TUNL XXXVI

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TRIANGLE UNIVERSITIES NUCLEAR LABORATORY

DUKE UNIVERSITY
NORTH CAROLINA STATE UNIVERSITY
UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL

BOX 90308, DURHAM, NORTH CAROLINA 27708-0308, USA
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Contents

Introduction vii

Personnel xv

1 Fundamental Symmetries in the Nucleus 1
   1.1 Parity-Mixing Measurements .............................. 1
      1.1.1 Parity Violation with Polarized Epithermal Neutrons (The TRIPLE Collaboration) - General 1
      1.1.2 Parity Violation with Polarized Epithermal Neutrons (The TRIPLE Collaboration) - Status of Experiments 4
      1.1.3 Parity-Violation Tests with Charged Particles ................. 5
   1.2 Time-Reversal Invariance .................................. 8
      1.2.1 Neutron Resonance Tests of P-even T-violation ............ 8
      1.2.2 Statistics of On-Resonance Deformation-Effect Measurements .... 10
   1.3 Quantum Chaos in Nuclei ................................... 13
      1.3.1 A Complete Level Scheme for $^{30}$P ........................ 13
      1.3.2 Reduced Transition-Probability Distributions ............. 15

2 Internucleon Reactions 17
   2.1 Neutron-Proton Interaction ................................. 17
      2.1.1 Measurements of the Longitudinal Spin Dependent Total $\bar{n}-\bar{p}$ Cross-Section Difference .................... 17
      2.1.2 Sensitivity of $n-p$ Phase-Shift Data to Variations of $^3P_j$ Phase Shifts 19
      2.1.3 Results of the TUNL Neutron-Proton Scattering Length Experiment 22
   2.2 Neutron-Neutron Interaction ............................... 25
      2.2.1 Measurement of the $^1S_0$ Neutron-Neutron Scattering Length Using the $^2\text{H}(\pi^-\mu\gamma)$ Reaction: LAMPF E1286 ............. 25
      2.2.2 Preliminary Results of the TUNL Neutron-Neutron Scattering Length $(a_{nn})$ Experiment .......................... 28
   2.3 Proton-Proton Interaction ................................. 31


3 Dynamics of Very Light Nuclei

3.1 Four and Five-Nucleon Reactions

3.1.1 Measurement of Longitudinal and Transverse Polarization Transfer in the $^7\text{Li}(\vec p, \vec n)$ Reaction at Low Energies

3.1.2 The $^4\text{He}(\gamma, d)^2\text{H}$ Reaction at $E_{\gamma} = 150 - 250$ MeV

3.1.3 Measurements of the $^3\text{He}(d, p)^4\text{He}$ Reaction at Low Energies

3.2 Measurements of D States of Very Light Nuclei Using Transfer Reactions

3.2.1 Analyzing Powers of $(^6\text{Li}, d)$ Reactions and the D State of $^6\text{Li}$

3.2.2 Cross-Section Measurements of the $^28\text{Si}(^6\text{Li}, \alpha)^30\text{P}$ Reaction

3.3 Radiative-Capture Reactions and Few-Nucleon Systems

3.3.1 Measurement of $iT_{11}$ for the Reaction $p(\vec d, \gamma)^3\text{He}$ at $E_d = 80 - 0$ keV

3.3.2 Measuring the $\gamma$-Ray Analyzing Power for $^2\text{H}(\vec p, \gamma)^3\text{He}$

3.3.3 Formalism for $\gamma$-Ray Polarizations in Radiative-Capture Reactions Induced by Polarized Beams

4 Nuclear Astrophysics

4.1 Radiative-Capture Reactions

4.1.1 Cross-Section Studies of the $^7\text{Li}(p, \gamma)^8\text{Be}$ Reaction at Low Energies

4.1.2 The $^9\text{Be}(\vec p, \gamma)^{10}\text{B}$ Reaction at $100 - 0$ keV

4.1.3 The $^{11}\text{B}(\vec p, \gamma)^{12}\text{C}$ Reaction at Low Energies

4.1.4 Feasibility Study of the $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$ Reaction

4.1.5 Measurement of the $^{16}\text{O}(\gamma, \alpha)^{12}\text{C}$ Cross Section at Astrophysically Significant Energies
4.1.6 The $\beta$-Delayed Proton Decay of $^{17}$Ne and the $^{12}$C($\alpha,\gamma$)$^{16}$O Reaction Cross Section ................................................. 71
4.1.7 Investigation of $^{22}$Ne($p,\gamma$)$^{23}$Na and $^{23}$Na($p,\gamma$)$^{24}$Mg Using ($^3$He,$d$) Spectroscopy .................................................. 72
4.1.8 Determination of the Rate for the $^{24}$Mg($p,\gamma$)$^{25}$Al Reaction at Low Stellar Temperatures .................................................. 73
4.1.9 Measurement of $^{40}$Ca($\alpha,\gamma$)$^{44}$Ti at $E_\alpha \leq$ 6.0 MeV .................. 75
4.2 Nucleon Induced Reactions ............................................................. 77
  4.2.1 The $^9$Be($p,d$)$^8$Be and $^9$Be($p,\alpha$)$^6$Li Reactions at Low Energies .... 77
  4.2.2 The Reaction $^{35}$Cl($p,\alpha$)$^{32}$S in Explosive Hydrogen Burning .......... 78
  4.2.3 Proton Single-Particle Reduced Widths for Unbound States .................. 80
  4.2.4 Stellar Reaction Rates for Explosive Hydrogen Burning .................... 82
4.3 Radioactive Beams ................................................................. 85
  4.3.1 Nuclear Astrophysics at HRIBF ................................................. 85

5 Weak-Interaction Studies .............................................................. 87
  5.1 Double-Beta Decay ................................................................. 87
    5.1.1 Search for $\gamma$ Rays Following the $\beta\beta$ Decay of $^{100}$Mo to the First Excited $0^+$ State of $^{100}$Ru ............................................. 87

6 The Many-Nucleon Problem .............................................................. 88
  6.1 High-Spin Spectroscopy and Superdeformation ................................... 88
    6.1.1 Differential Lifetime Measurements in Nuclei near $^{152}$Dy ................ 88
    6.1.2 Differential Lifetime Measurements and Identical Superdeformed Bands in $^{192,194}$Hg ......................................................... 89
    6.1.3 Lifetime Measurements and Dipole Transition Rates for Superdeformed States in $^{190}$Hg ................................................. 91
    6.1.4 Lifetime Measurements of Superdeformed Bands in $^{142}$Sm .............. 93
    6.1.5 Coulomb Excitation of Actinide Nuclei ...................................... 95
  6.2 Phenomenology of Preequilibrium Nuclear Reactions ............................ 97
    6.2.1 Information from 14 MeV Data ............................................... 97
    6.2.2 Equilibrium Shell Corrections .............................................. 98
    6.2.3 Surface Effects in Neutron Induced Reactions .............................. 100
  6.3 Neutron Scattering .................................................................... 101
    6.3.1 The Neutron-Nucleus Interaction from -20 to 80 MeV ..................... 101
    6.3.2 Exploring Variations of the Dispersive Optical Model .................... 102
    6.3.3 Analyzing Power Measurements for $^{12}$C($n,\alpha$)$^{12}$C from 2.2 to 8.5 MeV 105
  6.4 High-Resolution Resonance Studies at Münster and Böchum .................. 109
    6.4.1 Vibrations of Solid Neon .................................................... 109
    6.4.2 Precision Determination of Resonance Strengths and Widths ............ 109
6.5 Nuclear Data Evaluation for $A = 3–20$ .................................................. 111
6.5.1 Data Evaluation Activities ................................................................. 111
6.5.2 ENSDF ................................................................. 111
6.5.3 World-Wide Web Services ................................................................. 111

7 Nuclear Instruments and Methods ................................. 113
7.1 Tandem Accelerator Operation ............................................................. 113
  7.1.1 Tandem Operation ................................................................. 113
  7.1.2 Vacuum System Improvements ......................................................... 114
7.2 KN Accelerator Operation ................................................................. 116
  7.2.1 KN Accelerator ................................................................. 116
  7.2.2 Laboratory Improvements and Modifications ...................................... 117
7.3 Nuclear Astrophysics Facility ............................................................. 118
  7.3.1 The Low-Energy Nuclear Astrophysics Facility .................................... 118
7.4 Polarized Ion Source ................................................................. 121
  7.4.1 Atomic Beam Polarized Ion Source .................................................. 121
7.5 Polarimeters ................................................................. 124
  7.5.1 A Proton Polarimeter for Polarization-Transfer Experiments ............... 124
  7.5.2 Low-Energy Deuteron Vector Polarimeter Using the $^{12}\text{C}(d,p)^{13}\text{C}$ Reaction ................................................................. 125
  7.5.3 TJNAF Hall B Moeller Polarimeter .................................................. 126
  7.5.4 A Compton Scattering $\gamma$-Ray Polarimeter .................................. 128
7.6 DFELL/TUNL High-Intensity Gamma-Ray Source (HIGS) .......... 130
  7.6.1 First Measurements of Backscattered Gamma Rays at HIGS ............... 130
  7.6.2 Keck Building Shielding Results ................................................... 132
  7.6.3 Development of an Electron-Positron Pair Spectrometer for Use with HIGS ................................................................. 133
  7.6.4 Acquisition of the Neutral Meson Spectrometer from Los Alamos .......... 134
7.7 Polarized Target ................................................................. 135
  7.7.1 Enhancements to the TUNL Dynamically Polarized Proton Target and NMR System ................................................................. 135
7.8 Detector Developments ................................................................. 137
  7.8.1 Cryogenic Microcalorimeters ......................................................... 137
  7.8.2 Progress with the Enge Spectrometer and the Focal-Plane Detector .......... 139
7.9 Gas-Jet Target ................................................................. 142
  7.9.1 Acquisition of the Erlangen Recirculating Gas-Jet Target ................. 142
7.10 Data-Acquisition Systems ................................................................. 144
  7.10.1 New Data Analysis and Data-Acquisition Systems for TUNL ............ 144

Appendices ................................................................. 146
Introduction

The Triangle Universities Nuclear Laboratory (TUNL) – a collaboration of Duke University, North Carolina State University, and the University of North Carolina at Chapel Hill – has had a very productive year. The following reports cover parts of the final and first year of three-year grants between the U.S. Department of Energy and the three collaborating universities.

During the current grant period TUNL physicists have achieved several major successes:

- **Gamma rays from a free-electron laser:**
  A nearly monochromatic beam of 100% linearly polarized $\gamma$ rays has been successfully produced at the Duke Free-Electron Laser Laboratory. Two 1.2 mA bunches of 500 MeV electrons circulating in the Duke Storage Ring repeatedly passed through the OK-4 undulator, creating $379.4 \text{ nm (} \sim 3.3 \text{ eV)}$ photons. These photons were captured in an optical cavity and scattered from the electrons in the ring, producing a beam of $\gamma$ rays with a peak energy of 12.2 MeV. The measured flux, energy resolution, and polarization of the $\gamma$-ray beam agree with predictions. The $\gamma$-ray beam has a divergence angle of $\sim 1 \text{ mrad}$ and with simple collimation the energy spread was about 1%.

- **Parity nonconservation in the nuclear interaction:**
  We performed measurements at LANSCE with a new large-area and high-polarization proton filter, a $^{10}$B-loaded liquid scintillator system, and a large solid-angle CsI detector for capture studies. New transmission and capture measurements have been carried out on a number of targets ($^{238}$U, $^{232}$Th, In, Ag, $^{113}$Cd). PNC effects were observed in all of these nuclei. The previously observed sign correlation in $^{232}$Th is confirmed with greater statistical significance, but the signs of the other parity violations appear to be randomly distributed.

- **Neutron-neutron scattering length:**
  The neutron-neutron scattering length $a_{nn}$ was determined from our neutron-deuteron breakup data and, for the first time, an accurate value was obtained that agrees very well with the “two-body” result extracted from the $\pi^-d$ capture reaction. The
analysis of our new $\pi^-d$ data measured at LANL also supports the earlier results obtained for $a_{nn}$ from this reaction.

- **Meson-exchange currents:**
  Our $\vec{d}-p \ iT_{11}(\theta)$ data provide a precision test of MEC effect treatments in three-nucleon calculations.

- **Astrophysical S factor:**
  Data on the $^7\text{Li}(p,\gamma)^8\text{Be}$ reaction between 40 and 100 keV reveal a negative slope for the S factor. This can be explained if the 16.6 MeV resonance state is formed at 40 fm. This interpretation accounts for our $A_y(\theta)$ data and doubles the S factor.

- **Chaos in the nucleus:**
  With the new Compton-suppression spectrometer and the excellent beam energy resolution of $\sim 200$ eV, we continued our studies of resonances in the $^{20}\text{Si}(p,\gamma)^{30}\text{P}$ reaction in order to obtain a complete level scheme of $^{30}\text{P}$. The measured elastic scattering and capture spectra limit the quantum numbers of both initial (resonant) and final states. The complete level scheme will not only provide a definitive study of the statistical properties of eigenvalues and transition-matrix elements in light nuclei, but will also clarify the effect of symmetry breaking on these quantities.

- **Neutron-proton scattering length:**
  The comparison of our accurate results obtained for $a_{np}$ from the neutron-deuteron breakup reaction with the value measured in free neutron-proton scattering clearly shows that three-nucleon force effects are less important in three-nucleon scattering systems than previously thought.

- **The tensor force in the nucleon-nucleon interaction:**
  By scattering longitudinally polarized neutrons from a longitudinally polarized proton target we measured the spin-dependent neutron-proton total cross-section difference $\Delta\sigma_L$ between 5 and 20 MeV. Our high-accuracy data rule out any low-energy anomaly in the nucleon-nucleon tensor force.

- **Proton-deuteron scattering:**
  We made scattering measurements of protons from deuterons and vice versa at center-of-mass energies as low as 430 keV. These experiments show that the discrepancy between rigorous 3N calculations and data for $A_y(\theta)$ and $iT_{11}(\theta)$ approaches the stunning value of 100% at these low energies. A phase-shift analysis based on our cross-section and analyzing power results strongly indicates a low-energy pole such as has been observed for $n-d$ scattering.

- **$^6\text{Li}$ D state:**
  We have used ($^6\text{Li}, d$) reactions to determine the asymptotic D/S state ratio $\eta$ for $^6\text{Li}$. 
Our result is the most accurate value obtained to date and it is considerably smaller than theoretically predicted.

- **Globular clusters:**
  Observations of anomalous abundances of Na and Al in globular-cluster giants challenged models of stellar structure and evolution. We have been surveying reactions responsible for producing these signatures. So far, it appears that physics can not account for these effects.

- **Commissioning of the Daresbury Recoil Separator:**
  The Daresbury Recoil Separator has been installed at the Holfield Radioactive Ion Beam Facility to serve as the end station for nuclear-astrophysics experiments with radioactive beams. It is currently being tested with stable beams in order to establish the operating parameters for its modified geometry. Its mass resolution and rejection of primary beam are clearly adequate for our purposes. Radioactive beam experiments are scheduled to begin soon.

- **Cryogenic microcalorimeters:**
  We constructed and successfully tested our first prototype cryogenic microcalorimeter. These devices are being developed for measurements of $\beta$ spectra in weak-interaction studies.

- **Charged-particle parity violation studies:**
  A $2\pi$ $\alpha$-particle detector system with 64 segments consisting of 4 large silicon strip detectors was successfully commissioned. This detector will be used for charged-particle parity violation studies.

- **Gas-jet target:**
  We are installing a windowless high-density recirculating gas-jet target that we recently acquired from the University of Erlangen.

- **Focal-plane detector for Enge split-pole spectrometer:**
  We completed the commissioning of a new focal-plane detector that dramatically enhances our high-resolution spectroscopy capabilities.

- **Nuclear data project:**
  We completed the review “Energy Levels of Light Nuclei $A=20$”. Recently, a preliminary version for $A=5$ has been completed and distributed. We also increased our World Wide Web (WWW) service. Energy Level Diagrams in the style of Fay Ajzenberg-Selove for $A=4-20$ are available as well as a short version of the Table of Isotopes which has information about $A=1-20$ nuclei. We added abridged versions of Fay Ajzenberg-Selove’s most recent evaluations of $A=5-10$, and they are available
online. We are currently working to make modified versions of all her compilations available online.

TUNL seeks to be on several of the nuclear physics research frontiers identified in the 1996 NSAC Long Range Plan. The TUNL research program focuses on the following areas:

- Precision test of parity-invariance violation in resonance neutron scattering at LANSCE/LANL.
- Parity violation measurements using charged-particle resonances in $A=20-40$ targets and the $A=4$ system at TUNL.
- Chaotic behavior in the nuclei $^{30}$P and $^{34}$Cl from studies of eigenvalue fluctuations in nuclear level schemes.
- Search for anomalies in the level density (pairing phase transition) in $1f-2p$ shell nuclei using GEANIE at LANSCE/LANL.
- Chaotic behavior in the nucleus $^{166}$Ho from studies of amplitude correlations in neutron resonances.
- Nuclear astrophysics, using the refurbished Enge split-pole spectrometer, the Low-Energy Beam Facility, a new 200 keV accelerator for high-intensity unpolarized beams, and the KN accelerator (all at TUNL); facilities at HRIBF, TRIUMF, and Yale; and the planned HIGS facility at Duke’s FELL. Emphasis is placed on the following topics:
  - abundance anomalies in globular clusters
  - explosive nucleosynthesis in novae
  - evolution of massive stars
  - origin of galactic radioactivity
  - the solar neutrino problem
- Few-body nuclear systems, with specific experiments to address:
  - radiative-capture reactions on hydrogen isotopes to investigate non-nucleonic degrees of freedom
  - the role of three-nucleon forces in the 3N and 4N continuum using hadronic and electromagnetic probes
  - the strength of the tensor force in the NN interaction
  - determination of the charged $\pi NN$ coupling constant
  - the $A_\pi(\theta)$ and $iT_{11}$ puzzles in 3N scattering
Intr oduction

- electron screening
- reactions on helium isotopes to determine astrophysical S factors via analytic continuation techniques
- the quark structure of nucleons in experiments at Bates and TJNAF

- Study of double $\beta$ decay to excited $0^+$ states
- High-spin spectroscopy and superdeformation
- Nuclear Data evaluation for $A=3$–20 for which TUNL is now the international center. Extensive services are provided through our WWW site and are constantly being improved.

Developments in technology and instrumentation are vital to our research and training program. We continued our innovative work in:

- polarized beam development
- polarized target development
- new cryogenic systems
- new detectors
- new polarimeters for charged particles and $\gamma$ rays
- improving high-resolution beams for the KN and FN accelerators
- development of an unpolarized Low-Energy Beam Facility for radiative capture studies of astrophysical interest.

During the last year we worked on a major new initiative to develop an intense beam of polarized $\gamma$ rays. This High-Intensity Gamma-ray Source (HIGS) will utilize the facilities of the Duke Free-Electron Laser Laboratory (DFELL). The DFELL currently includes a 500 MeV LINAC injector, a 1.1 GeV electron storage ring, and the OK-4 undulator. It is possible to tune the electron beam in a manner which allows the FEL photons produced by one electron bunch to backscatter from a second electron bunch, all within the ring. This leads to an intense beam of almost 100% polarized $\gamma$ rays whose energy can be readily tuned from about 2 MeV to greater than 200 MeV. Furthermore, beam energy spreads of less than 1% can be obtained by purely geometrical collimation. In order to achieve the full range of energies, it will be necessary to upgrade the energy of the injected beam to 1.2 GeV and to make modifications in the electron beam optics in the FEL storage ring.
Funds for upgrading the injected beam energy to 1.2 GeV, which will allow us to produce γ rays up to about 170 MeV (above the photo-pion production threshold), will constitute the major part of a supplemental proposal that will be submitted to DOE this Fall.

In the development of polarized targets we plan to convert the dynamically polarized proton target at TUNL into a vector (or tensor) polarized deuteron target.

With respect to innovative detector and target developments, we are currently optimizing our rapid-cycle cryogenic microcalorimeter-bolometer, a device that operates in the mK temperature regime to detect incident radiation with superb energy resolution. We are also improving our recently installed focal-plane detector for the Enge spectrometer, and are installing a recirculating gas-jet target.

The Nuclear Data Evaluation project for nuclei $A=3-20$, which was moved to TUNL in 1990, continues not only to benefit our local research, but is also providing an important service to the international nuclear physics community.

The TUNL seminar program continues with characteristic vigor, supplemented by 16 in-house lectures on TUNL instrumentation and safety procedures. A related program, the Triangle Nuclear Theory seminars, is also beneficial to TUNL faculty and students.

The talents and enthusiasm of the 18 faculty members, 8 research staff and post-doctoral associates, and 30 graduate students from the three Triangle universities are responsible for the successes of our research program. We also benefit from collaborations with Tennessee Technological University, North Georgia College and State University, North Carolina A&T State University, North Carolina Central University, State University of New York-Geneseo, China Institute of Atomic Energy and Tsinghua University (Beijing), and Jagellonian University (Cracow).

The TUNL Advisory Committee - Drs. David Balamuth (University of Pennsylvania), Baha Balantekin (University of Wisconsin), James Friar (Los Alamos National Laboratory), Gerald Garvey (Los Alamos National Laboratory), and Steven Vigdor (Indiana University) - continues to provide valuable advice on the research program.

The research summaries presented in this progress report are preliminary. They should not be referenced in other publications. If you wish to know the current status of a project, please contact the person whose name is underlined in the author list.
Personnel

Department of Physics, Box 90308, Duke University,
Durham, NC 27708-0308
Department of Physics, Box 8202, North Carolina State University,
Raleigh, NC 27695-8202
Department of Physics and Astronomy, University of North Carolina,
Chapel Hill, NC 27599-3255

Faculty

Bilpuch, E. G. (Professor Emeritus\textsuperscript{1})
Brune, C. R. (Research Assistant Professor)
Champagne, A. E. (Professor)
Clegg, T. B. (Professor)
De Braekeleer, L. (Assistant Professor)
Gould, C. R. (Professor)
Haase, D. G. (Professor)
Howell, C. R. (Associate Professor)
Iliadis, C. (Assistant Professor)
Karwowski, H. J. (Professor)
Ludwig, E. J. (Associate Director, Professor)
Merzbacher, E. (Professor Emeritus)
Mitchell, G. E. (Associate Director, Professor)
Moore, E. F. (Assistant Professor)
Roberson, N. R. (Associate Director, Professor)
Seagondollar, L. W. (Professor Emeritus)
Seely, M. L.\textsuperscript{2} (Research Assistant Professor)
Tilley, D. R. (Professor)
Tornow, W. (Director, Research Professor)
Walter, R. L. (Professor)
Weller, H. R. (Professor)
Wilburn, W. S.\textsuperscript{3} (Research Assistant Professor)

\textsuperscript{1}Since 3/97
\textsuperscript{2}Since 10/96 at TJNAF
\textsuperscript{3}Since 12/96 at LANL
Personnel

TUNL Advisory Committee

Balamuth, D. P.  University of Pennsylvania
Bakunkekin, A. B.  University of Wisconsin
Friar, J. L.  Los Alamos National Laboratory
Garvey, G. T.  Los Alamos National Laboratory
Vigdor, S. E.  Indiana University

Associated Faculty

Fletcher, K. A.  State University of New York, Geneseo
Jackson, C. R.  North Carolina A & T State University
Prior, R. M.  North Georgia College and State University
Shriner, J. F.  Tennessee Technological University
Soldi, A.  North Carolina Central University

Research Staff

Blackmon, J. (Research Associate)  UNC
Crowe, B. (Research Associate)  UNC, Duke
Hansper, V. (Research Associate)  UNC
Kalbach Walker, C. (Senior Research Scientist)  Duke
Kelley, J. (Research Associate)  Duke
Lemaitre, S. (Research Associate)  UNC
Spraker, M. (Research Associate)  Duke
Wallace, P. 1 (Research Associate)  Duke
Westerfeldt, C. (Research Scientist, Radiation Safety Officer)  Duke

Technical Support Staff for TUNL

Carter, E. P.  Accelerator Supervisor
Cheves, C. M.  Project Coordinator
Johnson, K. M. 2  Research Secretary
Dunham, J. D.  Accelerator Technician
Edwards, S. E.  Computer Maintenance Supervisor

1Since 1/97 at Hampton-Sydney College, VA
2left 2/97
Gibson, P. M.  
Muilkey, P. H.  
O’Quinn, R. M.  
Pulis, H. E.  
Rogers, M. V.  

Staff Assistant  
Electronics Technician  
Accelerator Technician  
Research Secretary  
Editorial Assistant  

Graduate Students

Beal, W.  
Bertone, P.  
Braun, R.  
Canon, S.  
Chen, Q.  
Crawford, B.  
Crowell, A.  
Fisher, B.  
Geist, W.  
Godwin, M.  
Gonzalez, D.  
Grossman, C.  
Hale, S.  
Holzknuecht, K.  
Junkin, D.  
Keener, G.  
McDevitt, D.  

NCSU  
UNC  
Duke  
Duke  
Duke  
Duke  
Duke  
UNC  
UNC  
Duke  
NCSU  
UNC  
Duke  
NCSU  
UNC  
Duke  
NCSU  

McLean, L.  
Leonard, D.  
Novotny, S.  
Poole, J.  
Powell, D.  
Raichle, B.  
Rice, B.  
Roper, C.  
Sabourov, K.  
Salinas, F.  
Schreiber, E.  
Veal, K.  
Walston, J.  
Wood, M.  
Wulf, E.  
Wymore, M.  

NCSU  
UNC  
UNC  
NCSU  
Duke  
Duke  
Duke  
NCSU  
UNC  
Duke  
NCSU

Visiting Scientists

Timothy Black  
Rob Cavallo  
Roland Diehl  
Kurt Fletcher  
Victor Huhn  
Vladimir Hnizdo  
Alejandro Kievsky  
Mahmoud Nagadi  
Gaylon Ross  

10/96  
3/97  
6/97  
7/97  
5/97  
7/97  
10/96  
4/97  
7/97  

IUCF  
University of Maryland  
MPI Garching, Germany  
SUNY-Genesee  
University of Bora, Germany  
University of Witswatersrand, South Africa  
INFN, Pisa, Italy  
KFUPM, Dhahran, Saudi Arabia  
University of Central Arkansas  

\(^1\) graduated between Sept. 96 and Aug. 97
### Personnel

<table>
<thead>
<tr>
<th>Name</th>
<th>Time Frame</th>
<th>Institution/Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Krzysztof Russek</td>
<td>9/96</td>
<td>INS, Warsaw, Poland</td>
</tr>
<tr>
<td>Filip Santos</td>
<td>1/97–5/97</td>
<td>Lisbon, Portugal</td>
</tr>
<tr>
<td>Eduard Sharapov</td>
<td>6/97–8/97</td>
<td>JINR, Dubna, Russia</td>
</tr>
<tr>
<td>Joann Shriker</td>
<td>5/97–8/97</td>
<td>Tennessee Technological University</td>
</tr>
<tr>
<td>Ivo Slaus</td>
<td>11/96</td>
<td>Rudjer Boskovic, Zagreb, Croatia</td>
</tr>
<tr>
<td>Sharon Stephenson</td>
<td>5/97–8/97</td>
<td>Gettysburg College</td>
</tr>
<tr>
<td>Hongqing Tang</td>
<td>7/97–present</td>
<td>CIAE, Beijing, China</td>
</tr>
<tr>
<td>H.-P. Trautvetter</td>
<td>4/97</td>
<td>Ruhr-Universität Bochum, Germany</td>
</tr>
<tr>
<td>Lothar Wätzold</td>
<td>5/97</td>
<td>University of Bonn, Germany</td>
</tr>
<tr>
<td>Christian Weber</td>
<td>5/97</td>
<td>University of Bonn, Germany</td>
</tr>
<tr>
<td>Gary Weisel</td>
<td>4/97–7/97</td>
<td>State College, PA</td>
</tr>
<tr>
<td>Henryk Witala</td>
<td>9/96, 8/97</td>
<td>Jagellonian University, Cracow, Poland</td>
</tr>
</tbody>
</table>

### Temporary Student Personnel

- Yamamoto, Y. - Duke

### Undergraduates

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution/Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burton, A.</td>
<td>NCA&amp; T</td>
</tr>
<tr>
<td>Cox, J.</td>
<td>Tennessee Tech. Univ.</td>
</tr>
<tr>
<td>Fennall, S.</td>
<td>NCCU</td>
</tr>
<tr>
<td>Ganzhorn, S.</td>
<td>NCSU</td>
</tr>
<tr>
<td>Goldsmith, C.</td>
<td>Duke</td>
</tr>
<tr>
<td>Kehler, B.</td>
<td>UNC</td>
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<tr>
<td>Knight, J.</td>
<td>Tennessee Tech. Univ.</td>
</tr>
<tr>
<td>Lokitz, S.</td>
<td>Lipsaps</td>
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<tr>
<td>Marsh, S.</td>
<td>UNC</td>
</tr>
<tr>
<td>Messimore, J.</td>
<td>NCSU</td>
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<tr>
<td>Reisner, W.</td>
<td>Reed College</td>
</tr>
<tr>
<td>Sensoy, B.</td>
<td>Duke</td>
</tr>
<tr>
<td>Tornow, T.</td>
<td>Duke</td>
</tr>
<tr>
<td>Zeibel, J.</td>
<td>Duke</td>
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</tbody>
</table>