LA--11670-PR

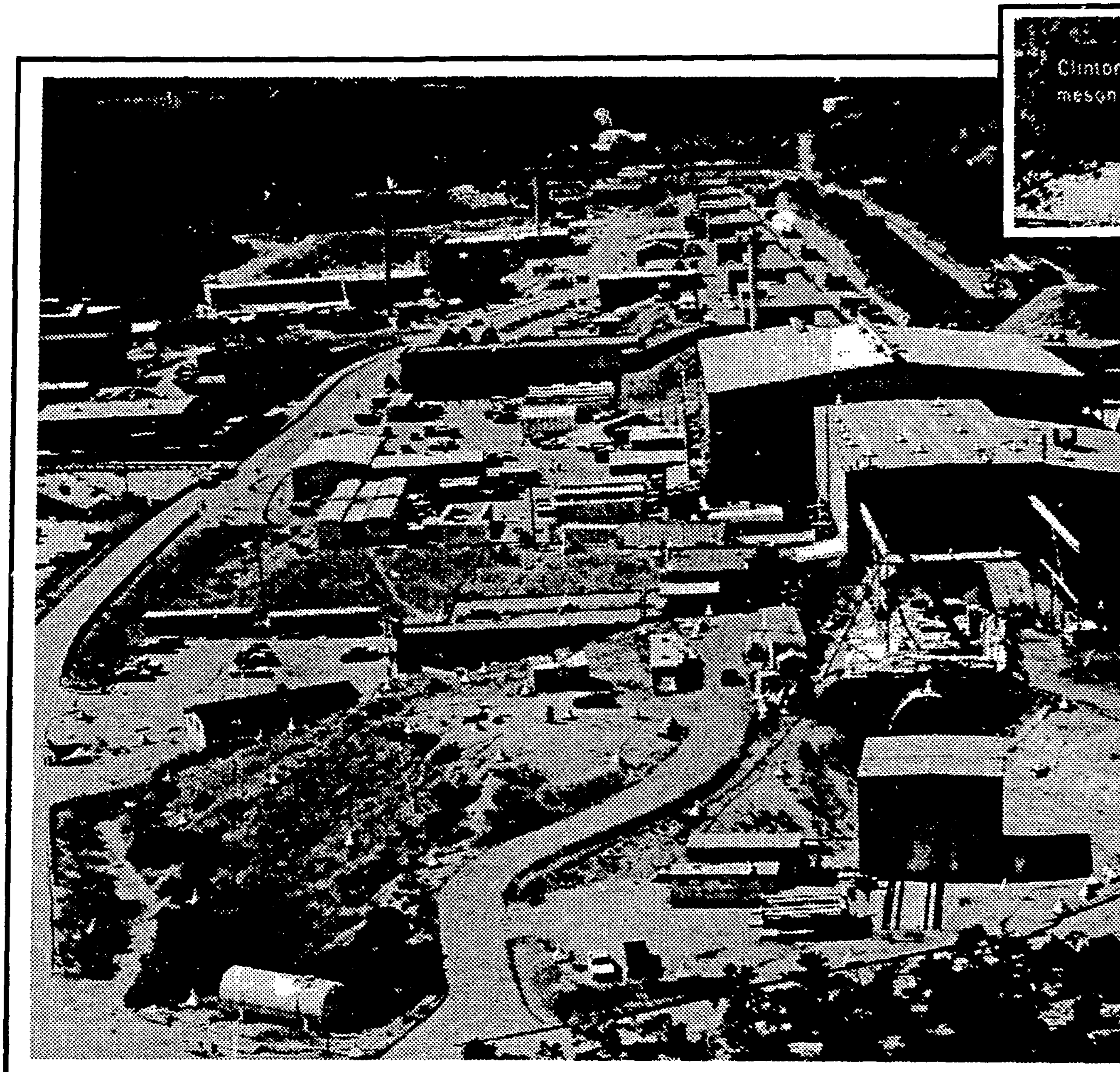
DE90 001809

Progress at LAMPF

January - December 1988

Clinton P. Anderson Meson Physics Facility

Los Alamos National Laboratory


Clinton
meson

Progress at LAMPF

January–December 1988
LA-11670-PR
Progress Report
UC-410 and UC-414
Issued September 1989

EDITOR

Karen Poelakker

SCIENTIFIC EDITORIAL BOARD

Richard L. Hutson

Mario E. Schillaci

Olin B. van Dyck

D. Hywel White

WORD PROCESSING

Jeanne Bowles

ILLUSTRATIONS

Chris Francis

ABSTRACT

"Progress at LAMPF" is the annual progress report of MP Division of the Los Alamos National Laboratory. Included are brief reports on research done at LAMPF by researchers from other institutions and other Los Alamos Divisions.

FOREWORD

In the past year it has been gratifying to see conclusive results from some established research programs and outstanding accomplishments in more recent initiatives. The LAMPF community can be proud of its vigor in this time of increasing budgetary pressure.

Recent LAMPF experiments in neutrino physics have provided both a measured cross section for ν_e-e scattering (in agreement with predictions of the Standard Model), and a new, improved limit for neutrino oscillations. The multi-institutional MEGA team has placed much of the sophisticated detector system under construction and intends to obtain data over the next two years that will lead to a significant improvement in the branching ratio limit for $\mu \rightarrow e\gamma$ as a new stringent test of the Standard Model.

In nucleon physics the Neutron Time-of-Flight (NTOF) facility will allow charge-exchange reactions to be studied with unprecedented resolution over the entire energy range of LAMPF. In the first use of the full NTOF system for research, resolution around 0.7 MeV was achieved at 650 and 500 MeV on $^{14}C(p,n)$. Our capability for developing and using polarized nuclear targets was demonstrated in the performance of an ambitious $\vec{p}$– $^{13}\vec{C}$ scattering experiment. Both the high intensity polarized ion source (OPPIS) and the Medium-Resolution Spectrometer (MRS) for (n,p) reaction studies will be brought on-line during the coming summer. By the mid-1990s the nuclear physics community should have obtained an excellent characterization of the spin-isospin modes of nuclear excitation as well as the effects of the nuclear medium on the interaction of the nucleon in the nuclear field.

All three of the LAMPF pion channels were heavily utilized with emphasis on employing SCX, DCX, and pion-nucleus-scattering reactions as probes of nuclear structure and the pion-nucleus interaction. LAMPF's high beam flux, flexible capabilities, and strong user motivation came together in an experiment on LEP using the Large-Aperture Spectrometer that gave a limit on particle-stable $T = 2$ $pp\pi^+$ and $nn\pi^-$ systems of several hundred picobarns for positive excitation energies. The capability for good resolution nuclear spectroscopy using low-energy pions will be extended by locating a superconducting rf cavity at the exit of the LEP channel that will provide a compression of pion momentum spread by a factor of five from its present value. The popularity of pion physics in the LAMPF user community was amply illustrated by the receipt of more than twenty proposals in this area at the August 1988 meeting of the Program Advisory Committee.

A DOE review of LAMPF took place in June 1988. The review was quite positive about LAMPF management, quality of the research programs, and interactions with the user community. The DOE review committee stated, "Generally speaking, the Laboratory has succeeded in building a strong, balanced physics program that has been sensibly focused on the unique capabilities of LAMPF. In our view, LAMPF is a world leader in medium-energy pure and applied physics."

The LAMPF community should be proud to have received another endorsement of the caliber given by the Vogt committee in 1982, that "LAMPF is the flagship of U. S. nuclear science." However, in the context of budget projections, we are being forced to accommodate a smaller total research program. Our present thoughts about the impact of these budget projections on LAMPF operations and research have been distributed recently to our users and the DOE.

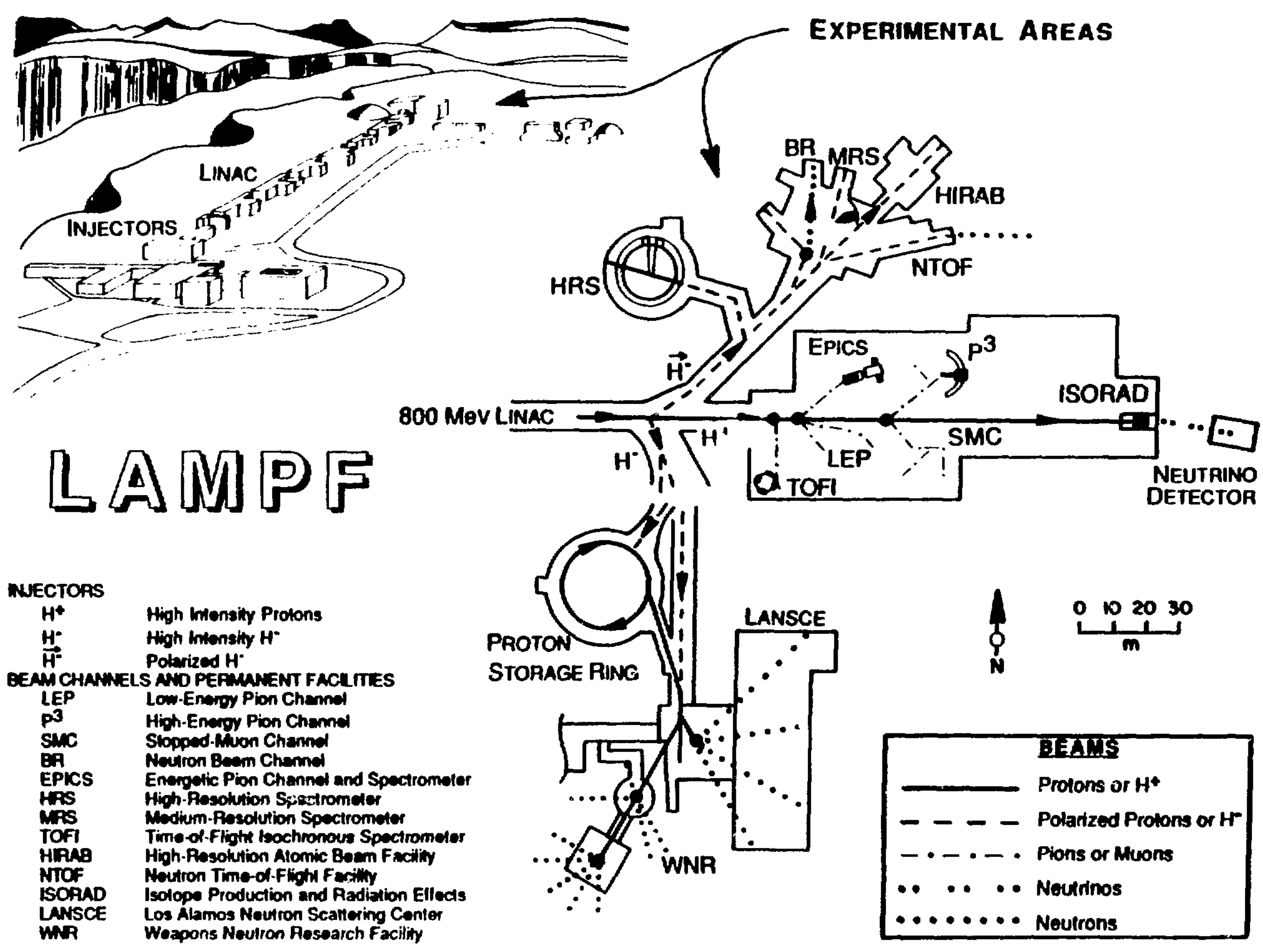
Budget projections strongly affect LAMPF's future activities. Another factor is the anticipated time frame for initiating a major accelerator upgrade. This date seems later than we had initially expected, which means that we must think in terms of planning for long-term (5–10 years) operation of LAMPF in its present form as the nation's largest nuclear science facility. Our intent, despite a shrinking budget, is to continue our world-class research and crucial educational role based on an effective staff, a vigorous user community, and strong, flexible facility capabilities, and to retain the enthusiasm and competence to address a major facility upgrade at the appropriate time.

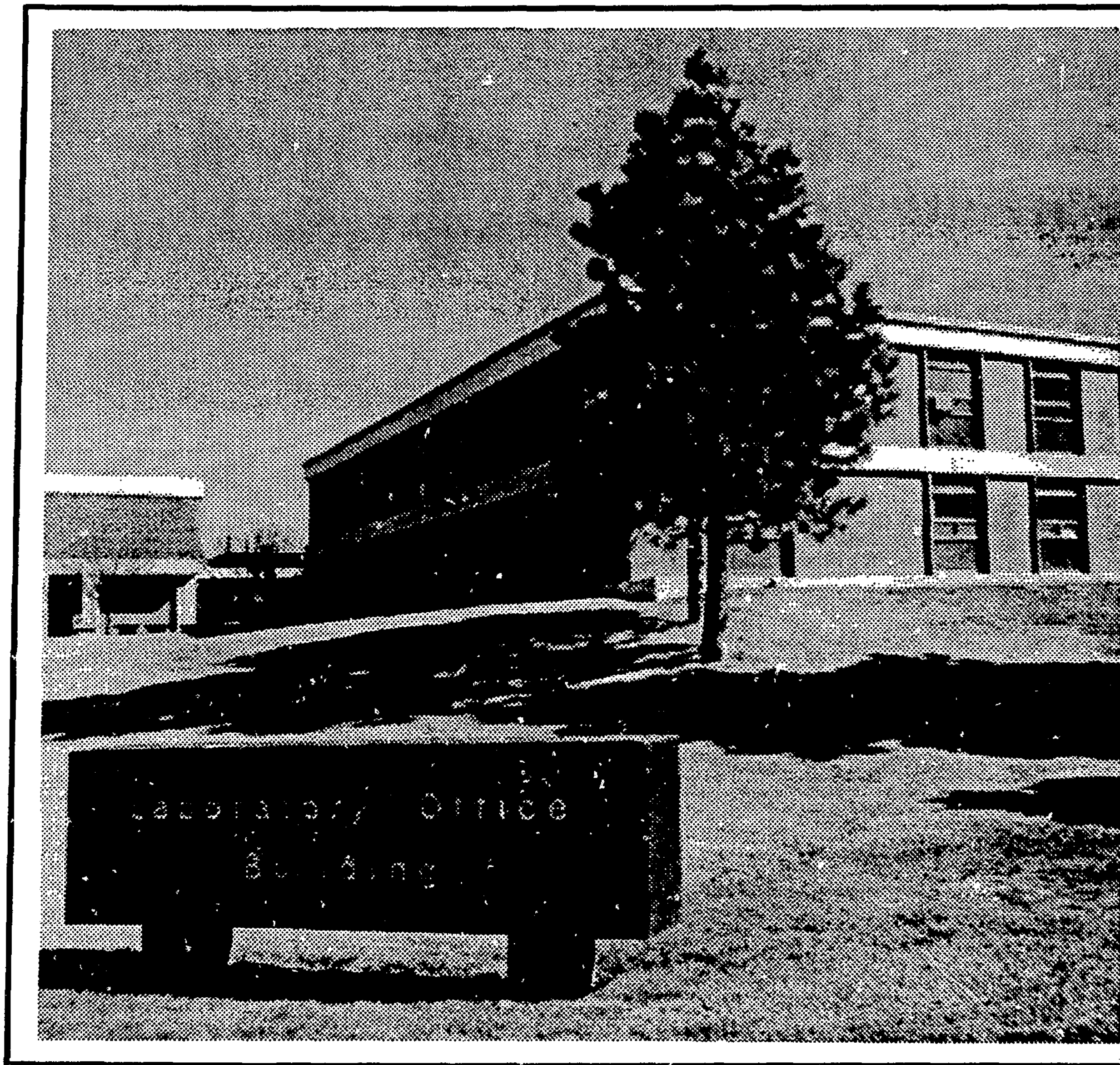
Gerald T. Garvey
Director of LAMPF

CONTENTS

Contents

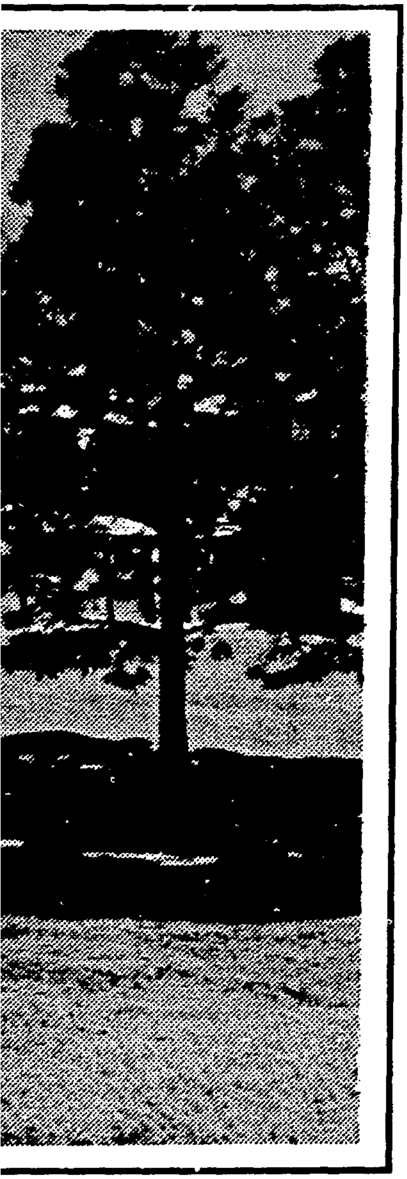
LAMPF Experimental Areas





Photograph by Rick Bolton

LAMPF Users Group



Twenty-Second Annual Meeting

Committees

Workshops

Visitors Center

Twenty-Second Annual Meeting

The Twenty-Second Annual Meeting of the LAMPF Users Group, Inc., was held in Los Alamos on October 17–18, 1988, with 146 attendees. Chairman Stanley Hanna (Stanford University) presided at the first session, which included the following presentations:

"Welcome," Warren Miller, Deputy Director;
"Report from Washington," Clarence Richardson, Department of Energy;
"Status of LAMPF," Gerald Garvey, Director of LAMPF;
"MP-Division Report," Donald Hagerman, MP-Division Leader; and
"The Associated Western Universities Program," Thomas Squires, Director (AWU).

In honor of Louis Rosen's 70th birthday, there were the following presentations:

"Introductory Remarks," Stanley Hanna (Stanford University); and
"Louis Rosen and Nuclear Physics," Herman Feshbach (Massachusetts Institute of Technology).

The Louis Rosen Prize was presented to Edward R. Kinney (Massachusetts Institute of Technology) for his thesis entitled, "Inclusive Pion Double Charge Exchange in ^{4}He at Intermediate Energies."

The afternoon session was conducted by incoming Chairman Peter Riley (University of Texas). The following talks were given during the session:

"Report from the Users Group," Stanley Hanna (Stanford University);
"Recent Pion-Nucleus Physics," William Gibbs (Los Alamos);
"Pion-Nucleus Reactions," Gary Kyle (New Mexico State University);
"Spin Physics at LAMPF," Kevin Jones (Los Alamos);
"Nucleon-Induced Charge-Exchange Reactions," Parker Alford (University of Western Ontario and TRIUMF); and
"Radiative Muon Capture," Michael Hasinoff (University of British Columbia).

On the second day of the meeting the session was conducted by the new Chairman-Elect Robert McKeown (California Institute of Technology). The following talks were given during the session:

"Neutrino Oscillations," Felix Boehm (California Institute of Technology);
"Research at Paul Scherrer Institute," Manfred Daum (PSI); and
"Status of the Advanced Hadron Facility," Gerald Garvey (Los Alamos).

During the remainder of the day, various working groups met.

Committees

Board of Directors

The Board of Directors comprises a Liaison Officer and seven members elected by the LAMPF Users Group, Inc., whose interests they represent and promote. They concern themselves with LAMPF programs, policies, future plans, and especially with how users are treated at LAMPF. The Board also nominates new members for the Program Advisory Committee (PAC). Users should address problems and suggestions to individual Board members.

The 1989 membership and term expiration dates are listed below.

James Bradbury
(Liaison Officer)
Los Alamos

Terms Expiring in 1989

Stanley Hanna
(Past Chairman)
Stanford University

Gary Kyle
New Mexico State University

John McClelland
Los Alamos

Terms Expiring in 1990

Wick Haxton
University of Washington

Ed Hungerford
University of Houston

Peter Riley (Chairman)
University of Texas

Terms Expiring in 1991

Robert McKeown
(Chairman-Elect)
California Institute of Technology

Experimental Facilities Panel

The Experimental Facilities Panel (EFP) provides technical recommendations to the Board of Directors and LAMPF management about the development of experimental facilities and support activities. The chairman of the Board of Directors will also act as chairman of the EFP. The EFP consists of not more than fifteen (15) members, each of whom serve for two (2) years, chosen so that approximately half of the panel consists of continuing members each year, and so that the major experimental facilities and beam channels are represented. The duties of the EFP members are to: (1) solicit information from the Users and from LAMPF staff on problems, suggested improvements, and future developments; (2) disseminate such information to the Users; (3) report on User activities, problems, and suggestions at meetings of the EFP; and (4) chair working group meetings at the annual Users Meeting. The EFP will meet at least twice a year, and members of the Board of Directors and the Liaison Officer are to be members ex officio.

Members and term expiration dates are listed below.

Terms Expiring in 1989

George Burleson—Polarized
Targets
New Mexico State University

Frank Clinard—Materials
Science
Los Alamos

Martin Cooper—SMC
Los Alamos

Keven Jones—HRS
Los Alamos

Thomas Kozlowski—Computer Facilities
Los Alamos

Christopher Morris—EPICS
Los Alamos

Evan Sugarbaker—NTOF
Ohio State University

Jan Wouters—Nuclear Chemistry
Los Alamos

Terms Expiring in 1990

Richard Allen—Neutrino Facilities
University of California, Irvine

Michael Leitch—LEP
Los Alamos

Michael McNaughton—NPL
Los Alamos

Bernhard Mecking—Member-at-Large
CEBAF

R. Jerry Peterson—P^3
University of Colorado

Greg Smith—Member-at-Large
TRIUMF

Workshops

LAMPF workshops and meetings in 1988:

MEGA Collaboration Meeting
(Stanford, California)
January 11–12, 1988

Program Advisory Committee (PAC)
January 25–29, 1988

Advanced Hadron Facilities Accelerator Design Workshop
February 22–26, 1988

MEGA Collaboration Meeting
(Charlottesville, Virginia)
April 11–12, 1988

Third Conference on the Intersections Between Particle and Nuclear Physics
(Rockport, Maine)
May 14–19, 1988

Nuclear and Particle Physics on the Light Cone
July 18–22, 1988

MEGA Collaboration Meeting
July 28–29, 1988

Program Advisory Committee (PAC)
August 22–25, 1988

LAMPF Users Meeting
October 17–18, 1988

MEGA Collaboration Meeting
November 3–4, 1988

The following LAMPF workshops are scheduled in 1989:

Workshop on Future Options for Data Acquisition and Analysis
January 11–13, 1989

Program Advisory Committee (PAC)
January 17–20, 1989

AHF Accelerator Design Workshop
February 20–25, 1989

Workshop on Double Charge Exchange
August 9–11, 1989

LAMPF Users Meeting
November 6–7, 1989

Visitors Center

During this report period, 585 research guests worked on LAMPF-related activities or participated in experiments at LAMPF; of these, 276 were foreign visitors.

LAMPF Users Group Membership

Membership

Non-Laboratory	818
Los Alamos National Laboratory	204
TOTAL	1,022

Institutional Distribution

Membership by Institutions

Los Alamos National Laboratory	204
National or Government Laboratories	95
U.S. Universities	477
Industry	24
Foreign	190
Hospitals	7
Nonaffiliated	25
TOTAL	1,022

Number of Institutions

National or Government Laboratories	21
U.S. Universities	126
Industry	21
Foreign	109
Hospitals	7
Nonaffiliated	7
TOTAL	291

Regional Breakdown

East

Pennsylvania, New Jersey, Delaware, Washington DC, Massachusetts, New York, Connecticut, Vermont, Rhode Island, New Hampshire, Maine	12.8%

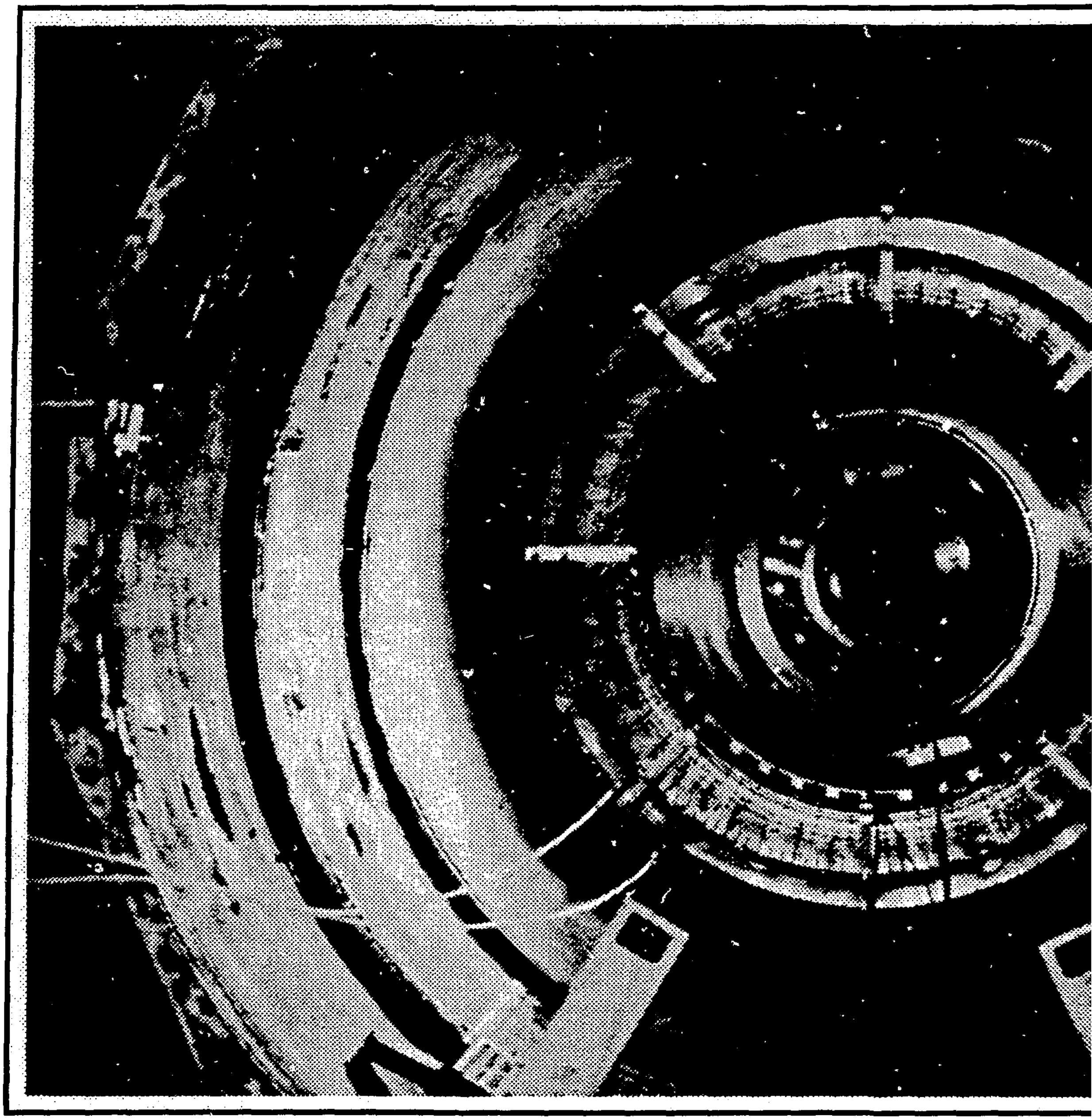
Midwest

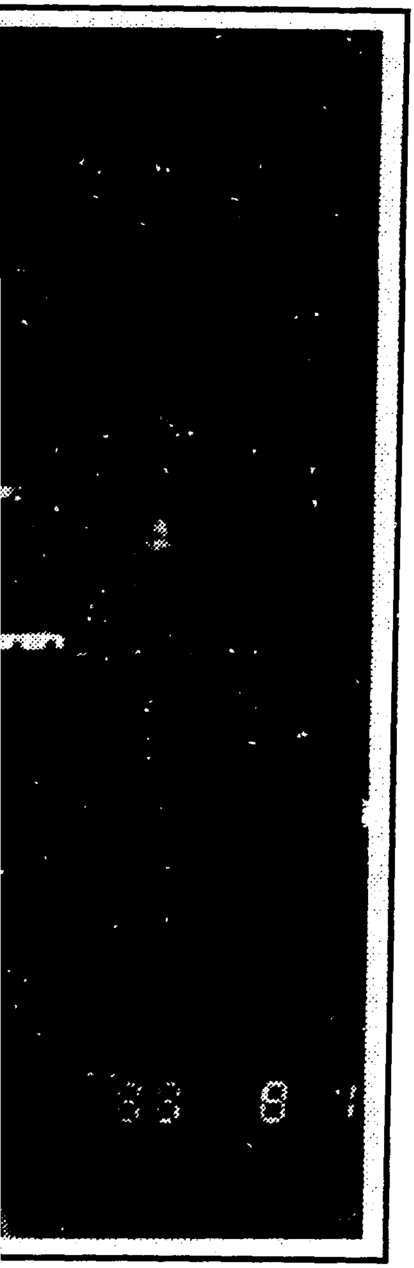
Ohio, Missouri, Kansas, Indiana, Wisconsin, Michigan, Illinois, North Dakota, South Dakota, Nebraska, Iowa, Minnesota	12.5%

South

Maryland, Virginia, Tennessee, Arkansas, West Virginia, Kentucky, North Carolina, Alabama, Mississippi, Louisiana, Georgia, Florida, South Carolina	10.4%

Southwest, Mountain	
Montana, Idaho, Utah, Wyoming, Arizona, Colorado, New Mexico (excluding Los Alamos), Oklahoma, Texas	15.5%
West	
Alaska, Hawaii, Nevada, Washington, Oregon, California	9.6%
Foreign	18.9%
Los Alamos National Laboratory	20.3%





Research

Nuclear and Particle Physics

Astrophysics

Atomic and Molecular Physics

Materials Science

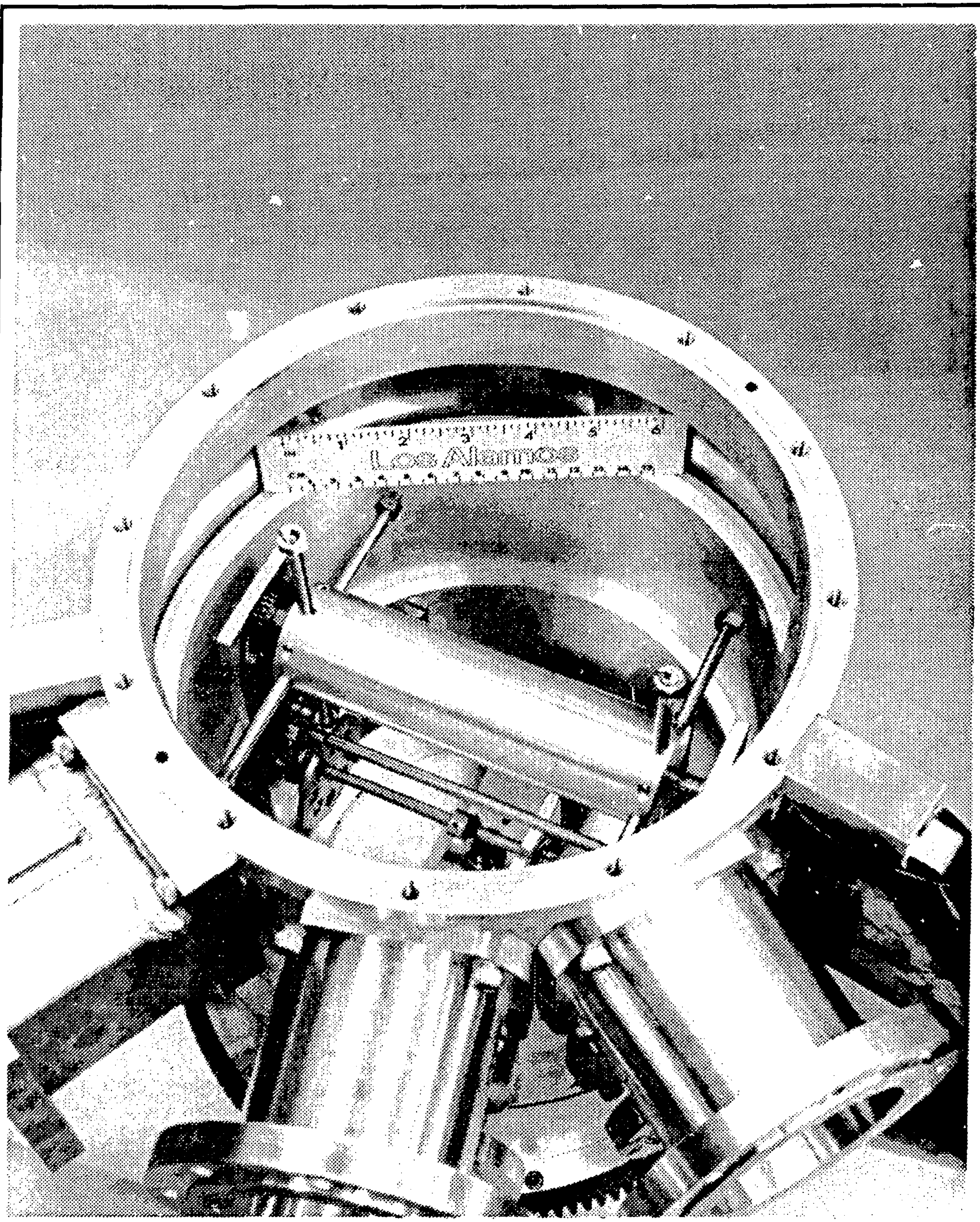
Nuclear Chemistry

Radiation Effects

Radioisotope Production

Theory

MP-Division Publications


Los Alamos

Nuclear and Particle Physics

EXPERIMENT 791 — BNL AGS

A Study of Very Rare K_L^0 Decays

UC Irvine, UCLA, Los Alamos, Univ. of Pennsylvania, Stanford Univ., Temple Univ., College of William & Mary

Spokesmen: R. D. Cousins (UCLA) and W. R. Molzon (UC Irvine)

Participants: C. Mathiazhagan, W. R. Molzon, R. D. Cousins, J. Konigsberg, J. Kubic, P. P. Rubin, W. E. Slater, D. Wagner, G. W. Hart, W. W. Kinnison, D. M. Lee, R. J. McKee, E. C. Milner, G. H. Sanders, H. J. Ziock, K. Arisaka, P. Knibbe, J. Urheim, S. Axelrod, K. A. Biery, G. M. Irwin, K. Lang, J. Margulies, D. A. Ouimette, J. L. Ritchie, Q. H. Trang, S. G. Wojcicki, L. B. Auerbach, P. Buchholz, V. L. Highland, W. K. McFarlane, M. Wivertz, M. D. Chapman, M. Eckhause, J. F. Ginkel, A. D. Hancock, D. Joyce, J. R. Kane, C. J. Kenney, W. F. Vulcan, R. E. Welsh, R. J. Whyley, and R. G. Winter

Experiment 791 at the Brookhaven National Laboratory Alternating Gradient Synchrotron (BNL AGS) is a study of very rare K_L^0 decays, primarily $K_L^0 \to \mu e$, which is forbidden in the standard model of electroweak interactions, and $K_L^0 \to \mu\mu$ and $K_L^0 \to ee$, which are allowed. The first decay is forbidden because it would violate conservation of separate lepton number, but is an allowed process in theories extending the standard model to include unification of the lepton families. The second decay has been previously observed, with the branching ratio $K_L^0 \to \mu\mu = 9.1 \times 10^{-9}$. The standard model prediction for the third decay is $BR(K_L^0 \to ee) \approx 4 \times 10^{-12}$, which is below our present sensitivity.

At the beginning of 1988, there were three experimental collaborations in the world conducting searches for $K_L^0 \to \mu e$: BNL Exp. 780, KEK Exp. 137, and BNL Exp. 791. The relative sensitivities of the experiments can be judged approximately by the number of $K_L^0 \to \mu\mu$ events simultaneously collected. Experiment 780 has been completed (Ref. 1), setting a limit of $BR(K_L^0 \to \mu e) < 1.9 \times 10^{-9}$ (90% C.L.), while observing 10 $K_L^0 \to \mu\mu$ events. The Japanese group at Exp. 137 had obtained about 20 $K_L^0 \to \mu\mu$ candidates by November 1988, and hopes to eventually collect a total of 100 events by the end of the experiment in 1989. By comparison, in Exp. 791 about 80 $K_L^0 \to \mu\mu$ events were found in 1988, and about 400 more events should be added to this sample from data collected in 1989. Note that before these three experiments began, the world total of $K_L^0 \to \mu\mu$ events was 28, gathered in three experiments done about ten years ago. It appears that Exp. 791 is currently the most powerful rare K_L^0 decay experiment and should remain so for the foreseeable future.

The 1988 data run was 12 weeks long, with an average of $\approx 3 \times 10^{12}$ protons per pulse (3.2-s macrocycle time, with a 1.2-s beam spill) striking the kaon-production target, yielding about 5×10^7 kaon decays per spill within the spectrometer acceptance. A total of 2500 high-density data tapes were written, containing about 2×10^8 events. No examples of the decays $K_L^0 \to \mu e$ or $K_L^0 \to ee$ were found. The central results from the analysis of these data are a limit (preliminary) of $BR(K_L^0 \to \mu e) < 3 \times 10^{-10}$ (90% C.L.) and the identification of about 80 $K_L^0 \to \mu\mu$ candidate events. Plots of the reconstructed invariant mass versus colinearity angle for these decays are shown in Fig. 1. A fit to the $K_L^0 \to \pi^+\pi^-$ spectrum demonstrating a spectrometer resolution of 1.4-MeV FWHM (meeting the design goals) is shown in Fig. 2. It is noteworthy that the once rare, but now commonplace, CP-violating $K_L^0 \to \pi^+\pi^-$ decay is now used in studying spectrometer characteristics and in normalizing the sensitivity to rare decays.

The 2500 hours of beam time originally allotted to Exp. 791 were exhausted at the end of the 1988 run, but a request for an additional 2500 hours was recently approved by the AGS PAC. The 1989 run is scheduled for January through May, with the following enhancements to the experiment:

1. higher intensity beam of $\approx 8 \times 10^{12}$ protons per pulse on target,
2. a beam macrocycle time of 2.5 s with a spill 1.2 s long, and

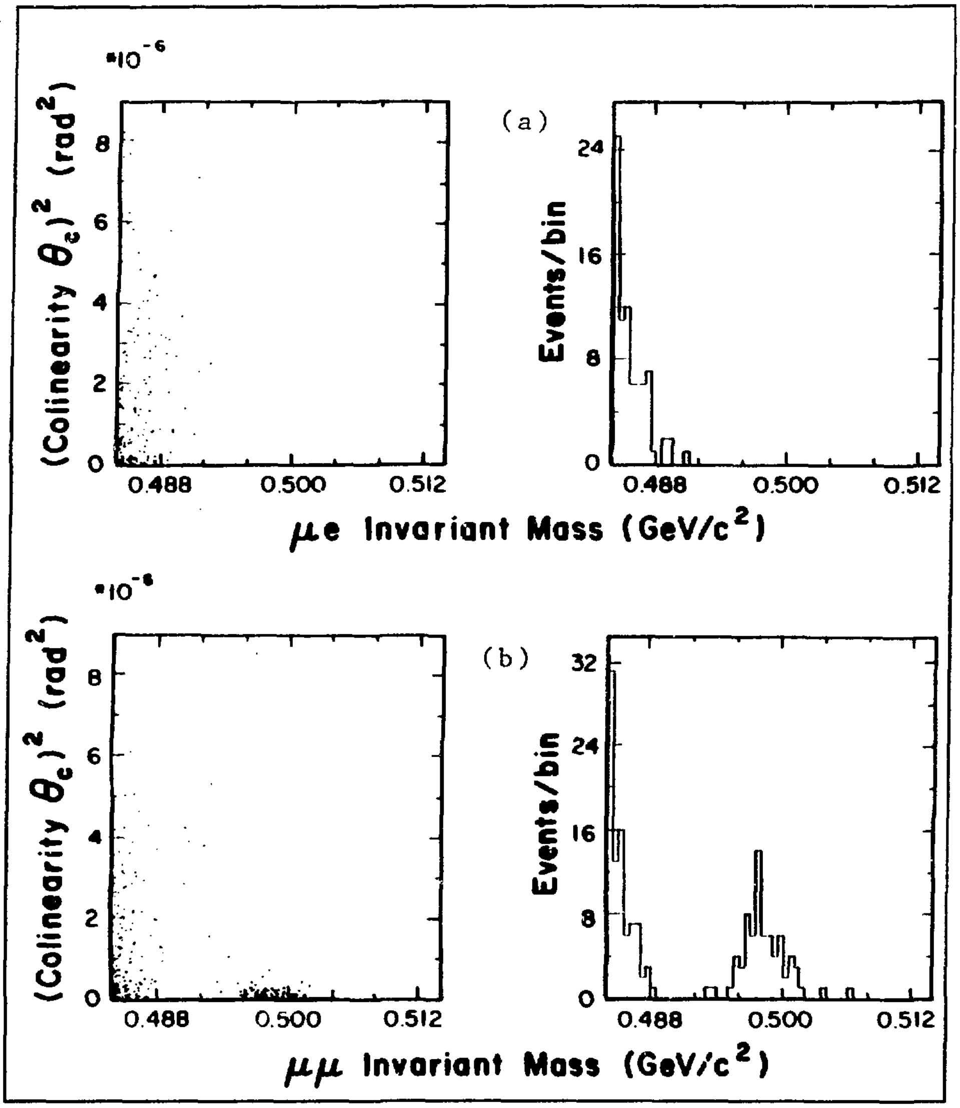


Fig. 1. Plots from the preliminary analysis of the 1988 Exp. 791 data showing the reconstructed invariant mass for the decays (a) $K_L^0 \to \mu e$ and (b) $K_L^0 \to \mu\mu$. The first plot for both cases is of invariant mass versus the square of the colinearity angle θ_c. Colinearity is the angle between the vector from the kaon-production target to the decay vertex and the measured momentum vector of the reconstructed decay. The second plot for both decays is a mass histogram of all events with colinearity less than 1 mrad^2. In the $K_L^0 \to \mu e$ plots there are no events appearing within three standard deviations (of the spectrometer resolution) of the 497.67 MeV/c^2 kaon mass. Note that the $K_L^0 \to \mu\mu$ events are well separated from the background contributions appearing below 488 MeV/c^2.

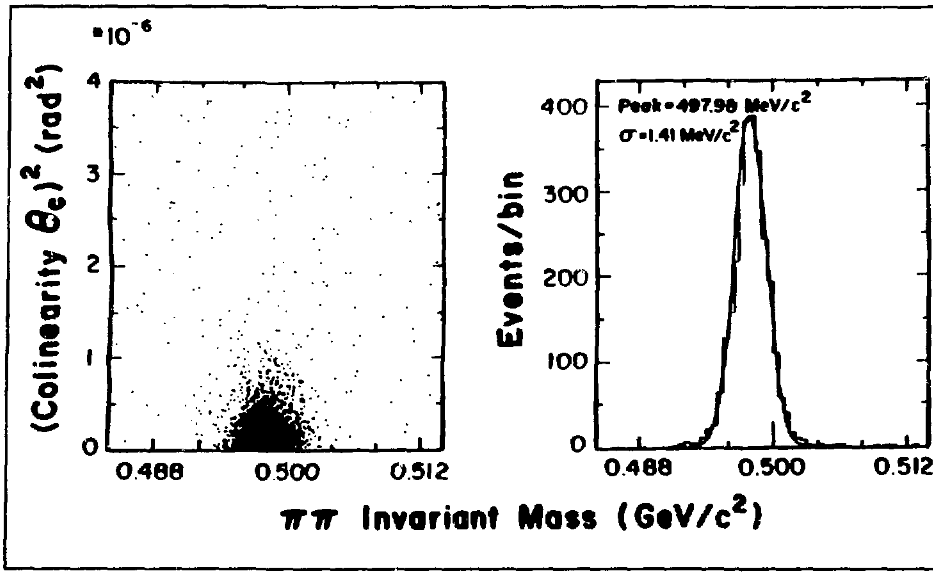


Fig. 2. Histogram showing a fit to a representative $K_L^0 \to \pi^+\pi^-$ sample demonstrating a spectrometer resolution of 1.4 MeV.

3. changing the proton beam targeting angle to 1° from 2.5°, to increase the kaon flux in the detector acceptance region.

The effect of these changes should provide a factor of five increase in sensitivity, allowing us to observe the $K_L^0 \to \mu e$ decay mode if it occurs with a branching ratio in the 10^{-11} range.

More formal discussions of Exp. 791 can be found in the papers published by the collaboration in 1988. The results of the 1987 run, including the limits $BR(K_L^0 \to \mu e) < 1.1 \times 10^{-8}$ (90% C.L.) and $BR(K_L^0 \to ee) < 1.1 \times 10^{-8}$ (90% C.L.), were presented in a Rapid Communication in Physical Review (Ref. 2). Two papers on the muon range finder/polarimeter were submitted to the IEEE Nuclear Science Symposium in Orlando (Ref. 3), and a paper describing the range-finder proportional tubes was published (Ref. 3). Two papers discussing the data-acquisition electronics were also submitted to journals in 1988 (Ref. 4).

The LANL participants in Exp. 791, along with our collaborators from the College of William and Mary, have primary responsibility for the muon range-finder/polarimeter component of the apparatus. In 1987–88, we completed final construction, installation, and testing of the proportional chambers and electronics, which were used to observe the stopping position of muon tracks in the 300 tons of marble and aluminum. For the 1988 data run, the absorber stack was instrumented with 26 pairs of x- and y-measuring planes, with a total of 11,648 sense wires in 5,824 cells. The proportional tubes were highly reliable, producing good quality data throughout the run, which were used in the final data analysis for muon identification and positive confirmation of $K_L^0 \to \mu\mu$ events. In Fig. 3, an event display for a typical $K_L^0 \to \mu\mu$ decay is shown. The momentum measured for both muon tracks in the range finder agrees well with that measured in the spectrometer. An average momentum resolution of $\pm 10\%$ was achieved for muon tracks, meeting the design goal.

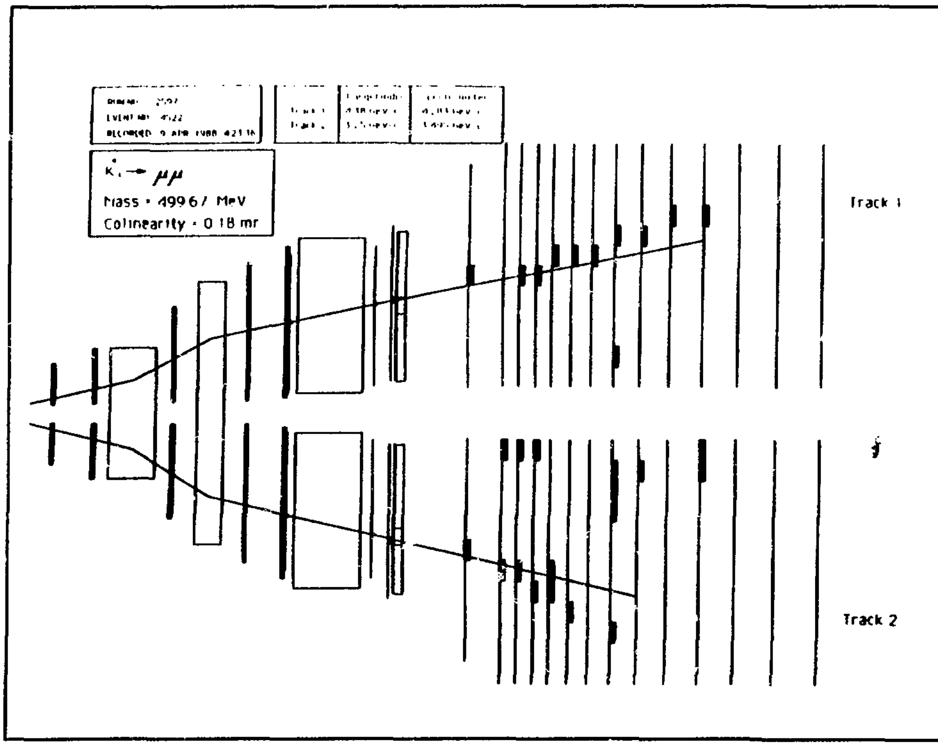


Fig. 3. An event display for a typical $K_L^0 \to \mu^+\mu^-$ decay, a rare process with a branching ratio equal to 9.1×10^{-9}. For this event, there is good agreement between the spectrometer-derived momentum and that given by the depth of penetration of the tracks into the muon-range stack. For "track 1," the spectrometer-measured momentum was 4.283 GeV/c, while the range-finder-derived momentum was 4.38 GeV/c. For "track 2," the momentum in the spectrometer was 3.495 GeV/c, and 3.25 GeV/c measured in the range finder. The lines drawn to indicate the tracks correspond to a straight-line projection from the tracks found in the spectrometer drift chambers. Because of multiple scattering, the actual muon tracks deviate from the projection in the range finder. The asterisks shown between the two range-finder arms mark the end of the track found by the track-finding algorithm. The maximum depth between x- and y-views is taken as the end of the track. The x-view is shown in this figure, but in the y-view the track on the beam-right side was one gap longer, so the line drawn to guide the eye extended one plane further than the last apparent track hit.

To summarize, Exp. 791 is leading the search for very rare K_L^0 decays, critically testing the standard model. Significant improvement in the limits on the decays $K_L^0 \rightarrow \mu e$ and $K_L^0 \rightarrow ee$ were obtained, while simultaneously collecting the largest number of $K_L^0 \rightarrow \mu\mu$ events ever seen. A five-month-long data run commences in early 1989, with the prospect of improving these measurements by a factor of five.

References

1. H. B. Greenlee, H. Kasha, E. B. Mannelli, M. Mannelli, S. F. Schaffner, M. P. Schmidt et al., *Phys. Rev. Lett.* **60**, 893 (1988); E. Jastrzembski, R. C. Larsen, L. B. Leipuner, W. M. Morse, H. B. Greenlee, H. Kasha et al., *Phys. Rev. Lett.* **61**, 2300 (1988).

2. R. D. Cousins, J. Konigsberg, J. Kubic, P. Mélèse, P. Rubin, W. E. Slater et al., *Phys. Rev. D* **38**, 2914 (1988).

3. J. S. Frank, G. W. Hart, W. W. Kinnison, D. M. Lee, R. J. McKee, E. C. Milner et al., "A Tracking Rangefinder for Muons from Kaon Decays," *IEEE Trans. Nucl. Sci.* **36**, 79–85 (1989); C. J. Kenney, M. Eckhause, J. F. Ginkel, P. P. Guss, J. R. Kane, W. F. Vulcan et al., "Use of Proportional Tubes in a Muon Polarimeter," *IEEE Trans. Nucl. Sci.* **36**, 74–78 (1989); D. M. Lee, James R. Bilskie, and Gary H. Sanders, "The Response of Drift Tubes to Variations in Wire Diameter and Gas Fillings," *Nucl. Instrum. and Methods A* **256**, 329 (1987).

4. R. D. Cousins, C. Friedman, and P. L. Mélèse, "32-Channel Digital 6-bit TDC with 2.5 ns Least Count," *IEEE Trans. Nucl. Sci.* **36**, 646–649 (1989). R. D. Cousins, J. Konigsberg, J. Kubic, P. L. Mélèse, G. W. Hart, W. R. Molzon et al., "Fast Parallel Pipelined Readout Architecture for a Completely Flash Digitizing System with Multilevel Trigger," *Nucl. Instrum. and Methods A* **277**, 517–531 (1989).

EXPERIMENTS 770 AND 960 — BR

NP Spin Physics at Line BR

Argonne, New Mexico State Univ., Texas A&M Univ., Tokyo Institute of Technology, Los Alamos, Univ. of Montana, Washington State Univ.

Spokespersons: ***G. Burleson, R. Wagner, H. Spinka, K. F. Johnson, and L. C. Northcliffe***

Participants: ***R. Garnett, M. Rawool, V. Carlson, D. Hill, K. F. Johnson, D. Lopiano, Y. Ohashi, T. Shima, H. Spinka, R. Stanek, D. Underwood, A. Yokosawa, M. Beddo, G. Burleson, J. A. Faucett, G. Kyle, H. Shimizu, G. Glass, S. Nath, L. Northcliffe, J. J. Jarmer, J. Hiebert, R. Kenefick, R. Jeppesen, G. Tripard, D. Grosnick, D. Underwood, R. Wagner, and R. Damjanovich***

Nucleon-nucleon (NN) elastic scattering is one of the most basic reactions in the intermediate energy region (up to 1 GeV). A complete determination of the five isospin-1 ($I = 1$) and five $I = 0$ elastic-scattering amplitudes requires a minimum of nine observables[1] in both the proton-proton (pp) and neutron-proton (np) systems at each energy and scattering angle to determine an unambiguous set of amplitudes. The $I = 1$ elastic-scattering amplitudes are fairly well known up to about 1 GeV from pp elastic-scattering experiments.[2–5] The $I = 0$ amplitudes are poorly known, particularly above 500 MeV, as a result of insufficient data.[2,4–6] There are significant numbers of np differential cross section and polarization measurements, but only a few measurements of other spin parameters. These include a number of observables from TRIUMF[7] up to 495 MeV and from LAMPF[8,9] up to 790 MeV.

A comparison of the behavior of the $I = 0$ and $I = 1$ nucleon-nucleon amplitudes should be quite important. The interpretation of resonance-like behavior of the $^3P_0$, $^1D_2$, and $^3F_3$ partial waves seen in phase-shift analyses[2–5,10] has been clouded by the presence of the $NN \rightarrow \pi d$ and $N\Delta$ channels,[11] which contribute only to $I = 1$. Large inelasticities fitted to the Argand diagrams, for these partial waves, attest to the importance of these inelastic channels. The $I = 0$ channel has a much smaller total inelastic cross section at these energies. Suggestions of resonance-like behavior for some $I = 0$ partial waves have been presented.[12] If confirmed, their interpretation would be free from the difficulties encountered in the $I = 1$ case.

Experiment 770 measured the mixed spin-spin correlation parameter $C_{\sigma\sigma} \approx 0.5C_{SS}$–$0.8C_{SL}$ for np elastic scattering for incident-neutron-beam kinetic energies of 484, 634, and 788 MeV over the center-of-mass angles from $\simeq$75° to 180°. These $C_{\sigma\sigma}$ data are important for determining the $I = 0$ nucleon-nucleon amplitudes and provide strong constraints on the phase-shift solutions.

The experimental setup is shown in Fig. 1. A polarized neutron beam, produced by polarization transfer, was scattered from a polarized proton target (HERA) and the recoil proton was momentum-analyzed in a magnetic spectrometer system.

The fields of the spin-precession magnets LORRAINE and CASTOR were adjusted to provide an $\hat{S}$ beam spin orientation before the polarized target. The laboratory coordinate system is defined by the unit vectors $\hat{L}$, $\hat{S}$, and $\hat{N}$ where $\hat{L}$ is parallel to the beam momentum, $\hat{N}$ is up, and $\hat{S} = \hat{N} \times \hat{L}$. The neutron beam polarization was 40–50% and its direction was flipped once every two minutes. Knowledge of the absolute beam polarization is tied to np analyzing power data; see Ref. 13.

The polarized target material consisted of a mixture of 85% ethylamine (C_2NH_7) and 15% borane ammonia (BH_3NH_3) which gave $\sim$ 16% polarizable hydrogen by weight. The effects of polarized $^{8,9}B$ and ^{14}N in the target was estimated to be negligible.[14] The HERA superconducting magnet was rotated so that the magnetic field direction was at an angle of 37.5° with respect to the

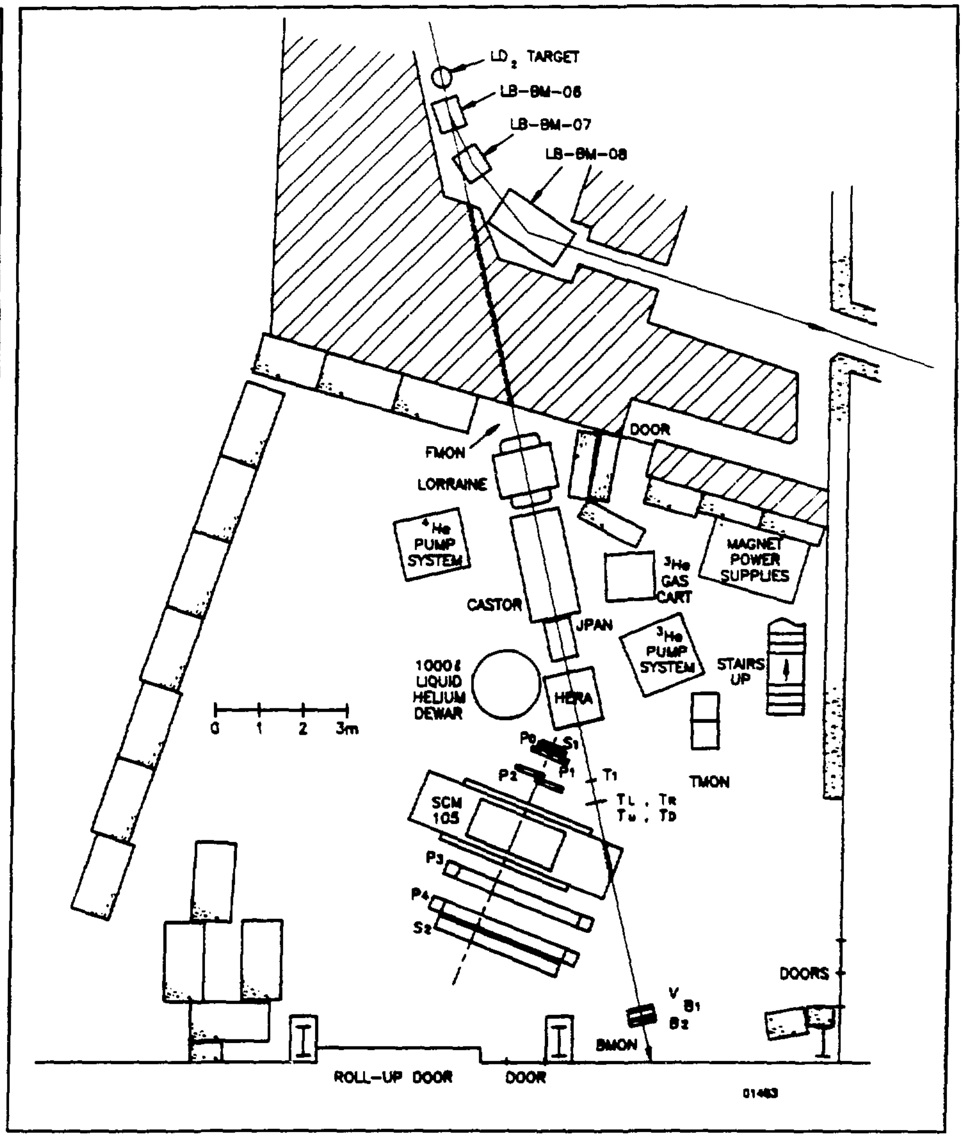


Fig. 1. Schematic diagram of the apparatus. The beam enters at the top.

incident neutron beam direction. Laboratory scattering angles in the range $0° \leq \theta \leq 83°$ were observed. The coil geometry of the magnet prevented a rotation of 90°, which would have allowed measurement of pure C_{SS}. Instead, a linear combination of spin-spin correlation parameters, denoted by $C_{\sigma\sigma}$, was measured. The target polarization direction was changed (parallel and antiparallel to the field) every few hours to cancel systematic effects; its absolute value was typically 75–80%.

Missing-mass spectra were obtained for each energy, angular bin, and relative beam and target polarization. Each spectrum showed the elastically scattered neutron peak on a roughly exponential background whose shape and relative size depended on energy and angle. The typical signal-to-noise ratio at the peak was 0.7. Spectra obtained for each angular bin using a carbon target were used to subtract most of the background. The remaining small residual background was fitted with a quadratic polynomial by the least-squares method.

The spin-spin correlation parameter, $C_{\sigma\sigma}$, was calculated using the formula

$$C_{\sigma\sigma}(\theta) = \frac{1}{P_b P_t} \frac{I^+(\theta) - I^-(\theta)}{I^+(\theta) + I^-(\theta)} ,$$

where $I^{\pm}(\theta)$ are the background-corrected intensities for elastic np scattering at a center-of-mass angle θ. The superscript + (−) indicates parallel (antiparallel) spin states. P_b and P_t are the beam and target polarizations, respectively. The mixed spin-spin correlation parameter, $C_{\sigma\sigma}$, can be written in the form

$$C_{\sigma\sigma} = aC_{SS} + bC_{NN} + dC_{LL} + eC_{SL} ,$$

where a, b, d, and e are the spin admixture coefficients given in Table I. These coefficients were determined by calculating the precession of the neutron spin and the rotation of the scattering plane caused by the polarized target magnetic field. The error bars reflect the statistical uncertainty and an estimate of the uncertainty in the background fitting procedure. The latter uncertainty was generally small and was estimated by comparing linear and quadratic fits to the residual background.

Table I. Spin Component Admixture Coefficients for the C_{SS} Data.

Energy	a	b	d	e
484 MeV	0.475	0.088	0.139	−0.744
634 MeV	0.506	0.064	0.163	−0.809
788 MeV	0.528	0.050	0.178	−0.824

The measured values of $C_{\sigma\sigma}$ are shown in Fig. 2. The most recent phase shift predictions of the VPI,[2] Basque,[15] and Saclay[16] groups and the meson-exchange model predictions of Lee et al.[17] and Machleidt et al.[18] are also shown. Predictions for the pure spin-spin correlation parameters C_{SS}, C_{NN}, C_{LL}, and C_{SL} at the desired scattering angles and energies were used, along with the spin component admixture coefficients, to calculate $C_{\sigma\sigma}$.

Data analysis to determine the pure spin-spin correlation parameter, C_{LL}, at smaller center-of-mass angles is in progress. In addition, work is in progress to extract several spin observables for the $np \rightarrow \pi^0 d$ inelastic reaction from our data.

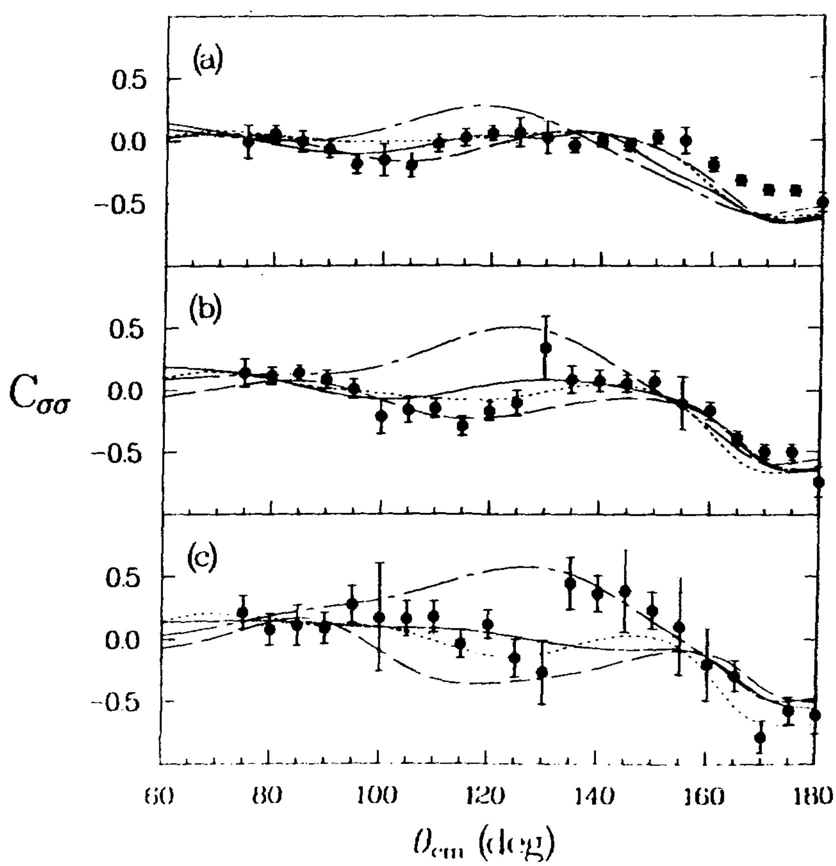


Fig. 2. Measured values of (a) 484-MeV $C_{\sigma\sigma}$, (b) 634-MeV $C_{\sigma\sigma}$, and (c) 788-MeV $C_{\sigma\sigma}$. The curves are the predictions of Arndt, Hyslop, and Roper, solid line; the Saclay group, dash-dot line; the Basque group, dotted line; Lee et al., dashed line; and Machleidt et al., chain-dash line.

Data taking for Exp. 960 has been completed. The total cross-section difference, $\Delta\sigma_L^{\rm tot}(np) = \sigma_L^{\rm tot}(\rightleftarrows) - \sigma_L^{\rm tot}(\rightrightarrows)$, was measured at the five incident-neutron-beam kinetic energies 484, 567, 634, 721, and 788 MeV. Currently, a "first pass" data analysis is in progress in an attempt to understand sources of systematic error. An attempt is being made to reject bad beam spills on the basis of the behavior of the beam current monitor (SEM) and the RF-buncher (as measured by a QVT multichannel analyzer). Additional quantities such as front monitor ratios and event/trigger rates are also being analyzed on a spill-by-spill basis. Studies are in progress to determine correlations between the various monitor quantities and the data. Preliminary results show that we can expect an $\sim\pm 1$ mb error bar at 800 MeV and ± 2–5 mb at the lower energies for $\Delta\sigma_L^{\rm tot}(np)$.

References

1. M. Kamram, *Phys. Rep.* **108**, 275 (1984).
2. R. A. Arndt, J. S. Hyslop, and L. D. Roper, *Phys. Rev. D* **35**, 128 (1987).
3. N. Hoshizaki, *Prog. Theor. Phys.* **60**, 1796 (1978) and **61**, 129 (1979); K. Hashimoto, Y. Higuchi, and N. Hoshizaki, *Prog. Theor. Phys.* **64**, 1678 (1980); K. Hashimoto and N. Hoshizaki, *Prog. Theor. Phys.* **64**, 1693 (1980).
4. R. Dubois, D. Axen, R. Keller, M. Comyn, G. A. Ludgate, J. R. Richardson et al., *Nucl. Phys. A* **377**, 554 (1982).
5. J. Bystricky, C. Lechanoine-Leluc, and F. Lehar, *J. Phys. (Paris)* **48**, 199 (1987).
6. R. A. Arndt, *Phys. Rev. D* **37**, 2665 (1988).
7. A. S. Clough, D. R. Gibson, D. Axen, R. Dubois, L. Felawka, R. Keeler et al., *Phys. Rev. C* **21**, 988 (1980); D. Axen, R. Dubois, R. Keeler, G. A. Ludgate, C. J. Oram, L. P. Robertson et al., *Phys. Rev. C* **21**, 998 (1980).
8. R. D. Ransome, C. L. Hollas, P. J. Riley, B. E. Bonner, W. R. Gibbs, M. W. McNaughton et al., *Phys. Rev. Lett.* **48**, 781 (1982).
9. T. S. Bhatia, G. Glass, J. C. Hiebert, L. C. Northcliffe, W. B. Tippens, B. E. Bonner et al., in *Polarization Phenomena in Nuclear Physics–1980*, G. G. Ohlsen, Ronald E. Brown, Nelson Jarmie, M. W. McNaughton, and G. M. Hale, Eds., *AIP Conference Proceedings* **69** (American Institute of Physics, New York, 1981), p. 123.
10. M. I. Dzhgarkava, Yu. M. Kazarinov, I. Strakhota, and M. R. Khayatov, *Yad. Fiz.* **35**, 65 (1982) [*Trans. Sov. J. Nucl. Phys.* **35**, 39 (1982)].
11. R. L. Shypit, D. V. Bugg, D. M. Lee, M. W. McNaughton, R. R. Silbar, N. M. Stewart et al., *Phys. Rev. Lett.* **60**, 901 (1988); A. B. Wicklund, M. W. Arenton, D. S. Ayres, R. Diebold, E. N. May, L. J. Nodulman et al., *Phys. Rev. D* **35**, 2670 (1987); M. G. Ryskin and I. I. Strakovsky, *Phys. Rev. Lett.* **61**, 2384 (1988)

and R. L. Shypit, D. V. Bugg, D. M. Lee, M. W. McNaughton, R. R. Silbar, N. M. Stewart et al., *Phys. Rev. Lett.* **61**, 2385 (1988).

12. W. Grein, A. Konig, and P. Kroll, *Phys. Lett.* **96B**, 176 (1980); K. Hashimoto, Y. Higuchi, and N. Hoshizaki, *Prog. Theor. Phys.* **64**, 1678 (1980); *Prog. Theor. Phys.* **64**, 1693 (1980).

13. P. J. Riley, C. L. Hollas, C. R. Newsom, R. D. Ransome, B. E. Bonner, J. E. Simmons et al., *Phys. Lett.* **103B**, 313 (1981); J. S. Chalmers, W. R. Ditzler, T. Shima, H. Shimizu, H. Spinka, R. Stanek et al., *Phys. Lett.* **153B**, 235 (1985); D. V. Bugg and C. Wilkin, *Nucl. Phys. A* **467**, 575 (1987).

14. D. Kurath, private communication, Argonne (1985).

15. D. Bugg, private communication, Los Alamos (1988).

16. F. Lehar, private communication, Los Alamos (1988).

17. T.-S. H. Lee, private communication, Argonne (1988).

18. R. Machleidt, private communication, Los Alamos (December 1988).

EXPERIMENT 988 — EPICS

T = 13 Double Isobaric Analog State in ^{138}Ce via Pion-Induced Double Charge Exchange

Univ. of Pennsylvania, Ben-Gurion Univ. (Israel), Univ. of Texas, Los Alamos

Spokesman: C. L. Morris (Los Alamos)

Participants: J. M. O'Donnell, H. T. Fortune, S. Mordechai, C. F. Moore, C. L. Morris, J. D. Silk, S. H. Yoo, and J. D. Zumbro

The Energetic Pion Channel and Spectrometer (EPICS) facility at LAMPF has been used to observe the T = 13 double-isobaric-analog state (DIAS) in ^{138}Ce populated using pion-induced double charge exchange on ^{138}Ba. This is the first observation of the DIAS in the rare-earth region of the periodic table. Measurements of the Q value (-27.38 ± 0.07 MeV), cross section (0.64 ± 0.07 μb/sr) and natural width (250 ± 40 keV) were obtained from the data. This is the second measurement of the width of the DIAS in a heavy nucleus. Figure 1 shows the data and the fit used to extract these measurements.

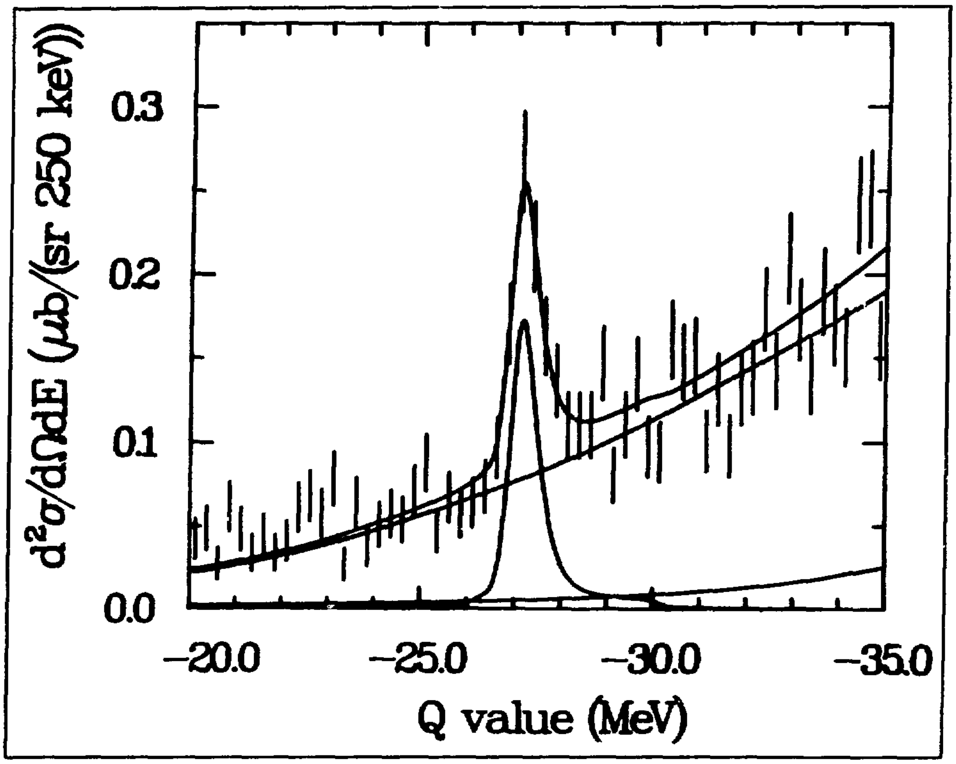


Fig. 1. Fit to the DIAS observed in $^{138}Ba(\pi^+,\pi^-)^{138}Ce$.

An incident pion energy of 292 MeV was used, and a scattering angle of 5° in the laboratory, in order to maximize the peak to background ratio. The Q value was determined by comparison with the known Q value for double charge exchange on ^{12}C.[1] Energy losses in the targets were determined by measuring the elastic peak. The elastic line shape (with a width of 440 keV) was then folded with a Lorentzian of width 250 ± 40 keV to fit the DIAS. The cross section was extracted by first removing a background, fitted with a fourth order polynomial. The absolute normalization of the cross section was obtained by comparison with the known cross section for elastic scattering from hydrogen.[2]

Some properties of the DIAS can be related to properties of the isobaric analog state (IAS). The IAS in ^{138}La has not been observed and so we have estimated some of the properties from the neighboring lanthanum nuclei.[3,4] The width of the DIAS has been predicted to be twice that of the IAS.[5] Our result is consistent with the estimate of 128 ± 60 keV. This is the first test of the width prediction for the DIAS in a heavy nucleus. The Q value can be calculated from the coulomb displacement energies for ^{138}La and ^{138}Ce. These have been estimated from neighboring nuclei,[4] and give a prediction of −26.997 MeV, which is less negative than our value of −27.38 ± 0.07 MeV. This disagreement is also apparent in a comparison between the parameters of the isobaric multiplet mass equation which can be deduced from the data, and systematic estimates of these parameters.[6] The measured cross section is strongly reduced in comparison to the known systematics.[7] The systematic estimate of 0.94 μb/sr is more than four sigma above our measurement of 0.64 ± 0.07 μb/sr.

References

1. G. R. Burleson, G. S. Blanpied, G. H. Daw, A. J. Viescas, C. L. Morris, H. A. Thiessen et al., *Phys. Rev.* C**22**, 1180 (1980).

2. R. A. Arndt, Pion-Nucleon Phase-Shift Analysis Program, SAID.

3. N. Williams, G. C. Morrison, J. A. Nolen, Jr., Z. Vager, and D. von Ehenstein, *Phys. Rev.* C**2**, 1538 (1970); H. Seitz, D. Reick, P. von Brentano, J. P. Wurm, and S. A. A. Zaidi, *Nucl. Phys.* A**140**, 673 (1970); P. von Brentano, N. Marquadt, J. P. Wurm, and S. A. A. Zaidi, *Phys. Lett.* **17**, 124 (1965).

4. W. J. Courtney and J. D. Fox, *Atomic Nuclear Data Tables* **39**, 281 (1988).

5. N. Auerbach, *Phys. Lett.* **41B**, 403 (1972).

6. A. Pape and M. S. Antony, *Atomic Nuclear Data Tables* **39**, 201 (1988).

7. R. Gilman, H. T. Fortune, J. D. Zumbro, C. M. Laymon, G. R. Burleson, J. A. Faucett et al., *Phys. Rev.* C**35**, 1334 (1987).

EXPERIMENT 1032 — EPICS

Pion Scattering from ^{3}He and ^{3}H at the Non-Spin-Flip Dip

UCLA, George Washington Univ., Los Alamos, New Mexico State Univ., Rudjer Bošković Institute (Yugoslavia)

Spokesmen: B. M. Nefkens (UCLA), W. J. Briscoe, and B. L. Berman (George Washington Univ.)

Participants: D. B. Barlow, K. S. Dhuga, S. Greene, R. S. Kessler, G. J. Kim, S. Mathew, C. Pillai, J. W. Price, I. Slaus, C. Smith, D. Smith, and J. A. Wightman

Interactions of π^+ and π^- with the ^{3}H and ^{3}He nuclei can be used to explore many fundamental questions in nuclear and particle physics.[1] The information can be complementary to that obtainable from the electron scattering experiments where the interaction is electromagnetic in nature. The choice of $A = 3$ nuclei has the advantage that accurate theoretical calculations are possible for these nuclei. The experiment described below is part of an ongoing program by our group to study pion scattering from $A = 2$ and 3 nuclei to understand the fundamental nuclear forces in detail. The primary objective of this experiment was to measure the strength of the spin-flip amplitude in π^+ and π^- scattering on ^{3}H and ^{3}He, which is important for the following reasons:

1. To investigate the odd nucleon matter form factor in ^{3}H and ^{3}He. These matter form factors may be compared to the elastic-charge and magnetic form factors obtained from elastic electron scattering to measure the contribution from meson exchange current.[2]

2. To measure the charge symmetric superratio R and the "simple ratios" r_1 and r_2 at the Non-Spin-Flip (NSF) dip to get more information about the violation of charge symmetry as observed in the deviation of these ratios from unity in our previous experiments[3,4] (Exps. 546 and 905):

$$R = \frac{d\sigma(\pi^+ \, ^3\mathrm{H})}{d\sigma(\pi^- \, ^3\mathrm{He})} \times \frac{d\sigma(\pi^- \, ^3\mathrm{H})}{d\sigma(\pi^+ \, ^3\mathrm{He})}$$

$$r_1 = \frac{d\sigma(\pi^+ \, ^3\mathrm{H})}{d\sigma(\pi^- \, ^3\mathrm{He})} \quad \text{and} \quad r_2 = \frac{d\sigma(\pi^- \, ^3\mathrm{H})}{d\sigma(\pi^+ \, ^3\mathrm{He})} \; .$$

   Charge symmetry implies that the above ratios must be equal to unity at all energies and angles.

3. To test new models and calculations in pion nucleus interaction.

The Experiment

The experiment was performed in the EPICS channel of the Los Alamos Meson Physics Facility from June 16–28, 1988. The setup was identical to our previous Exp. 905. We used five cylindrical gas targets containing ^{3}H, ^{3}He, ^{2}H, ^{1}H, and ^{4}He. The number of atoms in each sample was determined by direct weighing as well as by pressure, temperature and volume measurement to within an accuracy of 0.3%. All the safety features as used in Exp. 905 were installed for this experiment also.

Since the absolute position of the NSF dip has never been measured, we made a search for it by measuring the yield from π^+ ^{3}He angle settings of the spectrometer around the roughly known dip angle. For example, in the case of 180-MeV incident energy, the search was done for the spectrometer angle settings of 65°, 73°, 75°, and 77°. For each angle the spectrometer covered 3°. Therefore, we could extract the yields for three angles with one setting of the spectrometer by binning the missing mass spectrum into three bins. Once the position of the dip was determined, the spectrometer was set at this angle and the yields from ^{3}H and ^{3}He were measured with the spectrometer set for π ^{3}H kinematics. Deuterium, hydrogen and empty target runs were taken for background subtraction. For the absolute normalization we used the ^{2}H target with the spectrometer set for π ^{2}H kinematics and in few cases we also used the ^{1}H target with spectrometer set for π ^{1}H kinematics as a double check. Beam monitoring was done using an ion chamber downstream of the target inside the scattering chamber, a secondary emission monitor on the A2 target and the output from a toroid in the beam line upstream of the A1 target. Two muon counters downstream of the scattering chamber were also used to monitor the beam. Consistency of the runs was checked throughout the experiment by comparing the ratios of these monitors.

Preliminary analysis of the data shows some interesting results. Figure 1 shows a sample missing-mass spectra for π^+ on ^{3}H and ^{3}He at 220 MeV, 69° (lab). It is evident from the large π^+ ^{3}H cross section that near the NSF dip

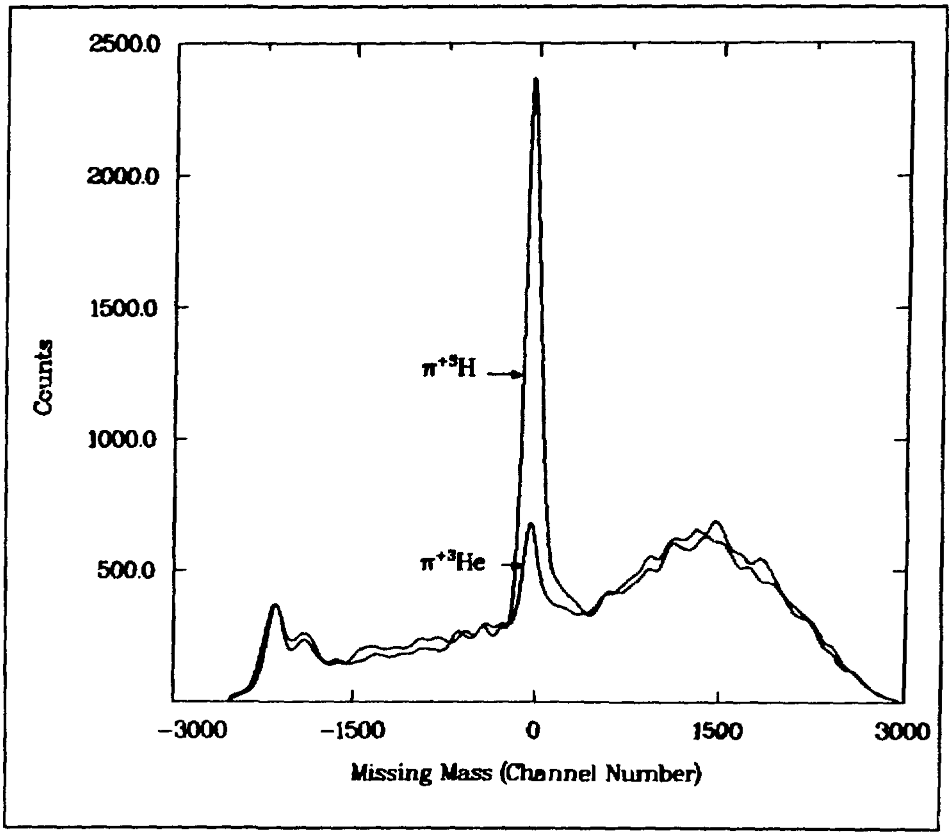


Fig. 1. Missing-mass spectra for π^+ elastic scattering from ^{3}H and ^{3}He for 220-MeV incident energy at 69° lab angle.

the scattering is dominated by the spin flip scattering on the odd proton. (Spin flip scattering on the protons in ^{3}He is not allowed due to Pauli blocking.) The same is true of neutrons for π^- on ^{3}He and ^{3}H. In the preliminary analysis we concentrated mainly on the ratios

$$\rho^+ = \frac{d\sigma(\pi^+\,{}^3\mathrm{H})}{d\sigma(\pi^+\,{}^3\mathrm{He})} \quad \text{and} \quad \rho^- = \frac{d\sigma(\pi^-\,{}^3\mathrm{H})}{d\sigma(\pi^-\,{}^3\mathrm{He})} \ .$$

These ratios are independent of the absolute beam normalization and the detector efficiency. Table I gives results from the preliminary analysis for these ratios ρ^+ and ρ^- at incident energies of 180, 220, and 295 MeV incident energies. Figs. 2(a) and (b) show the online results for these ratios at 256 MeV as a function of c.m. angle. Final analysis of the data is in progress.

Table I. Online Results for ρ^+ and ρ^- for 180, 220, and 295 MeV.

Energy	*Angle (lab)*	ρ^+	ρ^-
180	73°	2.41 ± 0.08	0.53 ± 0.02
220	69°	4.63 ± 0.40	0.80 ± 0.07
295	73°	0.11 ± 0.04	12 ± 12*

*Estimated upper limit.

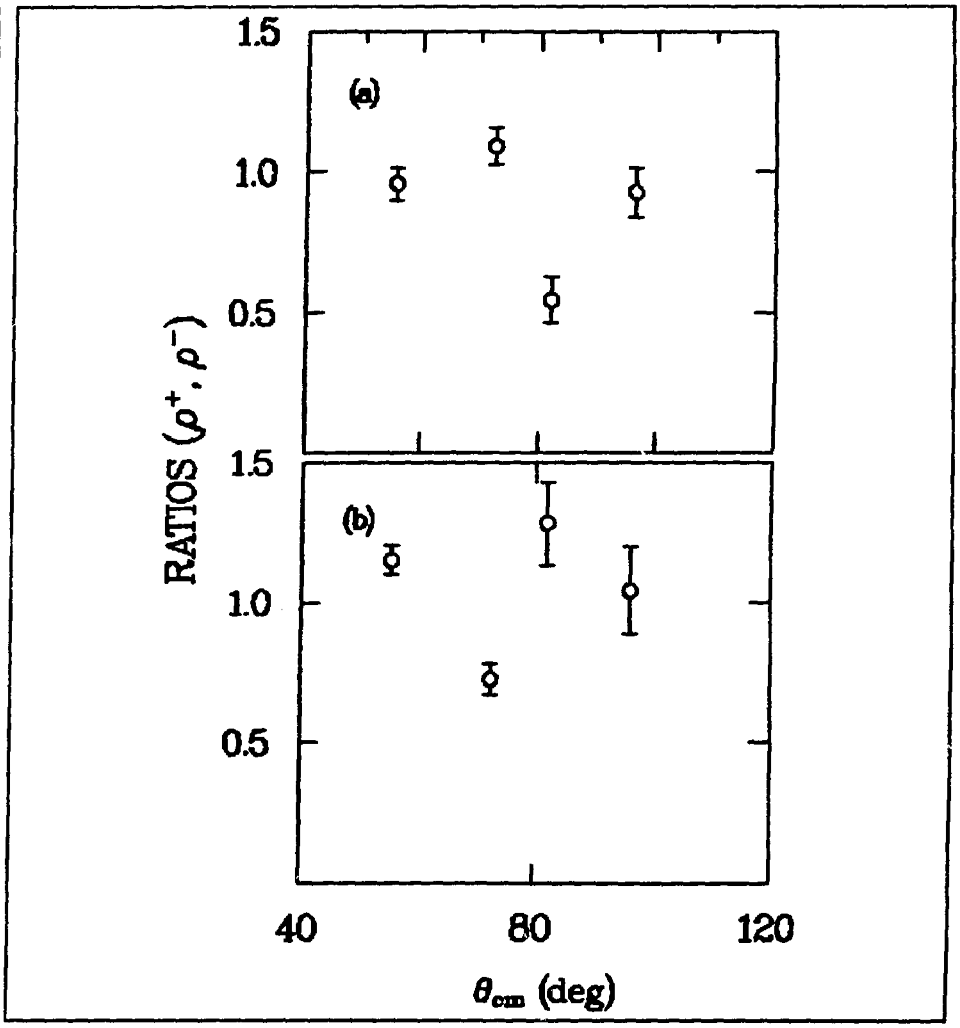


Fig. 2. Preliminary results for the ratios (a) ρ^+ and (b) ρ^- for 256 MeV as a function of the c.m. angle.

References

1. "The Three-Body Forces in the Three-Nucleon System," B. L. Berman and B. F. Gibson, Eds. (Springer-Verlag, Heidelberg, 1986).
2. E. Hadjimichael, B. Goulard, and R. Bornais, *Phys. Rev.* C**27**, 831 (1983).
3. B. M. K. Nefkens, W. J. Briscoe, A. D. Eichon, D. H. Fitzgerald, J. A. Holt, A. A. Mokhtari et al., *Phys. Rev. Lett.* **52**, 735 (1984).
4. C. Pillai, D. B. Barlow, B. L. Berman, W. J. Briscoe, A. Mokhtari, B. M. K. Nefkens et al., *Phys. Lett.* **207**, 389 (1988).

EXPERIMENT 1039 — EPICS

^{208}Pb$(\pi,\pi' p)^{207}$Tl Coincident Measurement in the Region of the Giant Resonances

Univ. of Colorado, Los Alamos, Univ. of Texas at Austin, Univ. of Minnesota, Louisiana State Univ.

Spokesmen: D. S. Oakley (Univ. of Colorado) and C. L. Morris (Los Alamos)

Participants: S. H. Yoo, A. Williams, S. Mordechai, C. F. Moore, S. J. Seestrom-Morris, M. K. Jones, S. M. Sterbenz, D. Dehnhard, and A. Fazely

The response of the continuum of nuclear states above nucleon break-up threshold to inelastic scattering has been the subject of intensive research.[1] Transitions to the giant resonances can proceed in competition with the quasi-elastic-scattering process. Thus, a detailed understanding of the reaction mechanism is needed in order to unravel the structure of the continuum. For example, the extent to which isospin is a good quantum number for the giant resonances is of great importance in the study of nuclear structure.[2] We believe that coincidence measurements between the inelastically scattered probes and emitted secondary particles provide a powerful tool for these investigations. The isospin selectivity of π^+ and π^- scattering makes pion probes particularly useful in a study of the continuum.

Coincidence experiments involving pions as a probe can be divided into two groups: experiments in the region where quasi-elastic scattering dominates ($E_x \geq$ 40 MeV and backward angles)[3,4,5,6,7] and experiments in the region of the giant resonances ($E_x \leq 40$ MeV and forward angles).[8,9] Indeed, Chant et al.[10] have shown that quasifree-single-nucleon-knockout calculations, carried out with the code THREEDEE,[11] are in good agreement with the measured ^{12}C$(\pi^+,\pi^{+\prime}p)^{11}$B(g.s.) cross sections of Ziock et al.[4] at large momentum transfer and high excitation energies. These calculations use a factorized form of the distorted-wave impulse approximation (DWIA), and include optical-model distortions of the incoming pion, outgoing pion and final-state proton. The processes that contribute to the lower excitation energy region of the continuum, however, are more complicated. It has been suggested[8,12] that, in this GR region, direct decay (due to quasifree-knockout scattering) and semidirect decay (due to resonant inelastic scattering to states of good isospin) compete with each other in a coherent way.

Experiment 1039 is aimed at the excitation region near the giant-dipole resonance (GDR) of ^{12}C. In this progress report, we compare cross sections for the ^{12}C$(\pi^\pm,\pi^{\pm\prime}p)$ reaction with DWIA calculations performed with the code THREEDEE in order to evaluate the importance of quasifree-knockout scattering in the excitation energy region near the GDR. We also present values for the ratio

$$R = \frac{\sigma(\pi^+,\pi^+p)}{\sigma(\pi^-,\pi^-p)}$$

which may provide information on the isospin structure of the continuum. The experiment was performed using the Energetic Pion Channel Spectrometer (EPICS).[13] Protons were detected in coincidence with the scattered pions using five plastic BGO (bismuth-germanate) "phoswich" detectors mounted in the vacuum-scattering chamber. Each phoswich detector was made up of a 3-mm-thick plastic scintillator disc coupled to the front face of a 5.1-cm-long and 10.2-cm-diameter BGO crystal. This combination of scintillators was viewed by a 7.6-cm-diameter phototube coupled to the back face of the BGO crystal. The assembly was mounted in an aluminum can with a thin (0.013-mm) light-tight aluminum entrance window. The solid angle subtended by each proton detector was about 140 msr.

We were able to obtain both energy loss (ΔE) and energy (E) information from this detector because of the very different decay times of the scintillation light from the plastic scintillator ($\tau \simeq 3$ ns) and the BGO crystal ($\tau \simeq 300$ ns). To take advantage of this difference, the anode signal from the tube is split and sent into two different linear gates, followed by integrating analog to digital converters (ADC). The ΔE signal from the plastic is obtained using a short (~15-ns) gate and the E signal from the BGO is obtained using a longer (~400-ns) gate. In addition to E and ΔE from the detectors, the time of flight of the decay particles with respect to the pions detected in the spectrometer was measured and used for identification of particles that stopped in the thin plastic scintillator. The combination of E-ΔE and time of flight allowed us to separate protons from neutral particles and also from heavier charged particles (deuterons, alphas, etc.). A typical E-ΔE plot is shown in Fig. 1.

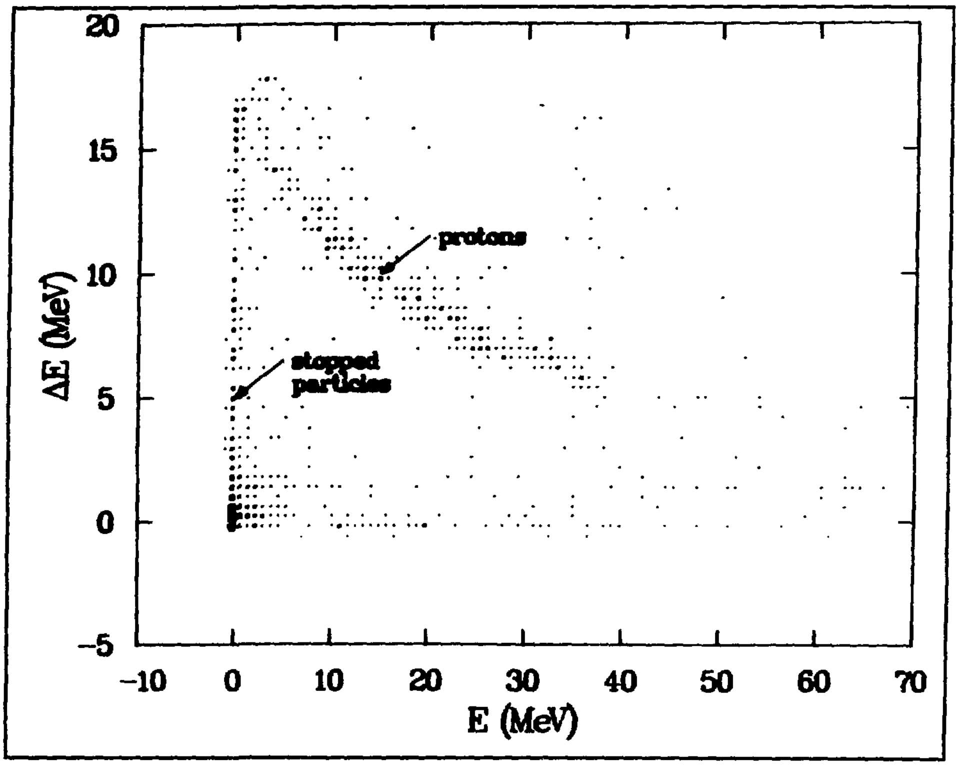


Fig. 1. Typical ΔE-E plot. Vertical axis is ΔE, the energy loss of a particle in the thin plastic scintillator. Horizontal axis is E, the energy of a particle detected in the BGO crystal. The band-labeled protons correspond to particles that have ΔE and E expected for protons that deposit energy in both the plastic scintillator and the BGO. The band-labeled stopped particles correspond to charged particles that stop in the plastic scintillator. Particle identification for these was provided by using their time of flight.

Our measurements of the $^{12}C(\pi^{\pm}, \pi^{\pm\prime}p)$ reaction were made at an incident pion energy of 180 MeV. The target was a carbon foil of natural isotopic composition and of areal density 91 mg/cm^2 mounted at 60° with respect to the beam direction. The energy loss in the phoswich entrance foil and in the target limited the minimum detectable proton energy to about 4 MeV (at the center of the target). The pion scattering angle, θ_{lab}, was chosen to be at 20° near the maximum in the angular distribution for the GDR in ^{12}C.[14] Protons were detected at laboratory scattering angles $\theta_p = -120°, -90°, -60°, 60°$, and 90° with respect to the incident beam. A relative measure of the pion beam intensity was provided by a toroidal pickoff upstream of the pion-production target, which measured the primary proton beam current. Typical average pion fluxes were $\approx 2.8 \times 10^7$/s for π^+ and 1.5×10^7/s for π^-. The data were normalized by comparing yields measured for π^+ and π^- scattering from hydrogen (using a CH_2 target of areal density 73 mg/cm^2) to cross sections calculated using the π-N phase shifts of Rowe, Salomon, and Landau.[15]

Acceptance-corrected missing-mass spectra for π^+ and π^- scattering are plotted in Fig. 2. Singles spectra for π^+ (solid) and π^- (dashed) are plotted in the upper portion. The π^+ and π^- cross sections are nearly equal everywhere as expected in a self-conjugate nucleus because of charge symmetry. The only clear exception occurs for a known isospin-mixed doublet near 19 MeV.[16]

Plotted in the middle part of the figure is the pion missing-mass spectrum, gated by the requirement of detecting a coincident proton at an energy that implies that the excitation energy of the residual nucleus, ^{11}B, is less than 10 MeV, and summed over all proton detectors. In contrast to the singles spectra, the $(\pi, \pi'p)$ coincidence yields are larger for π^+ than π^- throughout the spectrum. The missing-mass spectrum gated by detecting a proton leading to excited states of ^{11}B higher than 10 MeV is plotted in the lower part of Fig. 2. In this case, which includes multiparticle breakup states, the $(\pi^+, \pi^{+\prime}p)$ and $(\pi^-, \pi^{-\prime}p)$ cross sections are about the same at all energies.

The inequality of the $(\pi^-, \pi^{-\prime}p)$ and $(\pi^+, \pi^{+\prime}p)$ cross sections for $E_x(^{11}B) <$ 10 MeV can be qualitatively understood by simple arguments. If the reaction process is quasifree knockout, we expect a ratio between π^+ and π^- scattering close to the 9:1 ratio for π^+ and π^- scattering from free protons. Nearly as large a ratio is obtained from the factorized DWIA calculations performed with the code THREEDEE. The curves plotted in Fig. 2(b) correspond to scattering from a proton bound in the (1p)-shell. A spectroscopic factor $C^2S = 3.98$, the summed p-shell spectroscopic factor predicted by Cohen and Kurath,[17] and a separation energy S_p = 15.8 MeV were assumed. The calculations in Fig. 2(c) are for scattering from a (1s)-shell proton with $C^2S = 2.0$, the value of the shell-model limit, and S_p = 34.3 MeV. Both sets of calculations show π^+ scattering to be larger than π^- by nearly the free π-p ratio (for example, we calculate $R \sim 7.36$ for 1p knockout near the GDR). However, the experimental ratio is only 1.59 on the average.

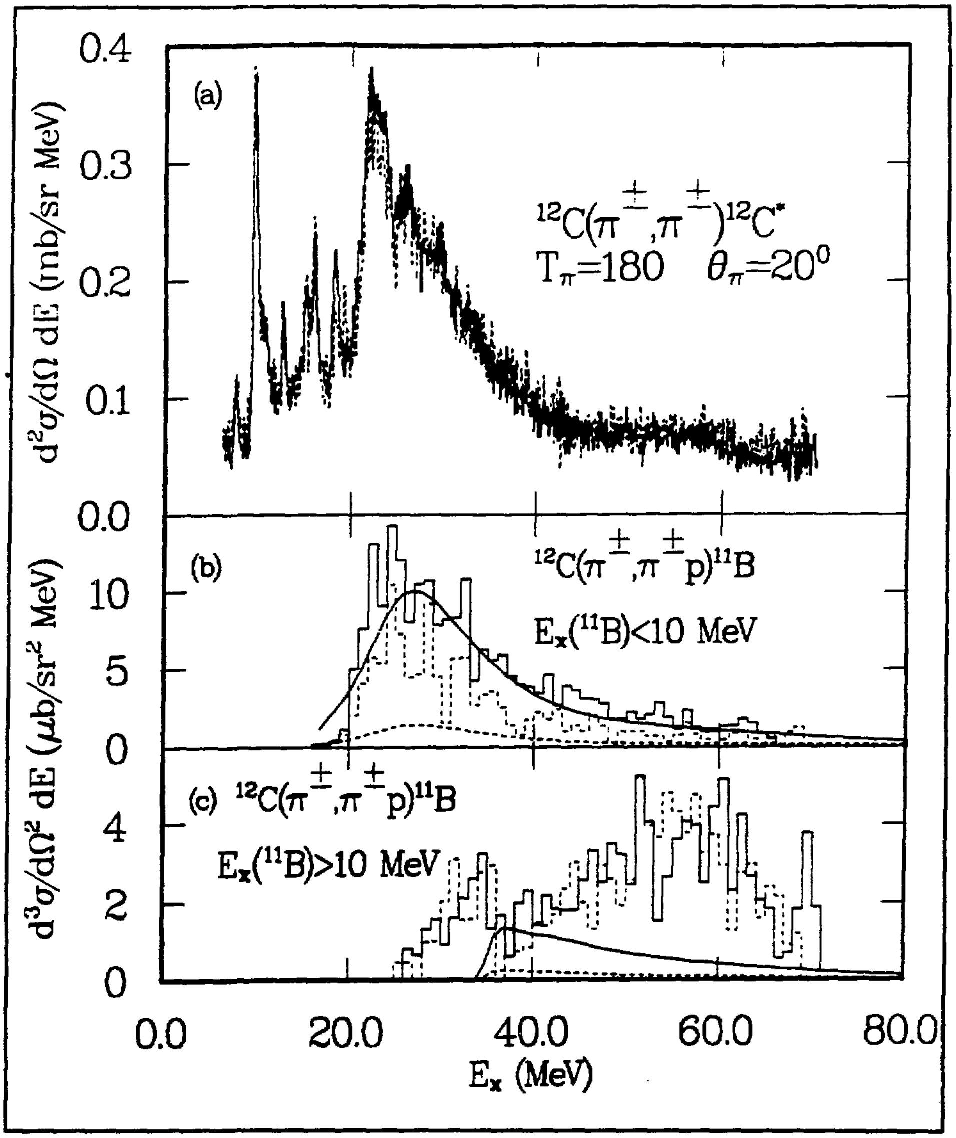


Fig. 2. Missing-Mass Spectra. Dash for π^- and solid for π^+. (a) $^{12}C(\pi^\pm,\pi^{\pm\prime})^{12}C^*$ singles spectra at θ_π = 20° and T_π = 180 MeV. (b) $^{12}C(\pi^\pm,\pi^{\pm\prime}p)^{11}B$ coincidence spectra, gated by $E_x(^{11}B) \leq 10$ MeV. Solid (dashed) curve is a DWIA calculation of π^+ (π^-) 1p-shell knockout. (c) $^{12}C(\pi^\pm,\pi^{\pm\prime}p)^{11}B$ reaction, gated by $E_x(^{11}B) \geq 10$ MeV. Solid (dashed) curve is a DWIA calculation of π^+ (π^-) 1s-shell knockout.

Both the shape and magnitude of the $(\pi^+,\pi^{+\prime}p)$ spectrum for low excitation in ^{11}B are well described by the DWIA. However, the $(\pi^-,\pi^{-\prime}p)$ data for the same ^{11}B excitation energies are much larger than the predicted value [Fig. 2(b)]. This discrepancy would be even larger if we had used the p-shell spectroscopic factor of 2.9 reported in Ref. 10. For the higher ^{11}B excitation energies the agreement between the experiment and the DWIA prediction is poor for both π^+ and π^- scattering [Fig. 2(c)].

The angular distributions of the emitted protons provide another source of information on the excitation of the continuum of ^{12}C. In Fig. 3, cross sections are plotted as a function of the outgoing proton angle in the center-of-mass system of the recoil ^{12}C. The cross sections for events leading to the ground state or the low excitation states of ^{11}B, i.e., $E_x(^{11}\mathrm{B}) < 10$ MeV, summed over the excitation energies near the GDR in ^{12}C (20–30 MeV), are plotted in Fig. 3(a). In Fig. 3(b), data for the higher excitation states of ^{11}B, $E_x(^{11}\mathrm{B}) \geq 10$ MeV, are summed for excitation energies in ^{12}C from 41 to 70 MeV. The curves plotted with the data are the DWIA calculations described earlier. Here, again, the $(\pi^+, \pi^{+\prime}p)$ data for low excitation in ^{11}B are reasonably well described by the DWIA. On the other hand, the $(\pi^-, \pi^{-\prime}p)$ data exhibit a nearly isotropic-angular distribution. In contrast to the $(\pi^+, \pi^{+\prime}p)$ data, the $(\pi^-, \pi^{-\prime}p)$ data show no clear peak in the recoil direction.

The calculations discussed so far include only the quasifree-knockout process. Another process that can contribute to this $(\pi^\pm, \pi^{\pm\prime}p)$ reaction in the GR region is a semidirect one, where the pion excites a state of ^{12}C in the GR region that subsequently decays through emission of a proton. If the state in ^{12}C has good isospin and if the difference between the neutron and proton penetrabilities is neglected, R must be equal to one at all emitted proton angles. In this case, the decay of the state is governed by branching ratios and these are independent of the manner in which the state was created. Furthermore, the angular distribution should be symmetric about 90°. The $E_x(^{11}\mathrm{B}) < 10$ MeV data could be qualitatively explained by a mixture of these two processes—direct (due to quasifree knockout) and semidirect (due to inelastic scattering to states of good isospin). The angular distributions of the decay proton indicate that the $(\pi^+, \pi^{+\prime}p)$ is preponderantly dominated by the direct decay, whereas the $(\pi^-, \pi^{-\prime}p)$ must have a strong contribution from the semidirect process. The strong-angle dependence of R is probably due to an interference between the amplitudes for these two processes.

In order to describe a situation that lies between the limits of quasifree knockout and the excitation and decay of states of good isospin, one may use a form of doorway model.[18] In this model, the interaction of the pion probe with the nucleus leads to proton-particle-hole and neutron-particle-hole states in the continuum with amplitudes approximately in the ratio of the free pion-nucleon couplings. These continuum states couple either to the ground states with width Γ_R, or they decay directly into a potential scattering state with width Γ_D (the quasifree process). The decay of the GR states would lead to equal amplitudes for proton and neutron emission and, therefore, equal (π^+, π^+p) and (π^-, π^-p) cross sections, but the presence of, and interference with, the quasifree process causes

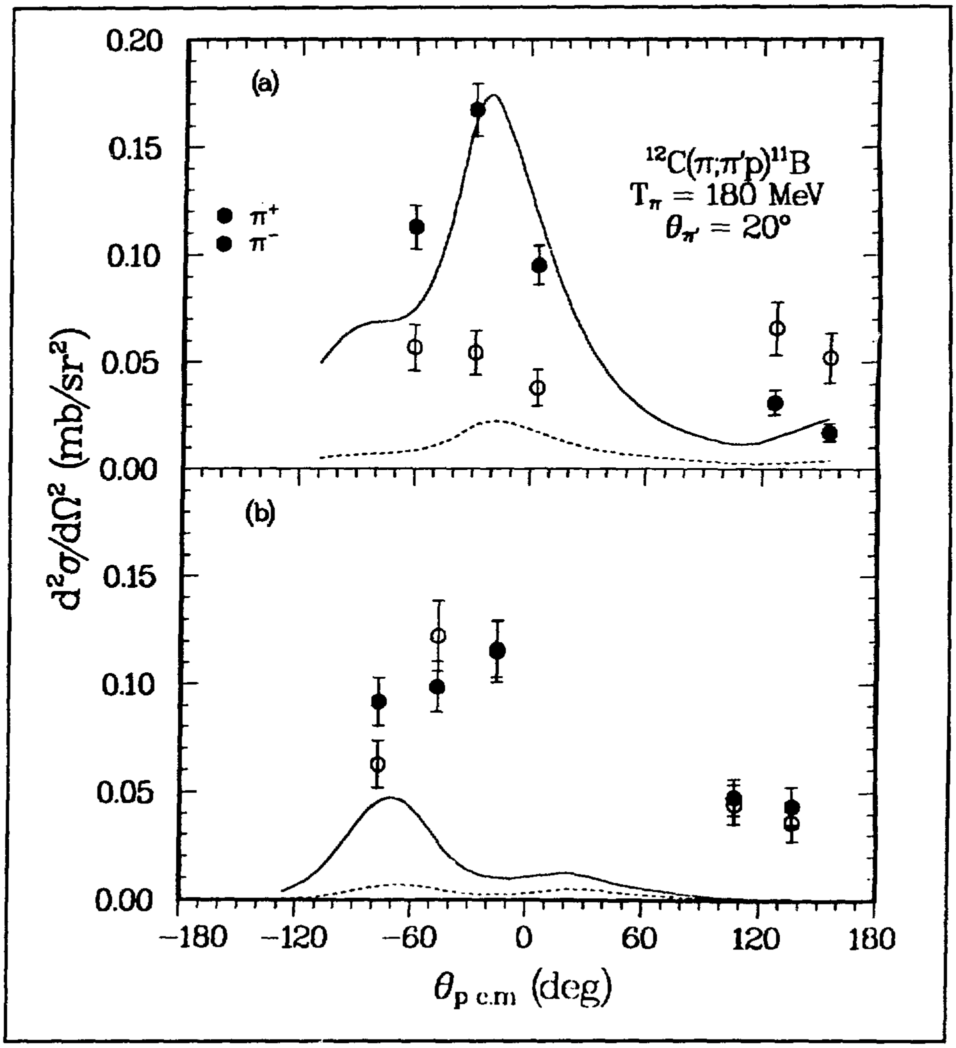


Fig. 3. Angular distribution in the center-of-mass system of the recoil $^{12}C^*$. The missing-mass spectra was summed over (a) $E_x(^{12}C)$ = 20 to 30 MeV and $E_x(^{11}B) \leq 10$ MeV. Solid (dashed) curve is a DWIA calculation of π^+ (π^-) 1p-shell knockout. (b) $E_x(^{12}C)$ = 41 to 70 MeV and $E_x(^{11}B) \geq 10$ MeV. Solid (dashed) curve is a DWIA calculation of π^+ (π^-) 1s-shell-knockout calculations.

π^+/π^- asymmetries. The enhancement of proton decay observed in the current $(\pi^-, \pi^{-\prime}p)$ data above the DWIA calculations indicates that Γ_R and Γ_D must be comparable in size for the continuum near the GR region of ^{12}C. Therefore, the decay of the continuum in the region of the GR is largely governed by how it was excited. Our conclusions are based on the failure of simple DWIA calculations to reproduce the data. No attempt was made to include higher-order effects in the π-nucleus scattering such as those that have been predicted to arise from the Δ-hole model.[7]

These observations in the region of the GDR in ^{12}C can be contrasted with the result obtained at higher excitation energies in ^{12}C [Fig. 2(c) and Fig. 3(b)]. Here we find that more than half of the cross section seen in the coincidence spectrum corresponds to excitation energies in ^{11}B above 10 MeV. For these events, we observe a broad bump in Fig. 2(c) centered near 55 MeV of excitation in ^{12}C. The angular distribution of protons associated with this bump also appears to peak near the recoil direction, but the ratio R [Fig. 3(b)] is near unity at all angles. The DWIA calculations for $1s$-shell knockout do not resemble these data at all. The near equality of the $(\pi^+, \pi^+ p)$ and $(\pi^-, \pi^- p)$ cross sections suggests that protons and neutrons are involved equally in the reaction. However, we do not believe that for excitation energies above 40 MeV, states of good isospin would play a major role except for possible double resonances.[19] It is more likely that direct two-, three-, and four-nucleon removal are important here. The thresholds for two-, three-, and four-nucleon removal are at 27, 34, and 36 MeV, respectively. Lourie et al. (Ref. 20) also observed considerable strength in this region of excitation energy in the $^{12}C(e, ep)$ reaction. They interpreted this strength as due to multinucleon-reaction mechanisms. The failure of the one-nucleon-knockout calculations with THREEDEE to reproduce the magnitude and the near equality of the π^+ and π^- data suggests the importance of such processes also for $(\pi, \pi' p)$.

In summary, cross sections have been measured for the $^{12}C(\pi^\pm, \pi^{\pm\prime} p)$ reactions, and the results were compared with the factorized DWIA calculations. Neither the DWIA calculations, which assume a quasifree-knockout process, nor the assumption that the reaction is dominated by states of good isospin in ^{12}C (the GDR) can explain the data. This leads to the speculation that inelastic scattering to the giant-dipole region in ^{12}C contains two components, one of which is direct (quasifree), the other being semidirect (resonance). The ratio R shows an angular dependence that indicates coherent interference between these amplitudes.

References

1. C. C. Chang, in *Giant Multipole Resonances*, F. E. Bertrand, Ed. (Harwood-Academic, Chur, Switzerland, 1979), p. 191.

2. S. S. Hanna, in *Giant Multipole Resonances*, F. E. Bertrand, Ed. (Harwood-Academic, Chur, Switzerland, 1979), p. 1.

3. H. J. Ziock, R. J. Ellis, K. O. H. Ziock, J. Bolger, E. Boschitz, J. Arvieux, R. Corfu, and J. Piffaretti, *Phys. Rev. Lett.* 43, 1919 (1979).

4. H. J. Ziock, R. J. Ellis, K. O. H. Ziock, J. Bolger, E. Boschitz, J. Arvieux, R. Corfu, and J. Piffaretti, *Phys. Rev. C* 24, 2674 (1981).

5. E. Piasetzky, D. Ashery, A. Altman, A. I. Yavin, F. W. Schlepütz, R. J. Powers et al., *Phys. Rev. Lett.* **46**, 1271 (1981); E. Piasetzky, D. Ashery, A. Altman, A. I. Yavin, F. W. Schlepütz, R. J. Powers et al., *Phys. Rev. C* **25**, 2687 (1982).

6. J. R. Hurd, J. S. Boswell, R. C. Minehart, L. B. Rees, Y. Tzeng, H. J. Ziock, and K. O. H. Ziock, *Nucl. Phys. A* **462**, 605 (1987).

7. G. S. Kyle, P.-A. Amaudruz, Th. S. Bauer, J. J. Domingo, C. H. Q. Ingram, J. Jansen et al., *Phys. Rev. Lett.* **52**, 974 (1984).

8. C. L. Morris, M. Plum, M. K. Jones, S. K. Nanda, S. Sterbenz, D. Dehnhard et al., "^{4}He$(\pi, \pi' p)^3$H Reaction Isospin in the Continuum," Los Alamos National Laboratory document LA-UR-88-2399 (to be published in *Physical Review Letters*, 1989).

9. C. L. Morris, *Bull. Am. Phys. Soc.* **33**, 1093 (1988); M. Jones, Ph.D. thesis, University of Minnesota (in preparation).

10. N. S. Chant, L. Rees, and P. G. Roos, *Phys. Rev. Lett.* **48**, 1784 (1982).

11. N. S. Chant, code "THREEDEE", unpublished, and L. Rees, N. S. Chant, and P. G. Roos, *Phys. Rev. C* **26**, 1580 (1982).

12. H. Überall, *Electron Scattering from Complex Nuclei*, (Academic Press, New York, 1979) Vol. B, p. 729.

13. H. A. Thiessen and S. Sobottka, Los Alamos National Laboratory report LA-4534-MS (1970).

14. L. C. Bland, Ph.D. thesis, University of Pennsylvania (1984); and Los Alamos National Laboratory report LA-9960-T (1984).

15. G. Rowe, M. Salomon, and R. H. Landau, *Phys. Rev. C* **18**, 584 (1978).

16. W. B. Cottingame, K. G. Boyer, W. J. Braithwaite, S. J. Green, C. J. Harvey, R. J. Joseph et al., *Phys. Rev. C* **36**, 230 (1987).

17. S. Cohen and D. Kurath, *Nucl. Phys. A* **101**, 1 (1967).

18. H. Feshbach, A. K. Kerman, and R. H. Lemmer, *Ann. Phys. (N.Y.)* **41**, 230 (1967).

19. S. Mordechai, N. Auerbach, M. G. Burlein, H. T. Fortune, S. J. Greene, C. F. Moore et al., "Double Giant Dipole Resonances from Pion Double Charge Exchange" (to be published in *Physical Review Letters*, 1989).

20. R. W. Lourie, H. Baghaei, W. Bertozzi, K. I. Blomqvist, J. M. Finn, C. E. Hyde-Wright et al., *Phys. Rev. Lett.* **56**, 2364 (1986).

EXPERIMENT 1135 — HRS

Feasibility Study of Tagged Eta Meson Production

UCLA, Los Alamos, Arizona State Univ., Case Western Reserve Univ., Academia Sinica (Taiwan), Rudjer Bošković Institute (Yugoslavia)

Spokesmen: D. B. Barlow, C. Pillai (UCLA), and C. S. Mishra (Los Alamos)

Participants: D. B. Barlow, B. M. K. Nefkens, C. Pillai, J. W. Price, J. A. Wightman, K. W. Jones, M. J. Leitch, C. S. Mishra, C. L. Morris, J.-C. Peng, J. M. Tinsley, M. J. Wang, P. K. Teng, and I. Slaus

Continued interest in pursuing η meson physics at LAMPF has led us to consider using the HRS spectrometer and beam line to look for tagged η production from several possible reactions. Knowing the cross section for η production will allow us to assess the feasibility of using such a tagged beam of η's to study its rare and forbidden decays. A summary of the physics that can be learned from η decay is presented in Refs. 1–3.

Our motivation for looking into the possibility of a tagged η beam at LAMPF was the result of a recent experiment performed at Saturne,[4] which measured η production from the reaction $pd \rightarrow {}^3\mathrm{He}\eta$ by detecting the scattered ^{3}He. The cross section for this reaction was measured to be ~50 nb/sr near threshold. A 99% pure beam of 1000 tagged η's per second has been produced via this reaction, and a factor-of-10 increase in the rate could easily be achieved. Such a beam could be used to study many of the decay channels listed in Refs. 1–3. Unfortunately, the threshold for this reaction is $T_p = 856$ MeV, which is just out of reach of the LAMPF beam energy. However, the reaction $p\mathrm{T} \rightarrow {}^4\mathrm{He}\eta$ has a threshold of 756 MeV, within range of beam energy available at LAMPF. If this reaction proves capable of producing a clean beam of 1000 or more tagged η's per second it would provide a viable alternative to the reaction $pd \rightarrow {}^3\mathrm{He}\eta$. The maximum production of tagged η's is most likely to occur at beam energies just above threshold, where the cross section is highest and the large cm-to-lab Jacobian causes the tagging particles to go forward in the lab within a cone of small opening angle. This presents two problems: cleanly identifying the tagging particle, and operating the detector at very forward angles. These two problems were studied in detail during a development run for this experiment at HRS.

The reaction $p\mathrm{T} \rightarrow {}^4\mathrm{He}\eta$ does have one drawback and that is the necessity of using a highly radioactive target, namely tritium. A solid target was used to avoid some of the hazards of a high-pressure T_2 gas target. The solid target consisted of powdered titanium injected with T_2 gas at a temperature above 400°C. Concentrations of 1 Ci of T_2 per mg of titanium can be achieved by this technique, and the target is stable at temperatures below 400°C. Such targets have been fabricated by Oak Ridge National Laboratory and used in several other experiments. A target was made for this development run by Oak Ridge, which measured 2 cm by 1 cm by 0.23 cm thick and was filled with approximately 500 mg of Ti containing 500 Ci (50 mg) of T_2 encapsulated in a container of 10-mil stainless steel (SS). Unfortunately the target developed a small T_2 leak during vacuum testing at LAMPF. Since the target could not be repaired or replaced in time for the development run, we were not able to use it to look for η production from T. However, we were able to do a comprehensive study of ^{4}He detection and background rates at forward angles and to look for η production from a target of ^{6}Li.

The development run was begun at a beam energy of 733 MeV by looking for heavy ($A \geq 2$) particle production from a carbon target. Figure 1 shows a two-parameter scatter plot of scintillator pulse height (PH) vs time-of-flight

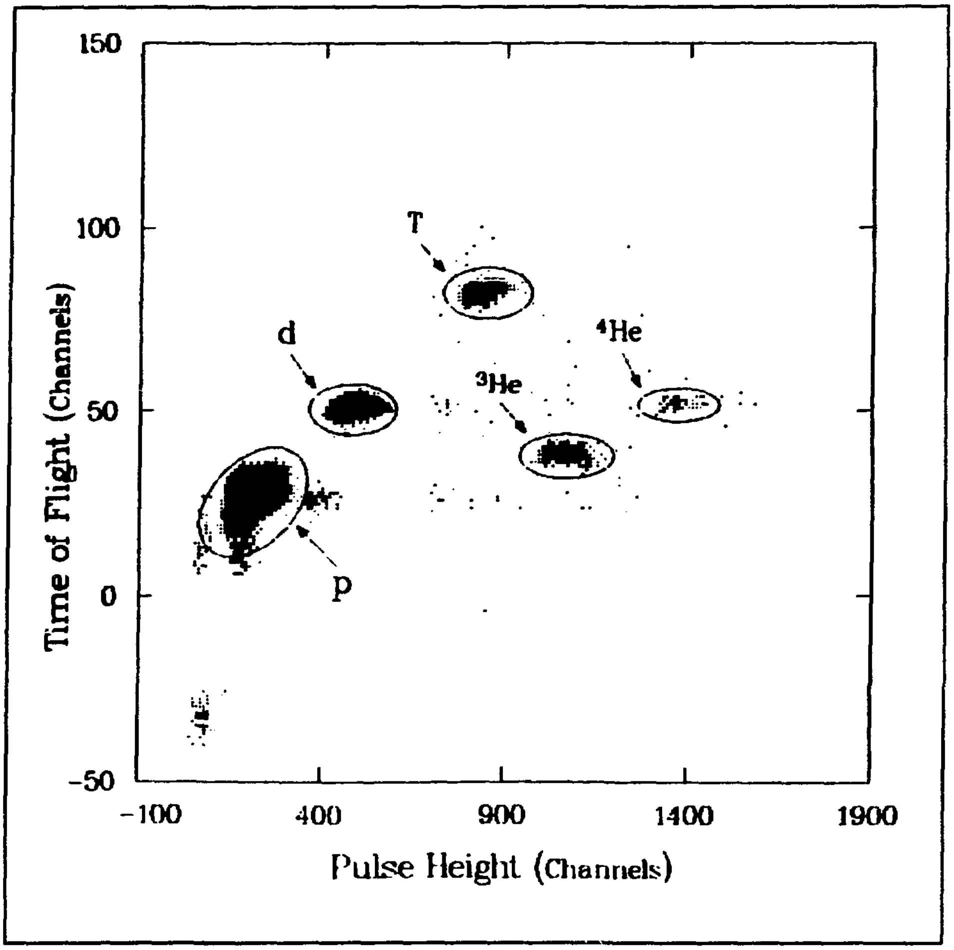


Fig. 1. HRS focal plane PH vs TOF for p, d, T, ^3He, and ^4He production from ^{12}C at 9° and spectrometer momentum of 700 MeV/c.

(TOF) taken at an angle of 9° and spectrometer momentum of 700 MeV/*c*. The particle identification can easily be made knowing the relative PH and TOF of the detected particles. After establishing the identity of the particles the scintillator PMT voltages were lowered to reduce sagging and the discriminator thresholds were increased to eliminate protons, deuterons, and tritons from the event trigger. By reducing the trigger rate we were able to move the spectrometer to very forward angles to measure the production rates of ^3He and ^4He at angles as low as 0°. At angles less than 2° the proton beam enters the spectrometer and travels part way through it before striking the iron yoke of the magnet. Initially it was thought the backgrounds produced by the beam in the spectrometer would prevent the HRS from running at anything more than a mere trickle of beam. However, this turned out to be only a minor problem and we were able to run comfortably at beam intensities of 1/2 nA at 0° and 1–2 nA at larger angles.

The beam energy was increased at this point to 800 MeV where it remained for the rest of the development run. In anticipation of running in the future with a working TiT_2 target we measured the background rate of ^{4}He production from a Ti target using kinematics suitable for the reaction $pT \rightarrow {}^4\mathrm{He}\eta$ (Fig. 2). The 700 mg/cm^2 density of the target was close to the combined density of the SS and Ti in the TiT_2 target we plan to use later. For more general background information, the doubly differential cross sections for ^{4}He and ^{3}He production were also measured, from targets of carbon, titanium, and lead, at excitation energies from 300 to 650 MeV, and spectrometer angle of 6° (Figs. 3 and 4).

The remaining time was spent searching for η production from the reaction $p^6\mathrm{Li} \rightarrow {}^7\mathrm{Be}\eta$. The spectrometer was placed at 0° and the fields set to detect ^{7}Be from the forward branch of the kinematics for η production. A thin, 15 mg/cm^2, target was used to minimize the energy loss of the outgoing ^{7}Be. Since the ^{7}Be stops in the first scintillator of the HRS focal plane, we were not able to measure TOF between two scintillators. Instead, the timing of the accelerator RF signal with respect to the first scintillator was used to determine the RF-TOF, which was corrected in software for the variation in path length through the spectrometer. As before, the PMT gains were lowered to reduce sagging and the discriminator thresholds increased to eliminate low pulse-height particles from the trigger. The large dE/dX of the ^{7}Be and other particles causes saturation in the scintillator resulting in a nonlinear energy response. This problem combined

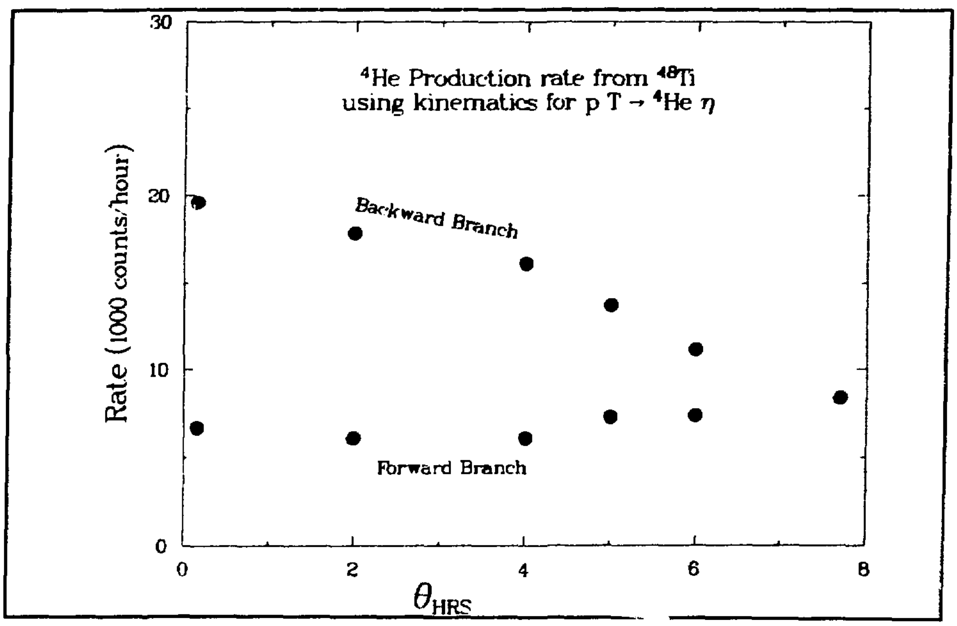


Fig. 2. ^{4}He production rate from Ti using kinematics for $pT \rightarrow {}^4\mathrm{He}\eta$. The rate is for a 700 mg/cm^2 target, and a 1-nA beam of 800-MeV protons. The systematic error is ~10% and the statistical error is about the size of the data points.

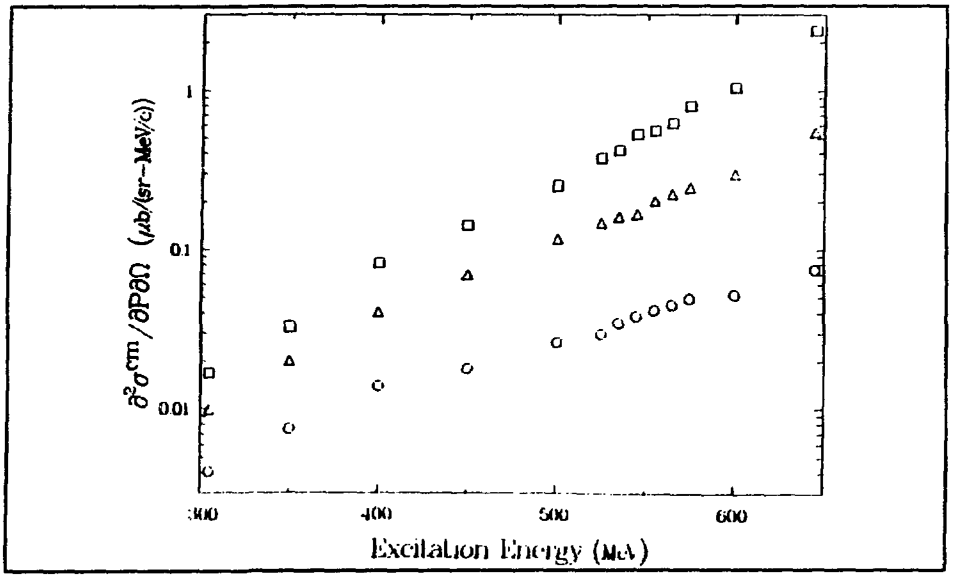


Fig. 3. *[4]He cross section as a function of excitation energy for targets of C (circles), Ti (triangles), and Pb (squares). The beam energy is 800 MeV and the spectrometer angle is 6°. The systematic error is ~10% and the statistical error is about the size of the data points.*

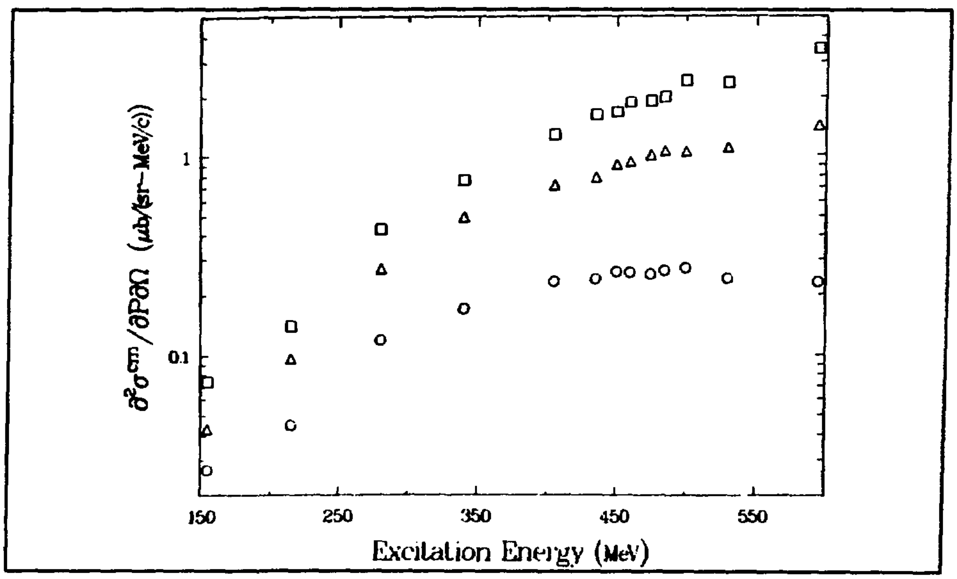


Fig. 4. *[3]He cross section as a function of excitation energy for targets of C (circles), Ti (triangles), and Pb (squares). The beam energy is 800 MeV and the spectrometer angle is 6°. The systematic error is ~10% and the statistical error is about the size of the data points.*

with the lack of a good TOF measurement led to a rather poor determination of the particles PH and TOF. However, by comparing calculated vs measured PH and TOF one can make a fairly unambiguous identification of the various particles and predict where to look for ^{7}Be. Preliminary analysis of these data failed to show any evidence of ^{7}Be from the production of η's. This negative result puts an upper limit of $\sim$1 nb/sr (cm) on the cross section for $p^6\mathrm{Li} \to {}^7\mathrm{Be}\eta$.

References

1. P. Herczeg, "Exotic Decays of Light Mesons," Los Alamos National Laboratory document LA-UR-88-1857 (1988).
2. B. M. K. Nefkens, "Testing the Standard Model with Rare and Forbidden Decays of the η and Other Light Mesons," University of California document UC-10-p25-143 (1988).
3. A. Soni, *Proceedings of Physics with Light Mesons,* W. Gibbs and B. Nefkens, Eds., Los Alamos National Laboratory conference proceedings LA-11184-C, p. 55 (1987).
4. J. Berger, M. Boivin, A. Boudard, P. Fleury, J. F. Germond, L. Goldzahl et al., *Phys. Rev. Lett.* 61, 919 (1988).

EXPERIMENT 1098 — LEP/Clamshell

Energy Dependence of Low-Energy Pion Double Charge Exchange

Los Alamos, Tel Aviv Univ., Arizona State Univ., TRIUMF

Spokesmen: H. W. Baer, M. J. Leitch (Los Alamos), and Z. Weinfeld (Tel Aviv Univ.)

Participants: H. W. Baer, A. Klein, M. J. Leitch, C. S. Mishra, C. L. Morris, E. Piasetzky, Z. Weinfeld, J. Comfort, J. Tinsley, and D. H. Wright

Our recent measurements of pion double charge exchange (DCX) at energies 20 to 70 MeV are providing a new means for studying nucleon-nucleon correlations in nuclei. At these energies the nucleus is relatively transparent, allowing simpler theoretical models to be used in interpreting the data. An important effect near 50 MeV in the DIAS transitions proceeds largely through nonanalog intermediate states. Recent theoretical studies by several groups have shown that while transitions through the analog route involve relatively long nucleon-nucleon distances, those through nonanalog intermediate states obtain nearly half their strength from nucleon pairs with less than one-Fermi separation. Thus, DCX near 50 MeV is an excellent way to probe short-range nucleon-nucleon correlations.

This year we began to measure the energy dependence of forward-angle DCX cross sections for both double-isobaric-analog states (DIAS) and ground state (g.s.) transitions on $f_{7/2}$ shell nuclei. We developed with MP-10 a new forward-angle scattering system for the Clamshell spectrometer using a sweep magnet just downstream of our target. This allowed us to make clean measurements at angles as small as 15°. Some of these are shown in Fig. 1. In Fig. 2 are shown preliminary cross sections obtained in this year's runs. There are interesting rapid variations in the cross sections with energy which are already beginning to help determine what new physics is required in the theoretical models.

The phenomenological two-amplitude model is now seen to give an excellent representation of the data. The two amplitudes are A, representing transitions through the intermediate analog state (long-range nucleon pairs) and B, representing those through nonanalog intermediate states (short-range nucleon pairs). The strength of A and B and their relative phase can be fit to three cross sections and then others can be predicted. In Table I, the overall agreement with the data at 35 and 65 MeV is shown. For those transitions where the pure seniority model is not appropriate, the generalized seniority scheme of Auerbach, Gibbs, Ginocchio, and Kaufmann[1] is used. The success of this model essentially shows that (1) a two-amplitude picture works for a large body of data and can be used to isolate the short-range nucleon-nucleon physics contained in the B term, and (2) the correlations inherent in the shell model are essential.

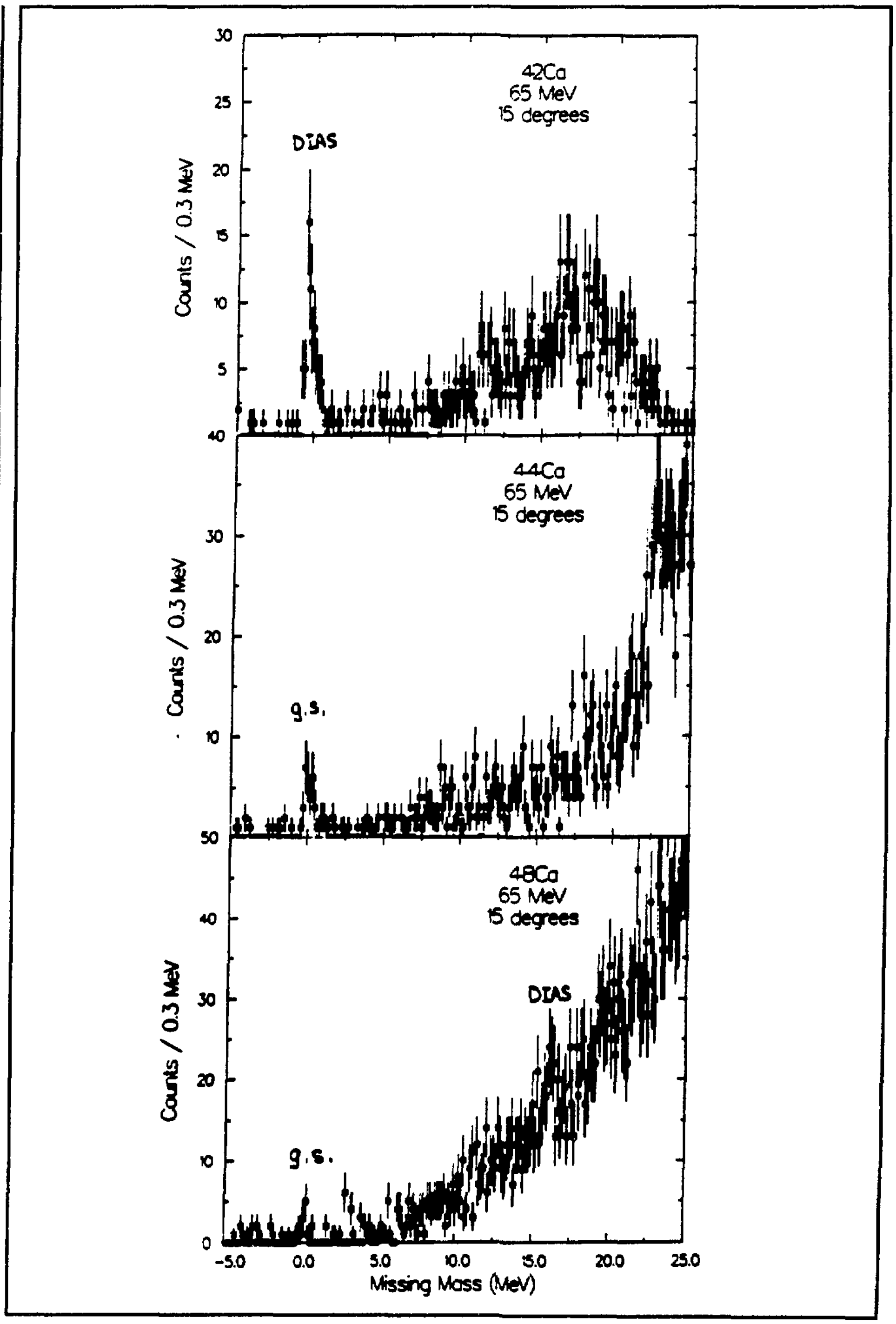


Fig. 1. Spectra from our LAMPF Exp. 1098 for 65 MeV DCX on calcium isotopes.

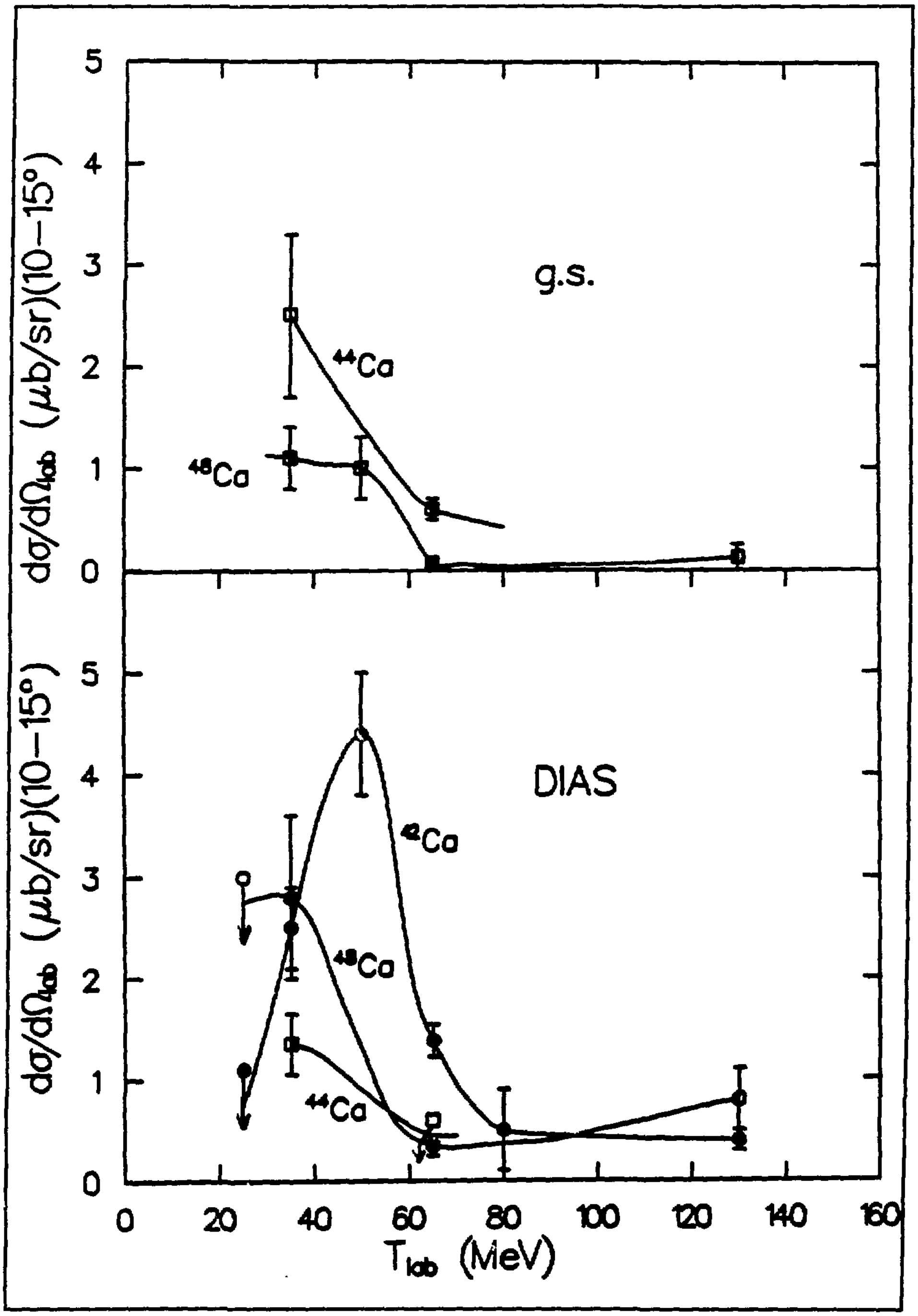


Fig. 2. Preliminary data on the energy-dependence of DIAS and ground-state transitions on calcium isotopes from our most recent run (Exp. 1098). The data at 130 MeV are from Kaletka et al. (Ref. 2).

Table I. Seniority Model Fits (preliminary data).*

35 MeV		25 deg Data	25 deg AB	40 deg Data	40 deg AB	70 deg Data	70 deg AB
DIAS	^{42}Ca	2.27 ± 0.29	2.27	1.9 ± 0.3	1.9	0.4 ± 0.08	0.4
DIAS	^{44}Ca	1.09 ± 0.16	1.09	1.1 ± 0.15	1.1	0.16 ± 0.04	0.16
DIAS	^{50}Ti	1.55 ± 0.27	1.47	1.38 ± 0.18	1.45	0.71 ± 0.13	0.83
DIAS	^{48}Ca	2.7 ± 0.9	2.7	2.4 ± 0.6	2.4	2.2 ± 0.5	2.2
DIAS	^{46}Ti	2.53 ± 0.35	2.29	2.11 ± 0.30	1.87	0.47 ± 0.12	0.48
DIAS	^{54}Fe	1.5 ± 0.4	2.27	0.9 ± 0.2	1.9	0.04 ± 0.03	0.4
g.s.	^{44}Ca	—	1.01	—	0.77	—	0.31
g.s.	^{48}Ca	1.3 ± 0.3	0.87	—	0.67	—	0.27

65 MeV		15 deg Data	15 deg AB
DIAS	^{42}Ca	1.38 ± 0.16	1.21
DIAS	^{44}Ca	<0.6	0.66
DIAS	^{48}Ca	0.34 ± 0.11	0.34
g.s.	^{44}Ca	0.6 ± 0.1	0.61
g.s.	^{48}Ca	0.07 ± 0.04	0.37

*For the 35-MeV ^{42,44,48}Ca the DIAS cross sections are fit; at 65 MeV the ^{42,48}Ca DIAS and the ^{44}Ca g.s. cross sections are fit.

References

1. N. Auerbach, W. R. Gibbs, Joseph N. Ginocchio, and W. B. Kaufmann, *Phys. Rev.* C38, 1277 (1988).

2. M. Kaletka, Ph.D. thesis, Northwestern University, Los Alamos National Laboratory report LA-9947-T.

EXPERIMENT 645 —
Neutrino-A

A Search for Neutrino Oscillations

Ohio State Univ., Argonne, Caltech, Lawrence Berkeley Laboratory, Louisiana State Univ., Los Alamos

Spokesmen: *T. Y. Ling and T. A. Romanowski (Ohio State Univ.)*

Participants: *L. S. Durkin, R. W. Harper, T. Y. Ling, J. W. Mitchell, T. A. Romanowski, E. S. Smith, M. Timko, S. J. Freedman, J. Napolitano, B. K. Fujikawa, R. McKeown, K. T. Lesko, W. C. Choi, A. Fazely, R. L. Imlay, W. J. Metcalf, R. D. Carlini, J. B. Donahue, G. T. Garvey, and V. Sandberg*

Experiment 645 began its physics run in June of 1987. It is a collaboration of Ohio State, Louisiana State, Argonne, Los Alamos, Berkeley, and Caltech. The experiment searches for the appearance of electron antineutrinos, which can result from the oscillation of muon antineutrinos produced in the LAMPF A6 beam stop.

The results of the first run, which took place between June and December 1987, have been published in the October 1988 issue of *Physical Review Letters*. A total of 5100 Coulombs of protons was incident on the LAMPF beam stop, yielding 4.2×10^{18} neutrinos incident on the 20-ton detector. After subtracting the cosmic-ray rate of 0.10 ± 0.02 events per day, there was a beam excess of 12.3 ± 4.7 events. These events are well explained by background neutrino interactions and there is no evidence for neutrino oscillations. The 90% confidence level limits are $\delta m^2 < 0.11$ eV^2 for maximal mixing, and $\sin^2(2\theta) < 0.014$ for large δm^2.

The experiment ran again in 1988, accumulating another 4200 Coulombs of protons on target for a total exposure of 9300 Coulombs. The preliminary results are consistent with the analysis of the 1987 data. An analysis, which exploits neutron detection, is in progress.

Experiment 645 will run for one more year with no major changes. Analysis of the entire data set should result in 90% confidence-level limits of $\delta m^2 < 0.085$ eV^2 for maximal mixing, and $\sin^2(2\theta) < 0.008$ for large δm^2, assuming that there are no surprises in the data. Continued running will not improve the oscillation limits much and any continuation of the experiment beyond calendar 1989 will be based on other physics motivation.

EXPERIMENT 1052 — NTOF

Calibration of the LAMPF Neutron Time-of-Flight Facility Detector System Using a Tagged Neutron Beam

Los Alamos, Ohio State Univ., IUCF, Ohio Univ., Univ. of Colorado, Univ. of Texas at Austin, UCLA

Spokesmen: L. J. Rybarcyk, T. A. Carey, and J. B. McClelland (Los Alamos)

Participants: R. G. Jeppesen, W. C. Sailor, T. N. Taddeucci, D. G. Marchlenski, E. R. Sugarbaker, C. D. Goodman, W. Huang, J. Rapaport, D. Mercer, D. Prout, D. E. Ciskowski, and E. Gulmez

Experiment 1052 was motivated by a desire to better understand the response of the Neutron Time-of-Flight (NTOF) detector system to intermediate energy neutrons.

The NTOF detector array contains three planar neutron detectors mounted parallel to one another and transverse to the beam. Each plane is a stainless steel tank filled with BC517s, a mineral-oil based liquid scintillator, and divided into ten optically-isolated 10 cm x 10 cm x 105 cm cells, viewed at each end by a 2-in phototube (Amperex XP2262). Each phototube is coupled to a high rate base (CERN type 4244), constant-fraction discriminator and individual FERA ADC and TDC channels. The detector array also contains two planes of thin plastic scintillator paddles located upstream of the first and second neutron-detector planes to provide the capability of tagging charged particles seen by the detector array.

The goal of this study was to determine the integral and differential neutron-detection efficiency and obtain position resolution information for a single NTOF plane. This experiment was mounted in Area BR where we employed a tagged neutron beam. The data-acquisition portion of the experiment was completed during cycle 51. Over the course of the experiment the NTOF detector was illuminated with tagged neutrons in the energy range from 100 to 730 MeV. The online result for the integral efficiency versus neutron energy is shown in Fig. 1.

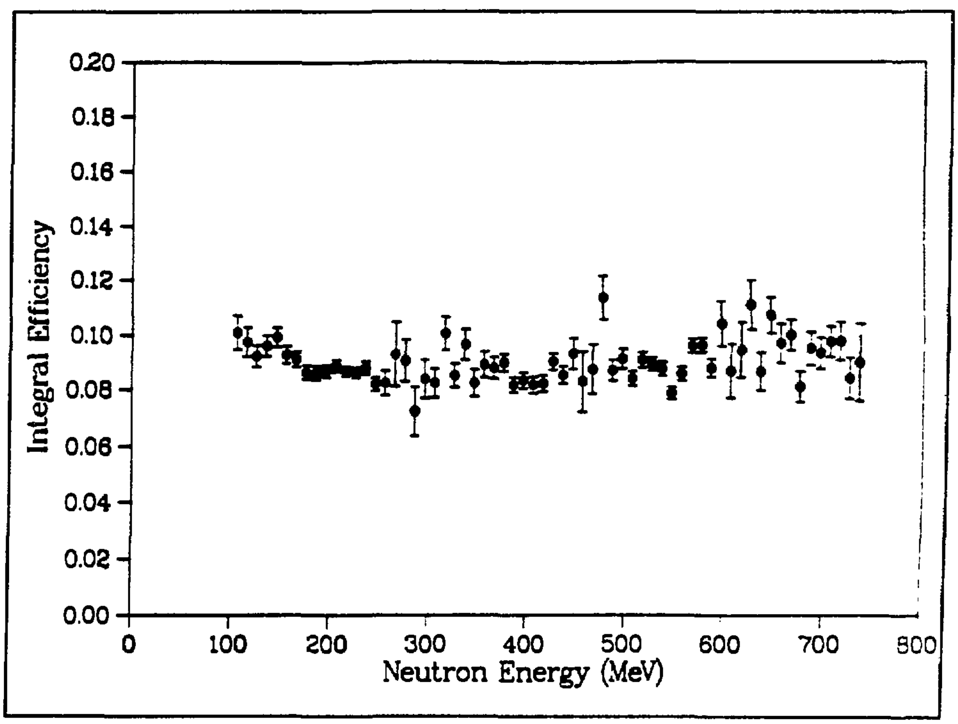


Fig. 1. Online result of integral efficiency vs neutron energy for a single NTOF neutron-detector plane (pulse-height threshold ~3 MeV).

EXPERIMENT 1062 — NTOF

Study of Pure Fermi and Gamow-Teller Transitions in the $^{14}C(n,p)^{14}N$ Reactions

Ohio State Univ., Los Alamos, IUCF, Univ. of Colorado, UCLA, Ohio Univ., Univ. of Texas at Austin, Univ. of West Ontario

Spokesmen: E. Sugarbaker (Ohio State Univ.) and T. N. Taddeucci (Los Alamos)

Participants: T. A. Carey, R. Byrd, J. B. McClelland, L. J. Rybarcyk, D. Marchlenski, J. Kruzan, P. Keman, E. Gulmez, C. Whitten, C. D. Goodman, W. Huang, D. Ciskowski, J. Rapaport, D. Prout, D. Mercer, and W. P. Alford

This experiment was the first to use the full Neutron Time-of-Flight (NTOF) facility, including the long flight path. Optimal neutron energy resolution was required to resolve the two transitions of primary interest in this study, the 1^+ 3.95-MeV and 0^+ 2.31-MeV states in ^{14}N populated via the $^{14}C(p,n)^{14}N$ reaction. Since the nuclear matrix elements mitigating these pure Gamow-Teller (GT) and Fermi (F) transitions, respectively, can be deduced from beta decay, the cross-section ratio for the two transitions reflects the relative strength of the square of the volume integrals of the isovector spin-flip ($V_{\sigma\tau}$) and non-spin-flip (V_τ) central components of the effective interaction. These measurements are the first to extend such investigations to energies above 500 MeV using the optimal ^{14}C reaction. Results should be instrumental in defining the energy dependence of the isovector-effective interactions at medium energies.[1]

Measurements were made using the recently commissioned long flight path at the NTOF facility. Three stainless steel tanks, each composed of ten optically isolated 10 cm × 10 cm × 105 cm cells containing BC517s liquid scintillator, were placed at the end of the long flight path. The distance from the target in the NTOF cave to the first detector tank was 617.7 m. Each tank provided a neutron detection singles efficiency of about 9%. However, singles data obtained under such mode of operation were characterized by long low-energy tails associated with each peak. While the cause for these tails is still under investigation, it was quickly noted that the tail-to-peak ratio could be significantly reduced by considering only events that involved a coincidence between the first detector tank and either of the other two tanks located approximately 1.5 m further out on the flight path. By employing the high (~60 nA average) H^- beam intensities available, we were able to obtain about ±5% statistical uncertainties, even under this low-efficiency mode of operation.

A large beam-pulse spacing was required to remove the contribution from frame overlap in the neutron time-of-flight (TOF) spectra. The H^- beam was chopped to provide a micropulse spacing of five microseconds. At the two lower energies studied, 500 and 650 MeV, the "rebunching" technique was used to produce a time focus of the beam at the neutron detectors. This was accomplished by using one of the nonaccelerating cavities of the linac to appropriately modify the phase space of the beam.[2] Typical total energy resolutions (FWHM) obtained under these conditions were 630 keV at 500 MeV and 700 keV at 650 MeV. The neutron-energy spectrum shown in Fig. 1 for the $^{14}C(p,n)^{14}N$ reaction at a scattering angle of 0° is representative of data obtained at these two bombarding energies. At 800 MeV the "rebunching" technique was not possible, resulting in energy resolutions in excess of 2.5 MeV due to the momentum spread in the beam. Attempts to limit this spread using the Line X strippers resulted in approximately 1.3-MeV FWHM resolution with only 10 nA average 800-MeV beam on target. A sample spectrum from the $^{13}C(p,n)^{13}N$ reaction at 0° scattering angle at 800 MeV is shown in Fig. 2. This latter resolution was not sufficient to cleanly resolve the states of interest in the $^{14}C(p,n)^{14}N$ reaction. However,

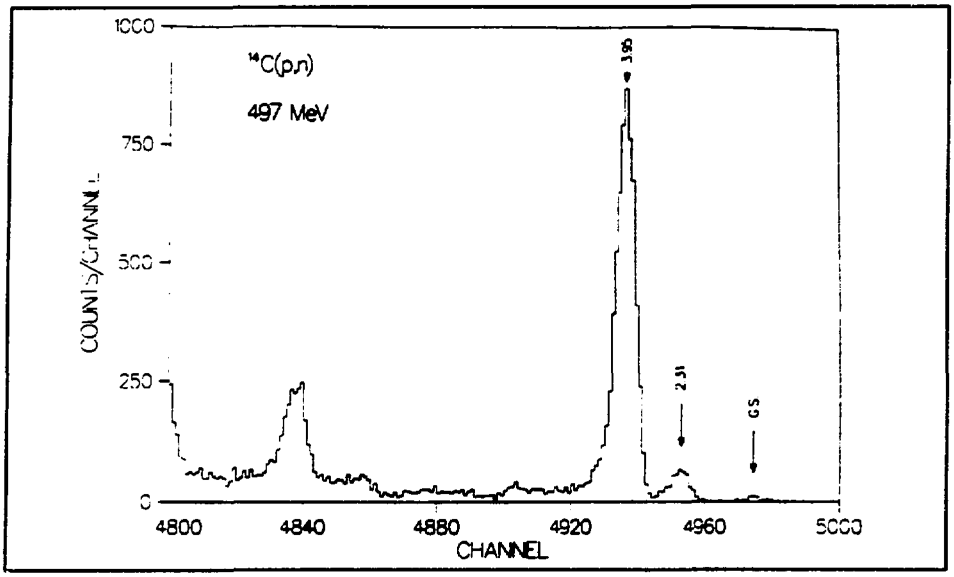


Fig. 1. Neutron-energy spectrum for the $^{14}C(p,n)^{14}N$ reaction at 497-MeV beam energy and 0° scattering angle. The g.s., 0^+ 2.31-MeV, and 1^+ 3.95-MeV states of ^{14}N are well resolved.

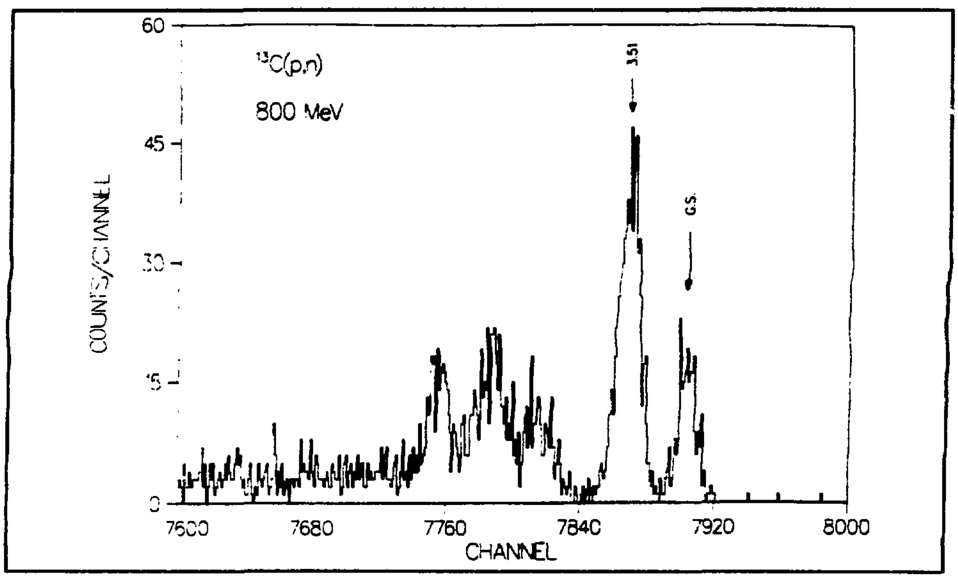


Fig. 2. Neutron-energy spectrum for the $^{13}C(p,n)^{13}N$ reaction at 800-MeV beam energy and 0° scattering angle. The 1.4-MeV FWHM resolution is adequate to resolve the mixed GT + F g.s. and the pure GT 3.51-MeV excited state.

preliminary off-line analysis of these 800-MeV data suggest that some degree of separation of the two ^{13}N transitions of interest will be possible.

The ratio R^2 of the GT to F cross sections per respective unit beta-decay strengths can be obtained either from pure GT and F states (as in the case of ^{14}N) or from a mixed GT + F state and a pure GT state (as in ^{11}C and ^{13}N).[3] Due to limited energy resolution, previous studies of R^2 above 500 MeV have been limited to values based on the less precise odd-mass cases.[4,5] For comparison with such studies, forward-angle data were also obtained on targets of ^{11}B, ^{12}C, and ^{13}C. Preliminary values of R^2 extracted from the ^{14}C data at 500 MeV and 650 MeV are 9.2 ± 0.5 and 6.6 ± 0.4, respectively.

More complete angular distributions were measured at 650-MeV and 800-MeV beam energies for the $^{7}Li(p,n)^{7}Be$(g.s. + 0.43 MeV) transition. These measurements provide a calibration of the efficiency of the neutron detection by comparison to an activation measurement.[6] Simultaneous low-resolution measurements utilizing the full five-microsecond spacing between beam pulses also provided cross section data for momentum transfers out to about 3 fm^{-1} on the quasifree and delta-excitation regions.

References

1. W. G. Love, K. Nakayama, and M. A. Franey, *Phys. Rev. Lett.* **59**, 1401 (1987).

2. J. B. McClelland, "The Neutron Time-of-Flight (NTOF) Project," in "Progress at LAMPF, January–December 1987," Los Alamos National Laboratory report LA-11339-PR (September 1988), p. 251.

3. T. N. Taddueci, C. A. Goulding, T. A. Carey, R. C. Byrd, C. D. Goodman, C. Gaarde, J. Larsen, D. Horen, J. Rapaport, and E. Sugarbaker, *Nucl. Phys. A* **469**, 125 (1987).

4. N. S. King, P. W. Lisowski, G. I. Morgan, P. N. Craig, R. G. Jeppesen, D. A. Lind, J. R. Shepard, J. L. Ullmann, C. D. Zafiratos, C. D. Goodman, and C. A. Goulding, *Phys. Lett. B* **175**, 279 (1986).

5. J. Rapaport, P. W. Lisowski, J. L. Ullmann, R. C. Byrd, T. A. Carey, J. B. McClelland et al., "Fermi and Gamow-Teller Strength in *p*-Shell Nuclei from (*p*, *n*) Reactions at 492 and 590 MeV" (in press, *Physical Review C* **39**, 1989).

6. J. D'auria, M. Dombsky, L. Moritz, T. Ruth, G. Sheffer, T. E. Ward et al., *Phys. Rev. C* **30**, 1999 (1984).

EXPERIMENT 1022 — P^3-East

Search for Nuclear Bound States of the Eta Meson

George Mason Univ., Los Alamos, College of William & Mary, Louisiana State Univ., Virginia State Univ.

Spokesmen: B. J. Lieb (George Mason Univ.) and L. C. Liu (Los Alamos)

Participants: E. Cheung, B. J. Dropesky, R. Estep, A. Fazely, H. O. Funsten, N. L. Fuqua, Q. Haider, B. J. Lieb, L. C. Liu, C. Lyndon, J. MacKenzie, C. L. Morris, C. F. Perdrisat, V. Punjabi, C. Stronach, and P. Ulmer

Several years ago, Liu and Haider[1] calculated that the eta meson could be bound in nuclei having a mass number $A > 11$. They have termed these bound systems eta-mesic nuclei. Their calculations were based on the attractive interaction between an eta meson and a nucleon at very low energies. This attraction was indicated by the analysis of $\pi^- + p \rightarrow \eta + n$ reaction[2] and can be more easily understood on the argument that the threshold for ηN channel is situated just slightly below the mass of the $N^*(1535)$ resonance.[3]

Experimental observation of these nuclear bound states could open new ways for studying the basic interaction between the nucleon and the eta meson, for which a beam is not available. Such studies would be very similar to the studies of basic hyperon-nucleon interactions that have been pursued on hypernuclei for many years. For (π^+, p) reactions in the $N^*(1535)$ resonance region, the cross section for the formation of an eta-nucleus bound state is a function of the coupling constants $f_{\pi NN^*}$ and $f_{\eta NN^*}$ whereas the binding energy of the bound state depends on $f^2_{\eta NN^*}$. Thus, a knowledge of the cross section and binding energy can allow a good determination of both these coupling constants. Since $N^*(1535)$ is not a SU(6) ground state of the quarks, experimental information on these coupling constants can be used to provide tests for models of the quark excitation mechanism in N^*. It may also shed light on the structure of the still not fully understood eta meson. The eta-mesic nuclear levels correspond to an excitation energy of ~540 MeV, to be compared with an excitation energy of ~200 MeV associated with Λ- and Σ-hypernuclei. The existence of nuclear bound states with such high excitation energies would probably lead to new studies in nuclear systems.

In Liu and Haider's original calculation,[4] the signature for eta-mesic nucleus production was a peak in the forward-proton-energy distribution in the (π^+, p) reaction on nuclei. The protons were observed at forward angles in order to minimize the recoil momenta of the eta produced. If such a peak were to occur for proton energy corresponding to the production of an eta meson having a mass less than its free-space value, it would be indicative of an η that was bound in the nuclear potential.

We carried out our search (Exp. 1022) for η-mesic nuclei on the LAMPF P^3 channel, using a 657-MeV/c π^+ beam. Data were accumulated for ^{7}Li, ^{12}C, ^{16}O, and ^{27}Al targets. A coincidence with the expected η-mesic nucleus decay products is required because the predicted singles cross sections were too small at LAMPF beam momenta for inclusive observation of the bound states. We assumed that the η-mesic nucleus would decay via the processes $\eta + N \rightarrow N^* \rightarrow \pi^- + p$, or $\pi^0 + n$, or $\pi^+ + n$, or $\pi^0 + p$. In the experiment, we detected forward protons in coincidence with one of these decay products, using the LAMPF BGO ball, which is an array of 30 BGO detectors subtending approximately an angle of 4π. The BGO detectors have a scintillator in front for proton identification, but they are unable to determine the energy or the sign of the p's. In order to correct for this, we attempted to detect the large energy deposited (referred to as a star) at the end of the π^- range in a large plastic scintillator. An iron absorber was used to center the range at the expected π momentum (460 MeV/c). This star counter was placed at an angle of ~90° with respect to the beam. Because we were using a π^+ beam, seeing at this large angle a high-momentum π^- in coincidence with the forward proton will represent clearly an exclusive signature of the decay of η-nucleus bound states. Although the decay schemes of the η-mesic nucleus also include the π^+ mode, seeing π^+'s of high momentum at 90° alone is, however, not as exclusive a decay signature as is the case with seeing π^-'s.

We recorded events in the five forward-angle BGO detectors in coincidence with triggers in at least two other BGO detectors or an event in the star counter. In replay, we accumulate spectra of protons in these five forward BGO detectors in coincidence with various signatures in the other detectors.

A preliminary analysis of the data on the ^{16}O target shows evidence that the η bound state, $^{15}_{\eta}$O may have been produced. Figure 1(a) shows a summed spectrum of protons in four of the five forward detectors (detectors #2,3,4,5) when a coincidence is required with a second proton and with a pion detected in

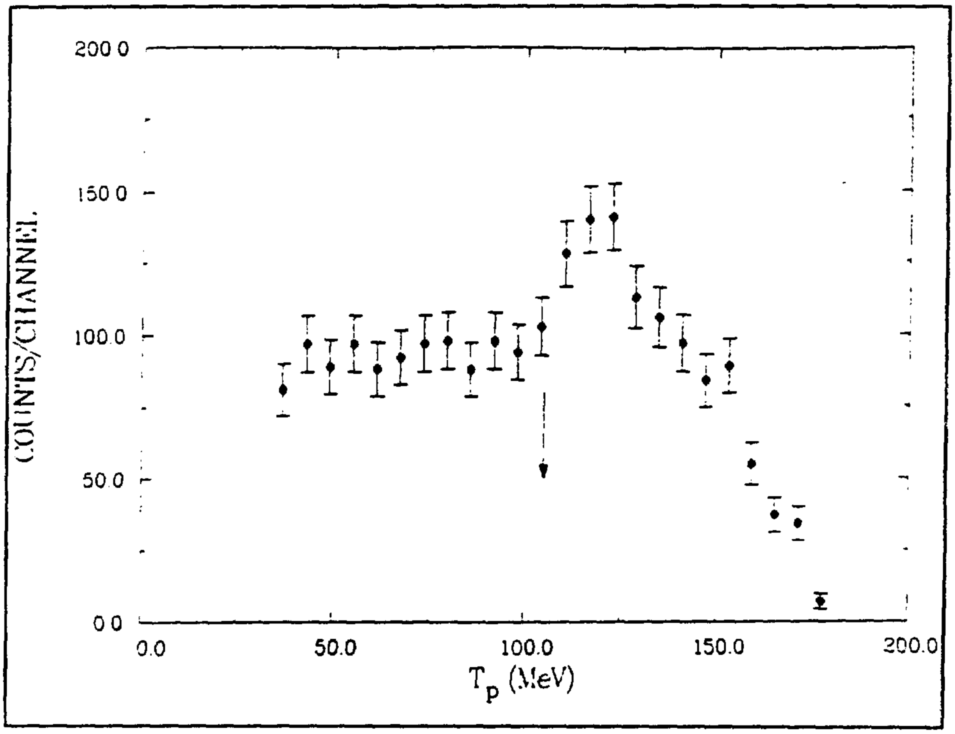


Fig. 1(a). Combined spectrum of protons from the $^{16}O(\pi^+, p)$ reaction. The protons were detected in four forward detectors and in coincidence with a second proton and a pion detected at conjugate directions. The arrow indicates the nuclear threshold for free η production. A peak at proton energy greater than this threshold would be indicative of the production of bound state $^{15}_{\eta}$O.

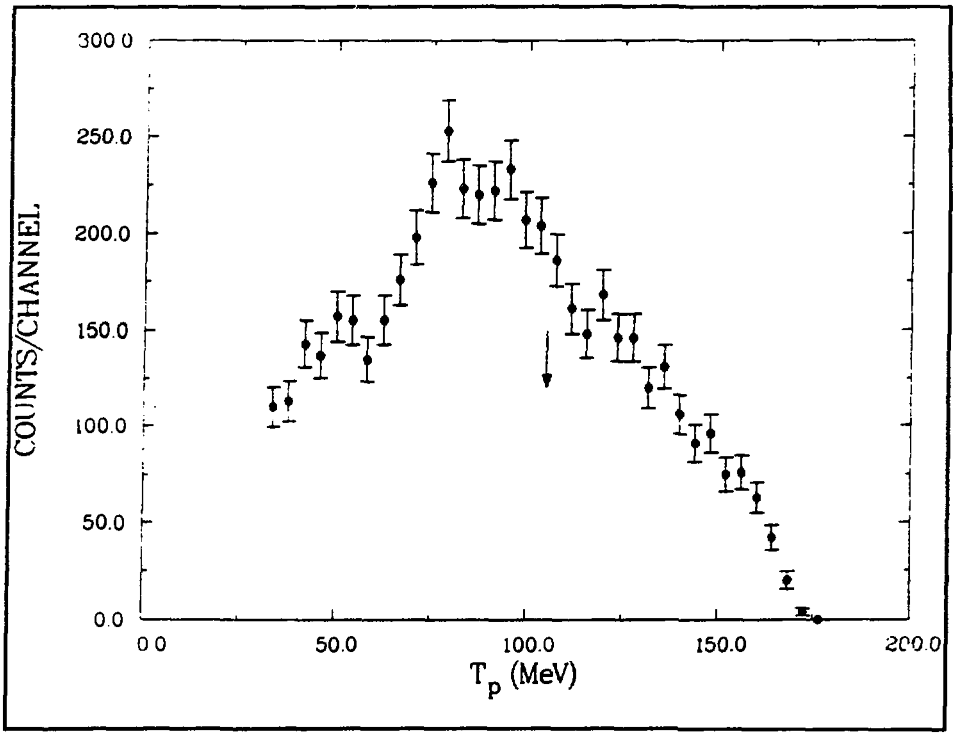


Fig. 1(b). Combined spectrum of protons from the $^{16}O(\pi^+, p)$ reaction. The protons were detected in forward detectors and in coincidence with a second proton and another trigger. The structure at proton energies smaller than the nuclear threshold for free η production is assumed to be due to quasifree eta processes.

conjugate directions in the BGO ball. The nuclear threshold for free η production corresponds to $T_p \simeq 105$ MeV. Hence, the peak to the right of this threshold is at the expected energy for a bound state. A similar peak results when we require a coincidence with the star counter (spectrum not shown).

There has been another experimental search for these bound states, a singles experiment at Brookhaven.[5] That experiment resulted in an upper limit of 8.7 μb/(sr·MeV). The preliminary cross section from this experiment is about 0.6 μb/(sr·MeV), so the two experiments are not in disagreement.

There are still problems with the data and the energy calibration that must be resolved before these results are final. In particular, we are attempting to resolve the problem that the proton spectrum of one of the forward detectors [not included in Fig. 1(a)] also has a peak but at a different energy. Another problem is with the star counter. We are confident that it sees π's with momenta >460 MeV/c but we are not certain that it sees only π^-.

There is also evidence of quasifree η production. For example, the broad structure in Fig. 1(b) results when only a single proton is the coincidence requirement. The shape of this structure, which we assume is due to quasifree processes, changes with the angle of the coincident proton.

References

1. Q. Haider and L. C. Liu, *Phys. Lett.* *B* **172**, 257 (1986); (E)*B* **174**, 465 (1986).
2. R. S. Bhalerao and L. C. Liu, *Phys. Rev. Lett.* **54**, 865 (1985).
3. L. C. Liu, *AIP Conf. Proc.* **150**, 930–933 (1986).
4. L. C. Liu and Q. Haider, *Phys. Rev.* C **34**, 1845 (1986).
5. R. E. Chrien, S. Bart, P. Pile, R. Sutter, N. Tsoupas, H. O. Funsten et al., *Phys. Rev. Lett.* **60**, 2595 (1988).

EXPERIMENT 1015 — PSR

A Large Čerenkov Detector for Neutrino Physics

UC Irvine, UCLA, UC Riverside, Univ. of Colorado, CEBAF, College of William & Mary, Los Alamos, Univ. of New Mexico, Univ. of Pennsylvania, Temple Univ.

Spokesman: D. H. White (Los Alamos)

Participants: R. C. Allen, X.-Q. Lu, G. J. Igo, E. Gulmez, C. Whitten, G. VanDalen, Sun Yui Fung, J. Kang, J. Layter, B. C. Shen, R. Ristinen, R. Smythe, R. C. Carlini, R. Burman, J. Donahue, D. Fitzgerald, W. Foreman, M. Hoehn, T. Kozlowski, D. M. Lee, W. C. Louis, R. Macek, J. McGill, E. C. Milner, M. Oothoudt, V. Sandberg, G. Sanders, M. Schillaci, R. Werbeck, R. Westervelt, D. H. White, D. Whitehouse, M. L. Brooks, B. B. Dieterle, C. P. Leavitt, R. Reeder, W. Frati, A. K. Mann, M. Newcomer, R. van Berg, L. A. Auerbach, V. L. Highland, W. K. McFarlane, and R. T. Seigel

A collaboration from Los Alamos, University of California at Irvine, University of California at Los Angeles, University of California at Riverside, CEBAF, University of Colorado, University of New Mexico, University of Pennsylvania, Temple University, and College of William and Mary has proposed an experiment to measure neutrino-electron scattering to high accuracy. From a measurement of the ratio

$$R = \sigma(\nu_\mu e)/[\sigma(\nu_e e) + \sigma(\overline{\nu}_\mu e)] \ ,$$

$\sin^2\theta_W$ will be determined to a precision of 1%, and a comparison of this value of $\sin^2\theta_W$ to that obtained from the measured masses of the W and Z bosons provides a sensitive test of the Standard Model of electroweak interactions and a promising means to learn about physics beyond the Standard Model. Other physics topics that can be studied in the experiment include searches for neutrino oscillations, limits on the neutrino-charge radius or magnetic moment, lepton-number violation, supernova-neutrino bursts, and upward-going muons in the GeV range.

The detector consists of a 7000-ton imaging water Čerenkov tank with approximately 10,000 photomultiplier tubes of 10-in diameter lining the surfaces of the tank. The LAMPF Proton Storage Ring (PSR) will produce a proton pulse of 2.5×10^{13} protons in a duration of 270 ns at a 45-Hz repetition rate, corresponding to an average current of 180 μA. These protons interact in a copper beam stop that will be located near the center of the detector and will be well shielded to reduce neutron backgrounds to acceptable levels. Positive pions produced in the beam stop will quickly come to rest and decay in the sequence $\pi^+ \rightarrow \mu^+\nu_\mu$, which will be followed by muon decay according to $\mu^+ \rightarrow e^+\nu_e\overline{\nu}_\mu$. The experiment will take advantage of the 270-ns PSR beam spill in order to separate the neutrinos from pion decay (26-ns lifetime) from the neutrinos from muon decay (2200-ns lifetime), and because the different neutrinos will be produced in almost exactly equal numbers from pion and muon decay at rest, the beam-stop source will provide neutrino beams with well defined spectra. Electrons scattered by the neutrinos will produce Čerenkov light, which is then detected by the photomultiplier tubes. From a reconstruction of the hit phototubes, the position, angle, time, and energy of the electron will be determined to good accuracy.

A considerable amount of work has gone into designing and simulating the detector and understanding the backgrounds that can be expected from the experiment. An initial design has been completed, along with engineering studies and a cost estimate. The worst backgrounds appear to be the beam-associated backgrounds from neutron interactions in the water and neutrino-oxygen scattering, although other backgrounds such as cosmic rays, nonuniform efficiency, and systematic time and energy shifts have also been studied. Measurements of neutron-related background have commenced. It has been estimated that for a complete run of 625 days, the systematic error in the determination of $\sin^2\theta_W$ will be roughly half of the statistical error, and the estimated total error is approximately 0.9%.

The first prototypes of the new 10-in photomultiplier tube were shipped to Los Alamos by Burle Industries. Early test results show that these tubes greatly exceed our expectations and that a new very high quality, large, fast photomultiplier tube has been brought into existence. A time resolution of 2.3 ns FWHM has been observed (Fig. 1) for one photoelectron per event and full-face illumination. Single photoelectrons are resolved (Fig. 2) with a peak to valley ratio of 3:1.

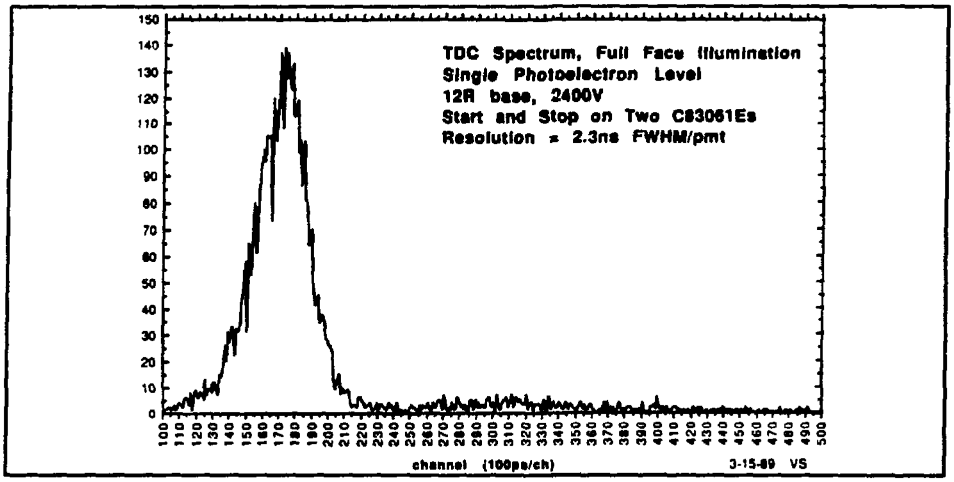


Fig. 1. The TDC spectrum resulting from the full face illumination at the single photoelectron level of two C83061E photomultiplier tubes. One tube triggered the TDC start, and the other tube the TDC stop. The timing resolution corresponds to 2.3 ns FWHM/tube.

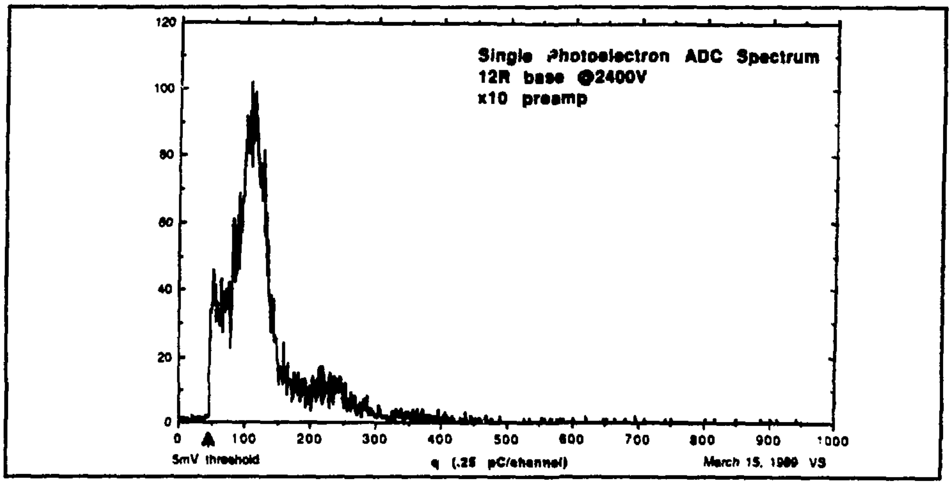


Fig. 2. The ADC spectrum resulting from the full face illumination of a C83061E photomultiplier tube. The dominant peak is due to single photoelectrons and is clearly separated from the broader, two-photoelectron peak.

The final design of the experiment will be completed in the next year. In addition to continued simulations of the detector, various supplementary measurements will be made to insure that the experimental design is adequate for a precise determination of $\sin^2\theta_W$. These measurements include studies of pion and photon production from background neutrons, low-energy neutron fluxes from the Exp. 225 beam dump, and Čerenkov photon detection from an electron beam in water. Furthermore, development work will proceed on each major system of the experiment. Additional photomultiplier tubes will be evaluated, front-end electronics and data-acquisition design will continue, iron for neutron shielding will be procured, and beam-line magnet design will begin. The group is planning to start construction in about one and one half years and to have first beam to the detector in about three and one half years.

TIME-REVERSAL INVARIANCE — PSR

Study of Parity and Time-Reversal Symmetries in Neutron-Nucleus Scattering

Los Alamos, Duke Univ., North Carolina State Univ., Univ. of Technology (The Netherlands), TRIUMF, Univ. of Virginia, Max-Planck-Institut (W. Germany)

Spokesman: J. D. Bowman (Los Alamos)

Participants: C. D. Bowman, J. D. Bowman, P. Herczeg, J. Knudsen, S. Seestrom-Morris, J. Szymanski, V. W. Yuan, S. Pentilla, C. R. Gould, D. G. Haase, G. E. Mitchell, C. Frankle, N. R. Roberson, X. Zhu, P. P. J. Delheij, H. Postma, B. Tippens, and E. D. Davis

Neutron-nucleus scattering provides an excellent laboratory to test time-reversal symmetry with unprecedented precision. The total cross section for n-nucleus scattering as a function of neutron energy exhibits large peaks corresponding to resonances in the daughter nucleus. The spacing of these peaks is a few eV, since the levels of daughter that are populated are at excitation energies of about 7 MeV, the compound nucleus regime. Due to the small level spacings, mixings between energy levels are larger than for levels near the nuclear ground state. If a symmetry-violating force is present in the nuclear Hamiltonian, it will introduce large symmetry-violating mixings between nearly degenerate nuclear states having suitable quantum numbers. The dependence of a scattering process on dynamical variables that exhibit symmetry violation will be enhanced by a large symmetry-violating wave-function admixture.

The dynamical variables that we use are neutron spin s, neutron momentum k, and target spin j, as well as combinations of these variables. The neutron helicity $s \cdot k$ is parity-odd and time-reversal-even. The dependence of a total cross section for a particular resonance on $s \cdot k$ is an unambiguous signal that the resonance has mixed parity. Remarkably large parity-violating asymmetries have been observed for a number of p-wave resonances. The most spectacular case is the 0.734 eV resonance in ^{139}La where the parity-violating asymmetry is 9.4%. The observation of such a large parity-violating effect demonstrates the existence of substantial nuclear structure enhancement of symmetry-violating observables. Time reversal-odd observables are the threefold correlation $s \cdot j \times k$, which is parity-odd, and the fivefold correlation $(s \cdot j \times k)(j \cdot k)$, which is parity-even. It is the latter that will be the object of our first round of time-reversal tests.

Such symmetry tests are done by measuring the dependence on neutron spin of the transmission of a neutron beam through an unpolarized, polarized, or aligned nuclear target. A polarizing filter prepares a neutron beam in a definite polarization state. The polarization is reversed by a spin flipper. The transmission of the neutron beam through a target is measured by a polarization insensitive detector.

During 1988, we developed a polarized neutron beam at the Proton Storage Ring (PSR) spallation source. The neutrons are polarized by passing them through a cell of polarized protons. The protons, which are present as waters of hydration in a lanthanum magnesium nitrate crystal, are dynamically polarized. Cooling to 1.1 K is provided by a pumped ^{4}He bath. The n-p cross section is much larger for spins antiparallel than parallel and so one neutron spin state is filtered out. The neutron beam is polarized in the energy range from 0.1 to 100,000 eV. The polarization at 1 eV is 58%. We developed two methods of neutron spin reversal. The first is to change the microwave frequency. This changes the hyperfine transitions that are pumped and reverses the proton polarization, and hence the neutron polarization, without changing any magnetic field. This method precisely reverses the neutron polarization, but requires several hours, making it unsuitable for symmetry test measurements. The second method involves passing the neutron through a spin flipper: an apparatus with two configurations of magnetic fields, one adiabatically flips the neutron spin and the other provides for a sudden non-spin-flip transition through the guide field. The state of the spin flipper can be changed in a few milliseconds. Together, these two methods can be used in a double-modulation technique that reduces the effects of slow drifts using the fast flip and compares precisely opposite spin states.

During 1987–88, we developed neutron detectors and the current-mode neutron-detection technique. Neutrons are detected on an array of ^{6}Li-doped glass scintillators via the $n + {}^6\text{Li} \rightarrow {}^4\text{He} + {}^3\text{H}$ reaction. The scintillation light is converted to a current and amplified by photomultiplier tubes. Because neutrons impinge on this detector at instantaneous rates of up to 10^{12} per second, it is not possible to register individual pulses. In order to use the full neutron flux available at the PSR, we developed current-mode neutron detection. The current output is digitized to 12 bits at 100-ns intervals. Eight thousand successive time bins provide a record of the neutron transmission as a function of time of flight (neutron energy) for each PSR pulse. Typical neutron flight times are a few milliseconds so that all neutrons' energies in the range from a few to a few hundred eV are recorded. We have demonstrated that current-mode neutron detection provides energy resolution and statistical accuracies comparable to those that would be obtained if it were possible to register individual neutron pulses.

We repeated the measurement of the size of the helicity dependence of the total cross section for the 0.734-eV resonance in ^{139}La. We obtained a longitudinal asymmetry of $-8.33 \pm 0.66 \pm 1.25$, in agreement with earlier results. We searched for parity-violating asymmetries in ^{235}U, ^{238}U, and ^{165}Ho targets. We discovered a new parity-violating resonance in ^{238}U at a neutron energy of 63.52 eV. The preliminary value for the longitudinal asymmetry is $-0.61 \pm 0.09 \pm 0.09$. This is the highest neutron energy at which a parity-violating asymmetry has been observed. The extension results from the high-neutron epithermal fluxes available at the PSR.

EXPERIMENT 969 — SMC

MEGA: Search for the Rare Decay $\mu^+ \rightarrow e^+\gamma$

UCLA, Univ. of Chicago, Univ. of Houston, Fermilab, Los Alamos, Princeton Univ., Stanford Univ., Texas A&M Univ., Valparaiso Univ., Univ. of Virginia, VPI, Univ. of Wyoming, Yale Univ.

Spokesman: M. D. Cooper (Los Alamos)

Participants: D. Barlow, R. Kessler, B. M. K. Nefkens, C. Pillai, J. Price, J. Crocker, S. C. Wright, M. Dzemidzic, J. Flick, E. V. Hungerford III, K. Johnston, K. Lan, B. W. Mayes II, L. Pinsky, L. Tang, W. von Witch, P. S. Cooper, J. F. Amann, K. Black, R. D. Bolton, S. Carius, M. D. Cooper, W. Foreman, C. Hansen, R. Harrison, G. Hart, V. Hart, C. M. Hoffman, N. Hoffman, T. Hunter, G. E. Hogan, N. June, D. Kercher, J. Little, T. Kozlowski, R. E. Mischke, F. J. Naivar, J. Novak, M. A. Oothoudt, S. Schilling, W. Smith, J. Sturrock, J. Szymanski, J. Van Dyke, R. D. Werbeck, C. Wilkinson, A. Hallin, E. B. Hughes, C. Jui, J. N. Otis, R. W. Ritter, C. Gagliardi, G. Kim, F. Liu, R. E. Tribble, L. Van Ausdeln, R. J. Fisk, D. D. Koetke, R. Manweller, R. Marshall, W. Stephens, B. Tippens, K. O. H. Ziock, L. E. Piilonen, A. R. Kunselman, K. Hahn, and J. K. Markey

The search for $\mu \rightarrow e\gamma$ at LAMPF is called MEGA, an acronym standing for Muon decays into an Electron and a GAmma ray, and is an experiment with a branching-ratio sensitivity of roughly 10^{-13}. Such a search is important because there is no known reason for conservation of muon family number, though the observation of the decay would indicate the need for an extension to the Standard Model of electroweak interactions. At the end of 1988, the experiment had the second of two runs, where the purpose was to test engineering ideas in the detector. This run culminated the year's work and its results are presented here.

The MEGA apparatus is shown in Fig. 1. The apparatus is contained in a large magnet that has been obtained from SLAC; it has a 1.5-T field, a clear bore of 1.85 m, and a length of 2.9 m. Assembly of the magnet and its cryogenics system is complete.

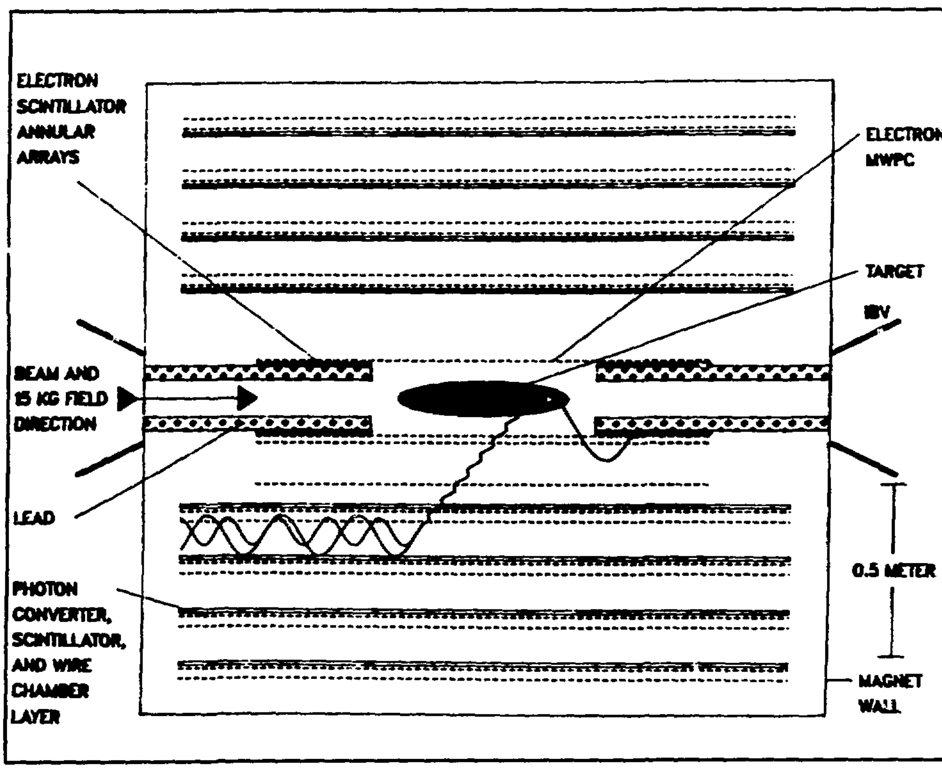


Fig. 1. A sectioned-plan view of the MEGA apparatus with an idealized $\mu^+ \rightarrow e^+\gamma$ event shown.

The required muon stopping rate is 3×10^7 Hz (average). Development runs at SMC have demonstrated an excess of flux from the channel. Tunes have been developed that discard the excess in a way that very little beam is dropped near the apparatus. Preliminary results show that minor changes in the tune do not induce backgrounds in the photon spectrometer. The beam separator operates reliably for multiple-week periods at 200 kV, though there are lingering problems in obtaining the full 250 kV across the plates.

The detector is divided into a positron spectrometer and a series of photon-pair spectrometers. All of the charged particles arising from muon decay are confined to a maximum radius of 29 cm, leaving the photon detectors in a relatively quiet environment.

The positron arm consists of two parts, a set of MWPC's for momentum determination and scintillators for timing. The MWPC design for the positron spectrometer is called "Snow White and the Seven Dwarfs." There is a central, cylindrical chamber of 11.25-cm radius that is kept relatively clean by instrumenting only the ends of the chamber with cathodes. Seven small "dwarf" chambers encircle "Snow White" to provide the necessary redundancy for pattern recognition.

Chamber design has been pursued by constructing two prototypes, one planar chamber to test the small details of the design and one cylindrical chamber to test construction techniques. The first has settled the type of wire, wire spacing, cathode readout, and electronics that is desired. Two important new results have been obtained with this prototype in the last year. The first is that the chamber is extremely stable against high-voltage breakdown with the selected gas, 80%-CF_4:20%-isobutane, if the pressure is 760 torr, while it is sensitive to breakdown if the chamber is run at the local atmospheric pressure of 580 torr. As a result, the details of sealing the final chamber have been worked out to allow operation at substantial overpressure. The second result is to show that the required chamber lifetime can be achieved. Using an intense radioactive source, the chamber showed no degradation in efficiency after being irradiated with an accumulated charge, after wire amplification, of 0.05 C/cm. The test was halted because this amount surpasses our anticipated requirements by a factor of two, but is still well below what other groups have obtained by irradiating for longer periods. The second prototype is being used to evaluate the construction of the ends of a dwarf chamber. It differs from a dwarf only in that it is 10 cm long. High voltage breakdowns in earlier attempts were blamed on poor mechanical tolerances. The current prototype maintains the half-gaps to ± 50 μm. One key feature of the construction is the precision machined end rings made from ceramic alumina. Another improvement is to make our scratched cathode foils out of 200 nm of Cu evaporated on 25 μm of Kapton. The change solves the electrical contact problems of the foils to the electronics. The electronics is approaching its final design and a configuration has been worked out that fits all preamplifiers within the required space.

The second part of the positron spectrometer consists of banks of scintillators arranged in a cylindrical geometry about the beam near the end of the shielding. The positrons enter the scintillators after at least one revolution in the chamber. Positrons trapped in the field for more than eight loops are rejected by their relative time with respect to the photon. Each bank is divided into 90 elements to keep the individual counter rates manageable. A section of 30 scintillators was tested this year. Attaching a $0.6 \times 0.9 \times 30\ cm^3$ scintillator (rhomboid cross section) to a 1.5-m fiber optics light-guide, necessary to get the photomultiplier tubes outside the magnetic field, has yielded 0.5-ns FWHM resolution for minimum ionizing radiation, a value equal to the experimental design. The magnetic shielding of the photomultiplier tubes is sufficient to make the field have a negligible effect on the tube output. The singles rates in the scintillators are completely consistent with the muon stopping rate in the target. Hit multiplicities agree with Monte Carlo simulations of standardly illuminated scintillators. The multiplicities are plotted in Fig. 2, normalized to the number of single hits. The Monte Carlo calculations are quite sensitive to the energy-deposition threshold, and it is reassuring that the best agreement shown was obtained at the value actually imposed on the data by the electronic discriminators.

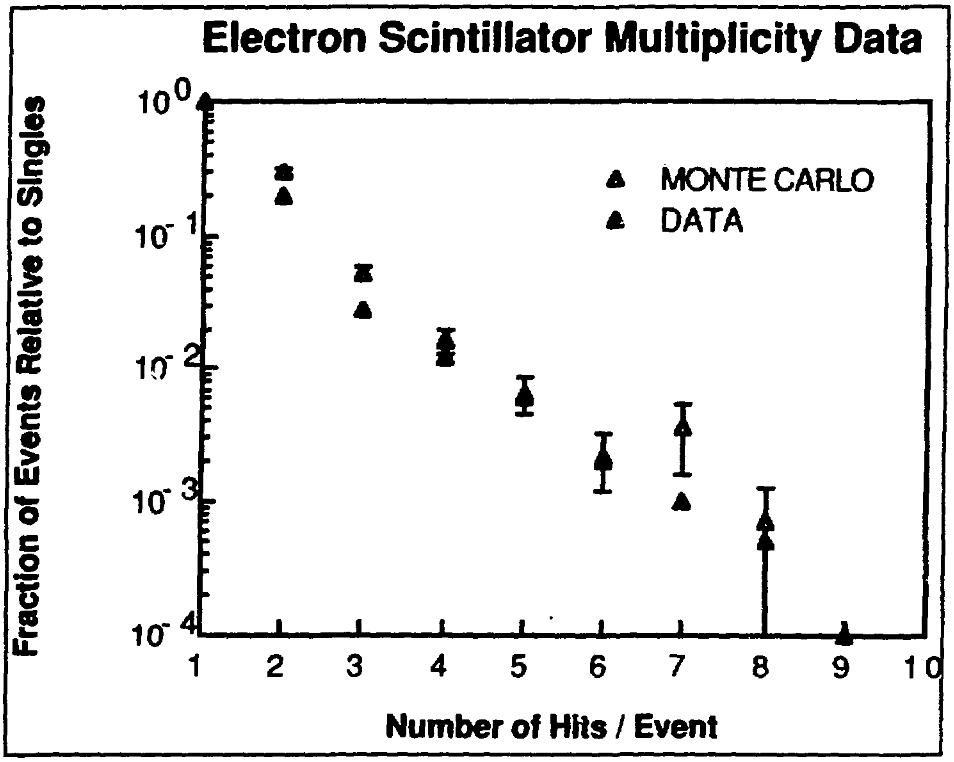


Fig. 2. The multiplicity of hits in the electron scintillators.

The photon arm is four concentric pair spectrometers of essentially identical construction. One pair spectrometer was available for evaluation in the beam run. Each pair spectrometer is made of lead converters, MWPC's, drift chambers, and scintillators. The detailed arrangement is shown in Fig. 3, and has changed substantively in the last year due to results from the test. The scintillators continue

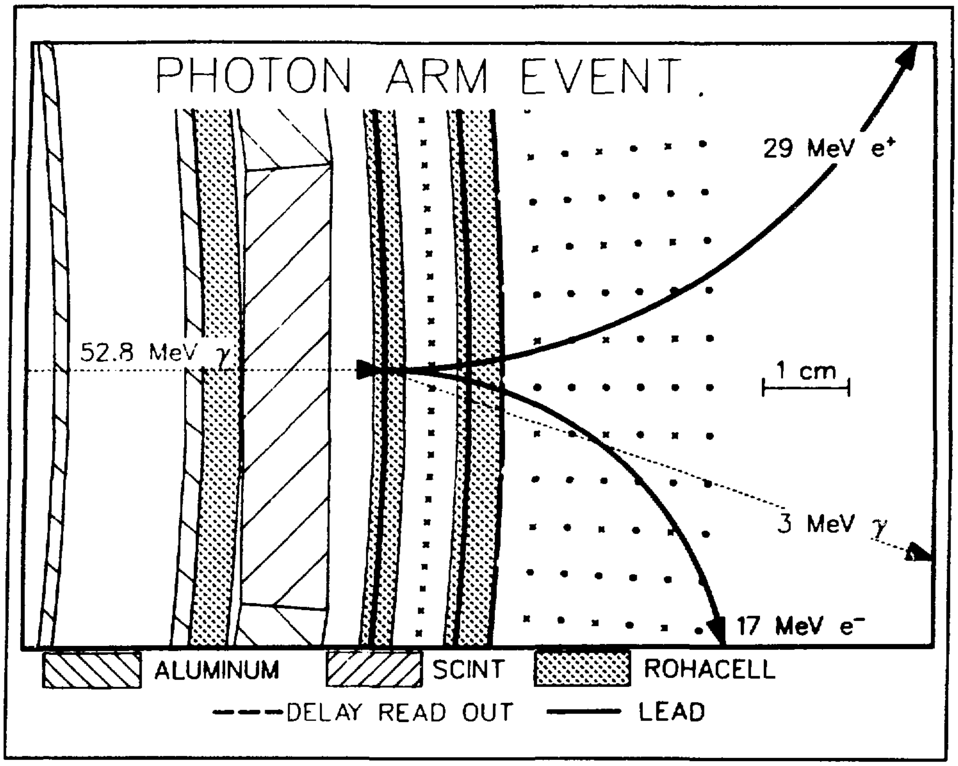


Fig. 3. An exploded view of a pair spectrometer layer seen parallel to the magnetic field.

to perform according to specifications. Results on the singles and coincidence rates in these counters under data taking conditions are in rough agreement with calculations in the proposal. Due to mechanical difficulties in the construction of the chambers, the chambers never reached a sufficient voltage to have high efficiency. Many of the design changes are intended to relieve the mechanical problems. However, recognizable pair events have been seen. Preamplifiers, amplifier-discriminators, and multiplexers have been built and tested. Modifications will be necessary to eliminate ground loops and oscillations.

The MEGA trigger relies on an electronics circuit that measures the azimuthal width of the hit pattern from photon-induced pairs. One such module has been built and partially tested. Of greater than 10^4 random patterns generated by a computer, all are filtered properly. No pattern-recognition failures have been observed during the beam period. The module uses programmable array logic and has a propagation delay of less than 30 ns. In a separate test, the width of photon-induced patterns has been measured in 2-cm bins and is compared to Monte Carlo predictions in Fig. 4. The trigger appears to give the required rate suppression when set at a width of 9. The probability of accidental pile up in

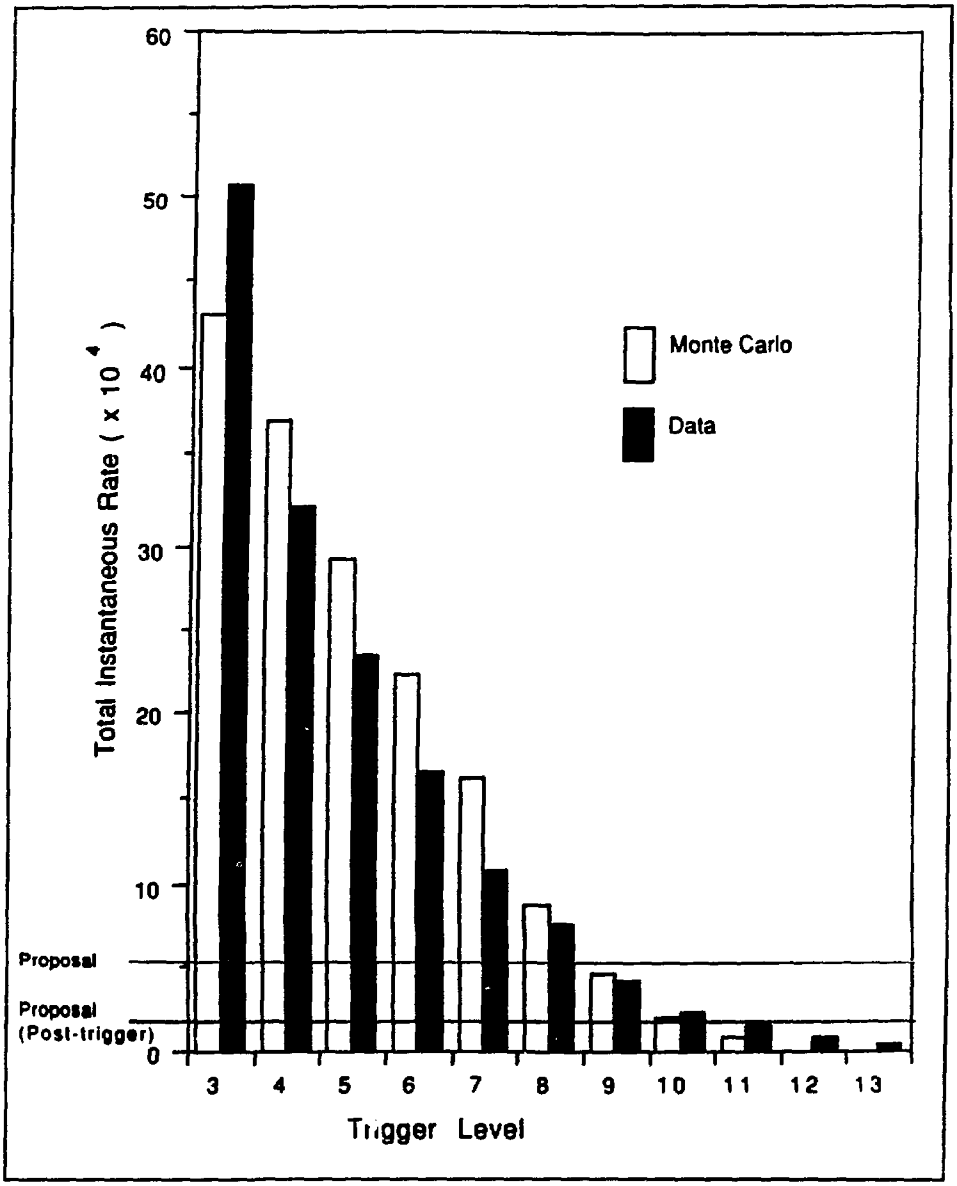


Fig. 4. The azimuthal width of photon-induced shower patterns in 2-cm bins.

the patterns and real cross talk from low-energy secondary photons is measured to be commensurate with the proposal and at the few percent level.

The MEGA data-acquisition system consists of FASTBUS front-ends and memories, a VME-based microprocessor farm, and a MicroVAX control computer. This year we took data with five FASTBUS modules and eight microprocessors of the final design style, and eight slower FASTBUS modules without memories. The system was remarkably stable and required only one restart due to a hardware failure in the three weeks of running. Production FASTBUS TDC's and latches will be available in quantity soon. ADC's are needed for next year and have a tight schedule. The microprocessor farm (Advanced Computer Project) along with its Fermilab software, all interconnecting modules, and the FASTBUS master (General Purpose Master) performed nominally. It remains to be seen if the system will remain reliable when expanded to its full size of 32 microprocessors and 200 FASTBUS modules.

One of our calibration tasks is to have a clean source of photons near 50 MeV. Our proposed source of photons is from the reactions $\pi^- p \rightarrow \pi^0 n$ and $\pi^- p \rightarrow \gamma n$. Both coincidence and single photons were observed almost without accidental background in the pair spectrometer with rates of 2 and 25 Hz, respectively. The pion beam seems adequate, but further work is required to optimize the stopping target so that a response function can be measured.

In the next year, the collaboration hopes to bring together enough of the detector to begin data taking in 1989. All the tested components appear close to working. Sufficient equipment to set new limits on the $\mu \rightarrow e\gamma$ process will have to wait for 1990, with the more stringent measurements in 1991.

Beam Development for MEGA at the SMC

C. Pillai, D. Barlow, B. M. K. Nefkens, J. Price, and R. Kessler (UCLA), M. D. Cooper and C. M. Hoffman (Los Alamos)

The MEGA experiment, which looks for the decay $\mu \rightarrow e\gamma$ at the level of 10^{-13} or better, demands a clean beam of surface muons with an intensity of 3×10^7 μ/s. The primary responsibility of developing such a beam was undertaken by the Particle Physics Group at UCLA led by Ben Nefkens. The Stopped Muon Channel (SMC) at LAMPF consisting of 21 quadrupole magnets and four bending magnets is basically designed[1] for muons from pion decay in flight; not for surface muons. Surface muons are produced by the decay of the stopped pions in the production target.[2] The pions should stop near the surface of the target so that the decay muons can escape. The maximum momentum of these muons will be only 32 MeV/c. The only significant contamination of such a beam is from the large number of positrons present at such low momentum. Surface muons are only produced from π^+ because the π^- that stop in the target are captured by the nuclei before they can decay.

We developed various tunes for the channel for surface muons using the beam transport codes like TRANSPORT, TURTLE, and REVMOC. Each tune is different regarding the rate, beam size, background and momentum bite. Theoretically it is possible to get $\sim 1 \times 10^8$ μ/s for a tune designed to get the maximum rate from a production target of 4 cm in length at 1 mA at the SMC. Four short beam-development runs were performed starting in August 1987, to study the properties of the channel and develop the required tune. The main objectives of all these development runs were to:

(1) optimize the beam for the best μ/e separation,

(2) measure the beam rate for various tunes,

(3) measure the beam profile along the axis of the MEGA solenoid, and

(4) try to reduce the background due to beam halo.

We developed a number of different tools along the way to achieve all these objectives.

The Separator

A crossed-field separator was designed and built to separate the positrons from the muons. The effective length of the separator is 1.03 m and the gap distance 20 cm. It is designed to hold 250 kV across the gap. Conditioning the new separator took a long time. We were only able to hold 200 kV during the last MEGA run, but plan to go up to 250 kV during the next run. The separation of positrons from the 28.5-MeV/c muons is 10.4 cm at the exit of the separator with 200 kV across the gap. The number of positrons was found to be about 10 times that of the muons at the entrance of the solenoid with the separator off. During the last MEGA run there was no direct evidence of positron contamination in the solenoid with the separator on. An adjustable lead collimator was installed downstream of the separator to stop the positrons after separation. Figure 1

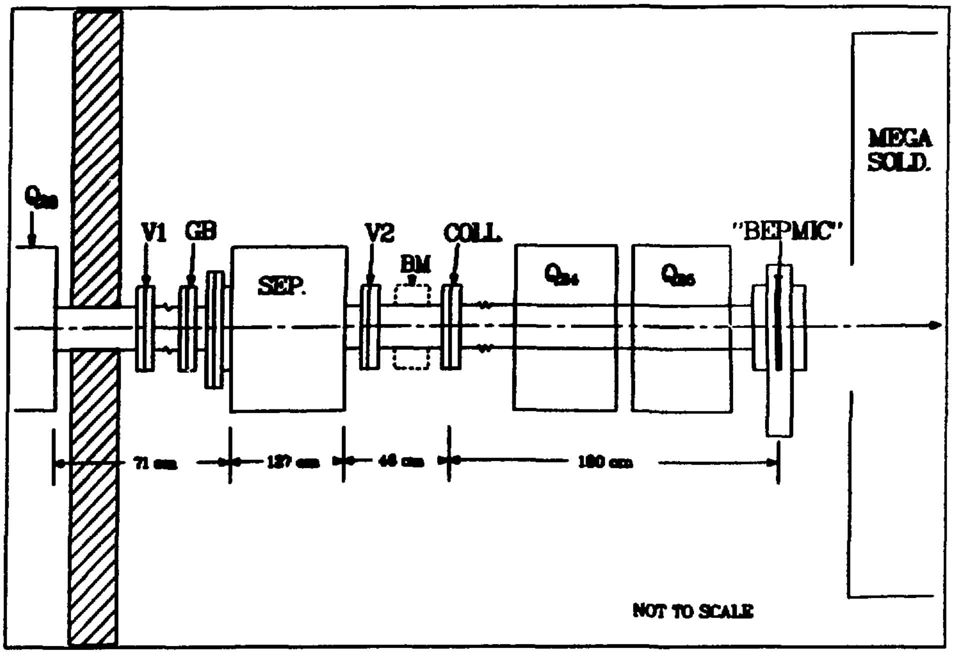


Fig. 1. A schematic of the SMC beam line section inside the cave where all of the improvements to the line were done for MEGA. GB is a 0.5-mil mylar gas barrier to stop the radioactive gas coming from upstream.

gives a schematic of the beam line section inside the MEGA cave where all of the improvements to the line were made.

The High Voltage Power Supply

The hv power supplies for the MEGA separator were furnished by the Gamma High Voltage Research, Inc., of New York.[3] The power supplies are designed to give 125 kV at a current of 1.25 mA. The Cockcroft-Walton multiplier unit of the power supply was originally placed inside a plastic box potted with cellastic, which made it difficult to repair the unit when components inside fail. Therefore, a change was made to a pressurized SF_6 gas enclosure for the multiplier. The enclosure box was designed at LAMPF in collaboration with the UCLA Particle Physics Group. The sides of the box are made of aluminum, the top and bottom of transparent LEXAN. Two O-ring seals are used to make the unit gas tight. The dimension of the box is 37.5 cm x 39.4 cm x 17.1 cm; it can withstand a pressure of 25 psi and normally operates at 10–12 psi. It is complete with hermetically sealed feed-through connector, gas-filling valve, a pressure gauge, and a pressure-relief valve. We made several improvements to the layout of the components inside the gas-filled power supply so that the units operate more reliably. These modifications are incorporated by the supplier in future units.

Ion Chamber (IC)

In order to measure the beam rate at full intensity, we designed an Ion Chamber (IC) with an effective area of 15 cm x 15 cm. A thin scintillator (0.16 cm) with fiber optics for light guides and special photomultiplier tube bases to handle high rates was also made to calibrate the IC. Figure 2 shows the response of the IC as a function of the rate in the scintillator. A rate of 1×10^7 to 2×10^7 μ/s was obtained for a 1-cm production target depending on the tune used.

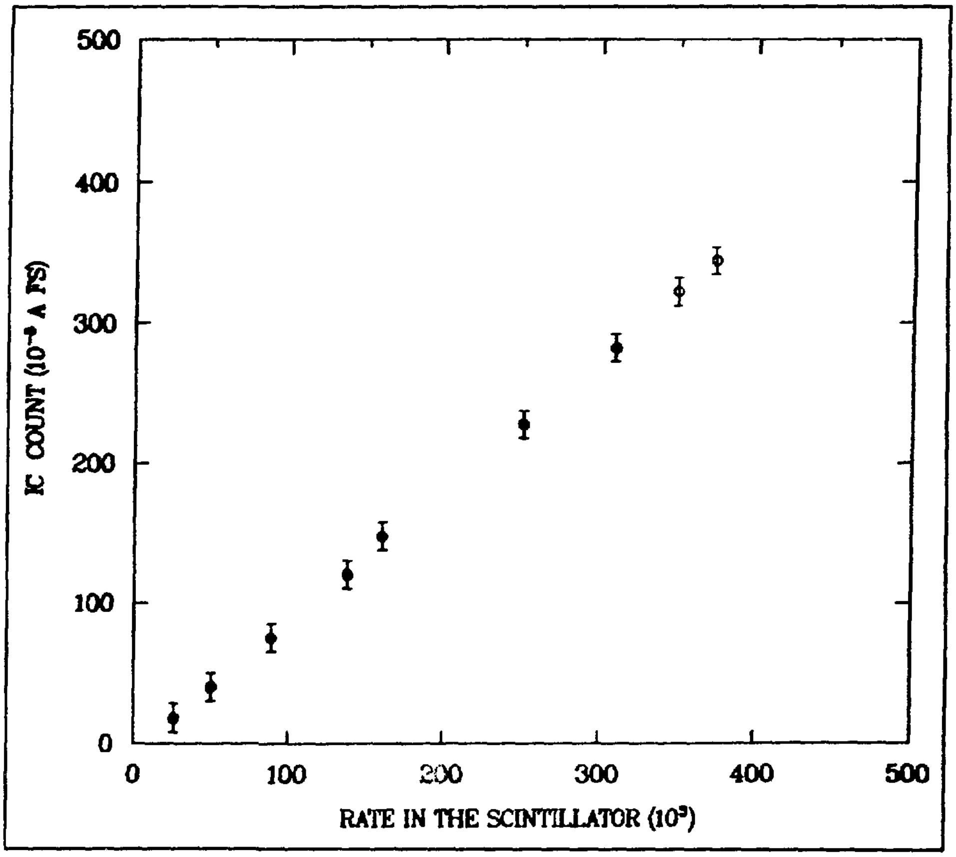


Fig. 2. The calibration curve of the IC against the absolute rate measured by the scintillator. The scintillator is thin enough so that the positrons deposit very little energy whereas the pulse height due to the muons is large.

Beam Profile Monitor + Ion Chamber ("BEPMIC")

Since the energy of surface muons is very low (~4 MeV), ordinary beam profile monitors are too thick to function properly. Therefore, a low-pressure low-mass unit was built to look at the beam profile at the entrance of the solenoid to tune the beam. This particular unit also has the option of being used as an ion chamber with one external switch to change the function. It uses the standard P-10 gas at 100-torr pressure regulated by a special gas-handling system to within 1 torr. The whole unit operates inside the vacuum of the beam line and can be withdrawn from the beam during data taking. This unit was calibrated against the scintillator and the ion chamber to measure the absolute beam rate. Figure 3 gives the intensity of the muon beam as a function of IC output, as measured by a CD1010 current digitizer, against the absolute rate. The rate is varied

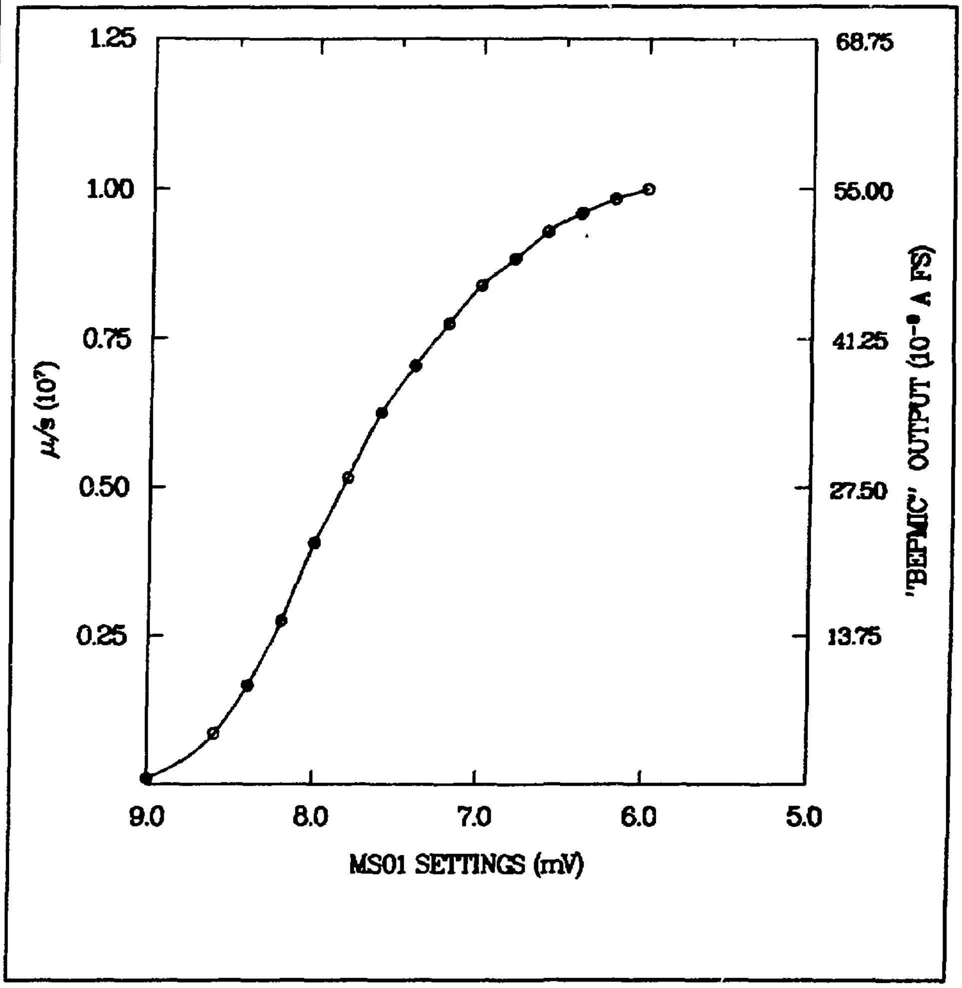


Fig. 3. A calibration curve for the "BEPMIC" against the opening of the upstream vertical slit MS01, which is given in mV. A reading of 9.25 mV means that the slit is completely closed and a 6-mV reading means that it is fully opened. The Y-scale on the left side gives the absolute rate of muons for the tune used in the last MEGA run with 1-cm A2 target and the scale on the right side gives the output of the "BEPMIC" as measured by the current digitizer CD1010. It has a digitized output of 10 MHz for full-scale reading.

by changing the vertical slit, MS01, upstream. This calibration was found to be reproducible to within 2% between beam tuning. A similar unit was used along a track to measure the beam profile along the axis of the solenoid. The beam size along the axis of the solenoid confirmed the predicted oscillatory behavior with a pitch of about 35 cm.

References

1. P. A. Thompson V. W. Hughes, W. P. Lysenko, and H. F. Vogel, *Nucl. Instrum. and Methods* **161**, 391 (1979).

2. A. E. Piefer, T. Bowen, and K. R. Kendall, *Nucl. Instrum. and Methods* **135**, 39 (1976).

3. Gamma High Voltage Research, Inc., Mt. Vernon, N.Y. 10550.

Studies of the (n,p) Reaction at the WNR Target Four White Neutron Source

Los Alamos, Univ. of California, Davis, Ohio Univ., Duke Univ.

Spokesmen: J. L. Ullmann, R. C. Haight (Los Alamos), and J. Rapaport (Ohio Univ.)

Participants: D. S. Sorenson, A. Ling, P. W. Lisowski, N. S. P. King, F. P. Brady, J. R. Romero, J. R. Drummond, R. W. Finley, X. Aslanoglou, V. Mishra, W. Abfalhter, G. Stevens, C. Howell, and W. Tornow

The white neutron source at the Weapons Nuetron Research (WNR) facility provides a source of neutrons with energies from 1 to about 700 MeV, with a usable flux for nuclear physics experiments up to about 250 MeV. During the last year, a facility for studying neutron-induced reactions near 0°, particularly the (n,p) reaction, has been constructed. The motivation for the current interest in the (n,p) reaction is provided by exciting new information on isovector modes of nuclear excitation from studies of the (p,n) reaction. One of these modes is the Gamow-Teller state, whose excitation in the (p,n) reaction has been found to be proportional to B(GT), the Gamow-Teller beta-decay matrix element. The (p,n) experiments have revealed several interesting puzzles concerning excitation of the Gamow-Teller state. Studies of the (n,p) reaction, which go to states of isospin $T_z = T_{zo} + 1$, may help to understand these puzzles.

The facility was built at 90 m from the neutron source to provide time-of-flight information on the neutron energy. The detector consists of a 0.5 T magnet to bend forward-scattered protons out of the neutron beam followed by an E-DE-detector array. This consists of a plastic DE detector, followed by a 10.5-in × 17.5-in array of CsI(Tℓ) detectors as a calorimeter. A multiple target array is used to increase the count rate, and events in each target are tagged by multiwire proportional counters. Multiwire drift chambers before and after the clearing magnet are used to measure the scattering angle and location of event in the detector array. Cross sections are measured with respect to hydrogen using a CH_2 target.

During 1988, ^{13}C and ^{12}C targets were studied. Preliminary spectra for $^{13}C(n,p)$, which represent about 10% of the data, are shown in Fig. 1. The spectra are summed over the angle range 0° to 4°, and are displayed in several incident energy bins. The $(3/2)^-$ ground state at $Q = 12.65$ MeV, which is excited by a pure Gamow-Teller excitation, is well separated from the first excited state at 3.48 MeV.

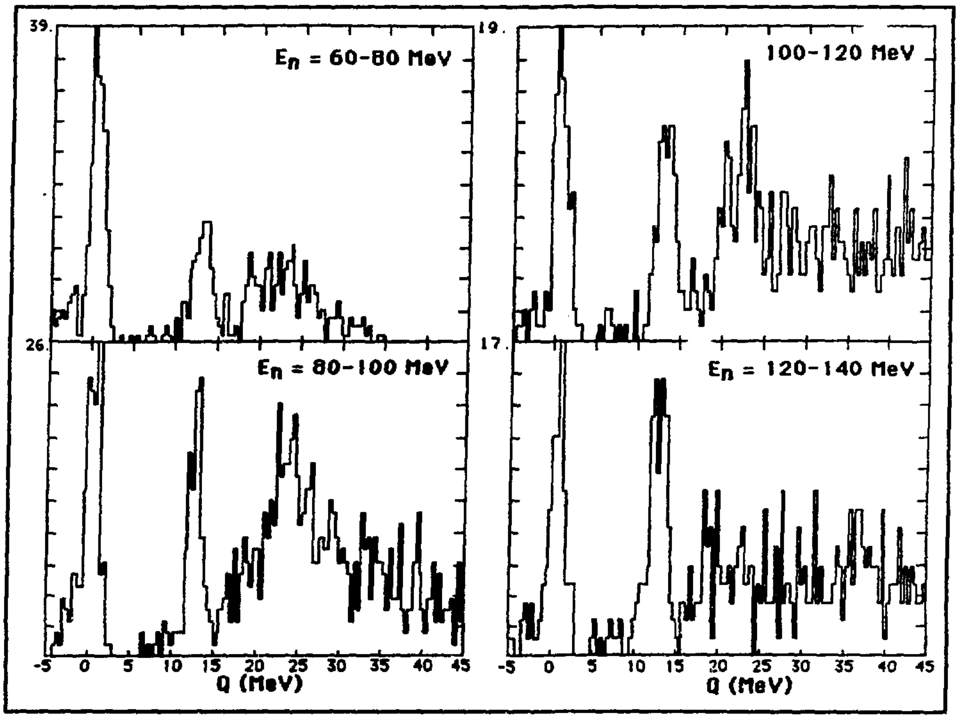


Fig. 1. Forward-angle (0° to 4°) $^{13}C(n,p)$ spectra summed into several incident energy bins. The large bump at $Q = 0$ is due to hydrogen contamination in the target.

Astrophysics

CYGNUS Project

Los Alamos, Univ. of Maryland, George Mason Univ., UC Irvine, Univ. of Southampton (UK), Argonne

Spokesman: *D. E. Nagle (Los Alamos)*

Participants: *D. E. Nagle, R. L. Burman, K. B. Butterfield, M. Potter, V. Sandberg, C. Wilkinson, C.-Y. Chang, B. Dingus, J. A. Goodman, T. Haines, D. A. Krakauer, R. L. Talaga, R. W. Ellsworth, R. C. Allen, D. Alexandreas, S. Biller, S. de Laye, G. Dion, G. B. Yodh, J. Lloyd-Evans, and R. Talaga*

The objective of the CYGNUS project is the development and operation of a gamma-ray telescope, operating in the energy band 10^{14}–10^{17} eV, and the study of celestial sources of gamma rays by the extensive air-shower technique. The number of muons contained in these showers is being studied. The work is supported by LANL Institutional Support for Research and Development (ISRD) funds. Our collaborators have National Science Foundation (NSF) support.

Concerning the scientific importance of this work, we may quote Abdus Salam: "The fundamental study of physics for the next 50 years is astroparticle physics." This particular study bears on the nature of the accelerators producing particles of energies 1000 TeV and above, the nature and geometry of certain binary star systems that are emitters, how the neutral beams may be absorbed in traveling through the Galaxy, and how they interact in the Earth's atmosphere.

The "CYGNUS" array is the only installation in the U.S. currently producing data above 1 TeV (with the exception of the Fly's eye, when they operate in a Čerenkov mode). The CYGNUS array is unique in the world today in that it has a well-shielded counting detector of muons with a tracking capability. This is important for the very topical question of the muon content of the showers associated with these sources.

Progress to Date

We have expanded the size of the CYGNUS array from the original 10^4 m^2 and the number of detectors from the original 64. We operated in FY 1988 with an array of 96 scintillation detectors sampling an area of 2×10^4 m^2. The former Exp. 225 system was operated as a muon detector. By the end of FY 1988, the number of detectors deployed was 107.

We recorded about 10^7 showers during 1986. Analysis presently is focused on two sources: Her X-1 and Cyg X-3. Signatures from both sources were obtained from the 1986 data. We published the *first* observation of a pulsar by an array, based on the 1986 Her X-1 data. The muon content of the showers is much higher than had been expected on the basis of conventional shower theory for a photon primary.

A search for bursts of about an hour's duration was conducted on a sample of the 1987 Her X-1 data. Several bursts were found showing the pulsar periodicity. A full analysis of the 1987 data is planned. Although, averaged over the entire year 1986, Cyg X-3 displayed no significant activity in ultrahigh energy, during April–May 1986, the star was active, displaying the well-known 4.79-h orbital period. During 1986, Cyg X-3 was quiet also in the radio bands.

A search for bursts in the Cyg X-3 1987 data is under way. Preliminary indications are that there is burst activity and periodicity in the data. The analysis is proceeding.

Publications and Papers

Phys. Rev. Lett. **60**, 1789 (1988).

Phys. Rev. Lett. **61**, 1906 (1988).

D. Nagle, T. Gaisser, and R. Protheroe, *Ann. Rev. Part. Nucl. Sci.* **38**, 609–657 (1988).

Eight papers by the CYGNUS group at the 20th International Conference on Cosmic Rays.

Seminars and Lectures

Seminars and Lectures were given at Erice, APS Storrs, UC San Diego, UCLA Gamma Ray Workshop (2), Moriond Conference, Aspen Astrophysics Conference, UC Berkeley Particle Astrophysics Workshop (2), Texas Symposium on Relativistic Astrophysics, Goddard Space Science Laboratory, University of Virginia, Johns Hopkins University, and many others.

Atomic and Molecular Physics

EXPERIMENT 963 — SMC

Determining the Parameters of Muon-Catalyzed *d-t* Fusion

Idaho Research, Los Alamos, Idaho National Engineering Laboratory, Brigham Young Univ.

Spokesmen: S. E. Jones (Brigham Young Univ.) and M. Paciotti (Los Alamos)

Participants: A. N. Anderson, O. K. Baker, J. N. Bradbury, J. S. Cohen, M. Leon, H. R. Maltrud, M. A. Paciotti, L. L. Sturgess, A. J. Caffrey, S. E. Jones, and S. S. Taylor

The LAMPF muon-catalyzed fusion program has amassed a good deal of data on the muon cycling rate λ_c as a function of target temperature, density, and composition.[1,2] Even with all of these data, it has proven quite difficult to extract the parameters of the underlying physical processes. Since the cycling time is completely dominated by the time the negative muon spends in the $d\mu$ or the $t\mu$ ground states, the normalized steady-state rate in a d-t target can be written as[3]

$$\frac{1}{\lambda_c} = \frac{q_{1s}C_d}{\lambda_{dt}C_t} + \frac{3}{4}\frac{1}{\lambda_{10}C_t + \lambda^1_{dt\mu}C_d} + \frac{\frac{1}{4}+\frac{3}{4}\chi}{\lambda^0_{dt\mu}C_d} \quad . \tag{1}$$

Here C_d and C_t are the deuterium and tritium fractions, λ_{dt} is the rate for transferring the muon from the $d\mu$ to the $t\mu$ ground state, q_{1s} is the probability that an initially-formed $d\mu$ atom will survive to reach the ground state, λ_{10} is the rate of triplet to singlet transitions of ground-state $t\mu$ atoms in collisions with tritons, and the resonant molecular formation rates (for singlet and triplet $t\mu$'s) are given by

$$\lambda^{0,1}_{dt\mu}C_d = \lambda^{0,1}_{dt\mu-d}C_{D_2} + \lambda^{0,1}_{dt\mu-t}C_{DT} \quad , \tag{2}$$

corresponding to formation in collisions with D_2 and DT molecules. The branching ratio χ is given by

$$\chi = \frac{\lambda_{10}C_t}{\lambda_{10}C_t + \lambda^1_{dt\mu}C_d} \quad . \tag{3}$$

Fortunately, there are compelling theoretical reasons for believing that only $\lambda^0_{dt\mu-d}$ is significant for temperatures $\lesssim 200$ K.[3] The probability q_{1s} as a function of density ϕ and C_t has been calculated by Menshikov and Ponomarev,[4] but there have been indications that this theoretical q_{1s} does not fit the experiments very well.[2,5]

In this report we present some results of a global fit to the LAMPF cycling rate data (nearly 300 runs), carried out and reported recently by A. N. Anderson.[6] Details of the functional forms used can be found in Ref. 6. When the q_{1s} is constrained to the theoretical result, the temperature dependences (for a range of densities ϕ) of $\lambda^0_{dt\mu-d}$ and $\lambda^0_{dt\mu-t}$ for minimizing χ^2 are as shown in Fig. 1; in addition, $\lambda_{10} \simeq 500\ \mu s^{-1}$, a value small enough so that a rising transient should have (but did not) show up clearly in the very low C_t PSI experiment reported by Kammel et al.[7] When the shape of q_{1s} is allowed to vary freely, the $\lambda^0_{dt\mu-x}$ (T, ϕ) and $q_{1s}(C_t, \phi)$ shown in Fig. 2 result, along with a larger λ_{10} and very much smaller χ^2. (The LAMPF results reported in Ref. 2 show a stronger ϕ-dependence for $\lambda^0_{dt\mu-d}$ than seen in Fig. 2; that is largely because a ϕ-independent form for q_{1s} was used in Ref. 2.)

Recent and future data will presumably allow more accurate determination of these quantities. Even now the results have significant implications for theory.

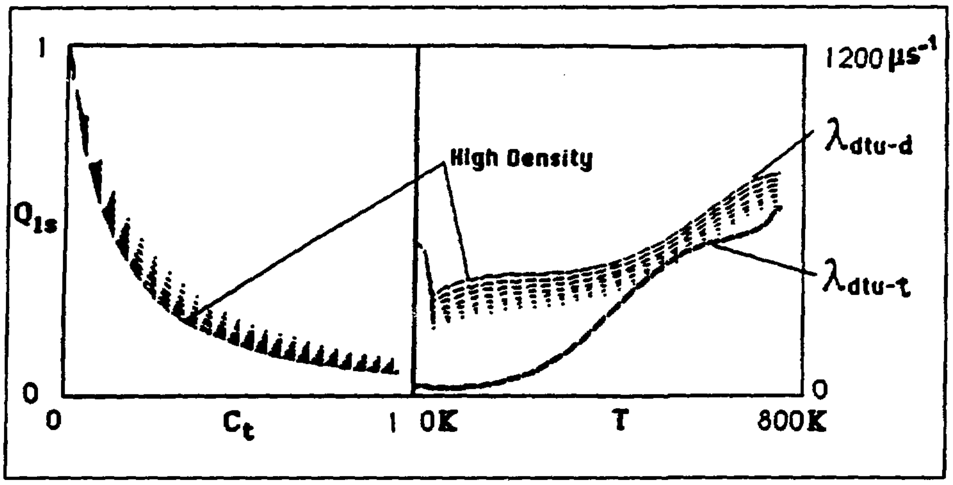


Fig. 1. Molecular formation rates (right side) assuming the theoretical q_{1s} (left side). The different curves correspond to density ϕ (relative to liquid H_2) from 0.1 to 0.7 in steps of 0.1.

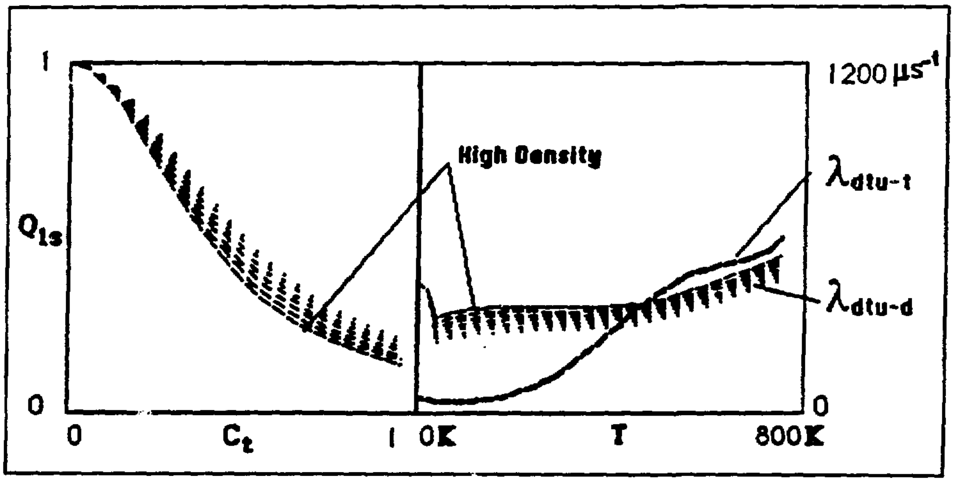


Fig. 2. As in Fig. 1, allowing q_{1s} to vary.

References

1. S. E. Jones, A. N. Anderson, A. J. Caffrey, J. B. Walter, K. D. Watts, J. N. Bradbury et al., *Phys. Rev. Lett.* **51**, 1757 (1983).

2. S. E. Jones, A. N. Anderson, A. J. Caffrey, C. DeW. Van Siclen, K. D. Watts, J. N. Bradbury et al., *Phys. Rev. Lett.* **56**, 588 (1986).

3. M. Leon, *Phys. Rev. Lett.* **52**, 605 (1984).

4. L. I. Menshikov and L. I. Ponomarev, *JETP Lett.* 39, 663 (1984).

5. W. H. Bruenlich, M. Cargnelli, P. Kammel, J. Marton, N. Naegele, P. Pawlek et al., *Phys. Rev. Lett.* 58, 329 (1987).

6. A. N. Anderson, in the proceedings of the Muon Catalyzed Fusion Workshop, Sanibel Island, May 1988, to be published.

7. P. Kammel, P. Ackerbauer, W. H. Breunlich, M. Cargnelli, M. Jeitler, J. Marton et al., *Muon Catal. Fusion* 3, 483 (1988).

EXPERIMENTS 1075 AND 1076 — HIRAB

Laser Spectroscopy of H^-

Univ. of New Mexico, Los Alamos, Drexel Univ., Univ. of Connecticut, Western Washington Univ.

Spokesmen: H. C. Bryant (Exp. 1075), R. A. Reeder (Exps. 1075 and 1076), A. H. Mohagheghi (Exp. 1076), and C. R. Quick (Exp. 1076)

Participants: H. C. Bryant, D. A. Clark, S. Cohen, J. B. Donahue, P. G. Harris, J. N. Knudson, D. W. MacArthur, W. H. McCulla, A. H. Mohagheghi, T. D. Nichols, C. R. Quick, R. A. Reeder, R. K. Sander, W. W. Smith, J. E. Stewart, C. Y. Tang, and V. Yuan

With the High-Resolution Atomic Beam (HIRAB) building now fully operational, the series of photodetachment experiments at LAMPF was able to continue in the dedicated facility. The 1988 runs, Exps. 1075 and 1076, provided definitive data to complement that of 1986 on the effects of electric fields on the photodetachment cross section of H^- and the interaction of thin foils with relativistic H^- ions. In addition, the way was opened to an exciting new area in atomic physics: the first multiphoton detachment of H^- was observed. Publications in 1988 include an earlier study[1] of high-lying resonances in H^- and a paper on photodetachment in electric fields;[2] three further papers—covering multiphoton detachment, the foil studies, and weak-field photodetachment studies—are expected to be completed shortly.

In each of these experiments, a high-powered laser beam was allowed to intersect the relativistic ion beam; the photon energy in the barycentric system is Doppler shifted, and the laser may, thus, effectively be tuned (through a range as great as a factor of ten) by changing the angle of intersection of the two beams, as illustrated in Figs. 1 and 2.

The HIRAB facility was designed specifically for photon-ion colliding beam physics. It provides a high-quality H^- beam with a low divergence and energy spread; both of these factors provide limits to the resolution in relativistic ion beam spectroscopy. In addition, as a dedicated facility, it allows optics to be set up and aligned precisely, well in advance of the experiment itself, which was not

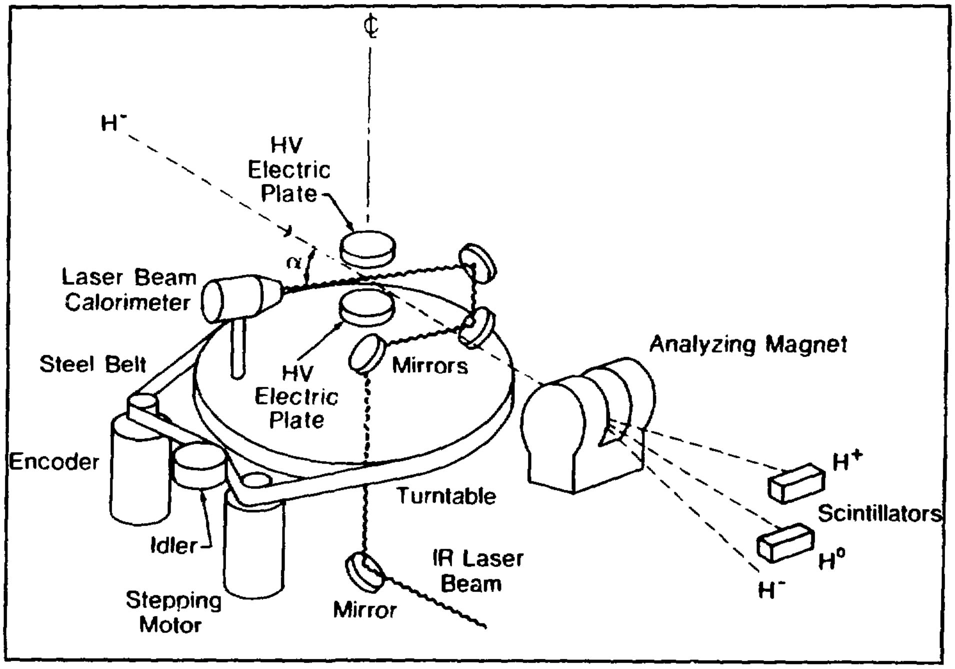


Fig. 1. Schematic of experimental apparatus for photodetachment in a weak electric field.

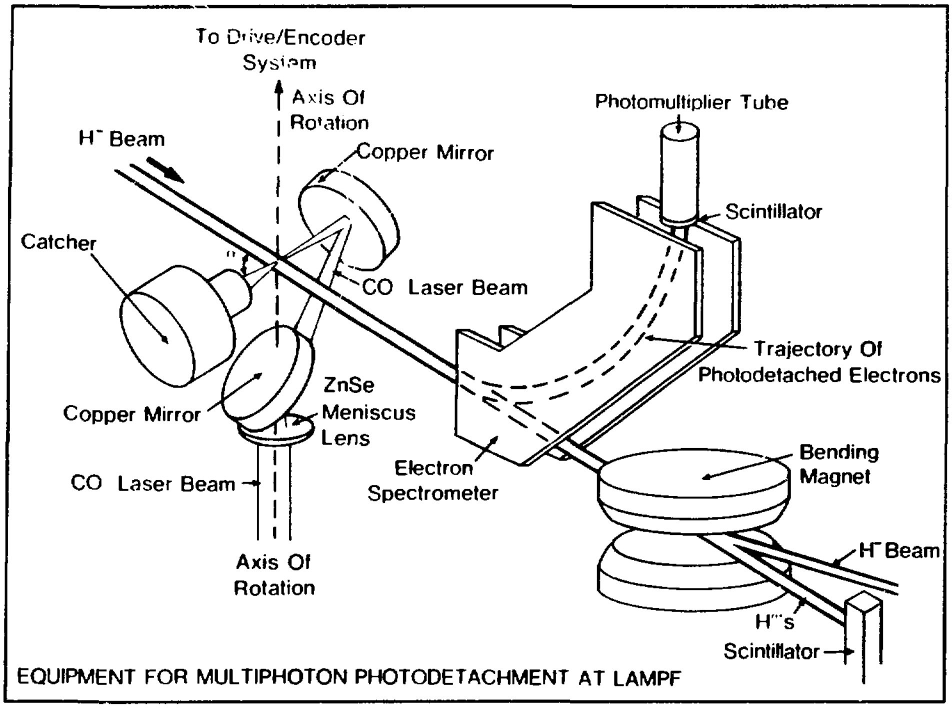


Fig. 2. Schematic of experimental apparatus for multiphoton photodetachment at LAMPF.

previously possible; the building also contains a massive vibration isolation slab on which the entire optical system may be mounted. Beam line diagnostics are also considerably improved, simplifying, especially, beam tuning and location.

Following the discovery in 1986 of electric-field-induced structure on the H^- photodetachment-threshold cross section,[3] further investigations of the effect were undertaken. The earlier experiment made use of the transformations of relativistic electrodynamics, whereby a small magnetic field in the lab frame is seen as a large electric field in the barycentric frame of the ion. Near-threshold photodetachment in such a field, with the incident-light polarized parallel to the field, produced a ripple-like interference pattern on the cross section itself. The results were of great interest to theorists; they may, however, be understood in terms of a simple model in which the wave packet of the photoejected electron, spreading preferentially in the direction of polarization of the incident light, will for a π-polarized laser-beam spread "upstream" and "downstream" in the electric field; the wave spreading "upstream" will then, upon reflection from the potential barrier, interfere coherently with the wave moving "downstream." The process may be regarded as an atomic analog to a Michelson interferometer.

To test theoretical models of this effect, the ions were exposed to both strong and weak fields, particularly to investigate the range of field strengths in which electron tunneling is important. Tunneling is brought into play by lowering the potential barrier of the atom; thus, it is in this range that any effects due to the atom itself should be manifested. Further, it was important to verify that the structure seen so far was, in fact, due to the electric field and not to magnetic effects. A pair of polished electric plates, designed to be held accurately 1 cm apart and at a potential difference of up to 60 kV, was therefore inserted around the laser-particle beam interaction region, to provide an electric field of up to 96 kV/cm in the barycentric frame. Once again, the ripple-like structure was seen in these low fields; data from this experiment are currently being analyzed.

Unfortunately, problems during the "shakedown" run in July prevented the anticipated progress in this area. Although extensive equipment, including a large magnet capable of providing a barycentric electric field of up to 5 MV/cm, was prepared and tested, time did not permit any runs under high field conditions.

Experiment 1075 measured the yield of some excited states of neutral hydrogen atoms, produced by the passage of relativistic H^- ions through thin foils, as a function of foil thickness, composition, and beam energy; in particular, we used carbon, Formvar, and aluminum foils at beam energies of 500, 581, and 226 MeV.

The experiment consisted of two segments. The first segment was the laserless study of the distribution of high Rydberg hydrogen atoms ($n > 10$) by field-ionizing the excited H^0 atoms in a magnetic electron spectrometer, which also separated different excited states. The motional electric field seen in the rest frame of the relativistic H^0 atoms caused them to split into Stark states, each having a lifetime depending on the strength of the gradually rising field. Hence, different Rydberg states decayed in different positions within the spectrometer, and their liberated electrons followed different trajectories. By gradually changing the magnetic field of the spectrometer the signal electrons were brought to a focus where they were detected by a scintillator. A spectrum was formed by counting the number of electrons detected versus the magnetic field value.

In order to extract information about the initial distribution of the excited H^0 atoms, a Monte Carlo program was developed, which followed a given distribution of excited H^0 atoms through the beam line and the spectrometer. A qualitative comparison of a portion of the experimental data with the Monte Carlo spectra suggested a $1/n$ distribution of the excited atoms, where n is the principal quantum number of the atoms. In addition, a bending magnet downstream of the spectrometer separated the H^-, H^0, and H^+ beams, which were then observed by a fluorescence screen. The light from the screen was digitized with a CCD camera, which provided data on the production of the three charged states as a function of foil thickness. An extensive study of the experimental data is currently under way, which should give more detailed information about the distribution of high Rydberg atoms produced by the passage of relativistic H^- ions through thin foils.

In the second segment of the experiment, a Nd:YAG laser pulse was made to intersect the excited H^0 atoms, and was Doppler tuned to induce transitions from

$n = 2, 3, 4$ to $n = 13$ and 15. These laser-excited Rydberg atoms were then field-ionized in the electron spectrometer, which gave us information about the yield of the lower-lying states as a function of foil thickness. In one measurement the thickness of a Formvar foil was continuously changed by rotating the foil along an axis perpendicular to the beam direction. A preliminary analysis of the experimental data shows oscillations in the yield of excited H^0 atoms with principal quantum numbers of $n = 2$ and $n = 3$ (Fig. 3), suggesting a coherent excitation mechanism. A complete analysis of the experimental data is under way.

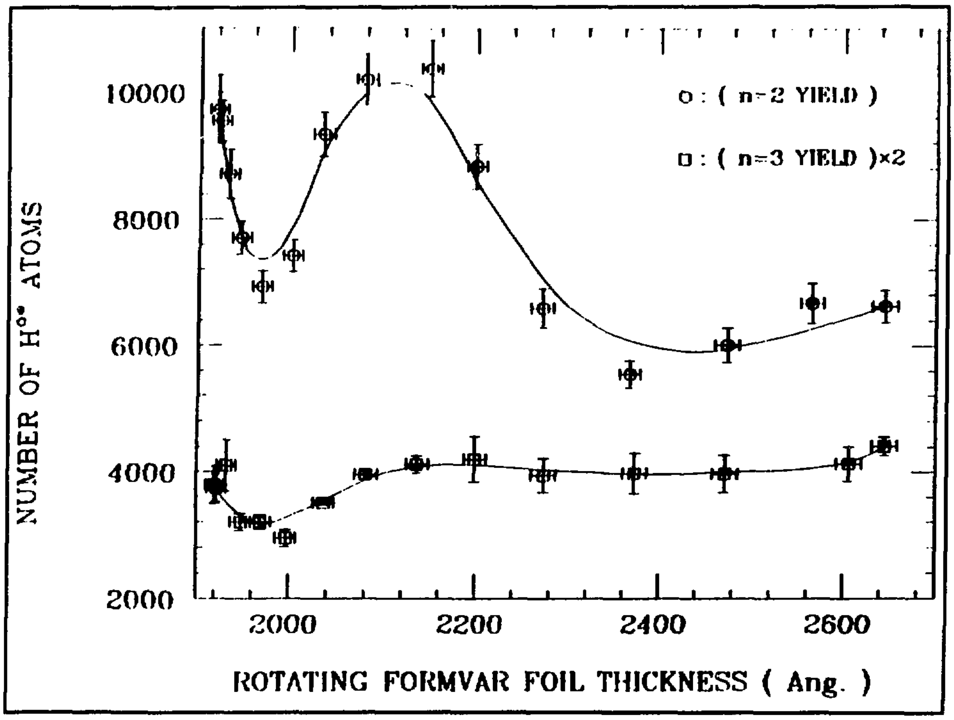


Fig. 3. Typical yield of H^0 ($n = 2$ and $n = 3$) produced by the passage of a relativistic H^- beam through a thin foil, as a function of foil thickness. The error bars are statistical only.

Multiphoton ionization (MPI) of the negative hydrogen ion has recently attracted much attention.[4–8] H^- has several characteristics that make it an especially interesting system with which to investigate multiphoton absorption physics. It has a very low electron affinity (0.754 eV) and no excited states below the detachment threshold. A low electron affinity means that MPI can take place with photons of much lower frequency than typical MPI experiments with neutral atoms; thus, ponderomotive forces (which are proportional to intensity/frequency^2) can lead to potential energies larger than not only the photon energy being used but also the electron affinity. There being no intermediate states has the effect of simplifying the absorption process in one-electron MPI, as there are no resonance-induced effects. Furthermore, because the departing electron is not subject to a long coulombic tail, but rather to a short-range potential, the above threshold ionization (ATI) process[9] will probably be significantly altered. Finally, electron correlation is important in the description of H^- electronic states,[10] thus allowing the possibility of examining electron correlation effects on the MPI process.

We have observed nonresonant multiphoton-electron detachment of H^- ions in moderately intense ($\geq$ few tens of GW/cm^2) laser fields. The 581-MeV H^- beam was intersected by focused 10.6-μm radiation from a pulsed CO_2 laser (Fig. 2). Once again, using the relativistic Doppler shift to tune the barycentric photon energy, the minimum number of simultaneous photons required for electron detachment was varied from three up to sixteen. Definite signals were observed for the minimum photon number ranging from three to eight. Both the H^0 atoms and detached electrons were observed in coincidence with the laser pulse. Our preliminary results show evidence for structure in the relative total cross section; it is hoped that next year we may expand the experiment significantly, to provide important new data in this exciting area.

References

1. S. Cohen, H. C. Bryant, C. J. Harvey, J. E. Stewart, K. B. Butterfield, D. A. Clark et al., *Phys. Rev. A* **36**, 4728 (1988).
2. J. E. Stewart, H. C. Bryant, P. G. Harris, A. H. Mohagheghi, J. B. Donahue, C. R. Quick et al., *Phys. Rev. A* **38**, 5628 (1988).
3. H. Bryant, A. Mohagheghi, J. E. Stewart, J. B. Donahue, C. R. Quick, R. A. Reeder et al., *Phys. Rev. Lett.* **58**, 2412 (1987).
4. M. Crance and M. Aymar, *J. Phys. B* **18**, 3529 (1985).
5. M. G. J. Fink and P. Zoller, *J. Phys. B* **18**, L373 (1985).
6. G. P. Arrighini, C. Guidotti, and N. Durante, *Phys. Rev. A* **35**, 1528 (1987).
7. R. Shakeshaft and X. Tang, *Phys. Rev. A* **36**, 3193 (1987).
8. T. Mercouris and C. A. Nicolaides, *J. Phys. B* **21**, L285 (1988).
9. T. Mercouris and C. Nicolaides, "Polyelectronic Theory of Atoms in Strong Fields" (to be published in the *Journal of Chemical Physics*, 1989).
10. P. H. Bucksbaum, M. Bashkansky, and T. J. McIlrath, *Phys. Rev. Lett.* **58**, 349 (1987).

Materials Science

Optical Detection of Surface Impurity Phases in High-Temperature Superconductors

D. W. Cooke, J. L. Smith, M. A. Maez, B. Bennett, W. L. Hults, I. D. Raistrick, D. E. Peterson, J. A. O'Rourke, S. A. Richardson, J. D. Doss, E. R. Gray, B. Rusnak, G. P. Lawrence, and C. Fortgang (Los Alamos), and M. S. Jahan (Memphis State Univ.)

Major impediments to the technological application of high-T_c superconductors are their low transport critical current density (J_c)[1] and relatively high radio frequency (rf) surface resistance (R_s).[2,3] A possible source of this problem is the presence of insulating impurity phases at the surface or at grain boundaries[4,5] of the superconductor. Various research groups have investigated[6,7] the microstructure and composition of grain boundaries and their role on the superconducting properties of high-T_c materials. The general result is that J_c can be increased by increasing the grain size (reducing the number of grain boundaries). Similarly, by removing the second phases (insulating grain boundary material), which produce rf losses, we have observed a concomitant decrease in R_s. Thus, one must have a sensitive, quick, and inexpensive technique for detecting insulating phases in high-T_c superconductors for technological applications. We have recently demonstrated[8,9] that the insulating impurity phases commonly found in high-T_c superconductors increase R_s and exhibit luminescence, and that the technique of thermally stimulated luminescence (TSL) is ideally suited for detecting their presence. Moreover, the technique is sensitive to impurity phases at <1% level with a probe depth of <1 μm, which is the region of interest for rf cavity applications. The magnitude of TSL is correlated with the surface resistance of the superconductors.

Samples of Y_2O_3, Y_2BaCuO_5, $YBa_2Cu_3O_{6.2}$, $BaCO_3$, Ba_3CuO_4, $BaCuO_2$, and $YBa_2Cu_3O_x$ were investigated. The samples were exposed to 1.53×10^5 R of ^{60}Co radiation at room temperature to induce charge trapping. The result of this exposure is to produce metastable electron-hole pairs in the insulating material, which recombine upon heating to yield luminescence. No radiation effect upon the superconducting properties is anticipated because the exposure is so small. Following gamma exposure the samples were heated to near 400°C in a commercial thermoluminescent reader (Harshaw/Filtrol Partnership) and the TSL signal recorded. In addition, the area under this curve, which is proportional to the total light emitted by the sample, was also measured. In its simplest form the TSL apparatus consists of a sample holder with heater and thermocouple output and a photomultiplier tube all mounted in a light-tight box. Current from the tube is amplified and plotted as a function of temperature with the resulting curve being referred to as a TSL glow curve.

Figures 1, 2, and 3 show typical TSL glow curves for all samples. Note that the intensities are given in arbitrary units; absolute intensities are shown by the bar chart of Fig. 4. These values are determined by normalizing the area under each curve to the mass and to the surface area of the sample. Because all the samples investigated are opaque, we estimate that the absorption coefficient is fairly large, 10^4–10^6 cm^{-1}, implying that the photons producing the TSL signal emanate from within less than ~1 μm of the surface. For this reason we normalize to surface area as well as to mass. The superconducting material may have an absorption coefficient that is different from the insulating phases, but its value certainly should fall within the above-stated limits.

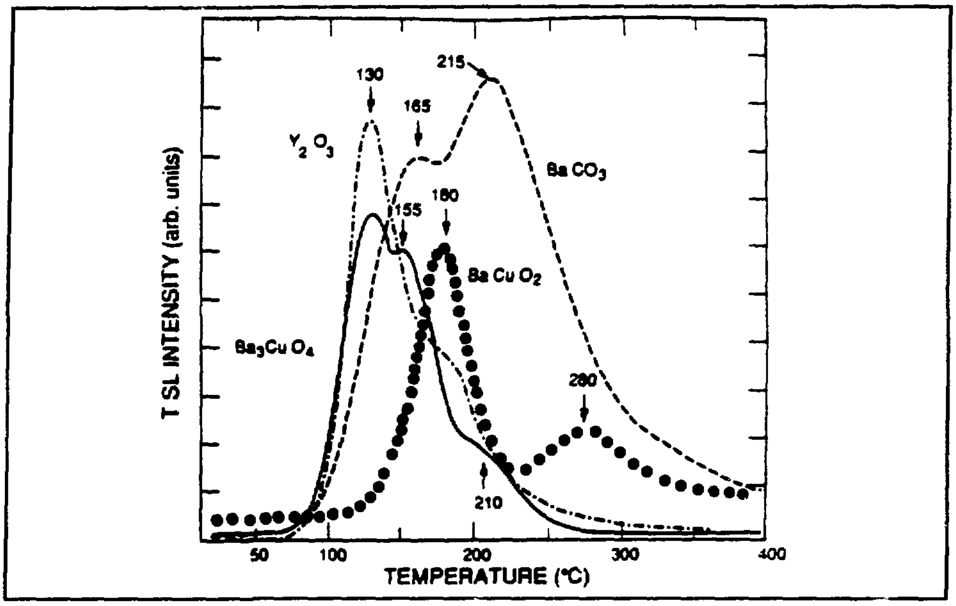


Fig. 1. Thermally stimulated luminescence glow curves of Y_2O_3, Ba_3CuO_4, $BaCuO_2$, and $BaCO_3$. All samples were given an exposure of 1.53×10^5 R of ^{60}Co at room temperature.

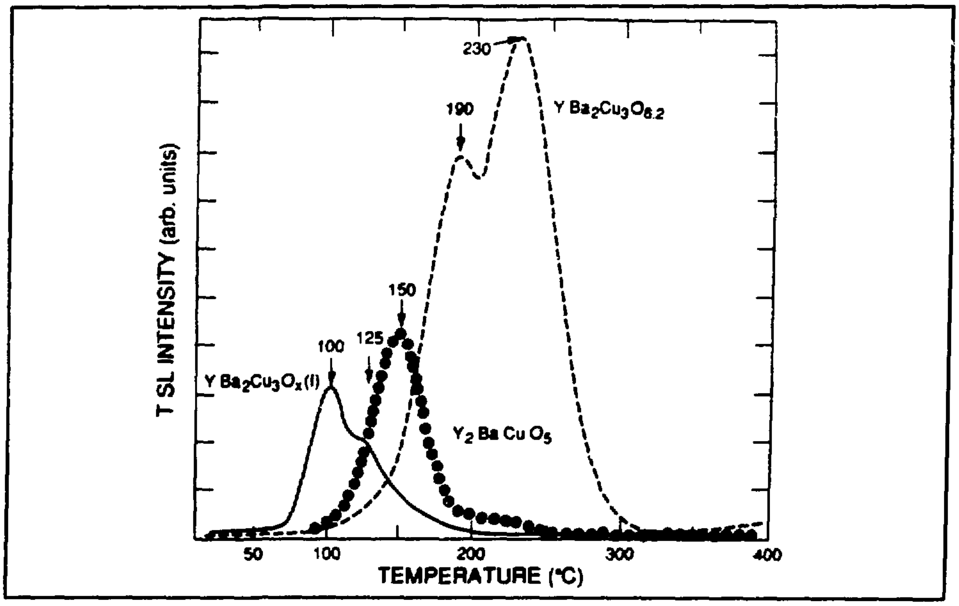


Fig. 2. Thermally stimulated luminescence glow curves of Y_2BaCuO_5, $YBa_2Cu_3O_{6.2}$, and $YBa_2Cu_3O_x(I)$. Experimental conditions were the same as given in Fig. 1.

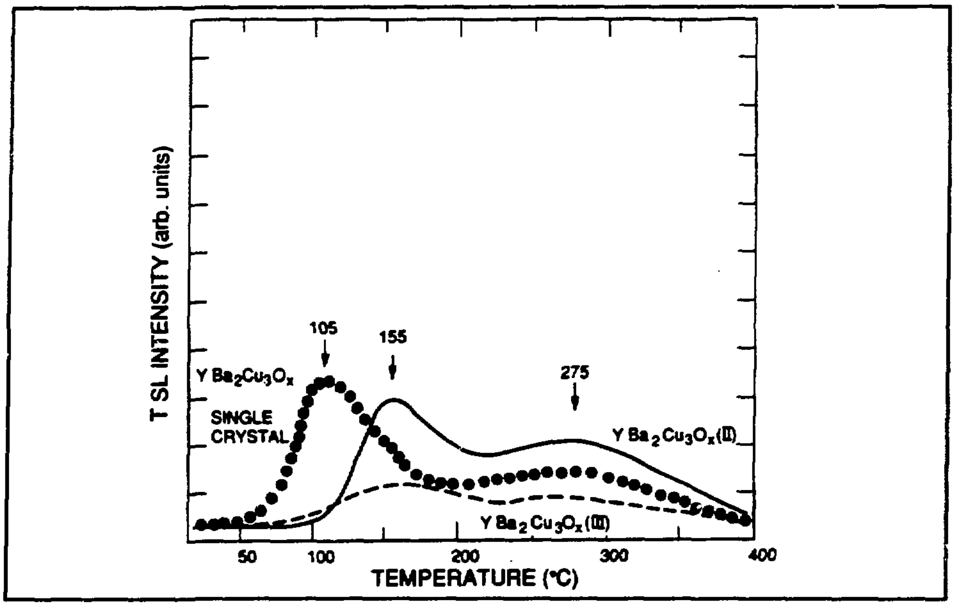


Fig. 3. Thermally stimulated luminescence glow curves of single-crystal $YBa_2Cu_3O_x$ and two sintered samples of $YBa_2Cu_3O_x$.

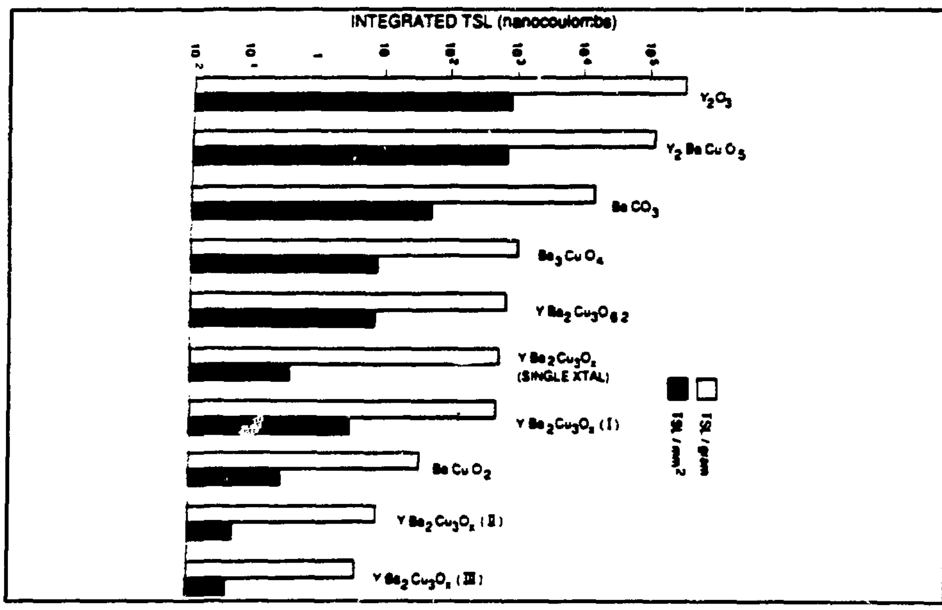


Fig. 4. Absolute TSL intensities of the samples whose glow curves are shown in Figs. 1, 2, and 3. The integrated TSL is normalized to mass and surface area.

The insulating phases, Y_2O_3, Ba_3CuO_4, $BaCuO_2$, $BaCO_3$, and Y_2BaCuO_5, all exhibit characteristic TSL glow curves with well-defined maxima. In addition, we observe strong luminescence from a sample that has been depleted of a large fraction of the oxygen content (see curve labeled $YBa_2Cu_3O_{6.2}$ in Fig. 2). Note that this sample was made from $YBa_2Cu_3O_x$(III) (shown in Fig. 3), which is characterized by very weak TSL. This result demonstrates that not only can TSL detect the impurity phases present, but it can also detect the non-superconducting tetragonal phase, which results from poor oxygenation of $YBa_2Cu_3O_x$. No TSL can be observed from the superconducting orthorhombic phase ($x \geq 6.5$); as for all metals there is no band gap of sufficient magnitude to trap the radiation-induced charges. This feature of TSL studies of high-T_c materials is important; it implies that *no pure superconductor will exhibit TSL—any observed signal must come from insulating surface impurities*. Thus, TSL can serve as a quick and inexpensive method for determining the quality of a high-T_c superconductor, and is especially applicable to these materials that are formed by sintering, and, consequently, are very susceptible to inclusion of insulating secondary phases.

An important application of the high-T_c superconductors is rf accelerating cavities. The success of this application depends on how well these materials compete with established superconductors such as Nb.[10] To date, measured values of R_s at 4 K for sintered pellets of high-T_c superconductors are considerably higher than Nb at the same temperature.[11] The important question is whether these high values are due to some inherent physics limitation, which is presently thought to be zeros in the superconducting energy gap, or to materials properties associated with processing. We suggest that relatively high R_s values of bulk material are, in part, associated with insulating surface impurity phases present in the material.

The TSL glow curves for several superconductors are shown in Figs. 2 and 3. $YBa_2Cu_3O_x$(I) is a low-quality superconductor as evidenced by its low diamagnetic shielding value and by the indication of second-phase constituents from x-ray diffraction measurements. Accordingly, it is characterized by strong luminescence and a high value of R_s (42.1 mW) as measured in a 3-GHz Nb cavity operating in the fundamental mode TM_{010} at 4 K. Typical values of R_s for high-T_c materials at this frequency and temperature are 0.4–0.7 mW.[11] In contrast, $YBa_2Cu_3O_x$(II) and $YBa_2Cu_3O_x$(III) are both high-quality samples exhibiting 100% diamagnetic shielding. As shown in Fig. 3, they exhibit weak luminescence—two orders of magnitude less than $YBa_2Cu_3O_x$(I). Their corresponding R_s values are 0.1–0.2 mW, i.e., more than two orders of magnitude less than R_s measured for $YBa_2Cu_3O_x$(I). These results demonstrate that insulating surface impurities contribute to high values of R_s, and that these values correlate with TSL.

In summary, we have demonstrated that TSL is a quick, sensitive, and inexpensive technique that can be used to determine the presence of insulating impurity phases in high-T_c superconductors. The estimated probe depth is $\sim 1\ \mu m$, or less, making it ideally suited for examining those superconductors whose applications are based on surface properties. In particular, we have shown that rf surface resistance is correlated with TSL intensity.

References

1. J. D. Verhoeven, A. J. Bevolo, R. W. McCallum, E. D. Gibson, and M. A. Noack, *Ap. Phys. Lett.* 52, 745 (1988).
2. H. Padamsee, K. Green, J. Gruschus, J. Kirchgessner, D. Moffat, D. L. Rubin, J. Sears, Q. S. Shu, R. Buhrman, D. Lathrop, T. W. Noh, S. Russek, and A. Sievers, Conference on Superconductivity and Applications, Buffalo, New York, April 18–20, 1988. CLNS 88/835, Cornell University, April 14, 1988.
3. M. Hein, N. Klein, G. Mueller, H. Piel, and R. W. Roth, in *Proceedings of the Third Workshop on RF Superconductivity*, K. W. Shepard, Ed. (Argonne National Laboratory, September 14–18, 1987) p. 197.
4. S. Nakahara, G. J. Fisanick, M. F. Yan, R. B. van Dover, T. Boone, and R. Moore, *J. Crystal Growth* 85, 639 (1987).
5. J. Tafto, M. Suenaga, T. Wang, R. L. Sabatini, A. R. Moodenbaugh, and S. Levine, in *High-Temperature Superconductors, MRS Symposium Proceedings Vol. 99*, M. Brodsky, R. Dynes, K. Kitazawa, and H. Tuller, Eds. (Materials Research Society, Pittsburgh, 1988), p. 511.
6. S. Jin, R. A. Fastnacht, T. H. Teifel, and R. C. Sherwood, *Phys. Rev. B* 37, 5828 (1988).
7. F. Parmigiani, G. Chiarello, and N. Ripamonti, *Phys. Rev. B* 36, 7148 (1987).
8. D. W. Cooke, M. S. Jahan, J. L. Smith, M. A. Maez, W. L. Hults, I. D. Raistrick, D. E. Peterson, J. A. O'Rourke, S. A. Richardson, J. D. Doss, E. R. Gray, B. Rusnak, G. P. Lawrence, and C. Fortgang (to be published in *Applied Physics Letters*, 1989).
9. D. W. Cooke, T. Trkula, R. E. Muenchausen, N. S. Nogar, and J. L. Smith (to be published in the *Journal of the Optical Society of America B*, 1989).
10. H. Padamsee, MIT DOE/EPRI Workshop on Novel Applications of High Temperature Superconductors, Salem, Massachusetts, June 22–24, 1988. CLNS 88/844, Cornell University, July 1988.
11. H. Piel, M. Hein, N. Klein, A. Michalke, G. Mueller, and L. Ponto, *Physica* C 153–155, 1604 (1988).

Nuclear Chemistry

EXPERIMENTS 1024 AND 1100 — TOFI

Using the TOFI Spectrometer to Measure the Half-Lives of Exotic Nuclei

Utah State Univ., Pacific Northwest Laboratory, Los Alamos, Univ. of Munich, Nanjing Univ.

Spokespersons: R. A. Warner (Pacific Northwest Laboratory) and J. M. Wouters (Los Alamos)

Participants: Y.-K. Kim, P. L. Reeder, D. J. Vieira, W. K. Hensley, K. E. G. Löbner, Z.-Y. Zhou, and Y. G. Lind

The initial design goal of the Time-of-Flight Isochronous (TOFI) spectrometer was to perform systematic direct mass measurements for the wide variety of neutron-rich nuclei that are produced at the Los Alamos Meson Physics Facility (LAMPF). TOFI has achieved this goal[1,2] and continues to advance our understanding of the nuclear mass surface through additional mass measurements. In this report we describe developments that have enabled TOFI to be used as a recoil-tagging device such that the half-life of several beta-delayed neutron-emitting nuclei can be measured.

The experimental arrangement for this new work is shown schematically in Fig. 1. Neutron-rich nuclei are produced by a high-intensity (1-mA) 800-MeV proton beam when it strikes the 1.0-mg/cm^2 ^{nat}Th target located in the Thin Target/Switchyard Area of the LAMPF accelerator. Many of these reaction products recoil out of the target with energies of ~3 MeV/amu and with little angular preference. Some of these recoils are transported to the entrance of the spectrometer by four quadrupole triplets and a crude mass-to-charge (M/Q) prefilter. The TOFI spectrometer, which consists of four 81° integrated-function dipole magnets, is designed to be isochronous such that the time-of-flight for an ion passing through the spectrometer is independent of its velocity and depends only on the M/Q ratio. Measurements of the ion's energy and velocity uniquely define the charge state. Several additional features of TOFI make this system suitable for studying exotic reaction products.

1. The transit times are short (typically 1 μs);
2. The acceptance is reasonably large (Ω = 2.5 msr, $\delta(p/Q)/(p/Q)$ = 4%); and
3. The system is nondispersive overall, which means that all transmitted ions (both unknown and known species) are concentrated in a small focal spot (20 mm ϕ).

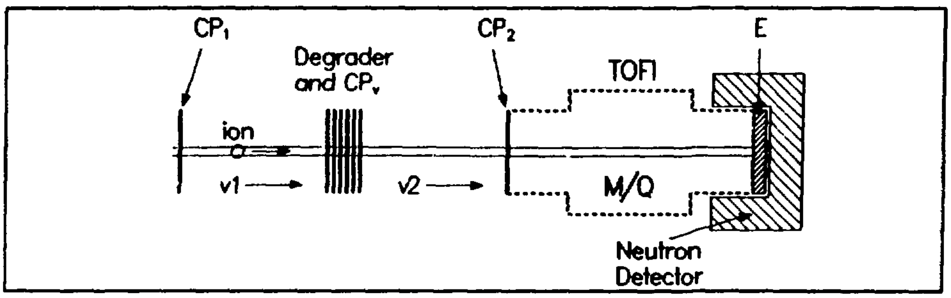


Fig. 1. The experimental setup used to tag each recoil according to M, Z, and Q and to measure half-lives using a delayed coincidence technique. CP refers to secondary-electron, microchannel plate, fast-timing detectors. The time-of-flights measured between CP1-CPV, LCPV-CP2, and CP2-E constitute measurements of the ion's velocity before the degrader (v1), velocity after the degrader (v2), and the mass-to-charge ratio, respectively.

To discriminate between isobaric members (that is, nuclei with the same mass number but different atomic numbers), we determine the atomic number (Z) of each recoiling ion from its rate of energy loss, dE/dx. In this experiment, we have employed a passive uniform degrader (a stack of six 0.4-mg/cm^2 nitrocellulose foils) placed at an intermediate focus position in the transport line. By combining measurements of the ion's velocity before and after the degrader with its mass as determined in TOFI, we can calculate the energy loss in the degrader. From a plot of this calculated energy loss vs the average velocity, as shown in Fig. 2, we obtain the characteristic Z ridge lines indicative of the ion's dE/dx. In this way we determine the atomic number of each ion, mass independently, with resulting Z resolutions ranging from 1.4–2.0% (FWHM). These results are consistent with our measurements being limited by fluctuations in the energy-loss process.[3]

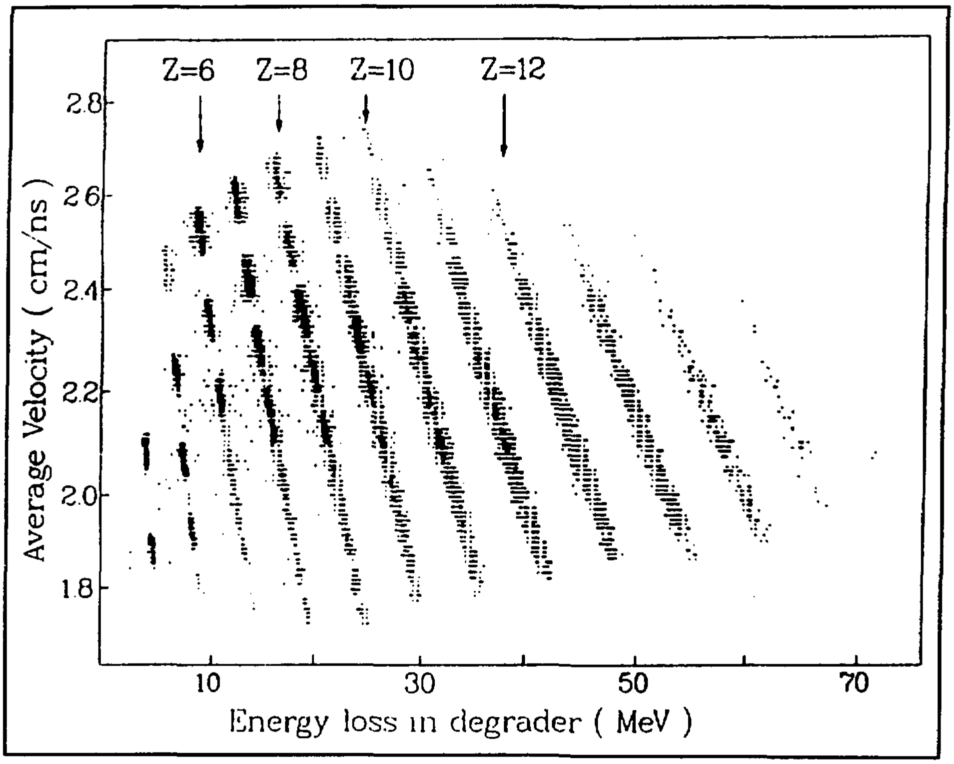


Fig. 2. A plot of the calculated energy loss in the degrader ($\Delta E = M(v1^2 - v2^2)/2$) vs the average velocity ($v_{ave} = (v1 + v2)/2$) yields the characteristic Z ridge lines indicative of the ion's stopping power.

Because the Z identification was performed ahead of the spectrometer itself, we were able to place a large high-efficiency neutron counter, which consisted of 40 ^{3}He proportional tubes in a polyethylene moderated housing, around a single-silicon detector at the exit of TOFI. This single-silicon detector provides both the stop time for the mass-to-charge measurement and the total energy needed to determine the charge state. The neutron counter is used to detect the subsequent beta-delayed neutron emission of identified neutron-rich reaction products. Because β-delayed neutron emission occurs only in the most neutron-rich nuclei accessible by TOFI, the use of this decay signature proved valuable in selecting out the exotic species from the more abundant, but less neutron-rich species which were also implanted in the silicon detector. We measure the half-lives of these beta-delayed neutron-emitting nuclei by a delayed coincidence technique in which both the ion-arrival times and the delayed-neutron times are recorded by a free-running common clock.

Decay curves, such as those in Fig. 3, are obtained by producing time-difference histograms between M-, Z-, and Q-gated ion start events and all subsequent neutron stop events that occur within 1 s after the ion-arrival time.[4] All of the decay curve data can be decomposed into an exponential decay component and a chance coincidence background component that is slightly time dependent. This fairly large background arises because (1) other delayed-neutron emitters are continuously being implanted in the stop detector, or (2) neutrons arise from sources outside the detector, such as neutrons produced directly by the primary beam. We use ^{13}B, which has a negligible delayed-neutron-emission probability (P_n = 0.3%), to determine the time-dependent shape of the background. The absolute magnitude of this background is determined from the 125-s integrated

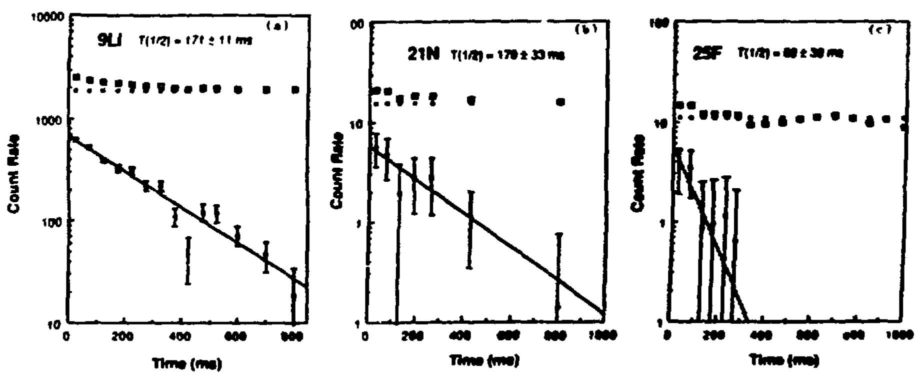


Fig. 3. Time-difference histograms for (a) ^{9}Li, (b) ^{21}N, and (c) ^{25}F. Open squares = total counts. Filled squares = normalized background counts (based on ^{13}B). Points given with error bars = net counts. Solid line = half-life determined from fit to net counts.

count rate measured for each particular species of interest. We subtract this normalized background point by point to obtain the net decay curve data from which we are able to extract the half-life of the nuclide of interest.

During a proof-of-principle experiment,[5] we determined the half-lives of 11 nuclei that ranged from $^{9,11}Li$ to ^{25}F (see Table I). We found good agreement between our measurements and those reported in the literature for nine nuclei that had been previously measured. The half-lives of ^{21}N and ^{25}F are reported here for the first time. When we examine the shell-model calculations of Wildenthal and Brown[6] and the gross theory of beta-decay predictions of Tachibana,[7] our results show that the half-life of ^{25}F was well predicted, but the half-life of ^{21}N is three to four times longer than expected from theory. Further studies of ^{21}N are needed to explain this discrepancy.

Table I. Beta-Decay Half-Lives (ms) from this Experiment Compared to Previous Experimental Results, Shell-Model Predictions (Ref. 6), and Gross Theory of Beta Decay Predictions (Ref. 7). Uncertainties are given in parentheses.

Isotopes	*This Measurement*	*Previous Measurements*	*Shell Model*	*Gross Theory*
^{9}Li	171 (11)	177 (1)[a]	127	101
^{11}Li	6 (4)	8.7 (0.1)[b]	3.8	7.6
^{15}B	8.7 (0.5)	10.3 (0.3)[c,d,e]	12.3	24.3
^{16}C	734 (41)	747 (8)[a]	1560	489
^{17}C	150 (50)	198 (15)[c,e,f]	400–700	181
^{18}C	70 (40)	66 (+25/−15)[d]	183	64
^{19}C	70 (60)	49 (4)[g]	—	—
^{19}N	290 (20)	242 (30)[d,e,f]	350	287
^{20}N	130 (20)	100 (+30/−20)[d]	—	100
^{21}N	170 (33)	—	40	52
^{25}F	60 (30)	—	61	117

[a]From Ref. 8.
[b]From Ref. 9.
[c]From Ref. 10.
[d]From Ref. 11.
[e]From Ref. 12.
[f]From Ref. 13.
[g]From Ref. 14.

In summary, this work represents the first use of the TOFI spectrometer as a recoil-tagging device to facilitate the decay characterization of exotic nuclei. A passive degrader/velocity difference approach has been advanced to determine the atomic number of the recoil and we have measured the half-lives of several beta-delayed neutron-emitting nuclei. Future experiments are planned using TOFI in this mode to undertake additional half-life measurements and to search for unknown isomeric states that could complicate the extraction of ground state masses.

References

1. D. J. Vieira, J. M. Wouters, K. Vaziri, R. H. Kraus, H. Wollnik, G. W. Butler, F. K. Wohn, and A. H. Wapstra, *Phys. Rev. Lett.* **57**, 3253 (1986).
2. J. M. Wouters, R. H. Kraus, D. J. Vieira, G. W. Butler, and K. E. G. Löbner, *Z. Phys. A* **331**, 229 (1988).
3. Y.-K. Kim, M.S. thesis, Utah State Univ. (1989).
4. J. Glatz and K. E. G. Löbner, *Nucl. Instrum. and Methods* **94**, 237 (1971).
5. P. L. Reeder, R. A. Warner, W. K. Hensley, D. J. Vieira, and J. M. Wouters, "Half-Lives of Neutron-Rich Li-Na Nuclides" (submitted by Pacific Northwest Laboratory to *Physical Review* C, 1988).
6. B. H. Wildenthal, M. S. Curtin, and B. A. Brown, *Phys. Rev.* C **28**, 1343 (1983); B. A. Brown, private communication (see also Refs. 10 and 12).
7. T. Tachibana, M. Yamada, and K. Nakata, Report of Science and Engineering Research Laboratory, Waseda Univ., No. 88-4 (1988).
8. D. E. Alburger and D. H. Wilkinson, *Phys. Rev.* C **13**, 835 (1976) and references therein.
9. T. Bjornstad, H. A. Gustafsson, P. G. Hansen, B. Jonson, V. Lindfors, S. Mattsson, A. M. Poskanzer, and H. L. Ravn, *Nucl. Phys. A* **359**, 1 (1981).
10. M. S. Curtin, L. H. Harwood, J. A. Nolan, B. Sherrill, Z. Q. Zie, and B. A. Brown, *Phys. Rev. Lett.* **56**, 34 (1986).
11. A. C. Mueller, D. Bazin, W. D. Schmidt-Ott, R. Anne, D. Guerreau, D. Guillemaud-Mueller, M. G. Saint-Laurent, V. Borrel, J. C. Jacmart, F. Pougheon, and A. Richard, *Z. Phys. A* **330**, 63 (1988).
12. M. Samuel, B. A. Brown, D. Mikolas, J. Nolen, B. Sherrill, J. Stevenson, J. S. Winfield, and Z. Q. Xie, *Phys. Rev.* C **37**, 1314 (1988).
13. J. P. Dufour, R. Del Moral, A. Fleury, F. Hubert, D. Jean, M. S. Pravikoff, H. Delagrange, H. Geissel, and K.-H. Schmidt, *Z. Phys. A* **324**, 487 (1986).
14. J. P. Dufour, R. Del Moral, F. Hubert, D. Jean, M. S. Pravikoff, A. Fleury, A. C. Mueller, K.-H. Schmidt, K. Summerer, E. Hanelt, J. Rehaut, M. Beau, and G. Giraudet, *Phys. Lett. B* **206**, 195 (1988).

Radiation Effects

EXPERIMENT 1139 — Beam Stop Irradiation Facility

Testing of Radiation of Read-Out Chips for Use in High-Rate Nuclear and Particle Physics Applications

Los Alamos, UC Santa Cruz

Spokesmen: C. M. Hoffman, W. F. Sommer (Los Alamos), and H. F.-W. Sadrozinski (UC Santa Cruz)

Participants: M. Borden, C. M. Hoffman, D. Holtkamp, W. W. Kinnison, W. F. Sommer, H. J. Ziock, W. Rowe, H. F.-W. Sadrozinski, A. Seiden, and E. N. Spencer

The large hadron colliders of the future (SSC, LHC) will require high luminosity to achieve their physics goals. This, together with the large hadronic cross section, implies that detector elements will be subjected to very high radiation doses from charged particles and from albedo neutrons. For example, a silicon tracking detector located 8 cm from the beam line at the SSC has to survive about 1 MR and 10^{13} neutrons/cm^2 per year. The read-out electronics will have to be placed very close to the detector. Thus, the front-end electronics must be radiation-hard.

In this study, we evaluated various 2μ CMOS processors for their ability to withstand high radiation doses. We have irradiated various test structures on 2μ CMOS chips with neutrons at the LAMPF beam stop irradiation facility.[1] The neutron spectrum here is similar to the one expected in the SSC detectors with a characteristic neutron energy of 1 MeV. The fluxes employed here were between 0.1 to 100 times those expected at the SSC.

We have quantified the radiation damage to CMOS transistors by measuring the drain-source current, I_{DS}, as a function of the gate voltage and by determining the shift in the threshold voltage, V_{th}, as a function of dose: V_{th} is defined as the gate voltage that produces a drain-source current of 1 μA. The measurements were performed *in situ* providing a continuous history of the damage vs dosage. Table I lists some of the devices tested and shows the threshold voltage shifts and estimated neutron fluences. Devices #1, #2, and #3 were furnished by MOSIS[2] out of non-rad-hard runs from 1987–88 by ORBIT:[3] devices #4–#7 are rad-hard devices from UTMC.[4] Figure 1(a) shows I_{DS} for the non-rad-hard device #2 while Fig. 1(b) shows I_{DS} for the rad-hard device #7, for different neutron doses. Figure 2 shows V_{th} as a function of neutron fluence for the same two devices.

Table I. Summary of the Devices Tested.

Device #	*Foundry*	*Transistor Type*	Δ_{th} *(mV)*	*Fluence (neutrons/cm²)*	*Remarks*
1	ORBIT	*n*	>600	4×10^{12}	Gate Oxide :400 Å
2	ORBIT	*p*	3200	3×10^{14}	Gate Oxide :400 Å
3	UTMC	*n*	520	3×10^{14}	Gate Oxide :200 Å
4	UTMC	*n*	45	9×10^{14}	rad-hard process A
5	UTMC	*p*	300	9×10^{14}	rad-hard process A
6	UTMC	*n*	<10	2×10^{14}	rad-hard process B
7	UTMC	*p*	<20	2×10^{14}	rad-hard process B

Clearly the transistors manufactured in non-rad-hard processes are damaged by the neutron irradiation. The rad-hard transistors from UTMC survive well, even fluences of 10^{15} neutrons/cm^2. A major reason for the difference in radiation resistance is the thickness of the gate oxide, where neutrons displace heavily

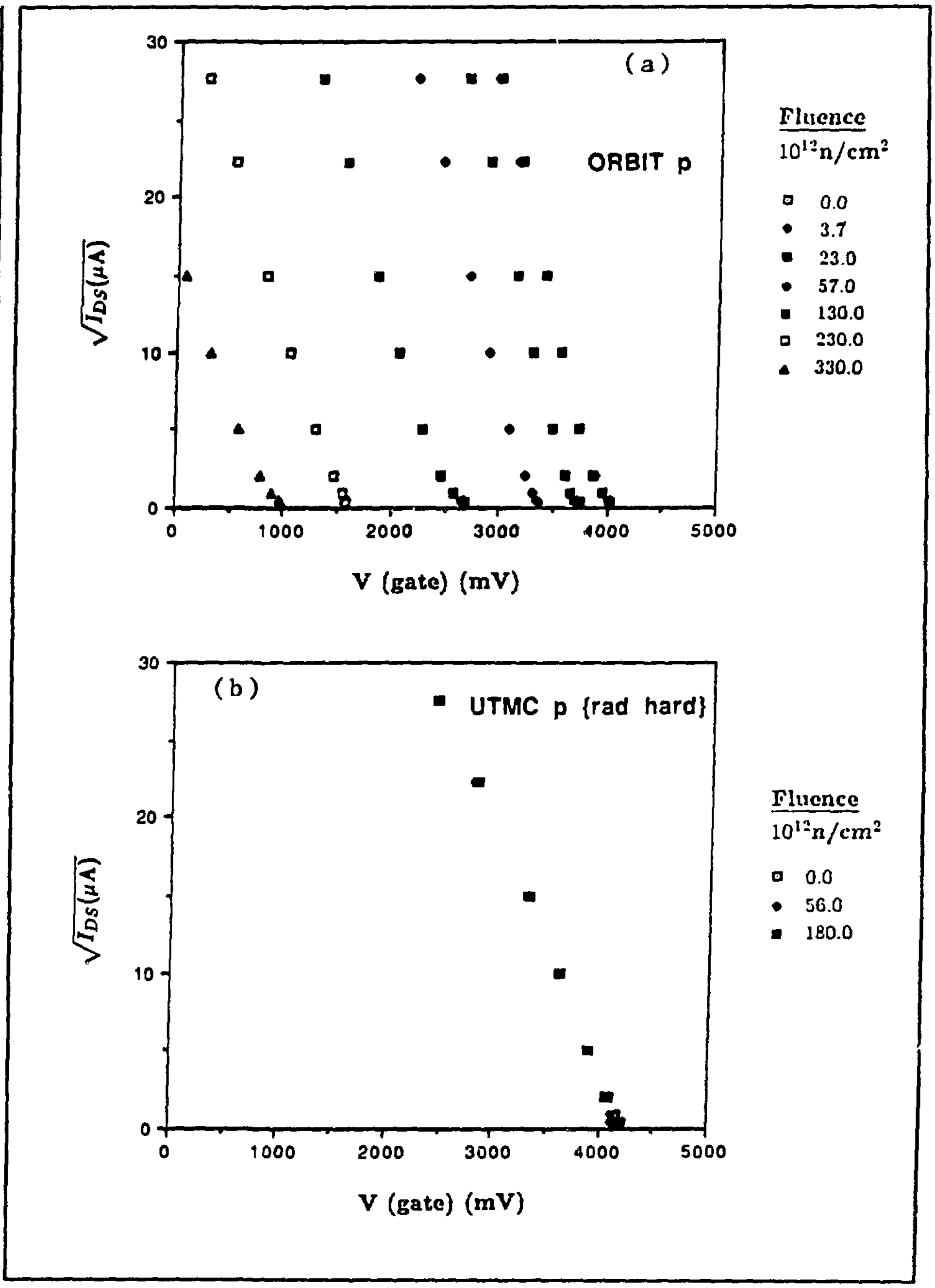


Fig. 1. Square root of the drain-source current I_{DS} as function of the gate voltage for (a) the non-rad-hard p transistor #2 manufactured by ORBIT for different accumulated neutron fluences and (b) the rad-hard p transistor #7 manufactured by UTMC for different accumulated neutron fluences.

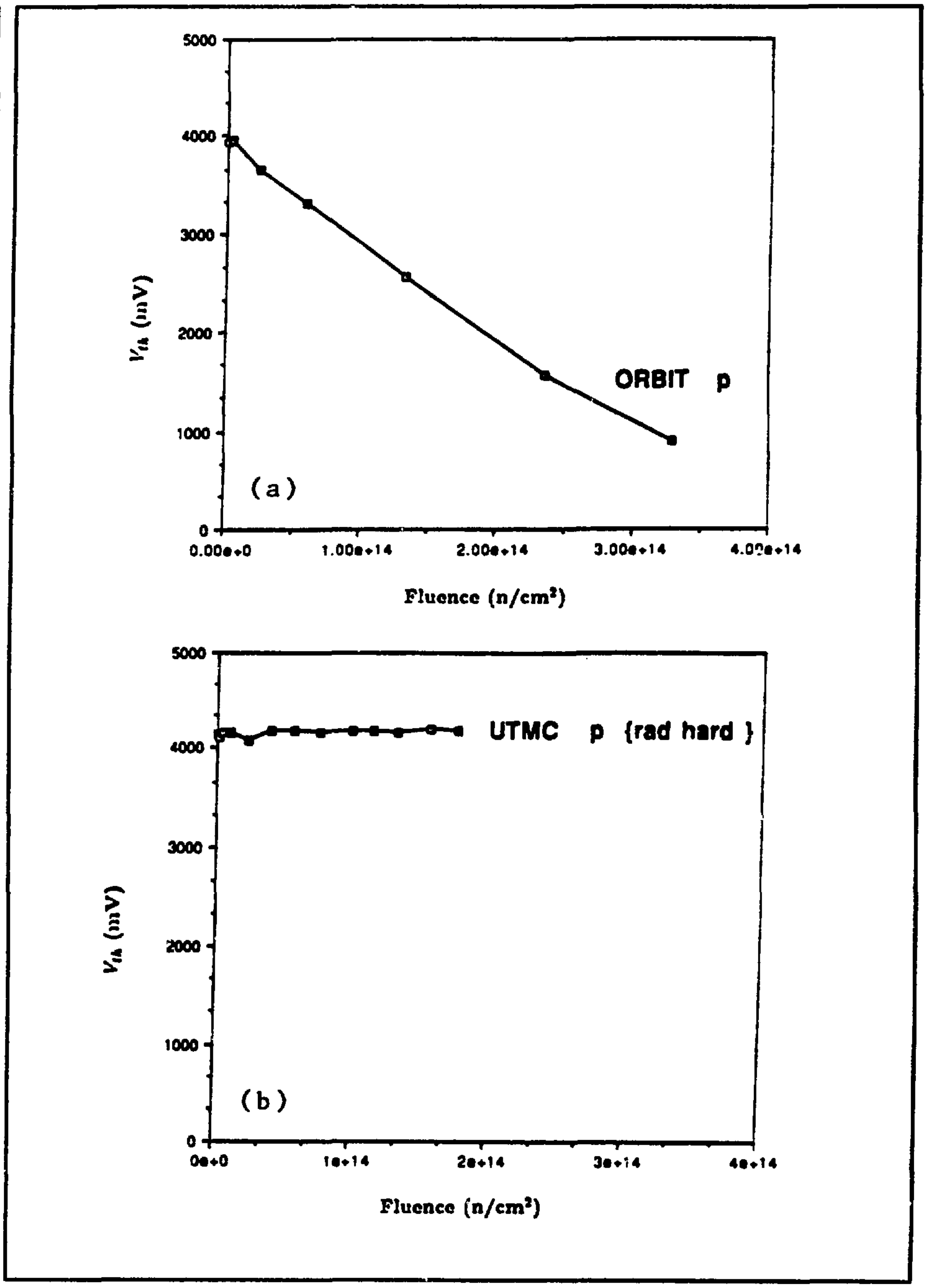


Fig. 2. Threshold voltage V_{th} vs neutron fluence for (a) the non-rad-hard p transistor #2 manufactured by ORBIT and (b) the rad-hard p transistor #7 manufactured by UTMC.

ionizing Si atoms; heavily ionizing radiation is known to cause charge trapping. The rad-hard devices have also been shown to resist several MR of ionizing radiation.[5] It appears that these devices offer sufficient radiation resistance for application at hadron colliders.

We plan to continue evaluating various production processes under exposure to both neutrons and to 800-MeV protons and to test the functionality of read-out chips after irradiation.

References

1. W. F. Sommer, W. Lohmann, K. Graf, I. K. Taylor, and R. M. Chavez, "Operating Experience at the Los Alamos Spallation Radiation Effects Facility at LAMPF," *Influence of Radiation on Material Properties: 13th International Symposium (Part II), ASTM STP 956*, F. A. Garner, C. H. Henager, Jr., and N. Igata, Eds., American Society for Testing and Materials, Philadelphia, Pennsylvania, 1987, pp. 718–729.
2. MOS Implementation Service, USC Information Services Institute, Marina del Rey, CA 90292. We thank V. Tyre for his help.
3. Orbit Semiconductor, Inc., Sunnyvale, CA 94068.
4. United Technologies Microelectronics Center, Colorado Springs, CO 80907.
5. R. Woodruff, UTMC, private communication (1988).

Radioisotope Production

INC-11 Radioisotope Production Activities

A. H. Herring, R. M. Lopez, R. A. Mitchell, M. A. Montoya, D. C. Moody, M. A. Ott, C. P. Padilla, M. Peeples, K. E. Peterson, D. R. Phillips, L. M. Schneider, F. H. Seurer, R. C. Staroski, F. J. Steinkruger, W. A. Taylor, and D. H. Vigil

Stable and Radioactive Isotope Production and Separation

A significant portion of the Group INC-11 Radioisotope program involves producing and shipping radioisotopes for the medical research community. These radioisotopes are generally unavailable commercially or can be made in high yields only at LAMPF. Group INC-11 provides these radioisotopes on a cost-recovery basis to interested researchers. During FY1988, we shipped isotopes to a total of 64 organizations around the world and to four groups at Los Alamos, including our own Medical Radioisotopes Research Program (see Table I).

Table I. Medical Radioisotope Shipments.

Isotope	*Customer*	*No. of Shipments*	*Shipped (mCi)*	*Received (mCi)*
^{26}Al	Atom Sciences, Inc. Univ. of Munich, West Germany	2	(61.00) (nCi)	(61.00) (nCi)
^{72}As	Univ. of Texas	1	12.00	6.30
^{73}As	GTE Products Corp. U.S. Bureau of Mines U.S. Geological Survey Univ. of Central Florida	6	13.10	13.00
^{7}Be	Amersham International, UK Australian Nucl. Sci/Tech, Australia Isotope Products Labs Lovelace Biomedical	10	249.30	227.30
^{207}Bi	Martin Marietta Energy Systems	1	3.00	3.00
^{77}Br	NeoRx Corporation Univ. of California, Lawrence Berkeley National Laboratory Univ. of Alabama Washington Univ.	4	169.30	127.00
^{82}Br	Los Alamos/ESS-4	3	197.40	110.01

Table I (Cont)

Isotope	*Customer*	*No. of Shipments*	*Shipped (mCi)*	*Received (mCi)*
^{109}Cd	Fish/Oceans Fresh, Inst./Canada Isotope Products Labs Los Alamos/INC-11 Los Alamos/LS-3 Univ. of Texas	13	2051.02	2044.02
^{67}Cu	Albert Einstein College of Medicine California State Univ. Hunter College IBM Research Center Los Alamos/INC-11 Los Alamos/P-3 Martin Marietta Energy Systems Medical Research Council, UK National Institute of Health Purdue Univ. Texas A&M Univ. Univ. of California Davis Univ. of Arkansas Univ. of California Univ. of Texas Washington Univ.	63	3169.00	25[illegible]
^{151}Gd	Isotope Products Labs	1	(399.00) (nCi)	(399.00) (nCi)
^{68}Ge	Brookhaven National Laboratory Centre de Med. Nucl., France Compagnie Oris Industrie, France Computer Tech. & Imaging Duke Univ. Medical Center E. I. Dupont/NEN Products	30	1426.20	1411.00

Table I (Cont)

Isotope	*Customer*	*No. of Shipments*	*Shipped (mCi)*	*Received (mCi)*
^{68}Ge	Inst. Nat. des Radioelements, Belgium			
	Isotope Products Labs			
	Liege Univ., Belgium			
	McMaster Univ., Canada			
	M. D. Anderson Hospital			
	MRC Cyclotron/ Hammersmith Hospital, UK			
	North Shore Univ. Hospital			
	Paul Scherrer Institute, Switzerland			
	Pett Electronics			
	San Raffaela Institute, Italy			
	Siemens Gammasonics			
	Societe Gondrand, France			
	Turku Univ., Finland			
	Univ. of Michigan			
	Univ. of Pennsylvania			
	Univ. of Washington			
	Univ. of Wisconsin			
	Washington Univ.			
^{22}Na	Brookhaven National Laboratory/E. I. Dupont/ NEN Products	4	2264.30	2258.00
	E. I. Dupont/NEN Products			
	Ruhr Universitat Bochum, West Germany			
^{83}Rb	Univ. of California, Lawrence Livermore National Laboratory	1	1.30	1.30
^{101}Rh	Eastman Kodak Company	1	1.00	1.00
^{72}Se	Los Alamos/INC-11	1	0.10	0.10

Table I (Cont)

Isotope	*Customer*	*No. of Shipments*	*Shipped (mCi)*	*Received (mCi)*
^{82}Sr	E. R. Squibb & Sons Univ. of California, Lawrence Berkeley National Laboratory	10	3848.90	3745.00
^{48}V	North Carolina State Univ. Risø National Laboratory, Denmark Stanford Univ. Hospital	3	50.00	52.00
^{127}Xe	Brookhaven National Laboratory	3	16500.00	15100.00
^{88}Y Sp*	Amersham International, UK Isotope Products Labs John Muir Cancer Research National Institute of Health	5	85.68	80.00
^{88}Y Zr*	Center for Molecular Medicine Coulter Immunology Cytogen Corp. E. I. Dupont/NEN Products E. R. Squibb & Sons Isotope Products Labs National Institute of Health Science Applications International Corp. University of California, Davis	12	36.76	36.75
^{88}Zr	Argonne National Laboratory	1	0.50	0.50
	TOTAL	177	30108.36	27793.38

*Sp = Spallation Produced.
Zr = Grown from ^{88}Zr Parent.

Theory

Meson-Exchange Contributions to Eta Production in Proton-Proton Collisions

L. C. Liu (Los Alamos) and
F. Wellers (CEN, Saclay)

Field-theoretical meson-exchange models have been very successful in describing nucleon-nucleon interaction below pion production threshold.[1] It has also been applied to the study of low- and intermediate-energy strong interactions involving hadrons with strangeness,[2] for example, the kaon-nucleon interaction. In the few GeV region, there is a rich spectrum of isospin-3/2 Δ resonances and isospin-1/2 N^* resonances. This region represents the next interesting energy domain to test the applicability of meson-exchange models. We have undertaken this theoretical investigation by considering nucleon-nucleon collisions above the η meson production threshold. Because η has isospin zero, the ηN system can only couple to the N^* resonances. This isospin selectivity greatly reduces the number of reaction mechanisms to be considered.

A recent measurement[3] of the reaction $pd \rightarrow {}^3\mathrm{He}\eta$ in the threshold region has generated strong theoretical interests in the understanding of nuclear η-production processes.[4] However, the basic $NN \rightarrow NN\eta$ process remains largely unexploited, either experimentally or theoretically. For this reason, we have studied the elementary $pp \rightarrow pp\eta$ reaction for proton-kinetic energy T_p between 1.26 GeV (the threshold) and 3 GeV, using the framework of field-theoretical meson-exchange models. At this stage of our theoretical study, we have considered only the one-boson exchanges, namely the $pp \rightarrow pN^* \rightarrow pp\eta$ processes due to the exchange of one pion and/or one ρ meson. We have included in our calculations three N^* resonances; the $N^*(1440)$, $N^*(1535)$, and $N^*(1520)$. The coupling constants and form factors of the πNN and ρNN vertices are taken from Ref. 1. Those of the πNN^* vertices are taken from an off-shell unitary analysis.[5] Because no ρ-meson beam is available, we have deduced ρNN^* coupling constants from the πNN^* coupling constants of Ref. 5 by assuming a same relation as the one between the ρNN and πNN coupling constants.

Theoretical results given by the one-boson-exchange contributions are compared with the few existing data[6] in Fig. 1. The dashed curve represents the results given by π-exchange alone. The dotted curve includes both the π and ρ contributions. We note that the π- and ρ-exchanges interfere constructively.

Our calculations indicate that the one-boson-exchange model can qualitatively reproduce the trend of the data. We are currently studying effects of higher-order meson exchanges (the box-diagrams). In case the meson-exchange theory is successful, we shall have a good theoretical framework for the studies of η meson production in proton-nucleus and heavy-ion collisions. Clearly, in order to achieve this latter goal more and higher-quality data are needed.

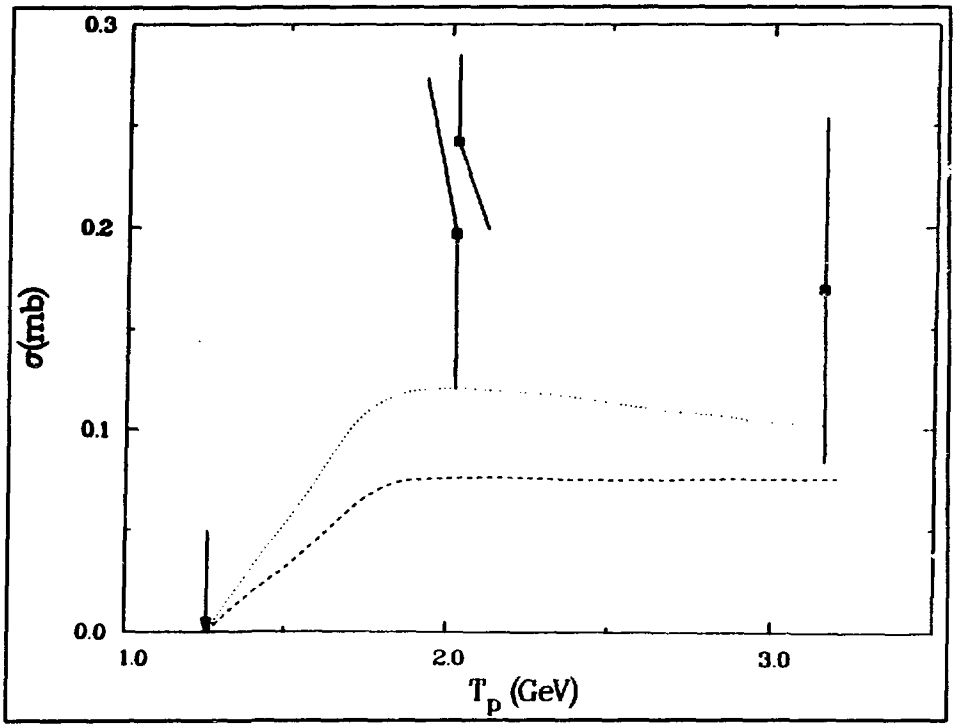


Fig. 1. Total cross sections for the pp → ppη reaction. The dashed curve is due to one-pion exchange; the dotted curve includes contributions from both the π- and ρ-meson exchanges. Data are taken from Ref. 6. The arrow indicates the η-production threshold.

References

1. R. Machleidt, K. Holinde, and Ch. Elster, *Phys. Rep.* **149,** 1 (1987).
2. Rainer Buttger, Ph.D. thesis, Institute of Nuclearphysick, Univ. of Jülich, Federal Republic of Germany.
3. J. Berger, M. Boivin, A. Boudard, P. Fleury, J.-F. Germond, L. Goldzahl et al., *Phys. Rev. Lett.* **61,** 919 (1988).
4. J. M. Laget and J. F. Lecolley, to appear in *Physical Review Letters,* and in Report of DPhN/Saclay No. 2510; see also, Colin Wilkin, "Final State Interactions in Meson Production," contribution to Workshop on Heavy-Meson Production, Saclay, France, March 1988.
5. R. S. Bhalerao and L. C. Liu, *Phys. Rev. Lett.* **54,** 865 (1985).
6. E. Pickup, D. K. Robinson, and E. O. Salant, *Phys. Rev. Lett.* **8,** 329 (1962); L. Bodini, L. Case, J. Kudd, C. Caso, F. Conte, M. Dameri et al., *Nuovo Cimento* **58A,** 475 (1968).

Report of the T-5 Theoretical Group

L. Heller (Los Alamos)

Briefly summarized here are a few of the research topics considered during 1988 by members of the Medium Energy Physics Theory Group (T-5) of the Theoretical Division at Los Alamos. These topics span a very wide range of subject matter from conventional nuclear physics to physics of direct interest to LAMPF and to problems that could be addressed with a LAMPF upgrade.

Dibaryons with $I = 2$

The search for dibaryons has mainly consisted of looking for resonance-like behavior in nucleon-nucleon scattering, which can only produce particles having zero or one unit of isospin. It was very exciting, therefore, when a LAMPF experiment studying pion double charge exchange on the deuteron reported preliminary evidence for a dibaryon with $I = 2$. The simplest hadronic composition such a particle could have is two nucleons and one pion, and the reported mass was actually below the $NN\pi$ threshold, representing a bound state of these three particles.

We noticed that if such a particle exists, it should also be produced by radiative capture of a stopped π^- on a deuteron. This process has the advantage that all the needed hadrons are already present in the initial state. We proposed that this experiment be performed, and it has already been completed by a group at TRIUMF. The result is an upper limit on the branching ratio to form such a particle of (1 to 6) $\times\ 10^{-4}$ over the γ-ray energy interval from 10 to 30 MeV.

On the basis of our calculations of the radiative capture rate using very simple wave functions, the TRIUMF experiment appears to rule out a $J^\pi = 0^-$ particle in which all the orbital angular momenta are zero. On the other hand, these same calculations show that the TRIUMF experiment is not sensitive enough to rule out a 2^- bound state, which is the favored candidate in one theoretical study of the $NN\pi$ system.

Since that time, an improved pion double-charge-exchange experiment on the deuteron at LAMPF also finds no evidence for such a particle. Because of the difficulty in doing reliable theoretical calculations of the cross section for double charge exchange, the radiative capture experiment, especially at greater sensitivity, provides an interesting alternative method to search for such particles.

Weak Asymmetry in pp Scattering from Pion Exchange

We have now completed the first stage of a calculation of the pion-exchange contribution to the parity-violating asymmetry in polarized proton-proton scattering. The calculation applies the strong interaction amplitudes from our coupled NN, $NN\pi$ three-body model to dress a weak $NN \rightarrow N\Delta$ amplitude. The major conclusions we have reached are these:

1. The contribution to A_L from pion exchange is negative and comparable in size to earlier predictions for A_L from ρ and ω exchange.

2. As a result, the combined theoretical prediction for A_L does not agree with the LAMPF experiment at 800 MeV (assuming the "best" theoretical value for the weak $NN\pi$ coupling constant).
3. There are both elastic and inelastic contributions to A_L from pion exchange. Thus, $A_L^{(\pi)}$ is nonzero and sizable even below pion-production threshold. This complicates the analysis of the 230-MeV experiment, now in progress at TRIUMF, measuring this asymmetry.
4. The effects of strong distortion of the weak amplitude enhance the magnitude of $A_L^{(\pi)}$, rather than reduce it (as a Watson-type treatment would imply).

The present calculation of $A_L^{(\pi)}$ is being extended in several ways. These include the incorporation of a weak $N\Delta \rightarrow N\Delta$ transition and the weak modification to the nucleon's propagator. The hope is to cure the present discrepancy with the experiment at 800 MeV with the help of other (conventional) mechanisms that are expected to contribute.

Analysis of the $NN \rightarrow NN\pi$ Reaction

A recent experiment at LAMPF measured spin-spin correlations and analyzing powers in the $pp \rightarrow np\pi^+$ reaction at five energies from 500 to 800 MeV. These data have been analyzed to extract, for the first time, low-L "elastic $N\Delta \rightarrow N\Delta$" phase shifts. (The high-L partial waves in the analysis were taken from a unitary pion-exchange model.) The analysis, preliminary results for which were published this last spring, shows that there are no broad dibaryon resonances in the 2^+, 2^-, and 3^- NN and $N\Delta$ coupled systems. The fitted $N\Delta \rightarrow N\Delta$ phase shifts are either falling or are small and flat with energy. None of them show a rapid rise through 90°, as would be expected for an inelastic resonance whose major coupling is to the $N\Delta$ channel (and which does not significantly leak back into the NN channel).

More recently we have continued this analysis with several refinements and with an expansion of the database to include data available from other experiments. One effort here is to reduce the model dependence of the results and to be able to present the results in a way that can be reproduced by independent workers. Our earlier conclusions regarding dibaryons have not changed, but the quality of the fits at the higher energies has been much improved.

$\pi^{\pm}$ Scattering from $^3H/^3He$

The n-p force is slightly stronger than the n-n or p-p force. Therefore, the radius of the odd nucleon in the trinucleon system is smaller than the radius of the like pair. State-of-the-art Faddeev calculations yield a difference of about 0.16 fm in ^3H. Including the Coulomb interaction leads to an increase in the proton (like nucleon) radius of 0.03–0.04 fm. Thus, the theoretical $r_p(^3He)$-$r_p(^3H)$ difference [0.16 + (0.03–0.04) fm] is consistent with the nominal difference in the elastic-electron-scattering values of $r_p(^3He) = 1.76 \pm 0.04$ fm and $r_p(^3H) = 1.57 \pm 0.04$ fm. It is difficult to extract a neutron radius for ^{3}He from magnetic electron scattering, because meson exchange current corrections are sizable. It is impossible to extract such a neutron radius for ^{3}H because the odd nucleon, which carries most of the spin, is the proton.

Thus, one is led to pursue pion scattering to determine the relative radii in the $A = 3$ nuclei. Near resonance the π^+-p interaction dominates π^+ scattering and the π^--n interaction dominates π^- scattering. If multiple-scattering effects can be properly accounted for, ratio measurements should be very sensitive to differences in the odd-nucleon and like-nucleon distributions. The ratio

$$r_1 = \sigma(\pi^+ \, ^3\mathrm{H}/\sigma(\pi^- \, ^3\mathrm{He})$$

involves primarily the pion strong interaction with the odd nucleon. Clearly the coherent Coulomb scattering does not cancel, but the strong interaction should be much more important beyond forward angles. Thus, r_1 should be sensitive to the ratio of the odd-nucleon form factors. In contrast, the ratio

$$r_2 = \sigma(\pi^- \, ^3\mathrm{H})/\sigma(\pi^+ \, ^3\mathrm{He})$$

involves, in the region of the (3,3) resonance, primarily the pion strong interaction with the like nucleons in each case. Again, Coulomb effects do not cancel, but the ratio is sensitive to the ratio of like-nucleon form factors. Finally, the "super ratio"

$$R = r_1 r_2$$

should be least sensitive to model uncertainties in the treatment of the pion-nucleus scattering theory. Also, while the Coulomb interaction still does *not* cancel, the calculation of R should be less sensitive to any model dependence on those effects than either r_1 or r_2, individually. Because ^{3}He is expected to be larger than ^{3}H, we anticipate that $R > 1$ in general.

Pion-trinucleon-scattering calculations, in which strong interaction model parameters (πN s-wave off-shell range, πN p-wave off-shell range, πN spin-flip off-shell range, and energy shift) are varied, have demonstrated that the pion-nucleon interaction model dependence is minimal between 40° and 80°. Also, the multiple-scattering results follow the general trend of the form-factor ratios. [Keeping only the dominant $\pi^+ p$ and $\pi^- n$ interactions in the single-scattering (impulse) approximation, one would calculate just such a form-factor ratio.] From our model studies we conclude that the $\pi^\pm$-^{3}He/^{3}H ratios are much more sensitive to the relative sizes of the matter distributions of the trinucleons than to the pion-nucleus-scattering model uncertainties. Current LAMPF experiments of this type should prove to be a more sensitive measurement of the ^{3}He/^{3}H relative size than are the absolute charge radii obtained from elastic-electron scattering.

Pion Double Charge Exchange from Medium Weight Nuclei

Within the last year it has been shown that pion double-charge-exchange (DCX) experiments on the calcium isotopes to the double-analog state (DIAS) at both low and high energies can be explained in terms of the $f^n_{7/2}$ seniority model. Within this model an analytic formula for the pion DCX amplitude has been derived, which has a simple dependence on the number of valence nucleons n. The coefficients in this expression depend on two complex amplitudes. One amplitude represents the short-range interaction of the pion with the two neutrons in the nucleus; the other represents the long-range part of this interaction. A computer code has been developed that calculates the double-charge exchange reaction and that includes the distortion of the initial pion, the distortion of the intermediate pion as it propagates from one neutron to the other neutron, and the distortion of the pion as it leaves the nucleus, but assumes closure over the intermediate nuclear states. This model explains the data at 292 MeV to within 20%, but only to within a factor of two at 35 MeV where the short-range interaction is more important. This work has been extended to ground-state transitions as well for which the seniority model is not valid. At the low pion energies these predicted transitions are comparable to the transitions to the DIAS, and have motivated a number of DCX experiments to measure these ground-state transitions.

Recently this model has been extended to nonanalog transitions, which do not change isospin. Again, within the seniority model, the transition is an analytical formula with a simple dependence on n and involves only two amplitudes, one long range and one short range. The relative dependence on n between the long-range amplitude and the short-range amplitude is almost identical to the analog transition. However, the total cross section grows with the number of nucleons times the number of nucleon holes, in contrast with the analog transition which grows quadratically with the number of nucleons. This formula is valid for transitions to all states with different angular momenta within the $f^n_{7/2}$ shell model space. However, the two amplitudes will depend on that angular momentum (and other quantum numbers as well). These amplitudes are being studied to determine what new information about nucleon correlations will be learned from these nonanalog transitions.

The inclusion of the double-spin-flip route was completed this past summer. The code is currently being modified to allow configuration mixing. It was found that the double spin flip cancels strongly against the nonspin-flip route reducing the cross section by as much as an order of magnitude around 120 MeV. This explains some, but by no means all, of the mysteries in the DCX reaction around the 3-3 resonance region. In particular, the forward minimum (around 20°) in the angular distribution seen in several reactions is not reproduced.

Virtual Coulomb Excitation in Pion Elastic Scattering

The work on an effective pion-nucleus potential to represent virtual Coulomb excitation has been completed. We find that the effect should be included for the extraction of relative neutron-proton radii if π^+/π^- comparisons are to be made. The failure to include this potential will lead to errors in the determination of relative neutron-proton radii (depending on the energy of the experiment) as large as 0.1–0.2 fm. Errors from other sources can probably be held to the order of 0.04 fm. Because this effect is much larger for π^+ than for π^-, the use of π^- scattering only for measuring isotopic differences in neutron radii is much less affected. The work has been written up and submitted for publication.

S-Shell Λ-Hypernuclei with Realistic Forces

The A = 4 Λ-hypernuclear isodoublet provides an ideal opportunity to test our ability to calculate the properties of few-body systems microscopically. Both ground state (0^+) and spin-flip-excited state (1^+) exist for ${}^4_\Lambda$He and ${}^4_\Lambda$H. Exact equation (separable potential) calculations have demonstrated the importance of treating explicitly ΛN-ΣN coupling in understanding the 0^+–1^+ binding energy difference (ΔB_Λ = 1 MeV) and have shown that the ${}^4_\Lambda$He–${}^4_\Lambda$H ground-state binding energy difference ($\Delta B_\Lambda \approx 0.35$ MeV) appears to be consistent with the charge symmetry breaking exhibited in some hyperon-nucleon potential models. However, no microscopic calculations have been reported that use directly the realistic hyperon-nucleon interactions that exist in the literature.

We have initiated Monte-Carlo-variational calculations for the A = 4 and 5 Λ-hypernuclei utilizing the realistic Nijmegen soft-core, one-boson-exchange models of the nucleon-nucleon and hyperon-nucleon interactions. Explicit ΛN-ΣN coupling is included. Estimates of the 0^+ ground state and 1^+ excited state binding energies for the ${}^4_\Lambda$He–${}^4_\Lambda$H isodoublet have been made. Estimates of the binding energy for the ${}^5_\Lambda$He ground state are in progress.

Initial results for the $A = 4$ 0^+ state indicate that one can attain agreement for the ground state binding energy ($B_\Lambda \simeq 2$ MeV) within the model uncertainties quoted for the hyperon-nucleon interaction. However, the 1^+ state is apparently unbound. The difficulty appears to reside in the lack of attraction in the ΛN component of the spin-triplet force. The attraction in the present model resides in the $\Lambda N \leftrightarrow \Sigma N$ transition component of the potential. Because the average ΛN potential in the 1^+ state is 5/6 spin triplet, this excited state is quite sensitive to this character of the Nijmegen model. (The average ΛN potential in the 0^+ state is only 1/2 spin triplet.) Because the average interaction in ${}^5_\Lambda$He is 3/4 spin triplet, we anticipate that the A = 5 system will exhibit the same underbinding problem.

Coupled Channel Poles and Shadow Poles

An important question in coupled-channel-scattering problems concerns what effect poles on the many Riemann sheets have on scattering observables. That is, a pole on one of two sheets describing a single-channel system will appear on two of the four sheets that describe the two-channel system. The shadow pole, or second copy of the resonance pole that lies near the physical region, lies on a sheet far removed from the physical region. In the limit of weak coupling between the channels, a determination of the specific sheet on which a pole appears identifies with which channel the resonance is associated; i.e., in which channel the resonance existed before the channels were coupled. Also, the signature of a narrow pole on a sheet far removed from the physical region is large in elasticity ($\eta \approx 0$).

Recently, the pole positions for the $n\alpha$-dt system were extracted from an R-matrix analysis of the available elastic scattering and reaction data. A pole-shadow pole pair associated with the $J^{\pi} = 3/2^{+}$ resonance was found. From the sheet on which the shadow pole resided, it was concluded that the cross-section structure was due to an $n\alpha$ resonance instead of the usual interpretation in terms of a dt resonance. However, after a thorough analysis of coupled separable potential systems, we have demonstrated that it is not possible to determine on which sheet the shadow pole originated once one has departed from the weak-coupling limit. In particular, in the $n\alpha$-dt example, the shadow pole is much closer to the real axis than is the resonance pole (which leads to sharp structure in the reaction cross section), and it is not possible to say with impunity whether the shadow pole has just crossed from one sheet to another.

Interesting phase shifts were observed when two channels that both possess resonance poles were coupled. In particular, when the original poles are positioned such that the pole in the channel with the higher threshold lies slightly higher in energy than the first-channel pole, then in the weak-coupling situation it is possible to obtain an Argand diagram in which a small loop is superimposed on a larger (typical) loop. The structure is remarkably similar in form to the Karlsruhe-Helsinki P_{11} πN amplitudes.

We find strong cusp effects in the cross section only at the opening of a new channel when there is a pole associated with that channel on an unphysical sheet that is far from the physical region. If the pole instead lies sufficiently close to the physical region, then a (rounded) resonance peak appears instead of a cusp. There is clearly a gray area where it is not obvious whether the result will be cusp or resonance peak. In particular, in the $K^{-}d \rightarrow \pi\Lambda N$ reaction the existence of a ΣN bound state in the absence of ΛN-ΣN coupling cannot be inferred from the cusp/peak nature of the reaction cross section at the ΣN threshold.

Rare and Forbidden Decays of the η

We investigated a number of subjects in the field of the rare and forbidden decays of the η-meson. This was stimulated by the recent discovery at Saclay of the possibility of high-flux tagged η-beams. Below we describe our results concerning the decay $\eta \to \mu e$ and the longitudinal polarization of muons in $\eta \to \mu^+\mu^-$.

Lepton-family number-violating decays, such as $\mu \to e\gamma$, $K_L \to \mu e$, etc., probe the existence of interactions beyond the minimal standard model. The decay $\eta \to \mu e$ is sensitive to isoscalar μe-quark interactions. In addition to couplings containing the u- and d-quarks, these may contain couplings involving the s-quark and heavier quarks. We calculated the contribution of a general μe-quark interaction to the $\eta \to \mu e$ branching ratio $B(\eta \to \mu e) \equiv \Gamma(\eta \to \mu e)/\Gamma(\eta \to \text{all})$. We included terms involving the s-quark and ignored the couplings of heavier quarks. The μe-quark interaction, which gives rise to $\eta \to \mu e$, contributes also to noncoherent $\mu^- \to e^-$ conversion in nuclei. The experimental results on $\mu^- \to e^-$ conversion in ^{32}S imply a stringent upper limit for $B(\eta \to \mu e)$. The size of the upper limit depends on the strength $\widetilde{F}_A$ of the $N \to N$ matrix elements of the current $\bar{s}\gamma_\lambda\gamma_5 s$. For $\widetilde{F}_A = 10^{-2}\ F_A$, where F_A is the strength of the $N \to N$ matrix element of the current $(\bar{u}\gamma_\lambda\gamma_5 u + \bar{d}\gamma_\lambda\gamma_5 d)/2$, we obtain $B(\eta \to \mu e) \lesssim 7 \times 10^{-10}$. For $\widetilde{F}_A = 10^{-1}\ F_A$, we would have $B(\eta \to \mu e) \lesssim 7 \times 10^{-12}$. There is no direct experimental information on $\eta \to \mu e$. A limit $B(\eta \to \mu e) < 8 \times 10^{-2}$ has been established from the total branching ratio for charged η-decays and from branching ratios of particular charged η-decays.

An interesting observable in the decay of a pseudoscalar meson (M) into two charged leptons ($M \to \ell^+\ell^-$) is the degree of longitudinal polarization $P_{L\ell}^{(M)}$ of the ℓ^+ or ℓ^-. If the meson is an eigenstate of CP, the leptons can have a longitudinal polarization only in the presence of a CP-violating quark-lepton coupling. A search for lepton polarization in $\pi^0 \to e^+e^-$ or in $\eta \to e^+e^-$ would be forbiddingly difficult because of the small branching ratios and the small analyzing power for $e^\pm$-polarization measurements. A search for muon polarization in $\eta \to \mu^+\mu^-$ might be less demanding because of the possibility to measure the polarization of the muon through muon-decay, and also because of the relatively large branching ratio.

We calculated the polarization of the muon in $\eta \to \mu^+\mu^-$ due to a general CP-violating lepton-quark interaction, and found that values of $P_{L\mu}^{(\mu)}$ as large as $\sim$0.2 are not ruled out. The above upper limit is dictated by the experimental limit on the electric dipole moment of the neutron. In the minimal standard model $P_{L\mu}^{(\eta)}$ is negligibly small since (neglecting admixtures of CP = +1 states in the η) it can arise only at the two-loop level. This is in contrast with muon polarization in $K_L \to \mu^+\mu^-$, where $P_{L\mu}^{(K)}$ receives a contribution $\sim 10^{-3}$ from the K_1-component of K_L, and can receive also a large contribution at the one-loop level from the K_2-component if the standard Higgs boson is light.

Excited States of the Ω^-

One of the key issues in trying to describe nuclei in terms of quarks is the nature of the confining part of the interaction. Many attempts to calculate the nucleon-nucleon interaction start from the assumption that quarks interact via a sum of two-body potentials. We showed some time ago that while this is valid for the short-range part of their interaction, it is unsound both theoretically and phenomenologically for the confining part. We also derived, from the MIT bag model, a many-body confining potential.

The simplest place to test this question is in a single baryon; and to try to avoid the complications arising from the relativistic nature of the light quarks, we examined the Ω^- baryon consisting of three strange quarks. The ground-state and low-lying excited-state energies and wave functions were calculated. Since at that time only the ground state Ω^- (1672) was known experimentally, we did not bother to include the color hyperfine interaction in the calculation.

Recently two excited states have been reported, and the lower one at 2251 $\pm$ 12 MeV is in the range covered by our calculations. We have now included the hyperfine interaction and find seven positive parity candidates for this state with J-values ranging from 1/2 to 7/2. This is to be compared with a calculation of Chao, Isgur, and Karl, which used a sum of two-body potentials, and which found two candidates for the observed state with J-values 3/2 and 5/2. If future experiments determine that the spin of this state is either 1/2 or 7/2, it would favor our approach, whereas a 3/2 or 5/2 assignment would not allow any conclusion.

Experimental observation of the negative-parity p-state or the first excited s-state would appear to be a more definitive test of this question because the two types of calculations differ in their predictions of these energies by 40 MeV and 115 MeV, respectively.

A Strong Dibaryon Test of QCD Models

For several years, we have been developing a quark model of nuclear structure, which has been found to reproduce ^{4}He adequately, and which predicts a qualitatively correct EMC effect. We continue to refine the model and improve the input potential on which it is based. In addition, however, the model naturally lends itself to the study of dibaryons other than the deuteron. We have in the past reported on a strangeness -3 dibaryon most suitable for study at the AHF, and which is presently being searched for in a Fermilab experiment.

In the course of this study, we examined several large multiplets with dibaryon quantum numbers and discovered a previously unappreciated significance of one particular dibaryon candidate. It is an isospin zero, $J^\pi = 3^+$ particle, which is most naturally thought of as an excitation of the deuteron (and so, labelled d^*). The significance resides in the fact that, unlike nuclear systems and most other dibaryons, the two principle effects in multiquark structures both act to enhance the binding of this system relative to the natural reference threshold (which here is given by the mass of two Δ's, the "fall-apart" s-wave two-baryon system). These effects are

1. A lowering of quark kinetic energies due to delocalization in the larger hadronic system; and
2. The color hyperfine interaction.

The latter usually opposes formation of large multiquark systems, and instead favors formation of local, color singlet (3-quark) baryons. In this case, however, its effect is neutral before taking quark delocalization into account, and even attractive when delocalized wave functions are used. (This is not necessarily the case even for the celebrated, proposed H-dibaryon.)

Although we first derived this in our particular model where the binding energy is 200 MeV, we have been able to show the feature is generic to all known models of QCD that incorporate semilocal color confinement and the color magnetic spin interaction. We recommend a search for the d^* in $np \to d^* \to X$ and $\pi d \to \pi d^*$. In the former, the very small resonance bump in the large total cross section will be very difficult to see despite the narrow width of the state ($\lesssim$ 10's MeV); a partial-wave analysis is required ($^3D_3$). In the latter, we estimate a total-production cross section of order 100 nb for the final pion recoiling against the fixed value of missing mass corresponding to the d^*. In addition to mass and width estimates, we can provide differential cross sections for such searches.

Because the result is generic, this d^* dibaryon must exist. Conversely, if it can be ruled out, then all current QCD models of confinement must be seriously flawed.

Electromagnetic Mass Differences and Charge Symmetry Breaking

Working from the same quark model described above, we have discovered that, due to the infrared growth of the strong coupling and the nonexistence of a quark mass-shell, electromagnetic vertex corrections enhance the strong quark-gluon vertex for up-type quarks more than for down-type quarks. The sign of this effect is clearly such as to reduce the mass of the proton relative to that of the neutron, which is opposite to previously identified electromagnetic effects. Since the dominant systematic effect of this electromagnetic contribution is the same as that for a difference between the masses of the down and up quarks, this raises a question regarding the conventional value of this difference.

If we assume that all of that difference is due to our effect, we can then also estimate the change of the size of the effect due to quark delocalization in nuclei. Preliminary results, both in our model and in the nonrelativistic quark model, then suggest that the heretofore unaccounted for difference between the ^{3}He and ^{3}H binding energies may now be much better understood.

Nuclear Three-Body Force

Discrepancies exist between measurements of ^3H and ^3He physical observables and theoretical values calculated using wave functions generated from contemporary model Hamiltonians comprised of realistic nucleon-nucleon forces that reproduce much of the available two-body scattering data and properties of the deuteron. In particular, such model trinucleons are generally underbound and correspondingly oversized, and the neutron-deuteron doublet scattering length is a factor of 2 too large. The fault could lie in more than one place—relativistic effects, quark-gluon and/or meson degrees of freedom, three-nucleon forces, etc. The three-body force possibility has been explored by several groups. It is natural to assume that the long-range component of the three-nucleon force is determined principally by the two-pion-exchange ($2\pi E$) mechanism. The essential ingredient is the πN scattering amplitude. However, the πN amplitude in the $2\pi E$ force involves an off-mass-shell pion, and it is not necessarily dominated by the same terms as the on-mass-shell amplitude. In particular, the PCAC current algebra representation of low-energy πN amplitudes, when extrapolated off mass shell, yields s-wave terms that are of the same magnitude as the p-wave terms. However, these s-wave terms are absent from any model πN amplitude based upon the lowest excited-nucleon state (the Δ isobar) or extrapolated from threshold where the s-wave πN scattering lengths nearly vanish, due perhaps to a dynamical accident.

Our goal was to compare the triton binding-energy contributions of the s-wave and p-wave terms comprising the Tucson-Melbourne $2\pi E$ three-nucleon force. Must one use the full three-body model interaction to obtain accurate results? Or can one reliably utilize a Δ-isobar model force such as that which results from the Hannover approach in which πN s-wave terms in the three-nucleon force are assumed to be negligible? Our numerical studies based upon configuration-space solutions of the Faddeev equations for the triton system indicate that the s-wave πN-amplitude terms of the Tucson-Melbourne $2\pi E$ three-nucleon force play an essential role. (For example, neglecting the s-wave terms can lower the 1.6-MeV binding-energy enhancement due to the full three-body force by as much as 0.6 MeV.) They cannot be neglected, and they generate non-perturbative effects in the resulting triton wave functions. (Variational estimates for the s-wave three-body forces terms yield energies 0.3–0.7 MeV below the Faddeev solutions, which include those terms.) While the triton binding-energy contributions of the πN s-wave terms are clearly not equal to those of the p-wave terms, they are not negligibly small as one might infer from the nature of the phenomenological three-body force of the Urbana group and the Δ-isobar model of the Hannover group. We conclude that a careful treatment of the full $2\pi E$ three-nucleon force is required of any properly founded theoretical three-nucleon force before phenomenological shorter-range terms are included. That is, one should model completely the $2\pi E$ long-range component before adjusting the short-range phenomenological terms to fit the data used to normalize the strength of the complete interaction.

Trinucleon Magnetic Moments

Using the same two-body force Hamiltonian and a variety of calculational techniques, different authors have obtained remarkable agreement for the triton binding energy as well as for the related physical observables such as the rms charge radii and wave function asymptotic normalization constants, which are determined primarily by the asymptotic (large radial distance) part of the wave function. However, such widespread agreement has not been seen in the case of the trinucleon magnetic moments. We have carried out a numerical study of the impulse approximation and isovector pion-exchange current contributions to the trinucleon magnetic moments using wave functions generated from solutions of the configuration-space form of the Faddeev equations from various contemporary nucleon-nucleon force models and the Tucson-Melbourne and Brazilian two-pion-exchange three-nucleon force models. The introduction of a three-body force improved the agreement between the calculated value of the isovector magnetic moment and the experimental value by enhancing the meson-exchange current contribution. The value of the isoscalar magnetic moment was only slightly modified, because the pion exchange current is isovector in nature. The dependence upon the model binding energy is very weak: a 2% variation in the moments for a 15% change in the binding energy. Using the preferred value of the three-body force cutoff (5.8 pion masses), one obtains theoretical isovector and isoscalar magnetic moments that agree with the experimental values to better than 3% and 7%, respectively. Given that relativistic corrections and heavy-meson exchanges have been neglected, the agreement between theory and experiment appears quite reasonable.

Trinucleon Asymptotic Normalization Constants

Asymptotic normalization constants for the trinucleon bound states (the size of the wave function as the N-d clusters are separated to very large distances—also related to nuclear spectroscopic factors and vertex constants in dispersion theory) have become the subject of increased attention. This is, in part, because of the desire to utilize these physical observables to discriminate among ^{3}H and ^{3}He wave functions generated from various "realistic" nucleon-nucleon potential models. Physically the asymptotic normalization constants echo the internal dynamics of the wave function through the overall normalization.

We have extended our original calculations ($^1S_0$, $^3S_1$, $^3D_1$ five-channel results) to models that include two-body nucleon-nucleon force partial waves up to $j \leq 4$ (34 three-body channels), as well as to contemporary two-pion-exchange three-nucleon force models by the Tucson-Melbourne and Brazilian groups. Special emphasis was given to treating correctly Coulomb effects, so that one can compare ^{3}He and ^{3}H results. By interpolating our model results as a function of the trinucleon binding energies, we have obtained best estimates of the physical observables, which can be compared with existing experimental data. Our best estimates for the asymptotic-normalization parameters are $C_S(^3\mathrm{H}) = 1.85 \pm$

0.02, $C_S(^3\mathrm{He}) = 1.85 \pm 0.02$, $C_D(^3\mathrm{H}) = 0.085 \pm 0.001$, $C_D(^3\mathrm{He}) = 0.080 \pm 0.001$, $\eta(^3\mathrm{H}) = 0.046 \pm 0.001$, and $\eta(^3\mathrm{He}) = 0.043 \pm 0.001$.

Improved experimental precision is needed to fully test these predictions. In the case of C_S, the present data from medium energy $^3\mathrm{He}(p,p)dp$ studies are in conflict (1.55 vs 1.87). A direct measurement of C_D does not exist. The experimental values for η (extracted from extrapolating the tensor polarization in the $^4\mathrm{He}(\vec{d},^3\mathrm{H})^3\mathrm{He}$ transfer reaction to the pole) are quoted as $\eta(^3\mathrm{H}) = 0.050 \pm 0.006$ and $\eta(^3\mathrm{He}) = 0.036 \pm 0.006$. These are consistent with the theoretical model predictions at the level of one standard deviation, but the large spread in the nominal values of the measurements compared with the near equality of the theoretical values is disturbing in view of the fact that the model predictions for other low-energy properties (rms radii, magnetic moments, and neutron-deuteron scattering length) agree more closely with experiment.

Trinucleon Solutions for Momentum-Dependent Potentials

Realistic nucleon-nucleon potentials are constructed to reproduce as well as possible properties of the two-nucleon systems, such as the deuteron binding energy and the nucleon-nucleon phase shifts. One of the fundamental challenges of nuclear physics is to determine whether such potentials can account for the properties of many-body systems. In this regard the three- and four-nucleon systems are special, because the Schrödinger equation can be solved exactly (numerically) for them, unlike heavier nuclei.

A major question in such investigations is whether three-body forces, which are fundamental forces depending on the simultaneous coordinates of three nucleons, are required in order to obtain an accurate description of nuclei. All contemporary "realistic" potentials, except for recent versions of the Bonn potential, produce triton binding energies in the range 7.5 ± 0.2 MeV. The various Bonn potentials bind near 8.3 MeV. The most notable characteristic of the latter potentials is their momentum dependence, structurally similar to that of the Paris potential. Faddeev calculations for the latter potential have been in substantial disagreement. One other realistic potential, the Nijmegen model, also has such a momentum dependence, but no triton calculations have been performed with it.

The triton properties for these three potential models (Paris, Bonn, Nijmegen) were calculated in order to determine whether the explicit momentum dependence was an essential component of large binding. Our Paris solutions confirmed a previous (low) result of 7.47 MeV, as well as the various Bonn results. The Nijmegen potential produced a triton binding energy of 7.63 MeV. These calculations showed that the momentum dependence plays no essential role in the Bonn result. The latter's large binding energy appears to result from an uncharacteristically weak tensor force, which has not been ruled out by NN scattering measurements, because the uncertainties resulting for the $^3S_1$-$^3D_1$ mixing parameter are quite large. The circumstantial evidence from all other triton calculations implies that three-body forces contribute roughly 1 MeV to the binding of the three-nucleon systems.

Low-Energy Nucleon-Deuteron Scattering

The scattering of two systems provides more opportunities for studying the dynamics underlying the interaction of those systems than their bound state alone would (if it exists). Studying nucleon-deuteron scattering in the elastic channel and in the breakup channel (into three free nucleons) should greatly enrich our knowledge of the three-nucleon systems and provide additional detailed knowledge about the adequacy of describing such systems solely in terms of pairwise interactions between nucleons. During the past five years, the ^{3}H and ^{3}He systems have been well investigated by several groups in terms of "realistic" potential models, and general agreement has been reached that pairwise forces produce roughly 1 MeV too little binding, which presumably must be supplemented by three-nucleon forces. It is hoped that one can obtain complementary information on three-nucleon forces from *n-d* and *p-d* scattering. At the present time few calculations of the necessary quality have been performed. Furthermore, discrepancies exist among the reported (and very difficult) calculations.

Few calculations of *n-d* scattering for local potentials have been performed and even fewer for *p-d* scattering. All of the latter have been performed by the Leningrad and Los Alamos-Iowa groups. The former's calculations agree with the so-called experimental results and are in serious disagreement with the latter calculations. Both the Leningrad calculations and the experimental results for the scattering length are obtained by computing the effective-range function from the phase shifts at moderately high (0.5–2.0 MeV) energies and extrapolating to zero energy. We have shown that the effective range function for the *p-d* case has a pole at very small negative energies, which must be taken into account in order to achieve reliable results for the scattering lengths. The Leningrad calculations and the "experimental" results for the scattering lengths are consequently in error. Our phase shifts at finite energy are in good agreement with the experimental data, which are too imprecise and too high in energy to reveal the effect of the pole.

GFMC Calculations of ^{4}He

Exact calculations with "realistic" nucleon-nucleon interactions have proven to be extremely difficult for $A > 3$. We have developed novel Green's function Monte Carlo methods to treat few-nucleon systems exactly, and applied these methods to the ground state of the alpha particle. A variety of ^{4}He properties have been studied, including the binding energy, one- and two-body distribution functions, and the *D*-state probability.

We have found that previous variational studies of ^{4}He have underestimated the binding energy by 1.5 to 2 MeV depending upon the interaction model.

This difference is very small on the scale of the kinetic or potential energies ($\approx$100 MeV), but it is a significant fraction of the difference between experiment and theoretical results with two-nucleon interactions alone. Using exact Faddeev and GFMC results for $A = 3$ and 4, respectively, it is possible to fit the strength of a model three-nucleon interaction to the experimental binding energies; such a fit requires nearly a 30% reduction in the two-pion-exchange three-nucleon interaction compared to that obtained with variational results.

The charge form factor of the alpha particle has also been determined with GFMC. The most significant differences found are a reduction at small q due to the increased binding, and a shift in the position of the diffraction minimum. The strength of the secondary maximum in $F(q)$ may differ significantly from variational results, but impulse approximation results are nevertheless much smaller than the experimental data, similar to the differences found between $A = 3$ experimental and theoretical results. Exchange currents make a significant contribution to the form factor at these values of q.

We have also examined the two-particle distribution functions; in particular the proton-proton distribution, which (along with the charge form factor) determines the Coulomb sum rule measured in electron scattering. Variational and GFMC results for this sum rule are in good agreement with each other and with experimental results. We have also examined the dependence of $\rho_{pp}(r)$ upon the choice of interaction model. Although the experimental results for ^{3}He do indicate the presence of strong proton-proton correlations, there is insufficient sensitivity in the Coulomb sum rule to allow one to choose between various interaction models.

Finally, we have examined the D-state probability in the alpha particle ground state. Some previous calculations had given abnormally low ($\approx$8%) values; but we find results ranging from 11 to 14%, rising to 15 to 17% when the effect of three-nucleon interactions is included. Naive counting arguments suggest that the alpha particle would have roughly three times the D-state component of the deuteron. The ratio determined from these calculations is closer to 2.3, which nevertheless indicates a very sizable D-state component. This large value underscores the need for a much more thorough understanding of the $d+d \rightarrow \alpha+\gamma$ reaction, for example, which at low energy depends strongly upon this component of the alpha-particle ground state.

Low-Energy Photonuclear Reactions

We have initiated a microscopic study of low energy photonuclear reactions in light nuclei. The goal of these studies is to gain a microscopic understanding of these reactions, beginning with a realistic nucleon-nucleon interaction model. Initial studies are being carried out for the $^3\text{He} + n \rightarrow \alpha + \gamma$ and $^3\text{H} + p \rightarrow \alpha + \gamma$ reactions, which can be approximated as single-channel problems at low energy. Microscopic studies of these scattering states (and the ground state) can also be used to understand one of the (small) contributions to the background in solar-neutrino experiments.

Preliminary results indicate that microscopic calculations can produce a reasonable description of the few-body nuclear-scattering state; the next stage of the calculation requires simply determining the electromagnetic-matrix elements between the scattering and ground states of $A = 4$. In future work, we hope to extend the methods to allow the treatment of multichannel problems, allowing us to treat, for example, the combined $d+d$, $t+p$, and ^{3}He $+n \rightarrow \alpha+\gamma$ reactions.

Hartree-Fock-Bogolyubov and Random Phase Approximation in the Fermion Dynamical Symmetry Model

The fermion dynamical symmetry model (FDSM) is a schematic fermion shell model that includes monopole and quadrupole pairing in nuclei and recently has been successful in describing the collective properties of the low-lying states in nuclei. The FDSM has two dynamical symmetries, $SP(6)$ and $SO(8)$, each of them providing a generalization of the $SU(2)$ quasispin group of monopole pairing to a larger group, which includes both monopole and quadrupole pairing. The FDSM can be solved relatively simply, even analytically for certain interactions, but is of sufficient complexity to make it a valuable model for testing various many-body approximation methods in nuclear physics. By using fermion coherent states, we have constructed the energy surface of the FDSM Hamiltonian in terms of the collective quadrupole variables β (deformation) and γ. We have shown that the coherent state, which minimizes the energy surface, is equivalent to the Hartree-Fock-Bogolyubov transformation. Also we have shown that, for interactions for which the pairing interaction and quadrupole interaction have equal strength, the nucleus is spherical and the energy surface is "b-soft"; that is, the energy surface is very flat to vibrations, and the energy surface becomes more flat as the number of valence nucleons is increased. Evidence for this type of collective behavior has been seen in the ruthenium and palladium isotopes. We have also shown that if the strength of the quadrupole interaction is larger than the pairing interaction, then for small valence nucleon number, the nucleus is spherical, but for a critical value of the nucleon number, the nucleus becomes an axially symmetric rotor, where this critical number depends on the ratio of the quadrupole and pairing interaction strengths. Furthermore, the nucleus can make a transition from an axially symmetric rotor to an asymmetric rotor due to the Pauli principle.

We have studied the excited states using the random phase approximation (RPA). We have derived analytical expressions for the excitation energy of the the first 2^+ excited state and the transition strength to the ground state within the spherical RPA. In general, the RPA excitation energies and transitions are accurate to order Ω^{-1}, where Ω is one-half the number of single-nucleon states in a shell. Furthermore for "b-soft" nuclei, the RPA excitation energy can collapse and the transition strength becomes infinite. These effects follow from the fact that the RPA is a small-amplitude oscillation around a local minimum, but for these nuclei there is no real minimum. The RPA ground-state correlations are now being studied.

Effect of Surface Fluctuations on the Nuclear Density

We have investigated the following recent claims by Barranco and Broglia:

(a) Changes in the nuclear density in ^{40}Ca arising from shape fluctuations are of the order of 5% and 20% for the radius and diffusivity, respectively;

(b) The systematic behavior of the charge densities throughout the Ca isotopes deduced from electron and muon atom measurements might be understood based on these shape fluctuations; and

(c) The parameters of the effective forces used in Hartree-Fock (HF) calculations should not be adjusted to fit the static nuclear properties, but rather the adjustment should be made only after the zero-point fluctuations are taken into account.

It was shown that the reliability of theoretical estimates of the admixture of collective zero-point fluctuations in the nuclear ground state is currently limited by uncertainties in the effective nucleon-nucleon interaction and the existence of double-counting corrections arising from various sources. When including some of these corrections in a microscopic HF + Random Phase Approximation calculation, results are found that are considerably smaller than recently reported.

Resonant-energy pion-scattering data may provide a sensitive means for studying these surface fluctuations because the scattering is surface dominated and can be used to differentiate between neutrons and protons. Such a study is important because it identifies a mechanism (the inclusion of medium-range and long-range dynamical correlations) that might explain the systematic discrepancy between calculated and experimental values of rms radii throughout the Ca isotopes.

Core Polarization Effects in *sd*-shell Nuclei and Charge Symmetry Breaking in the Nuclear Mean Field

The elastic scattering of protons and neutrons on the same $N = Z$ nucleus can be seen in complete analogy with, and as an extension of, the comparison of binding energies of two mirror nuclei.

For the deformed *sd*-shell nuclei ^{28}Si and ^{32}S quadratically constrained Hartree-Fock calculations (CHF) have been performed in order to study the multipole decomposition of the symmetry potential, i.e., that part of the nuclear potential that results from the difference in the $T = 0$ and $T = 1$ parts of the n-p interaction.

It was found that there is no particular enhancement in asymmetry between the self-consistent proton and neutron potentials $U_{p,n}(r,\theta)$ due to a long-range deformed component in the mean field. However, the order of magnitude of the effect depends strongly on the probes used: for weakly distorted projectiles the charge-asymmetric potential will affect the cross sections only on the 1% level; for particles that experience stronger distortion effects and are absorbed at the surface there will be a 3 to 5% effect.

Quantum Gravity

We have been studying the phenomenological implications of the construction of consistent quantum field theories of gravity, including those encompassing unification of all forces. In the past, we have noted that the class of such theories generically includes (at least one of each of) vector and scalar components in addition to Einstein's (metric) tensor component. Since these additional components do not couple precisely to the stress-energy tensor, and since there is no symmetry to keep the gravivector and graviscalar partners of the graviton massless, the exchange of these particles produces (of order) gravitational strength forces, which are substance dependent and which violate Newton's inverse square law due to their finite ranges. Since, for ordinary matter, the vector produces a repulsive, and the scalar an attractive force, centuries of experiments strongly constrain these additional components to cancel quite precisely. However, those experimental results do not constrain the strength or range of the components separately. For antimatter interacting with ordinary matter, on the other hand, the sign of the vector force is reversed and a much larger substance dependence effect is expected. An antimatter experiment led by Los Alamos (PS-200) is pursuing this approach at LEAR.

Recently, there have been several experiments to search for substance-dependent and inverse-square-law-violating effects, which have produced apparently contradictory results. One of our most important observations to date has been a demonstration that the differing results may be due to geophysical effects on 10–100-km scales. (A competing conjecture involving a single new force is inconsistent with the full data set.) Our analysis principally encompasses the inverse-square-law mine experiments of Stacey et al., and the substance-dependent experiments of Theiberger and of Adelberger et al., but can include the more recent tower results of Eckhardt et al. Our observation of the importance of geophysical effects has strongly influenced new inverse-square-law experiments in Greenland and in the North Pacific.

We have also completed a study of astrophysical constraints on the parameters of quantum gravity models, and have searched for possible new terrestrial experiments. The results have provided significant bounds on the two new components separately, and are not in conflict with observed evidence for these new effects. All the new laboratory experiments considered so far, which use ordinary matter alone, are unlikely to be sensitive enough to provide new information, thereby reaffirming the importance of geophysical-scale experiments. Only the proposed measurement of the effect of gravity on antimatter will produce new constraints on the model parameters, which will be insensitive to geophysical structures.

Chiral Symmetry Breaking, Instantons, and Confinement

Recently, there have been several assaults on the conventional wisdom regarding the mass difference between up and down quarks. These have involved the effects of instantons, which should nominally affect both quarks equally, but then can still affect the ratio of their masses. We have studied the interplay between such quark level effects and descriptions in terms of effective chiral Lagrangians. Although this work is not yet complete, it is now clear that these effects are not related to the chiral nature of confinement.

Automated Symbolic Manipulation of Quantum Angular Momentum Algebra

We have created a package for symbolically carrying through calculations of quantum mechanical angular momentum recouplings on a PC microcomputer. Typically these calculations have been done "by hand." They are tedious and prone to phase and factor errors, so a mechanical means of evaluating such quantities—which are ubiquitous in any kind of spectroscopy—would be a welcome addition to the theorist's toolbox.

We solved the question of how to carry out the algebra by converting a graphical technique into a set of manipulations on binary trees that can be handled by a LISP program. The program has been tested on a large number of examples and, besides giving correct answers, usually ends up with the most economical recoupling scheme. We have interfaced the program with the user for the input of his problem in two ways. One, for a novice, leads him through a series of windows and menus to extract the input information for the particular problem he wants to do. (In the present version, this is a partial-wave decomposition of a one-meson-exchange potential.) The other mode of operation, for an expert, is to let the user input the initial coupling and desired final recoupling and then turn the evaluation over to the machine.

A good start has been made on a conventional (two-dimensional) display of the final results. We have also begun to prepare an operator's manual for using the program. We anticipate that a "beta version" of the software will be available for distribution to friendly users within a few months.

Control of Charged-Particle Beams

The prototype "spreadsheet" for designing optical systems for charged-particle beams has now almost reached the stage where the software-hardware tool could actually be used for a realistic problem by a beamline designer. This has been a cooperative project with members of MP-6 and AT-Division. The basic point has been to amalgamate the beam optics code TRANSPORT with expert system software, running on a LISP workstation. This would enable the designer, working interactively, to concentrate on the development of the beamline rather than on details of how to run the TRANSPORT code. In a real sense, the LISP machine is acting as a "front end" to a rather complicated FORTRAN code.

The graphical display of output has been much improved, as has a more flexible method, using menus and the mouse, of manipulating beamline elements and their parameters. There are also now menus for more general manipulation of the user's screen; he can choose what kinds of information he wants displayed, as well as perform various housekeeping chores, such as saving from the present beamline setup to the disk.

Group T-5

Anyone wishing further information on these matters may contact Group T-5 members J. L. Friar (Group Leader), W. R. Gibbs, B. F. Gibson V, J. N. Ginocchio, T. Goldman, L. Heller, P. Herczeg, and R. R. Silbar. B. C. Pearce and G. Wenes held postdoctoral appointments in T-5 during 1988. J. A. Carlson was a J. Robert Oppenheimer Fellow. The long-term visitors during 1988 were N. Austern (University of Pittsburgh), J.-P. Dodonder (University of Paris-Sud), G. D'Ambrosio (INFN, Italy), W. B. Kaufmann (Arizona State University), B. Loiseau (University of Paris, Orsay), K. R. Maltman (York University), J. Missimer (SIN), G. L. Payne (University of Iowa), I. Talmi (Weizmann Institute), J. A. Tjon (University of Utrecht), E. L. Tomusiak (University of Saskatoon), and S. Wallace (University of Maryland).

T-5 Publications

A. T. M. Aerts and L. Heller, "Excited States of the Ω^-" (submitted to *Physics Letters B*).

M. E. Ander, T. Goldman, R. J. Hughes, and M. M. Nieto, "Possible Resolution of the Brookhaven and Washington Eötvös Experiments," *Phys. Rev. Lett.* **60**, 1225–1228 (1988).

M. E. Ander, T. Goldman, R. J. Hughes, and M. M. Nieto, "Ander et al. Reply to Niebauer et al.," *Phys. Rev. Lett.* 61, 2273 (1988).

M. E. Ander, T. Goldman, R. J. Hughes, and M. M. Nieto, "Ander et al. Reply to Bartlett et al." (to be published in *Physical Review Letters*).

N. Auerbach, J. Bartel, and G. Wenes, "Core Polarization Effects in *sd*-Shell Nuclei and Charge Symmetry Breaking in the Nuclear Mean Field," (to be published in *Physical Review* C).

N. Auerbach, W. R. Gibbs, Joseph N. Ginocchio, and W. B. Kaufmann, "Pion-Nucleus Double Charge Exchange and the Nuclear Shell Model," *Phys. Rev.* C **38**, 1277 (1988).

F. Cannata, J. P. Dedonder, and W. R. Gibbs, "Optical Potential for Charged Hadron-Nucleus Scattering: the Role of Coulomb Excitations," Los Alamos National Laboratory document LA-UR-88-3284 (submitted to *Physical Review* C).

J. Carlson, "Alpha Particle Structure," *Phys. Rev.* C **38**, 1879 (1988).

J. Carlson, "Green's Function Monte Carlo Calculations of ^{4}He," Conference on Electron Scattering from Nuclei, Marciana Marina, Italy, June 7–16 1988 (to be published in the proceedings).

J. Carlson, L. Heller, and J. A. Tjon, "Stability of Dimesons," *Phys. Rev.* D **37**, 744 (1988).

J. Carlson, Jules W. Moskowitz, and K. E. Schmidt, "Model Hamiltonians for Atomic and Molecular Systems" (to be published in the *Journal of Chemical Physics*).

C. R. Chen, G. L. Payne, J. L. Friar, and B. F. Gibson, "Low-Energy Nucleon-Deuteron Scattering," *Physical Review* C (in press).

X. Chen, C. Wu, D. Feng, J. N. Ginocchio, J. Chen, and Z. Lee, "The Fermion Dynamical Symmetry $USP_6 \otimes U_2$ Model," [to be submitted to *Physical Review* C (1987)].

F. Cooper, J. N. Ginocchio, and A. Wipf, "Derivation of the *S*-Matrix Using Supersymmetry," *Phys. Lett.* **129A**, 145 (1988).

F. Cooper, J. N. Ginocchio, and A. Wipf, "Supersymmetry, Hidden Shape Invariance and Exactly Solvable Potentials," Los Alamos National Laboratory document LA-UR-87-4101 (submitted to *Nuclear Physics B*).

J. L. Friar, "Electromagnetic Polarizabilities of Hadrons," invited lecture at the "Workshop on Electron-Nucleus Scattering," Marciana Marina, Italy, June 7, 1988 (to be published in the proceedings).

J. L. Friar, B. F. Gibson, D. R. Lehman, and G. L. Payne, "Trinucleon Asymptotic Normalization Constants: Comparison of ^{3}He and ^{3}H," *Phys. Rev.* C**37**, 2859 (1988).

J. L. Friar, B. F. Gibson, and G. L. Payne, "^{3}H and ^{3}He Solutions for Momentum-Dependent Potentials," *Phys. Rev.* C**37**, 2869 (1988).

J. L. Friar, B. F. Gibson, G. L. Payne, and S. A. Coon, "*S*-Wave πN Scattering Effects in the Nuclear Three-Body Force," *Few-Body Systems* (in press).

J. L. Friar, B. F. Gibson, G. L. Payne, E. L. Tomusiak, and M. Kimura, "Trinucleon Magnetic Moments: 34 Channel Results," *Phys. Rev.* C**37**, 2852 (1988).

J. L. Friar and G. L. Payne, "Bipolar Harmonic Reduction Formulae," *Phys. Rev.* C**38**, 1 (1988).

W. R. Gibbs, W. B. Kaufmann, and J. P. Dedonder, "The Pion-Nucleus Resonance and Nuclear Translucence" (submitted to *Physical Review C*).

J. N. Ginocchio, G. Wenes, R. Amado, D. Cook, N. Hintz, and M. Gazzaly, "Medium Energy Proton Scattering from ^{154}Gd and the Interacting Boson Model of Nuclei," *Phys. Rev.* C**36**, 2436 (1987).

J. N. Ginocchio, "Fermion Dynamical Symmetry and the Nuclear Shell Model," in *Proceedings of the International Symposium on Particle and Nuclear Physics*, N. Hu and C. Wu, Eds. (World Scientific Press, Singapore, 1986) p. 309.

J. N. Ginocchio, "Pion Double Charge Exchange and Nuclear Structure," in *Pion-Nucleus Physics: Future Directions and New Facilities at LAMPF*, R. J. Peterson and D. Strottman, Eds. (AIP Proceedings, New York, 1987) p. 425.

T. Goldman, "The Standard Model and Its Problems: The Physics Background for an Advanced Hadron Facility," in *Proceedings of the RAND Workshop on Antiproton Science and Technology*, RAND Corporation, Santa Monica, California, October 6–9, 1987, B. W. Augenstein, B. E. Bonner, F. E. Mills, and M. M. Nieto, Eds. (World Scientific, New Jersey, 1988), p. 123.

T. Goldman, "An Advanced Hadron Facility: Prospects and Applicability to Antiproton Production," in *Proceedings of the RAND Workshop on Antiproton Science and Technology*, RAND Corporation, Santa Monica, California, October 6–9, 1987, B. W. Augenstein, B. E. Bonner, F. E. Mills, and M. M. Nieto, Eds. (World Scientific, New Jersey, 1988), p. 446.

T. Goldman, "Multiquark Interactions," Topical Conference on Nuclear Chromodynamics, Argc...ne National Laboratory, May 19–21, 1988 (to be published in the proceedings).

T. Goldman, "Parity Violating Total Cross Sections," Symposium on Future Polarization Physics at Fermilab, June 13–14, 1988 (to be published in the proceedings).

T. Goldman, R. J. Hughes, and M. M. Nieto, "Gravity and Antimatter," *Sci. Am.* 256, 48–56 (May 1988).

T. Goldman, R. J. Hughes, and M. M. Nieto, "Exclusion of an Isospin Fifth Force From Kaon Decay," *Mod. Phys. Lett. A* **3**, 1243–1249 (1988).

P. Halse and J. N. Ginocchio, "The $SU(3) \times SU(4)$ Limit of an Isospin Invariant Fermion Dynamical Symmetry Model," *Phys. Rev. C* **36**, 2611 (1987).

L. Heller, "Heavy Multiquark States," in *The Elementary Structure of Matter*, J.-M. Richard, E. Aslanides, and N. Boccara, Eds. [*Springer Proceedings in Physics* **25** (1988)] p. 35.

L. Heller and A. W. Thomas, "Structure Functions of Nuclei in the 'Instant' Form of Dynamics" (submitted to *Physical Review* C).

L. Heller and W. R. Gibbs, "π^- Capture on the Deuteron as a Dibaryon Search," Los Alamos National Laboratory document LA-UR-88-3411 (submitted to *Physical Review* C).

P. Herczeg, "Exotic Decays of Light Mesons," invited talk at the Workshop on Production and Decay of Light Mesons, Paris, France, March 3–4, 1988, Los Alamos National Laboratory document LA-UR-88-1857 [to be published in the proceedings (World Scientific, Singapore, 1988)].

P. Herczeg, "T-Violation in Nuclear Interactions—an Overview," invited talk at the Workshop on On-Line Nuclear Orientation and Related Topics, Oxford, England, September 1–4, 1988, Los Alamos National Laboratory document LA-UR-88-3568 (to be published in the proceedings in *Hyperfine Interactions*).

R. J. Hughes, T. Goldman, and M. M. Nieto, "Gravity in Greenland," in *Proceedings of the DPF Meeting*, Storrs, Connecticut, August 1988.

R. J. Hughes, M. M. Nieto, and T. Goldman, "An Eötvös versus a Galileo Experiment: A Study in Two-versus Three-Dimensional Physics," *Phys. Lett.* **212B**, 18–21 (1988).

R. J. Hughes, T. Goldman, and M. M. Nieto, "Quantum Gravity and New Forces," in *Proceedings of the VIIIth Moriond Workshop*, O. Fackler and Tran Thanh Van, Eds. (Editions Frontieres, Paris, 1988), pp. 603–608.

M. B. Johnson and G. Wenes, "Effect of Surface Fluctuations on the Nuclear Density," *Phys. Rev.* C38, 386 (1988).

M. J. Leitch, H. W. Baer, R. L. Burman, C. L. Morris, J. N. Knudson, J. R. Comfort, D. H. Wright, R. Gilman, S. H. Rokni, E. Piasetzky, Z. Weifeld, W. R. Gibbs, and W. B. Kaufmann, "The $^{14}C(\pi^+,\pi^-)^{14}O$ Reaction Between 19 and 80 MeV," Los Alamos National Laboratory document LA-UR-88-4096 (submitted to *Physical Review* C).

K. Maltman, T. Goldman, G. J. Stephenson, K. E. Schmidt, and Fan Wang, "Inevitable Dibaryons and the Quark Mechanisms of Nuclear Forces," (to be published in the proceedings of Cluster '88, July 1988).

M. M. Nieto, T. Goldman, and R. J. Hughes, "Phenomenological Aspects of New Gravitational Forces. I. Rapidly Rotating Compact Objects," *Phys. Rev.* D36, 3684–3687 (1987).

M. M. Nieto, T. Goldman, and R. J. Hughes, "Phenomenological Aspects of New Gravitational Forces. II. Static Planetary Potentials," *Phys. Rev.* D36, 3688–3693 (1987).

M. M. Nieto, T. Goldman, and R. J. Hughes, "New Gravitational Forces from Quantum Theory," in *Proceedings of the 5th Marcel Grossmann Meeting*, D. Blair and P. Veitch, Eds. (to be published).

M. M. Nieto, T. Goldman, and R. J. Hughes, "Phenomenological Aspects of New Gravitational Forces. IV. New Terrestrial Experiments," *Phys. Rev.* D38, 2937 (1988).

M. M. Nieto, T. Goldman, and R. J. Hughes, "The Inverse-Square Law and Quantum Gravity," in *Proceedings of the Workshop on Relativistic Gravitation Experiments in Space*, T. Hellings, Ed. (to be published).

M. M. Nieto, K. I. Macrae, T. Goldman, and R. J. Hughes,"Phenomenological Aspects of New Gravitational Forces. III. Slowly Rotating Astronomical Bodies," *Phys. Rev.* D36, 3694–3699 (1987).

D. E. Schultz and R. R. Silbar, "Toward Automatic Control of Particle Accelerator Beams," Proceedings of Third International Conference on Applications of Artificial Intelligence in Engineering, Stanford, California, August 1988, published in *Artificial Intelligence in Engineering: Diagnosis and Learning*, J. S. Gero, Ed. (Elsevier/Computational Mechanics Publications, Southampton, 1988), pp. 161-174.

R. L. Shypit, D. V. Bugg, D. M. Lee, M. W. McNaughton, R. R. Silbar, N. M. Stewart, A. S. Clough, C. L. Hollas, K. H. McNaughton, P. J. Riley, and C. A. Davis, "A_{SL}, A_{LL}, and A_{NO} for $NN \rightarrow \pi D$ at 492, 729, and 796 MeV," *Nucl. Phys. A* **477**, 541 (1988).

R. L. Shypit, D. V. Bugg, D. M. Lee, M. W. McNaughton, R. R. Silbar, N. M. Stewart, A. S. Clough, C. L. Hollas, K. H. McNaughton, P. J. Riley, and C. A. Davis, "Evidence Against Broad Dibaryons," *Phys. Rev. Lett.* **60**. 901 (1988).

R. L. Shypit, D. V. Bugg, D. M. Lee, M. W. McNaughton, R. R. Silbar, N. M. Stewart, A. S. Clough, C. L. Hollas, K. H. McNaughton, P. J. Riley, and C. A. Davis, "Shypit et al. Reply" (to a Comment on "Evidence Against Broad Dibaryons" by Ryskin and Strakovsky), *Phys. Rev. Lett.* 61, 2385 (1988).

R. R. Silbar, W. M. Kloet, L. S. Kisslinger, and J. Dubach, "Pion-Exchange Contribution to the Parity-Violating Asymmetry in *pp* Scattering" (submitted to *Physical Review* C).

R. R. Silbar, "An Interactive Interface to the Beam Optics Code TRANSPORT," Workshop on Linear Accelerator and Beam Optics Codes, La Jolla, California, January 1988 (to be published in the proceedings).

R. R. Silbar and D. E. Schultz, "Automation of Particle Accelerator Control," in *Proceedings of ASME International Conference on Computers in Engineering*, San Francisco, California, August 1988, in *Computers in Engineering 1988–Volume One*, V. A. Tipnis and E. M. Patton, Eds. (American Society of Mechanical Engineers, New York, 1988), pp. 79–83.

R. R. Silbar, W. M. Kloet, L. S. Kisslinger, and J. Dubach, "Pion-Exchange Contribution to the Parity-Violating Asymmetry in *pp* Scattering," Eighth International Symposium on High Energy Spin Physics, Minneapolis, Minnesota, September 1988 (to be published in the proceedings).

R. R. Silbar, "Summary Talk for Intermediate-Energy Hadron Interactions," Eighth International Symposium on High Energy Spin Physics, Minneapolis, Minnesota, September 1988 (to be published in the proceedings).

G. J. Stephenson, T. Goldman, K. Maltman, and K. E. Schmidt, "Exchange Effects in Double Beta Decay," Third Conference on Intersections Between Nuclear and Particle Physics, Rockport, Maine, May 14–19, 1988, Gerry Bunce, Ed. (American Institute of Physics, New York, 1988), Vol. 176, pp. 930–935.

G. Wenes and J. N. Ginocchio, "An Algebraic Approach to Medium Energy Proton Scattering," *J. Phys. G: Nucl. Phys.* **14**, Supplement S65 (1988).

G. Wenes and J. N. Ginocchio, "Random Phase Approximation in the Fermion Dynamical Symmetry Model," Los Alamos National Laboratory document LA-UR-88-2998 (to be published in *Physical Review* C).

G. Wenes, T. Otsuka, and J. N. Ginocchio, "*F*-Spin Effects in Inelastic Electron Scattering from Low-Lying Collective States of ^{154}Gd," *Phys. Rev.* C **37**, 1878 (1988).

W. M. Zhang, D. H. Feng, and J. N. Ginocchio, "Geometrical Interpretation of $SO(7)$: A Critical Dynamical Symmetry," *Phys. Rev. Lett.* **59**, 2032 (1987).

W. M. Zhang, D. H. Feng, C. L. Wu, H. Wu, and J. N. Ginocchio, "Symmetry Constrained Hartree-Fock-Bogolyubov Theory" (to be published in *Physical Review* C).

W. M. Zhang, D. H. Feng, and J. N. Ginocchio, "Geometrical Structure and Critical Phenomena of the Fermion Dynamical Symmetry Model $SO(8)$," *Phys. Rev.* C **37**, 1281 (1988).

W. M. Zhang, C. L. Wu, D. H. Feng, and J. N. Ginocchio, "Geometrical Structure and Critical Phenomena of the Fermion Dynamical Symmetry Model $SP(6)$," *Phys. Rev.* C **38**, 1475 (1988).

MP-DIVISION PUBLICATIONS

Publications

Nuclear and Particle Physics Research

K. Abe, E. W. Beier, L. S. Durkin, A. K. Mann, F. M. Newcomer, L. A. Ahrens, S. H. Aronson, B. G. Gibbard, M. J. Murtagh, S. Terada, K. Amako, S. Kabe, T. Shinkawa, J. L. Callas, D. Cutts, M. V. Diwan, J. S. Hoftun, R. E. Lanou, D. Hedin, M. D. Marx, E. Stern, Y. Kurihara, Y. Nagashima, Y. Suzuki, Y. Yamaguchi, and D. H. White, "Determination of $\sin^2\theta_W$ from Measurements of Differential Cross Sections for Muon Neutrino and Antineutrino Scattering by Electrons," Los Alamos National Laboratory document LA-UR-89-418 (submitted to *Physical Review Letters*, December 1988).

L. A. Ahrens, S. H. Aronson, B. G. Gibbard, M. J. Murtagh, D. H. White, J. L. Callas, D. Cutts, M. Diwan, J. S. Hoftun, R. E. Lanou, Y. Kurihara, K. Abe, K. Amako, S. Kabe, T. Shinkawa, S. Terada, Y. Nagashima, Y. Suzuki, Y. Yamaguchi, E. W. Beier, L. S. Durkin, S. M. Heagy, A. K. Mann, D. Hedin, M. D. Marx, and E. Stern, "A Study of the Axial-Vector Form Factor and Second-Class Currents in Antineutrino Quasielastic Scattering," *Phys. Lett. B* **202**, 284 (1988).

L. A. Ahrens, S. H. Aronson, P. L. Connolly, T. Erickson, B. G. Gibbard, M. J. Murtagh, S. J. Murtagh, S. Terada, D. H. White, J. L. Callas, D. Cutts, M. Diwan, R. S. Dulude, J. S. Hoftun, B. W. Hughlock, R. E. Lanou, J. T. Massimo, T. Shinkawa, Y. Kurihara, K. Amako, S. Kabe, Y. Nagashima, Y. Suzuki, S. Tatsumi, Y. Yamaguchi, K. Abe, E. W. Beier, D. C. Doughty, L. S. Durkin, R. S. Galik, S. M. Heagy, M. Hurley, A. K. Mann, F. M. Newcomer, R. van Berg, H. H. Williams, T. York, P. Clarke, D. Hedin, M. D. Marx, and E. Stern, "A Massive, Fine-Grained Detector for the Elastic Reactions Induced by Neutrinos in the GeV Energy Region," *Nucl. Instrum. and Methods* **A254**, 515-528 (1987).

W. M. Alberico, A. DePace, M. Ericson, M. B. Johnson, and A. Molinari, "Spin-Isospin Nuclear Responses with Hadronic Probes," *Phys. Rev. C* **38**, 109 (1988).

R. C. Allen, X-Q. Lu, K. Gollwitzer, G. J. Igo, E. Gülmez, C. Whitten, G. VanDalen, J. Layter, Sun Yui Fung, B. C. Shen, R. Ristinen, R. Smythe, R. C. Carlini, K. Black, R. Burman, J. Donahue, D. Fitzgerald, W. Foreman, M. Hoehn, T. Kozlowski, D. M. Lee, W. C. Louis, R. Macek, J. McGill, E. C. Milner, M. Oothoudt, V. Sandberg, G. Sanders, M. Schillaci, R. Werbeck, R. Westervelt, D. H. White, B. B. Dieterle, C. P. Leavitt, J. Kang, W. Frati, A. K. Mann, F. M. Newcomer, R. van Berg, L. A. Auerbach, V. J. Highland, W. K. McFarlane, and R. T. Seigel, "A Proposal for a Precision Test of the Standard Model by Neutrino-Electron Scattering (Large Čerenkov Detector Project)," Los Alamos National Laboratory report LA-11300-P (March 1988).

D. Ashery, J. Lichtenstadt, E. Piasetzky, C. L. Morris, J. D. Zumbro, R. Gilman, M. W. Rawool, S. Mordechai, B. Boyer, A. Fuentes, K. Johnson, J. W. McDonald,

M. J. Smithson, A. Williams, S. H. Yoo, and C. Fred Moore, "A Search for πNN Bound Systems," *Phys. Lett. B* **215**, 41 (1988).

P. Astier, G. Bernardi, G. Carugno, J. Chauveau, P. Chrysicopoulou, J. Dumarchez, M. Ferro-Luzzi, F. Kovacs, A. Letessier-Selvon, J.-M. Levy, M. J. Murtagh, J.-M. Perreau, Y. Pons, J. L. Stone, A.-M. Touchard, F. Vannucci, P. Wanderer, and D. H. White, "Search for Neutrino Oscillations," CERN/EP 88 (submitted to *Physics Letters B*, 1988).

H. W. Baer, "Probing Two-Nucleon Correlations with Pion Double-Charge Exchange," in *Proceedings of the Third Conference on the Intersections Between Particle and Nuclear Physics*, Rockport, Maine, (May 14–19, 1988) Gerry Bunce, Ed. (American Institute of Physics, New York, 1988) Vol. 176, pp. 589–600.

H. W. Baer, H. Crannell, and R. J. Peterson, Eds. "Proceedings of the LAMPF Workshop on Photon and Neutral Meson Physics at Intermediate Energies," Los Alamos National Laboratory report LA-11177-C (December 1987).

H. W. Baer, J. A. Johnstone, C. L. Morris, S. J. Seestrom-Morris, C. J. Harvey, D. Dehnhard, D. B. Holtkamp, and S. J. Greene, "Elastic π^+ and π^- Scattering on ^{14}C at 164 MeV," *Phys. Rev.* C**33**, 1454 (1986).

H. W. Baer, M. J. Leitch, R. L. Burman, M. D. Cooper, A. Z. Cui, B. J. Dropesky, G. C. Giesler, F. Irom, C. L. Morris, J. N. Knudson, J. R. Comfort, D. H. Wright, and R. Gilman, "The Double-Analog Transition $^{48}Ca(\pi^+, \pi^-)^{48}Ti$ at 35 and 50 MeV," *Phys. Rev.* C**35**, 1425 (1987).

D. B. Barlow, A. Saha, K. K. Seth, T. S. Bhatia, G. Glass, J. C. Hiebert, R. A. Kenefick, S. Nath, L. C. Northcliffe, W. B. Tippens, J. J. Jarmer, J. E. Simmons, R. H. Jeppesen, and G. E. Tripard, "Measurement of Spin Correlation Parameters $A_{\ell\ell}$ and $A_{s\ell}$ for the Reaction $pp \rightarrow d\pi^+$ in the Energy Region 500–800 MeV," *Phys. Rev.* C**37**, 1977 (1988).

C. Biino, J. F. Greenhalgh, P. Kaaret, W. C. Louis, K. T. McDonald, S. Palestini, F. C. Shoemaker, A. J. S. Smith, C. E. Adolphsen, J. P. Alexander, K. J. Anderson, J. S. Conway, J. G. Heinrich, J. E. Pilcher, A. Possoz, and E. I. Rosenberg, "J/ψ Longitudinal Polarization from πN Interactions," *Phys. Rev. Lett.* **58**, 2523 (1987).

G. S. Blanpied, B. G. Ritchie, M. L. Bartlett, G. W. Hoffman, J. A. McGill, E. C. Milner, K. W. Jones, S. K. Nanda, and R. deSwiniarski, "Elastic and Inelastic Scattering of 0.8-GeV Polarized Protons from ^{24}Mg and ^{26}Mg," *Phys. Rev.* C**37**, 1987 (1988).

G. S. Blanpied, J. Hernandez, C. S. Mishra, W. K. Mize, C. S. Whisnant, B. G. Ritchie, C. L. Morris, S. J. Seestrom-Morris, C. Fred Moore, P. A. Seidl, R. A. Lindgren, B. H. Wildenthal, and R. Gilman, "High Resolution Study of Pion Elastic and Inelastic Scattering from ^{24}Mg and ^{26}Mg," (submitted to *Physical Review* C, October 1988).

G. S. Blanpied, B. G. Ritchie, M. L. Barlett, R. W. Fergerson, G. W. Hoffmann, and J. A. McGill, "Elastic and Inelastic Scattering of 0.8-GeV Protons from ^{20}Ne and ^{22}Ne," *Phys. Rev.* C **38**, 2180 (1988).

R. D. Bolton, M. D. Cooper, J. S. Frank, A. L. Hallin, P. A. Heusi, C. M. Hoffman, G. E. Hogan, F. G. Mariam, H. S. Matis, R. E. Mischke, L. E. Piilonen, V. D. Sandberg, G. H. Sanders, U. Sennhauser, R. Werbeck, R. A. Williams, S. L. Wilson, R. Hofstadter, E. B. Hughes, M. W. Ritter, D. Grosnick, S. C. Wright, V. L. Highland, and J. McDonough, "Search for Rare Muon Decays with the Crystal Box Detector," *Phys. Rev.* D **38**, 2077 (1988).

T. J. Bowles, A. R. Brown, R. E. Brown, R. L. Burman, D. Clark, S. Clearwater, T. Dombeck, H. Kruse, D. Lee, L. Auerbach, S. Datta, V. Highland, Y. Huang, W. K. McFarlane, B. Aas, G. Igo, B. Bassalleck, B. Dieterle, R. Hill, J. Kang, C. Leavitt, D. Beavis, S. Y. Fung, B. Gorn, G. J. VanDalen, C. Newsom, R. Fisk, D. D. Koetke, D. S. Koetke, and R. W. Manweiler, "Analysis of the Exclusive Interaction $\nu_\mu\ ^{12}C \rightarrow \mu^-\ ^{12}N$ Near Threshold," in *Proceedings of the Third Conference on the Intersections Between Particle and Nuclear Physics*, Rockport, Maine, (May 14–19, 1988) Gerry Bunce, Ed. (American Institute of Physics, New York, 1988) Vol. 176, pp. 912–917.

T. J. Bowles, A. R. Brown, R. E. Brown, T. W. Dombeck, R. L. Burman, D. A. Clark, H. W. Kruse, D. M. Lee, S. M. Clearwater, B. Aas, G. Igo, C. R. Newsom, D. Beavis, S. Y. Fung, B. Gorn, R. T. Poe, G. J. VanDalen, B. Bassalleck, B. Dieterle, R. E. Hill, J. H. Kang, C. Leavitt, L. Auerbach, S. Datta, Y. Huang, R. Fisk, D. D. Koetke, D. S. Koetke, and R. W. Manweiler, "A Study of the Inclusive Muon-Neutrino Carbon Charged-Current Interaction in the Energy Range Just Above the Muon Threshold," Los Alamos National Laboratory document LA-UR-87-2652 (submitted to *Physical Review C*, July 1988).

C. D. Bowman, J. D. Bowman, J. M. Anaya, V. W. Yuan, P. J. Delheij, and H. Postma, "Facility for Parity Violation and Time-Reversal Experiments with Intense Neutron Beams," Los Alamos National Laboratory document LA-UR-88-2367 (submitted to the *Proceedings of the Workshop on On-Line Nuclear Orientation and Related Topics*, Oxford, England, August 31–September 4, 1988).

C. D. Bowman, J. D. Bowman, P. Herczeg, J. Szymanski, V. W. Yuan, J. M. Anaya, R. Mortensen, H. Postma, P. J. Delheij, O. K. Baker, C. R. Gould, D. G. Haase,

G. E. Mitchell, N. R. Roberson, X. Zhu, A. B. McDonald, D. Benton, B. Tippens, and T. E. Chupp, "Facility for Parity and Time-Reversal Experiments with Intense Epithermal (eV) Neutron Beams," (submitted to the *Proceedings of the Workshop on On-Line Orientation and Related Topics*, Oxford, England, August 31–September 4, 1988).

J. D. Bowman, "Conceptual Design of a High-Resolution π^0 Spectrometer," Los Alamos National Laboratory document LA-UR-87-2853, in *Proceedings of the Workshop on Photon and Neutral Meson Physics at Intermediate Energies*, Los Alamos, New Mexico (January 7–9, 1988).

J. D. Bowman, "Tests of Time-Reversal in Neutron-Nucleus Scattering," in *Proceedings of the Third Conference on Intersections Between Particle and Nuclear Physics*, Rockport, Maine, (May 14–19, 1988) Gerry Bunce, Ed. (American Institute of Physics, New York, 1988) Vol. 176, pp. 1112–1117.

J. D. Bowman, E. Lipparini, and S. Stringari, "Isovector-Monopole Excitation Energies," *Phys. Rev. B* 197, 497 (1987).

D. Brown, "Subnanosecond High-Voltage Pulse Generator," *Rev. of Sci. Instrum.* 58, 8 (1987).

R. L. Burman and E. S. Smith, "Parameterization and Reaction Cross Sections at LAMPF Energies," Los Alamos National Laboratory report LA-11502-MS (November 1988).

H. Butler, "Coping with Large Sextupole Errors in Bending Magnets," Los Alamos National Laboratory document AHF Technical Note 88-022 (October 1988).

E. P. Colton, "Design of a Second-Generation Proton Storage Ring at LAMPF," Los Alamos National Laboratory document LA-UR-88-4033 (submitted to the *Proceedings of ICANS-X*, Los Alamos, New Mexico, October 3–7, 1988).

E. P. Colton, "Longitudinal Phase-Space Formulas for Stationary Buckets," in the *Proceedings of the Workshop on RHIC Performance*, Brookhaven National Laboratory (March 21–26, 1988) BNL-41604, pp. 449–453 (1988).

E. P. Colton, "LMATCH Description," Los Alamos National Laboratory document AHF Technical Note 88-001 (January 1988).

E. P. Colton, "LTRACK," Los Alamos National Laboratory document AHF Technical Note 88-003 (January 1988).

E. P. Colton, "New Compressor at Los Alamos," Los Alamos National Laboratory document LA-UR-88-3782 (submitted to the *Proceedings of the 1988 Summer Study on High-Energy Physics in the 1990's*, Snowmass, Colorado, June 27–July 15, 1988).

E. P. Colton, "PAINT," Los Alamos National Laboratory document AHF Technical Note 88-002 (January 1988).

E. P. Colton, "Strawman 1.6 GeV Compressor Design," in *Proceedings of the Accelerator Design Workshop*, Los Alamos National Laboratory report LA-11432-C (February 22–27, 1988).

E. P. Colton, J. Bisognano, and E. Gianfelice, "Coupled-Bunch Instabilities in RHIC," in *Proceedings of the Workshop on RHIC Performance*, Brookhaven National Laboratory, March 21–26, 1988, BNL-41604, pp. 411–423 (1988).

E. P. Colton and A. Lombardi, "PSR Injection Strategies—1988 and Beyond," Los Alamos National Laboratory document AHF Technical Note 88-007 (March 1988).

E. P. Colton, D. Shi, and Z. Parsa, "Transverse Space-Charge Effects in the AGS Booster During Injection," Brookhaven National Laboratory informal report BNL-41465 (April 1988).

E. P. Colton and H. A. Thiessen, "H^- Injection into the Low-Energy Booster of the SSC," Lawrence Berkeley Laboratory report SSC-N-558 (August 1988).

John Conway and W. C. Louis, "Longitudinal Polarization of High x_F in Muon Pair Production," in *Proceedings of the XXIIIrd Recontre de Moriond*, Les Arcs, France (March 13–19, 1988) J. Tran Thanh Van, Ed.

M. D. Cooper, "The MEGA Experiment: A Search for $\mu \to e\gamma^*$," in *Proceedings of the Third Conference on the Intersections Between Particle and Nuclear Physics*, Rockport, Maine (May 14–19, 1988), Gerry Bunce, Ed. (American Institute of Physics, New York, 1988) Vol. 176, pp. 845–849.

R. D. Cousins, J. Konigsberg, J. Kubic, P. Melese, P. Rubin, W. E. Slater, J. S. Frank, G. W. Hart, W. Kinnison, D. M. Lee, E. C. Milner, G. H. Sanders, H. J. Ziock, K. Arisaka, P. Knibbe, W. R. Molzon, J. Urheim, W. D. Wales, S. Axelrod, K. A. Biery, G. Bonneaud, G. M. Irwin, K. Lang, C. J. Martoff, D. A. Ouimette, J. L. Ritchie, Q. H. Trang, S. G. Wojcicki, L. B. Auerbach, P. Buchholz, V. L. Highland, W. K. McFarlane, M. B. Sivertz, M. D. Chapman, M. Eckhause, J. F. Ginkel, P. P. Guss, D. Joyce, J. R. Kane, C. J. Kenney, W. F. Vulcan, R. E. Welsh, R. J. Whyley, and R. G. Winter, "Search for the Decays $K_L^0 \to \mu e$ and $K_L^0 \to ee$," *Phys. Rev.* D**38**, 2914 (1988).

B. L. Dingus, "Ultra-High Energy Emission from Cygnus X-3 and Hercules X-1," Ph.D. thesis, University of Maryland, Los Alamos National Laboratory report LA-11431-T (November 1988).

B. L. Dingus, D. E. Alexandreas, C. Y. Chang, J. A. Goodman, S. K. Gupta, T. J. Haines, D. A. Krakauer, R. L. Talaga, R. W. Ellsworth, R. L. Burman, K. B. Butterfield, R. Cady, J. Lloyd-Evans, D. E. Nagle, M. Potter, V. D. Sandberg, C. A. Wilkinson, R. C. Allen, and G. B. Yodh, "Ultrahigh-Energy Pulsed Emission from Hercules X-1 with Anomalous Air-Shower Muon Production," *Phys. Rev. Lett.* **61**, 1906 (1988).

B. L. Dingus, C. Y. Chang, J. A. Goodman, S. K. Gupta, D. A. Krakauer, R. L. Talaga, G. B. Yodh, R. W. Ellsworth, R. L. Burman, K. B. Butterfield, R. Cady, R. D. Carlini, J. Lloyd-Evans, D. E. Nagle, V. D. Sandberg, C. A. Wilkinson, J. Linsley, and R. C. Allen, "Search for Signals from Cygnus X-3 at Energies Above 50 TeV," *Phys. Rev. Lett.* **60**, 1785 (1988).

L. S. Durkin, R. W. Harper, T. Y. Ling, J. W. Mitchell, T. A. Romanowski, E. S. Smith, M. Timko, S. J. Freedman, J. Napolitano, B. K. Fujikawa, R. McKeown, K. T. Lesko, W. C. Choi, A. Fazely, R. L. Imlay, W. J. Metcalf, R. D. Carlini, J. B. Donahue, G. T. Garvey, and V. D. Sandberg, "Limits on $\overline{\nu} \rightarrow \overline{\nu}_e$ Oscillations," *Phys. Rev. Lett.* **61**, 1811 (1988).

L. S. Durkin, J. S. Fitch, R. W. Harper, J. W. Heimaster, D. R. Larson, T. Y. Ling, J. W. Mitchell, T. A. Romanowski, C. J. Rush, V. K. Sehgal, E. S. Smith, M. Timko, B. K. Fujikawa, R. McKeown, W. C. Choi, A. Fazely, R. L. Imlay, W. J. Metcalf, W. Marterer, J. B. Donahue, and V. Sandberg, "A Fine Grain Modular Detector for Low Energy Particles" (to be published in *Nuclear Instruments and Methods*, 1988).

R. Fergerson, J. McGill, C. Glashausser, K. Jones, S. Nanda, S. Tsu-hsun, M. Barlett, G. Hoffmann, J. Marshall, and J. McClelland, "Polarization Transfer for Inclusive Proton-Nucleus Inelastic Scattering at 800 MeV," *Phys. Rev.* C**38**, 2193 (1988).

J. Frank, G. W. Hart, W. W. Kinnison, D. M. Lee, R. J. McKee, E. C. Milner, G. H. Sanders, H. J. Ziock, M. Chapman, M. Eckhause, J. F. Ginkel, P. P. Guss, D. Joyce, J. R. Kane, C. J. Kenney, R. E. Welsh, R. J. Whyley, R. Winter, and W. F. Vulcan, "A Tracking Rangefinder for Muons from Kaon Decay," Los Alamos National Laboratory document LA-UR-88-3733 (submitted to the *Proceedings of IEEE Nuclear Science Symposium*, Orlando, Florida, November 8–11, 1988).

J. Frank, G. W. Hart, W. W. Kinnison, D. M. Lee, E. C. Milner, G. H. Sanders, H. J. Ziock, M. Chapman, M. Eckhause, J. Ginkel, P. Guss, D. Joyce, J. Kane, C.

Kenney, R. Welsh, R. Whyley, R. Winter, and W. Vulcan, "Tracking Rangefinder/ Calorimeter for K_1 Decay Muons," in *Proceedings of the 1988 IEEE Nuclear Science Symposium* (May 1988).

R. W. Garnett, "Measurement of np Elastic Scattering Spin-Spin Correlation Parameters at 484, 634, and 788 MeV," Ph.D. thesis, New Mexico State University, Los Alamos National Laboratory report LA-11491-T (November 1988).

G. T. Garvey, "Summary Talk—International Conference on Spin Observables of Nuclear Probes," Los Alamos National Laboratory document LA-UR-88-2918 (submitted to the *Proceedings of the Telluride Conference on Spin Observables of Nuclear Probes*, Telluride, Colorado, March 14–17, 1988).

G. T. Garvey, "Nuclear and Hadronic Structure Functions at an Advanced Hadron Facility," Los Alamos National Laboratory document LA-UR-88-2685 (submitted to the *Proceedings of the 1988 Summer Study on High-Energy Physics in the 1990's*, Snowmass, Colorado, June 27–July 15, 1988).

P. A. M. Gram, S. A. Wood, S. Høibraten, E. R. Kinney, P. Mansky, J. J. Matthews, T. Soos, G. A. Rebka, Jr., and D. A. Roberts, "Dependence of the Cross Section for Inclusive Pion Double Charge Exchange on Nuclear Mass and Charge," Los Alamos National Laboratory document LA-UR-88-940 (submitted to *Physical Review Letters*, March 1988).

G. Guignard, "Alternative Design of the Main Ring Lattice for a Hadron Facility," Los Alamos National Laboratory document LA-UR-88-3704 (unpublished).

G. Guignard, "Relative Merits of Different Lattices in Presence of Sextupoles," Los Alamos National Laboratory document AHF Technical Note 88-021 (September 1988).

G. Guignard, "Sextupole Optimization in the Compressor Lattice Using DYNAP," Los Alamos National Laboratory document AHF Technical Note 88-019 (August 1988).

J. C. Gursky, H. Baer, F. F. Flick, and D. Gallegos, "Precision Nuclear Targets for Drell-Yan Cross-Section Measurements at 800 GeV," Los Alamos National Laboratory document LA-UR-88-3041, presented at the Nuclear Instrumentation in Physical Research 14th World Conference of the International Nuclear Target Development Society, GSI, Darmstadt, FGR (September 5–9, 1988) (to be published in *Nuclear Instruments and Methods*, 1988).

T. J. Haines, D. E. Alexandreas, R. C. Allen, S. Biller, R. L. Burman, K. B. Butterfield, D. R. Cady, C. Y. Chang, B. L. Dingus, G. Dion, R. W. Ellsworth, J. A.

Goodman, S. K. Gupta, D. A. Krakauer, J. Lloyd-Evans, D. E. Nagle, M. Potter, V. D. Sandberg, R. L. Talaga, C. A. Wilkinson, and G. B. Yodh, "Ultra-High Energy Signals from Hercules X-1," Los Alamos National Laboratory document LA-UR-89-278 (submitted to the *13th International Conference on Neutrino Physics and Astrophysics*, Boston, Massachusetts, June 5–11, 1988).

T. J. Haines, M. Cherry, L. Coleman, R. Ellsworth, J. Gaidos, J. Goodman, D. Kielczewska, W. Kropp, C. Lane, J. Learned, M. Lieber, F. Loeffler, R. March, C. McGrew, D. E. Nagle, R. Novick, M. Potter, L. Price, F. Reines, A. Rollefson, J. Schultz, H. Sobel, R. Steinberg, R. Svoboda, A. Szentgyorgyi, C. Wilson, D. Wold, and G. Yodh, "The GRANDE Collaboration: An Experiment to Search for Cosmic Gamma Rays and Cosmic Neutrinos," Los Alamos National Laboratory document LA-UR-89-279 (submitted to the *Proceedings of the International School of Cosmic-Ray Astrophysics, 6th Course: Cosmic Gamma Rays and Cosmic Neutrinos*, Erice, Italy, April 20–30, 1988).

T. Haines, A. Adams, C. B. Bratton, V. Chaloupka, M. Cherry, L. Coleman, R. Ellsworth, J. Gaidos, J. Goodman, D. Kielczewska, W. Kropp, C. Lane, J. Learned, M. Lieber, F. Loeffler, R. March, C. McGrew, D. E. Nagle, M. Nelson, R. Novick, M. Potter, L. Price, F. Reines, A. Rollefson, J. Schultz, G. Sembroski, H. Sobel, R. Steinberg, R. Svoboda, A. Szentgyorgyi, J. Wefel, R. J. Wilkes, C. Wilson, D. Wold, and G. Yodh, "A Novel Approach to Gamma-Ray and Neutrino Astro-Particle Physics: The GRANDE Experiment," Los Alamos National Laboratory document LA-UR-89-280 (submitted to the *Proceedings of the 14th Texas Symposium on Relativistic Astrophysics*, Dallas, Texas, December 11–16, 1988).

P. G. Harris, H. C. Bryant, A. H. Mohagheghi, C. Y. Tang, J. B. Donahue, C. R. Quick, R. A. Reeder, S. Cohen, W. W. Smith, J. E. Stewart, and C. H. Johnstone, "Further Studies of the Photodetachment Cross Section of the H^- Ion in Electric Fields," (submitted to *Physical Review A*, 1988).

N. M. Hintz, D. Cook, M. Gazzaly, M. A. Franey, M. L. Barlett, G. W. Hoffmann, R. Fergerson, J. McGill, G. Pauletta, R. L. Boudrie, J. B. McClelland, and J. W. Jones, "Energy Dependence of Neutron-Proton Matrix Element Ratios Derived from 25–800 MeV Energy Proton Scattering," *Phys. Rev.* C**37**, 692 (1988).

C. M. Hoffman, "A New Limit for the Branching Ratio for the Decay $\pi^0 \rightarrow \nu\nu'$ from Beam-Dump Experiments," *Phys. Rev. B* **208** (1) 149 (1988).

G. W. Hoffmann, M. L. Barlett, R. W. Fergerson, J. A. Marshall, J. A. McGill, E. C. Milner, L. Ray, and J. F. Amann, "Differential Cross Section and Analyzing Power Measurements for $p + p$ Elastic Scattering at 497.5 MeV," *Phys. Rev.* C**37**, 397 (1988).

G. Igo, A. Masaike, B. Aas, D. Adams, E. Bleszynski, M. Bleszynski, M. Gazzaly, S. J. Greene, H. Hasai, S. Ishimoto, S. Isagawa, K. Jones, D. Lopiano, J. B. McClelland, F. Nishiyama, Y. Ohashi, A. Okihana, G. Pauletta, F. Sperisen, Tsu-Hsun Sun, N. Tanaka, G. S. Weston, and C. A. Whitten, Jr., "Spin Observables in Small-Angle Elastic $\uparrow p \uparrow d \rightarrow \uparrow pd$ Scattering with an N-type Polarized Target at 800 MeV," *Phys. Rev. C* 38, 2777 (1988).

K. W. Jones, "Nuclear Spin Response Studies in Inelastic Polarized Proton Scattering," Los Alamos National Laboratory document LA-UR-88-1272 (submitted to the *Proceedings of the Telluride Conference on Spin Observables of Nuclear Probes,* Telluride, Colorado, March 14–17, 1988).

M. B. Johnson, "Instantaneous Meson-Exchange Potentials on the Light Front," in *Proceedings of the CEBAF Users Group Meeting,* Newport News, Virginia, June 20–24, 1988).

M. B. Johnson, "Light-Front Potentials from Meson Field Theory," Los Alamos National Laboratory document LA-UR-88-4295 (to be published in *Proceedings of the Nuclear and Particle Physics on the Light Cone Workshop,* Los Alamos, New Mexico, July 18–22, 1988).

M. B. Johnson, "Pion Scattering and Nuclear Dynamics," Los Alamos National Laboratory document LA-UR-88-2893 (submitted to the *Proceedings of the IV International Symposium on Mesons and Light Nuclei* (European Conference on Few Body Physics) Prague, Czechoslovakia, September 5–10, 1988).

M. B. Johnson and L. Kisslinger, Eds., *Proceedings of the Nuclear and Particle Physics on the Light Cone Workshop,* Los Alamos National Laboratory document LA-UR-88-4295 (to be published by World Scientific) Los Alamos, New Mexico, (July 18–22, 1988).

M. B. Johnson and G. Wenes, "Effect of Surface Fluctuations on the Nuclear Density," *Phys. Rev. C* 38, 386 (1988).

G. Karady, H. A. Thiessen, and E. J. Schneider, "Resonant Power Supplies for a Rapid-Cycling Accelerator," *Nucl. Sci.* 35, 1092 (1988).

G. J. K. Kim, "Measurement of the Left-Right Asymmetry in Pion-Proton Radiative Exchange and Charge Exchange Scattering from 301 to 625 MeV/c on a Transversely Polarized Target," Ph.D. thesis, University of California at Los Angeles, Los Alamos National Laboratory report LA-11273-T (February 1988).

E. R. Kinney, "Inclusive Pion Double Charge Exchange in ^{4}He at Intermediate Energies," Ph.D. thesis, MIT, Los Alamos National Laboratory report LA-11417-T (October 1988).

T. Kozlowski, J. F. Amann, M. D. Cooper, W. M. Foreman, G. E. Hogan, F. J. Naivar, M. A. Oothoudt, W. Smith, P. S. Cooper, E. B. Hughes, C. C. H. Jui, J. N. Otis, R. Fisk, D. Koetke, R. Manweiler, K. I. Hahn, and J. K. Markey, "The MEGA Experiment and the Use of Microprocessors for Data Acquisition and Event Selection," (submitted to the *Proceedings of the Conference on Impact of Digital Microelectronics and Microprocessors on Particle Physics*, Trieste, Italy, March 28–30, 1988).

J. N. Knudson, J. R. Comfort, R. A Gianelli, B. G. Ritchie, D. Rothenberger, D. Pocanic, S. S. Hanna, J. D. Bowman, H. W. Baer, A. G. Bergmann, P. A. Heusi, F. Irom, C. J. Seftor, S. Hibraten, R. A. Loveman, S. H. Rokni, H. Crannell, D. I. Sober, W. J. Fickinger, and H. Marshak, "Excitation of the Isobaric Analog State of ^{165}Ho by Pion Single-Charge Exchange," *Phys. Rev.* C **35**, 1382 (1987).

M. J. Leitch, H. W. Baer, R. L. Burman, M. D. Cooper, F. Irom, A. Cui, B. J. Dropesky, G. C. Giesler, C. L. Morris, J. N Knudson, J. R. Comfort, D. H. Wright, and R. Gilman, "Energy Dependence for Low Energy Pion Double Charge Exchange on ^{14}C," (to be published in *Physical Review* C, 1988).

A. G. Ling, "Small Angle Elastic Scattering of Protons Off of Spinless Nuclei," Ph.D. thesis, University of California at Los Angeles, Los Alamos National Laboratory report LA-11330-T (July 1988).

J. Lisantti, F. E. Bertrand, D. J. Horen, R. L. Auble, B. L. Burks, E. E. Gross, R. O. Sayer, D. K. McDaniels, K. W. Jones, J. B. McClelland, S. J. Seestrom-Morris, and L. W. Swenson, "Collective Model DWBA Analysis of 500-MeV Proton Scattering from ^{40}Ca," (submitted to *Physical Review* C, April 1988).

D. J. Liska, R. H. Kraus, R. D. Brown, and J. R. Cost, "The Development of Small-Scale Quadrupoles to Operate at 20 to 50 K," Los Alamos National Laboratory document LA-UR-88-3260 (submitted to the *Proceedings of the 1988 Linear Accelerator Conference*, Williamsburg, Virginia, October 3–7, 1988).

J. Liu, S. J. Greene, and H. A. Thiessen, "Preliminary Designs of Dipole and Quadrupole Magnets for a Rapid Cycling Synchrotron," Los Alamos National Laboratory document AHF Technical Note 88-010 (May 1988).

J. Liu and H. A. Thiessen, "A Correction of the Magnetic Stored Energy Calculation for the Poisson Computer Code," Los Alamos National Laboratory document AHF Technical Note 88-008 (March 1988).

J. Liu and H. A. Thiessen, "A Massless Septum Magnet Design for Beam Extraction from an AHF Main Ring," Los Alamos National Laboratory document AHF Technical Note 38-012 (May 1988).

J. Liu and H. A. Thiessen, "Stripper Magnet Calculations for Neutralization of H^- Ion Beam at PSR," Los Alamos National Laboratory document AHF Technical Note 88-011 (May 1988).

K. B. Luk, A. Beretvas, L. Deck, T. Devlin, R. Rameika, R. Whitman, R. Handler, B. Lundberg, L. Pondrom, M. Sheaff, C. Wilkinson, P. T. Cox, E. C. Dukes, J. Dworkin, O. E. Overseth, and K. Heller, "New Measurements of Properties of the Ω^- Hyperon," *Phys. Rev. D* **38**, 19 (1988).

R. J. Macek, D. H. Fitzgerald, R. L. Hutson, M. A. Plum, and H. A. Thiessen, "Analysis of Beam Losses at PSR," Los Alamos National Laboratory document LA-UR-88-1682 (submitted to the *Proceedings of the European Particle Accelerator Conference*, Rome, Italy, June 7–11, 1988).

F. Mariam, "Design and Performance of Modularization Naℓ(Tl) Detectors with Rectangular Crystal Elements: An Array of 49 and the Crystal Box," *Nucl. Instrum. and Methods* **A264**, 263 (1988).

F. Mariam, "New Searches for the C-Noninvariant Decay $\pi/0 \rightarrow 3\gamma$ and the Rare Decay $\pi/0 \rightarrow 4\gamma$," *Phys. Rev. D* **38**, 2121 (1988).

J. B. McClelland, "Isovector Spin Observables in Nuclear Charge-Exchange Reactions at LAMPF," Los Alamos National Laboratory document LA-UR-88-1116 (submitted to the *Proceedings of the Telluride Conference on Spin Observables of Nuclear Probes*, Telluride, Colorado, March 14–17, 1988).

J. McDonough, V. L. Highland, W. K. McFarlane, R. D. Bolton, M. D. Cooper, J. S. Frank, A. L. Hallin, P. Heusi, C. M. Hoffman, G. E. Hogan, F. Mariam, R. E. Mischke, L. E. Piilonen, V. D. Sandberg, U. Sennhauser, R. D. Werbeck, R. A. Williams, S. L. Wilson, D. P. Grosnick, and S. C. Wright, "New Searches for the C-Noninvariant Decay $\pi^0 \rightarrow 3\gamma$ and the Rare Decay $\pi^0 \rightarrow 4\gamma$," *Phys. Rev. D* **38**, 2121 (1988).

R. E. Mischke, "Parity Nonconservation in the Proton-Deuteron Total Cross Section at 800 MeV," Los Alamos National Laboratory document LA-UR-88-3031 (submitted to the *Proceedings of the Eighth International Symposium on High Energy Spin Physics*, Minneapolis, Minnesota, September 12–17, 1988).

C. S. Mishra, B. Fick, M. Blecher, W. Burger, R. L. Burman, G. Ciangoru, J. Escalante, K. Gotow, M. V. Hynes, B. M. Preedom, B. G. Ritchie, C. S. Whisnant,

and D. Wright, "Elastic Scattering of 50 MeV $\pi^{\pm}$ from ^{58}Ni, ^{60}Ni, ^{64}Ni," *Phys. Rev. C* **38**, 1316 (1988).

S. Mordechai, N. Auerbach, M. Burlein, H. T. Fortune, S. J. Greene, C. Fred Moore, C. L. Morris, J. M. O'Donnell, M. W. Rawool, J. D. Silk, D. L. Watson, S. H. Yoo, and J. D. Zumbro, "Pion Double Charge Exchange to the Double Dipole," *Phys. Rev. Lett.* **61**, 531 (1988).

S. Mordechai, N. Auerbach, H. T. Fortune, C. F. Moore, and C. L. Morris, "Isospin Splitting of the Giant Dipole Built on the Isobaric Analog State," *Phys. Rev. C* **38**, 6 (1988).

S. Mordechai, N. Auerbach, S. Greene, C. L. Morris, J. M. O'Donnell, H. T. Fortune, G. Liu, M. Burlein, A. Wuosmaa, S. H. Yoo, and C. F. Moore, "Properties of the Giant Dipole Resonance Built on the Isobaric Analog State," Los Alamos National Laboratory document LA-UR-88-4239 (submitted to *Physical Review C*, December 1988).

S. Mordechai, H. T. Fortune, J. M. O'Donnell, G. Liu, M. Burlein, A. Wuosmaa, S. Greene, C. L. Morris, S. H. Yoo, and C. F. Moore, "Double Giant Dipole Resonances from Pion Double Charge Exchange," Los Alamos National Laboratory document LA-UR-88-4240 (submitted to *Physical Review Letters*, December 1988).

S. Mordechai, H. T. Fortune, R. Gilman, J. D. Zumbro, K. Dhuga, G. R. Burleson, D. Oakley, M. J. Smithson, C. F. Moore, M. A. Plum, Z. F. Wang, N. Auerbach, and C. L. Morris, "Giant Dipole Resonances Built on Isobaric Analog States in Pion Double Charge Exchange," *Phys. Rev. Lett.* **60**, 408 (1988).

C. L. Morris, M. A. Plum, M. K. Jones, S. K. Nanda, S. Sterbenz, D. Dehnhard, J. D. Zumbro, A. Hussein, D. S. Oakley, M. J. Smithson, A. L. Williams, J. McDonald, M. A. Bryan, A. H. Fuentes, M. Lynker, D. Crockett, M. A. Machuca, S. Mordechai, and C. F. Moore, "^{4}He$(\pi,\pi')^3$H Reaction Isospin in the Continuum," Los Alamos National Laboratory document LA-UR-88-2399 (submitted to *Physical Review Letters*, July 1988).

D. E. Nagle, T. K. Gaisser, and R. J. Protheroe, "Extensive Air Showers Associated with Discrete Astrophysical Sources," *Ann. Rev. Nucl. Part. Sci.* **38** 609–657 (1988).

D. E. Nagle, "PeV Gamma Ray Astronomy" (submitted to the *Proceedings of the Particle Astrophysics Workshop Forefront Experimental Issues*, Berkeley, California, December 8–10, 1988).

J. J. Napolitano, S. J. Freedman, G. T. Garvey, M. C. Green, K. T. Lesko, J. E. Nelson, J. N. Worthington, K. P. Coover, J. W. Dawson, W. Haberichter, and E.

P. Petereit, "Construction and Performance of A Large Area Liquid Scintillator Cosmic Ray Anticoincidence Detector," (to be published in *Nuclear Instruments and Methods*, 1988).

D. Neuffer, "Multipole Correction in Large Synchrotrons," in *Proceedings of the Second Advanced ICFA Beam Dynamics Workshop*, Lugano, Switzerland, April 11–16, 1988, CERN-88-04, pp. 179-185 (1988).

D. Neuffer, E. P. Colton, G. W. Swain, H. A. Thiessen, B. Blind, R. A. Hardekopf, A. J. Jason, G. P. Lawrence, R. E. Shafer, T. W. Hardek, J. W. Hurd, R. J. Macek, and M. A. Plum, "Transverse Collective Instability in the PSR (Proton Storage Ring)," in *Particle Accelerators 1988* (Gordon and Breach Science Publishers, Inc.) Vol. 23, pp. 133–148.

D. S. Oakley, P. D. Kunz, and C. L. Morris, "Coulomb-Nuclear Interference in Pion Inelastic Scattering," Los Alamos National Laboratory document LA-UR-88-3381 (to be published in *Physical Review Letters*, October 1988).

D. S. Oakley, R. J. Peterson, D. J. Rilett, C. L. Morris, S. J. Greene, B. Boyer, K. Johnson, A. H. Fuentes, J. W. McDonald, M. J. Smithson, A. L. Williams, S. H. Yoo, and C. F. Moore, "Energy Dependence of Pion Inelastic Scattering to the 1^+ States In ^{12}C," *Phys. Rev. C* **38**, 2978 (1988).

J. M. O'Donnell, S. Mordechai, C. L. Morris, J. D. Zumbro, S. H. Yoo, and C. F. Moore, "$T = 13$ Double Isobaric Analog State in ^{138}Ce via Pion Induced Double Charge Exchange," Los Alamos National Laboratory document LA-UR-88-3415 (submitted to *Physics Letters B*, October 1988).

S. Ohnuma, "Expected Motion of the Beam Along the Transfer Line," Los Alamos National Laboratory document AHF Technical Note 88-020 (August 1988).

M. A. Oothoudt, J. F. Amann, R. D. Bolton, M. D. Cooper, W. M. Foreman, G. E. Hogan, J. Kozlowski, F. J. Naivar, W. Smith, E. B. Hughes, C. C. H. Jui, J. N. Otis, P. S. Cooper, K. Hahn, R. B. Lauer, and J. K. Markey, "The MEGA Data Acquisition System," *IEEE Trans. Nucl. Sci.* **34**, 840 (1987).

E. Oset, M. J. Vicente-Vacas, M. B. Johnson, D. Strottman, H. T. Fortune, and R. Gilman, "The Δ Interaction to Double Charge Exchange," *Nucl. Phys.* **A483**, 514 (1988).

J. C. Peng, D. M. Alde, T. A. Carey, C. Lee, M. J. Leitch, J. W. Lillberg, P. L. McGaughey, C. S. Mishra, G. T. Garvey, J. M. Moss, H. W. Baer, A. Klein, C. N. Cooper, Y. B. Hsiung, R. Guo, D. M. Kaplan, R. L. McCarthy, C. Danner, M. J.

Wang, M. L. Bartlett, and G. W. Hoffmann, "Lepton-Pair Production in Hadron-Nucleus Collisions," (to be published in the *Proceedings for LAMPF Workshop on Nuclear and Particle Physics on the Light Cone*, Los Alamos, New Mexico, July 18–22, 1988).

J. C. Peng, M. J. Leitch, J. D. Bowman, F. Irom, J. Kapustinsky, T. K. Li, J. E. Simmons, Z. F. Wong, and C. Smith, "Performance of a Lead-Glass Spectrometer for Detecting η Mesons," *Nucl. Instrum. and Methods* **A261**, 462 (1987).

A. Pisent, "The Optics of a Helical Siberian Snake," Los Alamos National Laboratory document LA-UR-88-2558 (unpublished).

A. Pisent, "A 19-Magnets Siberian Snake," Los Alamos National Laboratory document AHF Technical Note 88-015 (May 1988).

S. Raby, G. B. West, and C. M. Hoffman, "Are There Really Any Experimental Limits On A Light Higgs Boson?," *Phys. Rev. D* **39**, 828 (1988); and in the *Proceedings of 1988 International Symposium on Hypernuclear and Low-Energy Kaon Physics*, Padova, Italy, September 12–16, 1988).

S. Raby, G. B. West, and C. M. Hoffman, "Are There Really Any Experimental Limits On A Light Higgs Boson?," Los Alamos National Laboratory document LA-UR-88-3911 (submitted to the *Proceedings of Rare Decay Symposium*, Vancouver, B.C., Canada, November 29–December 3, 1988).

R. D. Ransome, V. R. Cupps, S. Dawson, R. W. Fergerson, A. Greene, C. L. Morris, J. A. McGill, J. R. Comfort, B. G. Ritchie, J. Tinsley, J. D. Zumbro, R. A. Loveman, P. C. Gugelot, D. L. Watson, and C. F. Moore, "Charged Particle Multiplicities Following Pion Absorption on ^{6}Li," Los Alamos National Laboratory document LA-UR-88-4233 (submitted to *Physical Review Letters*, December 1988).

M. Rawool, "The Measurement of the Spin Correlation Parameters C_{SL} and C_{LL} in $\uparrow n \uparrow p \rightarrow np$ Scattering at Energies 484, 634, and 788 MeV," Ph.D. thesis, New Mexico State University, Los Alamos National Laboratory report LA-11387-T (October 1988).

S. H. Rokni, H. W. Baer, A. G. Bergmann, J. D. Bowman, F. Irom, M. J. Leitch, C. J. Seftor, J. Alster, E. Piasetzky, B. L. Clausen, R. A. Loveman, R. J. Peterson, J. L. Ullmann, J. R. Comfort, J. N. Knudson, and U. Sennhauser, "Isobaric-Analog-State Transitions in Pion Charge-Exchange Reactions Above the $\Delta(1232)$ Resonance," *Phys. Rev. B* **202**, 35 (1988).

V. D. Sandberg, "Center of Buoyancy Definition," Los Alamos National Laboratory report LA-11416-MS (June 1988).

G. H. Sanders, "Present and Future Neutrino Physics Research at the Los Alamos Meson Physics Facility," in *Proceedings of the XVI INS International Symposium on Neutrino Mass and Related Topics*, Tokyo, Japan, March 16–18, 1988, S. Kato and T. Ohshima, Eds. (World Scientific, Singapore, 1988) pp. 326–334.

D. E. Schultz, J. W. Hurd, and S. K. Brown, "Artificial Intelligence Approach to Accelerator Control Systems," Los Alamos National Laboratory report LA-11130-C (1988) in *Proceedings of the International Workshop on Hadron Facility Technology*, Santa Fe, New Mexico (February 1987).

M. D. Slaughter, "Is the $f_0(1590)$ the 0^{++} Scalar Glueball?," *Mod. Phys. Lett. A* **3**, 1361 (1988).

M. D. Slaughter and S. Oneda, "The $J/\psi \to \eta_c \gamma$ Decay, Glueballs, and Mass Squared Formulae in QCD," Los Alamos National Laboratory document LA-UR-88-617 (submitted to *Physical Review Letters*, February 1988).

M. D. Slaughter, "Radiative Meson Decays—An Algebraic Approach," Los Alamos National Laboratory document LA-UR-88-2827 (submitted to *Proceedings of the Brookhaven National Laboratory Workshop on Glueballs, Hybrids, and Exotic Hadrons*, August 28–September 1, 1988).

M. D. Slaughter and S. Oneda, "$1^{--} \to 0^{\pm}$ Meson Radiative and Pionic Transitions and Mass Splittings," Los Alamos National Laboratory document LA-UR-88-3380 (to be published in *Physical Review D*, September 1988).

J. E. Stewart, H. C. Bryant, P. G. Harris, A. H. Moghagheghi, J. B. Donahue, C. R. Quick, R. A. Reeder, V. Yuan, C. R. Hummer, W. W. Smith, and S. Cohen, "Effects of Electric Fields on the Photodetachment Cross Section of the H^- Ion Near Threshold," *Phys. Rev. A* **38**, 5628 (1988).

G. Swain, "A Formula Estimating the Low-Frequency Longitudinal Impedance of Vacuum Ports," Los Alamos National Laboratory document AHF Technical Note 88-013 (May 1988).

G. Swain, "Design of a Main Ring Cavity," in *Proceedings of the Accelerator Design Workshop* (February 22–27, 1988) Los Alamos National Laboratory report LA-11432-C (1988).

G. Swain, "Main Ring RF Cavity," Los Alamos National Laboratory document LA-UR-88-3715 (submitted to the *Proceedings of the 1988 Summer Study on High-Energy Physics in the 1990's*, Snowmass, Colorado, June 27–July 15, 1988).

G. Swain, "The ZLT Code for Beam Coupling Impedances," Los Alamos National Laboratory document AHF Technical Note 88-014 (May 1988).

J. J. Szymanski, J. F. Amann, J. K. Black, M. D. Cooper, S. C. Wright, J. Crocker, and H. Sanders, "The MEGA Hardware Trigger System," Los Alamos National Laboratory document LA-UR-88-3919 (submitted to the *Proceedings of the Rare Decays Symposium*, Vancouver, B.C., Canada, November 29–December 3, 1988).

T. N. Taddeucci, "The Empirical Connection Between (p, n) Cross Sections and Beta Decay Transition Strengths," Los Alamos National Laboratory document LA-UR-88-2924 (submitted to the *Proceedings of the Telluride Conference on Spin Observables of Nuclear Probes*, Telluride, Colorado, March 14–17, 1988).

C. Y. Tang, P. G. Harris, A. H. Mohagheghi, H. C. Bryant, C. R. Quick, J. B. Donahue, R. A. Reeder, S. Cohen, W. W. Smith, and J. E. Stewart, "First Observation of Multiphoton Detachment of the H^- Ion," (submitted to *Physical Review A*, 1988).

H. A. Thiessen, "Minimum Cost Linac for AHF," Los Alamos National Laboratory document AHF Technical Note 88-017 (July 1988).

H. A. Thiessen, Ed. "Proceedings of the Accelerator Design Workshop," Los Alamos, New Mexico, February 22–27, 1988, Los Alamos National Laboratory report LA-11432-C (August 1988).

H. A. Thiessen, "Technical Summary of the Accelerator Design Workshop, February 22–27, 1988," in *Proceedings of the Accelerator Design Workshop*, Los Alamos, New Mexico, Los Alamos National Laboratory report LA-11432-C (1988).

H. A. Thiessen, "Towards an Advanced Hadron Facility at Los Alamos," in *Proceedings of the Accelerator Design Workshop*, Los Alamos, New Mexico, (February 22–27, 1988), Los Alamos National Laboratory report LA-11432-C (1988).

H. A. Thiessen, "Trip Report on Snowmass APS Workshop: 'Physics of the 1990's,' " Los Alamos National Laboratory document LA-UR-88-2619 (submitted to the *Proceedings of the 1988 Summer Study on High-Energy Physics in the 1990's*, Snowmass, Colorado, June 17–July 15, 1988).

H. A. Thiessen, "Ultimate Limit of Stripper Caused Losses in H^- Injection System," Los Alamos National Laboratory document AHF Technical Note 88-006 (March 1988).

J. L. Ullmann, J. Rapaport, P. W. Lisowski, R. C. Byrd, T. Carey, T. N. Taddeucci, J. McClelland, L. Rybarcyk, R. C. Haight, N. S. P. King, G. L. Morgan, D. A.

Lind, R. Smythe, C. D. Zafiratos, D. Prout, E. Sugarbaker, W. P. Alford, and W. G. Love, "Ratio of Gamow-Teller to Fermi Strength Observed in $^{13,14}C(p,n)$ at 492 and 590 MeV," Los Alamos National Laboratory document LA-UR-88-1787 (submitted to the *Proceedings of the International Conference on Spin Observables of Nuclear Probes*, Telluride, Colorado, March 14–19, 1988).

O. van Dyck, "Industrial Collaboration at Los Alamos," *CERN Courier* (August 1988).

O. B. van Dyck, R. L. Hutson, M. E. Schillaci, and D. H. White, Eds., "Progress at LAMPF, January–December 1987," Los Alamos National Laboratory report LA-11339-PR (May 1988).

L. Walling, D. E. McMurry, D. Neuffer, and H. A. Thiessen, "Transmission Line Impedance Measurements for an Advanced Hadron Facility," Los Alamos National Laboratory document LA-UR-88-3533 (submitted to *Nuclear Instruments and Methods*, October 1988).

T. S. Wang, E. Colton, and D. Neuffer, "The Tune Dependence of the Stability Threshold Current in the PSR," in *Proceedings of the Accelerator Design Workshop*, Los Alamos, New Mexico, February 22–27, 1988, Los Alamos National Laboratory report LA-11432-C (1988).

J. M. Watson, R. C. Arnold, J. M. Bogaty, R. J. Burke, E. P. Colton, S. Fenster, M. H. Foss, T. K. Khoe, R. L. Kustom, R. L. Martin, M. G. Mazarakis, K. K. Menefee, J. S. Moenich, A. Moretti, E. F. Parker, L. G. Ratner, R. L. Stockley, and H. Takeda, "The Argonne Heavy Ion Fusion Program: Accelerator Demonstration Facility (Phase Zero)," in *Proceedings of the 8th International Conference on Plasma Physics and Controlled Nuclear Fusion Research*, Brussels, July 1–10, 1988, IAEA-CN-38/p-4-1.

Z. Weinfeld, E. Piasetzky, H. W. Baer, R. L. Burman, M. J. Leitch, C. L. Morris, D. H. Wright, S. H. Rokni, and J. R. Comfort, "Low-Energy Pion Double Charge Exchange on Ca Isotopes," *Phys. Rev.* C **37**, 902 (1988).

D. H. White, "Neutrino-Electron Scattering at LAMPF—Large Čerenkov Detector Experiment," Los Alamos National Laboratory document LA-UR-88-3886 (submitted to the *Proceedings of the New Directions at Fermilab Workshop*, September 14–16, 1988).

D. H. White, "Summary of Neutrino Presentations," in *Proceedings of the Third Conference on the Intersections Between Particle and Nuclear Physics*, Rockport, Maine, (May 14–19, 1988) Gerry Bunce, Ed. (American Institute of Physics, New York, 1988) Vol. 176, pp. 230–240.

C. Wilkinson, R. Handler, B. Lundberg, L. Pondrom, M. Sheaff, P. T. Cox, E. C. Dukes, J. Dworkin, O. E. Overseth, A. Beretvas, L. Deck, T. Delvin, K. B. Luk, R. Rameika, R. Whitman, and K. Heller, "Polarization and Magnetic Moment of the Σ^+ Hyperon," *Phys. Rev. Lett.* 58, 855 (1987).

A. Williams, L. Agnew, L. G. Atencio, H. W. Baer, M. Burlein, G. R. Burleson, K. S. Dhuga, H. T. Fortune, G. S. Kyle, J. A. McGill, C. F. Moore, C. L. Morris, S. Mordechai, J. M. O'Donnell, M. W. Rawool, S. Schilling, J. D. Silk, and J. D. Zumbro, "Pion Double Charge Exchange Above the $\Delta(1232)$ Resonance," Los Alamos National Laboratory document LA-UR-88-2594 (to be published in *Physics Letters B*, August 1988).

S. L. Wilson, R. Hofstadter, E. B. Hughes, Y. C. Lin, R. Parks, M. W. Ritter, J. Rolfe, R. D. Bolton, J. D. Bowman, M. D. Cooper, J. S. Frank, A. L. Hallin, P. Heusi, C. M. Hoffman, G. E. Hogan, F. G. Mariam, H. S. Matis, R. E. Mischke, D. E. Nagle, L. E. Piilonen, V. D. Sandberg, G. H. Sanders, U. Sennhauser, R. Werbeck, R. A. Williams, D. P. Grosnick, S. C. Wright, and J. McDonough, "Design and Performance of Modularized NaI(Tℓ) Detectors with Rectangular Crystal Elements: An Array of 49 and the Crystal Box," *Nucl. Instrum. and Methods* **A264**, 263–284 (1988).

R. S. Winje, "A Preliminary Design of the Los Alamos Fast Kicker Magnet Pulser and Power Supply," Los Alamos National Laboratory document LA-UR-88-3363 (1988).

D. H. Wright, M. Blecher, R. L. Boudrie, R. L. Burman, M. J. Leitch, B. G. Ritchie, D. Rothenberger, Z. Weinfeld, M. Alsolami, G. Blanpied, J. A. Escalante, C. S. Mishra, G. Pignault, B. M. Preedom, and C. S. Whisnant, "Elastic Scattering of 19.5 and 30.0 MeV Negative Pions from ^{12}C," *Phys. Rev.* C35, 2139 (1987).

D. H. Wright, M. Blecher, K. Masutani, R. Seki, R. L. Boudrie, R. L. Burman, M. J. Leitch, M. Alsolami, G. Blanpied, J. A. Escalante, C. S. Mishra, G. Pignault, B. M. Preedom, C. S. Whisnant, and B. G. Ritchie, "Indication of Pionic-Atom Anomalies in Pion-Nucleus Elastic Scattering," *Phys. Rev.* C35, 2258 (1987).

D. H. Wright, M. Blecher, B. G. Ritchie, D. Rothenberger, R. L. Burman, Z., Weinfeld, J. A. Escalante, C. S. Mishra, and C. S. Whisnant, "Elastic Scattering of 19.5 and 30 MeV Positive and Negative Pions from ^{40}Ca," *Phys. Rev.* C37, 1155 (1988).

V. Yuan, H. Frauenfelder, R. W. Harper, J. D. Bowman, R. Carlini, D. W. MacArthur, R. E. Mischke, D. E. Nagle, R. L. Talaga, and A. B. McDonald, "Measurement of Parity Nonconservation in the Proton-Proton Total Cross Section at 800 MeV," *Phys. Rev. Lett.* 57, 1680 (1986).

B. Zeidman, D. F. Gessaman, P. Zupranski, R. E. Segel, G. C. Morrison, C. Olmer, G. R. Burleson, R. L. Boudrie, C. L. Morris, L. W. Swenson, G. S. Blanpied, B. G. Ritchie, and C. L. H. Johnstone, "Inelastic Scattering of Pions by ^{10}B," *Phys. Rev.* C 38, 2251 (1988).

M. S. Zisman, J. Bisognano, E. Colton, F. Khiari, D. Neuffer, E. Raka, S. Tepikian, S. A. Bogacz, E. Gianfelice, G. Lambertson, K.-Y. Ng, and P. Schoessow, "Summary of Working Group on Collective Instabilities," in *Proceedings of the Workshop on the RHIC Performance*, Brookhaven National Laboratory, March 21–26, 1988, LBL-25334, ESG Note 38.

Applications-Oriented Research

C. Boekema, J. A. Flint, S. P. Weathersby, R. L. Lichti, K. C. Chan, D. W. Cooke, R. L. Hutson, M. E. Schillaci, H. Rempp, V. A. M. Brabers, and J. Oostens, "Spin-Cluster Effects in the Spin-Glass $Fe_{2-x}Ti_{1+x}0_5$ as Observed by Transverse-Field Muon Spin Relaxation" (submitted to the *Proceedings of the Fourth Joint MMM-Intermag Conference*, Vancouver, Canada, July 1988).

R. D. Brown and J. R. Cost, "Radiation-Induced Changes in Magnetic Properties of Nd-Fe-B Permanent Magnets," Los Alamos National Laboratory document LA-UR-88-2852 (to be published in *IEEE Transactions in Magnetics*, August 1988).

S. Carpenter, M. N. Cornforth, M. R. Raju, M. E. Schillaci, M. E. Wilder, D. T. Goodhead, and W. F. Harvey, "Radiobiology of Ultrasoft X-Rays IV. Flat and Round-Shaped Hamster Cells (CHO-10B, HS-23)," Los Alamos National Laboratory document LA-UR-88-4073 (submitted to *Radiation Research*, December 1988).

J. S. Cohen and M. Leon, "Approximations Used in Calculating Many-Body Effects in Resonant $[(dt\mu)dee]^*$ Formation," (to be published in *Physical Review A*, March 1988).

J. S. Cohen and M. Leon, "Note on Epithermal $dt\mu$ Formation," *Muon Catal. Fusion* 3, 497 (1988).

J. S. Cohen, M. Leon, and N. T. Padial, "Pressure Broadening of the $[(dt\mu)dee]^*$ Formation Resonances," in *Proceedings of the Muon-Catalyzed Fusion Workshop, Sanibel Island, Florida*, S. E. Jones, J. Rafelski, and H. J. Monkhorst, Eds. (AIP Conference Proceedings, New York, 1989), Vol. 181, pp. 111–123.

D. W. Cooke, "Charge Trapping and Luminescence in Biochemical Systems," Los Alamos National Laboratory document LA-UR-88-2488 (submitted to *International Journal of Radiation Applications and Instrumentation (Part C: Radiation Physics and Chemistry)* 1988).

D. W. Cooke, R. L. Hutson, R. Kwok, M. Maez, H. Rempp, M. Schillaci, J. Smith, J. Willis, R. Lichti, K. Chan, C. Boekema, S. Weathersby, J. Flint, and J. Oostens, "Muon Depolarization and Magnetic Field Penetration Depth in Superconducting $GdBa_2Cu_3O_x$," *Phys. Rev. B* 37, 9401–9404 (1988).

D. W. Cooke, R. L. Hutson, R. Kwok, M. Maez, H. Rempp, M. Schillaci, J. Smith, J. Willis, R. Lichti, K. Chan, C. Boekema, S. Weathersby, and J. Oostens, "Muon Spin Depolarization in Gd-$EuBa_2Cu_3O_x$," *High Temperature Superconductivity—The First Two Years* (Gordon and Breach), pp. 125–130 (1988).

D. W. Cooke, R. Hutson, R. Kwok, M. Maez, H. Rempp, M. Schillaci, J. Smith, J. Willis, R. Lichti, K. Chan, C. Boekema, S. Weathersby, and J. Oostens, "Muon Spin Rotation Measurement of Magnetic Field Penetration and Flux Pinning in Superconducting $EuBa_2Cu_3O_x$," Los Alamos National Laboratory document LA-UR-88-1814 (submitted to *Physical Review B*, June 1988).

D. W. Cooke, M. S. Jahan, J. L. Smith, M. A. Maez, W. L. Hults, I. D. Raistrick, D. E. Peterson, J. A. O'Rourke, S. A. Richardson, J. D. Doss, E. R. Gray, B. Rusnak, G. P. Lawrence, and C. Fortgang, "Detection of Surface ($\sim$1 μm) Impurity Phases in High-T_C Superconductors," Los Alamos National Laboratory document LA-UR-88-3591 (submitted to *Physical Review Letters*, October 1988).

D. W. Cooke, M. T. Trkula, R. E. Muenchausen, N. S. Nogar, and J. L. Smith, "Characterization of High-Temperature Superconductors by Optical Techniques," Los Alamos National Laboratory document LA-UR-88-3760 (submitted to *Journal of the Optical Society of America B*, November 1988).

J. D. Davies, F. D. Brooks, W. A. Cilliers, J. B. A. England, C. J. Pyle, G. T. A. Squier, A. Bertin, M. Bruschi, M. Piccinini, A. Vitale, A. Zoccoli, S. E. Jones, P. Li, L. M. Rees, E. V. Sheeley, J. K. Shurtleff, S. F. Taylor, G. H. Eaton, B. Alper, V. R. Bom, C. W. E. van Eijk, H. de Haan, A. N. Anderson, A. J. Caffrey, J. Zabriskie, M. A. Paciotti, O. K. Baker, J. N. Bradbury, J. S. Cohen, H. R. Maltrud, and L. N. Sturgess, "μCF Thoughts from Birmingham and the Rutherford Appleton Laboratory," in *Proceedings of the μCF Workshop*, Sanibel Island, Florida, S. E. Jones, J. Rafelski, and H. J. Monkhorst, Eds. (AIP Conference Proceedings, New York, 1989), Vol. 181, pp. 52–56.

J. D. Doss, D. W. Cooke, P. N. Arendt, M. A. Natasi, R. E. Meunchausen, and J. R. Tesmer, "Instrument for Characterization of Superconducting Films," Los Alamos National Laboratory document LA-UR-2907 (submitted to *Journal of Physics-E*, October 1988). (Super Conductor Science and Technology).

J. D. Doss, D. W. Cooke, C. W. McCabe, and M. Maez, "Non-Contact Methods for Characterization of Superconductors," *Rev. of Sci. Instrum.* 4, 659 (1988).

J. D. Doss and C. W. McCabe, "Total Implants for Hyperthermia Application and Therapy," *Int. J. Hyperthermia* 4, 617 (1988).

R. H. Heffner, D. W. Cooke, R. L. Hutson, M. E. Schillaci, H. Rempp, J. L. Smith, J. O. Willis, D. E. MacLaughlin, C. Boekema, R. L. Lichti, and J. Oostens, "Muon Spin Rotation in the Magnetic and Superconducting Ground States of (U,Th)Be_13 and (U,Th)Pt_3," Los Alamos National Laboratory document LA-UR-88-3584, (submitted to *Physics Review B*, October 1988).

M. S. Jahan, D. W. Cooke, H. Sheinberg, J. L. Smith, and D. P. Lianos, "Environmental Effects on Luminescence Yield of Superconducting $YBa_2Cu_3O_x$," Los Alamos National Laboratory document LA-UR-88-3672 (submitted to *Journal of Materials Research*, November 1988).

M. Leon, "Theoretical Survey of Muon Catalyzed Fusion," in *Proceedings of the μCF Workshop*, Sanibel Island, Florida (1988).

M. Leon, O. K. Baker, J. N. Bradbury, J. S. Cohen, H. R. Maltrud, M. A. Paciotti, L. L. Sturgess, A. N. Anderson, J. M. Harris, S. E. Jones, A. J. Caffrey, C. DeW. Van Siclen, and K. D. Watts, "^{3}He Scavenging as a Source of Information in Muon-Catalyzed *d-t* Fusion," *Muon Catal. Fusion*, **2**, 231 (1988).

D. E. MacLaughlin, D. W. Cooke, R. H. Heffner, R. L. Hutson, M. W. McElfresh, M. E. Schillaci, H. D. Rempp, J. L. Smith, J. O. Willis, E. Zirngiebl, C. Boekema, R. L. Lichti, and J. Oostens, "Muon Spin Rotation and Magnetic Order in the Heavy-Fermion Compound URu_2Si_2," *Phys. Rev. B* **37**, 3153 (1988).

M. A. Paciotti, O. K. Baker, J. N. Bradbury, J. S. Cohen, M. Leon, H. R. Maltrud, L. N. Sturgess, S. E. Jones, P. Li, L. M. Rees, E. V. Sheeley, J. K. Shurtleff, S. F. Taylor, A. N. Anderson, A. J. Caffrey, J. Zabriskie, F. D. Brooks, J. D. Davies, G. J. Pyle, G. T. A. Squier, A. Bertin, M. Bruschi, M. Piccinini, A. Vitale, A. Zoccoli, V. R. Bom, C. W. E. van Eijk, H. de Haan, and G. H. Eaton, "First Direct Measurement of α-μ Sticking in *dt*-μCF," in *Proceedings of the μCF Workshop*, Sanibel Island, Florida (1988).

N. T. Padial, J. S. Cohen, and M. Leon, "Impact Broadening of the $dt\mu$ Formation Resonances," *Phys. Rev. A* **38**, 1172 (1988).

M. R. Raju, S. G. Carpenter, J. J. Chmielewski, M. E. Schillaci, M. E. Wilder, J. P. Freyer, N. F. Johnson, P. L. Schor, R. J. Sebring, and D. T. Goodhead, "Radiobiology of Ultrasoft X Rays: I. Cultured Hamster Cells (V79)," *Radiat. Res.* **110**, 396 (1987).

M. E. Schillaci, S. Carpenter, M. R. Raju, R. J. Sebring, M. E. Wilder, and D. T. Goodhead, "Radiobiology of Ultrasoft X-Rays II, Cultured C3H Mouse Cells (10T 1/2)," Los Alamos National Laboratory document LA-UR-88-2800 (to be published in *Radiation Research*, August 1988).

J. O. Willis, D. W. Cooke, R. D. Brown, J. R. Cost, J. F. Smith, R. M. Aikin, and M. Maez, "Proton Radiation Damage in Superconducting Eu- and $GdBa_2Cu_3O_x$," *Appl. Phys. Lett.* 53, 417–419 (1988).

J. O. Willis, J. R. Cost, R. D. Brown, J. D. Thompson, and D. E. Peterson, "Radiation Damage in $YBa_2Cu_3O_7$ by Fast Neutrons," *Mat. Res. Soc. Symp. Proc.* **99**, 391 (1988).

Accelerator Operations

E. P. Colton, D. Neuffer, H. A. Thiessen, H. S. Butler, G. R. Swain, A. Lombardi, D. H. Fitzgerald, F. Mariam, M. A. Plum, R. Ryder, R. J. Macek, D. A. Clark, J. W. Hurd, R. L. Hutson, J. A. McGill, T. W. Hardek, R. Shafer, G. Lawrence, A. J. Jason, B. Blind, and R. A. Hardekopf, "Status Report on the Los Alamos Proton Storage Ring," in *Proceedings of the Third Conference on Intersections Between Particle and Nuclear Physics*, Rockport, Maine (May 14–19, 1988) Gerry Bunce, Ed. (American Institute of Physics, New York, 1988) Vol. 176, pp. 302–308.

J. W. Hurd and J. P. McGill, "Modification of Acceleration Element in 'Transport'," *Accelerator Engineering and Technology* 28, 1198–1200 (1987).

J. B. McClelland, D. A. Clark, J. L. Davis, R. C. Haight, R. W. Johnson, N. S. P. King, G. L. Morgan, L. J. Rybarcyk, J. Ullmann, P. Lisowski, W. R. Smythe, D. A. Lind, C. D. Zafiratos, and J. Rapaport, "Longitudinal Linac Beam Focusing for Neutron Time-of-Flight Measurements," Los Alamos National Laboratory document LA-UR-88-2357 (to be published in *Nuclear Instruments and Methods*, 1988).

R. V. Poore, L. L. Byrnes, M. P. Harrington, R. B. Stuewe, and R. T. Westervelt, "Implementation of a Distributed Computer Control System at the Los Alamos Proton Storage Ring," Los Alamos National Laboratory document LA-UR-88-3414 (to be published in the *Proceedings of the Eighth Workshop on Distributed Computer Control Systems*, September 13–15, 1988).

G. J. VanDalen, B. Aas, L. Auerbach, B. Bassalleck, D. Beavis, T. J. Bowles, A. Brown, R. E. Brown, R. L. Burman, D. A. Clark, S. Clearwater, S. Datta, B. Dieterle, T. Dombeck, R. Fisk, S. Y. Fung, W. Gorn, C. Gregory, Y. Huang, R. E. Hill, G. Igo, J. H. Kang, D. D. Koetke, D. S. Koetke, H. Kruse, C. Leavitt, D. Lee,

R. Manweiler, C. Newsome, and R. T. Poe, "Observation of Anomalous Exclusive Interactions Near Threshold," (submitted to *Physical Review Letters*, 1988).

Experimental Facilities and Research Support

D. B. Barlow, B. M. K. Nefkens, C. T. Pillai, and K. W. Jones, "Production of High Momentum Negative Pions by 800 MeV Protons at 0° to 20°," *Nucl. Instrum. and Methods* **A271**, 471 (1988).

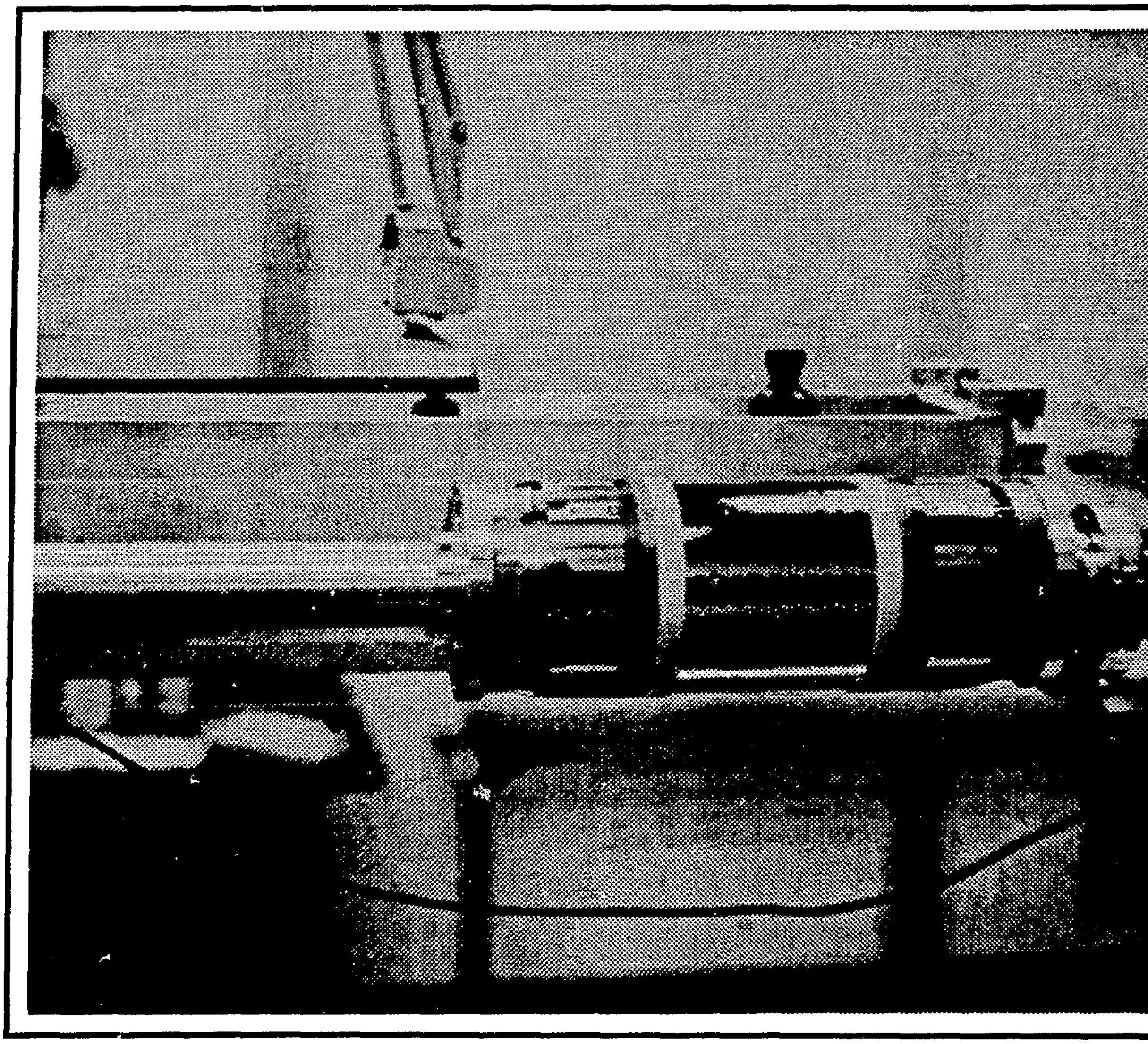
T. A. Dombeck, A. Finch, and D. L. Grisham, "Details of a Water Target Used in a High Current Application for a Neutrino Physics Experiment and the Direct Measurement of the Incident Proton Beam by the Induced Change in the Water Conductivity," *Nucl. Instrum. and Methods* **A272**, 650–659 (1988).

W. F. Kielhorn, J. J. Jarmer, S. I. Penttilä, and E. Gülmez, "Deuteron Polarization in a Dynamically Polarized Ammonia Target," Los Alamos National Laboratory document LA-UR-88-2719 (submitted to the *Proceedings of the Eighth International Symposium on High Energy Spin Physics*, Minneapolis, Minnesota, September 10–17, 1988).

M. M. Meier, W. B. Amian, D. A. Clark, C. A. Goulding, J. B. McClelland, G. L. Morgan, and C. E. Moss, "Differential Neutron Production Cross Sections and Neutron Yields from Stopping-Length Targets for 113-MeV Protons," Los Alamos National Laboratory document LA-UR-88-3699 (submitted to *Nuclear Science and Engineering*, November 1988).

S. I. Penttilä, J. F. Amann, J. J. Jarmer, K. W. Jones, N. Tanaka, M. L. Barlett, G. W. Hoffmann, W. F. Kielhorn, G. Pauletta, and M. J. Purcell, "First Polarization Results From the LAMPF ^{13}C Target," Los Alamos National Laboratory document LA-UR-88-2718 (submitted to the *Proceedings of the Eighth International Symposium on High Energy Spin Physics*, Minneapolis, Minnesota, September 10–17, 1988).

J. D. Zumbro, H. A. Thiessen, C. L. Morris, and J. A. McGill, "Uses of Superconducting RF Structures in Pion Beams at LAMPF," Los Alamos National Laboratory document LA-UR-88-2492 (submitted to the *Proceedings of the Tenth Conference on the Application of Accelerators in Research and Industry*, Denton, Texas, November 7–9, 1988, and to be published in *Nuclear Instruments and Methods*, 1988).



Facility Development

The MEGA Data-Acquisition System

M. A. Oothoudt, J. F. Amann, R. D. Bolton, M. D. Cooper, W. M. Foreman, G. E. Hogan, T. Kozlowski, F. J. Naivar, W. Smith (Los Alamos), P. S. Cooper (Fermilab), E. B. Hughes, C. C. H. Jui, J. N. Otis (Stanford Univ.), R. J. Fisk, D. D. Koetke, R. Manweiler (Valparaiso Univ.), K. I. Hahn, and J. K. Markey (Yale Univ.)

The MEGA experiment will acquire data at rates beyond the capabilities of standard LAMPF data-acquisition systems. Furthermore, the volume of raw data will be so high (the equivalent of 400,000 tapes of data) that some form of on-line event rejection is required. To meet these needs, a data-acquisition system has been developed,[1] making use of Fastbus front end modules and an array of microprocessors. Figure 1 shows an overview of the system.

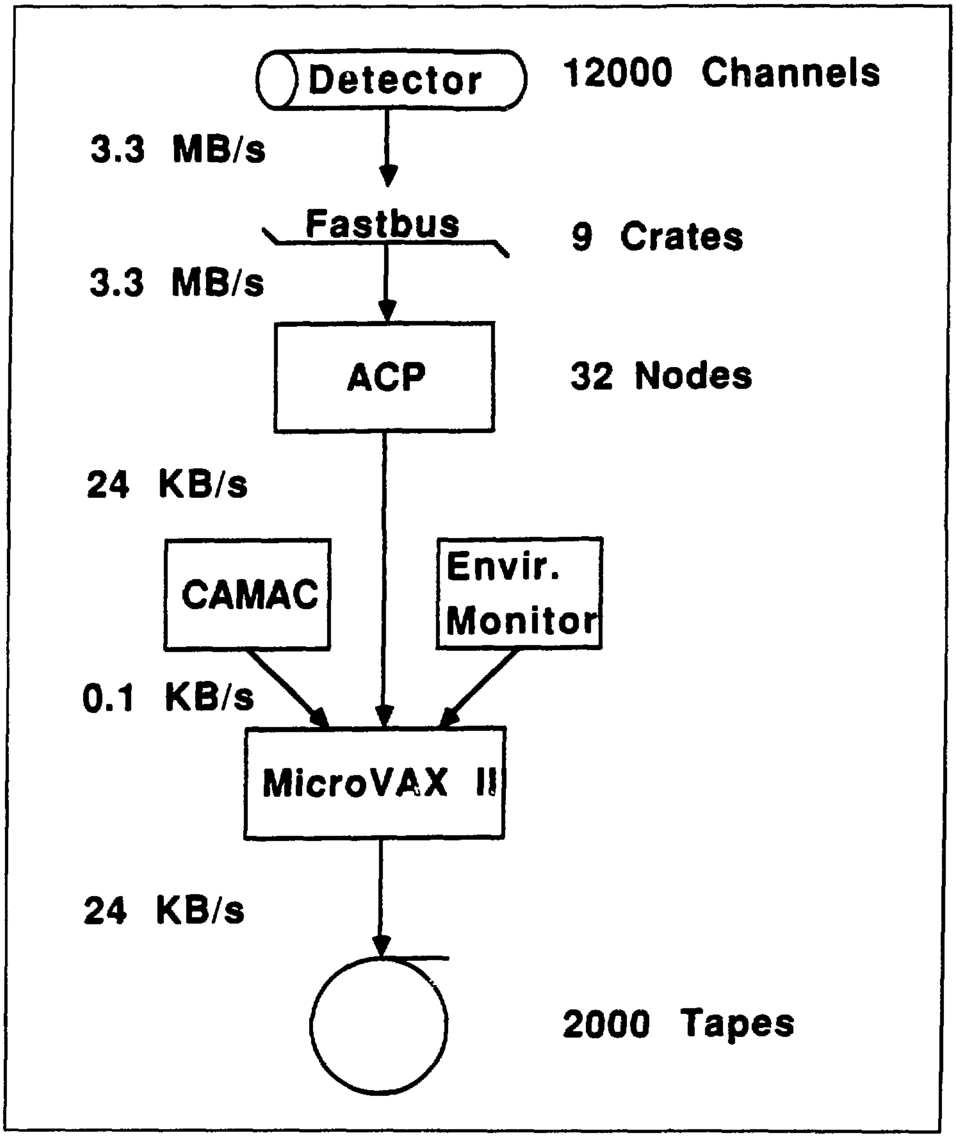


Fig. 1. Overview of data-acquisition subsystems. Data rates are shown on the left. Element counts are shown on the right.

The MEGA experiment will observe a total of 3×10^{14} muon decays at an instantaneous rate of 5×10^{8} decays per second. A hardware trigger will reduce this to an average rate of 2400 events (3.3 megabytes) per second. During a 500-μs beam pulse, events are buffered in memories of Fastbus modules supplied by Phillips Scientific.[2] The experiment requires 1000 channels of ADCs (analog-to-digital converter), 1200 channels of TDCs (time-to-digital converter), and 9500 channels of latches residing in nine Fastbus crates. The Phillips modules support a rapid readout scheme (called "MEGAblock"), which allows up to a full crate of modules to be read by a single Fastbus block read.

In the time between beam bursts, a Fastbus master (the CERN-designed General Purpose Master (GPM)[3]) will read data stored in the Fastbus modules and dump it to the array of microprocessors. The GPM incorporates a Motorola 68000 processor, which is programmable in both assembler and higher level languages (FORTRAN and PASCAL). Code is loaded into the GPM from the VAX host computer over RS232 terminal lines. A set of Fastbus standard subroutines has been written for the GPM[4] to support low-speed operations for run control and monitoring.

The GPM dumps all data from a beam burst into one of the 32 Motorola 68020 microprocessors residing in VERSAbus E (VME) crates. The microprocessors and the software they run were designed by the Fermilab Advanced Computer Program (ACP).[5] The ACP system was originally designed for the off-line analysis of high-energy-physics data. However, without modification of ACP hardware or software, it proved possible to use the ACP system for MEGA data acquisition. Communication between Fastbus and VME is performed through the Fermilab Fastbus to Branch Bus Controller[6] designed for use by the Collider Detector Facility (CDF) experiment.

The primary function of the ACP system is to reconstruct the raw events sufficiently so that 99.5% of the least promising candidate events can be discarded. Event reconstruction code is written in FORTRAN77, but time-critical subroutines may be written in assembler. Facilities will be available for histogramming data and maintaining statistics on the number of events failing criteria in the event reconstruction. Data for events passing the reconstruction criteria plus related calculated quantities will be sent to the host MicroVAX II from the ACP system at a rate of 24 KB/s. In the host, the LAMPF Q Data Acquisition system will write the Fastbus data to tape along with low rate data (scalers) from CAMAC and from an Environmental Monitor system. Approximately 2000 6250-bpi tapes will be produced for more stringent off-line event reconstruction.

Preliminary test runs were carried out during 1987 and 1988. Tests showed that the data-acquisition system met the requirements of the experiment with two exceptions:

1. Overhead in the GPM prevents reading all data for a beam pulse before the next beam pulse. The code responsible for this overhead is being rewritten and is expected to meet its speed requirements by the 1989 run.

2. Event reconstruction in the ACP nodes was not done because insufficient detector hardware was available. For the 1989 run, a simplified reconstruction algorithm will be used with the partial detector system available for that run.

References

1. T. Kozlowski, J. F. Amann, M. D. Cooper, W. M. Foreman, G. E. Hogan, F. J. Naivar, et al., "The MEGA Experiment and the Use of Microprocessors for Data Acquisition and Event Selection," *Proc. Conf. on the Impact of Digital Microelectronics and Microprocessors on Particle Physics,* Trieste (March 1988), M. Budinich, E. Castilli, and A. Colavita, Eds. (World Scientific, Singapore), p. 303.

2. Phillips Scientific, 305 Island Road, Mahwah, New Jersey 07430.

3. H. Muller, "Online Fastbus Processor for LEP," *Proc. Conf. on Computing in High Energy Physics,* Amsterdam, Netherlands, 1985.

4. T. Kozlowski and W. M. Foreman, "An Implementation of the New IEEE Standard Routines for Fastbus," *IEEE Trans. Nucl. Sci.* **NS-34,** 800–803 (1987).

5. I. Gaines, H. Areti, R. Atac, J. Biel, A. Cook, M. Fischler, R. Hance, D. Husby, T. Nash, T. Zmuda, "The ACP Multiprocessor System at Fermilab," *Comput. Phys. Commun.* **45,** 323–329 (1987).

6. M. Larwill, "FASTBUS To Branch Bus Controller (FBBC) Preliminary Specification," Fermilab CDF453 (1986).

EPICS Facility Report

S. J. Greene (Los Alamos)

The EPICS facility was run in its standard as well as double-charge-exchange configurations during LAMPF cycles 50 and 51. Development running during the course of the year indicated no significant resolution problems were created by the channel front-end realignment. Four-jaw FJ02, on the downstream side of the separator box, was refurbished and is now operable. It has been used to eliminate the slit scattering bump originating at the channel front-end fixed collimator. Its use in this manner decreases the pion flux by a factor of two. The FJ01 vertical slits are again being used for flux control in the channel. FJ05 vertical slits in the front detector box on the spectrometer have been used to mask S1 and F12 detectors from protons scattering at the top edge of experiment targets. The box has enabled very good reproducibility on positioning S1 and F12 in or out of the beam without changing the chamber calibrations.

The vacuum pumping and controls system is being upgraded by the replacement of thermocouple guages with convectron units. Vacuum valve status and controls will soon be available in the EPICS counting house. Shunts on the dipole magnets are being replaced by new, higher-capacity units featuring new technology and improved stability. Preliminary tests with the new spectrometer (BM05) shunt give a shunt stability of $\Delta = 0.06\%$, which translates to a magnetic-field stability of 0.005%. New reversing switches for the magnet polarities, having higher current capacity, are being installed on all the dipole power supplies. The new digital magnet controllers from MP-6 have operated well and now have front-panel programmable upper-cycle limits.

The data acquisition/controls computer has been changed from a VAX 750 to a MicroVAX II. The new machine is up to twice as fast as the old in some applications. The experiment user's disk has a capacity of 300K blocks, requiring much tighter disk management policies than in the past.

The Line-A shielding on the southwest cave wall is being reworked to allow spectrometer access to floor angles of at least 120°, which enables back-angle scattering to 180° with the Eurydice setup. A detailed neutron/gamma survey of the bare wall was made at the end of cycle 51 using primary beam intensity of 1 mA; radiation intensity and a neutron-energy spectrum were measured. New custom-designed concrete blocks will be added to the wall face, which increase the shielding thickness while limiting intrusion onto the spectrometer floor space. We are also investigating the placement of $n\gamma$ shielding (borated poly, lead) around the spectrometer focal-plane detectors.

Thinner mylar windows are being fabricated and tested for use in the F12 front chambers, for the purpose of reducing the multiple-scattering contribution to the spectrometer energy resolution. Also, a superconducting polarizing/holding field magnet is being designed for the frozen-spin polarized ^{13}C experiment (Exp. 1025) at EPICS. The magnet will occupy the pivot position on the spectrometer frame and operate at fields up to 2.5 T, requiring special attention to magnetic forces and shielding schemes.

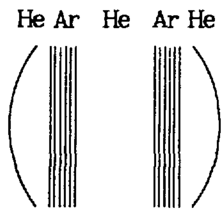
EPICS Energy Resolution

C. L. Morris, L. Atencio, R. L. Boudrie, and S. J. Greene (Los Alamos)

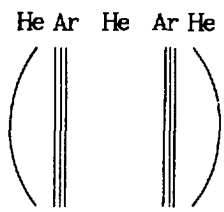
Energy resolution from the EPICS channel system is currently at the level of about 130 keV. This is limited by multiple scattering in the front chambers and exit window from the spectrometer. In order to improve upon this we have undertaken a development project to

1. construct thinner vacuum widows by using kevlar-supported mylar films, and
2. reduce the number of chamber planes required in the front of the spectrometer by using cathode-strip readouts in addition to the delay-line readout anode planes.

The effect of using fewer planes and thinner windows for the front chambers is illustrated in Fig. 1. We expect to obtain a factor of nearly two reduction in multiple scattering which should give a similar improvement in resolution.



MATERIAL	L/Lrad (x10^{-4})	
mylar	7.30	for T_π=180MeV
Ar	2.56	
He	0.02	θ_{fwhm}=3.7 mrad
total	9.88	



MATERIAL	L/Lrad (x10^{-4})	
mylar	1.50	for T_π=180MeV
Ar	1.05	
He	0.02	θ_{fwhm}=1.9 mrad
total	2.57	

Fig. 1. Effect of proposed new front-chamber windows.

The kevlar-supported mylar windows will be constructed by performing them to a cylindrical shape. Mylar will be wrapped around an aluminum mandrel and then will be wrapped with epoxy wetted kevlar yarn using a filament winding machine in MST division. The window will then be glued into a properly shaped frame. This method will allow the density of kevlar to be controlled to provide the required strength and will minimize mechanical stressing of the mylar film. Initial tests of this procedure are in progress. The existing exit window from the spectrometer, which is 180 μm, will be replaced with an equivalent thickness of 63 μm. This should reduce multiple scattering by a factor of about 1.7. Similar but thinner windows will be used for the front-chamber vacuum windows.

Two problems need to be solved in order to use cathode strip readouts for the front chambers. First, the extra material introduced by the cathode strips needs to be kept small. We hope to solve this problem by using 8.5-μm kapton foil, coated with 1000 A of copper for fabricating the cathode planes. This will be laminated with G-10 circuit board material and etched using conventional circuit board techniques. Second, some form of multiplexing is necessary in order to keep the readout costs reasonable. This will be accomplished by summing the signal from every sixteenth cathode strip on the chamber and by reading out more coarsely spaced strips on the adjacent cathode plane in order to resolve the ambiguity introduced by this multiplexing scheme. This will result in a factor of eight reduction in the number of needed ADC channels (from 512 to 64). This is schematically illustrated in Fig. 2.

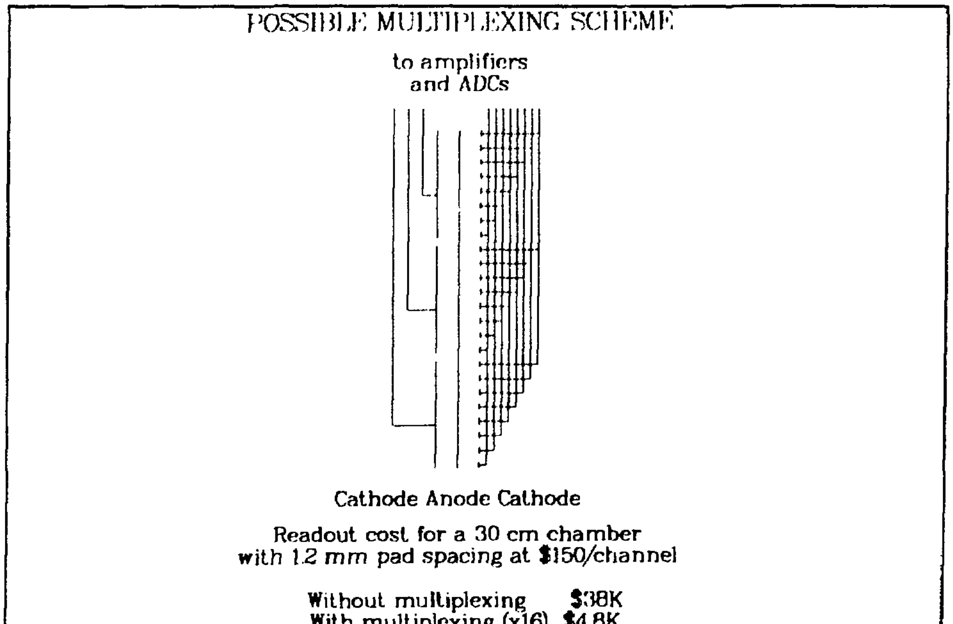


Fig. 2. Cathode strip readout multiplexing scheme.

Progress at the HRS Facility

K. W. Jones (Los Alamos)

The High-Resolution Spectrometer (HRS) maintained good availability and use during the 1988 calendar year production period. Details are included below. Planned work for the 1988/1989 shutdown includes an upgrade of the vacuum control system, installation of a new polarimeter in the front end of the beamline to permit measurement of L-spin at most energies, and relocation of the front-end beam-current monitor upstream of the first beam plug to allow current sharing between Line B and Line C to be set up effectively when the area is open. Some aspects of the safety instrumentation at HRS will be altered in conjunction with the Line X safety upgrade, but these changes will be essentially transparent to the user. It is anticipated that control of most aspects of the beamline polarimeters will move to the equipment room B racks, with only target selection being available in the counting house.

The most noteworthy accomplishment at HRS this year was a successful run using an N-type polarized ^{13}C target conducted by a University of Texas (Austin) and Los Alamos collaboration. Angular-distribution data were taken for A_{nn} as well as some three-spin observable data at a selected angle. Target polarizations between 25 and 30% were obtained, and techniques for monitoring the target polarization were successfully demonstrated. The effort involved in executing this A-priority experiment was substantial, and the experimental team is to be commended.

Cycle 52 saw a wide variety of experiments conducted at HRS. Experiment 1080 took data at 580 MeV, even though this energy prevented acquisition of N-type data to the necessary precision. This experiment seeks to perform a spin-longitudinal and spin-transverse $[(\vec{\sigma} \cdot \vec{q})$ and $(\vec{\sigma} \times \vec{q})]$ decomposition of continuum excitations in ^{40}Ca. This is a continuation of an extensive program aimed at understanding the spin-isospin response of the nucleus to hadronic probes at intermediate energies.

Resolution on the order of 40 keV was obtained at a beam energy of 650 MeV to enable high-resolution studies of Pt isotopes to be performed. This successful run enabled the completion of Exp. 903. During this run some difficulty with the HRS multipole magnets was encountered; instabilities that caused resolution to degrade rather than improve were seen. The cause of these instabilities is under investigation.

Some preliminary development was done to study the completed HRS Faraday cup. This rather massive device was inserted into the beam-dump entrance in the HRS dome. Vacuum-dependent leakage currents were observed, but successful measurement of beam currents was made. An upgrade of the vacuum system is planned, and it is anticipated that calibration of this device will be done on the EP line (possibly in the HIRAB room) in 1989. The Faraday cup is an essential ingredient of an ambitious experiment to measure precision cross sections at the HRS.

The end of production saw some effort devoted to a search for η production at the HRS. Unfortunately, the titanium tritide target purchased for this measurement was found to be externally contaminated and could not be installed.

Comprehensive background studies were made using a titanium target, and it was demonstrated that the measurement could be made if the target problems could be resolved.

Line-X Safety Upgrade

K. W. Jones (Los Alamos)

The Line-X safety upgrade is a high-priority shutdown project for 1988/1989. It has been acknowledged that there are credible accident scenarios resulting in the delivery of high-intensity H^- beam to Line X and subsequent beamlines, which could result in unacceptable radiation dose rates and integrated exposures to personnel working in some polarized-beam experimental areas. This problem is particularly severe in the Medium-Resolution Spectrometer (MRS), High-Resolution Atomic Beam (HIRAB), and Neutron Time of Flight (NTOF) areas.

The problem is being addressed by the installation of additional concrete shielding around the switcher cave adjacent to MRS and NTOF, and by upgrade of shielding in other strategic locations. These shielding changes have been determined by detailed radiation-level surveys in the affected areas. In addition, new self-checking current limiters are being installed, two in Line X and one in Line B upstream of the B/EP split. A system of 23 nitrogen-filled ion chambers incorporating self-checking features will also be installed to act as loss monitors in addition to the existing scintillation activation protection system. A total of twenty-six Albatross neutron detectors will be installed throughout the experimental areas, and the existing RM-16 system will be expanded to cover all experimental areas.

The addition of these new devices has necessitated a complete restructuring of the Run-Permit logic for Line X and downstream beamlines. The design phase of this project has been completed and installation is in progress. The large number of additional devices has necessitated the installation of a new RICE module (73) to provide interface with the Central Control Room.

The goal of the new layered system is to limit background levels and accidental exposures for credible accident scenarios to division guidelines. Implementation and testing of the system will take place at the beginning of the 1989 production period.

Polarized Beam Precession System

J. D. Little (Los Alamos)

The stand-alone system used to control the cryogenics for the Line B and EP superconducting solenoid magnets was totally refurbished to provide:

1. better operator interface via graphic panels and automatic report generation.
2. clean up of a ponderous wire plant that was difficult to maintain.
3. unattended normal operation with provisions to "secure" the system in "present condition" when some unusual situation occurs.

The system is built around a commercial programmable logic controller. The "ladder logic" device is a microprocessor with many varieties of input/output available.

This rebuild was a joint effort of MP-6 and MP-7.

Farewell to the Quench Ratio

M. W. McNaughton (Los Alamos)

The Lamb-shift polarized ion source has served us well for twelve productive years. The first quench-ratio calibrations[1] of the beam-line polarimeters were completed in 1977. In 1988, the Lamb-shift ion source was turned off for the last time, to be replaced by the new Optically Pumped Polarized Ion Source (OPPIS). In the intervening years, a wealth of polarimeter calibration data was accumulated, and is summarized in this report.

In 1980, the polarized beam energy was varied from 318 to 800 MeV, giving polarimeter calibrations at thirteen energies; these data are published in Ref. 1 and are summarized in Table I (1980 column). In subsequent years these calibrations have been checked repeatedly, and additional calibrations obtained at two other energies (see Table I). The internal agreement among these data is consistent with the estimated uncertainty of ±1% in the quench-ratio calibrations.

Table I. Analyzing Power A as a Function of Beam Energy (318–800 MeV) and Year Measured (1980–1988), for a Good-Geometry LAMPF Polarimeter (MSPO).

Beam Energy (MeV)	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*
318	0.416		0.412		0.416	0.418	0.417	0.417	
398	0.449								
447	0.469								
496	0.489	0.484	0.491	0.486	0.486	0.490	0.492	0.489	0.494
530	0.504								
547	0.515								
581	0.532					0.534			0.534
597	0.536	0.530	0.537						
630	0.544								
647	0.542			0.543	0.543	0.542			0.540
699	0.530	0.536	0.532						
733		0.515				0.514		0.519	0.520
750	0.508		0.505						
766							0.499		
800	0.484	0.483	0.483	0.483	0.483	0.485	0.485	0.484	0.484

The *pp*-elastic analyzing power at 17°lab. is 1.022 to 1.025 times the polarimeter analyzing power.[1] This allows us to compare the LAMPF calibrations with data from TRIUMF,[2] SIN-PSI,[3] and SATURNE[4] (see Fig. 1). The agreement among the four labs is within the experimental uncertainties. Also shown, for comparison, are the phase-shift analyses of Arndt[5] and Bystricky.[6] (Further cross checks of polarization calibrations including polarized targets and the p-carbon analyzing power are discussed in Refs. 7 and 8.)

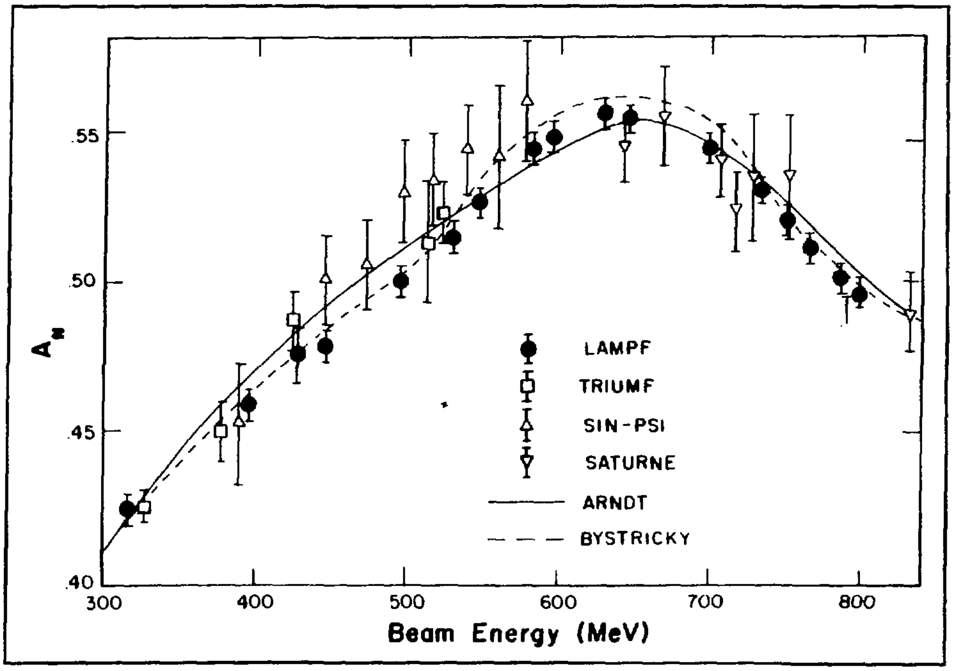


Fig. 1. Analyzing power A_N for pp elastic scattering near 17° lab.

In summary, we have a set of polarimeter calibrations with an estimated uncertainty of ±1%, that are internally consistent to ±1%, and that agree with calibrations at TRIUMF, SIN-PSI, and SATURNE within the experimental uncertainties of ±2%.

References

1. M. W. McNaughton and E. P. Chamberlin, *Phys. Rev.* C**24**, 1778 (1981).
2. D. V. Bugg, J. A. Edgington, C. Amsler, R. C. Brown, C. J. Oram, K. Shakarchi et al., *J. Phys.* G**4**, 1025 (1978).
3. E. Aprile, R. Hausammann, E. Neer, R. Ness, C. Lechanoine-Leluc, W. R. Leo et al., *Phys. Rev.* D**34**, 2566 (1986).
4. J. Bystricky, P. Chaumette, J. Deregel, J. Fabre, F. Lehar, A. De Lesquen et al., *Nucl. Phys.* **B262**, 727 (1985).
5. R. A. Arndt, John S. Hyslop III, and L. D. Roper, *Phys. Rev.* D**35**, 128 (1987).
6. J. Bystricky, C. Leluc, and F. Lehar, *J. Phys.* **48**, 199 (1987).
7. M. W. McNaughton, *AIP Conf. Proc.* **69**, 818 (1981).
8. M. W. McNaughton, B. E. Bonner, H. Ohnuma, O. B. Van Dyck, Sun Tsu-Hsun, C. L. Hollas et al., *Nucl. Instrum. and Methods* **A241**, 435 (1985).

Los Alamos Spallation Radiation Effects Facility

W. Sommer (Los Alamos)

After irradiation in the neutron flux at Target Station A-6 for two years, the insert carrying high-temperature furnaces and samples for the following experiments was retrieved from the facility in March 1988:

Exp. 986 "Spallation Neutron Irradiation of Non-Oxide Ceramics for First Wall Fusion Reaction Applications," B. Thiele, KFA Jülich;

Exp. 987 "Fast Neutron Irradiation Screening Test of Polycrystalline Graphites under First-Wall Fusion Conditions," W. Delle and B. Thiele, KFA Jülich;

Exp. 1014 "Proton, Spallation Neutron, and Fission Neutron Irradiation of Copper," A. Horsewell, Risø National Laboratory, Denmark, W. Sommer, Los Alamos;

Exp. 943 "Microstructural Evolution and Mechanical Property Changes in 316 Stainless Steel, Al and Mo under Irradiation with Different Displacement/Helium Production Rates and Ratios," J. Yu, Institute of Atomic Energy, People's Republic of China, M. Borden, New Mexico Institute of Mining and Technology, W. Sommer, Los Alamos.

Using the Monitor remote handling system, the Group MP-7 Remote Handling and Targeting Section removed the furnaces from the insert. Furnaces used for Exp. 986, Exp. 987, and Exp. 1014 were packaged and transported to KFA Jülich. The samples were removed from the furnaces in the KFA hot cells and found to be clean; a helium atmosphere at 400°C was maintained on the specimens during irradiation. Mechanical and physical properties tests on the samples are now being conducted. Transmission electron microscopy studies are being planned to determine the microstructural evolution of the material.

Initial scoping experiments aimed at determining radiation damage to electronics components for the Superconducting-Super-Collider project were completed. A region of low neutron flux ($\sim 10^{8}$–10^{10} $cm^{-2}s^{-1}$) was used; a systematic drift in electrical characteristics was measured for some memory chips and diodes. A formal research effort in this area, including irradiation with low fluxes of protons, is now being formulated.

LAMPF Data Analysis Center (DAC)

J. F. Harrison, A. G. Chavez, J. A. Faucett, E. Gavron, E. E. Martinez, W. K. Nissen, P. A. Rose, and C. J. Tregellas (Los Alamos)

The LAMPF Data Analysis Center (DAC) has steadily been expanding to meet the needs of the LAMPF user community. This is being accomplished by removing obsolete hardware, upgrading some hardware, and adding new hardware, providing additional software packages, and providing connections to external computer networks.

During the last three years the remaining VAX 11/780 computers have been replaced with a second VAX 8600 computer and the two VAX 8600 computers were replaced with two VAX 8650 computers, each with about six times the computing power of a VAX 11/780. This has allowed the DAC to considerably improve the response time for interactive users and reduce the turn around time of batch jobs significantly as well as provide additional computing capacity. With LAMPF's reduced support for the RSX11M operating system, the two PDP 11/70 computers were replaced with one PDP 11/44 computer, which is available for those users who still need to access a computer running RSX11M.

A VAX 8700 computer was bought for the LAMPF Control System (LCS) to increase response time and to increase throughput. When the capacity of the VAX 8700 is not required for tuning or monitoring the LAMPF accelerator, the additional CPU cycles have been made available for DAC users with computer-intensive batch jobs. Access to the VAX 8700 is made available upon request. One of the disk drives (456 MB) on the LCS computer cluster is available for these users.

As the CPU speed of the computers increases, additional disk capacity is required. All of the old removable disk drives have been eliminated and replaced with Winchester disk drives. We currently have 16 RA82 disk drives (622 MB per drive), 15 RA81 disk drives (456 MB per drive), and two RP07 disk drives (516 MB per drive) for a total of 17.8 GB of disk memory. Only the part of the disk space that is allocated for system files and user "permanent" files is backed up on a regular basis. The remaining space is reserved for scratch, most of which is allocated for temporary files that are deleted after three days. This temporary scratch space is intended to store data from experiments that will be analyzed by batch jobs and for the output data from the analysis. At present, approximately half of the disk capacity is reserved for scratch space.

To provide the DAC users with the capability of reading industry-standard nine-track magnetic tape, the DAC houses three 6250/1600/800 bpi tape drives, five 6250/1600 bpi tape drives, and six 1600/800 bpi tape drives. All of these drives are start/stop tape drives and run at 125 in./sec.

The two VAX 8650 computers are clustered using Digital Equipment Corporation's computer interconnect hardware. Also in this cluster are four Hierarchical Storage Controllers (HSC50). The RA series disks are connected to the HSC50 controllers to provide central file storage capability for the cluster. Three of the 6250/1600 bpi tape drives are also connected to HSC50 controllers.

The DAC supports an Ethernet network, which runs from the LAMPF Laboratory Office Building (LOB) to all the experimental areas. Connected to the Ethernet are the DAC VAX computers, computers in the LOB, and MicroVAX computers in the counting houses. The LCS Ethernet is bridged to the DAC Ethernet so that DAC users with accounts on the LCS VAX 8700 can conveniently transfer files back and forth between the DAC and the VAX 8700. The P-LANSCE Ethernet is also bridged to the DAC network so that LANSCE users can have easy access to the DAC resources.

Each of the VAX 8650 computers has the capability of supporting the direct connection of 48 terminals through the Micom Port Selector. Users whose terminals are not connected to the Port Selector are connected to one of several DECserver local-area terminal servers. These DECservers are connected to LAMPF's Ethernet networks and are located at several convenient locations at LAMPF. DECservers provide the capability for terminals to directly connect not only to the DAC computers, but also directly to data acquisition computers. DECservers in the DAC are also used to support dial-in modems. Hence, users can dial the DAC and access the data acquisition computers, allowing the monitoring of experiments from locations other than the counting houses.

Another use of DECservers is to support printers and plotters. These printers and plotters have been installed at many locations throughout LAMPF so that users do not have to go to the DAC for their paper output. These output devices can be accessed by any of the LAMPF computers connected to LAMPF's networks. Because they are not connected directly to a specific computer, these devices are available even if a computer goes down.

The DAC supports some of MP Division's needs for word processing by supporting the TeX text processing language, providing standard laser printers and PostScript laser printers at convenient locations, and by supporting video terminals with TeX previewing capabilities. Since TeX is not an editor, any of the text editors supported by the DAC can be used to edit TeX input files.

In addition to the TeX software package, there are many other software packages and libraries that are available to DAC users. These include most of the graphics and math packages supported by C Division for the VMS operating system; libraries from CERN; graphics packages from TRIUMF; the INGRES database system; EUNICE, which is a UNIX shell running on top of VMS; CALOUT, which allows DAC users to dial out and connect to other computers; TEAMWORK from Cadre, which is a computer-assisted software engineering package; and several software products from Digital Equipment Corporation (DEC). This DEC software provides not only language compilers such as FORTRAN, PASCAL, BASIC, and BLISS; but also software engineering support tools such as CMS (code management system), MMS (module management system), PCA (performance and coverage analyzer), SCA (source code analyzer), LSE (language sensitive editor), and a test manager. A spread-sheet program called DECalc is also available. Another useful DEC software product recently added to the DAC is VAX Notes, which provides a conferencing (i.e., bulletin board) capability.

Several local AppleTalk networks have been installed at LAMPF to support the increasing number of Apple Macintosh computers and Apple LaserWriters in use at LAMPF. An investigation has been started to provide a means of connecting these AppleTalk networks, as well as stand alone Apple Macintosh computers and IBM PC computers, to the DAC. To support these additional capabilities and other DAC connectivity requirements, the DAC Ethernet network continues to be expanded.

The DAC now provides support for the following wide area networks: BITNET, which is a network connecting many universities, national labs, and several European institutions; MFENET (ESNET), which started out as the magnetic-fusion-energy network and is becoming the Energy Sciences Network; and HEPNET (ESNET/DECNET), which started out as the high-energy-physics network and is now being integrated into ESNET. Connections to additional networks such as TECHNET, ARPANET, and SPAN are available through C Division. C Division also provides support for the Lab-wide XNET (eXtended NETwork).

LAMPF Control System (LCS)

J. F. Harrison, E. A. Bjorklund, M. J. Burns, G. P. Carr, J. E. Cavanaugh, P. A. Rose, Stuart C. Schaller, and D. E. Schultz (Los Alamos)

The upgrade of the LAMPF Control System from an SEL 840 and multiple PDP-11 computers to more modern VAX and MicroVAX computers is essentially complete. All that remains is the replacement of one remaining MicroPDP-11 (RIU-11) scheduled for the 1989–90 shutdown. All of the control software has been completely rewritten and has been running successfully for the past two years on the VAX-based LCS. However, this software is still being improved as hardware changes and as enhancements are requested.

One of the two VAX 11/780 control computers, which was used for the 1987 run cycles, was replaced for the 1988 run cycles with a VAX 8700 that is about six times faster than a VAX 11/780. The VAX 8700 was installed just in time for startup of the accelerator and it improved the response of the control system by better than a factor of two and increased the throughput of the system by approximately a factor of six. This increase in throughput allowed the operators and accelerator physicists to use all the operator consoles effectively during tuning. They were also able to tune the accelerator more quickly because some of the computer intensive-tuning applications run significantly faster. The VAX 8700 has indeed been a welcome addition to the LCS.

The other computer hardware in the LCS consists of six remote diskless MicroVAX computers, the RIU-11, and two disk-based MicroVAX computers. All of the MicroVAX computers, except for one of the diskless MicroVAX computers, have been installed in the last two years. The MicroVAX and VAX computers are connected via an Ethernet LAN running from one end of the accelerator to the other.

The remote computers are MicroVAX II computers and they run the VAX ELN real-time operating system. These systems are downline loaded from one of the control computers. They are used to interface to CAMAC based hardware in the transport area (TA computer), transition region (TR computer), Line B area (LB computer), Area A (XA computer), and switch yard (SY computer). The remote computer MT in the central control room (CCR) controls the master timer. The master timer generates all the timing signals for the accelerator.

The two disk-based VAX computers are MicroVAX II computers and run the VAX VMS operating system. They are used to control two of the three LAMPF ion sources—the H^- ion source (IB computer, Injector B) and the P^- ion source (IC computer, Injector C). The software running on these systems is a subset of the LCS so that these computers can be run without the main control system running. However, these systems are connected to the LCS Ethernet and thus the data for the injectors can be accessed by the main control computers. In addition to these two disk-based computers, there are two other disk-based MicroVAX II computers that are not directly part of the control system, but are connected to the LCS Ethernet and run the LCS software. One is used to control the ion source test stand (ISTS), and the other is used for control system development (MCCR).

The RIU-11 is a MicroPDP 11/73 that runs RSX11M. It is used by the VAX control computers to communicate with the Remote Information and Control Equipment (RICE) hardware. The RIU-11 is connected to the two VAX control computers via point-to-point links. When this is replaced with a MicroVAX computer, any computer on the network will be able to access RICE data directly because the point-to-point links will be replaced with an Ethernet connection.

The two control computers, the VAX 8700 and VAX 11/780, are connected to two hierarchical storage controllers (HSC50) via the computer interconnect (CI). The two HSC50 controllers are each connected to nine RA81 disk drives (456 MB per drive) and two TA81 streaming tape drives. One of the goals of the current control system is to eliminate single points of failure that could bring the whole control system down. Having two control computers and two HSC50 controllers reduces this possibility.

The control system contains three operator consoles and two program-development consoles. The program-development consoles are a subset of the operator consoles. The computer-related operator console hardware consists of a color CRT and keyboard (with trackball) interfaced via CAMAC, three RS232 graphics terminals, two RS232 touch-panel terminals (VT100 with touch-panel interfaces), and two knob panels (three knobs per panel), also interfaced via CAMAC. The VAX software for the color CRT/keyboard is unique in that it can be shared among multiple software applications.

One of the major improvements to the operator consoles was the capability of good fast hard copy of the graphics terminals. A laser printer was connected directly to the Ethernet so that hard copy could be directed to it from any of the graphics terminals. Hard copies can be generated in 20 to 40 seconds depending upon the complexity of the graphics image. Another laser printer was added as a report printer so that applications programs could generate good hard copy containing status information.

In addition to the enhancements to many of the LCS application programs, improvements were made to the LCS data system that allowed universal access to accelerator data. This means that the control computers including IB, IC, ISTS, and MCCR can access data from any computer on the network. This also means that data from the PSR control system can be accessed by the control computers in the CCR. Using the LCS application program DATASCAN, which is used to record and monitor devices on predefined time intervals, problems with the PSR Line-D magnets were discovered and corrected.

With the reorganization of MP Division, the PSR controls section and the LCS section were merged into one section called the Control Systems section. The configuration of the LAMPF Control System is shown in Fig. 1. People working in the controls section during 1988 were: Ray V. Poore (section leader), Eric A. Bjorklund, Janis F. Builta, Mary J. Burns, Lorie L. Byrnes, Timothy N. Callaway, Gary P. Carr, Joseph E. Cavanaugh, Ehud Gavron, James F. Harrison, Margye P. Harrington, Franz Krafft, Deborah A. Kubicek, Patricia A. Rose, Stuart C. Schaller, David E. Schultz, Thaddeus C. Stevens, Robert B. Stuewe, and Robert T. Westervelt.

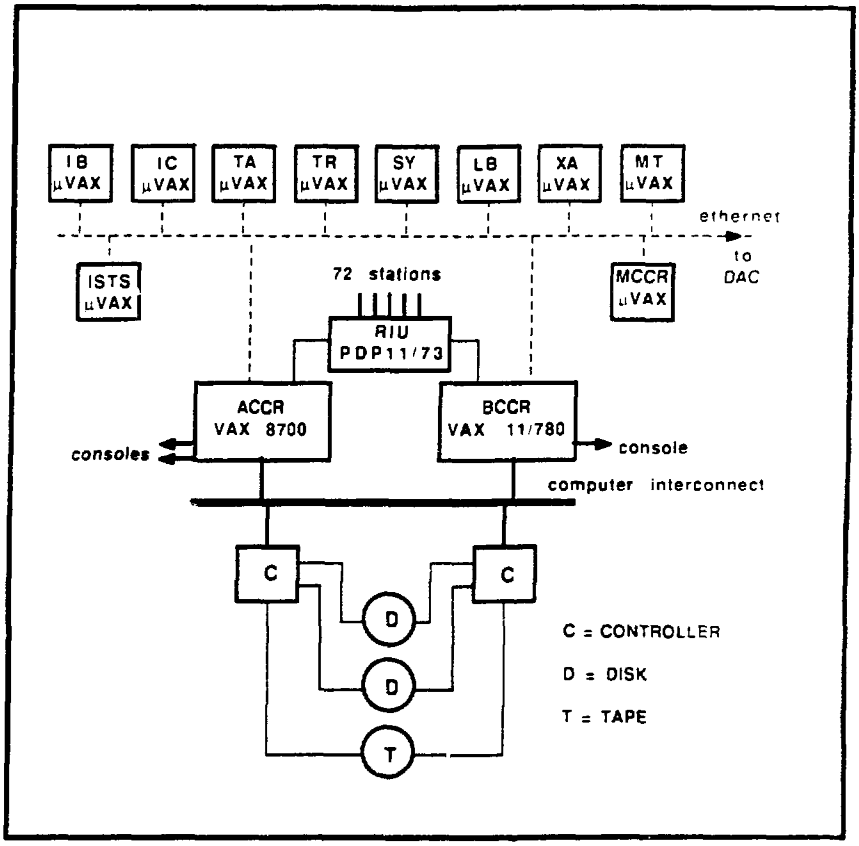


Fig. 1. Configuration of the LAMPF Control System.

Circular Machines

H. A. Thiessen (Los Alamos)

Several projects of mutual interest to the TRIUMF KAON initiative are under way with the LAMPF PSR and AHF development teams.

A major effort is the ferrite-tuned accelerating cavity as described in last year's "Progress at LAMPF" (1987). A 50-MHz cavity suitable for the main ring in a new machine at LAMPF or TRIUMF was built here and will be tested in the PSR this year. These tests will include:

(1) beam loading;

(2) beam stability with a high Q cavity;

(3) painting in longitudinal and transverse phase space; and

(4) synchrotron-betatron oscillations.

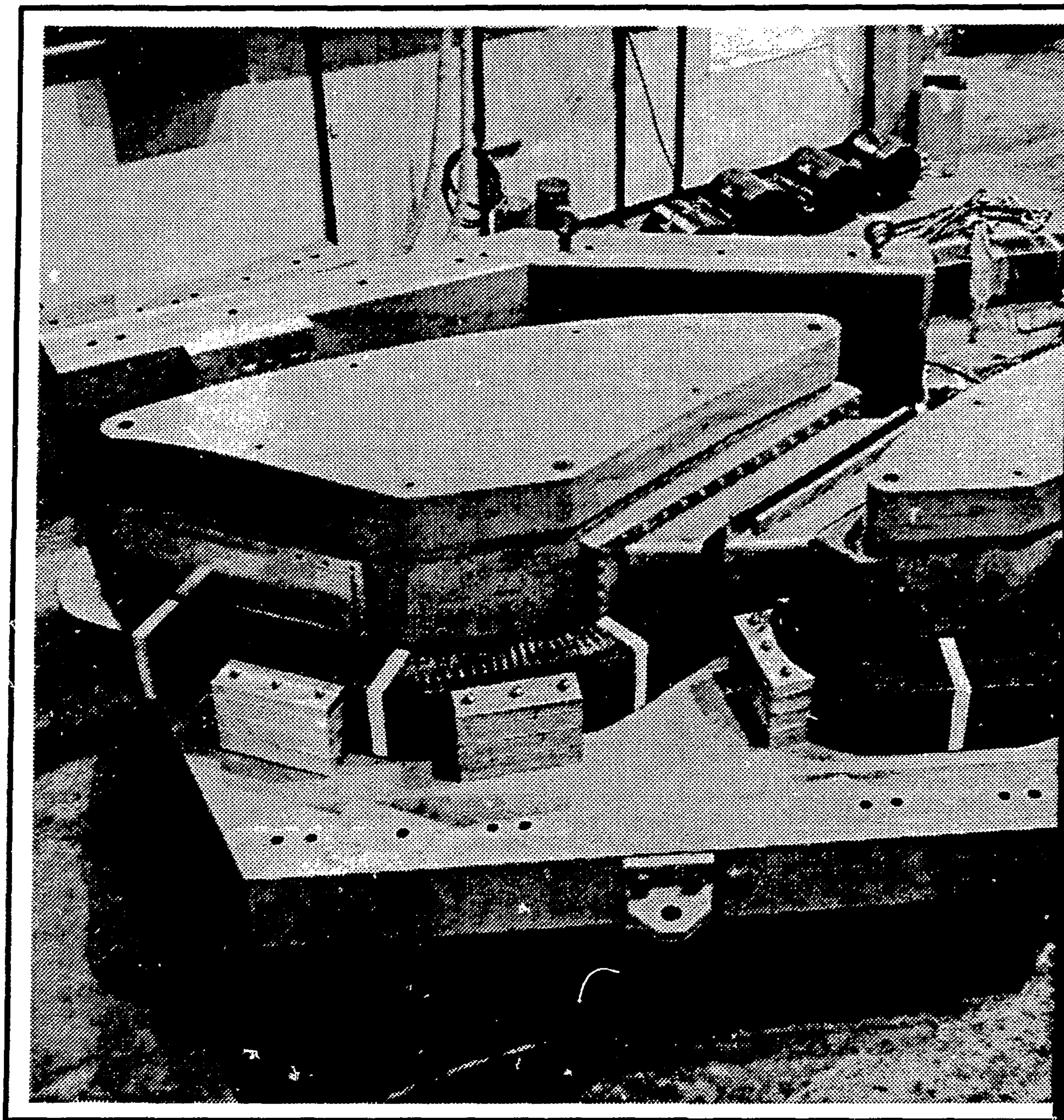
The TRIUMF group will supply a transistorized driver amplifier.

A second phase in ceramic vacuum-chamber development will be completed in the next 18 months. Three development-model ceramic pipes will be delivered. The first will be a striped pipe with blocking capacitors on each pipe. The second will be a pipe one-meter long with all connections and flanges appropriate for use in a synchrotron. The third pipe will be a three-meter long unit, which is curved to match the bending radius of a booster synchrotron. The goal of these developments demonstrates the feasibility of using ceramic vacuum chambers with integral conducting stripes in a rapid-cycling synchrotron.

In collaboration with TRIUMF, several BPM processing schemes were tested at PSR. These included narrow-band detection at 2.8 MHz and amplitude-to-phase modulation conversion near 2.8 MHz. Both schemes work, but neither had sufficient sensitivity to obtain a beam position from the first injected turn. (It is necessary to see the first turn in order to verify the injection orbit.) Further tests will be conducted during the next running period of the PSR.

The AHF design group will turn its attention to creating a menu of accelerator design options, which cover the range from a modest stand-alone kaon factory to a full 60-GeV design with combined spallation source. For each option, we will develop a technical design and preliminary cost estimate. This design effort started with an international accelerator workshop in Los Alamos, in February 1988, and will continue with a second workshop in February 1989.

After the completion of the first design study, it will be necessary to start work on a proof-of-principle high-field magnet and power supply. The high-energy (45–60 GeV) kaon factory requires 17–22 kilogauss bending magnets for the main ring. Rapid-cycling magnets of such a high field have not previously been used in synchrotrons. A second development will be work on either a mass-less magnetic septum or a thin-wire electrostatic septum for the slow extraction system for any of the proposed options.



Accelerator Operations

Accelerator Operations

David Helfer (Los Alamos)

This report covers operating cycles 51 and 52. The accelerator was in operation from June 6 through October 11, 1988. Beams were provided for research use for 112 days, and for facility development for five days. The accelerator was operated for an additional five days to provide low-duty low-energy beam to the HIRAB facility for neutral particle beam development. A summary of information on beams provided for research is given in Table I.

Table I. Beam Statistics for Cycles 51 and 52.

	Cycle 51	*Cycle 52*
No. of experiments served[a]	19	30
H^+ scheduled beam hours	1144	1432
H^- PSR scheduled beam hours	1140	1352
H^- Line X scheduled beam hours	0	352
P^- Line X scheduled beam hours	1127	1009
H^+ beam availability (%)	77	81
H^- PSR beam availability (%)	77	80
H^- Line X beam availability (%)	—	77
P^- Line X beam availability (%)	74	71
H^+ average current (μA)	947	948
H^- PSR average current (μA)	35	35
H^- Line X average current (μA)	—	1
P^- Line X average current (nA)	10	10
H^+ beam duty factor (%)	6.0	6.0
H^- PSR beam duty factor (%)	0.5	0.5
H^- Line X beam duty factor (%)	—	1.9
P^- Line X beam duty factor (%)	3.0	3.0

[a]Does not include experiments performed at the PSR-LANSCE/WNR areas.

Two significant changes were made during the shutdown. A low-power RCA 4664 tube had been used in the first module in the drift-tube linac. However, problems obtaining spare tubes necessitated a conversion from an RCA 4664 tube to a much higher power 7835 tube. The 7835 tube is used as the final amplifier stage in the other drift-tube modules, thus making all four modules the same.

During the shutdown one of the Digital Equipment Corp. VAX 11/780 computers in the LAMPF control system was replaced by a VAX 8700. The increased computing capacity shown by the 8700 has improved response time for control of the accelerator.

During CY 1988 neutrons were delivered down the 600-m flight path of the NTOF (Neutron Time of Flight) facility for the first time. No major problems were encountered.

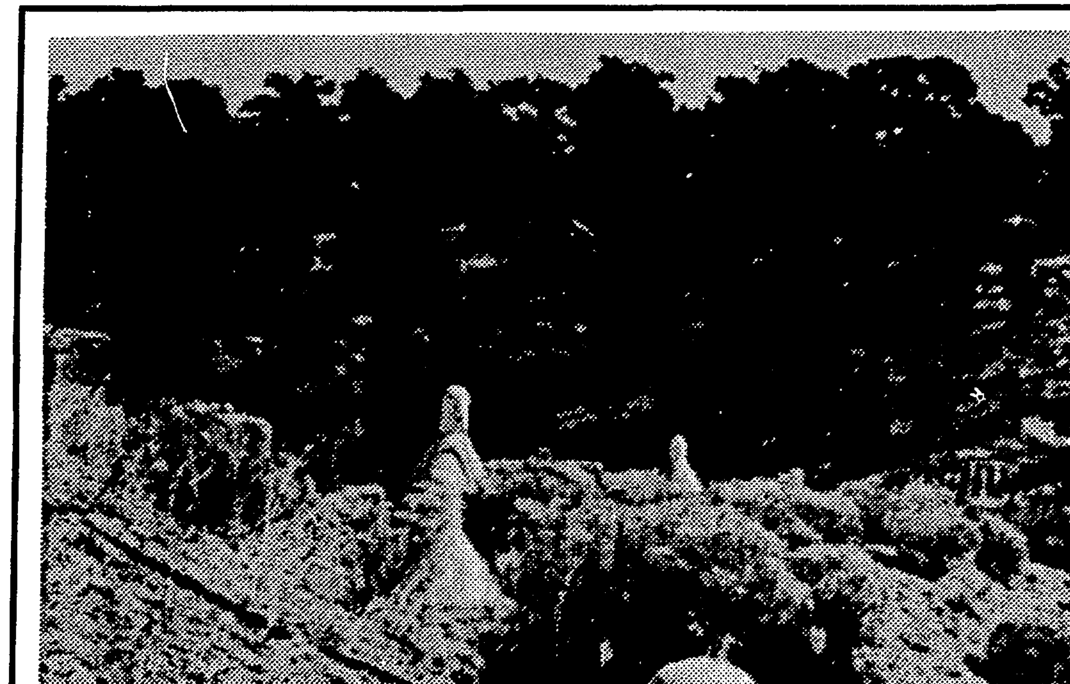
A summary of unscheduled facility downtime during research shifts is given in Table II. Because some of the outages are concurrent, and because some affected only one of the three beams, the total is much greater than the beam downtime.

Table II. Unscheduled Machine Downtime.

Category	*Downtime (h)*	*Percent of Total*
201-MHz amplifiers and transmission lines	220	27
805-MHz amplifier systems	96	12
Vacuum systems	44	5
Magnets	29	4
Magnet power supplies	36	4
Interlocks	15	2
Ion sources and Cockcroft-Walton high-voltage supplies	268	33
Cooling water systems	40	5
Computer control and data acquisition	5	—
Production targets	33	4
Pulse-timing systems	5	—
Miscellaneous (utilities, power interruptions from lightning, etc.)	26	3
TOTAL	822	

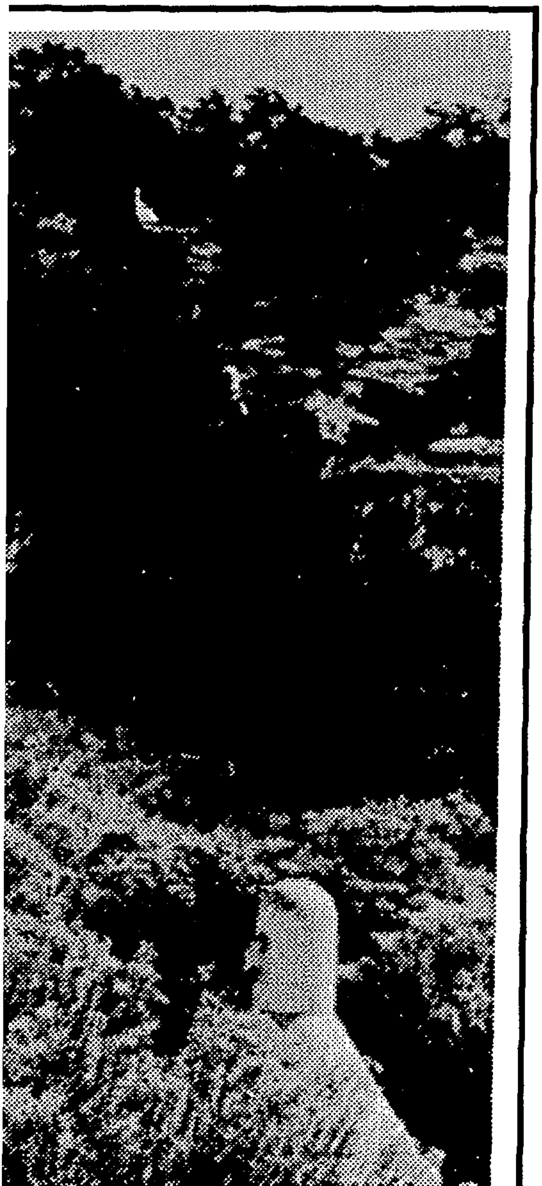
The high downtime attributed to the 201-MHz amplifier systems was primarily from vacuum problems with Module 3 and installation problems with the 7835 high-power amplifier in Module 4. The amplifier installation problems have been resolved and the vacuum problem has been greatly reduced with the installation of an extra 2000 liter-per-second ion-pump.

The P^- source was recycled on an as-needed basis rather than in a (non-downtime impacting) prescheduled mode. This contributed 100 hours to the downtime figures. An excessive arcdown rate on the H^- source 80-kV column also contributed to the high unscheduled downtime.



Photograph by Rick Bolton

Milestones



MILESTONES

CLINTON P. ANDERSON
MESON PHYSICS
FACILITY

1968

Official Ground Breaking	February 15, 1968
Spinoff: Adoption of LAMPF Accelerating Structure for X-Ray Therapy and Radiography Machines	*ca* 1968

1970

5-MeV Beam Achieved	June 10, 1970
Adoption of a LAMPF Standard Data-Acquisition System	August 1970

1971

100-MeV Beam Achieved	June 21, 1971
211-MeV Beam Achieved	August 27, 1971

1972

800-MeV Beam Achieved	June 9, 1972
Spinoff: First Use of Electrosurgical Forceps in Open-Heart Surgery (University of New Mexico)	September 13, 1972
Discovery of ^{236}Th (Experiment Zero)	September 25, 1972
Dedication to Senator Clinton P. Anderson	September 29, 1972
Spinoff: First Hyperthermic Treatment of Animal Tumors	October 1972

1973

First H^- Injector Beam	March 28, 1973
First Simultaneous H^+ and H^- Beams	May 4, 1973
Beam to Area B	July 15, 1973
First Experiment (#56) Received Beam	August 24, 1973
First Meson Production, Beam to Area A	August 26, 1973

1974

Beam to Area A-East	February 6, 1974
First Medical Radioisotope Shipment	July 30, 1974
Usable 100-μA Beam to Switchyard	September 5, 1974
Pi-Mesic Atoms with "Ticklish" Nuclei	October 13, 1974
First Experimental Pion Radiotherapy	October 21, 1974
First Tritium Experiment (80 000 Ci)	November 1974
Start of Great Shutdown	December 24, 1974

1975

New Precise Measurements of Muonium Hyperfine Structure Interval and μ^+ Magnetic Moment	1975-77-80
Q Data-Acquisition Software Operational	June 1975
Spinoff: First Use of ^{82}Rb for Myocardial Imaging in Humans (Donner Lab, Lawrence Berkeley National Laboratory)	June 1975
Spinoff: First Hyperthermic Treatment of Human Cancer (University of New Mexico)	July 11, 1975
Accelerator Turnon	August 1, 1975
Acceptable Simultaneous 100-μA H^+ and 3-μA H^- Beams to Switchyard	September 14, 1975
Production Beam to Area B	October 7, 1975

1976

First Pions Through EPICS	March 18, 1976
Production Beam in Areas A and A-East: End of Great Shutdown	April 5, 1976
Muon-Spin-Relaxation Program	June 1976
Spinoff: First Hyperthermic Treatment of Cancer Eye in Cattle (Jicarilla Reservation)	June 3, 1976
100-μA Production Beam in Area A	August 1976
Experiment in Atomic Physics (H^- + laser beam): Observation of Feshbach and Shape Resonances in H^-	October 1976
Double Charge Exchange in ^{16}O: LEP Channel	October 5, 1976
Startup of Isotope Production Facility	October 15, 1976
HRS Operation Begins	November 1976
Maintenance by "Monitor" System of Remote Handling	Fall 1976

1977

Proton Beam to WNR	March 12, 1977
Polarized-Proton Beam Available	April 1977
Spinoff: First Practical-Applications Patent Licensed to Private Industry	April 12, 1977
Pion Radiotherapy with Curative Intent	May 1977
Proton-Computed Tomography Program	June 1977
Experimental Results at Neutrino Facility	July 1977
Cloud and Surface Muon Beams: SMC	July 1977
EPICS Operation Begins	August 1977
300-μA Production Beam in Area A	Fall 1977

1978

AT Division Established	January 1, 1978
π^0 Spectrometer Begins Operation	February 1978
Operation of Polarized-Proton Target	Spring 1978
Successful Water-Cooled Graphite Production Target	November 1978

1979

Spinoff: First Thermal Modification of Human Cornea (University of Oklahoma)	July 11, 1979
600-μA Production Beam in Area A	November 1979
New Limit on $\mu \rightarrow e\gamma$	December 1979

1980

Experimental Measurement of the Strong-Interaction Shift in the $2p$-$1s$ Transition for Pionic Hydrogen	1980-81-82
Commercial Production of Radioisotopes	January 1980
Spin Precessor Begins Operation	February 1980
Data-Analysis Center Operational	April 1980
Variable-Energy Operation	June 1980
Single-Isobaric-Analog States in Heavy Nuclei	June 1980
Spinoff: First Use of ^{82}Rb for Brain Tumor Imaging in Humans (Donner Lab, Lawrence Berkeley Laboratory)	September 1980
Production of Fast Muonium in Vacuum	Fall 1980
Double-Isobaric-Analog States in Heavy Nuclei	October 1980
Focal-Plane Polarimeter Operational at HRS	October 1980
Safety Award to LAMPF Users Group, Inc., for Working One Million Man-Hours Since 1975 Without a Disabling Injury	October 27, 1980
New Measurement of Pion Beta Decay—Improved Test of Conserved-Vector Current	November 1980

1981

First Excitation of Giant Dipole Resonance by Pion Single Charge Exchange	March 1981
First Observation of Isovector Monopole Resonance in ^{120}Sn and ^{90}Zr by Pion Single Charge Exchange	March 1981
Negative Evidence for Critical Opalescence in ^{40}Ca	September 1981

1982

Average Beam Current of LAMPF Accelerator Established at 750 μA	1982
Staging Area Constructed	1982
"Dial-a-Spin" Capability on Line B Permits Different Spin Orientations for HRS, Line B, and EPB Simultaneously	1982
Improved Test of Time-Reversal Invariance in Strong Interactions by Comparison of the Polarization in the Reaction $pd \rightarrow \overrightarrow{n}pp$ with the Analyzing Power in the Interaction $n\overrightarrow{p} \rightarrow pn$	1982
dt Fusion Catalyzed by Muons	November 1982

1983

LAMPF Accelerator Produces Proton Beam of 1.2 mA	February 7, 1983
First Observation of ν_e-e^- Scattering	October 1983
Result for Asymmetry in $\overrightarrow{p}p$ Scattering Caused by Parity Violation: $A_L = (2.4 \pm 1.1) \times 10^{-7}$ at 800 MeV	November 1983

1984

Duty Factor $\geq$ 9% Achieved	February 1984
Total Cross Section for ν_e-e^- Scattering $\sigma_T = 10^{-44}\ E_\nu$ (GeV) cm^2	May 1984
Clamshell Spectrometer On Line	June 1984
High-Intensity H^- Source Operational	September 1984

1985

New Beam Stop Installed by Remote-Handling System	Spring 1985
High-Intensity H^- Injector Operational	April 1985
New Switchyard Permits Three-Beam Operation	April 1985
Proton Beam to Proton Storage Ring (PSR)	May 1985
Routine Production at Beam Current of 1 mA	Summer 1985
Precise Near-Threshold Measurements of $\pi^- p \rightarrow \pi^0 n$ Reaction	July 1985
η-Meson Production on Nuclei Observed Near Threshold	August 1985

17-mA Peak Current Achieved	September 1985
Precise Test of the Relativistic Doppler Effect at 0.84c by Collision of an Atomic Beam with Laser Light	1985

1986

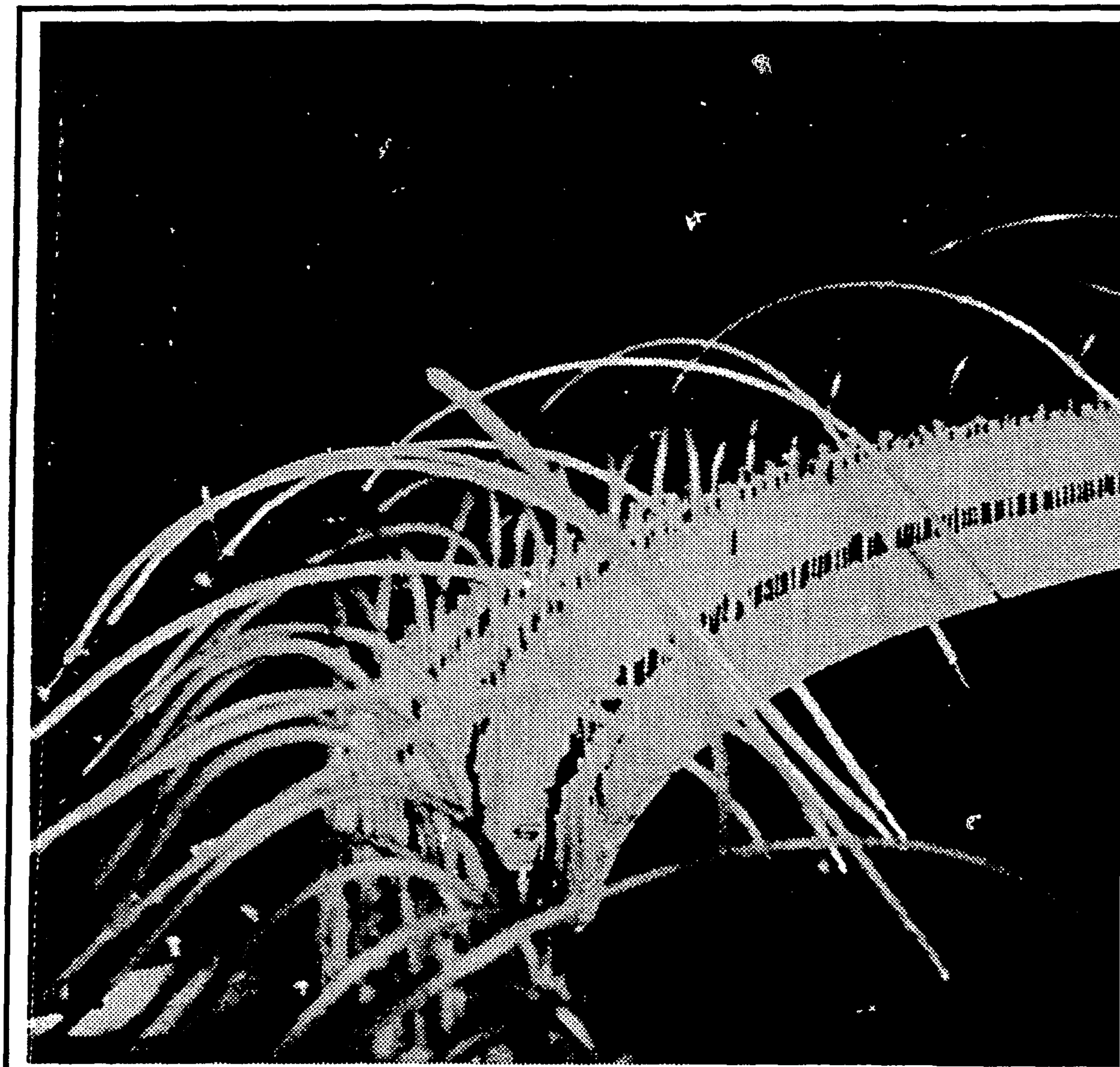
Verification of Destructive Interference Between the Charged-Weak and Neutral-Weak Amplitudes in ν_e Scattering (Exp. 225)	1986
Group MP-5 Formed to Maintain and Develop Line D and the Proton Storage Ring	1986
Masses of 12 New Isotopes Measured by TOFI System	1986
Polarized Beam Delivered with 10-MHz Micropulse Structure for Neutron Timing	1986

1987

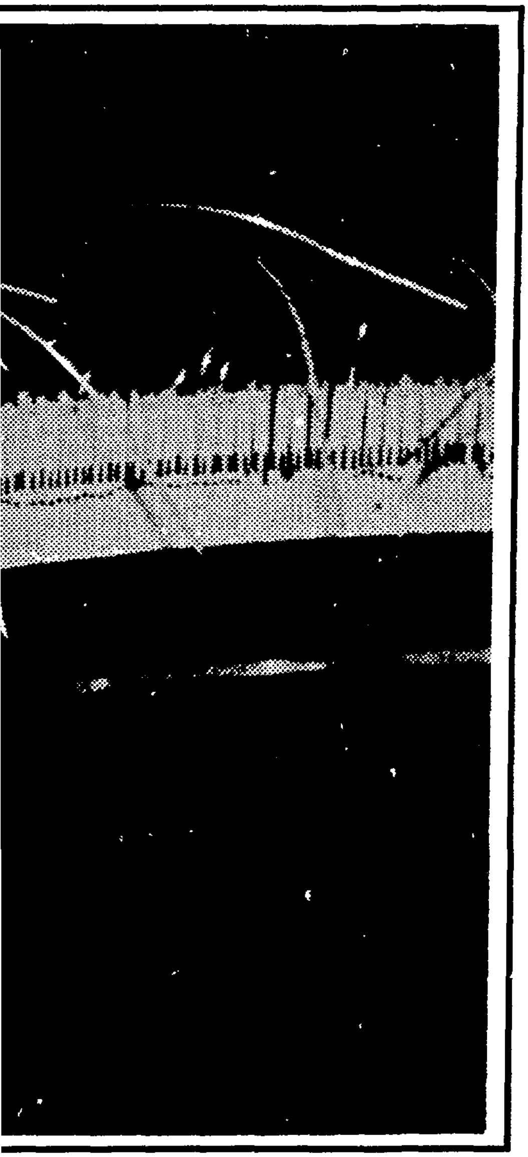
Neutron Time-of-Flight Facility Short-Flight-Path Commissioned (New Beam Line in NPL)	1987
Linac Rebuncher Scheme Implemented to Produce Time-Focused Micropulses at WNR and NTOF	1987
113-MeV Beam Delivered to WNR/Lowest Energy Delivered by LAMPF to an Experimental Area	1987
Operation with Three Beam Energies to Line A, Line D, and Line X	1987
Development of Medium-Resolution (0.2%) Tune for P^3	1987

1988

Polarized Nuclear Target Used in Research (^{13}C on HRS for Exp. 955)	1988
CYGNUS Experiment (Uses LAMPF Neutrino Detectors) Publishes Results on Muon Excess from Ultra-High-energy Cosmic Ray Showers	1988



Appendixes



Experiments Run in 1988

New Proposals During 1988

LAMPF Visitors During 1988

Information for Contributors

APPENDIX A: Experiments Run in 1988

Exp. No.	Channel	Beam Hours	Title
267	ISORAD	1888	Preparation of Radioisotopes for Medicine and the Physical Sciences Using the LAMPF Isotope Production Facility
645	Neutrino-A	2041	A Search for Neutrino Oscillations at LAMPF
849	P^3	594	A. Measurement of the Differential Cross Section on $\pi^- p \rightarrow \pi^0 n$ at 0° and 180° in the Momentum Region 471–687 MeV/c B. Test of Isospin Invariance
869	SMC	328	Higher Precision Measurement of the Lamb Shift in Muonium
872	TTA	348	Direct Atomic Mass Measurements of Neutron-Rich Isotopes in the Region Z = 13–17 Using the Time-of-Flight Isochronous Spectrometer
903	HRS	91	A Study of Transition Nuclei in the Rare Earth Region by Proton Inelastic Scattering
917	P^3	122	Pion Charge Exchange to Delta-Hole States of Complex Nuclei
955	HRS	458	Search for Experimental Proof of the Existence of Lower Components in the Nuclear Wave Function
960	BR	711	Measurement of $\Delta\sigma_L$ and $\Delta\sigma_T$ in Free Neutron-Proton Scattering Between 300 and 800 MeV
963	SMC	222	Experimental Investigation of Muon Catalysis
964	EPICS	174	Study of (π^-, p) and (π^+, p) Reactions with EPICS
969	SMC	671	MEGA—Search for the Rare Decay $\mu^+ \rightarrow e^+\gamma$
978	P^3	161	A Coincidence Measurement of Pion Double Charge Exchange: $^4\text{He}(\pi^+, \pi^- p)^3p$
981	EPICS	534	Do Bound States of Real Pions Exist?

Exp. No.	Channel	Beam Hours	Title
1016	EPICS	238	Inelastic Pion Scattering From ^{27}Al and ^{28,29}Si
1026	P^3	102	A Study of the ^{3}H(π^+, π^0)^{3}He Reaction
1027	HRS	58	Development of a High Energy Polarimeter Based on Coulomb-Nuclear Interference and Measurement of the Spin-Averaged Slope Parameter for *pp* Elastic Scattering Between 1.1 and 1.5 GeV/*c*
1030	HRS	10	Preliminary Search for Recoil Free Δ Production in the ^{208}Pb(p,^{3}He) Reaction
1032	EPICS	243	π^+ and π^- Elastic Scattering on Tritium and ^{3}He around 78°
1038	EPICS	124	Pion Inelastic Scattering from ^{48}Ti, ^{52}Cr, and ^{56}Fe at 180 MeV: A Study of Anomalously Shaped Angular Distributions
1050	EPICS	451	A Search for Analog-Dipole and Double-Dipole Excitations using Pion Double Charge Exchange
1052	BR	284	Calibration of the LAMPF Neutron Time-of-Flight Facility Detector System Using a Tagged Neutron Beam
1062	NTOF	0	Study of Pure Fermi and Gamow-Teller Transitions in the ^{14}C(p, n)^{14}N Reaction
1069	LEP	472	Low-Energy Pion Single-Charge Exchange on ^{14}C to Resolved Low-Lying States
1072	MRS	732	*pp* Elastic Absolute Cross Section
1073	SMC	590	Measurement of Muonium to Antimuonium Conversion with Improved Sensitivity
1075	HIRAB	258	Photodetachment of H$^-$ Near Threshold in an Electric Field, "An Atomic Interferometer"
1079	HRS	20	Development of Experimental Techniques to Study Relativistic Effects in Proton-Nucleus Elastic Scattering at Forward Angles

Exp. No.	Channel	Beam Hours	Title
1080	HRS	120	The Longitudinal/Transverse Decomposition of the Enhanced Nuclear Spin Response in ^{40}Ca
1083	EPICS	219	Elastic Scattering of π^+ and π^- from ^4He at Far Forward Angles
1085	LEP	613	Total and Differential Cross Sections for $\pi d \rightarrow pp$ Below 20 MeV
1096	LEP	396	Study of $(\pi NN)_{T=2}$ Bound System by $d(\pi^\pm, \pi^\mp)$
1098	LEP	376	Energy Dependence of Low-Energy Double-Charge Exchange
1100	TTA	1255	Mass Measurements of Neutron-Rich Nuclei with Z = 18–32
1106	P^3	376	Study of Pion-Nucleus Elastic Scattering at Energies Above the Δ Resonance
1107	P^3	540	Studies of Pion Double Charge Exchange Scattering at Energies Above the Δ Resonance
1115	SMC	122	Characterization of High-Temperature Superconductors by Muon Spin Relaxation
1119	MRS	101	Unpolarized Differential Cross Section for Proton-Deuteron Elastic Scattering at Intermediate Energies
1135	HRS	40	Feasibility Study of Tagged Eta Meson Production in $p + {}^3H \rightarrow {}^4He + \eta$

APPENDIX B: New Proposals During 1988

Exp. No.	Spokesperson	Title
1093	C. F. Moore Univ. of Texas, Austin S. Mordechai Ben-Gurion Univ.	Search for Double Resonances Using High-Energy Pion Double Charge Exchange
1094	F. T. Baker Univ. of Georgia	Extended Angular Range of S_{nn} Measurements in ^{40}Ca
1095	C. F. Moore Univ. of Texas, Austin C. L. Morris Los Alamos E. Piasetzky Tel Aviv Univ.	A Search for $T = 2$ Dibaryons via a Coincidence Measurement of the $p(p, X^{+++})\pi^-$ Reaction
1096	C. L. Morris Los Alamos D. Ashery Tel Aviv Univ.	Study of $(\pi NN)_{T=2}$ Bound System by $d(\pi^{\pm}, \pi^{\mp})$
1097	D. L. Adams Rice Univ. G. Mutchler Rice Univ. N. E. Davison Univ. of Manitoba P. J. Riley Univ. of Texas, Austin	Single Pion Production in *np* Scattering
1098	H. W. Baer Los Alamos M. J. Leitch Los Alamos Z. Weinfeld Tel Aviv Univ.	Energy Dependence of Low-Energy Double-Charge Exchange
1099	G. J. Igo UCLA	Unpolarized Differential Cross Section for Proton-Deuteron Elastic Scattering at Intermediate Energies
1100	J. M. Wouters Los Alamos	Mass Measurements of Neutron-Rich Nuclei with $Z = 18–32$

Exp. No.	Spokesperson	Title
1101	A. Fazely Lousiana State Univ. A. I. Yavin Tel Aviv Univ.	A Search for a Possible (πN) Bound System with Pion Double Charge Exchange Reaction on a Proton
1102	A. Fazely Lousiana State Univ. H. T. Fortune Univ. of Pennsylvania L. C. Liu Los Alamos	Study of Pion Double Charge Exchange Reactions on Se Isotopes
1103	A. L. Williams Univ. of Texas, Austin C. F. Moore Univ. of Texas, Austin S. Mordechai Ben-Gurion Univ.	Measurement of the Ratio of $(\pi^+, \pi+')$ vs $(\pi^-, \pi^{-'})$ at $T_\pi = 450$ MeV on ^{13}C, ^{14}C, and ^{15}N
1104	S. J. Seestrom-Morris Los Alamos	Study of the Giant Quadrupole Resonance by High-Energy Pion Scattering
1105	C. L. Morris Los Alamos S. H. Yoo Univ. of Texas, Austin	$(\pi, \pi' p)$ Coincidence Measurement Above Particle Emission Threshold
1106	J. A. McGill Los Alamos K. S. Dhuga George Washington Univ.	Study of Pion-Nucleus Elastic Scattering at Energies Above the Δ Resonance
1107	G. R. Burleson New Mexico State Univ.	Studies of Pion Double Charge Exchange Scattering at Energies Above the Δ Resonance
1108	C. F. Moore Univ. of Texas, Austin C. L. Morris Los Alamos J. Lichtenstadt Tel Aviv Univ.	The $p(p, \pi^-)X^{+++}$ Reaction—A Search for $T = 2$ Dibaryons
1109	R. J. Peterson Univ. of Colorado	Pion-Induced Fission

Exp. No.	Spokesperson	Title
1110	J. D. Bowman Los Alamos R. J. Peterson Univ. of Colorado	Spin-Isospin Studies with a High-Resolution Neutral Meson Spectrometer
1111	D. K. Dehnhard Univ. of Minnesota L. J. Rybarcyk Los Alamos S. K. Nanda CEBAF S. M. Sterbenz Univ. of Minnesota	The $^{4}He(\vec{p},\vec{n})^{4}Li$ Reaction at 500 MeV
1112	K. K. Seth Northwestern Univ.	Analog DCX on ^{48}Ca at 50 MeV
1113	J. D. Silk Univ. of Pennsylvania	The $^{12}C(\pi, \pi pp)$ Reaction
1114	C. Pillai UCLA C. S. Mishra Los Alamos D. F. Barlow UCLA J. A. Wightman UCLA	Production of Tagged Eta Mesons by the Reaction $p + {}^{3}He \rightarrow {}^{4}He + \eta$
1115	C. Boekema San Jose State Univ. D. W. Cooke Los Alamos	Characterization of High-Temperature Superconductors by Muon Spin Relaxation
1116	F. Clinard Los Alamos	Insulator Research for Space Reactor
1117	B. G. Ritchie Arizona State Univ. D. S. Oakley Univ. of Colorado R. J. Peterson Univ. of Colorado	Interfering Amplitudes in Spin-Isospin Inelastic Scattering at Low Pion Beam Energies

Exp. No.	Spokesperson	Title
1118	C. F. Moore Univ. of Texas, Austin S. Mordechai Ben-Gurion Univ.	Isospin Splitting of Isovector Resonances in Pion Double Charge Exchange
1119	E. Gulmez UCLA	Unpolarized Differential Cross Section for Proton-Deuteron Elastic Scattering at Intermediate Energies
1120	J. D. Silk Univ. of Pennsylvania	Coincidence Study of Two-Step Pion-Induced Reactions
1121	J. B. Donahue Los Alamos P. G. Harris Univ. of New Mexico	High Excitations and Double Escape in the Negative Hydrogen Ion
1122	H. T. Fortune Univ. of Pennsylvania K. W. Johnson Univ. of Texas, Austin S. Mordechai Ben-Gurion Univ.	Mass Dependence of the Giant Dipole Resonance Built on the Isobaric Analog State
1123	C. A. Whitten UCLA	Measurement of Gamow-Teller Strength in the $^{16}O(p, n)^{16}F$ Reaction
1124	G. J. Igo UCLA	Measurement of Correlated Spin Asymmetries and Spin Transfer Observables in 800 MeV Proton-Deuteron Elastic Scattering Using the Medium Resolution Spectrometer with $\hat{N}$ and $\hat{S}$ type Polarized Deuteron Targets
1125	C. F. Moore Univ. of Texas, Austin C. L. Morris Los Alamos	Pion Elastic and Inelastic Scattering from Self-Conjugate Nuclei at 180 MeV
1126	L. C. Smith Univ. of Virginia R. C. Minehart Univ. of Virginia	Two-Nucleon Pion Absorption in ^{4}He

Exp. No.	Spokesperson	Title
1127	C. R. Quick Los Alamos H. C. Bryant Univ. of New Mexico	Multiphoton Detachment of Electrons from the H^- Ion
1128	A. Fazely Louisiana State Univ. H. T. Fortune Univ. of Pennsylvania S. Mordechai Ben-Gurion Univ.	Effects of Two-Nucleon Collectivity on Double Charge Exchange
1129	C. L. Morris Los Alamos J. N. Knudson Los Alamos	Search for Neutral Pions from the Spontaneous Fission of ^{252}Cf
1130	A. Fazely Louisiana State Univ. H. T. Fortune Univ. of Pennsylvania L. C. Liu Los Alamos	Study of Low-Energy Pion Double Charge Exchange Reactions $^{128}\mathrm{Te}(\pi^+,\pi^-)^{128}\mathrm{Xe}$(g.s.) and $^{130}\mathrm{Te}(\pi^+,\pi^-)^{130}\mathrm{Xe}$(g.s.)
1131	C. Glashausser Rutgers Univ. G. W. Hoffmann Univ. of Texas, Austin K. W. Jones Los Alamos	Measurements of Polarization Transfer for 800 MeV Inclusive Proton Scattering at the MRS
1132	C. Glashausser Rutgers Univ. S. K. Nanda CEBAF	Spin Response in the $^4\mathrm{He}(\vec{p},\vec{p}\,')$ $^4\mathrm{He}^*$ Reaction at 500 MeV
1133	A. Sethi Univ. of Minnesota	Inelastic Proton Scattering from ^{182,184}W and the IBA Model
1134	N. M. Hintz Univ. of Minnesota	Spin Response in Transfer Reactions at Low q and High ω

Exp. No.	Spokesperson	Title
1135	C. Pillai UCLA C. S. Mishra Los Alamos D. F. Barlow UCLA	Feasibility Study of Tagged Eta Meson Production in $p + {}^3H \rightarrow {}^4He + \eta$

APPENDIX C: LAMPF Visitors During 1988

David Adams, Rice Univ., USA
Gary Adams, Rensselaer Polytechnic Institute, USA
Terry Adams, Texas Tech Univ., USA
Steven Adrian, George Washington Univ., USA
Dharam Ahluwalia, Jet Propulsion Laboratory, USA
Hyo Ahn, Yale Univ., USA
Gabriel Alba, Rutgers Univ., USA
Wanda Alberico, Univ. of Torino, Italy
Charles Albert, Texas A&M Univ., USA
Dimitris Alexandreas, Univ. of Maryland, USA
W. Alford, Univ. of Western Ontario, Canada
Richard Allen, Univ. of California, Irvine, USA
John Allred, Los Alamos, USA
Peter Alons, Indiana Univ., USA
Jonas Alster, Tel-Aviv Univ., Israel
Walter Amos, Univ. of Pennsylvania, USA
Alan Anderson, Nonaffiliated, USA
G. Anderson, George Washington Univ., USA
Matthew Anderson, Ohio State Univ., USA
Konrad Aniol, UCLA, USA
Katsushi Arisaka, Univ. of Pennsylvania, USA
Richard Arndt, VPI/State Univ., USA
Raymond Arnold, Stanford Univ., USA
Daniel Ashery, Tel-Aviv Univ., Israel
Alan Astbury, TRIUMF, Canada
Briggs Atherton, Univ. of New Mexico, USA
Naftali Auerbach, Tel-Aviv Univ., Israel
Jorthrn Aukdal, Riso National Laboratory, Denmark
Todd Averett, Arizona State Univ., USA
Michael Avery, Thorne EMI Electron Tubes, Inc., USA
Richard Baartman, TRIUMF, Canada
Mark Bachman, Univ. of Texas, USA
Naoum Bakalis, National Hellenic Research Foundation, USA
F. Baker, Univ. of Georgia, USA
John Baker, INEL, USA
Oliver Baker, North Carolina State Univ., USA
Janise Baldo, Drexel Univ., USA
R. Baltrusaitis, Univ. of Utah, USA
Martin Barlett, Univ. of Texas, USA
David Barlow, UCLA, USA
David Beatty, Rutgers Univ., USA
Michael Beddo, New Mexico State Univ., USA
Shelton Beedoe, UCLA, USA
Michael Begala, Univ. of Texas, USA
Jean-Jean Benoit, Univ. of New Mexico, USA
Robert Bent, Indiana Univ., USA
Donald Benton, Princeton Univ., USA
Bruce Berger, Argonne, USA
Branko Berkes, PSI, Switzerland
Barry Berman, George Washington Univ., USA
Hans Bethe, Cornell Univ., USA
Rajeev Bhalerao, Tata Institute of Fundamental Research, India

Steven Biller, Univ. of California, Irvine, USA
Louis Bimbot, I.P.N. Orsay, France
Azizuddin Biyabani, MIT, USA
Ewart Blackmore, TRIUMF, Canada
Gary Blanpied, Univ. of South Carolina, USA
Marek Bleszynski, UCLA, USA
David Blevins, Nonaffiliated, USA
Peter Blum, W. Germany
Paul Boberg, Univ. of Maryland, USA
Carolus Boekema, San Jose State Univ., USA
Peter Bogdanov, State Committee on Atomic Energy, USSR
Scott Bonham, College of William & Mary, USA
Malcolm Boshier, Yale Univ., USA
Jacques Bouchez, Univ. of Annecy, France
Jeffrey Brack, Univ. of Colorado, USA
Franco Bradamante, INFN Trieste, Italy
John Bradick, Phillips Scientific, USA
Michael Braunstein, Univ. of Colorado, USA
Bernhard Brinkmoller, Institut fur Kernphysik, W. Germany
William Briscoe, George Washington Univ., USA
Rolf Brockmann, Univ. of Mainz, W. Germany
Mary Dell Brockway, Los Alamos, USA
B. Brooks, Nonaffiliated, USA
Melynda Brooks, Univ. of New Mexico, USA
Ruth Brooks, UK
Gaston Bruge, CEN-Saclay, France
Howard Bryant, Univ. of New Mexico, USA
Peter Buckolz, Temple Univ., USA
David Bugg, Univ. of London, UK
Doris Burckhart, CERN, Switzerland
Helfried Burckhart, CERN, Switzerland
Ray Burge, TRIUMF, Canada
Michael Burlein, Univ. of Pennsylvania, USA
George Burleson, New Mexico State Univ., USA
Mary Burns, Los Alamos, USA
Peter Busch, Michigan State Univ., USA
Jiri Bystricky, DPHPE-SEPH, France
Pavel Bystricky, Ecole Nationale Superieure d'Electrochiuie, France
Robert Cady, Univ. of Notre Dame, USA
Augustine Caffrey, EG&G, Idaho, Inc., USA
John Cameron, Indiana Univ., USA
Simon Capstick, Univ. of Guelph, Canada
Gloria Carillo, Univ. of Minnesota, USA
Staffan Carius, Los Alamos, USA
Daniel Carman, Rensselaer Polytechnic Institute, USA
Kent Carroll, Abilene Christian Univ., USA
Kevin Carroll, Abilene Christian Univ., USA
Hamilton Carter, Ohio State Univ., USA
Giovanni Carugno, CERN, Switzerland
Friedrich Caspers, CERN, Switzerland
Gordon Cates, Princeton Univ., USA
Joseph Cavanaugh, Los Alamos, USA

Soumya Chakravarti, California State Polytechnic Univ., USA
Kwai-Chow Chan, Texas Tech Univ., USA
Chung-Yun Chang, Univ. of Maryland, USA
Lali Chatterjee, Jadavpur Univ., India
Xiao-Yan Chen, Univ. of Colorado, USA
Naipor Cheung, College of William & Mary, USA
Francis Chmely, Yale Univ., USA
Katherine Choi, Univ. of Virginia, USA
Manjit Chopra, Nuclear Shielding Supplies and Services, USA
Connel Chu, Univ. of Houston, USA
Aleksandr Chudakov, Academy of Sciences of the USSR, USSR
Gary Chulick, Purdue Univ., USA
Timothy Chupp, Harvard Univ., USA
Ivan Chuvilo, Institute of Theoretical and Experimental Physics, USSR
Douglas Ciskowski, Univ. of Texas, USA
Anselm Citron, W. Germany
Jolie Cizewski, Rutgers Univ., USA
Benjamin Clausen, Univ. of Virginia, USA
Francis Close, SERC, USA
Jeromeo Cobbs, Univ. of Arkansas, USA
Steven Coberly, Brown Univ., USA
Fritz Coester, Argonne, USA
Joseph Cohen, Los Alamos, USA
Stanley Cohen, Cohen Mechanical Design, USA
Joseph Comfort, Arizona State Univ., USA
David Cook, Univ. of Minnesota, USA
Peter Cooper, Fermilab, USA
Dylan Cors, MIT, USA
Kevin Coulter, Princeton Univ., USA
Michael Craddock, Princeton Univ., USA
Hall Crannell, Catholic Univ. of America, USA
Horace Crater, Univ. of Tennessee, USA
Gregory Crawford, Case Western Reserve Univ., USA
John Crocker, Univ. of Chicago, USA
Kevin Cromer, Univ. of Virginia, USA
William Cummings, Stanford Univ., USA
Vernon Cupps, Los Alamos, USA
Guy Danner, Princeton Univ., USA
Karsten Danzmann, Stanford Univ., USA
Manfred Daum, PSI, Switzerland
Dorothy Davidson, Jomar Systems, Inc., USA
Norman Davison, Univ. of Manitoba, Canada
Steven Dawson, Rutgers Univ., USA
W. Dawson, TRIUMF, Canada
Wayne Dawson, San Jose State Univ., USA
R. DeLay, Univ. of California, Irvine, USA
Paul Debevec, Univ. of Illinois, USA
Dietrich Dehnhard, Univ. of Minnesota, USA
Daniel Deptuck, Princeton Univ., USA
Jules Deutsch, Universite Catholique de Louvain, Belgium
Michael Devereux, Earlham College, USA
Satish Dhawan, Yale Univ., USA

Kalvir Dhuga, George Washington Univ., USA
John Dicello, Jr., Clarkson Univ., USA
Jean-Pierre Didelez, Institut Physique Nucleaire, France
Brenda Dingus, Univ. of Maryland, USA
Gerard Dion, Univ. of California, Irvine, USA
Ned Dixon, Franklin & Marshall College, USA
Chaden Djalali, Michigan State Univ., USA
Gail Dodge, Stanford Univ., USA
Peter Doe, Univ. of California, Irvine, USA
Donald Dohan, TRIUMF, Canada
Alan Donley, Abilene Christian Univ., USA
Jacob Doornbos, TRIUMF, Canada
Maria Dowell, MIT, USA
William Dunwoodie, Stanford Univ., USA
Lloyd Durkin, Ohio State Univ., USA
Steven Dytman, Univ. of Pittsburgh, USA
Mario Dzemidzic, Univ. of Houston, USA
Venedick Dzhelepov, Joint Institute for Nuclear Research, USA
Zbigniew Dziembowski, Warsaw Univ., Poland
E. Earle, Atomic Energy of Canada, Ltd., Canada
Morton Eckhause, College of William & Mary, USA
Robert Eisenstein, Univ. of Illinois, USA
Tor Ekenberg, Univ. of Pennsylvania, USA
Morten Eldrup, Riso National Laboratory, Denmark
Juan Elizando, Univ. of New Mexico, USA
Clive Ellegaard, Niels Bohr Institute, Denmark
Robert Ellsworth, George Mason Univ., USA
Terry Enegren, TRIUMF, Canada
Jon Engelage, Lawrence Livermore National Laboratory, USA
Peter Englert, San Jose State Univ., USA
John Ensworth, Arizona State Univ., USA
Ivan Entchevitch, TRIUMF, Canada
Torleif Ericson, CERN, Switzerland
Torbjorn Erikson, Royal Institute of Technology, Sweden
David Ernst, Texas A&M Univ., USA
Serguei Essine, Institute for Nuclear Research, USSR
Yoseph Ezra, Tel-Aviv Univ., Israel
Glennys Farrar, Rutgers Univ., USA
John Faucett, Los Alamos, USA
Michael Faux, Univ. of Pennsylvania, USA
Ali Fazely, Louisiana State Univ., USA
Michael Featherby, UK
Alan Feldman, Univ. of Maryland, USA
Xi Zhang Feng, Institute of High Energy Physics, PRC
Raymond Fergerson, CEN-Saclay, France
Charles Findeisen, Univ. of Wisconsin, USA
Bruce Flanders, Univ. of Maryland, USA
Johan Flick, Univ. of Houston, USA
Gottfried Flik, Max-Planck-Institut, W. Germany
Jeffrey Flint, San Jose State Univ., USA
Helmut Folger, GSI, W. Germany
H. Fortune, Univ. of Pennsylvania, USA

Michael Franey, Univ. of Minnesota, USA
Stuart Freedman, Argonne, USA
James Freeman, Fermilab, USA
Gerhard Fricke, Univ. of Mainz, W. Germany
Linda Fritz, Franklin & Marshall College, USA
Bernard Frois, CEN-Saclay, France
Alvaro Fuentes, Univ. of Texas, USA
Brian Fujikawa, Caltech, USA
Kenji Fukushima, Tokyo Metropolitan Univ., Japan
Herbert Funsten, College of William & Mary, USA
Norman Fuqua, Virginia State Univ., USA
Carl Gaarde, Niels Bohr Institute, Denmark
Carl Gagliardi, Texas A&M Univ., USA
Avraham Gal, Hebrew Univ., Israel
Francesca Galluccio, Instituto Nazionale di Fisica Nucleare, Italy
Carmen Garcia-Recio, Universidad de Valladolid, Spain
Ian Gardner, Rutherford-Appleton Laboratory, UK
Susan Gardner, New Mexico State Univ., USA
Robert Garnett, Argonne, USA
J. Gasser, Univ. of Bern, Switzerland
Evangelos Gavathas, Florida State Univ., USA
M. Gazzaly, Univ. of Minnesota, USA
Giovanni Gelato, CERN, Switzerland
Hartmut Gemmeke, Rutherford-Appleton Laboratory, UK
Vahe Ghazikhanian, UCLA, USA
Robert Giannelli, Arizona State Univ., USA
Talat Gilani, New Mexico State Univ., USA
Dane Gillespie, Univ. of Texas, USA
Ronald Gilman, Argonne, USA
Manoj Gilra, Univ. of Maryland, USA
Camille Ginsburg, Northwestern Univ., USA
Kevin Giovanetti, Univ. of Virginia, USA
Charles Glashausser, Rutgers Univ., USA
George Glass, Texas A&M Univ., USA
Roy Glauber, Harvard Univ., USA
Johann Goergen, Arizona State Univ., USA
Charles Goodman, Indiana Univ., USA
Jordan Goodman, Univ. of Maryland, USA
Christopher Gould, North Carolina State Univ., USA
Kaleen Graessle-Smith, Abilene Christian Univ., USA
Andrew Green, Rutgers Univ., USA
Craig Greenhill, TRIUMF, Canada
Keith Griffioen, Univ. of Pennsylvania, USA
David Grosnick, Argonne, USA
Willy Gruebler, Institute F. Mittelenergiephysik, W. Germany
Gilbert Guignard, CERN, Switzerland
Erhan Gulmez, UCLA, USA
David Haase, TRIUMF, Canada
William Haberichter, Argonne, USA
Ernst-Ulrich Haebel, CERN, Switzerland
Kevin Hahn, Univ. of Houston, USA
Todd Haines, Univ. of Maryland, USA

Aksel Hallin, Princeton Univ., USA
Stanley Hanna, Stanford Univ., USA
Niels Hansen, Riso National Laboratory, Denmark
Dennis Hanson, George Washington Univ., USA
John Hardie, Univ. of Pittsburgh, USA
Avaroth Harindranath, Ohio State Univ., USA
Ronnie Harper, EG&G, Los Alamos, Inc., USA
Jeffrey Harris, Brigham Young Univ., USA
Philip Harris, Univ. of New Mexico, USA
Richard Harris, W. Germany
Michael Hasinoff, TRIUMF, Canada
Tino Haupke, W. Germany
Gillian Hayes, Univ. of York, Canada
Ju He, Institute of High Energy Physics, PRC
Andrew Heekin, Univ. of Texas, USA
Walter Hensley, Battelle Pacific Northwest Laboratory, USA
Steven Heppelmann, Pennsylvania State Univ., USA
Christopher Herbert, Franklin & Marshall College, USA
Daniel Hill, Argonne, USA
Tony Hill, Abilene Christian Univ., USA
Edward Hill, III, Princeton Univ., USA
Norton Hintz, Univ. of Minnesota, USA
Thomas Hippchen, Kernforschunjeanlage Juelich Gambh, W. Germany
Gerald Hoffmann, Univ. of Texas, USA
Gerhard Hohler, W. Germany
Steinar Hoibraten, MIT, USA
Bo Hoistad, Uppsala Univ., Sweden
Karl Holinde, Univ. of Bonn, W. Germany
Gavin Holland, Abilene Christian Univ., USA
Roy Holt, Argonne, USA
G. Holzwarth, Wake Forest Univ., USA
Pervez Hoodbhoy, Quaid-E-Azam Univ., Pakistan
Charles Horowitz, Indiana Univ., USA
Andy Horsewell, Riso National Laboratory, Denmark
Steven Horvath, Horvath Energy International, Ltd., Australia
Weidong Huang, Indiana Univ., USA
Garth Huber, Indiana Univ., USA
E. Hughes, Stanford Univ., USA
Vernon Hughes, Yale Univ., USA
Ed Hungerford, Univ. of Houston, USA
Hadeem Hussain, Stanford Univ., USA
Ahmed Hussein, King Fahd Univ. of Petroleum and Minerals, Saudi Arabia
Gerald Hutter, GSI, W. Germany
Minh Huynh, Franklin & Marshall College, USA
Scott Hyman, Univ. of Maryland, USA
Masaharu Ieiri, KEK, Japan
George Igo, UCLA, USA
Richard Imlay, Louisiana State Univ., USA
Quentin Ingram, PSI, Switzerland
Erik Insko, Univ. of Pennsylvania, USA
Larry Isenhower, Abilene Christian Univ., USA
Masahiko Iwasaki, Univ. of Tokyo, Japan

Takashi Iwata, Japan
Ovid Jacob, Carnegie-Mellon Univ., USA
Robert Jaffe, MIT, USA
Muhammad Jahan, Memphis State Univ., USA
Mark Jakobson, Univ. of Montana, USA
Tomasz Jaroszewicz, UCLA, USA
B. Jennings, TRIUMF, Canada
Randolph Jeppesen, Univ. of Montana, USA
Ronald Jeppesen, Los Alamos, USA
Ryong Cheung Ji, North Carolina State Univ., USA
Huan-Quin Jiang, Institute of High Energy Physics, PRC
Rafael Jiminez, Universidad de Valencia, Spain
Kevin Johnson, Univ. of Texas, USA
Kathleen Johnston, Univ. of Houston, USA
Frederick Jones, TRIUMF, Canada
Mark Jones, Univ. of Minnesota, USA
Phyllis Jones, Lincoln Univ., USA
Steven Jones, Brigham Young Univ., USA
Thomas Jorgensen, Niels Bohr Institute, Denmark
Charles Jui, Stanford Univ., USA
Klaus Jungmann, Physikalsades Institut des Universitat, W. Germany
Marios Kagarlis, Univ. of Pennsylvania, USA
George Kahrimanis, Univ. of Texas, USA
E. Kajfasz, Center for Particle Physics, France
Peter Kammel, Univ. of Vienna, Austria
John Kane, College of William & Mary, USA
Ju Hwan Kang, Univ. of California, Riverside, USA
Sergei Kapitza, Institute for Physical Problems, USSR
Peter Karen, Univ. of Virginia, USA
Thomas Kasprzyk, Argonne, USA
Bradley Keister, Carnegie-Mellon Univ., USA
James Kelly, Univ. of Maryland, USA
Robert Kenefick, Texas A&M Univ., USA
Peter Kernan, Ohio State Univ., USA
Richard Kessler, UCLA, USA
Steve Kettell, Yale Univ., USA
Mahbubul Khandaker, Univ. of Maryland, USA
William Kielhorn, Univ. of Texas, USA
Motohiro Kihara, KEK, Japan
George Kim, Texas A&M Univ., USA
Jaewan Kim, Univ. of Houston, USA
Yi-Kyung Kim, Utah State Univ., USA
Bruce King, Stanford Univ., USA
Edward Kinney, Argonne, USA
Leonard Kisslinger, Carnegie-Mellon Univ., USA
Peter Kitching, TRIUMF, Canada
Andres Klein, New Mexico State Univ., USA
Jeffrey Klein, Univ. of Philadelphia, USA
Norbert Klein, W. Germany
Donald Koetke, Valparaiso Univ., USA
Matthew Kohler, Univ. of Colorado, USA
Daniel Koltun, Univ. of Rochester, USA

Ralph Korteling, Simon Fraser Univ., Canada
Anke Korthauer, W. Germany
Shane Koscielniak, TRIUMF, Canada
Heribert Koziol, CERN, Switzerland
Franz Krafft, Max-Planck-Institut, W. Germany
Daniel Krakauer, Univ. of Maryland, USA
Robert Kraus, Los Alamos, USA
Jack Kraushaar, Univ. of Colorado, USA
Sig Krewald, Institut fur Kernphysik, W. Germany
John Kruzan, Ohio State Univ., USA
Michael Kswzyminski, Abilene Christian Univ., USA
Yunan Kuang, College of William & Mary, USA
Gerfried Kumbartzki, Rutgers Univ., USA
A. Raymond Kunselman, Univ. of Wyoming, USA
Kei-Ichi Kuroda, CNRS, France
Peter Kutt, Univ. of Pennsylvania, USA
Slawomir Kwiatkowski, TRIUMF, Canada
Nickolas Kylafis, Univ. of Crete, Greece
Gary Kyle, New Mexico State Univ., USA
Mark Laffoon, Univ. of California, San Diego, USA
Masoud Laghai, Univ. of New Mexico, USA
Rejian (Allan) Lane, Univ. of Houston, USA
Derek Lane, Abilene Christian Univ., USA
K. Larson, Univ. of New Mexico, USA
Juergen Last, Physikalisches Institut Univ. Heidelberg, W. Germany
Renzo Leonardi, Universita' di Trento, Italy
Kevin Lesko, Lawrence Berkeley Laboratory, USA
Jechiel Lichtenstadt, Tel Aviv. Univ., Israel
Roger Lichti, Texas Tech Univ., USA
B. Lieb, George Mason Univ., USA
Jit Ning Lim, Louisiana State Univ., USA
Shaofei Lin, Institute of Atomic Energy, PRC
David Lind, Univ. of Colorado, USA
V. Lind, Utah State Univ., USA
Alan Ling, Los Alamos, USA
Ta-Yung Ling, Ohio State Univ., USA
John Linsley, Univ. of New Mexico, USA
Fan Liu, Texas A&M Univ., USA
Genbao Liu, Univ. of Pennsylvania, USA
Jianyang Liu, Institute of Atomic Energy, PRC
Jeremy Lloyd-Evans, Univ. of Southampton, UK
K. E. G. Lobner, Univ. of Munich, W. Germany
Benoit Loiseau, Institut Physique Nucleaire, France
Augusto Lombardi, CERN, Switzerland
David Lopiano, Argonne, USA
William Love, Univ. of Georgia, USA
Robert Loveman, Nonaffiliated, USA
Xing-Qi Lu, Univ. of California, Irvine, USA
Gregory Ludwig, Valparaiso Univ., USA
Christopher Lyndon, College of William & Mary, USA
Malcolm MacFarlane, Indiana Univ., USA
Shinji Machida, Japan

Ruprecht Machleidt, Univ. of Idaho, USA
Anthony Mack, Univ. of Minnesota, USA
George MacKenzie, TRIUMF, Canada
John MacKenzie, Nonaffiliated, USA
Christopher Maher, MIT, USA
Lech Mankiewicz, Nicholas Copernicus Astronomical Center, Poland
John Manley, Nonaffiliated, USA
Alfred Mann, Univ. of Pennsylvania, USA
Robert Manweiler, Valparaiso Univ., USA
Donald Marchlenski, Ohio State Univ., USA
William Marciano, Brookhaven, USA
John Markey, Yale Univ., USA
Richard Marshall, Univ. of Virginia, USA
William Marterer, Louisiana State Univ., USA
Charles Martoff, Stanford Univ., USA
Clark Maruyama, UCLA, USA
Akira Masaike, Kyoto Univ., Japan
Reinhard Maschuw, UFK Karlsruhe, W. Germany
Yasuhiro Masuda, KEK, Japan
Maria Masullo, Italy
Douglas Mathis, Arizona State Univ., USA
Sergei Matinian, Erevan Physical Institute, USSR
Teiichiro Matsuzaki, Univ. of Tokyo, Japan
Edward Matthews, George Washington Univ., USA
June Matthews, MIT, USA
Scott Matthews, George Washington Univ., USA
Bjorn Matthias, Yale Univ., USA
Eckart Matthias, W. Germany
Victor Matveev, Institute of Nuclear Research, USSR
James Maxwell, Brigham Young Univ., USA
Benjamin Mayer, CEN-Saclay, France
Bill Mayes, Univ. of Houston, USA
Robert McCarthy, State Univ. of New York, USA
Ian McCubbin, Martin and Martin, Australia
Arthur McDonald, Princeton Univ., USA
James McDonald, Univ. of Texas, USA
Joseph McDonald, Univ. of Texas, USA
Marilyn McDonald, Univ. of Texas, USA
Kenneth McFarlane, Temple Univ., USA
Robert McKeown, Caltech, USA
Matthew McKinzie, Univ. of Pennsylvania, USA
Kok-Heong McNaughton, Univ. of Texas, USA
Victoria McVeigh, Abilene Christian Univ., USA
David Measday, TRIUMF, Canada
Bernhard Mecking, CEBAF, USA
David Mercer, Univ. of Colorado, USA
William Metcalf, Louisiana State Univ., USA
Thomas Meyer, Univ. of Maryland, USA
Aaron Michalowicz, CNRS, France
Richard Michel, Univ. of Colorado, USA
Dimitris Mihailidis, Univ. of Minnesota, USA
David Mince, Brigham Young Univ., USA

Ralph Minehart, Univ. of Virginia, USA
Gary Mitchell, North Carolina State Univ., USA
Joseph Mitchell, McGill Univ., Canada
Wendell Mize, Univ. of South Carolina, USA
Amir Mohagheghi, Univ. of New Mexico, USA
Rodney Montrose, USA
C. Moore, Univ. of Texas, USA
Snow Moore, Univ. of New Mexico, Los Alamos, USA
Shaul Mordechai, Ben-Gurion Univ., Israel
Bernard Morel, Institute National Polytechnique de Grenoble, France
Yoshiharu Mori, KEK, Japan
Marcel Morlet, CNRS, France
Alfred Mueller, Univ. of California, Santa Barbara, USA
Rene Muhlberg, Arizona State Univ., USA
Sanjoy Mukhopadhyay, Northwestern Univ., USA
Peter Mulders, NIKHEF, The Netherlands
Hans Muller, CERN, Switzerland
Klaus Muller, Univ. of Wuppertal, W. Germany
Hans Mundingerr, Physikalisches Institut Univ. Heidelberg, W. Germany
Michael Murillo, Univ. of New Mexico, USA
Lyle Murphy, Univ. of Colorado, USA
Tomofumi Nagae, KEK, Japan
Kanetada Nagamine, Univ. of Tokyo, Japan
Ramesan Nair, Florida State Univ., USA
Kozi Nakai, Japan
Sirish Nanda, CEBAF, USA
James Napolitano, Argonne, USA
Mohammed Nasser, King Fahd Univ. of Petroleum and Minerals, Saudi Arabia
Subrata Nath, Texas A&M Univ., USA
Itamar Navon, Tel-Aviv Univ., Israel
Vladimir Nazarenko, Leningrad Nuclear Physics Institute, USSR
Jurgen Neffe, Geo Magazine, USA
Bernard Nefkens, UCLA, USA
John Negele, MIT, USA
James Nelson, Argonne, USA
Peter Nemethy, New York Univ., USA
Benwen Ni, Indiana Univ., USA
Alain Nicholas, Laboratore d'Electro-Technique, France
Laurent Nicholas, Laboratore d'Electro-Technique, France
Nancy Nicholas, George Washington Univ., USA
Philip Nickel, Valparaiso Univ., USA
Kunihiko Nishiizumi, Univ. of California, San Diego, USA
Tetsuo Noro, Osaka Univ., Japan
Lee Northcliffe, Texas A&M Univ., USA
Blaine Norum, Univ. of Virginia, USA
John O'Donnell, Univ. of Pennsylvania, USA
John O'Reilly, Northwestern Univ., USA
David Oakley, Univ. of Colorado, USA
Yuji Ohashi, Argonne, USA
Shoroku Ohnuma, Univ. of Houston, USA
Jean Oostens, Univ. of Cincinnati, USA
Herbert Orth, Gesellschaft fur Schwerioneuforschung, W. Germany

Eulogio Oset, Universidad de Valencia, Spain
Peter Ostroumov, Institute for Nuclear Research, USSR
John Otis, Stanford Univ., USA
Doreen Panichella, Franklin & Marshall College, USA
Brett Parker, Northwestern Univ., USA
Craig Parman, Univ. of Minnesota, USA
John Parmentola, West Virginia Univ., USA
Hans Parr, Univ. of California, San Diego, USA
Zohreh Parsa, Brookhaven, USA
Gianni Pauletta, Univ. of Texas, USA
Bruce Pearce, Flinders Univ. of South Australia, Australia
Justin Peatross, Brigham Young Univ., USA
Oskar Pelc, Tel-Aviv Univ., Israel
Peter Penfold, Oxford Instruments of North America, Inc., USA
Seppo Penttila, Los Alamos, USA
Aldo Penzo, INFN-Trieste, Italy
Charles Perdrisat, College of William & Mary, USA
Yves Perrin, CERN, Switzerland
Robert Perry, Ohio State Univ., USA
Herbert Perten, Phillips Scientific, USA
Henri Pessard, Univ. of Annecy, France
Roy Peterson, Univ. of Colorado, USA
Alain Petit, Univ. of Colorado, USA
Richard Phelps, Univ. of Houston, USA
Eliazer Piasetzky, Tel-Aviv Univ., Israel
Alan Picklesimer, Los Alamos, USA
Francois Pierre, CEN-Saclay, France
Leo Piilonen, VPI/State Univ., USA
Fulvia Pilat, CERN, Switzerland
Chandrasekhara Pillai, UCLA, USA
Lawrence Pinsky, Univ. of Houston, USA
Andrea Pisent, CERN, Switzerland
Hans Plendl, Florida State Univ., USA
Dinko Pocanic, Univ. of Virginia, USA
Roger Poirier, TRIUMF, Canada
Robert Pollock, Indiana Univ., USA
Leonid Ponomarev, IV Kurchatov Institute of Atomic Energy, USSR
Norbert Porile, Purdue Univ., USA
H. Portis, Univ. of California, Berkeley, USA
Michael Potter, Los Alamos, USA
Bogdan Povh, Max-Planck-Institut, W. Germany
Barry Preedom, Univ. of South Carolina, USA
John Price, UCLA, USA
David Prout, Univ. of Colorado, USA
Michael Puglisi, Brown Univ., USA
Vina Punjabi, College of William & Mary, USA
Michael Purcell, Univ. of Texas, USA
Thomas Putnam, Nonaffiliated, USA
John Putz, Univ. of Pennsylvania, USA
Xijun Qiu, Institute of Nuclear Research Academia Sinica, PRC
Johann Rafelski, Univ. of Arizona, USA
Azriel Rahavi, Tel-Aviv Univ., Israel

Robert Randal, Thorne EMI Electron Tubes, Inc., UK
Ronald Ransome, Rutgers Univ., USA
Jack Rapaport, Ohio Univ., USA
Arthur Rask, Nonaffiliated, USA
Glenn Rasmussen, Univ. of Pennsylvania, USA
R. Rau, Brookhaven, USA
Bill Rawnsley, TRIUMF, Canada
Mohini Rawool, New Mexico State Univ., USA
R. Ray, Univ. of Texas, USA
Glen Rebka, Univ. of Wyoming, USA
Paul Reeder, Battelle Pacific Northwest Laboratory, USA
Randolph Reeder, Univ. of New Mexico, USA
Grahame Rees, Rutherford-Appleton Laboratory, UK
James Reidy, Univ. of Mississippi, USA
Klaus Reiniger, Canada
Horst Rempp, Nonaffiliated, W. Germany
Monica Ricci, Ohio State Univ., USA
Darrell Rilett, Univ. of Colorado, USA
Peter Riley, Univ. of Texas, USA
Robert Ristinen, Univ. of Colorado, USA
Barry Ritchie, Arizona State Univ., USA
N. Roberson, Duke Univ., USA
B. L. Roberts, Boston Univ., USA
Donald Roberts, Univ. of Michigan, USA
Laura Rocha, Arizona State Univ., USA
Ronald Rockmore, Rutgers Univ., USA
Kathleen Roemheld, Univ. of California, Irvine, USA
Sayed Rokni, Stanford Univ., USA
Thomas Romanowski, Ohio State Univ., USA
Thomas Rosson, Univ. of Oklahoma, USA
Dennis Rothenberger, Arizona State Univ., USA
Lawrence Rybarcyk, Los Alamos, USA
Michael Sadler, Abilene Christian Univ., USA
Hartmut Sadrozinski, Univ. of California, Santa Cruz, USA
William Sailor, Los Alamos, USA
Surender Saini, Oak Ridge, USA
Satoru Saito, Tokyo Metropolitan Univ., Japan
Harutaka Sakaguchi, Kyoto Univ., Japan
Lorenzo Salcedo, Universidad de Valencia, Spain
Lorenzo Santi, Universita degli Studi, Italy
Haitook Sarafian, Pennsylvania State Univ., USA
Miguel Sarmiento, Northwestern Univ., USA
George Satchler, Oak Ridge, USA
David Saunders, United States Air Force Academy, USA
H. Schaefer, Yale Univ., USA
Georg Schaffer, KFA, W. Germany
Irene Schilling, W. Germany
Karlheinz Schindl, CERN, Switzerland
Paul Schmor, TRIUMF, Canada
Horst Schoenauer, CERN, Switzerland
Wolfgang Schott, Technical Univ. of Munich, W. Germany
Jos Schouten, Oxford Instruments of North America, Inc., USA

John Sculli, New York Univ., USA
Colin Seftor, George Washington Univ., USA
Hardy Seifert, Justus-Liebig Universitat Giessen, W. Germany
Helmut Seifert, Univ. of Maryland, USA
Yurij Senichev, Institute for Nuclear Research, USSR
Roger Servrancky, Canada
Kamal Seth, Northwestern Univ., USA
Anil Sethi, Univ. of Minnesota, USA
Carol Shakin, Brooklyn College, USA
Eugene Sheely, Brigham Young Univ., USA
James Shepard, Univ. of Colorado, USA
Danling Shi, Northwestern Univ., USA
Tokushi Shibata, Univ. of Tokyo, Japan
Horst Shilling, W. Germany
Tomikazu Shima, Argonne, USA
Haruki Shiraishi, National Research Institute for Metals, Japan
James Shurtleff, Brigham Young Univ., USA
Rickey Shypit, Jet Propulsion Laboratory, USA
James Silk, Univ. of Pennsylvania, USA
Amihai Silverman, Tel-Aviv Univ., Israel
Anthony Simon, Texas A&M Univ., USA
Bachu Singh, Riso National Laboratory, Denmark
Manohar Singham, Case Western Reserve Univ., USA
Douglas Singleton, Univ. of Virginia, USA
Michael Sivertz, Temple Univ., USA
Ivo Slaus, Rudjer Boskovic Institute, Yugoslavia
Sven Slyckt, Sweden
Christian Smith, George Washington Univ., USA
Elton Smith, CEBAF, USA
L. Smith, Univ. of Virginia, USA
Landa Smith, W. Germany
Winthrop Smith, Univ. of Connecticut, USA
Michael Smithson, National Science Foundation, USA
W. Smythe, Univ. of Colorado, USA
Michael Snell, Univ. of Texas, USA
Troy Soos, MIT, USA
Rayappu Soundranayagam, Northwestern Univ., USA
Madeline Soyeur, CEN-Saclay, France
Joseph Speth, KFA, W. Germany
Karin Spiess, W. Germany
Susanne Spiess, W. Germany
Wolfgang Spiess, W. Germany
Harold Spinka, Argonne, USA
Melvin Spurlock, Virginia State Univ., USA
Robert Stanek, Argonne, USA
Shirvel Stanislaus, TRIUMF, Canada
Keith Stantz, Valparaiso Univ., USA
Edward Stephenson, Indiana Univ., USA
Stephen Sterbenz, Univ. of Minnesota, USA
James Stevens, New Mexico State Univ., USA
Nigel Stevenson, TRIUMF, Canada
James Stewart, Western Washington Univ., USA

Bruce Storm, Jr., Univ. of Georgia, USA
Brian Stringham, Brigham Young Univ., USA
Carey Stronach, Virginia State Univ., USA
Evan Sugarbaker, Ohio State Univ., USA
Ivan Supek, Rudjer Boskovic Institute, Yugoslavia
Jeremy Sutton, Oxford Instruments Company, UK
Robert Svoboda, University of California, Irvine, USA
T. Symons, Lawrence Berkeley Laboratory, USA
Krzysctof Szalewicz, Univ. of Florida, USA
Richard Talaga, Argonne, USA
Peter Tandy, Kent State Univ., USA
Chen-Yau Tang, Univ. of New Mexico, USA
Liguang Tang, Univ. of Houston, USA
Morton Taragin, George Washington Univ., USA
Albert Tavkhelidze, Academy of Sciences of the USSR, USSR
Robert Taylor, Arizona State Univ., USA
Stuart Taylor, Brigham Young Univ., USA
David Tedeschi, Rensselaer Polytechnic Institute, USA
James Templer, Abilene Christian Univ., USA
Michael Thies, Free Univ., The Netherlands
Mark Timko, Ohio State Univ., USA
James Tinsley, Arizona State Univ., USA
W. Tippens, Univ. of Virginia, USA
Lester Towell, Abilene Christian Univ., USA
Rusty Towell, Abilene Christian Univ., USA
Robert Tribble, Texas A&M Univ., USA
Gerald Tripard, Washington State Univ., USA
Steve Trokenheim, Northwestern Univ., USA
Amos Trudell, Yale Univ., USA
Christoph Tschalar, PSI, Switzerland
Martin Tschirner, W. Germany
Traudel Tschirner, W. Germany
Xiao-Lin Tu, Utah State Univ., USA
Anthony Turkevich, Univ. of Chicago, USA
Ioannis Tzamouranis, Univ. of Houston, USA
Paul Ulmer, College of William & Mary, USA
David Underwood, Argonne, USA
Julia Vail, MIT, USA
Leo Van Ausdeln, Texas A&M Univ., USA
Gerard van der Steenhoven, MIT, USA
Alan Van Drie, Univ. of California, Irvine, USA
Gordon VanDalen, Univ. of California, Riverside, USA
James Vary, Ohio State Univ., USA
Atlant Vassiliev, State Committee on Atomic Energy, USSR
Vladimir Vassiliev, State Committee on Atomic Energy, USSR
Mike Vetterli, TRIUMF, Canada
Manuel Vicente-Vacas, Universidad de Valencia, Spain
Palahalli Vishwanath, Univ. of California, Irvine, USA
Karen Visnovsky, Purdue Univ., USA
Erich Vogt, TRIUMF, Canada
Dietrich von Harrach, Max-Planck-Institut, W. Germany
Wolfram von Witsch, Rice Univ., USA

Aleksandr Voyevodskiy, Academy of Sciences of the USSR, USSR
Miguel Vrinat, Matra Data Vision, USA
Benjamin Wallace, Georgia Institute of Technology, USA
Dirk Walliser, Univ. of New Mexico, USA
Angel Wang, Univ. of South Carolina, USA
Guorong Wang, Nanjing Univ., PRC
Mark Wang, MIT, USA
Ming-Jer Wang, Case Western Reserve Univ., USA
Minghong Wang, New Mexico State Univ., USA
Zhiguo Wang, Univ. of Minnesota, USA
Ray Warner, Battelle Pacific Northwest Laboratory, USA
Douglas Watson, Univ. of York, Canada
Stephen Weathersby, San Jose State Univ., USA
Peter Weber, TRIUMF, Canada
Monroe Wechsler, Iowa State Univ., USA
Jeff Weiler, Univ. of New Mexico, USA
Zeev Weinfeld, Tel-Aviv Univ., Israel
John Weinstein, Univ. of Toronto, Canada
Heinz Weyer, Basel Univ., Switzerland
C. Whisnant, Brookhaven, USA
Charles Whitten, UCLA, USA
Hans-Ulrich Wienands, TRIUMF, Canada
Jay Wightman, UCLA, USA
Bryan Wildenthal, Univ. of New Mexico, USA
Harvey Willard, Nonaffiliated, USA
Allen Williams, Univ. of Texas, USA
Donna Williams, Univ. of Texas, USA
Alain Willis, CNRS, France
David Wolf, Univ. of Texas, USA
Samuel Wong, Univ. of Toronto, Canada
Stephen Wood, Univ. of Illinois, USA
Kim Woodle, Brookhaven, USA
Heather Woolverton, Univ. of Mississippi, USA
Dennis Wright, TRIUMF, Canada
S. Wright, Univ. of Chicago, USA
Alan Wuosmaa, Univ. of Pennsylvania, USA
Wei-Peng Xu, Johns Hopkins Univ., USA
Zhihua Xu, Univ. of Houston, USA
Akira Yamaguchi, Tohoku Univ., Japan
Maraharu Yamazaki, Univ. of Pittsburgh, USA
Toshishige Yamazaki, KEK, Japan
Yevgenij Yanovich, Institute of Nuclear Research, USSR
Victor Yarba, Institute of High Energy Physics, USSR
Yi-Fen Yen, Univ. of Minnesota, USA
Gaurang Yodh, Univ. of Maryland, USA
Jacques Yonnet, CEN-Saclay, France
Sung Yoo, Univ. of Texas, USA
John Zabriskie, EG&G, Idaho, Inc., USA
Gabriele Zacek, CERN, Switzerland
Viktor Zacek, CERN, Switzerland
Chris Zafiratos, Univ. of Colorado, USA
Ismail Zahed, State Univ. of New York, USA

Philip Zecher, Ohio Univ., USA
Benjamin Zeidman, Argonne, USA
Anatolij Zelensky, Institute for Nuclear Research, USSR
Xiao-Gang Zhou, Utah State Univ., USA
Zongyuan Zhou, Nanjing Univ., PRC
Xianzhou Zhu, Duke Univ., USA
Klaus Ziock, Univ. of Virginia, USA
Gisbert zu Putlitz, Physikalisches Institut de Universitat, W. Germany
John Zumbro, MIT, USA

Information for Contributors

Progress at LAMPF is the progress report of MP Division of Los Alamos National Laboratory. In addition, it includes brief reports on research done at LAMPF by researchers from other institutions and Los Alamos National Laboratory divisions.

Progress at LAMPF is published annually on April 1. This schedule requires that manuscripts be received by December 1.

Published material is edited to the standards of the *Style Manual* of the American Institute of Physics. Papers are not refereed, hence presentation in this report does not constitute professional publication of the material nor does it preempt publication in other journals. Readers should recognize that results reported in *Progress at LAMPF* are sometimes preliminary or tentative and that authors should therefore be consulted in the event that these results are cited.

Contributors can expedite the publication process by giving special care to the following specifics:

1. When possible, furnish computer files for text and MAPPER files for illustrations, together with a hardcopy of your paper. *Progress at LAMPF* can accept files from computers, stand-alone word processors, and personal computers. TeX files are especially welcome.
2. Drawings and figures submitted should be of quality suitable for direct reproduction after reduction to single-column width, 55 mm (2-1/4 in.). MAPPER files should be printed on laser printers.
3. Figure captions and table headings must be furnished. The *AIP Style Manual* requires that every figure have a caption that is "complete and intelligible in itself without reference to the text."
4. References must be complete and accurate. If a reference cites a paper submitted for publication, the title of the paper and the journal where it has been submitted or where it is to be published must be given. Laboratory standards prefer that six authors be listed before et al. is used in reference lists.
5. Abbreviations and acronyms should be avoided if possible (in figures and tables as well as text), and when used must be defined.
6. All numerical data should be given in *Système International* (SI) units.
7. Authors are reminded that it helps the reader to have an introduction that states the purpose(s) of the experiment before presentation of the data.

Research reports should be brief but complete. A list of recent publications relating to the experiment, for separate tabulation in this report, is much appreciated.

Contributors are encouraged to include as authors all participants in experiments so that they may receive credit for authorship and participation.

Questions and suggestions should be directed to Karen Poelakker, Los Alamos National Laboratory, MS H846, Los Alamos, NM 87545.

☆U.S. GOVERNMENT PRINTING OFFICE: 1989-673-034/00180