in the T_n , and in the $\cos \theta_{e\nu}$ distributions. They have been treated as statistically independent, and as a consequence the corresponding errors are slightly underestimated. The values obtained from all the distributions except for the electron spectrum correspond to $|g_1/f_1|$. We will discuss information about the sign of g_1/f_1 in subsection 6.3.

The value obtained for $|g_1/f_1|$ from the different distributions are consistent for the various samples. There is a strong correlation between the value of the neutron kinetic energy (T_1, T_2) and of $\cos \theta_{e\bar{\nu}}$. The distribution of the quantity $(1 - T_n/T_n^{\max})/(1 - \cos \theta_{e\bar{\nu}})$ shown in Fig. 6 has a width of 18% (FWHM). The corresponding correlation between the pseudo-quantities is weaker.

The value of $|g_1/f_1|$ was obtained by combining the values derived from the Dalitz plot, the neutron energy spectrum and the $\cos \theta_{e\bar{\nu}}$ distribution. The correlation between the various distributions has been taken into account. For the 130 GeV/c $\Sigma \rightarrow n e \bar{\nu}$ data sample we obtain a combined value of

$$|g_1/f_1| = 0.33 \pm 0.04 ,$$

where the error is statistical only. In Fig. 7 the neutron kinetic energy and the $\cos \theta_{e\bar{\nu}}$ distributions (using T_1, T_2) are shown for the data (histograms) and for the MC (curves) with $|g_1/f_1| = 0.33$. The χ^2 variation as a function of $|g_1/f_1|$ is shown in Fig. 8 for the T_n distribution.

The 100 GeV/c data sample gives

$$|g_1/f_1| = 0.38 \pm 0.07 ,$$

a value compatible with that obtained from the large sample.

Possible systematic effects on the value of $|g_1/f_1|$ have been studied. In the next section we will see that neglecting the q^2 -dependence of the form factors causes a significant error on $|g_1/f_1|$ which is increased by +0.06. Varying the vector mass M_V or the axial mass M_A by ± 0.15 GeV/c² causes a shift $\Delta(|g_1/f_1|) = \pm 0.007$. Other possible systematic effects have been investigated by varying the kinematical and the geometrical cuts and the amounts of the backgrounds from other decays. The observed deviations from the central values are always small and are consistent with statistical fluctuations. Another possible systematic effect is due to the uncertainty in the average beam momentum which affects the value of $|g_1/f_1|$. From a detailed study of the $\Sigma \rightarrow n \pi$ prescaled events, it is concluded that the uncertainty on the mean beam momentum is $\Delta p/p = \pm 0.5\%$, which corresponds to a change $\Delta(|g_1/f_1|) = \pm 0.02$.

By combining the determinations of $|g_1/f_1|$ at the two energies, we deduce a combined value

$$|g_1/f_1| = 0.34 \pm 0.05 ,$$

where the statistical uncertainty is 0.035 and we have assigned a systematic uncertainty of 0.035.

6.2.2 Comparison with previous experiments

We have attempted to compare our result with those of earlier experiments [8,12] by repeating our analysis, neglecting the q^2 -dependence of f_1 and g_1 . However, it should be noted that such a comparison is of limited use since the q^2 correction depends upon the acceptance of each experiment and thus its magnitude can vary over a wide range.

The results are $|g_1/f_1| = 0.39 \pm 0.04$ for 130 GeV/c sample and $|g_1/f_1| = 0.45 \pm 0.07$ for the 100 GeV/c sample. The quoted errors are statistical only. The 100 GeV/c data and the 130 GeV/c data give compatible results; they are combined to obtain

$$|g_1/f_1| = 0.40 \pm 0.05 ,$$

where the error includes the estimate of systematic effects. We emphasize that this value should only be used for comparison with the results of previous experiments which have not included the q^2 dependence in their analysis. In Table 4 we compare previous measurements with our result. The two experiments with highest statistics (Refs. 11 and 12) were in significant disagreement; our measurement is in agreement with Ref. 11.

6.3 Sign of the form factor ratio g_1/f_1

The electron-antineutrino correlation and the neutron kinetic energy distribution yield a value of $|g_1/f_1| = 0.33$ for the 130 GeV/c data, independent of the sign of g_1/f_1 . However, the electron energy spectrum and hence the Dalitz plot distribution are weakly sensitive to the sign of g_1/f_1 . Figure 9 shows a comparison between the electron spectrum for the 130 GeV/c data with the backgrounds subtracted and the two MC distributions corresponding to $g_1/f_1 = -0.33$ and $g_1/f_1 = +0.33$, respectively.

The χ^2 distribution obtained by comparing the data with the MC as a function of g_1/f_1 corresponds to the full line of Fig. 10. The minimum of the curve corresponds to a value $g_1/f_1 = -0.34 \pm 0.19$, where the quoted error is statistical only. The negative sign of g_1/f_1 is preferred, in agreement with the Cabibbo theory expectation. The difference between the χ^2 values obtained for the two opposite signs of g_1/f_1 and $|g_1/f_1| = 0.33$ is 13, corresponding to a 3.5 standard deviation statistical effect.

However, small systematic effects can cause shifts of the electron momentum spectrum. There are two types of uncertainties:

a) Those which affect, in the same way, the momenta of both pions and electrons, e.g. momentum calibrations. This type of systematic uncertainty is directly controlled (within the limits of the statistical errors) from the distribution of the pion momentum in the centre-of-mass system for $\Sigma \rightarrow n\pi$ decays. Figure 4 shows a comparison between the pion momentum spectrum of the hadronic data sample and that of the Monte Carlo. We assign a systematic uncertainty $\Delta p/p = \pm 0.4\%$ on the basis of this comparison.

b) Those which are specific to the electron, e.g. effects of external or internal bremsstrahlung, or momentum dependence of the electron detection efficiency. The two additional curves in Fig. 10 show the χ^2 distributions obtained when the amount of matter causing external bremsstrahlung (estimated to be 0.085 radiation lengths) is modified by ± 0.01 radiation lengths [a $\Delta p/p = \pm 1\%$ shift of the electron momentum, of the type discussed in (a), has a very similar effect]. We have applied radiative corrections [13] in the calculation of the distributions of all kinematic quantities. The effect of these corrections is negligible in the form factor analysis, except for the result obtained from the electron spectrum. The radiative corrections which were applied shift the electron spectrum for our experimental conditions by an amount equivalent to the effect of adding 0.007 r.l. of matter. We have also applied to the electron spectrum a different set of radiative corrections given by Baltas et al. [14]. The corresponding shift is equivalent to that caused by adding 0.009 r.l. of matter. If the latter corrections had been used,

the negative sign of g_1/f_1 would have been even more favoured statistically. We have also studied the effect of possible variations of the electron detection efficiency as a function of the electron momentum. For the effects which are specific to the electrons, we estimate that the systematic uncertainty corresponds to ± 0.007 r.l.

To conclude, for all the effects discussed above we assign a global systematic uncertainty corresponding to that caused by a change of ± 0.01 r.l. The least significant result for the sign of g_1/f_1 corresponds to the case where the amount of bremsstrahlung would have been overestimated and/or the electron momentum underestimated. Taking into account the quoted systematic uncertainty, the negative sign of g_1/f_1 , which is expected within the Cabibbo theory framework, is favoured by at least 2.6 standard deviations. A similar conclusion is obtained by studying the Dalitz plot distribution.

In a recent experiment [15] the electron asymmetry was measured in the $\Sigma \rightarrow n e \bar{\nu}$ decay of polarized hyperons. The result of that experiment favours a positive sign of g_1/f_1 .

6.4* Weak magnetism and pseudotensor form factors

The results presented above have been obtained with the pseudotensor form factor $g_2 = 0$ and the weak magnetism term $f_2 = f_2^{\text{CVC}}$, the value expected from the CVC hypothesis. With the particular normalization [1] we have used, $f_2^{\text{CVC}}/f_1 = -1.137$.

For $g_2 = 0$, a two-parameter fit (g_1, f_2) to the Dalitz plot of the 130 GeV/c data sample gives

$$f_2 = (0.90 \pm 0.30) f_2^{\text{CVC}},$$

where the quoted error corresponds to an increase of χ^2 by 1.

The variation of g_1/f_1 as a function of the value assumed for g_2/f_1 is shown in Fig. 11 for the negative (full curve) and positive (dashed curve) solutions. Both curves are well described by the approximate formula:

$$(g_1/f_1) - (g_1/f_1)_{g_2=0} = 0.24(g_2/f_1).$$

The hatched strip in Fig. 11 is obtained from the electron spectrum. The boundaries correspond to ± 1 standard deviations on g_1/f_1 . The negative g_1/f_1 solution is clearly favoured, independently of the value of g_2/f_1 .

7. CONCLUSIONS

We have measured the ratio between the axial-vector and the vector form factors for the $\Sigma \rightarrow n e \bar{\nu}$ decay:

$$|g_1/f_1| = 0.34 \pm 0.05 .$$

This value has been obtained under the following assumptions: terms involving f_3 , g_2 , and g_3 were neglected, and for f_2 the value predicted by the CVC hypothesis, f_2^{CVC} , was used. The dependence of the form factors g_1 and f_1 upon the square of the four-momentum transfer q^2 has been taken into account.

From the measurement of the lepton momentum spectrum, the negative sign of g_1/f_1 is preferred, in agreement with the Cabibbo theory expectation.

The weak magnetism term has been measured:

$$f_2 = (0.90 \pm 0.30) f_2^{\text{CVC}} ,$$

and the variation of g_1/f_1 as a function of the value assumed for the pseudotensor form factor g_2 has been studied. For $|g_2/g_1| \sim 20\%$, the level of SU(3)-breaking in the masses within the baryon octet, the value of g_1/f_1 is shifted by about ± 0.016 .

The $\Sigma \rightarrow n e \bar{\nu}$ branching ratio has been determined:

$$\Gamma(\Sigma \rightarrow n e \bar{\nu})/\Gamma(\Sigma \rightarrow n \pi) = (0.96 \pm 0.05) \times 10^{-3} .$$

We have stressed that because of the assumptions made in the analysis of previous experiments, which affect their acceptance used to determine the branching ratio, it is not meaningful to combine the published results to obtain an average value.

With the same apparatus our experiment has gathered high-statistics information on $\Sigma \rightarrow \Lambda e \bar{\nu}$, $\Sigma \rightarrow n e \bar{\nu}$, $\Lambda \rightarrow p e \bar{\nu}$, and $\Xi \rightarrow \Lambda(\Sigma^0) e \bar{\nu}$. Results on the other decays have already been published. The primary aim of the experiment was to test the Cabibbo

theory as stringently as possible, and a global fit to our data, including a detailed discussion of the effects of radiative corrections and of other form factors, is reported in a separate paper.

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Table 1

Leptonic backgrounds in the branching ratio sample and in the form factor samples. The percentages are relative to the good $\Sigma \rightarrow ne\bar{\nu}$ events

Backgrounds	Branching ratio sample (%)	Form factor samples	
		130 GeV/c (%)	100 GeV/c (%)
$\Sigma \rightarrow \Lambda e\bar{\nu}$	1.4	1.2	1.6
$\Xi \rightarrow \begin{smallmatrix} \Sigma^0 \\ \Lambda \end{smallmatrix} e\bar{\nu}$	3.5	2.0	-
$\Lambda \rightarrow pe\bar{\nu}$	1.7	0.6	-
Total	(6.6 ± 2.2)	3.8	1.6

Table 2

Branching ratios (in units of 10^{-3})

	R	R'	$\Delta R/R$ (%)
Sechi-Zorn (1973)	1.05 ± 0.07	0.99	-5.6
Ebenhöh (1974)	1.09 ± 0.06	1.07	-1.5

Table 3

Fitted values of $|g_1/f_1|$ and of g_1/f_1

	Events with $D > 0$	All events
Dalitz plot	0.339 ± 0.037 *)	
Neutron kinetic energy	0.317 ± 0.036 *)	
e- ν correlation	0.314 ± 0.036 *)	
Electron momentum	-0.223 ± 0.170	-0.338 ± 0.191
Pseudo-Dalitz plot	0.371 ± 0.049	0.342 ± 0.038
Pseudo-neutron kinetic energy	0.332 ± 0.049	0.324 ± 0.039
Pseudo-correlation	0.319 ± 0.044	0.349 ± 0.034

*) For these distributions the two solutions T_1 and T_2 have been treated as independent entries; thus the errors are slightly underestimated.

Table 4

Comparison to previous experiments

Reference	Events	$ g_1/f_1 $
Colleraïne et al. [8]	49	0.23 ± 0.16
Eisele et al. [9]	33	$0.37 \begin{matrix} + 0.26 \\ - 0.19 \end{matrix}$
Baltay et al. [10]	36	0.29 ± 0.28
Tanenbaum et al. [11]	3507	0.435 ± 0.035
Decamp et al. [12]	519	$0.17 \begin{matrix} + 0.07 \\ - 0.09 \end{matrix}$
This experiment	4456	0.40 ± 0.05

Figure captions

- Fig. 1 : Plan view of the apparatus. T,A: beam and halo counters; DCO-DC8: drift chambers; He: helium bag; Li: lithium radiators; Xe: xenon-filled MWPC.
- Fig. 2 : Momentum spectra of branching ratio sample. Histogram: data. Full curve: sum of $\Sigma \rightarrow n\bar{\nu}$ and all backgrounds. Monte Carlo calculated spectra for $\Sigma \rightarrow n\bar{\nu}$ ($-\cdot-\cdot-$), $\Sigma \rightarrow \Lambda e\bar{\nu}$ ($\cdot\cdot\cdot\cdot$), and $\Xi \rightarrow \Lambda e\bar{\nu}$ ($---$). Spectrum of $\Sigma \rightarrow n\pi$ breakthrough ($-\cdot\cdot\cdot-$).
- Fig. 3 : $(\Sigma - \pi)$ missing-mass spectrum of the hadronic sample. Histogram: data. Curve: Monte Carlo.
- Fig. 4 : Pion momentum spectrum in the centre-of-mass system for the hadronic sample. Histogram: data. Curve: Monte Carlo.
- Fig. 5 : $(\Sigma - \pi)$ missing-mass spectrum of branching ratio sample. Histogram: data. Dashed curves: Monte Carlo calculated spectra for $\Sigma \rightarrow n\bar{\nu}$ decays and for leptonic backgrounds. Full curve: sum of $\Sigma \rightarrow n\bar{\nu}$ and leptonic backgrounds. The excess in the histogram arises from $\Sigma \rightarrow n\pi$ contamination.
- Fig. 6 : Distribution of the quantity $(1 - T_n/T_n^{\max})/(1 - \cos \theta_{e\bar{\nu}})$. Histogram: 130 GeV data sample. Curve: Monte Carlo simulation (two entries per event).
- Fig. 7 : Neutron kinetic energy and $\cos \theta_{e\bar{\nu}}$ distributions. Histograms: 130 GeV/c $\Sigma \rightarrow n\bar{\nu}$ data sample. Curves: Monte Carlo simulation (two entries per event).
- Fig. 8 : χ^2 distribution as a function of $|g_1/f_1|$ for the neutron kinetic energy.
- Fig. 9 : Electron momentum spectrum. Histogram: 130 GeV/c data sample with background subtracted;
 — Monte Carlo simulation with $g_1/f_1 = -0.33$;
 --- Monte Carlo simulation with $g_1/f_1 = +0.33$.

Fig. 10 : χ^2 distribution as a function of g_1/f_1 for the electron momentum spectrum. The full curve is derived using a Monte Carlo program which simulates the amount of material in the apparatus. The other curves are obtained by changing the amount of material by ± 0.01 radiation lengths.

Fig. 11 : Variation of the fitted values of g_1/f_1 as a function of g_2/f_1 . The full curve shows the negative solutions, the dashed curve the positive solutions. The hatched strip corresponds to ± 1 standard deviations on the evaluation of g_1/f_1 from the electron spectrum.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11