Can neutrinos help explain what's the matter with antimatter?

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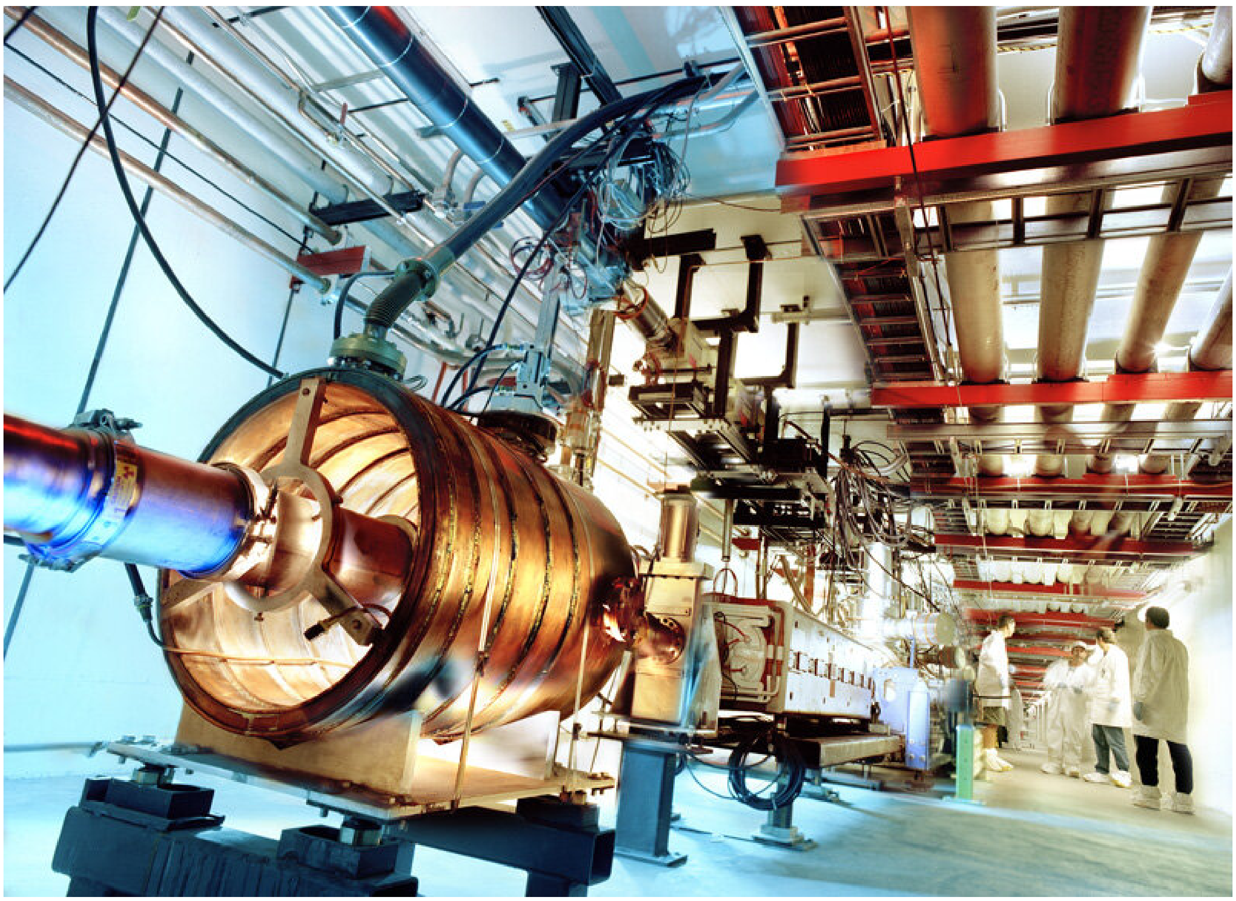

The Main Injector is a powerful particle accelerator at Fermilab near Chicago. It is also the source of the world's highest-energy neutrino beams that will be used in the Deep Underground Neutrino Experiment (DUNE), an international flagship neutrino experiment involving researchers at Penn. (Image: Peter Ginter/Fermilab)

In physics, antimatter is simply the "opposite" of matter. Antimatter particles have the same mass as their counterparts but with other properties flipped; for example, protons in matter have a positive charge while antiprotons are negative. Antimatter can be made in a lab using high-energy particle collisions, but these events almost always create equal parts of both antimatter and matter and, when two opposing particles come in contact with one another, both are destroyed in a powerful wave of pure energy.

What puzzles physicists is that most everything in the universe, people included, is made of matter, not of equal parts matter and antimatter. While looking for insights that could explain what kept the universe from creating separate matter and antimatter galaxies, or exploding into nothingness, researchers found some evidence that the answer could be hiding in very common yet poorly understood particles known as neutrinos.

A team of researchers led by Christopher Mauger published results from the first set of experiments that can help answer these and other questions in fundamental physics. As part of the Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrino (CAPTAIN) program, their results, published in *Physical Review Letters*, are an important first step towards building the Deep Underground Neutrino Experiment (DUNE), an experimental facility for neutrino science and particle physics research.

Particle colliders, such as the Large Hadron Collider at CERN, do experiments on quarks, one type of elementary particle. These experiments found some evidence that explains matter-antimatter symmetry, but only part of it. Experiments on another type of elementary particle, leptons, hints that these particles could more fully explain this universal asymmetry. Previous research on neutrinos, a type of lepton, found unexpected patterns in the three neutrino "flavors," results which physicists believe might also mean that their asymmetry might be larger than expected.

But the challenge with studying neutrinos is that they rarely interact with other particles; a single neutrino can pass through a light-year of lead without doing anything. Finding these rare interactions means that researchers need to study a large number of neutrinos for long periods of time. As an added challenge, the steady stream of muons produced by cosmic ray interactions in the upper atmosphere can make it difficult to spot the infrequent interactions that researchers are more interested in seeing.

The outer structures (red) for two prototype DUNE detectors that are currently being evaluated at CERN. (Image: CERN)

The solution? Go 5,000 feet underground, build four 10-kiloton detectors filled with liquid argon, and fire a beam of neutrinos made in a particle accelerator that's 800 miles away. This is the eventual goal of DUNE, an international neutrino research facility run by Fermilab, a particle physics and accelerator laboratory near Chicago. Excavations for the detector, which will be installed at the Sanford Underground Research Facility in South Dakota, are underway, and researchers are now busy with experiments before the first detector is installed in 2022.

As the first publication to come from CAPTAIN, researchers addressed a key technical challenge: How to handle measurements on other particle interactions. For example, when a neutrino interacts with argon, the neutrino picks up a charge and kicks out neutrons. A large fraction of the energy from the interaction will go into the neutron, but it has not been possible to determine the amount. "We must understand argon-neutron interactions if we want to properly do the experiment that's going to impact our understanding of matter and antimatter asymmetry," says Mauger.

He and his team built a 400-kilogram prototype of the DUNE detector, known as Mini-CAPTAIN, and collected data from a neutron beam at the Los Alamos National Laboratory. Former Penn postdoc Jorge Chaves, who worked as the analysis leader for this research, says that the bulk of the work involved reconstructing the signals from the detector into meaningful insights about the properties that they are interested in studying further.

As the first-ever dataset on neutron interactions in liquid argon at the energy ranges that will be used in DUNE, Chaves says that he is encouraged by the results obtained so far, even though they still need to get additional data. "Before, there was no measurement of this interaction cross-section, but now we have provided actual experimental results," he says. "With more data of the same quality, we would be able to make an even more precise measurement."

In the near-term, the CAPTAIN team will focus on refining the methods developed for this paper as well as on running other experiments before DUNE begins collecting data in 2026. Once the project officially kicks off, researchers hope to be able to use this facility to help answer questions from the fields of particle physics, nuclear physics, and even astrophysics.

Mauger considers the ongoing efforts of CAPTAIN and other projects as "Physics R&D," work that will help researchers collect important measurements and study phenomena in a way never done before. The many lofty goals of DUNE will take decades to complete, but Mauger says that what they are trying to achieve makes the effort worthwhile.

"Neutrinos are so hard to measure, sort of enigmatic, and there's some kind of allure in trying to understand how they work. Studying this really interesting particle that's all around us, and yet is so hard to measure, that could hold the key to understanding why we're here at all, is exciting—and I get to do this for a living," says Mauger.

More information: B. Bhandari et al. First Measurement of the Total Neutron Cross Section on Argon between 100 and 800 MeV, *Physical Review Letters* (2019). [DOI: 10.1103/PhysRevLett.123.042502](https://doi.org/10.1103/PhysRevLett.123.042502)

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