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Cracow, 2 August 2018

“New physics” charmingly escapes us

In the world of elementary particles, traces of a potential “new physics” may be concealed in processes related to the decay of baryons. Analysis of data from the LHCb experiment at the Large Hadron Collider performed by scientists from the Institute of Nuclear Physics of the Polish Academy of Sciences in Cracow have, however, shown that one of the rarest decays of baryons containing the charm quark so far shows no anomalies.

Baryons, which are composite particles made of three quarks, can decay into lighter particles. These types of decays usually occur indirectly via intermediate state (resonant). Sometimes, however, the decay proceeds directly in one step (nonresonant). The Standard Model, the best tool of modern physics formulated half a century ago to describe phenomena occurring among elementary particles, predicts that some of nonresonant baryon decays are extremely rare: depending on the type of baryon they should occur once per billion cases or even less frequently.

“If the frequency of some nonresonant decays were to be different than predicted by the Standard Model, it could indicate the existence of processes and particles not known yet, that indicate existence of 'new physics'. This is why nonresonant decays have attracted our attention for so long,” explains Prof. Mariusz Witek from the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Cracow.

Prof. Witek led a five-member group of physicists from Cracow searching for nonresonant decays of charmed baryon *Lambda c* in data collected in 2011 and 2012 by the international LHCb experiment at the Large Hadron Collider in Geneva.

Why was the attention of the researchers drawn this time to *Lambda c* baryons, i.e. particles made of down (*d*), up (*u*) and charm (*c*) quarks? The most massive top (*t*) quark decays so fast that it does not combine with other quarks at all, so it does not create baryons, whose decays could be observed. The decays of particles containing the second largest quark in terms of mass, the beauty (*b*) quark, has already been analyzed earlier on, because their decays were slightly easier to detect. The Cracow group was involved here and contributed to observation of interesting deviation from theoretical predictions (https://press.ifj.edu.pl/news/2016/03/). In this situation, only the decays of charmed byrons remained largely unexplored.

“The Standard Model predicts that nonresonant decays of *Lambda c* baryons into three particles: a proton and two muons, should occur more or less once in hundreds of billions of decays. This is a much rarer phenomenon than the decays of baryons containing the beauty quark, which we were analysed earlier,” emphasizes Dr. Marcin Chrzaszcz (IFJ PAN) and adds, “Measurements and analyses are now much more difficult, we have to look into a much larger group of events registered in the LHCb experiment. However, it is worth doing, because as a reward you can come across a trail of much more subtle processes. If we manage to observe any inconsistencies with predictions, this would most likely be a signal of a 'new physics'."

With such rare phenomena, the distinguishing of nonresonant decays of *Lambda c* baryons from background has proved to be a hard and time-consuming task. Nonetheless, the Cracow-based physicists have managed to improve an upper limit on frequency of nonresonant decays by up to 100 times. It was estimated to be less than one in hundreds of millions.

"The taking into account of additional data, including the second run of the LHC accelerator, should soon improve our result by a factor of 10. So we would be very close to the predictions of the Standard Model. If some sort of 'new physics' is manifesting itself in the decays of *Lambda c* baryons, this will be the last chance for it to reveal itself. At present, there is not the slightest trace of it," sums up Prof. Witek.

During the analyses, the Cracow-based researchers also observed resonant decays, in which the *Lambda c* baryon decayed into a proton and *omega* meson. The lack of signals indicating yet another path of resonant decay – into a proton and a *rho* meson – was somewhat surprising. However, this result turned out to be in line with theoretical predictions.

The Henryk Niewodniczański Institute of Nuclear Physics (IFJ PAN) is currently the largest research institute of the Polish Academy of Sciences. The broad range of studies and activities of IFJ PAN includes basic and applied research, ranging 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 methods of nuclear physics in interdisciplinary research, covering medical physics, dosimetry, radiation and environmental biology, environmental protection, and other related disciplines. The average yearly yield of the IFJ PAN encompasses more than 600 scientific papers in the Journal Citation Reports published by the Thomson Reuters. The part of the Institute is the Cyclotron Centre Bronowice (CCB) which is an infrastructure, unique in Central Europe, to serve as a clinical and research centre in the area of medical and nuclear physics. IFJ PAN is a member of the Marian Smoluchowski Kraków Research Consortium: "Matter-Energy-Future" which possesses the status of a Leading National Research Centre (KNOW) in physics for the years 2012-2017. The Institute is of A+ Category (leading level in Poland) in the field of sciences and engineering.

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SCIENTIFIC PAPERS:

1. "Search for the rare decay $\Lambda_ {c}^{+}\to p\mu^+\mu^-$"
LHCb Collaboration
Physical Review D 97, 091101(R)
DOI: https://doi.org/10.1103/PhysRevD.97.091101

LINKS:

http://lhcb-public.web.cern.ch/lhcb-public/
The website of the LHCb experiment.

http://www.cern.ch/
The website of the European Organization for Nuclear Research (CERN).

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:

IFJ180802b_fot01s.jpg **HR:** http://press.ifj.edu.pl/news/2018/08/02/IFJ180802b_fot01.jpg

Baryons containing a charm quark can decay at once into a proton and two muons. Using data from the LHCb experiment, scientists from the Institute of Nuclear Physics of the Polish Academy of Sciences in Cracow have shown that in these extremely rare processes there are still no signs of the 'new physics'. The signal of the nonresonant decay is visible at the top, the signal of the resonant decay into a proton and *omega* meson is presented below. (Source: IFJ PAN, CERN, The LHCb Collaboration)