The Cyclotron Institute

A BRIEF OVERVIEW

The Texas A&M University Cyclotron Institute, a Department of Energy University Facility, is jointly supported by DOE and the State of Texas and is a major technical and educational resource for the State and the Nation.

At the Institute we focus on conducting basic research, educating students in accelerator-based science and technology, and providing technical capabilities for a wide variety of applications in space science, materials science, analytical procedures and nuclear medicine. Approximately 100 Institute members – scientists, engineers, technicians, support staff, graduate students and undergraduate students – are involved in these programs.

Internationally recognized for its research contributions, the Institute provides the primary infrastructure support for the University's graduate programs in nuclear chemistry and nuclear physics.

Institute staff constructed, and now operate, our K500 superconducting cyclotron and its advanced ECR ion sources. Together, these provide a powerful arsenal of intermediate-energy projectiles for use in both fundamental and applied studies. A large complement of sophisticated state-of-the-art detectors and spectrometers provides the associated instrumentation necessary for modern research in the areas of nuclear structure, weak interactions, exotic nuclei, nuclear astrophysics, intermediate-energy reaction dynamics, nuclear thermodynamics, the nuclear equation of state, atomic physics and applied nuclear science. In addition to housing the locally based program, the Institute also serves as a technical support base for collaborative research programs at other major national and international accelerator facilities. Institute research accomplishments are detailed in the over 50 papers per year published by Institute scientists in leading scientific journals.

As an important national resource for accelerator-based science and technology, the Cyclotron Institute welcomes appropriate use of its facilities. Potential users of the facility are encouraged to contact:

Professor R. E. Tribble, Director
Cyclotron Insitute
Texas A&M University
College Station, TX 77843-3366
Phone: (979) 845-1411
Fax: (979) 845-1899
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IN THE BEGINNING...

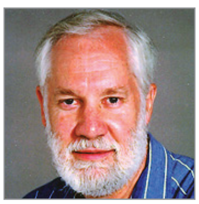
Texas A&M faculty and staff (top) began constructing the Cyclotron Institute (bottom) in 1965 and dedicated the 88" cyclotron two years later.

In 1987 the Institute's current mainstay, a K500 Superconducting Cyclotron – one of only five in the world – became operational. Though now idle, the 88" cyclotron will be recommissioned as part of a planned facility upgrade.

Graduate Faculty

Members of the graduate faculty having research programs based at the Cyclotron Institute are listed below together with their departmental affiliations and major areas of research interest. Students wishing to carry out their dissertation research at the Cyclotron Institute must be formally enrolled in the graduate program of either the Department of Physics or the Department of Chemistry, but may elect to work with any Institute faculty research advisor, irrespective of that advisor's departmental affiliation.* Research programs at the Cyclotron Institute are funded by the U.S. Department of Energy, the National Science Foundation, and the Robert A. Welch Foundation.

Carl A. Gagliardi
PHYSICS
Fundamental interactions and nuclear astrophysics
- *Fellow, American Physical Society*



John C. Hardy
PHYSICS
Fundamental interactions and exotic nuclei
- *Fellow, Royal Society of Canada*
- *Fellow, American Physical Society*

Che Ming Ko
PHYSICS
Theoretical hadron physics and heavy-ion collisions
- *Humboldt Research Award*
- *Fellow, American Physical Society*

Joseph B. Natowitz
CHEMISTRY
Heavy-ion reaction dynamics and thermodynamics
- *ACS Award in Nuclear Chemistry*
- *Fellow, American Physical Society*

Richard P. Schmitt
CHEMISTRY
Nuclear reaction mechanisms

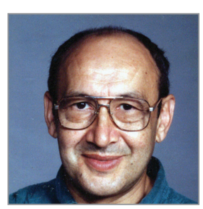
Shalom Shlomo
PHYSICS
Theoretical Nuclear Physics
- *RIKEN Eminent Scientist Award*
- *Fellow and Chartered Physicist, Institute of Physics*

Robert E. Tribble
PHYSICS
Fundamental interactions and nuclear astrophysics
- *Alfred P. Sloan Foundation Fellowship*
- *Fellow, American Physical Society*

Rand L. Watson
CHEMISTRY
Interaction of highly-charged ions with matter
- *Association of Former Students Distinguished Achievement Award in Teaching*

Sherry J. Yennello
CHEMISTRY
Heavy-ion reactions and isospin studies
- *NSF National Young Investigator*
- *University Faculty Fellow*

Dave H. Youngblood
PHYSICS
Giant resonances and nuclear matter
- *Fellow, American Physical Society*

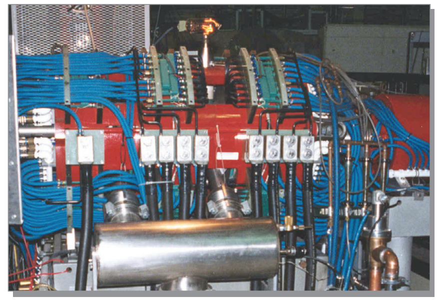


Akram Zhanov
PHYSICS
Theoretical astrophysics, few-body problems and atomic charge transfer and ionization processes

**More information on the application process for the graduate program is on the back cover of this document.*

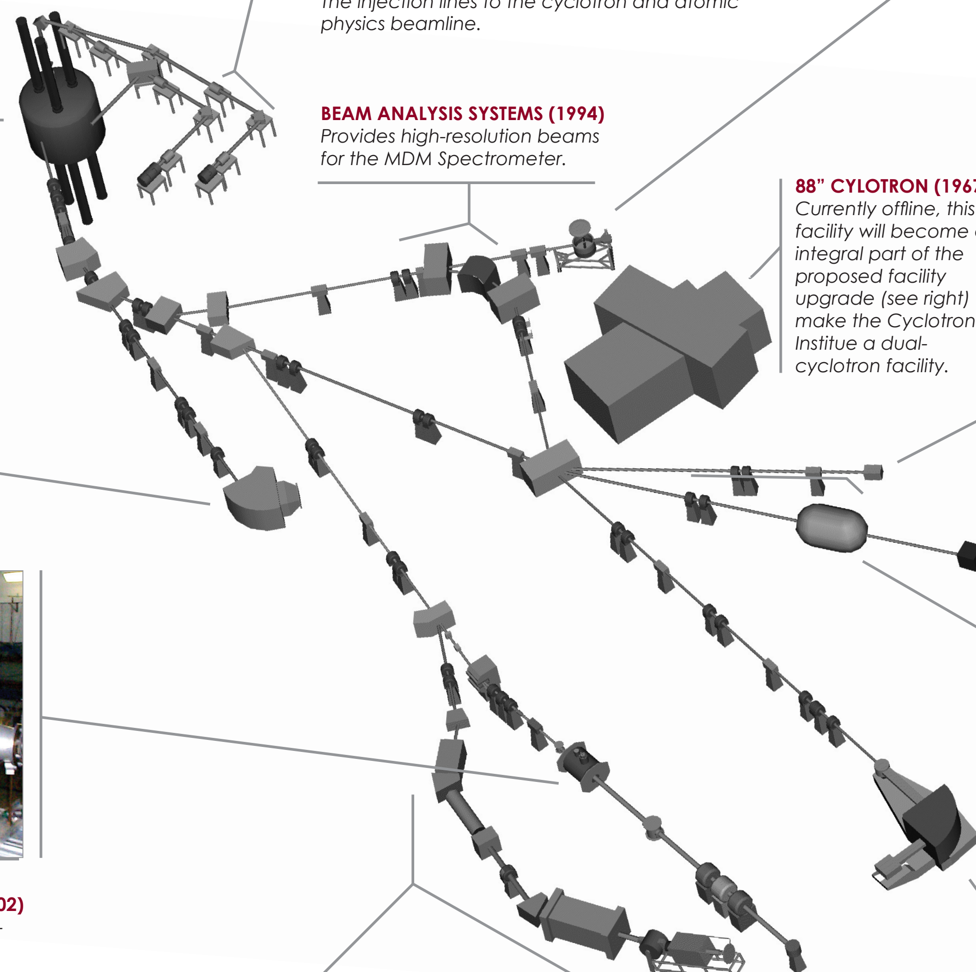
Facility Schematic

The Cyclotron Institute has expanded steadily since commissioning its original cyclotron in 1967. The diagram below shows the variety of sophisticated detectors and spectrometers that now enhance the Institute's capacity for nuclear research.



ELECTRON CYCLOTRON RESONANCE (ECR) ION SOURCES (2002)
The injection lines to the cyclotron and atomic physics beamline.

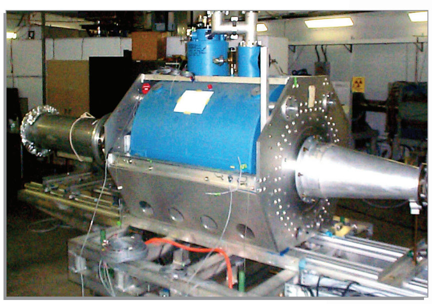
K500 SUPERCONDUCTING CYCLOTRON (1987)
The Cyclotron Institute at Texas A&M University operates one of only five K500 superconducting cyclotrons in the world.



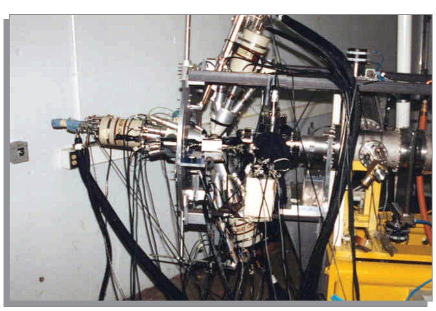
BEAM ANALYSIS SYSTEMS (1994)
Provides high-resolution beams for the MDM Spectrometer.

88" CYLOTRON (1967)
Currently offline, this facility will become an integral part of the proposed facility upgrade (see right) to make the Cyclotron Institue a dual-cyclotron facility.

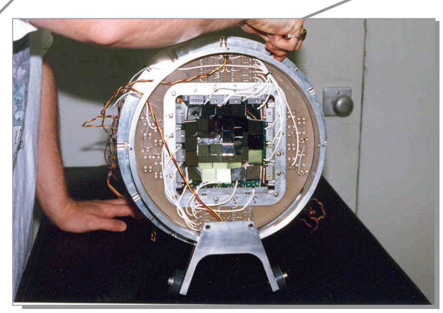
PROTON SPECTROMETER (1992)
Large solid-angle magnetic spectrograph optimized for the detection of multiple correlated particles.



BIG SOL: UNIVERSITY OF MICHIGAN 7-TESLA SUPERCONDUCTING SOLENOID MAGNET (2002)
Large acceptance collector for radioactive-ion work.

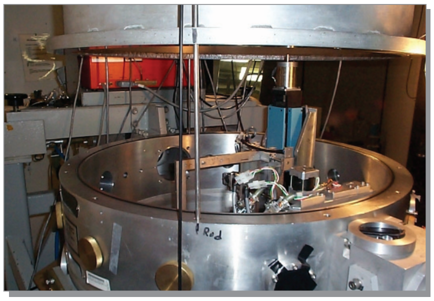


MARS RECOIL SPECTROMETER (1992)
Spectrometer for production and separation of radioactive ions

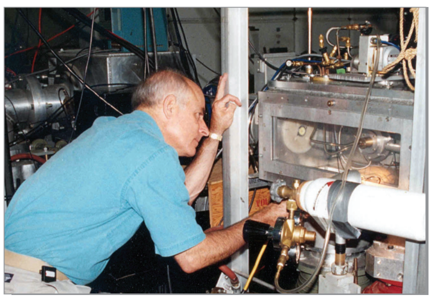


FAUST (1997)
Forward array capable of isotopic resolution.

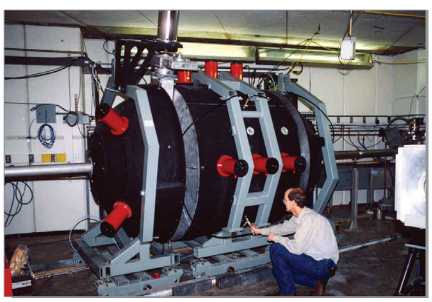
PRECISION ON-LINE γ-DECAY FACILITY (1999)
Isolates pure samples of short-lived isotopes for high-precision decay measurements.



RADIATION EFFECT FACILITY (1994, 2000)
Available for commercial, governmental and educational use, the testing facility is installed on a dedicated beam line with complete diagnostic equipment and controls. With the modern K500 superconducting cyclotron and the advanced ECR ion source, a diverse range of particle beams and energies is available for radiation-effects testing.



ION INTERACTIONS LINE (1995)
Gas jet and time-of-flight system for recoil-ion momentum spectroscopy



NIMROD (1999)
High efficiency detection of both neutrons and charged particles

MDM SPECTROMETER (1993, 2000)
High-resolution, broad-range spectrometer.

FACILITY UPGRADE

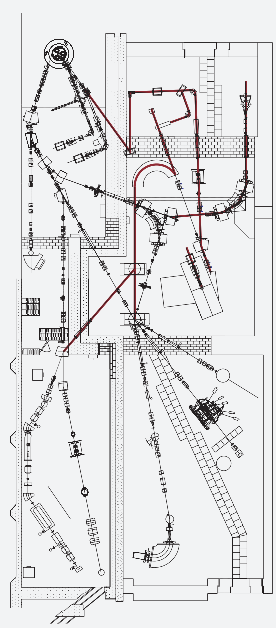
Recently, our capabilities for production of exotic beams and isolation of rare nuclei were expanded with the installation of the BigSol beam line, which employs the University of Michigan 7-Tesla Superconducting Solenoid Magnet, BigSol, as a spectrometer and filter of reaction products.

New programs being initiated with this device include studies of exotic beam production in deep-inelastic reactions, isospin equilibration in reactions with exotic beams, and mechanisms of heavy element production. It will also be used for work on collection, transport and ionization of radioactive species for re-acceleration as part of TAMU development efforts for the proposed national Rare Isotope Accelerator (RIA).

RIA has been designated the highest priority new construction project by the American nuclear physics community.

These development efforts are also central to the realization of a proposed upgrade of the TAMU accelerator facility. This upgrade is described in greater detail in a white paper found at:

http://cycnt.tamu.edu/facility_upgrade.htm



41,586 SQ

— new equipment

2002 CORYELL AWARD

Sean Liddick (*right*) was the recipient of the 2002 Coryell Award given by the Division of Nuclear Chemistry and Technology of the American Chemical Society. Sean worked with Sherry Yennello as an undergraduate on the isospin dependencies in fragment emission from Fe and Ni reactions. This work also was the basis of his senior honors thesis. Sean went on to pursue a Ph.D. at Michigan State University.

FACULTY AWARDS

Robert E. Tribble (left), Professor of Physics, was awarded the Association of Former Students Distinguished Achievement Award for Research in 2002. This award recognized Tribble's research accomplishments that "exemplify leadership in the field of physics."

Carl Gagliardi (right),Professor of Physics, was awarded the Association of Former Students Distinguished Achievement Award for Teaching in 2001. This award recognized Carl as " an inspiration, a mentor and a model for his students."

Research Program

OVERVIEW

The Institute research program focuses on the atomic nucleus, a many-body system of strongly interacting constituents bound together by the strongest forces known in nature. The properties investigated often can be described in terms of the motions of single nucleons (neutrons and protons), the correlated motions of several nucleons, and the collective motions of many nucleons. On a finer scale, they can be understood in terms of the degrees of freedom of quarks and gluons, the nucleon constituents. Nuclei are very rich in a fascinating array of phenomena associated with the interactions of these underlying constituents.

In addition to providing a fundamental understanding of nuclear properties, research in nuclear science contributes both insights and techniques to a number of related scientific disciplines, for example, astrophysics, elementary particle physics, atomic/molecular physics, and condensed-matter physics. Nuclear science techniques are also very important in a broad range of analytical, medical, materials science, and energy-producing applications.

Aided by advances in the technology of accelerators, computers, and detector systems, the frontiers of nuclear science continue to expand. The facilities available at the Cyclotron Institute provide a rich variety of opportunities for graduate research. Much of the current activity at the Institute is focused on studies in the following general areas:

(a) Collective properties of the nucleus – physical phenomena associated with deformation, oscillation, rotation, or fission of the nucleus.

(b) Reaction dynamics and properties of nuclei under unusual conditions created by increased angular momentum, excitation energy, and temperature and by changes in the neutron/proton ratio.

(c) Nuclear astrophysics – laboratory determinations of rates of reactions important in stellar processes.

(d) Tests of the minimal Standard Model of the weak, electromagnetic and strong interactions.

(e) Nuclear structure and reactions – phenomena associated with the nucleon degrees of freedom described in terms of a strongly interacting many-body system.

(f) Theoretical description of nuclear phenomena in terms of quarks and gluons.

(g) Properties and propagation of hadrons in the nuclear medium.

(h) Atomic and molecular collisions with fast, highly charged ions.

Brief descriptions of programs currently in progress at the Cyclotron Institute are provided on the following pages.

1. HEAVY-ION REACTIONS

The availability of energetic, light- and heavy-ion beams from the K500 Superconducting Cyclotron provides many possibilities for exploring new aspects of nuclear behavior. Using a wide variety of projectiles and bombarding energies, we achieve a more detailed understanding of the dynamics of nuclear collisions, casting new light onto the temporal evolution of quantal systems under a broad range of conditions and yielding fertile testing grounds for theories of many-body systems, chaotic-regime dynamics and the statistical mechanics of strongly-interacting, finite systems. At the same time, we investigate the properties and the decay modes of nuclear systems up to their very limits of thermal and rotational stability.

Advanced instrumentation plays a key role in these investigations. A 4π neutron and charged-particle detection system, NIMROD, and FAUST, a forward array capable of isotopic resolution, are used to study these collisions. Dynamic and thermodynamic information is derived from the observed multiplicities, energies, angular distributions and isotopic composition of the particles and fragments produced.

Besides the obvious implications of an improved understanding of nuclear behavior, reaction-mechanism studies can profoundly impact other areas of science. In particular, thermodynamic information concerning the behavior of nuclear systems derived from these investigations can shed light on the nuclear equation of state. This yields important input data required to solve problems in nuclear astrophysics, such as the Big Bang, stellar evolution and the dynamics of supernova explosions.

2. FUNDAMENTAL INTERACTIONS

The Standard Model, which unifies the strong, electromagnetic and weak forces, has been remarkably successful in describing the interactions of quarks and leptons. However, the model is incomplete, and it is the goal of this research program to sensitively probe its limits. Though in most cases we use the nucleus as a micro-laboratory for testing the Standard Model, the implications of the results extend far beyond nuclear physics to particle and astrophysics. Texas A&M experiments use the unique capabilities of the MARS Spectrometer and the precision on-line γ-decay facility at the Cyclotron Institute, but also exploit the facilities at the Argonne National Laboratory and at the TRIUMF Laboratory in Canada.

Nuclear reactions can be used to synthesize radioactive isotopes, but the reactions themselves are not very specific – they produce many different isotopes at one time. MARS makes it possible to analyze reaction products from the cyclotron beam, separating one synthesized isotope from all the others produced, so that one selected radioactive decay can be studied without interference from unwanted activities. In this way, we make very precise measurements on the decay of short-lived isotopes that have been specially chosen for their sensitivity to the fundamental weak interaction.

We are now measuring “superallowed” β-decay in a particular set of nuclei to test both the constancy of the weak vector coupling constant and the Standard Model’s definitive predictions for quark mixing. We also use β-decay to probe for the presence of meson-exchange currents in nuclei.

Collaborative experiments are also underway with the Canadian Penning Trap (CPT) at Argonne National Laboratory. The CPT mass spectrometer is designed to set a new standard for precision in measurement of the atomic masses of unstable isotopes. Results from experiments there will tie in directly with complementary decay measurements made at the Institute, extending our superallowed β-decay probes of the Standard Model.

3. NUCLEAR ASTROPHYSICS

The deployment of new ground-based and satellite-based observatories, including the Hubble space telescope, has led to an explosion of information in astrophysics over the past decade, ranging from a glimpse at the earliest events in our universe to details about the continual evolution in stellar systems that surround us. Popular cosmology theories tell us that, within an instant after the Big Bang, nuclear synthesis has driven the evolution of the universe. To understand this evolution, we require information about a wide range of nuclear reactions, many of which involve an unstable nucleus capturing a proton or an alpha particle and transmuting to a new unstable nucleus. Until the recent advent of radioactive ion beams, any study of these reactions in the laboratory has been nearly impossible. We are using radioactive beams in the MARS Spectrometer to learn more about some of the important nuclear reactions governing the behavior and evolution of our own sun and other stars. Combining radioactive-beam induced reactions with conventional nuclear physics techniques, we are measuring reaction rates for proton-capture reactions such as $^7Be(p,\gamma)^8B$, which is the sole source of high energy neutrinos from our sun.

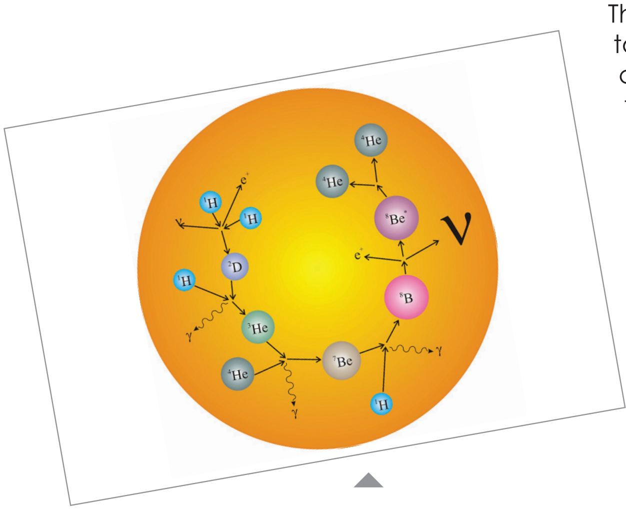
4. INTERACTION OF HIGHLY CHARGED IONS WITH MATTER

The interaction of high-energy heavy-ions with matter is a topic of importance in many areas of science. For example, the mechanisms whereby highly ionized atoms de-excite and return to charge neutrality are of great concern in the design of thermonuclear fusion reactors, where energy transfer to impurity ions injected from the walls of the containment vessel can seriously affect the plasma stability. The development of materials for use in outer space must take into account the destructive effects of cosmic rays. Such considerations are particularly important in the application of miniaturized semiconductor devices, and may ultimately limit the size scale of electronic circuits, both in space and on Earth. A detailed understanding of energy loss processes of heavy-ions is imperative in various applications of particle accelerators – including those relating to medical therapeutic techniques – and in the operation of ion storage rings.

Many of the important dynamic properties of highly charged ions may be investigated under the well-defined conditions possible through the use of a particle accelerator. The ECR ion sources and K500 cyclotron can provide beams of fully stripped ions up to Z=30 and heavier ions up to U^{65+}. This capability opens many exciting prospects for exploring the interactions of highly charged ions with atoms, molecules, and surfaces.

The atomic physics research program focuses on a variety of topics involving ion-atom and ion-molecule collisions, including (a) charge transfer mechanisms, (b) inner-shell ionization phenomena, (c) fragmentation of molecules, (d) charge-state equilibration in gases and solids, and (e) atomic structure of few-electron ions.

In addition to characterizing the fundamental properties of collisions involving highly charged ions, these studies supply data needed for applications in other fields, such as wavelengths of atomic transitions, line identifications, transition probabilities, and cross sections for ionization, excitation, and electron transfer. Spectra from foil-excited heavy-ion beams also contribute to the general understanding of atomic structure, and they provide the resonance line systematic required for plasma diagnostic purposes as well as for the interpretation of astrophysical phenomena. From the theoretical point of view, experiments with highly charged ions offer new possibilities for testing the accuracy of atomic structure calculations – especially those dealing with the effects of relativity, developing models of multi-electron exchange processes, and exploring the role of electron correlations.



$^7Be(p,\gamma)^8B$: A PROTON-CAPTURE REACTION

Nuclear astrophysics research measures reaction rates for proton-capture reactions such as $^7Be(p,\gamma)^8B$, which is the sole source of high energy neutrinos from our sun.

5. THEORETICAL NUCLEAR PHYSICS

Progress toward understanding the structure and behavior of strongly interacting many-body systems requires detailed theoretical study. The theoretical physics program concentrates on the development of fundamental and phenomenological models of nuclear behavior. In some systems, the nucleons move quite freely and independently, while in others they behave in a very cooperative and coherent manner. To understand this dichotomy and search for new modes of collective motion are central problems of contemporary many-body theory. Many of the theoretical techniques developed for such strongly interacting systems have proven to be very useful in other fields of physics, particularly condensed matter physics.

Characterization of the properties of nuclear matter under extreme conditions of density is a new frontier activity in nuclear science. The study of the very dense states of matter, which are expected to be created in the initial stages of heavy-ion collisions, is a tremendous theoretical and experimental challenge. The theoretical aspects of this problem are being examined with the objectives of understanding the hadron in-medium properties using models based on quantum chromodynamics and effective hadronic theories, developing a comprehensive theory for heavy-ion collisions, and proposing various signatures for hot dense nuclear matter and the quark-gluon plasma.

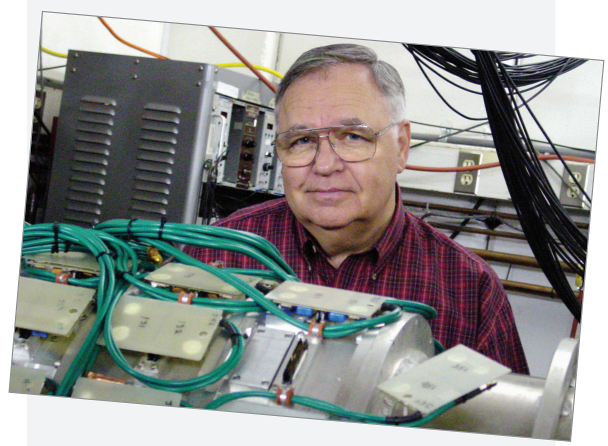
6. NUCLEAR STRUCTURE

Nuclear structure studies at the Institute explore a wide range of single-particle and collective properties of the nucleus. The most extensive study in this area is centered about the determination of the nuclear compressibility with measurements of the properties of giant resonance states in a variety of nuclei. The nuclear compressibility is a quantity of great importance to the understanding of the nuclear equation of state and plays a critical role in the evolution of heavy-ion induced reactions and of supernovae.

The dependence of nuclear compressibility on mass and neutron number is being explored through studies of the behavior of the Isoscalar Giant Monopole Resonance (breathing mode) excited by inelastic alpha particle scattering. The extension of these studies to unstable nuclei through inverse reactions is also being explored. The MDM Spectrometer and the National BaF_2 Array are employed in these experiments.

1999 DISSERTATION IN NUCLEAR PHYSICS AWARD

Eric Hawker was awarded the 1999 Dissertation in Nuclear Physics Award by the Division of Nuclear Physics of the American Physical Society for his work with Dr. Robert Tribble. The award recognized his major contributions to the measurement and analysis of the Drell-Yan cross section that made possible the first determination of the ratio of anti-up quark and anti-down quark densities in the nucleon as functions of the anti-quark momentum fraction. Dr. Hawker currently works at FERMILAB.



2002 BRIGHT CHAIR IN NUCLEAR SCIENCE

Joseph B. Natowitz, professor and nuclear chemist, is the inaugural holder of the Cyclotron Institute Bright Chair in Nuclear Science, one of 30 endowed chairs established at Texas A&M University through the H.R. "Bum" Bright Chair Matching Program.

External Collaborations

OVERVIEW

A number of research projects involving Institute scientists are carried out at other large national and international accelerator facilities in collaboration with groups from other universities and laboratories worldwide. Many of these are directly complementary to the local experimental program. Others, such as those discussed below, explore other frontiers.

1. RELATIVISTIC HEAVY-ION REACTIONS

Cyclotron Institute scientists carry out research within the BRAHMS and STAR collaborations at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. In collisions of ultra-relativistic heavy-ion beams at center-of-mass energies up to 200 GeV/nucleon pair, ordinary nuclear matter is predicted to undergo a phase transition to a quark-gluon plasma, a new state of matter that existed during the first second after the Big Bang. The BRAHMS group focuses on the study of very high rapidity phenomena, stringently testing theoretical models of the collision. Texas A&M participation in the STAR collaboration focuses on studies of high transverse momentum phenomena in ultra-relativistic nucleon-nucleus and nucleus-nucleus collisions and on studies of the spin of the proton. High transverse momentum particles produced very early in nucleus-nucleus collisions propagate through the high-density medium that is created. They may be used to determine the gluon density in the heavy nucleus and to provide essential normalization for the nucleus-nucleus measurements.

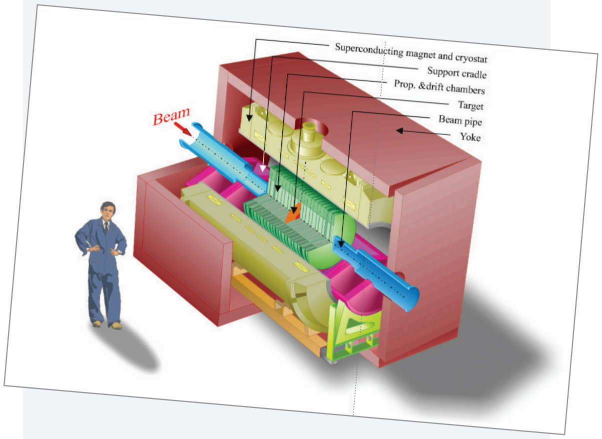
2. PROTON SPIN

The proton has a rich substructure including three valence quarks, the gluons that bind them together, and a "sea" of additional quark-antiquark pairs. Although the naïve quark model predicts that the valence quarks provide the spin angular momentum of the proton, detailed experiments have shown that the quarks actually contribute very little.

Most of the proton spin must be carried by the gluons or result from orbital angular momentum. To resolve this puzzle, the STAR experiment at RHIC will measure the polarization of gluons within the proton with high precision. TAMU is participating in the STAR spin-physics program and the construction of the STAR Endcap Electromagnetic Calorimeter, which will play a key role in the gluon polarization study.

3. MUON DECAY

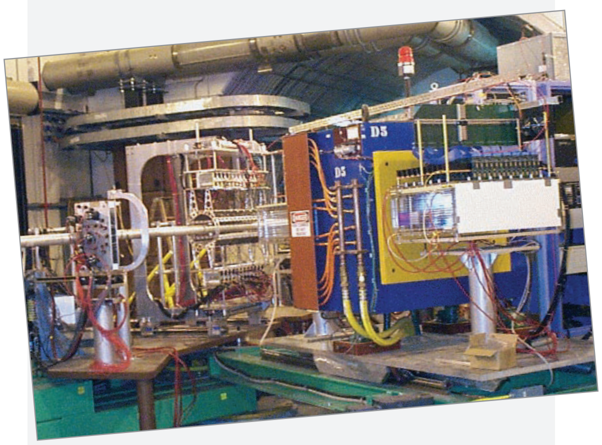
Institute scientists comprise one of the lead groups in an experiment to measure the Michel parameters in normal muon decay at the TRIUMF "meson factory" in Vancouver, British Columbia. The Michel parameters characterize the shape of the positron spectrum from the muon decay as a function of energy and angle. The Standard Model provides definite predictions for each of the Michel parameters, based on its assumption that the weak interaction is purely left-handed. Any deviation between the measured values and the predictions would be extremely important, since it would require the introduction of right-handed weak currents or other new physics outside the current Standard Model.



TWIST: PRECISION μ^+ DECAY

The distribution of e^+ energies and angles as emitted from muon decay is precisely predicted by the electroweak Standard Model.

TWIST, a collaboration of Institute scientists and others across the country, will test this model by making a precise map of this probability distribution.



BRAHMS: MID-RAPIDITY SPECTROMETER AND GLOBAL DETECTORS

The magnet (blue and labeled D5) is used to bend charged particles to provide a measure of their momentum. Particles are tracked in a time-projection chamber (TPC) in front of and behind the magnet. The global detectors around the beampipe provide event characterization. Beam-beam counters provide additional event characterization as well as a beam vertex determination.

Interested in working with the Cyclotron Institute?

FOR GRADUATE STUDENT APPLICATION INFORMATION:

Application information regarding enrollment in the graduate program may be obtained by writing the graduate advisor of your department or by contacting:

Professor Sherry Yennello, Cyclotron Institute, Texas A&M University, College Station, TX 77843-3366, PH: (979) 845-1411, E-MAIL: yennello@comp.tamu.edu

FOR COLLABORATION AND/OR RESEARCH INFORMATION:

As an important national resource for accelerator-based science and technology, the Cyclotron Institute welcomes appropriate use of its facilitites. In addition to its primary role, that of research and education in nuclear science, the Texas A&M Cylotron Institute also provides important technological capabilites for applications of nuclear techniques in other areas.

Institute facilities have been used for cancer therapy, radiation dosimetry, studies of plant physiology, precise analytical determinations, development of mass-spectrometric techniques, studies of "high T" superconductors, evaluation of nuclear waste transmutation techniques and simulation of cosmic-radiation-induced effects on microelectronic circuits.

Potential users of the facility are encouraged to contact:

Professor R. E. Tribble (Director), Cyclotron Insitute, Texas A&M University, College Station, TX 77843-3366, PH: (979) 845-1411, FX: (979) 845-1899, E-MAIL: tribble@comp.tamu.edu

FOR MORE INFORMATION ABOUT THE CYCLOTRON INSTITUTE

For all other inquiries, please see our website at: **http://cyclotron.tamu.edu**.