Fast emission processes and isospin dynamics at Fermi energies

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In the last decades the community of nuclear physicists has made a great effort in the study of the Equation of State of Nuclear Matter (nEOS), i.e. of the dependence of the binding energy per nucleon on the characteristics of the surrounding nuclear medium (density, temperature). Also due to its link with astrophysics (i.e. the description of neutron star characteristics), the study of asymmetric nuclear matter (with an exotic N/Z ratio) is actually a hot topic. The effect of the unbalance of neutron (N) to proton (Z) number in nuclei (also known as isospin-asymmetry and measured by the ratio N/Z) is taken into account by introducing in the nEOS the so called symmetry energy term ($E_{sym}(\rho)$)[1]. In laboratory this subject is studied by exploiting nuclear collisions. Here, the dependency of the binding energy on the isospin asymmetry is responsible of the isospin-transport phenomenon, which consists of different proton and neutron drifts inside the medium leading to a modification of the isospin content in specific regions of the interacting system during the collision. Consequently , isospin related observables, such as the ratio of the yields of a given isotope produced in colliding systems differing just for the isospin content (i.e. having different N/Z ratios) or the widths of isotopic distributions of a nuclear species produced in a given nuclear reaction[2–5], can be used to study the behavior of $E_{sym}(\rho)$ far from ground state conditions ($E/A = 0\ MeV/A$, $\rho = \rho_0 = 0.17\ fm^{-3}$). However, the pre-equilibrium emission of light particles and fragments that occurs in the early stages of nuclear reactions tends to reduce both the internal energy of the system (carried away by emitted particles) and the asymmetry of the system. Pre-equilibrium emission is a phenomenon that increases with bombarding energy [6] and can be relevant for reactions at the Fermi regime (above 25MeV/u); moreover, it is expected that for neutron-rich systems the pre-equilibrium emission of neutrons exceed that of protons, thus lowering the possible initial N/Z unbalance. The fragment isotopic distributions which are measured by the detectors are also affected by the statistical decay of the primary species which are formed during the reactions. Indeed, along much larger time scales, the excited species decay towards the ground state also emitting neutron and charged particles.

The NUCL_EX group [7] has actively participated in these studies since many years, performing experiments in different energy regimes using the GARFIELD+RCo apparatus [8] at Laboratori Nazionali di Legnaro (LNL) ($E < 20\ MeV/A$) and the FAZIA apparatus [9] at Laboratori Nazionali del Sud (LNS) in Catania (Fermi energy regime). Both experimental apparatuses are multi-detector arrays for charged particles detection that exploit various techniques ($\Delta E - E$ and Pulse Shape Analysis) to achieve isotopic identification of the nuclear species produced in the studied reactions.

My PhD thesis will focus on these subjects, mainly exploiting the experimental data that the group will be taking in an experimental campaign with the FAZIA apparatus at LNS in spring 2017 [10], studying the two reactions $^{40,48}Ca + ^{12}C$ at different bombarding energies (25, 45 MeV/A for both reaction), in order to probe both the isospin and excitation energy degrees of freedom. The aim of this experiment is to see whether and how the effects due to the larger initial neutron abundance (with ^{48}Ca) on the final observables are partially reduced, by pre-equilibrium emission of exceeding neutrons, when the bombarding energy increases. Moreover, taking into account the rather small mass of the interacting systems and the energy involved, the reactions will allow also for studies on the formation and decay of resonances and clusterized states inside the nuclear medium. This topic is also closely connected to another experimental campaign, scheduled in March 2017 at LNS with FAZIA [11], having as main focus the alpha-particle clustering phenomena. Starting from the raw data-set as it is produced by the experimental campaign, I will proceed to the calibration of the various detectors of the FAZIA array. After the calibration, I will deal with the data analysis and the comparison of the experimental results with the predictions of dynamical and statistical models, in order to get a deeper understanding of the physical processes involved.

I also plan to carry on the work that I have started during my master thesis, concerning the technical upgrade of the digital read-out electronics of the GARFIELD+RCo apparatus [12,13] which will be used for experiments just on the subject of alpha-clustering in nuclei at lower energies. I mention that this improvements will be exported to the FAZIA equipment in view of the long and important experimental phase planned since 2018 with the beams delivered by the GANIL facility (France)

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