Nuclei are complex structures made of protons and neutrons. One of the fundamental question in the field of nuclear physics is how subatomic matter organises itself and which phenomena can emerge. Such question has been at the heart of nuclear physics studies since Day One. The ultimate goal of nuclear structure studies is to build a coherent framework that explains all the properties of the nuclei. This goal, although very ambitious is within reach. In order to achieve it, a large amount of information on the properties of exotic nuclei, i.e. with very large or very small neutron excess with respect to the stable isotopes, needs to be collected. The production and investigation of these rare isotopes requires state-of-the-art experimental facilities, where accelerators and electromagnetic separators allow to produce and isolate the nuclei to study. Moreover, innovative experimental set-ups (detectors and electronics) need to be developed for performing such studies. Needless to mention that challenges of science drive, and benefit from, technological development.

Most of the nuclei in the chart of nuclei decay by beta-particle emission (β^+ and β^- for proton- and neutron-rich nuclei, respectively). One of the best ways to gain information on the structure of nuclei is to study the gamma radiation emitted following beta decay populating excited states in the daughter nuclei. This method works best not too far from the valley of beta-stability: at the limits of stability other phenomena dominate the decay pattern of isotopes. For very exotic nuclei, the energy needed to remove one or more particles (proton, neutron, multiple protons, …) from the nucleus can become very small. Hence, if we populate nuclear excited states, e.g. through beta-decay, which lie above such energy thresholds, spontaneous emission of particles can occur. Such phenomenon is known as beta-delayed (multi-) particle emission and proton(s) or neutron(s) are emitted in the process. In these cases, traditional gamma spectroscopy measurements are not very useful and (beta-delayed) particle spectroscopy is the only way to access information on excited states of exotic nuclei. In this work, very rare decay modes, like beta-delayed three-proton, proton-alpha and tritium decay, will be searched for in ^{27}S, ^{23}Si and ^{8}He, respectively, and their properties studied. Beta-delayed three-proton and tritium emission have been observed only in a few cases along the whole chart of nuclei, while beta-delayed proton-alpha emission hasn't been seen, yet.

In rare cases it can happen that the nucleus decays spontaneously by emission of two protons. This is the so-called two-proton radioactivity, the latest mode of decay discovered (it was first observed in 2002). This spontaneous decay can happen when a nucleus is unbound towards emission of two protons, i.e. it can spontaneously emit them without energy being supplied, but is bound towards emission of a single proton. It has been observed in 3 cases only, namely ^{45}Fe, ^{48}Ni and ^{54}Zn. In the latter two cases, only a handful of ions for each of the two isotope was produced. In order to understand the physical properties of this decay mechanism more detailed studies are needed, in particular on how the energy available for the nucleus to decay is shared between the two protons and on the angle between the two emitted protons. Technological progress of radioactive beam facilities allows now for a more intense production of ^{54}Zn and hence the measurement of its two-proton decay with sufficient statistics. These studies will shed light into the decay mechanism and into the way the two protons interact with each other. The study of two-proton radioactivity of ^{54}Zn is part of this project.

These studies will be performed by means of a novel technique that allows to take images of the decay. This method uses a gas-filled detector immersed in an electric field. The exotic nucleus of interest is stopped in the centre of the detector where it decays. The charged particles emitted in the decay ionise the gas along their tracks. The electrons generated in the ionisation process drift along the lines of the electric field towards the anode, they are multiplied and converted into light, which is registered by a CCD camera and a photomultiplier tube. The image collected by the CCD camera of the tracks generated by the ions gives the projection on the (horizontal) plane of the 3D trajectory of the particle, while the time distribution of the signal of the light collected by the photomultiplier tube allows to get the third (vertical) coordinate of the track (after correction for the constant drift velocity of the electrons in the electric field is applied). This technique is instrumental to the success of these (multi) charged-particle emission measurements, as was demonstrated in the pioneering experiments on two-proton radioactivity of ^{45}Fe and ^{48}Ni.