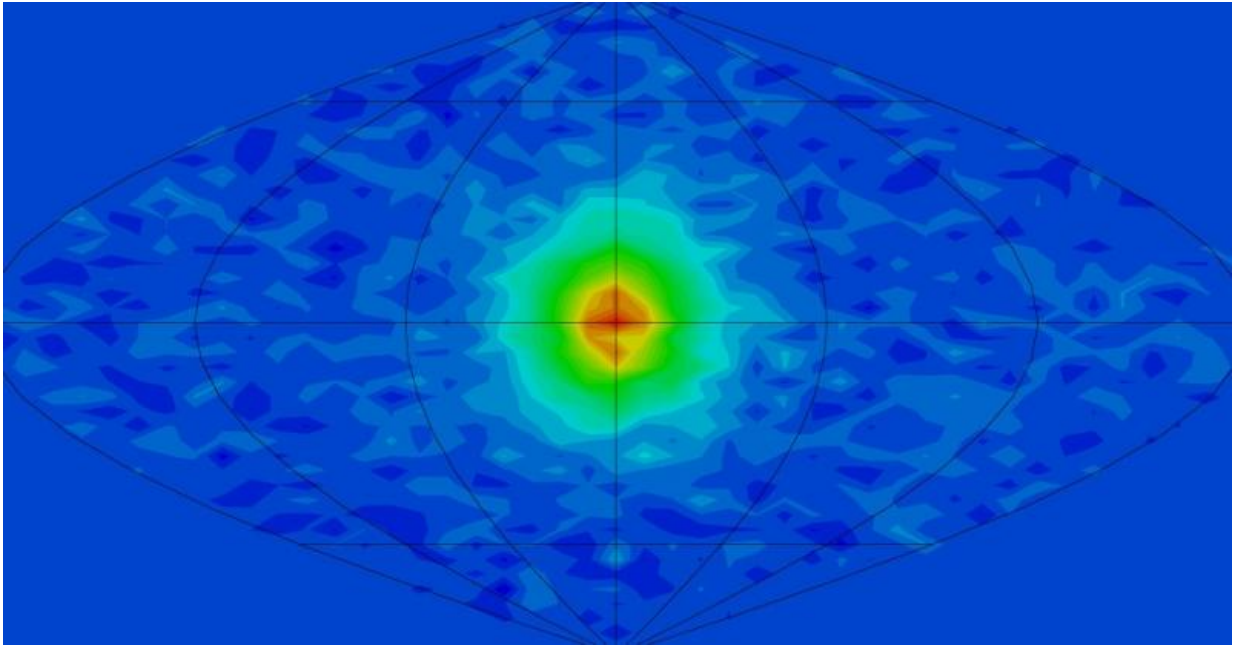


Mysterious neutrinos take the stage at SLAC

September 24 2015



Neutrinos are abundantly produced in nuclear processes in the universe, for instance inside the sun. This image shows the sun in “neutrino light” as seen by the Super-Kamiokande neutrino detector in Japan. Credit: Kamioka Observatory, ICRR, University of Tokyo

Of all known fundamental particles, neutrinos may be the most mysterious: Although they are highly abundant in the universe and were discovered experimentally in 1956, researchers still have a lot left to learn about them. To find out more about the elusive particles and their potential links to cosmic evolution, invisible dark matter and matter's

dominance over antimatter in the universe, the Department of Energy's SLAC National Accelerator Laboratory is taking on key roles in four neutrino experiments: EXO, DUNE, MicroBooNE and ICARUS.

Neutrinos were also the central theme of the 43rd annual SLAC Summer Institute for particle physics and astrophysics. The tradition-rich educational event, held Aug. 10-21, attracted more than 150 scientists from around the globe and featured lectures by some of the world's leading neutrino experts.

"Neutrinos are a hot research topic and have become a major focus of U.S. high-energy physics," said SLAC theorist Thomas Rizzo, one of the summer school's organizers. "There are many things we want to know about neutrinos. For instance, what are the masses of the known neutrinos? Are there other types of neutrinos that we don't know about? Do neutrinos and antineutrinos behave differently? Or are neutrinos their own antiparticles?"

Francis Halzen, principal investigator of the international IceCube Neutrino Observatory at the South Pole and neutrino specialist at the University of Wisconsin, gave the summer institute's opening lecture. He said neutrinos have a high potential for scientific discovery – and they are also never boring. As a matter of fact, the history of neutrino research has seen a few surprising twists and turns.

Elusive and Mysterious Neutrinos

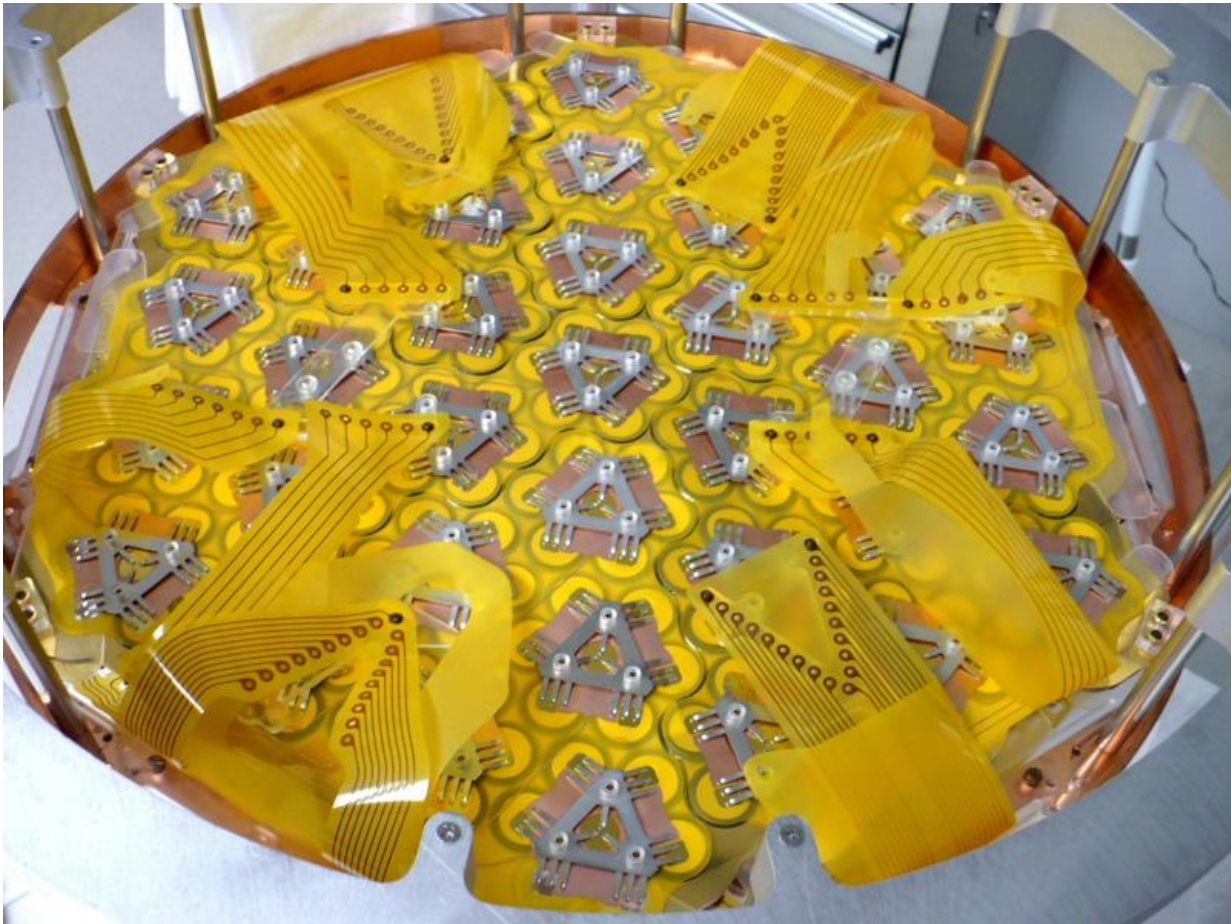
Neutrinos are one of the most common fundamental particles in the universe. They are abundantly produced in supernova explosions, star-powering nuclear fusion and other nuclear processes, resulting in trillions of neutrinos passing through us every minute. Yet, they are very difficult to study because they rarely interact with their surroundings and easily evade detection. This explains why it took researchers nearly 30 years to

catch a first glimpse of neutrinos, although their existence had been first postulated in 1930 to explain an apparent violation of the conservation of energy in the radioactive decay of unstable atomic nuclei known as beta decay.

A few years after the initial discovery in 1956, researchers were caught by surprise when more than one type of neutrino showed up in their experiments. By the turn of the millennium, they had identified three different types, or flavors, each associated with another fundamental charged partner particle: the electron, muon and tau.

For the longest time, neutrinos were thought to be massless. But in 1998, scientists discovered that neutrinos frequently change from one flavor into another – a process called neutrino oscillation that can only occur if neutrinos do, in fact, have mass. Although the exact masses remain unknown, researchers estimate neutrinos to be two million times lighter than the next heavier particle, the electron, and this large mass difference is one of the great puzzles of neutrino physics.

EXO: The Origin of the Neutrino Mass



Part of the EXO-200 underground detector used to search for a hypothesized radioactive decay that could reveal how neutrinos acquire their incredibly small mass. Credit: EXO Collaboration

The origin of neutrino masses could be different from the origin of the masses of other particles. This could explain why neutrinos are incredibly light. One sign that this is true would be if they were their own antiparticles. This is only possible for neutrinos, since they carry no electric charge. The Enriched Xenon Observatory (EXO) is searching for a theorized rare nuclear process – neutrinoless double beta decay – that would prove that neutrinos and antineutrinos are identical.

Located almost half a mile underground at the Waste Isolation Pilot Plant in New Mexico, protected from cosmic radiation, the sensitive EXO experiment uses 200 kilograms of enriched liquid xenon that could potentially undergo the sought-after decay. If it exists, it would be so rare that it would take billions of times longer than the age of the universe for half of the radioactive xenon nuclei to decay. Only the large number of xenon atoms in the experiment allows researchers to search for such a long-lived decay.

"Neutrinoless double beta decay would not only tell us that neutrinos must be their own antiparticles," said SLAC particle physicist and EXO team member Martin Breidenbach. "From the measured decay rate, we could also determine the effective [neutrino mass](#)."

SLAC co-lead the construction of the experiment's 200-kilogram version (EXO-200), which also serves as a test bed for a more sensitive future ton-scale version (nEXO) that would give researchers a much better chance of seeing neutrinoless [double beta decay](#).

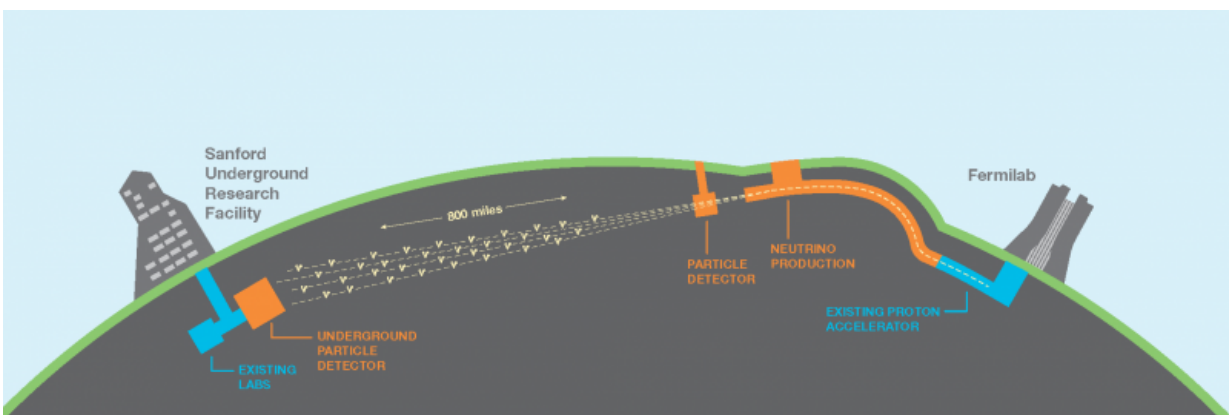
DUNE: Trio of Neutrino Masses and Matter-Antimatter Imbalance

SLAC researchers are also taking part in another neutrino experiment – the Deep Underground Neutrino Experiment (DUNE), which will be constructed by a new international collaboration hosted at the Long-Baseline Neutrino Facility (LBNF) as the centerpiece of the particle physics program in the U.S.

As part of LBNF, neutrinos and antineutrinos will be sent 800 miles through the Earth from Fermi National Accelerator Laboratory in Illinois to the DUNE detector in South Dakota – an "eye" for neutrinos that will eventually consist of four 10,000-ton modules of liquid argon.

Scientists will then track how the particles morph from one neutrino flavor into another along the way.

By comparing the oscillations of antineutrinos with those of neutrinos, DUNE researchers will be able to determine if the matter-antimatter siblings behave differently. If they do, the difference could potentially help explain why our universe is made of matter rather than antimatter.



The future DUNE experiment will send neutrinos and antineutrinos 800 miles through the Earth to determine the relative masses of the three known neutrino types and study whether neutrinos and antineutrinos behave differently. Credit: Fermi National Accelerator Laboratory

"Since each neutrino flavor interacts differently with the material in the Earth, the experiment will also tell us which of the three neutrino types is the lightest and which is the heaviest," said researcher Mark Convery, who heads SLAC's LBNF/DUNE group.

DUNE's liquid argon detector may also make other experiments possible. It could be used, for instance, to catch a glimpse of neutrino

bursts from supernova explosions, which could tell us more about the physics of collapsing stars. Scientists at the joint SLAC/Stanford University Kavli Institute for Particle Astrophysics and Cosmology (KIPAC) are particularly interested in this research opportunity.

MicroBooNE and ICARUS: Search for Unknown Neutrinos

However, DUNE will not be ready until the mid-2020s. In the meantime, Convery and his team are also engaging in the current MicroBooNE and future ICARUS experiments at Fermilab. These are so-called short-baseline experiments with detectors just hundreds of yards away from the neutrino source, rather than hundreds of miles away.



The MicroBooNE neutrino detector at Fermilab will help researchers better understand the three neutrino types and look for a hypothetical fourth one.

Credit: Fermi National Accelerator Laboratory

"MicroBooNE and ICARUS will help us prepare for DUNE, but they also have the potential to discover completely new physics," Convery said. "They'll follow up on previous short-baseline studies that observed anomalies in neutrino oscillations."

Researchers believe that these anomalies could hint at the existence of a fourth, "sterile" neutrino. This hypothetical particle could potentially be linked to dark matter, the invisible substance that is five times more prevalent in the universe than regular matter.

MicroBooNE's 170-ton liquid argon detector began collecting data in August 2015, while ICARUS, which is three-and-a-half times heavier, is being upgraded at the European particle physics laboratory CERN. Both experiments will eventually become part of a three-detector short-baseline neutrino program at Fermilab, scheduled to launch in 2018 and designed to clarify whether previous hints at sterile [neutrinos](#) are correct or not.



View of the inside of the MicroBooNE detector at Fermilab before it was filled with 170 tons of liquid argon for neutrino detection. The experiment will help researchers better understand the three neutrino types and look for a hypothetical fourth one. Credit: Fermi National Accelerator Laboratory

Provided by SLAC National Accelerator Laboratory

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