Dean's Representative for Scientific Communication: press.contact@fuw.edu.pl

Faculty of Physics University of Warsaw

Pasteura 5, 02-093 Warsaw, Poland tel. +48 22 5532935 fax +48 22 5532999 email: dziekfiz@fuw.edu.pl WWW: www.fuw.edu.pl

Warsaw, 9 September 2015

Our view inside the atomic nucleus just got a whole lot clearer

How can we know what is going on inside atomic nuclei? One important source of information comes from mesons, particles emitted during nuclear collisions. But until now it was not clear which mesons are actually carrying reliable information about a nucleus, and which ones were only interfering. Warsaw University physicists have published a careful analysis of data gathered by the international FOPI collaboration, which makes our ability to peer inside the atomic nucleus much more transparent.

Seeing is not enough – the one has to be able to understand what one is seeing. Physicists are able to make deductions about the processes that take place within atomic nuclei through various indirect means, including the observing of mesons (particles that arise when nuclei collide). The results provided by meson observations were not fully reliable, however, because it was never clear how many of the observed mesons actually did come from inside the atomic nuclei in question. Physicists from the Institute of Experimental Physics, Faculty of Physics at the Warsaw University (Poland) have completed an analysis of the data collected at the German nuclear research center in Darmstadt within the international FOPI collaboration. They found that a surprisingly high fraction of mesons is obscuring the picture of nuclear matter.

“We are able to perceive our day-to-day world thanks to light, in other words: photons. In nuclear physics, the role of photons is played by K mesons, also known as kaons. These particles are created in collisions of atomic nuclei, and because they are capable of leaving the collision zone and are poorly absorbed, we can detect them. But unfortunately, to date we have not known what these mesons are actually allowing us to see,” explains Prof. Tomasz Matulewicz (Institute of Experimental Physics, UW Physics).

Mesons are short-lived elementary particles composed of a quark and an antiquark. They occur in a few dozen types, with masses that range from several hundred times the mass of an electron up to tens of thousands of electron masses. For nuclear physicists, K^- and K^+ mesons and the phi mesons are particularly important. The K^+ meson consists of an up quark and a strange antiquark, whereas a K^- meson consists of an up antiquark and a strange quark (therefore making it the antiparticle of the K^+). The phi meson, in turn, contains a quark and a strange antiquark.

Under normal conditions, the mass of K mesons is about 1,000 times that of an electron. But when K mesons are formed within nuclear medium, as a result of strong forces and many quantum effects, they have a different effective mass at the moment of creation: for K^- mesons it drops to around 800 electron masses, while for the K^+ it increases to about 1150 (the effect depends on the density of matter). It is only once the mesons leave the nucleus that their masses become equal to their nominal value.

Kaons would be excellent carriers of information about phenomena occurring inside a given atomic nucleus if it were not for the fact that they can also be generated out in a vacuum, away from the nucleus. This is because phi mesons can also be emitted during the collisions of atomic nuclei. Before they decay, phi mesons can sometimes travel a distance up to several times greater than the diameter of a large atomic nucleus. That is considerably problematic for physicists, because half of phi mesons decay into K^- and K^+ mesons. That means that only some of the particles in the stream of K mesons registered by detectors actually carry valuable information about the atomic medium itself, whereas some of them never had anything to do with.

“The situation is a bit reminiscent of what happens on April Fool’s Day. We read a lot of news stories on that day that seem legitimate – and in fact they are. But on that particular date, we may come across a story or two that have been concocted. If we lend credence to them, we will arrive at some misguided conclusions. So, mindful of this, we become mistrustful and start to doubt the credibility of the real reports as well. The problem with K mesons was that we were essentially playing the April Fool’s game all the time,” explains Dr. Piotr Gasik (UW Faculty of Physics, currently at the Physics Department of Technische Universität München)

To determine the source of the K mesons detected in collisions of heavy atomic nuclei, a series of measurements were taken in past years at the GSI Helmholtzzentrum für Schwerionenforschung GmbH nuclear research center in Darmstadt using the FOPI detector, which was constructed with a significant contribution by physicists at the University of Warsaw’s Institute of Experimental Physics. The detector registered collisions between nickel 58Ni nuclei with other nuclei of the same type. Of the approx. 300 million collisions observed, after careful analysis physicists from the UW managed to identify 170 cases involving a phi meson.

“If someone managed to pick out a single specific individual from among a crowd of all the inhabitants of the city of Warsaw, that would surely be quite a feat. But it would have to be repeated nearly 200 times to come close to the precision of our result!” says Dr. Krzysztof Piasecki (UW Institute of Experimental Physics) and explains why phi mesons appeared so rarely: “The energy of the atomic nuclei collided in the FOPI detector was not sufficient to produce phi mesons. Fortunately, the particles in the nucleus are also moving and sometimes the energy of their motion was added to the collision energy. Then there was a chance of a phi meson being generated.”

The registered decays of phi mesons made it possible to estimate how many K mesons get emitted out in a vacuum. And it turns out that nearly one in every four kaons (around 22%) emitted has nothing to do with the atomic nucleus! Even worse, the number of kaons from outside the nucleus varies non-trivially depending on the energy of the mesons: there is somewhat more of them at certain energies, somewhat fewer at others.

The results achieved by the UW physicists, factored into new theoretical models, will help us to better understand the phenomena occurring during collisions of atomic nuclei and more accurately interpret the data collected by particle detectors. Interestingly, the results are also important for astronomers studying neutron stars. Under existing models, the largest mass of a neutron star should not exceed 1.4 times the mass of the Sun, yet ones with masses nearly twice that of the Sun have been recently observed. This surprising discrepancy can probably be explained by assuming that the nuclei of neutron stars actually contain not exclusively neutrons, but also large numbers of protons and K mesons.

The study of particles that contain a strange quark, like the K meson, is a longstanding tradition at the UW Institute of Experimental Physics. It was initiated in 1952, when Professors Marian Danysz and Jerzy Pniewski here discovered hypernuclei, or atomic nuclei where one of the protons or neutrons is replaced with a hyperon. With time it turned out that a hyperon is a particle built of three quarks: an up quark, a down quark, and a strange quark. The discovery of hypernuclei was the first case of the detection within an atomic nucleus of a particle other than protons and neutrons, and was of great importance for the advancement of nuclear physics. It is also considered one of the most important discoveries made by the Warsaw-based center of subatomic physics research.

This work by researchers from the UW Institute of Experimental Physics on the emission of mesons from atomic nuclei was supported by Polish (Ministry of Science and Higher Education) and European research programs.

Physics and Astronomy first appeared at the University of Warsaw in 1816, under the then Faculty of Philosophy. In 1825 the Astronomical Observatory was established. Currently, the Faculty of Physics' Institutes include Experimental Physics, Theoretical Physics, Geophysics, Department of Mathematical Methods and an Astronomical Observatory. Research covers almost all areas of modern physics, on scales from the quantum to the cosmological. The Faculty's research and teaching staff includes ca. 200 university teachers, of which 88 are employees with the title of professor. The Faculty of Physics, University of Warsaw, is attended by ca. 1000 students and more than 170 doctoral students.

CONTACTS:

Prof. **Tomasz Matulewicz**
Institute of Experimental Physics, Faculty of Physics, University of Warsaw
tel. +48 22 5532655
email: tomasz.matulewicz@fuw.edu.pl

Dr. **Krzysztof Piasecki**
Institute of Experimental Physics, Faculty of Physics, University of Warsaw
tel. +48 22 5532656
email: krzysztof.piasecki@fuw.edu.pl

SCIENTIFIC PAPERS:

"Influence of Phi mesons on negative kaons in Ni + Ni collisions at 1.91A GeV beam energy"; FOPI Collaboration; Physical Review C 91, 054904 (2015); DOI: 10.1103/PhysRevC.91.054904

RELATED LINKS:

http://gsi.de/
The website of the GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt.

http://www.fuw.edu.pl/
Faculty of Physics at the University of Warsaw website.

http://www.fuw.edu.pl/informacje-prasowe.html
Press Office for the Faculty of Physics at the University of Warsaw.

IMAGES:

FUW150909b_fot01s.jpg **HR:** http://www.fuw.edu.pl/press/images/2015/FUW150909b_fot01.jpg
Nearly one in every four K mesons is generated outside the atomic nucleus. (Source: UW Physics)