# First detections of collider neutrinos generate excitement FREE

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Future measurements of high-energy neutrinos at the Large Hadron Collider could yield insights into tau neutrinos, the strong force, and even new physics.

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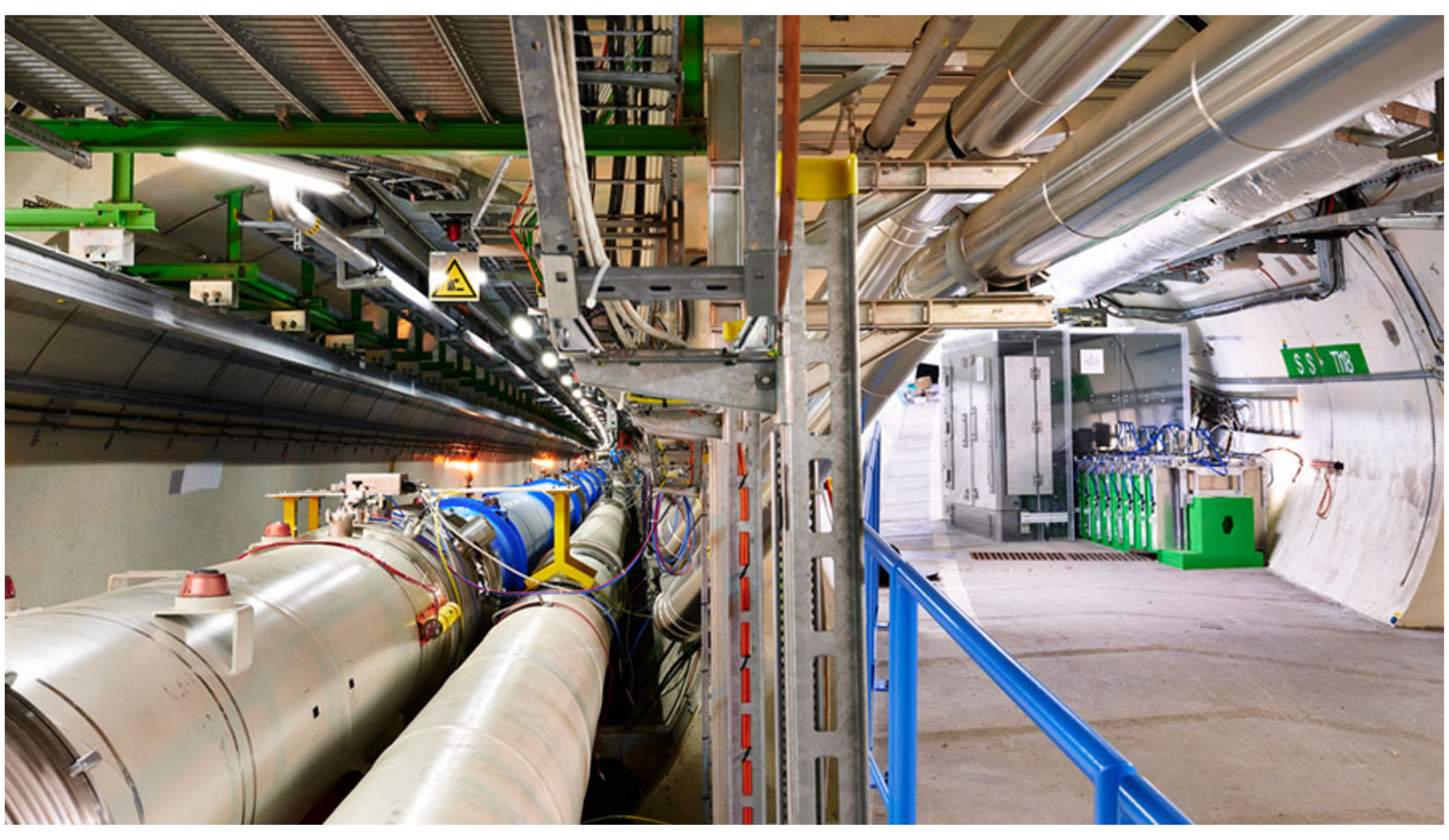

The SND@LHC experiment (right) resides in a side tunnel of the Large Hadron Collider, about a half kilometer from the point where protons collide inside the much-larger ATLAS detector. Credit: Maximilien Brice/CERN

To capture the ultralight, chargeless neutrino, scientists have built numerous vast arrays of underground detectors. Various experiments target neutrinos that originate in nuclear reactors, fusion reactions within the Sun, and powerful astrophysical phenomena such as supernovae. Recently the IceCube Neutrino Observatory, an enormous detector embedded in the ice of Antarctica, caught the first confirmed evidence of neutrinos that are billions of times as energetic as solar neutrinos originating within our Milky Way.

Now two studies in *Physical Review Letters* confirm the detection of some 160 neutrinos that were produced in experiments at the world's most powerful particle accelerator, the Large Hadron Collider (LHC) at CERN. It marks the first time neutrinos have been detected in a collider experiment and the highest recorded energies for neutrinos that were both produced and detected in a laboratory environment.

"It's pretty much a fact that every time you see neutrinos in a new way, you learn something absolutely amazing about our universe," says Jonathan Feng of the University of California, Irvine, who is co-spokesperson for one of the groups that detected neutrinos. The properties of the LHC neutrinos open the possibility of new insights, including a better understanding of the force that holds quarks together and improved measurements of the exceedingly hard-to-detect tau neutrino.

The novel neutrino observations were made by the LHC's two newest detectors. The concept for the Forward Search Experiment (FASER) came from a 2017 paper written by Feng and three Irvine postdocs. They noted that there was a hole in the LHC's detection strategy: When the LHC's two proton beams are shot at each other, detectors such as ATLAS and CMS surround the point of collision—almost. The gaps are the openings in the detectors that allow the beams through. There are particles produced in the collision that continue through those holes and down the beam pipe in what is called the forward direction.

FASER, which began collecting data last year, is designed to detect those previously unaccounted-for particles, including neutrinos, which are unaffected by the LHC's powerful steering magnets. An aluminum box containing a ton of tungsten sits in an LHC side tunnel, where it can catch the neutrinos that continue forward from the ATLAS experiment's point of collision. When a neutrino interacts with a tungsten atom, a charged particle comes shooting out. The identity of the particle corresponds with whichever of the three flavors of neutrino produced it—muon, electron, or tau.


The Forward Search Experiment detects some of the particles that evade detection within the nearby ATLAS experiment. Credit: Maximilien Brice/CERN

So far, all of FASER's confirmed neutrinos are of the muon and electron varieties. (The electron neutrino detections were reported at a neutrino workshop in August.) The team expects to detect tau neutrinos in future runs of the experiment. Detecting a tau particle requires that the source neutrino have a lot of energy, because the tau's mass is roughly 17 times the mass of a muon and 3500 times that of an electron. In other experiments, Feng says, "the incoming neutrino doesn't have enough energy so that you can actually produce the tau particle." Considering the energy of the LHC, however, FASER "doesn't really have that problem."

Last year also marked the first science run of the Scattering and Neutrino Detector at the LHC. Unlike FASER, SND@LHC is located slightly off the collision axis. That positioning favors the detection of neutrinos that are produced in the decays of relatively heavy particles, particularly the charm quark, says collaboration spokesperson Giovanni De Lellis of the University of Naples. The collaboration hopes to use its neutrino measurements to better understand the strong forces that hold charm quarks together.

De Lellis says the measurements done at the LHC also will be applicable to astrophysics. With energies exceeding a trillion electron volts, the neutrinos at the LHC are comparable to many of those that form when high-energy cosmic rays collide with molecules in Earth's atmosphere. Among the intermediate products of those collisions are charm quarks, which decay and produce neutrinos.

Dennis Soldin, a University of Utah particle physicist who was not involved in the LHC research, says the collider experiment data are relevant to his work with IceCube. "We have backgrounds from neutrinos that are produced in the atmosphere, and those neutrinos are produced exactly at the same energies that the LHC probes," he says. Having the measurements from the LHC should help Soldin and his IceCube colleagues reduce uncertainties in their measurements of the neutrino backdrop and home in on the astrophysical sources that produce high-energy neutrinos.

In their *Physical Review Letters* papers, the FASER team reported detecting about 153 neutrinos and the SND@LHC collaboration roughly 8. "The current experiments are too small to be able to actually realize their whole physics potential," says Juan Rojo, a Vrije Universiteit Amsterdam particle physicist who was not involved in the work. The upcoming high-luminosity upgrade to the LHC could allow the teams to increase their rate of neutrino detection into the thousands per day.

With sufficiently strong statistics, the LHC experiments could make observations that indicate physics beyond the standard model, potentially leading to explanations for dark matter. If there are any exotic particles that have been moving in the forward direction and evading detection, De Lellis says, then FASER and SND@LHC have the potential to catch them. Says Soldin, "It's the start of an absolutely new kind of program at the LHC that opens a window to a huge variety of physics."





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