# deconstruction: neutrino experiments

Neutrinos zip straight through the Earth, while rarely leaving a trace. Yet these particles may hold answers to many of the key questions of 21st century particle physics. Around the world, scientists are creating an array of increasingly sophisticated neutrino experiments to find these answers.

## What do we know about neutrinos?

Scientists have discovered many surprising and often puzzling things about neutrinos since 1956, when Frederick Reines and Clyde Cowan found the first experimental evidence for these elusive particles in an experiment that they referred to as Project Poltergeist. Today we know:

- Neutrinos are among the most abundant types of particles in the universe.
- Neutrino sources include fusion processes in the sun; the fission processes in nuclear power stations; the decays of isotopes such as tritium and germanium; the collisions of cosmic rays with atoms in Earth's atmosphere; the collisions produced by particle accelerators; supernovae.
- Neutrinos have no electric charge and are immune to the strong nuclear force.
- Neutrinos have a tiny mass: the heaviest neutrino has less than a millionth the mass of an electron.
- Neutrinos come in three different types, or flavors: electron, muon, and tau neutrinos.
- Neutrinos can change (oscillate) from one type to another. The sun, for example, creates electron neutrinos. By the time they arrive on Earth, the majority have turned into muon and tau neutrinos.
- Neutrinos are hard to detect. Because they only interact with ordinary matter via the weak nuclear force, most of them zip through the earth unscathed.


MINOS


ICARUS


DOUBLE CHOOZ


EXO


SNO/SNO+


DAYA BAY

## Neutrino experiments address the key questions of particle physics

In 2004, the *Quantum Universe* report, published by the U.S. Department of Energy and the National Science Foundation, identified the nine most important questions to be addressed by future particle physics experiments. Neutrino experiments will play a major role in finding the answers to most of them:

Are there undiscovered principles of nature: new symmetries, new physical laws?
**Important quantum principles fail when applied to cosmic physics. Solving the problem requires new forces and particles.**

How can we solve the mystery of dark energy?
**The dark energy that permeates empty space must have a quantum explanation. Is it related to the Higgs field?**

Are there extra dimensions of space?
**String theory, which could reshape our concept of gravity, predicts undiscovered dimensions of space.**

Do all the forces become one?
**At the most fundamental level, all forces might be manifestations of a single grand unified force.**

Why are there so many kinds of particles?
**Why are there three families of quarks and leptons? Why do their masses differ so dramatically?**

What is dark matter? How can we make it in the laboratory?
**Most of the matter in our universe seems to be dark matter, probably particles remaining from the big bang.**

What are neutrinos telling us?
**What role did neutrinos play in the evolution of the universe? Their tiny nonzero masses may signal new physics.**

How did the universe come to be?
**Understanding the universe's inflationary expansion and formation of matter after the big bang requires new theories.**

What happened to the antimatter?
**The big bang should have produced equal amounts of matter and antimatter, yet the antimatter is gone. What happened?**

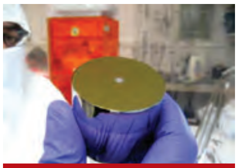
## Neutrino experiments

Experiments around the world, including those below, aim to answer fundamental questions about neutrinos. They use different neutrino sources, particle detector technologies and experimental strategies.

| Name | Country | Type | Source | Status | Questions |
|---|---|---|---|---|---|
| MINOS | USA (Fermilab) | long baseline | particle accelerator | operating | A, E, H |
| T2K | Japan (J-PARC) | long baseline | particle accelerator | operating | A, E, H |
| OPERA | Switzerland-Italy | long baseline | particle accelerator | operating | A, H |
| ICARUS | Switzerland-Italy | long baseline | particle accelerator | operating | A, H, R&D |
| NOνA | USA (Fermilab) | long baseline | particle accelerator | under construction | A, B, H |
| Double Chooz | France | neutrino disappearance | nuclear reactor | starting up | A, H |
| Daya Bay | China | neutrino disappearance | nuclear reactor | starting up | A, H |
| RENO | Korea | neutrino disappearance | nuclear reactor | starting up | A, H |
| MINERνA | USA (Fermilab) | various targets | particle accelerator | operating | F, H |
| KATRIN | Germany | nuclear decay | tritium | under construction | G, H |
| GERDA | Italy (Gran Sasso) | nuclear decay | germanium | operating | C, H |
| Cuore | Italy (Gran Sasso) | nuclear decay | tellurium | under construction | C, H |
| EXO | USA (WIPP) | nuclear decay | xenon | prototype operating | C, H |
| Majorana | USA (Sanford Lab) | nuclear decay | germanium | under construction | C, H |
| SNO+ | Canada (SNOLAB) | nuclear decay | neodymium | under construction | C, H |
| MiniBooNE | USA (Fermilab) | short baseline | particle accelerator | operating | A, E, H |
| MicroBooNE | USA (Fermilab) | short baseline | particle accelerator | close to construction | A, E, H, R&D |
| LBNE | USA (Fermilab) | long baseline | particle accelerator | in design | A, B, D, H |

Numerous neutrino astrophysics experiments, not listed here, look for cosmic neutrinos to learn more about celestial objects.

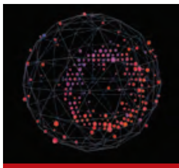
KATRIN



MAJORANA

T2K/SUPER-K

MINERνA



MINIBOONE

## The most pressing questions about neutrinos

Scientists have specific questions about neutrinos and their role in our universe. By addressing these questions, neutrino experiments help answer the key questions of 21st-century particle physics. The most important neutrino questions include:

A: Do all the neutrino types oscillate into all the other types?
**Scientists are eager to find strong evidence for the quick transformation of muon neutrinos into electron neutrinos.**

B: How do neutrino masses stack up? One light and two heavy? Two heavy, one light?
**The NOνA experiment aims to find out which neutrino is the lightest and which one is the heaviest.**

C: Are neutrinos their own antiparticles? How do neutrinos get their mass?
**If neutrinos are their own antiparticles, they are very different from all other known building blocks of matter.**

D: Do neutrinos interact differently with matter than with antimatter?
**If neutrinos break the matter-antimatter symmetry, they could be the reason antimatter disappeared in the early universe.**

E: Are there more than the three known types of neutrinos?
**Anomalies in the data of several neutrino experiments hint at additional neutrinos or new types of neutrino interactions.**

F: How do neutrinos interact with different types of atoms?
**Scientists need to understand how neutrinos interact with the materials that make up the bulk of neutrino detectors.**

G: How heavy is a single neutrino?
**The KATRIN experiment aims to measure the mass of a single neutrino.**

H: Again and again, neutrino experiments have led to unexpected discoveries. What future surprises are awaiting us?
**In the past fifty years, neutrino-related discoveries have been recognized with three Nobel Prizes. What's next?**

**Text: Kurt Riesselmann**