UPDATES

Matter–antimatter asymmetry is observed in baryon decay

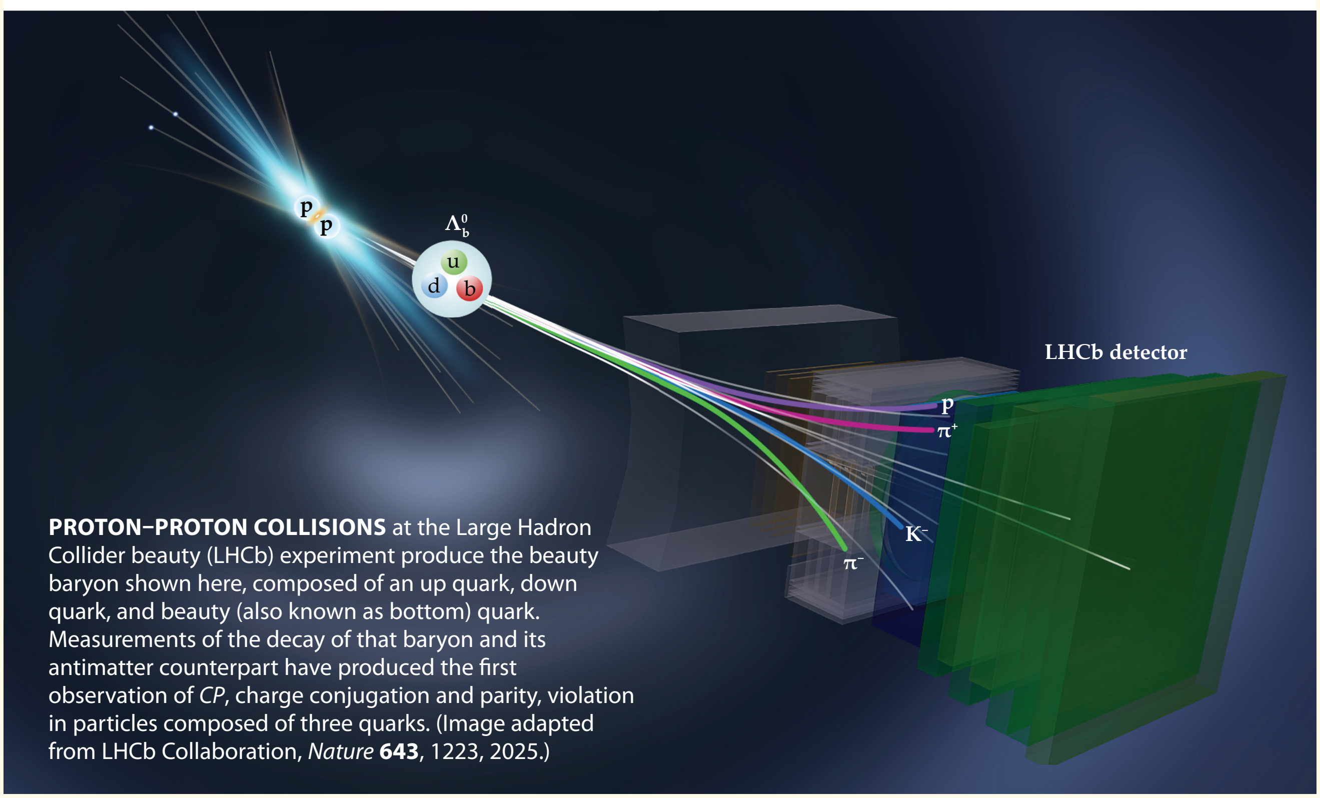
Previous detections of *CP* violation had been limited to the decay of quark–antiquark pairs. But it's baryons—particles composed of three quarks—that make up the observable universe.

Why is there matter in the universe? Matter and antimatter annihilate one another, and according to theory, equal amounts of each were produced in the Big Bang. If matter and antimatter exhibited perfectly symmetric and opposite behavior, everything would have been annihilated, and we wouldn't live in the matter-filled universe we see today. Somehow, for every billion matter–antimatter pairs that annihilated in the early universe, one particle of matter survived. The source of that asymmetry, though, is yet to be fully understood. Now, the Large Hadron Collider beauty (LHCb) collaboration at CERN has made the first observation of asymmetry in the decay rate of a baryon—a subatomic particle made of three quarks—and that of its antibaryon counterpart.

The first measurement of matter–antimatter asymmetry—specifically, the violation of *CP*, charge conjugation and parity, symmetry—in particle decays came in 1964 by James Cronin and Val Fitch. That detection and subsequent ones involved the decay of mesons, short-lived particles made up of a quark and an antiquark (see Physics Today, August 2019, page 14). Because they are generally lighter and less complex than baryons, mesons take less energy to make, and the theoretical calculations are easier to do. Extending *CP* violation searches to baryons is an important step because the observable universe is made of baryons: The protons and neutrons that make up atomic nuclei are baryons that are composed of up quarks and down quarks.

As its name suggests, the LHCb experiment was specifically designed to measure beauty (also known as bottom) quarks, which are known contributors to *CP* violation in meson decays (see Physics Today, September 2001, page 19). In the experiment, protons that are accelerated to relativistic speeds are smashed into each other about 40 million times per second. The collisions produce, among many things, beauty baryons—made of an up quark, a down quark, and a beauty quark—that quickly decay. Researchers focused on a beauty baryon decay channel that has four decay products: a proton, a kaon, and two pions, as shown in the figure.

It took tens of thousands of decay events, measured during two LHC runs



PROTON–PROTON COLLISIONS at the Large Hadron Collider beauty (LHCb) experiment produce the beauty baryon shown here, composed of an up quark, down quark, and beauty (also known as bottom) quark. Measurements of the decay of that baryon and its antimatter counterpart have produced the first observation of *CP*, charge conjugation and parity, violation in particles composed of three quarks. (Image adapted from LHCb Collaboration, *Nature* **643**, 1223, 2025.)

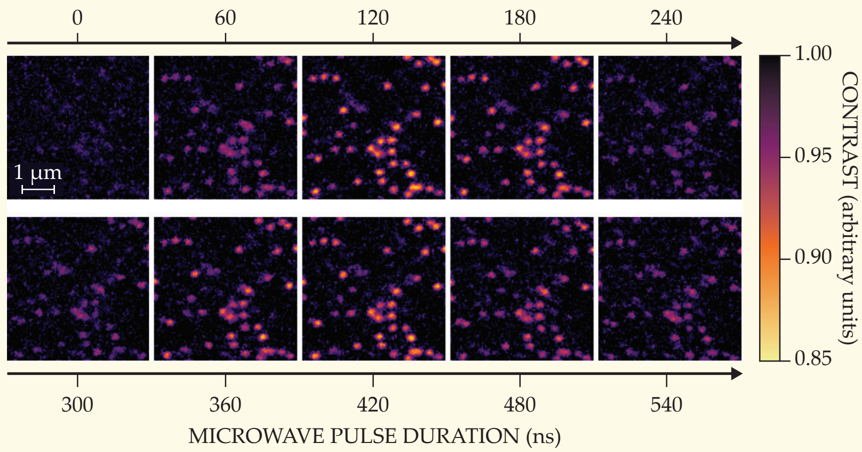
(at 7–8 TeV from 2011–12 and at 13 TeV from 2015–18), to home in on a reliable measure of *CP* violation in the baryons. Baryons and antibaryons are produced at slightly different rates, and the rate difference was corrected for in the analysis. Because the detector is made of matter, it also has a higher detection efficiency, which was accounted for as well, for matter than for antimatter. The researchers found that the beauty baryon decay rate was higher than that of its antibaryon counterpart: The relative difference of about 2.5% agrees with, and provides a more precise number than, existing theory.

Don Lincoln, a senior scientist at Fermilab and member of the Compact Muon Solenoid (CMS) collaboration, says he expects that researchers at other CERN experiments, such as CMS or ATLAS, will look to their own data to validate the result. Though the latest observation hasn't solved the mystery of matter–antimatter asymmetry, it does offer clues for where to look. Another next step will be to focus on intermediate processes in the baryon decay chain for which the observed *CP* violation is even greater, as high as 5.4%, than it is for the entire decay chain. (LHCb Collaboration, *Nature* **643**, 1223, 2025.)

Laura Fattaruso

Diamond-defect clusters are measured with speed and precision

The improvement in measuring nitrogen–vacancy quantum sensors could make them more useful for observing correlated condensed matter, biological systems, and more.



THE BRIGHT SPOTS in each panel show fluorescing nitrogen–vacancy (NV) centers over time. Two research groups each controlled dozens of NV centers in parallel and obtained spatially and temporally precise images of them with high-sensitivity cameras. (Image adapted from K.-H. Cheng et al., *Phys. Rev. X* **15**, 031014, 2025.)

In a crystal of diamond, the combination of a nitrogen atom and a nearby empty lattice site forms a nitrogen–vacancy (NV) center. NV centers are point defects that behave like tiny, atomic-scale magnetometers. Because of their sensitivity to magnetic fields, electric fields, temperature, and even strain, NV centers are useful quantum sensors for measuring surface chemistry, subcellular temperatures, and various other properties. (See the article by Lilian Childress, Ronald Walsworth, and Mikhail Lukin, Physics Today, October 2014, page 38.)

Optical measurements of an NV center's electronic and magnetic states offer nanoscale spatial resolution, but they show what's happening at only one location. Individual NV centers can be measured sequentially to cover a larger area, but that approach is slow and can't show what's happening in multiple locations at the same time. Alternatively, groups of many NV centers are measurable simultaneously, but signal averaging limits the spatial resolution.

Now researchers have combined the imaging benefits of single and multiple NV centers in one experimental platform, without each approach's limitations. Two independent groups—one led by Shimon Kolkowitz of the University of California, Berkeley, and the other by Nathalie de Leon of Princeton University—controlled and measured dozens of NV centers simultaneously. The parallel observations from multiple NV centers have the point-like precision of previous measurements of single NV centers.

In neutral-atom quantum computing, dozens or hundreds of qubits are observed simultaneously. To make the observations, researchers have recently developed arrays of optical tweezers, in which each tweezer traps a single atom or molecule. Then a high-sensitivity camera can image the atoms or molecules in parallel by precisely counting the photons generated by the molecules' or atoms' fluorescence. Both Kolkowitz and de Leon, working with their collaborators, reasoned that a similar approach could work in diamond for NV centers. The two groups used the same high-sensitivity cameras for NV center readout and then added specialized optical instrumentation that controls the NV centers and manipulates their charge and spin states.

The speedy, simultaneous, and high-resolution measurements of dozens to hundreds of NV centers allow for the study of how one NV center's state may be correlated with another's. The investigation of temporally and spatially coherent fluctuations could be useful in studying noise or other stochastic properties in superconducting materials, for example. The new capability could also be useful for observing single biological molecules *in vivo* and measuring their chemical and dynamical interactions. (M. Cambria et al., *Phys. Rev. X* **15**, 031015, 2025; K.-H. Cheng et al., *Phys. Rev. X* **15**, 031014, 2025.)

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