Application for the JINR Prize 2020

Title: Neutrino mass, double-beta decay and nuclear structure - *Масса нейтрино, двойной бета-распад и структура ядра*

Applicants (10, 4 from the JINR): **Fedor Šimkovic,** Andrej Babič, Rastislav Dvornický, Hiro Ejiri, Sergei Kovalenko, Mikhail Krivoruchenko, Adam Smetana, Dušan Štefánik, John Vergados, Petr Vogel (in red young scientists)

Institutes: 4 - JINR Dubna, 3 – Comenius University in Bratislava, 3 – IEAP CTU in Prague, 1 – Univ. of Valparaiso, 1 – Univ. of Ioannina, 1 – ITEP Moscow, 1 - CALTECH

Abstract: 90 years ago neutrino was postulated by Pauli in his letter to a workshop in Tuebingen. Nowadays neutrino physics is one of the fastest evolving fields in physics. After neutrino oscillations discovery, which proved that neutrinos have tiny mass, the physics community worldwide is concentrating on the next challenging problem, finding whether neutrinos are identical (Majorana) or different (Dirac) to their own antiparticles. It is an important issue as our understanding of the Universe and its evolution depends on it. To solve this problem, many experiments are looking for a signal of the neutrinoless double-beta decay ($0\nu\beta\beta$-decay), or are in construction/preparation in underground laboratories worldwide.

The atomic nucleus has been promoted to study the fundamental properties of ν's. A significant progress has been achieved in the description of the $0\nu\beta\beta$-decay in the context of the ν-mass generation, mechanisms of this process associated with the left-right symmetric models and involved nuclear structure. The main achievements are as follows: i) A mechanism of generation of Majorana neutrino mass due to spontaneous breaking of chiral symmetry (SBCS) accompanied by a formation of quark condensate was advocated. It was manifested that the smallness of neutrino masses is due to a large ratio between the lepton number violating scale and the scale of the SBCS. Consequences of this see-saw mechanism of neutrino mass generation for the $0\nu\beta\beta$-decay, tritium beta decay and cosmological measurements were drawn. ii) A novel effect in the $0\nu\beta\beta$-decay associated with nuclear environment was presented. It was demonstrated that the impact of nuclear medium via lepton-number-violating (LNV) four-fermion interactions of neutrinos with quarks from a decaying nucleus is a generation of an effective in medium Majorana neutrino mass. It was found that the enhanced rate of the $0\nu\beta\beta$-decay can lead to the apparent incompatibility of observations of the $0\nu\beta\beta$-decay with the value of the neutrino mass determined or restricted by the β-decay and cosmological data. iii) The light and sterile neutrino exchange mechanisms of the $0\nu\beta\beta$-decay with the inclusion of the right-handed leptonic and hadronic currents were revisited. The question was addressed whether light and heavy neutrino contributions to $0\nu\beta\beta$-decay are experimentally distinguishable. In that context the interpolating formula for the $0\nu\beta\beta$-decay was introduced. Several simplified benchmark scenarios within left-right symmetric models were considered and the conditions for the dominance of the light or heavy neutrino mass mechanisms were presented. iv) The attention was paid also to the problem of a reliable calculation of the $0\nu\beta\beta$-decay nuclear matrix elements (NMEs). A connection between the $2\nu\beta\beta$-decay and $0\nu\beta\beta$-decay matrix elements was found. Further improvement in the calculation of the $0\nu\beta\beta$-decay NMEs was achieved within QRPA with partial restoration of the isospin and the spin-isospin SU(4) symmetries. v) Alternative modes of $2\nu\beta\beta$- and $0\nu\beta\beta$-decays in which one electron goes over to a continuous spectrum and the other occupies a vacant bound level of the daughter ion, were proposed and discussed. It was concluded that the 2ν mode can be observed in the next-generation double-beta decay experiments, most notably

SuperNEMO. vi) An improved formalism of the $2\nu\beta\beta$-decay rate was presented. It was found that one can get information about axial-vector coupling constant g_A in nuclear medium once the ratio of involved NMEs is deduced from the measured electron energy distribution. vii) In the context of the $0\nu\beta\beta$-decay the formalism of muon capture in nuclei was revisited. The QRPA was used in evaluation of the total muon capture rates for the final nuclei participating in double beta decay. The resulting capture rates are in good agreement with the experimental values. It was concluded that there is no necessity for an empirical quenching of g_A. Finally, 2 review articles covering recent progress in the theoretical and experimental investigation of the $0\nu\beta\beta$-decay and in related topics were presented.

These theoretical investigations were performed **in support** of the experimental studies of the $0\nu\beta\beta$–decay (SuperNEMO, GERDA and LEGEND), muon capture (MONUMENT) and neutrino oscillations (Daya Bay and JUNO) with a strong participation **of experimental groups from the JINR Dubna**.