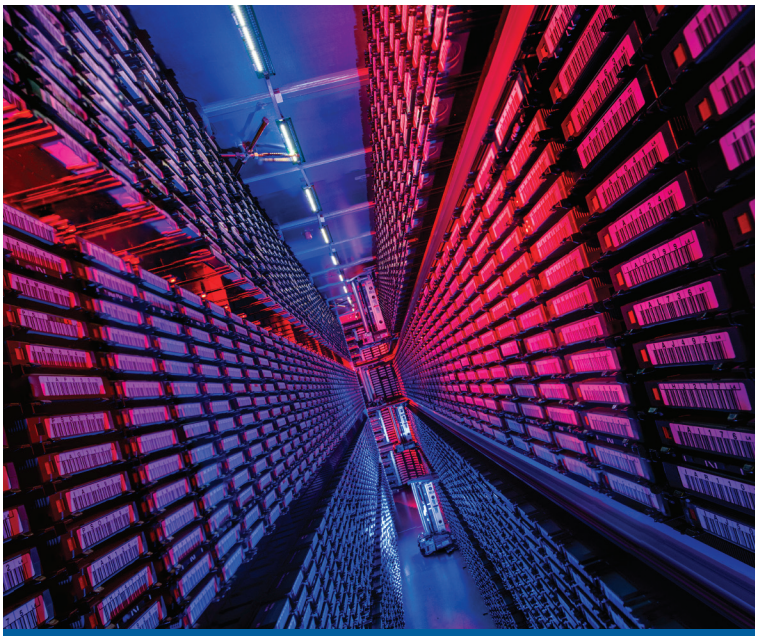
Artificial intelligence research at Fermilab

Artificial intelligence research at Fermilab plays an important role in every aspect of high-energy physics: in the operation of particle accelerators, the analysis of data captured by particle detectors, sweeping surveys of stars and galaxies, quantum simulations of physical phenomena.



Fermilab is using cutting-edge AI algorithms and hardware implementations to work with large and complex data sets produced by big experiments such as the Deep Underground Neutrino Experiment, CMS and the Dark Energy Survey. Photo: Reidar Hahn, Fermilab

AI for physics, physics for AI

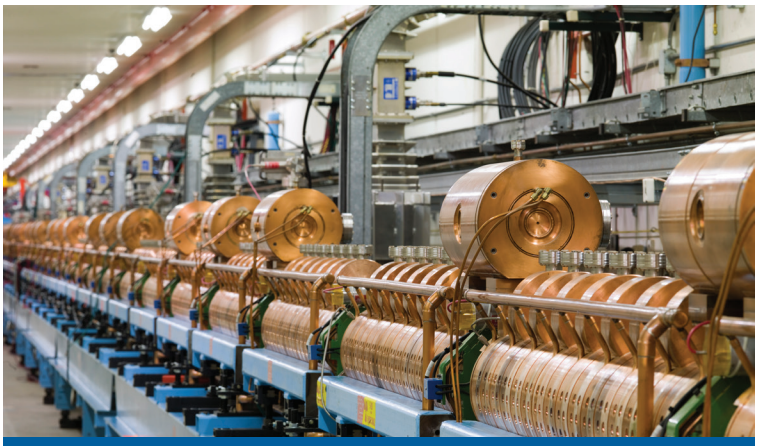
The unique challenges of high-energy physics research present opportunities for advancing AI technologies. From the principles of fundamental physics underlying massive and rich data sets to building and operating some of the world's most complex detector and accelerator systems, the technologies we are developing have potential connections to a broad domain of cutting-edge AI research.

Fermilab is committed to artificial intelligence research and development to enhance the scientific mission of particle physics:

Accelerate science with the goal of solving the mysteries of matter, energy, space and time.

Develop AI capabilities within the national ecosystem that build on high-energy physics challenges and technologies, including training the next generation of AI researchers.

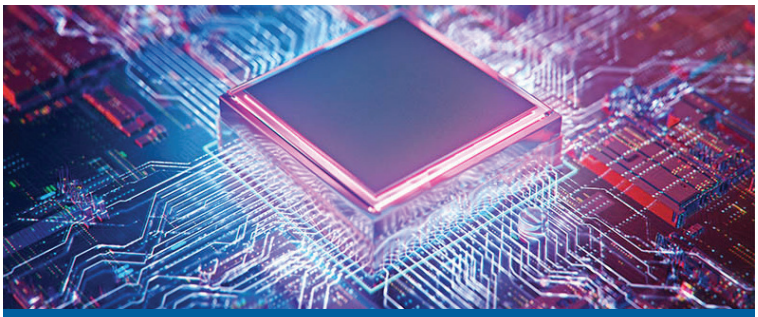
Build community around cross-cutting problems in order to share the work of Fermilab and the high-energy physics community with the world.



AI will enable more efficient operations at the Fermilab Linear Accelerator. Photo: Reidar Hahn, Fermilab

Accelerator physics

Fermilab builds and operates high-energy, high-intensity particle accelerators. The lab's strict demands for safety and scientific rigor drive innovation in machine learning. The accelerators are a prime test bed for a diverse suite of possible machine learning applications, such as reinforcement and online learning, efficient data collection, and automated control systems.



Modern detectors require ultrafast and powerful AI for data processing embedded into sensor electronics.

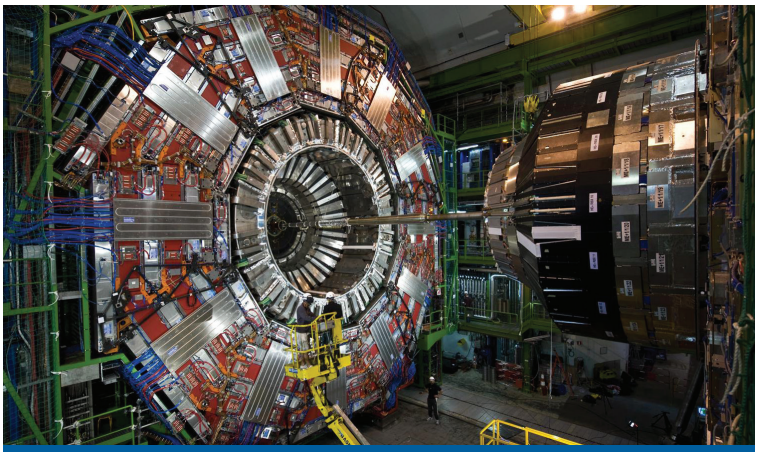
Smart detectors, accelerated compute, and real-time AI

Increasingly complex science applications are exponentially raising demands on underlying detector systems to optimize data flow. To enable real-time performance, detectors need to be faster, efficient, and more proactive, identifying and responding to bottlenecks before they become significant. To achieve this, Fermilab is developing and co-designing state-of-the-art AI chips, circuits, and coprocessors for fast inference and more efficient use of AI algorithms.

Fermilab researchers use AI to study astronomical objects, for example as part of the Dark Energy Survey, which uses the Blanco Telescope at Cerro Tololo Inter-American Observatory to survey the night sky. Photo: Reidar Hahn, Fermilab

Astrophysics

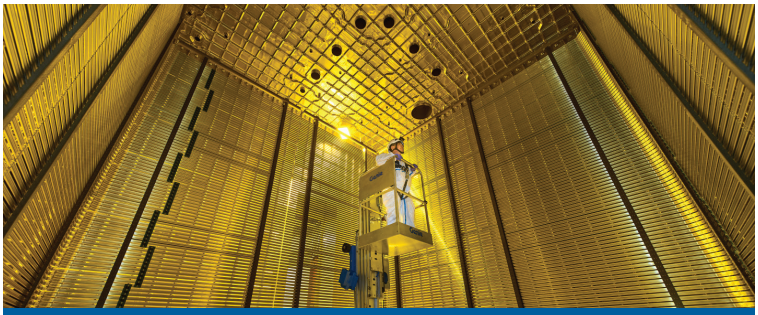
Fermilab researchers are using cutting-edge AI algorithms to bring astronomy research into the big-data era. Fermilab is deeply involved in the biggest current and future astronomical surveys, such as the Dark Energy Survey and surveys at the South Pole Telescope and the Vera C. Rubin Observatory. Researchers use AI to detect and study astronomical objects and related phenomena, as well as for automation and self-driving telescopes.



Fermilab is a leader at the CMS experiment at CERN. Photo: CERN

Particle physics at the CMS experiment

Fermilab is a leader in the CMS experiment at CERN's Large Hadron Collider and is deploying AI techniques across a broad range of applications and technologies. Current developments include early data-processing tasks, reconstruction of particle events, pattern recognition, improving efficiency in event generation with neural networks, and analysis and extraction of physical observables.



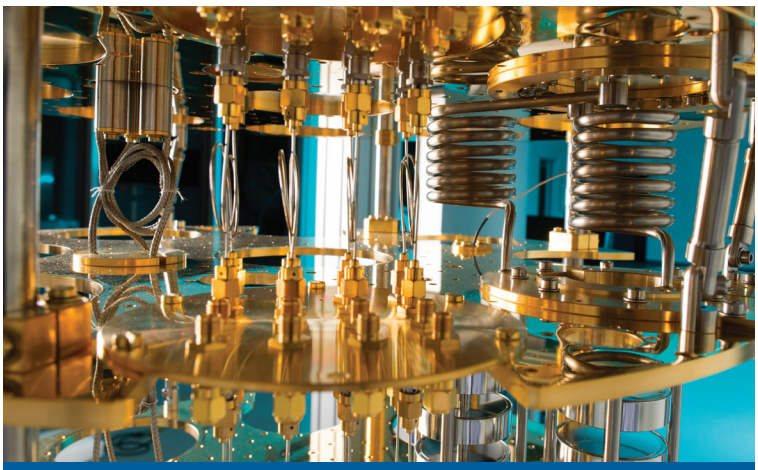
This neutrino detector, located at CERN, is a prototype for the international, Fermilab-hosted Deep Underground Neutrino Experiment detector. Photo: CERN

Neutrino experiments

Subatomic particles called neutrinos are among the most elusive in the particle kingdom. Fermilab is the premier U.S. laboratory for studying neutrinos and hosts the Deep Underground Neutrino Experiment, an international flagship experiment to unlock the mysteries of these particles, bringing together scientists from 30-plus countries. At Fermilab, researchers are using AI and developing state-of-the-art methods for detecting and studying nature's most mysterious particles, including expediting experiment work flow and enhancing event reconstruction.

Foundational AI algorithms

Fermilab scientists are developing novel AI algorithms. Partnering with other labs, universities and industry, Fermilab is driving forward the developments of AI for high-energy particle physics and beyond. Some examples are quantifying uncertainties in machine learning algorithms, carrying out computations on graphs, ultra efficient AI optimization and normalizing flows for phase space integration.



Fermilab advances technologies for quantum science, including quantum computers and sensors. Photo: Reidar Hahn, Fermilab

Quantum information science

Quantum machine learning is the use of quantum resources in machine learning problems or the use of machine learning to control or optimize quantum resources. Most applications to date have studied QML applied to classical data, but the most promising applications are actually using quantum data, for example from quantum simulation or from a quantum sensing experiment.