P-25: Subatomic Physics

Measurement of the Electric Dipole Moment of the Neutron

M. D. Cooper [(505) 667-2929], L. J. Marek, D. Tupa (P-25), M. A. Espy (P-21), S. K. Lamoreaux, S. I. Penttila, J. S. Sandoval (P-23), G. L. Greene (LANSCE-DO)

The Electric Dipole Moment (EDM) project is a new project in which we will develop an experiment to measure the EDM of the neutron. A nonzero value of the neutron's EDM would imply that a fundamental symmetry of space-time reversal has been violated. The only example of such a violation is in the neutral kaon system, although the violation is expected to be a general, but small, phenomenon. A measurement of the neutron's EDM is important for understanding the baryon-antibaryon asymmetry of the universe and for searching for physics beyond the standard model of electroweak interactions, especially grand-unified supersymmetry. We propose to take advantage of the construction of the Long Pulse Spallation Source at LANSCE to build a special superthermal source of ultracold neutrons that will allow us to measure the EDM to a level of 10^{-28} e•cm, an improvement of three orders of magnitude over past measurements. The international collaboration for this complicated experiment is just beginning to form, and development work is commencing in preparation for submitting a funding proposal to DOE at the end of 1998.

MEGA

M. D. Cooper [(505) 667-2929], M. Brooks, A. V. Chernyshev, G. W. Hart, G. E. Hogan, M. A. Kroupa, V. D. Laptev, D. M. Lee, G. B. Mills, R. E. Mischke (P-25), F. J. Naivar, C. Pillai, J. C. Sturrock (LANSCE-6), collaborators from Fermi National Accelerator Laboratory, University of Houston, Indiana University, Texas A&M University, Valparaiso University, University of Virginia, and Virginia Polytechnic Institute and State University

The apparent conservation of muon number remains a central problem of weak-interaction physics. Searching for processes that violate muon-number conservation will give insight into the possible extensions of the minimal standard model of weak interactions. MEGA (muon decays into an electron and a gamma ray) is designed to make such a search at LAMPF, now known as LANSCE. This past year was the final year of acquiring production data. The combined data from the summers of 1993–1995 should yield a sensitivity of roughly 7×10^{-13}, an improvement by a factor of 70 in the current world sensitivity to this process. The MEGA collaboration made substantial strides in developing algorithms to extract the results. The three major components of the analysis include reconstructing the kinematic properties of the photon and of the positron and determining their relative timing. The photon analysis is nearly complete, and the other two components have reached an advanced stage.

Theory

M. B. Johnson [(505) 667-6942], D. Ahluwalia (P-25), J. D. Bowman (P-23), collaborators from institutions in the United States, Canada, France, Israel, Kazakhstan, Russia, and Taiwan

The Subatomic Physics group has a small theory component. We are currently developing a theory for connecting hadron properties in free space, and we have also explored phenomenological approaches that use data to determine masses and coupling constants for higher-mass resonances in nuclei. In addition, we are developing a theory for connecting mean-square matrix elements of the parity-violating interaction (measured by TRIPLE in compound-nuclear resonances) to the underlying parity-violating force. This theory exploits the chaotic properties of the compound nucleus. Another project involves the reaction theory of pion scattering from nuclei. In this project we are simplifying the description of specific reactions so that these reactions can more easily be used for specific purposes, such as evaluating hadron transport in nuclear collisions and interpreting results of dibaryon resonance searches. One group member investigated the phenomenon of neutrino oscillations within a three-state mixing model and found that all reported neutrino-oscillation data are consistent with a mass mixing-angle analysis in terms of three neutrinos. His "Gravitationally Induced Neutrino-Oscillation Phases" is the Gravity Research Foundation's First Award Essay for 1996. Participants at a relativistic heavy-ion meeting held during the summer of 1995 determined that essentially all relativistic heavy-ion transport event generators are incapable of reproducing pion production data taken at LANSCE. We are investigating why the data are irreproducible; the answer could have a significant impact on our heavy-ion and PHENIX experimental programs.

Experiments E866, E789, and E772: Quark-Gluon Physics at FNAL

M. J. Leitch [(505) 667-5481], M. Brooks, T. A. Carey, G. T. Garvey, D. M. Lee, P. McGaughey, J. M. Moss, J.-C. Peng, P. E. Reimer, W. E. Sondheim, T. N. Thompson (P-25), B. K. Park (NIS-6), collaborators from Abilene Christian University, Argonne National Laboratory, Fermi National Accelerator Laboratory, Georgia State University, Illinois Institute of Technology, Louisiana State University, New Mexico State University, Oak Ridge National Laboratory, Texas A&M University, and Valparaiso University

This program at the Fermi National Accelerator Laboratory (FNAL) has been highly visible and productive. Our group was the first to exploit high-energy hadronic processes for exploring the quark structure of nuclei. We are investigating the nuclear dependence of lepton-pair production with proton beams to understand how the quark and gluon structure in nuclei differs from that in free nucleons. During the past year we made substantial progress in the construction and refurbishing of the

FNAL Meson-East spectrometer, where E866 began taking data in July 1996. In that experiment we are searching for deviations in the distributions of anti-up and anti-down quarks in the proton to provide insight into hadronic and partonic descriptions of the nucleonic sea. We also continued major analysis efforts on past experiments E772 and E789. We developed Monte Carlo and analysis software that will enable us to extract cross sections from 1.5 million Drell-Yan and Upsilon production events from the copper beam dump of E772. In addition, we finished analyzing and published the first B-meson cross-section data for 800-GeV proton-nucleus interactions and published the nuclear dependence of J/Ψ production in the negative x-Feynman region.

Electroweak Physics at the Liquid Scintillator Neutrino Detector

W. C. Louis [(505) 667-6723], R. L. Burman, F. J. Federspiel, G. T. Garvey, G. B. Mills, V. Sandberg, R. Tayloe, D. H. White (P-25), J. B. Donahue (LANSCE-7), collaborators from the University of California at Riverside, University of California at San Diego, University of California at Santa Barbara, Embry-Riddle Aeronautical University, University of California Intercampus Institute for Research at Particle Accelerators, Linfield College, Louisiana State University, Louisiana Tech University, University of New Mexico, Southern University, and Temple University

With the Liquid Scintillator Neutrino Detector (LSND) at LANSCE, we are searching for evidence of neutrino oscillations, in which neutrinos transform from one flavor into another. These oscillations would imply that neutrinos have mass, an implication that contradicts the standard model of particle physics. If neutrinos have mass, they may profoundly affect cosmology and the evolution of the universe. The LSND collaboration has published papers describing the detector and the analysis of the full decay-at-rest data sample through December 1995. The LSND paper "Evidence for Neutrino Oscillations from Muon Decay at Rest" was published in the November 1996 issue of *Physical Review C*. We have also analyzed our decay-in-flight data and have observed an excess of events that is consistent with neutrino oscillations and with our decay-at-rest data. Because the decay-at-rest and decay-in-flight searches have completely different backgrounds and systematics, this decay-in-flight analysis provides strong additional evidence that we are indeed observing neutrino oscillations.

Applied Programs: The Role of Proton Radiography in Stockpile Stewardship

J. B. McClelland [(505) 667-7291], J. F. Amann, J. G. Boissevain, C. J. Espinoza, J. Gomez, G. W. Hart, G. E. Hogan, C. Morris, H. A. Thiessen, H.-J. Ziock, J. D. Zumbro (P-25), collaborators from P-23, DX Division, LANSCE Division, T Division, X Division, ESA Division, Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, Brookhaven National Laboratory, Indiana University Cyclotron Facility, and Bechtel

The decisions to forgo underground nuclear testing and to restrict the nuclear stockpile to an increasingly smaller number of weapons have forced DOE and its laboratories to rethink their role in stockpile stewardship. Much of this reassessment has been embodied in the philosophy of science-based rather than test-based stockpile stewardship. Proton radiography offers several advantages over conventional x-ray techniques for radiographing thick, dense, dynamic systems. These advantages include (1) high penetrating power, (2) high detection efficiency, (3) very small scattered background, (4) no need for a conversion target and the consequent phase space broadening of the beam, (5) inherent multipulse capability, and (6) the ability to tolerate large stand-off distances from the test object and containment vessel for both the incoming and outgoing beams. Additionally, proton radiography provides the unique possibility of measuring both the density and the material composition of a test object with a pulsed system. Protons interact with matter through both the long-range Coulomb force and the short-range strong interaction. Focusing protons using a magnetic lens allows the magnitude and Z-dependence of the interaction to be changed simply by looking at an object through different angular apertures and, thus, leads to the capability for assessing material composition. Multiple images can be made on a single axis by using multiple detectors, lenses, and irises. P-25 leads this effort together with a strong cross-divisional team that includes P, DX, LANSCE, T, and X Divisions.

Booster Neutrino Experiment at FNAL

G. B. Mills [(505) 667-7330], W. C. Louis, V. D. Sandberg, R. L. Tayloe (P-25), collaborators from Columbia University, Louisiana State University, and University of California at Riverside

Los Alamos has long been a world leader in subatomic-particle physics, especially in the field of the elusive neutrino particle. The recent success of the LSND at LANSCE has excited the physics community around the world. The LSND experiment has been in operation since 1993, and plans are to continue its operation until roughly the year 2000. The startling discovery of neutrino oscillations at LSND has given Los Alamos physicists the motivation to take the next step in this line of research: to make precise measurements of the oscillation phenomena. The ideal setting for these measurements takes us away from Los Alamos to FNAL in Batavia, Illinois. Proton beams from a rapid cycling booster synchrotron at 10 times the energy of the LANSCE beams are available to produce neutrinos at FNAL. The Booster Neutrino Experiment (BOONE) will capitalize on the technology developed for the LSND experiment. It will reuse much of the equipment that is currently being used in the LSND experiment. The neutrino beams to be developed at FNAL will give a 40-fold increase in the rate of neutrino-oscillation events over the current LSND experiment. The ultimate goal will be to measure the oscillation parameters with a precision of a few percent. A more challenging goal will be to study the fundamental symmetries of the neutrino mixing matrix, especially the charge-conjugation and parity-reversal properties of neutrinos. These studies require the use of neutrino and antineutrino beams, which can be made available at FNAL.

RHO Experiment: Measurement of the Michel Parameter

R. E. Mischke [(505) 667-6814], J. F. Amann, M. D. Cooper, G. W. Hart, G. E. Hogan, T. Kozlowski (P-25), R. D. Bolton (NIS-6), W. Foreman (NIS-8), R. Harrison (DX-5), C. Pillai (LANSCE-6), S. A. Schilling (ESA-DE), collaborators from the University of Chicago, Fermi National Accelerator Laboratory, University of Houston, Indiana University, Texas A&M University, Valparaiso University, University of Virginia, and Virginia Polytechnic Institute and State University

The energy spectrum for positrons emitted in normal muon decay contains a portion that is independent of polarization, and the shape of this portion is governed by the Michel parameter, ρ. In this project we measured ρ with the MEGA positron spectrometer. The standard model predicts ρ to be 0.75; it is currently known to within 0.3% of that value. Deviations from 0.75 might indicate the need for right-handed currents in the standard model. Collected data will enable us to measure ρ with a precision of 0.05%, but we are still evaluating the systematic errors. Such a precision would allow us to check the reported deviations from the standard model in neutron decay. Our analysis should be complete by early 1997.

PHENIX Experiment at the Relativistic Heavy-Ion Collider at Brookhaven National Laboratory

J. M. Moss [(505) 667-1029], V. Armijo, M. J. Bennett, J. G. Boissevain, M. Brooks, T. A. Carey, D. J. Clark, B. V. Jacak, W. W. Kinnison, D. M. Lee, M. J. Leitch, L. J. Marek, P. L. McGaughey, M. M. Murray, P. Reimer, B. Schlei, J. E. Simon-Gillo, W. E. Sondheim, J. P. Sullivan, H. W. van Hecke (P-25), J. Kapustinsky (LANSCE-DO), T. Kozlowski (LANSCE-12), collaborators from NIS Division, ESA Division, and institutions in Canada, China, Germany, India, Israel, Japan, Russia, South Korea, Sweden, and the United States

The quark-gluon plasma (QGP) is a postulated phase of matter in which quarks and gluons are deconfined. Proof of its existence has, to date, eluded experimentalists, although theoretical speculations about its nature abound. If the QGP phase transition does occur, then the characterization of that transition is of intense interest and importance to nuclear and particle physics.

The PHENIX detector is a large, multipurpose detector designed to detect the QGP and characterize its properties at the Relativistic Heavy Ion Collider (RHIC) being built at Brookhaven National Laboratory. PHENIX is being constructed by a large collaboration of physicists and engineers from universities and laboratories around the world. The detector design as a whole focuses on leptons (that is, electrons and muons), photons, and hadrons. Los Alamos collaboration members continue to have a significant impact on this major thrust of the nationwide nuclear-physics effort. P-25 members are responsible for the construction of the muon arms and the silicon multiplicity/vertex detector (MVD). The Los Alamos PHENIX muon-tracker team leads the conception, design, construction, and commissioning of the two large muon spectrometers that are crucial to the search for signatures of the quark-gluon plasma. The Los Alamos PHENIX MVD team leads the conception, design, construction, and commissioning of the MVD. Both construction efforts continue to meet major milestones. The Muon Station 2 has been fully prototyped and tested; it met or exceeded all requirements, including those for resolution and efficiency. The Station-3 full-size prototype was constructed and tested to demonstrate the feasibility of the design. The silicon-MVD preliminary design and safety plan have been reviewed with high marks, and there has been a successful beam test to demonstrate the design.

PHENIX Spin Program

J. M. Moss [(505) 667-1029], J. G. Boissevain, M. Brooks, T. A. Carey, D. Clark, J. Kapustinsky, W. W. Kinnison, T. Kozlowski, D. Lee, M. Leitch, J. McClelland, P. L. McGaughey, M. Murray, J. Simon-Gillo, J. P. Sullivan, H. W. van Hecke (P-25), PHENIX Collaboration

The scattering of high-energy, polarized muons from polarized protons at the European Center for Nuclear Research (CERN) revealed a big surprise about ten years ago. The spin of the proton receives only a small contribution from its valence quarks, those elusive building blocks of matter that determine most of the proton's other attributes. More recent experiments have refined and confirmed the CERN results, but they have added little hard evidence about the location of the missing spin. We hope that a new generation of polarized proton experiments, to be carried out at the Relativistic Heavy-Ion Collider at Brookhaven National Laboratory (BNL), will allow us to determine directly the contribution of specific degrees of freedom (such as quarks and antiquarks) to the proton's spin. The highly successful Los Alamos/RIKEN (Institute for Physical and Chemical Research, Tokyo [Wako], Japan) collaboration culminated two years of work, resulting in the final specification of the RIKEN contribution to the spin-structure function program of the PHENIX detector. RIKEN funding will purchase the PHENIX south-arm magnet plus the associated muon tracking and identification systems. This contribution greatly enhances the high-mass dimuon acceptance of the PHENIX detector and permits us to carry out a large menu of experiments on unique spin-structure function. Equally important, the muon upgrade will substantially increase the physics reach of the relativistic heavy-ion program.

Education and Outreach

A. P. T. Palounek [(505) 665-2574], J. F. Amann (P-25)

As members of three education programs run by the Laboratory, P-25 group members continue to be active in education and outreach activities. Group members visited every teacher and school in the TOPS (Teacher Opportunities to Promote Science) and TOPS Mentor programs at least once; conducted regional meetings for TOPS teachers, TOPS mentors, and TOPS alumni; and led several workshops in Los Alamos and Albuquerque. During the most recent workshop, TOPS mentors built (from scratch) a simple lightning detector designed by physicists from NIS-1 and P-25. Group members were also active in the PRISM (Preservice Institute for Science and Math) program. As a part of this program, we guided students through a comparison of the transmission qualities of various brands of sunglasses.

Experiment E907 at the Brookhaven National Laboratory Alternating-Gradient Synchrotron: Hypernuclear Physics

J.-C. Peng [(505) 667-9431], C. Edwards, C. Morris (P-25), collaborators from institutions in the United States, Croatia, and Japan

Los Alamos led the effort to propose a new hypernuclear experiment at the BNL Alternating-Gradient Synchrotron (AGS) using the LANSCE Neutral Meson Spectrometer (NMS) to measure the (K^-,π^0) reaction. Our proposal for this experiment was approved by the AGS Program Advisory Committee in late 1994. The experiment will demonstrate the feasibility of using the (K^-,π^0) reaction as a novel tool to produce Λ-hypernuclei with resolution significantly better than the existing (K^-,π^-) and (π^+,K^+) experiments, and it will measure the Λ-hypernuclear π^0 weak decay modes never before studied. The NMS and associated equipment were moved from LANSCE to the AGS in December 1995, and the first test run was completed in May 1996. The LANL team will assume responsibility for the NMS operation and physics direction in this experiment.

Pion Research

C. M. Riedel [(505) 665-4516], J. F. Amann, C. L. Morris, D. Tupa, J. D. Zumbro (P-25), M. A. Espy (P-21), S. I. Penttila, S. J. Seestrom (P-23), R. L. Boudrie (DX-6), J. N. Knudson (LANSCE-7), B. K. Park, M. W. Rawool-Sullivan (NIS-6), collaborators from institutions in the United States, Canada, Croatia, Germany, Japan, Russia, Switzerland, and the United Kingdom

We are currently analyzing pion data from the final 1995 LANSCE run and from previous runs. Of particular interest are the recent data taken with the NMS from the $p(\pi^-,\pi^0)$ reaction. The pi-nucleon charge-exchange database has historically been weak, and these recent measurements are expected to contribute to topics such as chiral symmetry breaking in the nucleon and isospin symmetry breaking in the pi-nucleon system. We expect to finish analyzing data collected at LANSCE, including pion charge-exchange data taken with the NMS as well as other elastic and inelastic pion-scattering experiments, and we will soon publish the final measurements of the low-energy cross sections and intermediate-energy analyzing powers for the pi-nucleon charge-exchange reaction. This work is being done in collaboration with colleagues from a number of institutions.

The NA44 Experiment: Relativistic Heavy-Ion Collisions at the European Center for Particle Physics

J. P. Sullivan [(505) 665-5963], J. G. Boissevain, D. E. Fields, B. V. Jacak, J. E. Simon-Gillo, W. E. Sondheim, H. van Hecke (P-25), collaborators from institutions in Denmark, France, Japan, Sweden, Switzerland, and the United States

Heavy-ion collisions at very high energies provide an opportunity to recreate the conditions that existed very early in the universe, just after the big bang. Experiment NA44 at the European Center for Particle Physics (CERN) is a second-generation relativistic heavy-ion experiment that searches for evidence that quarks and gluons are deconfined in matter at very high energy densities. The experiment focuses on correlations among identical particles as a function of transverse momentum in order to provide a closer look at the space-time extent of the central-region heavy-ion collisions. A long lifetime of matter in the central region is an indication of the formation of deconfined quarks and gluons.

In 1995 and 1996 the experiment took data with 160-GeV/nucleon lead-ion beams. Among the heavy-ion experiments at CERN, NA44 is unique in its ability to compare correlations of identified pions, kaons, and protons. Comparison of pion and kaon results clarifies the effects of resonance decays versus the time evolution of the emitting source. The high statistics from NA44 allow a careful study of the behavior of the chaoticity parameter (which is usually not well understood) and the exact shape of the correlation function. NA44 also measures single-particle distributions. Measurements of the distributions of protons emitted in Pb + Pb collisions and measurements of the ratio of negative- to positive-pion production both suggest significant stopping in these collisions, meaning that the protons and neutrons in the incident nuclei do not pass through one another in the collision (that is, they do not have transparency) but are slowed down significantly.

Members of the collaboration also interact with theoretical colleagues to study correlation functions predicted by the Relativistic Quantum Molecular Dynamics (RQMD) event generator and to compare those predictions with NA44 data. This work has provided the first detailed explanation of the information contained in the shape of the correlation function.

Measurements of Beta Asymmetry and Atomic Parity Nonconservation: Fundamental Symmetry Studies with Trapped Radioactive Atoms

D. Tupa [(505) 665-1820] (P-25), S. G. Crane, R. Guckert, M. J. Smith, D. J. Vieira, X. Zhao (CST-11), S. J. Brice, A. Goldschmidt, A. Hime, S. K. Lamoreaux (P-23)

With the advent of optical and magnetic traps for neutral atoms, a new generation of fundamental symmetry experiments can exploit point-like, massless samples of essentially fully polarized nuclei. At Los Alamos we are probing the origin of parity violation in the electroweak interaction by attempting to measure the beta-spin correlation function in the beta decay of ^{82}Rb confined to an atomic trap. By exploiting the geometry and the intrinsic features of such traps, we plan to measure the beta-spin correlation as a continuous function in both energy and angle of the emitted beta particles relative to the nuclear polarization. This continuous measurement would allow us to simultaneously extract new physics, such as the existence of right-handed currents, and recoil order effects, such as weak magnetism. With these traps we may also extract further information, such as the recoil ion momentum, that would allow a study of a much wider range of correlation parameters. Finally, we envision a new generation of atomic parity nonconservation experiments that test the neutral current portion of the weak interaction.

In these experiments, measurements with a series of radioactive isotopes of cesium and/or francium could eliminate uncertainties about atomic structure that presently limit the precision. A fundamental ingredient for performing these symmetry measurements is the efficient trapping of selected radioactive species. To this end we are using a magneto-optical trap (MOT) that is coupled to a mass separator. To date we have developed one of the world's largest MOT traps; it can trap up to 4×10^{10} atoms. By coating the inside of the glass trapping cell with a special nonstick coating of Dryfilm, we have measured a trapping efficiency of 20%. If we couple the MOT to a mass separator, we can introduce the species of interest into the trap without the deleterious effects of gas loading. In recent work using the mass separator–MOT system, we have successfully trapped stable ^{85}Rb, and we are currently attempting to trap a million ^{82}Rb atoms using a 2-mCi mother source of ^{82}Sr. We have also made good progress in modeling and designing the beta-asymmetry detection system and polarization trap.