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 at the Bates Linear Accelerator Center and the Center for Theoretical Physics. Almost half of the Department of Physics faculty conducts research through the LNS. During FY2011, total research funding provided by the US Department of Energy (DOE), the National Science Foundation, the Army Research Office, and other sources was $25.4M, an increase of more than $2M from the previous year, in part due to one-time stimulus funding through the American Recovery and Reinvestment Act of 2009. The LNS is hosting the triennial Particles and Nuclei International Conference in July 2011, a date that marks 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 Fermilab (the Fermi National Accelerator Laboratory) outside Batavia, IL. The overall objective of current research in high-energy particle physics is to test as precisely as possible the Standard Model of particles and forces, 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 and ATLAS experiments at the Large Hadron Collider, or LHC, at CERN. 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 the Compact Muon Solenoid experiment, LNS scientists are engaged in data acquisition and distribution systems; in ATLAS, the effort is concentrated mainly on muon detection systems. LNS scientists also are leading the program to study high-energy heavy-ion collisions with the Compact Muon Solenoid experiment. A small effort has continued with the Collider Detector at Fermilab until the end of operation of the Tevatron particle accelerator in September 2011. Both the collider detector and the initial LHC efforts are focused on detecting the Higgs particle, which is a key to the puzzle of how particles develop mass. Data collection at the LHC continues through 2012, followed by a major shutdown for a reliability upgrade to achieve the design collider energy.

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. The prototype Dark Matter Time Projection Chamber was installed in the underground laboratory at the DOE's Waste Isolation Pilot Plant near Carlsbad, NM, with a larger 1 m^3 detector under construction. This detector seeks direct detection of dark matter particles by observing recoiling nuclei from their collisions with gas molecules in the detector. In addition, researchers have begun new efforts to study the fundamental properties of neutrinos that involve the Booster Neutrino Experiment (MiniBooNE) and related experiments at Fermilab and at the Double Chooz reactor in France.

The Alpha Magnetic Spectrometer experiment (AMS-02) is designed to look for cosmic antimatter and evidence for dark matter by operating a large 6717 kg magnetic spectrometer above Earth's atmosphere. The international AMS collaboration consists of more than 500 scientists (primarily particle physicists) led by an LNS group. The AMS-02 spectrometer was launched on the shuttle *Endeavour*'s last mission, STS-134, to the International Space Station on May 16, and delivered to the space station on May 19. All systems are functioning as intended and data collection began shortly after arrival at the space station. Data collection by the AMS is planned for the next 10–18 years.

Experimental Nuclear Physics

At present, experimental nuclear physics has three main thrusts: hadronic physics, heavy-ion physics, and nuclear structure/fundamental properties. The 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 the LNS for the DOE as a national user facility. In 2005, Bates transitioned from a national user facility for nuclear physics to an MIT-LNS Research Center. The DOE 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 in 2003–2005 with the Bates Large Acceptance Spectrometer Toroid (BLAST) detector provided precision data on nucleon structure.

LNS researchers have assembled a new experiment, OLYMPUS, at the DORIS electron/positron storage ring at the Deutsches Elektronen-Synchrotron in Hamburg, Germany, to use BLAST to determine fundamental aspects of electron scattering from the proton. Data collection will begin this coming year. The high-performance research computing facility at Bates supports 71 water-cooled racks, each with up to 1 kW power, for LHC data analysis, for the Laser Interferometer Gravitational-Wave Observatory experiment, for ocean and climate modeling, and for other MIT research uses.

In addition, a compact synchrotron for proton cancer therapy, invented and developed by professor V.E. Balakin from the Lebedev Physics Institute, and further developed at Bates under a grant from ProTom International, will be installed at the McLaren Health Care Regional Medical Center in Flint, MI, this fall. This compact system is estimated to cost about one-third of traditional systems used for proton therapy, thus allowing for much greater use of this important technique. Systems for scanning cargo are being developed with industrial partners under grants from the US Department of Homeland Security.

LNS nuclear physics researchers are leading several important efforts at national accelerator facilities. These facilities include the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory in New York, the Thomas Jefferson National

Accelerator Facility in Virginia, and the Spallation Neutron Source at Oak Ridge National Laboratory in Tennessee. The main thrust of these experiments is a detailed understanding of the properties of the proton, the neutron, and light nuclei. An investigation of the spin structure of the proton is being made using the Solenoidal Tracker at RHIC (STAR) detector in polarized proton-proton collisions. A new detector subsystem for STAR, the Forward GEM Tracker, is nearing completion, with installation beginning this fall. This system will greatly increase the acceptance for detection of charged W-bosons; recent results from STAR suggest that the contribution by virtual antiquarks inside the proton toward 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, 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 Heavy Ion Group plays a leading role in the Compact Muon Solenoid experiment heavy-ion program. During the past year, the first Pb-Pb collision data were collected, with hydrodynamic flow observed even at these ultra-high collision energies, more than 10 times larger than at the RHIC. An important result of this research is the discovery that the quark-gluon plasma is essentially a perfect liquid; theorists at the LNS and the Center for Theoretical Physics (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 experiment at Karlsruhe, Germany, which will make a new, extremely precise measurement of the mass of the electron neutrino. Data collection is planned to begin in 2012.

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 to the history and large-scale structure of the universe. A few examples of recent work are mentioned below.

String theory aims to unite strong, electroweak, and gravitational force 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 also are 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 next-generation 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 DOE's Scientific Discovery through Advanced Computing initiative. These efforts parallel a new thrust in the study of QCD at finite density and pressure. Recent advances in computing power have allowed these calculations to be accomplished at the physical pion mass. The outstanding agreement of the theoretical calculations and the physically observed spectral properties of nucleonic systems has provided a convincing basis for our understanding of these systems using QCD, a long-sought result.

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, the Jefferson Laboratory, the Deutsches Elektronen-Synchrotron, and the 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.

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 dynamics of plasmas that are dominated by collective modes, emphasizing fusion-burning plasmas relevant to the upcoming generation of experiments, and high-energy astrophysical plasmas.

PANIC11

The LNS will host the 19th Particles and Nuclei International Conference in July 2011, with 539 registrants from 34 countries. Broad support for this conference was provided by the DOE, the National Science Foundation, national and foreign research laboratories, and MIT. The conference promises to be outstanding, both scientifically and organizationally, and a fitting tribute to the centennial of the discovery of the atomic nucleus by Lord Ernest Rutherford and the 65th anniversary of the founding of the LNS. During the conference, a reception will be held at the MIT Museum for MIT alumni conference attendees and friends of the LNS to celebrate the anniversary. A celebration of professor William Bertozzi's 80th birthday will be held in conjunction with the conference. Professor Bertozzi, who has supervised more than 50 graduate students and numerous postdoctoral associates, recently received the first Mentoring Award from the American Physical Society's Division of Nuclear Physics.

Education

Since its founding, the 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. The LNS has educated a significant portion of the leaders of nuclear and particle physics in this country and abroad.

A summer research program for undergraduates has been initiated with Hampton University in Virginia, a historically black college. Four undergraduates selected by Hampton are spending two months at MIT working on the design of a next-generation accelerator to study the fundamental structure of matter.

Personnel Transitions

Dr. Evgeni Tsentalovich was promoted to principal research scientist. Ernest Ihloff and James Crosby were promoted to research engineer. Lawrence McMahon became the head of the LNS fiscal office, replacing Arthur Scully, who continued half time. Andrew Gallant replaced the retiring Peter Morley as supervisor of the Central Machine Shop.

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