Office of Science

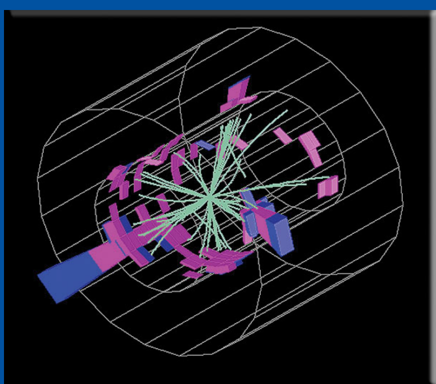
U.S. Department of Energy

High Energy Physics

The Office of Science's High Energy Physics (HEP) program provides the majority of 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. From the "earth, air, fire, and water" of the ancients to the quarks, leptons, and bosons of today, each new level of structure unveiled has given us new insights into the heart of matter and revolutionary new technical tools as well.



Simulation of a Higgs bonson event as it might appear in a detector at Fermilab

As we approach the centennial of Einstein's theory of relativity, we find ourselves at the threshold of discoveries equally profound. 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?

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 its laboratories and universities. With these and other tools, the HEP program will pursue the following challenges:

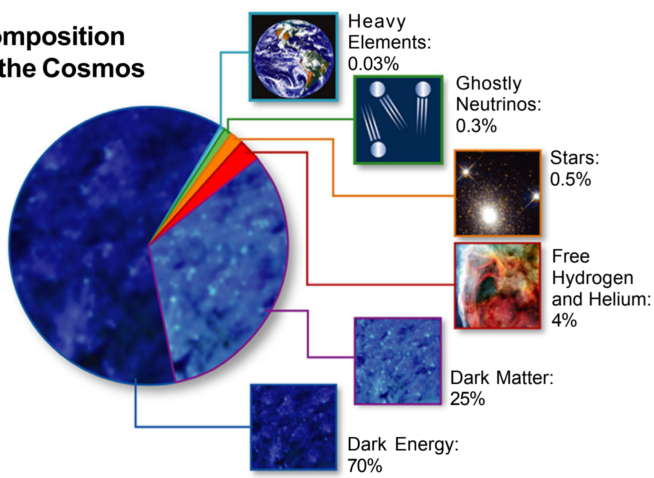
Tevatron acclerator at Fermi National Laboratory

The Search for Unification. Our current theory of fundamental particles and forces, the Standard Model, explains much but leaves some questions unanswered. What is the source of mass? The Standard Model attributes mass to a "Higgs" field, but it has not 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. Can we 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 could be discovered with present accelerators. Unification theories require more than three dimensions, and indications of extra dimensions may be found. The Tevatron collider at Fermi National Accelerator Laboratory (FNAL) and the Large Hadron Collider (LHC) collider at CERN will test these ideas. An electron-positron linear collider is being considered by the U.S., Europe, and Asia as a powerful new international facility for unification research.

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 must have mass. Different mass states of a neutrino would evolve at different rates, resulting in an undulating mixture of neutrino types or "flavors." Thus an electron neutrino from the sun could change to a muon or tau neutrino by the time it reaches earth. Such oscillations have been demonstrated by several experiments (Sudbury Neutrino Observatory in Canada and Super Kamiokande and KamLAND in Japan) using neutrinos from the sun and other sources, proving that neutrino flavor and mass mixing does occur. Measuring the parameters of this complex pattern is important because they are related to the energy scale at which fundamental forces unify, and may help explain the dominance of matter over antimatter in the universe. To measure neutrino parameters, two experiments at FNAL-MiniBooNE and MINOS-will use neutrino beams from an accelerator, and other experiments will use neutrinos from the sun, the atmosphere, and natural radioactivity.

Dark Energy, Dark Matter, and the Accelerating Universe. Recent studies of supernovae at Lawrence Berkeley National Laboratory have shown that the universe is expanding at an accelerating rate, rather than slowing down due to gravity. The outward push is attributed to "dark energy," a new form of energy

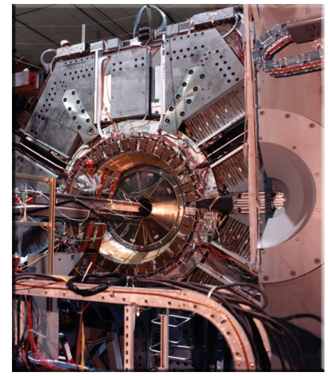
Composition of the Cosmos



estimated to comprise 70% of the universe. Another 25% is made of invisible "dark matter," and normal matter (including all 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 to use supernovae to chart the expansion history of the universe and help us to solve the mystery of dark energy. Some scientists think dark matter consists of light supersymmetric particles, which will be sought by accelerator experiments. Another space telescope is being built to study cosmic gamma rays, which might see supersymmetric dark matter particle interactions, as well as black holes and pulsars.

Scientists using the B Factory electron-positron collider at the Stanford Linear Accelerator Center are studying B meson decays. A subtle asymmetry known as Charge-Parity (CP) violation may give clues to new physics and help explain the surprising predominance of matter over antimatter in the universe.



The BaBar detector at the B-Factory

Investment Plan

HEP will use its existing 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, dark matter, and cosmic gamma rays. 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 matter and energy. 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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