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Press release

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# Charge radius of Helium-3 measured with unprecedented precision

**Research findings from the PRISMA+ Cluster of Excellence and the Paul Scherrer Institute published in Science**

A research team led by Professor Randolf Pohl from the Institute of Physics at Johannes Gutenberg University Mainz (JGU) has achieved a significant breakthrough in determining fundamental properties of atomic nuclei. For the first time, the team conducted laser spectroscopy experiments on muonic helium-3 at the Paul Scherrer Institute in Switzerland. Muonic helium-3 is a special form of helium in which the atom’s two electrons are replaced by a single, much heavier muon. Yesterday, the results have been published in the prestigious journal Science. “Our experiments with muonic helium-3 provide the most accurate value to date for the charge radius of this nucleus,” says Randolf Pohl, who is also a member of the PRISMA+ Cluster of Excellence at JGU. “This is primarily because the heavy muon orbits much closer to the atomic nucleus than electrons in regular atoms, making it far more sensitive to the nucleus’s size and structure.”
Helium nuclei always consist of two protons—this is what defines them as helium. Different isotopes are distinguished by the number of neutrons in the nucleus: helium-3 contains one neutron alongside the two protons, while the heavier helium-4 contains two neutrons. Professor Pohl's team had already successfully measured helium-4 using laser spectroscopy and muons several years ago.

Measurement Confirms Theoretical Models

Traditionally, nuclear radii are determined using particle accelerators, such as MAMI at JGU or, in the future, MESA. However, the new value obtained from muonic helium measurements is fifteen times more precise, coming in at 1.97007 ± 0.00097 femtometers. Laser spectroscopy with electrons has previously been successfully applied to the lightest atomic nuclei, such as hydrogen and deuterium. For helium, highly precise measurements also exist, but the presence of two electrons in the helium atom makes theoretical calculations more complex, preventing accurate determination of the nuclear radius from such measurements alone. Nevertheless, it has already been possible to determine the difference in charge radii between various helium isotopes (nuclei with the same number of protons but different numbers of neutrons). The new results from muonic helium measurements align well with recent experiments on regular helium conducted by a research team in Amsterdam, also published in Science, yesterday.
“In combination with our earlier results on muonic helium-4, which were published in Nature in 2021, we have now been able to precisely determine the difference in charge radii between helium-3 and helium-4—an important advancement,” says Pohl.

Close Interaction Between Theory and Experiment in the PRISMA+ Cluster of Excellence

The strong agreement between the measurements conducted by the Mainz and Amsterdam teams confirms existing knowledge about the nuclear physics of the lightest atomic nuclei. This knowledge is based in part on key theoretical calculations of nuclear structure, also carried out within the PRISMA+ Cluster of Excellence.
Professor Sonia Bacca’s team calculated the influence of the muon on the structure of the helium nucleus, while Professor Marc Vanderhaeghen and Dr. Franziska Hagelstein explored the roles of protons and neutrons. These

theoretical foundations enabled the extraction of reliable information about the atomic nucleus from the precise experimental data.
"Accurate knowledge of nuclear charge radii is essential for determining fundamental physical constants such as the Rydberg constant," Pohl explains. "It is also crucial for the search for new physics — particles and forces not yet included in the Standard Model. The previous lack of precise data in this area introduced significant uncertainties."

Precise Measurement of Additional Atomic Nuclei Planned

Looking ahead, the team of experimental and theoretical physicists at Mainz plans to apply their methods to other atomic nuclei—from lithium to neon—with ten times the accuracy compared to particle accelerator-based methods. Instead of lasers, they will use innovative X-ray detectors. This work, like the previous experiments led by Pohl's group, is supported by the German Research Foundation (DFG) as part of the Collaborative Research Center 1660 at JGU.

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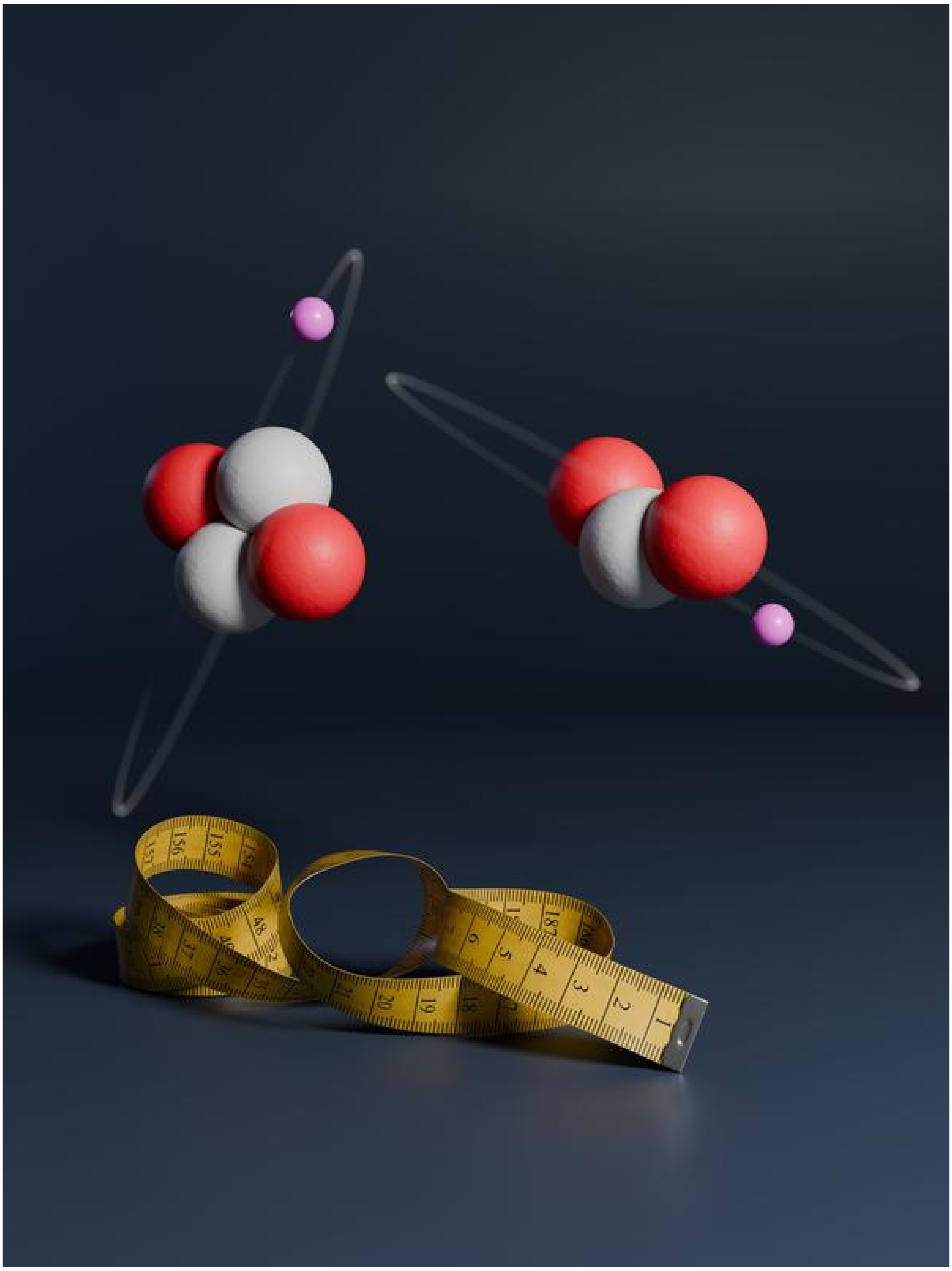
— press release: "Size of helium nucleus measured more precisely than ever before" (27.01.2021)



For the first time, researchers from the PRISMA+ Cluster of Excellence have determined the charge radius of helium-3 and thus also the exact difference to the radius of helium-4. This precision opens up new horizons in the search for prev. unknown physics
Julian Krauth
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