THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

RADZIKOWSKIEGO 152
31-342 KRAKÓW, POLAND
SWITCHBOARD: +48 12 662 8000
DIRECTOR: +48 12 662 8200
FAX: +48 12 662 8458
www.ifj.edu.pl
press@ifj.edu.pl

Cracow, 9 February 2022

From matter to antimatter, to and fro – trillions of times a second

We think of matter and antimatter as being as opposite as fire and water. There are, however, particles that can behave as representatives once of the world of matter, once the world of antimatter. An international group of scientists working on experiments at the LHCb detector have reported their measurement of the extreme speed of oscillation of these sorts of particles between the two worlds.

Like a child on a swing, moving back and forth, there are particles that can change their properties many times with incredible speed, acting as representatives of the world of matter at one moment only to behave like antimatter in the next. Oscillations of particle properties between matter and antimatter are considered to be one of the most fascinating phenomena of quantum mechanics. In the case of the mesons known as B_s^0, these oscillations have been measured with unprecedented accuracy. The results of this unusual measurement were reported by a group of scientists carrying out experiments in the LHCb detector at the Large Hadron Collider. An article describing their work has appeared in *Nature Physics*.

"The first measurement of the B_s^0 meson oscillation was carried out back in 2006, as part of the CDF experiment at the US Fermilab laboratory. We have now managed to improve the accuracy of the original measurement by as much as two orders of magnitude!", says Dr. Agnieszka Dziurda from the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Cracow. Dr. Dziurda leads the international team of physicists who carried out this research.

The constituents of matter that make up the visible Universe are mainly up and down quarks, electrons and electron neutrinos. Inside the Standard Model, a complex theoretical tool that describes the world on atomic and subatomic scales, these particles are grouped into one generation. It is known that two other generations exist. Both contain particles with similar properties to the first generation, only that they become more and more massive in subsequent generations.

In the Standard Model, every particle of matter has its counterpart in the form of an antiparticle that differs mainly in the sign of its electric charge (in the case of electrically neutral neutrinos, other quantum properties are important). Quarks do not like loneliness and always combine with others into particles. The simplest of these are mesons, i.e. pairs made up of a quark and an antiquark (not necessarily of the same kind).

"Mesons may carry an electric charge, but they do not have to. Those devoid of electric charge, referred to as neutral, exhibit an intriguing feature – they oscillate between matter and antimatter forms. We focused on analysing the oscillation frequencies of neutral mesons B_s^0 containing a third-generation beauty quark b and a second-generation strange quark s," explains Dr. Dziurda.

As unstable particles, mesons decay quickly. It is no different with B_s^0 mesons, whose life in the experiment in question ended after a single picosecond (that's a fraction of a second with 12 zeros after the decimal point). During this time B_s^0 mesons covered a distance of about one centimetre and, as it turned out, they oscillated several times.

From a technical point of view, measuring a phenomenon of such high frequency proved to be extremely difficult. In particular, it required a deep understanding of the experimental techniques used in the detector, as these could have distorted the measurement. Only with this knowledge physicists were able to precisely reconstruct the trajectory of the recorded mesons and identify the particles into which it decayed.

"Quantum mechanics predicts that the decay products of the B_s^0 meson must be different depending on whether it was in a state of matter or antimatter at the time of the decay. Thus, only after recording and identifying the decay products of a given meson we could determine whether it decayed as a representative of the matter or antimatter world. Combining this knowledge with information about the nature of the particle at the time of its production allowed us to measure the oscillation frequency," explains Dr. Dziurda.

The data analysed concerned B_s^0 mesons created in proton-proton collisions with a total energy of 13 teraelectronvolts, recorded at the LHCb detector between 2015 and 2018. Ultimately, the researchers were able to determine that B_s^0 mesons oscillate between matter and antimatter three trillion times per second, which is 300 times faster than the oscillation of a typical atomic clock built using caesium.

The result obtained by physicists from the LHCb experiment is not an empty encyclopaedic curiosity from the exotic world of quanta, but a measurement of wider significance. On the one hand, it agrees with the predictions of quantum mechanics at a new level of accuracy and is its beautiful illustration. On the other hand, the measured oscillation frequency of B_s^0 mesons significantly narrows the search areas for particles undescribed by the Standard Model, including those suggested by many theorists to explain the anomalies observed in recent years. Perhaps traces of this new physics can be detected when the upgraded LHCb detector resumes recording collisions in 2022.

The Henryk Niewodniczański Institute of Nuclear Physics (IFJ PAN) is currently one of the largest research institutes of the Polish Academy of Sciences. A wide range of research carried out at IFJ PAN covers basic and applied studies, from particle physics and astrophysics, through hadron physics, high-, medium-, and low-energy nuclear physics, condensed matter physics (including materials engineering), to various applications of nuclear physics in interdisciplinary research, covering medical physics, dosimetry, radiation and environmental biology, environmental protection, and other related disciplines. The average yearly publication output of IFJ PAN includes over 600 scientific papers in high-impact international journals. Each year the Institute hosts about 20 international and national scientific conferences. One of the most important facilities of the Institute is the Cyclotron Centre Bronowice (CCB), which is an infrastructure unique in Central Europe, serving as a clinical and research centre in the field of medical and nuclear physics. In addition, IFJ PAN runs four accredited research and measurement laboratories. IFJ PAN is a member of the Marian Smoluchowski Kraków Research Consortium: "Matter-Energy-Future", which in the years 2012-2017 enjoyed the status of the Leading National Research Centre (KNOW) in physics. In 2017, the European Commission granted the Institute the HR Excellence in Research award. The Institute holds A+ category (the highest scientific category in Poland) in the field of sciences and engineering.

CONTACTS:

Dr. **Agnieszka Dziurda**
Institute of Nuclear Physics, Polish Academy of Sciences
tel.: +48 12 6628086
email: agnieszka.dziurda@ifj.edu.pl

SCIENTIFIC PUBLICATIONS:

"*Precise determination of the $B_s^0 - \bar{B}_s^0$ oscillation frequency*"
LHCb Collaboration
Nature Physics, 2022
DOI: https://doi.org/10.1038/s41567-021-01394-x

LINKS:

http://www.ifj.edu.pl/
The website of the Institute of Nuclear Physics, Polish Academy of Sciences.

http://press.ifj.edu.pl/
Press releases of the Institute of Nuclear Physics, Polish Academy of Sciences.

IMAGES:

IFJ220209b_fot01s.jpg **HR:** http://press.ifj.edu.pl/news/2022/02/09/IFJ220209b_fot01.jpg
The B_s^0 mesons oscillate between the material form composed of the strange quark *s* and the beautiful antiquark *b bar*, and the antimatterial form composed of the beautiful quark *b* and the strange antiquark *s bar*. (Source: IFJ PAN)

VIDEOS:

IFJ220209b_vid01.mp4 **HR:** http://press.ifj.edu.pl/news/2022/02/09/IFJ220209b_vid01.mp4
The B_s^0 mesons oscillations. (Source: IFJ PAN)