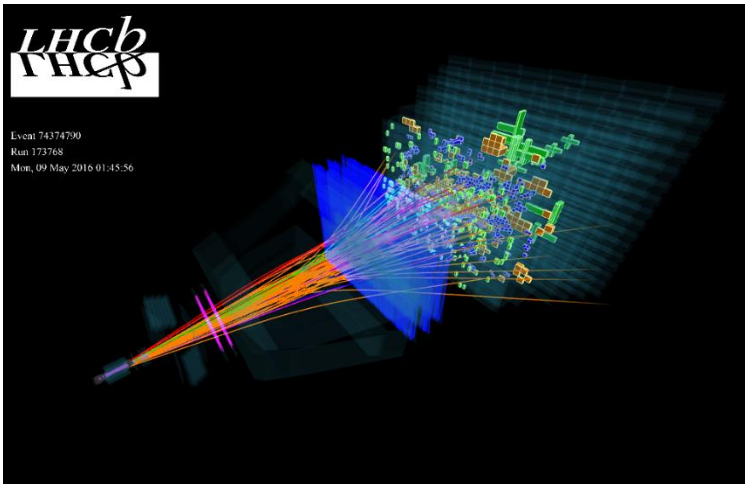
International Particle
Physics Outreach Group

PASSPORT TO THE INFINITE

Understanding Antimatter

Where has all the antimatter gone, now almost completely absent from our Universe? To address the question, antimatter is created in laboratories during particle collisions and studied by experiments such as LHCb.



Credit: CERN

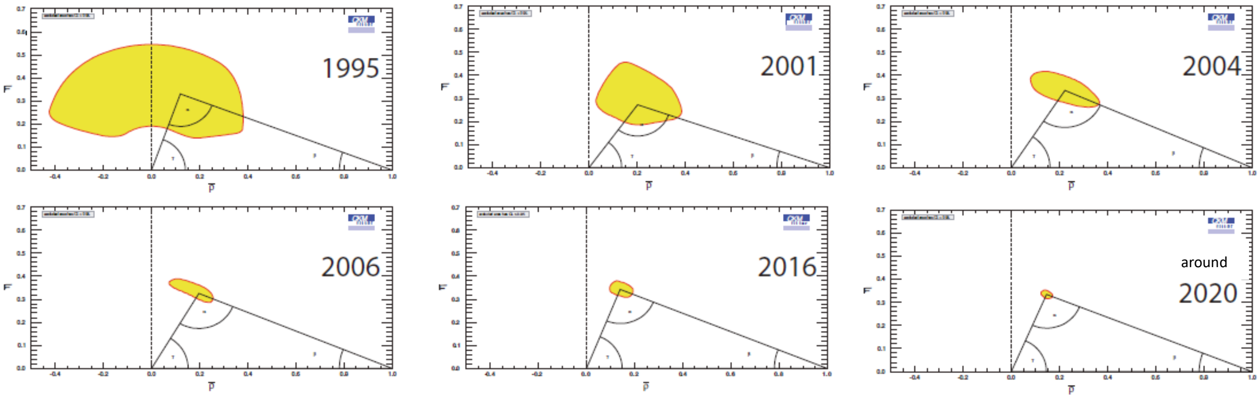
Simulation of a proton-proton event in the LHCb detector

The image shows the different layers of the detector which enable physicists to identify and measure the properties of the various particles. Each line represents the path of a charged particle.

During the Big Bang, matter and antimatter were created in equal quantities, but the latter has almost entirely vanished from our Universe. To uncover the yet unknown phenomena responsible for this asymmetry, experiments focus on studying antimatter. One key investigation area involves B mesons and their antiparticles, denoted $\bar{B}$. B mesons consist of a b quark (the second heaviest quark, roughly five times the mass of a proton) paired with an antiquark of another, lighter type. By comparing the decays of B mesons and $\bar{B}$ mesons, which produce lighter particles, physicists can look for differences related to a particle-antiparticle asymmetry.

BaBar (California) and Belle (Japan) experiments recorded billions of electron-positron collisions up until 2008. Their results brilliantly confirmed the validity of the model of six quarks grouped into three families, which predicts particle-antiparticle asymmetry. The 2008 Nobel Prize in Physics was awarded to Japanese scientists Kobayashi and Maskawa, who ‘invented’ this theory along with the Italian physicist Cabibbo. This further confirmation of the Standard Model’s validity was just one step: the related asymmetry is far too weak to explain the disappearance of antimatter in the first moments of the Universe. Other mechanisms must have been at work, which new experiments are trying to identify.

In Japan, the Belle-II experiment took over from Belle in 2018 and plans to record 50 times more electron-positron collisions. At CERN,



Credit: CERN

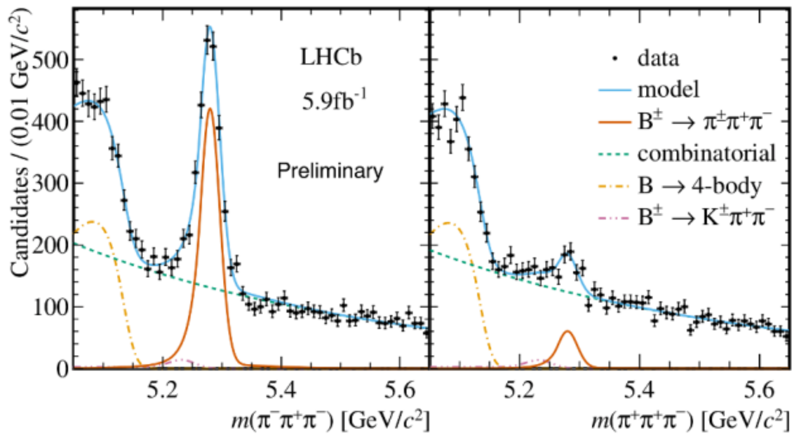
LHCb is the LHC experiment that has been studying B mesons produced during proton-proton collisions since 2010, using an asymmetric detector and an original filtering system. In both cases, the number of B mesons produced is unparalleled. In particular, LHCb has revealed significant asymmetries in a series of specific decay channels.

None of the asymmetries measured so far are sufficient to explain what happened in the early stage of the Universe, and the research spectrum has now been extended to include neutrinos. However, precise measurements of the parameters in the Cabibbo-Kobayashi-Maskawa (CKM) model remain crucial for understanding this aspect of the Standard Model, and progress in this area has been remarkable.

Researchers are also exploring very rare B meson decays, which may be more sensitive to new physics beyond the Standard Model. This approach is also being pursued by NA62, another CERN experiment in which high-energy protons collide with a beryllium target to produce billions of K^+ mesons, consisting of an $\bar{s}$ antiquark paired with an up quark. A handful of extremely rare decays could be significantly affected by the new physics.

Our understanding of matter-antimatter asymmetry

These figures illustrate the evolution of measurements of two of the four parameters describing the matter-antimatter asymmetry in the Standard Model. More specifically, the height of the triangle quantifies the importance of this asymmetry. The apex of the triangle is located in the yellow area, favoured by theoretical predictions and experimental results. This area shrinks over the years, while remaining 'centred' in the same place. The last figure was a simulation exercise to anticipate possible progress around 2020 with the results of LHCb and Belle-II experiments. In 2024, expected results are in and the quest continues.



Credit: CERN

Example of asymmetry in B meson decays

While studying in detail the decay properties of the B^+ and B^- mesons, the LHCb collaboration presented this example in 2022: a clear signal from the B^- (left plot) and B^+ candidates (right plot) is visible as a peak in the events where 3 pions are selected. If there were perfect symmetry between particles and antiparticles in terms of decay, the two numbers would be identical, which is not the case here: the two red peaks are of different sizes.

Translated from 'Comprendre l'antimatière', Passeport pour les deux infinis, IN2P3/Dunod, https://pass2i.ijclab.in2p3.fr/ (French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG