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The ALICE team is one of the smaller collaborations at the Large Hadron Collider.

M. SCHWEIZER/CERN

THE LARGE HUMAN COLLIDER

Social scientists have embedded themselves at CERN to study the world's biggest research collaboration. **Zeeya Merali** reports on a 10,000-person physics project.

"I am here to watch you." So began anthropologist Arpita Roy when introducing herself in 2007 to a roomful of particle physicists. At the time, those scientists were racing to finish work on the world's biggest machine, the Large Hadron Collider (LHC) at CERN, Europe's high-energy physics laboratory near Geneva, Switzerland.

The LHC carries the hopes of generations of physicists, who have designed it to reach energies never before achieved in a collider and — possibly — to produce a zoo of particles new to science. But the LHC is also a huge human experiment, bringing together an unprecedented number of scientists. So in recent years, sociologists, anthropologists, historians and philosophers have been visiting CERN to see just how these densely packed physicists collide, ricochet and sometimes explode.

"The LHC allows a unique sociological study of how an experiment develops in real time: how scientists form opinions, make technical decisions and circulate knowledge in such a big project," says Arianna Borrelli, a particle physicist and philosopher of physics at the University of Wuppertal in Germany.

Sergio Bertolucci, CERN's research director, is acutely aware of the importance of cohesive collaboration. "This is an incredible social experiment," he says, noting that roughly 10,000 physicists around the world are taking part in the LHC experiments and 2,250 of them are employed at CERN. Just reflecting on the size of the collaboration he co-manages makes Bertolucci's head ache. "Imagine the organization needed when 3,000 people all want to know in advance if they can go home for Christmas," he says.

Managers at CERN have endured a series of headaches since the LHC powered up in September 2008. A little more than a week after the collider came online, a faulty electrical coupling caused an explosion that brought the project to a halt for 14 months. That setback demoralized the scientists at CERN, particularly the graduate students, who worried about the fate of their degrees, says Roy. A graduate student herself, from the University of California, Berkeley, Roy has been camped out at CERN on and off for three years to observe the "language, taboos and rituals of this exotic community".

> "It's a cognitive bubble that you can't escape — that you don't want to escape."

The collider restarted in November 2009 and should gather two years of data before it shuts down for a year of scheduled upgrades in 2012. Next month, the LHC is expected to achieve record energies of 7 teraelectronvolts. The collider will reach such an extreme by accelerating two beams of protons to nearly the speed of light and then sending them in opposite directions around a 27-kilometre underground track. The beams cross each other at four spots along the ring, and it is here that the real science happens, within giant detectors surrounding each collision zone. The two biggest particle detectors, A Toroidal LHC Apparatus (ATLAS) and the Compact Muon Solenoid (CMS) experiment, are the size of apartment buildings and each boasts a team of nearly 3,000 people.

Population explosion

Each generation of collider has brought a jump in the size of the experimental collaborations (see graph, opposite), a trend that provides ample opportunities for researchers interested in human interactions. Karin Knorr Cetina, a sociologist at the University of Constance in Germany, is one of the few social scientists to have witnessed this growth directly over multiple generations. She has been studying CERN's collaborations for almost 30 years.

When Knorr Cetina first arrived, physicists there were working on a smaller collider and their detector teams were less than one-tenth the size of today's. "In those days 100 people in a team was considered huge," she says. Knorr Cetina says she was met with friendly bemusement by particle physicists, who were helpful, but thought of a sociologist "as a poor cousin of real scientists".

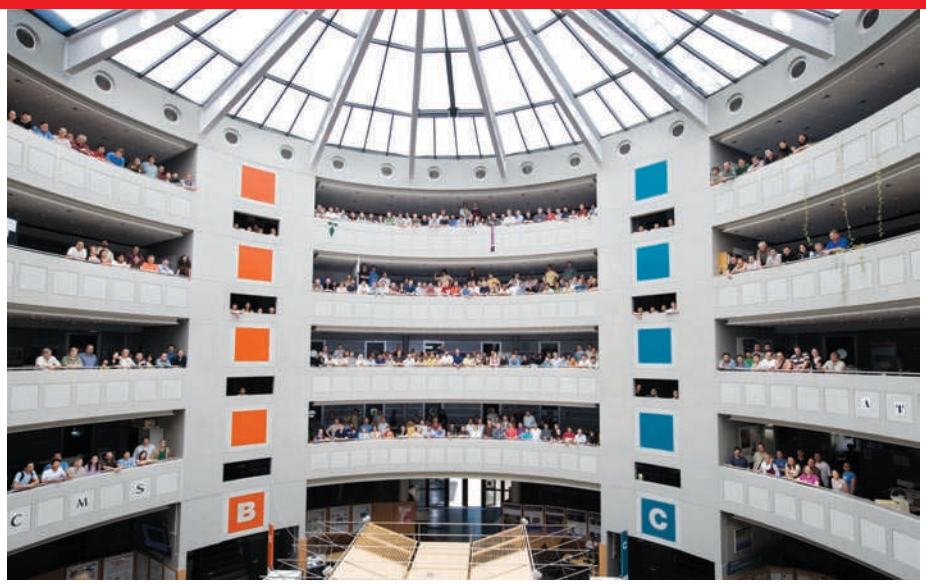
That attitude continues today, says Roy. "What can you say? Physicists are professionally contemptuous," she says.

Social scientists say they earn the trust of the physicists at CERN by immersing themselves in the culture, just as they would with any other population. Knorr Cetina used this approach to unravel the politics of peacekeeping among the thousands of scientists at the lab.

When she first started, she says, "I expected the same lines of command we know from other complex organizations — industry or government". But she didn't find that hierarchy at CERN. Although there are spokespeople who hold positions of authority in the collaboration, there is no top-down decision-making because there are so many highly specialized teams working on different parts of the detector. Knorr Cetina says that at CERN, "the industrial model cannot work. One human simply cannot make technical decisions on such a large scale."

CERN's unconventional structure stems in part from its history and philosophy. The lab was established on the Swiss–Franco border in 1954 to unite a Europe that had been fractured by war. "It's a place for global collaboration, where science exists beyond the politics of nationality," says Bertolucci. But within the lab, the idealism runs into the tensions of conducting actual research. "The paradox is that science is not democratic; we don't determine who is right by a vote or the majority decision."

If not an industry or a democracy, what is the structure? Knorr Cetina says that CERN functions as a commune, where particle physicists gladly leave their homes and give up their individuality to work for the greater whole. The communal lifestyle is encouraged by the fact that the laboratory stands on its own international territory. "Even the Swiss police cannot come in and grab us," says Bertolucci. It has its own restaurants, post office, bank and other facilities.



Hundreds of US scientists at CERN gathered for a group photo in one of the main science buildings.

C. MARCELLONI; J. GOBIN/CERN

"You can live forever within CERN, without ever needing to visit nearby Geneva," says Knorr Cetina. "It's a cognitive bubble that you can't escape — that you don't want to escape."

Bertolucci says that this immersion is essential to CERN's success as a global enterprise. "People coming here from around the world don't feel like they are visiting someone else's country, they feel they are coming home."

"The laboratory does feel like a commune with so many people coming from around the world to work towards a collective goal," says Kevin Black, a postdoc with the ATLAS collaboration.

Sacrificing identity

Around the CERN campus, the atmosphere is welcoming, and its two restaurants live up to their reputation for offering some of the best food of any physics canteen in the world. But it takes more than comfort and the promise of discovering new particles to persuade thousands of physicists to join the commune. Knorr Cetina points to the organizational structure of the collaborations as a factor that leads physicists to sacrifice their identity to the LHC.

As a window into that structure, she describes the evolution of the LHC's largest experimental collaboration, the ATLAS team, which she has studied since its formation in the late 1980s from the remnants of older groups at CERN. ATLAS will be looking for, among other things, the elusive Higgs particle, hypothesized to give other elementary particles their mass.

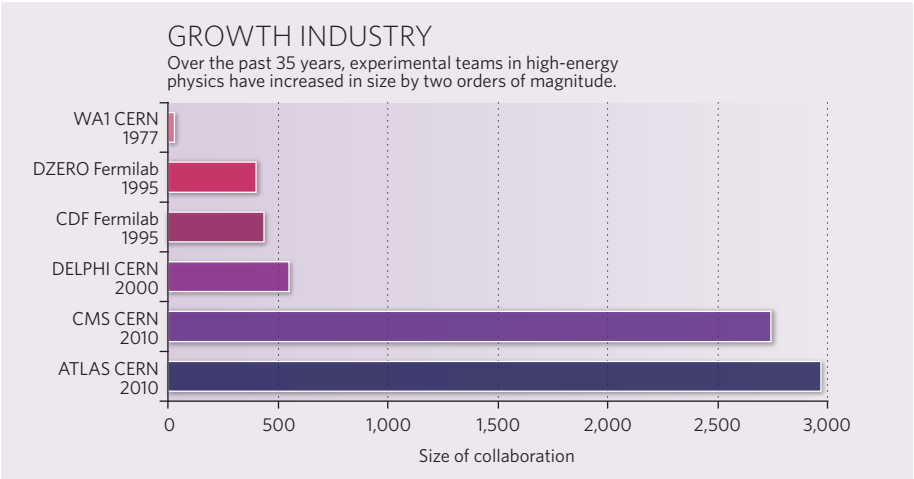
During the 'birth stage' of the ATLAS collaboration, LHC management had to choose between various proposals for detector designs offered by rival groups at different universities and institutes. It might seem that the most obvious and efficient strategy would be for a committee of experts to a make a decision about which technology to use. However, the ATLAS group did not take that path, says Knorr Cetina.

Instead, the birth stage was a laborious process in which competing groups were repeatedly sent back to retest their designs, until they all agreed on a single plan. In this way, they avoided alienating groups and losing the manpower needed to build the detector. "It's an interesting strategy to get groups to accept losing out, yet remain committed to the collaboration," says Knorr Cetina.

This prolonged process inevitably delayed construction. Physicists at the lab laugh that there are still brochures at CERN that advertise "the start-up of the LHC coming in 2000" — a deadline that was missed by almost a decade. Such delays were no doubt frustrating for physicists but, at least in some cases, they were the necessary cost of keeping the collaboration together, says Knorr Cetina.

Albert de Roeck, deputy spokesman for the CMS experiment, notes other practical reasons behind the strategy. "Spokespersons are considered to be the 'bosses' of the experiment, but we actually have no means of enforcing tyrannical decisions," he says. In industry, if people don't agree with you and refuse to carry out their tasks, they can be fired, but the same is not true in the LHC collaborations, he says. "On our experiments, physicists are often employed by universities, not by us."

John Krige, a historian at the Georgia



SOURCE: CERN; FERMILAB

C. MARCELLONI/CERN

Like a giant commune, members of the ATLAS collaboration work, eat and party together.

Institute of Technology in Atlanta who studied the collaboration structure at CERN before the formation of ATLAS, agrees that there is no simple top-down decision-making at the laboratory. However, he notes that the word "commune" implies that there is little rivalry between the members of the collaboration. By contrast, he says, the collaboration thrives on healthy "organized competition" between subgroups working to build different components for the detector quickly and effectively.

Now that the collider is running, there are other policies within the collaborations that reinforce the communal over the individual, essentially divorcing physicists from ownership of their research, says Knorr Cetina. All papers containing experimental results must list the name of every member of the thousands-strong collaborations alphabetically by country, giving little hint of the real originators of the work.

"This could never happen in biology, where the most intense disputes are about publishing, and reputations are established by your publications," says Knorr Cetina, who has also studied the lab life of molecular biologists.

"So much of the narrative of science is about the genius of the individual — even the Nobel can only be shared by three people," says Maria Ong, a sociologist at TERC, an education research collaborative in Cambridge, Massachusetts. "The LHC is an amazing anti-example of that."

Who can review?

Collective authorship opens up questions about the construction of knowledge in particle physics, says Peter Galison, a historian at Harvard University in Cambridge, Massachusetts. In February, the CMS collaboration published its first paper based on an analysis of LHC data that showed that a larger than expected number of exotic particles, known as mesons, were produced during the first collisions (CMS Collaboration *J. High Energy Phys.* doi:10.1007/JHEP02(2010)041; 2010). The paper includes 15 pages of author names, totalling between 2,200 and 2,300 people (the collaboration leaders are unsure of the exact number). "Can it be said that any one person truly understands all the knowledge that it contains?" says Galison. And who, he asks, can externally review the papers produced? "You reach a stage where the only people qualified to truly review the work are within the collaboration," Galison says.

De Roeck says that the size of particle-physics collaborations does inevitably affect peer review. The CMS paper went through months of rigorous checks and revisions during its internal review process; by contrast, it passed through external peer review by the *Journal of High Energy Physics* in just four days. "External peer review for publication in journals is becoming less important because it is far less stringent than our internal peer-review process," he says.

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Although the collaboration's strength comes from stressing the communal good, recent developments may strain the system. A rising number of particle physicists are turning to the individualistic pursuit of blogging. Although most posts are not controversial, the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, has had to deal with cases in which physicists broke ranks and leaked information before their collaborations were ready to release it. James Gillies, CERN spokesman, says that the European laboratory has no desire to censor blogs, but it does provide strict guidelines about when it is appropriate to discuss results.

Even with these guidelines in place, the blogging phenomenon at CERN — and its possible tension with official lines of communication — is something that will be closely followed by Borrelli as part of a team of more than 20 historians, philosophers and sociologists — "a huge collaboration in the humanities," Borrelli jokes — that will begin investigating the LHC this year, with funding by the German Research Foundation (DFG).

"This will be a real-time study of how knowledge circulates in such a big project," says Borrelli. She is particularly interested in the immediacy of publication in the physics community via the online repository www.arXiv.org, where a hundred or so non-peer-reviewed high-energy physics preprints are deposited every day and are openly accessible. "How do physicists select papers and orient themselves given this onslaught of information?" she asks.

Social scientists are looking beyond the professional lives of the scientists to assess how the collective collaborations affect the physicists on a personal level. Knorr Cetina says that many particle physicists are plagued by nightmares in which their actions cause the project to fail. "These are the nightmares of those who perceive themselves as a link in a chain, not as an individual," she says.

Abnormal stress

Knorr Cetina argues that the anxiety displayed by particle physicists is heightened beyond the usual career stress because they strongly identify with the detector (K. Knorr Cetina *Interdiscipl. Sci. Rev.* **32,** 361–375; 2007). "This is an object that they built with their hands, but they describe it as a friend," says Knorr Cetina. When reporting their nightmares, physicists described being shaken by the imagined loss of the detector as though it was the death of a beloved family member — something not routinely seen in other experimental scientists.

De Roeck agrees that physicists at the LHC are under extreme pressure. Each experiment is made up of subgroups who oversee different components of the experiment and no subgroup wants to be the weakest link that lets thousands of other people down. But he cautions against making too much of the relationship between experimenter and detector. "I wouldn't go so far as to say that physicists have some psychological problem where they start mistaking the detector for a friend and talking to it," he says with a laugh.

Ultimately, it is the ever-growing detectors that are to blame for the increasing size of collaborations in particle physics. The invention of the bubble chamber for tracking the path of particles in the 1950s required groups of 10 physicists — at the time thought to be a large collaboration.

Physicists are already making plans for the next generation of particle accelerators. But these may provide little new territory for social scientists to explore. "There won't be another step up in collaboration size to 25,000 physicists," says Galison. "We're hitting the limits of people in high-energy physics." ■

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