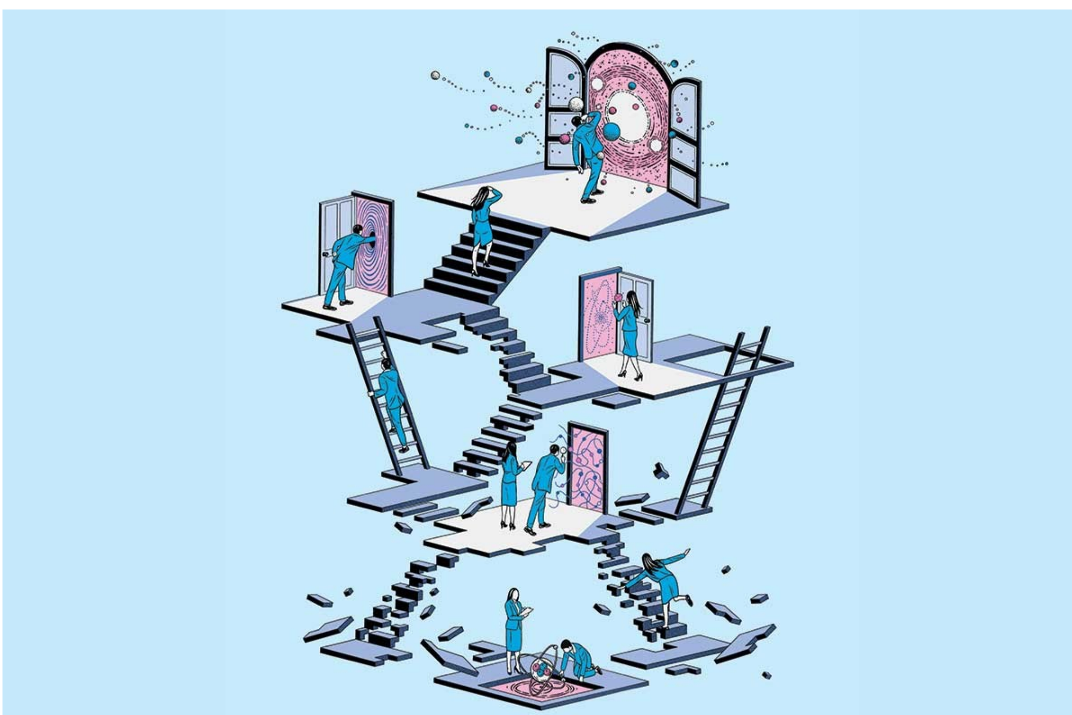
New Scientist

Bigger than the Higgs, bigger even than gravitational waves…

FEATURE March 2, 2016 – By Matthew Chalmers, Bristol, UK
https://www.newscientist.com/article/2078975-bigger-than-the-higgs-bigger-even-than-gravitational-waves/

It looks like the LHC may have found a surprise massive particle that gives a glimpse into a better – and entirely unexpected – theory of reality.

IF IT is anything, it is what Gian Giudice has been waiting for his entire scientific life. "We are not talking about a confirmation of an established theory, but about opening a door into an unknown and unexplored world," says Giudice, a theoretical particle physicist based at CERN near Geneva, Switzerland.



That's if it turns out to be anything. At the moment, all we have are hints emerging from the debris of collisions within CERN's showpiece particle smasher, the Large Hadron Collider. But if those hints firm up in the course of the coming weeks and months, it could be the big one. Forget the Higgs, forget even gravitational waves: 2016 could go down as the year when a new picture of nature's fundamental workings was unveiled.

The hopes spring from two "bumps" that have appeared independently, in the same place, in the latest data from the LHC's two big detectors, ATLAS and CMS. They point to the existence of a particle that dwarfs even the Higgs boson, the giver-of-mass particle discovered at CERN in July 2012.

The Higgs was a milestone, but ultimately one that marked the end of a road. It was the last particle to be found of those predicted by the standard model of particle physics. This clutch of sophisticated equations matches every experimental result to date with exquisite precision, and explains the workings of three of the fundamental forces of nature: electromagnetism and the weak and strong nuclear forces. But it is a manifestly incomplete model, silent on the fourth force, gravity, and unable to explain why the Higgs and the 16 or so other particles it is built on have the properties they do – not to mention what makes the invisible dark matter that is thought to dominate the universe.

To break free from the standard model, we need to find something completely new.

Hence the excitement surrounding hints contained in the LHC's data from 2015, the first full year when it was running at close to its maximum design energy. Theorist John Ellis of King's College London says he hasn't seen anything like it since the ill-fated 2011 announcement by physicists in Italy that neutrinos travel faster than light.

That turned out to be a trick of the light: an incorrectly attached fibre optic cable was skewing the experiment's timings. Such an error is unlikely to be the cause here, but cruel teases from inconclusive data are an occupational hazard for researchers at a machine like the LHC.

Sifting through the debris of its proton collisions, which happen billions of times a second, to determine whether it contains anything unexpected is a complex and messy business. Look long and hard enough and, once in a while, you're likely to see any pattern you want. Certainty, however, comes only by observing the same thing many times over.

If you get three tails in the first three tosses of a coin, you would be inclined to put the result down to chance. Get more than five tails in a row, and you might start to suspect the coin is loaded. Particle physicists' "gold standard" for declaring a discovery corresponds to there being a chance of only 1 in 3.5 million that the observed pattern is a fluke – a threshold you reach between the 21st and 22nd consecutive tails.

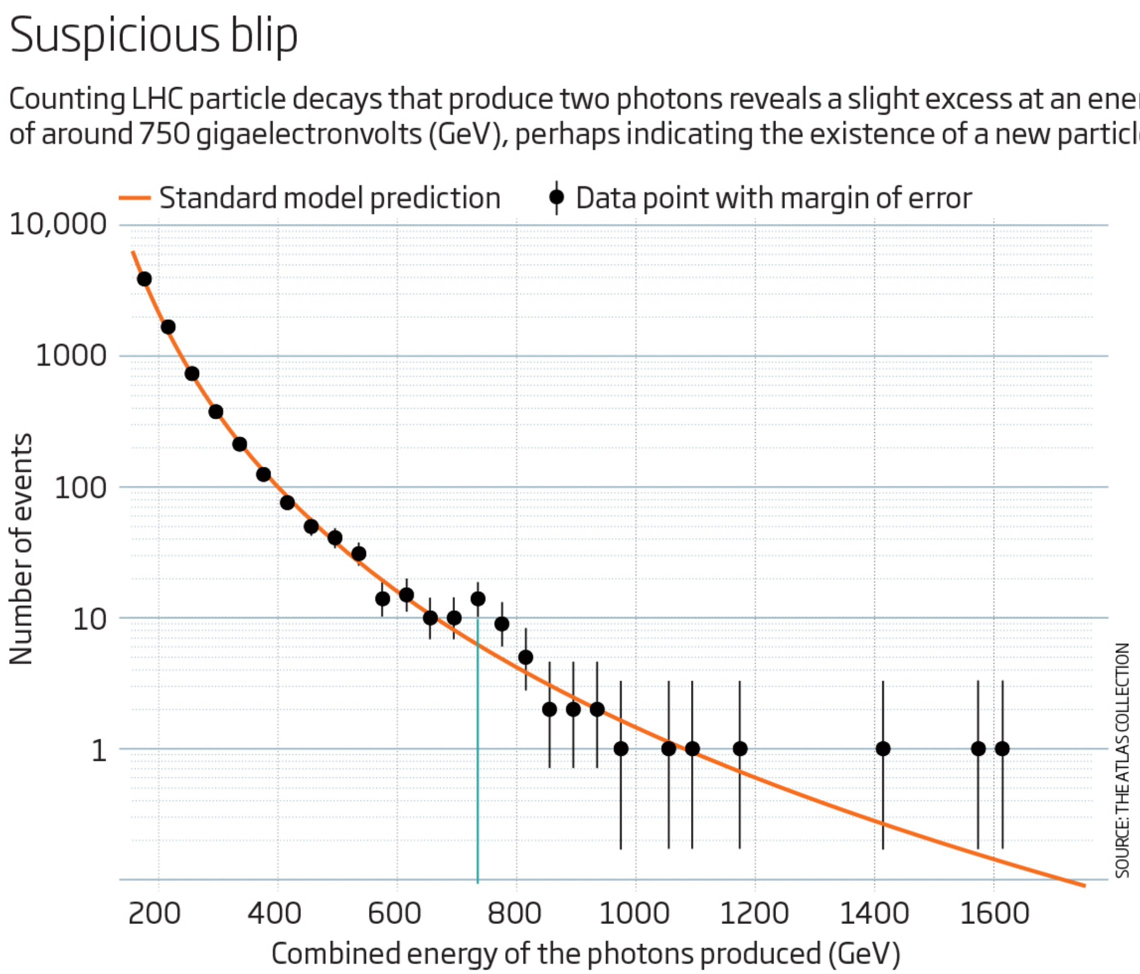
We're not there yet with the latest LHC bumps. They were spotted in collisions that produce two high-energy photons of light. Such collisions should generally produce fewer very energetic photons, purely because these take more energy to make. And indeed ATLAS and CMS see a declining number of "background" events, stemming from other well-known processes that produce two photons, as energy increases.

But at an energy of 750 gigaelectronvolts (GeV) shared between the two photons, the detectors see a slight upwards blip (see graph). This hints at something. Particles have set masses, and when they decay, that mass is converted into mass and energy of the decay products. Seeing an excess of photons with energy totalling 750 GeV suggests they came from the decay of an as yet unknown particle with just this amount of energy in the form of mass.

Decays into two photons are very "clean" processes – photons are easier to detect than other particles, and the expected rate of background events is well known. A similar bump in the graph at 125 GeV was how the Higgs first hinted at its existence. This newest bump would represent the most massive particle yet discovered, and by some margin, with a mass six times that of the Higgs and almost four times that of a lead atom.

The signal is eerily similar to the size of the Higgs bumps six months before they were confirmed as a discovery. It is almost impossible to calculate an exact figure, but combine ATLAS and CMS's latest results, announced in December, and the likelihood that the bumps are a statistical fluctuation is one in several hundred. That is equivalent to flipping maybe nine or 10 tails in a row – enough to become suspicious that the coin is loaded, but not to convince.

Even so, the spark has ignited a fuse. Barely a week after the ATLAS and CMS bumps were made public, theorists had posted more than 100 possible explanations to the arXiv server, a repository where physicists post data before formal publication, and the number has been skyrocketing ever since. Yasunori Nomura of the University of California, Berkeley, was one of the first. "I don't normally jump in on anomalies such as these because most of them are just too crappy, but this one is relatively clean," he says. "We're desperate to some degree because we have lots of problems to solve and no data."



Fifth force?

There are some things we can already say about the putative particle. It has no electrical charge, for a start, and its spin – a quantum mechanical property – is constrained. The mathematics of spin mean that any particle that decays into two photons, which have a spin of 1, cannot itself have a spin of 1. It must also have whole-number spin. So the particle might have a spin of 2, exciting the idea among some theorists that it is a type of graviton – a hypothetical spin-2 particle that transmits gravity. That would be the first herald of a long-awaited theory beyond the standard model that unifies gravity with the other known forces of nature.

Or the particle might have spin 0, as does the Higgs – in fact, another theory is that the apparition is a heavier cousin of the Higgs. But if it does have spin 0, Nomura's analysis suggests it is not an elementary particle: if it were, the vagaries of quantum theory would mean a sea of other, short-lived elementary particles would bubble up from the vacuum around it, sending its mass ballooning far higher than it is even now.

Instead, Nomura thinks, it must be a composite particle similar to the protons and neutrons within the atomic nucleus. These are made up of quarks bound together by the strong nuclear force. The mystery particle, on the other hand, would be the first in a family bound by an entirely new fifth force that only kicks in at high energies.

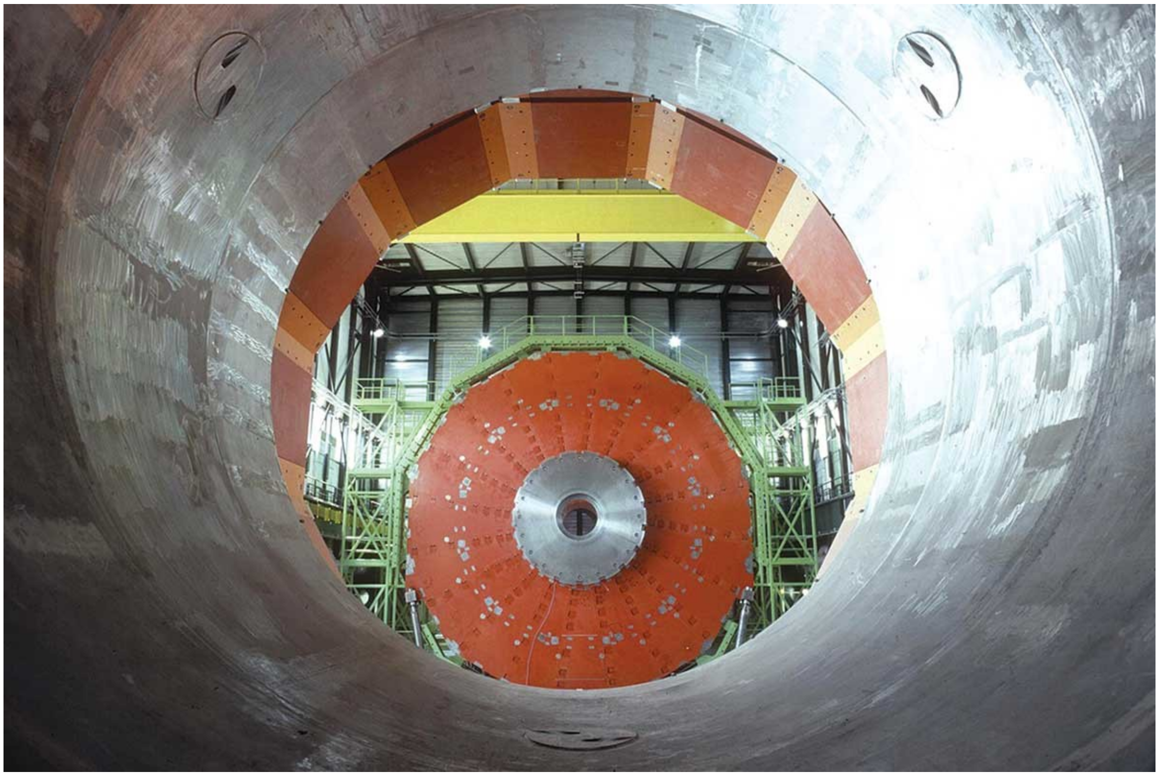
That might sound far-fetched, but it would just be history repeating itself. In the 1950s and 1960s, the discovery of a barrage of particles that turned out to be made up of quarks led physicists to the idea of the strong force. Nomura says that, together with his postdoctoral researcher, he threw several tests at the idea – and it passed every one.

Other theorists say the same about their pet theories, and Ellis urges caution – given our level of ignorance, he says, the particle could still be either elementary or composite. "We can't rule out much. The spin of the particle is wide open too."

Strangely, the only thing we probably can rule out is that the particle is what many theorists, including Ellis, would like it to be: a supersymmetric particle. Supersymmetry is a theory that plugs many holes in the standard model by conjuring up a raft of heavier particles that partner each known particle. The LHC has in general failed to turn up any evidence of supersymmetry, and even from the little we know about this latest particle, it doesn't correspond to anything found in the simplest supersymmetry models.

A further oddity is that a particle so massive should decay into two photons only indirectly, via particles of at least half its mass – but there is no sign of these. "If this thing is real then it can't just come alone. It demands the existence of further new particles," says Ellis.

The fact that there is no off-the-shelf model such as supersymmetry that supplies a particle with the right properties makes things all the more intriguing for Giudice. "This is the most exciting part of the story," he says. His own hunch chimes with Nomura's – that the particle heralds a bevy of particles interacting through an as yet unknown fifth fundamental force. If so, we should expect to see a lot more such things at even greater masses as ATLAS and CMS accumulate data.



A giant magnet for novel phenomena: the LHC's CMS experiment Patrice Loïez; Max Brice/CERN

They might not be the only source of surprises. In a separate development, the LHCb experiment is also seeing anomalies that could point to the existence of unidentified particles – although where those fit into the bigger picture remains unclear (see "Shadows of something big").

Getting more data is the foremost task of experimentalists like Jim Olsen of CMS. While trying to remain cool-headed, he is as excited as his theorist colleagues. If the ATLAS and CMS bumps grow after the LHC resumes high-energy particle collisions next month, then it's "absolutely major", he says. "It is a completely new object to study and the first thing outside the standard model."

Or perhaps such hopes will be crushed, as they have been often enough before. Most recently in 2014, CMS and ATLAS saw tentative blips in data from lower-energy collisions that produce jets of particles. It hinted at a possible particle with a mass of about 2000 GeV, and had a significance about the same as that of the latest bump.

Theorists duly trotted out explanations – the most popular being a particle carrying a new force – only for this bump to fade into nothing when the 2015 data was analysed, even as this latest bump reared up.

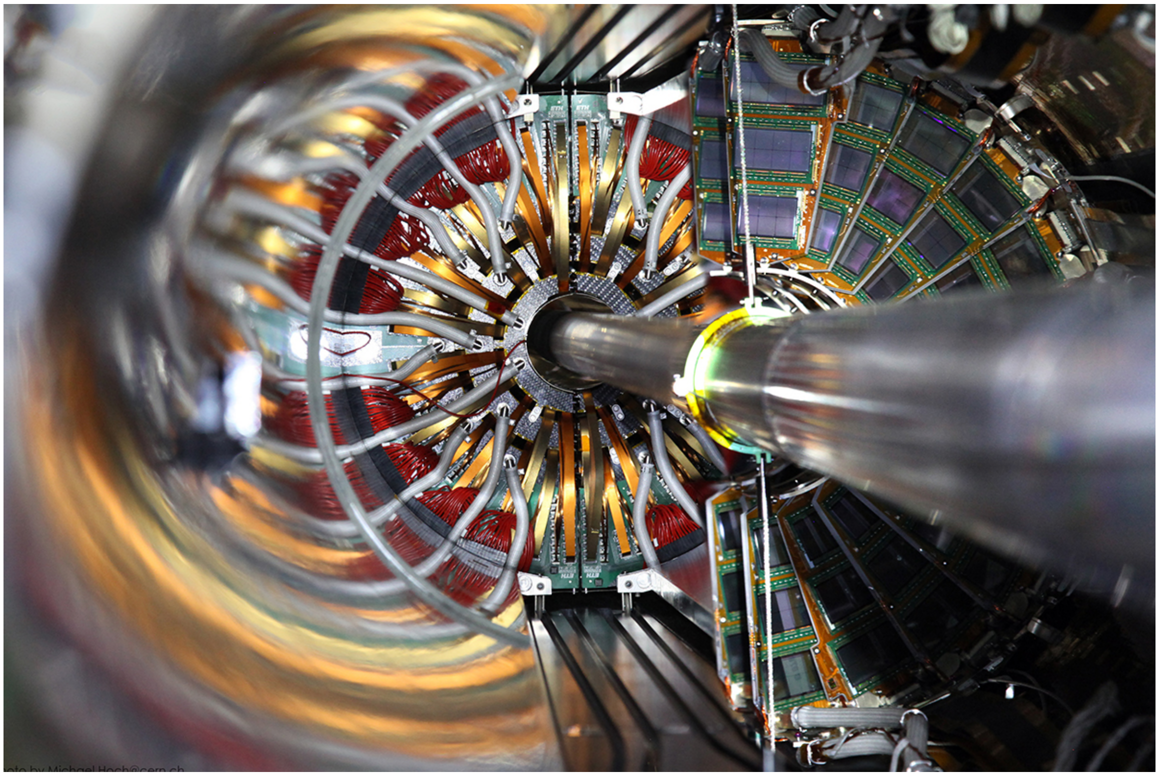
“Statistics may play games with us, as always, so I would just wait for the data to come,” says Patrick Janot of CMS. “With physicists searching for so many things in the LHC data, it would be abnormal not to find a few excesses of this magnitude.” The same point is emphasised by Marumi Kado of ATLAS. “We already have a host of different analyses searching for many signatures, which makes the probability of a mere fluctuation of the background more likely,” he says.

Make or break time could be very soon. The LHC did not deliver as much data as anticipated in 2015, and problems with the giant magnet that bends particles through the CMS detector meant that not all of that was as useful as it might have been. If the researchers have since managed to compensate for the missing magnet in their data analysis, more clarity could be forthcoming as CERN physicists gather for a winter conference in the Italian Alps starting next week. Otherwise, we will have to sit tight until the summer, when the first data from the round of particle smashing starting in April should be available.

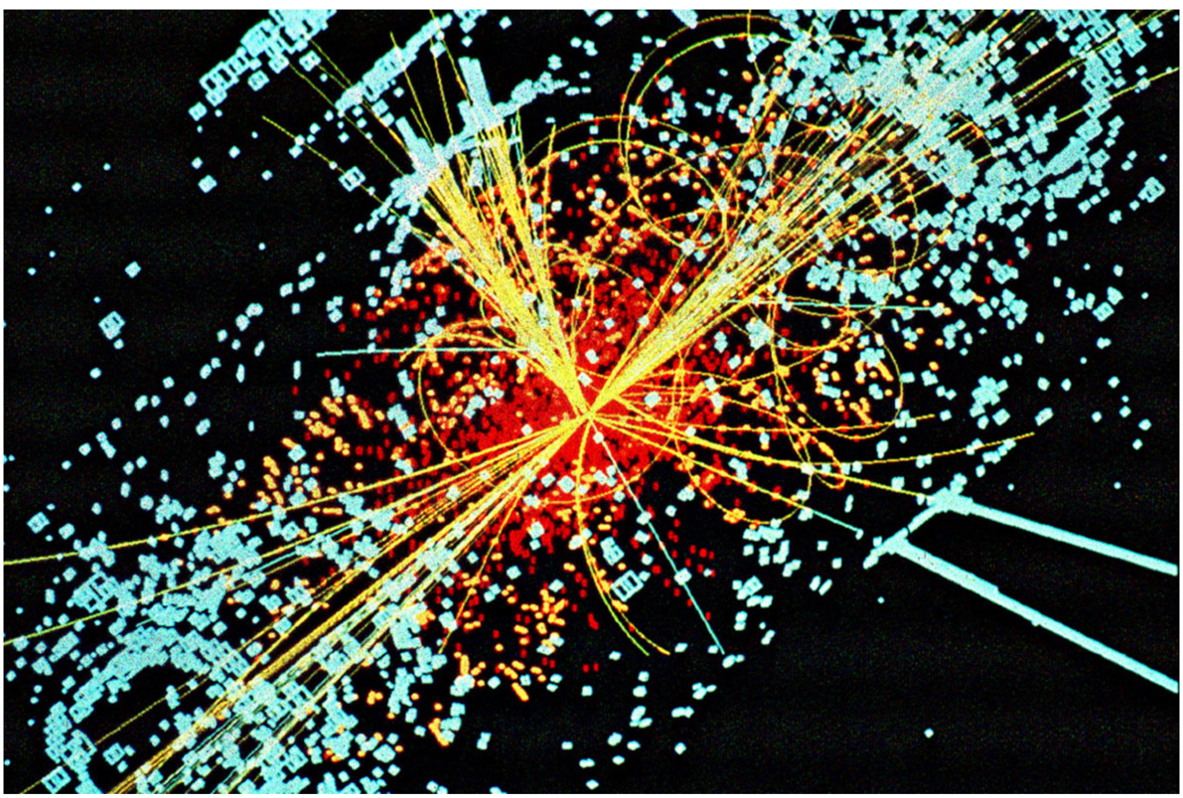
Particle physicists are hoping that 2016 will take them back to the unparalleled excitement of the 1960s, when our picture of matter’s make-up was shaken by the discovery of quarks and the strong force. First, though, they have the tough task of balancing the facts with the lure of finding something new. Bump into someone you know in a big city once and you are likely to be amazed by the coincidence, forgetting the 99 times you didn’t bump into them, says LHCb physicist Ulrik Egede of Imperial College London. Our human minds are primed to see causes for effects even where there might be none. “But at the same time you have to be excited because otherwise you can’t get anywhere in science.”

In 2008, a decades-long wait ended with the firing up of the Large Hadron Collider, the world's most muscular particle accelerator. Among its aims: to find the mysterious Higgs boson, the particle thought to give all others mass that would finally complete the "standard model" of particle physics.

Physicists have been pinning their hopes on the LHC providing new insights into reality’s makeup for almost a decade now. And we’ve been following the journey: The LHC fires up



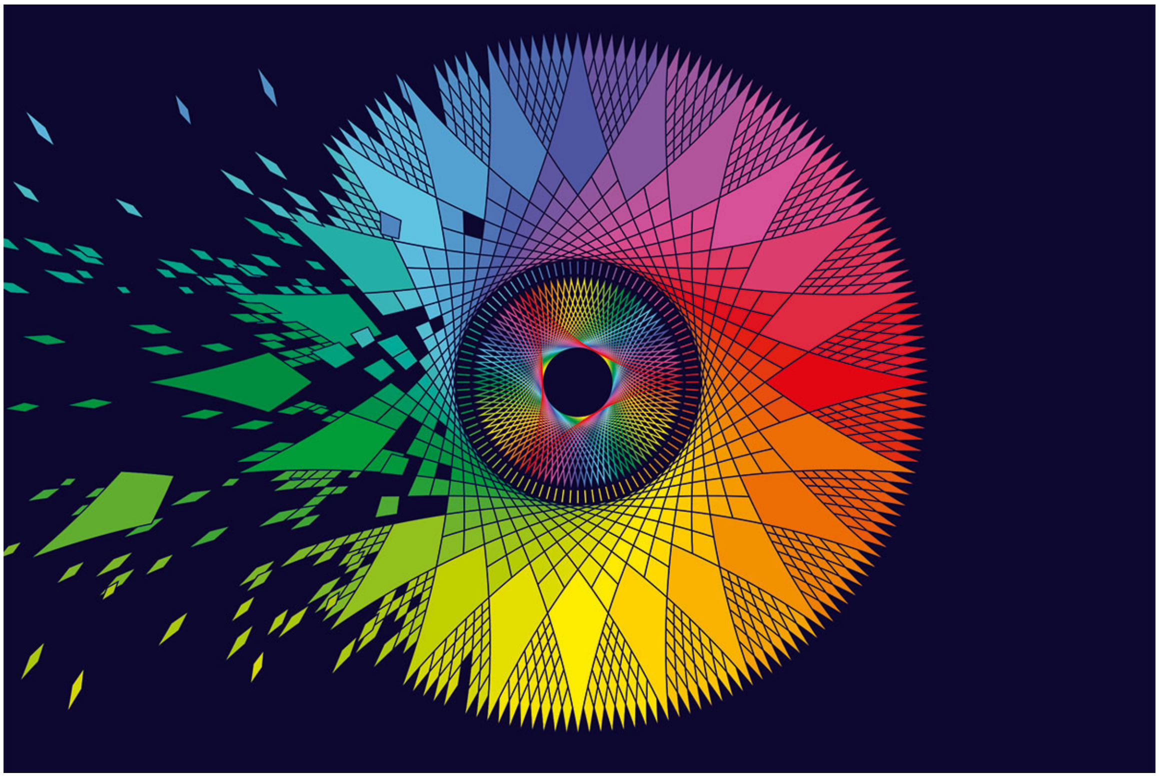
(Image: CERN)



(Image: CERN)

What it's really looking for

The Higgs would be nothing, though, compared with finding hints of a new and better theory of reality. Many hopes were pinned on supersymmetry, which predicted new particles to solve problems such as the identity of dark matter and paints a picture of nature more harmonious than the standard model.



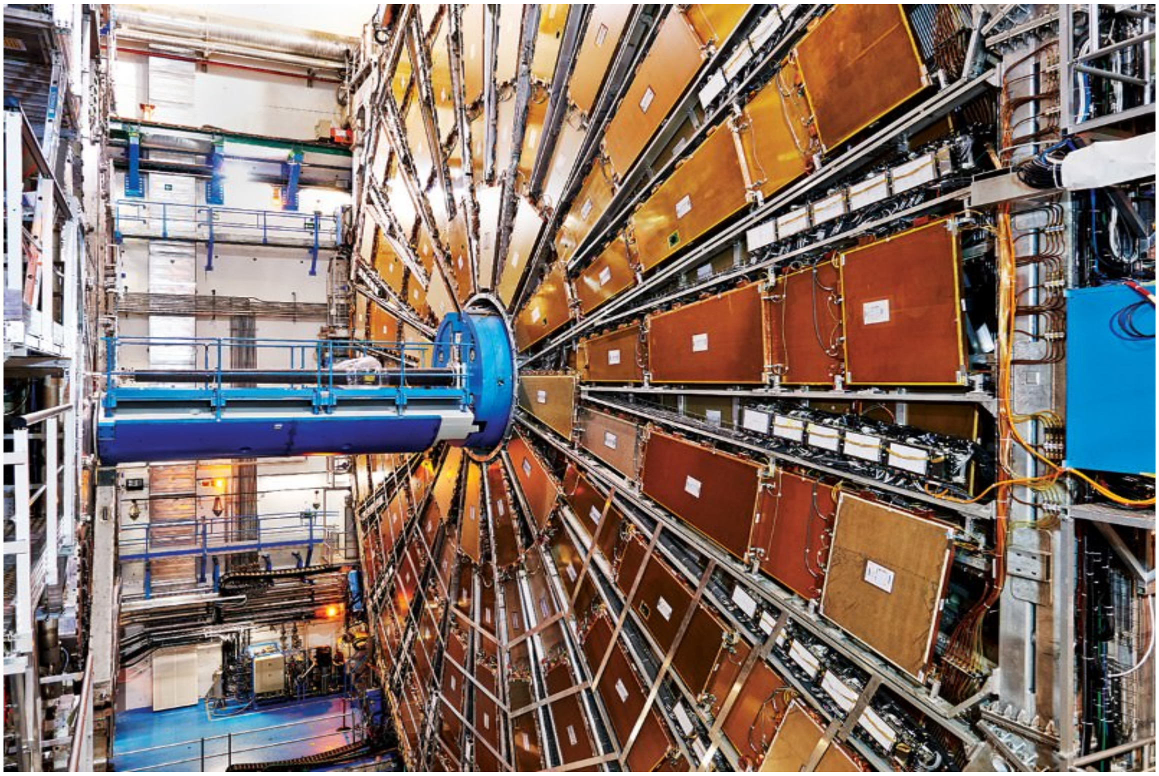
(Image: Stuart Daly)

Search for supersymmetry

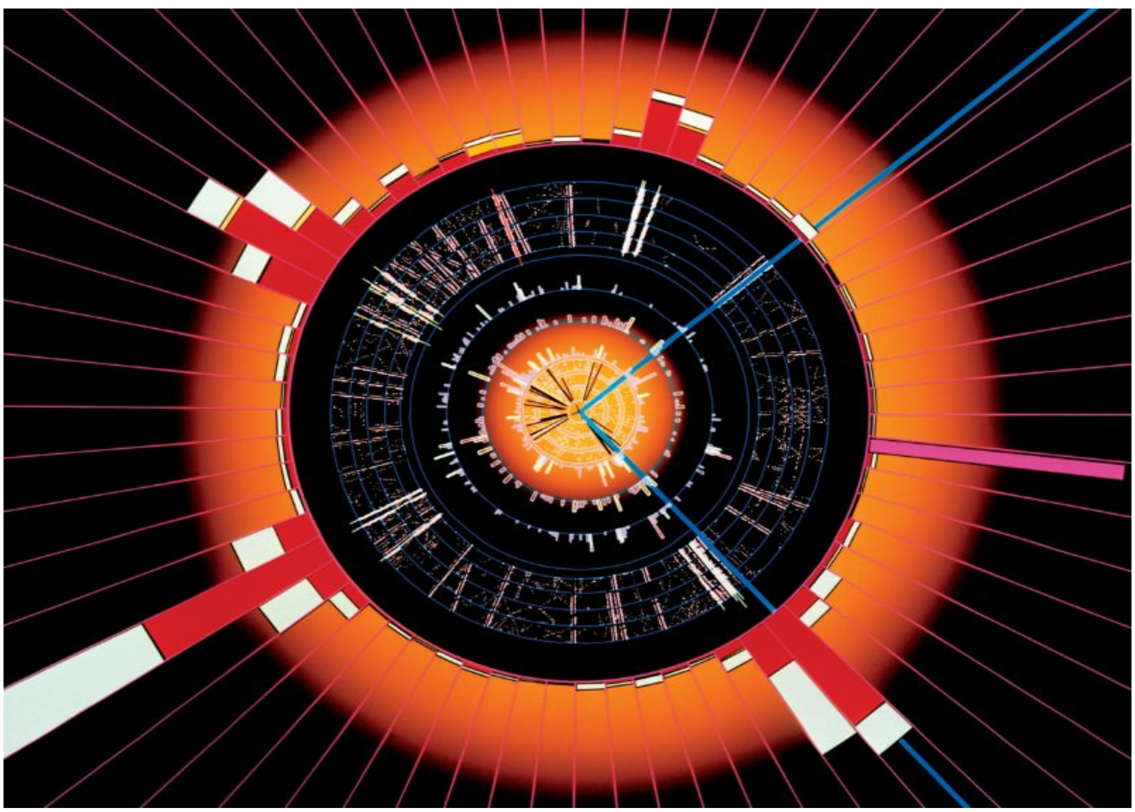
By 2011, the LHC had produced tantalising hints of the Higgs – but worryingly, not a peep of anything new. Physicists were getting nervous.

LHC gets an upgrade

In its first few years, the LHC was only smashing particles at half the energy it potentially could. Physicists' best hope was that the upgraded machine, switched on in 2015, would finally have the oomph to make a breakthrough.



(Image: Enrico Sacchetti)



(Image: Fermilab/SPL)

The Higgs discovery

The discovery of the Higgs, eventually confirmed in July 2012, only compounded the problem. The standard model was complete – with no indication of how to progress beyond it.

Shadows of something big

Situated between the ATLAS and CMS detectors around the Large Hadron Collider's 27-kilometre underground ring is a third experiment, LHCb. Unlike its larger cousins, which search for new particles by measuring debris from their decay, LHCb makes precise measurements of the decays of composite particles called B mesons, comparing them with predictions from the standard model of particle physics.

Hints of a couple of deviations have been hanging around for a while. One is in the rate at which B mesons disintegrate into lighter K mesons and a pair of muons, heavier cousins of electrons. Others concern the rates at which B mesons decay into electrons, muons and a third, heavier type of particle, tau leptons. The standard model says all three decay rates should all be the same – but LHCb measurements seems to indicate deviations from the standard model, although the degree of statistical significance varies.

Ethereal dance

None is significant enough to say something is definitely amiss – and yet the feeling is that the whole might be more than the sum of its parts. "We've seen things come and go in the past, but what is interesting now is that we have all these anomalies together," says LHCb's Ulrik Egede of Imperial College London. "People are getting excited that there are multiple effects that might be related."

If these are real effects, the likelihood is that they are down to the influence of undiscovered massive particles participating in the ethereal quantum dance of the subatomic world. That might appear to tie in well with the anomalies that have recently popped up at ATLAS and CMS, which provide more direct evidence for a new particle. But according to LHCb, the unseen ghost would have a spin of 1 – about the only thing that the ATLAS and CMS results definitively rule out (see main story). ■

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About Brillouin Energy

Brillouin Energy is a clean-technology company based in Berkeley, California, which is developing, in collaboration with Stanford Research International (SRI), an ultra-clean, low-cost, renewable energy technology that is capable of producing commercially useful amounts of thermal energy from LENR.

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