INTRODUCTION TO BEACH 2012

Roland Winston

Schools of Natural Science and Engineering, University of California Merced

Director, California Advanced Solar Technologies Institute (UC Solar)

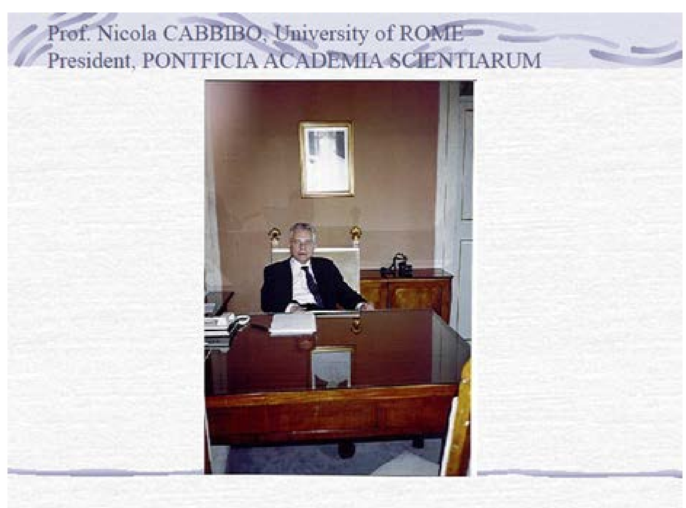
rwinston@ucmerced.edu http://ucsolar.org

I have been asked by the organizers to place Nicola Cabibbo’s contributions to hyperon physics in perspective. ------ Also to substitute for Leon Lederman. I have some hope to fulfill the first assignment, but little hope for the second.

All I can do is recall my first encounter with Leon. I was a Chicago grad student attending a conference at Argonne Lab. Chicago and Columbia were famously rivals, each having their own cyclotron. Val Telegdi (my thesis sponsor) was first speaker, Leon second, and Yoichiro Nambu third. When it was Leon’s turn he began: “I feel like a piece of ham - sandwiched as I am between two such well-bred speakers”. The audience roared with laughter--- the ice was broken.

In 1999 I made a visit to Nicola in Rome, arranged by a mutual friend Cesare Silvi, then President of ISES. (Nicola had been director of INEA) This began a friendship that lasted over a decade. Every trip to Rome would start with a cultural experience and a “lesson”. This one was a visit to his office in the Vatican.

Nicola Cabibbo’s Vatican Office



It has been two years since the we lost Nicola Cabibbo; A long time in the life of a physicist, but a short time to form a perspective on a scientist's contributions. It takes more like 50 years to assess contributions to science (S, Chadrasekhar, private communication) In what follows I will use Nicola's words whenever possible*, even though he was writing in the third person.*

Intimations of Cabibbo Universality

A key clue can be found in the thesis of Feynman's student Sam Berman

The issue was the comparison between the experimental value of the Fermi coupling constant as deduced from neutron and muon beta decay: Could the slight discrepancy be accounted for by radiative corrections? Berman and Feynman discovered that radiative corrections for beta decay had the opposite sign from that needed to close the gap between beta decay and muon decay. The conclusion of the thesis was, "The disagreement between experiment and theory appears to be outside the limit of experimental error and might be regarded as an indication of the lack of universality even by the strangeness conserving part of the vector interaction."

In 1963 Cabibbo proposed a theory of the weak current, parameterized by a single mixing angle θ_c, in the context of the octet model of SU(3) symmetry.

UNITARY SYMMETRY AND LEPTONIC DECAYS

Nicola Cabibbo
CERN, Geneva, Switzerland
(Received 29 April 1963)

The central assumption was that the weak current J_α is a member of an octet of currents $J_\alpha^i = V_\alpha^i + A_\alpha^i$, where V_α^i and A_α^i are octets of vector and axial currents,

$$J_\alpha = \cos\theta_C \left(J_\alpha^1 + i\,J_\alpha^2\right) + \sin\theta_C \left(J_\alpha^4 + i\,J_\alpha^5\right). \qquad 1.$$

By assuming that the vector and axial parts of the weak current are "parallel," i.e., the same element of the respective octets, the theory included the $V - A$ hypothesis,[1] and it also included the conserved vector current (CVC) hypothesis by assuming that the vector part of the weak current belongs to the same octet as the electromagnetic current.

In September 2008, during a visit to UC Merced, Nicola told me this was the highest cited PRL

When expressed in terms of quarks, which were only proposed in 1964, Cabibbo's weak current takes the simple form

$$J_\alpha = \cos\theta_C \bar{u}\gamma_\alpha(1+\gamma_5)d + \sin\theta_C \bar{u}\gamma_\alpha(1+\gamma_5)s. \qquad 2.$$

Also in 1964 Bjorken & Glashow (73) proposed the existence of a fourth charge 2/3 quark, the charmed quark, coupled to the $(\cos\theta_c\, s - \sin\theta_c\, d)$ combination. The mixing between d and s quarks would then be described by a 2×2 matrix.

Intimations of CP Violation

Soon after Cabibbo proposed the mixing hypothesis, S. Glashow suggested to him that the same picture could naturally accommodate CP violation by allowing the mixing angle to be complex (adding a phase). However, it was obvious that a 2x2 unitary matrix (in the case of four quarks) can always be reduced to a form with real elements and thus necessarily preserves CP.

In 1973, Kobayashi & Maskawa noted that the mixing of three quark families entails a single complex phase that cannot be eliminated by field redefinitions. They thus proposed that the four-quark model should be extended to a six-quark model in which mixing offers a natural explanation for the existence of CP violation.

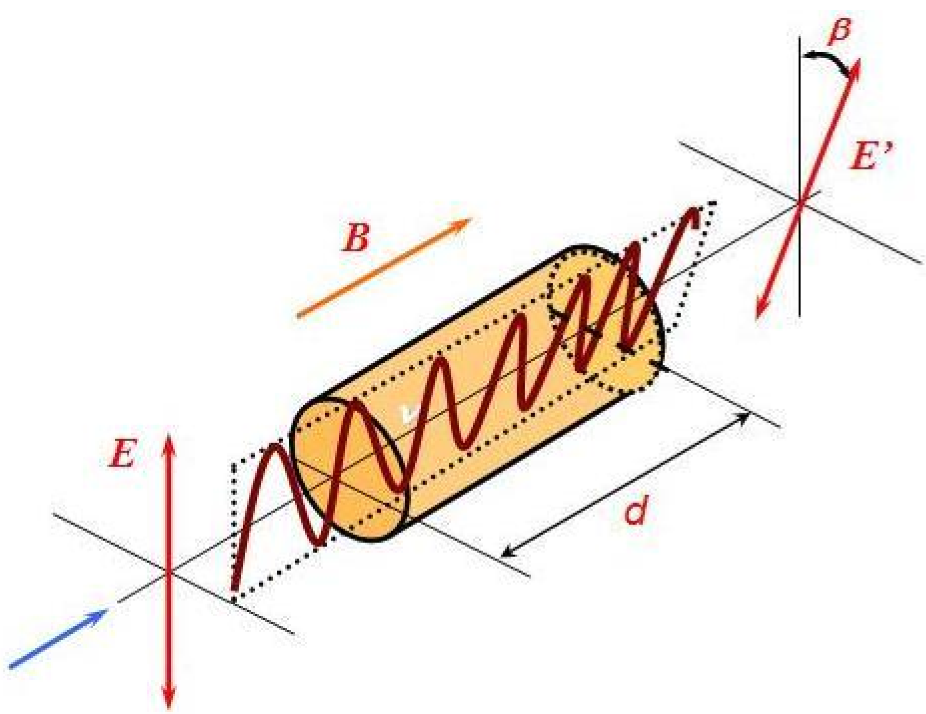
Intimations of CP Violation

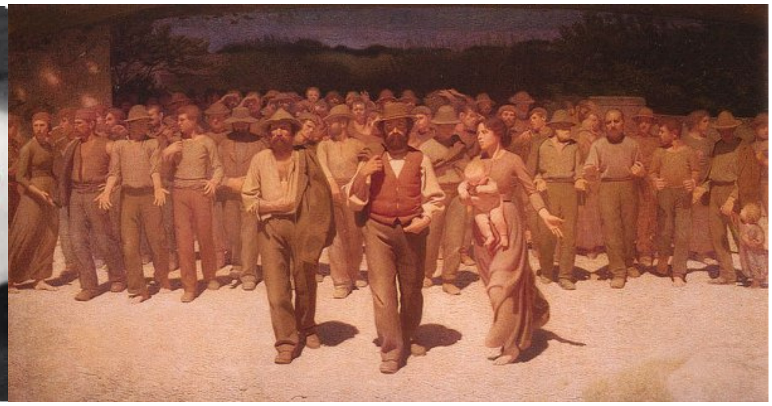
In the standard model with six quarks, the network of transition amplitudes between the charge $-1/3$ quarks d, s, b and the charge $2/3$ quarks u, c, t is described by a unitary matrix V, the CKM matrix, whose effects can be seen as a mixing between the d, s, b quarks,

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}. \qquad 3.$$

The next visit was to give a seminar a University of Rome La Sapienza But first the **Galleria Nazionale d'Arte Moderna** and the role of **Margherita Sarfatti** in 20th century Italian art

Then over a pizza in the museum park, I learned that Nicola had derived his inspiration for a rotating the weak current from a **Faraday Rotation of the Electric Field**





Giuseppe Pelizza da Volpedo Il Quarto Stato

A road map for four decades of experiments

I note (personal bias) the three most influential measurements to validate Cabibbo theory, the beta decays of (polarization correlation information included)

lambda, sigma minus, neutral cascade

Table I. Predictions for the leptonic decays of hyperons.

Decay	Branching ratio From reference 2	Branching ratio Present work	Type of interaction
$\Lambda \to p + e^- + \bar{\nu}$	1.4 %	0.75×10^{-3}	$V - 0.72\,A$
$\Sigma^- \to n + e^- + \bar{\nu}$	5.1 %	1.9×10^{-3}	$V + 0.65\,A$
$\Xi^- \to \Lambda + e^- + \bar{\nu}$	1.4 %	0.35×10^{-3}	$V + 0.02\,A$
$\Xi^- \to \Sigma^0 + e^- + \bar{\nu}$	0.14 %	0.07×10^{-3}	$V - 1.25\,A$
$\Xi^0 \to \Sigma^+ + e^- + \bar{\nu}$	0.28 %	0.26×10^{-3}	$V - 1.25\,A$

Form factors, the language of hyperon decays

2.1. Baryon Matrix Elements

The transition matrix element for the generic hyperon beta-decay process $B \rightarrow be^{-}\overline{\nu}$, where B and b are the initial- and final-state baryons, can be written in the form

$$\mathcal{M} = \frac{G_S}{\sqrt{2}}\overline{u}_b\left(O_\alpha^V + O_\alpha^A\right)u_B\overline{u}_e\gamma^\alpha(1+\gamma_5)v_\nu, \qquad 5.$$

where

$$O_\alpha^V = f_1(q^2)\gamma^\alpha + \frac{f_2(q^2)}{M_B}\sigma_{\alpha\beta}q^\beta + \frac{f_3(q^2)}{M_B}q_\alpha \qquad 6.$$

and $$O_\alpha^A = \left(g_1(q^2)\gamma^\alpha + \frac{g_2(q^2)}{M_B}\sigma_{\alpha\beta}q^\beta + \frac{g_3(q^2)}{M_B}q_\alpha\right)\gamma_5. \qquad 7.$$

The momentum transfer is $q^\alpha = (p_e + p_\nu)^\alpha = (p_B - p_b)^\alpha$, and the coupling strength is $G_S = G_F V_{us}$ for $|\Delta S| = 1$ and $G_S = G_F V_{ud}$ for $\Delta S = 0$, where G_F is the Fermi coupling constant and V_{us}, V_{ud} are the appropriate CKM matrix elements. We employ the metric and γ-matrix conventions of Reference 22.[2]

How to measure form factors

TABLE 2 The contribution of different measurements to the determination of the form factors in hyperon beta decay

Measured quantity	f_1	f_2/f_1	g_1/f_1	g_2/f_1
Branching fraction	√			
Polarization			√	√
e–ν correlation[a]	√		√	√
Electron spectrum		√		

[a]The e–ν correlation is only sensitive to the *magnitude* of g_1/f_1 and g_2/f_1.

Throughout the 1960's and 70's there was an abundance of competing models. During this time period S. Glashow called RW enquiring about the latest sign of A/V in lambda beta decay, citing a theory that would prefer a *negative* sign**.**

It was important to measure the sign of g_1/f_1 (Axial Vector/Vector) form factors using *polarized* hyperons.

PHYSICAL REVIEW D VOLUME 16, NUMBER 7 1 OCTOBER 1977

Measurement of the angular correlation parameters in the β decay of polarized Λ hyperons*

J. Lindquist,[†] E. C. Swallow,[‡] R. L. Sumner,[§] J. M. Watson,[‖] R. Winston,[¶] and D. M. Wolfe[**]
Enrico Fermi Institute, The University of Chicago, Chicago, Illinois 60637

K. Reibel, D. M. Schwartz,[††] and A. J. Stevens[‡‡]
Ohio State University, Columbus, Ohio 43210

T. A. Romanowski
Argonne National Laboratory, Argonne, Illinois 60439
and Ohio State University, Columbus, Ohio 43210

(Received 28 October 1975; revised manuscript received 23 May 1977)

We present our final results from an experimental investigation of the β decay of polarized Λ hyperons with a large-aperture magnetic spectrometer. Our data sample consists of 544 events. We obtain $A_\nu = 0.72 \pm 0.12$, $A_e = 0.05 \pm 0.12$, and $A_p = -0.47 \pm 0.12$ for the three spin-asymmetry parameters, and $A_{e\nu} = 0.07 \pm 0.12$ for the electron-neutrino correlation. The lepton-plane correlation with the Λ spin, $D = 0.11 \pm 0.20$, is consistent with no violation of time-reversal invariance. Our data yield an axial-vector-to-vector form-factor ratio of $g_1/f_1 = 0.53^{+0.11}_{-0.09}$. The Cabibbo-model value is $g_1/f_1 = 0.71$.

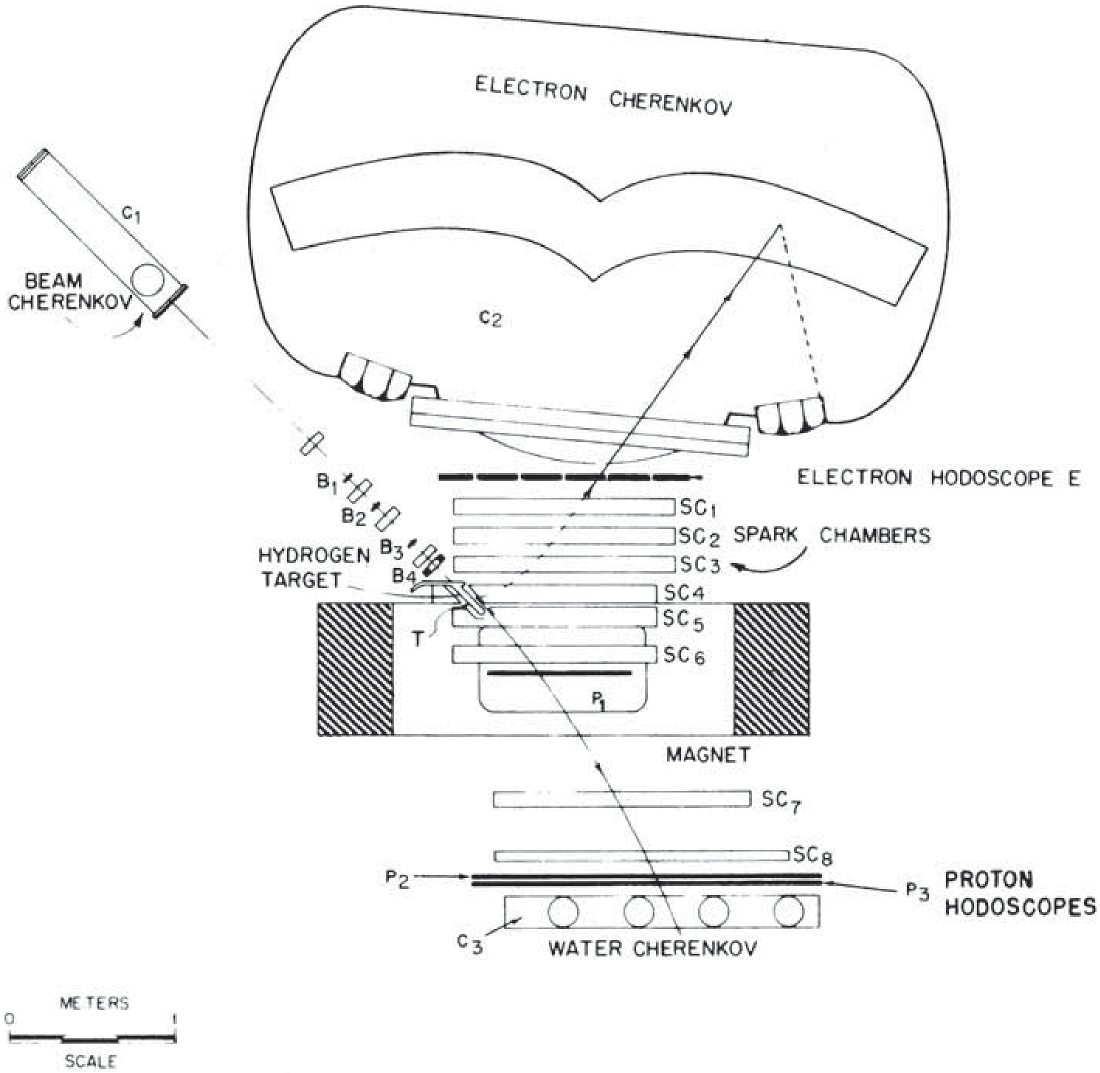


FIG. 2. Plan view of the experimental apparatus.

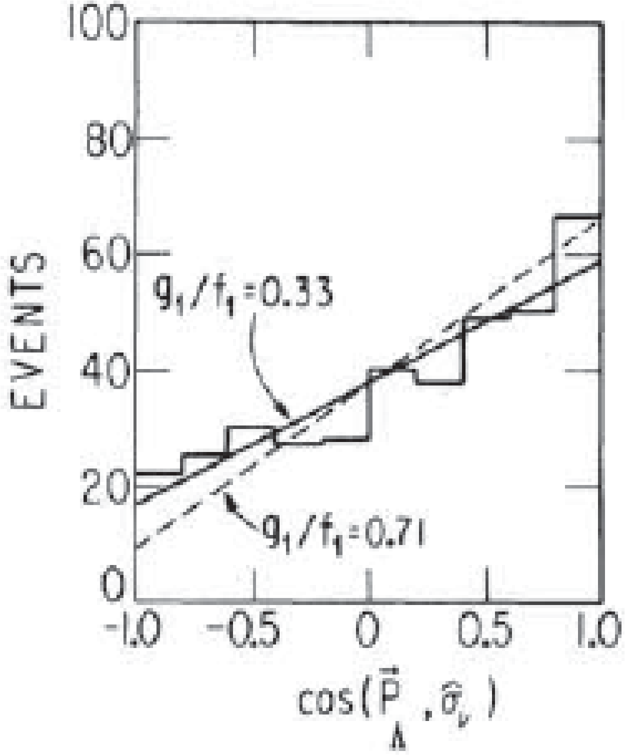


FIG. 7. Center-of-mass neutrino-spin cosine distribution.

compared to $g_1/f_1 = 0.628^{+0.038}_{-0.035}$ from $A_{e\nu}$. A combined fit to all four parameters gives $g_1/f_1 = 0.611^{+0.033}_{-0.032}$ with $\chi^2 = 5.42$ for three degress of freedom (probability 14%). It is apparent that the g_1/f_1 value from the spin asymmetries is smaller than that from $A_{e\nu}$, and that results from all polarized Λ experiments agree on this point. The mediocre χ^2 for the combined fit also reflects this dichotomy. An analogous χ^2 computation using the conventional Cabibbo form-factor values gives $\chi^2 = 7.44$ for four degrees of freedom (probability 11%).

These consistent differences could indicate some additional contribution to the decay matrix element not contained in the conventional analysis. One such possibility would be the presence of a g_2 term.[24] It is, of course, also possible that the experiments are subject to some common systematic problem; for example, an error in the determination of the $\Lambda - p\pi$ asymmetry parameter[9,25] which sets the scale for the Λ polarization.

These questions aside, hyperon β-decay experiments, and particularly measurements on polarized $\Lambda - pe\bar{\nu}$, have unambiguously established the relative sign of the vector and axial-vector interaction in strangeness-changing weak processes.[25] However, to definitively test the Cabibbo model,[26] and to explore the nature of symmetry breaking, additional high-statistics polarized hyperon β-decay experiments are needed.

ACKNOWLEDGMENTS

We are grateful to Argonne National Laboratory for its hospitality and for the vital support provided by the staff of the Zero Gradient Synchrotron. The scientific contributions of P. R. Phillips and the engineering contributions of C. J. Rush and J. Terandy were invaluable. Technical assistance from D. Burandt, E. Hayes, G. Karambis, L. Lavoie, B. Nelson, J. Tate, and J. Upton is gratefully acknowledged. We also thank our scanning and measuring personnel, particularly B. Stevens and C. Fineberg, for their efforts. We are indebted to S. Watson for her diligent help with the data processing.

A side benefit of the first polarized hyperon beta decay experiment was the invention of *nonimaging optics* which has had applications to many areas; detectors, infra red astronomy, solar energy, illumination

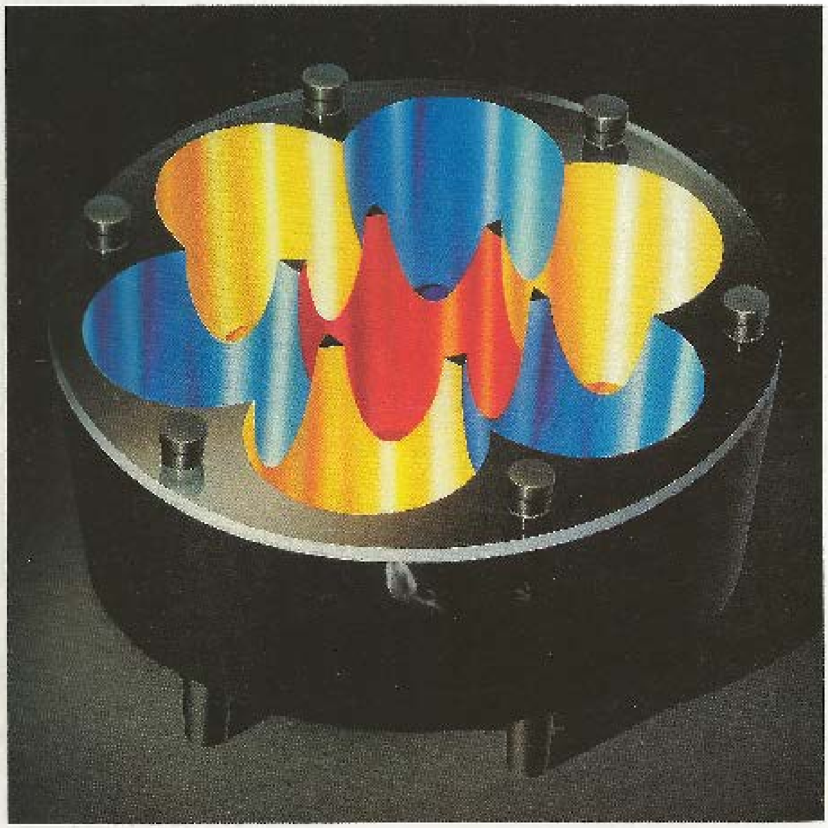
SCIENTIFIC AMERICAN

MARCH 1991
$3.95

How rising continents cooled the earth.

Will drugs ever cure drug addiction?

The Russian weed that won the West.



Funnels for light *can concentrate solar energy to supersolar intensity.*

The advent of Hyperon Beams

At the time of the last *Annual Review of Nuclear and Particle Science* article on hyperon decays (20), nearly 20 years ago, the key experimental tests of the Cabibbo theory had not yet been done. Although the Lorentz structure of lambda beta decay had been found to be approximately $V - A$ as required, the theory faced its first critical test in $\Sigma^- \to ne^-\bar{\nu}e$ decay. Taking the F/D ratio from any two decays, say neutron and lambda, the theory required the Lorentz structure of Σ^- beta decay to be $V + A$. This surprising sign reversal was considered at the time the "go or no-go" test of the Cabibbo theory. Measuring the sign convincingly required polarized Σ^-. Low-energy experiments relied on tertiary polarized sigmas from pions or kaons. The statistics were meager, the control of systematics problematic, and the results less than compelling. If anything, the data appeared to favor the $V - A$ sign (20a).

The turning point was determined by an experimental innovation, the invention and development of hyperon beams. When such beams were discovered to be significantly polarized, a new era of precision experiments with excellent control of systematics began. With the ability to produce *and reverse* polarization, correlations between momenta and polarization could be measured in a precise and bias-cancelled way. New precise experiments settled the question of the Σ^- beta decay in favor of the Cabibbo prediction (see Section 3.2). The high-energy hyperon beam proved to be the enabling technology for carrying out precision measurements of hyperon-decay properties.

Proceedings of APS Division of Particles and Fields, Seattle, August 27-29, 1975

BNL-21009

Conf 750858 -17

STRONG INTERACTIONS OF HYPERONS

P. Némethy, V. Hungerbuehler, R. Majka, J.N. Marx,
J. Sandweiss, W. Tanenbaum, and W.J. Willis
Yale University, New Haven, Connecticut 06520
M. Atac, S. Ecklund, P.J. Gollon, J. Lach, J. MacLachlan,
A. Roberts, R. Stefanski, and D. Theriot
Fermilab, Batavia, Illinois 60510
C.L. Wang
Brookhaven National Laboratory, Upton, New York 11973
W. Cleland, E. Engels, Jr., D. Lowenstein†
N. Scribner, and J. Thompson
University of Pittsburgh, Pittsburgh, Pennsylvania 15213

ABSTRACT

We present a summary of the strong interaction results obtained with the Yale-FNAL-BNL hyperon beam at the Brookhaven AGS. We report differential cross sections for hyperon-proton elastic scattering with samples of 6200 $\Sigma^- p$ events and 67 $\Xi^- p$ events. We also report on our search for hyperon resonances in inelastic scattering. Finally, we review the prospects for new results on hyperon interactions.

INTRODUCTION

In order to do high statistical experiments on charged hyperons, we have built a "hyperon beam" at Brookhaven National Laboratory. Because of the short lifetime of hyperons, the beam is designed to be very short and to take advantage of relativistic time dilation. The hyperons are produced in a target in the slow extracted proton beam at the AGS. A heavily shielded magnetic channel selects forward negative hyperons with $\gamma \sim 20$. Protons and neutrons are absorbed in the channel wall.

We have used this beam to study the production, weak decays, and strong interactions of negative hyperons.[1] Here we report on our results for hyperon scattering.

Σ^- ELASTIC SCATTERING

The channel delivers a flux of approximately 1 Ξ^-, 100 Σ^- and $10^4 \pi^-$ per machine pulse at a momentum of 23 GeV/c. Figure 1 depicts the beam and associated detection apparatus for elastic scatters; a detailed description appears elsewhere.[2] Beam particles of mass less than 1 GeV/c^2 are tagged by a threshold Cerenkov counter which forms part of the channel. A cluster of high pressure, high resolution (100 μm) spark chambers determines the momentum of the emerging

† Presently with Brookhaven National Laboratory, Upton, New York 11973

beam particle to $\pm 1\ ^o/_o$. A 40 cm long liquid hydrogen scattering target is followed by a second high resolution spark chamber[3] cluster that measures the scattering angle to ± 1mr. A set of 5 small scintillation counters defines the beam. A hole veto counter behind a lead sheet discriminates against upstream hyperon decays and against inelastic scatters with π^0s.

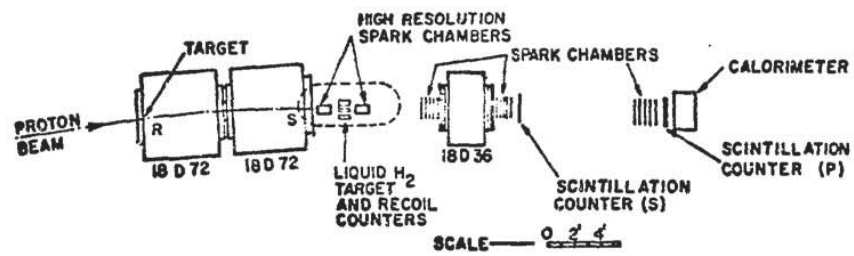


Fig. 1. Apparatus for elastic scattering.

The hydrogen target is surrounded by a recoil detector (Fig. 2) which selects scattered events. The pulse height of an inner, thin scintillator (DE) measures dE/dx. The protons are stopped in a 4 inch thick scintillator (E) which measures their total kinetic energy. Surrounding counter E is a veto counter which guarantees that protons stop in counter E.

A 50 inch decay region downstream of the second high resolution chamber is followed by a magnetic spectrometer with conventional wire spark chambers which measures the momentum of the slow pion (< 10 GeV) from the dominant decay $\Sigma^- \rightarrow n\pi^-$ to about $5\ ^o/_o$. An iron-scintillator calorimeter detects hadrons and rejects muons.

The recoil detector is used to select Σ^-p and π^-p elastic scatters. A scattergram of the pulse height in DE (α dE/dx) vs. pulse height in E (α kinetic energy) is shown in Fig. 3a. A clear recoil mass band corresponding to the proton

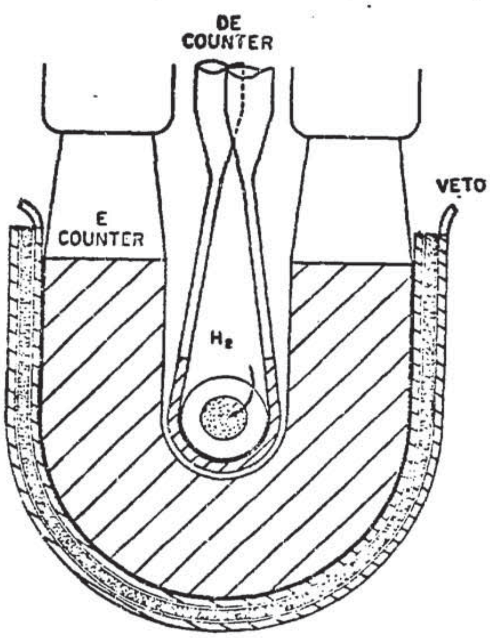


Fig. 2. Recoil Detector.

POLARIZED SIGMA BETA DECAY

From right to left:

Peter Cooper

Alexey Vorobyov

Joe Lach

Roland Winston

Earl Swallow

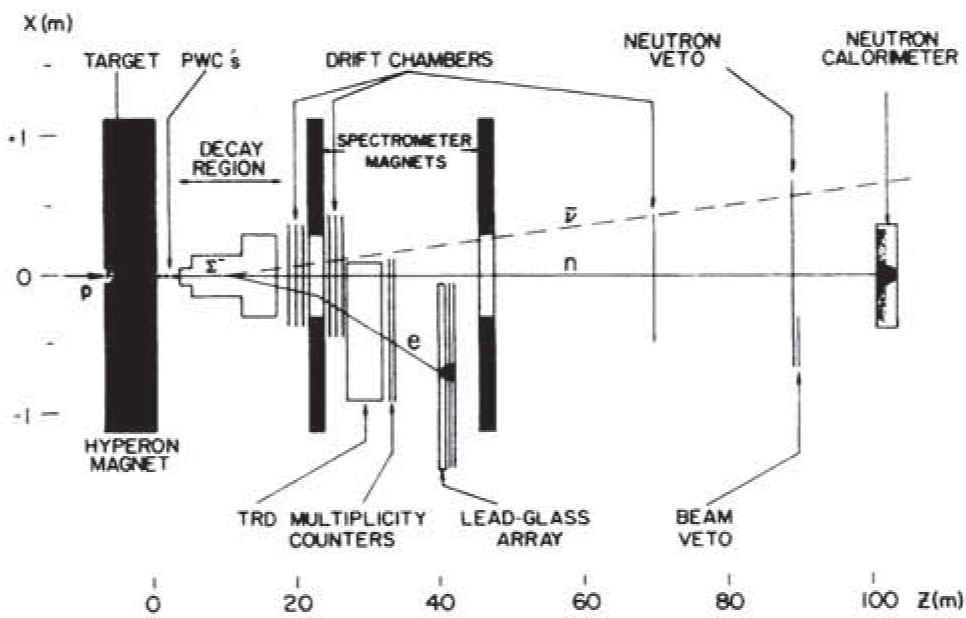


FIG. 1. Plan view of the experimental apparatus.

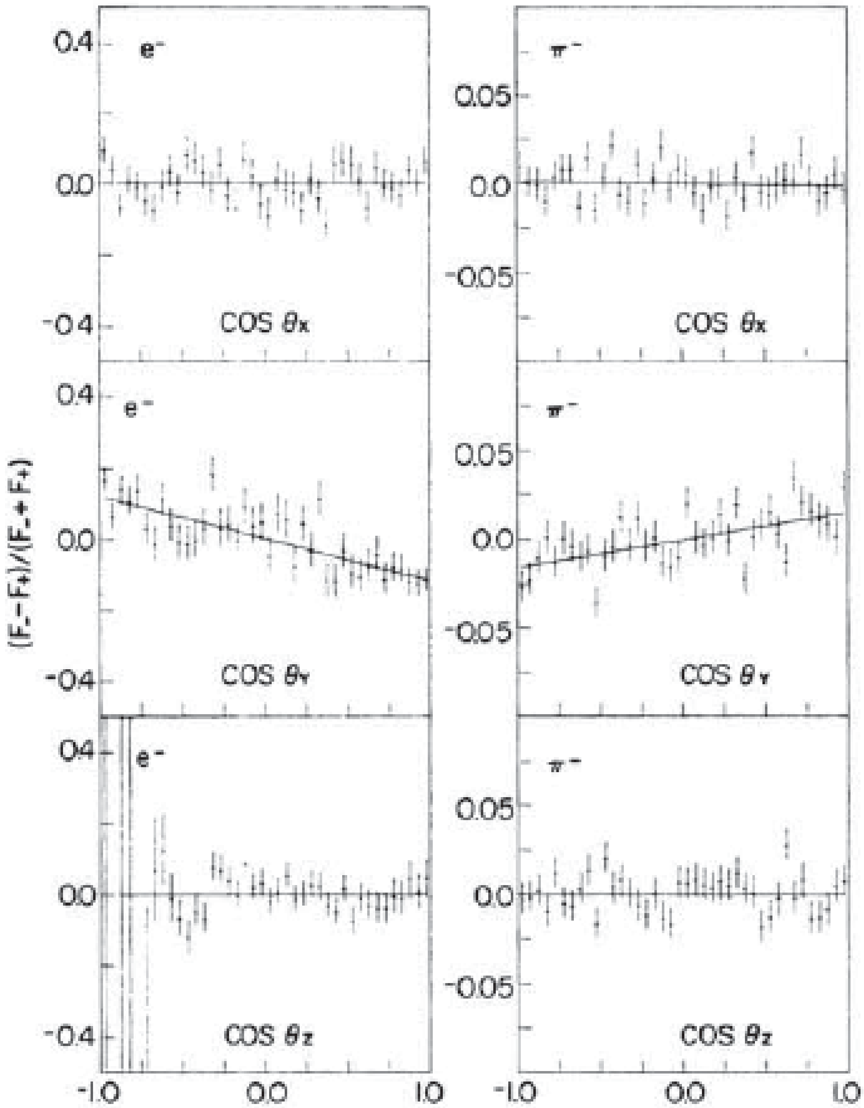


FIG. 17. Electron and pion c.m. decay distributions for θ_h data. Parity conservation in the Σ^- production process requires zero slope for the $\cos(\theta_x)$ and $\cos(\theta_z)$ distributions. Note the differing ordinate scales for the pion and electron plots.

This is the first high-statistics experiment in which all of the $\Sigma^- \rightarrow ne^- \bar{\nu}$ decay products were reconstructed using a polarized Σ^- beam. The control and investigation of systematic errors was greatly facilitated by our ability to reverse the direction of the Σ^- polarization and to orient it in either the horizontal or vertical plane. By simultaneously recording a sample of $\Sigma^- \rightarrow n\pi^-$ events, we were able to use the known value[18] of α_π to determine the Σ^- polarization to be $P = +0.236 \pm 0.043$ at our 2.5-mrad average production angle. Including both systematic and statistical uncertainties, we determine the decay asymmetry parameters to be $\alpha_e = -0.519 \pm 0.104$, $\alpha_n = +0.509 \pm 0.102$, and $\alpha_\nu = -0.230 \pm 0.061$.

With these values, we have unambiguously established the sign of the axial-vector-to-vector form-factor ratio g_1/f_1 to be negative. This was done by three distinct

The next visit was to work on our review. But first the Villa Borghesa and the Gallery. I was asked to particularly examine a Correggio and report what I saw. Nicola called my attention to the thin dark line across each finger nail. The artist had faithfully depicted dirt under the finger nails of the model. That was when I truly understood Nicola's attention to detail.

By this time we were deep into our new project, writing a review of hyperon beta decay

Annu. Rev. Nucl. Part. Sci. 2003. 53:39–75
doi: 10.1146/annurev.nucl.53.013103.155258

SEMILEPTONIC HYPERON DECAYS

Nicola Cabibbo,[1] Earl C. Swallow,[2,3] and Roland Winston[4]
[1]*Department of Physics, University of Rome-La Sapienza, Piazzale A. Moro 5, 00185 Rome, Italy; email: nicola.cabibbo@roma1.infn.it*
[2]*Department of Physics, Elmhurst College, Elmhurst, Illinois 60126;* [3]*Enrico Fermi Institute, The University of Chicago, Chicago, Illinois 60637; email: earls@elmhurst.edu*
[4]*Division of Natural Sciences, University of California, Merced, Merced, California 95344; email: rwinston@ucmerced.edu*

. $\Xi^0 \rightarrow \Sigma^+ e^- \bar{\nu}_e$

This may appropriately be called "the last hyperon beta decay." It is the last of the observable beta decays of the octet to be measured. The experiment was long considered sufficiently problematic to be below the radar of most compilations. A notable exception was the original Cabibbo proposal (1).

Paradoxically, this is in some respects the most accessible beta decay. The Σ^+ is a unique signature for the beta-decay mode (the analog two-body mode is forbidden by energy conservation), so event samples are remarkably free of two-body backgrounds that typically plague experiments. Moreover, the final-state Σ^+ polarization is self-analyzing because of the large asymmetry of the decay $\Sigma^+ \rightarrow p\pi^0$ ($\alpha = -0.98$). It is thus sufficient to study angular correlations with the proton. However, attaining a sufficient event rate required a new generation of hyperon experiments that combine the high-energy advantages of hyperon beams with the high phase-space acceptance of neutral kaon beams.[4] Beams with the desired properties arose in the context of recent precision studies of *CP* violation in neutral kaon decays (56, 16). In place of the narrow phase-space selection of a hyperon-beam magnet, the new experiments use an identifying feature of either the production or decay process. In effect, the event is "tagged." In the decay $\Xi^0 \rightarrow \Sigma^+ e^- \overline{\nu}_e$, only the beta-decay mode has sufficient *Q*-value to produce a Σ^+. Identified $\Xi^0 \rightarrow \Lambda\pi^0$ can be used as the primary source for the study of Λ decay.

VOLUME 87, NUMBER 13 PHYSICAL REVIEW LETTERS 24 SEPTEMBER 2001

First Measurement of Form Factors of the Decay $\Xi^0 \rightarrow \Sigma^+ e^- \overline{\nu}_e$

A. Alavi-Harati,[12] T. Alexopoulos,[12] M. Arenton,[11] K. Arisaka,[2] S. Averitte,[10] R. F. Barbosa,[7,*] A. R. Barker,[5] M. Barrio,[4] L. Bellantoni,[7] A. Bellavance,[9] J. Belz,[10] R. Ben-David,[7] D. R. Bergman,[10] E. Blucher,[4] G. J. Bock,[7] C. Bown,[4] S. Bright,[4] E. Cheu,[1] S. Childress,[7] R. Coleman,[7] M. D. Corcoran,[9] G. Corti,[11] B. Cox,[11] M. B. Crisler,[7] A. R. Erwin,[12] R. Ford,[7] A. Glazov,[4] A. Golossanov,[11] G. Graham,[4] J. Graham,[4] K. Hagan,[11] E. Halkiadakis,[10] J. Hamm,[1] K. Hanagaki,[8] S. Hidaka,[8] Y. B. Hsiung,[7] V. Jejer,[11] D. A. Jensen,[7] R. Kessler,[4] H. G. E. Kobrak,[3] J. LaDue,[5] A. Lath,[10] A. Ledovskoy,[11] P. L. McBride,[7] P. Mikelsons,[5] E. Monnier,[4,†] T. Nakaya,[7] K. S. Nelson,[11] H. Nguyen,[7] V. O'Dell,[7] M. Pang,[7] R. Pordes,[7] V. Prasad,[4] X. R. Qi,[7] B. Quinn,[4] E. J. Ramberg,[7] R. E. Ray,[7] A. Roodman,[4] M. Sadamoto,[8] S. Schnetzer,[10] K. Senyo,[8] P. Shanahan,[7] P. S. Shawhan,[4] J. Shields,[11] W. Slater,[2] N. Solomey,[4] S. V. Somalwar,[10] R. L. Stone,[10] E. C. Swallow,[4,6] S. A. Taegar,[1] R. J. Tesarek,[10] G. B. Thomson,[10] P. A. Toale,[5] A. Tripathi,[2] R. Tschirhart,[7] S. E. Turner,[2] Y. W. Wah,[4] J. Wang,[1] H. B. White,[7] J. Whitmore,[7] B. Winstein,[4] R. Winston,[4,‡] T. Yamanaka,[8] and E. D. Zimmerman[4]

(KTeV Collaboration)

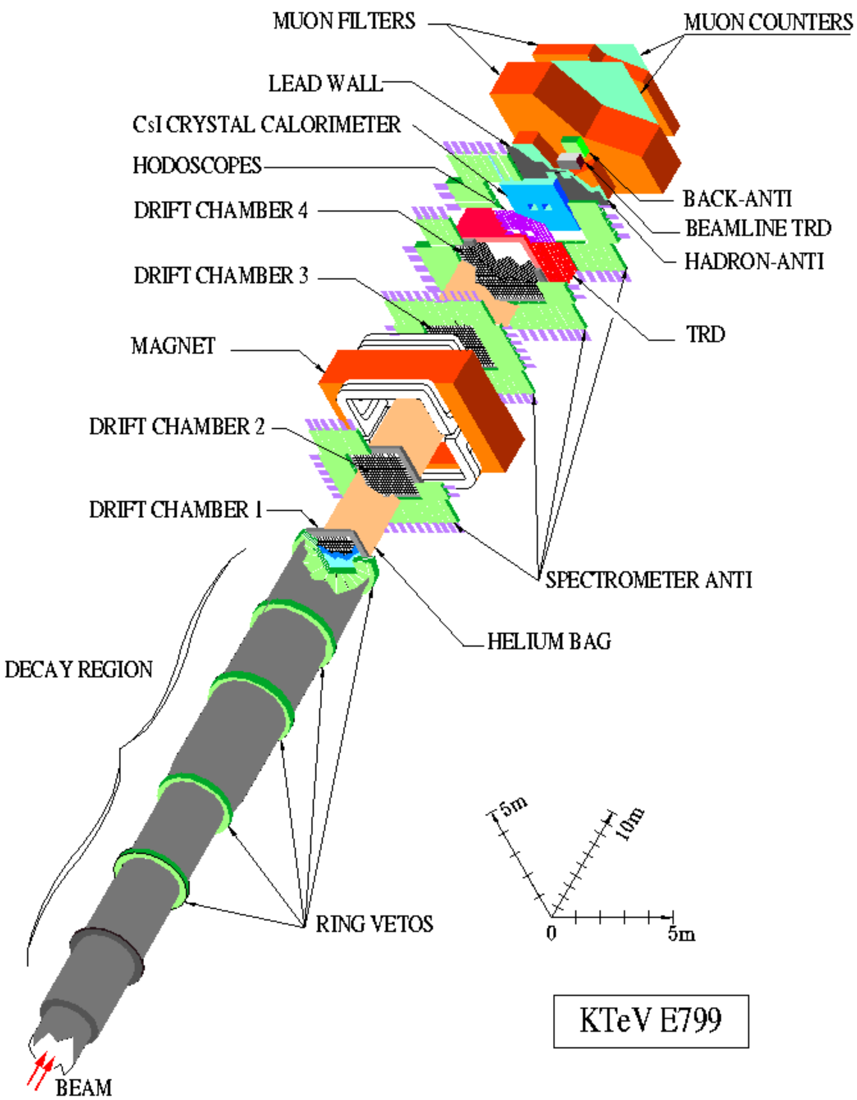
[1]*University of Arizona, Tucson, Arizona 85721*
[2]*University of California at Los Angeles, Los Angeles, California 90095*
[3]*University of California at San Diego, La Jolla, California 92093*
[4]*The Enrico Fermi Institute, The University of Chicago, Chicago, Illinois 60637*
[5]*University of Colorado, Boulder, Colorado 80309*
[6]*Elmhurst College, Elmhurst, Illinois 60126*
[7]*Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[8]*Osaka University, Toyonaka, Osaka 560-0043 Japan*
[9]*Rice University, Houston, Texas 77005*
[10]*Rutgers University, Piscataway, New Jersey 08854*
[11]*The Department of Physics and Institute of Nuclear and Particle Physics, University of Virginia, Charlottesville, Virginia 22901*
[12]*University of Wisconsin, Madison, Wisconsin 53706*

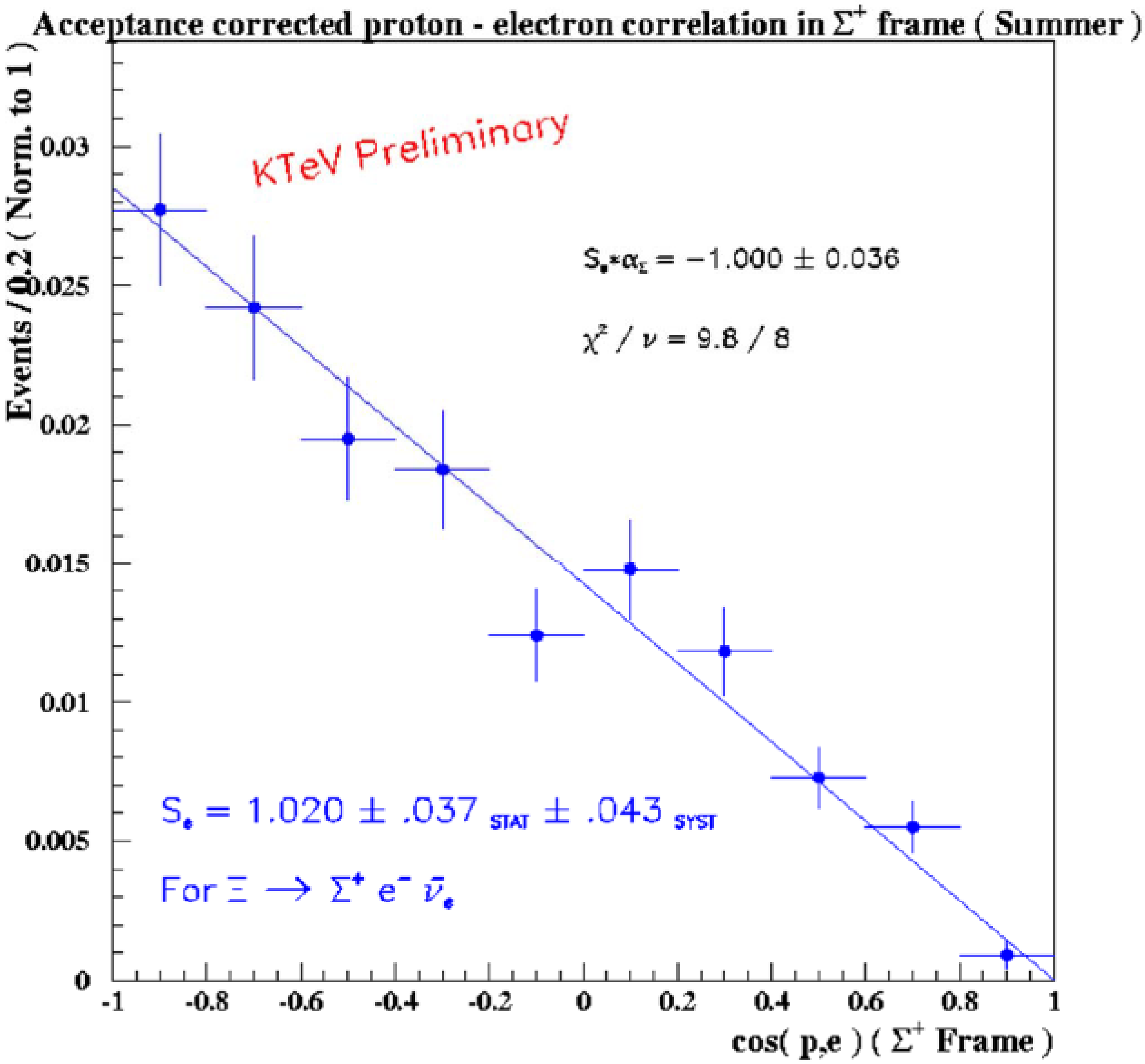
(Received 10 May 2001; published 11 September 2001)

We present the first measurement of the form factor ratios g_1/f_1 (direct axial vector to vector), g_2/f_1 (second class current), and f_2/f_1 (weak magnetism) for the decay $\Xi^0 \rightarrow \Sigma^+ e^- \overline{\nu}_e$ using the KTeV (E799) beam line and detector at Fermilab. From the Σ^+ polarization measured with the decay $\Sigma^+ \rightarrow p\pi^0$ and the $e^- - \overline{\nu}$ correlation, we measure g_1/f_1 to be $1.32\ ^{+0.21}_{-0.17}$ (stat) $\pm$ 0.05(syst), assuming the $SU(3)_f$ (flavor) values for g_2/f_1 and f_2/f_1. Our results are all consistent with exact $SU(3)_f$ symmetry.

---

[4]The feasibility was first studied by N. Solomey working with University of Chicago undergraduate A. Affolder.


MUON FILTERS
MUON COUNTERS
LEAD WALL
CsI CRYSTAL CALORIMETER
HODOSCOPES
DRIFT CHAMBER 4
DRIFT CHAMBER 3
MAGNET
DRIFT CHAMBER 2
DRIFT CHAMBER 1
BACK-ANTI
BEAMLINE TRD
HADRON-ANTI
TRD
SPECTROMETER ANTI
HELIUM BAG
DECAY REGION
RING VETOS
BEAM
5m
10m
0
5m
KTeV E799



Acceptance corrected proton - electron correlation in Σ+ frame (Summer)
Events / 0.2 (Norm. to 1)
KTeV Preliminary
S_e*α_Σ = −1.000 ± 0.036
χ² / ν = 9.8 / 8
S_e = 1.020 ± .037 STAT ± .043 SYST
For Ξ → Σ+ e− ν̄_e
cos(p,e) (Σ+ Frame)
0
0.005
0.01
0.015
0.02
0.025
0.03
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

TABLE 3 Summary of octet baryon beta-decay data (Values are drawn from Reference 11 unless noted otherwise)

Decay	Lifetime (s)	Branching fraction	Rate (μs^{-1})	g_1/f_1
$n \to pe^-\bar{\nu}$	885.7(8)	1	$1.1291(10)10^{-9}$	1.2670(30)[a]
$\Lambda \to pe^-\bar{\nu}$	2.632(20)[b] 10^{-10}	0.832(14) 10^{-3}	3.161(58)	0.718(15)
$\Sigma^- \to ne^-\bar{\nu}$	1.479(11)[c] 10^{-10}	1.017(34) 10^{-3}	6.88(24)	−0.340(17)
$\Sigma^- \to \Lambda e^-\bar{\nu}$	1.479(11)[c] 10^{-10}	0.0573(27) 10^{-3}	0.387(18)	$f_1/g_1 = -0.01(10)$[d]
$\Sigma^+ \to \Lambda e^+\nu$	0.8018(26) 10^{-10}	0.020(5) 10^{-3}	0.250(63)	
$\Xi^- \to \Lambda e^-\bar{\nu}$	1.639(15) 10^{-10}	0.563(31) 10^{-3}	3.44(19)	0.25(5)
$\Xi^- \to \Sigma^0 e^-\bar{\nu}$	1.639(15) 10^{-10}	0.087(17) 10^{-3}	0.53(10)	
$\Xi^0 \to \Sigma^+ e^-\bar{\nu}$	2.900(90) 10^{-10}	0.257(19)[e] 10^{-3}	0.876(71)	1.32(+.22/−.18)

[a] $S = 1.6$

[b] $S = 1.6$

[c] $S = 1.3$

[d] $S = 1.5$

[e] Mean of two independent measurements (3, 57) by the KTeV Collaboration.

What we have measured

SU(3) breaking in Hyperon decays

First order SU(3) symmetry breaking effects are expected to manifest themselves in g_1/f_1. The recently measured decay $\Xi^0 \to \Sigma^+ e^- \bar{\nu}$ provides a direct test because it is predicted to have the same form factor ratio as the well-measured neutron beta decay: $n \to p\, e^- \bar{\nu}$. The KTeV results are consistent with this prediction, but the errors are currently rather large. One can fit the data of the 5 semileptonic decays for the linear combinations $F + D$ and $F - D$ which will then have essentially uncorrelated errors. This fit yields

$$F + D = 1.2670 \pm 0.0035; \quad F - D = -0.341 \pm 0.016; \quad \chi^2 = 2.96/3d.f.$$

Surprisingly, even with today's improved measurements, no clear evidence of SU(3) symmetry breaking effects emerges. They appear to be much smaller than expected!

There have been many attempts to compute SU(3) breaking effects for the vector form factor $f_1(0)$, with results ranging from positive to negative corrections. I expect the final word to come from Lattice QCD, and that the corrections will be small.

NEW since annual review article

Abstract

From 56 days of data taking in 2002, the NA48/1 experiment observed 6316 $\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e$ candidates (with the subsequent $\Sigma^+ \to p\pi^0$ decay) and 555 $\overline{\Xi^0} \to \overline{\Sigma^+} e^+ \nu_e$ candidates with background contamination of 215 ± 44 and 136 ± 8 events, respectively. From these samples, the branching ratios $\mathrm{BR}(\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e) = (2.51 \pm 0.03_{\mathrm{stat}} \pm 0.09_{\mathrm{syst}}) \times 10^{-4}$ and $\mathrm{BR}(\overline{\Xi^0} \to \overline{\Sigma^+} e^+ \nu_e) = (2.55 \pm 0.14_{\mathrm{stat}} \pm 0.10_{\mathrm{syst}}) \times 10^{-4}$ were measured allowing the determination of the CKM matrix element $|V_{us}| = 0.209^{+0.023}_{-0.028}$. Using the Particle Data Group average for $|V_{us}|$ obtained in semileptonic kaon decays, we measured the ratio $g_1/f_1 = 1.20 \pm 0.05$ of the axial-vector to vector form factors.

Conversely, the g_1/f_1 ratio could be extracted from Eq. (18) using the current V_{us} value obtained from kaon decays [18]:

$$g_1/f_1 = 1.20 \pm 0.04_{\mathrm{br}} \pm 0.03_{\mathrm{ext}}, \tag{20}$$

where the uncertainty coming from the present branching ratio measurement (br) takes into account the weak dependence of the acceptance on g_1/f_1 itself. The external error (ext) includes the contributions from V_{us}, Ξ^0 lifetime and f_2/f_1 uncertainties. Our measurement is in agreement with exact SU(3) symmetry

Available online at www.sciencedirect.com
ScienceDirect
Physics Letters B 645 (2007) 36–46
PHYSICS LETTERS B
www.elsevier.com/locate/physletb

Measurement of the branching ratios of the decays $\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e$ and $\overline{\Xi^0} \to \overline{\Sigma^+} e^+ \nu_e$

NA48/1 Collaboration

J.R. Batley, G.E. Kalmus [1], C. Lazzeroni, D.J. Munday, M. Patel, M.W. Slater, S.A. Wotton

Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, UK [2]

R. Arcidiacono, G. Bocquet, A. Ceccucci, D. Cundy [3], N. Doble [4], V. Falaleev, L. Gatignon, A. Gonidec, P. Grafström, W. Kubischta, F. Marchetto [5], I. Mikulec [6], A. Norton, B. Panzer-Steindel, P. Rubin [7], H. Wahl [8]

CERN, CH-1211 Genève 23, Switzerland

E. Goudzovski, P. Hristov [9], V. Kekelidze, L. Litov, D. Madigozhin, N. Molokanova, Yu. Potrebenikov, S. Stoynev, A. Zinchenko

Joint Institute for Nuclear Research, Dubna, Russia

E. Monnier [10], E.C. Swallow [11], R. Winston [12]

The Enrico Fermi Institute, The University of Chicago, Chicago, IL 60126, USA

R. Sacco [13], A. Walker

Department of Physics and Astronomy, University of Edinburgh, JCMB King's Buildings, Mayfield Road, Edinburgh EH9 3JZ, UK

W. Baldini, P. Dalpiaz, P.L. Frabetti, A. Gianoli, M. Martini, F. Petrucci, M. Scarpa, M. Savrié

Dipartimento di Fisica dell'Università e Sezione dell'INFN di Ferrara, I-44100 Ferrara, Italy

A. Bizzeti [14], M. Calvetti, G. Collazuol [15], E. Iacopini, M. Lenti, G. Ruggiero [9], M. Veltri [16]

Dipartimento di Fisica dell'Università e Sezione dell'INFN di Firenze, I-50125 Firenze, Italy

M. Behler, K. Eppard, M. Eppard [9], A. Hirstius [9], K. Kleinknecht, U. Koch, L. Masetti, P. Marouelli, U. Moosbrugger, C. Morales Morales, A. Peters [9], R. Wanke, A. Winhart

Institut für Physik, Universität Mainz, D-55099 Mainz, Germany [17]

A. Dabrowski, T. Fonseca Martin [9], M. Velasco

Department of Physics and Astronomy, Northwestern University, Evanston, IL 60208-3112, USA

0370-2693/$ – see front matter
doi:10.1016/j.physletb.2006.12.028

Experiment:

g_1/f_1 = 1.20 +/- 0.05

For neutron decay

2012 PDG value is 1.2701 +/- .0025

Even for this SU(3) mirror of the neutron which is 40% more massive There is no evidence for symmetry breaking!

What can we say about weak electricity (g_2)?

In determining g_1 from the Dalitz plot ($e\nu$ correlation)

one is *actually* measuring $g_1^* \approx g_1 - \delta g_2$ ($\delta = \Delta M/M$)

Rate ~$V_{us}^2 [f_1^2 + 3 g_1^{*2} + 2 \delta g_1^* g_2]$

g_2 hides inside the axial vector Like the SHADOW

TABLE 5 Values of V_{us} derived from g_1/f_1 and rate

Decay	Rate (μs^{-1})	g_1/f_1	V_{us}
$\Lambda \to pe^-\bar{\nu}$	3.161(58)	0.718(15)	0.2224 ± 0.0034
$\Sigma^- \to ne^-\bar{\nu}$	6.88(24)	−0.340(17)	0.2282 ± 0.0049
$\Xi^- \to \Lambda e^-\bar{\nu}$	3.44(19)	0.25(5)	0.2367 ± 0.0099
$\Xi^0 \to \Sigma^+ e^-\bar{\nu}$	0.876(71)	1.32(+.22/−.18)	0.209 ± 0.027
Combined	—	—	0.2250 ± 0.0027

PDG 2012: Vus = 0.2252 (9) from kaon decays

An interesting calculation

Let's reverse the reasoning and introduce the correct rate (including g_2)

and treat Vus as a known quantity (0.2252) from pure vector K-decays.

Let $x^* = (g_1 - \delta g_2)/f_1$ and $y = g_2/f_1$

We can *rescale* Vus as $\frac{Vus}{0.2252} \approx 1 + \frac{\delta x{*}y}{1+3x{*}^2}$

The trend is to have a small (negative) g_2 in both lamba and sigma beta decay $(y \approx -0.3)$

However, the values are *not* yet statistically significant.

Appeal to Experimentalists:

Refined Hyperon Beam experiments to measure the Axial Vector form factors more precisely

Motivation: Historically, the axial vector form factor g1 in neutron decay was connected to spontaneous symmetry breaking) and Nambu-Goldstone boson (p) by the famous Goldberger-Trieman relation

Appeal to Theorists

So far we have g1 beautifully following the SU(3) pattern predicted by Cabibbo.

How about dynamical calculations, (like the G-T relation) for the hyperons.

And while we are at it, how about calculations for the induced terms, like g2 which may not be so small after all.

Concluding remark

During his September 2008 visit to UC Merced, we made a trip to nearby Yosemite National Park. Nicola was an avid photographer, with the characteristic attention to detail evident in his science. His images of *El Capitan* (courtesy of Paola Cabibbo), much like the celebrated hay stacks of Monet, convey the grandeur and solidity of both the mountain and of his contributions to particle physics.