# Effects of QRPA correlations to nuclear matrix elements of neutrinoless double-beta decay through overlap matrix

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Determination of the neutrino mass is one of the most challenging problems of physics today. The neutrino has been assumed to be massless in the standard theory, however this assumption has been denied by the observation of the neutrino oscillation [1]. One of few methods for determining the effective neutrino mass is to use the neutrinoless double-beta decay of nucleus, and a few tens of experimental projects are in progress [2]. The primary purpose of these experiments is to clarify if the double-beta decay occurs, and, if the decay is observed, it would be established that the neutrino is the Majorana particle, and the lepton number conservation is broken. If the transition probability of the neutrinoless double-beta decay is measured, then, it is possible to determine the effective neutrino mass with that experimental data and the transition matrix element obtained by the theoretical calculation independently of the experiments. Here, the theoretical problem is how the values of the nuclear part of the transition matrix element, called nuclear matrix elements, can be obtained accurately, in particular because there is no method to check the calculated values directly by experiments; in addition, the lightest candidate of the parent nuclei considered in the experiments is $^{48}$Ca, and approximation is essential for obtaining the nuclear wave functions.

We use the quasiparticle random-phase approximation (QRPA), which has a long history in application to the nuclear matrix elements, see e.g. [3]. The long standing problem is that the QRPA values are typically larger than the values of the shell-model calculations by a factor of 2 [4]. This problem persists in spite of the fact that several significant improvements have been made in the QRPA calculations, e.g. the extension from the spherical formulation to the deformed one [5].

We examine the effects of a new major improvement in the QRPA approach, that is, to calculate the overlap of the QRPA states obtained from the initial and the final states including the QRPA correlations correctly [6]. The equation of the overlap is derived by defining the QRPA ground state to be the vacuum to the quasi-bosons. This definition provides us with the principle to bring the QRPA correlations correctly to the overlap. We show that the QRPA correlations have an effect to reduce the overlap by increasing the normalization factor; therefore the nuclear matrix elements decrease.

Our numerical calculations have been performed mainly using the K computer, AICS, RIKEN, and mira, ALCF, ANL. The technical aspects of our large-scale parallel computations will also be mentioned.

**References**

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