PhD position in experimental nuclear physics

In-source laser spectroscopy of neutron deficient Pd isotopes

The study of exotic nuclear matter and related radioactive ion beam technologies is at the forefront of modern subatomic physics. Atomic physics techniques - more specifically, optical measurements of the atomic structure - readily yields fundamental and model-independent data on the structure of ground and isomeric nuclear states. The competition and balance between nuclear shell and collective effects results in a spectacular range of shapes and sizes within nuclear systems. Such shapes and structures perturb the atomic energy levels of atoms and ions at the ppm level and although this is a small absolute effect, it is readily probed and measured by modern laser spectroscopic methods, i.e. in-source laser spectroscopy at Jyväskylä and in-gas jet laser spectroscopy at GANIL-Spiral2. These techniques are particularly suitable for the study of short-lived radionuclides with lifetimes as short as a few milliseconds, and production rates often only a few hundred isotopes/isomers per second.

The IGISOL facility, Jyväskylä, uses the ion guide method of producing exotic radioactive ion beams, providing unique access to refractory elements which cannot be extracted from typical ISOL-based facilities. In-source laser spectroscopy is one of the main workhorses of the facility, with recent developments using hot-cavity ion source techniques offering access for certain elements to the N=50 shell closure.

The S3-LEB facility of GANIL-Spiral2, will produce exotic radioactive beams by fusion-evaporation reactions, the ions of interest will be transmitted through the S3 spectrometer up to the final focal plane where the LEB (Low Energy Branch) set-up will be placed. This specific set-up will allow to access to nuclear properties of exotic nuclei by means of in-gas jet laser spectroscopy.

Both laboratories permit access to regions of the nuclear chart which are currently either inaccessible to the majority of facilities, or are challenging to probe spectroscopically due to the complexity of the atomic structure. One such region lies between the refractory systems of Zr (Z=40) which exhibit strong changes in nuclear shape, and the more single-particle-dominated region around Sn (Z=50). This transitional region serves up a rich landscape of shape transitions, shape coexistence and triaxiality.

Optical information of Pd isotopes has been the subject of two PhD thesis from students of our collaboration (Sarina Geldhof and Alejandro Ortiz-Cortes). The experiments were carried out at IGISOL facility in Jyvaskyla, Finland. The goal of such measurements was to shed light into the shell and shape evolution of the Pd isotopes, from ^{98}Pd to ^{118}Pd. The results led to two articles, one already published (S. Geldhof et al., Phys. Rev. Lett 128, 152501 (2022), focused on the changes of mean-squared charge radii. The results were compared to state-of-the-art energy density (EDF) functionals revealing a clear link between the charge radii and the pairing correlations in neutron-rich nuclei. The second article is about to be submitted (A. Ortiz-Cortes, to be submitted to Phys. Rev. C) and focuses on the odd-mass Pd systems, allowing a detailed analysis of the odd-even staggering of the charge radii to benchmark the Fayans EDF and beyond mean field models including the Gogny parametrization and SCCM methods. These results reveal the shape evolution of the Pd isotopes from strongly oblate deformation in the neutron-deficient region, through soft triaxial shapes at the mid shell and recovering the axial prolate symmetry in the neutron-rich nuclei when approaching the N=82 shell closure.

This thesis will focus on the neutron-deficient Pd isotopes, reaching the N=50 shell closure and beyond. Recent optical information on the Ag chain has been provided, with charge radii measurements crossing the N=50 shell closure for the first time in the immediate vicinity of the self-conjugate ^{100}Sn nucleus (M. Reponen et al., Nature Com. 12,4596 (2021)). It is well-known that there is a kink in the difference of mean-squared charge radii when crossing a shell closure. The result on the Ag chain reveals a difference somewhat larger than expected when compared to other (lighter) isotopic chains where spectroscopic information is available (i.e. Zn and Mo). The results were compared with theoretical calculations that fail to reproduce the observed data. In order to shed light on the N=Z region below ^{100}Sn and the kink in the mean-squared charge radii when crossing the N=50 shell gap, it is necessary to provide new optical information on the nuclei below Sn and moving towards the well-deformed Zr isotopes around N=Z=40. The planned measurements of mean-squared charge radii of the lighter Pd isotopes are of utmost importance and a natural extension to our existing work.

This thesis work will concentrate on the use of laser spectroscopy (and possible variants) to probe ground and isomeric states of neutron-deficient Pd isotopes, produced via heavy-ion induced fusion-evaporation reactions. The extracted data (nuclear spins, magnetic moments and mean squared charge radii) will be analyzed and will serve to provide fundamental insight into the shell evolution and development of nuclear collectivity away from closed. Comparison with state-of-the-art shell model theories will be sought, aiming to provide insight into the effect of triaxiality on the electromagnetic moments in the region.

The doctoral student will spend considerable time working within the laser team of the IGISOL group, thus learning all aspects of ion beam production, manipulation techniques, the use of state-of-the-art laser systems, frequency stabilization and atomic spectroscopy. In parallel, the student will also have an opportunity to take advanced courses in Jyväskylä connected to optical spectroscopy and mass measurement techniques for fundamental nuclear structure. In addition, the student will participate on the commissioning of the S3-LEB set-up at LPC-Caen (France), gaining experience with in-gas jet laser spectroscopy techniques. The thesis work will provide valuable training in methods which may be directly implemented at future large-scale facilities.

Soft and transferrable skills will also be developed including presentation work, scientific writing for publications and so forth. The thesis work will be performed in collaboration with researchers from the UK, Finland, Belgium and elsewhere. Similar efforts are underway at the CARIBU facility, Argonne National Laboratory, and therefore working within international teams will provide valuable experience for a young researcher and networking opportunities required for a possible future career.

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