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Proceedings of the Twenty-Second LAMPF Users Group Meeting

Los Alamos National Laboratory
Los Alamos, New Mexico
October 17–18, 1988

Compiled by
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MASTER

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PROCEEDINGS OF THE TWENTY-SECOND
LAMPF USERS GROUP MEETING
Los Alamos National Laboratory
Los Alamos, New Mexico
October 17-18, 1988

ABSTRACT

The Twenty-Second Annual LAMPF Users Group Meeting was held October 17-18, 1988, 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-SECOND LAMPF USERS GROUP MEETING

Los Alamos National Laboratory October 17–18, 1988

Chairman: *Stanley S. Hanna - Stanford University*
Chairman-Elect: *Peter J. Riley - University of Texas, Austin*

Monday, October 17 LAMPF Auditorium, Laboratory-Office Building

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8:00 - 8:30 a.m. **REGISTRATION**

MORNING SESSION
Stanley Hanna, Presiding

8:30 - 8:45 "Welcome" - *Warren Miller* - Deputy Director - *Los Alamos National Laboratory*

8:45 - 9:10 "Report from Washington" - *Clarence Richardson - Department of Energy*

9:10 - 9:30 "Status of LAMPF" - *Gerald Garvey* - Director, *LAMPF*

9:30 - 9:50 "MP Division Report" - *Donald Hagerman* - MP Division Leader

9:50 - 10:00 "The Associated Western Universities Program" - *Thomas Squires* - Director

10:00 - 10:20 **COFFEE BREAK**

LOUIS ROSEN CELEBRATION

10:20 - 10:40 "Introductory Remarks" - *Stanley Hanna - Stanford University*

10:40 - 11:20 "Louis Rosen and Nuclear Physics" - *Herman Feshbach - Massachusetts Institute of Technology*

11:20 - 12:00 Presentation of the **Louis Rosen Prize**
Address by Recipient

12:00 - 1:10 p.m. **LUNCH**

AFTERNOON SESSION
Peter Riley, Presiding

1:10 - 1:40 "Report from the Users Group" - *Stanley Hanna - Stanford University*

1:40 - 2:30 "Recent Pion-Nucleus Physics" - *William Gibbs - Los Alamos*

2:30 - 3:10 "Pion Nucleus Reactions" - *Gary Kyle - New Mexico State University*

3:10 - 3:50 "Spin Physics at LAMPF" - *Kevin Jones - Los Alamos*

3:50 - 4:15 **COFFEE BREAK**

4:15 - 4:55 "Nucleon Induced Charge-Exchange Reactions" - *Parker Alford - University of Western Ontario and TRIUMF*

4:55 - 5:35 "Radiative Muon Capture" - *Michael Hasinoff - University of British Columbia*

RANCHO ENCANTADO

7:00 - 7:30 p.m. **No-Host COCKTAIL PARTY**

7:30 **BANQUET - Tickets to this event must be purchased in advance.**

MORNING SESSION

New Chairman-Elect, Presiding

8:30 - 9:10 a.m.	"Neutrino Oscillations" - *Felix Boehm* - *California Institute of Technology*	
9:10 - 9:50	"Research at Paul Scherrer Institute" - *Manfred Daum* - *PSI (SIN)*	
9:50 - 10:30	"Status of the Advanced Hadron Facility" - *Gerald Garvey* - Director, *LAMPF*	
10:30 - 10:50	**COFFEE BREAK**	

WORKING GROUP MEETINGS

10:50 - 12:10	EPICS - *Christopher Morris* - *Los Alamos*	Auditorium
	NPL - *Harold Spinka* - *Argonne National Laboratory*	A234
	Neutrino Facilities - *Peter Doe* - *University of California, Irvine*	D105
12:10 - 1:15 p.m.	**LUNCH**	
1:15 - 2:30	P^3 - *June Matthews* - *Massachusetts Institute of Technology*	A234
	HRS - *Kevin Jones* - *Los Alamos*	Auditorium
	NTOF - *Evan Sugarbaker* - *Ohio State University*	D105
2:30 - 3:45	LEP - *Ralph Minehart* - *University of Virginia*	Auditorium
	SMC - *Martin Cooper* - *Los Alamos*	A234
	Polarized Targets - *George Burleson* - *New Mexico State University*	D105
3:45 - 4:15	**COFFEE**	
4:15 - 5:30	Computer Facilities - *Thomas Kozlowski* - Los Alamos	MP-14 Conf Rm
	Nuclear Chemistry - *Jan Wouters* - *Los Alamos*	A234
	Materials Science - *Frank Clinard* - *Los Alamos*	D105
	Study Group Higher Energy Facilities - *Joseph Comfort* - *Arizona State University*	Auditorium

REPORT FROM WASHINGTON

Clarence Richardson
Division of Nuclear Physics, Office of Energy Research
Department of Energy
October 17, 1988

As indicated in my assigned title, I am here to give a "Report from Washington." Before starting on that, however, I would like to take a moment to say something else. That is, that I am very pleased to be invited here today and have the opportunity to acknowledge the debt owed by the nuclear science community in general and by LAMPF and its users in particular to Louis Rosen. We all recognize that this facility would not be here today without his strong dedication and tireless efforts for so many years. The tradition of commitment to excellent, important science rests on the firm foundation laid and built upon by Louis. He can be justly proud of his accomplishments, and I am sure that it is a source of great satisfaction to him that that commitment continues unabated.

An outline of the other items that I plan to cover this morning is shown in the first vugraph [Number 1]. I will try to give a little insight about how we at DOE view LAMPF and its associated community in the context of the National nuclear physics program as supported by DOE. I will then discuss briefly the implications for LAMPF of our bringing into being another important component of the nuclear physics program: the 4 GeV CW electron facility called CEBAF. I will summarize the findings of a recent review of the LAMPF scientific program. That review, chaired by Bob Eisenstein, was carried out in a most perceptive way by a very astute and diligent panel. I will conclude by touching briefly on the question of AHF.

Let me begin by reading a quotation, as shown in the next vugraph [Number 2]. "LAMPF was designed [in the early 1960's], when the meson factories emerged, to span the whole range of science between traditional low energy nuclear physics and particle physics. It was created by the vigorous team of scientists of the Los Alamos Laboratory and has continued as the major basic science facility of Los Alamos. Because of its size, the diversity of its science program and its large user community, LAMPF is clearly the flagship of American nuclear science."

That statement is a very strong positive statement of the importance of LAMPF in our nuclear science program. The statement was taken from the report of a review - chaired by Erich Vogt - that was sometimes called the BLT review because it covered Bates, LAMPF, and The Bevalac. The statement was true in 1982 and it remains true. LAMPF is the flagship of American nuclear science and will continue in that important role not only until major new facilities are added, but until such other facilities are able to demonstrate that they can achieve and maintain the breadth and depth of scientific output that LAMPF continues to produce.

The fact that our office stands behind these statements can be illustrated with evidence of commensurate budge allocations. The next vugraph [Number 3] shows the amounts of Medium Energy Nuclear Physics funding allocated by DOE in 1987-89 for the LAMPF program. Note that I have added in an amount each year representing expenditures connected with LAMPF-based research by outside users supported by DOE Medium Energy Nuclear Physics funds. I have also made a deduction for some Medium Energy supported LANL work not connected with LAMPF. For comparison, the Medium Energy program totals and the DOE Nuclear Physics operating expense totals are also shown. This illustrates that the LAMPF Program accounts for more than 60% of Medium Energy funds and nearly 30% of Nuclear Physics operating expense totals each year. The next largest DOE Nuclear Physics base of operations, the Bevalac at LBL, amounts to about half the totals shown for LAMPF. So the budget allocations are, indeed, consistent with the importance ascribed to the LAMPF program.

Now, however, you will also observe that the LAMPF allocation is decreasing as a fraction of the totals for the second and third years shown. You are all aware, I am certain, that this is strongly related to the emergence of the CEBAF laboratory, which got its first construction funding in FY 1987. The establishment of a new laboratory for that facility will require an increasing fraction of available operating expenses for the next several years. That is not unexpected since we are introducing a significantly new level of scientific and technical standards for the electromagnetic component of the nuclear physics program. When LAMPF was brought into being in the late 1960's and early 1970's, considerable belt tightening was required in the previously existing parts of the nuclear physics program. It is probably not reasonable - and certainly not prudent - to expect to add a major new capability to any public funded program without some redirection of existing activities. After having consulted whatever experts he could, looking at previous similar situations, then reading bones, tea leaves, and entrails, Dave Hendrie deduced that about half of the operations costs of any new facility should come by redirection from existing operations throughout the total program. This estimate is also consistent with projections of research activity that would transfer to CEBAF from the existing facilities. A fundamental part of this scenario is our intent to maintain the scientific research base and funding for new equipment at a strong and vigorous level throughout medium energy physics and, indeed, throughout the entire nuclear physics program.

Now CEBAF is going through gestation and we at DOE have had to arrive at a plan for accommodating its requirements. A part of that plan that is of direct relevance to LAMPF management and users is that of reducing the projected budget for LAMPF operations by a total of about 10%, with that reduction spread over a five year period. This ramping down started with a reduction in FY 1988 and is planned to continue through FY 1992. We understand that such a reduction will work hardships and require sacrifices. We have discussed possibilities with LAMPF management, and since we all share the conviction that priority must be given to keeping the machine hours for research at a reasonable level, it is clear that experimental support services will be an area where reductions can be expected. However, since LAMPF has had the well-deserved reputation for providing the best experimental support of any major user facility in the world, I am certain that the users will continue to find this a very hospitable environment for their research activities.

I should also point out that, since such projections necessarily make assumptions about the total funds available for us to distribute, adjustments will have to be made each year as the funds are actually appropriated. Because it seems that there perennially exists some budget deficit or other exigency that the OMB or Congress needs to deal with, we often get less funds appropriated than we have been allowed to plan for in our projections. You may also be aware that we have a new Director of Energy Research in DOE. He is Robert Hunter, a west coast scientist with background in laser research. He is very sharp, active, and driven by scientific motives. His assessment of the funding outlook is that budget balancing considerations will continue to be very strong and that we should expect rather flat budgets for science for the near future. Also, of course, as we have experienced may times, budget actions are particularly unpredictable in the opening stages of a new administration - independent of which party wins.

We must also deal with the insidious effects of inflation. The next vugraph [Number 4] shows the DOE Nuclear Physics funding history for the last dozen or so years. The past years have been converted to FY 1989 dollars using the most valid price change indices we have been able to derive. As you can see, in real buying power, our budgets have remained remarkably constant over that period. We see some growth in the construction part of the budget in recent years, associated with the CEBAF project. But the long term constancy of the operating budget illustrates that the predictions of flat budgets in the future have a solid basis in history. I remain optimistic, however, and I will say a few more words about this at the end of my report.

Let me turn now to a brief discussion of our recent review of the LAMPF scientific program. The next vugraph [Number 5] shows the essence of the charge to the review panel. "The DOE is interested in evaluating the quality of LAMPF scientific research in a world perspective. The Panel is therefore asked to evaluate the scientific effectiveness and merit of each research program at LAMPF. In doing so, it will be necessary to evaluate the competence, creativity, and productivity of the scientific users (both from inside and outside the facility), as well as to determine whether or not the facilities are scientifically competitive. The Panel is also asked to comment on the impact that the LCD project would have on the overall LAMPF program, and whether or not that program is sufficiently well balanced."

As you can appreciate, it was a rather ambitious charge. But we recruited a chairman and panel that proved equal to the task. The next vugraph [Number 6] lists the panel members. The members were:Bob Eisenstein (who was chairman), John Domingo, Don Geesaman, Charlie Glashausser, Barry Holstein, Ernie Moniz, Herb Steiner, and Steve Wallace. As I said earlier the review was carried out in a most perceptive way by this very astute and diligent group. One of the astute features of the Panel is that it produced a report that was not easily amenable to summarizing, so the report must be read thoroughly to extract the full meaning of the findings. Nevertheless, I will attempt to give you the flavor of the Panel's conclusions.

Some of the positive findings are listed in the next vugraph [Number 7]. The Panel concluded that the LAMPF physics program is very strong and that the program emphasizes the unique capabilities of the facility. They found that LAMPF has an excellent scientific staff that does good physics while providing outstanding user support. The Panel further said that LAMPF management provides needed leadership and a proper view to the future in an excellent intellectual climate. The Panel found this to be a very mature and efficient operation; that LAMPF can do whatever it decides to do technically. The Panel also noted that LAMPF management reacts to scientific opportunities in a timely manner. There was an exception to this point that the Panel mentioned. That was in the area of polarized ion sources. I understand that there has been a very recent milestone in this connection, which I am sure we will hear about shortly.

The Panel also found some areas where they could make suggestions for possible improvements, and some of these are shown in the next vugraph [Number 8]. In areas needing attention, the Panel felt that both the present and planned LAMPF programs would benefit from a stronger coupling to the Los Alamos theorists. This point has been noted previously - in the Vogt Panel Report, for example. I believe it is true that the theorists and experimentalists are located together at most major accelerator laboratories, and that this propinquity seems to be valuable. The Panel mentioned again the inhibiting effects on the LAMPF program resulting from the limits on access to LAMPF by foreign nationals. We really did not need an example such as the present, most regrettable, situation to illustrate the point. It is clearly an issue that needs to be dealt with, and will get continuing attention. On another issue, the Panel supported the Barish Panel recommendations on the LCD project, recognizing that it is a very ambitious undertaking in terms of science, manpower, and costs. The Eisenstein Panel recognized that no significant part of the funding for such a project could be expected to be provided from within the projected LAMPF funding levels described earlier. Lastly, the Panel noted that the high energy physics community is not taking full advantage of LAMPF's particle physics capabilities, and that such participation should be actively encouraged. I will continue to interact with LAMPF management on these issues. All in all, the Panel found little to be strongly concerned about on the basis of its review. In sum, with reasonable reaction to these areas of concern, the Panel saw a scientifically interesting and productive future for LAMPF for the next five to ten years even without a major upgrade.

Of course, this still leaves THE BIG ISSUE for the longer term future: What about AHF? Well, if AHF is to be a Nuclear Physics funded project, the first hurdle it must get over is for the nuclear science community - via the Nuclear Science Advisory Committee - to put it in the queue as the choice for the next major construction project following CEBAF and RHIC. We plan that NSAC will be requested to produce a new Long Range Plan for Nuclear Science next year. In the course of their deliberations, NSAC will almost certainly find the future of AHF physics to be one of its major issues. In the meantime, of course, the Canadians are moving ahead aggressively with their KAON proposal. At this very moment, a subcommittee of NSAC is considering the issues relevant to the level of priority the US nuclear science research community should give to pursuing science in that range of energies and intensities. Of course, the central question being dealt with is, "What is the level of scientific merit and interest for nuclear physics in the range of multi-GeV hadrons?" As part of that question there must evolve a crisper understanding of the roles and interests of the nuclear physics and high energy physics communities at their interface. On these bases, NSAC can evaluate whether it looks attractive to throw in with the Canadians. But, no matter what the answer is to that question, a great deal of preliminary work on AHF-related issues will have been accomplished as NSAC begins deliberations on its new long range plan. So, it appears to me that when the next Long Range Plan is issued - or perhaps sooner - the US nuclear science community will have taken a clear position on the AHF issue.

One final note. I think it is broadly recognized that nuclear physics is in an exciting period. In fact, as shown in the next vugraph [Number 9], I note that a highly placed source in DOE has just recently been quoted in the press that nuclear physics has had a renaissance. So, notwithstanding, my earlier mention of pressures for flat budgets in the near future, I am firmly convinced that the system will always be able to react favorably to well-motivated requests to bring in new capability in forefront areas that show that they are capable of living up to their promise.

So, keep up the good work, because that is an essential ingredient.

REPORT FROM WASHINGTON

- LAMPF IN THE CONTEXT OF THE NATIONAL NUCLEAR PHYSICS PROGRAM
- PHASING IN OF CEBAF OPERATION - RESULTING TIGHTNESS
- FINDINGS OF RECENT REVIEW OF LAMPF SCIENTIFIC PROGRAM
- WHAT ABOUT AHF?

VUGRAPH NUMBER 1

"LAMPF WAS DESIGNED [IN THE EARLY 1960'S], WHEN THE MESON FACTORIES EMERGED, TO SPAN THE WHOLE RANGE OF SCIENCE BETWEEN TRADITIONAL LOW ENERGY NUCLEAR PHYSICS AND PARTICLE PHYSICS. IT WAS CREATED BY THE VIGOROUS TEAM OF SCIENTISTS OF THE LOS ALAMOS LABORATORY AND HAS CONTINUED AS THE MAJOR BASIC SCIENCE FACILITY OF LOS ALAMOS. BECAUSE OF ITS SIZE, THE DIVERSITY OF ITS SCIENCE PROGRAM AND ITS LARGE USER COMMUNITY, LAMPF IS CLEARLY THE FLAGSHIP OF AMERICAN NUCLEAR SCIENCE."

- FROM A REPORT PREPARED BY THE AD HOC PANEL OF THE DEPARTMENT OF ENERGY TO REVIEW ITS MAJOR PHYSICS INSTALLATIONS.

JUNE 1982

VUGRAPH NUMBER 2

DOE NUCLEAR PHYSICS FUNDING

OPERATING EXPENSES

(BUDGET AUTHORITY IN $000)

	FY 1987	FY 1988	FY 1989
MEDIUM ENERGY NUCLEAR PHYSICS			
LOS ALAMOS NATIONAL LABORATORY			
LAMPF OPERATIONS	$ 40,600	$ 41,325	$ 41,580
IN-HOUSE RESEARCH	6,512	6,600	7,000
NON-LAMPF-RELATED	(835)	(860)	(870)
OUTSIDE USERS RESEARCH			
UNIVERSITY	3,589	3,425	3,545
NATIONAL LABORATORY	1,075	1,130	1,135
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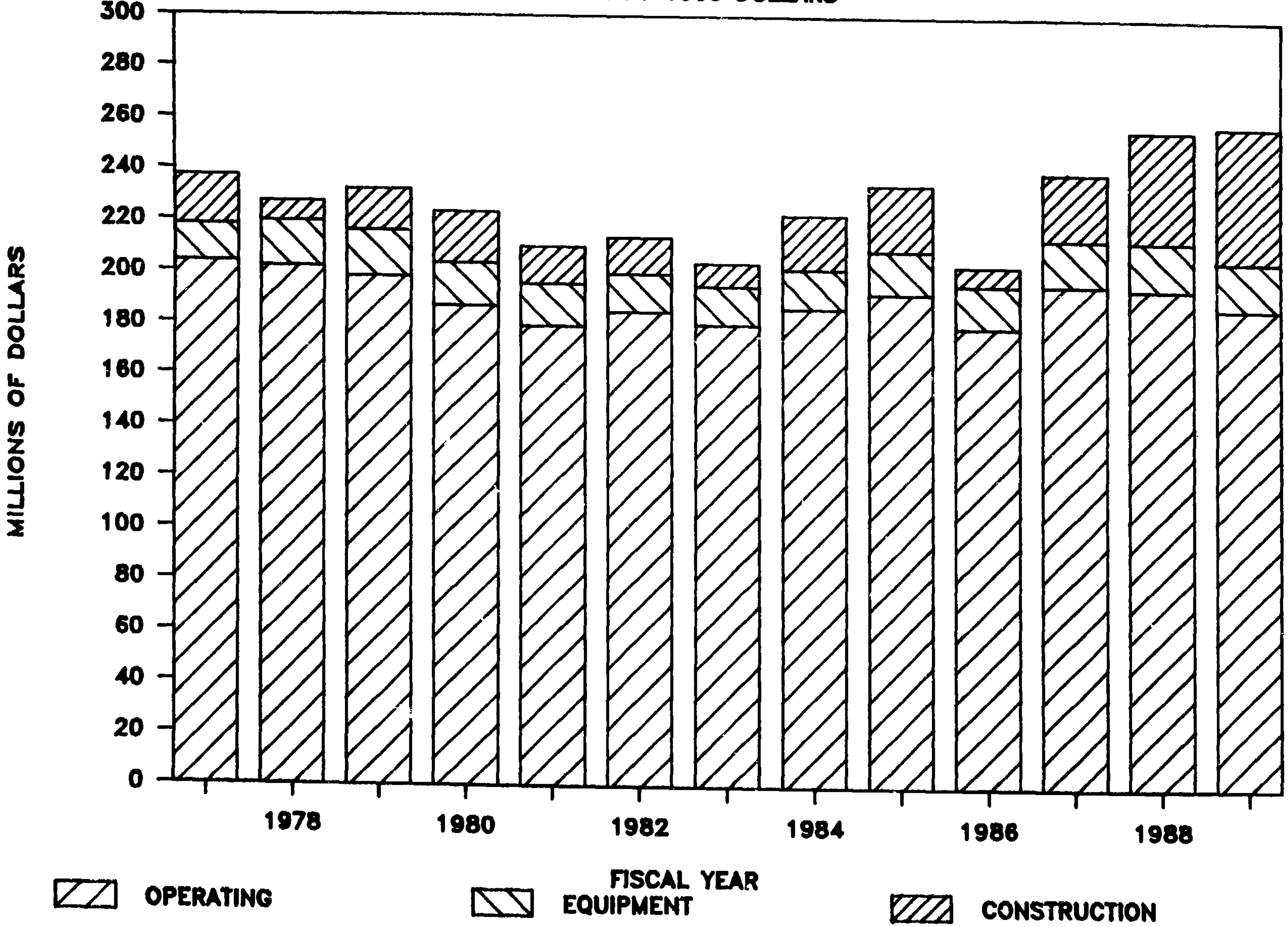
TOTAL LAMPF-RELATED	$ 50,941	$ 51,620	$ 52,390
TOTAL MEDIUM ENERGY OP. EXP.	$ 80,943	$ 83,974	$ 85,711
LAMPF-REL. % OF MED. EN.	62.9%	61.5%	61.1%
TOTAL NUCLEAR PHYSICS OP. EXP.	$177,029	$185,956	$189,812
LAMPF-REL. % OF NP OP. EXP.	28.8%	27.8%	27.6%

VUGRAPH NUMBER 3

NUCLEAR PHYSICS FUNDING

B/A IN FY 1989 DOLLARS



VUGRAPH NUMBER 4

ESSENCE OF CHARGE TO REVIEW PANEL

THE DOE IS INTERESTED IN EVALUATING THE QUALITY OF LAMPF SCIENTIFIC RESEARCH IN A WORLD PERSPECTIVE. THE PANEL IS THEREFORE ASKED TO EVALUATE THE SCIENTIFIC EFFECTIVENESS AND MERIT OF EACH RESEARCH PROGRAM AT LAMPF. IN DOING SO, IT WILL BE NECESSARY TO EVALUATE THE COMPETENCE, CREATIVITY AND PRODUCTIVITY OF THE SCIENTIFIC USERS (BOTH FROM INSIDE AND OUTSIDE THE FACILITY), AS WELL AS TO DETERMINE WHETHER OR NOT THE FACILITIES ARE SCIENTIFICALLY COMPETITIVE. THE PANEL IS ALSO ASKED TO COMMENT ON THE IMPACT THAT THE LCD PROJECT WOULD HAVE ON THE OVERALL LAMPF PROGRAM, AND WHETHER OR NOT THAT PROGRAM IS SUFFICIENTLY WELL BALANCED.

VUGRAPH NUMBER 5

LAMPF REVIEW PANEL

ROBERT EISENSTEIN, UNIVERSITY OF ILLINOIS - CHAIRMAN

JOHN DOMINGO, CONTINUOUS ELECTRON BEAM ACCELERATOR FACILITY

DONALD GEESAMAN, ARGONNE NATIONAL LABORATORY

CHARLES GLASHAUSSER, RUTGERS UNIVERSITY

BARRY HOLSTEIN, UNIVERSITY OF MASSACHUSETTS

ERNEST MONIZ, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

HERBERT STEINER, UNIVERSITY OF CALIFORNIA, BERKELEY

STEPHEN WALLACE, UNIVERSITY OF MARYLAND

VUGRAPH NUMBER 6

PANEL REVIEW OF LAMPF PHYSICS PROGRAM

SOME OF THE GOOD NEWS

- PHYSICS PROGRAM VERY STRONG OVERALL - EMPHASIZES UNIQUE CAPABILITIES
- EXCELLENT SCIENTIFIC STAFF DOES GOOD PHYSICS AND PROVIDES OUTSTANDING USER SUPPORT
- LAMPF MANAGEMENT PROVIDES NEEDED LEADERSHIP AND VIEW TO THE FUTURE IN EXCELLENT INTELLECTUAL CLIMATE
- LAMPF OPERATION VERY MATURE AND EFFICIENT: "LAMPF CAN DO WHATEVER IT DECIDES TO DO TECHNICALLY"
- LAMPF REACTS TO SCIENTIFIC OPPORTUNITIES IN A TIMELY MANNER

VUGRAPH NUMBER 7

PANEL REVIEW OF LAMPF PHYSICS PROGRAM

SOME AREAS NEEDING ATTENTION

- o STRONGER COUPLING TO THEORISTS FOR BOTH PRESENT AND PLANNED PROGRAMS
- o LIMITS ON ACCESS TO LAMPF BY FOREIGN NATIONALS IS INHIBITING TO OVERALL PROGRAM
- o IMPACT OF LCD IN PERIOD OF DECLINING SUPPORT
- o HIGH ENERGY PHYSICS COMMUNITY SEEN AS NOT TAKING FULL ADVANTAGE OF PARTICLE PHYSICS CAPABILITIES AT LAMPF

VUGRAPH NUMBER 8

10/14/88

Los Alamos Monitor

Physicist talks of rebirth

SANTA FE (AP) — A government nuclear physicist said there's a renaissance going on in the field of nuclear physics.

David Hendrie, director of nuclear physics for the Department of Energy's Office of Energy Research, was among speakers at a conference here who said nuclear physics has benefitted from recent research advances and stands to gain more from two new particle accelerators.

The annual meeting of the American Physical Society's nuclear division began Thursday and attracted more than 500 nuclear physicists, scientists who are concerned with the workings of the atomic nucleus.

Nuclear physicists search for unusual properties of the particles that comprise the atomic nuclei. As research progresses, they hunt for ever more unusual properties.

Scientists attending the Santa Fe meeting will be considering how to best use the 4-billion electron-volt Continuous Electron Beam Accelerator Facility being built at Newport News, Va., and the 100-billion electron-volt Relativistic Heavy Ion Collider that DOE expects to begin building in 1990 at Brookhaven National Laboratory in New York.

Officials at Los Alamos National Laboratory in northern New Mexico hope the next project after those two will be its Advanced Hadron Facility, a collection of machines that will take part of its Meson Physics Facility's 800-million electron-volt beam of protons and boost it to energies of 60 billion electron volts.

VUGRAPH NUMBER 9

SUMMARY OF THE MP DIVISION REPORT

(Donald C. Hagerman, MP Division Leader)

LAMPF beam availability during the 1988 June-September production period was adequate (75-80%) to satisfy the needs of the experimental program yet was below optimum in terms of demands on the operating staff and inconvenience to the experimentalists. During the shut-down period (October 1988-April 1989) we shall keep reliability as an essential goal in the activities of the division.

We have decided that the development of the Optically Pumped Ion Source (OPPIS) has proceeded far enough so that we shall install it during this shutdown, and we hope to have beam available from this source for friendly users midway through next summer's operation. Thus far we have demonstrated stable source operation at the few microampere level for a ten day period and have found that operation of the ECR source is relatively easy. Measurements of laser pumping characteristics are in accord with our expectations. Further testing of laser system lifetime under operating conditions is needed as well as optimization of the extraction optics of the ECR source. The effort on this problem has been increased by one staff member and one post-doc. After initial installation and operation of the source with the accelerator, we see significant opportunities for major improvements after further development work.

During the past year MP Division and LAMPF have been subjected to the scrutiny of external review committees; the most important of these was a committee formed by the DOE and chaired by Bob Eisenstein. These committees have strongly supported the present LAMPF program and have, in fact, advocated expansion of the program.

The Large Cherenkov Detector (LCD) passed scientific and initial cost and planning reviews during the year; the DOE stance at present is equivocal in that they are concerned about its overall cost, the impact on the rest of the program, and support in the high energy community. This project will next be reviewed by NSAC. Funding for this project will be separate from the on-going support of LAMPF operations.

During the next year we expect that the construction of the MRS will be completed, and this spectrometer will be in use in the research program during the summer of 1989. An accelerator improvement project has been started that will correct some of the problems in the low energy H+ transport system. The energy compressor for LEP is underway; this will provide both new physics opportunities in terms of better pion beams as well as an opportunity for LAMPF to exploit some of the advances in rf superconducting technology.

The LAMPF program does not include the activities at LANSCE, nor at WNR, yet beams for these other experimental programs are provided by the LAMPF accelerator; further, MP

Division does have the responsibility for the PSR/WNR beam delivery system. Thus, these other experimental programs have some overlap with the LAMPF activities. It was gratifying that during the summer of 1988 some 88 separate condensed matter physics experiments were run at LANSCE and some 18 nuclear physics experiments were run at WNR. Both the LANSCE and the WNR programs include significant numbers of scientists from institutions other than LANL. Beam availability from PSR was quite disappointing and was as low as 30% during the first half of the summer; this was improved by about a factor of two for the last half but still is completely unsatisfactory. In recognition of this problem, the LANL management has determined that adequate funds will be made available to make LANSCE a world class facility both in terms of beam availability and current; it is expected that this upgrade program will require about three years to complete.

The major problem facing the LAMPF users and the LAMPF management is the continuing decline in the purchasing power of the LAMPF operating budget. This decline is expected to continue until FY 1992 according to the present DOE plan .

Overall, the decline in purchasing power exceeds 20% between 1984 and 1992. For several years we have been convinced that for small budget changes we have a leverage factor of four if we simply adjust the running hours to reflect the new budget; that is, a 1% change in the budget will change running hours by 4%. During the period between 1984 and 1988, we have been more or less successful in accommodating the reduced budgets. Part of this has been due to the fact that we no longer are in the midst of such activities as a major rebuilding program of the Line-A target cells; also, part of the accommodation has been made by some success in building a more efficient operation. We have now run out of ideas for further cost savings—we will need to reduce service and your input in this matter is vital.

For FY 89 we have decided to reduce beam hours to 2400 instead of the more usual 3000 hours. We believe that this action is not appropriate for FY 90 and beyond. Our challenge then is to adjust the experimental program so that we can return to 2800 beam hours and maintain the vitality and excellence of the continuing LAMPF experimental program. In deciding how to make the necessary changes we must keep excellence in research as our top priority. We must also pay due attention to the educational aspects of the LAMPF program so that during the transition period we do not jeopardize the Ph. D. research of the graduate students using LAMPF.

Input from the LAMPF User community is vital in making these decisions. We shall be discussing these issues during the PAC meeting in January and on a continuing basis with the DOE and representatives of the LUGI. Input from the user community will be solicited through the LAMPF Newsletter; we shall also use the newsletter to keep you informed on these important problems. We expect to have an initial impact statement to the DOE by early spring of 1989; following discussion (and revision if needed) of this initial statement by the DOE and the user community we shall take the necessary steps to put the plan into effect in FY 1990.

LOUIS ROSEN

by

Herman Feshbach

To begin with, I would like to thank the organizers of this meeting for this opportunity to express my admiration and affection for Louis and Mary Rosen. These sentiments are the consequence of nearly thirty years of friendship and of a close collaboration on behalf of the nuclear physics community. I don't quite remember where or when I first met Louis. It was certainly well before the Bethe panel on which I served as we were both very much interested in the interaction of neutrons with nuclei. But a few years after that panel met I started to come to Los Alamos and came every summer for more than 15 years. I only stopped because of MIT adminstration duties. In addition, I came because I served on the LAMPF policy board, as well as the first PAC. I chaired the Program Committee for the Sante Fe meeting of the PANIC conference in 1975. And I was a member with Louis of many committees, of which the most important one was probably the Friedlander Committee of the NAS.

In the summer of 1967 I arrived in Louis' office ready to start the summer program when Eleanor Dunn gave me the devastating news that Mary and Louis has been in a terrible accident at a town called Truth or Consequences. Both had been badly injured, as I recall Louis' injuries were the more severe ones. For some months we anxiously waited for the recovery and the nature of that recovery. As you all know they both did recover and went on to fruitful and productive careers.

I have divided this presentation into three parts:

1. Louis Rosen the physicist — which refers to Louis Rosen's research contributions;
2. Louis Rosen the builder — which refers to his central role in bringing LAMPF into existence and then management;
3. Louis Rosen, statesman of science which refers to his activities on behalf of physics generally.

Turning to the first, I shall mention three of Rosen's important experimental innovations. These are experiments which had a particular influence on my own work. One was the use of emulsions to study reactions involving neutrons as a final product. One result, that I quoted in a recent historical article was the demonstration that the angular distribution of the neutrons emitted in a statistical reaction is spherical. It is perhaps needless to add here that the measurement of neutron spectra and angular distributions had certain applications. A second set of experiments performed just after the war were on fusion. Louis and his collaborators, which by the way included Joe Fowler, measured the energy spectrum of fission fragments as well as the neutron energy spectrum. The latter was for many years used in applications such as the design of reactors. Perhaps Louis' most important research was his seminal paper studying the elastic scattering of protons by a wide variety of nuclei. I first heard of this investigation in a conference on the optical model held in 1959 at the F.S.U. Not satisfied with the execution of this innovative experiment, Rosen and his colleagues developed an optical model, which now included a spin orbit term to fit the data. The results of this analysis are still quoted whenever optical models are discussed. I won't enter into a further discussion as Stanley Hanna has covered these experiments in the preceding talk. We turn now to Part 2.

There is no question that the major achievement of Louis' career so far is the authorization, construction and management of the Facility of which you are all users, the Los Alamos Meson Production facility which delivers today 1 ma of protons at 800 MeV. These protons are used to produce a variety of secondary and tertiary projectiles. When one considers the variety of projectiles, the intensity of the beam, the available variation in energy, the variety of spectrographs of differing characteristics, one must conclude that this is one of the most effective of the scientific laboratories. There were many others involved in the construction of LAMPF, Nagle, Knapp, Hagerman, are a few of the names that come to mind. But there is no doubt that Rosen played a central role.

The construction of such an institution is a complex task. Beyond the obvious need to have a good design, and talented people to follow through on it, there were and are to this day several constituencies which have to approve of and support the project. There was the Los Alamos administration — and here Louis had the strong support of Norris Bradbury, the Director of LASL at the time. This support was obviously essential for otherwise the project would never have seen the light of day. This support had a concrete expression in the Ran D phase of the project. Funds obtained from the Laboratory management were of inestimable value at the beginning of the project. Beyond LASL one had to deal with the funding agency, the AEC, and non-trivially the BOB, Bureau of the Budget, now called the OMB, which had trouble digesting what it considered to be an extraordinarily large appropriation. Then there was Congress; the committee of importance was the JCAE, the Joint Committee on Atomic Energy. At least that aspect was simpler than today's Congressional structure. Very important to the project was the support of the community — a support which had to be expressed in terms of (1) a positive evaluation of the scientific opportunities which the project would generate; (2) a willingness by the community to entrust the Los Alamos Laboratory with the construction of the accelerator and management of its operation, and (3) a willingness of the community to come to Los Alamos to do the experiments and to discuss this physics. There was, for, example almost automatic opposition from those who were accustomed to having their laboratories within walking distance. At the time there was no NSAC which would have provided a framework for obtaining the nuclear physics community's response. We know a great deal more today about these hurdles, Congress, the DOE, OMB, the community and how to deal with them — not that it makes it any easier. But in the early sixties they were, for most nuclear physicists, a new set of problems *aterra incognita* involving if you wish what I will call "foreign relations," the relations to the outside world.

Louis dealt with these problems, relations with the AEC, with Congress and with the community with consummate skill. He developed the relationship with Congress, JCAE, with the New Mexican delegation, with the legislative aides in the Appropriation Committee, relationships which have prevailed to this day. It required real dedication — persistence as well as the ability to produce reasoned, data-based non-technical arguments which inspired confidence in the laboratory and in Louis Rosen. And of course these relationships must be and have been maintained after the facility came into being.

Louis recognized that scientific merit would not be sufficient to win the support of Congress. We all wish it were enough — but it isn't. The funding of an expensive facility is a political issue. All the dimensions of any political issue enter. The importance of such a scientific facility for all of the Southwest was emphasized. The universities in that region had formed an association which supported the Los Alamos proposal. Louis also felt very strongly about the potential usefulness of π mesons for treating cancer. Both of these issues, I would guess were influential.

The AEC adoption of the LAMPF project followed from the recommendations of the Bethe panel appointed in 1964 by the President's Science Advisor — that panel included Bethe, Gove, Havens, Christy, Phillips, and Bob Wilson besides myself. Four proposals were considered: Los Alamos, UCLA, Yale–Brookhaven, and Oak Ridge. The panel testified to PSAC, which if my memory is correct, supported the conclusions of the panel. The general recommendations of the panel effectively selected Los Alamos as the winner of the competition. The UCLA design was later used at TRIUMF, while the Yale–BNL group became active users of the Los Alamos facility.

However, it was still a long road ahead before the start of construction. In March 1965 an open hearing was held in Washington in Congress. Rosen testified with regard to LAMPF, while Glenn Seaborg stated that the Bethe panel report was AEC policy. Sometime during this period the Pake panel, reviewing all of physics, gave strong support to the construction of such a facility for what came to be called medium energy physics. The project made the FY 1966 budget with \$1.2 M for A/E work and \$2 M for R&D. The appropriation was not passed until long into FY 1966. The FY 1967 budget increased these sums to \$3 M and \$3.9 M, respectively. The AEC request for 1968 involved \$50.3 M for the project. However, at that point a new procedure was put into place by the BOB. Annual appropriations were made rather than one total appropriation at the beginning. Since that time all large accelerations have been funded in this fashion. It meant an annual pilgrimage of Louis to Washington; a pilgrimage consisting of several trips and presentations. Physical construction started in the early spring of 1968. four years after the Bethe report. Instead of \$10.4 M appropriated by Congress, Los Alamos received a total of \$3.7 M. Full beam was obtained four years later in June 1972; on time and within the budget. I tell this tale in order to illustrate two themes – Faint heart never won a fair lady — and Rome wasn't build in a day. And of course I wanted to document the investment by Rosen and Bradbury in their relationship with Washington. And I might add any large size scientific project must run a similar Washington gauntlet with the added problem that annual funding can be used to stretch the project out in time. Even in the good old days of the Johnson administration, it took four years between AEC and Congressional approval.

It is not appropriate for me to go into the various issues that came up during the construction. However there are a few that I would like to mention. One had to do with wage guide structure — the invention of the side-coupled cavity resonator by Knapp and Nagle. A second was the construction of a prototype electron accelerator which demonstrated the feasibility of the LAMPF design — but that electron accelerator has by now become the unique instrument for the production of high energy multi MeV X-rays useful for a wide variety of industrial and medical purposes. And one more, Rosen took the daring step of having the final machining, assembly and precision turing of the wave guide units done at Los Alamos. Industry was simply not up to performing, for example, the brazing which the 352 accelerator tank sections required. It was done here at Los Alamos and is indicative of the resources of this Laboratory had in terms of talented work force. The high intensity of the beam required a quality beam and a computer control had to be designed and installed. It was also necessary to devise remote handling equipment and transport.

A third leg of the triad was and is the relationship to the nuclear physics community. That turned out to be the easiest problem to solve. The community needed the project and the project needed the community. Well before construction started, during the proposal phase, Louis organized workshops involving the interested researchers from both inside the outside the laboratory. The product was the famous Blue Book which detailed experiments which the new facility would make possible. There were several important consequences. One was the education of the community as to the opportunities the facility presented. A second was an important input into the issuer of beam lines, spectrographs and defectors. Here the experience with the BNL accelerator, the Cosmotron, was very helpful. In this way, a constituency which would support the construction of the facility and stood ready to help design the necessary ancillary equipment and who were anxious to participate in the exploitation of the facility was created. Eventually this was formalized into the Technical Advisory Panel. The LAMPF users group was formed in 1968. Harry Palevsky was the first Chairman.

Two other organizational units should be mentioned. The LAMPF Policy Board and the PAC. The first was appointed by Bradbury, in early 1968. It had nine members of which only one was from Los Alamos. It met roughly every six months. I am a great believer in this type of review. We have it at MIT for both the Department of Physics, for our Laboratory of Nuclear Science and for our various interdepartmental laboratories. At these meetings Rosen and his colleagues would describe the status of the construction, research plans, *etc.* Policy matters of importance to the community were the subject of discussion and recommendations were made to Bradbury to (1) make LAMPF a total open laboratory; (2) have the services in place as well as the impedance matching personnel that users need; (3) develop housing; (4) augment the LAMPF staff and develop the involvement of the theorists. Some of us were particularly concerned with the graduate students and post-docs, parts of the teams doing experiments at Los Alamos. A most important part of a student's education is the interaction with other students. Being away from their home campus deprived the students of this interaction and there were no courses they would take. But their education could be enhanced if they interacted with the students in other groups — and if there were an active relevant lecture series. Louis resonated with these thoughts. His dedication to the students is reflected in today's prize. It's a prize which fits the honoree!

The second organization to be mentioned is the PAC. And I don't mean political action committee: rather the Program Advisory Committee, which recommends to the Director, in this case Louis Rosen and his successor, experiments, time allotment, *etc.* I don't need to describe its functions to you. The important points are that these selections are made on the basis of scientific merit. Note that the Committee has and had a strong representation of the outside, non-Los Alamos community.

The details are not important. What is important is that the community was reassured. It felt that the best experiments as judged by the objective PAC would be performed, that the users had a voice in the development of facilities and in the logistics of their use and that they, the users, would work in a supportive atmosphere. And the principal architect of that structure and attitude was Louis Rosen.

We turn now to Louis Rosen, the statesman of science. Much of this facet of Louis' activities are not in the public record — membership on committees both in New Mexico and nationally. Louis was Chairman of POPA, the APS Panel of Public Affairs, Chairman of the APS Division of Nuclear Physics, and a member of the Friedlander National Academy of Sciences Committee on the future of nuclear science whose report was a forerunner of the NSAC long-range plans, and many, many more. But there is a more subtle and not so visible component of his activities. Louis always realized the importance of the general health of nuclear physics for the U.S. science effort and indeed the importance for Los Alamos. It was thus possible for the nuclear community to call on Louis to go to his friends in the Congress and the Executive is its behalf. Louis never refused, and, as I know, rarely needed to be asked. This is hardly the only thing Louis did in the public interest. But I though it would be of particular interest to this audience.

What of the future? I am roughly one year older than Louis, so that I came to the ripe age of seventy more than a year ago. My feelings at the time were a bit mixed and are perhaps best represented by this *New Yorker* cartoon which providentially appeared more than a year ago. I'll read the subtitle: "It's a damned outrage, Faversham. Do you realize that in a mere fifteen years we've gone from fifty-five to seventy?" I haven't gotten Louis' comments on this cartoon, but I am sure he feels just as I do. And how do I know? Well let us see what Louis is up to now! He is into arms control — and because of his many trips to the Soviet Union and his many friends there, he is able to evaluate Soviet science policy and comment on the recent astounding changes in the Soviet Union. He, by the way, continues to serve on the US/USSR Joint Coordinating Committee for the Fundamental Properties of matter.

Right now he is organizing an international conference on technology based confidence building, especially between the superpowers. This, let me assure you, is an extremely difficult area in which to make an impact. But I am sure that if anyone can, Louis will. It is a very important project because as arms control proceeds, and the number of nuclear weapons is reduced as a reaction to the fact the nuclear war is suicidal for the nation attacking, the implementation of measures which will give each nation assurance that the provisions of a treaty are being carried out is essential. Good luck, Louis — My best wishes for success as you start on still another career.

SOME RECENT RESULTS IN HADRONIC PHYSICS WITH PIONS

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ABSTRACT

Three topics in modern hadronic physics are developed with regard to their fundamental importance to our understanding of the strong interaction in general and nuclei in particular. These three subjects are: low energy pion-nucleon scattering and charge exchange, the study of the three nucleon system with elastic scattering of pions, and double charge exchange of pions on nuclei. In each case the studies are presented in terms of the fundamental motivations underlying them and the spectacular new data which is bringing new insight into these areas

Introduction

I wish to discuss three topics in the field of strong interaction physics. These research areas are on the very forefront of our understanding of hadronic interactions. I will talk about them in intuitive terms and emphasize motivations rather than presenting technical details. One of the things that I hope you will appreciate is the spectacular quality of the data which is being taken to address these questions.

Low Energy Pion-nucleon Scattering

While this subject is an old one, the questions it poses to modern hadronic physics are no less demanding. In fact, it has recently taken on additional interest for several reasons. First of all it is the data on this process which lies at the basis of the determination of the so-called "sigma-term", the measure of chiral symmetry breaking in the strong interaction. This quantity represents the amount that the mass of the nucleon is altered by the fact that we live in a world in which chiral symmetry is not perfect. The numerical value of the sigma term is obtained (in principle) from the extrapolation of a combination of the s-wave pion-nucleon scattering amplitudes to a negative energy point. While there has been a great debate over the years on just how this should be done (in fact it still rages) the most common value obtained for this number is around 60 MeV. From theories based directly on quark models one calculates a value around 30 MeV. This discrepancy has been known for a long time. It was pointed out a few years ago by Donoghue and Nappi [1] that, if one assumes that there is a sea of quark-antiquark pairs with about one quarter of them being strange quarks, then these two numbers could be reconciled. Recently there has been a measurement of the π^--hydrogen atomic level shift [2] which, if correct, would change the low energy π^--nucleon parameters enough to move the experimental determination of the sigma term to 30 MeV, thus obviating the need for any strange quarks in the proton sea. There are also some pion-nucleon phase shift analyses which give smaller numbers for the sigma term so that the question of the experimental value of the sigma term cannot be considered as closed.

Let us examine the general situation for the low energy s-wave phase shifts. There are two of them, of course, the isospin 1/2 and 3/2 waves. Figure 1 shows these phase shifts (from an analysis[3] of low-energy charge exchange data[4]) plotted as a function of the center-of-mass momentum up to a kinetic energy of 100 MeV. They are plotted vs. k_{cm} because that is the variable used in an effective range expansion. The slope of these curves at zero energy is the scattering length.

First of all, we see that the two phase shifts behave very differently. The isospin 3/2 phase shift is essentially linear below 30 MeV while the isospin 1/2 line has curvature even down to 5 MeV. The qualitative conclusion that one draws is that the interactions for the two isospins have very different ranges. The curves shown were calculated from fits of separable potentials to data. The range for the derived potential for the 1/2 case is slightly greater than 1 fm while the 3/2 case has a range of less than 1/3 of that. Can we understand physically why this is the case?

Consider the simple view of the nucleon consisting of a quark core surrounded with a meson cloud. If we take this picture literally then an incoming projectile can interact with either the core or the pion cloud.

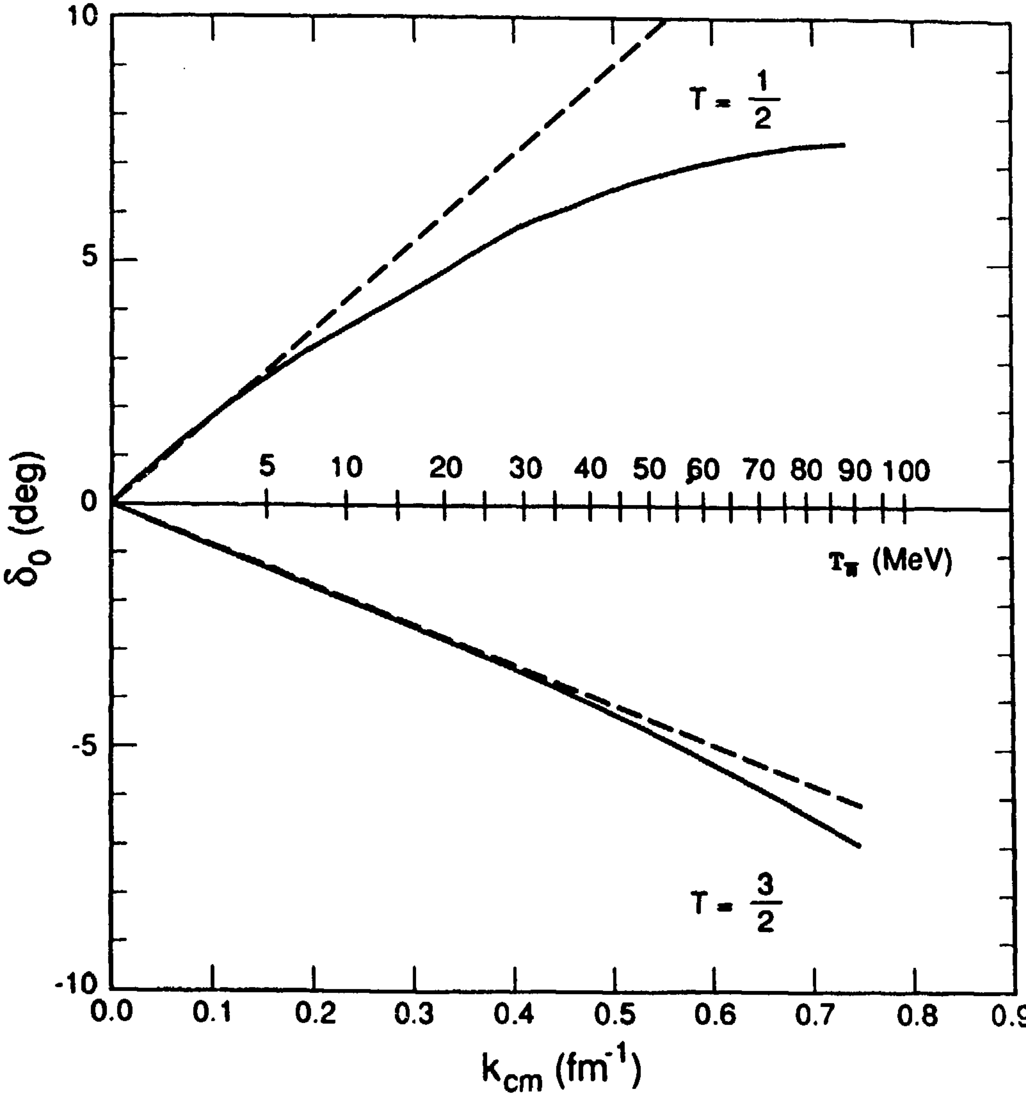

Fig. 1 The isospin 1/2 and 3/2 s-wave pion nucleon phase shifts as a function of center of mass momentum. The kinetic energy is also indicated on the center scale

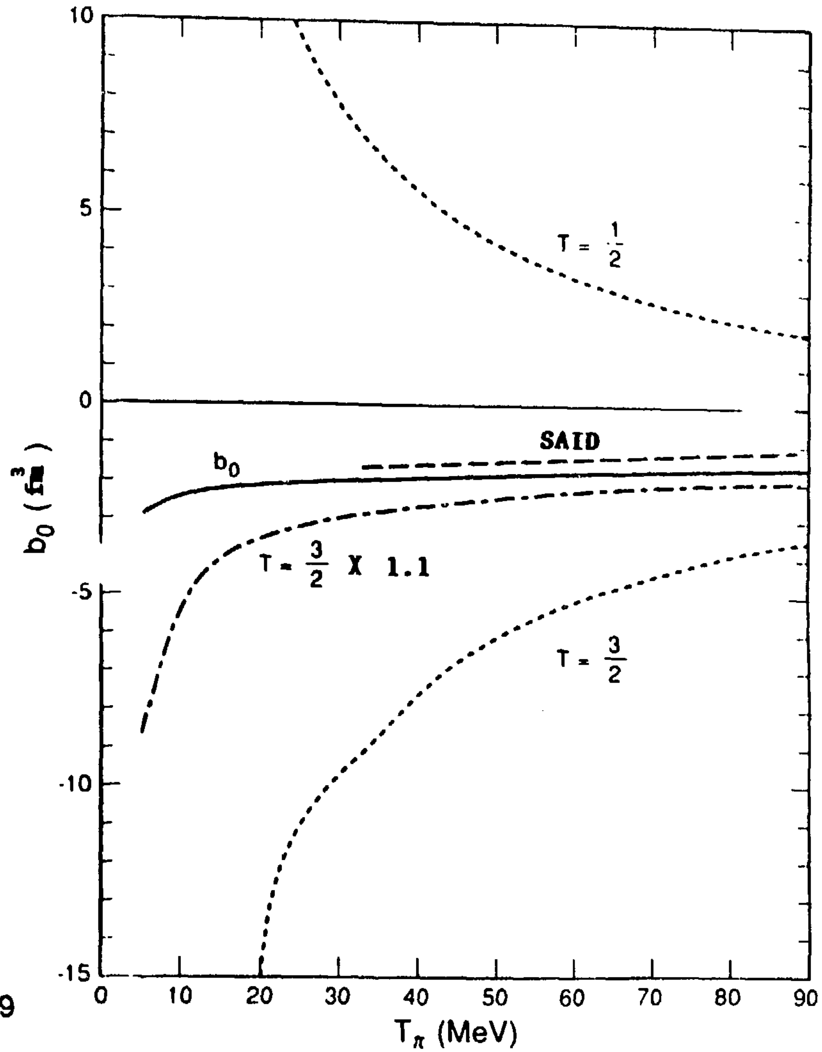

Fig. 2. The pion-nucleus "s-wave" parameter "b_0". The contributions arising from the two isospins are shown by the dotted curves. The value of b_0 from Arndt's analysis is given by the dash-dot curve. The result is also shown for the case in which the isospin [illegible] phase shift is multiplied by a factor of 1.1 as indicated.

Note that, in this picture, the isospin selection in the π-nucleon system makes an important selection in the hadronic interaction.

To see this, let us decompose the I=1/2 nucleon into its I=1/2 core and the I=1 pion in the cloud. It is clear, with a little recoupling, that the π-π interaction in the I=1/2 pion-nucleon system must be only in the I=0 state and by the same token, it must be in the I=2 state for the I=3/2 pion-nucleon system (there is no I=1 π-π state in the s-wave). To see this directly note that if the two pions are coupled to I=0 then the I=1/2 core can only stretch to a total isospin of 1/2 and if the two pions are in an I=2 state we can only reach I=3/2. Now the π-π interaction in the isospin zero state is about an order of magnitude larger than that in I=2. This tells us that there should be a strong contribution from the pion cloud in the I=1/2 state, but not for the I=3/2 wave. The pion cloud represents the largest extension in the system so it would lead to a long range potential; so the picture is consistent with the ranges found. If we try to calculate the magnitude of the I=1/2 π-nucleon scattering from the π-π I=0 scattering we don't do too badly. The π-π scattering amplitude is not very well known and we don't know how many pions to put into the cloud, so getting a precise number with this simple model is not easy. Putting one pion into the cloud, one gets to within a factor of two of the right answer. Since the π-π interaction in the I=3/2 π-nucleon scattering is very small we expect that what remains must be dominant, i.e. the interaction with the quark core. This also makes sense if we compare with specific calculations as we will now see.

It was pointed out many years ago [5] that, if one uses any model which involves quark exchange, there should be relationships between different reactions with the same number of "active" quarks to be exchanged. A good candidate for this comparison is π^+- and K^+-proton scattering. If we neglect the antiquark in each case (the antiquark for the kaon is strange and hence is inactive while for the pion its annihilation with the down quark in the proton would lead to an I=3/2 s-wave resonance which is very high in energy) then the number of up quarks to be exchanged (along with one or more gluons, for example) is two in each case. Therefore the two systems evolve under the action of the same potential. Because the two mesons don't have the same mass, the solution of the scattering problem will be different, but, assuming a reasonable range for the potential, one is able to use one of the scattering lengths to predict the other. With this in mind, it is not hard to understand that, in fact, the cloudy bag model is able to get the correct value for the π^+-proton[6] and K^+-proton[7] scattering lengths. We note that for the isospin 1/2 case the cloudy bag model is a disaster, that is until meson exchange contributions (sigma etc.) are included. This is simply another indication of what I said before; the meson cloud dominates the I=1/2 and the quark core dominates the I=3/2 π-nucleon s-wave scattering. Thus nature has provided us with a laboratory for separating quark and meson degrees of freedom.

We can even obtain an estimate for the purity of the separation from the following arguments. For the K^+-nucleon scattering case the fact that the neutron has half as many up quarks as the proton means that the quark prediction of the K^+-neutron scattering amplitude is only half that of the K^+-proton amplitude. In terms of isospin this means that the I=0 amplitude is zero. Experimentally it is found to be very small. Applying the same arguments to the pion case we find that the quark prediction for the I=1/2 amplitude is 1/4 of the I=3/2 amplitude. Since I=3/2 scattering length is only (in magnitude) 1/2 that of the I=1/2 scattering length we may estimate the quark contamination of the I=1/2 scattering length to be only ~1/8 or 10-20%. Above the very low energies we would need a more complete model to make such an estimate.

Things get even more interesting when we realize that the chiral symmetry conserving combination of these two quantities that cancels at zero pion mass and at zero energy is exactly the same combination that occurs in the calculation of one part of the pion-nucleus optical potential for scattering from an isospin-zero nucleus. Of course, because of the difference in the energy dependence of the two isospin waves, the two contributions do not completely annihilate away from zero energy but the cancellation is still significant, as shown in figure 2. Here the separate contributions have been divided by k^2 because of a conventional factor included in that part of the optical potential which arises from the pion-nucleon s-wave. I have shown the "b_0" obtained from the analysis quoted before [3], but also shown is the one which comes from Arndt's analysis [8]. While, in general, there is little difference between the two sets of phase shifts, the large cancellation accentuates this uncertainty. The values of "b_0" needed to fit the pion-nucleus scattering data are well known to be more negative than the ~ -2 that I have shown here, predicted from the fundamental amplitudes. We also know that a part of this discrepancy comes about because some of the p-wave part of the interaction.

which is much stronger than the s-wave, gets mixed into b_0. However, it has always been difficult to find enough strength from this effect to get agreement with the experimentally determined b_0.

One explanation for the EMC effect has been that the bag-like core of the nucleon "swells" slightly thus partially deconfining the quarks [9]. The increase in the size of the quark core is estimated to be of the order of 10-15%. If we assume that the pion cloud is unaffected by the immersion of the nucleon in the nucleus (obviously an oversimplification) and simply increase the core radius (and hence, in a hard-core model, the I=3/2 phase shift) by a factor of 1.1 the value of b_0 is made more negative. The curve so labeled is also shown in figure 2. Because of the cancellation already noted, the 10% change in the bag size gives a 50% change in the value of b_0, at least at the lowest energies.

It is worthwhile pointing out that the pion wave lengths are, in fact, the right size to carry out this kind of investigation. In order to distinguish two different length scales the wave length should be in the range where the smaller size system has the appearance of a delta function (or at least a short range) in coordinate space and the other has a clear finite extension as evidenced by a momentum or energy dependence. That is to say, the wave length should be between the two scales. Since the pion wave length is typically of the order of 1 fm for low energy pion scattering this condition is satisfied.

I hope it is now clear from what I have just said that, from several points of view, the low energy pion-nucleon phase shifts constitute a crucial data set. How do we get an accurate measurement of them?

Note again that the isospin 3/2 phase shift is linear in k_{cm} below 30 MeV so that measurements below that energy are not essential for this isospin. Note also that π^+-proton scattering gives this number directly, since it is purely isospin 3/2. Hence, good π^+-proton data down to 30 MeV are sufficient for the determination of this phase shift. Such data has recently been taken by Brack et al. [10] and should fill the bill.
The isospin 1/2 amplitude poses a different problem. First of all, there is no single experiment which directly measures this amplitude. There are two choices; extract it from either π^--proton elastic scattering or charge exchange data. Of course, one would like to have both sets of data to check that isospin violations due to the Coulomb potential and mass differences have been properly taken into account, and that there are no nasty surprises from some other source. However, the π^--proton scattering

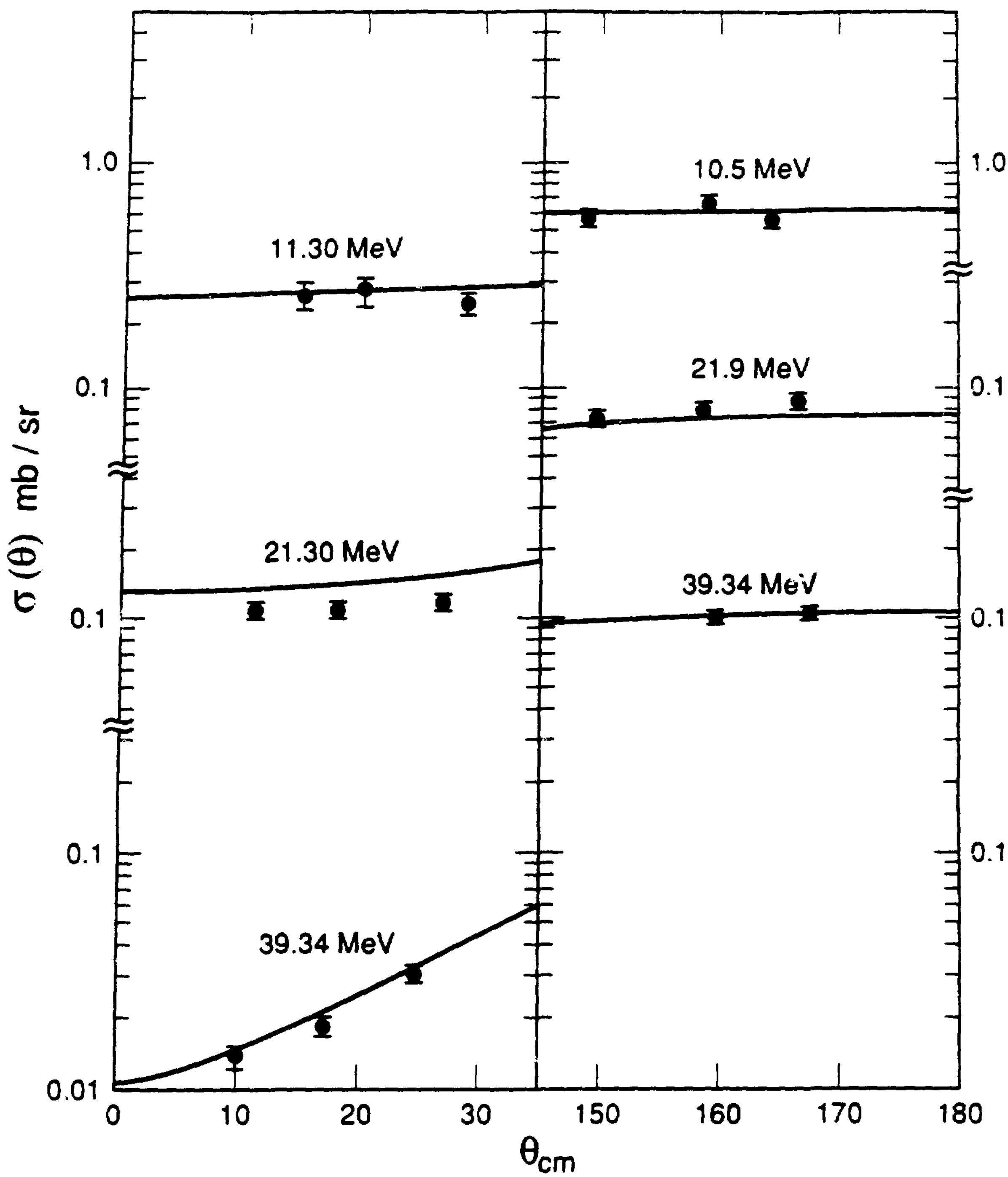

Fig. 3. Comparison of the new (preliminary) data of ref. 11 with the predictions of ref. 3. Note that the agreement at 40 MeV and 10 MeV is satisfactory while the comparison at 20 MeV indicates that a readjustment of the parameters will be necessary.

is very difficult to do at the very low energies needed because the Rutherford amplitude is coherent with the strong scattering and tends to dominate. In this case one would have to measure the differential cross section very accurately in order to extract the strong component. Of course the pion beam must be transported to the target before scattering and from the target to the spectrometer after scattering in order to measure the absolute cross section with high precision and, at low energies, the pion decay makes this difficult. The charge exchange reaction is much more promising. First of all, there is no coherent Coulomb amplitude. That is not to say that there is no Coulomb effect, but only that it is much smaller. Secondly, the beam need only be transported to the target; the π^0 decays immediately and is detected by means of the two photons from the decay. This detection method is adequate since energy resolution is not an overwhelming consideration here.

What is really sensational is that such data have just recently been taken down to 10 MeV, and preliminary results reported by Isenhower et al. [11] Figure 3 shows this data compared with the predictions of the potential analysis mentioned earlier. It is interesting that the agreement is very good around 40 MeV (it should be, since the fits were made to the previous charge exchange data [4] in this energy region) and at the lowest energy, but that there is a noticeable difference around 20 MeV. This means that, in a reanalysis, the curvature is going to be somewhat different than that obtained before. It will very interesting to see what effect the results of an analysis of the final data will have on the value of the sigma term (and the number of strange quarks in the nucleon?). Remember that the sigma term comes from an extrapolation of the data below threshold so that a knowledge of the effective ranges is as important as that of the scattering lengths. The accurate determination of this curvature is significant.

π^+ and π^- Scattering on the $^3He/T$ Systems

The n-p force is slightly stronger than the n-n (or p-p) force. The deuteron is bound and the n-p spin-singlet scattering length (-23.7 fm) is larger in magnitude than the nn scattering length ($\approx$ -17 fm). Therefore, one expects the radius of the odd nucleon in the trinucleon system to be smaller than radius of the like pair. That is, the proton radius of ^3H should be smaller than the neutron radius. State-of-the-art Faddeev calculations employing contemporary nucleon-nucleon force models yield a difference of about 0.16 fm.

In the absence of the Coulomb interaction between the two protons in ^{3}He, the ^{3}H and ^{3}He systems would be identical. Including the Coulomb interaction in the Faddeev calculations leads one to an increase in the proton radius of 0.03 - 0.04 fm. The repulsive Coulomb interaction also affects the neutron radius. The increased separation of the two protons means that the neutron is less bound. That is, the neutron distribution is also expanded, and the neutron radius is increased by 0.02 - 0.03 fm.

The proton radii of ^{3}H and ^{3}He are known experimentally from elastic electron scattering:

$$r_p(^3\text{He}) = 1.76 \pm 0.04 \text{ fm}$$

$$r_p(^3\text{H}) = 1.57 \pm 0.04 \text{ fm}$$

The difference of 0.19 fm is consistent with the results of the Faddeev calculations: 0.16 + (0.03 - 0.04) fm.

What can be said about the neutron radii? It is difficult to extract a neutron radius for ^{3}He from magnetic electron scattering, because meson exchange current corrections are sizeable. It is impossible to extract a neutron radius for the ^{3}H because the odd nucleon, which carries most of the spin, is the proton.

Thus, one is led to pursue pion scattering to determine the relative radii in the A=3 systems. Meson exchange current contamination is minimal. Near resonance, the π^+-p interaction dominates the π^+scattering and the π^--n interaction dominates the π^- scattering. Assuming that multiple-scattering effects can be properly accounted for, ratio measurements should be very sensitive to differences in the odd nucleon and like nucleon matter distributions.

One might ask about the effect of three-nucleon forces on these systems. Contemporary two-pion-exchange three-nucleon force models were included in the above mentioned Faddeev calculations. These proposed three-body force models are isoscalar in nature. Thus, they tend to decrease the difference between the proton and neutron radii. One can see in Fig. 4 from ref. 12 that, while the introduction of a three-body force can improve the binding energy (and low-energy properties such as radii), three-body forces do not resolve the discrepancy between theory and

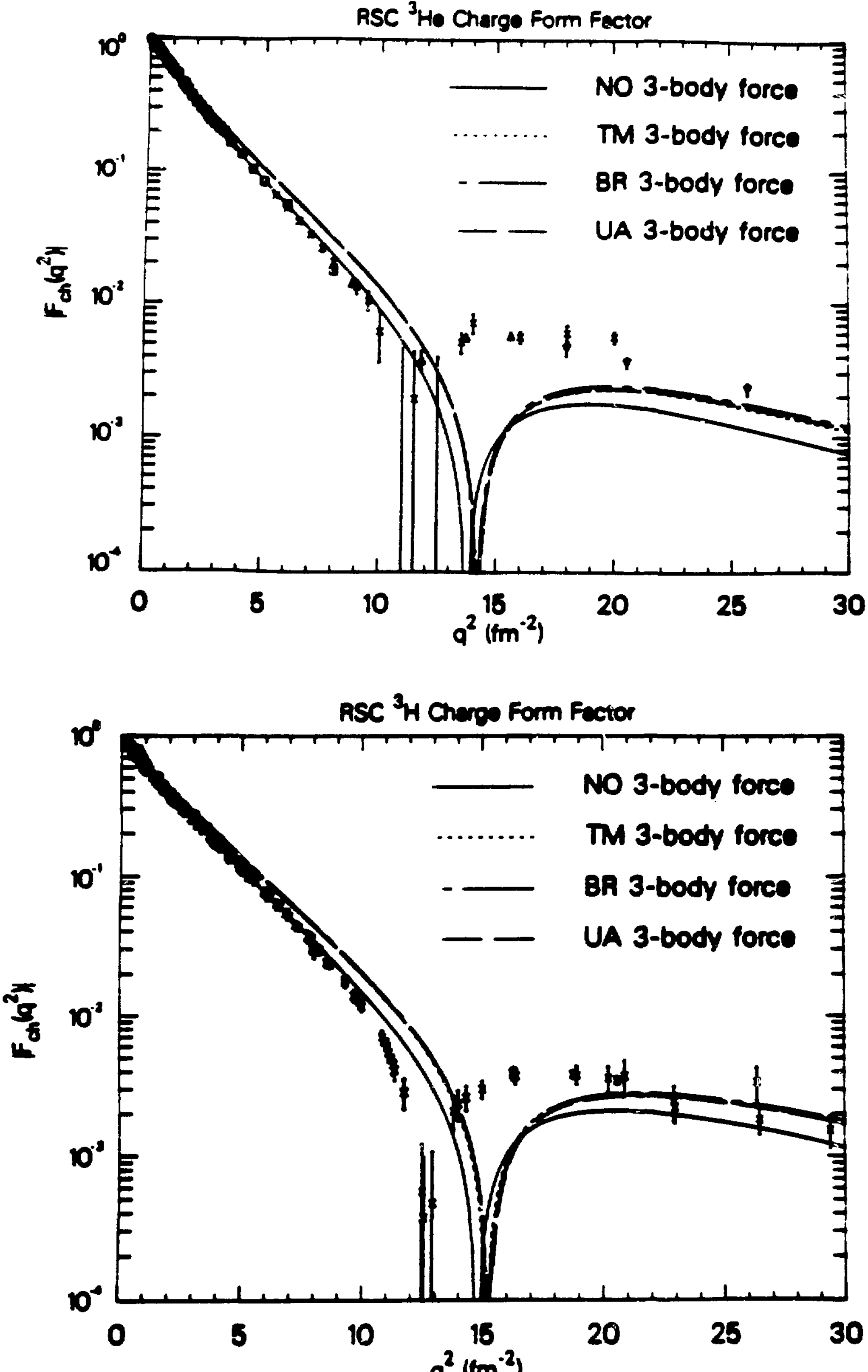

Fig. 4. ^{3}He and ^{3}H form factors from the Faddeev calculations in ref. 12 with and without three-body forces.

experiment for the higher momentum transfer region of the charge form factors.

Let us consider three ratios of pion-trinucleon cross sections. First, the ratio

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

involves primarily the pion strong interaction with the odd nucleon in each case. That is, in the region of the (3,3) resonance, π^+p and π^-n scattering dominate over π^-p and π^+n. Clearly the coherent Coulomb scattering does not cancel from the ratio, but the strong interaction should be much more important. Thus, r_1 should be sensitive to the ratio of the odd-nucleon form factors -- in the single scattering (impulse) approximation, this is what one would calculate keeping only the dominant π^+p and π^-n interactions. Both spin-flip and non-spin-flip scattering from the odd nucleon are important.

Second, the ratio

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

involves primarily the pion strong interaction with the like nucleons in each case. Again the Coulomb effects do not cancel in the ratio. However, because the like nucleons are essentially paired in spin (to spin 0), spin-flip scattering is minimal. Thus, r_2 is sensitive to the ratio of the like-nucleon form factors.

Finally, the "super ratio"

$$R = r_1 r_2$$

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

should be least sensitive to model uncertainties in the treatment of the pion-nucleus scattering theory (as well as experimental normalizations). While the Coulomb interaction does not cancel, the calculation of R should be less sensitive to any model dependence on those effects than the individual ratios r_1 and r_2.

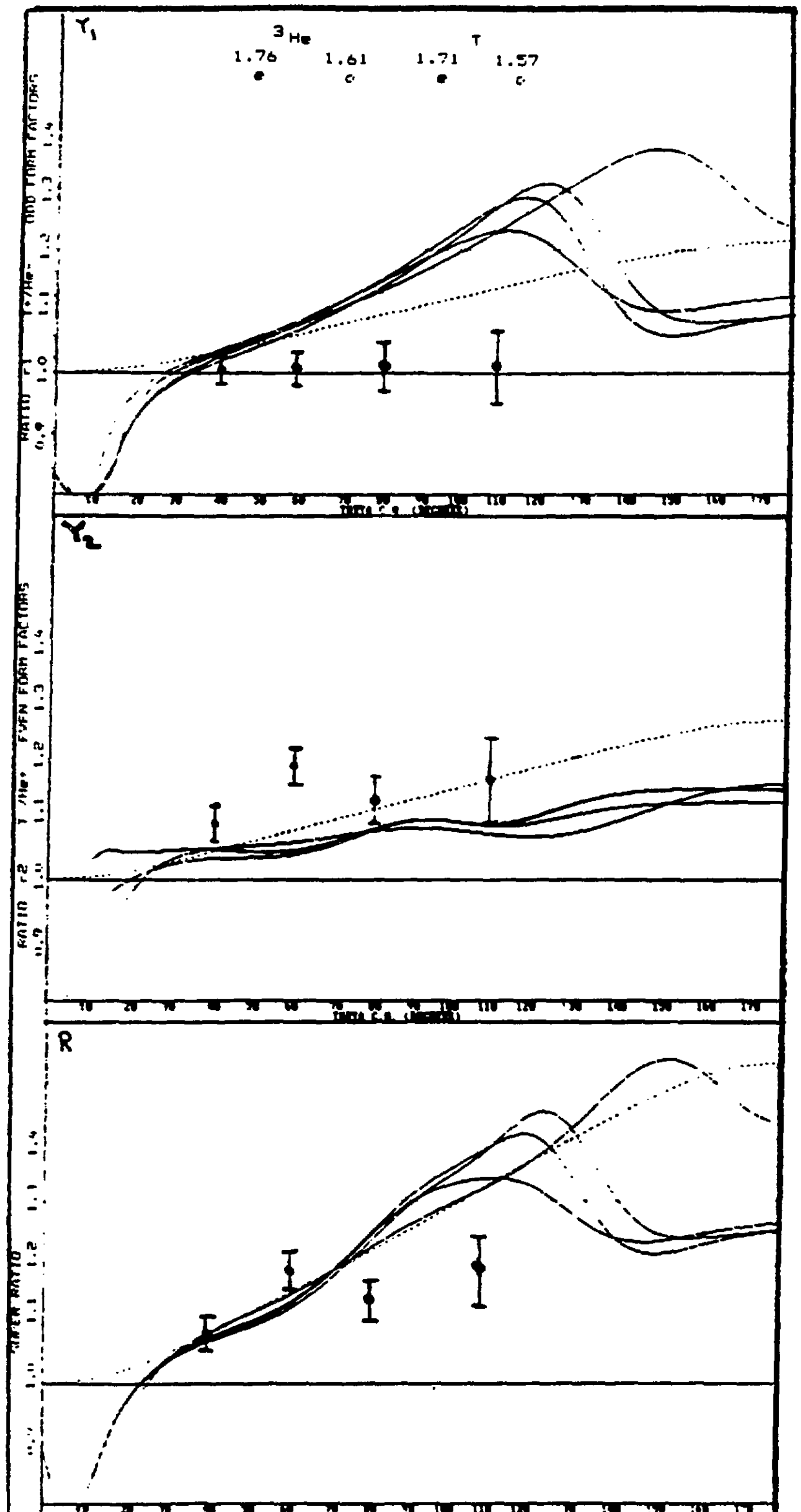

Fig 5 The π-nucleus cross section ratios for the model radii indicated, corresponding to extrapolations to the experimental binding energy from ref 12. The dashed curves are form factor ratios. The solid curves are multiple scattering calculations for various πN scattering amplitude variations. The data is from ref 13

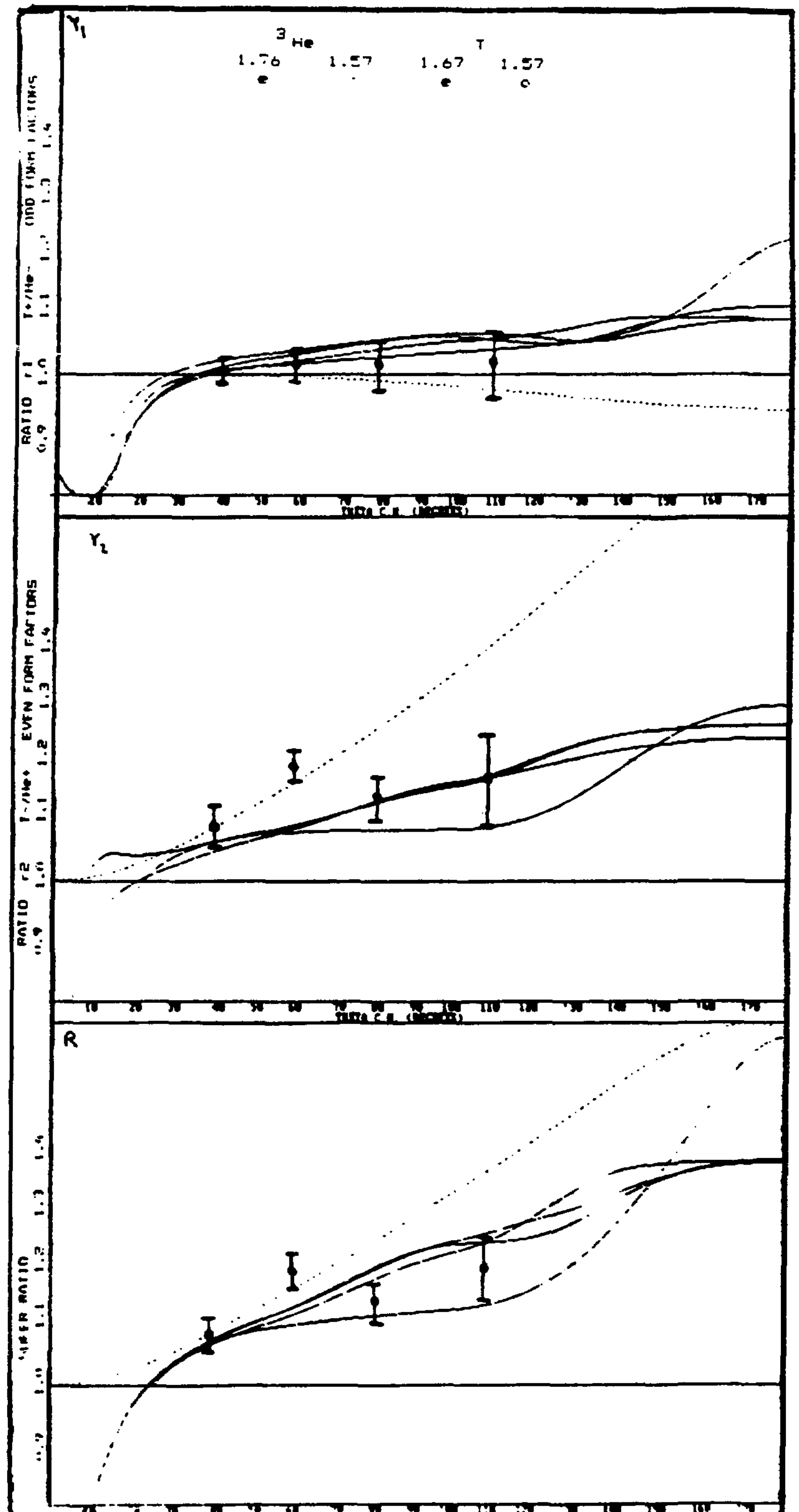

Fig 6 The π-nucleus cross section ratios for A=3 radii adjusted to give reasonable fits to R. The dashed curves are form factor ratios The solid curves are multiple scattering calculations for various πN scattering amplitude variations.

Because ^{3}He is expected to be larger than ^{3}H, such that its form factor falls faster, we anticipate (in general) that R>1. Similar conclusions can be reached for r_1 and r_2, although they are subject to greater uncertainty due to Coulomb interference effects.

Looking at Fig. 5, we see the relevant form factor (impulse approximation retaining only the strongest interaction) ratios plotted as dashed lines. The solid lines represent pion-trinucleon scattering calculation results in which variations among the strong interaction model parameters (πN s-wave off-shell range, πN p-wave off-shell range, πN spin-flip off-shell range, and energy shift) were made. It is clear that the model dependence in terms of the πN interaction is minimal between 40° and 80°. Also, the multiple scattering results do follow the general trend of the form factor ratios.

In Fig. 6 we display the same set of curves BUT for trinucleon matter densities which have been modified to account more reasonably for the existing data. We have assumed that the shape of the trinucleon distributions are adequately defined by the Faddeev calculations. Thus, the difference in the ^{3}He/^{3}H structure between the calculations presented in Figs. 5 and 6 is given entirely in terms of the rms radii of the odd nucleon and like nucleon pair, for each nucleus (i.e. the radius variable in each density was rescaled so that the cited rms radius was obtained, the normalization being corrected as well). We have furthermore assumed that the radii determined by elastic electron scattering from ^{3}He (the radius of the like protons) and from ^{3}H (the radius of the odd proton) are fixed by those measurements. Therefore, the odd-nucleon radius of ^{3}He was decreased (1.61 → 1.57 fm) to improve the theoretical ratio r_1. Similarly, the like-nucleon radius in ^{3}H was decreased (1.71 → 1.67 fm) to improve the fit to r_2 and R. The changes made (0.04 fm) are no larger than the absolute uncertainties in the measured values of $r_p(^3He)$ and $r_p(^3H)$. However, the relative sizes of the resulting radii for ^{3}He and for ^{3}H disagree completely with the predictions for the odd-nucleon and like-nucleon radii given by the Faddeev calculations. Thus we see that the measurement of the relative radii provides a much more stringent test than the comparison of the two proton radii alone.

It is clear from looking at the model differences reflected in the plots shown in Figs. 5 and 6 that the ratios are much more sensitive to the relative sizes of the matter distributions of the trinucleons than to the pion-nucleus scattering model uncertainties. It is also evident that the relative sizes of the odd-nucleon and like-nucleon matter distributions in the trinucleons can be more precisely determined from the proposed rat measurements than they are now known from the absolute measurements made via elastic electron scattering. Recent preliminary data taken at 256 MeV and presented at Santa Fe [14] shows that the super ratio is <u>less</u> than one. This not only violates our naive expectation expressed above but also disagrees with the extrapolations from both calculations just discussed. The individual ratios r_1 and r_2 are not yet available and we await the final data reduction before attempting even a speculative explanation.

Pion-Nucleus Double Charge Exchange

The DCX reaction has been considered for many years as one of the best hopes for probing the correlation structure of the nucleus. This is due to the fact that (at least) two nucleons must be affected by this reaction; there is no first order (or single scattering) term. How to actually extract information on the nucleon-nucleon correlations from this reaction has not been clear. The problems are the usual ones, i.e. the nucleus is a many-body problem and scattering is, at least, a many-plus-one-body problem. Clearly approximations and insight are needed to develop a technique for extracting information.

To do this we begin with the shell model, starting with the simplest form and gradually adding increasing complexity as warranted by the data and our ability to deal with the scattering aspects. From this point of view we start with the simplest, non-trivial, case we can find. The system chosen, for both experimental and theoretical reasons, is that of the calcium isotopes and more generally, the "$f_{7/2}$" shell. We assume, to begin with, that all active particles are in $f_{7/2}$ orbitals. The case of the transitions to the double analog from calcium isotope targets is the most straightforward. From the nuclear structure point of view we note that (for the case of only neutrons in a single shell, $j \leq 7/2$) the seniority model [15] is exact in the sense that it gives the same answer as a full diagonalization of the type of, say, MBZ [16]. In the seniority model in general, one finds for DCX, as in the case of the original formula for energy levels, that there are only two amplitudes that contribute and that one of the amplitudes is long range, being sensitive to the entire nuclear volume, while the other depends only on the components of the wave function of the two active nucleons representing the situation when they are close to each other. It was not obvious that such a formula is valid for DCX since its derivation for the nuclear energy levels (for which it was originally created) depends on the assumption of a scalar interaction between the two nucleons and the DCX scattering operator is by no means a spatial scalar. This same simplification comes about in this case because the transition proceeds from a 0^+ initial state to a 0^+ final state so that only the scalar part of the DCX operator is sampled.

Carrying out the calculation assuming such wave functions [17] yields the following table for double analog transitions in the calcium isotopes. The nuclei listed at the right of the table are the particle-hole conjugates of those on the left and completely equivalent insofar as the shell structure is concerned.

^{42}Ca	$\|A+B\|^2$	^{54}Fe
^{44}Ca	$6\|A+\frac{1}{9}B\|^2$	^{52}Cr
^{46}Ca	$15\|A-\frac{1}{15}B\|^2$	^{50}Ti
^{48}Ca	$28\|A-\frac{1}{7}B\|^2$	

Table I. Expressions for the analog cross section for double charge exchange in terms of the two amplitudes "A" and "B".

The amplitude "A" corresponds to the long range (uncorrelated) part of the total amplitude and, if it were the only contributor, the cross section would be proportional to the "pairs factor" appearing in the front of the expression, so called because it is simply the number of excess neutron pairs. We see that a violation of this pairs factor rule is a sign that, either the assumptions made in deriving these formulae are wrong, or that the "B" term, representing correlations, is present.

It has been known for some time that the pairs factor rule is broken by a considerable amount, especially at low energies where, e.g., the ^{44}Ca cross section was measured to be only 1/2 of that of ^{42}Ca instead of 6 times greater as predicted by this simple rule. Thus it seemed likely that the "B" term, arising from correlations, was playing a significant role.

How do we prove to ourselves that the understanding of DCX truly lies in the existence of the correlation term "B"? We can use measurements of several of these isotopes to perform a test. Notice that "A" and "B" are two complex amplitudes and, since the overall phase is irrelevant, there are only 3 independent numbers which must describe all of the cross section at each energy and angle (at least in the pure seniority model). Thus the measurement of 3 isotopes determines these numbers and permits the prediction of additional cross sections based on these formulae. The following table presents a series of measurements made at 35 MeV in the summer of 1987 to check these relationships. This kind of analysis was made by Z. Weinfeld but the cross sections given here are actually due to Mike Leitch [18].

	Double Analog Transition		Ground State Transition	
	Experiment	Prediction	Experiment	Prediction
		25°		
^{42}Ca	2.27 ±0.29	<2.27>		
^{44}Ca	1.09 ±0.16	<1.09>		
^{50}Ti	1.55 ±0.27	1.47		
^{48}Ca	2.70 ±0.90	<2.70>	1.30 ±0.30	2.39 (0.87)
^{46}Ti	2.53 ±0.35	4.52		
		(2.29)		
^{54}Fe	1.50 ±0.40	2.27		
		40°		
^{42}Ca	1.90 ±0.30	<1.90>		
^{44}Ca	1.10 ±0.15	<1.10>		
^{50}Ti	1.47 ±0.18	1.45		
^{48}Ca	2.40 ±0.60	<2.40>		1.83 (0.67)
^{46}Ti	2.11 ±0.30	3.69		
		(1.87)		
^{54}Fe	0.90 ±0.20	1.90		
		70°		
^{42}Ca	0.40 ±0.08	<0.40>		
^{44}Ca	0.16 ±0.04	<0.16>		
^{50}Ti	0.71 ±0.13	0.83		
^{48}Ca	2.20 ±0.50	<2.20>		0.74 (0.27)
^{46}Ti	0.47 ±0.12	0.95		
		(0.48)		
^{54}Fe	0.04 ±0.03	0.40		

Table II. DCX cross sections (in μb/sr) at 35 MeV. Angle brackets "< >" indicate values used for the fit. Parentheses indicate predictions beyond the seniority model.

The cross sections in the angle brackets are the values used to fix the amplitudes A and B and the rest are predictions of the theory. First, let us look at the predicted cross sections for ^{50}Ti (which is the particle-hole conjugate of ^{48}Ca, the later being a rather expensive target for pions.) One sees that the predictions are equal to the experimental cross sections, within errors, at each of the three angles which means that the expressions involving the correlation term work very well for this simple case where the seniority model is exact. This is a test of the assumption of the pure $f_{7/2}$ model for the calcium isotopes, or at least for the constancy of the correction to this model across the shell. Note that this is not a trivial result; to be able to predict three cross sections within 15% is significant.

Next, let us examine the cross sections for ^{46}Ti. For this case the seniority model is not equivalent to the shell model and we must go beyond the two-amplitude expression [19]. In order to calculate a cross section from the amplitude B already determined experimentally we use a correction (the numbers given in parentheses below the numbers given for the seniority model) which has some model dependence. We see that the seniority model does not work, as was expected, but that the full (single orbital $f_{7/2}$) shell model does predict the cross section within the 15% errors.

We now proceed to the case of ^{54}Fe which is the p-h conjugate of ^{42}Ca so may be expected to have the same cross section. However that expectation assumes that, among other things, the nuclei are of the same size. But these two nuclei are at opposite ends of the shell, as implied by the conjugate relationship. The orbitals should have rather different spatial extensions so we should not be surprised to find a difference in the form of a more rapid fall-off of the iron differential cross section. This is, in fact, what is observed. Our microscopic calculations indicate that the difference seen is about the right size. Of course it is also possible that the structure of ^{54}Fe contains different components from that of ^{42}Ca as well.

It is possible to predict, not only the analog transitions, but the transitions to the final ground state both in the seniority scheme and the more general model [19]. Table II shows the cross section for the one ground state that has been measured at 35 MeV for ^{48}Ca. We note that the agreement with the extended prediction is marginally satisfactory.
This same data is shown plotted in figure 7 to demonstrate the evolution of the angular distribution from ^{42}Ca to ^{48}Ca with the later being much more nearly isotropic, a feature which can also be understood from the equations given above. Since it is beyond the scope of the talk here I refer you to reference 19.

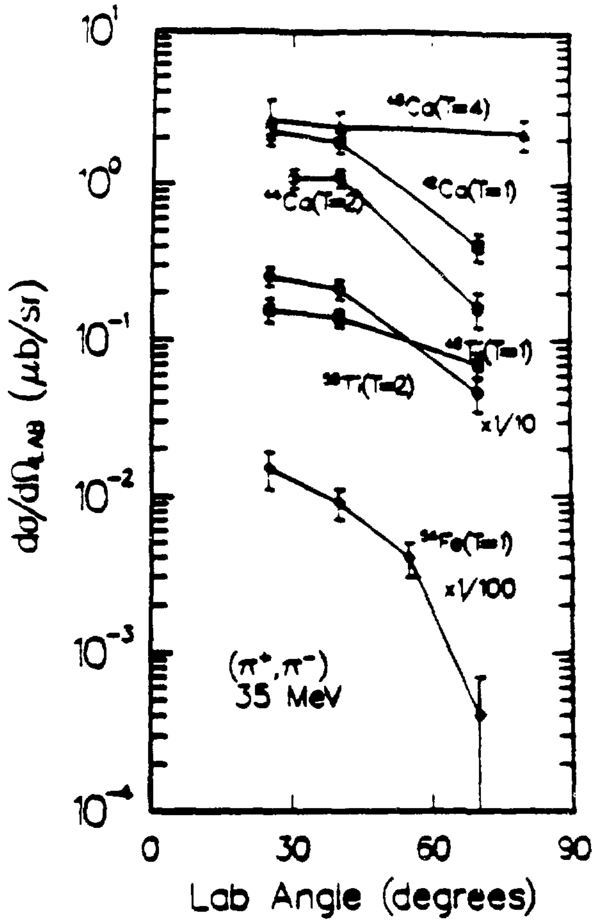

Fig. 7. Plot of the experimental data [18] shown in Table II.

This past summer additional data were taken to measure the energy dependence of the cross sections. There were several surprises. First of all, enough data could be assembled at 65 MeV to start a similar analysis to that at 35 MeV. Here we note that the ground state of ^{44}Ca (as corrected for the full $f_{7/2}$ shell model) was needed to help fix the parameters. It is clear that there is a problem with the ground state of ^{48}Ca (actually the problem is with the ratio ^{48}Ca/^{44}Ca). It is much too small to fit into the scheme. It is possible that the problem is related to the rapid energy dependence to be discussed below.

	Double Analog Transition Experiment	Double Analog Transition Prediction	Ground State Transition Experiment	Ground State Transition Prediction
^{42}Ca	1.38±0.60	<1.21>		
^{44}Ca	<0.6	0.66	0.6±0.1	1.19 <(0.61)>
^{48}Ca	0.34±0.11	<0.34>	0.07±0.04	1.02 (0.37)

Table III. DCX cross sections (in μb/sr) at 15° and 65 MeV.

Before going on to present the results achieved so far for the energy dependence let me explain why it is so interesting.

Let us consider two of the ways that the double charge exchange reaction might take place. The first, and most often computed, is the sequential process shown in figure 8a. There the reaction proceeds through two independent single charge exchanges, (although not necessarily with the intermediate nucleus in the single analog state). The part of the

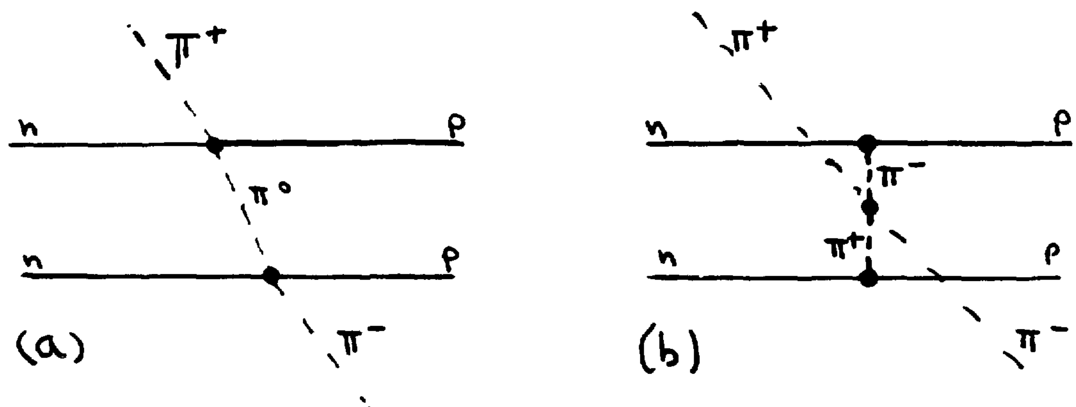

Fig. 8. Diagrams for the a) sequential and b) "meson exchange current process.

amplitude which arises from the intermediate analog route in the sequential model is to be identified with the amplitude "A". The rest of the possible intermediate states contribute to "B". Figure 9 shows a plot of |A| and |B| (computed with the sequential mechanism and without distortion) as a function of the internucleon distance. That is to say, what is plotted is the value that these two quantities would have if there were no contribution from inside the corresponding internucleon range which labels the abscissa. As we see, the quantity "A" has contributions from the entire nucleus while "B" only receives strength from short internucleon spacings. We may well believe that this sequential model is suitable for the calculation of "A" since reactions occurring far apart are likely to be independent. However, for the "B" amplitude the sequential model is questionable since it assumes independence even when the nucleonic constituents are overlapping.

The pion clouds associated with the nucleons should sometimes overlap and in this case the double charge exchange reaction can take place in a

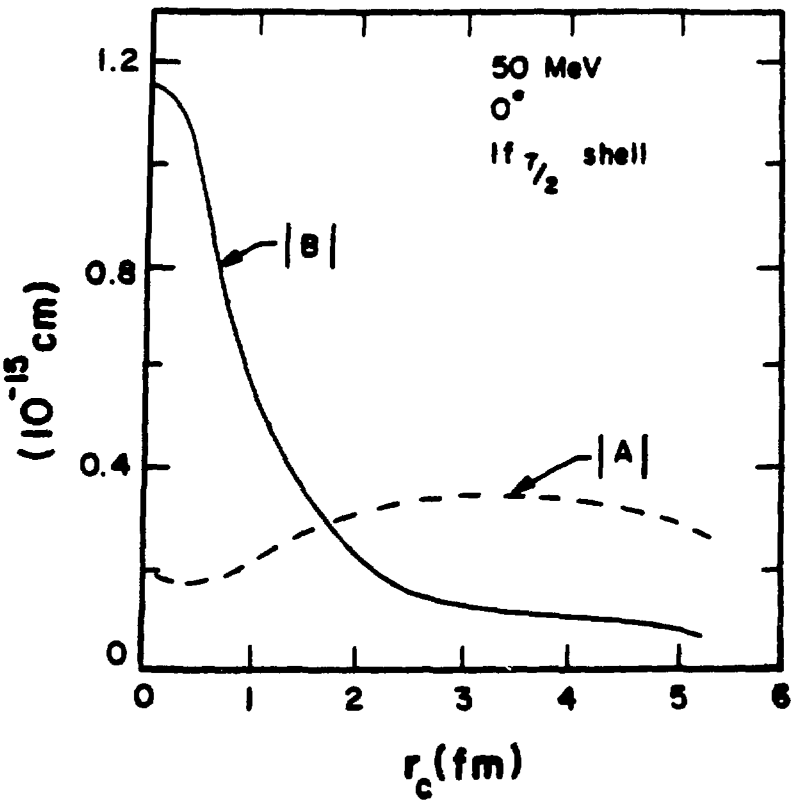

Fig. 9. The magnitude of "A" and "B" as a function of the internucleon spacing showing the region of contributions.

single step as shown in figure 8b. This process has been considered for a number of years [20] and calculations of it have always claimed to give substantial cross sections. An interesting feature of this mechanism is that the cross section does not depend on energy (in plane-wave calculations with a constant π-π vertex) but only on momentum transfer. Therefore at 0° the DCX cross section would be independent of energy. Of course the energy dependence arising from the variation of the distortion of the initial and final waves is present in any realistic calculation.

On the other hand for the sequential process, aside from this same energy variation arising from the distorted waves, there are two additional sources of energy dependence coming from the transition amplitude itself -- the two delta resonances (one at each charge exchange) and the s-p interference at 50 MeV. The idea presents itself that perhaps we can separate the contributions of these two mechanisms by examining the energy variation of the DCX cross sections.

Figure 10 shows a distorted wave calculation of the ^{42}Ca double analog cross section with the meson exchange mechanism only. We see that the nuclear transparency around 50 MeV causes a large structure in the cross section. Of course the sequential calculation will show similar, but more complicated structure.

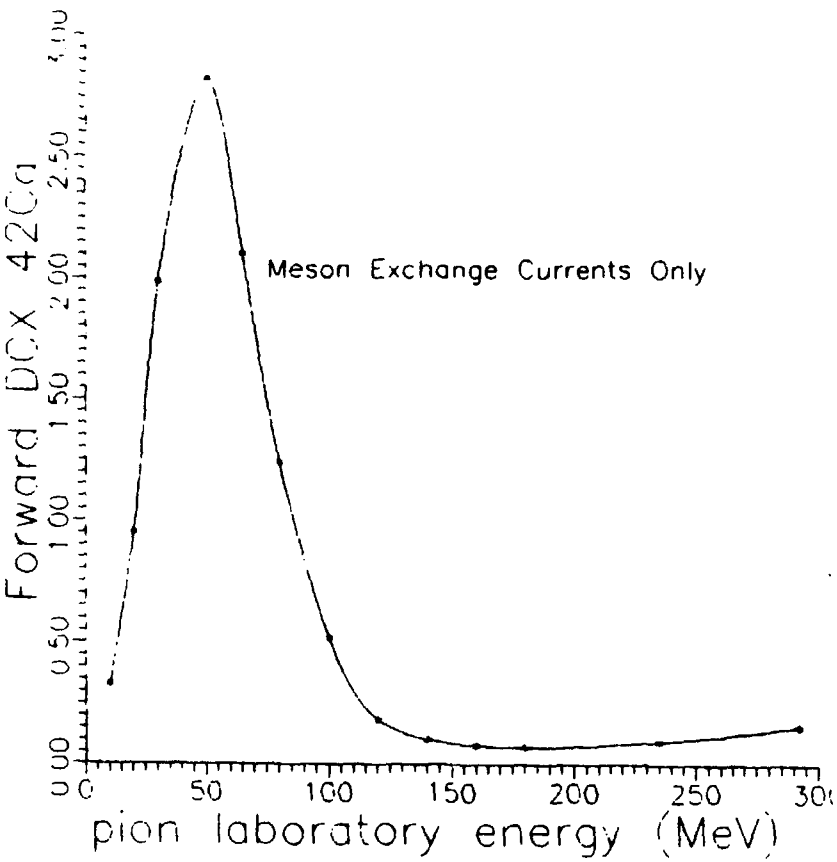

Fig. 10. Distorted wave calculation of the MEC contribution at 0° as a function of pion energy.

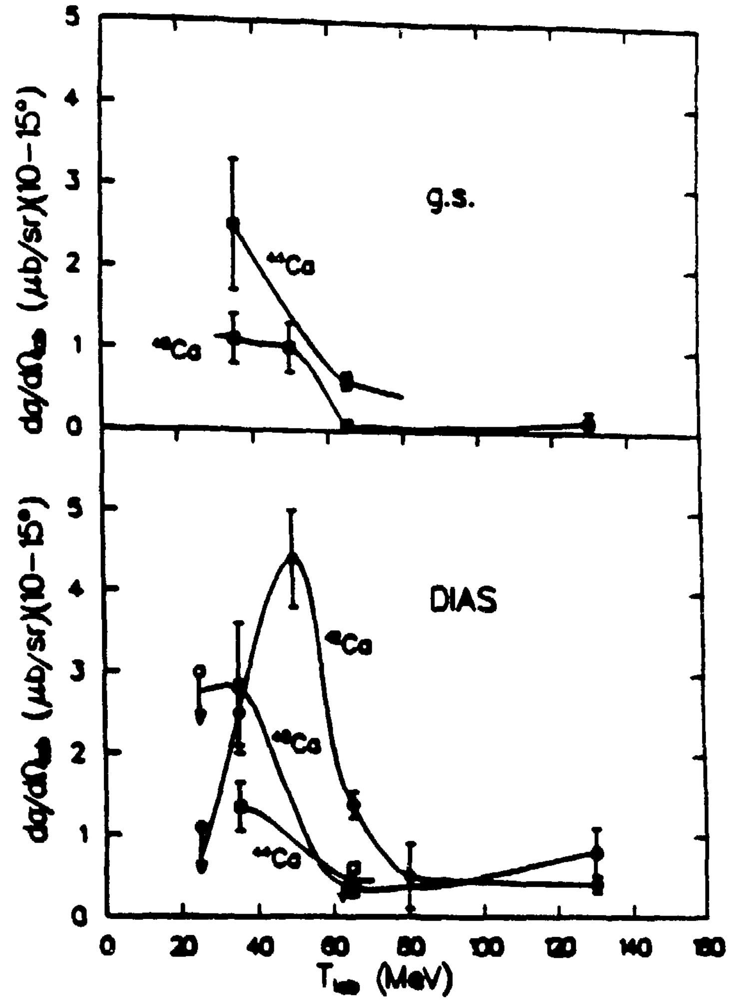

Fig. 11. Experimental measurements of the analog and ground state cross sections [illegible] ref. 20.

Figure 11 shows the measured energy dependence of the analog and ground states as presented by Mike Leitch (preliminary data) at the Santa Fe DNP [20] meeting. We see several interesting features. For one thing the rapid energy variation around 50 MeV causes us to question assumptions such as: the corrections due to the difference in Q-values are small. If the outgoing pion energy differs by 10 MeV between two different cases, that can make a significant difference to the cross section and might explain the difficulties mentioned above for the ratio of the ^{48}Ca/^{44}Ca ground states.

One of the most striking features is the structure in the ^{42}Ca analog cross section. It very much resembles that shown in figure 10 for the meson exchange current. It would be premature, however, to conclude that we have seen evidence for such an effect since the sequential process can produce similar structure. Additional information is available from the fact that the meson exchange graph contributes to A and B in a well defined manner. We note that the ability to separate the reaction into two parts, (plus the sharp energy dependence) is apparently providing us with a microscopic view into the nucleus, permitting us to investigate the very basis of the structure of the hadronic interaction.

Acknowledgements

Since this talk consisted primarily of a review and discussion of recent experimental data, and its interpretation, I have a great number of people to thank. First of all I must thank Donald Isenhower and Mike Sadler (and the rest of the team) for allowing me to quote their striking data on low energy pion-nucleon charge exchange before publication. That experiment is a real tour de force.

Next I thank Barry Berman, Ben Nefkens, Bill Briscoe, Kalvir Dhuga (and the rest of the group) for letting me use their exciting data on the ratio measurements on the three nucleon system. I especially thank Ben Gibson for helping me to think through the relevant physics. The expertise on the three body system is totally his.

For the low energy DCX work I thank to the whole team but especially Mike Leitch who gave me the data, provided the fits I have shown and even allowed me to steal some of his figures. I also wish to thank Bill Kaufmann, a collaborator in the DCX work, especially for the calculation of the meson exchange cross section.

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QUASI-FREE PION-NUCLEUS REACTIONS

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1. INTRODUCTION

Interest in pion induced quasi-free reactions in nuclei has increased in recent years. Last year, at the Twenty-first LAMPF Users Meeting, Michael Thies summarized our understanding of these processes with emphasis on the interplay of experiment and theory.[1] But already several new results are available, including some very important ones from LAMPF. There is not time today to discuss all these data, and I apologize in advance to my colleagues whose results are not mentioned. I will try today to present a few important problems in the field and show a some of the many new results which impact upon them.

Quasi-free pion-nucleus reactions are important for many reasons. Foremost among these, in my mind, is the possibility to study the interactions of the Δ(1232) with nucleons in nuclei. Most of what we know about the complexities of hadronic interactions at low energies has come from studies of the interactions of a single hadronic specie, the nucleon. These studies alone have said rather little about the role of explicit quark degrees-of-freedom, which should be important at short distances ($\lesssim$ 1 fm.), where the nuclear potential changes rapidly in character from maximum attraction to the hard repulsive core. The Δ is a strong, cleanly separated resonance. Thus, it is both experimentally accessible and theoretically tractable. It has a different structure from the nucleon and very different interactions, some of which are illustrated in Fig. 1. The elastic, exchange, and excitation processes have analogs in the N-N system, but unique to the Δ is the possibility of de-excitation, resulting in pion absorption. Here, the large relative momenta of the outgoing nucleons implies that the de-excitation must occur on a very short distance scale. The observed strength of the absorption process is such that it may make important contributions at small distances to the isospin 1 part of all the other processes pictured. Therefore these reactions may be especially suitable to probe the hadronic interaction in the region of quark confinement.

There are many other reasons to study quasi-free pion induced reactions. The reaction dynamics are fundamental to all of intermediate energy nuclear physics, and given some understanding of the underlying interactions, a theory of reaction mechanism becomes possible. Most interesting is an understanding of the role of off-shell processes. Another open question is the existence of strong coherent multi-nucleon processes, which could arise for absorption and pion-production reactions from a strong double-delta excitation mechanism.[2,3] Little is known about these dynamics. Also, the large energy transfer in pion absorption allows study in an interesting

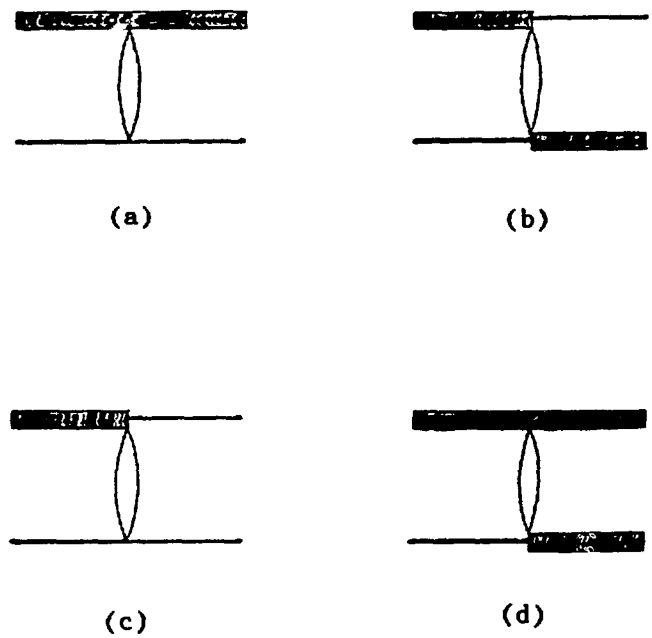

Fig. 1. Schematic diagrams of some types of delta-nucleon interactions; (a) elastic, (b) exchange, (c) absorption and (d) excitation interactions. Deltas are represented by heavy lines and nucleons by solid lines. The interaction mechanism is not specified.

regime of the mechanisms by which energy is dissipated in nuclear matter eg. the importance of direct, few nucleon processes as compared to evaporative ones.

In addition, when the final state is completely specified, the quasi-free reaction dynamics are sensitive to the wavefunction of the nucleon cluster involved. To date, much of our knowledge of the two-nucleon wave function in nuclei has come from transfer reactions, which are highly momentum mismatched resulting in a lack of sensitivity to much of the momentum space. Sizeable deviations from the two nucleon wavefunctions of Cohen and Kurath have been seen in nuclear pion absorption.[4,5] There are also large differences in the spectroscopic factors obtained from knockout of protons by electromagnetic and hadronic probes, which are not understood, but could arise from the effects of correlations.

This talk is divided according to reaction channels which illustrate a particular physical phenomenon. It begins with how information about the strength and isospin decomposition of the elementary Δ-N interaction may be determined from the (π,πN) reaction. We then turn to reaction dynamics, in particular, the role of on-shell and off-shell processes. On one hand, there is new evidence of on-shell pion propagation in quasi-free double charge exchange, the $(\pi,\pi NN)$ reaction. On the other hand, coherent many-body processes make an important contribution to pion absorption, the (π,XN) reaction. As discussed by Thies possibly all these reactions are fundamentally related by the same underlying physics, the evolution of a delta-hole doorway state. Therefore, it is likely that both on-shell and off-shell mechanisms will contribute to these processes.

2. THE $(\pi,\pi N)$ REACTION

Pion quasi-free scattering in nuclei directly measures the pion-nucleon interaction in the nuclear medium. In recent years, large deviations from quasi-free ratios for the isospin channels $^{16}O(\pi^{\pm},\pi^{\pm}p)^{15}N$ and $^{16}O(\pi^{+},\pi^{0}p)^{15}O$ for transitions to discrete low-lying states for pion energies near the Δ-resonance have been reported.[6-9] The most striking effects were seen in the $(\pi^{\pm},\pi^{\pm}p)$ reactions where ratios for π^{+}/π^{-} of up to 40, as compared to the quasi-free value of about 9, were observed as shown in Fig. 2. These anomalous ratios had been predicted by the delta-hole model, when extended to include the interference of direct pion-induced knockout with the coherent delta-induced knockout amplitudes.[10] This effect was of great interest because of its direct sensitivity to the delta-nucleon (Δ-N) interaction. The experiments and their analysis were a cooperative effort of groups at PSI and LAMPF which utilized the strengths of each facility.

The most complete calculation to date of these reactions was reported recently by Takashi Takaki.[11] These calculations use the model of Ref. 10 and include full medium modifications and distortion effects. He assumed a zero range Δ-N potential driven by virtual absorption (resulting in a strongly imaginary isospin-1 part),

$$V_{\Delta-N} = C_{21}\ \delta(\vec{r}_{\Delta} - \vec{r}_{N})\ P_{\Delta N}(^{5}S_{21}) \quad ,$$

where $P_{\Delta N}(^{5}S_{21})$ is a projection operator onto the Δ-N quantum numbers associated with quasi-deuteron absorption, $L = 0$, $J = 2$, $I = 1$. Deviations from quasi-free isospin ratios arise from the isospin-1 part of the interaction. For pion energies near 240 MeV the maximum interference effect occurs at forward pion angles. The effect on the cross section is about +10% for $(\pi^{+},\pi^{+}p)$, +30% for $(\pi^{+},\pi^{0}p)$ and -90% for $(\pi^{-},\pi^{-}p)$ (destructive interference). The choice, $C_{21} = +6 - i17.09$ fm^{2}, gave the best overall fit to the $(\pi^{\pm},\pi^{\pm}p)$ data, shown in Fig. 2, however better fits were obtained by choosing a stronger (weaker) value at forward (backward) pion angles. Such an effect would be produced by a finite range interaction. The positive real part of the potential indicates a repulsive Δ-N interaction at these rather low energies.

Single charge exchange (SCX) reactions have always presented a puzzle; generally the observed cross sections are much larger than are predicted by DWIA. This is not only true in the quasi-free reactions, but also in SCX to isobaric analog states (IAS). The inclusion of explicit Δ-N interactions in addition to the DWIA amplitude had been

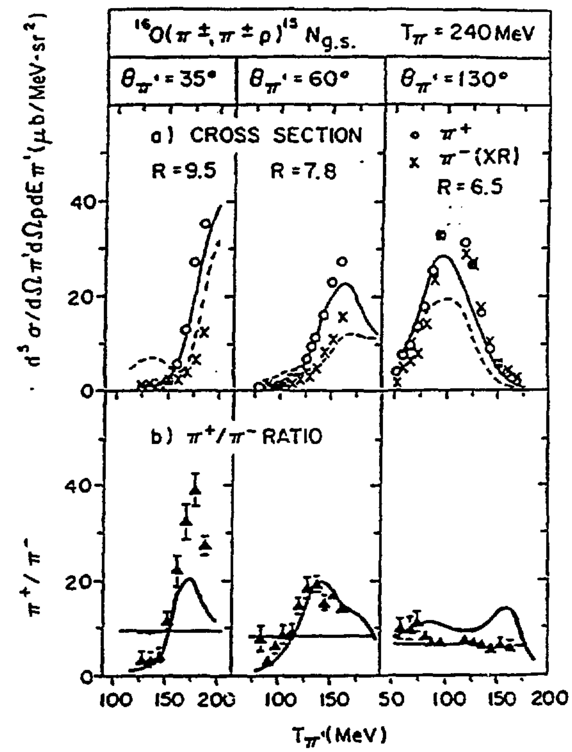

Fig. 2. Triple differential cross sections (upper figure) and corresponding ratios of cross sections (lower figure) for $^{16}O(\pi^{\pm},\pi^{\pm}p)^{15}N$(g.s.) at three different pion angles at 240 MeV. The π^- data are multiplied by the free π-p cross section ratio R. The cross section calculations of Takaki for π^+ (solid curve) and π^- (dashed curve) are shown. The experimental ratios are compared with the calculations and with the ratio R (horizontal line).

found to improve the cross section predictions for the IAS transition,[12] and also does so for the quasi-free process, as shown in Fig. 3, but the improvement is insufficient to explain the data. It has been pointed out that enhancement of the SCX cross section could be a result of weakened coupling to absorption channels for isovector transitions, but the underlying cause is not understood.[12]

In conclusion, it appears that isospin ratios in quasi-free reactions are a valuable tool for separation of competing reaction amplitudes with wide application. Generally for any process which may be reasonably described by the DWIA, isospin ratios will be relatively insensistive to effects of nuclear wavefunctions and optical distortions, but very sensitive to interference effects. In the case of quasi-free scattering, the interfering amplitudes are directly sensistive to the Δ-N interaction. The simple zero-ranged $V_{\Delta-N}$ chosen by Takaki produces a qualitative description of the observed effects. Improvements on these calculations could come by using a finite range interaction, which can introduce the necessary kinematic dependence,

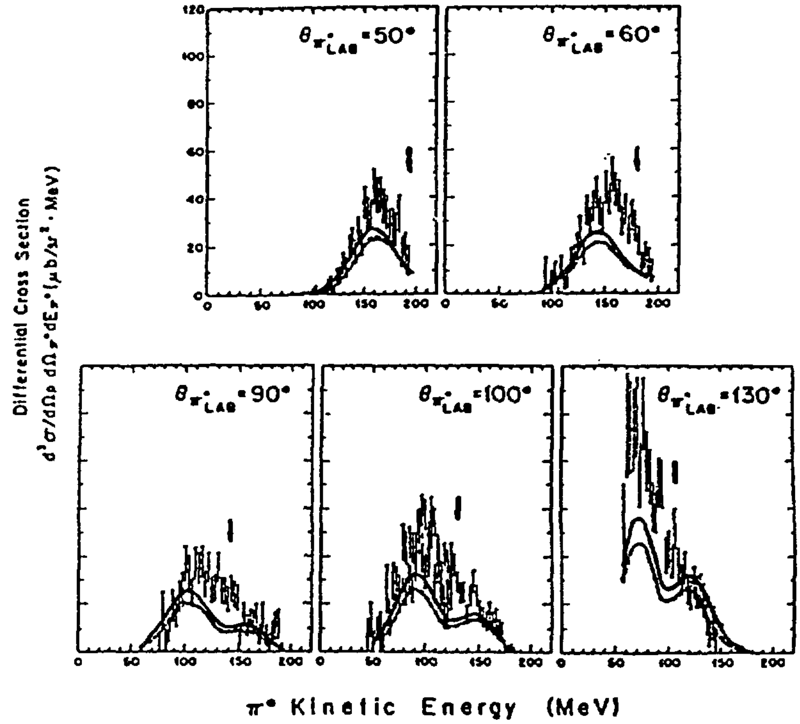

Fig. 3. Differential cross sections for $^{16}O(\pi^+,\pi^0 p)^{15}O$ at 5 pion scattering angles for $T_\pi = 245$ MeV for summed $p_{1/2}$ and $p_{3/2}$ removal. Solid curves are calculations including the Δ-N interaction. Dashed curves are DWIA calculations without Δ-N interaction.

and by inclusion of the isospin-2 part (which can change isospin ratios in second order).

Experimentally, the comparison of isospin channels could be extended with higher LAMPF energies into the region of isospin-1/2 resonances. Also, studies of deep hole states would be interesting because of the higher central nucleon density which should increase these effects. Kinematic separation of these states from a continuum of multi-particle removal would, however, require a large acceptance (4π sr.) detector with good resolution.

3. THE (π,πNN) REACTION

In analogy with the (π,πN) reactions, the (π,πNN) reactions could be exploited to study competing mechanisms such as hard Δ-N knockout or on-shell pion rescattering. Exclusive measurements are important to understanding these processes, since the Δ-N kinematics and isospin can be defined. The amplitudes are possibly dominated by different isospin states; thus, ratios among isospin channels might be useful in their separation. A 4π sr. detector is necessary for such measurements. None have been made, although some are planned.[13]

The MIT-LANL-Wyoming group at LAMPF recently made an impressive study of the inclusive reactions, $^4He(\pi^{\pm},\pi^{\mp})$ and $^4He(\pi^{\pm},\pi^{\pm\prime})$, which were reported in the thesis of E. Kinney (for which he was awarded the Louis Rosen prize in 1988).[14] The simplicity of these nuclear systems makes them particularly interesting. The notable feature of the double charge exchange (DCX) data is a double peak in the outgoing pion energy spectra for forward pion angles at the higher incident energies. This feature rapidly disappears with increasing nuclear mass, as shown in Fig. 4, and is not apparent at backward angles. It was believed to result from an on-shell pion double scattering process, since the dominantly p-wave π-N single scattering peaks in the forward and backward directions. Double scattering to forward angles can result from either two forward single scatterings or two backward ones, which result in the high energy and low energy peaks respectively. However, a simple cascade calculation was unable to reproduce the positions and magnitudes of the observed features.

Kinney made calculations which included several refinements suggested by M. Thies, including medium-modified π-N verticies (Δ-binding), nucleon Fermi motion, Pauli blocking, and relativisitic kinematics. The calculations used undistorted, on-shell pion

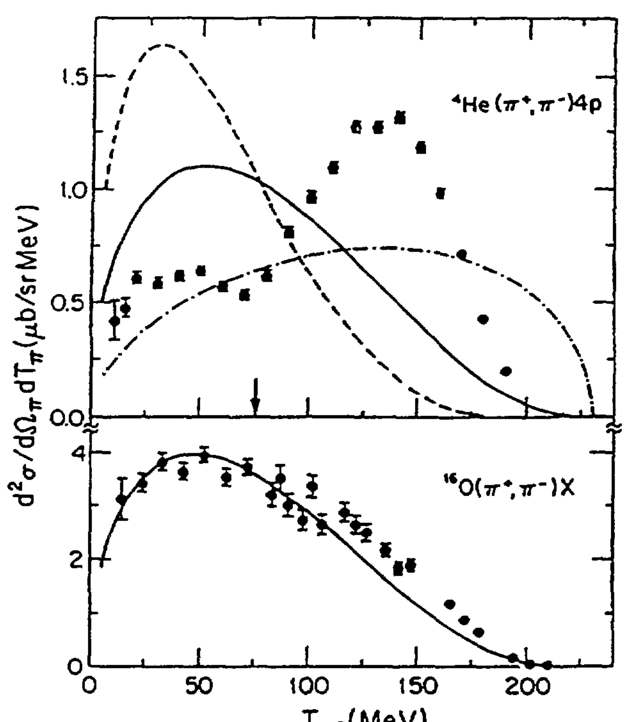

Fig. 4. Differential cross sections for inclusive DCX in ^4He and ^{16}O at 240 MeV and 25° compared with 3-body (dot-dashed), 4-body (solid) and 5-body (dashed) phase space distributions.

propagators, which neglected coupling to the absorption channels. They describe the shape of the data very well, as seen in Fig. 5. It appears that quasi-free DCX displays the kinematic signature of on-shell pion propagation. However, the good agreement of the magnitude of the undistorted calculation with the data at higher energies is surprising. The large experimental cross section is reminiscent of SCX,. It could result from a weakened coupling to the absorption channels or from increased contributions from other processes, such as Δ-N interactions or multi-nucleon ones. Clearly, coincidence measurements, where the various isospin channels may be compared, are needed to separate these effects.

4. THE (π,XN) REACTION (PION ABSORPTION)

The pion absorption process is probably the most interesting and important in pion-nuclear physics for many reasons. The short ranged ΔN → NN interaction could manifest explicit quark effects. The πd → pp reaction studies this interaction for $^3S_{10}$ pairs in a very

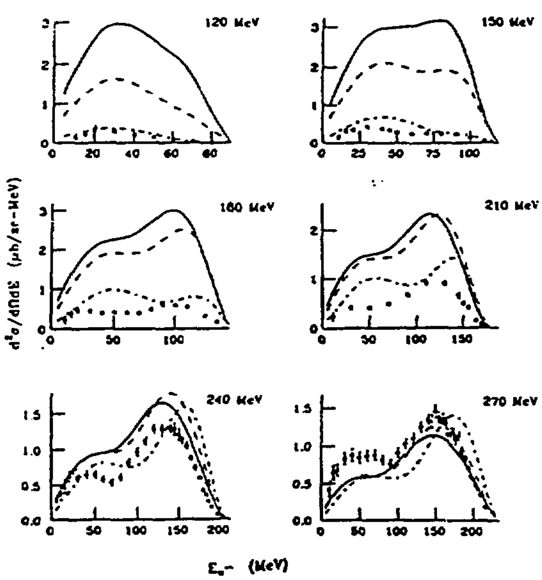

Fig. 5. Doubly differential cross sections for the $^4He(\pi^+,\pi^-)4p$ reactions at 25° scattering angle and several incident pion energies compared to the calculation of Kinney. The curves result from different choices of the Δ binding potential.

loose system. Studies in nuclei can involve smaller clusters and select other quantum numbers, and possibly be more sensitive to short range interactions. The importance of the $\Delta N \rightarrow \Delta\Delta$ interaction is another open question. This process could contribute to a strongly energy dependent multi-nucleon absorption mode. On a longer distance scale, the absorption process couples an on-shell pion into the virtual pion field. Thus, multi-nucleon absorption might also result from many-body nuclear forces. In addition, the coupling of absorption to other pion-nucleus interactions is not understood; for example, the possibility mentioned above of weakened coupling to isovector processes. Finally, absorption must explicitly involve two or more nucleons in the nucleus and is sensitive to the wave function of the absorbing nucleon cluster. Unlike transfer reactions, quasi-free reactions allow wide variation of the kinematic conditions without momentum mismatch to probe the full energy and momentum space.

In this talk I will only discuss the issue of multi-nucleon absorption mechanisms and refer the reader to some recent articles for discussion of other aspects.[15-19] The data described below are among the best of the current generation of coincidence experiments, in which relatively few counters with limited phase space coverage are used. These data show many interesting effects but also leave many questions unanswered and raise new ones. The advantages of large acceptance detectors for these studies have been emphasized elsewhere,[19] and we may expect more high quality data soon from the latest generation of experiments at LAMPF and PSI. However, the need for more theoretical work to explain the present data cannot be underemphasized.

Recently the collaboration of Northwestern - Virginia - Argonne National Laboratory - Tel Aviv - Kent State measured the reactions $^3He(\pi^+,pp)$ and $^3He(\pi^-,pn)$ at LAMPF for energies at and above the delta resonance. Preliminary results have been reported in the Ph. D. theses of C. Smith and S. Mukhopadhyay[20,21] and will soon be published.[22] They complement and extend to higher energies the previously reported measurements at PSI by the Basel - Karlsruhe - Zagreb collaboration and at TRIUMF by the Cal State - British Columbia - TRIUMF - Tel Aviv groups.[23-26] The three nucleon final state is particularly simple since the kinematics may be completely determined by detection of two particles. By extrapolation, the total absorption cross section may be determined. In addition, by reconstruction of the momentum of the unobserved nucleon, a separation of the two-nucleon process with an unobserved spectator nucleon from a process where the energy in shared among all three nucleons may be made. As shown in Fig. 6, after subtraction of a 3-N phase space component, the spectator momentum distribution agrees very well with the nucleon Fermi distribution obtained from electron scattering. In the PSI and LAMPF experiments, backgrounds, which could be confused with a 3-N process, are effectively suppressed by kinematic reconstruction of the target mass.

We see in Fig. 7 that the total absorption cross section in ^3He clearly exhibits the presence of the Δ resonance. Near the peak it follows the shape of the $\pi d \rightarrow pp$ cross section renomalized by a factor of 1.5; the value naively expected for a quasi-deuteron absorption

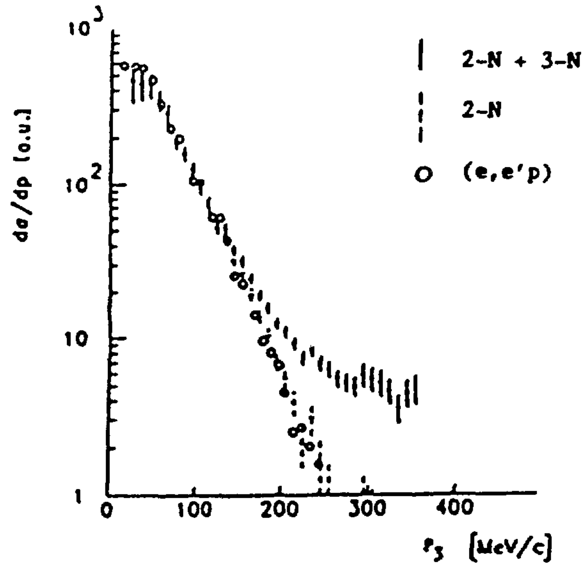

Fig. 6. Differential cross sections plotted versus spectator momentum for $^3He(\pi^+,pp)p$ at 120 MeV. Full data are indicated by solid points. Data after subtraction of 3-body phase space (dashed points) are compared to the momentum distribution from (e,e'p) (open points).

process unperturbed by initial or final state interactions, since there are 1.5 isospin-0 spin-1 nucleon pairs (quasi-deuterons) in the ^{3}He ground state. At higher energies the ^{3}He cross section is significantly enhanced to about 2.5 times the cross section for $\pi d \rightarrow pp$. The decomposition of the absorption cross section into 2-body and 3-body final states is less well determined in these experiments, and quantitative statements are difficult. As seen in Fig. 8, the 3-body fraction increases with pion energy to more than 25% of the total absorption at the cross section peak. Above the resonance this fraction remains rather flat at about 40%. These are very interesting results which raise many questions. Among these: what are the kinematic dependences of the multi-nucleon absorption? Why does it not enhance the absorption cross section near the resonance above the naive quasi-deuteron model? Could the enhancement at higher energies result from a process driven by the $\Delta N \rightarrow \Delta\Delta$ interaction? No calculations addressing these questions exist for ^{3}He.

Multi-nucleon processes might be more important in heavier nuclei. In particular the $\Delta N \rightarrow \Delta\Delta$ interaction should couple strongly to a four nucleon absorption process. There is apparently an anomalous increase in the total absorption cross section from ^{3}He to ^{4}He, as seen in Fig. 9, and a corresponding drop in the inelastic

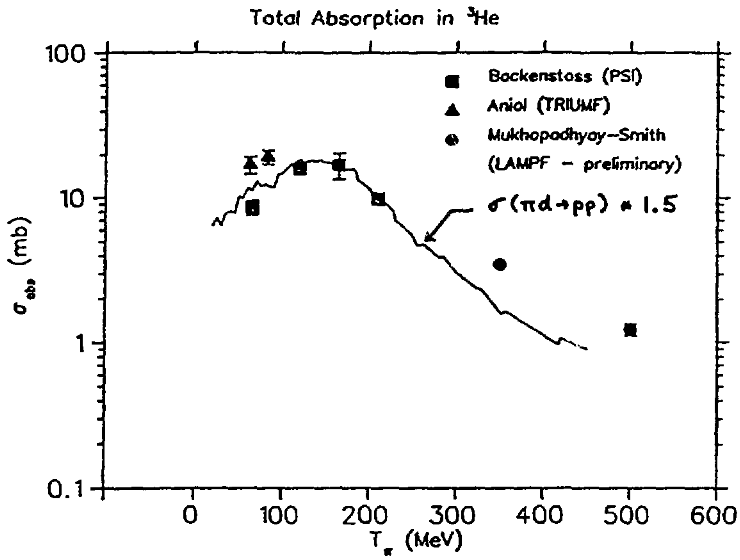

Fig. 7. Total absorption cross sections in ^3He (from Refs. 21,25,26).

cross section,[27] which could signal the onset of a new absorption process. Separation of the various absorption processes is difficult. The dependencies upon kinematic conditions and isospin channels must be examined. Determination of the complete final state kinematics requires measurement of the vector momenta of all the outgoing nucleons over the full phase space. Gaps in the solid angle coverage or significant energy thresholds, lead to large extrapolations and model assumptions in the analysis which result in large uncertainties. However, these uncertainties are least for the two-nucleon reaction.

The collaboration of Maryland - MIT - NMSU - PSI have measured the reaction $^{16}O(\pi^+,pp)^{14}N$ for 115 and 165 MeV pions at PSI. These experiments are the Ph. D. theses of D. Mack and S. Hyman at Maryland.[28-30] The momenta of two outgoing protons were measured, and the final excitation of ^{14}N was reconstructed. We expect that states below 20 MeV of excitation arise mostly from unperturbed absorption on p-shell nucleon pairs. The region from 20 to 70 MeV contains unperturbed absorption on p-p, s-p and s-s pairs, the two nucleon process perturbed by hard initial and final state interactions, and true multi-nucleon absorption processes. We expect no unperturbed two-nucleon absorption at higher excitation energies. For the purposes of this talk, a crude separation of the two-nucleon process at 115 MeV was attempted using the criteria that the Fermi broadened angular correlation, $d^2\sigma/d\Omega_1 d\Omega_2$, should peak near the $\pi d \rightarrow pp$

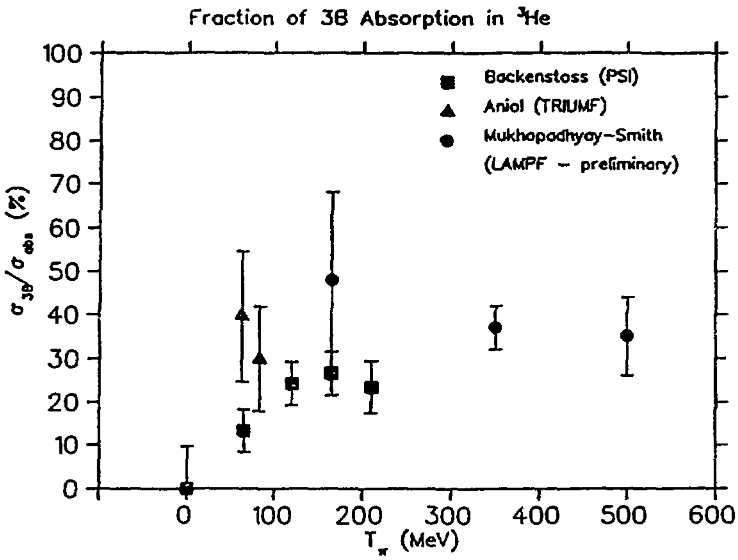

Fig. 8. The fraction of 3-body absorption in ^{3}He (from Refs. 21,25,26).

kinematics, and the differential cross section, $d\sigma/d\Omega_1$, should follow that of $\pi d \rightarrow pp$. Some assumptions about the multi-nucleon processes which form a background under the quasi-deuteron peak are necessary. Inclusive final state interactions and multi-nucleon processes in this region were assumed to fill phase space and have an approximately isotropic differential cross section. However, on-shell initial pion scattering followed by absorption on a quasi-deuteron pair would tend to preserve the angular correlation. Typical angular correlations and a possible multi-nucleon background (essentially three nucleon phase space) are shown in Fig. 10. Any enhancement above phase space is contained in the angular range, $\Delta\theta_2$ and $\Delta\phi_2$, of $\pm 50^{0}$ about the quasi-free angle, which was assumed to include the entire quasi-deuteron angular correlation including some broadening by on-shell initial state interactions. With these excitation energy and angle restrictions, most of the multi-nucleon phase space is excluded, and its eventual subtraction is minimized. The experimental vertical acceptance did not fully cover this range and an extrapolation of the data of typically 25% was required.

After integration over the restricted angular correlation, the differential cross sections shown in Fig. 11 were obtained. The cross sections for low excitations are seen to follow the shape of the $\pi d \rightarrow pp$ cross section very closely and are about 3 times larger. Those for all excitations below 70 MeV do not follow $\pi d \rightarrow pp$ due to

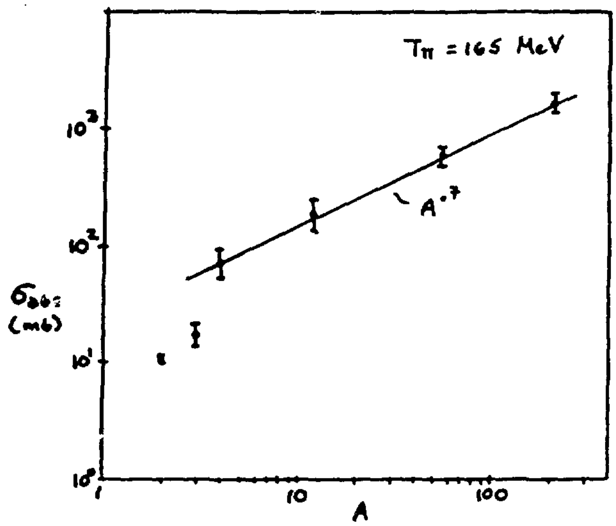

Fig. 9. Total pion-nuclear absorption cross sections measured at 165 MeV for different nuclear masses A. The solid line follows $A^{.7}$.

contributions from other processes. Removal of an isotropic background contribution yields a component which does follow $\pi d \rightarrow pp$ with a normalization of about 5. The large contribution to the cross section from the higher excitation region is not surprising since 12 of the 22.5 nucleon pairs in ^{16}O having deuteron quantum numbers are s-p or s-s ones. Thus, a significant shielding of the s-shell nucleons is still indicated.

The integrated quasi-deuteron cross section must be corrected for hard final state interactions, which lie outside the narrow angular correlation. This has been done by comparing DWIA calculations with and without the imaginary part of the nucleon optical potential, which results in correction factors between 2.0 and 2.5, which correspond to a nucleon mean free path of about 5 fm. These calculations are consistent with observed ratios of $^{16}O(\pi^+,p)/^{16}O(\pi^+,pp)$ near the quasi-free peak.[19,28,29] The integrated quasi-deuteron cross sections after this correction as a fraction of the total absorption are shown in Fig. 12 together with the results of Altman, et al,[31] for ^{12}C at higher energies, and the calculations of Oset, Futami, and Toki for ^{12}C.[32] At 115 MeV the quasi-deuteron process may contribute as much as 75% of the total absorption. For 165 MeV our analysis has not been completed, and only cross sections for low excitations are shown, but we might guess that even after including cross shell absorption less than half of the total is explained by a quasi-deuteron process.

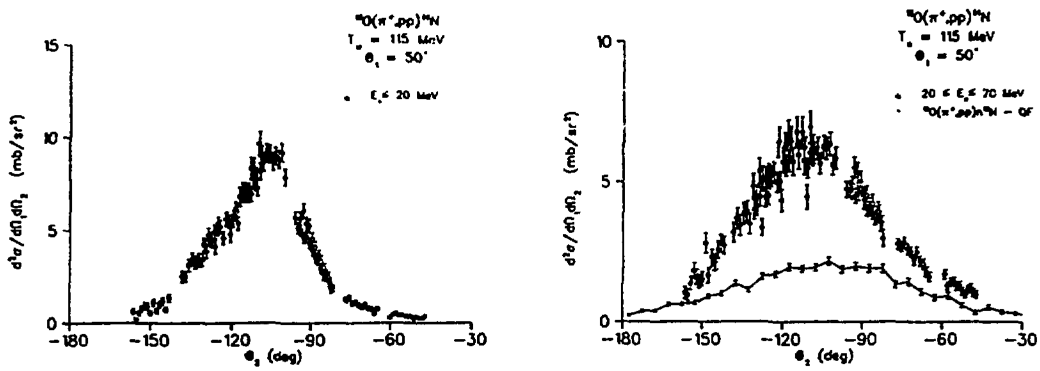

Fig. 10. Angular correlations for $^{16}O(\pi^+,pp)^{14}N$ for excitations $E_x \leq 20$ MeV (left) and $20 \leq E_x \leq 70$ MeV (right). Also shown is a Fermi-broadened 3-nucleon phase space distribution (solid points).

There is some discrepancy between our 165 MeV result and that of Altman which will be discussed below, but it appears that the fraction continues to decrease with energy, perhaps more strongly than for absorption in ^3He. However, large uncertainties must be placed on these conclusions, due to the many assumptions in obtaining the quasi-deuteron absorption, apparent discrepancies between the different experiments, and the large uncertainties in the total absorption cross sections.

At 165 MeV our cross sections cut on excitation energies less than 20 MeV are already significantly larger than those of Altman, where the excitation energy was not determined. This discrepancy should grow when we include higher excitations. A direct comparison of the angular correlations under similar kinematic conditions, with the *same angular and energy* cuts applied to data is shown in Fig. 13. It appears that the Altman results may under-represent the quasi-deuteron cross section by up to a factor of two. This difference is the same size as that found by Burger in the case of Ni.[33] At present these discrepancies are not understood, but clearly the higher energy data should be remeasured.

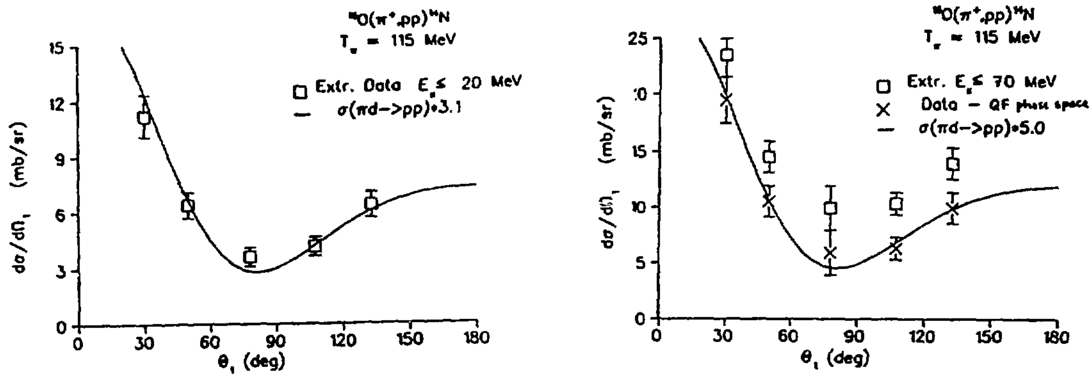

Fig. 11. Angular distributions for $^{16}O(\pi^+,pp)^{14}N$ for excitations $E_x \leq 20$ MeV (left) and $E_x \leq 70$ MeV (right) after extrapolation and integration over θ_2. The solid curve is the renormalized $\pi d \rightarrow pp$ cross section. Shown in the right figure is the data before (square points) and after (x) subtraction of an isotropic component.

In summary, it appears that true multi-nucleon absorption processes constitue a significant fraction of the total absorption even for nuclei as light as ^{3}He. Whether the $\Delta N \rightarrow \Delta\Delta$ process contributes in the case of ^{3}He is unclear, awaiting a calculation. The fraction of multi-nucleon absorption in ^{16}O is comparable to in ^{3}He at and below resonance. Discrepancies in the higher energy data make the situation above resonance unclear. The large uncertainties in these results arise primarily from the lack of phase space coverage and incomplete determination of the final state kinematics. We expect considerably more and better data will be obtained with large acceptance detectors. Hopefully, we will soon see increased theoretical efforts as well.

5. THE FUTURE AT LAMPF

Experimentally the future of the field of quasi-free pion-nucleus lies with large acceptance detectors having good kinematic resolution. These detectors will allow measurement of precise integrated pion-nucleus cross sections and study of their energy and A

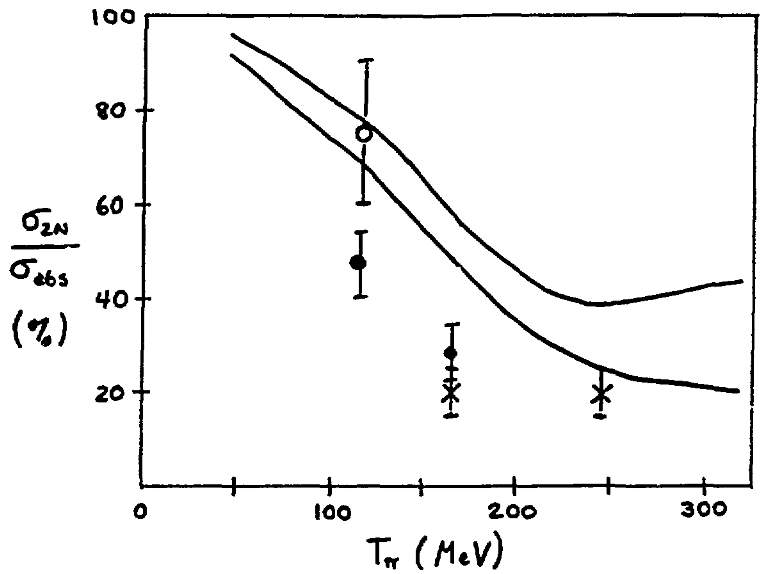

Fig. 12. Fraction of absorption proceeding via a two nucleon process extracted from the data of Refs. 28,29,30 for $E_x \leq 20$ MeV (solid points) and $E_x \leq 70$ MeV (open point) and the data of Ref. 31 (x).

dependencies, which are only roughly determined at present, and multiplicity and isospin dependencies, for which almost no information exists. Also, with sufficient resolution, cross sections to discrete states may be obtained, permitting studies of the structure of these states and the reaction dynamics. One interesting possibility is that deep-hole states could be clearly separated from the continuum.

The BGO-ball at LAMPF is an inexpensive, first generation device which will provide valuable new information eg. about final state nucleon multiplicities and energy spectra for pion absorption.[34] But it has some deficiencies, most important of which is poor angular resolution, which does not permit analysis of detailed kinematic dependencies eg. according to spectator momentum. The LADS detector now under construction at PSI corrects many of these deficiencies. It will begin measurements of pion absorption at resonance energies in 1989, and its use as a second arm with an external neutron detector or magnetic pion spectrometer is forseen. The relatively poor duty factor of the LAMPF machine makes competitive experiments here more difficult. However, LAMPF has many unique capabilities. The new π^0-spectrometer will have an energy resolution comparable to that of many charged pion spectrometers, and would be a unique facility for studies of isovector transitions. With the MRS, delta production

$^{16}O(\pi^+,2p)$ @ 165 MeV

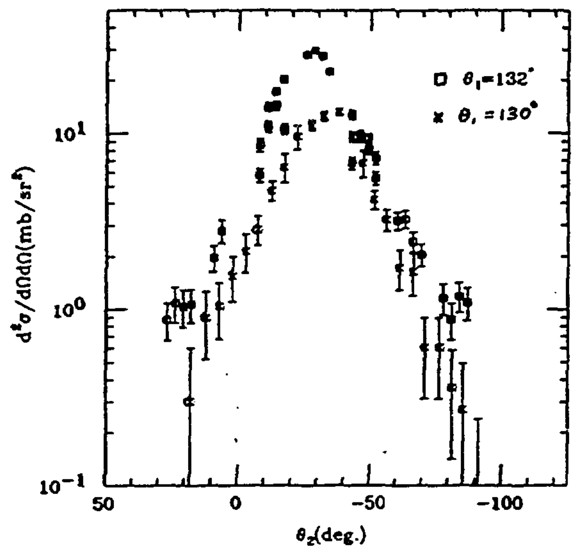

Fig. 13. Comparison Hyman and Altman experiments for $^{16}O(\pi^+,pp)$ at 165 MeV and θ_1 near 130 degrees. The Hyman data (square points) has been analyzed with the same $\Delta\Omega_2$ acceptance cuts as the Altman experiment (x).

reactions, $(p,p'\Delta)$, could be used to map the properties of the $\Delta(1232)$ resonance as a function of q_Δ and ν_Δ. Also, LAMPF produces copious high energy pions and, as seen above in the case of absorption in ^3He, can make unique contributions in the very interesting energy range above the $\Delta(1232)$ resonance. The LAS spectrometer is capable of good resolution measurements at these energies. Therefore, there is great interest in building a new large acceptance system for use with these devices.

These new detectors will produce copious high quality data, but much good data lies around unexplained right now. Further progress in the field depends critically upon greater theoretical activity. Meaningful calculations are often difficult. It is incumbent upon the experimentalist to recognize these difficulties and to design experiments from which the interesting physics may be extracted with minimal uncertainties from uninteresting complications. Often most useful are data to data comparisons, such as isospin ratios or A dependencies.

In closing, I would like to thank E. Kinney, C. Smith, S. Mukhopadhyay, D. Mack, and S. Hyman and their thesis advisors J. Matthews, R. Minehart, R. Segel, N. Chant, and P. Roos, and also

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SPIN PHYSICS AT LAMPF

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ABSTRACT

Spin physics has been and continues to be a major element of the nuclear science program and the Los Alamos Meson Physics Facility (LAMPF). The cornerstone of this element of the LAMPF program has been the availability of variable intermediate energy beams of polarized nucleons, facilities (both mature and new) for analysis of the polarization of scattered nucleons, and a variety of polarized targets. While spin effects in the interaction of pions with nuclei have also been studied, these will not be addressed here; the emphasis will be on the interaction of polarized nucleon projectiles with targets. An overview of facilities and hardware capabilities will be given. Elements of the nucleon-nucleon program will be discussed, followed by elements of the nucleon-nucleus program. Discussion of the nucleon charge- exchange reaction will be deferred to another presentation at this meeting.

FACILITIES

Facilities available to the user are six in number. The High Resolution Spectrometer (HRS), instrumented with a focal plane polarimeter[1], permits high resolution studies of elastic and inelastic proton scattering from nuclei; cross sections, analyzing powers, induced polarization and spin transfer coefficients may be measured. Transfer reactions and pion production may also be studied.

Area BR provides a polarized neutron beam which has traditionally been used to study the nucleon-nucleon interaction with particular emphasis on spin transfer and spin correlation experiments utilizing both unpolarized and polarized proton targets. The anticipated commissioning of the Medium Resolution Spectrometer (MRS) in 1989 will provide the capability to study the $(\vec{n},\vec{p})$ reaction. Instrumentation of this device with a focal plane polarimeter similar to the HRS or JANUS[2] will permit measurement of polarization transfer coefficients in this reaction.

The External Proton Line (EP Line) provides a proton beam which may be switched between four user areas: MRS, EP North, HIRAB, and NTOF. The MRS channel will permit use of the MRS to study inelastic proton scattering, transfer, and coincidence experiments with full polarimetry capability. The EP North area provides for standalone experimental set-ups, such as the recent precision measurement of absolute $p-p$ scattering cross sections[3]. The High Resolution Atomic Beam facility (HIRAB) permits study of laser-induced atomic excitations and other atomic physics effects. The NTOF facility[4] permits study of the (p,n) reaction with full polarimetry capability and good resolutions.

Key elements in support of the broad experimental program available at these facilities are as follows. The new Optically Pumped Polarized Ion Source (OPPIS) is expected to be commissioned in 1989. Bunching and chopping capabilities are available for the polarized beam to aid in time-of-flight measurements. Time spread rebunching for selected beam energies below 800 MeV is available; this capability is essential for high resolution studies at NTOF. Variable beam energies from 200 to 800 MeV are available, and the three main beamlines associated with Line X are generally spin compatible, and fully instrumented for measurement of incident beam polarization.

ELEMENTS OF NUCLEON-NUCLEON PHYSICS

A. The $p-p$ Elastic Channel

The recent completion of a 1% absolute measurement of the differential cross section for elastic $p-p$ scattering by McNaughton et al.[3] at beam energies from 500 to 800 MeV will provide substantial additional constraints on phase shift solutions in this energy range[5]. This measurement essentially concludes data taking for the I = 1 elastic $p-p$ channel. The extensive spin transfer and spin correlation data set [see Ref. 5 and references contained therein] is now deemed to be adequate for most analyses which can be envisaged.

Measurement of A_{NN} for pp elastic scattering at 800 and 650 MeV in the Coulomb-nuclear interference region has been reported[6]. These data are shown in Figure 1. Values for $Re\beta_N(0)$ at these energies have been extracted from the data and compared with results of forward dispersion relation (FDR) calculation. While agreement is observed at 800 MeV, there is significant disagreement at 650 MeV; the valued determined from the data at this energy is -0.68 ± 0.14 while the FDR yields -1.22.

B. The $n-p$ Elastic Channel

Data for the isospin-zero channel are certainly more sparse. The advent of OPPIS will permit measurement of the spin transfer coefficients K_{ij} for polarized neutrons incident on an upolarized target[7]. This will complement recent spin correlation data[8,9] and should permit a more reliable phase shift analysis and represents continued progress in obtaining a unique determination of the I = 0 nucleon-nucleon amplitudes in the energy range 500 - 800 MeV. Examples of these data are shown in Figure 2.

C. The $p-p$ Inelastic Channel

Recent evidence obtained from measurement of the spin-correlation parameters A_{LL}, A_{SL}, A_{NL}, A_{N0}, A_{S0}, A_{L0}, and A_{0L}, for the reaction $\vec{p}\vec{p} \rightarrow np\pi^+$ at energies from 500 to 800 MeV indicates a strong threshold enhancement in the $N\Delta$ channel, and conclusively rules out broad dibaryons in the $^1D_2$, $^3F_3$, and $^3P_2$ partial waves at these energies[10]. The dramatic energy dependence of the phase $\delta_{N\Delta}$ for $^1D_2 \rightarrow ^5S_2$ is illustrated in Figure 3. This particularly difficult measurement, requiring a triple coincidence between a neutron and two charged particles, illustrates the ability to perform coincidence experiments even with the low duty factor of the LAMPF beam.

Measurement of the spin correlation parameter A_{LL} in inelastic $\vec{p}\vec{p} \rightarrow d\pi^+$ scattering has yielded a determination of $\Delta\sigma_L$ ($\vec{p}\vec{p} \rightarrow NN\pi$)[11]. These data, combined with other measurements of $\Delta\sigma_L$(tot) and $\Delta\sigma_L$ ($\vec{p}\vec{p} \rightarrow pp$) allow extraction of the $NN\pi$ inelasticity. The data for A_{LL} together with the extracted data (filled circles) are shown in Figure 4. The curves are described in Ref. 11. There is pronounced disagreement between these

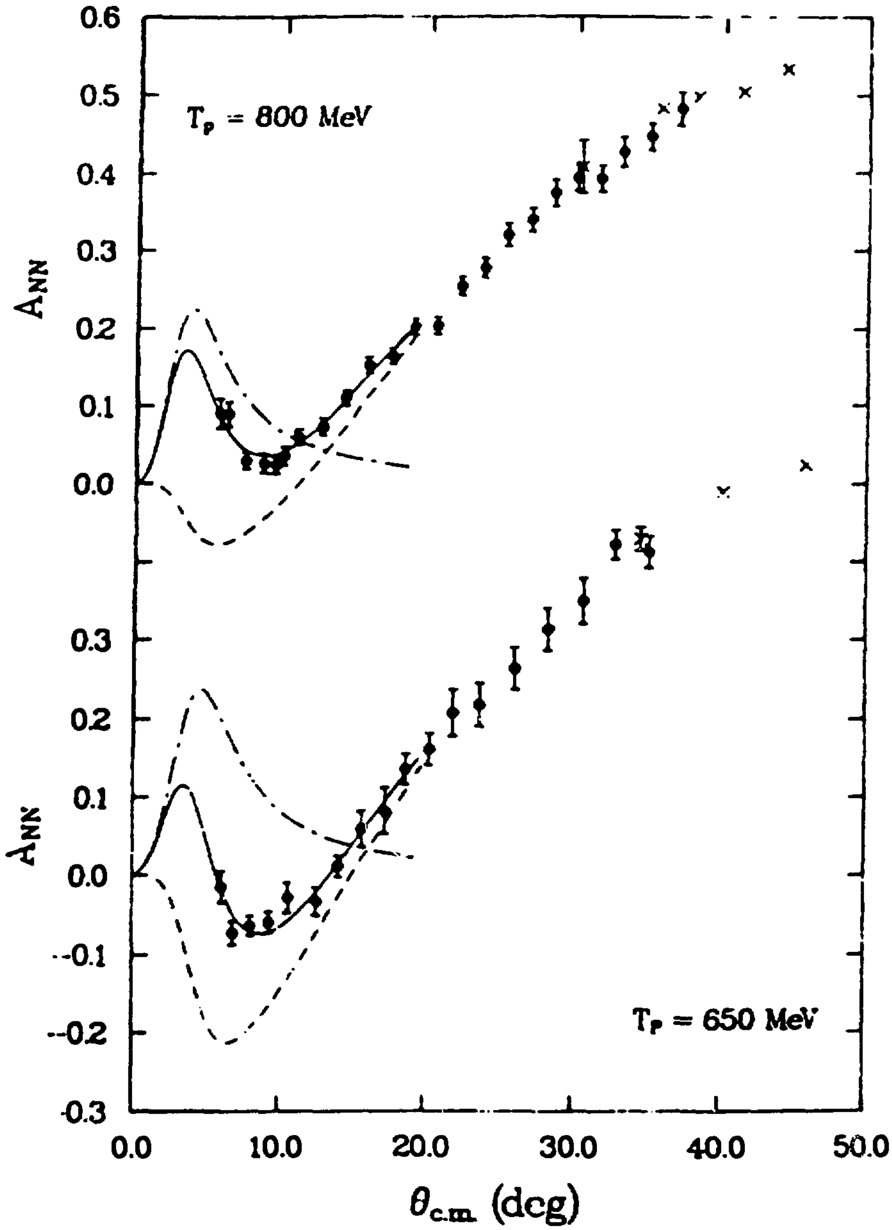


Figure 1. Data for A_{NN} for p-p elastic scattering at 800 and 650 MeV. Data are from Ref. 6.

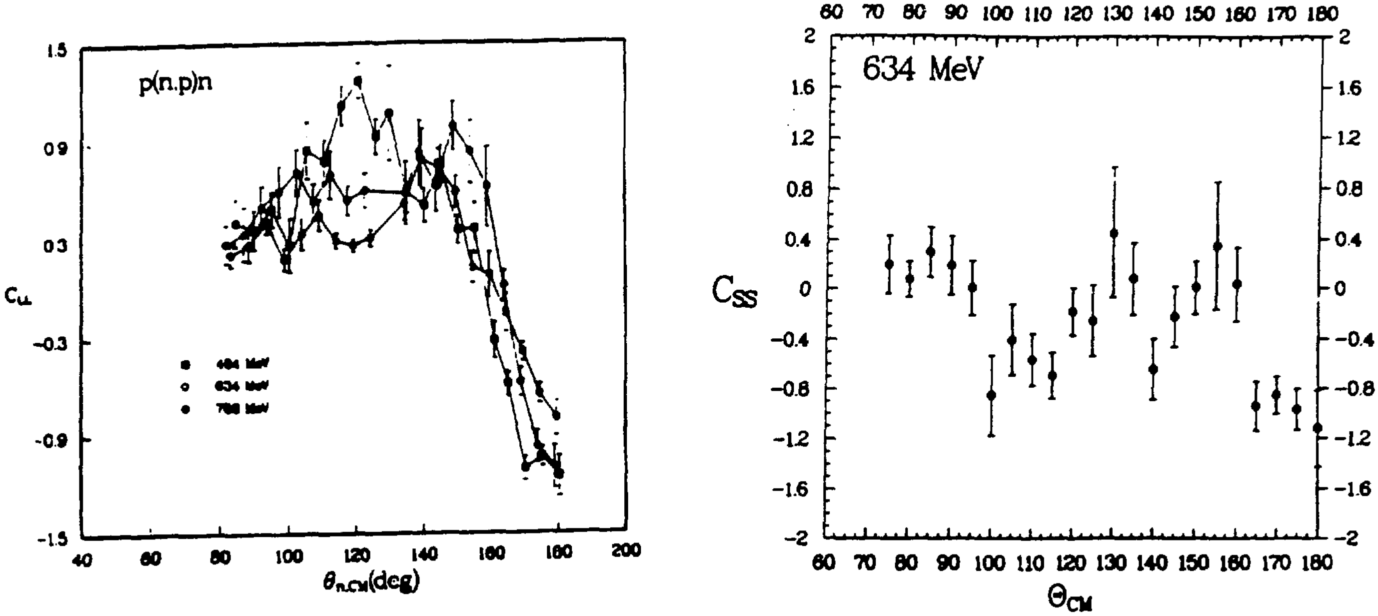
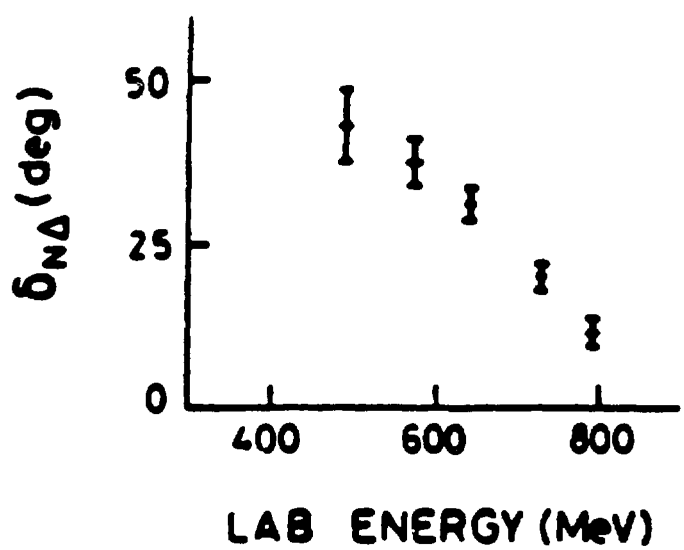


Figure 2. Spin correlation data for free neutron-proton scattering. Data are from References 8 and 9.



The phase $\delta_{N\Delta}$ for $^1D_2 \rightarrow {}^5S_2$.

Figure 3. Data are taken from Reference 10.

data and the prediction of conventional theories. The success of these measurements relied heavily on the excellent angular and momentum resolution of the HRS.

D. The $n-p$ Inelastic Channel

Little work has been done at LAMPF energies to study the np inelastic channels[12,13]. A substantial effort has been proposed[14] to study cross section, analyzing power, and spin correlation data for single pion production in np scattering. Measurements of $\Delta\sigma_L$ in this channel have recently been completed[15] and analysis of the data is in progress.

ELEMENTS OF NUCLEON-NUCLEUS PHYSICS

A. Light Target Nuclei

An extensive program to characterize the proton-deuteron scattering amplitude at 800 Mev, led by G. Igo (UCLA) and collaborators, has been pursued both at Los Alamos and at Saclay. This program has included cross section, analyzing power, spin transfer, and spin correlation experiments. A typical spin observable is given by

$$C_{a\alpha,b\beta} = \frac{Tr(F\sigma_a J_\alpha F^\dagger \sigma_b J_\beta)}{Tr(FF^\dagger)}$$

Usually, $\beta = 0$; if $b = 0$ then $A_{a\alpha} = C_{a\alpha,00}$

The scattering amplitudes so determined are a useful ingredient in determining prescriptions for proton-nucleus scattering analyses, and also exhibit sensitivity to off-shell components of the effective nucleon-nucleon interaction. Data have been obtained at several momentum transfers for scattering of polarized protons from L- and N-type polarized deuterium targets[16-18]. Examples of these data are shown in Figure 5.

Radiative capture of 800 MeV polarized protons by deuterium has been studied using the HRS. One of the interesting aspects of this study is the application of a coincidence measurement between detection of the ^{3}He in the spectrometer and the γ in a lead-glass Čerenkov counter. Measurement of the analyzing power A_y has shown sensitivity to two-body amplitude contributions in the reaction mechanism[19]. Data are shown in Figure 6, and the details of the calculations are described in Ref. 19. The data agree well with the conventional meson-exchange picture of the reaction, despite the large values of momentum transfer encountered.

Measurement of analyzing power for the reaction $\vec{p}+{}^3\text{He}\rightarrow d+X$ has recently yielded interesting and speculative results[20]. Prompted by the observation of narrow structures in the differential cross section for this reaction observed by Tatischeff et al.[21], the analyzing power was measured for similar momentum transfer and missing mass region. While no structures were observed in $d\sigma/d\Omega$, the analyzing power data were found to be very suggestive. Data are shown in Figure 7; gaussian shapes over both resonant and non-resonant backgrounds have been fitted to peaks in the data. Agreement of the peak locations with predictions of the rotational band model of MacGregor[22] and with bag model predictions of Mulders et al.[23] is suprisingly good. Further study of this reaction is indicated.

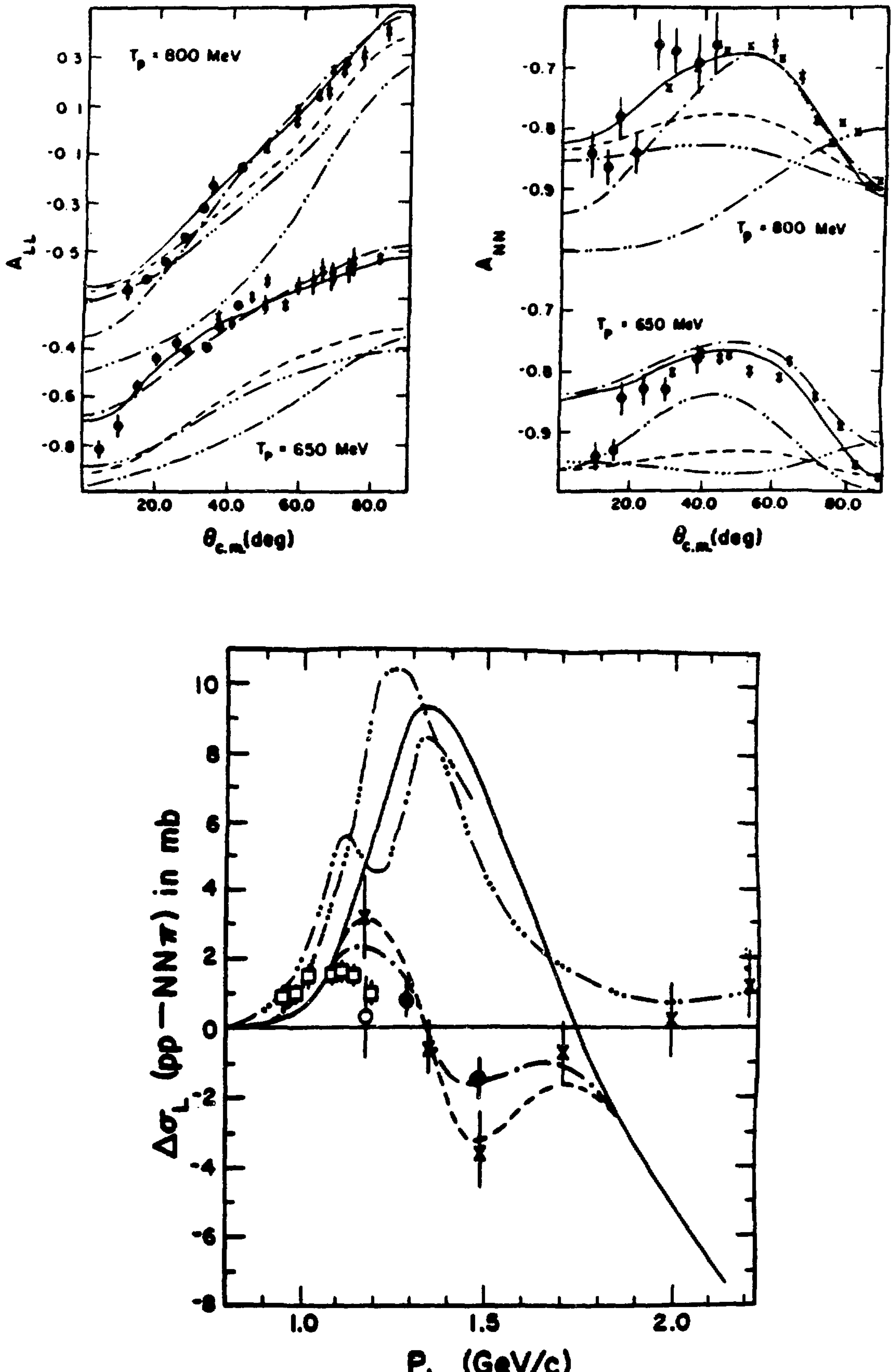


Figure 4. A_{LL} for free proton-proton scattering in the CNI region and extracted inelasticities at 800 and 650 MeV.

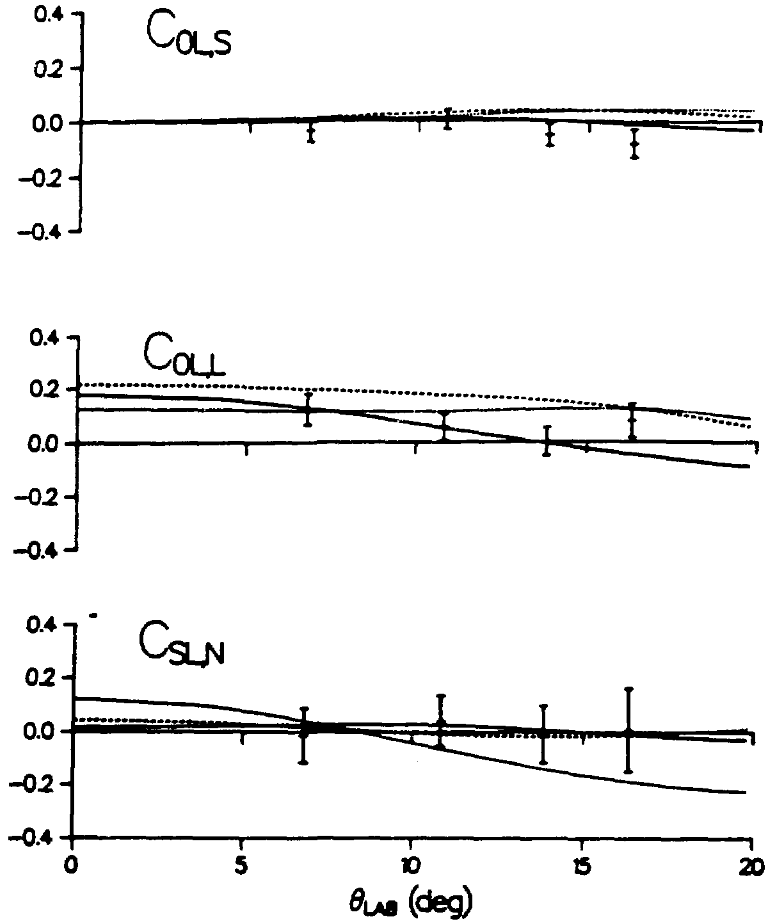


Figure 5. Typical three-spin observable data for scattering of polarized protons from an L-type polarized deuteron target. Data are from Reference 16.

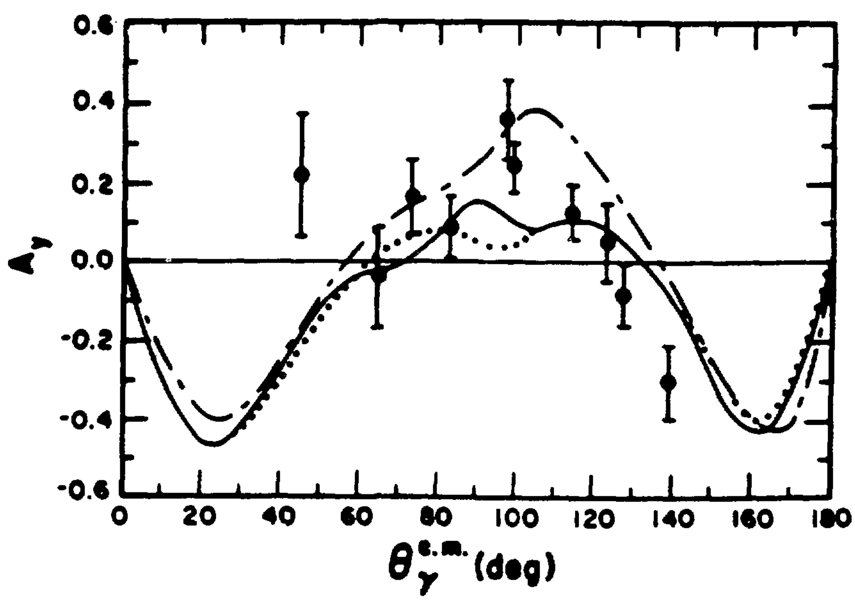


Figure 6. Analyzing power for radiative capture of polarized protons by deuterium at 800 MeV. Data are taken from Reference 19.

B. Proton-Nucleus scattering for A > 3

Effort in this area has been concentrated at the HRS facility for the last decade. The advent of polarimetry capability in 1980 opened a substantial area of investigation. Many groups have pursued studies in such topics as reaction dynamics, nuclear structure, medium modifications to the effective nucleon-nucleon interaction, Dirac formulation, and the spin decomposition of the effective interaction. It is fair to say that the measurement of proton-nucleus spin observable data at the HRS facility has had a major impact on intermediate energy nuclear physics; most notably, the pioneering measurements of the spin rotation parameter Q and spin transfer parameters D_{ij} have led to the development of relativistic dynamics and studies of the nuclear response. These measurements[24-30] and theoretical analyses accompanying them[31,32] are well documented in the literature and will not be discussed in detail here. Data obtained for un-natural parity transitions in $(\vec{p},\vec{p}\,')$ scattering have provided an opportunity to test both non-relativistic and relativistic models as well as the $\Delta S = 1$, $\Delta T = 0,1$ components of the nucleon-nucleon interaction[33-35]. The small momentum transfer region for $\Delta T = 0$ transitions has proved to be particularly sensitive to differences between relativistic and non-relativistic approaches.

Spin observables which may be measured at the LAMPF facilities are outlined in the next equation:

$$\begin{pmatrix} p_{s'} \\ p_{n'} \\ p_{l'} \end{pmatrix} = \left\{ \begin{pmatrix} D_{ss'} & 0 & -D_{ls'} \\ 0 & D_{nn'} & 0 \\ D_{sl'} & 0 & D_{ll'} \end{pmatrix} \begin{pmatrix} p_s \\ p_n \\ p_l \end{pmatrix} + \begin{pmatrix} 0 \\ P(\theta) \\ 0 \end{pmatrix} \right\} \frac{1}{1 + p_n A_y}$$

The Wolfenstein parameters D_{ij} and the induced polarization $P(\theta)$ may be determined by measuring the incident and outgoing polarization vectors $\vec{p}$ and $\vec{p}\,'$. Linear combinations of these observables are especially useful as "filters" for studying both discrete and continuum nuclear responses. For example, longitudinal $(\vec{\sigma}.\vec{q})$ and transverse $(\vec{\sigma} \times \vec{q})$ spin-flip probabilities are given by[36]

$$I_0 S_L = \frac{1}{4} I_0 [1 - D_{nn'} + (D_{ss'} - D_{ll'}) sec\theta_{lab}]$$

and

$$I_0 S_T = \frac{1}{4} I_0 [1 - D_{nn'} - (D_{ss'} - D_{ll'}) sec\theta_{lab}]$$

respectively.

Complete sets of these polarization transfer observables have been measured[37,38] for 500 MeV proton scattering from ^{2}H, Ca(nat), and Pb(nat) spanning the excitation energy range 20-100 MeV at a momentum transfer of 1.75 fm^{-1}. Ratios of the spin longitudinal to the spin transverse responses extracted from these data show little deviation from unity for both Ca and Pb, and do not favor any pion collectivity in the spin longitudinal channel.

An additional parameter of interest is the quantity S_{nn} given by

$$S_{nn} = \frac{1}{2}(1 - D_{nn})$$

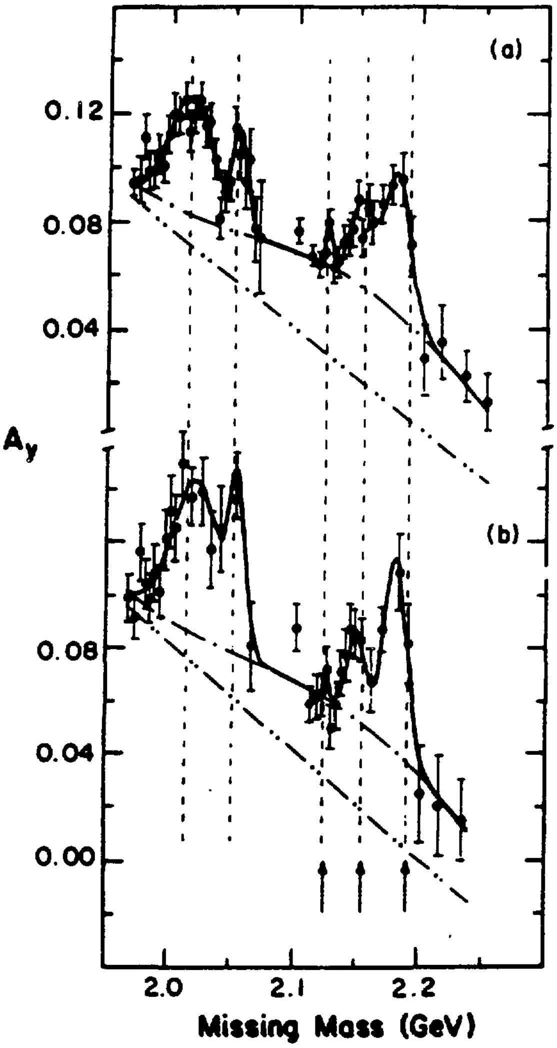


Figure 7. Analyzing power data showing structure which may be attribut to narrow dibaryon structures. Data are from Reference 20.

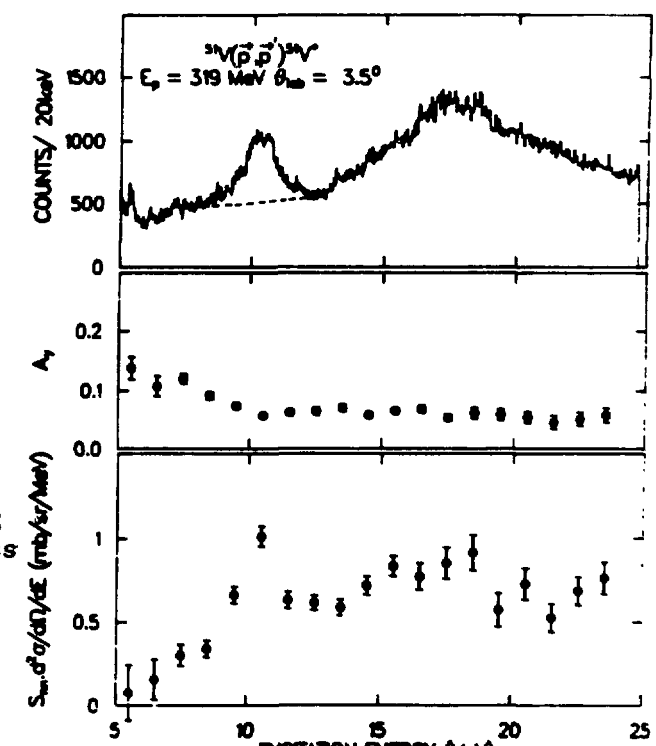


Figure 8. Cross section, analyzing power and spin-flip cross section data for polarized proton scattering from ^{51}V. Data are from Ref. 39.

which measures the probability that a particle incident with spin up (normal to the scattering plane), for example, is scattered with spin down after interaction with the target nucleus. This quantity, when combined with the doubly-differential cross-section $\sigma = d^2\sigma/d\Omega dE$, provides highly selective information in the form of spin-flip and non-spin-flip cross sections:

$$\sigma_{SF} = \sigma S_{nn}$$

$$\sigma_{NSF} = \sigma(1 - S_{nn})$$

The search for "missing" $M1$ strength in nuclei has been aided considerably by measurement of these quantities. A recent example is the confirmation of the $M1$ nature of the 10.2 MeV resonance in proton scattering from ^{51}V. These data[39] are illustrated in Figure 8. The strong peak in the σ_{SF} spectrum clearly illustrates the predominantly $\Delta S = 1$ nature of this excitation, and when taken together with the angular distribution data for the cross section provides compelling evidence for the $M1$ nature of the resonance.

The quantity S_{nn} has been shown to be relatively insensitive to structure effects, reaction mechanisms, and the like. Examples of spin-flip probability data are shown in Figure 9, where data a presented for ^{40}Ca and ^{90}Zr up to excitation energies of about 40 MeV at an incident proton energy of about 300 MeV. Roughly similar behaviour has been observed in all nuclei studied thus far, from ^{12}C to ^{90}Zr. It has been observed that, in general, σ_{SF} tends to increase relative to σ as excitation energy increases, the ratio becoming roughly constant at an angle-dependent excitation energy. A detailed discussion of these observations may be found in Ref. 40.

Introducing the cross sections for pure $\Delta S = 1$ and $\Delta S = 0$ transitions as σ_1 and σ_0 respectively, and a model-dependent parameter α which is essentially the spin-flip probability for a pure $\Delta S = 1$ transition, we obtain

$$\sigma_1 = \frac{\sigma_{SF}}{\alpha}$$

and

$$\sigma_0 = \sigma - (\frac{\sigma_{SF}}{\alpha})$$

In a factorized approximation[41-43], the nuclear and free cross-sections are related by

$$\sigma_i^A = N_{eff}.f_i.\sigma_i^f$$

where the subscript i denotes channel $\Delta S = i$, superscripts f and A denote free and nuclear cross-sections respectively, and f_i denotes the nuclear response for channel i. After some manipulation the following quantities may be obtained:

$$\frac{f_1}{f_0} = \frac{S_{nn}}{\alpha - S_{nn}} / \frac{\sigma_1^f}{\sigma_0^f}$$

and

$$R_s = \frac{f_1}{f_0 + f_1}$$

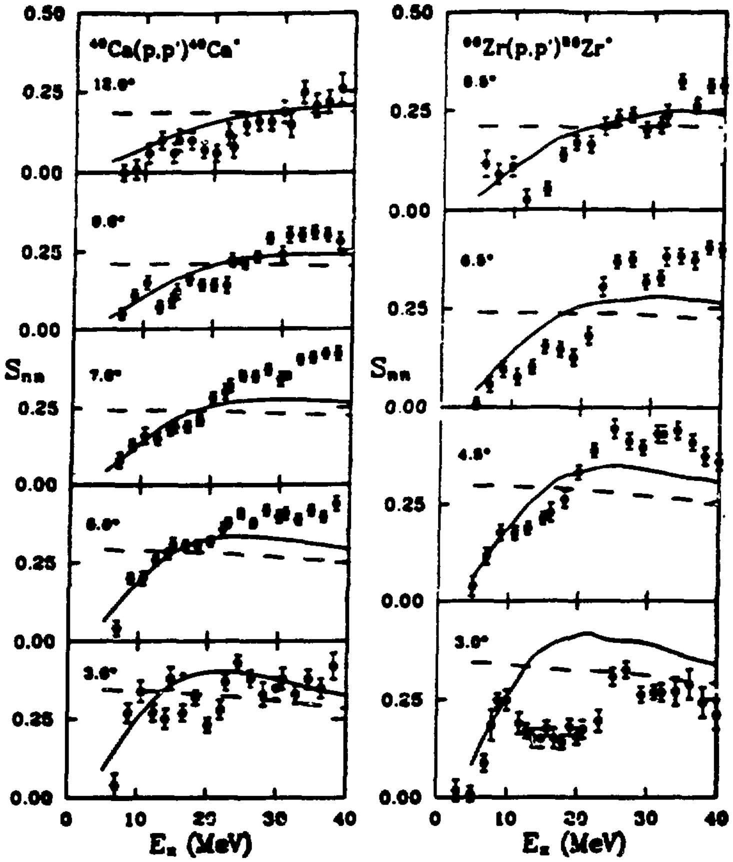


Figure 9. Spin flip probability for inelastic proton scattering from ^{40}Ca and ^{90}Zr at 319 MeV. Data are from Ref. 40.

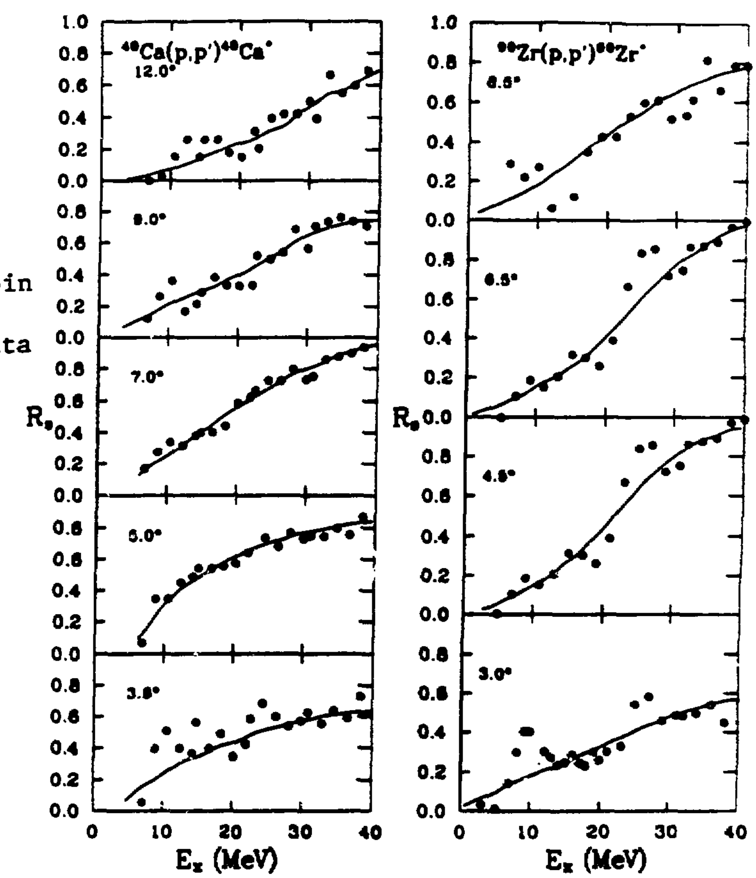


Figure 10. Relative nuclear spin response fc spin slip probability data in Fig. 9.

The quantity R_s is essentially that fraction of the nuclear response due to $\Delta S = 1$ excitations, and, as such, can be used to obtain a "picture" of the relative nuclear response derived from data with only a single model-dependent parameter. If the nuclear medium werer a non-interacting Fermi gas, the R_s would be 0.5. Since the free cross sections are known, measurement of S_{nn} enables calculation of R_s provided α is known. The trend of R_s so extracted from the data for ^{40}Ca and ^{90}Zr is shown in Figure 10, which shows that spin excitations dominate the nuclear response at the higher excitation energies[40,44]. This effect has been shown to persist at an incident energy of 800 MeV, with the nuclear response appearing to be energy independent, as it should.

Analysis of backgrounds under giant resonances excited by inelastic proton scattering has been problematical. Baker et al.[45] have demonstrated that the decomposition of the continuum into σ_0 and σ_1 partial cross sections holds the promise of allowing a much better estimate of this background than was previously possible. Sample spectra showing this decomposition are presented in Figure 11, and the results of a multipole decomposition of the $\Delta S = 0$ strength are shown in Figure 12. Energy-weighted sum rules for the giant dipole resonance are in reasonable agreement with photon absorption data.

Fergerson et al.[46] have reported measurement of polarization transfer observables for scattering of 800 MeV protons from a variety of nuclei with energy losses up to 400 MeV. Specifically nuclear effects are shown to be essentially absent; the nucleus seems to behave approximately as a Fermi gas and a single-step reaction mechanism seems sufficient.

THE FUTURE

A significant investment of time remains to clarify the I=0 nucleon-nucleon picture. It is hoped that this will be accomplished in the next three to four years.

The advent of the MRS and NTOF provides LAMPF with comprehensive facilities to study both inelastic scattering and charge exchange processes for discrete and continuum nuclear excitations with full polarimetry capability. The data yet to be obtained will permit decomposition of the spin response of the nucleus into isospin components, as well as further aid in the study of the separate longitudinal and transverse responses.

A detailed study of the quasielastic and delta regions is beginning. Development of coincidence techniques using dual spectrometer assemblies (MRS and Large Acceptance Spectrometer for example) to study reactions such as $(\vec{p}, \vec{p}\,'\pi)$ resulting from excitation of the delta region should provide useful insights into reaction mechanisms.

The recent study of elastic scattering of polarized protons from a polarized ^{13}C target represents the first such data of its kind. Analysis is in progress, and studies such as these with new spin degrees of freedom in the nuclear medium will allow target relativistic effects to be studied, amongst others.

While much has been accomplished, the advent of new facilities and capabilities holds the promise that established programs will be completed in a timely manner and that exciting new physics opportunities will manifest themselves.

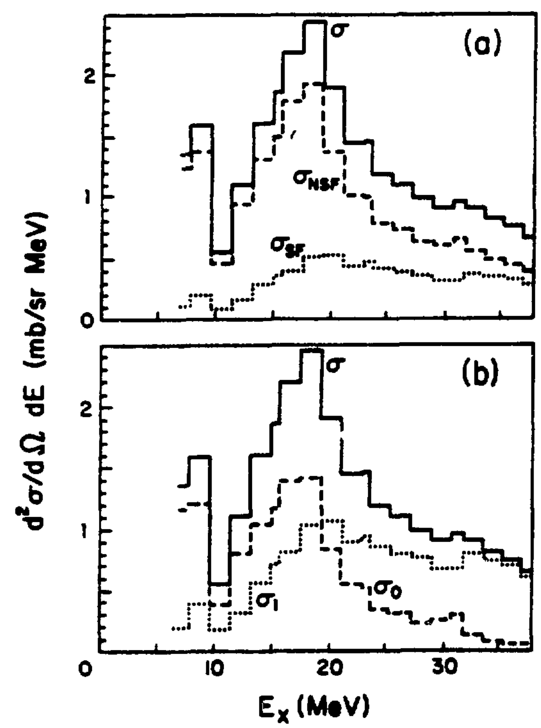


Figure 11. Spin channel decomposition of the cross section for inelastic scattering of 319 MeV protons from ^{40}Ca at 7 deg. Data are from Reference 45.

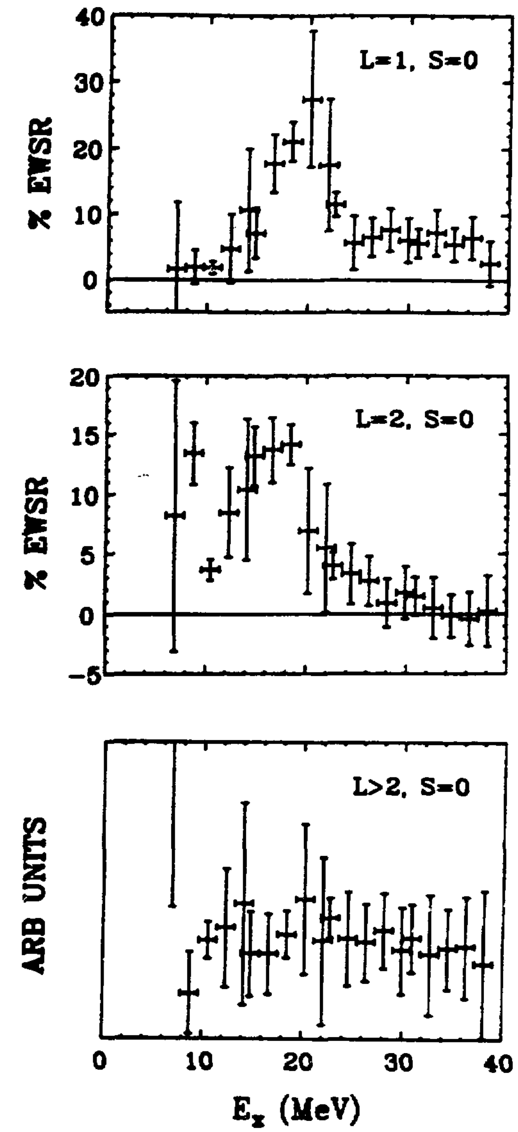


Figure 12. Strengths extracted from multipole analysis of the non-spin-flip cross secti in Reference 45.

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(p,n) and (n,p) Reactions at Intermediate Energies

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and

TRIUMF

1) INTRODUCTION

Over the past ten years, the investigation of charge exchange reactions at intermediate energies has proven to be a powerful and fruitful approach to the study of isovector effective interactions, and has led to important new insights into models of nuclear structure. In this talk, I want to quickly review the background of these studies as a basis for considering some current problems of interest. Several new facilities are now coming into operation, and I would finally like to indicate their capabilities, and plans for further work.

The emphasis will be on nucleon-induced charge exchange reactions because of limitations of time, but I note in passing that interesting results have also been obtained in studies of (^{3}He,t) [1] and (d,^{2}He) [2] reactions, mainly at Saturne, and from studies of heavy-ion induced charge exchange reactions.[3]

2) BACKGROUND DEVELOPMENTS

Current interest in charge-exchange studies can be traced to low-energy studies of (p,n) reactions [4] by Anderson and co-workers in 1961. Those measurements showed a selective excitation of transitions between isobaric analog states which are also connected by super-allowed beta decay, and demonstrated the importance of the $\vec{\tau}_1 \cdot \vec{\tau}_2$ part of the nucleon-nucleus effective interaction. Soon after, Ikeda et al.[5] predicted the existence of nuclear giant resonances associated with the Gamow-Teller (GT) operator $\sigma\tau^-$ and noted that most of the resonance strength would be energetically inaccessible to beta decay. This strength should however be excited via the $\vec{\tau}_1 \cdot \vec{\tau}_2 \; \vec{\sigma}_1 \cdot \vec{\sigma}_2$ part of the nucleon-nucleus effective interaction, and might also be seen in (p,n) reactions. GT transitions to isolated states were observed in (p,n) studies, but it was not until 1975 that Doering et al [6] were able to demonstrate the excitation of the predicted GT giant resonance in the $^{90}Zr(p,n)\,^{90}Nb$ reaction at 45 MeV.

The first facility for (p,n) studies at intermediate energies [7] was developed at IUCF by Goodman and co-workers about ten years ago. This facility used large-volume scintillation detectors with a flight path of 100 meters to provide the capability for zero-degree (p,n) measurements up to 200 MeV, with energy resolution of 1 MeV or better.

A number of exciting results were quickly obtained with this new facility. The most important ones were: the identification of the GT giant resonance as a general feature of nuclear excitations; [8] demonstration of the strong energy dependence of the isovector central effective interactions; [9] a calibration of the zero-degree (p,n) cross section relative to the β^- decay strength between the states involved[10], the existence of other isovector spin-flip giant resonances[11], and the demonstration that the readily identifiable GT strength did not satisfy the GT sum rule[12]. Another important development was the introduction of zero degree spin transfer measurements in order to investigate the spin-flip response at high excitation energies.

The results from IUCF demonstrated the interesting physics to be probed by charge exchange reactions at intermediate energies, and raised a number of further questions such as the energy dependence of the effective interaction at higher energies, the importance of β^+ strength (probed by the (n,p) reaction) in the GT sum rule, and the significance of the missing strength. It was also observed that there were significant variations in the ratio of zero degree (p,n) cross section to beta decay strength[13]. These results stimulated interest in the field, and a number of other facilities have come into operation in the past few years. These are listed in Table 1. For (p,n) studies, IUCF, LAMPF and Brookhaven use time-of flight spectroscopy with large scintillation detectors, on flight paths indicated. TRIUMF uses a medium resolution spectrometer to detect proton recoils from a hydrogenous radiator in order to infer the incident neutron spectrum. For (n,p) studies, Davis, Uppsala and LAMPF WNR use a combination of wire counters and a simple bending magnet (raytrace) to determine the origin, initial direction and energy of the reaction protons of interest, while TRIUMF and LAMPF NTOF use a full magnetic spectrometer. The IUCF, TRIUMF and Davis facilities have now been in operation for some time, and are described in standard references. [7,14,15] The LAMPF, Brookhaven and Uppsala facilities are just being commissioned and will be described later in more detail.

TABLE 1: INTERMEDIATE ENERGY CHARGE-EXCHANGE FACILITIES

LABORATORY	E MeV	TYPE
	(p,n)	
IUCF	80-200	TOF
TRIUMF	200-500	MRS
LAMPF	200-800	TOF
BNL	50-200	TOF
	(n,p)	
DAVIS	65	RAYTRACE
TRIUMF	200-500	MRS
UPPSALA	50-200	RAYTRACE
LAMPF WNR	50-600	RAYTRACE, WHITE SOURCE
LAMPF NTOF	200-800	MRS

3) PROBLEMS OF CURRENT INTEREST

3a) Energy depencence of the isovector effective interaction

In considering reactions involving transfer of spin and isospin between an incident projectile **p** and target nucleon **i** the effective interaction may be written in the form [16]:

$$V_{int}(E_p,q) = V_o + V_\sigma(\vec{\sigma}_p \cdot \vec{\sigma}_i) + V_{so}\,(\vec{\sigma}_p + \vec{\sigma}_i)\cdot\vec{L} + V_T S_{12}$$

$$+ \quad [V_\tau + V_{\sigma\tau}\,\vec{\sigma}_p\cdot\vec{\sigma}_i + V_{so\tau}\,(\vec{\sigma}_p + \vec{\sigma}_i)\cdot\vec{L} + V_{T\tau}\,S_{12}]\,\vec{\tau}_p\cdot\vec{\tau}_i$$

For charge-exchange reactions, of course, only the isovector components are of interest. It is also known that the central parts of the interaction, V_τ and $V_{\sigma\tau}$ are most important for small momentum transfer, while the tensor term is dominant[17] for momentum transfers $q \sim 1\ fm^{-1}$. The isovector spin orbit term is small and is sometimes neglected.

Using the Distorted Wave Impulse Approximation (DWIA) as a reaction model, the charge-exchange cross section at small momentum transfer may then be written: [9]

$$\frac{d\sigma}{d\bar{\omega}}(q=0) = \left[\frac{\mu}{\pi h^2}\right]^2 \frac{kf}{ki} \left| J_\alpha \right|^2 D_\alpha B_\alpha$$

The quantity B_α is obtained from measured beta decay between the states of interest: $B_F + (g_A/g_V)^2 B_{GT} = \frac{6166}{ft}$

The nuclear distortion factor D_α is calculated from the reaction model, and the measured cross section then yields $|J_\alpha|^2$, the volume integral of the effective interaction for q = 0. The most direct determinations of the Fermi and Gamow-Teller parts of the interaction, $|J_\tau|^2$ and $|J_{\sigma\tau}|^2$, have been obtained from studies of the $^{14}C(p,n)\,^{14}N$ reaction. The Fermi transition to the $0^+ T = 1$ state at 2.31 MeV may be clearly resolved from the GT transition to the 1^+ T=0 state at 3.95 MeV, and values of B_F and B_{GT} are known from beta decay of the analog nucleus ^{14}O. The results [18] of measurements at IUCF of the ratio of interaction strengths up to 200 MeV are shown in Fig. 1, along with results of a calculation using the Love-Franey t-matrix interaction[17]. The first measurements undertaken with the TRIUMF facility were an extension of these results up to 450 MeV, and those results are also shown[19]. More recently, measurements at 500 MeV were carried out at WNR [20] and at 500 and 650 MeV at NTOF[21]. The data points shown for these last measurements are preliminary at this time.

In an effort to understand the significance of the differences between the data and the DWIA calculations, Love et al have carried out further calculations with density dependent G-matrix interactions[16]. Some results illustrated in Fig. 2 show that the calculated ratio may be quite sensitive to the density dependence. It is also seen that different interactions may give rather different pedictions for ρ=0. The same authors have also compared the measured ratio of cross-sections at zero degrees with a prediction using the central components of the interaction only, and one using the full interaction with both spin-orbit and tensor components as well. Although the non-central transition amplitudes are small at zero degrees, they have a very appreciable effect on the cross-section ratio, as shown in Fig. 3.

In addition to cross section ratios, absolute cross-sections have now been measured[22] up to 450 MeV. These are shown in Fig. 4, along with results of calculations by Nakayama and Love [23] using three different effective interactions; a t-matrix based on the Arndt phase shifts, a G-matrix using the Paris potential, and a G-matrix using one of the Bonn potentials. In each case the DWIA cross sections were calculated using optical potentials derived from a folding model using the corresponding effective interaction. In addition, at energies up to 200 MeV, calculations with the Bonn potential were carried out using phenomenological potentials. In the data comparison, it should be borne in mind that the measured cross sections are subject to systematic uncertainties of about 12% due to uncertainties in target thickness and detector efficiencies.

It would appear that the G-matrix calculation using the Bonn potential provides the best overall fit to the data. There appear to be significant differences for the GT cross section at lower energies, which might be due to limitations of the reaction model. Similar data from 500 to 800 MeV will soon be available from LAMPF to provide a further test of the calculations.

3b) Gamow-Teller Sum rule and missing strength

The GT sum rule states:

$$S^- - S^+ = \sum_f B_f^-(GT) - \sum_f B_f^+(GT) = 3\,(N-Z)$$

where S^- and S^+ are the total strengths for β^- and β^+ transitions from a given nucleus, which can be measured via (p,n) and (n,p) reactions respectively. Measurements of zero degree (p,n) cross sections at IUCF showed that for a wide range of nuclei S^- was about 60% of the lower limit, 3(N-Z), required by the sum rule[12]. S^+ was not measured, but was expected to be small for heavy nuclei because of Pauli blocking. In case $S^+ \neq 0$, then S^- should be increased above the sum rule limit. One explanation for this missing strength involved the possibility of substantial mixing of (Δ-isobar) - (nucleon-hole) configurations with low-lying nucleon particle-hole configurations[24]. A more prosaic explanation was that the expected particle-hole strength was spread over a large range of excitation energies by mixing with 2p-2h states[25]. Because of the q dependence of the GT effective interaction, this distributed strength at high excitations is difficult to identify experimentally above the background of transitions to other states.

Calculations to explore this second explanation for the missing strength have been carried out by several authors[26,27]. Rather than focussing just on GT transitions, these calculations have included all transitions up to L=4 expected for the p-h excitations produced in the (p,n) reaction. The spreading of the expected strength was introduced by an extension of RPA calculations to include 2p-2h excitations, or by an empirical broadening of the GT resonances predicted in standard RPA. The results of a calculation by Osterfeld et al [26] using the second approach for the reaction ^{90}Zr(p,n) ^{90}Nb at 200 MeV are shown in Fig. 5. The calculations were carried out both with and without the inclusion of Δ-isobar excitations for comparison with the measured spectra at several angles. The authors conclude that the fit to the data is satisfactory without the inclusion of Δ-isobars. From this they conclude that the experimental results are consistent with $S^- = 3$ (N-Z), so that there is no missing strength, provided $S^+ = 0$.

A search for GT$^+$ strength has been carried out[28] at TRIUMF using the ^{90}Z(n,p) ^{90}Y reaction at 200 MeV. Data were taken at several angles out to about 20° in order to search for the L=0 cross section associated with GT$^+$ strength. The measured spectrum at 1.8° is shown in Fig. 6 along with a prediction of the GT$^+$ strength by Bloom et al. [29] on the basis of shell model occupancies measured in single-particle transfer reactions. The predicted GT$^+$ peak is not seen, and in fact no L=0 strength can be clearly identified in the data. Yen et al point out that even if the angular distribution information is ignored, and the total zero-degree (n,p) cross-section up to 10 MeV excitation is assumed to represent GT$^+$ strength, this total strength would be only $S^+ \simeq 3.4$. Thus the Osterfeld analysis, along with the TRIUMF result would imply that the measured S^- is consistent with the sum rule to within about 10%.

Calculations by Towner and Khanna [30] suggest that there should be some effects of Δ-isobar excitations in low-lying nuclear states, which might lead to small deviations from the G-T sum rule, consistent with the above conclusion. However we will not likely be able to draw any firmer conclusions regarding the missing strength unless some characteristic signature for the existence of Δ excitations or for weak GT strength at high excitations can be found.

3b) Model calculations of isovector spin flip strength in the (n,p) reaction

In the ^{90}Zr(n,p) ^{90}Y reactions, simple RPA calculations predict no GT^+ strength since such transitions are Pauli-blocked. They do however predict isovector spin flip transitions [27,31] with L > 0 and these are seen in the measured (n,p) spectra. Fig. 7 shows data for the ^{90}Zr(p,n) reaction at 0° and ^{90}Zr(n,p) at 6°, along with results of RPA calculations by Smith and Wambach for both reactions[31]. The overall fit to the (p,n) spectrum is quite good. For (n,p), calculations predict two prominent peaks arising from the spin-dipole giant resonance. The angular distributions of the two obvious peaks observed in the measured spectrum, are consistent with DWIA predictions with L-1, and can be confidently assigned as arising from spin-dipole transitions. The observed peaks are close to the energies predicted by the RPA calculations, but are significantly broader than predicted, and the measured cross section at excitation energies between 10 and 30 MeV is significantly greater than predicted. The calculated cross section for two-step processes [31] is also shown, and would account for the difference between DWIA calculations and data at 40 MeV. These (n,p) results illustrate a general finding that for nuclei in the (fp) shell, model calculations usually show poorer agreement with (n,p) than with (p,n) measurements.

The reason for this is suggested by consideration of calculations of GT strength in (sd) shell nuclei by Wildenthal[32]. Fig. 8 shows predicted GT strength for both (p,n) and (n,p) reactions on T_0 = 1 targets in (sd) shell nuclei. The dashed bar is the strength predicted using a very simple wave function, just the single strongest component in the full model wave function. The solid bars show predictions for the wave function calculated using the complete (sd) model space. It is clear that the $T_f = T_0 + 1$ strength, which is measured in (n,p), is very sensitive to the details of the wave function, or by implication, to the effective interaction used in the calculation.

An illustration of this phenomenon in the (fp) shell is provided by a comparison of the $^{48}Ca(p,n)\,^{48}Sc$ and $^{48}Ti(n,p)\,^{48}Sc$ reactions. Data for the (p,n) reaction at zero degrees [33] is fitted quite well by a shell model calculation [34] of GT^- strength assuming only transitions to $(f_{7/2})^8$ or $(f_{7/2})^7\, f_{5/2}$ configurations in ^{48}Sc, but with amplitudes calculated for (2p-2h) admixtures in the final state. A similar calculation [35] for the $^{48}Ti(n,p)$ reaction predicts about 80% of the GT^+ strength in a single transition to a state at 6 MeV excitation in ^{48}Sc. A more detailed calculation which allows both 1p-1h and 2p-2h excitations in $(f_{7/2})^8$ shows much greater fragmentation and spreading of GT^+ strength, but still is in poor agreement with the measured distribution, as shown in Fig. 9. It is clear that further (n,p) measurements in the (fp) shell should be useful in improving model calculations, either by better defining the effective two-body interaction used in model calculations, or a suitably truncated model space.

It should be noted that there is considerable interest in calculations of the distribution of B^+ (GT) in (fp) shell nuclei in connection with such problems as electron capture rates in supernova models [36] or calculations of double-beta decay lifetimes[37]. In the latter problem, the result depends very sensitively on the distribution of B^+(GT), and model calculations of quality comparable to those for (sd) shell nuclei are required for useful data comparisons.

3d) Relationship between zero-degree cross sections and beta decay strength.

An exciting early result of IUCF measurements was the demonstration that $\sigma(p,n)$ at zero degrees was closely proportional to B^-(GT) between the corresponding states[10], demonstrating that the nuclear matrix element for the reaction near q=o was the same as that measured by the beta decay ft value. This result was then the basis for the determination of the strength distribution and total strength in the GT giant resonance. In addition, the result was applied to other problems such as the determination of efficiencies for proposed solar neutrino detectors[38].

Further work however has shown that the proportionality is not exact, and Taddeucci et al [18] have provided a valuable survey showing the results of measurements of the quantity $\hat{\sigma} = \sigma((p,n)\ q=o)/B^{-}(GT)$ for a large number of transitions for which $B^{-}(GT)$ is known from beta decay. These authors show that model calculations predict variations in $\hat{\sigma}$ at the 10% level, depending on the shell model states involved in the transition. The data, as illustrated in Fig. 10 shows deviations as large as 50% between data and DWIA predictions. Deviations are particuarly large for the isobaric analog transitions on targets of ^{13}C, ^{15}N and ^{39}K.

There have been some TRIUMF measurements directed at understanding these variations in $\hat{\sigma}$. For one thing, measurements of (n,p) cross sections on ^{6}Li, $^{12,13}C$ have been compared with transitions to analog states seen in (p,n)[39]. Results of these measurements are shown in Table 2, where it is seen that there is agreement between (p,n) and (n,p) results for ^{6}Li and ^{12}C, nuclei for which the DWIA correctly predicts $\hat{\sigma}$. For ^{13}C, where the DWIA prediction is in disagreement with the data for $\hat{\sigma}(p,n)$ there is also disagreement between $\hat{\sigma}(p,n)$ and $\hat{\sigma}(n,p)$.

TABLE 2: COMPARISON OF $\hat{\sigma}^{+}$ WITH $\hat{\sigma}^{-}$

$$\hat{\sigma}_{GT} = \frac{d\sigma}{d\Omega}(q=o)/B_{GT}$$

Target	$\hat{\sigma}^{-}$ (pn)	$\hat{\sigma}^{+}$ (np)
^{6}Li	9.1±0.5	9.90±0.36
^{12}C	9.2±0.9	9.42±0.31
^{13}C	14.7±1.1	10.97±0.56

A number of possible explanations for the observed variations in $\hat{\sigma}$ have been suggested. One is the possibility that the operator for beta decay may be more complicated than the assumed GT operator. Towner and Khanna [30] have shown for instance that effects such as isobar excitations, meson exchange currents and relativistic effects lead to modifications of the standard GT operator and to significant changes in predicted spin observables. There may also be important contributions to the reaction transition amplitude arising from interactions such as non-central forces or knock-on exchange, which are not present in the beta decay matrix element. An observation that knock-on exchange with the tensor part of the effective interaction may have quite different effects for different shell model transitions [18] deserves further investigation.

At this point, the source of the large variations in $\hat{\sigma}$ is still an open question. It is important to understand this however if measurements of charge-exchange cross sections are to be useful for quantitative measurements of GT strength.

3e) Spin observables in charge-exchange reactions

The theoretical background of this topic has been covered in the previous talk by Kevin Jones. In addition, I should note that I have done little work in this field, so that I will not try to treat it with the completeness it deserves, even though I want to indicate its importance.

In efforts to understand the significance of the missing GT strength, there has been considerable interest in the distribution of spin-flip strength at high excitations. It is known that the spin-transfer coefficient D_{nn} provides an indication of spin-flip transitions which is not very sensitive to the effects of nuclear distortion, or optical model parameters[40]. As a result, measurements of D_{nn} at zero degrees have been carried out at IUCF to map the distribution of spin-flip strength in the continuum, and to provide comparisons with model calculations.[41,42] Some results [41] are shown in Fig. 11 for $^{90}Zr(p,n)$ at several beam energies, and it is seen that agreement between data and calculations is satisfactory at excitation energies up to about 30 MeV. It would clearly have been interesting to have measurements at higher beam energies where the DWIA reaction model should be better. In this connection, a measurement of $D_{nn}(0^o)$ for $^{54}Fe(p,n)$ ^{54}Mn has recently been carried out at 300 MeV at TRIUMF[43], but results have not yet been analyzed.

Up to the present, the other spin observable studied in charge exchange reactions is the asymmetry Ay, observed in $(\vec{p},n)$ studies. Measurements of Ay for the reaction $^{48}Ca(\vec{p},n)$ ^{48}Sc at 134 MeV [44] show that for transitions to discrete states, the asymmetry is reproduced well by simple model calculations. However, in the reaction $^{15}N(\vec{p},n)$ ^{15}Ogs at 500 MeV the observed asymmetry [45] is not reproduced by either relativistic or non-relativistic calculations, even though the shell model structures of the states involved is presumably very simple. More recently, measurements of Ay have been carried out for $^{12}C(\vec{p},n)$ at 290, 420 [46], and 500 MeV [47]. In these studies, transitions to the continuum excited in quasi-free scattering were studied. At the higher energy, for excitation energies near the quasi-free peak, the observed value of Ay was consistent with that expected for free nucleon-nucleon scattering. At the lower energies, measurements were made at excitation energies corresponding to the low-excitation side of the quasi-free peak for both $^{12}C(p,n)$ and $^{54}Fe(p,n)$. In these cases, the results were not consistent with the asymmetry predicted for nucleon-nucleon scattering. Further measurements of Ay are clearly needed to understand the reasons for the disagreements noted here.

4) NEW FACILITIES AND FUTURE CAPABILITIES

Most of the results discussed so far have come from the IUCF TOF facility at energies up to 200 MeV or from TRIUMF at energies from 200 to 450 MeV. These have been described in references 7 and 14. I now want to briefly describe the capabilities of the other facilities listed earlier, and to indicate some of the research likely to be emphasized by them.

4a) LAMPF-WNR (p,n) facility

A TOF facility [49] was developed several years ago at WNR using large-volume scintillators for neutron detection on a 250 m flight path. A target positioning arrangement within the field of a bending magnet permits measurements over the angular range from 0° to about 15°.

This system was used for measurements of the $^{13}C(p,n)$ reaction at 800 MeV [50], with typical results as shown in Fig. 12. Although the energy resolution was no better than 2.7 MeV, these data provided the first estimates of $|J_{\sigma\tau}/J_{\tau}|^2$ at 800 MeV. During the past year, the energy resolution at beam energies below 800 MeV has been improved by using a new rebunching system[51].

With this system, one of the idle linac cavities is driven to compensate for beam energy spread so as to produce a time focus for neutrons reaching the detector. The effect of this rebuncher is shown in Fig. 13; the improvement in resolution is quite dramatic.

Even without rebunching, this facility should be useful for measurements of (p,n) cross sections to the continuum, including the quasi-elastic and delta-isobar regions. The principal limitation of the system is that only unpolarized beams are available, so that only measurements of cross-sections can be carried out.

4b) LAMPF NTOF

This new facility [52] has just come into full operation during the past summer, and provides for measurement of neutron energies by TOF over a 600 m flight path. A series of beam swinger magnets, similar to the IUCF system [7], permits measurements over an angular range from $-5°$ to $+52°$ corresponding to momentum transfers up to 3 fm^{-1} at beam energies of 800 MeV.

Fig. 14 shows a zero degree spectrum for the $^{13}C(p,n)\,^{13}N$ reaction at 647 MeV, with an energy resolution of about 700 keV, or $\Delta E/E \simeq 10^{-3}$. This was obtained with the rebuncher in operation. Even without rebunching, energy resolution $\Delta E \simeq 1.3$ MeV was observed at 800 MeV. Probably more important than the high energy resolution of the NTOF facility is its capability for carrying out measurements for a full range of spin observables, similar to what is currently available for (p,p′) measurements. So far, the only such measurements have been of the asymmetry Ay in the reaction $^{15}N(\vec{p},n)\,^{15}O$, and in $^{12}C(\vec{p},n)$ to the quasi-free region, both of which were mentioned earlier[45,47].

Measurements of spin-transfer observables will require more intense polarized beams, which will be available from the new optically-pumped polarized source, scheduled to be operational by late summer of 1989.

4c) BNL neutron time-of-flight facility

This facility [48] which is expected to begin operation in the summer of

1989, will initially have a 100 m flight path, with large area scintillation detectors. Incident proton energies up to 200 MeV will be available, so that the facility will have capabilities similar to those of IUCF. In the next few years, it is expected that heavy ion beams with energies to about 1 GeV per nucleon will become available, and the flight path will be extended to 500 m. This would then provide a unique facility for the study of heavy-ion induced charge-exchange reactions.

4d) UPPSALA (n,p) facility

This facility [53,54] is intended to permit (n,p) studies over the energy range 50-200 MeV. Noteworthy features of this system are the excellent shielding of the neutron production source and good collimation of the neutron beam. The detection system, which I have characterized as "ray trace" in Table 1, is shown schematically in Fig. 15. It consists of a bending magnet to separate reaction protons from the incident neutron beam, drift chambers to define proton trajectories from the target, and scintillators to provide particle identification by measurements of dE/dx and possibly E.

Energy resolution of about 1 MeV is expected. Initial tests earlier this year showed somewhat poorer resolution, and work is in progress to improve this. This facility will provide a nice overlap between the capabilities at 65 MeV at UC Davis[15], and the TRIUMF capabilities above 200 MeV. It also should be noted that with the low background levels expected with this well-collimated beam, other studies such as (n,n') might be feasible.

4e) WNR (n,p) facility

This system [49,55] has been commissioned during the past summer, and has just produced its first results. The neutron beam used is a continuum obtained by bombarding a thick tantalum target with 800 MeV protons. The resulting spectrum has useful intensity for neutron energies up to about 650 MeV.

For (n,p) studies, the incident neutron energy is defined by time of flight over a 89 m flight path, providing a source energy resolution of < 1

MeV up to 200 MeV. Reaction protons are detected using a ray-trace system similar to that in Fig. 15. Proton energies are masured by a bank of CsI scintillators capable of stopping protons of energies up to 260 MeV. At present measurements of (n,p) cross sections can be made over the angular range 0° to 15° for incident energies between 50 and 260 MeV. Some initial results are shown in Fig. 16.

4f) <u>NTOF (n,p) facility</u>

A new medium resolution spectrometer [56] is currently under construction and is scheduled to go into operation for charged particle studies in thesummer of 1989. Important features of the spectrometer will be a large momentum acceptance ($\Delta p/p = \pm\ 0.2$) and large solid angle ($\Delta\Omega$ = 9 msr). Momentum resolution will be about 0.4%, but can be improved to 0.04% with reduced acceptance. It will be instrumented with a focal plane polarmeter to permit measurements of the full range of spin observables.

By the summer of 1990 it is planned to have a high quality collimated neutron beam available, which will permit (n,p) measurements to be carried out using the MRS as detector. For these measurements, the MRS will be moved on air pads from the initial location for charged particle studies, to the neutron beam location. It is expected that the energy resolution of this system will be about 1 MeV, determined largely by target energy losses, both in the neutron production target and in the (n,p) target.

The system will be available for high resolution studies of discrete states over a limited energy range, or for low-resolution studies in the continuum, where a large momentum acceptance is needed. With polarized incident beam and focal plane polarimeter it is even possible to contemplate measurements of spin transfer coefficients in the $(\vec{n},\vec{p})$ reaction, though count rates will be low.

<u>SUMMARY</u>

I have tried to give an overview of the important new physics that has come from nucleon-induced charge-exchange studies over the past decade, as well as some of the interesting questions raised by these results.

Within the past year, the capabilities for important extensions of previous studies have been enhanced by new facilities coming into operation in several laboratories. In particular the NTOF (p,n) facility will permit studies of both cross sections and spin observables in an energy range where there is very little data at present. I personally look forward to exciting new results from these facilities over the next few years.

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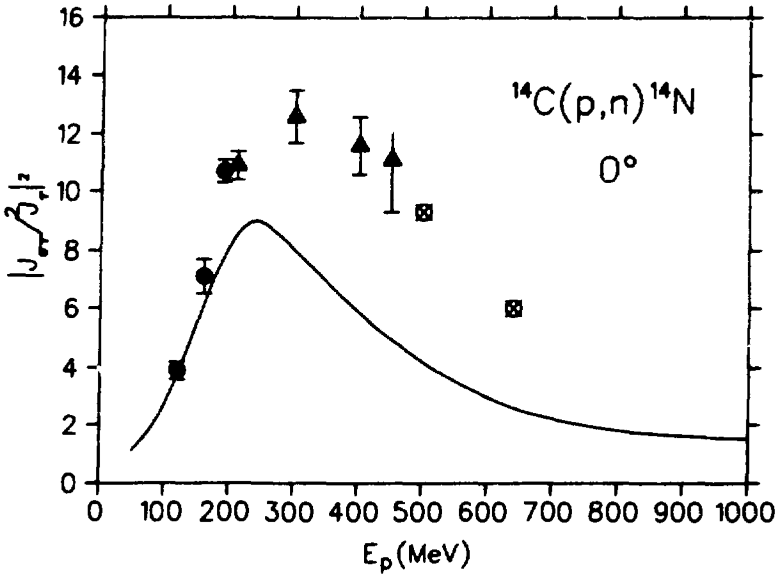

Fig. 1: Ratio of GT to Fermi effective interaction strengths as determined from zero degree cross sections for the $^{14}C(p,n)$ $^{14}N^*$ reaction. Data points at 500 and 650 MeV are preliminary results from WNR and NTOF. The curve is the result of DWIA calculations using a t-matrix interaction (ref. 17)

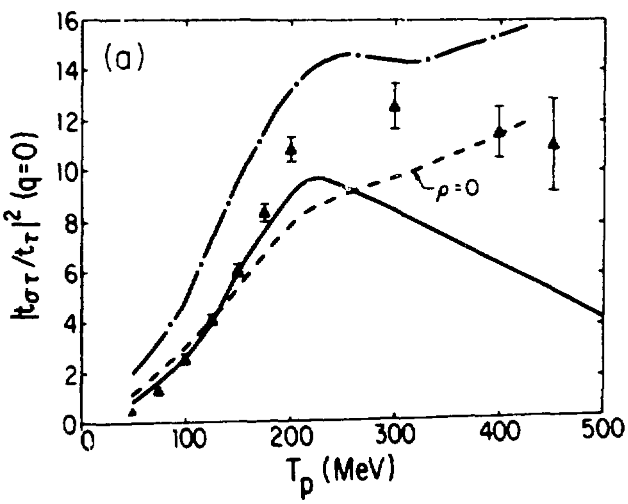

Fig. 2: Ratio of GT to Fermi effective interaction strengths calculated with the SP84 t-matrix interaction: (——), and the HM86 G matrix interaction: (----(k_f = 0.0)), (—. —. (k_f = .95)). (ref. 16)

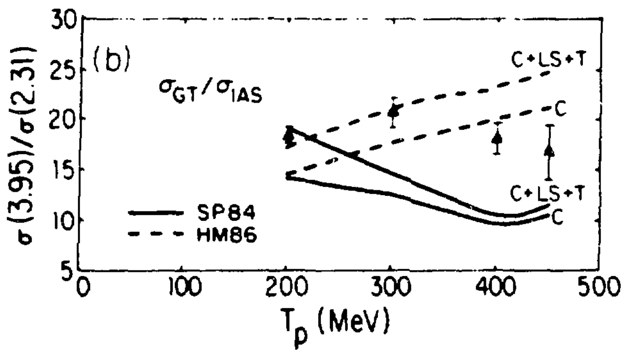

Fig. 3: Ratio of cross sections for GT and Fermi transitions in $^{14}C(p,n)$ $^{14}N^*$, compared with results of calculations with two different interactions using central only, and central plus spin orbit plus tensor components. (ref. 16)

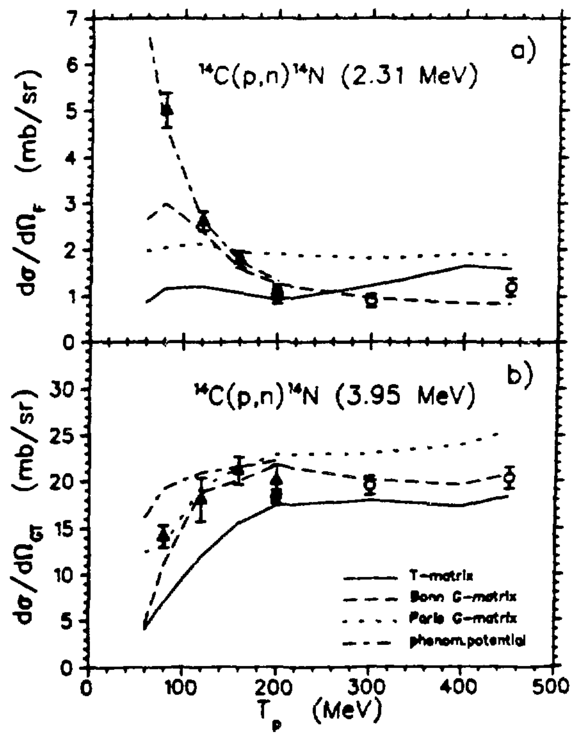

Fig. 4: Zero degree cross sections for the $^{14}C(p,n)$ $^{14}N^*$ reaction, compared with results of calculations from ref. 23. Optical potentials for DWIA calculations were obtained from a folding model using the corresponding effective interaction. At lower energies, a calculation using phenomenological potentials was also carried out for the Bonn G matrix interaction.

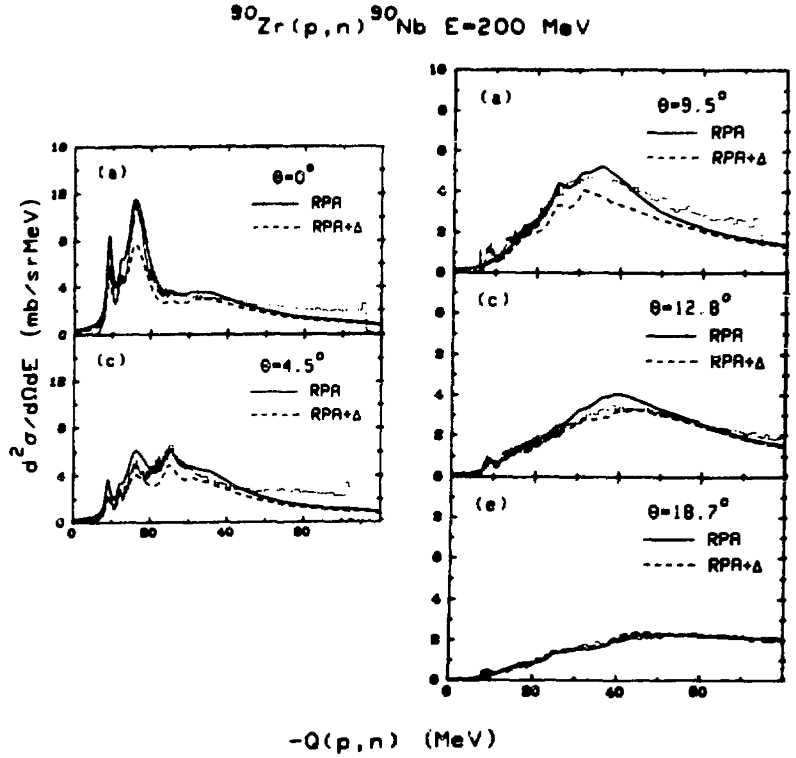

Fig. 5: Calculated cross section for $^{90}Zr(p,n)$ ^{90}Nb with and without the inclusion of Δ isobar excitations. The data is shown as the fine solid line. (ref. 26)

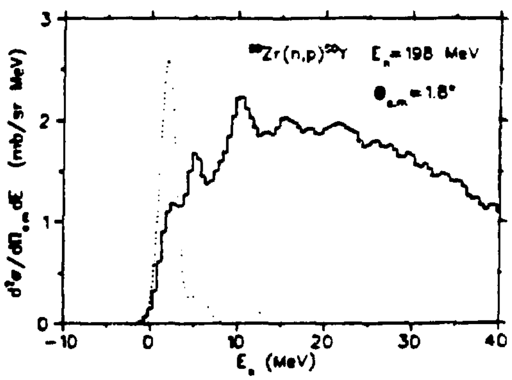

Fig. 6: Measured cross section for $^{90}Zr(n,p)$ ^{90}Y at 1.8°. The dashed curve is the GT^+ strength distribution calculated by ref. 29. Data is from ref. 28.

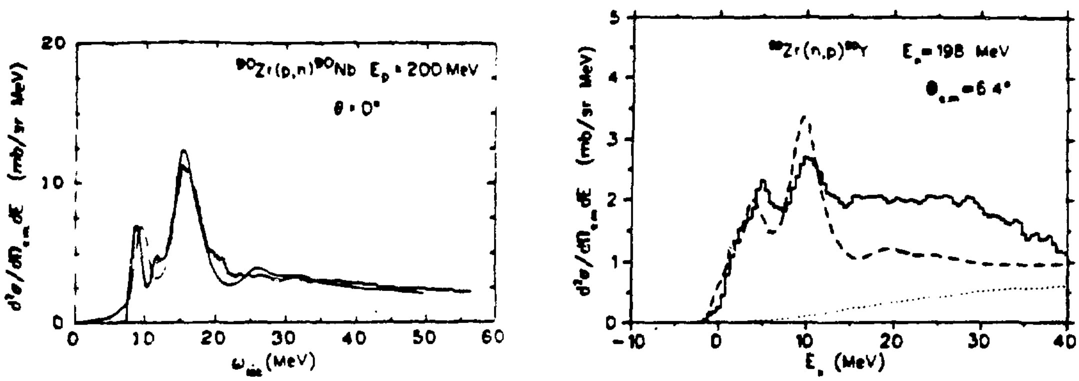

Fig. 7: Spectra for $^{90}Zr(p,n)$ at 0° (ref. 11) and $^{90}Zr(n,p)$ at 6° (ref. 28) compared with results of RPA-DWIA calculations by Smith and Wambach (ref. 31). The dotted curve is an estimate of two step contributions to the (n,p) cross section.

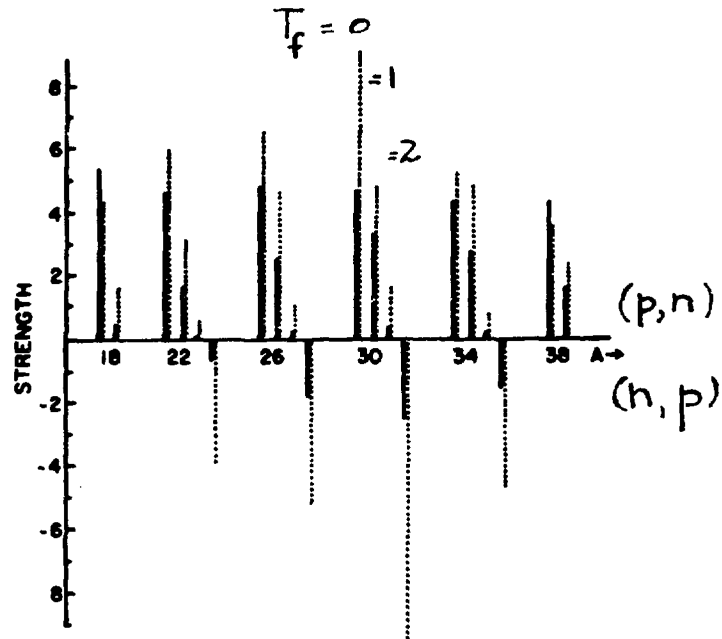

Fig. 8: GT strength calculated for T=1 targets in the (sd) shell. The dashed bars are calculated with a truncated one-component shell model wave function; the solid bars with full (sd) wave functions (ref. 32).

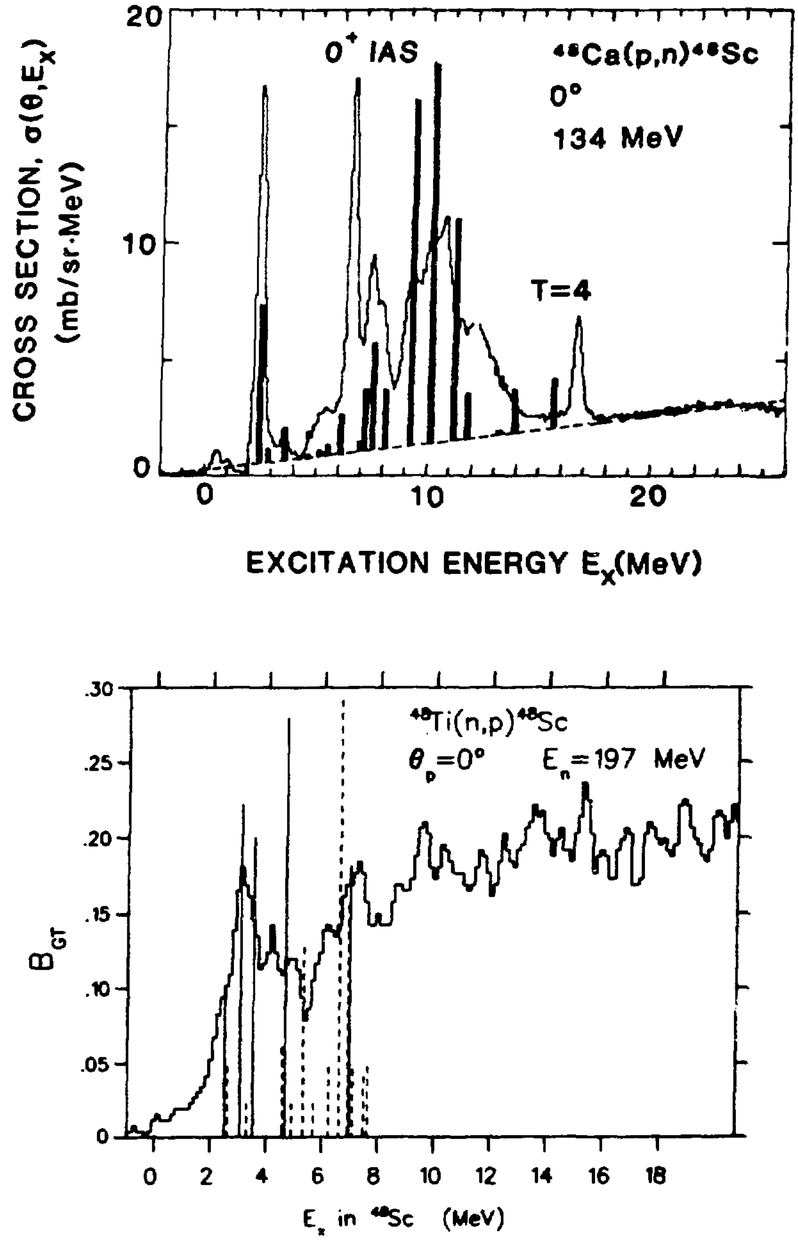

Fig. 9: Comparison of measured GT strength for $^{48}Ca(p,n)$ and $^{48}Ti(n,p)$ reactions with results of shell model calculations. For $^{48}Ca(p,n)$ the measured strength is assumed proportional to the zero degree cross section, and calculations are shown as solid bars. For $^{48}Ti(n,p)$ the GT strength deduced from angular distribution measurements is shown as solid bars, and the results of calculations by dashed bars.

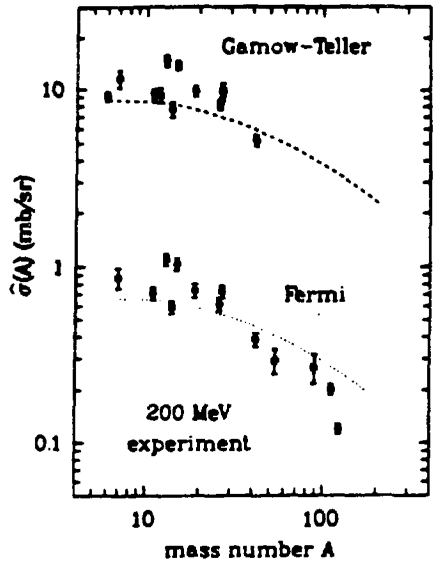

Fig. 10: $\hat{\sigma}$ as obtained from measurements of zero degree (p,n) cross sections at 200 MeV. The dashed curves show the A dependence expected from DWIA calcualtions (ref. 18).

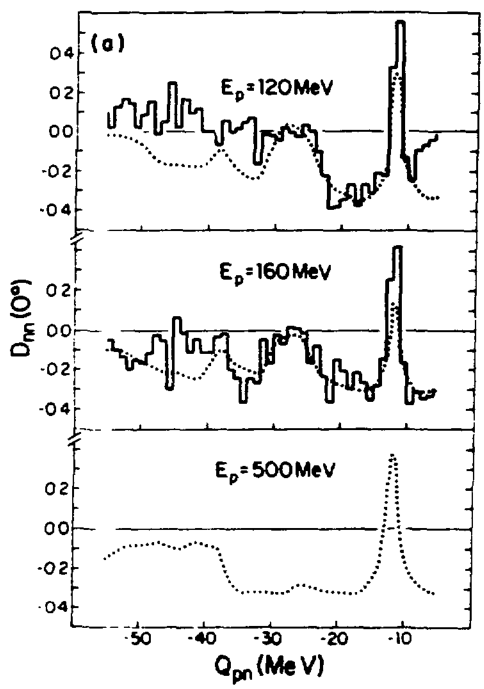

Fig. 11: $D_{nn}(0^o)$ for $^{90}Zr(p,n)\,^{90}Nb$. (ref. 41) The dotted curves are the result of calculations by Love et al. (ref. 16).

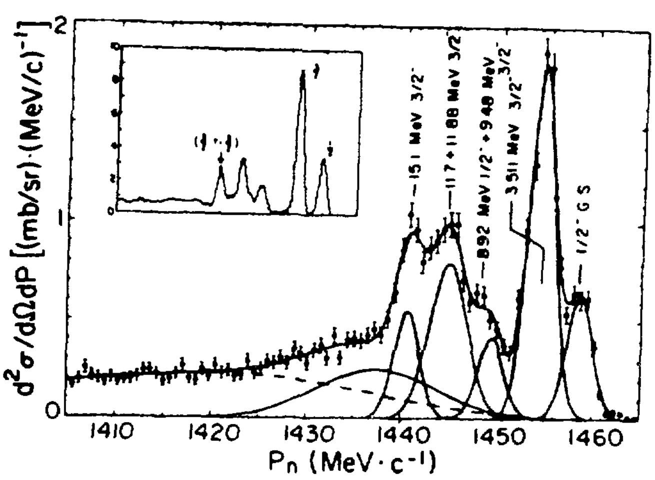

Fig. 12: Zero-degree spectrum for the $^{13}C(p,n)$ reaction at 800 MeV as measured with the WNR TOF facility. (ref. 50).

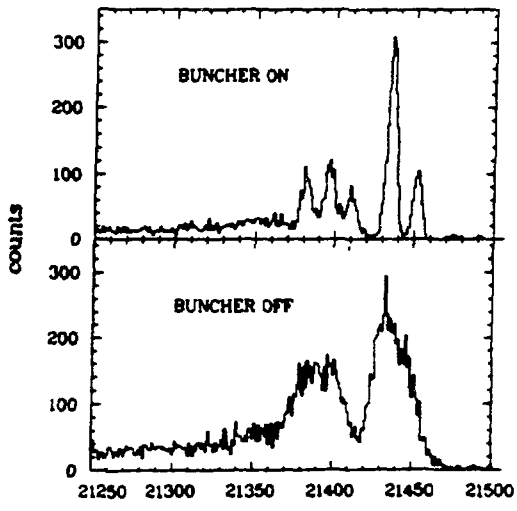

Fig. 13: Zero degree spectrum for $^{13}C(p,n)$ at 492 MeV measured at WNR TOF with and without rebunching. (ref.20).

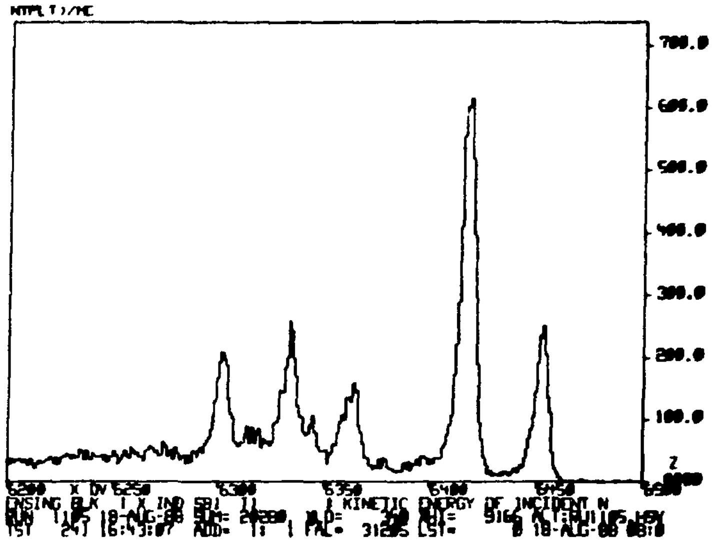

Fig. 14: On-line zero degree spectrum for $^{13}C(p,n)$ at 647 MeV measured at NTOF with rebunching. The energy resolution is about 700 keV. (ref. 21).

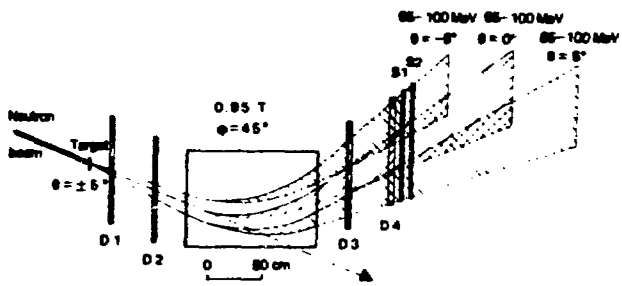

Fig. 15: "Raytrace" (n,p) detector system (ref. 53). "D" represents drift chambers, "S" scintillators.

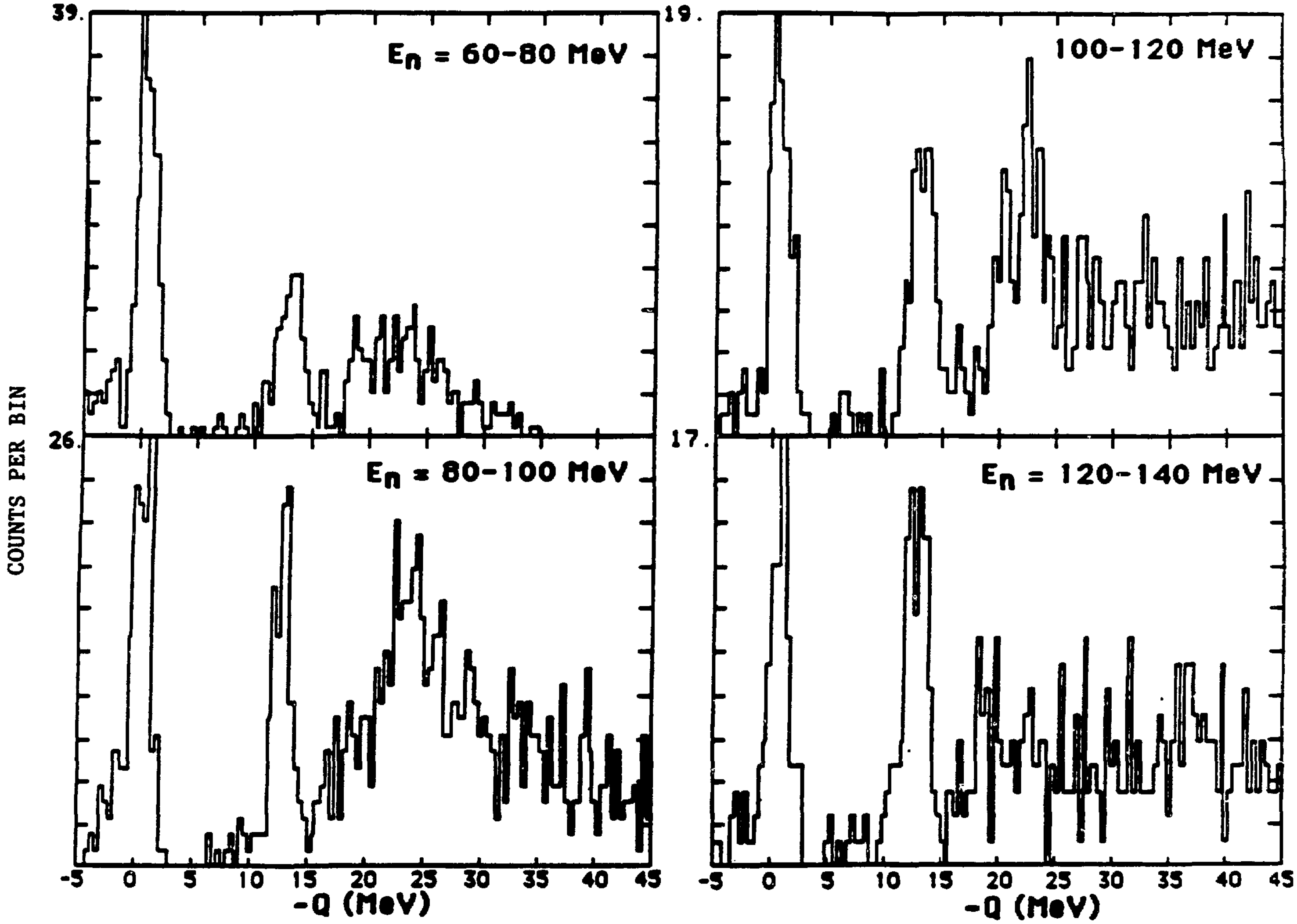

Fig. 16: Proton spectra from the 13C (n,p) reaction obtained with the WNR (n,p) facility. The angular range in each spectrum is (0° to 4°). The peak at Q=0 arises from the 1H (n,p) reaction on hydrogen in the target material. The peak at Q= -13 MeV arises from the transit ion to the 13B ground state.

Status Report of the Medium Energy Nuclear Data Library Project

D.C. George
E.R. Siciliano

Phase I of the Medium Energy Nuclear Data Library Project, MENDLIB,[1] a joint effort of T-2 and MP division, consisted of definition of a data base system to contain LAMPF generated data, code development of an interactive, user-interface to access this data, and collection of data to be included in the library.

Since MP division owns a license for INGRES, a relational database management system, it was selected as the database system for Phase I of MENDLIB. Three tables were defined in INGRES format to contain the bibliographic information: author, journal, submitters name, etc; the measurement description: beam, target, reaction, etc; and the actual data: independent variable, dependent variable, and error.

Code development consisted of writing a FORTRAN inquiry program to serve as a front-end user-interface. This program asks the user in an interactive, user-friendly mode, to supply parameters with which to search the database for entries that match the request. It then generates the appropriate retrieve request for INGRES to process. Additionally system links were provided so that interested persons can dial in to the LAMPF computer and access MENDLIB without having a LAMPF account. The data retrieved by INGRES can be displayed on the user's terminal or written to a file which can then be printed at LAMPF or copied to the user's own disk space if he has a LAMPF account.

All LAMPF users were contacted and encouraged to contribute data to MENDLIB. Data can be submitted via electronic mail to DENISE@LAMPF, on an IBM PC or MACINTOSH diskette, or on magnetic tape. Data that are not in computer readable format may be submitted in paper copy form, and they will be typed up and entered as time permits. Submissions of reference lists are also encouraged. These entries are marked as bibliographic information only. As shown in Fig. 1, only on the order of 17,000 data points have been submitted, representing about 150 references. The data include elastic, inelastic, SCX, DCX, pion absorption and production, knock-out, pick-up and quasi-elastic reactions of proton, pion, deuteron, neutron and gamma beams on numerous targets. According to our estimates, the amount of data in MENDLIB now is less than 17% of the total amount of published LAMPF data. The most important remaining goal for Phase I is to acquire more data. Thus, your help (contributions, hints, hot leads) in collecting these data is greatly needed.

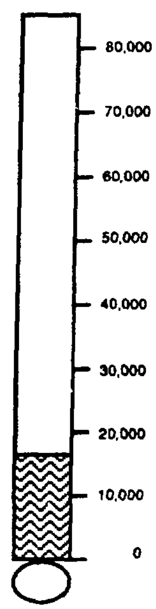

Fig. 1: Number of Data Points in MENDLIB

1. E.R. Siciliano, E.D. Arthur, *Medium-Energy Nuclear Data Library (MENDLIB): Phase I*, LA-11085-MS, October 1987.

MINUTES

EPICS Working Group

October 24, 1988

submitted by C. L. Morris

Attendees:

C. Fred Moore	UT Austin
D. Dehnhard	U Minnesota
J. Peterson	U Colorado
S. Sterbenz	U Minnesota
A. Williams	UT Austin
C. Morris	LANL
J. Amann	LANL
S. Greene	LANL
G. Burleson	NMSU
M. Jones	U Minnesota
Yi-Fen Yen	U Minnesota
Sung Yoo	UT Austin
L. Isenhower	ACU
M. Sadler	ACU
S. Mordechai	Ben-Gurion
J. Zumbro	MIT Bates
A. Klein	NMSU
W. Foreman	LANL

Eighteen members of the EPICS Working Group met during the Twenty-Second LAMPF Users Group Meeting. The users present were generally happy with the performance of the EPICS channel and spectrometer during beam Cycles 51 and 52. However, several continuing problems need to be addressed, including:

1. Shielding: Large backgrounds of neutron flux near the shielding wall post both personnel hazards and experimental limitations for large-angle measurements.

2. Magnet Stability: Continuing problems with the magnet stability due to the outdated and unreliable shunts for both the spectrometer and channel were noted. It is hoped these will be replaced and thoroughly tested before run Cycle 53. The users hope this effort will be vigorously pursued during the shutdown.

3. CAMAC Control Problems: Hardware problems with the CAMAC used to readout and control the channel and spectrometer were discovered at the beginning of run Cycle 51. Because of these CAMAC control of the beam plugs was not available during Cycles 51 and 52. The users hope these problems will be fixed.

In addition to these problems the users wish to express their support for development projects to increase the pion flux and improve the resolution of the spectrometer. Specific recommendations include:

1. Efforts to improve the resolution by making thinner front chambers are strongly supported. The University of Texas at Austin has offered machine shop time to this end and the University of Colorado has offered some electrical engineering time.

2. Nearly all current EPICS experiments can use either higher rates or brighter beams. Higher rates can be obtained from a thicker or denser target at A-1. Users would support efforts for development along this lines. Beam current cuts in Line A could be accommodated by EPICS users by doubling the A-1 target thickness.

Computer Facilites Working Group

Thomas Kozlowski

October 18, 1988

CPU capacity at DAC is now at 2 VAX-8650s, plus 3/4 of a VAX-8700 (in Operations) for batch jobs. This amounts to approximately 15 VAX-11/780 equivalents. "Processor farm" software should be available in few months that will allow users on the DAC VAX cluster to submit jobs to a batch queue for execution on the 8700 or potentially any other VAX on the LAMPF Local Area Network (DECNET). The past policy continues of expanding DAC disk capacity to track with CPU capacity. Problems in DAC staffing are being addressed. Of the 4 positions vacated in the last year or so, 2 have been filled by transfers from the Control Section, and MP-6 is attempting to hire 2 more.

Two thirds (400) of DAC accounts are presently active BITNET users. Usage has been steadily increasing in last few years. C-Division will take over support in the future (MP-Division will continue to have a direct BITNET connection).

DAC now supports a public connection to HEPNET, the high energy physics community DECNET. The connection is at present a 9600 baud line (approximately 1 kilobyte/sec) to FNAL. In November HEPNET nodes will be "visible" at DAC. Future expansion of HEPNET capabilities (56 Kbaud for example) will be made via ESNET. ESNET (presently MFENET) is available at DAC. However, its present functionality is inadequate (not all capabilites of DECNET are available). Within the next year DECNET (HEPNET) should be running on top of MFENET/ESNET. The LANL connection is presently a 56Kb/s line. In a few years T1 (1 Mb/s) trunk-lines will be available. C-Division intends to support most links to external networks in the future. Martha Hoehn represents us on the ESNET nuclear physics community panel. She requests input on user external network needs (HOEHN@LAMPF).

The FNAL ACP (Advanced Computer Program) system is an array of micro-processors intended for cost effective off-line (and on-line) "event oriented" computing. There are commercially available hardware components, and software support is available from FNAL. An ACP system is incorporated into the MEGA data acqusition system. In addition, a P-2/MP-6 collaboration has implemented a system at the DAC for the analysis of data from an FNAL experiment. The DAC system has 48 Motorola 68020 nodes (approximately 30 micro-VAX-II equivalents). The total cost was about $50K plus the cost of a micro-VAX host. It includes a production system and a development system for developing codes for production running. LAMPF users may make use of the system on a time available basis. If you are interested contact Tom Carey in P-2. This type of loosely coupled parallel system is a possible future direction for LAMPF off-line and on-line event processing.

A data acquisition "bulletin board" will be available in November on the DAC cluster via DEC VAX-NOTES software. It will provide the status of known Q problems, suggestions and help on using Q, a user's "forum" for exchange of comments and ideas, and allow submission of problem reports from users.

The present major responsibility of the Data Acquisition Section is the MEGA experiment (50-75% of available time). Depending on the funding situation, the LCD effort is likely to become more important (growing to 50-75% over the next several years). The time remaining is devoted to maintaining and improving general data acquisition capabilities. MP-6 is attempting to hire an additional person for the section so that more effort can be devoted to development and improvements in general data acquisition support.

Approximately every 5 years MP-6 has surveyed computing needs of LAMPF for purposes of future planning. The time is again appropriate for such a study; a group representing MP-Division, users, and outside facilities will meet January 11-13, 1989 to study LAMPF data analysis and data acquisition needs and to make recommendations. Most sessions will be public and user attendance is welcomed. User input has also been solicited via a questionnaire distributed at the time of the user meeting.

ATTENDEES:

J. Amann
S. Hoibraten
T. Carey
M. Paciotti
W. Louis
G. Tripard
R. H. Jeppesen
W. Foreman
D. Alexandreas
J. Zumbro
M. Hoehn
L. Rybarcyk
J. Faucett
M. Oothoudt
M. Leitch
G. Hogan
G. Glass
M. McNaughton
K.H. McNaughton
R. Jeppesen
T. Kozlowski

Research at PSI

M. Daum

November 24, 1988

In January 1988 the Swiss Institute for Nuclear Research (SIN) and the Federal Institute for Reactor Research (EIR) were combined to the Paul Scherrer Institute, a national research laboratory. The research divisions of this institute and their research fields are the following:

1. Nuclear and Particle Physics
   - Precision Measurements
   - Rare Decays
   - Polarised Particles
2. Biomedical Research
   - Radiation Therapy
   - Radiation Pharmacy
   - Radiation Hygienics
3. Solid State Physics
   - Solid State Research using Cyclotron (channelling, μSR, neutron spallation source)
   - Materials Science
   - Technical Physics
4. Energy Research
   - Nuclear Energy Research
   - General Energy Research

In the following a selection of recent results from the research performed in the division of Nuclear and Particle Physics is presented.

Precision Measurement of the Mass Difference $m_{\pi^-} - m_{\pi^0}$

R-85-10, PSI-Virginia

J. F. Crawford, M. Daum, R. Frosch, B. Jost, P.-R. Kettle, R. M. Marshall, B. Wright, K. O. H. Ziock

The main purpose of this experiment is to determine the mass difference between charged and neutral pions, $D_\pi \equiv m_{\pi^-} - m_{\pi^0}$, which is needed *e.g.* for comparisons of the measured rate of pion beta decay, $\pi^\pm \to \pi^0 e^\pm \nu$, with theoretical predictions. As a side result, the kinetic energy distribution function $f(T_{\pi p})$

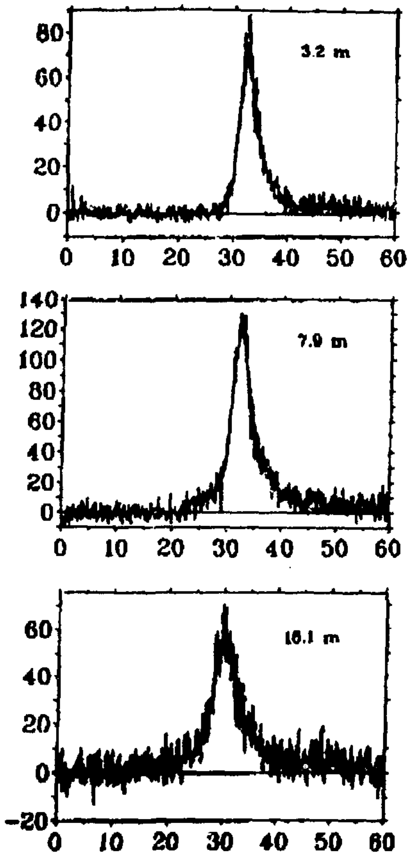

Figure 1: Time-of-flight spectra of neutrons from reaction (1), after background subtraction, for flight paths of 3.2, 7.9, and 18.1 *m*. Time, in *ns*, is from an accidental photon peak[1] about 30 *ns* before the neutron peak.

of $\pi^- p$ atoms in liquid hydrogen, just before nuclear $\pi^- p$ capture, can be derived from our data. This provides a test of calculations concerning the de-excitation mechanisms in exotic hydrogen atoms.

In our measurements, negative pions are stopped in a liquid hydrogen target, where pionic hydrogen atoms are formed. About 60 percent of these $\pi^- p$ atoms undergo the charge exchange reaction

$$\pi^- p \rightarrow \pi^0 n \ . \tag{1}$$

The time-of-flight (*TOF*) distribution of neutrons from reaction (1) is measured over distances up to 18 *m*.; they are shown in Fig. 1.

If one were to neglect that the $\pi^- p$ atoms have a finite kinetic energy $T_{\pi p}$, and are in different atomic states at the time of reaction (1), then all neutrons from that reaction would be predicted to have the same velocity v_n. If the assumption of the initial $\pi^- p$ atoms being at rest is abandoned, the predicted neutron *TOF* distribution $F(\tau)$ for a given neutron flight path l_n has a finite width. It can be shown that, for an isotropic distribution of the directions of the $\pi^- p$ atom velocities, the mean of the neutron *TOF* distribution is equal to the *TOF* for $\pi^- p$ atoms at rest. The standard deviation of the *TOF* distribution function $F(\tau)$ is

$$\sigma_\tau = [2\overline{T_{\pi p}}/(3m_{\pi p})]^{1/2}\, l_n/v_n^2 \ , \tag{2}$$

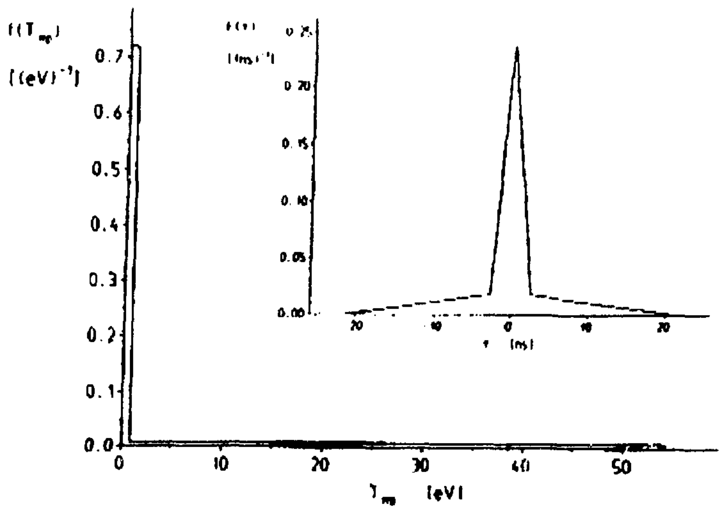

Figure 2: Distribution function $f(T_{\pi p})$ found to fit the neutron *TOF* spectra of Fig. 1; $T_{\pi p}$ is the kinetic energy of the $\pi^- p$ atoms at the time of reaction (1); $F(\tau)$ is the corresponding neutron *TOF* distribution for a flight path of 18.1 m.

where $\overline{T_{\pi p}}$ is the mean kinetic energy of the $\pi^- p$ atoms. It is seen from Eq. (4) that the standard deviation of the *TOF* distribution increases linearly with the neutron flight path l_n.

Such a broadening of the *TOF* peak with increasing flight path is indeed observed in the spectra of Fig. 1. The time axes of these plots start at the centre of an accidental photon peak[1] about 30 ns before the neutron peak. The tails to the right of the neutron peaks in Fig. 1 are due not only to the finite kinetic energies of the $\pi^- p$ atoms, but also to neutrons which have reached the neutron detector after scattering in the materials in and around the flight channel[1]. In contrast, the tail to the left is not contaminated by neutron scattering; this tail, not visible at 3.2 m, extends to about 10 ns (20 ns) before the peak at 7.9 m (18.1 m), corresponding to a kinetic energy distribution $f(T_{\pi p})$ extending to about 70 eV.

A kinetic energy distribution $f(T_{\pi p})$ found to fit the data is shown in Fig. 2, together with the corresponding neutron *TOF* distribution $F(\tau)$ for a fixed flight path of 18.1 m. The model used for the function $f(T_{\pi p})$ was:

$$\begin{aligned} f(T_{\pi p}) &= f_1, \quad 0 < T_{\pi p} < T_1 \; ; \\ f(T_{\pi p}) &= f_2, \quad T_1 < T_{\pi p} < T_2 \; ; \\ f(T_{\pi p}) &= 0, \quad T_2 < T_{\pi p} \; . \end{aligned} \qquad (3)$$

The resulting neutron velocity for $\pi^- p$ atoms at rest is

$$v_n = 0.894266 \pm 0.000063 \; cm/ns \; . \qquad (4)$$

The corresponding pion mass difference is

$$D_\pi = m_{\pi^-} - m_{\pi^0} = 4.59366 \pm 0.00048 \; MeV/c^2 \; . \qquad (5)$$

The uncertainty in Eq. (7) is the quadratic sum of the uncertainty due to Δv_n, $\pm 4.7 \times 10^{-4} MeV/c^2$, and that due to the uncertainty of the mean binding energy

$\overline{E_B}$, $\pm 1.0 \times 10^{-4} MeV/c^2$. The result of Eq. (7) agrees with our previous value[1] based on data taken at flight paths of 2.8 m and 8.4 m. The deviation from the former world average is thus confirmed. Subtraction of the mass difference of Eq. (7) from the π^- mass, 139.56752 ± 0.00053 MeV/c^2, gives the new π^0 mass value

$$m_{\pi^0} = 134.97386 \pm 0.00072\ MeV/c^2\ . \qquad (6)$$

As a test of our experimental method we recorded and analyzed TOF distributions of the 8.9 MeV neutrons from the radiative capture reaction (2). The resulting neutron velocity, 4.09090 ± 0.00075 cm/ns[2], leads to a π^- mass value of 139.587 ± 0.027 MeV/c^2, which is consistent with the value quoted above.

The resulting parameters for the kinetic energy distribution function $f(T_{\pi p})$ of the $\pi^- p$ atoms according to Eq. (5) are:

$$\begin{aligned} f_1 &= 0.596 \pm 0.085\ (eV)^{-1}; \\ f_2 &= 0.00626 \pm 0.00062\ (eV)^{-1}; \\ T_1 &= 0.94 \pm 0.13\ eV; \\ T_2 &= 71.5 \pm 6.1\ eV. \end{aligned} \qquad (7)$$

The corresponding mean kinetic energy of the $\pi^- p$ atoms is

$$\overline{T_{\pi p}} = (T_1{}^2/2) \cdot (f_1 - f_2) + (T_2{}^2/2) \cdot f_2 = 16.2 \pm 1.3\ eV. \qquad (8)$$

This $\overline{T_{\pi p}}$ value is larger by 2.1 standard deviations than our previous result[1], which was obtained on the assumption of Gaussian time distributions, but confirms the strong deviation from the velocity spread quoted in Ref.[3], which corresponded to $\overline{T_{\pi p}} = 115 \pm 43\ eV$.

The high-energy tail of the distribution $f(T_{\pi p})$ may be due to Coulomb de-excitation of the $\pi^- p$ atom near one of the protons of the surrounding liquid hydrogen. In this process the de-excitation energy is partly transformed into kinetic energy of the $\pi^- p$ atom; the energy $T_{\pi p}$ of those $\pi^- p$ atoms which have just undergone the $5 \to 4$ ($4 \to 3$) Coulomb de-excitation is around 30 eV (70 eV).

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[2] J. F. Crawford et al., Phys. Lett. 213B (1988) 391.

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Search for Admixtures of Massive Neutrinos in the Decay $\pi^+ \to \mu^+ + \nu$

R-80-11, Virginia-PSI
M. Daum, B. Jost, P.-R. Kettle, R. M. Marshall, R. C. Minehart, W. A. Stephens, B. K. Wright, and K. O. H. Ziock

If one considers the possibility of nonzero masses for neutrinos, for consistency one must also consider the leptonic mixing which would in general occur in analogy to the quark mixing. As pointed out by Shrock [1], this mixing would also appear in weak decays. The weak eigenstates ν_l would consist of a mixture of mass eigenstates

$$\nu_l = \sum_i U_{li} \nu_i. \tag{9}$$

Here ν_i are the mass eigenstates and U_{li} the corresponding transformation matrix elements. Thus, if neutrinos are massive and nondegenerate then for instance the energy spectrum of the muons in the decay $\pi^+ \to \mu^+ + \nu$ if kinematically allowed would consist of monochromatic lines at $T_i = (m_\pi^2 + m_\mu^2 - 2m_\pi m_\mu - m_\nu^2)/(2m_\pi)$. Here T_i is the kinetic energy of the muons, and m_π, m_μ, and m_ν are the masses of the pion, the muon, and the neutrino in the i^{th} mass eigenstate, respectively.

In this experiment we stopped positively charged pions in the center of a germanium detector telescope, and measured the energy of the decay muons in the same detector using a pulse sampling technique. The experimental method and first results are presented in ref.[2].

The radiative decay $\pi^+ \to \mu^+ + \nu + \gamma$ provides a small but irreducible background for our experiment. The energy spectrum from the radiative decay convoluted with the gaussian resolution curve derived from the 4.12 MeV peak is displayed in Fig. 3 together with the experimental data. One can see a narrow peak with a line width of 10.4 keV (fwhm) at an energy of 4.12 MeV corresponding to the two-body decay of a pion at rest (2) where $m_{\nu_\mu} \leq 270$ keV/c^2. There is no evidence for additional lines.

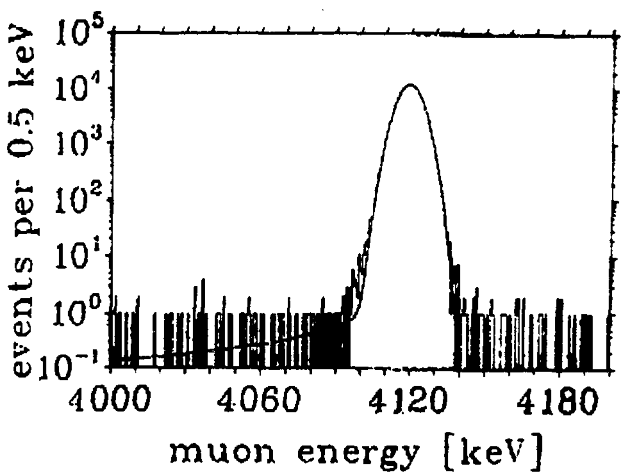

Figure 3: Gaussian distribution convoluted with the muon energy spectrum from radiative decay and fitted to the experimental data.

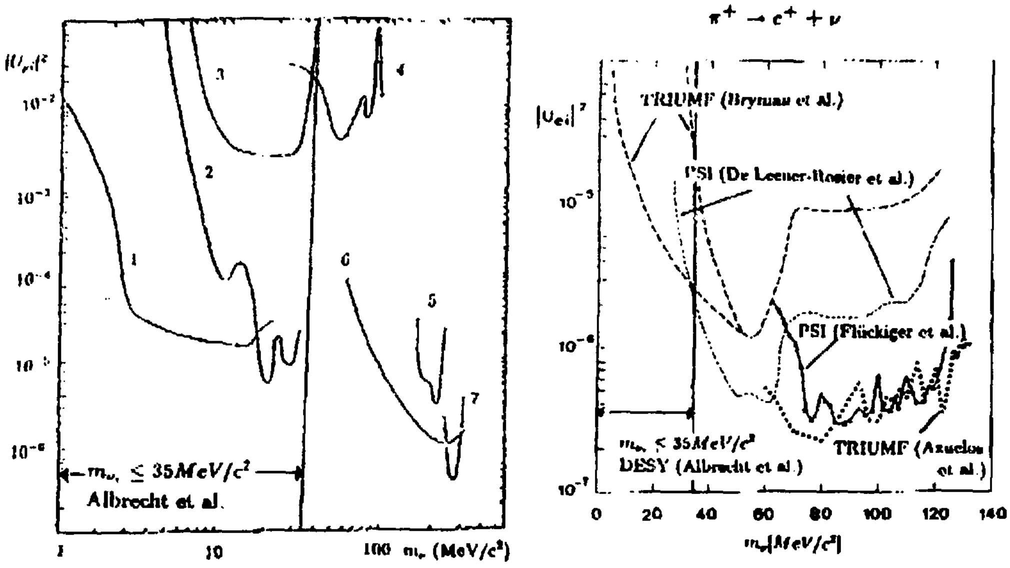

Figure 4: Upper limits for $U_{\mu i}$ and U_{ei} (90 % confidence level). 1 Ref.[3], 2 Ref.[4], 3 Ref.[5] 4 Ref.[6], 5 Ref.[7], 6 Ref.[8], 7 Ref.[9]

A plot of our result is shown in Fig. 4 along with a comparison to other experiments. Our data yield a significant improvement in the upper limit η of the branching ratio for neutrino masses less than 16 MeV/c² and extend the neutrino mass range with a significant η-value down to about 1 MeV/c²[3]. Recent results from measurements of U_{ei} performed both at PSI and at TRIUMF are displayed for comparison.

In a recent data taking period several improvements to our apparatus were installed. For further suppression of the background a different detector geometry was chosen and the electronics was improved to optimize the energy resolution of our detectors. With this upgraded system about $5 \cdot 10^7$ events have been recorded. The analysis is in progress and improved results are expected in the near future.

References

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Search for the Two Photon Decay of a Light Penetrating Particle from a 590 MeV Proton Beam Dump

R-81-06, AACHEN - BERLIN - PSI

A. Badertscher, M. Daum, R. Dietlicher, H. Faissner, W. Heinrigs, P. Kostka, K. Lanius, S. Nowak, A. Preussger, J. Reitz, D. Samm, C. Spiering, H. Tuchscherer, M. Walter, and A. Zehnder

A search was performed for the two-photon decay of a light, penetrating particle (e.g. an axion) produced in the 590 MeV proton beam dump of SIN. The apparatus was situated behind the beam dump and 8 m of iron-concrete shielding. The detector consisted of two counter triggered optical spark chambers placed 2 m apart. Photons were converted in a lead foil at the entrance of either spark chamber. From connecting the conversion points in the two modules the primary particle direction is determined to 1 degree (rms).

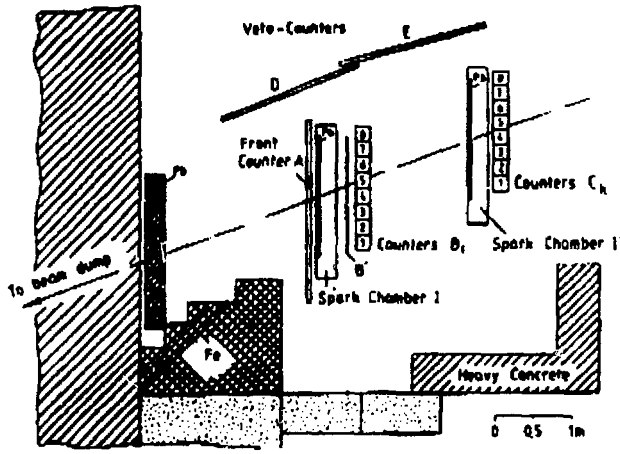

Figure 5: Experimental arrangement. The numbers of the counter slabs B_i and C_k were used to define the hit pattern. The moveable iron wall is shown in the position leaving the decay region open.

The detector proper, as shown in Fig. 5, was to detect both photons from a decay $a^0 \to 2\gamma$ in two essentially identical spark chamber and counter set-ups. In order to suppress cosmic ray background the two modules were mounted, at a distance of 2 m, on a slanting line, looking down at the beam dump under an average angle of 20^0 with respect to the horizontal. An open space of 2 m length was left between the shielding and the first counter. This decay region could be blocked by a moveable plate containing 20 cm of iron and 5 cm of lead.

It was the idea of the experiment to identify the surmised decay $a^0 \to 2\gamma$ by requesting one photon to convert in the first spark chamber, and the other one in the second chamber. When this condition is met, one can determine the direction of the primary particle with high accuracy from the conversion points of the photons: for a parent particle mass of 250 keV/c^2 and an average photon energy of 80 MeV, the typical decay angle of a photon with respect to the primary direction is about 2 mrad. Thus connecting the two conversion points would yield the primary particle

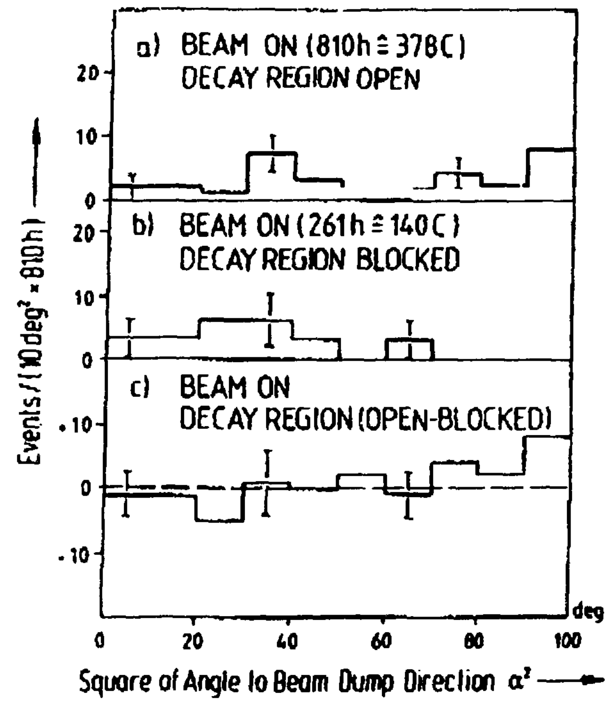

Figure 6: Angular distribution of 2γ events, observed with beam on: a) decay region open, b) decay region blocked, c) difference of the two distributions. Gammas originating from $a^0 \rightarrow 2\gamma$ decay were expected to show up in the first angular bin. Clearly no decay signal is visble in excess of the background in the bins $\alpha^2 \geq (10^0)^2$.

direction very accurately. Data have been taken with the decay region open and blocked, both with beam on and off. The apparatus was exposed to 518 coulomb of protons, and the background was measured during almost 1000 hours with beam off. The complete angular distribution, as obtained with beam on, is given in Fig. 6. No two-photon decay signal was found in excess of the background in the sharp forward peak expected for a light particle decay. This null result places restrictive limits on the production and the decay of axions and similar particles.

Within standard axion theory all relevant axion properties can be given in terms of the Higgs parameter X, provided one fixes the number of quark generations N_q, and assumes a definite value for the ratio of quark masses $Z = m_u/m_d$. We take the usual values N_q= 3 and Z = 0.56, and obtain in Fig. 7 the number of 2γ events $N_{\gamma\gamma}$ expected for the present experiment as a function of X. A similar event rate had been expected in the experiment of the CHARM collaboration [1], in which no candidate event was observed. The difference between the two curves stems from different assumptions about the contribution of η-mesons to the expected axion flux. We have also indicated the limit of the previous experiment [2,3], and the limit recently obtained at SLAC [4]. The limit obtained in the present experiment is close to that derived by CHARM, and excludes the classical axion, except for a narrow range of X values near 1. A detailed report on this experiment is given in Ref. [5].

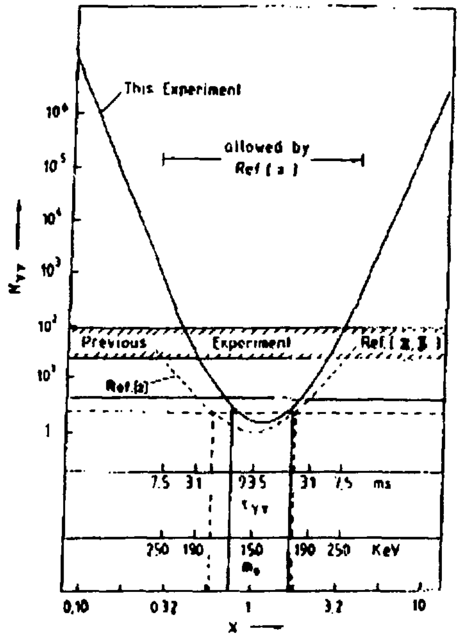

Figure 7: Limits on the properties of the standard axion, as imposed by this experiment. The broken lines refer to the CHARM experiment [1]. Also indicated are the levels from the previous experiment [2,3] and the limits set (with 95 % c. l.) by Bjorken [4].

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K. Winter, private communication.

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see also W. Heinrigs, Aachen Report PITHA 82/11 (1982).

[3] H. Faissner et al., Phys. Rev. D28 (1983) 1198.

[4] J.D. Bjorken, Report-Fermilab-84/33-T (1984).

[5] H. Faissner et al., Z. f. Physik C37 (1988) 231.

MEASUREMENT OF THE SPIN DEPENDENT TOTAL CROSS SECTION $\Delta\sigma_T$ IN NEUTRON-PROTON SCATTERING

R-86-14, Freiburg/FRG - Geneva - PSI - Saclay

R. Binz, B. van den Brandt, R. Büchle, M. Daum, Ph. Demierre, J. Franz, G. Gaillard, N. Hamann, R. Hess, J. A. Konter, F. Lehar, C. Leluc-Lechanoine, S. Mango, R. Peschina, D. Rapin, E. Rössle, P. A. Schmelzbach, H. Schmitt, and R. Todenhagen.

We have investigated the possibility of using the proton-neutron spin transfer K_{okko} and K_{onno} on a carbon target at small neutron emission angle. The experiment was performed in the nE1 beam line, using the target E as the production target and taking advantage of the high intensity of the polarized proton beam of SIN (beam current 3-5 μA, proton polarization ~85 %, beam pulse frequency 17 MHz). The neutrons are produced by quasifree elastic and inelastic (pn) processes; Fig. 8 shows the energy spectrum of the neutrons for energies above 200 MeV.

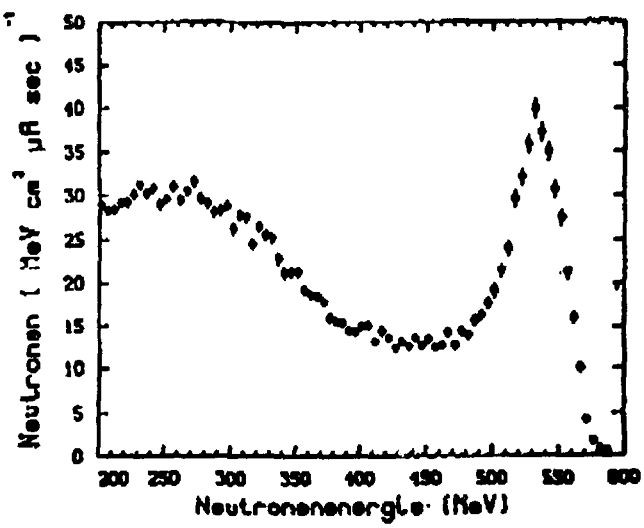

Figure 8: Energy spectrum of the neutrons with energies above 200 MeV, produced on a carbon target located at the target station E, as measured in the nE1A area of SIN.

The proton time-of-flight was used to select elastic (np) scattering and to eliminate the energy ambiguities of the n-beam. Figure 9 shows, as a function of the neutron energy, the neutron polarization obtained by use of the K_{okko} and K_{0nn0}, respectively. As a result a 40 % longitudinally polarized neutron beam was obtained above 300 MeV; Table 1 summarizes its properties.

The design of the new NA1 beam line is now based on this method. The experimental target in NA1 will be only 12-15 meters away from the production target and an increase of the intensity by a factor 16-25 is expected. Thus a polarized neutron beam can be realized with a flux similar to that of the present unpolarized neutron beam in the nE1A area. The layout of this new area is shown in Fig. 10.

Shortly after the development of a polarised neutron beam at SIN the parameter A_{ookk} was measured in December 1986, the parameters A_{ooss} and A_{ooks} in February 1987, and finally the experiment was completed in September 1987 by investigating polarised as follows. In order to control the polarisation of the proton beam, the beam was split and 200 nA were continuously sent to the PIREX station where a carbon target was used as a proton polarimeter. To turn the polarisation of the proton beam at the neutron production target E into the longitudinal direction a superconducting solenoid is used in combination with the last bending magnet in the beam line. The neutron beam is produced via polarization transfer with a longitudinal polarisation. A magnet in the neutron beam was used to rotate the neutron spin into the vertical direction for the measurement of $\Delta\sigma_T$. Preliminary results of the spin dependent total cross section $\Delta\sigma_L$ and $\Delta\sigma_T$ are shown in Fig. 11.

Neutron production target	carbon
Present intensities	
Primary beam [μA proton]	5
Neutron flux [10^5n/(s.cm^2)]	5 (nE1B)
Future intensities	
Primary beam [μA proton]	2-10
Neutron flux [10^5n/(s.cm^2)]	10-50(NA1)
Neutron beam polarization	~ 40 %
Neutron energy (MeV)	200-580
Resolution FWHM (MeV)	11-50
Duty cycle	100 %

Table 1. Properties of the PSI polarised neutron beams.

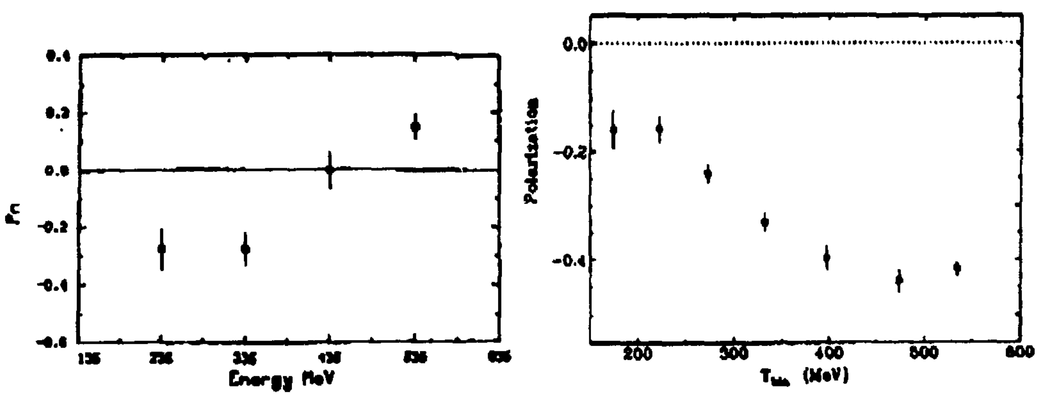

Figure 9: Polarization of the SIN-nE1 neutron beam using K_{okko} and K_{onno}, respectively.

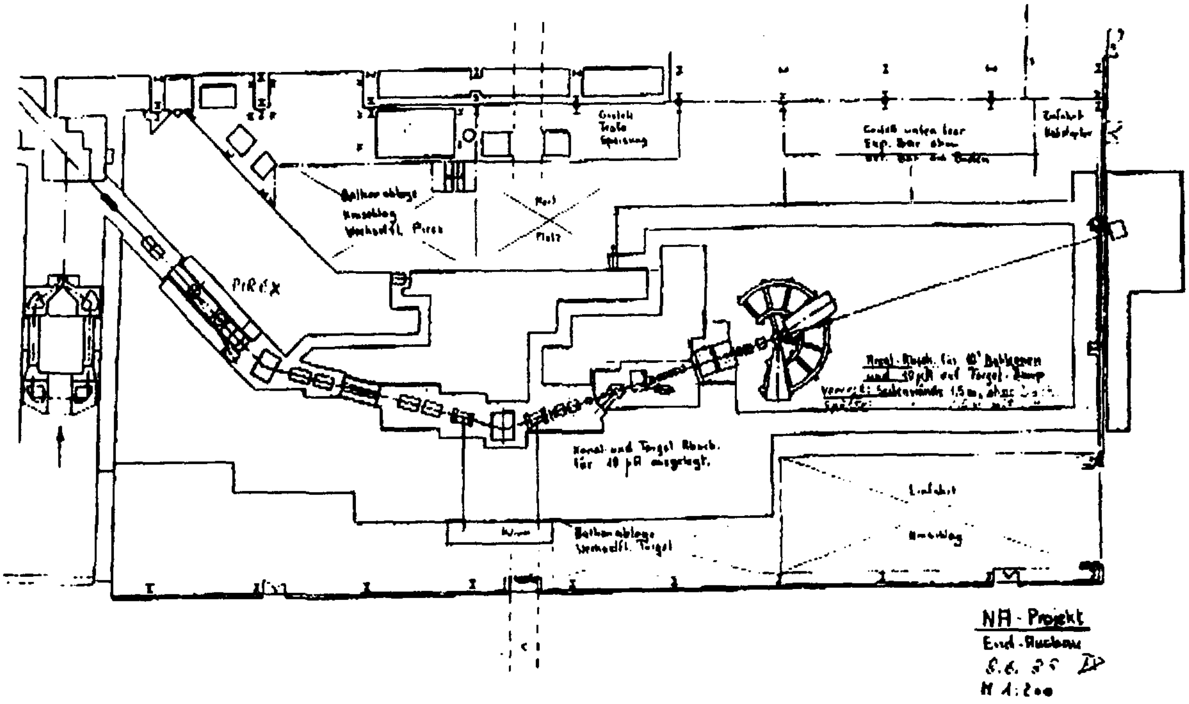

Figure 10: Layout of the NA1 area for the production of polarized neutrons

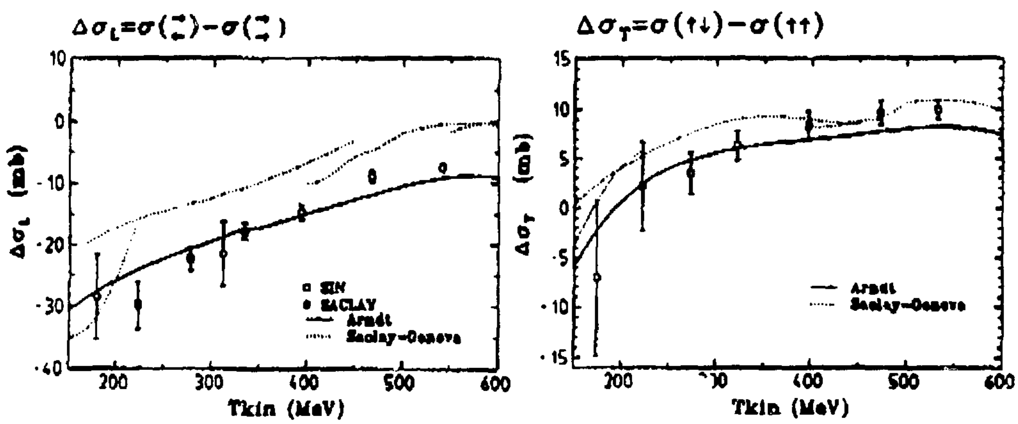

Figure 11: Preliminary results of the spin dependent total cross-section $\Delta\sigma_T$(np) and $\Delta\sigma_L$(np). The curves are the PSA predictions.

SEARCH FOR THE DECAY $\mu \rightarrow 3e$ WITH SINDRUM I

R-80-06, AACHEN - ETHZ - SIN - SACLAY - ZÜRICH
U. Bellgardt, W. Bertl, S. Egli, R. Eichler, R. Engfer, L. Felawka, Ch. Grab, M. Grossmann-Handschin, E. A. Hermes, N. Kraus, N. Lordong, J. Martino, F. Muheim, C. Niebuhr, G. Otter, H. Pruys, A. v. d. Schaaf, D. Vermeulen, H. K. Walter

The analysis of rare and forbidden processes offers a possibility to observe interactions or particles beyond the predictions of the standard model. With the SINDRUM I detector, a large solid angle magnetic spectrometer for multi-electron final states the decays $\mu^+ \rightarrow e^+e^+e^-$ [1], $\mu^+ \rightarrow e^+\nu\bar{\nu}e^+e^-$ [2] $\mu^+ \rightarrow e^+\theta$ ($\theta \rightarrow e^+e^-$) [3], $\pi^+ \rightarrow e^+\nu e^+e^-$ [4], $\pi^+ \rightarrow e^+\nu\theta$ ($\theta \rightarrow e^+e^-$) [3] and $\pi^0 \rightarrow e^+e^-$ have been studied.

The search for the muon-number violating decay $\mu^+ \rightarrow e^+e^+e^-$ has been continued and a total number of $\sim 10^{13}$ muon decays has been studied in 1986. The average stop rate was $5 \cdot 10^6$/s and the overall efficiency was 15.5 %. Since more stringent trigger conditions were applied the acceptance for the decay $\mu^+ \rightarrow e^+\nu\bar{\nu}e^+e^-$ was reduced by 40 %. No prompt events are seen in a region containing 95 % of the simulated $\mu \rightarrow 3e$ events. The new upper limit including the data of the first measuring period is $B_{\mu \rightarrow 3e} < 1.0 \cdot 10^{-12}$ ($90\% C.L.$)[5].

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[4] SINDRUM collaboration, Phys. Lett. 175B (1986) 97.

[5] U. Bellgardt et al., Nucl. Phys. B299 (1988) 1.

MEASUREMENT OF THE BRANCHING RATIO OF THE DECAY $\pi^0 \rightarrow e^+e^-$ with SINDRUM I

R-85-14, AACHEN - ETHZ - SIN - SACLAY - ZÜRICH - VANCOUVER
U. Bellgardt, W. Bertl, S. Egli, R. Eichler, L. Felawka, M. Grossmann-Handschin, E. Hermes, T. Koslowski, N. Lordong, J. Martino, R. Meijer-Drees, F. Muheim, C. Niebuhr, S. Playfer, H. Pruys, A. v. d. Schaaf, D. Vermeulen, H. K. Walter, C. Waltham

The electromagnetic contribution to the transition probability of pseudoscalar mesons into lepton pairs can be calculated with a precision of the order 20% leading to the theoretical prediction for the branching ratio of $R_{\pi^0 \rightarrow e^+e^-} = 6 \times 10^{-8}$. In the cases of $\eta \rightarrow \mu^+\mu^-$ and $K_L \rightarrow \mu^+\mu^-$ the experimental values agree with the predictions whereas measurements of the decay $\pi^0 \rightarrow e^+e^-$ [1,2] give a result $R = (1.8 \pm 0.7) \times 10^{-7}$ indicating that other, non-electromagnetic, contributions might be involved. To reach definite conclusions on such contributions the large experimental uncertainty has to be reduced by an improved experiment. The experimental set-up is shown in Fig. 12. The π^0's are produced by the reaction $\pi^- p \to \pi^0 n$ in a liquid hydrogen target positioned at the centre of the SINDRUM spectrometer. To improve the momentum resolution for the e^+e^- pair the magnetic field was raised to 7 kG. The neutron detector was an array of sixty plastic

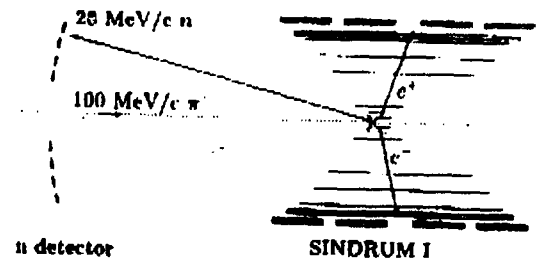

Figure 12: Schematic view of the detection system. The hydrogen target, wire chambers, hodoscope and magnet coils are shown. The beam enters along the symmetry axis. The neutron flight distance is 130 cm.

scintillator discs grouped around the beam pipe in front of the last quadrupole. The light produced by a recoil proton with energy less than 420 keV is equivalent to the light output of an electron of 50 keV or less. In order to obtain the required detection efficiency and time resolution an extremely high light collection efficiency is required. For this reason the scintillators were positioned directly in front of the cathodes of 2" photomultipliers. In this way a yield of two photo-electrons per keV was obtained giving a time resolution of the order of 2 ns. This corresponds to a neutron momentum resolution of about 1.5% for the flight distance of 130 cm.

Since the detector determines the momenta of all three particles produced from a system at rest there are several useful conserved quantities. The following constraints were chosen to select three-body processes ($\pi^- p \to e^+e^- n$ and $\pi^- p \to \pi^0 n$, followed by $\pi^0 \to e^+e^-$):

1. the angle between the e^+e^- momenta projected on a plane perpendicular to the neutron direction should be equal to 180^0
2. the velocity of the state decaying into the e^+e^- pair as determined from the neutron momentum should be equal to the velocity as determined from the angles in the decay plane
3. the total energy should be equal to 138 MeV.

The decay $\pi^0 \to e^+e^-$ is then selected by requiring the neutron momentum to be 28 MeV/c. The neutron momentum resolution function is measured by the various π^0 decay modes whereas the resolution functions of the three-body observables are measured by the process $\pi^- p \to e^+e^- n$. The sensitivity of the measurement is demonstrated in Fig. 13a. Here the neutron momentum distribution is shown for events fullfilling the three-body constraints. The decay $\pi^0 \to e^+e^-$ is contained in this sample and would manifest itself as a peak at 28 MeV/c. The experimental resolution function as measured by the other π^0 decay modes is shown in Fig. 13b. From the data a preliminary upper limit for the branching ratio of 1.2×10^{-7} is deduced.

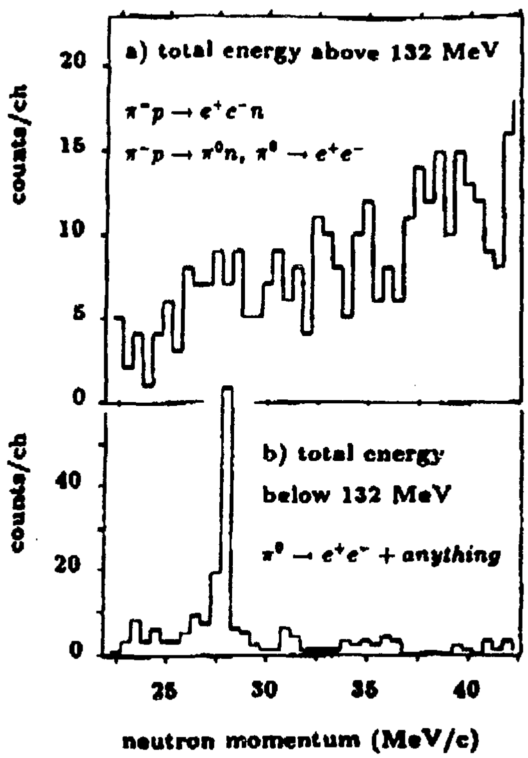

Figure 13: Neutron momentum distribution for coplanar events with total energy above (a) and below (b) 132 MeV.

References

[1] J. Fischer et.al., Phys.Lett.73B (1978) 364.

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Participants

J. F. Amann, MP-10

M. Daum, Paul Scherrer Institute

W. Foreman, MP-6

K. W. Jones, MP-10

K. H. McNaughton, University of Texas at Austin

M. W. McNaughton, MP-10

A. J. Simon, Texas A and M University

Joint NPL/NTOF/HRS Meeting

The major portion of the HRS working group meeting was devoted to a joint session with the NPL and NTOF working groups.

R. York and O. van Dyck presented a status report on the new optically pumped polarized ion source (OPPIS). The source has functioned well on the test stand, producing peak beam intensities in the 5-7 microampere range. It is believed that the goal of 10 microamperes is attainable. Reasonable reliability has been achieved, and the decision has been made to install the source during the 1988/1989 shutdown. The Lamb shift source has been removed from the injector dome, and preparations are in progress for the installation of OPPIS early in the new year. One source of concern is the fact that the polarization of the beam has yet to be measured. A limited window of opportu- nity remains to make a measurment on the test stand using the Lyman Alpha technique. It is possible, given adequate resources, that the prototype Low Energy Polarimeter (LEPO) could be made functional to allow polarization measurements at 750keV after the source is installed in the dome. This would allow tuning of source parameters without the necessity of accelerating the beam through the Linac. Additional staffing for the project has been obtained, and the development team is now at full strength.

M. McNaughton presented a proposal for a new spin cycle for control of OPPIS. It was proposed that there be three states, designated by +, -, and U for "Normal", "Reverse", and "Unpolarized" respectively. After some discussion and there being no substantive objections, this proposal was adopted by consensus.

K. Jones discussed the Line X Safety Upgrade, a high priority shutdown project for 1988/1989. It was acknowledged that there are credible accident scenarios resulting in the delivery of high-intensity H- beam to Line X and subsequent beamlines which could result in unacceptable radiation dose rates and integrated exposures to personnel working in some polarized beam experimental areas. This problem is particularly severe in the MRS, HIRAB, and NTOF areas.

The problem is being addressed by the installation of additional concrete shielding around the switcher cave adjacent to MRS and NTOF, and by upgrade of shielding in other strategic locations. In addition, new self- checking current limiters are being installed in Line X. A system of ion chambers incorporating self-checking features will also be installed to act as spill monitors, and additional Albatross neutron detectors will be installed throughout the experimental areas. The plan, generated by R. Werbeck, will be reviewed by the LAMPF Operational Safety Committee, and implementation will be supervised by K. Jones. The goal of the new layered system is to limit background levels and accidental exposures for credible accident scenarios to division guidelines. Implementation and testing of the system will take place at the beginning of the 1989 production period.

Cost Reduction Options

Little consensus was reached on this matter. The aspects of the discussion were very similar to those expressed in the NPL working group minutes. Given the overhead in running at least one polarized beam facility, it was felt that there was little incremental cost in running the two additional facilities. The wide variety of experiments now run at HRS precludes any definitive statement as to the desirability of reducing duty factor or average current.

HRS status

HRS maintained good availability and use during the last production period. Details are available in the August PAC report. Planned work for the 1988/1989 shutdown includes an upgrade of the vacuum control system, installation of a new polarimeter in the front end of the beamline to permit measurement of L-spin at most energies, and relocation of the front end beam current monitor upstream of the first beam plug to allow current splits to be set up effectively while the area is open.

K. Jones will continue to act as chairman of the HRS working group for one more year.

Minutes of the meeting of the
Polarized Target Working Group
October 18, 1988

At the meeting of the Polarized Target Working Group, presentations were given on the status of polarized targets at TRIUMF and PSI and on plans for polarized targets at LAMPF.

George Burleson presented information on polarized targets at TRIUMF, based on material supplied by Greg Smith, TRIUMF. The group there consists of one full-time and two part-time physicists, with two full-time and one part-time technician. They operate two target systems, which are used in five target setups this year, a typical number. Both targets are of small volume, compared with most of those that have been used at LAMPF. They are of the frozen spin type and use butanol as the target material. One is a proton target which has been used primarily in neutron beams, and the other is a deuteron target. Typical values of polarization achieved have been about 80% for the former and 30-35% for the latter.

Gary Kyle presented information on the targets at PSI. The target group there consists of three staff physicists and two technicians, who are responsible for cryogenic and polarized targets. They use one basic target design, which is fairly compact and transportable and is again smaller than the targets generally used at LAMPF. Four copies of this design exist, with vertical and horizontal orientations of the superconducting solenoid. The auxiliary equipment for the operation of the targets is contained in three racks, which include the electronics, the gas handling system, and the vacuum pumps. The dilution cryostat has achieved 88% proton polarization and 43% deuteron polarization. Butanol, pentanol, and propanediol target material in the form of beads or solid slabs have been used. Irradiated $^{14}ND_3$ and $^{15}NH_3$ materials for a polarized nitrogen target are on site. A larger volume target system is currently being designed.

John Jarmer presented plans for the use of polarized targets at LAMPF for the next year or two. For 1989, an N-type polarized ^{13}C target will be installed at LEP for Experiments 1023/1025 (pion single charge exchange and elastic scattering), which will be in place for two running cycles. The polarized target group will also work on completing a new dilution refrigerator system, which can be used in either a horizontal or vertical configuration and can supply 100 mW of cooling, so that fairly large targets can be used with it. For 1990, a major project is preparation for the installation of a polarized ^{13}C target system at EPICS. This system will use the new dilution refrigerator and will require in addition a new magnet to provide a holding field for the frozen-spin target.

Jarmer also discussed new materials for polarized nuclear targets, all of which have been tested. These include $^{6,7}Li$ (in irradiated LiH or LiD, with achieved polarizations of 36% and 44% respectively), ^{11}B (chemical doping, with a polarization of 54%), ^{14}N (deuterated ammonia, irradiated, 20%), ^{15}N (irradiated ammonia, 12%), and ^{19}F (as F_3H_6O, with chemical doping, 80%). Proposals for the use of these targets are invited, but the the preparation for their use will require some development work, for which there is opportunity for user involvement.

Following this, there was a discussion of the request from Don Hagerman for suggestions of ways to accomodate reductions in the breadth of the LAMPF experimental program, in the light of expected budget cuts. Many ideas were brought up, but no general consensus was reached.

MINUTES OF THE LAMPF WORKING GROUP SESSION ON MATERIALS SCIENCE
October 18, 1988

Frank Clinard, LANL
Working Group Chairman

In attendance at this meeting were: R. D. Brown, MP-7; F. W. Clinard, Jr., MST-4; D. W. Cooke, MP-14; H. M. Frost, MST-4; and J. C. Kennedy, MST-4.

The Materials Science Working Group presently consists entirely of radiation effects people. It was pointed out that many LAMPF users in this technical area are stationed at overseas facilities and so could not attend this meeting.

Discussions at the Working Group meeting fell into two categories: reports from various investigators, and comments about the use of LAMPF as an irradiation source. In the first area, Bob Brown reported on his neutron irradiation studies of magnet materials for LAMPF applications, and expressed interest in doing more work utilizing neutrons. Studies would include both magnet materials and high-temperature superconductors.

Frank Clinard and Jim Kennedy described their ongoing experiment to make in-situ dc measurements of electrical properties of ceramic insulators for space reactor applications. The goal is to develop a functioning, low-noise irradiation capsule and insert that into the zone of intense neutron flux near the beam stop. Clinard and Kennedy currently have an irradiation capsule operating at 825°C, in the A-6 experimental area but out of the neutron flux. A modified version of the capsule will be inserted into the neutron flux prior to startup in the spring of 1989.

Wayne Cook reported on irradiation tests that he and his colleagues have carried out on high-temperature superconductors, using the proton beam. That team plans to continue such studies, using both protons and neutrons.

Hal Frost described an experiment, presently in the planning stage, that would involve in-situ measurement of ac dielectric properties of ceramic insulators. This work is in support of a fusion reactor project. The concept involves placing a high-frequency coaxial transmission line in the proton beam and measuring properties of an annular sample separating the center and outer conductors. It was suggested by Cooke and Brown that beam line B would be a good choice for this experiment, especially in its early stages.

The general discussion centered on LAMPF as a uniquely-appropriate irradiation facility. Benefits include the capability for conducting either proton or neutron irradiations, LAMPF's excellent accessibility compared with that for a fission reactor, large working volumes (especially for neutrons) and the choice of a high-intensity proton beam (line A) or a lower intensity beam (line B). Line B is especially useful for developing experiments prior to their being moved to line A, or for conducting irradiation tests of damage-sensitive materials such as high-temperature superconductors.

All participants expressed concern that LAMPF will operate on a shortened cycle next spring. Users from the materials science community, like other users, certainly benefit from having as much beam time as can be supplied.

Minutes of the Neutron Time-of-Flight Working Group

OCTOBER 19, 1988

Attendees:

E. Sugarbaker, Chair	Ohio State Univ.
T. Carey	LANL, P-2
R. Jeppesen	LANL, P-2
W. Sailor	LANL, P-2
W. P. Alford	Univ. of W. Ontario, TRIUMF
X. Chen	Univ. of Colorado
E. Gulmez	UCLA
A. Ling	LANL, P-3
J. Ullmann	LANL, P-3
P. Riley	Univ. of Texas
D. Prout	Univ. of Colorado
L. Rybarcyk	LANL, MP-10
T. N. Taddeucci	LANL, MP-10

Most of the time available for this working group session was taken up in a joint meeting with the HRS and NPL groups. During this joint session, representatives from MP division gave presentations of mutual interest to users in these areas. O. van Dyck reported on the progress made with OPPIS and that installation was proceeding such that polarized beam from OPPIS would hopefully be availabe to "friendly" users during the latter running periods in 1989. Only unpolarized beam would be available prior to this, due to the required removal of the Lamb-shift source. For 1989, it was suggested that 100-200 nA average intensity beam, polarized at 50-65% for 2 week periods might be expected. M. McNaughton presented his suggestions for dealing with polarimetry under OPPIS operation. His proposed spin cycles involved alternating 110 s discrete spin state and about 10 s unpolarized beam production. He also proposed taking the opportunity to change the previous "N,R" terminology to a less confusing "+,-" one. K. Jones reported on recent radiation safety surveys that had been made in Line X which indicated the need for improved shielding and personnel safety hardward (such as strategically placed ion chambers). Improvements were under consideration and the impact of such on user access to various areas while operating in nearby areas will be re-evaluated.

In the short time remaining for a separate NTOF working group meeting, E. Sugarbaker reviewed the significant progress which had been made at NTOF since last year's meeting. The success of the short-flight path study of E1061 at the end of Cycle 50 and the excellent energy resolution (almost 1 in 1000) obtained in E1062 using the full 617 m flight path during Cycle 52 are very encouraging. Addtional progress with regard to understanding the operation of the detector system via the tagged neutron calibration of E1052 and a recent polarimetry development run was also reported. A short discussion of the 1989 running schedule under OPPIS was initiated. Relatively little of the proposed physics at NTOF depends on unpolarized beam, leaving the 1989 program at NTOF heavily dependent on the initial performance of OPPIS. It was generally agreed that an optimistic tack should be taken and that proposals should be written/updated on the assumption of quality polarized beam being available by the beginning of Cycle 55.

MINUTES OF THE 1988 NPL WORKING GROUP MEETING

Participants

L. Agnew	MP-DO
R. L. Boudrie	MP-10
Manfred Daum	PSI
J. A. Faucett	New Mexico State University
R. Garnett	Argonne National Laboratory
G. Glass	Texas A & M University
E. Gulmez	University of California at Los Angeles (UCLA)
P. Harris	MP-7
R. H. Jeppesen	University of Montana
K. W. Jones	MP-10
Jim Knudson	MP-7
Kok Heong McNaughton	University of Texas at Austin
Mike McNaughton	MP-10
Peter Riley	University of Texas at Austin
A. J. Simon	Texas A & M University
H. Spinka	Argonne National Laboratory
G. E. Tripard	Washington State University
O. van Dyck	MP-DO

1) Area B Counting House

Plans for the Area B counting house were presented by Dick Boudrie. A 1500 square foot structure will be constructed immediately outside the MRS room. Space for 70 racks of electronics for MRS, HIRAB and a "stand alone" experiment in either BR or EPB will be available. In addition, two micro-VAX computers for data acquisition and polarized target controls will be located in this counting house. Bids are due by mid November, and the contract for construction is expected to be awarded in December. The estimated construction time of 4-5 months will result in a completion date close to the beginning of the 1989 run.

2) MRS Status

Dick Boudrie also described progress on MRS. Fabrication of many components is proceeding, and MRS is expected to be ready for beam next summer. Assembly of the magnets will begin in the next few weeks, as soon as the yokes and coils begin arriving. The scattering chamber is presently being designed. Initially, the focal plane detectors may include an upgraded JANUS polarimeter. Dedicated chambers and scintillators for MRS will be built for 1990 running after experience with rates and backgrounds is gained in 1989.

The initial commissioning of MRS will be with proton beams for a few weeks. However, it is uncertain whether this will occur in EPB (the MRS room) or in BR. It is hoped to run MRS for at least a week in BR with a neutron beam. This test will be important to understand backgrounds, since (n,p) studies are expected to represent an important component of the MRS program.

3) Beamline Magnets

Mike McNaughton discussed the need for new BR spin precession magnets for E-876 [Kij(np → np)]. The present magnets, Lorraine and Castor, have 3" gaps and are well matched to a 2" diameter neutron collimator, current polarized targets, and the MRS acceptance. However, E-876 could use a 6" collimator, which is easily accomplished by removing the collimator inserts from the existing gunbarrel. He has suggested widening the gap in Castor to replace Lorraine, and constructing a new solenoid with a 9" bore. The estimated cost would be on the order of $140K. The working group endorsed this plan, since it would substantially reduce the running time required for E-876.

Olin van Dyck discussed the possibility of replacing two superconducting, spin rotating solenoids in the polarized beamlines. Running time losses this past year were estimated to be 10% or less, but maintenance and operating costs are significant. Operating funds would not be used for the construction of these solenoids, unlike the case of the BR spin precession magnets. The working group supported a plan to replace the solenoids.

4) Cost Reduction Options

Various methods to reduce LAMPF operating expenses were considered by the members of the working group. It was noted that only three of the five polarized beam areas (BR, EPB/MRS, HIRAB, HRS, and NTOF) could run simultaneously. Thus, turning off one beamline would have little impact on operating costs. Savings would be substantial only for turning off P- altogether or reducing the number of support personnel. Kevin Jones also stressed the desirability of having more students living in Los Alamos and working on various facilities to lessen the need for some support personnel.

In a discussion of tradeoffs between reducing beam hours or duty factor, no consensus was reached. For some experiments, good duty factor is important to minimize the running period. For others, a longer running period is beneficial for debugging complicated apparatus and for taking into account overheads associated with polarized targets, etc. It was stated that HIRAB would prefer a reduction in duty factor rather than in beam hours. A reduction in duty factor at the beginning of a running period was considered a reasonable option to somewhat reduce operating costs.

In general, the working group members were anxious to fully utilize the many new facilities/capabilities just now becoming available - beam bunching and chopping, MRS, NTOF, and OPPIS. Thus there was little enthusiasm for a sizeable reduction in either beam hours or duty factor.

5) Joint NPL/NTOF/HRS Meeting

A joint meeting of the NPL, NTOF and HRS working groups occurred after the NPL meeting. Topics discussed included a new spin cycle suggestion for OPPIS by M. McNaughton, an OPPIS update by O. van Dyck and R. York, and a discussion of radiation problems in area B by K. Jones. These are summarized in more detail in the HRS working group report.

Mike McNaughton was elected unanimously as the next chairman for the 1989 NPL Working Group.

LEP Working Group Meeting

Oct. 18, 1988

Ralph Minehart, EFP Representative

Attendees: R. L. Boudrie(MP-10), Don Cochran (MPDO), Joseph Comfort (ASU), Will Foreman (MP-6), Steinar Hoiliraten (MIT), Jim Knudson (MP-7), Mike Leitch (P-2), John Zumbro (MIT-Bates).

The working group met at 2:30 P.M. R. Minehart reported on the activities of the Experimental Facilities Panel (EFP) since the last meeting of the working group. Mike Leitch was unanimously elected to be the new LEP representative to the EFP.

Jim Knudson reported on the status of the LEP channel. The previous running period was quite successful, despite some annoying problems with the channel equipment. A water leak developed in QD02, but before it could be repaired the water stopped leaking. This will be checked out during the present shut down. Efforts to eliminate ground faults in QD01/2 and BM03/4 will also be made. The beam stop, BL-1, also failed, in less than one year since its previous repair. Slits CL9,10 failed when it was attempted to use them in place of the beam plug. A new NMR system manufactured by Scanditronix is on order and will be installed during the current shutdown in BM03/4.

Jim Knudson also reported that the LEP cave will be enlarged to accomodate the use of LAS with the polarized ^{13}C target. This enlargement will include extension of the steel floor in the cave. Jim also reported that the enlargement of the cave would eliminate the test channel for next year.

The LEP counting house will undergo some improvements, such as repainting and installation of carpet. The air-conditioning of the house will be improved by replacing the three roof-mounted compressors and by some re-ducting. Several participants complained about the noise level in the counting house and various suggestions for reducing the noise level were discussed. The noise arises from the air conditioners, CAMAC crates and magnetic tape drives. Jim also told us that replacement of the counting house was unlikely.

The participants expressed continued support of the SCRUNCHER, of the polarized target group, and of the proposal for a new π^0 spectrometer. There did not seem to be any enthusiasm for the proposal to add a chopped beam capability.

In response to a request from Jim Bradbury, LAMPF response to a proposed 10% budget cut was discussed. Although it was not clear what a cut in "user services" would entail, the group generally felt that such cuts would tend to be counter productive in the sense of meeting the laboratory goal of maximizing the output of experimental physics research. Lower beam current would result in no direct savings. Lower duty factor would reduce the power costs, but there was little enthusiasm even for operating with lower duty factor for even a portion of the running cycle. Such operation would make coincidence measurements more difficult, and Jerry Peterson pointed out that it was directly contrary to the recommendations of the recent Eisenstein committee on the LAMPF program, which stated in its report that more emphasis should be placed on coincidence measurements.

The working group made the following recommendations: 1) There should be an increase in the support of secondary beam lines, with a staff physicist given responsibility for liaison with the users. This need not be a different person for each beam line. 2) The upgrade of the counting house was strongly supported. Attention to noise reduction was strongly urged. 3) The LEP computer continues to crash about once every two days. This problem should be solved. 4) The laboratory should provide maintenance of general purpose beam line apparatus, such as beam profile monitors and ionization chambers. Immediate attention should be given to the repair of existing beam profile monitors, many of which do not now work. The group believed that LEEP was not equiped to make these repairs, and that they should be done by technicians in MP4, MP5, or MP10.

Minutes of 1988 Nuclear Chemisty Working Group Meeting
18. October, 1988

Attendees List:

Gil Butler, INC-11
Dean Cole, INC-11
Malcolm Fowler, INC-11
G. F. Grisham, INC-11
Dawn Lewis, INC-11
Dave Moody, INC-11
Janet Mercer-Smith, INC-11
Louis Schulte, INC-11
Hardy Seifert, University of Giessen
Xiao-Lin Tu, Utah State University
Dave Vieira, INC-11
Jan Wouters, INC-11, Chairman
Xiao-Gang Zhou, Utah State University
Zong-Yuan Zhou, Nanjing University

Dave Vieira presented a summary of the activities supported by the nuclear chemistry section during the past year. The three counting laboratories were combined into two rooms to make space for a new detector laboratory. This laboratory will be used by Jerry Wilhelmy and Malcolm Folwer for detector development and testing. The proximity of this laboratory to the TOFI detector laboratory should be beneficial to both groups for future collaborative work.

All chemistry laboratories and the beta-gamma counter continue to be heavily used. Dave reported that seven groups had used the chemistry laboratories during the last year while eight had used various detectors supported by INC division.

Dean Cole from INC-11 gave a presentation on recent promising research directed towards the early detection and localization of lung cancer in humans. During a recent trip to Colorado, Dean and his collaborators ran a series of tests on uranium miners. They discovered that when porphyrin is mixed with saliva coughed up by a human the porphyrin will concentrate in cancer cells. Since porphyrin fluoresces the cancer cells can easily be detected even at a very early stage indicating that an individual has or will shortly get lung cancer. This technique is much simpler to administer than the only other technique (sputum analysis developed by Dr. Saccommano) now used for the early detection of lung cancer.

During the next several years Dean and his collaborators hope to attach a radioactive nuclide such as ^{67}Cu to the porphyrin. By administering this radioactively labelled porphyrin to a patient they hope to not only diagnose lung cancer, but to localize the cancer at an early stage so that it can be treated surgically. The only way to currently isolate the cancer is to wait (up to 8 years) until it can be seen in an x-ray by which time the survival rate is less than 10%. The ultimate goal is to actually treat the lung cancer in situ by attaching a radioactive nuclide to the porphyrin or related molecule that can destroy the cancer.

There was a lively discussion about cost cutting at LAMPF. Suggestions included: 1) reducing the average beam current down to 500 μamps, 2) having an extended low duty factor, low intensity beam at the beginning of each cycle for tuneup, and 3) being very conservative in the hiring of personnel at LAMPF. Cutting back in beam hours was not thought to be a viable solution and the nuclear chemistry working group strongly supported the efforts of the LAMPF management to find other areas for budget cutting. Concern was expressed over LANSCE's cost to LAMPF and the laboratory. The working group recommended that before the laboratory committed $10 million in internal funds to the fixing of LANSCE that the scientific merit of a full intensity LANSCE facility should be re–evaluated.

Finally, it was felt that a stronger effort needed to be made in achieving a balance between small and large experiments. Small experiments have historically been very productive at LAMPF and to concentrate too many experimental resources into just one or two large experiments would compromise the broad support that nuclear science has given to LAMPF and reduce its flexibility in attacking new, exciting topics.

A renewed interest in the AHF fostered by the NSAC long range planning effort was described and it was felt that a broadening of the justification should be explored. If asked, the nuclear chemistry community is interested in helping with the AHF planning and scientific justification. In particular, the Isotope Production group wanted serious consideration given to preserving the ISORAD facility in any new facility. This facility could be moved to a new dedicated beam line that comes off the accelerator at 100 MeV. Such a move would permit the front end of the accelerator to continue running for extended periods producing radioisotopes while the remainder of the accelerator was shutdown for maintenance or cost savings.

Finally, the topic of nuclear chemistry representation on the LAMPF Program Advisory Committee was brought up. Since Dr Norbert Porile recently ended his term of service on the PAC, the nuclear chemistry community is represented soley by Dr. Ralph Korteling whose term ends next year. The nuclear chemistry working group recommended that a new nuclear chemist should be nominated immediately to represent our interests and overlap with Dr Korteling before his term expired. Dr George Walker from Indiana University was nominated and he has indicated he would serve on the PAC. Though he is not a nuclear chemist, he has been on the INC Division visiting committee during the past three years and thus is very familiar with the direction of the nuclear chemistry community's programs. His physics expertise it was felt would help bridge the gap between nuclear physics and nuclear chemistry.

Neutrino Facilities Working Group

Peter Doe, Chairperson
October 18,1988

Attendance: Richard Allen, Felix Boehm, Robert Burman,
Peter Doe, Joey Donahue, Ali Fazely,
Gary Sanders, Vern Sandberg.

The Neutrino Facilities Working Group met at 10:50 in room D105. Brief presentations were given by representatives of E886 (Burman), E225 (Allen), E1015 (Sanders) and E645 (Fazely). There followed the election of a new EFP representative (and ν Working Group Chair). Consideration of how the Neutrino Users could best respond to the present financial pressures of the Lab. took place, followed by a free ranging discussion of the vitality and competitiveness of the future neutrino program at LAMPF.

Burman reported the status of E866, the calibration of the beamstop neutrino source. Pion production and decay had been measured in a well defined geometrical mock-up of the LAMPF beamstop. A Monte Carlo simulation of this experiment is in excellent agreement with the data. Having established the validity of the Monte Carlo, it was then used for a detailed simulation of the LAMPF beam stop, including the water degrader and the varying number of radio isotope production stringers. A significant contribution to pion production is attributed to the aluminum in these stringers. The final π^+/P ratio of ~ 0.09 776 MeV, includes a 30% enhancement of π production due to the effect of the water degrader and a "typical" stringer configuration. The neutrino production is now known to $\sim$ 6%. It was generaly agreed that to significantly improve upon this number would be a major undertaking. These results will be submitted to Nucl. Instr. and Meth. for publication in the near future.

Allen gave the final status report for E225. Now that the neutrino flux is known, this experiment can (at last!) publish its final results. These include an $\sim$18% measurement of the $\nu_e e$ elastic scattering cross section, based on 242 $\pm$ 49 events. We noted that BNL E734 has only 160$\pm$18 $\nu_\mu e$

and 97±14 $\bar{\nu}_\mu e$ events in their final sample. Until LCD turns on, this will be the worlds largest sample of $\nu_e e$ events. The interference between the charged and neutral currents in this reaction has been found, at a 3.5σ level, to be destructive - as predicted. A value of 0.2 was obtained for $\sin^2\theta$, the same as obtained by BNL 734, but lower than the world average of 0.23. The reaction $\nu_e + ^{12}C$ yielded 195±17 candidate events, giving a cross section in good agreement with theory. Like the $\nu_e e$ signal, this is both the first observation and a cross section measurement for this reaction. "Other physics", such as limits on oscillations, and electromagnetic properties of the neutrino are also being prepared. It is hoped that these results will all be submitted for publication by early '89.

The current status of E1015 (LCD) was presented by Sanders. They have had a busy year, having succesfully passed their Technical and Scientific Review (Barrish Committee) and a review by the Temple Committee of the cost estimates for the project. The proposal is now under consideration by DOE Nuclear Physics, with the possibility of major funding being avaliable in FY90. Meanwhile the R&D program continues apace.

Fazely gave the status of E645. Based on one year of data (5,100 C of protons on the beamstop), they find no evidence of oscillations for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$. Their limits of $\delta m^2 \leq 0.11$ eV^2 (for maximum mixing) and $\text{Sin}^2(2\theta) \leq 0.014$ rule out the region where BNL found possible evidence of oscillations. This years data is being analysed and the collaboration anticipates running for one more year, expecting to improve their current oscillation limits by a factor of ~3.

In a triumph for the Democratic Process (and arm twisting), **Richard C. Allen** from UC Irvine was elected as the new Neutrino Representative to the Experimental Facilities Panel (EFP). Dick has excellent credentials for the job, being involved with E225, LCD, and CYGNUS at LAMPF and the Sudbury Neutrino Observatory (SNO) in Canada. He may be contacted at RALLEN@UCIVMSA.

The Working Group considered the impact of the current financial difficalties of the Laboratory upon the neutrino program. Although a reduction in beam time may be unavoidable, it is vital to the future running of E645 that this be at the highest possible current in order to maximize the quality (signal to noise) of the data. A short duty factor is an additional advantage for neutrino operations. Apart from the above requirements, this experiment is essentialy parasitic. After the coming year, no neutrino experiments are anticipated to be taking data at the A6 Neutrino Facility. The next approved experiment is LCD which will operate at the PSR beam stop in approximately three years time. The Working Group was particularly concerned about possible consequencies to the R&D program necessary to ensure the success of LCD in a timely fashion. **It strongly recomends the continued and full support of this R&D program and access to the engineering and technical skills of the Laboratory. The Neutrino Working Group believes that LCD is the best technical expression of the neutrino program at LAMPF.**

The working group urges that the cosmic ray shielding and anticoincidence system associated with E225 be left undisturbed while it is being used by the CYGNUS experiment to study the muon content of high energy air showers.

Finally, a free ranging discussion of the competitiveness of the neutrino physics program at LAMPF took place. It was agreed that if LAMPF succeeds in providing a high flux, time separated neutrino source, as planned for the PSR, then the Laboratory has a unique opportunity to undertake world class physics. Aside from LCD, such experiments as coherent νP scattering and neutrino interactions with complex nuclei were considered as worthwhile goals which would require dedicated neutrino running at a PSR beamstop. Based on the findings of recent workshops, the future neutrino physics program at LAMPF appears to offer significantly more interesting possibilities than either the reactor or high energy neutrino accelerator sources.

MINUTES OF THE SMC WORKING GROUP

The stopped muon channel (SMC) working group met in room A234 of the LAMPF office building from 2:30-3:30 p.m.on October 18. The meeting was conducted by the chairman, Martin Cooper (MP-4). Other attendees were Dave Barlow (UCLA), Joe Donahue (MP-7), Martha Hoehn (MP-6), Cy Hoffman (MP-4), Gary Hogan (MP-4), George Kim (Texas A & M), Bjorn Mathias (Yale), Mike Paciotti (MP-DO), Carol Wilkinson (MP-4), Kim Woodle (Yale), and Klaus Ziock (Virginia).

Martha Hoehn discussed channel utilization for 1988 and 1989. The 1988 usage was broken down as follows: Yale-48%, MEGA-35%, catalysis-10%, and μSR-6%. It is expected that in 1989 the breakdown may be: MEGA-200 shifts, Yale-125 shifts, catalysis- 70 shifts, and μSR-25 shifts. The sum of these requests exceeds the 400 shifts of expected time by 5%.

Channel upgrades were discussed. The following suggestions were made:

1) The beam plug should be fixed. The work is under way.
2) The 30 second time delay between "keys returned" and "horn ready" should removed from the PSS system. It is annoying and serves no known useful safety purpose.
3) Cave "scram" switches should be moved farther away from the "reset" buttons to prevent accidental accelerator shutdowns.
4) MEGA would like new power supplies for its last quadrapoles. They are needed for only 250 amps or less, but must regulate well at 20 amps. The old PPA supplies work very marginally and are a maintenance headache.
5) There is a water leak into the counting house that can be fixed where runoff pours onto the cable tray, heading for the Yale trailer, and runs back into the counting house.
6) The input cooling water for the MEGA FASTBUS racks is hot (85°) and should be made to be cool.
7) It may be useful to have the emergency generator from BIOMED hooked up for use by catalysis and Yale.

A discussion of low intensity chopped proton beam ended with the conclusion that no SMC user had an immediate use for it.

At request of the LAMPF management, economy measures were discussed. All the suggestions from LAMPF seemed pretty unpleasant. The three possibilities that deserve further investigation were:

1) Scheduling periods of lower intensity or duty factor during the times when experiments are setting up. Return to normal production for data taking periods.
2) Leaving larger inter-cycle gaps so that experimental setup becomes more efficient and beam time is used more efficiently.
3) Retargeting of the proton beam on the A2 target leads to higher surface muon rates, thereby reducing the need for maximum proton flux.

It should be noted that the Yale group intends to use the old μSR chopper, a separator, next year, and the scheduling of experiments should try to avoid conflicts over this piece of equipment. If it is broken, it will need repair.

Tuesday, October 18, 1988

Minutes

P[3] WORKING GROUP MEETING

Attendees: Donald Cochran (MP-DO), Joey Donahue (MP-7), Donald Isenhover (Abilene Christian University), June Matthews (MIT) (Acting Chairman), Ralph Minehart (University of Virginia), Michael Oothoudt (MP-6), R. Jerry Peterson (University of Colorado), Glen Rebka (University of Wyoming), Michael Sadler (Abilene Christian University), Ivan Supek (Rudjer Boskovic Institute), Richard Verbeck (MP-7), John Zumbro (MIT)

1. Election of new Chairman/EFP Representative

Jerry Peterson (University of Colorado) was elected as the Experimental Facilities Panel Representative for the P[3] Channel. He will serve a two-year term beginning January 1, 1989.

2. Experiments run on P[3] during 1988 (brief reports)

Michael Sadler reported on a highly successful study of the $\pi^- p \to \pi^0 n$ reaction at forward angles in the momentum range 400-600 MeV/c (Exp. 849). The data will provide a precise test of isospin invariance. The pion flux was monitored both by beam counters and activation; the latter method yielded a 10% lower result than the former. This puzzle is under investigation.

Jerry Peterson reported on Exp. 917 which consisted of inelastic charge exchange measurements on eight target nuclei at three angles and three acceptances each, for pions of incident momentum 600 MeV/c.

John Zumbro reported on the elastic scattering and double charge exchange measurements (Exps. 1106 and 1107) performed with the dispersed beam and the Large Acceptance Spectrometer (LAS), and described some of the modifications to the spectrometer which have resulted in an improvement of the energy resolution to better than 1.5 MeV at 400-500 MeV. A muon rejector has been installed, and the use of isobutane (rather than Freon) in the threshold Cherenkov counter has produced a factor of two greater efficiency. The angular resolution (by traceback to the target) of the spectrometer is about 1.2°. Measurements were performed of the A-dependence of the (π^+,π^-) (DIAS) reaction at high energies; a relatively flat A-dependence was found, in contrast to the results obtained at lower energies at EPICS.

June Matthews reported on Exp. 978, a study of the $^4He(\pi^+,\pi^- p)3p$ reaction. A ^6Li target was used in a test run to evaluate the performance of a set of silicon and plastic proton telescopes in coincidence with the Little Yellow Spectrometer (LYS). Telescopes placed at 25° were found to be severely affected by beam halo (presumably muons); a scraper upstream of the target chamber will be installed for the next run. Matthews also reported on a short test run on Exp. 1026, in which the LYS was equipped with an array of surface barrier detectors, within the vacuum, at the focal plane. This experiment will detect the recoil ^{3}He particles in the ^{3}H(π^+,π^0)^{3}He reaction, using an adsorbed Ti^{3}H target. The purpose of this test was to measure the (π^+,^{3}He) background from Ti at incident pion energies at which no previous data are available.

3. High-energy, high-flux, good-resolution operation

Various steps are planned to enhance the capability of P^3 at high pion energies. New wire chambers and a vacuum (rather than helium) path will be installed in LAS, in order to reach an energy resolution goal of 1 MeV.

A set of jaws is being constructed which will limit the length of the A2 production target seen by the P^3 channel to the ~1 cm needed for high-resolution operation, while allowing the SMC channel to view the entire target length. It is hoped that these jaws can be installed for the 1989 running cycles.

4. Problems with operation of the channel

A few problems with the P^3 channel were reported. A water leak due to a hose coming off BM2 was easily fixed. The water leak in Q2 is not repairable; the magnet itself must be replaced. Components have been ordered and it is hoped that they will be assembled and operational before the start of running in 1989. Some non-operational jaw position readouts have been fixed. It is planned to replace the channel magnet power supplies and their controllers; standard DAC's will be utilized. This should answer the frequently heard complaints of hard-to-turn knobs and hard-to-read DVM. Several experiments have been adversely affected by the high (70°) temperature of the input water used for spectrometer magnet cooling; this problem is under investigation and it is hoped that a solution will be found before running recommences.

5. Schedule for P^3 in 1989

Present plans call for 2400 hours of running in 1989, to be carried out in three cycles between May and September. It is planned that LAS reside in P^{3}E during the first and third cycles. In the second cycle beam will be available for LYS in P^{3}W.

6. Future plans for P^3 channel

The P^3 channel at LAMPF provides a capability which is unique in the world for research with high energy pions. There are a number of high-priority proposals awaiting beam time. It is vital that this facility continue to receive optimal support from the Laboratory.

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October 17 - 18, 1988

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RESEARCH PROPOSAL ABSTRACTS

Prop. 1093 Search for double resonances using high-energy pion double charge exchange

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Recent data obtained from high energy (T_π = 300 → 500 MeV) DCX at P^3 indicate the existence of previously unobserved peaks at high excitation in the continuum region. The peaks are located at energies where the dipole-analog and double-dipole resonances are expected to appear. Evidence for the dipole-analog have been seen also using DCX at the EPICS spectrometer. We propose to further study the properties of these resonances using higher energy pions at P^3. This proposal is a part of a program to study double resonances in DCX, and should be considered as the High energy phase of proposal #1050 (at EPICS).

Prop. 1094 Extended angular range of S_{nn} measurements in ^{40}Ca

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Measurements of spin-flip probabilities (S_{nn}) in ^{40}Ca performed in Experiment 907 are complete and of high quality. These measurements, because one of the original motivations was to look for Ml strength in the continuum, cover only the angular range of 3°-12°. In the process of analyzing these data we have been looking also at the S=0 spectrum. The measurement of S_{nn} appears to provide an excellent way to remove the "background" which is a chronic problem in the study of S=0 giant resonances. The multipole analysis of our deduced S=0 spectra yields results for the giant dipole resonance (GDR) which are in excellent agreement with other measurements. The results for the giant quadrupole resonance are quite provocative but less definitive than for the GDR. The reason is the limited angular range as discussed in the proposal. We, therefore, propose to extend the angular range of the data to pursue this promising development in studying the multipole content of the S=0 continuum. Of course, new information on the S=1 spectrum will also be acquired which should provide information on spin resonances as well.

Prop. 1095 A search for T=2 dibaryons via a coincidence measurement of the $p(p,X^{+++})\pi^-$ reaction

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Recent data obtained from the pion induced double charge exchange reaction has provided evidence for particle stable states in the T=2 $pp\pi^+$ and $nn\pi^-$ systems using the $d(\pi^+,\pi^-)X^{+++}$ and $d(\pi^-,\pi^+)X^-$ reactions, respectively. Another reaction suitable for observing the X^{+++} ($pp\pi^+$) state is provided by the double pion production reaction $p(p,X^{+++})\pi^-$. We propose to study this reaction below the pion production threshold by detecting the π^- and the X^{+++} in coincidence. If X^{+++} candidates are observed the measurement will allow a determination of their lifetimes.

Prop. 1096 Study of $(\pi NN)_{T=2}$ bound system by $d(\pi^{\pm},\pi^{\mp})$

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Recent data obtained from the pion induced pion production reaction show evidence for particle stable states in the T=2 $pp\pi^+$ and $nn\pi^-$ systems using the $d(\pi^+,\pi^-)T^{+++}$ and $d(\pi^-,\pi^+)T^-$ reactions, respectively. Previous measurements were done using the Clamshell spectrometer at LEP, and later verified by remeasuring this reaction at the EPICS spectrometer. In both cases the background and counting rate were limiting factors. We propose to develop a spectrometer/channel system that will allow us to do the measurement about an order of magnitude more efficient than the last EPICS measurement. With the improved system we propse to further study the properties of these T^{+++} and T^- systems.

Prop. 1097 Single pion production in np scattering

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Prop. 1098 Energy dependence of low-energy double-charge exchange

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We propose measuring the energy evolution of both the DIAS and the non-DIAS transitions on the Calcium Isotopes and on ^{50}Ti and ^{54}Fe. These measurements will enable us to check the validity of the shell-model two-amplitude picture of DIAS transitions for low-energy DCX. With this model we can then separate the long- and short-range parts of the interaction by studying the latter learn about the underlying dynamics of the short-range N-N interaction. We also propose an exploratory measurement of the DIAS transition on ^{58}Ni with the intention of extending the measurement to other isotopes later.

Prop. 1099 Unpolarized differential cross section for proton-deuteron elastic scattering at intermediate energies

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Measurements of up to 25 spin-observables have been completed at certain bombarding energies corresponding to s $\cong$ 11, 11.4, 11.6, 12.2, 13 GeV^2. Reliable measurements of the unpolarized differential cross section $d\sigma/dt$ are generally not available at these energies. We propose to measure $d\sigma/dt$ at four of the bombarding energies referred to above in the interval $0 < -t \leq 1.0$ (GeV/c)^2 with a sufficient number of points to clearly delineate the dependence on -t (one bombarding energy in this proposal). The fractional statistical uncertainty on individual measurements will be ≤ 0.01, with an absolute fractional uncertainty as close to 0.02 as we can accomplish. Reliable values of $d\sigma/dt$ meeting the criteria noted just above provide a sensitive test of multiple scattering phenomenology and provide needed data to the data bank which is used or will be used in the future to determine the scattering amplitude experimentally.

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Measurements of the differential cross section, the analyzing power and spin correlation parameters for the np $\rightarrow$ ppπ^- reaction are proposed. The incident neutron energy ranges from 500 to 800 MeV. The LAMPF primary proton beam will be bunched. A polarized neutron beam (P $\approx$ 0.4) given by longitudinal polarization transfer from the LAMPF polarized proton beam bombarding a liquid deuterium target will be scattered in phase I from an unpolarized liquid hydrogen target, and in phase II from a longitudinally polarized, frozen spin, hydrogen target. Forward going reaction products will be detected in a large solid angle ($\approx 2\pi$) detector with multiple track capability. All three charged particles will be detected in a pair of cylindrical wire chambers and the energies of the protons will be measured using time of flight. Measuremen's will be made with S-, N- and L-type polarized neutron beams. Phase I allows us to measure the differential cross section and the incoming neutron single-spin observables. Phase II will be used to measure incoming double-spin observables and one proton single-spin observable as well as to remeasure the spin observables of phase I. The following spin observables will be measured.

<u>Phase I:</u>

$A_{S0} = (S,0;0,0) = A_{00;S0}$
$A_{N0} = (N,0;0,0) = A_{00;N0}$
$A_{L0} = (L,0;0,0) = A_{00;K0}$

<u>Phase II:</u>

$A_{SL} = (S,L;0,0) = A_{00;SK}$
$A_{NL} = (N,L;0,0) = A_{00;NK}$
$A_{LL} = (L,L;0,0) = A_{00;KK}$
$A_{0L} = (0,L;0,0) = A_{00;0K}$

These measurements complement existing NN $\rightarrow$ NNπ data providing information on the isospin zero channel and greater sensitivity to "nonresonant" channels.

Prop. 1100 Mass measurements of neutron-rich nuclei with Z=18-32

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We propose to measure for the elements argon through germanium the masses of ~ 4-6 neutron-rich isotopes beyond the known mass surface. These measurements (over 70 masses) will provide the basis from which to explore several nuclear structure/binding energy issues such as: (1) the existence/nonexistence of a new neutro-rich region of deformation near N = 32, (2) the inclusion of isospin in the description of nucleon pairing, and (3) the degree of stability exhibited by nuclei near the doubly magic nucleus ^{78}Ni. Mass surface systematics far from stability are essential to improving mass model descriptions; these in turn will lead to improved predictions of even more neutron-rich nuclei that are of importance to astrophysical calculations especially those related to the R-process. Refined calculations will eventually permit localization of the R-process astronomical environment.

Prop. 1101 A search for a possible (πN) bound system with pion double charge exchange reaction on a proton

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We propose to perform a search for a possible πN bound system by measuring pion double charge exchange reaction cross sections on a single proton. Recent studies of the $d(\pi^-,\pi^+)X^-$ and $d(\pi^+,\pi^-)X^{+++}$ were strongly indicative of the existence of a T = 2, πNN bound system. The presence of an attractive short-range π-N interaction could lead to such a bound state. However, if such a short-range π-N force exists, it could also lead to πN bound system. Therefore, we intend to investigate the possible existence of such an object. For these measurements, we plan to use the same setup that was proposed for the $(\pi NN)_{T=2}$ studies.

Prop. 1102 Study of pion double charge exchange reactions on Se isotopes

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We propose to measure forward-angle nonanalog 0^+(g.s.) $\rightarrow$ 0^+(g.s.) and $0^+ \rightarrow 0^+$ double analog transition cross sections for ^{74}Se, ^{76}Se, ^{78}Se, ^{80}Se, and ^{82}Se in the Δ_{33} resonance region. The relative magnitudes of the DCE cross sections for these nuclei can be of value in nuclear structure studies. For example it is interesting to find out if both, the ratios of double analogs and the nonanalogs for different isotopes scale the same way. The ratio of the nonanalog ^{82}Se(0^+, g.s.) $\rightarrow$ ^{82}Kr(0^+, g.s.) cross section to the previously measured ^{130}Te(0^+, g.s.) $\rightarrow$ ^{130}Xe(0^+, g.s.) cross section in ^{130}Xe is of special interest in $\beta\beta$-decay studies. Also, recent observation of $\beta\beta$-decay in ^{82}Se makes it more interesting now than even before to set limits on lepton number violation using the relation between the neutrinoless $\beta\beta$-decay rate and the forward-angle DCE cross section. These limits can be compared with similar limits obtained from different nuclear structure calculations, which happen to disagree from one another by as much as two orders of magnitude.

Prop. 1103 Measurement of the ratio of $(\pi^+, \pi^{+'})$ versus $(\pi^-, \pi^{-'})$ at T_π = 450 MeV on ^{13}C, ^{14}C and ^{15}N

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The best known research accomplishment of pion nuclear physics in recent years is the comparison $(\pi^+, \pi^{+'})$ with $(\pi^-, \pi^{-'})$ for various inelastic nuclear excitations on the $\Delta_{3/2,3/2}$ resonance at $T_\pi \simeq$ 164 MeV. These measurements have been mainly done at EPICS. Although the largest differences between $(\pi^+, \pi^{+'})$ and $(\pi^-, \pi^{-'})$ have been found in ^{13}C,[1] ^{14}C,[2] and ^{15}N,[3] measurements of neutron versus proton strength in the nuclear transition density has been measured for a large number of transitions in many experiments. The purpose of this proposal is to determine the feasibility of extending these measurements to the next pion-nucleon resonance, at $T_\pi \simeq$ 450 MeV. At this "Roper" resonance $(\pi^+, \pi^{+'})$ versus $(\pi^-, \pi^{-'})$ should be inverted from the situation at $T_\pi \simeq$ 164 MeV.

In past π inelastic scattering at the $\Delta_{3/2,3/2}$ resonance, comparisons of $(\pi^+, \pi^{+'})$ with $(\pi^-, \pi^{-'})$ have yielded results so remarkable that the theoretical ratio of 9:1 has even been exceeded. The explanation for this is destructive interference between the neutron and proton pieces of the transition density.

We would like to extend these successful measurements into the region of the next resonance in the πN system, which requires $T_\pi \simeq$ 450 MeV. Figure 4 shows the excitation function for πN scattering, and the known resonances are indicated in the figure.

The P^3 channel must be used to achieve this pion energy. The LAS spectrometer will be used to analyze the outgoing particle energies.

Prop. 1104 Study of the giant quadrupole resonance by high energy pion scattering

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We propose to measure cross sections for π^+ and π^- scattering to the giant resonance region in ^{40}Ca, ^{90}Zr, ^{118}Sn, and ^{208}Pb at incident pion energies of 350, 450, and 550 MeV. These measurements will be made on the P^3 beam channel using modified LAS spectrometer. The objective is first to measure the ratio of π^- to π^+ cross sections for excitation of the giant quadrupole resonance as a function of energy through the energy region where the isospin structure of the pion-nucleon interaction is changing and where the pion is less strongly absorbed than it is near the [3,3] resonance. The data will be used in a unified analysis including the existing resonance energy data. Such an analysis should be able to help separate reaction mechanism from nuclear structure effects.

Prop. 1105 $(\pi, \pi' p)$ Coincidence measurement above particle emission threshold

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The reaction $^4He(\pi^{\pm}, \pi^{\pm\prime} p)^3H$ has recently been investigated at EPICS. In the GDR region the $(\pi, \pi' p)$ double differential cross sections were found to be a factor of 20 times higher for π^+ than for π^- even though the singles spectra are nearly equal. More recent measurements give ratios of between 4 and 2 in the continuum region of ^{12}C and near 1 for ^{208}Pb. We propose measurements of this ratio on targets of ^2D, ^3He, ^{16}O, and ^{18}O. These measurements will help in separating reaction dynamics from nuclear structure and should help in developing a theory of the nuclear continuum capable of explaining this data.

Prop. 1106 Study of pion-nucleus elastic scattering at energies above the Δ resonance

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We propose to measure π^+ and π^- elastic scattering on ^{12}C, ^{16}O, ^{40}Ca, ^{48}Ca, ^{90}Zr and ^{208}Pb at 300, 400, 500 MeV, in the angular range 15 to 90 degrees. We will use these measurements to examine in detail the general expectation (based on microscopic potential models) that the effects of binding, Fermi motion, Pauli blocking, and distortions are small in this energy region. These measurements will also provide a quantitative handle on the isoscalar component of the optical potential, a necessary ingredient in the theoretical description of single- and double-charge-exchange reactions.

By comparing π^+ and π^- elastic scattering, we will investigate in detail the variation of the proton and neutron densities across a wide mass region, and also provide a data base for the study of the isospin structure of the pion-nucleus interaction (at these high energies) through pion inelastic scattering.

Prop. 1107 Studies of pion double-charge-exchange scattering at energies above the Δ resonance

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In Experiment No. 1028, successful measurements of cross sections for pion double-charge-exchange (DCX) scattering at energies between 300 and 550 MeV were carried out. Data on forward-angle excitation functions for several nuclei and on an angular distribution for one nucleus were produced, but further measurements in this energy region are needed to understand this process. We propose to carry out a program of such measurements. The results will give information on forward-angle excitation functions, angular distributions, and A dependencies, for T=1, T>1 and the T=0 nuclei. The theoretical analysis of these results will involve methods used for previous studies of DCX at lower energies, described in the proposal, as well as models appropriate to these higher energies. The total time requested is 1000 hours, with part in 1988 and part in 1989. For running after 1988, a new set of front-end jaws for P^3 channel will probably be needed.

Prop. 1108 The p(p,π^-)X^{+++} reaction – a search for T=2 dibaryons

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Recent data obtained from the pion induced double charge exchange reaction has provided evidence for particle stable states in the T=2 ppπ^+ and nnπ^- systems using the d(π^+,π^-)X^{+++} and d(π^-,π^+)X^- reactions, respectively. Another reaction suitable for observing the X^{+++} (ppπ^+) state is provided by the double spin production reaction p(p,π^-)X^{+++}. We propose to study this reaction below the double pion production threshold using the HRS spectrometer to observe the outgoing π^-, in an effort to verify the signature obtained in the pion double charge exchange reaction.

Prop. 1109 Pion-induced fission

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We request 114 hours with LEP to study π^+- and π^--induced fission cross sections using in-beam track detector methods. We will make detailed mass surveys in the actinides and near ^{208}Pb, a wide mass survey at one energy, and a detailed excitation function for a few targets.

Prop. 1110 Spin-isospin studies with a high-resolution neutral meson spectrometer

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With a new Neutral Meson Spectrometer capable of at least 0.3 MeV (FWHM) resolution, we propose to measure peak differential cross sections for isovector 1^+, 2^+ and 2^- multipolarities in the ^{6}Li, ^{12}C(π^-, π^0)^{6}He, ^{12}B reactions at beam energies from 80 to 300 MeV. For well-understood nuclear transitions, this excitation function will be sensitive to the delta-nucleus interaction as the beam energy is varied through the 3-3 resonance.

Prop. 1111 The ^{4}He($\vec{p}$, $\vec{n}$)^{4}Li reaction at 500 MeV

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Large discrepancies exist between the parameters describing the levesl of ^{4}Li and ^{4}H deduced from phase shift analyzes and three different nuclear reactions. The ^{4}He($\vec{p}$, $\vec{n}$) reaction should allow a direct determination of the level energies and widths for ^{4}Li. In addition, this reaction will allow a measurement of the isovector spin flip strength about which very little is known.

We propose to do the measurements in two phases. In phase one the unpolarized H beam at 500 MeV will be used to measure the differential cross sections for the (p,n) reaction on ^{4}He. In phase two, polarized P^- from the new ion source will be used to measure analyzing powers, and spin transfer variables for the ^{4}He($\vec{p}$, $\vec{n}$)^{4}Li reaction at the same energy.

Prop. 1112 Analog DCX on ^{48}Ca at 50 MeV

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It is pointed out that the measurement of 50 MeV analog DCX cross sections for ^{48}Ca will provide a crucial test of the dramatic predictions made by Auerbach, Gibbs, Ginocchio, and Kaufmann on the basis of a simple model which takes shell-model pairing-correlations into account. The unusual feature of these predictions is that at 50 MeV the differential cross sections for ^{48}Ca are expected to be almost isotropic. To test these predictions it is proposed to measure $^{48}Ca(\pi^+, \pi^-)^{48}Ti$ analog cross sections at a number of large angles.

Prop. 1113 The 12C(pi,pipp) reaction

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J. M. O'Donnell   J. D. Silk

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We propose to study the kinematic and isospin structure of the two step deep inelastic scattering and double charge exchange via the 12C(pi,pipp) reaction.

Prop. 1114 Production of tagged eta mesons by the reaction p + ^{3}H $\rightarrow$ ^{4}He + η

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We propose to measure the production of tagged eta mesons in the reaction p + ^{3}H $\rightarrow$ ^{4}He + η from threshold at 756 MeV to 800 MeV by detecting the recoil ^{4}He using the HRS facility. The objectives are: (a) to obtain the necessary data for the setup of a possible η factory at LAMPF of 10^3 tagged, monochromatic η's/sec, (b) to investigate the η-production mechanism in p-nucleus interactions, (c) to explore the means for vastly improving the mass measurement of the η which is known only to an accuracy of 0.6 MeV.

RESEARCH PROPOSAL ABSTRACTS

Prop. 1115 Characterization of high-temperature superconductors by muon spin relaxation

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The proposed utilizes muon spin rotation and relaxation (μSR) to investigate local magnetic behavior of high-temperature superconducting materials, $RE\mathrm{Ba_2Cu_3O_x}$ (RE=rare-earth), $\mathrm{YBa_2Cu^3O_x}$, and $\mathrm{YBa_2(Cu_{1-x}Zn_x)_3O_7}$. Some of the materials contain large electronic magnetic moments (Gd and Er, for example) which interact strongly with the relatively large muon moment (3.18 μ_B). For these systems one can investigate the magnetic behavior over a large temperature interval (3-300K in our apparatus); specifically one can probe the approach to magnetic ordering, and also the interplay between superconductivity and the local magnetism. Even for those systems that do not contain a magnetic rare earth (Eu, for example), it has been shown that Cu exhibits local moment behavior with magnitude $\sim 0.3\mu_B$, and in the case of $\mathrm{YBa_2(Cu_{1-x}Zn_x)_3O_7}$, the effective magnetic moment rises to 1.73 μ_B. Thus μSR is ideally suited to probe the magnetic behavior of these superconductors. Transverse field experiments will probe information on the superconducting state by measuring the local field and the width of the field distribution at the muon site; the increased magnetic field inhomogeneity due to the vortex state causes a large increase in the muon depolarization rate. From these measurements one can extract the magnetic field penetration depth as well as the superconducting electron carrier density, important quantities that are necessary for building a theoretical model which adequately describes these materials. Longitudinal and zero-field muon relaxation experiments will also be performed on the superconductors to examine the dynamics of the fluctuating magnetic moments.

Prop. 1116 Insulator research for space reactor

Spokespersons: F. Clinard

Determine the mechanisms by which electrical insulators in thermionic emitter power systems are degraded by high temperatures, electric fields, and neutron fluxes. Use this information to develop improved materials.

Prop. 1117 Interfering amplitudes in spin-isospin inelastic scattering at low pion beam energies

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We propose to use the superconducting scruncher cavity at LEP to provide enough beam flux to enable the clamshell spectrometer to measure the weak 1^+ and 2^- inelastic scattering cross sections in ^{12}C and ^6Li at a 65 MeV beam energy. Striking interference effects, constructive for $\Delta T=0$ and destructive for $\Delta T=1$, are predicted in DWIA calculations due to competing P-wave amplitudes at low beam energies. This will be demonstrated also by a limited excitation function at one angle. Our calculations indicate that uncertainties in the reaction model distortions will not obscure any influences of the nuclear medium to change the elementary amplitudes from their free-space values.

Prop. 1118 Isospin splitting of isovector resonances in pion double charge exchange

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In a previous work we demonstrated that the charge-exchange giant-dipole resonances built on the isobaric analog state (GDR⊗IAS) are observable in pion DCX although they are located at high excitation energy where background from DCX to the continuum is large. A detailed analysis of the GDR⊗IAS from the DCX study on ^{56}Fe shows that the resonance splits into three peaks, each observed to have a dipole angular distribution. The cross-section ratios of the members are in close agreement with isospin geometry arguments for an isovector excitation built on the isobaric analog state, giving a strong support for the identification of the three resonances as the isospin members of the charge-exchange dipole built on the isobaric analog state. The main object of this proposal is to measure the isospin splitting of this new mode of nuclear excitation on a few selective target nuclei with different isospins. They proposed study will also give a direct measurement of the isovector and the isotensor potentials of isovector excitations.

Prop. 1119 Unpolarized differential cross section for proton-deuteron elastic scattering at intermediate energies

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We propose to measure absolute proton-deuteron elastic scattering cross sections at 500, 600, 650, and 800 MeV to an accuracy of 2-3%. These measurements will cover an angular range of 30° to 130° (C.M.). The apparatus will be identical to that planned for Experiment 1072 except for a change of the target.

Prop. 1120 Coincidence study of two-step pion induced reactions

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Over the past year there has been a breakthrough in our understanding of pion absorption to four body final states. We propose to apply the lessons learned after three years of studying the (π^+,3p) reaction to the (π, πpp) reaction. Like the absorption channel, the two step pion scattering process constitutes a substantial portion of the π-nucleus cross section.

The experiment would use the LAS Spectrometer as the pion detector and the BGO Ball to detect protons. By taking advantage of a novel kinematic arrangement, many problems associated with detector acceptance and interpretation of results can be circumvented. The results will shed light on several puzzles which have been raised by inclusive (π^+,π^+) and (π^+,π^-) studies regarding the kinematic and isospin signatures of two-step pion scattering in the nucleus. We will show herein that problems associated with the LAMPF duty cycle and the muon halo do not preclude the acquisition of high quality multiparticle coincidence data with good statistics.

Prop. 1121 High excitations and double escape in the negative hydrogen ion

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The two-electron atoms He and H^- have served as prototypes for the spectroscopy of multiple excitations, much as the H^0 atom has historically served for single excitation. The mechanism for double escape near threshold has been called one of the most important outstanding problems in non-relativistic quantum mechanics.

The H^- ion can be studied with electron impact ionization or photodetachment. Photoabsorption has the advantage that it prepares the complex in a well-defined state whereas electron impact ionization prepares the state in a mixture of angular momentum states. Photodetachment also offers much better experimental energy resolution since it is difficult to prepare monochromatic electron beams.

Our colliding beam technique will be used to measure the relative cross section for the photodetachment of both electrons (photo-double detachment) from the negative hydrogen ion $\gamma + H^- \rightarrow H^+ + e^- + e^-$ as well as single detachment $\gamma + H^- \rightarrow H^0 + e^-$. The relative cross section for double detachment was first measured in our survey experiment in 1982. At that time we were restricted to the threshold region because a suitable excimer laser was not available. We now have an ArF excimer laser which will allow us to explore the photo-double detachment region up to 21 eV. The new HIRAB facility allows us to reduce the ion beam divergence from about 0.5 milliradian to below 10 microradians. We will also reduce the laser divergence using new optics and the ion beam energy spread using momentum bunching. These improvements will reduce our energy resolution in the threshold region from 7 meV to less than 1 meV.

Our survey experiment basically confirmed the Wannier threshold law but was also suggestive of oscillatory behavior. The publication of this data spawned several theoretical articles. The bumps in the data could possibly be produced by stray electric fields, as has recently been demonstrated for the photo-single detachment threshold, or by field ionization of Rydberg states. The present experiment will be carefully shielded and will have a means to apply a weak electric field.

The survey experiment also showed evidence for a series of new resonances converging on the n=6 level of hydrogen in a single detachment cross section. The analyzer magnet will be able to separate the resonance signal from the much larger nonresonant background by field ionization. The existence of a series of resonances below each threshold and their spacing and widths have been predicted by theory. These resonances will be carefully studied and a search will be made for other series of resonances.

Prop. 1122 Mass dependence of the giant dipole resonance built on the isobaric analog state

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In a recent work we reported the first observation of giant dipole resonances (GDR) built on the isobaric analogue state (IAS) in (π^+,π^-) double charge exchange (DCX) on ^{56}Fe, ^{80}Se, and ^{208}Pb. For even-even target nuclei these resonances have a single J^π value of 1^-. The angular distribution has a dipole shape and the excitation energies were found to be consistent with an $A^{-1/3}$ mass dependence. The study shows a unique feature of pion DCX in exciting giant resonances built on excited states. The main object of this proposal is to use pion DCX to gain more information on this interesting newly discovered resonance in nuclei, and examine the N, Z, and A dependence of the cross section. These measurements are unique to pion DCX and therefore they will help in giving more insight on the DCX reaction dynamics and the nucleon correlations in nuclei. We plan to do the experiment in two phases. In phase I, we will measure the DCX on ^{80}Se, ^{120}Sn, ^{138}Ba and ^{197}Au. In phase II, we indent to measure the resonance using ^{93}Nb, ^{128}Te, ^{130}Te and ^{139}La targets.

Prop. 1123 Measurement of Gamow-Teller strength in the ^{16}O(p,n)^{16}F reaction

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In this proposed experiment the $^{16}O(p,n)^{16}F$ reaction at 500 MeV will be used to measure the strength of Gamow-Teller transitions in a case where this strength is entirely due to particle-hole correlations in the target ground state. The measurment of Gamow-Teller strength in this particular reaction is also directly applicable to the calculation of $^{16}O(\nu_e,e)^{16}F$ cross sections which produce an important background in another proposed experiment: The Large Cherenkov Detector (LCD) proposal. It is expected that this experiment will set an upper limit of 0.5-0.6 for the summed B(GT) strength to states in ^{16}F up to an excitation energy of 40 MeV.

Prop. 1124 Measurement of correlated spin asymmetries and spin transfer observables in 800 MeV proton-deuteron elastic scattering using the medium resolution spectrometer with $\hat{N}$ and $\hat{S}$ type polarized deuteron targets

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Proton-deuteron elastic scattering spin observables will be measured using $\hat{N}$, $\hat{L}$, and $\hat{S}$ type 800 MeV proton beams. $\hat{N}$ and $\hat{S}$ type, vector polarized ND_3 targets, operated at full field and continuously pumped, will be used in the two phases of the experiment. The MRS will be used to detect the scattered protons and the MRS focal plane polarimeter will be used to measure the $\hat{N}$, $\hat{L}$, and $\hat{S}$ components of the polarization of the scattered proton. A second arm will be used to detect the recoil deuteron for $-t > 0.25$ $(GeV/c)^2$ when the $\hat{N}$ type, vector polarized target is used.

Prop. 1125 Pion elastic and inelastic scattering from self-conjugate nuclei at 180 MeV

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We propose to measure elastic and inelastic $\pi^{\pm}$ scattering from the self conjugate nuclei, ^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si, ^{32}S and ^{40}Ca. Special emphasis wil be placed on careful ($\simeq$2%) normalizations. Data will be taken at T_π = 180 MeV, and at laboratory scattering angles between 25° and 80°. These data will be used to provide more information about Coulomb induced isospin mixing in nuclei.

Prop. 1126 Two-nucleon pion absorption in ^4He

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We propose a program to study the isoscalar and isovector two-nucleon pion absorption mechanisms in ^4He at 500 MeV. The ^4He nucleus is the simplest in which all three of the following processes can be observed:

1. $\pi^+ + (pn)^3S_1 \rightarrow pp$: Quasideuteron absorption,
2. $\pi^+ + (nn)^1S_0 \rightarrow pn$: Dineutron absorption,
3. $\pi^- + (pp)^1S_0 \rightarrow pn$: Diproton absorption.

Quasifree kinematics, missing mass and recoil momentum analysis will be used to isolate the two-body absorption component from three- and four-body absorption. Central to this study are direct comparisons (where applicable) between ^4He and ^3He of the magnitude and shape of the angular distributions, measured under identical experimental conditions.

Our motivation is to see how pion absorption depends on differences which exist in the two-nucleon wave function between deuterium, ^3He and ^4He. Study of the above three reactions in the s-shell A=3,4 nuclei offers a simple and efficient means of generalizing this aspect of our knowledge of the two-nucleon mechanism. Large correlations predicted to exist in the ^4He ground state generate high momentum components in the wave function to which the above reactions are sensitive in various degrees. By performing this measurement at high energy with quasifree kinematics, we hope to enhance sensitivity to the short-range components of the two-nucleon system. Isoscalar absorption (1) can be compared directly to absorption on a free deuteron as well as those bound in ^3He, for which a previous LAMPF experiment measured a stronger than expected quaisfree yield at 500 MeV. The isovector reactions (2) and (3) are known to be insensitive to the ΔN interaction and may probe directly the short-range part of the NN potential where quark degrees of freedom are relevant. Direct comparison of the charge symmetric reactions (2) and (3) should reveal the effects of the Coulomb interaction between the absorbing pp pair. This study will complement similar pion absorption measurements planned at SIN, TRIUMF, and LAMPF at lower energies, where (ΔN) rescattering mechanisms are more important.

The P^3E channel will be tuned a pion energy of 500 MeV to provide comparison with previous measurements on ^3He. Further measurements on ^3He will also be necessary. A cryogenic liquid $^3He/^4He$ target will be used and the Large Acceptance Spectrometer (LAS) will momentum analyze protons in coincidence with protons/neutrons whose time-of-flight will be measured with an array of plastic scintillators. Absolute normalization and calibration of the apparatus will be provided by the $\pi p \rightarrow \pi p$ and $\pi d \rightarrow pp$ reactions CD_2 and CH_2 targets.

Prop. 1127 Multiphoton detachment of electrons from the H^- ion

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We propose to carry out an experimental study of multiphoton detachment processes in H^- using a crossed atom/laser beam technique. The H^- system is especially interesting because its simplicity could lead to detailed and quantitative comparisons of experimental data with theoretical models and predictions.

Multiphoton detachment of H^- has not yet been observed. The relativisitic beam at LAMPF allows great tunability of photon energy via the Doppler effect so that we may investigate various multiphoton processes in the H^-. By varying the angle of intersection of a CO_2 laser beam (lab photon energy 0.117 eV) with the H^- beam, we can vary the number of photons required to provide the binding energy (0.754 eV) of an electron to H^0. At 800 MeV, for example, the number of photons required for the detachment process ranges from 2 (laser beam nearly head on) to 22 (rear end collision). Calculations indicate that a focused CO_2 laser beam of some 10 GW/cm^2 (which is already in hand) should be adequate to observe multiphoton processes in H^-.

The experiment will have two phases. In the first phase we plan to measure 2, 3, 4, 5,... -photon detachment cross-sections as a function of the center-of-mass laser wavelength, polarization and intensity. A high energy H^- beam would be preferable for this phase to give us maximum range of tunability. In the second phase, we will study the angular distribution of electrons ejected from the H^- beam, allowing us to infer the center-of-mass energy distribution. In this way one can monitor "above threshold ionization" (ATI) processes in which the detached electron emerges after absorbing more quanta than the minimum required for detachment. A low H^- beam energy would be desirable for the second phase.

Prop. 1128 Effects of two-nucleon collectivity on double charge exchange

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We propose to measure forward-angle non-analog 0^+(g.s.) $\rightarrow$ 0^+(g.s.) and 0^+ $\rightarrow$ 0^+(DIAS) cross sections for ^{76,78,80,82}Se at T_π = 292 MeV and 164 MeV at EPICS and at 50 MeV at LEP. An additional three days will allow measurement of the DIAS cross sections on ^{128,130}Te at 292 MeV only. The aim is to look for enhancements arising from two-nucleon collectivity. Using information from two-nucleon transfer, we predict enhancement factors 1.5-2.8 over the simple expectations.

Prop. 1129 Search for neutral pions from the spontaneous fission of ^{252}Cf

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We propose to undertake an extended search for neutral pions emitted during the fission of ^{252}Cf. Preliminary studies of this phenomenon with the BGO Ball and with the π^0 Spectrometer indicate a possible signal consistent with a branching ratio of a few by 10^{-10}. Our intention is to run for a total time of about 60 days, with the time about equally divided between source in and source out. In this amount of time our maximum sensitivity is equivalent to branching ratio of about 3 x 10^{-12}.

Prop. 1130 Study of low energy pion double charge exchange reactions ^{128}Te$(\pi^+,\pi^-)^{128}$Xe(g.s.) and ^{130}Te$(\pi^+,\pi^-)^{130}$Xe(g.s.)

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We propose to measure forward-angle nonanalog 0^+(g.s) → 0^+(g.s.) double charge exchange (DCE) cross sections for ^{128}Te, ^{130}Te at $T_{\pi}{}^+ = 40$-80 MeV. Taken with data from earlier studies of 0^+ (g.s.) → 0^+ (g.s.) DCE on ^{12}C and ^{44}Ca, these data should permit a determination of whether A of (N-Z) dependence exist in nonanalog DCE transitions at low pion energies. Furthermore, the ratio of DCE cross sections for these two Te isotopes at low energy, where the pions probe the interior or the nucleus, would be valuable in $\beta\beta$-decay studies.

Prop. 1131 Measurements of polarization transfer for 800 MeV inclusive proton scattering at the MRS

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A complete set of spin observables D_{IJ} will be measured for 800 MeV inclusive proton scattering from ^{1}H, ^{2}H, and ^{40}Ca. Most of the data will be taken at a laboratory scattering angle of 20° over the energy loss region from about 25 MeV to 600 MeV. Statistical uncertainties will be typically ±0.025 for all D_{IJ} in 25-50 MeV bins. These high quality data will span the quasielastic and delta regions primarily to search for effects of the nuclear medium. Additional data will be taken for selected observables and energy losses at 11° and 30°, and for a ^{12}C target for comparison with previous work. The experiment also provides a broad initial test of the capabilities of the MRS.

Prop. 1132 Spin response in the $^4He(\vec{p},\vec{p}\,')^4He^*$ reaction at 500 MeV

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Spin-flip probabilities S_{nn} will be measured for inelastic proton scattering from ^4He at 500 MeV over the angular range from 5° to 30° in the laboratory for energy losses of about 20 to 50 MeV with the focal plane polarimeter at HRS. Preliminary spin-flip results (Exp. 938) for $^4He(\vec{p},\vec{p}\,')^4He^*$ at 500 MeV and 20° laboratory scattering angle suggest a significant enhancement of spin-flip probability over the free nucleon-nucleon scattering value even at a relatively large momentum transfer (370 MeV/c). In sharp contrast, spin-flip data from Exp. 741 measured at 345 MeV/c with 500 MeV protons on ^2H reveal essentially no difference from free NN scattering values. The present measurements on ^4He will provide some insight to the issue of enhancement of the nuclear spin response and perhaps determine the onset of spin collectivity in many-body systems. Total beam time requested is 214 hours.

Prop. 1133 Inelastic proton scattering from $^{182,184}W$ and the IBA model

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It is proposed to measure the angular distributions of cross-sections and analyzing powers for elastic and inelastic scattering of polarized protons from two tungsten isotopes $^{182,4}W$ at an energy of 650 MeV or less. In addition to analyzing the ground state rotational band, one of the main emphasis of this experiment will be to obtain the L = 4 direct excitation matrix elements to the three lowest 4^+ plates. It is hoped that this would illustrate the limitations of the simple IBA-1 model and suggest possible improvements to the model, such as inclusion of a single g-boson, importance of proton-neutron effects (IBA-2). Previous results from electron scattering for a ground state rotational band will also be helpful in this effort.

Prop. 1134 Spin response in transfer reactions at low q and high ω

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The goal of the experiment is to measure the $\hat{N}$ polarization for outgoing p, d, t and ^{3}He particles at $\theta_L = 7°$ and 3° from 650 MeV $\hat{N}$ polarized protons incident on C and Pb targets. Three MRS field settings will be used to cover an energy tranfer range, $\omega \sim 100$ to 500 MeV. The purpose of the experiment is to measure the spin-flip response in the continuum for inelastic proton scattering, and transfer reactions, and in particular to search for an enhanced response in the Δ-resonance region.

Prop. 1135 Feasibility study of tagged eta meson production in $p + {}^3H \rightarrow {}^4He + \eta$

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We propose to investigate the feasibility of tagged η mesons production in the reaction $p + {}^3H \rightarrow {}^4He + \eta$ near threshold by detecting the recoil ^{4}He using the HRS facility. The goal of the proposal is to obtain the necessary data in order to plan a more detailed program to study the rare and forbidden decays the η meson. The primary goal of the present proposal is to establish the rate of η production and to get detailed knowledge of the background in the tagged eta facility.

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