Modeling of Nuclear Structure and Low-Energy Reactions

Research group (staff members)

Maria Colonna (INFN-LNS)
Danilo Gambacurta (INFN-LNS)
Edoardo G. Lanza (INFN-CT)
Massimo Papa (INFN-CT)
Michelangelo Sambataro (INFN-CT)

Topics of interest

Our research activity is mainly devoted to theoretical developments in the field of nuclear structure and low-energy nuclear reactions.

The main objective is to attack some of the most significant problems concerning the structure of atomic nuclei, nuclear reactions and strongly interacting matter, combining the skills of our group members into a synergistic effort. In particular, our interests are directed to weakly bound systems at the edge of nuclear stability, as well as new nuclear excitations and, based on dissipative heavy-ion collisions, nuclear matter in different density and temperature conditions.

We also aim at matching these studies with the experimental progress currently underway in areas like the production of rare isotopes, the nuclear matter EoS and the physics of electroweak interactions and double-beta decay, both within INFN and in the more general international context. The consistent merging of structure and reaction theories will offer the opportunity to directly compare theoretical calculations with data obtained from experiments.

The members of our research group are collaborating within the INFN project MONSTRE and have a considerable experience in the field, as shown by the good publication rate and the quality of the international collaborations.

Current research lines

1) Collective phenomena, clustering and new excitation modes:

The understanding of collective phenomena remains a fundamental topic in nuclear physics, as also testified by the very strong correlated experimental activity.
Within this research line the quantitative description of excitation modes in the spin-isospin channel and the connections between collective modes and the EoS beyond magic nuclei is explored in great detail. The properties of collective excitations will be studied by using beyond mean-field approaches, based on the Energy Density Functional framework.
Particular attention is addressed to pygmy dipole states. Their properties and excitation mechanism will be investigated in deformed nuclei making use of semiclassical reaction theory as well as microscopic calculations of radial form factors.
We also intend to further deepen the study of collective excitations in self-conjugate nuclei. Nuclear quarteting has long been claimed to represent a crucial aspect of these

nuclei. The difficulty in handling alpha-like correlated structures has been recently overcome by a microscopic formalism which will be employed for the analysis of self-conjugate nuclei. The emergence of clustering and the formation of nuclear molecules and collective rotations and vibrations at low energy will be investigated in approaches that make use of discrete symmetries and point-groups.
Semiclassical approaches (CoMD) will be also used at higher energies to describe the interplay between excitation of pre-equilibrium collective phenomena (dipolar mode) and clustering aspects driven by heavy collisions in different reaction mechanisms. Actually, this aspect is strictly connected with isospin equilibration phenomena and the functionals describing the isovectorial interaction in a finite range of density $\rho < 1.4\ \rho_0$.

2) Exotic nuclei:

The intense development of radioactive beam facilities – with the opening, among others, of the INFN facility SPES and of FRIB at MSU in the near future - has led to an enormous progress in the experimental knowledge of nuclei far from the valley of stability. This subject is of primary interest for our collaboration, especially in view of the many applications in astrophysics. The study of unbound resonant states must involve an accurate treatment of the continuum, as well as a delicate matching between the study of structure and reactions. Specific investigations will also concern the calculation of absolute cross sections of transfer reactions, the study of excitation modes in nuclei far from the stability line and the role of pairing correlations.

3) Charge-exchange reactions and beta decay:

State of the art many-body techniques will be employed to compute nuclear matrix elements relevant for experiments with electromagnetic probes, including electron scattering, neutrino oscillations, radiative capture, single and double-beta decay. Extensive benchmarking will be carried out, in order to validate and discuss theoretical estimates, aiming at a clearer interpretation of experiments.
New efforts will be devoted to modeling, within quantum scattering theory, heavy ion double charge exchange reactions, and to explore the common aspects with double-beta decay.
Reactions of current experimental interest (NUMEN collaboration), involving nuclei candidates for the $0\nu\beta\beta$ process (such as ^{76}Ge-^{76}Se), will be investigated and many-body techniques will be employed for the evaluation of the corresponding charge-exchange nuclear matrix elements.

4) Heavy ion collisions and the nuclear EOS:

The understanding of dissipative heavy ions collisions at the Fermi energies and beyond is a powerful method to extract information on the Nuclear EoS far from the stability, of crucial importance for the physics of core-collapse supernove and neutron stars. The reaction dynamics will be modeled with upgraded transport theories (i.e. extended time-dependent Density Functional Theories employing the same functionals as in structure studies) incorporating many-body correlations, such as the Constrained Molecular Dynamics (CoMD) model and the stochastic mean-field (SMF) approaches.

Recent publications of the group in the following pages

Research line 1:

Burrello, S.; Colonna, M.; Colò, G.; et al.,
Interplay between low-lying isoscalar and isovector dipole modes: A comparative analysis between semiclassical and quantum approaches,
Phys. Rev. C **99**, 054314 (2019).

M. Papa et al,
Dipolar degrees of freedom and isospin equilibration processes in heavy ion collisions,
Phys. Rev. C **91**, 041601(R) (2015).

Bracco, E.G. Lanza and A. Talmi,
Isoscalar and isovector dipole excitations: Nuclear properties from low-lying states and from the isovector giant dipole resonance,
Prog. Part. Nucl. Phys. **106**, 360 (2019).

A. Vitturi, J. Casal, L.Fortunato, E.G. Lanza,
Transition densities and form factors in the triangular α-cluster model of ^{12}C with application to ^{12}C+α scattering
Phys. Rev. C **101**, 014315 (2020).

M. Sambataro and N. Sandulescu,
Four-body correlations in nuclei,
Phys. Rev. Lett. **115**, 112501 (2015).

M. Sambataro and N. Sandulescu,
Quartetting in odd-odd self-conjugate nuclei,
Phys. Lett. B **763**, 151 (2016).

M. Sambataro and N. Sandulescu,
Exact T=0 eigenstates of the isovector pairing Hamiltonian,
J. Phys. G: Nucl. Part. Phys. 47, 045112 (2020).

D. Gambacurta, M. Grasso, O. Vasseur,
Electric dipole strength and dipole polarizability in ^{48}Ca within a fully self-consistent second random–phase approximation,
Phys. Lett. B **777,** 163 (2018) 163-168.

D. Negrea, P. Buganu, D. Gambacurta, and N. Sandulescu,
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Phys. Rev. C **98**, 064319 (2018).

D. Negrea, N. Sandulescu, D. Gambacurta,
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Grasso, M.; Gambacurta, D.,
Beyond-mean-field effects on the symmetry energy and its slope from the low-lying dipole response of Ni-68,
Phys. Rev. C **11**, 064314, 2020

M. Grasso, D. Gambacurta, and O. Vasseur,
Beyond-mean-field effective masses in the nuclear Fermi liquid from axial breathing modes,
Phys. Rev. C **98**, 051303(R) (2018).

O. Vasseur, D. Gambacurta, and M. Grasso,
Systematic study of giant quadrupole resonances with the subtracted second random-phase approximation: Beyond-mean-field centroids and fragmentation,
Phys. Rev. C **98**, 044313 (2018).

D. Gambacurta , M. Grasso , O. Vasseur,
Electric dipole strength and dipole polarizability in 48Ca within a fully self-consistent second random–phase approximation,
Phys. Lett. B **777,** 163 (2018).

Research line 2:

D. Gambacurta, M. Grasso, and O. Sorlin,
Soft breathing modes in neutron-rich nuclei with the subtracted second random-phase approximation
Phys. Rev. C **100**, 014317 (2019).

D. Gambacurta and D. Lacroix,
Effects of deformation on the coexistence between neutron-proton and particle-like pairing in N = Z medium-mass nuclei
Phys. Rev. C **91**, 014308 (2015) .

Research line 3:

Lenske, Horst; Bellone, Jessica, I; Colonna, Maria; et al.
Group Author(s): NUMEN-Collaboration,
Theory of single-charge exchange heavy-ion reactions,
Phys. Rev. C **98,** 044620 (2018).

Jessica I.Bellone, Stefano Burrello, Maria Colonna, José-Antonio Lay, Horst Lenske
NUMEN Collaboration,
Two-step description of heavy ion double charge exchange reactions
Phys. Lett. B **807**, 135528 (2020).

Research line 4:

Colonna, M.,
Collision dynamics at medium and relativistic energies,
Prog. Part. Nucl. Phys. **113** , 103775 (2020).

Zhang, Ying-Xun; Wang, Yong-Jia; Colonna, Maria; et al.,
Comparison of heavy-ion transport simulations: Collision integral in a box,
Phys. Rev. C **97**, 034625 (2018).

D. Gambacurta, M. Grasso, J. Engel ,
Gamow-Teller strengths in 48Ca with the charge-exchange subtracted second random-phase approximation,
arXiv:2007.04957.