The search for a fourth neutrino

An international research program at Fermilab will probe one of the enduring mysteries of science: Are there only three types of ghostly particles known as neutrinos, or is a fourth type waiting to be discovered?

Probing hints at new physics

Neutrinos are everywhere. They are among the most abundant particles in the universe, and yet we know very little about them. Scientists discovered the third type of neutrino, called the tau neutrino, at Fermilab in 2000, and we know that the three types of neutrinos can transform into each other, like ghosts.

Theoretical models and data from previous experiments suggest there might be a fourth kind of neutrino, one that may not follow the rules of neutrino oscillations and interactions with matter as we know them. Searching for these so-called sterile neutrinos is the goal of more than 200 scientists from 45 institutions involved in Fermilab's short-baseline neutrino program. When construction is complete a chain of three particle detectors—placed in a straight line, about a third of a mile long—will probe a beam of muon neutrinos created by Fermilab's particle accelerators. Together these three detectors are powerful tools to investigate in great detail the evolution of neutrino oscillations over short time and distance, and thus explore whether the universe is even more complex than we think.

ICARUS: high-tech from Italy

The largest of the three detectors will make the longest journey to Fermilab. Scientists operated the 760-ton ICARUS detector at Gran Sasso National Laboratory in Italy for four years before shipping it for upgrades to the CERN research center near Geneva, Switzerland. In 2017, the detector will make its way across the ocean and into a new research hall at Fermilab. ICARUS is the largest detector of its type in the world: it uses liquid-argon technology to record neutrino interactions. This technology yields the most precise 3D images of the particle tracks created by neutrinos colliding with atoms.

The ICARUS detector on the road to the CERN laboratory in December 2014. The detector will be refurbished at CERN over the next two years and will make its way to Fermilab in 2017. *Photo: INFN*

The 160-ton MicroBooNE detector in place at Fermilab, in the path of the neutrino beam. The three on-site detectors will all use state-of-the-art liquid-argon time projection technology to track neutrino interactions.

MicroBooNE: testing an anomaly

The detector at the center of the chain is already complete. The 170-ton MicroBooNE detector will check an unexplained anomaly in the data of a previous neutrino experiment. This anomaly could have been caused by the presence of sterile neutrinos, but other explanations are also possible. MicroBooNE combines liquid-argon technology with a state-of-the-art 3D imaging process to spot neutrino interactions.

SBND: closest to the source

The Short-Baseline Near Detector, which will sit closest to the source of the neutrino beam, also will employ the high-precision liquid-argon technology. Scientists from the United Kingdom and Switzerland will work with the U.S. scientists on the design and construction of this 260-ton particle detector. It plays a unique role in the chain of detectors, measuring the purity of the muon neutrino beam produced by the Fermilab accelerators.