USC scientist works to verify enigmatic pentaquark

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Imagine you have just snapped a blurry picture of a new type of life form, something so weird it can't be classified as animal or plant or anything else scientists have ever seen. Now imagine that the entire lifespan of this tiny life form consists of just half a zeptosecond, a unit of time so absurdly small that you'd have to count 20 digits to the right of the decimal point before spotting anything other than a zero (0.000000000000000000001 of a second).

Would that be enough evidence? Would you believe it? And perhaps most importantly, how would you convince your friends?

One obvious answer might be that you'd go back and try to take a better picture.

Which is, in a way, what professor Dave Tedeschi of the University of South Carolina is working to do: Verify the existence of what could be the strangest object ever encountered by science.

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From one perspective, the pentaquark represents little more than a curiosity. It has no immediate applications, offers no promise of better medicines, cheaper electricity, faster microchips or bigger bombs.

Then again, Albert Einstein's Special Theory of Relativity didn't look all that exciting in 1905 -- which is why even the most abstract advances in physics tend to warrant special attention.

"What we're talking about," Tedeschi said, peering across his desk with eyes that continuously monitor his listener's comprehension, "is something that could change the way we look at the most fundamental forces in the universe."

Job 1: Imagine It

The language of quantum physics is so specialized that just describing Theta+ requires multiple trips to the white board in Tedeschi's drab seventh-floor office in the Jones Physical Sciences Center on Main Street.

That's part of the problem: Even the basic concepts of quantum physics are radically confusing to people raised on the standard Ping-Pong-ball model of the atom. It's the one most of us remember from school: neutrons clinging to protons in a nucleus that looked like a spherical blackberry, orbited by precisely ordered electrons.

The standard model was good enough to build the first atomic bomb, but it wasn't the whole story, and it hasn't been for more than 50 years. By the 1960s, it was clear to physicists that neutrons, protons and electrons were no longer the smallest Legos in the bin. The clean, deterministic world of traditional physics went spiraling down the quantum rabbit hole.

The new quantum physics seemed almost whimsical in comparison. It was a world in which a new fundamental particle, the quark, was described by attributes that defied description. Quarks had "flavors," "colors" and "spin," and every one of them had a corresponding anti-particle. A quark could be "up" or "down," "top" or "bottom." Some quarks were "charmed." Others were simply "strange."

And then it started getting weird. The Uncertainty Principle showed that even with perfect math, you simply couldn't tell where an electron was going to pop up at any given moment. Then it turned out that a photon can be either a wave or a particle, and what's more, the human act of observing that photon makes it pick one state or the other. Not only that, but the forces that bind quarks into larger particles just don't operate on the electromagnetic principles that govern the average floor lamp.

Consequently, discoveries in advanced physics since the 1970s have been largely indecipherable to the average person, not to mention most trained scientists.

"This is why when I go to parties, I talk about books, movies and my kids," Tedeschi said. "But science and technology are important. It isn't this mystical realm. Or it shouldn't be."

So to begin imagining how a pentaquark might fit into the grand scheme of things, think about it this way: The particles that we tend to think of as being "energy," such as photons and electrons, are classified as bosons and leptons. The particles we think of as "matter," like the neutron and the proton, are called hadrons. Neutrons and protons are further classified as baryons, which are particles composed of three quarks. A second class of hadrons, called mesons, consists of unstable pairings of quarks and antiquarks.

The number and type of quarks you combine determine the kind of hadron you get. Two ups and one down produce a proton. An up, a down and a strange give you a baryon particle called "lambda." A strange and an anti-up quark produce a meson called "kaon." And so on.

So the existence of a five-quark particle like Theta+ (two ups, two down and an anti-strange) would mean adding a new branch to the hadron family tree. It might also challenge our understanding of how quarks hook up and come apart in the first place.

Job 2: Prove It

Tedeschi's plunge toward the pentaquark began in earnest just moments after the Japanese team announced its initial report at an international conference in the fall of 2002.

"My colleagues and I gathered in the lobby of the convention center, looked at it together and said, 'We can do this,' " Tedeschi said. "We got to work on it right away."

Since there is no microscope powerful enough to peer into subatomic structures, scientists get to work on such things by slamming particles into each other and studying the wreckage. It's a technique not unlike studying electronics by smashing a TV set with a bowling ball. In the dark.

Tedeschi and his colleagues, a group referred to as the CLAS Collaboration, do their work at the Thomas Jefferson National Accelerator Facility (JLab) in Virginia. Particles whip around the site's vaguely oval underground track, gaining speed with each mile-around loop before being hurled toward a target. On those rare occasions when a particle "bullet" happens to strike an atomic nucleus, sensors detect the debris as it flies by.

The original Japanese experiments used carbon atoms as a target, but when the American physicists came home from that conference, they went to work reinterpreting old JLab accelerator data from tests involving deuterium, an isotope of hydrogen composed of an electron, a proton and a neutron. If the Japanese were correct, pentaquarks should have been created in those collisions. It was just a matter of looking for them.

Some members were excited by the results: Based on dozens of recorded collisions, they saw evidence that the bombardment was producing debris that included baryons, mesons and the exotic five-quark hadron the Japanese claimed to have found: Theta+.

On the other hand, CLAS member professor Curtis Meyer of Carnegie Mellon University in Pittsburgh looked at the same data and saw nothing but the faint echoes of a mathematical ghost.

Meyer questioned the statistical significance of the team's measuring technique and pointed to independent tests at competing labs that used different techniques to observe the similar events and found zero evidence of Theta+.

"Better resolution hasn't seen it," he said. "As more evidence comes out, I think it was just a statistical fluctuation in the data."

Meyer wasn't alone. Scientists would come great distances to attend talks on pentaquark research at JLab, and the debates were often lively. "This is the most intensely argued topic that I've seen in the 15 years since I've been here," said Linda Ware, JLab's public affairs manager.

But critique is a part of the scientific process, and in the spring of 2004 the CLAS team returned to the JLab accelerator with a mission: Acquire enough hard data to determine whether the pentaquark evidence was just a mirage. Physicists fired up JLab's unique "quark-hunter" accelerator for two separate sets of experiments, each of which involved continuous operation of the accelerator for three months. They wrapped up this year's work in early August with "new data sets that are 10 times better than the original," Tedeschi said.

The raw data amounts to 25 terabytes (that's 10 to the 12th power, a figure equal to a million million) of information -- enough to choke even the most robust mainframe computer. Meyer, who has yet to see the results, says the CLAS group is taking solid precautions to ensure that the final analysis will be credible. He hopes to see something in October.

Tedeschi is part of one of four groups now analyzing the 2004 data.

None of the groups knows what the others have found, and no one will know what it all means until the teams come together for a series of highly anticipated meetings this fall. "Now we've sort of hunkered down, and we're going to do the job and just let science run its course."

Picture note: The CEBAF Large Acceptance Spectrometer at the Thomas Jefferson National Accelerator Facility in Newport News, Va., is housed in a 98-foot-diameter underground building and positioned 18 feet above the floor. The facility's unique design accelerates a continuous beam of electrons to 99.999999987 percent of the speed of light — fast enough to split subatomic particles.

Job 3: Understand It

In the meantime, science appears to be tilting toward the pentaquark side of the argument. Physics World reported in June that more independent tests were confirming the CLAS results and, in July, Tedeschi was a featured speaker at a Japanese conference on the pentaquark phenomena.

What lies ahead for physics depends largely on the results from this year's experiments, but in the best-case scenario, scientists may find themselves developing new insights into a theory called Quantum Chromodynamics, or QCD.

QCD attempts to explain the primary force that binds together 99.9 percent of the everyday objects in the universe. Physicists describe QCD with words like "elegant," and Tedeschi speaks of the mathematics involved as "really very simple." But there is a problem.

"We think we know what the underlying equations are," said Meyers. "But we just can't solve them."

The equations work for high-energy events, such as accelerator experiments, then grind to a halt when presented with what appear to be relatively simple low-energy questions. Even supercomputers can't process the results. Tedeschi calls the breakdown "nature's little joke."

Expanding quantum theories to include the implications of pentaquarks might just offer physicists the insights they need to connect the high-energy and low-energy "languages" of QCD into a unified theory, a development with untold potential.

"If you can solve it, you can connect these fundamental forces to our everyday world," Tedeschi said. And forces can be harnessed.

Meyer says he's hopeful the pentaquark question will be settled one way or another this year.

Harnessing the forces that bind the universe together may take a bit longer.

Source: Jefferson Lab

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