DZero: Elusive Top Quark Discovery

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They came from institutions worldwide, built the world's most powerful accelerator, smashed tiny bits of matter together at nearly the speed of light and produced something remarkable: a fundamental particle that was abundantly present at the creation of our universe but had never before existed on our planet.

Fermi National Accelerator Laboratory is preparing to mark the 10th anniversary of its top-quark discovery with an Oct. 21 symposium at its Batavia campus. And experimental physicists at Northern Illinois University can't help but feel a pinch of pride knowing they played a part in finding the heaviest known elementary particle, one which exists for only a miniscule moment in time (10^{-24} seconds).

Current NIU physicists David Hedin, Gerald Blazey, Dhiman Chakraborty, Suzanne Willis and Michael Fortner all were members of the DZero collaboration, one of two large collaborative experiments at Fermilab's Tevatron collider that jointly announced discovery of the top quark during the spring of 1995. The NIU contingent, which also included about 50 NIU students, made key contributions to the construction, testing, commissioning and operation of the DZero detector, as well as data analysis.

Fundamental particles are the building blocks of nature; they cannot be broken down into smaller pieces. In 1897, British scientist J.J. Thomson was first to identify an elementary particle, the electron. The top quark was the 16th particle to be discovered, and it also proved to be the most elusive.

Scientists believe top quarks were created in abundance at the moment of the birth of the universe, but the particles can only be produced by such enormous bursts of energy. Even then, they make only a brief appearance in time before decaying into lighter particles.

It took the work of more than 1,000 scientists, engineers and technicians at Fermilab to “reach the top” by building a one-of-a-kind collider that could accelerate protons and anti-protons to near light speed and smash them together. Part of a family of quarks that are believed to form the nuclei of atoms, the top quark was identified by measurements of particles produced by its decay.

Hedin had joined the DZero collaboration at its inception in 1982 and worked on the system that tracked the behavior of particles known as muons, or heavy electrons. Willis and Fortner later joined the team examining muons, and NIU students were enlisted to help build and operate the system.

In 1992, DZero began collecting data from millions and millions of particle collisions. In January of the following year, scientists observed one collision that seemed to have the earmarking of a top-quark event. But it was unclear whether the energy level of a muon fit the parameters.

Working in the basement of his DeKalb home, Hedin took a computerized image of the subatomic event, enlarged it by tenfold, recorded measurements with a meter stick and made key adjustments to account for a software glitch. His analysis helped scientists conclude a month later that they had almost certainly made the first detection of a top quark.

“We were all pretty much convinced,” Hedin said. “We had a workshop here at NIU, where we spent a half day talking about the event.”

Other subsequent collisions recorded by DZero and CDF, the sister experiment at Fermilab, also would demonstrate that the laboratory's Tevatron accelerator was indeed producing top quarks. The formal announcement wasn't made until March of 1995, however. “It was a highlight of my career to be involved in the top-quark discovery,” said Blazey, who now serves as a co-spokesperson of the DZero experiment. “It was an amazing collaborative experience. Everyone had to do their job.”

Blazey, who joined DZero in 1986, helped construct and operate the uranium-liquid argon calorimeter, which measured the energies of particles. He and Fortner also served as the original DZero “triggermeisters,” the scientists who coordinated which events to record.

“The triggering system identified the collisions that were most interesting to scientists pursuing the top quark,” Blazey said. “You have to remember, there were millions of collisions each second and, at that time, we could only record two or three per second for further analysis.”

Fortner, who is now mayor of West Chicago and still a member of DZero, described the top-quark quest as the ultimate team experience. “Aside from the discovery, the collaboration itself was a major accomplishment, with scientists worldwide working together on one fundamental goal,” he said. “We really needed the contributions of all the different parts and experts in order to be successful. The only project I can think to equate it with might be the NASA space program.”

Chakraborty, who joined the NIU faculty in 2001, began working at Fermilab a decade earlier. For his Ph.D. thesis at the State University of New York at Stony Brook, he devised a way to distinguish the signal of top-quark events from background noise. Fermilab scientists used his method, among others, to detect the prized particle.

“It's quite literally like looking for a needle in the haystack,” said Chakraborty, who went on to lead DZero's top-quark physics group from 1998 to 2000. “We needed to use every means at our disposal to separate signal and background. Many processes can masquerade as signals.”

The Standard Model of particle physics—the best explanation scientists have of the nature of matter—predicted the top quark. “Our knowledge verged on certainty,” said Willis, now acting associate dean in the NIU Graduate School. “According to our understanding of the particles and their interactions, it had to be there.”

But the huge mass of the particle was a big surprise. The top quark mass is 40 times greater than the next heaviest quark and equal to the mass of a gold atom, which is made up of many particles and has a complex structure.

“Discovering the top quark was a monumental feat, but determining its mass was even more important,” Hedin said. “With our calculations for the mass of the top quark, we have a better idea of where to look for an even bigger prize, the Higgs boson.”

The Higgs boson is a mysterious and yet-to-be discovered particle that would help explain why subatomic particles have any mass at all. Discovery of the Higgs is considered among the most sought-after prizes in the field of particle physics.

Detection of the Higgs boson (through DZero and CDF at Fermilab or at a more powerful collider now under construction in Europe) would confirm the existence of the Higgs field, which is thought to permeate the universe. Scientists believe that when particles interact with this field, they gain mass. Without mass, all particles would travel at the speed of light, never sticking together, and only these tiny massless particles would populate a structureless universe.

Source: Northern Illinois University