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Editorial: Nuclear structure and dynamics with stable and unstable beams

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Editorial on the Research Topic
Nuclear structure and dynamics with stable and unstable beams

1 Nuclear reactions: A fundamental tool in nuclear physics

Since the beginning of nuclear physics, nuclear reactions appeared as a unique tool for the study of the most important nuclear properties. All the currently adopted classes of nuclear models (e.g., shell-, liquid-drop, Fermi gas, collective, cluster models) have been developed and/or finely tuned thanks to the large amount of data obtained in experiments of nuclear reactions.

For example, reactions between light nuclei produce a mine of information on the structure of ground and excited states of such few-body systems. In recent times, many of such investigations have been focused on the study of α-clustering rearrangement both in self- and non-self conjugate nuclei (see, e.g., [1–4]), a peculiar phenomenon that is linked to the presence of long-range correlations in nuclear forces. Nuclear reactions involving α-clustered systems are also a powerful tool to explore the competition between low-energy reaction mechanisms, such as elastic scattering and α-transfer Lichtenthäler Filho et al. [5]; Lépine-Szily et al. [6]. In nuclear astrophysics, high-precision measurements of reaction cross sections at low energy can be fundamental to understand particular aspects of stellar nucleosynthesis (e.g., the hotly debated ^{19}F production and destruction mechanisms in AGB stars [7–10] or in connection with the evolution of POP III stars [11], or the fate of type II core-collapse supernovae and the resulting elemental abundances [12]). Furthermore, nuclear reactions induced by weakly bound projectiles as deuterons and/or ^{3}He are still of paramount importance for the understanding of shell-model predictions in proton-rich or neutron-rich nuclei, even for particularly exotic nuclear systems [13,14]. In this respect, the availability of new, unstable, neutron rich beams triggered the development of new cryogenic d or ^{3}He target to be used in transfer experiments in inverse kinematics [15]. Another important tool to study the structure of excited states of nuclei far from the stability line is linked to the analysis of reactions induced by weakly bound ^{6,7}Li ^{10,11}B projectiles [16–29]. In this framework, fully optimized optical model potentials (as the Sao Paulo one [30–33]) can be profitably used in the framework of DWBA or CC calculations, with the aim of extracting spectroscopic information from reaction cross section data [34,35].

Nuclear clustering plays a role also when moving to heavy-ion collisions. At energies around 5–10 MeV/nucleon, the typical fusion-evaporation or fusion-fission scenarios [36,37] are gradually replaced by more complex mechanisms [38,39], with the presence of several fragments [40,41], often accompanied by nucleons or light clusters emitted in the pre-equilibrium phase [42–44]. This complex scenario, occurring in the domain of Fermi energies, can be explored thanks to high-performance multi-detector arrays as, for example, INDRA [45–47], CHIMERA [48–50], HiRA [51–53], LASSA [54], FAZIA [55–57], often coupled with high angular resolution hodoscopes as FARCOS [58,59] or OSCAR [60] to better sample specific region of the phase space. In this framework, it has been demonstrated the occurrence of spinodal decomposition of the system formed in central heavy-ion collisions at Fermi energies [61] due to mechanical instabilities; furthermore, the highly excited systems formed at different impact parameters can be characterized with thermometric [62] and calorimetric [63,64] measurements that can be useful also to unveil the nature of the phase transition from a liquid-like to a gas-like phase occurring in nuclear matter [65–67]. It is also possible that condensation phenomena could influence the yields of the observed light clusters [68]. In this context, also the neutron richness of the colliding system can play a strong role on the dynamical evolution and the fragment formation [69–73], and the comparison of data with several reaction models, based both on transport equations [74–79] or molecular dynamics approaches [80,81] is important to determine the isospin dependence of the equation of state of nuclear matter. This point is of paramount importance also for the description of the structure and stability of neutron stars.

2 A brief overview of the Research Topic

This Research Topic presents a collection of results that cover a broad domain of nucleus-nucleus collisions with stable and unstable ion beams, helping to push the frontiers of nuclear reactions studies towards new applications. One of the topics highlighted in the present collection is that of the development of new radioactive ion beam facilities. Martorana et al. report on the status of the FRAISE facility of INFN-LNS (Catania, Italy), discussing the use of recent Silicon Carbide detector technology for the diagnosis and tagging of high-intensity radioactive ion beams. These studies are particularly relevant because the development of radioactive ion beams in international facilities worldwide gives now the opportunity to extend our understanding of nuclear systems even far away from the stability, where exotic structure phenomena often occur.

The investigation of the spectroscopy of neutron-rich nuclei is a topic at the frontiers of contemporary nuclear physics. In this framework, improving the detection of neutrons, which are abundantly emitted in collisions involving neutron-rich systems, is fundamental to probe the structure of neutron-rich systems and the underlying collision dynamics. Advancements in neutron detection are reported by Pagano et al., where the authors discuss the development of the recent NArCoS array. The study of neutron-rich systems is also key to understand α-clustering and the occurrence of molecular structures in light systems. Possible new applications with NArCoS and a detailed plan to investigate clustering and molecular states at FRAISE are presented in Gnoffo et al., Charged-particle spectroscopy techniques are instead used by Vukman et al. to investigate cluster structures in ^{12}Be, exploiting radioactive ion beams available at TRIUMF (Vancouver, Canada).

The investigation of reaction mechanisms at low and intermediate energies is another key topic explored in the present Research Topic. At energies above the Coulomb barrier, multi-nucleon transfer phenomena gain importance and are a powerful tool to investigate shell-model aspects and nucleon-nucleon correlations in mid- and heavy-mass systems. Mijatović et al. report a review of multinucleon transfer reactions and recent results from the PRISMA collaboration. Finally, the present collection extends also to higher energy, towards the Fermi domain. In particular, Pagano et al. discuss the importance of investigating peripheral heavy-ion collisions in the Fermi energy domain, where the formation of a dilute neck of nuclear matter can be observed. From a detailed fragment-fragment correlation analysis it is possible to determine the time-scale of fragment emission, a fundamental information to understand the dynamics of heavy-ion reactions at intermediate energies.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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