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Considering the container to strengthen the weak force's signal

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Kurtis Bartlett won the 2018 JSA Thesis Prize for making measurements that helped determine the weak charge of the proton. Credit: DOE's Jefferson Lab

Nuclear physicists successfully measured the weak charge of the proton by shooting electrons at a cold liquid hydrogen target in an experiment carried out at the Department of Energy's Thomas Jefferson National Accelerator Facility. Dubbed Q-weak, the precision experiment featured many technical challenges for the physicists to solve for its successful conclusion.

One potentially confounding variable was the cold liquid hydrogen target itself. The target system was custom designed for Q-weak, with care being taken to build a system that could keep the hydrogen cold even while it was being bombarded by a merciless yet precise beam of spinning electrons.

The physicists even had to consider what impact the aluminum container that held the hydrogen would have on their result. For his part in solving this technical challenge and for the thesis he wrote about these efforts, Kurtis Bartlett was awarded the 2018 Jefferson Science Associates Thesis Prize.

The weak charge of the proton describes how much the weak force, one of the four fundamental forces of the universe, acts upon the proton.

"Probing the proton with an electron via the weak force, it allows you to actually measure the weak charge," Bartlett said.

But, as its name implies, the weak force is, well, weak. Electrons are far more likely to interact with protons via the electromagnetic force, another fundamental force.

Fortunately, the weak force has a unique marker: it violates a universal symmetry called parity. A process that conserves parity symmetry occurs with the same probability as its mirror image. The weak force exhibits asymmetry for parity transformations.

"Measuring this asymmetry gives access to the weak force," Bartlett said. "However, it's very difficult to actually do in the laboratory—it's a mathematical type of operation."

Instead, Q-weak used a stand-in for parity transformation. Before the electrons were accelerated, they were polarized so that they were all spinning either the same direction as the beam, or the opposite direction as the beam.

Because the electromagnetic force conserves parity symmetry, it interacts the same way with electrons spinning in either direction. But because the weak force violates parity symmetry, it interacts more with electrons spinning in one direction. Physicists are able to exploit this difference to get a measurement of the proton's weak charge.

Reaching that measurement, however, was not so simple. In the experiment, a small fraction of electrons that the physicists measure never actually hit the hydrogen target. Instead, some electrons scattered off the aluminum container that held the hydrogen, which contaminated the weak force signal the physicists were trying to measure.

That's where Bartlett came in. His task was to minimize this signal contamination by determining how much of the measured signal came from the aluminum target container.

"I went through the process of understanding how to correct our measured values," said Bartlett.

To do so, Q-weak removed the hydrogen target for some runs, replacing it with a piece of aluminum identical to the container. Then Q-weak again shot polarized electrons at the target, except instead of measuring parity asymmetry using a proton of hydrogen, Bartlett measured parity asymmetry using an aluminum nucleus.

"It's the first time that type of asymmetry has ever been measured, which is a pretty exciting thing," he said.

Bartlett worked on his thesis, "First Measurements of the Parity-Violating and Beam-Normal Single-Spin Asymmetries in Elastic Electron-Aluminum Scattering," at Jefferson Lab while pursuing his Ph.D. in experimental nuclear physics at William & Mary. His thesis advisor was Wouter Deconinck, an assistant professor of physics at William & Mary who also worked on the Q-weak experiment.

Bartlett presented his thesis work to the Jefferson Lab Users Organization Board of Directors, who oversee the JSA Thesis Prize award process. Users are scientists from across the U.S. and worldwide who conduct fundamental nuclear physics experiments with Jefferson Lab's research facilities and capabilities.

"I was excited to hear the news that I'd won, and I am very honored to receive it," Bartlett said. "Though I received this award for my dissertation, it is very much a group effort, and I want to highlight that Q-weak as a whole involved many scientists, engineers, technicians and administrative staff to get it all done."

The JSA Thesis Prize is awarded annually for the best Ph.D. student thesis on research related to Jefferson Lab science, and it includes a $2,500 cash award and a commemorative plaque. Nominations are judged on four criteria: the quality of the written work, the student's contribution to the research, the work's impact on the field of physics, and service (how the work benefits Jefferson Lab or other experiments).

The Southeastern Universities Research Association established the JSA Thesis Prize in 1999. It's now one of many projects supported by the JSA Initiatives Fund Program, which was established by Jefferson Science Associates to support programs, initiatives and activities that further the scientific outreach, and promote the science, education and technology missions of Jefferson Lab in ways that complement its basic and applied research focus.

"Graduate students are the driving force of any research enterprise, so the Jefferson Lab User Organization is proud to give out the thesis price this year again. We thank JSA for providing support for this prize," said Julie Roche, the 2018-2019 JLUO chair and professor at Ohio University. "As usual, the theses submitted were of very high quality and made deciding on a winner quite a challenge. I want to thank the selection committee lead by University of Virginia Professor Kent Paschke for its careful examination of the submissions. In the end, we are delighted to recognize Kurtis's work."

Bartlett is currently a postdoctoral research associate for the Space Science and Application Group at DOE's Los Alamos National Laboratory, where he develops space craft detectors that measure radiation to help determine the composition of planetary bodies.

"Although I'm developing hardware now, I'm still using the skill set developed in my dissertation research," Bartlett said.

Provided by Thomas Jefferson National Accelerator Facility