Understanding the properties of atomic nuclei is one of the fundamental questions in nuclear physics. Nuclei are very complex objects, composed of protons and neutrons. Particularly interesting is the understanding of what happens to the nuclear properties when we remove (or add) neutrons from (to) a stable nucleus, deviating more and more from the so-called valley of β-stability. It has been shown that new features/properties can appear in such exotic nuclear systems.

One of the main goals and challenges in the field is to devise a consistent theory for the description of atomic nuclei. In order to test and tune the theoretical models that describe nuclear properties of (very) exotic nuclei, it is necessary to gather experimental information on their properties. These are their mass, decay mode, half-life, probability for a given decay mode to happen (branching ratio), energy spectrum, etc. In order to be studied, such nuclei need to be produced in sufficient quantities. This requires the use of state-of-the-art facilities, where it is possible not only to produce the nuclei of interest, but also to select them among the enormous amount of other nuclear species produced at the same time, using electromagnetic selection. Efficient and innovative detectors are then employed to study the properties of these exotic nuclei.

A particularly interesting set of nuclei to study and understand is that formed by very neutron-deficient nuclei, i.e. with a large excess of protons, close to the so-called proton drip-line. These nuclei are characterized by very large energy window for their $\beta+$ decay. Moreover, $\beta+$ decay is often followed by prompt emission of a charged particle, like proton or alpha, but also several particles, like two or three protons, proton and alpha, etc. The phenomenon is called β-delayed charged-particle emission. Measuring the probability for charged particle emission to happen following β decay and the energy of the emitted properties allows a unique insight into the structure of highly excited states in the daughter nucleus, fed in β decay. Such information cannot be obtained through other methodologies, like e.g. traditional gamma spectroscopy.

In this work rare decay modes such as β-delayed particle emission is going to be studied for exotic nuclear system as ^{31}Ar, ^{31}Cl, ^{27}S, ^{26}P, ^{11}Be, and nuclei in the vicinity of ^{54}Zn. In particular, we will look for multi-proton emission and emission of proton and alpha. We also plan to investigate the very exotic ^{108}Xe nucleus, which is expected to decay by so-called "super-allowed" alpha decay. Another interesting characteristic of the medium mass nuclei mentioned above is their relevance in nucleosynthesis modeling. Their properties are in fact key input parameters for the models that calculate the abundance of the elements in the universe.

The majority of the studies proposed here will make use of a technique based on digital photography. The method uses a gas-filled detector immersed in an electric field. The rare exotic nucleus is stopped inside the detector and subsequently decays. Charged particles moving in the gas ionize it, generating electrons that drift along the electric field lines towards the anode. Here they are multiplied by a few orders of magnitude and visible light is generated. The light is recorded by a CCD camera and a photomultiplier tube. The analysis of the CCD image, combined with the signal from the photomultiplier, allow to reconstruct the track of the charged particle in 3D, which provides the energy and type of particle. Such detector was designed and built at the Faculty of Physics of the University of Warsaw. It has the advantage of having very high efficiency and sensitivity, a fundamental characteristic for the success of the measurements planned. Its capabilities were demonstrated in our previous research, e.g. in the pioneering experiments on two-proton radioactivity.