The synthesis of nuclei available topics for the Severo Ochoa PhD fellowships (2025 call)

Title: Nuclear shape coexistence in odd-A Hg isotopes investigated using the TAS technique

Contact: Sonja E. A. Orrigo (Sonja.Orrigo@ific.uv.es)

Summary: This experimental nuclear physics project investigates the frontier area of exotic nuclei (radioactive nuclei far from stability).

The shape transitional region around mass A=186 is considered a benchmark for studies related to shape transitions and shape effects. An almost unique feature in the nuclear chart appears in the exotic Hg nuclei: a staggered change in mean-square charge radii, indicating oblate/prolate shape changes [1]. The odd-A isotopes 183,185,187Hg are of particular interest for studying shape coexistence, as they are the first case in the entire nuclear chart where two different shapes are expected to coexist in the same nucleus (in the ground state and the 13/2+ isomeric state).

We performed the IS707 experiment at the ISOLDE facility of CERN to measure the beta decay of 183,185,187Hg using the Total Absorption Spectroscopy (TAS) technique [2]. The student will analyze data from this experiment, learning to handle complex experimental data using ROOT and Monte Carlo techniques. The ultimate goal is to extract the beta-decay strength distributions for these Hg isotopes. Since the Gamow-Teller strength distribution depends on nuclear deformation, different distributions are expected for the ground and isomeric states. Comparing this new experimental information with theoretical calculations of Gamow-Teller strength [3] will provide conclusive insights into the shapes of both ground and isomeric states in 183,185,187Hg for the first time.

Significant results are expected, which will be published in high-impact journals. In addition, the student will have the opportunity to present these results at important international conferences in the field.

References

[1] “Characterization of the shape-staggering effect in mercury nuclei”, B.A. March et al., Nature Physics 14, 1163 (2018).

[2] Experiment IS707 proposal: “Total absorption beta decay studies around 186Hg”, A. Algora, S.E.A. Orrigo, L.M. Fraile, et al. (2021), https://cds.cern.ch/record/2782429/files/INTC-P-617.pdf .

[3] “Bulk and decay properties of neutron-deficient odd-mass Hg isotopes near A = 185”, O. Moreno, P. Sarriguren, A. Algora, L.M. Fraile and S.E.A. Orrigo, Physical Review C 106, 034317 (2022).

Title: Neutron detection for nuclear astrophysics

Contact person: Ariel Tarifeño-Saldivia (atarisal@ific.uv.es)

Summary: The origin of heavy elements in the cosmos is one of the most exciting and challenging questions in modern nuclear physics. A significant portion of elements heavier than iron is synthesized through the rapid neutron capture process (r-process) in extreme astrophysical environments, such as neutron star mergers and core-collapse supernovae. However, there are still many uncertainties about the dominant sites that contribute to the Galactic r-process abundances. To deepen our understanding of

these processes, cutting-edge nucleosynthesis simulations rely heavily on nuclear physics inputs, including isotope masses, beta-decay rates, beta-delayed neutron branchings, and nuclear reaction rates.

This PhD research will focus on the development and use of state-of-the-art neutron detection systems for studying beta-delayed neutrons [1] and (alpha,n) reaction rates [2, 3], both of which are important for understanding r-process nucleosynthesis. The research will involve designing innovative neutron detectors for counting and spectrometry, aimed at improving measurements in these fields. The newly developed instrumentation will be employed in experiments with alpha beams at Spanish Unique Science and Technology Infrastructures (ICTS) and with exotic beams at world-leading laboratories such as FAIR, JYFL-IGISOL, ISOLDE, and GANIL. In the later stages of the project, the experimental data will be interpreted within nuclear models and applied to astrophysical simulations, providing deeper insights into the formation of the universe's heaviest elements.

References:

[1] Iris Dillmann and Ariel Tarifeño-Saldivia, 2018. The "Beta-Delayed Neutrons at RIKEN" Project (BRIKEN): conquering the most exotic beta-delayed neutron-emitters. https://doi.org/10.1080/10619127.2018.1427937

[2] J Bliss et al, 2017. Impact of (α, n) reactions on weak r-process in neutrino-driven winds. https://doi.org/10.1088/1361-6471/aa63bd

[3] N. Mont-Geli et al, 2023. Commissioning of miniBELEN-10A, a moderated neutron counter with a flat efficiency for thick-target neutron yields measurements. https://doi.org/10.1051/epjconf/202329001003

Title: Precision measurements in beta decay as fundamental physics probes

Contact person: Martín Gonzalez Alonso (martin.gonzalez@ific.uv.es)

Summary: Precision measurements in beta decay are precious probes of both standard and non-standard interactions. This project aims to improve the current state-of-the-art through the study of subleading effects (e.g. weak magnetism), new transitions (e.g. forbidden decays), new observables (e.g. β-ν angular correlation coefficient in the so-called mirror pairs, and electron capture), and their connection with neutrino physics (beta decays in reactors, in the Sun, ...). The studies will be carried out using Effective Field

Theories, which offer a model-independent framework, and can be used to connect these low-energy measurements with searches at high-energy colliders and neutrino experiments. The phenomenological study can be carried out in a comprehensive global fit, in a ladder of Effective Field Theories, from the nuclear level to the Standard Model level.

References:

Prog. Part. Nucl. Phys. 104 (2019) 165-223, JHEP 04 (2021) 126.

Title: Characterization of the largest Gamow-Teller transition: study of 100Sn beta decay by means of total absorption spectroscopy

Contact person: Alejandro Algora (algora@ific.uv.es)

Summary: 100Sn is a very special nucleus among all nuclei. 100Sn is the last particle bound N=Z double magic nucleus, and its beta decay shows the largest Gamow-Teller strength detected so far in the whole nuclide chart. The special character of this decay is related to the shell structure around at N=Z=50, and the large available Q window. Studying this decay remains very challenging, because even though remarkable developments have improved the primary beam intensities in the last decade, the low production cross section of this exotic nucleus remains a limiting factor. Two studies have tried to determine the states populated in the beta decay of 100Sn in 100In [1,2], but the excitation energy of the mainly populated 1+ state remains questionable. This open question is the main goal of this research topic.

We have an approved experiment at the RIKEN Nishina Center (Japan) to study this problem using the total absorption spectroscopy [3]. This calorimetric technique, because its high efficiency, can help to precisely determine the energy of this state. This will allow a more precise calculation of the largest Gamow Teller strength of all beta decays. State of the art theoretical studies show that this number also holds the key to a better understanding of the quenching of the axial vector constant (gA) in the nuclear medium from first principles that can also have a large impact in neutrino-less double beta decay studies and astrophysical calculations. This study remains a flag experiment of radioactive beam facilities of new generation around the World.

References:

[1] C. B. Hinke et al., Superallowed Gamow–Teller decay of the doubly magic nucleus 100Sn, Nature 486 (2012) 341

[2] D. Lubos et al., Improved Value for the Gamow-Teller Strength of the 100Sn Beta Decay, Phys. Rev. Lett. 122 (2019) 222502

[3] A. Algora et al., Beta-decay studies for applied and basic nuclear physics, Eur. Phys. J. A 57 (2021) 85

Title: Neutrino physics from gamma spectroscopy

Contact: Jose Javier Valiente Dobón (valiente@ific.uv.es)

Summary: Experimental studies of nuclear matrix elements (NMEs) related to neutrinoless double-β decays (DBDs) and astroneutrino (ν) inverse β decays (IBDs) are essential for advancing our understanding of neutrino physics beyond the Standard Model, as well as for astro-neutrino research. Accurate theoretical calculations of NMEs are challenging due to their strong sensitivity to the nuclear models and parameters used.

However, key NMEs associated with electromagnetic transition operators in both DBD and IBD processes—such as effective weak couplings—can be experimentally determined by measuring the

corresponding electromagnetic (gamma) transitions from the isobaric analog states (IASs) of the relevant nuclei. For example, a recent study presented a novel approach to estimating NMEs for neutrinoless double-β decays by investigating the relationship with the double gamma *γγ(M1M1)* transitions from Double Isobaric Analog States (DIAS) [1,2]. To address this, we have launched an innovative experimental campaign aimed at exploring the interface between gamma spectroscopy and neutrino physics.

The student is invited to join this cutting-edge project and focus on two main activities:

- Developing GEANT4 simulations to estimate the sensitivity of the detection setup for future experiments.
- Analyzing data collected from the first experiment of the campaign, which will focus on the gamma decay from IAS states important for solar neutrino and sterile neutrino studies and the rare decay of the DIAS state in ^{48}Ti important for neutrinoless double-β studies.

[1] B. Romeo, J. Menendez, C. Peña-Garay Phys. Lett. B 827, 136965 (2022)
[2] B. Romeo, D. Stramaccioni, J. Menéndez, J.J. Valiente-Dobón, Phys. Lett. B 860, 139186 (2025)

Title: Nuclear collectivity experimental studies, in nuclei in the vicinity of N=Z and in very n-rich nuclei, performed with the AGATA tracking array.

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Summary: In the last years the IFIC group in collaboration with INFN-LNL, GANIL, GSI-FAIR, and RIKEN, has started a research line to study the seniority conservation, as a dynamical symmetry, in medium mass and heavy nuclei. It has been suggested that in the heavy Z=28 nuclei (with □g9/2 valence orbital) the effective interaction for very neutron-rich nuclei might not preserve the seniority. This aspect of the nuclear structure is investigated measuring the evolution of collectivity in low lying states of quadrupole nature. We have started a programme to measure lifetimes in the region using AGATA at INFN-LNL for the moderately neutron-rich Ni isotopes with Multi-Nucleon Transfer Reactions (MNT) and complementary experiments at RIBs for the most exotic even-even Ni nuclei. The experimental activity is partially done and will continue in 2025.

We are also investigating the structure of nuclei with symmetry in the number of protons and neutrons, i.e. the region around N=Z, that has been on the focus of our research for some time already. Different aspects of the Nuclear Structure in the vicinity and at N=Z are of relevance, namely, the proton-neutron T=0 pairing, the nuclear structure phenomena associated with the isospin symmetry and the enhancement of collective properties of the nucleus due to the proton-neutron contributions, such as the quadrupole and octupole collectivities. We are presently preparing the AGATA ZeroDegree campaign that will allow to study nuclei far from stability in the vicinity of N=Z. This is made possible by AGATA in an enlarged configuration and the neutron detector array NEDA as tagging detector.

References

R. M. Pérez-Vidal, A. Gadea et al. Physical Review Letters 129 (2022) 112501

B. Cederwall et al. Nature 469 (2011) 68

A. Gadea et al., Physical Review Letters 97 (2006) 152501.