

PhD Course in Physics, Astrophysics, and Applied Physics - Università degli Studi di Milano
PhD cycle 41 (2025-2026)

All lectures will be given in English.

Course title	Introduction to ab initio nuclear theory
Teacher in charge of the course	Barbieri Carlo
List of the teachers of the course	Barbieri Carlo, Università degli Studi di Milano and INFN Sez. di Milano, carlo.barbieri@unimi.it
Training objectives	The student will be led to understand the principal microscopic methods used to study atomic nuclei and to interpret experiments with exotic isotopes. The student will be able to discuss critically the various approaches in nuclear theory and to explain the forefront developments in the field.
Prerequisites	Fundamentals of quantum mechanics and quantum field theory. Second quantization in the many-body framework. Knowledge at the introductory level of nuclear and subnuclear physics.
Detailed course program	Ab initio nuclear theory will be discussed with emphasis on the connection with experiments and the necessity of reaching accurate predictions for exotic isotopes. The course will cover the two pillars of first principles (a.k.a. ab initio) simulations of nuclei, namely the understanding the nuclear force, as grounded in the theory of QCD, and quantum many-body computations for strongly correlated isotopes. The course also has an interdisciplinary aspect in that it highlights common aspects of nuclear structure, quantum chemistry, condensed matter theory, and nuclear astrophysics. - General aspects of the nuclear force - Effective field theories (EFTs): chiral and pionless EFT interactions. - Nuclear forces from QCD on the lattice. - Strongly correlated fermionic systems. Concept of spectral function. - Relation between ab initio, shell model and nuclear DFT methods. - Wave-function based methods: FCI, quantum Monte Carlo, Lattice. - Configuration expansion methods: Many-body perturbation theory, Green's function theory, coupled cluster, IM-SRG. - Frontiers: neural network and uncertainty quantification. The theory material will be presented along with its applications to recent experimental endeavours. Although focussed on nuclear physics applications, the second part of the course introduces methods that are relevant to other subfields of many-body physics.
Examination modalities	Students will present a critical review of one of the arguments from the program, follow by a short oral examination.
Preliminary schedule	10 hours of lectures during one week in either January, March or April 2026. Course enrolment deadline: December 27, 2025.