Abstract

Title in English: Beta decay in nuclear energy density functional and beyond

Atomic nuclei form an excellent playground to investigate the primary building blocks of nature in the context of fundamental interactions between particles. Long-range electromagnetic Coulomb interaction, short-range strong interaction which binds nucleons into atomic nuclei (nucleon-nucleon interaction), and weak interaction responsible for beta decay pose a serious challenge in theoretical description of the nuclear chart where a deep understanding of all of them is a must. The field of study is highly interdisciplinary as the understanding of fundamental interactions have been the main goal of the Standard Model of particle physics - the theory which pretends to account for the fundamental laws of nature.

Binary structure of atomic nucleus - the quantum system composed of two types of particles protons and neutrons – causes the asymmetry of the nucleon-nucleon interaction due to, for instance, electromagnetic interaction which acts only between protons. The analysis of breaking of the isospin symmetry in the so-called superallowed Fermi beta decay provides a unique opportunity to verify the basic assumption of the Standard Model, where hadronic structure is built upon three generations of quarks. For that reason one of the key point of the thesis was to focus on the research of unitarity of the Cabbibo-Kobayashi-Maskawa (CKM) quark mixing matrix (Nobel prize 2008 "for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature"). So far, the calculation of nuclear beta decay with an effective nucleon-nucleon interaction does not contradict with this assumption. Therefore either, we live indeed in the three-generation-quark world or quarks of next generation are so massive that we need much more precise calculation to reach the required level of accuracy of the unitarity of CKM matrix.

The Fermi beta decay is by no means the only channel of beta transition. With nearly the same probability the nucleus may decay in the Gamow-Teller channel where the spin change is involved. Many years ago it turned out that the transition probability is systematically overestimated by the theory with respect to experimental data. The observed reduction is responsible for coining the term *quenching* for the reduction effect related to the coupling constant of Gamow-Teller type of electroweak currents. The coupling constant has been studied within both nuclear and particle physics. The conclusion that has been made within this work allowed to reject the main hypothesis behind the quenching. Instead of suspecting the drawbacks of the theoretical approach itself it turned out that the solution of the puzzle of the quenching was most probably related to many-body currents, which had been not included at any point in the calculation. Only very recently this statement has been confirmed by the ab initio calculations in several examples of the Gamow-Teller beta decay.

Furthermore, the Gamow-Teller transitions are crucial to settle up the research on neutrinoless double beta decay. It is one of the most sought-after process in physics as if measured, would indicate the existence of new physics beyond the Standard Model with neutrino being its own antiparticle with the non-zero mass. The discovery of the neutrino oscillation (Nobel prize 2015) made the subject even more vivid among scientists. It meant that neutrinos are massive. It is therefore obligatory for nuclear theory to perform extremely precise calculation indicating possible isotopes that may decay in that exciting neutrinoless double decay channel. The model that has been widely tested and explored within the thesis, especially in the context of Gamow-Teller transitions, is now almost ready for the calculation of the $0\nu\beta\beta$ channel.