Laboratory for Nuclear Science

The Laboratory for Nuclear Science (LNS) provides support for research by faculty and research staff members in the fields of high-energy and nuclear physics. These activities include those at the Bates Linear Accelerator Center and in the Center for Theoretical Physics (CTP). Almost half the Department of Physics faculty conducts research through LNS. During fiscal year 2007, the Department of Energy is expected to provide LNS $22.5 million in research funding.

Experimental High-Energy Physics

LNS researchers in experimental high-energy physics are active at several laboratories, including CERN in Geneva, Switzerland; Stanford Linear Accelerator Center (SLAC) in California; and Fermi National Accelerator Laboratory (Fermilab) in Illinois. The overall objective of current research in high-energy 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 leading roles in the BaBar experiment at SLAC, which has yielded important insights into the nature of charge symmetry/parity violation in the B-meson system. LNS researchers are playing a major role in the installation and commissioning of the CMS and ATLAS detectors at the Large Hadron Collider (LHC) at CERN, Geneva. Starting in 2008, these experiments will probe the high-energy frontier in physics and will search for new physics beyond the Standard Model. In CMS, LNS scientists are engaged in developing the data acquisition system; in ATLAS, the effort is mainly in developing the muon detection systems. Also, LNS scientists are leading the program to study high-energy heavy-ion collisions with CMS (figure 1).

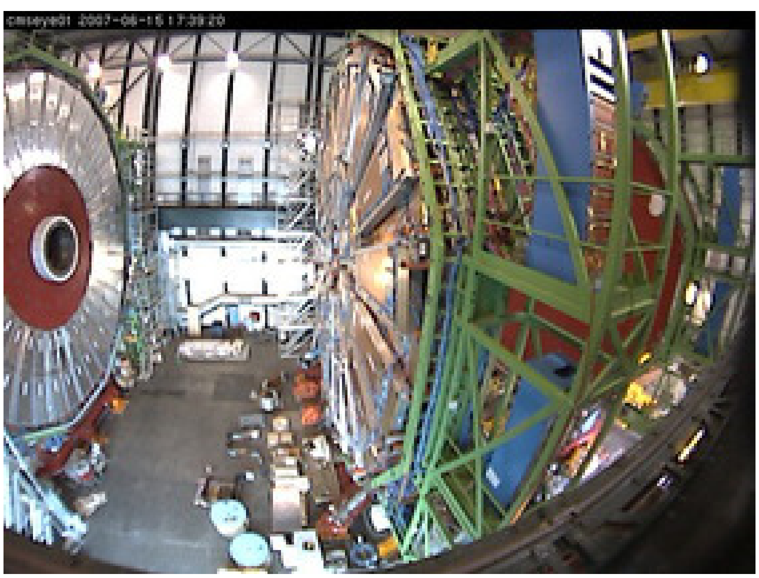

Figure 1: CMS construction at Point 5; image shows YE-3 closed

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 International Linear Collider, the machine planned for high-energy physics beyond the LHC.

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 under construction, and the experiment is scheduled for a several-year data-taking period on the International Space Station starting later in this decade (figure 2).

Experimental Nuclear Physics

Experimental nuclear physics at present has two main thrusts: hadronic physics and heavy-ion physics. LNS has active, leading groups in both of these subfields.

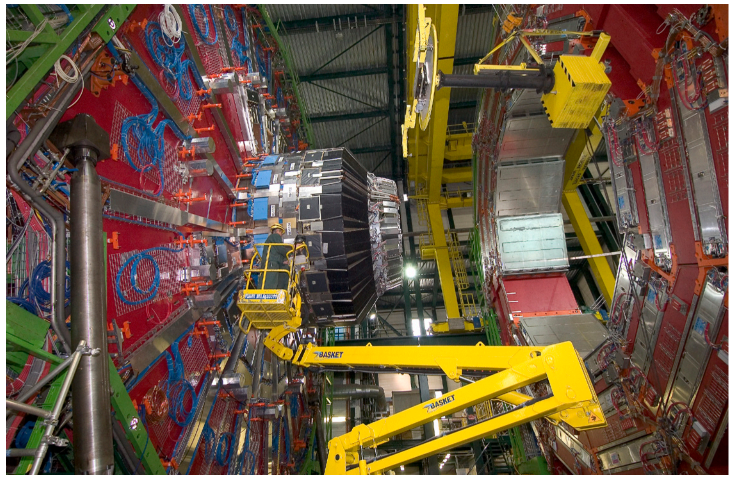

Figure 2: Alpha Magnetic Spectrometer (AMS) on the International Space Station

For the past three decades, the focus of LNS activities in hadronic physics has been the Bates Linear Accelerator Center, which is 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 detector in 2003–2005 are under analysis and have provided precision data on nucleon structure (figure 3).

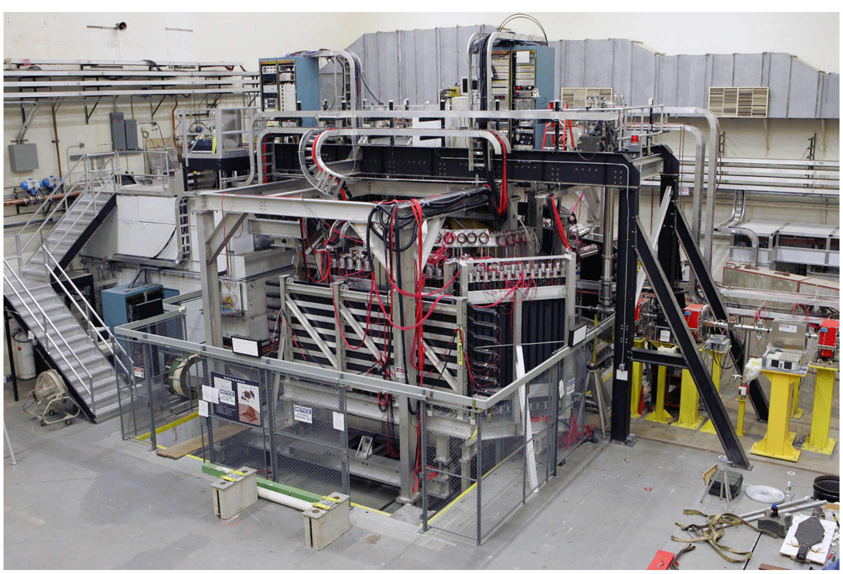

Figure 3: Bates Large Acceptance Spectrometer Toroid (BLAST)

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 Los Alamos Neutron Science Center in New Mexico, and Mainz 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 is an investigation of the spin structure of the proton using the STAR detector in polarized proton-proton collisions at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory.

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 so-called quark-gluon plasma, a state of matter that is predicted to exist at temperatures and densities 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.

LNS nuclear physicists are also entering the area of neutrino studies, playing a leadership role in a new, extremely precise measurement of the mass of the electron neutrino.

Theoretical Nuclear and Particle Physics

Research at the 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. The 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 supersymmetry 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 the 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. The 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, the DESY research center in Germany, and Brookhaven National Laboratory.

Finally, the 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.

Education

Since its founding, LNS has placed education at the forefront of its goals. Approximately 67 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 fraction of the leaders of nuclear and high-energy physics in this country and abroad.

Richard G. Milner
Director
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More information about the Laboratory for Nuclear Science can be found at http://www2.lns.mit.edu/.