Office of Science

U.S. Department of Energy

Nuclear Physics

The Office of Science's Nuclear Physics (NP) program provides most of the Federal support for nuclear physics research, delivering new insights into our knowledge of the properties and interactions of atomic nuclei and nuclear matter. About 1,500 scientists, including 800 doctoral students and postdoctoral research associates, receive support from NP. In addition, the program supports six national scientific user facilities.

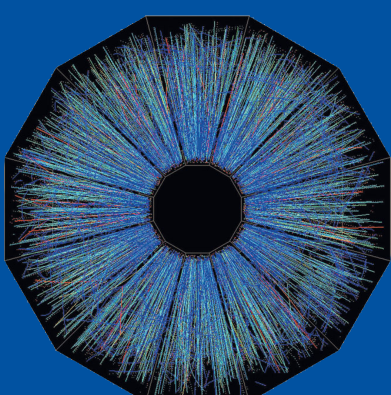
The Opportunity

The NP research program investigates all forms of nuclear matter, including that of the early universe, measures the quark structure of the proton and neutron, and studies the mysterious and important neutrino. Rapid advances in electronic circuits, computing, and superconducting technologies have enabled the construction of powerful accelerator, detector, and computing facilities. These provide the experimental and theoretical means to investigate nuclear systems ranging from tiny nucleons to stars and supernovae.

The Challenge

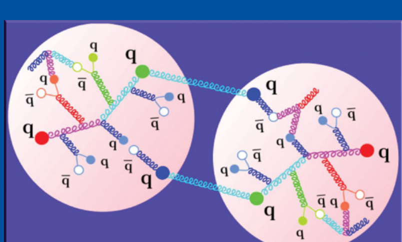
NP research addresses these opportunities through research programs that respond to the following challenges:

The Early Universe. Can we find a way today, on earth, to study the early universe as it was soon after the Big Bang? A unique research facility designed to do this, the Relativistic Heavy Ion Collider (RHIC), is operating at Brookhaven National Laboratory. RHIC accelerates two beams of gold nuclei to high energies and brings them into head-on collisions inside state-of-the-art detectors designed to observe the particles that emerge by the thousands from gold collisions. The objective is to see whether two colliding gold nuclei will sometimes form tiny, brief samples of extremely hot and dense plasma, composed of free quarks and gluons (normally confined inside protons and neutrons). Such quark-gluon plasma is believed to have made up much of the universe a few microseconds after its Big Bang origin 14 billion years ago. Our first physics results show that a new and very different form of nuclear matter is certainly created in the most central collisions. An intense experimental and theoretical program is underway to identify and study this new state of matter.

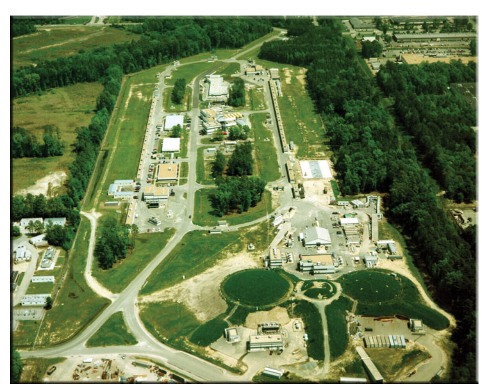


Thousands of particles emerge from a collision of gold nuclei at RHIC

Structure of the Nucleon. How do the basic quark "building blocks" bind together with gluons to form the proton and neutron, the nucleons that make up nuclei, and how do we account for the nucleon spin? The quarks alone make up only 2% of the mass of a nucleon and generate only about 25% of its intrinsic spin. The Thomas Jefferson National



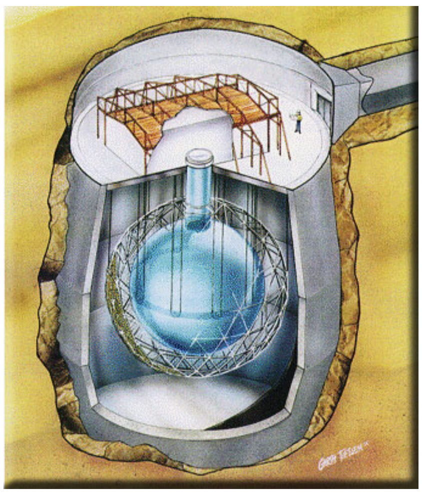
A conceptual sketch of the quark structure of the proton and neutron forming a deuteron



Thomas Jefferson National Accelerator Facility seen from the air

Accelerator Facility, the premier facility of its kind in the world, provides an intense polarized electron beam to study nucleon structure. The experimental results are now beginning to address these fundamental questions.

Neutrinos. Can we measure the basic properties of neutrinos? The first generation of solar neutrino experiments detected far fewer high-energy neutrinos than expected from our knowledge of nuclear processes in the sun. The deficit suggested that neutrinos might change from one type to another as they travel—a behavior that is not explained by the Standard Model of elementary particles. This early research was done by Raymond Davis of Brookhaven National Laboratory, who won a share of the 2002 Nobel Prize for the detection of cosmic neutrinos. The new Sudbury Neutrino Observatory (SNO) experiment in Canada, an international collaboration, is now studying solar neutrinos with much greater precision than previously possible. In 2002, SNO results showed definitively that solar neutrinos do change types en route to earth, and the KamLAND experiment in Japan showed that neutrinos from nuclear reactors also oscillate among types. These results prove that neutrinos must have a small mass. Precisely measuring neutrino masses and mixing parameters will be a major challenge.



The Sudbury Neutrino Observatory in its underground cavern

Origin of the Elements. What is the origin of the elements, how do stars evolve, and what is the source of high-energy cosmic rays and cosmic gamma rays? Experiments are now being carried out with beams of stable and short-lived nuclei at accelerator facilities at the Office of Science's Oak Ridge, Argonne, and Lawrence Berkeley national laboratories to measure the properties of nuclei and reaction rates needed to decipher the full range of astrophysical optical, x-ray, and gamma-ray data. Research and development are underway for a next generation accelerator with far more intense beams of short-lived nuclei. Experimental results from such a facility could have a profound impact on our basic knowledge of nuclear structure and the origin of the elements in stars and stellar explosions.

An exploding nebula

Investment Plan

The NP program's goal is to provide significant support for its major user facilities, allowing them to develop their full potential through expanded use by researchers. Support for theoretical studies will be enhanced through the development of new computational techniques and advanced simulations, in conjunction with another Office of Science program, Scientific Discovery through Advanced Computing (SciDAC).

The Benefits

The Office of Science's Nuclear Physics program will substantially advance our understanding of nuclear matter and the early universe. It will help the United States maintain a leading role in nuclear physics research, which has been central to the development of various technologies, including nuclear energy, nuclear medicine, and the nuclear stockpile. Highly trained manpower in fundamental nuclear physics is another important result of the program. This valuable human resource is essential for many applied fields, such as nuclear medicine, space exploration, and national security.

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