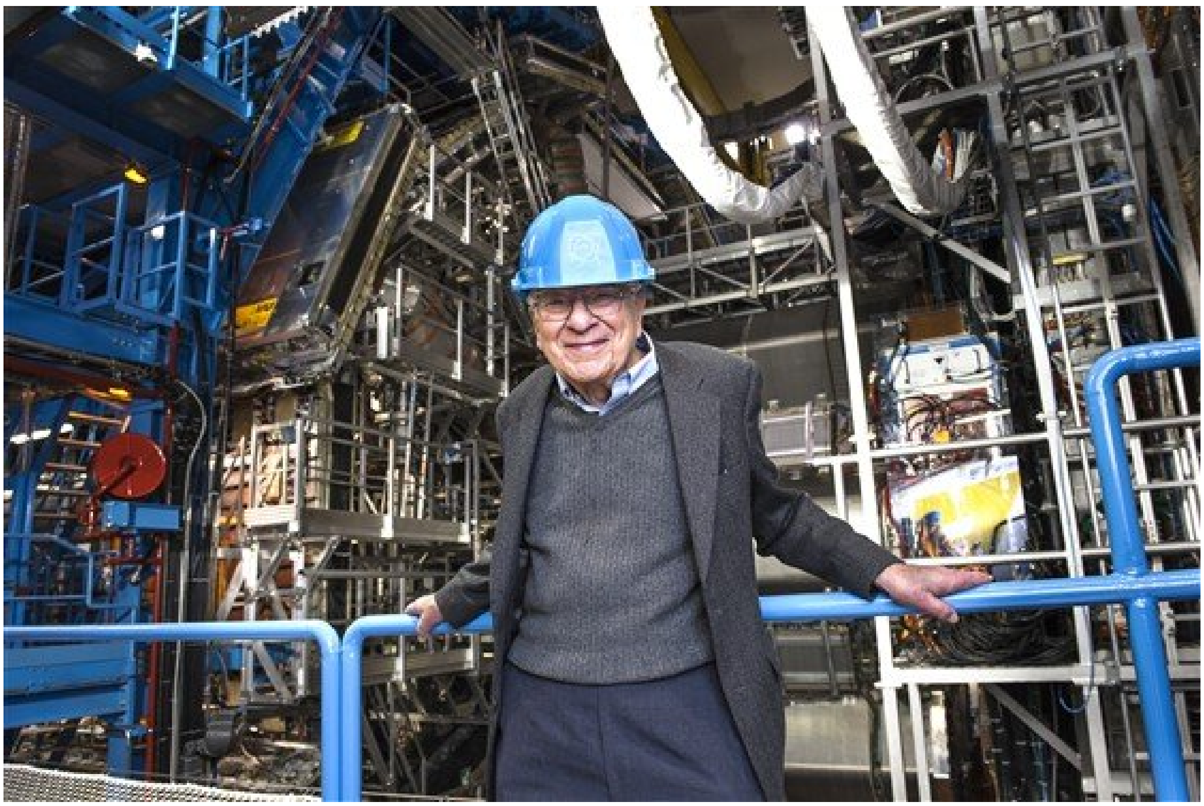
The Large Hadron Collider's official tally: 59 new hadrons and counting

March 3 2021, by Piotr Traczyk

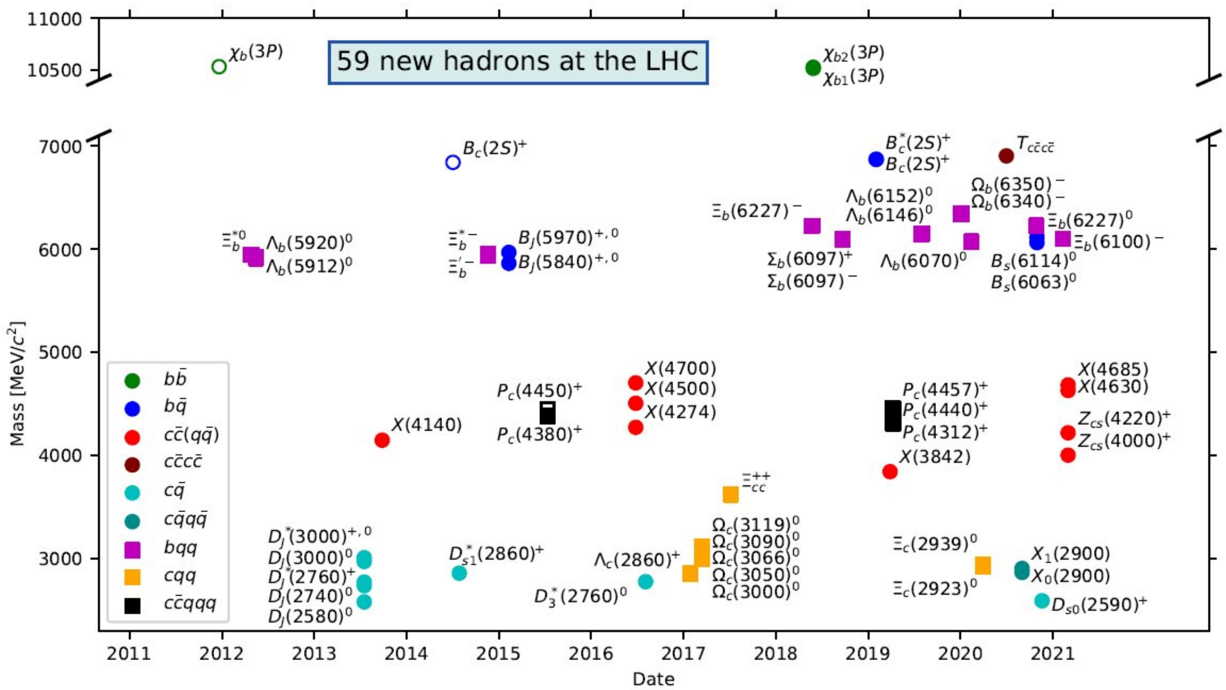


Professor Murray Gell-Mann in the ATLAS cavern in 2012. Gell-Mann proposed the quark model and the name "quark" in 1964 and received the Nobel Prize in Physics in 1969. Credit: CERN

How many new particles has the LHC discovered? The most widely known discovery is of course that of the Higgs boson. Less well known is the fact that, over the past 10 years, the LHC experiments have also found more than 50 new particles called hadrons. Coincidentally, the number 50 appears in the context of hadrons twice, as 2021 marks the 50th anniversary of hadron colliders: on 27 January 1971, two beams of protons collided for the first time in CERN's Intersecting Storage Rings accelerator, making it the first accelerator in history to produce collisions between two counter-rotating beams of hadrons.

So what are these new hadrons, which number 59 in total? Let's start at the beginning: hadrons are not elementary particles—physicists have known that since 1964, when Murray Gell-Mann and George Zweig independently proposed what is known today as the quark model. This model established hadrons as composite particles made out of new types of elementary particles named quarks. But, in the same way as researchers are still discovering new isotopes more than 150 years after Dmitri Mendeleev established the periodic table, studies of possible composite states formed by quarks are still an active field in particle physics.

The reason for this lies with quantum chromodynamics, or QCD, the theory describing the strong interaction that holds quarks together inside hadrons. This interaction has several curious features, including the fact that the strength of the interaction does not diminish with distance, leading to a property called color confinement, which forbids the existence of free quarks outside of hadrons. These features make this theory mathematically very challenging; in fact, color confinement itself has not been proven analytically to this date. And we still have no way to predict exactly which combinations of quarks can form hadrons.



The full list of new hadrons found at the LHC, organised by year of discovery (horizontal axis) and particle mass (vertical axis). The colours and shapes denote the quark content of these states. Credit: LHCb/CERN

What do we know about hadrons then? Back in the 1960s, there were already more than 100 known varieties of hadrons, which were discovered in accelerator and cosmic-ray experiments. The quark model allowed physicists to describe the whole "zoo" as different composite states of just three different quarks: up, down and strange. All known hadrons could be described as either consisting of three quarks (forming baryons) or as quark–antiquark pairs (forming mesons). But the theory also predicted other possible quark arrangements. Already in Gell-Mann's original 1964 paper on quarks, the notion of particles containing more than three quarks appeared as a possibility. Today we know that such particles do exist, but it took several decades to confirm in experiments the first four-quark and five-quark hadrons, or tetraquarks and pentaquarks.

A full list of the 59 new hadrons found at the LHC is shown in the image below. Of these particles, some are pentaquarks, some are tetraquarks and some are new higher-energy (excited) states of baryons and mesons. The discovery of these new particles, together with measurements of their properties, continues to provide important information for testing the limits of the quark model. This in turn enables researchers to further their understanding of the strong interaction, to verify theoretical predictions and to tune models. This is especially important for the research done at the Large Hadron Collider, since the strong interaction is responsible for the vast majority of what happens when hadrons collide. The better we can understand the strong interaction, the more precisely we can model these collisions and the better are our chances of seeing small deviations from expectations that could hint at possible new physics phenomena.

The hadron discoveries from the LHC experiments keep coming, mainly from LHCb, which is particularly suited to studying particles containing heavy quarks. The first hadron discovered at the LHC, $\chi b(3P)$, was discovered by ATLAS, and the most recent ones include a new excited beauty strange baryon observed by CMS and four tetraquarks detected by LHCb.

Provided by CERN