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

and

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

and

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

and

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

and

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

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. Vorobyov
Leningrad Nuclear Physics Institute, Leningrad, USSR

and

P. S. Cooper, P. Razis, and L. J. Teig
J. W. Gibbs Laboratory, Yale University, New Haven, Connecticut 06511 USA

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S. Y. HSUEH, D. MULLER, J. TANG, R. WINSTON, and G. ZAPALAC
Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637
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E. C. SWALLOW
Department of Physics, Elmhurst College, Elmhurst Illinois 60126
and Enrico Fermi Institute, 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 $a_e = -0.53 \pm 0.14$ based on 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 a_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 to the Cabibbo model[3] predicts[4] for $\Sigma^- \to ne\bar{\nu}$, $g_1/f_1 = -0.28 \pm 0.02$, which corresponds to a large negative electron asymmetry $a_e = -0.51 \pm 0.04$ (Fig.1). In fact, of all the hyperons, $\Sigma^- \to ne\bar{\nu}$ 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 $a_e = 0.26 \pm 0.19$. 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 sensitivity of the electron spectrum to (g_1/f_1) is very small and model dependent.

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, 400GeV/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 ±16GeV/c and 1 μsr; its composition was about 10% Σ^-, 0.5% Ξ^-, and the rest mostly π^-. By appropriately setting the incident proton angle in the horizontal plane, hyperons were produced polarized in the vertical direction. During data taking we alternated between -3, +3 and 0 mrad; the data at 0mrad 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 using a transition radiation detector (TRD) followed by a lead glass calorimeter (LGC). By this method the two-body decays were suppressed by a factor 50,000 while maintaining 94% efficiency for electrons. The TRD consisted of 12 identical modules[11], each containing a polypropylene foil radiator and a multi-wire proportional chamber filled with 70%Xe and 30%CH_4. The sensitive area of the TRD was $1.0\times0.6m^2$. Its efficiency was >99% for electrons with energies above 5 GeV. The LGC was a longitudinal stack of four layers, each layer consisting of 18 type SF5 glass blocks[12], 15x15x45 cm^3 each. The sensitive area of the LGC was 1.35x0.90 m^2 and its thickness 26 radiation lengths. Its energy resolution was 4.3%(FWHM) 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 25μrad in azimuth and dip which determined their momenta to an accuracy $\Delta p/p = 0.7\%$. Charged decay tracks were measured by the drift chamber spectrometer to a resolution (σ) of $\Delta(1/p) = 0.0004(\mathrm{GeV/c})^{-1}$, 150μrad in azimuth, and 50μrad 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($\geq$12 transition radiation photons detected by $\geq$7 chambers) and the detection of a neutron in the neutron calorimeter (no signal in the neutron veto counter and $\geq$20 GeV energy deposited in the NC). The $\Sigma^- \to n\pi^-$ trigger was identical except that the electron requirement was absent. The total trigger rate including calibration events was about 1800 per spill, about 5 of which were genuine $\Sigma^- \to ne\bar{\nu}$.

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 down-stream of the beam-defining PWC's. The electron momentum was required to be between 12.5 GeV/c 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: $K^- \rightarrow \pi^0 e\bar{\nu}$(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 (Fig.4). This agrees well with the world average Σ^- lifetime[14] of 148±1 psec.

To extract the electron asymmetry from $\Sigma^- \rightarrow n\, e\, \bar{\nu}$ 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 (-3mrad) or anti-parallel (+3mrad) 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 super-script +(-) refers to polarization parallel (anti-parallel) to the y axis. This procedure cancels possible effects of instrumental acceptance, so one expects $(F^+ - F^-)/(F^+ + F^-) = A^y{}_e\cos(\phi_y)$, where $A^y{}_e = a_e P_\Sigma$ and P_Σ is the magnitude of the Σ^- polarization. Figure 5a shows the relevant plot for beta decays which clearly demonstrates large asymmetry in $\cos(\phi_y)$: $A^y{}_e=-0.108\pm0.011$ before background corrections, and $A^y{}_e = -0.117\pm0.013$ after correction. As a check, the analogous quantity calculated with respect to ϕ_x is expected to show no asymmetry since there should be no Σ^- polarization in the x direction. Our data (Fig. 5c) supports this: $A^x{}_e = 0.012\pm0.011$.

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 $a_\pi = +0.068\pm0.008$. 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. 5b and 5d. As is evident from the figure, the asymmetry $A_\pi{}^y$ is *opposite* in sign from $A_e{}^y$. From this observation it follows directly that a_e has negative sign.

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

$$P_\Sigma = A_\pi{}^y/a_\pi = 0.22\pm0.04, \qquad (1)$$

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

$$a_e = A_e{}^y/P_\Sigma = -0.53 \pm 0.05 \text{ (statistical)} \pm 0.04 \text{ (systematic)}$$

$\pm$ 0.12 (polarization)

$$= -0.53 \pm 0.14 \text{ (combined)} \quad (2)$$

where the contributing errors have been combined in quadrature. Also, we have included the uncertainty in a_π in the error estimate.

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

$$g_1/f_1 = -0.29 \pm 0.07, \quad (3)$$

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 Corp., Bedford, MA. 01730.

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FIGURE CAPTIONS

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 (X) is the combined result from previous polarized Σ^- experiments (Refs. 5-8) and the result (solid dot) of this experiment.

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.

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 $0.85 \leq E/P \leq 1.15$, for which the hadron background is only 3%.

Fig. 4. Decay curve for our Σ^- beta decays. The fitted lifetime is 152±3 psec.

Fig. 5(a). Plot of $(F^+ - F^-)/(F^+ + F^-)$ vs. $\cos(\theta_y)$ for beta decays showing a fitted slope of $A^y_e = -0.108 \pm 0.011$ with $\chi^2/df = 0.83$.

(b). The same plot for two-body decays, giving a slope with opposite sign $A^y_\pi = 0.015 \pm 0.002$. For this plot, $\chi^2/df = 1.01$.

(c). Plot of $(F^+ - F^-)/(F^+ + F^-)$ vs. $\cos(\theta_x)$ for beta decays showing a fitted slope of $A^x_e = 0.012 \pm 0.011$ with $\chi^2/df = 1.08$, in agreement with no polarization in the x direction.

(d). The same plot for two-body decays, showing a fitted slope of $A^x_\pi = -0.002 \pm 0.002$ with $\chi^2/df = 0.74$, in agreement with no polarization in the x direction.

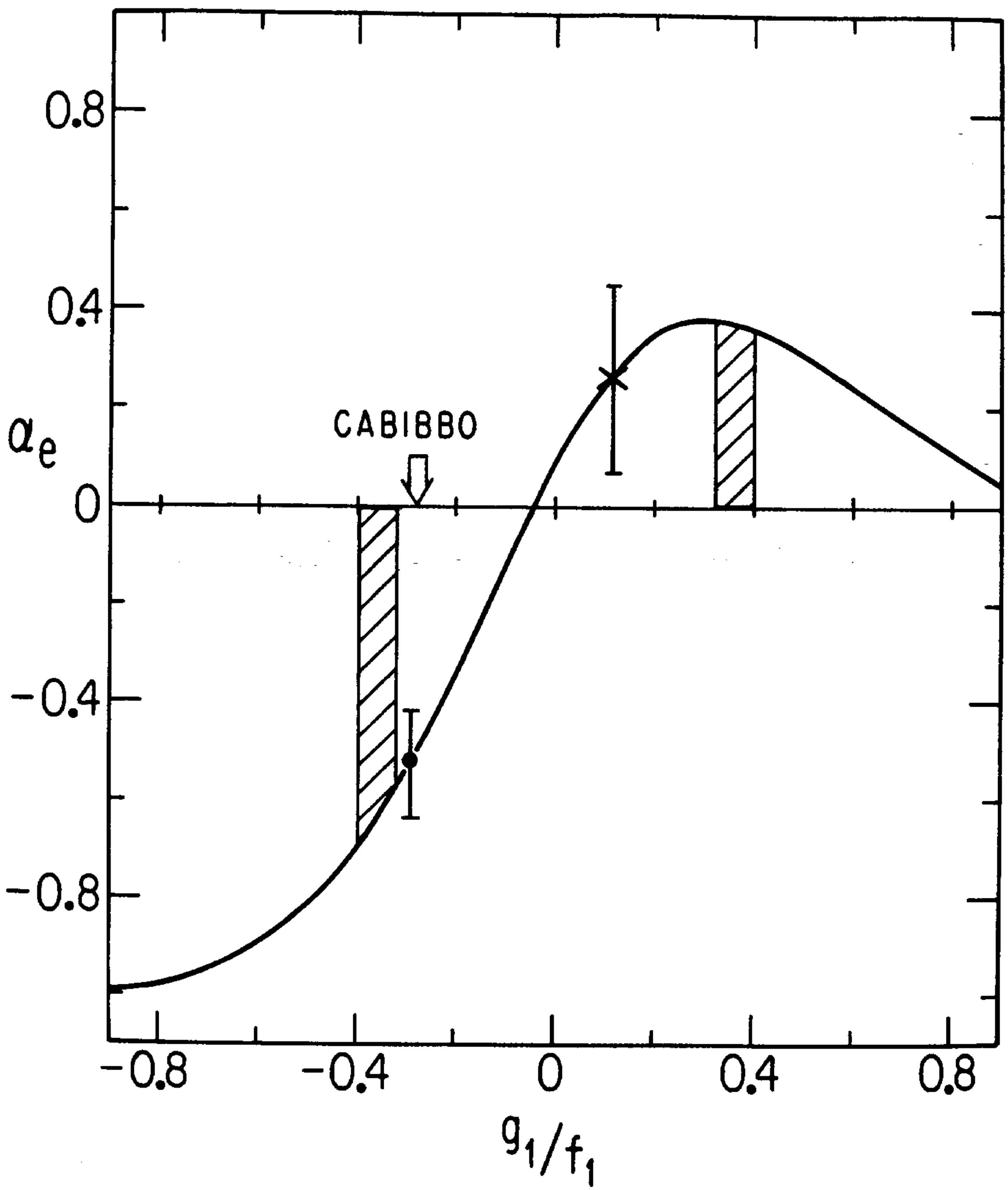

Fig. 1

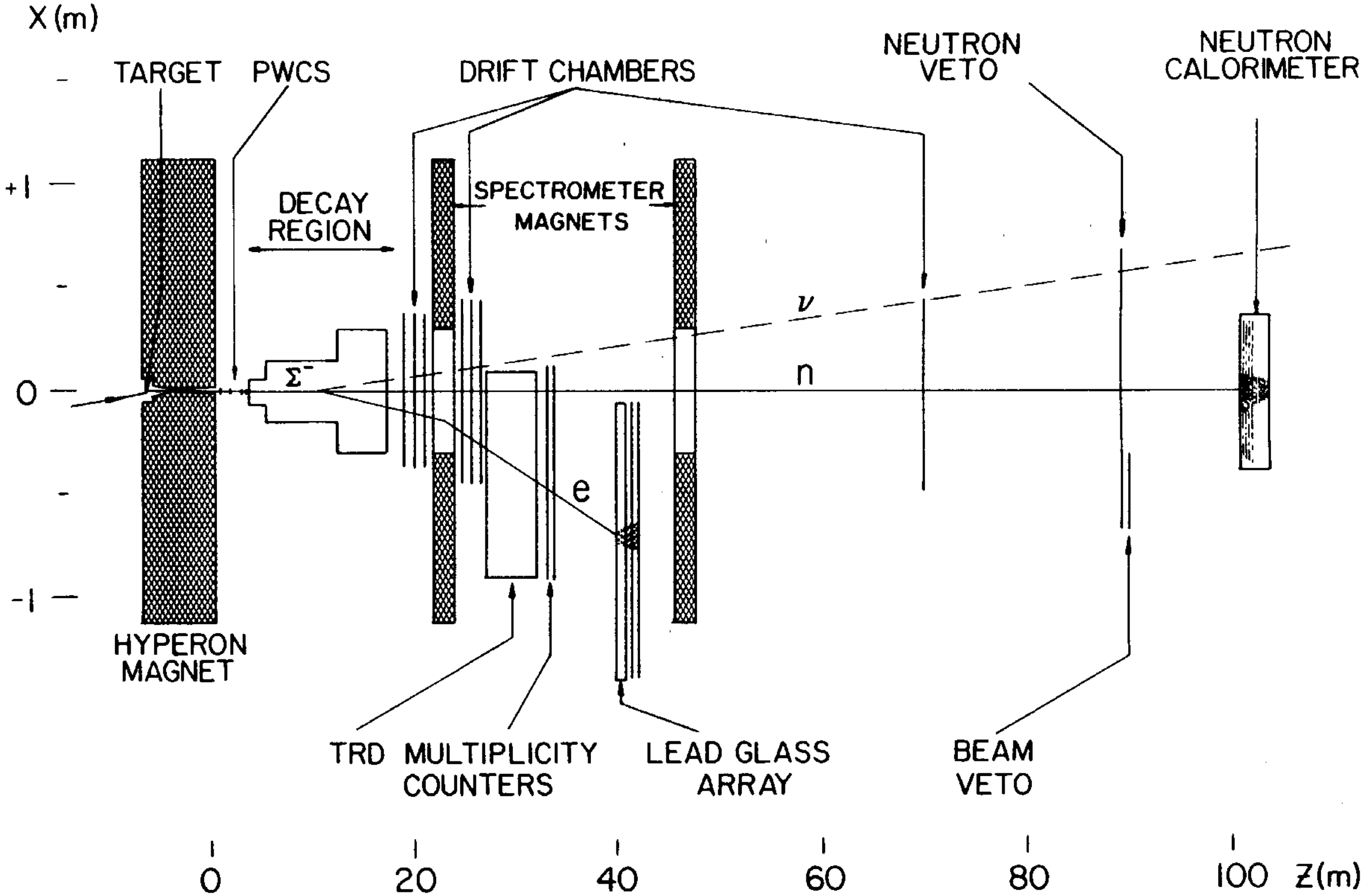
X (m)
+1
0
-1
TARGET
PWCS
DECAY REGION
DRIFT CHAMBERS
SPECTROMETER MAGNETS
NEUTRON VETO
NEUTRON CALORIMETER
Σ⁻
ν
n
e
HYPERON MAGNET
TRD
MULTIPLICITY COUNTERS
LEAD GLASS ARRAY
BEAM VETO
0
20
40
60
80
100
Z(m)

Fig. 2

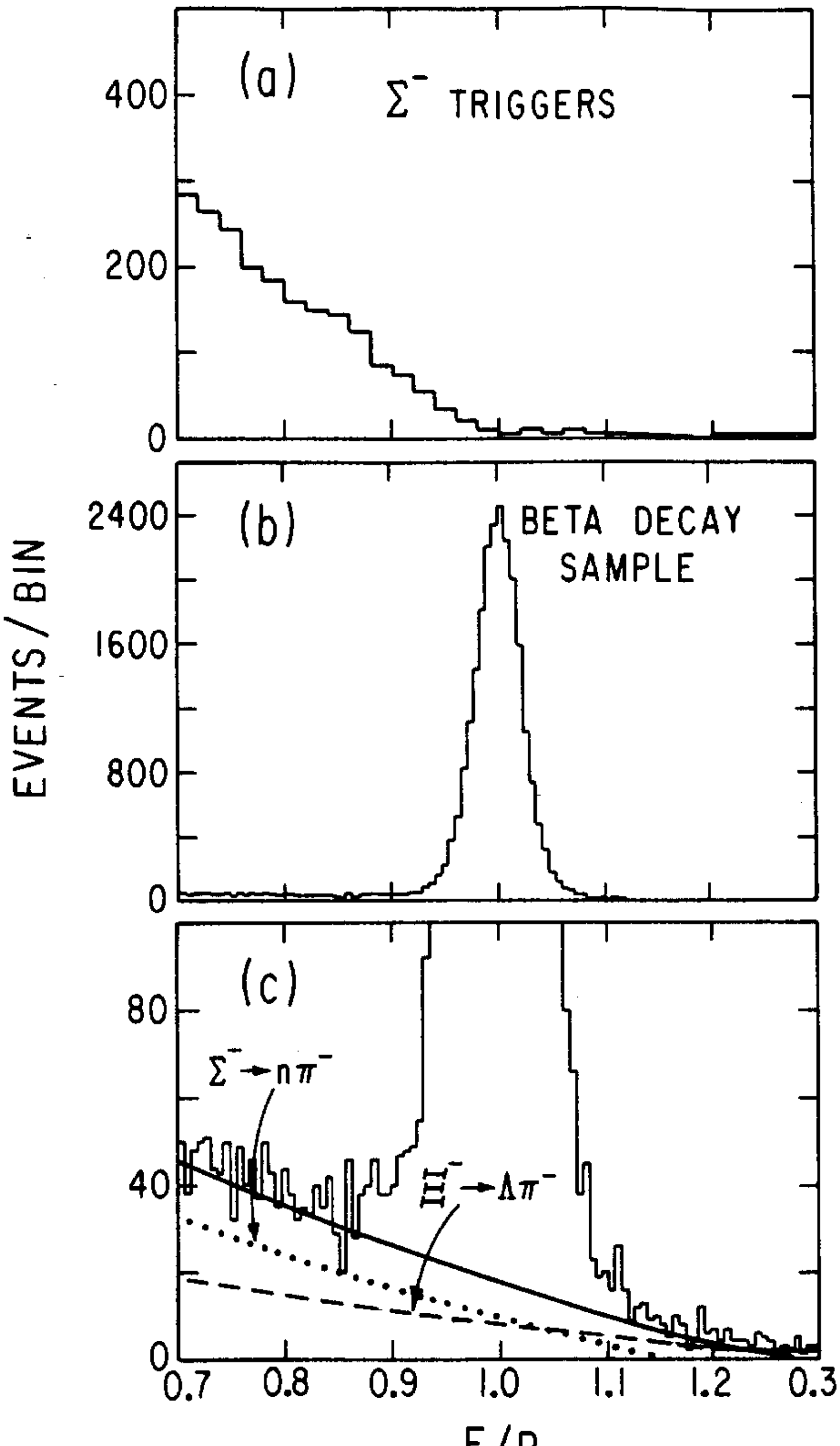
(a)
Σ⁻ TRIGGERS
400
200
0
(b)
BETA DECAY SAMPLE
2400
1600
800
0
EVENTS / BIN
(c)
80
40
0
Σ⁻ → nπ⁻
Ξ⁻ → Λπ⁻
0.7
0.8
0.9
1.0
1.1
1.2
0.3
E/P

Fig. 3

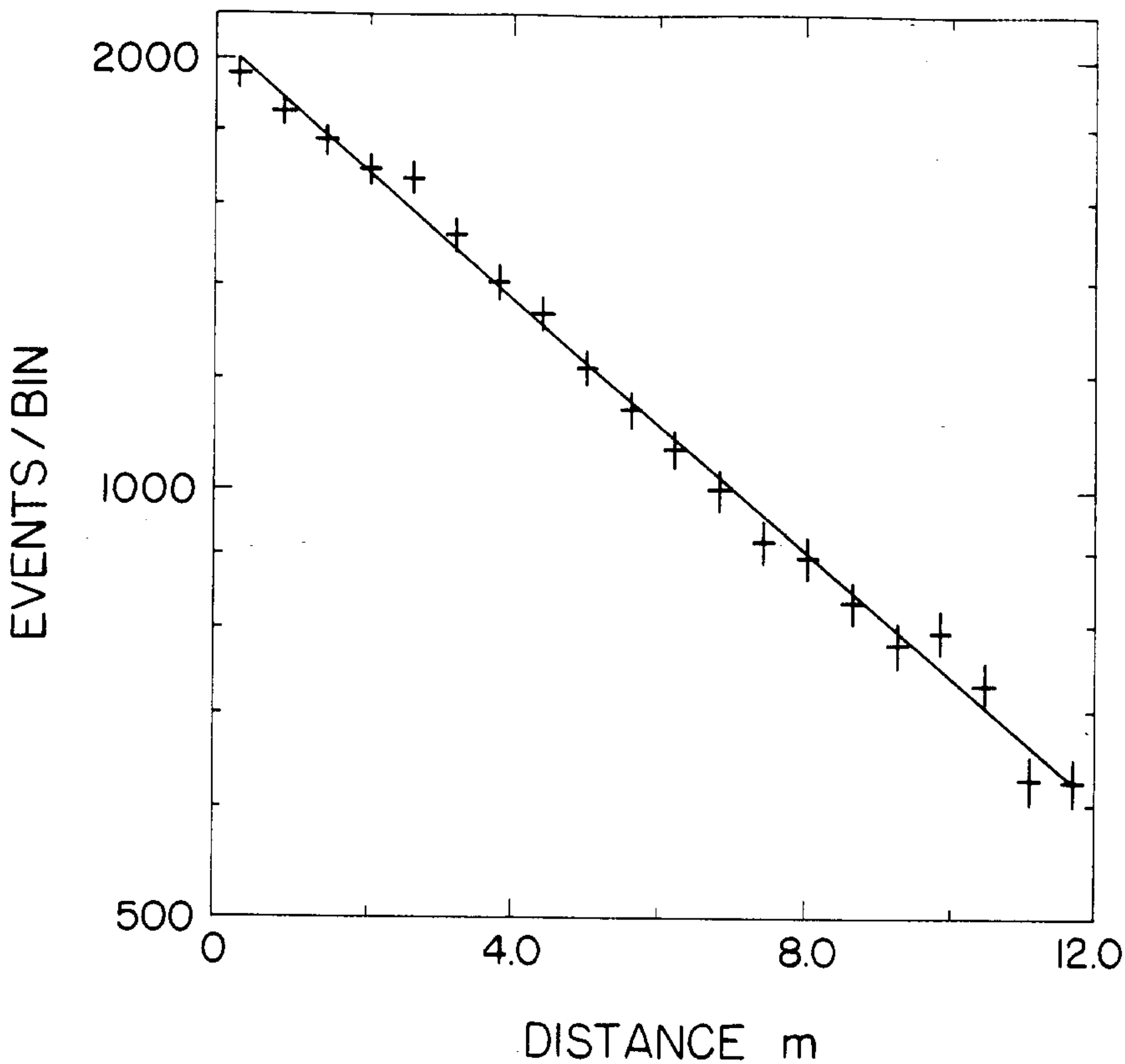

Fig. 4

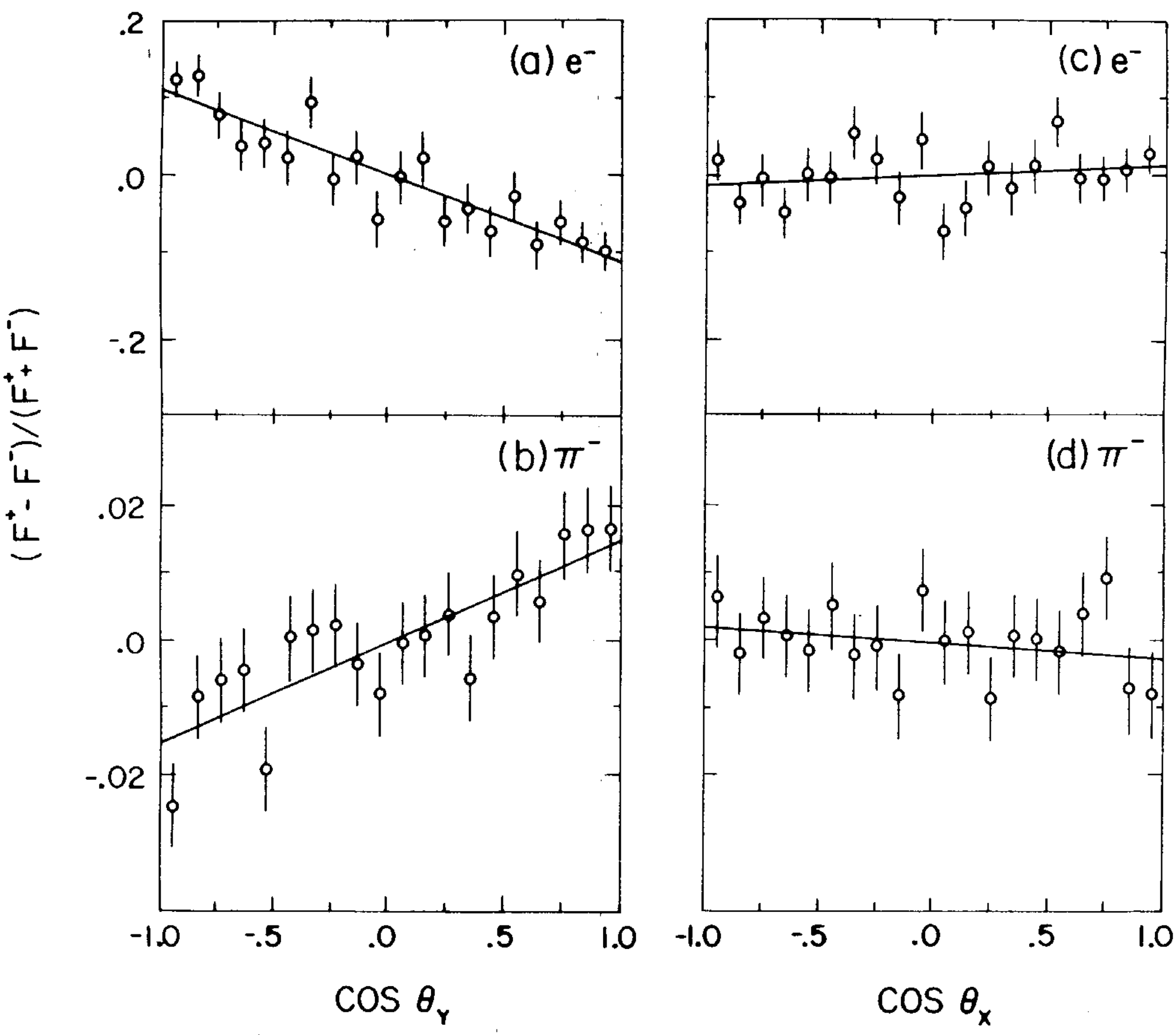

Fig. 5