Record-energy collisions coming soon at the LHC

The machine that discovered the Higgs boson is flexing its muscles again. The results could be stunning new findings or striking new mysteries.

As the Large Hadron Collider revs up for a new run, particle physicists everywhere are holding their breath to see what new physics might be revealed by proton–proton collisions at record-high energy and intensity. Does the Higgs decay as expected? Are there other Higgs particles? Will supersymmetric particles or higher dimensions show up? Will dark matter be found? What explains the imbalance of matter and antimatter?

After two years of repairs and upgrades, test beams coursed through parts of the 27-km-long circular accelerator in early March, and the first 13-TeV collisions are expected as early as June. The discovery of the Higgs with 8-TeV collisions was spectacular (see PHYSICS TODAY, September 2012, page 12), but the particle's mass and the lack of other new particles still have theorists guessing—and sometimes discouraged—about physics beyond the standard model (see the article by Joe Lykken and Maria Spiropulu, PHYSICS TODAY, December 2013, page 28). "If we don't see something now with 13 TeV, then we can't say it's around the corner," says Nima Arkani-Hamed of the Institute for Advanced Study in Princeton, New Jersey. "The LHC will at least begin to give us a real verdict on a broad class of theories. That's why it's a particularly dramatic time."

Almost new

During the long shutdown, 18 of the accelerator's 1624 dipole and quadrupole magnets were replaced due to wear and tear. Additionally, teams of engineers fitted shunts to more than 10 000 connections between superconducting magnets to provide a safe path for the 11 000-amp current in case a magnet suddenly goes normal. Such an event on 19 September 2008 led to the decision to operate at 8 TeV for the first run; this time the collisions will start at 13 TeV. Depending on what is found, the machine may be pushed to the full design energy of 14 TeV, says CERN director general Rolf-Dieter Heuer.

Smaller and more frequent proton bunches will result in more total particles per unit time, and thus a greater number of collisions; the bunches now consist of 1.2×10^{11} protons and are separated in time by 25 ns, compared with 1.7×10^{11} protons every 50 ns in the LHC's first run. "You have to be able to store energy in the beams, and you have to be able to steer the beams. The power could melt a ton of copper. That is what the protons carry," says Frédérick Bordry, CERN's director of accelerators and technology. With the upgrade, he adds, the LHC "is almost a new machine."

"It's the combination of everything that is making the upgrade so exciting," says theoretical physicist Neal Weiner of New York University. "You are going up in energy reach. You have the increased luminosity, so that signals that were borderline may show themselves." And, he adds, scientists will "take the opportunity to really analyze the data to look not only for things that stand out but also for things that may be less obvious."

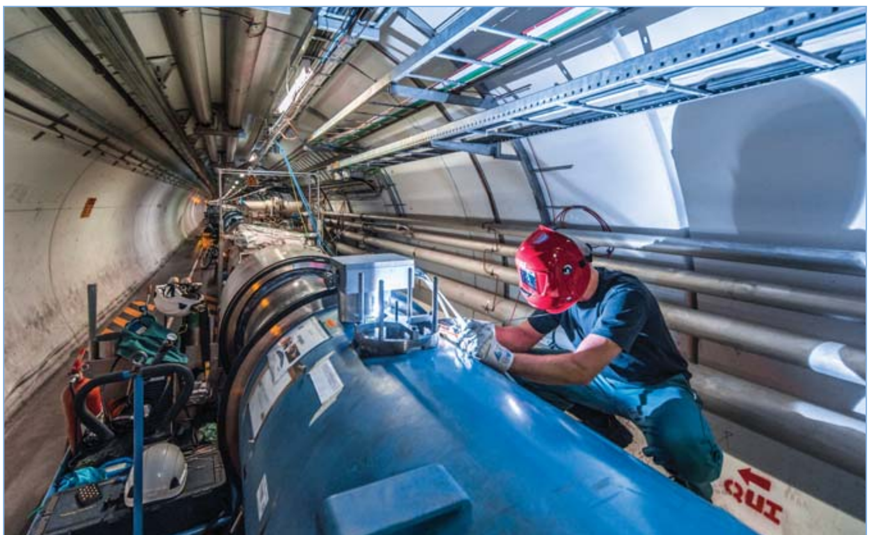
Coping with pileup

The biggest challenge for the LHC experiments will be coping with pileup, in which lots of events occur at the same time. Out of around a billion collisions per second, perhaps a few hundred events will be selected for study. "Statistically, most collisions are uninteresting," says John Paul Chou of Rutgers University, a member of the CMS collaboration. "We are pushing the [CMS] detector to its limits, so there has been a lot of work in designing algorithms to combat pileup."

The other LHC detectors have also been repaired and improved. On ATLAS, for example, the most notable upgrade is the placing of an additional particle tracker just a centimeter from the collision site. "Most particles either decay immediately, or they are stable when they smack into the detector," says Kyle Cranmer, a New York University physicist who works on ATLAS. "If we can tell some particle lasted a bit before decay, that could be a huge handle," he says. "This will help us spot collisions with a Higgs boson or a top quark." ATLAS and CMS are the largest and broadest detectors at the LHC. With the new run, says Cranmer, "We'll find out if the two are still equally matched. It's a bit of drama."

Besides ATLAS and CMS, the LHC hosts five additional detectors. With ALICE the main focus is the one month a year when heavy ions are dispatched through the accelerator. "One thing you observe in nuclear collisions is hydrodynamic flow patterns," says ALICE

CERN



One of the key repairs to the Large Hadron Collider was the welding of more than 27 000 shunts on the 10 000 connections between magnets to provide an alternative path for the high current in case circuit elements lose their superconductivity.

spokesman Paolo Giubellino, of CERN. The experiments, he says, could shed light on the transition from a primordial soup to an organized system that occurred in the first few seconds after the Big Bang. The LHCb detector measures parameters of the violation of *CP* symmetry in interactions of heavy particles containing the bottom quark. The LHCf detector looks at pions that come out of collisions in the near-forward direction; the idea is to gain insight into the origin of ultra-high-energy cosmic rays. TOTEM aims to measure the effective size of the proton. The seventh and newest experiment at the LHC is MoEDAL, a direct search for a magnetic monopole and highly ionizing stable massive particles.

“Please be patient”

Perhaps the most tantalizing puzzle that particle physicists hope to crack concerns “naturalness,” or hierarchy. It boils down to asking why quantum corrections keep the Higgs mass as low as it is. For several decades the leading theory has been supersymmetry, in which standard-model particles have supersymmetric partners that are heavier and carry different spin (see the article by Savas Dimopoulos, Stuart Raby, and Frank Wilczek in PHYSICS TODAY, October 1991, page 25). Much attention centers on observing the top quark’s putative supersymmetric partner, the stop. The other main theory postulates the existence of higher dimensions (see the article by Arkani-Hamed, Savas Dimopoulos, and Georgi Dvali in PHYSICS TODAY, February 2002, page 35), which can also be framed as the Higgs having substructure. “Those are the two ideas for explaining naturalness, and there is no evidence for either one,” says Chou.

“No really new radical ideas have emerged” since the end of the LHC’s first run, says CERN theorist Gian Giudice. “The mood among theorists has changed. The candidates have not changed. What has changed are the constraints. We now have to squeeze the theory into a corner.” Supersymmetry is “like a chameleon,” he adds. “It can show itself in a variety of colors and shapes.” It is not a single model, explains Heuer. “It is a platform with different parameters. One has to see what has been excluded, and what can come out with more energy, more luminosity, more collisions.” And, he adds, “I tell people, ‘it’s unpredictable. Please be patient.’ ”

If the LHC does not unveil supersymmetry, says Arkani-Hamed, “it doesn’t completely rule it out. But it certainly means that the vast majority of theories are wrong. Not seeing anything but the Higgs is the most shocking thing we can have. It would point to a paradigm shift. It would be a huge challenge to theoretical physics.” Says Giudice, “The idea of the multiverse may become more popular among theorists if supersymmetry is not found.”

Scientists are also keen to detect dark matter, which would show up as missing energy and momentum—and which fits well into some frameworks of supersymmetry. And they hope to explain the dominance of matter over antimatter. But the only science that can be counted on is a detailed exploration of the properties of the Higgs, which the higher-energy LHC will produce copiously. And of course there is the lure of the unknown. “We are restarting at a higher energy,” says Heuer. “It will open new windows, depending on the kindness of nature.”

A major upgrade is planned in 2023 to increase the LHC beam intensity. The collision rate will be about 1000-fold higher than during the original 2009–13 run. That intensity increase will necessitate significant upgrades to the experiments to deal with pileup. The LHC is expected to run through 2035.

Toni Feder

New ITER head is confident the fusion energy project will succeed

Bernard Bigot sees management of the seven-party international effort as a greater challenge than the technological demands.

The new director general of ITER brings with him strengthened authority to unify the assembly of the massive fusion experiment in France and the building of its components by ITER’s seven member states. Bernard Bigot (pronounced BEEGoh), who assumed his post on 5 March, says the decision-making process has been streamlined to help prevent further schedule slippages and cost overruns on the project, whose price tag and