Atomic nuclei are quantal systems governed by strong interactions, the most complex found so far in nature. Therefore, the structure of atomic nuclei in most of the cases has to be described by theoretical models based on quantum mechanics. However, it turns out that some of the nuclear features can also described by simpler classical models, which allow for easier understanding. This is because the strong interactions are of extremely short range, what causes that the density of nuclear matte is well localized. This in turn allows to introduce the classical notion of the nuclear surface, and thus the shapes of nuclei and their deformation. These classical features are rotation or vibration of the whole nucleus, where all the nucleons are collectively (in a coherent way) contributing to the excitation. Therefore we call those processes “collective”.

The hot compound nuclei (CN) can be created by using a fusion reaction with excitation energy and angular momentum distribution which generally depend on the projectile – target combination and the projectile energy. During the CN decay process the excitation energy is released through emission of light particles (neutrons, protons or alphas), and photons (high-energy γ rays). Such decay process usually creates cold evaporation residues.

Possible modes of nuclear excitations, observed in cold and hot excited nuclei, are collective rotations or collective vibrations. The most pronounced of such kind are so called isovector giant dipole resonances (IVGDR), interpreted as coherent (collective) vibrations of protons against neutrons, and pygmy dipole resonances (PDR), which might be understood as oscillation only of the excessive neutrons forming so-called neutron skin against the proton-neutron core of the nucleus. IVGDR has been investigated for many years, both in cold and hot nuclei, and has become very good tool for studies of nuclei properties as for example nuclear deformation. PDR and their gamma-decay have only been investigated so far only in cold nuclei. Although their existence in hot nuclei is predicted by theoretical models, they are very difficult to observe experimentally since their gamma decay energy region usually overlaps with the strong background of statistical gamma rays associated with the decay of hot and rotating nuclei and they sit on a tail of the gamma-decay of the IVGDR. In addition to the IVGDR and PDR other vibrational modes can potentially be excited in nuclei. However, their gamma decay is weaker by a few orders of magnitude than that of dipole excitations. The example of such an excitation is the isoscalar giant quadrupole resonance (ISGQR), which can be interpreted as the nuclear surface vibration. It was observed in the excitation function in most of nuclei, however information about its structure and dependence on the nuclear shape is very scarce. A more detailed way to study the structure of the ISGQR would be the gamma-ray spectrum from its decay. Unfortunately, such studies have so far only been performed in two cases and only to the ground state, both for ^{208}Pb. The reason for the lack of the experimental data for the ISGQR gamma-decay is the difficulty of the measurement: the γ decay above the neutron threshold is a very rare process, hindered by the competing channel of neutron emission (at least 1 million times stronger). The branching ratio (probability) for the gamma decay of ISGQR is at least 100 times smaller than the gamma decay of IVGDR. Nevertheless, it is very important to gather more information on such very difficult to observe, “elusive” γ-decays to the ground state and to the low-lying vibrational states in different nuclei. For instance, it has been theoretically predicted recently, that giant resonances’ γ-decay width to low-lying states is a unique probe of the resonance wave function, and a testing ground for nuclear structure models. In addition, the predictions have also been made showing that γ decay of the ISGQR should also be sensitive to the deformation.

The purpose of this project is to explore these “elusive” collective processes in cold and hot nuclei with different mass, deformation and isospin (N/Z ratio). Proposed investigations include gamma-decay of ISGQR both to ground-state and excited states, gamma-decay of PDR in hot nuclei, as well as the possible process of persistence or evolution of nuclear deformation in the decay. They will be studied by the measurement of photons (high-energy gamma rays) emitted from the decay of excited states in hot and cold nuclei. In all of the foreseen experiments the gamma-decay of the IVGDR will be also investigated in order to serve either as normalization or a tool for the study of elusive processes. We plan to study above mentioned nuclear features in experiments performed using hybrid setups of innovative multidetector arrays allowing selection of different conditions for the nuclei to be investigated at a few European laboratories: IJCLab in Orsay, France; IFIN-HH in Magurele, Romania and CCB of IFJ PAN in Krakow.

The results, we hope to obtain, apart from widening the knowledge about the nuclear structure, are expected to also have an impact on other science areas. In this respect, the research on pygmy dipole resonances seems to be the most important. These resonances, with energies close to or below particle binding energies, may play a very important role in stellar nucleosynthesis, as the additional strength might enhance the neutron capture cross sections. Moreover, the study of such collective excitation may be important for understanding gamma heat generation in fission reactors, as in the fission process of material used in reactors (uranium, plutonium) fission fragments (e.g., Krypton nuclei) are predicted to be created with relatively large excitation energies and high spins, hence with possible large non-spherical deformations.