EXOTIC FOUR-QUARK PARTICLE SPOTTED AT LARGE HADRON COLLIDER

Rare tetraquark could help physicists to test theories about strong nuclear force.

By Davide Castelvecchi

The Large Hadron Collider (LHC) is also a big hadron discoverer. The atom smasher near Geneva, Switzerland, is famous for demonstrating the existence of the Higgs boson in 2012, a discovery that slotted into place the final keystone of the current classification of elementary particles. But the LHC has also netted dozens of the non-elementary particles called hadrons – those that, like protons and neutrons, are made of quarks.

The latest hadron made its debut at the virtual meeting of the European Physical Society on 29 July, when particle physicist Ivan Polyakov at Syracuse University in New York unveiled a previously unknown exotic hadron made of four quarks. This brought the LHC's hadron bounty up to 62 (see 'Particle discoveries'), according to a tally kept by Patrick Koppenburg, a particle physicist with Nikhef, the Dutch National Institute for Subatomic Physics in Amsterdam. "These are all world firsts," says Koppenburg, who is based at CERN, the European particle-physics laboratory that hosts the LHC.

The established pantheon of particles, called the standard model, describes the basic building blocks of matter and the fundamental forces that act on them. It includes six flavours of quark, their six antimatter counterparts and several other elementary particles, including electrons and photons. The standard model also includes rules for how quarks form composite particles called hadrons. The quarks are held together by the strong nuclear force, one of the four fundamental forces. The two most common quarks in nature are called 'up' and 'down'; their possible combinations include neutrons (one up and two downs) and protons (two ups and one down).

Protons are the only hadrons known to be stable in isolation – neutrons are stable only when they are incorporated into atomic nuclei. All other hadrons form only fleetingly, from the collision of other particles, and decay in a fraction of a second. So the LHC creates new kinds of hadron by causing high-energy, head-on collisions between protons.

Quark quartet

Most of the LHC's new hadron types have been spotted by LHCb, one of the four giant detectors in the 27-kilometre-long circular tunnel that holds the LHC, and the particle announced by Polyakov was no exception. Sifting through data on the debris from proton collisions, Polyakov and his collaborator Vanya Belyaev at the Institute for Theoretical and Experimental Physics in Moscow found the expected signature of a 'tetraquark' – a four-quark hadron – called T_{cc}^{+}.

Tetraquarks are extremely unusual: most known hadrons are made up of either two or three quarks. The first tetraquark was spotted at the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan, in 2003, and LHCb has seen several more. But the new one is an oddity. Previous tetraquarks were likely to be pairs of ordinary quark doublets attached to each other like atoms in a molecule, but theoretical physicist Marek Karliner thinks that the latest one could be a genuine, tightly bound quadruplet. "It's the first of its kind," says Karliner, who is at Tel Aviv University in Israel and helped to predict the existence of a particle with the same properties as T_{cc}^{+} in 2017 (M. Karliner and J. L. Rosner *Phys. Rev. Lett.* **119**, 202001; 2017).

In nature, tetraquarks probably existed only during the first instants of the Universe, when all matter was compressed in an extremely tight space, says Belyaev. But creating them anew helps physicists to test their theories about how particles interact through the strong nuclear force.

The data revealed the new particle's properties so precisely that Belyaev was stunned. "My first reaction was: it's my mistake," he says. For example, the particle's mass, which is around 4 times that of a proton, was nailed with a margin of error nearly 3,000 times better than in the discovery of the Higgs boson. Belyaev adds that T_{cc}^{+} could have been discovered in data from the early years of the LHC, but he and his LHCb colleagues didn't find it until now because they had a long list of other particles to look for.

Limitless possibilities

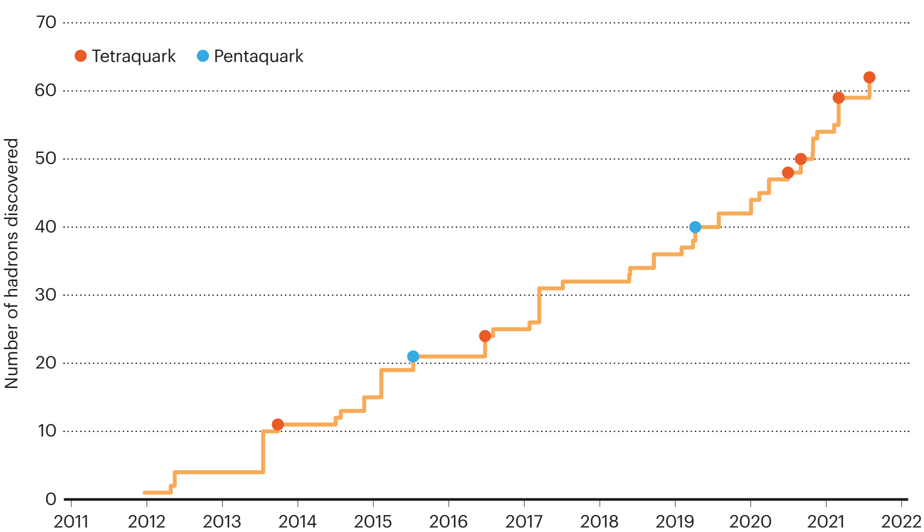
The search for new hadrons will go on. Dozens of combinations of quarks can give rise to hadrons. Karliner says that there are 50 possible 2-quark hadrons, all but one of which have been observed, and 75 possible quark triplets (and as many triplets of antiquarks), of which nearly 50 have been seen.

Moreover, for each combination of quarks, there is an almost limitless number of possible heavier 'excited states' – distinguished by, for example, how fast they spin – and each is classified as a separate particle. Many have been found experimentally, and in fact the majority of particles in Koppenburg's catalogue are excited states. "Who knows how many other states are there just hidden in plain sight, sitting in the data on a laptop," says Koppenburg, who, like Polyakov and Belyaev, is a member of the LHCb collaboration.

But he also wonders whether all these discoveries should be treated as discrete particles. "I tend to be increasingly convinced that we need a better definition of what a particle is," he says.

PARTICLE DISCOVERIES

The Large Hadron Collider discovered an elementary particle, the Higgs boson, in 2012. But it has also discovered 62 non-elementary particles, called hadrons, so far. These include tetraquarks and pentaquarks — particles made of four and five quarks, respectively.



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