Exploring the Quantum Universe

Pathways to Innovation and Discovery in Particle Physics

A Strategic Plan for US Particle Physics

P5 provides the long-term strategy and priorities for US investments in particle physics for the next 10 years within a 20-year vision. The 2023 P5 report reaffirms the ongoing priorities and outlines future opportunities for discovery.

US particle physics advances the frontiers of discovery science, builds and sustains an inclusive workforce, and advances US leadership in a worldwide context.

The top priorities in 2024 are to complete current construction projects, support operations of ongoing experiments, and strengthen support for research at universities and national laboratories to maximize the opportunities for scientific discoveries.

Support for big data analysis, innovative instrumentation development, a vibrant theory program, and developing future accelerator technologies is essential to maintain US leadership and to train the next generation of scientists and innovators. US particle physics also plays a key role in advancing and leveraging national initiatives in microelectronics, AI/ML, and quantum.

It is critical to complete construction and deliver science of the following projects:

High-Luminosity Large Hadron Collider (HL-LHC) accelerator and CMS and ATLAS detector upgrade projects, in order to continue the highly successful LHC program and bilateral partnership with CERN.

Deep Underground Neutrino Experiment (DUNE), the first US-hosted world-leading international mega-science project, to determine fundamental properties of elusive neutrinos that permeate the cosmos.

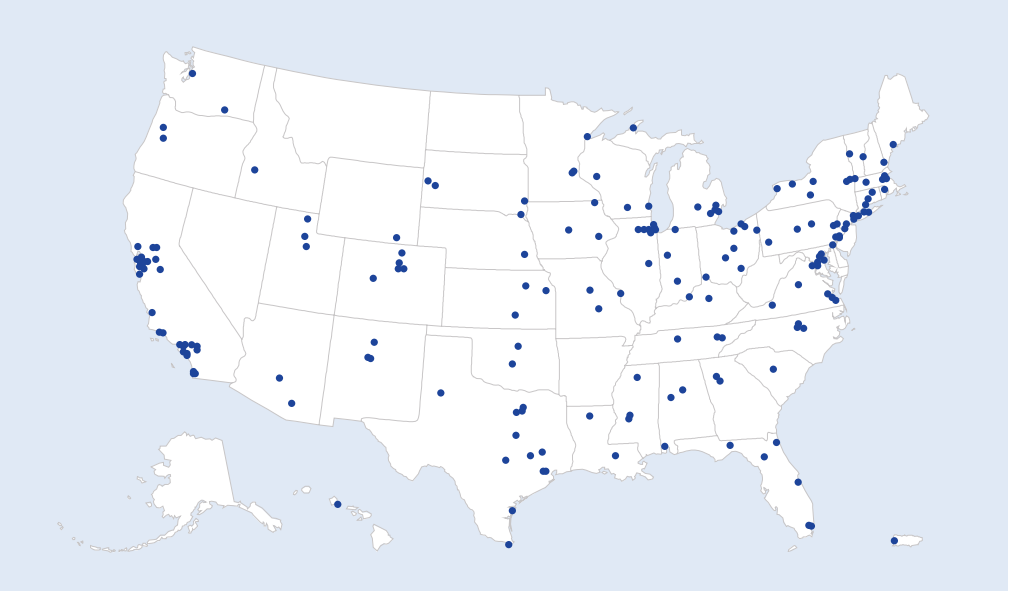
Vera C. Rubin Observatory, a major new telescope observatory that is now nearing completion in Chile, in order to understand what drives cosmic evolution and carry out the Legacy Survey of Space and Time.

CMB-S4, the next-generation cosmic microwave background experiment with 12 telescopes at the South Pole and in the Chilean Atacama desert, in order to observe the moments when the Universe was much smaller than the size of an atom. This project depends critically on access to South Pole science infrastructure.

These carefully chosen investments will enable a steady stream of exciting new results for many years to come and will maintain US leadership in key areas.

Particle Physics in the United States

Particle physics is both global and local. Scientists, engineers, and technicians at over 200 universities, institutes, and laboratories throughout the US are working in partnership with their international colleagues to build high-tech tools and components, conduct scientific research, and train and educate the next generation of innovators. Valuing equity, diversity, and inclusion, the field is committed to increasing participation of underrepresented groups. Particle physics activities in the US attract some of the best scientists from around the world.



The P5 strategy continues to be very successful. The 2023 P5 report builds upon these successes and charts the course to a new era of discovery, innovation, and US leadership for the next decade and beyond.

Recent Science Results

The **LHC experiments** continue to publish a vast range of new results with increasing precision and discovery reach. The ATLAS and CMS collaborations have each produced more than 1,200 refereed publications as they continue to probe the fundamental properties of the Higgs boson and expand their reach for new particles, forces of nature, and physical principles using ever larger datasets and novel techniques across a broad front. Among dozens of examples, they have probed the rarest of Higgs signatures and observed the simultaneous production of four top quarks. CMS has searched for many exotic species of long-lived new particles and ATLAS has achieved the highest-energy detection of quantum entanglement in top-quark pairs.

The **LHCb experiment** has discovered new states and configurations of multiple quarks, measured the rate of antimatter production in proton collisions, and reported an intriguing deviation from theoretical expectations in B-meson decays which may be quantum imprints of new phenomena.

The **Dark Energy Survey** collaboration has published definitive results from the analysis of the largest, deepest, most uniform data that includes 1500 distant supernovae. This has placed the strongest constraints on the expansion of the Universe ever obtained using supernovae, and revealed hints that the Universe's dark energy density may vary with time.

The **Muon g-2 experiment** at Fermilab has doubled the precision on the magnetic moment of muons, testing the underlying theory to unprecedented exactness, and provided hints of quantum imprints of undiscovered particles and interactions.

The **CDF collaboration** at Fermilab has made a new precision measurement of the W-boson mass that further motivates precision studies at the LHC. ATLAS reported its most precise measurement from the LHC so far, and a new precise measurement from CMS is nearing completion.

The **NOvA neutrino experiment** at Fermilab has produced the first joint data analysis with the T2K experiment on neutrino oscillations, and has provided new results on the mass ordering of neutrino flavors and CP violation which is related to the predominance of matter over antimatter in the universe.

The **LUX-ZEPLIN (LZ) dark matter experiment** in South Dakota has published its first results, providing important new constraints on the particle identity of dark matter across a vast range of mass scales, and promising greater sensitivity with continued data taking.

The **IceCube observatory** beneath the Antarctica ice sheet has created the first map of our Milky Way galaxy using neutrinos, that closely corresponds with gamma-ray galactic maps.

Program Advances and Milestones

The **CMS and ATLAS detector upgrades** are now in full production following recent Critical Decision approvals. The **first HL-LHC triplet magnet, delivered from Fermilab to CERN**, is based on the new superconductor technology using Niobium Tin and is part of the major US contributions to the HL-LHC accelerator. This technology paves the way to much higher energy colliders in the future.

The **Deep Underground Neutrino Experiment (DUNE)** is proceeding well. Excavation of the caverns has been completed in South Dakota and the first cryostat component has been delivered to the Sanford Underground Research Facility (SURF).

The **LSST Camera at the Vera Rubin Observatory**, the world's largest camera for astronomy for the Legacy Survey of Space and Time (LSST), weighing three tons and with 3.2 billion pixels, has been completed. The observatory dome is nearing completion, and the commissioning begins in summer 2024.

The **CMB-S4** conceptual design reviews by DOE and NSF are planned to be held in 2024 following the recent highly successful Director's review of the project.

The **Short Baseline Near Detector (SBND)** at Fermilab is being filled with liquid argon and preparing for taking data from the Booster neutrino beam.

All four **SuperCDMS** towers have been delivered from SLAC to SNOLAB in Canada, and construction of the main experiment is underway.

The **Dark Energy Spectroscopic Instrument (DESI)** made the first public data release that includes spectra and redshifts for 1.2 million galaxies and quasars, as well as observations of nearly half a million stars in our own Milky Way galaxy.

Theoretical physicists have discovered connections among quantum entanglement, information, and gravity, shedding important new light on the black hole paradox pointed out by the late Stephen Hawking, and suggesting novel ideas about the emergence of spacetime. They are also active in the use of AI/ML and developing QIS techniques to simulate the quantum world of elementary particles, as well as devising new ways to use quantum sensors in novel searches for dark matter.