Knock, knock, knocking on the proton's weak charge

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David Armstrong supervises a team of Ph.D. students in 2008. They're stretching the foil seals of one of the vertical drift chambers constructed in Small Hall. From left are John Leckey, Armstrong, Siyuan Yang and Carissa Capuano.

(Phys.org) —The weak force is, for laymen, the least known of the quartet of interactions that run the universe as we know it.

We all experience gravity and are served by electromagnetism. The strong force binds nuclei of atoms, and when the nucleus is split, it provides the release of energy that powers fission-based power plants.

That's three; the fourth is known as the weak force. The weak force, also known as the weak interaction, is what drives particle decay and nuclear fusion. It plays a very fundamental part in our daily life.

"If the weak force didn't exist," says David Armstrong, "the sun wouldn't burn."

Armstrong, Chancellor Professor of Physics at William & Mary and chair of the department, is a member of the Qweak Collaboration, a collection of scientists who recorded the first ever direct measurement of the weak charge of the proton at the Department of Energy's Thomas Jefferson National Accelerator Facility (Jefferson Lab).

Their paper, "First Determination of the Weak Charge of the Proton," was published in the journal *Physical Review Letters*.

Physics department contributors to the paper, in addition to Armstrong himself, are Wouter Deconinck, Todd Averett, the late Michael Finn and Roger Carlini, an adjuct faculty member whose principal appointment is at JLab. A number of postdoctoral researchers, graduate students and undergrads contributed to the project, as well.

"William & Mary is a relatively major player in the experiment," Armstrong said. "I like to think we're one of the most important institutions in the experiment. Our students and faculty and postdocs have been involved with all parts of it, but there's a key thing we did in terms of equipment."

That "key thing" was the design and construction of a set of vertical drift chambers—large detectors used for tracking scattered electrons after they bounced off the proton. Armstrong notes that the project had substantial funding support from the National Science Foundation.

"It was a very large project that took a large number of years," he said. "They were constructed and tested—using cosmic rays—right here in Small Hall. Then they were transported down to Jefferson Lab for the experiment."

Armstrong said the Qweak experiment has a William & Mary origin story, as well. About 15 years ago, he said, he and Finn were discussing ongoing experiments at JLab, which were aimed at discovering if the strange quark has a role in the construction of the proton. (It does, but not much.)

Fueled with coffee, Armstrong and Finn staked out a chalkboard and kicked around the idea of adapting the same technique they were using in the strange quark studies. Armstrong said they concluded that the same parity violating electron scattering approach could be used to measure the weak charge of the proton.

The execution was a matter of scale. Trying for the first direct measurement of the weak charge of the proton needed a more subtle touch than they used in the strange quark studies.

The weak force and electromagnetism are found to be intertwined to such a degree that physicists refer to the phenomenon as the electroweak interaction. (That "Q" in "Qweak" represents electrical charge to physicists, just as "m" represents mass.)

The challenge of the Qweak team was to find a way to tease out the electrons driven by the weak interaction from the much, much thicker thread of electromagnetism.

"We did this," Armstrong said, "by tickling the proton. In previous experiments at JLab, we really smacked the proton hard. But this required a softer touch."

Wouter Deconinck, assistant professor of physics, explains that the Qweak experiment is a part of the same larger task as the discovery of the Higgs boson at the Large Hadron Collider. It's all about the testing—and potential expansion—of the Standard Model, the physicists' inventory of the energies and particles that make up the universe.

"The implications of our paper for the Standard Model are not that strong—yet," Deconinck said. "The new thing about this data is that it's the first time that we've measured this one quantity—the weak charge—directly."

The search for the Higgs and the measurement of the weak charge of the proton make an interesting contrast, Armstrong said.

"The Higgs boson was the one missing piece of the Standard Model. It was predicted. It had to be there if the Standard Model is correct, but hadn't been seen," he said. "But the other approach to testing the Standard Model is to look indirectly at it. Look for some property of an ordinary, average, pedestrian familiar particle—like the proton. Look for a property, the weak charge of the proton, and measure it ultra precisely."

The contrast applies to the instrumentation; Armstrong characterized the 17-mile-wide Large Hadron Collider a "brute force" instrument, while the comparatively tiny Qweak detector is "more of a finesse thing," even though it towers over the scientists in the JLab.

Just as the work at the Large Hadron Collider will extend to investigate possibilities beyond the Standard Model, the Qweak paper marks a beginning rather than a conclusion. Deconinck pointed out that there are more data from the JLab to analyze. The final data set will be some 25 times greater than the one used in the paper, he said.

In addition to what the analysis of the full pile of JLab data will contribute, Armstrong also noted that their weak force measurement should be replicated for it to gain the confidence of the scientific community.

"And of course, you don't want to do it exactly the same way or at the same lab with the same people with the same apparatus," he said. "There could be some artifact of the apparatus that gives you a false result."

Experimenters always foresee some apparatus artifacts and incorporate allowances for them in the design of the experiment. For instance, Joshua Magee is a member of the team going through the Qweak data. He will write his William & Mary Ph.D. thesis on some of what he calls "ancillary measurements" of the experiment, focusing aspects of a known artifact—the aluminum box holding protons (in the form of liquid hydrogen) that are the target of the experiment.

"You can't just have protons hanging out in the middle of nowhere, so we have them in an aluminum box with very, very thin walls on the side," Magee said. "So when we take our electron beam and bring it to our target, we get quite a bit of scattering off the walls because aluminum is so much larger than the hydrogen inside it. My job is to compute the signal from the aluminum walls."

Magee's computations allow the experimenters to remove the "noise" introduced by the aluminum. Armstrong notes that Magee's work is valuable on several levels.

"He has to understand what fraction of the electrons that we see scattered off the aluminum and what was their asymmetry. Josh's thesis will include a measurement of this asymmetrical property of this aluminum which has never been measured by anyone before," he said.

Magee was only one of a number of William & Mary graduate students who took on important roles in the Qweak experiment. Another was Valerie Gray, a Ph.D. student in physics who Armstrong said may have set Jefferson Lab's record for numbers of hours of computer use.

"And it's still growing," Gray said. Her job was to set up a computer simulation of the experiment and compare the actual data with what was predicted.

"If everything matches up, in a perfect world we can go back and say this was our exact scattering angle, this was our exact scattering loss and so forth," she explained.

More information: First Determination of the Weak Charge of the Proton." D. Androic, D. S. Armstrong, A. Asaturyan, et al. *Phys. Rev. Lett.* 111, 141803 (2013) DOI: 10.1103/PhysRevLett.111.141803

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