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Atomic nuclei and leptons: Milestone reached in the calculation of cross sections

August 10 2021

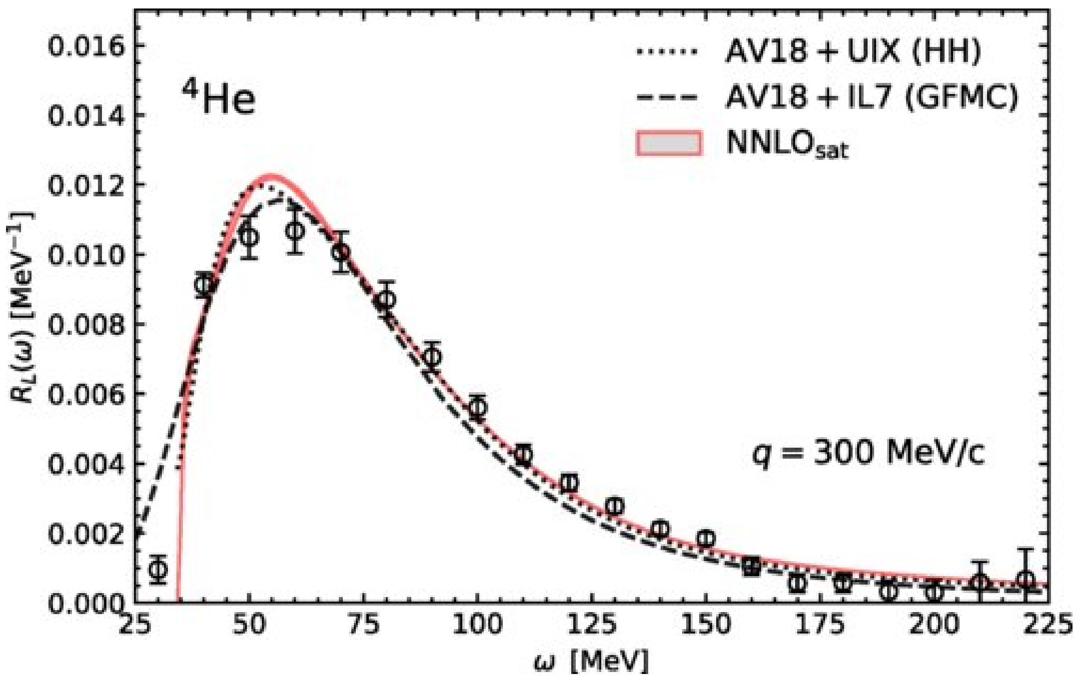

Figure 1. Longitudinal response function for ^{4}He at q=300MeV/c. HH results taken from Ref. [44], GFMC results from Ref. [43], and experimental data from Ref. [45]. Credit: DOI: 10.1103/PhysRevLett.127.072501

A team in the PRISMA+ cluster of excellence at the Johannes Gutenberg University in Mainz succeeded in computing how atomic nuclei of the Calcium element behave in collisions with electrons. Results agree very well with available experimental data. For the first time, a calculation based on a fundamental theory is capable of correctly describing experiments for a nucleus as heavy as Calcium. Of particular relevance is the potential that such calculations could have in the future to interpret neutrino experiments. The renowned journal *Physical Review Letters* reports on the achieved milestone in its current volume.

The new publication stems from the group lead by Prof. Sonia Bacca, Professor for theoretical nuclear physics in the cluster of excellence PRISMA+, in collaboration with Oak Ridge National Laboratory. Bacca works with great success in predicting various properties of atomic nuclei deriving them from the interactions among their constituents—the nucleons—which can be described within chiral effective field theory. Her research aims at providing a solid connection between experimental observations and the underlying theory of quantum chromodynamics. In physics, such a procedure is described as an ab initio calculation.

Also cross sections of atomic nuclei probed by external fields, for example through the interaction with electrons or other particles, can be described within the same theory. This procedure is key to explaining existing data and interpreting future experiments, for example in neutrino physics —an important focus of the PRISMA+ research program.

Understanding neutrinos

Neutrinos are elusive particles that are constantly penetrating our Earth but are very difficult to detect and understand. With new planned experiments, such as the DUNE experiment in the U.S., scientists want to investigate their fundamental properties, for example, the phenomenon in which one type of neutrinos transform into another —called in technical jargon, neutrino oscillation. In order to achieve that, they need important information from theoretical calculations. Specifically, the relevant question is: How do neutrinos interact with atomic nuclei in the detector?

Since experimental data on the scattering of neutrinos on atomic nuclei are rare, the team of researchers first looked at the scattering of another lepton —the electron— for which experimental data are available. "Calcium 40 is our test system, so to speak," explains Dr. Joanna Sobczyk, postdoc in Mainz and first author of the study. "With our new ab initio method we were able to calculate very precisely what happens with electron scattering and how the Calcium atomic nucleus behaves."

This is a great success: Until now it was not possible to carry out such calculations for an element as heavy as Calcium, which consists of 40 nucleons. "We are very pleased that we have succeeded in basically showing that our method works reliably," says Sonia Bacca. "Now a new era begins, where the ab initio methods can be used to describe the scattering of leptons—these include electrons and neutrinos—on nuclei, even for 40 nucleons."

"One of the nicest features of our approach is that it allows us to rigorously quantify uncertainties associated with our calculation. Uncertainty quantification is very time-consuming, but extremely important in order to be able to appropriately compare theory against experiment," comments Dr. Bijaya Acharya, PRISMA+ postdoc and also co-author of the study.

After they were able to show the potential of their method for Calcium, the research team wants to look at the element Argon and its interaction with neutrinos in the future. Argon will play an important role as a target in the planned DUNE experiment.

More information: J. E. Sobczyk et al, Ab Initio Computation of the Longitudinal Response Function in Ca40, *Physical Review Letters* (2021). DOI: 10.1103/PhysRevLett.127.072501

Provided by Universitaet Mainz