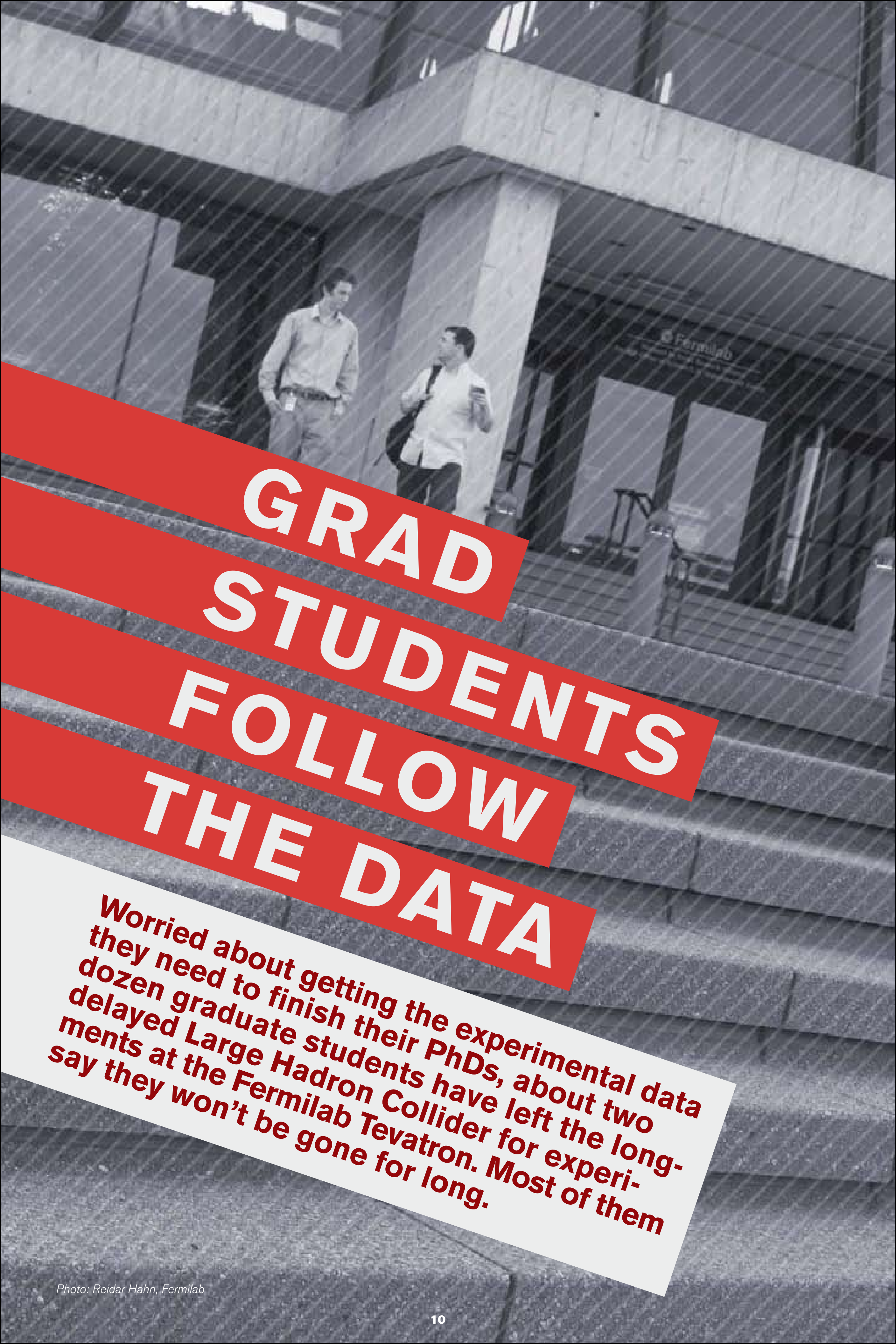


GRAD STUDENTS FOLLOW THE DATA

Worried about getting the experimental data they need to finish their PhDs, about two dozen graduate students have left the long-delayed Large Hadron Collider for experiments at the Fermilab Tevatron. Most of them say they won't be gone for long.

Photo: Reidar Hahn, Fermilab

By Katie Yurkewicz

When Martina Hurwitz started graduate school in 2003, she dove into the work of an experimental-physicist-in-training. As a student on the ATLAS experiment at the Large Hadron Collider, she installed electronics on the massive ATLAS detector, connected cables, wrote software, and prepared to analyze data from the LHC's very first high-energy collisions.

On September 10, 2008, Hurwitz celebrated with her fellow students and scientists as beams of protons circled the LHC's 27-kilometer tunnel for the first time. But nine days later, a connection between two of the superconducting magnets melted, putting the collider—and her graduation plans—out of commission.

Hurwitz, like most particle-physics graduate students at American universities, needs to analyze experimental data to complete her PhD. So after six years of work on ATLAS—three and a half of them living at CERN in Geneva, Switzerland—Hurwitz packed up and moved to the CDF experiment at Fermi National Accelerator Laboratory's Tevatron collider in Illinois. She's one of about 20 students who have left the LHC for the Tevatron over the past year.

"Moving was not ideal for me," says Hurwitz. "My boyfriend lives in Zurich, and most of the people I started graduate school with in Chicago have graduated. But the work made up for it. I would have loved to see ATLAS data, but since it wasn't there I wanted to go to Fermilab and look at something new."

Of all the LHC's 7000-odd scientists, graduate students were hit hardest by last year's breakdown. When a project's life is measured in decades, senior scientists take delays of months or even years in stride. But the same delays can be devastating to graduate students, who want or need experimental data to complete their doctoral dissertations and move on with their careers.

A need to get real

Why the need for experimental data?

A particle-physics graduate student attends classes, teaches, takes written and oral exams, learns how to build and operate complex detectors, and programs the software that monitors a detector and collects its data. But in the end, analyzing that data—discovering something new about nature—is the goal of earning an experimental-particle-physics PhD.

"Our major products, as particle physicists, are scientific results," explains Dmitri Denisov, spokesperson for the DZero experiment at Fermilab. "For those at Fermilab or the LHC, the results are based on particle collisions. From that point of view, being able to show that you're a young scientist capable of doing analysis, that's how you indicate that you're mature enough to get a PhD."

In countries such as the United Kingdom that provide funding to PhD students for only three or four years, universities sometimes allow students working on collider experiments to analyze data that doesn't come from collisions. They may write and defend doctoral dissertations based on analysis of cosmic rays that pelt their detector from space, data taken from parts of the detector placed in a test beam, or even Monte Carlo data—simulated data that mimics what scientists expect to happen in a new detector.

But American universities, whose students take five to six years or even longer to earn PhDs, traditionally do not accept analyses of anything but real experimental data—the debris from high-energy particle collisions collected in a massive particle detector, converted to electronic signals, and analyzed using sophisticated computing tools.

However, in the LHC era, when experiments take 15 years to build and colliders take years to start up, even the American tradition is changing.

"A number of US particle physics groups are being more creative than they have been in the past," says Mike Tuts, professor of physics at Columbia University and US ATLAS operations program manager. "Some are talking about Monte Carlo theses, or a combination of Monte Carlo, test-beam, and cosmic-ray data, rather than waiting for collision data."

That said, most university groups still require—and most students still want—data from real collisions.

Tough choices

When the LHC's first collisions were still many years away, American university groups suggested that some students spend part of their graduate research working on an LHC experiment while also analyzing data from the Tevatron experiments—which have been running since 2001—for their dissertations. In 2003, the first students from American universities began joining LHC experiments with the hope of analyzing live data when collisions began in 2007. When the date slid to 2008, a few students worried. But after last year's incident, students in their fourth, fifth, and sixth years began seriously contemplating their options.

For those whose university groups work only on LHC experiments, their only choice was to wait and hope that the collider would start up without incident and their analyses would be completed quickly. For others whose groups also collaborate on the DZero and CDF experiments, there was a second option: Abandon, at least temporarily, the LHC experiment they'd devoted years to, and complete their dissertations on data collected at the Tevatron.

Like Hurwitz, Ketino Kaadze decided to make the switch to a Tevatron experiment shortly after the LHC shut down for repairs. Kaadze, in her fourth year of graduate school at Kansas State University, switched from the CMS experiment at the LHC to DZero, and moved to Fermilab full-time.

"I was lucky that I didn't have to change group or advisor," says Kaadze. "I was able to start working on similar topics at DZero, searching for new physics. My CMS colleagues were sad that I was leaving, but saw that it was a good idea for me at this time in my studies."

A win-win

These smooth transitions from one experiment to another reflect the highly collaborative nature of particle physics, in which thousands of people from all over the world may work on a single experiment and many scientists work on more than one experiment at a time.

"It's a win-win situation," says Tuts, who saw three senior students from his university's group move from ATLAS to DZero. "The Tevatron experiments can use the help because they've got more data and more analyses than they can handle with the people they have, and our students get data."

With data flowing out of the Tevatron experiments at an unprecedented rate, 20 new students—an increase of 10% for CDF and DZero combined—makes an impact. For the ATLAS and CMS, however, it's a loss of just over one percent in a student population of 1400.

"We will miss the students who have moved to the Tevatron," says CERN's Fabiola Gianotti, spokesperson for the ATLAS experiment. "They are all brilliant, and I would have liked that they continue in ATLAS. But they will be well-taken care of by our colleagues on DZero and CDF, who have been kind enough to

Photos: Reidar Hahn, Fermilab
Collages: Sandbox Studio

help them get the data they need to meet their institutes' graduation requirements. We should also not forget that about 800 students continue their studies at ATLAS, and I am sure they will soon get exciting LHC data for their analyses."

A round-trip ticket

The students, by and large, don't plan to be gone for long. Most expect to find themselves back at the LHC experiments after graduation, working as postdoctoral researchers. A few have even elected to keep CERN as their home base after switching to Tevatron experiments, hoping to stay connected to the LHC and improve their chances of landing an ATLAS or CMS postdoc.

"I didn't choose ATLAS and work on ATLAS for five or six years just to leave when there's going to be data," says Mark Cooke from Columbia University, who remains at CERN but has taken

GRADUATE SCHOOL: WHAT TAKES SO LONG?

American universities award about 200 particle-physics PhDs each year. Most of those students spent five or six years in graduate school, but it's not unheard-of to spend seven or even eight. What do these students do, what does it take to survive, and why can it take so long?

For most particle-physics students, the first year or two of graduate school looks the same. They have to pass a certain number of graduate-level physics classes, along with at least one comprehensive, and usually grueling, written and oral exam. Many universities require graduate students to spend a semester or more teaching laboratory classes for undergraduates, acting as a recitation instructor, or grading papers.

"Taking graduate classes was one of the most consistently and intensively challenging—and time-consuming—things I've ever experienced," says Daniel Miner, a graduate student at the University of Rochester. "I found teaching to be rewarding when the students wanted to learn, but supremely frustrating and barely tolerable when they were unmotivated."

After the pressure of classes and exams is over, the real work begins. By the end of the second year, students make the most critical decisions of their careers—selecting a graduate advisor and research topic. Passing classes and exams only grants students the status of PhD candidates; research, supervised by their faculty advisor, gets them the rest of the way.

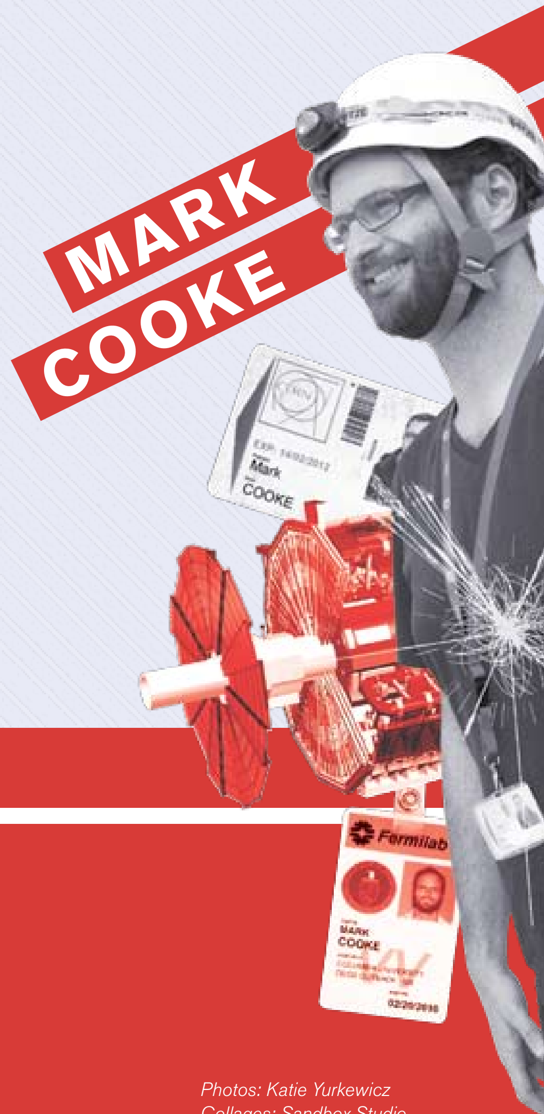
For students who choose experimental particle physics, the next three, four, or more years are devoted almost exclusively to hands-on research. The research can be roughly divided into two parts. In many cases the student spends the first year or two focusing on hardware and software—learning about particle detectors, working on the detector apparatus and learning how to build, operate, or program software to analyze the data it will yield.

Then the focus shifts to analyzing data—that is, making a new measurement of some aspect of nature. Although expertise in all of these areas is crucial for any particle physicist, data analysis is by far the most important for graduation, since it's the basis for the dissertation.

several extended trips to Fermilab to work with DZero. "I have every intention of finishing quickly and coming back to the LHC just when things are getting really interesting."

As the LHC restart date draws nearer, everyone—physicists from the LHC and Tevatron experiments, students who have remained and those who have switched—will be waiting impatiently for the first high-energy proton collisions. Only then will all the LHC's graduate students be able to move on with their careers, and the field of particle physics move forward.

"We're all in the same field, and it's very important that the LHC succeed," says CDF spokesperson Rob Roser. "All of us folks will want to move to one of those experiments one day."



Photos: Katie Yurkewicz
Collages: Sandbox Studio

"As a graduate student, you really get to own some work in ways that you don't later on," says Ken Bloom, a professor of physics at the University of Nebraska. "The work really has to take over your life for a while—and that can be fun, in its perverse way."

Once the analysis is complete, the new measurement is usually written up in a paper and submitted to a peer-reviewed journal. For students working in big detector collaborations, this process may involve many other people and take longer than they would prefer.

"The publication process was long and difficult," remembers Sarah Demers, now a professor at Yale University. "I had hundreds of comments on four pages of text from members of the CDF collaboration. When it was finally approved it felt like a real accomplishment."

The next hurdle is writing the dissertation, which describes, in multiple chapters, the new measurement and the process by which it was made. It is often written over a span of months, but can in some cases take years of on-and-off writing to complete.

The culmination of a graduate student's career is defending the dissertation—typically giving a public lecture on the topic and then answering questions, in a closed-door session, from faculty members on his or her PhD committee. If the defense is successful, the student becomes a PhD physicist.

Graduate school is an always-intense, often-grueling experience. Almost all particle-physics grad students receive stipends for research and training throughout their studies, which usually cover basic living expenses but little else. For those reasons and others, students are usually eager to finish their degrees and move on with their careers.

"There is a phase transition in grad school around year three," says Monica Dunford, a postdoctoral researcher at the University of Chicago. "In the beginning, you think 'This is great! I am getting paid to go to school!' At the end you think 'When is this process going to end? When am I going to make more money than this?'"

In the end, says current graduate student Regina Caputo, "To survive graduate school, you have to love it."