Nuclear physics explores the properties of the femtoworld, namely the atomic nucleus, which is about a million of millions times smaller than a table tennis ball, one billion times smaller than a red blood cell, and from ten thousand to one hundred thousand times smaller than an atom. And this is not even the smallest scale “visible“ to scientists.

In this project, we focus on atomic nuclei and the fascinating shapes, that they can possess: spherical like a soccer ball or an orange; elongated ellipsoidal shapes like a rugby ball or zucchini; flattened shapes like a frisbee or pumpkin; or even much more exotic forms, such as pear-shaped nuclei. The shape of an atomic nucleus is determined by the number of their building blocks, nucleons (protons and neutrons) and the nuclear interaction that acts between them.

Unfortunately, we do not have a magnifying glass that is strong enough, or even a microscope to observe directly an atomic nucleus. So how can we "see" the shape of an atomic nucleus? We can infer it indirectly by using a variety of probes, ranging from level energies and lifetimes measured via observation of electromagnetic decay, to spectroscopic quadrupole moments of ground states that can be obtained via laser spectroscopy. The constant progress in experimental techniques, including the use of increasingly efficient multi-detector systems, makes it possible to obtain rich and precise information on the properties of atomic nuclei. The method of choice in studies of nuclear shapes remains, however, low-energy Coulomb excitation. In this process, two colliding nuclei interact only through electromagnetic forces, without any direct contact. As a result, the nuclei become excited and then de-excite by emitting electromagnetic radiation known as gamma rays, which can be measured with high precision. By analyzing the energies and angular distributions of the emitted gamma rays, as well as how the nuclei scatter during the interaction, we can determine the shape of the nucleus, whether it is spherical, elongated, flattened, or more exotic.

Even more interestingly, certain nuclei exhibit a fascinating phenomenon known as shape coexistence, where their shapes change dramatically from one state to another within a narrow range of excitation energy. In most cases, shape coexistence involves only two distinct shapes. The occurrence of multiple shape coexistence, where more than two shapes coexist, is a much rarer phenomenon, with the best cases to date found in very neutron-deficient lead (Pb) and mercury (Hg) isotopes. Recently, indications of its presence have been obtained in other regions of the nuclear landscape, particularly in nickel (Ni) and cadmium (Cd) isotopes.

Cadmium (Cd) isotopes have played a pivotal role in the investigation of collective behavior in atomic nuclei for over 40 years. Initially, the stable even–even cadmium isotopes were regarded as nuclei whose low-energy structures could be described within the framework of the collective vibrational model, where the nuclear shape is interpreted as small oscillations (vibrations) around a spherical equilibrium shape. However, recent detailed gamma-ray spectroscopy studies and certain advanced theoretical models of nuclear structure are clearly disagree with this vibrational picture, instead suggesting the presence of a variety of shapes in ^{110}Cd and ^{112}Cd. Nevertheless, the existing experimental data can still be interpreted within a vibrational framework according to an alternative state-of-the-art theoretical approach. Therefore, there is a clear need for precise experimental data on the shapes of low-lying states in stable cadmium isotopes to discriminate between these two fundamentally different interpretations.

As a key part of this vast experimental effort, our collaboration initiated a experimental program to ascertain the shapes of low-lying 0^+ states in even-even Cd nuclei, starting from ^{110}Cd. This program included four Coulomb-excitation experiments to study ^{110}Cd using different reaction partners: ^{14}N, ^{32}S, ^{60}Ni and ^{208}Pb as well as complementary beta-decay measurements.

Within the present project, data from a low-energy Coulomb-excitation study of ^{110}Cd using ^{60}Ni beam, performed with the leading European gamma-ray spectrometer AGATA, will be analysed in order to determine shapes of individual nuclear states. This information will serve to discriminate between the two conflicting interpretations of ^{110}Cd structure resulting from state-of-the-art theoretical approaches. Moreover, it is important to mention that development of modern nuclear theories and models strongly relies on the availability of rich and precise experimental data, such as those that will be obtained within the proposed project.