World's smallest neutrino detector observes elusive interactions of particles

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During normal operations of the Spallation Neutron Source, a US Department of Energy user facility at Oak Ridge National Laboratory, this world-class 'neutron factory' also produces neutrinos in large quantities. Credit: Oak Ridge National Laboratory, U.S. Dept. of Energy; photographer Jason Richards

In 1974, a Fermilab physicist predicted a new way for ghostly particles called neutrinos to interact with matter. More than four decades later, a UChicago-led team of physicists built the world's smallest neutrino detector to observe the elusive interaction for the first time.

Neutrinos are a challenge to study because their interactions with matter are so rare. Particularly elusive has been what's known as coherent elastic neutrino-nucleus scattering, which occurs when a neutrino bumps off the nucleus of an atom.

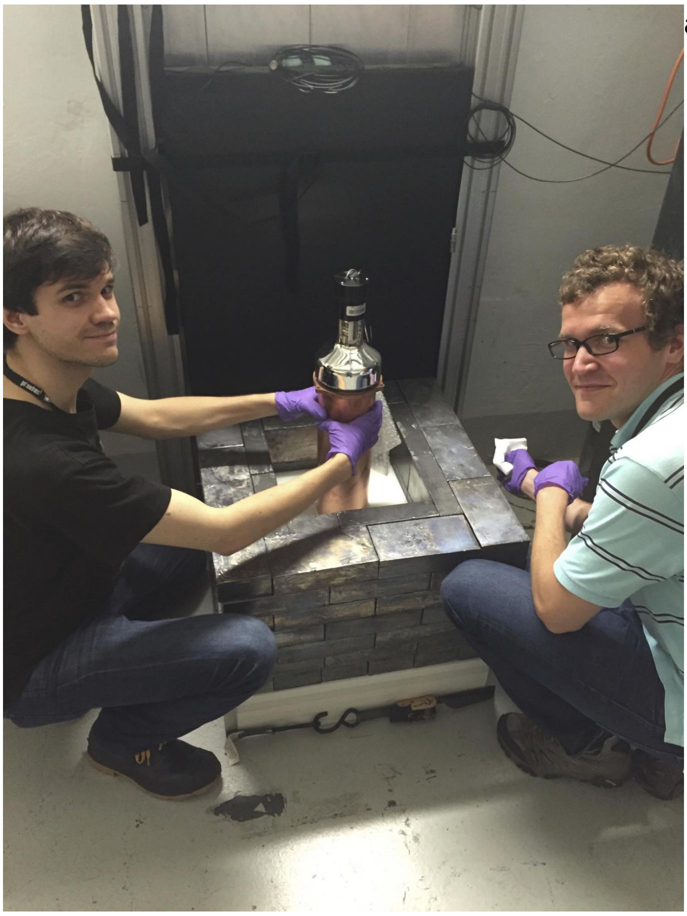
The international COHERENT Collaboration, which includes physicists at UChicago, detected the scattering process by using a detector that's small and lightweight enough for a reseacher to carry. Their findings, which confirm the theory of Fermilab's Daniel Freedman, were reported Aug. 3 in the journal *Science*.

"Why did it take 43 years to observe this interaction?" asked co-author Juan Collar, UChicago professor in physics. "What takes place is very subtle." Freedman did not see much of a chance for experimental confirmation, writing at the time: "Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution and background pose grave experimental difficulties."

When a neutrino bumps into the nucleus of an atom, it creates a tiny, barely measurable recoil. Making a detector out of heavy elements such as iodine, cesium or xenon dramatically increases the probability for this new mode of neutrino interaction, compared to other processes. But there's a trade-off, since the tiny nuclear recoils that result become more difficult to detect as the nucleus grows heavier.

"Imagine your neutrinos are ping-pong balls striking a bowling ball. They are going to impart only a tiny extra momentum to this bowling ball," Collar said.

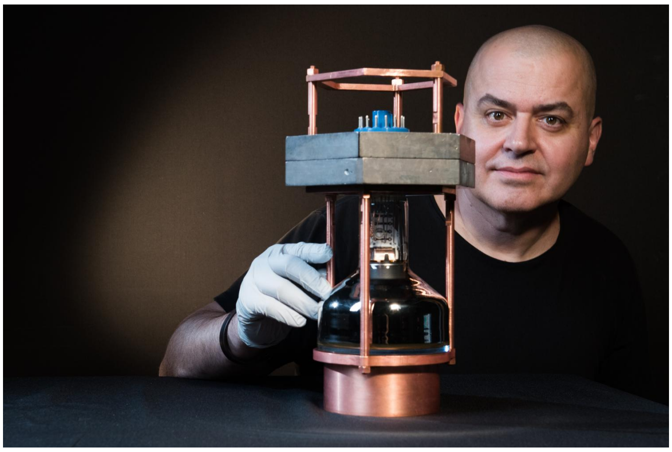
around it," said UChicago doctoral student Bjorn Scholz, whose thesis will contain the result reported in the *Science* paper. "We can now think about building other small detectors that can then be used, for example to monitor the neutrino flux in nuclear power plants. You just put a nice little detector on the outside, and you can measure it in situ."



Researchers Bjorn Scholz (left) and Grayson Rich (right) with the world's smallest neutrino detector as it's being installed along 'neutrino alley' at the Spallation Neutron Source at Oak Ridge National Laboratory in Tennessee. Credit: Juan Collar/University of Chicago

Neutrino physicists, meanwhile, are interested in using the technology to better understand the properties of the mysterious particle.

"Neutrinos are one of the most mysterious particles," Collar said. "We ignore many things about them. We know they have mass, but we don't know exactly how much."



Juan Collar, a professor in physics at the University of Chicago, with a prototype of the world's smallest neutrino detector used to observe for the first time an elusive interaction known as coherent elastic neutrino nucleus scattering. Credit: Jean Lachat/University of Chicago

To detect that bit of tiny recoil, Collar and colleagues figured out that a cesium iodide crystal doped with sodium was the perfect material. The discovery led the scientists to jettison the heavy, gigantic detectors common in neutrino research for one similar in size to a toaster.

No gigantic lab

The 4-inch-by-13-inch detector used to produce the *Science* results weighs only 32 pounds (14.5 kilograms). In comparison, the world's most famous neutrino observatories are equipped with thousands of tons of detector material.

"You don't have to build a gigantic laboratory

Through measuring coherent elastic neutrino-nucleus scattering, physicists hope to answer such questions. The COHERENT Collaboration's *Science* paper, for example, imposes limits on new types of neutrino-quark interactions that have been proposed.

The results also have implications in the search for Weakly Interacting Massive Particles. WIMPs are candidate particles for dark matter, which is invisible material of unknown composition that accounts for 85 percent of the mass of the universe.

"What we have observed with neutrinos is the same process expected to be at play in all the WIMP detectors we have been building," Collar said.

Neutrino alley

The COHERENT Collaboration, which involves 90 scientists at 18 institutions, has been conducting its search for coherent neutrino scattering at the Spallation Neutron Source at Oak Ridge National Laboratory in Tennessee. The researchers installed their detectors in a basement corridor that became known as "neutrino alley." This corridor is heavily shielded by iron and concrete from the highly radioactive neutron beam target area, only 20 meters (less than 25 yards) away.

This neutrino alley solved a major problem for neutrino detection: It screens out almost all neutrons generated by the Spallation Neutron Source, but neutrinos can still reach the detectors. This allows researchers to more clearly see neutrino interactions in their data. Elsewhere they would be easily drowned out by the more prominent neutron detections.

The Spallation Neutron Source generates the most intense pulsed neutron beams in the world for scientific research and industrial development. In the process of generating neutrons, the SNS also produces neutrinos, though in smaller quantities.

"You could use a more sophisticated type of neutrino detector, but not the right kind of neutrino source, and you wouldn't see this process," Collar said. "It was the marriage of ideal source and ideal detector that made the experiment work."

Two of Collar's former graduate students are co-authors of the Science paper: Phillip Barbeau, AB'01, SB'01, PhD'09, now an assistant professor of physics at Duke University; and Nicole Fields, PhD'15, now a health physicist with the U.S. Nuclear Regulatory Commission in Chicago.

The development of a compact neutrino detector brings to fruition an idea that UChicago alumnus Leo Stodolsky, SM'58, PhD'64, proposed in 1984. Stodolsky and Andrzej Drukier, both of the Max Planck Institute for Physics and Astrophysics in Germany, noted that a coherent detector would be relatively small and compact, unlike the more common neutrino detectors containing thousands of gallons of water or liquid scintillator. In their work, they predicted the arrival of future neutrino technologies made possible by the miniaturization of the detectors.

Scholz, the UChicago graduate student, saluted the scientists who have worked for decades to create the technology that culminated in the detection of coherent neutrino scattering.

"I cannot fathom how they must feel now that it's finally been detected, and they've achieved one of their life goals," Scholz said. "I've come in at the end of the race. We definitely have to give credit to all the tremendous work that people have done before us."

More information: D. Akimov el al., "Observation of coherent elastic neutrino-nucleus scattering," *Science* (2017). science.sciencemag.org/lookup/ … 1126/science.aao0990

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