Thesis abstract L. Heitz

« Renormalisation group, Ab Initio and covariant approaches to nuclear magicity and clustering; experimental search for double alpha decay »

This thesis eploires effective theories for nuclear structure to bridge ab initio approaches, grounded in QCD symmetries, and phenomenological models of the energy density functional (EDF) type. It combines methodological advances, conceptual analyses, and confrontation with data to connect emergent nuclear phenomena to the underlying theory.

First, the functional renormalization group (FRG) is explored as a nonperturbative tool to derive finite-density effective interactions from “bare” vacuum forces by progressively integrating out high-energy degrees of freedom. The results indicate that FRG offers a systematic and controllable route to generate such interactions while preserving low-energy observables, although a fully closed derivation remains to be established.

Second, within EDF theory, a global analysis of magicity (shell closures) shows—via semi-quantitative indicators—that the realization of pseudospin symmetry may provide a unifying mechanism for magic numbers in a single-particle description, shedding light on the evolution of shell structure along isotopic and isotonic chains.

On the ab initio side, the “symmetry breaking and restoration” strategy, implemented with the projected generator coordinate method (PGCM), is applied to clustering. For the Hoyle state of carbon-12, it reproduces the essential cluster correlations at moderate computational cost; expanding model spaces and including higher-order corrections are nonetheless required to consolidate convergence.

In parallel, EDF-based indicators of alpha preformation are proposed and applied to heavier nuclei, revealing correlations with other structural observables and offering guidance for potential exotic decays.

Finally, an experimental search for double-alpha decay was conducted in 2023 at ISOLDE (CERN) on ^222,220Ra and ^218,216Rn using double-sided silicon strip tracking detectors. No signal was observed, but upper limits on branching ratios were established, challenging certain EDF predictions by up to three orders of magnitude. These measurements provide the first quantitative constraints on this decay mode and inform future model refinements.