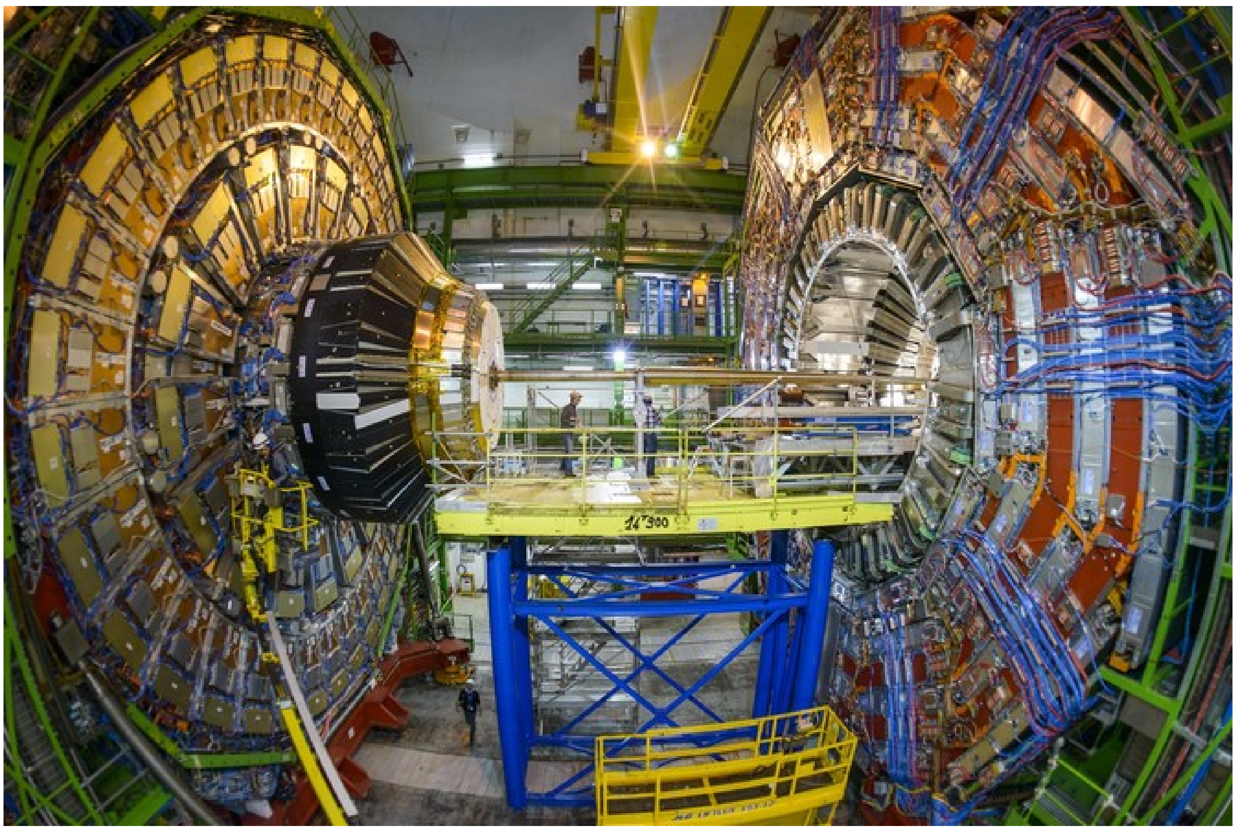
How does an experiment at the Large Hadron Collider work?

June 8 2015, by Gavin Hesketh



Supersize symmetry. Credit: Maximilien Brice/CERN

It's not every day my Twitter feed is full of people talking about flat-tops, squeezing and injections, but then Wednesday 3 June was not an average day for the Large Hadron Collider.

The LHC is the world's largest particle accelerator and lies in a tunnel below CERN, the European physics lab just outside Geneva. And on Wednesday it was restarted after two year break for repairs and upgrades, ready to push our understanding of the universe to new limits.

As my fellow physicists crowded into the control rooms and waited for things to get underway, I was at a workshop in France. But I was able to follow the switch-on online. Here's how things went down.

8.09am. Injection: Billions of protons are loaded into the LHC.

The LHC is a ring roughly 28km around that accelerates protons almost to the speed of light before colliding them head on. Protons are particles found in the atomic nucleus, roughly one thousand-million-millionth of a metre in size.

They are easiest to get from hydrogen, the simplest atom with just one electron orbiting one proton. The LHC starts with a bottle of hydrogen gas, which is sent through an electric field to strip away the electrons, leaving just the protons. Electric and magnetic fields are the key to a particle accelerator: because protons are positively charged, they accelerate when in an electric field and bend in a circle in a magnetic field.

9.45am. Ramp: Once the LHC is fully loaded, its two proton beams are slowly accelerated up to collision energy, now a world-record 6.5TeV per beam.

Accelerating billions of protons to close to the speed of light, directing them all the way around the LHC, and then colliding them head-on, is a delicate balancing act performed by high voltage equipment and giant magnets. This is an amazing technical achievement. Indeed one of the main applications of particle physics research is in the industrial applications of the technology it develops along the way, from proton therapy cancer treatment to the world wide web.

Big data. Credit: M.Brice/CERN

But for me, the excitement is in the science: the LHC is exploring the universe at the smallest scales. Everything we have learned so far is formulated in the Standard Model, a theory which describes the universe made of tiny particles, and gives the rules for how these particles behave. By smashing some of these particles together at high energy, we are able to test these rules and make new discoveries.

The LHC "Run 1" (2010-2013) provided enough data to test the Standard Model to new levels of precision and discover the Higgs boson. This particle was predicted in the 1960s and plays a central role in the Standard Model. But it was almost 50 years before we had a machine powerful enough to discover it. As well as high energy, it needed lots of data: the Higgs boson is a rare thing, and fewer than one in a billion collisions at the LHC produce one.

10.12am. Flat top: Beam energy levels off after reaching the target.

These were tense moments for the CERN team on Wednesday. The LHC was operating at the highest energy ever achieved in a particle accelerator. "Run 2" will collide protons at 60% higher energies than Run 1 by pushing the magnets and accelerators to the limit. We hope this extra reach will allow us to tackle some of the big questions in particle physics.

One of the main topics is dark matter. This seems to be a new type of particle spread through the entire universe. And with the LHC Run 2 we hope to make it in the lab for the first time. But if the Higgs boson is rare, dark matter is even rarer, and we will need to sort through a lot of collisions before having a hope of finding it.

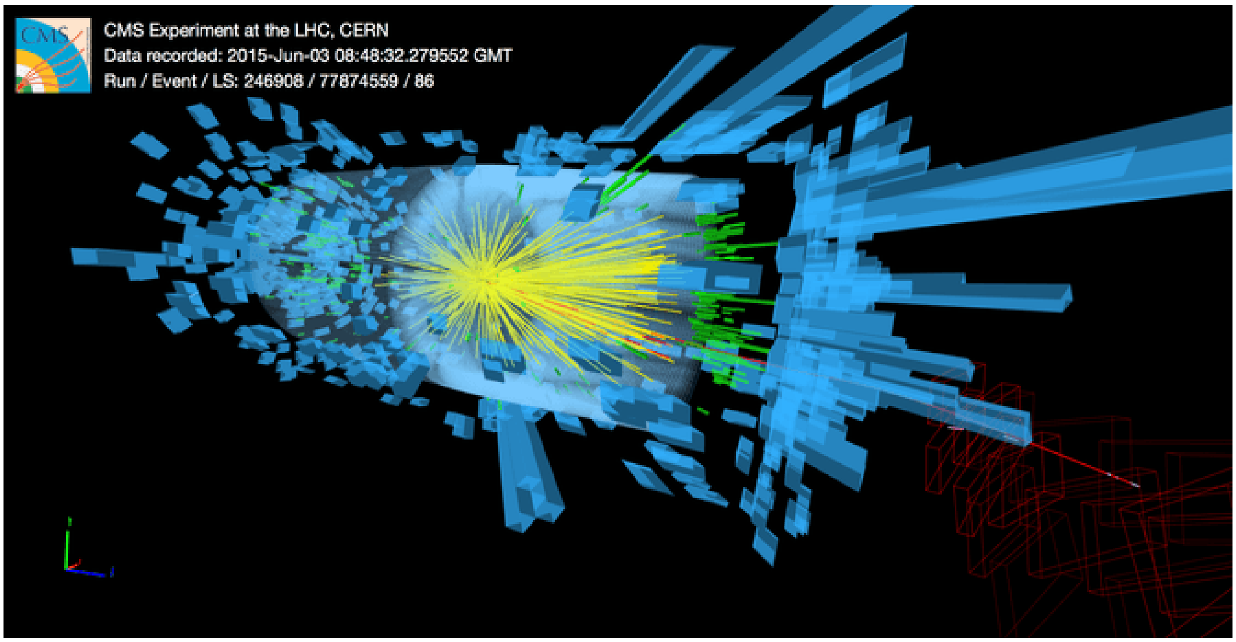
10.17am. Squeeze: The beams are fine-tuned, and focused at the four points around the LHC where they cross, and the experiments will record the collisions

Tense moments. Credit: Laurent Egli/CERN

Almost there. The experiments now need to wait for the all-clear before they can start recording, and we begin studying things that have never been seen before. Still, many of the collisions will not be interesting, as the protons just smash apart without doing anything exciting.

To make matters worse, the rare new particles we are looking for also tend to be very unstable, and decay too quickly to be seen directly. So the job of the experiments is to measure whatever particles do come out of a collision and try to reconstruct what happened, looking for evidence of something unusual.

As well as dark matter, there are many other ideas to test, such as supersymmetry, new gauge bosons, quantum black holes and heavy neutrinos, all of which we could reconstruct from the LHC collisions. Part of the joy and pain of science is that a new discovery could come in a matter of days, or a matter of years.



Worlds collide. Credit: CMS/CERN

10.43am. Stable beams: The LHC is now running smoothly, the beams are behaving as expected, and the experiments can start recording data.

Run 2 has begun! Champagne is flowing at CERN. Now the attention moves to analysing the new data, and it's time for the rest of us to get back to work.

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Champagne flowing. Mike Struik/CERN

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Citation: How does an experiment at the Large Hadron Collider work? (2015, June 8) retrieved 9 April 2024 from https://phys.org/news/2015-06-large-hadron-collider.html