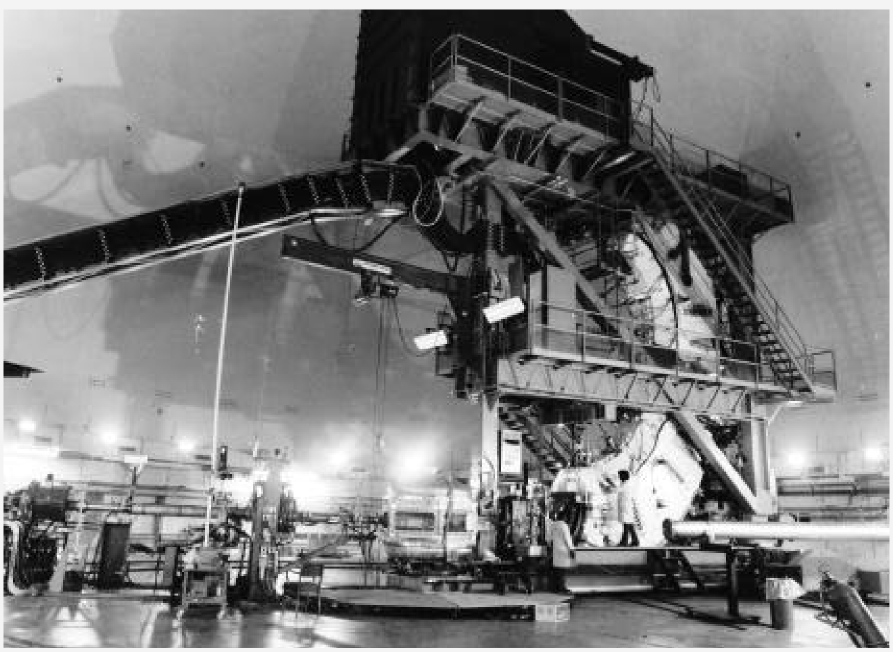
Medium-Energy Physics at LAMPF

Mikkel B. Johnson

The LAMPF accelerator provides primary beams of protons and negatively charged hydrogen ions as well as secondary beams of neutrons, pions, muons, and neutrinos. The uniqueness of LAMPF as an experimental facility derives from the high intensity of those beams and the consequent capability to exploit rare reactions to answer specific questions about particles and nuclei. Additionally, the high resolution of the spectrometers and other detectors available at LAMPF make precision measurements feasible. As a result, over the last twenty years LAMPF has helped to open up an entirely new field of basic research—medium-energy nuclear physics.

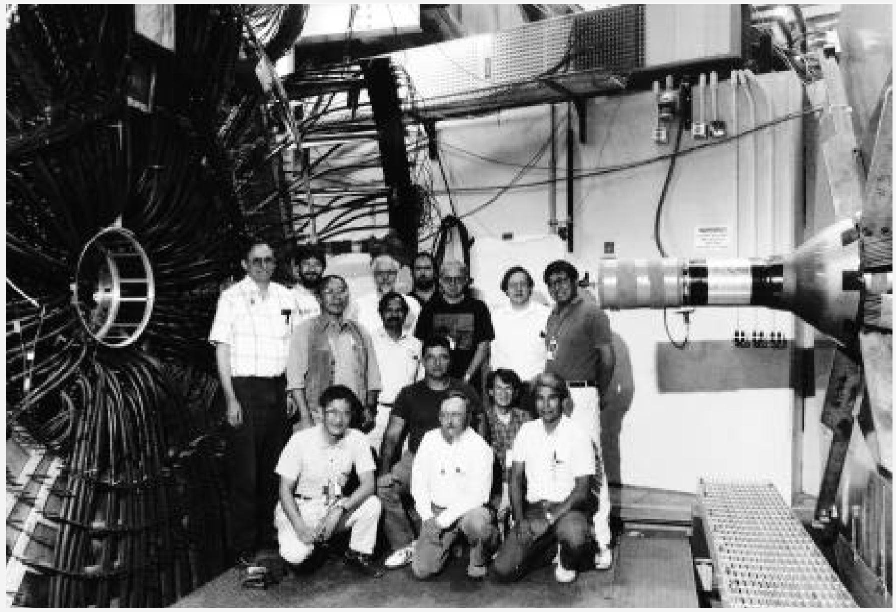
By using the tools available at LAMPF, nuclei can be explored in new ways. Experiments with muons, pions, and nucleons have quantified the size, shape, and composition of nuclear states and measured the response of nuclei to the addition of charge, energy, and momentum, as well as quanta of vibrational and rotational excitation. Some of the most interesting results have been obtained when the incoming particles cause the nuclei to respond in certain extreme ways. For example, in a pion double-charge-exchange experiment, nuclei can be forced to accept two units of charge at one time. Measurements of the dependence of the scattering cross section on the final state of the nucleus have led to a strikingly detailed picture of correlations in the motion of neutrons and protons. In addition, double-charge-exchange experiments have uncovered new modes of motion of nuclei in which two patterns of vibration coexist and have also led to the discovery and study of new nuclear species. In experiments with nucleon beams, nuclei have been forced to accept a small amount of energy and at the same time a large momentum in various spin configurations hitherto incapable of being distinguished. For reasons that are not completely understood but are being actively sought, theories that work well in more normal situations have been discovered to break down under those unusual conditions. And state-of-the-art studies in atomic physics have addressed previously inaccessible regions of the spectrum with a unique technique that combines a beam of laser light and a beam of negatively charged hydrogen ions.

Additionally, various scattering experiments and measurements of the decay products of muons and pions have focused on the nature of the underlying strong, weak, and electromagnetic interactions. Precision measurements with muons have yielded new insights into quantum electrodynamics. A sys-



The High-Resolution Proton Spectrometer at LAMPF. *This instrument, known as the HRS, is used to measure cross sections for elastic and inelastic scattering of protons from nuclei. Careful measurements with the HRS of the spin dependence of cross sections led to the widespread acceptance of relativistic descriptions of nuclear dynamics. HRS results also stimulated theoretical and further experimental investigations of how the nuclear medium affects the nucleon-nucleon interaction.*

tematic program extending over many years has completely mapped out the character of the nucleon-nucleon interaction over the entire energy range of LAMPF and has thus provided a bank of basic data for theorists and laid the foundation for interpreting nucleon-nucleus scattering experiments. An experiment using the world's most intense source of very-low-energy neutrons has led to development of a completely new technique for detecting a signature of breakdown of a fundamental symmetry in nuclear forces. The technique, which uses properties of complex nuclei to magnify the signal for the breakdown of parity (the mirror symmetry between left and right) by a factor of about 1 million, has uncovered unexpected results and opened a rich area of exploration. Other investigations of fundamental interactions include the scattering of neutrinos from various targets. Neutrinos interact so weakly that even experiments using the high-intensity neutrino beam available at LAMPF require several years to complete. One such experiment has provided the only available measurement of electron neutrino–electron scattering. The experimental results showed that the interplay predicted by the standard model between the charged and neutral parts of the electroweak interaction was indeed a reality. Therefore, since only the neutral part of the weak force is involved in the interaction of electrons with the muon neutrino or the tau neutrino, the interaction of the electron neutrino with electrons is fundamentally different from the interaction of the other neutrinos with electrons. That difference provides a possible explanation for the observed shortfall in electron neutrinos coming from the sun. Yet other experiments at LAMPF hunt for breakdowns of the standard model. Although none has been detected, the searches at LAMPF for the decay of a muon into an electron and gamma rays, which would herald such a breakdown, have consistently led the world in sensitivity.



The MEGA Detector at LAMPF. *This detector will be used in a search, scheduled to begin this summer, for the decay of a muon into an electron and a gamma ray. The occurrence of that reaction would signify a breakdown of the standard model. The sensitivity of the MEGA detector to the decay is two orders of magnitude greater than that of detectors used in previous searches.*

Experiments such as those mentioned above constitute some of the highlights of the contribution of LAMPF to nuclear science. They have provided answers to many specific questions and at the same time have paved the way for a slow but very important transformation in the way nuclear physicists think about their subject. Before the era of the meson factory, nuclei could be largely understood as a collection of nucleons undergoing nonrelativistic motion and interacting through potentials. That picture is no longer adequate to describe what the medium-energy beams "see" of nuclei. To understand the new data, the catalogue of constituents of nuclei has been enlarged to encompass mesons and excited states of nucleons themselves. Additionally, the picture of the dynamics of their motion has changed. Relativity can no longer be ignored, and interactions must be described in terms of the coupling of mesons to nucleons. Even today the picture is continuing to evolve as particle and nuclear physicists realize deeper connections between their once quite distinct fields. □

Mikkel B. Johnson, a Laboratory Fellow, has pursued research in theoretical nuclear physics at the Medium Energy Physics Division since 1972.