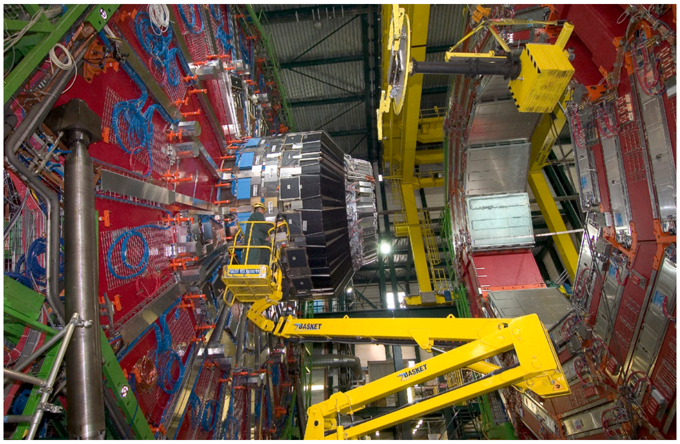
Laboratory for Nuclear Science

The Laboratory for Nuclear Science (LNS) provides support for research by faculty and research staff members in the fields of particle, nuclear, and theoretical plasma physics. This includes activities that take place at the Bates Linear Accelerator Center and the Center for Theoretical Physics. Almost half of the Department of Physics faculty conducts research through LNS. During FY2010, total research funding provided by the Department of Energy, the National Science Foundation, the Army Research Office, and other sources was $23 million. LNS plans to host the triennial Particles and Nuclei International Conference in July 2011. This date happens to mark the centennial of the discovery of the atomic nucleus by Ernest Rutherford.

Experimental Particle Physics

LNS researchers in experimental high-energy particle physics are active at several laboratories, including CERN in Geneva, Switzerland, and Fermi National Accelerator Laboratory (Fermilab) in Illinois. The overall objective of current research in high-energy particle physics is to test as precisely as possible the Standard Model, which has been very successful in describing a wide variety of phenomena, and to seek evidence for physics beyond the Standard Model. LNS researchers are playing principal roles in much of this research.

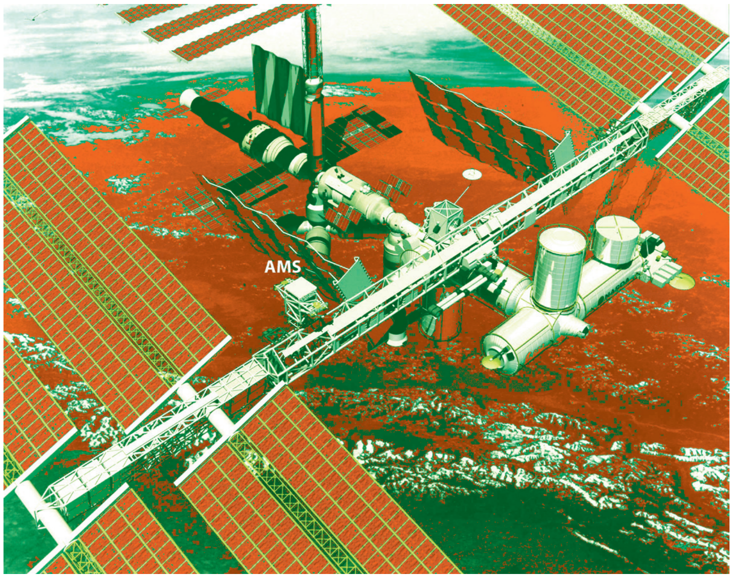
LNS researchers are playing a major role in the Compact Muon Solenoid (CMS) Experiment and the ATLAS Experiment at the Large Hadron Collider (LHC) at CERN in Geneva, Switzerland. These experiments have begun taking data that probes the high-energy frontier in physics and will search for new physics beyond the Standard Model. In CMS, LNS scientists are engaged in data acquisition and distribution systems; in ATLAS, the effort is concentrated mainly on the muon detection systems. Also, LNS scientists are leading the program to study high-energy heavy-ion collisions with CMS. A small effort is continuing with the Collider Detector at Fermilab (CDF) as a result of the extended delay incurred in the commissioning of the LHC. Both the CDF effort and the initial LHC effort are focused on detecting the Higgs particle, which is a key to the puzzle of how particles develop mass.



Installation of Muon Endcap Station 1 on YE+1

LNS researchers are active in developing experimental techniques, including development of unique detectors used to search for dark matter as well as research and development for the next generation of accelerators planned for high-energy physics beyond the LHC. There is a new research effort focused on the study of the fundamental properties of neutrinos.

The Alpha Magnetic Spectrometer (AMS) Experiment is designed to look for cosmic antimatter and evidence for dark matter by operating a large magnetic spectrometer above the earth's atmosphere. The international AMS collaboration is composed primarily of particle physicists and is led by an LNS group. An upgraded version of the AMS spectrometer is undergoing final assembly, with the experiment scheduled for a launch to the International Space Station in February 2011, followed by a several-year data-taking period.

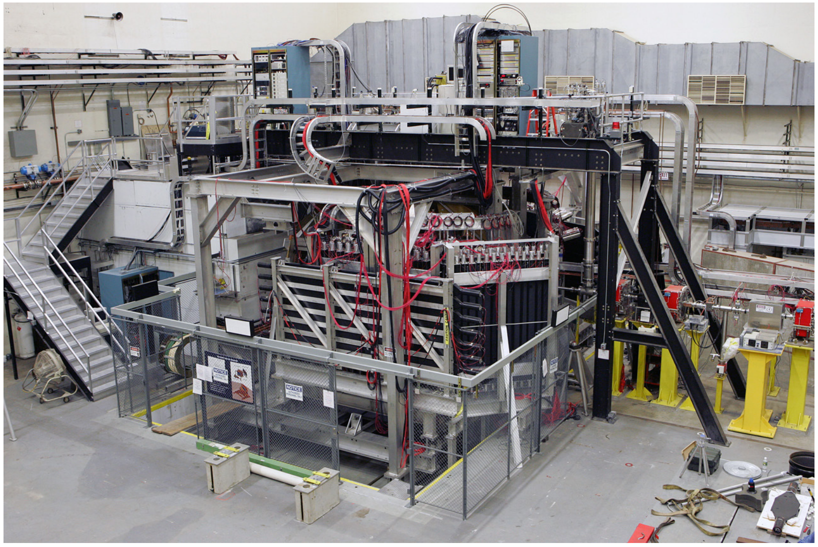


Alpha Magnetic Spectrometer on the International Space Station

Experimental Nuclear Physics

At present, experimental nuclear physics has three main thrusts: hadronic physics, heavy-ion physics, and nuclear structure/fundamental properties. LNS has active, leading groups in all of these subfields.

For the past three decades, the focus of LNS activities in hadronic physics has been the Bates Linear Accelerator Center, operated by LNS for the US Department of Energy as a national user facility. In 2005, Bates transitioned from a national user facility for nuclear physics to a MIT-LNS Research Center. The Department of Energy supports a research and engineering center where LNS faculty and their groups develop new instrumentation for frontier research. In addition, research using particle accelerators is a major focus at Bates, with MIT scientists developing and designing new accelerators for both fundamental and applied investigation. Data taken at Bates with the Bates Large Acceptance Spectrometer Toroid (BLAST) detector in 2003–2005 provided precision data on nucleon structure. LNS researchers are assembling a new experiment, OLYMPUS, at DESY (Deutsches Elektronen-Synchrotron) in Hamburg, Germany, to use BLAST to determine fundamental aspects of electron scattering from the proton. A new high performance research computing facility has recently been completed at Bates for analysis of data from the LHC and from the Laser Interferometer Gravitational Wave Observatory Experiment and for other researchers at MIT. In addition, several projects which utilize low energy accelerators are in preparation at Bates.



Bates Large Acceptance Spectrometer Toroid

LNS nuclear physics researchers are leading several important efforts at accelerator facilities other than Bates. These facilities include the Thomas Jefferson National Accelerator Facility in Virginia, the Spallation Neutron Source at Oak Ridge National Laboratory, and DESY in Germany. The main thrust of these experiments is a detailed understanding of the properties of the proton, the neutron, and light nuclei. A new initiative in hadronic physics involves an investigation of the spin structure of the proton using the Solenoidal Tracker (STAR) detector in polarized proton-proton collisions at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory on Long Island, NY. Recent results suggest that the contribution by virtual antiquarks inside the proton towards the spin of the proton will be able to be measured through the detection of charged W-bosons in polarized proton-proton collisions.

LNS researchers are prominent in relativistic heavy-ion physics. The principal goal of this field has been to investigate the existence and properties of the quark-gluon plasma (QGP), a state of matter that exists at temperatures and densities vastly higher than those present in normal matter and that may have been present in the very early universe. The MIT Heavy Ion Group has completed data taking with its PHOBOS experiment at RHIC and has transitioned to the CMS experiment at CERN. An important result of this research is the discovery that the QGP is essentially a perfect liquid with an extremely small viscosity; theorists at LNS-CTP have been able to calculate this viscosity using string theoretic techniques, the first direct comparison of string theory methods with experiment.

In fundamental properties, LNS nuclear physicists have entered the area of neutrino studies, playing a leadership role in the Karlsruhe Tritium Neutrino (KATRIN) Experiment at Karlsruhe, Germany, which will make a new, extremely precise measurement of the mass of the electron neutrino.

Theoretical Nuclear and Particle Physics

Research at the Center for Theoretical Physics (CTP) seeks to extend and unify our understanding of the fundamental constituents of matter. It seeks to advance the conceptual foundations of fundamental physics, especially as applied to the structure and interactions of hadrons and nuclei—new forms of matter that may be created experimentally or observed astrophysically—and the history and large-scale structure of the universe. A few examples of recent work are mentioned below.

String theory aims to unite the strong, electroweak, and gravitational interactions and to explain the observed hierarchy of particles and interactions. CTP has a strong and diverse group in string theory with important ties to particle physics. Important work includes the study of instabilities of "branes"—extended objects that occur in string theory—and their implications for field theories of strings. CTP theorists are also actively exploring matrix quantum mechanics, which may be the fundamental structure that unifies various versions of string theory, and studying tantalizing connections between string theories in anti-de-Sitter space and conformal quantum field theories.

String theories suggest patterns of super symmetry breaking, which may have implications for physics at the energy scales of the next accelerators. CTP researchers have been exploring these patterns. Also, string theory and quantum gravity suggest that space–time may have other dimensions that influence physical phenomena only indirectly. Predicted effects include manifestations of extra dimensions at energies quite close to those currently available at accelerators.

MIT theorists have been actively developing calculational tools for studying nonperturbative phenomena in quantum field theories. Variational methods, consistent with renormalization and adapted for easy numerical computation, have been developed and are being applied to problems that arise in the Standard Model.

A major effort in CTP has been in the area of lattice gauge theory, which provides a unique tool to solve, rather than model, quantum field theories beyond perturbation theory. CTP led the development of a national collaboration on high-speed computation in quantum chromodynamics (QCD), which receives funding as part of the Department of Energy's Scientific Discovery through Advanced Computing initiative. These efforts parallel a new thrust in the study of QCD at finite density and pressure. CTP researchers have suggested novel effects, such as color superconductivity, and explained how they may be observed in heavy-ion collisions.

CTP researchers continue to lead exploration of the spin and flavor structure of hadrons as seen in experiments (many led by MIT faculty) at Bates, Jefferson Laboratory, DESY, and Brookhaven National Laboratory.

Finally, CTP has initiated important work in quantum computing. New algorithms that exploit the adiabatic approximation in quantum mechanics offer hope of solving generic problems much faster than classic methods.

Physics of High Energy Plasmas

This effort addresses a broad spectrum of subjects in areas that are relevant to fusion research, astrophysics, and space physics. Specifically LNS researchers are involved in identifying the properties and the dynamic of plasmas that are dominated by collective modes, emphasizing fusion-burning plasmas relevant to the upcoming generation of experiments and high-energy astrophysical plasmas.

Education

Since its founding, LNS has placed education at the forefront of its goals. At present, approximately 71 graduate students are receiving their training through LNS research programs. A number of undergraduate students are also heavily involved in LNS research. LNS has educated a significant portion of the leaders of nuclear and particle physics in this country and abroad.

A new summer research program for undergraduates has been initiated with Hampton University in Hampton, VA, a historically black college. Three undergraduates selected by Hampton spent two months at MIT working on the design of the next generation accelerator for the study of the fundamental structure of matter.

Richard G. Milner
Director
Professor of Physics

More information about the Laboratory for Nuclear Science can be found at http://web.mit.edu/lns/.