Researchers discover first 'open-charm' tetraquark

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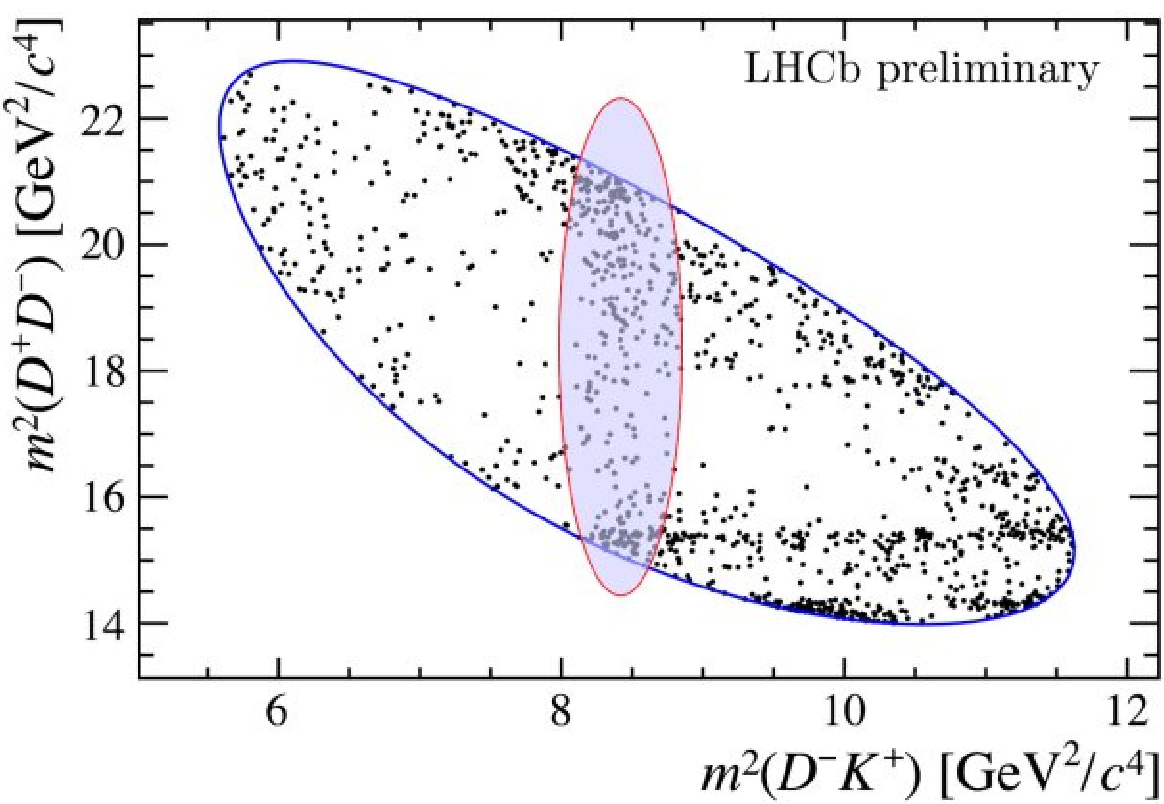

The band associated with the new tetraquark transforming into a D^- and a K^+ at a mass of 2.9 GeVc^2. Credit: HCb Collaboration/CERN

The LHCb experiment at CERN has developed a penchant for finding exotic combinations of quarks, the elementary particles that come together to give us composite particles such as the more familiar proton and neutron. In particular, LHCb has observed several tetraquarks, which, as the name suggests, are made of four quarks (or rather two quarks and two antiquarks). Observing these unusual particles helps scientists advance our knowledge of the strong force, one of the four known fundamental forces in the universe. At a CERN seminar held virtually on 12 August, LHCb announced the first signs of an entirely new kind of tetraquark with a mass of 2.9 GeV/c^2: the first such particle with only one charm quark.

First predicted to exist in 1964, scientists have observed six kinds of quarks (and their antiquark counterparts) in the laboratory: up, down, charm, strange, top and bottom. Since quarks cannot exist freely, they group to form composite particles: three quarks or three antiquarks form "baryons" like the proton, while a quark and an antiquark form "mesons."

The LHCb detector at the Large Hadron Collider (LHC) is devoted to the study of B mesons, which contain either a bottom or an antibottom. Shortly after being produced in proton–proton collisions at the LHC, these heavy mesons transform—or "decay"—into a variety of lighter particles, which may undergo further transformations themselves. LHCb scientists observed signs of the new tetraquark in one such decay, in which the positively charged B meson transforms into a positive D meson, a negative D meson and a positive kaon: $B^+ \rightarrow D^+ D^- K^+$. In total, they studied around 1300 candidates for this particular transformation in all the data the LHCb detector has recorded so far.

The well-established quark model predicts that some of the D^+D^- pairs in this transformation could be the result of intermediate particles—such as the $\psi(3770)$ meson—that only manifest momentarily: $B^+ \rightarrow \psi(3770) K^+ \rightarrow D^+ D^- K^+$. However, theory does not predict meson-like intermediaries resulting in a D^-K^+ pair. LHCb were therefore surprised to see a clear band in their data corresponding to an intermediate state transforming into a D^-K^+ pair at a mass of around 2.9 GeV/c^2, or around three times the mass of a proton.

The data have been interpreted as the first sign of a new exotic state of four quarks: an anticharm, an up, a down and an antistrange ($\bar{c}ud\bar{s}$). All previous tetraquark-like states observed by LHCb always had a charm–anticharm pair, resulting in net-zero "charm flavor." The newly observed state is the first time a tetraquark containing a sole charm has been seen, which has been dubbed an "open-charm" tetraquark.

"When we first saw the excess in our data, we thought there was a mistake," says Dan Johnson, who led the LHCb analysis. "After years of analyzing the data, we accepted that there really is something surprising!"

Why is this important? It so happens that the jury is still out as to what a tetraquark really is. Some theoretical models favor the notion that tetraquarks are pairs of distinct mesons bound together temporarily as a "molecule," while other models prefer to think of them as a single cohesive unit of four particles. Identifying new kinds of tetraquarks and measuring their properties—such as their quantum spin (their intrinsic spatial orientation) and their parity (how they appear under a mirror-like transformation) – will help paint a clearer picture of these exotic inhabitants of the subatomic domain. Johnson adds: "This discovery will also allow us to stress-test our theories in an entirely new domain."

While LHCb's observation is an important first step, more data will be needed to verify the nature of the structure observed in the B^+ decay. The LHCb collaboration will also anticipate independent verification of their discovery from other dedicated B-physics experiments such as Belle II. Meanwhile, the LHC continues to provide new and exciting results for experimentalists and theorists alike to dig into.

More information: indico.cern.ch/event/900975/at … ug-11_DanJohnson.pdf

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