What is the universe’s antimatter mystery? | Explained

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Updated – July 17, 2025 11:03 am IST – Chennai

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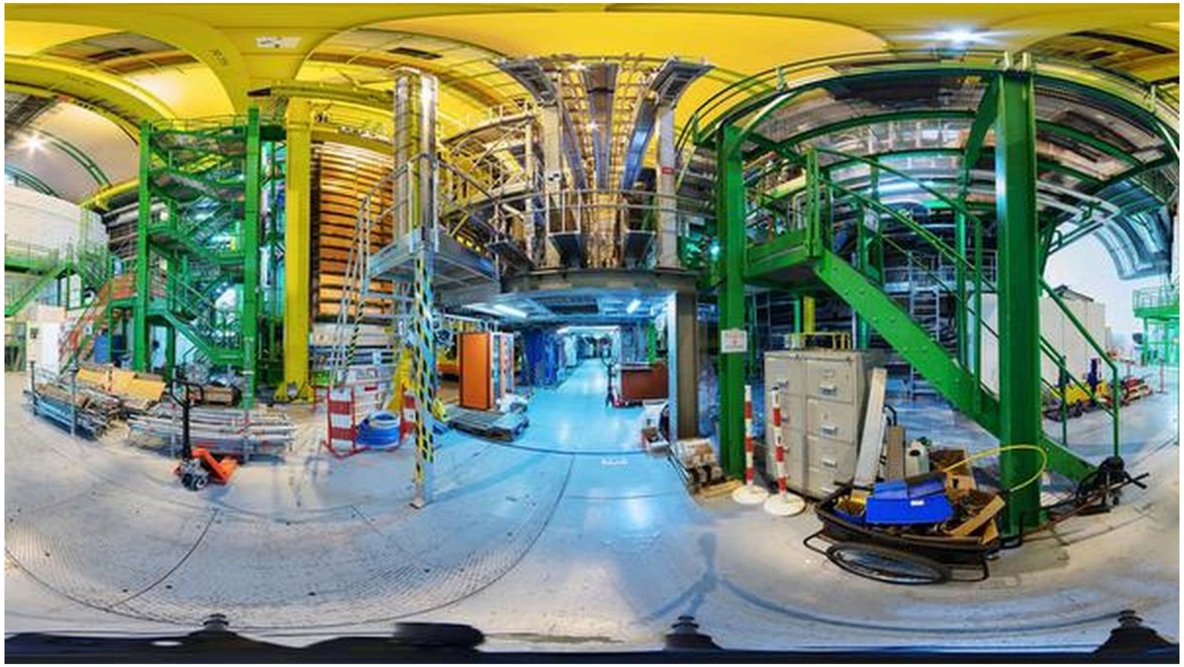

The LHCb detector at the Large Hadron Collider is designed primarily to study the decay of particles containing bottom quarks and and charm quarks. | Photo Credit: CERN

The story so far: On July 16, an international collaboration of scientists based in Europe reported that they had, for the first time, observed that the matter and antimatter versions of a type of subatomic particle called a baryon decay at different rates. The result revealed a new difference in their behavior that may help explain why the universe is made mostly of matter.

Why is the universe made mostly of matter?

The Big Bang 13.8 billion years ago should have created equal amounts of matter and antimatter. But when we look around, we see a universe filled with matter — stars, planets, people — while antimatter is almost nowhere to be found. This lopsidedness is one of the biggest unsolved mysteries in science. Physicists believe subtle differences in how matter and antimatter behave, especially something called CP violation, could be a major clue to understanding this imbalance.

CP stands for charge conjugation (C) and parity (P). Charge conjugation means swapping a particle for its antiparticle (which has the opposite electric charge) and parity means flipping left and right, like looking in a mirror. If the universe treated matter and antimatter exactly the same, even after a particle swap and a mirror flip we'd say CP symmetry holds. But experiments have shown that this symmetry can be broken. This is called CP violation.

CP violation is crucial because it’s one of the conditions necessary for a universe to end up with more matter than antimatter.

Has CP violation been seen before?

“While CP violation had previously been observed in mesons, particles made of quark-antiquark pairs, it had never before been seen in baryons, three-quark particles such as protons and neutrons that constitute the majority of visible matter in the universe,” Indian Institute of Science, Bengaluru, experimental high-energy physicist Minakshi Nayak told *The Hindu*.

The new result is the first to show CP violation in baryon decays, specifically in a particle called the Λb^0 baryon.

The Λb^0 baryon is a heavy subatomic particle made of three quarks: an up quark, a down quark, and a bottom quark. Its antiparticle, the Λb^0-bar, has the corresponding antiquarks. In the new study, scientists studied how the Λb^0 baryon decays into a proton, a negatively charged kaon, and two pions (one positive, one negative). They also looked at the same decay for the antiparticle but with opposite charges.

How’re particle decays observed?

The experiment took place at the Large Hadron Collider (LHC) in Europe, and data for its analysis was collected by the machine’s LHCb detector. Over several years, the team collected data from billions of proton-proton collisions, which occasionally produced Λb^0 and Λb^0-bar baryons. Sophisticated algorithms and machine learning techniques then helped the researchers pick out the rare events where these baryons decayed into the specific set of particles they were looking for.

The key is to compare how often the Λb^0 baryon decays into the chosen set of particles with how often its antiparticle does. If the laws of physics treated matter and antimatter identically, these rates would be the same. Any difference, after accounting for possible experimental biases, would be evidence of CP violation. The researchers measured a quantity called the CP asymmetry, which is the difference in decay rates divided by the total number of decays.

The researchers were very careful about identifying and removing other effects that mimic CP violation. For example, the LHC might produce slightly more Λb^0 baryons than Λb^0-bar antibaryons or the LHCb detector might be better at spotting one over the other. To correct for these effects, the team used a control channel, a similar decay where no CP violation is expected. By measuring any asymmetry in this control channel, they could subtract these nuisance effects and isolate the true CP violation signal.

What was the main result?

The researchers found a clear difference in the decay rates: the CP asymmetry was measured to be about 2.45%, with a very small uncertainty.

"Statistically, the measured CP asymmetry deviates from zero by 5.2 standard deviations, surpassing the 5-sigma threshold required to claim a discovery in particle physics," Dr. Nayak said. "This historic discovery holds the potential to deepen our understanding of the matter-antimatter imbalance".

It's a big step forward, although the amount of CP violation observed is still too small to account for the large imbalance between matter and antimatter in the universe.

Scientists can now look for CP violation in other baryon decays and try to measure it more precisely. Theoretically, they can work to understand the complex dynamics that produce these effects and search for signs of previously undiscovered particles and forces, in a bid to plug the gaps in our knowledge of our universe. The ultimate goal is to find out whether there are additional sources of CP violation that could explain matter's dominance.

The finding also addresses a fundamental question about our existence: why is there something rather than nothing? Every atom in your body, every star in the sky, exists because matter somehow won out over antimatter. By uncovering the subtle differences in how nature treats matter and antimatter, scientists are piecing together the story of how our universe came to be the way it is.

Published – July 17, 2025 11:00 am IST