Office of Science
U.S. Department of Energy

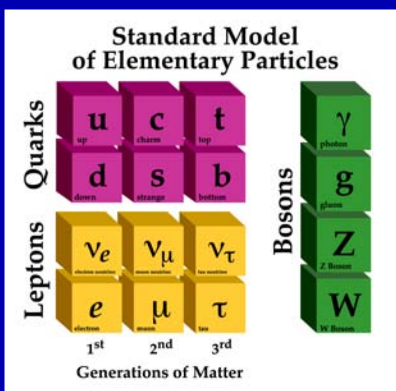
High Energy Physics

The Office of Science's High Energy Physics (HEP) program provides most of the Federal support for research in high energy physics, which seeks to understand the fundamental nature of matter, energy, space, and time. HEP funds research at more than 100 universities and 10 national laboratories and operates world-class research facilities serving 3,500 researchers each year.

The Opportunity

Since the dawn of civilization, man has sought to discover Nature's ultimate building blocks and forces and to understand the origin of the universe. From the "earth, air, fire, and water" of the ancients to the quarks, leptons, and bosons of today, each new level of understanding has given us new insights into the makeup of the universe and revolutionary new technical tools as well.

In the centennial year of Einstein's theory of relativity, we find ourselves at the threshold of profound discoveries. Do today's particles and forces unify at extremely high energies? Are there extra dimensions of space? What is the role of the elusive neutrino? What are the "dark energy" and "dark matter" that make up 95% of the universe? Why is the 5% we can see made only of matter, with no trace of antimatter?



Nature's Building Blocks and Forces.

The Challenge

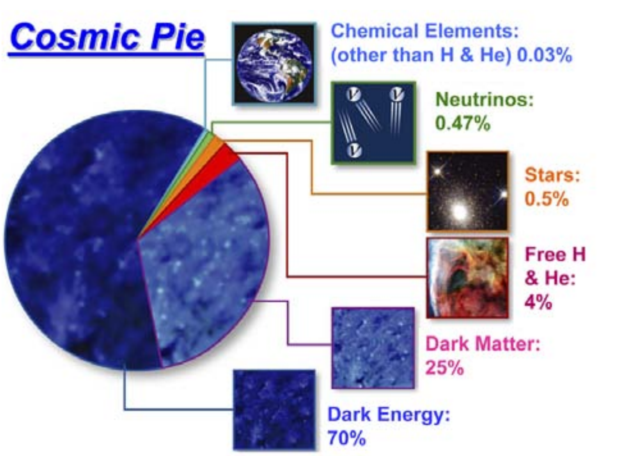
The major tools at hand to explore these fundamental questions are the high energy accelerator facilities built and operated by the Office of Science and used by the talented scientists it supports at laboratories and universities. Using these and other tools such as detectors underground and in space, and advanced computing, and working with the NSF, NASA and international partners, the HEP program is pursuing the following challenges:


Tevatron Accelerator at Fermi National Laboratory.

The Search for Unification. While our current theory of fundamental particles and forces, the Standard Model, explains much, it is mathematically flawed and incomplete. What is the source of mass? The Standard Model attributes mass to a "Higgs" field, but no such field has yet been observed. Theoretical explorations beyond the Standard Model suggest that the complex patterns of particles and forces we observe today arose from a much simpler universe at the extremely high energies that prevailed in its first moments. We should be able to see evidence of this unification, even though our accelerators operate at much lower energies. A new class of "supersymmetric" particles has been predicted, and some of these should be within reach of present accelerators. Unification theories require more than three space dimensions, and indications of such extra dimensions may be found. The Tevatron collider at Fermi National Accelerator Laboratory (FNAL) and the Large Hadron Collider (LHC) at CERN, in which the U.S. is playing a strong role, will test these ideas. An electron-positron linear collider is being considered by the U.S., Europe, and Asia as a powerful new and international facility for research into these phenomena.

The Role of Neutrinos. The neutrino is a ghostly particle that hardly interacts with matter but plays a key role in physics and astrophysics. The Standard Model treats neutrinos as massless, but recent experimental results provide compelling evidence that they have mass. Different mass states of a neutrino evolve at different rates, resulting in an oscillating mixture of neutrino types or "flavors." Thus a muon neutrino might change to an electron or tau neutrino by the time it has traveled a few hundred miles. Such oscillations have been demonstrated by several experiments, proving that neutrino flavor mixing does occur. Measuring the complex pattern of neutrino masses is important, because they may well be related to the energy scale at which fundamental forces unify, and may help explain the dominance of matter over antimatter in the universe. In the U.S., two experiments at FNAL—MiniBooNE and MINOS—are using neutrino beams from accelerators to measure neutrino parameters, and U.S. researchers are also working on experiments in Japan and Canada. A number of new experiments are being developed to continue this program using neutrinos from accelerators, power reactors, and natural radioactivity.

Dark Energy, Dark Matter, and the Accelerating Universe. Our understanding of what the universe is made of has changed radically. Recent studies of supernovae by Lawrence Berkeley National Laboratory have shown that the universe is expanding at an accelerating rate. The outward push is attributed to "dark energy," a remarkable and unexpected discovery. This new form of energy may account for as much as 70% of the universe. Another 25% seems to be made of invisible "dark matter," while normal matter (the kind described by the Standard Model, which includes all the stars and galaxies) contributes only 5%. There seems to be no antimatter, although plenty of it should have been produced in the early universe. A dedicated space telescope is being designed, as a joint project with NASA, to chart the expansion history of the universe and help us solve the mystery of dark energy. Experiments are underway to search for dark matter particles coming from space or being made in accelerators. The asymmetry between matter and antimatter may be related to neutrinos, or to a subtle difference between quarks and antiquarks that is being investigated using the B Factory electron-positron collider at the Stanford Linear Accelerator Center.



Composition of the Cosmos.

The BaBar Detector at the B Factory at the Stanford Linear Accelerator Center.

Investment Plan

HEP will use its research facilities to search for new physics beyond the Standard Model, study B meson decays, and investigate the neutrino. New experiments will investigate dark energy and dark matter. R&D investments directed toward a possible future linear electron-positron collider will continue.

The Benefits

The Office of Science's program in high energy physics substantially increases our fundamental understanding of the origin and content of the universe. In addition, unique HEP research facilities and a strong research program in high energy physics help the U.S. maintain a leading role in the field, educate young people in science, and transfer to industry the technologies developed for research.

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