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Proceedings of the Twenty-First LAMPF Users Group Meeting

Los Alamos National Laboratory
Los Alamos, New Mexico
November 9-10, 1987

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MASTER

Los Alamos Los Alamos National Laboratory
Los Alamos,New Mexico 87545

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PROCEEDINGS OF THE TWENTY-FIRST
LAMPF USERS GROUP MEETING
Los Alamos National Laboratory
Los Alamos, New Mexico
November 9-10, 1987

ABSTRACT

The Twenty-First Annual LAMPF Users Group Meeting was held November 9-10, 1987, at the Clinton P. Anderson Meson Physics Facility. The program included a number of invited talks on various aspects of nuclear and particle physics as well as status reports on LAMPF and discussions of upgrade options. The LAMPF working groups met and discussed plans for the secondary beam lines, experimental programs, and computing facilities.

TWENTY-FIRST LAMPF USERS GROUP MEETING

Los Alamos National Laboratory November 9–10, 1987

Chairman: *June L. Matthews - Massachusetts Institute of Technology*
Chairman-Elect: *Stanley S. Hanna - Stanford University*

Monday, November 9 LAMPF Auditorium, Laboratory-Office Building

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8:00 - 8:45 a.m.	**REGISTRATION**

MORNING SESSION
June Matthews, Presiding

8:45 - 9:00	"Research at Los Alamos" - *Siegfried Hecker* - Director, *Los Alamos National Laboratory*
9:00 - 9:30	"LAMPF Status and Future" - *Gerald Garvey* - Director, *LAMPF*
9:30 - 10:00	"MP Division Report" - *Donald Hagerman* - MP Division Leader
10:00 - 10:10	"The Associated Western Universities Program" - *Thomas Squires* - Director
10:10 - 10:40	**COFFEE BREAK**
10:40 - 11:15	Presentation of the **Louis Rosen Prize** Talk by ***Recipient***
11:15 - 11:45	Annual Users Group Report - *June Matthews* Discussion of Amendment to Bylaws
	LUNCH

AFTERNOON SESSION
Stanley Hanna, Presiding

1:00 - 1:30 p.m.	"Report from Washington" - *David Hendrie - Department of Energy*

PION PHYSICS

1:30 - 2:15	"Pion-nucleus Interactions" - *Michael Thies - Free University*, Amsterdam
2:15 - 2:45	"Highlights of August 17–21 Meeting on Pion-Nucleus Physics: Future Directions and New Facilities at LAMPF" - *R. Jerry Peterson - University of Colorado*
2:45 - 3:15	"Highlights of August 14 and 15 Workshops on Physics with Light Mesons and Pion-Nucleon Physics" - *Bernard Nefkens - University of California*, Los Angeles
3:15 - 3:45	"Higher Energy Pions at LAMPF" - *David Ernst - Texas A and M University*
3:45 - 4:15	**COFFEE BREAK**

ELECTROWEAK PHYSICS

4:15 - 4:45	"The MEGA Experiment" - *Martin Cooper - Los Alamos*
4:45 - 5:15	"Neutrino Physics at LAMPF" - *Hywel White - Los Alamos*
6:30	**BANQUET AT RANCHO ENCANTADO** **(Tickets to this event must be purchased in advance)**

WORKING GROUP MEETINGS

8:30 - 9:45 a.m.	EPICS - *David Oakley* - *University of Colorado*	Auditorium
	NPL - *George Glass* - *Texas A and M University*	Room A234
	Neutrino Facilities - *Joey Donahue* - *Los Alamos*	Room D105
9:45 - 11:00	P^3 - *Michael Sadler* - *Abilene Christian University*	Room A234
	HRS - *Sirish Nanda* - *CEBAF*	Auditorium
	NTOF - *Evan Sugarbaker* - *Ohio State University*	Room D105
11:00 - 11:15	**COFFEE BREAK**	
11:15 - 12:30	LEP - *James Knudson* - *Los Alamos*	Auditorium
	SMC - *Martin Cooper* - *Los Alamos*	Room A234
	Polarized Targets - *George Burleson* - *New Mexico State University*	Room D105
	LUNCH	
2:00 - 3:15 p.m.	Computer Facilities - *Kok-Heong McNaughton* - *University of Texas*	Auditorium
	Higher Energy Facilities - *Joseph Comfort* - *Arizona State University*	MP-14 Conf Rm
	Nuclear Chemistry - *Lon-Chang Liu* - *Los Alamos*	Room A234
	Materials Science - *Ron Livak* - *Los Alamos*	Room D105
3:15 - 3:30	**COFFEE BREAK**	

CLOSING SESSION

Auditorium

New Chairman-elect, Presiding

3:30 - 3:45	"The Medium Energy Nuclear Data Library Project" - *Denise George* - *Los Alamos*
3:45 - 4:30	"Spin Physics — Polarization and Relativity" - *Lanny Ray* - *University of Texas*
4:30 - 5:15	"Results of Cygnus Experiment" - *Darragh Nagle* - *Los Alamos*

ADDRESS TO THE LAMPF USERS GROUP

November 9, 1987

Gerald T. Garvey

Introductory Comments

It is a great pleasure to see so many of you at this 21st Annual Meeting of the LAMPF Users Group Incorporated (LUGI). June Matthews, the present chairperson of the LUGI, has organized an informative and forward-looking program for the meeting. I have enjoyed working with June over the past year and believe that she has done a great deal to facilitate effective communication between the users and LAMPF management. I look forward to working with Stan Hanna over the next year and expect that additional progress will be made.

I want to thank Sig Hecker, Director of Los Alamos National Laboratory, for coming to LAMPF this morning and sharing with us his views on the importance of LAMPF to the Laboratory and his expressions of the high priority he attaches to the realization of our plans for an Advanced Hadron Facility. Such support from high places is both welcome and absolutely necessary to the eventual success of bringing a new, forefront facility to LAMPF.

Even though the FY88 budget is far from certain at this time, I would like to publicly thank all the LAMPF Users who were active in informing the Congress of the continuing importance of appropriate fiscal support for LAMPF. The DOE/Nuclear Physics staff had done an excellent job in preparing the FY88 budget submission to Congress. They had paid careful attention to achieving a proper balance between new initiatives (CEBAF) and the ongoing program. Apparently well intentioned advice was offered to the Congress that would have unduly upset this balance in favor of new construction. However, clear and swift response from all quarters of the community supporting the DOE budget submission had a significant impact that is represented in the present action of both the House and Senate Appropriation Committees. I will speak about the present status of the FY88 budget and its effect on LAMPF later in this talk.

Scientific Accomplishments in 1987

There has been a great deal of science accomplished over the past year. The facility has operated extremely well during 1987. Additionally, thanks to the effort of Bob Macek and the members of MP-5, there is a clear understanding of the improvements needed to bring the PSR to its design capability.

Just about one year ago there was enormous concern about the viability of our large neutrino oscillation experiment (E645). You will recall that the LAMPF beam-stop provides a unique and powerful source of neutrinos. As shown in Fig. 1, the negative pions produced by the stopping protons are absorbed by a variety of nuclear processes. The decay chain of the remaining positive pions produces muon neutrinos, antineutrinos, and electron neutrinos. The electron antineutrino is conspicuously absent. The electron antineutrino can be readily detected by the inverse beta decay process

$$\tilde{\nu}_e + p \rightarrow e^+ + n \ .$$

At higher energy where neutrino beams are created by decay-in-flight, beams cannot be created with a purity much better than 1%. Additionally, if one is looking for oscillation into an electron-neutrino or antineutrino at high energy, there is a background generated from the reaction

$$\nu_\mu + A \rightarrow \nu_\mu + \pi_0 + X \ .$$

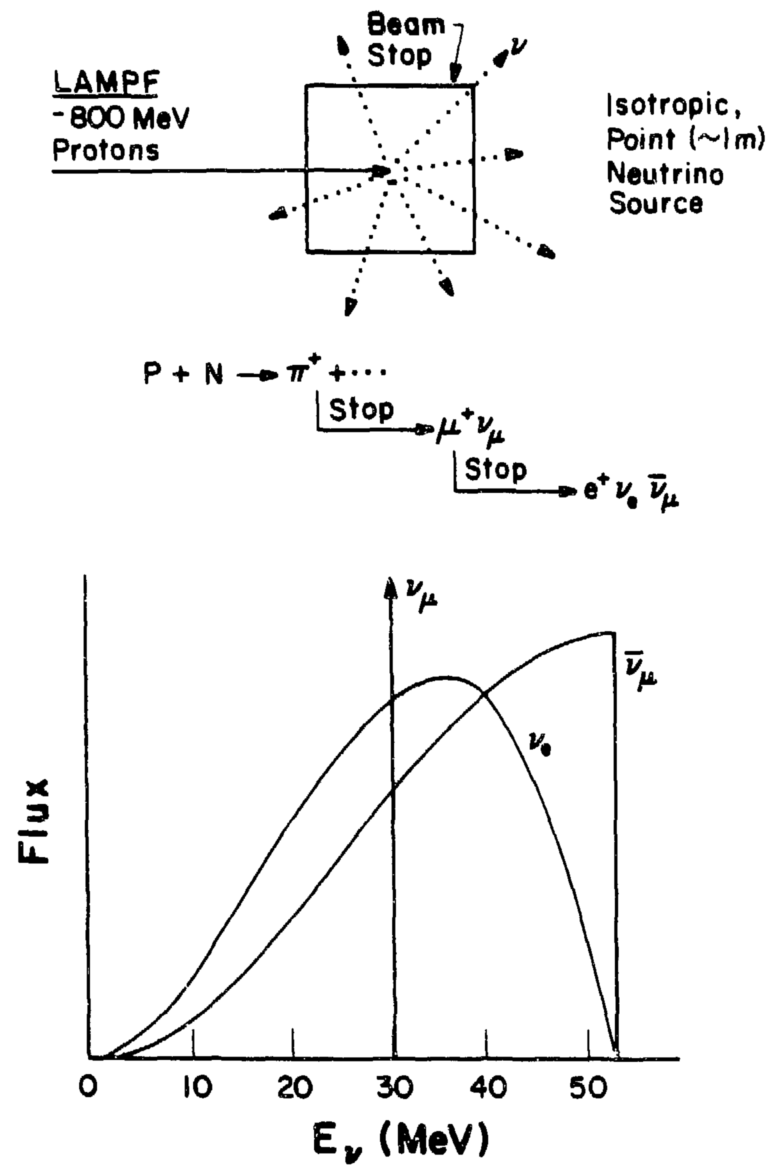

Fig. 1. Neutrinos produced at the LAMPF beam stop.

The resulting electromagnetic shower from diffractively-produced π_0s can be mistaken for an electron-neutrino event.

$$\nu_e + A \rightarrow e + X \ .$$

Thus, an experiment such as E645 is, in principle, more sensitive than higher-energy studies. Figure 2 shows the E645 set-up at the LAMPF beam stop. The detector itself is a 20-ton sandwich array made up of 40 planes. These planes consist of a scintillator plane with vertical and horizontal proportional drift chambers to measure the location of successive hits. The detector trigger requires the firing of at least three successive scintillator planes with no coincident event occurring in the liquid scintillator shield that surrounds the detector. Because of the relatively large duty factor at

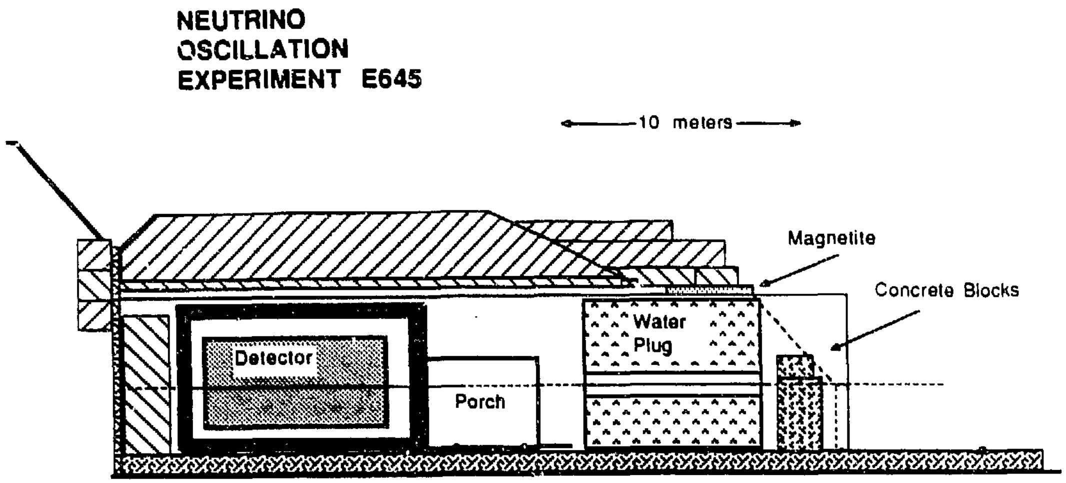

Fig. 2. Layout of E645 detector and associated shielding. The black border around the detector is an active liquid scintillator anticoincidence shield.

LAMPF (9%), the principle difficulty in carrying out a sensitive neutrino oscillation experiment is the background arising from neutral cosmic rays and beam-generated neutrons. The neutron flux from the beam must be attenuated by a factor of $e^{39}(10^{17})$ in order to achieve sufficient sensitivity. Thus, we were sorely perplexed last November when the rate in the detector was some 10^3 times larger than expected. Diligent work on the part of the experimenters, especially Joey Donahue, plus calling upon the LAMPF corporate memory revealed that back about 1970 when LAMPF was being built a pipe viewing the beam stop through two meters of steel was put in place and then buried in the fill. Figure 3 shows that the end of the long tube terminated some seven meters in front of the E645 detector. The tube has now been sealed with a concrete plug and the neutron flux at the detector has vanished. This is great news for E645, but equally as important, it shows that we really know how to compute neutron attenuation. Hence, we can proceed confidently with the LCD proposal now that the neutron rates are properly accounted for. E645 has now run for some 45 days without seeing any positive evidence for ν oscillation and is fixing the lowest limits yet observed for this phenomena. Interestingly, our results apparently conflict with data still under analysis that was taken at the BNL/AGS. Continued running of E645 is a high priority until a background limit is encountered, or human endurance fails.

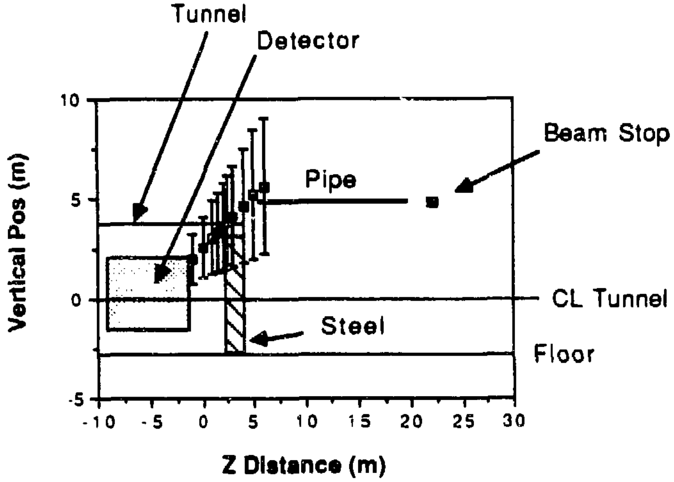

Fig. 3. Reconstruction in the vertical direction for proton recoil tracks induced by beam-related neutrons. Zero distance is at 3.87 m from the tunnel headwall.

Enormous progress over a relatively short time has been made in bringing the Neutron-Time-of-Flight (NTOF) system into operation. Starting after the beam was shut off last December, John McClelland and his team have: (1) put together a complex beam line, (2) provided the shielding and a structure to house it, and (3) set up the targetry and an initial flight path with a working detector and analysis system. They have also learned how to retune the LAMPF beam so that for less than maximum energies the last resonators in the linac are tuned to produce minimum time-spread in the neutrons arrival time at the detector. Figure 4 shows a spectrum they achieved this week on the $^{15}N(p,n)^{15}O$ reaction at 450 MeV. Figure 5 shows how well they are doing in the normalization of the yield. The agreement with previous data looks excellent. All this work was accomplished within budget and on a very ambitious schedule. They are to be congratulated for an excellent job! We expect to learn a great deal from NTOF about the role of spin- and isospin-degrees-of-freedom in nuclear structure as well as the nuclear-medium modifications of the free nucleon-nucleon interaction.

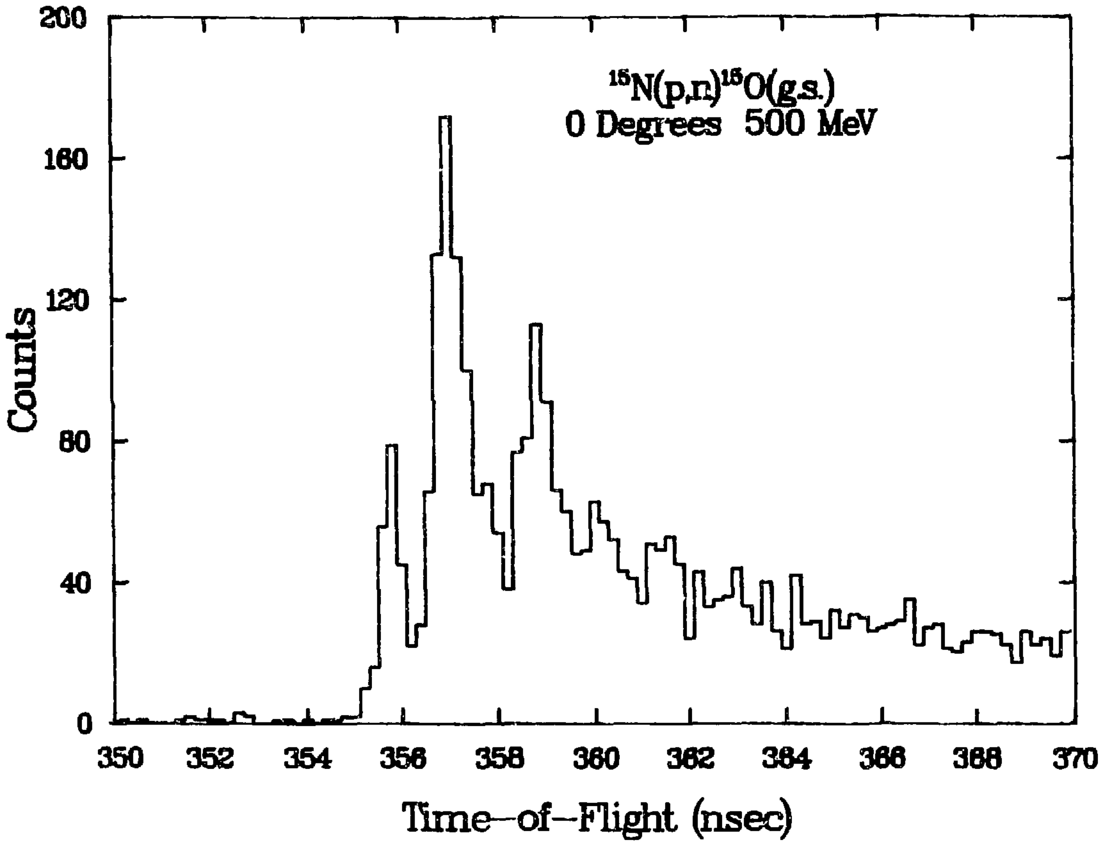

Fig. 4. The $^{15}N(p,n)^{15}O$ yield observed at LAMPF. The peaks from left to right are the ^{15}O ground state, the 6.18, $3/2^-$ state in ^{15}O, and the ^{12}N ground state. The latter is due to a ^{12}C impurity in the ^{15}N target.

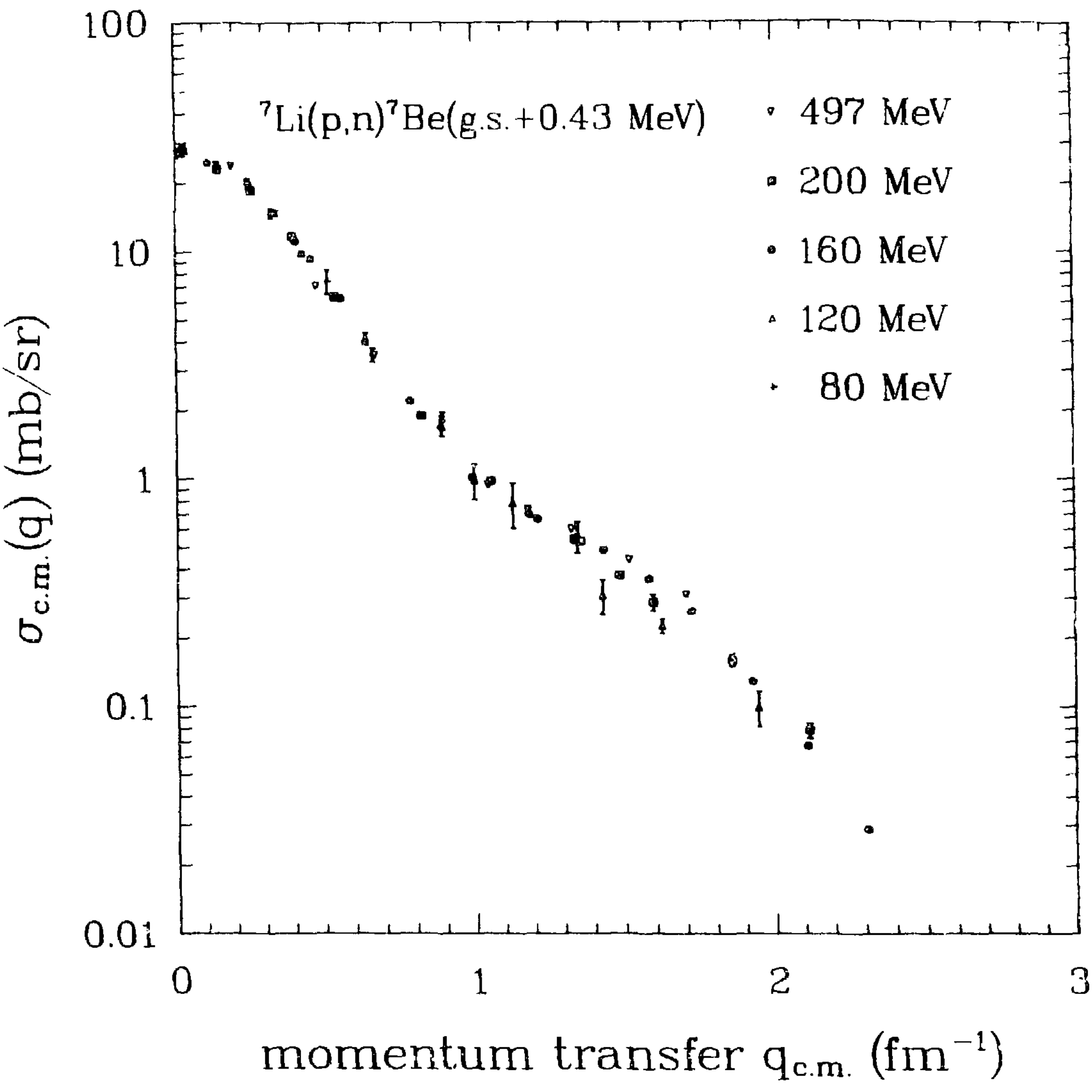

Fig. 5. The ^{7}Li(p, n)^{7}Be ground state plus 0.43 MeV cross section. The open triangles are data points from the new NTOF facility.

One of the exciting and contentious activities going on over the past year has been the search for a bound $T = 2$, $B = 2$ system. (T is the system isospin and B is the baryon number.) Figure 6 shows the known $B = 2$ systems. To be bound, the mass of the $T = 2$ system must lie below that of two nucleons plus a pion. In such a case, the $T_Z = 2$ and -1 members of the isospin multiplet will decay weakly with a lifetime somewhere between 10^{-10} and 10^{-8} s. The stable members of such

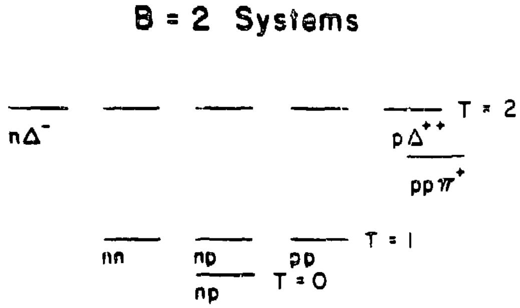

Fig. 6. The isospin multiplets with baryon number equal to 2 and strangeness equal to 0.

a system are $(pp\pi^+)$ and $(nn\pi^-)$ which would decay via

$$(pp\pi^+) \to e^+ + \nu_e + pp \tag{1}$$

and

$$(nn\pi^-) \to e^- + \widetilde{\nu}_e + nn \quad . \tag{2}$$

Two proposals, E979 and E981, were presented in 1985. Both proposed to pursue this improbable piece of exotica via the pion double charge exchange reaction

$$d(\pi^\pm,\pi^\mp) \begin{array}{l} pp\pi^+ \\ nn\pi^- \end{array} \quad . \tag{3}$$

E979 gathered some data in the 1985 running cycle and completed the analysis this spring. At that time they brought forth some weak evidence for a peak below $(NN\pi)$ threshold in the (π^+,π^-) reaction. They were granted additional time on two occasions to improve the data, resulting in supportive but not convincing data. The cross section for this bound state, if it exists, is small ($<$10 nb/sr). The results to that time were presented to the PAC at its August 24-27, 1987, meeting. The PAC endorsed the high physics interest in this research and assigned a large block of time on EPICS to E979 for a long and hopefully definitive run on (π^+,π^-). If positive results were forthcoming, the plan was to allocate more beam time in this calendar year for additional study into the nature of this possible bound state. Unfortunately, the results obtained by E979, while continuing to suggest a state some 15 MeV below the $pp\pi^+$ threshold, were not sufficiently convincing to merit further additional running. The preliminary spectra associated with this recent run are shown in Fig. 7.

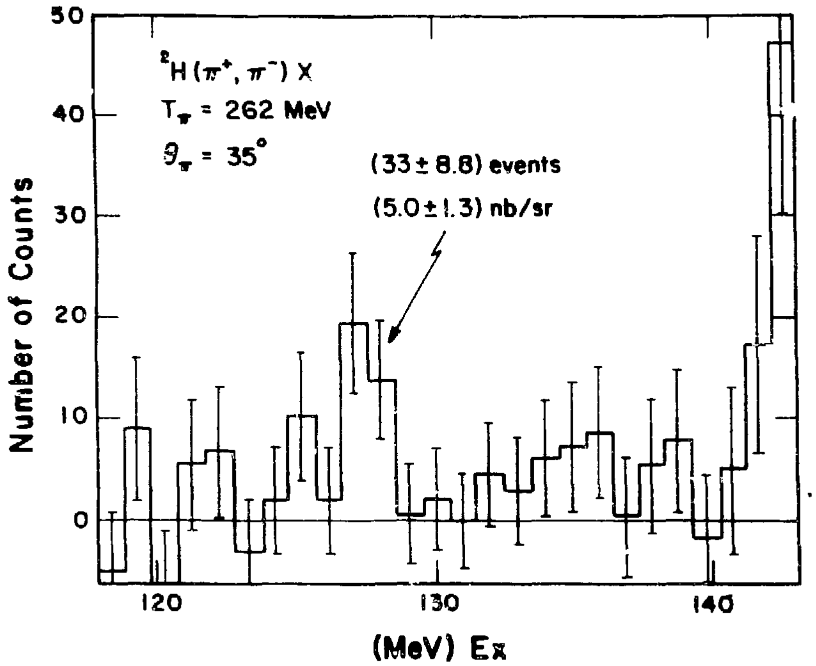

Fig. 7. Spectrum of π^- observed in the $^2H(\pi^+,\pi^-)X$ reaction below the $pp\pi^+$ threshold.

As you can see, the data are suggestive of a peak. However, even if there is a peak, it need not be due to the process depicted in Eq. (3). The observed cross section is small and the targetry difficult. It is very desirable to set up a coincidence experiment that would be definitive at the level of a single event. I encourage you to think about it and propose such an experiment. It is a very exciting possibility! Should one prove that such a bound state existed, the reason for its binding would have to be found in hadron physics, as quark gluon degrees-of-freedom cannot produce such an object.

The last development I would like to showcase at this time is a major advance in high-flux, low-energy neutron counting. The Los Alamos Neutron Scattering Center (LANSCE) provides an intense source of thermal and epithermal neutrons created from short pulses (0.3 μ/s) of 800-MeV protons from the Proton Storage Ring (PSR). Thus, the arrival time of a neutron at a detector is a direct measure of its energy. Dave Bowman, MP-4, and Charlie Bowman, P-3, have recently shown how to measure the neutron flux without having to count individual neutrons. If one employs a ^{6}Li doped scintillator and simply measures the photomultiplier output current as a function of time, the result is the sample's neutron scattering cross section as a function of energy. Figure 8(a) shows the total cross section for n + ^{165}Ho as a function of energy. Figure 8(b) shows what the Bowmans observe in just 0.4 s using the LANSCE neutron source. The system shows long-term stability as can be seen in the higher statistics spectrum obtained in one hour of running, Fig. 9. This new tool greatly enhances one's ability to carry out very sensitive symmetry tests and measurements of symmetry breaking using neutrons from 1 to 500 eV. Table I lists the parity and time reversal violating interactions that can be investigated with polarized neutrons and/or polarized targets. It is expected that the above developments will allow the observation of several hundred parity violating resonances which evidence a sizable asymmetry due to small s-wave admixtures into dominantly p-wave resonances. With such a large sample of resonances, reliable statistical procedures can be employed to extract a useful hadronic weak interaction.

Table I. Fundamental Symmetry Measurements with Neutrons.

Parity Violating

$$H_{mA} = \underset{\sim}{\sigma} \cdot \underset{\sim}{K}, \ \underset{\sim}{J} \cdot \underset{\sim}{K}$$

Time Reversal Odd—Parity Conserving

$$H_{mA} = (\underset{\sim}{\sigma} \cdot \underset{\sim}{J} \times \underset{\sim}{K})(\underset{\sim}{J} \cdot \underset{\sim}{K})$$

Time Reversal Odd—Parity Violating

$$H_{mA} = \underset{\sim}{\sigma} \cdot \underset{\sim}{I} \times \underset{\sim}{K}$$

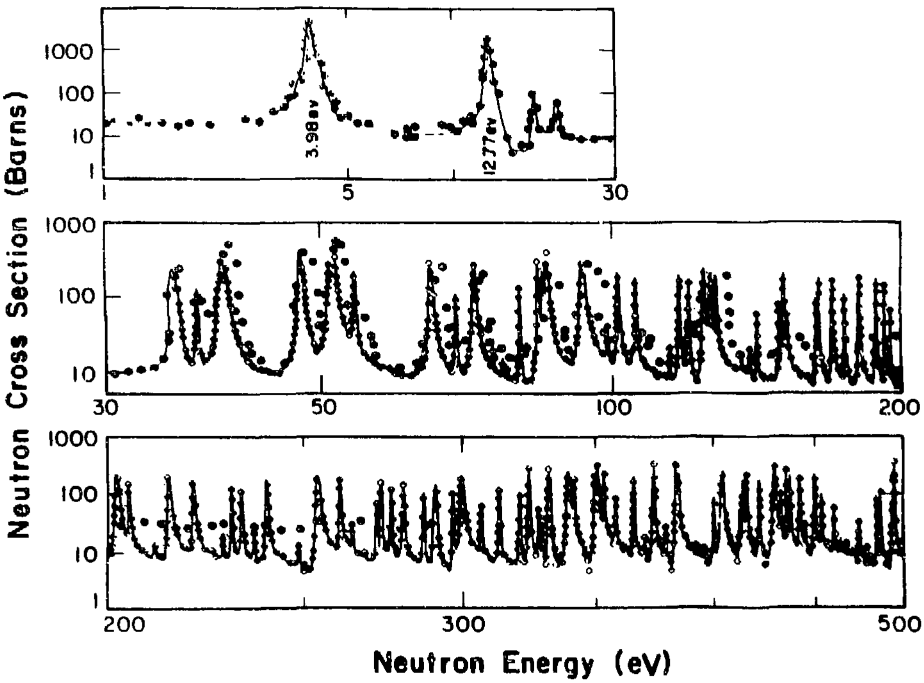

Fig. 8(a). $^{165}Ho + n$ as a function of energy.

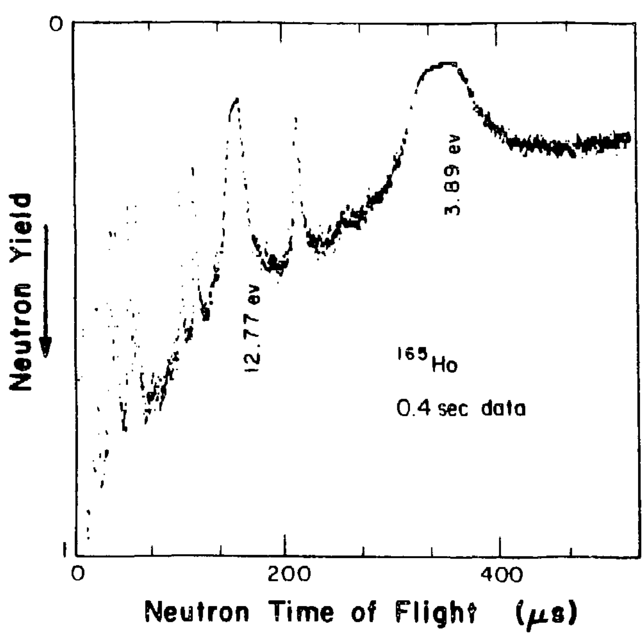

Fig. 8(b). $^{165}Ho + n$ yield as observed from four pulses at the PSR-LANSCE. The yield is plotted as a function of neutron flight time.

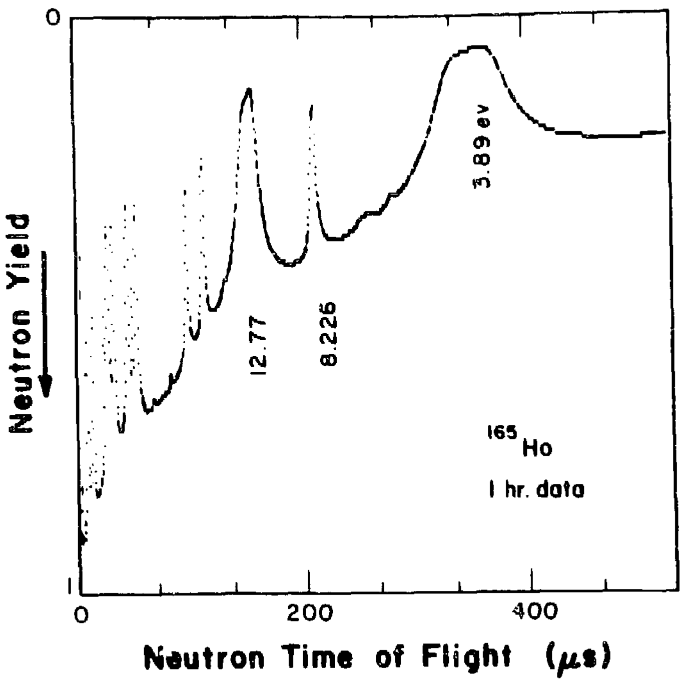

Fig. 9. High statistics run of ^{165}*Ho + n yield as measured at PSR-LANSCE.*

Thus, you see, there continue to be very exciting possibilities for research and development at LAMPF There is great promise for future research. The ingenuity and dedication of our users are absolutely crucial as the scientific stimulus to our enterprise and I continue to both applaude and support your efforts.

Proposals

The newly reorganized PAC met in August and considered 24 new proposals and 14 updates. The previous arrangement of 9 subcommittees associated with each beam line has been collapsed to 3 committees, each with much broader physics purview. The idea is to make the proposal approval process more physics driven and to allow more of the subcommittee to hear and directly evaluate each proposal. I think that the reorganization was generally very successful so far as the PAC and the LAMPF management are concerned. There has not been a great deal of reaction yet from users; however, a few have confessed to confusion regarding the new system, particularly with regard to the matter of what is meant by a physics program. Let me try to be clear about our view. A proposal to LAMPF must specifically state: (1) what is to be measured and to what degree of accuracy, (2) what beam line is required, and (3) LAMPF equipment requirements. The physics motivation and justification should be clearly spelled out with appropriate references to relevant theory and experiment. In a science as complex as nuclear physics, it is often the case that a particular measurement will not reach any meaningful physics conclusion, but rather a series of measurements is required. In these instances, it is important in the proposal to indicate how that program of measurements is to be carried out. Do the proposers themselves plan to carry to completion the necessary series of experiments and the requisite analyses, or do they assume that the subject is so interesting that the necessary additional work will be carried out by others? Over what time scale could the necessary research be carried out? To some this may appear bureaucratic and an interference with free scientific investigation. However, I consider it a necessary exercise to understand what else needs to be done beyond the individual, proposed experiment in order that the desired physics objectives be achieved. This issue is far too often left totally unaddressed in a proposal. It is then left up to the reader to imagine the necessary set of circumstances that would allow useful incorporation of the result of the proposal into the body of scientific knowledge. I would commend to you as an excellent example of a well written and defended proposal, E1080 with C. Glashauser and K. Jones as spokesmen. Incidentally, it was also approved *with A^- priority!*

Table II lists the new PAC. It should be a very effective group to evaluate the research proposals of the next few years. In the future, it is likely that the size of the PAC will decrease to 15-18 members.

Table II. Program Advisory Committee — Winter 1988.

Nucleon Physics	*Pion Physics*	*Electroweak Physics*
J. Cameron	H. Crannell	J. Friar
P. Debevec	J. Domingo	P. Herczeg
B. Frois	D. Ernst*	W. Marciano
R. Holt	D. Koltun	R. McKeown
G. Love	R. Korteling	P. Nemethy
J. Negele*	D. Measday	F. Sciulli*
J. Shepard	N. Porile	H. White
	D. Strottman	

*Chairman

Foreign Visitors

The problem of obtaining the necessary approvals for our foreign colleagues to work at or to visit LAMPF continues unabated. We became alerted to this issue over one year ago when for unexplained reasons the approval chain became an extreme obstacle. Despite vigorous effort and expressions of concern and regret there has been no progress on any front in this matter. Simply stated, the approval chain within DOE for defense laboratories is erratic in assigning **either** approval or disapproval. The only constants of the system are that Iranians are all denied approval, even in cases where they are permanently employed elsewhere in the DOE system. Approvals are late no matter how early the requests are submitted, arriving at the earliest two days before a visit is to begin. The situation is, in a word, *dreadful.* It consumes vast amounts of my time and that of upper Laboratory management. We are appalled by the inadequate and rude way that these issues are dealt with, and are working toward a resolution. However, since we have been in this state for some months now, I can offer you no idea as to when it will be seriously addressed by responsible parties in DOE, much less resolved.

LAMPF Operating Budget

The large federal budget deficit has forced the Congress to act to reduce federal commitments for FY88. Should the reductions be accomplished via the Gramm-Rudman-Hollings Amendment, it is expected that nuclear physics would receive some 8.6% below the FY88 President's budget request. If this were passed directly to LAMPF, it would result in a funding level for FY88 some 5% below our FY87 allocation. That is a cut of some $2.0 M and would severely reduce our level of activity and service to you. We suffered a similar cut in FY86 and had just in this past year begun to recover from its unfavorable impact on accelerator operation. As I said, a sizable cut in FY88 will severely curtail our activity and we may well have to drop a major part of the program. It is clear that such cuts make it difficult, if not impossible to contemplate very large projects such as LCD. The large cost of that undertaking makes it necessary that it be provided for as a line item. The LCD proposal has a final scientific review in February 1988. I believe that Hywel White and the members of the LCD collaboration have effectively dealt with all technical issues and engineering design questions. However, even if LCD passes technical review, its eventual funding is not assured because of very tight resources at the national level.

Any course of action we take in response to budget reductions will eventually impact your capability to do research; hence, we will keep the LUGI informed at all stages of our FY88 budget exercises. I met with the LUGI Board of Directors yesterday and they have graciously agreed to help us in this regard.

Future

Before closing, let me speak of the future beyond next year. Thinking about and planning for the future is one of the most important responsibilities of the LAMPF Director. The most crucial input into this task is the physics ideas, enthusiasm, and specific proposals generated within the scientific community. Workshops are one of the most effective ways for consolidating the community's previous experience and developing new ideas for future directions. In August we had two related workshops on the use of pion beams. The first was arranged by Ben Nefkins on *Physics with $\eta, \rho,$ and ω: A New Role for Meson Factories.* The second was organized by Jerry Peterson and Dan Strottman on *Pion Nucleus Physics: Future Directions and New Facilities at LAMPF.*

The proceedings of these very interesting meetings will soon be available. I hope you will avail yourselves of them and read them carefully. At these meetings, strong and cogent arguments for moving to higher pion energies than are presently available at LAMPF were presented. The investigation of many new aspects of pion-nucleus interactions can be carried out by upgrading present LAMPF capability. I believe we should do this. To put together a sensible program of pion-nucleon physics, pion-kaon hypernuclear physics, and eta research requires a high-quality, intense-pion beam at nearly 1 GeV. At present it is not economically attractive to undertake boosting the LAMPF pion energy to 1 GeV. However, the research program indicated at $E_\pi = 1$ GeV is attractive and should not wait for a full blown kaon factory before it is at least explored. The present possiblities are: the Japanese Hadron Project, the AGS, and an as yet unforeseen modest energy upgrade of one of the three existing pion factories.

I spent time in Russia recently looking into the progress of the Institute for Nuclear Research–Los Alamos National Laboratory collaboration in a gallium solar neutrino measurement. The experiment is to be carried out in the Baksan Valley Cosmic Ray Observatory in the Caucasus Mountain range. The Institute for Nuclear Research of the USSR Academy of Sciences is the same

Institute that is constructing the Meson Factory at Troitsk. There have been several delays in completion of this facility. As a result, Soviet scientists at the Institute have a real interest in becoming involved in LAMPF experiments. There are many excellent researchers at the Institute for Nuclear Research and I hope that those of you contemplating large projects will think about possible Soviet involvement. They have much to bring to our research efforts. As you know, Soviet scientists have proved to be strong and reliable colleagues at Fermilab and CERN.

In closing, let me say a few words about a recent development. On October 28, a Canadian delegation approached the Department of Energy and the National Science Foundation seeking rather substantial ($75.0 M over 5 years) United States commitment to help support an upgrade of TRIUMF to the status of a kaon factory. From a scientific point of view, this approach is timely as the major nations involved in nuclear and particle science need to set the future direction of this subject. It is clear to everyone here that at least one high-intensity, high-energy facility is required if we are to continue pressing on the limits of the minimal standard model and investigating the possiblities of usefully applying QCD to hadronic physics. The United States government has not yet worked out a procedure to address the Canadian request. We believe the Los Alamos plan termed an Advanced Hadron Facility is scientifically and technically more attractive than the TRIUMF proposal and we shall be strongly pushing this point of view. However, should the United States not come up with any clear plan of how it will effectively upgrade the existing LAMPF facility, supporting the Canadian approach may be the most scientifically responsible course-of-action.

Summary of a Report on MP Division
1987 LAMPF Users Meeting

Donald C. Hagerman

During the past two years, the responsibilities of MP Division have increased significantly. The principle thrust of our activities is connected with LAMPF and include major components of the LAMPF research program, operation and development of the facility, and support of all of the research activities. Our physics research activities also include significant roles in large experiments at the AGS and Fermilab. The responsibility for commissioning and operating the PSR/WNR beam delivery system was assigned to MP Division early in 1986. This new responsibility significantly increased our role in accelerator development, and this work complements the continuing development of the LAMPF accelerator and the planning for a major upgrade to the LAMPF facility during the early 1990s.

Development activities proceeded at a commendable pace during the past year. The construction and initial checkout of the Neutron Time-of-Flight (NTOF) facility was particularly gratifying. During the next year we expect the NTOF construction to be completed and that significant progress will be made on the Medium Resolution Spectrometer (MRS) with completion expected in 1989. The progress on the Optically Pumped Polarized Ion Source (OPPIS) is on schedule with operation of the new source expected in 1989. Reasonable operation of the PSR facility has been achieved at 30 microamperes average current; during the next year we expect significant beam time for research and a definition of the necessary changes to bring this facility to design current. In the experimental program, MEGA is our highest priority with some development runs using beam expected during November of this year. The Large Čerenkov Detector (LCD) is a major initiative in neutrino physics; we shall have a definitive scientific review of this project early in 1988. With major support from the senior Laboratory management, we continue planning for a high energy, high current facility at LAMPF during the 1990s.

Operation of the facility during 1987 was quite satisfactory showing a significant improvement in beam availability for all three beams (H^+, H^-, and P^-) as compared with the 1986 operation. Our goal for future years is to retain this level of beam availability and maintain over the long term something like 3000 hours of beam time per year; these goals for calendar 1988 may be somewhat compromised by the confusing budget problems seen early in FY 1988. As soon as definitive budget information is available, the operating schedule for the summer of 1988 will be released. Our transition to spring-summer operation should be completed by 1989.

EXPERIMENTAL FACILITIES PANEL

(June L. Matthews)

The new LUGI bylaw which proposed to rename and reorganize the Technical Advisory Panel was passed by a large majority at the November 9-10 Users Meeting. The newly created Experimental Facilities Panel (EFP) met for the first time on November 11. As described in the September newsletter, the EFP is to consist of no more than 15 members, chosen so that the major experimental facilities and beam channels are represented. At present, such facilities comprise the following: Computer Facilities, EPICS, HRS, LEP, Material Science, Neutrino Facilities, NTOF, Nuclear Chemistry, NPL, P^3, Polarized Targets, and SMC. Additional facilities may be included at the discretion of the LUGI Board of Directors, based on user interest and activity. Additional members-at-large of the EFP, if any, may be appointed by the Board. The members of the Board also sit on the EFP, as members *ex officio*. The current membership of the EFP, with their institutions, facility affiliations, and year of expiration of their terms, is given below.

Peter Doe, University of California at Irvine, Neutrino Facilities (1988)
Ralph Minehart, University of Virginia, LEP (1988)
Harold Spinka, Argonne National Laboratory, NPL (1988)
Edward Stephenson, Indiana University, member-at-large (1988)
George Burleson, New Mexico State University, Polarized Targets (1989)
Frank Clinard, Los Alamos, Materials Science (1989)
Martin Cooper, Los Alamos, SMC (1989)
Peter Gram, Los Alamos, P^3 (1989)
Kevin Jones, Los Alamos, HRS (1989)
Tom Kozlowski, Los Alamos, Computer Facilities (1989)
Evan Sugarbaker, Ohio State University, NTOF (1989)
Jan Wouters, Los Alamos, Nuclear Chemistry (1989)
(to be elected), EPICS (1989)

PION NUCLEUS INTERACTIONS

M. Thies

Natuurkundig Laboratorium der Vrije Universiteit
Postbus 7161, 1007 MC Amsterdam, The Netherlands

Abstract

Some recent progress and outstanding problems in pion nucleus physics are reviewed, special attention being paid to the interaction between theory and experiment.

1. INTRODUCTION

The title of my talk was chosen by the organizers of this meeting. It is so general that I cannot possibly do justice to it. Therefore, I assume that I should feel free to talk about anything I like. It seems to me that an appropriate theme for this users meeting is the interplay between theory and experiment in pion physics. So, while reviewing some of the past achievements and outstanding problems in our field, I shall try to indicate in each case the role played by theory and experiment. Needless to say, an experimentalist would give an entirely different talk on the same subject!

Historically, the thrust of pion-nucleus physics was heavily influenced by prior experience with proton-nucleus inter= actions. There, the problem for theory is rather obvious: Assume a NN two-body interaction (constrained by two-body data) and try to predict proton-nucleus reactions. A compari= son with experiment should then teach us about off-shell effects and certain nuclear structure aspects difficult to study with electrons (e.g. neutron properties, short range correlations).

The pion-nucleus problem is too complex to be fitted into the same general scheme. Even if we would have the complete information about the π-N and N-N interactions, we would not be able to predict π-nucleus reactions, not because of technical problems, but in principle! There are three main novel features which can be held responsible for this fact:

1) The π-N system couples strongly to the Δ-resonance, which in turn can interact with the nuclear medium. If one considers the Δ as a baryon in its own right (as suggested by the quark model) rather than a πN resonance, one needs the Δ-N interaction as additional independent input. But this is hard to determine because of the instability of the Δ.

2) The pion can be absorbed on two or more nucleons, a process which is very likely to occur, but not directly related to π-N and N-N interactions[1].

3) According to current ideas based on Quantum Chromodynamics (QCD), the pion itself has a rather complicated sub= structure. Its dual character as a Goldstone boson of broken chiral symmetry and a $q\bar{q}$ bound state suggests to identify the pion with a low-lying, collective excitation of the QCD vacuum[2]. If this vacuum structure

plays any role at all in nuclei, then again there is room for dynamics beyond the two-body interactions.

In view of these unknown dynamics (which are specific for pions), one cannot expect conventional multiple scattering theory to have a high predictive power. On the other hand, these three points are so interesting that they deserve to be put into the main focus of pion-nuclear studies. By evaluating as reliably as possible the conventional interactions and comparing theory with experiment, one may learn a great deal about points 1-3 and hence about strong interactions in general. This is the attitude I take here. The idea is to minimize the 'classic' uncertainties (off-shell effects, nuclear structure), typically by concentrating on quasi-free processes. Alternatively, one can try to minimize the effects 1-3 and use pions as a nuclear structure probe. This complementary use of pions has been remarkably successful here at LAMPF, particularly in those cases where one has to rely only on the qualitative features of the π-nucleus interaction. For detailed quantitative questions, such attempts remain full of pitfalls as long as we don't understand the pion specific dynamics well enough.

2. SOME THINGS WE KNOW

Here, I want to concentrate on those aspects of the hadron-nucleus interaction which are not specific for pions and fairly unambiguous[3]. As is well known, elastic hadron-nucleus scattering is most conveniently described in terms of an optical potential. At high energies, the impulse approximation (IA) relates the optical potential to the elementary hadron-nucleon interaction (t-matrix) and the nuclear ground state wavefunction:

$$U_{opt} = \langle 0| \sum_{i=1}^{A} t_i |0\rangle \qquad \text{(IA)} \qquad (1)$$

At low energies, we can think of various medium corrections to eq. (1), and the question arises how to proceed systematically. By far the most appealing way of establishing a certain hierarchy of corrections is provided by the hole-line expansion[4]. Processes contributing to U_{opt} are ordered according to the number of target nucleons which, at a given time, have left their original orbits. Roughly speaking, the leading term describes the interaction of the projectile with "one nucleon at a time", taking into account the fact that this nucleon is bound and cannot occupy states blocked by other nucleons. To this order, (1) gets replaced by

$$U_{opt} = \langle 0| \sum_{i=1}^{A} g_i |0\rangle \qquad \text{(one hole-line)} \qquad (2)$$

where g is the Brueckner g-matrix[5]. Independently of whether eq. (2) is realistic enough, it can never be inferior to the IA, eq. (1), which it contains as high energy limit. Technically, the evaluation of a g-matrix for finite nuclei is very involved. For proton-nucleus scattering, such a calculation has not yet been done without additional simplifications, to the best of my knowledge. In the case of resonant pions, the dominance of a single π-N partial wave (P_{33}) and the small mass ratio m_π/m_N render the problem tractable, although at the cost of quite some numerical effort. The resulting optical potential accounts automatically for Δ-propagation (due to correct treatment of Fermi-motion and recoil), Pauli-quenching of the Δ width and binding effects (Fig. 1). This is the backbone of the "Δ-hole model[6]" as applied to pion-nucleus scattering. I tried to

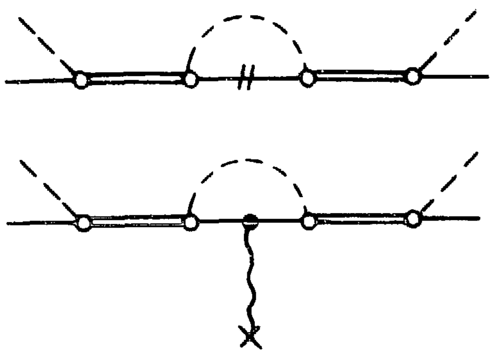

FIGURE 1
Pauli blocking correction (a) and binding correction (b) contained in the π-N g-matrix.

avoid this name as long as possible because it might suggest something exotic, which it certainly is not. As we shall see below, the Δ-hole model actually goes beyond the one-hole-line level, but in a phenomenological way.

Now let me briefly turn to our main theme, the interplay between theory and experiment. Can we test the dynamics contained in eq. (2) and Fig. 1 by comparing a calculation with data? The answer is definitely no! We have left out many things, not because we think that they are less important, but simply because we cannot predict them with any comparable degree of confidence (cf. points 1-3 in Sect. 1). Fig. 2 shows indeed that the g-matrix based optical potential gives a very poor description of reality. The assumption that the pion interacts with "one nucleon at a time" only is clearly untenable. The discrepancies in Fig. 2 set the scale for the amount of non-trivial information contained in the data.

Suppose we would have used the IA (1) instead of eq. (2), and made additional approximations in order to get a simple optical potential in coordinate space (static approximation,

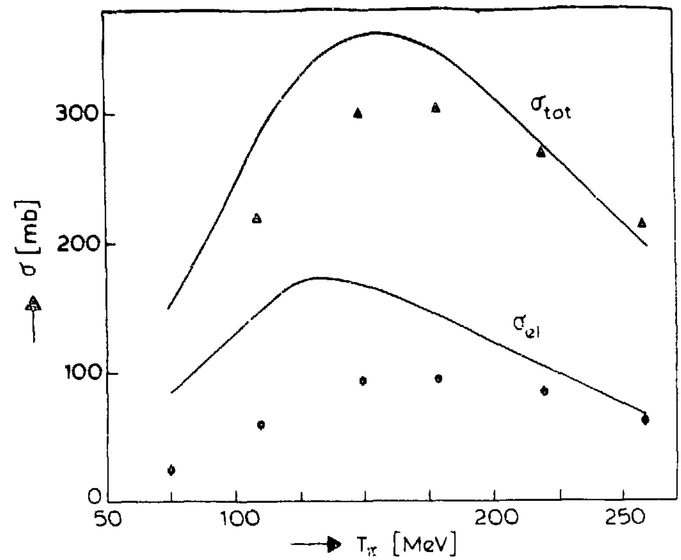

FIGURE 2

π-⁴He total and integrated elastic cross-sections as predicted by eq.(2) (adapted from ref.6).

zero range interactions). Suppose furthermore that this simple calculation would agree better with the data than the full evaluation of (2), possibly after some slight parameter re-adjustments (this is a situation not uncommon in pion-nucleus physics!) Could we then conclude that "we don't need the Δ-hole model", and proceed with the static IA? I believe that this would be a misuse of experimental data. Although experiment is the ultimate judge of any theory, we cannot use it to justify simplifying approximations. This is something which ought to be settled theoretically. Clearly, such a truncated calculation of U_{opt} would give a very misleading picture of the underlying physics, even if it would parametrize the data.

3. LEARNING ABOUT DELTAS IN NUCLEI

In the previous section, I argued that the interaction of the pion with one bound nucleon is well understood theo= retically. By contrast, the dynamics where two or more nucleons are actively involved presents an unsurmountable problem. In the resonance region, it is plausible that these interactions can be rephrased in terms of Δ-nucleon inter= actions, as illustrated in Fig. 3 for the simplest absorption mechanism. It is then tempting to introduce a phenomenolo= gical Δ-nucleus "optical potential" which supplements the known contributions of Fig. 1, with strength parameters to be determined from π-nucleus elastic scattering data. This

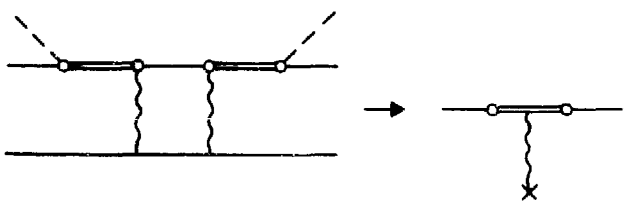

FIGURE 3
Pion absorption in the Δ-region generates a Δ-nucleus potential

is the route followed by the Δ-hole approach. Introducing such a Δ-nucleus potential allows to account for the in= fluence of pion absorption (and possibly other unknown effects) on pion scattering in a natural way, without unduly increasing the complexity of the calculations sketched in Sect. 2.

From the analysis of several light, closed-shell nuclei, it was found that a simple parametrization of the Δ-nucleus potential with two complex parameters (central and spin-orbit potentials) is adequate[6]. The depth of the central potential is typically

$$V_{\Delta} = -25 - i40 \text{ MeV} \qquad (3)$$

as compared to the nucleon optical potential of -50 - i15 MeV, at comparable energies. Such a Δ-nucleus potential completely eliminates the discrepancy between theory and experiment shown in Fig. 2. At the same time, it allows to reproduce fairly well the elastic angular distributions (see Fig. 4 for ^{12}C), with the notable exception of the rising backward cross-sections near resonance.

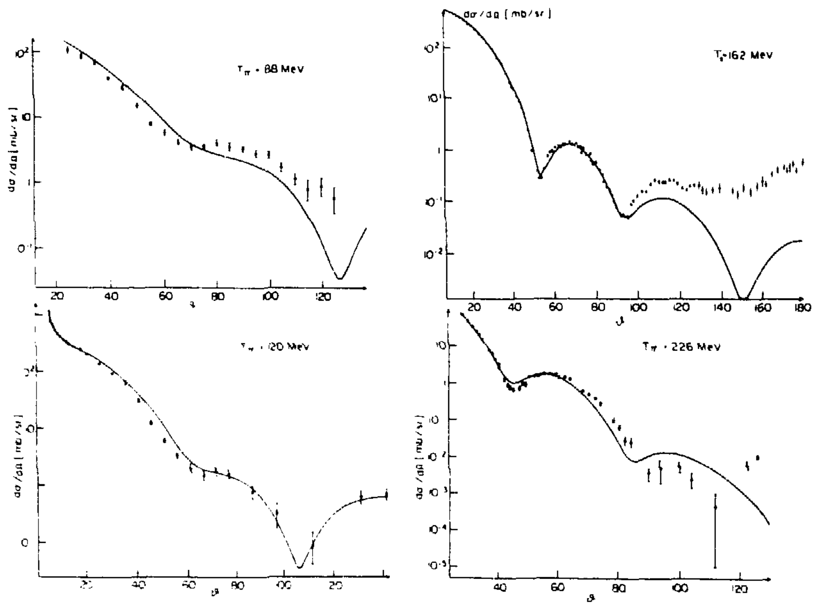

FIGURE 4
$\pi-^{12}C$ elastic differential cross-sections, as obtained by adjusting the Δ-nucleus potential[6].

In order to gain confidence in this phenomenological approach, one has to establish that it can correlate data which have not been employed when adjusting the free parameters. One immediate prediction follows if one tentatively attributes the large imaginary part of V_Δ, eq. (3), to absorption. Then, one can calculate the total pion absorption cross-section, and the results agree well with the measurements (Fig. 5). This clearly demonstrates that pion absorption influences pion scattering - we have inferred σ_{abs} from elastic scattering data alone.

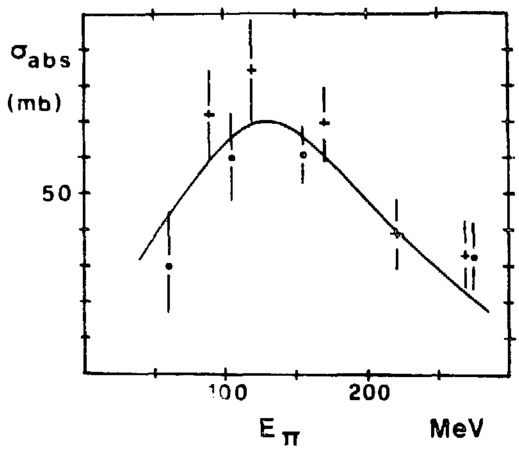

FIGURE 5
π-^{4}He total absorption cross-section as predicted by the Δ-hole model (adapted from Ref. 7)

Another prediction is the fact that the π-N interaction in the nuclear medium should be weaker than the free one, near resonance. Schematically,

$$t_{\pi N} = F \frac{1}{E-E_r+i\Gamma/2-T_\Delta-V_\Delta} F^+ \qquad (4)$$

and Im V_Δ increases the width of the Δ, thereby reducing $t_{\pi N}$. The most direct way of "measuring" $t_{\pi N}$ in nuclei is via quasi-free scattering[7,8]. Fig. 6 confirms nicely the weakening of $t_{\pi N}$ at resonance. The opposite effect observed

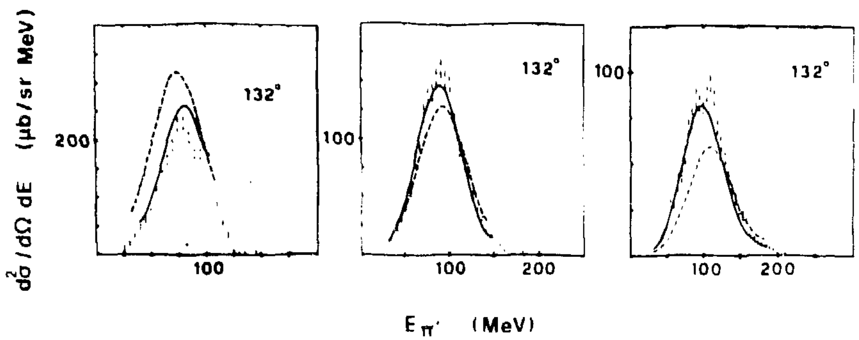

FIGURE 6

(π,π') on ^{4}He at 132° and 3 energies (left: 170, center: 220, right: 270 MeV). Solid curves: Δ-hole model, dashed curves: free πN t-matrix used in transition operator (Ref. 7).

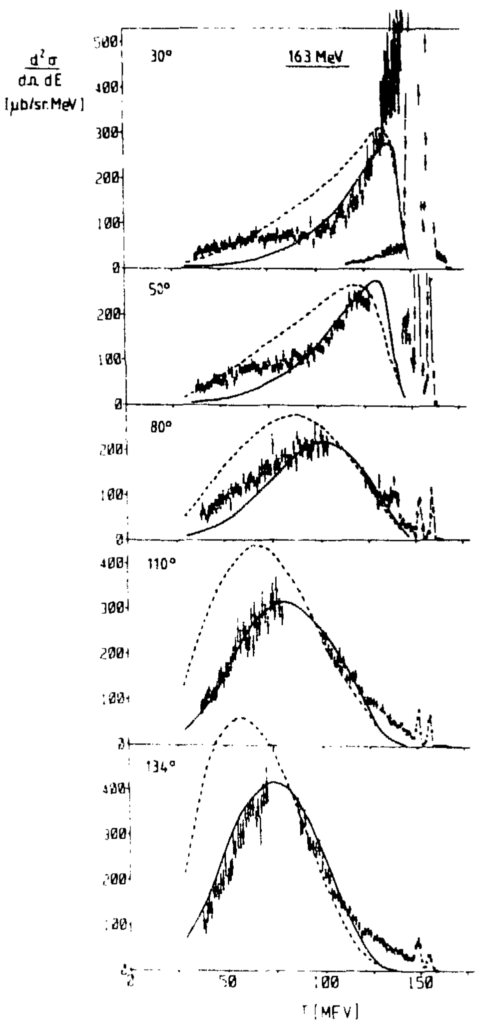

FIGURE 7

(π,π') on ^{16}O at 163 MeV. Solid curves: Δ-hole calcu= lation, dashed curves: Static, first order treat= ment of both the transition operator and the pion dis= torted waves[8].

at higher energies can be traced back to the influence of the real part of V_Δ. Fig. 7 illustrates that a static IA calculation, although sometimes successful for discrete excitations, disagrees with the bulk of the inelastic (π,π') cross-section in ^{16}O, in contrast to the Δ-hole model.

Recently, much effort was spend on studying quasi-free scattering via coincidence measurements. The hope is to get more detailed information about deltas in nuclei than contained in the one complex number, V_Δ. For ^{16}O, all three isospin channels, i.e. (π^+,π^+p), (π^-,π^-p) and $(\pi^+,\pi^o p)$, have been investigated at SIN[9] and LAMPF[10]. If the process is indeed quasi-free, one expects from Δ-dominance purely geometrical isospin ratios of

$$\sigma_{\pi^+p\to\pi^+p} \; : \; \sigma_{\pi^+n\to\pi^o p} \; : \; \sigma_{\pi^-p\to\pi^-p} \; = \; 9 : 2 : 1 \qquad (5)$$

The strong $\pi^+p\to\pi^+p$ channel seems to be well explained by the Δ-hole calculation of Takaki[11] (Fig. 8). However, the isospin ratios observed experimentally differ strongly from eq. (5), charge exchange being enhanced and $\pi^-p\to\pi^-p$ being suppressed relative to $\pi^+p\to\pi^+p$. Such violations of isospir. ɿtios

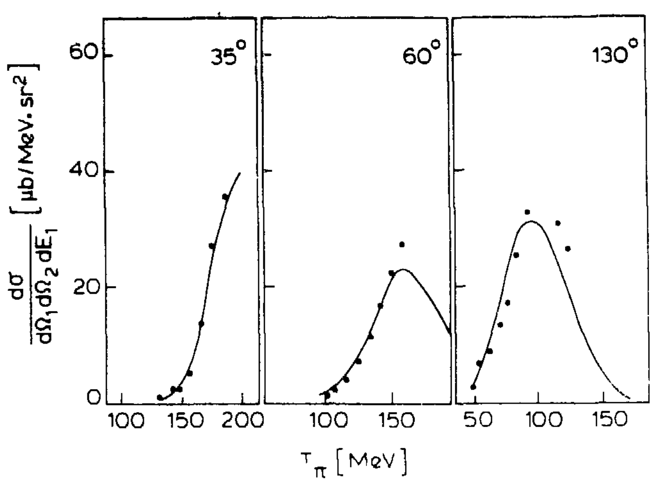

FIGURE 8

Comparison of Δ-hole calculation for $^{16}O(\pi^+,\pi^+p)^{15}N_{gs}$ (Ref. 11) with data[9]. The pion energy spectrum is shown for 3 pion angles, the proton angle being determined by quasi-free kinematics.

(which had been noted before in other pion-nucleus reactions) cannot be understood if the influence of the nuclear medium on the delta is summarized by an "optical potential", no matter how complicated this is. Eq. (5) always holds if the scattered pion and the knocked-out nucleon come from the decay of a delta, $\Delta \rightarrow N\pi$ (Fig. 9a). However, if the Δ experiences a strong potential, nothing can prevent it from knocking out nucleons occasionally, a process which has a different isospin structure and which may interfere with the standard one (Fig. 9b). If one could demonstrate such a process, one would perhaps have the nicest proof that the Δ plays an active,

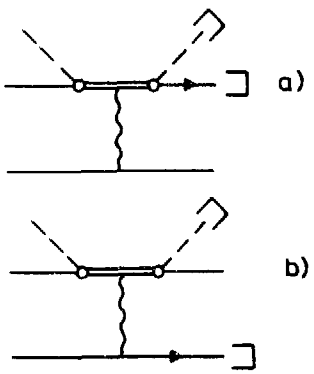

FIGURE 9
Schematic illustration of $(\pi,\pi'N)$ reaction where the detected nucleon comes either from Δ-decay (a), or where it has been knocked out by the delta (b).

dynamical role in π-nucleus reactions. Calculations by Takaki[11] using a simple, zero-range ΔN interaction gave encourageing results (Figs.10,11), although the model does not work quantitatively. In particular, the discrepancies in the single charge exchange are very systematic and reminiscent of similar findings in the charge exchange on ^{13}C to the isobaric analogue state. Notice that in the calculation, only the T=1, S=2 ΔN channel was taken into account, in order to avoid unconstrained, free parameters. For the imaginary part of the ΔN t-matrix, this is certainly the dominant contribution, but little is known about the real part. When studying $1^+(T=0,1)$ excitations in ^{12}C along the same lines, Takaki found it necessary to assume a strong, repulsive ΔN interaction in the T=1, S=1 channel, in order to reproduce the measured isospin-ratio[12]. This would be an example of an effect not related to absorption. It is interesting that this is one of the channels where the quark-model predicts a hard-core type interaction with a large radius (≳0.8 fm) between nucleon and delta, as a result of the Pauli principle for quarks[13]. Although it would be premature to draw conclusions, it is gratifying to see how very different theoretical and experimental efforts may eventually merge and reveal a new piece of strong interaction dynamics.

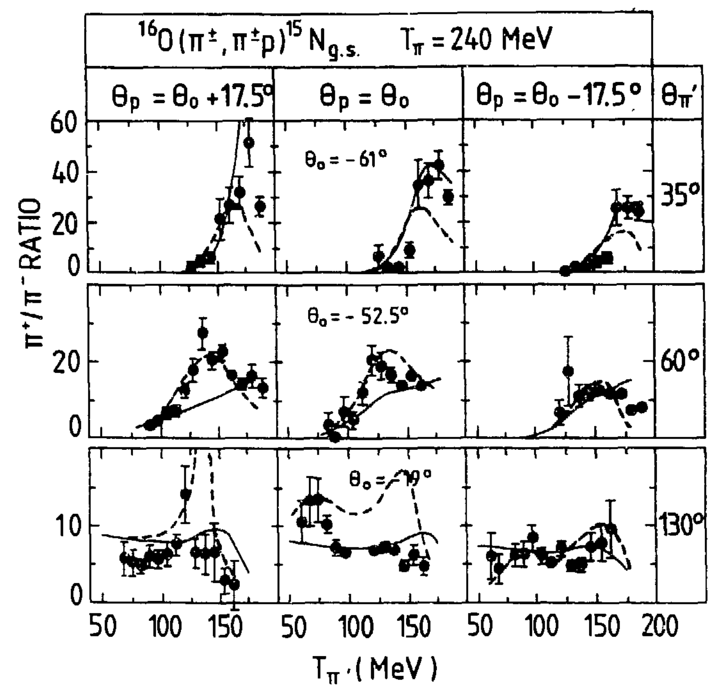

FIGURE 10

Isospin ratios in $^{16}O(\pi^\pm,\pi^\pm p)^{15}N_{gs}$ (Ref. 9), compared with simple estimate of the process depicted in Fig. 9b (solid curves[9]), and preliminary Δ-hole calculation results (dashed curves[11]).

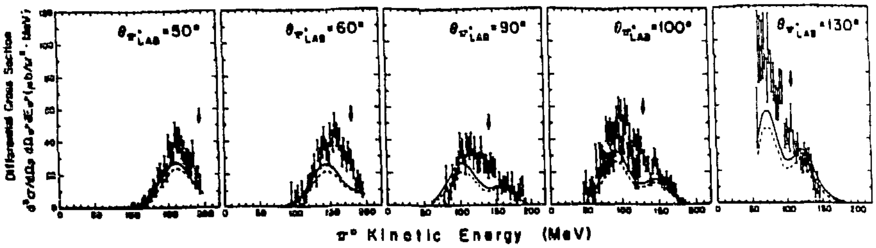

FIGURE 11

LAMPF data[10] for $^{16}O(\pi^+,\pi^0 p)$, compared with Δ-hole calculations[11]. The solid curves in= clude the process shown in Fig. 9b, the dashed curves don't.

Finally, let me add a word of caution. In the Δ-hole cal= culations of $(\pi,\pi'N)$ discussed above, the spectroscopic factors have simply been taken from the shell model. Recent (e,e'p) studies however have yielded significantly lower occupation numbers: For the p-shell in ^{16}O, only 55% of the shell model spectroscopic strength was found[14]. If we interprete this result as a genuine nuclear structure effect, we have to divide the calculation shown in Fig. 8 by 2 and cannot explain the absolute magnitude of the data. Notice that other hadronic reactions (e.g. pick-up, (p,pp) etc.) also have a tendency to yield spectroscopic factors closer to the shell model values than electrons. One would be inclined to blame this discrepancy on distortion effects and the poorly understood hadronic reaction mechanism. For pions in the resonance region however, the theory is con= strained by many other data. It is hard to think of any correction which would change the (π^+,π^+p) cross sections by a factor of 2, without destroying the quantitative agree= ment between theory and experiment in elastic and inclusive

(π,π') scattering. Moreover, nucleon final state interactions can be ruled out as a possible source of drastic errors since the same type of nucleon optical potential has been used in the analyses of (e,e'p) and (π,π'p) reactions. Therefore, we are unable to reconcile the pion and electron quasi-elastic scattering data at this moment.

4. LEARNING ABOUT PIONS IN NUCLEI

As we have seen in the last section, resonant pions teach us more about deltas in nuclei than about pions. In order to focus on the pion itself, it is necessary to go off resonance. The energy region between 0 and 80 MeV is the domain where simple, semi-phenomenological optical potentials of the type first introduced by the Ericsons[15] have some justification and are still being widely used. Of all the features which have been discovered, the most surprising is perhaps what one might call the "anomalous s-wave repulsion". Let me remind you that the general form of the pion optical potential is assumed to be

$$U_{opt}(\vec{r}) = B(r) + \vec{\nabla}\cdot A(r)\vec{\nabla} \qquad (6)$$

The local term B(r) should represent π-N and π-NN s-wave interactions. The IA predicts very small values of B(r) due to the vanishing of the isoscalar π-N scattering length (chiral symmetry). At threshold, one expects

$$U_{opt}(r=0) = \frac{49.1\cdot N - 45.6\cdot Z}{A} \text{ MeV} \quad (\pi^-) \qquad (7)$$

i.e. a few MeV only. Early fits to pionic atom data and low energy elastic scattering yielded values of $B(0)\cong 20-i10$ MeV.

The repulsive real part was attributed partly to Pauli-blocking and kinematical effects, partly to dispersive effects from absorption. Repulsive local potentials of 20-30 MeV depth where also inferred from Δ-hole calculations below resonance, at energies up to 100 MeV[6,16] (Fig.12). If one takes the data from strongly bound levels in pionic atoms at face value (e.g. the anomalously small width of the 3d level in ^{208}Pb[17,18]), one is lead to conclude that the repulsion in the nuclear interior may even be larger.

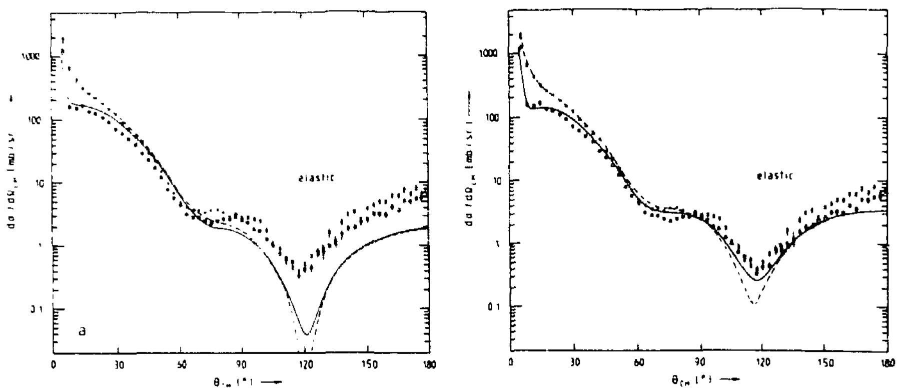

FIGURE 12

$\pi^{\pm}$-^{12}C elastic scattering at 100 MeV (Ref.16)
Left: Best fit obtained within Δ-hole model.
Right: Including s-wave potential 30-i10 MeV

By and large, the s-wave repulsion seems to be too strong and too "universal" to be attributed to s-wave scattering or absorption, but no plausible explanation has yet been found. A group at Leningrad[19] has been able to generate 100's of MeV of repulsion via relativistic effects ($N\bar{N}$ pair terms, σ-fields), but they cannot resolve the basic puzzle why the same strong interaction is not seen in free πN scattering. It is amusing to speculate that the effect is related to pion substructure, i.e. item 3) of the intro=

duction. Indeed, take the extreme model where the nucleus consists of one big "bag", the nucleons being colour singlet clusters of 3 quarks strongly correlated by residual inter= actions. Then, the electromagnetic probe, which couples to the charged quarks, would see nothing unusual: It would simply tell us that the nucleus is made out of nucleons. The pion on the contrary would be very sensitive to the enlarged bag volume: It would loose its "collective" character inside the nucleus and turn into a $q\bar{q}$-state with a mass of 300-400 MeV (the bag model pion). This illustrates a mechanism for generating strong repulsion which is not related to the free πN interaction, and would be very specific for the pion. It might also explain why this re= pulsion does not seem to show up in inelastic transitions[16]. Obviously, in order to generate a few tens of MeV increase in pion mass only, one would get away with a much less extreme picture of the nucleus.

5. PION ABSORPTION PUZZLE

Having reviewed some aspects of pion nucleus interactions which either can be settled theoretically (Sect. 2), or where a joint effort of theory and experiment has been benefitial (Sects. 3,4), let me finally turn to a subject where experiment has left theory way behind: Pion absorption. Fortunately, it is possible to illustrate the kind of problems we are facing here by mere data-to-data compari= sons.

Two targets have been investigated in considerable detail: The deuteron and ^3He. In ^3He, kinematically complete measurements have allowed to identify quasi-free absorption on deuteron-like $^3S_1$ pairs unambiguously[20]. The angular distribution agrees almost perfectly with that of the elementary $\pi^+d \rightarrow pp$ reaction, and the momentum distribution of the spectator nucleon leaves no doubt about the quasi-free nature of the process (Figs. 13,14). Besides, π^- absorption on $^1S_0$ pp-pairs has been observed with about 1/10 of the strength of absorption on $^3S_1$ pairs, and there is some featureless background of unknown origin which seems to follow three-body phasespace[21]. The total absorption cross-section for π^+-^{3}He adds up to about 20 mb near reso=nance, as compared to 12 mb for the deuteron (Ref. 20).

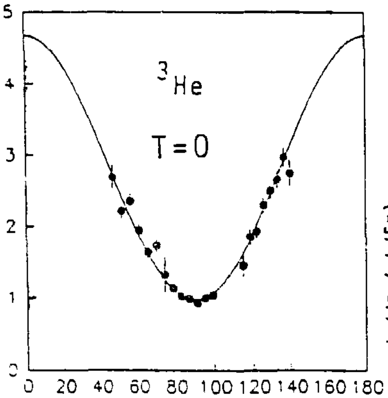

FIGURE 13

(π^+,pp) on ^{3}He at 120 MeV: Angular distribution of the quasi-deuteron ab=sorption mode (Ref. 20)

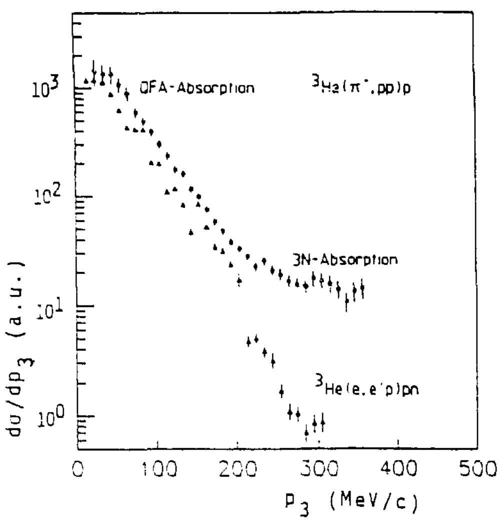

FIGURE 14

Spectator momentum distri=bution for the reaction (π^+,pp) on ^{3}He at 120 MeV, compared with results ex=tracted from (e,e'p) data[20].

For heavier targets, total absorption cross-sections are usually determined via a subtraction method[1]. One measures the total cross-section by a transmission experiment and subtracts the integrated (π,π') scattering cross-section (elastic and inelastic). The result has yet to be corrected for single charge exchange, and the final errors quoted for total absorption cross-sections are of the order of 15-30%. This method has been employed for nuclei throughout the periodic table, down to ^{4}He (Ref. 7). As shown in Fig. 15, the results do not match onto those obtained directly for the A=2 and 3 systems: There is a significant gap between ^{3}He and ^{4}He. If these data are correct within the error bars, they strongly suggest that a major new absorption channel opens up in ^{4}He.

Indications that something like that may indeed happen have been around already for some time. For instance, quasi-free

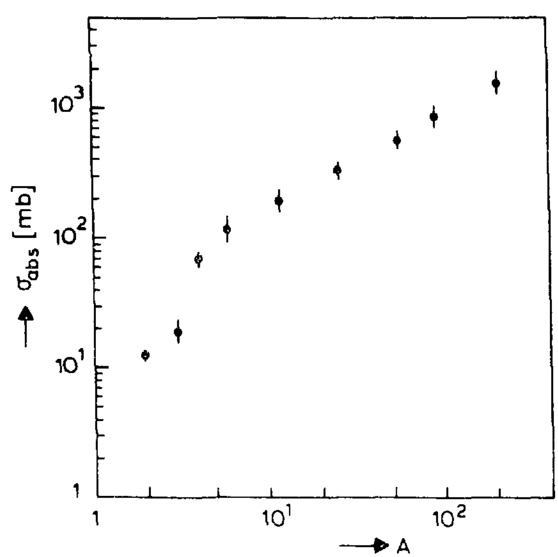

FIGURE 15
A-dependence of total $\pi^{\pm}$-nucleus ab= sorption cross-sections at 165 MeV[1,6,20].

scattering behaves anomalously, if one compares the deuteron with He-isotopes[22]. The inclusive $(\pi^+,\pi^{+\prime})$ cross-section at 100 MeV increases by a factor of 2 between the deuteron and ^3He, but then drops by 30% as one goes to ^4He. This may reflect the onset of strong absorption which quenches πN scattering in ^4He, as discussed in Sect. 3. Besides, as emphasized repeatedly by J. Schiffer and coworkers, the inclusive proton spectra after pion absorption point towards a larger number of nucleons participating in the absorption process than was originally anticipated[23]. In my opinion, the ongoing discussion whether there is "sequential" or "genuine" multi-nucleon absorption still suffers very much from a lack of well defined concepts. Anyway, the mere possibility that σ_{abs} might increase substantially between ^3He and ^4He is reason enough to devote a major experimental effort to ^4He, ideally with the newly planned 4π-detectors at the meson factories. π-α absorption may soon get the status of an "elementary process", much like the (π^-,pn) reaction on ^3He, which simply cannot be studied on an elementary di-proton. This situation justifies going ahead with experiments, even if theory is not capable of providing much guidance at the moment.

6. CONCLUDING REMARKS

In this talk, I have taken the view that the main interest in pion-nuclear physics lies beyond the "one-body level". Pions have the attractive feature that one can easily identify processes which involve two (or more) nucleons, even in single arm experiments: Think for instance of double charge exchange, isospin ratios in exclusive or inclusive (π,π') reactions, or the high energy part of proton spectra. However, we have also learned that these reactions are not easy to interprete. The quest for more specific experi= mental "clues" naturally leads into coincidence experiments and multi-particle detection. It is noteworthy that the same trend can also be observed in modern electron scattering and heavy ion physics. It seems to be unavoidable, given the complexity of strong interaction phenomena at intermediate energies. If this trend persists, a considerable amount of dedication and ingenuity (and perhaps luck) will be demanded, both from experiment and theory, in order to filter out the relevant physics information from a huge amount of data.

I would like to thank June L. Matthews for the invitation to give this talk at the Twenty-First LAMPF Users Meeting. Justus H. Koch has contributed valuable criticism and advice to the manuscript. Parts of this talk are inspired by conversations which I had at SIN with Frieder Lenz and Ernie J. Moniz in August 1987.

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Pion-Nucleus Physics: Future Directions and New Facilities at LAMPF

R. J. Peterson

University of Colorado

Studies of the interactions of pions with nuclei have been a very important part of the LAMPF program, as foreseen in the initial proposals and going far beyond. But what next? In some cases the obvious next generation of experiments to test and to further existing ideas will require new instrumentation, perhaps even new beams. Theoretical methods for the future may seem adequate now, but without conclusive tests. And among the many experiments so far carried out, which might point to the most insightful and effective subjects for future work?

A series of workshops and meetings has been carried out since August of 1986 to ask these questions, to generate new and critical thinking and to specify the needs of a vigorous program in pion-nucleus physics. Those discussions most relevant for LAMPF researchers are listed in Table I. Not many of us were able to get to all of these, but some degree of documentation is available from each, suitable for information and reference.

The largest of these get-togethers was held at the J. Robert Oppenheimer Study Center in Los Alamos, August 17-21, with the general title of "Pion-Nucleus Physics" and a very specific subtitle, "Future Directions and New Facilities at LAMPF." Nearly 200 registrants from around the world heard 38 invited speakers and a few shorter contributions. The program is appended. Contributed papers are available from the Los Alamos preprint series as LA-UR-87-2719, and the texts of the invited papers will be published by the American Insitute of Physics late in 1987.

There is no fair way to present the highlights of the meeting, and I have adopted rules that allow only experimental summaries, especially those for which good figures were readily available. I also emphasize those talks with the most explicit suggestions for future studies. From the theoretical presentations made, the general impression given was that this side of the physics is going to turn out all right.

In the lightest of nuclei, there are impressive data on cross sections for essentially all reaction channels available for pions on deuterons. With a polarized target, a rich set of new observables is available. It is unfortunate that LAMPF has not partaken of this bounty, pursued mainly at SIN and TRIUMF. As an example, Figure 1 shows data presented by Ed Boschitz in the first talk. In the $\pi D \to \pi np$ reactions, the differential cross sections show little sensitivity to the reaction model, being fit by the very heavy curve for the impulse approximation as well as by the lighter solid curve from a more sophisticated calculation. Greater differences are predicted for the vector (iT_{11}) and tensor (T_{20}) analyzing powers, with the quality of the data for the former almost sufficient to select one curve.

If somewhat higher pion beam energies at good intensity could be available with a spectrometer as good as EPICS, there are many opportunities to explore hypernuclei in detail. An entire new spectroscopy is awaiting study when a neutron is changed to a Λ, as emphasized by Avraham Gal. State-of-the-art data were shown by Jen-Chieh Peng, including the spectrum reproduced in Figure 2, obtained at Brookhaven. The gross structure of major shells can be discerned, but the details are yet to be seen.

New instrumentation could be built up from the many recent advances in high resolution tracking detectors, as summarized by John Carr of the University of Colorado. In Figure 3 the spatial separation is shown for tracks in a charge-coupled device separated by only 40μ.

The richness of the processes following pion absorption was emphasized by Danny Ashery and others. The importance of this absorption can be seen in Figure 4, taken from Ashery's talk. A large part of the reaction cross section for heavy nuclei involves absorption, and the rest mass energy that goes with it. There are unanswered basic questions. How many nucleons does it take to absorb a pion? How correlated were those nucleons? Did they exist as clusters?

Extensive new instrumentation is available or planned to study the many-particle states following absorption. Ron Ransome showed results from the LAMPF BGO ball, a 4π phoswich detector. Gary Kyle and Greg Smith showed designs for sophisticated 4π tracking detectors for SIN and TRIUMF, respectively.

Being stuck with zero spin, the pion cannot be polarized to enable measurements of spin observables. We can, however, plan to build polarized nuclear targets. A polarized ^{165}Ho target has already been used at LEP for a charge-exchange reaction. George Burleson outlined the methods of and the reasons for further efforts. In Figure 5 the polarization is shown for elastic π^+ and π^- scattering on ^{3}He at three beam energies. The two curves give the range of predictions possible within the present uncertainty of the ^{3}He magnetic form factor. With the proper target, this is a question that would seem to be settled quite readily.

An existing array of NaI was described by Jim Miller for detection of high energy photons. With 1.8% resolution at 330 MeV, this detector is well-suited to studies of pion radiative capture, as in $^{15}N(\pi^+,\gamma)^{15}O$. Ground state total and differential cross sections have been predicted, as shown in Figure 6, for this readily-resolved example.

Pions are obviously of special importance for the study of deltas in nuclei, and we do resonance experiments utilizing this relation. At higher beam energies than pions available from any of the meson factories, it is also possible to excite directly the delta in complex nuclei. Jim O'Connell showed electron scattering spectra, and compared these to photoabsorption data, as in Figure 7. The delta is apparent for all targets, with a difference from the free proton case. The nuclear environment has influenced the delta reaction, but in a fashion independent of the target nucleus for anything beyond lithium. This observation should serve as an important guide for pion-induced reactions.

One afternoon of the meeting in August was set aside for four sessions to plan and propose specific experiments and new facilities. The topics and supervisors (for that afternoon alone, it must be emphasized) are listed on the program. General conclusions for each group were also summarized on the last afternoon. It is hoped that proposals for new instruments and experiments will result from these sessions.

My own impressions of the future were highly positive. Exciting physics abounds, but new tools are needed; fortunately, the technology for these tools is available. Many speakers emphasized the need for more complete coincidence measurements, and many also pointed out the advantages of higher pion beam energies. Even the 200 MeV head start LAMPF has on SIN and TRIUMF can yield important insights.

It was, however, not just the physics that made the August meeting a success. My thanks are extended to many - the advisory committee for their thought, the session chairmen for their firm hands on the reins, the Liaison Office for imposing order and making arrangements, and especially, to Dan Strottman for his organization of so many things.

Table I

A number of meetings in recent months have examined the status, future and needs of a healthy program in pion-nucleus physics. Those most directly related to LAMPF users have been:

1. Future Directions in Pion-Nucleus Physics at LAMPF, LAMPF PAC, August 13, 1986.

2. Workshop on Photon and Neutral Meson Physics at Intermediate Energies, LAMPF, January 7-9, 1987.

3. New Directions in High-Energy Pion Physics, LAMPF, February 1, 1987.

4. Physics with Light Mesons, LAMPF, August 14, 1987.

5. Second International Workshop on πN Physics, LAMPF, August 15, 1987.

6. Pion-Nucleus Physics: Future Directions and New Facilities at LAMPF, J. Robert Oppenheimer Study Center, August 17-21, 1987, AIP Conference Series. Contributions in preprint form, LA-UR-87-2719.

7. Meeting on Hadronic Probes, Arizona State University, October 22-23, 1987.

Program

Pion-Nucleus Physics: Future Directions and New Facilities at LAMPF

J. Robert Oppenheimer Study Center

Los Alamos National Laboratory

Monday, August 17, 1987

Introduction - **R. Jerry Peterson** - University of Colorado

Welcome - **Gerald Garvey** - Director, LAMPF

FEW BODY QUESTIONS

Chairman: **Willi Gruebler** - ETH

Edmund T. Boschitz - Karlsruhe - "Recent Experiments on the Interaction of Pions and Deuterons"

Contributions: **Kim, Smith, Klein**

CHARGE EXCHANGE REACTIONS

Chairwoman: **June Matthews** - Massachusetts Institute of Technology

Naftali Auerbach - Tel Aviv University - "Pion Double Charge Exchange on Nuclei"

R. J. Glauber - Harvard University - "Nucleon-Nucleon Correlations Detected via Pion Double Charge Exchange Reactions"

Helmut Baer - Los Alamos National Laboratory - "Pi-Nucleus Single Charge Exchange Reactions Above the Δ (1232)"

Peter A. M. Gram - Los Alamos National Laboratory - "Systematics of Inclusive Double Charge Exchange"

Eulogio Oset - University of Valencia - "Computer Simulations of Inclusive Pion Reactions"

J. David Bowman - Los Alamos National Laboratory - "A High Resolution π^0 Spectrometer"

Tuesday, August 18, 1987

HEAVIER MESONS

Chairman: **Robert Chrien** - Brookhaven National Laboratory

Avraham Gal - Hebrew University - "Issues in Hypernuclear Physics"

Jen-Chieh Peng - Los Alamos National Laboratory - "The (π,η) and (π,K) Reactions in Nuclei"

Contributions: **Lieb, Liu**

Bernard M. K. Nefkens - University of California, Los Angeles - "Highlights of the η,ρ,ω Workshop and of the Second International Workshop on Pion-Nucleon Physics"

John Carr - University of Colorado - "Recent Developments in High Resolution Tracking Detectors"

LOW ENERGY PION REACTIONS

Chairman: **Barry Ritchie** - Arizona State University

Philip Roos - University of Maryland - "Nuclear Reactions and Scattering with Low Energy Pions"

Gerald Miller - University of Washington - "Pion-Nuclear Scattering and the EMC Effect"

Contributions: **Rockmore**

Ryoichi Seki - California State University, Northridge - "The Pionic Atom Anomaly"

Wolfgang Kluge - Karlsruhe - "Chiral Symmetry and the Sigma Term in Pion-Nucleon Scattering"

Wednesday, August 19, 1987

PION ABSORPTION

Chairman: **John Schiffer** - Argonne National Laboratory

Daniel Ashery - Tel Aviv University - "Future Directions in Pion Absorption"

Ronald Ransome - Rutgers University - "Pion Absorption in Nuclei Near the Delta: The BGO Ball"

Contributions: **Loveman, Backenstoss, Smith**

William Gibbs - Los Alamos National Laboratory - "Monte Carlo Analysis of Pion Absorption Processes"

Gary Kyle - New Mexico State University - "Studies of Pion Absorption at SIN"

PROPOSAL DEVELOPMENT COMMITTEES

$\pi^{\circ}\Pi$ - LOB Building, Room A234 - **Hanna**

Improvements at P^3 - LOB Building, Room D105 - **Matthews**

Absorption - LOB Building, Auditorium - **Schiffer**

High Energy Pions at LAMPF - MP-14 Conference Room - **Hungerford**

Thursday, August 20, 1987

PHYSICS IN THE CONTINUUM

Chairman: **Joseph Cohen** - Indiana University

Henning Esbensen - Argonne National Laboratory - "Surface Response Model for Quasielastic Scattering"

Renzo Leonardi - University of Trento - "Sum Rule Methods"

T.-S. Harry Lee - Argonne National Laboratory - "Pion Production in the Quark Compound Bag Model of the Nucleon-Nucleon Interaction"

Contributions: **Speth**

Mikkel Johnson - Los Alamos National Laboratory - "Pions and the Nuclear Spin-Isospin Response"

Charles Glashausser - Rutgers University - "Polarization Transfer Studies in Inelastic Proton Scattering at High Excitation Energies"

NUCLEAR STRUCTURE

Chairman: **B. Hobson Wildenthal** - University of New Mexico

H. Terry Fortune - University of Pennsylvania - "Nuclear Structure Aspects of Pion Double Charge Exchange"

George Burleson - New Mexico State University - "Pion Interactions with Polarized Nuclear Targets"

Contributions: **Bartel, Singham**

D. John Millener - Brookhaven National Laboratory - "Shell Model Transition Densities for Electron and Pion Scattering"

Joseph Ginocchio - Los Alamos National Laboratory - "Study of Nuclear Structure with Pion Double Charge Exchange"

James Miller - Boston University - "In-flight Radiative Pion Capture as an Alternative to Charged Pion Photoproduction"

Friday, August 21, 1987

DELTAS IN NUCLEI

Chairman: **Max Huber** - University of Bonn

Kozi Nakai - KEK - "Genuine Quasifree Delta Production in Nuclei"

Kalvir Dhuga - New Mexico State University - "Delta Effects in Elastic Scattering"

Richard Johnson - University of British Columbia - "$(\pi,2\pi)$ Reactions"

David Ernst - Texas A&M University - "Momentum-Space Approach to Pion-Nucleus Reactions above the Resonance"

OPEN QUESTIONS

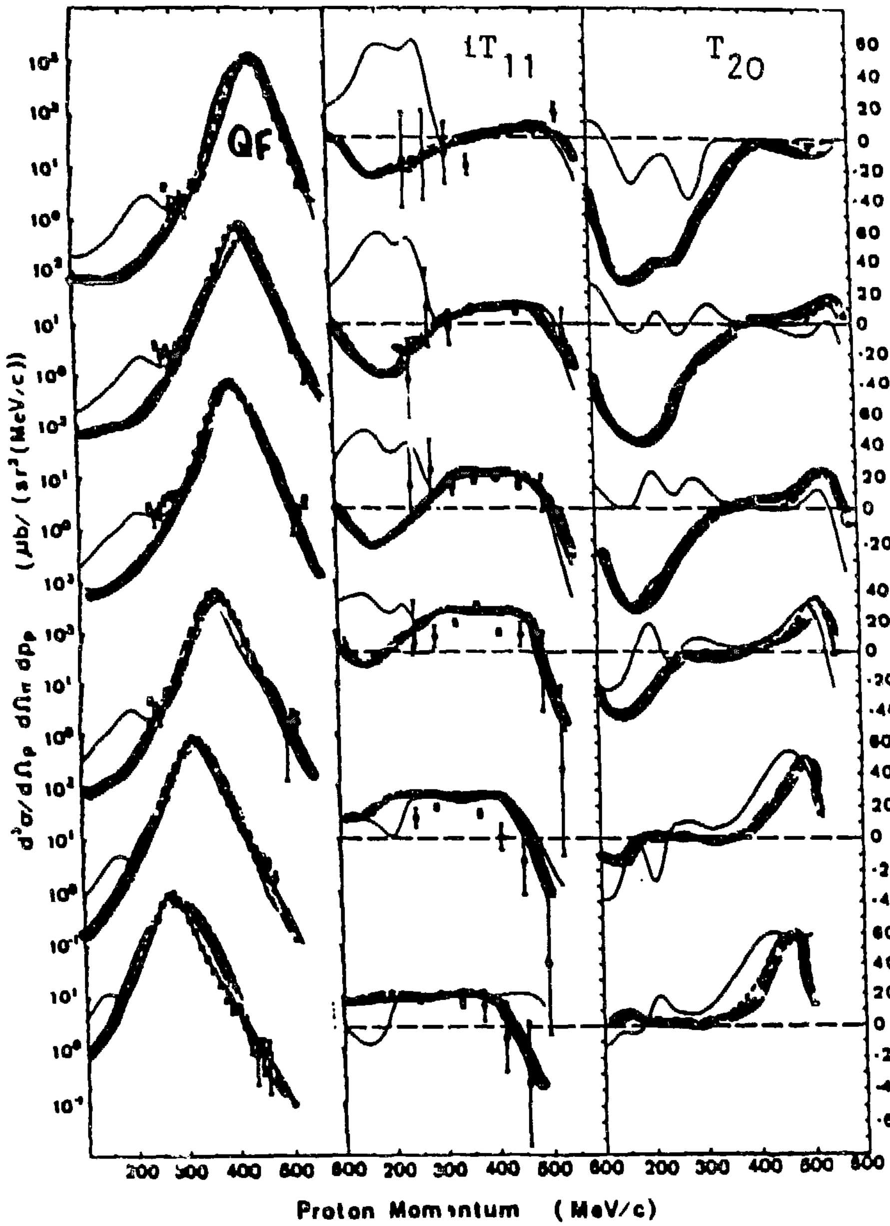
Chairman: **Bernard Frois** - Saclay

Wolfram Weise - University of Regensburg - "Unsolved Problems in Pion Physics"

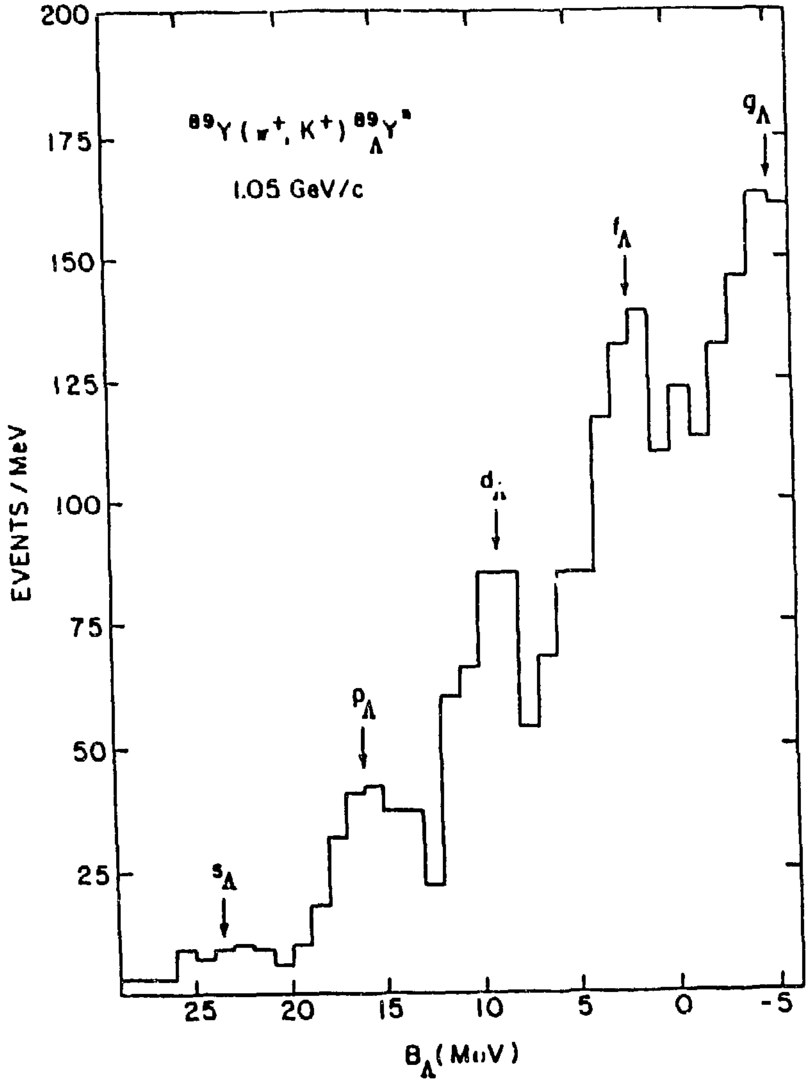
Henry A. Thiessen - Los Alamos National Laboratory - "The Future of Super Conducting RF at LAMPF"

Discussions of Proposals

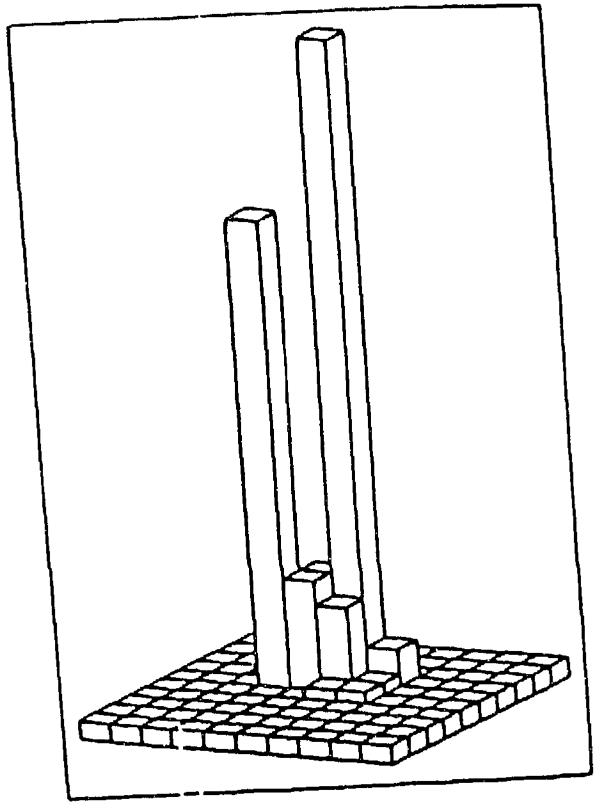
Erich Vogt - TRIUMF - "Summary"



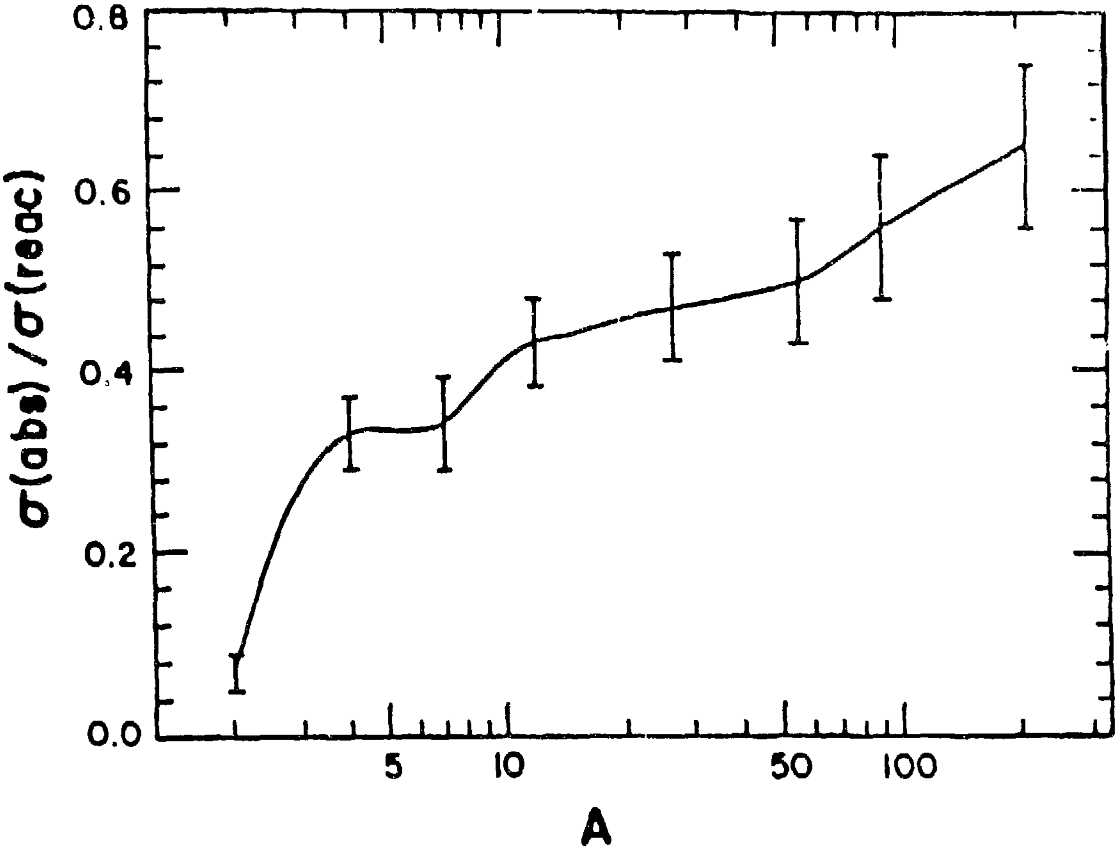
1. Data from SIN, shown by Boschitz, for cross sections and vector polarizations for the $\pi\vec{D}\rightarrow\pi np$ reaction at six angle pairs. The heavy curve shows the impulse approximation expectation. Polarization observables add important new information.



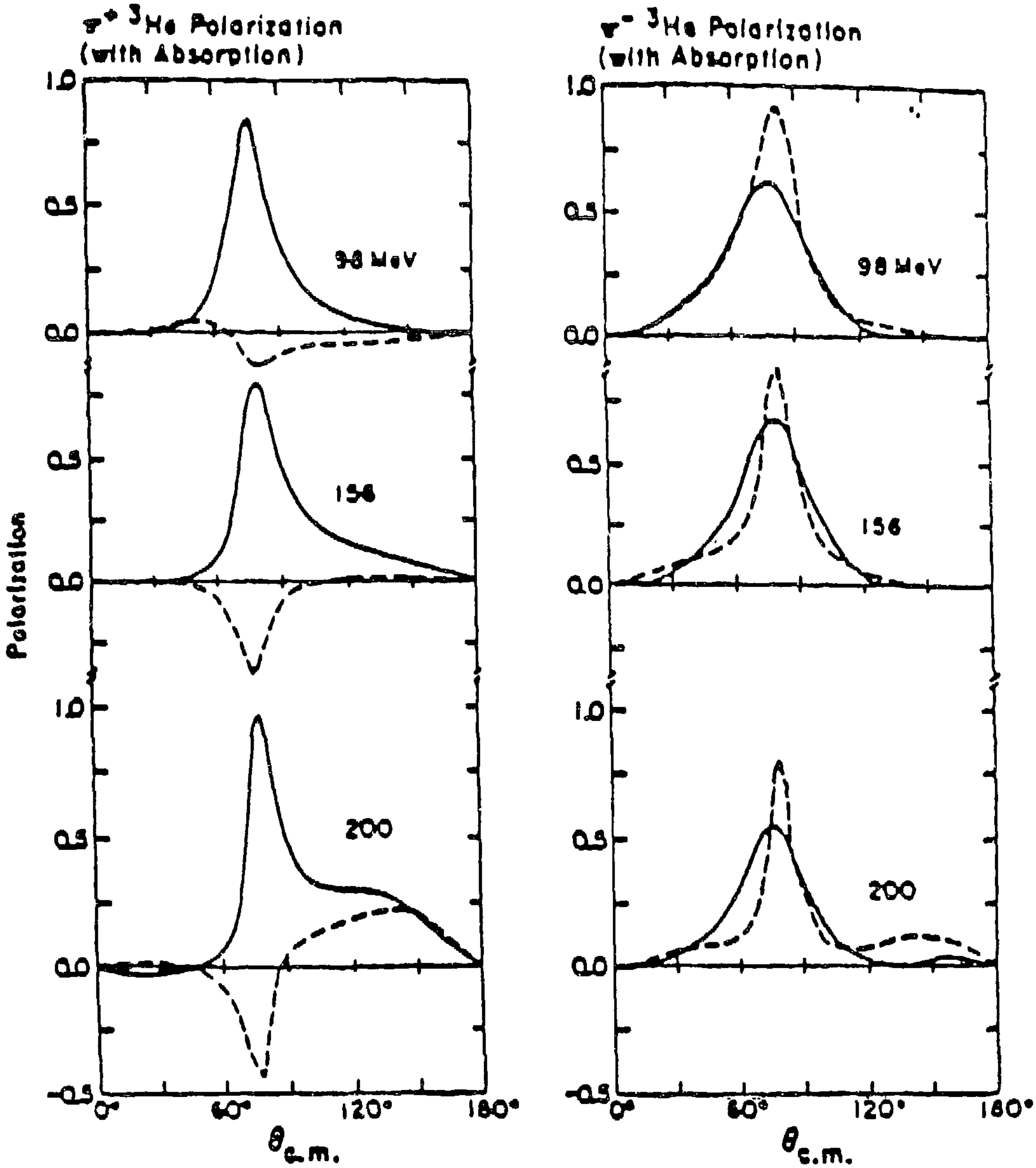
2. The excitation spectrum of the $^{89}{}_{\Lambda}Y$ hypernucleus as measured in the (π^+,K^+) reaction at p_L=1.05 GeV/c for θ_L=10°. The arrows identify the predicted values of binding energies (B_Λ) based on a Wood-Saxon potential for the Λ. With better resolution, it is clear that more detail could be observed.



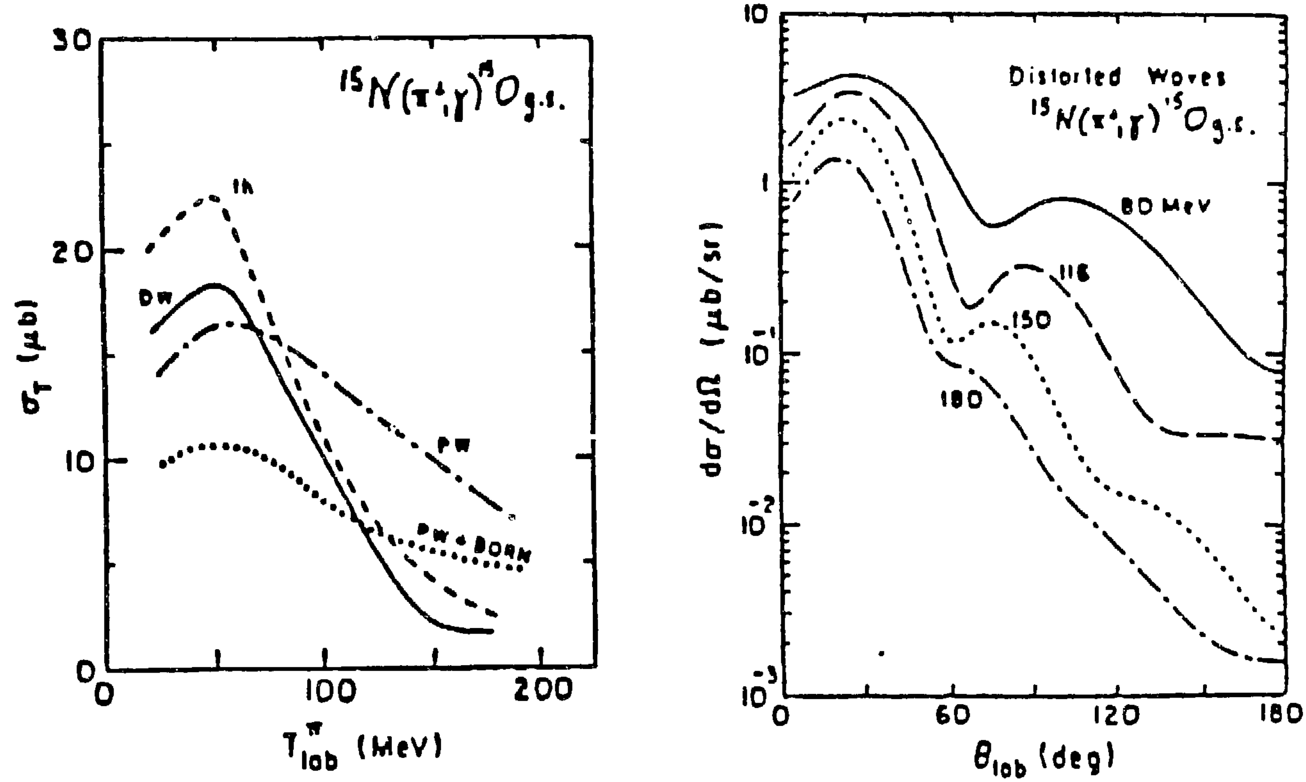
3. Data from a charge-coupled device for two minimum ionizing tracks separated by only 40μ, as shown by Carr. Such technology could form the basis for new detectors for nuclear physics.



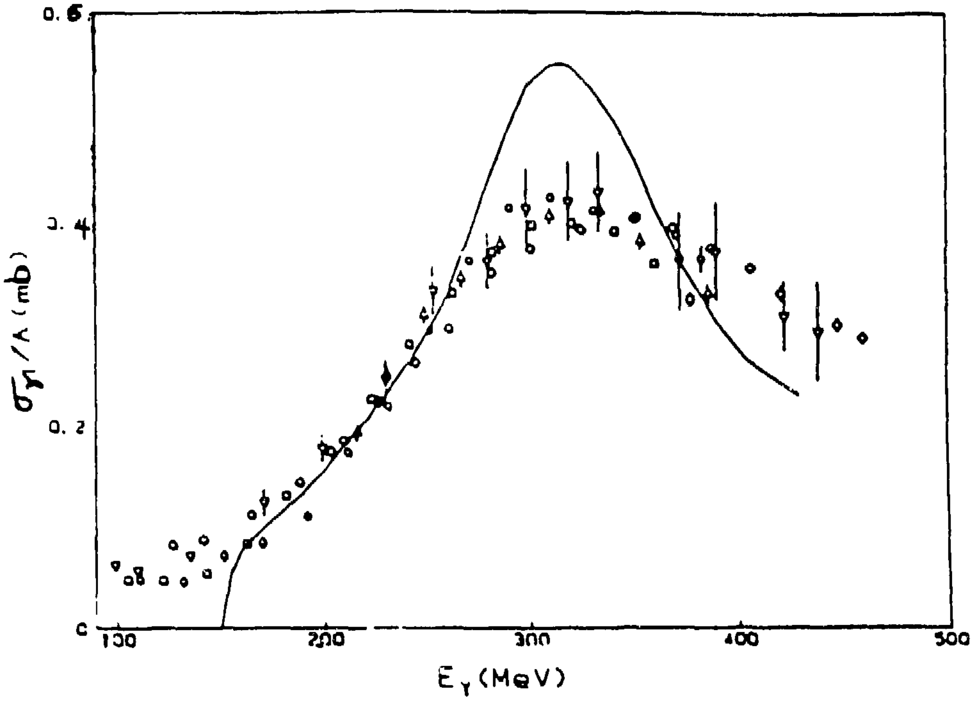
4. Measured fractions of the pion reaction cross section due to absorption, at resonance energies, shown by Ashery to illustrate the importance of these absorption processes.



5. Calculations of Landau for the asymmetry in elastic scattering of π^+ and π^- from a polarized ^{3}He target at 98, 156, and 200 MeV. The sensitivity to the uncertainty in the ^{3}He magnetic moment form factor $F_{mag}(q)$ is shown at each energy. The solid line corresponds to the lower limit and the dashed line to the upper limit. These curves were shown by Burleson to show the value of polarized targets.



6. Predictions shown by Miller for pion radiative capture on ^{15}N. with modern photon detectors such transitions can be resolved. Both total and differential cross sections are shown for several models and beam energies.



7. Total photon absorption cross section per nucleon for Li, Be, C, Pb, and U. The solid curve is the free nucleon cross section. These data were shown by O'Connell to illustrate the mass-independent nature of the delta-hole excitation in complex nuclei, and the difference from the excitation of a free nucleon to a delta.

Workshop Highlights

from

"PHYSICS WITH LIGHT MESONS" and

"THE SECOND INTERNATIONAL WORKSHOP ON πN PHYSICS"

B.M.K. Nefkens
Physics Department, UCLA, Los Angeles, CA 90024

A one day workshop was held at LAMPF in August to enumerate some of the nuclear and particle physics to be learned in the just-above-LAMPF energy regime; it also served to gauge the interest of the physics community. This workshop was followed by the "Second International Worshop on πN Physics." The turnout was gratifying as over a hundred and twenty physicists participated, double the original estimate. The enthusiasm carried over to the following week to the pion-nucleus workshop where during a working group session, an ad hoc steering committee on new facilities was formed. You will hear more about this tomorrow in the organizational meeting of a new LAMPF working group on new facilities steered by Joe Comfort. Here, I will concentrate on the important physics issues that we discussed.

The program of the first workshop is given in Table I; included are talks on quark models, QCD, the production and propagation of light mesons in nuclei, ρ-ω interference, rare and forbidden decays of light mesons for precision testing of the Standard Model, the use of η mesons as a nuclear probe, and at the end, a session on plans for new accelerators.

Table I Subjects and Speakers of the Workshop "Physics With Light Mesons η, ρ, ω, etc", LAMPF, August 14, 1987

Charge Symmetry Breaking and Meson Mixing, G.A. Miller (U. of Washington)
Light Mesons in the Quark Model, J. Weinstein (U. of Toronto)
Production and Propagation of Light Mesons in Complex Nuclei, W.R. Gibbs (Los Alamos National Laboratory)
Scalar Mesons as Building Blocks for Low-Energy QCD, M. Scadron (U. of Arizona)
Theoretical Aspects of Rare and Forbidden Decays of η, ρ, etc., A. Soni (UCLA)
Experimental Aspects of Rare and Forbidden Decays of η, ρ, and ω, U. Sennhauser (S.I.N.)
η-Mesons as a Probe of Hadron Interactions, M. Huber (U. of Bonn)
η's in Nuclei, L.C. Liu (Los Alamos National Laboratory)
The ASTOR Project, U. Sennhauser (S.I.N.)
A Plan for a Japanese Hadron Project, O. Hashimoto (INS Tokyo)
PILAC, H. Thiessen (Los Alamos National Laboratory)
COSY, J. Speth (IKK, Julich)

I. ρ-ω Interference

The nucleon-nucleon interaction at medium range features ρ and ω exchange. As these mesons belong to the same nonet, they exhibit mixing which has interesting consequences for nuclear physics. The three charged ρ's form an isotriplet; they decay predominantly into two pions, $\rho \rightarrow \pi\pi$. The ω, which has nearly the same rest mass as the ρ, is an isoscalar particle and it cannot decay strongly into two pions, $\omega \not\rightarrow \pi\pi$. Since both ρ and ω are vector mesons they may be converted into a photon giving rise to electromagnetic mixing $\omega \leftrightarrow \gamma \leftrightarrow \rho \leftrightarrow 2\pi$. This may be investigated in a clean way free of strong absorption corrections in e^+e^- colliders by measuring $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ as a function of the total c.m. energy. It is found Experimentally that ρ-ω mixing is about seven times larger than the calculations based on the known electromagnetic transition, furthermore, the interference term has the wrong sign. These facts can be fully explained by quark models in which the down quark is 2-4 MeV heavier than the up quark. Such a quark mass difference is consistent with other evaluations and it implies a small intrinsic violation of nuclear charge symmetry that comes independent of the common electromagnetic violation. Among the consequences for nucleon-nucleon interactions is a difference in the pp and nn scattering length. Eg., Coon and Burnett obtain for a variety of N-N potentials

$$|A_{nn}| - |A_{pp}| = +0.9 \text{ to } 1.35 \text{ fm} .$$

This agrees very nicely with the experimental value of +1.2 ± 0.8 fm.

Another effect of ρ-ω mixing which has been calculated is the non-Coulombic binding energy differences between ^{3}He and ^{3}H, namely +45 to 89 keV; this is close to the 80 keV that are missing when only charge symmetric NN forces are used.

II. Production and Propagation of Light Mesons in Nuclear Matter

An interesting case for studying the production, propagation and annihilation of η mesons in nuclear matter may be the pion double charge exchange reaction. Consider the process $\pi^+ + {}^{12}C \rightarrow \pi^- + X$. At a sufficiently high energy the incoming π^+ may be converted into an eta meson, $\pi^+ + n \rightarrow \eta + p$ competing with the pion charge exchange reaction which is dominant at low energies. Because of the expected large cross section this η can scatter inelastically and become a pion again including one with a negative electric charge, $\eta + n \rightarrow \pi^- + p$. Fig. II-1 shows the π^- momentum spectrum calculated by W. Gibbs using an intranuclear cascade computer code. The peak at 400 MeV/c is a unique signature for the intermediate state involving the η. The magnitude of this peak depends on the η-nucleon mean free path and other things.

There are two light, unflavored mesons with a mass close to the mass of a pair of K mesons namely the $f_0(975)$ meson with $0^+(0^{++})$, it was formerly called the $S^*(975)$, and the $a_0(980)$ meson with $1^-(0^{++})$ that used to be the δ(980). The nature of these particles is unclear. The three possibilities considered are: ordinary $q\bar{q}$ states, exotic $q^2\bar{q}^2$ resonances, or molecular bound states of K and $\bar{K}$ in a I = 0 and I = 1 configuration, respectively. These different possibilities may be differentiated by studying the propagation in nuclear matter which is expected to be much greater for a $q\bar{q}$ state than for the other two possibilities.

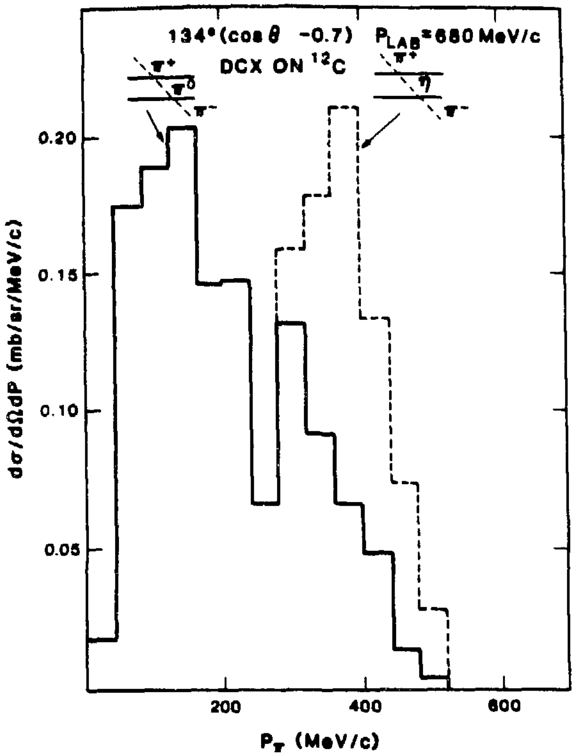


Fig. II-1 π^- momentum spectrum in π^+ double charge exchange on ^{12}C at 134^o due to two mechanisms involving either an intermediate π^0 or η; calculation by W. Gibbs.

III. Eta Mesons as a Selective Probe for Certain Hadronic Intermediate States

The nucleon may be excited to one of four dozen resonances. Most of these decay under the emission of one or more pions. A noteworthy exception is the $S_{11}(1535)$ N^* resonance which decays mainly by η emission. M. Huber is an early proponent of the idea that one may monitor the excitation of the $S_{11}(1535)$ in nuclear matter by studying its characteristic η decay. Recent work at Saturne II on η production in pd interactions has shown an abundant yield of η's making Huber's proposal a very timely one. The same basic idea may be applied to the use of Λ or K decay modes to study the formation of the $P_{11}(1710)$ resonance which has a 15% branching ratio to the ΛK mode.

IV. η - Mesic Nuclei

The ηN interaction at low energy has been found to be attractive. L.C. Liu recommends the value

$$a_0 = +(0.28 + 0.20\, i)\ \text{fm}$$

for the S_{11}-wave ηN scattering length. Thus, the possibility exists for having bound nuclear systems that include the η as a constituent;, they are called η-mesic nuclei. Detailed calculations show that their mass number should be $A > 10$. A characteristic signature for an η-mesic nucleus would be a peak in the proton spectrum in the reaction

$$\pi^+ + {}^{16}O \rightarrow p + {}^{15}{}_{\eta}O.$$

An experiment is under way at BNL to look for this. At LAMPF a search is under way based on the reaction

$$\pi^+ + {}^{16}O \rightarrow p + {}^{15}_{\eta}O \rightarrow p + \pi^- + X.$$

The signature for the production is a high energy π^- that is in coincidence with a prompt proton.

V. Rare and Forbidden Decays of Light Mesons (non strange)

The so called "Standard Model" is our best available particle physics theory; it covers a wide spectrum of intermediate and high energy results. Its many vocal proponents like to quote a very impressive list of accomplishments ranging from predicting the correct masses of the W and Z intermediate boson to calculating the $\pi \rightarrow e\nu$ decay rate to three decimal places. Yet few physicists would propose that the Standard Model is the ultimate theory. Among its shortcomings is the fact that it features 17 types of elementary constituents and that it has more than two dozen parameters such as coupling constants, mixing angles, and masses that must be determined by experiment. So, one might expect to find limitations of the Standard Model. The two complementary ways to test the Standard Model are:

1) looking for new particles at ultra high energies such as at the colliders of Fermilab, CERN, or SSC;
2) precision experiments at modest energies, especially involving the rare and forbidden decays of the μ, K, and η. Despite the relatively short half-life of the η compared to the K-meson or muon, the η has something unique, namely it has the same quantum numbers as the vacuum , thus

$$Q = I = C = S = B = L = 0;$$

only the parity is negative.

There is widespread anticipation that some or all of the "convenience" conservation laws are only approximately obeyed because they are inconsistent with schemes for a grand unification of the basic forces. The "convenience" conservation laws include those of lepton family number, baryon number, CP and T invariance; they emerged to provide a convenient explanation for many unobserved processes. It is important to test these conservation laws in as many different reactions as possible. Some examples are given in Table V-1.

Table V-1 Eta meson decay modes for precision tests of the Standard Model and the electroweak Theory, also for new particle searches and QCD-type physics. Note that the η has the same quantum numbers as the vacuum: $Q = I = S = C = B = L = 0$.

	Reaction	Test	BR
A. Tests of Standard Model:			
1.	$\eta \to \pi^+\pi^-$	CP viol	10^{-13}
2.	$\eta \to 3\gamma$	C viol	10^{-13}
3.	$\eta \to \mu e$	Lepton flavor viol	0
4.	$\eta \to \pi^0 e^+ e^-$	C viol	
B. Tests of the Electroweak Theory:			
1.	$\eta \to \pi e \nu$	2nd class currents	$<10^{-10}$
2.	$\eta \to \pi\pi e \nu$	Wess-Zumino term	$<10^{-10}$
C. Search for new particles:			
1.	$\eta \to e^+e^-$	Lepto-quark	$R>8\times10^{-9}$
2.	$\eta \to \pi^0 H \to \pi^0\mu^+\mu^-$	Light Higgs	10^{-8}
3.	$H \to \gamma\nu\bar{\nu}$	#ν families	10^{-15}
4.	$\eta \to \pi\pi a \to \pi\pi e^+e^-$	axion	10^{-10}
D. QCD Physics:			
1.	$\eta \to \gamma\gamma$		
2.	$\eta \to \pi^+\pi^-\pi^0/\pi^0\pi^0\pi^0$		
3.	$\eta \to \pi^0\gamma\gamma$	VMD	10^{-3}
4.	$\eta \to \mu^+\mu^-\gamma$	form factor	10^{-4}

A1. The decay $\eta \to \pi^+\pi^-$ is forbidden by CP and P conservation. The present experimental upper limit is a paltry 0.15%. Theoretical estimates for a violation based on the standard model are small. η-K^0 mixing, which is a consequence of conventional reaction sequences such as $\eta \leftrightarrow 3\pi \leftrightarrow K^0$, yields $BR(\eta \to \pi^+\pi^-) \approx 10^{-13}$. The known upper limit to the electric dipole moment of the neutron can be used to obtain a limit $BR(\eta \to \pi^+\pi^-) < 10^{-15}$. Nevertheless, experiments to test CP violation are of great significance, in particular ones outside the K^0 system. . The standard model prediction for $\eta \to \pi^+ \pi^-$ should be checked.

A2. The decay modes $\pi^0 \to \mu e$, $\eta \to \mu e$, and $\eta' \to \mu e$ are all forbidden by conservation of lepton family number. Many theories that go beyond the standard model -- e.g., horizontal gauge and extended technicolor models -- allow such decays. The current limits on lepton number conservation come mainly from kaon and muon decays; they have the advantage over η decay of a huge factor in the lifetime of order 10^9 to 10^{13}. Sensitive searches for exotic K and μ decays are being pursued at LAMPF, BNL, and elsewhere. It is important for limiting the options of adventurous theorists that a decent upper limit for η and $\eta' \to \mu e$ be established as none is now known.

A3. The decay modes $\pi^0 \to 3\gamma$, $\eta \to 3\gamma$, and $\eta' \to 3\gamma$ are forbidden by C conservation. The present upper limits are given in Table V-2; they are not impressive. The standard model allows a small C-violation just as it predicts a tiny parity violation in hadronic interactions. Estimates based on dimensional arguments indicate that $BR(\eta \to 3\gamma) \approx 10^{-13}$ which could make this decay a prime candidate for testing the validity of C conservation. Other tests of C invariance that could be improved are shown in Table V-2.

TABLE V-2 Tests of C-invariance

Decay mode	Current limit
$\eta \to 3\gamma$	BR < 7×10^{-4}
$\pi^0 \to 3\gamma$	BR < 3.8×10^{-7}
$\eta \to \pi^0 e^+e^-$	BR < 5×10^{-5}
$\eta \to \pi^0\mu^+\mu^-$	BR < 5×10^{-6}
$\eta \to \pi^+\pi^-\pi^0$	asymmetry < $(2+2) \times 10^{-3}$
$\eta \to \pi^+\pi^-\gamma$	asymmetry < $(9\pm4) \times 10^{-3}$

A4. The decay $\eta \to e^+e^-$ via electromagnetic interactions has been calculated to have a branching ratio of 1.7×10^{-9}. This is thus an especially suitable decay to search for new types of interactions or novel particles such as leptoquarks. The leptoquark is a hypothetical particle suggested by Pati and Salam that provides a direct link between quarks and leptons. The experimental upper limit is $BR(\eta \to e^+e^-) < 3 \times 10^{-4}$. The decay $\eta \to \mu^+\mu^-$ is predicted to occur at the level 4.1×10^{-6}; the experimental result is $BR(\eta \to \mu^+\mu^-) = (6.1\pm2.1) \times 10^{-6}$ which is a good check on the correctness of the calculation of $\eta \to e^+e^-$. The decay $\pi^0 \to e^+e^-$ is predicted to occur at the level 4.7×10^{-8} which is some three times smaller than two experimental results; however, the experiments are hard and they need to be repeated.

A5. The decay $\eta \to \pi e\nu$ proceeds via a so-called second class current, i.e., isospin violation is required. A rough guess is that $BR(\eta \to \pi e\nu) \approx 10^{-10}$, it has never been seen.

A6. The decay $\eta \to \pi\pi e\nu$ is driven by the "anomalous Wess-Zumino term" and thus makes for an interesting study, unfortunately, the expected BR $\approx 10^{-10}$.

A7. There is one glaring shortcoming of the famous Weinberg-Salam model which has otherwise done very well, it is its inability to predict the mass of a key particle, the Higgs boson. Prejudice goes towards a heavy Higgs with a mass in the region of the W-boson. Nevertheless, it is worthwhile to search for a light Higgs particle, H; suggested possibilities include $\eta \to \pi H$, $\eta' \to \eta H$, and $\eta' \to \pi H$ with $H \to \mu^+\mu^-$. For $\eta' \to \pi\mu\mu$, the current experimental bound of $< 6 \times 10^{-6}$ is not sufficiently sensitive.

A8. The final group of decay modes that is especially interesting involve pairs of neutrinos or of photons; they are experimentally challenging. The decay rate for $\eta \to \gamma + \nu\bar{\nu}$ is a measure of the number of lepton families. The axion is a light, pseudoscalar particle that was proposed to dispose of the CP-violating angle Θ in QCD. It couples only weakly to matter; it is light and decays to e^+e^- and $\gamma\gamma$. An early axion candidate, the G.S.I. (e^+e^-) peak at about 1.8 MeV is about to be ruled out. Axion-like particles can be searched for in decays such as $\eta \to \pi\pi a \to \pi\pi\gamma\gamma$ etc. A. Soni has emphasized that such searches are quite compatible in sensitivity with ones involving the decay of the K-meson despite the ten orders of magnitude difference in lifetime.

VI. New Experimental Facilities

1. The Japanese hadron project. This proposal is cleverly put together in that it caters to the needs of four groups simultaneously namely, the nuclear, particle, high energy, and condensed matter communities, and it builds on an existing facility, KEK. The accelerator complex consists of a 1 GeV proton linear accelerator that feeds a 200 μA rapid cycling 2GeV cyclotron with a stretcher ring; it also acts as a powerful injector to the existing KEK machine which is a 12 GeV PS, see Fig. VI-1. Four areas have been designated namely:

a)the kaon facility, featuring high intensity, well-separated K, π, etc., beams, the duty factor is 90%; b)the meson and muon facility featuring high intensity pion beams in the GeV region and several eV-keV muon lines; c) the neutron facility featuring pulsed neutron sources, and finally d) the exotic nuclei area to accommodate beams of unstable nuclei produced by the 1 GeV linac.

The project has just received the approval of the Japanese science council, and it is presently planned to start in 1989. It is emphasized that the project is international and interdisiplinary although it began as a project of only the nuclear physics community in Japan.

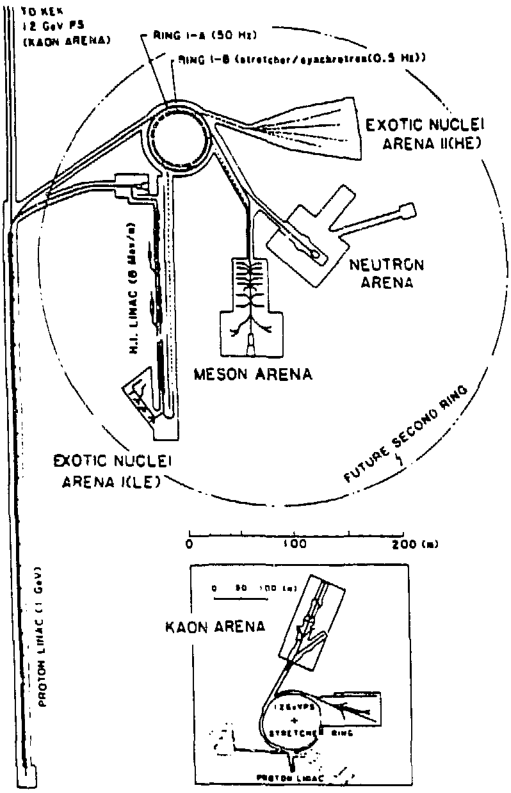


Fig. VI-1 Proposed accelerator complex and experimental facilities of the Japanese Hadron Facility.

2. COSY. This is a new facilty to accelerate 10^{11} protons to an energy >2.5 GeV. Electron and stochastic cooling will be used to reduce the spread in the beam momentum. Internal targets are planned as well as slow and fast extraction. The facility will be located in Julich, West Germany. The project is approved and funded, and the construction time is >4 years.

3. PILAC. The idea of a pion linac for accelerating secondary beams at LAMPF is being reconsidered in the light of the availability of superconducting cavities. Off-the-shelf models have a gradient of 5 MeV/meter. The expected π^+ yield if P^3 were used as input is shown in Fig. VI-2. There is a small 200 MeV booster; the estimated cost of which is very roughly $35 M, and a larger

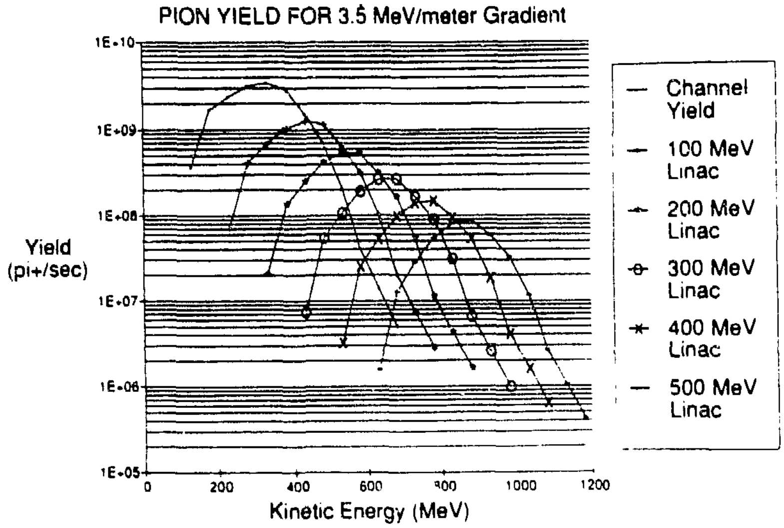


Fig. VI-2 π^+ yields of PILAC.

version that boosts the energy by 500 MeV, costing perhaps $50 M. An important advantage of PILAC for π^+ beams would be that it gets rid of the protons that otherwise severely clutter beams of positive particles. Another desirable feature of PILAC would be the momentum contraction which has the net effect for experiments that need a narrow beam momentum spread of increasing the beam intensity. The π^- beams could be used to produce copious tertiary, tagged beams of light mesons in reactions such as $\pi^- p \rightarrow \eta n$, $\pi^- p \rightarrow \omega n$, etc.

4. ASTOR. The heart of this Accelerator and Storage Ring, is an isochronous cyclotron of 16 sector magnets. An important aspect is the generation of tertiary beams of light mesons. The optimum conditions appear to be a proton machine with an energy of 3.5 GeV yielding $\pi^\pm$ beams with high intensities as shown in Fig. VI-3. These beams are the source of copious tagged η, ρ, ω, η', ϕ, even ϕ "beams" as shown in Table VI-1.

The cost estimates are on the order of $100 M. Currently ASTOR is not the top project of SIN, as design studies are now carried out for a B-meson facility as a possible replacement to SIN.

TABLE VI-1 Production rates of light mesons using 10^8 π/sec on a 0.65 gram hydrogen target

Meson	Mass (MeV)	$p(\pi^-)$ (MeV/c)	σ (mb)	ASTOR rate s^{-1}
η	549	820	2.5	10^5 - 10^7
ρ	770	1400	3.0	12×10^5
ω	783	1400	1.5	06×10^5
η'	958	1600	0.10*	4×10^3
ϕ	1020	1800	0.16*	6×10^3

*30-50% errors

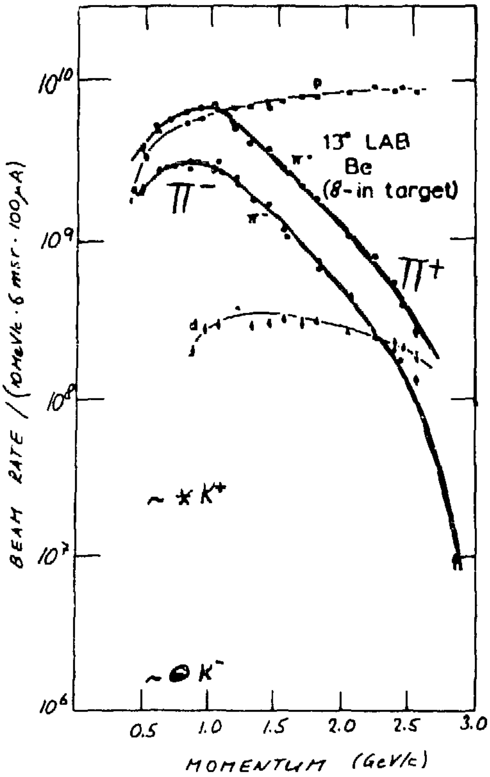


Fig. VI-3 π^+ yields of ASTOR.

πN PHYSICS

The very intense and well attended workshop on the physics of the light nuclei was followed on Saturday, August 15, 1987 by the "Second International Workshop on Pion Nucleon Physics." It is hardly necessary to elaborate on the importance of the πN interaction as the key to nucleon-nucleon scattering, nuclear matter, and nuclear physics. Furthermore, it is well established that the N* and Δ resonances are the simplest observable three-quark systems, and as such their characteristics are important for testing different models of the strong interaction like the small, cloudy, or large MIT quark bags, hybrid models, and Skyrmion calculations. The program of the workshop is shown in Table II.

TABLE II Subjects and Speakers of the "Second International Workshop on πN Physics", LAMPF, August 14, 1987

Light Hybrid Baryons, F. Close (Rutherford)
The πN Resonances in the Particle Data Table, G. Hohler (U. of Karlsruhe)
Interpretation of the Even-Parity Baryon Resonances, R. Cutkosky (Carnegie-Mellon U.)
The VPI πN Partial Wave Analysis, R. Arndt (Virginia Polytechnic Institute)
Light Baryon Resonances, S. Capstick (U. of Guelph)
πN Scattering Experiments, M. Sadler (Abilene Christian U.)
Skyrmions, M. Mattis (U. of Chicago)
Baryon Resonances in an Effective π-ρ-ω Model, G. Holzwarth (U. of Siegen)
Color Magnetism and Radiative Δ-Decay, N. Mukhopadhyay (R.P.I.)
Low Energy Phenomena in the πN System, P. Siegel (U. of Regensburg)
πN → πN and Strange Quarks in the Proton, J. Gasser (U. of Bern)
On the Contents of the Nucleon, J. Donoghue (U. of Massachusetts)
Theoretical Implications of the Large πN Sigma Term, M. Scadron (U. of Arizona)

VII. Where are the gluons?

It is becoming a bit embarrassing that there is so little evidence for gluons in hadronic systems at low and medium energies. The glueball, a color singlet composed of two or more gluons, has never been positively identified and it may be a while before that happens. So, naturally the attention has turned to hybrid systems which are identifiable $\bar{q}qG$ and qqqG systems. Their spectrum could be quite similar to the familiar three-quark systems. The best possibilities are offered by the $P_{11}(1710)$, and the Roper resonance in case the $P_{11}(1440)$ would turn out to be a doublet state. F. Close remarked that it has taken 20 years of experimental effort before the quark structure of the hadrons was clear. It may also take twenty years before the gluon structure is uncovered.

VIII. The πN Resonances in the Particle Data Table

The most frequently quoted reference in particle physics surely is the Review of Particle Properties (RPP) or Particle Data Table. It is important that the considerations and criteria that guide the authors of this important compilation be discussed at an appropriate open forum. G. Hohler of Karlsruhe, the author of the RPP section on the N* and Δ resonances, gave such a presentation at the workshop. The first problem noted is that a hadronic resonance is not precisely defined. RPP gives the full collection of the resonance-like phenomena as they appear in the πN partial wave analyses (PWA). They show a continuous transition of textbook-type resonances to tiny wiggles on a large background. Since the expressions for the measureable quantities in πN elastic scattering are bilinear in the amplitudes, a unique set of amplitudes cannot be determined from the experimental data alone. Therefore, all analyses have used theoretical constraints.

There are three modern πN PWAs. The analysis by the Karlsruhe-Helsinki (K-H) group is the most extensive; it is the only one that covers the full energy range. It uses 2-variable analyticity and other theoretical input to obtain a unique solution and employs isospin invariance, but it is over 8 years old and has not been updated. The Carnegie-Mellon University - Lawrence Berkeley Laboratory (C-L) work goes to 2.0 GeV; it also relies on special dispersion relations and is over seven years old. There is good agreement between the resonance parameters deduced from K-H and C-L. The Virginia Polytechnic Institute (VPI) analysis is the most current; it is regularly being updated. However, it only covers resonances up to about 1700 MeV, and it uses an ansatz for the energy-dependent solution which awaits proof that it is compatible with analyticity requirements.

From 400 to 700 MeV/c a lot of high quality data has been gathered in the last few years including complete data sets at identical incident energies. The experimental information in the region of the higher resonances is far from satisfactory. No immediate improvement is in sight for lack of experimental facilities. This is particularly unfortunate as it leaves open the important questions of how many clusters of resonances there are in the πN system and why there is clustering.

IX. The VPI πN Partial Wave Analysis

The SAID computer package has made the VPI PWA easily accessible to many users. R. Arndt and collaborators do a great job in incorporating new data. The data bank has been carefully pruned using a star award system which now contains 9176 good data points going up to T_π = 1200 MeV. Perhaps surprising is the fact that the low energy region, $T_\pi < 150$ MeV, is not in good shape. The existing data is inconsistent, and a substantial effort is warranted to improve it in order to have good data on scattering lengths and especially to be able to reliably evaluate the important sigma-term, see below.

The VPI method for extracting resonance parameters is somewhat different than the K-H and C-L analyses. The partial waves are paramatrized and extended to complex energies. Rather than resonance masses and widths, the VPI group reports the pole positions in the complex plane, residues, and zeros. The listing includes the now famous two nearby poles in the P_{11} wave close to the Roper resonance.

X. Is the Roper Resonance Split?

The VPI group has reported two poles in the P_{11} wave, at about (1359-100i) MeV and (1420-80i) MeV, based on a certain amplitude parametrization. It conjures the notion of two nearby P_{11} resonances (the "Roper" and the "Arndt"). This would be in serious conflict with the popular, simple quark shell model. R. Cutkosky recognizes several possibilities brought about by this dilemma:

1) A new degree of freedom is being activated. This is perhaps associated with the gluon. One might even think of a hybrid state (q^3G) as discussed earlier by F. Close. Improved πN scattering data in the range 0.8-1.2 GeV/c is needed to probe this.

2) There is diquark clustering. Evidence would include the disappearance of the $P_{11}(1710)$ resonance and the discovery of additional P_{13} and P_{31} resonances around 1600 MeV. Complete data sets on πN scattering around 1 GeV would help in clarifying the situation.

3) The narrow resonance approximation is not applicable because of the coupling to open channels. This implies that $q^4\bar{q}$ and $q^5\bar{q}^2$ quark configurations besides the q^3, are important. Experiments that would very much help the situation include $\pi^-p \rightarrow \gamma n$ and $\pi^-p \rightarrow \pi\pi N$ especially when extended to include a polarized target.

G. Hohler notes that the P_{11} amplitudes obtained by the three modern PWAs are very similar. Interestingly, the K-H amplitude for the P_{11} also has two poles when parametrized in the VPI fashion. Hohler favors the third option above, a notion that is shared to some extent by Cutkosky. A multichannel resonance usually has more than one pole on different Riemann sheets, and the VPI double pole in the P_{11} is likely associated with the opening of the important $\pi\Delta$ channel. There is a lingering question to this scenario. Why have double poles not been seen in similar cases such as the S_{11}?

XI. The Siegel-Gibbs Analysis of πN Interaction at T_π <70 MeV

An interesting approach to the amplitude analysis of low energy πN data has been made by Siegel and Gibbs. They employ a coupled channel potential model to include the effects of the Coulomb interaction, pion and nucleon mass differences, and the photo-production channel. They exploit the deep dip in the forward π^- charge exchange cross section near 50 MeV to constrain the amplitudes, see Fig. XI-1. Results obtained include $a_{1/2} - a_{3/2} = 0.292 \pm 0.008\ \mu^{-1}$. An example of their fit to existing π^+p data is shown in Fig. XI-2.

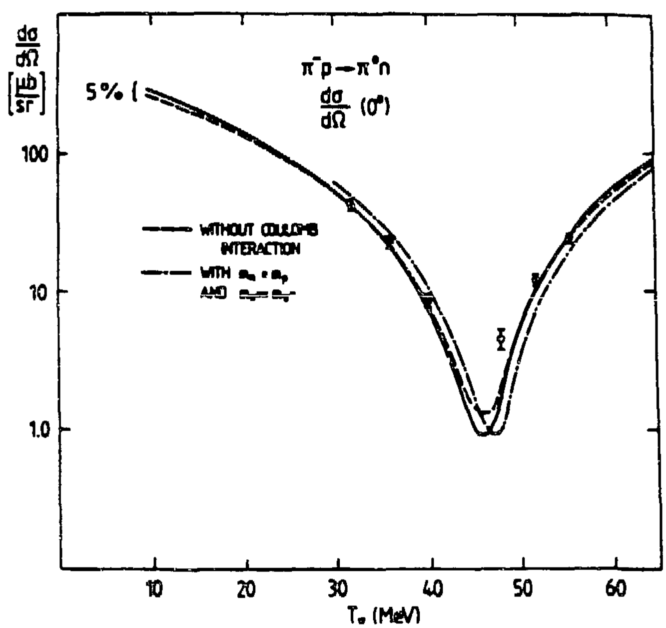


Fig. XI-1 Fit of the Siegel-Gibbs model to the LAMPF low energy charge exchange data at 0^0.

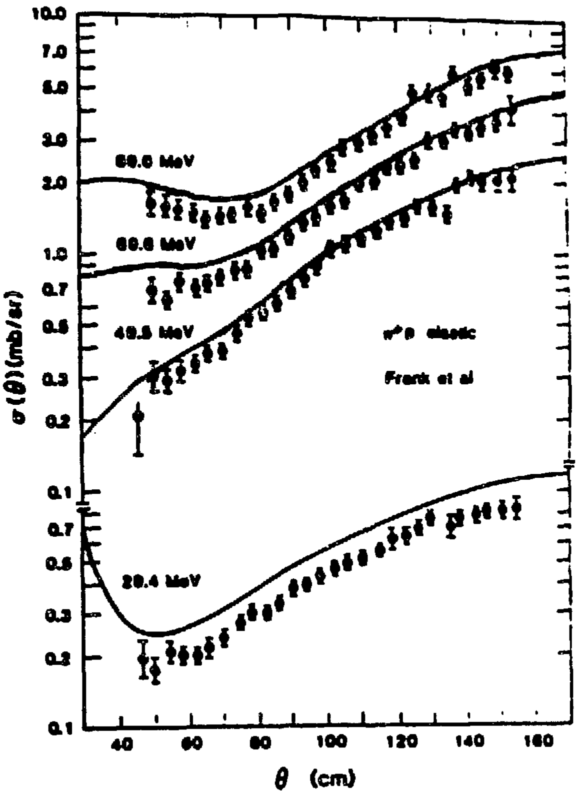


Fig. XI-2 Comparison of the Siegel-Gibbs calculation with the LAMPF π^+p elastic scattering data by Frank et al.

XII. The Skyrme Success Story

For the first time a full set of Argand diagrams of the πN scattering waves has been calculated based on the Skyrme model. Except for the S and P waves, they resemble substantially the "experimental" waves given by the PWAs, see Figs. XII-1, 2. Furthermore, the skyrmion hedgehog approach has yielded a set of Clebch-Gordon type relations between isospin 1/2 and 3/2 amplitudes which have never been considered before and which are obeyed by the data. Also, Holtwarth et al., have obtained the pion photo production amplitudes, see Figs XII 1-3. There is hope that in certain situations in the low energy regime QCD may reduce to an effective meson theory in which baryons emerge as solitons.

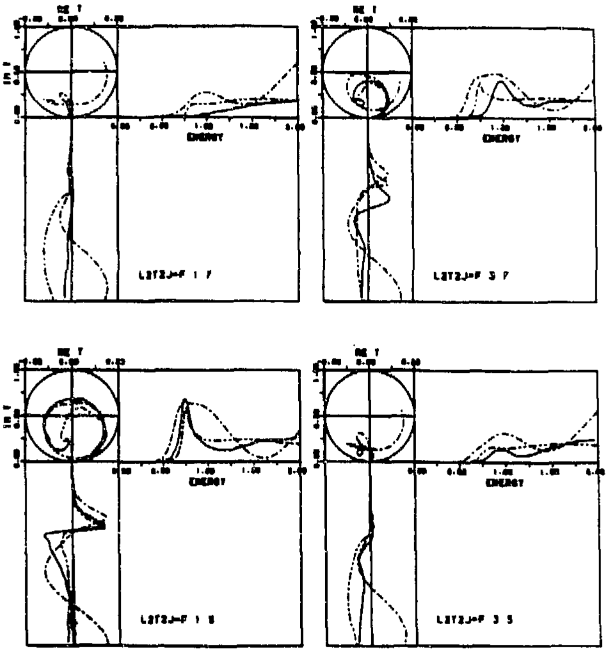


Fig. XII-1 Comparison of Argand diagrams of F-waves in πN scattering with Skyrme model calculations. The full curves are the experimental data, the dash-dotted lines are the standard Skyrme model, the dash-double-dotted lines include ρ and ω mesons.

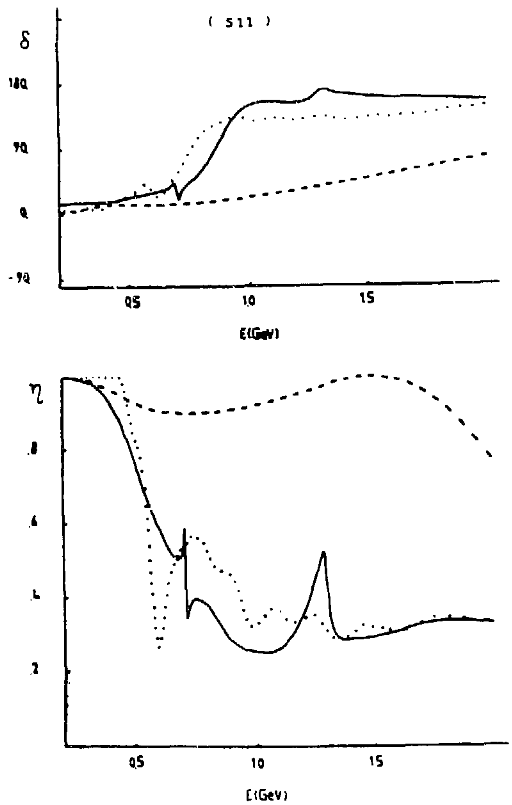


Fig. XII-2 Same as XII-1 for the S_{11} πN wave.

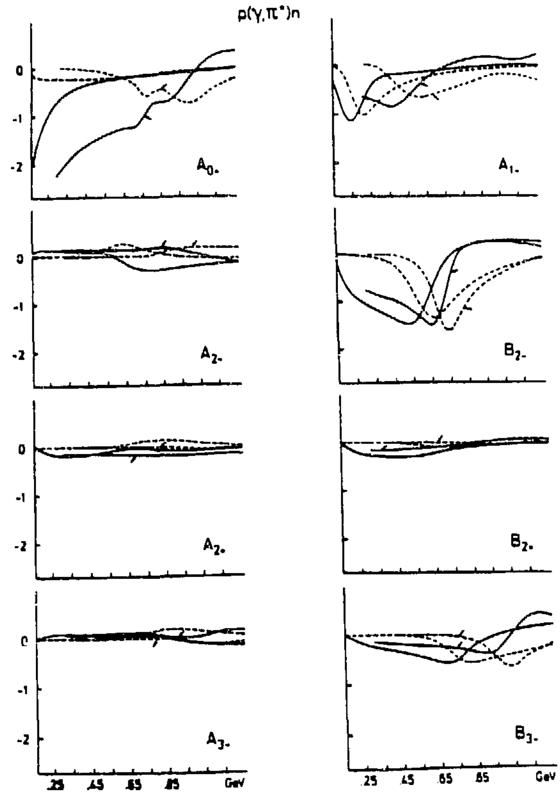


Fig. XII-3 Photoproduction amplitudes compared with Skyrme model calculations by Holzwarth et al.

XIII. Experimental Advances

There are now available complete sets of data obtained at the same incident energies by the same team, of all the independent πN scattering variables in the range 400-700 MeV/c. Specifically, we now have very accurate $d\sigma/d\Omega$ data for $\pi^{\pm}p \to \pi^{\pm}p$ and $\pi^{-}p \to \pi^{0}n$ as well as left-right asymmetry values. Furthermore, the Wolfenstein spin rotation parameters A and R have been obtained for $\pi^{\pm}p \to \pi^{\pm}p$ from 427 to 657 MeV/c Examples are shown in Fig. XIII-1. At the lower energies the data are in agreement with all three PWAs, at higher energies the left-right data for $\pi^{-}p \to \pi^{0}n$ which is most sensitive, see Fig. XIII-3, clearly favors the VPI solution over the K-H and C-L.

The low energy data, $T_{\pi} < 150$ MeV, is inconsistent and incomplete, an example is shown in Fig. XIII-4, 5. There is need for new high quality data here. This should be a challenge for all three pion factories!

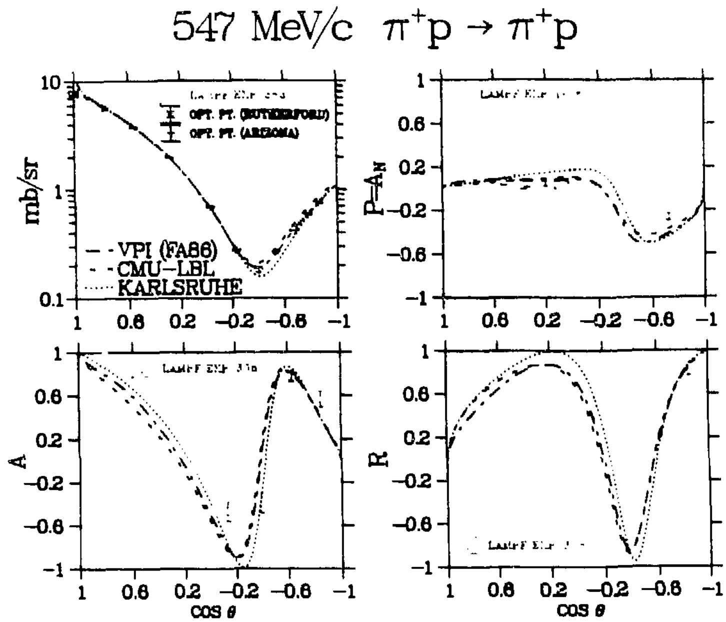


Fig. XIII-1 Complete data set for $\pi^+p \rightarrow \pi^+p$ at 547 MeV/c obtained at LAMPF by the UCLA group.

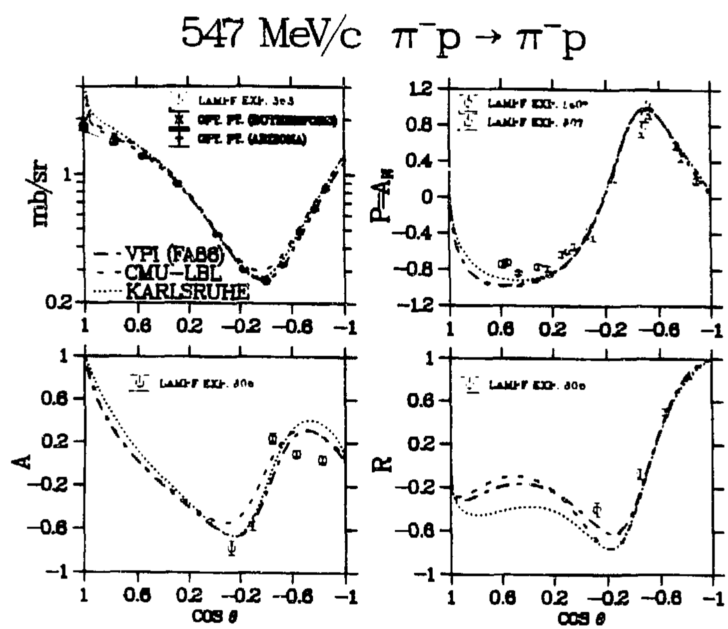


Fig. XIII-2 Same as Fig. XIII-1 for $\pi^-p \rightarrow \pi^-p$.

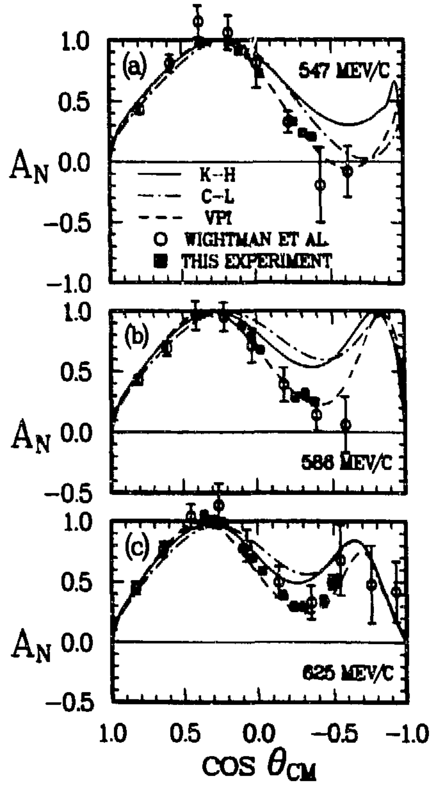


Fig. XIII-3 $A_y(\pi^- p\uparrow \rightarrow \pi^0 n)$ compared to recent πN PWA's; the measurements were obtained at LAMPF by the UCLA group.

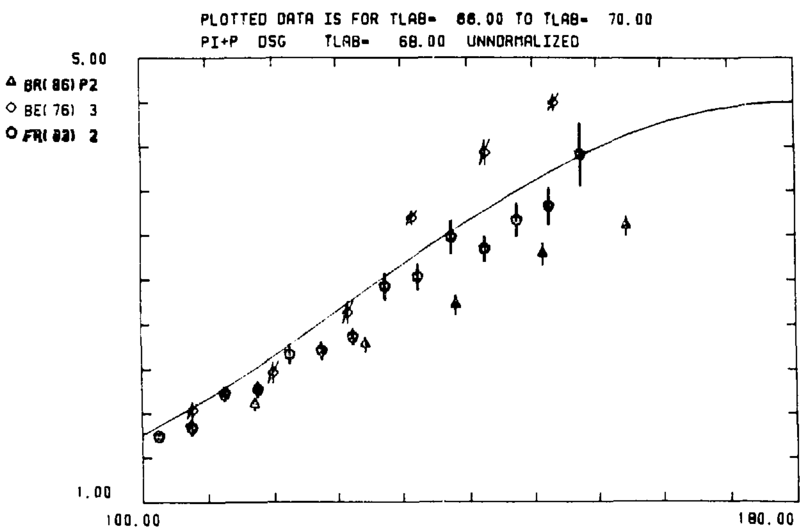


Fig. XIII-4 Discrepancies in low energy $d\sigma(\pi p \rightarrow \pi p)$.

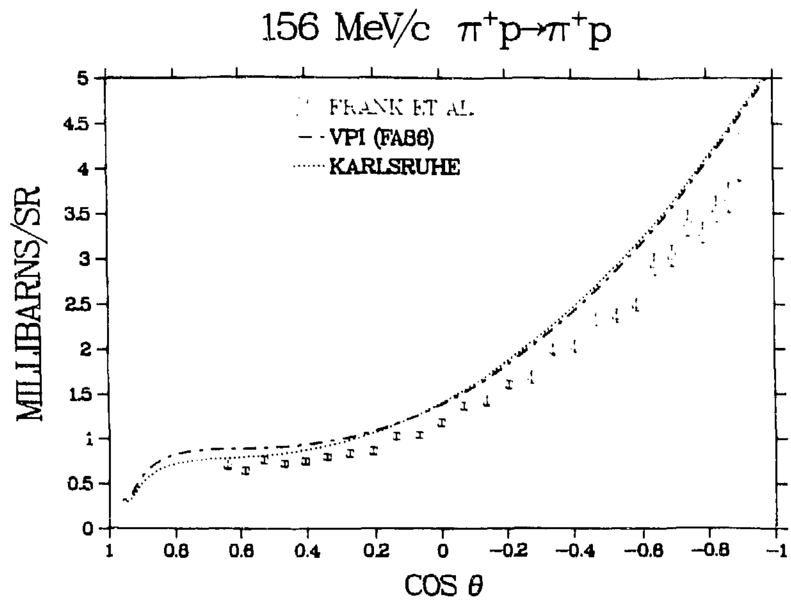


Fig. XIII-5 Comparison of π^+p data at 256 MeV/c with the recent PWA.

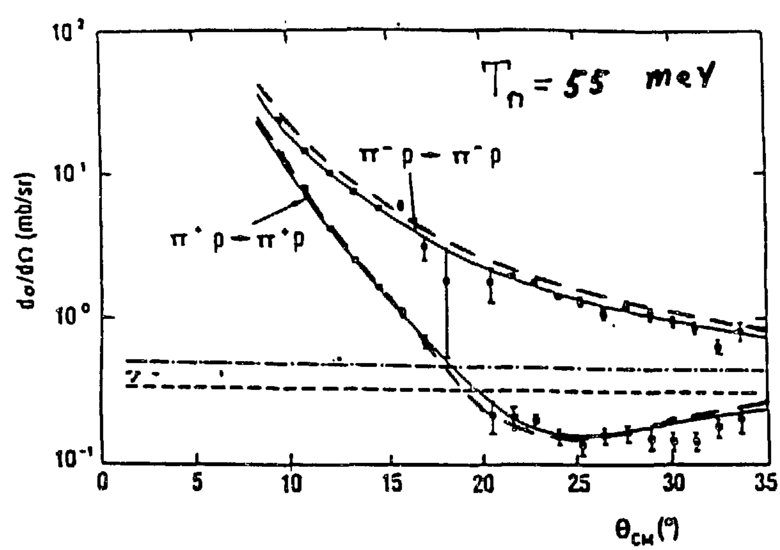


Fig. XIII-6 Comparison of a recent Karlsruhe experiment at SIN on $\pi p \to \pi p$ elastic scattering at forward direction with the Siegel-Gibbs calculations.

XIV. The Sigma-Commutator

The somewhat esoteric notion of the σ-commutator has recently become the center of attention. Improved calculations show it to be a practical way for investigating the $s\bar{s}$ quark content of the proton, and some experiments are not inconsistent with a 30% contribution.

Very loosely speaking, the σ-commutator is related to the u- and d- quark content of the proton. The pion-nucleon σ-term in $\pi^{\pm}p$ elastic scattering is

$$\sigma \equiv \frac{m_u + m_d}{2\,M_p} < p\,|\bar{u}u + \bar{d}d|\,p >.$$

σ can be expressed in terms of the physical masses of the nucleon, Σ and Ξ baryons and the parameter y which is the strange particle content of the proton,

$$y = \frac{2\,<p|\bar{s}s|p>}{<p|\bar{u}u+\bar{d}d|p>}\ .$$

The most refined evaluation by J. Gasser yields the result

$$\sigma = \frac{(35\pm 5)\ \text{MeV}}{1-y}\ .$$

σ can also be obtained by a suitable extrapolation into the unphysical domain of π^+p and π^-p elastic scattering amplitudes. The current status of the σ determination is given in Table III. Thus, the current data is not inconsistent with a substantial strange quark content of the nucleon. It is amazing that simple, low energy πN scattering data can be such a powerful tool in particle physics; one is actually in a position to make a direct check on a lattice calculation in QCD.

TABLE III. Determination of the σ commutator, the strange particle content of the nucleon (y), and the nucleon mass in the chiral limit (m_0)

		σ (MeV)	y	m_0 (MeV)
Koch, Hohler	$d\sigma/d\Omega$	56	0.37	<600
Arndt et al.	$d\sigma/d\Omega$	36	~ 0	870
Siegel, Gibbs	$d\sigma/d\Omega$	54	0.35	<600
Bovet et al	π^-p capt	37	~ 0	870
Gensini	π^--nuclei	47±4	0.27	<750
Hamber	Lattice QCD	30±8	0	

The foregoing dozen topics which were selected somewhat arbitrarily, are only half of the number of subjects discussed at the two workshops. The full proceedings of both meetings contain the references omitted in the above. They are available from the author at UCLA or W. Gibbs at LANL.

Higher Energy Pions at LAMPF

D. J. Ernst
Texas A&M University, College Station, Texas 77843

Abstract

The physics that can be done with pion beams in the energy region 300-500 MeV is discussed. Those properties of the pion-nucleon amplitude which make this an interesting region for nuclear structure studies are reviewed. Reseults of recent theoretical work on the single-charge exchange reaction to analogue states are presented. The physics that might lie in the near term with modest improvements to the P^3-channel is outlined. A brief overview of the longterm is provided in the context of the physics which would become available with a pion beam of $T_\pi \leq 6$ GeV.

The future of pion-nucleus physics at LAMPF could take several directions. There are three areas in which new experimental capablities at LAMPF could expand pion physics into substantive new areas. These are extending the energy range of the available pion beams to lower energies, extending the energy range to higher energies, or adding improved resolution spectrometers, particularly a π^0-spectrometer, for the present energy range. There are strong physics arguments in favor of each of these directions and, in the best of all funding worlds, they should all be pursued. I shall in this talk concentrate on the physics which might be pursued with higher energy pion beams. This is not to be construed as a choice that this is necessarily the best direction in which to invest limited resources. In a talk of limited length, it is difficult to do justice to the diversity of physics that is opened up by any one of these developments; it would be impossible to cover all three. The choice of discussing higher energy pions at LAMPF is motivated by the simple expedient that this is an area in which I have been working recently. This is probably an appropriate place to point out that there remains an active interest in pion-nucleus physics. This is evident to someone on the PAC where the Pion Subcommittee receives the largest number of proposals and is often involved in the liveliest and most controversial decisions. If this interest and momentum is to be maintained, we must plan for the future, and new experimental capabilities are necessary if the field is to remain vital.

In discussing the future of high energy pions at LAMPF, the discussion naturally breaks into three categories — the very near future, the intermediate future, and the long term. The near future is exciting because the P^3-channel has recently been improved and the first round of data is now being taken. This, together with the single-charge exchange data from Sayed Rokni's thesis, constitute the first look into pion-nucleus physics in the energy range T_π=300 to 500 MeV. The intermediate future lies in upgrades or modifications which would improve capablities in the range of T_π=300 to maybe 700 MeV, while the long term lies in a new accelerator with proton energies in the range of about 3 GeV at the lower end to 60 GeV at the upper end as proposed for the Advanced Hadron Collider.

Let's begin with the near term. In the energy region from $T_\pi = 300$ to 500 Mev the total body of data which presently exists consists[1] of 0° differential cross sections for pion single-charge exchange to the analogue state for targets ^{7}Li, ^{14}C, ^{27}Al, ^{60}Ni, ^{90}Zr, ^{120}Sn, and ^{208}Pb. The corresponding elastic cross sections and double charge exchange cross sections do not yet exist but an approved proposal #1028 is presently running. A single elastic differential scattering cross section[2] on ^{16}O at 356 MeV has been measured at SIN and elastic and inelastic cross sections[3] for $\pi^\pm$ on ^{12}C and ^{40}Ca at 673 MeV have been measured at the AGS. There exists two previous articles[4,5] on the physics of the pion-nucleus interaction in this energy region. Both of these were motivated by an EPICS II spectrometer that was part of the original LAMPF II proposal.

The first qualitative understanding of this energy region arises from examining elastic pion-nucleon scattering. In Fig. 1 the total cross section for pions elastically scattering from nucleons is depicted. We note that the pertinent cross section is the total *elastic* cross section. In Refs. 4,5 the use of total cross sections gave erroneous estimates of the isospin factors that would enter pion-nucleus reactions. From Fig. 1 we clearly see the dominance of the Δ_{33} below 300 MeV with the famous 9:1 ratio of the $\pi^+ p$ to $\pi^+ n$ cross sections on resonance. This ratio falls smoothly above the resonance until it reaches about 1:1 just below 550 MeV. This is a useful attribute for nuclear structure studies. The difference between $\pi^+ p$ ($\pi^- n$) and $\pi^+ n$ ($\pi^- p$) allows one to compare π^+ induced reactions with π^- induced reactions to separately measure the proton and neutron contributions to the reaction. A difficulty is always the ability to separate reaction mechanism effects from nuclear structure effects. A strong constraint on extracting reliable nuclear structure would be to extract target information which was independent of the energy over a range where the isospin dependence of the two-body amplitude is smoothly varying. On this point there is a clear advantage of going on up in energy to 700 MeV where the ratio reverses and becomes 1:2.

The spin dependence of the two-body amplitude also varies smoothly over this energy range. A thorough discussion can be found in Ref. 4.

The most striking feature of the pion-nucleon interaction in this energy region is that the total cross section (averaged over protons and neutrons) falls from a maximum of approximately 120 mb on resonance to 20 mb at 500 MeV. This holds two implications. First, the pion will penetrate further into the nucleus as the energy increases. Second, a decreasing interaction strength implies an increasingly convergent multiple scattering theory. We will examine the increasing penetrability by following an argument from Ref. 6.

The mean-free-path for a pion in nuclear matter ($\lambda \equiv 1/(\rho(0)\sigma)$) at 160 MeV is $\lambda = 0.4$ fm, while at 475 MeV, $\lambda = 2.3$ fm. We may translate this into penetrability by defining a profile function $S(b)$ by

$$S(b) = \frac{1}{\rho(0)} \int_{-\infty}^{+\infty} \rho(z, b)\, dz \tag{1.}$$

where we divide by $\rho(0)$ to give $S(b)$ the units of length. Intuitively, $S(b)$ is simply the

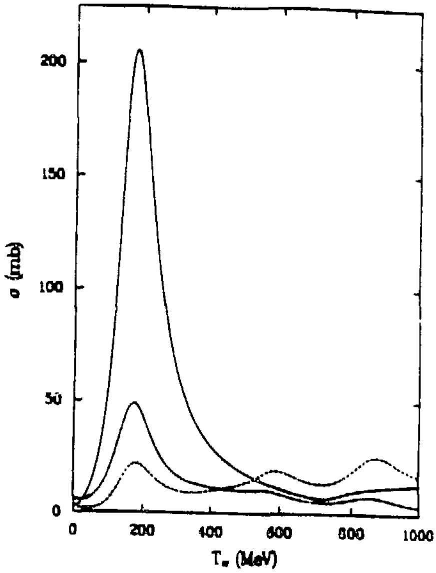


Fig. 1. Pion-nucleon total cross elastic cross section as a function of energy. The solid line is $\pi^+ p$ (or $\pi^- n$), the dotted line is $\pi^+ n$ (or $\pi^- p$), the dot-dash line is the single charge exchange channel.

distance in fermis that a particle would pass through a nucleus while traveling on a straight line in the z-direction along an impact parameter b. This can readily be understood in the case when $\rho(0)$ is a constant. Then $\rho(0)$ would cancel and the integral dz would give the distance across the nucleus at an impact parameter b. The argument of Ref. 6 gives that the radius of maximum penetration R can be found from the value of b at which the profile function is equal to one mean-free-path,

$$S(R) = \lambda \ . \tag{2.}$$

This is an intuitive result, i.e. it states that a particle penetrates into a nucleus a distance determined by the condition that the particle pass through less than one mean-free-path of matter.

This result is pictured in Fig. 2 where the profile functions for ^{12}C, ^{40}Ca, and ^{208}Pb are pictured. The points where the profile function is equal to one mean-free-path for T_π equal to 115, 160, 240, and 475 MeV are indicated by the arrows. We see that by going to energies above the resonance, the pion does penetrate significantly further into the nucleus, but, by no means, does it make it into the deep interior.

As was mentioned, the decreasing pion-nucleon cross section also leads to a more rapidly convergent perturbation theory. Here we follow an argument from Ref. 7. There, the ratio of the second-order optical potential to the first order term was estimated to be

$$R \equiv \frac{U^{(2)}}{U^{(1)}} = \sqrt{\sigma}\,\frac{\ell_c}{k}\,\rho \ . \tag{3.}$$

The derivation in Ref. 7 is formal but the answer is intuitive. The $\sqrt{\sigma}$ occurs because the higher order term necessarily involves an extra t-matrix whose magnitude is the square

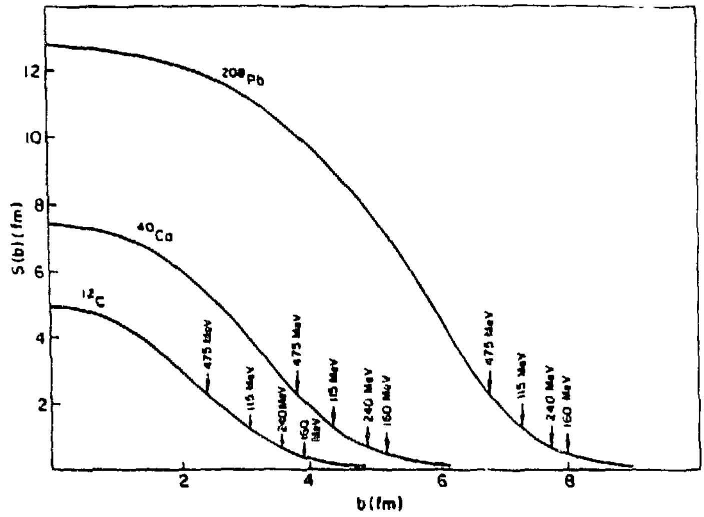


Fig. 2. The profile function of ^{12}C, ^{40}Ca, and ^{208}Pb as a function of impact parameter b. The point where the profile function is one mean-free-path thick is marked for pions of energies 115 MeV, 160 MeV, 240 MeV, and 475 MeV.

root of the cross section. The factor ℓ_c is the correlation length; it enters because we have arranged the optical potential in a correlation expansion so that the higher order terms are proportional to the two-body density minus the square of the one-body density, i.e. proportional to the correlation function. The factor k^{-1}, with k the pion wave number, arises from the extra propagator which occurs in a higher order correction. Finally there is the density ρ which occurs simply because the more dense the nucleus, the easier it is to find a second nucleon. If we substitiute typical numbers into Eq. 3, we find that at 160 MeV $R \approx 0.1$, where ℓ_c was taken to be 1 fm. and the density was taken to be .15 times nuclear matter density as is indicated by Fig. 2. At higher energies, we find $R \approx 0.04$ at 500 MeV. Here we have used a nuclear density of one half nuclear matter, but because of the smaller cross section and increased k, the series is more convergent.

These estimates, particularly on resonance, are overly optimistic. This is because the estimate does not include corrections due to pion true absorption or dispersive effects. The rapid energy dependence of the two-body t-matrix near resonance enhances[8] the importance of dispersive corrections. The magnitude of the true absorption correction could be estimated utilizing similar arguments. The factor $\sqrt{\sigma}$ should be replaced by an estimate of the magnitude of the pion-nucleon to nucleon coupling and the correlation length ℓ_c should be replaced by the interparticle distance as the true absorption correction involves the full two-body density, not the correlation function.

In order to take advantage of the enhanced convergence of the multiple scattering series at the higher energies, we must be able to calculate, without approximation, the leading term (or impulse approximation) of the optical potential. In addition, we require a formal theory which unambiguously defines what is meant by the impulse approximation and also provides explicit expressions for the many higher-order corrections. Both the formalism[9] and the numerical technology[10] to accomplish this have been developed over the past several years. Below we will review these developments and present recent results[11] for pion single-charge exchange to isobaric analogue states in the energy region 300 to 500 MeV.

In collaboration with Mikkel Johnson, a formalism has been developed for the pion-nucleus optical potential[9] that has been structured to treat consistently the basic field-theoretic properties of the pion. Some of the unique features of this approach are that the creation or annihilation of the pion is incorporated without double counting, the backward going pion is correctly treated as the forward going antiparticle crossing symmetry in the two-body amplitude leads to crossing symmetry in the many-body problem, and the crossed amplitudes are taken off-shell as U-channel singularities. Although these are all desirable feature, in the energy range 300-500 MeV they have little consequence for numerical results and conventional multiple scattering theory together with Lorentz invariance would be sufficient.

The impulse approximation to the optical potential is given by

$$\langle \mathbf{P}'_\pi \mathbf{P}'_A | U(E) | \mathbf{P}_\pi \mathbf{P}_A \rangle =$$
$$\sum_\alpha \int \frac{d^3 P_{A-1}}{2\bar{E}_{A-1}} \langle \Psi_\alpha(\mathbf{P}'_A) | \mathbf{P}'_N \mathbf{P}'_{A-1} \rangle \langle \mathbf{P}'_\pi \mathbf{P}'_N | T(E) | \mathbf{P}_\pi \mathbf{P}_N \rangle \langle \mathbf{P}_{A-1} \mathbf{P}_N | \Psi_\alpha(\mathbf{P}_A) \rangle , \quad (5.)$$

where the notation is defined in Ref. 12. There are several nonstandard features in this equation. The first is that the target wave function $\langle \mathbf{P}_{A-1} \mathbf{P}_N | \Psi_\alpha(\mathbf{P}_A) \rangle$ is writtten as a function of the total nucleus momentum $\mathbf{P}_A$, the momentum of the nucleon $\mathbf{P}_N$, and the momentum of the $A-1$ nucleon core $\mathbf{P}_{A-1}$. This wave function contains an implicit momentum conserving delta function and a reduced matrix element which is a function of the relative momentum between the nucleon and the $A-1$ core. This definition allows one to correctly[12,13] include the recoil of the target nucleus into the theory. It also allows one to utilize modern shell-model wave functions which treat the center-of-mass motion of the nucleus in a completely parallel way. In addition, there appears a phase space factor $\bar{E}_{A-1}$ which arises because we use invariant normalizations for our wave functions.

The execution of Eq. 4 requires two ingredients: (1) a dynamical model of the pion-nucleon t-matrix is necessary and (2) the integral over the momentum of the struck nucleon (fermi averaging or resonance recoil) must be performed. The model of the pion-nucleon t-matrix must be dynamic in the sense that it is derived from an underlying Hamiltonian. This is necessary because we require the two-body scattering amplitude off the energy shell. Given an underlying Hamiltonian, our many-body theory provides a unique continuation of the t-matrix off the energy sheel. Furthermore, to be consistent with the invariance of the many-body theory and to be valid at these high energies, the two-body model should utilize covariant kinematics, invariant normalizations, and work with invariant amplitudes which are free of kinematic singularities.

The two-body model must also be extended to fit the D- and F-wave pion-nucleon partial waves. This model we take from the recent thesis[11] of Greg Parnell. The model is

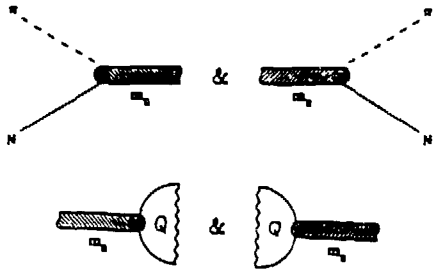


Fig. 3. The interaction of a pion with a nucleon in the doorway resonance model

motivated by the observation that for those partial waves which have a resonant behavior, the coupling to the pion production and other inelastic channels is substantial but only becomes large at the energy at which the phase of the t-matrix rises through ninety degrees. This led us to postulate a Hamiltonian which couples the pion-nucleon to a resonance as in a Lee Model, but also couples the resonance to the inelastic channels. No coupling of the pion-nucleon system directly to the inelastic channels is included. The Hamiltonian is pictured in Fig. 3. The model is solvable in the sense that if we take the coupling of the elastic channel to the inelastic channels from data, then the model can predict the phase shift. Results for the D_{13} channel are pictured in Fig. 4.

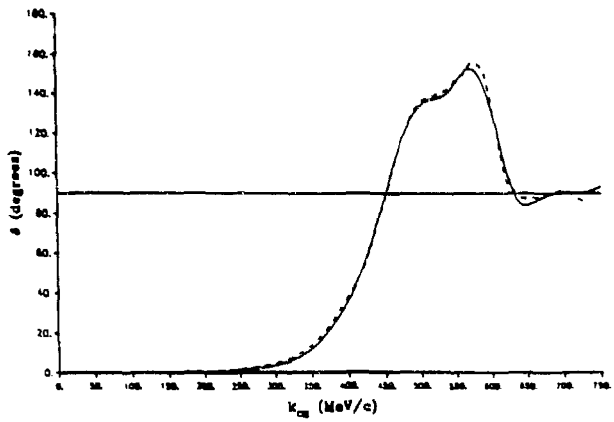


Fig. 4. The phase δ of the pion-nucleon t-matrix in the D_{13} channel verses pion center-of-momentum. The dotted curve is the data from Ref. 15, the solid curve is the result of the doorway resonance model.

Working in momentum space, the recoil of the Δ_{33}, the recoil of the other resonances, and the exact incorporation of relativistic kinematics and all nonlocalities requires the numerical evaluation of the integral over the momentum of the struck nucleon in Eq. 4. A very useful technology developed by H. Garcilazo[14] and D. Giebink[12] allows one to maintain all the invariant kinematics and perform the fermi integration in an efficient way. This technology is embodied in "relativistic three-body recoupling coefficients" and is described in detail in Refs. 12 and 14. The computer code ROMPIN[10] incorporates all of this physics and is publicly available.

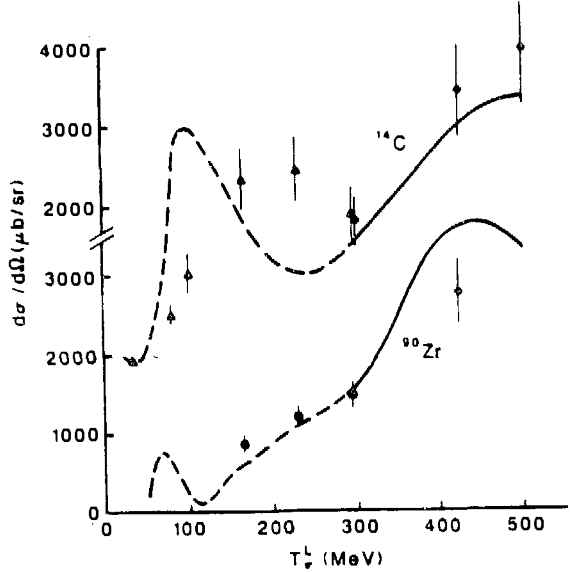


Fig. 5. The zero degree differential cross section for pion single-charge exchange to the analogue state of ^{14}C and ^{90}Zr as a function of pion laboratory kinetic energy. Notice that separate scales are used for the two targets. The data below 300 MeV are from Ref. 16, the data above 300 MeV are from Ref. 1.

The results of this theory for the zero-degree differential cross sections for pion single-charge exchange to the analogue state for ^{14}C and ^{90}Zr are depicted in Fig. 5. We see that for ^{14}C the theory and the data are in quantitative agreement for pion kinetic energies above 300 MeV. For ^{90}Zr the theory is slightly less than one standard deviation above the one data point at 425 MeV. The chi-square per data point for all the data at 300 MeV or higher is about 0.5. This is most encouraging; however, it is too early to draw definitive conclusions. We do not yet know how well the distorted waves are being calculated because we do not have data in the dominant elastic channel.

The only other calculations for single charge exchange in this energy region are the Glauber calculations in Ref. 1. Our results disagree with those results in a qualitative way. There, the results had to be renormed by a substantial amount in order to come into agreement with the ^{14}C data. We require no such renormalization. If these Glauber results are renormed to fit ^{14}C, they still predict cross sections that are about three times larger than the data for ^{90}Zr. We see no such A-dependent effect. A source of these differences lies in the off-shell model of the t-matrix that is used in the Glauber approach. There, the t-matrix is assumed to be local as it is parameterized as a simple function of momentum transfer. The t-matrix arises from the high energy tail of the P_{33} resonance, the P_{11} resonance, and the low energy tail of the higher resonances. This structure of having individual channels each with its own energy dependence does not lead to an off-shell t-matrix which is a simple function of momentum transfer. The more dynamic model of the two-body t-matrix used here predicts significantly smaller cross sections in better agreement with the data.

The near future of pions in this energy region is clear. The elastic and double-charge exchange data from experiment #1028 will place the next constraint on the theory. However, if one is to make use of the unique properties of the pion in this energy region to study nuclear structure, an improved beam and a substantially improved spectrometer will be necessary. Interesting nuclear structure is not often found in the low lying states of closed-shell nuclei; a capability to resolve states in other regions of the periodic table is necessary if a truly exciting program of nuclear structure studies is to be undertaken. Present capabilities, however, could yield quite informative information on the isospin structure of the giant resonance region by comparing π^+ to π^- excitation over the range of 200 to 500 MeV.

There are two interesting fields that slightly higher energy pions could open. The first of these is to study the propagation of mesons other than the pion in a nucleus. The first excited meson is the η. Fortunately, LAMPF was built at an energy which is above the η production threshold. Unfortunately, LAMPF is only slightly above the η threshold. This has allowed some beginning first work on η-nucleus physics but, because the pion energy is so near the threshold, any small increase in energy greatly enhances the quality of η physics which can be done. The reader is referred to the August workshop on The Future of Pion Physics for reviews of the present status of this field.

The second interesting field is the study of the interaction of excited baryons with the nucleus. One of the interesting pieces of physics which is still being explored in the Δ-resonance region is the delta-nucleus interaction. The next resonance is the Roper or $P_{11}(1470)$. This resonance, however, is very broad with a width of approximately 200 MeV and couples strongly (about half of the time) to the two pion and η production channels. This means that it does not produce a bump in the pion-nucleon cross section and it will be difficult to disentangle it from the other partial waves. The invariant mass of 1470 MeV corresponds to a pion laboratory kinetic energy of 530 MeV. This is just at the maximum energy that presently exists at P^3. Thus looking at the P_{11} in a nucleus may already be possible but much work, both theoretical and experimental, are required before a convincing case could be made that the physics arising from this single two-body channel can been isolated from the other channels.

The next higher energy baryons are the D_{13} and S_{11} which occur at an invariant mass of 1520 and 1535 MeV, respectively. The width of these resonances is about 125 - 150 MeV. They occur in the pion-nucleon system at a pion laboratory kinetic energy of 760 MeV. Thus an additional 200 MeV in pion energy is necessary if we are to study these resonances. Unfortunately, there appears to be no reasonable way of adding 200 MeV of energy to the present beam so that the near term upgrades must focus on studying nuclear structure in the 300-600 MeV range, the enhancement of the η-nucleus physics program, and the possibility of studying the P_{11} resonance in the nucleus.

In the energy region from 600 MeV to 3 or 6 (or maybe 15) GeV, an entirely new physics becomes available. The physics which one can do with nucleon targets focuses on one of the least understood aspects of QCD — the property of confinement. It does this by investigating hadron spectroscopy at a detailed level not possible without intense beams and by searching for exotic states. These may be states with significant gluon content, perhaps the pure-glue glueball states, or dibaryon resonances, including strange (i.e. S=−1) dibaryon states. In this respect, the pion is very much the complement of the photon (and the proposed program at CEBAF) and is a probe that can couple with the nucleon to produce directly (not going through the exchange of a third particle) many of the known and to be discovered states — a distinct advantage of the pion.

The rare decays of the η offer a rich variety of physics. Ben Nefkins' talk at this meeting will detail many possible studies. The η production cross section peaks at a pion energy of about 1.5 GeV and thus a proton beam of 3 Gev is adequate for this work.

A truly exciting field in the general area of new forms of matter is the use of the (π^+, K^+) reaction to produce hypernuclei. These hypernuclei can be built with Λ, Σ, Ξ, or Λ^* hyperons, or two Λ's or Σ's. Although the associated production (π^+, K^+) cross section is smaller than the direct production of hypernuclei with a kaon beam, this is more than compensated for by the increased flux of the pion beam. In addition, associated production can produce slow moving strange particles in the nucleus and is thus capable of populating low lying bound states.

Above 1 GeV the pion-nucleon cross section is flat, is about 20 mb, and not particularly different from any other srong interaction. This is therefore not a region to pursue detailed nuclear structure work. The pion does provide a complement to the quasi-elastic electron scattering progam at CEBAF. The (π, π'), $(\pi, \pi' N)$, and $(\pi, \pi' NN)$ reactions are complements to (ϵ, ϵ'), $(\epsilon, \epsilon' N)$ and $(\epsilon, \epsilon' NN)$ reactions. These reactions could be carried out in the range $\Delta E_\pi = .05 - 3$ GeV and $\Delta p_\pi = .2 - 3$ GeV/c probing the same region as is availble at CEBAF. The quasi elastic scattering could probe deeply bound nuclear states, could help disentagle current corrections from nuclear structure effects, and when measuring two nucleons, probe nuclear correlations. Since these studies are not always theoretically clean for the electron induced reactions, having the pion as a complementary probe to the electron is necessary if we are to produce unambiguous and believable results. An interesting question that arises here is how can one use a strongly interacting probe to investigate the same physics as is seen in the EMC experiments? There is presently a K^+ experiment being performed along these lines.

As was mentioned earlier, the use of a nuclear target affords us the opportunity to study the interaction of a variety of mesons with the nucleon. The pion can produce the meson in the nucleus and then the final state interactions can be used to study the meson-nucleon interaction. The η, ρ, ω, η', S^*, δ, ϕ, B and D mesons are candidates that could be investigated. Of these the $S^*(975)$ has been proposed to be of special interest. This meson may either be a standard $q\bar{q}$ state, a four quark $q^2\bar{q}^2$ state, or maybe a bound state composed of $K\bar{K}$. Each of these models would produce qualitatively different interactions with the nucleon and thus could be distinquished by measuring the S^*-nucleon cross section. The ϕ also is interesting. Electroproduction of the ϕ in a nucleus indicates a total cross section with the nucleon of 8 mb, an abnormally small number. There is also evidence, although not at all convincing, that there is a ϕ-nucleon bound state. The ρ nucleon cross section is only known roughly for energies below 1 GeV. For each of these mesons, the study of the meson-nucleon interaction offers another piece of information to be folded into our understanding of hadron spectroscopy. The most exciting aspect of this is the search for an exotic state, but identifying a state as exotic is not easy. An anomalous cross section with the nucleon could be a key piece of information.

As was also mentioned before, we could study the interaction of excited baryons, N^*'s and Δ's, with the nucleus. Below a pion kinetic energy of 3 GeV there are 27 excited hadrons, counting the three and four star resonances. This is a program in which we have much experience from the work with the $\Delta(1232)$. The present work with the Δ I don't believe has yet come to a final understanding as refinements and extensions are underway. Nevertheless, all of what has been learned here could be applied to the higher energy resonances where the problem becomes more difficult because the resonances overlap and are highly inelastic. Qualitative results could be quite exciting if an anomalously large or small interaction is found.

The $(\pi, 2\pi)$ reaction offers another new field of study. The interaction on the single nucleon allows one to study the π-π interaction. With the more intense beam and modern detectors a substantial improvement over existing work on this interaction would be possible. The π production process in a nucleus could offer an approach to studying modifications to the nucleon when it is in the nuclear medium or to studying the virtual pion content of the nucleus, with the possible probing of the precursor to the pion condensate. This reaction would also allow the study of inclusive pion propagation in the nuclear medium. A quantitative understanding of this problem will be necessary if one is to interpret many of the results to emerge from RHIC. Pion interferometry could be studied here in a much simpler context as a test of its ability to produce unambiguous results.

Only the highlights of the physics which could be done with pions produced at a facility with a 3 to 6 GeV intense proton beam have been mentioned here. The Astor proposal and the talks presented at the August workshop provide more detail. The physics is certainly rich and will hopefully become available in the relatively near future.

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The MEGA Experiment

M. D. Cooper
Los Alamos National Laboratory, Los Alamos, NM 87544, USA

The search for $\mu \to e\gamma$ 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}. The motivation for pressing the search for this neutrinoless muon decay is sufficiently strong to attract over 60 scientists and engineers from 12 institutions to carry out the measurement.[1] Such enthusiasm is engendered because the observation of the process would herald physics not explained by the minimal Standard Model of electroweak interactions that currently accounts for all observations of relevant processes.

The Standard Model is a periodic table for particle physicists that allows classification of the quarks and leptons. The up and down quarks as well as the electron and its neutrino are placed into left handed doublets and right handed singlets to reflect the observed parity violation. This grouping is repeated two more times with the remaining quarks and and leptons. Unlike the chemical periodic table, the reason for this repetition of families of particles is unknown.

The separation of particles into disconnected families is built into the model because processes which change, for example, muon number are unseen to very small branching ratios. The conservation of muon number appears ad hoc because it is not rooted in any known fundamental principle. By contrast, conservation of energy, momentum, and angular momentum arise from the translational and rotational invariance of space-time, whereas the conservation of electric charge and color is due to the gauge invariance of a field coupled via a massless gauge boson. The lack of a deeper reason for the apparent conservation of muon number further stimulates the belief that such processes are not truly forbidden.

The observation of $\mu \to e\gamma$ would indicate a radical departure from the minimal Standard Model. The simplest modification to allow $\mu \to e\gamma$ is to give the neutrinos mass. The formula[2] for the branching ratio for $\mu \to e\gamma$ is

$$B_{\mu\to e\gamma}=\frac{3\alpha}{32\pi}|U^{*}_{\mu\tau}U_{\tau e}|^2\frac{(m_{\nu\tau}-m_{\nu\mu})^2(m_{\nu\tau}-m_{\nu e})^2}{M_W^4},$$

where U_{ij} is the elements of the neutrino mixing matrix, the $m_{\nu i}$ are the neutrino masses, and M_W is the mass of the W boson. Substituting the upper limit[3] for the tau neutrino mass of 70 MeV and the experimental limits[4] on the mixing angles of 3×10^{-3}, the value of B is $<10^{-18}$. Such a small branching ratio is completely out of the reach of current experiments, and implies any observation will require some more exotic mechanism.

Candidates for new mechanisms to allow $\mu \rightarrow e\gamma$ abound. Theoriticians have invented many extensions to the Standard Model to explain its possible shortcomings. Most of the extensions allow $\mu \rightarrow e\gamma$ by design or accident. Some models with reasonable parameters allow the rate to be observable by the new generation of experiments. In addition to $\mu \rightarrow e\gamma$, there are many other candidate processes such as $\mu \rightarrow eee$, $\mu \rightarrow e\gamma\gamma$, $\mu A \rightarrow eA$, $K_L \rightarrow \mu e$, and $K^+ \rightarrow \pi^+ \mu e$ that may be triggered. Depending on the model and its parameters, a different one of these processes may have the biggest branching ratio. An important point is that each of these must be pursued experimentally because the theories lack detailed predictive power. The MEGA experiment searches for one of these which is prominent in models that embody more generations, right-handed neutrinos, a complicated Higgs sector, composite particles, and supersymmetry. Models containing horizontal symmetries and technicolor do not favor $\mu \rightarrow e\gamma$.

One can illustrate the reason for different processes being favored by different ideas by examining Fig. 1. In part a) of the figure, mediation of rare decays by a heavy neutrino requires three vertices for $\mu \rightarrow e\gamma$ and four for $\mu \rightarrow eee$, favoring $\mu \rightarrow e\gamma$ by roughly 10^3. The situation is reversed in part b) where $\mu \rightarrow eee$ is better by 10^3 because only two weak vertices are needed.

The $\mu \rightarrow eee$ process in part b) also illustrates the mass dependence of the branching ratio. The propogator for the horizontal gauge boson Y^0 will enter the transition rate formula with a factor $(q^2+M^2)^{-2}$. For low momentum transfer, the rate will vary as M^{-4}. The fourth power dependence on an unknown particle mass applies to most predictions; e.g. it is seen in the equation for neutrino masses above. The consequence of so strong a dependence is that a very big improvement in branching ratio is needed for a modest improvement in sensitivity to unknown particles. In spite of such an unfavorable situation, experimentalists have made significant strides to expand the frontiers of knowledge. Current rare-decay experiments[5] are sensitive supersymmetric particles of mass greater than 42 GeV and composite structures of mass greater than 6×10^5 TeV. Experiments under construction will raise these limits substantially. The rate of improvement is also competitive with the rise in accelerator energies as illustrated in Fig. 2. The slope of $\mu \rightarrow e\gamma$

accomplishments is comparable to the exponential rise[6] in beam energy of various proton colliding beam accelerators raised to the inverse fourth power (to include the mass dependence of branching ratios.)

The design of the MEGA experiment calls for a factor of 500 improvement in the branching ratio for $\mu \rightarrow e\gamma$. To accomplish the goal, the design optimizes the requirements of a clean signature for the process, the observation of a large number of decays (high rate capability) with good solid angle and efficiency, sufficient resolution for a background free experiment, a trigger to control the data rates, and a measurable process of known branching ratio to verify the detector performance. The signature for $\mu \rightarrow e\gamma$ is particularly simple and purely kinematic; it is the observation of coincident photons and positrons arising from a common vertex that are back-to-back and each of 52.8 MeV. The known background process is muon radiative decay $\mu \rightarrow e\gamma\nu\bar{\nu}$. There are two major backgrounds for $\mu \rightarrow e\gamma$, the radiative decay and accidental coincidences. The latter comes from two separate muon decays that mock up the kinematic conditions and is the more severe. Both backgrounds are suppressed with good resolution. A comparison of the MEGA design to the best previous experiment[5] shows that MEGA has 70 times the rate capability, one-quarter the solid-angle-efficiency-product, and improved resolutions that eliminate background 50,000 times more effectively.

The experimental layout is shown in Figs. 3 and 4. The apparatus is divided into two concentric spectrometers that are both contained in a large solenoidal magnet. The muon target is centered in the magnet, is a planar ellipse canted at a steep angle to the beam, and is just thick enough to stop the 3×10^7 muons taken from the channel.

The 15 kG magnetic field is sufficient to contain all decay positrons inside the 30 cm radius spectrometer. The momentum of the decay positron is found by measuring the curvature of the helix in the spectrometer with multi-wire proportion chambers (MWPC) and its time is ascertained with plastic scintillators. The positron chambers present only a total of 10^{-3} radiation lengths of material to the particles in the central region. The chamber arrangement involves one chamber that is surrounded by seven smaller chambers. This design keeps the MWPC out of the highest rate region about the target, but gives sufficient tracking for pattern recognition. After less than eight revolutions, the positron hits one of the 200 scintillators before stopping in the lead shielding. The spectrometer resolution should be 0.6% (FWHM) for energy, 0.2 cm for position, 0.6^0 for angle, and 0.5 ns for time.

The decay photon propagates out to a series of four pair spectrometers that measure its kinematic properties. The four spectrometers consist of two layers of 0.025 cm lead converters separated by a MWPC to identify the layer of conversion. The converters surround a barrel of 1 x 5 x 180 cm^3 scintillators for timing. Outside the lead, each layer has three drift chambers to measure the momenta of the electron-positron pair. The resolutions of the spectrometer are expected to be 3% for energy, 10^0 in angle, and 0.5 ns in time. Some background suppression of high energy photons is obtained by looking at low energy positrons that accompany high energy photons from radiative muon decay. These low energy positrons follow the field lines and are detected at the magnet ends by the internal bremsstrahlung veto (IBV) counters.

The electron chambers are cylindrical, with 0.1 cm pitch wires running 132 cm parallel to the symmetry axis. At a half-gap of 0.175 cm, there are cathode foils of 0.0025 cm aluminized mylar. By overpressuring the inside, the foils keep a cylindrical shape to 0.01 cm. Spiral cathode readout is possible by scratching away the aluminum to make stripes. In a planar prototype, the geometry has been checked, with both the anode wires and cathode foils coming on plateau with a 79.5%-CF_4:20%-isobutane:0.5%-isopropyl alcohol gas mixture. Electro-mechanical instabilities need to be prevented by attaching the wires to garlands, and these structures have been fabricated from 0.01 cm nylon filaments attached to the wires with epoxy. Data taken at two angles of incidence have been compared with a Monte Carlo simulation to check the model and the nice results are shown in Fig. 5. A wire winder for cylindrical chambers has been developed that strings two quadrants of a chamber in a few hours. A cylindrical chamber has yet to reach plateau.

Many aspects of the pair spectrometers have been simulated by computer or prototype. Pattern recognition of the spiraling pairs has yielded an algorithm for finding the vertex and the perpendicular momenta. The parallel momenta are still under study. Drift patterns for ions inside the chambers continue to have a simple time to distance relationship even in the presence of a magnetic field. A 180 cm prototype with 0.25 cm pitch planar chamber has come on plateau. The scintillators have been connected to photomultiplier tubes at each end with 300 cm fiber optics light guides to yield 0.6 ns resolution.

MEGA has a staged trigger. The trigger depends on the rapidly falling photon spectrum that implies a 38 MeV energy cut will eliminate all but one in 10^4 muon decays. Such a cut is imposed by demanding a transverse spread of the pair of 16 cm in the scintillators and MWPC's. Data that passes the level one hardware is encoded and stored in FASTBUS latches, time-to-digital converters, and analog-to-digital converters with on-board memories that store a macro-pulse worth of events[7] A schematic of the data acquisition system is given in Fig. 6. The memories are read out as a single block by the General Purpose Master[8] and transferred into a VME microprocessor via the FASTBUS to Branch Bus Connector[9] The microprocessor farm is the Advanced Computer Project from Fermilab[10] There is no level two trigger, but the microprocessors provide the level three cuts by analyzing the positron spectrometer data to find high energy, in-time candidates that point at the photon of the level one trigger. Eventually there will be nearly 200 FASTBUS modules and 32 microprocessors.

This report finds MEGA in the middle of development and construction. Many exciting steps have been taken, but a great deal of work stands between the present and a running experiment. The project is within six months of being on the schedule established at proposal time that calls for first data in 1989. The physics motivation for the measurement remains as strong as ever and keeps the experimenters vigorously pursuing the goal of either finding the $\mu \to e\gamma$ process or setting an upper limit on the branching ratio near 10^{-13}.

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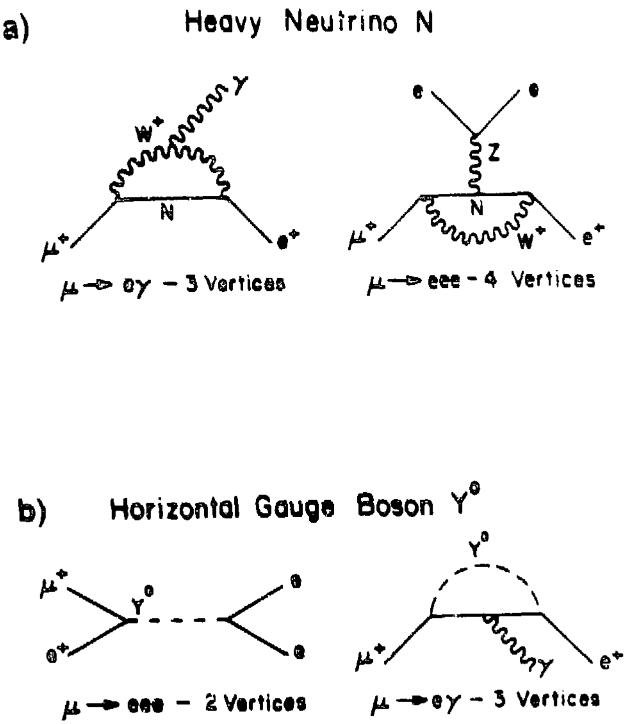

Fig. 1. Feynman diagrams for μ → eγ and μ → eee in models containing a) heavy neutrinos and b) horizontal gauge bosons.

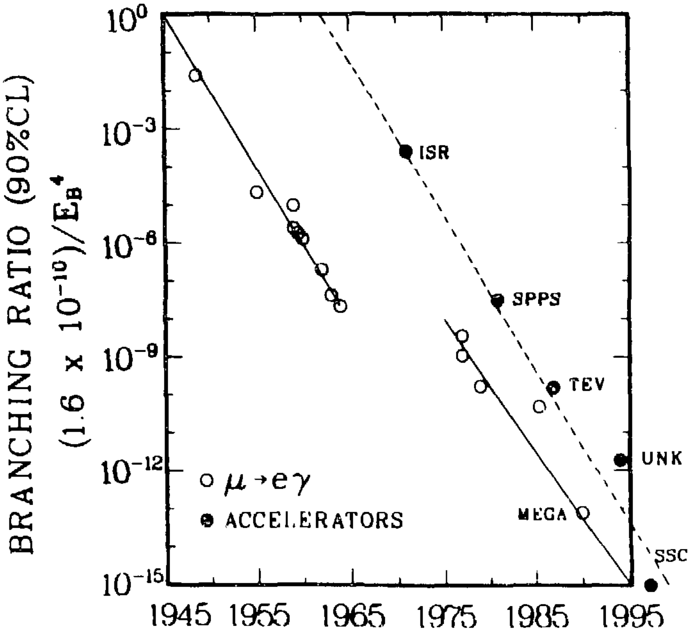

Fig. 2. Improvements in branching ratios for rare decays as a function of time. The solid line in the improvement in μ → eγ, with the break separating investigations at cyclotron laboratories from those at meson factories. The dashed line is the energies E_B of colliding proton beam machines raised to the inverse fourth power.

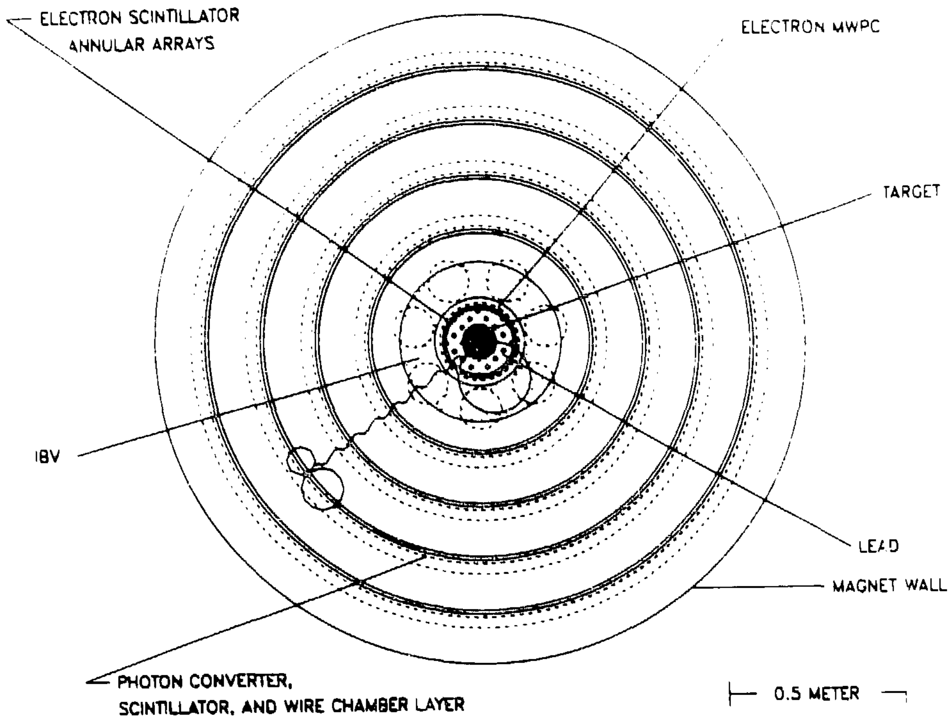

Fig. 3. A view of the MEGA detector configuration viewed along the direction of the beam and the magnetic field.

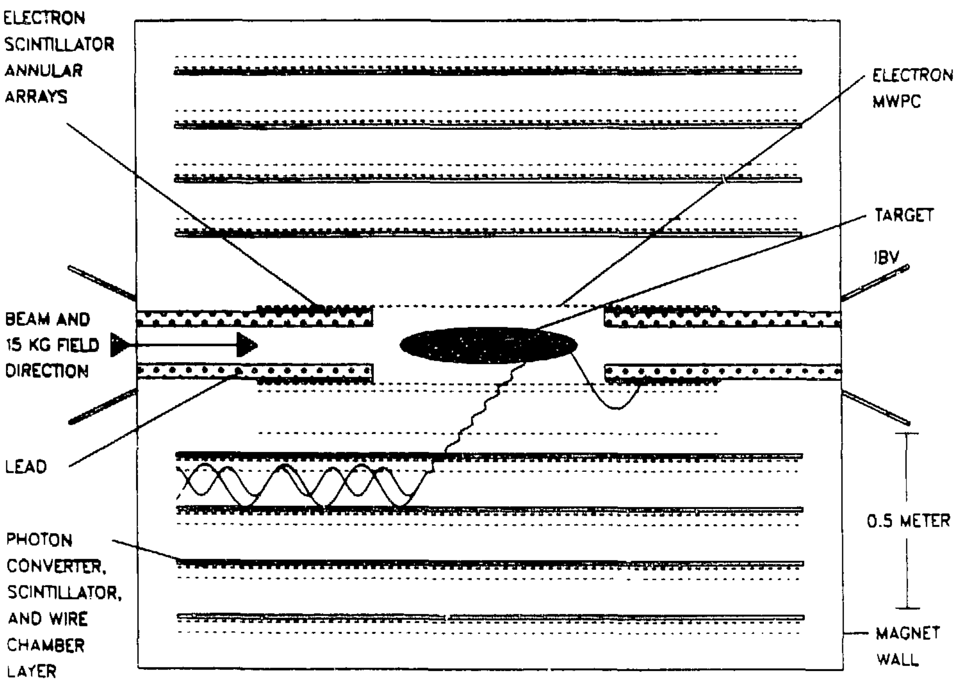

Fig. 4. A sectioned plan view of the MEGA detector.

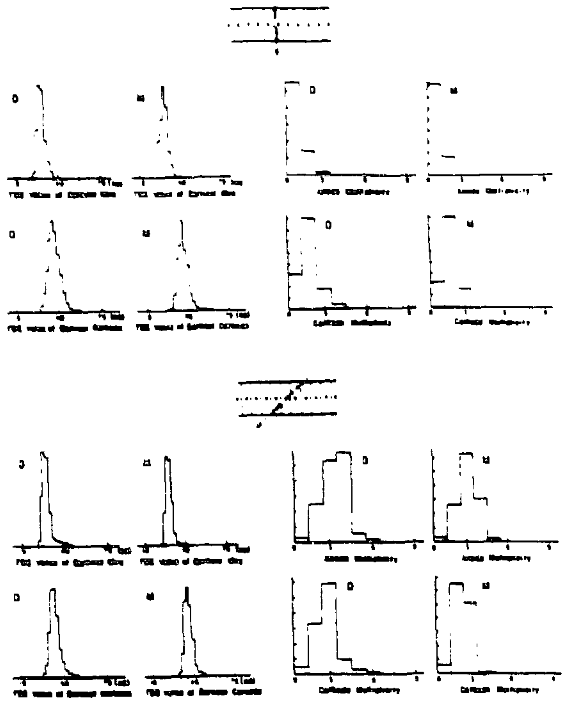

Fig. 5. A comparison between data and Monte Carlo simulation of the time of arrival and multiplicity of pulses from the planar MWPC prototype. The upper half of the figure is for normally incident particles; the lower part is for 45° incidence. The D refers to the data and the M to the Monte Carlo simulation.

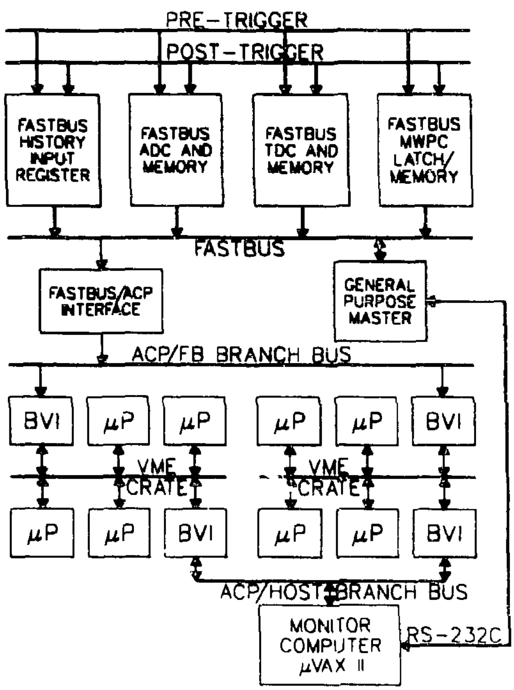

Fig. 6. A schematic of the MEGA data acquisition hardware.

L. Ray
Department of Physics
University of Texas
Austin, Texas 78712

Introduction

Recent years have witnessed a heightened interest in relativistic descriptions of nuclear systems.[1-4] The reason for this activity is primarily due to the startling success provided by Dirac phenomenology[5,6] and the relativistic impulse approximation (RIA) - Dirac equation model[7,8] in quantitatively explaining the intermediate energy proton-nucleus (pA) elastic scattering analyzing power and spin rotation data obtained at the LAMPF - HRS facility, particularly at 500 MeV.[9-11] The key to the recent excitement concerning possible relativistic processes in nuclear physics derives from analyses of pA spin observable measurements at intermediate energies.

While all will agree that Lorentz invariance should, in principle, be incorporated in any correct theoretical description of the nucleus, the expedience and general success afforded by the many-body nonrelativistic (NR) Schrodinger equation approach continue to make it an appealing formalism to work with. After all, since typical particle velocities in nuclei are of order 0.3c or less and because nucleon binding energies and interaction strengths (in Pauli form) are much less than the nucleon mass, one might reasonably expect all of the essential physics to be contained in a NR many-body Schrödinger equation theory. Indeed for many years it appeared that relativistic models in nuclear physics merely added unnecessary complications to the already difficult process of computing nuclear properties and nuclear scattering observables without providing any improvement in the description of experiment. Before 1983 the strongest claim of improvement in the explanation of data by advocates of the relativistic models was the correct prediction of the binding energy and saturation density for infinite nuclear matter,[1,2] two hypothetical quantities which are obtained from a special limit of the semi-empirical mass

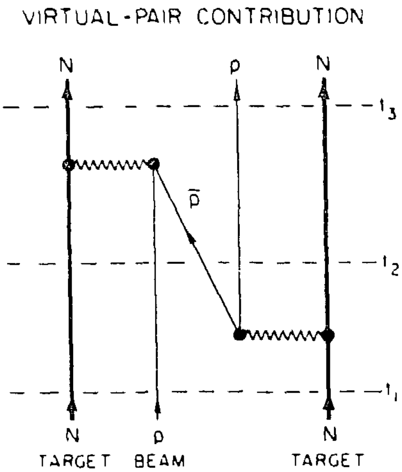

Fig 1. Virtual $N\bar{N}$ pair process involving the beam projectile proton and two target nucleons.

formula and from the interior density of ^{208}Pb. This situation began to change in 1981 with the first measurement of the pA elastic scattering spin rotation parameter at LAMPF[10] which was successfully predicted by Dirac phenomenology[6] and in 1983 with the development and success of the RIA.[7,8]

Before discussing the new relativistic models and their results it is useful to clarify what is meant by a "relativistic process" in a nuclear system. For 800 MeV protons where the incident velocity is 0.84c use of relativistic kinematics is mandatory and has always been employed, even in the NR Schrödinger equation applications.[12] The relativistic effects under discussion here are dynamical and involve intermediate scattering processes in which the projectile nucleon propagates through virtual, negative energy states. This type of process is also referred to as virtual $N\bar{N}$ pair production because of the time ordered form of the accompanying Feynman diagram (see Fig. 1). Formally this reaction mechanism contributes to the scattering process through terms of the form $U^{+-}G^{-}U^{-+}$ where U^{+-} and U^{-+} represent the NN effective interaction which couples positive and negative energy states of the projectile and G^{-} is the Dirac propagator for negative energy states. Clearly if the NN interaction strengths were only a few tens of MeV this term would be insignificant since G^- is of order $(2m)^{-1}$ However, in relativistic meson exchange theory[13] and in the RIA model[7,8] the NN effective interaction strengths are of the order (m/2) (when expressed in Lorentz invariant form[14]), resulting in significant contributions of the virtual $N\bar{N}$ pair processes to the predicted many-body observables. For example, for intermediate energy pA elastic scattering the real, spin-independent and imaginary, spin-orbit optical potentials are affected by large amounts, varying from 50 - 100% of the nonrelativistic impulse approximation (NRIA) values throughout the intermediate energy range [15] The imaginary, spin-independent and real, spin-orbit pA optical potentials are not significantly affected by the virtual $N\bar{N}$ pair terms, however. These results, from Ref. 15, are shown in Figs 2-5 for p + ^{40}Ca where the optical potential volumes per target nucleon for the RIA, NRIA, and Dirac phenomenology are compared.

In this presentation I will briefly mention a few of the key developments in relativistic nuclear physics which have led to the present status, followed by a brief outline of traditional nonrelativistic multiple scattering theory and the RIA - Dirac equation approach. After this I will then discuss the crucial role which experiment has had in guiding the development of relativistic nuclear scattering models with particular emphasis being given to polarization and spin observable measurements. New experiments, designed to further test NR and relativistic theoretical models and to differentiate between alternate relativistic models will also be discussed. Some concluding remarks will be given at the end.

Historical Perspective

Throughout the history of nuclear physics many attempts have been made to apply the principles of relativistic quantum mechanics and relativistic quantum field theory (RQFT) to models of infinite nuclear matter and to the description of nuclear structure.[1] The meson exchange theory of the nucleon-nucleon (NN) interaction of Yukawa[16] utilized covariant equations of motion for the meson fields. From the 1950's through the 1970's numerous investigations of relativistic descriptions of the nucleus were conducted; many of these are discussed in the introductory section of the review article by Serot and Walecka.[1] Recent work in this field includes the quantum

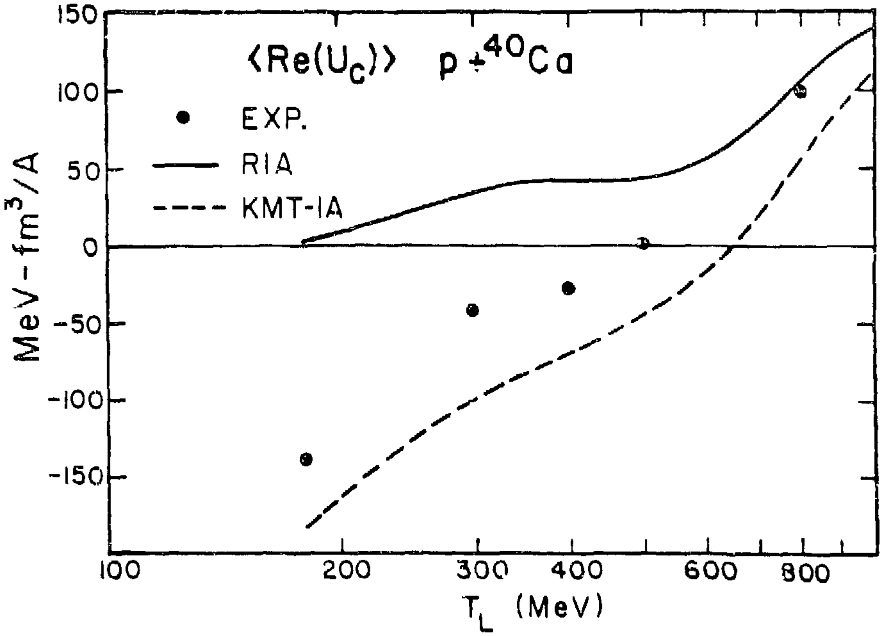

Fig. 2. Volume per nucleon of the real, spin-independent optical potential for p + ^{40}Ca. The dots indicate the results of Dirac phenomenological fits to data (from Refs. 5 and 6). The RIA and NRIA predictions are shown by the solid and dashed curves, respectively (from Ref. 15).

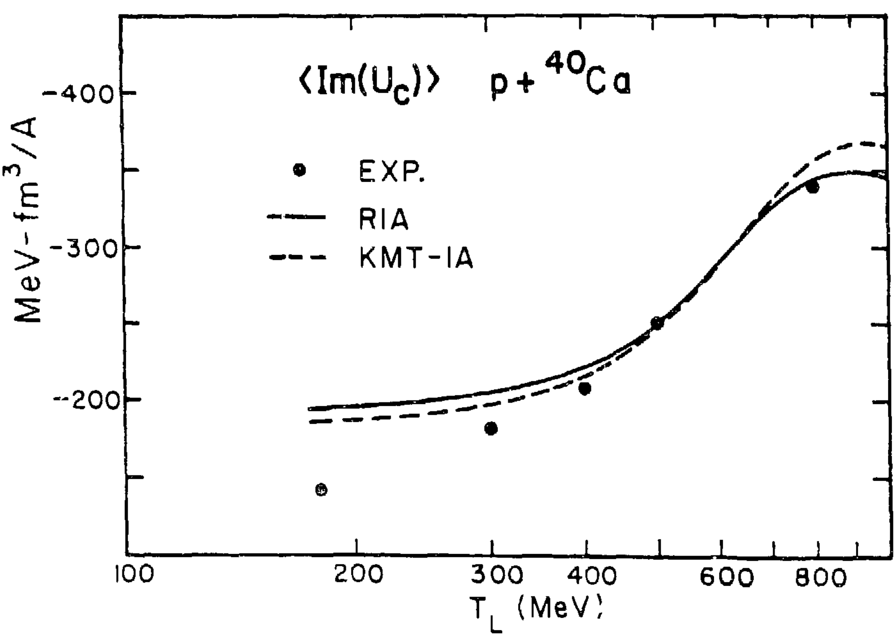

Fig. 3. Same as Fig. 2, except for the imaginary, spin-independent optical potential.

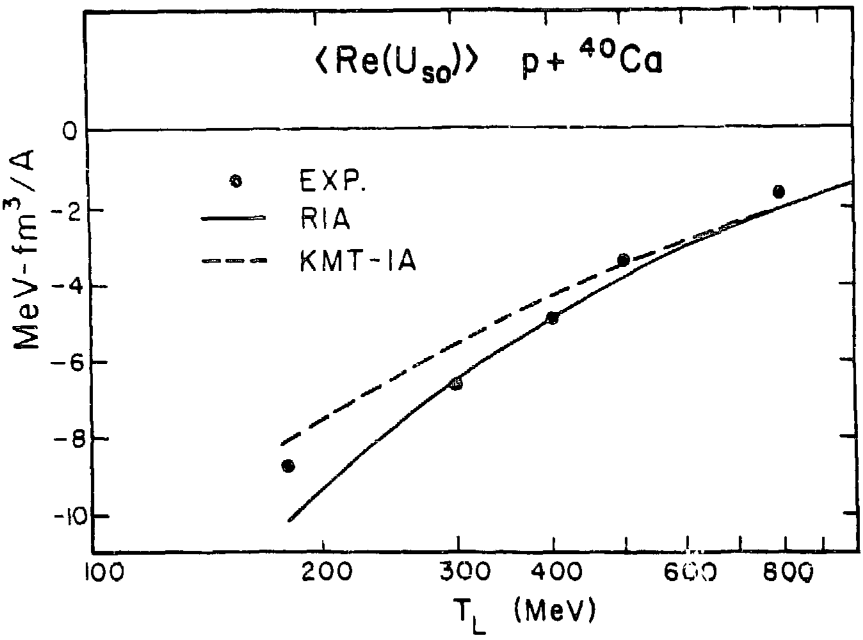

Fig. 4. Same as Fig. 2, except for the real, spin-orbit optical potential.

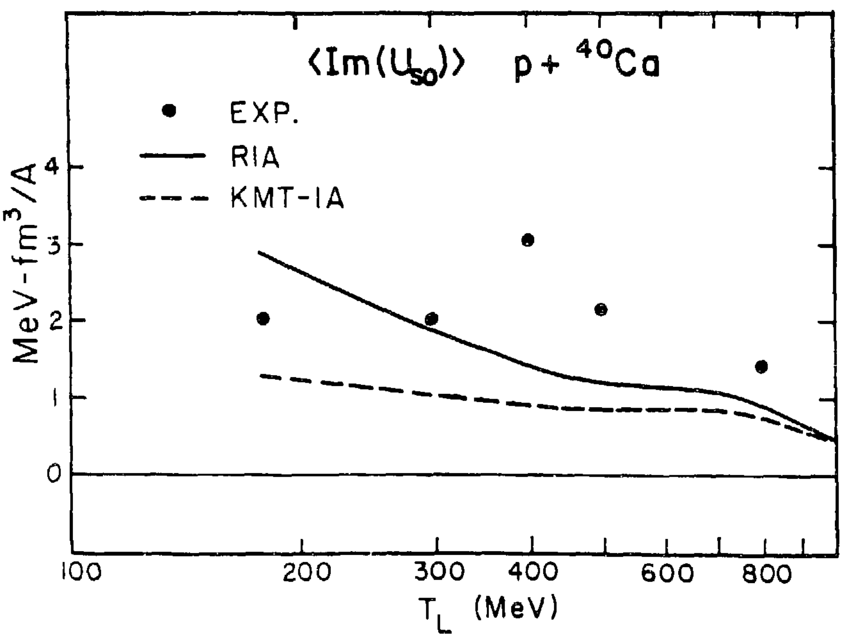

Fig. 5. Same as Fig. 2, except for the imaginary, spin-orbit optical potential.

hadrodynamic models QHD-I and QHD-II of Walecka, Serot and Horowitz (Refs 1 and 17) for infinite nuclear matter and finite nuclei and an important extension of nonrelativistic (NR) Brueckner theory, the so-called relativistic Brueckner-Hartree-Fock model, being developed by Shakin and collaborators[2] A common feature and a crucial aspect of these models which was pointed out by Miller and Green[18] are the large scalar and time-like vector binding potentials which essentially cancel to yield a fairly weak central, spin-independent attractive interaction but which add to produce a strong nuclear spin-orbit force of just the correct size

During the 1970's and early 1980's Clark and co-workers[5,6] achieved remarkable success in obtaining a simple, phenomenological description of low and medium energy nucleon-nucleus elastic scattering data, including both differential cross section and polarization measurements using the Dirac equation to describe the motion of the projectile nucleon. The most significant outcome of this work was the demonstrated ability of the Dirac phenomenology to predict, with quantitative accuracy, the spin rotation parameter, $Q(\vartheta)$, a quantity proportional to the amount by which the projectile polarization vector rotates in the scattering plane during the reaction.[19] (Proton beams polarized in the scattering plane and measurement of the outgoing proton polarization vector in the plane of scattering are required in the determination of Q) The spin rotation predictions of the Dirac phenomenology were available prior to the first measurement of Q in 1981 (Ref 10) and the spectacular agreement between these predictions and the new data led workers in the field to recognize the value of a covariant description of proton-nucleus scattering The success of Dirac phenomenology combined with a Lorentz invariant form of the NN scattering amplitude[14] led in 1983 to the development of the relativistic impulse approximation - Dirac equation model for nucleon-nucleus scattering.[7,8] This model is, so far, the only one which provides a successful theoretical description of intermediate energy proton-nucleus elastic scattering polarization data above 400 MeV and spin rotation data at all energies, traditional nonrelativistic multiple scattering models with no free parameters have utterly failed to describe these types of data[9]

Prior to 1983 the majority of microscopic theoretical calculations performed and used in the analysis of nuclear reaction data involved approximate solutions of the many-body Schrodinger equation with static, two-body interaction potentials between the constituent nucleons For the discussion here I will be primarily interested in nucleon induced scattering for which the NR many-body equation of motion is,

$$[T_p + H_A + \sum_{i=1}^{A} v_{pi}]\Psi_{pA} = E\Psi_{pA} \tag{1}$$

where $T_p = -\hbar^2\nabla_p^2/(2\mu)$ is the projectile nucleon kinetic energy operator, μ is the reduced mass, H_A is the target nucleon Hamiltonian, v_{pi} is the two-body interaction between the projectile and the i^{th} target nucleon, and Ψ_{pA} is the projectile-target nucleus many-body wave function. A number of schemes exist in the literature for the approximate solution of Eq. (1) when A, the number of target nucleons, is large. The original Watson multiple scattering series[20] and the reformulation given by Kerman, McManus and Thaler (KMT)[21] are particularly useful at intermediate energies. For example, in the Watson and KMT approaches antisymmetrization between the projectile nucleon and the target constituent nucleons is neglected and the scattering transition operator is expanded in terms of an optical potential The lowest order expression for the Watson optical potential is given by

$$U^{opt}_{f,i} = \sum_{i=1}^{A} \langle \Phi_f | t_{pi} | \Phi_i \rangle + \cdots \tag{2}$$

where Φ_i and Φ_f represent the initial and final target wave functions, respectively, and t_{pi} is given by

$$t_{pi} = v_{pi} + v_{pi} GQ t_{pi} . \tag{3}$$

The t-matrix, t_{pi}, is still a very complicated many-body operator since it includes the full many-body propagator G and the target excited state projection operator Q. The utility of the Watson and KMT formalisms is that the optical potential series implied in Eq. (2) converges rapidly[12] and t_{pi} can be readily approximated with either the free NN t-matrix (i.e., the impulse approximation (IA)) or with two-body t-matrices in which Pauli blocking, Fermi motion averaging and target nucleon binding effects are estimated using an infinite medium and the local density approximation (LDA).

This lowest order form for the pA optical potential yields the well known "$t\rho$" form, so-called because of the convolution of two-body effective interaction t-matrices with one body target densities. In the NR formalism the two-body t-matrix is expressed in Pauli spin matrix form and is easily related to the usual NN elastic scattering amplitude, f, given by,

$$f = A + B\sigma_{1n}\sigma_{2n} + C(\sigma_{1n} + \sigma_{2n}) + D\sigma_{1q}\sigma_{2q} + E\sigma_{1p}\sigma_{2p}, \tag{4}$$

where $\sigma_{ix} = \vec{\sigma}_i \cdot \hat{x}$, $i = 1,2$ denotes nucleons 1 and 2, and the usual NN center-of-momentum (c. m.) coordinate system is defined by the unit vectors $(\hat{n},\hat{q},\hat{p})$. The amplitudes in Eq. (4) are readily obtained from analyses of NN elastic scattering data.

At energies of a few hundred MeV the NR approach is reasonably satisfactory provided Fermi motion averaging, Pauli blocking, binding energy corrections, exchange effects, and other nonlocalities are treated realistically. The most successful model of this type is the density dependent G-matrix effective interaction of von Geramb[22] which has been extensively applied to pA scattering data below 400 MeV.

At 800 MeV where most of the HRS data exists, the KMT-NRIA approach is satisfactory[23,24] and theoretical corrections to the lowest order "$t\rho$" calculation are small.[12] However, at proton energies between 400 and 800 MeV the KMT-NRIA approach dramatically fails to describe pA polarization data.[9,25] At present theoretical activity in the area of NR scattering theory is concerned with calculating realistic off-shell effects at low energies[26,27] and with extending the estimates of medium effects to energies well above 400 MeV.[28]

In principle, a relativistic formulation for the many nucleon system containing one continuum nucleon and many bound nucleons could be based on a RQFT approach analogous to QHD-II, such a model has yet to be developed however. Eventually a formulation based on QCD might even become feasible. In the mean time calculations done so far in which relativistic dynamics are included have been based on a semi-relativistic, many-body Hamiltonian approach, analogous to the NR Watson and KMT formulations.[25]

The model in Ref. 25 begins with a many-body equation of motion given by,

$$[\vec{\alpha}\cdot\vec{p} + \beta m + \beta \sum_{i=1}^{A} v_{pi} + H_A]\Psi_{pA} = E\Psi_{pA} \qquad (5)$$

where $\vec{\alpha}$, β are the 4 x 4 Dirac matrices, $\vec{p}$ is the projectile momentum operator, m is the projectile (proton) mass, H_A is the NR many-body target nucleus Hamiltonian, and Ψ_{pA} is a factorized product of the 4-component projectile wave function times the NR many-body target wave function. Formal solution of Eq. (5) proceeds analogously to that for NR multiple scattering theory where in the final, reduced form the proton elastic scattering wave function, φ_p, is obtained by solving the one-body Dirac equation,

$$(\vec{\alpha}\cdot\vec{p} + \beta m + \beta U_{Rel})\varphi_p = E_p\varphi_p. \qquad (6)$$

In lowest order the relativistic pA optical potential, U_{Rel}, is given by

$$U_{Rel} = \sum_{i=1}^{A} \langle\tilde{\Phi}_{gs}|T_{pi}|\tilde{\Phi}_{gs}\rangle, \qquad (7)$$

where $\tilde{\Phi}_{gs}$ is the 4-component representation of the target nucleus ground state wave function and T_{pi} is the 4 x 4 matrix form for the NN t-matrix.

The relativistic projectile-nucleon t-matrix, T_{pi}, is related by kinematic quantities to the Lorentz invariant NN amplitude, $\hat{F}$, according to[29]

$$T_{pi} = -2\pi \frac{(\hbar c)^2}{m} \frac{P_{LAB}}{P_{NNcm}} \hat{F}_{pi} \qquad (8)$$

where P_{LAB} and P_{NNcm} are the incident nucleon laboratory and NN c. m. system momenta, respectively. Three forms for the Lorentz invariant NN amplitude are in current usage, including the original RIA prescription,[7,8] the one-meson exchange Feynman diagram model of Horowitz,[30] and the covariant Bethe-Salpeter meson exchange model of Tjon and Wallace [31]

In the RIA prescription $\hat{F}_{pi}$ is assumed to be of the following, local form.[14]

$$\hat{F}_{pi} = F_S + F_P\, \gamma_p^5 \gamma_i^5 + F_V\, \gamma_p^{\mu} \gamma_{i\mu} + F_A\, \gamma_p^5 \gamma_p^{\mu} \gamma_i^5 \gamma_{i\mu} + F_T\, \sigma_p^{\mu\nu} \sigma_{i\mu\nu} \tag{9}$$

where γ^5, γ_{μ} and $\sigma^{\mu\nu}$ are the usual Lorentz invariant 4 × 4 matrices. The five invariant amplitudes are determined by requiring that for specific initial and final NN spin configurations the positive energy transition probability amplitude for $\hat{F}$ be identical to that computed for the 2 × 2 Pauli spin matrix representation. For a given total NN energy and momentum transfer it is therefore required that

$$\bar{u}_{s_1'}(\vec{k}')\bar{u}_{s_2'}(-\vec{k}')\ \hat{F}\ u_{s_1}(\vec{k})u_{s_2}(-\vec{k}) = \chi^{\dagger}_{s_1'}\chi^{\dagger}_{s_2'}\ f\ \chi_{s_1}\chi_{s_2} \tag{10}$$

where $\vec{k}(\vec{k}')$ is the initial (final) NN c. m. relative momentum, $u_s(\vec{k})$ is a positive energy 4-component Dirac spinor, χ is a 2-component Pauli spinor, and the free NN amplitudes, f, are as defined in Eq. (4).

Horowitz[30] has derived an alternate form for $\hat{F}$ based on covariant one-meson exchange Feynman diagrams with direct and exchange diagrams explicitly included. Physical meson exchanges with realistic ranges are assumed where the coupling constants are made complex and varied to fit the NN scattering amplitudes. The pion-nucleon coupling is assumed to be pseudovector (i.e., $\gamma^5 \not{q}/2m$, $\not{q} = (k^{\mu}-k^{\mu\prime})\gamma_{\mu}$) rather than pseudoscalar (γ^5) as implied in the original RIA prescription. Although the positive energy projections of the Horowitz amplitude and the RIA are identical [due to the constraint represented by Eq. (10)], the negative energy projections differ and hence the pA predictions differ.

Tjon and Wallace, in a series of articles,[31] have used the covariant NN meson exchange model of Van Faassen and Tjon[32] to calculate all possible positive and negative energy projections of the NN invariant operator $\hat{F}$. Again, the positive energy projections are constrained as in Eq. (10), however, the negative energy projections differ, both from that prescribed by the RIA and from that predicted by Horowitz.[30] Predicted pA elastic scattering observables also differ somewhat, both from that of the RIA model and from that of Horowitz.

A variety of forms for $\tilde{\Phi}_{gs}$ have been used. Conventional NR models (in 4-component representation) or the RQFT QHD-II wave functions of Horowitz and Serot[17] have been used. NR shell model forms have also been used in calculations of inelastic scattering where lower component strength must be assigned by some prescription.[33]

For elastic scattering from $J^{\pi} = 0^{+}$ targets only the scalar, the time-like vector, and the (very small) tensor terms of the full set of NN amplitudes in Eq. (9) contribute to the optical potential. For this case $U_{Rel}(r)$ becomes,

$$U_{Rel}(r) = U_S(r) + \gamma^0 U_V(r) - 2i\vec{\alpha}\cdot\hat{r}U_T(r). \tag{11}$$

For local NN t-matrices, U_S, U_V, and U_T are obtained by convolution of the scalar, vector and tensor densities of the target with the corresponding NN amplitudes. These three target densities are given in terms of the single particle wave functions of the independent particle model according to the following.[17]

$$\rho_S(r) = \sum_{n\ell j} \frac{2j+1}{4\pi} \left(|\varphi_{n\ell j}|^2 - |\lambda_{n\ell j}|^2\right), \tag{12a}$$

$$\rho_V(r) = \sum_{n\ell j} \frac{2j+1}{4\pi} \left(|\varphi_{n\ell j}|^2 + |\lambda_{n\ell j}|^2\right), \tag{12b}$$

$$\rho_T(r) = 2 \sum_{n\ell j} \frac{2j+1}{4\pi} \varphi_{n\ell j}\lambda_{n\ell j}, \tag{12c}$$

where $\varphi_{n\ell j}$ and $\lambda_{n\ell j}$ are the upper and lower components of the (n,ℓ,j) sub-shell wave function, respectively. The relativistic single particle wave function is given by

$$u_{n\ell j\mu}(\vec{r}) = \begin{pmatrix} \varphi_{n\ell j}(r) \\ -i\vec{\sigma}\cdot\hat{r}\ \lambda_{n\ell j}(r) \end{pmatrix} \mathcal{Y}_{\ell j}^{\mu}(\hat{r}) = \begin{pmatrix} \varphi_{n\ell j}(r)\ \mathcal{Y}_{\ell j}^{\mu}(\hat{r}) \\ i\lambda_{n\ell j}(r)\ \mathcal{Y}_{\tilde{\ell} j}^{\mu}(\hat{r}) \end{pmatrix} \tag{13}$$

where $\mathcal{Y}_{\ell j}^{\mu}(\hat{r})$ is the usual spin angle function and in the second expression $\tilde{\ell} = \ell \pm 1$ whenever $j = \ell \pm 1/2$.

To emphasize the dependence of pA predictions on the negative energy projection of $\hat{F}$ consider the Lippmann-Schwinger operator solution of Eq. (6),[25,34]

$$T_{00} = U_{Rel} + U_{Rel} PGT_{00}. \tag{14}$$

where subscripts (00) denote the target initially and finally in the ground state and P projects the target ground state in intermediate scattering states. The Dirac propagator, G, includes both positive and negative energy intermediate scattering states of the projectile. In order to evaluate Eq. (14) for a positive energy incoming and outgoing nucleon we must solve the following set of coupled integral equations,

$$T_{00}^{++} = U_{Rel}^{++} + U_{Rel}^{+-} PG^{-} PT_{00}^{-+} + U_{Rel}^{++} PG^{+} PT_{00}^{++} \tag{15a}$$

$$T_{00}^{-+} = U_{Rel}^{-+} + U_{Rel}^{--} PG^{-} PT_{00}^{-+} + U_{Rel}^{-+} PG^{+} PT_{00}^{++} \tag{15b}$$

where $T_{00}^{\pm\pm} \equiv \Lambda_{\pm} T_{00} \Lambda_{\pm}$, $U_{Rel}^{\pm\pm} \equiv \Lambda_{\pm} U_{Rel} \Lambda_{\pm}$, $G^{\pm} = \Lambda_{\pm} G \Lambda_{\pm}$, and $\Lambda_{\pm}$ projects ($\pm$) energy projectile states.[35] Solving for T_{00}^{++} yields,

$$T_{00}^{++} = U_{eff}^{++} + U_{eff}^{++} G^{+} T_{00}^{++} \tag{16}$$

where

$$U_{eff}^{++} = U_{Rel}^{++} + U_{Rel}^{+-} \frac{1}{(G^{-})^{-1} - U_{Rel}^{--}} U_{Rel}^{-+}. \tag{17}$$

The first term in Eq (17) roughly corresponds to the NR-KMT optical potential (except in a 4×4 matrix representation) while intermediate propagation of negative energy states of the projectile is provided by the second term in Eq. (17). For example, terms in $\hat{F}$ which contribute to the matrix element $<\bar{u}_1 \bar{u}_2 |\hat{F}| v_1 u_2>$ (where v is a negative energy Dirac spinor) but which vanish for $<\bar{u}_1 \bar{u}_2 |\hat{F}| u_1 u_2>$, therefore making no contribution in Eq (10), can affect pA scattering predictions by contributing to the second term in the effective optical potential in Eq. (17). Hynes et al[34] have explicitly shown that pA observables computed from Eq. (16) where $U^{++}_{eff} \approx U^{++}_{Rel}$ only is used agree essentially with NRIA results, and that the principal difference between NRIA and RIA - Dirac equation predictions originates with the intermediate propagation of virtual negative energy states of the projectile as given in the second term in Eq. (17).

It is therefore important to test the different relativistic models by comparing each of their predictions with data. This is the only empirical means available for constraining the choice of form for $\hat{F}$ and is the best method for providing guidance for future theoretical work.

Role of Experiment in Relativistic Nuclear Physics

The final arbiter in the competition between the traditional nonrelativistic many-body theories and the various relativistic models will, of course, have to be experiment. In this section I will discuss the results of investigations of pA elastic scattering and other types of experiments intended to search for evidence of relativistic dynamical processes in nuclear systems It should be remembered that what one actually does is test for deficiencies in the NR many-body models and then determine whether or not the data can be explained by introducing relativistic dynamics. Such procedures do not prove the existence of virtual $N\bar{N}$ pair processes but they can, at least, demonstrate the existence of physical processes not accounted for in NR many-body models and provide valuable tests of the only theoretical alternative presently available.

In principle, one could look for direct evidence of relativistic effects in NN scattering. The lack of knowledge of the short range behavior of the NN interaction, however, makes futile such efforts. The next simplest system for investigation would be the three body system or p + d elastic scattering.

Bleszynski and collaborators[36] have shown the inability of NR scattering theory to account for the medium energy proton polarization measurements. Relativistic effects are significant for this system and work is in progress to try and explain the LAMPF p + d proton polarization data.[37] The analysis of proton elastic scattering data from the deuteron and other very light targets is fairly difficult owing to the large contribution of NN double spin flip amplitudes and significant dependence on details of the target nucleus wave function. The description of proton scattering from A>>1 nuclei is actually simpler than that for small A nuclei since target nucleon spin effects tend to average out to zero and correlation effects become less important relative to the one-body density contribution. Thus proton scattering from heavy nuclei is probably the best type of experiment to conduct with respect to searches for physical processes not included in NR theories. For purposes of this discussion I will therefore consider only proton induced reactions on A>>1 nuclei.

Consider initially pA elastic scattering at energies below the normal LAMPF energy range. For few hundred MeV pA scattering the NR G-matrix, density dependent interaction model of von Geramb[22] provides high quality descriptions of pA elastic scattering differential cross sections and analyzing power data. Nonlocality and off-shell effects are small[27] (with the exception of two-body exchange effects which are routinely included at these energies), as are correlation,[12] isobar[28] and other multiple scattering corrections. Although practitioners in the NR theory of low energy pA elastic scattering continue to implement improvements in their calculations, the present results seem to be more or less converged. Thus it is very significant that these NR calculations fail to describe[38,39] the recently obtained 290 MeV p + ^{208}Pb forward angle spin rotation data.[40] Both the NRIA and NR density dependent calculations disagree with the data by many standard deviations at forward angles from 5° - 15° c. m. On the other hand, the RIA[38] (at forward angles) and the Horowitz predictions[39] quantitatively reproduce these data.

Below 400 MeV the RIA model is not satisfactory, particularly with respect to differential cross sections.[25,41] However, when the pseudovector invariant form is used together with explicit treatment of NN exchange the Horowitz model[30,39] (including Pauli blocking) and the Tjon and Wallace model[31] (including vacuum polarization corrections to the target nucleus scalar density, Ref. 42) achieve an accurate description of all the pA elastic scattering data. The inconsistency between the various relativistic calculations with respect to medium modifications and vacuum polarization corrections makes it difficult to identify and compare the predicted effects due to relativistic dynamics in each type of model. Much development work is required of the new relativistic models in order to achieve a standard "bench mark" calculation which will allow consistent comparisons between the models and with data and which will permit clear identification of relativistic effects. However, the critical role played by the forward angle spin rotation data provides impetus for further experimental work of this type.

At energies greater than 400 MeV the RIA and Tjon and Wallace predictions are very similar and are in very good overall agreement with data.[25,31] Problems exist, however, at 800 MeV, with respect to the very light mass targets (^{12}C and ^{16}O) and for heavy targets such as ^{208}Pb (Ref. 24). For light nuclei the differential cross section predictions of the relativistic models are too small in overall magnitude and the spin observable predictions display structure which is too sharp compared with the data.[24] For p + ^{208}Pb the differential cross section predictions are too large whereas the analyzing power predictions have too little structure. This mass dependence problem at the higher energies (it is not apparent at 500 MeV) is currently a subject of interest.

A few sets of pA elastic scattering data at higher energies greater than 1 GeV would be quite useful in testing the convergence of the relativistic and NR models which one would expect to occur owing to the increased absorption and weaker spin-orbit interaction at the higher energies.

Before leaving the subject of pA elastic scattering from even-even targets I will briefly mention some recent calculations[43] which demonstrate considerable sensitivity in the 500 MeV forward angle differential cross section predictions to relativistic versus NR dynamics and to differences between various relativistic models. Forward angle $d\sigma/d\Omega$ predictions for 500 MeV p + ^{40}Ca and ^{208}Pb from 1^o to 5^o [the Coulomb nuclear interference (CNI) region] display 15 – 25% differences in magnitude between the RIA and NRIA as shown in Fig. 6. The uncertainty in the theoretical predictions due to errors in the input ingredients required in the calculations and due to inaccuracies in the estimates of corrections is about ±2% – ±6%. Comparison with high quality data would therefore provide an unambiguous test of relativistic versus nonrelativistic models. Furthermore the RIA and Tjon and Wallace models differ by 15% in the predicted differential cross section

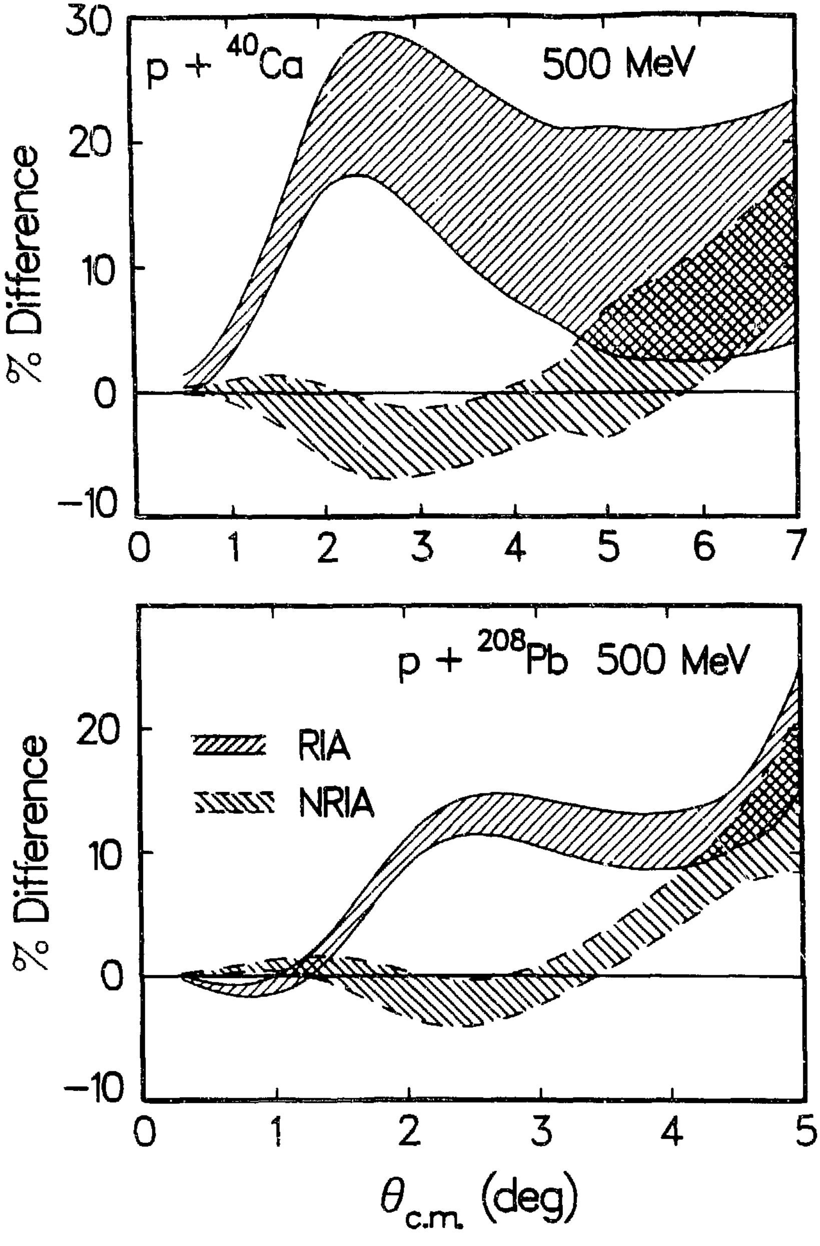

Fig. 6. Uncertainty bands for the forward angle differential cross sections for 500 MeV p + ^{40}Ca and ^{208}Pb from the standard NRIA (shaded bands between the dashed curves) and RIA (shaded bands between the solid curves) models described in the text (from Ref. 43). The quantities shown are percent differences with respect to the NRIA calculation using densities fixed by (e,e) measurements and Hartree-Fock predictions as discussed in Ref. 25. The errors are applied to the $|\chi|^2$ minimized NRIA and RIA fits (neutron surface geometry adjusted to fit differential cross section data as discussed in Ref. 25).

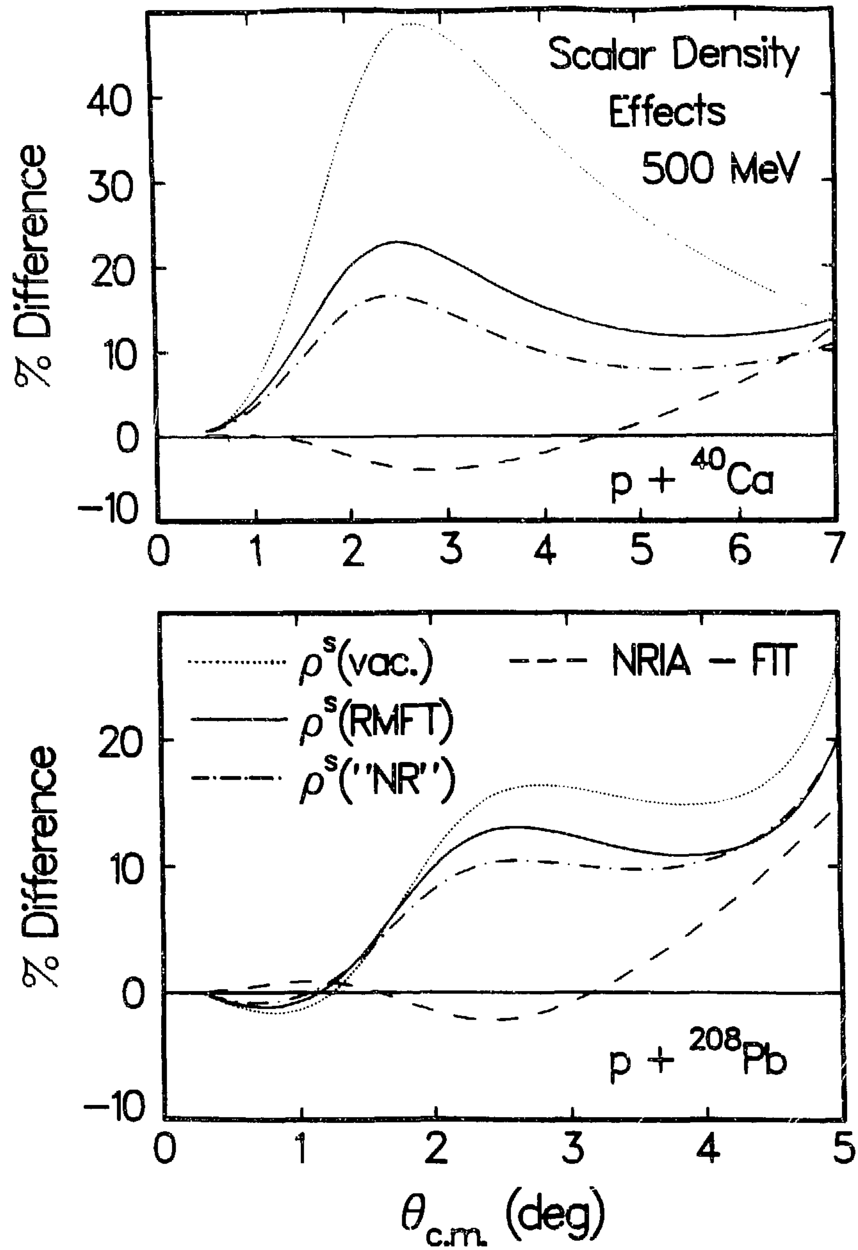

Fig. 7. Percent differences for forward angle differential cross sections for 500 MeV p + ^{40}Ca and ^{208}Pb of the NRIA fit (dashed curves) and RIA fits assuming RMFT scalar densities (solid curves), "nonrelativistic" scalar densities (dashed-dotted curves), and vacuum polarization corrected scalar densities (Ref. 42) (dotted curves) as discussed in the text (from Ref. 43). The percent differences are with respect to the fixed neutron density NRIA result.

magnitudes at 2.5° c.m. (for ^{40}Ca at 500 MeV) and reasonable variations in the scalar density result in about 30% effects (for ^{40}Ca at 500 MeV in this same angular region) as shown in Fig. 7. A proposal to accurately measure (to ~ ± 1%) the absolute normalization of the 500 MeV p + ^{40}Ca and ^{208}Pb differential cross sections in the CNI region is currently being planned for the HRS.[44] Data of this accuracy will provide an important constraint on the developing relativistic models.

Proton induced inelastic scattering to strong, low-lying collective states would not be expected to yield substantially different information regarding relativistic processes than can already be obtained through analyses of elastic scattering since the same isoscalar, scalar and time-like vector interactions drive both reactions and each is sensitive to roughly the same low Fourie components of the NN interaction and density. Comparisons of relativistic and NR predictions for 500 MeV (p,p′) spin observable data demonstrate considerable preference for the relativistic models in much the same manner as is seen in elastic scattering (see Fig. 1 of Ref. 45).

In a recent analysis[46] of 500 MeV (p,p′) data it was found that the predicted transitions to strong collective states are sensitive to shape and magnitude differences between phase equivalent optical potentials determined for the elastic channel. Analyses of high quality (p,p′) data for collective states may prove useful in further testing relativistic and NR optical potentials.

Theoretical predictions for proton induced non-natural parity transitions are quite sensitive to relativistic effects for both the projectile and target, to medium modifications, and to the treatment of NN exchange processes.[33] The latter two complications arise primarily at low energies. Shepard and collaborators[33] have compared relativistic distorted wave impulse approximation predictions with 150 and 400 MeV polarization data for the $^{12}C(p,p')^{12}C^*$(12.71 MeV, 1^+ T=0) and $^{12}C(p,p')^{12}C^*$(15.11 MeV, 1^+ T=1) transitions. NR calculations, with and without medium modifications are compared with relativistic distorted wave calculations in Fig. 6 of Ref. 33 (see the last article listed) for the polarization combination $(P - A_y)$ and for the spin flip probability. Although these results do not clearly prefer one or the other models they do demonstrate significant sensitivity to relativistic processes in certain spin observables for this (p,p′) transition. Comparison between theory and data at higher energies (in the

LAMPF energy range) would facilitate studies of relativistic processes since the complications due to exchange and medium effects would be minimized.

Analyzing power and spin depolarization (D_{ij}) measurements for intermediate energy proton induced quasielastic scattering might also prove to be a fertile area for investigating relativistic effects. Horowitz <u>et al.</u>[47] have shown that significant changes in the predicted analyzing power and D_{ij} values for the quasielastic region of the (p,p′) excitation spectrum occur whenever relativistic enhancement of the projectile and target nucleon lower components is included. Improved descriptions of the 500 MeV ^{208}Pb(p,p′) and ^{40}Ca(p,p′) analyzing power and D_{NN} measurements result when relativistic effects are included, however the fits to D_{SS} and D_{LL} are made worse. The predictions from Ref. 47 for D_{SL} at the quasielastic peak are generally in agreement with the data and are not affected by relativistic processes.

In the remainder of this presentation I will discuss purely computational results for which no corresponding data exist at present, but which are related to two important development programs at LAMPF, these being the polarized ^{13}C target[48] and the neutron time of flight (NTOF) facility.

The importance of proton polarization measurements in studies of projectile relativistic effects in pA reactions suggests that similar theoretical analyses of polarization measurements involving the spins of the target nucleons may reveal information concerning relativistic dynamics in ordinary bound nuclei. Such was the motivation for the analyses of the Colorado group[33] of spin observable data for (p,p′) spin-flip transitions. In order to study target nucleon spin flip contributions in the <u>elastic channel</u> odd nuclear targets must be used. Estimates based on the RIA - distorted wave Born approximation (DWBA) model reveal that certain spin observables for polarized odd nuclei (specifically ^{13}C) are quite sensitive to relativistic dynamics in the bound states of nuclei and to the Lorentz form of the NN effective interaction.[49-52] In the following I will briefly discuss these calculations and summarize the results.

The calculations of Refs. 50 and 51 utilize the RIA - DWBA scattering model. The p + ^{13}C elastic scattering amplitude is given by

$$f_{m_s'\mu',m_s\mu}(\vec{k},\vec{k}') = f^{core}_{m_s'm_s}(\vec{k},\vec{k}')\delta_{\mu'\mu} - \frac{m}{2\pi(\hbar c)^2}\langle\chi^{(-)}_{c,\vec{k}'m_s'}|U^{sp}_{\mu',\mu}|\chi^{(+)}_{c,\vec{k}m_s}\rangle, \tag{18}$$

where f^{core} is the exact RIA scattering amplitude from the 12 nucleon core, m is the proton mass, $(m_s,\vec{k})$ $[(m_s',\vec{k}')]$ are the initial [final] spin projection and momentum of the projectile, χ_c is the relativistic distorted wave function for the p + 12 core nucleons only, and $U^{sp}_{\mu',\mu}$ is the $1p_{1/2}$ neutron portion of the p + ^{13}C RIA optical potential given by

$$U^{sp}_{\mu',\mu}(\vec{r}) = \int d^3r'\ \bar{u}_{1p_{1/2}\mu'}(\vec{r}')\ t_{pn}(|\vec{r}-\vec{r}'|)\ u_{1p_{1/2}\mu}(\vec{r}'). \tag{19}$$

In Eq. (19) $u_{1p_{1/2}\mu}(\vec{r})$ is the valence nucleon wave function with total angular momentum projection μ given in Eq. (13). Calculations were performed in Refs. 50 and 51 by introducing partial wave expansions for χ_c and a multipole expansion for t_{pn}. The assumption of the pseudovector invariant form requires that the matrix elements of $F_P\gamma_1^5\gamma_2^5$ in the NN Lorentz invariant interaction be modified by the following terms, $(1 + U_S/m)$ and $(1 + U^{core}_{S,opt}/m)$, where U_S and $U^{core}_{S,opt}$ are the scalar portions of the Dirac single particle binding potential used to generate $u_{1p_{1/2}}(r)$ and the scalar part of the p + 12 nucleon RIA core optical potential used to generate χ_c.

The assumption that the $J^\pi = 0^+$ 12 nucleon core contributes only to the scalar and time-like vector portion of the p + ^{13}C optical potential (plus a small tensor contribution) is not justified in light of recent considerations of isoscalar magnetic moments in Dirac-Hartree models of odd nuclei.[53,54] The so-called "backflow" response of the 12 core nucleons to the presence of a single odd neutron causes a contribution to the total isoscalar three-vector current which partially cancels the $1p_{1/2}$ neutron portion of this current. In fact, based on calculations of this effect in nuclear matter at zero momentum transfer, the core "backflow" cancels completely the enhancement of the isoscalar three-vector current arising from the increased strength of $\lambda_{1p_{1/2}}(r)$ caused by the strong, Dirac-Hartree binding potentials. Thus, at

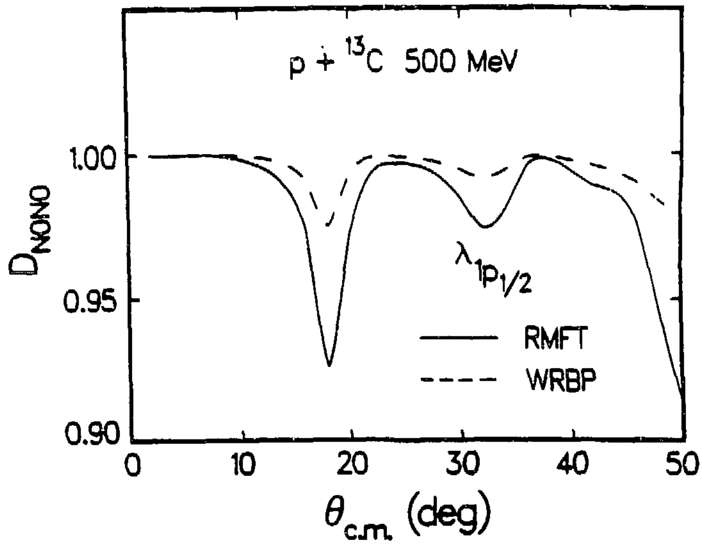

Fig. 8. Predicted sensitivity in D_{NONO} to λ in the RIA model. The two curves were generated assuming either the RMFT value (Ref. 17) for λ (solid curve), or the weak binding potential limit from Eq. (20) (dashed curve) as explained in the text (see Ref. 50). Note the expanded scale.

least for low momentum transfers, the p + ^{13}C isoscalar three vector current should be obtained from the $1p_{1/2}$ odd nucleon matrix element where the weak relativistic binding potential (WRBP) limit for $\lambda_{1p_{1/2}}(r)$ (also referred to as the "nonrelativistic lower component") is used. This WRBP lower component for the $1p_{1/2}$ neutron wave function can be obtained from the Dirac equation and is given by

$$\lambda^{WRBP}_{1p_{1/2}}(r) = \frac{\hbar c}{2m-\varepsilon}\left(\frac{d}{dr} - \frac{\langle\vec{\sigma}\cdot\vec{\ell}\rangle}{r}\right)\varphi_{1p_{1/2}}(r), \tag{20}$$

where ε is the $1p_{1/2}$ neutron binding energy and $\varphi_{1p_{1/2}}(r)$ is assumed to be the RMFT value. Calculations of this effect have been performed for finite momentum transfers for finite nuclei[55] and will eventually be applied to this scattering problem.

RIA – DWBA calculations assuming the pseudoscalar invariant form and neglecting the core nucleon contribution to the isoscalar three-vector current display considerable sensitivity to relativistic effects in the valence nucleon lower component as shown in Figs. 8 – 10. The solid curves

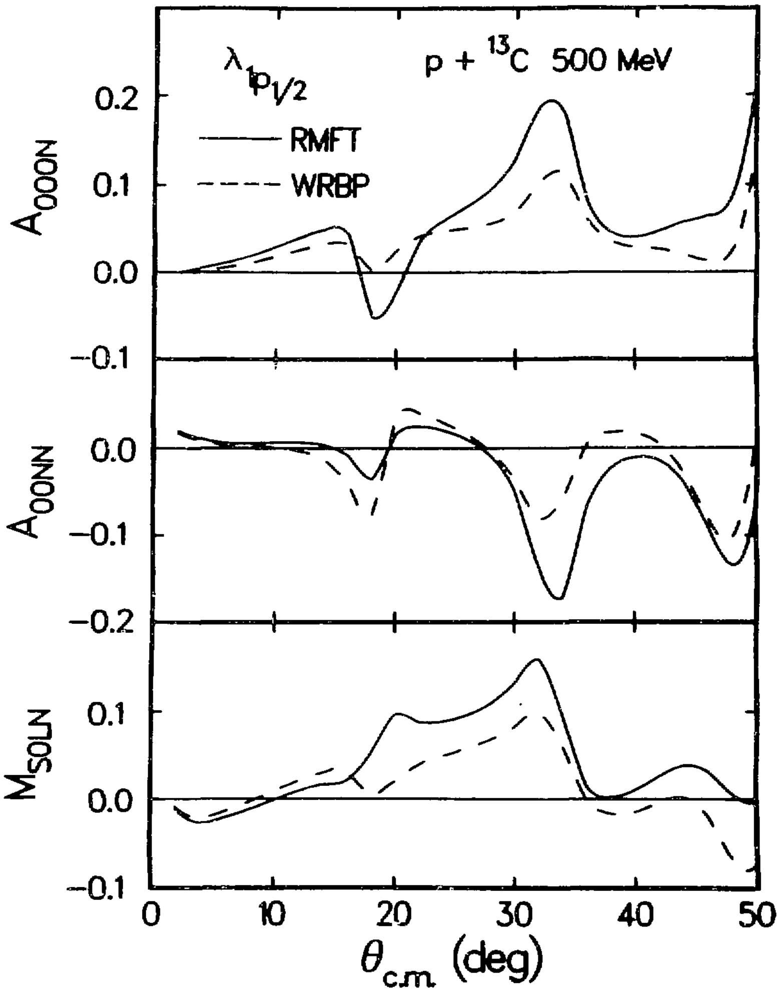

Fig. 9. Same as Fig. 8, except for A_{OOON}, A_{OONN}, and M_{SOLN}.

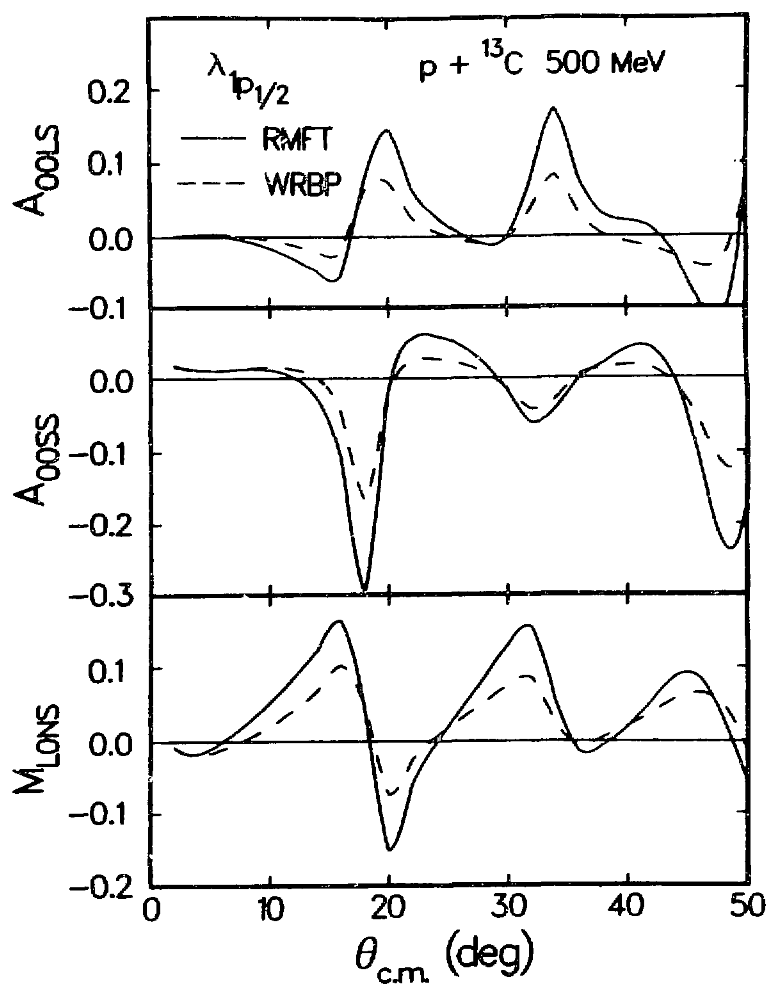

Fig. 10. Same as Fig. 8, except for A_{OOLS}, A_{OOSS}, and M_{LONS}.

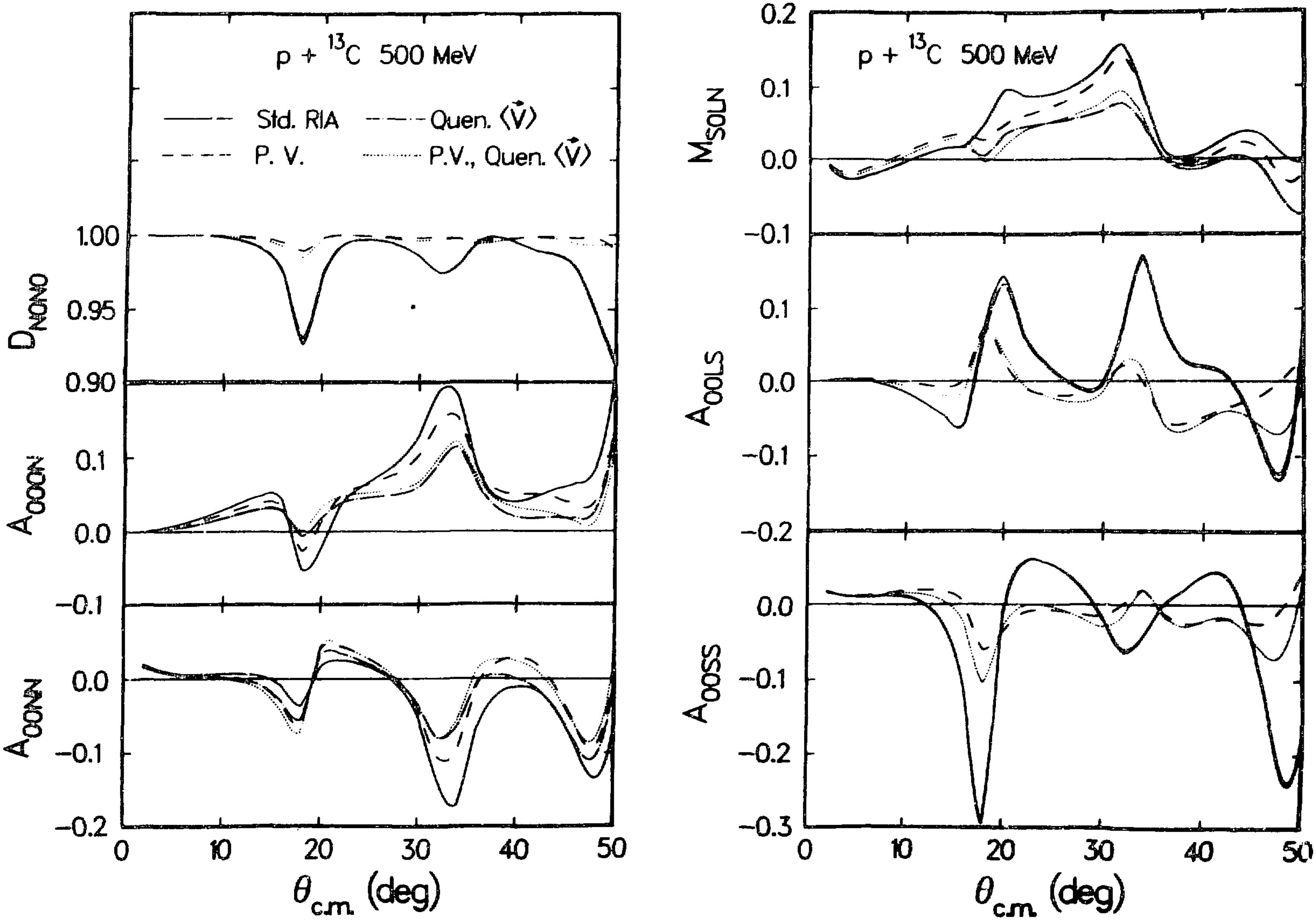

Fig. 11. Summary of various predictions (*from* Ref. 50) for D_{NONO}, A_{OOON}, A_{OONN}, M_{SOLN}, A_{OOLS}, and A_{OOSS} for $\vec{p}$ + $^{13}\vec{C}$ elastic scattering at 500 MeV assuming either the standard RIA model (solid curves), pseudovector coupling (dashed curves), core suppression of the isoscalar three-vector current (dashed-dotted curves), or both pseudovector coupling and core suppression of the isoscalar three-vector current (dotted curves) as discussed in the text.

correspond to calculations assuming the relativistic mean field theory values for $\varphi_{1p_{1/2}}(r)$ and $\lambda_{1p_{1/2}}(r)$ from Horowitz and Serot.[17] The dashed curves utilize $\lambda^{WRBP}_{1p_{1/2}}(r)$. Calculations assuming the pseudovector form eliminate this sensitivity to $\lambda_{1p_{1/2}}(r)$ for $\hat{s}$-type polarized target observables and D_{NONO} (unpolarized target, $\hat{n}$-type polarized beam and measured $\hat{n}$-component of polarization of scattered proton, see Ref. 56 for definitions of polarized target spin observables). Core contributions to the isoscalar three-vector current (assuming the nuclear matter result at all momentum transfer) negate model sensitivity to $\lambda_{1p_{1/2}}(r)$ for the $\hat{n}$-type polarized target spin observables. Several RIA model predictions for a variety of 500 MeV p + ^{13}C elastic scattering spin observables are displayed in Fig. 11. The solid, dashed, dashed-dotted, and dotted curves represent calculations assuming the pseudoscalar form, pseudovector form, pseudoscalar form with quenched three-vector current, and pseudovector form with quenched three-vector current, respectively. In all cases, relativistic binding potential enhancement of the $1p_{1/2}$ valence neutron lower component is assumed. Differences between the solid and dashed curves indicate the size of the pseudoscalar versus pseudovector effect while the differences between the solid and dashed curves indicate the estimated size of the core nucleon "backflow" contribution to the isoscalar three-vector current. Considerable sensitivity to a variety of interesting relativistic nuclear physics effects is demonstrated in these model estimates and confrontation with the forthcoming data from LAMPF-HRS experiment 955 (Ref. 48) will be very interesting, informative and will certainly challenge the relativistic and nonrelativistic theories of pA elastic scattering and nuclear structure.

A similar theoretical study has been conducted for the isobaric analogue state (IAS) transition in (p,n) induced charge exchange reactions.[57,58] Theoretical studies for the 160 MeV $^{90}Zr(\vec{p},\vec{n})^{90}Nb$(IAS) transition reveal considerable predicted sensitivity in the spin rotation parameter to relativistic versus NR dynamics for the projectile proton and outgoing neutron.[58] RIA-DWBA calculations for $^{13}C(p,n)^{13}N$(IAS) (Ref. 57) demonstrate negligible sensitivity to relativistic binding effects in $\lambda_{1p_{1/2}}(r)$ but, considerable, qualitative sensitivity in the unpolarized target, spin depolarization (D_{ij}) observables to the pseudoscalar versus pseudovector form for the NN amplitude as shown in Figs. 12 and 13. Both of these reactions along with $^{15}N(p,n)$ (Ref. 59) will be carried out at the new NTOF facility and the data examined for possible information concerning relativistic

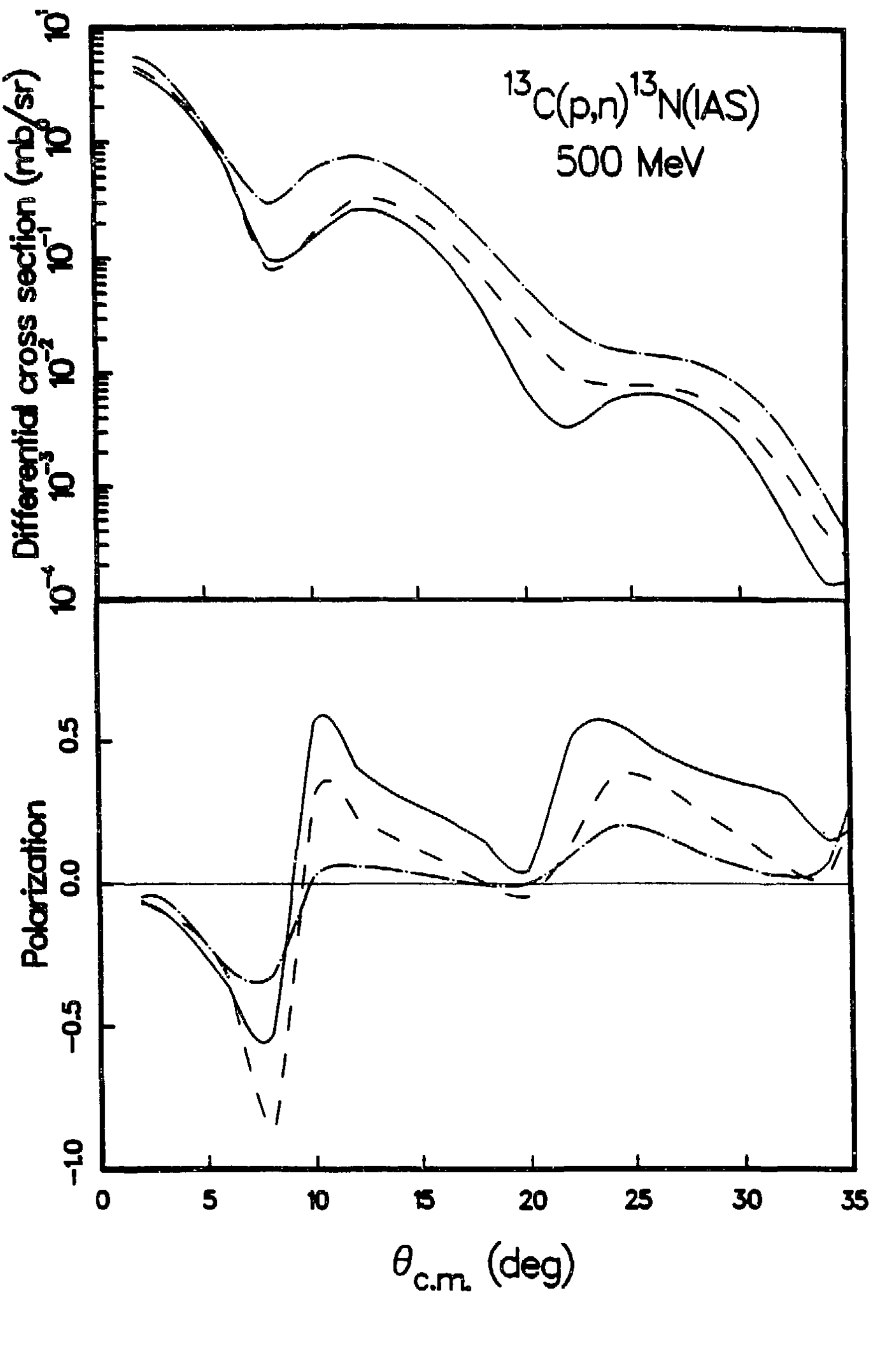

Fig. 12. Relativistic distorted wave impulse approximation predictions for 500 MeV $^{13}C(p,n)^{13}N(IAS)$ differential cross section and polarization (from Ref. 57). The results of calculations assuming the pseudovector form with $\lambda^{RMFT}(r)$, the pseudoscalar form with $\lambda^{WRBP}(r)$, and the pseudoscalar form with $\lambda^{RMFT}(r)$ are shown by the solid, dashed, and dashed-dotted curves, respectively.

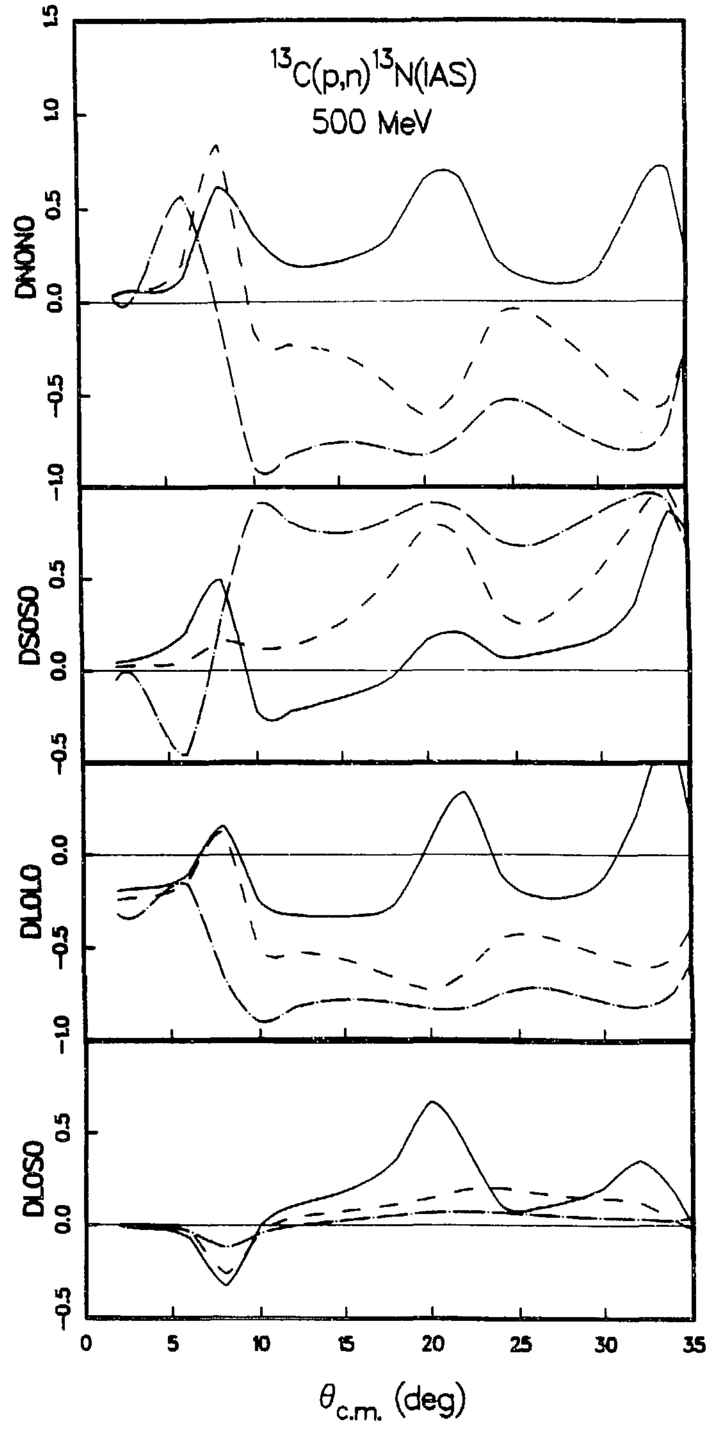

Fig. 13 Same as Fig. 12, except for nucleon spin depolarization parameters D_{NONO}, D_{SOSO}, D_{LOLO}, and D_{LOSO}.

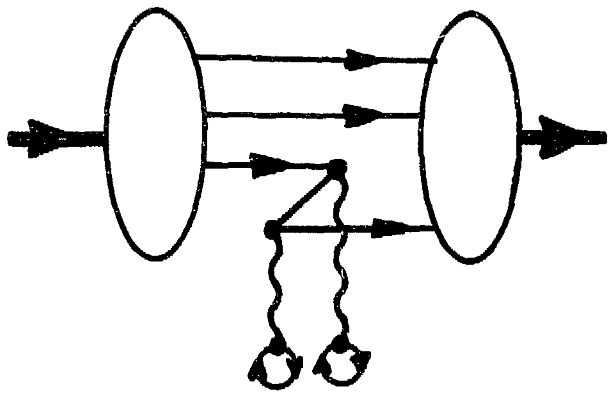

Fig. 14. Z-diagram for constituent quark model with scalar and vector meson exchange (wavy lines) between two different target nucleons (from Ref. 60).

processes related to the isovector components of the NN interaction and for constraints on the choice of Lorentz form for the pseudoscalar, pion exchange component of the NN effective interaction.

With respect to the study of charge exchange, it is important to call attention to a recent paper by E. Bleszynski et al.[60] who argue that single quark-antiquark z-diagrams (see Fig. 14) may, in reality, represent the physical process which is being accounted for in the Dirac equation models. In the Dirac equation approach the projectile-target-nucleon system with finite sizes is replaced with a point-like, spin-1/2 Dirac particle interacting with the target nucleus via an optical potential. The virtual $N\bar{N}$ pair process or so-called "z-diagram" mechanism (see Fig. 1) occurs in this model with point like baryons. Finite nucleon size effects are included to some extent in the calculations by way of the finite ranges of the effective interactions. It has been argued that the finite size of the nucleon will suppress the virtual pair processes predicted by a relativistic model which assumes point-like baryons.[61] The authors in Ref. 60 claim that for isoscalar processes the two types of diagrams in Figs. 1 and 14 should yield similar results (within the simple additive quark model). On the other hand, for isovector processes, the two models could result in different pA observable predictions. Calculations of relativistic processes at the quark level remain to be done but this work suggests a new and interesting aspect of the study of relativistic nuclear phenomena which has not yet entered the mainstream of discussion. It is absolutely necessary for physicists to investigate this question and design experiments to further test and differentiate the various relativistic models. Charge exchange reaction data from NTOF may provide important new insight into the nature of possible relativistic processes.

Conclusions

In this presentation I have surveyed many of the areas of investigation into relativistic aspects of nuclear physics and have discussed how polarization and other experimental studies conducted at LAMPF and other medium energy facilities have affected, and will continue to impact this important area of physics. To date the best evidence for the existence of reaction mechanisms not included in traditional NR nuclear physics is the analysis of intermediate energy pA elastic scattering spin observable data, the 500 MeV p + ^{40}Ca case providing the best example.[7,8] Manifestations of relativistic processes in reactions which are driven primarily by the spin-flip and/or isovector components of the NN effective interaction have yet to be unambiguously demonstrated and await further improvements in the theoretical models and additional intermediate energy data. Unambiguous experimental evidence for or against relativistic descriptions of bound nuclei does not yet exist. I also note that careful inclusion of exchange, off-shell dependences and medium modifications in standard NR multiple scattering calculations, at and above 500 MeV, remains to be done, although such effects are not expected to be very important.

Much work remains to be done of course. Theoretically, critical examination and improvement in the models for virtual $N\bar{N}$ pair production are needed. Corrections arising from off-shell dependences and the nuclear medium also need to be investigated. Attempts to understand the types of vacuum corrections which will result from a RQFT approach to the intermediate energy pA scattering system should be made. It is encouraging that much data pertaining to many of these questions exist and that, where lacking, new experiments are already being planned. Few hundred MeV pA elastic scattering spin rotation data, intermediate energy (p,n) data, polarized target data, higher energy (p,p′) spin excitation data, and quasielastic data are all pertinent to the study of relativistic effects in nuclear physics.

The unambiguous establishment of bona fide relativistic processes in nuclear physics would, if it occurs, have a profound impact on the way physicists think about nuclear systems. The evidence for such is, at present, very suggestive but is admittedly inconclusive. Such a large investigation is worthwhile and fundamental and the users at LAMPF are in an ideal position to carry out the required measurements and to lead the way in the study of these phenomena.

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Minutes from 1987 EPICS working group session

Mike Braunstein (University of Colorado)
George Burleson (New Mexico State University)
Mark Jones (University of Minnesota)
Peter Kutt (University of Pennsylvania)
June Mathews (MIT)
David Oakley (University of Colorado)
Herbert Orth (GSI, Germany)
R. J. Peterson (University of Colorado)
Michael Thies (Free University, Amsterdam)

Meeting called to order at 8:45 a.m. David Oakley reviewed the minutes from last years session and discussed the latest developments with the EPICS channel. Steve Green was scheduled to speak on this subject but was unable to attend the meeting.

The attendees agreed that another mp10 tutorial would be helpful for next summer. It was also agreed that because of the light turnout of EPICS users to this meeting, the EPICS representative to the Experimental Facilities Panel should be selected through mail-in ballots. Jerry Peterson and George Burleson volunteered to be the nominating committee. David Oakley suggested that next years representative supervise the compilation of an EPICS users manual that would be put on the VAX in the form of a HELP file. June Mathews suggested that it would also be helpful if the representative would keep the users informed on EPICS developments through BITNET.

George Burleson then talked about the EPICS polarized target facility. This included methods of polarization, costs, time frames, and counting rates. Examples of the type of physics that would be learned from this experiment include tests of the $\Delta - hole$ model, which is sensitive to L·S coupling, from elastic scattering and the investigation of single-particle transitions in inelastic scattering.

Minutes of the 1986 NPL Working Group Meeting

Participants

Lewis Agnew	MP-DO
Dick Boudrie	MP-10
Gary Crawley	NSF
Robert Garnett	New Mexico State University
George Glass	Texas A&M University (Chairman)
John Jarmer	MP-7
Kevin Jones	MP-10
George Kahrimanis	University of Texas at Austin
James Knudson	MP-7
Kok Heong McNaughton	University of Texas at Austin
Mike McNaughton	MP-10
Matthew Murray	MP-10
Tetsuo Noro	MP-10
Lee Northcliffe	Texas A&M University
Seppo Penttila	MP-7
Peter Riley	University of Texas at Austin
R. R. Silbar	T-5
Hal Spinka	Argonne National Laboratory
O. van Dyke	MP-DO
Dick Werbeck	MP-7

1) Area B Counting House

Dick Boudrie presented plans for a new Area B Counting House. This new structure would house electronics, controls and computers for experiments in Area B with the exception of HIRAB and NTOF. The plan calls for a 2000 sq. ft. structure with space for 70 relay racks and two computers to service MRS, polarized targets, and various experiments. It is hoped to start construction by summer, 1988 in order to be ready for MRS commissioning in 1989. This will require FY1988 GPP funds, which have not been received yet. The construction will require the relocation of some existing trailors and cabling, such as for the polarized target, which may impact ongoing programs.

2) Status of MRS

Dick Boudrie reported that the startup of MRS is still expected to be spring, 1989. The spectrometer steel is presently being forged in France and copper conductor has been ordered from Finland. Work is proceeding on final machining drawings. A new beam stop is to be built in EPB to handle higher beam intensities. The scattering chamber will be similar to that in EPICS. The detector system is not completely specified yet.

3) Status of HIRAB

Jim Knudson reported on progress at HIRAB. Construction and electrical work have been completed in the experimental area, but purchases for apparatus have been limited by budgets. Their first attempt to control beam jitter upstream of the BR/EPB split was not successful. A beam divergence of < 10 μrad has been achieved, and a $\lesssim 1$ μrad divergence appears feasible with the installation of some strippers and a bending magnet.

A new beam diagnostic, developed for HIRAB, to measure these small divergencies was also described. The technique employs a thin wire and a precision phosphor with a very linear response. A long path (14m at HIRAB) is present between the wire and phosphor. The shadow of the wire is observed at the phosphor after subtracting the beam profile with the wire removed. This system will be permanently installed for HIRAB and it may be useful for other LAMPF beams as well.

4) Status of OPPIS

Olin van Dyke described work on the new high intensity optically pumped polarized ion source (OPPIS). Two recent milestones were reported with the new source. The sodium vapor cell has achieved polarizations up to 90% with densities of 2 x 10^{13} atoms/cm^2. Secondly, the ECR proton source has achieved an intensity of 15 mA at 5 KeV. These numbers are consistent with requirements for a 10 μA polarized beam intensity with polarization ~ 60%.

The 16 kg superconducting solenoid magnet for the new source has also operated reliably. The liquid helium heat loss is about 1 liter/day in the persistent mode with magnet current leads removed from the cryostat. This allows for batch liquid helium fills once every month; no liquid nitrogen is used.

There are concerns about the laser reliability and stability as they affect the beam polarization. Difficulties with keeping the lasers tuned to the proper frequency and power level are expected. There will be two different lasers, each with a fixed frequency (one for each polarization direction), that could allow rapid spin reversal if desired for a particular experiment. Thus, the beam current and position should not change between spin NOR and REV, but the polarization magnitude may differ depending on the laser light intensity from each laser.

The Lyman-alpha polarimeter was also described. It gives the absolute beam polarization and will be moved to various points within the source for testing.

The progress of OPPIS is consistent with it being installed and operational for experimental runs in 1989.

Hal Spinka was elected as the next chairman for the 1988 NPL Working Group.

Neutrino Facilities Working Group

Joey B. Donahue, Chairman
November 10, 1987

Attendance: Vern Sandberg, Gary Sanders, Kim Woodle, Hans-Jurgen Mundinger, Don Cochran, Elton Smith, Todd Haines, Jack Lightbody, Bill Louis, (illegible), Amir Mohagheghi, Ali Fazely, Tom Romanowski, Martha Hoehn, Joey Donahue

The Neutrino Facilities Working Group met at 8:30 am in room D105 of the LAMPF office building. Joey Donahue chaired the meeting in place of Roger Carlini.

Donahue announced that the present Technical Advisory Panel (TAP) representative is Peter Doe. If the proposed amendment to the User Group bylaws is passed, Peter will become chairman of this working group and he will become the neutrino representative to the new Experimental Facilities Panel (EFP). His term will be up in 1988 at which time the working group will have to elect another representative for a two-year term. The working group members were encouraged to vote (Note added in proof: The amendment did pass).

The working group members were sad to learn that Professor Herb Chen of U.C. Irvine lost his battle with leukemia and died this past weekend. His leadership in the neutrino physics community, especially at LAMPF, will be missed.

Short talks were then given by representatives of E225/866 and E645. The E225 talk was to be given by Mike Potter who has recently come to LAMPF from U.C. Irvine to work on the Cygnus experiment. However, since Mike went to attend Herb Chen's funeral, the talk was given by Vern Sandberg. The E645 talk was given by Elton Smith of Ohio State University.

Sandberg described E225 as a measurement of electron-neutrino, electron elastic scattering with an accuracy of about 15%. LAMPF is the only place where experiments can be done with electron neutrinos. The experiment is shielded from the beam stop by 6.3 meters of iron. The experiment has run for about four years and data acquisition is complete. The experiment accumulated 4.6 Amp-hours of protons on target (about one-sixth of a gram of protons!) and got 304 candidate events. The experiment is consistent with destructive interference and rules out no interference by 2.1 standard deviations and constructive interference by 4.6 standard deviations. E225 is presently awaiting the results of the normalization experiment, E866, to reduce the final error. It was mentioned that the LCD experiment avoids this problem by taking a ratio. In response to a question by Lightbody, Sandberg stated that E225 could measure the neutrino-carbon cross section to about 20%.

Sandberg also described the beam stop normalization experiment, E866. This experiment calibrates the neutrino production in the beam stop by measuring the number of muon decays per incident proton. The experiment is a community effort involving participants from E225, E645 and Rutherford Appleton Laboratory. Data acquisition is complete for copper, water/copper and lead beam stops at proton beam energies of 800, 766 and 716 Mev. The water/copper combination was chosen to closely resemble the actual LAMPF beam stop while lead was chosen to be an approximation to the spallation source for the KARMEN experiment at Rutherford. E866 is being analyzed independently in Maryland by Krakauer and at Irvine by Potter. The Irvine analysis is complete and the Maryland analysis is nearing completion. The preliminary results are about 20% lower than the flux which was obtained by scaling the old LBL results. The final results are expected to be accurate to 4 or 5 per-cent with the biggest uncertainty coming from difficulties with removing the tail from the stopping pion signal.

Smith described E645 as a search for neutrino oscillations at the LAMPF beam stop. This experiment had been plagued by beam and cosmic ray neutron backgrounds during the engineering run in 1986 and shielding was added during the last shutdown in the hopes of reducing the beam related background by a factor of 100 and the cosmic ray background by a factor of ten. These problems have now been solved; the beam-related backgrounds were attenuated by better than a factor of 100 and can no longer be measured while the cosmic ray background was reduced by a factor of twenty. The desired background rate was 0.1 event per day. The collaboration expects to publish a result early next year and the experiment will run at least one more year.

Following the talks, there was a general discussion about the fate of the E225 and E645 detectors after the experiments are complete. There were several ideas for future experiments but the general consensus was that the Large Cherenkov Detector (LCD) experiment is the future of neutrino physics at LAMPF. However, the Cygnus cosmic ray experiment would like to keep the active cosmic ray shields as muon identifiers. This would require that at least 1000 g/cm^2 of shielding be left as an overburden which may conflict with the plans for LCD to reuse most of this shielding. The Cygnus collaboration is also planning to cut up part of the E225 plastic scintillator for their shower array.

Minutes of the 1986 P^3 Working Group Meeting

The P^3 Working group convened at 9:45 on 10 Nov. 1987 with Michael Sadler (Abilene Chritian University) presiding. Present were:

Lewis Agnew	MP-DO
Helmut Baer	MP-4
David Barlow	UCLA
David Bowman	MP-4
George Burleson	NMSU
Kalvir Dhuga	George Washington University
David Ernst	Texas A and M University
Bill Gibbs	T-5
Peter Gram	MP-4
Martha Hoehn	MP-7
June Matthews	MIT
John McGill	MP-5
Ben Nefkens	UCLA
Jerry Peterson	University of Colorado
Mohini Rawool	ANL
Glen A. Rebka, Jr.	University of Wyoming
Michael Sadler	Abilene Christian University
Ivan Supek	Rudjer Boskovic Institute
H. A. Thiessen	MP-14
Michael Thies	Free University of Amsterdam
Jay A. Wightman	UCLA
John Zumbro	MP-5

A program of three presentations was heard.

John McGill (MP-5) presented on-line results illustrating the success of an effort to set up a momentum-dispersed beam in P^3East. The beam and the spectrometer adapted to use with it have produced data with an overall momentum resolution of 0.5% at 400 MeV, good enough clearly to resolve the peak in the $^{14}C(\pi^+, \pi^-)^{14}O$(DIAS) reaction. A program of DCX measurements in the pion energy range from 400 to 525 MeV can now be accomplished during the remainder of this running cycle.

The beam alone is thought to have a resolution approaching 0.2%. Some improvement in the resolution of the spectrometer is believed possible and is being worked on.

The beam uses a thin (1.1 cm) production target which will remain in place for the rest of the running cycle. Future use of this beam will require the installation of insertable target-defining slits so that other experiments can use the standard thick (5 cm) production target. The target defining slits have been planned; construction and installation, which involves access to the innermost region of the target cell, are thought to require 12 months and to cost $\$1x10^5$.

David Barlow (UCLA) showed results of a measurement of the cross sections for the production of negative pions at 0^0 by 800 MeV protons. The possibilities of zero-degree pion beam lines were discussed. Substantial increases in the pion flux at 500 to 600 MeV over those now available P^3 appear to be possible. Such a channel might cost between $\$3 \times 10^6$ and $\$5 \times 10^6$ and would involve a complete shutdown of area A for a lengthy period of time during installation.

Arch Thiessen (MP-14) discussed the possible performance and costs of several energy compression and pion accelerator schemes based on superconducting rf cavities. The simplest of these is a one-cavity energy compressor ("scruncher") for LEP that could improve the pion flux at 50 MeV by a factor of 6 at an energy resolution of 0.2%. It could be built for about $\$7 \times 10^5$.

More ambitious are pion linacs that would increase the pions' energy by 30 or 100 MeV in the two examples that were presented. 30 MeV is a very modest gain in energy, but near the kinematic limit for pions produced by 800-MeV protons (really 785 at P^3), it would produce a factor of 5 increase in the flux by accelerating the more numerous pions available at a slightly lower energy. Because the very numerous protons that accompany positive pions at high energies would experience no net acceleration in these rf fields, even a small boost in the pion's energy would make it possible to get rid of the protons by subsequent magnetic analysis. A 30-MeV accelerator might cost $\$10 \times 10^6$ and a 100-MeV accelerator $\$20 \times 10^6$. These accelerators were recognized to be very expensive; convincing demonstration that they would offer unique capability will be needed to build them.

A resolution urging LAMPF management to increase the research and development effort directed toward producing higher energy pions was adopted by a vote of 22-2.

Minutes of the HRS working group meeting
November 10, 1987
Chairman: Sirish Nanda

Attendees:

D. Adams, Univ. of Texas at Austin
M. Barlett, Univ. of Texas at Austin
R. L. Boudrie, LANL
J. Comfort, Arizona State Univ.
G. Crawley, NSF
A. Green, Rutgers
S. Hanna, Stanford
J. He, Beijing, China
K-H. McNaughton, Univ. of Texas at Austin
G. W. Hoffmann, Univ. of Texas at Austin
K. Jones, LANL
M. Jones, Univ. of Minnesota
G. Kahrimanis, Univ. of Texas at Austin
J. Lightbody, NSF
A. Ling, UCLA
S. Nanda, CEBAF
M. Purcell, Univ. of Texas at Austin
L. Ray, Univ. of Texas at Austin
S. Saini, ORNL
A. Sethi, Univ. of Minnesota
J. R. Tinsley, Arizona State Univ.
C. Whitten, UCLA

HRS status report

Kevin Jones presented a status report for the HRS. The facility operated without major problems last year. It was pointed out that every experiment completed in Cycles 48 and 49 received its allocated beam time. There was some concern over loss of beam intensity in transmission through line C earlier in the year. This problem has been corrected and about 95% transmission is routinely obtained prior to collimation. The need for absolute beam intensity measurement has been a long standing issue at HRS. A beam line toroid capable of measuring average intensities above 1 nA has been installed and will be operational in Cycle 51. The new FERA data acquisition electronics have performed well. Chamber calibrations have been stable and overall performance of the detection systems has been very reliable. The front end starburst event processor has worked well in polarization transfer measurements. It was also noted that suggestions of the instrumentation review committee for development of a consistent set of beam diagnostics and beam polarization monitoring devices have been adopted. Redundant beam polarization measurements using LC, LB, EP, and NTOF polarimeters are now available to HRS. He added that the 100 ns chopped beam during the last cycles of the year did not interfere with the successful completion of the scheduled experiments at HRS and in fact were of benefit to several.

PAC/Scheduling

Most of the participants were supportive of the unified PAC for all facilities sharing the polarized beam (HRS, MRS, HIRAB and NTOF). Some users expressed concern over the large rejection ratio (about 50proposals at the last PAC. In view of the new format of the PAC, users were encouraged to submit proposals with a broader range of physics interest. Issues concerning scheduling conflicts such as beam current requirements, spin compatibility, and prime-time criteria for polarized beam experiments were discussed. Low energy beam for HRS was clearly regarded as the requirement for HRS to be prime user of polarized beam. In addition, careful attention should be paid to spin-incompatibility in the horizontal plane in the scheduling of HRS and NTOF experiments. There was concern among most users over the proposed 200-250 ns chopping pattern of the beam in the future.

Items of Concern

The participants strongly endorsed a motion for annual workshops for new students and graduate student orientation during startups. Some users expressed concern over the lack of standard MP-10 software for the analysis of polarization transfer measurements. Kevin Jones accepted the the task of putting the program DNC in MP-10 supported software package. There was some questions raised about the reliability of beam polarization measurements with line C polarimeter. This question is being addressed and replacement of the polarimeter with the new high intensity version is being considered.

Kevin Jones was elected as the chariman of the HRS working group and representative to the Experimental Facilities Panel.

MINUTES OF THE NEUTRON TIME-OF-FLIGHT (NTOF) WORKING GROUP

November 10, 1987

Participants:

M. Barlett	University of Texas
M. Braunstein	University of Colorado
R. Byrd	LANL (P-2)
T. Carey	LANL (P-2)
D. Ciskowski	University of Texas
D. Cochran	LANL (MP-DO)
C. Goodman	IUCF
E. Gulmez	UCLA
G. Hoffmann	University of Texas
E. Hoffman	LANL (MP-1)
J. McClelland	LANL (MP-10)
M. Murray	LANL (MP-10)
T. Noro	LANL (MP-10)
S. Penttila	LANL (MP-7)
P. Riley	University of Texas
B. Sailor	LANL (P-2)
E. Sugarbaker (Chairman)	Ohio State University
T. Taddeucci	LANL (MP-10,P-2)
O. van Dyck	LANL (MP-DO)
C. Whitten	UCLA
Y. Yariv	LANL

This was the first formal meeting of the NTOF Working Group, created in the spring of 1987 by the Board of Directors to provide specific representation for those planning to use the new NTOF facility. Evan Sugarbaker, appointed by the BOD to serve as the initial NTOF representative on the TAP, chaired the meeting. This was consistent with the dual role to be assumed by members of the newly redefined TAP, the Experimental Facilities Panel (EFP). In keeping with the BOD's's desire to "adiabatically" approach a user-elected EFP, this Working Group will not elect a new EFP representative (and Working Group Chairperson) until the 1989 annual users meeting. Users were encouraged to transmit problems and suggestions associated with productive use of NTOF to Sugarbaker (BITNET%SUGARBAKOHSTPY).

A short review of the initial experiments presently awaiting completion of the NTOF facility was made. John McClelland then presented the current status of the facility. The first development/E1061 run in which the beam swinger and neutron detector system were in full operation was in progress at the time of this meeting. He reported the delivery of 497 MeV protons on target having a time spread of only about 0.3 nsec. This extremely good timing was obtained through longitudinal focusing accomplished via application of non-accelerating rf modules at the high end of the linac as buncher cavities. The timing without longitudinal focusing was measured to be about 1.3 nsec. The neutron polarimeter and FERA-based acquisition system were reported to be functioning well and as per expectations. John also reported that significant progress had been made toward completion of the full 600 meter neutron flight path and of the neutron spin precession system to immediately follow the beam swinger. These final components of the NTOF facility should be completed by the start of the first running cycle of 1988.

Since all available rf cavities will not be instrumented for use as high-energy bunchers, user input was requested as to which energies would be most in demand. John McClelland suggested that energies similar to those frequently used at HRS would be reasonable, although fairly low energies might also be possible. If a user has specific beam energies in mind which would benefit from longitudinal focusing, he/she was encouraged to communicate these to John as soon as possible.

Other user concerns included a question of the peak current which one might anticipate being able to deliver to NTOF. This remains an open question, since the 40 nA peak current delivered to date is far less than the design maximum value. Another user concern was that the completion date for OPPIS not be further delayed, since intense polarized beams are required for many of the proposed experiments at NTOF.

MINUTES OF THE 1987 LOW ENERGY PION (LEP) WORKING GROUP

Attendees:

James N. Knudson	*MP-7, Chair*
Don Cochran	*LANL*
Stan Hanna	*Stanford*
John Zumbro	*MP-5*
Philip Harris	*UNM*
Tetsuo Noro	*MP-10*
Peter Kutt	*University of Pennsylvania*
Michael Theis	*Free University of Amsterdam*
Bill Gibbs	*LANL*
Mike Leitch	*P-2*
James Tinsley	*Arizona State University*
Dick Werbeck	*MP-7*
Donald Isenhower	*Abilene Christian University*
Joey Donahue	*MP-7*
Jerry Peterson	*University of Colorado*
R. L. Boudrie	*MP-10*
Angel Wang	*UCLA*
Jack Lightbody	*NSF*
June Matthews	*MIT*
Martha Hoehn	*MP-7*

The meeting of the LEP Working Group was called to order by James Knudson. The results of the balloting to install the Experimental Facilities Panel amendment to the LUGI bylaws were announced. Ralph Minehart, the LEP representative to the TAP was unable to attend the Users Meeting, but sent word through June Matthews that he would be willing to step down if the Working Group wished to elect an EFP representative. No new candidates were brought forward; therefore Ralph will continue as the LEP representative until the end of his term in 1988.

John Zumbro gave a presentation describing a superconducting RF-cavity energy compressor (scruncher) which could be placed at the end of the LEP channel. This device would effectively give an improved flux rate for a given momentum bite by squeezing the energy spread of the pion beam. It would be effective for pion energies of 34 MeV to about 150 MeV, giving about a factor of six improvement in fluxes in this energy range. Such a rate boost would be useful for most experiments at LEP, but would certainly be very useful for the pion double charge exchange work being done with the Clamshell spectrometer. John indicated that a complete system ready to turn on could be acquired for about $700k; alternatively, a cavity and cryostat could be had for about $250k, with the division providing the RF. The location of the cavity would be the point on the floor where the Clamshell pivot is currently located. The time estimate for receiving the device once it is ordered is from 1 to 2 years.

Dick Boudrie spoke next concerning the channel controls. The DVM readings of the jaws and shunts can now be read out into the LEP computer, thanks to the efforts of John McGill; the Clamshell is already making use of this ability. The six channel magnet power supplies, as well as the Clamshell power supply, all have digital controllers installed. These have been tested and shown to be able to control fields reproducibly to within 0.5 gauss. The digital controllers are not so convenient for tuning the quadrupoles, so an analog controller is available for tuning. Once the desired shunt settings are known, the digital controllers may be replaced. Another limitation of the digital controllers is the fact that CYCLE function does not operate properly - the magnets trip before the 10-volt reference point is reached. This problem will be corrected; however, further development of these controllers will not proceed any further as MP-11 is working on a new control system to be compatible with the new C&M chassis.

Mike Leitch inquired about the possibility of some kind of beam diagnostic for the Clamshell. His experience is that it requires a three hour turnaround to put in an ISICS to see where the beam is on target. Dick Boudrie responded that a prototype device using scintillator strips is being tested. It would be mounted in the scattering chamber and would be remotely retractable. This device could be ready for the next Clamshell running if manpower needs are met.

Other items of common concern:

NMR: no progress in finding a replacement NMR system has been yet found. The current system was manufactured by the Cyclotron Corporation, which has gone out of business. MP-7 is out of spare probes and preamps, which are vulnerable to radiation damage. MP-10 makes their own probes, but the preamps used custom chips and are not reproducible. As noted a year ago, no other commercial system has the dynamic range which is available in a single Cyclotron Corporation probe (1 - 20 kG). Users are encouraged to contact MP-7 (Werbeck, Donahue or Knudson) if they are aware of a replacement for the NMR. Jack Lightbody mentioned a flowing water system used at Mainz; MP-7 will follow up this idea.

Computer: the LEP MicroVAX continues to crash at rates of up to 2-3x per day. No consistent cause of these crashes has been discovered. A fair amount of suspicion remains in the SCRs in the magnet power supplies mounted on the roof of the counting house. MP-1 installed a power analyzer for a time, but no correlation between crashes and power glitches was found.

Clamshell: could resolution be improved over the present 350 keV? Dick Boudrie responded that no effort would be put into the Clamshell resolution unless proposals were submitted that would drive such an effort.

Channel: the momentum jaws CL6A and CL6B are not centered. A measurement of rate as a function of indicated $\Delta p/p$ done during E899 shows that the jaws close at an indicated $\Delta p/p = -0.11\%$. There also seems to be some horizontal beam steering in the channel. These problems may not be terribly serious as no experiment uses muon decay detectors. Dick Werbeck commented that making modifications to the system so that the jaw pairs would move independently would be very expensive. The boxes in which the mechanisms are currently mounted would have to be enlarged, and the location of the box is not amenable to remote handling.

Counting house: with two sets of permanent electronics in the counting house (π^0 and Clamshell spectrometers), crowding is a problem. The counting house also seems to collect junk from finished experiments that do not clean up after themselves. Many people are bothered by the roof-mounted air conditioners. Dick Werbeck commented that the roof A/C units were a temporary fix, but that the real fix to the A/C problem may require more money than is available.

Ralph Minehart asked, through June Matthews, whether there is interest in the low energy pion beam (5 - 10 MeV), and would an energy compressor help at low energies. It was pointed out the the best way to achieve stopping beams was to degrade higher energy beams. There is no separator development occurring at LAMPF for the general user community, and no support of the devices previously available. Discussion returned to the scruncher idea, where Bill Gibbs indicated that in his opinion the physics return for the money is best at LEP of all LAMPF pion channels, and that perhaps a scruncher should go into LEP before P^3. It was moved by Leitch that "A scruncher at LEP would greatly enhance the physics capability." Seconded by Matthews; the motion was passed unanimously.

MINUTES OF THE SMC WORKING GROUP

The stopped muon channel (SMC) working group met in room A234 of the LAMPF office building from 11:15-11:45 a.m. on November 10. The meeting was conducted by the chairman, Martin Cooper (MP-4). Other attendees were Martha Hoehn (MP-7), Cy Hoffman (MP-4), Gary Hogan (MP-4), George Kahrimanis (Texas), Steve Kattell (yale), Tom Romanowski (Ohio State), and Elton Smith (Ohio State).

Martha Hoehn discussed channel utilization for 1987 and 1988. The 1987 usage was broken down as follows: Yale-38%, catalysis-29%, MEGA-15%, μSR-11%, micro-electronics-3%, and radio-nuclides-6%. It is expected that in 1988 the breakdown may be: catalysis 5-6 weeks, MEGA 4-5 weeks, Yale 4-5 weeks, and micro-electronics 1 week.

Channel upgrades were discussed. Steve Kattell made a number of good suggestions:

1) The racks in the counting house have a number of old chassis in them. Anything not in use should be removed to make room for either controls for currently used separators, readout and control of the PPA power supplies, or the controls for the low-current power-supplies.
2) Switching the control circuitry in the PPA power supplies from 120 volts to 24 volts.
3) Power breakers on the balcony of Area A that can effect clean or dirty power should not be turned off without consulting the experimenters because they can shut off pumps or other vital control circuitry.
4) Yale still needs the PPA supplies and they should not be dedicated to MEGA.

Other issues brought up included the fact that the counting house still leaks in rain storms. The working group guesses that all that can reasonably be done has been tried and experiments should protect their electronics.

A planned power outage for the east end of area A to replace a PCB filled transformer should be coordinated with MEGA. Good times look like December 14-18 or sometime in March. The latter could be done with a warm magnet and would obviate the need for a big diesel generator.

The MEGA FASTBUS rack needs to be isolated so that it does not dirty the clean power.

POLARIZED TARGET WORKING GROUP - MINUTES

A talk on the status of polarized targets at LAMPF was given by John Jarmer, MP-7. The polarized target group currently consists of 2 staff members and 4 technicians. It sets up and operates two target systems per year and also works on the development of new target components. In 1987, one of these systems was set up in EPB for Exp. 818 (polarized deuterons) and Exp. 1035 (polarized protons) and the other was set up in BR for Exp. 960. For 1988, the plans are to run tests on the polarized ^{13}C target system for Exp. 955 early in the year. If these are successful, the target will be set up at HRS for polarized proton scattering, but if they are not successful by February, 1989, a decision will be made not to set up that target. In either case, Exp. 960 would continue to use the target system in BR in 1988. There are no plans as yet for 1989. A new dilution refrigerator system for use with polarized targets has been designed, but no work on fabrication has been carried out. In order for work on this to go forward, assistance from users is needed. Possibliities for this are currently under discussion with some of the users. Plans for future experiments with ^{13}C targets at LEP (for pion single charge exchange) and EPICS were also mentioned. This was followed by a lively discussion with some of the users.

An election was held for a new chairman of the working group for 2 years, who will also be a representative to the Experimental Facilities Panel. Two were nominated, and George Burleson was elected.

POLARIZED TARGET WORKING GROUP

November 10, 1987
11:15 - 12:30 p.m.

Attendees:

George Burleson, New Mexico State University
Gerald Hoffmann, University of Texas
Lewis Agnew, Los Alamos National Laboratory
Evan Sugarbaker, Ohio State University
Bill Coulter, Los Alamos National Laboratory
Mick Purcell, University of Texas
Dave Yeamans, Los Alamos National Laboratory
Olin van Dyck, Los Alamos National Laboratory
Lanny Ray, University of Texas
Mike McNaughton, Los Alamos National Laboratory
David Adams, University of Texas
Chuck Whitten, UCLA
Peter Riley, University of Texas
Kok Heong Mc Naughton, University of Texas
George Glass, Texas A&M University
Joseph Comfort, Arizona State University
Seppo Penttila, Los Alamos National Laboratory
John Jarmer, Los Alamos National Laboratory

Computer Facilities Working Group Minutes

Kok Heong McNaughton

November 10, 1987

Attendees: *Earl Hoffman* MP-1
Kok Heong McNaughton University of Texas
Tom Kozlowski MP-1
Mike Oothoudt MP-1
Gail Anderson MP-1
James Harrison MP-1
Mike Leitch P-2
Gary Hogan MP-4
David Adams University of Texas
Rusty Ragan MP-1
Jim Knudson MP-7
Mike McNaughton MP-10
Elvira Martinez MP-1
Arthur Chavez MP-1
Peter Kutt University of Pennsylvania
Mohini Rawool Argonne National Lab
Sharon Lisowski MP-1
Jim Bradbury MP-DO
Connie Treyellas MP-1
Jim Amann MP-10
Tetsuo Noro MP-10
Dimitris Alexandreas MP-4

EFP Representative

Tom Kozlowski, current TAP representative, will now become our EFP representative for the next two years.

BITNET Update

A year ago, users were pushing for our own BITNET connection in addition to the ARPANET connection available through CCF. Elvira Martinez gave an update of our BITNET facility.

Since October of 1987, BITNET has become available on MPX1 with a Class D connection to UNM. This allows us not only to send Mail messages but also binary files to other Class D nodes.

The different classes of BITNET connections as well as their restrictions in usage were discussed. Methods for sending and receiving binary files were briefly mentioned. Users were referred to a more detailed article by Gail Anderson on the subject in the November issue of the LAMPF Computing Facility newsletter.

MFENET Update

Art Chavez talked about the MFENET facility at LAMPF

MFE was originally created to link universitites and DOE laboratories to the Magnetic Fusion Computer Center at Livermore. The services have now been extended to other research laboratories. Beginning in November, LAMPF began installing and using this facility. One advantage of MFENET over BITNET is the ability for interactive connection between MFE host nodes. As long as users have an account on any of these nodes, they can log in via this network. In addition to file transfer and electronic mail, MFENET users can also access file storage systems in all the connected nodes.

As this facility is new, users will be informed of future development via system mail and the Computing Facility newsletter.

Counting House Facilities

Mike Oothoudt gave a short presentation of computing facilities in the counting houses. Most counting houses now have μVAX-II's except for some which have VAX 11/750's. Disk storage is typically 71 megabytes. Line-printers are wearing out and users seem to prefer LN03s instead of buying new line-printers as long as some maintenance procedures are accessible.

The Q-section, consisting of Mike Oothoudt, Tom Kozlowski and Will Foreman, have been devoting their time with MEGA. Some of their experiences from MEGA can be filtered into future Q development, eg, histogramming of REAL, as opposed to INTEGER data. Fastbus hardware is cheap, but the software is very expensive and difficult to make work. It is recommanded that if users can live with CAMAC, they should do so. Data distribution system (DDS) and processor farms (ACP) were also discussed.

Front End Processing

Tom Kozlowski discussed different Front End Processing techniques used at LAMPF. These include data compression and event selection at the hardware and software levels. At the hardware level, one could use fast analog or digital logic, look-up memories, special camac modules that are capable of supressing zero data words, pedestal subtraction and encoding. At the software level, the front end processing can be done in any of the programmable devices, MBD, ACC, ACP or the host computer. The Q software supports user "filtering" of events by loggin user-generated rather than raw data.

ORGANIZATIONAL MEETING FOR WORKING GROUP FOR HIGHER ENERGY FACILITIES

Joseph Comfort (Arizona State University) reviewed the history of proposals for higher energy facilities, starting with LAMPF II proposal. Pointed out that funding for AHF is at earliest ~ 1992 and start up ~ 2000. Looking for alternate opportunities for the interim. We have NTOF and MRS underway. Pion physics, however, in beyond the present ability and plans. What facilities can be built? How do we get to meson and hadron spectroscopy, rare decays, etc. An attractive alternative would be a 5±2 GeV proton machine.

Ben Nefkens (UCLA) summ rized the recent meeting at ASU, and summ rized the physics that could be done with a 5±2 Gev proton machine.

1. QCD
   (a) understanding confinement
   (b) gluon degrees of freedom
   (c) validity of quark models
   (d) exotic states, hybrids
   (e) quark clusters
2. Meson and N* degrees of freedom
   (a) ρ N, ω N, interactions
   (b) N* interactions
   (c) role of η
3. Hypernuclei
4. Precision tests of Standard model and Electroweak theory

Joseph Comfort described possible scenarios of the future.

Gerry Garvey offered encouraging remarks for the user's thoughts and ideas on the future. Pointed out the problem of detectors and their ability to handle increased flux. Ben Nefkens asked about the continuity problem in manpower.

Joseph Comfort proposed a resolution to formally establish a standing working group. After many comments from the audience concerning the breadth of the subject matter that should be the concern of this group, the motion passed.

Joseph Comfort volunteered to lead the effort in delineating the physics that can be done with a 5 GeV machine.

How to form a group that would examine detector designs was discussed.

The plans for the APS meeting in Santa Fe was briefly described by Garvey.

WORKING GROUP ON HIGH ENERGY FACILITIES

November 10, 1987
2:00 - 3:15 p.m.

Attendees:

Joseph Comfort, Arizona State University
Ben Nefkens, UCLA
Bill Gibbs, Los Alamos National Laboratory
Helmut Baer, Los Alamos National Laboratory
Glen Rebka, University of Wyoming
Peter Gram, Los Alamos National Laboratory
Dave Ernst, Texas A&M University
Donald Hagerman, Los Alamos National Laboratory
Ivo Slaus, UCLA & University of Zagreh
Ivan Supek, Institute Rodzer Bosfovic
Lewis Agnew, Los Alamos National Laboratory
Dick Werbeck, Los Alamos National Laboratory
Jim Bradbury, Los Alamos National Laboratory
George Glass, Texas A&M University
Jay A. Wightman, UCLA
Dave Barlow, UCLA
Seppo Penttila, Los Alamos National Laboratory
John Faucett, New Mexico State University
Donald Isenhower, Abilene Christian University
Chandra Pillai, UCLA
Michael Thies, Free University, Amsterdam
Richard Kozack, Los Alamos National Laboratory
Mark Jones, University of Minnesota
Philip Harris, University of New Mexico
Martha Hoehn, Los Alamos National Laboratory
Angel Wang, UCLA
Peter Riley, University of Texas
John McGill, Los Alamos National Laboratory
Arch Thiessen, Los Alamos National Laboratory
Jerry Peterson, University of Colorado
Gerald Garvey, Los Alamos National Laboratory
Michael Sadler, Abilene Christian University
Joey Donahue, Los Alamos National Laboratory
Kalvir Khuga, George Washington University
Elton Smith, Ohio State University
Ju He, Los Alamos National Laboratory & Institute of High Energy Physics, Beijing, China
Jack Lightbody, National Science Foundation
John Jarmer, Los Alamos National Laboratory
Stan Hanna, Stanford University
John Zumbro, Los Alamos National Laboratory
Thomas Romanowski, Ohio State University
Michael Braunstein, University of Colorado

Minutes of 1987 Nuclear Chemistry Working Group Meeting
November 10, 1987
Prepared by Lon-chang Liu, Working Group Chairman

The meeting was held on November 10, 1987 at Room A234 in the LAMPF main office building and was called into order at 2:00 pm. Sixteen LAMPF users attended the meeting.

Dave Vieira of INC-11, LANL, summarized LAMPF nuclear chemistry research activities. He reported that six experiments had been completed: two nuclear mass measurements; three meson reaction studies; and one feasibility study of He-Jet coupled mass separator. In addition, two TOFI-related devices were successfully tested.

Dave Vieira also reported that during the past year, INC11 has provided service supports to users from P-, MP-, AT, and ESS-Division, and from many out-of-lab institutions, by supplying well-maintained detectors and counting equipments in the nuclear chemistry laboratory at D-wing of LOB building.

Merle Bunker of INC-5, LANL, gave a presentation on the status of the feasibility study of He-jet coupled mass separatator at LAMPF. He emphasized that because this separator will enable one to study large numbers of new nuclei far from stability by using thicker targets and at a beam intensity available at LAMPF. This will endow LAMPF a unique capability that no one else can have in the forseeable future. Consequently, it represents a promising direction of nuclear chemistry at LAMPF. He elucidated why the data obtained in these studies will spur new theoretical efforts in new symmetries, nucleosynthesis, and nuclear structure calculations. In addition, he pointed out the potential applications of this facility to astrophysics, neutrino physics, material sciences, reactor technology, isotope production, and weapon research.

Jan Wouters of INC-11, LANL, was elected as the next chairman of the Nuclear Chemistry Working Group.

The participants then discussed various topics related to further improvements of LAMPF nuclear chemistry laboratory.

The meeting was ajourned at 3:15 pm.

Attendees List:

Janet Mercer-Smith, INC-11
Paul L. Reeder, Pacific Northwest Laboratory
Bruce R. Erdal, INC-DO
Don Cochran, MP-DO
Jan Wouters, INC-11
Gil Butler, INC-11
Russ Gritzo, INC-11
Yi-Kyung Kim, Utah State University
Robert Estep, INC-11
Robert Reedy, ESS-8
Alex Gancarz, INC-DO
Merle Bunker, INC-5
Lon-Chang Liu, INC-11
David Moody, INC-11
Zongyuan Zhou, INC-11
Hal O'Brien, P-3

MINUTES OF THE LAMPF SOLID STATE PHYSICS AND MATERIALS SCIENCE WORKING GROUP

November 10, 1987

Attendees:

Ron Livak, Chairman, MST-5, E546
Frank Clinard, MST-5, E546
Shaofei Lin, IAE PRC (MP-3), H809
Pavel Bystricky, MP-4, H846
John Allen, MP-5, H838
Michael Borden, MP-5, H838
Raymond Chavez, MP-5, H838
Cal Hansen, MP-5, H838
Walt Sommer, MP-5, H838
Kit Taylor, MP-5, H838

During the annual meeting of this working group, Frank Clinard was elected to serve as chairman and representative to the newly formed Experimental Facilities Panel. Walt Sommer discussed the present status of the A-6 radiation effects facility. Several experiments in progress and a planned experiment were described by the respective spokesmen.

The proposed new bylaw creating an Experimental Facilities Panel (EFP) to replace the Technical Advisory Panel had been approved by the LAMPF Users Group (see attached ballot). The principal purpose of the EFP will be to facilitate more effective interactions between the users and staff at LAMPF in order to improve operations and future developments. The point was made that a person not associated with MP Division would be more effective in providing user input to the EFP. Frank Clinard (MST-5) was elected to be the EFP representative for 1988 and 1989 and will also chair the working group meetings during the annual Users Meeting.

Walt Sommer discussed the current status of the A-6 facility. Progress is expected during the next two to three years to make modifications that will permit radioactive specimens to be tranferred from the target area to a hot cell for examination. Addititonal resources are needed for the routine operation of the A-6 radiation effects beam line to facilitate ongoing participation by outside users. Progress was made this past year in maintaining a more constant proton source. Because LAMPF is a multiuser facility, the availability of the proton beam is subject to the demands and priorities of other experimenters.

Walt Sommer reviewed some of the capabilities of the A-6 facility. Three proton irradiation ports, each with a usable volume of 150 cm^2, are available with a proton flux in the beam center of $2\text{-}4 \times 10^{14}$ protons/cm^2s. Cooled holders are available for proton irradiations that hold forty 3 mm diameter disks for transmission electron microscopy. Three of the twelve neutron irradiation ports have a neutron flux of $2\text{-}6 \times 10^{13}$ neutrons /cm^2s as determined by activation foil measurements and Monte Carlo calculations.

Neutron irradiation capsules with furnaces have operated up to 650°C with specimens in an inert atmosphere. Closed-loop water and helium heating/cooling systems are available for irradiation experiments. Remote handling of radioactive samples have permitted experiment changes to be made in 6 h during a scheduled LAMPF maintenance day.

The current status of five active experiments was briefly described by Walt Sommer. In Experiment #769 "Proton Irradiation Effects on Candidate Materials for the German Spallation Neutron Source", it was found that precipitation hardened Al-Mg-Si alloys and cold worked Al-Mg alloys are reduced in strength to the annealed level at a low proton dose of 3×10^{20} protons/cm² and a temperature ≤100°C. Experiment #943 "Microstructural Evolution and Mechanical Property Changes in 316 Stainless Steel, Al, and Mo under Irradiation with Different Displacement/Helium Production Rates and Ratios" is continuing as a basic study of microstructural evolution. Two experiments (#986 and #987) by German investigators are studying the spallation neutron irradiation of non-oxide ceramics and polycrystalline graphite for first-wall fusion reactor applications. A basic study comparing the radiation effects produced by different damaging particles is underway as Experiment #1014 "Proton, Spallation Neutron, and Fission Neutron Irradiation of Copper". A continuation of this work is beginning to measure point defect concentrations in several metals produced by 800-MeV proton bombardment.

Calvin Hansen described work done by Bob Brown, Jim Cost, and himself to study radiation damage by 800 MeV proton of Mumetal and amorphous Metglas. Mumetal is presently used at LAMPF to make 6" diameter magnetic toroids used for measuring the proton beam current. These magnets need to be replaced annually because the magnetic permeability degrades. Although the Metglas has an initially lower permeability, there is little change in this property during proton irradiation. These results indicate that current monitors made of Metglas should have twice the useful service life compared to Mumetal magnets. Magnets made of Metglas are now being fabricated for this application.

Frank Clinard described an experiment that is being prepared to study the neutron irradiation response of alumina (Al_2O_3). The purpose of this work is to establish the materials and environmental parameters that affect performance and lifetime of insulators for thermionic converters in nuclear power systems. The environmental parameters to be studied include temperature, DC electric field, oxygen activity, and neutron flux. Both single crystal and polycrystalline alumina, with and without titanium doping, will be included in this experiment. The electrical behavior of the samples will be monitored in-situ during neutron irradiation. The results will be used to model alumina's response in terms of the parameters studied.

ATTENDEES
21ST LAMPF USERS MEETING
NOVEMBER 9 - 10, 1987

DAVID L ADAMS (U OF TEXAS)
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831
LOS ALAMOS NM 87545

LEWIS AGNEW
LOS ALAMOS NATL LABORATORY
MPDO MAIL STOP H850
LOS ALAMOS NM 87545

DIMITRIS ALEXANDREAS
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

JOHN C ALLRED
LOS ALAMOS NATL LABORATORY
MPDO MAIL STOP H850
LOS ALAMOS NM 87545

JAMES F AMANN
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

HELMUT W BAER
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

MARTIN BARLETT
PHYSICS DEPARTMENT
UNIVERSITY OF TEXAS
AUSTIN TX 78712

DAVID B BARLOW
PHYSICS DEPARTMENT
UNIVERSITY OF CALIFORNIA
LOS ANGELES CA 90024

JOE BERGSTEIN
LOS ALAMOS NATL LABORATORY
MP2 MAIL STOP H812
LOS ALAMOS NM 87545

RICHARD D BOLTON
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87544

RICHARD L BOUDRIE
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

CHARLES D BOWMAN
LOS ALAMOS NATL LABORATORY
P3 MAIL STOP D449
LOS ALAMOS NM 87545

J DAVID BOWMAN
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

JAMES N BRADBURY
LOS ALAMOS NATL LABORATORY
MPDO MAIL STOP H844
LOS ALAMOS NM 87545

ANDREW BROWMAN
LOS ALAMOS NATL LABORATORY
MPDO MAIL STOP H844
LOS ALAMOS NM 87545

RONALD E BROWN
LOS ALAMOS NATL LABORATORY
P3 MAIL STOP D449
LOS ALAMOS NM 87545

HOWARD C BRYANT
DEPT OF PHYSICS/ASTRONOMY
UNIVERSITY OF NEW MEXICO
ALBUQUERQUE NM 87131

GEORGE BURLESON
PHYSICS DEPARTMENT
NEW MEXICO STATE UNIVERSITY
LAS CRUSES NM 88003

ROBERT BURMAN
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

GILBERT W BUTLER
LOS ALAMOS NATL LABORATORY
INC11 MAIL STOP J514
LOS ALAMOS NM 87545

ROGER C BYRD
LOS ALAMOS NATL LABORATORY
P2 MAIL STOP D456
LOS ALAMOS NM 87545

A J CAFFREY
TRA 652
EG AND G IDAHO
BOX 1625
IDAHO FALLS ID 83415

THOMAS CAREY
LOS ALAMOS NATL LABORATORY
P2 MAIL STOP D456
LOS ALAMOS NM 87545

DONALD R F COCHRAN
LOS ALAMOS NATL LABORATORY
MPDO MAIL STOP H832
LOS ALAMOS NM 87545

JOSEPH COMFORT
PHYSICS DEPARTMENT
ARIZONA STATE UNIVERSITY
MESA AZ 85281

MARTIN D COOPER
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

G M CRAWLEY
NATL SCIENCE FOUNDATION
1800 G STREET NW
WASHINGTON DC 20550

KALVIR DHUGA
PHYSICS DEPARTMENT
GEORGE WASHINGTON UNIVERSITY
WASHINGTON DC 20052

JOHN B DONAHUE
LOS ALAMOS NATL LABORATORY
MP7 MAIL STOP H840
LOS ALAMOS NM 87545

DAVID ERNST
TEXAS A AND M UNIVERSITY
PHYSICS DEPARTMENT
COLLEGE STATION TX 77843

JOHN A FAUCETT
LOS ALAMOS NATL LABORATORY
MPDO MAIL STOP H831 (NMSU)
LOS ALAMOS NM 87545

ALI FAZELY (LOUISIANA STATE)
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831
LOS ALAMOS NM 87545

DANIEL FITZGERALD
LOS ALAMOS NATL LABORATORY
MP5 MAIL STOP H838
LOS ALAMOS NM 87545

WILL M FOREMAN
LOS ALAMOS NATL LABORATORY
MP1 MAIL STOP H828
LOS ALAMOS NM 87545

H TERRY FORTUNE
PHYSICS DEPARTMENT E 1
UNIVERSITY OF PENNSYLVANIA
PHILADELPHIA PA 19104

ROBERT W GARNETT
PHYSICS DEPARTMENT
NEW MEXICO STATE UNIVERSITY
LAS CRUCES NM 88003

GERALD T GARVEY
LOS ALAMOS NATL LABORATORY
LAMPF/DIR MAIL STOP H836
LOS ALAMOS NM 87545

WILLIAM GIBBS
LOS ALAMOS NATL LABORATORY
T5 MAIL STOP B283
LOS ALAMOS NM 87545

BENJAMIN F GIBSON
LOS ALAMOS NATL LABORATORY
T5 MAIL STOP B283
LOS ALAMOS NM 87545

JOSEPH GINOCCHIO
LOS ALAMOS NATL LABORATORY
T5 MAIL STOP B283
LOS ALAMOS NM 87545

GEORGE GLASS (TEXAS A AND M)
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831
LOS ALAMOS NM 87545

CHARLES D GOODMAN
INDIANA UNIV CYCLOTRON FAC
MILO B SAMPSON LANE
BLOOMINGTON IN 47405

PETER GRAM
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

STEVEN J GREENE
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

DONALD C HAGERMAN
LOS ALAMOS NATL LABORATORY
MPDO MAIL STOP H850
LOS ALAMOS NM 87545

TODD HAINES (U OF MARYLAND)
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831
LOS ALAMOS NM 87545

STANLEY HANNA
STANFORD UNIVERSITY
PHYSICS DEPARTMENT
STANFORD CA 94305

CALVIN HANSEN
LOS ALAMOS NATL LABORATORY
MP5 MAIL STOP H838
LOS ALAMOS NM 87545

JAMES F HARRISON
LOS ALAMOS NATL LABORATORY
MP1 MAIL STOP H810
LOS ALAMOS NM 87545

JU HE
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

PETER HERCZEG
LOS ALAMOS NATL LABORATORY
T5 MAIL STOP B283
LOS ALAMOS NM 87545

ROBERT E HILL
LOS ALAMOS NATL LABORATORY
MP2 MAIL STOP H812
LOS ALAMOS NM 87545

NORTON HINTZ
PHYSICS DEPARTMENT
UNIVERSITY OF MINNESOTA
MINNEAPOLIS MN 55455

MARTHA V HOEHN
LOS ALAMOS NATL LABORATORY
MP7 MAIL STOP H840
LOS ALAMOS NM 87545

CYRUS M HOFFMAN
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

EARL W HOFFMAN
LOS ALAMOS NATL LABORATORY
MP1 MAIL STOP H828
LOS ALAMOS NM 87545

GERALD HOFFMANN
PHYSICS DEPARTMENT RLM 5 208
UNIVERSITY OF TEXAS
AUSTIN TX 78712

GARY E HOGAN
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

RICHARD L HUTSON
LOS ALAMOS NATL LABORATORY
MP5 MAIL STOP H838
LOS ALAMOS NM 87545

DONALD ISENHOWER
ABILENE CHRISTIAN UNIVERSITY
PHYSICS DEPARTMENT
ACU STATION BOX 7646
ABILENE TX 79699

JOHN J JARMER
LOS ALAMOS NATL LABORATORY
MP7 MAIL STOP H840
LOS ALAMOS NM 87545

KEVIN W JONES
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

GEORGE KAHRIMANIS (U OF TEXAS)
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

STEVE KETTELL
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831 (YALE)
LOS ALAMOS NM 87545

ANDI KLEIN
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

JAMES N KNUDSON
LOS ALAMOS NATL LABORATORY
MP7 MAIL STOP H840
LOS ALAMOS NM 87545

THOMAS KOZLOWSKI
LOS ALAMOS NATL LABORATORY
MP1 MAIL STOP H828
LOS ALAMOS NM 87545

PETER H KUTT
PHYSICS DEPARTMENT E 1
UNIVERSITY OF PENNSYLVANIA
PHILADELPHIA PA 19104

GARY KYLE
PHYSICS DEPARTMENT
NEW MEXICO STATE UNIVERSITY
LAS CRUSES NM 88003

DAVID M LEE
LOS ALAMOS NATL LABORATORY
MP13 MAIL STOP H838
LOS ALAMOS NM 87545

MICHAEL LEITCH
LOS ALAMOS NATL LABORATORY
P2 MAIL STOP D456
LOS ALAMOS NM 87545

MELVIN LEON
LOS ALAMOS NATL LABORATORY
MPDO MAIL STOP H844
LOS ALAMOS NM 87545

GORDON LIND
PHYSICS DEPARTMENT
UTAH STATE UNIVERSITY
LOGAN UT 84322

JOHN W LIGHTBODY
NATL SCIENCE FOUNDATION
1800 G STREET NW
WASHINGTON DC 20550

LON-CHANG LIU
LOS ALAMOS NATL LABORATORY
INC11 MAIL STOP H824
LOS ALAMOS NM 87545

JEREMY LLOYD-EVANS
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

WILLIAM LOUIS
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

DUNCAN W MACARTHUR
LOS ALAMOS NATL LABORATORY
N2 MAIL STOP J562
LOS ALAMOS NM 87545

ROBERT MACEK
LOS ALAMOS NATL LABORATORY
MPDO MAIL STOP H848
LOS ALAMOS NM 87545

DONALD R MACHEN
SCIENTIFIC SYSTEMS INTERNATL
3491B TRINITY DRIVE
LOS ALAMOS NM 87544

FESSEHA G MARIAM
LOS ALAMOS NATL LABORATORY
MP5 MAIL STOP H805
LOS ALAMOS NM 87545

JUNE L MATTHEWS
DEPARTMENT OF PHYSICS 26 435
MASSACHUSETTS INSTI OF TECH
CAMBRIDGE MA 02139

JOHN B MCCLELLAND
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

JAMES MCDONOUGH
PHYSICS DEPARTMENT
YALE UNIVERSITY
NEW HAVEN CT 06511

JOHN A MCGILL
LOS ALAMOS NATL LABORATORY
MP5 MAIL STOP H838
LOS ALAMOS NM 87545

KOK-HEONG MCNAUGHTON
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831 U OF TEXAS
LOS ALAMOS NM 87545

MICHAEL MCNAUGHTON
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

RICHARD E MISCHKE
DIVISION OF NUCLEAR PHYSICS
ER 23 GTN
US DEPARTMENT OF ENERGY
WASHING DC 20545

AMIR MOHAGHEGHI
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831 (UNM)
LOS ALAMOS NM 87545

DAVID C MOODY
LOS ALAMOS NATL LABORATORY
INC11 MAIL STOP J514
LOS ALAMOS NM 87545

SHAUL MORDECHAI (U OF TEXAS)
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

HANS-JUERGEN MUNDINGER
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831 (YALE)
LOS ALAMOS NM 87545

DARRAGH E NAGLE
LOS ALAMOS NATL LABORATORY
MPDO MAIL STOP H830
LOS ALAMOS NM 87545

SIRISH NANDA
CEBAF
12070 JEFFERSON AVENUE
NEWPORT NEWS VA 23606

BERNARD M K NEFKENS
PHYSICS DEPARTMENT P J01
UNIVERSITY OF CALIFORNIA
LOS ANGELES CA 90024

BENWEN NI (YALE)
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831
LOS ALAMOS NM 87545

TETSUO NORO (OSAKA UNIVERSITY)
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

DAVID OAKLEY
PHYSICS DEPARTMENT
UNIVERSITY OF COLORADO
BOULDER CO 80309

HAROLD A O'BRIEN
LOS ALAMOS NATL LABORATORY
P3 MAIL STOP D449
LOS ALAMOS NM 87545

MICHAEL OOTHOUDT
LOS ALAMOS NATL LABORATORY
MP1 MAIL STOP H828
LOS ALAMOS NM 87545

HERBERT ORTH
GESELLSCHAFT FUR
SCHWERIOUEUFORSCHUNG
PO BOX 110552
D 6100 DARMSTADT
WEST GERMANY

JEN-CHIEH PENG
LOS ALAMOS NATL LABORATORY
P2 MAIL STOP D456
LOS ALAMOS NM 87545

SEPPO PENTTILA (U OF TURKU)
LOS ALAMOS NATL LABORATORY
MP7 MAIL STOP 840
LOS ALAMOS NM 87545

ROY JERRY PETERSON
UNIVERSITY OF COLORADO
NUCLEAR PHYSICS LABORATORY
CAMPUS BOX 446
BOULDER CO 80309

CHANDRA PILLAI
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831 (UCLA)
LOS ALAMOS NM 87545

BARRY PREEDOM
PHYSICS DEPARTMENT
UNIVERSITY OF SOUTH CAROLINA
COLUMBIA SC 29208

MICHAEL PURCELL (U OF TEXAS)
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

MOHINI W RAWOOL
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831 (ARGONNE)
LOS ALAMOS NM 87545

LANNY RAY
PHYSICS DEPARTMENT
UNIVERSITY OF TEXAS
AUSTIN TX 78712

GLEN A REBKA JR
PHYSICS DEPARTMENT
UNIVERSITY OF WYOMING
LARAMIE WY 82071

PAUL L REEDER
BATTELLE PACIFIC NW LAB
PO BOX 999
RICHLAND WA 99352

CLARENCE F. RICHARDSON
DIVISION OF NUCLEAR PHYSICS
ER 23 GTN
US DEPARTMENT OF ENERGY
WASHINGTON DC 20545

PETER RILEY
PHYSICS DEPARTMENT
UNIVERSITY OF TEXAS
AUSTIN TX 78712

THOMAS A ROMANOWSKI
PHYSICS DEPARTMENT
SMITH LABORATORY
OHIO STATE UNIVERSITY
COLUMBUS OH 43210

LAWRENCE RYBARCYK
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

RICHARD D RYDER
LOS ALAMOS NATL LABORATORY
MP5 MAIL STOP H838
LOS ALAMOS NM 87545

MICHAEL SADLER
PHYSICS DEPARTMENT
ABILENE CHRISTIAN UNIVERSITY
ACU STATION BOX 7646
ABILENE TX 79699

VERNON D SANDBERG
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

GARY SANDERS
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

MARIO SCHILLACI
LOS ALAMOS NATL LABORATORY
MPDO MAIL STOP H844
LOS ALAMOS NM 87545

EDWARD SICILIANO
LOS ALAMOS NATL LABORATORY
T2 MAIL STOP B243
LOS ALAMOS NM 87545

RICHARD SILBAR
LOS ALAMOS NATL LABORATORY
T5 MAIL STOP B283
LOS ALAMOS NM 87545

JAMES D SILK
PHYSICS DEPARTMENT E 1
UNIVERSITY OF PENNSLYVANIA
PHILADELPHIA PA 19104

IVO SLAUS (R BOSKOVIC)
PHYSICS DEPARTMENT
UNIVERSITY OF CALIFORNIA
LOS ANGELES CA 90024

ELTON SMITH (OHIO STATE)
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831
LOS ALAMOS NM 87545

WALTER SOMMER
LOS ALAMOS NATL LABORATORY
MP5 MAIL STOP H838
LOS ALAMOS NM 87545

HAROLD M SPINKA JR
ARGONNE NATL LABORATORY
BUILDING 362 HEP
ARGONNE IL 60439

THOMAS G SQUIRES
ASSO WESTERN UNIVERSITIES
142 EAST 200 SOUTH 200
SALT LAKE CITY UT 84111

GILBERT SUAZO
LOS ALAMOS NATL LABORATORY
MPDO MAIL STOP H850
LOS ALAMOS NM 87545

EVAN R SUGARBAKER
PHYSICS DEPARTMENT
OHIO STATE UNIVERSITY
1302 KINNEAR ROAD
COLUMBUS OH 43212

JULES W SUNIER
LOS ALAMOS NATL LABORATORY
P2 MAIL STOP D456
LOS ALAMOS NM 87545

IVAN SUPEK (ABILENE CHRISTIAN)
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831
LOS ALAMOS NM 87545

MICHAEL THIES
FREE UNIVERSITY
DE BOELELAAN 1105
PB 7161
1007MC AMSTERDAM
THE NETHERLANDS

HENRY A THIESSEN
LOS ALAMOS NATL LABORATORY
MP14 MAIL STOP H847
LOS ALAMOS NM 87545

JAMES R TINSLEY
PHYSICS DEPARTMENT
ARIZONA STATE UNIVERSITY
TEMPE AZ 85287

JOHN ULLMANN
LOS ALAMOS NATL LABORATORY
P3 MAIL STOP D449
LOS ALAMOS NM 87545

OLIN B VAN DYCK
LOS ALAMOS NATL LABORATORY
MPDO MAIL STOP H848
LOS ALAMOS NM 87545

DAVID J VIEIRA
LOS ALAMOS NATL LABORATORY
INC11 MAIL STOP H824
LOS ALAMOS NM 87545

ANGEL T M WANG (UCLA)
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831
LOS ALAMOS NM 87545

RICHARD D WERBECK
LOS ALAMOS NATL LABORATORY
MP7 MAIL STOP H840
LOS ALAMOS NM 87545

D HYWEL WHITE
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

CHARLES A WHITTEN
PHYSICS DEPARTMENT
UNIVERSITY OF CALIFORNIA
LOS ANGELES CA 90024

JAY A WIGHTMAN
PHYSICS DEPARTMENT
UNIVERSITY OF CALIFORNIA
LOS ANGELES CA 90024

BRYAN HOBSON WILDENTHAL
DEAN OF ARTS AND SCIENCE
UNIVERSITY OF NEW MEXICO
ALBUQUERQUE NM 87131

CAROL A WILKINSON
LOS ALAMOS NATL LABORATORY
MP4 MAIL STOP H846
LOS ALAMOS NM 87545

ALLEN WILLIAMS (U OF TEXAS)
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

DAVID WOLF (U OF TEXAS)
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

KIM WOODLE (YALE)
LOS ALAMOS NATL LABORATORY
MPVC MAIL STOP H831
LOS ALAMOS NM 87545

SUNG HOON YOO (U OF TEXAS)
LOS ALAMOS NATL LABORATORY
MP10 MAIL STOP H841
LOS ALAMOS NM 87545

JOHN D ZUMBRO
LOS ALAMOS NATL LABORATORY
MP5 MAIL STOP H838
LOS ALAMOS NM 87545

1988 BOARD OF DIRECTORS OF THE LAMPF USERS GROUP, INC.

The Board of Directors consists of a Secretary/Treasurer 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. Users should address problems and suggestions to individual Board members.

The Board also nominates new members to the Program Advisory Committee (PAC).

The 1988 membership and term expiration dates are listed below.

1989	Stanley Hanna (Chairman) Stanford University
1990	Peter Riley (Chairman-Elect) University of Texas
1988	June Matthews (Past-Chairman) Massachusetts Institute of Technology
	James Bradbury (Secretary/Treasurer) Los Alamos National Laboratory
1988	Joseph Ginocchio Los Alamos National Laboratory
1989	Gary Kyle New Mexico State University
1989	John McClelland Los Alamos National Laboratory
1988	R. Jerry Peterson University of Colorado

LAMPF EXPERIMENTAL FACILITIES PANEL (EFP)

The Experimental Facilities Panel (EFP) consists of not more than fifteen members, each of whom will serve for two 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 shall be 1) to solicit information from the Users and from LAMPF staff on problems, suggested improvements, and future developments; 2) to disseminate such information to the Users; 3) to report on User activities, problems, and suggestions at meetings of the EFP; and 4) to 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. The Chairman of the Board of Directors will act also as Chairman of the EFP.

The 1988 membership and term expiration dates are listed below.

1990	George Burleson New Mexico State University	Polarized Targets
1990	Frank Clinard Los Alamos National Laboratory	Materials Science
1989	Martin Cooper Los Alamos National Laboratory	Stopped-Muon Channel (SMC)
1988	Peter Doe University of California Irvine	Neutrino Facilities
1989	Peter Gram Los Alamos National Laboratory	High-Energy Pion Channel (P^3)
1990	Kevin Jones Los Alamos National Laboratory	High-Resolution Spectrometer (HRS)
1989	Thomas Kozlowski Los Alamos National Laboratory	Computer Facilities
1988	Ralph Minehart University of Virginia	Low-Energy Pion Channel (LEP)
1990	Christopher Morris Los Alamos National Laboratory	Energetic Pion Channel and Spectrometer (EPICS)
1988	Harold Spinka Argonne National Laboratory	Nucleon Physics Laboratory (NPL)
1988	Edward J. Stephenson Indiana University	Member-At-Large
1989	Evan Sugarbaker Ohio State University	Neutron Time of Flight (NTOF)
1990	Jan Wouters Los Alamos National Laboratory	Nuclear Chemistry

LAMPF PROGRAM ADVISORY COMMITTEE (PAC)

The Program Advisory Committee (PAC) consists of about 25 members appointed for staggered 3-year terms. Members advise the Director of LAMPF on the priorities they deem appropriate for the commitment of beam time and the allocation of resources for development of experimental facilities. The PAC meets twice each year for one week during which all new proposals that have been submitted at least two months before the meeting date are considered. Old proposals, and the priorities accorded to them, also may be reviewed.

Terms Expiring in 1988

Hall L. Crannell
Catholic University of America

David J. Ernst
Texas A&M University

James L. Friar
Los Alamos National Laboratory

Daniel S. Koltun
University of Rochester

W. Gary Love
University of Georgia

Norbert T. Porile
Purdue University

D. Hywel White
Los Alamos National Laboratory

Terms Expiring in 1989

Paul T. Debevec
University of Illinois

Ralph G. Korteling
Simon Fraser University

Robert McKeown
California Institute of Technology

John W. Negele
University of Colorado

Daniel D. Strottman
Los Alamos National Laboratory

Terms Expiring in 1990

John Cameron
Indiana University

John Domingo
SIN

Bernard Frois
CEN/Saclay

Peter Herczeg
Los Alamos National Laboratory

Roy Holt
Argonne National Laboratory

William Marciano
Brookhaven National Laboratory

David Measday
University of British Columbia

Peter Nemethy
New York University

Frank Sciulli
Columbia University

LAMPF USERS GROUP, INC.

The LAMPF Users Group, Inc. (LUGI), Board of Directors (BOD) on February 3 and 4, June 16, November 8 and 10, 1987. All meetings were chaired by June Matthews.

There were 150 registrants for the 1987 Annual Users Meeting. The papers presented at the meeting and the minutes of the workshops are given in the proceedings.

The Program Advisory Committee (PAC) met in February and August 1987. For these two sessions 60 new proposals were received. The breakdown follows:

HRS	12
EPICS	15
LEP	13
Nuclear Chemistry	3
NPL	7
SMC	2
P^3	2
HIRAB	5
MRS	1

The BOD selected James McDonough (Temple University) as the recipient of the Louis Rosen Prize for 1987 with his thesis "A Search for the C-Noninvariant Decay $\pi^0 \rightarrow 3\gamma$."

The following workshops are scheduled to be held at LAMPF.

Advanced Hadron Facility Accelerator Design Workshop
February 22-27, 1988

Nuclear and Particle Physics On The Light Cone
July 18-22, 1988

Annual Users Meeting
October 17-18, 1988

RESEARCH PROPOSAL ABSTRACTS

Prop. 1033 Study of the Excitation of Giant Resonances in Pion Charge Exchange and the Proton-Neutron Density Distributions in Nuclei

Spokesmen: F. Irom and J. D. Bowman
Participants and Institutions:

Los Alamos National Laboratory

A. Bergmann	J. D. Bowman
F. Irom	J. N. Knudson
A. Shariv	

University of Colorado

J. J. Kraushaar	R. A. Loveman
R. J. Peterson	D. Prout
R. Ristinen	

Stanford University
D. Pocanic

We propose to use the pion single-charge-exchange reactions, ^{40}Ca $(\pi^\pm, \pi^0)$ and ^{32}S$(\pi^\pm, \pi^0)$ to measure ratio of the maximum (π^-, π^0) cross sections to the maximum (π^+, π^0) cross sections for the analog states of the isovector electric giant-dipole resonance in energies below and above (3,3) resonance. In previous studies on ^{40}Ca at 165 MeV we have seen that the (π^-, π^0) cross section is 1.69 times the (π^+, π^0) cross section. This is contrary to one might expect from charge symmetry, that is that the cross section for (π^-, π^0) cross section should be equal to (π^+, π^0) cross section for T=0 nuclei. We plan to measure this ratio for energies below and above (3,3) resonance to examine the role of the pion mean-free-path for this breakdown of the charge symmetry.

Prop. 1034 Measurement of Light Fragment Emission Spectra From Pion True Absorption

Spokesman: R. A. Loveman
Participants and Institutions:

University of Colorado

J. T. Brack	M. R. Braunstein
B. L. Clausen	J. J. Kraushaar
R. A. Loveman	R. J. Peterson
R. A. Ristinen	K. Vaziri

We propose to measure at LEP the inclusive spectra of light fragments following pion interactions with Ag at 160 MeV. A 'hot spot' model developed initially to describe heavy ion interactions has been applied to pion true absorption. This experiment will provide a conclusive test of the applicability of this model to pion true absorption by examining a wide range of ejectiles. If the model proves valid for this broad set of data, as it did for the limited set of existing data, then the understanding of the dynamics of the hot spot as provided by this model will be a crucial part of the understanding of pion true absorption.

Prop. 1035 Two- and Three-Spin Measurements in pp-pp

Spokesman: M. McNaughton
Participants and Institutions:

Los Alamos National Laboratory
M. McNaughton S. Penttila

University of California, LA
D. Adams J. Bystricky
E. Gulmez G. Igo
A. Ling M. Moshi
M. Nasser

Texas A & M University
G. Glass L. Northcliffe

University of Texas
B. Kielhorn K. McNaughton
G. Pauletta P. Riley
S. Sen

We propose to measure 12 spin dependent parameters in pp elastic scattering at 733 MeV. Angular coverage would be 50 to 80° cm; accuracy would range from ±0.01 to ±0.04. The apparatus used (in EPB) would be identical to that used in exp. 818, except for a change of target material. The time requested is the same as that approved for exp. 960 in BR.

Prop. 1036 The Analyzing Power in the ^{9}Be(p,$\pi\pm$) Reactions at 800 MeV and Its Relation to the Free Pion-Nucleon Scattering Data

Spokesmen: B. Höistad and G. S. Adams
Participants and Institutions:

Renselear Polytechnic Institute
G. S. Adams P. Stoler
D. Tedeschi

University of Minnesota
M. Gazzaly

The Gustaf Werner Institute, Uppsala
B. Höistad

Los Alamos National Laboratory
J. A. McGill K. Jones

University of Texas, Austin
G. Pauletta

Angular distributions of the analyzing power for the ^{9}Be(p,π^+) ^{10}Be and ^{9}Be(p,π^-)^{10}C reactions will be measured at 800 MeV. A phenomenological comparison, based on a model for pion emission from the target nucleus, will be made between the analyzing power from the (p,π) reaction and polarization data from pion nucleon scattering. A link between data from the (p,π) reaction and πN is indicated by recent (p,π) data obtained at 650 MeV. The aim of the present measurements is to confirm or dismiss the hypothesis that the analyzing power in the (p,π) reaction at high energies can qualitatively be understood from on shell pion nucleon scattering data.

Prop. 1037 Study of the $(p, 2\pi^+)$ Reaction in Al at 750 MeV

Spokemen: X. Feng and B. J. Dropesky
Participants and Institutions:

Los Alamos National Laboratory
X. Feng B. J. Dropesky

This is a proposal to carry out a relatively simple activation experiment to measure the cross section for the $(p,2\pi^+)$ reaction in aluminum at 750 MeV yielding 21-hour ^{28}Mg. We propose to irradiate a high-purity Al foil (10 mil) for about 40μAh (20μA for 2 hours) in an available isotope production stringer during a beam development period. The experiment requires radiochemical separation and purification of the magnesium fraction from the dissolved target and counting of the characteristic 1.342 MeV γ ray of ^{28}Mg with our calibrated Ge(Li) γ-ray spectrometer.

Although this $(p,2\pi^+)$ reaction is energetically possible at 750 MeV, we expect the cross section to be small because of the high probability of final state interactions by the produced pions. But we estimate we can measure down to about 10 nanobars, and therefore, we consider the experiment feasible.

Prop. 1038 Pion Inelastic Scattering from ^{48}Ti, ^{52}Cr, and ^{56}Fe at 180 MeV: A Study of Anomalously Shaped Angular Distributions

Spokesman: D. S. Oakley
Participants and Institutions:

Los Alamos National Laboratory
C. L. Morris

University of Texas
C. F. Moore S. Mordechai
M. J. Smithson D. S. Oakley
M. A. Bryan A. Williams

University of Pennsylvania
H. T. Fortune M. Burlein

A recent experiment has measured angular distributions from pion-nucleus scattering at $T_\pi = 180$ MeV and found several angular distributions to not compare with the shape predicted by the known ℓ-transfer. A possible uncertainty, however, has been introduced by an elastic impurity in the EPICS beam arising from the installation of a new collimator in 1984.

Because of the importance of the theoretical interpretations of these findings, we propose to remeasure these states at a later date when the collimator problem is remedied.

Prop. 1039 ^{208}Pb$(\pi,\pi'p)^{207}$Tl Coincidence Measurement Near the Giant Resonance Region: An Investigation of Structure and Charge Symmetry

Spokesmen: D. S. Oakley and C. L. Morris
Participants and Institutions:

University of Texas
C. F. Moore S. Mordechai
D. S. Oakley M. J. Smithson

University of Minnesota
D. Dehnhard M. Jones

Los Alamos National Laboratory
C. L. Morris

Louisiana State University
A. Fazely

The reaction $^4He(\pi,\pi'p)^3He$ near the GDR region has recently been measured at EPICS and the π^+ channel was seen to be an order of magnitude higher than the π^- channel. Measurements of the Giant Quadrupole Resonance in ^{208}Pb have yielded ratios of π^- to π^+ cross sections that are unexpectedly large. A possible explanation of both of these anomalies involves isospin violations. We propose to measure the proton decay of the ^{208}Pb GQR in coincidence with $(\pi^\pm,\pi^\pm)$ in order to investigate these processes.

Prop. 1040 Spin Variable Measurements for the $(\vec{p},n')$ Inclusive Reaction on Several Nuclei

Spokesmen: G. W. Hoffmann and C. Goodman
Participants and Institutions:

University of Texas, Austin
M. L. Barlett D. Ciskowski
G. W. Hoffmann M. Purcell
G. Pauletta L. Ray
W. Thirion

IUCF
C. Goodman

Los Alamos National Laboratory
T. A. Carey K. Jones
N. King J. B. McClelland
T. N. Taddeucci

University of Colorado
D. Lind J. Shepard

Ohio State University
E. Sugarbaker

Ohio University
J. Rapaport

We propose to use the Neutron Time of Flight Facility (NTOF) to measure spin-depolarization data (D_{NN}) on ^{1}H, ^{2}H, ^{12}C, ^{40}Ca, ^{90}Zr and ^{208}Pb at 0 degrees and one larger angle at 800 MeV for inclusive $(\vec{p},\vec{n})$ spectra spanning the energy loss range from the IAS and Gamow-Teller (GT) peaks through the region of quasifree delta production. Along with these data we automatically get the corresponding analyzing power data. We will also measure analyzing power data in 5° steps from 0 - 30° without the corresponding D_{NN} at 800 MeV, 650 MeV, and 500 MeV. The inclusive data will encompass the quasielastic and quasifree Δ-production regions and will complement existing inclusive $(\vec{p},p')$, (p,n′, n,p′) , (^{3}He,t′), (e,e′), and inclusive

γ-absorption data which exhibit the same two-body quasifree excitations and (1) will shed light on the isovector part of the reactive content of the p + A optical potential, (2) may be sensitive to the delta-nucleon (Δ-N) interaction in the nuclear medium, (3) may help in the determination of medium modifications to the isovector part of the free nucleon-nucleon (N-N) interaction, (4) may provide important constraints upon the various N-N isobar models (or other N-N inelastic models), and (5) may provide insight which leads to an understanding of some of the other inclusive data.

Prop. 1041 Study of the $^{13}C(\vec{p}, \vec{n})$ Reaction at 500 MeV

Spokesmen: G. W. Hoffmann and D. Ciskowski
Participants and Institutions:

University of Texas, Austin

M. L. Barlett, D. Ciskowski
G. W. Hoffmann, M. Purcell
G. Pauletta, L. Ray
W. Thirion

IUCF

C. Goodman

Los Alamos National Laboratory

T. A. Carey, K. Jones
N. King, J. B. McClelland
T. N. Taddeucci

University of Colorado

D. Lind, J. Shepard

Ohio State University

E. Sugarbaker

Ohio University

J. Rapaport

We propose to use the Neutron Time of Flight Facility (NTOF) to measure cross section ($d\sigma/d\Omega$), analyzing power ($A_y(\theta)$), and spin-depolarization-rotation (D_{ij}) data for the $^{13}C(\vec{p}, n)$ reaction at 500 MeV. Continuous differential cross section and analyzing power angular distributions will be measured between 0° - 20° laboratory scattering angle with statistical (absolute) uncertainties ± 1-2% (± 0.01-0.02) respectively. Spin depolarization (D_{NN}) and spin-rotation (D_{LL}, D_{LS}, D_{SS}, and D_{SL}) data will be obtained at 0°, 2°, 5°, 8°, 12°, and 16° with statistical uncertainty $\Delta D = \pm 0.05$. A total time of 1017 hours is requested.

Prop. 1042 A Proposal to Extend p + ^{40}Ca, ^{208}Pb, 500 and 800 MeV Data to Large Momentum Transfer

Spokesmen: G. W. Hoffmann and L. Ray
Participants and Institutions:

University of Texas, Austin

M. L. Barlett	D. Ciskowski
G. W. Hoffmann	M. Purcell
G. Pauletta	L. Ray
W. Thirion	

Los Alamos National Laboratory

J. F. Amann	K. Jones

University of Minnesota

M. Gazzaly	N. Hintz

Using the HRS we will extend the 500 and 800 MeV $\vec{p}$ + ^{40}Ca and ^{208}Pb elastic scattering cross sections and analyzing powers to regions where the cross sections are $\sim 3 \times 10^{-7}$ mb/sr with at least 10% statistical accuracy. These new data will provide information regarding the energy, momentum transfer and target mass dependence of the systematic breakdown seen in comparisons of microscopic scattering models with previous large angle data. A total time of 300 hours is requested, with 150 hours at each energy.

Prop. 1043 A Dependence of Non-Analog DCX at Low Energies

Spokesmen: H. T. Fortune and J. D. Zumbro
Participants and Institutions:

University of Pennsylvania

H. T. Fortune	J. D. Zumbro
M. G. Burlein	J. M. O'Donnell
S. Weiser	P. Kutt

Los Alamos National Laboratory
C. L. Morris

New Mexico State University

K. S. Dhuga	G. R. Burleson
M. Rawool	

We propose to measure low-energy cross sections for the non-analog DCX reactions ^{40,44}Ca(π^+, π^-)^{40,44}Ca(g.s.) at one angle and 3-5 energies for each target. Energy interval to be searched is 30-80 MeV. We would like to use these data, combined with earlier data for ^{12}C, to determine the A dependence for low-energy non-analog DCX. With that information, we should be able to explain (we hope) the confusing situation for DIAS DCX.

We remind the reader that at resonance energies, it has turned out that non-analog DCX is much simpler and easier to understand than is analog DCX. We expect the same to be true here.

Prop. 1044 Double Charge Exchange to Excited 0^+ States

Spokesmen: H. T. Fortune and M. B. Burlein
Participants and Institutions:

University of Pennsylvania

H. T. Fortune	J. D. Zumbro
M. G. Burlein	J. M. O'Donnell
S. Weiser	P. Kutt

Los Alamos National Laboratory
C. L. Morris

New Mexico State University

K. S. Dhuga	G. R. Burleson
M. Rawool	

University of Texas, Austin

M. J. Smithson	S. Mordechai
A. Williams	J. McDonald
M. Bryan	C. F. Moore

Argonne National Laboratory
R. Gilman

We propose to measure cross sections for excited 0^+ states in $^{56}Fe(\pi^+, \pi^-)$ DCX at 164 MeV, using a "thin" DCX target and taking data at two angles - 5° and 15°.

Prop. 1045 Low-Energy Pion Double Charge Exchange on N=28 Isotones

Spokesmen: H. W. Baer, M. J. Leitch and E. Piasetzky
Participants and Institutions:

Los Alamos National Laboratory

M. J. Leitch	J. C. Peng
H. W. Baer	R. L. Burman
A. Klein	C. L. Morris

Tel Aviv

E. Piasetzky	Z. Weinfeld

Arizona State University

J. Comfort	J. Tinsley

Virginia Polytechnic Inst.
D. H. Wright

We propose to measure the differential cross section for pion double charge exchange on ^{50}Ti, ^{51}V, ^{52}Cr, ^{54}Fe at 35 MeV. Together with the available data at this energy on the $^{42,44,48}Ca$ isotopes the measurements will allow future insight into the large observed irregularity of the double- isobaric-analog transitions as a function of the neutron excess number, and will help reveal the mechanisms responsible for the phenomena. Our current understanding is that it has to do with one of the central questions of nuclear dynamics: the short-range part of the N-N correlations.

Prop. 1046 Neutron Emission from Pion Absorption Near the $\Delta_{3/2,3/2}$ Resonance

Spokesmen: R. D. Ransome
Participants and Institutions:

Los Alamos National Laboratory
K. W. Jones | J. A. McGill
C. L. Morris

Arizona State University
J. R. Comfort | B. G. Ritchie
J. Tinsley

New Mexico State University
G. S. Kyle

Rutgers University
R. W. Fergerson | C. Glashausser
R. D. Ransome

University of Colorado
R. A. Loveman

University of Pennsylvania
J. D. Zumbro

University of Texas, Austin
C. F. Moore

University of Virginia
P. C. Gugelot

We propose to measure the energy spectrum of neutrons emitted in coincidence with two protons for π^+ absorption in ^{208}Pb and ^{12}C. Data will be taken for π energies of 100 and 200 MeV.

Prop. 1047 Search for Low Lying Magnetic States in an $f_{7/2}$ Shell Nucleus

Spokesmen: N. M. Hintz
Participants and Institutions:

University of Minnesota
B. Bayman | D. C. Cook
M. Gazzaly | N. M. Hintz
M. Franey | A. Mack
S. Nanda

University of Texas
M. Barlett | G. Hoffman
G. Pauletta

Rutgers University
L. Zamick

We propose to search for predicted low lying ($E_x \leq 7$ MeV) magnetic multipole states (λ = 1,3,5,7) in ^{48}Ti by measuring A_y and the spin flip cross section, σs_{nn} in (p,p′) near 325 MeV. Such states are predicted in the $f^n_{7/2}$ configuration model for nuclei between N, Z = 20 and 28, and are expected to possess an appreciable fraction of the single particle strength. The low lying M(1) states in the $f_{7/2}$ region bear a close resemblance to the recently discovered "scissor modes" in the deformed region. The experiment would be the first to test the predictions of the simple $f^n_{7/2}$ model for the little known magnetic excitations of multipolarity, $\lambda > 1$.

Prop. 1048 A Complete Measurement of Elastic Observables from ^{58}Ni with $\simeq$ 325 MeV Protons

Spokesmen: D. C. Cook

Participants and Institutions:

University of Minnesota

N. M. Hintz   M. Gazzaly

A. Hack

University of Texas

G. Pauletta   M. Barlett

G. W. Hoffmann

We propose to measure the cross section, analyzing power, and spin rotation parameter Q on ^{58}Ni at a proton bombarding energy near 325 MeV. A_y will be measured from 4° - 38.5° at 1.5° intervals. We will obtain Q by measuring D_{SS}, and D_{LS}, from 4° - 29.5° in 1.5° intervals. The short term goal of this experiment is to extablish the most successful way to treat the optical potential phenomenologically. This will help us in the analysis of ^{58}Ni(p,p′) inelastic cross section data taken previously at this incident energy. The longer term goal is to understand whether effects due to the nuclear medium, or relativistic effects, or both are contributing to the present difficulties in reproducing elastic spin observables in this energy regime. Also, the cross sections and analyzing powers obtained for the strong collective states will provide a further test of the distorting potential and available N-N interactions.

Prop. 1049 Operational Test of a He-Jet System for Transporting Short-Lived Nuclei Produced at LAMPF

Spokesmen: W. L. Talbert, M. E. Bunker

Participants and Institutions:

Los Alamos National Laboratory

M. E. Bunker   W. L. Talbert

J. W. Starner   R. J. Estep

We propose to install a He-jet target chamber in the LAMPF main beam in Area A6 and study its operational characteristics. Ultimately, the He-jet system would be used to transport to an isotope separator the short-lived radionuclides far from stability produced in high-energy proton-induced reactions. There are several hundred unknown radioisotopes far from stability, not available at any other facility in the world, that could be isolated for study with such a system.

The principal objectives of the present experiment will be (1) to establish that our He-jet target-chamber design provides efficient transport of reaction products under the extreme radiation conditions posed by the 1-mA beam; and (2) to establish that the uranium targets will remain intact for weeks under 1-mA bombardment.

The target chamber will be mounted in the radiation effects area of A-6 on the end of the movable vertical stringer, outside the main vacuum line. The diagnostic equipment will be located in the new staging area. A He-jet capillary transport line will be installed between the target chamber and a heavily-shielded collection chamber located on the staging-area floor. The target chamber, which is to be water cooled, is sufficiently thin that it will not perturb downstream experiments. Thus, our experiment will be parasitic in the sense that it will not normally compete for beam time.

Prop. 1050 A Search for Double-Dipole Excitation Using Pion Double Charge Exchange

Spokesmen: M. J. Smithson, S. Mordechai and C. L. Morris

Participants and Institutions:

University of Texas

M. J. Smithson, S. Mordechai, C. F. Moore, D. S. Oakley, J. W. McDonald, M. A. Bryan, A. L. Williams

Los Alamos National Laboratory

C. L. Morris

University of Pennsylvania

J. D. Zumbro, H. T. Fortune, M. G. Burlein, J. M. O'Donnell, S. Weiser

New Mexico State University

K. S. Dhuga, G. R. Burleson, J. A. Faucett, R. W. Garnett

We propose to use pion double charge exchange to look for double-dipole excitation in ^{40}Ca, ^{90}Zr and ^{208}Pb at T_π = 290 MeV. The measurements will be at two angles, at a forward angle of 5° and at around 25°, the second peak of the theoretical angular distribution for the double dipole. Our primary aim is to detect these previously unseen modes of nuclear excitation. We have chosen closed-shell nuclei for this study because giant dipole resonances have minimum width (FWHM $\simeq$ 4 MeV) in these nuclei. Static coupled-channel impulse-approximation calculations show that the cross section for exciting the dipole increases by about a factor of 2.5 for ^{40}Ca as the incident pion energy is increased from 165 to 290 MeV. Thus we propose to make the measurements at the highest possible energy at EPICS. The requested running time of 12 days is based on the predicted peak cross section for the double dipole, 0.6, 0.8, and 0.5 μb/sr for ^{40}Ca, ^{90}Zr and ^{208}Pb, respectively, at T_π = 290 MeV.

Prop. 1051 Measurement of M1 and M2 Strength in ^{140}Ce and Comparison with Other Experiments

Spokesmen: F. T. Baker
Participants and Institutions:

Los Alamos National Laboratory
K. Jones

University of Georgia
F. T. Baker A. Sethi

Rutgers University
R. Fergerson C. Glashausser
A. Green

University of Minnesota
S. Nanda

Orsay
L. Bimbot

Michigan State University
C. Djalali

Previous measurments using (e,e′), (p,p′), and scattering of polarized tagged photons disagree regarding the relative M1 and M2 strengths present in the excitation-energy range of 7.5-11 MeV. The proposed experiment will be able to simultaneously measure both strengths without the usual uncertainties associated with the underlying natural-parity backgrounds; this will be achieved by measuring the spin-flip cross section which is approximately zero for this background. In addition, data will be taken up to about 40 MeV excitation to extend our survey of the spin response of nuclei to heavier targets. Attention will also be paid to the data for the non-spin-flip spectrum with the goal of deducing the strengths of giant resonances of natural parity.

Prop. 1052 Calibration of the LAMPF Neutron Time-of-Flight Facility Detector System Using a Tagged Neutron Beam

Spokesmen: J. B. McClelland and T. A. Carey
Participants and Institutions:

Los Alamos National Laboratory
T. A. Carey N. S. P. King
J. B. McClelland T. N. Taddeucci

Ohio State
E. Sugarbaker L. Rybarcyk

University of Texas
D. Ciskowski G. Hoffmann

Indiana University
C. Goodman

University of Colorado
D. Lind J. Shephard

Ohio University
J. Rapaport

We propose to measure integral and differential efficiencies as well as position resolution and systematic effects for the newly developed Neutron Time-of-Flight (NTOF) neutron detector array using a tagged neutron beam for neutron energies $50 < T_n < 750$ MeV. Early in the commissioning phase of NTOF the integral efficiency of the detector system will be needed to perform cross section measurements in the (p,n) reaction. Differential efficiencies, position resolution, and cross-talk systematics for the new array will be essential in understanding the system in the polarimeter mode.

Prop. 1053 Feasibility Study for Detecting Gamma Rays in Coincidence with Scattered Protons at the HRS

Spokesmen: H. Funsten, R. Fergerson, J. Comfort, S. Nanda
Participants and Institutions:

Los Alamos National Laboratory
K. Jones

Arizona State University
J. Comfort J. Tinsley

Rutgers University
R. Fergerson C. Glashausser

William and Mary
H. Funsten V. Punjabi

Virginia State University
C. Stronach

George Mason University
J. Lieb

University of Minnesota
S. Nanda

Florida State University
H. Plendl

University of Mississippi
J. Reidy

We propose to test the feasibility of performing gamma-ray correlation experiments at the LAMPF HRS spectrometer by using BGO scintillation counters placed close to the target to detect the gamma rays. If successful, a variety of correlation experiments between gamma rays and the effects of various Line C collimator settings and tunes as well as shielding arrangement and detector placement on the BGO randoms rate. We do not ask for Line X control.

Prop. 1054 Ultrahigh Precision Measurements on Muonium Ground State: Hyperfine Structure and Muon Magnetic Moment

Spokesmen: V. W. Hughes, G. zu Putlitz and P. A. Souder
Participants and Institutions:

Los Alamos National Laboratory
F. G. Mariam

University of Heidelberg
K. P. Arnold, H. J. Mundinger
G. zu Putlitz

Syracuse University
P. A. Souder

William and Mary
M. Eckhause, P. Guss
J. Kane

Yale University
S. Dhawan, V. W. Hughes
S. Kettell, Y. Kuang
B. Matthias, B. Ni
R. Schaefer

An ultrahigh precision measurement of the muonium hyperfine structure interval $\Delta\nu$ and of the magnetic moment ratio μ_μ/μ_p is proposed at LAMPF with the goal of determining $\Delta\nu$ to 5 ppb and μ_μ/μ_p to 50 ppb, which correspond to improvement factors of 5 to 10 over present experimental values. The microwave magnetic resonance spectroscopy method will be employed, using the intense and pure subsurface μ^+ beam from SMC, a large homogeneous solenoid, and a line-narrowing method involving a chopped μ^+ beam.

Prop. 1055 Total and Differential Cross Sections for $\pi^+ d \rightarrow pp$ Below 20 MeV

Spokesmen: R. C. Minehart and B. G. Ritchie

Participants and Institutions:

Arizona State University
J. Comfort, B. G. Ritchie, J. Tinsley

University of South Carolina
G. S. Blanpied, B. M. Preedom

University of Virginia
R. M. Marshall, R. C. Minehart, L. C. Smith

Virginia Polytechnic Inst.
D. H. Wright, M. Blecher

The total and differential cross sections for $\pi^+ d \rightarrow pp$ will be measured at energies of 10, 15, and 20 MeV. Uncertainties will be reduced to 5% for the total cross section. The low energy beams will be transported through the LEP channel to the LAMPF electrostatic separator located in the LEP cave at the exit of the channel. The techniques will be similar to those used in Exp. 828. During that experiment the separator was quite effective but the electron and muon contamination before the separation was so large that the pions made up only about 10% of the beam on target at 10 MeV. The precision of our measurement of this fraction was only about 30%. In the new experiment we intend to measure the pion flux to about 3%. In addition we plan to do further development on the 10 MeV beam to increase both the pion fraction and the absolute pion flux. The results from this experiment will provide a check on the only measurements available at these energies for the energy dependence of the total cross section (those by Rose), which have large absolute uncertainties and will test the theoretical predictions for s-wave pion production at very low energies. 400 hours of beam time in the low energy pion channel are requested.

Prop. 1056 The $^{10}Be(\pi^+, \pi^-)^{10}C$ Reaction

Spokesmen: J. D. Zumbro

Participants and Institutions:

Los Alamos National Laboratory
C. L. Morris

University of Pennsylvania
M. G. Burlein, H. T. Fortune, J. O'Donnell, J. D. Zumbro

New Mexico State University
K. S. Dhuga

Argonne National Laboratory
R. Gilman

University of Texas
C. F. Moore

We propose to measure the cross section for the $^{10}Be(\pi^+, \pi^-)^{10}$ C(DIAS) reaction at 292 MeV and a laboratory angle of 5° with a statistical precision of approximately 5 percent. This measurement will permit us to decide between a pure $A^{-7/3}$ dependence for the $T=1$ analog transitions and a two-amplitude model in which the analog amplitude squared is $A^{-10/3}$. (Standard $A^{-10/3}$ is already known not to work for $T=1$ targets.)

Prop. 1057 Study of Pion Double Charge Exchange Reactions ^{76}Ge(π^+,π^-)^{76}Se(g.s), ^{82}Se(π^+,π^-)^{82} Xe(g.s.), ^{100}Mo(π^+,π^-)^{100}Ru(g.s.)

Spokesmen: A. Fazely and L. C. Liu
Participants and Institutions:

Los Alamos National Laboratory
S. J. Greene L. C. Liu
C. L. Morris

University of Pennsylvania
M. Burlein H. T. Fortune
J. D. Zumbro

University of New Mexico
B. Dieterle C. Leavitt

New Mexico State University
K. S. Dhuga R. Garnett

Louisiana State University
A. Fazely

University of Massachusetts
S. J. Rokni

University of York
D. Watson

We propose to measure forward-angle nonanalog 0^+(g.s.) $\rightarrow$ 0^+(g.s.) double charge exchange (DCE) cross sections for ^{76}Ge, ^{82}Se and ^{100}Mo in the Δ_{33} resonance region. As there is a relation between the neutrinoless $\beta\beta$-decay rate and the forward-angle DCE cross section, the measured cross sections can be used to set a tighter limit on lepton number violation. Furthermore, the nuclear structure information obtained from these measurements will help in better understanding strengths of neutrinoless $\beta\beta$-decay rates for these nuclei. These measurements also provide a global test of the A-dependence of the nonanalog DCE cross sections.

Prop. 1058 Study of the Isovector Monopole Interior Transition Density

Spokesmen: S. H. Rockni, R. A. Loveman and J. D. Bowman
Participants and Institutions:

Los Alamos National Laboratory
J. D. Bowman D. Fitzgerald
A. Klein

University of Colorado
R. A. Loveman R. J. Peterson

Stanford University
D. Pocanic B. King

Utah State University
S. H. Rokni

We propose an experiment to demonstrate that in the interior of the nucleus the Isovector Monopole Resonance transition density has the opposite sign from the nuclear surface. In the energy region between the peak of the (3,3) resonance and 500 MeV, the pion mean free path changes from the 0.7 fm to 3 fm, so that the reaction changes from surface peaked to a regime where the interior of the nucleus is probed.

We propose to measure the ratio of maximum cross section for the Isovector Monopole Resonance (IVM) to the Giant Dipole Resonance (GDR) in the $^{60}Ni(\pi^-, \pi^0)$ reaction at beam energies 300, 365, 425, and 500 MeV. The measurements will cover a range of momentum transfers well beyond the first minimum of the IVM and GDR. A detailed analysis of the energy dependence of the IVM to GDR ratio will be made to determine the radius at which the IVM transition density crosses zero.

Prop. 1059 90° Spin Correlation, A_{SL}, and Deuteron Vector Polarization for $\vec{p}\,\vec{p}, \rightarrow \vec{d}\,\pi$ at 733 MeV

Spokesmen: G. Glass and L. Northcliffe

Participants and Institutions:

Los Alamos National Laboratory
N. Tanaka

University of California, LA
D. Adams D. Barlow

University of Minnesota
M. Gazzaly

Texas A & M University
G. Glass H. Hiebert
R. Kenefick S. Nath
L. Northcliffe

University of Montana
R. Jeppesen

University of Texas
K. H. McNaughton G. Pauletta
S. Sen P. Riley

ANL/NMSU
M. Rawool

University of Udine
L. Santi

Washington State University
G. Tripard

We propose to measure the spin correlation parameter A_{SL} and the vector polarization of the deuteron in the reaction $\vec{p}\,\vec{p} \rightarrow \vec{d}\,\pi$ at one energy 733 MeV and at 90 ° center of mass by taking the advantage of a spectrometer system already setup to measure elastic pd scattering.

Prop. 1060 Measurement of the π^-/π^+ Cross Section Ratio for the Giant Quadrupole Resonance in ^{90}Zr, ^{118}Sn and ^{208}Pb at 65 MeV

Spokesmen: J. J. Kraushaar and R. J. Peterson

Participants and Institutions:

Los Alamos National Laboratory
C. L. Morris J. L. Ullmann

University of Colorado
J. J. Kraushaar R. A. Loveman
R. J. Peterson R. A. Ristinen

Arizona State University
B. Ritchie J. R. Tinsley

It is proposed that the cross sections for the π^- and π^+ excitation of the giant quadrupole resonances in ^{90}Zr, ^{118}Sn and ^{208}Pb be measured at a pion energy of 65 MeV with the Clamshell spectrometer on the LEP beamline. At energies nearer to the (3,3) resonance, π^- to π^+ ratios for the excitation of the GQR have been found to range from 2 to 3 for ^{118}Sn and ^{208}Pb. These values are considerably larger than those given by the standard hydrodynamic model. Several explanations that have been put forth can be critically tested by the use of low energy pions, where the increase in wavelength and mean free path length will deemphasize the contribution of the neutron-rich nuclear surface.

Prop. 1061 Polarization Transfer and Analyzing Power Measurements for the ^{15}N(p,n)^{15}O Reaction at E_p = 500 MeV

Spokesmen: J. R. Shepard and T. N. Taddeucci
Participants and Institutions:

Los Alamos National Laboratory
R. Byrd — T. A. Carey
N. S. P. King — J. B. McClelland
T. N. Taddeucci

Colorado School of Mines
J. A. McNeil

Ohio State University
E. Sugarbaker — L. J. Rybarcyk

Indiana University
C. D. Goodman

University of Colorado
D. A. Lind — R. A. Loveman
J. R. Shephard — C. D. Zafiratos

Ohio University
J. Rapaport

University of Texas
G. W. Hoffman — M. L. Bartlett
D. Ciskowski

Simon Fraser University
R. G. Jeppesen

We propose to measure a complete set of polarization transfer observables for the ^{6}Li(p,n)^{6}Be(g.s.) and ^{15}N(p,n)^{15}O(g.s.) reactions at 500 MeV. In addition, we propose to measure the analyzing power for the ^{15}N(p,n) reaction to judge its suitability as a polarized neutron source reaction for polarimeter and neutron spin processor calibrations.

^{15}N is of interest because of its simple description as a closed shell $\pm$ 1 nucleus. In spite of this simple model description, surprising variations in (p,n) cross section magnitudes relative to cross sections for other p-shell nuclei have been observed. Similar cross section anomalies have also been observed for nuclei such as ^{13}C and ^{39}K, which have led to speculations about required modifications of the Gamow-Teller transition operator. A larger body of data, including polarization transfer measurements (for $E_p \leq 200$ MeV), seems to contradict some of these speculations, however. Thus, no convincing explanation of the cross section magnitudes has yet been given for this and related transitions and additional experimental information is clearly needed. The measurements proposed here, in conjunction with data from other probes such as (e,e′), will provide stringent tests of the nuclear structure involved. These measurements will make it possible to isolate for the first time specific structure contributions such as the transverse and longitudinal spin responses. The ^{6}Li measurements to be made in parallel with the ^{15}N measurements will provide a calibration of the reaction model with a classic, well-understood Gamow-Teller transition.

Prop. 1062 Study of Pure Fermi and Gamow-Teller Transitions in the $^{14}C(p,n)^{14}N$ Reaction

Spokesmen: E. Sugarbaker and T. N. Taddeucci

Participants and Institutions:

Los Alamos National Laboratory

R. Byrd, T. A. Carey, N. S. P. King, J. B. McClelland, T. N. Taddeucci

Ohio State University

L. J. Rybarcyk, E. Sugarbaker

Indiana University

C. D. Goodman

University of Colorado

D. A. Lind, J. R. Shepard

Ohio University

J. Rapaport

University of Texas

G. W. Hoffman, M. L. Bartlett, D. Ciskowski

We propose to measure 0° cross sections for the $^{14}C(p,n)^{14}N$ reaction at bombarding 350, 500, 650, and 800 MeV, and the analyzing power and 0° polarization transfer at 500 MeV. This reaction provides a unique opportunity to study the isovector spin-flip and non-spin-flip components of the effective nucleon-nucleon interaction. The special feature of this particular reaction is that the ^{14}N(2.31 MeV) state populated via a pure Fermi (F) $0^+ \rightarrow 0^+$ transition is separated by 1.6 MeV from its nearest neighbor, populated via a Gamow-Teller $0^+ \rightarrow 1^+$ transition. This reaction thus provides the best experimental opportunity with which to cleanly resolve F strength in a (p,n) reaction in this energy range. The ratio GT to F 0° cross sections can be related to $|J_{\sigma\tau}/J_\tau|$, the ratio of effective isovector interaction strengths at $q = 0$. Experimental results between 200-450 MeV from IUCF and TRIUMF have revealed significant discrepancies with calculated values for the interaction-strength ratio based on a free NN t-matrix. The proposed measurements will provide a quantitative description of $\Delta S=1$ and $\Delta S=0$ transitions in an energy range for which no precise data currently exist. Empirical values for the ratio of GT to F cross sections will be very useful in the interpretation of future (p,n) data obtained at LAMPF.

At 0°, the resolved IAS transition also provides a source of neutrons having the same polarization as the incident proton beam, thus permitting an accurate absolute calibration of the neutron polarimeter. Determination of the polarimeter effective analyzing power for both transverse components will require measurements with N and S incident proton polarization. Such measurements in conjunction with a neutron spin processor will also provide an exacting test of the operation of this device.

Prop. 1063 The Relative $\Delta S=1/\Delta S=0$ Spin Response in ^{40}Ca

Spokesmen: L. Bimbot and G. Glashausser
Participants and Institutions:

Los Alamos National Laboratory
K. W. Jones

University of Georgia
F. T. Baker

Rutgers University
D. Beatty F. Fergerson
C. Glashausser A. Green

Orsay
L. Bimbot M. Morlet
A. Willis

University of Minnesota
S. K. Nanda

The spin-flip probability S_{nn} will be measured for inelastic scattering from ^{40}Ca at 800 MeV over the angular region from about 3° to 10°. The excitation energy ω will extend to about 45 MeV. The cross section σ, the analyzing power A_y, and the spin-flip cross section σS_{nn} will be measured over the same range. The main goal is to determine the nuclear response in the spin transfer ($\Delta S=1$) channel relative to the response in the channel without spin transfer ($\Delta S=0$); this is directly related to S_{nn}. The results will test the accuracy of a similar determination of this relative response for ^{40}Ca as measured in Experiment 903 with 319 MeV protons. A surprising enhancement of the nuclear response was observed at some angles at ω near 40 MeV in Exp. 903; the $\Delta S=1$ response was 30% or more of the total response. The requested time is 196 hours.

Relationship to other approved experiments: This experiment is essentially the same as the ^{40}Ca portion of Exp. 903 of our group which has been completed; the only difference is that it is being run at a different energy, 800 MeV instead of 319 MeV.

Prop. 1064 Pion Scattering from ^{3}H and ^{3}He Near 180° in the Region of the Δ_{1232} Resonance

Spokesmen: W. J. Briscoe, B. L. Berman, and B. M. K. Nefkens
Participants and Institutions:

George Washington University
W. J. Briscoe   B. L. Berman
A. Mokhtari   M. F. Taragin

University of California, LA
B. M. K. Nefkens   C. Pillai
J. A. Wightman   G. Kim
D. B. Barlow

Abilene Christian University
M. E. Sadler   D. Isenhower

Ruder Boskovic Institute
I. Slaus

We propose to measure the four differential cross sections for the back-scattering of charged pions from ^{1}H and ^{3}He to a precision of 3 to 5%. These cross sections will be normalized to those for ^{3}H and ^{2}H measured under the same experimental conditions. The measurements will be performed for incident pion energies between 140 and 260 MeV and angles from 160° to 180°. The target cells were used successfully in Exp. 905; a new sample changer will be built for this experiment. The sample masses will be determined by direct measurement.

Because of the vanishing of the spin-flip amplitude at 180°, the use of a polarized target is not needed to determine the non-spin-flip scattering amplitude (independent of the spin-flip amplitude and the relative phase). In this experiment, we will obtain this information for the paired and unpaired nucleons in both of the three-body nuclei. In a simple view, differences between pairs of these four quantities would indicate charge symmetry ascribable either to medium effects (three-body forces) or to isospin non-conservation in the pion-nucleon reaction mechanism. Equality of these quantities, on the other hand, is a strong indication that the charge asymmetry observed in previous measurements is ascribable to the spin-flip part of the cross section.

The momentum-transfer dependence of the form factors will be measured up to the very large value of 12 fm^{-2} in this experiment. This makes it possible for us to explore any differences in the form factors for ^{3}H and ^{3}He where such differences (if they exist) would be roughly a factor of five larger than in the non-spin-flip dip.

Prop. 1065 Simulations of the Production of Cosmogenic Nuclides in Meteorites by Galactic-Cosmic-Ray Protons

Spokesmen: A. J. Englert

Participants and Institutions:

San Jose State University
P. A. J. Englert

Los Alamos National Laboratory
R. C. Reedy

University of Hannover
R. Michel

Max Planck Institut fuer Chemie
F. Begemann H. Weber

University of Cologne
P. Dragovitsch U. Herpers

Institute for Reactor Development
P. Cloth D. Filges

Institute for Crystallography and Petrography
P. Signer R. Wieler

Institute for Middle Energy Physics
W. Woelfli

Racah Institute of Physics
D. Fink M. Paul

University of Pennsylvania
J. Klein R. Middleton

Rutgers University
G. F. Herzog

Lawrence Livermore Laboratory
M. Caffe R. C. Finkel
B. Hudson C. Velsko

University of California, SD
J. R. Arnold K. Marti
K. Nishiizumi

University of Arizona
D. J. Donahue T. Jull

A large variety of stable and radioactive cosmogenic nuclides is produced by the interaction of galactic cosmic radiation with extraterrestrial matter. Measurements of those cosmogenic nuclides provide the only source of information on the past history of the galactic cosmic ray fluxes and on the irradiation history of individual extraterrestrial objects, provided that there exist reliable models describing cosmogenic nuclide production processes. For the complete description of the depth dependent production of cosmogenic nuclides in meteorites the existing models are in need of improvement. To alleviate the problem the irradiation of small spherical meteorite models with 800 MeV protons to simulate the cosmit rav interaction is proposed.

The meteorite models are spherical objects of radii between 10 and 25 cm, made of material that resembles the average common meteorite composition and density. The meteorite models provide locations within their structure that allow the exposure of pure elements and chemical compounds during irradiation. The spheres will be moved within the proton beam such that the isotropical exposure in space is simulated. Thus, the model body will produce the secondary particle cascade under proton bombardment that will produce cosmogenic nuclides within the materials exposed. These materials will be retrieved and analyzed for their cosmogenic nuclide content by instrumental or radiochemical methods.

Thin targets of the same elements and compounds exposed within the meteorite model will be irradiated separately and/or simultaneously upstream of the model in order to determine the primary proton production rates.

The combination of thin and thick target bombardments will allow the deconvolution of primary and secondary nucleon spectra as a function of location in the models and energy. Further, information will be obtained on depth profiles of the production rates of cosmogenic stable and radioactive nuclides. These data will provide a basis for the interpretation of cosmogenic nuclide production in meteorites, especially with respect to their irradiation histories.

Prop. 1066 The Exotic Nucleus Helium-9 and Its Excited States

Spokesmen: K. K. Seth
Participants and Institutions:

Northwestern University
K. K. Seth R. Soundranayagam

University of Massachusetts
B. Parker

In a recent experiment the ground state of the exotic nucleus, ^{9}He was identified and its mass was measured. It was found that not only is the ground state width quite small, $\leq$ 600 keV, (it is unbound by only $\sim$ 1.1 MeV), but there is evidence that the widths of several excited states are also quite small. It is proposed to make a good resolution, good statistics study of the $^9Be(\pi^+,\pi^-)^9He$ reaction at $T(\pi^+) \approx 200$ MeV at θ(lab) = 5° and 25° in order to firmly establish the existence of these excited states, measure their widths and hopefully J^π in a few favourable cases. Comparison will be made with the predictions of recent 'no core' shell-model calculations.

Prop. 1067 Study of Pion Induced DCX on ^{88}Sr

Spokesmen: K. K. Seth
Participants and Institutions:

Northwestern University
K. K. Seth R. Soundranayagam

University of Massachusetts
B. Parker

Basic understanding of the mechanism of pion double charge exchange reactions (π^+,π^-) appears to be now at hand. This is primarily due to the excellent experimental data obtained in the resonance region for a large number of analog and non-analog transitions and due to the efforts of several theoretical groups. However, all the experiments to date are confined to studies in light nuclei with $A \leq 60$, and it is indeed an open question whether the existing models will have any success for heavier nuclei. It is proposed to make a detailed study of the DCS excitation of the 17.2 MeV analog state in the $^{88}Sr(\pi^+,\pi^-)\,^{88}Zr$ reaction. Excitation function at $\theta = 5°$ will be measured in the range 130 MeV to 292 MeV and angular distributions will be measured at $T(\pi^+) = 180$ MeV and 292 MeV. At 180 MeV, the non-analog g.s. transition will also be measured at $\theta = 5°$.

Prop. 1068 Analog DCX on ^{42}Ca at 50 MeV

Spokesmen: K. K. Seth
Participants and Institutions:

Northwestern University
K. K. Seth R. Soundranayagam

University of Massachusetts
B. Parker

Interesting and unexpected systematics has been recently revealed in double analog transitions in pion induced DCX at low energies, $T(\pi) \approx 50$ MeV. In marked contrast to the $\sim A^{-10/3}$ decrease of forward angle DCX cross sections at the resonance energies, it is found that at 50 MeV the DCX cross sections for ^{14}C, ^{18}O, and ^{26}Mg targets are nearly identical. What is even more surprising, an exploratory measurement made by us shows that the 50 MeV forward cross section for even ^{42}Ca is nearly the same as for the lighter targets. It is now proposed to make a good statistics measurement of $^{42}Ca(\pi^+,\pi^-)^{42}Ti$ (g.s.) angular distribution at $T(\pi) = 50$ MeV in the range of $\theta = 20° - 100°$. It is believed that such a measurement will provide important constraints for the theories of low energy DCX which are being currently developed.

Prop. 1069 Low-energy pion single-charge exchange on ^{14}C to resolved low-lying states

Spokesman: M.J. Leitch
Participants and Institutions:

Los Alamos National Laboratory

M. E. Anderson	R. C. Byrd
T. A. Carey	J. S. Kapustinsky
M. J. Leitch	C. S. Mishra
J. C. Peng	T. Taddeucci
J. L. Ullmann	H. W. Baer

We propose to make the first measurements of pion single-charge exchange to the Gamow-Teller spin-flip and other non-analog states in the residual nucleus. The proposed measurements near 50 MeV begin with the reaction $^{14}C(\pi^+, \pi^0)^{14}O$, resolving the low-lying states in the residual nucleus from each other including Gamow-Teller spin-flip state at 3.95 MeV excitation. The isobaric-analog state transition, which is important for the interpretation of double-charge exchange (DCX) on ^{14}C, will also be isolated and its uncontaminated cross section determined. Further measurements on ^6Li, $^{12,13}C$, and ^{27}Al will follow to establish the trends for these transitions and to provide direct comparisons for specific nuclear transitions with results from (p,n) studies. In order to separate these states the upgraded P-2 η spectrometer will be used to obtain a missing mass resolution of 1 MeV fwhm.

Prop. 1070 Proton induced neutral meson production in nuclei

Spokesmen: C. S. Mishra and J. C. Peng
Participants and Institutions:

University of South Carolina

G. S. Blanpied	B. M. Preedom

Los Alamos National Laboratory

M. E. Anderson	J. S. Kapustinsky
M. J. Leitch	C. S. Mishra
J. C. Peng	C. L. Morris
J. N. Knudson	

University of Pittsburgh

S. Dytman	J. Hardie
K. VonReden	

We propose to measure the polarized proton induced neutral meson production on nuclear targets. The newly constructed η-spectrometer will be used for the detection of the $(\vec{p}, \pi^0)$ and $(\vec{p}, \eta)$ reactions. The angular distribution of the differential cross-section and the analyzing power for discrete and continuum states in the residual nucleus will be measured. Our proposed measurements will greatly improve our understanding of the $(\vec{p}, \pi^0)$ reaction, which has only been measured so far on light targets ($A \leq 2$). The $(\vec{p}, \eta)$ reaction has never been measured before. The proposed measurements on the $(\vec{p}, \eta)$ reaction, together with the $(\vec{p}, \pi^0)$ data and (π, η) data, should provide important information on the mechanism of meson production and the interaction of η mesons with nuclei.

In the first phase of this experiment we would like to do this measurement with 800 MeV polarized protons at four angles and on four targets. Later we will request beam time at 600, 650, 700, 750 and 800 MeV to study the energy and mass dependence of these reactions.

Prop. 1071 Study of pion absorption in ^3He and ^4He

Spokesmen: S. Mishra and C. L. Morris

Participants and Institutions:

Los Alamos National Laboratory

M. J. Leitch — C. S. Mishra

J. McGill — C. L. Morris

University of South Carolina

G. S. Blanpied — B. M. Preedom

C. S. Whisnant

University of Maryland

N. S. Chant — M. Khandaker

New Mexico State University

M. Rawool

University of Pennsylvania

J. D. Zumbro

Rutgers University

R. D. Ransome

University of Virginia

C. Smith — R. Minehart

University of Texas

F. Moore

We propose to measure the cross section for the π^- and π^+ absorption on $^{3,4}He$, in which the final state includes one or more free deuterons, protons or neutrons. The energy and angular distribution of the outgoing protons, neutrons, and deuterons will be measured using a large solid angle (30/32 x 4π) BGO ball detector.

Data will be taken at 50, 62.5, 75, 82.5, 100, 125, 150, 180, 200 MeV using the LEP channel.

Prop. 1072 pp elastic absolute cross section

Spokesman: M. McNaughton

Participants and Institutions:

Texas A & M University

G. Glass — J. Hiebert

S. Nath — L. Northcliffe

Los Alamos National Laboratory

J. Amann — L. Atencio

R. Harrison — N. Hoffman

K. Jones — D. Lee

M. McNaughton — C. Morris

J. Novak — O. van Dyck

University of Texas

M. Barlett — G. Hoffman

K. McNaughton — P. Riley

Rutgers University

R. Ransome

We propose to measure the differential cross section for pp elastic scattering to an absolute accuracy of 1%. The measurements would extend from 500 to 800 MeV in 66 MeV steps, and from (approx.) 15 to 90 degrees cm.

Prop. 1073 Measurement of muonium to antimuonium conversion with improved sensitivity

Spokemen: H. R. Schaefer and V. W. Hughes
Participants and Institutions:

College of William & Mary
M. Eckhause J. Kane

University of Heidelberg
H. J. Mundinger G. zu Putlitz
H. J. Rosenkranz

University of Mississippi
J. Reidy

Yale University
H. Ahn V. W. Hughes
S. Kettell Y. Kuang
B. Matthias B. Ni
H. R. Schaefer

We propose to search for muonium to antimuonium conversion at a sensitivity in the coupling constant of $G_{M\bar{M}} \sim 10^{-2} G_F$ which would correspond to an improvement factor of about 100 over present experimental values. The experiment will utilize the production of thermal muonium from a SiO_2 target with the intense and pure subsurface μ^+ beam from the Stopped Muon Channel at LAMPF. The event signature will be the position sensitive detection of Michel electrons in a magnetic spectrometer with MWPC detector planes allowing track reconstruction to the origin of the μ^- decay from the $(M\bar{M})$ system.

Prop. 1074 High velocity search for small deviations from special relativity

Spokesmen: D. W. MacArthur and J. B. Donahue
Participants and Institutions:

Los Alamos National Laboratory
J. B. Donahue J. N. Knudson
D. W. MacArthur W. H. McCulla
C. R. Quick R. A. Reeder
R. K. Sander V. Yuan

University of New Mexico
H. C. Bryant P. G. Harris
A. H. Mohagheghi T. D. Nichols
C. Y. Tang

Drexel University
S. Cohen

University of Colorado
J. L. Hall

University of Connecticut
W. W. Smith

Western Washington University
J. E. Stewart

We will use the techniques during the H^O and H^- spectroscopy experiments (339, 449, 586, and 588) to test the predictions of special relativity. Our first measurement of this type (exp. 587) was made in EPB using an un-optimized H^- beam and the existing experiment facilities. We plan to repeat that experiment with the better resolution available in the new HIRAB beam line and with equipment designed for precision measurements.

This experiment depends on the fact that photons seen by a moving atom are shifted in energy from the photon energy as seen in the rest frame. This is the relativistic Doppler effect; in this case $E = E_0\gamma(1 + \beta\cos\alpha)$, where E_0 is the lab frame photon energy, and β and α are the usual relativistic factors. The angle α is the angle of intersection between the particle beam and the laser beam. If one collides fourth-harmonic photons from a Nd:YAG laser ($E_0 = 4.66$ eV) with the 800-MeV LAMPF H^- beam ($\beta = 0.84$); the atom can see photon energies ranging from 1.2 eV and 15.6 eV. Thus, if effect, one has a continuously tunable high-energy laser.

Generalizing the Lorentz transformations leads to a relativistic Doppler shift formula given by $E = E_0(1/g_o)\gamma(1 + \beta\cos\alpha)$ where g_o is one of the free parameters in a test theory of special relativity. Comparing the energies of known states in moving hydrogen (measured via the Doppler effect) with the known energies of these states measured at rest, constitutes a measurement of g_o. Any deviation of g_o from 1 (the Lorentz prediction) is evidence of a violation of special relativity at the atom's velocity. Our previous experiment resulted in confirming special relativity to 2.7 parts in 10^4 at $\beta = 0.84$. This is about the current state-of-the-art. The proposed experiment would represent an improvement of two to three orders of magnitude.

Prop 1075 Photodetachment of H^- near threshold in an electric field "an atomic interferometer"

Spokesmen: H. C. Bryant and R. A. Reeder
Participants and Institutions:

University of New Mexico
H. C. Bryant P. G. Harris
A. G. Mohagheghi T. D. Nichols
C. Y. Tang

Drexel University
S. Cohen

Los Alamos National Laboratory
D. A. Clark J. B. Donahue
J. N. Knudson D. W. MacArthur
W. H. McCulla C. R. Quick
R. A. Reeder R. K. Sander
V. Yuan

University of Connecticut
W. W. Smith

Western Washington University
J. E. Stewart

The photodetachment cross section of the H^- ion will be measured over a range of photon energies near threshold in an electrostatic field and in the presence of crossed electric and magnetic fields. The relative yield of H^0 atoms from the 450 MeV H^- beam, when intersected by a YAG laser beam, will be determined as a function of intersection angle and laser polarization. The structure in the continuum photodetachment cross section will be studied as a function of electric field and photon energy from 0.75 eV to 3 eV in the atom's frame. Near 497 MeV the threshold region at 0.7542 eV can be observed with optimum resolution. A constant magnetic field, always parallel to the direction of the laser beam, transforms in the H^- rest frame as a large electric field perpendicular to a small magnetic field.

In the case of π polarization in an electric field, the H^- atom behaves as an atomic interferometer, giving fringes modulating the continuum cross section whose visibility is determined by the coherence length of the laser photon. Data will be compared with the theories of Reinhardt and Rau.

Prop. 1076 Interaction of relativistic H^- ions with matter

Spokesmen: A. H. Mohagheghi, C. R. Quick and R. A. Reeder
Participants and Institutions:

University of New Mexico
H. C. Bryant   P. G. Harris
A. G. Mohagheghi   T. D. Nichols
C. Y. Tang

Drexel University
S. Cohen

Los Alamos National Laboratory
D. A. Clark   J. B. Donahue
J. N. Knudson   D. W. MacArthur
W. H. McCulla   C. R. Quick
R. A. Reeder   R. K. Sander
V. Yuan

University of Connecticut
W. W. Smith

Western Washington University
J. E. Stewart

We propose to study the distribution of excited states ($n \geq 2$) of neutral hydrogen atoms produced by the passage of a high energy H^- beam through a thin foil. We will measure the relative yields of excited states as function of beam energy, type of neutralizing foil, and thickness of foil. Excited H^0 atoms produced when an energetic H^- beam interacts with a thin neutralizing foil are field-ionized in a magnetic spectrometer. Aluminum, carbon, and Formvar (polyvinyl formal) of various thicknesses will be used. The spectrometer used to ionize and sort out the excited H^0 states consist of a dipole electromagnet whose magnetic field can be varied. The motional electric field seen by the relativistic H^0 atoms can thus be adjusted to field ionize various states selectively. The electrons liberated are deflected by the magnetic field of the spectrometer into a scintillator and counted. For Rydberg states the resulting trajectories of the electrons in the magnetic field of the spectrometer are studied by Monte Carlo methods.

In segment one, we will simply observe the yield of states ($n \geq 11$, depending on beam energy) that can be ionized with the spectrometer. In segment two, a laser beam will induce transitions from n=3,4,5 to n=15,16,... so that the distribution of these lower lying states may also be determined.

Prop. 1077 A search for spontaneous electric fields in near-luminal frames

Spokesmen: H. C. Bryant and D. W. MacArtur
Participants and Institutions:

University of New Mexico
H. C. Bryant   P. G. Harris
A. G. Mohagheghi   T. D. Nichols
C. Y. Tang

Drexel University
S. Cohen

Los Alamos National Laboratory
D. A. Clark   J. B. Donahue
J. N. Knudson   D. W. MacArthur
W. H. McCulla   C. R. Quick
R. A. Reeder   R. K. Sander
V. Yuan

University of Connecticut
W. W. Smith

Western Washington University
J. E. Stewart

If possible pathologies in the Lorentz transformation are parameterized according to a method proposed by Robertson, it can be shown that an electric field may appear in the barycentric frame of an atom moving through a region of spacetime where, in the preferred frame (which we assume is essentially the rest frame of the lab), no field exists.

In addition, under the same conditions, nature will show a preference for a particular gauge. The size of the effect depends on the preferred gauge and it can be altered using an impressed vector potential.

The plan of the experiment is to look for Stark splitting of highly excited Rydberg states of an H^0 moving near the speed of light. In this region of space, where there are no electric or magnetic fields, an adjustable vector potential gradient is established by means of two magnetic toroids. The experiment will be done in two stages: The first will use toroids formed of ferromagnetic material (iron) and excited by ordinary currents. The second phase will involve superconducting toroids and a higher sensitivity. In both phases the chief experimental limit will be the magnitude of the stray field in the interaction region.

Prop. 1078 Determination of the real part of the double spin-flip amplitudes and the inelasticities for the proton-proton system at intermediate energies

Spokesmen: M. Gazzaly, G. Pauletta, and N. Tanaka
Participants and Institutions:

University of Minnesota
N. Hintz

University of Udine
R. Garfagnini L. Santi

Los Alamos National Laboratory
K. Jones J. Jarmer
S. Penttila

University of Texas
M. Barlett G. Hoffmann

University of Petroleum and Minerals
M. A. Nasser

We propose to measure the spin asymmetries A_{LL}, A_{NN} and A_{SS} betwen 2°-20° in the laboratory at three beam energies (500, 560 and 730 MeV) for the reactions $\vec{p} + \vec{p} \to p + p$ and $\vec{p} + \vec{p} \to d + \pi^+$. The measurements can be performed in Line C using the HRS and a thin polarized target as was first demonstrated by Exps. # 583, 709, and 790. This technique will be emulated in 1988 by Exp. # 955 to study the scattering of polarized protons from an N-type polarized nuclear target. The identical set-up can be used for the A_{NN} measurements proposed here.

The purpose of the measurements in the elastic channel is part of a broader plan to use the Coulomb-Nuclear Interference (CNI) and analyticity for the systematic study of the forward spin-dependent amplitudes. The energy-dependence of the real parts is of particular interest at intermediate energies where it is needed for a correct interpretation of the rich structure observed in the corresponding imaginary parts. This need has been emphasized by the results of Exps. # 583 and 709 which reveal that the predictions of forward dispersion relations (FDR) are in need of improvement.

The purpose of the measurements in the inelastic channels is to obtain the energy dependence of the total cross sections in pure spin states for the $\vec{p} + \vec{p} \to NN\pi$ inelastic channel because theoretical predictions of these quantities are particularly sensitive to details of the NN interaction.

Prop 1079 Development of experimental techniques to study relativistic effects in proton – nucleus elastic scattering at forward angles

Spokesmen: G. W. Hoffmann, K. W. Jones and R. L. Ray
Participants and Institutions:

University of Texas, Austin

M. L. Barlett · D. Ciskowski
G. W. Hoffmann · M. Purcell
G. Pauletta · R. L. Ray

Los Alamos National Laboratory

J. F. Amann · K. W. Jones
N. Tanaka

University of California, LA

G. J. Igo · A. Ling

Rutgers University

R. W. Fergerson · C. Glashausser

Ohio State University

B. C. Clark

IBM

R. L. Mercer

We will develop techniques to obtain p + A elastic angular distributions with absolute uncertainty $< \pm 1\%$. The techniques will be used to obtain data for 500 MeV p + ^{40}Ca, ^{208}Pb over the angular range 1° - 15° to search for expected relativistic effects associated with virtual $N\bar{N}$ pair processes and relativistic scalar densities.

The absolute normalization of much of the vast body of 300-800 MeV HRS angular distribution data accumulated over the past decade will then be determined for enough selected cases so that absolute normalization of all HRS cross section data taken in the past and the future can then be reliably and accurately obtained to the level of ± 1%.

Prop. 1080 The longitudinal/transverse decomposition of the enhanced nuclear spin response in ^{40}Ca

Spokesmen: C. Glashausser and K. Jones
Participants and Institutions:

University of Georgia

F. T. Baker

Los Alamos National Laboratory

K. W. Jones

Rutgers University

A. Green

Rutgers University

A. Green · C. Glashausser
D. Beatty · V. Cupps

Orsay

L. Bimbot · C. Djalali
M. Morlet · A. Willis

CEBAF

S. K. Nanda

A complete set of spin observables D_{ij} will be measured for inelastic scattering from ^{40}Ca at 500 MeV over the angular range from 5° to 15° in the laboratory for energy losses of about 30 to 42 MeV. This region of excitation energy and scattering angles corresponds to the region where an enhanced relative $\Delta S = 1/(\Delta S = 0 + \Delta S = 1)$ nuclear response was observed in D_{nn} measurements on ^{40}Ca (and a number of other nuclei) in 318 MeV scattering. The combination $[- D_{nn} \pm (D_{ss}\text{-}D_{ll})]$are proportional to the spin longitudinal and spin transverse response functions in a simple approximation. The energy of 500 MeV makes it possible to carry out this complete set of measurements with reasonable efficiency; at 318 MeV, l type outgoing components cannot be measured because of the 360° rotation of the spin in the HRS. These measurments also complement the measurements of Exp. 741, where the same set of data were measured at 18.5° on ^{2}H, ^{40}Ca, and ^{208}Pb at a number of (mostly) higher excitation energies by T. Carey and collaborators. Their results were interpreted as evidence against the pionic interpretation of the EMC effect. The time requested is 447 hours.

Prop. 1081 Double charge exchange within the $(f_{7/2})^n$ shell-model space

Spokesmen: H. T. Fortune, C. L. Morris, and J. D. Zumbro
Participants and Institutions:

University of Pennsylvania
H. T. Fortune   J. D. Silk
M. G. Burlein   J. M. O'Donnell

Los Alamos National Laboratory
C. L. Morris   J. D. Zumbro

New Mexico State University
G. R. Burleson   M. W. Rawool

Argonne National Laboratory
R. Gilman

University of Texas
C. F. Moore

University of York
D. L. Watson

We propose to measure the cross section for the reactions ^{46}Ti, ^{50}Cr, $^{54}Fe(\pi^+, \pi^-)^{46}Cr$,$^{50}Fe$,$^{54}Ni$ (ground state + double isobaric analog state) at 292 MeV and a laboratory angle of 5°. These measurements will provide a test of a model which describes double charge exchange cross sections to the dipole isobaric analog state in the $(f_{7/2})^n$ shell-model space.

Prop. 1082 Measurement of spin observables for elastic and charge exchange reactions on the A=3 nuclei

Spokesmen: G. Igo, M. Bleszynski, T. Jaroszewicz, and R. Machleidt
Participants and Institutions:

University of Texas
P Riley

University of California, LA
D. Adams E. Gulmez
S. Trentalange

LAMPF is constructing exciting new facilities which make it possible to study the charge exchange reactions $^3He(\vec{n}, \vec{p})^3H$ and $^3He(\vec{p}, \vec{n})^3H$. NTOFF will be available with a 600 m flight path at the beginning of 1988 operations. This makes it possible to be one of the most important experiments in the field of spin physics, the study of two A=3 nuclei.

At NTOFF, it will be possible to measure the differential cross section, the uncorrelated vector asymmetry and the spin transfer observables by utilizing a ^3H target (Jan Novak, head, cryogenics group at LAMPF is very interested in constructing a self-contained ^3H target for proton beam experiments which will meet safety requirements).

The charge-exchange reaction proceeds through different combinations of isoscalar and isovector parts of the N-N interaction than the elastic scattering, the measurement of the same set of spin observables in the $^3H(\vec{p}, \vec{p})^3H$ reactions will provide very interesting probing of the interaction. Combining this data with data for the $^3He(\vec{p}, \vec{p})^3He$ elastic channel will provide a sensitive test of both the relativistic effects in nuclear reactions involving few nucleon systems, as well as current nucleon wave functions for the A=3 nuclei.

We propose to measure the unpolarized differential cross section $I_O = d\sigma/dt$, nucleon analyzing power A_y, and the Wolfenstein parameters D_{LS}, D_{SL}, D_{SS}, D_{NN}, D_{LL} for both elastic scattering and charge exchange reactions on A=3 nuclei at 300 MeV for laboratory scattering angles 5, 10,15, 20, 30, 40, 50, 60, 70, 80 deg.

Prop. 1083 Elastic scattering of π^+ and π^- from ^4He at far forward angles

Spokesman: D. Dehnhard
Participants and Institutions:

Los Alamos National Laboratory
C. L. Morris S. M. Greene

University of Minnesota
M. K. Jones C. E. Parman
S. M. Sterbenz Yi-Fen Yen

University of Pennsylvania
J. D. Zumbro

University of Texas, Austin
C. F. Moore S. Mordechai

The measurements of differential cross sections for elastic scattering of π^+ and π^- are to be extended into the far forward angle region. Our previous data cover the angular range from 30° to 170° at five energies between T_π = 90 and 180 MeV for π^+ and at 150 and 180 MeV for π^-. Large angle data for π^+ also exist at 240 MeV. We propose to measure cross sections between 5° and 30° at most of the energies and pion charges for which data at ≥30° at most of the energies and pion charges for which data at ≥30° already exist. The new measurements, which include the Coulomb-nuclear interference region (from ~5° to 15°), will complete a set of data which should provide a testing ground for π-nucleus reaction models.

Prop. 1084 Asymmetry of the ^{4}He($\vec{p}$;p',t)p and ^{4}He($\vec{p}$;p',^{3}He)n reactions at 800 Mev

Spokesmen: S. M. Sterbenz, D. Dehnhard, and L. C. Bland
Participants and Institutions:

Los Alamos National Laboratory
K. W. Jones C. L. Morris

University of Minnesota
D. Dehnhard C. E. Parman
S. M. Sterbenz M. K. Jones
Yi-Fen Yen

Indiana University
J. A. Templon B. A. Raue
K. Murphy L. C. Bland

University of Pennsylvania
J. D. Zumbro

We propose to measure the relative probability for proton and neutron emission from excited states in ^{4}He induced by 800 MeV inelastic proton scattering. The recoil tritium and protons are to be measured simultaneously, in coincidence with the inelastically scattered protons. This experiment is expected to provide important information on the nature of the ^{4}He* resonances and to help in understanding the anomalous ratio of ^{4}He photo-nucleon cross sections, $\sigma(\gamma,p)/\sigma(\gamma,n)$.

Prop. 1085 Total and differential cross sections for πd → pp below 20 MeV

Spokesmen: R. C. Minehart and B. G. Ritchie
Participants and Institutions:

Arizona State University

University of South Carolina

University of Virginia

Virginia Polytechnic Institute

The total and differential cross sections for $\pi d \rightarrow pp$ will be measured at energies of 5, 10,15, and 20 MeV. Uncertainties will be reduced to 5% for the total cross section. The low energy beams will be transported through the LEP channel to the LAMPF electrostatic separator located in the LEP cave at the exit of the channel. The techniques will be similar to those used in Exp. 828. During that experiment the separator was quite effective but the electron and muon contamination before the separation was so large that the pions made up only about 10% of the beam on target at 10 MeV. The precision of our measurement of this fraction was only about 30%. In the new experiment we intend to take advantage of the experience gained in experiment 828 and other very low energy pion beam development work at LEP in order to measure the pion flux to an accuracy of about 3%. In addition we plan to do further development on the 10 MeV beam to increase both the pion fraction and the absolute pion flux. The results from this experiment will provide a check on the only measurements available at these energies for the energy dependence of the total cross section (those by Rose), which have large absolute uncertainties, and will provide the first angular distributions for the reaction below 20 MeV. This data will provide a stringent test for theoretical predictions for s-wave pion production at very low energies. 400 hours of beam time in the low energy pion channel are requested.

Prop 1086 DCX to Excited 0^+ states

Spokesmen: M. Burlein and J. D. Silk
Participants and Institutions:

University of Pennsylvania
H. T. Fortune   M. Burlein
J. M. O'Donnell   J. D. Silk
P. Kutt

New Mexico State University
G. R. Burleson   M. W. Rawool

Argonne National Laboratory
R. A. Gilman

Los Alamos National Laboratory
C. L. Morris   J. D. Zumbro

University of York
D. L. Watson

Summary not provided.

Prop 1087 DCX on ^{18}O at large angles

Spokesmen: J. M. O'Donnell and H. T. Fortune
Participants and Institutions:

Los Alamos National Laboratory
C. L. Morris

New Mexico State University
G. R. Burleson   M. W. Rawool

University of York
D. L. Watson

Summary not provided.

Prop. 1088 Measurement of light fragment emission spectra from pion true absorption

Spokesman: R. A. Lovemen
Participants and Institutions:

University of Colorado
B. L. Clausen — M. Kohler
J. J. Kraushaar — R. A. Loveman
R. J. Peterson — D. J. Rilett
R. A. Ristinen — K. Vaziri

We propose to measure at LEP the inclusive spectra of light fragments following pion interactions with Ag at 160 MeV. Similar experiments have been done using protons, ^{3}He, and heavy ions as projectiles. All of these projectiles impart considerably more angular momentum at a given amount of energy delivered to a target nucleus than do pions. It will therefore be particularly interesting to compare the cross sections for production of light fragments by pions with those for each of these projectiles.

Prop. 1089 Mass dependence of analog DCX at 50 MeV

Spokesman: K. K. Seth
Participants and Institutions:

Northwestern University
C. Ginsburg — B. Parker
B. O'Reilly — M. Sarmiento
K. K. Seth — R. Soundranayagam
S. Trockenheim

Interesting and unexpected systematics have been recently revealed in double analog transitions in pion induced DCX at low energies, T(π) $\approx$ 50 MeV. In marked contrast to the $\sim A^{-10/3}$ decrease of forward angle DCX cross sections at the resonance energies, it is found that at 50 MeV the DCX cross sections for ^{14}C, ^{18}O, ^{26}Mg and ^{42}Ca targets are nearly identical. It is proposed to extend these measurements on T=1 targets, ^{54}Fe and ^{58}Ni in order to examine if the trend prevails in these 2p-shell nuclei. It is also proposed to measure the analog transition in ^{56}Fe. The pairing model predicts that this transition should be very weak in comparison to, for example, ^{54}Fe. It is proposed to make measurements for each of these targets at T(π) = 50 MeV and θ = 20° and 30°.

Prop. 1090 The (π^-, π^+ 2n) reaction

Spokesman: J. D. Silk
Participants and Institutions:

University of Pennsylvania
H. T. Fortune — M. Burlein
J. M. O'Donnell — J. D. Silk
P. Kutt

University of York
D. L. Watson

Previous study of the DCX reaction to the continuum raises a question as to the dominance of the simple two step reaction mechanism. The answer clearly lies in the study of the kinematically complete reaction. We propose to study the feasibility of using time of flight techniques to obtain moderate energy resolution and identify the exclusive (π^-, π^+2n) process.

Prop. 1091 A Study of the pionic fission reaction $^6Li + \pi^+ \rightarrow {}^3He + {}^3He$

Spokesman: K. K. Seth
Participants and Institutions:

Northwestern University

C. Ginsburg	B. Parker
B. O'Reilly	M. Sarmiento
K. K. Seth	R. Soundranayagam
S. Trockenheim	

It is proposed to make a study of the energy variation of the forward angle cross sections for the pionic 'fission' reaction

$$^6Li + \pi^+ \rightarrow {}^3He + {}^3He$$

Date in the region of the (3,3) resonance and above is expected to shed light on the reaction mechanism for this unusual reaction and also provide insight into the cluster structure of ^6Li.

Prop. 1092 Energy evolution of the mass dependence of analog DCX

Spokesmen: B. Parker and K. K. Seth
Participants and Institutions:

Northwestern University

C. Ginsburg	B. Parker
B. O'Reilly	M. Sarmiento
K. K. Seth	R. Soundranayagam
S. Trockenheim	

It is noted that the mass dependence of analog DCX at pion energies $\leq$ 140 MeV is extremely poorly known for the T=1 targets. It is pointed out that the measurement of the mass dependence of forward-angle DCX in the region 80-140 MeV is extremely important if we are to understand the drastically different mass dependence observed at 50 MeV. It is proposed to measure $\sigma(5^\circ)$ for targets of ^{26}Mg, ^{42}Ca and ^{58}Ni at several energies between 80 and 140 MeV.

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