symmetry
dimensions of particle physics

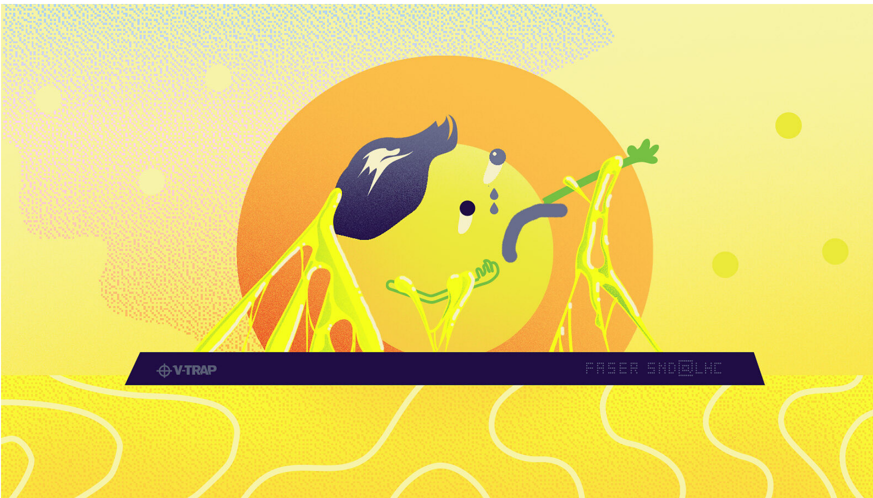

Illustration by Sandbox Studio, Chicago

Catching neutrinos at the LHC

09/20/22 | By Chetna Krishna

After the successful initiation of two new detectors, scientists have begun to envision an expanded suite of neutrino experiments at the Large Hadron Collider.

CERN physicist Jamie Boyd enters a tunnel close to the ATLAS detector, an experiment at the largest particle accelerator in the world. From there, he turns into an underground space labeled TI12.

“This is a very special tunnel,” Boyd says, “because this is where the old transfer line used to exist for the Large Electron-Positron Collider, before the Large Hadron Collider.” After the LHC was built, a new transfer line was added, “and this tunnel was then abandoned.”

The tunnel is abandoned no more. Its new resident is an experiment much humbler in size than the neighboring ATLAS detector. Five meters in length, the ForwArd Search ExpeRiment, or FASER, detector sits in a shallow excavated trench in the floor, surrounded by low railings and cables.

Scientists—including Boyd, who serves as co-spokesperson for FASER—installed the relatively small detector in 2021. Just in time before restarting the LHC in April, physicists nestled another small experiment, called Scattering and Neutrino Detector or SND@LHC, on the other side of ATLAS.

Both of the detectors are now running and have started collecting data. Scientists say they hope the two detectors represent the beginning of a new effort to catch and study particles that the LHC's four main detectors can't see.

> **"We are now guaranteed to see thousands of neutrinos at the LHC for the first time."**

Hiding in plain sight

Both FASER and SND@LHC detect particles called neutrinos. Not to be confused with neutrons—particles in the nuclei of atoms that are made up of quarks—neutrinos cannot be broken down into smaller constituents. Along with quarks, electrons, muons and taus, neutrinos are fundamental particles of matter in the Standard Model of physics.

These light, neutral particles are abundant across the galaxy. Some have been around since the Big Bang; others are produced in particle collisions, such as those that happen when cosmic rays strike the atoms that make up Earth's atmosphere. Every second, neutrinos pass through us in the trillions without leaving a trace—because they only rarely interact with other matter.

Neutrinos are also produced in collisions at the LHC. Scientists are aware of their presence, but for more than a decade of LHC physics, neutrinos went undetected, as the ATLAS, CMS, LHCb and ALICE detectors were designed with other types of particles in mind.

The four biggest LHC experiments cannot detect neutrinos directly, says Milind Diwan, a senior scientist at the US Department of Energy's Brookhaven National Laboratory. Diwan was an original proponent of and spokesperson for what is now the Deep Underground Neutrino Experiment hosted by Fermi National Accelerator Laboratory.

In 2021, FASER became the first detector to catch neutrinos at the LHC—or any particle collider.

A new way of looking at neutrinos

Neutrinos are the chameleons of the particle world. They come in three flavors, called muon, electron and tau neutrinos for the particles associated with them. As they travel through the universe at nearly the speed of light, neutrinos shift between the three flavors. Both FASER and SND@LHC can detect all three flavors of neutrinos.

The detectors will catch only a small fraction of the neutrinos that pass through them, but the high-energy collisions of the LHC should produce a staggering number of the particles. For example, during the current run of the LHC, which will last until the end of 2025, physicists estimate FASER and its new subdetector, called FASER*ν* (pronounced FASERnu), will experience a flux of 200 billion electron neutrinos, 6 trillion muon neutrinos, and 4 billion tau neutrinos, along with a comparable number of anti-neutrinos of each flavor.

"We are now guaranteed to see thousands of neutrinos at the LHC for the first time," says Jonathan Feng, co-spokesperson for the FASER collaboration.

Those neutrinos will be at the highest energies ever seen from a human-made source, says Tomoko Ariga, project leader for FASER*ν*, who previously worked on the DONUT neutrino experiment. "At such extreme energies, FASER*ν* will be able to probe neutrino properties in new ways."

The experiments will provide a new way of studying other particles as well, says Giovanni De Lellis, spokesperson for both SND@LHC and the OPERA neutrino experiment.

Because a large fraction of the neutrinos produced in the range accessible to SND@LHC will come from the decays of particles made of charm quarks, SND@LHC can be used to study charm-quark particle production in a region that other LHC experiments cannot explore. This will help both physicists studying collisions at future colliders and physicists studying neutrinos from astrophysical sources.

FASER and SND@LHC could also be used to detect dark matter, Diwan says. If dark-matter particles are produced in collisions at the LHC, they could slip away from the ATLAS detector alongside the beamline—right into FASER and SND@LHC.

A proposal for the future

These experiments could be just the beginning. Physicists have proposed five more experiments—including advanced versions of the FASER and SND@LHC detectors—to be built near the ATLAS detector. The experiments—FASER*ν*2, Advanced SND, FASER2, FORMOSA and FLArE—could sit at a proposed Forward Physics Facility during the next phase of the LHC, the High-Luminosity LHC.

The advanced FASER*ν* and SND@LHC detectors would boost the experiments' detection of neutrinos by a factor of 100, Feng says. "This means, for example, that instead of tens of tau neutrinos, they will detect thousands, allowing us to separate tau neutrinos from anti-tau neutrinos and do precision studies of these two independently for the first time."

The FLArE experiment, which would detect neutrinos in a different way from FASER and SND@LHC, could also be sensitive to light dark matter.

Even without the proposed future experiments, scientists are poised to learn more about neutrinos from their studies at the LHC. FASER*ν* and SND@LHC have already began taking physics data and are expected to present new results in 2023.

"Neutrinos are amazing," Feng says. "Every time we look at them from a new source, whether it is a nuclear reactor or the sun or the atmosphere, we learn something new. I am looking forward to seeing what surprises nature has in store."

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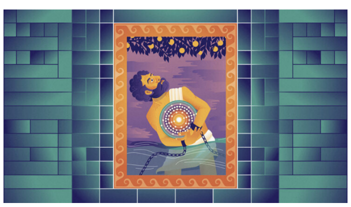

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