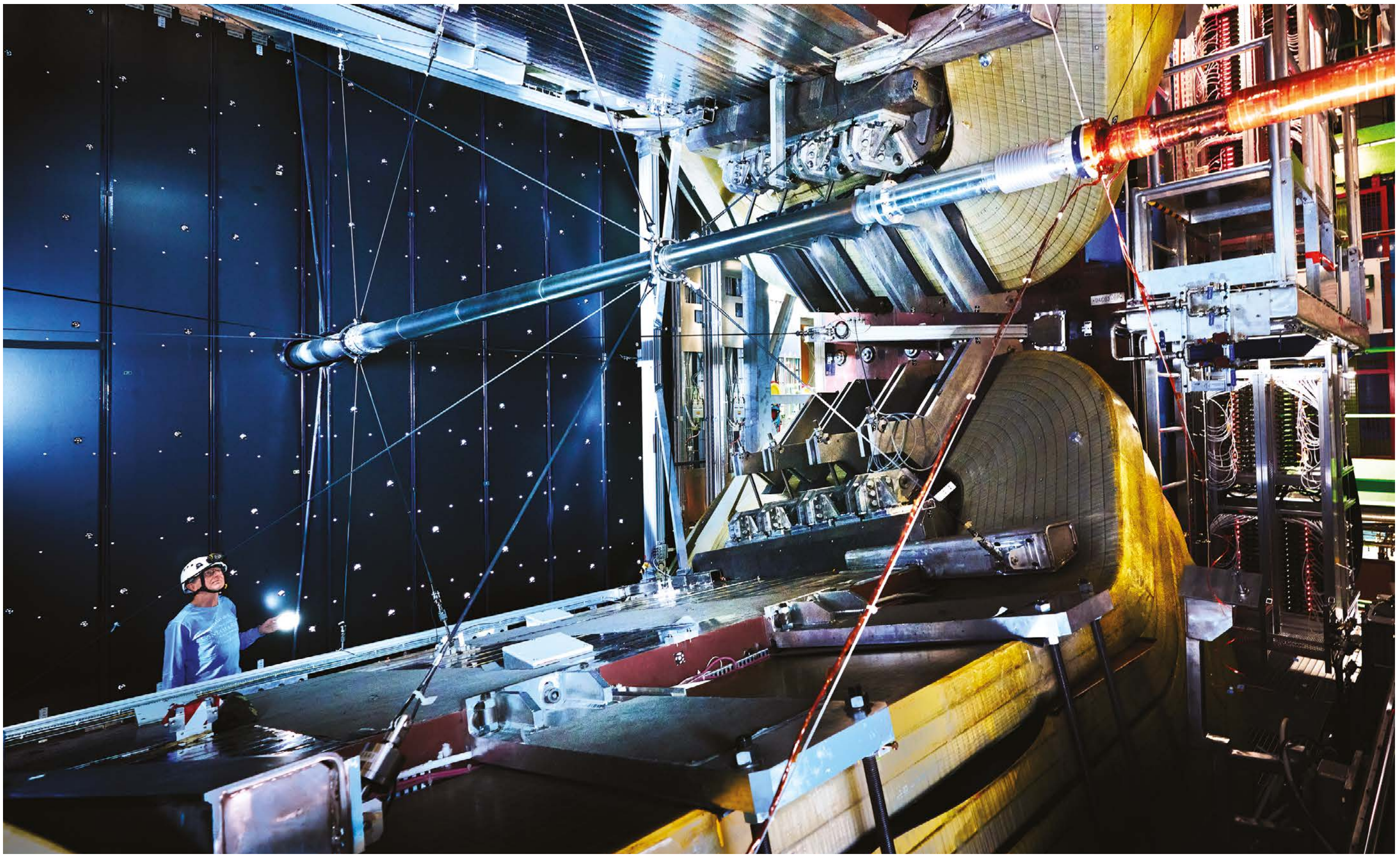
News in focus



MAXIMILIEN BRICE/CERN

The beampipe of the LHCb experiment at CERN.

UPGRADED LHC BEGINS EPIC RUN TO SEARCH FOR NEW PHYSICS

After a three-year shutdown, the Large Hadron Collider will smash particles together at the highest energies yet.

By Elizabeth Gibney

Experiments at the world's most powerful particle collider have restarted at CERN, Europe's particle-physics laboratory, after a three-year upgrade to the machinery. For the third run, the proton beams of the Large Hadron Collider (LHC) will circulate at higher intensities and record energies. Physicists want to use the collisions to learn more about the Universe at the smallest scales, and to solve mysteries such as the nature of dark matter.

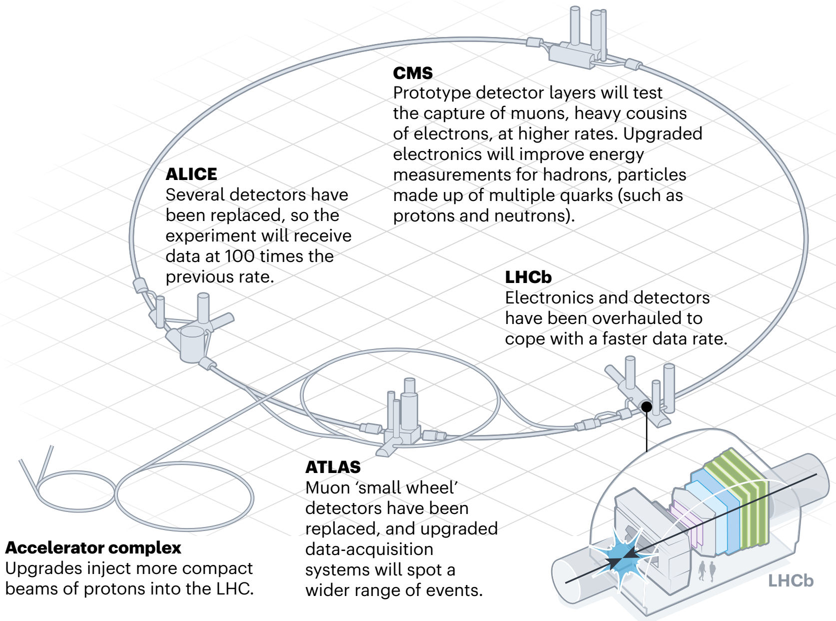
At 4.47 p.m. local time on 5 July, physicists at the laboratory, near Geneva, Switzerland, turned on the detectors and began taking data. The current run follows some in 2009–13 and 2015–18. "It is the first time in what feels like ages, after the pandemic, that we're opening a window on the Universe to look at what it's made of," says Tara Shears, a particle physicist at the University of Liverpool, UK, and member of the LHCb collaboration — which specializes in studying the behaviour of a fundamental particle called the 'b', or 'beauty', quark.

More-compact proton beams will allow the LHC to maintain the peak rate of collisions for longer, enabling experiments to collect more data than in the previous two runs combined. A collision energy of 13.6 trillion electronvolts (TeV), up from 13 TeV in the previous run, raises the probability of creating heavier and unknown particles (see 'Data boost'). "With higher-energy data and a larger amount of data we can look further. It is really quite thrilling," says Shears.

Physicists will use the data deluge to learn more about the Higgs boson, which was discovered at CERN ten years ago this week and about which myriad questions remain (see page 220). They will apply new analysis techniques to look for physics outside the standard model, which describes known particles and their interactions. And they'll explore a list of existing results that don't fit with the theory.

DATA BOOST

In the third run of the Large Hadron Collider (LHC), researchers expect to collect as much information on particle collisions as in the machine's first two runs combined. That's thanks to more tightly packed beams and upgrades at the machine's four main detectors.



NIK SPENCER/*NATURE*; SOURCE: CERN

These discrepancies include an apparent preference for bottom quarks to decay into electrons rather than their heavier cousins, muons, when the standard model predicts roughly equal numbers of both. If such anomalies are genuine, they could help physicists to explain mysterious features of the Universe that the standard model can't account for – such as why matter is everywhere but antimatter is scarce. But, if the anomalies arose through chance fluctuations, more data would see the hints fade away.

Back on the beam

Beams have been circulating in the LHC since April, and some collisions have taken place. But only on 5 July was the beam declared safe enough for the experiments to be switched on. Among them are ATLAS and CMS, the LHC's general-purpose experiments designed to study a wide range of physics.

The particle beam has the power to damage detectors and machinery, so engineers will start cautiously, circulating only a minimum number of protons. This number will then increase over the course of the year, says Mike Lamont, who is director for accelerators and technology at CERN. Eventually, the energy of the beam will be that of a train going at 150 kilometres per hour, "so we have to be very, very careful about this", he says.

During the shutdown – extended by the COVID-19 pandemic – the CERN team upgraded the accelerator complex, which generates and accelerates the particle beam. This included installing a new proton source to replace technology that had been in use since 1978. Physicists upgraded the experiments' detectors, in particular improving their electronics and computing system to deal with the greater collision intensity. In the CMS and ATLAS experiments, the LHC will collide bunches of around 100 billion protons at a rate of 40 million collisions per second. Each one will produce around 60 proton–proton smashes – each of which will generate hundreds of particles.

Two large experiments have been completely overhauled: LHCb and ALICE, which studies a dense form of matter known as quark–gluon plasma. Whereas CMS and ATLAS should, in effect, double their rates of data creation, LHCb's rate will be 10 times higher than it was, and ALICE will aim to record 50 times as many collisions as before.

High-luminosity machine

The beam, which feeds all the detectors, starts at a low intensity, so it will take months before enough data are available for analysis to begin in earnest, says Shears. Physicists will need to recalibrate the experiments to the new beam and check that the revamped detectors are working as hoped, before making new findings. "You're not going to see results coming out on day one," she says.

The LHC will run for four years, until collisions stop to make way for upgrades to an even more intensive machine. This one, known as the High-Luminosity LHC, will start operating in 2029 and will ultimately produce ten times the data of the LHC's first three runs combined.

Ahead of the start-up, CERN director-general Fabiola Gianotti said it was her dream for the LHC's third run to find particles that make up dark matter – the mysterious substance that physicists think accounts for 85% of the matter in the Universe. But the experiments' goals are not to chase any particular theory but to "understand how nature works at the most fundamental level", she said.

HIGGS BOSON 10 YEARS ON: WHAT SCIENTISTS DO AND DON'T KNOW

It's been a decade since the particle's discovery. But many of its properties remain mysterious.

By Elizabeth Gibney

On 4 July 2012, physicists at CERN, Europe's particle-physics laboratory, declared victory in their long search for the Higgs boson. The elusive particle's discovery filled in the last gap in the standard model – physicists' best description of particles and forces – and opened a new window on physics by providing a way to learn about the Higgs field, which involves a previously unstudied kind of interaction that gives particles their masses.

Since then, researchers at CERN's Large Hadron Collider (LHC) near Geneva, Switzerland, have been busy, publishing almost 350 scientific articles about the Higgs boson. Nevertheless, many of its properties remain a mystery.

Ten years after the Higgs boson's discovery, *Nature* looks at what it has taught us about the Universe, as well as some of the big questions that remain.

4 things scientists have learnt

The Higgs boson's mass is 125 billion electronvolts. Physicists expected to find the Higgs boson eventually, but they didn't know when. In the 1960s, physicist Peter Higgs and others theorized that what's now called a Higgs field could explain why the photon has no mass and why the *W* and *Z* bosons, which carry the weak nuclear force that is behind radioactivity,