ORO-1316-169

Nuclear Structure at Intermediate Energies

Progress Report

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T. W. Bonner Nuclear Laboratories

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

Project Abstract

During the year 1973 the program goals of carrying out experimental and theoretical studies in intermediate energy physics were continued.

Work at the Space Radiation Effects Laboratory on small angle pion Coulomb multiple scattering from nuclei was completed and the small angle Coulomb-nuclear interference studies and total cross sections were continued. Experiments on p-d breakup were started and, in addition to observing quasi-free nucleon-nucleon scattering, a strongly enhanced neutron-proton final state interaction was observed at 585 MeV for the first time.

In July 1973 the outfitting of the Rice-owned portable laboratory was completed, including operation of the AEC-owned PDP-11 on-line computer system, and the laboratory was moved to Los Alamos, New Mexico (LAMPF).

In the fall of 1973 the group aided the LAMPF staff in tuning the P^3 pion channel.

Principal collaborators in all 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, 1974, includes the following:

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

I. M. Duck, Professor of Physics

V. Valkovic, Associate Professor of Physics

R. F. Guertin, Assistant Professor of Physics

E. V. Hungerford, Assistant Professor of Physics

G. S. Mutchler, Visiting Assistant Professor of Physics

C. R. Fletcher (Ph.D., Univ. of Illinois) 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. Chang (B. A., St. John's University) Research Assistant

J. B. Cone (M.A., Rice University) Research Assistant

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

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

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

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

J. Windish, Technician

Physics Shop Personnel

Genevieve Wright, Secretary

All Reports Personnel

Experiments 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. Houston); Mutchler, Hungerford, Scott, and Phillips (Rice Univ.)

The small-angle multiple scattering of positive and negative pions has been measured for C, Al, Cu, and Pb targets throughout an energy range spanning the (3,3) resonance. The measurements were made using two-dimensional multiwire proportional counters placed in the pion beam. All previous multiple scattering data for electrons and protons as well as these new data for pions are used to recalculate the empirical terms in the Molierè theory of multiple scattering. A second-order Born approximation multiple scattering theory has been devised for spin zero particles. The modified Molieré theory gives a better fit to the experimental data than the second-order Born calculation. Because the updated Molieré theory contains much simpler equations and give closer agreement with experiment, it is recommended in place of the more sophisticated theory for the interpretation of new experimental data. A paper describing this work has been submitted to Physical Review.

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

We have determined $Ref_N(0^o)$ by measuring the small angle $\pi^{\pm}$ - ^{16}O scattering in the Coulomb-nuclear interference region (4^o-11^o) at 155, 180, and 213 MeV. In the region the difference of the π^+ and π^- scattering directly determines the sign and magnitude of $Ref_N(0^o)$. This information, plus the $Imf_N(0^o)$ obtained from total cross section data via the optical theorem, completely determines the nuclear scattering amplitude at 0^o. The small angle scattering of π^+ from ^{12}C and ^{9}Be have also been measured over a larger angular range (5^o-20^o). These data are being analyzed. This experiment will be continued at LAMPF as approved Experiment #80.

3. $\pi^{\pm}$ Nuclear Total Cross Sections Around the 3/2, 3/2 Resonance (Gabitzsch, Coulson, Fletcher, Hungerford, Mann, Mutchler, Phillips (Rice Univ.); Mayes, Hogstrom, Lee, Allred, and C. Goodman (Univ. Houston)

$\pi^{\pm}$ total cross sections have been measured for the nuclei ^{9}Be, ^{12}C, ^{16}O, and ^{27}Al. π^{+} energies were 115, 130, 155, 180, 195, and 210 MeV, while π^{-} measurements were taken at 155, and 210 MeV. Data were collected using multi-wire proportional counters (MWPC) which allowed for good angular resolution at small angles. Electrons were rejected with a gas Cerenkov detector and the muon impurity was measured using the target-out pion decay distributions. Preliminary analysis of the small angle scattering distributions and total cross sections indicate that the 3/2,3/2 resonance shifts to lower energies as the atomic number increases. Furthermore, Coulomb effects in π^{+} and π^{-} data are observed in the form of a slight difference in the π^{+} π^{-} total cross section for a given target. This work has been accepted for publication in Physics Letters. This experiment will be continued at LAMPF as approved Experiment #80.

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

The reaction cross sections for ^{12}C and ^{19}F production were measured for π^{+} on Carbon and Flourine at three energies by activation. This work will be continued at LAMPF in collaboration with LASL scientists as a parasite experiment to approved Exp. #80.

B. NUCLEON PHYSICS AT INTERMEDIATE ENERGIES

1. Proton Induced Deuteron Break-up at 585 MeV: Quasi-free Scattering (Furić, Fletcher, Gabitzsch, Mutchler, Witten, Phillips (Rice Univ.); Mayes, Lee, Warneke, Hudomalj, Gram, Allred, and Goodman (Univ. of Houston)

The D(p,pp)n reaction was studied using a deuterium gas target in the proton beam at the SREL 600 MeV synchrocyclotron. The trajectories of the two charged particles were determined with MWPC. The momentum of one proton was measured by a magnetic spectrometer; the time-of-flight of the other proton was also recorded. Good angular and momentum resolution with a large solid angle was achieved through the use of large MWPCs. The momentum spectra obtained in the symmetric 41°-41° geometry exhibited strong quasi-free scattering features. The momentum transfer dependence was examined in the range 0-200 MeV/c.

The p-p elastic scattering data accumulated with the same equipment and the Monte Carlo simulation of the experiment will be used for the absolute normalization and final analysis of the data, which are now in progress. This experiment will be continued at LAMPF as approved Experiment #81.

2. Neutron-Proton Final State Interaction in p-d Breakup at E_p = 585 MeV (Furić, Fletcher, Gabitzsch, Mutchler, Witten, and Phillips (Rice Univ.); Hudomalj, Lee, Gram, Mayes, Allred, and Goodman (Univ. of Houston)

The three-body break-up spectra concerning the reaction D(p,2p)n were accumulated at the SREL synchrocyclotron. The angular resolution of each arm in this two-arm experiment was 0.4°. The momentum of one proton was measured by a magnetic spectrometer. The momentum resolution was 1.5%. The kinematical conditions for two protons (41°-61°) were chosen so that the observation of the neutron-proton Final State Interaction (FSI) was possible. The enhancement in the spectrum corresponding to the effect was observed. This was the first report on the n-p FSI above E_p = 200 MeV. Qualitative features of the spectra can be explained with the Goldberger-Watson formula. The simple pole graph term, normalized to the lower energy data predicts the value of the cross section too low by an order of magnitude. This work has been accepted for publication in Physics Letters. This experiment will be continued at LAMPF as part of approved Experiment #81.

C. THEORY

1. The Effects of Nuclear Distortion on the Elastic Scattering of Pions from Oriented and Unoriented Nuclei (E. V. Hungerford III)

It is shown that nuclear distortions may introduce small fluctuations in the systematic determination of optical model parameters for pion elastic scattering from nuclear mass neighbors. In addition the measurement of $\pi^{\pm}$ total cross sections from oriented nuclei should provide a sensitive way to look for proton or neutron shape distortions. This work has been submitted for publication in Nuclear Physics.

2. DAMIT: A Small Computer Optical Model Code for Pion Scattering (E. V. Hungerford III)

A Fortran computer code for the optical model calculation of pion nucleus scattering has been written for small computer systems. The code is operational on both an IBM-1800 and a PDP-11 data acquisition computer. It allows calculation with both the Laplacian and Kisslinger optical models using either a modified Gaussian or a Fermi nuclear density. The code gives results in agreement with other pion optical model codes. This work has been published in Nuclear Instruments and Methods III (1973) 509-517.

3. Generalization of the Sakata-Taketani Equation to Arbitrary Spin (R. F. Guertin)

The Sakata-Taketani spin -0 and -1 equations for a massive particle have been generalized to arbitrary integer or half-odd integer spin 0^-. Although the theory is covariant, it is not manifestly covariant. However, there are only $2(2j + 1)$ components in the wavefunction, in contrast to the extra components that always appear in a manifestly covariant theory. Second quantization appears to require Bose statistics for any spin. A paper is in preparation to be submitted to the Journal of Mathematical Physics.

4. Electromagnetic Interactions for a Proposed Spin -1/2 Boson Equation (R. F. Guertin and John B. Cone)

Electromagnetic interactions have been introduced into a spin -1/2 Boson equation proposed by Guertin and Guth using minimal coupling. The covariance of this theory has not been proven. Nevertheless, one can evaluate the energy levels for a Coulomb potential and a constant homogeneous magnetic field, and in the appropriate limits for a certain arbitrary parameter, one obtains the usual results for both the Klein-Gordon equation and the Dirac equation.

5. Static Bootstrap Model for the ρ Meson Trajectories (R. F. Guertin and Bertrand Chang)

A static bootstrap model for the ρ meson trajectory in which the n^{th} particle on the trajecter is obtained self-consistently in the two-particle channel consisting of a π meson and the n^{th} particle on the π trajectory has been attempted. The isospin and angular momenta crossing matrices have been found to be inconsistent with the conjectured result.

6. Dibaryon Resonance Production in PP Scattering (V. S. Bhasin and I. M. Duck)

The angular distributions of negative pions produced in proton-proton collisions in the energy range of one to four GeV bombarding energy is calculated assuming the production of a low energy dibaryon resonance between the $\Delta(1236)$ and a proton. Triangle amplitudes involving $\pi^0 p \rightarrow \pi^- \Delta^{++}$ and $\pi^- p \rightarrow \pi^- p$ plus pion exchange, evaluated in the Yao approximation, dominate the triangle exchange amplitude and produce differential cross sections comparable to those for $pp \rightarrow \pi d$. This work has been accepted for publication in Nuclear Physics.

7. Estimate of $\sigma_{inel}/\sigma_{el}$ in Backward p-d Scattering at 1.0 GeV. (V.S. Bhasin, I. Duck, and V. Valkovic)

Some estimates have been made of the inelastic contributions in proton-deuteron scattering at 1.0 GeV due to deuteron break-up when one of the outgoing protons is observed in the backward direction. Based on the mechanism due to exchange of a nucleon as well as an isobar we compute $[(d\sigma/d\Omega)_{inel}/(d\sigma/d\Omega)_{el}]$ at $\theta_{C.M.} = 180^\circ$ taking account of both the spin singlet and triplet channels and keeping the relative energy of the scattered pair rather low. It is found that in the simple nucleon exchange mechanism the off-shell effects in the two-body amplitude due to the presence of hard-core in the singlet and tensor forces in the triplet channels manifest themselves in enhancing the inelastic contribution. On the other hand, the contributions of the resonance exchanges wherein the two-body amplitudes appear essentially on-shell get suppressed especially if the scattered pair is observed at rather low relative energy.

8. Rescattering Effects in Backward Proton-Deuteron Scattering at Intermediate Energies (V.S. Bhasin)

We study backward proton-deuteron scattering at intermediate energies (1.0-1.5 GeV) by considering a rearrangement process where the incident projectile picks up a neutron of the target leaving the target proton behind. By collecting terms up to second order in the multiple-scattering series and by employing the approximations suited to a high-energy large angle scattering behavior, we obtain the expression for the scattering amplitude similar (but not identical) to the one used by the Glauber model for small-angle scattering at these energies. We find that the double-scattering terms, in which the incident proton scatters with the neutron in the forward direction and then sends the target proton back, contribute most significantly. The lowest-order "pickup" and the

single-scattering terms become important if one includes the tensor component in the deuteron wave function. The calculated differential cross section (particularly at intermediate angles) is found to be in reasonable agreement with experimental data.

9. Pion Production in the Reaction $pd \rightarrow t\pi$ (V. S. Bhasin and I. M. Duck)

The Yao-Barry model is extended to the reaction $pd \rightarrow t\pi$ and provides a description of the cross section for incident proton energies from 340 to 670 MeV in terms of a single parameter, the triton nd wavefunction evaluated at the origin. The results are competitive with the predictions of the Ruderman model for the energy dependence of the forward cross section and show much larger backward cross sections. This work is published in Physics Letters 46B (1973) 309.

10. Exotic Nuclei and Resonance Production (I.M. Duck, V. S. Bhasin, and John Brown)

Calculations are in progress to investigate reaction mechanisms for production of Δ - P resonances at GeV energies. So far, we have production cross sections and angular distributions for resonances with spin 1 or 2, $J^{\pi} = 0^-, 1^-, 2^-, 3^-, 1^+$, and 2^+ produced in $pp \rightarrow \pi^- + (\Delta^{++}p)$ by a pion exchange mechanism. The evaluation of the pion exchange triangle amplitude which is supposed to be dominant is underway.

D. APPLIED PHYSICS (INTERMEDIATE ENERGY)

1. Pion Dosimetry

Preparation for approved LAMPF experiment #83, "Investigation of Multi-Wire Proportional Counters for Treatment Volume Visualization" (G. C. Phillips, Spokesman), and experiment #84, "Quality of Meson Radiation Fields" (G. C. Phillips, Spokesman) has continued. Experiment #83 collaborators, G. D. Oliver, Jr. (Edward Mallindkrodt Institute of Radiology, Washington University School of Medicine), Walter Grant (M.D. Anderson Hospital & Tumor Institute), and M. C. Taylor (Columbia Scientific Industries), have received funding from N.I.H. for their part in this work. The experimental system has been designed and test runs will be started in November, 1973 on the P^3 line at LAMPF as a parasite experiment. The work will continue in 1974 at LAMPF.

2. LAMPF Pion Beam Line (P^3) Calibration

Calibration of the Pion Beam Transport System (approved LAMPF experiment #79) was prepared in collaboration with Dr. Robert Macek for running in the summer or fall of 1973. Tests of the P^3 beam line commenced in September, October, and November of 1973.

3. Observation of Muonic X-rays from Bone (M. C. Taylor, L. Coulson, and G. C. Phillips)

The muonic x-ray, which results from the capture of a negative muon into orbit around a nucleus to form a "muonic atom," may be a useful diagnostic probe. The x-ray transition energies are about 200 times the energies from electronic transitions — the carbon K_α energy is of the order of 75 keV. Thus, muonic x-rays from light elements have considerable penetrating power and can escape from bulky media. Experimental results for negative muons stopped in bone are presented to demonstrate the potential of the technique for observing elements in the range from carbon to calcium in biological specimens. Advantages and disadvantages of this technique with respect to other methods of elemental analysis are discussed. This work published in Radiation Research 54, 335 (1973).

E. INSTRUMENTATION

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

In January, 1973 the outfitting of the instrumentation trailer was completed. The data processing system installed includes a PDP-11/20 central processor with two magnetic tape units, line printer, teletype, and disc drive. In addition, there are four standard relay racks of nuclear instrumentation. Airconditioning and heating are provided by two 3-ton units mounted externally on the nose of the trailer. A suspended acoustical-tile ceiling is used as the airconditioning supply duct. The walls are covered with plywood paneling from the floor to a height of four feet. From four feet to the ceiling the walls are covered with acoustical tile which dampens the considerable noise generated by the instrumentation. Built into the nose of the trailer are a bed, book shelves, a desk, and a refrigerator providing a study-rest area for long-running experiments. Fire protection is provided by a Halon 1301 system which is actuated by two smoke detectors.

All exposed wood surfaces are painted with Albi 107A fire-retardant coating. On July 1, the trailer was pulled to Los Alamos, a distance of 1,000 miles, with absolutely no damage to the computer, nuclear instrumentation, or trailer. This clearly proves the feasibility of transporting the trailer to distant accelerator facilities to conduct experiments in medium and high energy physics. The trailer and systems have been operating successfully at LAMPF since July, 1973.

2. 30" x 30" Multi-Wire Proportional Chamber (W. P. Madigan, E. Harmening, G. C. Phillips, and J. Windish)

The 30" x 30" MWPC to be used at the National Accelerator Laboratory in cooperation with the Stanford group headed by R. Hofstadter and Z. G.T. Guiragossian is scheduled for completion on November 30, 1973. It will have a useful active area of 30" x 30", an x-coordinate plane (304 wires), a y-coordinate plane (304 wires), an amplifier/discriminator readout for each wire, and a tapped delay line readout on each coordinate plane. The support frame for the chamber is designed to mesh with the support frame for the Stanford 30" dia. NaI crystals.

3. 12" Diameter MWPC Stands (W.P. Madigan, C. Belcher, P. DeVries, and E. W. Surles)

In August, six new MWPC stands were completed for use at LAMPF. They provide a vertical adjustment of $\pm$ 9 inches and a transverse adjustment of $\pm$ 1 inch. The MWPCs can be mounted singly or two at a time on a stand, permitting, e.g., the insertion of two counters between two closely-spaced magnets in a transport system. The stands have been in service at LAMPF since July, 1973.

4. Cryogenic Target Chamber (M. Furic, W. P. Madigan, P. DeVries, and G. C. Phillips)

Fabrication of the 13" diameter cryogenic scattering chamber to be used in the Rice-Univ. of Houston approved proton scattering experiment #81 at LAMPF is underway. The chamber will accommodate liquid hydrogen and liquid deuterium targets and will contain two retractable scintillation screens to ensure proper centering of the incident beam. Side windows will permit observation angles from 15^{o} to 165^{o} and 195^{o} to 345^{o} with respect to the incident beam direction. The top flange will fit to the standard Los Alamos cryogenic refrigerator. Completion of the chamber is scheduled for December 15, 1973.

5. Target Chamber for LAMPF Experiment #80 (T.M. Williams, Mutchler, Phillips, Hungerford, Witten, and Madigan)

A target chamber and collimator for LAMPF Exp. #80 is being designed. This chamber can be used for small angle scattering (down to 5°). The particle exit windows will extend from 5° to 30° on one side and from 10° to 160° on the other side of the beam. This will allow for coincidence measurements and/or parasite experiments to be run using this chamber.

6. Technique for Alignment and Placement of MWPCs (Hungerford, Williams, Flick, Madigan, and Phillips)

A system for the alignment of Multi-Wire Proportional Counters with respect to a magnet is being designed using a mirror in the magnet and aligning the magnet with a transit equipped with auto-reflection target. The mirror can then be rotated to make an accurate turn through any desired angle. This will allow correct placement of MWPCs behind the magnet.

7. RICE--A Multi-Processor Acquisition and Analysis System Incorporating CAMAC (H.V. Jones, Buchanan, Mann, McGrath, and M.N. Jones)

A two-processor data acquisition and analysis system incorporating CAMAC. The processors are a conventional mini-computer and a micro-programmed I/O processor which effects a programmable interface between the mini-computer and CAMAC. This work has been published in IEEE Trans. on Nuclear Science, Vol. NS-20, No. 1, February, 1973.

8. PDP-11 Systems Development (David Mann)

A data acquisition system using a PDP-11/20 (soon to be an 11/45) and a "MIOP" (micro-programmed I/O processor) is being used to tune the P^3 line at LAMPF. Fast calculations of various beam parameters allow coarse tuning of the beam using one-dimensional and two-dimensional on-line displays. Fine tuning of the beam is performed using a fast on-line optimizer program plus several tuning criterion. The magnets in the P^3 line can be periodically read by the computer to verify magnet stability.

9. Development of MWPC Readout in CAMAC (J. Buchanan)

The readout modules (in NIM) for the Rice Multi-Wire Proportional Counters (MWPC) have been redesigned into CAMAC format. In addition certain logic operations as well as

analogue and digital arithmetic operations can be performed at these modules to further improve the rejection of unwanted data.

10. Utilization of an Accelerator Beam's Micro-structure to Measure Beam Characteristics (W. H. Dragoset and G. C. Phillips)

Methods of using the detection of Cerenkov light to view the micro-structure of an accelerator beam, such as that at LAMPF, have been discussed. In particular, the correlation integral of an accelerator synchronized clock signal and the detected signal as a function of the location of the detector in the beam can be used with the methods of Fourier spectroscopy to yield information about the phase space of the beam. A system such as this could be used as a beam monitor, to measure time-of-flight, and possibly to determine the pion to muon ratio in a pion beam. Another promising method involves the use of a high-speed camera with an X and Y sweep synchronized by a clock pulse to form a circular trace from the detected light pulses. A microdensitometer could then be used to determine the relative intensities of the interesting segments of the trace.

Changes in Personnel

In August, 1973 Dr. Vlado Valkovic requested and received a 2-year leave-of-absence from his teaching duties at Rice. He will return to Rice to work in this laboratory for the period May-August, 1974. Dr. Gordon S. Mutchler resigned his Research Associateship to accept an appointment as Visiting Assistant Professor of Physics to carry on Dr. Valkovic's teaching duties. Dr. E. V. Hungerford resigned his Assistant Professorship at Rice to join the faculty at the University of Houston. He is continuing to be an active member of the Rice-University of Houston Group.

Norman D. Gabitzsch completed his work for the Ph.D. in September, 1973 and accepted an appointment as a Research Associate (this task).

Dr. C. R. Fletcher resigned his appointment as Research Associate on August 31, 1973 to accept a staff appointment with the Lockheed Industries Houston Aerospace Systems Division.

Publications in 1973

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 21, 1973

Publications since last report (1972 and 1973)

1. A Multi-Wire Proportional Counter System for Use in Low, Medium and High Energy Physics

   J. Buchanan, L. Coulson, N. Gabitzsch, E. V. Hungerford, G. S. Mutchler, R. Persson, M. L. Scott, J. Windish, and G. C. Phillips, Nucl. Instr. & Meth. 99, 159 (1972).

2. CAMAC Multi-Microprogrammed IO Processor

   James A. Buchanan and Hugh V. Jones, IEEE Transactions on Nuclear Science NS-19, 682 (1972).

3. An In-Flight Pion Beam Flux Monitor

   L. V. Coulson, C. R. Fletcher, E. V. Hungerford, G. S. Mutchler, G. C. Phillips, M. L. Scott, J. C. Allred, Clark Goodman, and B. W. Mayes, Nucl. Instr. & Meth. 101, 247 (1972).

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

   M. L. Scott, G. S. Mutchler, C. R. Fletcher, E. V. Hungerford, L. V. Coulson, G. C. Phillips, B. W. Mayes, L. Y. Lee, J. C. Allred, and Clark Goodman, Phys. Rev. Lett. 28, 1209 (1972).

5. Proton Small Angle Multiple Scattering at 600 MeV

   E. V. Hungerford, G. S. Mutchler, G. C. Phillips, and M. L. Scott, Nucl. Phys. A197, 515 (1972).

6. RICE--A Multi-Processor Acquisition and Analysis System Incorporating CAMAC

   H. V. Jones, J. A. Buchanan, D. Mann, K. McGrath, and M. N. Jones, IEEE Transactions on Nuclear Science NS-20, 691 (1973).

7. DAMIT: A Small Computer Optical Model Code for Pion Scattering

   E. V. Hungerford, III, Nucl. Instr. & Meth. 111, 509 (1973).

8. Zitterbewegung in Relativistic Spin-0 and $-\frac{1}{2}$ Hamiltonian Theories

   Ralph B. Guertin and Eugene Guth, Phys. Rev. D7. 1057 (1973).

9. Rescattering Effects in Backward Proton-Deuteron Scattering at Intermediate Energies

   V. S. Bhasin, Phys. Rev. D7, 2066 (1973).

Publications since last report (1972 and 1973)

10. Isobar Exchange Effects in p-d Backward Inelastic Scattering

V. S. Bhasin, I. M. Duck and V. Valković, Phys. Lett. 44B, 317 (1973).

11. Observations of Muonic X-rays from Bone

M. C. Taylor, L. Coulson and G. C. Phillips, Radiation Research 54, 335 (1973).

12. Pion Production in the Reaction $pd \rightarrow t\pi$

V. S. Bhasin and I. M. Duck, Phys. Lett. 46B, 309 (1973).