ORO-1316-184

Nuclear Structure at Intermediate Energies

Progress Report

G. C. Phillips

William Marsh Rice University

T. W. Bonner Nuclear Laboratories

April 1, 1974 - March 31, 1975

Prepared for the U. S. Atomic Energy Commission

Under Contract No. AT-(40-1)-1316

Project Abstract

During the year 1974 the program goals of carrying out experimental and theoretical studies in intermediate energy physics were continued.

The Rice University Portable Laboratory was at LAMPF until October, 1974, was at SREL until November, 1974, and then returned to Houston.

At LAMPF several experiments were accomplished: (1) completion of the tune-up of the P^3 pion beam; (2) the first phase of experiment 80: (a) π^+ small angle scattering from ^{12}C, ^{40}Ca, and ^{208}Pb, and (b) total cross sections; and (3) the first phase of experiment 81, pd → ppn two-arm coincidence studies of: (a) final state interactions and quasi-free scattering, and (b) pp → NNπ. Experiment 84 was initiated.

At SREL two experiments were carried out with a two-arm apparatus: (1) additional studies of pd → ppn and (2) initiation of pd → πdn studies.

During the year the PDP-11/20 was upgraded to PDP-11/45 and a new CAMAC readout system for multi-wire proportional counters was put in service.

Principal collaborators in this work were the University of Houston group.

Progress Report on Contract No. AT-(40-1)-1316, Task C

Rice University, Nuclear Structure at Intermediate Energies

Houston, Texas

Personnel working on the project during the year to March 31, 1975, includes the following:

G. C. Phillips, Professor and Director of the T. W. Bonner Nuclear Laboratories

S. D. Baker, Professor of Physics

I. M. Duck, Professor of Physics
V. Valkovic, Associate Professor of Physics
G. S. Mutchler, Assistant Professor of Physics

R. F. Guertin, Assistant Professor of Physics.

J. M. Clement, Jr. (Ph.D., Rensselaer Poly. Inst.) Research Associate

J. H. Gabitzsch (Ph.D., Univ. of Zagreb) Research Associate

N. D. Gabitzsch (Ph.D., Rice University) Research Associate

D. B. Mann (Ph.D., Rensselaer Poly. Inst.) Research Associate

T. R. Witten (Ph.D., Virginia Poly. Tech.) Research Associate

B. B. Chang (M.A., Rice University) Research Assistant

W. H. Dragoset, Jr. (B.S., Auburn University) Research Assistant

R. D. Felder (B.S., Texas A & M) Research Assistant

G. W. Pfeufer (M.S., University of Maryland) Research Assistant

T. M. Williams (B.S., Texas A & M) Research Assistant

J. A. Buchanan (B.S., University of Houston) Senior Research Engineer

W. P. Madigan (Georgia Tech. - no degree) Research Engineer

J. Windish, Technician

R. Miller, Lab Assistant

Sharon Ballard, Clerical Assistant

Genevieve Wright, Administrative Assistant

Physics Shop Personnel

Experiment in Intermediate Energy Physics

A. PION PHYSICS

B. NUCLEON PHYSICS

C. THEORY

D. APPLIED PHYSICS

E. INSTRUMENTATION

T. W. BONNER NUCLEAR LABORATORIES - RICE UNIVERSITY

A. PION PHYSICS

1. Pion Small Angle Multiple Scattering at Energies Spanning the (3,3) Resonance (Mayes, Lee, Allred, Goodman (Univ. of Houston); Mutchler, Hungerford, Scott, and Phillips (Rice Univ.)

   This work has been published in Nucl. Phys. A230, 515 (1974).

2. $\pi^{\pm}$-^{16}O Small Angle Scattering at 155, 180 and 213 MeV (Mutchler, Fletcher, Coulson, Hungerford, Gabitzsch, Phillips (Rice Univ.); Mayes, Lee, Goodman, and Allred (Univ. of Houston)

   This work has been submitted for publication in Phys. Rev. C.

3. Measurements of $^{12}C(\pi^+,\pi N)^{11}C$ and $^{19}F(\pi^+,\pi N)^{18}F$ Cross Sections Near the (3/2,3/2) Resonance (Hogstrom, Mayes, Lee, Allred, Goodman (Univ. of Houston); Mutchler, Fletcher, and Phillips (Rice Univ.)

   This work has been published in Nucl. Phys. A215, 598 (1973).

4. $\pi^{\pm}$-Total Cross Sections Around the (3/2,3/2) Resonance (Gabitzsch, Hungerford, Mutchler, Williams, Phillips (Rice Univ.); Mayes, Lee, Warneke, and Allred (Univ. of Houston)

Previous π^+ total cross section data on ^{9}Be, ^{12}C, ^{16}O, and ^{27}Al taken at the Space Radiation Effects Laboratory, Newport News, Virginia, have been published in Phys. Lett. 47B, 234 (1974). Additional π^+ data have been taken at LAMPF (Exp. 80) in conjunction with the $\pi^{\pm}$ small angle scattering experiments. The data were taken for π^+ on ^{12}C and ^{40}Ca at 120, 135, 150, 180, and 210 MeV pion kinetic energies. This data is currently being analyzed. When experiment #80 ($\pi^{\pm}$ small angle scattering on ^{16}O, ^{40}Ca and ^{208}Pb) resumes in 1975, π^- total cross sections will be measured.

5. Forward Elastic Scattering of Pions from Nuclei (Rice Univ. - Univ. of Houston Group*)

π^+ differential cross sections have been measured for the nuclei ^{12}C, ^{40}Ca and ^{208}Pb at energies of 100, 130, 160, 190, and 220 MeV, on the P^3 channel of LAMPF (Exp. 80). However, no data for ^{208}Pb was taken at 220 MeV. The range of measured angular distributions is from 5°-22°. At small angles (5°-10°) the interference of the nuclear and Coulomb potentials becomes measurable. The imaginary part of the elastic nuclear amplitude at 0° [Im $f_n(0°)$] is determined via the optical theorem from total cross section measurements (discussed in another section). From the nuclear-Coulomb interference and Im $f_n(0°)$ the real part of the elastic nuclear amplitude at 0° [Re $f_n(0°)$] is implied. Figure 1 is a drawing of the experimental setup. The

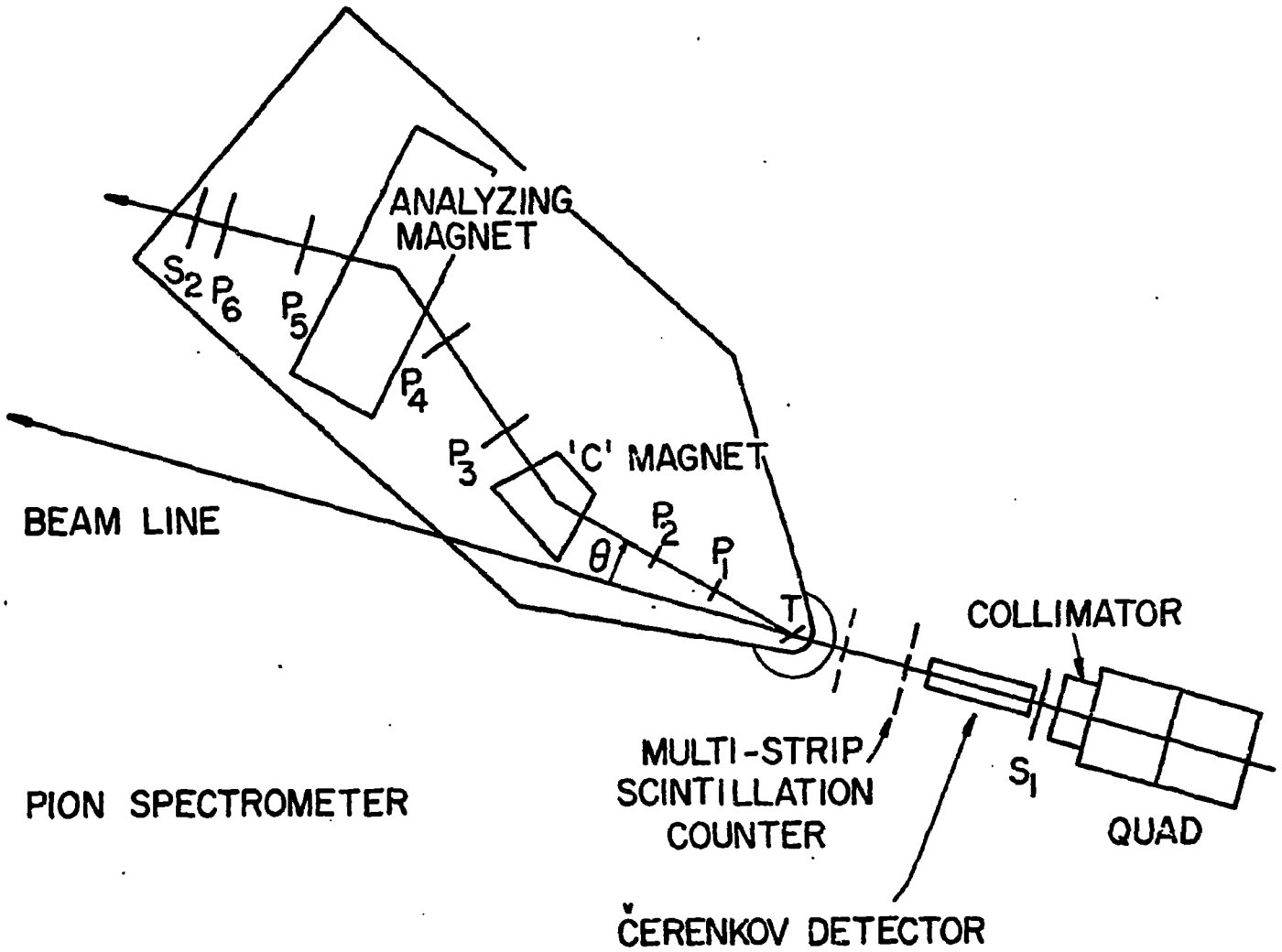
ANALYZING
MAGNET
S2 P6
P5
P4
P3
'C' MAGNET
BEAM LINE
P2
P1
θ
T
COLLIMATOR
MULTI-STRIP
SCINTILLATION
COUNTER
S1
QUAD
PION SPECTROMETER
ČERENKOV DETECTOR

Figure 1

incoming π^+ angle is measured by two multi-strip scintillation counters (MSSC) placed in the beam. Positron events are eliminated by a gas Cerenkov detector, while protons are degraded and absorbed in the P^3 channel. The muon impurity is measured by examining the decay muon spectrum with two multi-wire proportional counters (MWPC) placed to one side of the beam. Scattered π^+ angle and momenta are measured by a spectrometer consisting of six 2-dimensional (MWPC), one "C" magnet, and one "D" magnet. The effective solid angle of the spectrometer is 5° in width about a central setting. Thus, an angular distribution from 5°-22° can be measured with four spectrometer settings with each setting overlapping another. These data are now being analyzed. In the future π^- angular distributions will be measured at LAMPF.

6. Tune-Up of the LAMPF P^3 Pion Beam (Rice Univ. - Univ. of Houston Group*; R. Macek (LAMPF))

The group carried out the tune-up of the P^3 pion channel at LAMPF during the early months of 1974. This was done by placing multi-wire counters in the channel and tracing the orbits of particles. These measurements were successful and now allow confident use of the channel. Two publications are being submitted to Nuclear Instruments and Methods covering this work.

*University of Houston Personnel
M. Warneke
D. Lee
J. Gabitzsch
B. Mayes
E. Hungerford
J. C. Allred

Rice University Personnel
D. Mann
N. Gabitzsch
T. Williams
T. Witten
G. Mutchler
R. Felder
G. C. Phillips

B. NUCLEON PHYSICS

1. Neutron-Proton Final State Interaction in p-d Breakup at 600 to 800 MeV (Rice Univ.-Univ. of Houston Group*)

The reaction d(p,pp)n was studied using a LD_2 target at 800 MeV at LAMPF (Exp. 80) and at 600 MeV at SREL (Exp. IC-523). The setup is shown in Figure 2, which is similar for both experiments. The angle of each proton was measured with good resolution with multi-wire proportional counters (MWPC) P1-P6. Scintillation counters S1-S4 were used for fast timing. The momentum of one proton was measured by a broad band magnetic spectrometer, as was the time-of-flight of both. The magnetic field and counter angles were chosen so that the final state interaction between the neutron and one of the protons could be observed. An enhancement in the spectrum was observed for proton-neutron relative energies less than a few MeV. This peak is shown in some very preliminary results contained in Figure 3. Five angle combinations were observed at 800 MeV and two at 600 MeV. This research is a continuation of our earlier work which was published

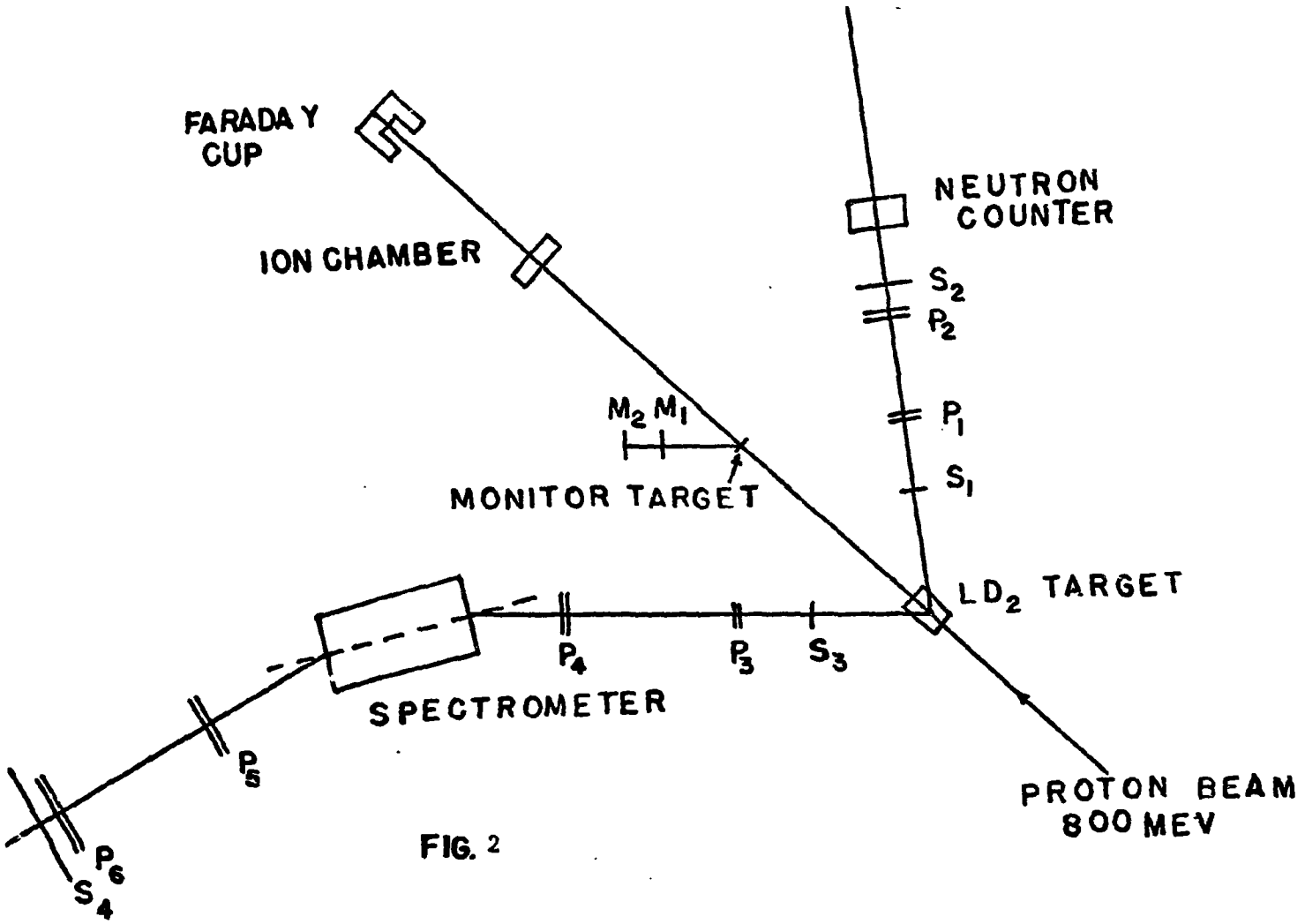
FARADAY CUP
ION CHAMBER
NEUTRON COUNTER
S_2
P_2
M_2 M_1
P_1
MONITOR TARGET
S_1
LD_2 TARGET
P_4
P_3
S_3
SPECTROMETER
P_5
PROTON BEAM 800 MEV
P_6
S_4

FIG. 2

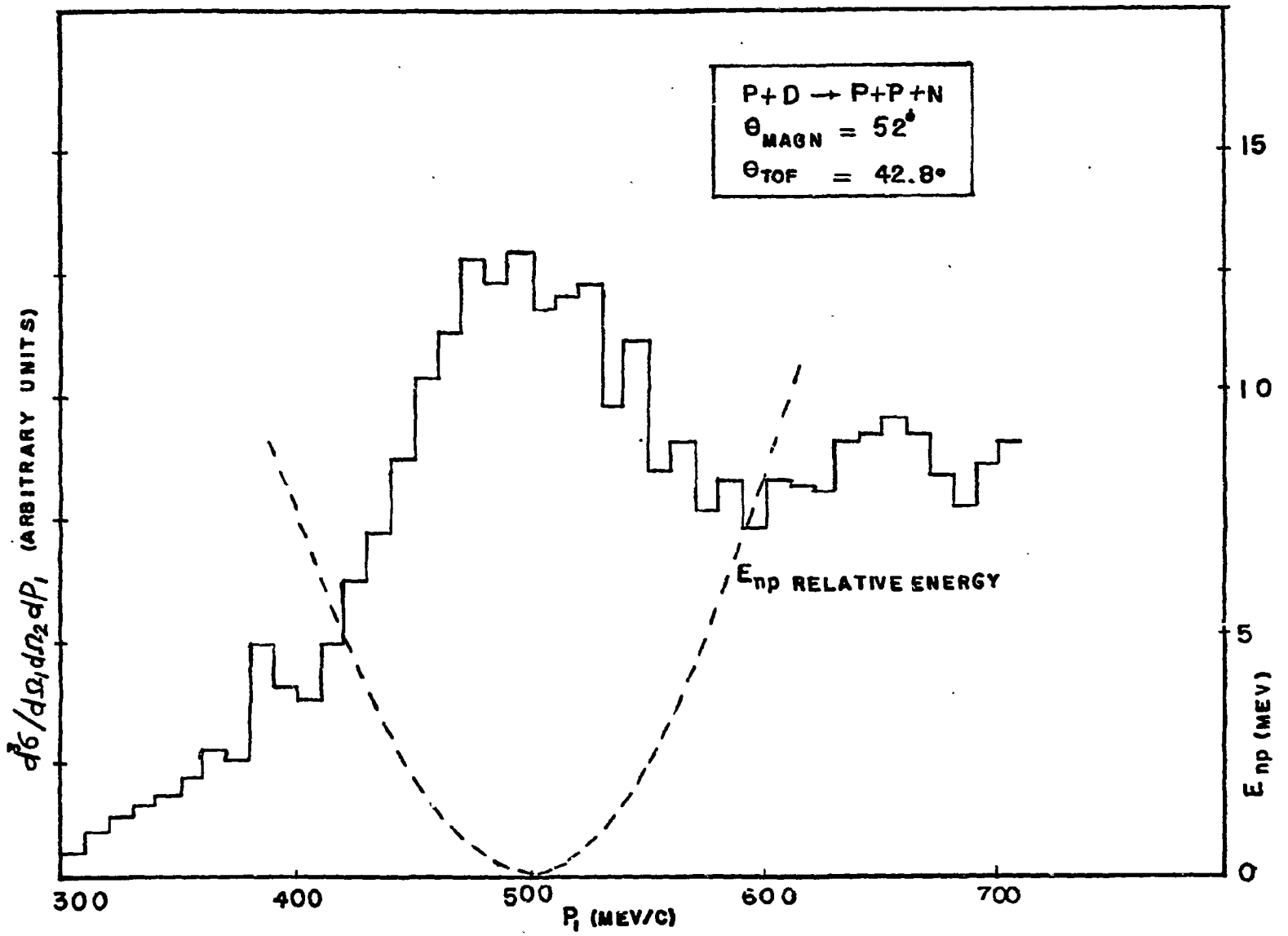
P+D → P+P+N
θMAGN = 52°
θTOF = 42.8°
Enp RELATIVE ENERGY
d²σ/dΩ1dΩ2dP1 (ARBITRARY UNITS)
Enp (MEV)
P1 (MEV/C)
300
400
500
600
700
0
5
10
15

FIG. 3

in Physics Letters (Physics Letters 47B (1973) 241). Analysis of the data has started.

2. Quasi-Elastic Deuteron Breakup by Protons at 600 and 800 MeV (Rice Univ.-Univ. of Houston Group*)

Using the same apparatus described above, the quasi-elastic breakup of the deuteron by protons was observed at LAMPF (Exp. 81) and at SREL (Exp. IC-523). A strong peak, shown in Figure 4, was observed around the region of phase space corresponding to free proton-proton elastic scattering. In addition, there was a large neutron counter behind the non-magnet arm, so that n-p coincidence data could be taken in addition to p-p coincidence data. The neutron data is discussed in the instrumentation section below. Data was taken for six symmetric angle combinations and for four other combinations. A paper has been prepared on the earlier 600 MeV results and the later 600 and 800 MeV data are being analyzed.

3. Pion Production from Proton-Proton Collisions at 800 MeV (Rice Univ.-Univ. of Houston Group*)

The reaction $p(p,p\pi^+)n$ was observed at 800 MeV at LAMPF (Exp. 81). The momentum of the pion was measured by a magnetic spectrometer. The time-of-flight and angles of both the proton and pion were also measured. Measurements were taken at four angle combinations. The momentum spectrum displayed a peak at the position for which the p-π relative energy was 150 MeV, as can be seen in Figure 5, which is very preliminary data. This corresponds to the center of the (3/2,3/2) resonance. Data were also taken for the reaction $p(p,pp)\pi^0$. Both protons were detected. This data is under analysis.

4. Pion Production for p-d (Rice Univ.-Univ. of Houston Group*)

An investigation of the proton induced pion production from deuterium has begun as a parasite to IC-523 at SREL. Data have been taken at SREL at 600 MeV in a complete kinematic experiment for the reactions:

$$p + d = d + \pi^+ + n$$
$$p + d = d + p + \pi^0$$

In particular the reaction $p + d = d + \pi^+ + n$ shows an enhancement (see Figure 6) of the cross section corresponding to the (3,3) resonance of a pion in the deuteron. Analysis of the data is continuing and will lead to publication shortly.

*Rice University Personnel

T. Witten
T. Williams
M. Furic
D. Mann
G. Mutchler
J. Gabitzsch
N. Gabitzsch
J. Clement
R. Felder
G. C. Phillips

University of Houston Personnel

B. W. Mayes
E. V. Hungerford
D. Lee
M. Warneke
J. C. Allred

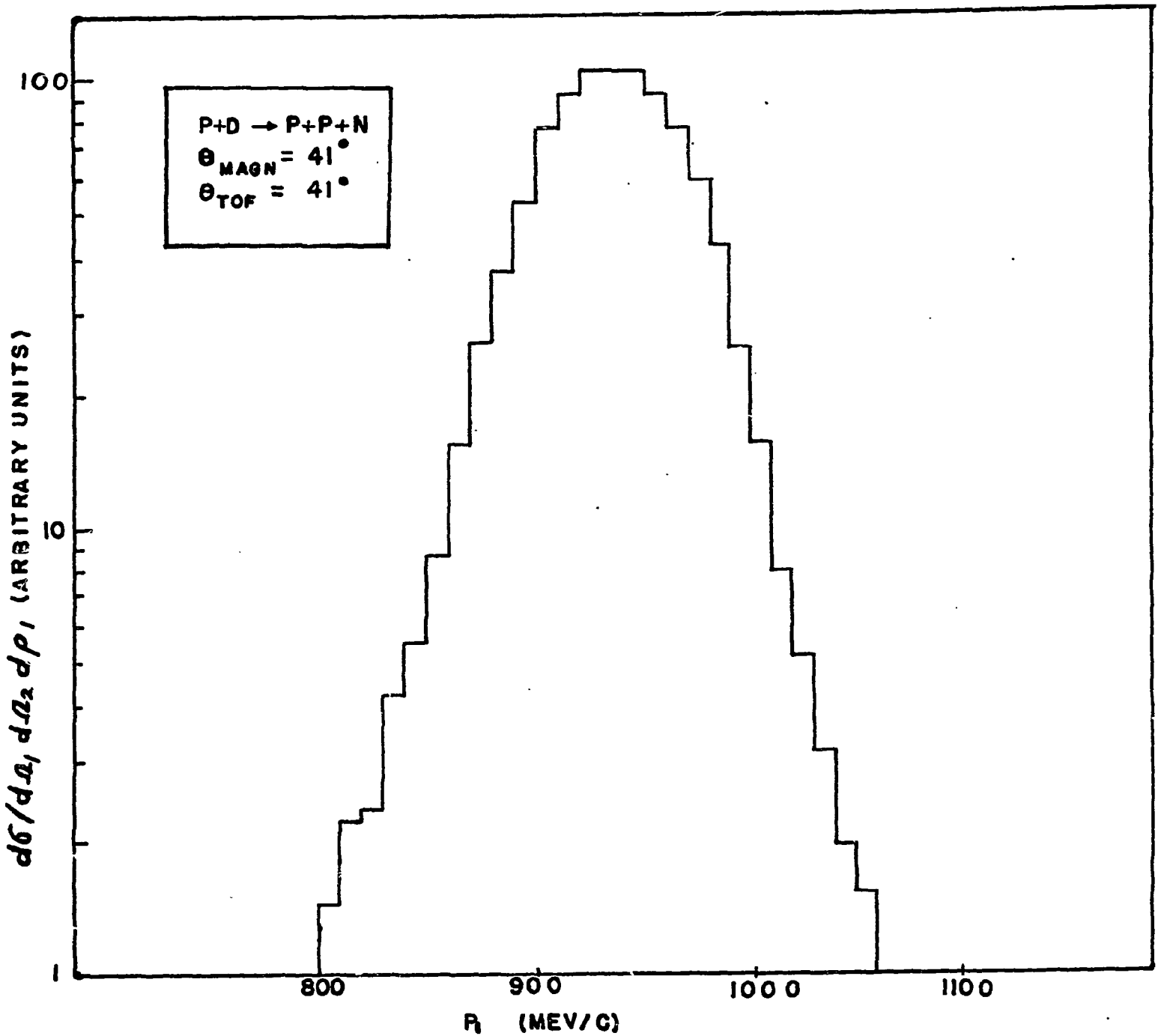
P+D → P+P+N
θ MAGN = 41°
θ TOF = 41°
100
10
1
800
900
1000
1100
dσ/dΩ1 dΩ2 dp1 (ARBITRARY UNITS)
P1 (MEV/C)

FIG. 4

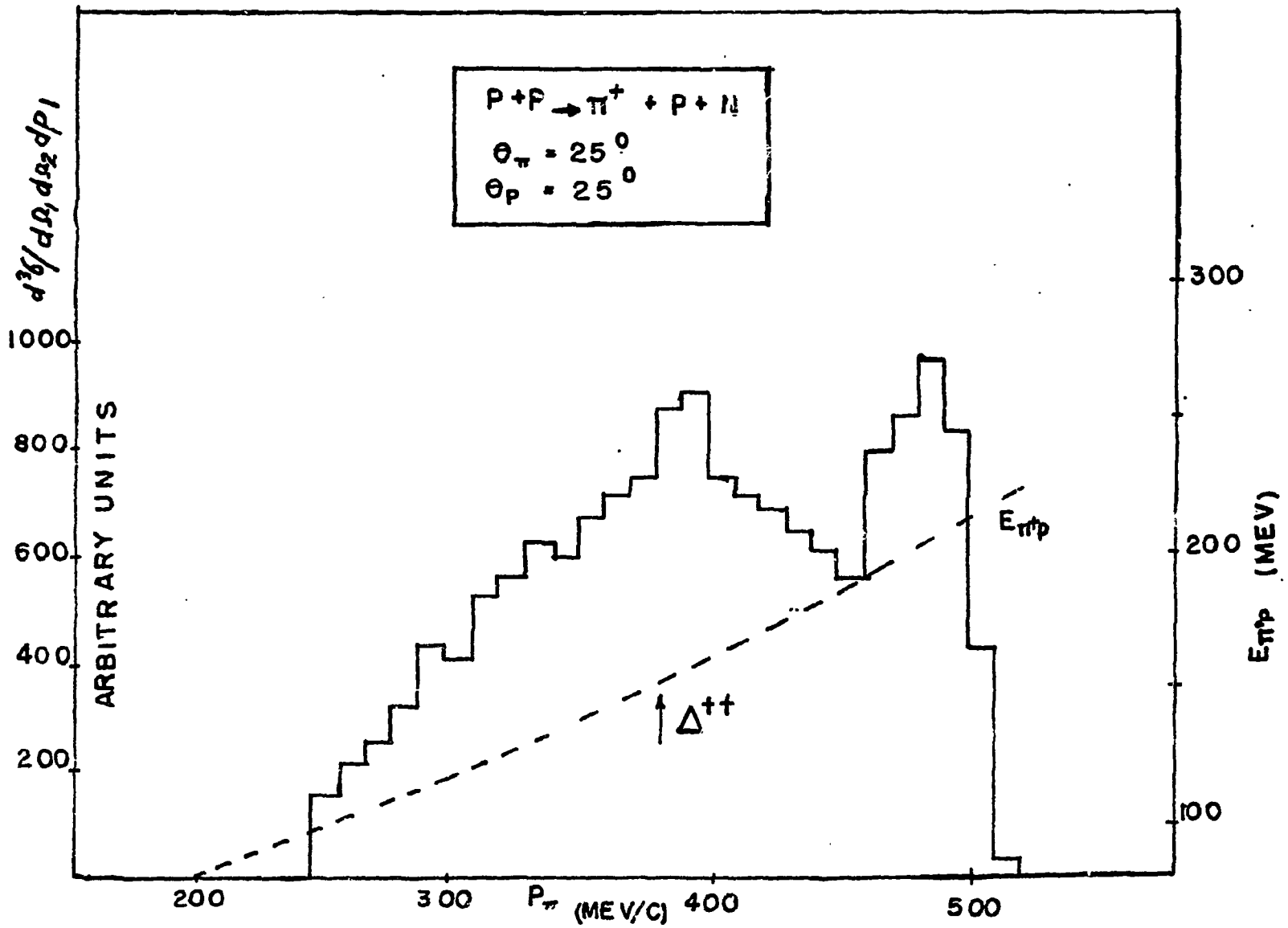
P + P → π⁺ + P + N
θπ = 25°
θP = 25°
d³σ/dΩ1 dΩ2 dP1
ARBITRARY UNITS
1000
800
600
400
200
300
200
100
Eπ'p (MEV)
Eπ'p
Δ++
200
300
Pπ (MEV/C)
400
500

FIG. 5

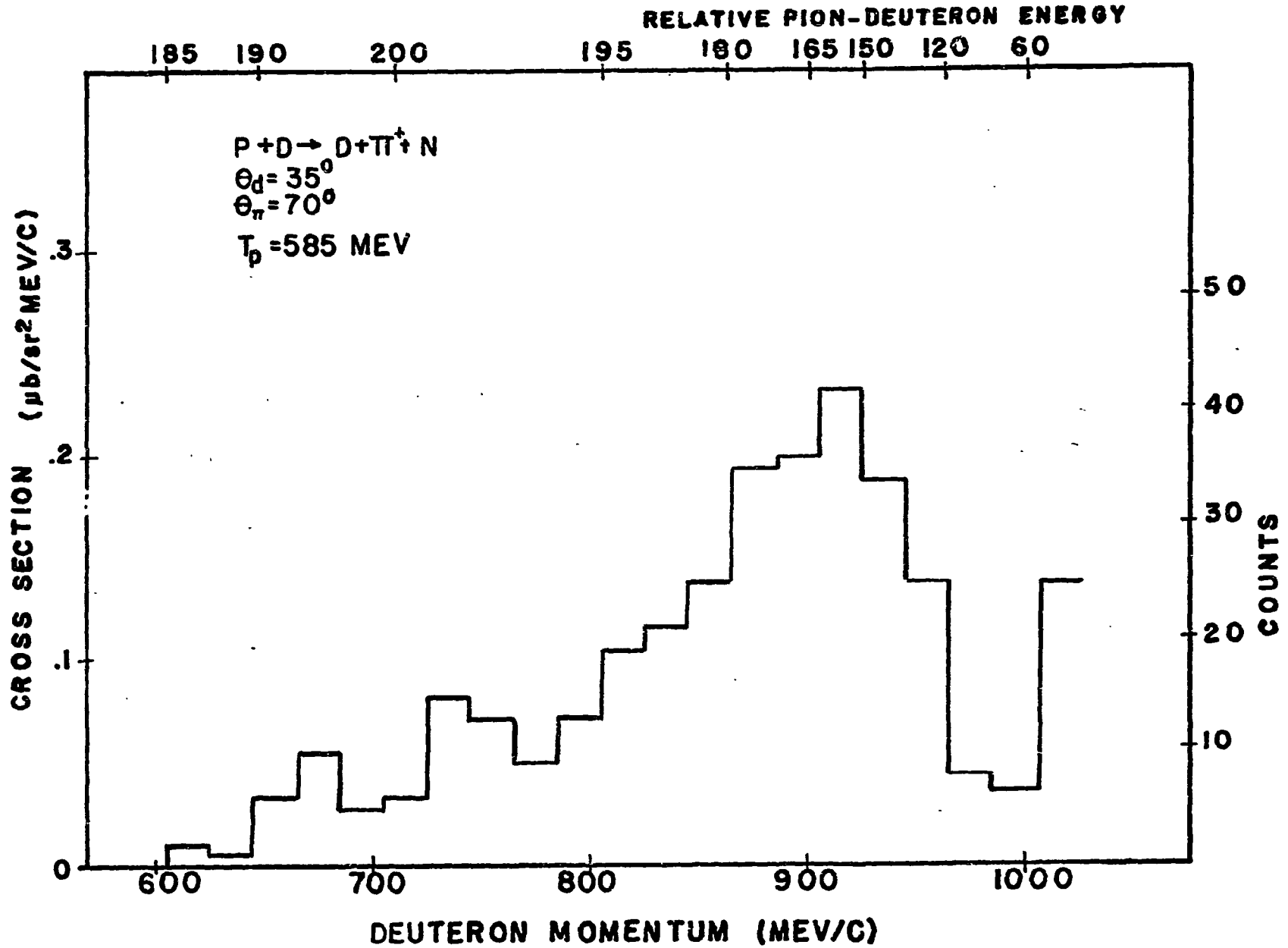
RELATIVE PION-DEUTERON ENERGY
185 190 200 195 180 165 150 120 60
P + D → D + π+ + N
θd = 35°
θπ = 70°
Tp = 585 MEV
CROSS SECTION (μb/sr² MEV/C)
.3
.2
.1
0
50
40
30
20
10
COUNTS
600 700 800 900 1000
DEUTERON MOMENTUM (MEV/C)

Figure 6

C. THEORY

1. Relativistic Hamiltonian Equation for Any Spin (R. Guertin)

A general formalism has been developed for 2(2J+1)-component Poincare-invariant Hamiltonian theories that describe free particles of definite mass and spin and that are subject to the conditions (a) every observable is either Hermitian (i.e., $\theta = \rho_3\, \theta^+\, \rho_3$) and (b) the theory is invariant under the discrete symmetries. All relations between the Hamiltonian H and the operator Γ that are both necessary and sufficient for $\kappa = \frac{1}{2}[\chi_1 H]_+ + \Gamma$ to generate Lorentz boosts have been found. Examples generalizing the Dirac and Sakata-Taketani equations to arbitrary spin have been given. [To be published in the Annals of Physics (N.Y.) 88 (1974)].

2. Foldy-Wouthuysen Transformation for Any Spin (R. Guertin)

The generalized Foldy-Wouthuysen transformation for any Hamiltonian theory of the above type has been found. The requirement that the Hamiltonian be defined in the rest frame specification and only one boost generator that is also defined at p = 0. [Submitted to Annals of Physics (N.Y.)].

3. Relativistic Hamiltonian Theories in an External Electromagnetic Field (R. Guertin)

The properties of a relativistic Hamiltonian theory when an external field is present are being investigated, in particular, the algebra that replaces the Lie Algebra for the free particle theory. Special attention is being given to the spin-1 Sakata-Taketani Hamiltonian.

4. Linear Wave Equations and Hamiltonians for Higher Spins (R. Guertin)

We are investigating the relationship between linear wave equations describing particles of a definite mass and spin, and the corresponding Hamiltonian. It is believed this will be relevant to the matter of understanding why all attempts to introduce an external electromagnetic field in manifestly covariant theories for spins J > 1 have led to non-causal effects.

5. Equation Describing Spin-½ Bosons (R. Guertin)

We are completing and preparing for publication our work on a free particle equation describing spin-½ bosons.

6. Glauber Model for Pion-Nucleus Scattering and Electromagnetic Interference (R. Guertin and B. Chang)

We are investigating the problem of taking into account corrections for the interference between the strong and electromagnetic

interaction in pion-nucleon scattering when the Glauber model is employed. We hope, in particular, to be able to investigate the neighborhood of the 3-3 resonance.

7. Role of the Δ-particle in Medium Energy Physics (I. Duck and J. Brown)

We have been studying a number of problems involving the role of the Δ_{1236} (3-3 pion-nucleon resonance) in the interactions of pions with light nuclei. One problem that has resurfaced is the question of ΔN bound states or resonances due to resonant pion exchange. This problem has been discussed before (Duck and Gale, Nuclear Physics B8 (1968) 109), but now Arenhovel (Physics Letters 49B (1974) 329) using a different calculational method has obtained opposite conclusions. It is our conclusion, soon to be published, that Arenhovel erred in two respects, using a static potential to describe the pion exchange and neglecting to antisymmetrize the two nucleon wave function, and that the partial waves which resonate in his model are in fact repulsive, as in our original calculations using the Faddeev equations. This study has led us to an examination of the Foldy-Walecha multiple scattering formalism (Annals of Physics 54 (1969) 447) in order to get some simple, analytic results in the πNN scattering problem and to determine the effect of nuclear binding on the location of the resonance energy. We obtain simple results (that the resonance in even partial waves is shifted to lower energies, that in odd partial waves to higher energies) in the case of an S wave πN resonance. The realistic case of a P wave resonance has proved much more difficult. Numerical work on this problem is still in progress and will constitute Brown's M.A. thesis in May, 1975 when we hope also to have some approximate analytical results which should clarify the resonance structure of elastic and inelastic pion-deuteron scattering, discussed numerically by Myhrer and Koltum (Physics Letters 46B (1973) 322).

D. APPLIED PHYSICS

1. Quality of Meson Radiation Fields (LAMPF Exp. 84) (G. Pfeufer, G. C. Phillips (Rice Univ.); M. C. Taylor (Columbia Scientific Industries); G. Oliver (Washington School of Medicine); W. Grant (M. D. Anderson Hospital); and J. C. Allred (Univ. of Houston)

Utilizing microdosimetry techniques, particle specific linear energy transfer (LET) spectra for the pion beam at the LAMPF biomedical facility are currently being measured. Specific LET spectra are obtained by making LET measurements coincident with a time-of-flight particle identification (π,μ,e) prior to incidence on a liquid tissue-equivalent (L. J. Goodman, Health Physics 16 (1969) 763) phantom. The channel tune used was that developed for human therapy. Data were taken at the pre-Bragg peak full width at half maximum point in the T-E phantom. The necessary analysis of the data is currently being performed. The experiment will measure particle specific spectra at several points along the central axis of the therapy beam: the Bragg peak, the two FWHM points of the peak, the plateau near the surface, the plateau near the tail of the peak, and post peak.

2. Treatment Volume Visualization (Approved Exp. 83 at LAMPF)

No work has been done on this experiment during this past year.

E. INSTRUMENTATION

1. CAMAC Readout of Multi-Wire Counters (J. A. Buchanan)

Construction of a new CAMAC MWPC readout system* was completed. The new system was installed in the Rice Portable Laboratory on site at LAMPF where it was used in the experiment #81 and later experiment #IC-523 at 3REL. Also testing and final assembly of 25 new MWPC amplifier cards (400 wires) was completed.

*CAMAC MWPC Readout System with Event Selection Logic, J. A. Buchanan, to be presented at 1974 Nuclear Science Symposium, Dec. 11-13, 1974.

2. PDP-11/45 Hardware and Software Changes (J. Buchanan and D. Mann)

During the year the PDP-11/20 was upgraded to a PDP-11/45 and the data capture software was upgraded.

3. Frequency Domain Measurements of Particle Fluxes (W. Dragoset and G. C. Phillips)

The problem of determining the time-of-flight spectrum of a particle flux has been approached from the view of signal theory. The results suggest that in some cases it is more reasonable to find the time-of-flight using a frequency domain measurement to replace the standard time domain methods. To test this idea on a pion beam at LAMPF, the following experiment has been set up: a Cerenkov detector placed in the beam produces light which is focused onto the photo-cathode of an image converter tube whose electron beam is swept in a circle at a rate synchronized to the rf frequency of the accelerator. An image intensifier is used to observe the circular trace. As the position of the detector is varied along the beam line the changes in the phases of the velocity components in the beam should be visible as variations in the intensity along the circular trace. An attempt in September, 1974 to observe this effect was unsuccessful due to an equipment failure. The experiment is rescheduled for December, 1974. Also, plans are underway for trying alternate methods of making frequency domain measurements.

4. Measurement of the Counting Efficiency of a NE-102 Neutron Detector (R. Felder)

Proton-deuteron quasi-free scattering (QFS) data taken during proton-induced deuteron breakup experiments at the Los Alamos Meson Physics Facility (LAMPF) will be used to determine the detection efficiency of a large cylinder (radius = 12.25 cm, length = 23.6 cm) of NE-102 scintillator

for neutrons in the energy range 190 MeV $\leq T_n \leq$ 470 MeV. A modified version of the program by Kurz (UCRL Report No. 11339 (1964) unpublished) has been used to calculate the efficiency of such a cylinder for comparison purposes. Analysis of the QFS data is in progress.

5. Instrument Trailer--The Rice Portable Laboratory (J. Buchanan, W. P. Madigan, G. C. Phillips, and J. Windish)

The data processing system in the trailer was updated and improved by replacing the PDP-11/20 central processor with the new PDP-11/45. The instrument trailer has been in service for nearly 1-1/2 years. In that time it was used at LAMPF for two experiments and at SREL for one experiment. Its high mobility provides us with an excellent means to effectively utilize the medium- and high-energy accelerators around the country.

6. 11" x 30" Multi-Wire Proportional Chambers (W. P. Madigan, N. D. Gabitzsch, J. A. Flick, and J. Windish)

Two multi-wire proportional counters, each with a useful active area of 11" x 30", were built and used as the output counters on the magnetic spectrometers used successfully in Exp. #81 at LAMPF and Exp. #IC-523 at SREL. The large area counters improved the spectrometer efficiencies and maximized the momentum bites, significantly increasing data collection rates.

7. Cryogenic Target Chamber (W. P. Madigan, M. Furic and A. Renzetti)

A 13-inch diameter target chamber was fabricated to accomodate a liquid deuterium target. The chamber has two side windows providing observation angles of $\pm$ 15° to $\pm$ 165° with respect to the beam direction. Two retractable scintillation screens provide a check on beam alignment. A retractable ambient temperature target support allows the replacement of the cryogenic target with a solid target without disturbing the vacuum. The chamber was used successfully in Exp. #81 at LAMPF and in Exp. #IC-523 at SREL.

8. Cryostat/Target Chamber Support (W. P. Madigan and A. Renzetti)

A support was built to suspend the cryogenic scattering chamber and cryostat above the pivot point of the spectrometer. Its cantilever design allows the support of the chamber without interference with the rotation of the spectrometer. The cryostat is attached to the support by means of a pneumatically actuated yoke. This yoke raises the cryostat and cryogenic target out of the beam line, allowing the insertion of an ambient temperature solid target with the retractable target support in the cryogenic target chamber.

9. Spectrometer Extension (W. P. Madigan and C. Belcher)

It was necessary to extend the surface of the spectrometer magnet cart used in experiment #81 at LAMPF in order to provide a support for the spectrometer output detectors. A cantilever which bolts to the cart was built. This cantilever structure extends the surface of the magnet cart 2 meters and supports a uniform weight of 1000 pounds.

Changes in Personnel

Dr. David Mann and Dr. Norman Gabitzsch resigned their positions as Research Associate; Dr. Mann on July 31, 1974 to accept a position with Schlumberger Corp. in Houston, and Dr. Gabitzsch on November 30, 1974 to join the staff at Shell Development Company in Houston.

During this year Dr. John M. Clement, Jr. joined our staff as Research Associate to fill the position vacated by Dr. Mann. Dr. Jozica Hudomalj Gabitzsch joined our staff as a Research Associate in September, 1974.

Professor Vlado Valković worked in our laboratory for 2-1/2 months this past summer; he will return from his sabbatical leave to take up his teaching and research duties at Rice in July, 1975. Dr. Gordon Mutchler was appointed an Assistant Professor of Physics in July, 1974 and continues to be an active member of our research group.

Publications in 1974

See attached list.

Incident Report

No incidents such as those outlined in attachment "A" have occurred during the contract year.

G. C. Phillips, Director
T. W. Bonner Nuclear Laboratories
and Principal Investigator

December 20, 1974

Rice University
Progress Report
AEC Contract No. AT-(40-1)-1316, Task C

Publications since last report (1973 & 1974)

1. Pion-Nuclear Total Cross Sections near the 3/2,3/2 Resonance

   N. D. Gabitzsch, G. S. Mutchler, C. R. Fletcher, E. V. Hungerford, L. Coulson, D. Mann, T. Witten, M. Furic, G. C. Phillips, B. Mayes, L. Y. Lee, J. Hudomalj, J. C. Allred, and C. Goodman, Phys. Lett. 47B (1973) 234

2. Measurements of $^{12}C(\pi^+,\pi N)^{11}C$ and $^{19}F(\pi^+,\pi N)^{18}F$ Cross Sections near the 3/2,3/2 Resonance

   K. R. Hogstrom, B. W. Mayes, L. Y. Lee, J. C. Allred, Clark Goodman, G. S. Mutchler, C. R. Fletcher, and G. C. Phillips, Nucl. Phys. A215 (1973) 598

3. Dibaryon Resonance Production in pp Scattering

   V. S. Bhasin and I. Duck, Nucl. Phys. B64 (1973) 289

4. Neutron Proton Final State Interaction in p-d Breakup at E_p = 585 MeV

   M. Furic, C. R. Fletcher, N. D. Gabitzsch, G. S. Mutchler, T. R. Witten, G. C. Phillips, J. Hudomalj, D. Y. Lee, P. A. M. Gram, B. W. Mayes, J. Allred, and C. Goodman, Phys. Lett. 47B (1973) 241

5. Nuclear-Coulomb Interference in π^+-^{12}C Scattering

   G. S. Mutchler, M. L. Scott, C. R. Fletcher, E. V. Hungerford, L. V. Coulson, N. D. Gabitzsch, G. C. Phillips, B. W. Mayes, L. Y. Lee, J. C. Allred, and Clark Goodman, Phys. Rev. C9 (1974) 1198

6. p-^{4}He Elastic Scattering at 1.05 GeV

   S. D. Baker, R. Beurtey, G. Bruge, A. Chaumeaux, J.-M. Durand, J. C. Faivre, J. M. Fontaine, D. Garreta, D. Legrand, J. Saudinos, J. Thirion, R. Bertini, F. Brochard, and F. Hibou, Phys. Rev. Lett. 32 (1974) 839

7. Pion Small-Angle Multiple Scattering at Energies Spanning the (3,3) Resonance

   B. W. Mayes, L. Y. Lee, J. C. Allred, Clark Goodman, G. S. Mutchler, E. V. Hungerford, M. L. Scott, and G. C. Phillips, Nucl. Phys. A230 (1974) 515