ATLAS & CMS

ATLAS and CMS are the two 'general-purpose' detectors at the LHC. They're looking for any new particles or unknown physics which the LHC's record-breakingly high energies might allow us to observe for the first time.

The Higgs boson

Probably the most famous goal of ATLAS and CMS is to spot the Higgs boson—a particle predicted independently and almost simultaneously by three groups of physicists, including Peter Higgs, which allows all other particles to have mass. It's a bizarre problem in modern physics that we can explain the properties of subatomic particles to incredible precision, but we're unable to explain why they have mass—in other words, what makes it hard to accelerate or decelerate them.

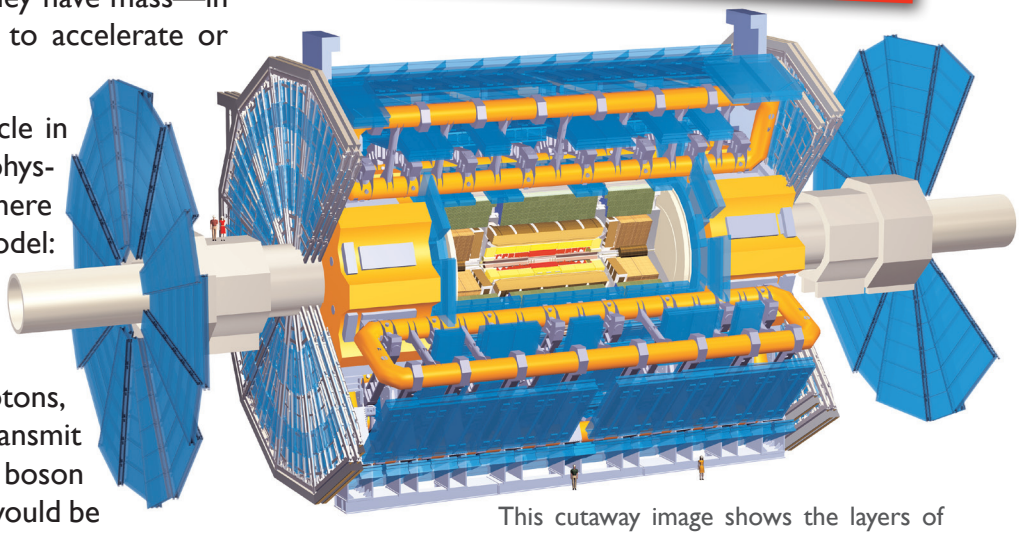
The Higgs boson is the only particle in the 'standard model' of particle physics which hasn't been observed. There are two types of particle in the model: fermions, which are 'stuff' (eg electrons, and the quarks which make up protons and neutrons); and bosons, which transmit forces (eg photons, which are particles of light, and transmit electromagnetic forces). The Higgs boson is one of the latter and, if it exists, would be responsible for giving particles mass. The theory says that the Universe is filled with a sticky soup of Higgs particles, and those particles which interact most strongly with the Higgs particles are bogged down by them. This is what we think of as mass—a tiny, light electron barely sees the Higgs particles, whilst a proton (which is 2,000 times heavier) is wading through a dense sea of them.

If we find it, it would be the last piece in the standard model's mathematical house of cards and, further new physics notwithstanding, our understanding of subatomic particles would be nearly complete. If we don't, it's perhaps more exciting for particle physicists, because suddenly a cornucopia of new potential theories is unleashed, ready for the LHC to test.

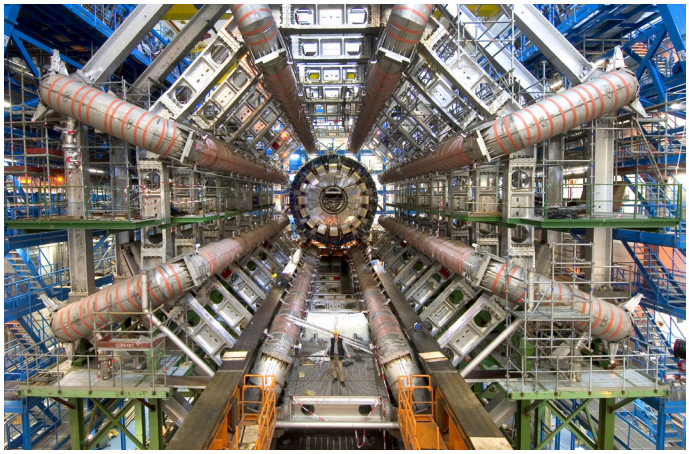
Vital statistics: ATLAS

A Toroidal **L**HC **A**pparatu**S**

diameter:	25 m
length:	46 m
mass:	7,000 tonnes



This cutaway image shows the layers of the ATLAS detector. Protons collide in the centre, and each layer is designed to detect different particle properties. Image © CERN.

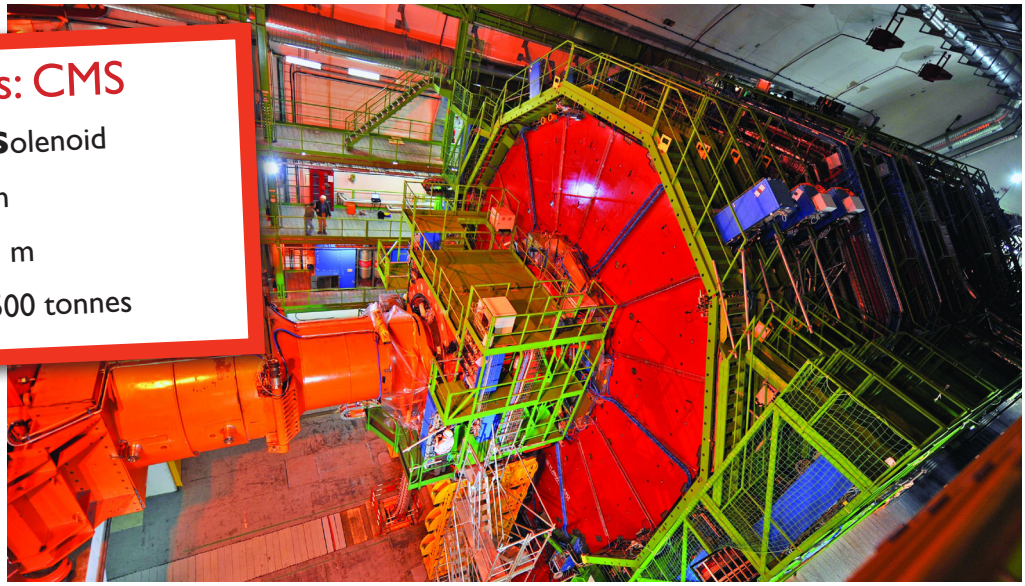


This iconic image shows the ATLAS detector cavern before the detector electronics were inserted. The person in a hard hat gives a sense of scale! Image © CERN.

Vital statistics: CMS

Compact **M**uon **S**olenoid

diameter:	15 m
length:	21.5 m
mass:	12,500 tonnes

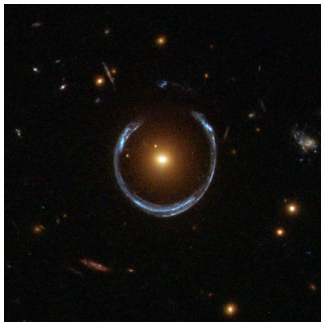


The completed CMS detector in its cavern. Protons travel through the orange pipe to the centre of the detector where the particles collide. Image © CERN.

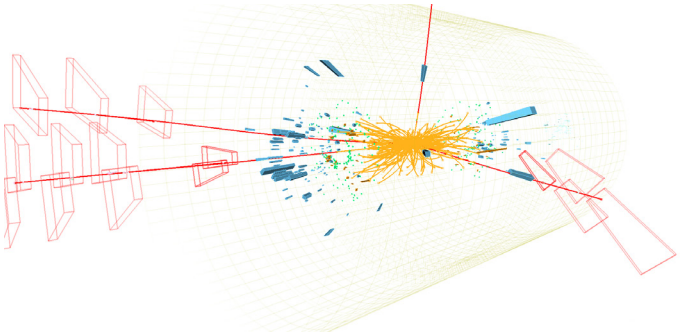
Dark matter

Astronomers have known for some time that there's something missing in our understanding of the Universe. We can predict with extremely high precision how objects in the cosmos should orbit one-another: in the Solar System, for example, this works extremely well, and we can predict the motion of planets and moons with incredible accuracy. However, when we try to apply these laws to whole galaxies, something goes wrong: stars near the edges of the galaxies are rotating around galactic cores much more quickly than we'd expect given the matter we can see with telescopes. This effect scales up to clusters of galaxies too. We can measure their mass using 'graviational lensing', where gravity bends the light from further-away objects. The curvature of the light's path is related to the amount of mass bending it, and this allows us to deduce that there's much more there than just the visible mass in the clusters.

What this mass is composed of we just don't know, but it's possible that it's made up of heavy, weakly-interacting subatomic particles. The hope is that some of these dark matter particles will be produced in the LHC.



The near-complete circle in this image is the light from a distant galaxy bent around the nearby galaxy at its centre. Images like this allow us to estimate the mass of the galaxy bending the light, and suggest the existence of dark matter. Image courtesy of ESA/Hubble and NASA.



A candidate Higgs event recorded at CMS, showing one of its characteristic signatures, decay into four muons (the red lines). Image © CERN.

New particles, unknown physics

It's easy to forget when we have some very definite ideas of what we might find at the LHC that we might see some things which we've never thought of before. The LHC is the highest energy particle collider which has ever been built, and might well allow us to create particles which are completely new to science. ATLAS and CMS would be the likely places that these kinds of results would be unearthed.

Sensitive measurements of the energies of particles created in a smash allow us to work out the mass of a new particle created thanks to $E = mc^2$. Then, more subtle measurements of what kind of daughter particles follow and their speed and direction of flight will hopefully allow scientists to work out exactly what they've made and work out what, if any, effect this has on existing theories—or entirely new ones!

LHCb

LHCb is looking specifically for certain types of particle decays involving B-mesons: particles containing a beauty quark. These reactions will allow us to very precisely differentiate matter and antimatter—but why does that, er, matter?

Where has all the antimatter gone?

All particles have an antimatter twin with the opposite electrical charge. For example, the negatively-charged electron's antiparticle is called a positron, for obvious reasons. As the Universe cooled from being a searing ball of pure energy in the moments after the Big Bang, it's thought that an equal amount of matter and antimatter should have been created.

Matter and antimatter are not happy bedfellows: when one comes into contact with the other, they annihilate in a flash of gamma radiation. Consequently, it's pretty obvious that there isn't a lot of antimatter here on Earth, otherwise life would be rather more hazardous than it is, with things forever disappearing in huge flashes of energy!

In fact, it seems that the observable Universe is pretty much entirely matter (there are no huge regions of annihilating matter and antimatter between the stars) which begs the question: where has all the antimatter gone?

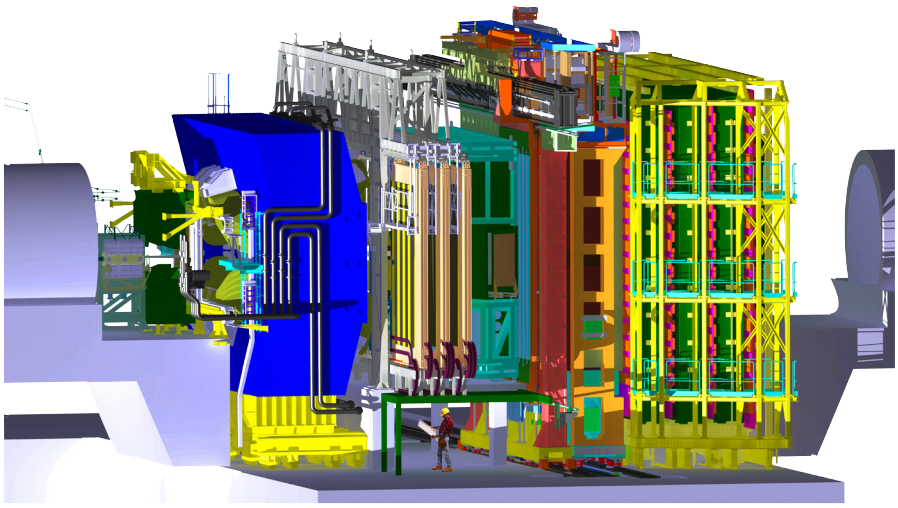
LHCb is looking for tiny differences in the way that matter and antimatter react, in an attempt to understand this mystery. Perhaps a little bit less antimatter was created in the first place, or perhaps it behaved a bit differently in subsequent reactions meaning that, when all the annihilating was over just after the birth of the Universe, a small excess of matter was left over which, ultimately, went on to form us.

It's looking at these tiny differences primarily using particles called B-mesons, which contain a beauty quark. Also known, less romantically, as a bottom quark, these are the second heaviest kind of quark known, a thousand times heavier than the up and down quarks which make up protons and neutrons.

Vital statistics: LHCb

LHC beauty

length:	20 m
mass:	4,500 tonnes
angle covered:	17° × 14°



The layout of the LHCb detector, with a picture of a construction worker for scale. LHCb looks quite different to the other experiments in the LHC, in that it's not cylindrical. That's because the B-mesons which it's looking for tend not to fly out in all directions, but instead fly at small angles to the direction of the incoming protons. Image © CERN.

ALICE

The ALICE detector is optimised for examining collisions between lead ions rather than protons, to probe the quark–gluon plasma which, at a staggering two trillion degrees, filled the Universe moments after the Big Bang.

Vital statistics: ALICE

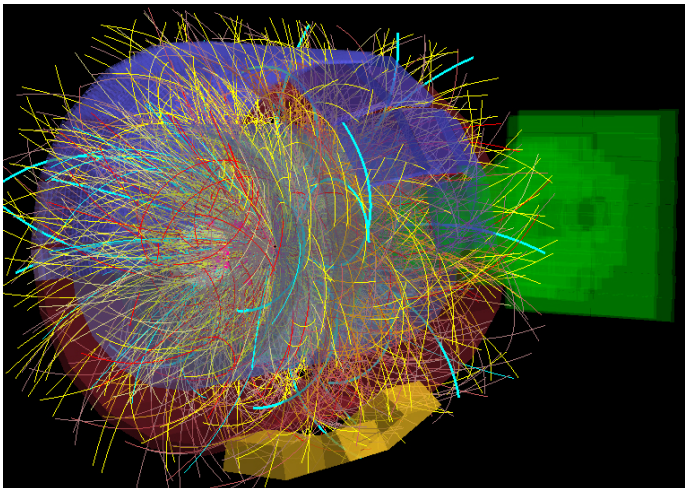
A Large **I**on **C**ollider **E**xperiment

diameter:	16 m
length:	26 m
mass:	10,000 tonnes

Part of the ALICE detector known as the time projection chamber. Image and ALICE logo © CERN.

What did the Universe look like just after the Big Bang?

The ALICE experiment is designed rather differently to the other detectors at the LHC. Rather than being optimised to examine collisions between individual protons, ALICE is used when the LHC is filled with lead ions, which contain 82 protons and about 125 neutrons each.



The chaotic aftermath of a lead-ion collision recorded in ALICE. Studying the tracks of these particles gives us an insight into what conditions were like in the quark–gluon plasma in the very early Universe. Image © CERN.

When these (relatively!) enormous ions smash together, they create a state of matter called quark–gluon plasma. Quarks are normally trapped inside protons and neutrons, stuck there very tightly by particles called gluons. In this plasma, quarks and gluons are all buzzing around completely free. Unsticking protons and neutrons requires an incredible amount of energy, meaning that the mixture must be incredibly hot: around two trillion degrees, or about 100,000 times hotter than the centre of the Sun! Temperatures like this only existed in nature a couple of millionths of a second after the Big Bang.

ALICE hopes to understand why quarks are never seen alone in the modern Universe, only ever assembled into particles, like protons and neutrons. The mechanism for this so-called 'confinement' is currently not fully understood. ALICE is also trying to work out why protons and neutrons weigh so much: if you add up the masses of the three quarks which make up the proton, you only get about 1% of the total mass. A deeper understanding of how quarks and gluons interact could explain where 99% of the mass of everything around us comes from.